Harmonized European Ground Snow Load Map: analysis and comparison of national provisions

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Abstract. The set-up of common approaches for the elaboration of climatic actions maps across borders of neighbouring countries in Europe is one of the most relevant and challenging objectives towards further harmonization of structural Eurocodes. EN1991-1-3 is the part of Eurocode 1 dealing with snow loads on structures; its Annex C provide guidance for the elaboration of harmonized national maps referring to the European ground snow load map, derived within the European Snow Load Research Project (ESLRP). In the paper, in view of the elaboration of the "second generation of the Eurocodes", the Ground Snow Load maps used in different countries, as given in their National Annexes to EN1991-1-3, are critically discussed and compared with the European ground snow load map provided in Annex C, in order to detect inconsistencies, if any. The results still show lack of full consistency of ground snow load values across administrative borders between countries, stressing the need of further investigations to eliminate or to better justify such inconsistencies, enhancing the harmonization of the European snow map.

Keywords: Snow Loads, Snow Maps, Eurocodes, Harmonization.

1. Introduction

The development of a harmonized ground snow load map for Europe was one of the main objectives of the extensive pre-normative oriented research work [4, 5], which results were extensively transferred in the Eurocode EN1991-1-3 published in 2003 [1]. EN1991-1-3 superseded the previous pre-standard ENV 1991-2-3:1995 [2], in which the presented snow maps for member states of the European Committee for Standardization (CEN) were taken, almost directly, from existing national snow loading codes, available at that time [3]. The ENV document was deliberately drafted as an interim solution, in view of producing an improved and harmonised snow map of Europe. In 1996 the European

Commission funded a specific pre-normative study, the European Snow Load Research Project [4] [5], aimed to provide sounder scientific basis [6] for the conversion phase from ENV into EN of the snow load standard. EN1991-1-3:2003 is fundamentally based on the outcomes of that research, in particular regarding:

- definition, identification and treatment of the so-called “exceptional ground snow loads”,
- conversion factors from ground to roof snow loads (shape coefficients),
- combination factors for snow load (ψ_0, ψ_1, ψ_2) to be used in the Ultimate Limit States (ULS) and Serviceability Limit States (SLS) combinations of actions, and
- the harmonized European ground snow loads map elaborated for the eighteen countries, that at time of the research were CEN members : Austria, Belgium, Denmark, Eire, France, Finland, Germany, Greece, Iceland, Italy, Luxemburg, Netherland, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom).

The main scope of the afore mentioned harmonized European ground snow loads map, reported in the informative Annex C to EN1991-1-3, was to support National Competent Authorities in drafting snow maps to be included in their national annexes to EN1991-1-3, in order to enhance ground snow load harmonization reducing inconsistencies at borders between CEN Countries.

In the present paper, the impact of its informative Annex C on National snow maps of CEN Countries and the current state of the harmonization process are critically discussed, also taking into account the CEN enlargement from 18 to 34 Countries.

The work is further motivated in view of the evolution of the Eurocodes’ suite, requested by Mandate M/515 [7] of the European Commission to CEN [8], leading to the adoption of the second generation of Eurocodes, awaited in 2020-2023.

2. The definition of snow load maps in structural Codes

Ground snow load is the basic information needed for the determination of snow load on structures to be used for structural design. Different approaches, based on the extreme value statistical analysis of snow depths and snow water equivalent data are commonly adopted, under the assumption of stationary climate, to estimate design load values considering a given probability of exceedance in one year. The selection of the probability of exceedance should follows well-established reliability-based design code calibration procedures [9].

A yearly probability of exceedance of 0.02 (mean recurrence interval of 50 years) is considered in EN1991-1-3 [1], ISO4355 [10], ASCE 7-10 [11], and in the current version of Canadian Building Code [12], where, until 2005 it was set to approximately 0.03, corresponding to a 30 years mean return period. A 100-years recurrence interval (corresponding to a yearly probability of exceedance around 0.01) is assumed as a reference in the Japanese code [13], while the recurrence rate of snow load is taken on average to be one every 25 years in Russia [14], i.e. leading to a probability of exceedance of 0.04 in one year. In the Chinese Building Code [15], the basic ground snow load is based on the 50-year mean return period, but 100-year return period value is also given and recommended for design of snow load sensitive structures, such as light-weight and large-span roofs. Clearly, the selection of the probability of exceedance (or of the associated mean recurrence interval) depends on the overall calibration of the standards in use in a country, involving the evaluation of design values for materials' resistances and a comparison among different values is not straightforward.

Different distributions are adopted for the statistical analysis of extreme snow loads but the most widely used is the Gumbel distribution, implemented for the determination of basic ground snow load in the development of EN1991-1-3 [1], Canadian Building Code [12], Chinese Building Code [15] and Architectural Institute of Japan (AIJ) recommendations [13], while Log-Normal distribution was adopted in ASCE7-10 [11].

The choice of the proper distribution for ground snow loads should depend on different climate conditions as shown in [16], where three different cumulative distribution functions (CDF), Gumbel, Weibull and Log-Normal, were tested at 125 weather stations in the Italian territory. Gumbel distribution was fairly the best fitting CDF for sites located at low altitudes (<1000m a.s.l., where the populated area in Italy concentrates) and where snow was more intermittent and irregular; Weibull distribution instead was found to be the best fitting CDF for sites located at high altitude (>1500m a.s.l.) and where snow normally accumulates and lasts for the whole winter season; finally the Log-Normal CDF resulted not adequate for mild climates, such as the Italian one and similar results were found in other CEN countries like Greece, Spain and southern France. Ellingwood [17] analysed water equivalent data from 76 weather stations located in the north-east quadrant of United States, where the Log-Normal distribution showed to be preferable to extreme value distributions to determine extreme ground snow loads; these conclusions lead to the adoption of Log-Normal distribution as the basis for the definition of ground snow loads in ASCE7-10 [11].

Starting from the ground snow load values obtained at the investigated weather stations, ground snow load maps are derived to provide load values at any site within a given region. Different methodologies may be followed and in the following section, a detailed description of the procedure developed within the European Snow Load Project to obtain a harmonized ground snow load map for Europe is presented together with the resulting snow map given in Annex C of EN1991-1-3 [1].

With regards to other structural Codes outside Europe:

- a ground snow load map for US is given in ASCE7-10 based on the analysis of 204 National Weather Stations (NWS), where ground snow loads were measured for at least 11 years during the period 1952–1992 and snow depths from 9200 NWS synoptic stations. The correlation of snow depth with snow load was derived by means of a nonlinear curve best fitting the 50-year depths and 50-year loads elaborated for the 204 NWS, where both data sets were available; such correlation was then adopted to estimate ground snow loads at the 9200 NWS synoptic stations, where only snow depths were observed. Snow loads are presented for different zones [18], that may contain limitation for use above given altitude limits. Due for example to orography reasons and lake-storm effects, as stressed in ASCE7-10 [11], some areas are characterized by significant local variations in ground snow loads which cannot be accounted for at the national scale of the US map [18], in these cases specific studies are required;

- in the Canadian Building Code snow load values are provided in tabular form at 655 locations, which may not coincide with weather stations where data were collected; values are based on the analysis of snow depth and rainfall data at 1618 weather stations [19]. A detailed description of the methodology used to define snow load at the selected locations is described in [19]; contour maps based on the recommended values in the Canadian Building Code and obtained by using ordinary co-kriging, with the elevation as a covariate, are presented in [20] together with updated snow load maps based on new observations;
- in China ground snow loads for structural design are specified in GB-50009 [15] and presented in tabular form for given locations; load values are based on the statistical analysis of ground snow measurements (SWE or snow depths) up to 2008 at 672 weather stations. Snow load contour maps obtained from the analysis of tabulated code values, using the ordinary kriging technique are presented in [21];
- in the Commentary of the Architectural Institute of Japan Recommendations for Load on Buildings [13], annual maximum snow depth and snow loads with a mean return period of 100 years are provided as tabulated values at 142 weather stations of the Japanese Meteorological Agency. The extrapolation of load values at a different site is then possible by means of an empirical formula which allows the estimation of snow depth at the site as a function of its altitude and the sea ratio, defined as the ratio between the sea area and the total area within a radius of 10 km around the site;
- in Russia snow loads are defined in the Code of Regulations CR 20.13330.2011 [22], the territory is divided in eight snow regions and a corresponding value of snow load is associated to each region.

Therefore, among the examined major countries outside CEN area, a ground snow load map is currently available only in US, it is currently missing for Japan, Canada and China, where only tabulated values are given; in the Russian standards a simplified snow load map without considering altitude variation is provided. Moreover, it is important to note that current snow load maps are mostly based on the analysis of data collected until more than 20 years ago and recent data are not systematically used to update them.

In Europe recent studies carried out by Blanchet et al. [23,24] and Gaume et al. [25] highlighted the possibility to characterize extreme snowfalls with the Generalized Extreme Value distributions for the Alpine region. Moreover, spatial modelling of extreme snowfalls [25] and snow depth [24] have been proposed by using max-stable processes and smooth spatial modelling techniques showing promising results in comparison with the classical station interpolation methodologies [24]. In [26] and [27] the authors proposed a Bayesian hierarchical model for snow load map definition and refinement taking into account also climate change effects by means of the analysis of climate models' output. However, currently these refined procedures have not yet been applied for the definition of climatic actions in structural Codes.

