# European Snow Booklet

Source: Bartłomiej Luks

EUROPEAN COOPERATION
IN SCIENCE & TECHNOLOGY

# Acknowledgements

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# List of Authors and Editorial Board

## Editor of the European Snow Booklet

**Anna Haberkorn**
WSL Institute for Snow and Avalanche Research SLF
Davos, Switzerland

## Lead authors of the European Snow Booklet

**Anna Haberkorn**
WSL Institute for Snow and Avalanche Research SLF
Davos, Switzerland

**Jürgen Helmert**
Deutscher Wetterdienst DWD
Offenbach, Germany

**Leena Leppänen**
Finnish Meteorological Institute FMI
Sodankylä, Finland

**Juan Ignacio López-Moreno**
Pyrenean Institute of Ecology CSIC
Zaragoza, Spain

**Roberta Pirazzini**
Finnish Meteorological Institute FMI
Helsinki, Finland

## Contributions of lead authors of the European Snow Booklet

As the editor of the European Snow Booklet (ESB), Anna Haberkorn managed its compilation and production. She wrote the main introduction (pp. 1–6) and the introductory sections of Part I and Part II of the ESB. In addition, Anna Haberkorn led the writing of Chapter I-1 and was in charge of requesting information and data on the European operational snow monitoring networks through the ESB Questionnaire (Appendix I-B). Julien Anet accomplished groundwork for these tasks. Anna Haberkorn was responsible for the overview of the national snow monitoring networks of the participating European countries (Chapter I-2 and Appendix I-A) and performed the European-wide analysis of the collected data (Chapter I-3). Finally, she wrote the summary of Part I of the ESB (Chapter I-4). Part II of the ESB includes summaries of important snow observation tasks, as well as the corresponding data and its analysis, accomplished within the COST Action HarmoSnow. Leena Leppänen and Juan I. López-Moreno, together with their working group colleagues, provided recommendations from HarmoSnow field campaigns (Chapter II-1). Outcomes of the questionnaires developed by the Action working groups (WGs) are summarised in Chapters II-2 and II-3. Roberta Pirazzini provided insights on the WG 1 – WG 2 Questionnaire (Chapter II-2), while Jürgen Helmert led the compilation of the WG 3 Questionnaire responses (Chapter II-3), both together with their working group colleagues.

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## Editorial board of the European Snow Booklet

# Partners

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1. http://www.cost.eu/ and https://ec.europa.eu/programmes/horizon2020/en
2. http://www.snf.ch/en/Pages/default.aspx
3. https://www.dwd.de/EN/Home/home_node.html
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9. https://naturalsciences.ch/organisations/scnat
10. https://www.slf.ch/en.html
11. https://www.zamg.ac.at/cms/en/news

# List of Key Acronyms

## Key Terms

| | |
|---|---|
| **a.s.l.** | Above sea level |
| **AWS** | Automatic weather station |
| **CS** | Coordinate system |
| **DA** | Data assimilation |
| **DEM** | Digital elevation model |
| **EnKF** | Ensemble Kalman filter |
| **ESB** | European Snow Booklet |
| **GNSS** | Global Navigation Satellite System |
| **GTS** | Global Telecommunication System |
| **HN** | Depth of snowfall |
| **HS** | Snow depth |
| **NWP** | Numerical weather prediction |
| **PSG** | Presence of snow on the ground |
| **SMP** | SnowMicroPen |
| **SPA** | Snow Pack Analyser |
| **SPICE** | WMO Solid Precipitation Intercomparison Experiment |
| **SWE** | Water equivalent of snow cover |
| **SYNOP** | Synoptical observation |
| **WE** | Water equivalent of snow sample |
| **WG** | Working group |

## Key Institutes and Organisations

| | |
|---|---|
| **AEMET** | Spanish State Meteorological Agency under the Ministry of Agriculture and Fishing, Food and Environment (Spain) |
| **AINEVA** | Italian Interregional Association of Snow and Avalanches (Italy) |
| **ANS** | Abisko Scientific Research Station and Swedish Polar Research Secretariat (Sweden) |
| **ARPAL** | Agenzia Regionale per la Protezione dell'Ambiente Lombardia (Italy) |
| **ARPAP** | Agenzia Regionale per la Protezione dell'Ambiente Piemonte (Italy) |
| **ARPAVA** | Agenzia Regionale per la Protezione dell'Ambiente Valle d'Aosta (Italy) |
| **ARPAV** | Agenzia Regionale per la Protezione dell'Ambiente Veneto (Italy) |
| **ARSO** | Slovenian Environment Agency (Slovenia) |
| **ASTA** | Administration des Services Techniques de l'Agriculture (Luxembourg) |
| **BMNT** | Austrian Federal Ministry of Sustainability and Tourism (Austria) |
| **CENMA** | Snow and Mountain Research Center of Andorra (Andorra) |
| **CHMI** | Czech Hydrometeorological Institute (Czech Republic) |
| **CNR** | National Research Council of Italy (Italy) |
| **COST** | European Cooperation in Science and Technology |
| **CYMET** | Department of Meteorology Cyprus under the Ministry of Agriculture, Rural Development and Environment (Cyprus) |
| **DHMZ** | Meteorological and Hydrological Service of Croatia (Croatia) |
| **DMI** | Danish Meteorological Institute (Denmark) |
| **DWD** | Deutscher Wetterdienst (Germany) |
| **ECCC** | Environment and Climate Change Canada (Canada) |
| **ECMWF** | European Centre for Medium-Range Weather Forecasts (United Kingdom) |

| | |
|---|---|
| **EDF** | Electricité de France EDF-DTG (France) |
| **ESI** | Earth Science Institute of the Slovak Academy of Sciences (Slovakia) |
| **ESTEA** | Estonian Environment Agency (Estonia) |
| **FHMI** | Federal Hydrometeorological Institute of the Federation of Bosnia and Herzegovina (Bosnia and Herzegovina) |
| **FMS** | Fondazione Montagna sicura – ufficio valanghe Valle d'Aosta (Italy) |
| **FMI** | Finnish Meteorological Institute (Finland) |
| **GCOS** | Global Climate Observing System |
| **GCW** | Global Cryosphere Watch |
| **GWD** | General Water Directorate – Hydrological Information Area under the Ministry of Agriculture and Fishing, Food and Environment (Spain) |
| **HAB** | Hydrographic Office of the Autonomous Province of Bolzano, South Tyrol (Italy) |
| **HarmoSnow** | A European Network for a Harmonised Monitoring of Snow for the Benefit of Climate Change Scenarios, Hydrology and Numerical Weather Prediction |
| **HMS** | National Hydrological and Meteorological Service, Republic of North Macedonia (Macedonia) |
| **HNMS** | Hellenic National Meteorological Service (Greece) |
| **HZB** | Austrian Federal Ministry of Sustainability and Tourism – Department Water Budget (Austria) |
| **IHMS** | Institute of Hydrometeorology and Seismology of Montenegro (Montenegro) |
| **IMGW** | Institute of Meteorology and Water Management – National Research Institute (Poland) |
| **IMO** | Vedurstofa Íslands – Icelandic Meteorological Office (Iceland) |
| **IPMA** | Instituto Português do Mar e da Atmosfera (Portugal) |
| **KNMI** | Royal Netherlands Meteorological Institute (the Netherlands) |
| **LEGMC** | Latvian Environment Geology and Meteorology Centre (Latvia) |
| **LfU** | Avalanche Warning Service in the Bavarian Ministry for Environment (Germany) |
| **LHMS** | Lithuanian Hydrometeorological Service under the Ministry of Environment (Lithuania) |
| **MA** | Servei de Meteorologia del Govern d'Andorra / Oficina de l'Energia i del Canvi Climàtoc (Andorra) |
| **MAPAMA** | Spanish Ministry of Agriculture and Fishing, Food and Environment (Spain) |
| **MC** | Meteomont Carabinieri – Italian Snow and Avalanche Forecast National Service (Italy) |
| **Met Éireann** | Irish Meteorological Service Met Éireann (Ireland) |
| **MeteoSwiss** | Federal Office of Meteorology and Climatology MeteoSwiss (Switzerland) |
| **METNo** | The Norwegian Meteorological Institute (Norway) |
| **MF** | Météo-France (France) |
| **MO** | Met Office (United Kingdom) |
| **NIMH** | National Institute of Meteorology and Hydrology of the Bulgarian Academy of Sciences (Bulgaria) |
| **NMA** | National Meteorological Administration Romania (Romania) |
| **NPRA** | Norwegian Public Roads Administration (Norway) |
| **NVE** | The Norwegian Water Resources and Energy Directorate (Norway) |
| **OMSZ** | Hungarian Meteorological Service (Hungary) |
| **OSCAR** | Observing Systems Capability Analysis and Review Tool of the World Meteorological Organization |
| **OSUG** | OSUG@2020 Investissements d'Avenir – ANR10 LABX56 (France) |
| **PAT** | Provincia Autonoma di Trento (Italy) |
| **RAVA** | Centro Funzionale Regione Autonoma Valle d'Aosta (Italy) |
| **RHMSS** | Republic Hydrometeorological Service of Serbia (Serbia) |
| **RMI** | Royal Meteorological Institute of Belgium (Belgium) |
| **ROSHYDROMET** | Federal Service for Hydrometeorology and Environmental Monitoring under the Ministry of Natural Resources and Ecology of the Russian Federation (Russia) |
| **SCNAT** | Swiss Academy of Sciences (Switzerland) |
| **SEP** | Swiss Snow, Ice and Permafrost Society (Switzerland) |
| **SHMU** | Slovak Hydrometeorological Institute (Slovakia) |
| **SHS** | State Hydrometeorological Service (Moldova) |
| **SLF** | WSL Institute for Snow and Avalanche Research SLF (Switzerland) |

| | |
|---|---|
| **SMHI** | Swedish Meteorological and Hydrological Institute (Sweden) |
| **SNSF** | Swiss National Foundation for Scientific Research (Switzerland) |
| **SSCV** | Corpo Forestale Regionale SSC Valanghe of the Autonomous Region of Friuli Venezia Giulia (Italy) |
| **SYKE** | Finnish Environment Institute (Finland) |
| **TSHW** | Turkish General Directorate of State Hydraulic Works (Turkey) |
| **TSMS** | Turkish State Meteorology Service (Turkey) |
| **UHMC** | Ukrainian Hydrometeorological Center (Ukraine) |
| **UHMI** | Ukrainian Hydrometeorological Institute (Ukraine) |
| **WIS** | Information System of the World Meteorological Organization |
| **WMO** | World Meteorological Organization |
| **WSL** | Swiss Federal Institute for Forest, Snow and Landscape Research WSL |
| **ZAMG** | Zentralanstalt für Meteorologie und Geodynamik (Austria) |

## Key Symbols

| Symbol | Units | Description |
|---|---|---|
| $L$ | m | Height of a snow sample |
| $m_{sample}$ | kg | Weight of a snow sample |
| $\rho_{snow}$ | kg $m^{-3}$ | Snow density |
| $R$ | m | Radius of the snow cylinder or tube |
| **SWE** | mm w.e. or kg $m^{-2}$ | Water equivalent of snow cover |
| **WE** | mm w.e. or kg $m^{-2}$ | Water equivalent of snow sample |

# Contents

# Introduction

## The importance of snow

Snow cover is a key driver of the Earth's climate system, with local, regional and global effects on atmospheric circulations. The physical properties of snow, mainly high albedo and low thermal conductivity, strongly control the surface energy balance. As an essential component of the cryosphere, snow cover influences soil temperature, freeze and thaw cycles, and permafrost stability (Zhang, 2005). Seasonal snow is additionally a critical component of the hydrological cycle and affects the hydrological budget all year round in many regions of the world, particularly at high elevations and high latitudes. Water stored in snow contributes to the timing and magnitude of streamflow, affecting water resource availability (Barnett et al., 2005; Beniston and Stoffel, 2014) during winter and during the snow melt season when rivers and reservoirs are filled up again. Seasonal snow cover is particularly sensitive to climate change, as changes in temperature and precipitation cause shifts in the snow cover regime (i.e. timing, duration). Furthermore, climate-driven changes in snow cover can affect atmospheric dynamics and thus regional weather patterns, permafrost distribution, biogeochemical fluxes, ecosystem dynamics, and the frequency and severity of snow-related natural hazards (GCW, 2018).

Hammond et al. (2018) investigated and mapped snow persistence and snow zones globally based on 15 years of satellite data (2001–2016). Snow persistence is defined as the fraction of the year that snow is present on the ground and can be used to map areas that display similar snow patterns, the so-called snow zones. Snow zones are defined as: (1) permanent zones (90–100% snow persistence) with snow year-round, (2) seasonal zones (30–90% snow persistence) with snow persisting through the winter and (3) intermittent zones (7–30% snow persistence) with discontinuous snow cover during winter. At the global level, average snow persistence generally increases at both higher elevations and higher latitudes (Fig. 1). In Europe in particular, at high latitudes (> 60° N) snow cover is seasonal near sea level because these areas are located near the coast (Fig. 1), while permanent snow zones occur mainly at elevations between 1 000 and 2 000 m a.s.l. Snow persistence in Europe decreases at latitudes < 45° N, especially at low elevations: no snow persists at elevations near sea level, while intermittent snow is found between approximately 800 and 2 000 m a.s.l. At latitudes between 35° N and 45° N snow persistence increases markedly at elevations > 2 000 m a.s.l., as large mountain ranges (e.g. European Alps) exist in this region and even feature permanent snow above 3 000 m a.s.l.

## COST Action ES1404 HarmoSnow

The quantification of snow cover, including its various micro- and macrophysical properties, is essential for environmental and economic impact assessments. Further, adequate description and assimilation of snow cover properties in numerical weather prediction (NWP), hydrological, land surface and climate models are indispensable. However, a detailed and coherent description of snow-related measurements in models relies heavily on the use of harmonised snow measurement approaches.

Practitioners and researchers worldwide have developed different best practices for snow-related in-situ measurements. The bulk of these guidelines are similar throughout the world, but local particularities are often included. These regional practices lack harmonisation and thus hamper further developments, such as NWP models, remote sensing applications and spatial analysis, used in hydrological and climatological applications. Both the operational and scientific communities recognised early on that such guidelines should be widely harmonised in order to easily exchange data and knowledge across borders and to use data that can be interpreted at the global level. Consistency is essential! A document that combines the needs of all communities interested in snow cover measurements, such as meteorology, hydrology, climatology, data assimilation, satellite product development, avalanche warning services and research, is urgently required. Creating such a document was exactly the goal of the European Union COST Action ES1404 "A European Network for a Harmonised Monitoring of Snow for the Benefit of Climate Change Scenarios, Hydrology and Numerical Weather Prediction"[12], hereafter referred to as HarmoSnow, which ran from November 2014 to November 2018 (HarmoSnow, 2018). More specifically, the aims of this Action were: (1) to harmonise practices and standards

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[12] http://www.harmosnow.eu/

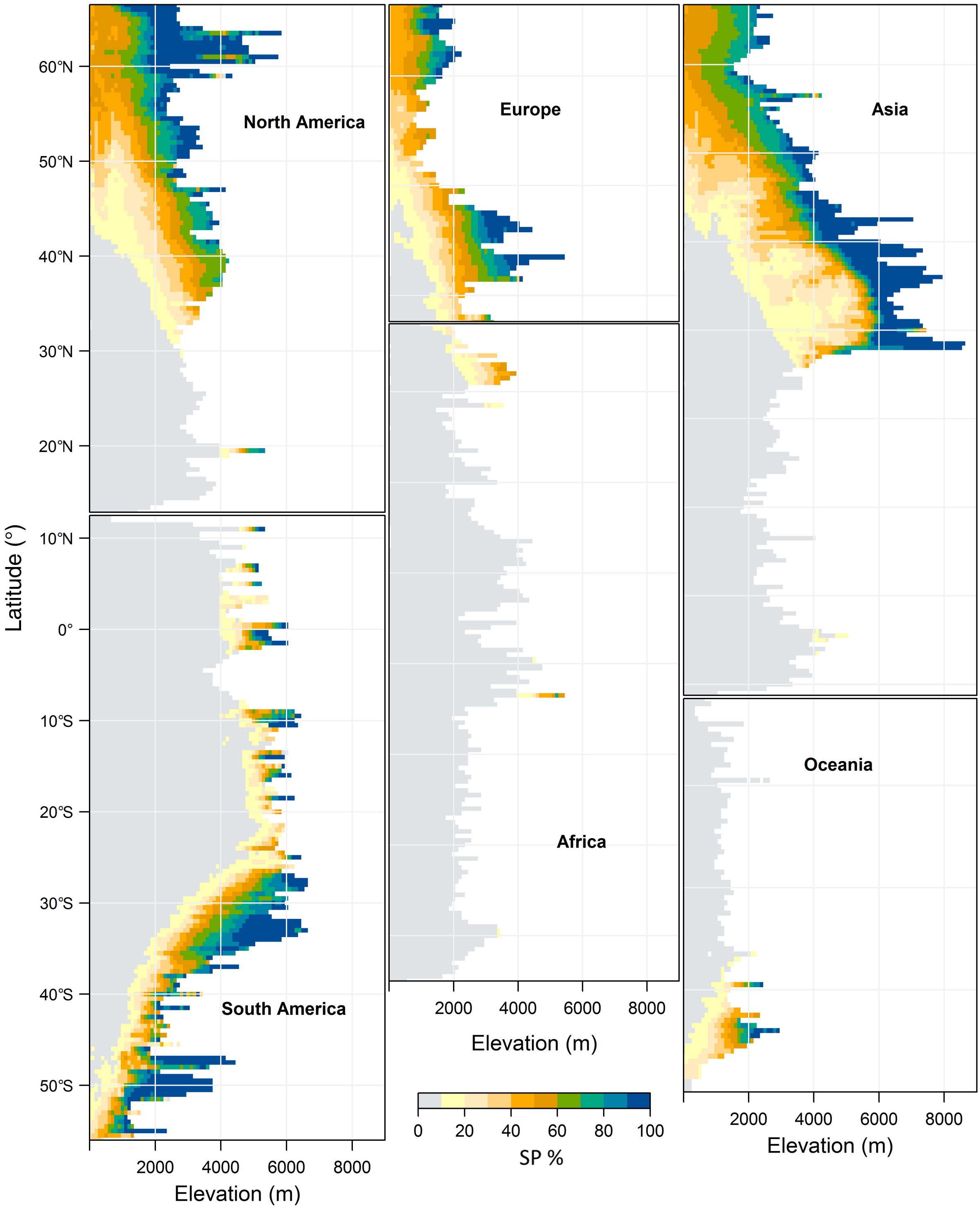

*Figure 1 The average 2001–2016 snow persistence (SP, %) by latitude and elevation for North America, South America, Africa, Asia, Europe and Oceania. Figure from Hammond et al. (2018).*

applied to snow measurements and (2) to build a better connection between snow measurements and models and between observers and researchers.

COST, the European Cooperation in Science and Technology[13] (COST, 2018), supports transnational cooperation among researchers, engineers and scholars in all fields of science and technology, including social science and the humanities, across Europe. COST has contributed to narrowing the gap between science, policy and society throughout Europe and beyond. COST Actions are flexible, effective and efficient science and technology networks open to researchers and stakeholders, and they are of public interest. Within the framework of Actions, which usually last four years, European researchers are allowed to develop ideas in any science or technology field and to cooperate and coordinate research activities using various networking tools, such as workshops, conferences, training schools, short-term scientific missions and dissemination activities.

At a time when there is a global call to harmonise snow-cover measurements and monitoring practices, the COST Action HarmoSnow provided the framework to make a large step forward in this endeavour, which will benefit the snow-related research communities and operational services in Europe. HarmoSnow focused on three main issues: (1) the physical characterisation of snow properties, (2) instrument and method evaluation, and (3) snow data assimilation and validation methods for NWP and hydrological models. With respect to these tasks, the main Action objectives of HarmoSnow were:

- Establish a European scientific network of snow measurements for their optimum use and develop applications that benefit from interactions between experts from different fields.
- Assess and harmonise practices, standards and retrieval algorithms applied to ground, air-borne and space-borne snow measurements and foster their acceptance by key snow network operators at the international level.
- Develop a rationale and long-term strategy for snow measurements, as well as their dissemination and archiving.
- Advance snow data assimilation (DA) in European NWP and hydrological models and show its benefit for relevant applications.
- Establish a validation strategy for climate, NWP and hydrological models against snow observations and foster its implementation within the European modelling communities.
- Train a new generation of scientists on snow science and measuring techniques, emphasising a broader and more holistic perspective linked with the various applications.

Three working groups (WGs) were established to accomplish the above-mentioned objectives:

- WG 1 dealt with the physical characterisation of snow properties.
- WG 2 addressed instrument and method evaluation.
- WG 3 focused on snow data assimilation and validation methods for NWP and hydrological models.

WG 1 and WG 2 were strongly connected to each other with cross-disciplinary tasks, e.g. with regards to defining the measured snow variables or to techniques for measuring essential snow variables. WG 3 was linked to the other WGs through the physical characterisation of the modelled snow variables and through observation uncertainties.

Twenty-nine European countries participated in the COST Action HarmoSnow (Fig. 2): Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom. In addition, two international partners, Andorra (located in Europe but not a COST member state) and Taiwan, were also involved in HarmoSnow.

At the Management Committee meeting of the COST Action HarmoSnow 2015 in Helsinki, Finland, the Action Chair *Ali N. Arslan* proposed the compilation of a publication on how to measure snow. This in turn motivated *Charles Fierz* and *Christoph Marty* to submit a proposal to the Swiss COST office, with the aim of securing the resources necessary to complete a project giving an overview of the current national operational snow monitoring networks in Europe within the Action's lifetime. The proposal "European Snow Booklet: Best Practices for Snow Monitoring" was funded by the Swiss National Foundation for Scientific Research on behalf of COST Switzerland.

# Why write a European Snow Booklet?

The European Snow Booklet (ESB) is a reference book of the national operational snow measurements in many European countries that has been produced within the framework of the COST Action HarmoSnow. The content of the ESB was motivated by experiences from the Global Cryosphere Watch[14] (GCW) of the World Meteorological Organisation[15] (WMO) and the WMO Solid Precipitation Intercomparison Experiment[16] (SPICE). Both of these international projects demonstrated that there are different measurement

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[13] http://www.cost.eu/
[14] http://globalcryospherewatch.org/
[15] https://www.wmo.int/pages/index_en.html
[16] http://www.wmo.int/pages/prog/www/IMOP/intercomparisons/SPICE/SPICE.html

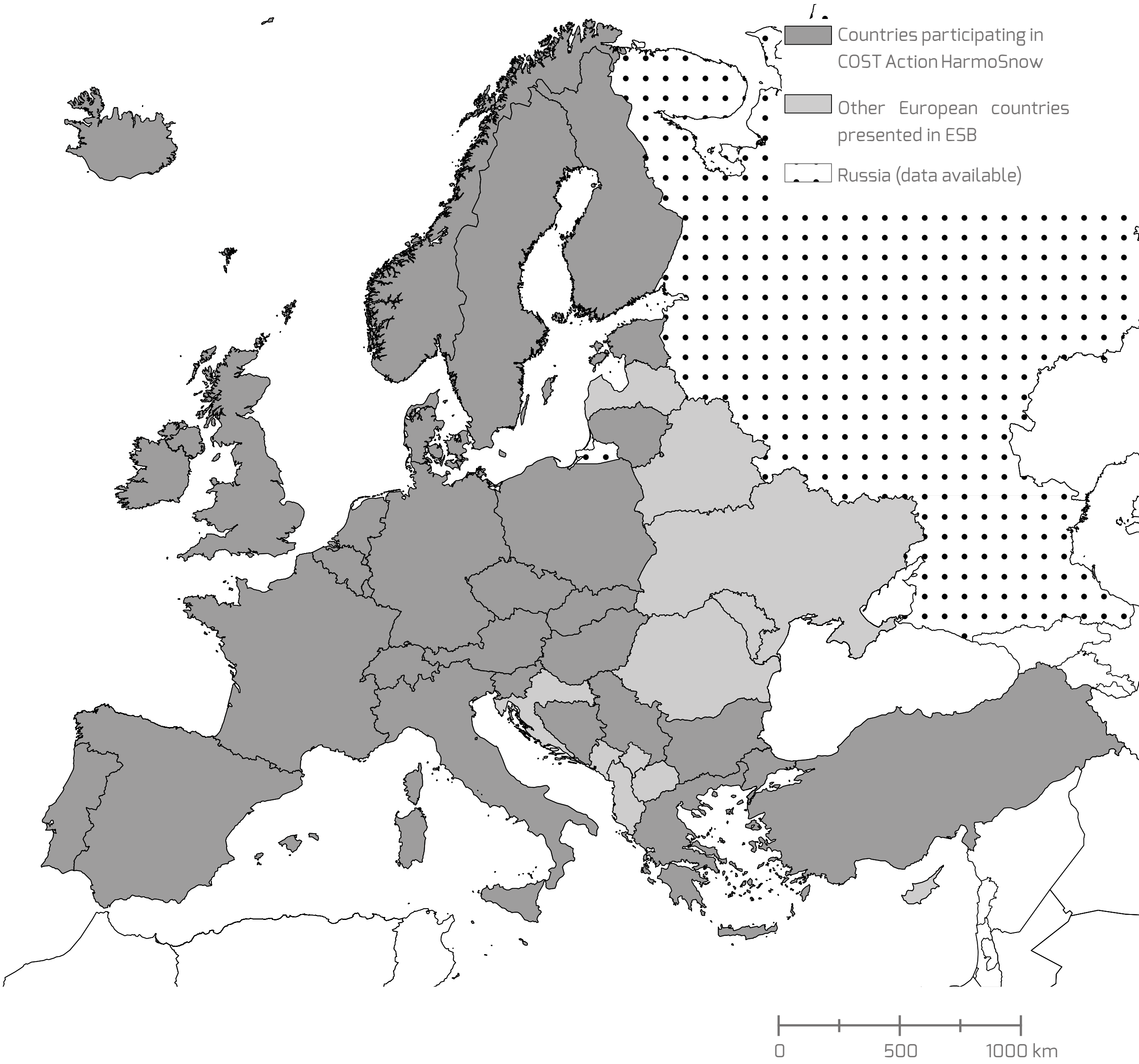

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*Figure 2 Countries participating in HarmoSnow (grey) and additional European countries (light grey) included in the European Snow Booklet (ESB). Data was also available from Russia (white with black dots).*

guidelines for snow in the individual countries within Europe. Therefore, the main idea behind the ESB was to extend our knowledge on current operational snow observations and the methods used to perform these measurements in the different European countries.

Operational snow monitoring stations were set up when national weather services were founded in the 19th century (e.g. 1865 in Switzerland and 1895 in Austria) in order to perform snow observations on a regular basis. Despite the fact that some long-term snow records are available, little is known about the measurement principles which were used during the past or those used today at the inter-European level. Therefore, the aim of the ESB is to improve the current knowledge and awareness of both the scientific community and the operational services dealing with snow measurements, as well as the general public, with regards to the different basic snow measurement methods applied in each European country. This is an important issue because the European snow science community currently lacks knowledge about which European countries operationally measure snow, not to mention which snow variables are measured with which methods.

A large network including both researchers and practitioners from all parts of Europe was established within the COST Action HarmoSnow, thus reducing the gap between research and applied sciences. The ESB is an essential contribution and a valuable dissemination product of the COST Action HarmoSnow beneficial for all actors involved in snow-related research and operational services, including: (1) (snow) scientists and (2) practitioners such as observers, national meteorological and hydrological services and engineers. Further, the ESB is relevant for stakeholders interested in snow observations, i.e. those in the fields of meteorology, hydrology, climatology, avalanche warning, data assimilation and satellite product development (e.g. stakeholders involved in the European Union's Earth Observation Program Copernicus[17]).

The ESB provides a unique collection of information about current operational snow observations in many European countries (Fig. 2) and the methods used to perform basic measurements of snow on the ground. In the ESB we focus on the following four basic snow variables (Chapter I-1):

- Snow depth (HS)
- Presence of snow on the ground (PSG)
- Depth of snowfall (HN)
- Water equivalent of snow cover (SWE)

Information and metadata on these basic snow variables were collected through a comprehensive survey, the so-called ESB Questionnaire (Appendix I-B), between August 2017 and March 2018.

Numerous institutions from 38 European countries (Fig. 3) provided detailed information on their operational snow monitoring network. Data from Russia was also available. Similarities and differences among the countries regarding the spatial and elevational distribution of measurement stations, the measurement intervals used and the methods applied are pointed out, indirectly showing the relevance of snow for each country. Based on the country-specific information provided, a country report was written for each European country (Chapter I-2), describing the current status of the operational snow observations and the methods used by one or several institutions. The core of the ESB is therefore 38 country reports, one for each European country that contributed data. A report on Russian snow measurements is presented separately (Appendix I-A). The ESB is a comprehensive overview of operational snow observations in Europe produced through collaboration with many European snow practitioners and snow scientists. Although complete information is not included for all countries, this inventory should be considered a great success because for many countries it is incredibly difficult to find out which institutions are responsible for operational snow measurements and to contact the correct country representatives.

# Outline of the European Snow Booklet

The intention of the ESB is to foster better knowledge transfer regarding snow measurements between the snow science and operational communities and to improve the communication of information to the general public. Apart from this introductory chapter, the book is divided into two main parts, Part I and Part II.

Part I features an overview of snow measurement principles and includes a description of the current European-wide status of operational snow monitoring networks. Part I is divided into three main chapters: Chapter I-1 consists of a detailed description of the four basic snow variables measured on the ground. Chapter I-2 is the inventory of operational snow measurements and methods applied in each European country, presented as 38 country reports. Chapter I-3 features a comprehensive analysis and evaluation of all country data. Chapter I-4 summarises Part I of the ESB and provides an overview on snow measurements in Europe.

Part II consists of summaries of three main activities accomplished within the COST Action HarmoSnow: Chapter II-1 includes details of three SWE intercomparison campaigns conducted within HarmoSnow and provides recommendations for SWE observations. Chapter II-2 consists of an overview of measurement methods used in Europe for a diverse set of snow observations and is based on the WG 1 – WG 2 Questionnaire. Chapter II-3 features a summary of the goals achieved by WG 3 and provides a discussion of snow data assimilation in research and operational applications.

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[17] https://insitu.copernicus.eu

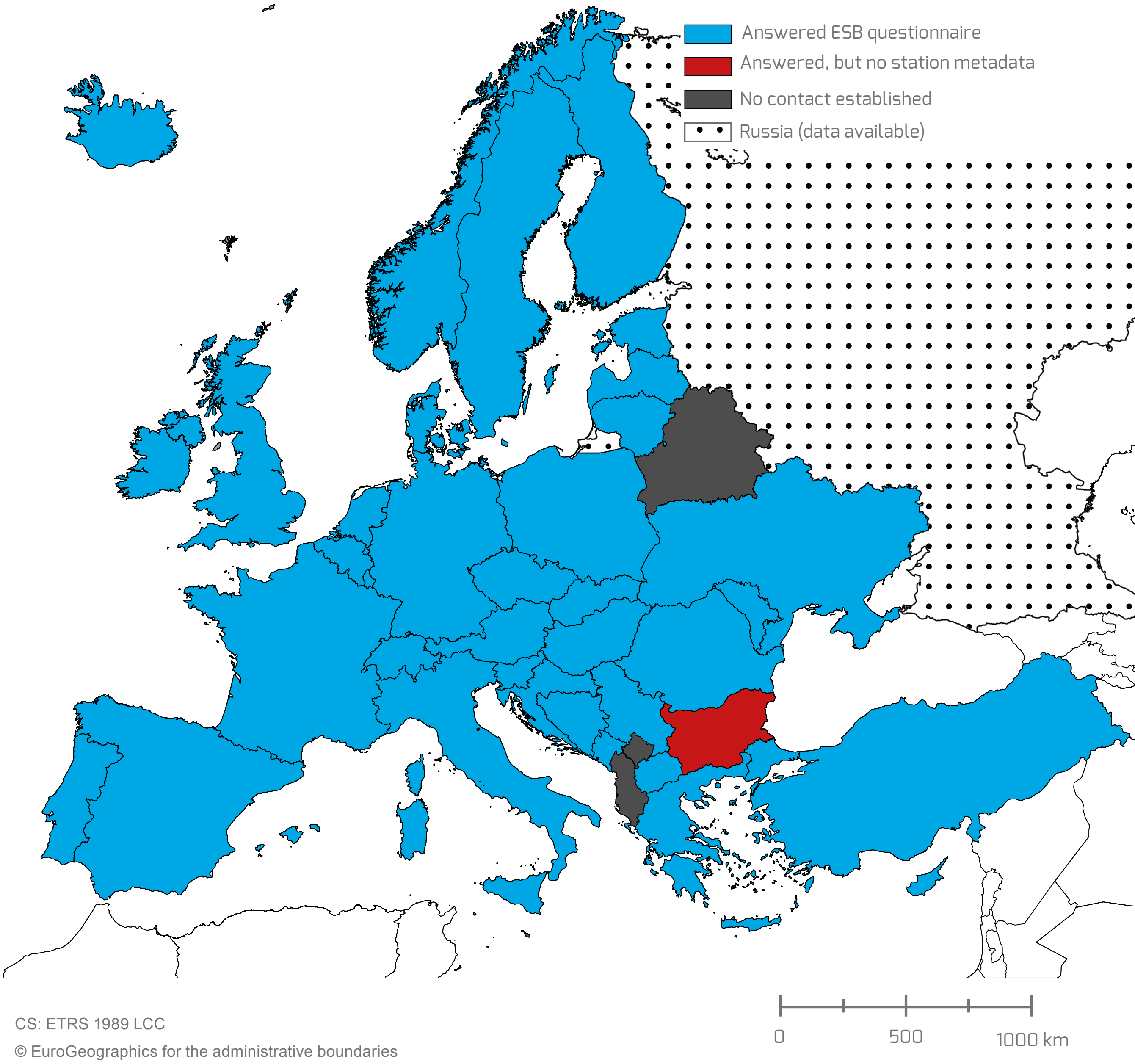

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*Figure 3 Overview of European countries that participated in the European Snow Booklet (ESB) Questionnaire. Countries shown in blue participated in the questionnaire and provided comprehensive information and metadata on their snow monitoring network. Bulgaria (shown in red) is the only country that responded to the questionnaire but did not provide complete station metadata. No reliable contact could be established for Albania, Belarus, Kosovo, Malta, Monaco, San Marino or Vatican City (shown in grey). Data was provided from Russia (shown in white with black dots; see Appendix I-A for country report) but was not included in the analysis presented in Chapter I-3.*

# Part I

Part I of the European Snow Booklet (ESB) is a unique collection of information about operational snow observations in European countries and the methods used to perform the in situ measurement of four basic snow variables: snow depth, presence of snow on the ground, depth of snowfall and water equivalent of snow cover. The chapters in Part I are built on each other. First, the four basic snow variables and the most common measurement methods and instruments are described in Chapter I-1 to avoid mixing terms and definitions in the following chapters of Part I. Chapter I-2 consists of detailed information on the operational snow measurement networks of 38 European countries and the methods applied. Finally, the analysis of this European-wide inventory in Chapter I-3 points out similarities and differences between the countries regarding the number of stations and their spatial and elevational distribution, thus indirectly showing the relevance of snow for each country. Finally, the importance of distributing national snow depth observations over WMO's Global Telecommunication System (GTS) is discussed.

# I-1 Snow Variables and Measurement Methods

A. Haberkorn

WSL Institute for Snow and Avalance Research SLF, Davos, Switzerland

The European Snow Booklet (ESB) focuses on four basic snow variables measured on the ground, where “ground” or “base surface” refers to any reference surface below the snow cover, e.g. soil. In this chapter the four snow variables and the most common measurement methods are briefly described. Additionally, the most common measurement instruments are presented in order to clearly distinguish between the different methods and devices and to avoid mixing terms and definitions in the other chapters of the ESB. Throughout Part I of the ESB, we therefore refer to the methods and instruments described below, showing the most common techniques used by institutions carrying out operational snow observations. However, some institutions additionally apply instrumentation and methods other than those described below, and they are emphasised in Chapter I-2.

When “operational” snow observations are described, the term “operational” is neither strictly nor clearly defined. National weather services often run operational stations of the World Meteorological Organisation (WMO), but not all national weather stations are WMO stations. Nevertheless, these stations are still treated as operational and thus included in the national snow station networks in Chapter I-2. In addition to snow observation stations of national weather services, stations operated by other institutions are included here as long as the long-term characteristics and the continuity of their measurements are ensured. With a few exceptions in Chapter I-2, no research stations are included in Part I because they are often linked to temporary scientific projects and thus they cannot be considered a source of long-term operational observations. However, in a few cases where long-term snow monitoring is assured, research stations are included in country data (e.g. Sections I-2.32, I-2.35). In contrast to the above-given explanation of “operational” snow stations included in Chapter I-2, for WMO’s Global Telecommunication System (GTS) station network (Section I-3.6) “operational” refers to all stations that distribute their data via the GTS. However, the station data distributed over the GTS depends on decisions made by the national weather services and is therefore also not homogeneous.

This chapter relies on the currently developed WMO Global Cryosphere Watch (GCW) Best Practices for measurements of snow (WMO No. 8, 2018) and the experiences of the working group that focused on snow on the ground during the WMO Solid Precipitation Intercomparison Experiment (SPICE). However, this chapter is not a guideline for setting up a snow monitoring station. For detailed guidance on the procedures and best practices for setting up a snow monitoring station, and for information on common sources of error when measuring snow on the ground, we refer readers to the WMO GCW Best Practices (WMO No. 8, 2018) and the WMO SPICE final report (Nitu et al., 2018).

The four basic snow measurements on which Part I of the ESB is based are:

- Snow depth (HS)
- Presence of snow on the ground (PSG)
- Depth of snowfall (HN)
- Water equivalent of snow cover (SWE)

The information provided is for both manual and automatic measurements (where applicable).

## I-1.1 Siting of snow observations

Generally, the ideal site for measuring snow is a flat, wind-sheltered area where the snow cover and the base surface are relatively homogeneous. However, the measurement area should also represent the surrounding landscape as much as possible. The exception to this is the measurement of depth of snowfall, which should, if possible, always be made in a sheltered location where the snow is allowed to fall undisturbed and the impact of wind is minimised. For forested sites, a measurement location within a clearing is preferred. In alpine terrain, a flat area large enough to make a representative measurement without encountering edge effects should be chosen, avoiding basins, slopes and ridges. All point and spatially distributed (snow course) measurements should be separated from obstructions by a distance of at least twice the obstruction height.

For manual point measurements of snow depth and water equivalent of snow cover, a measurement field should be established prior to the snowfall season. An optimal size is a 10 x 10 m area that will remain almost undisturbed over the course of the winter.

Unless the measurement area is very homogeneous, point measurements of snow depth and water equivalent of snow cover are not necessarily representative of the surrounding landscape. This is especially true for automatic snow depth measurements at the point scale. In contrast, for manual snow depth measurements the observer has some capability to average multiple point measurements before reporting a value. For some applications, e.g. hydrological, an extensive survey of snow depth and water equivalent of snow cover at least once per season (at the time of maximum snow accumulation) is recommended to assess the spatial representativeness of the point measurements. As spatial variability in the bulk density of the snow cover is generally much smaller than the snow cover depth (e.g. Dickinson and Whiteley, 1972), variability in water equivalent of snow cover can often be assessed with a snow depth survey alone.

## I-1.2 Snow depth

Snow depth is defined as the vertical distance from the snow surface to a stated reference level and is reported in full centimetres (cm). In most cases the reference level corresponds to the base surface (ground). Unless otherwise specified, a snow depth measurement refers to a measurement at a single location at a given time.

### I-1.2.1 Manual measurement of snow depth

Here we distinguish between two different approaches and their associated devices for the manual measurement of snow depth: (1) a graduated stake for permanently fixed measurements (Fig. I-1.2.1 a) and (2) a graduated (extendible) rod or ruler for non-fixed measurements (Fig. I-1.2.1 b, c). The choice of the measurement device may depend on both the permanency of the installation and the nature of the snowpack being measured. Regardless of permanency, the location of the measurement should be consistent for all measurements.

(1) For permanent (fixed) or semi-permanent (seasonally fixed) point measurements, a fixed snow stake (Fig. I-1.2.1 a) is used, with highly visible graduations so that it can be read at a distance. If the installation is seasonal, it is important that the stake is placed in the exact same location each year. Snow stakes should be observed from a sufficient distance so the snow near the stake is not disturbed. Observations should be made parallel to the snow surface and from approximately the same observation point each time.

(2) For a non-fixed snow depth observation, either a graduated (extendible) ruler (e.g. metre stick; Fig. I-1.2.1 b) or a graduated (extendible) rod (Fig. I-1.2.1 c) is manually inserted into the snowpack to the ground surface. For measuring deep and/or dense snowpacks or snowpacks with ice layers, the use of a rod is advisable so that it can be pushed through the snowpack until the pointed end contacts the base surface with rod extensions added as required for deep snowpacks. On inclined surfaces, the rod should be inserted vertically into the snowpack. The observation should be made in the same location each time, recognising that some adjustment may be required to sample undisturbed snow.

A measurement can be an observation at a single point or observations at many points along a snow course or in an area. Unlike a point measurement, the measurement of multiple snow depths along a snow course makes it possible to assess the spatial variability of snow depth at the observation site. For spatially distributed snow depth measurements, the length of the snow course and the number of stakes included are determined based on the snow variability at the study site. Generally, a snow course consists of 5 to 10 stakes installed 5 to 10 m apart. If measurements from multiple stakes in a snow course are averaged, the average should be reported in full centimetres.

For all the cases described above, a snow depth of 0 cm is recorded if more than 50% of the measurement field is snow free, even if there is still some snow at the stake itself. Reporting 0 cm snow depth under snow-free conditions, rather than reporting nothing, is extremely important (Section I-3.6) and has recently been regulated by WMO's Resolution 15 on "International exchange of snow data"[18] (WMO No. 69, 2017).

*Figure I-1.2.1 (a) Graduated snow stake installed before the onset of a snow cover (Source: ESTEA). (b) Snow depth measurement with a ruler in northern Finland (Source: FMI). (c) An extendible 1-cm-graduated snow rod (Source: ECCC).*

## I-1.2.2 Automatic measurement of snow depth

Automatic measurements of snow depth can be made using instruments employing either (1) sonic or (2) optical (laser) technology. Both sonic and optical devices measure the distance to a target (i.e. the snowpack, the base surface) rather than directly measuring the distance from the base surface to the top of the snow cover. Although other automated techniques are available, these two instrument types are the most commonly used. The choice of using a sonic or laser instrument mainly depends on the availability of a power source, as well as the requirements for measurement accuracy and spatial representativeness. Laser instruments have a higher degree of precision (approx. 0.1 cm) than sonic instruments (approx. 2 cm), but they require more power for operation.

(1) Sonic instruments (Fig. I-1.2.2 a) transmit an ultrasonic pulse towards the target and listen for a return signal reflected from that target. Sonic instruments usually measure the distance to the highest obstacle within the instrument response area. The response area is a conical footprint, the radius of which depends on the height of the instrument above the target.

(2) An optical or laser instrument (Fig. I-1.2.2 b) emits a modulated beam of light in the visible spectrum and determines the distance to a target by analysing the phase information from the reflected beam. Unlike sonic instruments, the response area of a laser instrument is quite small (< 5 mm radius at a distance of 4 m). Optical instruments sometimes have the capability of outputting a signal strength measurement, which can be useful for optically determining the presence of snow beneath the instrument.

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[18] https://library.wmo.int/index.php?lvl=notice_display&id=19919#.W4AgERZG1e5

For automatic point measurements, snow depth should be measured on a level surface. Surface irregularities under the instrument can be minimised by surface preparation prior to snowfall or by using an artificial surface target, especially during the season of active vegetation growth and at the beginning of the snow accumulation period. A high quality measurement can be achieved either by siting the instrument over closely mown grass (or another flat and bare natural surface) or by using an artificial target, e.g. artificial turf or a plastic surface with thermal properties similar to those of natural ground (Figs I-1.2.2, I-1.2.3). However, the colour or thermal property of such artificial targets can cause earlier or delayed snow melt compared to natural ground. Moreover, the signal strength of the measurement by laser technology can be strongly influenced by the reflective properties of the target.

*Figure I-1.2.2 Automatic snow depth instruments: (a) sonic instrument with artificial turf below (Source: FMI); (b) laser instrument with artificial target below (Source: DWD).*

*Figure I-1.2.3 A perforated and textured grey plastic target construction. Landscape fabric (thick textile) is installed beneath the target to minimise vegetation growth (Source: ECCC).*

# I-1.3 Presence of snow on the ground

Presence of snow on the ground is a binary observation of the presence of snow cover at the measurement location. The observation is usually performed manually in situ, although semi-automated or automated techniques can be used.

## I-1.3.1 Measurement of presence of snow on the ground

Manual measurement of presence of snow on the ground is generally a visual assessment by one observer of whether the field of view of the measurement site is more or less than 50% covered with snow of any depth. The field of view is generally an area of about 50 x 50 m and not less than 10 x 10 m, and it should not be limited to the area immediately surrounding the snow stake. The field of view of the measurement site is observed visually and the percentage of snow cover is assessed. If the percentage is greater than or equal to 50%, the observer reports that snow is present at the site. If the percentage is less than 50%, the observer reports that no snow is present (Section I-1.2.1).

Semi-automated or automated techniques, such as photometry, for measuring presence of snow on the ground are identical to manual visual measurements, except that the interpretation of coverage is done via a photograph or live video feed rather than in person.

# I-1.4 Depth of snowfall

Depth of snowfall is the vertical depth of freshly fallen snow that has accumulated during a specific period and is reported in units of centimetres (cm). Currently, no accepted automated technique is available for the measurement of depth of snowfall. The main reason for this is that depth of snowfall is measured as the accumulation of new snow on a snow-free surface, while suitable automatic snow depth instruments generally can only measure incremental increases to an existing snow cover. If there is snow on the ground before a measurement, it is incorrect to calculate depth of snowfall as the difference between two consecutive measurements of snow depth because lying snow settles and may undergo ablation processes, resulting in an underestimation of depth of snowfall. Therefore, only manual techniques are described here and only manual measurements are included in Chapter I-2.

## I-1.4.1 Manual measurement of depth of snowfall

Depth of snowfall is measured using a graduated device, such as a ruler, at a defined temporal interval, usually 24 hours. Snow is allowed to accumulate undisturbed on an artificial surface, such as a snow board (Fig. I-1.4.1 a), for the prescribed interval and then a ruler is inserted vertically into the accumulated snow to obtain a depth measurement rounded to the nearest 0.5 cm (Fig. I-1.4.1 b). The depth should be measured in several locations on the board if the snow is not evenly distributed, in which case the average depth should be reported. Following the observation, the artificial surface is cleared of snow (Fig. I-1.4.1 c) and replaced on top of the existing snowpack for the next interval. The cleared snow is used to fill the hole where the previous measurement was made. The snow board should be placed flush with the surface, which is the bare ground prior to the accumulation of snow. If the snow accumulated on the board covers less than 50% of its surface or if the snow cover is too thin to be measurable (less than 0.5 cm), the amount is recorded as “trace”. Surface frost on the snow board should not be considered as new snow and should be cleared from the board at the time of the observation. If the amount of new snow on the snow board differs strongly from the perceived depth of snowfall in the surrounding area, owing to wind redistribution, the observer should correct the measurement and indicate the correction with a note, such as “depth of snowfall corrected”. The corrected value is estimated by taking into account observations in the vicinity of the measurement field. In cases where no snowfall occurred but the snow board is snow covered because of blowing snow, the depth of snowfall is reported as 0 cm.

*Figure I-1.4.1 Method for measuring depth of snowfall. (a) Snow board with a graduated rod attached to the centre, which doubles as a measuring device and a handle (Source: AEMET). (b, c) Depth of snowfall measured with a graduated ruler on a snow board. This board has two handles at its edges to locate the board under the snow and to assist with clearing and replacing the board after each measurement (Source: SLF).*

# I-1.5 Water equivalent of snow cover

Water equivalent of snow cover (SWE), commonly referred to as snow water equivalent, is the vertical depth of water that would be obtained if the snow cover melted completely, which equates to the snow cover mass per unit area. It is expressed either in millimetres w.e. (water equivalent), where the addition of w.e. after the length unit is strongly recommended, or in kilograms per square metre. Water equivalent of snow cover is the product of the snow depth in metres and the vertically integrated density of the snow in kilograms per cubic metre (Goodison et al., 1981). It can represent the snow cover over a given region or a confined snow sample over its corresponding area. The reported resolution of SWE is 1 mm w.e. or 1 kg $m^{-2}$.

## I-1.5.1 Manual measurement of water equivalent of snow cover

There is a large variety of manual measurement techniques for SWE. Generally, all measurement techniques involve a snow sampler which collects a known (or calculable) volume of snow from which snow density can be derived. We focus on and distinguish between two general SWE measurement techniques and the associated instruments: (1) SWE measurements in snow pits using snow cylinders (Figs I-1.5.1, I-1.5.2) and (2) SWE measurements without snow pits (e.g. in snow courses) using snow tubes (Fig. I-1.5.3). Various snow cylinders and snow tubes are in use, and the type chosen largely depends on the nature of the snowpack being sampled (Chapter II-1). When referring to both instrument types, snow cylinder and snow tube, throughout the ESB, the hypernym "sampler" is used.

(1) SWE measurements in snow pits: Snow pits (Fig. I-1.5.1 a) involve manually digging a pit in the snowpack down to the reference surface so that an undisturbed face of the snowpack is exposed. Snow pits are additionally a useful technique for observing the stratigraphy and mechanical stability of the snowpack. A cylinder of a known cross-sectional area (in $m^2$) is inserted vertically into the snow and a sample is extracted and weighed (Fig. I-1.5.1 b, c). The snow density of the sample $\rho_{snow}$ (in kg $m^{-3}$) is then obtained as:

$$\rho_{snow} = \frac{m_{sample}}{(\pi R^2 L)} \qquad \text{(I-1.5.1)}$$

where $m_{sample}$ is the weight of the sample (in kg), $R$ is the radius of the snow cylinder (in m) and $L$ is the height of the snow sample (in m) in the snow cylinder. The water equivalent WE (mm w.e. or kg $m^{-2}$) of the sample is then determined as:

$$WE = L \times \rho_{snow} \;\; ; \;\; SWE = \sum_{sample} WE \qquad \text{(I-1.5.2)}$$

And the water equivalent of snow cover SWE is calculated by summing the WE values of all sampled layers.

Procedure and tools: SWE is observed by volumetrically sampling the snowpack in incremental steps, starting at the snow surface in the pit and continuing until the base is reached (Fig. I-1.5.2). After a pit is dug, a thin metal plate with a bevelled edge is inserted horizontally into the snowpack at a given depth; a graduated snow cylinder with one bevelled end is then inserted vertically into the snowpack until it reaches the plate (Figs I-1.5.1 a, I-1.5.2). After the corresponding sample height is read from the graduations on the cylinder, the sample is extracted using a crystal card, scraper or spatula (Fig. I-1.5.2) and either weighed with a scale (e.g. spring scale, steelyard balance) or bagged and weighed (e.g. with a bench scale). In cases where the weighing is performed at a later time the samples should be labelled. The maximum height of a measured snow sample is determined by the length of the cylinder. Snow density is determined by Equation I-1.5.1. The corresponding water equivalent of the sample can be either determined by Equation I-1.5.2 or directly read from the scale (see Section I-2.36 for an example).

To sample the next incremental level or layer, the remaining snow surrounding the sample horizontally is cleared away, the snow is removed from the cylinder, and the whole sampling procedure is repeated until the base surface is reached. Note that the sum of the layer thicknesses is often less than the measured snow depth, owing to uneven ground and/or the thickness of the metal plate. This measurement technique is destructive and requires a relatively homogeneous area for repeated measurements during the winter season.

(2) SWE measurements without snow pits: The snow tube (Fig. I-1.5.3 a) is inserted vertically into the snowpack (Fig. I-1.5.3 b) to the base surface, using tube extensions where required, and a snow core is extracted. The volume of the core is calculated from the height of the snow core in the tube, knowing the sampler radius. The snow sample is then either weighed with a snow tube cradle and scale (e.g. spring scale, Fig. I-1.5.3 c) or bagged and weighed with a scale (at a later time). Snow density can be calculated manually by Equation I-1.5.1, where in this case $R$ is the radius of the snow tube (in m), $L$ is the height of the snow sample (in m) in the snow tube and needs to be measured before the snow tube is extracted from the snowpack, and $m_{sample}$ is the weight of the sample (in kg)

excluding the weight of the tube or the sample bag. SWE (in mm w.e. or kg m$^{-2}$) is then calculated according to:

$$SWE = L \times \rho_{snow} \qquad \text{(I-1.5.3)}$$

Procedure and tools: SWE measurements without snow pits using snow tubes (Fig. I-1.5.3) can be performed in snow courses. A snow course is a multi-point transect, usually consisting of 5 to 10 SWE sample locations spaced 30 m apart. A snow course should be established prior to the beginning of the snow accumulation season. The starting point of the snow course and the remaining sample points should be marked, numbering the stakes sequentially, or their coordinates should be recorded.

First, the snow tube is inserted vertically (cutter end first) into the snow surface. The tube is gently rotated so that the cutter drills into the snow until it reaches the base surface. If resistance is encountered because of ice layers, the tube is rotated more aggressively using the handles and increasing vertical pressure is applied on the tube to allow the cutter to penetrate the ice layer and continue through the remaining snowpack. When the observer is confident that the cutter has reached the base surface, the depth of both the snowpack and the core sample are read from the graduations on the tube. Finally, additional vertical pressure is applied to the tube so that the cutter penetrates the surface beneath the snowpack by approximately 2 cm, ideally including an adequate soil plug to hold the snow sample in the tube during extraction from the snowpack. After extraction, the soil plug is removed from the cutter and either the tube is weighed or the core sample is bagged and weighed. Snow density and consequently SWE can be calculated using Equations I-1.5.1 and I-1.5.3. Afterwards, the sample

*Figure I-1.5.1 Water equivalent of snow cover (SWE) measured in snow pits using a snow cylinder and scale: (a) snow sampling with a cylinder in a snow pit (Source: SLF); (b) a snow cylinder being weighed with a spring scale (Source: SLF); (c) a snow cylinder hung on a steelyard balance (Sources: ESTEA and UHMC).*

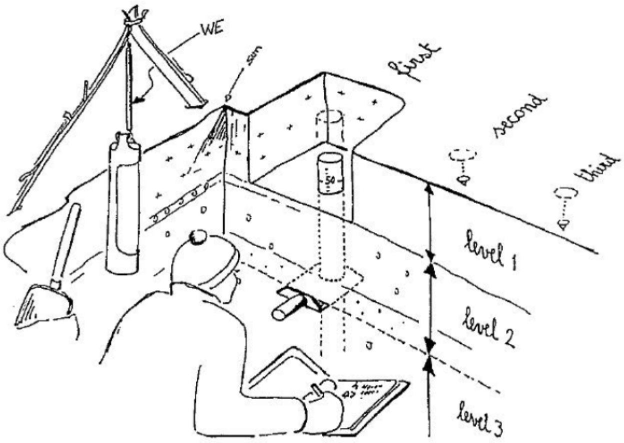

*Figure I-1.5.2 Conceptual sketch of a water equivalent of snow cover (SWE) measurement in a snow pit using a snow cylinder (Source: G. Kappenberger, SLF).*

*Figure I-1.5.3 Water equivalent of snow cover (SWE) measurements in snow courses using snow tubes (without snow pits): (a) snow tube (Source: ECCC); (b) SWE sampling with a snow tube (Source: ECCC); (c) snow tube placed in a snow tube cradle and attached to a scale (Source: ARPAVA).*

is emptied out of the tube. This method should be used in cases where SWE is not spatially homogeneous and thus spatially resolved sampling is required.

A snow course usually involves a technique called "double sampling", where multiple snow depth measurements (usually 10 to 15) are obtained between each SWE sample using a ruler or rod (Section I-1.2). The areal SWE is then calculated from the average density of the 5 to 10 snow tube samples and the average snow depth measured between the samples, using Equation I-1.5.3.

## I-1.5.2 Automatic measurement of water equivalent of snow cover

Several measurement approaches exist for the automatic measurement of SWE. The most common ones in operational use are (1) weighing mechanisms (e.g. snow pillows or snow scales; Fig. I-1.5.4 a) and (2) passive gamma radiation instruments (Fig. I-1.5.4 b). Other instruments, such as Global Navigation Satellite Systems (GNSS; e.g. Jacobson, 2010; Koch et al., 2014), cosmic ray sensors (e.g. Gottardi et al., 2012; Sigouin and Si, 2016; Sections I-2.13, I-2.34) or Snow Pack Analysing Systems (Sections I-2.6, I-2.37) are also available but are not introduced here.

(1) Weighing mechanisms: The measurement principles of snow pillows and snow scales are similar in that the instrument measures the weight of the snowpack on top of it, converting the weight of the snow to kg $m^{-2}$ or mm w.e. of SWE.

Snow pillows (Fig. I-1.5.4 a) consist of a synthetic rubber or stainless steel bladder filled with fluid (antifreeze). The hydro-static pressure in the bladder increases with increasing weight of the overlying snowpack and is measured with either a float device, which is pushed up into a vertical standpipe, or a pressure transducer. With snow scales (Fig. I-1.5.4 a), a weight measurement is made with an electronic load cell, eliminating the need for a fluid-filled bladder. Both snow scales and pillows must be installed level with the surface of the ground to prevent adverse edge effects.

(2) Passive gamma radiation instruments (Fig. I-1.5.4 b): This approach applies the principle that the natural breakdown of potassium or thallium in the soil produces a background level of gamma radiation which is attenuated by the water in the snowpack and the soil. The instrument, mounted above the ground surface, compares gamma radiation measurements of snow on the ground with measurements obtained over bare soil and calculates the attenuation due to the presence of snow. Passive gamma instruments generally should be installed 2 m above the height of the maximum snow depth, but note that its height above the snow surface impacts the radius of the instrument response area. In addition, only SWE values < 600 mm w.e. can be measured with reasonable accuracy.

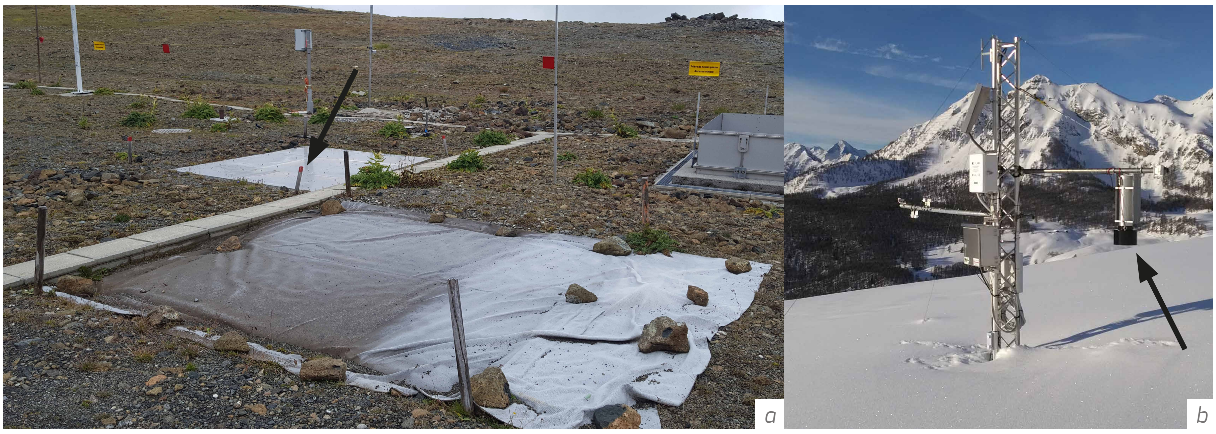

*Figure I-1.5.4 Automatic water equivalent of snow cover (SWE) measurement devices: (a) snow pillow (foreground) and snow scale (background; highlighted with black arrow) at Weissfluhjoch, Grison, Switzerland (Source: SLF); (b) automatic weather station with a passive gamma radiation instrument CS725 (highlighted with black arrow) in Valle d'Aosta, Italy (Source: ARPAVA).*

# I-2 Current Snow Monitoring in Europe (Country Reports)

A. Haberkorn

WSL Institute for Snow and Avalance Research SLF, Davos, Switzerland

## I-2.1 Introduction

This chapter forms the core of the European Snow Booklet (ESB). Information about current operational snow observations and methods used to perform basic measurements of snow on the ground in European countries is summarised in country-specific reports. These country reports are based on information and metadata on snow measurements (Chapter I-1) collected through a comprehensive survey, the ESB Questionnaire (Appendix I-B), between August 2017 and March 2018.

The ESB Questionnaire was sent to one or several institutions of the following 38 European countries (Fig. 2 on p. 4): Andorra, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Macedonia, Moldova, Montenegro, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland with Liechtenstein, Turkey, Ukraine and the United Kingdom. Questionnaire answers were received from one or several institutions from all the above-mentioned countries (Fig. 3 on p. 6). In addition, information and metadata on the snow monitoring network of Russia is available in Appendix I-A. Unfortunately, no reliable contact could be established for Albania, Belarus, Kosovo, Malta, Monaco, San Marino or Vatican City, and thus no information from these countries could be included in the ESB.

This chapter provides a comprehensive overview of operational snow observations in Europe. It is important to note that complete information does not exist for all countries, owing to missing metadata and the unresponsiveness of some institutions. It was not possible to question the representativeness of the contacts or the whole affiliated institution. Therefore, institutional representativeness is not ensured. In addition, the number of stations included in operational monitoring networks changes over time, owing to the opening and closure of stations, and consequently completeness cannot be guaranteed. Thus, station counts should be considered approximations that nonetheless represent the order of magnitude of the snow monitoring network of each country. All 38 country reports have the same structure and similar figures, such as maps giving an overview of the location of the countries within Europe, maps showing the elevational and spatial distribution of stations, and bar graphs showing the distribution of stations where snow depth (HS), depth of snowfall (HN) and water equivalent of snow cover (SWE) are measured. Please note that the y-axis scale for bar graphs indicates percentages (not absolute numbers) and therefore bar sizes should not be compared directly between countries.

The station metadata (e.g. location, elevation) from each country was provided by the institutions that contributed data. By answering the questionnaire the contacts agreed that the information and metadata provided could be presented in the ESB. This metadata is stored on the Environmental Data Portal EnviDat[19], a secure institutional data management portal of the Swiss Federal Institute for Forest, Snow and Landscape Research WSL and the WSL Institute for Snow and Avalanche Research SLF. Access to the country datasets can be requested at https://www.envidat.ch/dataset/european-snow-booklet. For cases where institutions indicated that information on station locations could be made publicly available, the metadata is additionally stored under the doi:10.16904/envidat.59.

The maps showing an overview of the location of the European countries are based on CNTR_2014_03M_SH[20] data provided by © EuroGeographics for the administrative boundaries. Most country-specific maps include a digital elevation model (DEM), the EU-DEM[21] (eudem_dem_3035_europe.tif), which was produced using Copernicus data and information funded by the European Union (© EU-DEM-layers, 2017). For our purposes, the EU-DEM cell size was

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[19] https://www.envidat.ch/dataset

[20] http://ec.europa.eu/eurostat/de/web/gisco/geodata/reference-data/administrative-units-statistical-units/countries

[21] https://www.eea.europa.eu/data-and-maps/data/eu-dem

resampled from 1 to 250 m resolution. Additionally, large rivers and lakes[22] are shown in the maps and are based on data from © European Environment Agency for large rivers. The coordinate system (CS) used in the above-mentioned maps is the projected coordinate system ETRS89 LCC. The station metadata of each country was provided in different CSs by the institutions that contributed data and has therefore been converted to the CS ETRS89 LCC. The scale of the overview maps showing all countries in Europe (the first map in each country report) is the same for all the reports (1:20 000 000). In contrast, the scale of the country-specific maps (including the EU-DEM) varies across the countries; however, scale bars included in the maps are always scaled to 100 km to facilitate comparisons of country sizes among the reports.

The mean country elevation given in each country report was calculated from the EU-DEM with a resolution of 250 m. This value strongly depends on the cell size, the CS projection and the country borders used. Values should therefore be considered approximations rather than precise values. In addition, in the country information in each country report a non-personal institution contact is usually provided. In some cases, however, non-personal institution contacts are not available and thus the contact of the country representative who filled in the questionnaire is used.

Although manual and automatic measurement procedures are always described for snow depth and water equivalent of snow cover, only manual methods are included for presence of snow on the ground (as part of the snow depth section) and depth of snowfall. Automatic measurements are not considered reliable for depth of snowfall (Section I-1.4). Detailed information on the snow variables and measurement methods is given in Chapter I-1.

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[22] https://www.eea.europa.eu/data-and-maps/data/wise-large-rivers-and-large-lakes

# I-2.2 Andorra

CS: ETRS 1989 LCC

*Figure I-2.2.1 Location of the Principat d'Andorra (black arrow) between France and Spain in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 468 km², 2 054 m a.s.l. |
| Authority responsible for snow measurements | Servei de Meteorologia del Govern d'Andorra / Oficina de l'Energia i del Canvi Climàtoc (MA)<br>C/ Prat de la Creu 62-64<br>AD-500 Andorra la Vella<br><br>Snow and Mountain Research Center of Andorra (CENMA)<br>Av Rocafort 21-23<br>Edifici Molí, 3r pis<br>AD-600 Sant Julià de Lòria |
| Contact | · MA<br>meteo@govern.ad<br>· CENMA<br>cenma@iea.ad |
| Near-real-time data URL and/or contact | · MA<br>www.meteo.ad (some time series are available online)<br>· CENMA<br>Not currently available, but real-time data and comparisons with historical average values should be provided online in the future. |
| Archived data URL and/or contact | · MA<br>www.meteo.ad (some time series are available online)<br>· CENMA<br>cenma@iea.ad (data on request)<br>www.feda.ad (some time series are available online) |

## General situation

The National Weather and Avalanche Warning Service of Andorra (MA), together with the Snow and Mountain Research Center of Andorra (CENMA), ski resorts and mountain rangers, are responsible for snow observations in Andorra. They measure snow depth, depth of snowfall and water equivalent of snow cover manually, while snow depth is additionally measured automatically. In Andorra, method development, data management, training, and equipment installation and maintenance for meteorological and snow observations are performed to a large extent within the framework of a Memorandum of Understanding with Météo-France.

In addition to the operation of one water equivalent of snow cover station by MA and CENMA, snow pit investigations, including stability tests three times per week during the winter season, are performed by the National Forest Rangers. These snow pit investigations are, however, not included in this country report because pits are dug in different areas depending on the synoptic situation and the avalanche activity. Hence, only the MA and CENMA snow measurement networks are discussed below.

## Overview of measurements (MA, CENMA)

Snow depth: stake, ultrasonic snow depth sensor (Figs I-2.2.2, I-2.2.3)
Depth of snowfall: snow board and ruler (Figs I-2.2.6, I-2.2.7)
Water equivalent of snow cover: snow cylinder, spring scale (Figs I-2.2.8, I-2.2.9)
Operational purpose of measurements: Avalanche warning, Climatology, Hydrology, Meteorology, Water management

## I-2.2.1 Snow depth measurements

Number of stations delivering snow depth data manually: 7
Number of stations delivering snow depth data automatically: 10

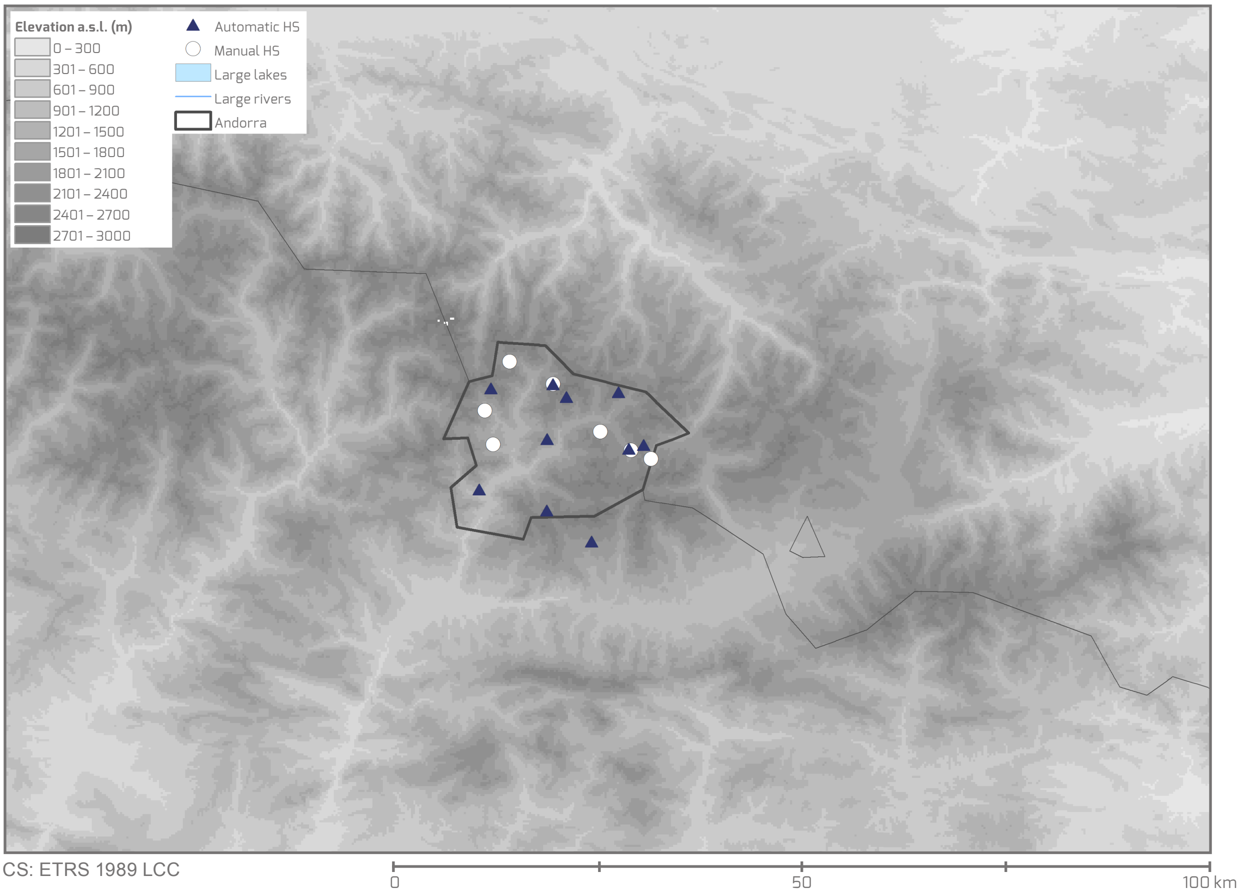

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*Figure I-2.2.2 Locations of stations in Andorra where snow depth (HS) is measured.*

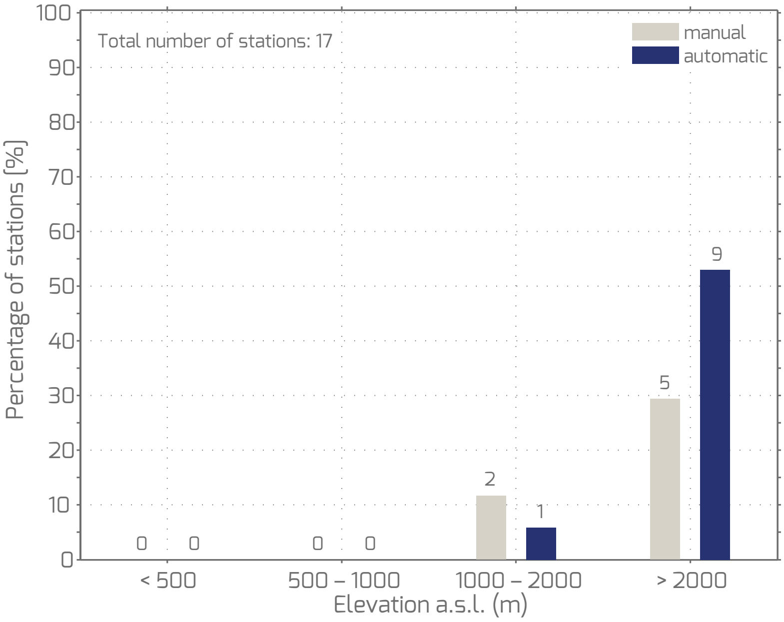

*Figure I-2.2.3 Elevational distribution of stations in Andorra with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours. Fixed stakes with a scale in centimetres are installed and used within measurement fields with a size of 5 x 5 m (Fig. I-2.2.4). Most manual measurement fields are located near or within ski resorts.

### Automatic measurements:

Automatic snow depth measurements are performed every 1 hour using an ultrasonic snow depth sensor (SR-50; Campbell Scientific, Logan, Utah, USA). Snow depth sensors are mounted 3–5 m above the ground (Fig. I-2.2.5).

### Presence of snow on the ground reporting method:

Presence of snow on the ground is not reported explicitly. No procedure is established for reporting patchy snow cover in the measurement field because no manual snow data is recorded after the ski resorts close in spring.

### Zero snow depth reporting method:

When no snow is present within a 1 m radius around the stake, 0 cm snow depth is reported.

*Figure I-2.2.4 Measurement field Arcalis, located in a ski resort in Andorra (Source: CENMA).*

*Figure I-2.2.5 Automatic snow depth measurement location in Sorteny, Andorra (Source: CENMA).*

## I-2.2.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 7

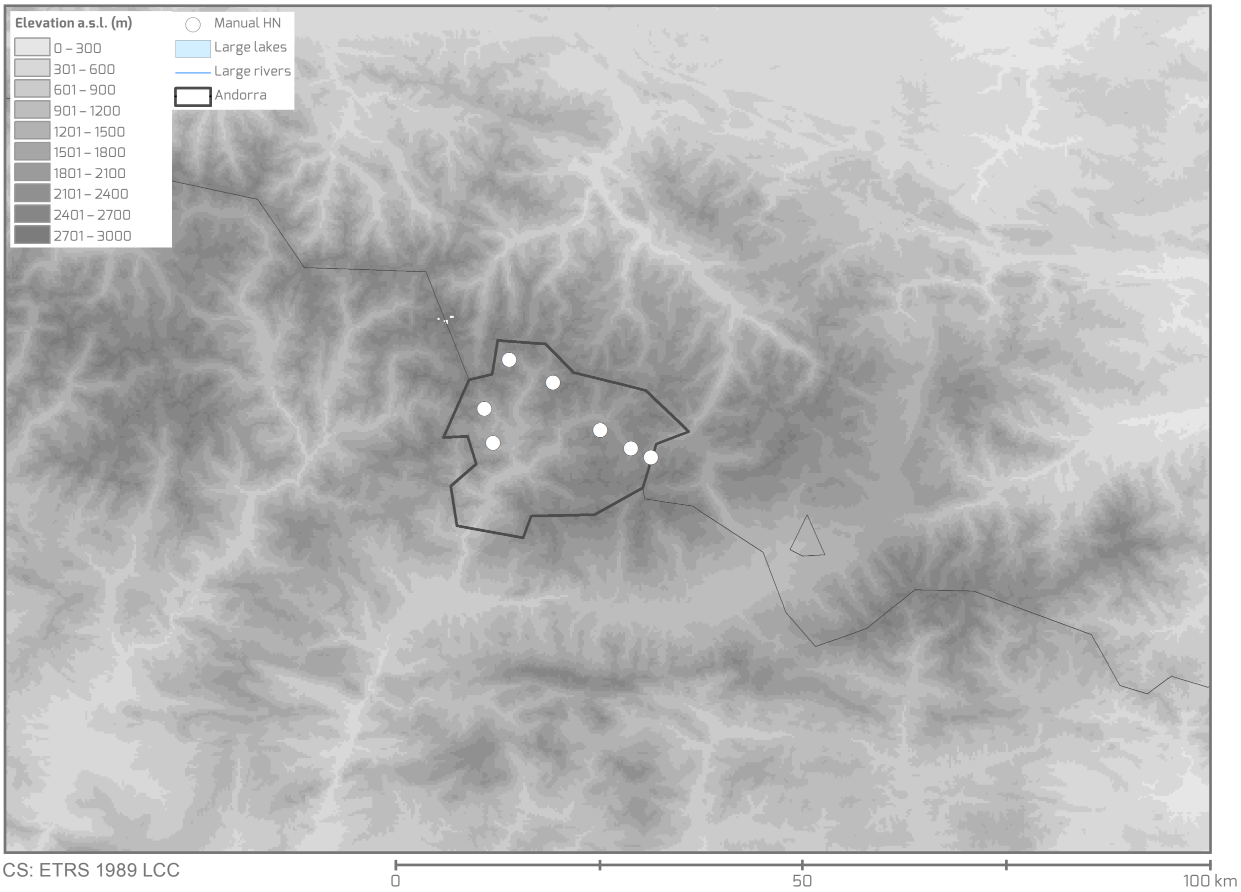

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*Figure I-2.2.6 Locations of stations in Andorra where depth of snowfall (HN) is measured.*

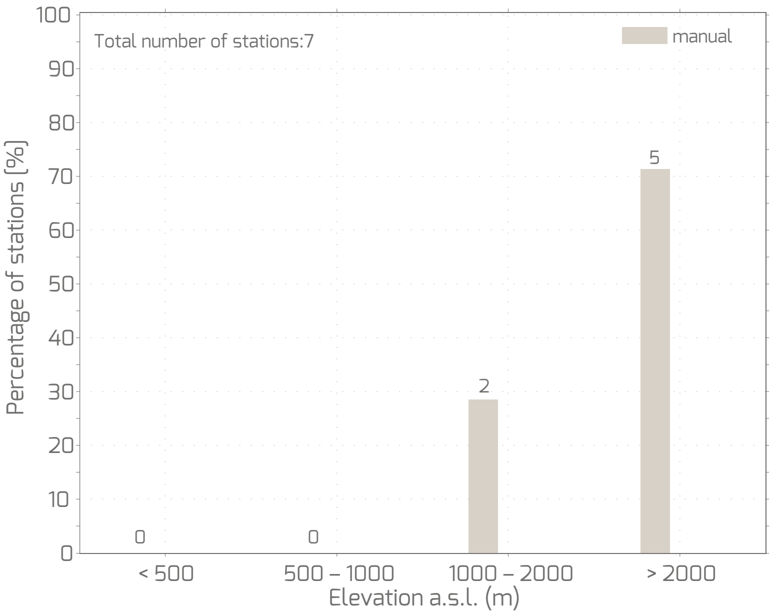

*Figure I-2.2.7 Elevational distribution of stations in Andorra with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours in parallel to manual snow depth measurements. Depth of snowfall is measured on a grey-painted snow board (50 x 50 cm) with a ruler. The snow board surface is fitted with two 1-m-long stakes so that the board can be located after a snowfall event. Depth of snowfall is measured at two to three points on the snow board and the average of all measurements is reported. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. The location of the depth of snowfall measurement is selected to minimise influence from the wind. Measured values are reported in full centimetres.

## I-2.2.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 1
Number of stations delivering water equivalent of snow cover data automatically: 0

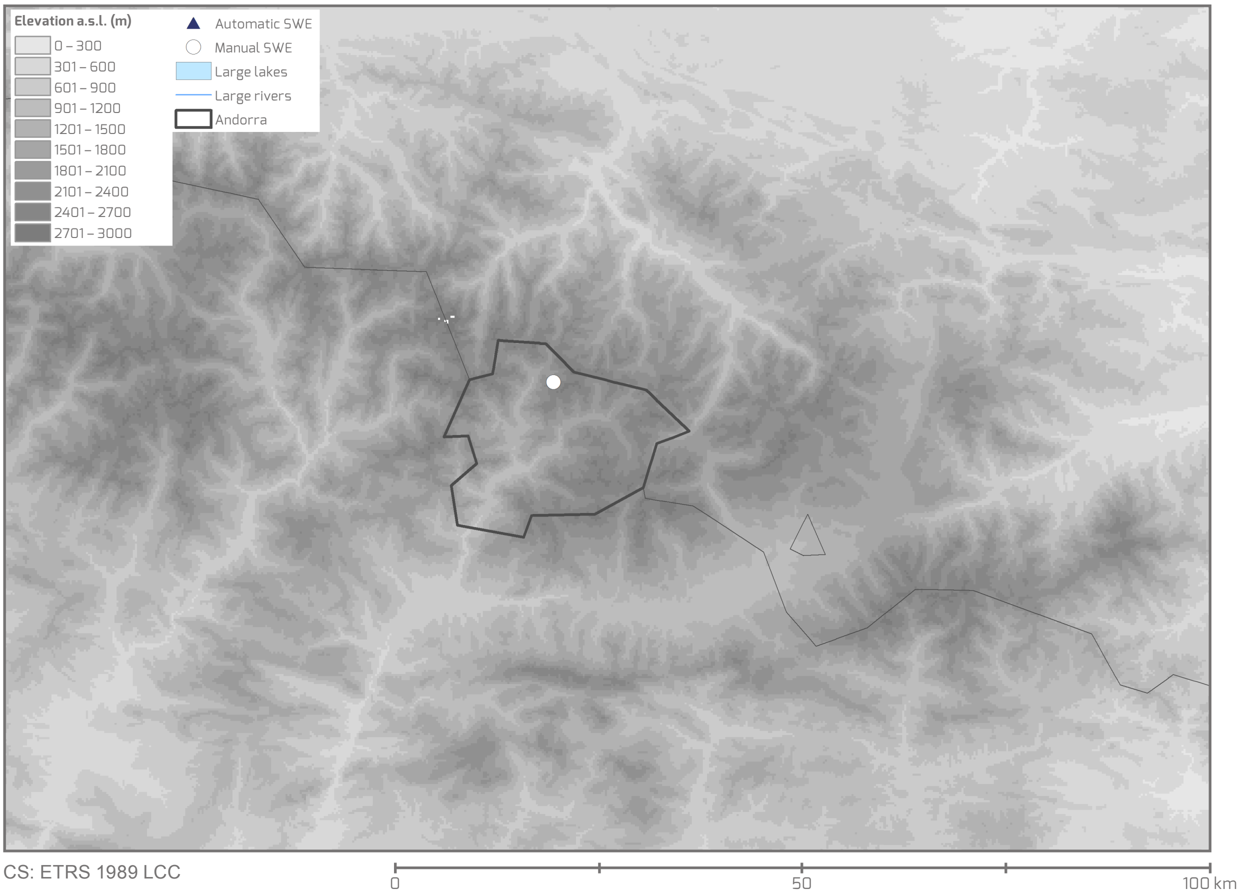

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*Figure I-2.2.8 Location of stations in Andorra where water equivalent of snow cover (SWE) is measured.*

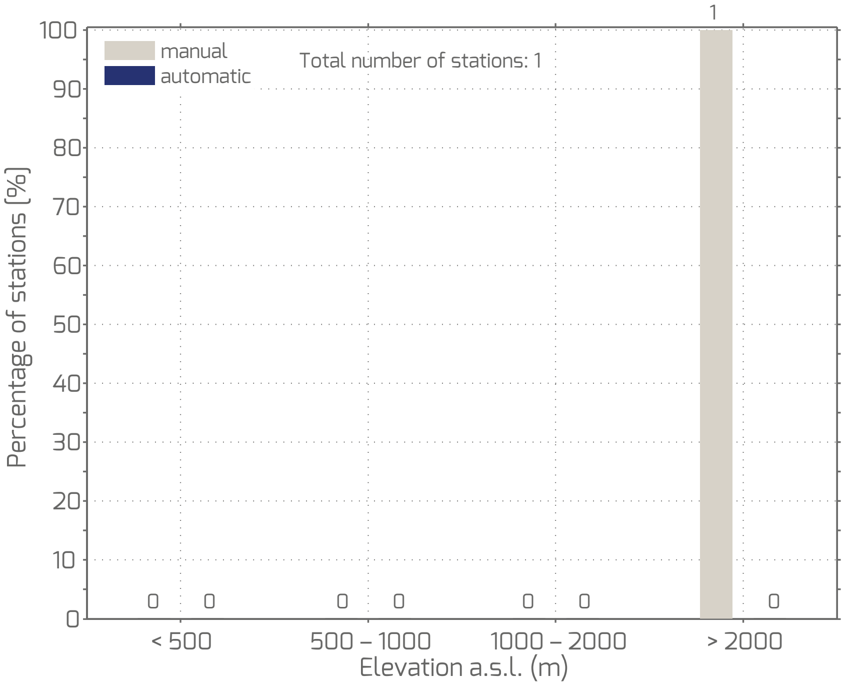

*Figure I-2.2.9 Elevational distribution of stations in Andorra with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits (and stratigraphic profiles) are performed once a week, usually by two observers. The gravimetric method is applied. Using a graduated aluminium snow cylinder with a cross-sectional area of 0.007 $m^2$ and a length of 0.55 m, a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), the snow cylinder is attached to a spring scale to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area (in $m^2$) of the snow cylinder. Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

**Automatic measurements:**

No measurements.

## I-2.2.4 Transition from manual to automatic measurements

Parallel measurements are carried out for several years when a station shifts from manual to automatic measurements.

## I-2.2.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (MA and CENMA)<br>AUTO: 1 hour (MA and CENMA) | MANUAL: 24 hours (MA and CENMA) | MANUAL: 1 week (MA and CENMA)<br>AUTO: no measurements |

# I-2.3 Austria

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*Figure I-2.3.1 Location of Austria in Europe.*

# I-2.3 Austria

## Country information

| | |
|---|---|
| Country area, mean country elevation | 83 879 km$^2$, 951 m a.s.l. |
| Authority responsible for snow measurements | Zentralanstalt für Meteorologie und Geodynamik (ZAMG)<br>Hohe Warte 38<br>AT-1190 Vienna<br><br>Austrian Federal Ministry of Sustainability and Tourism (BMNT)<br>Department – Water Budget (HZB)<br>Stubenring 1<br>AT-1012 Vienna |
| Contact | · ZAMG<br>derf_prod@zamg.ac.at<br>· BMNT<br>wasserhaushalt@bmnt.gv.at<br>viktor.weilguni@bmnt.gv.at (Viktor Weilguni) |
| Near-real-time data URL and/or contact | · ZAMG<br>Not available.<br>· BMNT<br>http://ehyd.gv.at/ (snow depth, depth of snowfall)<br>https://wasser.umweltbundesamt.at/hydjb/ (hydrographic information) |
| Archived data URL and/or contact | · ZAMG<br>klima@zamg.ac.at (ZAMG)<br>· BMNT<br>http://ehyd.gv.at/ (BMNT) |

## General situation

The Zentralanstalt für Meteorologie und Geodynamik (ZAMG) and the Water Budget Department (HZB) of the Austrian Federal Ministry of Sustainability and Tourism (BMNT) share the duty of performing operational snow observations in Austria. HZB coordinates activities of the Austrian Hydrographic Office.

Both the ZAMG and BMNT station networks are equally distributed over the alpine, midland and lowland regions of Austria. ZAMG has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. ZAMG and BMNT exchange their data and use the collective data for their various products. While snow depth and depth of snowfall are observed by both ZAMG and BMNT, water equivalent of snow cover is only regularly measured by BMNT and presence of snow on the ground is only observed by ZAMG.

In addition to the above-mentioned institutions, regional avalanche warning services (e.g. Styria, Tyrol, Vorarlberg) operationally measure various snow variables during the snow season in the mountainous regions. However, the station networks of the avalanche warning services are not included here because the applied snow measurement methods are not standardised, each regional service uses different snow observation techniques, and some of the regional avalanche warning services were non-responsive. In addition to the above-mentioned institutions, hydropower companies maintain their own snow monitoring networks. For instance, water equivalent of snow cover and snow temperature are measured by the Tiroler Wasserkraft AG. Data has been publicly available for a station in the Tyrolean mountains (Kühtai) since 1990. Additionally, the Bundesforschungszentrum für Wald (BfW) maintains an experimental site with snow observations in the Tyrolean mountains (Lizum/Walchen). Information on snow observations carried out by these institutions is not included here but can be found in the Global Climate Observing System (GCOS) report for Austria (Adler and Fürst, 2017). Hence, only the snow measurement networks operated by ZAMG and BMNT are discussed below.

## Overview of measurements (ZAMG, BMNT)

Snow depth: stake, ruler, ultrasonic snow depth sensor, laser snow depth sensor (Figs I-2.3.2, I-2.3.3)
Depth of snowfall: snow board and ruler (Figs I-2.3.5, I-2.3.6)
Water equivalent of snow cover: snow cylinder, spring scale, snow pillow (Figs I-2.3.7, I-2.3.8)
Operational purpose of measurements: Avalanche warning, Climatology, Flood forecasting, Hydrology, Meteorology, Road services, Water management

## I-2.3.1 Snow depth measurements

Number of stations delivering snow depth data manually: 880
Number of stations delivering snow depth data automatically: 136

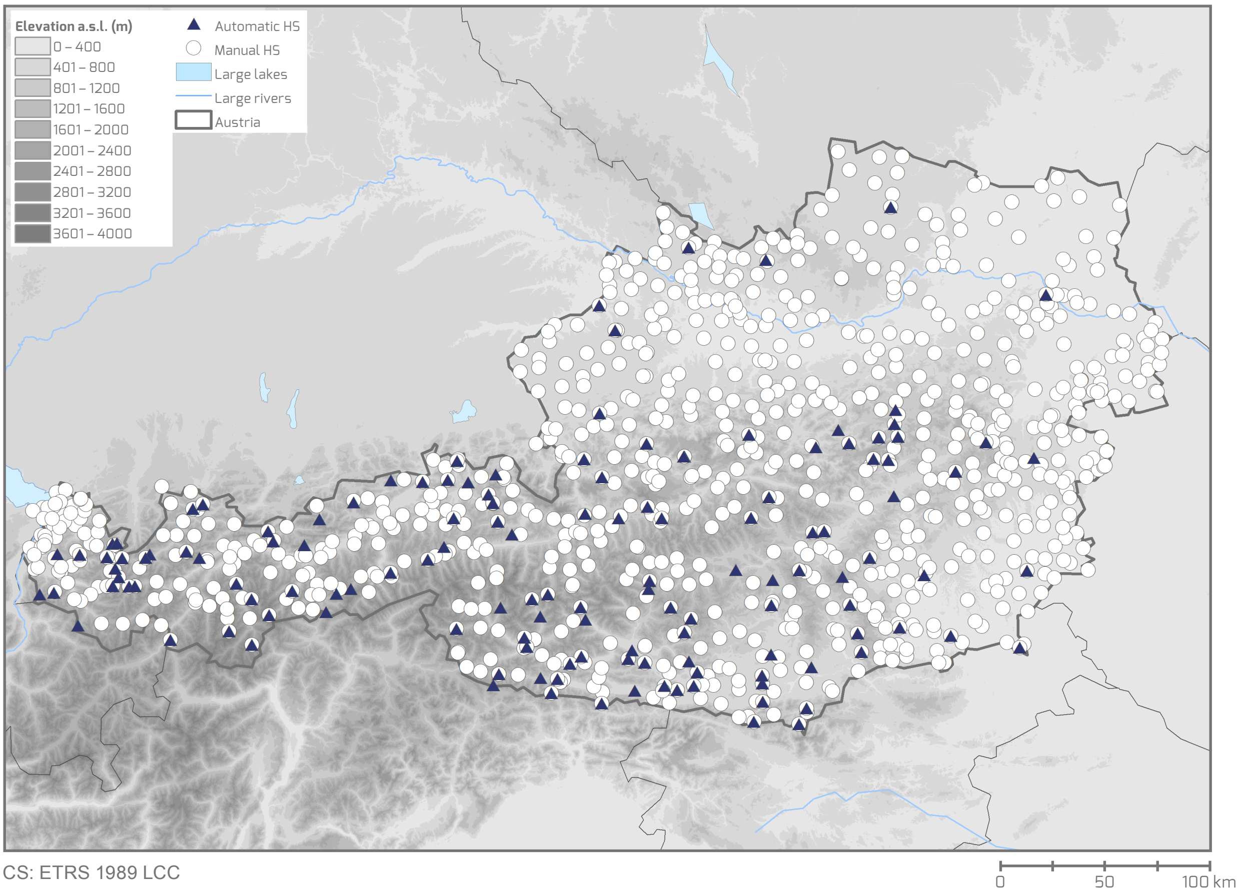

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*Figure I-2.3.2 Locations of stations in Austria where snow depth (HS) is measured.*

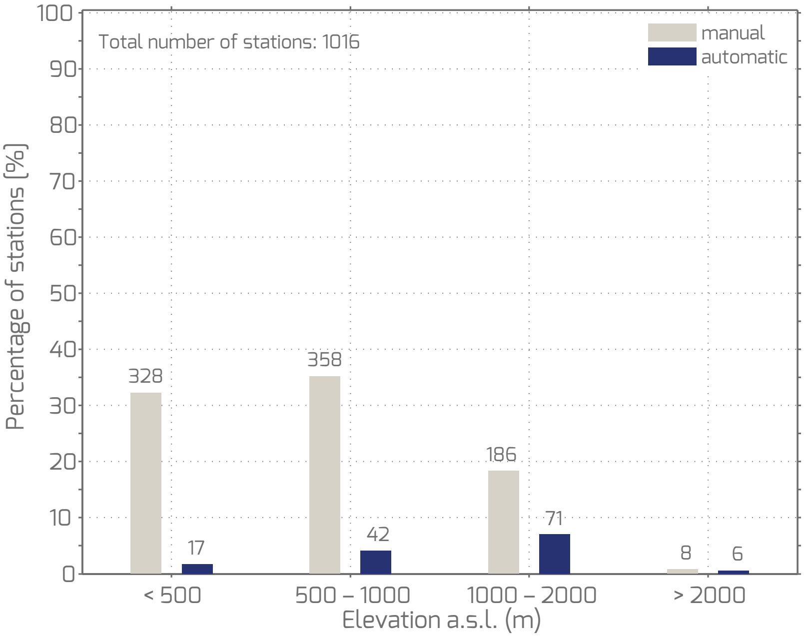

*Figure I-2.3.3 Elevational distribution of stations in Austria with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours at 0600 UTC. Depending on the site, fixed stakes or portable rulers are used by observers from ZAMG and BMNT. When rulers are used, up to three snow depth readings are conducted at representative locations in the observation field and the average is reported. The observation fields maintained by ZAMG cover an area of several square metres, while BMNT only operates single-stake stations. The locations of the measurement fields are chosen to minimise wind effects on the snow depth measurements, such as drifting and blowing snow. At ZAMG stations, total snow depth is reported as long as at least half of the measurement field is covered with snow. Measured values are reported in full centimetres.

### Automatic measurements:

An automatic snow depth measurement is recorded every 10 minutes at ZAMG stations. Laser snow depth sensors (SHM 30; Lufft, Fellbach, Germany) are used (Fig. I-2.3.4). The sensor mounting height and the use of an artificial surface target depend on the site. Snow depth sensors are usually mounted 2 m above the ground. Glass-fibre-reinforced plastic base plates are placed below the sensors to avoid snow depth reporting caused by growing vegetation during snow-free conditions. BMNT automatically measures snow depth every 15 minutes using ultrasonic snow depth sensors. The sensor mounting height and the use of an artificial surface target depend on the site.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported by observers at ZAMG stations in parallel to manual snow depth measurements, but it is not reported at BMNT stations.

### Zero snow depth reporting method:

ZAMG reports 0 cm snow depth when more than 50% of the measurement field is snow free, even if there is still some snow at the stake. Zero snow depth is also reported if the depth of the remaining snow is less than 0.5 cm, in order to indicate that traces of snow still exist. The area in the surroundings of the measurement field is also taken into account. In contrast to ZAMG, BMNT reports 0 cm snow depth if there is no snow at the stake, regardless of the snow cover extent in the surroundings.

*Figure I-2.3.4 (a, b) Snow observation fields operated by ZAMG (Source: ZAMG).*

## I-2.3.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 880

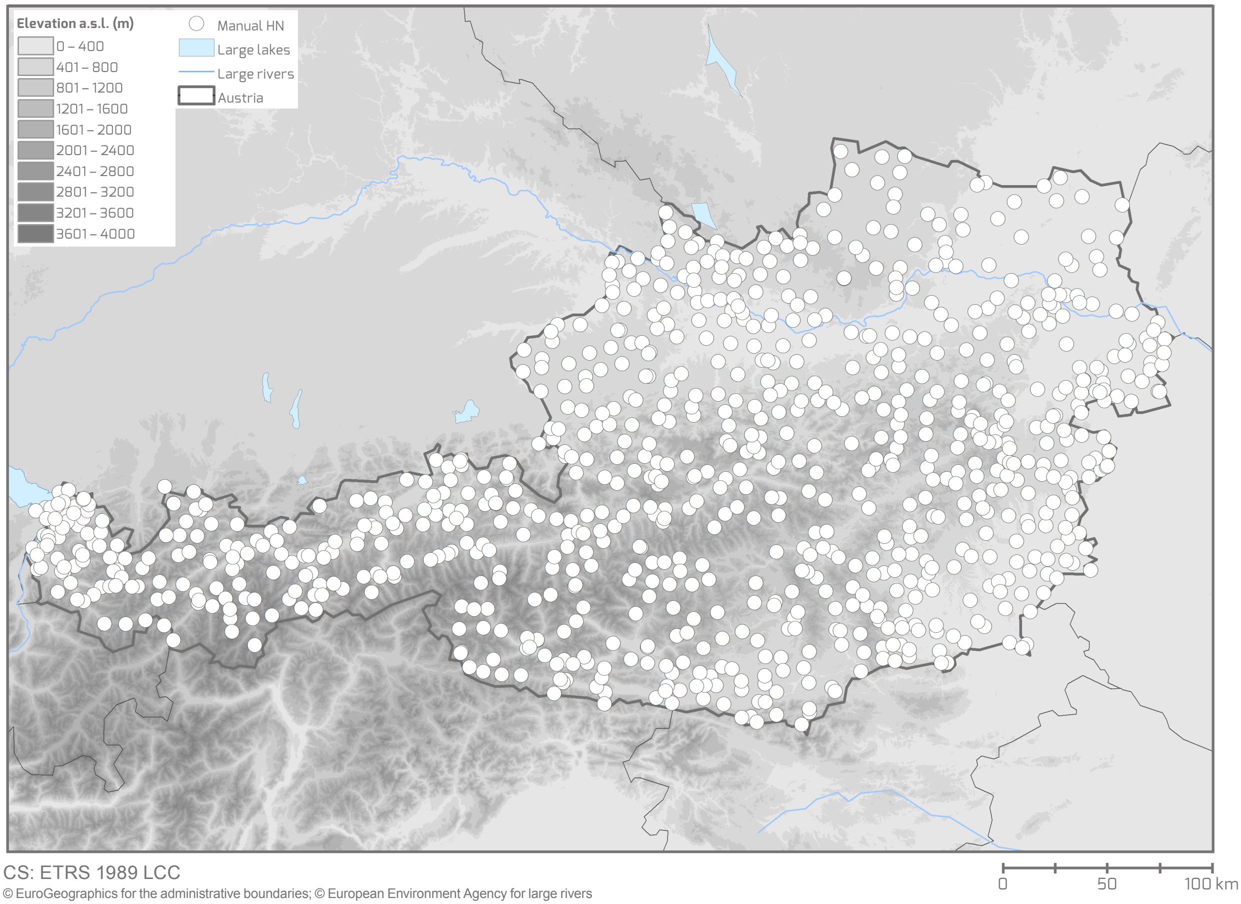

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*Figure I-2.3.5 Locations of stations in Austria where depth of snowfall (HN) is measured.*

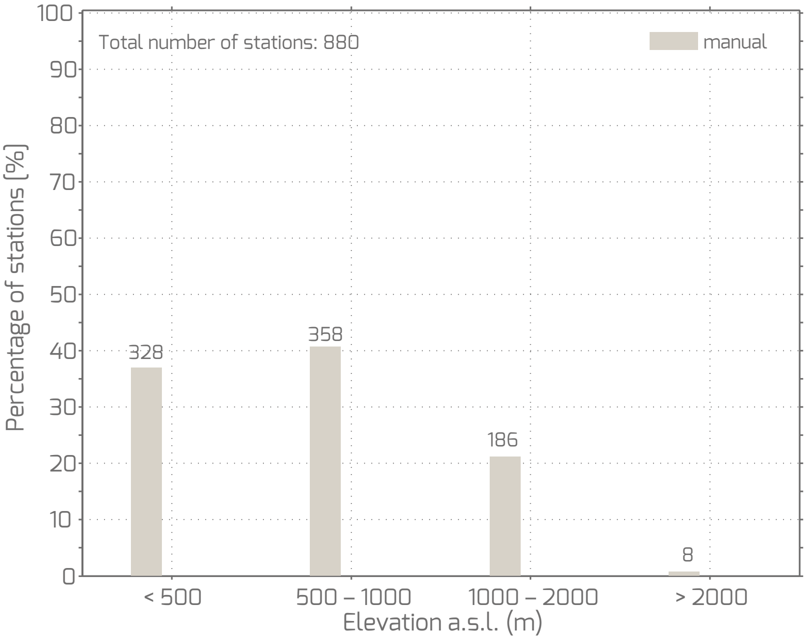

*Figure I-2.3.6 Elevational distribution of stations in Austria with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours at 0600 UTC, in parallel to manual snow depth measurements, by both ZAMG and BMNT. ZAMG observers measure depth of snowfall at two to three locations on a white-painted snow board with a ruler and report the average of the readings. The ZAMG snow board is fitted with two 50-cm-long stakes so that the snow board can be located after a snowfall event. In contrast, BMNT observers use a snow board fitted with one fixed graduated stake for depth of snowfall readings and for locating the snow board after a snowfall event. After each measurement, snow from the snow board is removed and the board is re-placed on the top of the snow cover (or bare ground), as evenly as possible in relation to the surrounding surface. Measured values are reported in full centimetres. If the measured depth of snowfall is less than 0.5 cm, traces of snow are reported. While ZAMG assigns depth of snowfall to the date of observation, BMNT assigns it to the day before.

## I-2.3.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 48
Number of stations delivering water equivalent of snow cover data automatically: 4

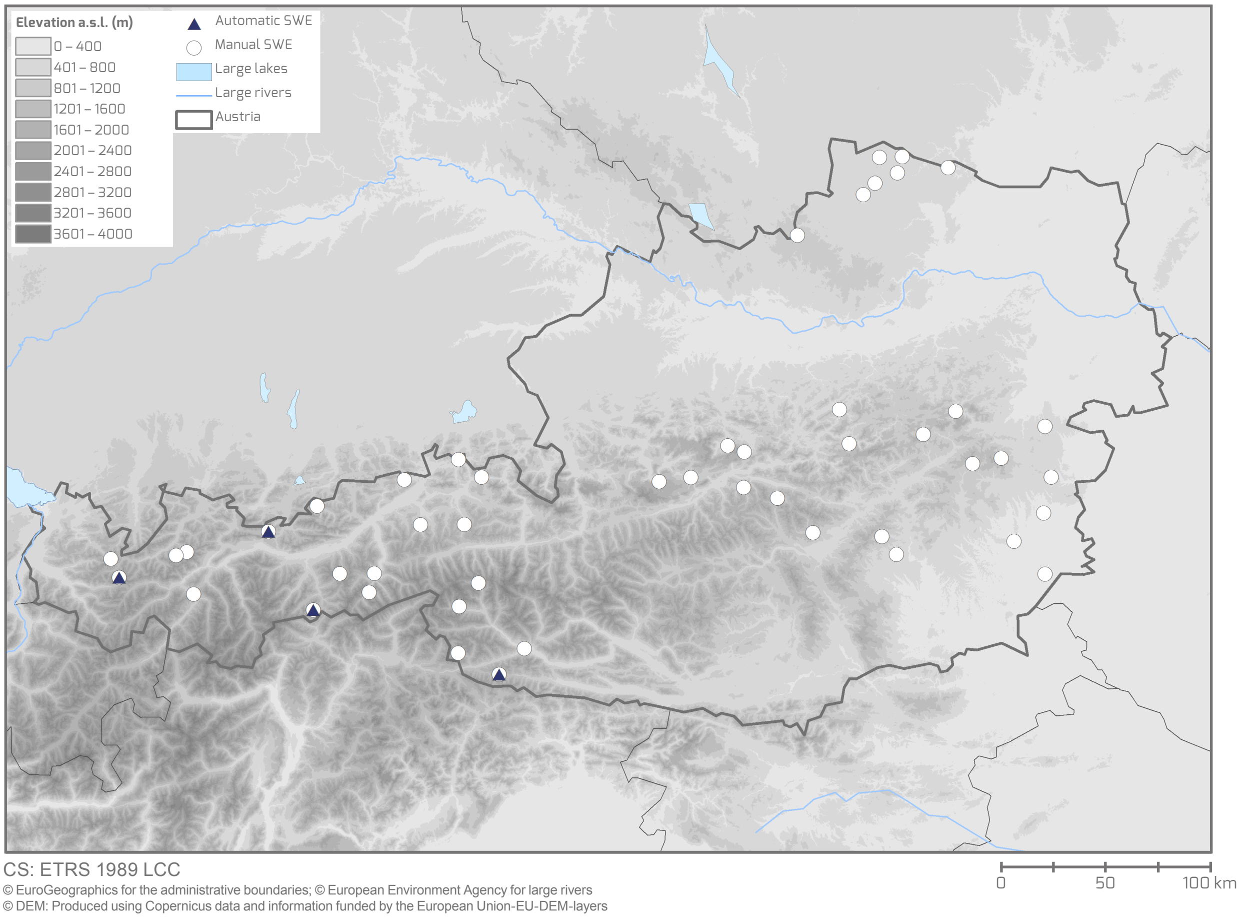

*Figure I-2.3.7 Locations of stations in Austria where water equivalent of snow cover (SWE) is measured.*

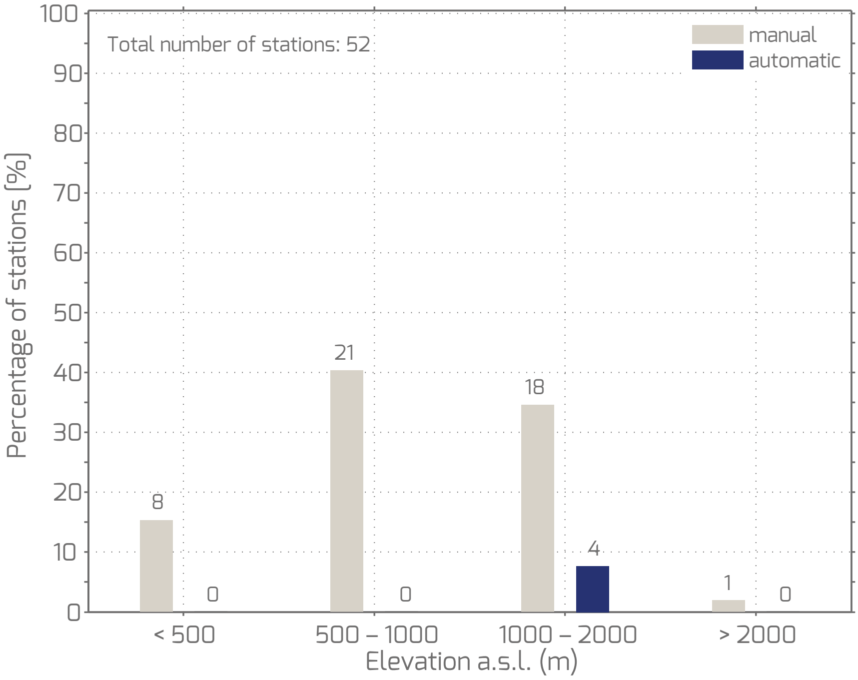

*Figure I-2.3.8 Elevational distribution of stations in Austria with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements (derived from snow density and snow depth measurements) in snow pits are supposed to be performed once every week for snow depths exceeding 5 cm, but in practice longer intervals are common. Using the gravimetric method, a snow sample is extracted vertically from the snowpack with a graduated snow cylinder. The snow cylinder is then attached to a spring scale to measure the total weight of the snow (in kg). The height of the snow sample is given in m. The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder (in $m^2$). Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

**Automatic measurements:**

Automatic water equivalent of snow cover measurements are performed every 15 minutes using a snow pillow.

## I-2.3.4 Transition from manual to automatic measurements

During the shift from manual to automatic observations, the use of parallel measurements depends on the site. ZAMG conducts parallel measurements as long as possible at sites with important snow depth data series, depending on the availability of observers. In contrast, no parallel measurements are conducted by BMNT.

## I-2.3.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (ZAMG and BMNT)<br>AUTO: 10 (ZAMG) or 15 minutes (BMNT) | MANUAL: 24 hours (ZAMG and BMNT) | MANUAL: 1 week (BMNT)<br>AUTO: 15 minutes (BMNT) |

# I-2.4 Belgium

*Figure I-2.4.1 Location of Belgium in Europe.*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 30 528 km², 156 m a.s.l. |
| Authority responsible for snow measurements | Royal Meteorological Institute of Belgium (RMI)<br>Ringlaan 3 Avenue Circulaire<br>BE-1180 Brussels |
| Contact | · RMI<br>ctricot@meteo.be (Christian Tricot) |
| Near-real-time data URL and/or contact | · RMI<br>ctricot@meteo.be (Christian Tricot) |
| Archived data URL and/or contact | · RMI<br>ctricot@meteo.be (Christian Tricot)<br>pascal.mormal@meteo.be (Pascal Mormal) |

### General situation

Three national organisations carry out operational snow observations in Belgium: the Royal Meteorological Institute of Belgium (RMI); Belgocontrol, which is responsible for civil aviation; and Meteo Wing, which is responsible for military aviation. In collaboration with RMI, the Hydrology Department of the Walloon Region (DGO2) has additionally recently begun to deploy and operate a network of automatic stations measuring snow depth and water equivalent of snow cover in the southern part of Belgium. This is justified by the importance of snow for hydrological purposes and flood forecasting.

The manual snow depth station network of RMI, Belgocontrol and Meteo Wing is evenly distributed over the Belgian territory. Only manual stations of Belgocontrol and Meteo Wing belong to the Belgian network of synoptic stations of the World Meteorological Organisation (WMO), and they transmit manual snow depth data in synoptic messages twice daily (at 0600 and 1800 UTC).

The number of synoptic stations where manual snow depth observations are carried out has decreased strongly over the past 10 years, and manual stations have not usually been replaced by automatic ones. Consequently, snow information available in the country has decreased considerably. Recent initiatives by RMI and DGO2 aim to stop this loss of snow information in Belgium.

A large amount of snow data is available in the RMI archive. For the climate network, the amount of data available in digital form is still relatively limited, and data covers only the most recent years. For some stations of the synoptic network, however, digitised data since the 1950s is available but not quality controlled for the oldest period. In Belgium, the longest time series of snow depth data (Uccle-Ukkel station) dates back to 1888.

The RMI is gradually becoming involved in a general Open Data policy. In the future, this will allow the public to easily access quality-controlled and digitised snow data online. In addition, encoding and digitising historical snow data should increase the amount of data available in the future.

Snow depth, presence of snow on the ground and depth of snowfall are observed manually by RMI, while snow depth is additionally measured automatically at a few stations. Recently, RMI developed a new operational procedure to quality control snow depth data. The procedure was tested and has been in use since winter 2017/2018. Belgocontrol and Meteo Wing also measure snow depth manually, while DGO2 only measures snow depth and water equivalent of snow cover automatically. All data observed by these three organisations is collected, quality controlled and archived by RMI, and thus it is referred to below simply as the RMI snow measurement network.

### Overview of measurements (RMI)

Snow depth: ruler, ultrasonic snow depth sensor, stake and webcam (Figs I-2.4.2, I-2.4.3)
Depth of snowfall: ruler and (sometimes) snow board (Figs I-2.4.4, I-2.4.5)
Water equivalent of snow cover: snow scale (Figs I-2.4.6, I-2.4.7)
Operational purpose of measurements: Climatology, Flood forecasting, Hydrology, Meteorology

## I-2.4.1 Snow depth measurements

Number of stations delivering snow depth data manually: 90
Number of stations delivering snow depth data automatically: 7

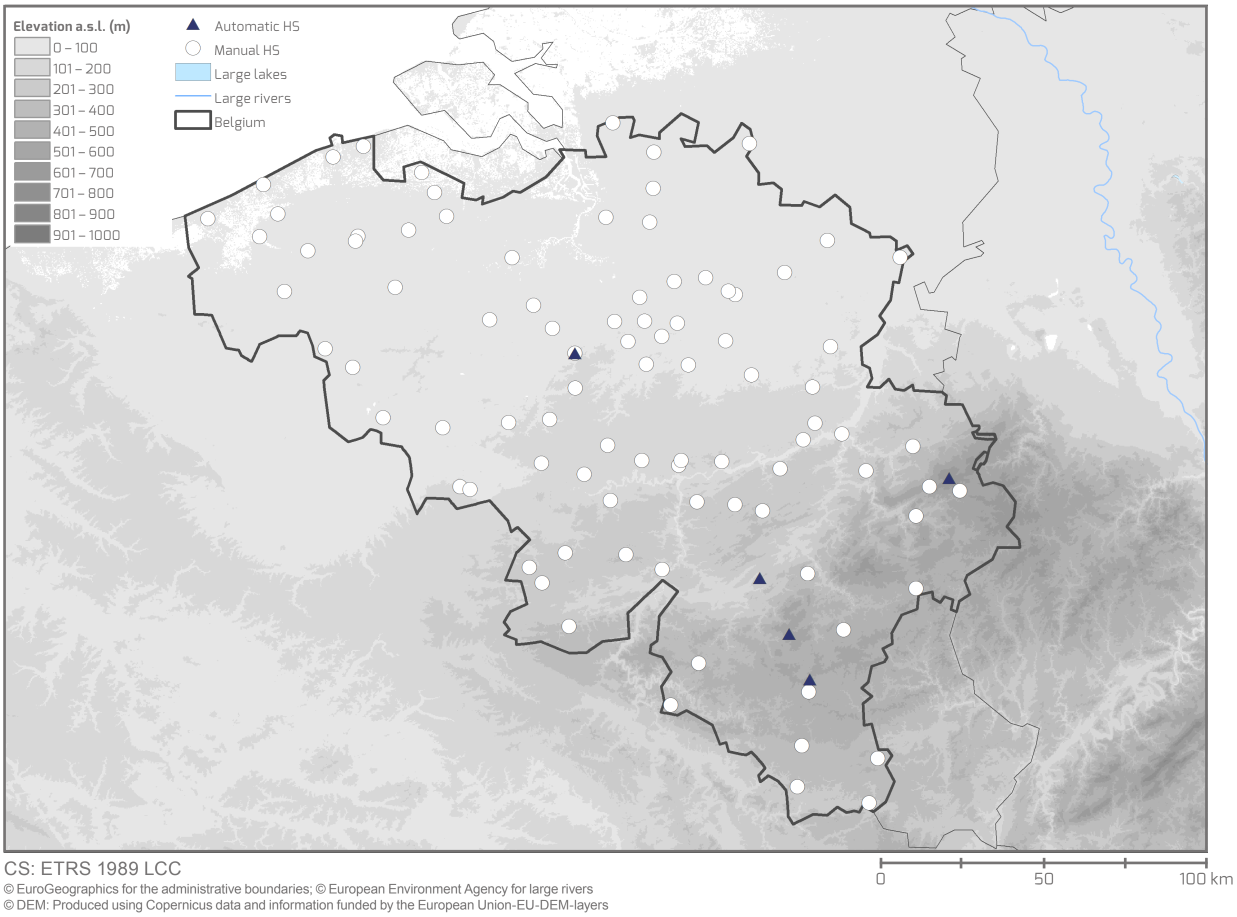

*Figure I-2.4.2 Locations of stations in Belgium where snow depth (HS) is measured. Only five automatic stations (blue triangles) are shown because both ultrasonic sensors and webcams are installed at two locations with automatic measurements.*

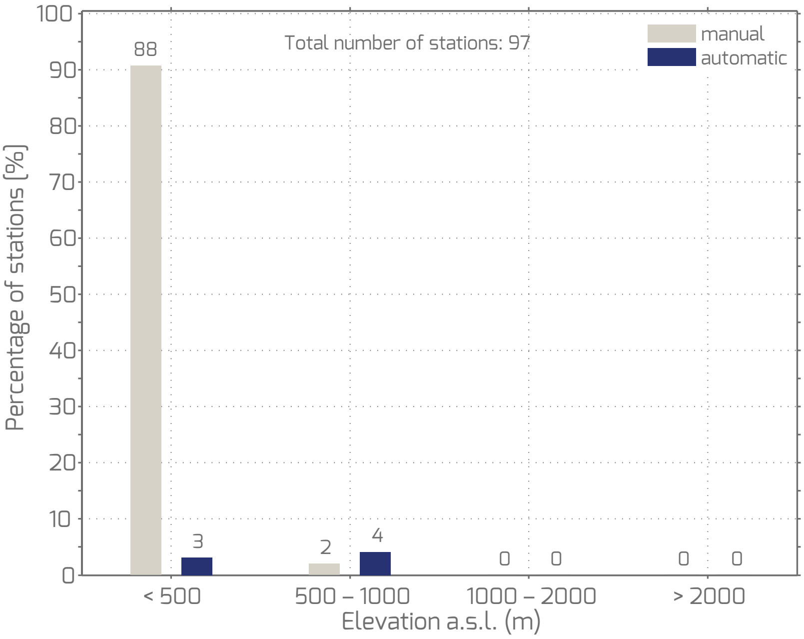

*Figure I-2.4.3 Elevational distribution of stations in Belgium with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed either every 12 hours at 0600 and 1800 UTC (9 stations) or every 24 hours at 0700 UTC (81 stations). Portable rulers with a scale in centimetres are used to measure snow depth at a minimum of three points located about 0.5 m apart. The average of all measurements is recorded as total snow depth and is reported in full centimetres. The grassy measurement field has a minimum area of 25 m$^2$, and the location is selected to minimise influence from the wind. Total snow depth is reported as long as at least half of the measurement field is covered with snow.

### Automatic measurements:

Automatic snow depth measurements are performed either every 5 minutes (1 station) or every 10 minutes (6 stations). At three stations ultrasonic snow depth sensors are used. At two of these stations, as well as at two other stations, webcams are used to observe fixed snow stakes with a 2 cm resolution (a photograph is taken once every 10 minutes). From the images, snow depth is estimated visually at 0700 UTC by an RMI observer.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported explicitly. RMI observers apply a coding system that considers conditions where the measurement field (area of 25 m$^2$) is heterogeneously covered with snow: (1) traces of snow; (2) at least 50% of the measurement field is snow free but some snow is present; and (3) more than 50% but not all of the measurement field is covered with snow.

### Zero snow depth reporting method:

When more than 50% of the measurement field is snow free, 0 cm snow depth is reported.

## I-2.4.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 21

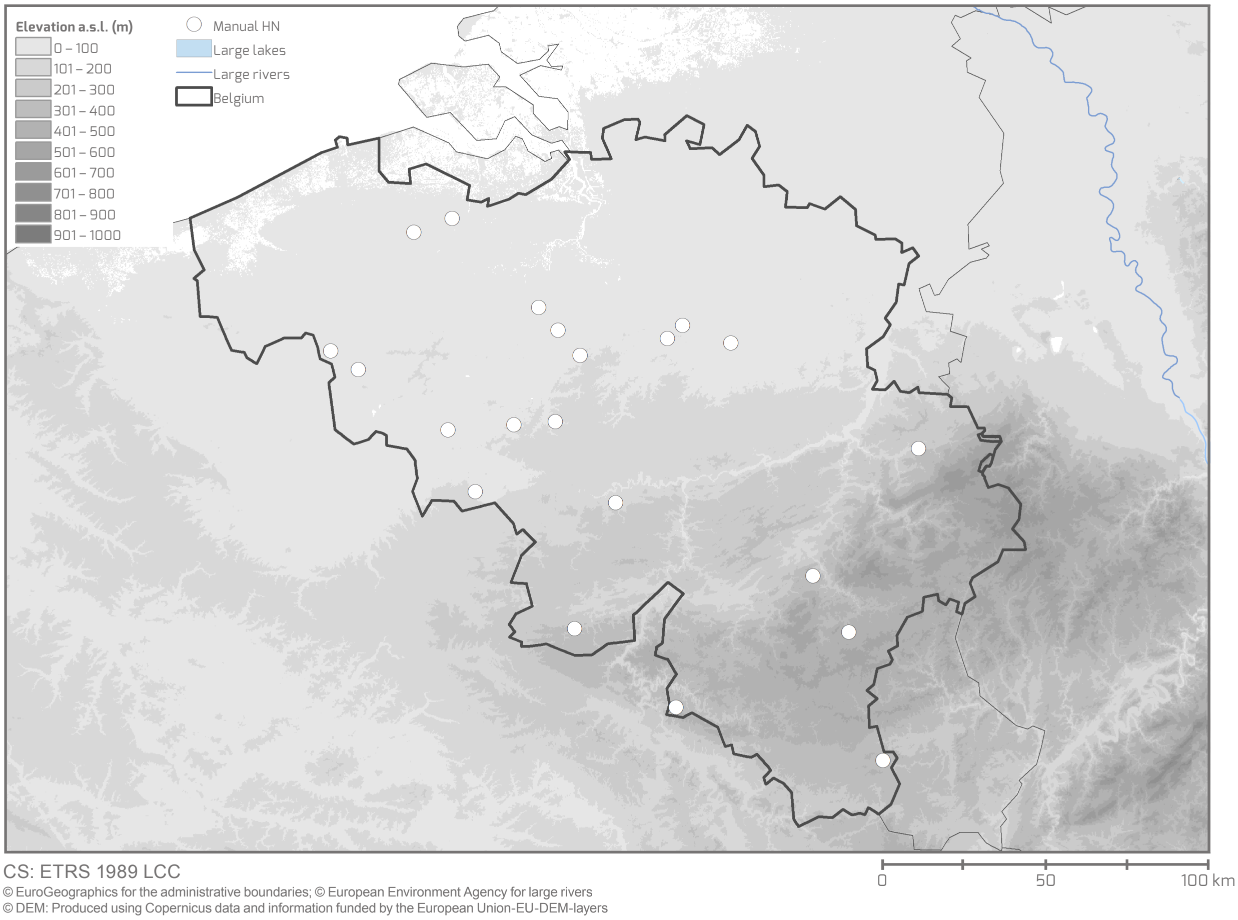

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*Figure I-2.4.4 Locations of stations in Belgium where depth of snowfall (HN) is measured.*

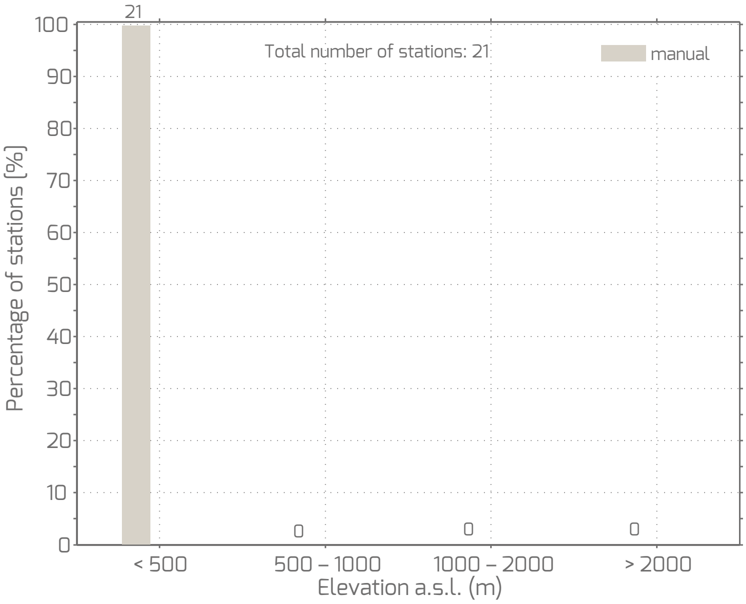

*Figure I-2.4.5 Elevational distribution of stations in Belgium with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours at 0700 UTC in parallel to manual snow depth measurements. Depth of snowfall is measured with a ruler on a flat surface (grass or snow board). After each measurement, either the snow is removed from the grassy surface or the snow board is cleaned.

## I-2.4.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 2

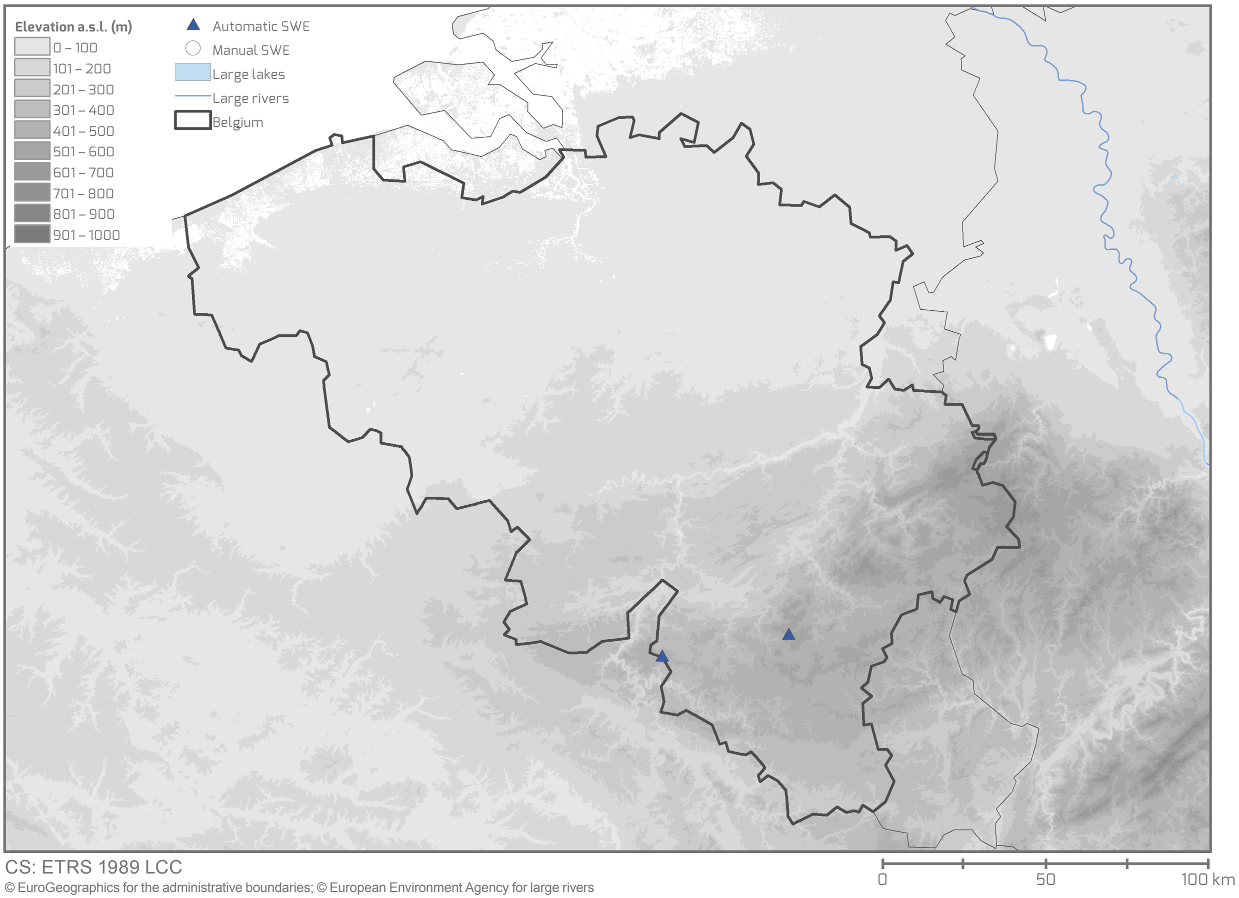

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*Figure I-2.4.6 Locations of stations in Belgium where water equivalent of snow cover (SWE) is measured.*

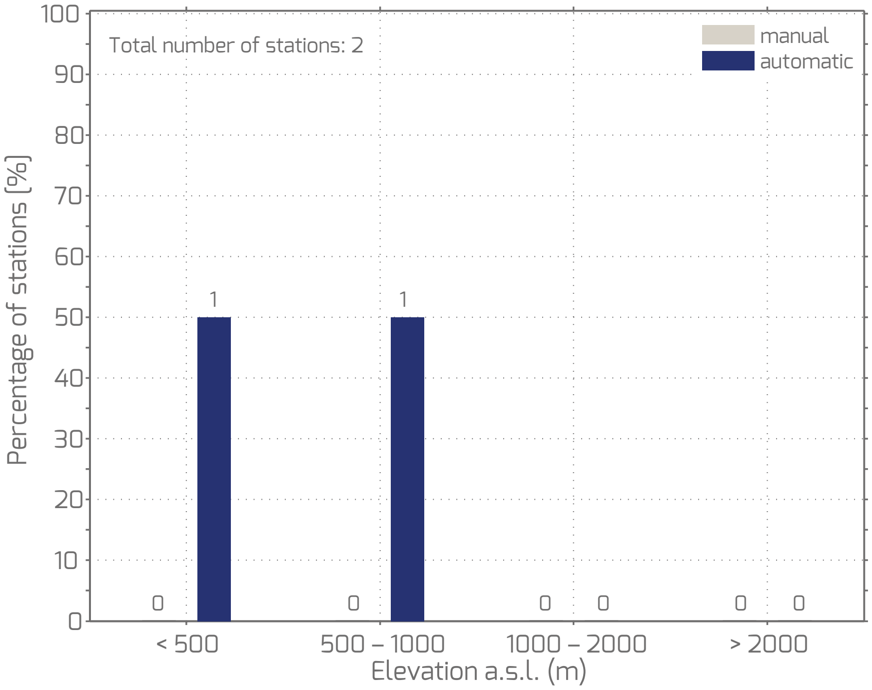

*Figure I-2.4.7 Elevational distribution of stations in Belgium with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

No measurements.

**Automatic measurements:**

Water equivalent of snow cover is measured automatically every 5 minutes using snow scales (SSG 1000; Sommer Messtechnik, Vorarlberg, Austria). Automatic SWE stations became operative between December 2016 and January 2017.

## I-2.2.4 Transition from manual to automatic measurements

Parallel measurements of snow depth have been carried out regularly since 2002 at one RMI station (Mont Rigi). In all other cases, automatic weather stations were installed at totally new locations or manual snow observations were stopped before new automatic stations were installed.

## I-2.2.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 12 or 24 hours (RMI)<br>AUTO: 5 or 10 minutes (RMI) | MANUAL: 24 hours (RMI) | MANUAL: no measurements<br>AUTO: 5 minutes (RMI) |

# I-2.5 Bosnia and Herzegovina

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*Figure I-2.5.1 Location of Bosnia and Herzegovina in Europe.*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 51 197 km$^2$, 688 m a.s.l. |
| Authority responsible for snow measurements | Federal Hydrometeorological Institute (FHMI) of the Federation of Bosnia and Herzegovina<br>Bardakčije<br>BA-71000 Sarajevo |
| Contact | • FHMI<br>bakir.krajinovic@fhmzbih.gov.ba (Bakir Krajinović) |
| Near-real-time data URL and/or contact | • FHMI<br>http://www.fhmzbih.gov.ba/latinica/AKTUELNO/snijeg.php |
| Archived data URL and/or contact | • FHMI<br>http://www.fhmzbih.gov.ba/latinica/KLIMA/godisnjaci.php |

### General situation

The Federal Hydrometeorological Institute (FHMI) is responsible for operational snow observations in the Federation of Bosnia and Herzegovina, which is only a part of the country Bosnia and Herzegovina. FHMI has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. All basic snow variables, i.e. snow depth, presence of snow on the ground, depth of snowfall and water equivalent of snow cover, are observed manually by FHMI. The snow observation network shown in this report is located only in the Federation of Bosnia and Herzegovina. Unfortunately, information on snow observation networks in other parts of Bosnia and Herzegovina was not available.

### Overview of measurements (FHMI)

Snow depth: stake (Figs I-2.5.2, I-2.5.3)
Depth of snowfall: snow board and ruler (Figs I-2.5.6, I-2.5.7)
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.5.8, I-2.5.9)
Operational purpose of measurements: Agriculture and Forestry, Climatology, Flood forecasting, Health and Sport, Hydrology, Meteorology, Road services, Water management

## I-2.5.1 Snow depth measurements

Number of stations delivering snow depth data manually: 14
Number of stations delivering snow depth data automatically: 0

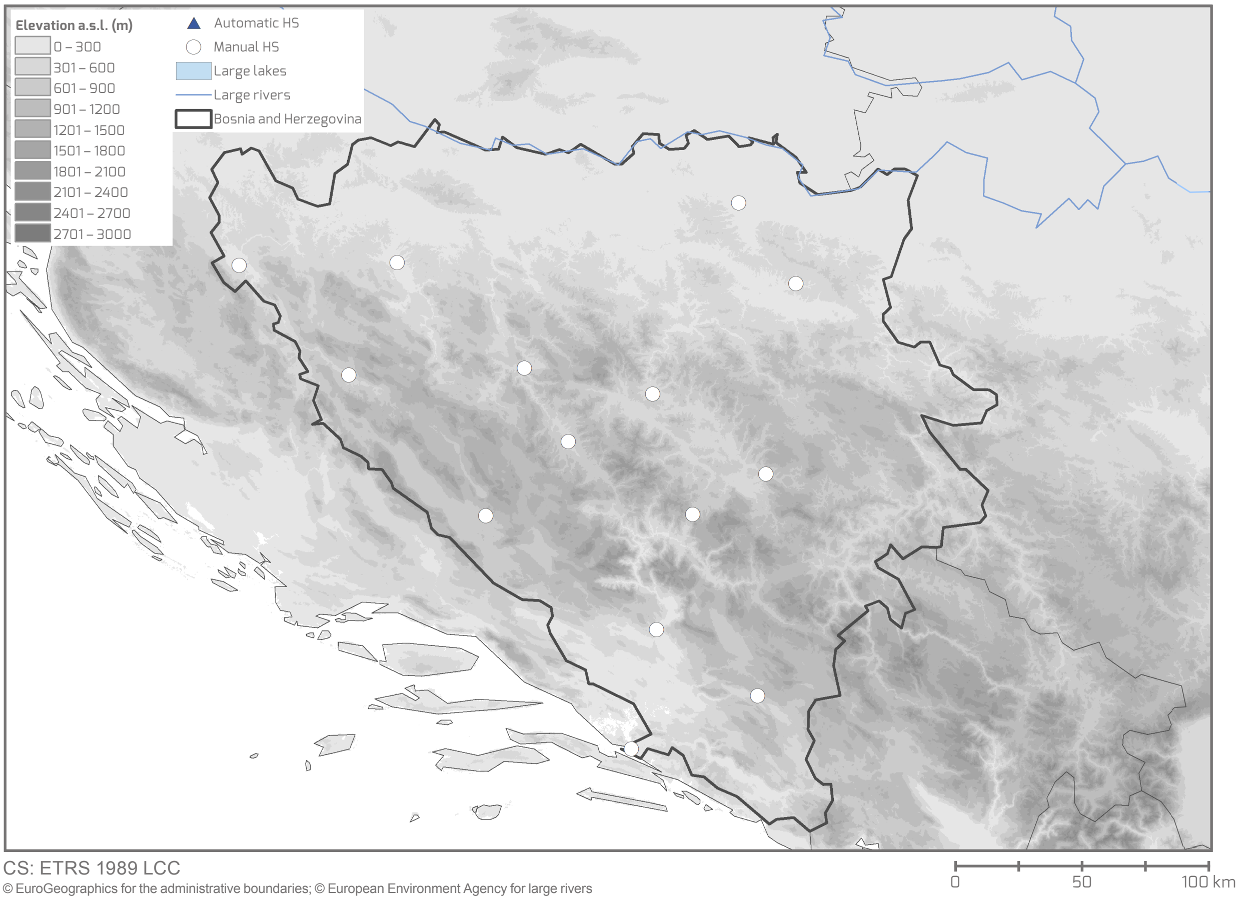

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*Figure I-2.5.2 Locations of stations in Bosnia and Herzegovina where snow depth (HS) is measured.*

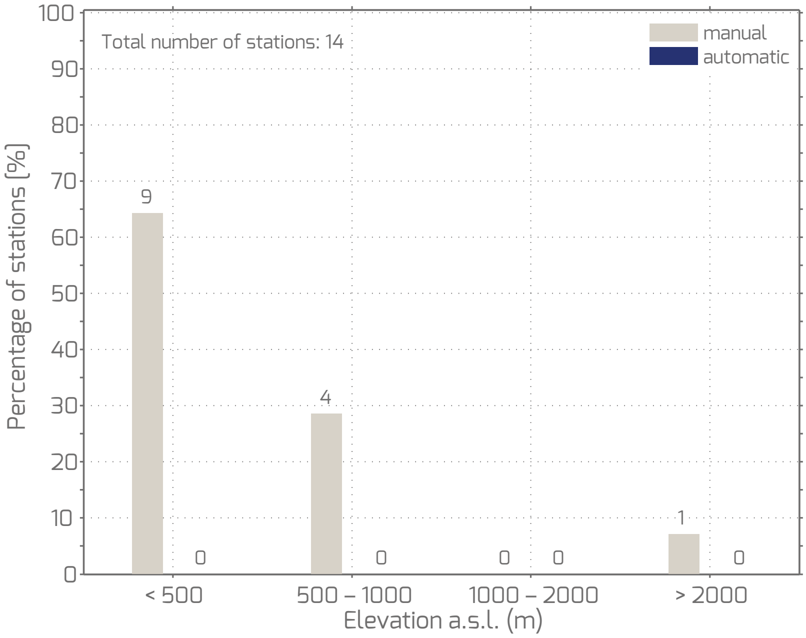

*Figure I-2.5.3 Elevational distribution of stations in Bosnia and Herzegovina with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours. Fixed stakes with a scale in centimetres are used (Fig. I-2.5.4). At each measurement site (20 x 20 m), three stakes are installed 10 m apart (Fig. I-2.5.5) and the average of measurements from all three points is reported as total snow depth. The measurement staff avoids disturbing the 3 x 3 m area around each stake. To prevent incorrect measurements, values are read as horizontally to the snow surface as possible. Total snow depth is reported as long as there is any snow in the measurement field.

