TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2015

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ASSESSING ENVIRONMENTAL ACTIONS FROM MODERN METEOROLOGY

OCENA ODDZIAŁYWAŃ ŚRODOWISKOWYCH W OPARCIU O NOWOCZESNĄ METEOROLOGIĘ

A b s t r a c t

This paper gives an overview of current achievements where modern weather forecasting techniques are implemented for the assessment of especially ice and wind loadings on electrical overhead lines, TV towers, masts and similar infrastructure. Modern numerical weather prediction models (NWP) incorporate far more details on e.g. cloud physics and dynamics than those generally necessary for regular weather forecasts. Such models describe in principle all physical and dynamical processes in the atmosphere in 3-D. In combination with detailed data on the physical properties of land and water surfaces, it is now possible to obtain realistic values of weather parameters related to wind, turbulence, precipitation and atmospheric icing down to a horizontal scale of a few hundred meters. Such models are therefore powerful tools for the planning and final design for various infrastructures in remote terrain where little or no weather data can provide sufficient bases for the establishment of extreme weather loads necessary for their design.

Keywords: wind engineering, atmospheric icing, wet snow load, environmental actions, numerical weather prediction models

S t r e s z c z e n i e

W artykule przedstawiono przegląd aktualnych osiągnięć w zakresie szacowania oddziaływań środowiskowych w oparciu o nowoczesne techniki prognozowania pogody. Szczególną uwagę zwrócono na oblodzenie i oddziaływanie wiatru w odniesieniu do napowietrznych linii energetycznych, wież telewizyjnych, masztów telewizyjnych, itp. Nowoczesne modele prognozowania (NWP) wykorzystują dużo więcej szczegółowych danych, np. odnośnie fizyki i dynamiki chmur, niż te, które są zazwyczaj potrzebne do zwykłego prognozowania pogody. Takie modele opisują zasady rządzące wszystkimi fizycznymi i dynamicznymi procesami atmosferycznymi w przestrzeni trójwymiarowej. W połączeniu ze szczegółowymi danymi odnośnie właściwości fizycznych powierzchni lądowych i wodnych, możliwe jest obecnie otrzymanie rzeczywistych wartości parametrów pogodowych związanych z wiatrem, turbulencją, opadami i oblodzeniem w skali poziomej sięgającej kilkuset metrów. Modele te są więc potężnym narzędziem pozwalającym na planowanie i końcowe projektowanie różnych elementów infrastruktury w odległych zakątkach, gdzie jest zbyt mało lub w ogóle brak jest danych pogodowych, niezbędnych do ustalenia ekstremalnych wartości obciążeń, które są potrzebne podczas projektowania.

Słowa kluczowe: inżynieria wiatrowa, oblodzenie atmosferyczne, obciążenie mokrym śniegiem, oddziaływania środowiskowe, numeryczne modele prognozowania pogody

DOI: 10.4467/2353737XCT.15.146.4183

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1. Introduction

To meet the constantly increasing demands from developing societies, as well as from industrialised countries, for the supply of electric power and telecommunication, the necessary infrastructure is more and more often forced to expand into new land and mountain areas. In such locations there is typically limited or no knowledge about the frequency or magnitude of adverse weather phenomena that need to be considered in the design of the new overhead lines or telecom towers. Likewise, in order to assess the operational reliability, as well as in the contingency planning, it is necessary also to consider the operational regularity and alternatives for maintenance under extreme weather, and the access conditions and reliability for their maintenance and repair under harsh weather conditions.

Local weather conditions in mountain areas having a complex topography are critical for planning, design and operation of overhead electric power lines, radio and TV towers, ski-lifts and other types of infrastructure in such areas. The evaluation of the design loads attributable to wind and ice, the operating characteristics such as conductor galloping and fatigue experienced by overhead line conductors, or signal reductions for microwave antennas, are dependent on both historical and actual local weather conditions. However, it has been almost impossible, by conventional methods, to obtain the necessary information from regular weather observation station data, with a spatial resolution adequate for the route of a transmission line or for a mountain top with a microwave antenna.