3. The European Ground Snow Load Map in ESLRP and EN1991-1-3-Annex C

As already mentioned, the current version of EN1991-1-3 is largely based on the outcomes of the European Snow Load Research Project (ESLRP) [4] [5].

In ESLRP snow precipitation data were collected across the 18 CEN countries at approximately 2'600 weather stations. Data series, generally longer than 50 years and not shorter than 30 years, consisted of water equivalent and snow cover depth measurements; snow heights were converted into snow loads by means of appropriate snow density functions defined for each Country or climatic zone. Snow data series were deeply checked and yearly maxima were extracted to be statistically processed through extreme values analysis, taking into account both zero and non-zero values (non-snowy winters and snowy ones), following the so-called "mixed distribution approach" [4].

Comparative studies, carried out within the research project, showed that the best fitting extreme value distribution in the majority of weather stations across the whole European territory was the Gumbel distribution one, while characteristic loads were defined as those having a probability of exceedance of 0.02 per year consistently with the general approach for climatic actions set out in the Eurocode Basis of Design (EN1990:2002 [9]).

In [5] at each weather station, the extreme values analysis was carried out excluding from the statistical sample the so-called outliers, i.e. exceptional values occurring by chance in the tail of the distribution (see, for example~~ also~~ [28~~,29~~]), specifying that ground snow load may be considered as an accidental action in locations where exceptional loads may occur. In the aforementioned research [5], ~~A~~a yearly snow load maximum was considered an exceptional value if it was bigger than 1.5 times the characteristic load, determined disregarding the considered exceptional value. However, although they were neglected for the estimation of the characteristic values, associated to the annual probability of exceedance of 1/50, they form the basis of separate statistics with the aim to identify extremely rare events with annual exceedance probability of 1/10,000, which were then treated as accidental loads.

The availability of characteristic values of ground snow loads, derived according to a common statistical approach, allowed the identification, through an iterative process, of ten different European climatic regions, characterised by homogeneous climatic features. The ten climatic regions (Iceland, Norway, Finland-Sweden, UK-Eire, Central West, Central East, The Alps, Mediterranean Region, Iberian Peninsula, Greece) together with the location of the 2’600 investigated weather stations are shown in Figure 1.

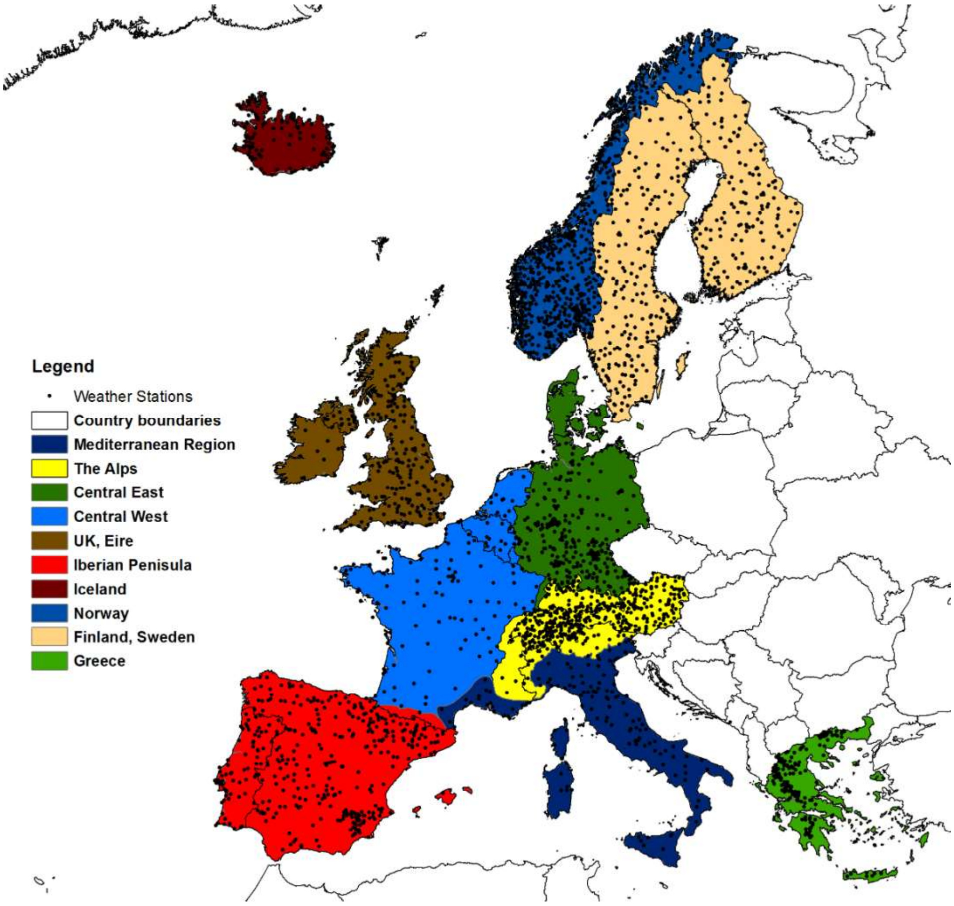

Figure 1. European Climatic Region defined in [3] and weather stations

The climatic regions were tailored in order to group areas in which a common relation between the characteristic ground snow load and the altitude of the site, where the weather station is located, was found to be satisfactorily representing the variation of the load with altitude in the whole region. Suitable altitude functions were tested on the climatic regions: a parabolic curve was adopted for the Iberian Peninsula, Mediterranean Region, Greece, Alpine Region and Central East, a linear-type altitude function was chosen for Sweden and Finland, UK and Eire and Central West, while for Iceland and Norway it was not possible to identify a clear altitude-snow load relationship and the ground snow load was presented in maps by means of isopleths. Finally, for each climatic region, different zones were defined in relation to the average altitude functions, assigning a zone number to each zone, which was used to modulate the load altitude correlation formula, to cover all the range of variation of loads at different altitudes in that region. Maps for each climatic region identifying the zones pertaining to the 18 CEN member Countries as well as the relevant load-altitude relationships employed in the elaborations are given in the already mentioned informative Annex C of the EN1991-1-3:2003. The maps, further elaborated by means of a GIS software, are summarized in Figure 2, where white spots identify sites at altitudes higher than 1500 m, generally requiring ad hoc studies, for which map does not apply.

It must be stressed again that Annex C, although not intended to be directly used for design purposes, represents a strong basis for the consistent development of national maps in European countries.

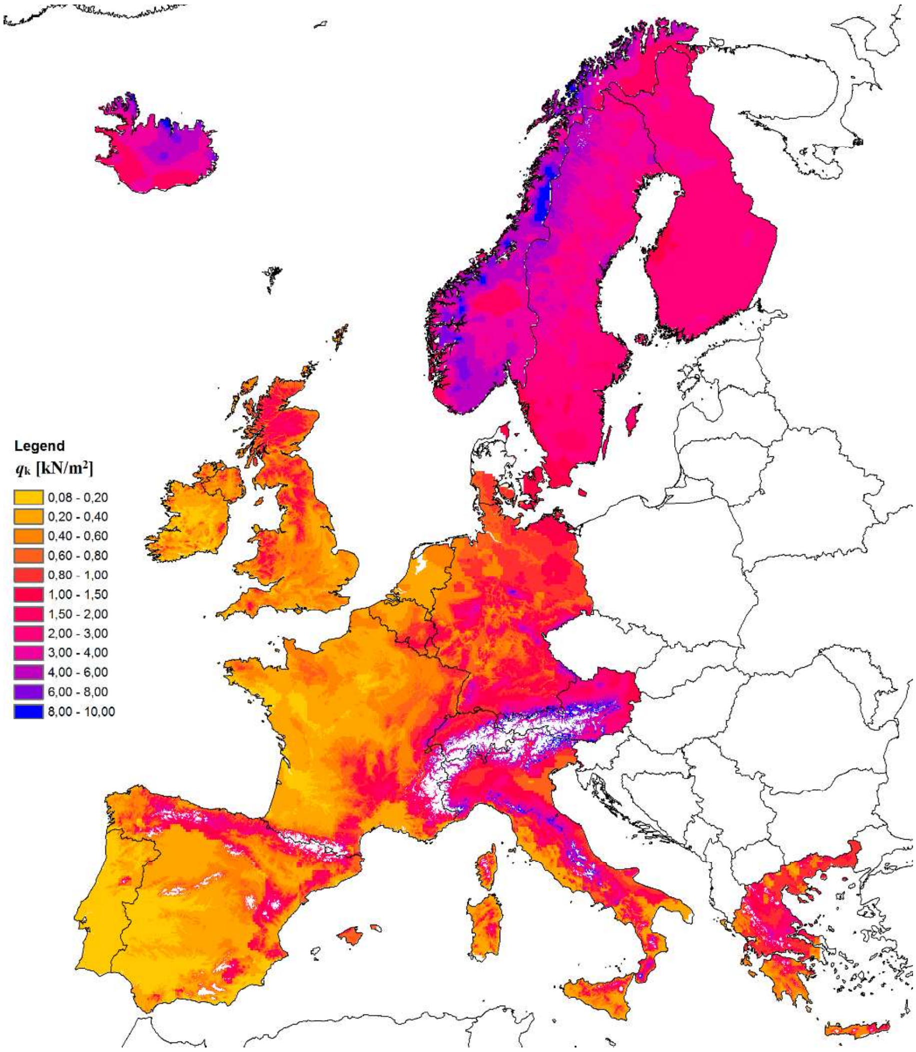

Figure 2. European Ground Snow Load Map defined by [1]

4. The national snow maps in EN 1991-1-3

As stated in their Foreword, Structural Eurocodes "*recognise the responsibility of regulatory authorities in each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level where these continue to vary from State to State*". As known, the safety policy is reflected in the Eurocodes by means of the so-called Nationally Determined Parameters (NDPs), which are the parameters, chosen at National level, to be used for the design of buildings and civil engineering works in a given CEN country. Since snow loads and ground snow maps in each country are typically safety related, they are also defined in the National Annex.

