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Climate Change: impact on snow loads on structures

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Abstract. A general procedure to evaluate future trends in snow loads on structures is illustrated aiming to study influences of climate change at European scale, to assess its impact on the design of new structures as well as on the reliability levels of existing ones, also in view of the next revision of the Eurocodes. Analysing high quality registered meteorological data of daily temperatures, rain and snow precipitations in nine Italian weather stations, conditional probability functions of occurrence of snow precipitation, accumulation and melting have been preliminarily determined as functions of daily air temperatures. By means of Monte Carlo simulations and based upon daily output of climate models (daily max. and min. temperatures and water precipitation) yearly maxima of snow loads for various time intervals of 40 years in the period 1980-2100 have been simulated, deriving, via the extreme value theory, the characteristic ground snow loads at the sites. Then, the proposed procedure has been implemented in a more general methodology for snow map updating, in such a way that the influence of gridded data of precipitation, predicted by global climate models, on extreme values of snow loads is duly assessed. Preliminary results demonstrate that the outlined procedure is very promising and allows to estimate the evolution of characteristic ground snow loads and to define updated ground snow load maps for different climate models and scenarios.

1 Introduction

As structural design is often governed by climatic actions, alterations of climatic actions caused by climate change could significantly impact design of new structures as well as the reliability of existing ones. For this reason some research groups, based in different areas of the world, are investigating the problem, especially aiming to study the possibility to transfer the outputs of climate models which refer to geographical cells of large dimensions on a suitably smaller scale, allowing to derive characteristic values of climatic actions from the above mentioned outputs. In particular, effects of climate change on snow loads have been recently investigate in Germany [1], Norway [2] and Canada [3], focusing on their influence on the reliability of built environment.

A general procedure for the estimation of climate change influence on ground snow loads is presented; such a procedure, combining the outputs of global climate models with measured data, allows to refine the snow load predictions arriving to a geographical resolution adequate to take into account also micro-climate effects, depending on the local orography.

The procedure, which is general enough to permit sound estimation of future trends in snow loading on structures, aims more specifically to address the impact of climate change on the assessment of new and existing structures, also in view of the evolution of the second generation of Eurocodes, and Eurocode EN 1991 - Part 1-3 - Snow loads [4] in particular, as requested by Mandate M/515 of European Commission [5] to CEN [6].

2 Snow load on structures: State of Art

2.1 Definition of ground snow load

The definition of snow loads on structures in the current version of the structural Eurocodes is largely based upon the results of the European Snow Load Research Project (ESLRP) [6] and, in particular, on the European Ground Snow Load Map elaborated within that research. This map was the first snow load map derived at European scale with a strong scientific basis [7] and its elaboration started from the analysis of the basic snow data collected across 18 European countries, which at that time were members of CEN. By applying extreme value statistics to these observations, the characteristic ground snow loads were derived corresponding to a given probability of exceedance (the 2% upper percentile on yearly base, corresponding to a return period of about 50 years), taking into account both the influence of exceptional snowfalls or no snowy winters. It must be also stressed that in [7], exceptional snow loads were considered for the first time at European scale, on sound scientific bases, giving also appropriate guidance for their identification.

2.2 European snow load maps

Beside the characteristic ground snow loads at weather stations, the research allowed to identify ten major European climatic regions, and the corresponding snow maps, elaborated through GIS software: generally, in each climatic region the ground snow load depends on the altitude according to suitably derived law, except in Norway and Iceland, where snow load is practically independent of altitude. Based on the above snow map, each National Standard Body of CEN member states, produced their own national map of ground snow load, published in the National Annex to EN 1991-1-3.

3 Problem statement

3.1 Climate change impacts

The evidence of climate change is unequivocal [8]: the average global temperature, currently around 0,8°C above pre-industrial level, continues to rise, even more

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evidently in Europe [9]. Consequences of climate change, like alteration of natural processes, modifications of precipitation patterns, melting of glaciers, rise of sea levels and so on, are increasingly evident. For this reason, whatever the warming scenarios and the level of success of mitigation policies, in the coming decades the impact of climate change needs to be considered, taking into account possible delay in achieving targets in reduction of greenhouse gas emissions as well as adaptation measures to deal with economic, environmental and social consequences of climate change [10].

A global assessment of climate change science is presented by the recent IPCC (International Panel on Climate change) Report [11]. The assessment considers new evidence of past, present and projected future climate change foresees by several independent scientific studies, based on observations of the climate system, theoretical studies of climate processes and simulations using climate models. Predictions of climate change are based on a set of four Representative Concentration Pathways (RCPs) scenarios, where radiative forcing target level, estimated for the year 2100, are fixed in comparison with pre-industrial values [12]. Globally, these scenarios generally lead to further warming and changes in the water cycle, but trends can be different or even opposite on local scale.

The EU response to climate change is an adaption strategy to enhance the capacity to withstand it and the readiness to respond to its impacts, particularly in most vulnerable key sectors like infrastructures and buildings, characterised by a long life span and high costs [10]. In this respect, a central role is played by technical standards and by their evolution during the lifetime cycle of the infrastructures and buildings [13]; implications of climate change for new and existing structures is then a key aspect in the development of second generation of Eurocodes [6]. In this context, the present study aims to determine the effects of Climate Change on snow loads on structures, implementing suitable numerical procedures to derive characteristic snow loads from available global and regional climate models.

3.2 Snow load in a changing climate

One of the trite remarks about global warming is that, as obvious consequence of it, a reduction of snow is generally expected, but it is not said. In fact, although in consequence the global warming frequency of snow events should reduce, the intensity of extreme snow events may increase, since the capacity of the atmosphere to hold moisture (and to form snow particles in case of sudden temperature's drop) increases with temperature. This may lead to the increase of both snow density and occurrence of extreme snowfalls in regions where temperatures still may happen to be below freezing level during precipitation events [1].

The above considerations are confirmed by some spectacular and catastrophic collapses of lightweight roof structures caused by snow, which occurred in the last years all around the Europe [14] and [15] like the roof collapse of the Katowice Exhibition Hall (2006), which caused 65 victims and over 170 injured people (Figure 1). A more wide illustration of some relevant failures can be found in [16], while the reliability level of existing structures designed with the current versions of Eurocodes, especially for those structures more sensitive to an increase of snow loads, like lightweight structures of widespan roofs, is discussed in [16] and [17].

Figure 1. Roof collapse of Katowice Exhibition Hall

To assess the evolution of the ground snow load and its impact on new and existing structures, future trends, in terms of intensity and frequency of precipitations in cold areas, should be compared with those adopted to develop current versions of snow load maps for structural design.