Over the last decades there has been a tremendous development in global weather observations and computer capacities, and so has also the knowledge of the physical and dynamical processes in the atmosphere similarly progressed. These developments have in turn led to significant improvements in the quality and reliability of modern regular weather forecasts in general. Following the same developments, the potential is similarly huge also for point studies of many weather parameters in any type of terrain, with a spatial resolution relevant for the span lengths of a transmission line or a singular tower on a mountain top, independent of the location or earlier measurements of meteorological data.

A particular numerical weather prediction model (NWP) is applied in this article for such type of local weather studies. This model is called the "WRF model" (WRF: Weather Research and Forecasting model), and is developed and maintained by universities mostly in the US. In principle this is a standard weather forecasting model, but instead of the regular coding limitation such models normally require in order to meet the time limitations for delivering the weather forecast in due time for media presentations, the WRF model is allowed to keep all physics, equations and expressions "undisturbed" and only deliver its output when all necessary calculations are done. In this case the WRF model is practical for special studies and research of particular weather phenomena.

As input to the WRF model is used 6-hourly gridded weather data for the whole atmosphere, available from a few regional weather data bases in the world. This weather data base contains assimilated and interpolated sets of all relevant weather parameters from regular weather stations, automatic stations, ocean buoys, weather radars, satellites, etc., and gives therefore a complete 3-D description of the state of the lower atmosphere (troposphere) globally at 6 hours intervals (Fig. 1). Combined with high resolution data for the characteristics of the surface of the Earth, such data therefore give a more comprehensive description of the weather at one location than a standard set of data from a regular weather station could provide.

The first approach along these lines was presented in [2]. Later, this method was implemented in order to study rime icing conditions for a Norwegian transmission line project in [5, 6] (Fig. 2). During the European COST collaboration under COST Action 727 "Atmospheric icing of structures" the method was successfully tested and applied on several locations in Europe, including in the Alps [7].

In addition to in-cloud icing (rime ice) electrical overhead lines are also exposed to accretions of wet snow. The accretion model for wet snow is also improved and tested on numerous field cases.

As a result of these developments it is now possible to perform case studies of historical severe weather events and study both rime icing and wet snow conditions along remote transmission line routes. Furthermore, it became possible to create new maps of ice loadings for design purposes for Great Britain and Ireland with grid size 500 m x 500 m.

It is also now proposed to combine the interests of CENELEC and CEN to develop homogeneous and coherent icing maps for Europe by using this technology to accomplish the needs for both the electric overhead line industry and the tower and mast sector.

This paper deals mainly with atmospheric icing. However, modern NWPs can be applied similarly for any other weather parameter emerging from these models, like for instance temperature, wind speed, wind direction, wind turbulence, precipitation, snow depth, snow drift, etc. as long as a good topographic model with appropriate resolution is available.