In order to discuss the level of harmonization of the European Ground Snow Load Map globally resulting from the present version of the National Annexes in force in the CEN member state, 30 available National Annexes to EN1991-1-3 were collected and analysed [30]-[59] (see Table 1).

As summarized in Table 1, snow load maps are presented in the National Annexes in different ways. Although the prevailing choice of National Standard Bodies was to plot snow maps in terms of climatic zones, each one associated with an appropriate load-altitude relationships, in some countries, like Cyprus, Hungary and Switzerland, a unique load-altitude law is given for the whole territory; in other countries, such as Belgium, the Netherlands and Denmark, a uniform value is given for the whole territory, while Bulgaria and Czech Republic provide a link to a website where the characteristic ground snow load at each site can be directly derived, consulting a digital map. In other countries, like Norway, values are presented in tabular form for each municipality, together with the recommended increase with altitude, due to the complex orographic features of the territory.

As already highlighted, for locations at altitudes higher than a given limit, generally 1500 m, ad hoc studies are needed. The limit of 1500 m, which is extended up to 2000 m in France and in Switzerland, is adopted in most of the countries; no altitude limits are given in Croatia, Czech Republic, Norway, Poland, Portugal, Romania, Slovakia and Slovenia, while different altitude limits, depending on the specific zone, are given in Spain.

Table 1. National Annexes to EN1991-1-3:2003 and details for the definition of Snow Maps.

	Country	Annex	Definition of Snow loads in Map	Altitude limit
1	Austria	ÖNORM EN 1991-1-3/NA	4 zones are defined with a load-altitude law.	1’500
2	Belgium	NBN EN 1991-1-3/NA	Minimum value equal to 0,5 kN/m^2 for A≤100m. Altitude law for 100m< A<700m.	Not relevant
3	Bulgaria	BDS EN1991-1-3/NA	Map of characteristic values for each location at http://gis.mrrb.government.bg/	1’500
4	Croatia	HRN EN1991-1-3/NA	4 zones and altitude variation given in a table in terms of 100 m intervals	No limit
5	Cyprus	CYS EN1991-1-3/NA	Formula for load-altitude variation obtained from Annex C - Mediterranean Region	1’500
6	Czech Republic	ČSN EN1991-1-3/NA	Minimum Value 0,7 kN/m^2, 8 zones are defined and values can be found for each location in the digital map on http://www.snehovamapa.cz	No limit
7	Denmark	DS EN1991-1-3/NA	1 kN/m^2 for all locations	Not relevant
9	Estonia	EVS-EN 1991-1-3/NA	3 Zones are defined with constant snow load: 1,25, 1,5 and 1,75 kN/m^2	Not relevant
10	Finland	SFS-EN 1991-1-37NA	Minimum values in a map. In areas where the values are not constant, intermediate values are obtained by linear interpolation in proportion to distances from the closest curves.	Not relevant
11	France	NF EN 1991-1-3/NA	8 zones are defined with minimum values. For altitude above 200m, different correction laws are given.	2’000
12	Germany	DIN EN 1991-1-3/NA	5 Zones are defined with minimum values; altitude correction laws are given for A>400m , 285m and 255m.	1’500
13	Greece	ELOT-EN 1991-1-3/NA	3 Zones are defined with altitude correction law.	1’500
14	Hungary	MSZT-EN1991-1-3/NA	Minimum value 1,25 kN/m^2 and unique load altitude relationship for the whole territory.	Not relevant
15	Iceland	ÍST EN 1991-1-3/NA	3 Zones are defined with constant minimum values (2,1; 3 and 5 kN/m^2) and a zone requiring site specific evaluation	1’000
8	Ireland	I.S. EN 1991-1-3/NA	Minimum Value 0,4 kN/m^2 4zones are defined with an unique altitude correction law for A>100m	Not relevant

16	Italy	UNI EN 1991-1-3/NA	4 Zones with constant minimum values (1,5; 1,5; 1 and 0,6 kN/m^2) and altitude correction laws for A>200m	1'500
17	Latvia	LVS EN 1991-1-3/NA	Minimum values are given in a map.	Not relevant
18	Lithuania	LST EN 1991-1-3/NA	2 Zones are defined with constant minimum values equal to 1,2 kN/m^2 and 1,6 kN/m^2	1'500
19	Luxembourg	ILNAS EN1991-1-3/NA	Minimum value equal to 0,5 kN/m^2 for A≤100m. Altitude correction law for 100m< A<600m.	Not relevant
20	Netherlands	NEN-EN 1991-1-3/NA	0,7 kN/m^2 for all locations.	Not relevant
21	Norway	NS EN 1991-1-3/NA	Values and altitude relationship are given for each municipality	No limit
22	Poland	PKN EN 1991-1-3/NA	5 zones are defined with minimum values and altitude correction laws.	No limit
23	Portugal	NP EN 1991-1-3/NA	3 zones are defined together with an altitude correction law.	No limit
24	Romania	SR EN 1991-1-3/NA	3 zones are defined with minimum values (1,5 2 and 2,5 kN/m^2) for altitude below 1000m. Altitude correction laws for A>1000m	No limit
25	Slovakia	STN EN 1991-1-3/NA	5 zones are defined together with altitude correction laws.	No limit
26	Slovenia	SIST EN 1991-1-3/NA	5 zones are defined together with altitude correction laws.	No limit
27	Spain	UNE EN 1991-1-3/NA	7 zones are defined together with altitude correction laws.	Defined for each zone
28	Sweden	SS EN 1991-1-3/NA	8 Zones are defined and constant values are given for each zone (1-5,5 kN/m^2)	1'500
29	Switzerland	SN EN 1991-1-3/NA	Minimum value 0,9 kN/m^2 and unique load altitude relationship for the whole territory.	2'000
30	United Kingdom	BS EN 1991-1-3/NA	6 zones are defined together with altitude correction laws.	1'500

Combining the information provided in the 30 National Annexes, the present version of the European ground snow load map illustrated in Figure 3 has been derived by means of a GIS software, considering, for the implementation of the relevant altitude laws, a digital elevation model with a horizontal resolution of 1x1 km.

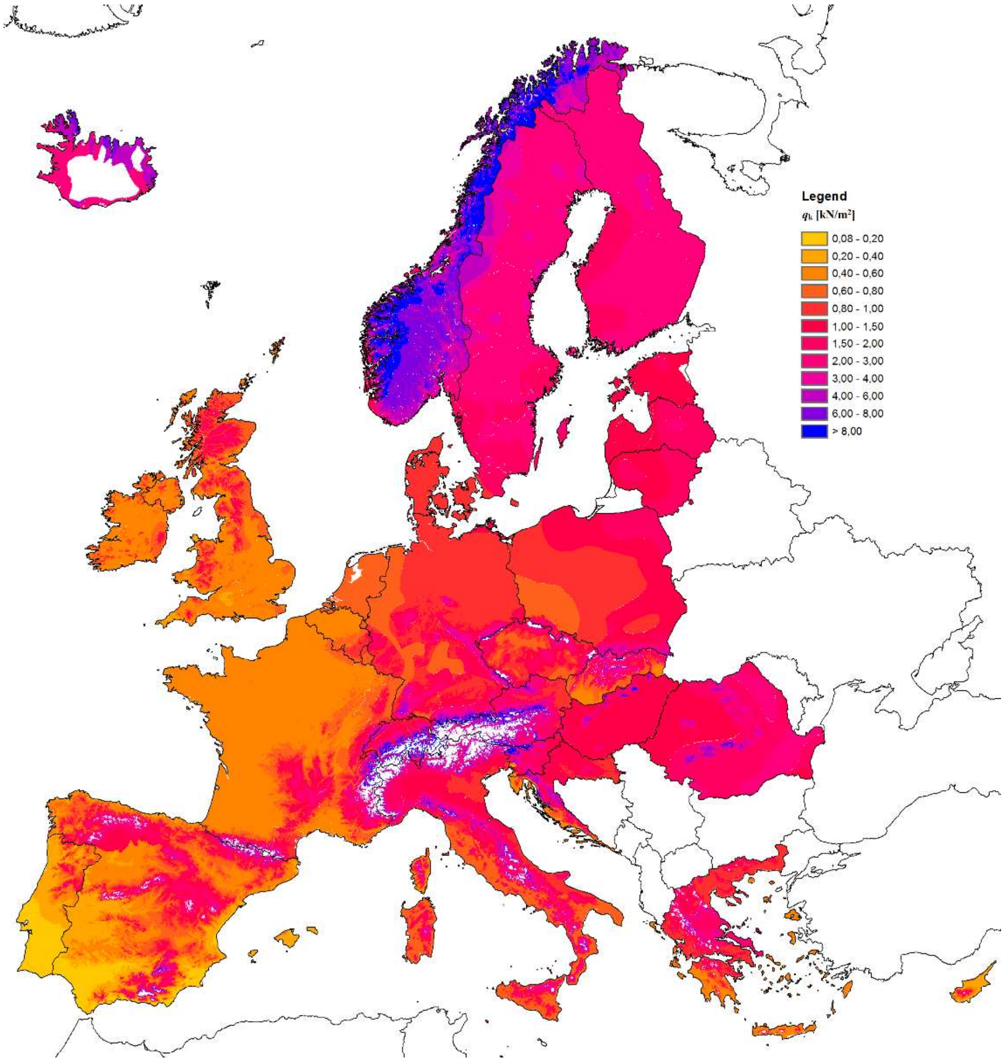

Figure 3. European Ground Snow Load Map resulting from CEN National Annexes.