A suitable numerical methodology is proposed in order to estimate characteristic ground snow loads from available results of global and regional climate models (GCMs and RCMs) in the mid to long term time, according different scenarios RCPs.

As just said, the interpretation of the outputs of climate models is complicated by their spatial resolution, typically too coarse to study specific sites, which does not allow a direct evaluation of snow load trends. For this reason, the proposed procedure has been calibrated and validated against high quality measured data available for time series of 50 or more years and particular attention has been devoted to identify suitable techniques to check the homogeneity of the available data populations.

Finally, it must be stressed that intrinsic uncertainty affecting climate projections in different climate models reflects on their outcomes, so that conclusions about increase/decrease of actions need careful interpretations.

4 Procedure for the estimation of future trends of ground snow loads

The proposed procedure consists of four steps:

- analysis of observed data series in order to derive conditional probability functions, linking snowfall and snow melting conditions with precipitation data and air temperature;
- development of a predictive model to evaluate snow loads from available meteorological data;
- calibration and validation of the model predictions against observed data series;
- implementation of the model on projected data series from global climate change models.

.4.1 Analysis of observed data series

Relevant meteorological data recorded in the past, daily temperatures and precipitation (water equivalent and snow cover depth), have been collected and analysed with the purpose to seek the conditions of maximum and minimum daily temperature, $T_{\max}$ e $T_{\min}$, at which snow cover depth increases, in case of precipitation of height h_r, or decreases, melting or increasing densities, and rainfalls are likely to occur.

In particular, seven different situations have been identified comparing day *n* and day *n-1*:

1. total melting of snow cover present at day *n-1*;
2. partial melting of the snow cover present at day *n-1*;
3. constant snow cover depth without precipitation;
4. rainfall in absence of snow cover at day *n-1*;
5. rainfall and total melting of the snow cover present at day *n-1*;
6. precipitation on snow cover with snow depth decreasing;
7. snowfall with increasing of snow cover;

and, following the flowchart shown in figure 2, the daily measured data can be allocated according to them.

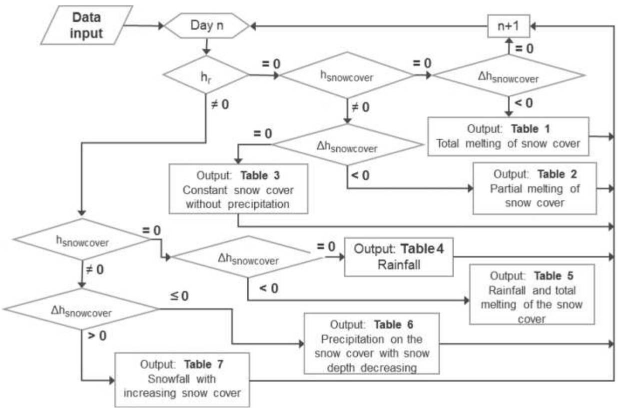


Figure 2. Flowchart for allocation of daily measured data

For each relevant situation, the frequency histograms have been then derived according to the conditions

$$Z(\bar{T}_{min}, \bar{T}_{max}) = number\ of\ cases\ of\ each\ situation\ for\ which$$
$$\left(\bar{T}_{max} - \frac{\Delta T}{2}\right) < T_{max,n} < \left(\bar{T}_{max} + \frac{\Delta T}{2}\right)$$
$$\left(\bar{T}_{min} - \frac{\Delta T}{2}\right) < T_{min,n} < \left(\bar{T}_{min} + \frac{\Delta T}{2}\right)$$
$$-20°C < \bar{T}_{min} < 40°C\ ; -20°C < \bar{T}_{max} < 40°C\ ;\ \Delta T = 1°C \quad (1)$$

The histogram of frequencies for each of the seven situations are then converted into continuous surfaces $f_j(T_{\max}, T_{\min})$ by means of up to three two-dimensional Gaussian functions

$$f_j = \sum_i a_i\, e^{-\frac{1}{2}\left\{\left[\frac{(T_{\max}\cos\beta_i + T_{\min}\sin\beta_i) - (\mu_{\max,i}\cos\beta_i + \mu_{\min,i}\sin\beta_i)}{\sigma_{\max,i}}\right]^2 + \left[\frac{(T_{\min}\cos\beta_i - T_{\max}\sin\beta_i) - (\mu_{\min,i}\cos\beta_i - \mu_{\max,i}\sin\beta_i)}{\sigma_{\min,i}}\right]^2\right\}} \quad (2)$$

being i the number of the Gaussian functions, which is assumed equal to the number of local maxima of the histogram.

In eq. (2), each Gaussian function is defined by 6 parameters:

- a_i amplitude
- β_i angle of rotation with respect to x-axis ($T_{\max}$)
- $\mu_{\max,i}$ median value with respect to x-axis ($T_{\max}$)
- $\mu_{\min,i}$ median value with respect to y-axis ($T_{\min}$)
- $\sigma_{\max,i}$ standard deviation with respect to x-axis ($T_{\max}$)
- $\sigma_{\min,i}$ standard deviation with respect to y-axis ($T_{\min}$).

The parameters $\beta_i, \mu_{\max,i}, \mu_{\min,i}$ are derived from the peak values of the histograms, while the other parameters, $\sigma_{\max,i}, \sigma_{\min,i}, a_i$ are estimated by means of least squares method and imposing the condition of unitary volume underlying the surface ($\sum_i a_i = 1$).

Once derived the probability distribution function of the seven conditions f_j for each relevant condition, *j*=1,…7, it is possible to define conditional probability functions of snowfall and snow melting for given values of the daily temperatures, $\bar{T}_{max}$ and $\bar{T}_{min}$. In particular, it results that

- the conditional probability function of snowfall in presence of precipitation is

$$P(snowfall(\bar{T}_{\max}\, \bar{T}_{\min}) \mid prec) = \frac{n_7 \cdot f_7}{n_7 \cdot f_7 + n_4 \cdot f_4} \quad (3)$$

where n_7 is the number of cases of effective snowfall (condition 7) and f_7 is the consistent probability function previously defined; n_{4-5} is the number of cases of rainfall (conditions 4 plus 5) and f_{4-5} is the consistent probability function (an example of such a function for the Italian weather station of Spigno Monferrato is reported in Figure 3);

