A EUROPEAN TIME SERIES OF DAILY SNOW COVER FROM AVHRR DATA OVER 36 YEARS: RESULTS OF THE TIMELINE PROJECT

Sebastian Roessler, Andreas Dietz, Stefanie Holzwarth

German Aerospace Center (DLR), Earth Observation Center (EOC), 82234 Wessling, Germany

ABSTRACT

The TIMELINE project is dedicated to generating comprehensive and consistent long-term time series using NOAA and METOP AVHRR data for Europe and North Africa, utilizing the extensive DLR-DFD historical data archive. Its primary objective is to address socially significant inquiries regarding climate change and identify potential trends. To achieve this, the project has developed a multitude of processors that produce essential data products pertaining to radiation, land surface, atmosphere, and cryosphere. Specifically focusing on the cryosphere, the daily estimation of the snow-covered area from AVHRR data between 1982 and 2018 in TIMELINE provides an unprecedented 36-year period of observation, almost doubling the duration of available MODIS snow product records in the region. This paper presents the snow cover processor, along with the initial outcomes of the time series analysis, shedding light on important insights gained from the data.

Index Terms— AVHRR, Climate Change, Snow Cover, TIMELINE, Time Series

1. INTRODUCTION

The boreal winter of 2022/23 once again exhibited a prevalent pattern across Europe, characterized by unusually mild temperatures and a significant lack of snow. The importance of this phenomenon in the broader context of climate becomes evident when considering the extent of seasonal snow cover, which spans an impressive 30% of the Earth's land surface [1]. In terms of area, the seasonal snow cover represents the largest component of the cryosphere. It is not merely a passive outcome of climatic conditions but actively influences them, primarily through its impact on albedo. Recognizing its significance, the World Meteorological Organization designates seasonal snow cover as an essential climate variable (ECV) and specifies requirements for its observation. Daily monitoring of the "area covered by snow" is necessary on a global scale, and with a minimum spatial resolution of 1 km (100 m in complex terrain). These demanding requirements can only be met through remote sensing techniques.

Various remote sensing approaches are available for detecting snow cover extent. Passive microwave sensors, although capable of providing information on water content, have limited suitability for monitoring due to their coarse resolution. Active radar systems, offering improved resolution, can only detect wet snow, while high-resolution optical sensors fail to meet the desired repetition rate (several days). Medium-resolution sensors have emerged as the optimal choice since the year 2000, with the MODIS sensor serving as the primary instrument [2], while before 2000, the AVHRR sensor was the sole available option.

The AVHRR data form the basis of the TIMELINE project, in which the snow cover is generated as a product in processing Levels 2 and 3. The data basis, the method and the first results of the trend analysis are shown below.

2. MATERIAL AND METHODS

2.1. Data Set and Study Area

The utilization of AVHRR datasets presents several challenges, including uncertainties in geolocation, sensor degradation, and platform drift, all within the constraints of a limited number of spectral and thermal channels. These challenges formed the basis for the objectives of the DLR TIMELINE project, an acronym for "‘TIMe Series Processing of Medium Resolution Earth Observation Data assessing Long-Term Dynamics In our Natural Environment"’ [3]. The project aimed to reprocess the entire AVHRR data archive available in the German Satellite Data Archive (D-SDA) maintained by the German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR). Over the past few years, a suite of processors has been developed within the project to address critical tasks such as calibration, geolocation, atmospheric correction, cloud masking using state-of-the-art methods, and the derivation of various parameters including land surface temperature, sea surface temperature, fire sources, normalized difference vegetation index, and snow cover.

The historical AVHRR data, spanning from 1982 until 2018, were processed in TIMELINE and are available in the HRPT (High Resolution Picture Transmission) format. These data correspond to continuous and real-time transmissions directly from NOAA satellites to Earth. HRPT data offer the highest achievable spatial resolution within the AVHRR system and are comparable to the limited Local Area Coverage (LAC) data. The TIMELINE project covers the entirety of Europe, as well as select regions in Russia, the Middle East, and North Africa.

Figure 1 illustrates the geographical extent of the investigated area, along with the mean snow cover duration. With a zonal extent of 6500 km and a meridional extension of 4600 km, the TIMELINE area covers an area of 29.9 million km², of which 46% is land area (13.8 million km²).