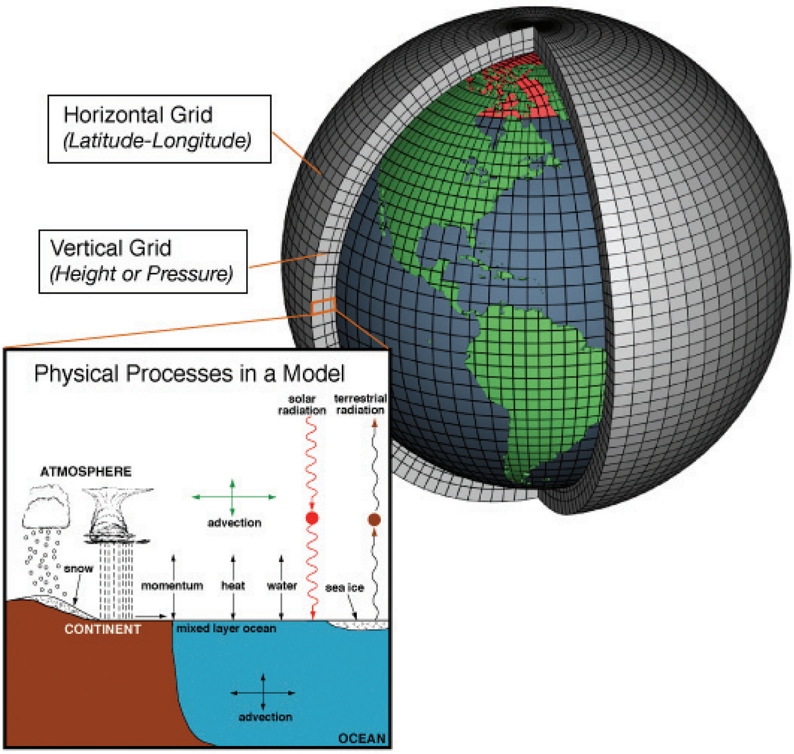

Fig. 1. Illustration of a global NWP modelling system

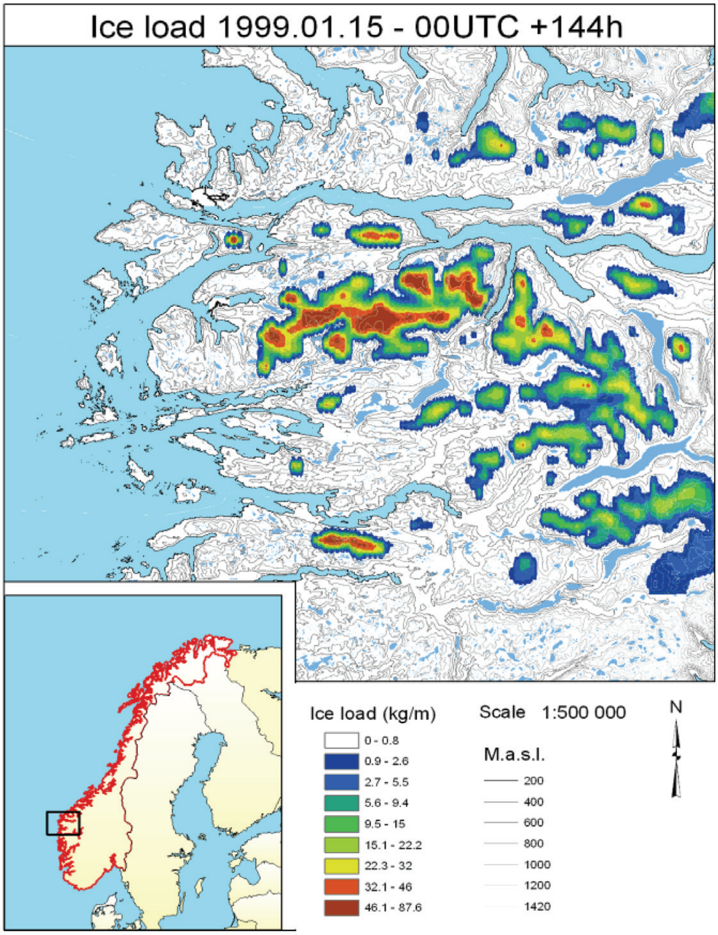

Fig. 2. Example of a local icing map produced from WRF model simulations (from [6]).

2. The WRF model

The Weather Research and Forecast (WRF) model is a state-of-the-art meso-scale (10 – 10 000 km horizontal resolution) numerical weather prediction system, used both in operational forecasting and in atmospheric research (http://www.wrfmodel.org/ and http://www.wrfuserspage.com). WRF solves coupled equations for all important physical processes (such as winds, temperatures, stability, clouds, radiation etc.) in the atmosphere based on both initial fields and lateral boundary values derived from global analysis data. Historic model runs can be initiated with three dimensional analysis of the state of the atmosphere obtained from the ECMWF (European Centre for Medium-range Weather Forecasting) data archive which goes several decades back.