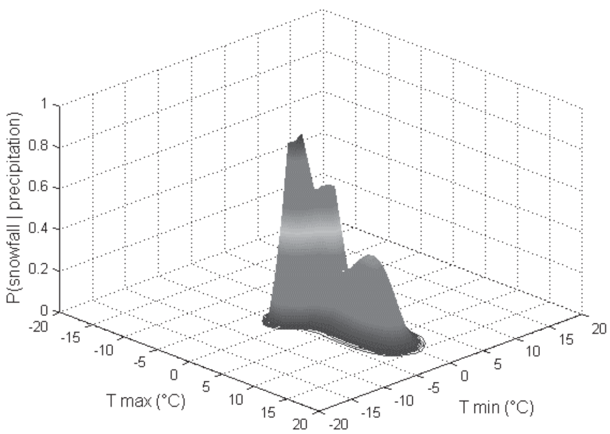


Figure 3. Conditional probability function of snowfall in presence of precipitation – (Spigno Monferrato – I)

- the conditional probability function of melting of snow cover in presence of snow cover is

$$P(snowmelt(\bar{T}_{max}\, \bar{T}_{min}) \mid snowcover) = \frac{n_{1-2} \cdot f_{1-2}}{n_{1-2} \cdot f_{1-2} + n_3 \cdot f_3} \quad (4)$$

where n_{1-2} is the number of cases of snow melting (conditions 1 plus 2) and f_{1-2} is the consistent probability function; n_3 is the number of cases of constant snow cover (condition 3) and f_3 is the consistent probability function previously defined and, obviously, $\bar{T}_{max} > 0°C$,(an example, for the Italian weather stations is reported in Figure 4)

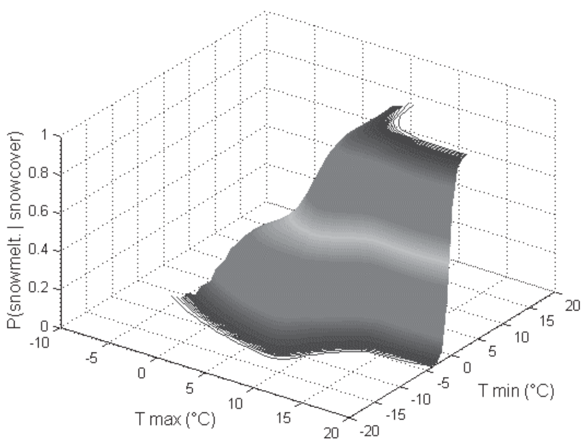


Figure 4. Conditional probability function of snow melting in presence of snow cover – Italy

4.2 Predictive model

A predictive model to evaluate ground snow loads has been then developed based on the previously determined conditional *pdfs*. In Figure 5, it is presented the flowchart of the algorithm which has been implemented through a suitable Monte Carlo simulation.

The input data of the algorithm are three relevant meteorological daily data: the maximum and minimum air temperatures, $T_{\max,n}, T_{\min,n}$, and the precipitation in mm of water, $h_{r,n}$, at the *n*-th day.

The probability of snowfall with increasing snow cover depth is estimated by checking the following conditions:

$$T_{min,n} < 5°C \ \wedge \ h_{r,n} \neq 0 \ \wedge \ P\big(snowfall(\bar{T}_{\max,n}, \bar{T}_{\min,n}) \mid prec\big) > R, \quad (5)$$

where 0≤*R*≤1 is derived from the randomly generated number, modified with the hypercube latin sampling technique.

When conditions (5) are satisfied, the increase of the ground snow load Δq_n at the *n*-th day is estimated in terms of water equivalent measured by the rain gauge:

$$\Delta q_n = 0{,}01 \cdot h_{r,n} \ \ \text{kN/m}^2 \ \ \text{with } h_{r,n} \text{ in [mm]} \ . \quad (6)$$

At the (*n+1*)-th day, several alternative and mutually exclusive events can happen, with an associated probability of occurrence:

- if snowfall conditions (5) are satisfied again, the ground snow load q_{n+1} is calculated as

$$q_{n+1} = q + 0{,}01 \cdot h_{r,n+1} \ \text{kN/m}^2 \quad (7)$$

- if snow melting conditions are satisfied, i.e.

$$P\big(snowmelt(\bar{T}_{\max,n+1}, \bar{T}_{\min,n+1}) \mid snowcover\big) > R \quad (8)$$

snow melts, partially or totally, being *R* defined before: the melting is assumed to be proportional to the value of $\bar{T}_{\max,n+1}$, so that the updated ground snow load becomes

$$q_{n+1} = q_n \cdot \left(1 - \left(\frac{T_{\max,n+1}}{20}\right)\right) \ where \ 0°C \leq \bar{T}_{\max,n+1} \leq 20°C \quad (9)$$

but, if $\bar{T}_{\max,n+1} > 20°C$ or $q_{n+1} < 0{,}025$ kN/m^2 total melting is considered.

- if rainfall precipitation occurs in case of snow cover, the new ground snow load is given by

$$q_{n+1} = q_n + h_{r,n+1} \cdot 0{,}01 \ \ \text{kN/m}^2 \leq 1{,}25 \cdot q_n \quad (10)$$

but, if $q_n < 0{,}01 \cdot h_{r,n+1}$ total melting is considered.