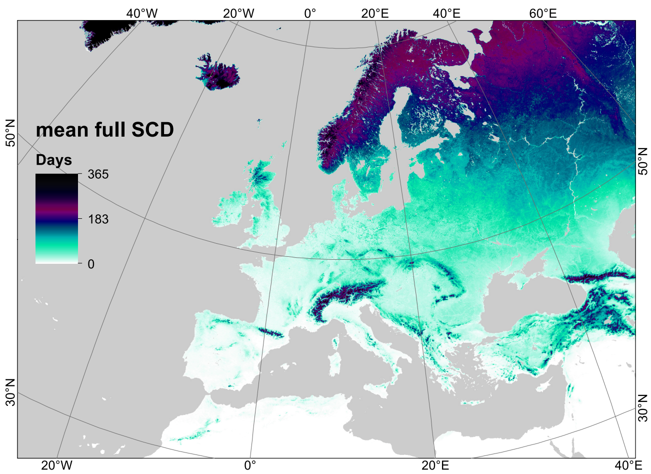

Fig. 1. TIMELINE area with mean snow cover duration (in ETRS89-extended / LAEA Europe projection).

2.2. Snow Cover Processor

The snow detection of the AVHRR Level 1b scenes is based on the Normalized Difference Snow Index (NDSI) [4], which determines the reflection difference between visible radiation (VIS) and short-wave infrared (SWIR) and divides it by their sum. Snow shows a very high reflection in the VIS and almost complete absorption in the SWIR. This NDSI method is also used in MODIS [2], but e.g. water shows a similar behavior (although a much lower reflection in the VIS), so that additional features are used for snow detection.

A static water mask and a reflection threshold of less than 3% in the VIS are used to mask water. Clouds are detected using the TIMELINE cloud mask [5] and a temperature difference to ERA5 Reanalysis data. The plausibility of the remaining ”snow pixels” is checked using the brightness temperature and a DEM as well as a maximum SWIR reflection of 35%. All pixels in question are reclassified as snow-free.

The result is a Level 2 snow mask including an accuracy layer in orbit projection for each Level 1b scene. From this, a daily composite is created in the Level 3 processor. The Level 2 scenes are first projected into the TIMELINE projection (ETRS89-extended / LAEA Europe) and then combined into a daily stack. The value with the highest accuracy is now assigned from the stack for each pixel. 10-day and monthly averages are also calculated from the daily composites. A more detailed description of the processor and a first validation with the MODIS snow product can be found in [6].

2.3. Gap Filling and Trend Analysis

Figure 2 depicts the percentage of land area affected by data gaps in the Level 3 products. During 1982 to 1988, limited availability of Level 2 scenes resulted in more gaps. From 1989 onwards, with the operational service of NOAA-11, the quality enhances and data gaps decreased significantly. The drop in data at the turn of the year is also noticeable, which is due to poor illumination conditions (polar night) and increased cloud coverage.

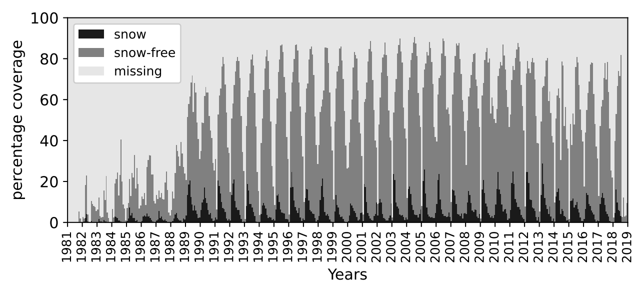

Fig. 2. Number of land pixels that are recognized as either ”snow” or ”snow-free” or are missing.

Since we are interested in the duration of snow cover without data gaps, the Global SnowPack processor [7] developed at DLR is used to fill these gaps. Originally developed for the daily MODIS snow product, it can be used to fill up data gaps in any medium-resolution snow cover dataset. It is a combined temporal and topographical algorithm that eliminates data gaps in 4 consecutive steps. Since an inter-sensor combination is not necessary, only 3-day interpolation, topographical interpolation and seasonal filling were performed.

After the gaps were filled, the development of snow cover duration (SCD) over the 36 years was examined. On the one hand, we considered the SCD of the entire hydrological year (from the beginning of meteorological autumn to the end of meteorological summer, 365 days) and, on the other hand, we divided it into an early snow season (until mid-winter, 136 days) and a late snow season (after mid-winter, 229 days). A pixel-based trend analysis of the three mentioned snow cover seasons was carried out as in [8]. In order to analyze the statistical significance of the trends of SCD, the Mann–Kendall (MK) test was performed, the magnitude of the trend was determined by the Theil–Sen slope. The MK test was performed for all valid land pixels, water bodies are omitted.