### Automatic measurements:

No measurements.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported explicitly.

### Zero snow depth reporting method:

When the measurement site is totally snow free, 0 cm snow depth is reported.

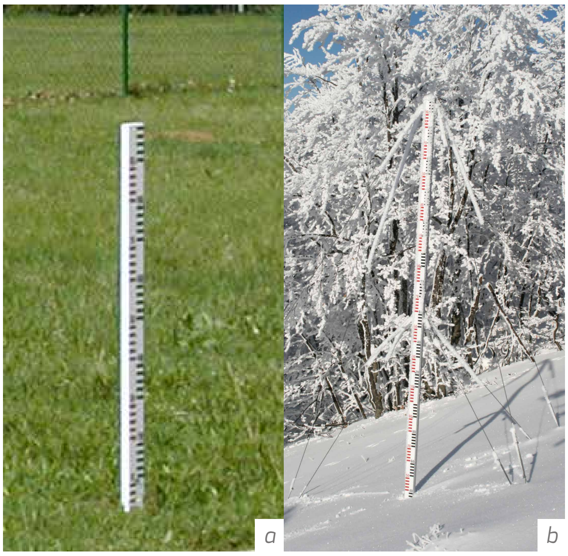

*Figure I-2.5.4 Snow stakes (a) during the snow-free season and (b) during winter (Source: DHMZ, FHMI).*

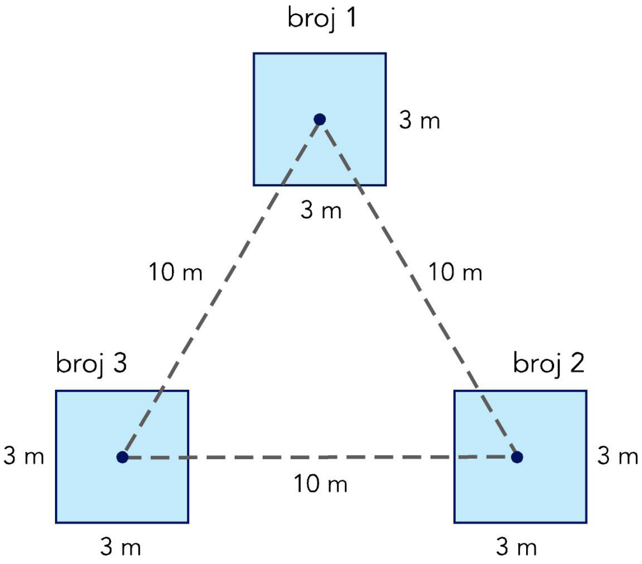

*Figure I-2.5.5 Measurement field (20 x 20 m) set-up used at sites in Bosnia and Herzegovina, including three stakes 10 m apart (Source: DHMZ, FHMI).*

## I-2.5.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 14

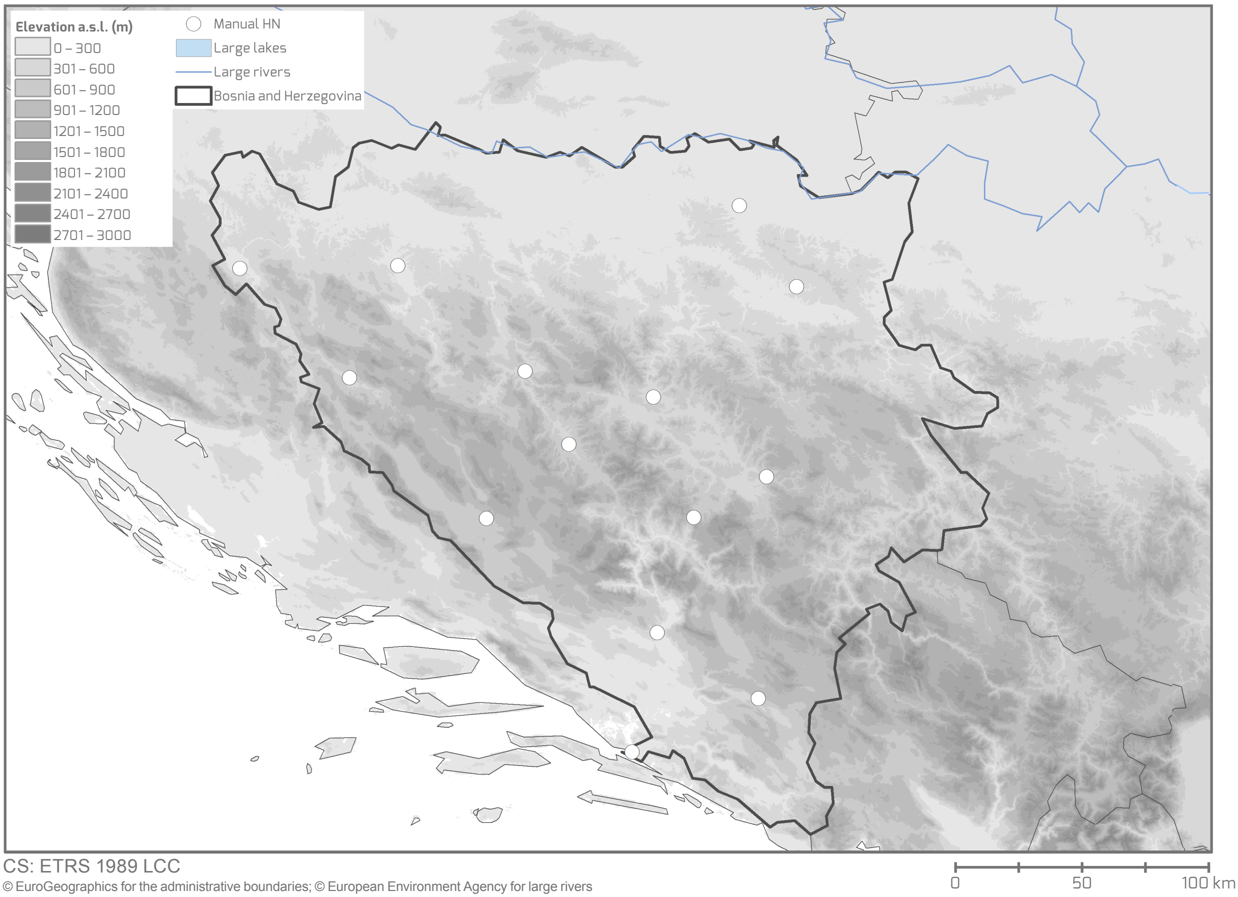

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*Figure I-2.5.6 Locations of stations in Bosnia and Herzegovina where depth of snowfall (HN) is measured.*

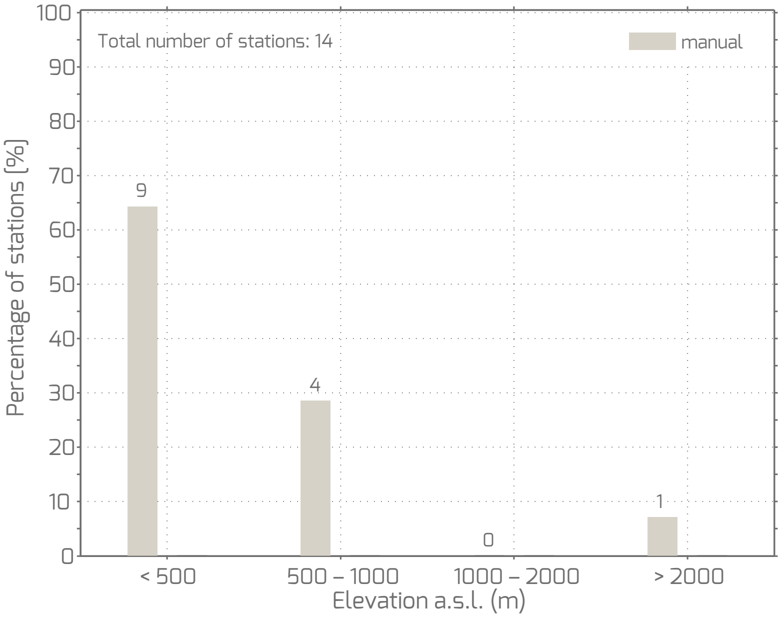

*Figure I-2.5.7 Elevational distribution of stations in Bosnia and Herzegovina with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours in parallel to manual snow depth measurements. Depth of snowfall is measured on a snow board with a ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface.

## I-2.5.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 11
Number of stations delivering water equivalent of snow cover data automatically: 0

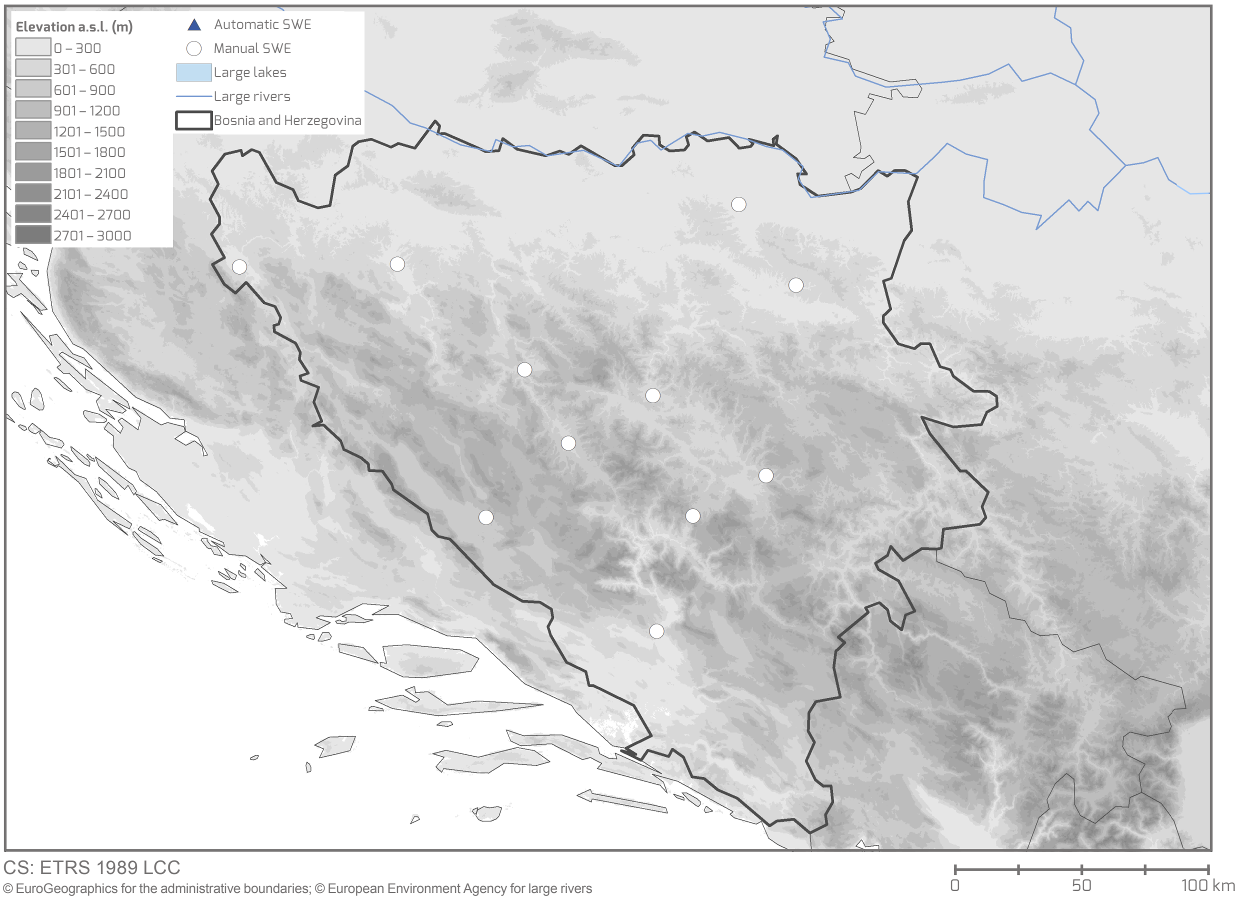

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*Figure I-2.5.8 Locations of stations in Bosnia and Herzegovina where water equivalent of snow cover (SWE) is measured.*

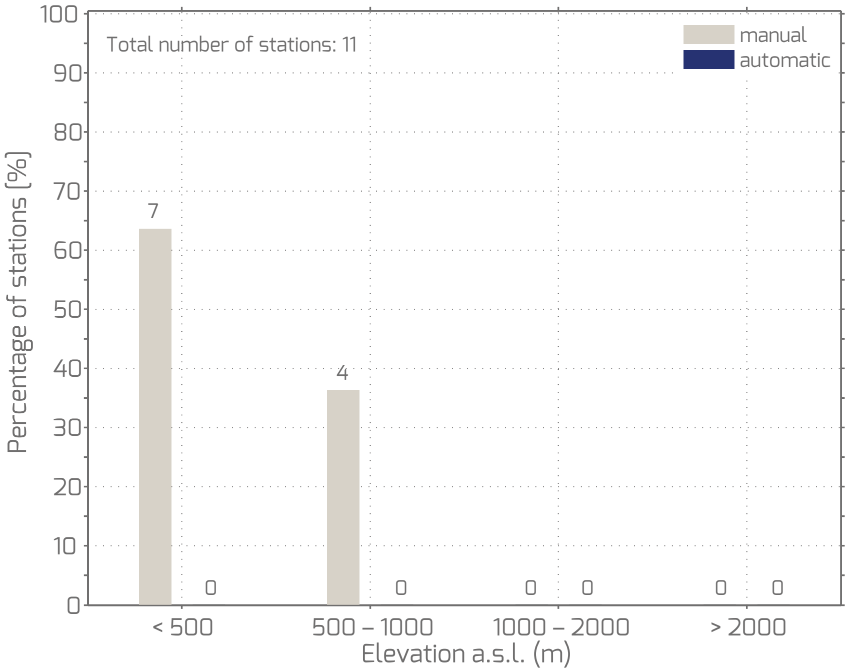

*Figure I-2.5.9 Elevational distribution of stations in Bosnia and Herzegovina with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every five days (5th, 10th, 15th, 20th, 25th and last day of the month) if the snow depth exceeds 5 cm. The gravimetric method is applied. Using a graduated iron snow cylinder (Figs I-2.5.10 a, I-2.5.11 a) with a certain cross-sectional area (in $m^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack (Fig. I-2.5.10 b). After the height of the snow sample (in m) is measured and excess snow on the external surface of the cylinder is removed, the snow cylinder is attached to a steelyard balance (Fig. I-2.5.10 a) to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. If the snow depth is greater than the length of the cylinder, the total snow depth is divided into multiple analogue "columns" using a small shovel (Fig. I-2.5.11 b, c). Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

Additional SWE measurements in snow pits are performed if: (1) the snow depth exceeds 5 cm for the first time in winter, irrespective of the day of the month; (2) rapid snow melting occurs during the ablation season, in which case SWE is measured daily; or (3) depth of snowfall exceeds 10 cm within 24 hours.

**Automatic measurements:**

No measurements.

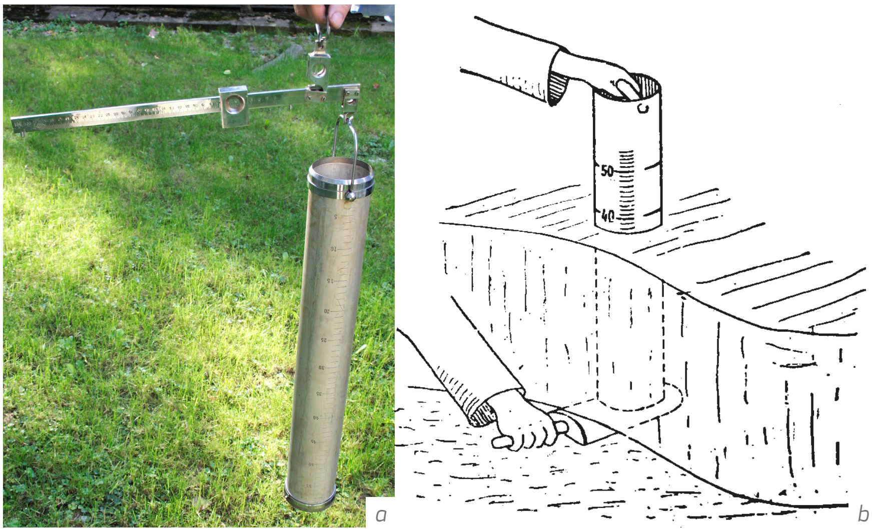

*Figure I-2.5.10 (a) Iron snow cylinder attached to a steelyard balance used to measure water equivalent of snow cover (SWE) at sites in Bosnia and Herzegovina. (b) Sketch of vertical snow sampling in a snow pit (Sources: DHMZ, FHMI).*

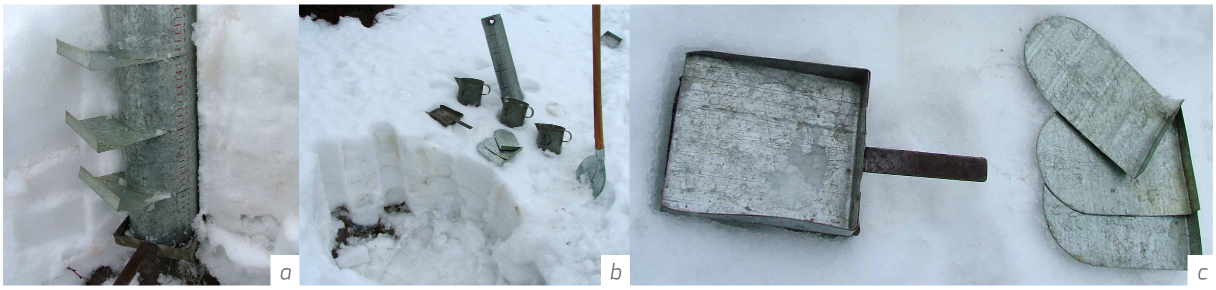

*Figure I-2.5.11 (a) Iron snow cylinder; (b, c) water equivalent of snow cover (SWE) measurement instruments including cans and small shovels (Source: DHMZ, FHMI).*

## I-2.5.4 Transition from manual to automatic measurements

No parallel measurements are carried out because only manual stations are in use.

## I-2.5.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (FHMI) | MANUAL: 24 hours (FHMI) | MANUAL: 5 days (FHMI) |
| AUTO: no measurements | | AUTO: no measurements |

# I-2.6 Bulgaria

*Figure I-2.6.1 Location of Bulgaria in Europe.*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 110 370 km$^2$, 474 m a.s.l. |
| Authority responsible for snow measurements | National Institute of Meteorology and Hydrology of the Bulgarian Academy of Sciences (NIMH)<br>66 Tsarigradsko Shose<br>BG-1784 Sofia |
| Contact | • NIMH<br>eram.artinian@meteo.bg (Eram Artinyan)<br>dimitar.nikolov@meteo.bg (Dimitar Nikolov)<br>tzvetan.dimitrov@meteo.bg (Tzvetan Dimitrov) |
| Near-real-time data URL and/or contact | • NIMH<br>http://arda.hydro.bg/data/snowparam.php |
| Archived data URL and/or contact | • NIMH<br>market@meteo.bg (data on request) |

### General situation

The National Institute of Meteorology and Hydrology of the Bulgarian Academy of Sciences (NIMH) is responsible for operational snow measurements in Bulgaria. NIMH observes snow depth and water equivalent of snow cover manually and automatically, while depth of snowfall is not measured. Manual measurements are only used operationally and automatic ones are only used for research purposes. Manual snow depth and manual water equivalent of snow cover observation stations are both located mainly in the Bulgarian lowlands, where there are very few days with snow cover per year. Only two stations with manual snow depth and water equivalent of snow cover measurements are located at synoptic stations in the mountainous regions of Bulgaria: at Peak Rojen in the Rhodope mountains and at Peak Botev vrah in the Balkan mountain range. The number of manual water equivalent of snow cover stations decreased by more than 50%, from 50 to 20 stations, in recent years.

In this country report, the elevational and spatial station distribution of only 17 of 356 NIMH stations measuring snow depth is shown. The metadata for the other 339 stations is not publicly available. The same is true for 20 manual water equivalent of snow cover measurement locations, which are not included here because the metadata is not available. Thus, metadata from only two automatic research stations measuring snow depth and water equivalent of snow cover, as well as from 15 manual snow depth stations, is available and illustrated in the maps below.

### Overview of measurements (NIMH)

Snow depth: stake, ultrasonic snow depth sensor (Figs I-2.6.2, I-2.6.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: snow cylinder, steelyard balance, snow scale, Snow Pack Analyser (Figs I-2.6.5, I-2.6.6)
Operational purpose of measurements: Flood forecasting, Hydrology, Meteorology

## I-2.6.1 Snow depth measurements

Number of stations delivering snow depth data manually: 15
Number of stations delivering snow depth data automatically: 2

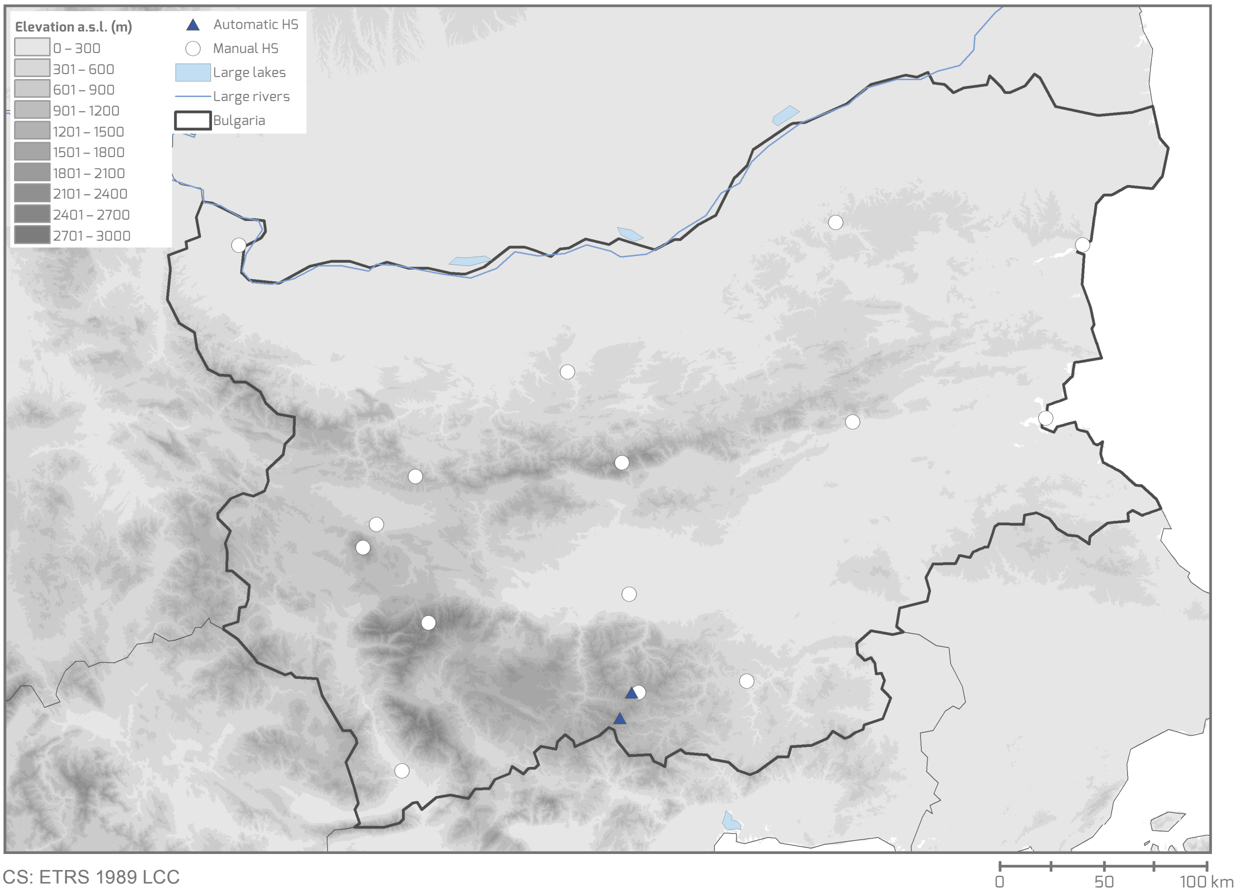

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*Figure I-2.6.2 Locations of stations in Bulgaria where snow depth (HS) is measured.*

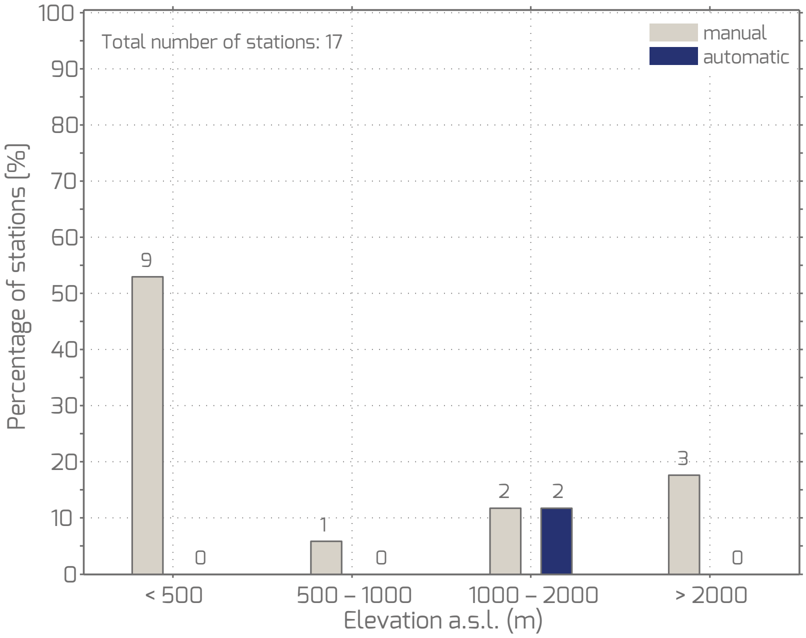

*Figure I-2.6.3 Elevational distribution of stations in Bulgaria with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours at 0530 UTC. Fixed stakes with a scale in centimetres are used and are located in areas representative of their surroundings. Most manual stations are located in the Bulgarian lowlands, where snow is rare. A single observer measures the snow depth at precipitation and climatological stations, while five observers are responsible for snow observations at synoptic stations. Total snow depth is reported as long as a continuous snow cover is present.

### Automatic measurements:

Snow depth is measured automatically every hour using ultrasonic snow depth sensors (USH-8; Sommer Messtechnik, Vorarlberg, Austria). The sensors are mounted 3.5 m above the ground (Fig. I-2.6.4).

### Presence of snow on the ground reporting method:

Presence of snow on the ground is not reported explicitly.

### Zero snow depth reporting method:

A snow depth of zero is not reported. When the measurement field is only partially covered with snow, snow depth is neither measured nor reported. However, a coding system is used to report which part of the measurement field is covered with snow.

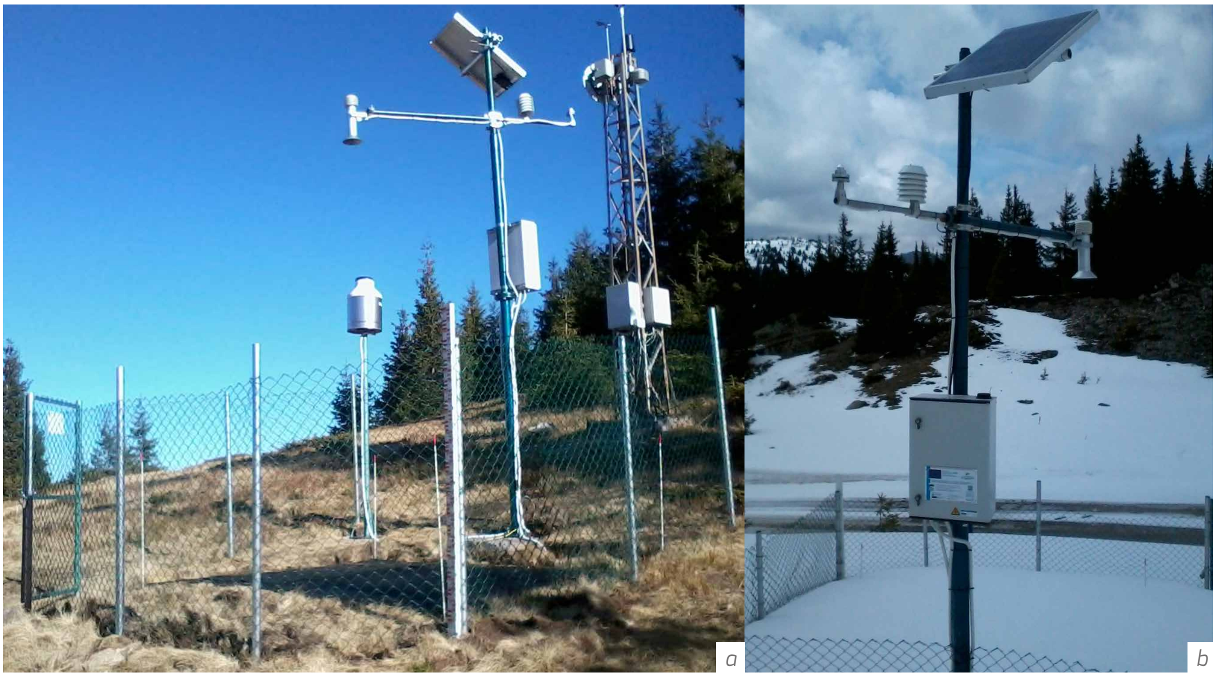

*Figure I-2.6.4 Automatic weather station Perelik (Bulgaria) with USH-8 snow depth sensor during (a) the snow-free season and (b) the snow-covered season (Source: NIMH).*

## I-2.6.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.6.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 2

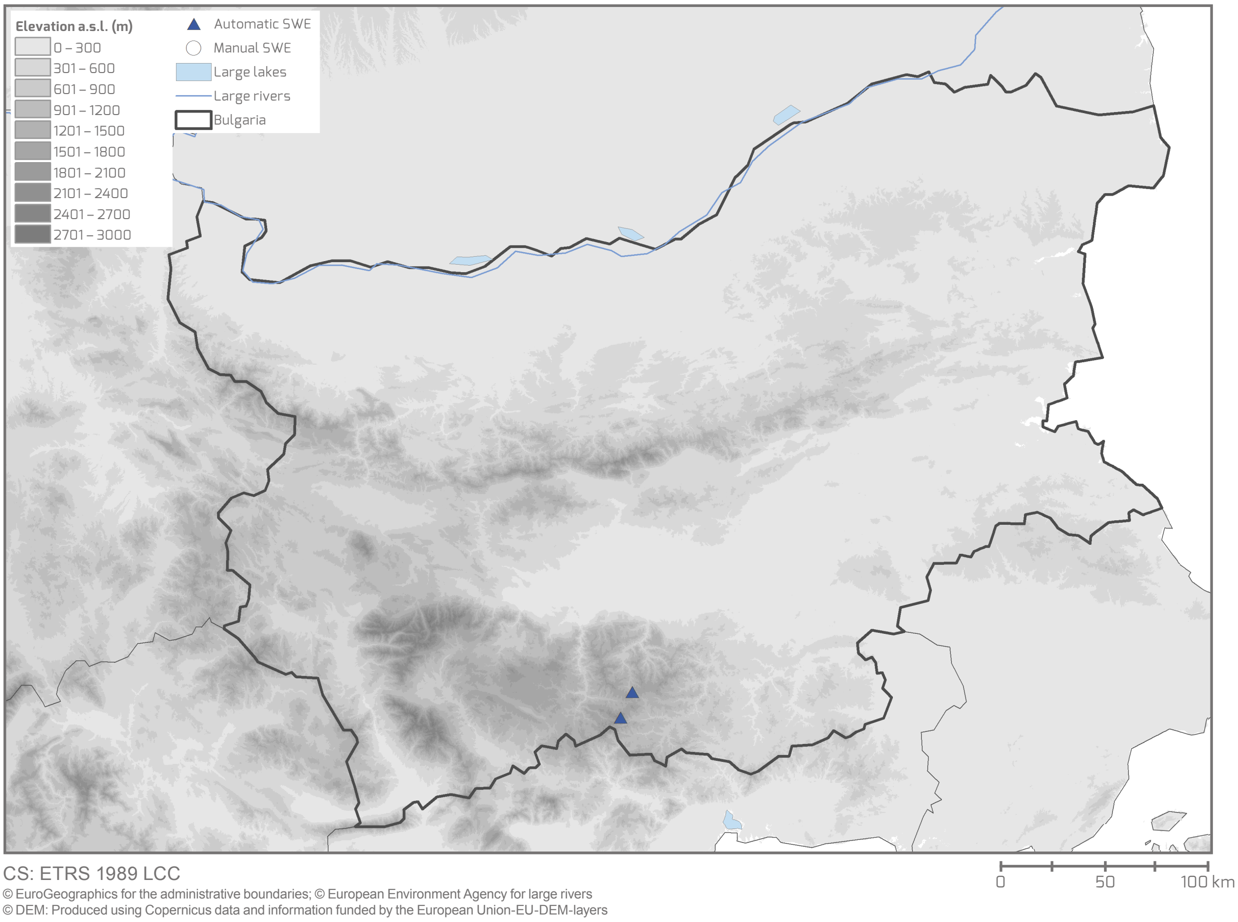

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*Figure I-2.6.5 Locations of stations in Bulgaria where water equivalent of snow cover (SWE) is measured.*

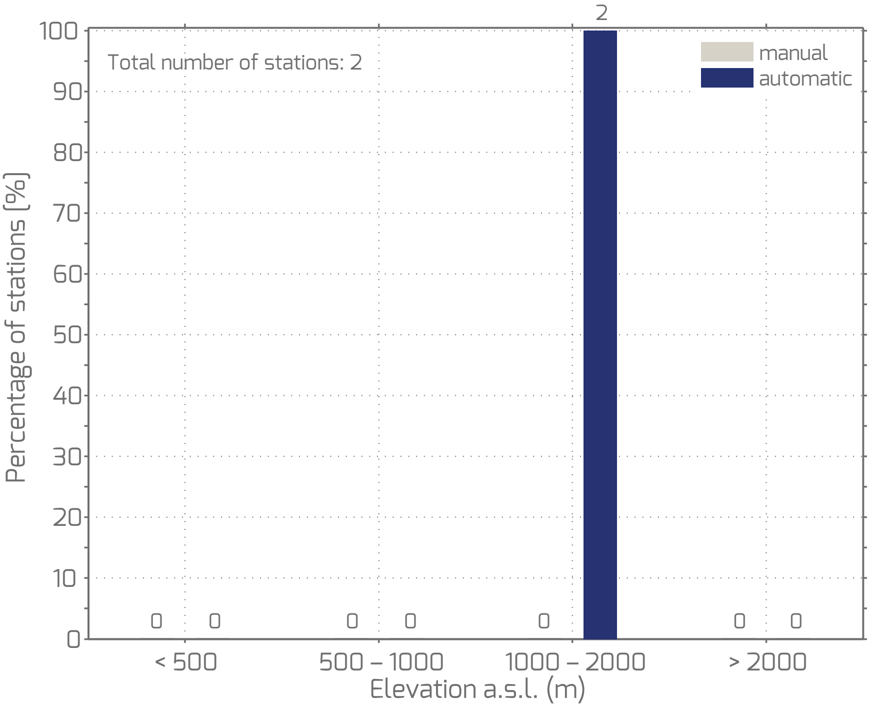

*Figure I-2.6.6 Elevational distribution of stations in Bulgaria with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Although no station metadata of manual SWE observations is available, the measurement principle is known and described here. Manual SWE measurements in snow pits are performed every five days during continuous snow cover. The gravimetric method is applied. Using a graduated 0.6-m-long snow cylinder, a snow sample is extracted vertically from the snowpack. The total weight of the snow is measured directly using a steelyard balance, which is attached to the cylinder. If the snow depth is greater than the length of the cylinder, the total snow depth is divided into multiple analogue "columns" and several 0.6-m-long snow samples are extracted. The weights of all snow samples are summed to derive the SWE of the snow cover.

**Automatic measurements:**

Water equivalent of snow cover is measured automatically every hour using either a snow scale or a Snow Pack Analyser (SPA; Fig. I-2.6.7). Both automatic stations are located in the Rhodope mountains.

*Figure I-2.6.7 Automatic station Rozhen (Bulgaria) with a Snow Pack Analyser and a USH-8 snow depth sensor (Source: NIMH).*

## I-2.6.4 Transition from manual to automatic measurements

No parallel measurements have been made because no stations have been shifted from manual to automatic measurements.

## I-2.6.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (NIMH)<br>AUTO: 1 hour (NIMH) | MANUAL: no measurements | MANUAL: 5 days (NIMH)<br>AUTO: 1 hour (NIMH) |

# I-2.7 Croatia

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*Figure I-2.7.1 Location of Croatia in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 56 594 km², 309 m a.s.l. |
| Authority responsible for snow measurements | Meteorological and Hydrological Service of Croatia (DHMZ)<br>Gric 3<br>HR-10000 Zagreb |
| Contact | · DHMZ<br>dhmz@cirus.dhz.hr |
| Near-real-time data URL and/or contact | · DHMZ<br>http://vrijeme.hr/aktpod_e.php?id=snijeg_e<br>http://klima.hr/klima.php?id=k4 |
| Archived data URL and/or contact | · DHMZ<br>https://meteo.hr/proizvodi_e.php?section=proizvodi_usluge&param=services |

## General situation

The Meteorological and Hydrological Service of Croatia (DHMZ) is responsible for operational snow observations in Croatia. As the national meteorological service, DHMZ has the duty to observe meteorological and hydrological variables for the sake of public interest, weather forecasting and climatological records. Currently, the DHMZ meteorological network consists of 40 main meteorological, 101 climatological and 331 precipitation gauge stations, all of which include snow measurements. The station network covers the coastal regions and islands of the Adriatic Sea, as well as mountainous regions and the Croatian backcountry. DHMZ measures the following snow variables: snow depth, presence of snow on the ground, depth of snowfall, snow density and consequently water equivalent of snow cover. All of these variables are measured manually, while no automatic measurements are yet in operational use. Automatic sensors are in a testing phase and are planned to be activated for operational purposes at 68 new locations by 2020.

In many cases all requirements for representative snow observations cannot easily be fulfilled. For example, at some main meteorological stations only one of three snow stakes is installed. Moreover, the coastal regions have a Mediterranean climate and days with snow cover are rare. Some precipitation and climatological stations operated by volunteers (located close to the sea) are not yet fully equipped to measure all snow variables, such as depth of snowfall (snow boards are missing).

The metadata available for the snow monitoring network is from 31 December 2016. A maximum snow depth of 3.22 m was measured at the main synoptic station Zavižan on 21 December 2013. All snow observations are quality controlled and stored in the DHMZ database. All station metadata and notes about station interruptions or relocations are stored in the DHMZ station catalogue and will be transferred into the WMO database in the future.

## Overview of measurements (DHMZ)

Snow depth: stake, ruler (Figs I-2.7.2, I-2.7.3)
Depth of snowfall: snow board and ruler (Figs I-2.7.6, I-2.7.7)
Water equivalent of snow cover: snow cylinder, steelyard balance, spatula, measuring cup (Figs I-2.7.8, I-2.7.9)
Operational purpose of measurements: Agriculture and Forestry, Building and Construction, Climatology, Energy production, Hydrology, Meteorology, Road services, Tourism, Water management

## I-2.7.1 Snow depth measurements

Number of stations delivering snow depth data manually: 472
Number of stations delivering snow depth data automatically: 0

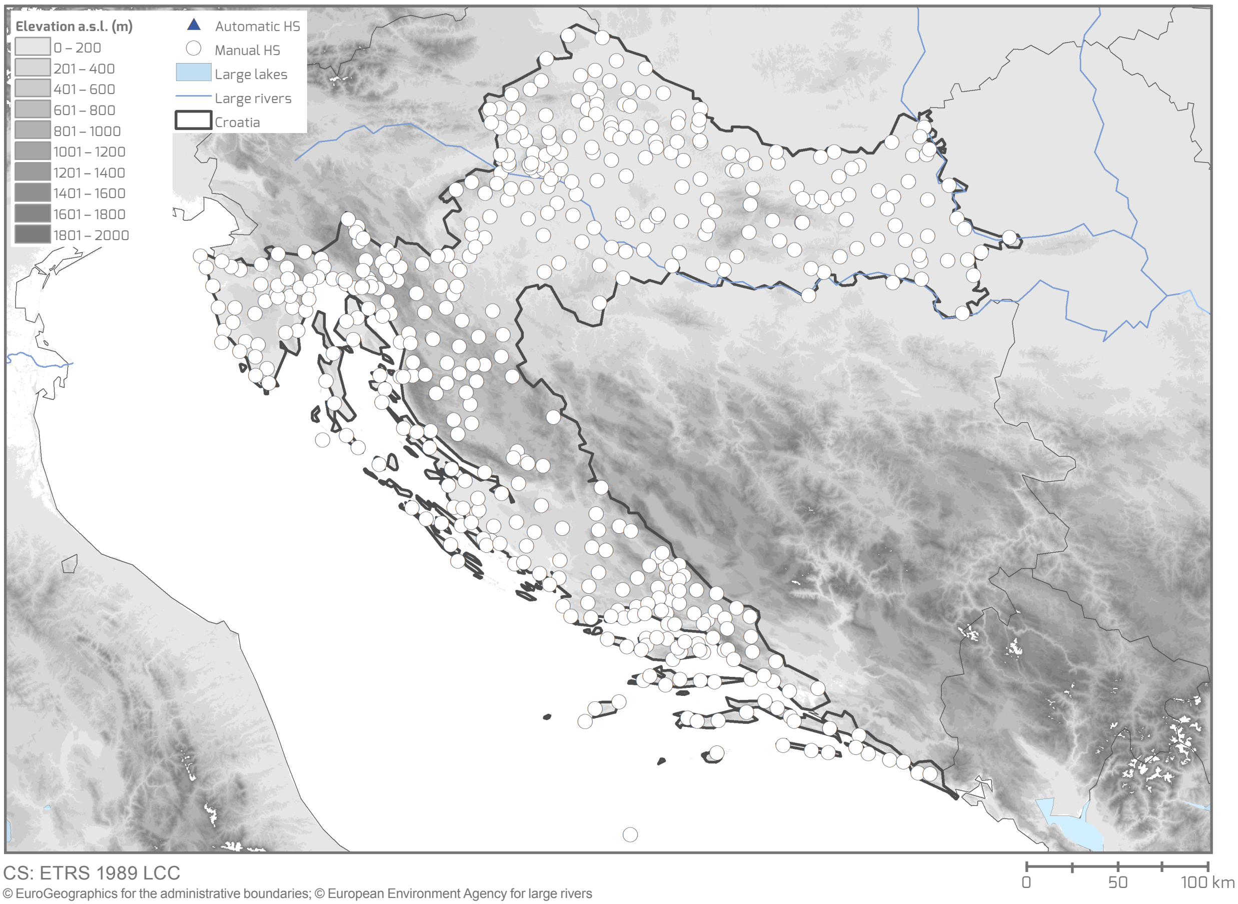

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*Figure I-2.7.2 Locations of stations in Croatia where snow depth (HS) is measured.*

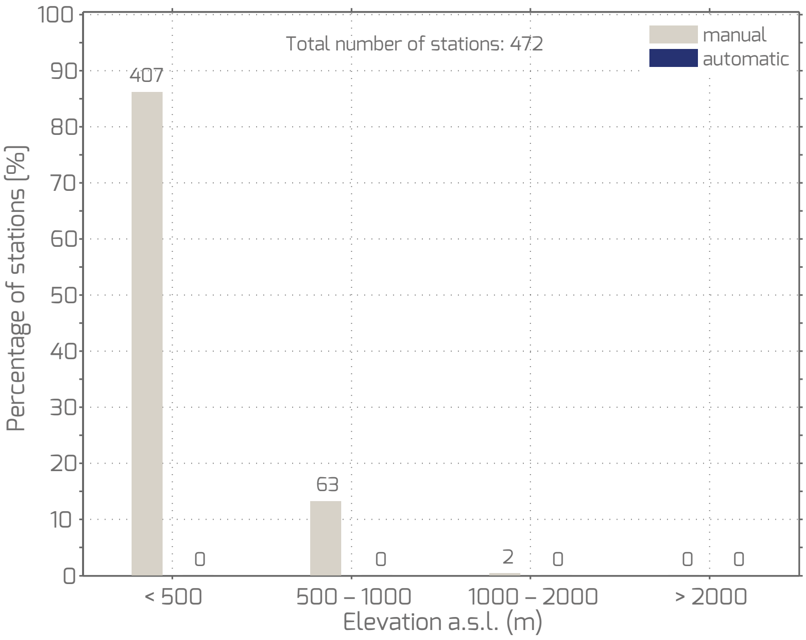

*Figure I-2.7.3 Elevational distribution of stations in Croatia with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed either every 12 hours at 0600 and 1800 UTC (40 main meteorological stations) or every 24 hours at 0600 UTC (101 climatological stations and 331 precipitation stations operated by volunteers).

For the main meteorological stations and the climatological stations, the measurement field is approximately 20 x 20 m (400 m$^2$) and is flat and grass covered where possible. Three fixed wooden snow stakes with a scale in centimetres and a length of 1 or 3 m are installed (Fig. I-2.7.4 a). The stakes are mounted in a triangular arrangement, 10 m apart. Around each stake, a 3 x 3 m area is left undisturbed (Fig. I-2.7.5). The average of the three readings is recorded as total snow depth and is reported in full centimetres.

In cases where the measurement field is not flat, the field is tilted to correspond to the general conditions of the terrain where the station is located (Fig. I-2.7.4 b). Permanent stakes are mounted in autumn (before the first snowfall) on freshly cut grassy ground. At mountain stations, the stakes remain in their positions for the whole year.

In areas with little snow (i.e. coastal areas with a Mediterranean climate) and at precipitation stations operated by volunteers (331 stations), snow depth is measured manually at three permanent locations using portable wooden rulers. The average of the three readings is reported. The wooden rulers are 1 to 3 m long with a scale in centimetres (Fig. I-2.7.4 c). The ends of the rulers are sharpened and wrapped with a 4-cm-long piece of tin.

Total snow depth is reported as long as at least 50% of the measurement field is covered with more than 0.5 cm of snow. Measured values are reported in full centimetres.

### Automatic measurements:

No measurements.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported explicitly in parallel to manual snow depth measurements. Snow coverage is reported for the measurement field and for the visible surroundings at same elevational level, but without taking into account river, lake or sea surfaces. A coding system is used (0 to 8): “0” means the measurement field is totally snow free; “1” means less than 10% of the measurement field is snow covered; and “8” means the measurement field is totally snow covered.

### Zero snow depth reporting method:

Snow depths less than 0.5 cm but covering more than 50% of the measurement field are reported as 0 cm snow depth and noted with the code “997”. If more than 50% of the measurement field and the surroundings is snow free, no further snow depth measurements are performed, meaning that 0 cm snow depth is not reported anymore and the SYNOP code “998” is used instead.

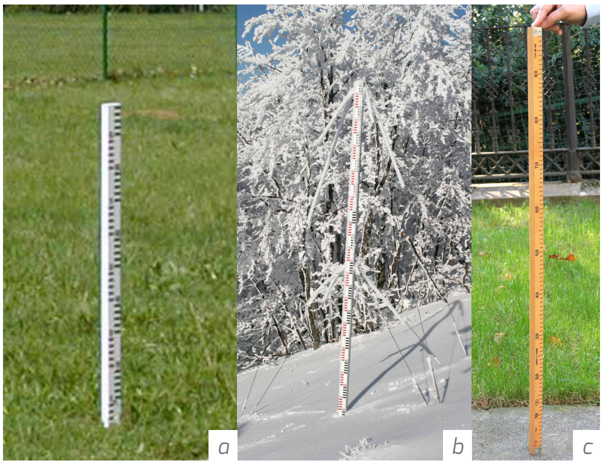

*Figure I-2.7.4 Fixed wooden stakes located within measurement fields: (a) on flat grassy ground during the snow-free season and (b) on a mountain slope during winter (Source: DHMZ, FHMI). (c) Portable wooden ruler used to measure snow depth at locations with little snow or at precipitation stations operated by volunteers (Source: DHMZ).*

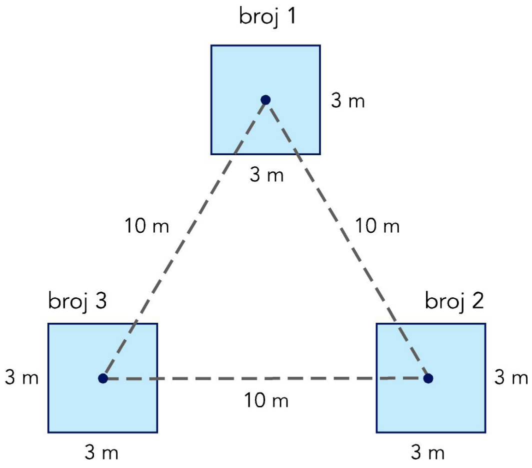

*Figure I-2.7.5 Sketch of a 20 x 20 m measurement field used at sites in Croatia. Three fixed stakes are installed 10 m apart, with a 3 x 3 m undisturbed area around each stake. In cases where snow depth is measured with rulers, the measurement field is similar (Source: DHMZ, FHMI).*

## I-2.7.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 247

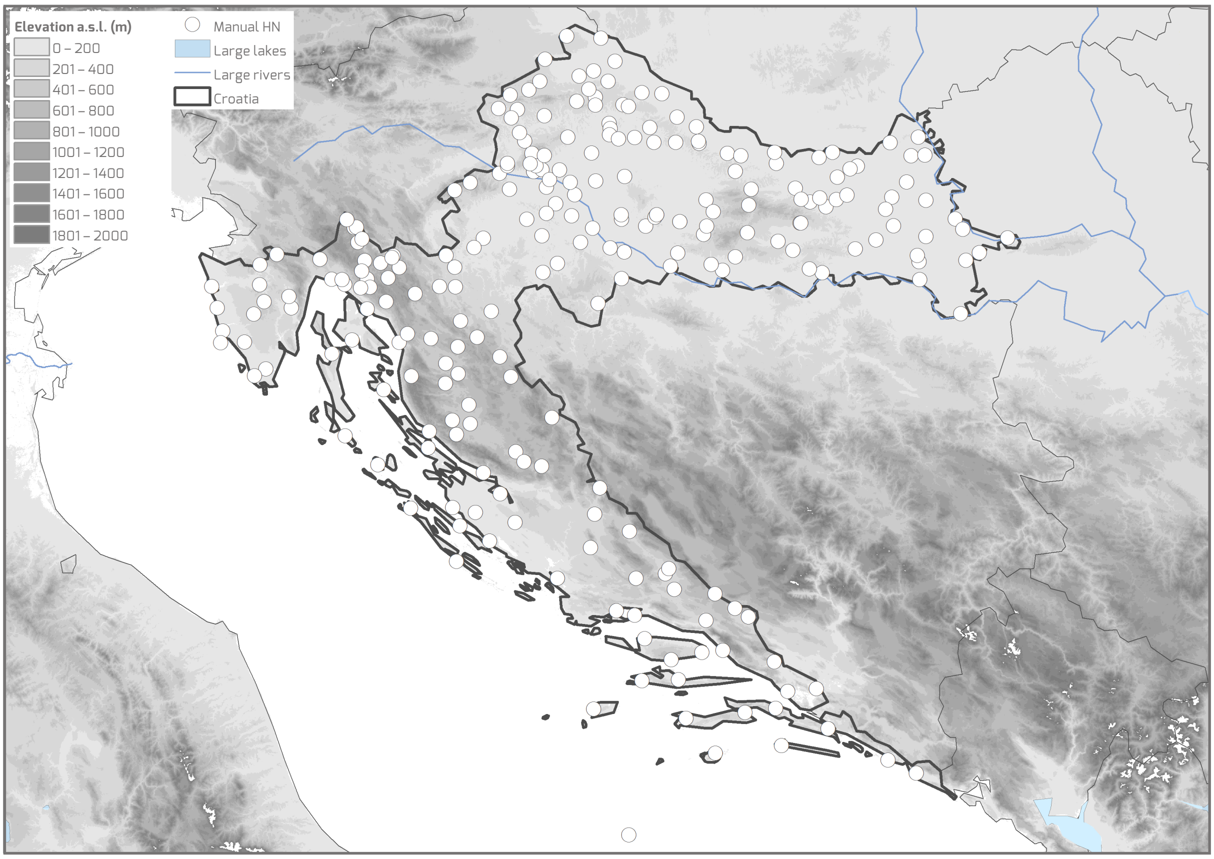

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*Figure I-2.7.6 Locations of stations in Croatia where depth of snowfall (HN) is measured.*

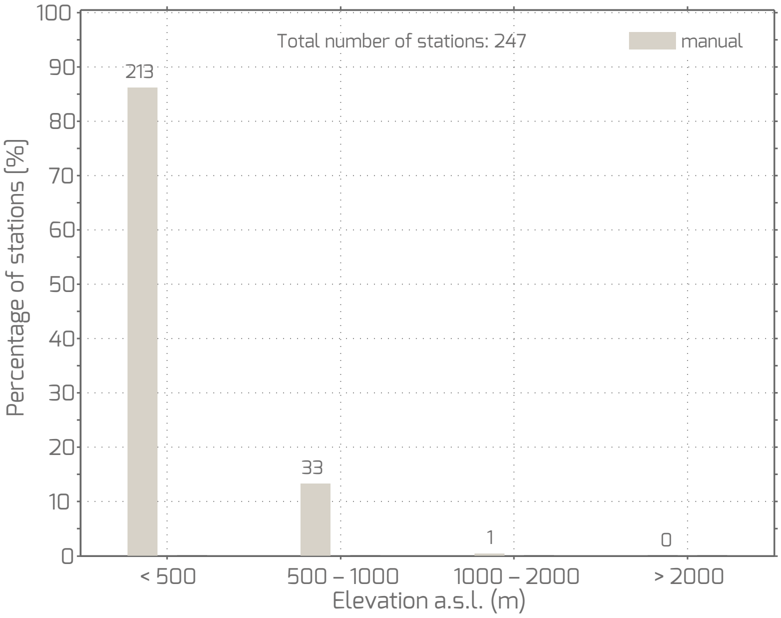

*Figure I-2.7.7 Elevational distribution of stations in Croatia with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed either every 12 hours at 0600 and 1800 UTC (main meteorological stations) or every 24 hours at 0600 UTC (other stations) in parallel to manual snow depth measurements. Depth of snowfall is measured on a white-painted wooden snow board (50 x 50 cm) with a wooden ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. The location of the depth of snowfall measurement is selected to minimise influence from the wind. Measured values are reported in full centimetres.

Due to forecasting needs, depth of snowfall is additionally reported at 1800 UTC at some of the 101 climatological stations. During rapid snow melt conditions, depth of snowfall is measured on the snow board at 1800 UTC, but the snow board is not cleaned until the next regular depth of snowfall measurement at 0600 UTC the following day.

## I-2.7.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 15
Number of stations delivering water equivalent of snow cover data automatically: 0

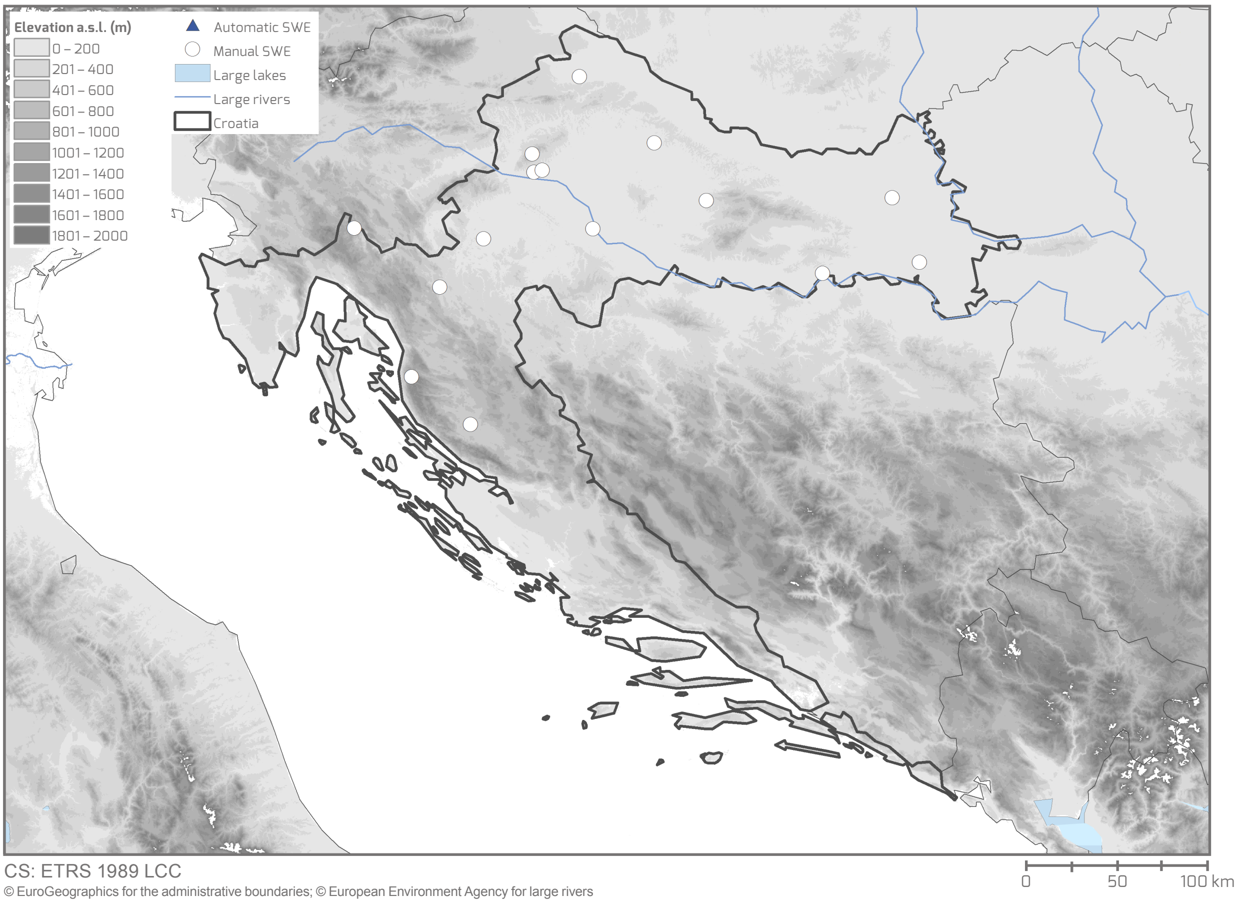

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*Figure I-2.7.8 Locations of stations in Croatia where water equivalent of snow cover (SWE) is measured.*

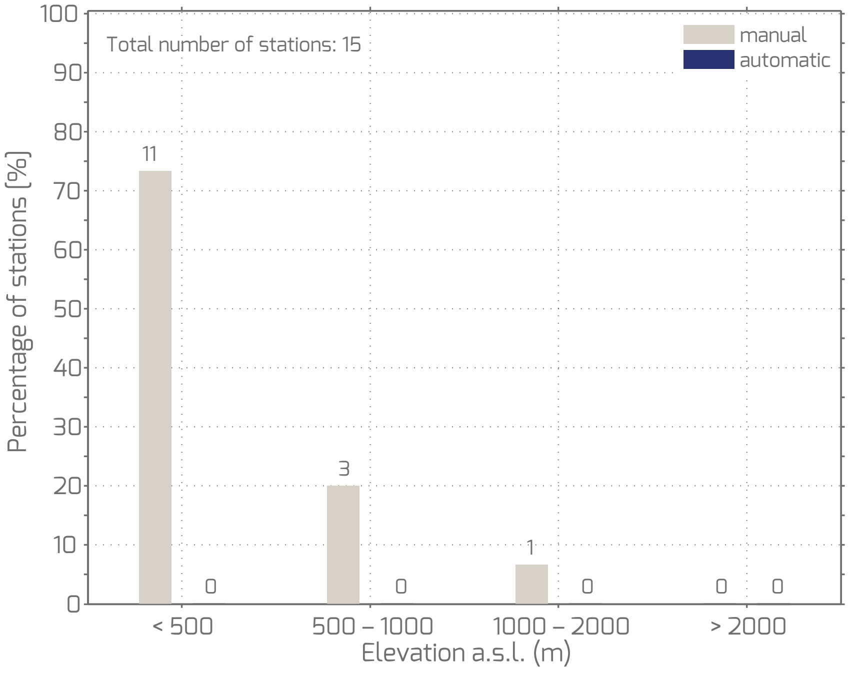

*Figure I-2.7.9 Elevational distribution of stations in Croatia with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow density and consequently SWE measurements in snow pits are performed every five days (5th, 10th, 15th, 20th, 25th and last day of the month) as long as the snow depth equals or exceeds 10 cm. Daily snow density and SWE measurements are performed (1) during rapid snow melt conditions and (2) on days with depth of snowfall measurements exceeding 10 cm. Snow density and hence SWE measurements are carried out at three designated points within the measurement field and the average of all measurements is reported. The gravimetric method is applied, using either (1) a "Hellmann" cylinder (Fig. I-2.7.10 a) or (2) a snow cylinder (Fig. I-2.7.11 a).

(1) The Hellmann cylinder (Fig. I-2.7.10 a) is a galvanised cylinder with a length of 0.6 m and a cross-sectional area of 0.01 m². Using the graduated Hellmann cylinder and a spatula (Fig. I-2.7.10 b), a snow sample is extracted vertically from the snowpack (as shown in Figure I-2.7.11 b). The height of the extracted snow sample can be measured with the centimetre divisions on the Hellmann cylinder. The snow sample is poured into a can and melted at room temperature (Fig. I-2.7.10 c). The water is then poured into a glass measuring cup to measure the water equivalent of the sample (WE; in mm w.e.). Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of each sampled layer. The Hellmann cylinder is only used at two main mountain stations, Puntijarka and Zavižan.

(2) At the other 13 stations, SWE is measured using a graduated iron snow cylinder and a steelyard balance (Fig. I-2.7.11 a). Using the snow cylinder (cross-sectional area 0.005 m², length 0.6 m) and a spatula, a snow sample is extracted vertically from the snowpack (Fig. I-2.7.11 b). After the height of the snow sample (in cm) is measured, the cylinder is attached to a steelyard balance to measure the total weight of the snow (in g). The corresponding snow density of the sample ( $\rho_{snow}$; in g cm$^{-3}$) is calculated by dividing the measured weight of the sample (in g) by the cross-sectional area of the snow cylinder (in cm²) and the height of the snow sample (in cm) in the snow cylinder. If the snow depth is greater than the length of the cylinder, the total snow depth is divided into multiple analogue "columns". Water equivalent of snow cover (SWE$_{snow}$; in mm w.e.) is derived by multiplying the snow depth $h_{snow}$ (in cm) by the mean snow density $\rho_{snow}$ (in g cm$^{-3}$):

$$\mathrm{SWE}_{snow} = 10 \times h_{snow} \times \rho_{snow} \qquad \text{(I-2.7.1)}$$

In cases where there is an ice layer within the snowpack, the snow cylinders or Hellmann cylinders are rotated in order to break through the layer. If the cylinder cannot break through the ice, a knife or other sharp object is used to cut through this layer. If the ice layer is too thick to penetrate, no measurement is performed. In cases where a basal ice layer is present, the snowpack is sampled until this ice layer is reached. The thickness of the basal ice layer is then measured with a ruler. If there are ice layers (or snow crusts) within the snowpack, SWE$_{sum}$ is calculated as the sum of SWE$_{snow}$ and SWE$_{ice}$ (both in mm w.e.):

$$\mathrm{SWE}_{sum} = \mathrm{SWE}_{snow} + \mathrm{SWE}_{ice} \qquad \text{(I-2.7.2)}$$

where SWE$_{ice}$ is the SWE value of the ice layer, calculated as follows:

$$\mathrm{SWE}_{ice} = 0.8 \times h_{ice} \qquad \text{(I-2.7.3)}$$

where $h_{ice}$ is the mean ice layer height (in mm) and 0.8 is the assumed density of the ice layer (in g cm$^{-3}$).

**Automatic measurements:**

No measurements.

*Figure I-2.7.10 (a) Hellmann cylinder; (b) snow spatula; (c) cans for melting snow (Source: DHMZ, FHMI).*

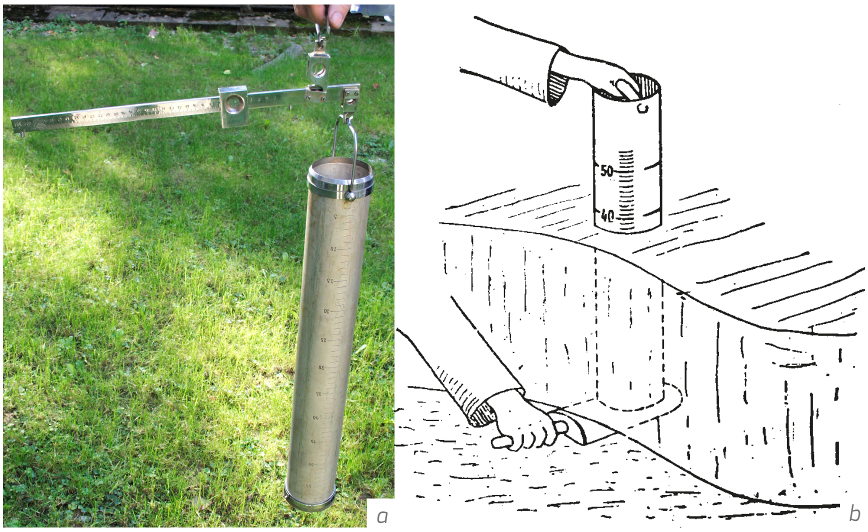

*Figure I-2.7.11 (a) Iron snow cylinder attached to a steelyard balance used to measure water equivalent of snow cover (SWE) at sites in Croatia. (b) Sketch of vertical snow sampling in a snow pit (Sources: DHMZ, FHMI).*

## I-2.7.4 Transition from manual to automatic measurements

No parallel measurements are carried out because only manual stations are in use.

## I-2.7.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 12 or 24 hours (DHMZ) | MANUAL: 12 or 24 hours (DHMZ) | MANUAL: 5 days (DHMZ) |
| AUTO: no measurements | | AUTO: no measurements |

# I-2.8 Cyprus

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*Figure I-2.8.1 Location of Cyprus in Europe.*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 9 251 km², 295 m a.s.l. |
| Authority responsible for snow measurements | Department of Meteorology Cyprus (CYMET) under the Ministry of Agriculture, Rural Development and Environment<br>CY-1418 Nicosia |
| Contact | · CYMET<br>metservice@dom.moa.gov.cy |
| Near-real-time data URL and/or contact | · CYMET<br>http://81.4.182.74/NWP/AWS/ALL_STATIONS_average.html (near-real-time snow depth data from TROODOS automatic weather station) |
| Archived data URL and/or contact | · CYMET<br>metservice@dom.moa.gov.cy (request to Head of Climatology and Applications of Meteorology) |

### General situation

The Cyprus Department of Meteorology (CYMET) is responsible for operational snow observations in Cyprus. CYMET has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. Snow is rare in Cyprus as a whole but is common in the mountainous regions. A single snow station where manual and automatic snow measurements are performed therefore exists in the resort of Troodos Square in the Troodos mountains, where CYMET measures snow depth manually and automatically, and depth of snowfall manually.

### Overview of measurements (CYMET)

Snow depth: stake, laser snow depth sensor (Figs I-2.8.2, I-2.8.3)
Depth of snowfall: snow board and ruler (Figs I-2.8.4, I-2.8.5)
Water equivalent of snow cover: no measurements
Operational purpose of measurements: Climatology, Meteorology

## I-2.8.1 Snow depth measurements

Number of stations delivering snow depth data manually: 1
Number of stations delivering snow depth data automatically: 1

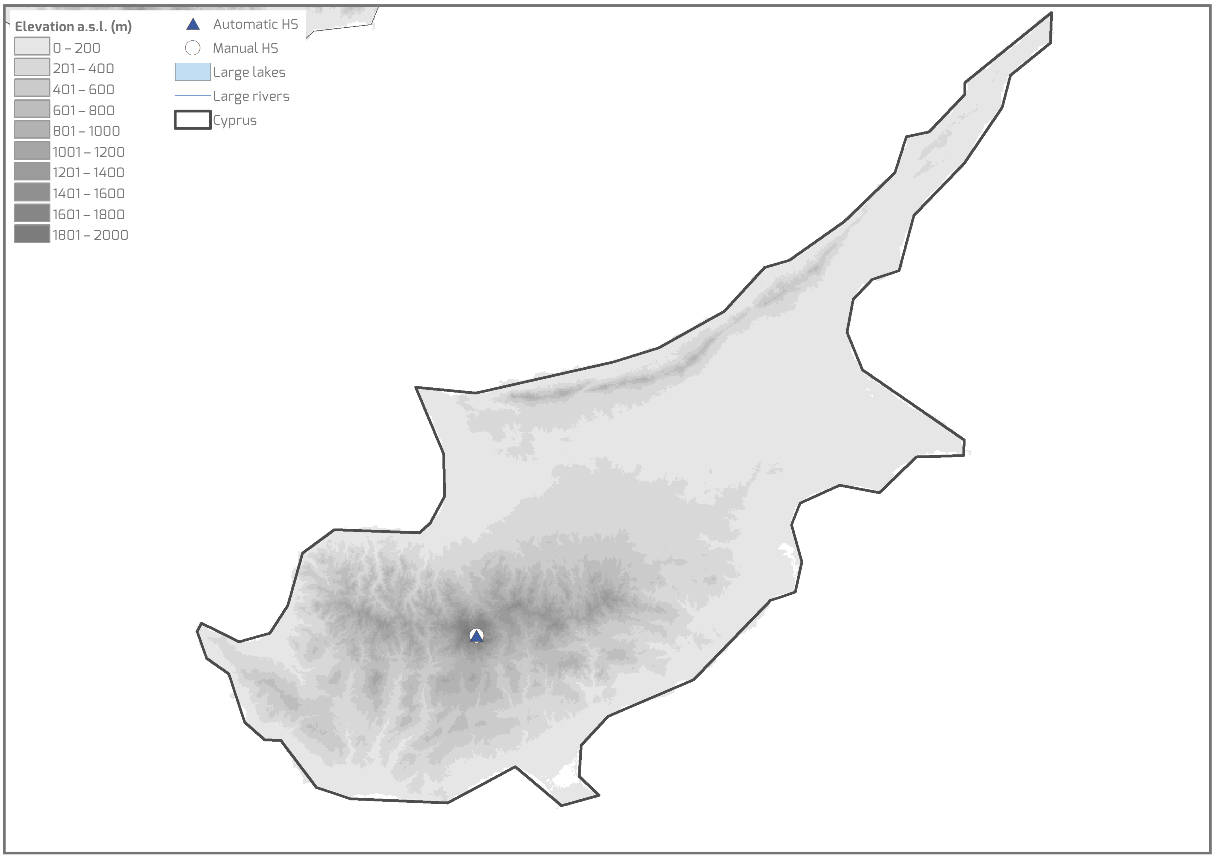

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*Figure I-2.8.2 Location of stations in Cyprus where snow depth (HS) is measured.*

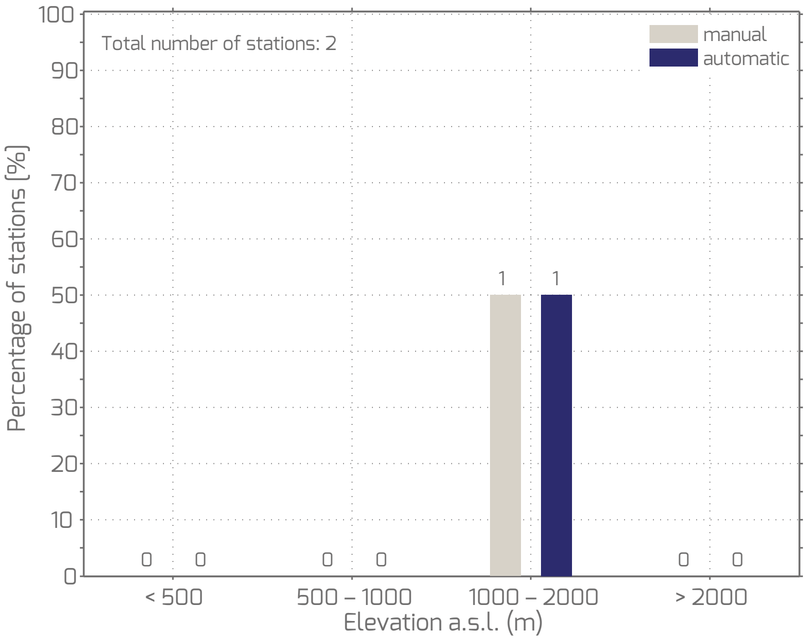

*Figure I-2.8.3 Elevational distribution of stations in Cyprus with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours at 0600 UTC using a fixed stake with a 5 cm resolution.

**Automatic measurements:**

Automatic snow depth measurements are performed every 10 minutes using a laser snow depth sensor.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is not reported explicitly.

**Zero snow depth reporting method:**

When the ground at the stake is snow free, 0 cm snow depth is reported.

## I-2.8.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 1

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*Figure I-2.8.4 Location of station in Cyprus where depth of snowfall (HN) is measured.*

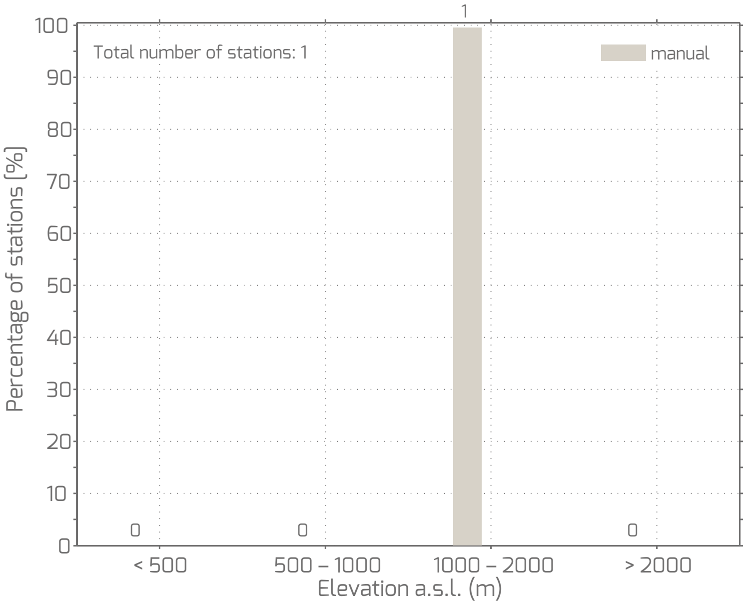

*Figure I-2.8.5 Elevational distribution of station in Cyprus with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours at 0600 UTC in parallel to manual snow depth measurements. Depth of snowfall is measured on a wooden snow board (60 x 60 cm) with a ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface.

## I-2.8.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 0

**Manual measurements:**

No measurements.

**Automatic measurements:**

No measurements.

## I-2.8.4 Transition from manual to automatic measurements

Parallel measurements are carried out for several seasons at the station in Troodos Square.

## I-2.8.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (CYMET)<br>AUTO: 10 minutes (CYMET) | MANUAL: 24 hours (CYMET) | MANUAL: no measurements<br>AUTO: no measurements |

# I-2.9 Czech Republic

*Figure I-2.9.1 Location of Czech Republic in Europe.*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 78 868 km$^2$, 451 m a.s.l. |
| Authority responsible for snow measurements | Czech Hydrometeorological Institute (CHMI)<br>Na Šabatce 2050/17<br>CZ-143 06 Praha 412-Komořany |
| Contact | · CHMI<br>bercha@chmi.cz (Šimon Bercha) |
| Near-real-time data URL and/or contact | · CHMI<br>http://portal.chmi.cz/files/portal/docs/poboc/CB/snih/aktual.htm<br>http://portal.chmi.cz/files/portal/docs/poboc/OS/OMK/mapy/prohlizec.html?map=SCE<br>http://portal.chmi.cz/files/portal/docs/poboc/OS/OMK/mapy/prohlizec.html?map=SNO<br>http://portal.chmi.cz/files/portal/docs/poboc/PR/grafy/snih-lnk.htm |
| Archived data URL and/or contact | · CHMI<br>bercha@chmi.cz (Šimon Bercha)<br>klima@chmi.cz (contact for the department of climatology) |

### General situation

The Czech Hydrometeorological Institute (CHMI) is responsible for operational snow observations in the Czech Republic. The manual snow station network is evenly distributed over the entire country, whereas automatic stations are only found in the mountainous regions. It is planned that 40 new automatic snow stations measuring snow depth will be installed by the year 2020. CHMI measures snow depth and water equivalent of snow cover both manually and automatically, while presence of snow on the ground and depth of snowfall are only assessed manually.

In addition to CHMI, the Charles University of Prague, the Czech University of Life Sciences Prague, the Network of State Enterprise of Catchments, the Czech road authorities and the Czech mountain rescue service maintain their own networks of snow stations. The network of the Czech mountain rescue service is mainly used for avalanche forecasting in three Czech regions. Cooperation between CHMI, the mountain rescue service, and ski resorts is increasing and has improved considerably in the last years. However, only CHMI data is included in this country report; data used for research and data from the Czech road authorities, the mountain rescue service and ski resorts is not included because no contacts could be established.

A brief summary about snow climatology throughout the Czech Republic is given here. Mean monthly snow depths exceed 0.5 m from October to March at most stations in the Czech highlands, whereas snow depths rarely exceed 0.2 m at lowland locations. At lowland stations, snow depth reaches its maximum by mid-January. In the eastern highlands the snow depth maximum is reached between the end of January and mid-February. In the western highlands snow depth increases slightly until mid-November, then increases much more rapidly until its maximum is reached in mid-February, and then finally starts to decrease again by the end of March. There are stations where two peaks in water equivalent of snow cover are observed, the first around mid-January and the second around the beginning of March. At a second group of stations a single peak in water equivalent of snow cover occurs in January, and at the remaining stations a single peak occurs in February.

Concerning snow anomalies, 12 of the 24 observed cold seasons were snow free in the lowlands: 1991/1992, 1992/1993, 1994/1995, 1997/1998, 1998/1999, 2000/2001, 2006/2007, 2007/2008, 2010/2011, 2011/2012, 2013/2014 and 2014/2015. The winter seasons 2006/2007, 2013/2014 and 2014/2015 had extremely little snow overall and the shortest snow cover durations, and therefore were negative anomalies for the number of days of snow cover and for water equivalent of snow cover. These winters were followed by persistent dryness during the beginning of the summer in 2007, 2014 and 2015. In the winter season 2013/2014, the large negative snow anomalies may have been caused by high temperature anomalies (up to 3.5 °C higher than the average of the reference period 1971–2000) and by a precipitation deficit of up to 50% in the northwestern and southeastern Czech lowlands. In winter 2013/2014, the spatially averaged snow cover over the entire Czech territory was only 27% of the long-term average. The lowest amount of snow accumulation was observed in the southern lowlands (around 12% of the long-term average), with maximum snow depths less than 0.03 m. This lack of snow led to the development of abnormally dry episodes during the spring and early summer of 2014. In contrast, only five seasons with anomalous large snow depths occurred: 1995/1996, 1996/1997, 2005/2006, 2009/2010 and 2012/2013. In the snow-rich season of 2005/2006, deep snow lasted until mid-March in the lowlands and was followed by an abrupt thaw in combination with heavy rainfalls in spring 2006, which led to a sudden increase in soil moisture in April to June.

Consecutive years with considerably fewer days of snow cover and lower water equivalent of snow cover values than average were recorded in the early 1960s, mid-1980s, late 1990s and most of the 2000s. The trend towards shorter snow cover durations accompanied by earlier melt out dates are found in both the lowlands and highlands (Potopová et al., 2016). However, advances in melt out dates have generally been more pronounced in hilly areas than in the lowlands. During winter, the occurrence of liquid precipitation (rather than solid precipitation) weakens the correlation between water equivalent of snow cover and days of snow cover, as well as between water equivalent of snow cover and early summer (April to June) soil moisture. Snow cover characteristics can strongly influence soil water saturation during the first part of the growing season, while the seasonal amount of water equivalent of snow cover can explain up to 45% of soil moisture variability during April to June. More than 52% of dry April to June months followed winters with little snow, and 42% of wet April to June months followed winters with abundant snow. The negative anomalous snow characteristics, in conjunction with winter and April to June drought, amplify the depletion of soil moisture in the later summer.

### Overview of measurements (CHMI)

Snow depth: stake, ruler, ultrasonic snow depth sensor, laser snow depth sensor (Figs I-2.9.2, I-2.9.3)
Depth of snowfall: snow board and ruler (Figs I-2.9.7, I-2.9.8)
Water equivalent of snow cover: snow tube, snow cylinder, digital scale, steelyard balance, snow pillow (Figs I-2.9.9, I-2.9.10)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Flood forecasting, Hydrology, Meteorology, Road services, Water management

## I-2.9.1 Snow depth measurements

Number of stations delivering snow depth data manually: 825
Number of stations delivering snow depth data automatically: 20

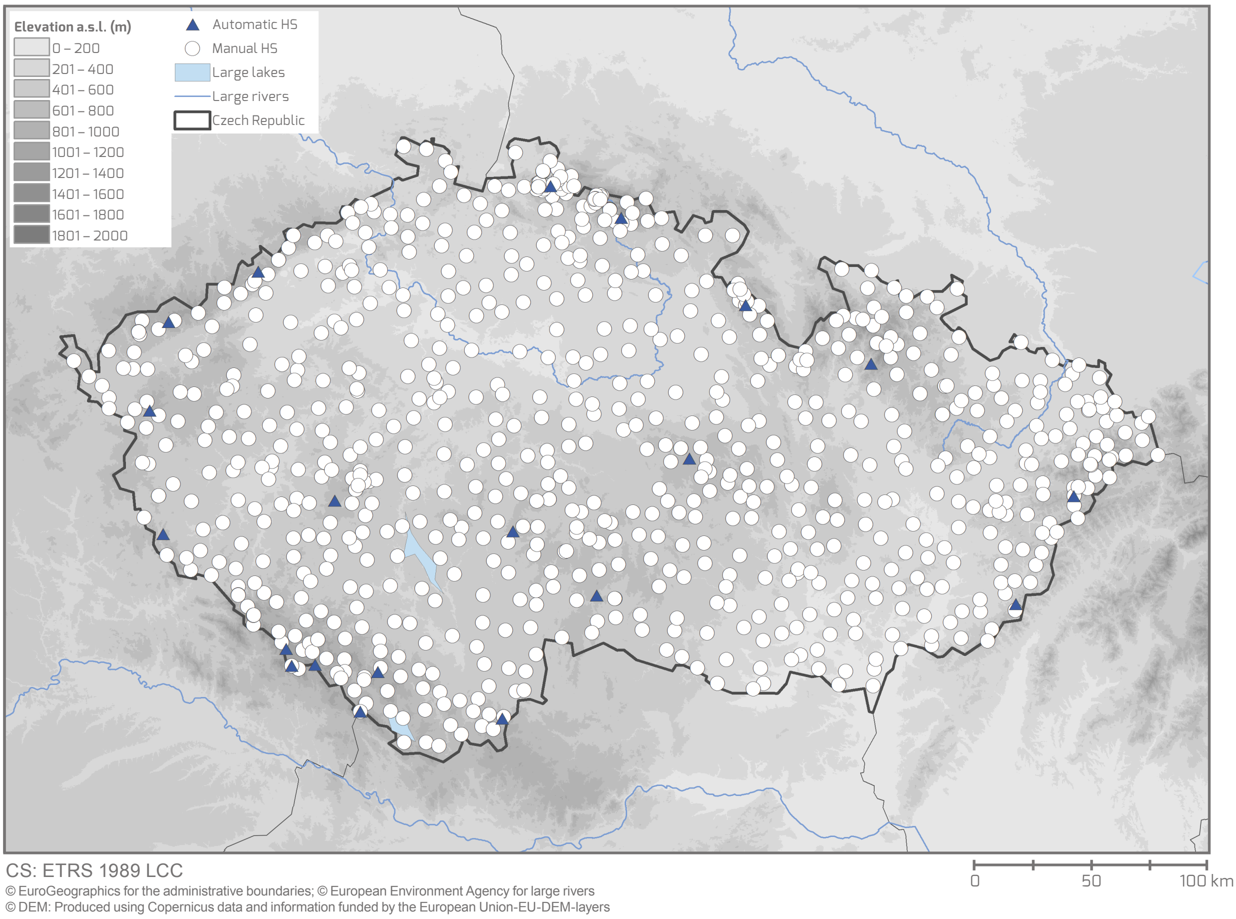

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*Figure I-2.9.2 Locations of stations in Czech Republic where snow depth (HS) is measured.*

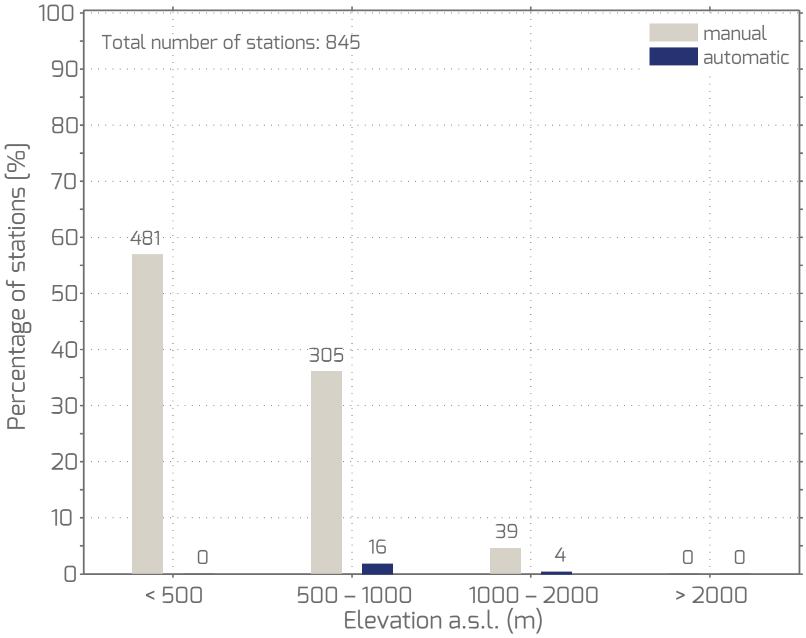

*Figure I-2.9.3 Elevational distribution of stations in the Czech Republic with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours at 0600 UTC. Depending on the site, either fixed stakes or portable rulers are used. Fixed stakes with a scale in centimetres are used at locations which are representative of their surroundings and only minimally affected by wind (Fig. I-2.9.4). In contrast, portable rulers are used at locations with only little or discontinuous snow cover. In the latter case, at least three ruler measurements are carried out (Fig. I-2.9.5) in order to obtain a representative snow depth measurement, and the average is reported as total snow depth.

In a few situations (mountains, problematic locations), spatially distributed snow depth measurements (snow courses) are performed. Along the 20- to 50-m-long snow courses, snow depth is measured at 10 points. All snow courses are located so they are representative of their surroundings.

Total snow depth is reported as long as at least half of the measurement field is covered with more than 1 cm of snow. All measurements are reported in full centimetres.

### Automatic measurements:

Automatic snow depth measurements are performed every 10 minutes. Ultrasonic or laser snow depth sensors are used to measure snow depth above close-cropped grass or gravelled ground (Fig. I-2.9.6).

### Presence of snow on the ground reporting method:

In parallel to manual snow depth measurements, presence of snow on the ground is reported explicitly. Although 0 cm snow depth is reported in cases where less than 50% of the measurement field is covered with snow, “discontinuous snow cover” is noted in the logbook.

### Zero snow depth reporting method:

When more than 50% of the measurement field is snow free and snow depth is less than 1 cm, 0 cm snow depth is reported. “Trace” is reported if there is a snow cover with a depth less than 0.5 cm.

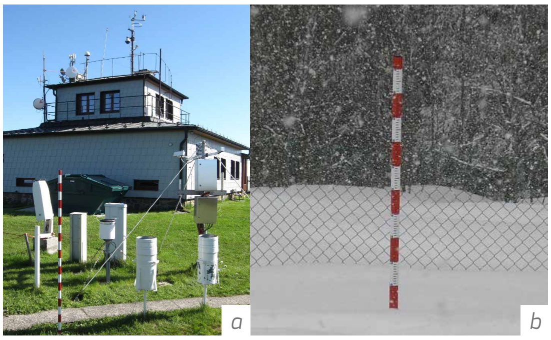

*Figure I-2.9.4 Manual measurement fields with a stake to measure snow depth in (a) summer and (b) winter (Source: CHMI).*

*Figure I-2.9.5 Manual snow depth measurement using a ruler (Source: CHMI).*

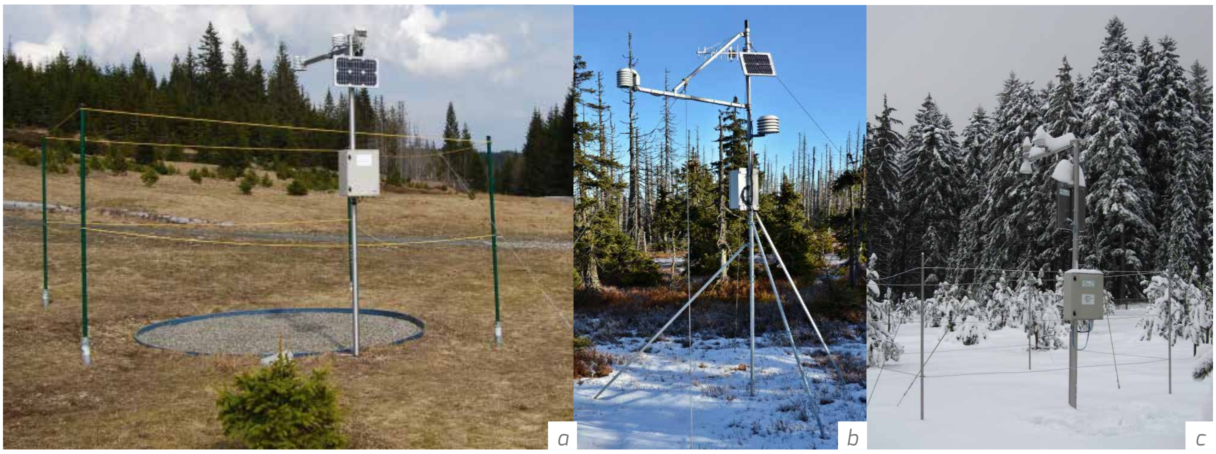

*Figure I-2.9.6 Automatic stations in the Czech Republic measuring snow depth and water equivalent of snow cover (SWE) in (a) summer, (b) autumn and (c) winter (Source: CHMI).*

## I-2.9.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 825

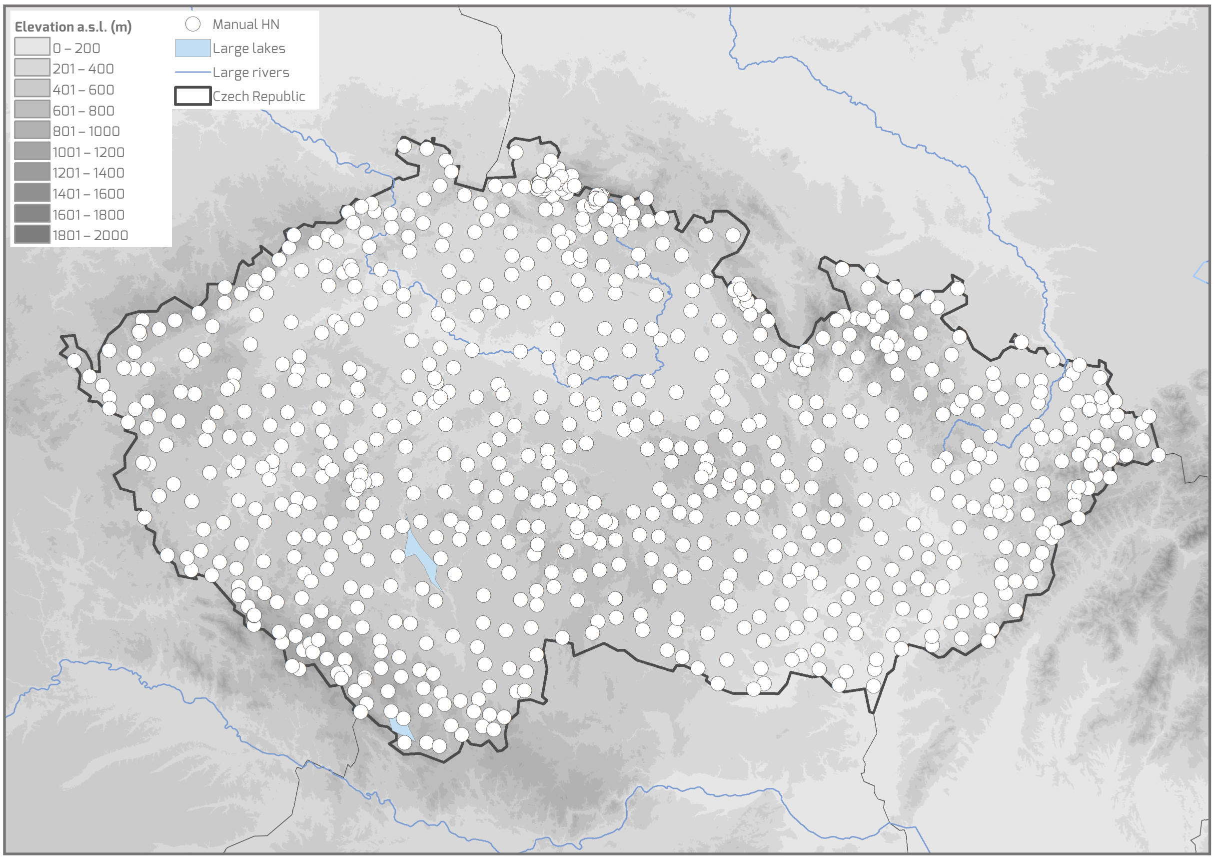

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*Figure I-2.9.7 Locations of stations in Czech Republic where depth of snowfall (HN) is measured.*

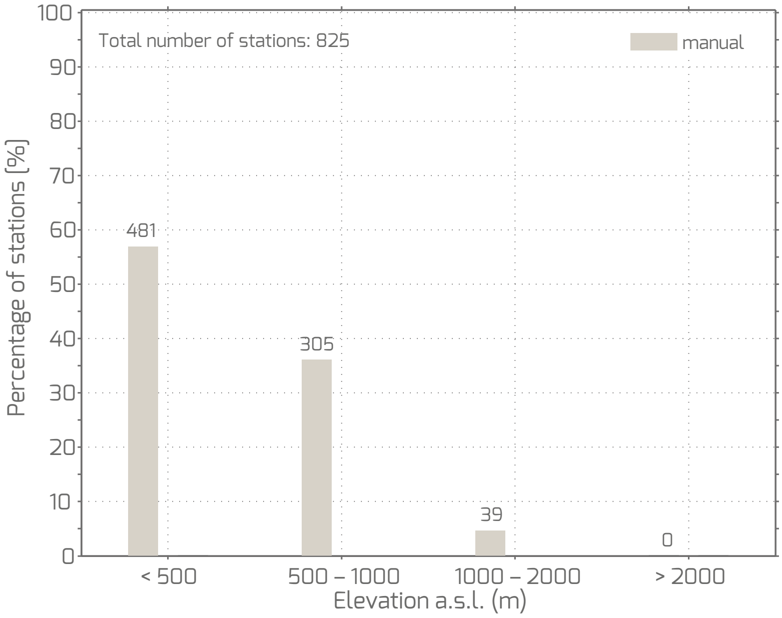

*Figure I-2.9.8 Elevational distribution of stations in Czech Republic with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours at 0600 UTC in parallel to manual snow depth measurements. Depth of snowfall is measured on a snow board with a ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. The location of the depth of snowfall measurement is selected to minimise influence from the wind. Measured values are reported in full centimetres.

### I-2.9.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 825
Number of stations delivering water equivalent of snow cover data automatically: 16

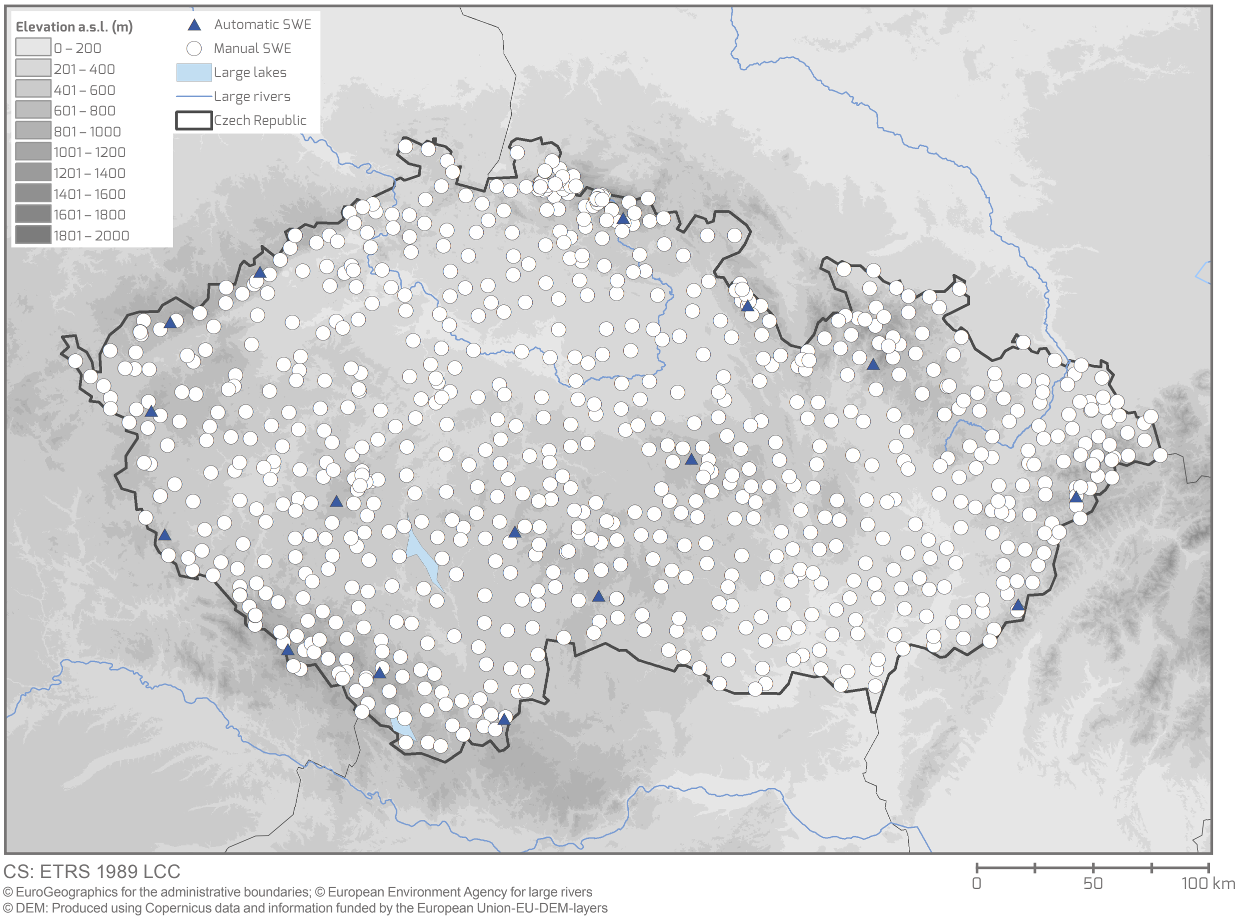

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*Figure I-2.9.9 Locations of stations in Czech Republic where water equivalent of snow cover (SWE) is measured.*

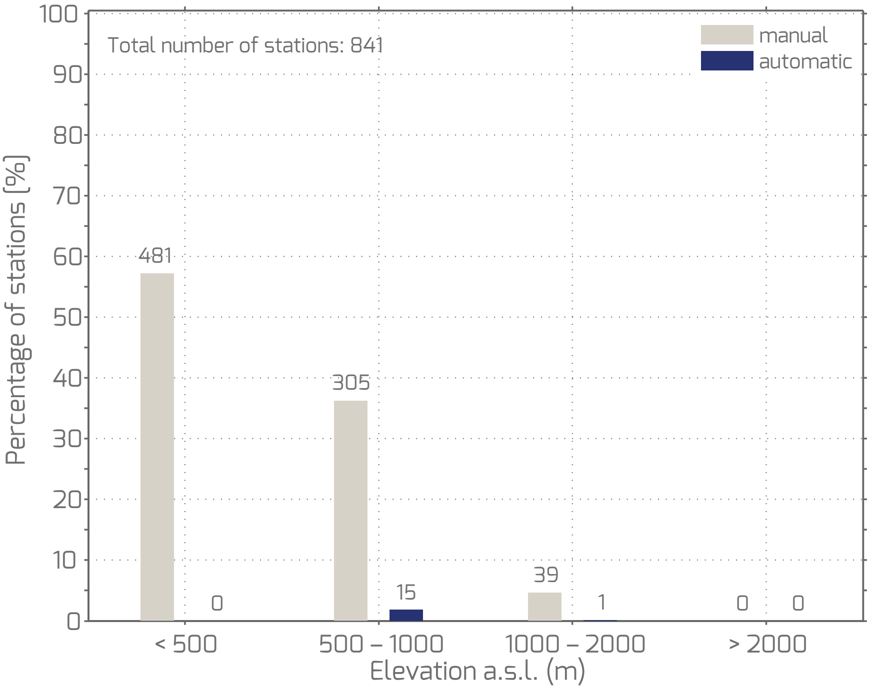

*Figure I-2.9.10 Elevational distribution of stations in Czech Republic with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements (without snow pits) are performed once every week (Monday at 0600 UTC) at 47% of all manual SWE stations and once every month at 53% of all manual SWE stations for continuous snow covers exceeding 4 cm depth. The gravimetric method is applied. At the majority of sites, laminated fibre glass snow tubes (Fig. I-2.9.11) are used. The snow tubes have a length of 1, 1.5 or 2 m. After the height of the snow sample (in m) is measured, the snow tube is attached to a steelyard or digital balance to measure the total weight of the snow (in kg). At some climatological stations SWE is still measured in snow pits using iron snow cylinders. After the height of the snow sample (in m) is measured, the snow cylinder is attached to a steelyard balance to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder (in $m^2$). Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers. Irrespective of the measurement device, SWE is always measured at three different points within a measurement field and the average of the measurements is reported as total SWE. The measurement fields are selected to be representative of their surroundings and to have as little wind influence as possible.

In certain situations (mountains, problematic locations; approx. 60 stations), spatially distributed SWE measurements are performed at three points along the 20- to 50-m-long snow courses. This is done in parallel to snow depth measurements along snow courses. All snow courses are located to be representative of their surroundings.

**Automatic measurements:**

Automatic SWE measurements are performed every 10 minutes using snow pillows (Fig. I-2.9.6 a). All automatic stations are located in the mountainous regions at elevations between 600 and 1 100 m a.s.l.

*Figure I-2.9.11 Manual measurements of water equivalent of snow cover (SWE) in the Czech Republic using a laminated snow tube and a digital balance (Source: CHMI).*

## I-2.9.4 Transition from manual to automatic measurements

At stations with long-term climatological data series that are considered highly valuable, parallel measurements are performed daily for a few years. In cases where automatic sensors are installed at new locations, manual control measurements are performed in parallel a maximum of five times per winter season.

## I-2.9.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (CHMI)<br>AUTO: 10 minutes (CHMI) | MANUAL: 24 hours (CHMI) | MANUAL: 1 week or 1 month (CHMI)<br>AUTO: 10 minutes (CHMI) |

# I-2.10 Denmark

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*Figure I-2.10.1 Location of Denmark in Europe.*

# I-2.10 Denmark

## Country information

| | |
|---|---|
| Country area, mean country elevation | 42 924 km$^2$, 31 m a.s.l. |
| Authority responsible for snow measurements | Danish Meteorological Institute (DMI)<br>Lyngbyvej 100<br>DK-2100 Copenhagen Ø |
| Contact | • DMI<br>evl@dmi.dk (Ellen Vaarby Laursen) |
| Near-real-time data URL and/or contact | • DMI<br>http://www.dmi.dk (during snow season) |
| Archived data URL and/or contact | • DMI<br>dmi@dmi.dk (data on request) |

## General situation

The Danish Meteorological Institute (DMI) is responsible for operational snow observations in Denmark. Snow depth has been observed manually by DMI since summer 2009, when the measurement network was established. All stations are national stations and are not included in the WMO network, but they do report their snow depth data over WMO's Global Telecommunication System (GTS; see Figure I-3.6.1 on p. 306). The DMI station network is evenly distributed over the Danish mainland and islands.

Snow is rare in Denmark. However, the purpose of the network is to monitor national snow coverage and the corresponding snow depths in order to publish climate maps and statistics on the DMI website and to inform the public, as well as the media, of snowfall events. Snow depth measurements are additionally valuable for research purposes, such as the calculation of climate statistics and the development and improvement of numerical weather prediction models.

## Overview of measurements (DMI)

Snow depth: stake, ruler (Figs I-2.10.2, I-2.10.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: no measurements
Operational purpose of measurements: Climatology, Meteorology

## I-2.10.1 Snow depth measurements

Number of stations delivering snow depth data manually: 70
Number of stations delivering snow depth data automatically: 0

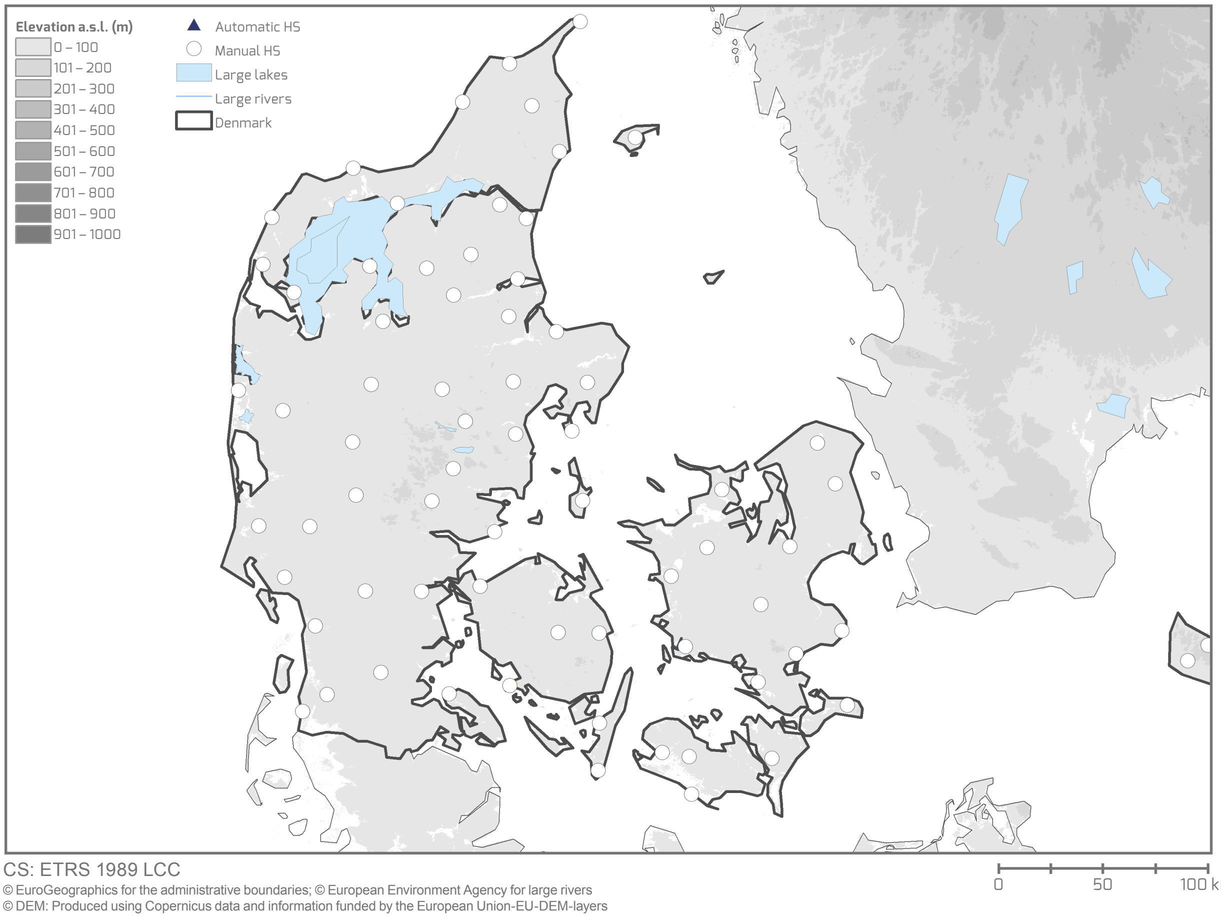

*Figure I-2.10.2 Locations of stations in Denmark where snow depth (HS) is measured.*

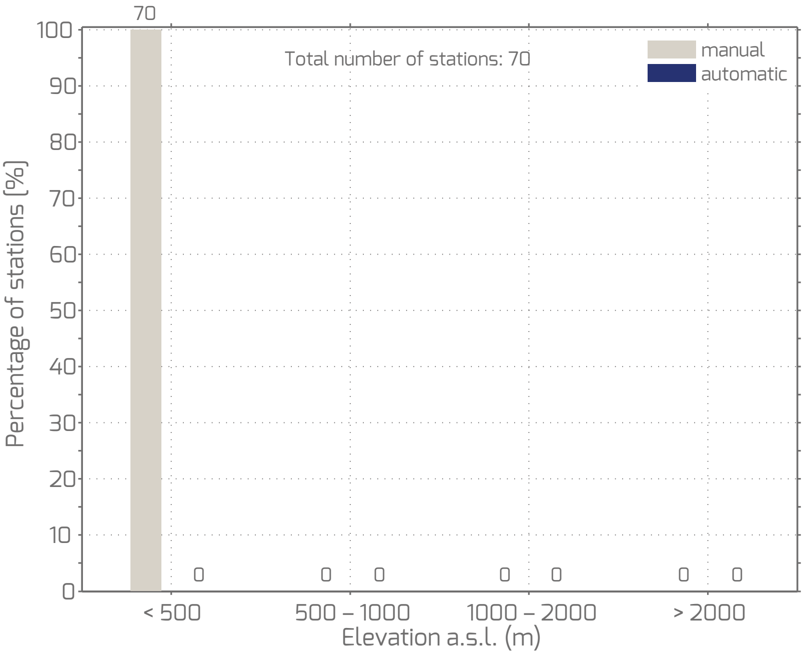

*Figure I-2.10.3 Elevational distribution of stations in Denmark with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours at 0700 UTC between October and April in measurement fields located in observers' private gardens. Fixed wooden stakes with a scale in centimetres and a length of 1.8 m are used. These stakes are painted with alternating white and red stripes, each with a width of 0.1 m (scale resolution is 0.1 m). The stake is located in the centre of the garden. In addition to stake observations, the spatial snow depth distribution in the measurement field (garden) is assessed with rulers with a centimetre resolution and a length of 2 m. Measurements are reported via a telephone ('key in') service immediately after each reading. Measurements are reported in millimetres.

**Automatic measurements:**

No measurements.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is not reported explicitly.

**Zero snow depth reporting method:**

When no snow is present at the stake or measurement point, 0 cm snow depth is reported.

## I-2.10.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.10.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 0

**Manual measurements:**

No measurements.

**Automatic measurements:**

No measurements.

## I-2.10.4 Transition from manual to automatic measurements

No parallel measurements are carried out because snow depth is only measured manually.

## I-2.10.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (DMI)<br>AUTO: no measurements | MANUAL: no measurements | MANUAL: no measurements<br>AUTO: no measurements |

# I-2.11 Estonia

*Figure I-2.11.1 Location of Estonia in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 45 227 km$^2$, 57 m a.s.l. |
| Authority responsible for snow measurements | Estonian Environment Agency (ESTEA)<br>Mustamäe tee 33<br>EE-10616 Tallinn |
| Contact | · ESTEA<br>teenused@envir.ee |
| Near-real-time data URL and/or contact | · ESTEA<br>http://www.ilmateenistus.ee/wp-con-tent/themes/emhi2013/data/sademetekaart/snowmap_eng.png (during snow season) |
| Archived data URL and/or contact | · ESTEA<br>teenused@envir.ee |

## General situation

The Estonian Environment Agency (ESTEA) is responsible for operational snow observations in Estonia. Estonia lies in a climatological transition zone, with a maritime climate on the islands and a continental climate on the mainland. Although Estonia covers a relatively small area, climate differences across the country are remarkable, especially in winter. In order to account for the different prevailing meteorological conditions, the ESTEA station network is relatively evenly distributed over the entire country. However, snow station coverage is sparser on the Estonian islands than on the mainland. Snow depth is measured both manually and automatically by ESTEA, while presence of snow on the ground and water equivalent of snow cover are observed manually. Only depth of snowfall is not measured by ESTEA.

## Overview of measurements (ESTEA)

Snow depth: stake, ultrasonic snow depth sensor (Figs I-2.11.2, I-2.11.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.11.8, I-2.11.9)
Operational purpose of measurements: Agriculture and Forestry, Climatology, Health and Sport, Hydrology, Meteorology, Road services

## I-2.11.1 Snow depth measurements

Number of stations delivering snow depth data manually: 18
Number of stations delivering snow depth data automatically: 25

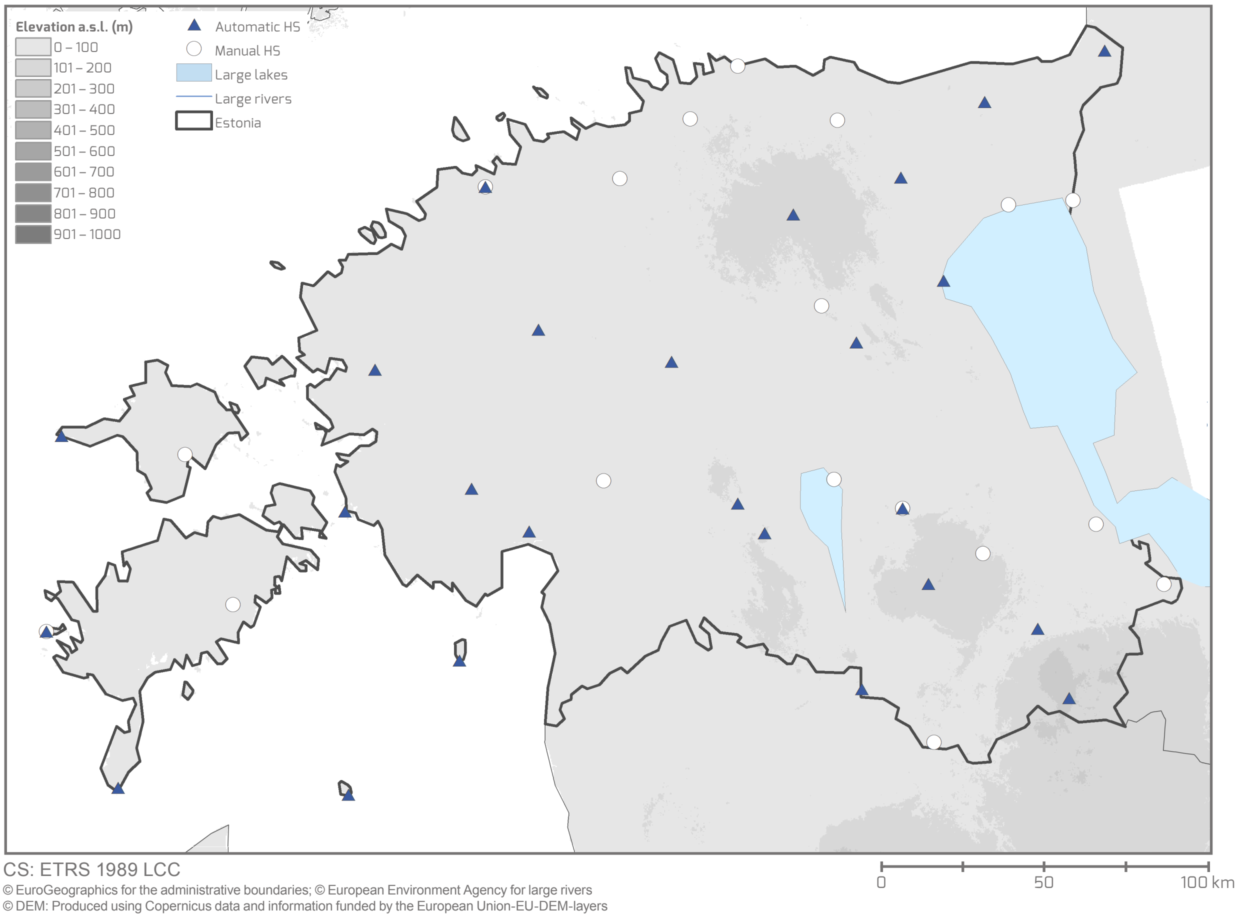

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*Figure I-2.11.2 Locations of stations in Estonia where snow depth (HS) is measured.*

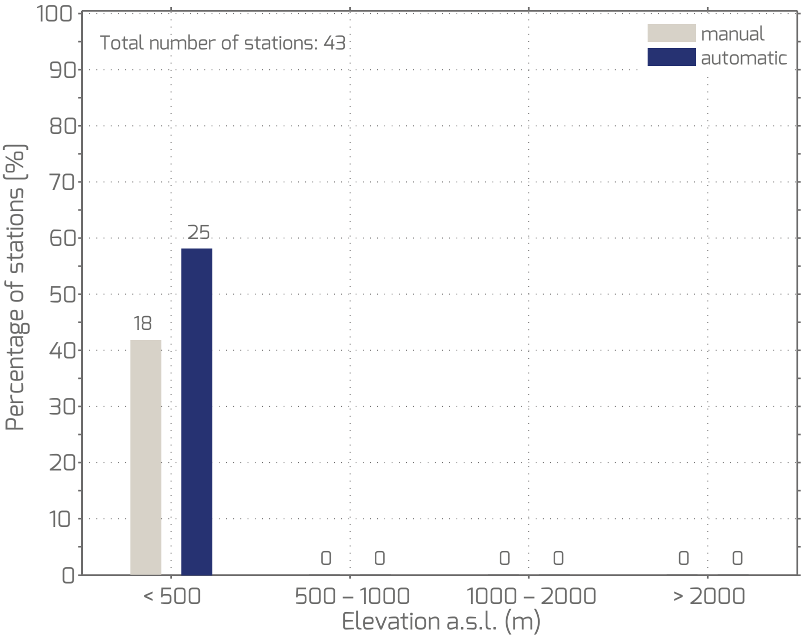

*Figure I-2.11.3 Elevational distribution of stations in Estonia with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours at 0600 UTC at meteorological stations. The measurement fields are located in flat areas with a minimum area of 320 m$^2$. Fixed stakes, with a length of 1.2 m and a scale in centimetres, are used (Fig. I-2.11.4 a). At each meteorological station, three stakes are arranged in a triangle, 10 m apart (Figs I-2.11.4 b, I-2.11.5). The average of the readings from the three stakes is reported as total snow depth. All measurements are reported in full centimetres.

In addition to point measurements, spatially distributed snow depth measurements (snow courses) are performed three times per month (10th, 20th and last day of the month) in high winter. During the ablation period snow courses are completed during a five-day period (usually starting between 25 February and 5 March). In flat areas 10 stakes are installed 50 m apart along snow courses with a total length of 500 m (Fig. I-2.11.6), while in forested areas 5 to 7 stakes are installed along 250-m-long snow courses. Snow course measurements are only performed for snow depths exceeding 5 cm. In parallel to manual snow depth measurements, the state of the ground and the specific snow cover types present (Table I-2.11.1), as well as the snow surface conditions (Table I-2.11.2), are reported.

Manual snow depth data has been available digitally since 1991.

### Automatic measurements:

Automatic snow depth measurements are performed every 24 hours at 0600 UTC. Ultrasonic snow depth sensors (USH-8; Sommer Messtechnik, Vorarlberg, Austria) are used and are located within a 1 m$^2$ measurement field (Fig. I-2.11.7). Snow depth sensors are mounted 2 m above the ground. In most cases automatic snow depth measurements started in January 2014.

### Presence of snow on the ground reporting method:

In parallel to manual snow depth measurements, presence of snow on the ground is reported daily at meteorological stations. Snow coverage and state of the ground are reported using a 10-point coding system (codes 0–9; Table I-2.11.1).

### Zero snow depth reporting method:

When the average of the three snow depth measurements at the fixed stakes is less than 0.5 cm, 0 cm snow depth is reported.

*Figure I-2.11.4 (a) Fixed stake used to measure snow. (b) Snow station Narva-Jõesuu (Estonia) with three fixed stakes on 06 April 2010 (Source: ESTEA).*

*Figure I-2.11.5 Snow station Tallinn-Harku (Estonia) with three fixed stakes: (a) on 31 October 2017; (b) on 13 February 2018 (Source: ESTEA).*

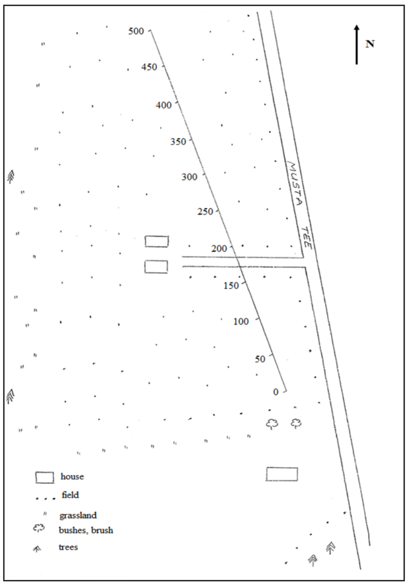

*Figure I-2.11.6 Schematic map of snow course measurements made along an open field snow course in Estonia (Source: ESTEA).*

*Figure I-2.11.7 Automatic snow station located in Tallinn-Harku, Estonia: (a) during the snow-free period in 2017; (b) during the snow-covered period in 2014 (Source: ESTEA).*

Table I-2.11.1 Ten-point coding system of snow coverage and state of the ground.

| Code | Snow cover type and state of the ground | |
|---|---|---|
| 0 | Homogeneous snow cover on frozen soil | Without snowbanks |
| 1 | Homogeneous snow cover on thawed soil | |
| 2 | Homogeneous snow cover, soil state unknown | |
| 3 | Heterogeneous snow cover on frozen soil | Small snowbanks (up to 0.5 m deep) |
| 4 | Heterogeneous snow cover on thawed soil | |
| 5 | Heterogeneous snow cover, soil state unknown | |
| 6 | Very heterogeneous snow cover on frozen soil | Large snowbanks (greater than 0.5 m deep) |
| 7 | Very heterogeneous snow cover on thawed soil | |
| 8 | Very heterogeneous snow cover, soil state unknown | |
| 9 | Patchy snow cover | |

Table I-2.11.2 State of snow surface conditions.

| Code | State of snow surface conditions |
|---|---|
| 0 | Fresh dust-like snow |
| 1 | Fresh fluffy snow |
| 2 | Fresh sticky snow |
| 3 | Old grainy snow |
| 4 | Old compacted snow |
| 5 | Old wet snow |
| 6 | Snow crust on the surface of the snow |
| 7 | Compacted snow with crust on the surface |
| 8 | Wet snow with crust on the surface |
| 9 | Water-saturated snow |

## I-2.11.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.11.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 14
Number of stations delivering water equivalent of snow cover data automatically: 0

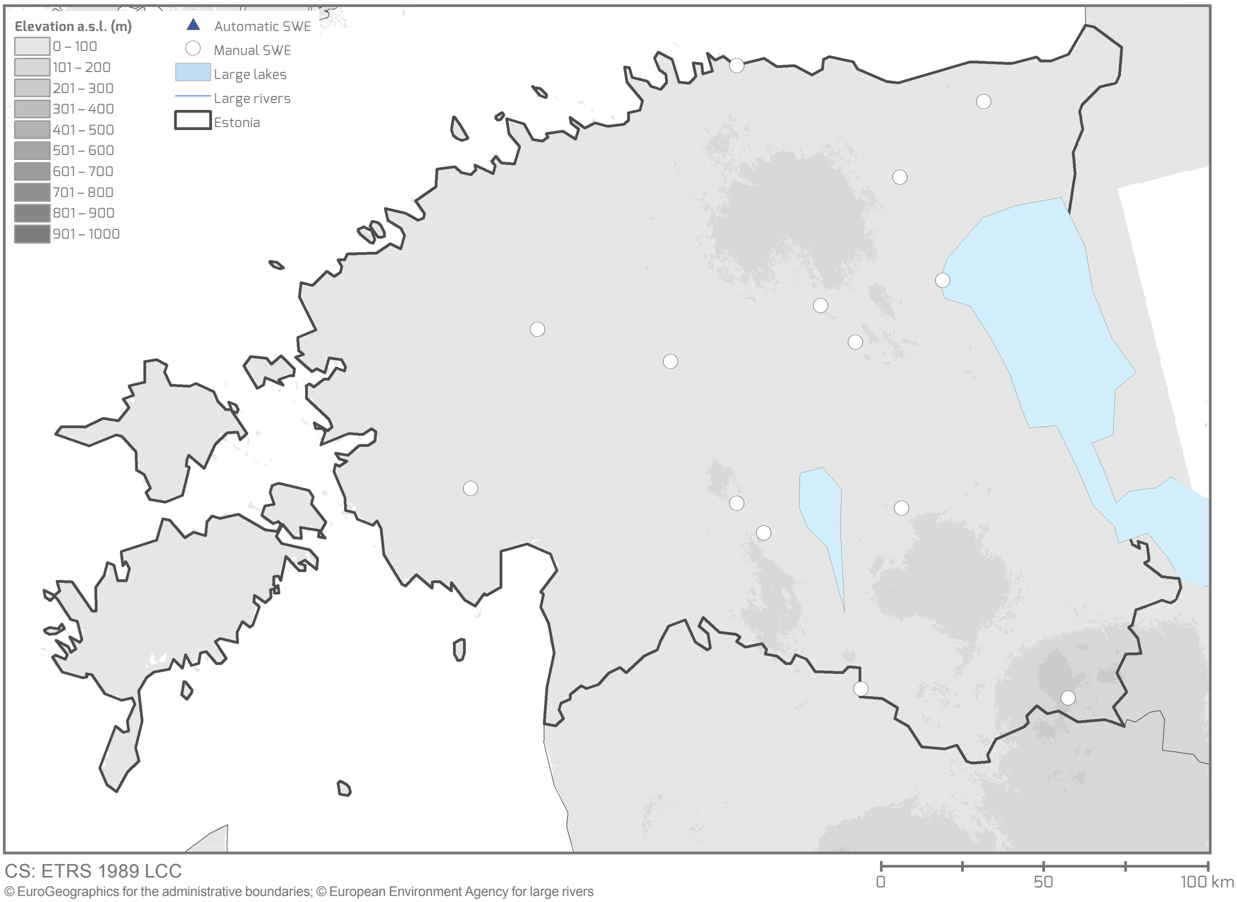

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*Figure I-2.11.8 Locations of stations in Estonia where water equivalent of snow cover (SWE) is measured.*

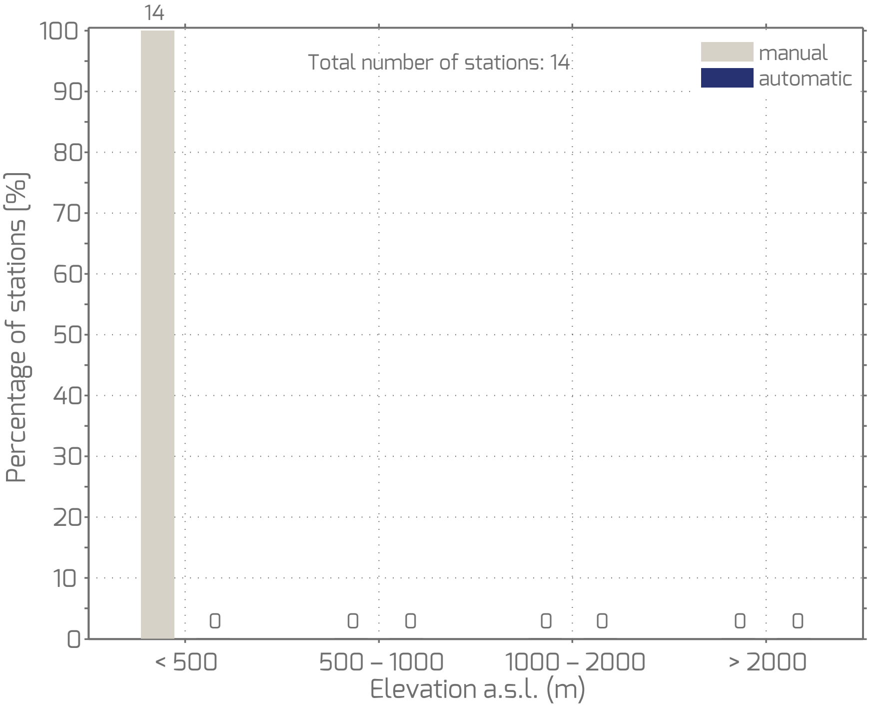

*Figure I-2.11.9 Elevational distribution of stations in Estonia with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

In parallel to the spatially distributed snow depth measurements along snow courses, manual SWE measurements in snow pits are performed three times per month (10th, 20th and last day of the month) in high winter. During the ablation period SWE measurements in snow courses are performed once every five days (usually starting between 25 February and 5 March). The gravimetric method is applied. Using a graduated iron snow cylinder (BC-43) with a cross-sectional area of 0.005 m$^2$ and a length of 0.6 m, a snow sample is extracted vertically from the snowpack. After the height of the snow sample (in m) is measured, the snow cylinder is attached to a steelyard balance (Figs I-2.11.10, I-2.11.11) to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

The number of snow course stations decreased from 79 in 1961/1962 to 33 in 2000/2001 and to 14 in 2016/2017. Therefore, a wealth of discontinued historical long-term data series of snow depth and SWE exist, but only data since 1991 is available digitally.

**Automatic measurements:**

No automatic measurements are currently performed, but they are planned for the near future.

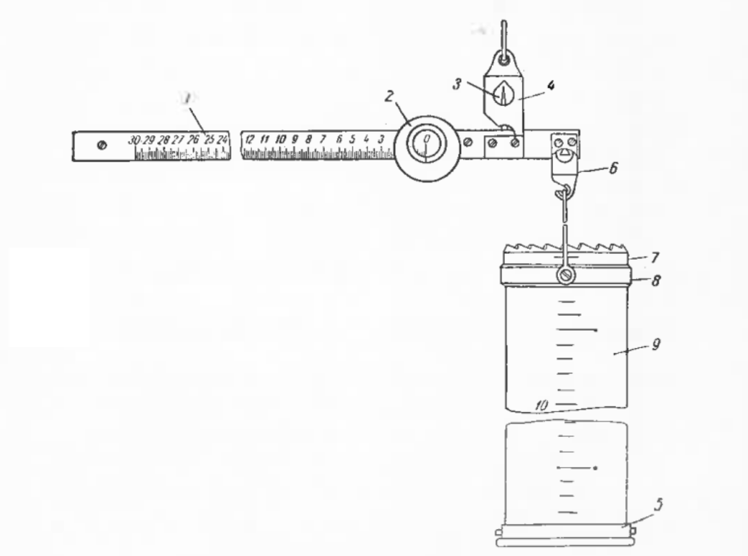

*Figure I-2.11.10 Sketch of the snow cylinder BC-43 in weighing position and attached to a steelyard balance: (1) metal ruler divided into two unequal arms by two knife-edge supports, (2) rider, (3) pointer, (4) left-hand knife-edge support, (5) removeable cylinder cover, (6) small shackle with hook, (7) toothed ring (at one end of cylinder), (8) collar which can move freely along the cylinder, (9) metal cylinder (Source: ESTEA).*

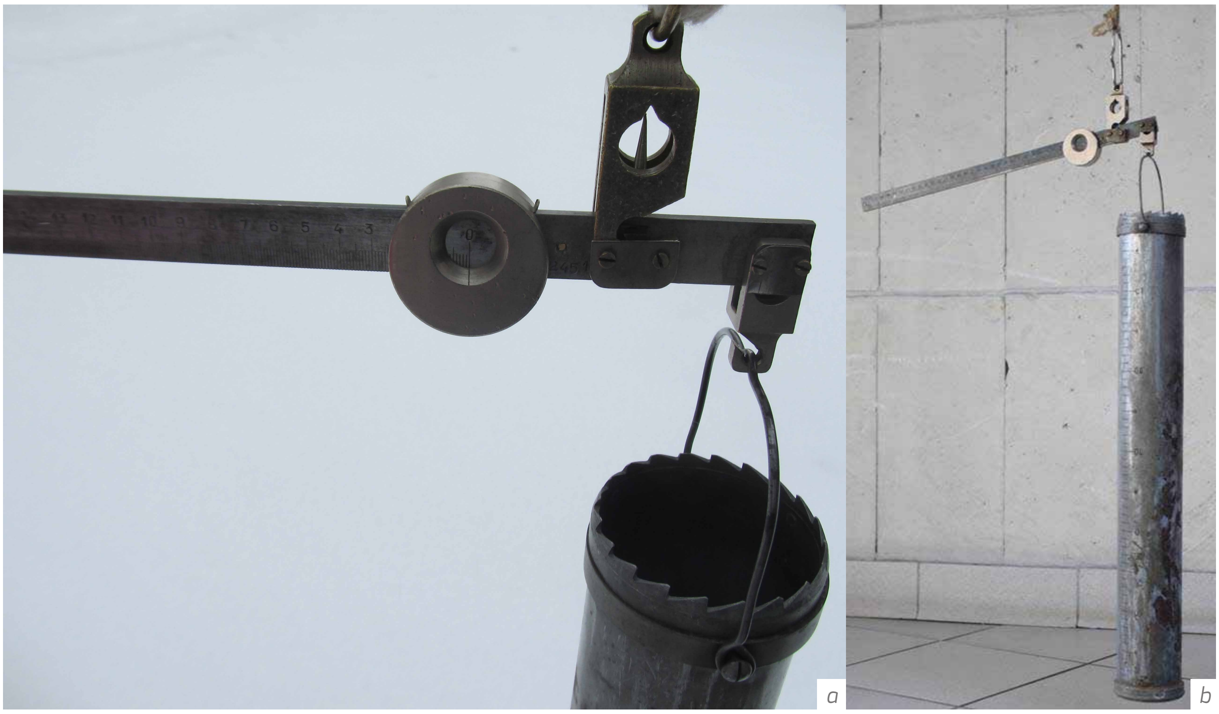

*Figure I-2.11.11 Snow cylinder BC-43: (a) in weighing position; (b) attached to a steelyard balance (Source: ESTEA).*

## I-2.11.4 Transition from manual to automatic measurements

No parallel measurements are carried out, but manual control measurements are performed every five days to check the accuracy of the automatic measurements.