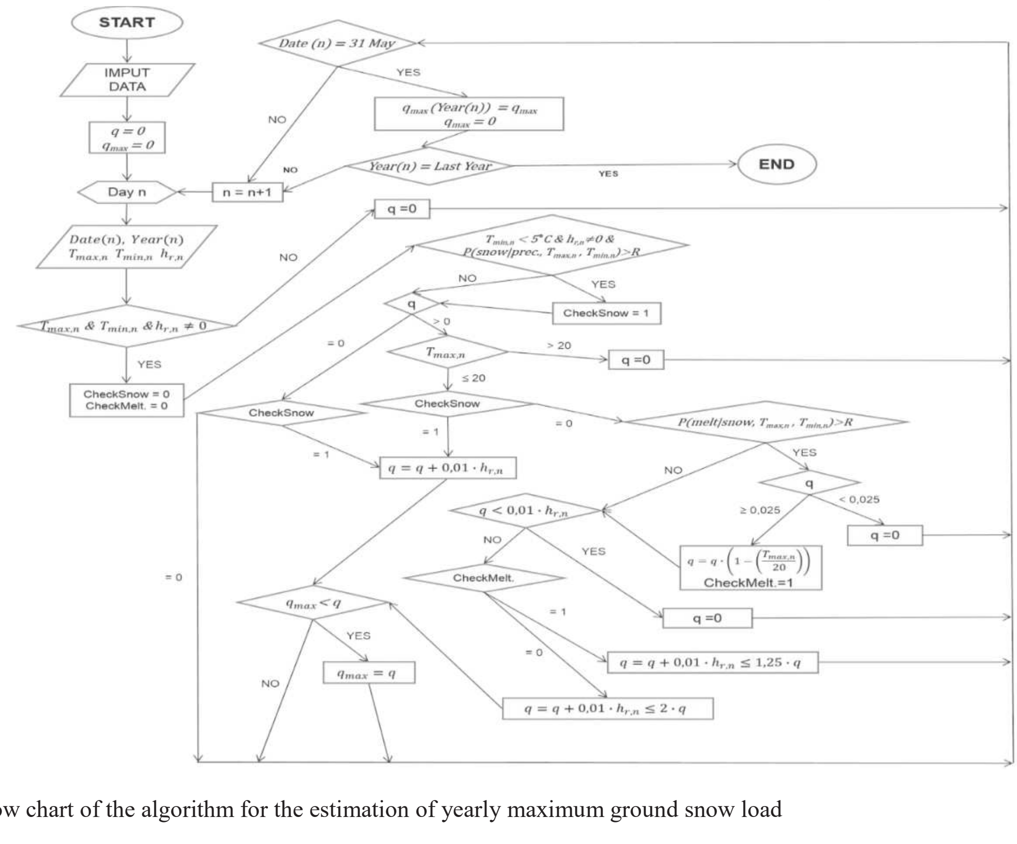
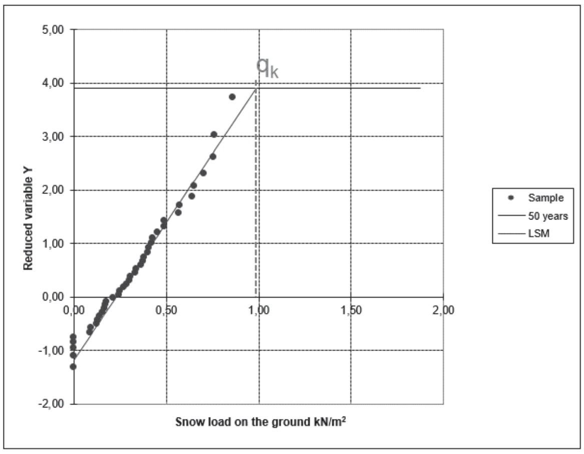


Figure 5. Flow chart of the algorithm for the estimation of yearly maximum ground snow load

The Monte Carlo simulation has been repeated for all days of the year, in order to estimate the yearly maximum ground snow load, $q_{\max}$. For each year, the process has been iterated 10'000 times: the median value of the distribution of each series has been taken as the best estimate of the maximum ground snow load for the examined year. Concerning the number of iterations, calibration exercises proved that 10^4, 10^5 or 10^6 iterations give practically coincident results.

From the set of the N yearly simulated maxima, the characteristic value q_k, associated to the probability of 2% to be exceeded in one year, has been finally derived, via extreme values analysis, as sketched in Figure 6.



Gumbel Probability Paper

Figure 6. Characteristic value of ground snow load

4.3 Calibration of the model

The methodology illustrated above has been initially tested against the observed data series of nine Italian weather stations (Figure 7), where high quality daily data are available for long time series (more than 50 years).

These weather stations have been selected between the 125 Italian stations, whose data were collected in the Database of the University of Pisa during the European Snow Load Research Project (ESLRP) [7].

The results compared with those obtained by ESLRP (Table 1) show that the outlined procedure is very promising and allows not only to derive characteristic ground snow loads, but also to assess the effects on solid precipitation measurements of snow transport phenomena caused by wind (Figure 8) [18] through an appropriate parameter, K_{corr}.

The parameter K_{corr}, which is characteristic of each climatic area, takes into account the systematic errors of snow precipitation measurements at the rain gauge [19] [20] which are mainly due to wind field deformation above the gauge orifice (Figure 9), and depend on the wind speed, the intensity of precipitation and the type of the gauge [19].

4.3 Analysis of climate projections

Once performed the calibration of the procedure against registered data series, which allowed to estimate the correction factor K_{corr}, the analysis has been extended to projected data series provided by different climate models (GCMs and RCMs) and different scenarios (RCPs) up to 2100. In particular, they have been used available high resolution data EUR11 (grid resolution of 12.5 km) developed within the EUROCORDEX initiative [21] [22] for the control period 1981-2005 (*Historical Experiment*) where "run" is forced by observed atmospheric composition changes[23] and for the future period 2006-2100 (*RCPs Experiment*) where "run" is forced by scenarios RCPs[23] illustrated in Table 2

The analysis has been carried out for subsequent time windows, each spanning over forty years; the obtained estimates of characteristic ground snow loads (q_k) are illustrated in Figure 10 for some of the nine tested Italian weather stations.

Country	Station	LON [°]	LAT [°]	Altitude [m]	q_{kESLRP} [kN/m²]
IT	*Ascoli Piceno*	13,56	42,90	136	1,12
IT	*Bologna*	11,36	44,50	51	1,67
IT	*Castelnuovo Garfagnana*	10,43	44,12	276	1,14
IT	*Lodi*	9,51	45,32	80	1,19
IT	*Massafra*	17,13	40,58	116	0,54
IT	*Pesaro*	12,91	43,92	11	1,07
IT	*San Giuseppe Jato*	13,19	37,97	450	0,94
IT	*Spigno Monferrato*	8,36	44,55	476	2,40
IT	*San Severo*	15,39	41,68	87	0,74

Figure 7. Italian weather station used in the analysis

Table 1. Results of the algorithm for ESLRP data.