Because atmospheric icing often occurs as a very local phenomenon, and icing intensity is varying greatly in space, especially in complex terrain, it is necessary to run the model at high horizontal resolution to produce useful icing maps. In order to obtain a good representation of the local terrain in the model, data sets at about 90 m horizontal resolution can be implemented.

The model is set up with nested domains, which means that the model goes stepwise from the global scale to local scale with a grid resolution in the range of 0.4 – 0.8 km in the finest resolution domain. This resolution is considered as extremely high for meso-scale models.

A second important factor for simulation of atmospheric icing is how the model computes or parameterises the cloud microphysics. A variety of so-called cloud microphysics parameterization schemes are available in current NWP models. There is however one particular scheme [10] which is considered to provide the best representation of the physical transformations of all water phases in clouds and precipitation, important for prediction of atmospheric icing, also at ground level [4, 8].

The icing simulations are carried out in a two step manner:

1. Meteorological data is produced at high spatial and temporal resolution using the WRF model. In addition to standard variables like wind speed, temperature and humidity, the WRF model also output data like mass concentration of supercooled cloud water, and also an estimate of the median volume cloud droplet size.
2. The data from WRF is processed through a time dependant accretion model for rime icing or wet snow, calculated using the standard ISO specification [6].

Accumulated ice load is calculated in all grid cells in the model domain, serving the basis for an icing map, which can also be used as an overlay in Google-Earth. The output files also contain information on predicted precipitation, wet snow and maximum wind speed. Meteograms showing the time evolution of icing together with weather parameters can be extracted from these files, as well as vertical profiles of the same parameters.

3. Application examples

This method has up to now been applied on several transmission line projects in Norway, Greenland, Chile, Newfoundland and the UK. In all these cases new overhead lines were planned in remote areas where very little or absolutely no relevant weather data was available, especially for the parts of these lines going through high level mountain terrain with varying exposure.

The first application of this approach was applied for a proposed route for a new 420 kV overhead transmission line in the western part of Norway, where a section of the line would be exposed to air coming directly in from the North Sea at an altitude of 1,100 m above mean sea level. Here the risk of extreme icing was expected to be very high. The model set-up included a control with 10 years of field measurements from a test site located roughly 150 km SSE of the line route, as well as with local measurements during one winter.

The calculated ice loads on a theoretical vertical cylinder of 30 mm in diameter resulted in a maximum ice load close to 50 kg/m for the test period of 10 years. The accumulated ice loads over the area for this particular extreme case is shown in Fig. 2. It is anticipated that the vertical cylinder represents a conservative assessment of the ice load on a horizontal conductor of the same size.

In December 1990 there was a major storm in England with significant amounts of wet snow in the Pennines (Fig. 3). Approximately 250 000 customers lost power from the failure of about 700 HV overhead line circuits and many low voltage networks in the area of one Distribution Network Operator (DNO). A WRF study of this event showed that the equivalent radial ice thickness (Req) could be about 30 mm. According to reports from the DNOs these results compared very well with their own observations and experiences from the event, in particular in terms of the areas mostly affected by this blizzard.