## I-2.11.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours or 10 days (5 days during ablation period) (ESTEA)<br>AUTO: 24 hours (ESTEA) | MANUAL: no measurements | MANUAL: 10 days (5 days during ablation period) (ESTEA)<br>AUTO: no measurements |

# I-2.12 Finland

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*Figure I-2.12.1 Location of Finland in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 338 440 km$^2$, 156 m a.s.l. |
| Authority responsible for snow measurements | Finnish Meteorological Institute (FMI)<br>Erik Palménin aukio 1<br>FI-00560 Helsinki<br><br>Finnish Environment Institute (SYKE)<br>Mechelininkatu 34a, Töölö<br>P.O. Box 140<br>FI-00251 Helsinki |
| Contact | · FMI<br>leena.leppanen@fmi.fi (Leena Leppänen)<br>· SYKE<br>heidi.sjoblom@environment.fi (Heidi Sjöblom) |
| Near-real-time data URL and/or contact | · FMI<br>http://en.ilmatieteenlaitos.fi/home<br>· SYKE<br>http://wwwi3.ymparisto.fi/i3/tilanne/fin/lumi/Lumi.htm (SWE map)<br>http://wwwi3.ymparisto.fi/i3/lumilinja/lumilinja.htm (SWE along snow courses)<br>http://wwwi2.ymparisto.fi/i2/90/lumi2/vesitilanne.html (SWE forecast map)<br>http://www.syke.fi/en-US/Open_information (SYKE's publicly available information) |
| Archived data URL and/or contact | · FMI<br>http://en.ilmatieteenlaitos.fi/home<br>http://en.ilmatieteenlaitos.fi/download-observations#!/<br>ilmastopalvelu@fmi.fi (FMI commercial service)<br>· SYKE<br>http://www.syke.fi/en-US/Open_information<br>heidi.sjoblom@environment.fi (Heidi Sjöblom) |

## General situation

The Finnish Meteorological Institute (FMI) is responsible for operational snow depth observations in Finland, while the Finnish Environment Institute (SYKE) is currently the only institution in charge of operational water equivalent of snow cover measurements in the country. The FMI snow depth station network (manual and automatic) and the SYKE water equivalent of snow cover snow course network are evenly distributed over Finland. The SYKE water equivalent of snow cover network dates back to the 1930s. FMI and SYKE exchange their data and use the collective data for their various products (e.g. forecasts, modelling, climatology). While manual and automatic snow depth measurements are performed operationally by FMI, water equivalent of snow cover is operationally assessed by SYKE. Both the FMI and SYKE snow measurement networks are discussed below.

In addition to FMI and SYKE, staff at the Värriö Subarctic Research Station (University of Helsinki) and the Oulanka Research Station (University of Oulu), have monitored long-term snow data (e.g. snow depth, water equivalent of snow cover) since 1967. More details about the Värriö Subarctic research station (Lapland) and its long-term snow records are available online at: https://www.atm.helsinki.fi/varrio/eng/?q=node/3#Lumilinjat. Information from Oulanka research station in central eastern Finland is available online at: http://www.oulu.fi/oulankaresearchstation/node/15853. However, data from these two research stations is not included here.

FMI has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. In support of weather forecasting services, intense snow research is done that requires frequent measurement of many variables. The earliest FMI operative snow depth measurements date back to the 1890s. By 1909 snow depth was already measured in over 100 locations. Digitised data from many snow depth measurement locations that are still in use date back to

1959. At most of these stations, snow depth was also recorded before 1959 but this data has not been digitised. Besides snow depth, water equivalent of snow cover was measured operationally between the 1910s and 1950s at FMI stations. Between the 1970s and 2000s, two operational short-snow-course measurements of snow depth (5 points) and water equivalent of snow cover (2 points) were made every 5 days at 35 locations across Finland. Despite the long history of operational water equivalent of snow cover measurements at FMI, this variable is currently measured only for research purposes.

In Sodankylä (Lapland), manual and automatic water equivalent of snow cover and snow depth observations are carried out by FMI for research purposes. At this location water equivalent of snow cover has been measured automatically using either Gamma Water Instruments (Astrock, Sodankylä, Finland; measurements since 2007) or SGG snow scales (Sommer Messtechnik, Vorarlberg, Austria; measurements since September 2015). Snow depth has been measured automatically with SR-50 sensors (Campbell Scientific, Logan, Utah, USA) since 2006 in a forest and a forest opening and since 2010 in a bog. Snow depth and water equivalent of snow cover have been measured manually weekly since 2006 (bi-weekly in 2014–2015) in a forest opening, and in both open and forested areas every five days (5th, 10th, 15th, 20th, 25th and last day of the month). Since 2002, these measurements have only been performed in January and March, whereas they were measured during the entire (operative) snow season between 1972 and 2002. In addition, water equivalent of snow cover and snow depth have been measured along two 4-km-long snow courses, combining 80 snow depth and 8 water equivalent of snow cover measurements, in collaboration with SYKE. Measurements have been performed monthly since 1959 (twice per month in 1991–1996 and 2009–2014) along the first snow course (located in Sodankylä), and were performed monthly in 2009–2014 along the second snow course (located in Tanhua, Lapland). Manual water equivalent of snow cover and snow depth datasets exist for: lake ice, monthly in 2008–2014; bog, weekly in 2009–2014 and bi-weekly in 2014–2015; and various locations around Sodankylä, every five days in 1909–1953 (operative).

In Finland, the winter season is defined as the period when the daily mean temperature is less than 0 °C. It typically begins between October and December but can start later in coastal areas. The winter season typically lasts 100 days in southwestern Finland and 200 days in northern Finland. The earliest recorded winter season start in northern Finland was 15 September 1986, which was followed by the longest winter season on record for northern parts of the country (230 days). The latest start dates of the winter season in northern Finland have been in mid-November. In the northernmost corner of Finland, the polar night lasts for 51 days. In southern Finland, the shortest day is about 6 hours long. The average air temperature from December to February is -3.5 °C in Helsinki (Southern Finland) and -12.6 °C in Sodankylä. The lowest winter air temperatures are typically -25 °C to -35 °C in coastal areas, -35 °C to -45 °C in southern Finland, and -45 °C to -50 °C in eastern and northern Finland. The coldest temperature on record, -51.5 °C, was measured in Pokka (Lapland) in January 1999. The first snow typically falls in September in northern Finland and in October elsewhere. Permanent snow cover typically starts in December in Helsinki, in November in Jyväskylä (central Finland) and in October in Sodankylä. Snow melt typically takes place in April in Helsinki and Jyväskylä and in May in Sodankylä. The maximum snow depth occurs between mid-March and early April, with values of 0.2–0.3 m in southwestern Finland and 0.6–0.9 m in eastern and northern Finland. The deepest snowpack was measured on 19 April 1997 in Kilpisjärvi (Lapland), with a value of 1.9 m. The largest daily change in snow depth ever recorded was 0.73 m in Merikarvia (west coast) on 8 January 2016. Maximum daily changes of 0.35–0.5 m are typical. The mean yearly total precipitation is 655 mm in Helsinki and 527 mm in Sodankylä. Values are based on 30-year (1981–2010) meteorological statistics.

### Overview of measurements (FMI, SYKE)

Snow depth: stake, ultrasonic snow depth sensor (Figs I-2.12.2, I-2.12.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: snow cylinder, mechanical scale (Figs I-2.12.4, I-2.12.5)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Flood forecasting, Health and Sport, Hydrology, Meteorology, Road services, Water management

## I-2.12.1 Snow depth measurements

Number of stations delivering snow depth data manually: 103
Number of stations delivering snow depth data automatically: 100

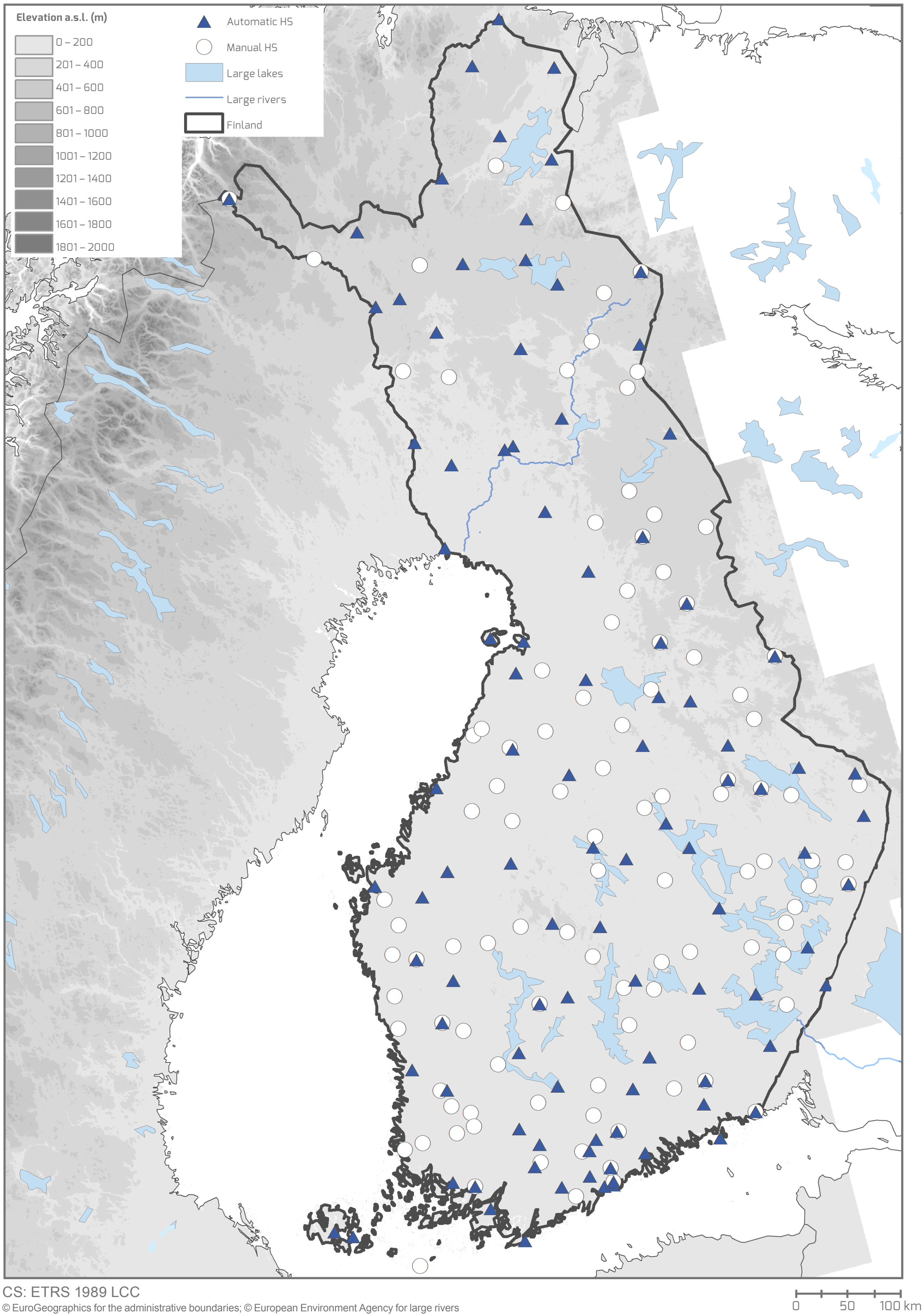

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*Figure I-2.12.2 Locations of stations in Finland where snow depth (HS) is measured.*

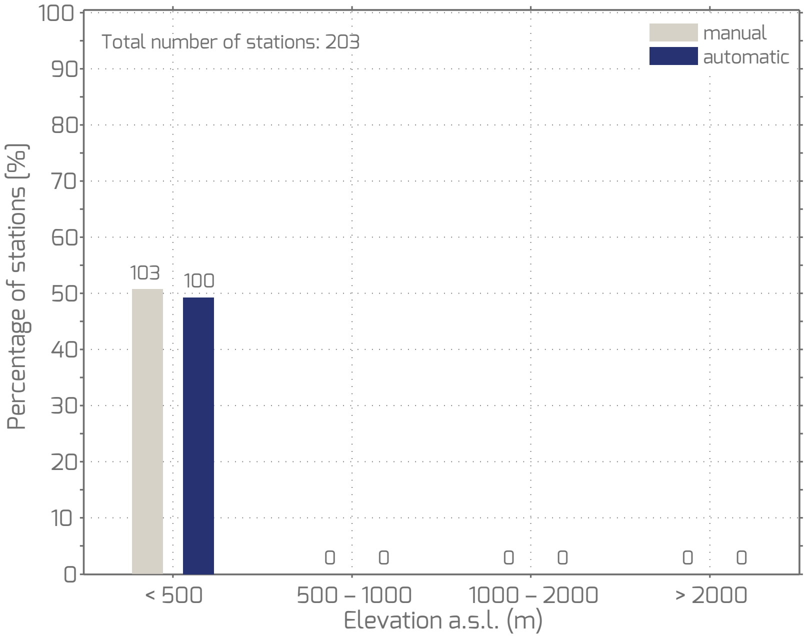

*Figure I-2.12.3 Elevational distribution of stations in Finland with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours at 0600 UTC. Fixed stakes with a scale in centimetres are used. The zero point of the stake is levelled with the ground surface and the vegetation is cut before the first snowfall event in autumn. The measurement locations are chosen to be flat, wind-protected areas. The observers avoid creating disturbances in the measurement field around the stake. To prevent incorrect measurements, snow depth is read from a distance of at least 2 m from the stake. Any snowbanks around the stake are removed before each snow depth observation. During the snow melt season, the snow surface is usually lower around the stake. Thus, the snow depth observation is made as horizontally to the surface as possible. Total snow depth is reported as long as snow is present at the stake itself and in the close surroundings. Measured values are reported in full centimetres.

**Automatic measurements:**

Automatic snow depth measurements are available every 10 minutes (average of 10 measurements made at 1 minute intervals) using ultrasonic snow depth sensors. At five stations, snow depth data is additionally available every 1 minute. The snow depth sensors are mounted 2 m above artificial green turf targets, which have a size of 2 x 2.5 m. The conditions of automatic sensor locations are similar to those of manual measurement locations.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is not reported explicitly by FMI, but during manual observations the variable 'soil quality' is recorded and therefore presence of snow on the ground is noted in the logbook.

**Zero snow depth reporting method:**

When the ground at the stake itself and in its close surroundings is snow free, 0 cm snow depth is reported even if open areas around the measurement locations are still snow covered.

## I-2.12.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.12.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 143
Number of stations delivering water equivalent of snow cover data automatically: 0

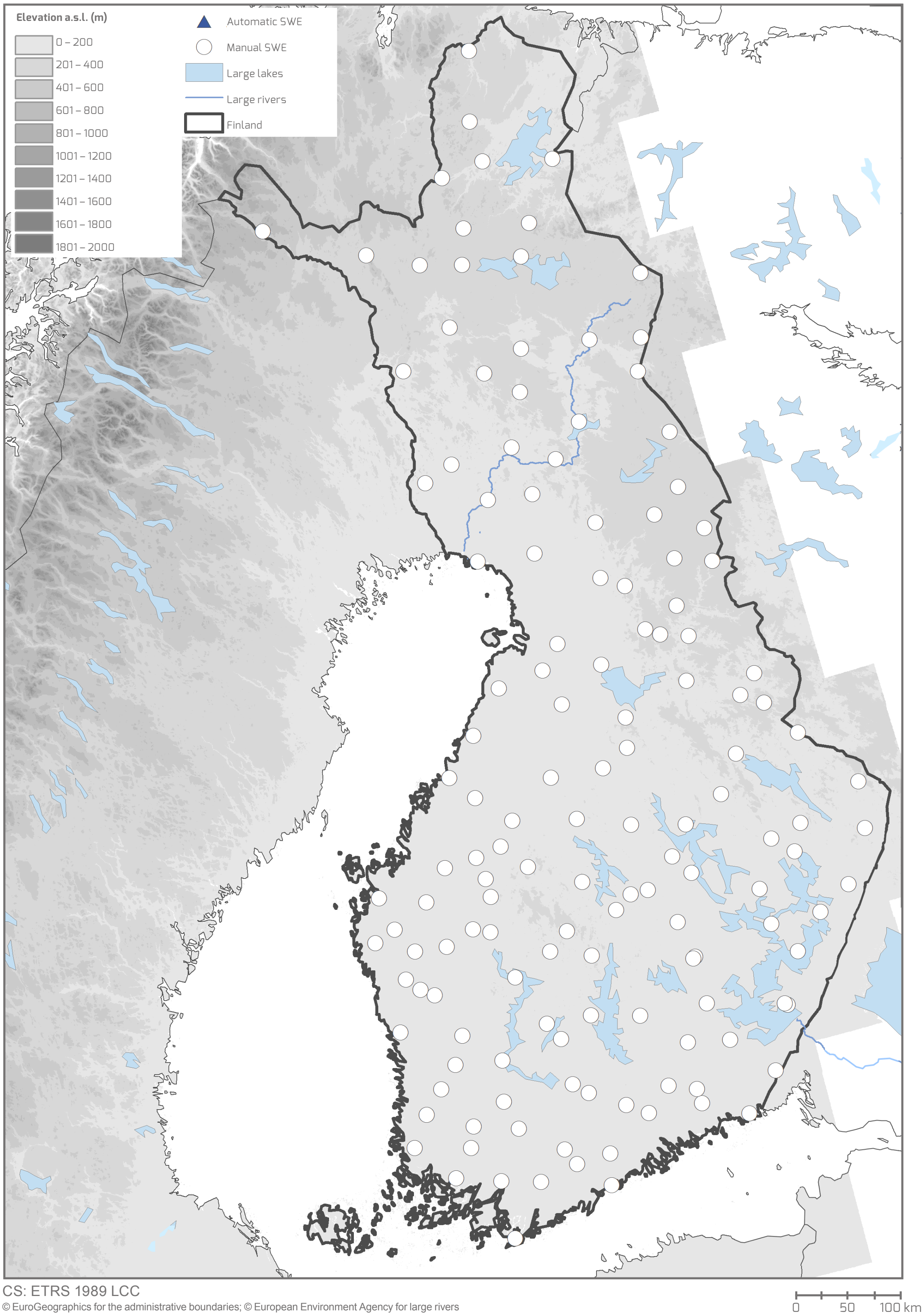

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*Figure I-2.12.4 Locations of stations in Finland where water equivalent of snow cover (SWE) is measured.*

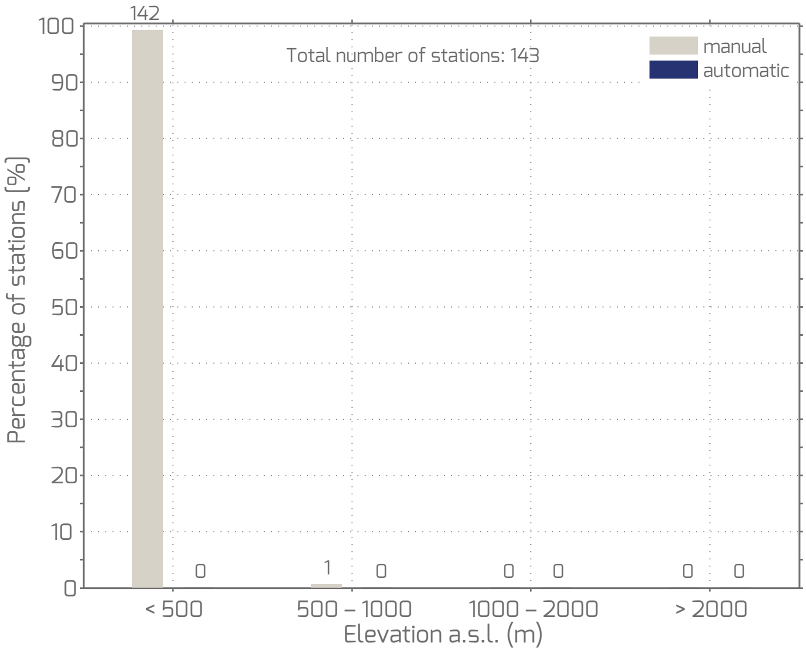

*Figure I-2.12.5 Elevational distribution of stations in Finland with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Spatially distributed SWE measurements in snow pits are performed manually along snow courses once per month (around the 16th day). During the snow melt season between March and May, SWE is measured two times per month at 15 locations. Snow courses have a length of 2 to 4 km and are located in different terrain types, such as coniferous and deciduous forest, open land and bog. Along a typical snow course, 80 snow depth measurements are performed and 8 snow samples are collected and weighed in order to quantify snow density (Figs I-2.12.6, I-2.12.7). SWE is calculated for each terrain type separately, as well as for the entire snow course, by multiplying average snow depth by snow density. For 29 snow courses (SYKE_ID numbers starting with 2), average SWE is calculated only for the entire snow course and not for different terrain types. In these cases, 50 snow depth measurements are coupled with 10 snow weight measurements (yielding snow density values). For snow depth measurements a simple wooden measuring rod is used, while for snow weight measurements a snow cylinder, mechanical scale and small spade are used.

Between the monthly manual SWE measurements, daily SWE values are calculated by SYKE along snow courses using a model. This snow course model is fed with weather observation data (air temperature, precipitation) provided by FMI. The SWE map for all of Finland is then interpolated from the calculated daily SWE values from snow courses (Fig. I-2.12.8). The areal SWE is calculated for approximately 110 watersheds.

### Automatic measurements:

No measurements.

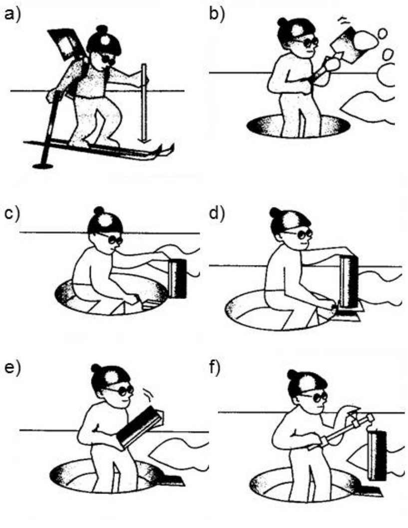

*Figure I-2.12.6 Procedure for snow density and consequently water equivalent of snow cover (SWE) observations: a) measuring snow depth with a rod; b) digging a snow pit; c) and d) sampling and lifting snow in the snow cylinder; e) turning the snow cylinder upside down; f) weighing the snow cylinder (Source: SYKE).*

Figure I-2.12.7 Snow density measurement in a snow pit along a snow course in Finland. A wooden snow rod is visible on the far right (Source: SYKE).

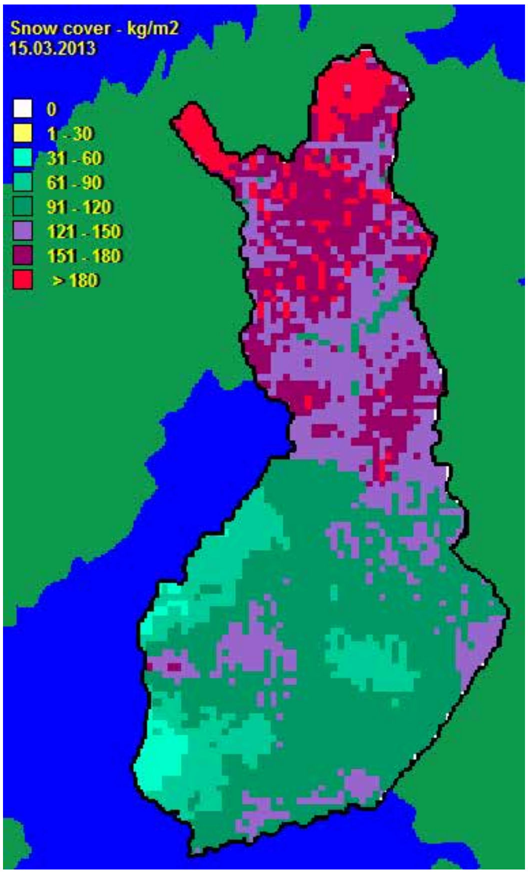

Figure I-2.12.8 Modelled water equivalent of snow cover (SWE) map of Finland (Source: SYKE).

## I-2.12.4 Transition from manual to automatic measurements

During the shift from manual to automatic snow stations, FMI usually performs parallel measurements for a few years. In some cases this has not been possible.

## I-2.12.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (FMI)<br>AUTO: 1 or 10 minutes (FMI) | MANUAL: no measurements | MANUAL: 1 month (2 weeks during ablation period) (SYKE)<br>AUTO: no measurements |

# I-2.13 France

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*Figure I-2.13.1 Location of France in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 633 187 $km^2$, 346 m a.s.l. |
| Authority responsible for snow measurements | Météo-France (MF)<br>73, avenue de Paris<br>FR-94165 Saint Mandé Cedex<br><br>Electricité de France EDF-DTG (EDF)<br>21 Avenue de l'Europe - BP-41<br>FR-38040 Grenoble Cedex 9 |
| Contact | • MF<br>publitheque@meteo.fr<br>• EDF<br>dtg-grenoble-secteur@edf.fr (EDF Alps)<br>dtg-toulouse-secteur@edf.fr (EDF Pyrenees)<br>dtg-brive-secteur@edf.fr (EDF Massif Central) |
| Near-real-time data URL and/or contact | • MF<br>https://donneespubliques.meteofrance.fr/?fond=produit&id_produit=94&id_rubrique=32 (manual observations in mountain areas);<br>Some observations are exchanged through the WMO GTS.<br>• EDF<br>Not available. |
| Archived data URL and/or contact | • MF<br>https://donneespubliques.meteofrance.fr/ (online portal)<br>• EDF<br>dtg-demande-donnees-hydro@edf.fr (on request) |

## General situation

Two institutions, the national meteorological service Météo-France (MF) and the French power company Electricité de France (EDF), perform operational snow observations in France. The extensive snow station network of MF is equally distributed over the alpine, midland and lowland regions, with 1 570 manual (snow depth and depth of snowfall) and 162 automatic (snow depth) stations. However, 941 of the manual measurement sites are likely to close within the next few years. Different data exchange mechanisms are used: some observations are exchanged through WMO's Global Telecommunication System (GTS; Section I-3.6), while others are exchanged in real time through collaborations with nearby services, such as those of Italian, Spanish and Swiss institutions. In the latter case, the exchanged data consists of regionally modified synoptical (SYNOP) codes of specific snow observations performed for the purpose of snow and avalanche forecasting.

The first measurements of snow depth and depth of snowfall date back to 1859. Currently, some stations report data in real time, some manual stations report with a 1 or 2 hour delay, and other stations report with a delay of up to 30 days. From 2019 onwards, depth of snowfall observations will not be carried out as part of MF synoptic observations. Depth of snowfall observations will only be performed as part of the climatological network and the snow observation network in mountain areas, but data of the latter network is currently not exchanged on the WMO GTS. The MF mountain observation network is operated in collaboration with local organisations, such as local authorities, ski resorts, forestry services and mountain rescue services. Manual observations are accomplished by on-site staff, whereas MF is responsible for training observers and providing measurement tools. In addition, MF processes and archives the data measured by local authorities in mountain regions.

EDF snow stations are only found in the mountainous regions of the Pyrenees, the Massif Central and the French Alps. At these stations, snow depth and water equivalent of snow cover are currently measured manually and automatically at 175 stations (139 manual, 36 automatic), while historical data is available from around 400 snow stations. In the first half of the 20th century, the EDF snow station network was established and dedicated mainly to hydraulic applications. Currrently, EDF's snow station network mainly supports an operational service in order to provide forecasts concerning water resources and dam management. This is done through snow depth measurements in winter and spring, which EDF uses to provide water resource forecasts in spring.

MF and EDF exchange their data and use the collective data for their various products (e.g. forecasts, climatology). While manual and automatic snow depth measurements are performed by both MF and EDF, depth of snowfall is only measured (manually) by MF, and water equivalent of snow cover is only measured by EDF. Neither of these institutions observes presence of snow on the ground. The MF and EDF snow measurement networks are both discussed below.

**Overview of measurements (MF, EDF)**

Snow depth: stake, ruler, rod, ultrasonic snow depth sensor, laser snow depth sensor (Figs I-2.13.2, I-2.13.3, I-2.13.4)
Depth of snowfall: snow board and ruler, snowpack excavation (Figs I-2.13.7, I-2.13.8, I-2.13.9)
Water equivalent of snow cover: snow tube, mechanical balance, bucket, cosmic ray sensor (Figs I-2.13.10, I-2.13.11)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Flood forecasting, Health and Sport, Hydrology, Hydropower production, Meteorology, Road services, Water management

## I-2.13.1 Snow depth measurements

Number of stations delivering snow depth data manually: 1 709
Number of stations delivering snow depth data automatically: 198

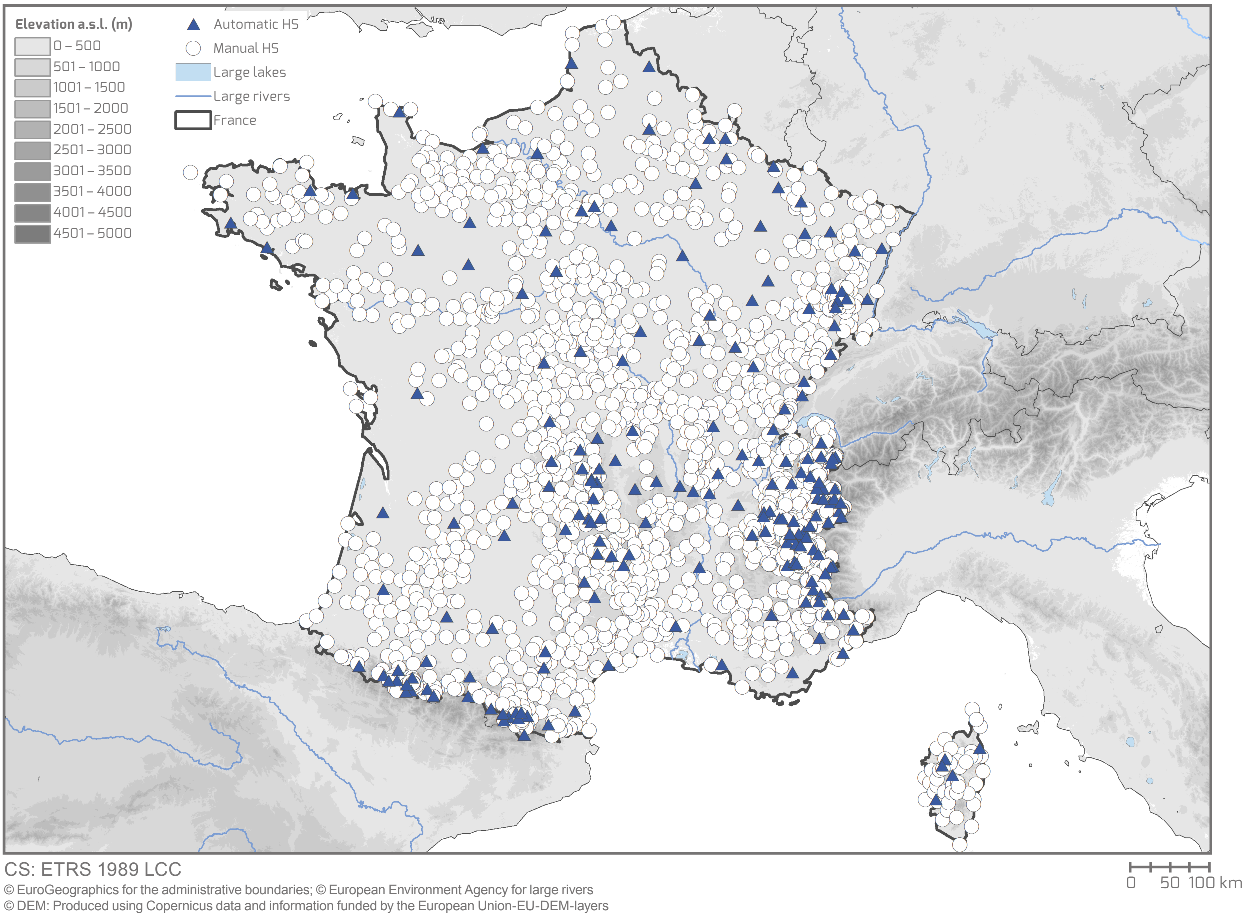

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*Figure I-2.13.2 Locations of stations in France where snow depth (HS) is measured.*

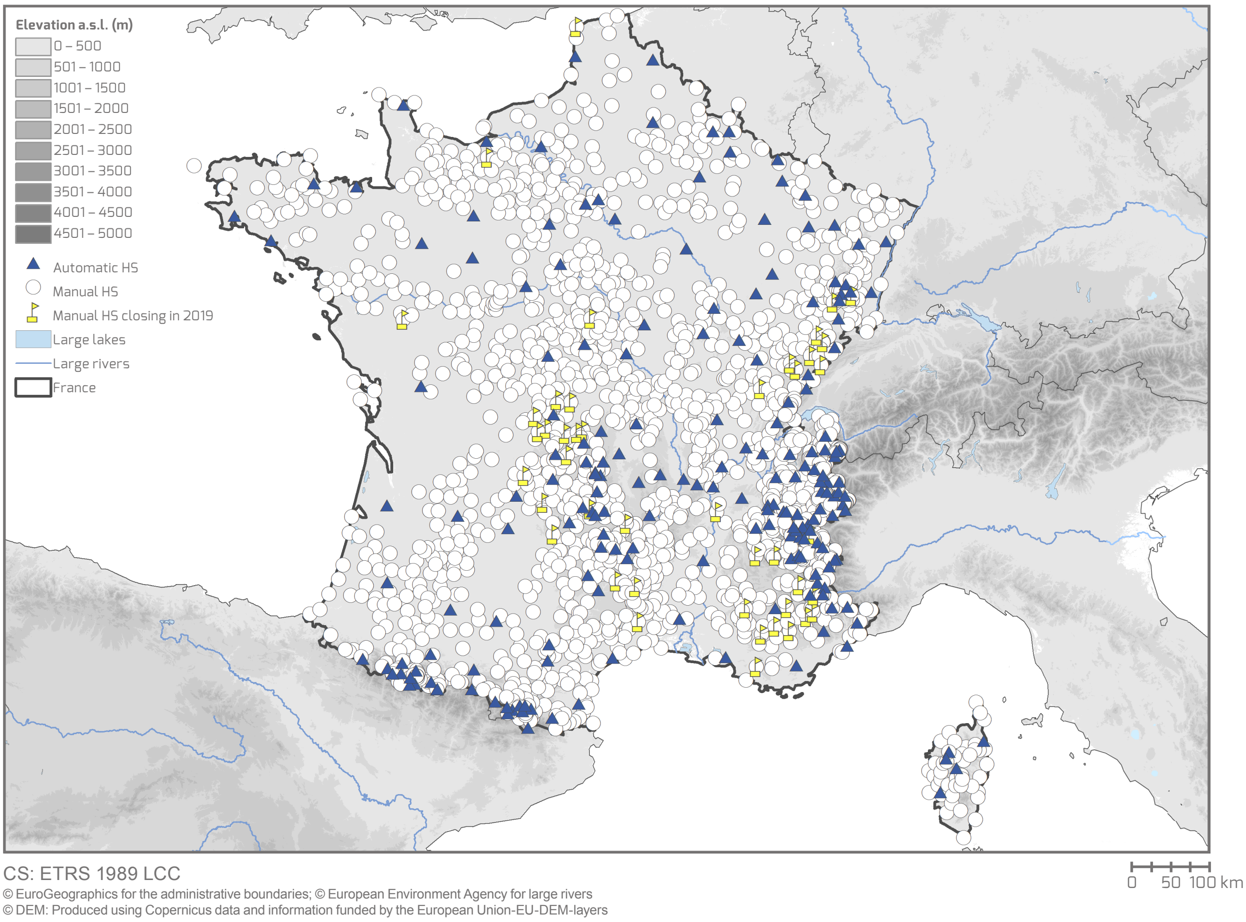

*Figure I-2.13.3 Locations of stations in France where snow depth (HS) is measured. The 44 locations marked with a yellow flag are manual sites where snow depth observations are only performed irregularly, which will close in 2019.*

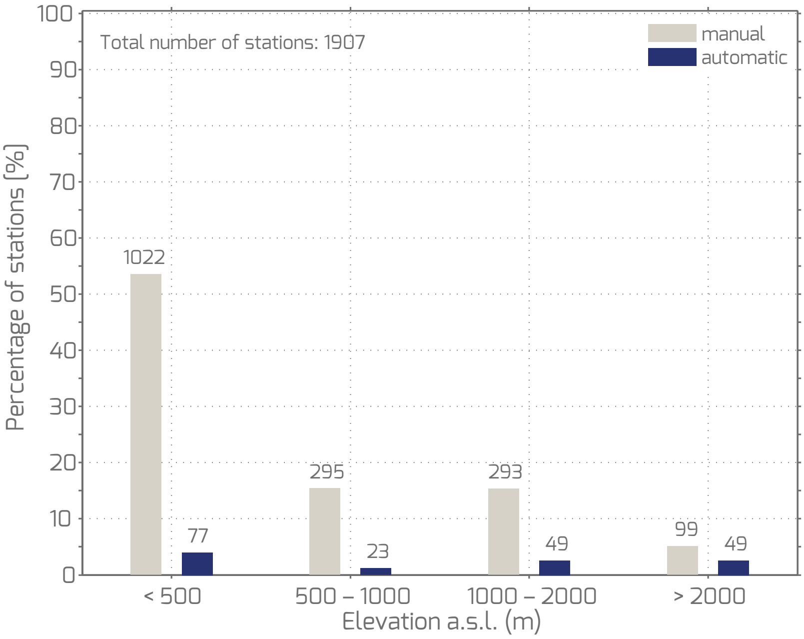

*Figure I-2.13.4 Elevational distribution of stations in France with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours by MF (1 570 stations). Depending on the site, snow depth is measured using (1) fixed stakes (8% of all MF stations) or (2) portable rulers (92%). At the 124 sites using stakes, observations are mostly performed between 15 December and 30 April. In 2019, 44 sites where snow depth is only irregularly observed using rulers will stop operating (Fig. I-2.13.3).

In contrast to MF, EDF measures snow depth manually every 15 days (139 stations). Fixed stakes are used for point measurements (Fig. I-2.13.5 a), while the spatial variability of snow depth around the stakes is assessed by five-point sampling using portable snow rods. The average of these five measurements is reported as spatially distributed snow depth. At each location, one observer is always in charge of snow observations. In addition to the measurements at the 139 manual stations, manual control measurements of snow depth are performed two to five times per year at all 36 automatic stations (not included here as manual stations).

### Automatic measurements:

Automatic snow depth measurements are performed hourly by MF (162 stations) and EDF (36 stations) using either ultrasonic or laser snow depth sensors. Ultrasonic sensors are in use at 90 MF stations, where they are mounted above either synthetic grass (61 stations) or natural ground (29 mountain stations). At the remaining 72 MF stations laser sensors with a concrete block below are used. All automatic snow depth observations are carried out at sites where air temperature, humidity and wind speed are also measured, along with precipitation and barometric pressure (except at high mountain sites).

The 36 automatic stations maintained by EDF only use ultrasonic snow depth sensors (made by Cimel, Paris, France or by Campbell Scientific, Logan, Utah, USA; Fig. I-2.13.5 b, c and Fig. I-2.13.6), which are mounted 6 m above the ground. Besides snow depth, air temperature, barometric pressure, humidity, precipitation, wind velocity and direction, and water equivalent of snow cover (using a cosmic ray sensor) are measured automatically.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is not explicitly reported by MF or EDF, but at EDF stations a remark about presence of snow on the ground is written in the logbook.

### Zero snow depth reporting method:

When the stake is snow free, 0 cm snow depth is reported.

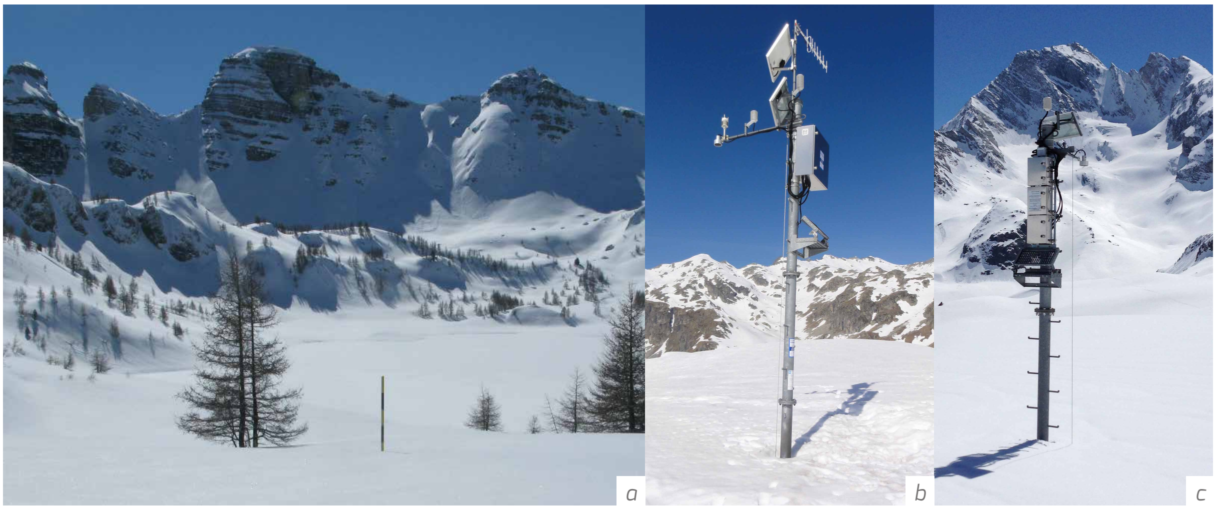

*Figure I-2.13.5 EDF snow stations: (a) manual station with a stake; (b, c) automatic weather stations (Source: EDF).*

*Figure I-2.13.6 Automatic weather station with a snow depth sensor, operated by EDF. To the left of the mast, a cosmic ray sensor measuring water equivalent of snow cover (SWE) automatically is visible as a white rectangular box on the ground (black arrow) (Source: EDF).*

## I-2.13.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 1 570

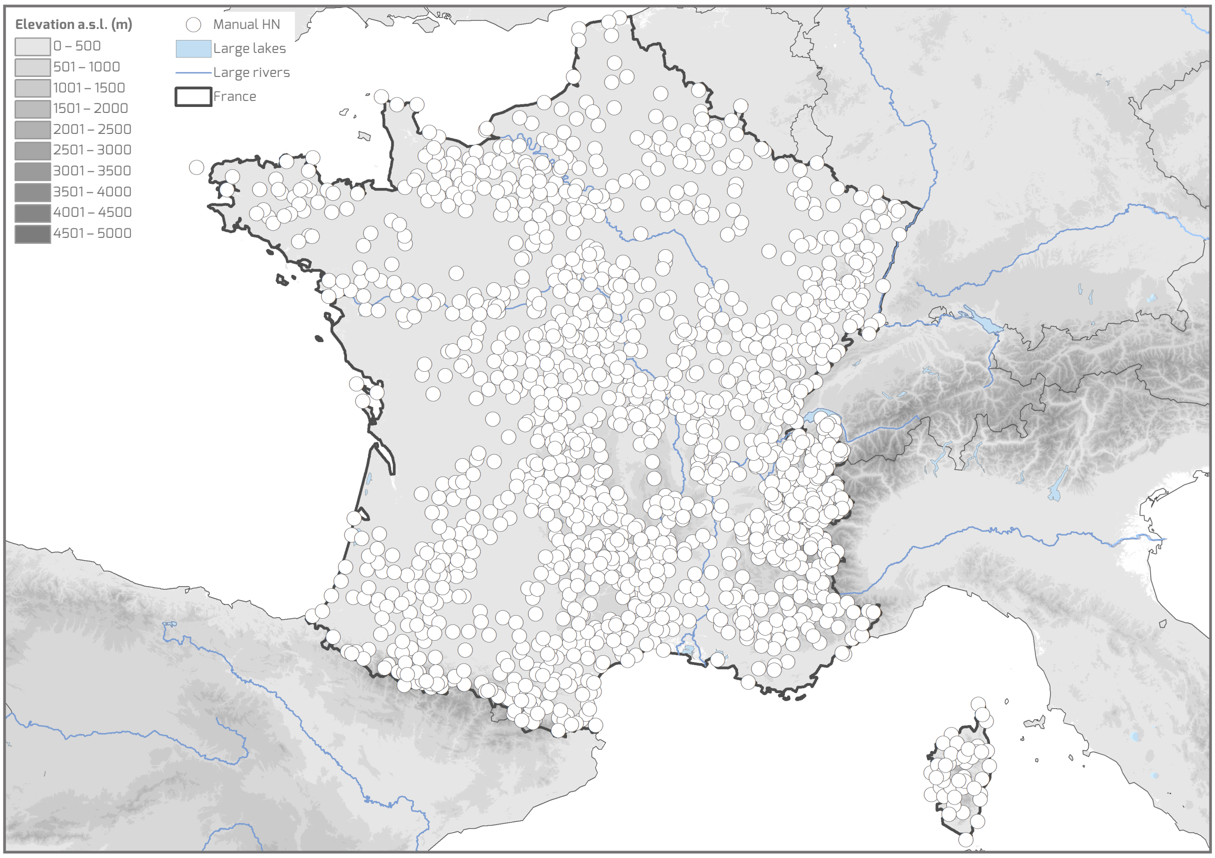

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*Figure I-2.13.7 Locations of stations in France where depth of snowfall (HN) is measured.*

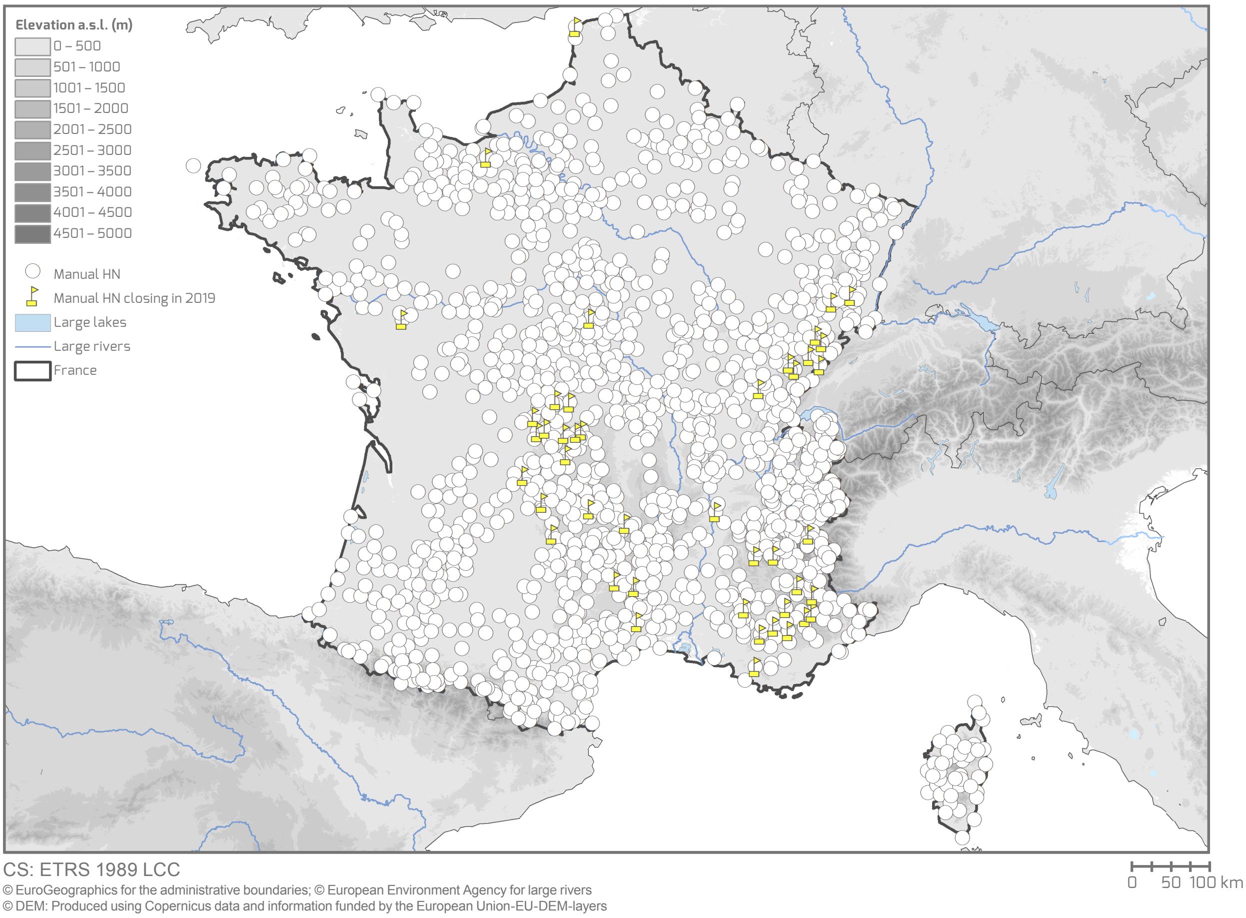

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*Figure I-2.13.8 Locations of stations in France where depth of snowfall (HN) is measured. The 44 locations marked with a yellow flag are manual sites where depth of snowfall observations are only performed irregularly, which will close in 2019.*

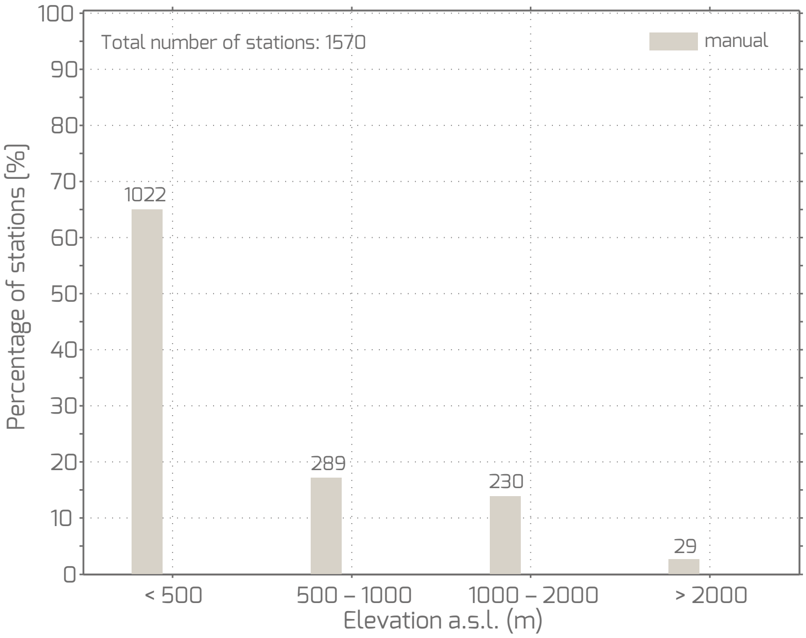

*Figure I-2.13.9 Elevational distribution of stations in France with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours by MF in parallel to manual snow depth measurements. Depending on the site, depth of snowfall is measured (1) on a white-painted snow board with a ruler (11% of all stations, mostly located in mountainous areas) or (2) while performing snowpack excavations (89% of all stations, mostly located in the lowlands where snowfall is rare).

(1) Depth of snowfall is measured at two to three points on the snow board, and the average of all measurements is reported as total depth of snowfall. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. At 124 sites, measurements are performed mostly between 15 December and 30 April.

(2) Depth of snowfall is measured during snowpack excavations by scraping away the snow down to the ground. In cases where there is a snowfall event and the ground is already covered in snow, observers must clear the snow from the ground over a sufficiently large area. This cleared and snow-free area is marked in order to assess depth of snowfall at that location 24 hours later by snowpack excavation. These stations belong to the climatological network and mainly cover the French lowlands where snow is rare and where snow is not the main measurement target (the focus is on air temperature and precipitation). At 44 of these sites, snow depth is measured only irregularly and will no longer be measured starting in 2019 (Fig. I-2.13.8).

## I-2.13.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 139
Number of stations delivering water equivalent of snow cover data automatically: 36

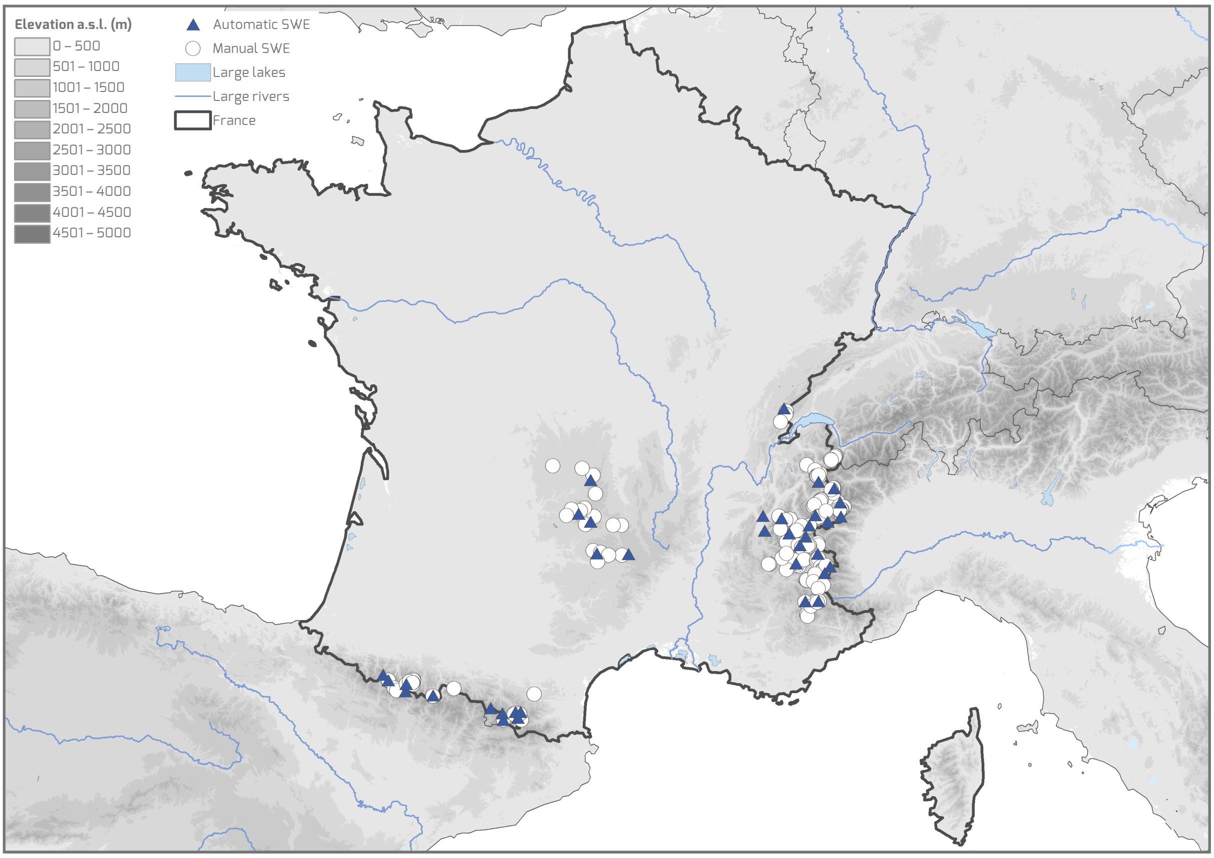

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*Figure I-2.13.10 Locations of stations in France where water equivalent of snow cover (SWE) is measured.*

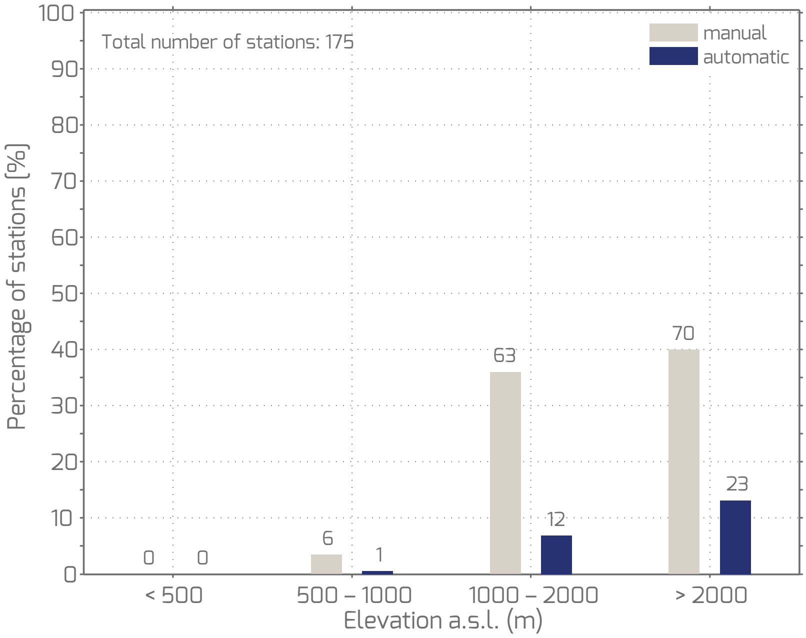

*Figure I-2.13.11 Elevational distribution of stations in France with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements are performed every 15 days by EDF in parallel to manual snow depth measurements. The spatial variability of SWE is accounted for with five-core SWE sampling using snow tubes (Fig. I-2.13.12). The gravimetric method is applied. In order to assess SWE (without digging a snow pit), a snow sample is extracted vertically from the snowpack with the snow tube. The single snow tube segments have a length of 1 m (Figs I-2.13.12, I-2.13.13) and can be fitted together in order to sample snow depths exceeding 1 m. After measuring the height (in m) of the snow sample, the snow tube is attached to a mechanical scale to measure the total weight (in kg) of the snow (Fig. I-2.13.12). Sometimes the snow sample is poured from the tube into a plastic bucket or bag and weighed using a mechanical scale (Fig. I-2.13.14). In addition to the SWE measurements performed at the 139 manual stations, manual control SWE measurements are performed two to five times per year at all 36 automatic stations (not included as manual measurement stations in this country report).

**Automatic measurements:**

Automatic SWE measurements are performed hourly using cosmic ray sensors developed by EDF. Unlike all other instruments, which are installed 6 m above the ground, the cosmic ray SWE sensor is buried in the ground close to the automatic station mast (white rectangular box on the ground marked with a black arrow in Fig. I-2.13.6). Cosmic ray sensors have been in use since 2000, while passive gamma radiation sensors were used before then.

*Figure I-2.13.12 Snow tube, consisting of multiple 1-m-long segments, attached to a mechanical scale at Gaougeta, France (Source: EDF).*

*Figure I-2.13.13 (a, b) Single snow tube segments, each with a length of 1 m (Source: EDF).*

*Figure I-2.13.14 Snow tube (lying on the snow) and bucket attached to a mechanical scale in order to measure the total weight of the snow (Source: EDF).*

## I-2.13.4 Transition from manual to automatic measurements

At a few MF snow stations, parallel measurements have been completed during the station transition from manual to automatic measurements in order to check that the new instruments are functioning properly, but not as a way to correct the discontinuity induced by the change in instrumentation. In contrast, when an EDF snow station is shifted from manual to automatic measurements, five manual control measurements are completed annually for the first three years and at least two parallel measurements are completed annually thereafter.

## I-2.13.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (MF) or 15 days (EDF)<br>AUTO: 1 hour (MF and EDF) | MANUAL: 24 hours (MF) | MANUAL: 15 days (EDF)<br>AUTO: 1 hour (EDF) |

# I-2.14 Germany

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*Figure I-2.14.1 Location of Germany in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 357 376 km$^2$, 263 m a.s.l. |
| Authority responsible for snow measurements | Deutscher Wetterdienst (DWD)<br>-Headquarters-<br>Frankfurter Strasse 135<br>DE-63067 Offenbach am Main<br><br>Avalanche Warning Service in the Bavarian Ministry for Environment (LfU)<br>Heßstraße 128<br>DE-80797 München |
| Contact | • DWD<br>reiner.kuner@dwd.de (Reiner Kuner)<br>info@dwd.de<br>• LfU<br>lawinenwarnzentrale@lfu.bayern.de |
| Near-real-time data URL and/or contact | • DWD<br>http://www.dwd.de/DE/klimaumwelt/cdc/cdc.htlm<br>• LfU<br>http://www.lawinenwarndienst-bayern.de/daten_meldungen/messstationen/ |
| Archived data URL and/or contact | • DWD<br>http://www.dwd.de/DE/klimaumwelt/cdc/cdc.htlm<br>• LfU<br>Henry.Schmoelz@lfu.bayern.de (Henry Schmölz) |

## General situation

The Deutscher Wetterdienst (DWD) is responsible for operational snow observations in Germany. The DWD station network is equally distributed over the alpine, midland and lowland regions. Snow depth is measured both manually and automatically, while depth of snowfall and water equivalent of snow cover are only observed manually.

Besides the Germany-wide DWD station network, the Bavarian Avalanche Warning Service (LfU) operationally measures snow, mostly in the Bavarian mountains. While snow depth and water equivalent of snow cover are periodically measured at automatic stations, manual snow depth measurements are performed once every two weeks in parallel to snow pit observations. Snow pits are only used to record snow stratigraphy, while snow density and manual water equivalent of snow cover measurements are not performed. Although depth of snowfall is measured manually at a few LfU locations, these stations are not included in this country report because measurements are not standardised and locations shift annually.

DWD and LfU exchange their data and use the collective data for their various products (e.g. forecasts, climatology). While manual and automatic snow depth measurements are performed by both DWD and LfU, presence of snow on the ground, depth of snowfall and water equivalent of snow cover are assessed manually only by DWD. Water equivalent of snow cover is only measured automatically by LfU. The DWD and LfU snow measurement networks are both discussed below.

## Overview of measurements (DWD, LfU)

Snow depth: ruler, stake, ultrasonic snow depth sensor, laser snow depth sensor (Figs I-2.14.2, I-2.14.3)
Depth of snowfall: snow grid and ruler (Figs I-2.14.6, I-2.14.7)
Water equivalent of snow cover: snow cylinder, steelyard balance, snow scale (Figs I-2.14.8, I-2.14.9)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Flood forecasting, Health and Sport, Hydrology, Meteorology, Road services, Water management

## I-2.14.1 Snow depth measurements

Number of stations delivering snow depth data manually: 1 541
Number of stations delivering snow depth data automatically: 169

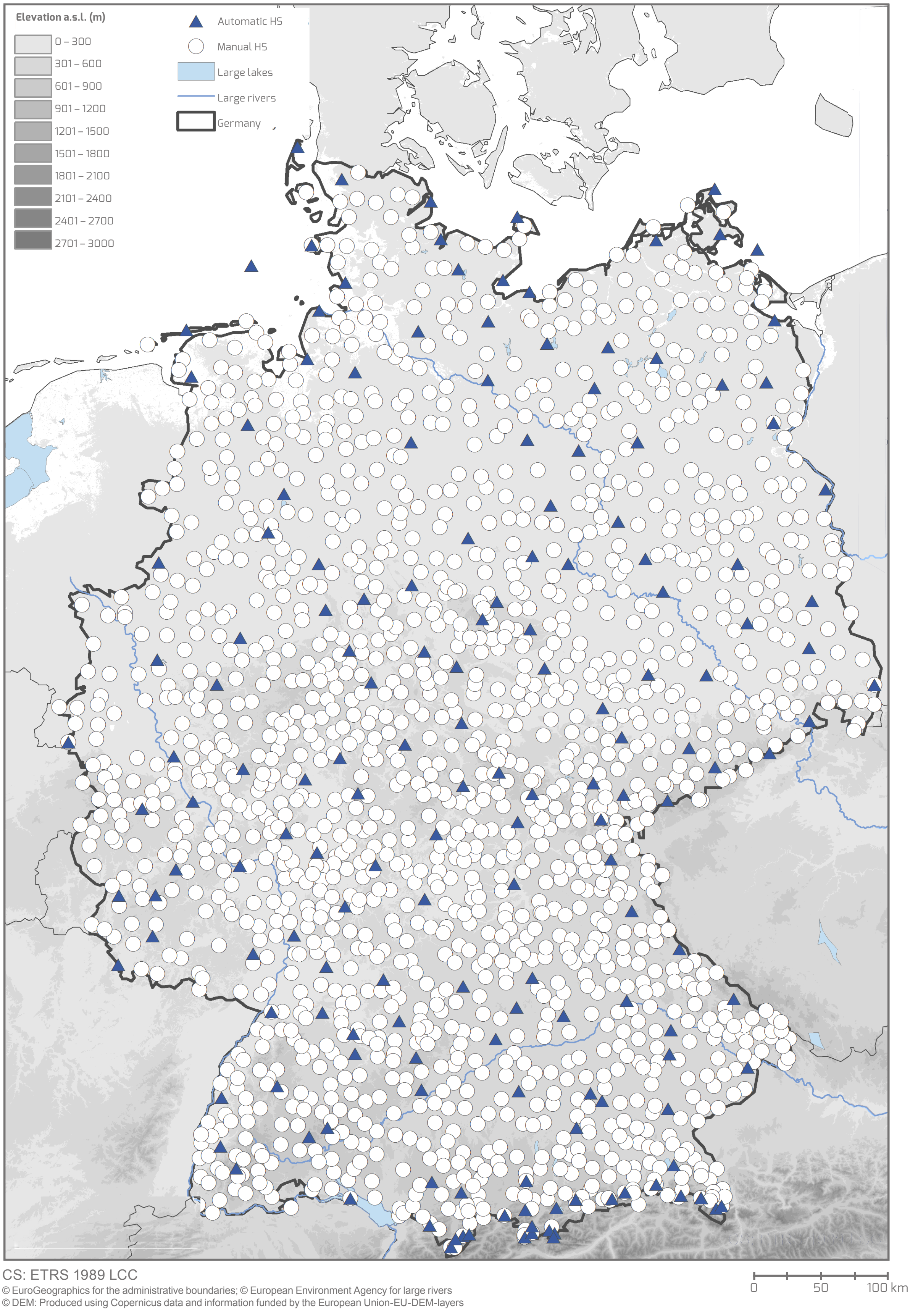

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*Figure I-2.14.2 Locations of stations in Germany where snow depth (HS) is measured.*

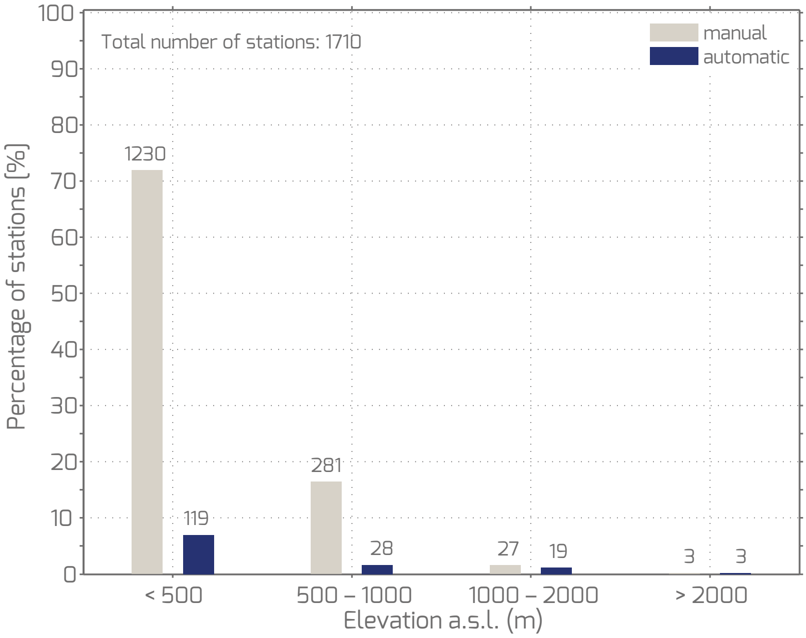

*Figure I-2.14.3 Elevational distribution of stations in Germany with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 6 hours at 0000, 0600, 1200 and 1800 UTC by DWD observers. Rulers with a scale in centimetres are used. Several snow depth measurements are performed within a measurement field (maximum distance of 100 m between the measurement points), and the average of all measurements is reported as total snow depth. At mountain stations, both portable rulers and fixed stakes are used to measure snow depth manually. Measured values are reported in full centimetres. In contrast, manual snow depth measurements are performed once every two weeks by LfU in parallel to snow pit investigations. Portable rulers with a scale in centimetres are used. Total snow depth is reported as long as at least half of the measurement field is covered with snow.

### Automatic measurements:

Snow depth is measured automatically every minute by DWD, but 30-minute (national) or 60-minute (international) averages are reported. Laser snow depth sensors (SHM 30; Lufft, Fellbach, Germany) are used and are located within a 25 x 25 m standard measurement field (Fig. I-2.14.4 a). Snow depth sensors are mounted 2.5 m above the ground, and grey boards with a size of 50 x 50 cm are placed below the sensors (Fig. I-2.14.4 b). Between May and September the laser sensors are disabled.

LfU measures snow depth automatically every 10 minutes. Ultrasonic snow depth sensors (USH-8; Sommer Messtechnik, Vorarlberg, Austria) are used (Fig. I-2.14.5). Snow depth sensors are usually mounted 4 m above the ground. Artificial targets below the sensors are not used.

### Presence of snow on the ground reporting method:

In parallel to manual snow depth measurements, presence of snow on the ground is reported explicitly by DWD observers. In contrast, presence of snow on the ground is not reported explicitly by LfU.

### Zero snow depth reporting method:

DWD reports 0 cm snow depth when more than 50% of the measurement field is snow free or when snow depths are less than 0.5 cm. LfU reports 0 cm snow depth when more than 50% of the measurement field is snow free.

*Figure I-2.14.4 (a) A DWD measurement field with a laser snow depth sensor (red circle). (b) Laser snow depth sensor SHM 30 operated by DWD with an artificial target below (Source: DWD).*

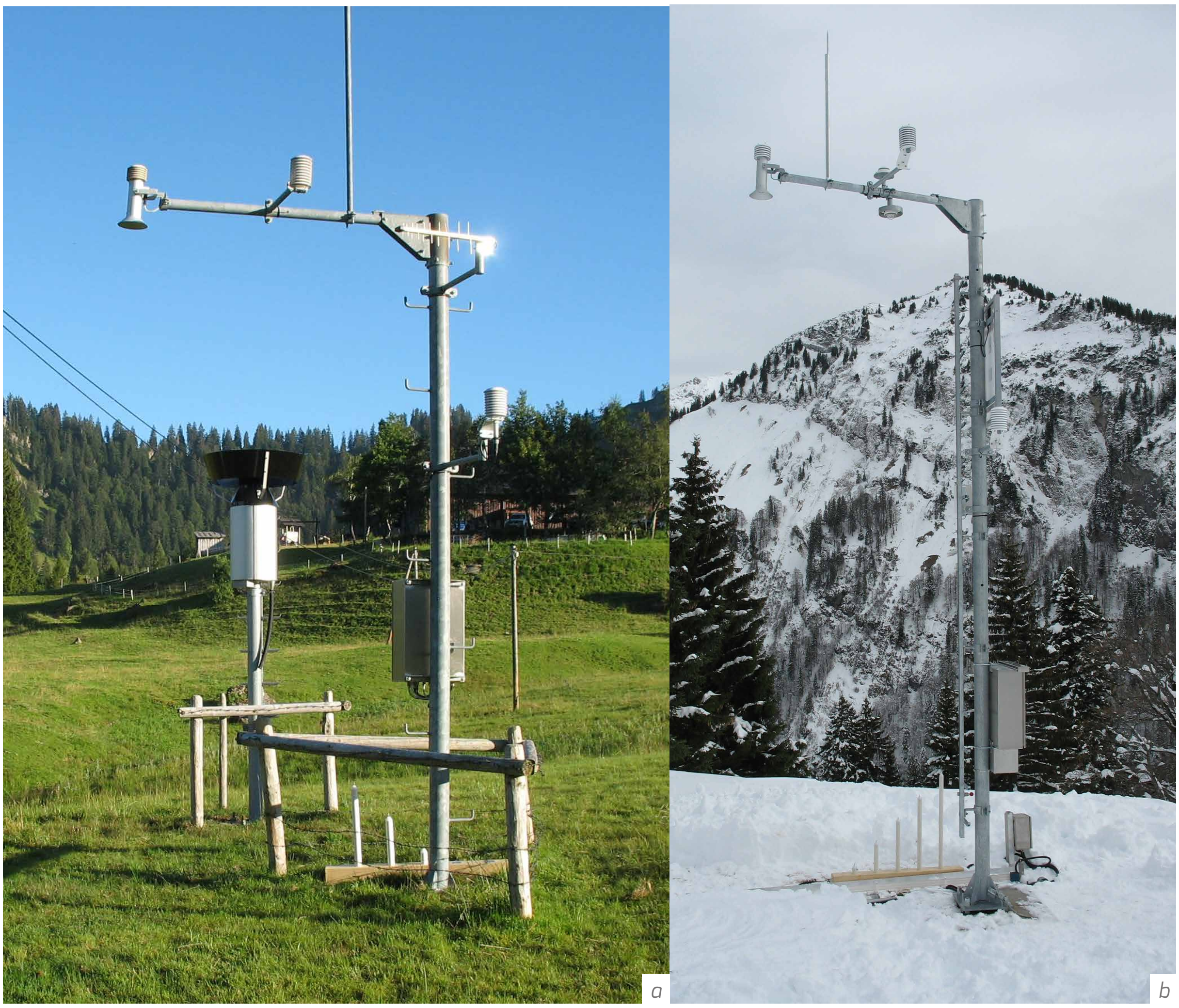

*Figure I-2.14.5 Automatic weather stations operated by LfU, including the ultrasonic USH-8 snow depth sensor: (a) during the snow-free season; (b) in winter (Source: LfU).*

## I-2.14.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 1 522

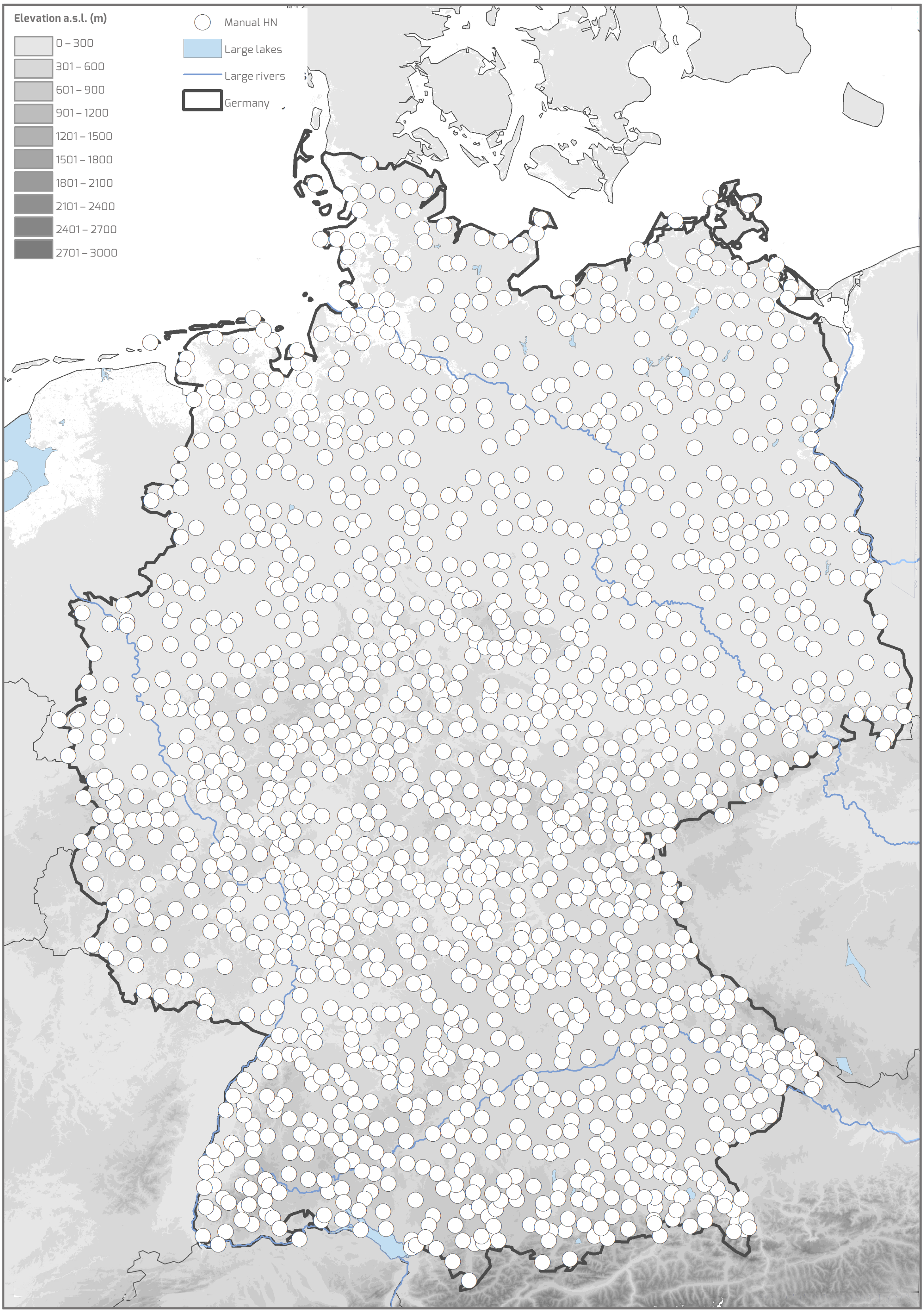

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*Figure I-2.14.6 Locations of stations in Germany where depth of snowfall (HN) is measured.*

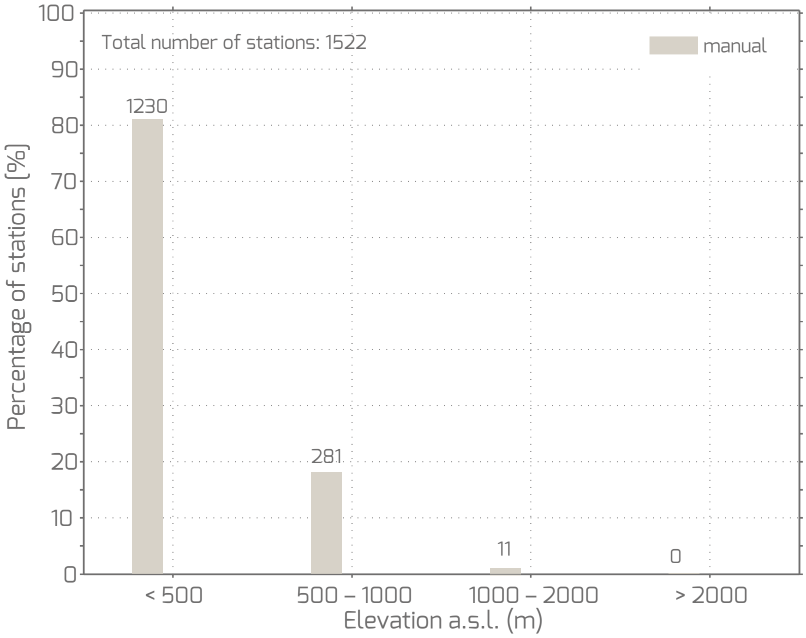

*Figure I-2.14.7 Elevational distribution of stations in Germany with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual measurements of depth of snowfall are performed daily (at 0600 UTC) and every 12 hours (at 0600 and 1800 UTC) at DWD stations. This is done in parallel to manual snow depth measurements. Depth of snowfall is measured on a snow grid (50 x 50 cm) with a ruler. In order to measure depth of snowfall in both 12 and 24 hour intervals, two snow grids are used in parallel. After each 12-hour or 24-hour measurement, the snow grids are cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface.

### I-2.14.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 500
Number of stations delivering water equivalent of snow cover data automatically: 4

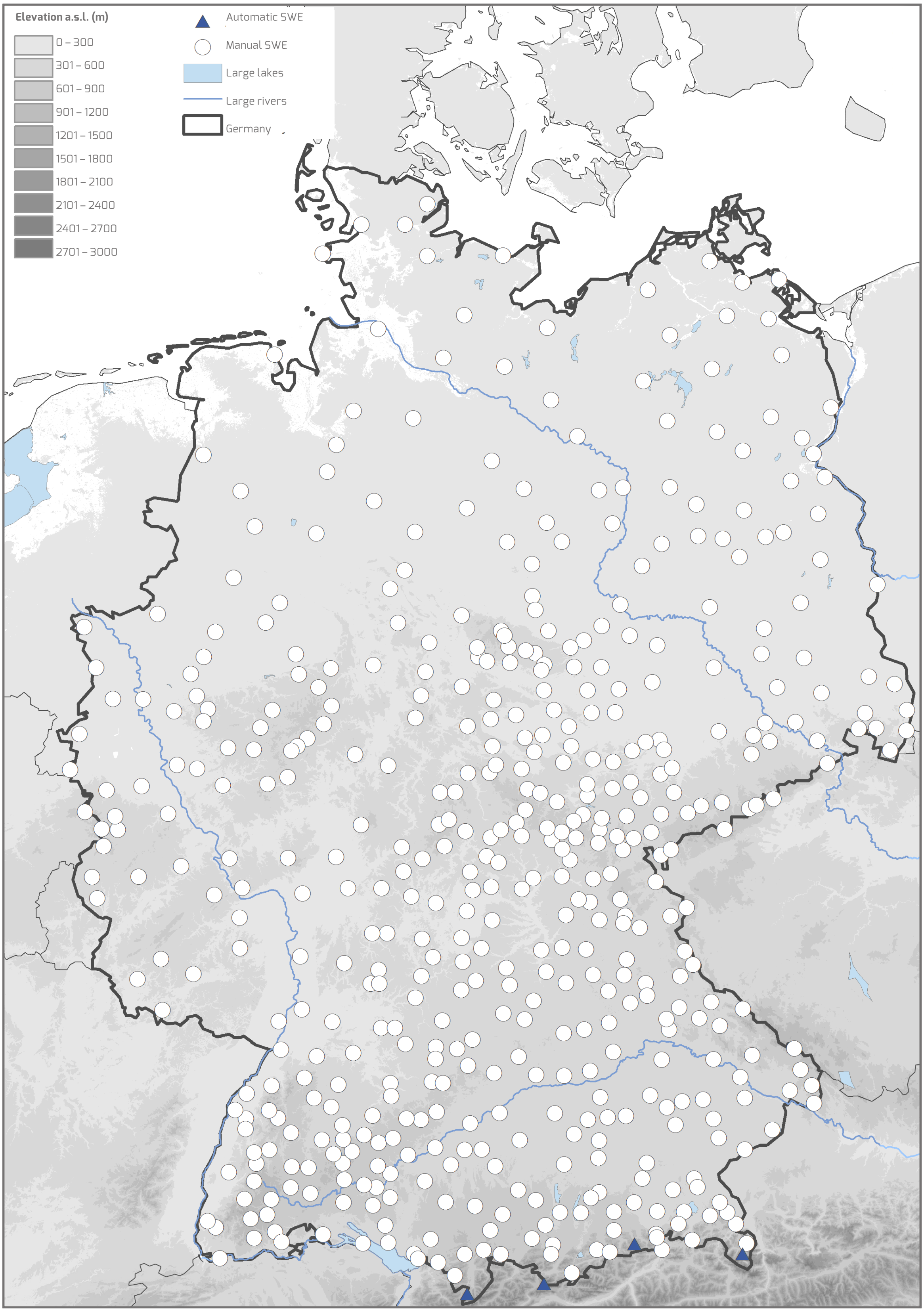

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*Figure I-2.14.8 Locations of stations in Germany where water equivalent of snow cover (SWE) is measured.*

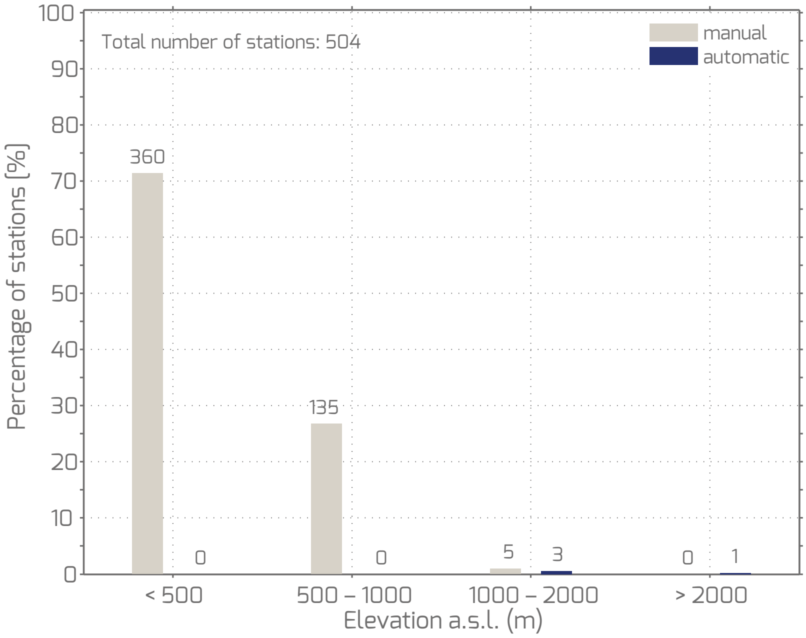

*Figure I-2.14.9 Elevational distribution of stations in Germany with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed daily at DWD stations at 0600 UTC for snow depths exceeding 5 cm and when more than 50% of the measurement field is snow covered. The gravimetric method is applied. Using a graduated aluminium snow cylinder (WS-43, which is similar to the snow cylinder BC-43 used by other countries) with a certain cross-sectional area (in $m^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), the snow cylinder is attached to a steelyard balance (Fig. I-2.14.10) to measure the total weight of the snow (in kg). Notably, DWD reports the specific water equivalent of the snow (in mm $cm^{-1}$) and not SWE (in mm w.e.). The simple conversion to SWE is provided on the DWD webpage. A location that has a flat snow surface and is representative of the surrounding area is selected for the SWE measurement. If ice layers are present within the snowpack, they are intersected by using gentle pressure and rotational movement of the snow cylinder.

**Automatic measurements:**

LfU operates stations where SWE is measured automatically every 10 minutes with a snow scale (SSG 1000; Sommer Messtechnik).

*Figure I-2.14.10 Snow cylinder WS-43 attached to a steelyard balance in order to measure water equivalent of snow cover (SWE) manually (Source: DWD).*

## I-2.14.4 Transition from manual to automatic measurements

Parallel measurements are not performed at DWD stations, although it is known that the shift from manual to automatic snow depth measurements is problematic because snow depths less than 2 cm cannot be measured automatically. Thus, it is not possible to determine 0 cm snow depth automatically. Parallel measurements are also not common at stations operated by LfU.

## I-2.14.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 6 hours (DWD) or 2 weeks (LfU)<br>AUTO: 1 (DWD) or 10 minutes (LfU) | MANUAL: 12 and 24 hours (DWD) | MANUAL: 24 hours (DWD)<br>AUTO: 10 minutes (LfU) |

# I-2.15 Greece

CS: ETRS 1989 LCC

*Figure I-2.15.1 Location of Greece in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 131 957 km², 479 m a.s.l. |
| Authority responsible for snow measurements | Hellenic National Meteorological Service (HNMS)<br>El. Venizelou 14<br>GR-16777 Hellinikon |
| Contact | • HNMS<br>info@hnms.gr<br>artpap@hnms.gr (Artemis Papapetrou) |
| Near-real-time data URL and/or contact | • HNMS<br>Not available. |
| Archived data URL and/or contact | • HNMS<br>sales@hnms.gr (official request to HNMS) |

## General situation

The Hellenic National Meteorological Service (HNMS) is responsible for operational snow measurements in Greece. The existing manual snow station network is distributed over the entire Greek territory including the Greek islands, though not evenly. The majority of the HNMS snow stations are located at low elevations, where snowfall is rare. In contrast, snowfall is frequent in the mountainous regions but there is a distinct lack of snow stations.

Snow measurements are carried out for the purpose of weather forecasting, snow climatology and the assessment of hydrological patterns in Greece. They are also used for forestry, agricultural applications and tourism purposes. HNMS measures snow depth and depth of snowfall manually.

## Overview of measurements (HNMS)

Snow depth: snow board and ruler (Figs I-2.15.2, I-2.15.3)
Depth of snowfall: snow board and ruler (Figs I-2.15.4, I-2.15.5)
Water equivalent of snow cover: no measurements
Operational purpose of measurements: Agriculture and Forestry, Climatology, Hydrology, Tourism, Water management

## I-2.15.1 Snow depth measurements

Number of stations delivering snow depth data manually: 61
Number of stations delivering snow depth data automatically: 0

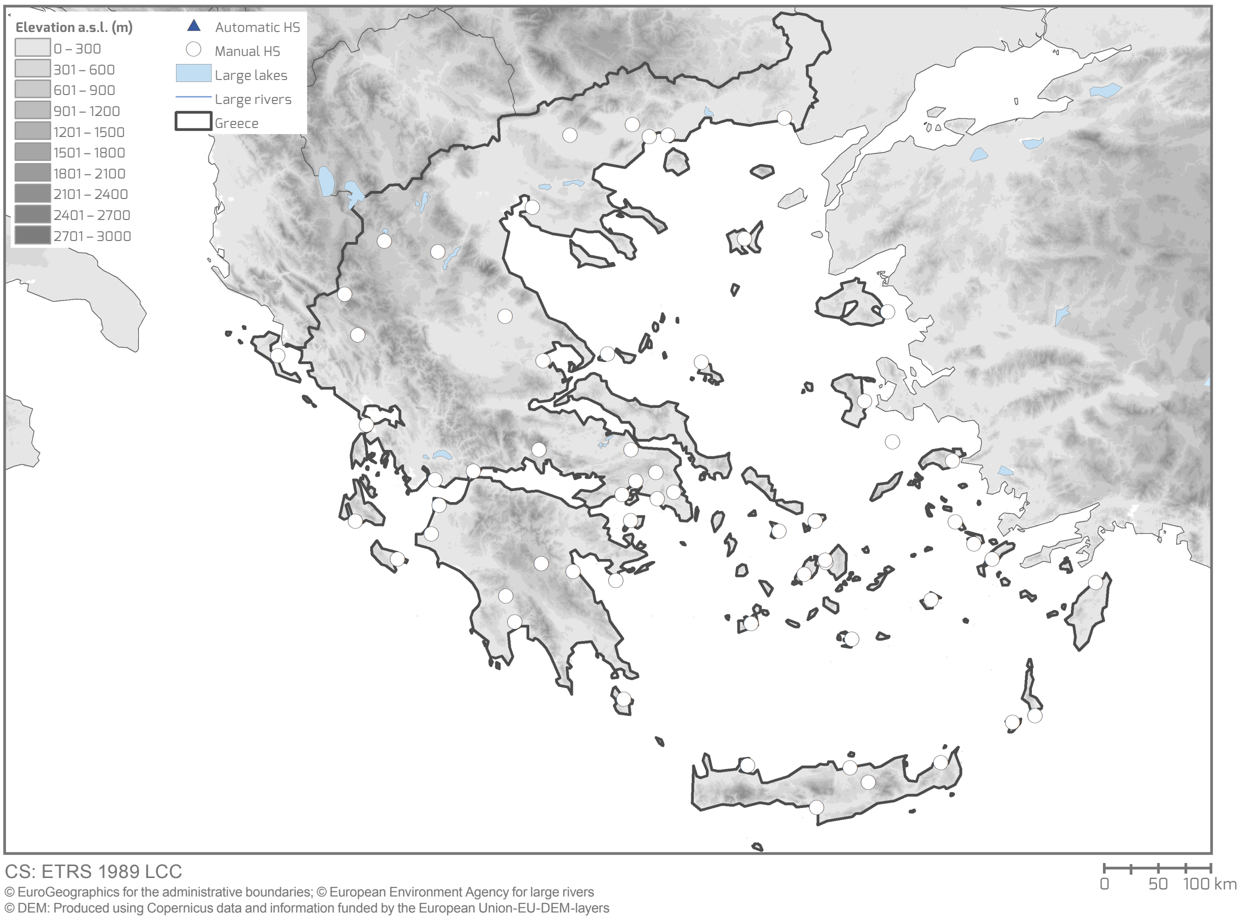

*Figure I-2.15.2 Locations of stations in Greece where snow depth (HS) is measured.*

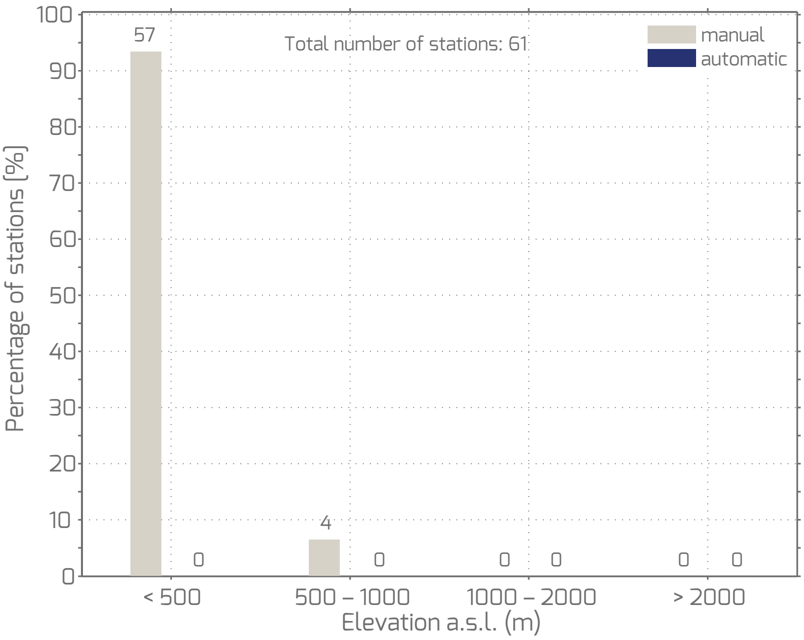

*Figure I-2.15.3 Elevational distribution of stations in Greece with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 12 hours at 0600 and 1800 UTC. Snow depth is measured in parallel to depth of snowfall measurements on a white-painted wooden snow board or a marble snow board (1 x 1 m) with a ruler. The snow board used for total snow depth measurements is not cleaned after each measurement so that the entire snowpack can be measured.

**Automatic measurements:**

No measurements.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is not reported explicitly.

**Zero snow depth reporting method:**

A snow depth of 0 cm is not reported. In cases where snow depth is less than 0.5 cm, it is reported using a code as part of the synoptic observations.

## I-2.15.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 61

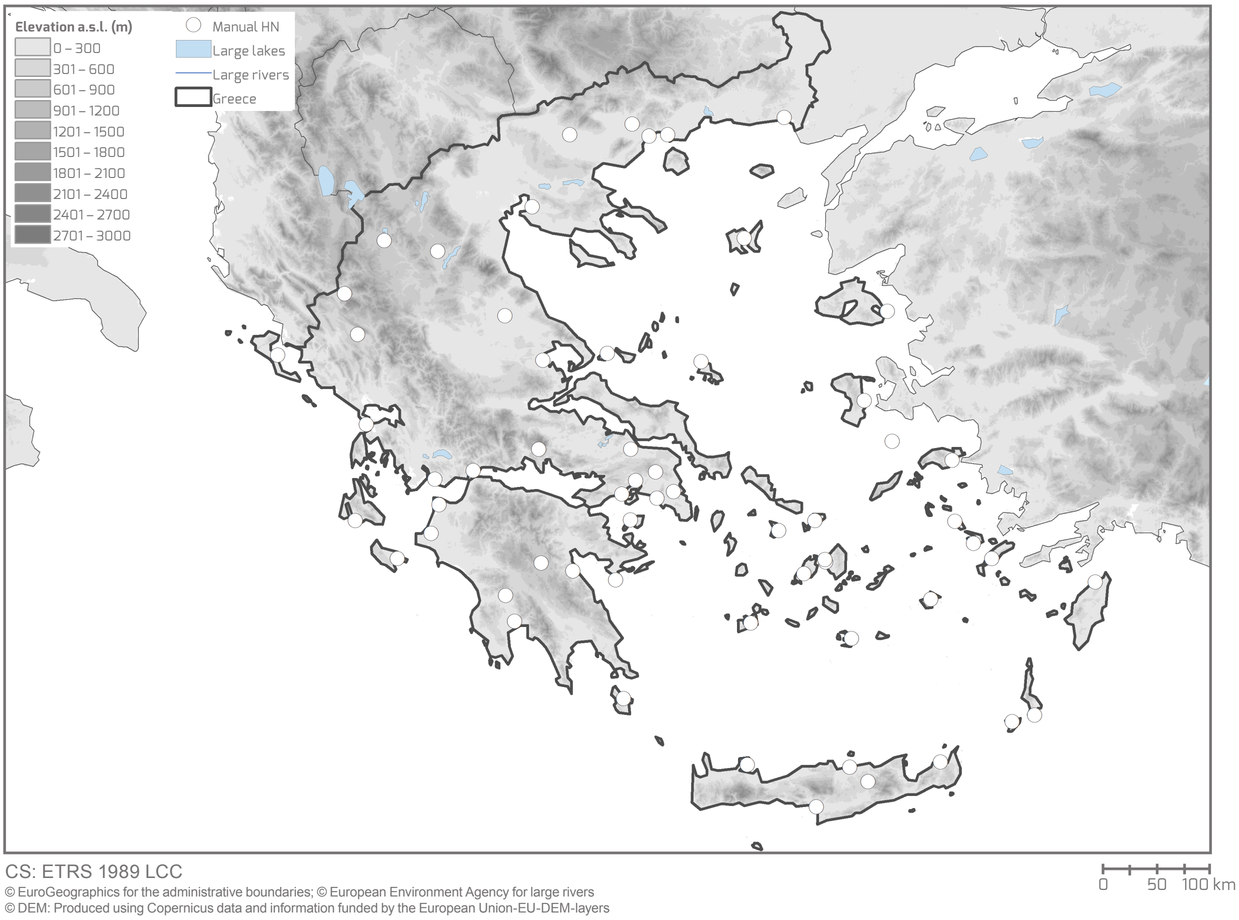

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*Figure I-2.15.4 Locations of stations in Greece where depth of snowfall (HN) is measured.*

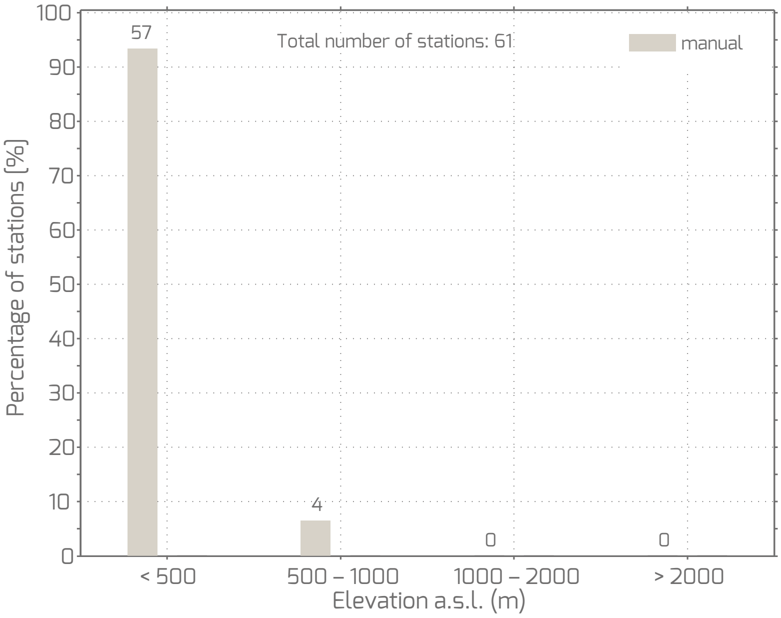

*Figure I-2.15.5 Elevational distribution of stations in Greece with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed either every 6 hours at 0000, 0600, 1200 and 1800 UTC (46% of all stations) or three times a day at 0600, 1200 and 1800 UTC (54% of all stations). In both cases, depth of snowfall is measured on a white-painted wooden snow board or a marble snow board (1 x 1 m) with a ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover (or bare ground), as evenly as possible in relation to the surrounding surface. The locations of the depth of snowfall measurements are selected to minimise influence from the wind or from obstacles in the surroundings, according to WMO guidelines.

## I-2.15.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 0

**Manual measurements:**

No measurements.

**Automatic measurements:**

No measurements.

## I-2.15.4 Transition from manual to automatic measurements

No parallel measurements are carried out because snow is not yet measured automatically.

## I-2.15.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 12 hours (HNMS)<br>AUTO: no measurements | MANUAL: 6 hours (3 or 4 measurements in 24 hours) (HNMS) | MANUAL: no measurements<br>AUTO: no measurements |

# I-2.16 Hungary

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*Figure I-2.16.1 Location of Hungary in Europe.*

## I-2.16 Hungary

### Country information

| | |
|---|---|
| Country area, mean country elevation | 93 030 $km^2$, 147 m a.s.l. |
| Authority responsible for snow measurements | Hungarian Meteorological Service (OMSZ)<br>Kitaibel Pál u. 1<br>HU-1024 Budapest |
| Contact | • OMSZ<br>toth.r@met.hu (Róbert Tóth) |
| Near-real-time data URL and/or contact | • OMSZ<br>www.met.hu<br>http://www.met.hu/en/idojaras/aktualis_idojaras/megfigyeles/hovastagsag/<br>http://www.met.hu/en/idojaras/aktualis_idojaras/hojelentes/ |
| Archived data URL and/or contact | • OMSZ<br>papp.g@met.hu (Gabriella Papp) |

### General situation

The Hungarian Meteorological Service (OMSZ) is responsible for operational snow observations in Hungary. The extensive snow station network is equally distributed over the midland and lowland regions. OMSZ has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. OMSZ measures snow depth and water equivalent of snow cover manually, while snow depth is measured automatically at only one station. Snow depth measurements started in the 1890s, when 16 snow stations were in use before the beginning of World War 2. Starting in the 1990s, 282 new measurement locations for snow depth and water equivalent of snow cover have been established.

Hungary is located in the temperate zone. Snow usually occurs from November until March, although in 2017 there was a severe snow storm in April in the Mátra mountains, causing serious forest damage. The snow density in Hungary varies from 100 to 450 kg $m^{-3}$. Snow cover in winter is important for agriculture because it provides frost protection. The largest difference in temperature between the snow surface and the soil ever observed was 24.7 °C on 15 January 1960, when the snowpack was 0.19 m thick. The maximum snow depth ever measured in Hungary was 1.46 m, measured at Kékestető station on 21 February 1963. The longest snow-covered period was 154 days, which occurred in the winter season of 1943/1944, also at Kékestető (Fig. I-2.16.2).

### Overview of measurements (OMSZ)

Snow depth: ruler, laser snow depth sensor (Figs I-2.16.3, I-2.16.4)
Depth of snowfall: no measurements
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.16.5, I-2.16.6)
Operational purpose of measurements: Agriculture and Forestry, Climatology, Flood forecasting, Health and Sport, Hydrology, Meteorology, Road services, Water management

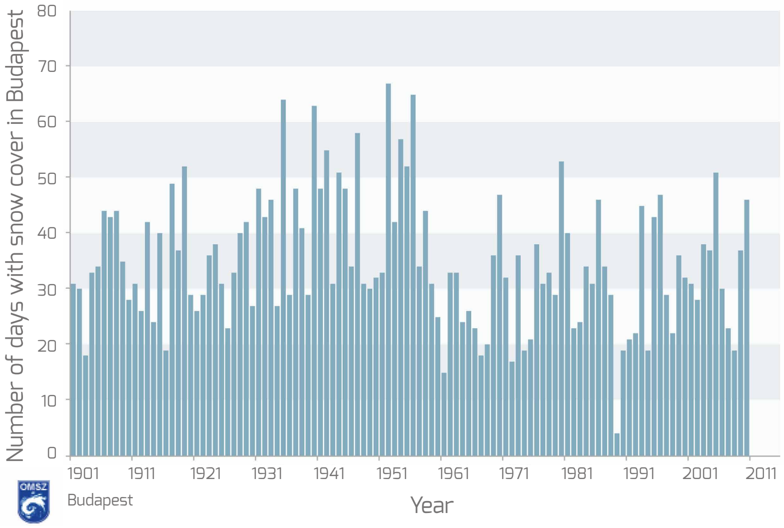

*Figure I-2.16.2 Number of days with snow cover in Budapest, shown for each year from 1901 to 2010 (Source: OMSZ).*

## I-2.16.1 Snow depth measurements

Number of stations delivering snow depth data manually: 468
Number of stations delivering snow depth data automatically: 1

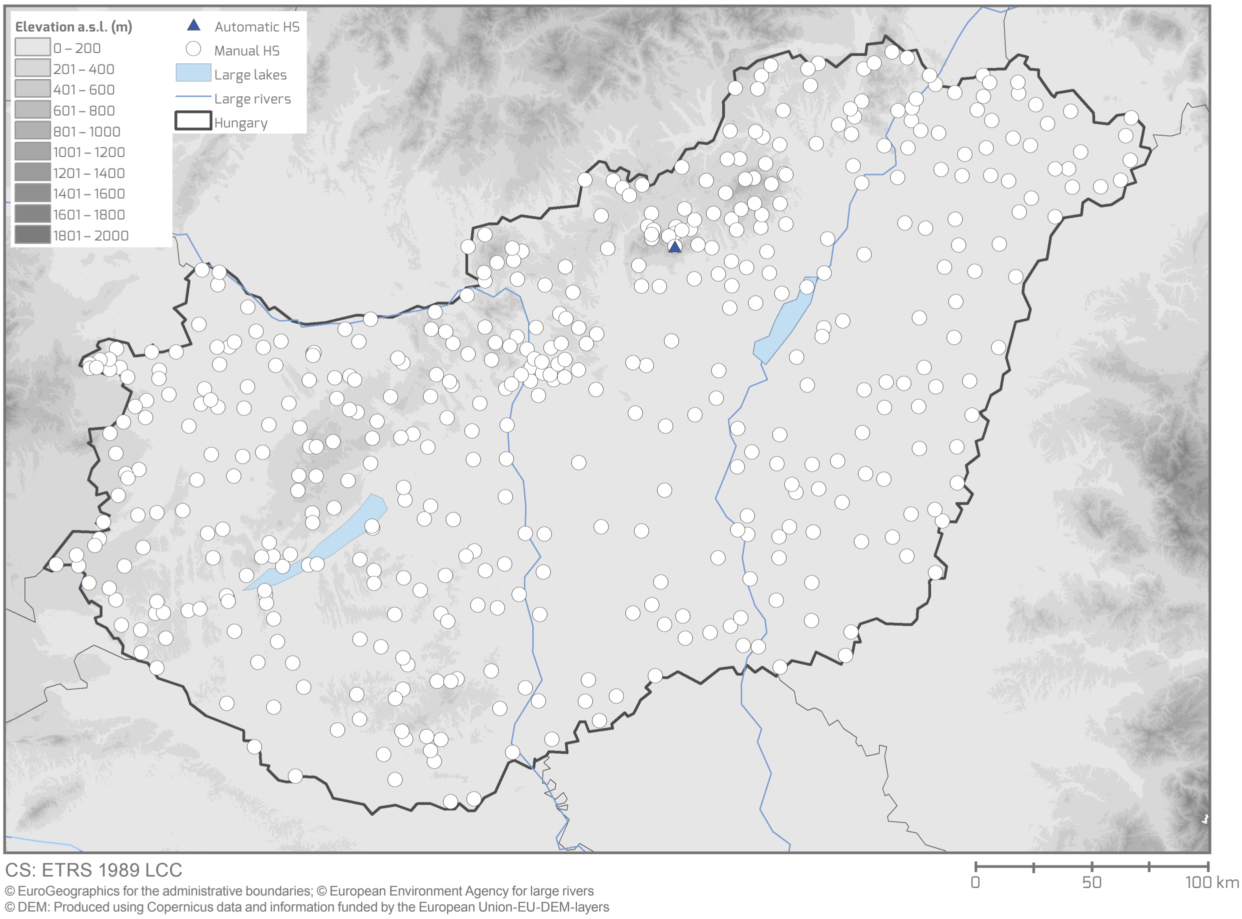

*Figure I-2.16.3 Locations of stations in Hungary where snow depth (HS) is measured.*

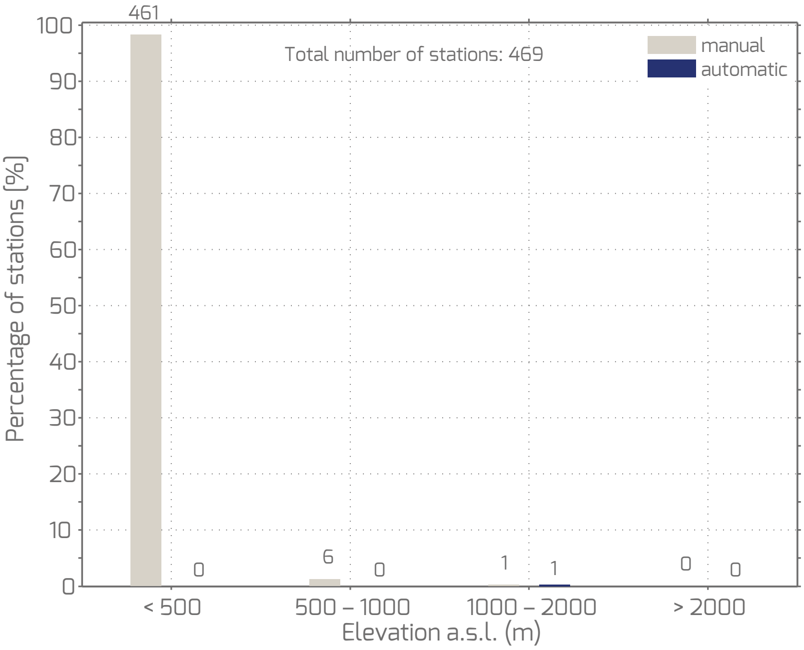

*Figure I-2.16.4 Elevational distribution of stations in Hungary with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours (449 stations), every 12 hours (12 stations) or every 6 hours (7 stations). Rulers with a scale in centimetres are used.

**Automatic measurements:**

Automatic snow depth measurements are performed every 1 minute at the WMO station Kékestető. A laser snow depth sensor mounted 2.5 m above the ground is used. No artificial target is installed below the sensor.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is not reported explicitly.

**Zero snow depth reporting method:**

Total snow depth is reported as long as the ground is covered with a continuous snowpack exceeding 1 cm depth. “Traces of snow” is reported if there is a continuous snow cover with snow depths less than 1 cm and “patchy snow cover” is reported if the snowpack is discontinuous.

## I-2.16.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.16.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 12
Number of stations delivering water equivalent of snow cover data automatically: 0

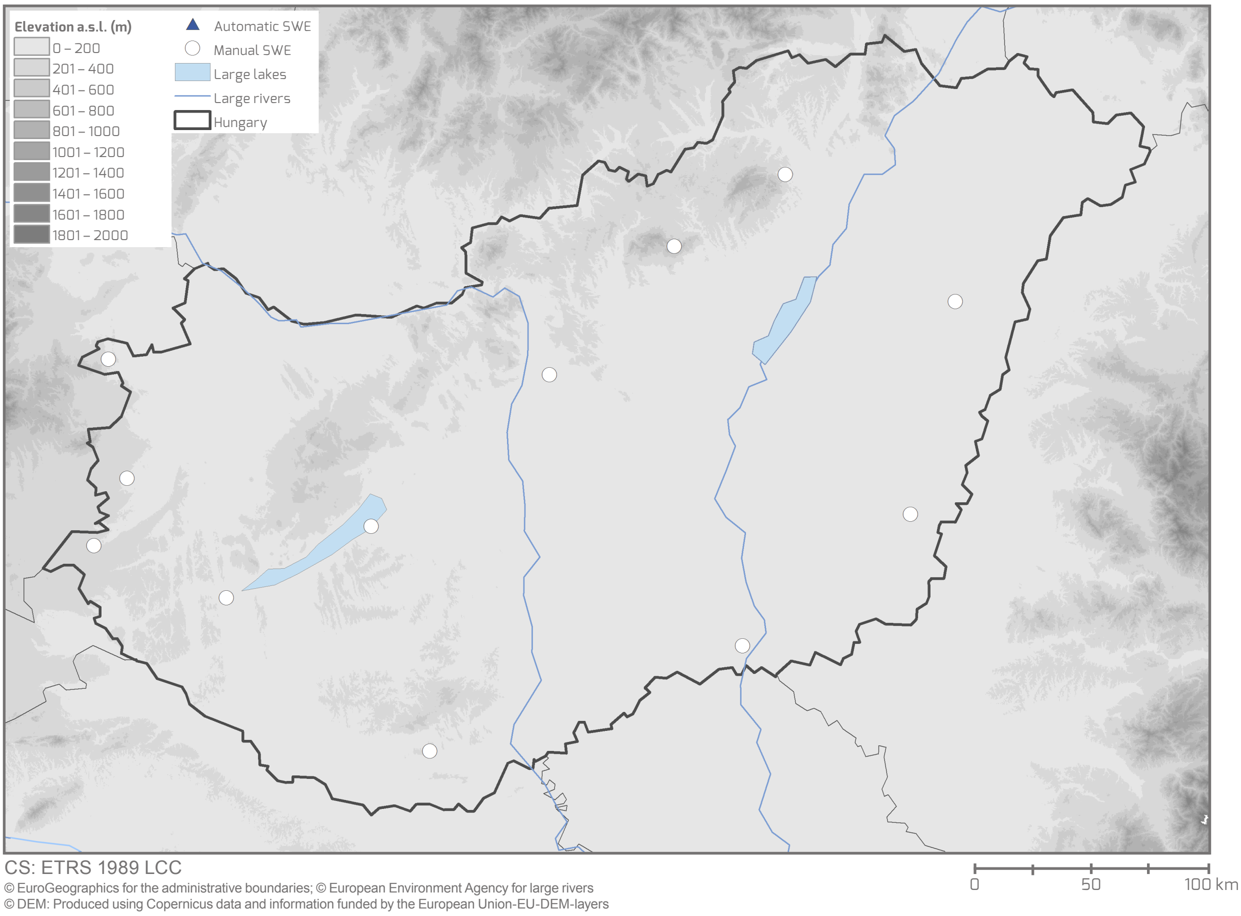

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*Figure I-2.16.5 Locations of stations in Hungary where water equivalent of snow cover (SWE) is measured.*

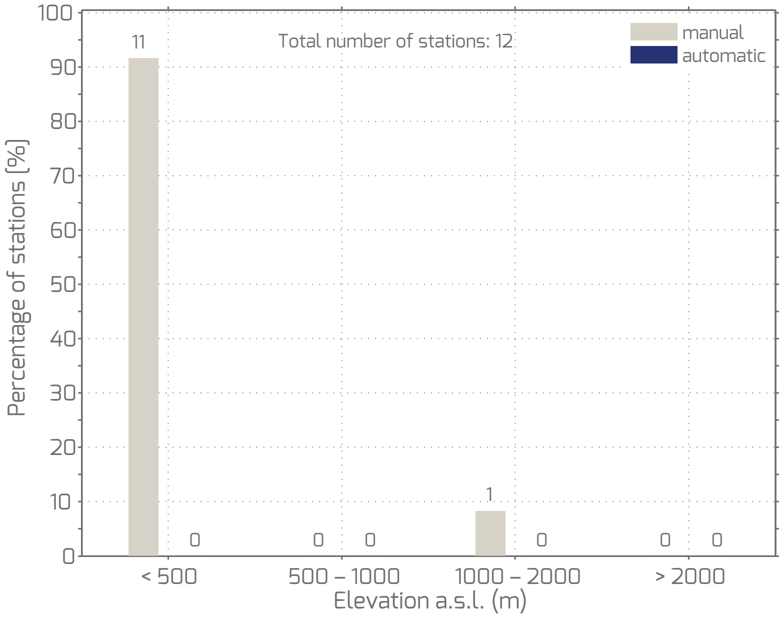

*Figure I-2.16.6 Elevational distribution of stations in Hungary with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every 24 hours for snow depths exceeding 3 cm. The gravimetric method is applied. Using a graduated iron snow cylinder with a certain cross-sectional area (in m$^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), the snow cylinder is attached to a steelyard balance to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. If the snow depth is greater than the length of the cylinder, the total snow depth is divided into multiple analogue "columns". Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

**Automatic measurements:**

No measurements.

## I-2.16.4 Transition from manual to automatic measurements

Parallel measurements have been performed for three years at Kékestető station.

## I-2.16.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 6, 12 or 24 hours (OMSZ)<br>AUTO: 1 minute (OMSZ) | MANUAL: no measurements | MANUAL: 24 hours (OMSZ)<br>AUTO: no measurements |

# I-2.17 Iceland

*Figure I-2.17.1 Location of Iceland in Europe.*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 103 000 km$^2$, 495 m a.s.l. |
| Authority responsible for snow measurements | Vedurstofa Íslands - Icelandic Meteorological Office (IMO)<br>Bústadavegi 7-9<br>IS-108 Reykjavík |
| Contact | · IMO<br>snjoflod@vedur.is (avalanche monitoring group) |
| Near-real-time data URL and/or contact | · IMO<br>http://brunnur.vedur.is/vefgogn/snjoflod/snjodypt/ (manual stake readings in mountains)<br>www.snowsense.is (manual snow depth data)<br>http://brunnur.vedur.is/athuganir/sjalfvirkar/snjodypt/ (automatic snow depth data)<br>http://www.vedur.is/vedur/athuganir/urkoma/ (manual snow depth data in lowlands) |
| Archived data URL and/or contact | · IMO<br>vedurhopur@vedur.is (data on request) |

### General situation

The Icelandic Meteorological Office (IMO) is responsible for operational snow observations in Iceland. IMO has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. IMO measures snow depth manually at 73 locations; most of them are close to the sea and none of them are in the highlands. At some of these stations only snow depth and precipitation are measured, while at other stations many different meteorological variables are observed. In addition to performing manual observations, IMO measures snow depth automatically at 23 locations, mostly in the mountains. These stations are part of the avalanche monitoring system and are located on steep slopes close to avalanche starting zones.

In addition, the IMO-affiliated avalanche warning service performs manual snow observations in steep slopes of the Icelandic mountains. Fixed stakes with a length of 4 m are used. The stakes are covered with alternating blue and white/yellow plastic stripes, each 30 cm wide. By looking through binoculars and counting the stripes that are above the snow surface, an observer roughly estimates snow depth. This manual stake network of the avalanche warning service is not included in this report.

Not only snow depth, but also water equivalent of snow cover is manually measured in various mountainous regions by the IMO-affiliated avalanche warning service. Observers measure water equivalent of snow cover in snow pits two times per winter (around 15 February and 15 April). Water equivalent of snow cover is calculated from bulk snow density, which is measured in 0.2 m intervals from the snow surface to the ground in snow pits. In Iceland, the snow depth distribution is strongly variable and snow depths can be as much as 5 m. The water equivalent of snow cover measurement locations of the avalanche warning service are not included here because 14 locations are only occasionally used and only 5 locations are operational.

In addition to IMO, the National Power Company of Iceland, Landsvirkjun (landsvirkjun@landsvirkjun.is), operationally measures snow. Snow depth is measured manually at 35 stations and automatically at 14 stations, while water equivalent of snow cover is measured manually at 6 stations and automatically at 3 stations. However, the operational snow network of Landsvirkjun is not included in this country report because of restrictions on sharing station data and metadata.

Only the operational snow measurement network of IMO, including manual and automatic snow depth measurements and observations of presence of snow on the ground, is included in this country report. Depth of snowfall is not observed, owing to strong winds and consequently spatially highly variable measurements.

### Overview of measurements (IMO)

Snow depth: stake, ruler, ultrasonic snow depth sensor, laser snow depth sensor, radar sensor, snow temperature sensor (Figs I-2.17.2, I-2.17.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: no measurements
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Flood forecasting, Health and Sport, Hydrology, Meteorology, Road services, Water management

## I-2.17.1 Snow depth measurements

Number of stations delivering snow depth data manually: 73
Number of stations delivering snow depth data automatically: 23

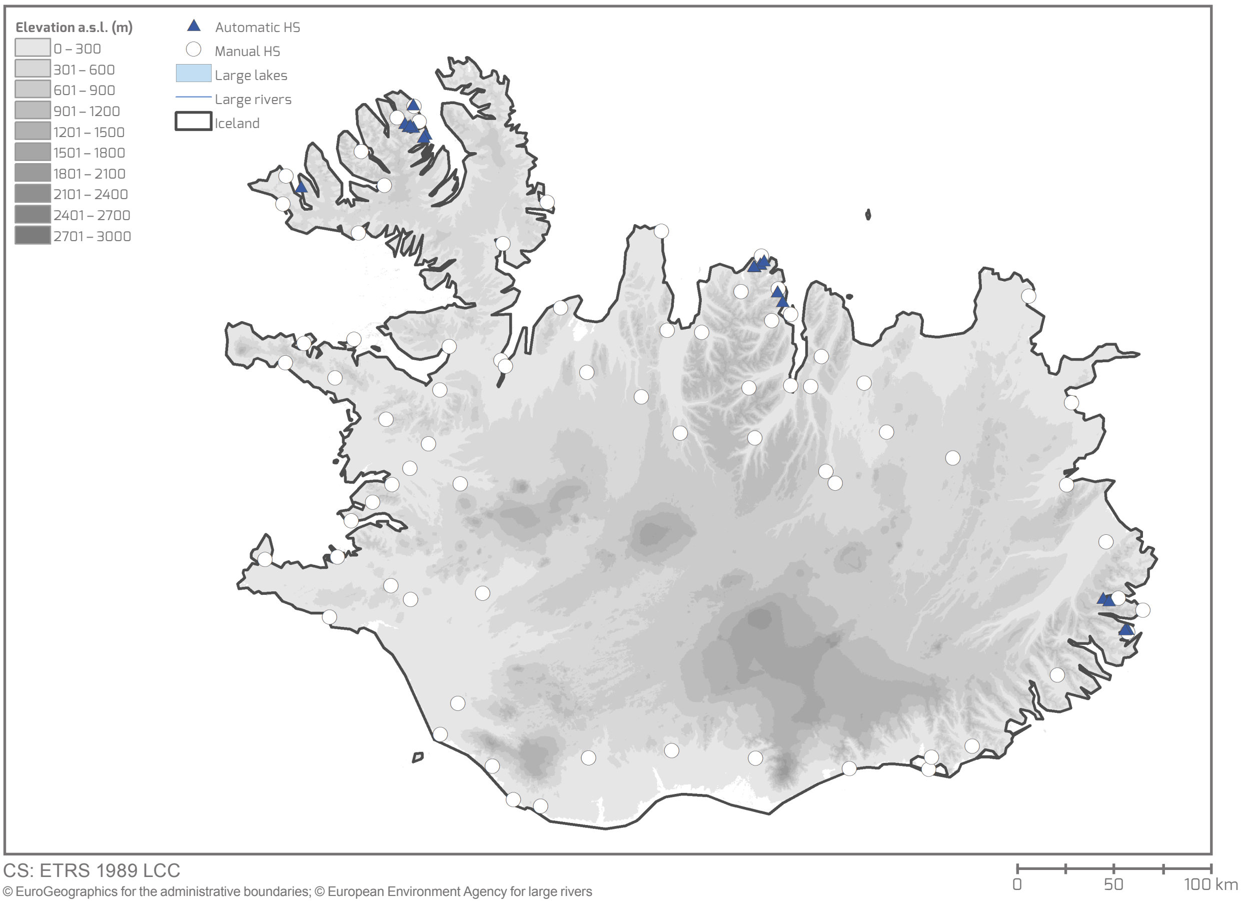

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*Figure I-2.17.2 Locations of stations in Iceland where snow depth (HS) is measured.*

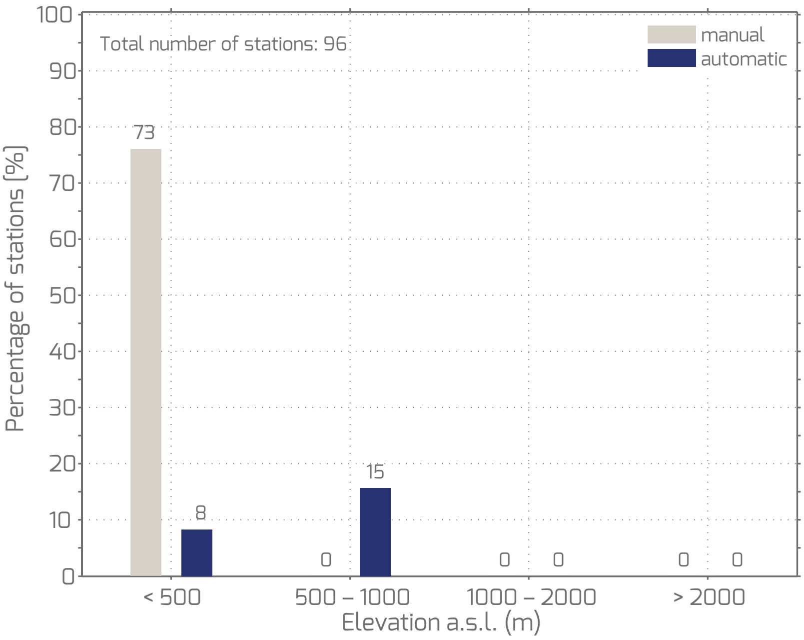

*Figure I-2.17.3 Elevational distribution of stations in Iceland with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours. Either fixed stakes or portable rulers are used, depending on whether the location is exposed to the wind. Fixed stakes with a scale in centimetres are only used if snow depth is measured in a sheltered and representative area with a uniform snow depth distribution. Although areas with strong winds, and consequently substantial snow drift and snow erosion, should be avoided for snow depth measurements, this is often not possible in Iceland. Thus, in wind-affected areas rulers with a scale in centimetres are used to measure snow depth at 5–10 points in order to account for the spatially variable snow depth distribution. The average of these measurements is reported as total snow depth. Total snow depth is also reported when there is a discontinuous snow cover, in which case a rough estimate from the observer is reported. Measured values are reported in full centimetres.

**Automatic measurements:**

Automatic snow depth measurements are performed either every 10 or every 60 minutes. Different sensor types are used: at 6 locations ultrasonic, radar or laser snow depth sensors are used to measure snow depth every 60 minutes, and at the remaining 17 automatic stations snow depth is measured every 10 minutes using snow temperature sensors (SM4) developed by POLS Engineering (Isafjordur, Iceland). The SM4 sensor is a cable on which thermistors with a fixed interval are mounted. Thus, snow depth is indirectly derived from a temperature profile based on an algorithm, as described in various publications (Ingólfsson and Grímsdóttir, 2008; Ingólfsson et al., 2012; Jónsson et al., 2014). Basically, the snow depth assessment relies on the distinction between measurements from sensors in the air and those from sensors buried in snow: the temperature profile of a snow-covered sensor is dampened, while the temperature profile of a snow-free sensor fluctuates strongly and follows air temperature.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is reported explicitly by IMO in parallel to manual snow depth measurements. IMO observers report whether the ground is (1) snow covered, (2) snow free or (3) covered with patches of snow.

**Zero snow depth reporting method:**

When more than 50% of the measurement field is snow free, 0 cm snow depth is reported.

## I-2.17.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.17.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 0

**Manual measurements:**

No measurements.

**Automatic measurements:**

No measurements.

## I-2.17.4 Transition from manual to automatic measurements

IMO stations are not yet affected by station shifts because all automatic snow depth sensors are located in mountainous regions where manual stations have never been operated.

## I-2.17.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (IMO) | MANUAL: no measurements | MANUAL: no measurements |
| AUTO: 10 or 60 minutes (IMO) | | AUTO: no measurements |

# I-2.18 Ireland

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*Figure I-2.18.1 Location of Ireland in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 69 797 km², 108 m a.s.l. |
| Authority responsible for snow measurements | Irish Meteorological Service (Met Éireann)<br>65/67 Glasnevin Hill<br>D09 Y921<br>IE-9 Dublin |
| Contact | · Met Éireann<br>david.fitzgerald@met.ie (David Fitzgerald) |
| Near-real-time data URL and/or contact | · Met Éireann<br>Not available. |
| Archived data URL and/or contact | · Met Éireann<br>enq@met.ie<br>www.met.ie |

## General situation

The Irish Meteorological Service (Met Éireann) is responsible for operational snow observations in Ireland. Snow depth and depth of snowfall are manually measured at Met Éireann's network of precipitation stations. Snow depth is measured automatically in operational mode at five Irish airports. Met Éireann follows WMO guidelines (WMO No. 8, 2008). In addition to running the current operational network, Met Éireann is currently installing and testing laser snow depth sensors (SHM 31; Lufft, Fellbach, Germany) at automatic synoptic stations, and nine of these sensors have been installed to date (Fig. I-2.18.2). These sensors are currently in a test phase and hourly data is only available for internal use; therefore, the system is not included in this country report. As snow is extremely rare in Ireland, datasets are limited.

## Overview of measurements (Met Éireann)

Snow depth: ruler, laser snow depth sensor (Figs I-2.18.3, I-2.18.4)
Depth of snowfall: ruler (Figs I-2.18.5, I-2.18.6)
Water equivalent of snow cover: no measurements
Operational purpose of measurements: Climatology, Meteorology

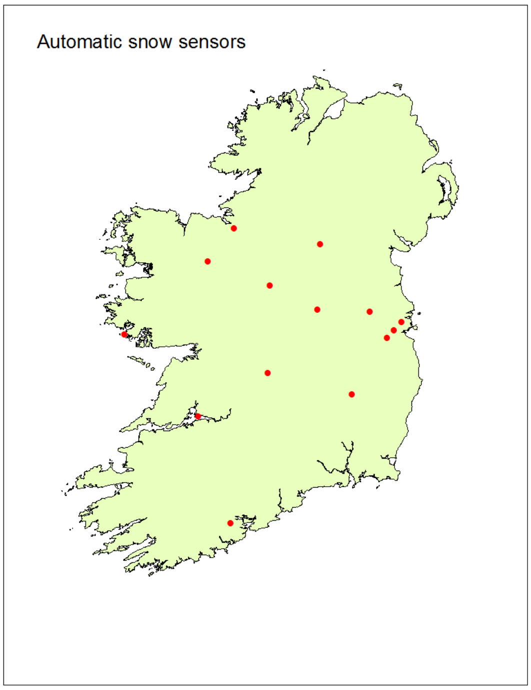

*Figure I-2.18.2 Locations of the five operational snow depth sensors at Irish airports and of the nine new laser snow depth sensors (SHM 31), which currently are in a test phase and only available for internal use (Source: Met Éireann).*

## I-2.18.1 Snow depth measurements

Number of stations delivering snow depth data manually: 5
Number of stations delivering snow depth data automatically: 5

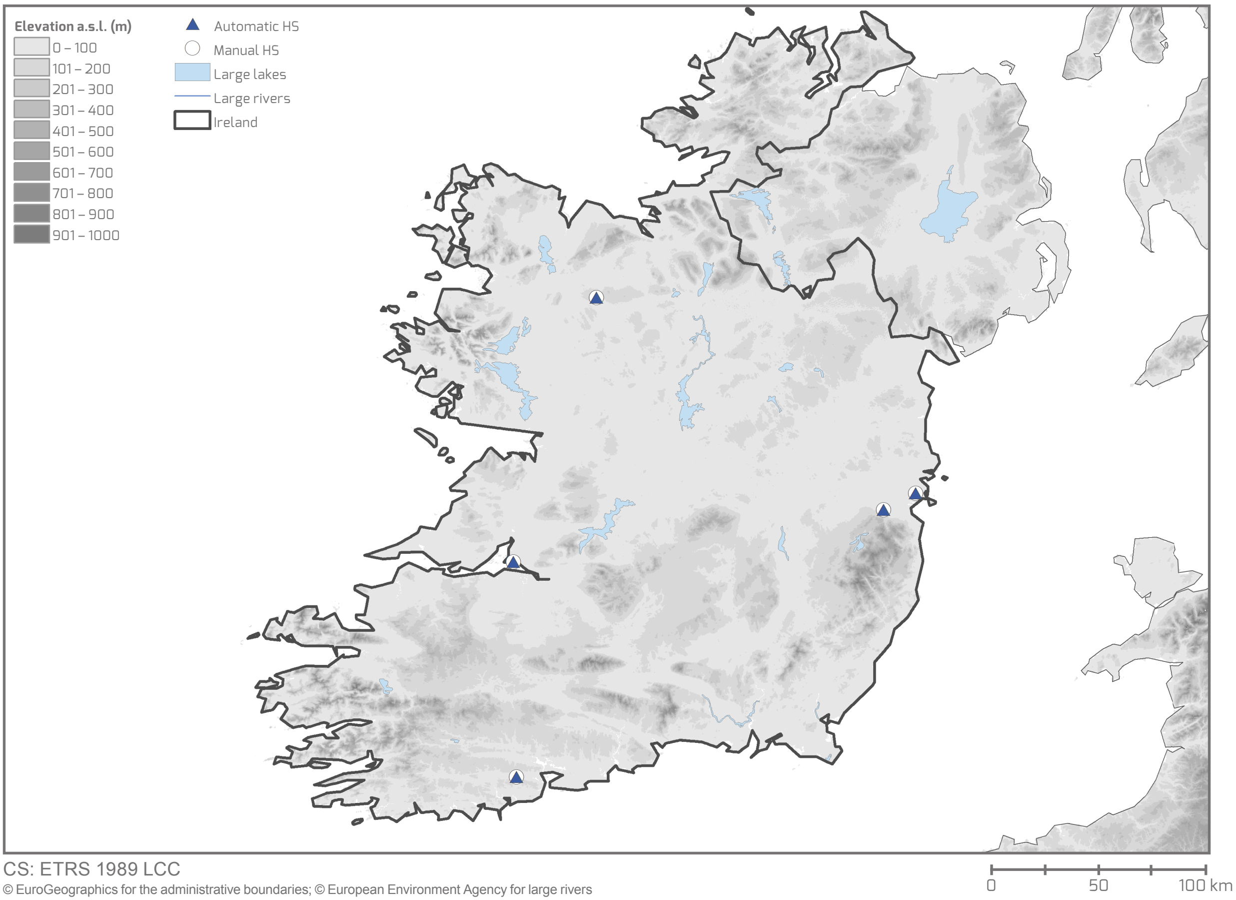

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*Figure I-2.18.3 Locations of stations in Ireland where snow depth (HS) is measured.*

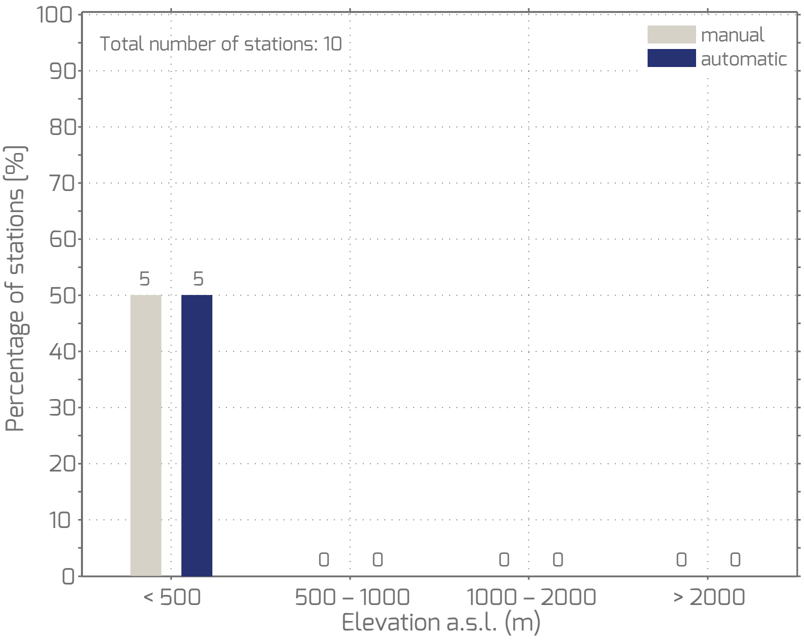

*Figure I-2.18.4 Elevational distribution of stations in Ireland with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every hour and are reported in the SYNOP report. Portable rulers with a scale in centimetres are used. The potential presence of snow drifts is accounted for because several snow depth measurements are performed within a measurement field, and the average of all measurements is reported as total snow depth.