Country	Station	Characteristic Ground Snow Load [kN/m²]		$K_{corr} = q_k/q_{kESLRP}$
		Tested Procedure q_k	ESLRP [7] q_{kESLRP}	
IT	*Ascoli Piceno*	0,68	1,04	**1,53**
IT	*Bologna*	0,99	1,66	**1,68**
IT	*Castelnuovo Garfagnana*	1,14	1,20	**1,05**
IT	*Lodi*	0,76	1,20	**1,58**
IT	*Massafra*	0,16	0,54	**3,38**
IT	*Pesaro*	0,67	1,07	**1,60**
IT	*San Giuseppe Jato*	0,50	1,21	**2,42**
IT	*Spigno Monferrato*	0,88	2,55	**2,90**
IT	*San Severo*	0,46	0,80	**1,74**

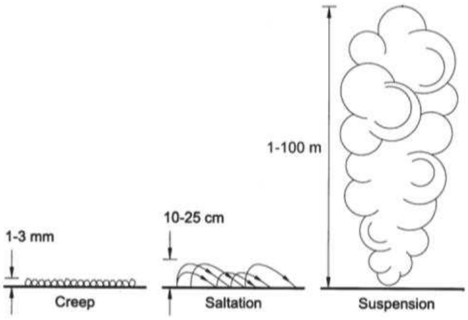


Figure 8. Snow transport phenomena [18]

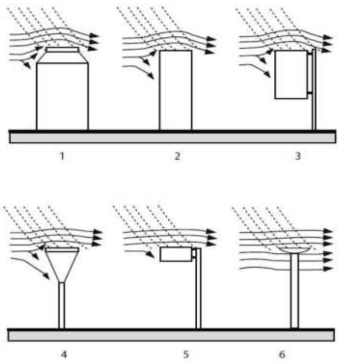


Figure 9. Wind field deformation at the rain gauge [14]

Table 2. Climate models and scenarios

RCM	Resolution	Driving GCM	Driving Experiment	Period
DMI-HIRHAM5	EUR11 (0,11°≈12.5km)	EC-EARTH	Historical	1981-2005
			RCP4.5	2006-2100
			RCP8.5	2006-2100
CNRM-ALADIN5.3	EUR11 (0,11°≈12.5km)	CNRM-CM5	Historical	1981-2005
			RCP4.5	2006-2100
			RCP8.5	2006-2100
KNMI-RACMO22E	EUR11 (0,11°≈12.5km)	HadGEM2-ES	Historical	1981-2005
			RCP4.5	2006-2090
			RCP8.5	2006-2100

Finally, to assess the variability of climate models and scenarios, for the nine investigated stations the characteristic values of ground snow loads associated to different scenarios ($q_{kRCP4.5}$ and $q_{kRCP8.5}$) have been compared, adopting different climate models.

Considering 40 years intervals shifted by 10 years, the ratio between $q_{kRCP8.5}$ and $q_{kRCP4.5}$ has been determined for the period 1981-2100, obtaining the trends shown in Figure 11.

The results show a general decrease of characteristic snow loads for the investigated stations, but the expected decreasing trend of the ratio $q_{kRCP8.5}/q_{kRCP4.5}$, namely a more marked decrease of snow loads linked to increasing emissions, is not confirmed for all of them.

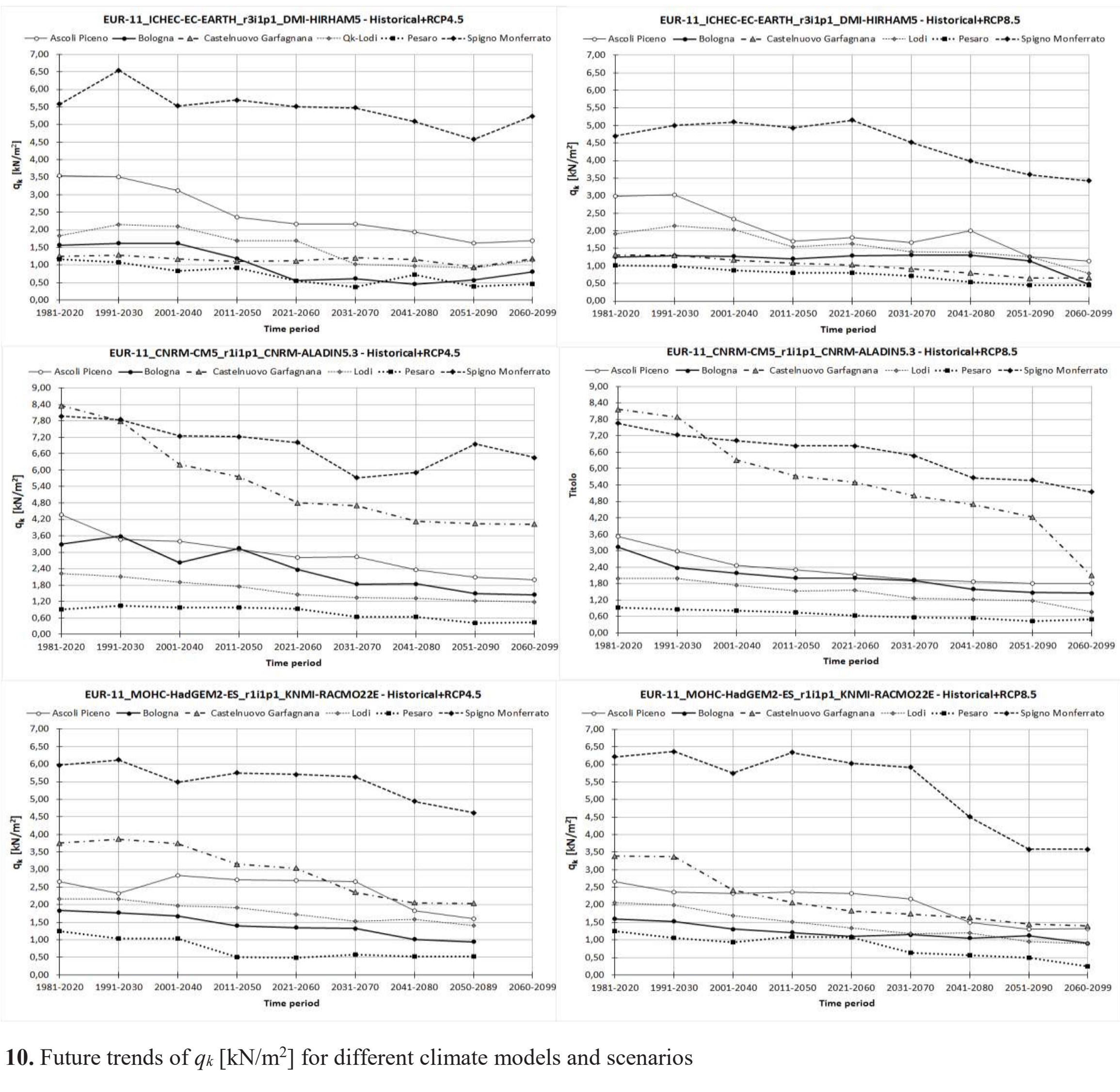


Figure 10. Future trends of q_k [kN/m^2] for different climate models and scenarios

