Modern Meteorology and Atmospheric Icing

Svein M. Fikke
Meteorological consultant – overhead lines, Lindeveien 1, 1470 Lørenskog, Norway
s.fikke@online.no

***Abstract*—Although the water cycle in the atmosphere is still not described well enough to provide reliable input parameters for the liquid water content of the air or precipitation rate, fine-scale atmospheric models can now describe wind speed, wind direction, air temperature and vertical stability taking topographical details into account with a horizontal scale of 100 m or less. This means that these models can provide much more detailed information than any observation network can do concerning both weather and icing data. Examples are shown on the application of such models for detailed studies on power lines. A comprehensive scheme for combining models for weather dependent impacts on overhead lines and weather forecasting models is suggested.**

I. INTRODUCTION

ATMOSPHERIC icing has been on the agenda for international collaboration since the very first IWAIS (although it was not called so then) in Hanover, New Hampshire, in 1982. Since then tremendous efforts are made by icing colleagues around the world, in order to advance our knowledge and understanding of the processes that take place within the fascinating substance of water around its freezing point. And yet there are still a lot more questions to be answered and problems to be solved, relating to icing itself and its impacts on the various structures that are exposed to it.

In this paper we will review briefly the occurrence of icing phenomena around the world and how it is modeled. The main purpose of the paper is to focus on how modern meteorology can be applied to obtain better quantifications of the weather input parameters to models, such as wind speed, wind direction, temperature, cloud water, precipitation rate, condensation, evaporation, etc. Although there are still a long way to go here too, it is the opinion of the author that probably the greatest potential for improvements of the various practical applications of existing models for selecting design values, or for case studies, are to be found along these lines.

II. ICING – WHAT IS IT AND WHERE DOES IT HAPPEN?

A. *Icing types*

During many years it was a bit difficult to discuss "icing" with colleagues from other countries and parts of the world, because they all had different perceptions of the phenomenon, according to local experiences. Now we all agree to encompass all phenomena that cause accretions of water in its frozen stage on any type of object into the term "icing" [1], [2]. We differentiate icing according to the process during which the accretion is formed.

"Atmospheric icing" is therefore now a global term for:

- in-cloud icing,
- precipitation icing, and
- hoar frost.

In-cloud icing is often also denoted as (soft and hard) rime icing.

Precipitation icing may result in

- freezing rain,
- wet snow, and
- dry snow.

Hoar frost is the result of a phase transition direct from vapor to solid, also called "ice condensation" (contrary to sublimation). Hoar frost is very light and has a fluffy appearance. As it mostly does not affect structures, it is not discussed further here.

Dry snow accretions are reported from Japan and Alaska [3]. This is a quite rare phenomenon and little information is available.

B. *Occurrence of icing*

We all know very well that atmospheric icing occurs from time to time in most northern countries, and many places several times per year. Freezing rain is frequent especially in Canada and northern USA. Wet snow is also an annual phenomenon in Iceland and Norway, but occurs frequently in all circumpolar countries, including Russia, Japan, Canada, US and in practically all European countries. Rime icing affects mostly high altitude structures in all these countries, in northern parts of Scandinavia it may however be found below 400 m above sea level (m asl).

The biggest ice load ever recorded on an overhead power line was observed in Norway in April 1961, 1400 m asl, see Fig. 1. The accretion had an elliptic shape with the longer diameter of 1.4 m and the shorter diameter 0.95m. 1 m length of this accretion was collected and taken down to the village and weighed to 305 kg!

The devastating freezing rain event in eastern Canada and the US in January 1998 is indeed very well known in this audience.

It may however be more surprising that icing can cause severe damage to power lines in countries like Spain, see Fig. 2 and South Africa, Fig. 3. As can be seen from these pictures, the icing in both these countries can be severe, and electric overhead lines as well as wind power installations have to be designed for the additional loads such ice accretions will impose on the structures.

Fig. 1. Rime icing on a 22 kV line on Lønahorgi, 1 400 m asl, near Voss, Norway, April 1961. (Photo: O. Whist)

Fig. 2. Icing on a power line in Spain January 2004 (Photo: Iberinco).

Fig. 3. Icing in South Africa. (Photo: Eskom.)

The message of these examples is that only few areas in the world can be considered to be totally “icing-free zones”. Wherever sub-freezing temperatures and snow can possibly occur, engineers should be aware of any impact of ice and snow accretions that may influence their structure in a negative way. Remember, they have skiing resorts in both Australia and New Zealand, therefore icing may be expected there too. In countries like Greece, Saudi Arabia and India icing events have been indicated, however, to my knowledge, not reported.