5. Comparison and results

5.1 Snow maps in National Annexes to EN1991-1-3:2003 and in EN1991-1-3:2003 – Annex C

The comparison of the European ground snow load map presented in the previous paragraph (Figure 3) with the one provided in Annex C of EN1991-1-3:2003 (Figure 2) allows to appreciate the effectiveness of the latter in the derivation of national snow maps, in view of European harmonization. In the map illustrated in Figure 4, they are plotted the differences Δq_k [kN/m^2] between ground snow loads given National Annexes and those given in Annex C, considering the 18 CEN member states covered by the European snow load research project.

The map in Figure 4 shows that snow loads in National Annexes are generally higher than those obtained according to Annex C in Norway, Finland, Portugal, Spain, France, Netherlands, Denmark and Ireland, and therefore safe-sided in approximately 64% of the investigated European territory. This trend is particularly marked in Norway, mainly due to the implementation of a load altitude relationship for each municipality, not considered in the Annex C.

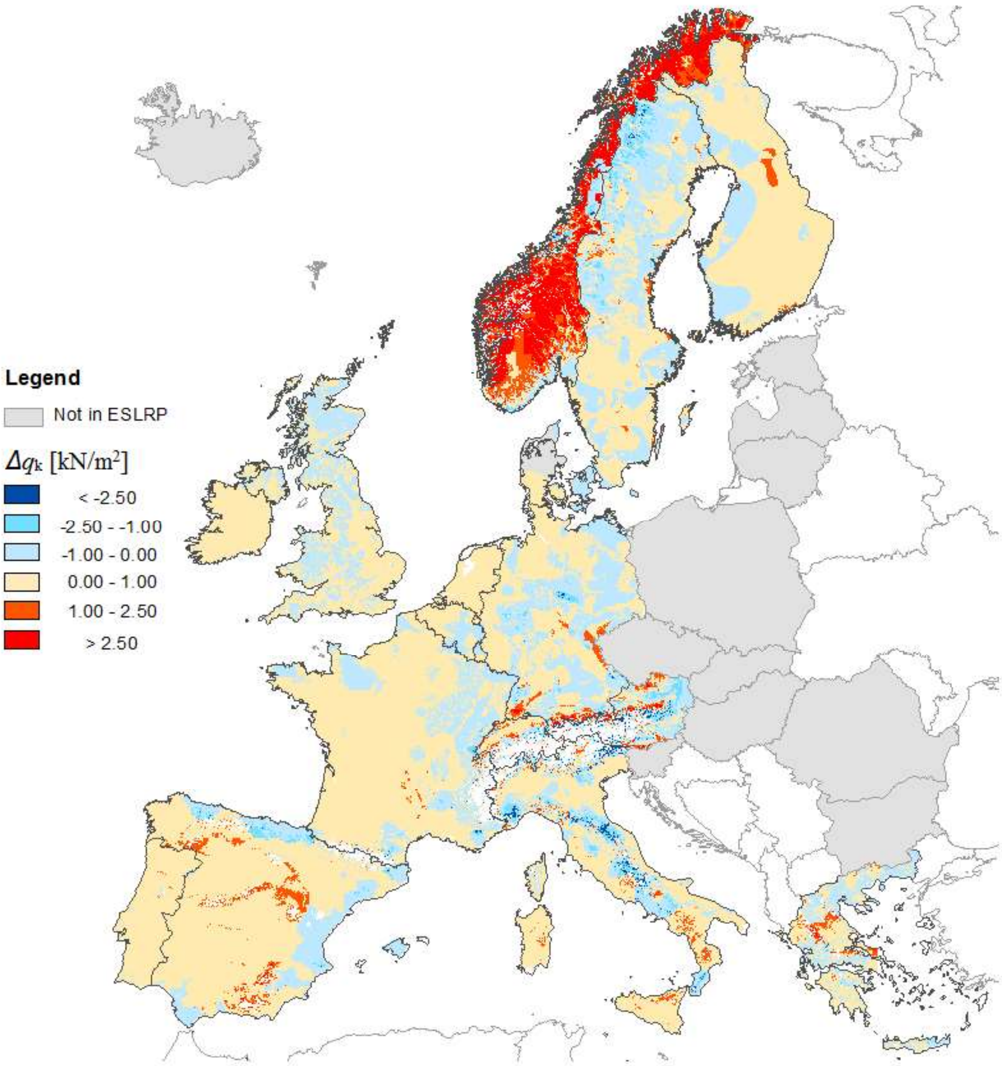

Figure 4. Differences between the snow load derived from the National Annexes to EN1991-1-3 and the snow load derived from Annex C.

Moreover, combining the results presented in Figure 4 with the map of the population density in the investigated territory (as shown in Figure 5) we can observe that snow loads in use for structural design purposes are higher than those obtained from Annex C in a large part, around 71%, of the most populated areas, i.e. with more than 10 inhabitants/km^2. Considering that the snow load maps given in Annex C directly represent the results of the statistical analysis performed on observed data series in the ESLRP framework, positive differences between National Annexes and Annex C values are safe-sided, so confirming the introduction of additional safeties in design for a large part of the populated European territory.

The increase of characteristic ground snow loads with respect to the values given in Annex C lead to an increase in reliability especially for snow load sensitive structures such as light-weight and large-span roofs for which, as discussed by Holicky and Sykora in [60] and [61], the present European standards could apparently lead to a reduced reliability level in comparison to other structural types.

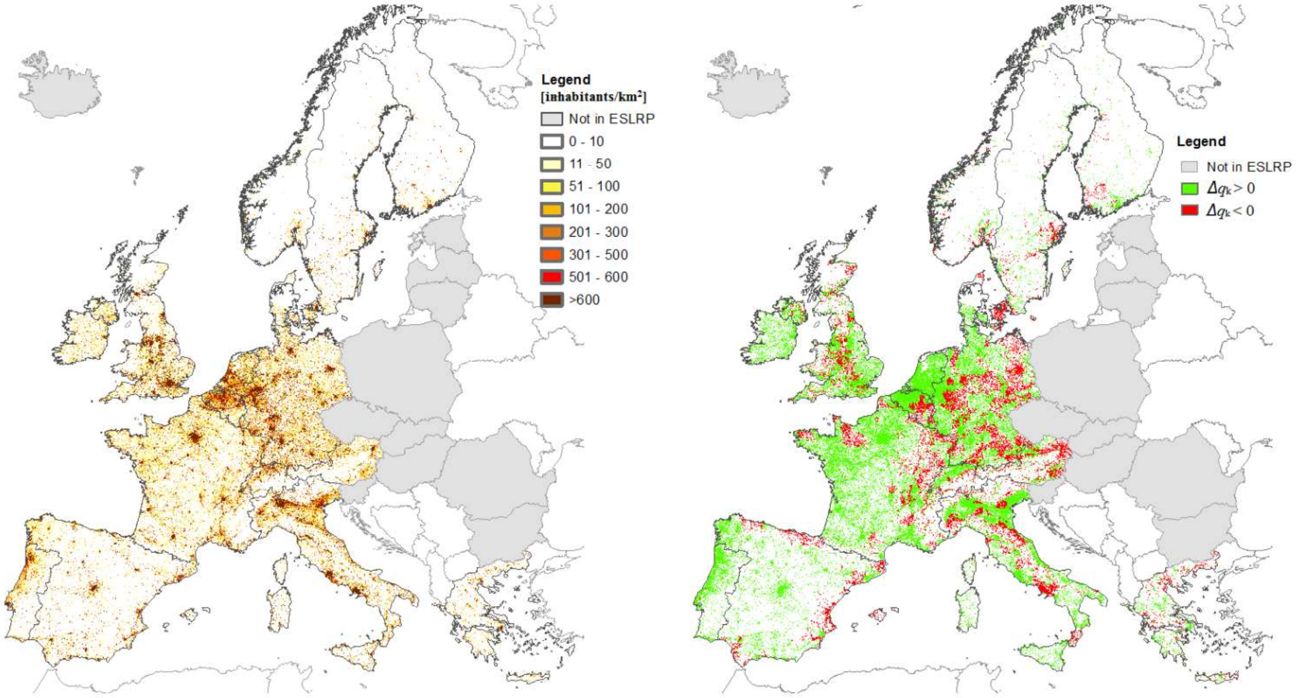

Figure 5. Differences in snow load definitions compared with a population density map.