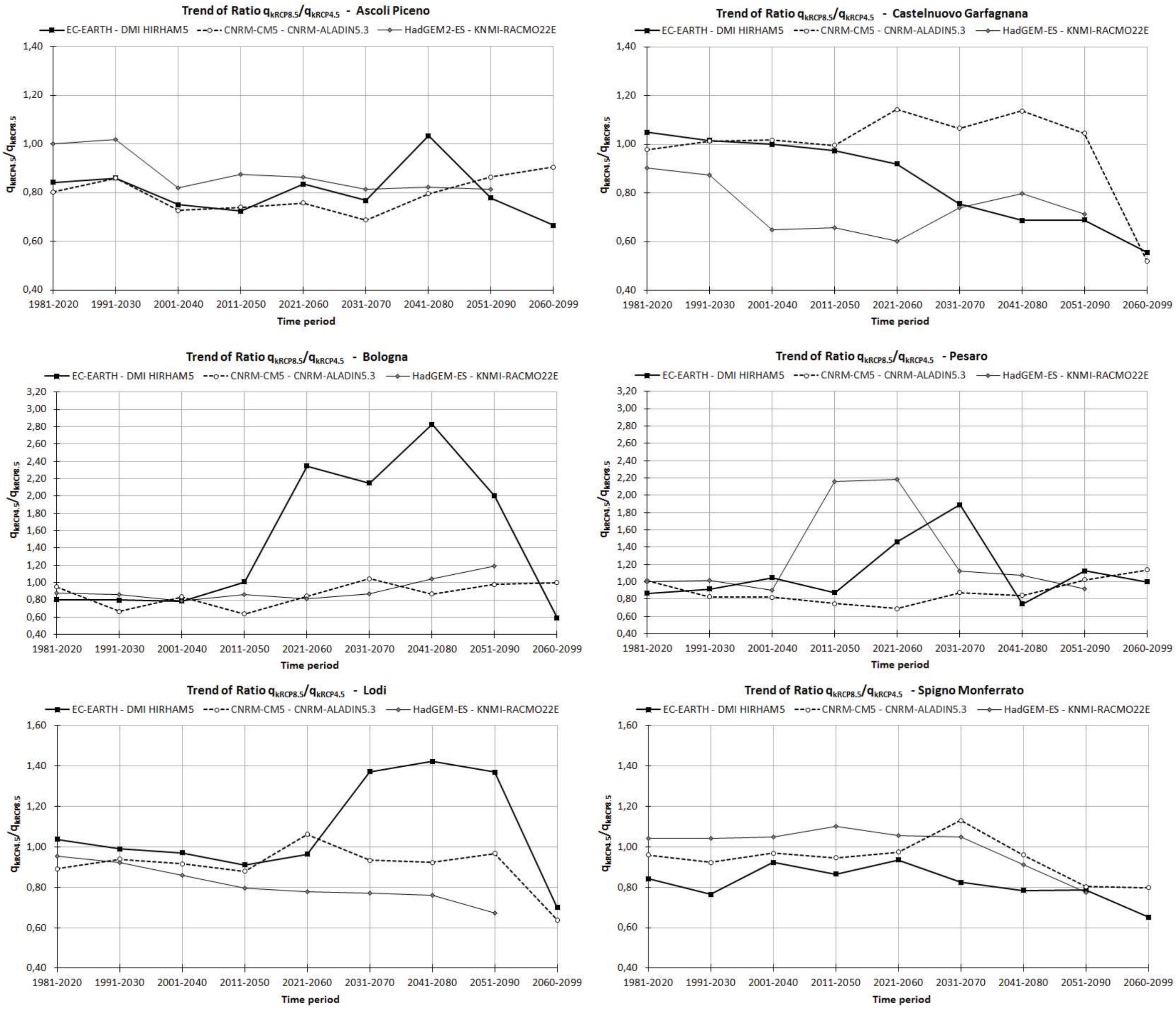


Figure 11. Trend of the ratio between $q_{kRCP8.5}$ and $q_{kRCP4.5}$ for different climate models and different stations

5 Preliminary results on snow map comparison

The proposed procedure seems very appropriate for creation of snow maps taking into account the effects of climate change, since it allows to estimate characteristic ground snow loads on the basis of daily data for the minimum and maximum temperature and precipitation, which are typically available as outputs of climate change projections for all possible scenarios.

Then, extending the previous analysis to a larger number of weather stations it is possible to obtain enough local information to update snow maps. The updated versions of the maps, critically compared with the current versions, will provide so a comprehensive overview of the impact of climate change, according to various RCPs scenarios [4].

However, before arriving to obtain consistent snow maps, further calibration is needed.

Indeed, climate projections are provided, in the higher resolution models, for cell of about 12,5×12,5 km (EUR11 - 0,11° on a rotated grid) and are generally agreed to represent area averaged data rather than point process data, especially for precipitation data [24]. Therefore, the analysis of gridded precipitation data can lead to an underestimation of extremes [24] [25].

5.1 Comparison of observed gridded data and observed point data

In order to assess a calibration method for the analysis of gridded datasets, able to correct the underestimation of extremes, the above mentioned issue has been especially studied for Italy, comparing characteristic ground snow loads obtained using grid cell data (E-OBS dataset) with those obtained by the European Snow Load Research Project (ESLRP) for the Mediterranean region [7]. In Figure 12, the location of the Italian weather stations considered in ESLRP is reported on the grid cell map of E-OBS.

The results confirm that characteristic values computed by the analysis of gridded data are typically lower than values obtained by point-data and that the difference

$$\Delta q_k = q_{kESLRP} - q_{kEOBS} \tag{11}$$

generally increases with the site altitude (Figure 13).

Starting from these results, a regression analysis has been carried out and a relationship between the difference of characteristic values Δq_k and altitude above the sea level A has been estimated as

$$\Delta q_k = a \cdot \left[1 + \left(\frac{A}{b}\right)^2\right] \frac{\text{kN}}{\text{m}^2} \text{ with A in [m]} \qquad (11)$$

where the parameters a and b have been calculated for each one of the four climatic zones defined by EN1991-1-3 for Mediterranean region in Italy obtaining the curves illustrated in Figure 14, 15 and 16. As in zones 3 and 4 the amount of available data is limited, the zones themselves have been merged.