3. RESULTS

Due to the page limitation, only few aspects of the results can be presented here. We will focus on the trends and tendencies of early and late SCD, as these can be used as an indicator of the beginning of snow accumulation and the beginning of melting. Figure 3 shows the mean early and late SCD for the full time period of 36 years.

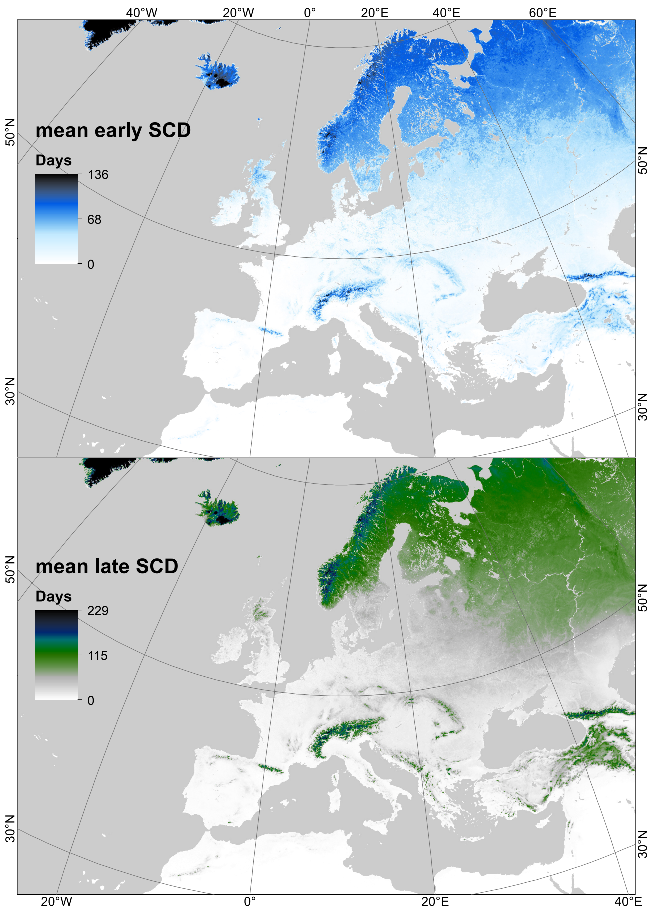

Fig. 3. Mean early and late SCD derived from 36 years.

3.1. Development of Early Snow Cover Duration

The early SCD ranges from the beginning of meteorological autumn to the middle of meteorological winter and lasts 136 days. Since the TIMELINE area is entirely in the Northern Hemisphere, this is the period from September 1st to January 14th.

Figure 4 shows the trend in early SCD (Theil-Sen slope) in days per year at the top and the associated significance levels (p-values) at the bottom. In general, there is a decrease in the duration of snow cover, which is particularly strong in areas of the Baltic States, Belarus, Ukraine and Russia. From a hydrological point of view, the decrease (which is also of high significance in this area) affects the Volga catchment area. Interestingly, almost the entire Caucasus also shows a decrease in early SCD with a high level of significance; the trend is also significant but lower in Arkhangelsk Oblast.