**Automatic measurements:**

Automatic snow depth measurements are performed every minute using laser snow depth sensors. Snow depth data is only stored in the rare case of snowfall.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is not reported explicitly.

**Zero snow depth reporting method:**

Not reported.

## I-2.18.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 5

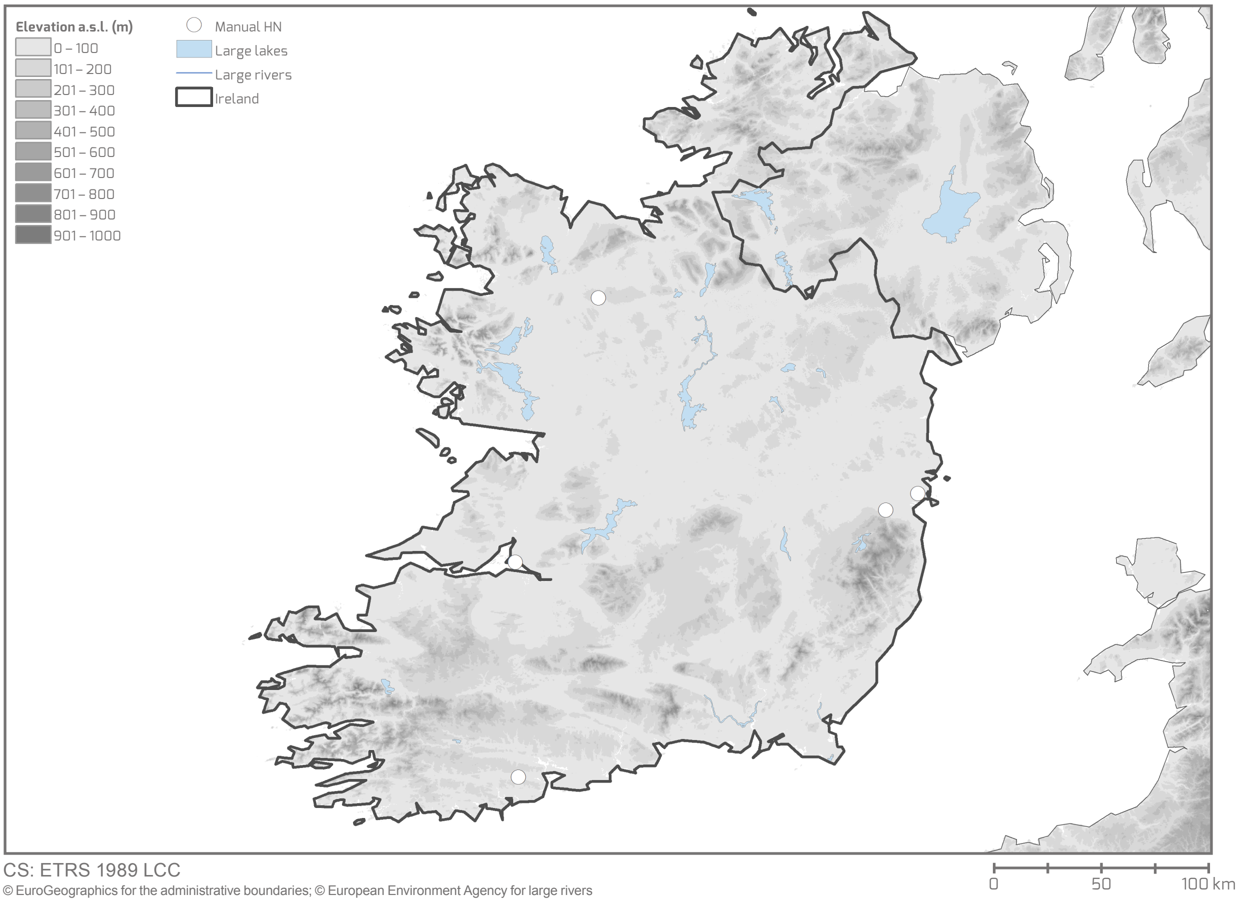

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*Figure I-2.18.5 Locations of stations in Ireland where depth of snowfall (HN) is measured.*

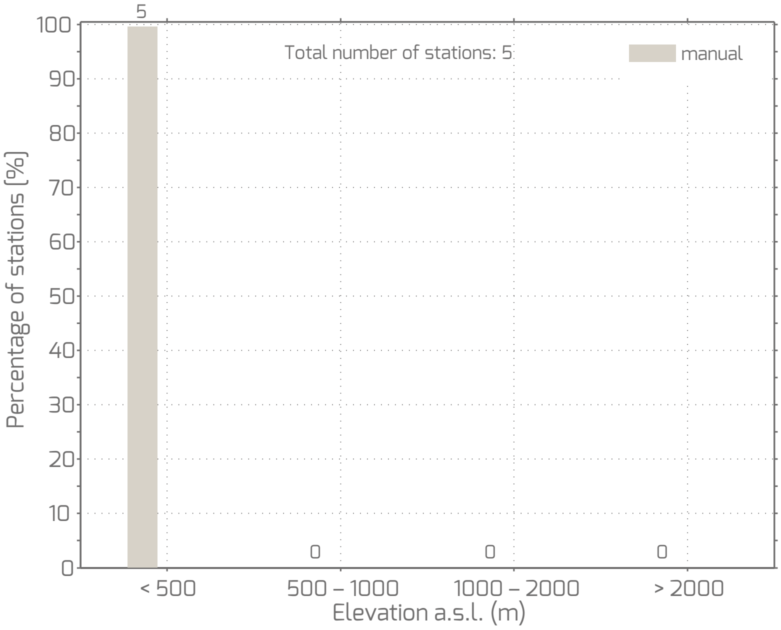

*Figure I-2.18.6 Elevational distribution of stations in Ireland with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual depth of snowfall measurements are performed every hour and reported in the SYNOP report. Depth of snowfall is measured on open ground using a graduated ruler with a scale in centimetres.

## I-2.18.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 0

**Manual measurements:**

No measurements.

**Automatic measurements:**

No measurements.

## I-2.18.4 Transition from manual to automatic measurements

The shift from manual to automatic measurements has not been completed to date.

## I-2.18.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 1 hour (Met Éireann)<br>AUTO: 1 minute (Met Éireann) | MANUAL: 1 hour (Met Éireann) | MANUAL: no measurements<br>AUTO: no measurements |

# I-2.19 Italy

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*Figure I-2.19.1 Location of Italy in Europe.*

# I-2.19 Italy

## Country information

| | |
|---|---|
| Country area, mean country elevation | 302 073 km$^2$, 534 m a.s.l. |
| Authority responsible for snow measurements | Nation-wide:<br>Meteomont Carabinieri – Snow and Avalanche Forecast (MC) National Service<br>Viale Romania 45<br>IT-00197 Roma<br><br>Autonomous Province of Bolzano-South Tyrol:<br>Hydrographic Office (HAB)<br>Drususallee 116<br>IT-39100 Bozen<br><br>Autonomous Region of Friuli Venezia Giulia:<br>Corpo Forestale Regionale SSC Valanghe (SSCV)<br>Via Sabbadini 31<br>IT-33100 Udine<br><br>Region of Lombardy:<br>Agenzia Regionale per la Protezione dell'Ambiente Lombardia (ARPAL)<br>Centro Nivometeorologico<br>Via Monte Confinale 9<br>IT-23032 Bormio<br><br>Region of Piemonte:<br>Agenzia Regionale per la Protezione dell'Ambiente Piemonte (ARPAP)<br>Dipartimento Sistemi Previsionali<br>Via Pio VII 9<br>IT-10135 Torino<br><br>Autonomous Province of Trento:<br>Provincia Autonoma di Trento (PAT)<br>Piazza Dante 15<br>IT-38122 Trento<br><br>Autonomous Region of Valle d'Aosta :<br>Fondazione Montagna sicura -ufficio valanghe (FMS)<br>Villa Cameron<br>Località Villard de la Palud 1<br>IT-11013 Courmayeur<br>and<br>Centro Funzionale Regione Autonoma Valle d'Aosta (RAVA)<br>Via Promis 2A<br>IT-11100 Aosta<br>and<br>Agenzia Regionale per la Protezione dell'Ambiente della Valle d'Aosta/<br>Environmental Protection Agency of Aosta Valley (ARPAVA)<br>Loc. Grande Charrière 44<br>IT-11020 Saint-Christophe<br><br>Region of Veneto:<br>Agenzia Regionale per la Protezione dell'Ambiente Veneto (ARPAV)<br>Avalanche Center Arabba<br>Via Pradat 5<br>IT-32020 Arabba |

| | |
|---|---|
| Contact | · MC<br>meteomont@carabinieri.it<br>· HAB<br>hydro@provinz.bz.it<br>· SSCV<br>neve.valanghe@regione.fvg.it<br>· ARPAL<br>nivometeo@arpalombardia.it<br>· ARPAP<br>info.meteo@arpa.piemonte.it<br>· PAT<br>ufficio.previsioni@provincia.tn.it<br>· FMS/RAVA<br>pdellavedova@fondms.org (Paola Dellavedova)<br>u-idrografico@regione.vda.it<br>· ARPAVA<br>u.morradicella@arpa.vda.it (Umberto Morra Di Cella)<br>· ARPAV<br>cva@arpa.veneto.it |
| Near-real-time data URL and/or contact | · MC<br>www.meteomont.gov.it<br>· HAB<br>http://wetter.provinz.bz.it/wetterstationen.asp<br>· SSCV<br>Not available.<br>· ARPAL<br>Not available.<br>· ARPAP<br>http://webgis.arpa.piemonte.it/meteoidro_webapp/<br>· PAT<br>http://www.meteotrentino.it/<br>· FMS/RAVA<br>http://cf.regione.vda.it/mappe_neve.php#prettyPhoto<br>· ARPAVA<br>http://www.arpa.vda.it/it/effetti-sul-territorio-dei-cambiamenti-climatici/neve/swe<br>· ARPAV<br>http://www.arpa.veneto.it/bollettini/meteo/h24/img20/Mappa_LIVNEVE.htm?x=20141 |
| Archived data URL and/or contact | · MC<br>meteomont@carabinieri.it (on request)<br>· HAB<br>carmen.oberparleiter@provinz.bz.it (Carmen Oberparleiter)<br>· SSCV<br>daniele.moro@regione.fvg.it (Daniele Moro)<br>· ARPAL<br>http://www.arpalombardia.it/siti/arpalombardia/meteo/richiesta-dati-misurati/Pagine/RichiestaDatiMisurati.aspx<br>· ARPAP<br>https://www.arpa.piemonte.it/rischinaturali/accesso-ai-dati/annali_meteoidrologici/annali-meteo-idro/banca-dati-meteorologica.html<br>https://www.arpa.piemonte.gov.it/dati-ambientali/dati-meteoidrografici-giornalieri-richiesta-automatica |

- PAT
  ufficio.previsioni@provincia.tn.it
- FMS/RAVA
  u-idrografico@regione.vda.it (RAVA)
  u-valanghe@regione.vda.it (FMS)
- ARPAVA
  http://www.arpa.vda.it/it/effetti-sul-territorio-dei-cambiamenti-climatici/neve/swe
  u.morradicella@arpa.vda.it (Umberto Morra Di Cella)
- ARPAV
  mauro.valt@arpa.veneto.it, mauro.valt@gmail.com (Mauro Valt)

## General situation

In Italy, operational snow observations are conducted at both the national and regional level. Meteomont Carabinieri (MC) is a National Service in charge of operational snow observations in Italy. In addition, the Servizio Meteorologico dell'Aeronautica Militare might perform national operational snow observations, but no contact could be established and therefore no station information is available. The Italian Interregional Association of Snow and Avalanches (AINEVA) is a non-government, not-for-profit corporation that serves as Italy's coordination structure of regional agencies for public avalanche safety and forecasting services. AINEVA's responsibilities include: (1) coordinating public avalanche safety programmes, (2) providing public avalanche safety warnings, (3) delivering public avalanche awareness and education, (4) providing avalanche training for professional and non-professional winter recreationists, (5) serving as the point of contact for public, private and government avalanche information, (6) leading and encouraging research in Italy, and (7) supporting, as a competence centre, the National Department of Civil Protection before, during and after the management of avalanche emergencies. Eight alpine regions and provinces are members of AINEVA: Piemonte Region (ARPAP), Valle d'Aosta Region (ARPAVA, FMS/RAVA), Lombardia Region (ARPAL), Autonomous Province Trento (PAT), Autonomous Province Bolzano (HAB), Veneto Region (ARPAV), Friuli Venezia Giulia Region (SSCV), and Apenninic Marche Region (CFMM). Depending on the region, one or several institutions operationally measure snow:

- Across Italy: Meteomont Carabinieri (MC)
- Across Italy: Servizio Meteorologico dell'Aeronautica Militare (national meteorological service, organisational unit of the Italian Air Force); snow observations might be performed but no contact was established
- In the Autonomous Province of Bolzano in South Tyrol: the Hydrographic Office (HAB)
- In the Autonomous Province of Friuli Venezia Giulia: the Corpo Forestale Regionale SSC Valanghe (SSCV)
- In the Region of Lombardy: the Centro Nivometeorologico ARPA Lombardia (ARPAL)
- In the Region of Marche (Apennines): an avalanche warning service performs operational snow observations, but its data was not available for this country report
- In the Region of Piemonte: the Dipartimento Sistemi Previsionali ARPA Piemonte (ARPAP)
- In the Autonomous Province of Trento: the Provincia Autonoma di Trento (PAT)
- In the Autonomous Region of Valle d'Aosta: the Fondazione Montagna sicura – ufficio valanghe (FMS) and the Centro Funzionale Regionale (RAVA; manages all automatic stations), as well as the Environmental Protection Agency – ARPA Valle d'Aosta (ARPAVA; in charge of water equivalent of snow cover measurements)
- Region of Veneto: the Avalanche Center Arabba – ARPA Veneto (ARPAV)

Most snow stations are located in the mountainous northern part of Italy. Moreover, most of the above-mentioned institutions are in charge of regional avalanche forecasting and thus most of their stations are located in the mountains. The number of snow observation stations varies for all institutions, and the numbers given in this country report should therefore be considered estimates only.

In the mountainous regions further south, Meteomont Carabinieri operates snow stations, most of which include only manual measurements and are located at high elevations. Besides manual snow depth, depth of snowfall and water equivalent of snow cover measurements, daily weather observations are performed at all 161 manual MC measurement sites. Additional measurements include wind speed and direction, minimum and maximum air temperature, snow temperature in different layers, snow density, and snow surface characteristics. Only 10 automatic weather stations (AWS) are operated by MC; in addition to measuring snow depth, they measure wind speed and direction, air temperature, humidity, barometric pressure and precipitation intensity, as well as temperature every 10 to 20 cm depth to characterise the vertical temperature gradient in the snowpack.

Within the PAT network, several manual and automatic snow stations are operated by ski resorts (e.g. Marmolada, Duron Pass, Caoria). However, these stations might be closed soon because data is not recorded regularly and depends on when the ski resorts open. In a given ski resort, measurement locations (automatic and manual) sometimes even change within one winter season, depending on the needs of the avalanche warning service. Therefore, the reliability of long-term data records from ski resorts is questionable. In addition to conducting snow depth measurements, PAT measures water equivalent of snow cover annually during glacier surveys, using snow tubes for snow course measurements, at the time of maximum snow accumulation in spring. However, these stations are not considered in this report.

ARPAVA coordinates the manual water equivalent of snow cover observation network of several institutions in Valle d'Aosta. In this region, water equivalent of snow cover is measured by the following institutions and groups: ARPAVA, the army, dam guardians, forest rangers (Corpo Forestale della Valle d'Aosta), and national park rangers (Mont Avic Natural Parc observers). The obtained water equivalent of snow cover data is shared with all regional institutions interested in snow monitoring in Valle d'Aosta. In addition to conducting weekly operational water equivalent of snow cover observations, ARPAVA is involved in four other large water equivalent of snow cover measurement campaigns which are not included in this country report: (1) At the time of maximum snow accumulation, ARPAVA is in charge of specific field campaigns to measure water equivalent of snow cover in five catchments with a total area of around 300 km$^2$ for hydropower production optimisation. Water equivalent of snow cover measurements are performed along snow courses using snow tubes. (2) ARPAVA has been involved in glacier mass balance monitoring at three regional glaciers since 2000. For this reason, specific annual field campaigns are carried out at the time of maximum snow depth in spring to measure water equivalent of snow cover of the winter snow accumulation. Either snow tubes and electronic scales or automatic ground-penetrating radar instruments are used. (3) Since 2015, ARPAVA has coordinated a water equivalent of snow cover intercomparison with a special focus on measurement aspects, such as methods, uncertainty and spatial variability. In the framework of this project, the snow tube Enel-Valtecne (Section I-2.19.3) has been developed. (4) ARPAVA models water equivalent of snow cover evolution distributed over the whole region using weekly measurements of snow density and water equivalent of snow cover, automatically measured snow depth, and satellite data of the snow-covered area (MODIS snow-covered area standard product) in order to support hydropower production planning (Compagnia Valdostana delle Acque SpA).

In Table I-2.19.1, the institutions in charge of operational snow observations and the corresponding station counts are shown. The MC, HAB, SSCV, ARPAL, ARPAP, PAT, FMS/RAVA, ARPAVA and ARPAV snow measurement networks are all discussed below.

*Table I-2.19.1 Number of manual (man) and automatic (auto) stations operated by institutions in different Italian regions (see above for full institution names). Measurements include snow depth (HS), depth of snowfall (HN) and water equivalent of snow cover (SWE). The observation of presence of snow on the ground (PSG) is indicated with "✓" for yes and "×" for no.*

| Institution | HS man | HS auto | HN man | SWE man | SWE auto | PSG |
|---|---|---|---|---|---|---|
| MC | 161 | 10 | 161 | 161 | 0 | ✓ |
| HAB | 90 | 21 | 90 | 22 | 0 | × |
| SSCV | 14 | 59 | 14 | 14 | 0 | ✓ |
| ARPAL | 31 | 45 | 31 | 0 | 0 | × |
| ARPAP | 34 | 77 | 34 | 4 | 2 | × |
| PAT | 52 | 33 | 52 | 52 | 0 | ✓ |
| FMS/RAVA | 37 | 31 | 37 | 0 | 0 | × |
| ARPAVA | 0 | 4 | 0 | 87 | 1 | ✓ |
| ARPAV | 22 | 20 | 22 | 39 | 0 | × |

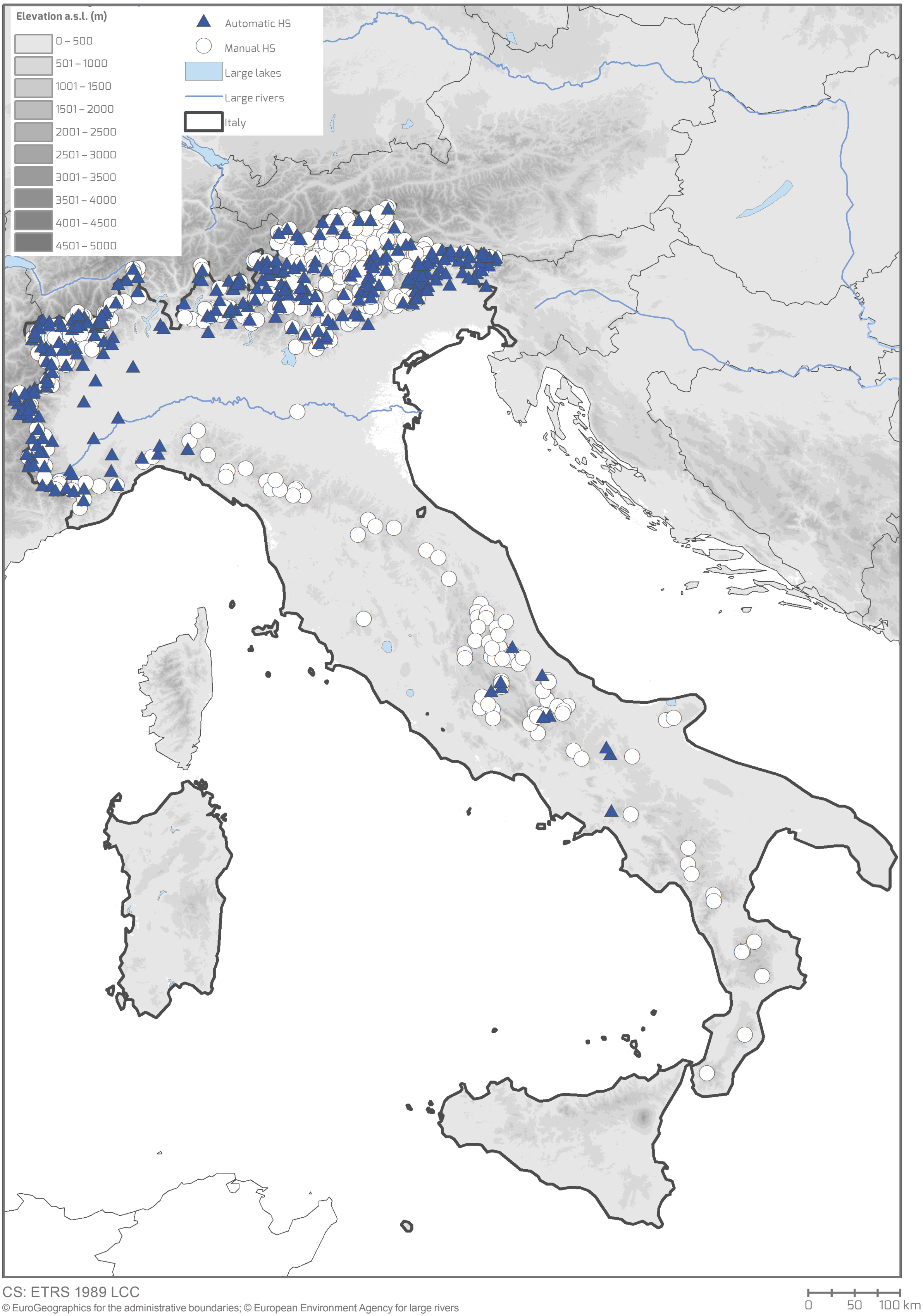
### Overview of measurements (MC, HAB, SSCV, ARPAL, ARPAP, PAT, FMS/RAVA, ARPAVA, ARPAV)

Snow depth: stake, ruler, ultrasonic snow depth sensor (Figs I-2.19.2, I-2.19.3)
Depth of snowfall: snow board and ruler (Figs I-2.19.11, I-2.19.12)
Water equivalent of snow cover: snow cylinder, snow tube, spring scale, electronic scale, snow pillow, passive gamma radiation sensor (Figs I-2.19.13, I-2.19.14)

Operational purpose of measurements: Avalanche warning, Climatology, Flood forecasting, Health and Sport, Hydrology, Hydropower production, Meteorology, Road services, Water management

## I-2.19.1 Snow depth measurements

Number of stations delivering snow depth data manually: 441
Number of stations delivering snow depth data automatically: 300



CS: ETRS 1989 LCC
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© DEM: Produced using Copernicus data and information funded by the European Union-EU-DEM-layers

*Figure I-2.19.2 Locations of stations in Italy where snow depth (HS) is measured.*

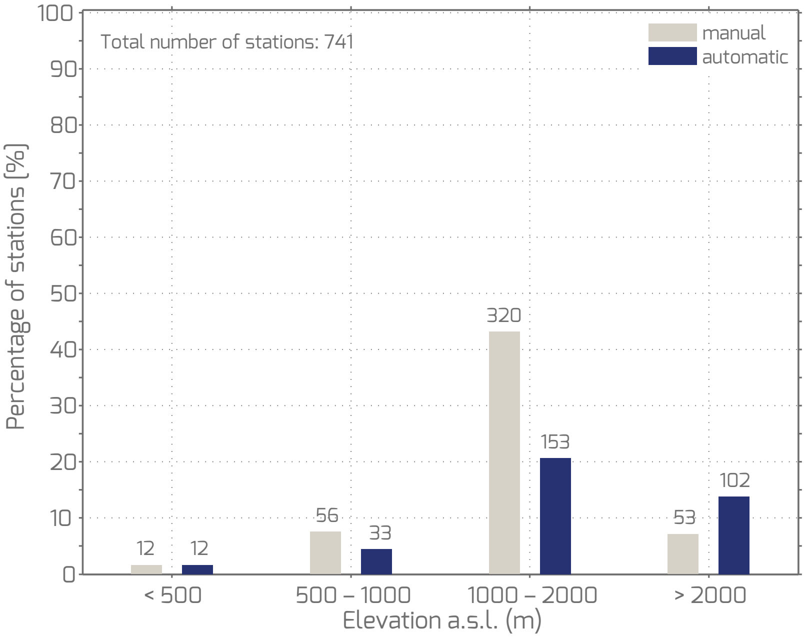

*Figure I-2.19.3 Elevational distribution of stations in Italy with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Apart from ARPAVA, all institutions (MC, HAB, SSCV, ARPAL, ARPAP, PAT, FMS/RAVA, ARPAV) measure snow depth manually (Table I-2.19.1). Manual snow depth measurements are performed every 24 hours between 0600 and 0800 UTC, except for at 21 ARPAV stations, where manual snow depth measurements are performed every five days when no new snowfall events have occurred, at 0730 UTC in cases of new snowfall, and on the third day after a snowfall event. Either fixed stakes (HAB, SSCV, ARPAL, ARPAP, PAT, ARPAV) or portable rulers (MC, FMS/RAVA) with a scale in centimetres are used (Figs I-2.19.4, I-2.19.5). The observers avoid creating disturbances in the measurement field around the stake. To prevent incorrect measurements, values are read as horizontally to the surface as possible. Measured values are reported in full centimetres.

Measurement field sizes vary among institutions: approximately 6 x 9 m at MC stations; non-standardised at HAB stations; 4 x 4 m at SSCV stations; between 20 and 30 m$^2$ at PAT stations; 6 x 10 m at ARPAV stations; and unknown at ARPAL, ARPAP and FMS/RAVA stations.

HAB, SSCV, ARPAP, PAT, FMS/RAVA and ARPAV report total snow depth as long as the measurement field is fully snow covered and snow is still present at the stake. In contrast, MC reports total snow depth as long as more than 50% of the measurement field is snow covered.

### Automatic measurements:

All institutions (MC, HAB, SSCV, ARPAL, ARPAP, PAT, FMS/RAVA, ARPAVA, ARPAV) measure snow depth automatically (Table I-2.19.1). Automatic snow depth measurements are performed every 10 minutes (HAB), every 15 minutes (ARPAL, PAT), every 30 minutes (SSCV, ARPAP, ARPAV) or every 60 minutes (MC, FMS/RAVA, ARPAVA). Ultrasonic snow depth sensors are used by all institutions (Figs I-2.19.6 – I-2.19.9). Snow depth sensors are mounted 4–6 m above the ground.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported explicitly by MC, SSCV, PAT and ARPAVA. ARPAVA operates webcams at two of its four AWS locations (Torgnon Tellinod and Torgnon Tronchaney) and derives presence of snow on the ground from pixel counts of the webcam images (Fig. I-2.19.10). Presence of snow on the ground is not explicitly reported by HAB, ARPAL, ARPAP, FMS/RAVA or ARPAV.

### Zero snow depth reporting method:

HAB, SSCV, ARPAP, PAT, FMS/RAVA, ARPAVA and ARPAV report 0 cm snow depth if there is a discontinuous snow cover within a measurement field or if no snow is present at the stake. Only FMS/RAVA and ARPAV note whether patchy snow is still visible in the measurement field. In contrast, MC reports 0 cm snow depth when more than 50% of the measurement field (6 x 9 m) is snow free, even if there is still some snow at the stake itself.

*Figure I-2.19.4 Manual measurement field operated by MC, with a snow stake and a freshly placed snow board (Source: MC).*

*Figure I-2.19.5 Manual snow measurement field operated by SSCV in the region Friuli Venezia Giulia, Italy (Source: SSCV).*

*Figure I-2.19.6 Automatic weather station operated by MC, with an ultrasonic snow depth sensor (Source: MC).*

*Figure I-2.19.7 Automatic weather station operated by SSCV in the region Friuli Venezia Giulia, Italy, with an ultrasonic snow depth sensor (Source: SSCV).*

*Figure I-2.19.8 Automatic weather station operated by ARPAV in Veneto, Italy, with an ultrasonic snow depth sensor (Source: ARPAV).*

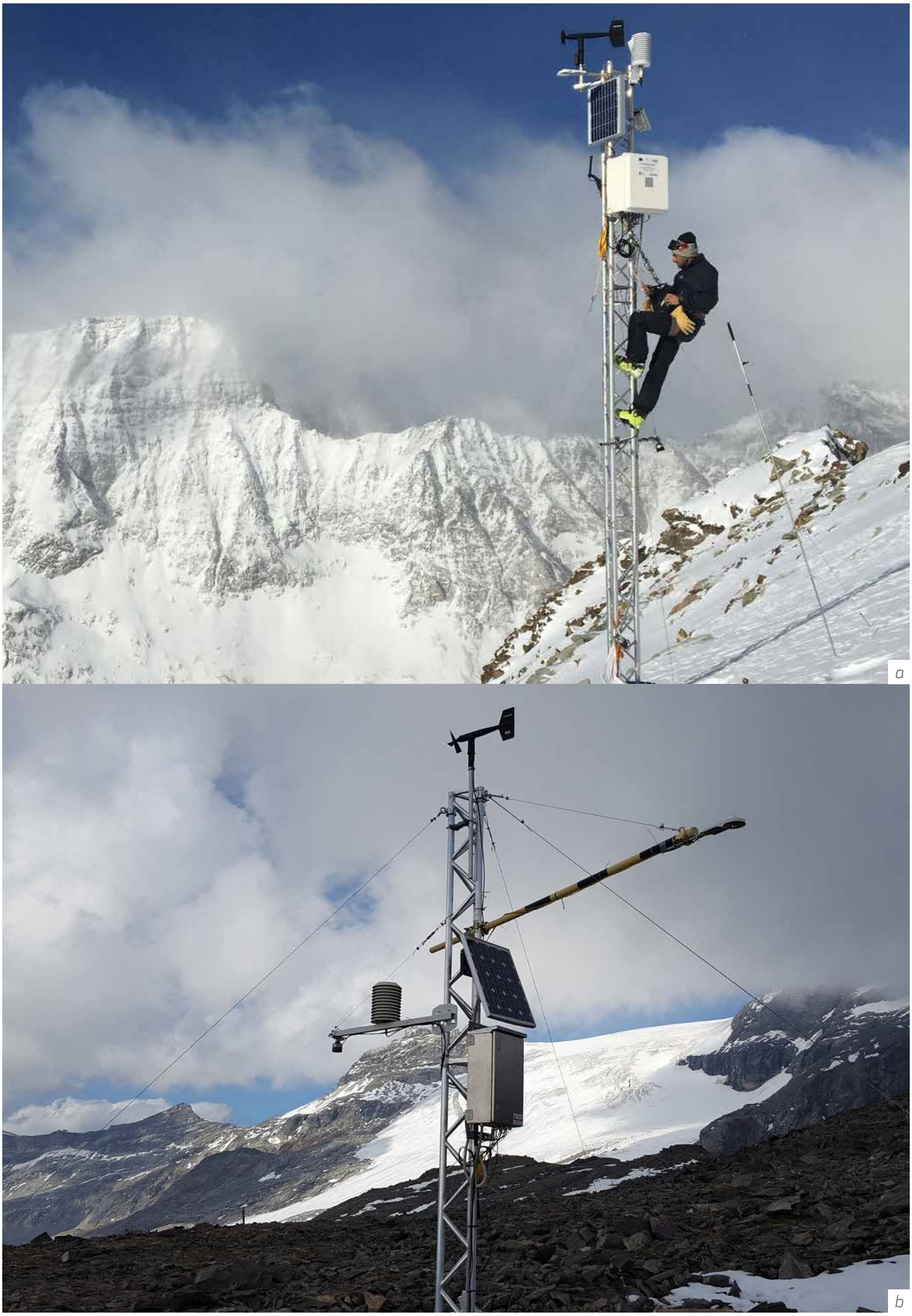

*Figure I-2.19.9 (a, b) Automatic weather stations operated by ARPAVA in Valle d'Aosta, Italy, with ultrasonic snow depth sensors (Source: ARPAVA).*

*Figure I-2.19.10 (a) Webcam used to assess, among other variables, presence of snow on the ground. (b) A series of webcam images showing the evolution of the snow cover. The station in the figure is located in Torgnon-Tellinod in Valle d'Aosta, Italy and is operated by ARPAVA (Source: ARPAVA).*

## I-2.19.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 441

*Figure I-2.19.11 Locations of stations in Italy where depth of snowfall (HN) is measured.*

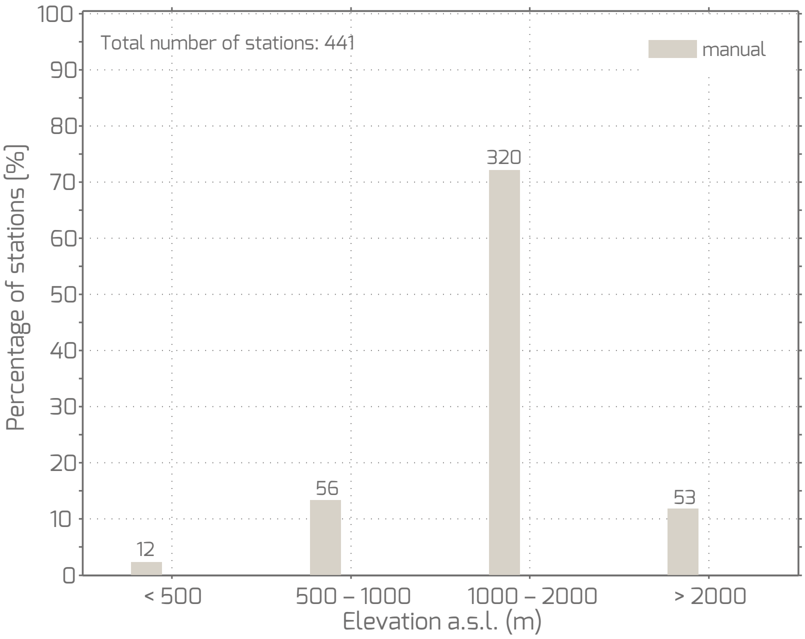

*Figure I-2.19.12 Elevational distribution of stations in Italy with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Most institutions (MC, HAB, SSCV, ARPAL, ARPAP, PAT, FMS/RAVA, ARPAV) measure depth of snowfall manually (Table I-2.19.1). Only ARPAVA does not measure depth of snowfall at all. Manual measurements of depth of snowfall are performed every 24 hours between 0600 and 0800 UTC in parallel to manual snow depth measurements. Depth of snowfall is measured on a white-painted snow board with a ruler (Fig. I-2.19.4) or with a measurement rod fixed in the middle of the board (the latter only by ARPAP). After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. The location of the depth of snowfall measurement is selected to minimise influence from the wind. Measured values are reported in full centimetres.

At all MC stations, depth of snowfall values less than 0.5 cm are reported as “0 cm”. At all ARPAP stations, traces of new snow are recorded as “1 cm” and additionally with the code “999” to count the day as one with snow cover. PAT observers similarly apply a coding system to report special cases associated with depth of snowfall measurements, where the depth of snowfall value refers to the previous 24 hours: (1) “HN=000” is reported in the absence of new snow. (2) If depth of snowfall was recorded over several days, an estimate for the last 24 hours is reported, along with the code “HN=///” to signify the different method. (3) If snow is redistributed by wind (i.e. snow accumulation or erosion), this is indicated in the “notes” section next to the depth of snowfall value. If the measured depth of snowfall value is clearly incorrect because of wind influence, the code “HN=///” is reported in addition to the measured (incorrect) and estimated (correct) depth of snowfall values.

## I-2.19.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 377
Number of stations delivering water equivalent of snow cover data automatically: 3

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*Figure I-2.19.13 Locations of stations in Italy where water equivalent of snow cover (SWE) is measured.*

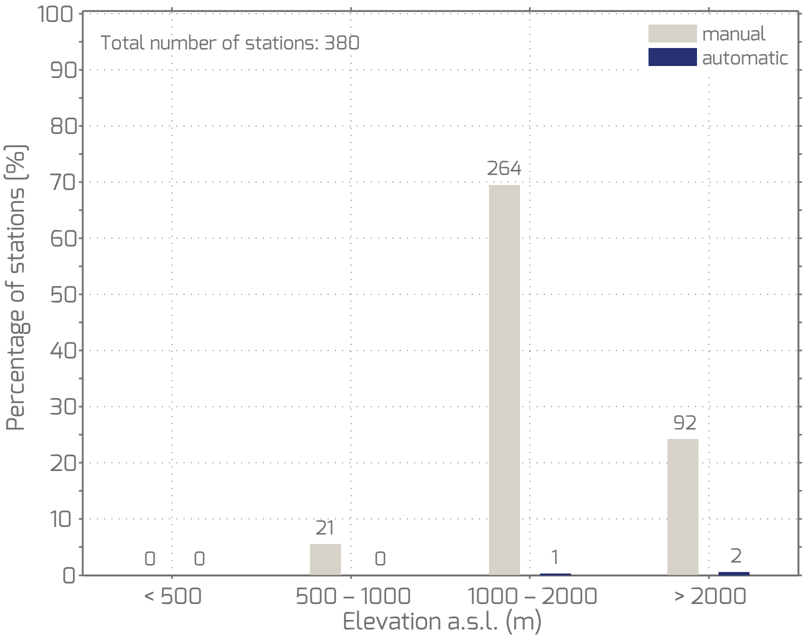

*Figure I-2.19.14 Elevational distribution of stations in Italy with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

MC, HAB, SSCV, ARPAP, PAT, ARPAVA and ARPAV measure water equivalent of snow cover manually (Table I-2.19.1), either: (1) in snow pits using snow cylinders or (2) without pits (e.g. along snow courses) using snow tubes.

(1) HAB, SSCV, PAT and ARPAVA perform manual SWE measurements in snow pits once every week in parallel to snowpack stratigraphy observations, while MC measures SWE every 24 hours. The gravimetric method is applied. Using a graduated snow cylinder (either aluminium or steel) with a certain cross-sectional area (in m$^2$) and a certain length (in m), in Italy often 0.2 m length and 0.0005 m$^3$ volume (Fig. I-2.19.15 a), a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), either the snow cylinder is directly attached to a spring scale (Fig. I-2.19.15 a) or the snow from the cylinder is poured into a plastic bag and the bag is attached to a spring scale to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. If the snow depth is greater than the length of the cylinder, the total snow depth is divided into multiple analogue "columns". Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

(2) ARPAP and ARPAV perform manual SWE measurements along snow courses using snow tubes (no snow pits) on fixed dates: 01 February, 01 March, 01 April, 15 April, 01 May, 15 May and 01 June. The snow tubes (Figs I-2.19.15 b, I-2.19.16) vary in length and volume: ARPAP uses tubes with a length of 0.8 m and a volume of 0.002 m$^3$, while ARPAV uses tubes with lengths of 0.5, 1.0 or 1.5 m and a cross-sectional area of 0.0025 m$^2$. Using a snow tube, a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample in the snow tube (in m), the total weight (in kg) is assessed using either a spring scale (ARPAP) or an electronic scale (ARPAV). The corresponding water equivalent of snow cover (SWE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow tube. At ARPAV sites, three snow tube measurements are performed at adjacent locations and the average of the three readings is reported as total SWE.

### Automatic measurements:

Only ARPAP and ARPAVA measure SWE automatically. ARPAP measures SWE every 30 minutes using a snow pillow. In contrast, ARPAVA measures SWE automatically at one location every 6 hours using a non-contact, passive gamma radiation sensor (CS725; Campbell Scientific, Logan, Utah, USA; Fig. I-2.19.17). The gamma radiation sensor measures SWE for a large area of up to 100 m$^2$ by passively detecting the change in natural gamma radiation from the ground after it passes through the snowpack. The gamma radiation sensor is mounted above the ground and has no contact with the snow.

*Figure I-2.19.15 (a) Snow cylinders, with volumes of 0.0001 and 0.0005 m³, and a spring scale (valid for a maximum weight of 0.5 kg) used to manually measure water equivalent of snow cover (SWE) in snow pits. (b) Snow tube Enel-Valtecne (developed in Italy) used to measure SWE (Source: PAT).*

*Figure I-2.19.16 (a) Plexiglas® snow tube (developed in Italy). (b) Manual water equivalent of snow cover (SWE) measurement (without snow pit) using a Plexiglas® snow tube, performed by ARPA Veneto (Source: ARPAV).*

*Figure I-2.19.17 Automatic weather station operated by ARPAVA in Torgnon-Tellinod in Valle d'Aosta, Italy, with a water equivalent of snow cover (SWE) gamma radiation sensor CS725 (Source: ARPAVA).*

## I-2.19.4 Transition from manual to automatic measurements

When a station is shifted from manual to automatic measurements, PAT and ARPAV typically perform parallel measurements for one winter season. At MC, HAB, SSCV, ARPAL, ARPAP, ARPAVA and FMS/RAVA stations, no shifts have been carried out and thus no parallel measurements have been needed.

## I-2.19.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (MC, HAB, SSCV, ARPAL, ARPAP, PAT, FMS/RAVA) or 5 days (ARPAV)<br>AUTO: 10 minutes (HAB), 15 minutes (ARPAL, PAT), 30 minutes (SSCV, ARPAP, ARPAV) or 60 minutes (MC, FMS/RAVA, ARPAVA) | MANUAL: 24 hours (MC, HAB, SSCV, ARPAL, ARPAP, PAT, FMS/RAVA, ARPAV) | MANUAL: 24 hours (MC), 1 week (HAB, SSCV, PAT, ARPAVA) or on fixed dates (ARPAP, ARPAV)<br>AUTO: 30 minutes (ARPAP) or 6 hours (ARPAVA) |

# I-2.20 Latvia

*Figure I-2.20.1 Location of Latvia in Europe*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 64 573 km$^2$, 89 m a.s.l. |
| Authority responsible for snow measurements | Latvian Environment, Geology and Meteorology Centre (LEGMC)<br>Maskavas Str. 165<br>LV-1019 Riga |
| Contact | • LEGMC<br>lvgmc@lvgmc.lv<br>Public phone number for information on meteorological measurements including snow: +37167032600 |
| Near-real-time data URL and/or contact | • LEGMC<br>https://www.meteo.lv/ |
| Archived data URL and/or contact | • LEGMC<br>https://www.meteo.lv/-observations-dataavailability |

### General situation

The Latvian Environment, Geology and Meteorology Centre (LEGMC) is responsible for operational snow observations in Latvia. Manual snow depth observations date back to the end of the 19th century. The data time series of the 34 snow depth stations presented here started between 1891 and 1950 and are ongoing. However, more than half of these stations (19) shifted from manual to automatic measurements between 2012 and 2016. The LEGMC snow station network is equally distributed over the lowland and midland regions. LEGMC measures snow depth manually and automatically, while presence of snow on the ground and water equivalent of snow cover are only observed manually. Depth of snowfall is not measured.

Usually, the first snow falls in October or November in Latvia. The earliest first snowfall event recorded was observed at the station Rēzekne (Eastern Lativa) on 23 September 1973. LEGMC observations show that only the eastern parts of Latvia are snow covered in the first half of November, whereas the whole country is snow covered by the end of November. The greatest snow depths usually occur between January and March. The national record snow depth (130 cm) was observed on 16 March 1931 in Gaiziņkalns (Vidzeme Upland). The snow cover typically lasts until the end of March in the western parts of Latvia and until the first half of April in the central and eastern regions. The latest snow cover on record was observed on 29 May 1953 at the station Kazdanga (south-western part of Latvia).

### Overview of measurements (LEGMC)

Snow depth: stake, ultrasonic snow depth sensor (Figs I-2.20.2, I-2.20.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.20.6, I-2.20.7)
Operational purpose of measurements: Agriculture and Forestry, Climatology, Flood forecasting, Health and Sport, Hydrology, Meteorology, Road services, Water management

## I-2.20.1 Snow depth measurements

Number of stations delivering snow depth data manually: 13
Number of stations delivering snow depth data automatically: 21

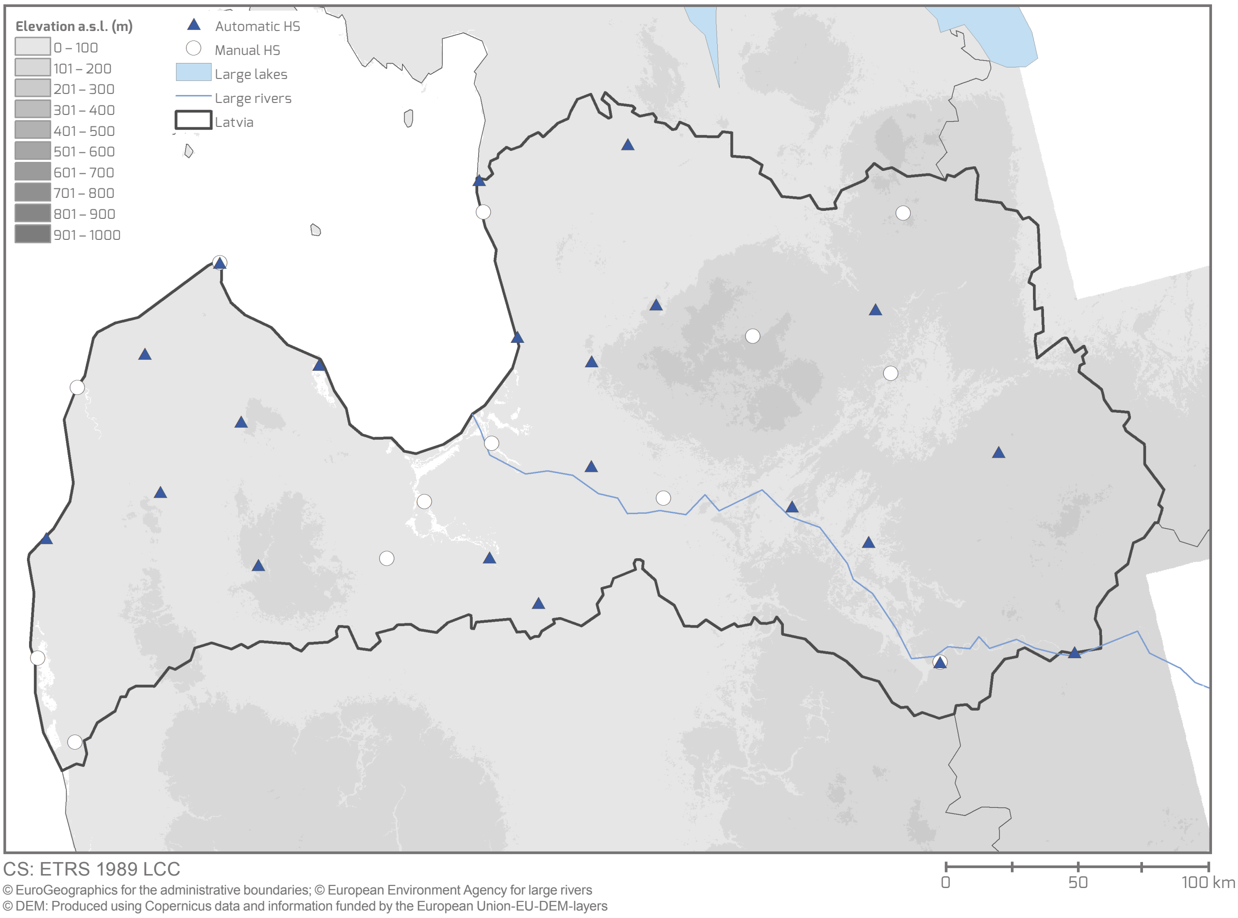

*Figure I-2.20.2 Locations of stations in Latvia where snow depth (HS) is measured.*

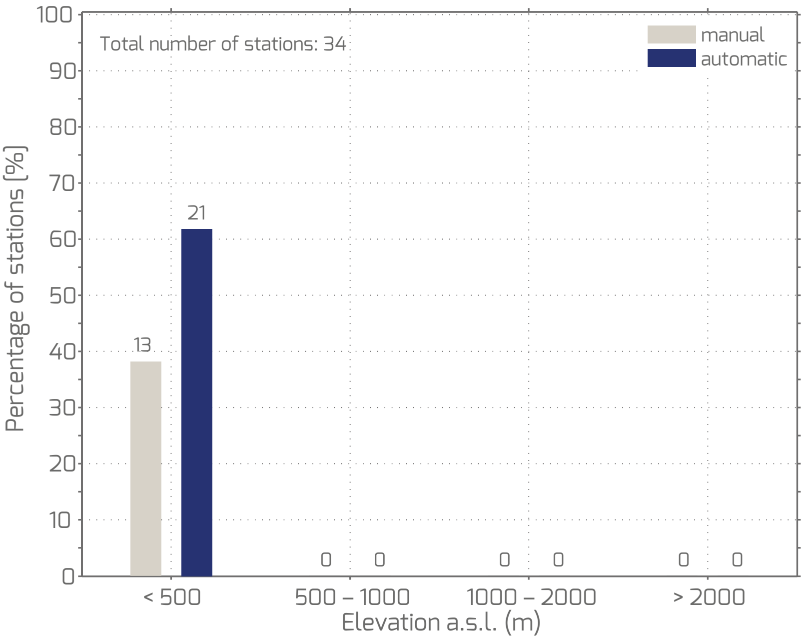

*Figure I-2.20.3 Elevational distribution of stations in Latvia with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours at 0600 UTC. Fixed wooden stakes with a scale in centimetres and a length of 1.3 or 1.8 m are used. Within a 43 m² measurement field, three snow stakes are arranged in a triangle, 10 m apart (Fig. I-2.20.4). The average of the three stake readings is reported as total snow depth. To prevent incorrect measurements, values are read as horizontally as possible to the surface and at a distance of 2 to 3 m from the stakes. Total snow depth is reported as long as at least half of the measurement field is covered with more than 0.5 cm of snow. Measured values are reported in full centimetres.

**Automatic measurements:**

Snow depth is measured automatically every minute but reported as an hourly average. Ultrasonic snow depth sensors (SR50AT; Campbell Scientific, Logan, Utah, USA; Fig. I-2.20.5 a) are used. The sensors are mounted 2 m above a 1.44 m² measurement area covered with sand and fine gravel. Automatic snow depth measurements have been available since 2013.

At all 21 automatic weather station (AWS) locations, snow stakes are installed and snow depth is additionally observed with a webcam (Fig. I-2.20.5 b) to validate the automatically measured values. If questionable automatically measured data is recognised, the zero point of the sensor and the area below the sensor are checked.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is not reported explicitly.

**Zero snow depth reporting method:**

If the average of the three snow depth readings at the stakes is less than 0.5 cm, 0 cm snow depth is reported.

*Figure I-2.20.4 A measurement field during the snow-free season, with three snow stakes arranged in a triangle for manual snow depth measurements (Source: LEGMC).*

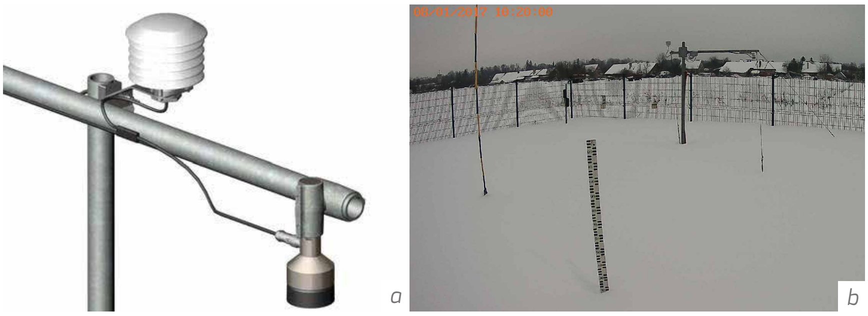

*Figure I-2.20.5 (a) Ultrasonic snow depth sensor SR50AT, used at automatic weather stations (AWSs) in Latvia. (b) Webcam image of a snow stake, used to validate the automatic snow depth observations (see AWS in background) (Source: LEGMC).*

## I-2.20.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

### I-2.20.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 21
Number of stations delivering water equivalent of snow cover data automatically: 0

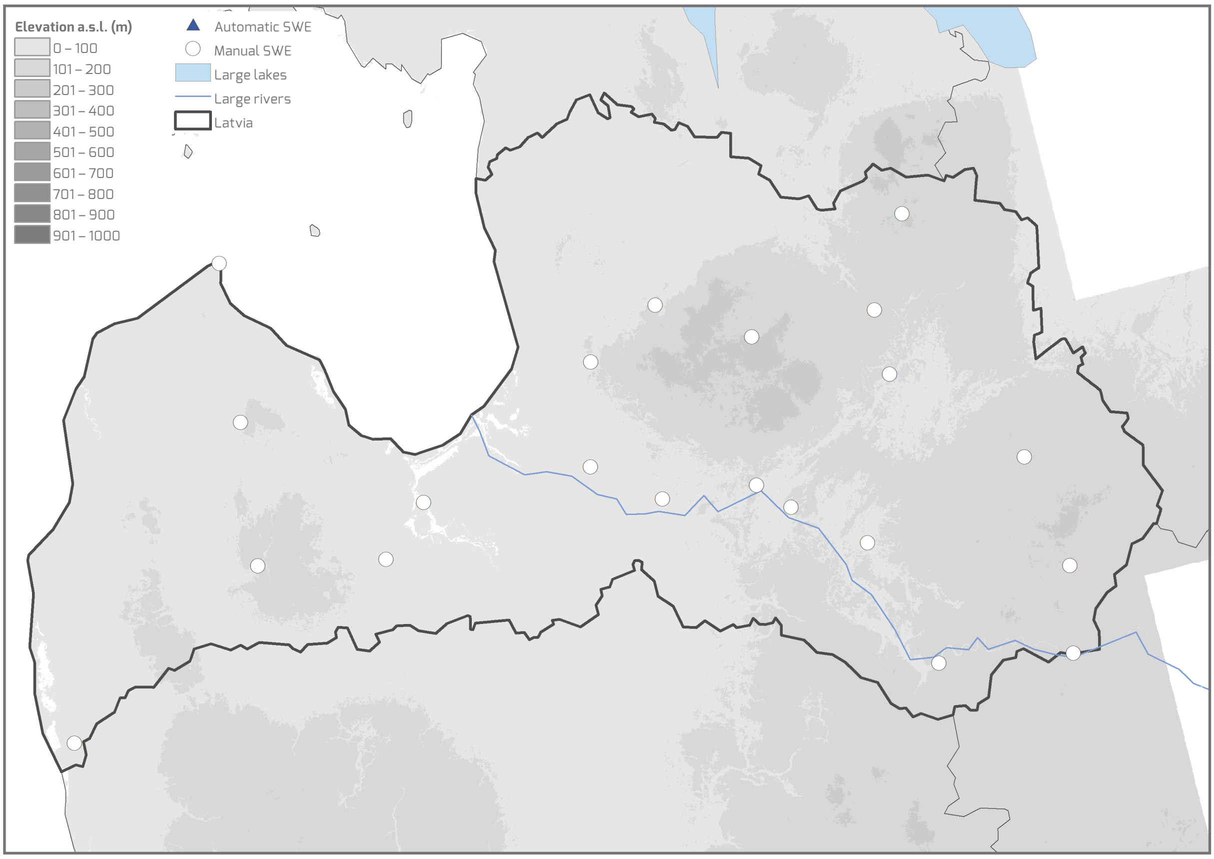

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*Figure I-2.20.6 Locations of stations in Latvia where water equivalent of snow cover (SWE) is measured.*

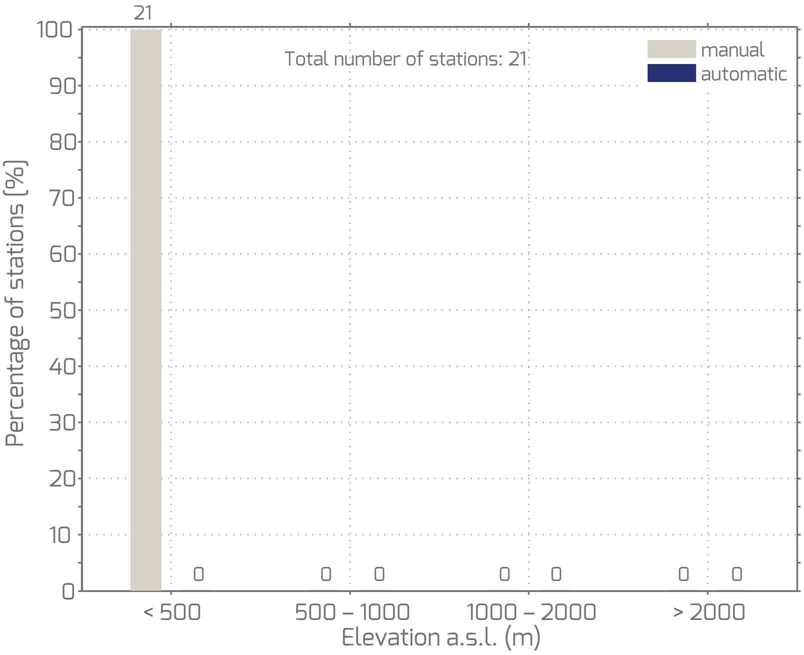

*Figure I-2.20.7 Elevational distribution of stations in Latvia with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every 10 days (10th, 20th and 30th day of the month), as long as more than 60% of the measurement field is snow covered. The water equivalent of snow cover is measured in a spatially distributed manner along snow courses. The gravimetric method is applied. Using a graduated iron snow cylinder with a cross-sectional area of 0.005 m$^2$ and a length of 0.6 m, a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), the snow cylinder is attached to a steelyard balance (Fig. I-2.20.8 a) to measure the total weight of the snow (in kg). The steelyard balance has a scale in points, with 1 point equal to 5 g. The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

At all 21 stations the length of the snow courses varies between 1 000 m in open fields and 500 m in forested terrain. Along the snow course, snow depth is measured every 10 m, resulting in 100 measurement points in open fields and 50 measurement points in forested areas. In addition to the spatially distributed snow depth measurements, snow density and consequently SWE are measured (Fig. I-2.20.8 b), at 10 points in open fields and at 5 points in forested areas. The average SWE value of all individual SWE observations made within a snow course is reported with an accuracy of 1 mm. If ice crusts, water-saturated snow layers or water layers exist within the snowpack, the depth and density of each layer is measured separately.

**Automatic measurements:**

No measurements.

*Figure I-2.20.8 (a) Iron snow cylinder attached to a steelyard balance. (b) water equivalent of snow cover (SWE) measurement along a snow course in the measurement field (Source: LEGMC).*

## I-2.20.4 Transition from manual to automatic measurements

Manual and automatic snow depth measurements are conducted in parallel at two locations. In addition, at all 21 locations with automatic snow measurements, snow stakes are installed and observed with a webcam. These measurements are used to check automatic measurements.

## I-2.20.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (LEGMC)<br>AUTO: 1 hour (LEGMC) | MANUAL: no measurements | MANUAL: 10 days (LEGMC)<br>AUTO: no measurements |

# I-2.21 Lithuania

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*Figure I-2.21.1 Location of Lithuania in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 65 286 km$^2$, 102 m a.s.l. |
| Authority responsible for snow measurements | Lithuanian Hydrometeorological Service under the Ministry of Environment (LHMS)<br>Rudinos Str. 6<br>LT-09300 Vilnius |
| Contact | • LHMS<br>lhm@meteo.lt |
| Near-real-time data URL and/or contact | • LHMS<br>http://www.meteo.lt/lt/faktiniai-orai |
| Archived data URL and/or contact | • LHMS<br>donatas.valiukas@meteo.lt (Dr. Donatas Valiukas, Head of Climatology Division) |

## General situation

The Lithuanian Hydrometeorological Service under the Ministry of Environment (LHMS) is responsible for operational snow observations in Lithuania. The LHMS station network is evenly distributed over the entire Lithuanian territory. Snow depth measurements in Lithuania started in 1891, and snow surveys for measuring water equivalent of snow cover started in 1946.

Snow depth and water equivalent of snow cover are measured manually by LHMS, while depth of snowfall and presence of snow on the ground are not observed. Automatic sensors are not in operational use, owing to insufficient data accuracy. Shallow snow covers with depths less than 0.05 m often occur, and ultrasonic snow depth sensors measure grass sticking out of the snow or give other erroneous values.

The following snow information is based on average values from 1981 to 2010. In Lithuania, winter weather phenomena, such as snow, are observed between October and April. The spatial distribution of the snow cover depends mainly on the distance from the Baltic Sea and on topography. The thinnest snow covers (averaging between 0.16 and 0.2 m) are observed in the coastal area of the Baltic Sea, on downwind slopes of Žemaičiai Upland and in southwestern Lithuania. In contrast, the thickest snow covers (averaging between 0.25 and 0.35 m) accumulate in the eastern part of the country. The average maximum annual snow depth in Lithuania is between 0.16 and 0.35 m. However, average snow depths exceed 0.1 m on only 33 days of the snow season. Snowfall events with snow depths exceeding 0.5 m are rare in Lithuania. The maximum snow depth ever recorded in Lithuania was 0.94 m, measured at Laukuva meteorological station in 1931.

The first snowfall event occurs, on average, between 26 and 30 October in northern and eastern Lithuania, while it is commonly two weeks later on the coast (between 10 and 12 November). The last snowfall events in Lithuania are typically observed between 8 and 10 April in the coastal areas and between 17 and 19 April in northeastern Lithuania. In rare cases, snow also falls in May. The average number of days with snow cover varies between 55 and 60 along the coast and between 95 and 105 in northeastern and eastern Lithuania. Generally, continuous snow cover starts in December and maximum snow depths are reached in the second half of February. The snow melt season starts in the beginning of April.

## Overview of measurements (LHMS)

Snow depth: stake, ruler (Figs I-2.21.2, I-2.21.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.21.4, I-2.21.5)
Operational purpose of measurements: Climatology, Flood forecasting, Hydrology, Meteorology, Road services, Water management

## I-2.21.1 Snow depth measurements

Number of stations delivering snow depth data manually: 37
Number of stations delivering snow depth data automatically: 0

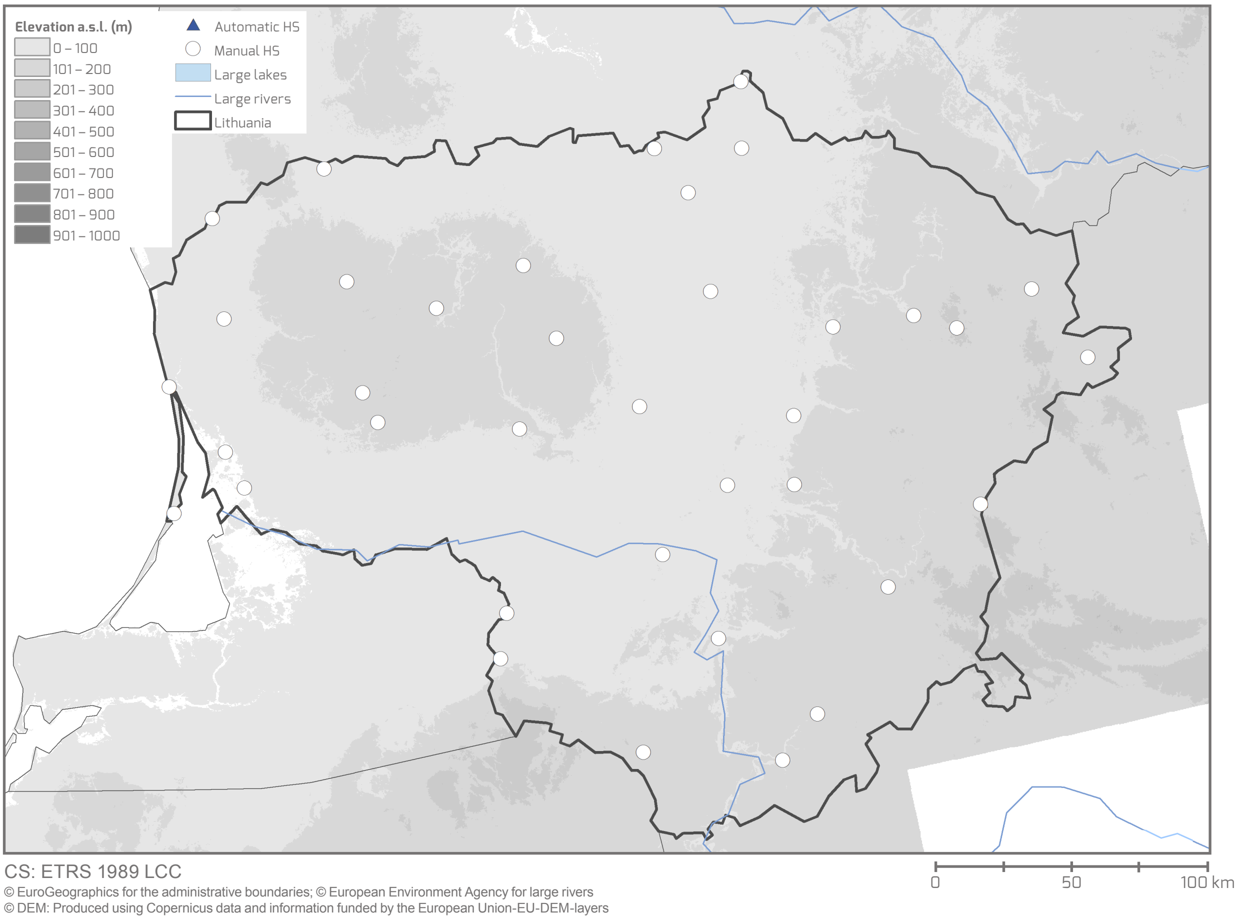

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*Figure I-2.21.2 Locations of stations in Lithuania where snow depth (HS) is measured.*

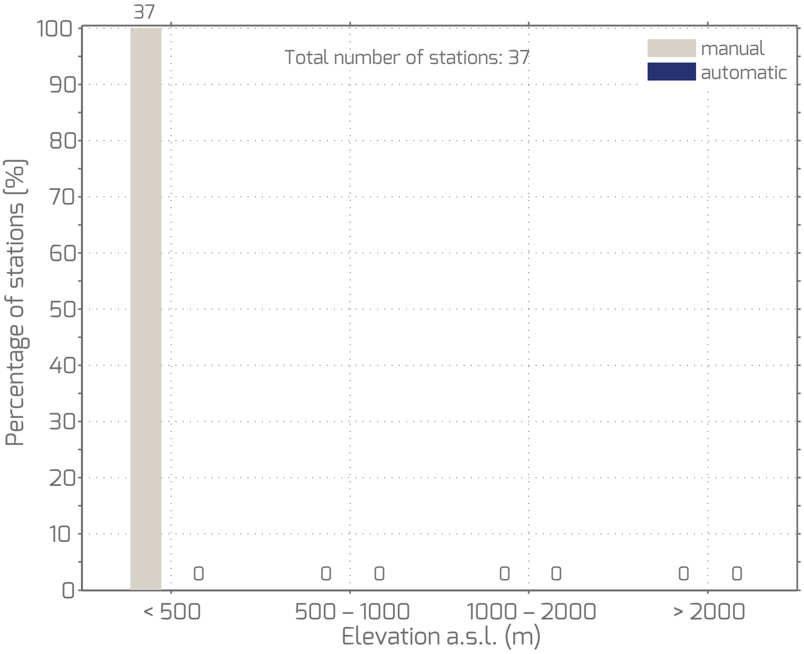

*Figure I-2.21.3 Elevational distribution of stations in Lithuania with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours, at either meteorological (18) or hydrological (19) stations. At hydrological stations snow depth is measured with a portable ruler. At meteorological stations fixed stakes with a scale in centimetres and a length of 1.3 or 1.8 m are used; the fenced measurement fields have a size of 16 x 16 m or 26 x 26 m, and three snow stakes are arranged in a triangle, 10 m apart. The average of the three stake readings is reported as total snow depth. Total snow depth is reported as long as snow depth at the stakes exceeds 0.5 cm. Measured values are reported in full centimetres.

**Automatic measurements:**

No measurements.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is not reported explicitly. However, in addition to snow depth observations, snow coverage is reported using a 10-point coding system (0–10). Snow coverage is reported for the measurement field and the visible area around the station. For the coding system, “0” means snow patches covering less than 10% of the measurement field are present, “1“ means snow coverage is around 10%, and “10” means there is 100% snow coverage. The coding system is only applied if snow is present in the measurement field.

**Zero snow depth reporting method:**

When the average snow depth at the three stakes is less than 0.5 cm, 0 cm snow depth is reported.

## I-2.21.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.21.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 37
Number of stations delivering water equivalent of snow cover data automatically: 0

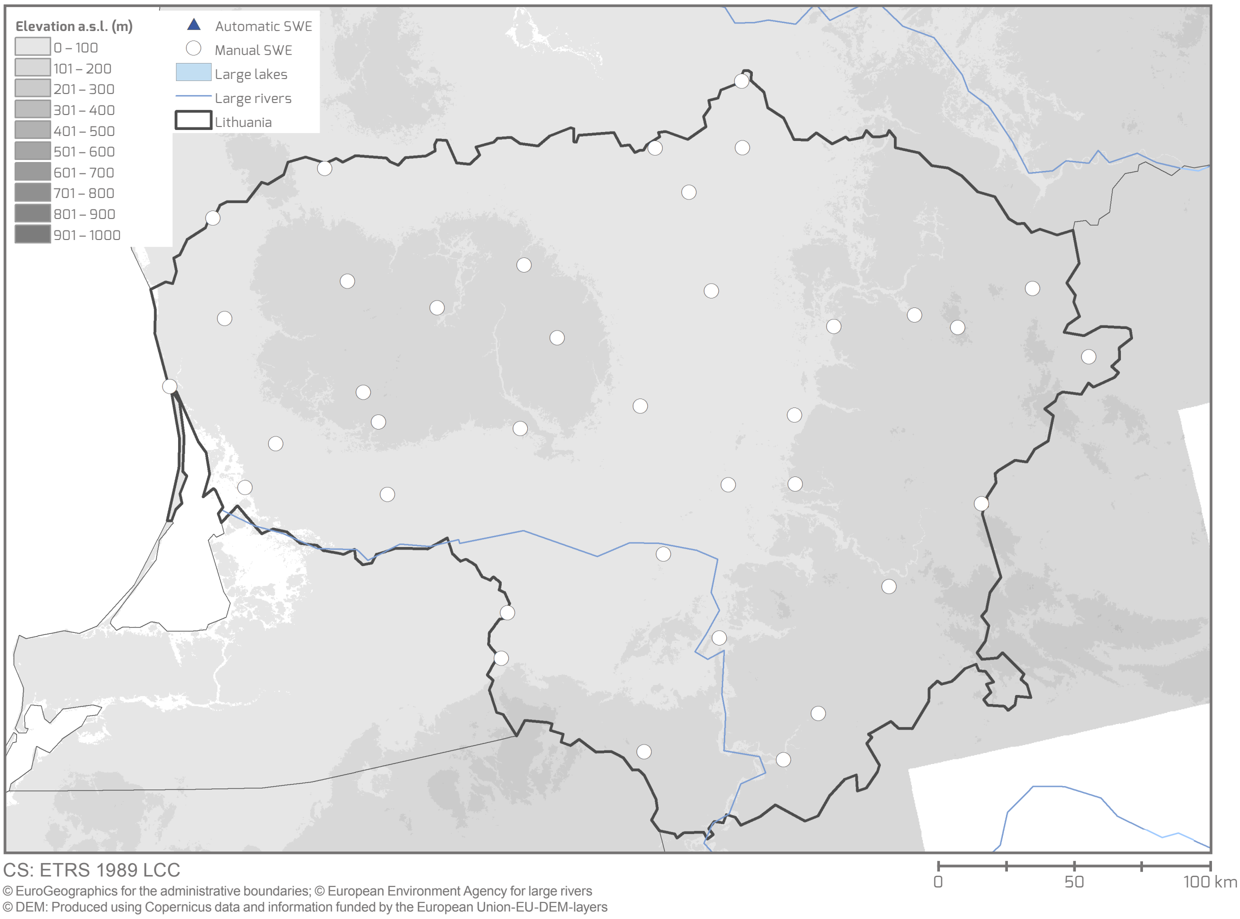

*Figure I-2.21.4 Locations of stations in Lithuania where water equivalent of snow cover (SWE) is measured.*

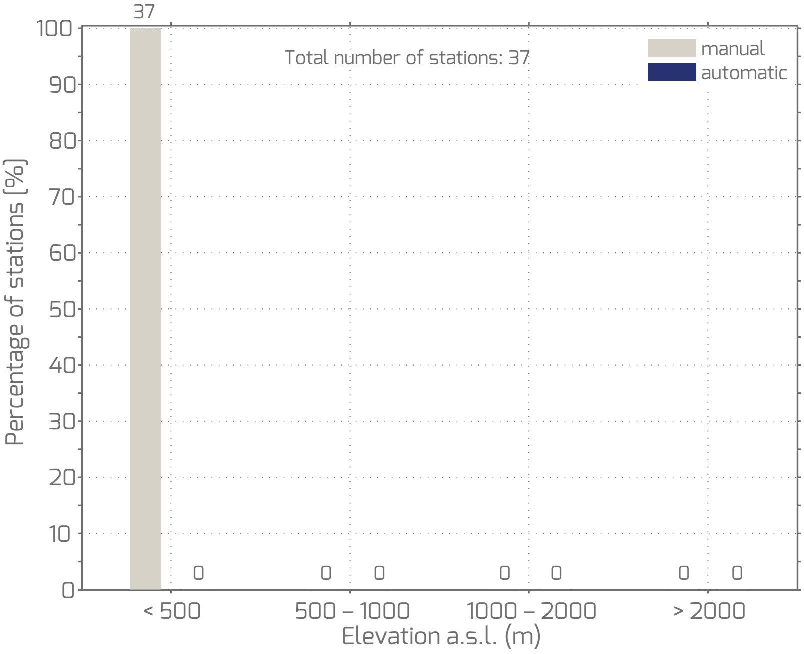

*Figure I-2.21.5 Elevational distribution of stations in Lithuania with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every 10 days during winter and every 5 days during the ablation period in spring, as long as snow covers at least 50% of the measurement field or the visible area around the station. SWE is measured in a spatially distributed manner along snow courses. The gravimetric method is applied. Using a graduated iron snow cylinder (BC-43) with a cross-sectional area of 0.005 m$^2$ and a length of 0.6 m, a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), the snow cylinder is attached to a steelyard balance to measure the total weight of the snow (in kg). The steelyard balance has a scale in points, with 1 point equal to 5 g. The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

At all 37 locations, the length of the snow courses varies from 1 000 to 2 000 m in open fields and is 500 m in forested terrain. Along the snow course, snow depth is measured every 10 m, resulting in 100 measurement points in open fields and 50 measurement points in forested areas. In addition to the spatially distributed snow depth measurements, snow density and consequently SWE are measured at 10 points in open fields and at 5 points in forested areas. The average value of all individual SWE observations made within a snow course is reported with an accuracy of 1 mm. If ice crusts, water-saturated snow layers or water layers exist within the snowpack, the depth and density of each layer is measured separately.

**Automatic measurements:**

No measurements.

## I-2.21.4 Transition from manual to automatic measurements

No parallel measurements are carried out because automatic snow depth sensors are not in operational use, owing to insufficient data accuracy. Snow stakes are installed at some non-operational automatic stations to validate the automatic data.

## I-2.21.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (LHMS)<br>AUTO: no measurements | MANUAL: no measurements | MANUAL: 10 days (5 days during ablation period) (LHMS)<br>AUTO: no measurements |

# I-2.22 Luxembourg

*Figure I-2.22.1 Location of Luxembourg in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 2 586 km², 348 m a.s.l. |
| Authority responsible for snow measurements | Administration des Services Techniques de l'Agriculture (ASTA)<br>16, rte d'Esch<br>P.O. Box 1904<br>LU-1470 Luxembourg |
| Contact | • ASTA<br>agrimeteo@asta.etat.lu |
| Near-real-time data URL and/or contact | • ASTA<br>http://www.am.rlp.de/Internet/AM/inetcntrLUX.nsf/cuhome.xsp?src=L941ES4AB8&p1=K1M7X321X6&p3=343G06H65M |
| Archived data URL and/or contact | • ASTA<br>http://www.am.rlp.de/Internet/AM/inetcntrLUX.nsf/cuhome.xsp?src=WY1BE977UP&p1=QOBOB9JITQ&p3=9VXL1WMS7M |

## General situation

The Administration des Services Techniques de l'Agriculture (ASTA) is responsible for operational snow measurements in Luxembourg. Snow depth is measured automatically at three automatic weather stations (AWSs), while presence of snow on the ground, depth of snowfall and water equivalent of snow cover are not observed.

The three AWSs where snow depth is observed are located at sites with different climatic characteristics: site 1 is located in a low and flat open area; site 2 is located in a low and wide valley with a temperate climate and very little snow; and site 3 is located in a hilly countryside with an occasionally extended snow coverage period. Sites 1 and 2 have historical long-term data series: site 1 since 1838 and site 2 since 1949. Measurements at the stations were shifted from manual to automatic in 2000 (site 1) and 2004 (site 2), while at site 3 snow depth has been measured automatically since measurements began in 2000.

## Overview of measurements (ASTA)

Snow depth: ultrasonic snow depth sensor (Figs I-2.22.2, I-2.22.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: no measurements
Operational purpose of measurements: Agriculture and Forestry, Climatology, Flood forecasting, Meteorology

## I-2.22.1 Snow depth measurements

Number of stations delivering snow depth data manually: 0
Number of stations delivering snow depth data automatically: 3

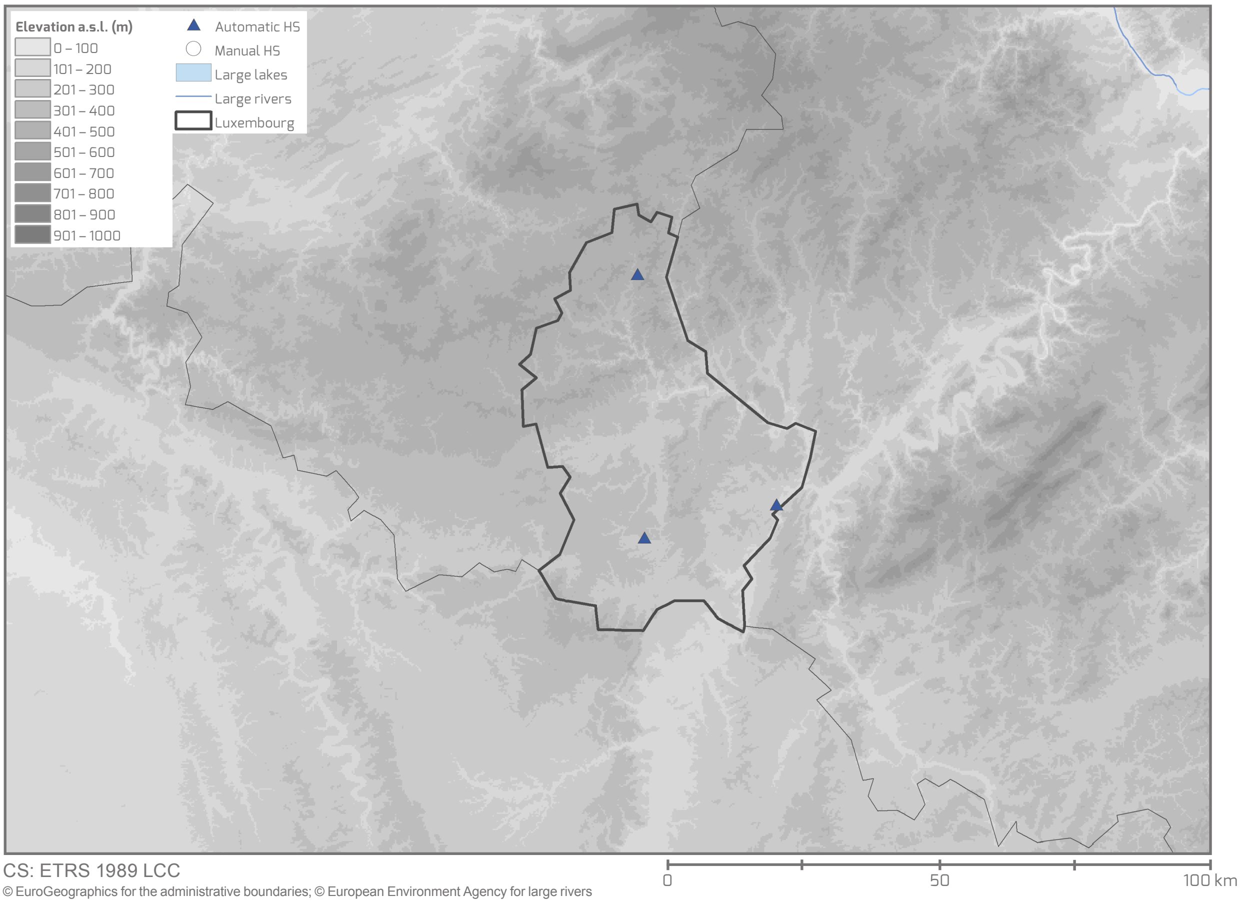

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*Figure I-2.22.2 Locations of stations in Luxembourg where snow depth (HS) is measured.*

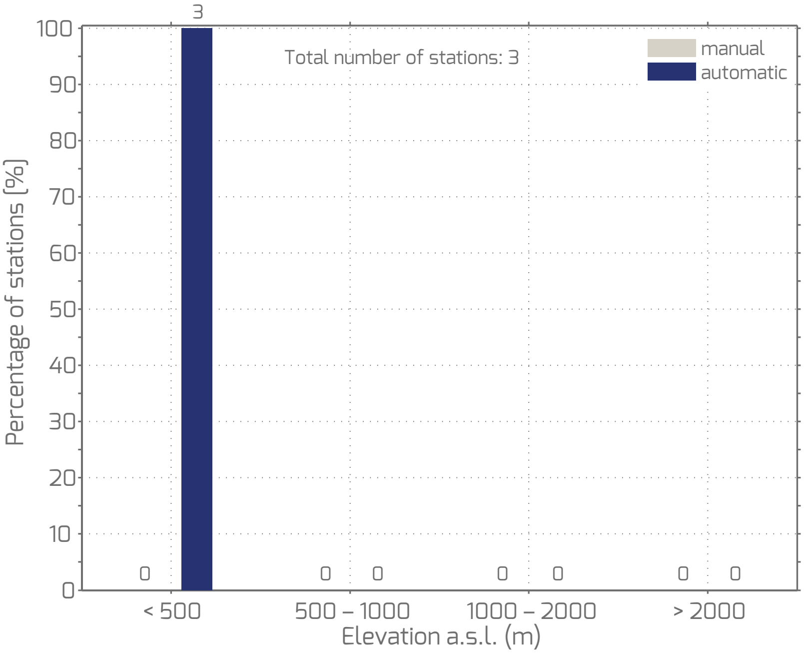

*Figure I-2.22.3 Elevational distribution of stations in Luxembourg with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

No measurements.

**Automatic measurements:**

Automatic snow depth measurements are recorded every 10 minutes and reported as an hourly average. Ultrasonic snow depth sensors (SR50; Campbell Scientific, Logan, Utah, USA) are used and are located within a 0.8 x 0.8 m measurement field. Snow depth sensors are mounted 1 m above the ground, and grey stone is used as the ground surface material below the sensor.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is not reported explicitly.

**Zero snow depth reporting method:**

Not reported.

## I-2.22.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.22.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 0

**Manual measurements:**

No measurements.

**Automatic measurements:**

No measurements.

## I-2.22.4 Transition from manual to automatic measurements

No parallel measurements were carried out during the transition from manual to automatic measurements.

## I-2.22.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: no measurements<br>AUTO: 1 hour (ASTA) | MANUAL: no measurements | MANUAL: no measurements<br>AUTO: no measurements |

# I-2.23 Macedonia (North)

*Figure I-2.23.1 Location of Macedonia in Europe.*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 25 713 km$^2$, 828 m a.s.l. |
| Authority responsible for snow measurements | National Hydrological and Meteorological Service Republic of North Macedonia (HMS)<br>Skupi Street 28<br>MK-1000 Skopje |
| Contact | · HMS<br>akaranfilovski@uhmr.gov.mk (Aleksandar Karanfilovski)<br>naleksovska@uhmr.gov.mk (Nina Aleksovska, Head of Meteorological Department) |
| Near-real-time data URL and/or contact | · HMS<br>Check website for latest data:<br>https://uhmr.gov.mk/?lang=en |
| Archived data URL and/or contact | · HMS<br>naleksovska@uhmr.gov.mk (Nina Aleksovska, Head of Meteorological Department) |

### General situation

The National Hydrological and Meteorological Service (HMS) is responsible for operational snow observations in the Republic of North Macedonia (officially; hereafter referred to as Macedonia). HMS was officially established in 1947 and has the duty to observe meteorological variables and extraordinary weather phenomena for the sake of public interest, weather forecasting, and hydrological and climatological records. Since 2000, the HMS has conducted its work as part of the Ministry of Agriculture, Forestry and Water Economy. Among other duties, HMS maintains and develops the Macedonian meteorological and hydrological observation network. Currently, mainly manual snow observations are performed, but automatic snow observations have been tested in order to shift some manual stations to automatic ones. Four automatic stations measuring snow depth are already in use and supply data complementary to manual snow depth, presence of snow on the ground, depth of snowfall and water equivalent of snow cover observations. In Macedonia, 129 manual snow depth and depth of snowfall stations exist. All stations follow WMO recommendations, but only 21 meteorological stations where measurements are carried out by professionals are included in the WMO network. Measurements at the other 108 stations (6 climatological stations and 102 precipitation gauge stations) are performed by non-professional staff, resulting in lower data quality. The HMS station network is equally distributed over the alpine, midland and lowland regions.

### Overview of measurements (HMS)

Snow depth: stake, ruler, ultrasonic snow depth sensor (Figs I-2.23.2, I-2.23.3)
Depth of snowfall: snow board, precipitation gauge, ruler (Figs I-2.23.4, I-2.23.5)
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.23.6, I-2.23.7)
Operational purpose of measurements: Agriculture and Forestry, Climatology, Flood forecasting, Hydrology, Meteorology, Road services, Water management

## I-2.23.1 Snow depth measurements

Number of stations delivering snow depth data manually: 129
Number of stations delivering snow depth data automatically: 4

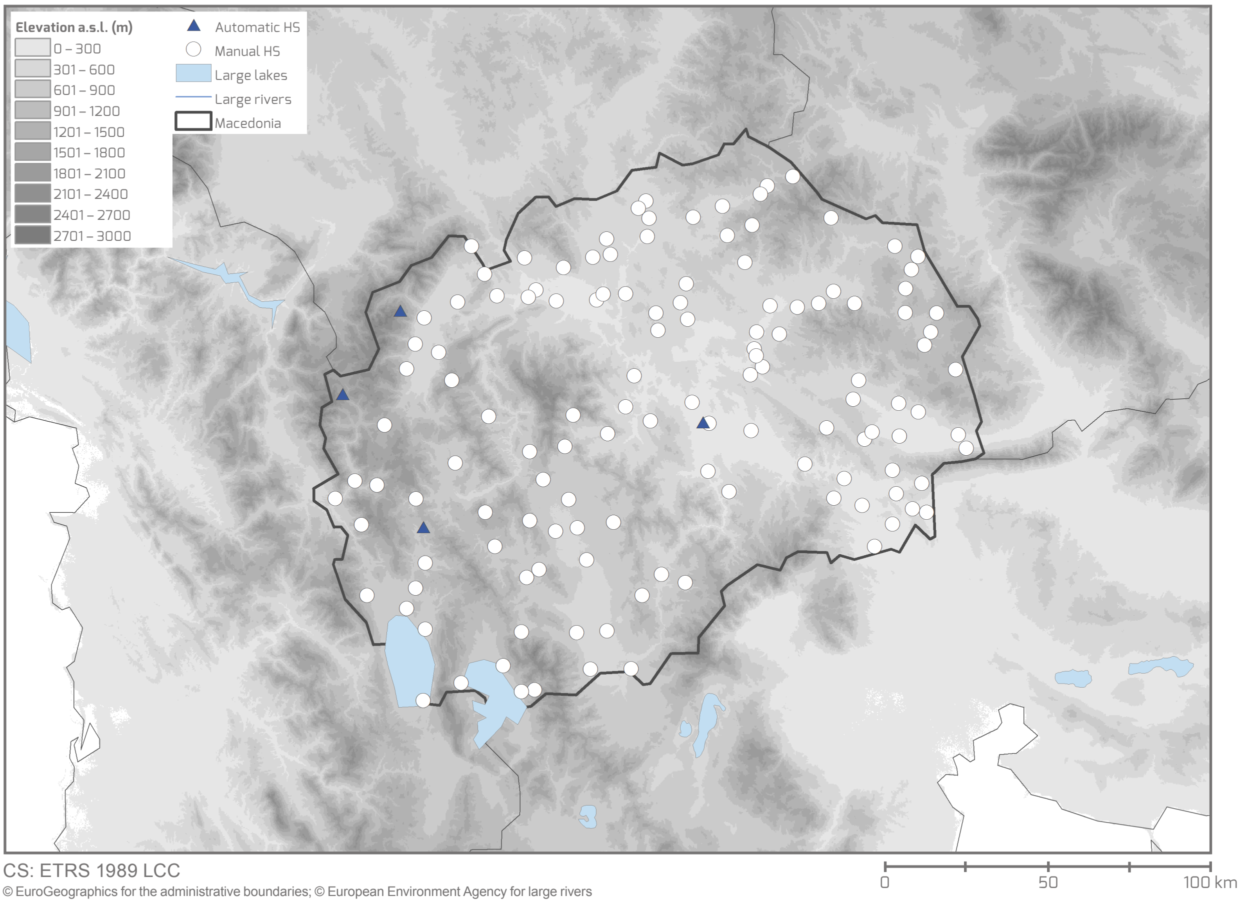

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*Figure I-2.23.2 Locations of stations in Macedonia where snow depth (HS) is measured.*

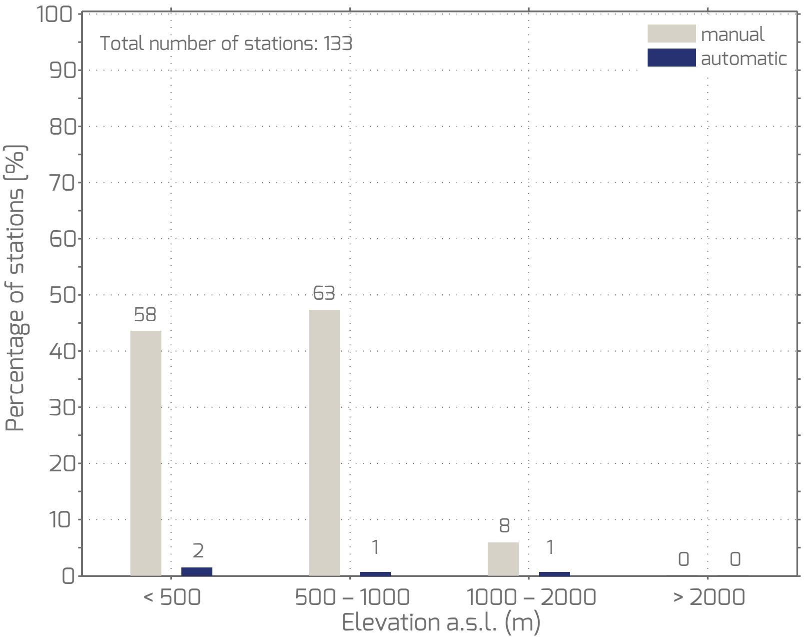

*Figure I-2.23.3 Elevational distribution of stations in Macedonia with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Three different station types are used to measure snow depth in Macedonia, and they provide data with varying quality: (1) 21 meteorological stations are included in the WMO network and usually provide data of high quality, whereas (2) 6 climatological stations and (3) 102 precipitation gauge stations provide data of lower quality.

Manual snow depth measurements are performed every 12 hours, at 0600 and 1800 UTC, at the 21 meteorological stations, and data is included in the SYNOP report twice a day. Fixed stakes with a scale in centimetres are used when there is a continuous snow cover in the measurement field. Meteorological stations have a size of either 15 x 15 m or 20 x 20 m. Portable rulers with a scale in centimetres are used if the snow distribution is inhomogeneous or patchy. With rulers, three snow depth measurements are conducted within the measurement field and the average of these measurements is reported as total snow depth.

At the 6 climatological and 102 precipitation gauge stations, snow depth is measured every 24 hours at 0600 UTC and reported monthly. Portable rulers with a scale in centimetres are used. The measurement fields of climatological stations are small, while measurements at precipitation gauge stations are typically performed in observers' private gardens, without any size regulations. Measurements made under inhomogeneous or patchy snow cover conditions are especially problematic and often result in low data quality.

At all stations, total snow depth is reported as long as at least 50% of the measurement field is covered with snow. Measured values are reported in full centimetres.

### Automatic measurements:

Automatic snow depth measurements are performed every 10 minutes using ultrasonic snow depth sensors.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported explicitly in parallel to manual snow depth measurements. In addition, snow conditions and snow coverage are noted in a logbook using the following categories: (1) less than 50% of the measurement field is covered with dry or wet snow, (2) more than 50% of the measurement field is covered with dry or wet snow, (3) 100% of the measurement field is covered with dry or wet snow, (4) more than 50% of the measurement field is covered with dry snow, (5) 100% of the measurement field is covered with dry snow.

### Zero snow depth reporting method:

When more than 50% of the measurement field is snow free, 0 cm snow depth is reported, even if there is still some snow present at the stake itself. Whether zero snow depth is reported depends strongly on the observer and can be a source of error, especially at the 108 stations with non-professional observers.

## I-2.23.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 129

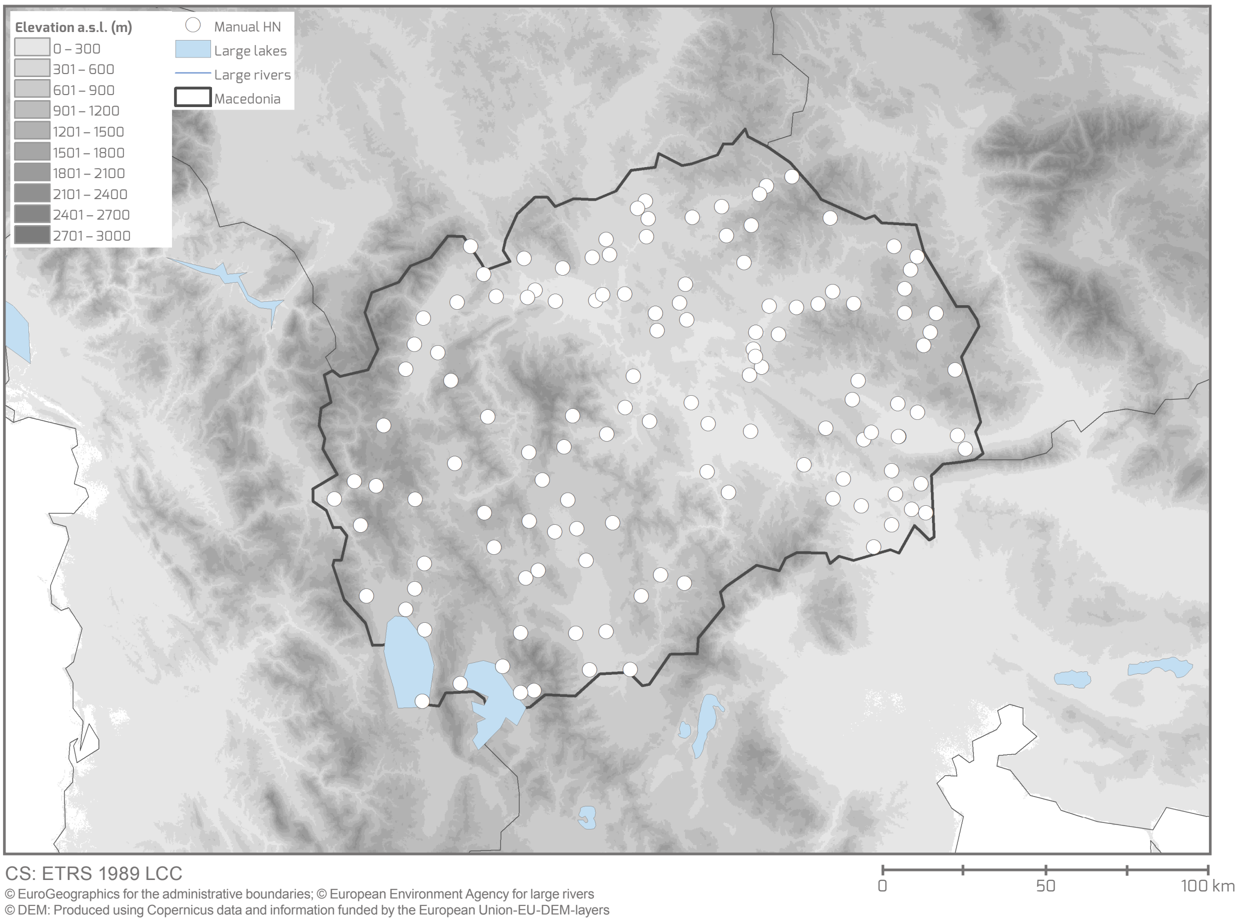

*Figure I-2.23.4 Locations of stations in Macedonia where depth of snowfall (HN) is measured.*

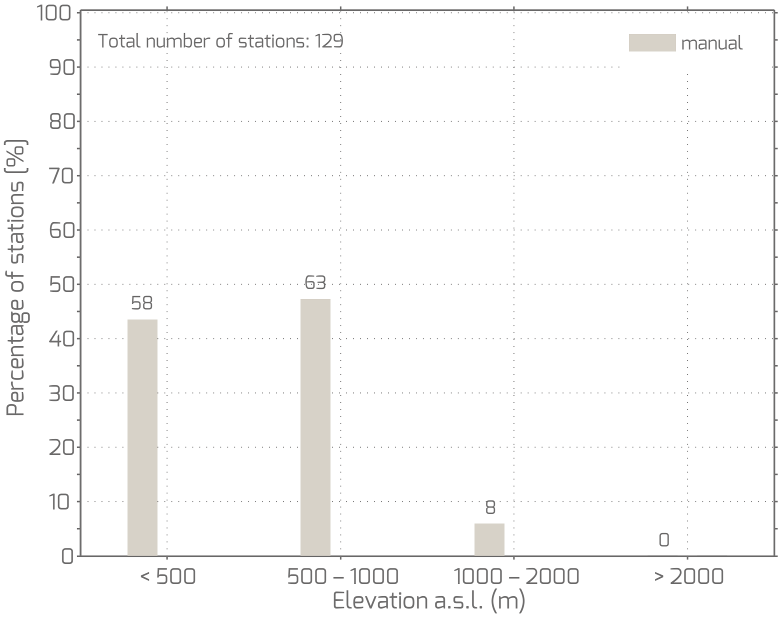

*Figure I-2.23.5 Elevational distribution of stations in Macedonia with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 12 hours, at 0600 and 1800 UTC, at the 21 meteorological stations and every 24 hours, at 0600 UTC, at the 6 climatological stations. Depth of snowfall is measured in parallel to manual snow depth measurements. At these stations, depth of snowfall is measured on a white-painted snow board with a ruler. Depth of snowfall is measured either at one point, if the new snow is homogeneously distributed on the snow board, or at two or three points, if the new snow is inhomogeneously distributed on the board. In the latter case, the average of all measurements is reported. After each 0600 UTC measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. Measured values are reported in full centimetres. Depth of snowfall values less than 0.5 cm are reported as 0 cm.

In addition to the above-described measurements, manual depth of snowfall measurements are performed every 24 hours, at 0600 UTC, at the 108 precipitation gauge stations. A ruler is used to measure depth of snowfall in the precipitation gauge, but the procedure is not standardised and depends on the observer.

## I-2.23.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 11
Number of stations delivering water equivalent of snow cover data automatically: 0

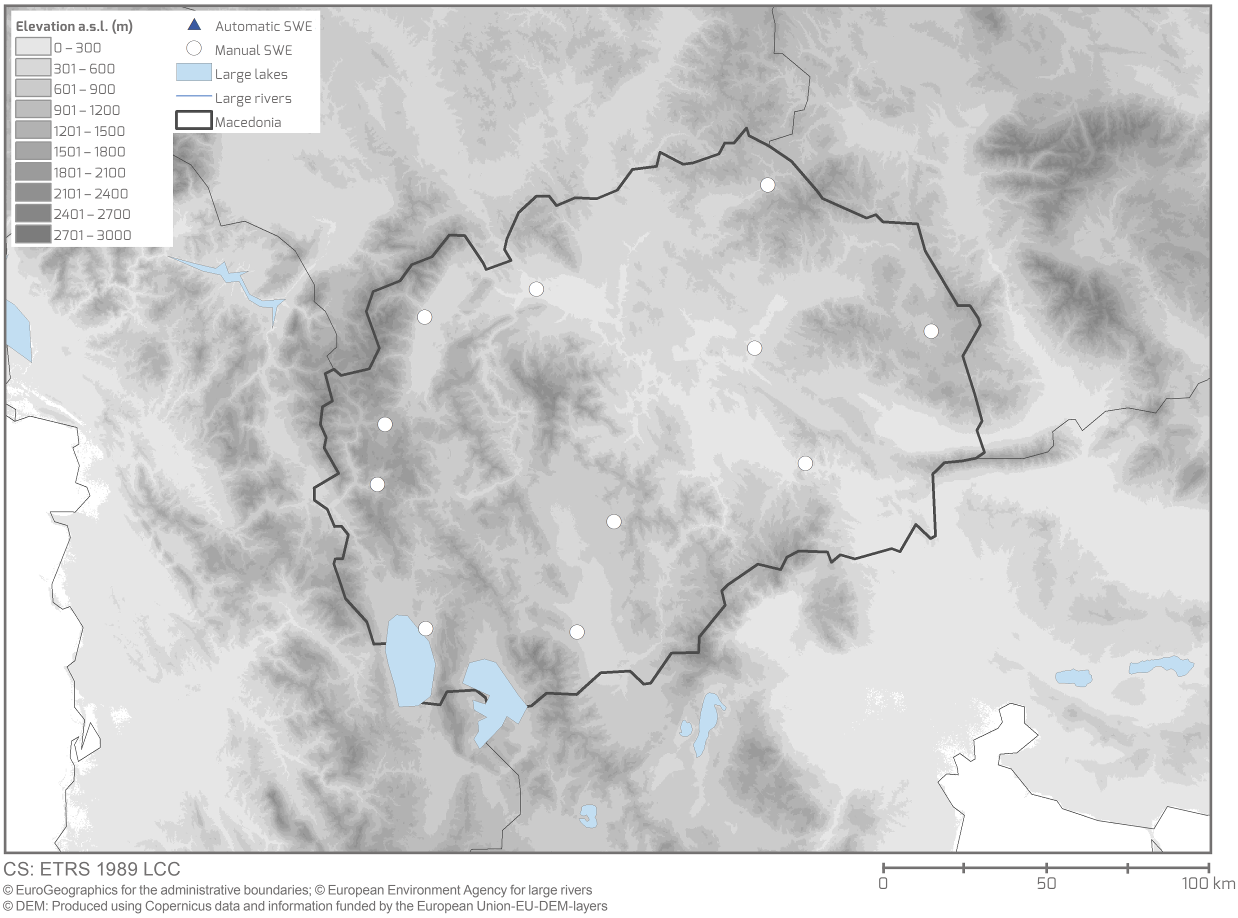

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*Figure I-2.23.6 Locations of stations in Macedonia where water equivalent of snow cover (SWE) is measured.*

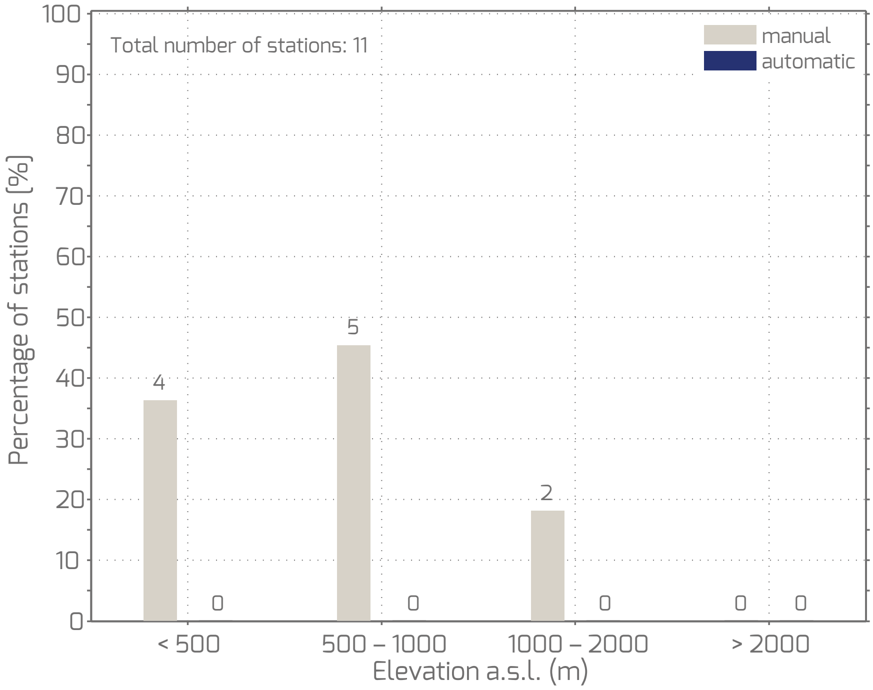

*Figure I-2.23.7 Elevational distribution of stations in Macedonia with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every five days (5th, 10th, 15th, 20th, 25th and last day of the month) for snow depths exceeding 5 cm. The gravimetric method is applied. Using a graduated iron snow cylinder with a certain cross-sectional area (in $m^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack. After the height of the snow sample (in m) is measured and excess snow on the external surface of the cylinder is removed, the snow cylinder is attached to a steelyard balance to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

**Automatic measurements:**

No measurements.

## I-2.23.4 Transition from manual to automatic measurements

No parallel manual and automatic measurements have been completed so far.

## I-2.23.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 12 or 24 hours (HMS)<br>AUTO: 10 minutes (HMS) | MANUAL: 12 or 24 hours (HMS) | MANUAL: 5 days (HMS)<br>AUTO: no measurements |

# I-2.24 Moldova

*Figure I-2.24.1 Location of Moldova in Europe*

# I-2.24 Moldova

## Country information

| | |
|---|---|
| Country area, mean country elevation | 33 846 km$^2$, 140 m a.s.l. |
| Authority responsible for snow measurements | State Hydrometeorological Service (SHS)<br>134 Grenoble Street<br>MD-2072 Chișinău |
| Contact | · SHS<br>lidia.trescilo@meteo.gov.md (Lidia Trescilo) |
| Near-real-time data URL and/or contact | · SHS<br>www.meteo.md (during snow season) |
| Archived data URL and/or contact | · SHS<br>hidrometeo@meteo.gov.md |

## General situation

The State Hydrometeorological Service (SHS) is responsible for operational snow observations in the Republic of Moldova (officially; hereafter referred to as Moldova). SHS has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. Manual snow depth observations date back to the 1940s. The data time series of 34 snow stations presented here started in the 1940s and 1950s and are ongoing. Snow depth, presence of snow on the ground and water equivalent of snow cover are manually observed by SHS, while depth of snowfall is not measured.

A continuous snow cover usually becomes established in winter, mainly in the northern and northeastern parts of the country. In these regions, continuous snow cover lasts for more than approximately 50% of all days in the winter season. In the rest of the country, continuous snow cover is rare and occurs on only 15% to 50% of all days in the winter season. A continuous snow cover usually becomes established by the end of December, but in the last few years it has not developed before mid-January. The longest period with a continuous snow cover, and consequently the longest period of snow observations, was in winter 1995/1996, when a snow cover was present for the whole winter season.

Owing to frequent snow melt periods in Moldova, the depth of the snow cover is relatively small. The mean snow depth is approximately 0.1 to 0.2 m in wind-affected areas and approximately 0.1 to 0.15 m in wind-protected areas. The maximum snow depth on record in Moldova is 0.89 m, observed in Briceni (Northern Moldova) in March 1973.

## Overview of measurements (SHS)

Snow depth: stake, ruler (Figs I-2.24.2, I-2.24.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.24.4, I-2.24.5)
Operational purpose of measurements: Agriculture and Forestry, Climatology, Flood forecasting, Hydrology, Meteorology, Road services

## I-2.24.1 Snow depth measurements

Number of stations delivering snow depth data manually: 55
Number of stations delivering snow depth data automatically: 0

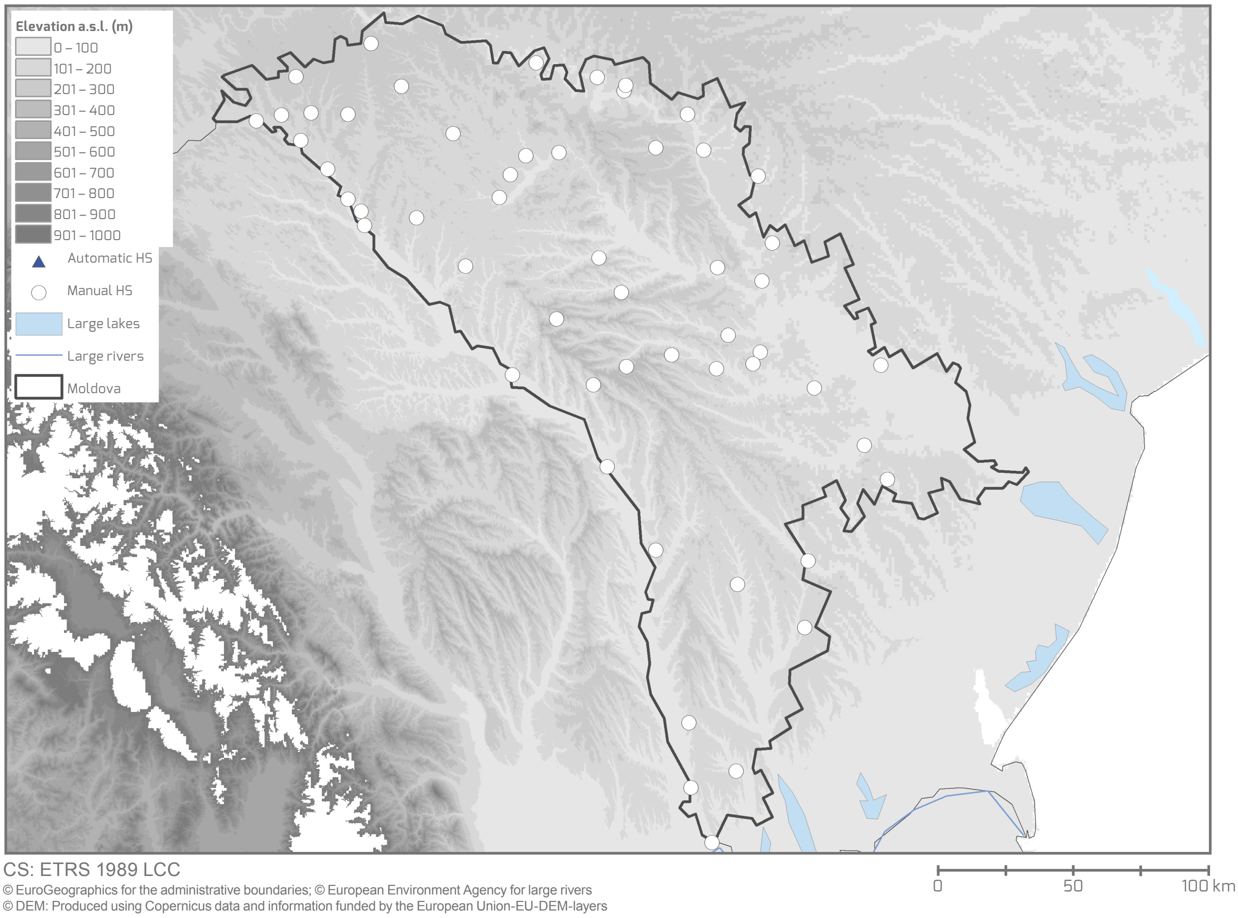

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*Figure I-2.24.2 Locations of stations in Moldova where snow depth (HS) is measured.*

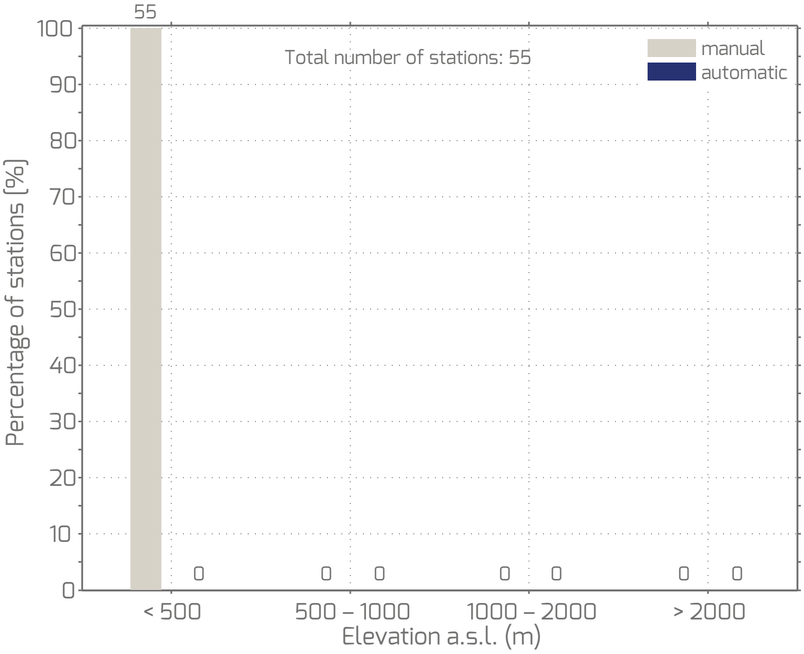

*Figure I-2.24.3 Elevational distribution of stations in Moldova with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours at 0600 UTC at meteorological (18), agrometeorological (16) or hydrological (21) stations. At agrometeorological and hydrological stations snow depth is measured with a portable ruler. At meteorological stations fixed stakes with a scale in centimetres are used; three snow stakes are arranged in a triangle, 10 m apart, and the average of the stake readings is reported as total snow depth. Total snow depth is reported as long as snow depth at the stakes exceeds 0.5 cm. Measured values are reported in full centimetres.

In addition to point measurements of snow depth, spatially distributed snow depth measurements (snow courses) are carried out every 5 days in the surroundings of all 55 snow stations. Snow depth is measured with portable rulers at 100 measurement points along the 2 000-m-long snow courses. The average of all measurements is reported as the total snow depth for a snow course. In parallel, snow density, snow cover characteristics, the structure of the snowpack (e.g. ice or water layers within the snowpack), snow surface conditions (e.g. dry, wet, saturated with water, compressed), and the state of the ground (frozen or thawed) beneath the snowpack are reported. The snow coverage along the snow course is observed visually.

**Automatic measurements:**

No measurements.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is not reported explicitly. However, in parallel to point and spatially distributed (snow course) snow depth measurements, snow coverage is reported at all sites using a 10-point coding system (0–10). Snow coverage is reported for the measurement field and the visible area around the station, as well as along all snow courses. For the coding system, "0" means snow patches cover less than 10% of the measurement field, "1" means snow covers around 10%, and "10" means snow coverage is 100%. The coding system is only applied if snow is present in the measurement field.

**Zero snow depth reporting method:**

If the average of the snow depth readings at the three stakes is less than 0.5 cm, 0 cm snow depth is reported.

## I-2.24.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.24.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 55
Number of stations delivering water equivalent of snow cover data automatically: 0

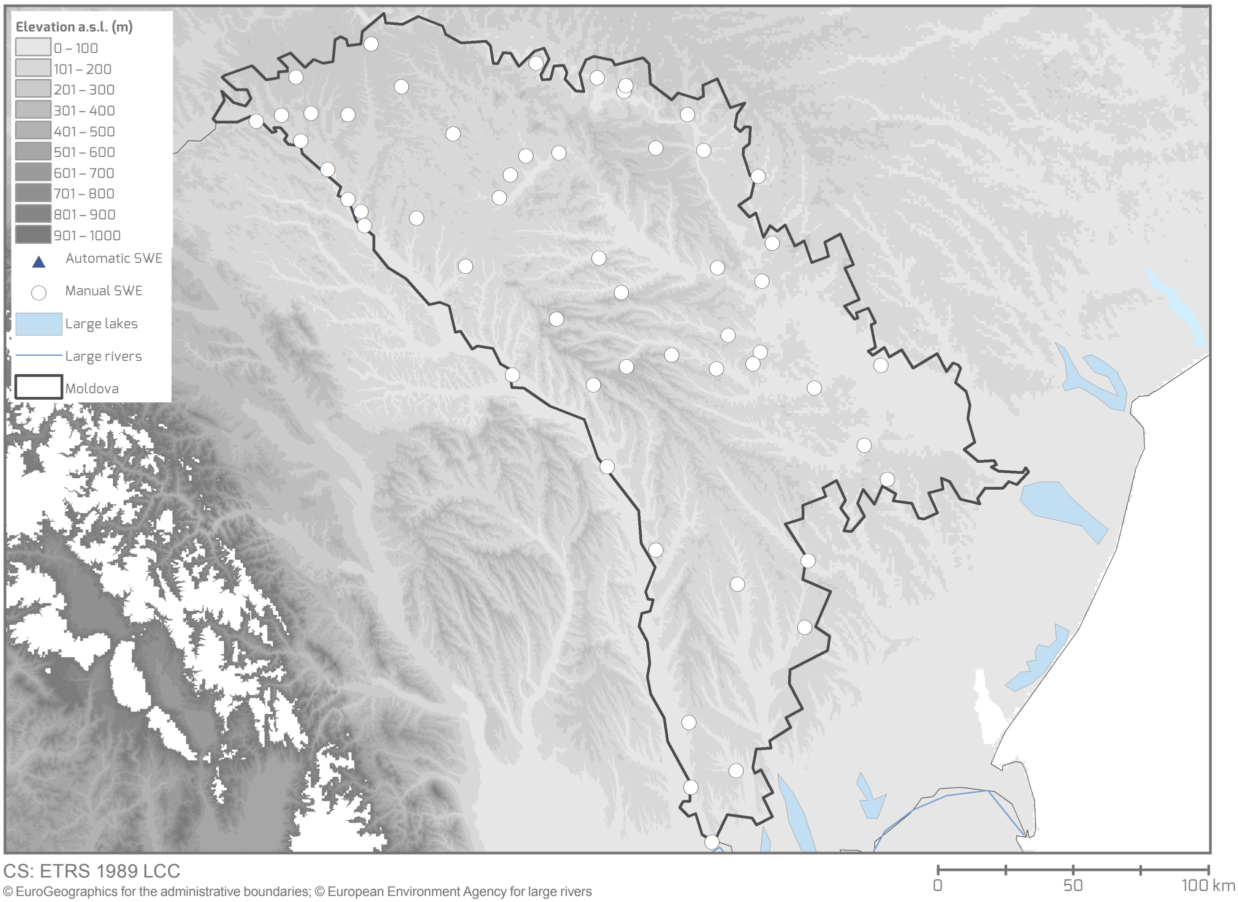

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*Figure I-2.24.4 Locations of stations in Moldova where water equivalent of snow cover (SWE) is measured.*

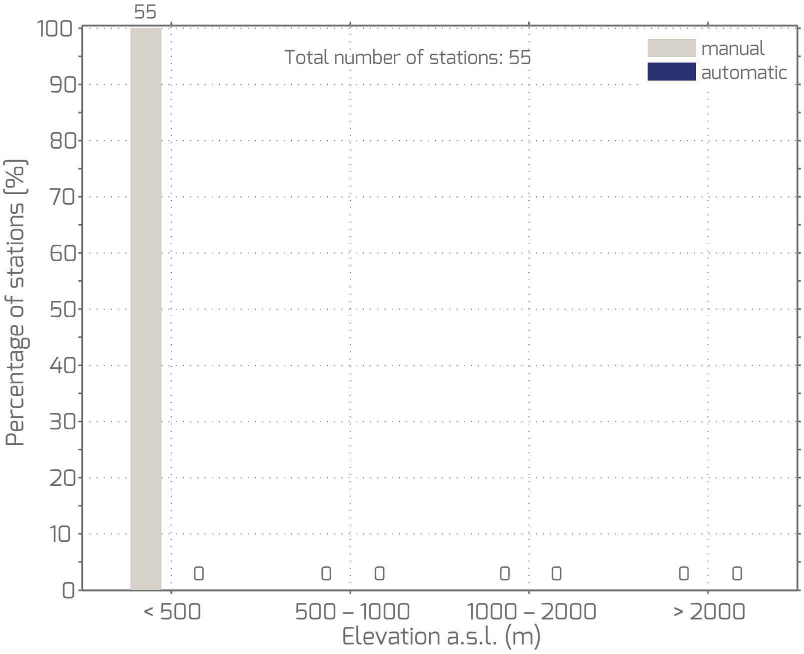

*Figure I-2.24.5 Elevational distribution of stations in Moldova with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every five days along snow courses in the surroundings of the meteorological sites. This is done in parallel to spatially distributed snow cover observations. The gravimetric method is applied. Using a graduated iron snow cylinder (BC-43) with a cross-sectional area of 0.005 $m^2$ and a length of 0.6 m, a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), the snow cylinder is attached to a steelyard balance to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

SWE is measured in a spatially distributed manner: snow density, and consequently SWE, is measured at 10 points and snow depth is measured at 100 points along the 2 000-m-long snow courses. The average value of all SWE observations made within a snow course is reported. As part of the snow density measurements, snow characteristics, the structure of the snowpack (e.g. ice or water layers within the snowpack) and the state of the ground (frozen or thawed) beneath the snowpack are reported. The snow coverage along the snow course is also noted.

**Automatic measurements:**

No measurements.

## I-2.24.4 Transition from manual to automatic measurements

No parallel measurements are carried out because no automatic measurements are performed.

## I-2.24.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours and 5 days (SHS)<br>AUTO: no measurements | MANUAL: no measurements | MANUAL: 5 days (SHS)<br>AUTO: no measurements |

# I-2.25 Montenegro

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*Figure I-2.25.1 Location of Montenegro in Europe.*

# I-2.25 Montenegro

## Country information

| | |
|---|---|
| Country area, mean country elevation | 13 812 km$^2$, 1 031 m a.s.l. |
| Authority responsible for snow measurements | Institute of Hydrometeorology and Seismology of Montenegro (IHMS)<br>IV proleterske 19<br>ME-81000 Podgorica |
| Contact | · IHMS<br>office@meteo.co.me |
| Near-real-time data URL and/or contact | · IHMS<br>Not available. |
| Archived data URL and/or contact | · IHMS<br>http://meteo.co.me/misc.php?text=reports<br>(these are links to yearly reports, not to actual snow data) |

## General situation

The Institute of Hydrometeorology and Seismology (IHMS) is responsible for operational snow observations in Montenegro. IHMS has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. To account for the different prevailing meteorological conditions, especially in the mountains, the IHMS station network is relatively evenly distributed over the entire Montenegrin territory. However, in recent years the number of snow and precipitation observation stations has decreased. Historical snow data until 2010 is available for some stations which are no longer in operational use. IHMS observes snow depth, presence of snow on the ground, depth of snowfall and water equivalent of snow cover manually, while automatic measurements are not yet established but are planned for the future.

## Overview of measurements (IHMS)

Snow depth: stake, ruler (Figs I-2.25.2, I-2.25.3)
Depth of snowfall: snow board and ruler (Figs I-2.25.4, I-2.25.5)
Water equivalent of snow cover: snow cylinder, spring scale (Figs I-2.25.6, I-2.25.7)
Operational purpose of measurements: Agriculture and Forestry, Climatology, Flood forecasting, Health, Hydrology, Meteorology, Road services, Water management

## I-2.25.1 Snow depth measurements

Number of stations delivering snow depth data manually: 39
Number of stations delivering snow depth data automatically: 0

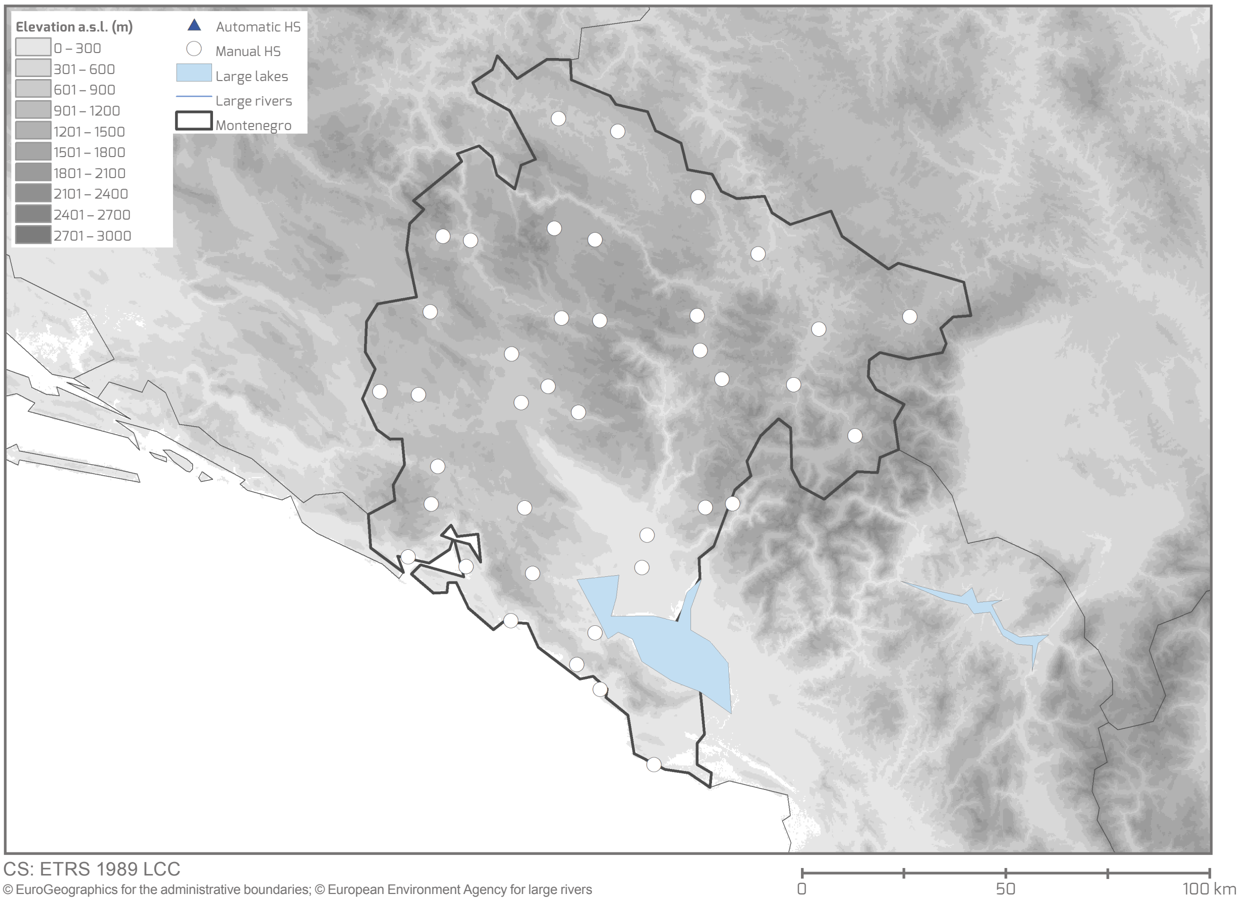

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*Figure I-2.25.2 Locations of stations in Montenegro where snow depth (HS) is measured.*

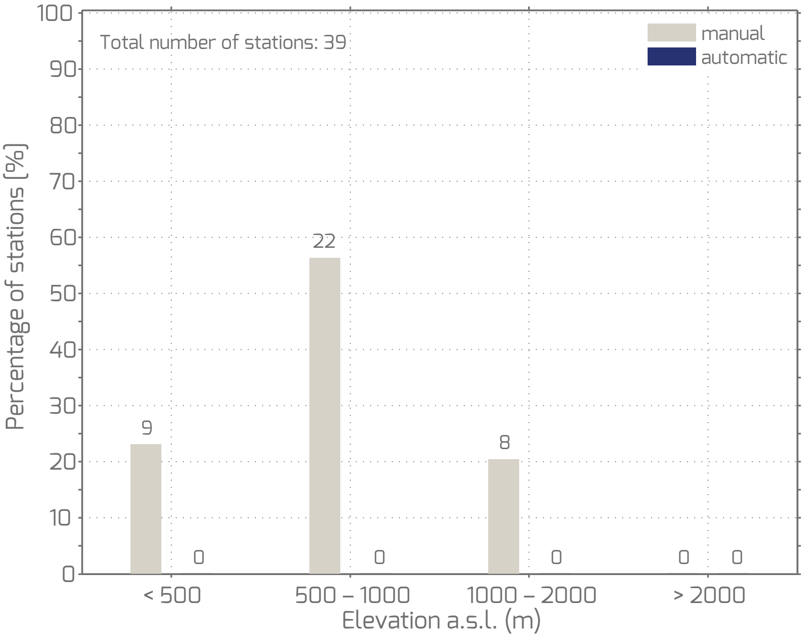

*Figure I-2.25.3 Elevational distribution of stations in Montenegro with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed either every 12 hours at 0600 and 1800 UTC (8 main meteorological stations) or every 24 hours at 0600 UTC (31 stations). Either fixed stakes or portable rulers, both with a scale in centimetres, are used. Total snow depth is reported as long as at least half of the measurement field is covered with snow. Measured values are reported in full centimetres.

### Automatic measurements:

No measurements.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported explicitly, in parallel to manual snow depth measurements. The snow coverage and the state of the ground are additionally reported using a coding system: "5" means compact/wet snow (with or without ice) covers less than 50% of the measurement field; "6" means compact/wet snow (with or without ice) covers more than 50% of the measurement field; "7" means compact/wet snow (with or without ice) covers 100% of the measurement field; "8" means loose dry snow covers more than 50% but less than 100% of the measurement field; and "9" means loose dry snow covers 100% of the measurement field.

### Zero snow depth reporting method:

When more than 50% of the measurement field is snow free, 0 cm snow depth is reported.

## I-2.25.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 39

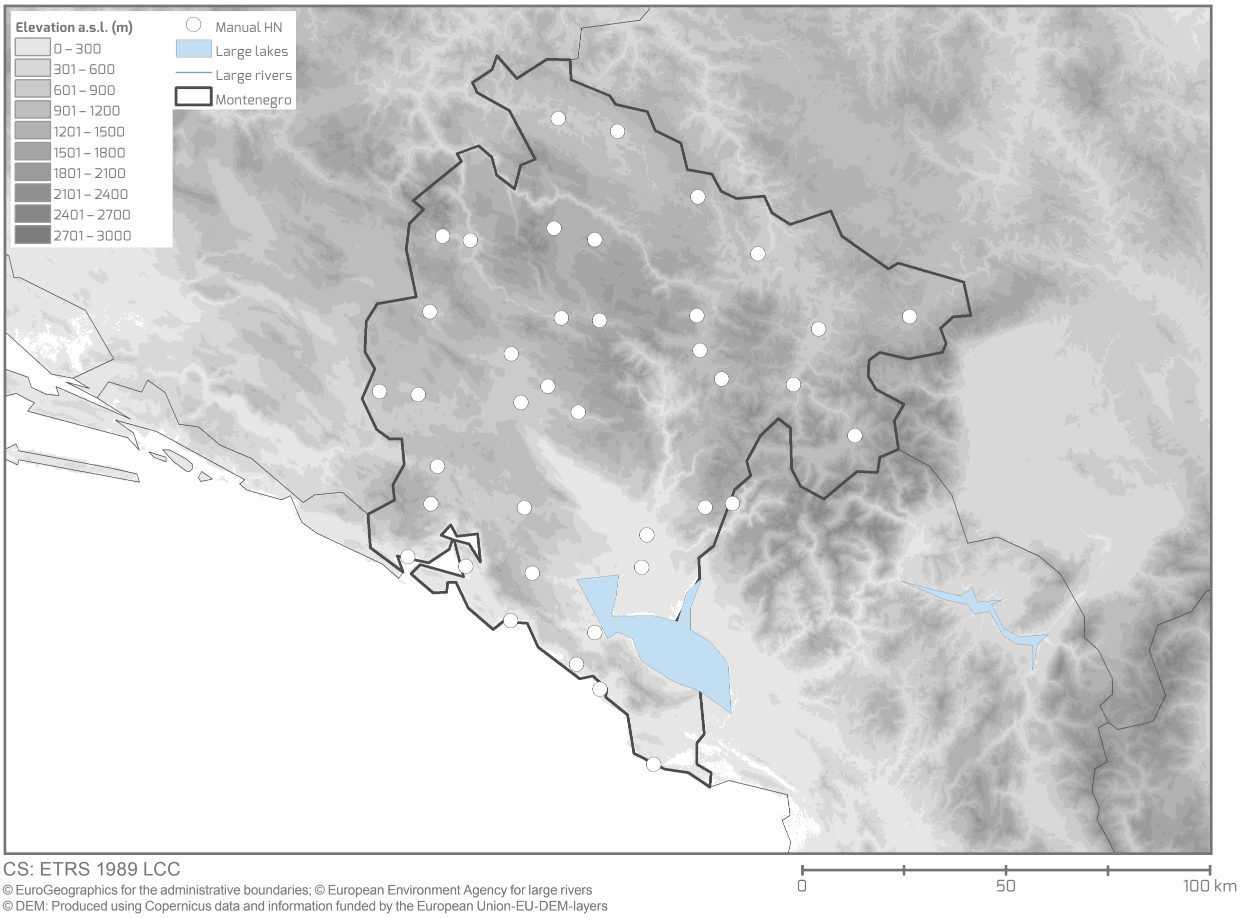

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*Figure I-2.25.4 Locations of stations in Montenegro where depth of snowfall (HN) is measured.*

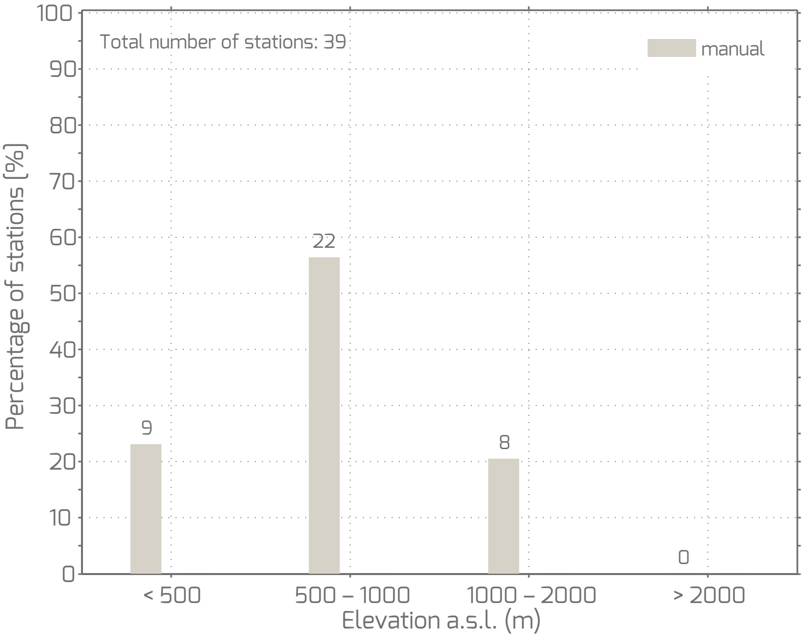

*Figure I-2.25.5 Elevational distribution of stations in Montenegro with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual measurements of depth of snowfall are performed either every 12 hours at 0600 and 1800 UTC (8 main meteorological stations) or every 24 hours at 0600 UTC (31 stations), in parallel to manual snow depth measurements. Depth of snowfall is measured at two to three points on a white-painted snow board with a ruler, and the average of all measurements is reported. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. Measured values are reported in full centimetres.