III. ICING PARAMETERS AND MODELS

The accretion of ice on structures is a very complex and nonlinear process which includes both conductor parameters and meteorological parameters. In order to fully understand the icing phenomena, and to establish icing models for practical applications, it is important to examine carefully *both* 1) the physical accretion processes themselves on an electric conductor wire, a telecommunication tower, wind turbine or other structures exposed to the icing, and 2) the meteorological environment that rules the input data to the models.

A. Physical Icing Models

Over the last decades many universities and researchers have studied the micro-scale processes of icing on both stiff and rotating objects of many kinds. A main reason for this is not only the engineers’ need for models to calculate loads on their structures, but I think also it is because H_2O is such a fascinating chemical substance, in particular around its freezing point, and hence provides a wide variety of theoretical challenges that appeal to researchers in fundamental physics and applied mathematics.

For in-cloud icing the most important parameters are related to:

- liquid water content in the air
- droplet size
- air temperature
- wind speed
- wind direction
- humidity (degree of vapor saturation)

For precipitation icing (wet snow and freezing rain) the similar parameters shall describe:

- precipitation rate
- surface air temperature
- liquid water content of snow flakes
- wind speed
- wind direction
- temperature
- humidity

These parameters describe the immediate environment of the object. It as likewise important to include parameters of the accreting object itself, such as surface property, shape, linear dimensions, torsional stiffness, etc.

The history and status of such models are not topics for this paper. Lozowski and Makkonen are handling them in another paper for this Conference [4]. The interested reader may also look at [5] and [2].

B. Models of the Atmosphere

As mentioned above, all icing models need input data describing the local weather conditions during the icing. If the models are not completed with good input data, then any icing model will not be as useful as it could be for practical applications on structures. The most relevant weather parameters are linked to:

- clouds (cover, base and type)
- trajectories of the wind (history of the air mass)
- stability (vertical temperature distribution (inversions, etc.))
- precipitation (type and intensity)
- topographical influence (regional and local scale)
- turbulence

The recent years of developments within meteorological sciences, together with computer technology, remote sensing, and telecommunication – also with internet, have improved their methods and tools dramatically. The increase in computer capacity has made it possible to refine the model grids, and horizontal resolutions down to a few tens of km have been adapted in operational weather forecasting models for limited areas for many years. Such models were often called "HIRLAM" ("High Resolution Limited Area Model"). This has advanced the weather forecasts significantly for both the public and for a great variety of industrial applications. With a few clicks on the web we can now find detailed weather forecasts for thousands of local places around the world. You can even get meteograms that show you the time development of various weather elements hour by hour several days ahead for the place where you live. The reason why these web sites have been so popular is not the result of the information technology only, but indeed also because these prognostic data for temperature, wind, rain, snow, etc. are much more accurate and reliable, both in timing and quantity, than they were five to ten years ago. And this development will continue. The weather forecasts in the next few years will be even more accurate and reliable, and hence applicable for other purposes than today.

As our overhead lines, telecommunication towers, wind turbines, buildings, and other structures are exposed to weather 24 hours a day and 365 days a year, their owners already take benefits of the improvements of today's weather forecasts, both for the design, operation and maintenance. However, it is the opinion of the author that there are great potentials for still more utilization of meteorological services within our industries.

In particular local scale atmospheric models have a great potential to be incorporated in the complete icing models. When an icing model shall be applied, engineers ask mostly for direct measurements of wind speed, wind direction, precipitation type, precipitation intensity, etc. as input parameters to the models. But when there are few data of the conventional type, or the data is less representative, atmospheric models can provide very useful "artificial" data for the icing models at a reasonable quality and resolution in many cases.

There are of course still shortcomings, especially with respect to the general water cycle in the atmosphere, and in particular the liquid water content of clouds. But it is in this respect very important to note that water vapor is the most important greenhouse gas, more important for the global air temperature than CO_2. According to this very significant influence on the global climate, there are tremendous efforts made world-wide in ongoing research and observation projects, with focus on water vapor in the air, evaporation, condensation, cloud formation, initiation of precipitation, precipitation intensity, etc. The most comprehensive study of this kind is the "Global Energy and Water Cycle Experiment" (GEWEX) and its sub-project "Global Water Vapor Project" (GVaP). GEWEX is headed by the World Meteorological Organization (WMO) in collaboration with the UNESCO World Climate Research Programme. It has been going on for many years and the results are constantly being implemented in dynamic and physical models for the atmosphere, both for climatic studies and indeed also for forecasting purposes.