The differences are mainly due to the different definition of zones as well as to the adopted load-altitude relationships. For example, according to EN1991-1-3-Annex C, the German territory, falling for a large part within the Central East climatic region and for the remaining southern part in the Alpine climatic region, should be divided in 8 different zones. In the German National Annex only five zones for the whole Country are established (see Figure 6). Since different load-altitude relationships are associated to each zone, the resulting snow load maps are shown in Figure 7, together with the differences between National Annex and Annex C values. It is interesting to notice how for low altitudes, the threshold values fixed in the National Annex leads to higher values of the load than those that were obtained by the statistical analysis of yearly maxima. This can be motivated by the decision to cover the uncertainty in the results of extreme value analysis in regions where the snow events are intermittent and few large snowfall events are observed

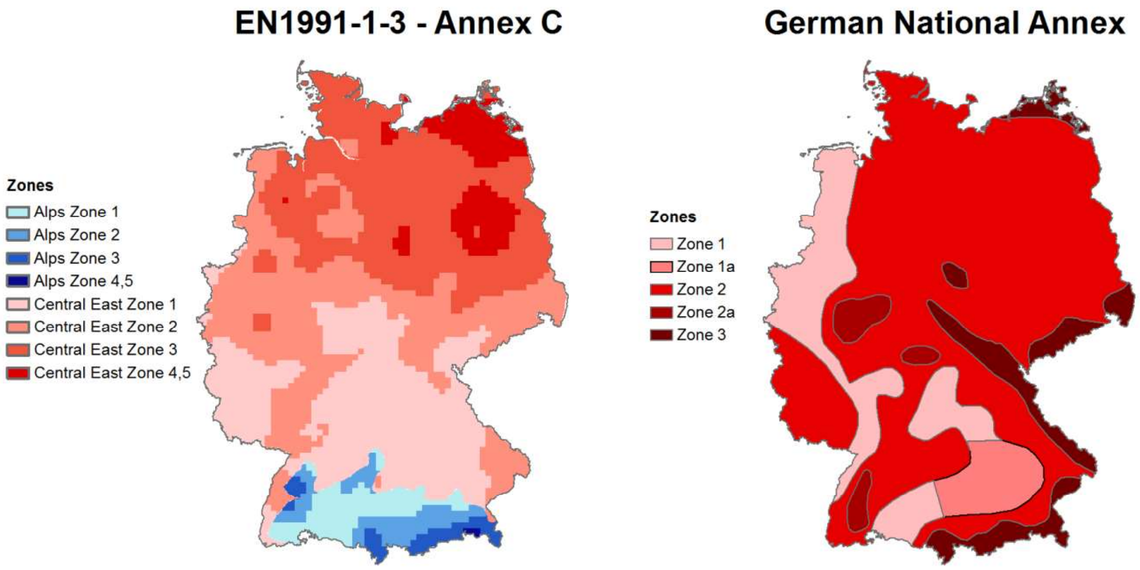

Figure 6. German snow load map zones in EN1991-1-3-Annex C and German National Annex.

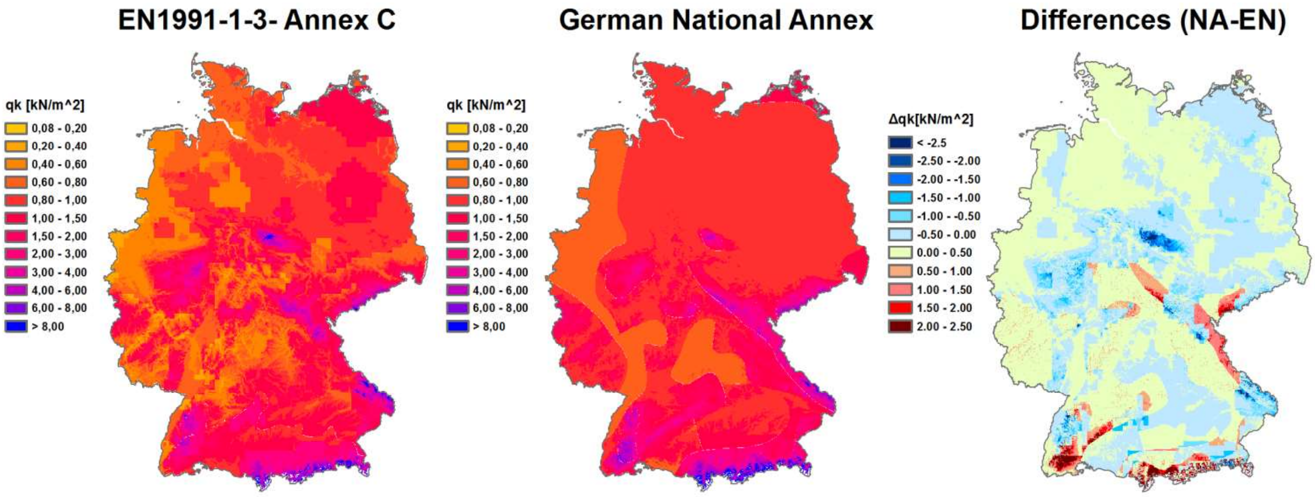

Figure 7. Comparison of characteristic ground snow load maps ESLRP – German National Annex.

There are multiple reasons explaining the detected differences: the quality and type of data (snow depths or snow water equivalent measurements), the time-series length, the homogeneous coverage of the territory as well as the different methodologies for their statistical treatment or the adopted interpolation and zoning procedures to derive load altitude relationships. In addition, in some cases, it is worth noting that the selection of load values, in particular where a minimum threshold is provided, was most probably influenced by traditional provisions of former National standards.

In order to quantify the differences due to each relevant aspect: type of snow measurements (snow water equivalent versus snow depths), length of records, statistical treatment, approach to zoning and set-up of safety thresholds, a detailed description about the procedure followed by each CEN Country in the development of their ground snow load map is needed.

To better understand the relevance of two main influences listed above, a quantification of the uncertainties related to the length of record and the statistical treatment of ground snow load were carried out for different locations in Italy. This comparison is further motivated as the length of the records commonly available doesn't allow to univocally appreciate the actual tail of the extreme value distribution.

In particular, 24 weather stations in the Italian territory characterized by the same type of measurements, i.e. daily snow cover depth, and period of measurements (1951-1990) were investigated. Three different type of distributions were selected for the comparative analysis: the Gumbel distribution (or Extreme Value Type I, EVI) adopted for the definition of ground snow load in Italy, the two-parameter Log-Normal distribution (LN) and the Generalized Extreme Value (GEV) distribution. The results, illustrated in Figure 8 and reported in Table 2, show that the estimated characteristic values according the GEV and LN model for the investigated stations can vary in range between -30% and +40% with respect to the adopted Gumbel distribution, which is the best fitting distribution for the Italian territory [16].

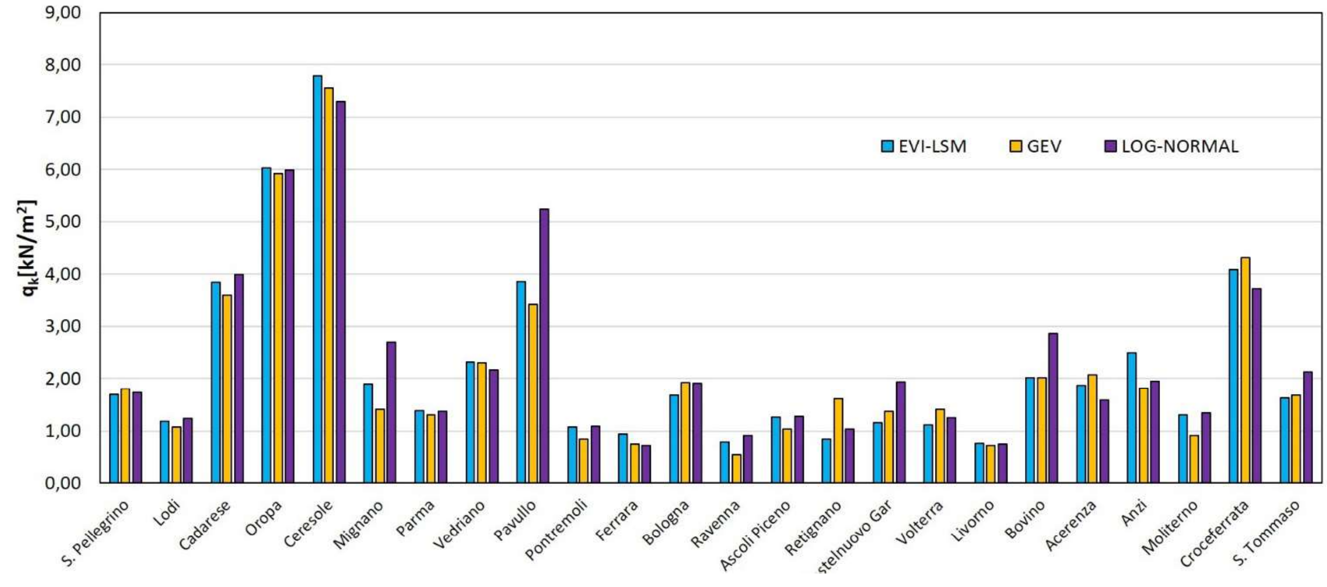

Figure 8. Comparison of characteristic ground snow loads obtained according Gumbel, GEV and LN distributions.

Table 2. Characteristic ground snow loads according Gumbel, GEV and LN distributions, percentage differences.