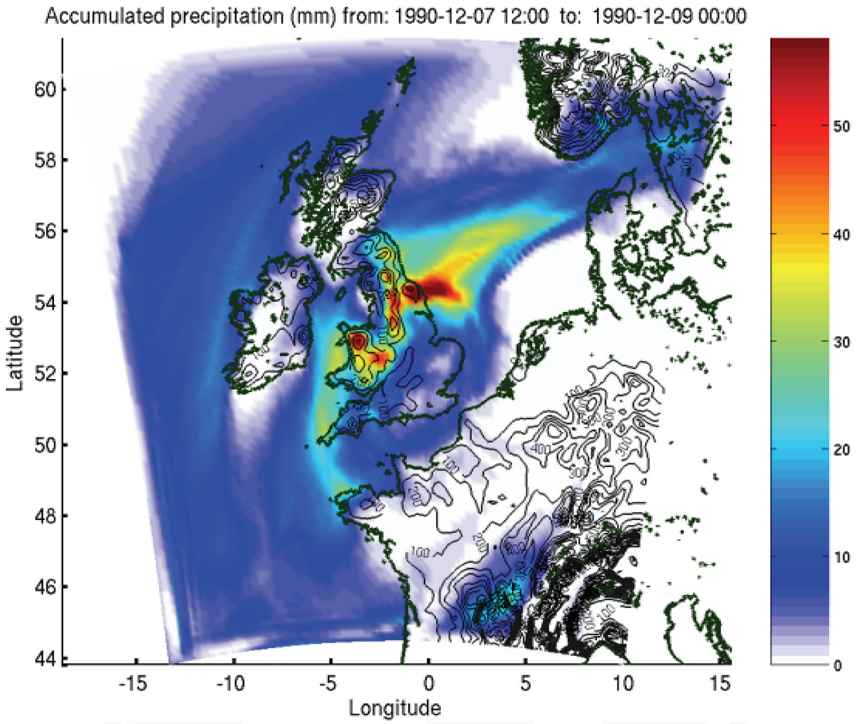

Fig. 3. Simulated accumulated surface precipitation for the 1990 wet snow event in the English Midlands

Another example from the British Isles is shown in Figure 4. Severe rime icing was observed on the EA Technology test site at Deadwater Fell (580 m amsl, near the English-Scottish border) during the period 11-14 January 2010. This icing case was tested with the WRF model and the model was also extended to cover the British Isles. The model confirmed rime ice loads in excess of 3 kg/m compared with measured loads of 3,5 kg/m at the Deadwater Fell site in this period. This confirms the successful prediction of rime icing levels that occurred over all high areas across the British Isles The highest loads in mountains being recorded in Scotland, Northern Pennines, Wales and Ireland. It was later confirmed by the Eire Supply Board (ESB) that severe outages and failures in distribution networks occurred as well in the Wicklow hills in the Eastern parts of Ireland during this event.

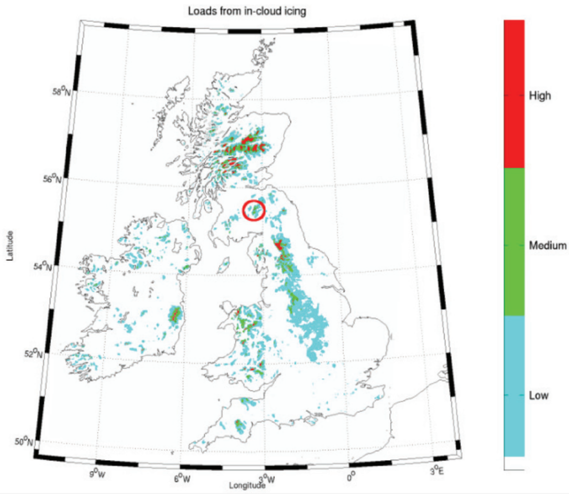

Fig. 4. Simulated rime icing during the period 11-14 January 2010. Based on WRF simulation with at horizontal grid spacing of 1.5 km

The output from the WRF model can also be embedded into Google Earth files, as shown in Figure 5. This provides a very useful tool for visualization, and makes it possible to move in and out of the landscape and see the local terrain in combination with the 3-D ice load outputs from any viewpoint of interest in each case. The value of this enhanced application was used in the assessment of ice loads for an exposed 420 kV line in the western Norway. The line suffered severe damage due to high rime ice loads accumulating during December 2013. The simulated ice loads corresponded very well with the measurements and the experiences collected at the site. The method is currently being applied to assess the local icing conditions for all new transmission line projects in Norway.