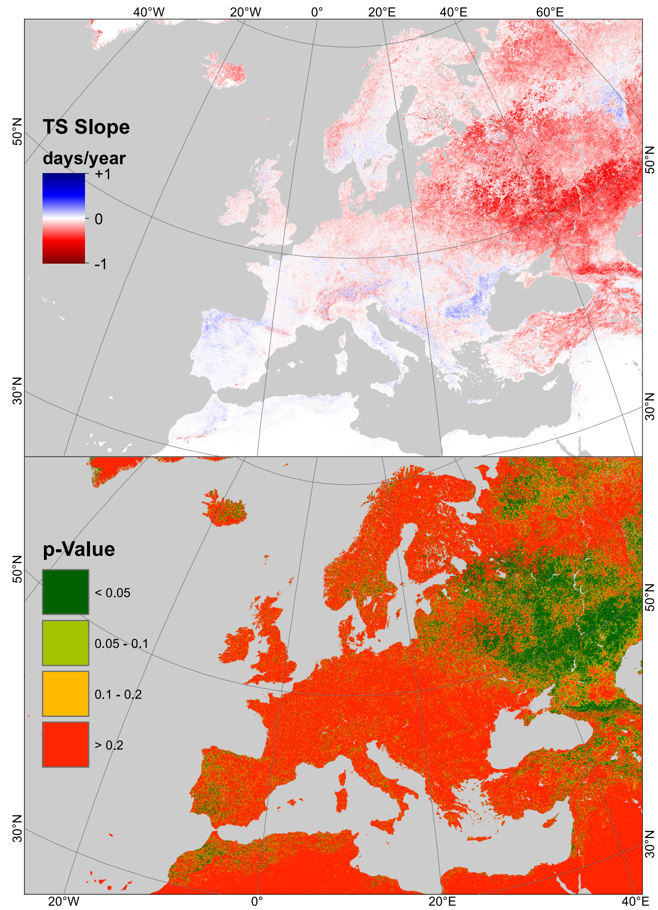

Fig. 4. Trend and significance levels of early SCD.

3.2. Development of Late Snow Cover Duration

The late snow cover season spans 229 days (230 for leap years) and runs from January 15 to August 31 in the Northern Hemisphere. Late SCD pixel-based trends and significance levels are shown in Figure 5. Compared to the development of early SCD, the picture here is much more heterogeneous. The developments are generally less significant, but here too some areas stand out.

In addition to the area of the Volga and the Caucasus, which also mostly show significant decreasing trends here, a large part of Turkey stands out with a significant decrease. In the east of Turkey and in the Pontic Mountains and the Taurus Mountains, the decrease is mostly significant. Also further south, at Mount Lebanon, the decrease of the late SCD is significant.

What is particularly noticeable, however, is the increase trend of late SCD in large parts of Central and Southern Europe, which is predominant area-wise. These developments are also significant, particularly on the Iberian Peninsula and in Morocco.

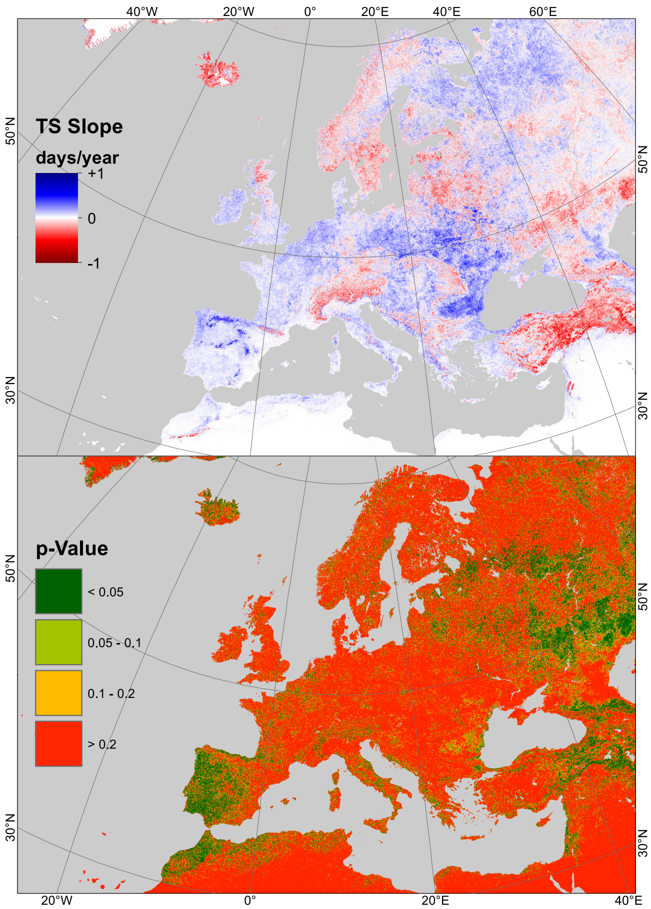

Fig. 5. Trend and significance levels of late SCD.

4. DISCUSSION AND CONCLUSION

In this article, the first pixel-based results of the trend analysis of the snow cover product created in the TIMELINE project are presented. We initially focused on the early and late SCD, as these can give an indication of later onset or earlier melting snow cover - which has a major impact on the hydrology. However, large areas had to be interpolated, which has a major impact on the accuracy. This is currently examined using Landsat scenes for validations. In addition, the analysis of other time periods (months, seasons) and the evaluation of certain areas (catchment areas, mountains, altitudinal zones) are planned.

There will also be an intersection with other TIMELINE products, such as the land surface temperature (LST) and the vegetation (i.e. NDVI) development over the period under consideration. The use of AVHRR is also to be continued with the integration of MetOp satellites. In addition, a validation with the MODIS snow product is planned for the overlapping area from February 2000.

5. REFERENCES

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