Station	*H a.s.l. (m)*	**EVI**	**GEV**	**LN**	**GEV-Δ%**	**LN-Δ%**
S. Pellegrino	355	1,69	1,80	1,74	6,4	2,7
Lodi	80	1,19	1,07	1,23	-9,6	3,8
Cadarese	725	3,84	3,58	3,99	-6,7	4,1
Oropa	1 180	6,03	5,92	5,99	-1,7	-0,6
Ceresole	1 579	7,79	7,56	7,30	-2,9	-6,3
Mignano	342	1,89	1,41	2,68	-25,7	41,9
Parma	56	1,38	1,30	1,37	-5,5	-0,7
Vedriano	590	2,31	2,30	2,17	-0,6	-6,4
Pavullo	682	3,86	3,41	5,23	-11,6	35,5
Pontremoli	215	1,07	0,83	1,09	-22,5	1,9
Ferrara	15	0,94	0,74	0,71	-21,0	-25,0

Bologna	51	1,68	1,92	1,91	14,8	14,1
Ravenna	4	0,78	0,54	0,92	-29,9	18,0
Ascoli Piceno	136	1,26	1,04	1,28	-17,5	1,5
Retignano	440	0,83	1,61	1,03	94,2	24,0
Castelnuovo Gar	276	1,15	1,37	1,94	19,2	68,5
Volterra	536	1,12	1,41	1,25	25,5	12,0
Livorno	3	0,75	0,71	0,74	-4,8	-0,9
Bovino	646	2,01	2,01	2,85	-0,1	41,8
Acerenza	833	1,87	2,06	1,59	10,6	-14,9
Anzi	1 066	2,48	1,81	1,95	-27,0	-21,4
Moliterno	879	1,30	0,91	1,34	-30,0	2,7
Croceferrata	970	4,08	4,31	3,72	5,6	-8,7
S. Tommaso	820	1,62	1,67	2,12	2,9	30,5
				Min	-30,0	-25,0
				Max*	25,5	41,9

*without Retignano

A comparative study was then carried out to estimate the differences that may arise in the presence of different length of the measurement period. Assuming a Gumbel distribution, series of 20, i.e. the minimum recording length recommended in ISO4355 [10] and EN1991-1-3 [1], and 30 consecutive years were analysed.

Recalling that the characteristic values, having probability of exceedance p=0.02 in one year, should be derived considering a 40-50 year period, the results so obtained should be duly modified considering the reduced observation period, so that the corrected yearly probability of exceedance becomes around p=0.01 for 20 year observation period and 0.015 for a 30 year period.

Comparing the outcomes obtained considering 20 or 30 consecutive years with those obtained analysing the whole 40 year observation period (1951-1990) for which data are available, results summarised in Figure 9 and Table 3, for the investigated Italian weather stations, have been derived.

In the Figure and the Table, they are reported the mean characteristic values for 20 and 30 year period as well as the characteristic value for 40 years. As evident from Table 3, differences range between -10% and +25% for 20 year period and -10% and +20% for 30 year period, which is not surprising considering that the coefficient of variation for Italian weather stations is around 0.6.

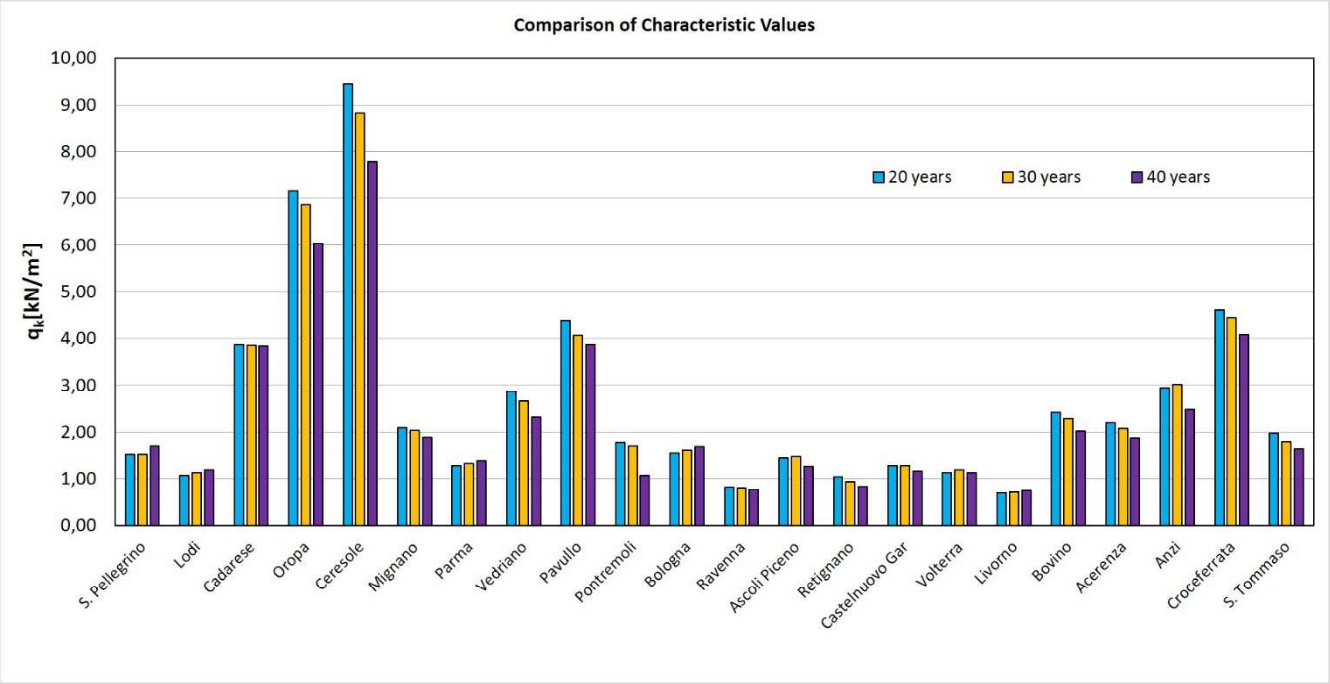

Figure 9. Comparison of characteristic ground snow loads considering 20, 30 and 40 years of measurements.

Table 3. Characteristic ground snow loads considering 20, 30 and 40 years of measurements, percentage differences.

Station	*H a.s.l. (m)*	**EVI Mean 20 years**	**EVI Mean 30 years**	**EVI 40 years**	**20-Δ%**	**30-Δ%**
S. Pellegrino	355	1,52	1,52	1,69	-10,3	-10,0
Lodi	80	1,07	1,12	1,19	-9,8	-5,7
Cadarese	725	3,86	3,85	3,84	0,6	0,4
Oropa	1 180	7,15	6,86	6,03	18,7	13,8
Ceresole	1 579	9,45	8,83	7,79	21,3	13,4
Mignano	342	2,09	2,03	1,89	10,4	7,5
Parma	56	1,27	1,32	1,38	-7,9	-4,6
Vedriano	590	2,87	2,65	2,31	23,9	14,6
Pavullo	682	4,39	4,08	3,86	13,7	5,6
Pontremoli	215	1,76	1,70	1,07	64,3	58,4
Bologna	51	1,54	1,61	1,68	-8,3	-4,1
Ravenna	4	0,81	0,80	0,78	5,1	3,3
Ascoli Piceno	136	1,44	1,47	1,26	14,8	17,2
Retignano	440	1,04	0,94	0,83	26,0	13,0
Castelnuovo Gar	276	1,27	1,28	1,15	10,3	11,0
Volterra	536	1,13	1,18	1,12	1,1	5,2
Livorno	3	0,69	0,71	0,75	-7,0	-4,3
Bovino	646	2,42	2,29	2,01	20,4	14,0
Acerenza	833	2,19	2,08	1,87	17,3	11,3
Anzi	1 066	2,93	3,02	2,48	18,2	21,6
Croceferrata	970	4,60	4,44	4,08	12,8	8,9
S. Tommaso	820	1,97	1,79	1,62	21,2	9,9
				Min	-10,33	-10,02
				Max*	25,95	21,65

*without Pontremoli

5.2 Evaluation of consistency of National Snow Load maps at borders

On the basis of the maps presented in the previous paragraph, a comprehensive analysis was carried out, using GIS software, to assess the consistency of maps at borders of neighbouring countries checking at the same time the degree of achievement of the objectives of the informative Annex C in terms of harmonization of national maps.

In Figure 10, they are plotted the values evaluated along the border between Switzerland and Germany (approximately 360 km from West to East), according to the two National Annexes, together with the point altitudes. The blue solid line represents snow load values obtained according to the Swiss NA [38], the red solid line represents corresponding values obtained according to the German NA [20], while in green the absolute difference between the two is shown compared to a threshold value equal to 0,2 kN/m^2 (black line). Percentage difference calculated with reference to snow loads on the Swiss side are also illustrated in the same Figure. The maximum difference $\Delta q_{\mathrm{k,max}}$ results equal to 1,16 kN/m^2 (approximately 38% of the corresponding Swiss load value).