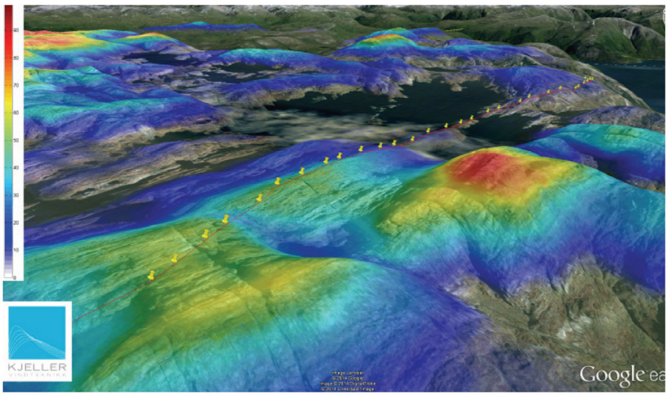

Fig. 5. Simulated rime ice loads in the terrain surrounding a 420 kV line in Norway. Based on a WRF simulation with 500 m x 500 m resolution

The WRF model based approach was also used to assess the icing conditions for a new HVDC line crossing the Long Range Mountains in Newfoundland, Canada. The planned line is crossing the mountain range at altitudes of about 600 m amsl, where again very little data are available on adequate weather conditions and potential ice loadings. This project is also supported by field measurements of temperature, wind speed, wind direction and accumulated ice load on 80 m long test spans. So far these measurements confirm the model output of the same parameters reasonably well.

The WRF model output includes values for identical parameters not only for the lowest layer closest to the earth surface, or in the range of 25–30 m above ground (depending of the grid size and inherent smoothing of the terrain), but also for higher levels. Figure 6 shows an example from the Long Range Mountains where the ice loads are calculated for the three lowest model levels (25 m, 90 m and 175 m above model ground, respectively) for five locations along the proposed line route and for three different case studies.

Case 1 gave the highest ice loadings relevant for the conductor levels above ground for all the five selected locations, especially locations 4 and 5. In this case the prevailing wind was easterly, and it is seen that the ice loads increase significantly at higher levels above ground, and most dramatically for locations 1, 2 and 3. This is because the selected line route in this case is reasonably well sheltered for this wind direction for all locations, but at locations 1-3 this shelter is very shallow. For locations 4 and 5 the ice loads increase by a factor of two from 25 m to 90 m, but no further increase to higher altitudes.

This event emphasizes then the importance and limitation of such a shelter. For the further planning of the line any displacement of the route into slightly higher altitude areas, or areas where there are some openings of the terrain towards the eastern sector, should for this reason be carefully avoided. Another point to make is that a double circuit line in vertical configuration, where the upper phase conductors and earth wires may reach more than 50 m above ground, may be at significantly higher risk concerning ice loads and high winds than a double circuit with a horizontal configuration.

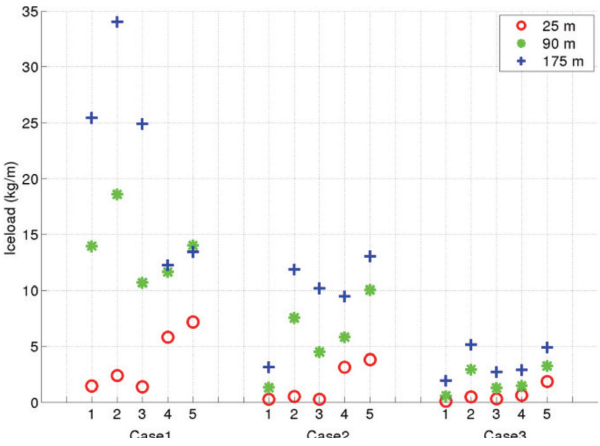

Fig. 6. Simulated ice loads at five locations along the transmission line route. At each location the icing is calculated at three height levels for three different icing cases. Based on WRF simulations with 400 m x 400 m resolution, covering central parts of Long Range Mountains, Newfoundland