More information on this can be found in www.gewex.org.

IV. APPLICATIONS OF METEOROLOGICAL MODELS FOR ICING

There are many examples on how data from regular weather stations are used in order to calculate ice loadings, as can be seen from many IWAIS proceedings. Some examples on synoptic and climatic conditions for icing can be found in [6], [7], [8], [9], [10], [11] and [12]. These examples show that there is a relatively good understanding of the atmospheric conditions for the various icing types. However to quantify loadings from weather parameters is not at all a straightforward task.

Probably the most advanced methods for this are established for freezing rain, as this phenomenon is often most severe in populated lowlands where good meteorological observations are relatively abundant, and also here the best possibilities exist for direct measurements and observations of the phenomenon itself, see for instance [13] and [14]. Rime icing (in-cloud) icing and wet snow accretions is much more difficult to model in a similar way. A few recent attempts on modeling from meteorological data shall however be mentioned in the following.

A. Rime icing

The first attempt to establish climatology for rime icing was probably made by Ahti and Makkonen in 1982 [15]. A recent work based on similar principles was made by K. Harstveit who used regular weather observations from airports to produce a map of rime ice risk zones in Norway, as shown in Fig. 4 [16]. He used a simple model to describe the cloud base and liquid water content to identify individual icing events at different height levels in mountainous areas around these stations. The model was applied on long time series of data to establish a data base as required by the recent ISO standard 12494 "Atmospheric icing of structures" [2].

Modeling rime icing from meteorological models has been done by W. Fuchs for aircraft icing [17], but so far, probably the only proposal for applying dynamic weather models for in-cloud icing near ground is made by A. Veal, P. Hopwood and A. Skea by using the UK Met. Office so-called Site Specific Model [18]. The UK regular meso-scale model has a horizontal resolution of 12km x 12km which is appropriate for regular weather forecasts, but still too coarse for identifying and forecasting weather phenomena which are dominating by strong local forcing, like radiation fog, local cloud formation, etc. Realizing that truly site-specific forecasts for numerous points within large areas (like the whole country) will not be achievable from 3D models for many years, they have developed a 1D site-specific model that could capture the flow features unique to a particular location situated anywhere within a meso-scale model grid-box.

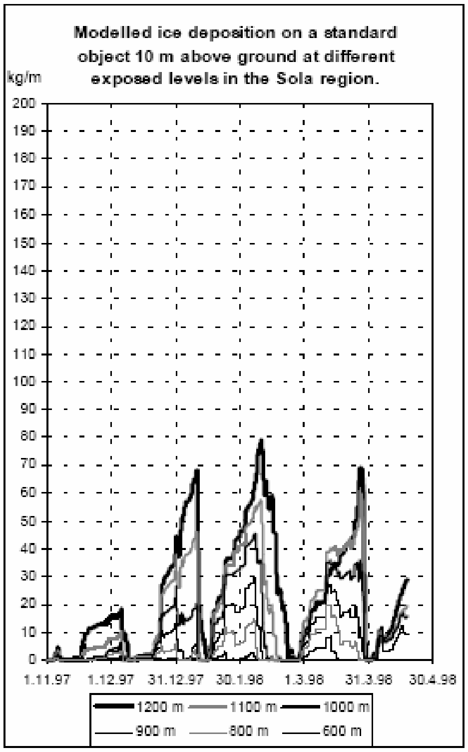

Fig. 4. Calculations of in-cloud icing during the winter 1997/98 at different levels in the area covered by Sola Airport, Norway. After [Harstveit IWAIS 2002]

The site-specific model contains the same physical parameterizations as their regular model, however with improvements as to the treatment of surface exchange and soil properties. The large-scale flow and forcing are defined by coupling to the operational meso-scale model, yet its local flow and forcing is provided by interaction with the surface characteristics within the upwind fetch of the chosen site. The upwind characteristics are treated as local "sources" in the model, as shown schematically in Fig. 5.

This model has been in operation since 1996 and has proved a significant improvement in site-specific forecast skill. It is now the intention to apply this model on icing data and local meteorological measurements from Deadwater Fell in the UK [18] and [19], hopefully to develop an icing model and establish a climatology for rime icing in the UK.