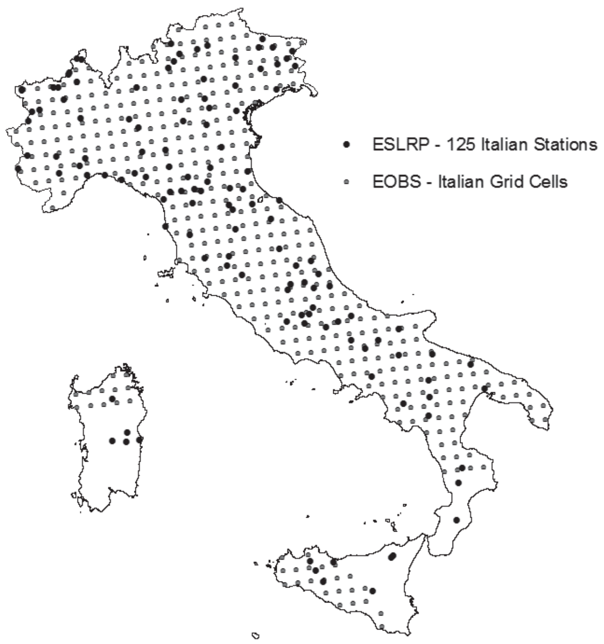


Figure 12. EOBS – Grid Cells and ESLRP weather stations for Italy

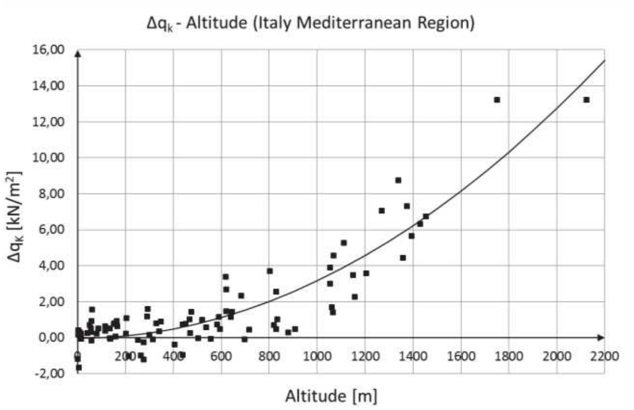


Figure 13. Δq_k– Altitude (Italy - Mediterranean Region)

Once these relationships are available, it is possible to draw, according to the results obtained by the analysis of gridded data, the snow load map on the ground, corrected in such a way that the data are referred to the sea level. This correction is very important because it allows to evaluate also results obtained for characteristic ground snow loads by the investigation of projected data with respect to the current code's previsions. (Figure 17).

Then, the next step will be the analysis of projected data, provided by different climate models, in order to derive maps of future trends of characteristic ground snow loads.

5.2 Actual trend of variation of ground snow load

Before the study of projected data, EOBS gridded data for Italian region have been analysed for subsequent time periods of thirty years in order to estimate both the actual trend of variation of characteristic ground snow loads and its future evolution.

The results are illustrated in Figure 18 and show different trends for Italian regions.

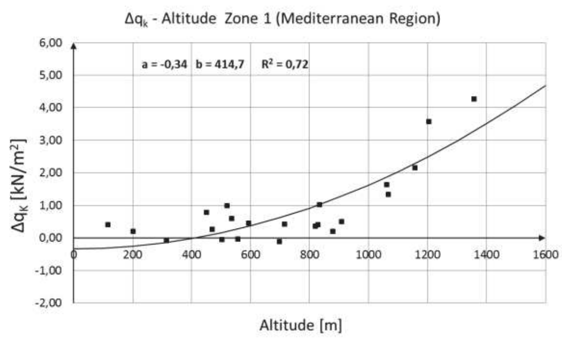


Figure 14. Δq_k -Altitude (Italy - Mediterranean region - zone 1)

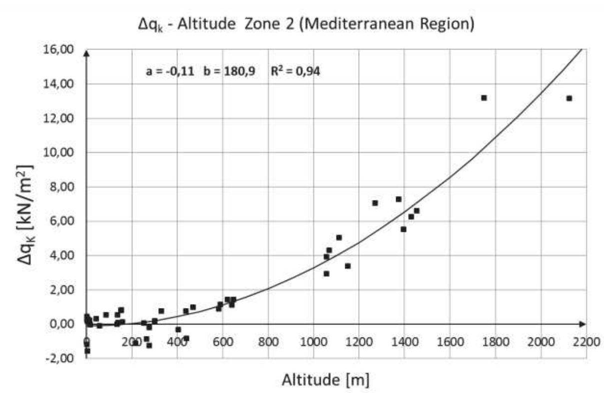


Figure 15. Δq_k– Altitude (Italy Mediterranean region-zone 2)

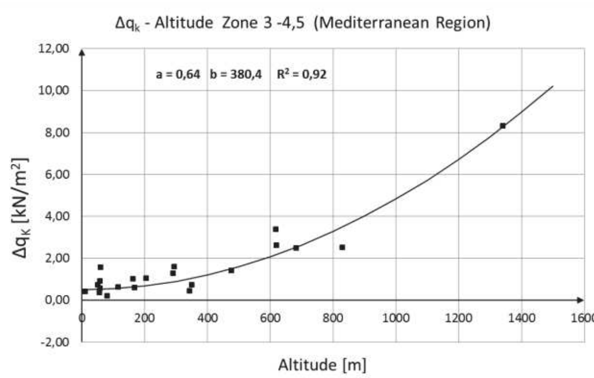


Figure 16. Δq_k–Altitude (Italy Mediterranean region-zones 3-4)