## I-2.25.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 2
Number of stations delivering water equivalent of snow cover data automatically: 0

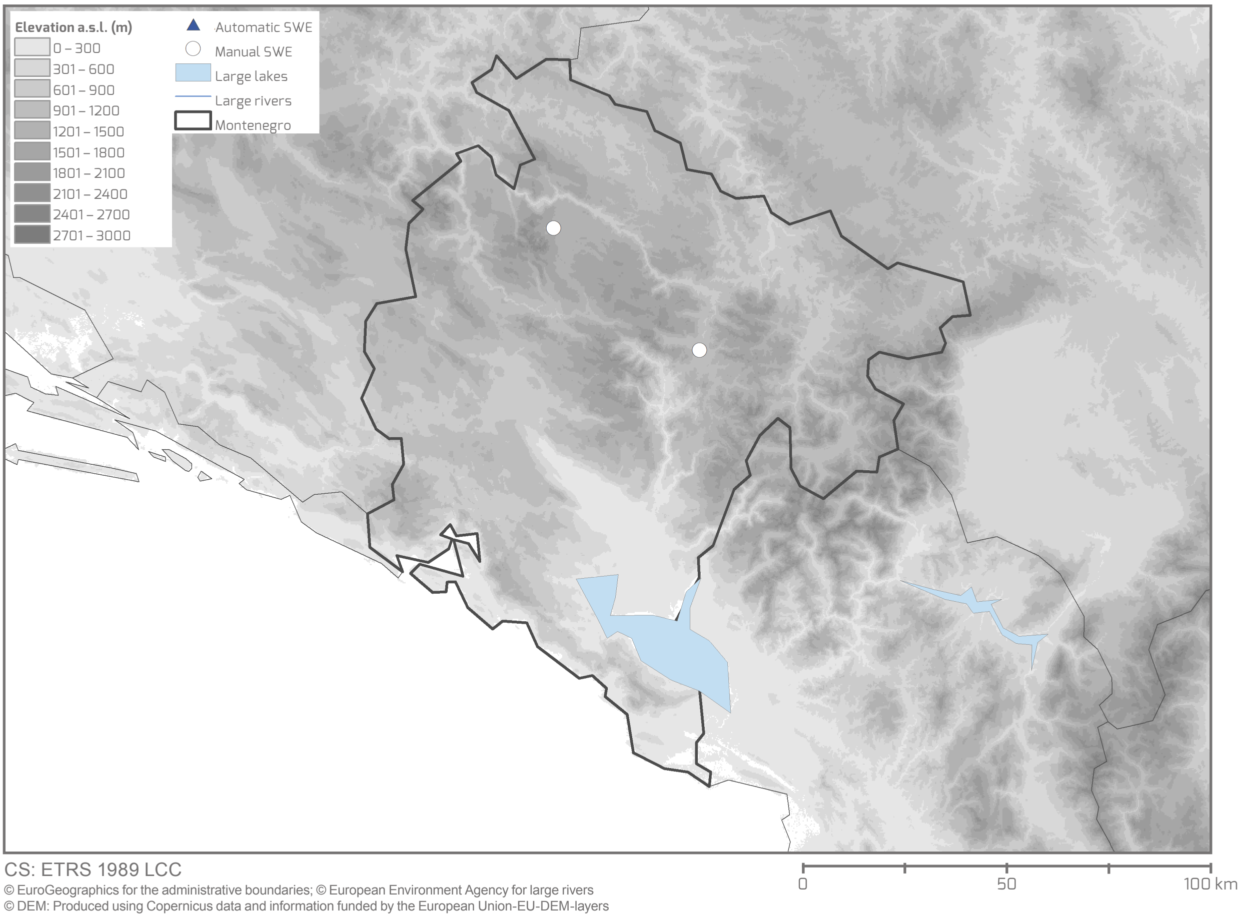

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*Figure I-2.25.6 Locations of stations in Montenegro where water equivalent of snow cover (SWE) is measured.*

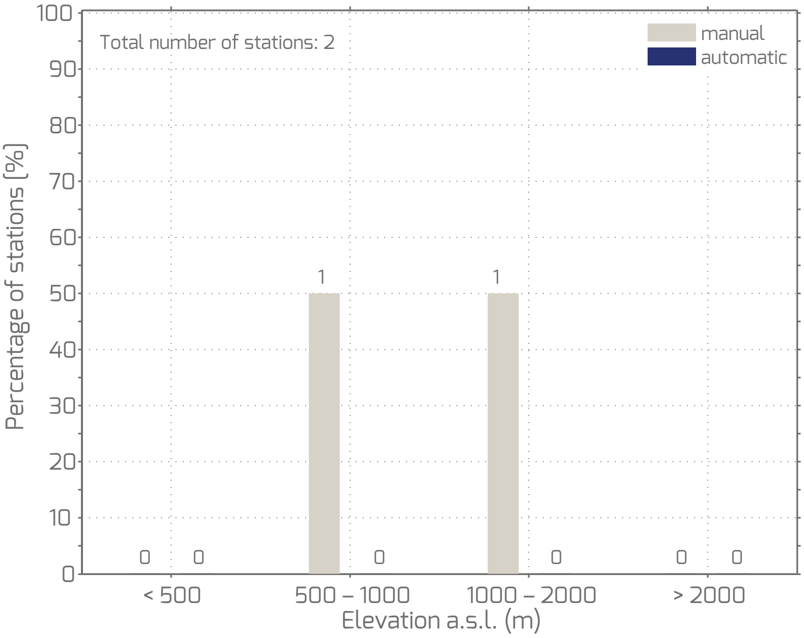

*Figure I-2.25.7 Elevational distribution of stations in Montenegro with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every five days using the gravimetric method. Using a graduated snow cylinder with a certain cross-sectional area (in $m^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), the snow cylinder is attached to a spring scale to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

**Automatic measurements:**

No measurements.

## I-2.25.4 Transition from manual to automatic measurements

No parallel measurements are carried out because only manual stations exist.

## I-2.25.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 12 or 24 hours (IHMS) | MANUAL: 12 or 24 hours (IHMS) | MANUAL: 5 days (IHMS) |
| AUTO: no measurements | | AUTO: no measurements |

# I-2.26 The Netherlands

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*Figure I-2.26.1 Location of the Netherlands in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 41 543 km$^2$, 9 m a.s.l. |
| Authority responsible for snow measurements | Royal Netherlands Meteorological Institute (KNMI)<br>Utrechtseweg 297<br>NL-3731 GA De Bilt |
| Contact | • KNMI<br>klimaatdesk@knmi.nl |
| Near-real-time data URL and/or contact | • KNMI<br>http://www.knmi.nl/nederland-nu/klimatologie-kaarten-en-grafieken |
| Archived data URL and/or contact | • KNMI<br>http://www.knmi.nl/nederland-nu/klimatologie/monv/reeksen |

## General situation

The Royal Netherlands Meteorological Institute (KNMI) is responsible for operational snow observations in the Netherlands. The KNMI station network is evenly distributed over the country. Only manual measurements of snow depth and presence of snow on the ground are performed. KNMI has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records.

## Overview of measurements (KNMI)

Snow depth: ruler (Figs I-2.26.2, I-2.26.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: no measurements
Operational purpose of measurements: Climatology, Meteorology

## I-2.26.1 Snow depth measurements

Number of stations delivering snow depth data manually: 321
Number of stations delivering snow depth data automatically: 0

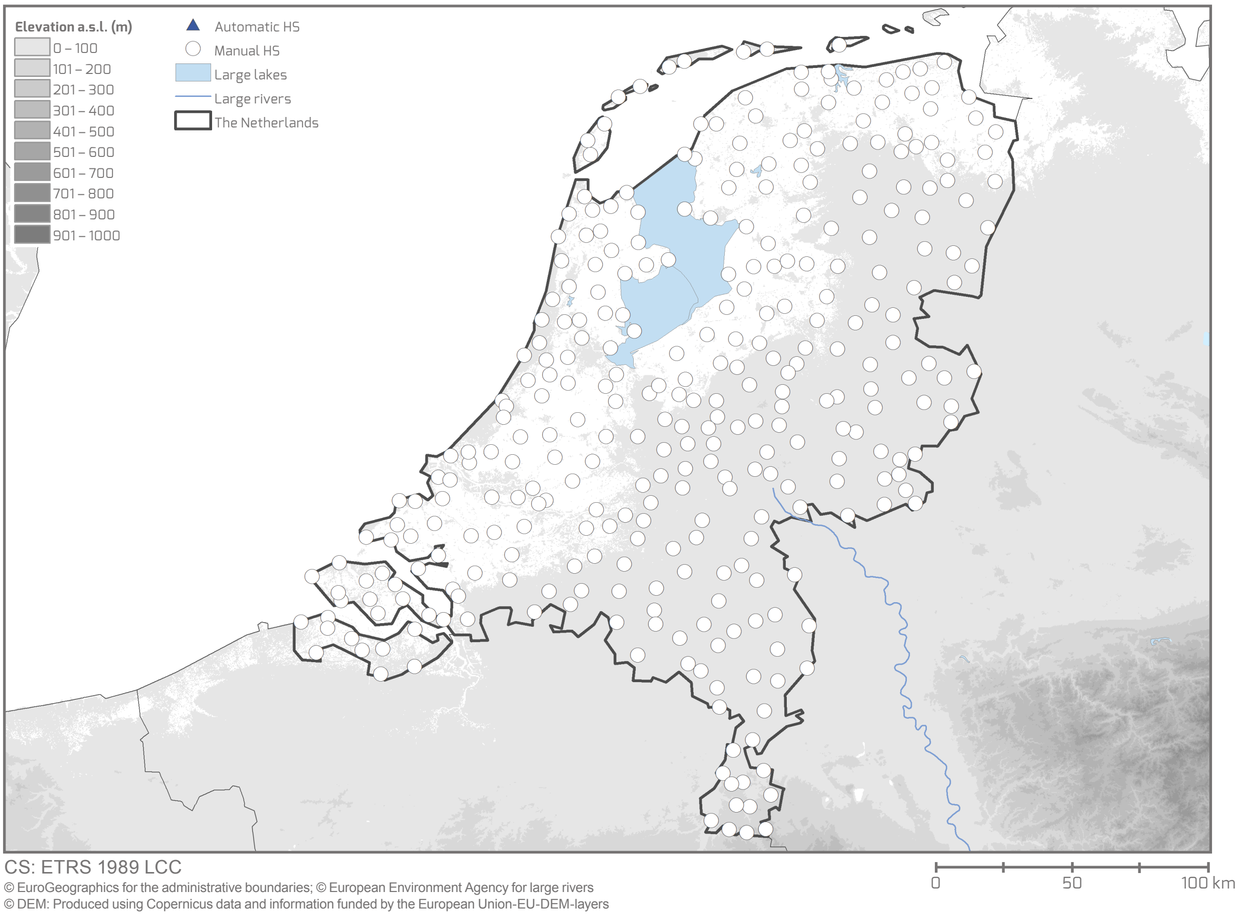

*Figure I-2.26.2 Locations of stations in the Netherlands where snow depth (HS) is measured.*

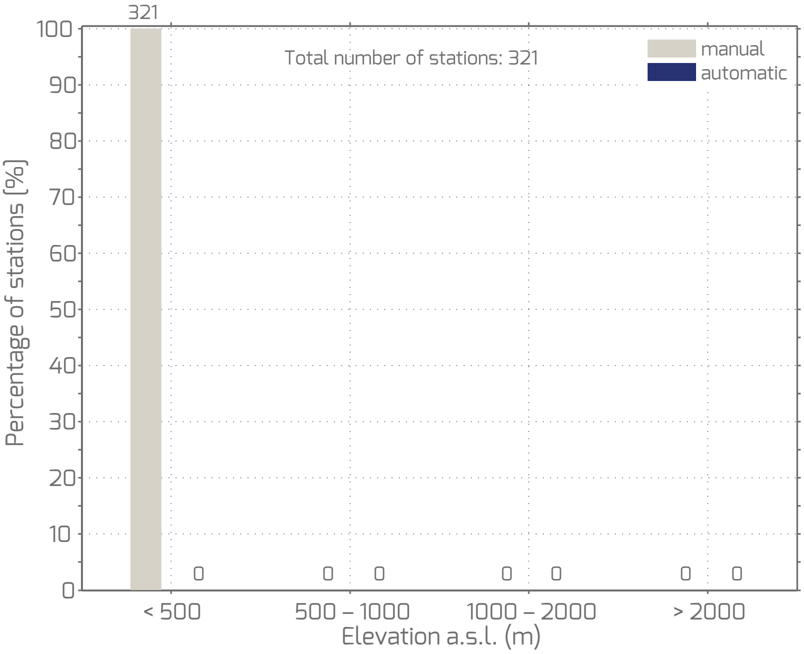

*Figure I-2.26.3 Elevational distribution of stations in the Netherlands with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours. Rulers with a scale in 0.5 cm increments and a total length of 30 cm are used (Fig. I-2.26.4). In parallel to manual snow depth measurements, precipitation is measured with a precipitation gauge located within each measurement field.

**Automatic measurements:**

No measurements.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is reported explicitly. A coding system is used to describe the snow coverage in the measurement field: (1) “997” means patchy snow cover is present, with depths less than 1 cm; (2) “998” means patchy snow cover is present, with depths exceeding 1 cm; and (3) “999” means the measurement field is fully snow covered.

**Zero snow depth reporting method:**

When the measurement field is 100% snow free, 0 cm snow depth is reported.

*Figure I-2.26.4 Ruler used by KNMI observers to measure snow depth (Source: KNMI).*

## I-2.26.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.26.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 0

**Manual measurements:**

No measurements.

**Automatic measurements:**

No measurements.

## I-2.26.4 Transition from manual to automatic measurements

No parallel measurements are performed and there are no plans to shift from manual to automatic stations.

## I-2.26.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (KNMI)<br>AUTO: no measurements | MANUAL: no measurements | MANUAL: no measurements<br>AUTO: no measurements |

# I-2.27 Norway

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*Figure I-2.27.1 Location of Norway in Europe.*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 323 802 km$^2$, 553 m a.s.l. |
| Authority responsible for snow measurements | The Norwegian Water Resources and Energy Directorate (NVE)<br>Middelthuns gate 29<br>NO-0368 Oslo<br><br>The Norwegian Meteorological Institute (METNo)<br>Postboks 43 Blindern<br>NO-0313 Oslo<br><br>Norwegian Public Roads Administration (NPRA)<br>Brynsengfaret 6A, P.O. Box 8142 Dep<br>NO-0033 Oslo |
| Contact | · NVE<br>snodata@nve.no<br>· METNo<br>klima@met.no<br>· NPRA<br>knut.orset@vegvesen.no (Knut Inge Orset) |
| Near-real-time data URL and/or contact | · NVE<br>http://sildre.nve.no/ (for all hydrological variables; only available in Norwegian)<br>http://www.senorge.no/<br>(simulated snow maps with the possibility to add stations with real-time measurements)<br>http://www.xgeo.no/ ('expert version' of senorge)<br>· METNo<br>senorge.no<br>· NPRA<br>www.xgeo.no/?p=snoskred&m=bmGeodataGraatone%3BMapLayer_fsw%3BMapLayer_st_snodyp%3B&l=no&e=-885137%7C6531655%7C1889225%7C7840265&ft=1%3B |
| Archived data URL and/or contact | · NVE<br>snodata@nve.no<br>· METNo<br>https://www.met.no/en/free-meteorological-data/Download-services<br>· NPRA<br>knut.orset@vegvesen.no (Knut Inge Orset) |

# I-2.27 Norway

## General situation

Three institutions – the Norwegian Water Resources and Energy Directorate (NVE), the Norwegian Meteorological Institute (METNo) and the Norwegian Public Roads Administration (NPRA) – share the duty of performing snow observations in Norway. METNo has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. NVE is the national centre for expertise in hydrological applications and climate research and is therefore also involved in research and development. In addition, NVE is responsible for forecasting natural hazards such as floods, landslides and snow avalanches. NPRA is responsible for the Norwegian national and county roads. NVE, METNo and NPRA exchange their data and use the collective data for their various products (e.g. forecasts, climatology), especially for snow avalanche forecasting.

Snow depth has been measured manually since 1883. Currently, the national network of manual and automatic snow depth stations consists of more than 450 stations operated by NVE, METNo and NPRA. While snow depth is measured frequently by NVE, METNo and NPRA, water equivalent of snow cover is only measured by NVE and presence of snow on the ground is only observed by METNo. Depth of snowfall is not measured operationally at all. More information on the Norwegian snow measurement network is available at www.nve.no or can be read in the publications by Ragulina et al. (2011), Ree et al. (2011) and Stranden et al. (2015). The manual and automatic snow depth station network of all three institutions together is equally distributed over the alpine, midland and coastal regions of Norway. A few manual water equivalent of snow cover stations exist in southern and central Norway, whereas automatic stations observing water equivalent of snow cover in real time are also found in northern Norway.

The most precipitation usually occurs in the western part of Norway, where water equivalent of snow cover is between 1 000 and 2 000 mm w.e. at the time of expected maximum snow depth. In both the eastern and the northernmost parts of Norway, the climate is generally drier. Some locations in the eastern part of the country and along the coastline can have less than 50–100 mm w.e. at the time of expected maximum snow depth. Various climate maps, including average and annual maximum water equivalent of snow cover, can be found online at: www.senorge.no/?p=klima.

In addition to the above-mentioned institutions, hydropower companies such as Statkraft have measured snow depth (manually and automatically) and water equivalent of snow cover (manually since the 1920s and automatically since 1967) in a large monitoring network for decades. The snow depth and water equivalent of snow cover monitoring network of these hydropower companies comprises between 300 and 400 stations. While automatic snow depth is measured frequently (e.g. every hour by Statkraft), manual measurements of snow depth and water equivalent of snow cover are performed on an annual basis at the time of expected maximum snow depth by several hydropower companies. Many of these companies report their annual measurements to NVE. However, their snow data is not publicly available and thus their stations are not included in this report. Only the NVE, METNo and NPRA snow measurement networks are discussed below.

## Overview of measurements (NVE, METNo, NPRA)

Snow depth: stake, ruler, rod, ultrasonic snow depth sensor, laser snow depth sensor, ground-penetrating radar (Figs I-2.27.2, I-2.27.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: snow cylinder, snow tube, spring scale, snow pillow, snow scale, passive gamma radiation sensor (Figs I-2.27.5, I-2.27.6)
Operational purpose of measurements: Avalanche warning, Climatology, Energy production, Flood forecasting, Hydrology, Natural hazard forecasting (e.g. landslides, rockslides)

## I-2.27.1 Snow depth measurements

Number of stations delivering snow depth data manually: 298

Number of stations delivering snow depth data automatically: 179

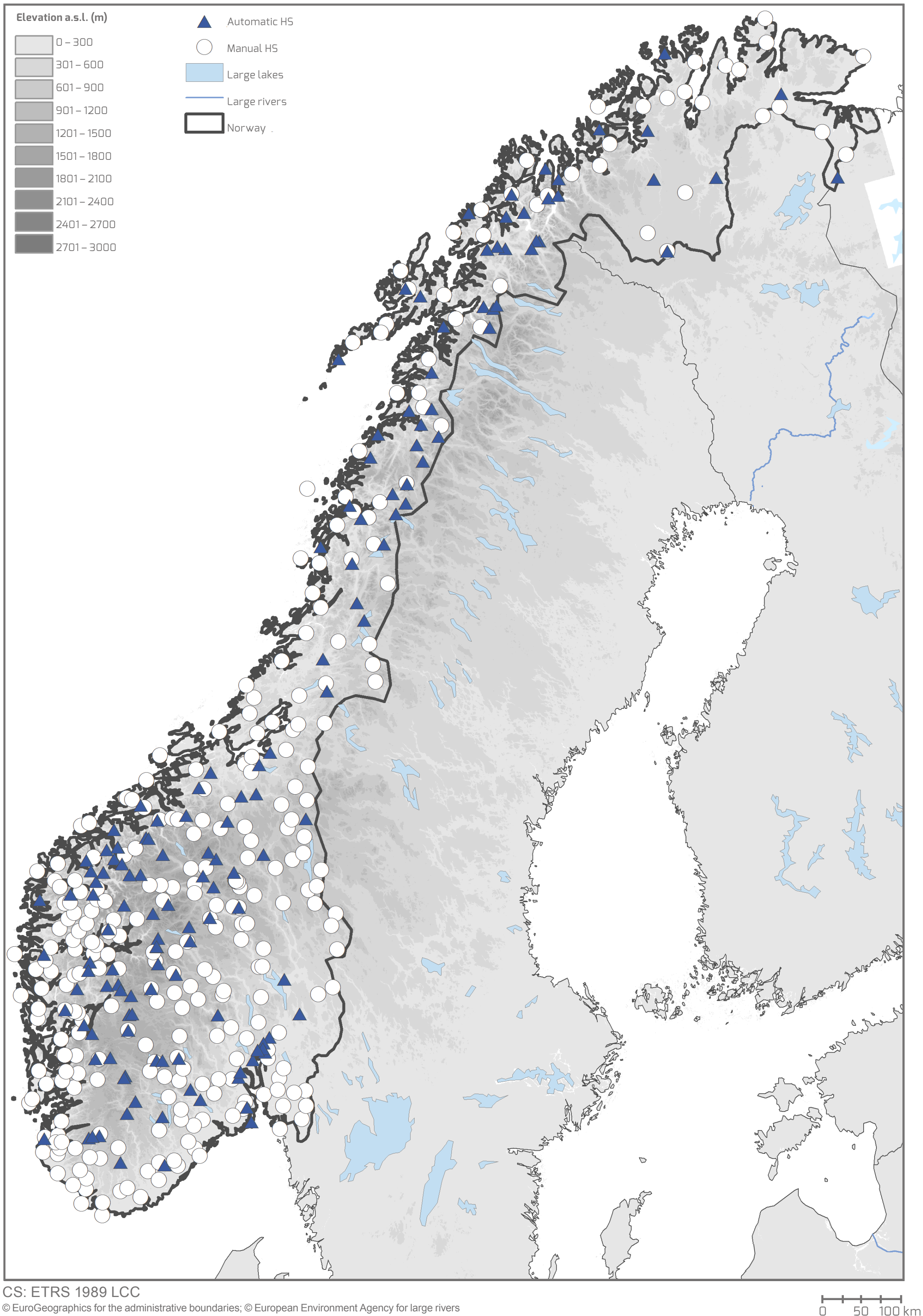

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*Figure I-2.27.2 Locations of stations in Norway where snow depth (HS) is measured.*

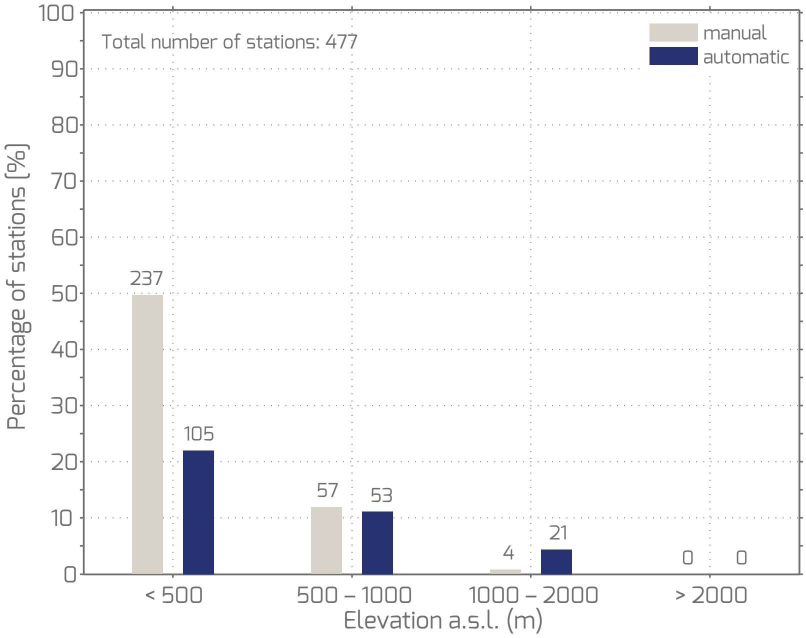

*Figure I-2.27.3 Elevational distribution of stations in Norway with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours by METNo. At most stations fixed stakes with a scale in centimetres are used (Fig. I-2.27.4 a). At only a few stations, snow depth is measured manually at different locations using a portable ruler. The average of these measurements is reported as total snow depth; it is reported as long as snow is present at the stake and in the close surroundings of the stake.

In contrast to METNo, NVE measures snow depth manually along snow courses once a year. This is done at the time of maximum snow depth, usually in March or April, in parallel to water equivalent of snow cover sampling. Portable devices such as rulers, (avalanche) rods and graduated stakes are used to measure snow depth along each snow course in defined steps, and the average of all readings (including readings of 0 cm depth) is reported as total snow depth for a snow course. The length of the snow courses varies among measurement locations: (1) At one location five snow courses exist, each at a different elevational level between 800 and 1200 m a.s.l., and the courses vary in length from 645 to 2300 m; snow depth is measured every 10 to 50 m. (2) At another location an 80-km-long snow course exists; snow depth is measured using a ground-penetrating radar, but also using a ruler or graduated stake every 2 km (40 point measurements in total). (3) At a third location snow depth measurements are carried out once every two weeks or once a month. For a snow course, the mean of all stake readings is reported as total snow depth. Snow course sections lacking snow are accounted for because 0 cm readings are included in the mean value. All measurements are reported in full centimetres by both NVE and METNo.

### Automatic measurements:

Automatic snow depth measurements are performed in different intervals: every 10 minutes by NPRA, every 60 minutes by METNo, and every 15 or 60 minutes by NVE. Various ultrasonic and laser snow depth sensors are in use. Ultrasonic snow depth sensors (SR50 and SR50A made by Campbell Scientific, Logan, Utah, USA or USH-8 made by Sommer Messtechnik, Vorarlberg, Austria) are used at 98 of 125 METNo stations, at all 20 NVE stations (Fig. I-2.27.4 b) and at 21 of 34 NPRA stations. Laser snow depth sensors (SHM30; Lufft, Fellbach, Germany) are only used by METNo (27 of 125 stations) and NPRA (13 of 34 stations). The snow depth sensor installation height varies depending on the site and expected maximum snow depth. Snow depth sensors operated by NVE are mainly mounted above a mass registration device, such as a snow pillow or snow scale; METNo sensors are installed above natural ground, gravel or glass fibre plates, whereas most NPRA sensors are installed above gravel. NVE performs manual control measurements at every automatic station location at least once during the winter season in order to verify automatic measurements. These complementary reference measurements are not included in this report.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is only reported explicitly by METNo. METNo reports that no snow is present only when there is a complete absence of snow. In addition to snow depth, the state of the ground is reported by METNo using a coding system following WMO recommendations.

**Zero snow depth reporting method:**

METNo reports 0 cm snow depth if no snow is present at the stake. If the situation is not entirely clear METNo observers use the following codes: "0" means snow depth is less than 0.5 cm at the stake; "-1" means no snow is present at the stake but snow exists in the surroundings; and "-3" means snow measurements cannot be made. NVE reports 0 cm snow depth for a snow course if the average of all measurement points is 0 cm.

*Figure I-2.27.4 Snow depth stations in Norway: (a) Manual site Aursund operated by METNo (Source: METNo). (b) Automatic station Anestølen operated by NVE (Source: NVE).*

## I-2.27.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.27.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 7
Number of stations delivering water equivalent of snow cover data automatically: 20

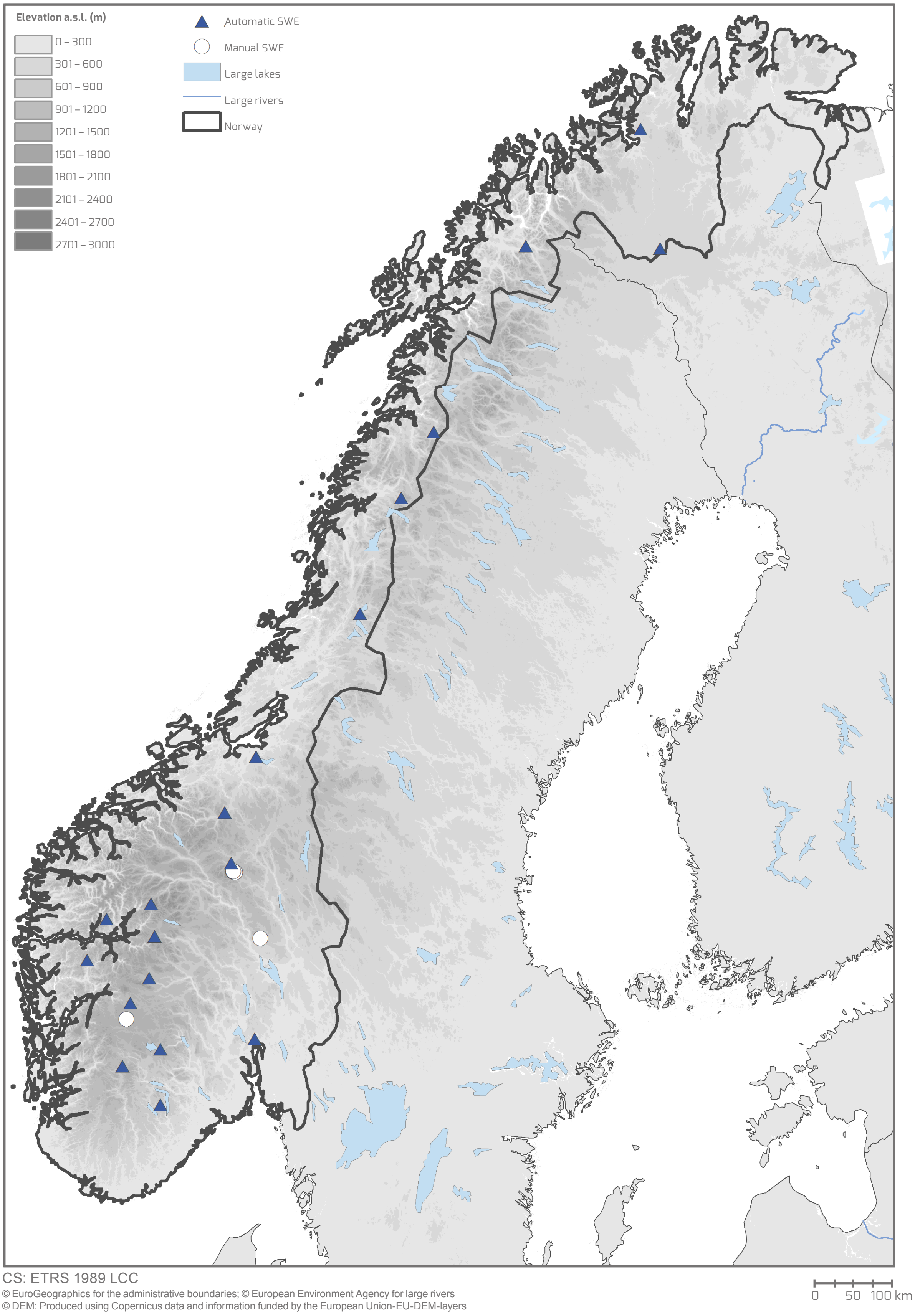

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*Figure I-2.27.5 Locations of stations in Norway where water equivalent of snow cover (SWE) is measured.*

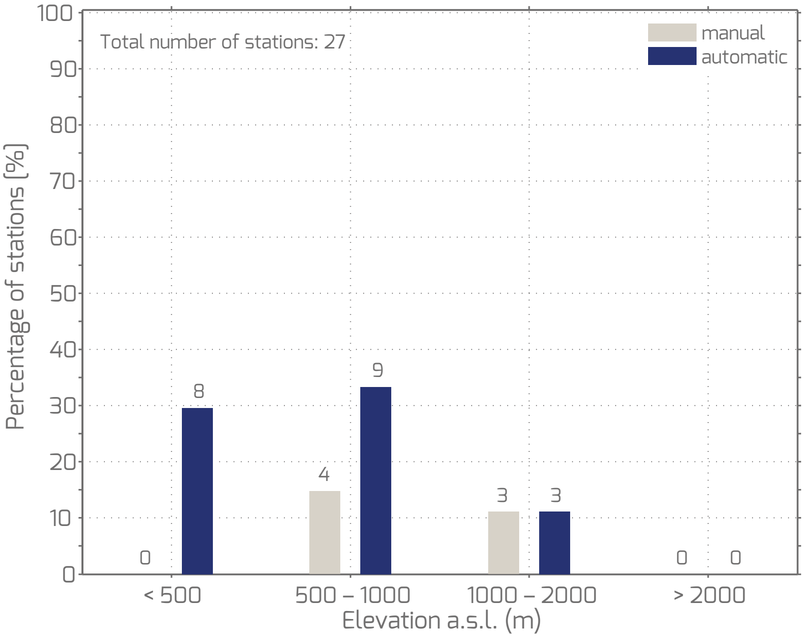

*Figure I-2.27.6 Elevational distribution of stations in Norway with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

NVE is the only governmental institution in Norway that measures SWE operationally. Water equivalent of snow cover is measured manually along snow courses either (1) in snow pits using snow cylinders or (2) using snow tubes (without snow pits). The gravimetric method is applied.

(1) A snow sample is extracted vertically from the snowpack using a graduated snow cylinder with a diameter of 0.072 m, a length of 0.5 m and a volume of 0.002 m$^3$ (Fig I-2.27.7 a). After the height of the snow sample (in m) is measured, the sample is transferred into a bag or bucket, which is then attached to a spring scale to measure the weight of the snow sample (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. If the snow depth is greater than the length of the snow cylinder (0.5 m), the total snow depth is divided into multiple analogue “columns”. Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

(2) A snow sample is extracted vertically from the snowpack using a snow tube (McCall sampler) with a diameter of 0.037 m (Fig I-2.27.7 b, c). After the height of the snow sample (in m) is measured, the sample is transferred into a bag or bucket, which is then attached to a spring scale to measure the total weight of the snow (in kg). The corresponding SWE of the snowpack (in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow tube.

For snow depths less than 0.5 m, snow cylinder measurements are preferred over snow tube measurements. A snow cylinder with a volume of 0.001 m$^3$ may also be used if the snow depth is less than 0.25 m. The average of all SWE readings is reported as the total SWE for a snow course.

The length of the snow courses and the measurement interval applied vary among measurement locations: (1) At one location SWE is measured manually along five snow courses once a year at the time of maximum snow depth, usually in March or April. The five snow courses cover a small catchment area, where each course is located at a different elevational level between 800 and 1200 m a.s.l. Snow density and SWE are measured at one point in each snow course, and values are used in combination with multiple snow depth measurements to calculate a mean SWE value for the snow course. (2) At another location with an 80-km-long snow course, SWE is measured manually once a year at the time of maximum snow depth. Every 2nd kilometre, snow density and consquently SWE are measured along with snow depth, resulting in 40 point measurements of SWE in total. (3) At a third snow course location SWE and snow depth measurements are carried out once every two weeks or once a month.

**Automatic measurements:**

Automatic SWE measurements are performed either every hour using various mass registration devices (snow pillow, snow scale; Fig. I-2.27.8 a) or daily using a passive gamma radiation sensor (CS725; Campbell Scientific; Fig. I-2.27.8 b) by NVE. Currently, three snow scales and around 20 snow pillows are in use. Snow pillows cover an area of 2.5 x 2.5 m, are made out of PVC and are filled with a mixture of glycol and water. A riser pipe is attached to the pillow and the pressure transducer is located in the riser pipe. Snow scales cover an area of 5 x 5 m, are made out of wood and are authorised for a maximum load of 25 000 kg. NVE performs manual control measurements at every automatic station location at least once during each winter season in order to verify automatic measurements. These complementary reference measurements are not included in this report.

*Figure I-2.27.7 Manual water equivalent of snow cover measurements: (a) in snow pits using a snow cylinder; (b, c) with snow tubes (Source: NVE).*

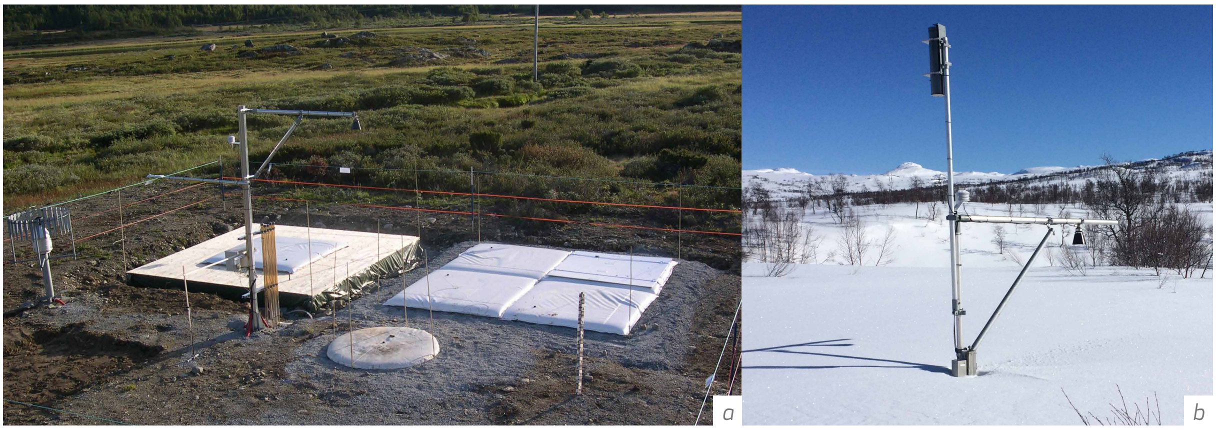

*Figure I-2.27.8 (a) Snow pillow and snow scale at the Filefjell station. (b) Gamma radiation sensor at the Breidvatn station (Source: NVE).*

## I-2.27.4 Transition from manual to automatic measurements

At NVE and NPRA stations a need for parallel measurements has not yet arisen. At some METNo stations parallel measurements are performed, but they are not mandatory and no official data analysis report is available.

## I-2.27.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (METNo), 2 weeks (NVE), 1 month (NVE) or 1 year (NVE)<br>AUTO: 10 minutes (NPRA), 15 minutes (NVE) or 60 minutes (METNo, NVE) | MANUAL: no measurements | MANUAL: 2 weeks, 1 month or 1 year (NVE)<br>AUTO: 60 minutes or 24 hours (NVE) |

# I-2.28 Poland

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*Figure I-2.28.1 Location of Poland in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 312 679 km$^2$, 171 m a.s.l. |
| Authority responsible for snow measurements | Institute of Meteorology and Water Management – National Research Institute (IMGW)<br>Ul. Podleśna 61<br>PL-01-673 Warszawa |
| Contact | · IMGW<br>bok@imgw.pl |
| Near-real-time data URL and/or contact | · IMGW<br>http://pogodynka.pl/polska/snieg/ |
| Archived data URL and/or contact | · IMGW<br>http://www.imgw.pl/kontakt/ |

## General situation

The Institute of Meteorology and Water Management – National Research Institute (IMGW) is responsible for operational snow observations in Poland. The IMGW station network is equally distributed over the alpine, midland and lowland regions. IMGW has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. IMGW observes snow depth, presence of snow on the ground, depth of snowfall and water equivalent of snow cover manually, while snow depth is additionally measured automatically. In addition to IMGW, the snow observation team of the Space Research Centre (CBK) – Polish Academy of Sciences operationally measures snow, but data from this group is not included in this country report.

## Overview of measurements (IMGW)

Snow depth: ruler, ultrasonic snow depth sensor (Figs I-2.28.2, I-2.28.3)
Depth of snowfall: snow board and ruler (Figs I-2.28.4, I-2.28.5)
Water equivalent of snow cover: snow cylinder, steelyard balance, electronic scale (Figs I-2.28.6, I-2.28.7)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Hydrology, Meteorology, Road services, Water management

## I-2.28.1 Snow depth measurements

Number of stations delivering snow depth data manually: 690
Number of stations delivering snow depth data automatically: 33

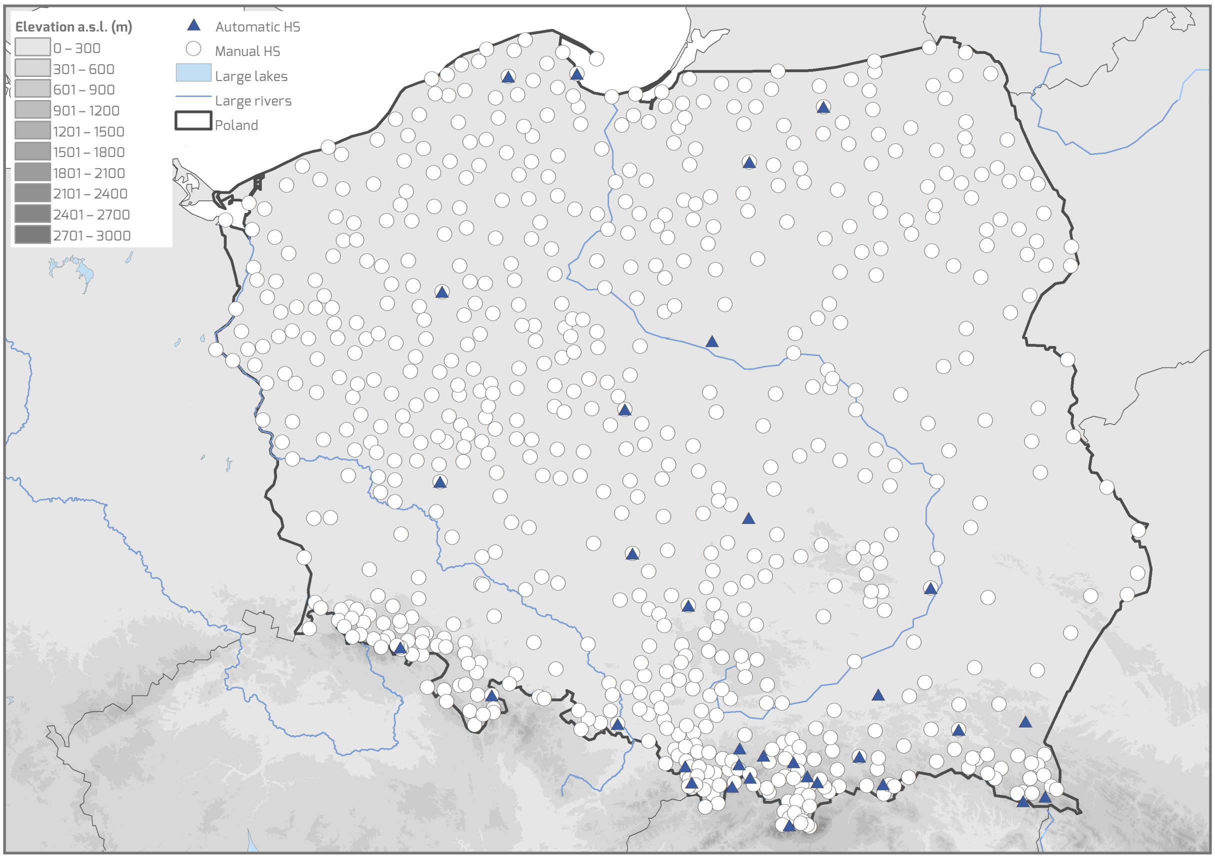

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*Figure I-2.28.2 Locations of stations in Poland where snow depth (HS) is measured.*

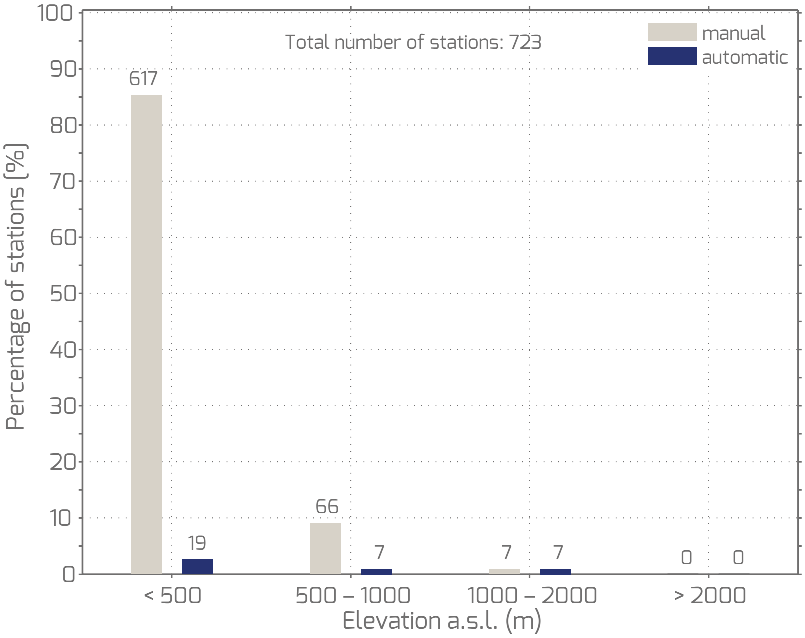

*Figure I-2.28.3 Elevational distribution of stations in Poland with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours at 0600 UTC. Portable rulers with a scale in centimetres are used. Several snow depth measurements are performed within a measurement field and the average of all measurements is reported. If snow falls between 0600 and 1800 UTC, an additional snow depth measurement is performed at 1800 UTC. Measured values are reported in full centimetres.

**Automatic measurements:**

Automatic snow depth measurements are performed every 10 minutes. Ultrasonic snow depth sensors (USH-8; Sommer Messtechnik, Vorarlberg, Austria) are used. Snow depth sensors are mounted 3 m above artificial targets made from Astro Turf®.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is reported explicitly by IMGW observers.

**Zero snow depth reporting method:**

For snow depths less than 0.5 cm, 0 cm snow depth is reported.

## I-2.28.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 690

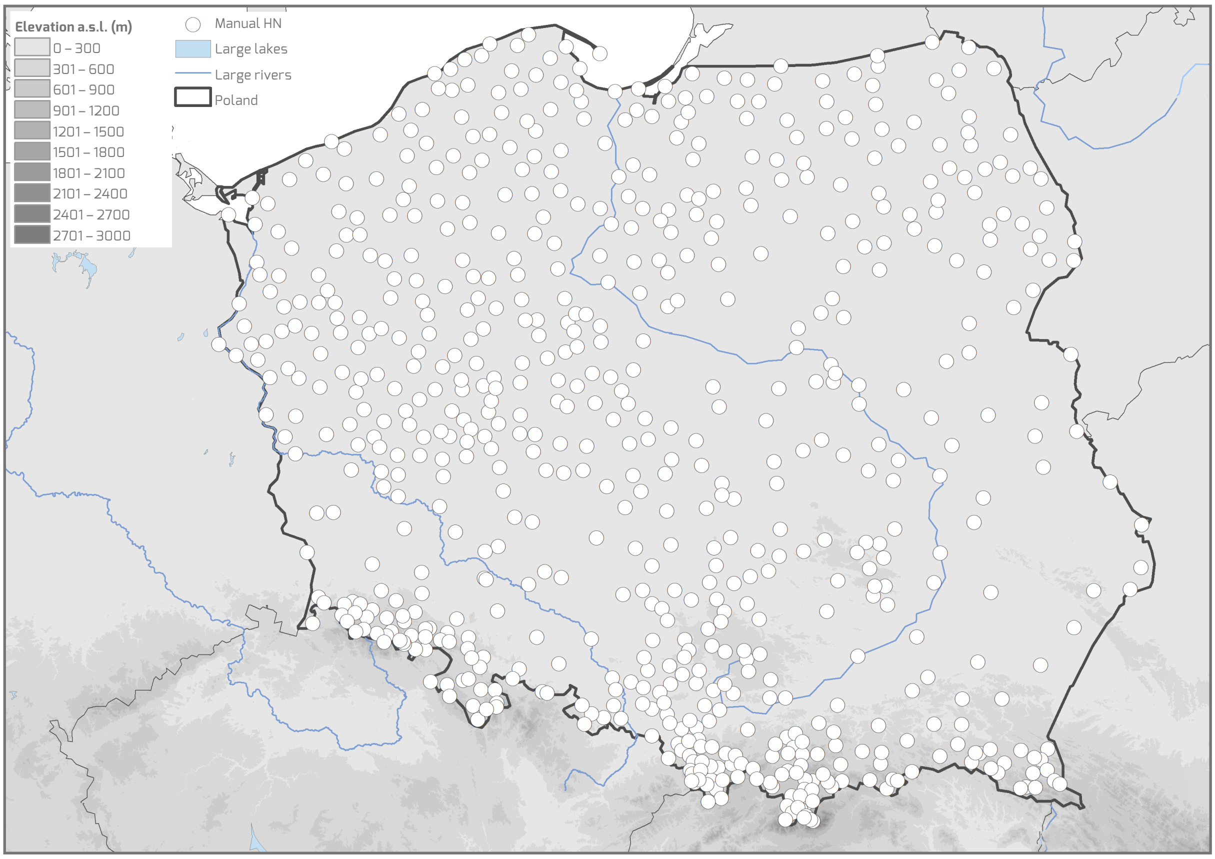

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*Figure I-2.28.4 Locations of stations in Poland where depth of snowfall (HN) is measured.*

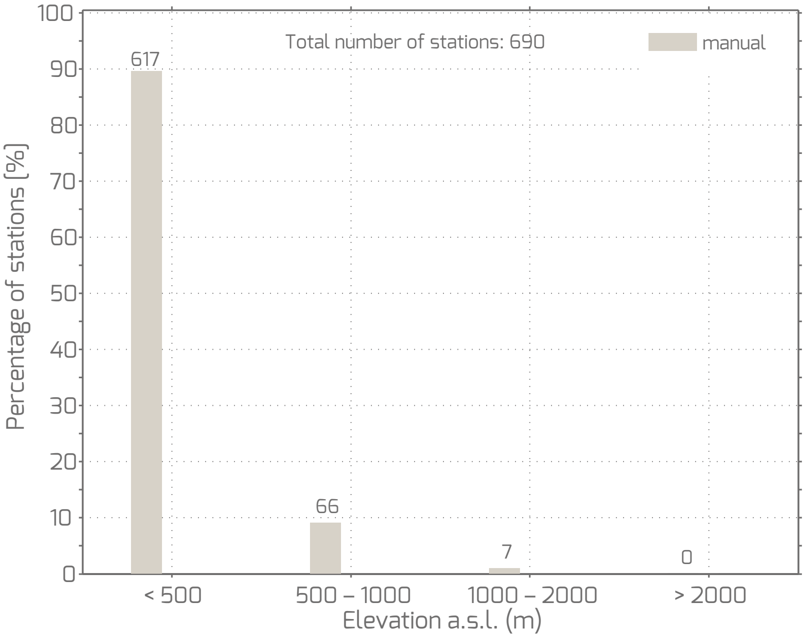

*Figure I-2.28.5 Elevational distribution of stations in Poland with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual measurements of depth of snowfall are performed every 6 hours at 0000, 0600, 1200 and 1800 UTC at the same stations where snow depth is manually measured. Depth of snowfall is measured on a white-painted snow board (0.6 x 0.6 m) with a ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. Measured values are reported in full centimetres.

## I-2.28.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 170
Number of stations delivering water equivalent of snow cover data automatically: 0

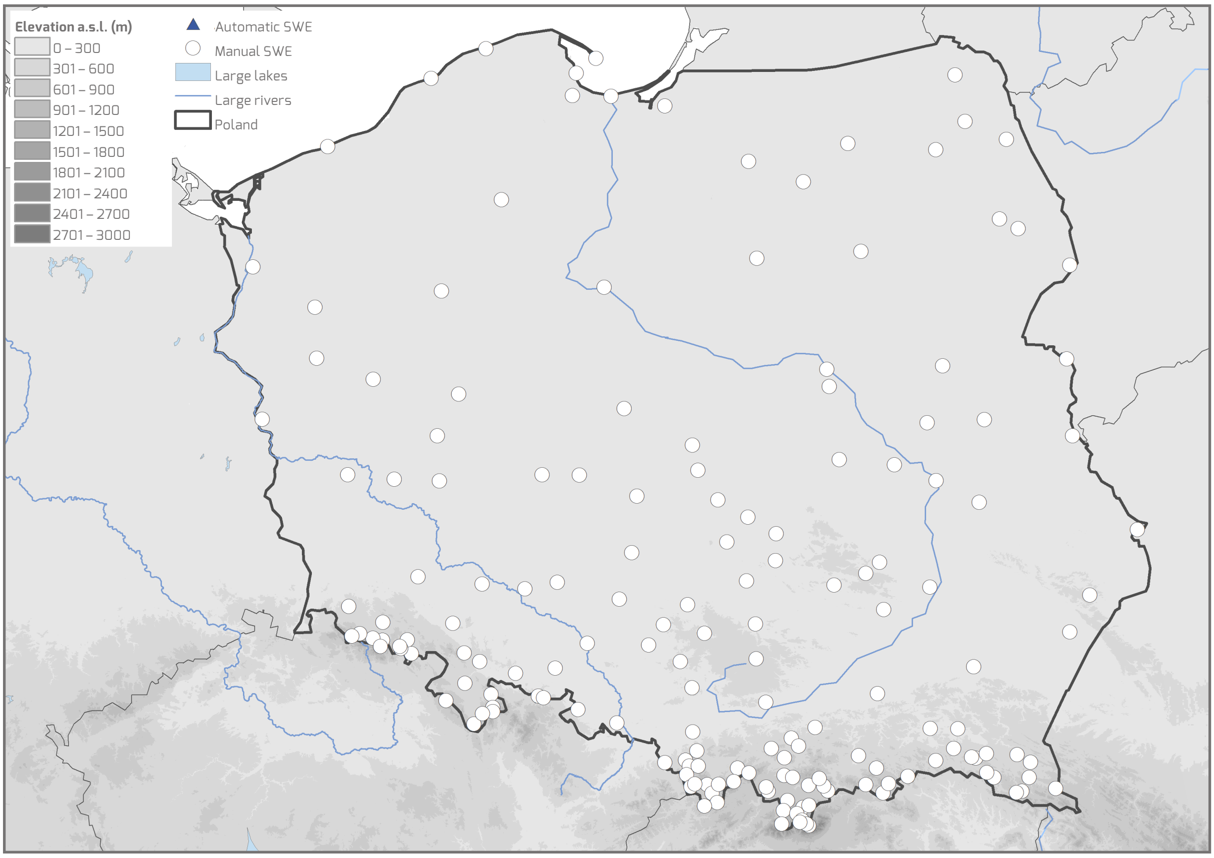

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*Figure I-2.28.6 Locations of stations in Poland where water equivalent of snow cover (SWE) is measured.*

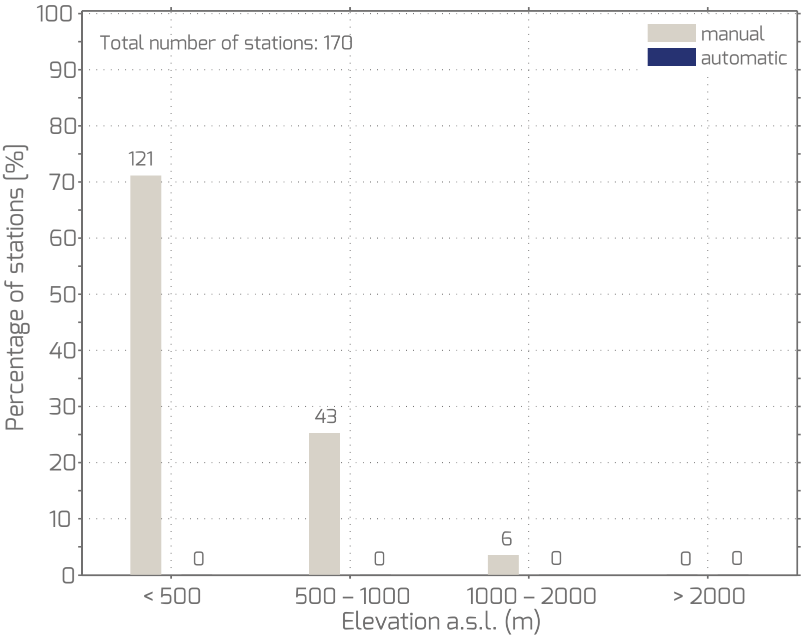

*Figure I-2.28.7 Elevational distribution of stations in Poland with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every 24 hours. The gravimetric method is applied. Using a graduated snow cylinder with a certain cross-sectional area (in $m^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), the snow cylinder is attached to a steelyard balance or to an electronic scale to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. If the snow depth is greater than the length of the cylinder, the total snow depth is divided into multiple analogue “columns”. Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

**Automatic measurements:**

No measurements.

## I-2.28.4 Transition from manual to automatic measurements

Parallel manual and automatic measurements are completed for a minimum of one year.

## I-2.28.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (IMGW)<br>AUTO: 10 minutes (IMGW) | MANUAL: 6 hours (IMGW) | MANUAL: 24 hours (IMGW)<br>AUTO: no measurements |

# I-2.29 Portugal

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*Figure I-2.29.1 Location of Portugal in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 92 226 km$^2$, 317 m a.s.l. |
| Authority responsible for snow measurements | Instituto Português do Mar e da Atmosfera (IPMA)<br>Rua C do Aeroporto<br>PT-1749-077 Lisboa |
| Contact | • IPMA<br>jorge.neto@ipma.pt (Jorge Neto) |
| Near-real-time data URL and/or contact | • IPMA<br>Not available. |
| Archived data URL and/or contact | • IPMA<br>jorge.neto@ipma.pt (Jorge Neto) |

## General situation

The Instituto Português do Mar e da Atmosfera (IPMA) is the Portuguese National Meteorological Service and is responsible for operational snow measurements in Portugal. IPMA has additional duties, such as: (1) monitoring weather and climate; (2) producing weather forecasts and, when appropriate, meteorological warnings; (3) providing daily briefings to the National Civil Protection department, including, when appropriate, high impact weather and fire risk indicators; (4) operating and maintaining the network of national meteorological stations; (5) monitoring seismic activity and operating a network of seismic stations; (6) contributing to research and development in meteorology, climatology, earth observation and seismology; and (7) monitoring ocean environmental conditions and the health of ocean biota. All these tasks include the responsibility to measure snow variables. Currently, only snow depth and presence of snow on the ground are manually observed by IPMA, while automatic snow depth measurements are planned for the future.

## Overview of measurements (IPMA)

Snow depth: ruler (Figs I-2.29.2, I-2.29.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: no measurements
Operational purpose of measurements: Meteorology

## I-2.29.1 Snow depth measurements

Number of stations delivering snow depth data manually: 9
Number of stations delivering snow depth data automatically: 0

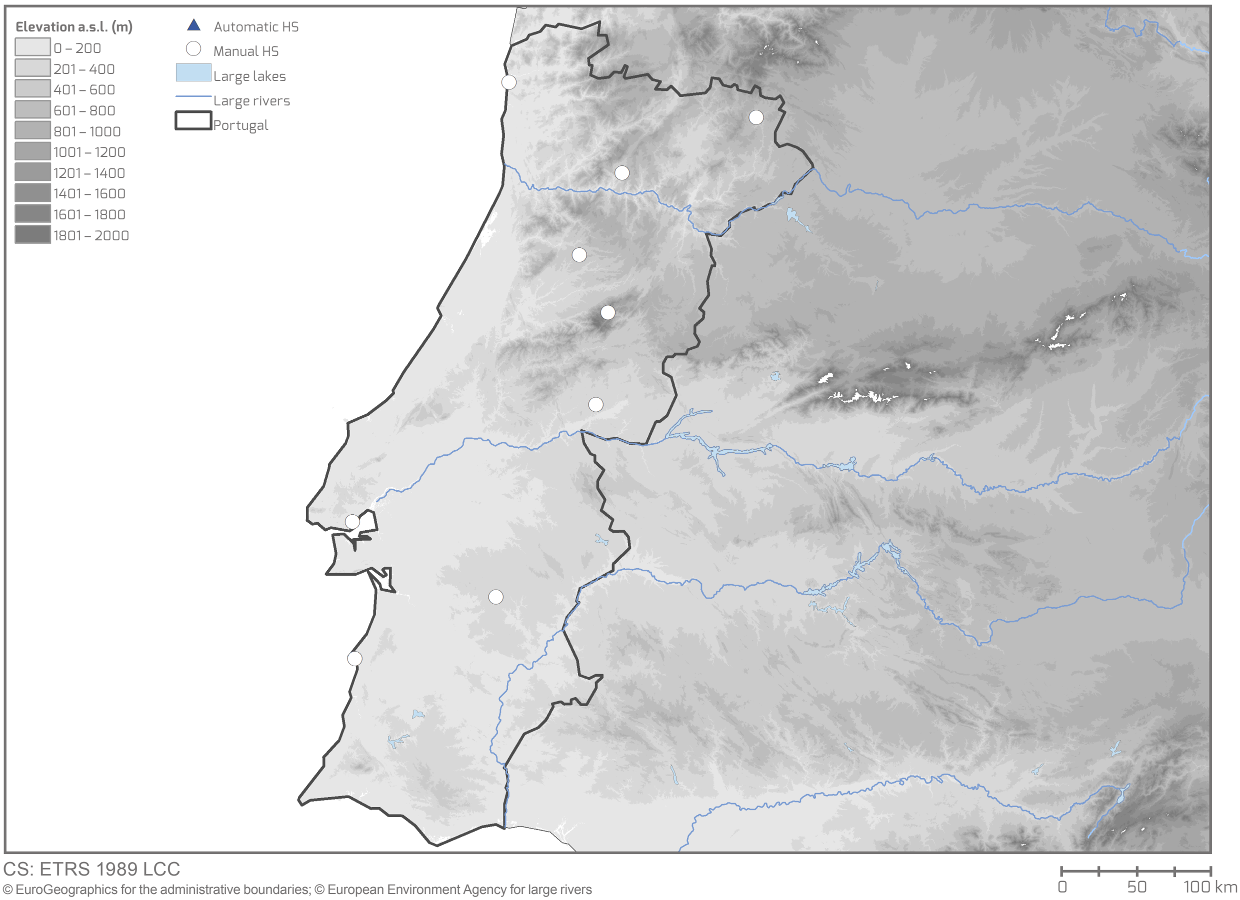

*Figure I-2.29.2 Locations of stations in Portugal where snow depth (HS) is measured.*

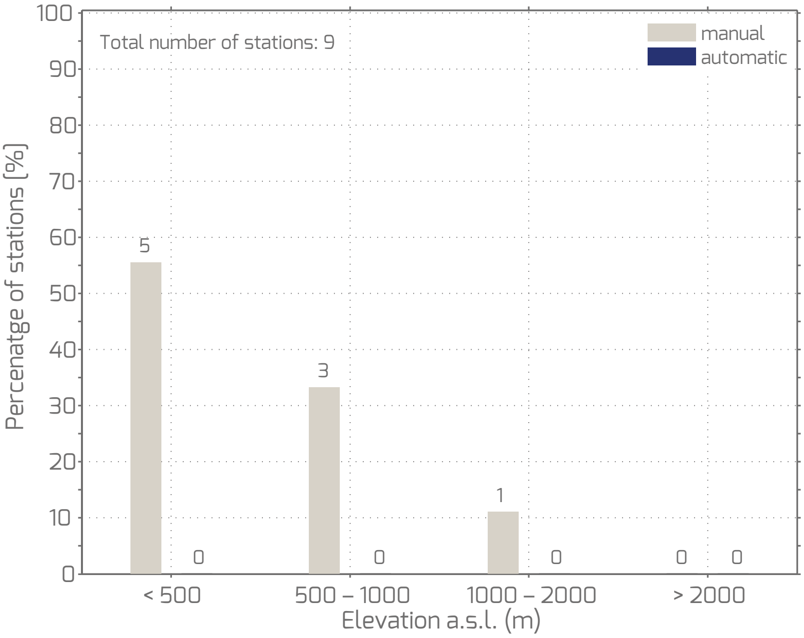

*Figure I-2.29.3 Elevational distribution of stations in Portugal with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed every 24 hours using rulers with a scale in centimetres. The measurement fields have a size of 1 x 1 m. Total snow depth is reported as long as at least half of the measurement field is covered with snow.

**Automatic measurements:**

No measurements.

**Presence of snow on the ground reporting method:**

Presence of snow on the ground is reported explicitly.

**Zero snow depth reporting method:**

When more than 50% of the measurement field (area of 1 m$^2$) is snow free, 0 cm snow depth is reported.

## I-2.29.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.29.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 0

**Manual measurements:**

No measurements.

**Automatic measurements:**

No measurements.

## I-2.29.4 Transition from manual to automatic measurements

No parallel measurements are carried out because no automatic measurements are performed.

## I-2.29.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (IPMA)<br>AUTO: no measurements | MANUAL: no measurements | MANUAL: no measurements<br>AUTO: no measurements |

# I-2.30 Romania

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*Figure I-2.30.1 Location of Romania in Europe.*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 238 391 km$^2$, 395 m a.s.l. |
| Authority responsible for snow measurements | National Meteorological Administration Romania (NMA)<br>Sos. Bucuresti-Ploiesti 97<br>RO-013686 Bucharest |
| Contact | · NMA<br>relatii@meteoromania.ro |
| Near-real-time data URL and/or contact | · NMA<br>www.meteoromania.ro (during snow season, search for map name: grosimea stratului de zapada) |
| Archived data URL and/or contact | · NMA<br>relatii@meteoromania.ro |

### General situation

The National Meteorological Administration Meteo Romania (NMA) and the National Institute of Hydrology and Water Management share the duty of performing snow observations in Romania. Both institutions have an extensive snow observation network. However, only information from NMA is included in this country report because the National Institute of Hydrology and Water Management did not complete the ESB Questionnaire.

NMA has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. Snow depth, presence of snow on the ground and water equivalent of snow cover are observed by NMA, while depth of snowfall is not measured. The NMA snow measurement network is discussed below.

### Overview of measurements (NMA)

Snow depth: stake, ultrasonic snow depth sensor (Figs I-2.30.2, I-2.30.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.30.5, I-2.30.6)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Flood forecasting, Hydrology, Meteorology, Water management

## I-2.30.1 Snow depth measurements

Number of stations delivering snow depth data manually: 148
Number of stations delivering snow depth data automatically: 4

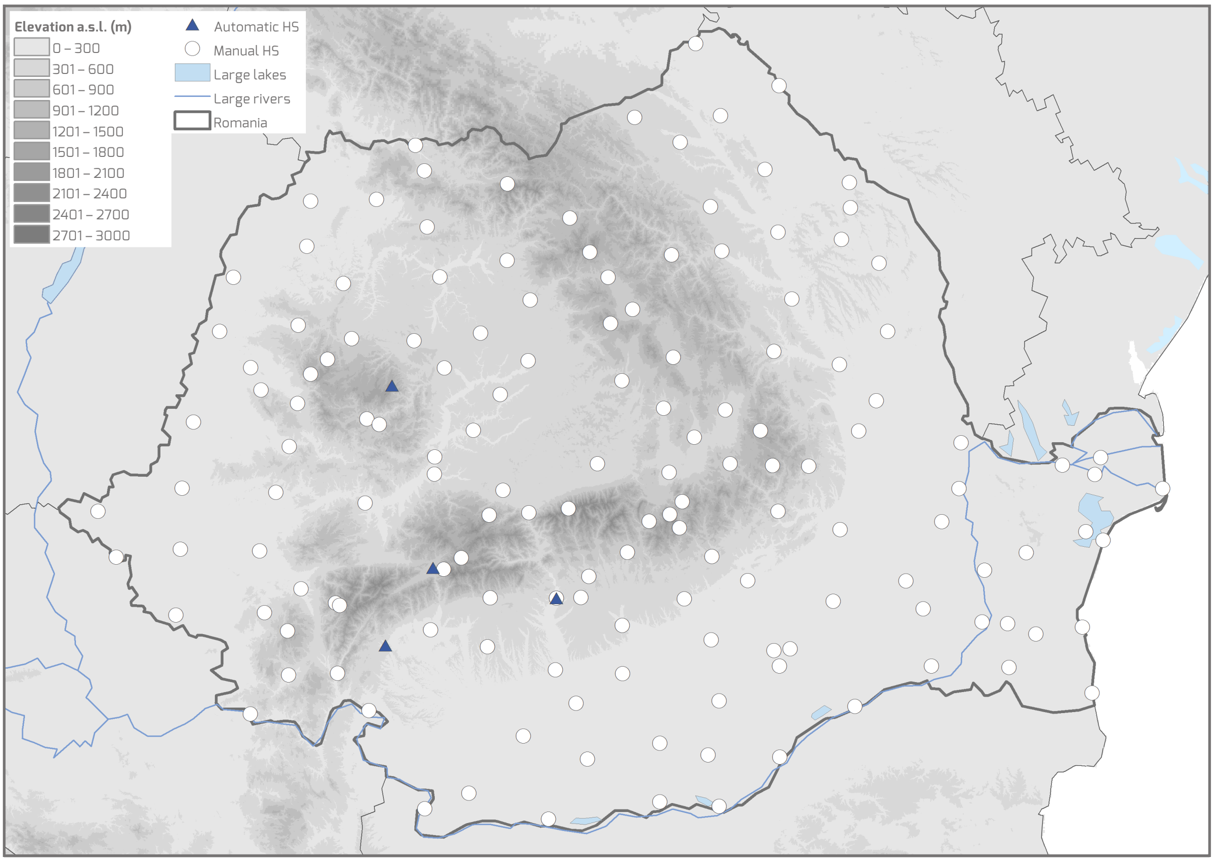

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*Figure I-2.30.2 Locations of stations in Romania where snow depth (HS) is measured.*

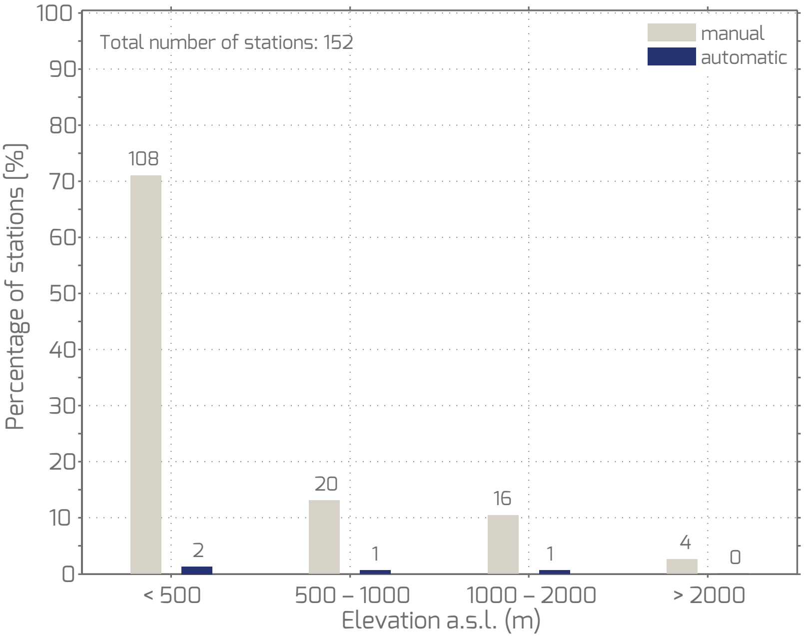

*Figure I-2.30.3 Elevational distribution of stations in Romania with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed in different intervals, depending on the station: (1) every 6 hours at 0000, 0600, 1200 and 1800 UTC (78 stations), (2) every 8 hours (60 stations), (3) every 12 hours at 0600 and 1800 UTC (1 station) and (4) every 24 hours at 0600 UTC (9 stations). However, in response to a new requirement from the Romanian National Center for Prognosis, in the future snow depth will be measured in parallel to synoptic observations every 6 hours (0000, 0600, 1200 and 1800 UTC) at all 148 snow depth measurement locations. Fixed stakes with a scale in centimetres are used (Fig. I-2.30.4 a). Within a measurement field, three snow stakes are arranged in a triangle, 10 m apart. The average of the three stake readings is reported as total snow depth. The observers avoid creating disturbances in the measurement field around the stake. To prevent incorrect measurements, values are read as horizontally to the surface as possible and at a distance of 2 to 3 m from the stakes. When the average snow depth at the three stakes is less than 1 cm, 0 cm snow depth is reported. Measured values are reported in full centimetres.

The snow stakes are installed in autumn and removed after the disappearance of snow during spring. The stake locations are marked when the stakes are removed so they can be re-installed at the exact same locations in the following autumn.

**Automatic measurements:**

Automatic snow depth measurements are performed every 6 hours using ultrasonic snow depth sensors (IRU-9429; Vaisala, Vantaa, Finland; Fig. I-2.30.4 b).

**Presence of snow on the ground reporting method:**

In parallel to all manual snow depth measurements, presence of snow on the ground is reported explicitly. If more than 12.5% of the measurement field is snow free, it is reported that no snow is present.

**Zero snow depth reporting method:**

When the average of the three stake readings is less than 1 cm, 0 cm snow depth is reported.

*Figure I-2.30.4 (a) Example of a measurement field with a snow stake; (b) ultrasonic snow depth sensor (Source: NMA).*

## I-2.30.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.30.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 139
Number of stations delivering water equivalent of snow cover data automatically: 0

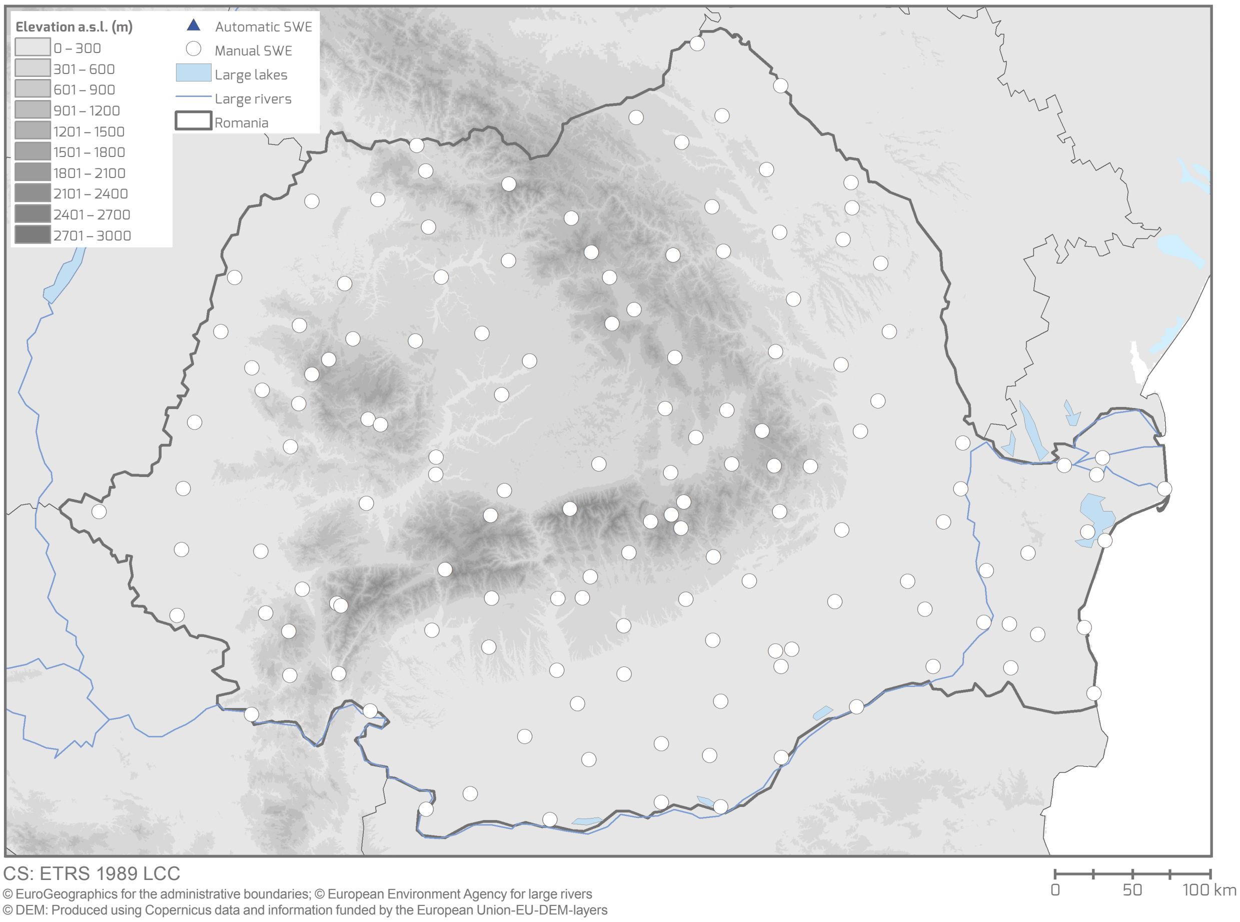

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*Figure I-2.30.5 Locations of stations in Romania where water equivalent of snow cover (SWE) is measured.*

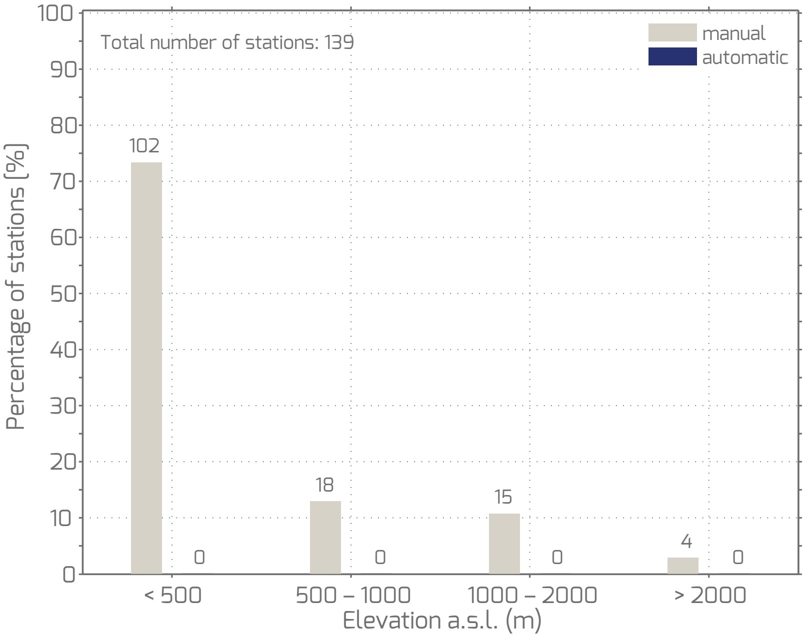

*Figure I-2.30.6 Elevational distribution of stations in Romania with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every five days (5th, 10th, 15th, 20th, 25th and last day of the month) if the snow depth exceeds 5 cm. The gravimetric method is applied. Using a graduated iron snow cylinder with a certain cross-sectional area (in $m^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack. After the height of the snow sample (in m) is measured and excess snow on the external surface of the cylinder is removed, the snow cylinder is attached to a steelyard balance to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. If the snow depth is greater than the length of the cylinder, the total snow depth is divided into multiple analogue "columns". Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers. To ensure a robust measurement, three samples are taken at locations with undisturbed, continuous snow cover and the average of all SWE observations is reported. The three locations are marked in order to avoid multiple measurements at the exact same location.

**Automatic measurements:**

No measurements.

## I-2.30.4 Transition from manual to automatic measurements

No parallel measurements are performed. However, at stations with both manual and automatic measurements, observers correct erroneous automatic data if necessary. This is not done to account for the discontinuity induced by the shift from manual to automatic instrumentation, but rather to correct automatic data.

## I-2.30.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 6, 8, 12 or 24 hours (NMA)<br>AUTO: 6 hours (NMA) | MANUAL: no measurements | MANUAL: 5 days (NMA)<br>AUTO: no measurements |

# I-2.31 Serbia

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*Figure I-2.31.1 Location of Serbia in Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 77 474 km$^2$, 460 m a.s.l. |
| Authority responsible for snow measurements | Republic Hydrometeorological Service of Serbia (RHMSS)<br>Kneza Višeslava 66<br>RS-11000 Belgrade |
| Contact | · RHMSS<br>office@hidmet.gov.rs |
| Near-real-time data URL and/or contact | · RHMSS<br>Not available. |
| Archived data URL and/or contact | · RHMSS<br>office@hidmet.gov.rs (by official request) |

## General situation

The Republic Hydrometeorological Service of Serbia (RHMSS) is responsible for operational snow observations in Serbia. Manual snow observations are well distributed over the entire Serbian territory. Snow depth measurements started in the 1920s and 1930s, and 82 snow stations were in use before the beginning of World War 2. Observations at these stations were interrupted during World War 2, which is why only discontinuous data is available from them. All other snow depth measurement series started between 1946 and 1962, while water equivalent of snow cover measurements were introduced in the 1960s. The snow data of the 307 snow observation locations presented here is digitised, while non-digitised historical data exists for around 900 stations.

The station network presented in this report is based on information from 2010. Therefore, it is possible that some stations are no longer in operation, as the number of operational snow stations decreases yearly. Manual water equivalent of snow cover observations are performed in both the lowlands and the mountainous regions. However, water equivalent of snow cover station coverage of the mountainous regions is insufficient, and water equivalent of snow cover data measured at lowland stations is often of low quality and questionable.

## Overview of measurements (RHMSS)

Snow depth: stake (Figs I-2.31.2, I-2.31.3)
Depth of snowfall: snow board and ruler (Figs I-2.31.4, I-2.31.5)
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.31.6, I-2.31.7)
Operational purpose of measurements: Agriculture and Forestry, Climatology, Flood forecasting, Hydrology, Meteorology, Road services

## I-2.31.1 Snow depth measurements

Number of stations delivering snow depth data manually: 307
Number of stations delivering snow depth data automatically: 0

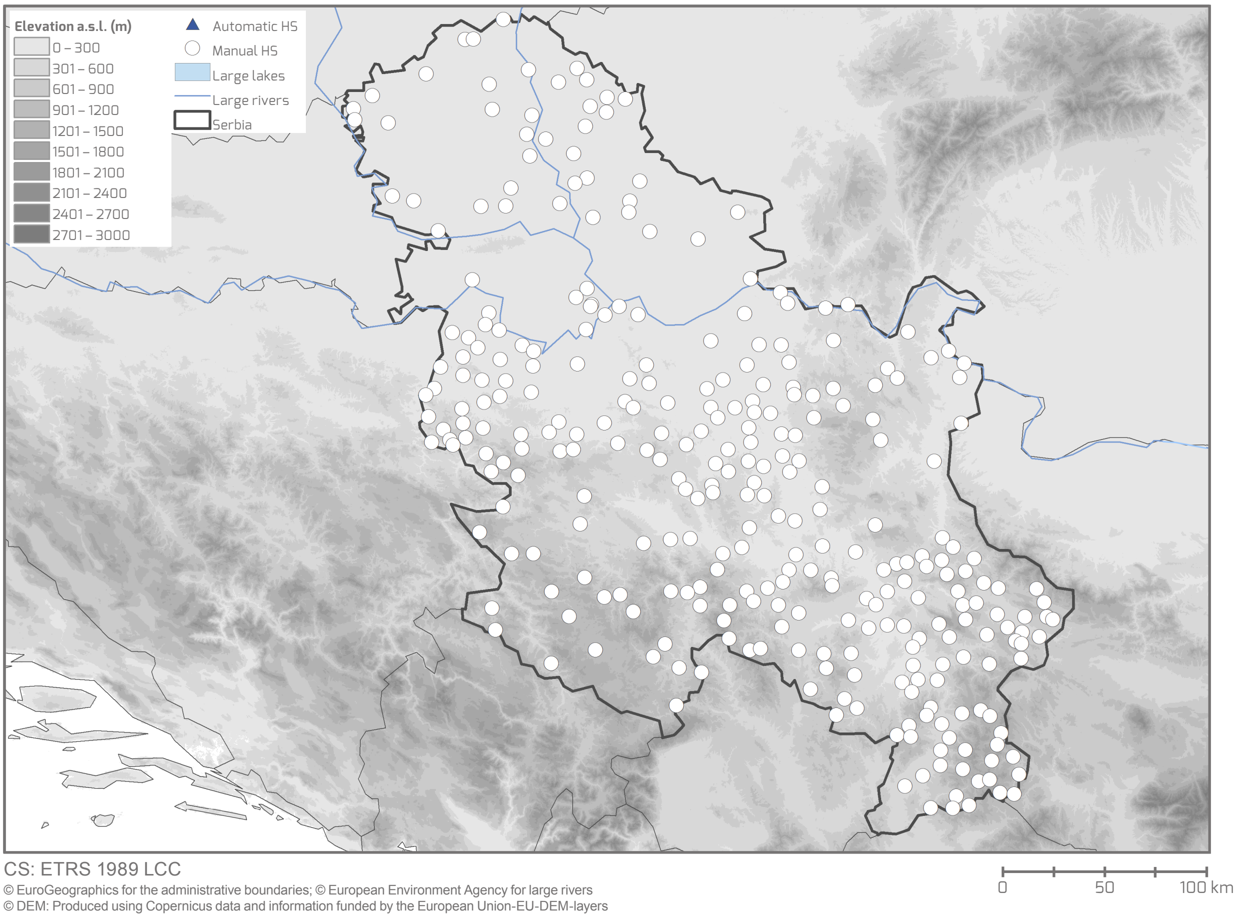

*Figure I-2.31.2 Locations of stations in Serbia where snow depth (HS) is measured.*

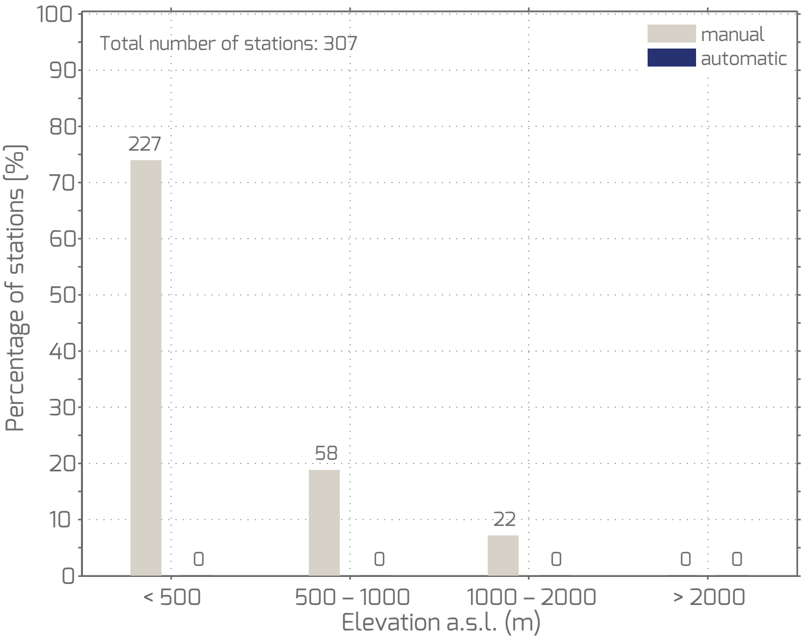

*Figure I-2.31.3 Elevational distribution of stations in Serbia with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual snow depth measurements are performed either every 6 hours at 0000, 0600, 1200 and 1800 UTC (30 WMO stations) or every 24 hours at 0600 UTC (277 stations). Fixed stakes with a scale in centimetres and a length of 1.2 m are used. Within each measurement field, three stakes are arranged in a triangle, 10 m apart, and the average of all three snow depth readings is reported as total snow depth. The 30 stations following WMO standards have a measurement field size of 20 x 20 m. At these stations, four to five observers are responsible for the continuity of the snow data series. The measurement fields of the remaining 277 non-WMO stations have a size of 10 x 10 m and are operated by one to two observers. Total snow depth is reported as long as at least half of the measurement field is covered with snow.

**Automatic measurements:**

No measurements.

**Presence of snow on the ground reporting method:**

In parallel to manual snow depth measurements, presence of snow on the ground is reported explicitly.

**Zero snow depth reporting method:**

When more than 50% of the measurement field is snow free, 0 cm is reported.

## I-2.31.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 307

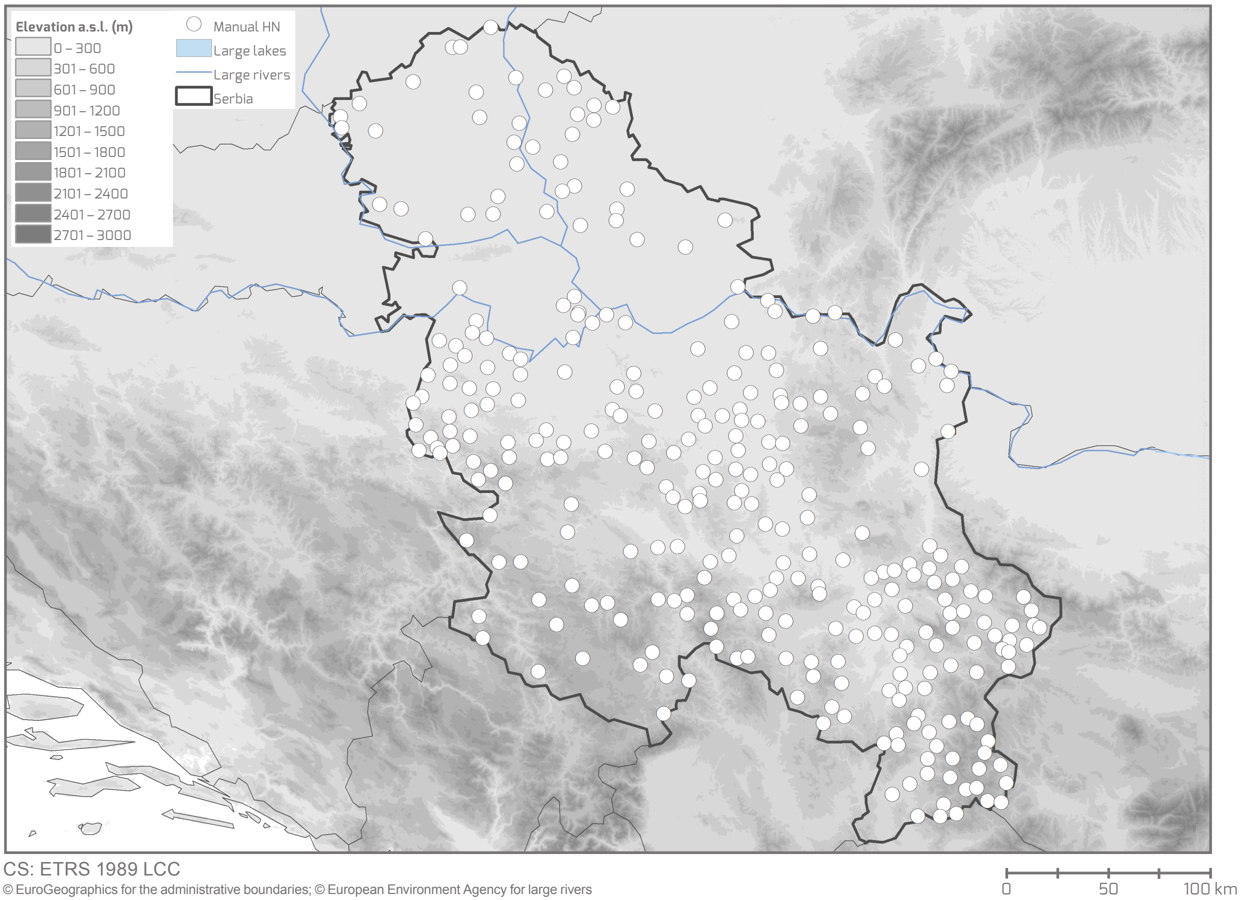

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*Figure I-2.31.4 Locations of stations in Serbia where depth of snowfall (HN) is measured.*

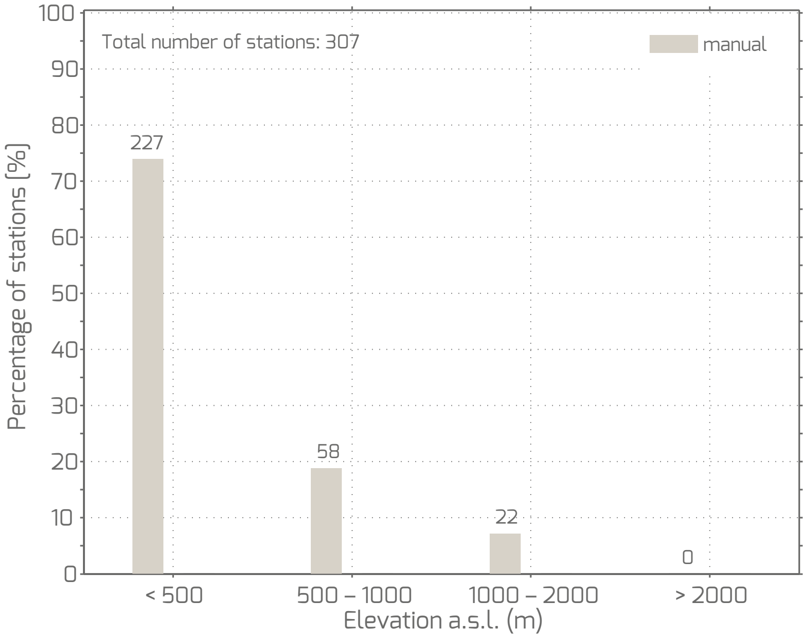

*Figure I-2.31.5 Elevational distribution of stations in Serbia with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual measurements of depth of snowfall are performed in parallel to manual snow depth measurements, every 12 hours at all 30 WMO stations and every 24 hours at all 277 non-WMO stations. Depth of snowfall is measured on a snow board with a ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface.

## I-2.31.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 27
Number of stations delivering water equivalent of snow cover data automatically: 0

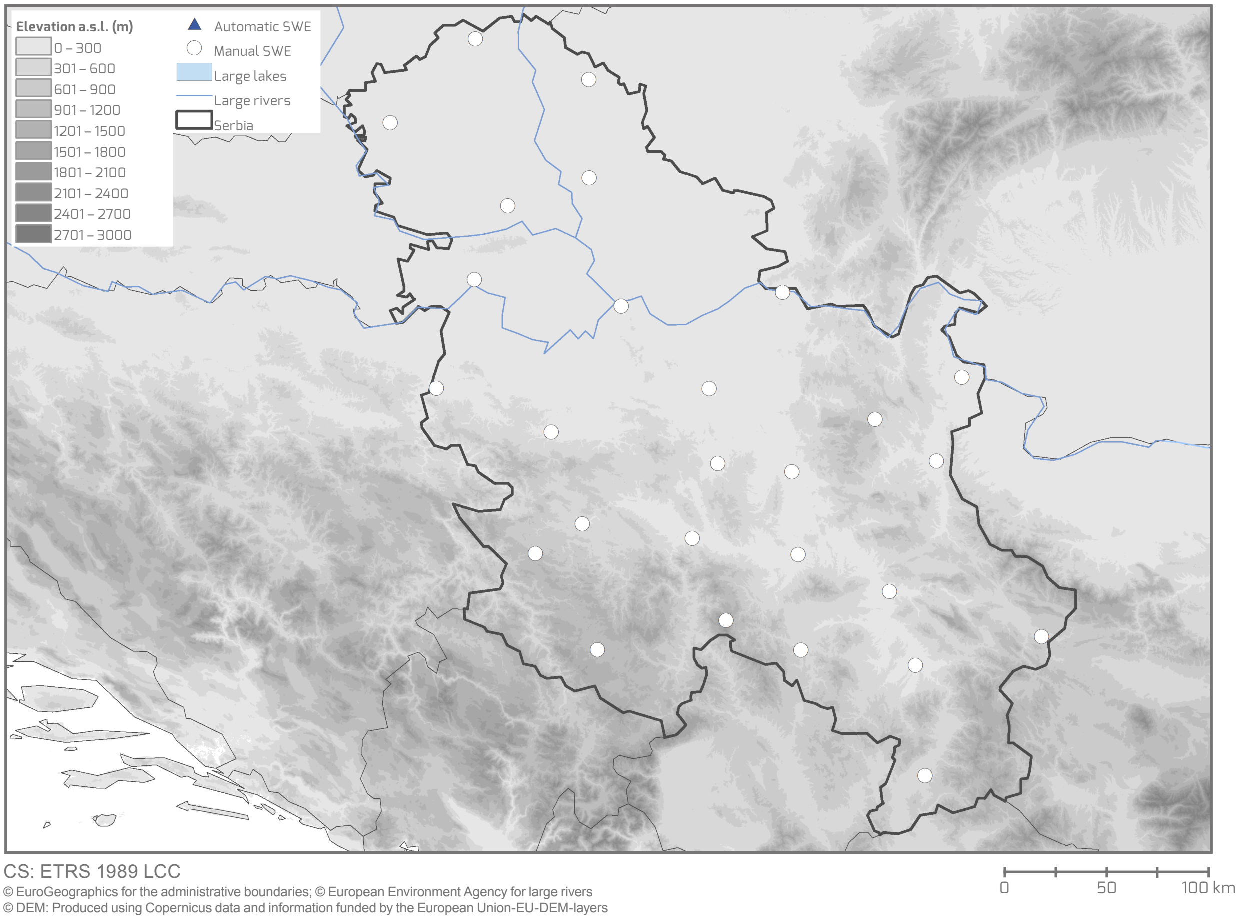

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*Figure I-2.31.6 Locations of stations in Serbia where water equivalent of snow cover (SWE) is measured.*

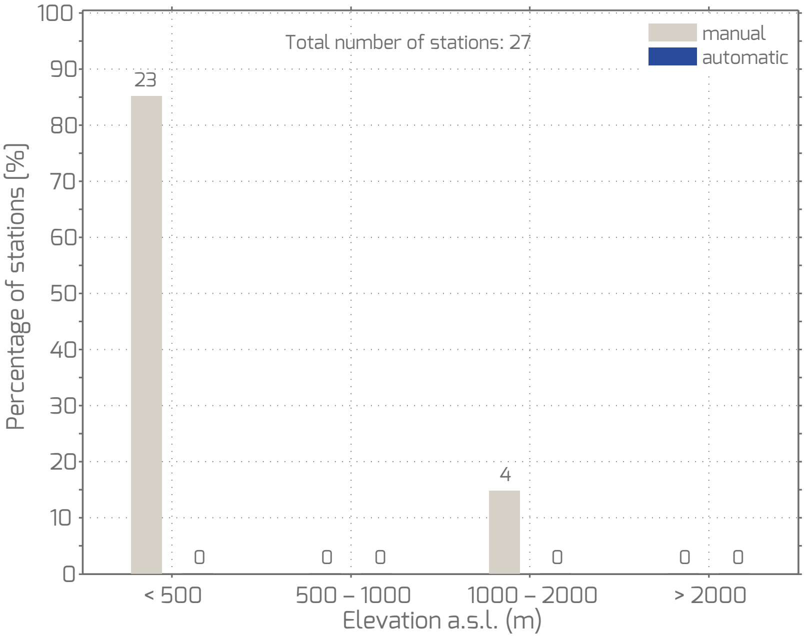

*Figure I-2.31.7 Elevational distribution of stations in Serbia with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every five days (5th, 10th, 15th, 20th, 25th and last day of the month) for snow depths exceeding 5 cm. This is done in parallel to the manual snow depth measurements at 27 WMO stations. The gravimetric method is applied. Using a graduated iron snow cylinder with a certain cross-sectional area (in $m^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack. After the height of the snow sample (in m) is measured, the snow cylinder is attached to a steelyard balance to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. If the snow depth is greater than the length of the cylinder, the total snow depth is divided into multiple analogue "columns". Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers. For each snow pit, SWE is measured at three points and the average of all measurements is reported.

Daily SWE measurements are performed: (1) in cases of rapid snow melt, i.e. more than 10 cm per day; (2) during the ablation season; and (3) if depth of snowfall exceeds 10 cm within 24 hours.

**Automatic measurements:**

No measurements.

## I-2.31.4 Transition from manual to automatic measurements

No parallel measurements are needed because no automatic measurements are performed.

## I-2.31.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 6 or 24 hours (RHMSS)<br>AUTO: no measurements | MANUAL: 12 or 24 hours (RHMSS) | MANUAL: 5 days (RHMSS)<br>AUTO: no measurements |

# I-2.32 Slovakia

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*Figure I-2.32.1 Location of Slovakia in Europe.*

# I-2.32 Slovakia

## Country information

| | |
|---|---|
| Country area, mean country elevation | 49 035 $km^2$, 453 m a.s.l. |
| Authority responsible for snow measurements | Slovak Hydrometeorological Institute (SHMU)<br>Jeséniova 17<br>SK-83315 Bratislava<br><br>Earth Science Institute of the Slovak Academy of Sciences (ESI)<br>Ústav vied o Zemi- Slovenskej akadémie vied<br>Dúbravská cesta 9, P.O. BOX 106<br>SK-84005 Bratislava |
| Contact | • SHMU<br>shmu@shmu.sk<br>• ESI<br>nejedlik@yahoo.com (Pavol Nejedlik) |
| Near-real-time data URL and/or contact | • SHMU<br>http://www.shmu.sk/sk/?page=1&id=klimat_tyzdennemapy (in 2019 the SHMU website will be changed and consequently also this link)<br>• ESI<br>Not available. |
| Archived data URL and/or contact | • SHMU<br>branislav.chvila@shmu.sk (Dr. Branislav Chvila)<br>• ESI<br>nejedlik@yahoo.com (Pavol Nejedlik, historical data available on request for research purposes) |

## General situation

The Slovak Hydrometeorological Institute (SHMU) is responsible for operational snow observations in Slovakia. Snow depth, presence of snow on the ground, depth of snowfall and water equivalent of snow cover are observed manually by SHMU, while snow depth is additionally measured automatically. In addition to the 609 manual snow stations operated by SHMU, the Earth Science Institute of the Slovak Academy of Sciences (ESI) operates one snow station measuring snow depth and depth of snowfall. Both institutions apply the same measurement principles. ESI (1 station) and SHMU professional stations (21 stations) assure homogenised, high-quality data because manual measurements are performed by trained staff. The other SHMU stations are operated by volunteers (588 stations) and thus provide data of variable quality.

In the various Slovakian mountain regions, the Slovak Mountain Rescue Service operates a network of automatic weather stations where snow depth measurements using ultrasonic sensors are performed regularly. These measurements are complemented by intermittent manual snow observations (snow depth and water equivalent of snow cover) carried out mainly for avalanche forecasting purposes. The automatic snow depth data of the Mountain Rescue Service is available online at: http://meteo.hzs.sk/index.html. Please use the username and password “user” to access the data. Although their snow depth data is freely available, data from the Mountain Rescue Service is not included in this country report because no contact could be established.

SHMU snow observations are mostly performed at locations representative of their larger surroundings. Only data from a few stations located in the mountains may not be representative of larger areas. ESI measures snow depth, both manually and automatically, within a so-called “meteorological garden” at a single station. The whole station is installed on a slope (from 800 to 2600 m a.s.l.) and the manual snow observations are performed at the edge of a small horizontal plain. While this location is not ideal for measuring snow, it is considered the best site in the area. The data series dates back to 1942, always with same methodology, which is why it is included here.

While manual and automatic snow depth measurements and manual presence of snow on the ground and depth of snowfall measurements are performed by both SHMU and ESI, water equivalent of snow cover is assessed manually only by SHMU. The SHMU and ESI snow measurement networks are both discussed below.

**Overview of measurements (SHMU, ESI)**

Snow depth: stake, ruler, laser snow depth sensor (Figs I-2.32.2, I-2.32.3)

Depth of snowfall: snow board, precipitation gauge, ruler (Figs I-2.32.5, I-2.32.6)

Water equivalent of snow cover: snow cylinder, several scale types (unbalanced Metra scale, steelyard balance, digital scale), measuring cup (Figs I-2.32.7, I-2.32.8)

Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Flood forecasting, Hydrology, Meteorology, Road services, Water management

## I-2.32.1 Snow depth measurements

Number of stations delivering snow depth data manually: 610

Number of stations delivering snow depth data automatically: 75

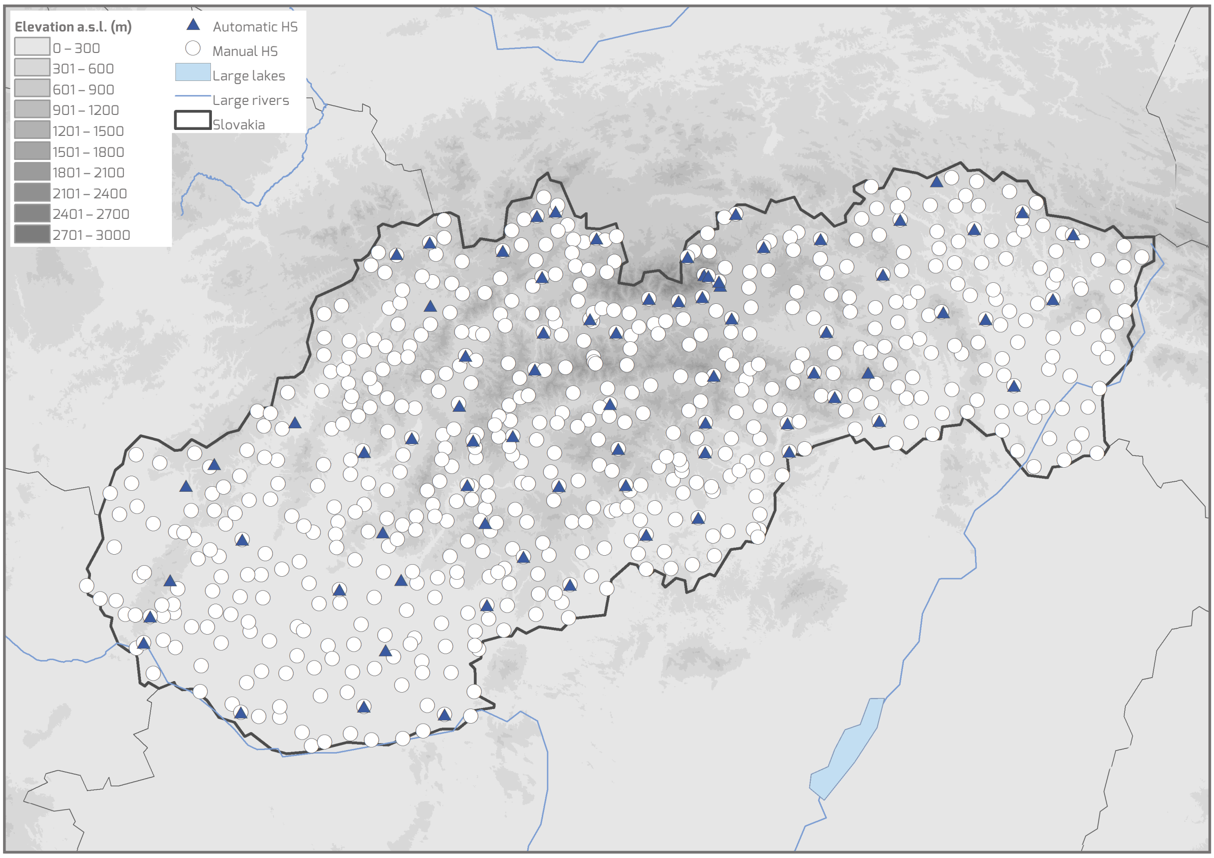

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*Figure I-2.32.2 Locations of stations in Slovakia where snow depth (HS) is measured.*

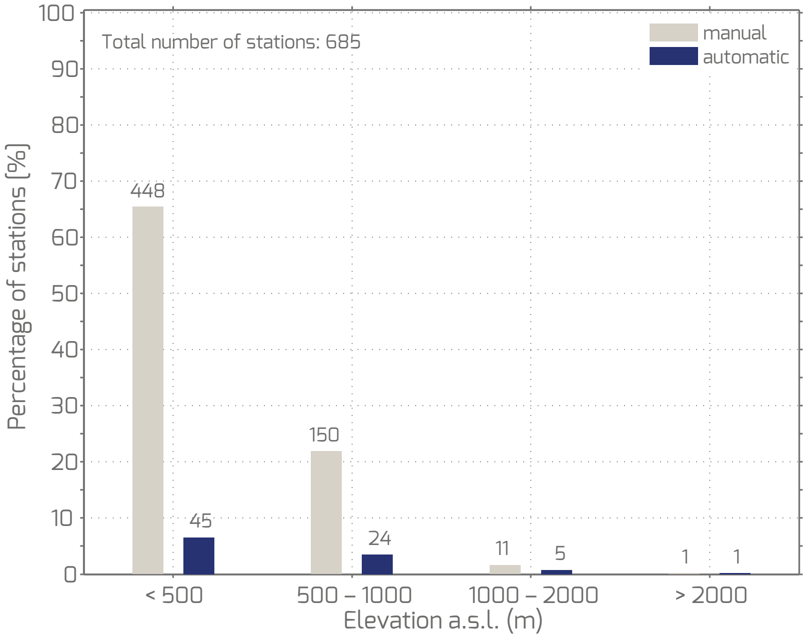

*Figure I-2.32.3 Elevational distribution of stations in Slovakia with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed at SHMU stations either every 24 hours at 0600 UTC (588 stations) or every hour (21 professional synoptic stations). In the latter case snow depth is reported twice a day at 0600 and 1800 UTC in SYNOP reports. At the ESI station (Fig. I-2.32.4) snow depth is measured manually three times a day at 0600, 1300 and 2000 UTC. Fixed stakes with a scale in centimetres and a length of 1, 2 or 3 m are used if there is a homogeneous snow cover, while rulers are used if there is a heterogeneous snow depth distribution (SHMU stations only). In the latter case at least three snow depth measurements are performed and the average is reported. The observers avoid creating disturbances in the measurement field, and the location of the snow depth measurement is selected to minimise influence from the wind. Total snow depth is reported as long as at least half of the measurement field is covered with more than 0.5 cm of snow. Measured values are reported in full centimetres. Values less than 0.5 cm are reported as “trace”.

### Automatic measurements:

Automatic snow depth measurements by both SHMU and ESI are performed once every minute using laser (optical) sensors (SHM 30; Lufft, Fellbach, Germany). Snow depth sensors are mounted 2–5 m above the ground.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported explicitly by both SHMU and ESI. In addition, a coding system is applied by SHMU and ESI in cases where the measurement field and the surrounding area in a radius of about 40 m are heterogeneously covered with snow: (1) code “999” means snow depths are less than 0.5 cm; and (2) code “995” means more than 50% of the measurement field is snow free but snow depth in the remaining snow patches exceeds 0.5 cm. The snow type (dry snow, wet snow, ice) and the state of the ground are additionally provided with a 10-point coding system.

### Zero snow depth reporting method:

Total snow depth is reported as long as at least 50% of the measurement field is covered with more than 0.5 cm of snow. When more than 50% of the measurement field is snow free, 0 cm snow depth is reported.

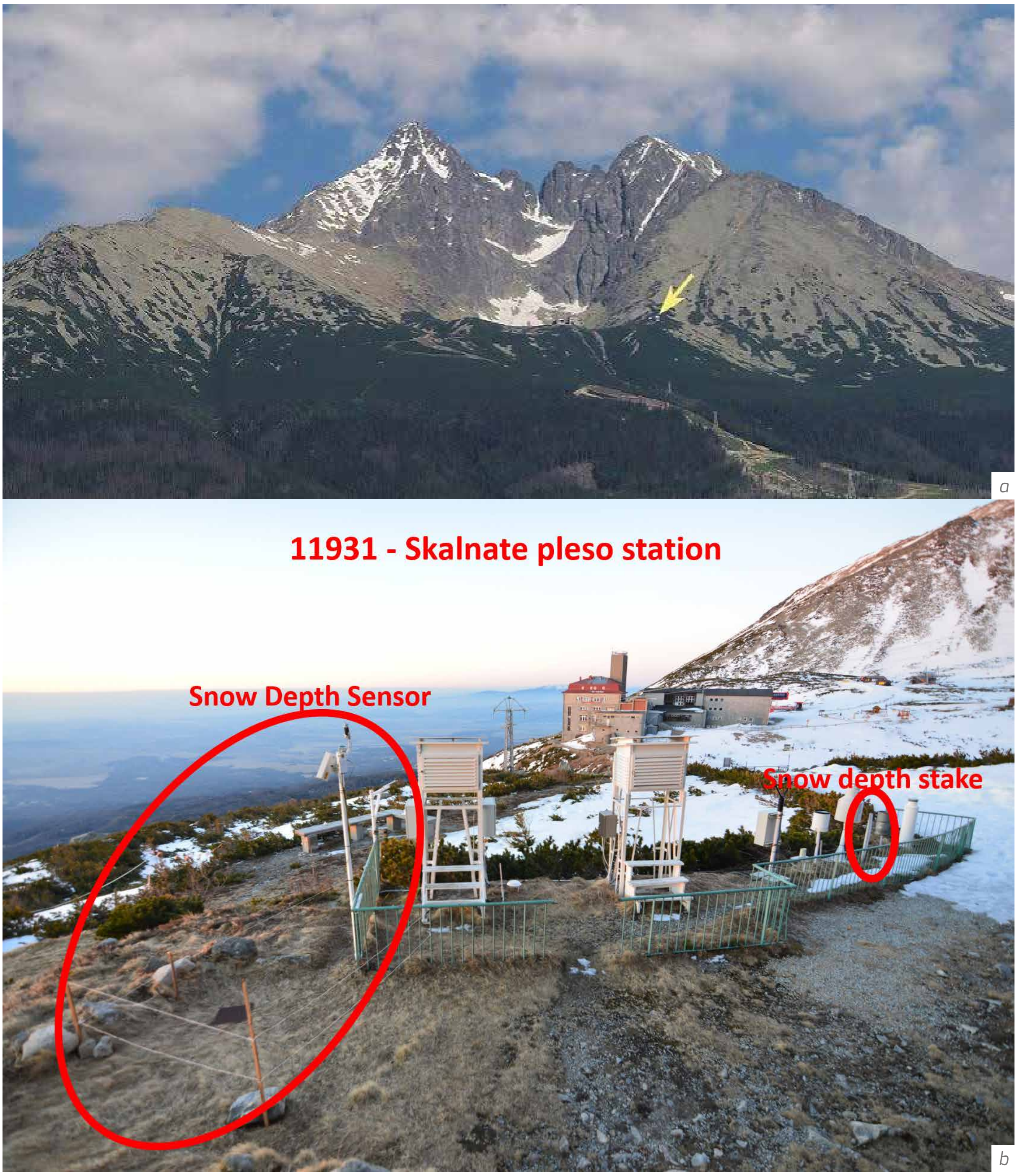

*Figure I-2.32.4 The Skalnate Pleso snow measurement station ("meteorological garden") operated by ESI. (a) The yellow arrow indicates the location of the station. The whole station is installed on a slope and the manual snow observations are performed at the edge of a small horizontal plain. (b) Locations of automatic (sensor) and manual (stake) snow depth measurements (Source: ESI).*

## I-2.32.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 610

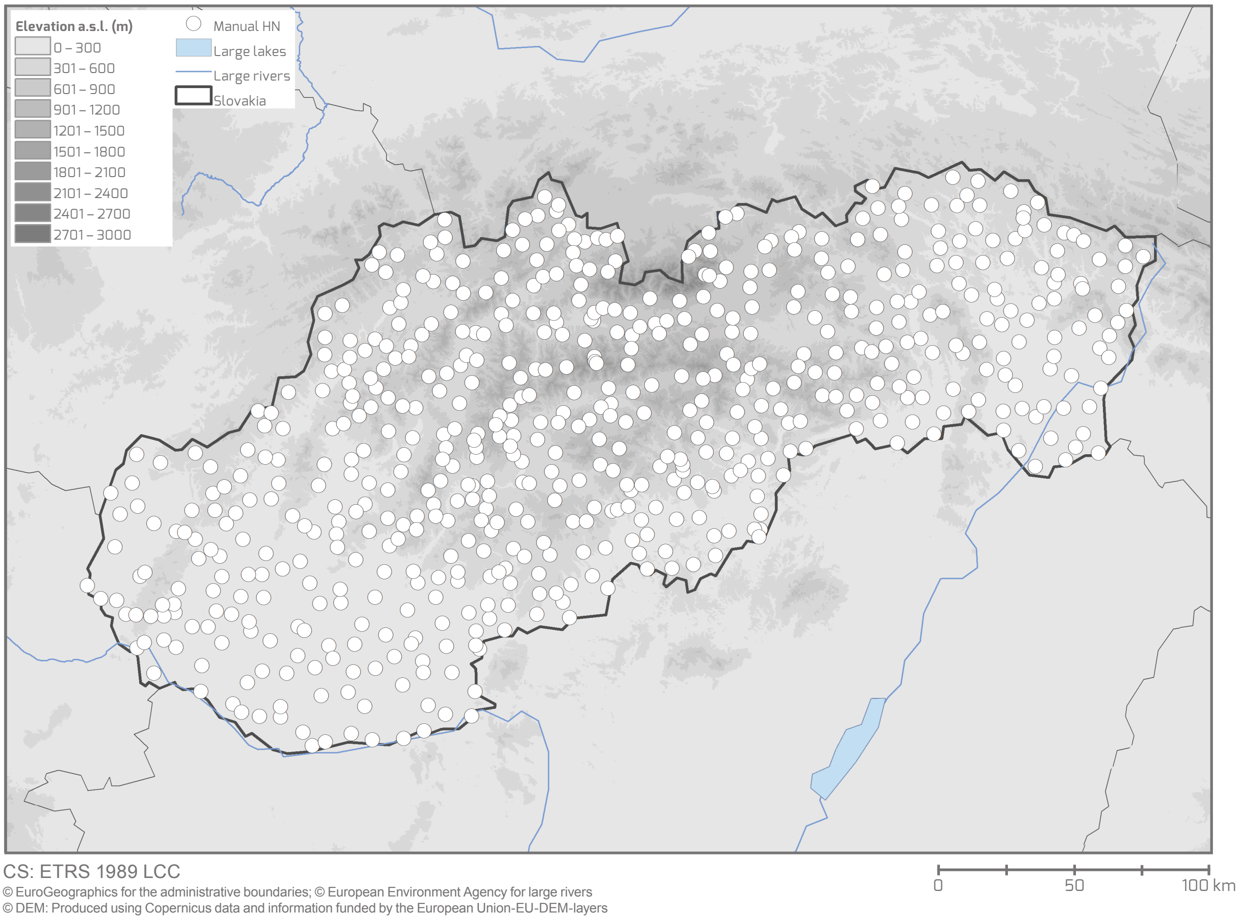

*Figure I-2.32.5 Locations of stations in Slovakia where depth of snowfall (HN) is measured.*

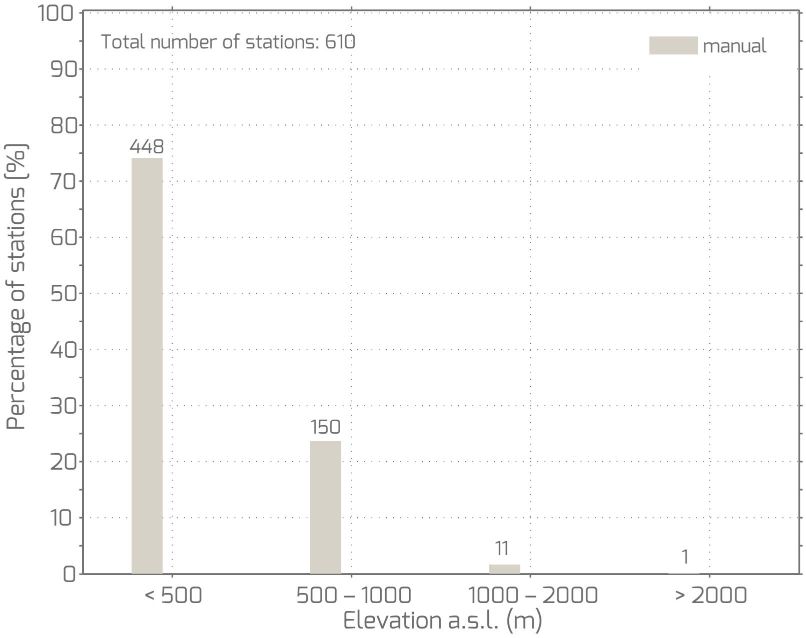

*Figure I-2.32.6 Elevational distribution of stations in Slovakia with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours at 0600 UTC in parallel to manual snow depth measurements. Depth of snowfall is measured on a snow board (30 x 30 cm) with a ruler by SHMU. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. At a few locations depth of snowfall is additionally measured three times a day. In this case two snow boards are used: depth of snowfall is measured daily on one snow board and at 0600, 1300 and 2000 UTC on the other board. The second snow board is cleaned after each of the three depth of snowfall measurements. ESI manually measures depth of snowfall three times a day in parallel to manual snow depth measurements. Depth of snowfall is measured in an on-site precipitation gauge with a ruler because the station location is too wind exposed to allow snow board measurements.

## I-2.32.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 607
Number of stations delivering water equivalent of snow cover data automatically: 0

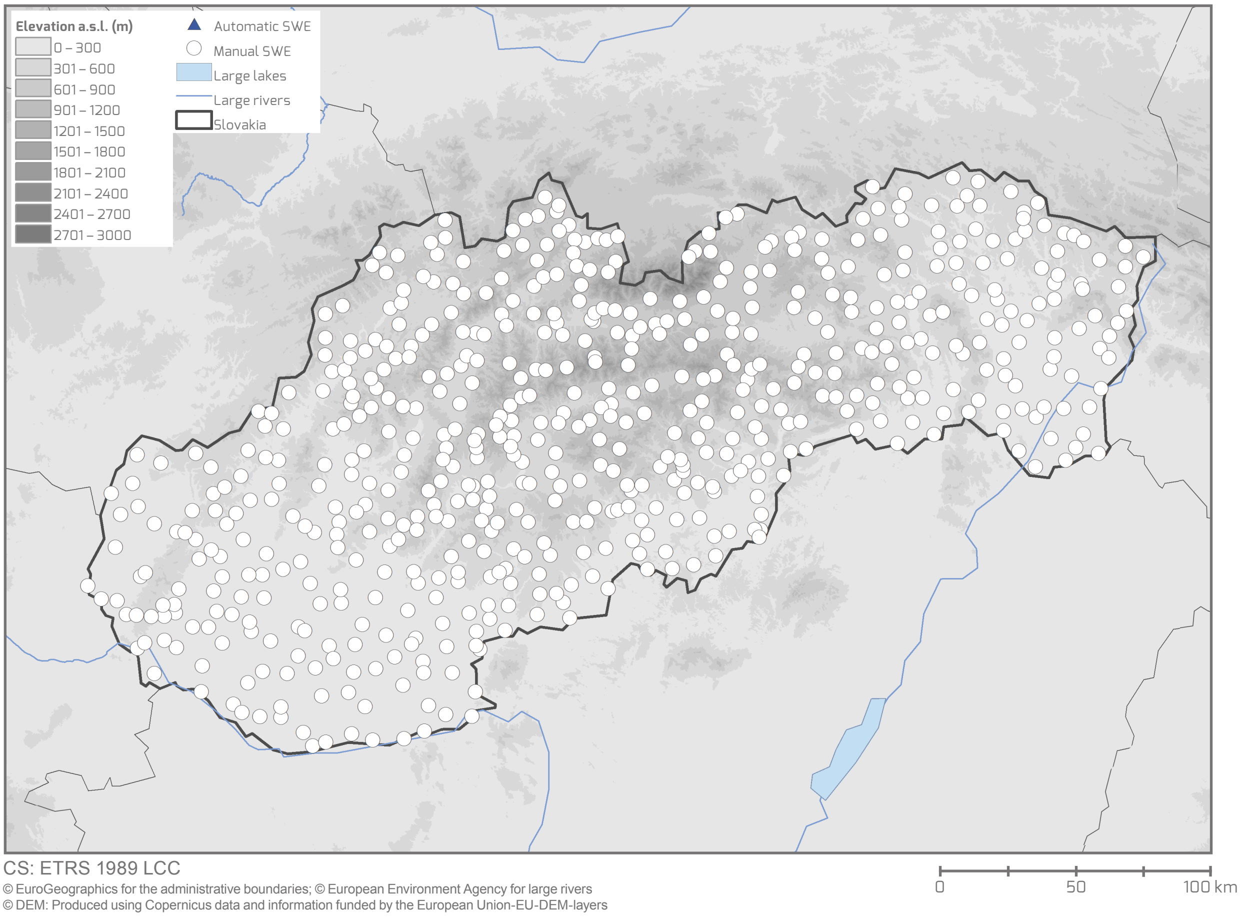

*Figure I-2.32.7 Locations of stations in Slovakia where water equivalent of snow cover (SWE) is measured.*

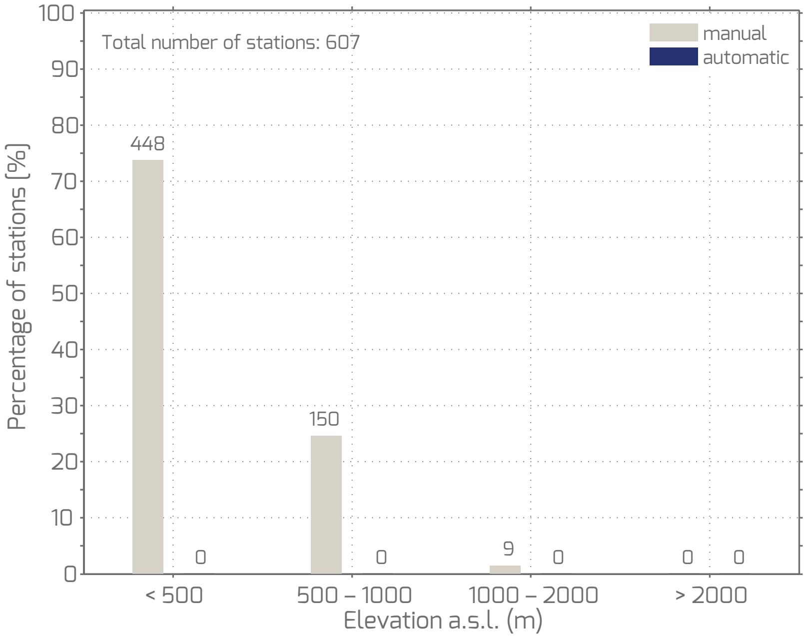

*Figure I-2.32.8 Elevational distribution of stations in Slovakia with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed once every week (Monday at 0600 UTC) by SHMU for snow depths exceeding 1 cm. The gravimetric method is applied. Using a snow cylinder with a certain cross-sectional area (in m$^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack. After the height of the snow sample (in m) is measured and excess snow on the external surface of the cylinder is removed, the snow cylinder is either (1) weighed or (2) melted:

(1) The snow sample is attached to a scale to measure the total weight of the snow (in kg). Different scales are used, such as the unbalanced Metra scale made in Czechoslovakia, the steelyard balance BC-43 made in Russia and Ukraine, the digital Kern CH15K20 scale or the digital Inspect WMD-03 scale. The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. If the snow depth is greater than the length of the cylinder, the total snow depth is divided into multiple analogue "columns". Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

(2) All snow samples are melted and the amount of water (in mm) is measured with a measuring cup.

SWE is measured at three different points within a measurement field and the average of all measurements is reported.

**Automatic measurements:**

No measurements.

## I-2.32.4 Transition from manual to automatic measurements

The shift from manual to automatic snow depth measurements by SHMU started in 2015. At the 58 sites with both manual and automatic measurements, parallel snow depth measurements have been carried out for two years. The plan is to continue these parallel measurements because depth of snowfall and water equivalent of snow cover are already measured manually at these stations. Another reason for continuous parallel measurements is that automatic snow depth measurements are error prone, e.g. lasers are affected by pollution. In addition, an automatic point measurement cannot account for snow drift. However, automatic snow depth stations are in use because automatic measurements are useful for weather forecasting and avalanche warning, especially if the data is transmitted in real time, even though they are of limited use for climatological purposes.

## I-2.32.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 1 or 24 hours (SHMU) or 3 measurements in 24 hours (0600, 1300, 2000 UTC) (ESI)<br>AUTO: 1 minute (SHMU, ESI) | MANUAL: 24 hours (SHMU) and/or 3 measurements in 24 hours (0600, 1300, 2000 UTC) (SHMU, ESI) | MANUAL: 1 week (SHMU)<br>AUTO: no measurements |

# I-2.33 Slovenia

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*Figure I-2.33.1 Location of Slovenia in Europe.*

# I-2.33 Slovenia

## Country information

| | |
|---|---|
| Country area, mean country elevation | 20 273 km$^2$, 563 m a.s.l. |
| Authority responsible for snow measurements | Slovenian Environment Agency (ARSO)<br>Vojkova 1b<br>SI-1000 Ljubljana |
| Contact | · ARSO<br>filip.stucin@gov.si (Filip Stucin) |
| Near-real-time data URL and/or contact | · ARSO<br>http://meteo.arso.gov.si/met/sl/weather/observ/surface/snow/<br>http://meteo.arso.gov.si/met/sl/service/ |
| Archived data URL and/or contact | · ARSO<br>http://meteo.arso.gov.si/met/sl/app/<br>webmet/#webmet==8Sdwx2bhR2cv0WZ0V2bvEGcw9ydlJWblR3Lw<br>Vnaz9SYtVmYh9iclFGbt9SaulGdugXbsx3cs9mdl5WahxXYyNGapZXZ8t<br>HZv1WYp5mOnMHbvZXZulWYnwCchJXYtVGdlJnOn0UQQdSf |

## General situation

The Slovenian Environment Agency (ARSO) is responsible for operational snow observations in Slovenia. The ARSO station network is equally distributed over the alpine, midland and lowland regions. Snow depth is measured both manually and automatically, while depth of snowfall and water equivalent of snow cover are manually observed. The automatic snow station network was built up recently and measurements began in 2014. The overview of operational snow observations presented in this country report includes only data from ARSO. However, several other institutions in Slovenia perform non-operational snow observations, which are addressed briefly below.

The Anton Melik Geographical Institute ZRC SAZU has observed the glaciers Triglav (Julian Alps) and Skuta (Kamnik and Savinja Alps) since 1946. More information on measurements is available online at: https://giam.zrc-sazu.si/en/green-avalanche#v. The Triglav glacier project is the longest running Slovenian research project ever. The volume of both glaciers is periodically measured or estimated on the basis of different methods and equipment, e.g. gas-drilling pipes and ground-penetrating radar, as well as aerial and terrestrial LIDAR scanning. Between 1976 and 2006 snow depth measurements took place near Triglav glacier. A considerable but temporary difference was found between these measurements and those of the nearby meteorological station Kredarica. In addition to monitoring glaciers, the Anton Melik Geographical Institute ZRC SAZU performs snow measuring campaigns, and such measurements were made regularly between 2012 and 2015 in Karavanks (nothwestern Slovenia). The purpose of these campaigns was to make an experimental local avalanche bulletin for the Middle Karavanks region in northern Slovenia for the winter seasons 2012/2013 and 2014/2015. The weather stations used for this program are still in use and are operated, as well as maintained, by the Avalanche Warning Service of Carinthia (Austria). The contact person for the above-listed activities is Miha Pavšek (miha.pavsek@zrc-sazu.si).

Snow data is additionally collected by individuals who run private manned or automatic weather stations. They are members of research teams from various companies, institutes and agencies, and they communicate using a social network (i.e. forum). Thanks to the combination of enthusiasm, professional skill and networking power, projects in the field of snow and meteorological measurements often run for over a decade. A good example is air temperature monitoring in frost hollows, which was started in 2005 by the Slovenian meteorological forum and Department of Geography, University of Ljubljana. Years of continuous air temperature data from tens of remote locations, from the lowland to the highest mountains, are now combined as datasets or in a database. Through the years this data and knowledge have been included in various research projects, thesis studies, papers and reports on the national and international level. The long-term monitoring in remote places without an official meteorological network serves as basic climate information which is valuable for a wide range of environmental studies. Some specific Slovenian Alpine locations, with a large snowpack accumulation (snow heights up to 5 m) and persistent and strong temperature inversions (record lows of −49 °C in valleys), are permanently equipped with air temperature data loggers and additionally serve as unique places for snow stratigraphy measurements and snow sampling for isotopic compositions. There are additionally test sites for real-time monitoring provided by the Laboratory for Electronic Devices (Slovenian Forestry Institute) and AMES Environmental Measurement Systems. Concerning snowpack, the Slovenian Forestry Institute monitors water discharge rates and levels, soil conditions and precipitation in forests; provides snow water quality analyses; and improves monitoring of the monosaccharide levoglucosan as a detection biomarker in aerosols. It runs an ongoing experiment on how precipitation and snow cover drive the quantitative and qualitative production of hypogenous fungi (truffles). The contact person for the above-listed activities is Iztok Sinjur (iztok.sinjur@gozdis.si) from the Slovenian Forestry Institute, who is also a member of the Slovenian Meteorological Forum.

In addition to traditional snow observations, the isotopic composition of oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$ and $\delta^{3}H$ activity concentration) in monthly composite precipitation (snow, rain) is monitored within the framework of national and international research projects. Sampling is performed as part of the Slovenian Network of Isotopes in precipitation, according to the IAEA/GNIP precipitation sampling guide (V2.1 September 2016), and adapted to research goals. The network now consists of six stations which are part of the ARSO meteorological station network and where the staff of the network collects daily precipitation from the precipitation gauge. Monitoring is currently performed by the Jožef Stefan Institute, which additionally performs sampling according to IAEA/GNIP guidelines at eight other stations that have no permanent staff. The contact person for the above-listed activities is Polona Vreča (polona.vreca@ijs.si), who is employed at the Jožef Stefan Institute.

Only the snow measurement network operated by ARSO is discussed below.

### Overview of measurements (ARSO)

Snow depth: ruler, stake, laser snow depth sensor (Figs I-2.33.2, I-2.33.3)
Height of new snow: snow board and ruler (Figs I-2.33.5, I-2.33.6)
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.33.7, I-2.33.8)
Operational purpose of measurements: Avalanche warning, Climatology, Hydrology, Meteorology

## I-2.33.1 Snow depth measurements

Number of stations delivering snow depth data manually: 182
Number of stations delivering snow depth data automatically: 68

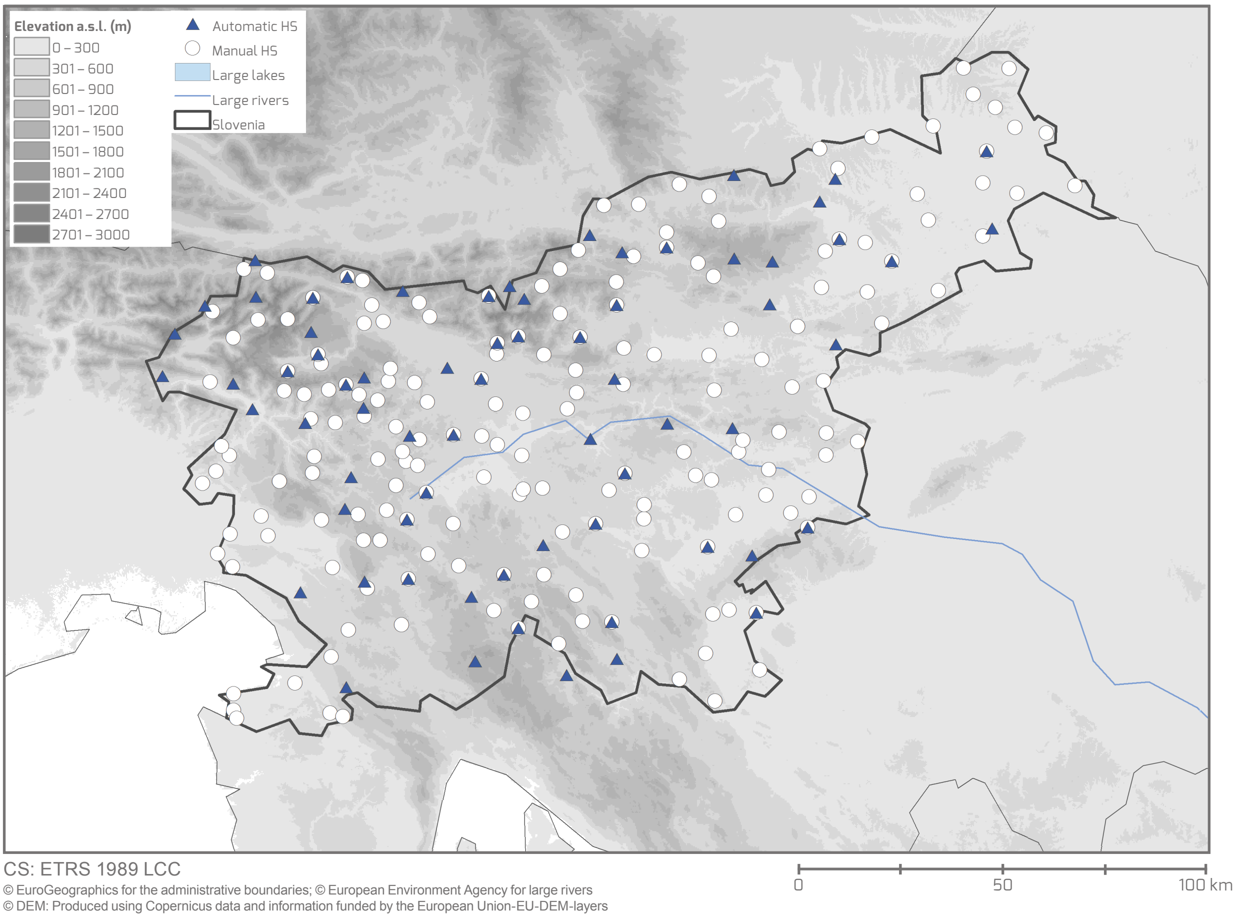

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*Figure I-2.33.2 Locations of stations in Slovenia where snow depth (HS) is measured.*

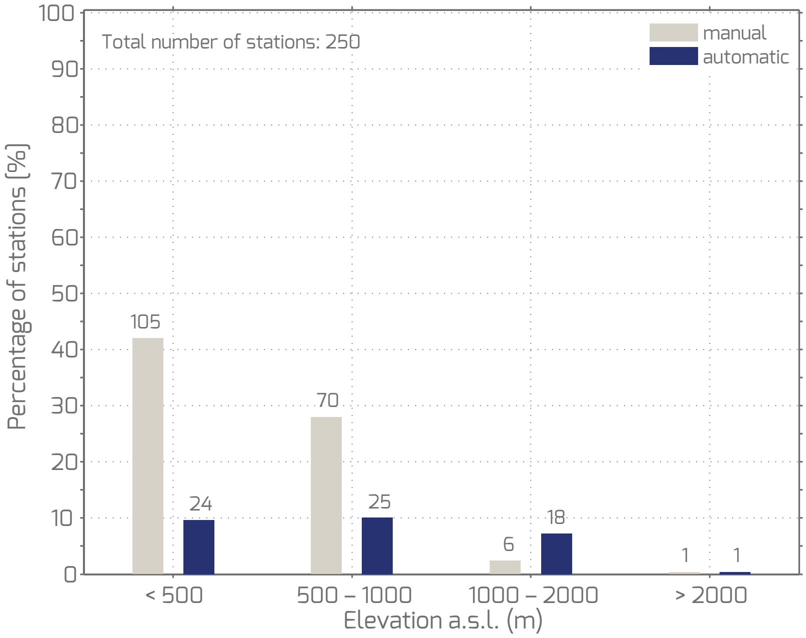

*Figure I-2.33.3 Elevational distribution of stations in Slovenia with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours at 0600 UTC. Depending on the site either fixed stakes or portable rulers are used. At meteorological measurement fields, fixed plastic or aluminium stakes with a length of 1.5 m are installed (Fig. I-2.33.4 a) and the observation area is fenced. At unprotected measurement locations, with no fence around the observation site, portable rulers are used to measure snow depth. Before each measurement an area with representative snow cover is determined by the observer. Total snow depth is reported as long as at least 50% of the measurement field is covered with snow. Measured values are reported in full centimetres.