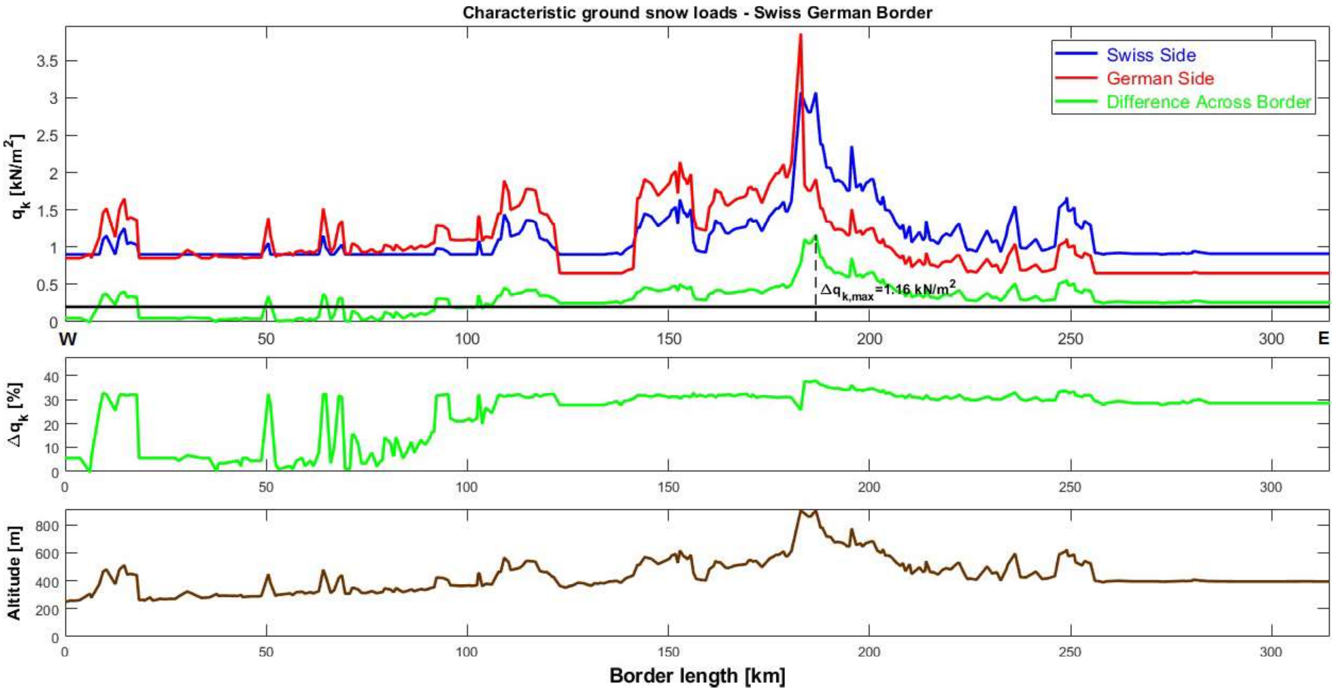

Figure 10. Comparison of characteristic ground snow loads at Swiss-German border.

Figure 10 and Figure 11 show similar diagrams for the borders between Switzerland and France (approximately 570 km from North to South) and France and Spain (approximately 650 km from the southwestern France and north-eastern Spain), respectively. The differences in percentage are calculated against Swiss values in Figure 10 and French values in Figure 11.

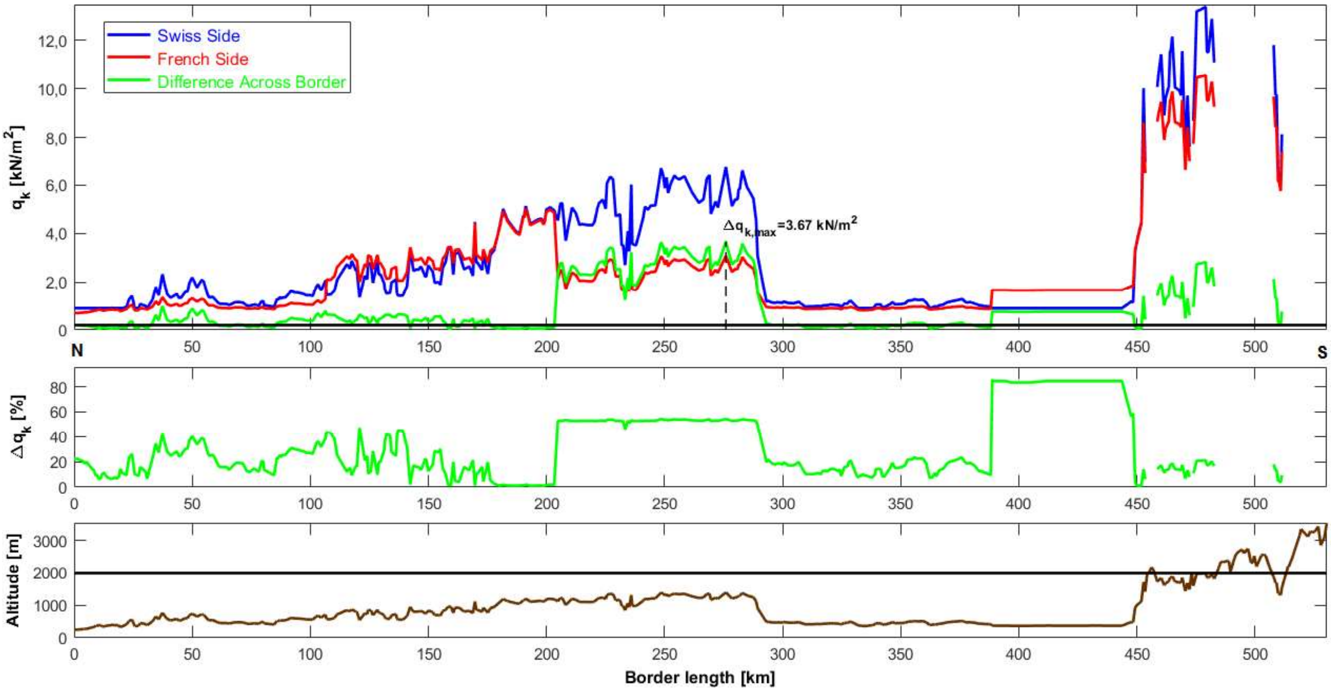

Figure 10. Comparison of characteristic ground snow load at French-Swiss border.

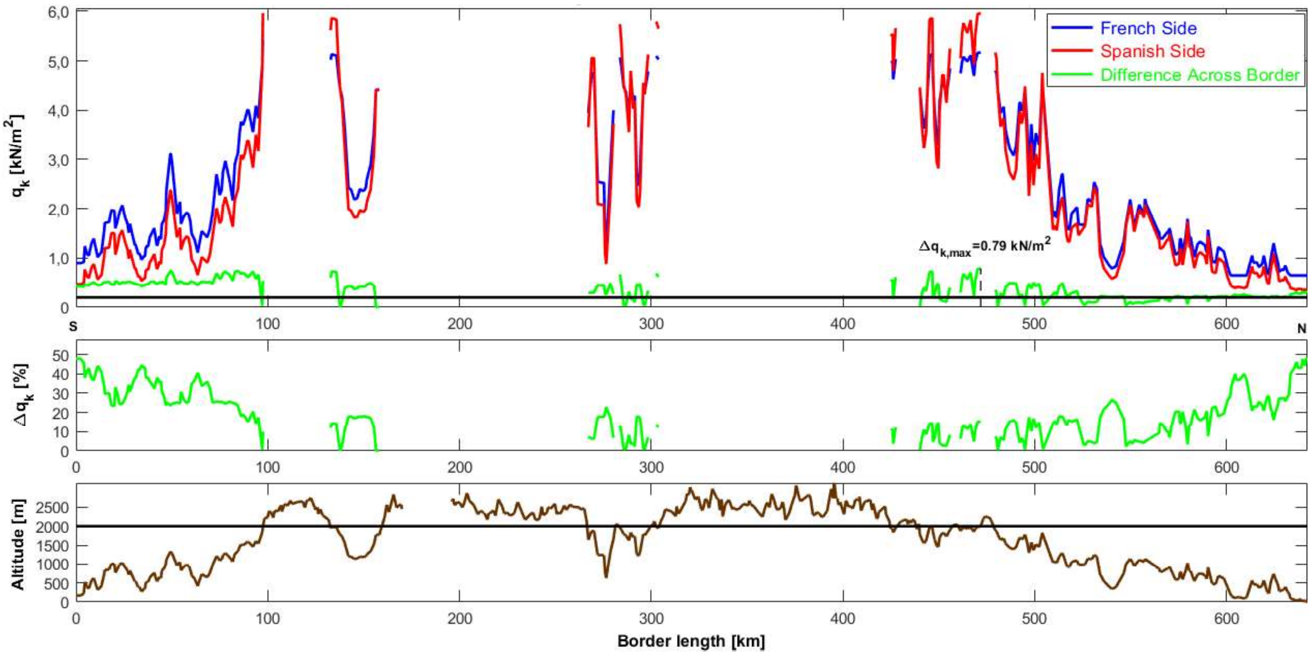

Figure 11. Comparison of characteristic ground snow load at French-Spanish border.

The comparisons presented in Figures 9 to 11 still show a lack of full consistency, which is mainly due to the difference in the altitude correlation functions adopted in the two neighbouring countries, but also to the adoption of different minimum threshold values, which can be regarded as a safety related issue, which is left to national determination and does not directly pertain to climatic reasons.

5.3 Difference across borders: climatic reasons

First of all, in the interpretation of the inconsistencies highlighted in the previous paragraph it must be considered that when administrative borders correspond to “climatic” boundaries identifying different climatic regions, these are justified. Mountain ridges or mountain slopes, may lead to a different definition of the load in the neighbouring climatic regions, as confirmed by ESLRP outcomes [5] [6].

As an example, the French-German administrative border overlaps the boundary between West and East climatic regions (see Figure 1). In Figure 12, the characteristic values of snow load evaluated along the border between France and Germany (approximately 450 km from North to South), are plotted according to the specifications given in EN1991-1-3 Annex C and the recommendations given in relevant National Annexes [19] and [20], together with point altitudes. In the Figure, the blue solid line represents snow load values obtained at the French side, the red solid line represents corresponding values obtained at the German side, while in green the absolute difference between the two is shown compared to a threshold value equal to 0,2 kN/m^2 (black line). Percentage difference calculated with reference to the French side load are also illustrated in the same Figure (green solid line for National Annexes and green dashed line for EN1991-1-3 Annex C).