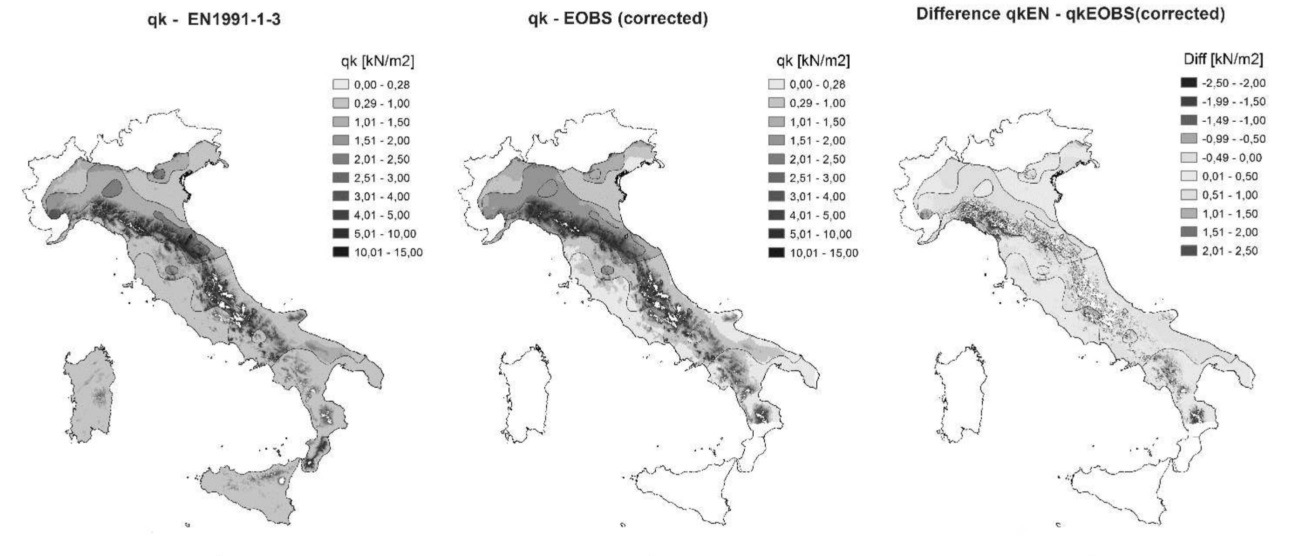


Figure 17. Comparison of Snow Load Map of EN1991-1-3 and Snow Load Map obtained using EOBS data corrected with altitude relationship

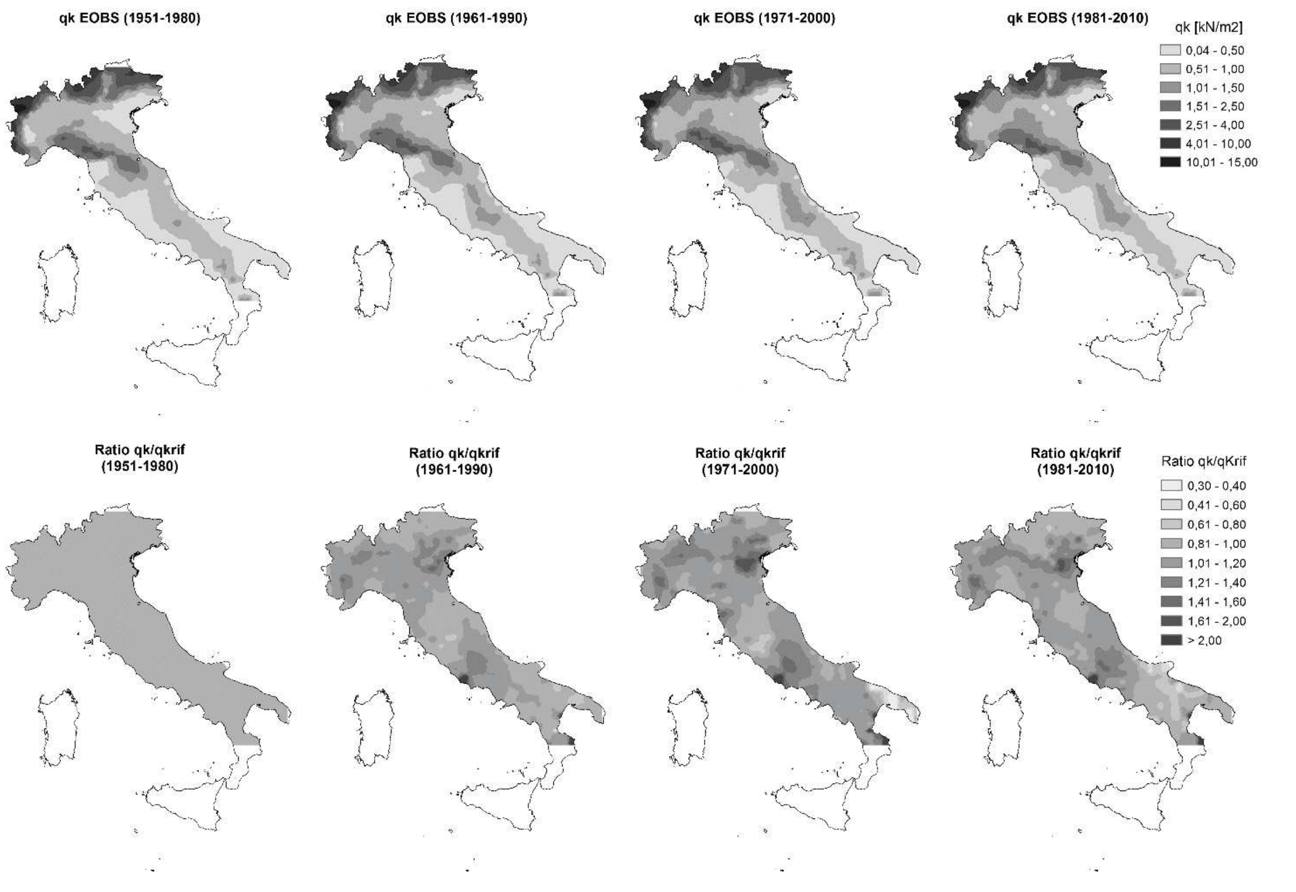


Figure 18. Snow load maps obtained using different periods of EOBS data

6 Conclusions

Implication of climate change on snow loads could have very high impact on design of structures as well as in assessment of existing ones. The problem is very relevant as it is demonstrated by a high number of structural collapses of lightweight structures due to snow.

For this reason, the setup of a suitable procedure to predict the snow load on ground according to various climate change scenarios could represents a very strong improvement in definition and adaption of snow load maps. This issue is particularly relevant in Europe, also in view of the development of future generation of Eurocodes.

Aiming to tackle this relevant issue, a general procedure to evaluate future trends of ground snow loads for structural design, taking into account the influence of climate change is proposed, based on Monte Carlo method.

The procedure, starting from the analysis of historical meteorological observations, allows to estimate ground snow loads and their characteristic values, on the basis of daily outputs of climate models, which are typically available (daily temperature extremes T_{max}, T_{min} and height of precipitation h_r).

The preliminary implementation of the outlined procedure is very promising and shows that there is a concrete possibility to arrive to define a general methodology for the estimate of characteristic snow loads on ground, according to prediction derived from climatological models, also on a local scale. Since the presented methodology seems to be able to appreciate the evolution of the snow load during the time, it should also allow proper refinement and updating of the snow load maps, according the real trends.

Extending the analysis to predicted data series covering a large enough number of weather stations across Europe, it will be possible to compare the future trends of snow loads, for each available emission scenario, with the current European snow load maps, assessing their evolution and their impact on structural design, in line with the requests by the European Commission to CEN in Mandate M515 within the European adaptation to climate change policy, in view of the development of the second generation of Eurocodes.

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