### Automatic measurements:

Automatic snow depth measurements (installed in 2014) are performed every 10 minutes. Laser snow depth sensors are used (Fig. I-2.33.4 b). The sensors are mounted 2–5 m above the ground, and artificial targets made from plastic plates are placed below the sensors.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is not reported explicitly.

### Zero snow depth reporting method:

When more than 50% of the measurement field is snow free, no data is reported.

*Figure I-2.33.4 (a) Fenced meteorological site in Murskasobota (Slovenia) with a fixed stake to measure snow depth manually (Source: ARSO). (b) Laser snow depth sensor at a station near the Vrsic Pass, Slovenia (Source: ARSO)*

## I-2.33.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 182

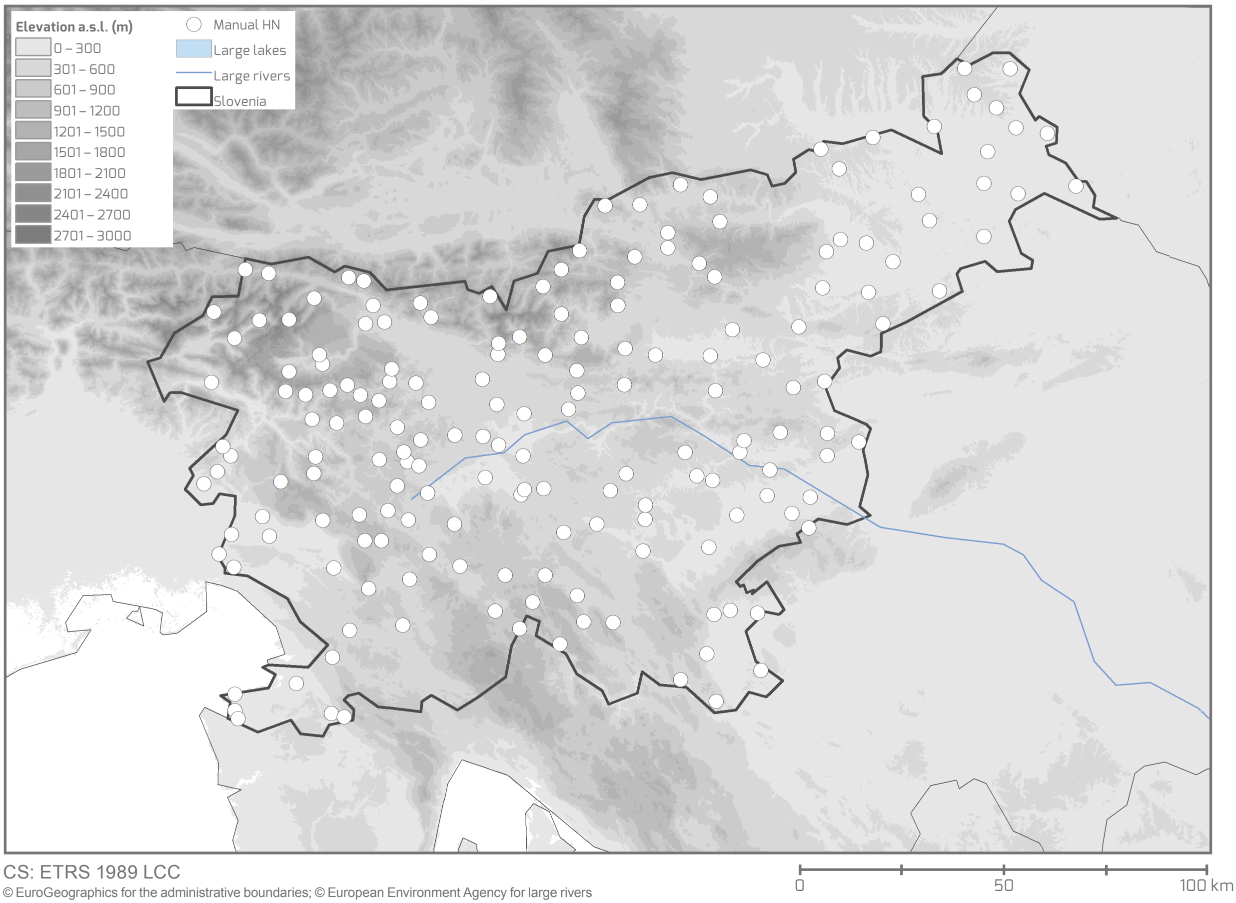

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*Figure I-2.33.5 Locations of stations in Slovenia where depth of snowfall (HN) is measured.*

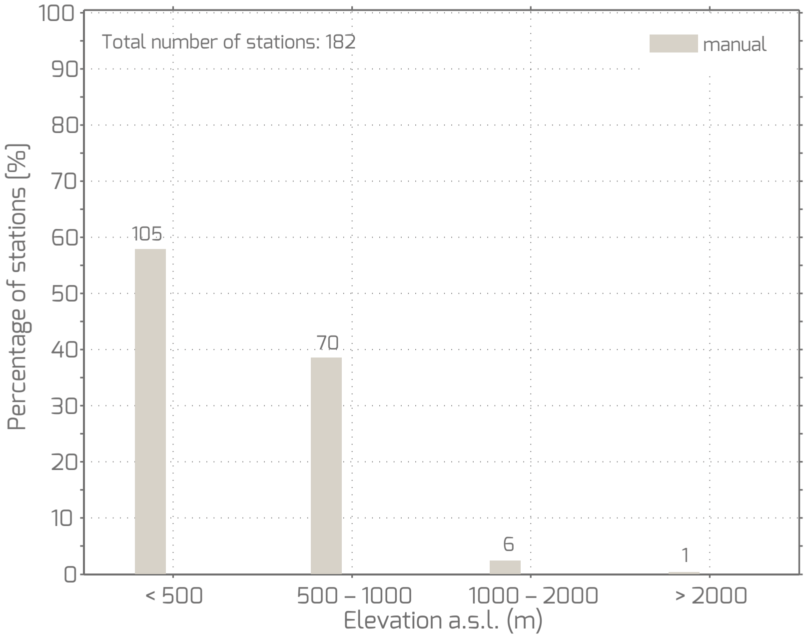

*Figure I-2.33.6 Elevational distribution of stations in Slovenia with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours at 0600 UTC in parallel to manual snow depth measurements. Depth of snowfall is measured on a white-painted snow board (50 x 50 cm) with a ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. The location of the depth of snowfall measurement is selected to minimise influence from the wind. Measured values are reported in full centimetres. Depth of snowfall measurements less than 0.5 cm are reported as 0 cm.

## I-2.33.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 3
Number of stations delivering water equivalent of snow cover data automatically: 0

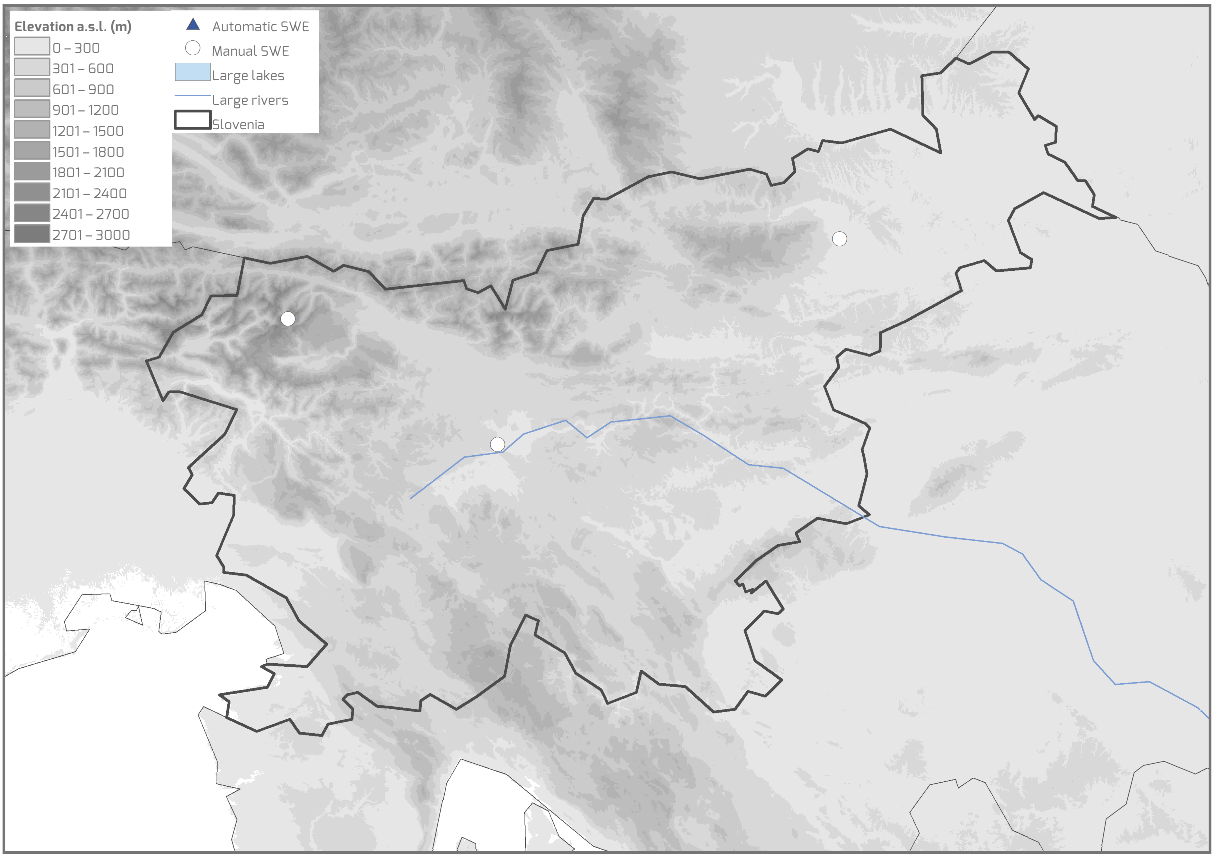

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*Figure I-2.33.7 Locations of stations in Slovenia where water equivalent of snow cover (SWE) is measured.*

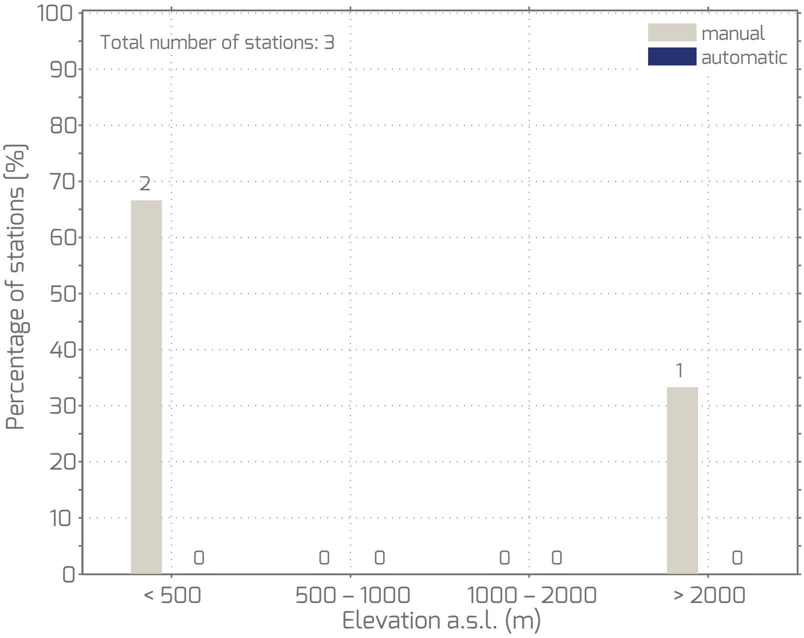

*Figure I-2.33.8 Elevational distribution of stations in Slovenia with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed every five days for snow depths exceeding 10 cm. The gravimetric method is applied. Using a graduated aluminium snow cylinder with a cross-sectional area of 0.005 $m^2$ and a length of 0.6 m (Fig. I-2.33.9 a), a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), the snow cylinder is attached to a steelyard balance to measure the total weight of the snow (in kg; Fig. I-2.33.9 b). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. If the snow depth is greater than the length of the cylinder (0.6 m), the total snow depth is divided into multiple analogue "columns". Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers.

**Automatic measurements:**

No measurements.

*Figure I-2.33.9 Manual water equivalent of snow cover (SWE) measurements in snow pits using snow cylinders: (a) cylinder in snow pit; (b) snow cylinder attached to a steelyard balance (Source: ARSO).*

## I-2.33.4 Transition from manual to automatic measurements

The automatic snow station network was built up recently and automatic sensors started measurements in 2014. Therefore, only a few comparisons have been completed to evaluate the general behaviour of the automatic measurement instruments.

## I-2.33.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (ARSO)<br>AUTO: 10 minutes (ARSO) | MANUAL: 24 hours (ARSO) | MANUAL: 5 days (ARSO)<br>AUTO: no measurements |

# I-2.34 Spain

*Figure I-2.34.1 Location of Spain in Europe.*

# I-2.34 Spain

## Country information

| | |
|---|---|
| Country area, mean country elevation | 505 944 km$^2$, 685 m a.s.l. |
| Authority responsible for snow measurements | Spanish State Meteorological Agency (AEMET) under the Ministry of Agriculture and Fishing, Food and Environment (MAPAMA)<br>Leonardo Prieto, 8 (Ciudad Universitaria)<br>ES-28071 Madrid<br><br>General Water Directorate – Hydrological Information Area (GWD) under the Ministry of Agriculture and Fishing, Food and Environment (MAPAMA)<br>Plaza San Juan de la Cruz s/n<br>ES-28071 Madrid |
| Contact | • AEMET<br>sbuisans@aemet.es (Samuel Buisan)<br>• GWD<br>FPastor@magrama.es (Fernando Pastor) |
| Near-real-time data URL and/or contact | • AEMET<br>Not available.<br>• GWD<br>Not available. |
| Archived data URL and/or contact | • AEMET<br>sbuisans@aemet.es (Samuel Buisan)<br>• GWD<br>FPastor@magrama.es (Fernando Pastor)<br>• MAPAMA (National Archive)<br>Snow depth data of the above-mentioned institutions is also available on official request from the National Archive. |

## General situation

Two national institutions – the Spanish State Meteorological Agency (AEMET) and the General Water Directorate Hydrological Information Area (GWD) – share the duty of performing operational snow observations in Spain. Both institutions belong to the Ministry of Agriculture and Fishing, Food and Environment (MAPAMA). However, for simplicity the Spanish State Meteorological Agency (AEMET) and the General Water Directorate Hydrological Information Area (GWD) are cited separately below as AEMET and GWD. GWD coordinates the regional hydrological services in Spain. Besides the national networks (AEMET, GWD), regional (e.g. Catalonia) and local networks exist and scientific institutions (e.g. the Spanish Research Council) operate their own snow monitoring networks across Spain, but these networks are not included in this country report. Currently, Samuel Buisan (AEMET, MAPAMA) and Fernando Pastor (GWD, MAPAMA) are the WMO country representatives for cryospheric measurements in Spain, which is why they are listed as contact persons in this report.

The snow depth data of both institutions is available in two different National Archives and data is available on request. It is planned that AEMET and GWD will adapt their snow observation methods according to WMO's guidelines on snow cover monitoring in the near future, thus making their snow data more comparable. The snow station network of both institutions is concentrated along the Spanish mountain ranges.

AEMET stations are mainly located in the Pyrenees, where the snow season usually lasts from mid-November to May at elevations above 2 000 m a.s.l. Snow station records from these locations date back to 1982. AEMET has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. AEMET observes snow depth, presence of snow on the ground and depth of snowfall manually, while snow depth is additionally measured automatically.

The GWD snow station network covers the Pyrenees but is also distributed over the alpine and midland regions in the north, middle and south of Spain. GWD measures snow depth and water equivalent of snow cover automatically on a regular basis, while manual snow depth observations are performed only once a year in spring in order to estimate the winter water resources. These manual measurements cover a far larger area than that of the automatic network.

The AEMET and GWD snow measurement networks are both discussed below.

**Overview of measurements (AEMET and GWD, both MAPAMA)**

Snow depth: stake, ultrasonic snow depth sensor, photographs (Figs I-2.34.2 – I-2.34.5)
Depth of snowfall: snow board and ruler (Figs I-2.34.13, I-2.34.14)
Water equivalent of snow cover: cosmic ray sensor (Figs I-2.34.16, I-2.34.17)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Flood forecasting, Hydrology, Meteorology, Road services, Water management

## I-2.34.1 Snow depth measurements

Number of stations delivering snow depth data manually: 42
Number of stations delivering snow depth data automatically: 31

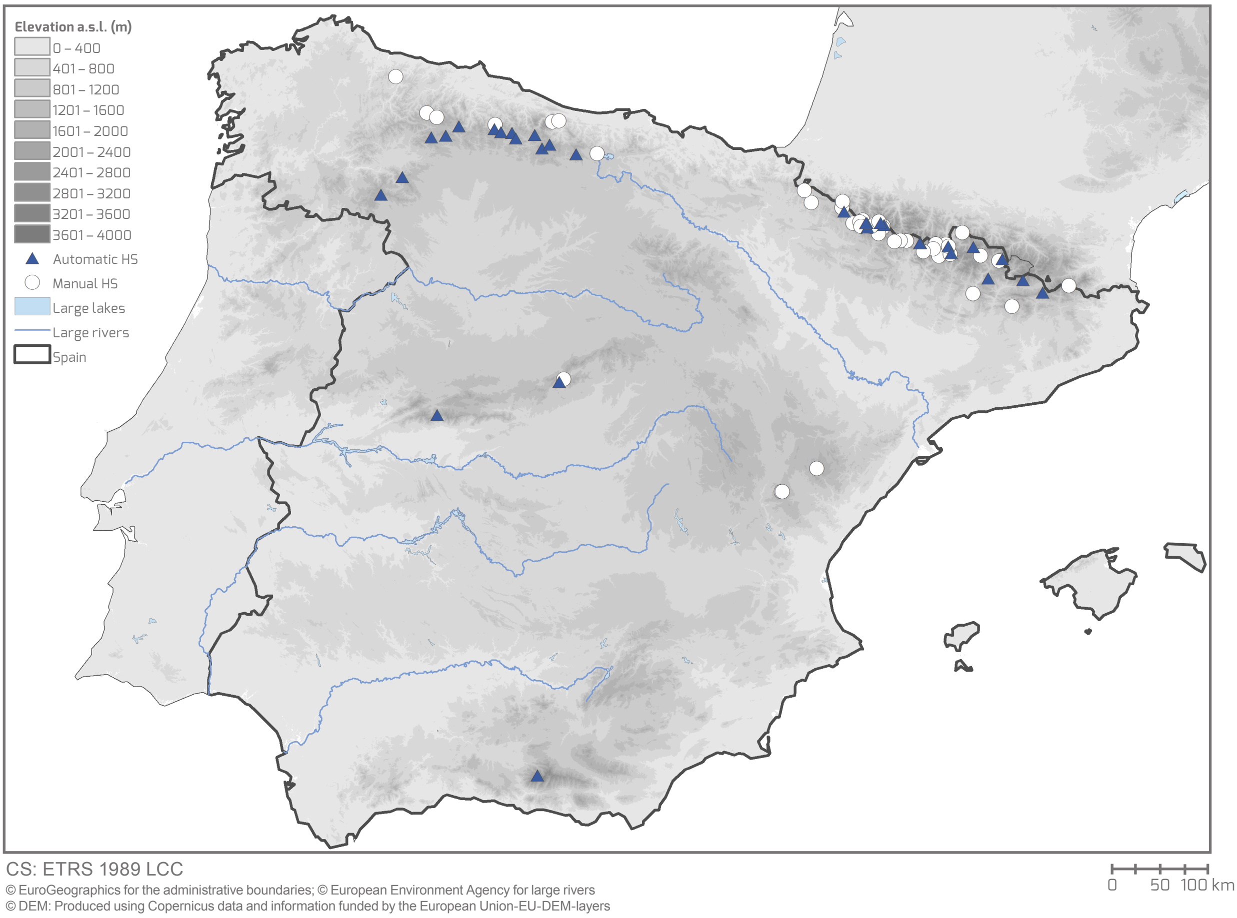

*Figure I-2.34.2 Locations of stations in Spain where snow depth (HS) is measured.*

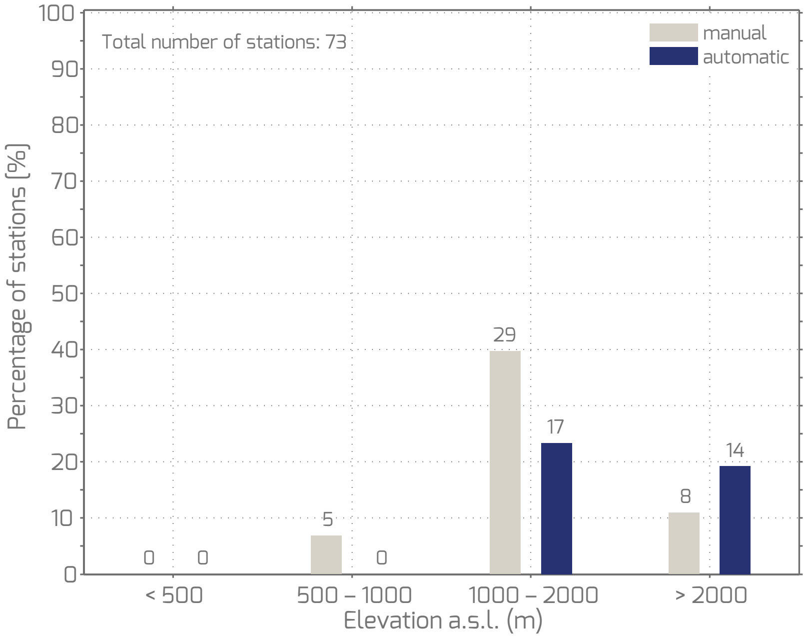

*Figure I-2.34.3 Elevational distribution of stations in Spain with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

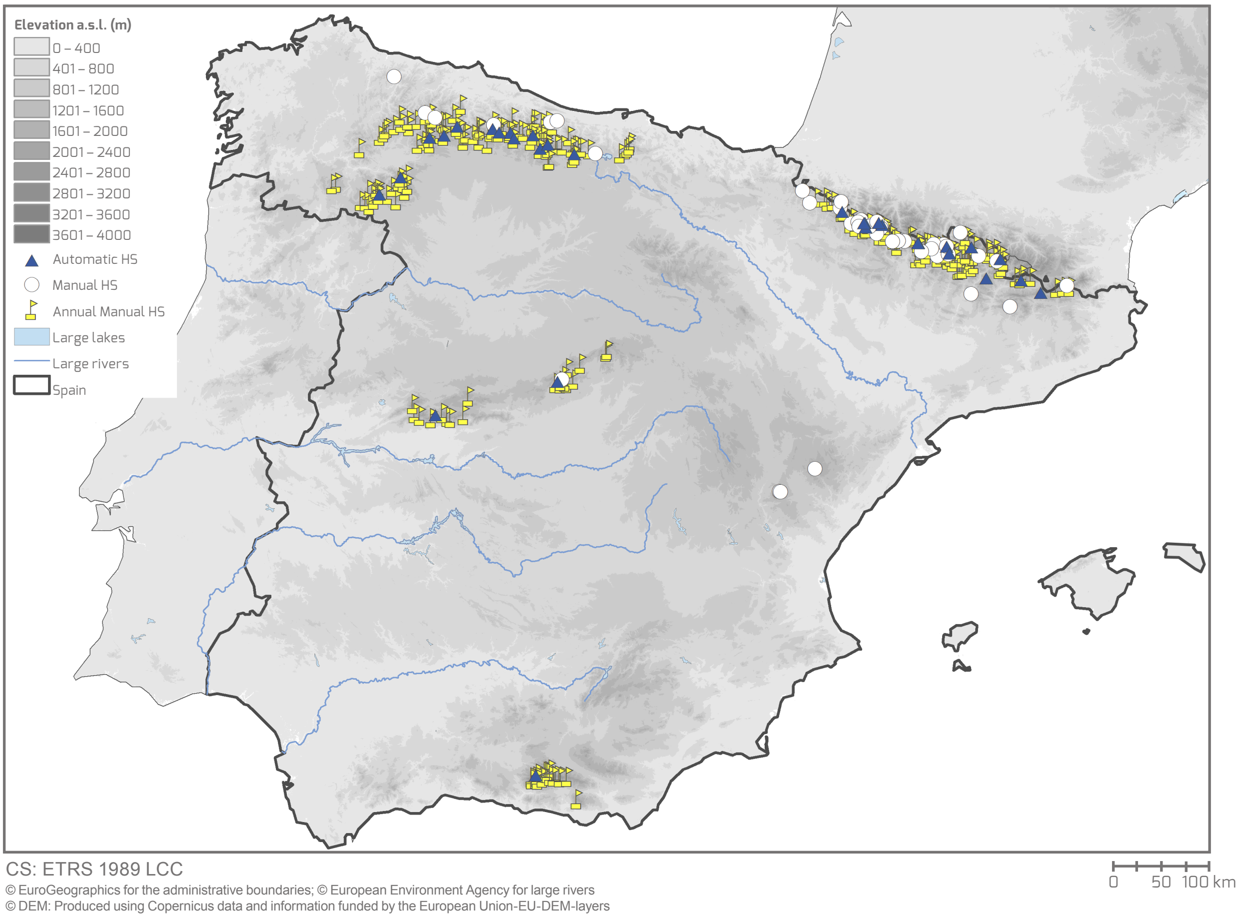

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*Figure I-2.34.4 Locations of stations in Spain where snow depth (HS) is measured continuously, as well as 265 manual stations (yellow flags) where GWD additionally measures snow depth on an annual basis in spring.*

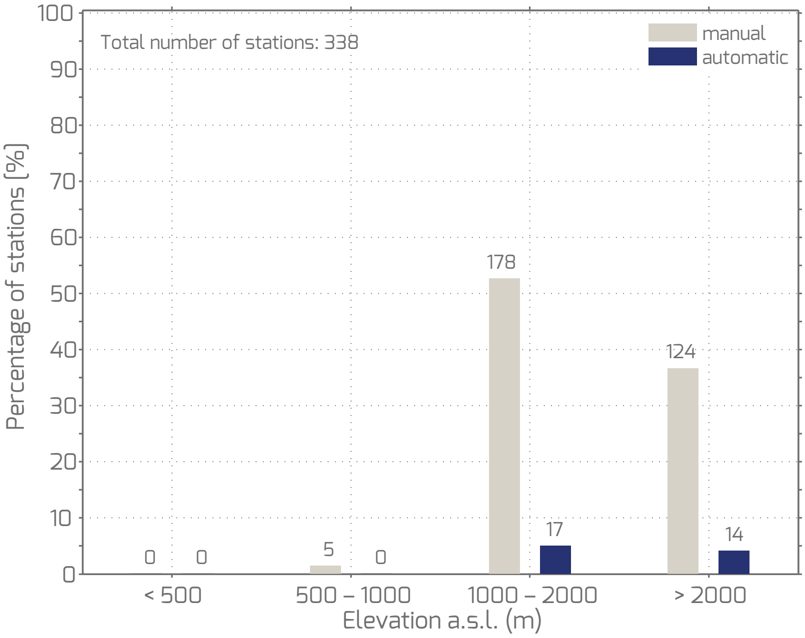

*Figure I-2.34.5 Elevational distribution of stations in Spain with manual and automatic continuous and annual (265 manual stations) snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours by AEMET. Fixed stakes with a scale in centimetres are used and read by volunteer observers (Figs I-2.34.6 – I-2.34.9). Measured values are reported in full centimetres.

In addition, GWD operates 265 locations (Figs I-2.34.4, I-2.34.5) with manual snow depth measurements performed annually in the beginning of spring. Fixed stakes with alternating coloured stripes (yellow, red, white, green; Fig. I-2.34.10) are used. Snow depth is roughly assessed from visual observations and photographs taken from a helicopter. In addition to the aerial stake readings, at 10% of these stakes manual on-site snow depth measurements are performed by an observer as a ground truth measurement.

### Automatic measurements:

Automatic snow depth measurements are performed every 60 minutes by both AEMET and GWD. Ultrasonic snow depth sensors are used and are mounted 3–4 m above the ground (Figs I-2.34.11, I-2.34.12).

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported explicitly at all stations operated by AEMET. By default, “no snow present” is noted. If there is snow on the ground “YES” must be noted. Presence of snow on the ground is not observed manually by GWD.

### Zero snow depth reporting method:

By default “0 cm snow depth” is noted, and this value has to be changed if snow is present on the ground. If snow depth data is not available “NA” is reported.

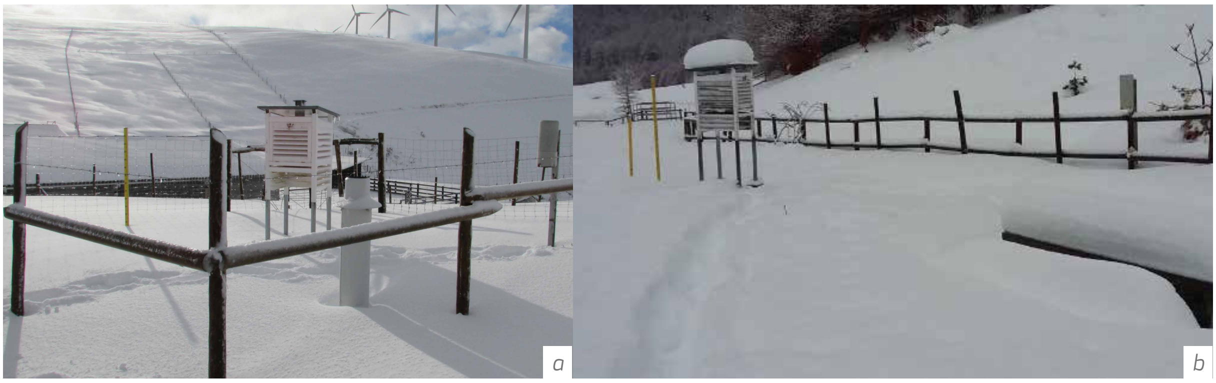

*Figure I-2.34.6 Manual measurement fields with snow stakes operated by AEMET in Spain: (a) in Illano; (b) in Linza (Source: AEMET and collaborators).*

*Figure I-2.34.7 Manual measurement fields with snow stakes operated by AEMET in Spain: (a) in Respomuso, Pyrenees; (b) in Ordesa National Park (Source: AEMET and collaborators).*

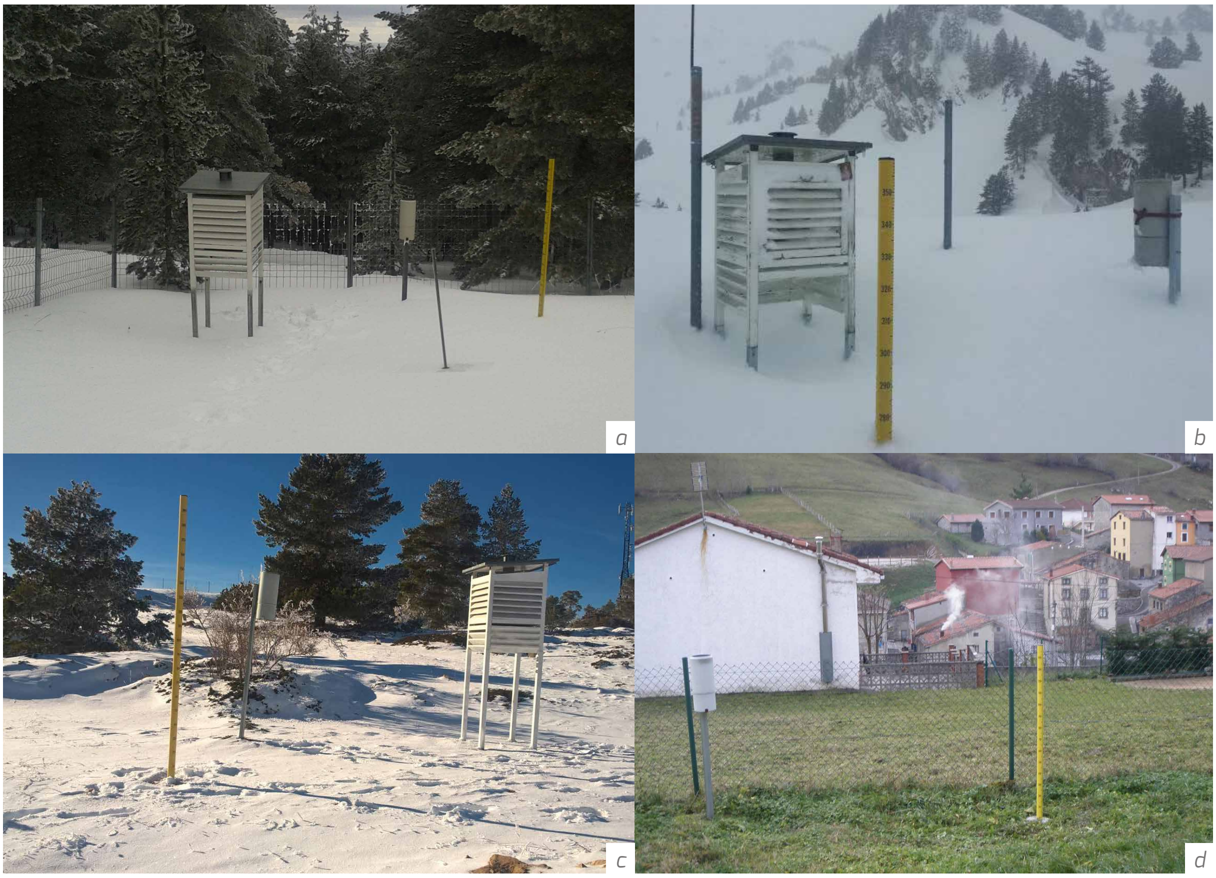

*Figure I-2.34.8 Manual measurement fields with snow stakes operated by AEMET in Spain: (a) in Valdelinares; (b) in Renclusa; (c) in Javalambre; (d) in Sotres (Source: AEMET and collaborators).*

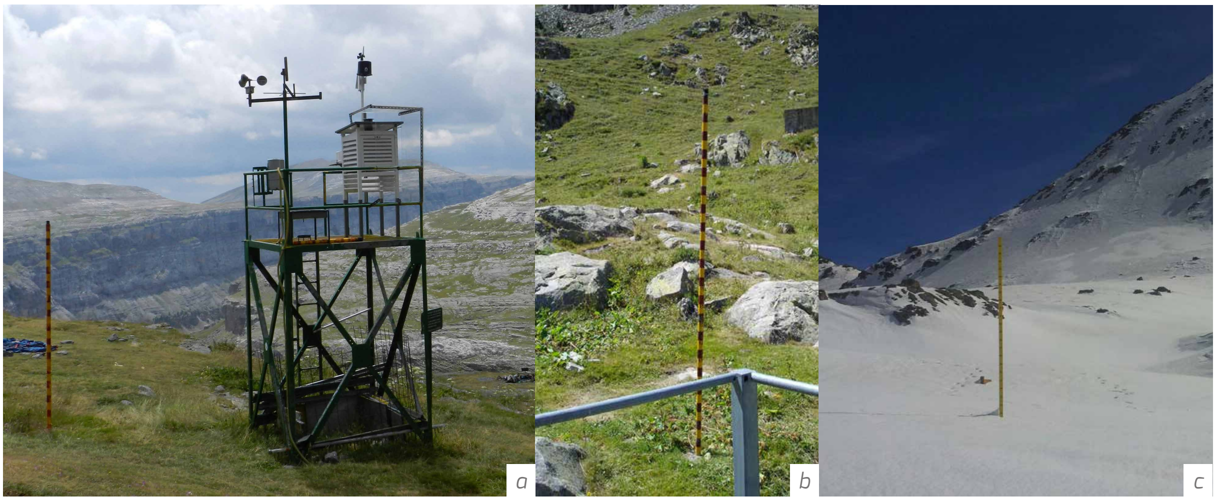

*Figure I-2.34.9 Snow stakes used to manually measure snow depth at mountain stations operated by AEMET in Spain: (a) in Goriz; (b) in Angel Orus; (c) in Llauset (Source: AEMET and collaborators).*

*Figure I-2.34.10 Snow stake and AWS operated by GWD in Izas, Spain (Source: GWD and collaborators).*

*Figure I-2.34.11 Automatic weather stations in the Pyrenees (Spain) operated by AEMET: (a) in Anayet; (b) in Formigal (Source: AEMET and collaborators).*

*Figure I-2.34.12 Automatic weather stations operated by AEMET in Spain: (a) in Navacerrada; (b) in Sierra Nevada (Source: AEMET and collaborators).*

## I-2.34.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 19

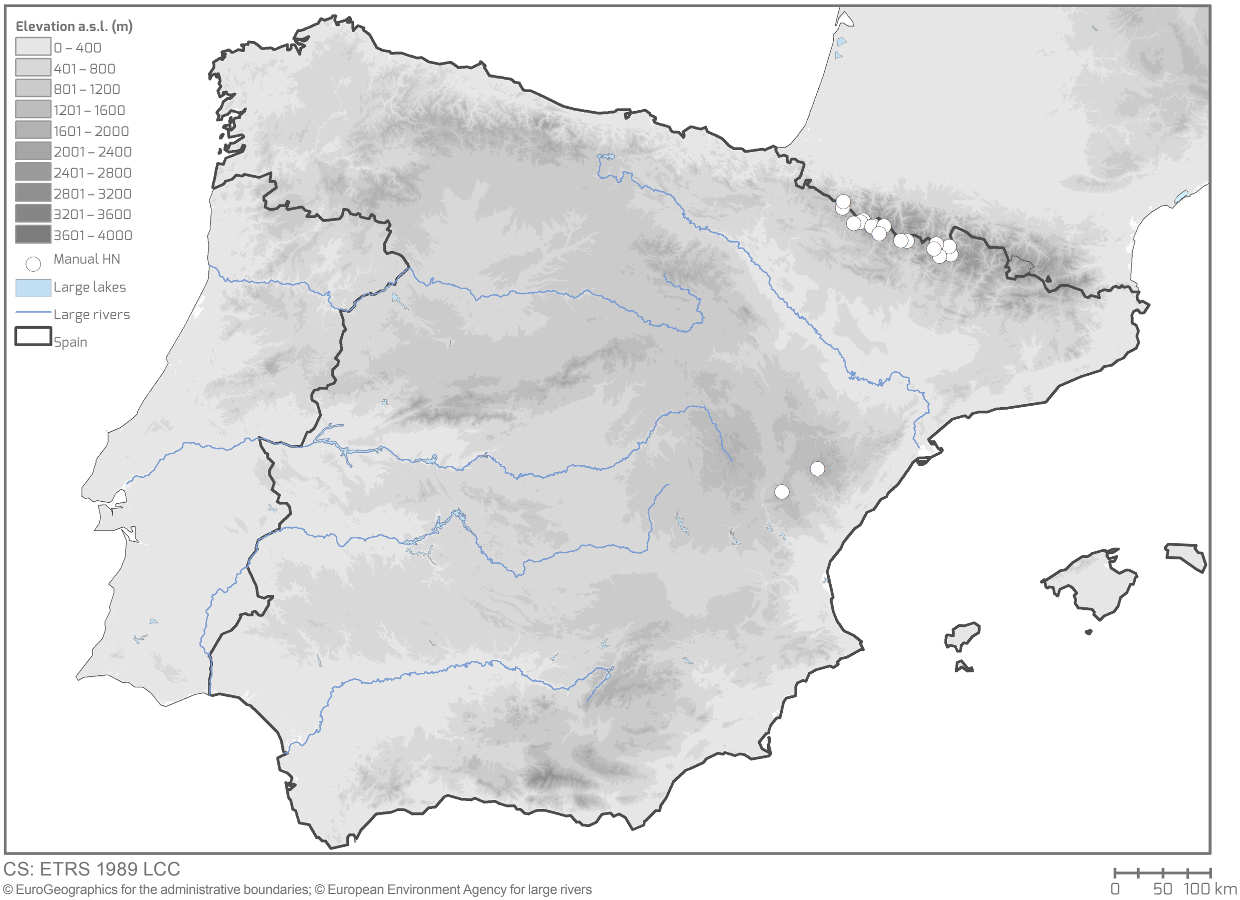

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*Figure I-2.34.13 Locations of stations in Spain where depth of snowfall (HN) is measured.*

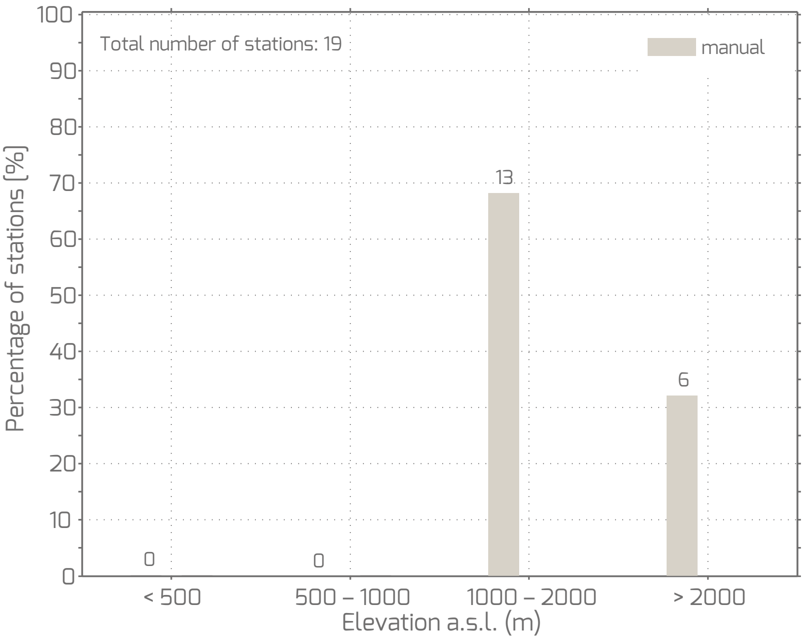

*Figure I-2.34.14 Elevational distribution of stations in Spain with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours by AEMET, in parallel to manual snow depth observations. Depth of snowfall is measured on a white-painted snow board with a measurement rod installed in the middle (Fig. I-2.34.15). The snow board is located close to the fixed stake where total snow depth is measured. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. Measured values are reported in full centimetres. Depth of snowfall data is not yet available in the AEMET National Archive.

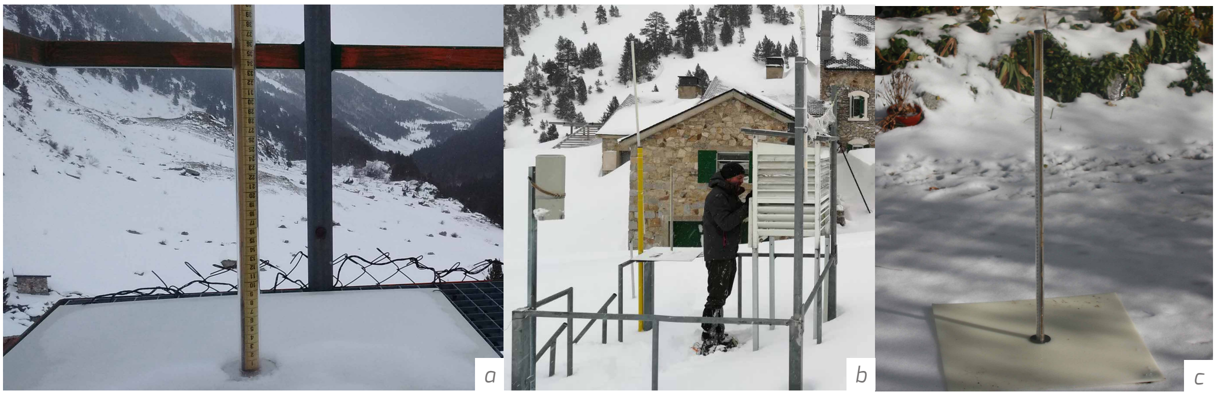

*Figure I-2.34.15 White-painted snow board with a measurement rod installed in the middle in order to measure depth of snowfall: (a) in Estos; (b) in Renclusa (between the yellow snow stake and the person); (c) in Casa De Piedra (Source: AEMET and collaborators).*

## I-2.34.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 22

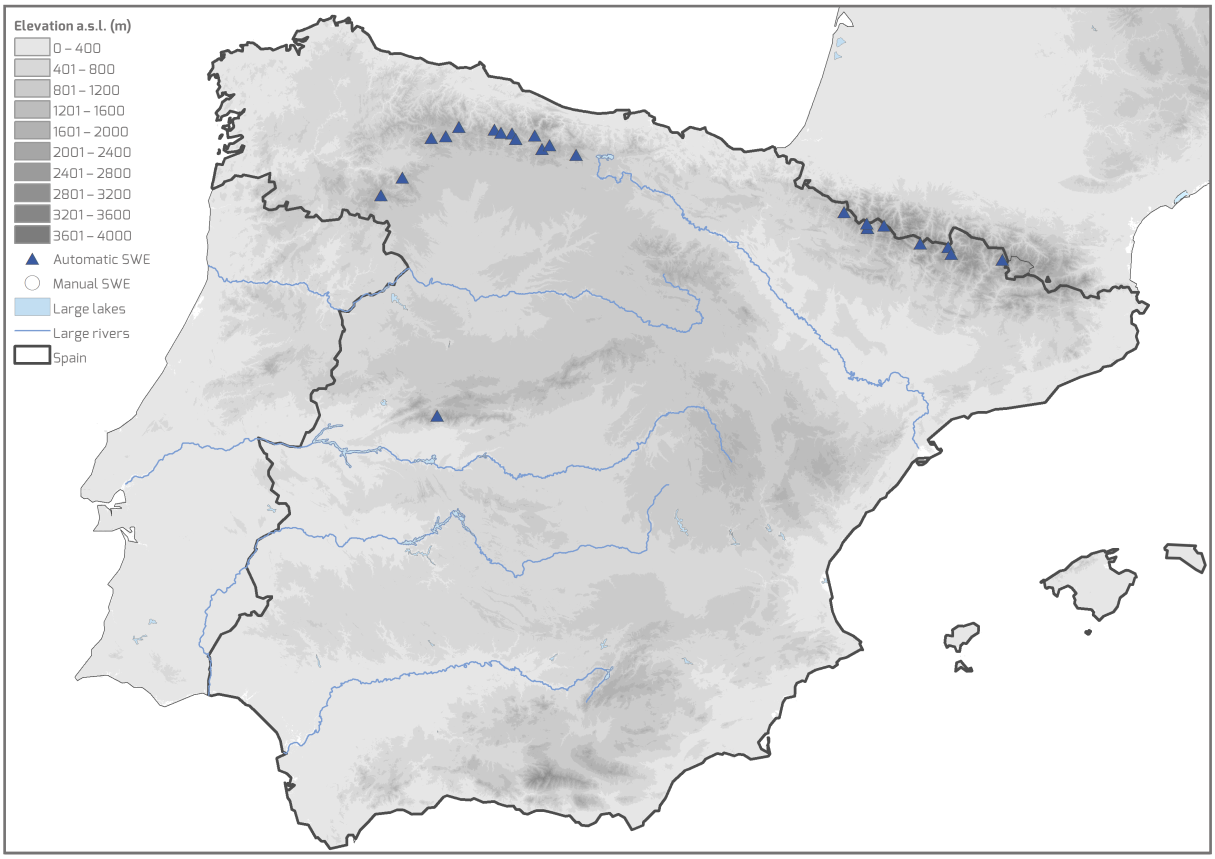

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*Figure I-2.34.16 Locations of stations in Spain where water equivalent of snow cover (SWE) is measured.*

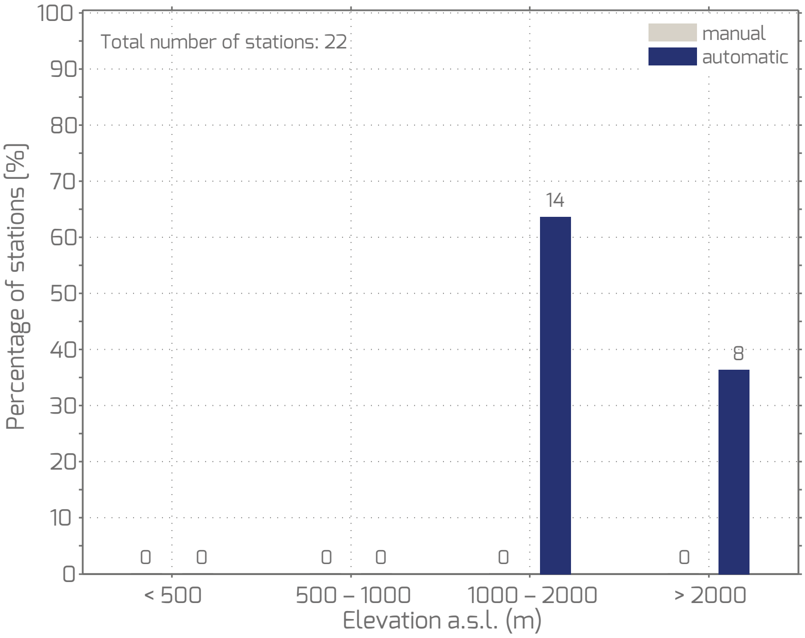

*Figure I-2.34.17 Elevational distribution of stations in Spain with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

No manual SWE measurements are operationally performed. However, GWD measures SWE manually at 10% of the 265 fixed stake locations, along with manual ground truth snow depth measurements, once a year in the beginning of spring. SWE is measured manually, either in snow pits using snow cylinders or without pits using snow tubes. In both cases the gravimetric method is applied. Using a graduated snow cylinder or snow tube with a certain cross-sectional area (in m$^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack. After measuring the height of the snow sample (in m), the snow cylinder or snow tube is attached to a spring scale to measure the total weight of the snow (in kg).

**Automatic measurements:**

Automatic SWE measurements are performed once every hour by GWD using cosmic ray sensors.

## I-2.34.4 Transition from manual to automatic measurements

No parallel measurements are needed because manual measurements have never been shifted to automatic ones at AEMET locations.

## I-2.34.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (AEMET)<br>AUTO: 1 hour (AEMET, GWD) | MANUAL: 24 hours (AEMET) | MANUAL: no measurements<br>AUTO: 1 hour (GWD) |

# I-2.35 Sweden

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*Figure I-2.35.1 Location of Sweden in Europe.*

### Country information

| | |
|---|---|
| Country area, mean country elevation | 438 574 km$^2$, 320 m a.s.l. |
| Authority responsible for snow measurements | Swedish Meteorological and Hydrological Institute (SMHI)<br>SE-60176 Norrköping<br><br>Abisko Scientific Research Station and Swedish Polar Research Secretariat (ANS)<br>Vetenskapens väg 38<br>SE-98107 Abisko |
| Contact | · SMHI<br>obs-meteorolog@smhi.se<br>· ANS<br>ans@polar.se |
| Near-real-time data URL and/or contact | · SMHI<br>http://www.smhi.se/vadret/vadret-i-sverige/snodjup<br>http://www.smhi.se/vadret/vadret-i-sverige/observationer#ws=wpt-a,proxy=wpt-a,param=s,tab=vader<br>http://opendata-download-metobs.smhi.se/explore/?parameter=8<br>· ANS<br>Not available, but planned for the near future. |
| Archived data URL and/or contact | · SMHI<br>http://opendata-download-metobs.smhi.se/explore/?parameter=8<br>· ANS<br>https://polar.se/forskning-i-abisko/vaderdata/ |

### General situation

The Swedish Meteorological and Hydrological Institute (SMHI) is the primary institution responsible for operational snow measurements in Sweden. In addition to SMHI, staff at the Abisko and Tarfala research stations, as well as hydropower companies (e.g. Vattenregleringsföretagen, Vattenfall, Uniper, Fortum), have measured snow depth for decades. However, only complementary data from the Abisko research station is included in this report because its long-term data series have been made available.

SHMI has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. The SMHI station network is equally distributed over the midland and lowland regions, whereas in alpine regions snow measurements are sparse, especially in northwestern Sweden.

In addition to SMHI, staff at the Abisko Scientific Research Station and the Swedish Polar Research Secretariat (ANS) have monitored long-term weather and snow data since 1913. More details about the Abisko research station (68° 21' N, 18° 49' E) and its long-term snow records are available online at: https://polar.se/en/research-in-abisko/ and can be read in publications (e.g. Kohler et al., 2006; Callaghan et al., 2010). In 2018 and 2019 ANS and the science infrastructure programme SITES (www.fieldsites.se) will extend their observation programme. Plans are in place to install two new automatic weather stations, which will include snow depth measurements, around the Abisko region. In cooperation with the Integrated Carbon Observation System (ICOS), ANS has operated an automatic weather station located in Stordalen (http://www.icos-sweden.se/station_stordalen.html) since 2013. Despite the fact that this data series is still short, the Stordalen station is included in this report because it is one of the few stations in northwestern Sweden. Data from this station is available on request from ICOS Sweden.

While observations of snow depth and presence of snow on the ground are performed by both SMHI and ANS, water equivalent of snow cover is only measured by SMHI and depth of snowfall is not measured at all in Sweden. Both the SMHI and ANS snow measurement networks are discussed below.

Snow data is also recorded at Tarfala research station. Initially, snow measurements were conducted primarily on glaciers, but in recent years the monitoring programme has been extended. A station network to monitor climate variables, including snow depth, was set up in the northern alpine regions. Station data is available online at: http://tarfala.insitu.se/ but is not included in this country report. Finally, the power industry has also measured snow depth and water equivalent of snow cover at hydrological stations in the Swedish mountains for many decades in order to estimate the water reservoir stored in mountainous regions. Therefore, there is no longer a lack of snow measurements in mountainous regions. However, this data is not included here because most snow data measured by power companies is not publicly available.

Swedish observations of snow have a history of more than 100 years. Observers were required to measure snow depth starting in the 1880s, but regular snow observations were not conducted until the winter season 1904/1905. From then on snow has been measured regularly. Until the mid-1990s, the observers had the option to make two different kinds of snow observations: either in open plains or in wooded grounds. This was because it was important to know the snow depth in the woods while transporting lumber during wintertime. As a result, two different snow depths from the same station were sometimes reported.

A large amount of historical snow data is available on the SMHI web page:

- Maps showing normal snow values for the period 1961–1990 are available at: https://www.smhi.se/klimatdata/meteorologi/sno
- Maps showing maximum snow depths from the winter periods 1904/1905 until 2016/2017 can be found at: https://www.smhi.se/klimat/klimatet-da-och-nu/klimatindikatorer/klimatindikator-vinterns-storsta-snodjup-1.91052
- Maps showing climatological indicators, such as the number of days with snow cover, from the winter seasons 1950/1951 to 2016/2017 are available at: https://www.smhi.se/klimat/klimatet-da-och-nu/klimatindikatorer/klimatindikator-antal-dagar-med-snotacke-1.91081
- More information on Swedish snow records is available at: https://www.smhi.se/kunskapsbanken/meteorologi/svenska-snodjupsrekord-1.88638

The greatest snow depths occur in the mountain areas. Many snow records have been carried out in these areas during the last couple of decades, possibly owing to the increasing number of stations in the mountains, where snow depth is measured on a more regular basis. In the southern part of Sweden there are fewer records, owing to the milder climate. Because of the more open landscape which is more exposed to the wind, however, severe drifting can create harsh snow conditions. The snow can pile up to impressive heights. The largest snow depth recorded at an official observation site in Sweden is 327 cm, which occurred at Kopparåsen (Northern Sweden) on 24–25 and 27–28 February 1926.

In Sweden the expression “snow canons” is sometimes used to describe heavy snowfall. This is basically the same as the Great Lake effect in the USA, where advection of cold arctic air over open water leads to massive amounts of snowfall. In a “snow canon” situation, concentrated, long areas of snow showers appear on the radar, almost as if the snow were shot with a canon. The entire eastern coast (more or less) of Sweden can be affected, as can the area south and southeast of the lakes Vättern and Vänern.

## Overview of measurements (SMHI, ANS)

Snow depth: ruler, stake, ultrasonic snow depth sensor (Figs I-2.35.2, I-2.35.3)
Depth of snowfall: no measurements
Water equivalent of snow cover: snow cylinder, spring scale, plastic bags (Figs I-2.35.5, I-2.35.6)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Building and Construction, Climatology, Energy production, Flood forecasting, Health and Sport, Hydrology, Meteorology, Research, Road services, Water management

## I-2.35.1 Snow depth measurements

Number of stations delivering snow depth data manually: 534
Number of stations delivering snow depth data automatically: 2

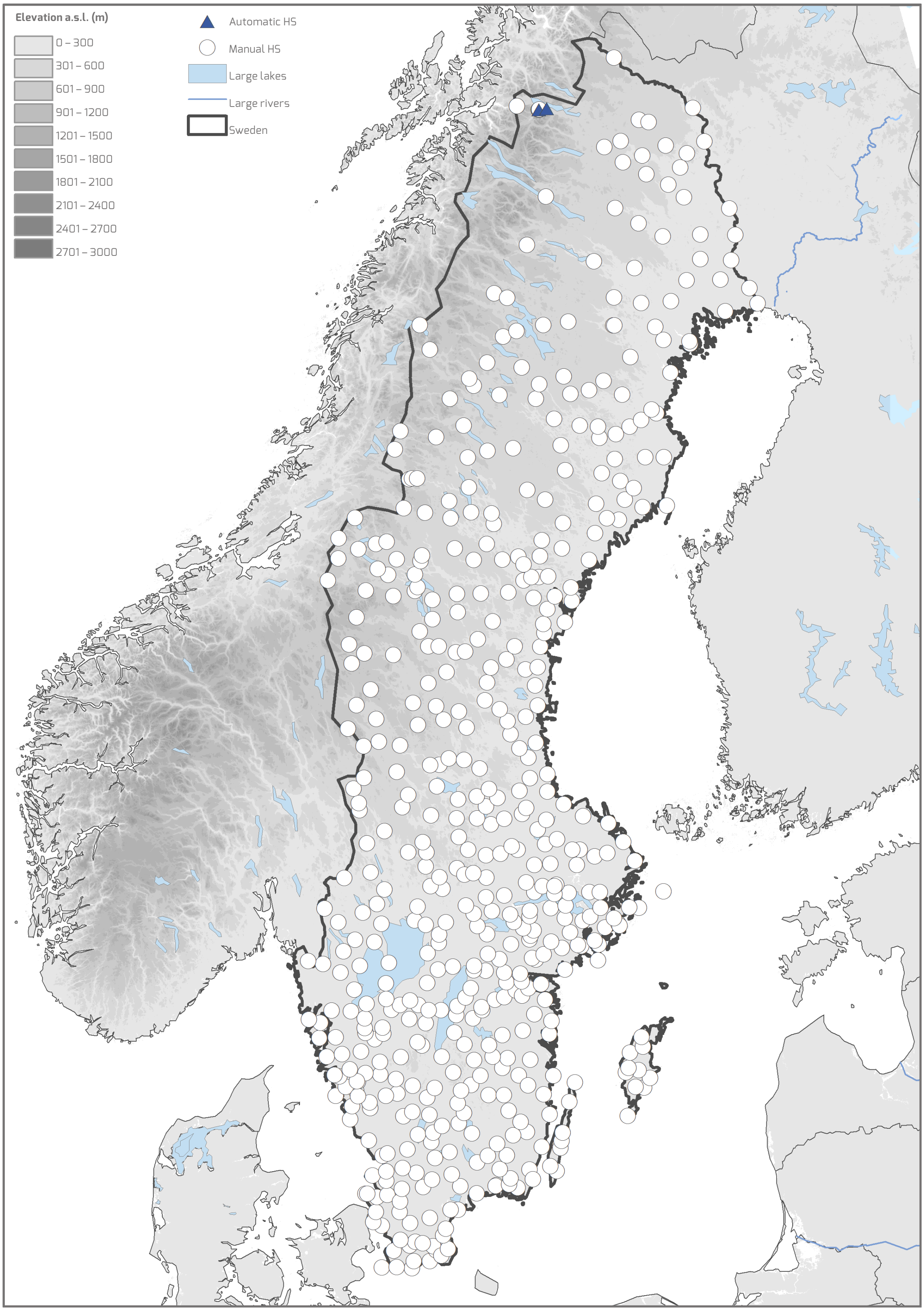

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*Figure I-2.35.2 Locations of stations in Sweden where snow depth (HS) is measured.*

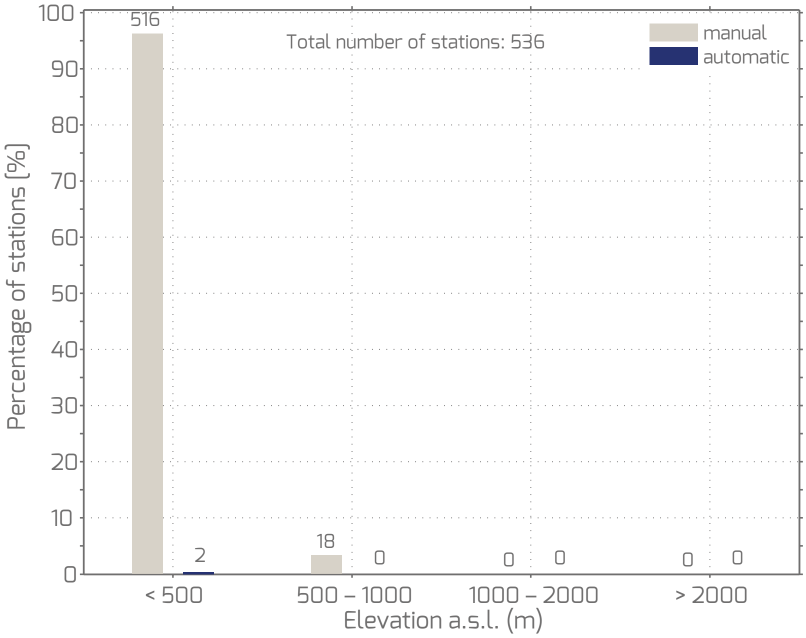

*Figure I-2.35.3 Elevational distribution of stations in Sweden with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours at 0600 UTC, from the first snowfall in autumn until the measurement site is snow free again in spring. Either fixed stakes or portable rulers are used, both with a scale in centimetres. All measurement equipment is provided by SMHI. The spatial variability in snow depth is accounted for because at least five snow depth measurements are carried out within a measurement field with a size of approximately 10 x 10 m. The average of these measurements is reported as total snow depth. To prevent incorrect measurements, the observations are performed in an even area representative of the surroundings and as wind protected as possible in order to avoid snow drifts. Total snow depth is reported as long as at least 50% of the measurement field is covered with snow. Measured values are reported in full centimetres.

ANS performs manual snow depth observations: (1) at one point every 24 hours at 0600 UTC (Fig. I-2.35.4 a) and (2) in a spatially distributed manner once every week along two snow courses (Fig. I-2.35.4 b). In both cases fixed stakes are used. For snow course measurements, 10 fixed stakes with a 5 cm resolution are installed along each course. Total snow depth is reported as long as snow is present at the stake.

### Automatic measurements:

Snow depth is measured automatically every 10 or 30 minutes using ultrasonic snow depth sensors. The stations are operated by ANS.

### Presence of snow on the ground reporting method:

In parallel to manual snow depth measurements, presence of snow on the ground is reported explicitly at both SMHI and ANS stations. At SMHI stations the observer additionally applies a coding system if there is a discontinuous snow cover in the 10 x 10 m measurement field: (1) "S" means the ground is almost totally snow covered; (2) "SB" means more than 50% but not all of the ground is covered with snow; (3) "BS" means more than 50% of the measurement field is snow free; and (4) "B" means the ground is almost but not entirely snow free. Presence of snow on the ground is not reported by SMHI observers if the measurement site is totally snow free. At ANS stations a coding system is applied by observers to report if the ground is (1) frozen, (2) unfrozen, (3) snow covered or (4) a combination of these three states.

### Zero snow depth reporting method:

When more than 50% of the ground is snow free (code "BS"), 0 cm snow depth is reported by SMHI observers. At the Abisko station, 0 cm snow depth is reported if no snow is present at the stake.

*Figure I-2.35.4 Snow observations at Abisko research station in Sweden: (a) snow depth point measurement at a stake; (b) spatially distributed snow depth readings along a snow course (Source: ANS).*

## I-2.35.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 0

**Manual measurements:**

No measurements.

## I-2.35.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 19
Number of stations delivering water equivalent of snow cover data automatically: 0

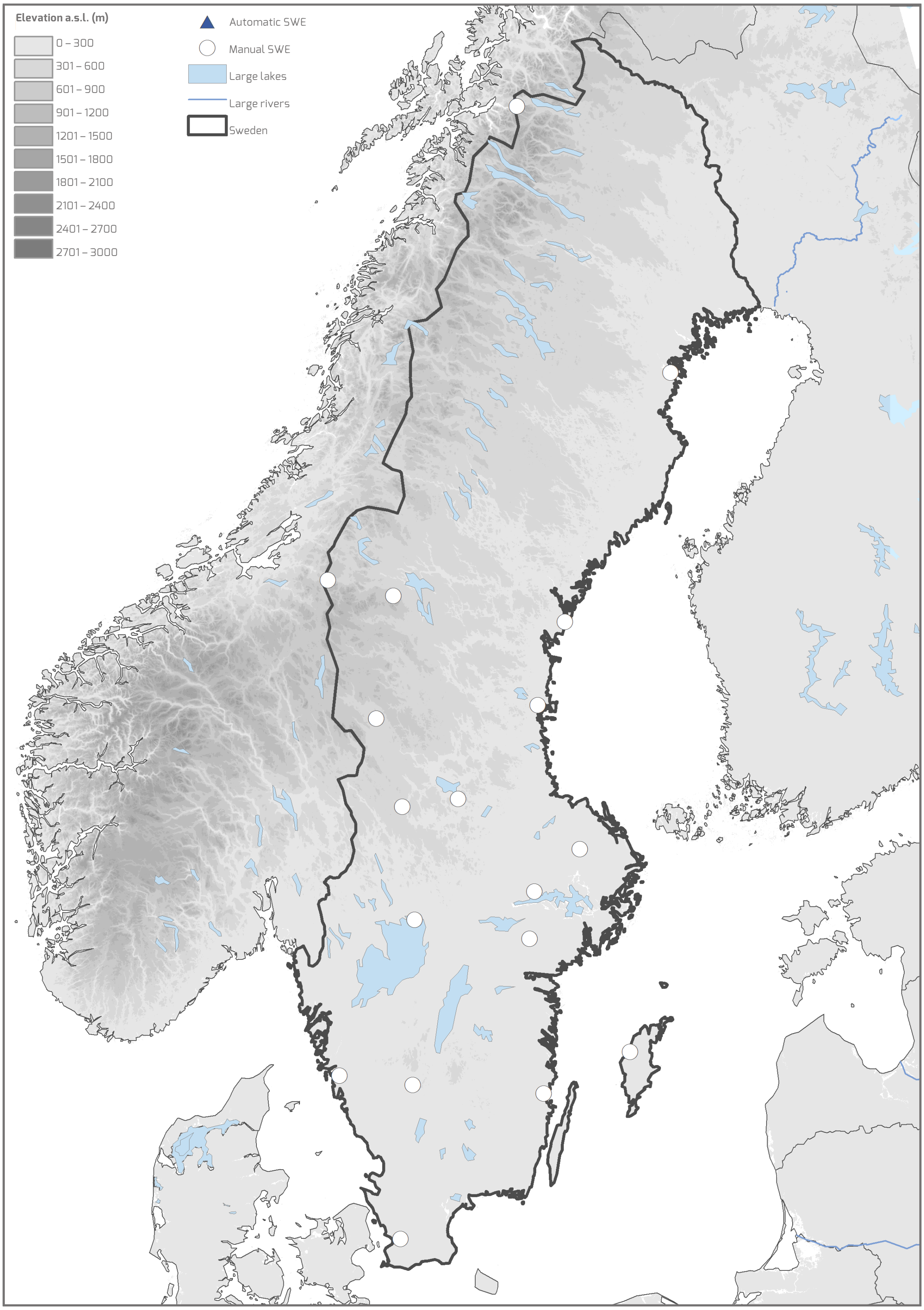

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*Figure I-2.35.5 Locations of stations in Sweden where water equivalent of snow cover (SWE) is measured.*

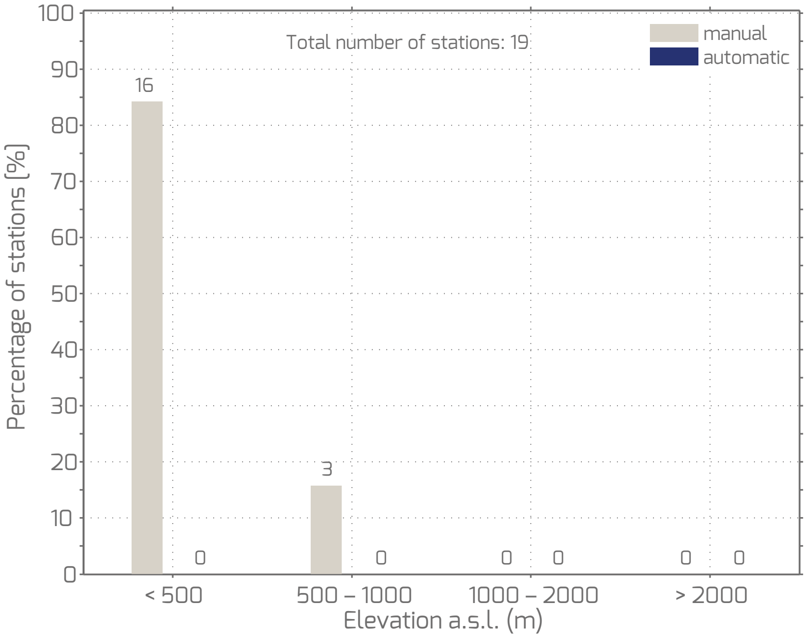

*Figure I-2.35.6 Elevational distribution of stations in Sweden with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed for snow depths exceeding 15 cm: for snow depths varying between 15 and 30 cm SWE measurements are performed once every two weeks, while for snow depths exceeding 30 cm SWE is measured once every week. The gravimetric method is applied. Using a graduated snow cylinder with a certain cross-sectional area (in $m^2$) and a certain length (1.2 m, 1.5 m or 2.0 m), three snow samples are extracted vertically from the snowpack close to each other. The height of each snow sample (in m) is measured and noted separately. Afterwards the snow from all three samples is poured into one plastic bag and the bag is attached to a spring scale to measure the total weight of the snow (in kg).

The location of the SWE measurement is selected to be representative of the surrounding area, wind protected and free of any vegetation or obstacles. In the special case that depth of snowfall exceeds 30 cm within a 24-hour interval or if weather conditions are of special interest, additional SWE measurements are performed.

**Automatic measurements:**

No measurements.

## I-2.35.4 Transition from manual to automatic measurements

No transition from manual to automatic measurements has been made at SMHI stations. At the Abisko research station, in contrast, parallel measurements have been performed since 2015 and will be continued.

## I-2.35.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (SMHI, ANS) or 1 week (ANS)<br>AUTO: 10 or 30 minutes (ANS) | MANUAL: no measurements | MANUAL: 1 or 2 weeks (SMHI)<br>AUTO: no measurements |

# I-2.36 Switzerland (with Liechtenstein)

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*Figure I-2.36.1 Location of Switzerland and Liechtenstein (between Switzerland and Austria) in Europe.*

## Country information

| | |
|---|---|
| Country area (with Liechtenstein), mean country elevation | 41 285 (41 445) km$^2$, 1 309 m a.s.l. |
| Authority responsible for snow measurements | Federal Office of Meteorology and Climatology MeteoSwiss (MeteoSwiss)<br>Operation Center 1, P.O. Box 257<br>CH-8058 Zurich-Airport<br><br>WSL Institute for Snow and Avalanche Research (SLF)<br>Flüelastrasse 11<br>CH-7260 Davos Dorf |
| Contact | · MeteoSwiss<br>kundendienst@meteoswiss.ch<br>· SLF<br>contact@slf.ch |
| Near-real-time data URL and/or contact | · MeteoSwiss<br>https://www.meteoswiss.admin.ch/home/measurement-values.html?param=messwerte-gesamtschnee-1d<br>· SLF<br>https://www.slf.ch/en/avalanche-bulletin-and-snow-situation/measured-values.html |
| Archived data URL and/or contact | · MeteoSwiss<br>kundendienst@meteoswiss.ch<br>· SLF<br>contact@slf.ch |

## General situation

Two institutions, the Federal Office of Meteorology and Climatology (MeteoSwiss) and the WSL Institute for Snow and Avalanche Research (SLF) share the duty of performing operational snow observations in Switzerland. The MeteoSwiss station network is equally distributed over the alpine and midland regions, whereas SLF stations only exist in the mountainous regions.

Among other duties, MeteoSwiss is responsible for observing meteorological variables for the sake of public interest, weather forecasting and climatological records. SLF is the authority responsible for avalanche forecasting, which is why its stations are mostly located in the mountains. Avalanche forecasts provided by SLF are supported by intense snow research at the institute, which requires frequent measurement of many variables.

SLF and MeteoSwiss exchange their data and use the collective data for their various products (e.g. forecasts, climatology). While snow depth and depth of snowfall measurements are performed by both MeteoSwiss and SLF, water equivalent of snow cover is only measured by SLF and presence of snow on the ground is only observed by MeteoSwiss. Additional details about snow observations are provided in the recently updated Swiss Global Climate Observing System (GCOS) report (Stalder et al., 2018). Snow measurements of the manual MeteoSwiss precipitation network (NIME), with more than 300 stations mainly located below 1 500 m a.s.l., are not included in this report because measurement intervals and variables are not standardised, the digitised time series are usually short and quality control is limited.

In addition to running the snow station network in Switzerland, SLF operates one automatic station with snow depth measurements and one manual station with snow depth, depth of snowfall and water equivalent of snow cover measurments in the territory of the Principality of Liechtenstein. These are the only operational snow observations performed in Liechtenstein, which is why they are included in this country report for Switzerland. The operational MeteoSwiss and SLF snow measurement networks are both discussed below.

## Overview of measurements (MeteoSwiss, SLF)

Snow depth: stake, ultrasonic snow depth sensor, laser snow depth sensor (Figs I-2.36.2, I-2.36.3)
Depth of snowfall: snow board and ruler (Figs I-2.36.5, I-2.36.6)
Water equivalent of snow cover: snow cylinder, spring scale, snow pillow (Figs I-2.36.8, I-2.36.9)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Health and Sport, Hydrology, Meteorology, Road services, Water management

## I-2.36.1 Snow depth measurements

Number of stations delivering snow depth data manually: 155
Number of stations delivering snow depth data automatically: 162

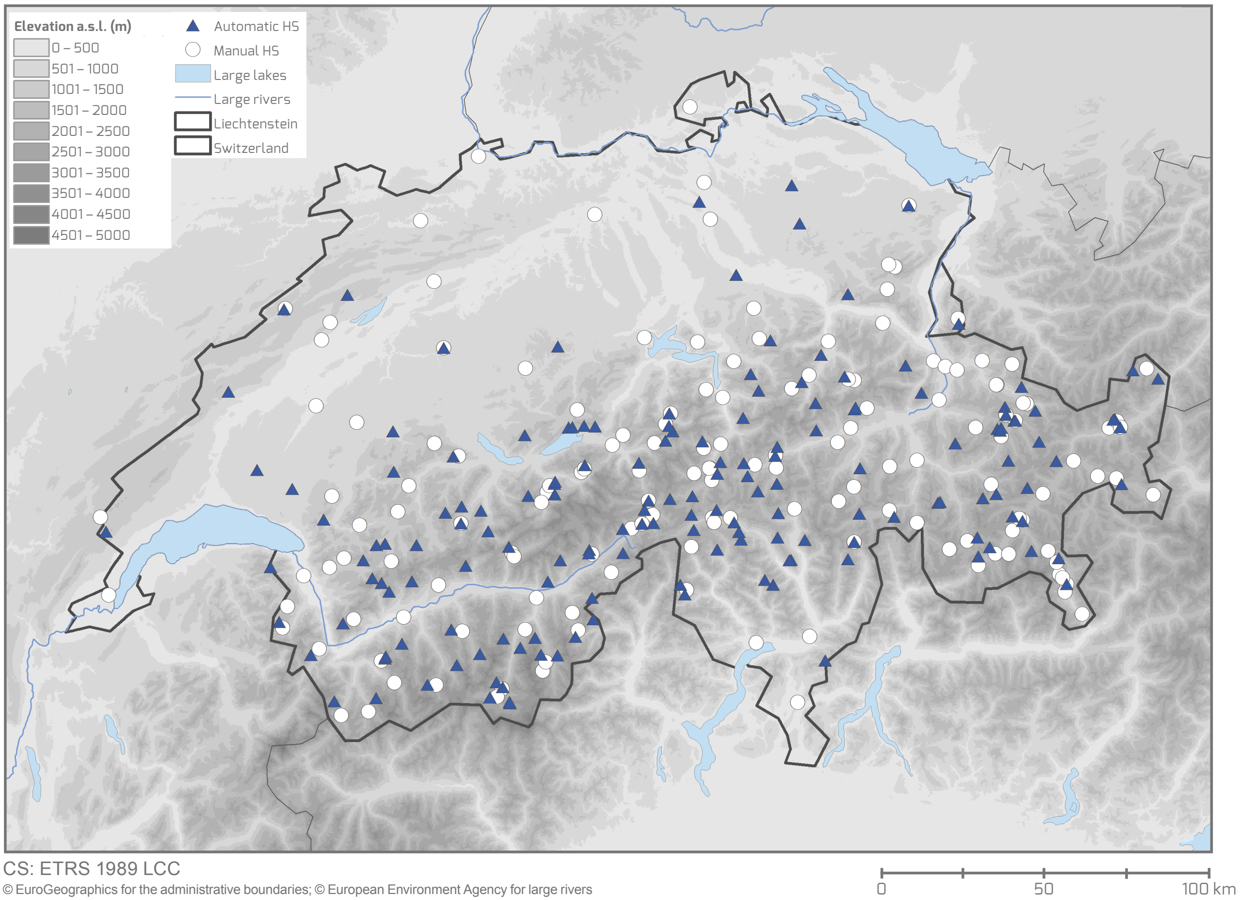

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*Figure I-2.36.2 Locations of stations in Switzerland and Liechtenstein where snow depth (HS) is measured.*

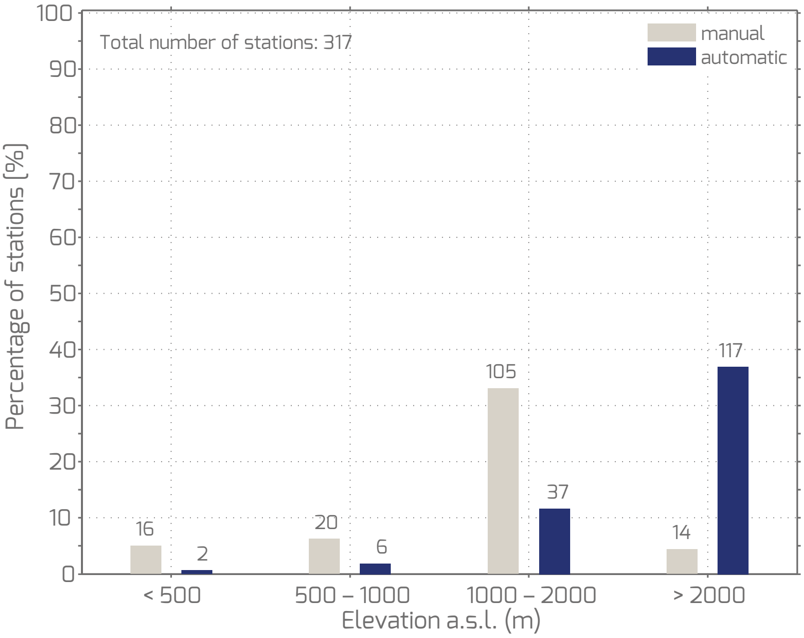

*Figure I-2.36.3 Elevational distribution of stations in Switzerland and Liechtenstein with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours at 0600 UTC by both MeteoSwiss and SLF. Fixed aluminium stakes with a scale in centimetres and a length of 1.5 or 4 m are used. Observers avoid creating disturbances in the 10 x 10 m measurement field around the stake (Fig. I-2.36.4). To prevent incorrect measurements, values are read as horizontally to the surface as possible. Total snow depth is reported as long as at least 50% of the measurement field is covered with snow. Measured values are reported in full centimetres.

### Automatic measurements:

Automatic snow depth measurements are available either every 10 minutes (average of 10 measurements) with laser snow depth sensors (32 MeteoSwiss stations) or every 30 minutes using ultrasonic snow depth sensors (130 SLF stations). Snow depth sensors are mounted 2–6 m above the ground. Only stations operated by MeteoSwiss use artificial targets (rubber plates). There is an ongoing project in which around 50 laser snow depth sensors will be installed on existing MeteoSwiss stations (time frame 2019–2022).

### Presence of snow on the ground reporting method:

In parallel to manual snow depth measurements, presence of snow on the ground is reported explicitly at 19 weather observation stations operated by MeteoSwiss (12% of all manual snow depth measurement locations in Switzerland). Presence of snow on the ground is reported daily at 0600, 1200 and 1800 UTC.

### Zero snow depth reporting method:

When more than 50% of the 10 x 10 m measurement field is snow free, 0 cm snow depth is reported, even if there is still some snow at the stake itself.

*Figure I-2.36.4 Example of a snow measurement field in Switzerland (Source: SLF).*

## I-2.36.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 146

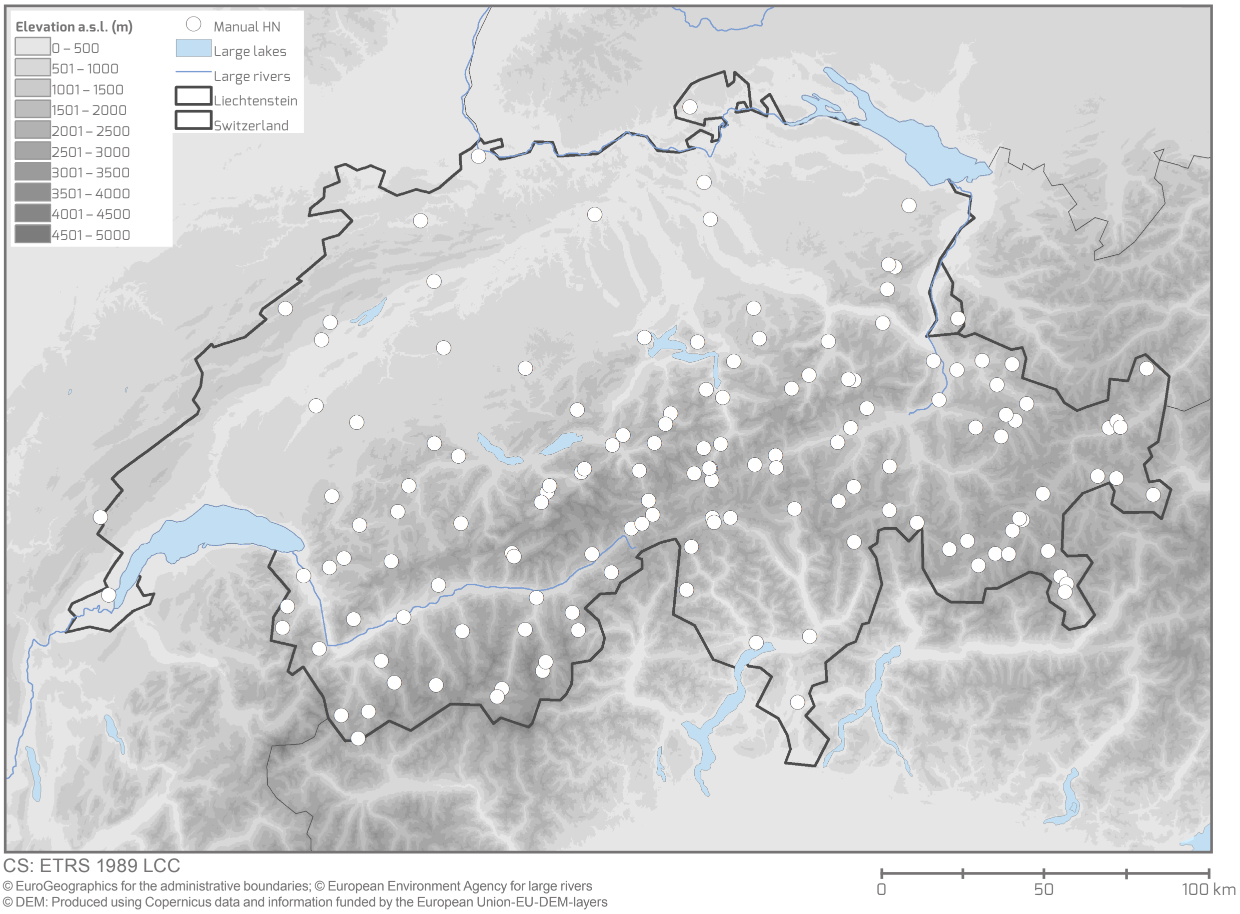

*Figure I-2.36.5 Locations of stations in Switzerland and Liechtenstein where depth of snowfall (HN) is measured.*

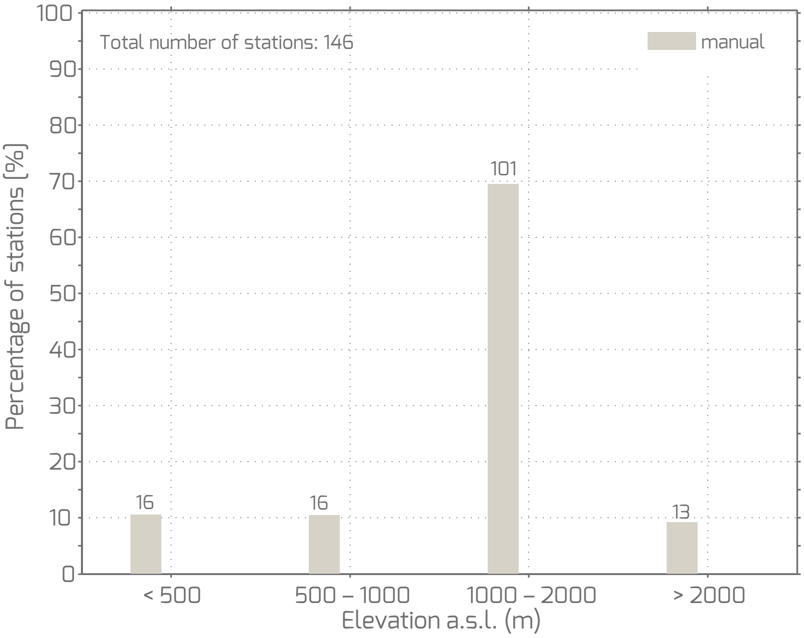

*Figure I-2.36.6 Elevational distribution of stations in Switzerland and Liechtenstein with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours at 0600 UTC, in parallel to manual snow depth measurements, by both MeteoSwiss and SLF. Depth of snowfall is measured on a white-painted snow board (50 x 50 cm) with a ruler. The snow board surface is fitted with two 50-cm-long rods so that the board can be located after a snowfall event (Fig. I-2.36.7 a). Depth of snowfall is measured at two to three points on the snow board (Fig. I-2.36.7 b) and the average of all measurements is reported. After each measurement, the snow board is cleaned and replaced on the top of the snow cover, as evenly as possible in relation to the surrounding surface. The location of the depth of snowfall measurement is selected to minimise influence from the wind. Measured values are reported in full centimetres. Depth of snowfall measurements less than 0.5 cm (in the case of MeteoSwiss) or 0.3 cm (in the case of SLF) are reported as 0 cm new snow.

Additional guidelines are respected for the following special cases: (1) Even if considerable snowdrift is recognised, depth of snowfall is always measured as described above. If the actual depth of snowfall in the surrounding area differs considerably from the depth of snowfall measured on the board, the observer additionally estimates a representative value and notes it in the logbook. (2) If there is snow on the snow board but it is certain that no precipitation fell in the last 24 hours, 0 cm is reported. (3) If new snow that fell within the last 24 hours has already melted away, depth of snowfall is estimated. The depth of snowfall is reported as 0 cm in the logbook but with a remark, e.g. “Depth of snowfall estimated at 3 cm, melted away”. (4) If a measurement field cannot be accessed for a longer period, owing to external circumstances, depth of snowfall is reported as 0 cm with a remark specifying the measured depth of snowfall and the corresponding period (e.g. “80 cm within 72 hours”).

*Figure I-2.36.7 (a) Snow board fitted with two 100-cm-long rods so that the board can be located after a snowfall event. In the background a graduated black and yellow snow stake to measure snow depth is visible. (b) An observer measuring depth of snowfall on a snow board (Source: SLF).*

## I-2.36.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 45
Number of stations delivering water equivalent of snow cover data automatically: 1

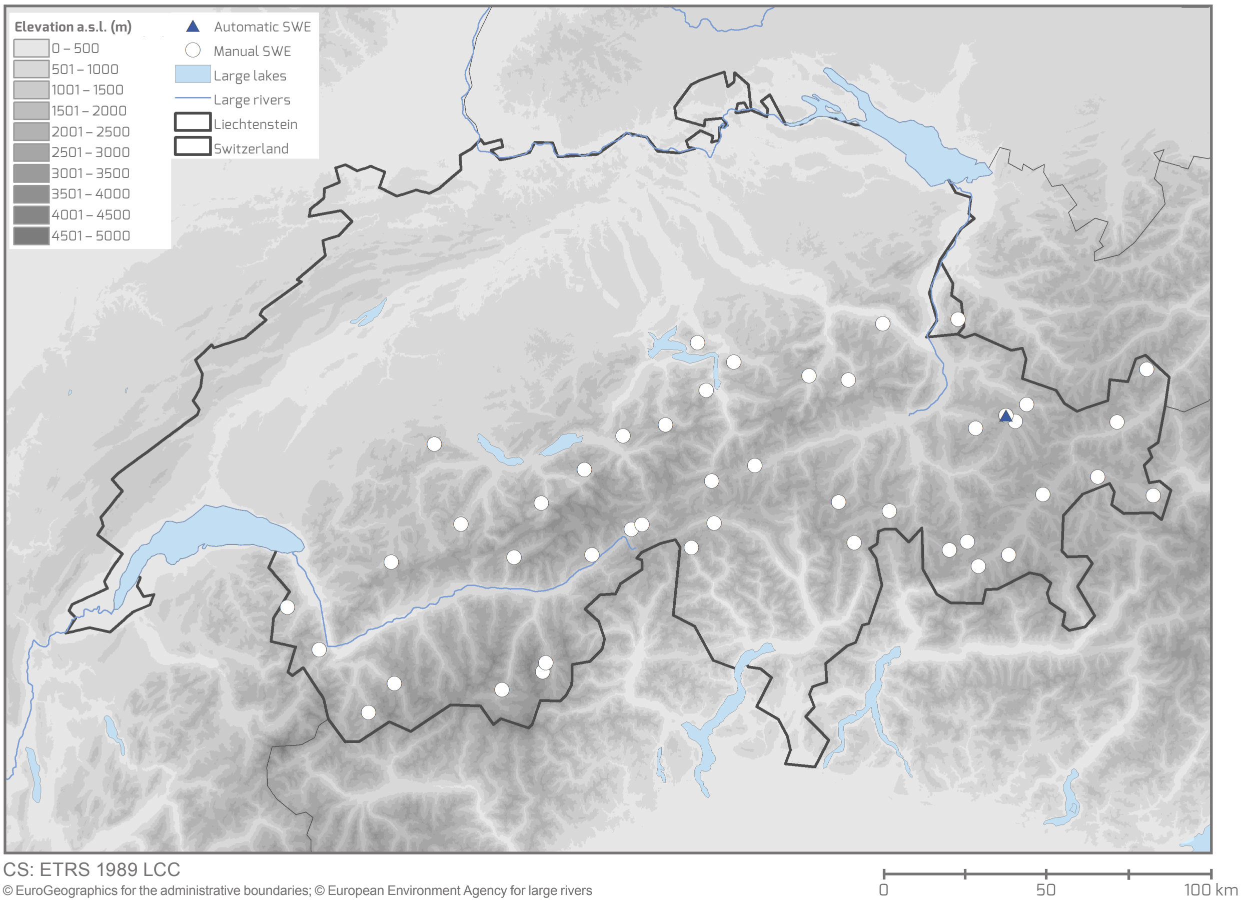

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*Figure I-2.36.8 Locations of stations in Switzerland and Liechtenstein where water equivalent of snow cover (SWE) is measured.*

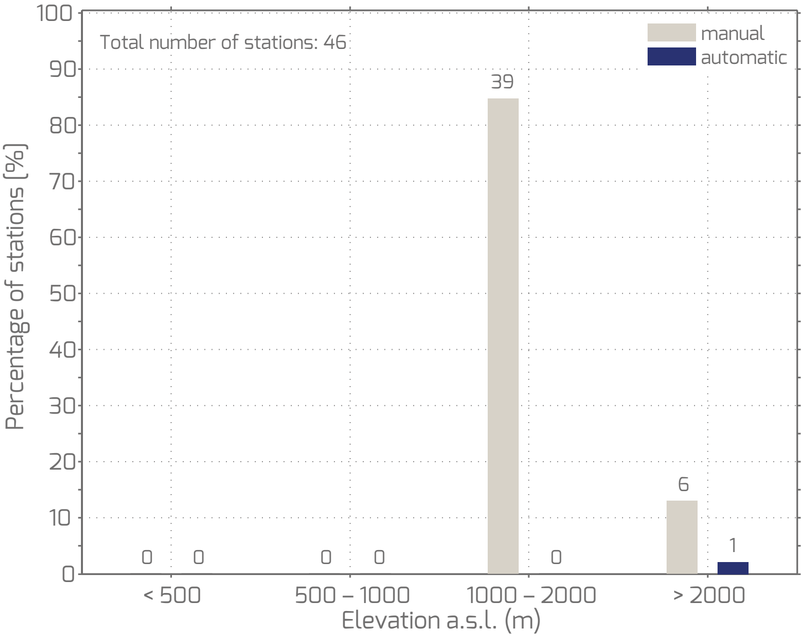

*Figure I-2.36.9 Elevational distribution of stations in Switzerland and Liechtenstein with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual SWE measurements in snow pits are performed once every two weeks by SLF observers using the gravimetric method. Using a graduated aluminium cylinder (ETH cylinder) with a cross-sectional area of 0.007 $m^2$ and a length of 0.55 m, a snow sample is extracted vertically from the snowpack (Fig. I-2.36.10). After the height of the snow sample (in m) is measured and excess snow on the external surface of the cylinder is removed, the snow cylinder is attached to a spring scale (Fig. I-2.36.11). The spring scale used by SLF shows values in water equivalents (WE; as mm w.e.) as well as in weight (in kg) of the sample, so WE can be read directly from the scale. If the snow depth is greater than the length of the cylinder (0.55 m), the total snow depth is divided into multiple analogue “columns”. Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers. The sum of the snow depths measured with the snow cylinder might not match the total snow depth, owing to ground inhomogeneities. Before the snow sample is weighed, the spring scale must be attached to an anchor and tared to 0 mm.

**Automatic measurements:**

Only one automatic SWE measurement location exists in Switzerland (Weissfluhjoch test site near Davos at 2 536 m a.s.l., operated by SLF), where SWE is measured every 30 minutes using a snow pillow.

*Figure I-2.36.10 Water equivalent of snow cover measurement in a snow pit; an observer is extracting snow using a snow cylinder (Source: SLF).*

*Figure I-2.36.11 (a, b) An ETH snow cylinder is attached to a spring scale during a water equivalent of snow cover measurement (Source: SLF).*

## I-2.36.4 Transition from manual to automatic measurements

Parallel measurements are carried out for a few years if a station includes a long-term climatological measurement series that is considered highly valuable.

## I-2.36.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (MeteoSwiss, SLF)<br>AUTO: 10 minutes (MeteoSwiss) or 30 minutes (SLF) | MANUAL: 24 hours (MeteoSwiss, SLF) | MANUAL: 2 weeks (SLF)<br>AUTO: 30 minutes (SLF) |

# I-2.37 Turkey

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*Figure I-2.37.1 Location of Turkey in relation to Europe.*

## Country information

| | |
|---|---|
| Country area, mean country elevation | 783 562 km$^2$, 1 139 m a.s.l. |
| Authority responsible for snow measurements | Turkish State Meteorology Service (TSMS)<br>Kütükçü Alibey Caddesi No: 4<br>06120 Kalaba<br>TR- Keçiören/ Ankara<br><br>Turkish General Directorate of State Hydraulic Works (TSHW)<br>Devlet Mahallesi Inonu Bulvari No: 16<br>TR-Çankaya / Ankara |
| Contact | · TSMS<br>eakyildiz@mgm.gov.tr (Eşref Akyildiz)<br>matilan@mgm.gov.tr (Mustafa Atilan)<br>· TSHW<br>bragip@dsi.gov.tr (Bekir Ragıp Yurtseven) |
| Near-real-time data URL and/or contact | · TSMS<br>https://mgm.gov.tr/eng/snowheights.aspx<br>· TSHW<br>Not available. |
| Archived data URL and/or contact | · TSMS<br>syildirim@mgm.gov.tr (S. Yıldırım)<br>msert@mgm.gov.tr (M. Sert)<br>· TSHW<br>bragip@dsi.gov.tr (Bekir Ragıp Yurtseven) |

## General situation

Two institutions, the Turkish State Meteorology Service (TSMS) and the Turkish State Hydraulic Works (TSHW), share the duty of performing operational snow observations in Turkey. While TSMS (founded in 1937) is the legal organisation which provides all meteorological information in Turkey, TSHW is mainly responsible for discharge measurements and thus also for water equivalent of snow cover measurements.

At TSMS, two departments are responsible for operational snow observations: one is in charge of manual observations of snow depth, presence of snow on the ground, depth of snowfall and water equivalent of snow cover, and the other is responsible for automatic snow depth and water equivalent of snow cover measurements. The automatic weather stations operated by TSMS are equally distributed over the alpine and midland regions, whereas manual stations are located close to cities and urban regions where little snow usually accumulates. TSMS operates almost 400 automatic stations, most of which were established in the last five years. In contrast to TSMS, TSHW mainly provides water equivalent of snow cover (included here) from the mountainous regions of Turkey. Both the TSMS and TSHW snow measurement networks are discussed below.

## Overview of measurements (TSMS, TSHW)

Snow depth: stake, ruler, ultrasonic snow depth sensor (Figs I-2.37.2, I-2.37.3)
Depth of snowfall: snow board and ruler (Figs I-2.37.5, I-2.37.6)
Water equivalent of snow cover: snow cylinder, snow tube, spring scale, electronic scale, Snow Pack Analyser (Figs I-2.37.7, I-2.37.8)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Climatology, Flood forecasting, Health and Sport, Hydrology, Meteorology, Road services, Water management

## I-2.37.1 Snow depth measurements

Number of stations delivering snow depth data manually: 143
Number of stations delivering snow depth data automatically: 376

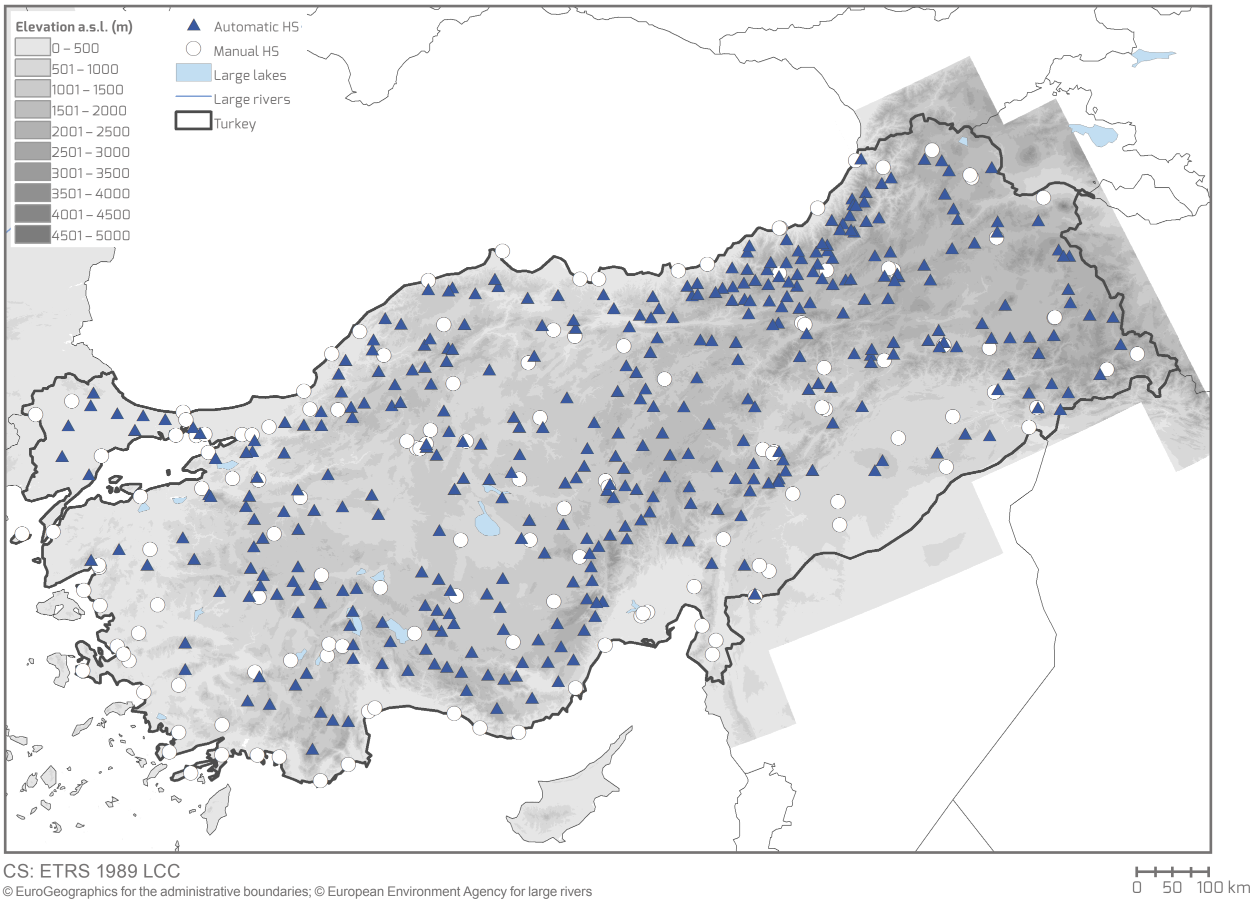

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*Figure I-2.37.2 Locations of stations in Turkey where snow depth (HS) is measured.*

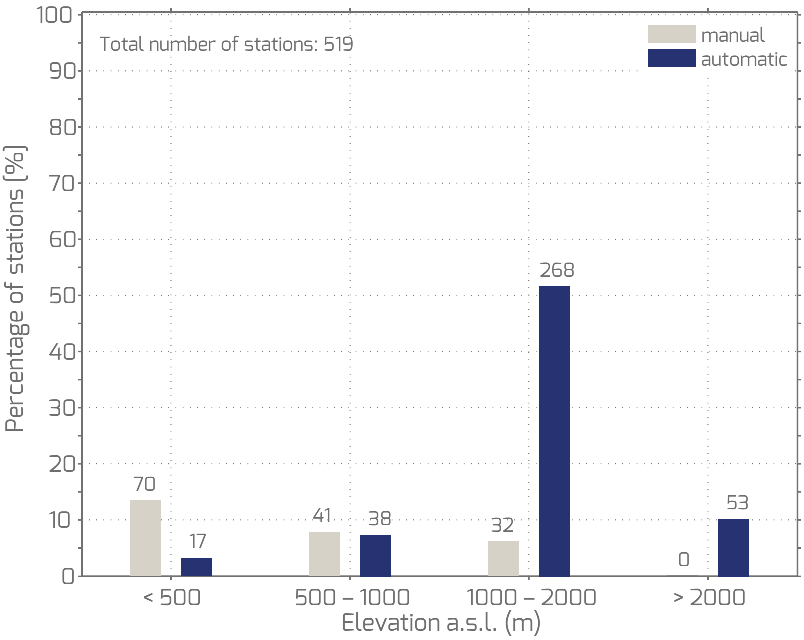

*Figure I-2.37.3 Elevational distribution of stations in Turkey with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours at 0600 UTC at TSMS stations, using portable rulers in urban areas and using stakes in mountainous regions and ski resorts.

### Automatic measurements:

Automatic snow depth measurements are performed every 10 minutes using an ultrasonic sensor, which is part of a Snow Pack Analysing system (SPA; Sommer Messtechnik, Vorarlberg, Austria; Fig. I-2.37.4) operated by TSMS.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported explicitly at stations operated by TSMS.

### Zero snow depth reporting method:

When the measurement field is 100% snow free, 0 cm snow depth is reported.

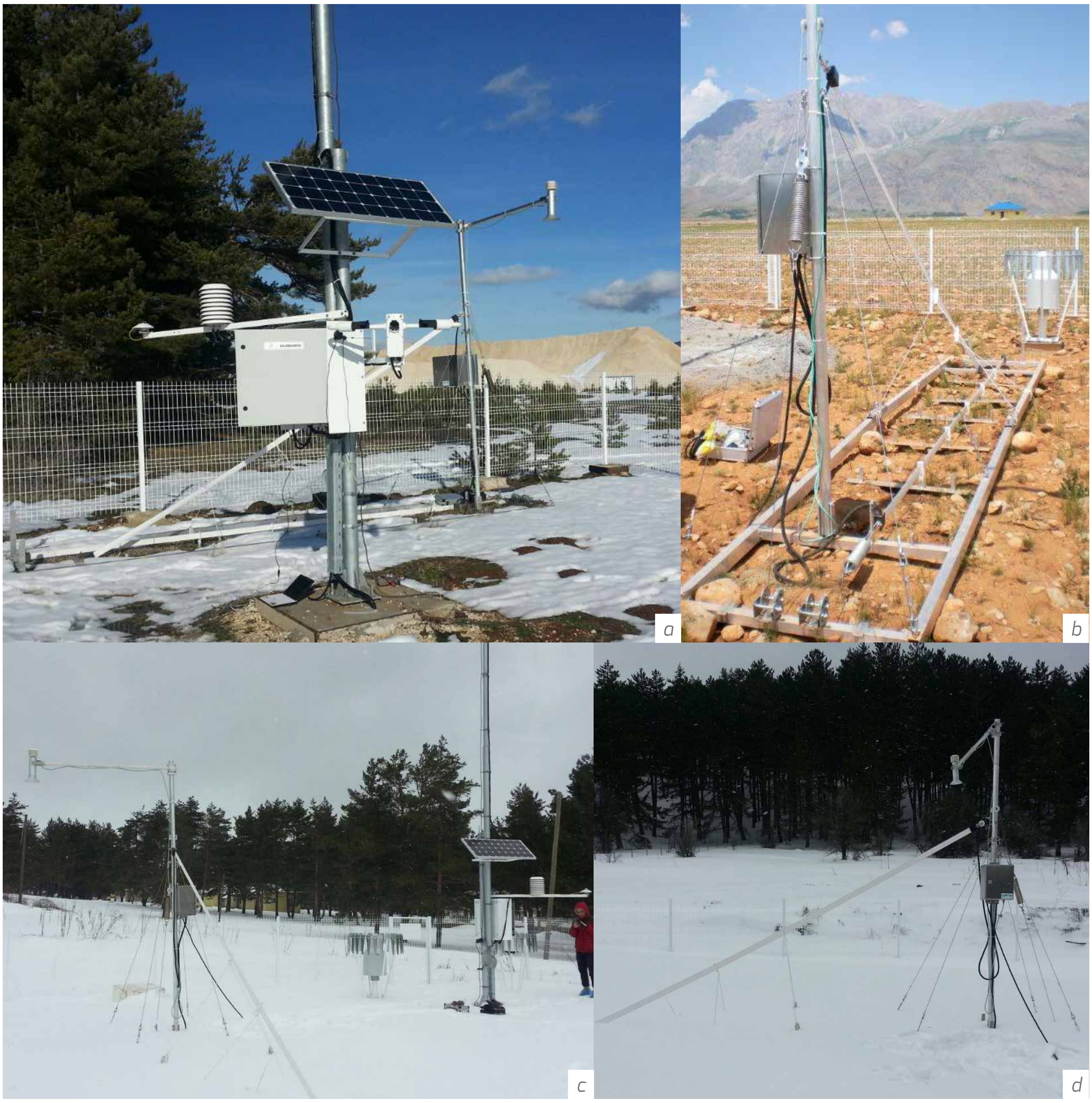

*Figure I-2.37.4 Automatic measurement sites in Turkey equipped with a Snow Pack Analyser (SPA) including an ultrasonic snow depth sensor. The system is shown during different seasons: (a) in Pınarbaşı in spring; (b) in Ovacık in summer; (c, d) in Çamkoru in winter (Source: TSMS).*

## I-2.37.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 131

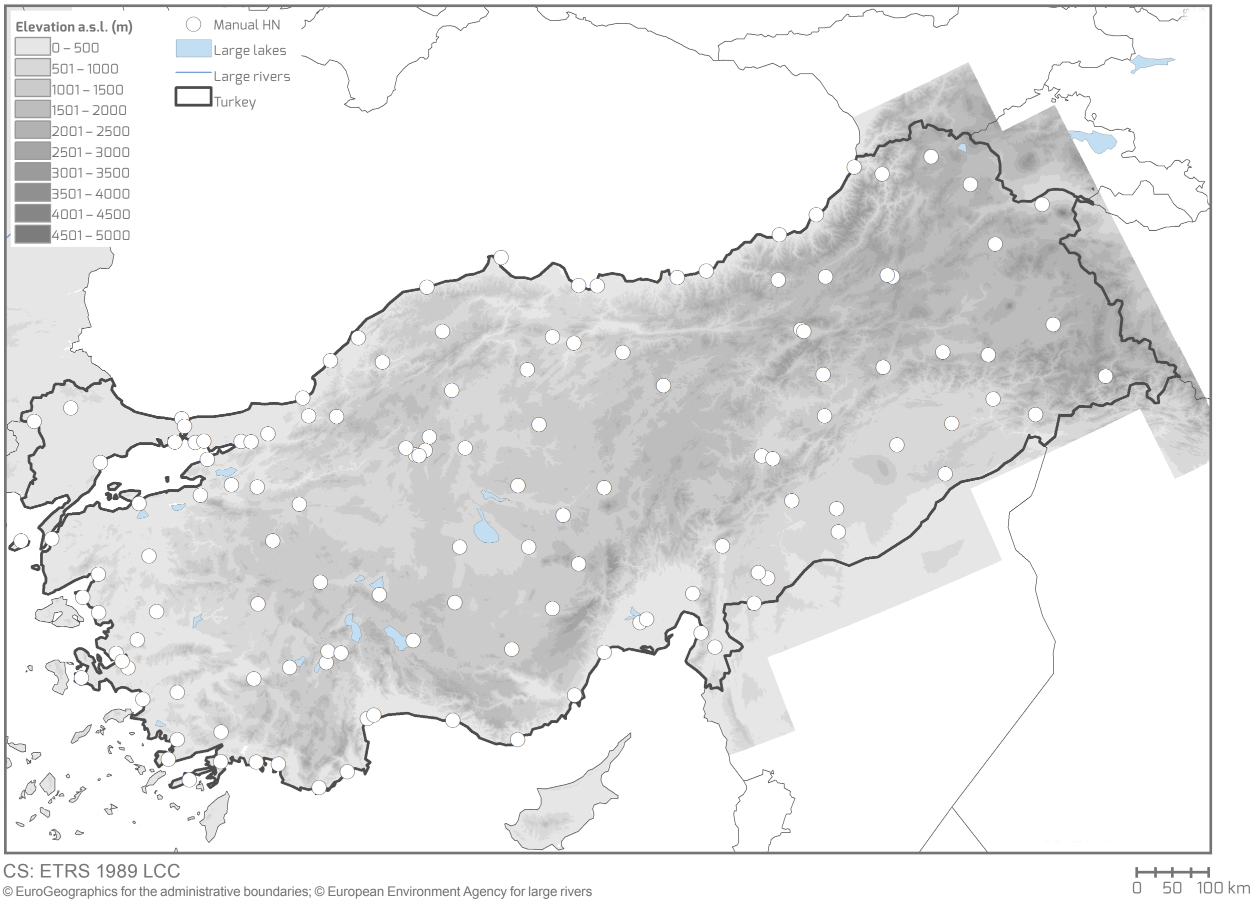

*Figure I-2.37.5 Locations of stations in Turkey where depth of snowfall (HN) is measured.*

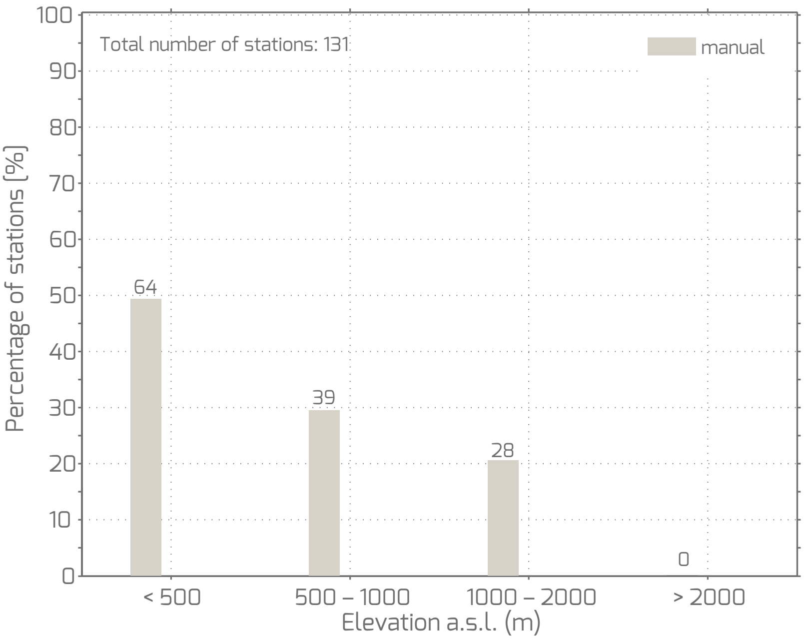

*Figure I-2.37.6 Elevational distribution of stations in Turkey with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed by TSMS every 24 hours at 0600 UTC in parallel to manual snow depth measurements. Depth of snowfall is measured on a snow board with a ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface.

## I-2.37.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 309
Number of stations delivering water equivalent of snow cover data automatically: 11

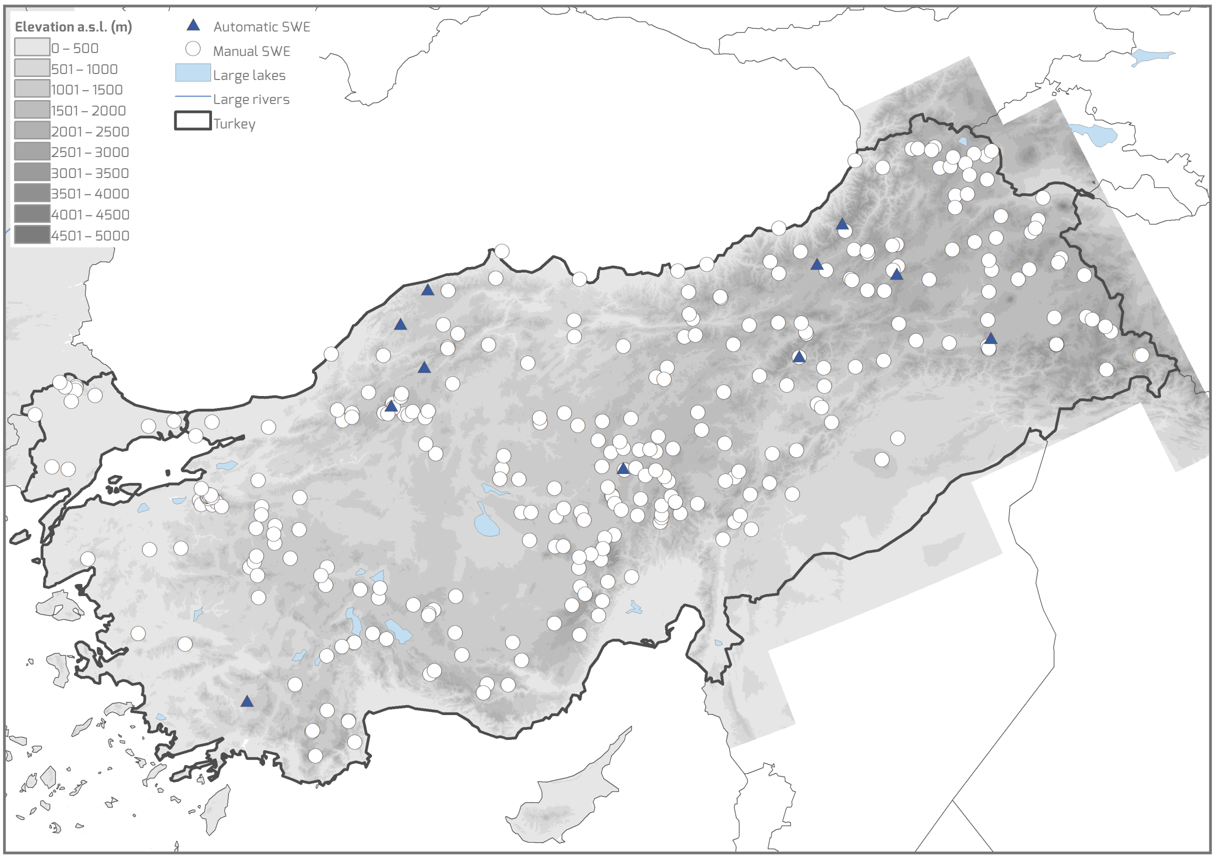

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*Figure I-2.37.7 Locations of stations in Turkey where water equivalent of snow cover (SWE) is measured.*

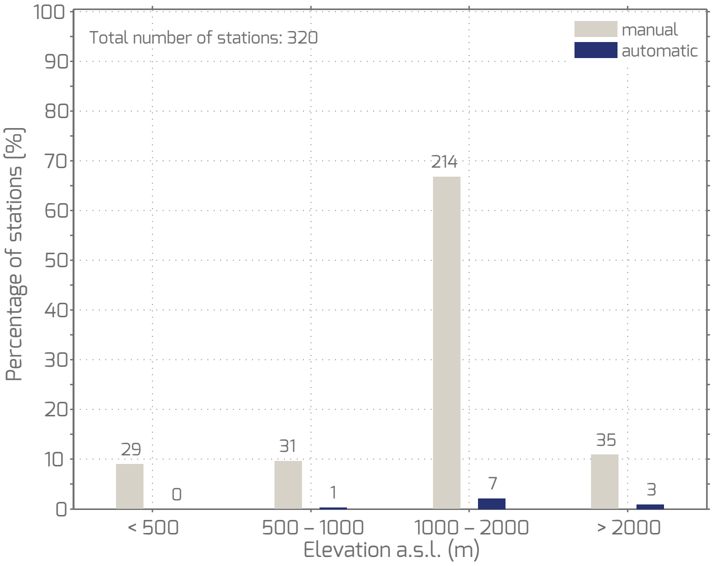

*Figure I-2.37.8 Elevational distribution of stations in Turkey with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

At the 58 stations operated by TSMS, manual SWE measurements in snow pits are performed every 24 hours at 0600 UTC for snow depths exceeding 5 cm. The gravimetric method is applied. Using a snow cylinder with a certain cross-sectional area (in $m^2$) and a certain length (in m), a snow sample is extracted vertically from the snowpack. The snow cylinder is not weighed, and instead the snow sample is melted in order to measure SWE (in mm w.e.) directly.

At the 251 stations operated by TSHW, SWE measurements along snow courses (no snow pits) are usually performed once every two weeks but are carried out only monthly under inclement weather or poor road conditions. A snow tube is used to assess both snow depth and SWE (Mt. Rose Federal snow tube; Fig. I-2.37.9). The snow tube segments have a length of 0.8 m or 1.0 m and a diameter of 0.04 m. Snow tube segments can be fitted together to sample deeper snowpacks. The gravimetric method is applied. Using the snow tube, a snow sample is extracted vertically from the snowpack (Fig. I-2.37.10 a, b). After the height of the snow sample (in m) is measured, the snow tube is placed in a snow tube cradle attached to a spring scale (Fig. I-2.37.10 c) or electronic scale to measure the total weight of the snow (in kg).

**Automatic measurements:**

Automatic SWE measurements are performed every 10 minutes using the SPA (Fig. I-2.37.4) operated by TSMS. The SPA consists of a 0.06-m-wide and 3- to 10-m-long flat ribbon sensor including three copper wires. In addition to measuring snow depth (see above), the SPA measures the dielectric constant and therefore the proportions of liquid water, ice and air in the snowpack, which are used to calculate snow density. SWE is determined from the calculated snow density and the measured snow depth.

*Figure I-2.37.9 Snow tube (Mt. Rose Federal) used to measure water equivalent of snow cover (SWE) manually at stations operated by TSHW (Source: TSHW).*

*Figure I-2.37.10 (a, b) A snow sample is extracted using a snow tube at a station operated by TSHW (Source: TSHW). (c) A snow tube is placed in a snow tube cradle and attached to a spring scale in order to measure the total weight of the snow (Source: TSHW).*

## I-2.37.4 Transition from manual to automatic measurements

At manned TSMS stations, manual measurements are performed in parallel to automatic ones.

## I-2.37.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (TSMS)<br>AUTO: 10 minutes (TSMS) | MANUAL: 24 hours (TSMS) | MANUAL: 24 hours (TSMS) or 2 weeks (TSHW)<br>AUTO: 10 minutes (TSMS) |

# I-2.38 Ukraine

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*Figure I-2.38.1 Location of Ukraine in Europe.*

# I-2.38 Ukraine

## Country information

| | |
|---|---|
| Country area, mean country elevation | 603 550 $km^2$, 177 m a.s.l. |
| Authority responsible for snow measurements | Ukrainian Hydrometeorological Center (UHMC)<br>6 Zolotovoritska Street<br>UA-01034 Kiev<br><br>Ukrainian Hydrometeorological Institute (UHMI)<br>39 Nauky Avenue, building 2<br>UA-03028 Kiev-28 |
| Contact | • UHMC<br>office@meteo.gov.ua<br>hydro@meteo.gov.ua<br>• UHMI<br>uhmi@uhmi.org.ua<br>aksiukalex@gmail.com (Oleksandr Aksiuk) |
| Near-real-time data URL and/or contact | • UHMC<br>http://meteo.gov.ua/en//33345/hmc/hmc_main<br>http://www.meteo.gov.ua/en/ |
| Archived data URL and/or contact | • UHMC (maybe on request)<br>office@meteo.gov.ua |

## General situation

The Ukrainian Hydrometeorological Center (UHMC) is in charge of operational snow observations in Ukraine. An extensive network of snow surveys exists in Ukraine, including manual measurements of snow depth, presence of snow on the ground, depth of snowfall and water equivalent of snow cover.

The Ukrainian Hydrometeorological Institute (UHMI) uses the data measured by UHMC for scientific purposes, but it does not operate a separate hydrometeorological station network. In addition, the Central Geophysical Observatory is a research and observation institution and one of the main hydrometeorological organisations in Ukraine. More information about the Central Geophysical Observatory is available online at: http://wdc.org.ua/en/partners/central-geophysical-observatory; contact: up-cgo@meteo.gov.ua. The Central Geophysical Observatory provides meteorological data online (http://www.cgo.kiev.ua/), and some historical data is available on request at: http://wdc.org.ua/en/data. However, no information was provided about a snow monitoring network operated by this institution.

In addition to standard meteorological observations performed by UHMC, an extensive snow measurement network exists in the Ukrainian mountains (Carpathians, Crimea; Fig. I-2.38.2). Here, spatially distributed snow observations of snow depth and water equivalent of snow cover are performed along snow courses in open fields and in the forest: 14 snow courses in the Carpathians and 17 on the Crimean Peninsula. Measurements are performed near the end of each month (e.g. 20 January, 20 February), as long as snow coverage exceeds 60% along the snow courses. Water equivalent of snow cover measurements finish at the start of the snow melt season. Along the snow courses, snow depth is measured at 20 points using portable rulers (M-46), and snow density is measured at 5 points if the snow depth exceeds 5 cm. The method used to manually measure water equivalent of snow cover at UHMC stations (see below) is applied. The average of all water equivalent of snow cover observations made within a snow course is reported. In addition, the snow structure, snow distribution, state of the soil and cloudiness are assessed, and air temperature and wind speed are measured. The measurement procedure in the mountains is explained in detail in the measurement handbook “Guide to measuring snow in mountains” (Chepelkina, 1991). Additional information on snow observations in the Ukrainian mountains can be found in a handbook written by a group of scientists under the auspices of UHMI (Grishchenko et al., 2013). A pdf version of this handbook is available online at: https://uhmi.org.ua/pub/.

In addition, stations in the Carpathian mountains operated by an avalanche warning service deliver information on snow depth along 98 remote snow courses at 1 000–1 750 m a.s.l. Complementary to these snow courses, there are four meteorological and eight experimental snow measurement sites. At the meteorological sites snow depth and precipitation are measured every 3 hours, while at the experimental sites properties of the seasonal snow cover are investigated with snow profiles every five days.

Only measurements performed within the UHMC station network are discussed below.

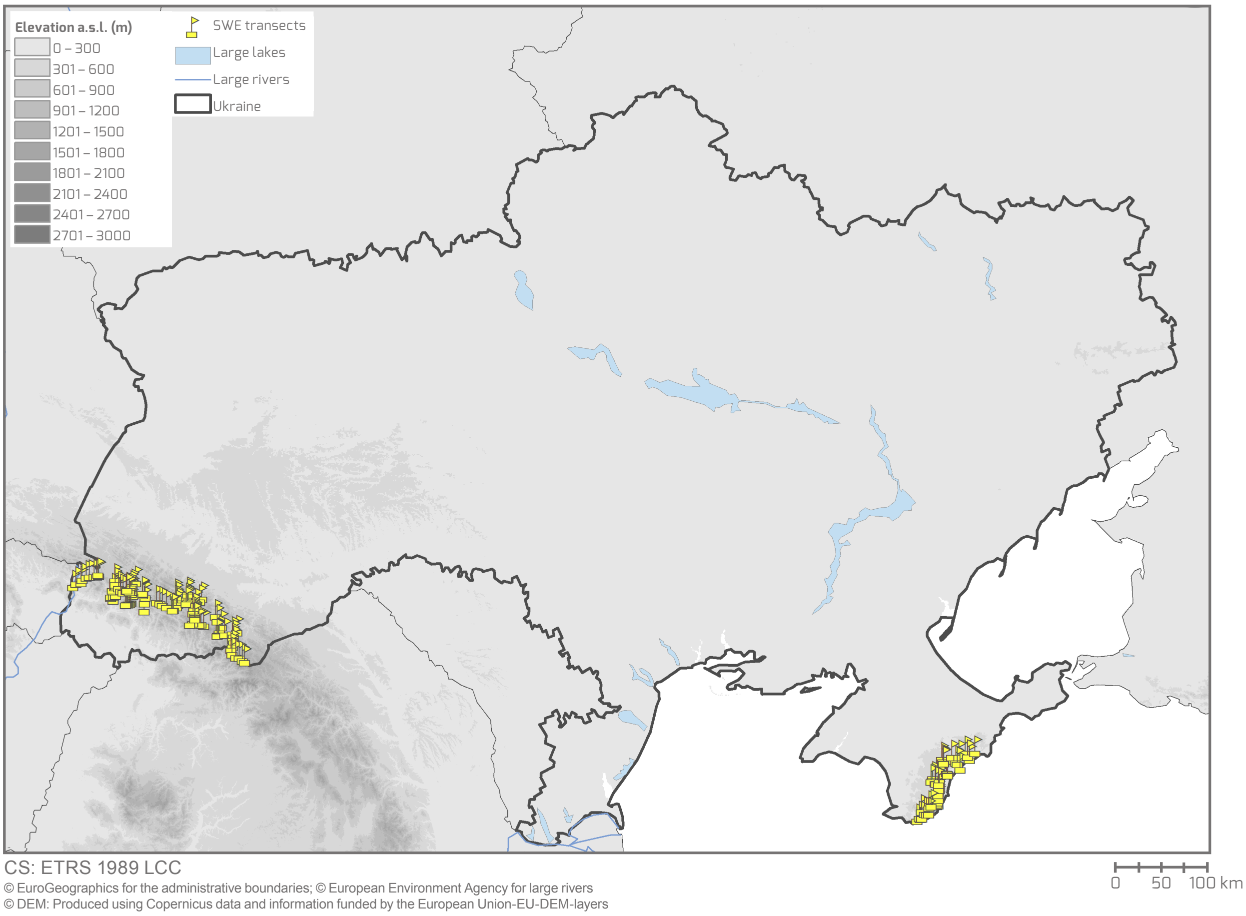

*Figure I-2.38.2 Locations of snow courses used for snow surveys in the Carpathian mountains and in the mountains on the Crimean Peninsula.*

### Overview of measurements (UHMC)

Snow depth: stake, ruler (Figs I-2.38.3, I-2.38.4)
Depth of snowfall: snow board and ruler (Figs I-2.38.9, I-2.38.10)
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-2.38.11, I-2.38.12)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Civil defence, Climatology, Flood forecasting, Energy production, Health and Sport, Hydrology, Meteorology, Road services, Water management

## I-2.38.1 Snow depth measurements

Number of stations delivering snow depth data manually: 534
Number of stations delivering snow depth data automatically: 0

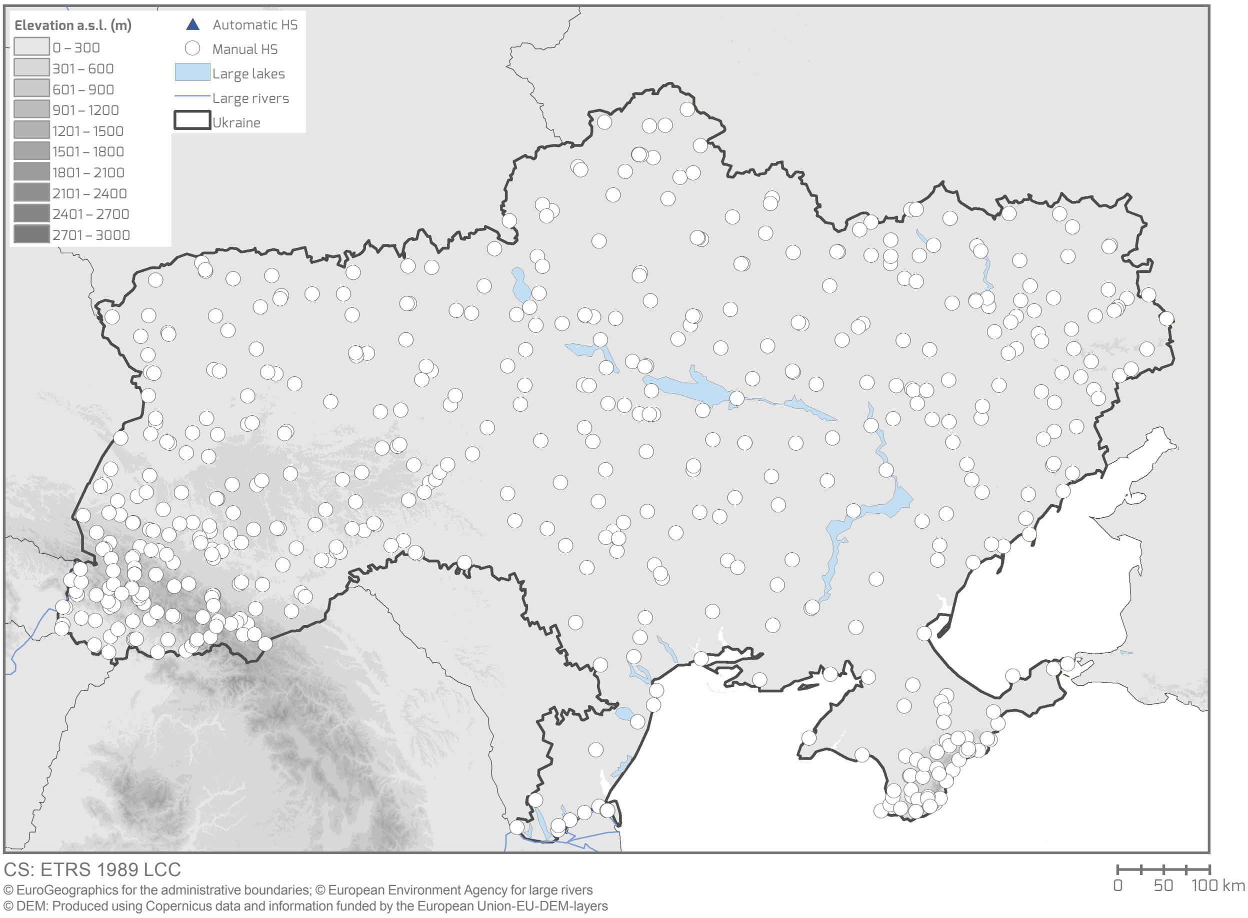

*Figure I-2.38.3 Locations of stations in Ukraine where snow depth (HS) is measured.*

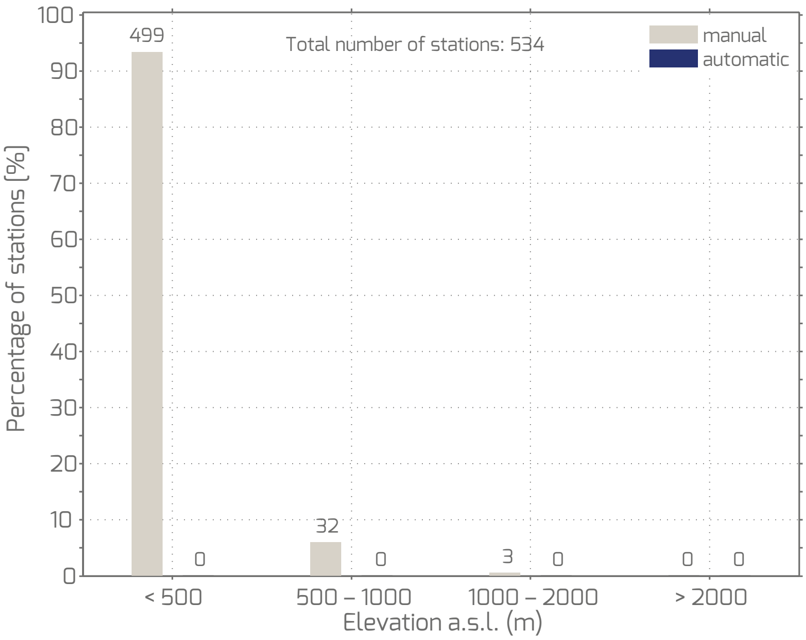

*Figure I-2.38.4 Elevational distribution of stations in Ukraine with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed every 24 hours at 0600 UTC. Fixed stakes (Fig. I-2.38.5) or portable aluminium rulers (Table I-2.38.1, Fig. I-2.38.6), both with a scale in centimetres and a total length of 1.5 or 2.5 m, are used. The ruler has a removable wooden handle which can be installed at any desired height. The tip of the ruler is made out of steel and has a wedge-like shape. To prevent incorrect measurements, values are read as horizontally to the surface as possible. Total snow depth is reported as long as at least half of the measurement field is covered with snow. Measured values are reported in full centimetres.