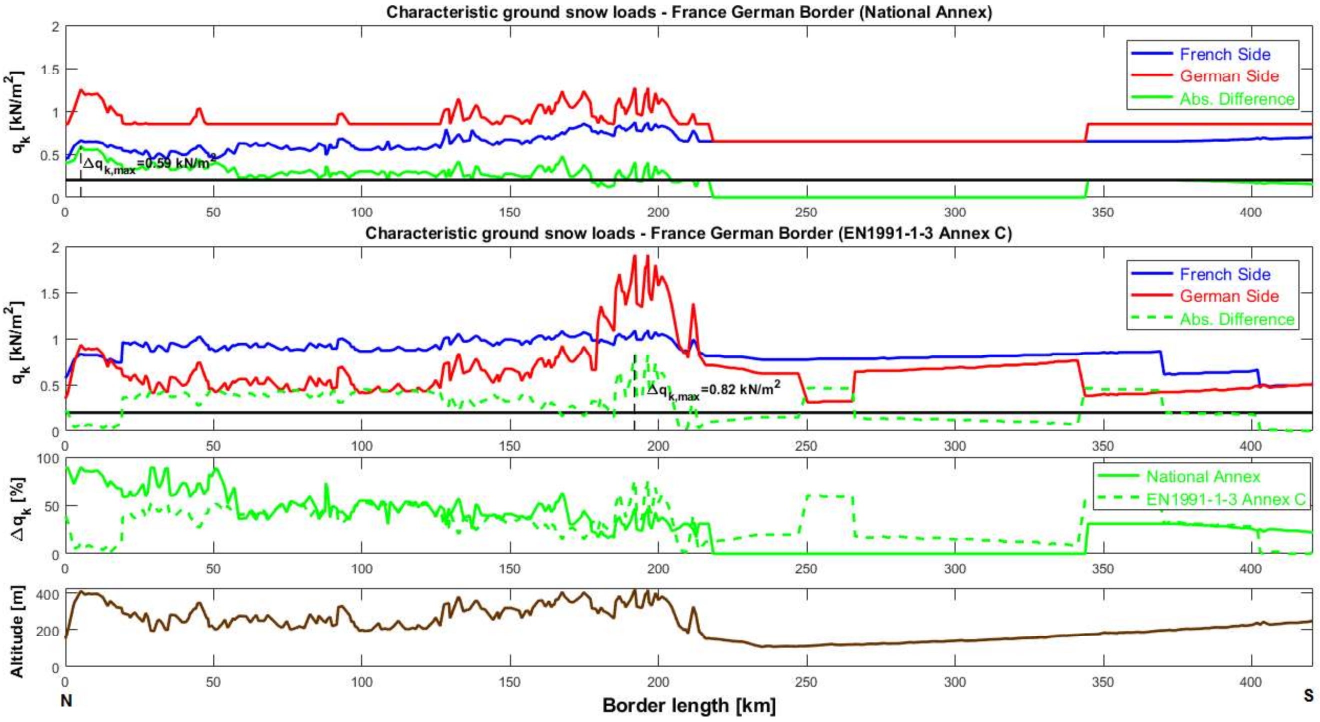

Figure 12. Comparison of characteristic ground snow load at French-German border according National Annexes and Annex C to EN1991-1-3:2003.

The maximum difference $\Delta q_{k,max}$ results equal to 0,59 kN/m^2 (approximately 89% of the corresponding French load value) according to National Annexes, being equal to 0,82 kN/m^2 (approximately 76% of the corresponding French load value) according to Annex C.

Snow load differences due to climatic boundaries can be observed also across other borders of climatic regions, for example focusing on the Italian territory, two climatic regions were identified in [5] and [6], the Mediterranean region and the Alpine region. As a consequence, if snow loads are computed at the two sides of the climatic boundary identifying the two regions, different values are found as shown in Figure 13.

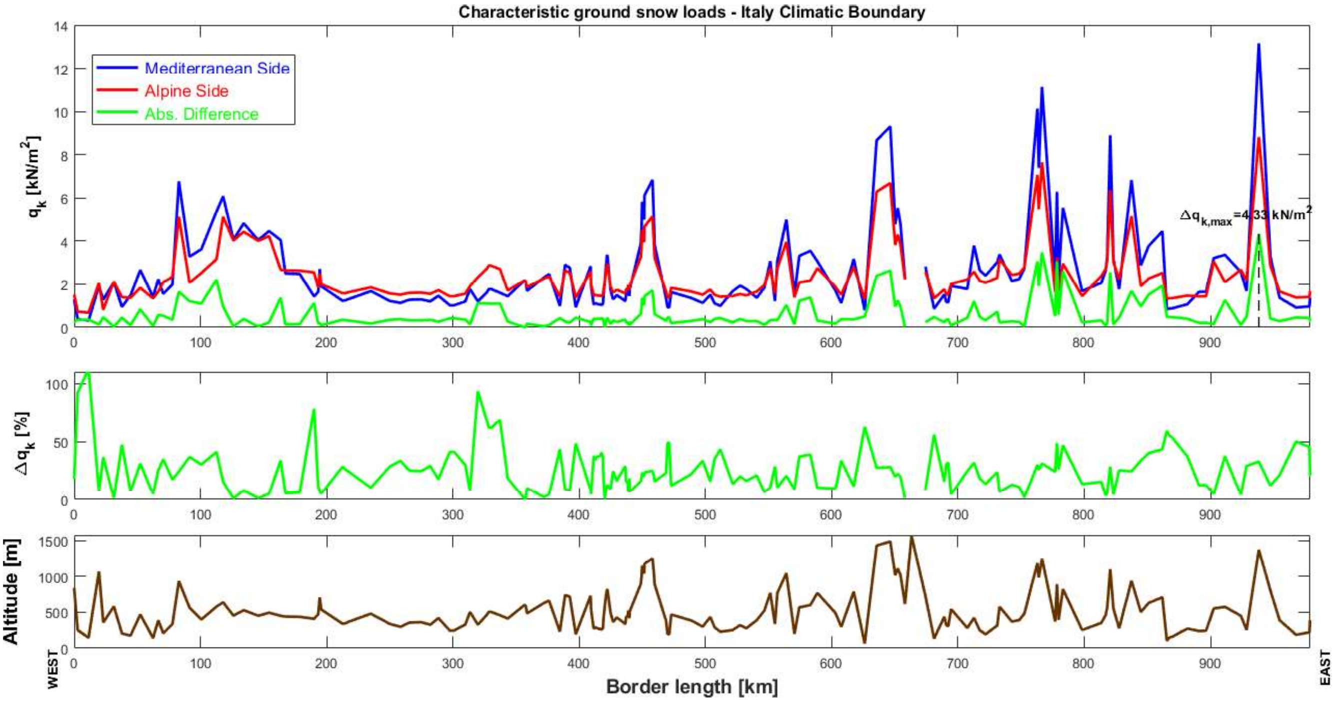

Figure 13. Comparison of characteristic ground snow loads at Italian climatic boundary according to Annex C to EN1991-1-3:2003.

6. Conclusions

Time is ripe to evaluate the impact of reference snow maps in Annex C to EN1991-1-3 on national choices in various National Annexes. After more than 20 years from the conclusion of the European snow loads research project, involving 18 European Countries, the paper discusses the state of the harmonization process in the CEN European countries.

A comprehensive comparison of the snow maps presented in 30 National Annexes to EN1991-1-3:2003 with the Annex C reference map shows that National Annexes are generally safe-sided for large part of the of the populated European territory.

In addition, in view of the elaboration of the “second generation of the Eurocodes”, to be published in 2020-2023, characteristic values of ground snow loads across borders of neighbouring countries have been compared. Despite in some cases the detected differences can be clearly related to orographic reasons, in other cases the interpretation is not obvious.

The study confirmed that lack of full consistency still exist at administrative borders and further harmonization work is needed to reduce these differences. The study indicates that snow load differences at borders are mainly related to:

- quality, time extension of the data series, nature of data and spatial density of weather stations;
- adoption of different techniques to derive snow loads from snow depth measurements (snow density model), where relevant;
- probabilistic modelling and extrapolation of data;
- implementation of different load-altitude correlations;
- minimum threshold load values, if any.

Another explanation for the differences is the result of national strategies and choices related to safety. It seems, for example, that in some countries the ground snow loads have been deliberately increased to introduce additional safety in the design of lightweight roofs.

On the basis of the considerations developed above, full explanation of the reasons of these differences requires further information. With this aim, National Standard Bodies (NSBs) have been asked for information about procedures followed for snow map definition in each CEN Country, in particular: available measurements; adopted probabilistic distribution of annual ground snow load maxima; and methodologies used for parameter estimation, interpolation, zoning and definition of load altitude relationships. An ad-hoc questionnaire on these relevant topics has been issued and distributed to CEN member states by the Project Team SC1.T2 – EN1991-1-3 Snow Loads [9] in charge of the preparation of the second generation of EN1991-1-3, which results are being evaluated in view of the finalization of the new standard.

At this stage, also in consideration of the fact that the safety policy in each CEN country is left to the national determination, rather than trying to develop a common European snow map, it is envisaged to agree a unique strategy for the elaboration of snow maps in National Annexes to the Eurocodes, where all the basic assumptions are precisely described and the additional safety, if any, is clearly indicated, so significantly enhancing future harmonisation.

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