Although less pronounced, similar effects can be seen in Case 2 when westerly winds prevailed during the ice accretion. Here there is also an increment in ice loads from 90 m to 175 m at locations 4 and 5, but very light icing above location 1. Case 3 had the lowest ice loads of all three cases, and the height increments are very small. In this case the icing was connected to northerly to north-easterly winds.

Similar output is certainly also applicable to tall tower and masts in mountain terrain.

4. Icing map for Great Britain

Following the promising results of the WRF modelling system, UK utilities decided to initiate a project on revising the wind and ice loading maps for Great Britain [9]. In this project the processes of wet snow and rime icing were studied separately and combined into one icing map for Great Britain as shown in Fig. 7. The wet snow analyses were made from precipitation data from British weather stations, and smoothed out by regression analyses. The rime ice part was analysed by a WRF model.

Fig. 7. High resolution ice load map showing 50 years return values for the Great Britain

A similar map is also produced for Ireland and Northern Ireland.

The underlying data base for these maps for the British Isles are provided in a horizontal grid squares where each grid is 500 m x 500 m, and the maps will be introduced in the next revision of EN 50341-1 as National Normative Annexes (NNA) for the mechanical design of electrical overhead line systems in these countries.

A similar approach has recently been studied also for wet snow load assessments for overhead line design in France [1].

The models used to establish Figure 7 are validated with various wet snow and rime ice data from Iceland, Norway and UK. The wet snow model is also qualitatively checked against reports and experiences from UK utilities, such as the one presented in Figure 3. See also (Nygaard et al., 2014).

5. Proposal for an icing map for Europe

The ISO Standard 12494 "Atmospheric Icing" has been widely used internationally for design purposes of especially antenna towers and masts since its first publication in 2000. CEN TC 250/SC1 has decided to transform this standard as a new part of the series of Eurocodes on Actions (EN 1991), and established a new WG (CEN/TC250/SC1/WG2 "Atmospheric Icing) for this task. The member countries of WG2 have clearly expressed the need for a European icing map in order to take full benefit of this new Eurocode. However, it has also been emphasized very clearly that such icing data will have much in common with the needs for similar information from the electric overhead line industry, represented by CENELEC.

Based on this understanding, CEN/TC250/SC1/WG2 sent in August 2014 a letter to CENELEC TC11 "Overhead lines", and inviting CENELEC to discuss a common icing map for Europe applicable for both industries. How such maps should be produced and financed are not yet neither discussed nor decided.

The letter from CEN certainly acknowledges the existence of such icing maps in many European countries, like for instance Czech Republic, Germany, France, as well as Great Britain and Ireland (see above). However, it is also realised that many of these maps are developed on various sets of data and methods. Hence maps from two neighbouring countries do not necessarily match along the common border.

Mostly, these maps are also developed on the basis of the needs for either the building industry or the electric overhead line industry, and therefore one map for one purpose is not necessarily applicable for the other.

However, the letter from CEN indeed also recognizes the aggregated knowledge and expertise on local icing conditions within all those countries that have already developed such maps. If the proposal for developing a new and comprehensive icing map for Europe should be accepted, it is extremely important that all countries involved contributes with their own experiences and knowledge from their earlier work in a possible all-European collaboration in this field.

It shall also be emphasized that an icing map like the one developed for Great Britain (Fig. 7), where the underlying icing data are given in a 500 m x 500 m grid, also opens for other meteorological information, such as extremes for wind speeds, temperature, precipitation, snow depths and combined ice and wind actions, as well as directional frequency distribution of wind speeds, turbulence parameters, or other information relevant for the industry, in a GIS format.

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