In Ukraine, a distinction is made between meteorological "stations" and "posts", depending on the observation programme, the instrument type and the number of observers. Meteorological stations (Fig. I-2.38.7) are squares, usually with a size of 26 x 26 m. Only stations with an incomplete observation program are allowed to have a minimum field size of 20 x 16 m. Station locations are selected to be more than 100 m away from water bodies (rivers, lakes, reservoirs, sea) and to have a north–south orientation. At every meteorological station two or more professional observers work in shifts. Meteorological posts (Fig. I-2.38.8) are squares with a size of 12 x 12 m. Only posts with little equipment and a reduced observation programme are allowed to have a minimum field size of 5 x 5 m. At meteorological posts only one observer is responsible for snow measurements. The measurement methods are explained in detail in the following measurement handbooks, which are available on request (uhmi@uhmi.org.ua):

- KD_52.4.8.03-11 "Guide for hydrometeorological stations and posts / Meteorological observations at stations" (Ser. 3, Part 1)
- KD_52.4.8.07 "Guide for hydrometeorological stations and posts / Meteorological observations at posts" (Ser. 2, Part 1)

### Automatic measurements:

No measurements.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is reported explicitly using a 10-point coding system. The snow coverage at the meteorological stations or posts are reported as follows: "0" means no snow is present; "1" means less than 10% of the measurement field is covered with snow; and "10" means there is 100% snow coverage.

### Zero snow depth reporting method:

Total snow depth is reported as long as at least 50% of the measurement field is covered with snow. If more than 50% of the measurement field is snow free, nothing is reported.

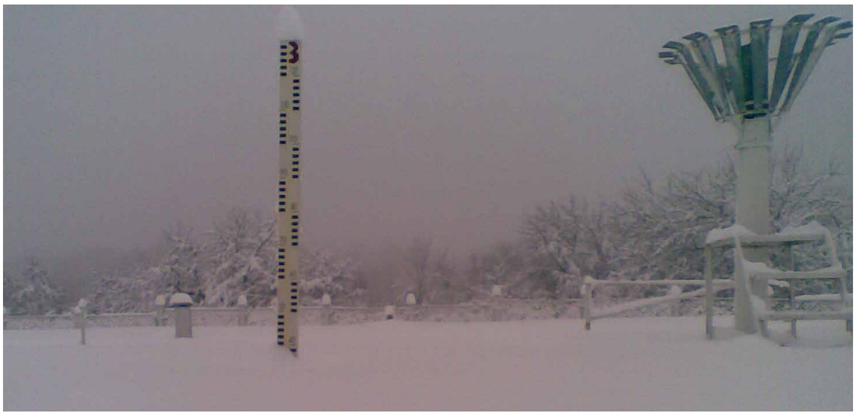

*Figure I-2.38.5 Snow measurement stake at a UHMC measurement station (Source: UHMI).*

*Table I-2.38.1 Specifications of rulers used to measure snow depth at UHMC stations.*

| Name | M-46-1 | M-46-2 |
|---|---|---|
| Measurement range (mm) | 0–1 500 | 0–2 500 |
| Dimensions (mm) | 20 x 240 x 1 600 | 20 x 240 x 2 600 |
| Weight (kg) | 2 | 3 |

*Figure I-2.38.6 (a) Portable ruler M-46 with a wooden handle. Observations in a snow pit of (b) snow characteristics and (c) snow depth using an M-46 ruler (Source: UHMI).*

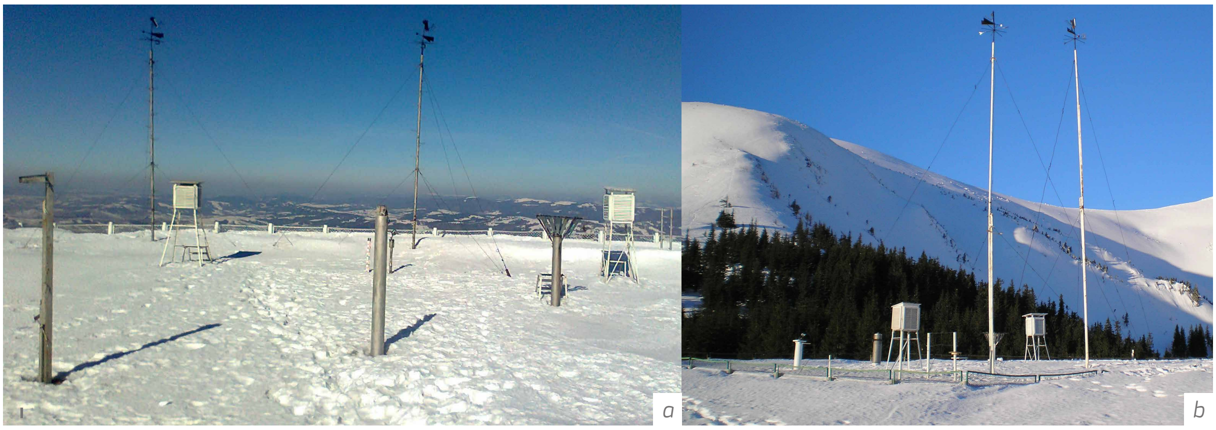

*Figure I-2.38.7 Standard meteorological stations operated by UHMC: (a) at Plai; (b) at the avalanche station Pozhezhevska (Source: UHMI).*

*Figure I-2.38.8 (a–d) Standard meteorological posts operated by UHMC (Source: UHMI).*

## I-2.38.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 2

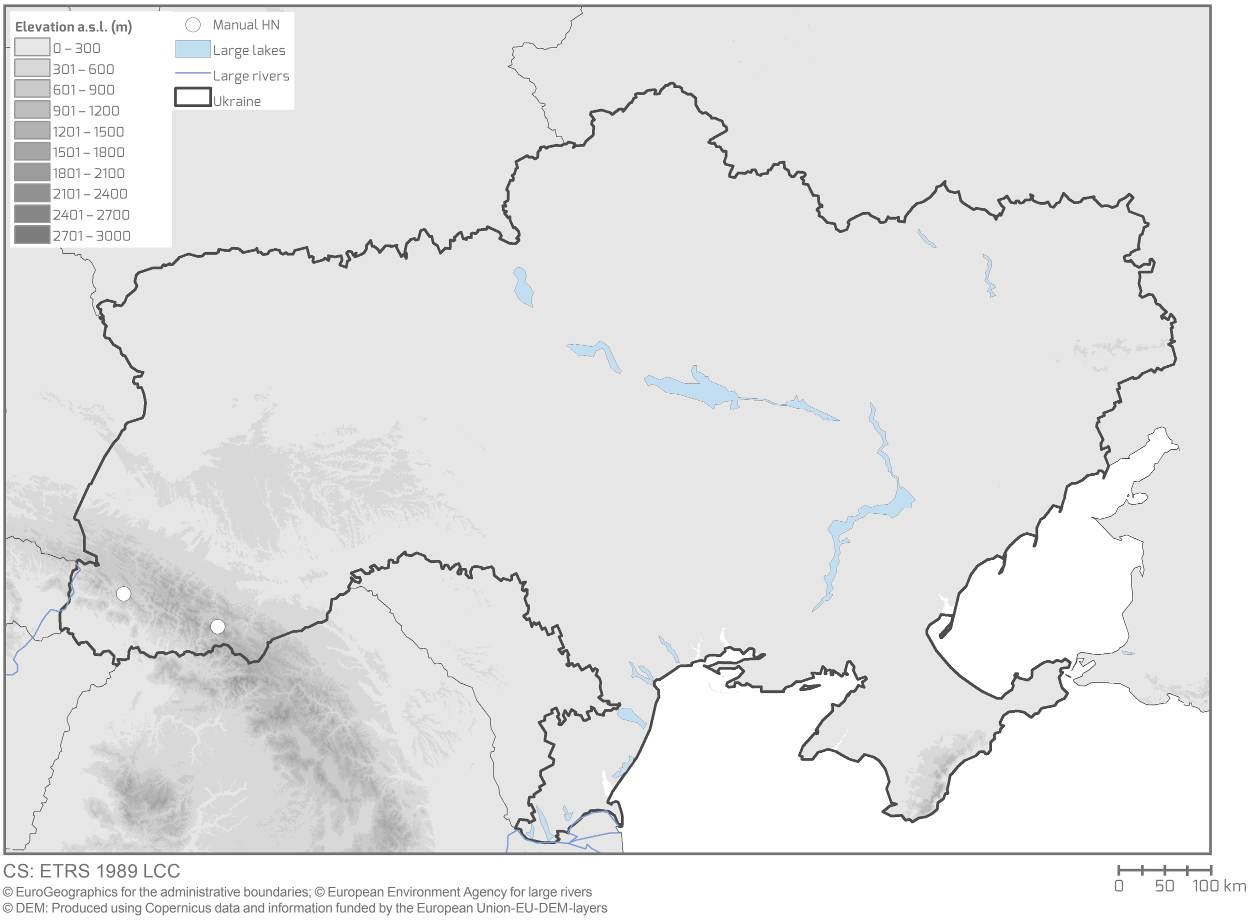

*Figure I-2.38.9 Locations of stations in Ukraine where depth of snowfall (HN) is measured.*

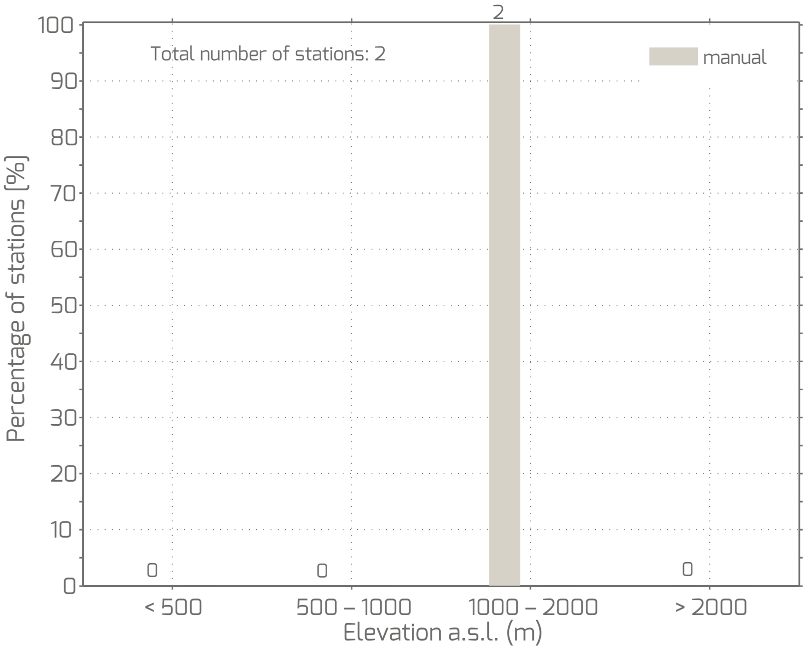

*Figure I-2.38.10 Elevational distribution of stations in Ukraine with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours. Depth of snowfall is measured on a snow board with a ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface.

## I-2.38.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 386
Number of stations delivering water equivalent of snow cover data automatically: 0

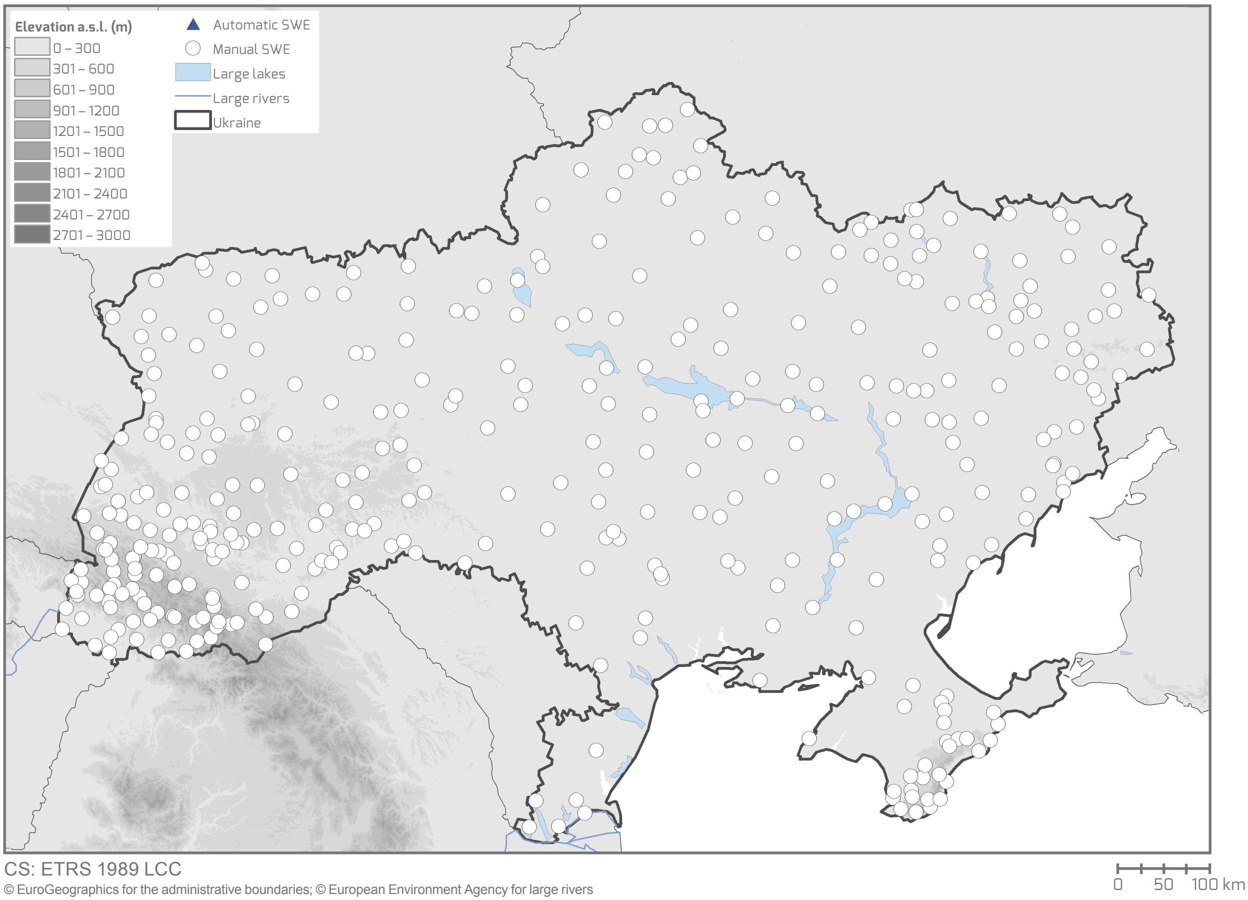

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*Figure I-2.38.11 Locations of stations in Ukraine where water equivalent of snow cover (SWE) is measured.*

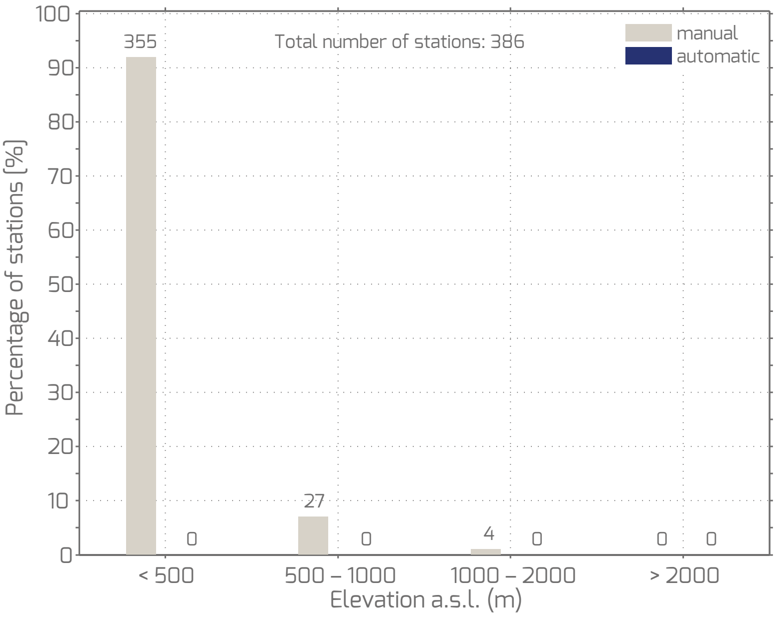

*Figure I-2.38.12 Elevational distribution of stations in Ukraine with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual SWE measurements in snow pits are performed every 5 days (5th, 10th, 15th, 20th, 25th and last day of the month) at the operational stations and posts, as well as every 10 days (10th, 20th and last day of the month) along snow courses in open fields and in the forest. SWE measurements are performed as long as snow coverage exceeds 60% of the measurement field or along the snow course. The gravimetric method is applied. Using a graduated iron snow cylinder (BC-43, made in Russia and Ukraine) with a cross-sectional area of 0.005 $m^2$ and a length of 0.6 m, a snow sample is extracted vertically from the snowpack. After the height of the snow sample (in m) is measured, the snow cylinder is attached to a steelyard balance (Figs I-2.38.13, I-2.38.14) to measure the total weight of the snow (in kg). The corresponding water equivalent of the sample (WE; in mm w.e.) is calculated by dividing the measured weight by the cross-sectional area of the snow cylinder. If the snow depth is greater than the length of the cylinder, the total snow depth is divided into multiple analogue "columns". Finally, the SWE of the snow cover (in mm w.e.) is calculated by summing the WE values of all sampled layers. Detailed SWE measurement instructions can be found in the measurement guide KD_52.4.8.03-11 (available on request). Note that 432 SWE stations were in use until 2014, while SWE is currently only observed at 386 stations.

### Automatic measurements:

No measurements.

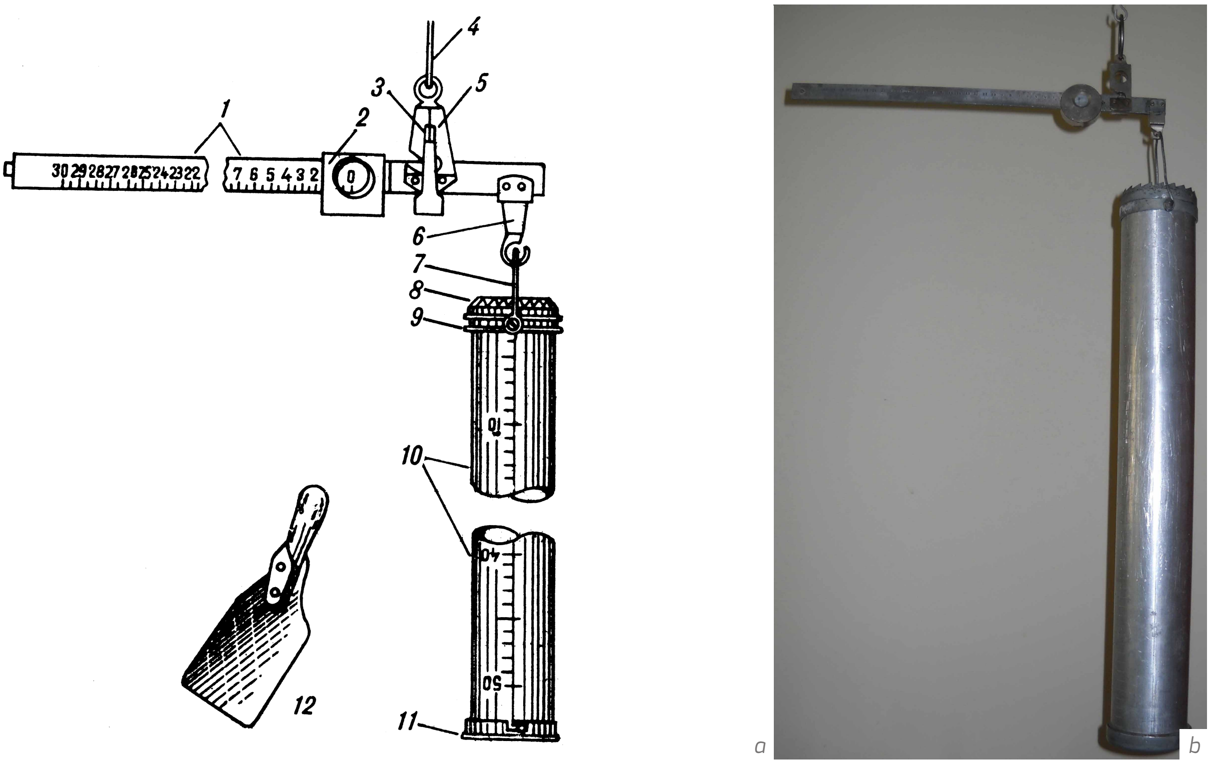

*Figure I-2.38.13 Sketch (a) and photograph (b) of an iron snow cylinder (BC-43) attached to a steelyard balance (Source: UHMI).*

*Figure I-2.38.14 (a-d) Measurements of water equivalent of snow cover (SWE) and snow density using a snow cylinder (BC-43) and steelyard balance (Source: UHMI).*

## I-2.38.4 Transition from manual to automatic measurements

No parallel measurements are carried out because no automatic measurements are performed.

## I-2.38.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours (UHMC)<br>AUTO: no measurements | MANUAL: 24 hours (UHMC) | MANUAL: 5 or 10 days (UHMC)<br>AUTO: no measurements |

# I-2.39 United Kingdom

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*Figure I-2.39.1 Location of the United Kingdom in Europe.*

# I-2.39 United Kingdom

## Country information

| | |
|---|---|
| Country area, mean country elevation | 248 528 km$^2$, 160 m a.s.l. |
| Authority responsible for snow measurements | Met Office (MO)<br>FitzRoy Road<br>Exeter/ Devon<br>UK-EX1 3PB |
| Contact | · MO<br>LandNetworksObservations@metoffice.gov.uk |
| Near-real-time data URL and/or contact | · MO<br>http://wow.metoffice.gov.uk (values are shown here; no other maps, figures or tables of snow data are available) |
| Archived data URL and/or contact | · MO<br>john.penman@metoffice.gov.uk (John Penman) |

## General situation

The Met Office (MO) is responsible for operational snow observations in the United Kingdom. MO has the duty to observe meteorological variables for the sake of public interest, weather forecasting and climatological records. MO observes snow depth and depth of snowfall manually and snow depth automatically, while water equivalent of snow cover is not measured at all by MO.

## Overview of measurements

Snow depth: ruler, laser snow depth sensor (Figs I-2.39.2, I-2.39.3)
Depth of snowfall: snow board and ruler (Figs I-2.39.4, I-2.39.5)
Water equivalent of snow cover: no measurements
Operational purpose of measurements: Climatology, Meteorology

## I-2.39.1 Snow depth measurements

Number of stations delivering snow depth data manually: 191
Number of stations delivering snow depth data automatically: 66

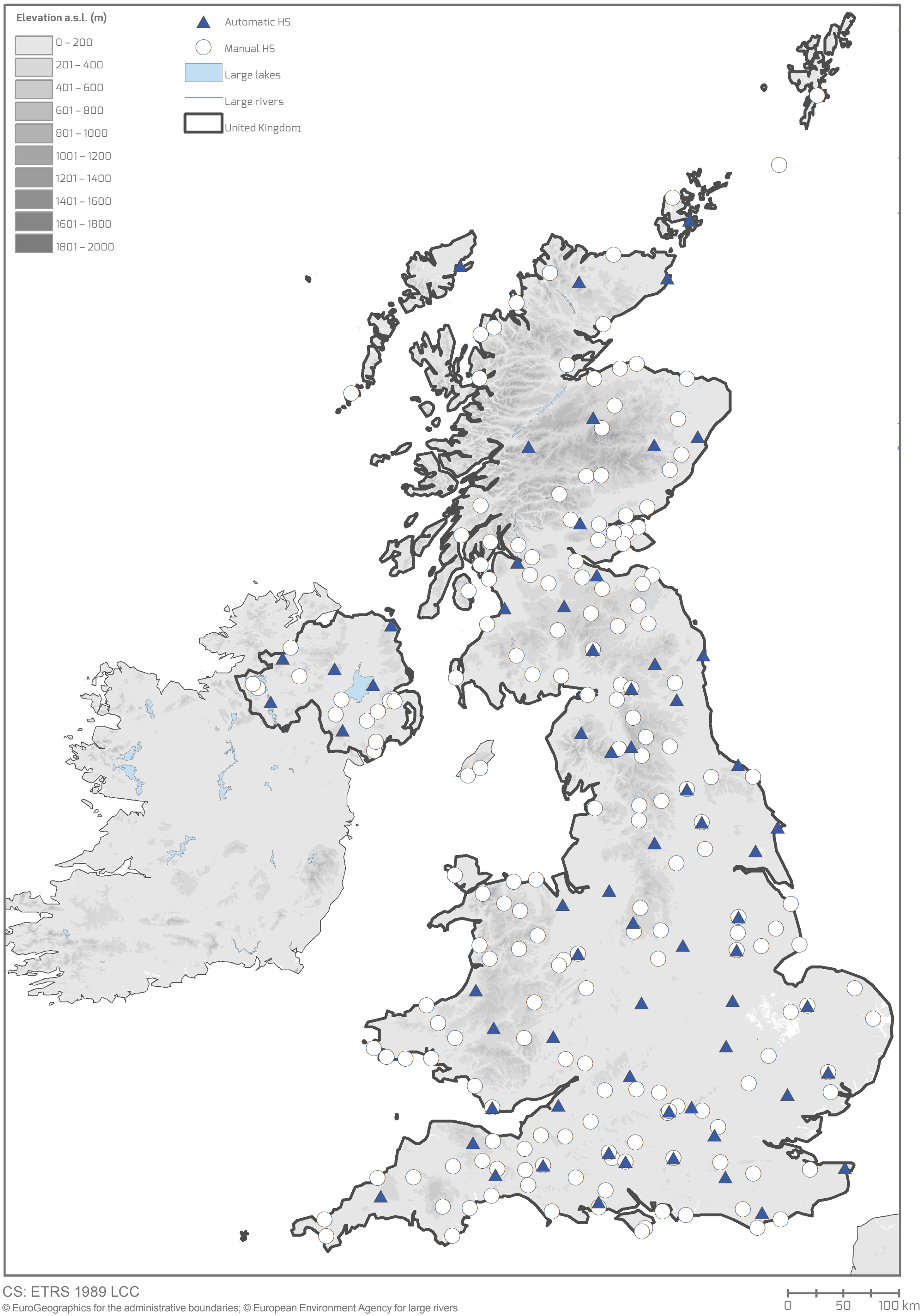

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*Figure I-2.39.2 Locations of stations in the United Kingdom where snow depth (HS) is measured.*

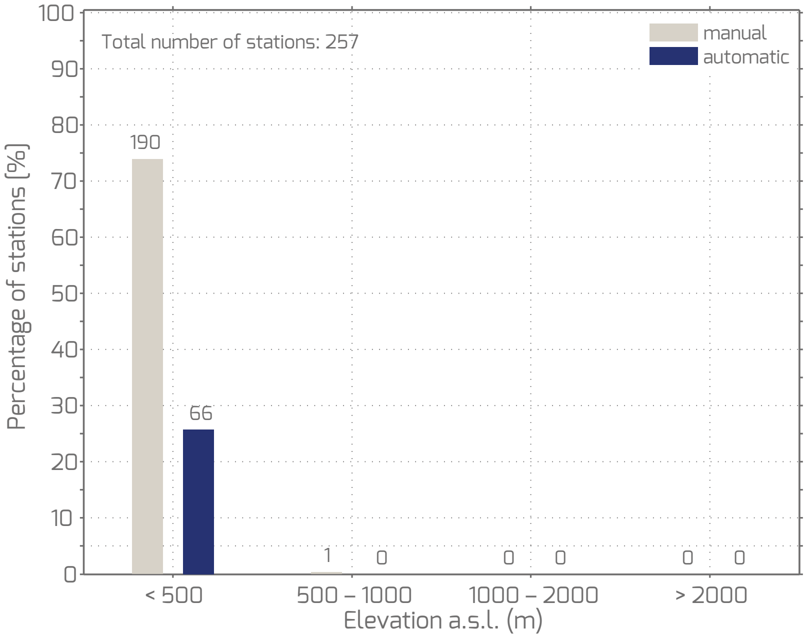

*Figure I-2.39.3 Elevational distribution of stations in the United Kingdom with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Manual snow depth measurements are performed either once every 24 hours at 0900 UTC (160 climate sites operated by volunteers) or once every hour (34 manned sites). Rulers with a scale in centimetres are used. Three snow depth measurements are performed within representative open areas in order to avoid snow drifts and/or sheltered areas. The average of all measurements is reported as total snow depth. The reading is made over short grass (as opposed to road or other paved surfaces), and not over the bare earth patch in the enclosure. Total snow depth is reported as long as at least half of the measurement field is covered with snow. Measured values are reported in full centimetres.

At the manned sites, snow depth data is submitted after each hourly measurement. At the sites run by volunteers, observers may submit snow depth data to the National Climate Message a month or more after taking the reading, and they can additionally report the state of the ground (with or without snow), number of snow-covered days, and the date of a snowfall event.

### Automatic measurements:

Automatic snow depth measurements are recorded every minute but the hourly average is reported, rounded to the nearest centimetre (hourly SYNOP message). Ultrasonic snow depth sensors were used until 2016. These sensors were replaced with laser snow depth sensors (SHM30; Lufft, Fellbach, Germany), which have been in use since 2017. Snow depth sensors are mounted 2 m above the ground at an angle of 30° from the vertical pole. Astro Turf® is used as an artificial target where possible. The minimum snow depth measured by the laser sensor is 1 cm, meaning that no snow depth is reported for depths less than 1 cm. This is due to the degree of uncertainty of the sensor.

At 14 manned stations snow depth is measured both automatically and manually. At these stations, the automatic measurement is overwritten by the hourly manual reading at the start of each hour, as long as a manual reading is provided.

### Presence of snow on the ground reporting method:

Presence of snow on the ground is not reported explicitly. The intention is to report presence of snow on the ground with BUFR tables in the future.

### Zero snow depth reporting method:

When more than 50% of the measurement field is snow free, the code "998" and the state of the ground are reported. However, no system is currently available to report 0 cm snow depth.

## I-2.39.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: 194

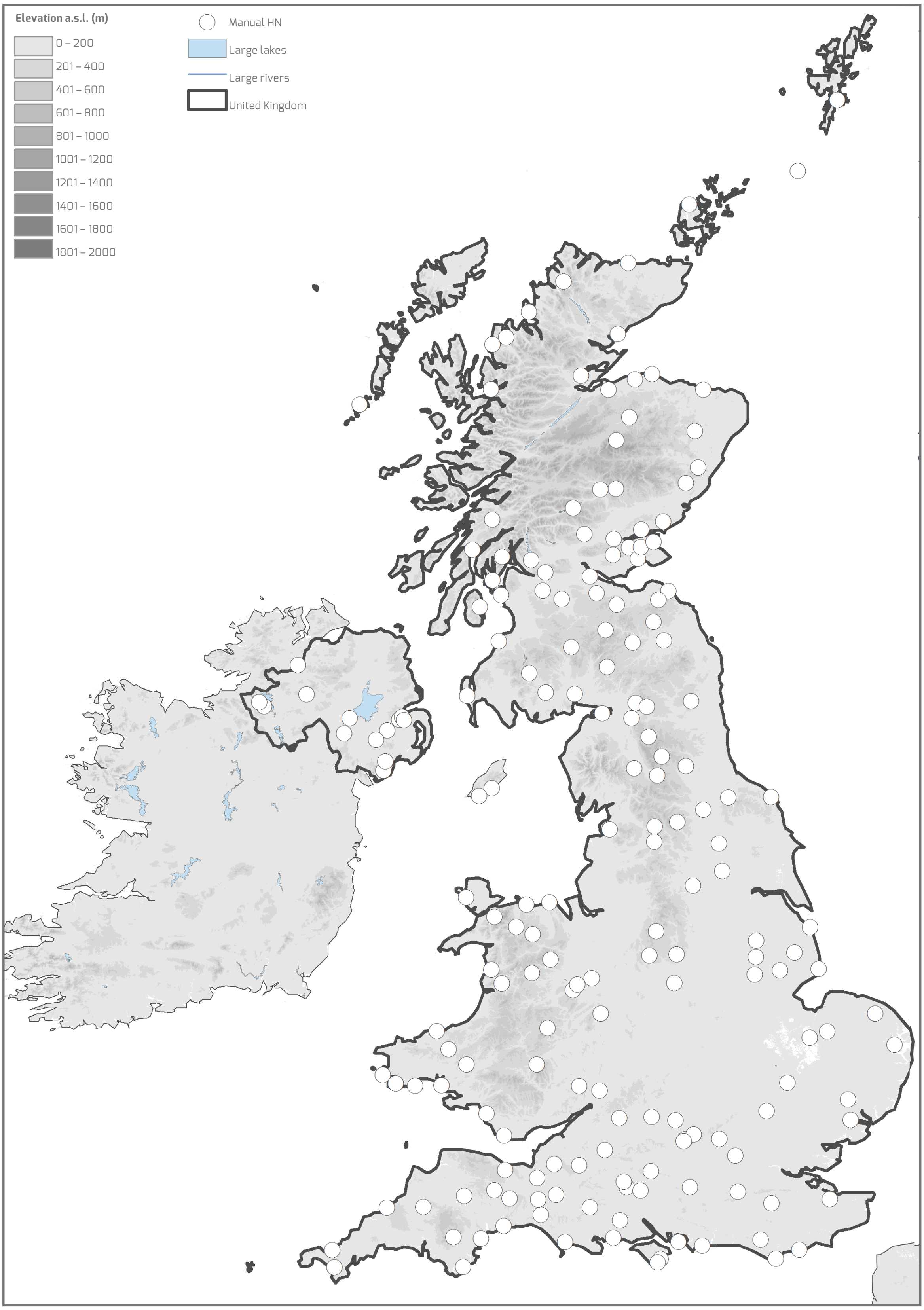

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*Figure I-2.39.4 Locations of stations in the United Kingdom where depth of snowfall (HN) is measured.*

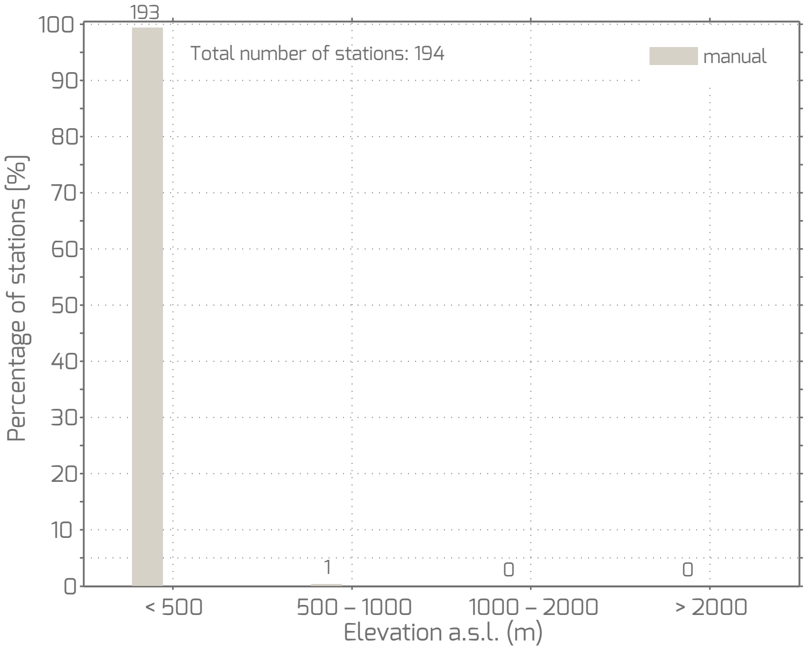

*Figure I-2.39.5 Elevational distribution of stations in the United Kingdom with manual depth of snowfall measurements. The corresponding number of stations is given above each bar.*

**Manual measurements:**

Manual measurements of depth of snowfall are performed every 24 hours at 0900 UTC if more than 50% of the measurement field is covered with snow. This is done in parallel to manual snow depth measurements, and values are reported in the National Climatological Message. Depth of snowfall is measured on a white-painted plastic board with a ruler. After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. The position of the snow board is marked so that the board can be located after a snowfall event.

## I-2.39.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 0
Number of stations delivering water equivalent of snow cover data automatically: 0

**Manual measurements:**

No measurements.

**Automatic measurements:**

No measurements.

## I-2.39.4 Transition from manual to automatic measurements

No parallel measurements are performed during the shift from manual to automatic measurements, largely owing to the highly infrequent occurrence of snowfall events. Installation of all automatic snow sensors is completed during summer.

## I-2.39.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 1 or 24 hours (MO)<br>AUTO: 1 hour (MO) | MANUAL: 24 hours (MO) | MANUAL: no measurements<br>AUTO: no measurements |

# I-3 Analysis of Country Data

A. Haberkorn

WSL Institute for Snow and Avalance Research SLF, Davos, Switzerland

## I-3.1 Introduction

This chapter includes a general analysis of information and metadata collected through the European Snow Booklet (ESB) Questionnaire (Appendix I-B) between August 2017 and March 2018. Unlike in the individual country reports (Chapter I-2), the information collected from the different countries is interlinked here, bringing the data into a global context. Finally, national European station data presented in Chapter I-2 is related to national snow depth data that is reported via the Global Telecommunication System (GTS; Section I-3.6) of the World Meteorological Organisation (WMO). The necessity of reporting and distributing national snow observations through GTS, as well as difficulties resulting from differences between national and global reporting systems, is discussed, thus demonstrating the importance of GTS data for numerical weather prediction (Chapter II-3).

Numerous institutions from European countries (Fig. 2 on p. 4) provided detailed information on their operational snow monitoring networks, which are described in 38 country reports (Chapter I-2): Andorra, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Macedonia, Moldova, Montenegro, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland with Liechtenstein, Turkey, Ukraine and the United Kingdom. Please keep in mind that complete information was not available for all countries. Furthermore, we cannot guarantee that the values presented are 100% correct and current because operational networks are prone to changes. Thus, rather than concentrating on the exact values presented here, we recommend focusing on the order of magnitude of the various results, which nonetheless provide a unique European overview. The snow monitoring network of Russia (Appendix I-A) is not part of this analysis, owing to incomplete data and missing digital elevation model (DEM) information.

As in the country-specific reports, most maps in this chapter include the EU-DEM, which was produced using Copernicus data and information funded by the European Union (© EU-DEM-layers, 2017). For our purposes, the EU-DEM cell size was resampled from 1 to 250 m resolution. Please note that the mean country elevation (Table I-3.1.1), the percentage of the country area that occurs in certain elevational ranges and the number of stations per 1 000 km² (Tables I-3.2.1, I-3.3.1, I-3.4.1; Fig. I-3.5.4) are based on the EU-DEM with a resolution of 250 m. Data accuracy strongly depends on cell size, coordinate system (CS) projection and the country borders used, and values should therefore be seen as approximations. The number of stations per 1 000 km² (Tables I-3.2.1, I-3.3.1, I-3.4.1; Fig. I-3.5.4) represents the station density of the manual and automatic snow monitoring networks of the European countries, calculated as follows (I-3.1.1):

$$\frac{\textit{total number of stations}}{\left(\dfrac{\textit{country area km}^2}{\textit{1 000 km}^2}\right)} \qquad \text{(I-3.1.1)}$$

*Table I-3.1.1 Name, ID, area and mean elevation of each country presented in a country report in the European Snow Booklet (ESB).*

| Country | Country ID | Area (km$^2$) | Mean country elevation a.s.l. (m) |
|---|---:|---:|---:|
| Andorra | AD | 468 | 2 054 |
| Austria | AT | 83 879 | 951 |
| Belgium | BE | 30 528 | 156 |
| Bosnia and Herzegovina | BA | 51 197 | 688 |
| Bulgaria | BG | 110 370 | 474 |
| Croatia | HR | 56 594 | 309 |
| Cyprus | CY | 9 251 | 295 |
| Czech Republic | CZ | 78 868 | 451 |
| Denmark | DK | 42 924 | 31 |
| Estonia | EE | 45 227 | 57 |
| Finland | FI | 338 440 | 156 |
| France | FR | 633 187 | 346 |
| Germany | DE | 357 376 | 263 |
| Greece | EL | 131 957 | 479 |
| Hungary | HU | 93 030 | 147 |
| Iceland | IS | 103 000 | 495 |
| Ireland | IE | 69 797 | 108 |
| Italy | IT | 302 073 | 534 |
| Latvia | LV | 64 573 | 89 |
| Lithuania | LT | 65 286 | 102 |
| Luxembourg | LU | 2 586 | 348 |
| Macedonia | MK | 25 713 | 828 |
| Moldova* | MD | 33 846 | 140 |
| Montenegro | ME | 13 812 | 1 031 |
| The Netherlands | NL | 41 543 | 9 |
| Norway | NO | 323 802 | 553 |
| Poland | PL | 312 679 | 171 |
| Portugal | PT | 92 226 | 317 |
| Romania | RO | 238 391 | 395 |
| Serbia | RS | 77 474 | 460 |
| Slovakia | SK | 49 035 | 453 |
| Slovenia | SI | 20 273 | 563 |
| Spain | ES | 505 944 | 685 |
| Sweden | SE | 438 574 | 320 |
| Switzerland | CH | 41 285 | 1 309 |
| Turkey | TR | 783 562 | 1 139 |
| Ukraine* | UA | 603 550 | 177 |
| United Kingdom | UK | 248 528 | 160 |

** Moldova and Ukraine are not fully covered by the EU-DEM; calculations for these two countries are therefore based on the DEM GTOPO30*[23,24] *, (1 000 m resolution) provided by the U.S. Geological Survey.*

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23. https://www.usgs.gov/centers/eros/science/usgs-eros-archive-products-overview?qt-science_center_objects=0#qt-science_center_objects
24. http://www.webgis.com/terr_world.html

## I-3.2 Snow depth

In all 38 European countries that contributed data, snow depth (HS) is measured operationally even though it is not measured by every single institute. Figure I-3.2.1 shows the elevational distribution of all manual and automatic stations where snow depth is measured. It is clear that snow depth is measured manually far more often than it is measured automatically. It is also apparent that most stations are located below 500 m a.s.l., which corresponds to the mean elevation below 500 m a.s.l. for many (27) European countries (Table I-3.1.1). Below this elevational level there are almost twelve times more manual stations than automatic ones. The ratio of manual to automatic stations decreases with increasing elevation. While between 1 000 and 2 000 m a.s.l. this ratio is around two, there are actually more automatic stations than manual ones at elevations above 2 000 m a.s.l. The relatively low mean elevation of the European countries considered is not the only reason for this pattern; the fact that manual measurements are often performed in the vicinity of urban areas and less frequently in sparsely populated mountainous regions is another contributing factor. In Figures I-3.2.2 and I-3.2.3 it is clear that in the Alps (e.g. Austria, France, Italy, Switzerland), as well as in other countries with large mountain ranges (e.g. Andorra, Spain, Turkey), many snow depth measurement stations are located above 1 000 m a.s.l.

In Figures I-3.2.2 and I-3.2.3 an overview of the number and elevational distribution of snow depth stations in each European country is shown. For better readability, Figure I-3.2.2 includes the 15 countries (39% of the 38 countries that contributed data) where either the manual or the automatic station network exceeds 250 stations, and Figure I-3.2.3 includes the remaining 23 countries where the manual and the automatic station networks both have fewer than 250 stations, although the total number of stations can exceed 250. For the countries presented in Figure I-3.2.2, the number of automatic stations is much smaller than the number of manual stations except in Turkey. Most countries with a considerable fraction of mountainous area operate snow depth stations above 2 000 m a.s.l., for example France, Italy and Turkey. France and Germany operate the largest networks in terms of total station count, although the station density per 1 000 km$^2$ in these countries is not high (Table I-3.2.1; Fig. I-3.5.4).

For the countries with smaller snow depth station networks, presented in Fig. I-3.2.3, it is likewise the case that more manual than automatic stations are used for snow depth measurements. However, in Andorra, Estonia, Finland, Ireland, Latvia, Spain and Switzerland the number of automatic stations is similar to the number of manual ones. In Andorra, Spain and Switzerland many snow depth measurement stations are located well above 1 000 m a.s.l. The number of automatic stations operated in these countries is large because the station locations (high mountains) make it impossible to establish sites that require on-site staff for daily operation. Automatic measurements are therefore important in high-elevation and often remote station locations, although installing and maintaining automatic stations is still labour intensive.

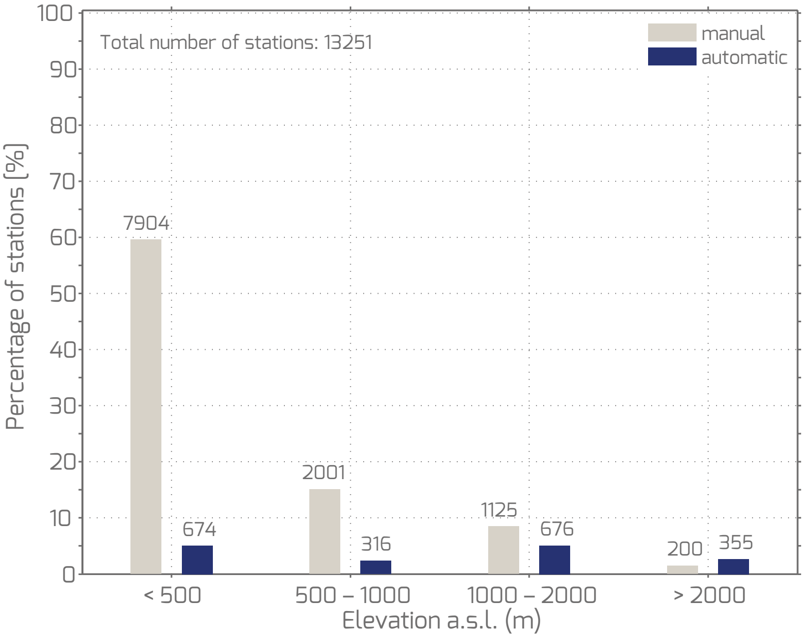

*Figure I-3.2.1 Elevational distribution of manual and automatic stations where snow depth (HS) is measured in the 38 European countries that contributed data. The corresponding number of stations is given above each bar.*

*Table I-3.2.1 Comparison of snow depth (HS) stations in the European countries included in the European Snow Booklet (ESB). The snow depth station density, i.e. the number of stations per 1 000 km², is given for each country, as well as the total number of snow depth stations. In addition, the number of snow depth stations located in certain elevational ranges (below 500 m a.s.l., 500 – 1 000 m a.s.l., 1 000 – 2 000 m a.s.l. and above 2 000 m a.s.l.) is given, as well as the percentage of the country area occurring in each elevational range.*

| Country | HS stations per 1 000 km² | Total number of HS stations | Number of HS stations | | | | Percentage of country area (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | < 500 m a.s.l. | 500 – 1 000 m a.s.l. | 1 000 – 2 000 m a.s.l. | > 2 000 m a.s.l. | < 500 m a.s.l. | 500 – 1 000 m a.s.l. | 1 000 – 2 000 m a.s.l. | > 2 000 m a.s.l. |
| Andorra | 36.3 | 17 | 0 | 0 | 3 | 14 | 0 | 1 | 39 | 60 |
| Austria | 12.1 | 1 016 | 345 | 400 | 257 | 14 | 31 | 30 | 29 | 9 |
| Belgium | 3.2 | 97 | 91 | 6 | 0 | 0 | 96 | 4 | 0 | 0 |
| Bosnia and Herzegovina | 0.3 | 14 | 9 | 4 | 0 | 1 | 39 | 36 | 25 | 0 |
| Bulgaria | 0.2 | 17 | 9 | 1 | 4 | 3 | 67 | 21 | 12 | 1 |
| Croatia | 8.3 | 472 | 407 | 63 | 2 | 0 | 79 | 17 | 4 | 0 |
| Cyprus | 0.2 | 2 | 0 | 0 | 2 | 0 | 80 | 17 | 3 | 0 |
| Czech Republic | 10.7 | 845 | 481 | 321 | 43 | 0 | 65 | 34 | 1 | 0 |
| Denmark | 1.6 | 70 | 70 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Estonia | 1.0 | 43 | 43 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Finland | 0.6 | 203 | 203 | 0 | 0 | 0 | 99 | 1 | 0 | 0 |
| France | 3.0 | 1 907 | 1 099 | 318 | 342 | 148 | 80 | 12 | 6 | 2 |
| Germany | 4.8 | 1 710 | 1 349 | 309 | 46 | 6 | 84 | 15 | 1 | 0 |
| Greece | 0.5 | 61 | 57 | 4 | 0 | 0 | 60 | 26 | 13 | 0 |
| Hungary | 5.0 | 469 | 461 | 6 | 2 | 0 | 99 | 1 | 0 | 0 |
| Iceland | 0.9 | 96 | 81 | 15 | 0 | 0 | 54 | 36 | 10 | 0 |
| Ireland | 0.1 | 10 | 10 | 0 | 0 | 0 | 99 | 1 | 0 | 0 |
| Italy | 2.5 | 741 | 24 | 89 | 473 | 155 | 63 | 21 | 12 | 4 |
| Latvia | 0.5 | 34 | 34 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Lithuania | 0.6 | 37 | 37 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Luxembourg | 1.2 | 3 | 3 | 0 | 0 | 0 | 97 | 3 | 0 | 0 |
| Macedonia | 5.2 | 133 | 60 | 64 | 9 | 0 | 25 | 44 | 29 | 1 |
| Moldova* | 1.6 | 55 | 55 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Montenegro | 2.8 | 39 | 9 | 22 | 8 | 0 | 16 | 27 | 56 | 1 |
| The Netherlands | 7.7 | 321 | 321 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Norway | 1.5 | 477 | 341 | 111 | 25 | 0 | 53 | 32 | 15 | 0 |
| Poland | 2.3 | 723 | 636 | 73 | 14 | 0 | 97 | 3 | 0 | 0 |
| Portugal | 0.1 | 9 | 5 | 3 | 1 | 0 | 78 | 21 | 2 | 0 |
| Romania | 0.6 | 152 | 110 | 21 | 17 | 4 | 71 | 19 | 10 | 0 |
| Serbia | 4.0 | 307 | 227 | 58 | 22 | 0 | 61 | 28 | 11 | 0 |
| Slovakia | 14.0 | 685 | 493 | 174 | 16 | 2 | 62 | 32 | 5 | 0 |
| Slovenia | 12.3 | 250 | 129 | 95 | 24 | 2 | 53 | 36 | 11 | 0 |
| Spain | 0.1 | 73 | 0 | 5 | 46 | 22 | 35 | 46 | 18 | 1 |
| Sweden | 1.2 | 536 | 518 | 18 | 0 | 0 | 80 | 18 | 2 | 0 |
| Switzerland | 7.7 | 317 | 18 | 26 | 142 | 131 | 16 | 30 | 30 | 23 |
| Turkey | 0.7 | 519 | 87 | 79 | 300 | 53 | 18 | 25 | 47 | 11 |
| Ukraine* | 0.9 | 534 | 499 | 32 | 3 | 0 | 97 | 2 | 1 | 0 |
| United Kingdom | 1.0 | 257 | 256 | 1 | 0 | 0 | 96 | 4 | 0 | 0 |

** Moldova and Ukraine are not fully covered by the EU-DEM; calculations for these two countries are therefore based on the DEM GTOPO30 (1 000 m resolution) provided by the U.S. Geological Survey.*

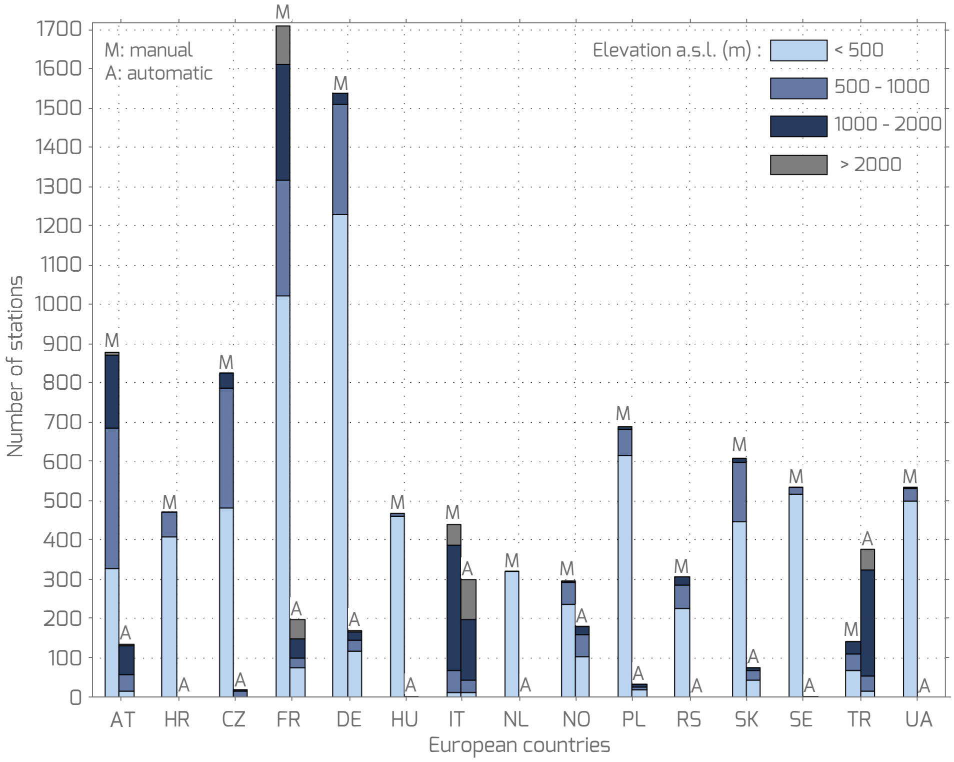

*Figure I-3.2.2 Number of snow depth (HS) stations in countries operating more than 250 manual (M) or automatic (A) stations within their HS monitoring network. The bars are stacked by elevational range. In cases where no bar is shown, no measurements are performed. The country IDs on the x-axis are defined in Table I-3.1.1.*

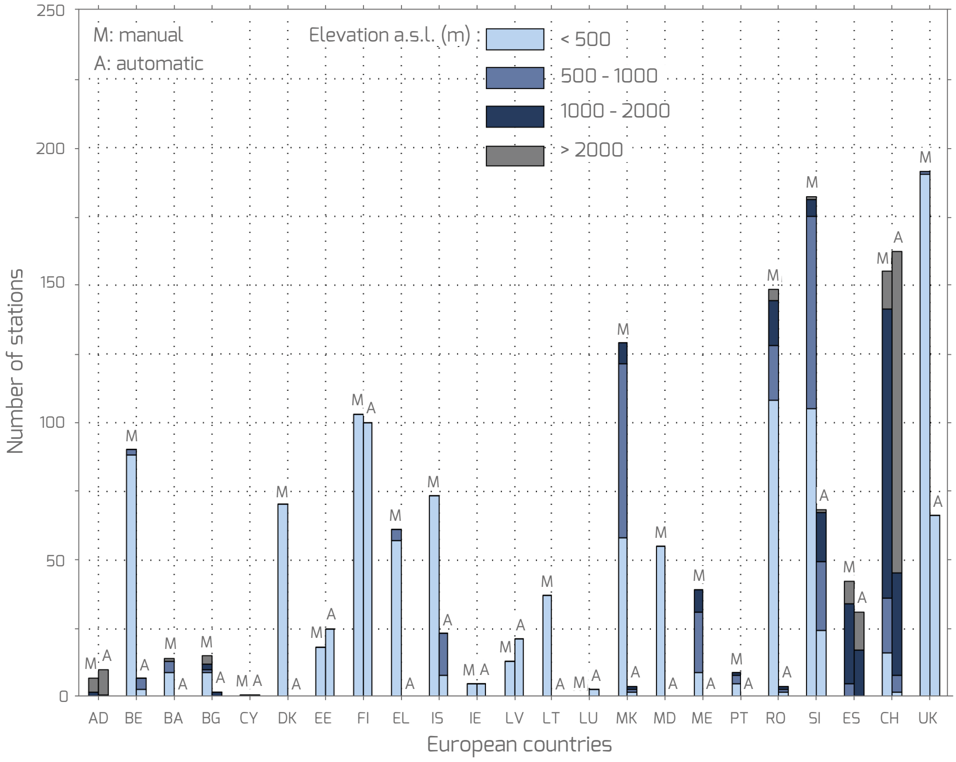

*Figure I-3.2.3 Number of snow depth (HS) stations in countries operating 250 or fewer manual (M) or automatic (A) stations within their HS monitoring network. Please note that the total number of stations can exceed 250 stations. The bars are stacked by elevational range. In cases where no bar is shown, no measurements are performed. The country IDs on the x-axis are defined in Table I-3.1.1.*

# I-3.3 Depth of snowfall

Depth of snowfall (HN) is operationally measured in only 23 of the 38 European countries that contributed data (Table I-3.3.1), which results in a far smaller total number of depth of snowfall stations than snow depth stations. Depth of snowfall is only measured manually, as explained in Section I-1.4. Figure I-3.3.1 therefore shows the elevational distribution of manual depth of snowfall stations. The stations with depth of snowfall measurements are mostly located below 500 m a.s.l. Only 1.5% of all European depth of snowfall stations are located above 2 000 m a.s.l., which is a result of the greater difficulty with measuring depth of snowfall at high elevations, owing to e.g. stronger wind and more snow redistribution, or of the considerable expenditure required to measure depth of snowfall manually every day at high-elevation stations that are often difficult to reach.

In Figures I-3.3.2 and I-3.3.3 an overview of the number and elevational distribution of depth of snowfall stations for each European country is shown. For better readability the countries are separated into two figures depending on the number of stations (≤ 250 or > 250). The number of manual depth of snowfall stations exceeds 250 in only eight countries (Fig. I-3.3.2), which is slightly more than half the number of countries with > 250 manual and/or > 250 automatic snow depth stations (Fig. I-3.2.2). While Hungary, the Netherlands, Norway and Sweden operate large snow depth monitoring networks, depth of snowfall is not operationally measured in these countries. Fewer than 250 depth of snowfall stations are operated in Croatia and in Turkey, corresponding to about half the number of snow depth stations in each country (Fig. I-3.3.3). As with snow depth stations, France and Germany have the largest number of depth of snowfall stations, although again the station density is not high in these countries (Table I-3.3.1; Fig. I-3.5.4). Few countries operate a depth of snowfall measurement network with an appropriate number of stations relative to the area in the country that is above 1 000 m a.s.l., i.e. Andorra, Austria, France, Italy, Spain, Switzerland and Turkey, and all of these countries feature large mountainous areas.

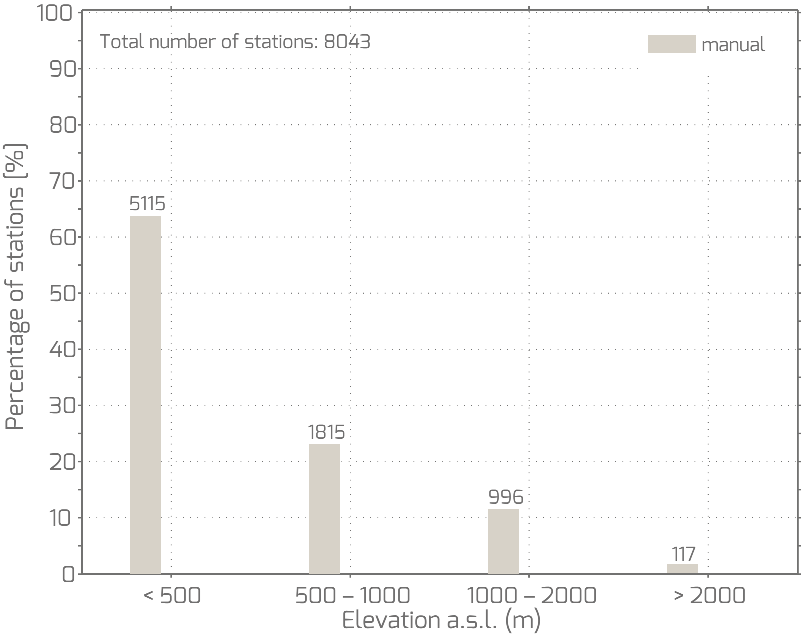

*Figure I-3.3.1 Elevational distribution of manual stations where depth of snowfall is measured in 23 of the 38 European countries that contributed data. The corresponding number of stations is given above each bar.*

*Table I-3.3.1 Comparison of depth of snowfall (HN) stations in the European countries included in the European Snow Booklet (ESB). The depth of snowfall station density, i.e. the number of stations per 1 000 km², is given for each country, as well as the total number of depth of snowfall stations. In addition, the number of depth of snowfall stations located in certain elevational ranges (below 500 m a.s.l., 500 – 1 000 m a.s.l., 1 000 – 2 000 m a.s.l. and above 2 000 m a.s.l.) is given, as well as the percentage of the country area occurring in each elevational range.*

| Country | HN stations per 1 000 km² | Total number of HN stations | Number of HN stations | | | | Percentage of country area (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | < 500 m a.s.l. | 500 – 1 000 m a.s.l. | 1 000 – 2 000 m a.s.l. | > 2 000 m a.s.l. | < 500 m a.s.l. | 500 – 1 000 m a.s.l. | 1 000 – 2 000 m a.s.l. | > 2 000 m a.s.l. |
| Andorra | 15.0 | 7 | 0 | 0 | 2 | 5 | 0 | 1 | 39 | 60 |
| Austria | 10.5 | 880 | 328 | 358 | 186 | 8 | 31 | 30 | 29 | 9 |
| Belgium | 0.7 | 21 | 21 | 0 | 0 | 0 | 96 | 4 | 0 | 0 |
| Bosnia and Herzegovina | 0.3 | 14 | 9 | 4 | 0 | 1 | 39 | 36 | 25 | 0 |
| Bulgaria | 0.0 | 0 | 0 | 0 | 0 | 0 | 67 | 21 | 12 | 1 |
| Croatia | 4.4 | 247 | 213 | 33 | 1 | 0 | 79 | 17 | 4 | 0 |
| Cyprus | 0.1 | 1 | 0 | 0 | 1 | 0 | 80 | 17 | 3 | 0 |
| Czech Republic | 10.5 | 825 | 481 | 305 | 39 | 0 | 65 | 34 | 1 | 0 |
| Denmark | 0.0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Estonia | 0.0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Finland | 0.0 | 0 | 0 | 0 | 0 | 0 | 99 | 1 | 0 | 0 |
| France | 2.5 | 1 570 | 1 022 | 289 | 230 | 29 | 80 | 12 | 6 | 2 |
| Germany | 4.3 | 1 522 | 1 230 | 281 | 11 | 0 | 84 | 15 | 1 | 0 |
| Greece | 0.5 | 61 | 57 | 4 | 0 | 0 | 60 | 26 | 13 | 0 |
| Hungary | 0.0 | 0 | 0 | 0 | 0 | 0 | 99 | 1 | 0 | 0 |
| Iceland | 0.0 | 0 | 0 | 0 | 0 | 0 | 54 | 36 | 10 | 0 |
| Ireland | 0.1 | 5 | 5 | 0 | 0 | 0 | 99 | 1 | 0 | 0 |
| Italy | 1.5 | 441 | 12 | 56 | 320 | 53 | 63 | 21 | 12 | 4 |
| Latvia | 0.0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Lithuania | 0.0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Luxembourg | 0.0 | 0 | 0 | 0 | 0 | 0 | 97 | 3 | 0 | 0 |
| Macedonia | 5.0 | 129 | 58 | 63 | 8 | 0 | 25 | 44 | 29 | 1 |
| Moldova* | 0.0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Montenegro | 2.8 | 39 | 9 | 22 | 8 | 0 | 16 | 27 | 56 | 1 |
| The Netherlands | 0.0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Norway | 0.0 | 0 | 0 | 0 | 0 | 0 | 53 | 32 | 15 | 0 |
| Poland | 2.2 | 690 | 617 | 66 | 7 | 0 | 97 | 3 | 0 | 0 |
| Portugal | 0.0 | 0 | 0 | 0 | 0 | 0 | 78 | 21 | 2 | 0 |
| Romania | 0.0 | 0 | 0 | 0 | 0 | 0 | 71 | 19 | 10 | 0 |
| Serbia | 4.0 | 307 | 227 | 58 | 22 | 0 | 61 | 28 | 11 | 0 |
| Slovakia | 12.4 | 610 | 448 | 150 | 11 | 1 | 62 | 32 | 5 | 0 |
| Slovenia | 9.0 | 182 | 105 | 70 | 6 | 1 | 53 | 36 | 11 | 0 |
| Spain | 0.0 | 19 | 0 | 0 | 13 | 6 | 35 | 46 | 18 | 1 |
| Sweden | 0.0 | 0 | 0 | 0 | 0 | 0 | 80 | 18 | 2 | 0 |
| Switzerland | 3.5 | 146 | 16 | 16 | 101 | 13 | 16 | 30 | 30 | 23 |
| Turkey | 0.2 | 131 | 64 | 39 | 28 | 0 | 18 | 25 | 47 | 11 |
| Ukraine* | 0.0 | 2 | 0 | 0 | 2 | 0 | 97 | 2 | 1 | 0 |
| United Kingdom | 0.8 | 191 | 190 | 1 | 0 | 0 | 96 | 4 | 0 | 0 |

** Moldova and Ukraine are not fully covered by the EU-DEM; calculations for these two countries are therefore based on the DEM GTOPO30 (1 000 m resolution) provided by the U.S. Geological Survey.*

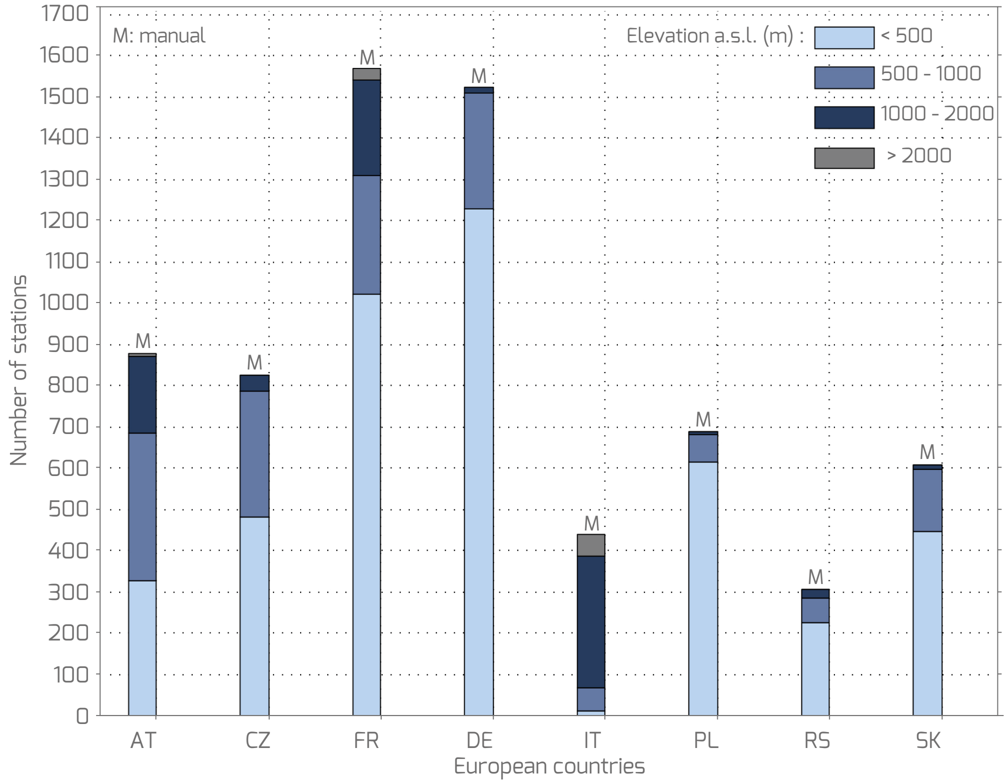

*Figure I-3.3.2 Number of depth of snowfall (HN) stations in countries operating more than 250 manual (M) stations within their HN monitoring network. The bars are stacked by elevational range. In cases where no bar is shown, no measurements are performed. The country IDs on the x-axis are defined in Table I-3.1.1.*

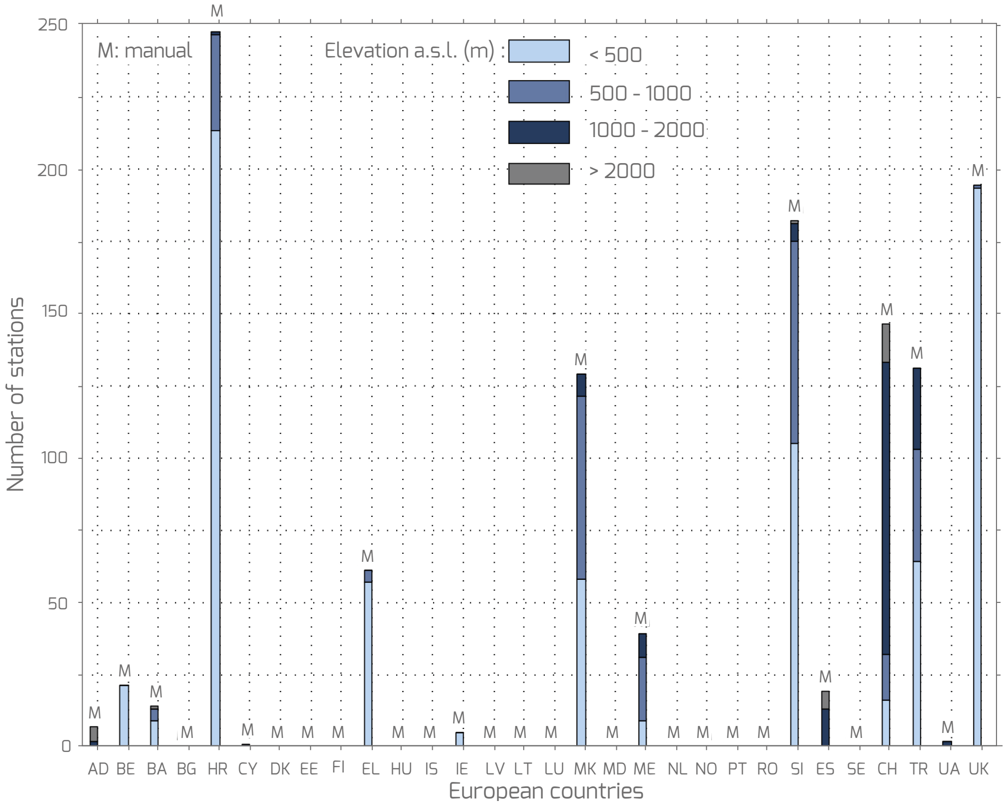

*Figure I-3.3.3 Number depth of snowfall (HN) stations in countries operating 250 or fewer manual (M) stations within their HN monitoring network. The bars are stacked by elevational range. In cases where no bar is shown, no measurements are performed. The country IDs on the x-axis are defined in Table I-3.1.1.*

## I-3.4 Water equivalent of snow cover

Water equivalent of snow cover (SWE) is measured manually and automatically for operational purposes, but the number of automatic SWE stations is extremely small (Fig. I-3.4.1). Although SWE is measured operationally in 29 of the 38 European countries that contributed data (Table I-3.4.1), the total number of SWE stations in all European countries is only half the total number of depth of snowfall stations and less than one-third the total number of snow depth stations. Although SWE measurements are important, manual observations are time consuming and labour intensive. Figure I-3.4.1 shows the elevational distribution of manual and automatic stations where SWE is measured. Most SWE stations are located below 500 m a.s.l. The number of SWE stations decreases strongly above 2 000 m a.s.l.

In Figures I-3.4.2 and I-3.4.3 an overview of the number and elevational distribution of SWE stations in each European country is shown. For better readability, Figure I-3.4.2 includes the countries where either the manual or the automatic station network exceeds 250 stations, and Figure I-3.4.3 shows the countries where the manual and the automatic station networks both have fewer than 250 stations, although the total number of stations can exceed 250. The number of manual SWE stations exceeds 250 in only six countries (Fig. I-3.4.2). In addition, the number of SWE stations per country is much smaller than the number of snow depth and the number of depth of snowfall stations in the corresponding country. While France and Germany operate the largest snow depth and depth of snowfall monitoring networks, the Czech Republic and Slovakia run the most SWE stations within their snow observation networks. In most countries SWE is mainly measured below 1 000 m a.s.l., but Austria, France, Italy, Romania, Spain, Switzerland and Turkey also have a wealth of SWE stations located above 1 000 m a.s.l. In France, for example, a total of about 100 manual and automatic SWE stations are located at elevations above 2 000 m a.s.l. (Fig. I-3.4.3), mainly for hydropower purposes. Overall, most countries have a very small number of automatic SWE stations. However, France (about 35 automatic SWE stations), Norway (about 20 automatic SWE stations) and Spain (about 20 automatic SWE stations), have a relatively large number of automatic SWE stations, mostly located in the mountains and above 1 000 m a.s.l.

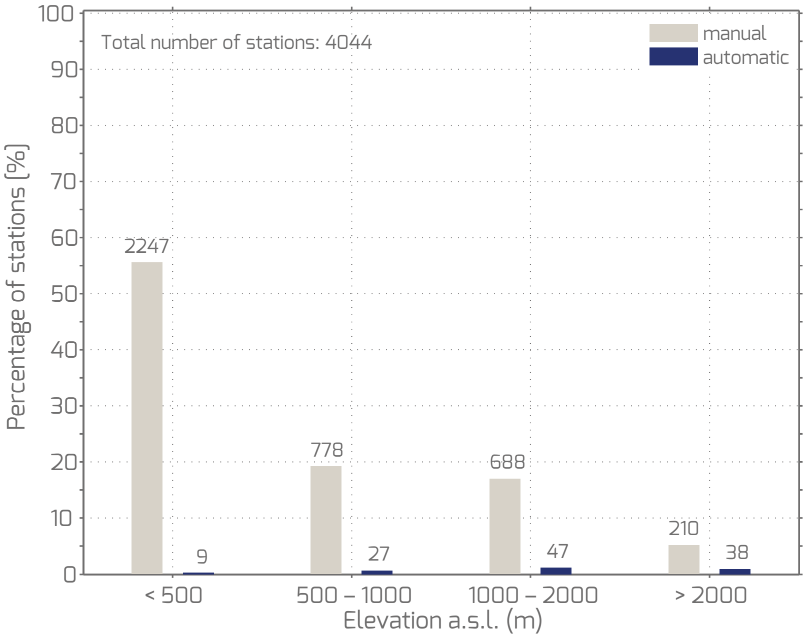

*Figure I-3.4.1 Elevational distribution of manual and automatic stations where water equivalent of snow cover is measured in 29 of the 38 European countries that contributed data. The corresponding number of stations is given above each bar.*

*Table I-3.4.1 Comparison of water equivalent of snow cover (SWE) stations in the European countries included in the European Snow Booklet (ESB). The SWE station density, i.e. the number of stations per 1 000 km$^2$, is given for each country, as well as the total number of SWE stations. In addition, the number of SWE stations located in certain elevational ranges (below 500 m a.s.l., 500 – 1 000 m a.s.l., 1 000 – 2 000 m a.s.l. and above 2 000 m a.s.l.) is given, as well as the percentage of the country area occurring in each elevational range.*

| Country | SWE stations per 1 000 km$^2$ | Total number of SWE stations | Number of SWE stations | | | | Percentage of country area (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | < 500 m a.s.l. | 500 – 1 000 m a.s.l. | 1 000 – 2 000 m a.s.l. | > 2 000 m a.s.l. | < 500 m a.s.l. | 500 – 1 000 m a.s.l. | 1 000 – 2 000 m a.s.l. | > 2 000 m a.s.l. |
| Andorra | 2.1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 39 | 60 |
| Austria | 0.6 | 52 | 8 | 21 | 22 | 1 | 31 | 30 | 29 | 9 |
| Belgium | 0.1 | 2 | 1 | 1 | 0 | 0 | 96 | 4 | 0 | 0 |
| Bosnia and Herzegovina | 0.2 | 11 | 7 | 4 | 0 | 0 | 39 | 36 | 25 | 0 |
| Bulgaria | 0.0 | 2 | 0 | 0 | 2 | 0 | 67 | 21 | 12 | 1 |
| Croatia | 0.3 | 15 | 11 | 3 | 1 | 0 | 79 | 17 | 4 | 0 |
| Cyprus | 0.0 | 0 | 0 | 0 | 0 | 0 | 80 | 17 | 3 | 0 |
| Czech Republic | 10.7 | 841 | 481 | 320 | 40 | 0 | 65 | 34 | 1 | 0 |
| Denmark | 0.0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Estonia | 0.3 | 14 | 14 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Finland | 0.4 | 143 | 142 | 1 | 0 | 0 | 99 | 1 | 0 | 0 |
| France | 0.3 | 175 | 0 | 7 | 75 | 93 | 80 | 12 | 6 | 2 |
| Germany | 1.4 | 504 | 360 | 135 | 8 | 1 | 84 | 15 | 1 | 0 |
| Greece | 0.0 | 0 | 0 | 0 | 0 | 0 | 60 | 26 | 13 | 0 |
| Hungary | 0.1 | 12 | 11 | 0 | 1 | 0 | 99 | 1 | 0 | 0 |
| Iceland | 0.0 | 0 | 0 | 0 | 0 | 0 | 54 | 36 | 10 | 0 |
| Ireland | 0.0 | 0 | 0 | 0 | 0 | 0 | 99 | 1 | 0 | 0 |
| Italy | 1.3 | 380 | 0 | 21 | 265 | 94 | 63 | 21 | 12 | 4 |
| Latvia | 0.3 | 21 | 21 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Lithuania | 0.6 | 37 | 37 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Luxembourg | 0.0 | 0 | 0 | 0 | 0 | 0 | 97 | 3 | 0 | 0 |
| Macedonia | 0.4 | 11 | 4 | 5 | 2 | 0 | 25 | 44 | 29 | 1 |
| Moldova* | 1.6 | 55 | 55 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Montenegro | 0.1 | 2 | 0 | 1 | 1 | 0 | 16 | 27 | 56 | 1 |
| The Netherlands | 0.0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Norway | 0.1 | 27 | 8 | 13 | 6 | 0 | 53 | 32 | 15 | 0 |
| Poland | 0.5 | 170 | 121 | 43 | 6 | 0 | 97 | 3 | 0 | 0 |
| Portugal | 0.0 | 0 | 0 | 0 | 0 | 0 | 78 | 21 | 2 | 0 |
| Romania | 0.6 | 139 | 102 | 18 | 15 | 4 | 71 | 19 | 10 | 0 |
| Serbia | 0.3 | 27 | 23 | 0 | 4 | 0 | 61 | 28 | 11 | 0 |
| Slovakia | 12.4 | 607 | 448 | 150 | 9 | 0 | 62 | 32 | 5 | 0 |
| Slovenia | 0.1 | 3 | 2 | 0 | 0 | 1 | 53 | 36 | 11 | 0 |
| Spain | 0.0 | 22 | 0 | 0 | 14 | 8 | 35 | 46 | 18 | 1 |
| Sweden | 0.0 | 19 | 17 | 2 | 0 | 0 | 80 | 18 | 2 | 0 |
| Switzerland | 1.1 | 46 | 0 | 0 | 39 | 7 | 16 | 30 | 30 | 23 |
| Turkey | 0.4 | 320 | 29 | 32 | 221 | 38 | 18 | 25 | 47 | 11 |
| Ukraine* | 0.6 | 386 | 355 | 27 | 4 | 0 | 97 | 2 | 1 | 0 |
| United Kingdom | 0.0 | 0 | 0 | 0 | 0 | 0 | 96 | 4 | 0 | 0 |

** Moldova and Ukraine are not fully covered by the EU-DEM; calculations for these two countries are therefore based on the DEM GTOPO30 (1 000 m resolution) provided by the U.S. Geological Survey.*

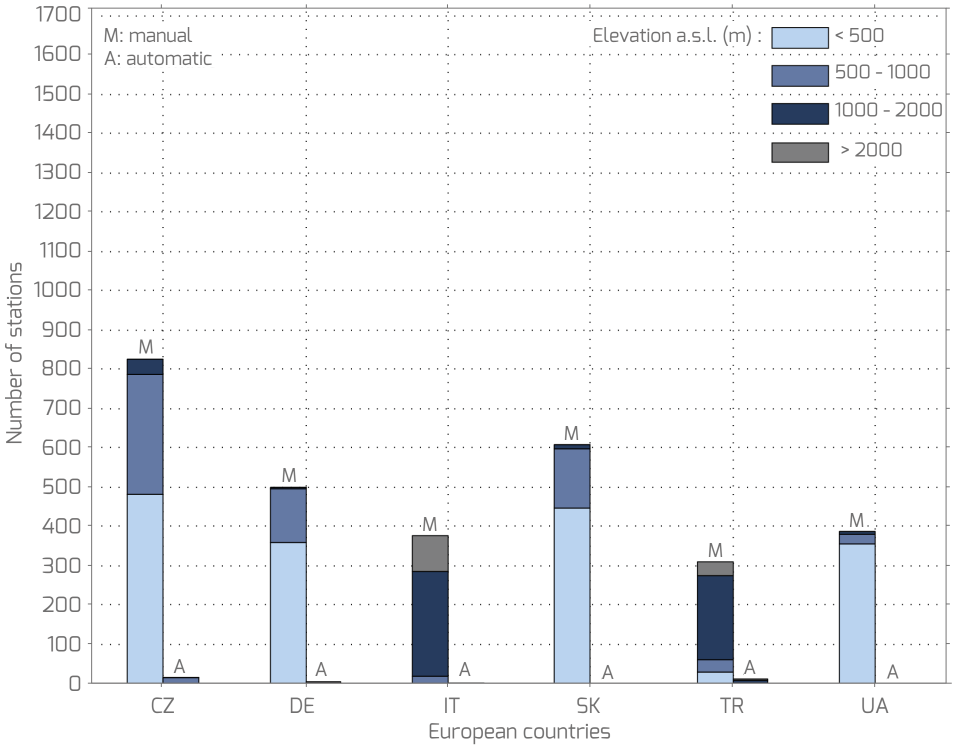

*Figure I-3.4.2 Number of water equivalent of snow cover (SWE) stations in countries operating more than 250 manual (M) or automatic (A) stations within their SWE monitoring network. The bars are stacked by elevational range. In cases where no bar is shown, no measurements are performed. The country IDs on the x-axis are defined in Table I-3.1.1.*

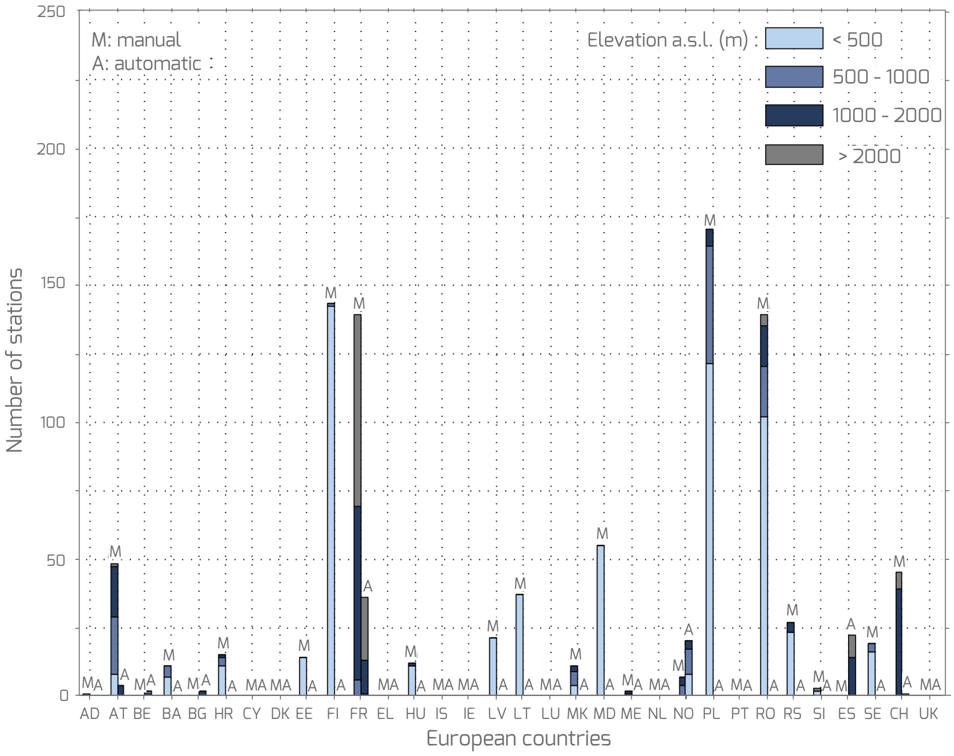

*Figure I-3.4.3 Number of water equivalent of snow cover (SWE) stations in countries operating 250 or fewer manual (M) or automatic (A) stations within their SWE monitoring network. Please note that the total number of stations can exceed 250 stations. The bars are stacked by elevational range. In cases where no bar is shown, no measurements are performed. The country IDs on the x-axis are defined in Table I-3.1.1.*

# I-3.5 Overview of measurements

Comparisons of the number of manual snow depth (HS), manual depth of snowfall (HN) and manual water equivalent of snow cover (SWE) stations in the 38 European countries included in the ESB are displayed in Figures I-3.5.1 and I-3.5.2. Only manual stations are shown because only manual measurements are performed for all three variables. For better readability, Figure I-3.5.1 includes countries where the observation network of at least one of the variables exceeds 250 stations, and Figure I-3.5.2 includes countries where all three variables are measured at fewer than 250 stations, although the total number of stations can exceed 250. In many countries (14 countries) the number of manual snow depth stations is similar to the number of depth of snowfall stations, most likely because these two measurements are often performed on a daily basis in the same measurement field. The number of manual measurement stations is equal for the three variables only in the Czech Republic and Slovakia, which both have a wealth of stations below 1 000 m a.s.l. Italy likewise has a similar number of manual stations for the three variables, particularly above 1 000 m a.s.l. The number of manual SWE stations is often much smaller than the number of snow depth or depth of snowfall stations in national networks where all three variables are measured (e.g. Austria, France, Germany, Macedonia, Montenegro, Poland, Serbia, Slovenia, Switzerland). Turkey is an exception in that more SWE than snow depth or depth of snowfall measurements are performed. In addition, in several Eastern European and Scandinavian countries only snow depth and SWE are observed operationally (e.g. Estonia, Finland, Hungary, Latvia, Lithuania, Moldova, Norway, Romania, Sweden). In countries where snowfall is rare, often only snow depth (e.g. Denmark, the Netherlands, Portugal) or snow depth and depth of snowfall (e.g. Cyprus, Greece, Ireland, the United Kingdom) are measured. In contrast, in countries with large mountain ranges, for example those where the Alps are located, all basic snow variables are measured. In Luxembourg, no manual observations are performed but automatic stations are in operational use (LU in Figs I-3.5.2 and I-3.5.3).

Figure I-3.5.3 features a comparison of the number of automatic snow depth and automatic SWE stations in the European countries that operate such networks. Depth of snowfall is not included in the figure because it is only manually observed. There are fewer than 50 automatic snow depth stations at elevations below 500 m a.s.l. in all the considered countries except Finland, France, Germany, Norway and the United Kingdom. Further, in countries with large mountain ranges most of the automatic stations within a monitoring network are located above 1 000 m a.s.l., with a relatively large proportion even situated above 2 000 m a.s.l. The largest automatic snow depth monitoring networks at elevations above 1 000 m a.s.l. are operated by Italy and Turkey. Italy operates around 150 automatic stations above 1 000 m a.s.l. and around 100 automatic stations above 2 000 m a.s.l., while the Turkish station network above 1 000 m a.s.l. is even larger, with around 315 automatic snow depth stations. A wealth of automatic snow depth stations are also operated above 1 000 m a.s.l. in Austria and France, and around 110 automatic stations are located above 2 000 m a.s.l. in Switzerland. In contrast to the large size of the automatic snow depth monitoring networks, the total number of automatic SWE stations in the European countries is extremely small. France is the only country operating more then 25 automatic SWE stations (around 35 stations, all located above 1 000 m a.s.l.) within their network, while Norway and Spain operate around 20 automatic SWE stations. In Spain these stations are located above 1 000 or even 2 000 m a.s.l. Overall, the automatic station networks are small compared with the manual ones.

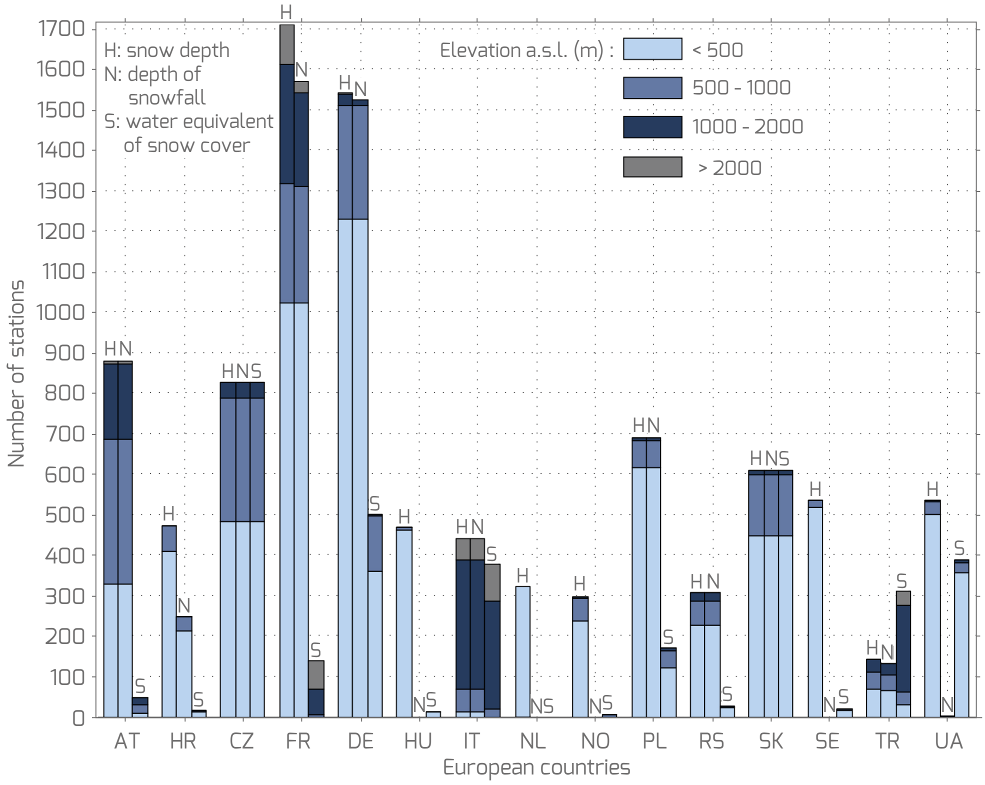

*Figure I-3.5.1 Number of manual snow depth (H), depth of snowfall (N) and water equivalent of snow cover (S) stations in countries operating more than 250 stations for at least one of these variables within their manual monitoring network. The bars are stacked by elevational range. The country IDs on the x-axis are defined in Table I-3.1.1.*

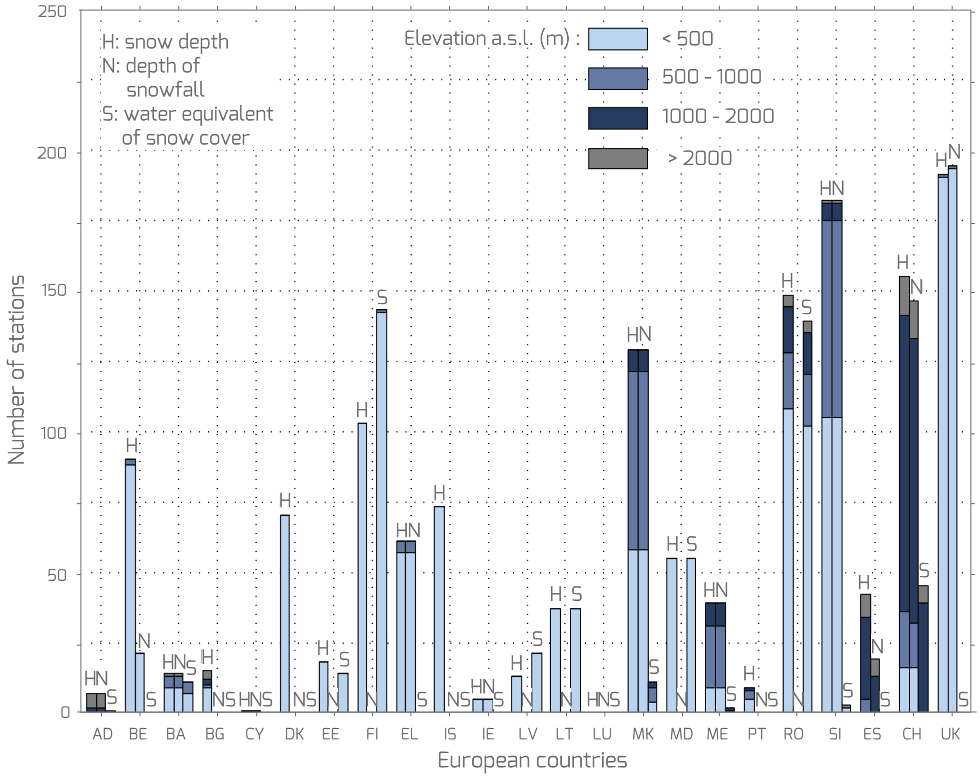

*Figure I-3.5.2 Number of manual snow depth (H), depth of snowfall (N) and water equivalent of snow cover (S) stations in countries operating 250 or fewer stations for each of these variables within their manual monitoring network. Please note that the sum of snow depth, depth of snowfall and water equivalent of snow cover stations can exceed 250. The bars are stacked by elevational range. For countries where no bar is shown, there are no manual stations but automatic ones may exist (e.g. Luxembourg (LU)). The country IDs on the x-axis are defined in Table I-3.1.1.*

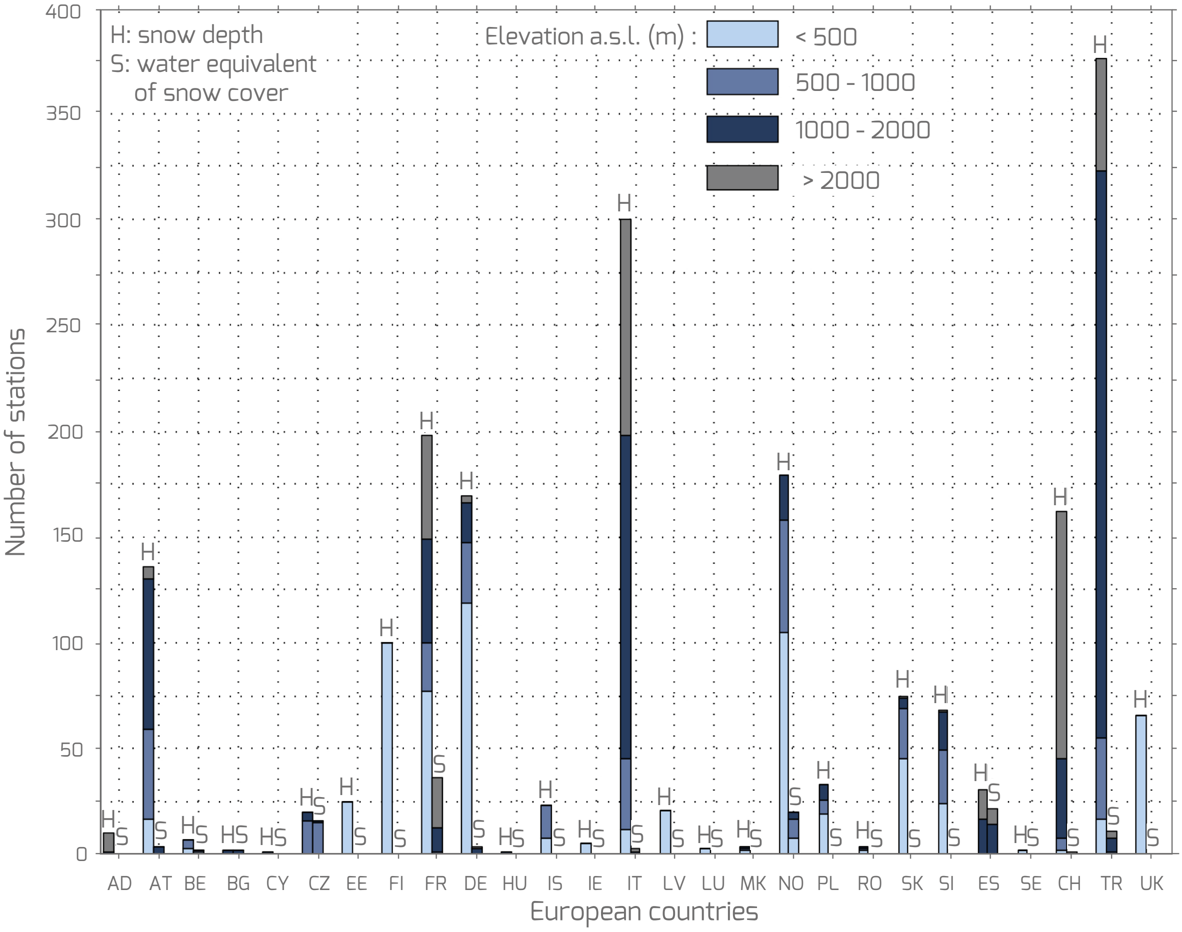

*Figure I-3.5.3 Number of automatic snow depth (H) and water equivalent of snow cover (S) stations in all countries operating an automatic monitoring network. Please note that the y-axis scale differs from that in Figures I-3.5.1 and I-3.5.2. The bars are stacked by elevational range. Only countries that operate an automatic monitoring network in addition to a manual one are shown. The country IDs on the x-axis are defined in Table I-3.1.1.*

The variation among the European countries regarding snow depth, depth of snowfall and SWE station densities (density = station number per 1 000 km²) is presented in Figure I-3.5.4. The Czech Republic and Slovakia operate monitoring networks with the largest number of stations per 1 000 km² for snow depth, depth of snowfall and SWE considered together, and the station density is similar for the three variables in each of these countries. With respect to snow depth and depth of snowfall observation networks in particular, station density is highest (> 5 stations per 1 000 km²) in Andorra, Austria, Czech Republic, Macedonia, Slovakia and Slovenia. In these countries, snow depth and depth of snowfall are often manually measured at approximately the same time and within the same measurement field. Further, Croatia, Hungary, the Netherlands and Switzerland each operate a dense network of snow depth stations within their monitoring networks (> 5 stations per 1 000 km²). In contrast to the snow depth and depth of snowfall networks, station density is extremely low for SWE observations, with fewer than 2.5 stations per 1 000 km² for all countries except the Czech Republic and Slovakia.

The number of snow depth, depth of snowfall and SWE measurement stations, summed over all European countries that contributed data, are presented in Table I-3.5.1, separated according to the decade when snow stations started operational measurements (activation decade). At many stations measurements started already in the 19th century. Please note that the decades and corresponding station counts given in the table convey an idea when snow observations started in Europe, but the absolute values should be treated with caution. Especially for periods when digitised data was not yet available, it is not entirely clear if these dates represent the opening of the meteorological station or if they indeed indicate the start of snow observations at a certain location. Additionally, for several stations no information on the activation date exists; while the percentage of such stations is rather small for snow depth stations (1.4%) and depth of snowfall stations (0.7%), it is markedly higher for SWE stations (13.6%).

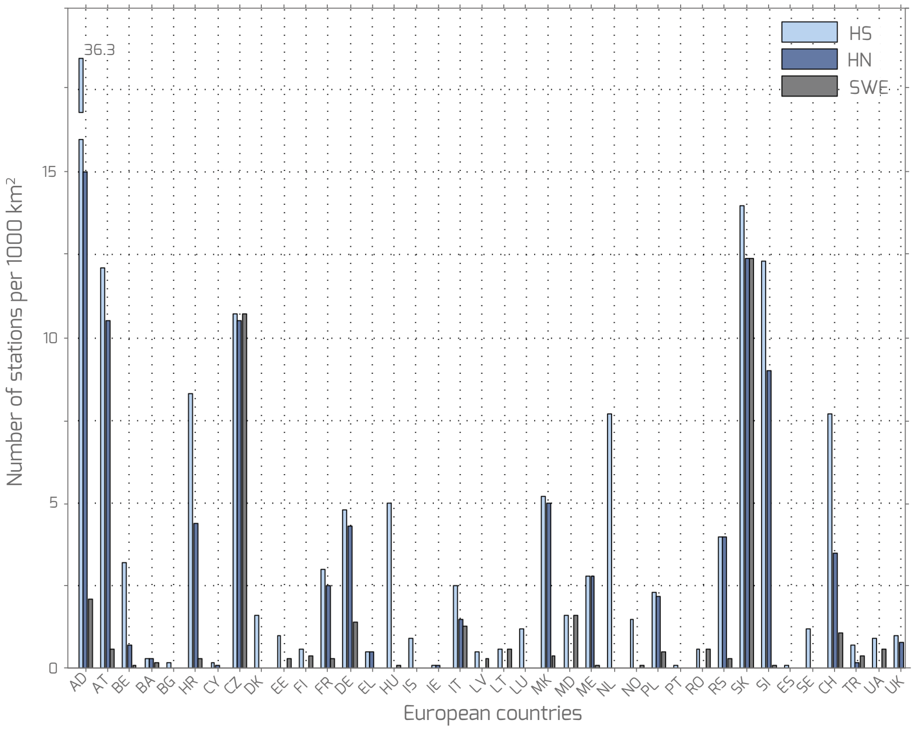

*Figure I-3.5.4 The total number of manual and automatic (where applicable) stations per 1 000 km² is shown for the snow depth (HS), depth of snowfall (HN) and water equivalent of snow cover (SWE) networks in each European country. The exact station density values are additionally given for each variable and country in Tables I-3.2.1., I-3.3.1. and I-3.4.1. The country IDs on the x-axis are defined in Table I-3.1.1.*

*Table I-3.5.1 Decades of first operation (activation) of stations where snow depth (HS), depth of snowfall (HN) and water equivalent of snow cover (SWE) are measured in all European countries that contributed data. For each 10-year period, the total number of stations starting operational measurements is given for each variable.*

| Activation decade | HS stations | HN stations | SWE stations |
|---|---|---|---|
| before 1850* | 12 | 1 | 0 |
| 1850 – 1859 | 16 | 6 | 1 |
| 1860 – 1869 | 29 | 14 | 4 |
| 1870 – 1879 | 41 | 12 | 5 |
| 1880 – 1889 | 128 | 28 | 15 |
| 1890 – 1899 | 523 | 223 | 90 |
| 1900 – 1909 | 298 | 147 | 77 |
| 1910 – 1919 | 169 | 66 | 24 |
| 1920 – 1929 | 534 | 364 | 266 |
| 1930 – 1939 | 590 | 194 | 86 |
| 1940 – 1949 | 1 364 | 801 | 214 |
| 1950 – 1959 | 1 725 | 751 | 323 |
| 1960 – 1969 | 687 | 358 | 119 |
| 1970 – 1979 | 646 | 363 | 167 |
| 1980 – 1989 | 984 | 644 | 251 |
| 1990 – 1999 | 1 264 | 639 | 300 |
| 2000 – 2009 | 1 880 | 1 068 | 536 |
| 2010 – 2018 | 1 983 | 2 306 | 998 |
| No information | 176 | 58 | 549 |
| Total number of stations** | 13 049 | 8 043 | 4 025 |

* Between 1758 and 1838, stations that currently include HS measurements went into operation at eleven locations in Germany and at one location in Luxembourg. In addition, one German station that currently includes HN measurements went into operation in 1836.

** The total number of stations in operation does not exactly match the total number of stations given in Fig. I-3.2.1 for HS and in Fig. I-3.4.1 for SWE because in many cases only the earliest activation date was given for station locations where both manual and automatic stations are now in operation.

# I-3.6 Global Telecommunication System

This section is an overview of national snow depth observations that are distributed over the Global Telecommunication System (GTS) of the World Meteorological Organisation (WMO; Fig. I-3.6.1). After an introduction to WMO's GTS, the added value of reporting and exchanging snow depth data via the GTS is emphasised. A comparison between national snow depth stations and those reporting data over the GTS (Fig. I-3.6.2) is presented to highlight differences between potentially available data and data reported over the GTS. Difficulties and inconsistencies between national operational snow observations and those reported via GTS are then described, followed by a discussion of problems arising because of differences between national and global reporting systems. All the analyses and discussions presented below are based on data provided on the GTS in December 2017.

The Global Telecommunication System is dedicated to meteorological observation exchange among national weather services and is defined as: "the co-ordinated global system of telecommunication facilities and arrangements for the rapid collection, exchange and distribution of observations and processed information within the framework of the World Weather Watch" (WMO No. 49, 2015).

According to the GTS information on the WMO website[25] (GTS, 2018): "This secured communication network is composed of a dedicated network of surface- and satellite-based telecommunication links and centres operated around the clock all year round. It interconnects all national meteorological and hydrological services of WMO members for the collection and distribution of all meteorological and related data, forecasts and alerts, including tsunami- and seismic-related information and warnings. More than 50 000 weather reports and several thousand charts and digital products are disseminated through the WMO GTS daily. Thus the WMO GTS is the backbone system for global real-time exchange of data and information, supporting weather, water and climate analyses and forecasts, and it is critical for forecasting and providing warnings of hydrometeorological hazards. WMO is currently extending its GTS to achieve an overarching WMO Information System (WIS), thereby enabling systematic access, retrieval, dissemination and exchange of data and information for the entire WMO and for related international programmes. The WIS will also be able to provide critical data to other national agencies and users dealing with many sectors, including disaster risk management."

Ground-based snow depth measurements are part of common meteorological observations, and their data should be distributed over GTS. This data is very important for assimilation into numerical weather prediction (NWP) models (Chapter II-3), validation of satellite-derived data, verification, and monitoring. Large snow depth observation networks often exist within countries (Chapter I-2), but much of that potentially valuable snow data is not reported over GTS and/or is not available outside the country of origin (Fig. I-3.6.2), despite the fact that the national weather services are expected to make their snow data available in near-real time on the GTS.

All stations reporting snow depth data via GTS in the European countries are shown in Figure I-3.6.1, based on data from December 2017. Snow depth is reported via GTS in all countries except Iceland, Kosovo and the Netherlands. The number of stations reporting snow depth via GTS varies strongly among the countries. In addition, the number of stations measuring snow depth in each country that contributed data and the number of stations reporting snow depth via the GTS differ widely (Fig. I-3.6.2). The order of magnitude of the density of stations reporting data via GTS is equal to that of the density of all national stations in only two countries, Norway and Denmark. Thus, improving the practice of reporting in-situ snow observations via the WMO's GTS is vital for increasing the exchange of real-time snow observations and for enhancing the availability of in-situ snow depth reports. This advancement would be of great value for all actors involved in snow-related operational services and research.

Another issue is that Figure I-3.6.1 shows, for example, Italian stations reporting snow depth data via GTS in non-mountainous regions or in Sicily and Sardinia, yet these stations are not described in the Italian country report (Section I-2.19). One explanation is that snow observations performed by the Servizio Meteorologico dell'Aeronautica Militare are reported over GTS but are not included in the country report because no contact could be established.

Besides attempting to increase the availability of national snow observations on GTS (e.g. for snow data assimilation or for NWP models; Chapter II-3), Global Cryosphere Watch's (GCW's) Snow Watch[26] recommends the reporting of "zero snow depth" rather than missing values. This initiative is justified by the following issue discussed by GCW (Snow Watch, 2018) and is regulated by WMO's Resolution 15 on "International exchange of snow data"[27] (WMO No. 69, 2017): "Currently, snow depth is often only reported when snow is present, with 'missing data' recorded for snow depth in snow-free conditions rather than '0 cm'. It is however not known whether this missing data indicates zero centimetre snow depth or a missing report for another reason (e.g. no observer on site). No data in case of snow free conditions must therefore be avoided because correct and thus valid reports of zero snow depth are very

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[25] http://www.wmo.int/pages/prog/www/TEM/GTS/index_en.html
[26] https://globalcryospherewatch.org/projects/snowreporting.html
[27] https://library.wmo.int/index.php?lvl=notice_display&id=19919#.W4AgERZG1e5

important for constraining model snow extent in NWP applications. Snow Watch is thus aiming to make reporting of snow depth a mandatory requirement whether snow is present or not." Discussions about this issue within the HarmoSnow community revealed that some countries recently started prefilling their snow depth data field with "0 cm" in order to fulfil national demands for nowcasting and GTS requirements. This means that snow-free conditions are incorrectly communicated in all cases where no snow depth measurement is available because of human or technical reasons.

Currently, snow depth (discussed in this section), water equivalent of snow cover, presence of snow on the ground and depth of snowfall can be reported and distributed via GTS. Please note that all stations in the GTS network are considered operational as long as they report their data via GTS. This differs somewhat from the definition applied in Chapters I-1 and I-2, where all long-term snow observations of national weather services or institutions are seen as operational, regardless of whether they report data over GTS.

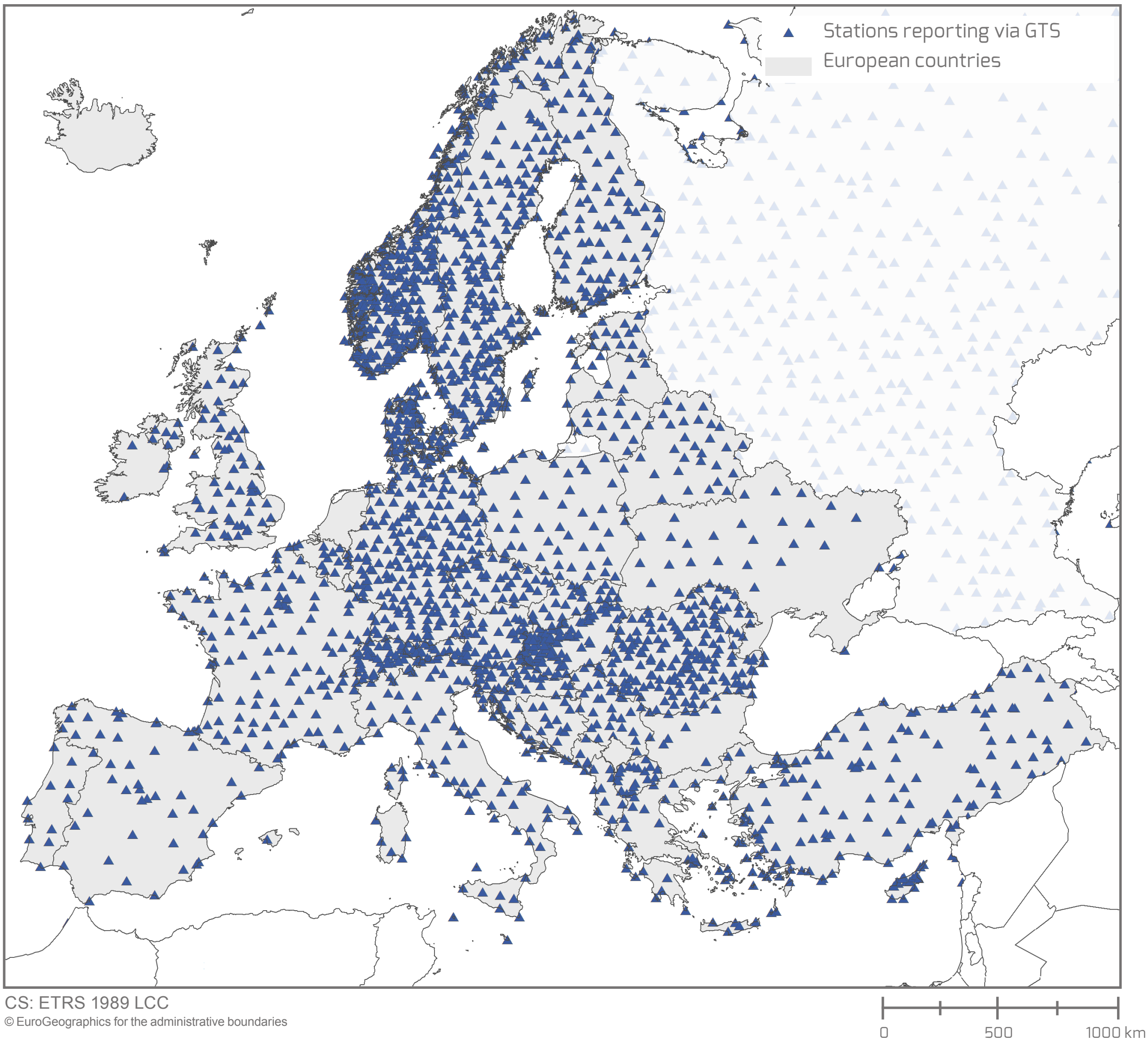

*Figure I-3.6.1 Stations (blue triangles) reporting snow depth (HS) or presence of snow on the ground (PSG) data via the WMO's Global Telecommunication System (GTS). Stations in Russia are shown but are greyed out because Russia is not part of this analysis. The map is based on data from December 2017.*

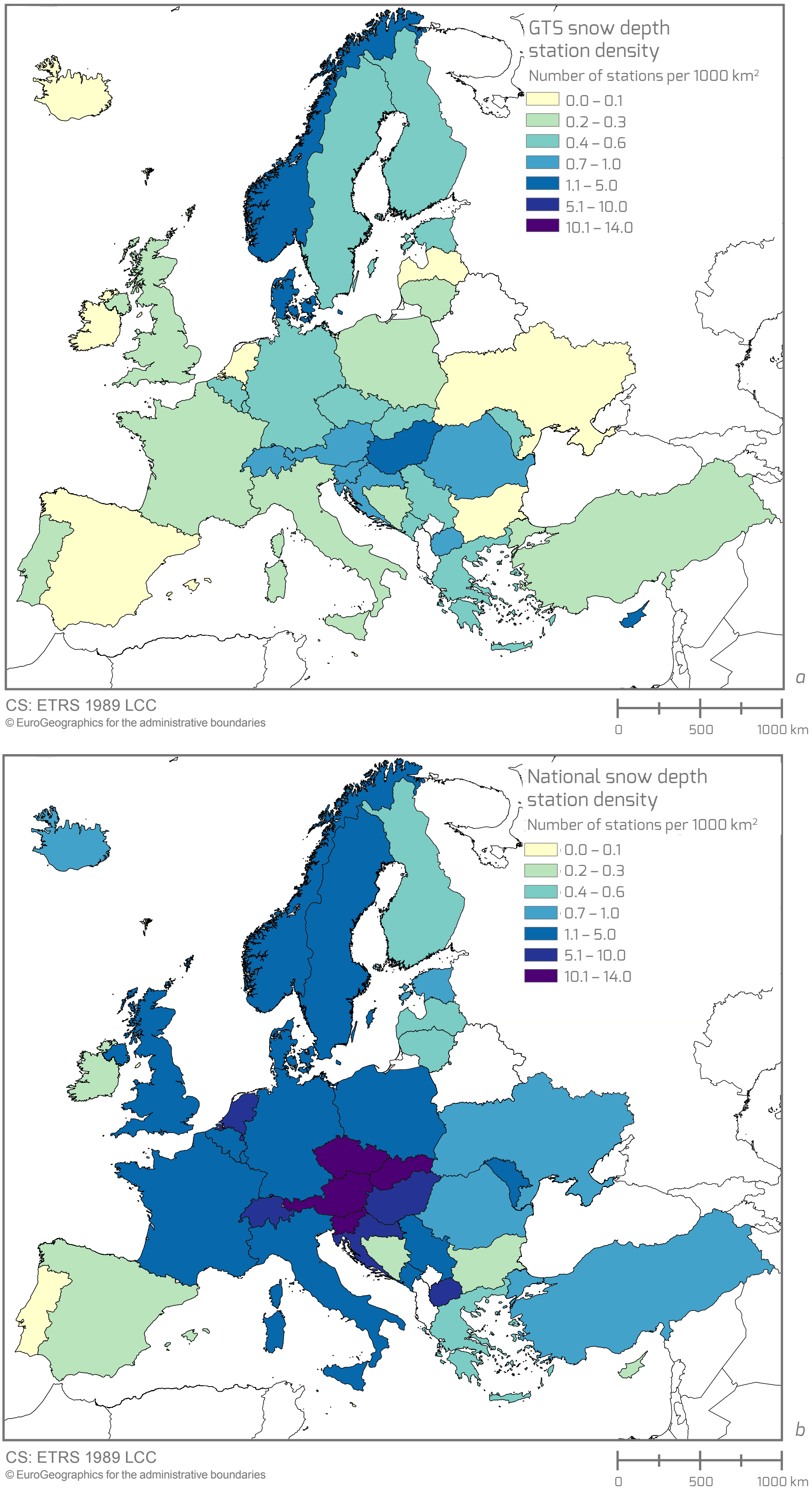

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*Figure I-3.6.2 Snow depth station density (number of stations per 1 000 km²) for each country that contributed data. The station density of stations reporting data over WMO's Global Telecommunication System (GTS) (a) is compared to the station density of all national stations reported in the ESB (b). Please see Table I-3.2.1 for more detailed information on the density of national snow depth stations. Albania, Belarus, Kosovo, Malta, Monaco, Russia, San Marino and Vatican City are not part of this analysis because no or incomplete national information was available for these countries (Section I-2.1). Map (a) is based on data from December 2017.*

Using France and Switzerland as examples, we explain below how differences exist between the snow depth stations included in the national monitoring networks and the stations reporting via GTS, and we discuss difficulties in comparing the total number of stations in these network types. France and Switzerland were chosen for this purpose because detailed network information was available for these two countries.

Table I-3.6.1, as well as Figures I-3.6.2, I-3.6.3 and I-3.6.4, emphasise how the number of snow depth stations included in the national snow monitoring networks can differ strongly from the number of stations reporting data over GTS. Overall, very few stations report data via GTS. Inconsistencies exist between snow depth data from the national weather service reported over GTS and the information provided for the ESB (Chapter I-2). For example, in some cases it is indicated that a station reports snow depth data via GTS at a particular location but no information about a snow monitoring station there was provided by the national institutions (black arrows in Figs I-3.6.3, I-3.6.4). Such discrepancies may be due to the ongoing opening and closure of stations in large monitoring networks. Additionally, in some cases the metadata of a station provided through the ESB Questionnaire by a national weather service differs from the metadata of the same station included in the GTS network. One well-known example of this issue from Switzerland is circled in Figure I-3.6.4. While the situation is clear for this station, i.e. manual snow depth measurements are performed far away from the automatic measurement station that reports data over GTS, it is less clear for other cases. Considering all European snow depth stations together, it seems that different metadata for the same stations included in the national network and in the GTS network occur quite often but cannot be explained.

Based on the above-mentioned issues, it is nearly impossible to compare the stations in national monitoring networks with those included in the GTS network without detailed information from the national services.

*Table I-3.6.1 Comparison of the total number of snow depth (HS) stations included in the national monitoring networks and the number of stations included in the GTS reporting network. France and Switzerland are used as examples.*

| Country | Total number of HS stations | Number of HS stations reporting via GTS |
|---|---|---|
| France | 1 907 | 122 |
| Switzerland | 317 | 41 |

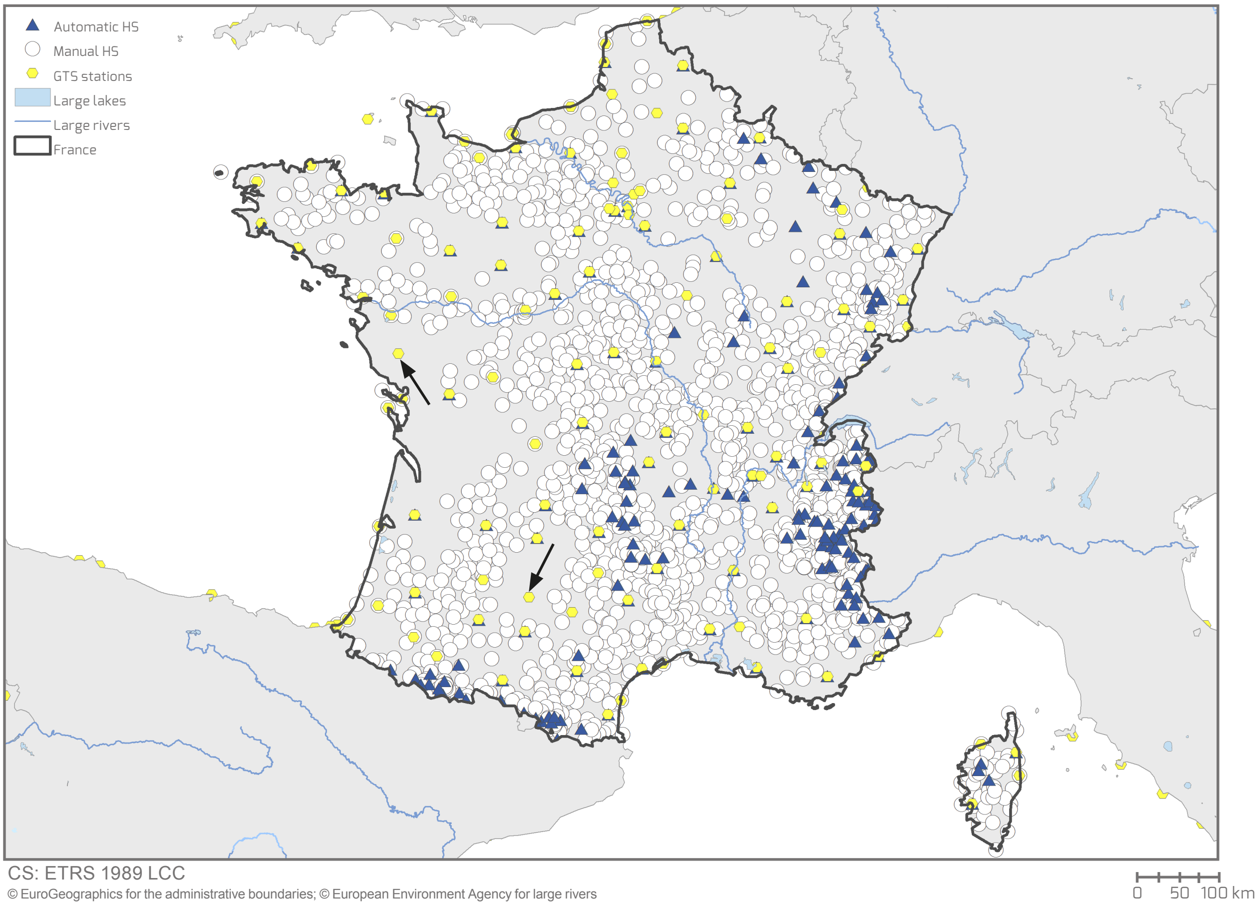

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*Figure I-3.6.3 Map of France showing manual and automatic snow depth (HS) stations operated by Meteo France and EDF. In addition, stations reporting HS data via GTS are marked (station metadata from December 2017). Two cases where data is reported via GTS but no station was reported by the national weather services for the European Snow Booklet (ESB) are marked with black arrows.*

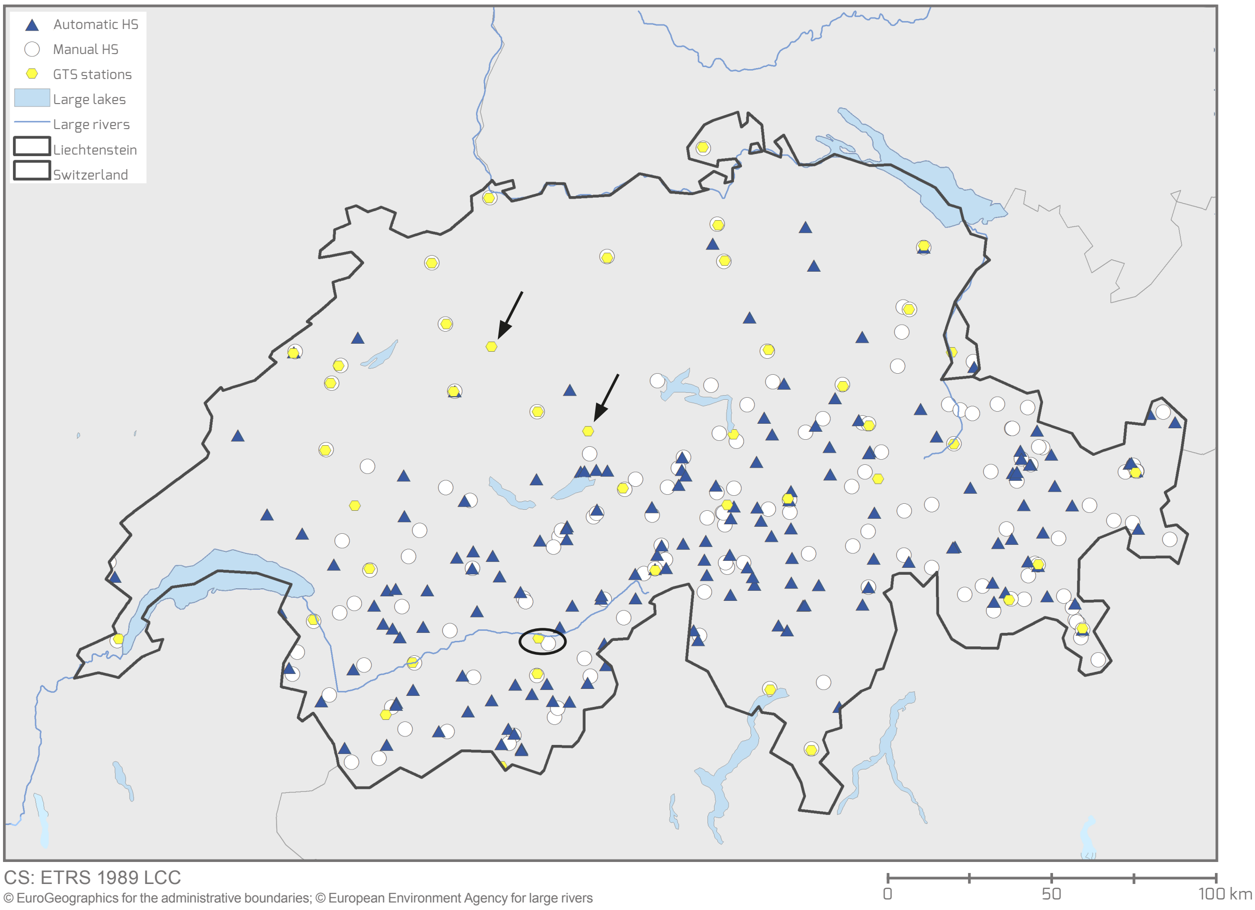

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*Figure I-3.6.4 Map of Switzerland showing manual and automatic snow depth (HS) stations operated by MeteoSwiss and SLF. In addition, stations reporting HS data via GTS are marked (station metadata from December 2017). The black arrows point to cases where data is reported via GTS but no station was reported by the national weather services for the European Snow Booklet (ESB). The black circled station highlights a case where the available geolocation information differs between a MeteoSwiss snow depth station and the same station reporting via GTS.*

# I-4 Conclusions and Outlook

A. Haberkorn

WSL Institute for Snow and Avalance Research SLF, Davos, Switzerland

The European Snow Booklet (ESB) is intended as a reference for snow measurements, produced in the framework of the European Union COST Action ES1404 HarmoSnow. Part I of the ESB is a unique collection of information about current operational snow observations in the European countries and the methods used to perform basic measurements of snow on the ground: snow depth (HS), presence of snow on the ground (PSG), depth of snowfall (HN) and water equivalent of snow cover (SWE). These four snow variables, along with the corresponding measurement instruments and methods most commonly applied, are described in Chapter I-1, based on the Best Practices for measurements of snow recently developed by the Global Cryosphere Watch (GCW) of the World Meteorological Organisation (WMO; WMO No. 8, 2018) and experiences from the WMO Solid Precipitation Intercomparison Experiment (SPICE; Nitu et al., 2018).

Numerous institutions from 38 European countries provided detailed information on their operational snow measurement networks for the ESB. Based on the information provided, a country report was written for each European country, describing the current status of the operational snow observations and the methods used by one or several institutions (Chapter I-2). Collecting and compiling the country-specific data revealed many similarities, but also interesting differences among the countries in the choice of snow variables to be measured, the measurement principles applied, the number of stations, and the spatial and elevational station distribution. The collection of country reports additionally indirectly demonstrates the relevance of snow for each country.

Snow depth is the variable that is measured at the most stations in the 38 European countries that contributed data, followed by depth of snowfall, which is measured at two-thirds of the total number of snow depth stations, in 23 of the 38 European countries. Although SWE is measured operationally in 29 of the 38 European countries, the total number of SWE stations is less than one-third of the total number of snow depth stations and half the total number of depth of snowfall stations. Contacts from 27 countries responded that presence of snow on the ground is reported in their network, but detailed information on station counts and measurement procedures cannot be given here because all countries have different standards for reporting presence of snow on the ground. The number of automatic stations is much smaller than the number of manual stations in nearly all the European countries. Only 15% of all operational snow depth stations include automatic measurements (2 021 stations), while the remaining 85% solely include manual measurements (11 230 stations). Manual snow depth observations are mainly performed with stakes and, in cases of heterogeneous snow depth distribution, additionally with rulers. For automatic snow depth measurements, ultrasonic sensors are used most frequently, although they are slowly being replaced by laser instruments in some countries. In addition to these commonly used automatic instruments, in a few cases snow depth is automatically measured using: ground-penetrating radar (Iceland, Norway), webcams or photographs (Belgium, Spain), or snow temperature measurements (Iceland). Depth of snowfall is only measured manually, mainly using a snow board and ruler. Depth of snowfall is measured with a ruler in a precipitation gauge, in addition to using a snow board, in Macedonia and Slovakia, and it is measured only with rulers (no snow boards) in Belgium and Ireland and in some locations in France. SWE is observed manually at 97% of all stations with SWE measurements. Most manual SWE observations are performed in snow pits using snow cylinders (in 27 countries). The choice of scale type differs among the countries, with spring scales used in 8 countries and steelyard balances used in 18. In addition to manual SWE observations using snow pits, observations using snow tubes (no snow pits) are performed in four countries (Czech Republic, Italy, Norway, Turkey). In France, SWE is only manually measured with snow tubes. Regarding automatic SWE measurements, only 3% of all stations include automatic measurements. Snow pillows and snow scales are used most commonly (four countries each), while Snow Pack Analyser, cosmic ray sensors and passive gamma radiation sensors are each used in two countries (Chapter I-2).

The choice of the main variables to be measured depends heavily on the background of the institutions in charge of the observations. While national weather services operate snow depth station networks and often also perform presence of snow on the ground and depth of snowfall observations, hydrological services often measure only SWE and sometimes snow depth. Differences in variable choices between countries are also clear. In several Eastern European and Scandinavian countries only snow depth and SWE are observed operationally (e.g. Estonia, Finland, Hungary, Latvia, Lithuania, Moldova, Norway, Romania, Sweden), whereas only snow depth is typically observed in countries where snowfall is rare (e.g. Denmark, the Netherlands, Portugal). In contrast, all basic snow variables are observed in countries with large mountain ranges such as the Alps.

Overall, stations measuring snow depth, depth of snowfall and/or SWE are mostly located below 1 000 m a.s.l. However, most countries with a considerable fraction of mountainous area operate snow depth stations at 1 000 – 2 000 m a.s.l. or > 2 000 m a.s.l., for example Andorra, Austria, France, Italy, Spain, Switzerland and Turkey. Only a small number of countries operate depth of snowfall and/or SWE measurement networks with an appropriate number of stations relative to the area in the country that lies above 1 000 m a.s.l., i.e. Austria, France, Italy, Spain, Switzerland and Turkey, and all of these countries feature large mountainous areas. This is a result of the greater difficulty of performing snow measurements at high elevations, owing to e.g. stronger wind and more snow redistribution, or of the considerable expenditure required to measure snow depth, depth of snowfall or SWE manually every day at high-elevation stations that are often difficult to reach.

Although international guidelines exist in which depth of snowfall and SWE are defined and their measurement principles are described in detail (WMO No. 168, 2008), these principles are diversely interpreted by the different countries. Incorrect interpretation methods are also applied in some cases but were not included in the country reports (Chapter I-2). For example, some country contacts responded that depth of snowfall is operationally measured as the difference between the current and the previous automatic snow depth measurement over a certain interval. However, subtracting automatically measured snow depth values to calculate depth of snowfall is not an accepted method according to current Best Practices. As another example, contacts from some countries indicated that SWE is measured in a precipitation gauge by melting the new snowfall that accumulates in the gauge and assessing the weight. This method provides the daily water equivalent of new snow, but calculating SWE by summing these values is not accepted as an SWE measurement of the snow cover. Although not as obvious as the issues described above, the non-standard practice of measuring depth of snowfall in a cylindrical container, such as a precipitation gauge, with a ruler is applied in two countries in Chapter I-2 (Macedonia, Slovakia). It is currently being discussed whether this measurement procedure should be an officially accepted method in the new WMO GCW Best Practice guidelines on snow observations (WMO No. 8, 2018).

The analysis of all country-specific data together and its links to data reported via WMO's Global Telecommunication System (GTS; Chapter I-3) clearly demonstrates that the exchange of snow data among European countries could be increased; doing so would be of great value for snow communities, e.g. weather services and scientists, also outside Europe. The country reports (Chapter I-2) revealed that large snow depth observation networks exist within many European countries, but large amounts of these potentially valuable snow data are not reported over GTS, as shown in Figure I-3.6.2. Despite initiatives already in place to promote the exchange of real-time observations across country borders, e.g. WMO's GCW and GCW's Snow Watch Activity, the ESB clearly shows the huge amount of work that is still required, in particular to improve and increase the availability of in-situ snow depth reports on the GTS or in the WMO OSCAR[28] (Observing Systems Capability Analysis and Review Tool) database still under development. Besides the WMO's GCW initiatives, the freely and openly accessible Earth Observation Program Copernicus[29] of the European Union aims to improve near-real-time data exchange on the global level. The Copernicus services process and analyse global data from satellites and in-situ ground-based, air-borne and sea-borne monitoring systems, thus transforming huge amounts of data into value-added information. Datasets stretching back for years and decades are made comparable and searchable, thus ensuring the monitoring of changes (e.g. climate change). Further, patterns extracted from this system can be used to create better forecasts (e.g. of the ocean and the atmosphere) and therefore support European civil protection (Copernicus Brochure, 2015; Copernicus Observations, 2018). Finally, an increase in the number of ground-based snow depth observations exchanged in near-real time, i.e. via GTS, will ultimately help improve assimilation of snow data into numerical weather prediction models, verification of models, and validation of satellite-derived data, thus benefitting society as a whole.

The ESB is a comprehensive overview of operational snow observations in Europe produced through collaboration with many European snow practitioners and snow scientists. Although complete information was not available for all countries, this inventory should be considered a great success that benefits all actors involved in snow-related research and operational services.

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[28] www.wmo.int/oscar
[29] https://insitu.copernicus.eu

# Appendix I–A
# Country Report Russia

*Figure I-A.1 Location of Russia in relation to Europe.*

## Country information

| | |
|---|---|
| Country area | 17 098 240 km$^2$ |
| Authority responsible for snow measurements | Federal Service for Hydrometeorology and Environmental Monitoring under the Ministry of Natural Resources and Ecology of the Russian Federation (ROSHYDROMET)<br>11-13, Bolshoy Predtechensky per.<br>RU-123242 Moscow |
| Contact | · ROSHYDROMET<br>inna.rozinkina@meteo.ru<br>evgenychur@gmail.com (Evgeny Chur) |
| Near-real-time data URL and/or contact | · ROSHYDROMET<br>http://meteo.ru/ (data on request) |
| Archived data URL and/or contact | · ROSHYDROMET<br>http://meteo.ru/<br>http://meteo.ru/english/climate/kat600_e.htm (some coordinates and information about meteorological stations)<br>http://aisori.meteo.ru/ClimateE (snow depth data at meteorological stations, as well as along snow courses for the period between 1948 and 2017; after free registration, one can log in with an email address, username and password)<br>http://meteo.ru/english/climate/descrip2.htm (description of measurement procedure and datasets) |

## General situation

The Federal Service for Hydrometeorology and Environmental Monitoring under the Ministry of Natural Resources and Ecology of the Russian Federation (ROSHYDROMET) is responsible for national operational snow observations in the Russian Federation (hereafter referred to as Russia). The central office of ROSHYDROMET is located in Moscow. In addition, 23 territorial administrations (Fig. I-A.2) and 6 other research institutes coordinate additional snow observations in individual regions. Owing to the wealth of snow observations in Russia and the shared responsibility of several institutions for snow observations, data completeness and correctness are uncertain. Please note also that the maps of Russia in this country report use the Albers Equal coordinate system (CS), not the ETRS 89 LCC coordinate system used to represent all other European countries (Chapter I-2).

Russian snow observations have a history of more than 200 years. Observers have been obligated to measure snow depth since 1772, but official snow observations started during the winter season of 1885/1886. Snow has been measured regularly ever since.

Until the year 2010, observers could choose between two options for snow depth and water equivalent of snow cover observations: point observations at meteorological stations or spatially distributed observations along snow courses. Snow depth is currently measured daily at one point at meteorological stations, while water equivalent of snow cover is measured every 5 to 10 days in a spatially distributed manner along 500-m-long snow courses in the forest and along 1 000-m-long snow courses in open fields. Snow depth and water equivalent of snow cover observations in the forest are important for hydrological forecasting, especially in spring when water discharge from snow melt must be estimated.

Operational snow observations are archived and are available online on the All-Russian Research Institute of Hydrometeorological Information – World Data Center (RIHMI – WDC) web page:

- The coordinates of snow depth and water equivalent of snow cover stations are mainly available at: http://meteo.ru/english/climate/kat600_e.htm
- Snow depth data for 24-hour periods is available at: http://aisori.meteo.ru/ClimateE Snow depth values are available for the period 1948 to 2017. After free registration, web page visitors must log in with an email address, username and password.
- Information from routine snow courses is available at: http://aisori.meteo.ru/ClimateE

The coordinates of the snow depth and water equivalent of snow cover stations presented in this country report are mainly available at the above mentioned web addresses.

Russian observers follow detailed official measurement protocols to measure snow depth and water equivalent of snow cover. These protocols, as well as other related documents, are available at:

- Description of datasets: http://meteo.ru/english/climate/descrip2.htm
- SYNOP code descriptions and guidelines for observers: https://meteoinfo.ru/images/media/books-docs/RHM/kn-01-synop.pdf

Snow depth is measured both manually and automatically by ROSHYDROMET, but metadata for the automatic stations and measurement principles are currently not available. In addition, presence of snow on the ground and water equivalent of snow cover are observed manually. Depth of snowfall is measured manually at several ROSHYDROMET stations, but no station information is currently available and therefore only information on measurement principles is given.

### Overview of measurements (ROSHYDROMET)

Snow depth: stake, ruler (Figs I-A.3, I-A.4)
Depth of snowfall: snow board and ruler
Water equivalent of snow cover: snow cylinder, steelyard balance (Figs I-A.8, I-A.9)
Operational purpose of measurements: Agriculture and Forestry, Avalanche warning, Building and Construction, Climatology, Energy production, Flood forecasting, Health and Sport, Hydrology, Meteorology, Research, Road services, Water management

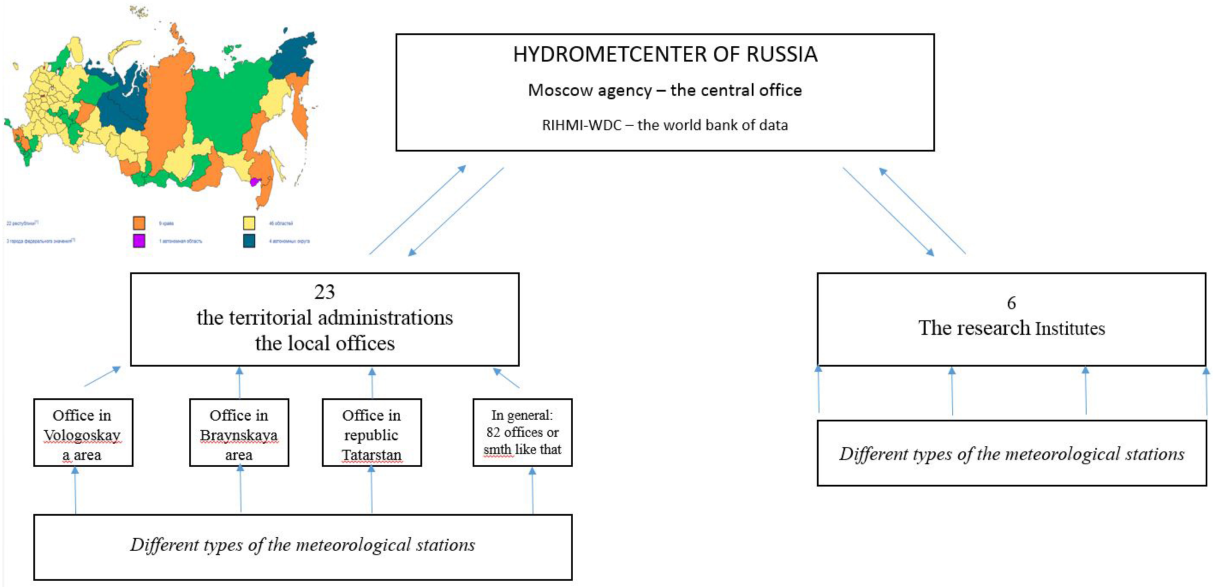

*Figure I-A.2 Overview of the organisational structure of ROSHYDROMET (Source: ROSHYDROMET).*

# Appendix I–A.1 Snow depth measurements

Number of stations delivering snow depth data manually: 1279
Number of stations delivering snow depth data automatically: unknown

*Figure I-A.3 Locations of stations in Russia where snow depth (HS) is measured.*

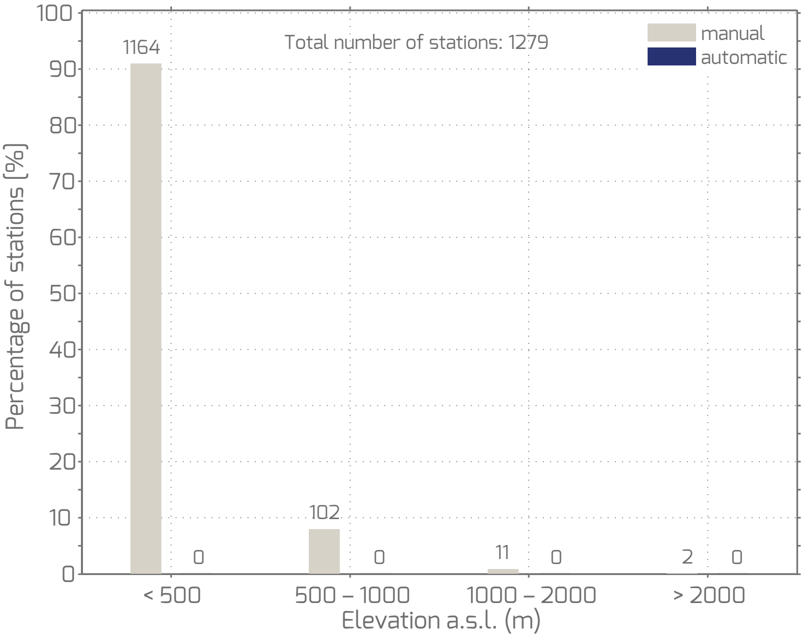

*Figure I-A.4 Elevational distribution of stations in Russia with manual and automatic snow depth measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

Operational snow depth observations are performed either (1) at meteorological stations or (2) in a spatially distributed manner along snow courses.

(1) Manual snow depth measurements at meteorological stations are performed every 24 hours at 0600 UTC from the first snowfall in autumn until all snow has melted in spring. Fixed wooden stakes with a length of 1.3 m (stake M-103) or 1.8 m (stake M-103-1) are used for snow depths less than 1.5 m. Metallic stakes (stakes M-46, M-47) are used if the snow depth exceeds 1.5 m (Fig I-A.5). Within a meteorological station with a size of 36 x 26 m, three stakes are arranged in a triangle, 10 m apart (Fig. I-A.6). The average of all three readings is reported as total snow depth. Sometimes portable rulers are also used, but detailed information about which instrument is used at each location is currently not available. To prevent incorrect measurements, snow depth values are read as horizontally to the surface as possible. Observations are performed in flat locations representative of the surroundings and protected from wind to avoid snow drift. All measurements are reported in full centimetres.
In parallel to manual snow depth measurements, the extent of snow coverage around the meteorological stations (codes 0–10) and specific snow characteristics (e.g. look-up table: snow cover types, ice layers, wet layers) are reported.

(2) In addition to point measurements, spatially distributed snow depth measurements (snow courses) are performed every 5 or 10 days. The locations where snow depth observations are performed along snow courses is not known, but it is certain that snow depth measurements along snow courses are not completed at all 1 279 locations with daily snow measurements. In open areas snow depth is observed every 20 m along snow courses with a length of 1 000 m, while in forested areas snow depth is measured every 10 m along 500-m-long snow courses. In parallel to manual snow depth measurements along the courses, snow density (in g cm$^{-3}$ or kg m$^{-3}$), water equivalent of snow cover (in mm w.e.), snow characteristics (look-up table: snow cover types, ice layers, wet layers, etc.) and the extent of snow coverage (codes 0–10) are reported.

### Automatic measurements:

Information on automatic snow depth measurements is not clear, especially as no metadata is available.

### Presence of snow on the ground reporting method:

In parallel to manual snow depth measurements, the presence of snow on the ground is explicitly reported daily at meteorological stations (36 x 26 m in area). Snow coverage is reported using a coding system (codes 0–10).

### Zero snow depth reporting method:

When more than 50% of the measurement field at a meteorological station is snow free, 0 cm snow depth is reported.

*Figure I-A.5 (a, b) Meteorological measurement fields with snow stakes (Source: ROSHYDROMET).*

*Figure I-A.6 (a, b) Meteorological stations with three snow stakes installed for performing manual snow depth observations (Source: ROSHYDROMET).*

## Appendix I–A.2 Depth of snowfall measurements

Number of stations delivering depth of snowfall data manually: unknown

**Manual measurements:**

Depth of snowfall is known to be measured at several stations in Russia, but no metadata is currently available. Manual measurements of depth of snowfall are performed every 24 hours. Depth of snowfall is measured on a 0.4 x 0.4 m snow board with a ruler (Fig. I-A.7). After each measurement, the snow board is cleaned and re-placed on the top of the snow cover, as evenly as possible in relation to the surrounding surface. The location of the depth of snowfall measurement is selected to minimise influence from the wind. Measured values are reported in full centimetres. Depth of snowfall values less than 0.5 cm are reported as “0”.

*Figure I-A.7 Snow board used to measure depth of snowfall (Source: ROSHYDROMET).*

## Appendix I–A.3 Water equivalent of snow cover measurements

Number of stations delivering water equivalent of snow cover data manually: 830
Number of stations delivering water equivalent of snow cover data automatically: 0

*Figure I-A.8 Locations of stations in Russia where water equivalent of snow cover (SWE) is measured.*

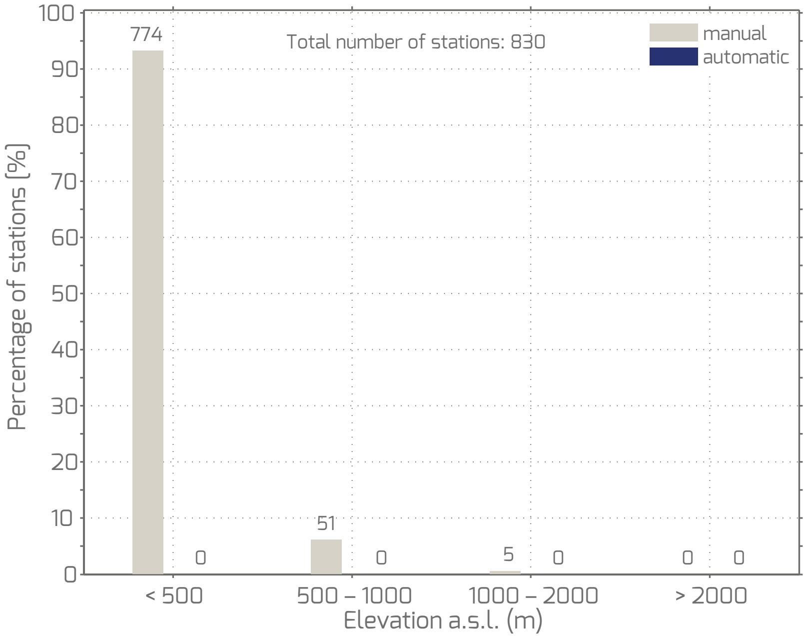

*Figure I-A.9 Elevational distribution of stations in Russia with manual and automatic water equivalent of snow cover measurements. The corresponding number of stations is given above each bar.*

### Manual measurements:

In parallel to the spatially distributed snow depth measurements along snow courses, manual SWE measurements in snow pits are performed every 10 days in high winter. During the ablation period SWE measurements in snow courses are completed every five days. The gravimetric method is applied. Using a graduated iron snow cylinder (VS-43, made in Russia and Ukraine) with a cross-sectional area (A) of 0.005 $m^2$ and a length of 0.6 m, a snow sample is extracted vertically from the snowpack. After the height $h$ (in cm) of the snow sample is measured, the snow cylinder is attached to a steelyard balance to measure the total weight of the snow (in kg). The density $\rho_{snow}$ (in g $cm^{-3}$ or kg $m^{-3}$) and water equivalent (WE; in mm w.e.) of the snow sample are calculated with the following equations:

$$\rho_{snow} = \frac{M - m}{\left(\frac{h}{10}\right) \times A}$$

$$\mathrm{WE} = 10 \times \frac{\rho_{snow}}{\rho_{water}} \times h$$

where $\rho_{water}$ is the density of water (in g $cm^{-3}$ or kg $m^{-3}$), $M$ is the weight read from the steelyard balance (in g or kg) and $m$ is a possible zero offset of the steelyard balance (in g or kg).

If the snow depth is greater than the length of the cylinder (0.6 m), the total snow depth is divided into multiple analogue “columns”. Finally, the SWE of the snow cover is calculated by summing the WE values of all sampled layers. Snow density and SWE are reported as the average of all measurements.

In open areas snow density and SWE are measured every 200 m along snow courses with a total length of 1 000 m (Fig. I-A.10), and snow depth is additionally measured every 20 m in between the snow density and SWE measurement points. In forested areas snow density and SWE are measured every 100 m along snow courses with a total length of 500 m (Fig. I-A.11), and snow depth is additionally measured every 10 m in between the snow density and SWE measurement points. The location of the measurements is selected to be representative of the surrounding area, wind protected and free of any vegetation and obstacles.

### Automatic measurements:

No measurements.

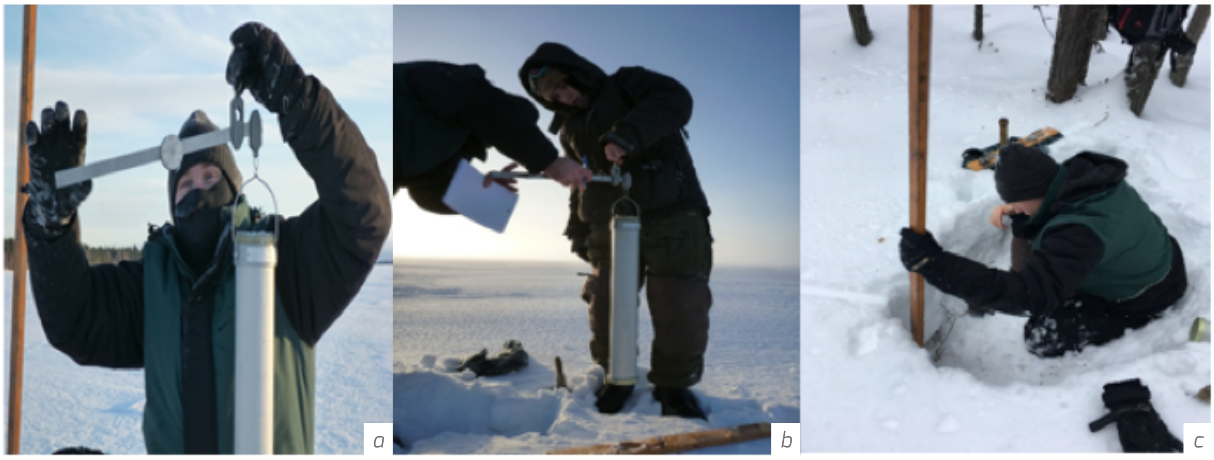

*Figure I-A.10 (a-c) Water equivalent of snow cover (SWE) observations in snow pits using a snow cylinder and steelyard balance along snow courses in flat, open areas (Source: ROSHYDROMET).*

*Figure I-A.11 (a-c) Water equivalent of snow cover (SWE) observations in snow pits using a snow cylinder and steelyard balance along snow courses in forested areas (Source: ROSHYDROMET).*

## Appendix I–A.4 Transition from manual to automatic measurements

Parallel measurements have been performed at a few meteorological stations with both manual and automatic measurements since 2014.

## Appendix I–A.5 Measurement intervals

| Snow depth | Depth of snowfall | Water equivalent of snow cover |
|---|---|---|
| MANUAL: 24 hours and 5 or 10 days (ROSHYDROMET)<br>AUTO: unknown | MANUAL: 24 hours (ROSHYDROMET) | MANUAL: 5 or 10 days (ROSHYDROMET)<br>AUTO: no measurements |

# Appendix I–B
# ESB Questionnaire

## European Snow Booklet: Questionnaire

Hello and welcome to this questionnaire. Please take a short moment to read through the instructions:

This questionnaire is part of an information collection effort in order to create the so-called European Snow Booklet (ESB). The ESB is one of the initiatives of the COST Action ES1404 HarmoSnow. Among other things, the ESB will contain a compilation of operational snow stations and snow measurement techniques in Europe. This will allow a first assessment of the distribution and measurement principles of basic, operational snow measurements in Europe. This is important, as some variables may be measured following a different approach, leading thus to inhomogeneities when considering a European-wide dataset. You have been selected as a contact person for operational snow measurements in your country. Should you feel you are not the right person for answering the eight questions of this questionnaire, feel free to forward it to whomever it concerns, please with CC to anna.haberkorn@slf.ch.

You have the possibility to browse through the questions first, in case you want to know what kind of questions are waiting for you.

We are totally aware that filling out a questionnaire takes some effort. You will therefore be given the option to save the current results and come back later, should you need more time. We estimate the time required for filling out the questionnaire thoroughly to be around 20–80 minutes, depending on your station network size. It would be beneficial for the process if you would have a detailed list of stations measuring snow variables at hand, as this information will be needed while browsing through the different questions. The questionnaire should be filled out to represent the current state of the operational network.

Although we prefer English, you should feel free to upload/enter the data in your native language (e.g. reports which are written in your country's language).

All data will be considered strictly confidential. By answering this questionnaire you agree that we can use your data for our project. Should you have any questions, just get in touch with Anna Haberkorn (anna.haberkorn@slf.ch).

Your effort is greatly appreciated!

Kind regards

Anna Haberkorn, Charles Fierz & Christoph Marty, on behalf of the European Snow Booklet Team from COST Action ES1404 HarmoSnow

| | |
|---|---|
| First name* | |
| Last name* | |
| Institute* | |
| Institute abbreviation* | |
| Country* | |
| Email* | |

**Required fields*

## Q1: Snow depth

| | |
|---|---|
| At how many stations are you measuring snow depth manually?* | |
| At how many stations are you measuring snow depth automatically?* | |

Add, if possible, known metadata from the stations listed above (e.g. WMO ID, coordinates in WGS1984, elevation, active since when, if the measurements are performed manually or automatically, measurement frequency, classification, etc.)

A template for the station information is available for download here: Template (Excel-File)

To upload the template, see instructions below. Otherwise, type in the metadata from the stations lower down.

| | |
|---|---|
| Metadata:<br>Example: NAME, WMOID, LAT, LON, ALT(m), ACTIVE SINCE, AUTOMATIC, MANUAL, INTERVAL(h)<br>"Weissfluhjoch Messfeld", NULL, 46.82963, 9.80924, 2536, 1937, 0, 1, 24 | |
| Did you provide the geographic information of the metadata in the WGS1984 coordinate system (Lat/Lon)?* | ○ Yes ○ No |
| If no: Please specify both the coordinate system and projection used.* | |
| If no: Any further remarks? | |
| Optional: Explain, in words and if possible with pictures/illustrations (upload instructions given below), how such a measurement is taken, for both manual and automatic measurements. Points which could be included: dimensions of the measurement field, location of the measurement site, procedure during the snow melt season when the field is inhomogeneously covered with snow, use of permanent stake or ruler, scale resolution, stake fixation, two or more than two observers, sensor type, sensor mounting height, target surface. | |

Here, you will be able to upload illustrations and/or a PDF document describing (some of) the points mentioned above. Please, if possible, ZIP your files into one package and name it as: yourname_yourinstitute_snowdepth.zip. The combined total size of all files per submission must not exceed 20 MB. Please contact Anna Haberkorn (anna.haberkorn@slf.ch) if the total file size exceeds 20 MB.

| | |
|---|---|
| Caution: Files already uploaded to the questionnaire will NOT be saved until the final submission. Please do not upload files until you are ready to submit! | File upload |

**Required fields*

## Q2: Presence of snow on the ground

Information about whether the ground is still covered with snow or can be described as "bare" or "snow free" is of utmost imortance for initiating weather forecasting models. Wrong information can lead to faulty temperature predictions, unrealistic convection and thus incorrect representation of precipitation. The European Snow Booklet will therefore have a section considering this problem. Let us consider following situation:

*It is springtime somewhere in a mountainous region. The snow stake shows decreasing values. Slowly but surely, 40, then 34, 28, 26, 20, 17, 13, 9, 4, then 0 cm can be read. However, around the stake there is still some snow – like in the picture (Source: SLF).*

| | |
|---|---|
| When would you note down "0 cm" for snow depth?* | |
| Does your authority also record "presence of snow on the ground" as a variable?* | ☐ Yes ☐ No |
| If yes: When would you note down "no snow is present"?* | |
| If no: Any further remarks? | |

**Required fields*

## Q3: Height of new snow

| | |
|---|---|
| At how many stations are you measuring the height of new snow manually?* | |
| At how many stations are you measuring the height of new snow automatically?* | |

Add, if possible, known metadata from the stations listed above (e.g. WMO ID, coordinates in WGS1984, elevation, active since when, if the measurements are performed manually or automatically, measurement frequency, classification, etc.)

A template for the station information is available for download here: Template (Excel-File)

To upload the template, see instructions below. Otherwise, type in the metadata from the stations lower down.

| | |
|---|---|
| Metadata:<br>Example: NAME, WMOID, LAT, LON, ALT(m), ACTIVE SINCE, AUTOMATIC, MANUAL, INTERVAL(h)<br>“Weissfluhjoch Messfeld”, NULL, 46.82963, 9.80924, 2536, 1937, 0, 1, 24 | |
| Optional: Explain, in words and if possible with pictures/illustrations (upload instructions given below), how such a measurement is taken, for both manual and automatic (if applicable at all) measurements. Points which could be included: dimensions of the measurement field, location of the measurement site, dimensions of the snow board, colour and material of the snow board, procedure during windy days. | |

Here, you will be able to upload illustrations and/or a PDF document describing (some of) the points mentioned above. Please, if possible, ZIP your files into one package and name it as: yourname_yourinstitute_newsnowheight.zip.

The combined total size of all files per submission must not exceed 20 MB. Please contact Anna Haberkorn (anna.haberkorn@slf.ch) if the total file size exceeds 20 MB.

| | |
|---|---|
| Caution: Files already uploaded to the questionnaire will NOT be saved until the final submission. Please do not upload files until you are ready to submit! | File upload |

**Required fields*

# Q4: Snow water equivalent (SWE) of the snowpack

| | |
|---|---|
| At how many stations are you measuring snow water equivalent (SWE) manually?* | |
| At how many stations are you measuring snow water equivalent (SWE) automatically?* | |

Add, if possible, known metadata from the stations listed above (e.g. WMO ID, coordinates in WGS1984, elevation, active since when, if the measurements are performed manually or automatically, measurement frequency, classification, etc.)

A template for the station information is available for download here: Template (Excel-File)

To upload the template, see instructions below. Otherwise, type in the metadata from the stations lower down.

| | |
|---|---|
| Metadata:<br>Example: NAME, WMOID, LAT, LON, ALT(m), ACTIVE SINCE, AUTOMATIC, MANUAL, INTERVAL(h)<br>“Weissfluhjoch Messfeld”, NULL, 46.82963, 9.80924, 2536, 1937, 0, 1, 24 | |
| Optional: Explain, in words and if possible with pictures/illustrations (upload instructions given below), how such a measurement is taken, for both manual and automatic measurements. Points which could be included: dimensions of the measurement field, location of the measurement site, whether a trench must be dug, procedure with different soil types (rocks, grass...), procedure when the snowpack has many ice layers. | |

Here, you will be able to upload illustrations and/or a PDF document describing (some of) the points mentioned above. Please, if possible, ZIP your files into one package and name it as: yourname_yourinstitute_swe.zip. The combined total size of all files per submission must not exceed 20 MB. Please contact Anna Haberkorn (anna.haberkorn@slf.ch) if the total file size exceeds 20 MB.

| | |
|---|---|
| Caution: Files already uploaded to the questionnaire will NOT be saved until the final submission. Please do not upload files until you are ready to submit! | File upload |

*Required fields

## Q5: Special provisions during a transition from manual to automatic measurements

| | |
|---|---|
| When a station shifts from manual measurements to automatic measurements (e.g. snow depth: stakes to ultrasonic sensor), how is the transition done? Do you, for instance, measure in parallel for several seasons? | |

If you have any reports concerning this specific topic, you can upload them below. Please, if possible, ZIP your files to one package and name it as: yourname_yourinstitute_Q5.zip. The combined total size of all files per submission must not exceed 20 MB. Please contact Anna Haberkorn (anna.haberkorn@slf.ch), if the total file size exceeds 20 MB.

| | |
|---|---|
| Caution: Files already uploaded to the questionnaire will NOT be saved until the final submission. Please do not upload files until you are ready to submit! | File upload |

## Q6: Snow measurement data accessibility

| | |
|---|---|
| Does your authority/institute have a non-personal email contact for questions regarding the snow measurement network?* | |
| Are there any maps, figures or tables of near-real-time snow measurement data available online?* | ☐ Yes ☐ No |
| If yes: Please provide a URL for accessing maps, figures or tables of snow measurement data.* | |
| If no: Any further remarks? | |

## Q7: Data archive

| | |
|---|---|
| Does your authority allow access to archived, long-term snow measurements online?* | ☐ Yes ☐ No |
| If yes: Please provide an email contact or a URL in case an interested scientist would like to have access to your long-term data series.* | |
| If no: Should somebody need access to long-term measurements (e.g. for science), who would they contact? Include an email-address, too:* | |

## Q8: Important information not covered above

| | |
|---|---|
| Should you wish to tell us something we missed (e.g. discontinued historical long-term data series), feel free to use this field or the upload button lower down for this purpose. | |

Please, if possible, ZIP your files to one package and name it as: yourname_yourinstitute_Q8.zip. The combined total size of all files per submission must not exceed 20 MB. Please contact Anna Haberkorn (anna.haberkorn@slf.ch) if the total file size exceeds 20 MB.

| | |
|---|---|
| Caution: Files already uploaded to the questionnaire will NOT be saved until the final submission. Please do not upload files until you are ready to submit! | File upload |

## Submit

**Required fields*

# Part II

In Part II of the European Snow Booklet (ESB) three main activities of the COST Action HarmoSnow are presented. Chapter II-1 provides recommendations from the HarmoSnow field campaigns, including details of three water equivalent of snow cover intercomparison experiments. Crucial insights from the field, as well as lessons learnt from measurements performed with different instruments by several observers, are discussed. Details will be presented in a manuscript currently in preparation (López-Moreno et al., submitted). Chapter II-2 consists of a summary of the WG 1 – WG 2 Questionnaire and the corresponding publication (Pirazzini et al., 2018). Chapter II-3 is based on outcomes of the WG 3 Questionnaire and provides a discussion of snow data assimilation in research and operational applications, which will be presented in detail in a manuscript (Helmert et al., 2018). Please note that the three chapters in Part II of the ESB were developed under the leadership of different authors and differ in scope from Part I.

# II-1 Uncertainty Estimation of Manual SWE Measurements: Experiences from three HarmoSnow Field Campaigns

L. Leppänen[1], J.I. López-Moreno[2], K. Gillemot[3], B. Luks[4], L. Holko[5], A.N. Arslan[1], R. Azzoni[6], P. Dagsson-Waldhauserova[7,8], D. Finger[9], C. Marty[10], A. Sanmiguel-Vallelado[2], A. Sensoy Sorman[11], A. Soncini[12], A. Sorman[11], K. Vint[13]

1. Finnish Meteorological Institute, Helsinki, Finland
2. Pyrenean Institute of Ecology, CSIC, Zaragoza, Spain
3. University of Vienna, Department of Geography and Regional Research, ENGAGE - Geomorphological Systems and Risk Research, Vienna, Austria
4. Polska Akademia Nauk, Instytut Geofizyki, Warszawa, Poland
5. Institute of Hydrology of the Slovak Academy of Sciences, Bratislava, Slovakia
6. Università degli Studi di Milano, Department of Earth Sciences, Milano, Italy
7. Agricultural University of Iceland, Hvanneyri, Iceland
8. Czech University of Life Sciences, Prague, Czech Republic
9. Reykjavik University, School of Science and Engineering, Reykjavik, Iceland
10. WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland
11. Anadolu University, Faculty of Engineering, Department of Civil Engineering, Eskişehir, Turkey
12. Politecnico di Milano, Department of Civil and Environmental Engineering, Milano, Italy
13. Estonian Environment Agency, Tallinn, Estonia

## II–1.1 Introduction

Water equivalent of snow cover (SWE) is one of the essential snow variables measured across Europe. Considering its importance for hydrological studies (e.g. flood risk assessment), harmonisation of the manual observation methodology is very important (Chapter II-2; e.g. Pirazzini et al., 2018). SWE can be measured in three ways: (1) by measuring a vertical density profile with a snow cylinder in an open snow pit, (2) by using a snow tube to extract a snow core and measure the density of the core by weighing it, and (3) through a number of automatic methods. While the manual methods are comparably slow, automatic methods (e.g. Kinar and Pomeroy, 2015) are still not widespread enough, leaving the manual gravimetric method as the approach most widely used by researchers and operational agencies alike (Pirazzini et al., 2018). Two main methods for measuring SWE manually, both based on the gravimetric principle, must be distinguished (Section I-1.5): (1) measurements in snow pits using snow cylinders and (2) measurements without snow pits using snow tubes. When the hypernym “sampler” is used, it refers to both cylinder and tube forms and consequently to both methods.

Small-scale variability of the snowpack and its properties, as well as instrument- and observer-induced error, may add uncertainty to the data acquired by manual snow corers (Stuefer et al., 2013). Quantifying these errors is a difficult task, and several previous studies have attempted to assess their effects in a systematic way (e.g. Beaumont and Work, 1963; Bindon, 1964; Freeman, 1965; Work et al., 1965; Beaumont, 1967; Bray, 1973; Peterson and Brown, 1975; Goodison, 1978; Farnes et al., 1980, 1982; Goodison et al., 1987; Berezovskaya and Kane, 2007; Fassnacht et al., 2010; Sturm et al., 2010; López-Moreno et al., 2011; Dixon and Boon, 2012; Stuefer et al., 2013; Proksch et al., 2016). Nonetheless, these surveys are usually confined to a number of subvariables, and only a few studies have compared the performance of the different types of manual corers in different snow conditions. Furthermore, most of the intercomparison and tube-characteristic error estimation efforts have been completed in North America, usually including the U.S. Federal sampler (Clyde, 1932; Beaumont, 1967; Goodison et al., 1981; Farnes et al, 1982; Goodison et al., 1987; Woo, 1997) and a number of other devices used less frequently for European snowpacks (e.g. Adirondack, Bowman, Rosen, High Plains, Leupold-Stevens, Glacier, Meteorological Service of Canada, and Eastern

Snow Conference samplers). Such intercomparisons have been described in several publications (e.g. Work et al., 1965; Beaumont, 1967; Farnes et al., 1980; Sturm et al., 2010; Dixon and Boon, 2012).

The device that has been described most thoroughly, the U.S. Federal snow tube, usually has an error rate of 5–11%, depending on snow conditions, if it has a slotted or non-slotted design and a sharp cutter. The Meteorological Service of Canada snow tube (Bindon, 1964; Goodison, 1978; Goodison et al., 1981) has an error rate of 6–8% and the SnowHydro snow tube (SnowHydro, 2004) has an error rate of 6–10%. The error rate of both of these snow tube types depends on the snow conditions, albeit less than in the case of the U.S. Federal snow tube, probably owing to their larger tube diameters. Interestingly, while in early studies it was found that these errors lead to an overestimation of SWE, underestimations have been demonstrated more recent (Sturm et. al., 2010; Dixon and Boon, 2012).

In order to increase our knowledge of errors caused by different snow conditions and by devices and observers, as a part of the COST Action HarmoSnow different manual devices used in Europe for SWE and snow depth observations were tested. Based on the results of these tests, a number of recommendations for observers were formed. The SWE measurement devices (samplers) were tested in three field campaigns in different environments to identify and quantify differences in measured snow characteristics. Results of the HarmoSnow field campaigns will be presented in detail in a manuscript by López-Moreno et al. (submitted).

The 1st HarmoSnow field campaign (in 2016 in Turkey) concentrated on demonstrating the wide variety in instrumentation used for snow measurements, the 2nd field campaign (in 2017 in Iceland) focused on measurement differences attributed to different instrumentation compared with the natural variability in the snowpack, and the 3rd field campaign (in 2018 in Finland) concentrated on device comparison and on the separation of the different sources of variability. The selection of a suitable device and observation technique depends on the snow properties (e.g. hardness, wetness, grain size and snow depth), and it is not possible to give one recommendation suitable for all snow conditions. Therefore, different sampling methods and device properties were recorded during the campaigns, and recommendations were formed based on the observations in shallow snowpacks with wet snow in Erzurum (Turkey), new and wind-packed snow in Reykjavik (Iceland), and dry taiga snow in Sodankylä (Finland). The instrumentation used in the three HarmoSnow field campaigns is described below (Section II-1.2), after which site descriptions, measurement protocols and the main results from each campaign are given separately (Sections II-1.3, II-1.4, II-1.5). The final two sections of the chapter consist of a discussion of lessons learnt (Section II-1.6) and a summary (Section II-1.7).

## II–1.2 Instrumentation

A detailed description of manual SWE measurements with cylinders and tubes is presented in Section I-1.5 and as part of the Best Practices for measurements of snow developed by the Global Cryosphere Watch (GCW) of the World Meteorological Organisation (WMO; WMO No. 8, 2018). During the three field campaigns, a total of 11 samplers were tested and compared. Eight of the samplers are used operationally in Europe: Dolfi is used for some measurements in the Czech Republic and Slovakia, Enel-Valtecne EV2[30] is used in some regions of Italy, ETH is used in Switzerland (Section I-2.36) and for some measurements in Spain, Korhonen-Melander (Korhonen, 1923) is used in some cases in Finland, Plexiglas is used in some regions of Italy (one institution in Section I-2.19), TSMS and U.S. Federal (Beaumont and Work, 1963) are used for some measurements in Turkey, and VS-43 – often referred to as BC-43[31] (Slabovich, 1985) – is used in some cases in Estonia, Germany, Lithuania, Moldova, Slovakia and Ukraine (Sections I-2.11, I-2.14, I-2.21, I-2.24, I-2.32, I-2.38). Samplers

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[30] http://valtecne.com/en/products/snow-measurement-tube-model-ev2/
[31] http://omskmeteo.com/content/snegomer-vesovoi-vs-43m

similar to VS-43 are used for some measurements in Bosnia and Herzegovina, Croatia, Latvia and Slovenia. In addition, three samplers – Custom EV2, IG PAS and SnowHydro (SnowHydro, 2004) – are used for research purposes in Europe. The tested SWE samplers consist of either a snow cylinder or a snow tube (variable diameter and length) and a scale; only the sampler of the Turkish State Meteorology Service (TSMS) requires snow melting. Snow samples are weighed in different ways: directly in the sampler with a scale or without the sampler after being emptied into a bag. In addition, observations sometimes include snow depth measurements made with a ruler or rod (Section I-1.2). The properties and method (pit or no pit) of each SWE sampler used in the HarmoSnow campaigns are given in Table II-1.2.1, and photos of instruments are featured in Figures II-1.2.1 and II-1.2.2. ETH, IG PAS, Korhonen-Melander, TSMS and VS-43 snow cylinders require a snow pit. Custom EV2, Dolfi, Enel-Valtecne EV2, Plexiglas, SnowHydro and U.S. Federal snow tubes are used without a snow pit, and Custom EV2, Enel-Valtecne EV2 and U.S. Federal snow tubes consist of several tube extensions which can be connected in deeper snowpacks. Most of the samplers have a scale outside the sampler used for the snow depth observations, but Custom EV2, Enel-Valtecne EV2 and TSMS samplers require a separate snow depth observation with a probe.

In the 1st field campaign seven samplers were used: ETH, Korhonen-Melander and TSMS snow cylinders, and Dolfi, Plexiglas, SnowHydro and U.S. Federal snow tubes. In the 2nd and 3rd field campaigns nine sampler types were included: ETH, IG PAS, Korhonen-Melander and VS-43 snow cylinders, and Custom EV2, Dolfi, Enel-Valtecne EV2, SnowHydro and U.S. Federal snow tubes. In the 2nd field campaign two VS-43 cylinders were tested (Estonian and Lithuanian).

*Figure II-1.2.1 Instruments used only in the 1st HarmoSnow field campaign: (a) TSMS cylinder from Turkey; (b) Plexiglas tube from Italy.*

*Figure II-1.2.2 Instruments used in the 3rd HarmoSnow field campaign (from left to right): Korhonen-Melander (made and used in Finland), Dolfi (made and used in Slovakia and the Czech Republic), VS-43 (used in Estonia; made in Russia and Ukraine), U.S. Federal (used in Turkey; made in USA), IG PAS (made and used in Poland), SnowHydro (used in Spain; made in USA), Custom EV2 (made and used in Italy), Enel-Valtecne EV2 (made and used in Italy) and ETH (made and used in Switzerland). In addition, the SnowMicroPen (made in Switzerland) is shown on the far right side (Source: Cansaran Ertas).*

*Table II-1.2.1 The water equivalent of snow cover (SWE) samplers used in the HarmoSnow field campaigns. In the column "Sampler extensions" the number of device elements is given; a snow cylinder usually consists of one part, while a snow tube may have several extensions. The columns "HS scale" and "Tooth cutter" indicate whether each of these elements is included in the sampler. The column "Snow pit" specifies which main manual SWE measurement method is used: "✓" represents SWE measurements in snow pits using snow cylinders and "×" represents SWE measurements without snow pits using snow tubes. The column "Sampler type" specifies the SWE sampler type and consequently the methods: "Cylinder" represents SWE measurements in a snow pit and "Tube" represents SWE measurements without a snow pit. The column "Bag" indicates how the weight of the extracted snow sample is measured: "✓" by pouring the snow sample into a bag and weighing the bag with a scale or "×" by attaching the cylinder or tube containing the snow sample directly to a scale. The column "Weighed / Melted" specifies whether the extracted snow sample is weighed (W) or melted (M) while using the designated sampler.*

| Name | Country of origin | Length (cm) | Diameter (cm) | Sampler extensions | HS scale | Tooth cutter | Snow pit | Sampler type | Bag | Weighed/ Melted | Scale unit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Custom EV2 | Italy | 50–300 | 6 | 0–5 | No | Yes | × | Tube | × | W | kg |
| Dolfi | Czech Republic | 100 | 8 | 0 | Yes | Yes | × | Tube | × | W | kg |
| Enel-Val-tecne EV2 | Italy | 50–300 | 6 | 0–5 | No | Yes | × | Tube | × | W | kg |
| ETH | Switzerland | 55 | 9.5 | 0 | Yes | No | ✓ | Cylinder | × | W | mm |
| IG PAS | Poland | 50 | 7 | 0 | Yes | No | ✓ | Cylinder | × | W | kg |
| Korhonen-Melander | Finland | 70 | 10 | 0 | Yes | No | ✓ | Cylinder | × | W | mm |
| Plexiglass | Italy | 65 | 7.5 | 0 | Yes | Yes | × | Tube | ✓ | W | kg |
| SnowHydro | USA | 165 | 6.1 | 0 | Yes | Yes | × | Tube | ✓ | W | kg |
| TSMS | Turkey | 65 | 16 | 0 | No | No | ✓ | Cylinder | ✓ | M | mm* |
| U.S. Federal | USA | 76–533 | 3.8 | 0–6 | Yes | Yes | × | Tube | × | W | kg |
| VS-43 | Russia, Ukraine | 60 | 8 | 0 | Yes | Yes | ✓ | Cylinder | × | W | kg |

** No scale is used for the TSMS snow cylinder because the snow sample is directly melted and measured in a measuring cup.*

# II–1.3 Erzurum, Turkey field campaign in 2016

## II–1.3.1 Introduction

The 1st HarmoSnow field campaign was held in Erzurum, Turkey on 1–3 March 2016. Its aim was to demonstrate different methods and devices used in Europe to observe snow depth (HS) and SWE. Seven SWE samplers (Dolfi, ETH, Korhonen-Melander, Plexiglas, SnowHydro, TSMS and U.S. Federal) were compared in a shallow (10–34 cm deep) wet snowpack at the first site in Guzelyayla (2 065 m a.s.l.). Some of the instruments were also compared in deeper snow (40–64 cm) at the second site in Senyurt (2 250 m a.s.l.). In total, 52 measurements were recorded. In addition, snow pit measurements were made at the Guzelyayla site.

The Guzelyayla site was a flat area (approx. 20 x 8 m) located next to the automatic weather station (AWS). The ground was not frozen and vegetation consisted mainly of grass and small pine trees. SWE was measured with seven samplers along eight parallel transects approximately 2 m apart. The Senyurt site was a slightly sloped area (approx. 40 x 40 m), also located in proximity to the AWS. The ground was covered with grass and gravel. In this case, the SWE measurements were made with SnowHydro, Dolfi and U.S. Federal samplers approximately 10–20 m from the AWS. In addition, the spatial variability of snow depth was observed throughout the site with several rod measurements.

## II–1.3.2 Results and discussion

The Guzelyayla site had a mean SWE of 78 mm w.e. (from the eight transects) with a relative standard deviation of 21%. Snow density varied from 260 to 431 kg m$^{-3}$, with mean value of 351 kg m$^{-3}$. In general, there was no straightforward relationship between snow sampler type and measured snow density (Table II-1.3.1, Fig. II-1.3.1). However, substantial differences between some parallel transects were found, probably caused by varying snow density in different parts of the studied plot (spatial variability), observer-related variability, and different characteristics of the samplers. Replicated measurements performed with Plexiglas and SnowHydro tubes along each parallel transect differed by less than 5% on average. Using the Dolfi tube resulted in lower densities in the first transect than those in the second one, suggesting that spatial variability of snow properties played a greater role than instrumental issues in measured SWE differences.

Average SWE at the Senyurt site was 216 mm w.e., with a relative standard deviation of 12% (three samplers used). Snow density varied from 373 to 447 kg m$^{-3}$. The mean snow depth measured with the rod was 50 cm, with a relative standard deviation of 21%.

The main differences between the tested samplers were the length and diameter of the cylinders or tubes, and whether direct weighing (and in some cases direct conversion to SWE) was possible. It is difficult to judge which samplers provide SWE estimates with a smaller error under Erzurum conditions because the differences in measured SWE were relatively small and natural variability was large. In this particular case (shallow, wet snow), samplers that were short and wide were easier to use. However, a hard crust layer in the snowpack meant that a sharp edge on one end of the sampler made measurements easier. Long samplers and those whose samples need to be emptied into a bag (i.e. SnowHydro snow tube) were less useful in such conditions. Other factors that might have affected the accuracy of the measurements were strong wind, which caused problems with weighing the samplers, and the amount of experience observers had with a particular sampler. It was concluded that the advantages or disadvantages of individual samplers depend on the snowpack conditions (e.g. depth, hardness, wetness). Therefore, follow-up campaigns with a larger set of measurements were deemed necessary to compare devices.

*Table II-1.3.1 Measurement results for the Erzurum field campaign at the two sites. “Mean SWE” is the mean of the water equivalent of snow cover measurements made at a single point with a single instrument. “Mean HS” is the mean of the snow depth measurements made at a single point with a single instrument. “RSD” is the relative standard deviation of the values, and “n” is the number of single measurements used for the mean values.*

| | Guzelyala | | | | Seynurt | | | |
|---|---|---|---|---|---|---|---|---|
| Instrument | Mean SWE (mm w.e.) | Mean HS (cm) | RSD (%) | n | Mean SWE (mm w.e.) | Mean HS (cm) | RSD (%) | n |
| Dolfi transect 1 | 56.3 | 16.5 | 30 | 5 | 124.3 | 55.2 | 11 | 6 |
| Dolfi transect 2 | 105.0 | 28.0 | 13 | 6 | | | | |
| ETH | 78.5 | 22.0 | 27 | 5 | | | | |
| Plexiglas | 63.0 | 19.0 | 20 | 4 | | | | |
| Korhonen-Melander | 67.5 | 19.5 | 4 | 2 | | | | |
| SnowHydro | 80.6 | 25.8 | 24 | 7 | 93.5 | 48.8 | 9 | 6 |
| TSMS | 68.7 | 21.0 | 47 | 2 | | | | |
| U.S. Federal | 75.0 | 21.5 | 3 | 2 | 139.4 | 58.0 | 13 | 5 |

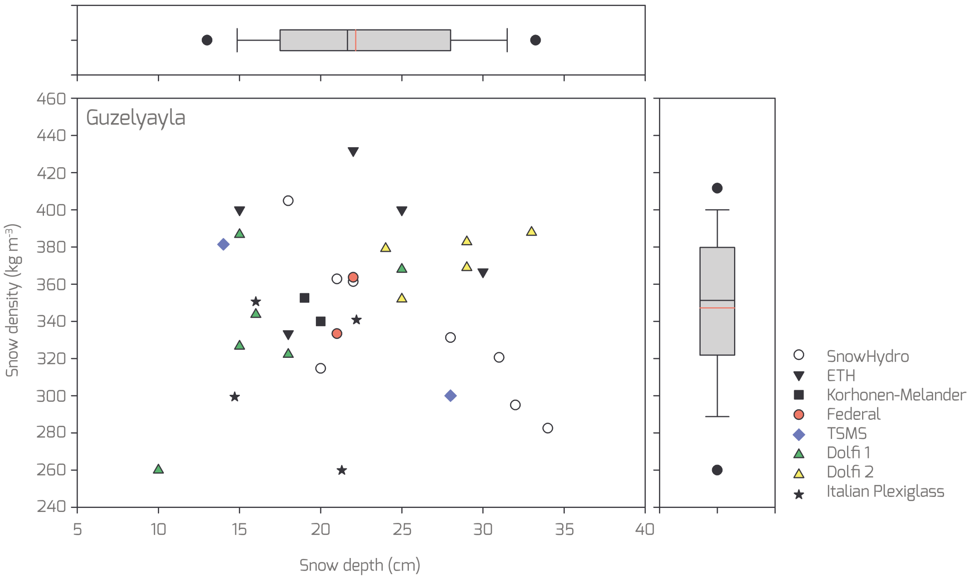


*Figure II-1.3.1 Results of snow depth and snow density measurements made along transects with seven different water equivalent of snow cover (SWE) sampler types (with two measurement transects made with Dolfi) at the Guzelyayla site as part of the 1st HarmoSnow field campaign in Erzurum, Turkey.*

# II-1.4 Reykjavik, Iceland field campaign in 2017

## II-1.4.1 Introduction

The 2nd HarmoSnow field campaign was held in Reykjavik (Iceland) from 28 February to 2 March 2017. It was focused on a more detailed comparison of SWE samplers used in Europe, under different snow conditions than those of the 1st HarmoSnow field campaign. In total, 10 samplers (Custom EV2, Dolfi, Enel-Valtecne EV2, ETH, IG PAS, Korhonen-Melander, SnowHydro, U.S. Federal, Estonian VS-43 and Lithuanian VS-43) were used for the SWE measurements and 138 observations were completed. Additionally, several different density cutters were used for snow density profile measurements. The measurements were made at three sites covering a 37–159 cm depth range of a rather dry snowpack.

The three measurement sites were all located approximately 25 km southeast of Reykjavik in the foothills of the Hengill volcano. Sites 1 and 2 were located in an open area close to the Hellisheiði geothermal power plant, and site 3 was in the vicinity of the Bláfjöll ski resort. All sites were characterised by a natural snowpack. Site 1 was located 200 m northwest of the geothermal power plant. The snowpack was dry and the mean snow depth was 53 cm. Under the hard surface layer, the snowpack consisted of soft layers separated by several hard layers. The site was located on a lava plateau covered by soft moss, which resulted in varying snow depth values. Site 2 was located approximately 190 m south of site 1. The measurements took place in the parking lot of the power plant. The snowpack structure was similar to that observed in site 1, except that the mean depth of snow was 48 cm. The main difference from site 1 was the ground surface, which was almost perfectly level and covered with grass and asphalt. Variability in snow depth at site 2 was induced by wind. Site 3 was located in the Bláfjöll ski resort, approximately 50 m north of a main road, and it was characterised by a lava field, making the ground surface very rough. The snowpack was dry with a relatively smooth surface, and snow depth varied widely with a mean of 123 cm (excluding observations of spatial variability made with a U.S. Federal sampler over a larger area).

At each site, a snow pit (transect) approximately 20 m long was dug, with a smooth southfacing wall. Two to three points at predetermined locations along the transect were measured with each sampler, and each point was measured one to six times, depending on the measurement duration. However, no measurements were made with the Custom EV2, Enel-Valtecne EV2 or U.S. Federal sampler at site 1, and no measurements were made with the Custom EV2, IG PAS, Korhonen-Melander or Estonian VS-43 sampler at site 3 . The approximate measurement locations within the transects were noted.

## II-1.4.2 Results and discussion

Snow depth varied from 37 to 67 cm at site 1, from 40 to 56 cm at site 2, and from 97 to 159 cm at site 3, while snow density varied from 189 to 268 kg m$^{-3}$ at site 1, from 159 to 392 kg m$^{-3}$ at site 2, and from 241 to 420 kg m$^{-3}$ at site 3 (Table II-1.4.1, Fig. II-1.4.1). Relative standard deviations for the snow density observations were 9%, 13% and 16% for sites 1, 2 and 3, respectively. Mean snow densities were 230, 261 and 354 kg m$^{-3}$ and mean SWE values were 121, 126 and 433 mm w.e. for sites 1, 2 and 3, respectively. U.S. Federal sampler measurements were excluded from site 3 mean calculations because they were not made in the same transect.

Seven of the samplers used at site 1 (ETH, IG PAS, Korhonen-Melander, Estonian VS-43 and Lithuanian VS-43 snow cylinders; Dolfi and SnowHydro snow tubes) differed from the site mean SWE by ≤ 10%. At site 2, eight samplers (ETH, IG PAS, Korhonen-Melander, Estonian VS-43 and Lithuanian VS-43 snow cylinders; Dolfi, SnowHydro and U.S. Federal snow tubes) differed from the site mean SWE by ≤ 10%. The Custom EV2 snow tube had values 13% higher and the Enel-Valtecne EV2 snow tube had values 33% higher than the mean SWE at site 2. At site 3, only Enel-Valtecne EV2 and SnowHydro snow tubes had a mean SWE value that differed from the site mean by ≤ 10%. The Lithuanian VS-43 snow cylinder had values 21% lower, the ETH snow cylinder had values 31% higher, and the Dolfi snow tube had values 14% higher than the site 3 mean SWE. The U.S. Federal snow tube had values 57% lower than the site mean SWE, based on measurements conducted outside the transect. These differences were mainly caused by the deep (> 100 cm) and wind-packed snow at site 3. Overall, spatial variability of snow depth and SWE was large at all three sites, which may have contributed to the observed differences.

To reduce the effect of snow depth variability, snow densities were compared to the site mean values. For all sites, Custom EV2, Estonian VS-43, ETH, IG PAS, Korhonen-Melander, Lithuanian VS-43 and U.S. Federal samplers gave density values that differed from the site means by ≤ 10%. The SnowHydro snow tube gave values 13% lower than the mean for site 2, and values that differed by ≤ 10% for sites 1 and 3. The Dolfi snow tube gave values 16% higher than the mean for site 3 and values with a maximum difference of 10% for sites 1 and 2. The Enel-Valtecne EV2 snow tube gave values 31% lower than the mean for site 2 and values 21% higher than the mean for site 3.

The results of this 2nd HarmoSnow field campaign show that, in the case of SWE, the mean values obtained for a transect with different samplers differ from the site mean value ≤ 10% if a suitable number of measurements are completed. Natural spatial variability in SWE is difficult to separate from variability originating from the observer and sampler, and it was not possible to do so for the dataset collected in this field campaign. Results also revealed that, under irregular ground conditions and shallow snowpack, variability in snow depth estimations may cause comparable or even greater variability in SWE estimations than variability in snow density. It was noticed during the campaign that sharp cutting teeth are important for penetrating hard layers inside the wind-packed snowpack (e.g. the sharpened edge of the Korhonen-Melander snow cylinder had difficulty penetrating all snow layers). At site 3 with a deeper snowpack, long snow tubes were easier and faster to use than short snow cylinders. It was also apparent that transparent plastic samplers were easier to fully empty than those that were not transparent. An additional campaign with a homogeneous ground surface and snowpack was needed to separate sources of variability.

*Table II-1.4.1 Measurement results for the Reykjavik field campaign at the three sites. "Mean SWE" is the mean of the water equivalent of snow cover measurements made at a single point with a single instrument. "Mean HS" is the mean of the snow depth measurements made at a single point with a single instrument. "RSD" is the relative standard deviation of the values and "n" is the number of single measurements used for the mean values. No RSD is listed in cases where only one measurement was made.*

| | | Site 1 | | | | Site 2 | | | | Site 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Instrument | Point | Mean SWE (mm w.e.) | RSD SWE (%) | Mean HS (cm) | n | Mean SWE (mm w.e.) | RSD SWE (%) | Mean HS (cm) | n | Mean SWE (mm w.e.) | RSD SWE (%) | Mean HS (cm) | n |
| Custom EV2 | 1 | | | | | 145.0 | 7.3 | 49.0 | 2 | | | | |
| Custom EV2 | 2 | | | | | 141.4 | | 52.0 | 1 | | | | |
| Dolfi | 1 | 113.8 | 13.3 | 49.0 | 6 | 135.6 | 2.9 | 47.0 | 5 | 519.2 | | 126.0 | 1 |
| Dolfi | 2 | 142.4 | 9.1 | 55.2 | 5 | 127.8 | 5.1 | 47.2 | 5 | 487.0 | 1.6 | 119.0 | 3 |
| Enel-Valtecne EV2 | 1 | | | | | 176.8 | 0 | 47.5 | 2 | 371.1 | 19.8 | 132.0 | 3 |
| Enel-Valtecne EV2 | 2 | | | | | 152.8 | | 54.0 | 1 | | | | |
| ETH | 1 | 127.0 | | 51.0 | 1 | 124.0 | | 48.0 | 1 | 569.3 | | 159.0 | 1 |
| ETH | 2 | 120.0 | | 47.0 | 1 | 146.0 | | 55.0 | 1 | | | | |
| ETH | 3 | 138.0 | | 54.0 | 1 | 134.0 | | 45.0 | 1 | | | | |
| IG PAS | 1 | 125.5 | 4.8 | 50.0 | 3 | 129.7 | 0 | 47.0 | 3 | | | | |
| IG PAS | 2 | | | | | 124.7 | | 48.0 | 1 | | | | |
| IG PAS | 3 | | | | | 116.9 | 0 | 46.0 | 3 | | | | |
| Korhonen-Melander | 1 | 125.2 | 5.2 | 58.0 | 4 | 125.5 | 1.1 | 44.0 | 2 | | | | |
| Korhonen-Melander | 2 | 137.0 | 12.3 | 54.6 | 5 | 132.0 | 6.3 | 50.7 | 4 | | | | |
| SnowHydro | 1 | 121.0 | 5.0 | 57.0 | 3 | 102.0 | 0 | 48.3 | 3 | 431.3 | 3.7 | 119.5 | 3 |
| SnowHydro | 2 | 128.0 | 8.8 | 61.0 | 3 | 130.5 | 1.1 | 55.1 | 6 | | | | |
| SnowHydro | 3 | 102.5 | 6.9 | 52.3 | 3 | 91.0 | 1.5 | 40.8 | 3 | | | | |
| U.S. Federal | 1 | | | | | 121.9 | 14.1 | 45.0 | 5 | 560.7 | 14.0 | 186.2 | 9 |
| U.S. Federal | 2 | | | | | 105.8 | 14.9 | 55.8 | 3 | | | | |
| U.S. Federal | 3 | | | | | 116.9 | 4.3 | 47.6 | 5 | | | | |
| VS-43 (Estonia) | 1 | 116.9 | 2.8 | 58.0 | 4 | 126.7 | 10.1 | 51.0 | 5 | | | | |
| VS-43 (Estonia) | 2 | 106.4 | 4.2 | 49.8 | 5 | | | | | | | | |
| VS-43 (Lithuania) | 1 | 123.9 | 3.7 | 50.8 | 5 | 135.4 | 2.9 | 49.7 | 5 | 341.4 | 0.5 | 99.0 | 2 |
| VS-43 (Lithuania) | 2 | 104.6 | 13.8 | 44.0 | 5 | 124.2 | 2.2 | 46.4 | 5 | | | | |

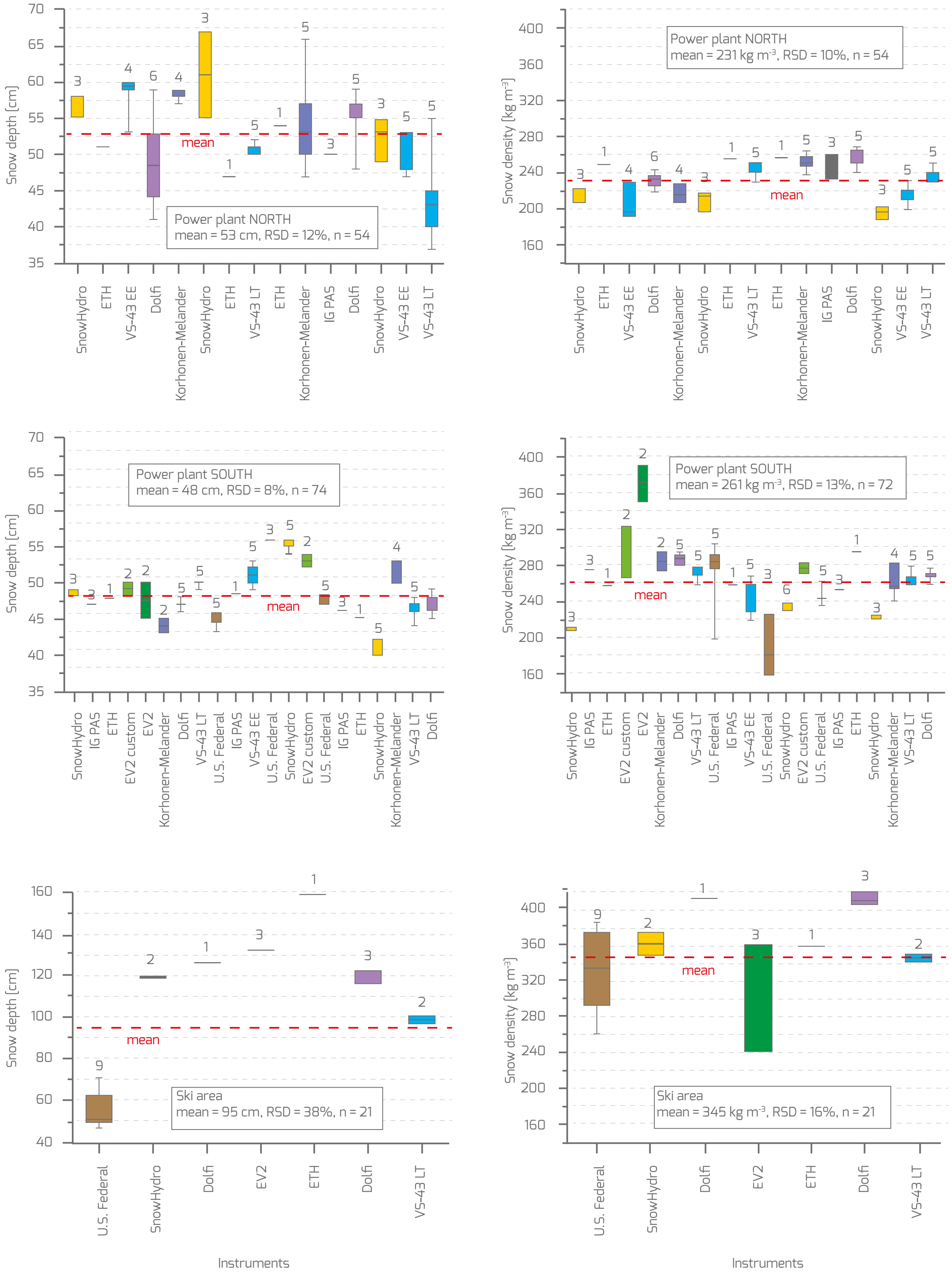


*Figure II-1.4.1 Boxplots of snow depth and density from water equivalent of snow cover (SWE) samplers for (top) site 1, (middle) site 2 and (bottom) site 3 of the 2nd HarmoSnow field campaign (Reykjavik, Iceland). The corresponding number of measurements is shown above each box. Solid lines represent the mean values, boxes indicate the 25th and 75th percentiles, and whiskers indicate the 10th and 90th percentiles. The red dashed line indicates the mean of the measurements. Site mean values (mean), relative standard deviation (RSD) and total number of measurements (n) are given for each plot. VS-43 LT denotes the Lithuanian VS-43 snow cylinder and VS-43 EE the Estonian one.*

# II-1.5 Sodankylä, Finland field campaign in 2018

## II-1.5.1 Introduction

The 3rd HarmoSnow field campaign was organised in Sodankylä (Finland) on 20–22 February 2018. The aim of the campaign was to systematically compare the SWE samplers in dry taiga snow conditions at different field sites, and to separate the errors induced by the observers from those caused by the specific instrument design. The same samplers as in the previous campaigns were purposefully used. A total of nine SWE samplers (Custom EV2, Dolfi, Enel-Valtecne EV2, ETH, IG PAS, Korhonen-Melander, SnowHydro, U.S. Federal and VS-43) were used (Fig. II-1.2.2) and 880 measurements were made. In addition, reference measurements using a SnowMicroPen (SMP) and snow pit measurements including stratigraphy, traditional grain size, specific surface area and density were made. The measurements were made in untouched snowpack at three fenced field sites approximately 10 x 20 m in area.

The first site, called “bog site”, had a mean snow depth of 54 cm. The ground beneath the snowpack was covered with smooth ice containing bits of grass and moss. The second site, called “forest opening site”, had a mean snow depth of 73 cm. The ground under the snowpack was covered with a mix of vegetation, including lichen, moss, lingonberry, heather and small pine trees. The third site, called “antenna site”, was a forest opening (larger than the second site) with a mean snow depth of 64 cm. Vegetation was mainly moss, lingonberry and some tree branches resulting from forest cutting.

The bog and forest opening sites had similar measurement setups. Four points were measured five times with every sampler. Two additional points were measured three times with every sampler by two new observers (not experienced with that sampler). At these points, additional measurements were collected by expert observers. Snow pits were made at each site in two locations. Water equivalent of snow cover measurements were made in the snow pits with a Korhonen-Melander snow cylinder (the sampler used regularly by FMI observers at Sodankylä). SMP measurements were made next to measurement points 1–4 and the snow pits. The antenna site had three points with five measurements by every sampler. In addition, a fourth wider measurement location was used for sampling in parallel transects (10 measurements per sampler in one transects with 30–50 cm gaps). At the antenna site only one snow pit was made. SMP measurements were made as at the other sites.

## II-1.5.2 Results and discussion

The traditional grain size profile and snow density profiles from the bog and forest opening sites are shown in Figure II-1.5.1. The general structure of the snowpack was similar at all sites, with only snow depth differing slightly. Precipitation particles and decomposed and fragmented precipitation particles were observed on top of the snowpack. The lowest densities (110–170 kg m$^{-3}$) were observed in the top surface layers. The smallest grain sizes (0.25–0.75 mm) were located in or below the surface layer. Typically, the middle part of the snowpack consisted of rounded grains or faceted crystals with one to four thin melt form layers. The bottom of the snowpack was formed by depth hoar. Snow density and grain size increased towards the bottom of the snowpack, with maximum values ranging from 285 to 315 kg m$^{-3}$ and 3 to 5 mm, respectively. Generally, the snow was typical dry taiga snow with large grains, a few thin hard crust layers, and a fragile structure of faceted crystal and depth hoar layers. The SMP measurements confirmed homogeneity of the sites. The mean parametrised snow density from SMP measurements had a relative standard deviation of less than 2% for every site.

Mean SWE values were 113 mm w.e. at the bog site, 156 mm w.e. at the forest opening site, and 134 mm w.e. at the antenna site (Table II-1.5.1). Snow depth varied from 48 to 63 cm with a mean of 54 cm at the bog site, from 63 to 83 cm with a mean of 73 cm at the forest opening site, and from 55 to 72 cm with a mean of 64 cm at the antenna site. Snow density varied from 81 to 291 kg m$^{-3}$ with a mean of 210 kg m$^{-3}$ at the bog site, from 144 to 329 kg m$^{-3}$ with a mean of 216 kg m$^{-3}$ at the forest opening site, and from 151 to 248 kg m$^{-3}$ with a mean of 210 kg m$^{-3}$ at the antenna site.

The results reveal that, under very homogeneous snow conditions, density estimations from the various samplers differed from the site mean by less than 10% in the majority of cases (Table II-1.5.1, Fig. II-1.5.2). Of all samplers tested, Custom EV2, Enel-Valtecne EV2 and U.S. Federal snow tubes resulted in the largest differences from the site mean. These snow tubes are extracted directly from the snow without digging a snow pit, and they have a smaller diameter than the other samplers tested. For each measurement location, repeated measurements of each sampler, which were carried out close to each other, gave very similar values for the majority of samplers, with differences usually less than 5%. Custom EV2, Enel-Valtecne EV2 and U.S. Federal snow tubes, as well as the IG PAS cylinder, provided the least consistent measurements, with differences close to 10% for some of the measurement points. Measurements made by new and experienced observers for each sampler are presented for the bog site and forest opening site in Figure II-1.5.2. Generally, the variability was approximately the same for both observer groups. However, it was larger for new observers for the U.S. Federal snow tube and for the ETH and IG PAS snow cylinders. This comparison is based on all measurements at the site, and the number of measurements was different for experienced and new observers, which may have affected the result. Variability among the replications of each sampler and among the different samplers were both less than 10% (Fig. II-1.5.3). However, the uncertainty introduced by using different samplers was higher than the uncertainty caused by observer error.

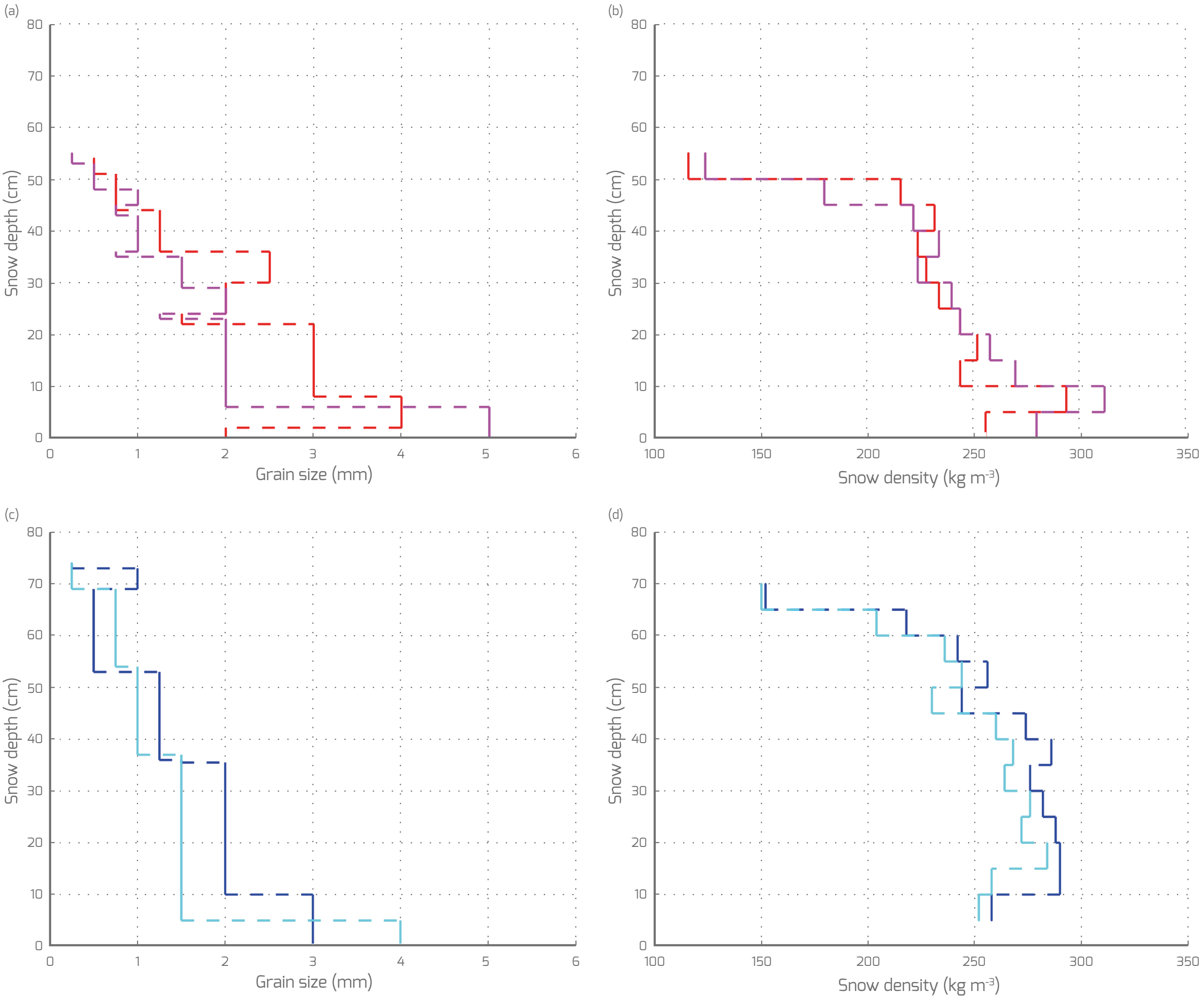


*Figure II-1.5.1 Grain size and snow density profiles measured in snow pits at (a, b) bog and (c, d) forest opening sites during the 3rd HarmoSnow field campaign (Sodankylä, Finland). The different colours within each graph represent the different profiles.*

*Table II-1.5.1 Measurement results for the Sodankylä field campaign at the three sites. "Mean SWE" is the mean of the water equivalent of snow cover measurements made at a single point with a single instrument. "Mean HS" is the mean of the snow depth measurements made at a single point with a single instrument. "RSD" is the relative standard deviation of the values. Points 1–4 are the points where the measurements were carried out by experienced observers. For the antenna site, point 4 was the measurement where sampling was done in parallel transects*

| | | Bog | | | | Forest opening | | | | Antenna | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Instrument | Point | Mean SWE (mm w.e.) | RSD SWE (%) | Mean HS (cm) | RSD HS (%) | Mean SWE (mm w.e.) | RSD SWE (%) | Mean HS (cm) | RSD HS (%) | Mean SWE (mm w.e.) | RSD SWE (%) | Mean HS (cm) | RSD HS (%) |
| Korhonen-Melander | 1 | 112.6 | 1.1 | 54.2 | 0.7 | 157.2 | 1.8 | 72.2 | 0.6 | 143.2 | 1.4 | 67.0 | 0.0 |
| VS-43 | 1 | 117.4 | 0.9 | 53.8 | 1.6 | 159.4 | 1.4 | 69.6 | 1.6 | 123.4 | 1.9 | 56.2 | 2.8 |
| U.S. Federal | 1 | 101.3 | 7.2 | 53.4 | 0.9 | 166.7 | 4.4 | 73.6 | 2.3 | 130.8 | 0.0 | 58.3 | 4.6 |
| SnowHydro | 1 | 112.3 | 3.5 | 54.8 | 0.7 | 153.2 | 3.4 | 73.6 | 2.0 | 141.0 | 1.6 | 66.0 | 1.1 |
| IG PAS | 1 | 122.2 | 5.8 | 54.0 | 0.0 | 161.2 | 7.2 | 71.4 | 1.5 | 124.8 | 5.7 | 59.2 | 2.5 |
| ETH | 1 | 114.4 | 1.1 | 54.6 | 0.9 | 141.0 | 4.6 | 69.6 | 5.2 | 122.2 | 2.6 | 59.0 | 2.0 |
| Enel-Valtecne EV2 | 1 | 118.2 | 3.9 | 56.6 | 0.8 | 143.6 | 4.9 | 75.4 | 0.7 | 115.4 | 8.0 | 61.8 | 2.6 |
| Dolfi | 1 | 112.8 | 3.9 | 55.0 | 0.0 | 144.4 | 5.3 | 71.6 | 1.5 | 129.6 | 6.0 | 60.6 | 4.8 |
| Custom EV2 | 1 | 119.5 | 5.8 | 54.8 | 1.4 | 146.4 | 7.0 | 75.0 | 1.3 | 106.8 | 8.2 | 58.8 | 1.4 |
| Korhonen-Melander | 2 | 113.0 | 1.0 | 55.0 | 0.0 | 158.4 | 0.9 | 72.2 | 1.5 | 141.8 | 2.9 | 66.8 | 1.9 |
| VS-43 | 2 | 120.6 | 0.7 | 54.2 | 1.4 | 154.4 | 3.8 | 70.2 | 7.1 | 145.4 | 5.2 | 62.2 | 3.1 |
| U.S. Federal | 2 | 104.6 | 8.6 | 53.6 | 0.9 | 171.6 | 4.8 | 74.2 | 2.4 | 147.1 | 0.0 | 64.4 | 0.8 |
| SnowHydro | 2 | 111.3 | 2.8 | 53.6 | 1.8 | 166.6 | 2.5 | 74.4 | 2.0 | 141.0 | 1.6 | 66.0 | 1.1 |
| IG PAS | 2 | 137.8 | 5.1 | 57.6 | 0.8 | 158.6 | 6.9 | 70.2 | 0.6 | 143.0 | 0.0 | 64.0 | 0.0 |
| ETH | 2 | 112.2 | 1.6 | 54.4 | 0.9 | 153 | 0.9 | 70.6 | 2.1 | 135.6 | 1.0 | 63.2 | 1.3 |
| Enel-Valtecne EV2 | 2 | 121.0 | 4.7 | 54.4 | 1.6 | 171.8 | 5.1 | 74.8 | 1.1 | 128.7 | 6.4 | 67.6 | 0.7 |
| Dolfi | 2 | 118.4 | 2.7 | 55.8 | 0.7 | 153.2 | 3.4 | 72.0 | 2.2 | 141.2 | 1.3 | 65.8 | 1.2 |
| Custom EV2 | 2 | 119.2 | 15.5 | 57.0 | 1.2 | 168.1 | 3.5 | 75.6 | 1.2 | 115.3 | 7.7 | 66.8 | 0.6 |
| Korhonen-Melander | 3 | 114.2 | 2.0 | 53.6 | 0.9 | 164.6 | 1.8 | 75.0 | 1.6 | 114.6 | 4.5 | 56.8 | 3.2 |
| VS-43 | 3 | 112.2 | 1.6 | 53.1 | 1.3 | 152.8 | 3.6 | 70.4 | 1.6 | 130.2 | 6.2 | 58.6 | 3.9 |
| U.S. Federal | 3 | 98.1 | 16.6 | 50.2 | 0.8 | 163.4 | 0.0 | 76.6 | 2.2 | 155.3 | 5.3 | 66.2 | 1.2 |
| SnowHydro | 3 | 110.0 | 1.5 | 54.0 | 0.0 | 159.7 | 2.8 | 75.0 | 0.0 | 143.2 | 3.9 | 65.8 | 1.7 |
| IG PAS | 3 | 127.4 | 8.5 | 54.2 | 0.7 | 161.2 | 4.4 | 70.0 | 1.0 | 137.8 | 5.2 | 63.0 | 1.6 |
| ETH | 3 | 107.8 | 2.0 | 51.6 | 0.9 | 151.6 | 2.6 | 71.0 | 2.4 | 132.2 | 4.1 | 62.8 | 4.5 |
| Enel-Valtecne EV2 | 3 | 109.7 | 4.5 | 53.2 | 2.4 | 143.7 | 6.2 | 72.8 | 6.0 | 123.8 | 9.3 | 69.8 | 1.1 |
| Dolfi | 3 | 114.8 | 0.9 | 54.1 | 0.3 | 157.2 | 3.8 | 73.6 | 1.5 | 134.4 | 7.4 | 61.4 | 4.4 |
| Custom EV2 | 3 | 131.6 | 3.2 | 53.2 | 0.7 | 154.6 | 6.0 | 75.4 | 1.2 | 110.3 | 2.7 | 60.8 | 1.8 |
| Korhonen-Melander | 4 | 99.6 | 1.3 | 50.8 | 0.7 | 159.0 | 0.9 | 74.2 | 1.1 | 128.0 | 6.4 | 64.6 | 3.3 |
| VS-43 | 4 | 103.8 | 4.2 | 50.4 | 0.9 | 160.6 | 7.7 | 71.2 | 4.8 | 139.5 | 4.1 | 63.8 | 5.3 |
| U.S. Federal | 4 | 104.6 | 13.9 | 50.0 | 1.4 | 166.7 | 8.2 | 74.2 | 5.1 | 138.9 | 0.0 | 63.8 | 0.5 |
| SnowHydro | 4 | 103.1 | 1.6 | 51.4 | 1.7 | 172.6 | 3.7 | 77.8 | 1.9 | 139.9 | 2.3 | 65.2 | 1.2 |
| IG PAS | 4 | 104.0 | 0.0 | 50.0 | 0.0 | 163.8 | 4.3 | 71.4 | 1.3 | 162.5 | 4.2 | 69.5 | 1.0 |
| ETH | 4 | 98.8 | 1.6 | 49.8 | 0.8 | 140.0 | 2.1 | 68.8 | 1.9 | 145.1 | 3.6 | 66.3 | 2.6 |
| Enel-Valtecne EV2 | 4 | 116.1 | 5.4 | 54.0 | 1.3 | 139.4 | 4.2 | 74.6 | 0.7 | 125.4 | 3.7 | 65.4 | 2.1 |
| Dolfi | 4 | 100.0 | 5.2 | 51.0 | 1.2 | 159.2 | 2.4 | 75.4 | 1.0 | 137.3 | 1.3 | 65.0 | 1.4 |
| Custom EV2 | 4 | 100.0 | 5.8 | 51.0 | 1.3 | 159.2 | 2.8 | 75.4 | 1.2 | 139.2 | 3.2 | 64.5 | 1.2 |

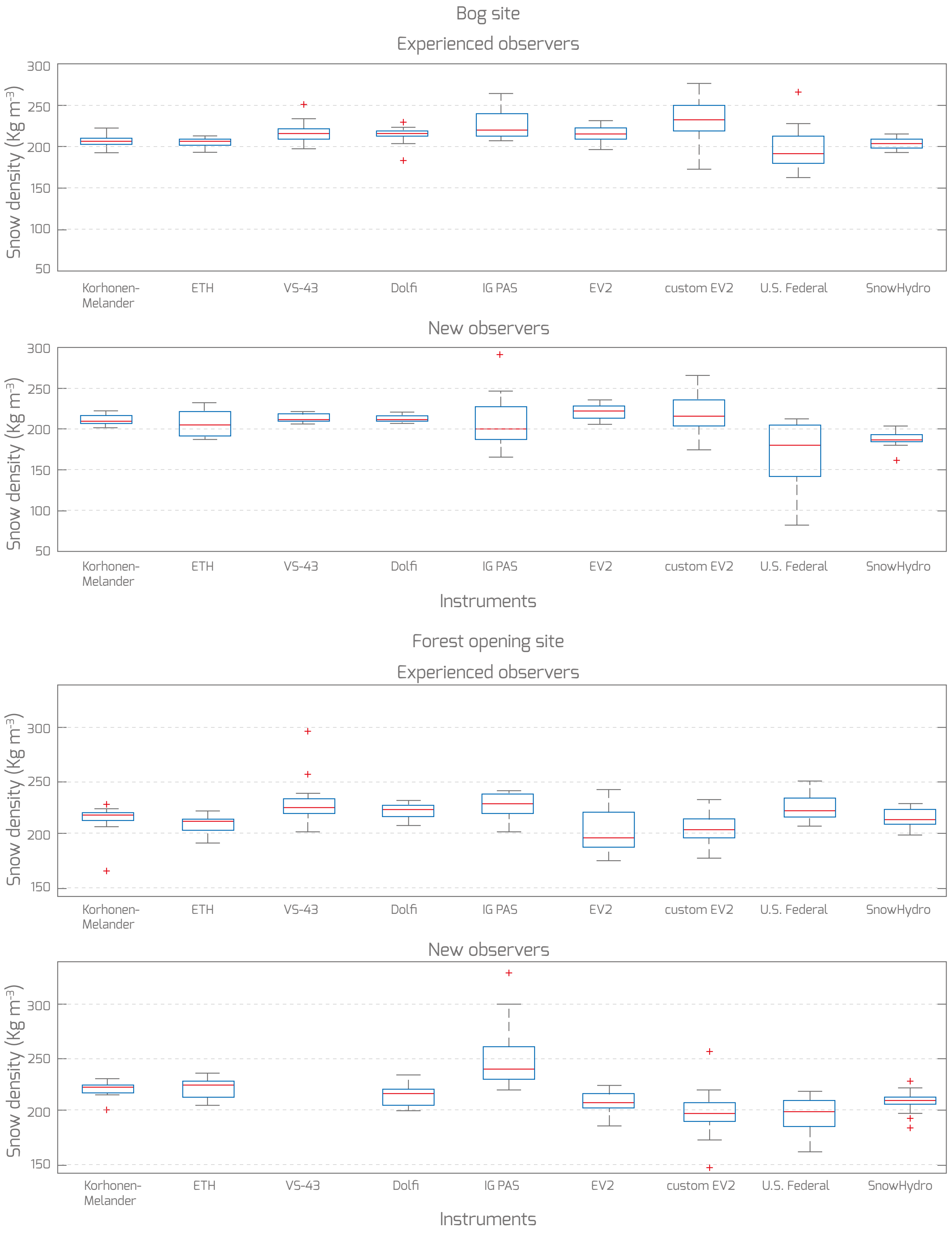


*Figure II-1.5.2 Boxplots of snow density measured with each sampler by experienced and new observers at the bog site (top two panels) and at the forest opening site (bottom two panels). The variability was less than 10% for both experienced and new observers. Red lines represent mean values, boxes indicate the 25th and 75th percentiles, whiskers indicate the 10th and 90th percentiles and red crosses indicate outliers.*

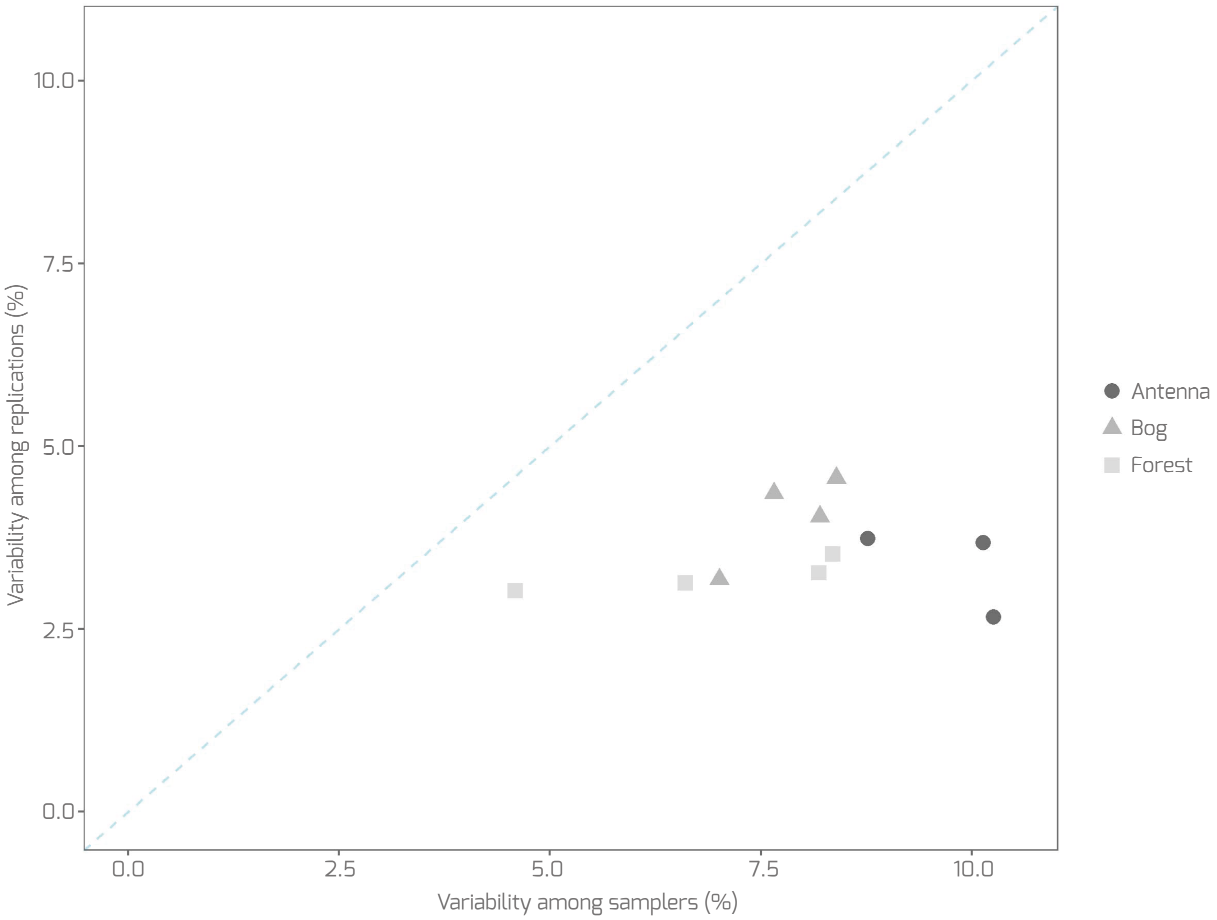


*Figure II-1.5.3 Average variability in snow density among water equivalent of snow cover (SWE) samplers (x-axis) and among repeated measurements of a given sampler (y-axis) carried out close to each other at the three field sites in Sodankylä, Finland.*

## II-1.6 Lessons learnt

The following general recommendations are based on the observations and expertise gathered during the three HarmoSnow field campaigns. The recommendations derived from these campaigns are fully in line with those published previously (e.g. Farnes et al., 1982). Nevertheless, these campaigns included more snow samplers and operators from different countries than earlier methodological investigations.

Accurate measurements with any SWE sampler require that observers carefully follow the measurement protocol: insert the cylinder or tube vertically into the snow surface, clean the cylinder or tube before using it again, and use scales well adapted to the shape and characteristics of the cylinder or tube. In order to avoid erroneous measurements, the observer must confirm that the excavated snow core corresponds approximately to the sampled snow depth and that no snow falls out from the snow tube during its extraction. Special care must be taken to avoid getting extra snow inside the sampler during measurements in deeper snowpacks when measurements are made with a short cylinder or tube. Using a cylinder or tube longer than the maximum snow depth is recommended. Transparent plastic samplers are easier to empty completely than those that are not transparent. In addition, to achieve reliable results it is recommended that observers use scales with a high precision and accuracy, and which work in a weight range suitable for the sampler used. Seasonal checks of weight repeatability in cold weather conditions are important, especially for electronic scales, which tend to give floating weight results with changing temperature. In addition, seasonal calibration of mechanical scales is recommended.

In the HarmoSnow field campaigns, samplers requiring a snow pit were not notably slower to use than the other samplers. However, the situation is different in deep snowpacks or for repeated measurements within a snow course. In these situations, snow tubes instead of snow cylinders are recommended. Under certain terrain conditions with a very irregular ground surface, or where the perception of reaching the ground is complicated by the existence of moss or shrub vegetation, a muddy ground surface, etc., the error in estimating snow depth could be comparable to the error associated with snow density and

SWE sampling. In such cases, it is recommended that rods with a sharp tip are avoided, as they might penetrate the ground and overestimate the snow depth.

Most of the tested samplers are designed for certain environments, and using them in different environments or under specific snow conditions could be more difficult and more time consuming. The 1st HarmoSnow field campaign showed that samplers that are made of dark material or difficult to clean are not suitable for sunny, wet-snow conditions, whereas the sharp edge of a sampler is useful for penetrating hard layers. The 2nd field campaign confirmed that cutting teeth are important for penetrating hard crusts or layers formed by wind. The 3rd HarmoSnow campaign showed that samplers with a larger diameter are better suited than narrow cylinders or tubes for taiga snowpack. Using different SWE samplers during the same field campaign or changing instrumentation during the snow season may introduce inhomogeneities in the dataset that may affect subsequent spatial and temporal analyses. When choosing a sampler, the above points should be taken into account while also considering the anticipated snow conditions.

# II-1.7 Summary

The COST Action HarmoSnow organised three field campaigns for testing different SWE samplers, with the aim of harmonising European SWE and snow depth observations. The 1st HarmoSnow field campaign demonstrated the use of different instruments and revealed natural variability in the snowpack which may lead to high measurement variability. The 2nd field campaign concentrated on comparing the SWE samplers and resulted in a comparison of mean values, but it did not provide enough data to distinguish between variability due to observer or sampler error and the natural variability of the snowpack. The aim of the 3rd field campaign was to produce a dataset for sampler intercomparison, as well as for assessing observer-related variability, in order to quantify the suitability of the samplers for observing taiga snowpack. In conclusion, when SWE observations from a shallow snowpack (snow depth less than the length of the sampler) are used, e.g. for validating snow models, variability of 5–10% among the observations should be expected. Within this range, the accuracy of carefully conducted point SWE measurements is comparable with that of other measurements conducted in hydrology. However, SWE measurement errors can be much larger for deeper snowpacks or under challenging snow conditions, such as in the presence of crust layers or on an irregular ground surface.

# II-2 Overview of European in-situ Snow Measurement Practices

R. Pirazzini[1], L. Leppänen[1], G. Picard[2], J.I. López-Moreno[3], C. Marty[4], G. Macelloni[5], A. Kontu[1], A. von Lerber[1], C.M. Tanis[1], M. Schneebeli[4], P. de Rosnay[6], A.N. Arslan[1]

1. Finnish Meteorological Institute, Helsinki, Finland
2. Université Grenoble Alpes, Institut des Géosciences de l'Environnement, Grenoble, France
3. Pyrenean Institute of Ecology, CSIC, Zaragoza, Spain
4. WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland
5. CNR – National Research Council of Italy, Sesto Fiorentino, Italy
6. European Centre for Medium-Range Weather Forecasts (ECMWF), Reading, United Kingdom

## II-2.1 Introduction

The in-situ instrumentation used to measure or retrieve snow properties has recently undergone major development, driven by the need for suitable reference and ground truth data for the validation of new satellite products, and for long-term, consistent data records for environmental monitoring. Traditional manual observations of fundamental properties, such as snow depth and water equivalent of snow cover, suffer from heterogeneity caused by the fact that different operators often apply different measurement procedures and tools. This measurement system is not sustainable in the long run because manual procedures require a large amount of effort. Automatic measurement methods can solve these problems in many cases, and several institutions and national agencies are gradually replacing manual methods with automatic ones. Up to this date, however, there are no international guidelines or recommendations on the optimal application of automatic instruments. Often, there is not even sufficient awareness of the available automatic techniques, as the most recently developed methods are often known of and applied only in specific research communities.

The main objective of the COST Action HarmoSnow was the harmonisation and enhancement of the international snow observation network for the benefit of weather and hydrological models, which are increasing in spatial resolution and therefore require a denser measurement network. The first step needed to reach this objective was the collection of information on the existing variety of snow measurement practices and instrumentations in use by European institutions. A few existing publications describe most of the observable snow properties (Fierz et al., 2009) and in-situ measurement techniques (Kinar and Pomeroy, 2015). They do not, however, cover the recently developed measurement techniques and the associated newly observable properties, and they do not provide information on the actual use of the measurement instruments. Therefore, a questionnaire was created to compile the different types of snow measurements (properties and techniques) carried out by the European countries for a large variety of applications. The questionnaire was advertised among the participants of the COST Action HarmoSnow and their national contacts or collaborators who perform snow observations, and it remained open from December 2015 to November 2017. There was no specification regarding the professional position the respondents should have, and the received answers were therefore heterogeneous with respect to their institutional representativeness. The questionnaire was answered by 125 participants from 99 operational, research and private institutions belonging to 38 European countries (Fig. II-2.1.1), and the results were presented in Pirazzini et al. (2018). In the following sections the main results are summarised and final remarks are given.

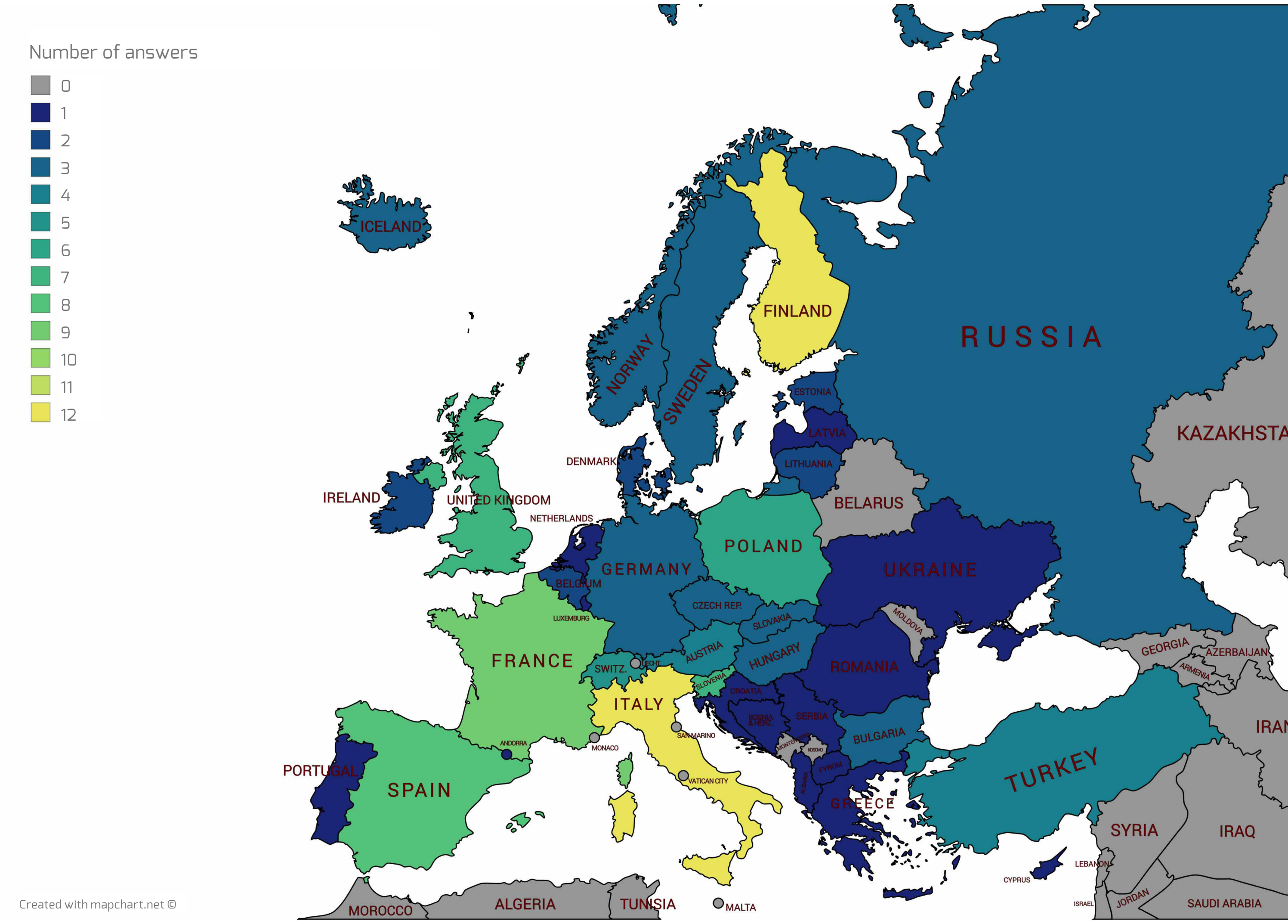


*Figure II-2.1.1 Map of Europe showing the countries that participated in the WG 1 – WG 2 HarmoSnow Questionnaire, where different colours indicate the number of answers per country.*

# II-2.2 Main results of the HarmoSnow Questionnaire on in-situ snow measurements

When selecting the purpose of the snow measurements, given the choice of "Research", "Operational" or "Both research and operational", the largest percentage of the respondents (43%) answered "Research". Responses from operationally oriented institutions (71) were more numerous than responses from research-only institutions (54); however, 55% of the respondents from operationally oriented institutions declared research objectives while respondents from research institutions usually did not indicate operational purposes. Thus, the majority of the received answers reflect snow measurement practices for research applications (Fig. II-2.2.1). In particular, general research and operational fields such as climatology, meteorology and hydrology were the snow measurement application areas selected most often, while more specific applications, such as avalanche risk forecasting, water management, and agriculture and forestry, were selected by fewer respondents, presumably because they are usually addressed in dedicated institutions.

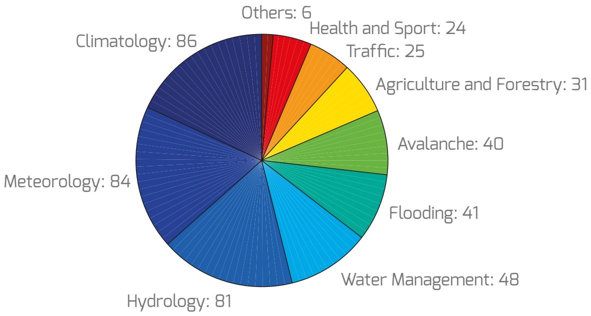


*Figure II-2.2.1 Application areas of the snow measurements and the number of respondents who selected them. The width of each slice corresponds to the number of times a given application area was selected relative to the total number of application areas (i.e. the sum of all numbers given in the figure).*

The snow properties addressed in the questionnaire were divided into five categories: snow macrophysical properties, snow microphysical properties, snow electromagnetic properties, precipitating and suspended snow properties, and snow composition. Figure II-2.2.2 illustrates, for four of the categories, how frequently each snow property is measured by the respondents relative to the total number of properties measured in that category. The percentage of respondents that measure each of the snow properties does not directly indicate how widely or frequently a given property is measured, but rather illustrates the measurement interests of the respondents. Responses from operationally oriented institutions were more numerous than responses from research-only institutions, but respondents from both institution types indicated that they pursue research objectives. Snow macrophysical properties (Fig. II-2.2.2 a) describe the bulk characteristics of the whole snowpack or of a single snow layer, providing essential input variables for hydrological and numerical weather prediction models. Thus, they are naturally the most commonly measured snow properties, and 117 respondents indicated that they measure one or (more often) several of them.

The responses regarding measurement techniques applied to measure macrophysical snow properties are displayed in Figure II-2.2.3. The most common measurement methods for snow depth (HS), presence of snow on the ground (PSG), water equivalent of snow cover (SWE) and snow density are not automated. However, the majority of the respondents apply both manual and automatic methods, highlighting the complementarity of the techniques. Ultrasonic and laser depth sensors are already well established and easily available tools to automatically detect snow depth; they are applied by about half of the respondents. Photography, including timelapse photography and webcams, is an emerging, inexpensive method that can be applied to automatically map snow depth and presence of snow on the ground over large, poorly accessible areas (DeBeer and Pomeroy, 2009; Arslan et al., 2017). Snow scales and snow pillows are the automatic methods traditionally used to measure water equivalent of snow cover, but they can only be installed on flat, undisturbed ground surfaces, and they are used by only about 10% of the respondents conducting snow macrophysical measurements. Manual snowfall gauges have been replaced by automatic ones at some sites. Global Navigation Satellite System (GNSS) reflectometry is an emerging method to automatically retrieve water equivalent of snow cover and other bulk snow properties (snow depth, snow density and liquid water content), and it can additionally be applied to the monitoring of waste areas (e.g. Larson et al., 2009; Jacobson, 2010; McCreight et al., 2014). Only two respondents indicated that they apply this technique, but its inexpensive technology and easy installation suggest that its usage could increase considerably in the near future.

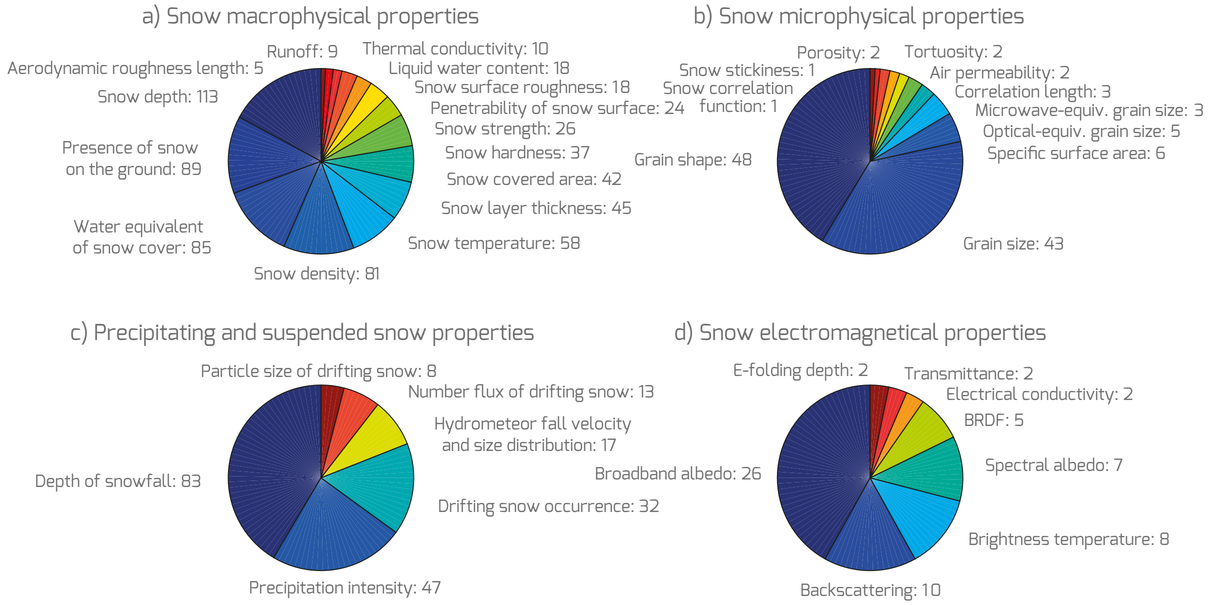


*Figure II-2.2.2 Measured (a) snow macrophysical properties, (b) snow microphysical properties, (c) precipitating and suspended snow properties, and (d) snow electromagnetic properties. The width of each slice corresponds to the number of times each snow property was selected relative to the total number of selected properties (i.e. the sum of all numbers given in each panel of the figure).*

Snow microphysical properties (Fig. II-2.2.2 b) describe the characteristics of the snow microstructure. Information about these properties is needed to simulate snow electromagnetic interactions for the remote sensing retrieval of snow properties (e.g. Pulliainen, 2006) and to represent the snow structure in physical models that support avalanche forecasting (Lehning et al., 2002; Vionnet et al., 2012). Snow grain shape and size are the most commonly observed snow microphysical properties, and they are generally measured with the traditional visual method. As with snow composition measurements (included in our questionnaire but not discussed here), which mainly concern light-absorbing impurities, water, and heavy metal isotopes, snow microphysical variables cannot yet be easily measured by fully automatic instruments. Indeed, the existing techniques rely on the collection of snow samples that are subsequently analysed in a laboratory (e.g. X-ray microtomography) or that employ electronic devices, such as the Ice Cube (Gallet et al., 2009) or the SnowMicroPen (Proksch et al., 2015), which need to be manually operated.

Snow precipitation properties are measured by 93 respondents, with depth of snowfall and precipitation intensity being the most frequently measured properties (Fig. II-2.2.2 c). These properties are applied as input into numerical weather prediction, hydrological and snow models used for avalanche risk forecasting (e.g. Bellaire et al., 2011; Dong, 2018). Microphysical properties of drifting snow (such as number flux and particle size distribution) are mainly measured with automatic devices, so far exclusively for research purposes (e.g. validation of polarimetric radar measurements). However, measurements of drifting snow properties would be beneficial for the management of traffic along roads, railway lines and aeroplane runways, especially in locations dominated by strong winds.

Snow electromagnetic properties (Fig. II-2.2.2 d) characterise the interaction of snow with electromagnetic radiation. Only 26% of the respondents measure these properties, and the majority of these respondents measure snow broadband albedo using pyranometers. The practical challenges involved in in-situ snow albedo measurements, (due to the often unavoidable impact of shadows, tilted surfaces and obstructions of field of view) probably prevent a more widespread use of pyranometers for the long-term monitoring of this variable, even though it is so crucial for climate, weather forecasting, and snow mass and water runoff estimation. In the microwave spectral region, snow backscatter and emissivity, measured by radars and radiometers, respectively, are applied to derive snow cover extent, water equivalent of snow cover and snow melting/freezing state. These measurements are mainly applied for research purposes, such as ground truthing of satellite observations and development/validation of snow retrieval algorithms and models for the snow electromagnetic interaction. The in-situ monitoring of snow extent, water equivalent of snow cover and snow melting/freezing state is delegated to the inexpensive and more practical instruments included in Figure II-2.2.3.

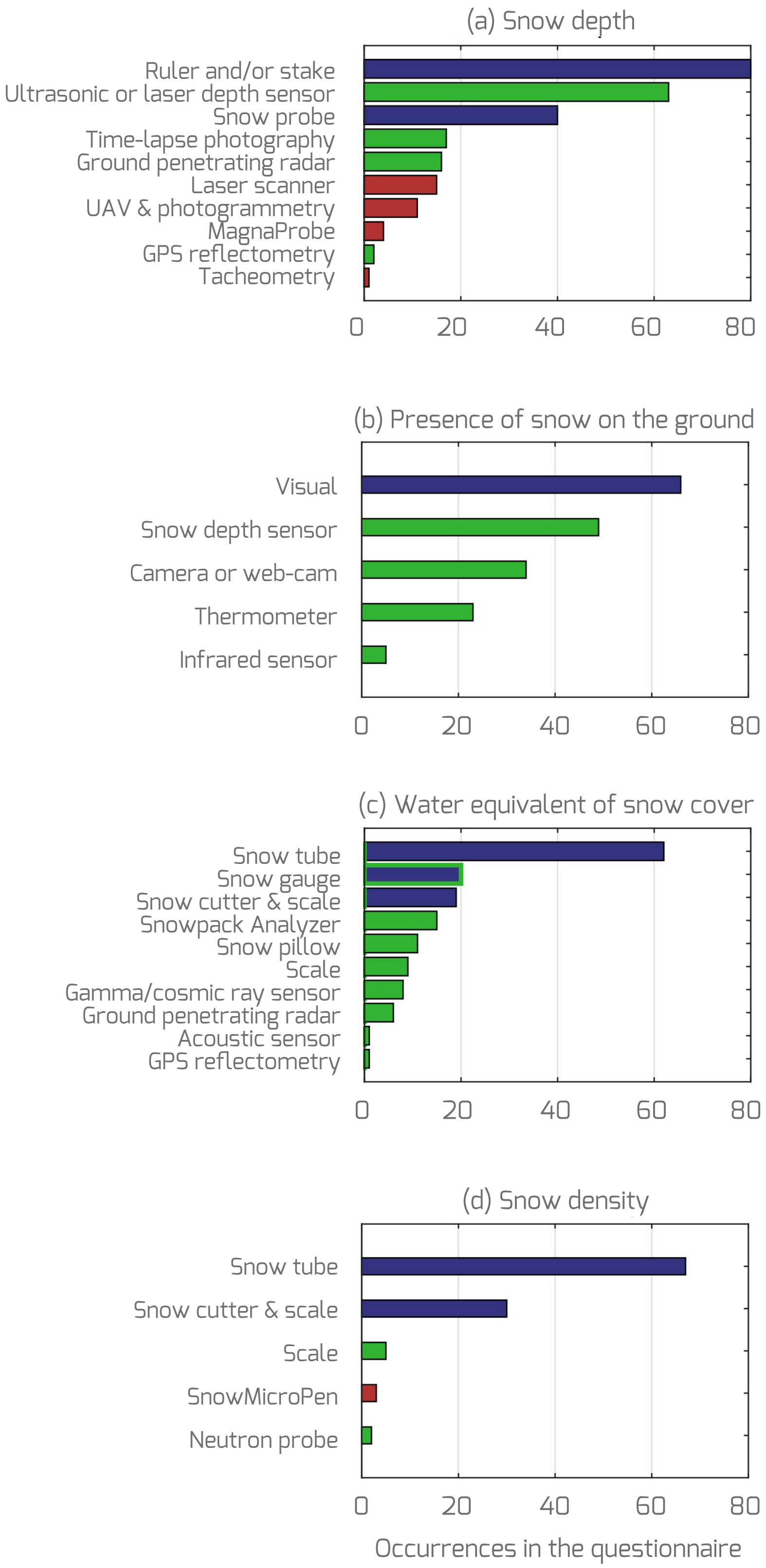


*Figure II-2.2.3 Frequency of the application of different instruments for measuring the four snow macrophysical properties: (a) snow depth, (b) presence of snow on the ground, (c) water equivalent of snow cover, and (d) snow density, based on responses to the questionnaire. The different colours denote: a manual instrument without electronics (blue), a manual instrument with electronics (red), either a manual instrument without electronics or a fully automatic instrument, depending on the version of the instrument (blue with green border), and a fully automatic instrument (green).*

# II-2.3 Final remarks

The results of the questionnaire on the practices and purposes of European in-situ snow measurements, carried out in the framework of the COST Action HarmoSnow, provide a panoramic view of the measured snow properties and the applied measurement techniques, some of which were developed in the last decade. These results offer the possibility to evaluate which of the existing automatic methods for measuring bulk snow properties have the greatest potential of being applied over larger scales for operational monitoring purposes. The development of faster techniques to derive microphysical snow properties clearly serves the increasing need for operational monitoring, although the measurements are not yet fully automatic and are therefore still very labour intensive. In addition, the automatic measurement of the microphysical properties of precipitating and suspended snow could possibly find more operational applications. To enhance the standardisation and comparability of the snow measurements, a final recommendation drawn from the results of the questionnaire is to increase the use of internationally agreed upon measurement protocols for each of the applied measurement techniques. The results of this questionnaire serve as basis for the advancement and harmonisation of in-situ snow observation methods, one of the main goals of HarmoSnow. These results may additionally help enlarge the communities that apply automatic measurements to operational monitoring and to advanced techniques for research purposes.

# II-3 Snow Data Assimilation and Evaluation Methods for Hydrological, Land Surface, Meteorological and Climate Models – A COST Action HarmoSnow Assessment Questionnaire

J. Helmert[1], A. Sensoy Sorman[2], P. de Rosnay[3], M. Lange[1], D. Finger[4], V. Potopová[5], E. Kurzeneva[6], D. Pulido-Velazquez[7,8], D. Vikhamar-Schuler[9], S. Pullen[10], M. Dumont[11], C. De Michele[12], R. Salgado[13], E. Shevnina[6], M. Derkova[14], A.N. Arslan[6]

1. Deutscher Wetterdienst, Offenbach, Germany
2. Anadolu University, Faculty of Engineering, Department of Civil Engineering, Eskişehir, Turkey
3. European Centre for Medium-Range Weather Forecasts (ECMWF), Reading, United Kingdom
4. School of Science and Engineering, Reykjavik University, Reykjavik, Iceland
5. Department Agroecology and Biometeorology, Czech University of Life Sciences Prague, Prague 6 – Suchdol, Czech Republic
6. Finnish Meteorological Institute, Helsinki, Finland
7. Instituto Geológico y Minero de España (IGME), Urb. Alcázar del Genil, Granada, Spain
8. Departamento de Ciencias Politécnicas, Escuela Universitaria Politécnica, Universidad Católica San Antonio de Murcia (UCAM), Murcia, Spain
9. The Norwegian Meteorological Institute, Oslo, Norway
10. Met Office, Exeter, United Kingdom
11. Université Grenoble Alpes, Université de Toulouse, Météo-France, CNRS, CNRM, Centre d'Etudes de la Neige, Grenoble, France
12. Politecnico di Milano, Department of Civil and Environmental Engineering, Milano, Italy
13. Departamento de Física and Instituto de Ciências da Terra, Universidade de Évora, Évora, Portugal
14. Slovak Hydrometeorological Institute, Bratislava, Slovakia

## II-3.1 Introduction

Owing to its unique physical properties, snow on the ground is an essential environmental variable that directly affects the Earth's energy balance. Proper description and assimilation of snow information into hydrological, land surface and meteorological models are therefore important for addressing the impact of snow on various phenomena, for predicting local snow water resources, and for providing warnings about snow-related natural hazards (e.g. Drusch et al., 2004; Finger et al. 2011; Etter et al., 2017; Lafaysse et al., 2017).

Information about the physical properties of snow comes from observations (in-situ and remotely sensed) and from physical snow models. However, the complexity and heterogeneity of snowpack processes lead to large uncertainties in datasets from both observations and model simulations (Dechant and Moradkhani, 2011).

In-situ measurements of the snowpack state are performed on the ground at numerous stations (e.g. synoptic observation (SYNOP) stations of the World Meteorological Organisation (WMO)) and during intensive field campaigns (e.g. HarmoSnow field campaigns; Chapter II-1). Simultaneous measurements of snow variables and soil moisture content are additionally valuable (Potopová et al.,

2016) but are only feasible at some stations. Unfortunately, depending on the region in which they are performed, in-situ snow measurements can have a relatively coarse spatial coverage and be representative of only a limited area, owing to spatial heterogeneities in the snow cover (Essery, 2013; Dechant and Moradkhani, 2011).

Remotely sensed data has the potential to provide estimates of the snow properties (De Lannoy et al., 2012) in regions with sparse in-situ snow measurements. In the visible and near-infrared spectral range, spaceborne remote sensing can be used to determine the snow-covered area and the fraction of snow-covered land at a high spatial resolution (e.g. MODIS, AVHRR).

Passive microwave remote sensing data makes it possible to estimate snow depth (HS) and water equivalent of snow cover (SWE) by relating the microwave brightness temperature to snow variables without an impact from clouds (Pulliainen and Hallikainen, 2001). However, the resolution of these products is typically coarser than that of remote sensing products from visible and near-infrared spectral bands, and their accuracy is sensitive to the assumptions applied, the topography and the properties of the snowpack (e.g. Foster et al., 2005; Li et al., 2014; Leppänen et al., 2015; Kontu et al., 2017). In contrast, active microwave sensors can determine snow depth from space with a higher resolution but require spaceborne measurements at appropriate frequencies (Ku-band; De Lannoy et al., 2012).

Continuous estimates of the snow properties from numerical model predictions are still limited by uncertainties in meteorological forcing data and by structural problems for snow processes in land surface models (De Lannoy et al., 2012). Three major classes of snowpack models are employed for various applications (Armstrong and Brun, 2008): single-layer snow schemes (e.g. De Michele et al., 2013), schemes of intermediate complexity (e.g. Koivusalo et al., 2001), and detailed snowpack models (e.g. Bartelt and Lehning, 2002). These model classes differ in the description and parameterisation of properties inside the snowpack and the related processes.

With data assimilation (DA), an improvement of the simulated snow properties from numerical models can be achieved by combining datasets from observations with numerical model predictions and by considering the uncertainties of observed and modelled variables (Liston and Hiemstra, 2008; Finger et al., 2012). Therefore, efforts have been made to merge snow observations and snow modelling using the DA method (e.g. Andreadis and Lettenmaier, 2006; De Lannoy et al., 2012; Finger et al., 2015). Recently, there has been increasing interest in investigating the potential of DA schemes to consistently improve model simulations by assimilating ground-based measurements or remotely sensed snow-related observations (e.g. Dziubanski and Franz, 2016).

Several DA methodologies have been developed for this purpose, but there is a gap in the level of sophistication of DA methods applied in different contexts. Specifically, the DA methods used for snow analyses in operational numerical weather prediction (NWP) are much simpler than the state of the art in DA (Essery, 2013) and lag behind the methods used for the initialisation of other surface variables (e.g. soil moisture). Furthermore, operational NWP systems assimilate snow depth from in-situ ground measurements and satellite-derived snow extent (Drusch et al., 2004; Pullen et al., 2011; de Rosnay et al., 2015), but water equivalent of snow cover is not considered during the assimilation cycle (Essery, 2013).

With the implementation of the Global Cryosphere Watch (GCW) in 2011, WMO established a programme which considers the growing demand for authoritative information on the past, present and future state of the world's snow and ice resources (Key et al., 2015). Although GCW is global in scope, the programme needs activities at all scales, including regional, national and local levels (GCW, 2011), and recognises the requirements for assimilation, model development and validation, such as through the WMO GCW Snow Watch Activity (Snow Watch, 2018). At the European level, the COST Action HarmoSnow (2014–2018) coordinated efforts towards harmonised snow data processing and handling practices (HarmoSnow, 2018).

## II-3.2 Questionnaire description and results

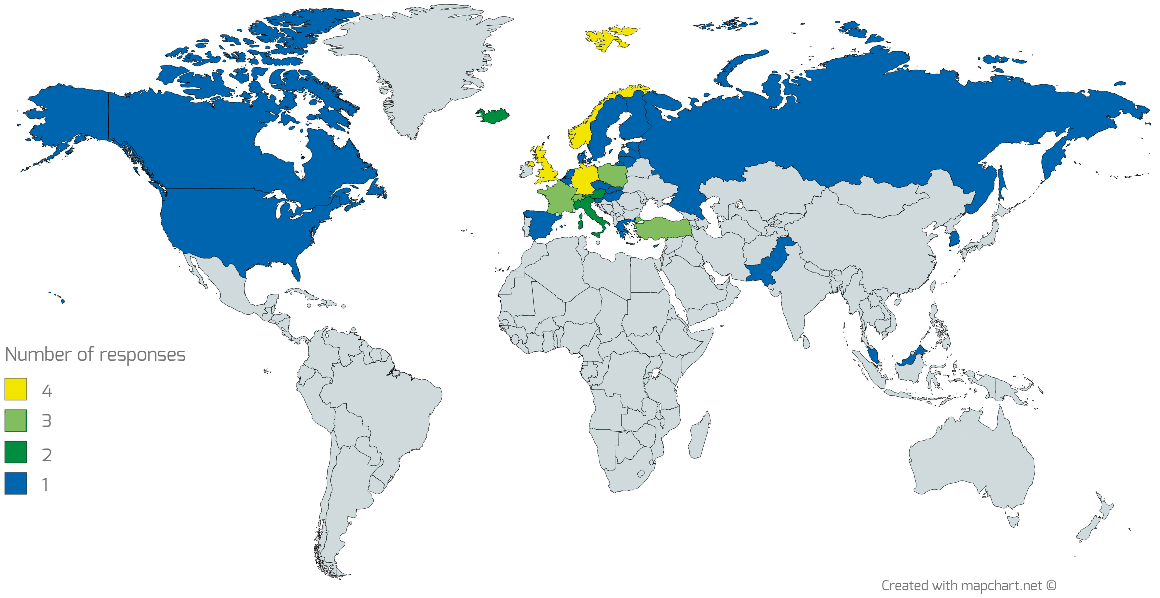
Within the framework of HarmoSnow, a questionnaire was developed by WG 3 to provide an overview of the DA methods and snow data processing used in NWP, hydrology and climate studies. The questionnaire was posted on the web page of HarmoSnow (HarmoSnow, 2018) from September 2015 to December 2017, with the specific aims of assessing the current usage of snow observations in DA, forcing, monitoring, validation and verification. The questionnaire was completed by 51 participants from 31 countries. For southern European countries, reporting on snow for climatological purposes is limited to the residential high elevation area, where it is an important consideration for meteorological and hydrological applications (e.g. Sorman et al., 2009).

The distribution of the responses from the countries is shown in Fig. II-3.2.1. Most European countries involved in HarmoSnow (Fig. 2 on p. 4) provided at least one response; thus, the acquired dataset provided a solid base for obtaining an overview of how snow data is used in NWP systems and hydrological models. In addition to all European countries, Arctic countries and territories (Russia, Canada, Alaska), the USA, and countries located in Asia were invited to contribute information to this analysis of the present state of snow DA for NWP and hydrology.

In most countries considered, only a few organisations support the national weather forecasting and hydrological services. This seems to be standard in most European countries, with one or two leading research institutes supporting these services, and one or two universities providing educational programmes on the hydrometeorological profile. In large countries (Russia, Canada and USA) with a territory covering several geographical zones, the national weather service and hydrological service usually consist of one leading agency supported by local institutions at the subregional level that have the capability to produce independent weather and hydrological forecasts.

The questionnaire results were partitioned according to the type of modelling environment used by the respondent. Of the institutes that provided responses, 16 use NWP models with DA, 6 use NWP models without DA, 23 use hydrological models, 10 use reanalysis, 4 use special snow models, and 8 use other (miscellaneous) models with snow observations. Eleven universities and two companies participated in the questionnaire. The model resolutions span from the global scale down to a single kilometre and an individual river catchment area.

The results of the questionnaire show that the optimal interpolation method and the Ensemble Kalman Filter (EnKF) are widely used (Fig. II-3.2.2). A detailed investigation revealed that snow DA for NWP purposes mostly relies on optimal interpolation schemes (Brasnett, 1999) or Cressman interpolation (Cressman, 1959). For hydrological applications Kalman filters (Kalman, 1960) or EnKF methods (Evensen,



Created with mapchart.net ©

*Figure II-3.2.1 Geographical distribution of responses to the questionnaire. Countries in grey did not take the questionnaire. In contrast to the European-wide maps shown in Part I of the European Snow Booklet (ESB), the global scale is used here because models (e.g. for numerical weather prediction) often run at this scale.*

1994) are generally used. For EnKF an ensemble of possible model realisations, based on the Monte Carlo approach, is needed (instead of a model linearisation) to determine the error estimates. Other more sophisticated methods that include, for example, the particle filter (Arulampalam et al., 2002), are also used for snow DA in hydrology. Similar to the EnKF, the particle filter is a sequential Monte Carlo method that accounts for uncertainties in the forcing data, model structure and observations. The particle filter, however, does not depend on the assumption of a Gaussian distribution of errors or of a Gaussian joint probability density function on the state variables and observations (Dechant and Moradkhani, 2011).

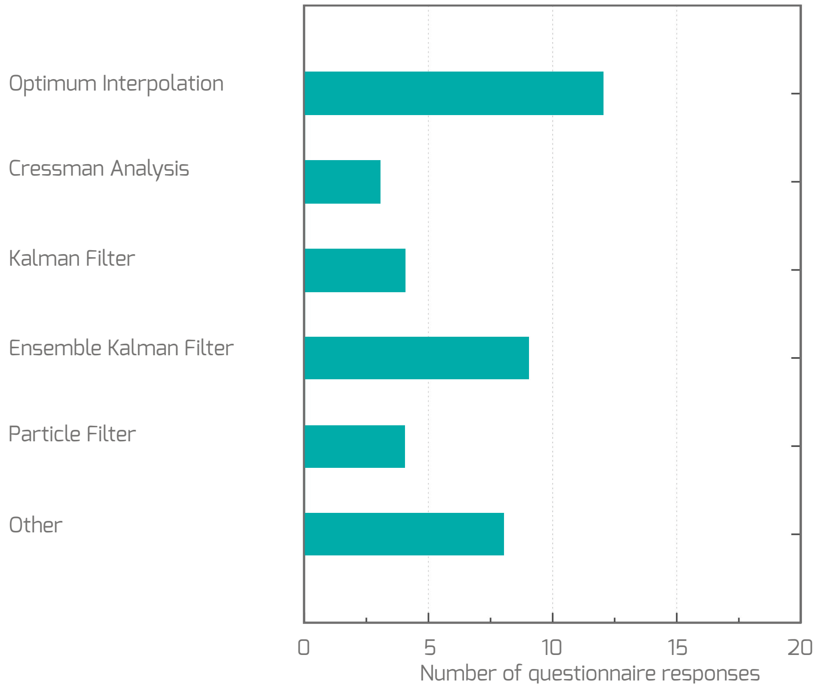


*Figure II-3.2.2 Distribution of data assimilation methods used by questionnaire participants.*

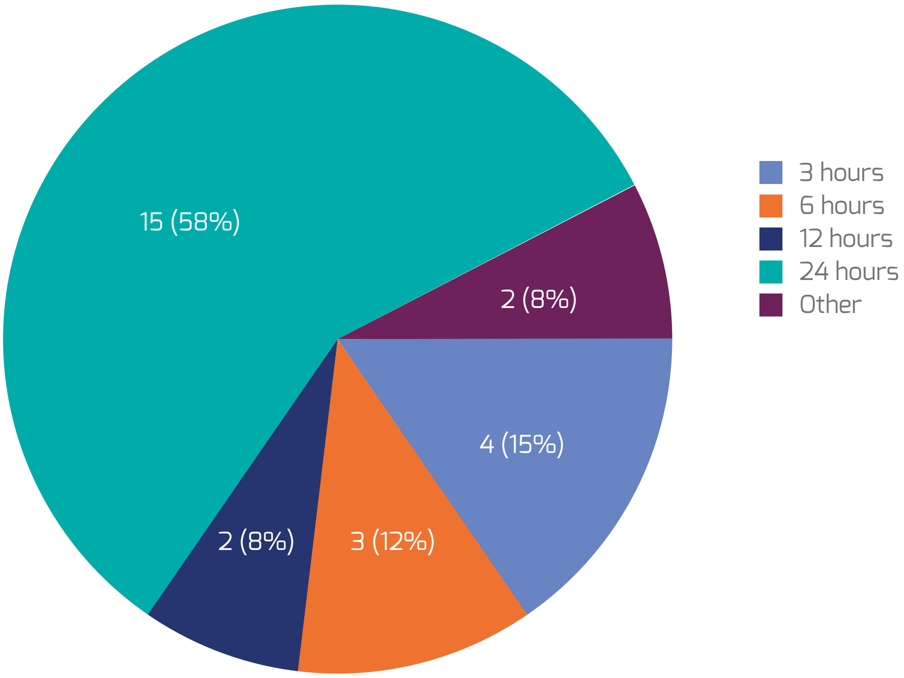


*Figure II-3.2.3 The percentages (rounded) of different update frequencies applied for snow data assimilation.*

Independent of the modelling environment, most DA systems perform a snow analysis every 24 hours (Fig. II-3.2.3). This is important for the assimilation of remote sensing data because not all satellite products are available on a daily basis. Even daily products for water equivalent of snow cover based on passive microwave remote sensing data have a coarse resolution (10 km), while water equivalent of snow cover products from active microwave sensors can reach a resolution of $10^{-2}$ km but with limited availability.

Snow observations from SYNOP and additional ground-based measurements are the most important data sources for NWP and hydrological forecasting (Fig. II-3.2.4). For these data sources, active reporting of snow-free conditions (zero snow depth) in the SYNOP messages, together with the exchange of data from non-GTS stations, is considered essential. The WMO Executive Council has recently approved standardisation of zero snow depth reporting (e.g. WMO No. 69, 2017).

Preprocessed remote sensing satellite products are often used in both NWP and hydrology (Finger et al., 2012, 2015; Duethmann et al., 2014; Etter et al., 2017). Compared to these products, satellite radiances, i.e. space-borne remote sensing data with a limited spectral range, are used much less frequently. Climatological datasets are considered for hydrological applications. Additional data used by questionnaire participants includes external snow analysis and multi-sensor satellite products. Most model users in hydrology who responded to the questionnaire use ground-based remote sensing measurements, but this is not the case for NWP or reanalysis. In many cases, the measurement system used includes ultrasonic or laser distance sensors (Lidar), but also cameras and COSMIC ray or radiation sensors. Preprocessed snow products are used in all model environments, but these products have special importance in NWP without DA, reanalysis and miscellaneous models. The products used are, for example, from Interactive Multi-sensor Snow and Ice Mapping Systems, satellite systems (MODIS, SEVIRI, AVHRR), Satellite Application Facilities (H-SAF, Land-SAF), NWP-based snow analysis or reanalysis.

One of the important features of a DA system is quality control of the data (Rood et al., 1994). This step is performed by comparing previous model forecasts with observations. This allows users to identify and eliminate spurious data. Furthermore, when this comparison is performed repeatedly, it is possible to calibrate observing systems and to identify biases or changes in observation system performance (Walker and Houser, 2005).

Quality control of snow observations and products is performed in the large majority of the model environments included in this questionnaire (Fig. II-3.2.5). Filtering of outliers, as well as manual and automatic treatment of missing data or implausible values, is used in all model environments, although with different levels of sophistication. Responses from the questionnaire indicate that DA in NWP is completed for this purpose.

Consistency or plausibility checks are used to check that the absolute value of observations and the rate of change over time are physically realistic (Walker and Houser, 2005). In addition, buddy checks are used to compare observations located close together, and background checks are completed to compare realistic changes in the observed values with the model predictions (Walker and Houser, 2005).

In comparison with quality control assessments, snow data consistency checks are performed by a smaller number of questionnaire participants (Fig. II-3.2.5). For this data preprocessing procedure, manual and automatic methods exist based on basic physical principles, where the snow cover is of particular importance.

Concrete plans for using new or upcoming data sources of snow observations exist for all model environments, in particular for NWP with DA, hydrology and reanalysis. The detailed responses to the questionnaire demonstrate that participants are interested in using more satellite data (optical, microwave), but also more groundbased remote sensing data, Global Navigation Satellite System (GNSS) or COSMIC ray sensors, and additional non-SYNOP networks.

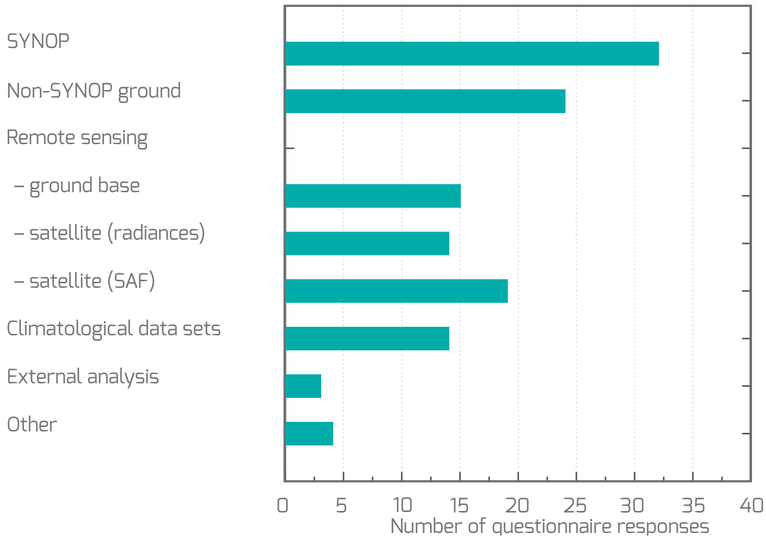


*Figure II-3.2.4 Distribution of snow observations and products included in the modelling systems used by questionnaire participants.*

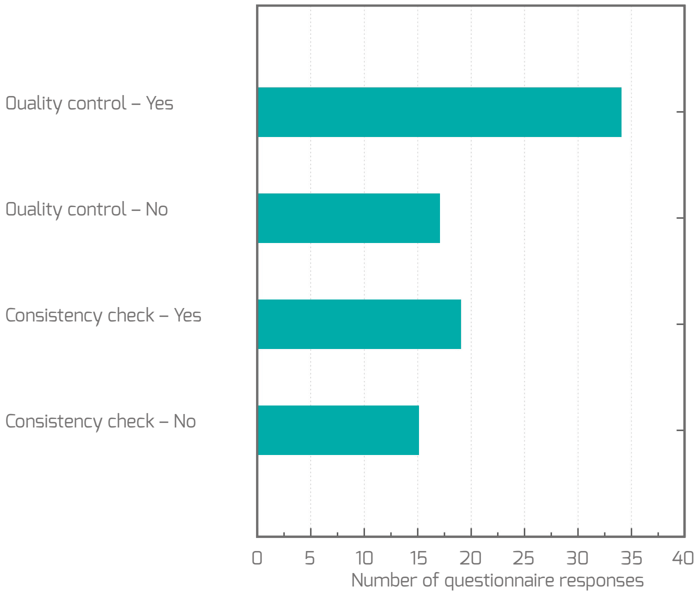


*Figure II-3.2.5 The number of questionnaire participants indicating that they perform quality control and/or consistency checks of their snow observations or products.*

# II-3.3 Summary

The questionnaire conducted by WG 3 of the COST Action HarmoSnow was supported by operational and research centres for NWP and hydrology, as well as by universities and companies. The results of the questionnaire show that present-day measurement networks, instruments and techniques are exploited well by existing DA systems used in model environments for NWP, hydrology and special snow models. Further, the questionnaire results reveal that there is a good fit of the snow macrophysical variables demanded by DA with the measurement environment, as snow depth, presence of snow on the ground, snow density and water equivalent of snow cover are the variables measured most often. It is important to take into consideration that in many cases these variables are measured with different instruments and techniques, in particular for snow depth and water equivalent of snow cover. On the other hand, developments in DA systems are necessary for exploiting the evolving capabilities of the observation systems, and vice versa. The increasing automation of the measurements requires enhanced data management in the DA system (quality control, consistency). There is an increasing demand for remotely sensed snow depth and water equivalent of snow cover observations from satellites to provide snow data in regions with sparse measurement networks, but this would require further developments in instrument technology (e.g. automatic measurement of snow microstructural properties), as well as advancement of DA systems in order to make use of such observations. There are concrete plans to use enhanced snow observations for all model environments, in particular for NWP with DA, hydrology and reanalysis. Data availability and resources to integrate data into the model environment are the current barriers and limitations for the use of new and upcoming snow data sources, independent of the model environment used.

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**COST Association**
Avenue Louise 149
1050 Brussels, Belgium
T +32 (0)2 533 3800
office@cost.eu

www.cost.eu

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