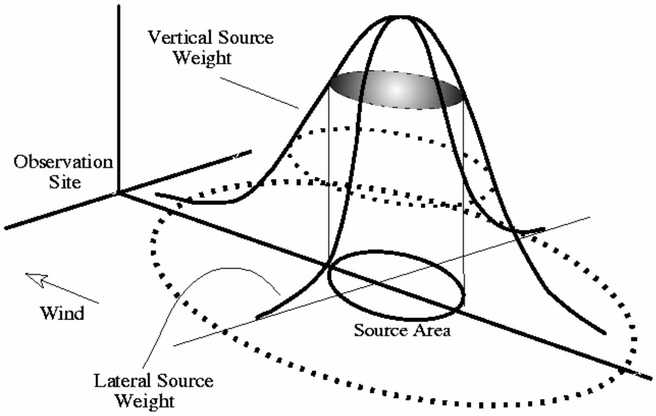

Fig. 5. Schematic view of the "Source area concept" as used by UK Met. Office in their "Site specific model". From [Veal Edinburgh].

B. Wet snow

Wet snow occurs within very narrow boarders of the meteorological parameters. In order to be "sticky" enough to accrete on conductors or lattice elements in steel towers it has strong restrictions as to the water/ice ratio of snow flakes as well as to environment parameters such as air temperature, relative humidity and wind speed perpendicular to the accreting object.

K. Finstad [20] used visibility as an indicator for snow fall rate and icing. This was compared with precipitation rate. An example is shown in Fig 6.

S. Krishnasamy, S.M. Fikke and O. E. Tveito [21] describe a model based on the highest 24 hours precipitation (approach 1) and the extreme value distribution of 24 hours precipitation (approach 2) during the winter months November – March, see Fig. 7. This model was calibrated according to the standard value for ice loading near one of the stations (39040 Kjevik).

Probably the best attempts toward wet snow modelling based on dynamic weather models are made in Iceland by H. Olafsson, A. J. Eliasson and E. Thorsteins [8] and [9]. Their model includes realistic description of mountains and is probably the first direct approach to connect wet snow modelling with regular weather forecasting models.

The most promising with the Icelandic work is probably that the modeled precipitation is very close to observations. In a mountainous topography like the Icelandic this is considered to be very difficult. It is therefore reason to be more optimistic than before concerning modeling wet snow accretions. Probably the most significant constraint is good field data of wet snow accretions with a time resolution that is adequate for the weather models. But the Icelandic people are clever here too.

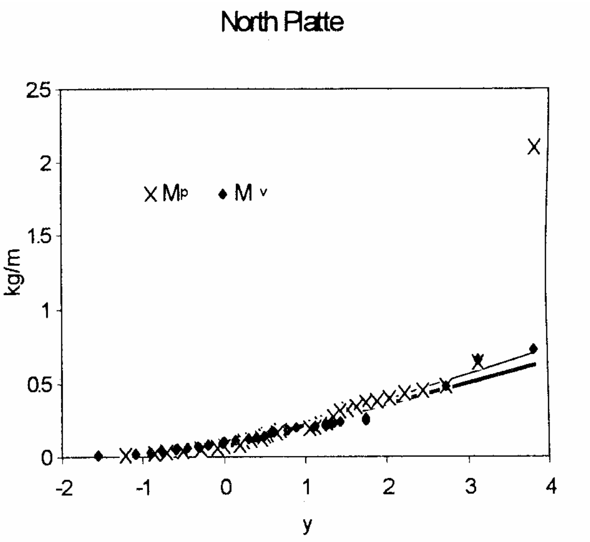

Fig. 6. Modeled wets snow accretion masses in kg/m plotted against reduced variate y according to Gumbel Type I distribution. Heavy line is according to snow fall rate and light er line according to visibility during wet snow accretion. After [KF iwais 98].

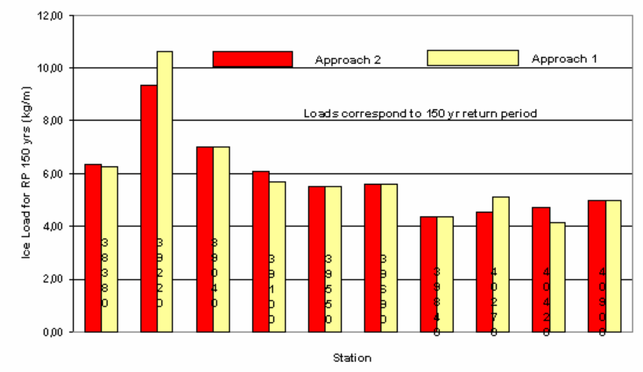

Fig. 7. Wet snow loads calculated according to the five highest 24 hours precipitation (appraoch 1) and extreme value distribution of precipitation (approach 2) during winter for weather stations in Norway. [Fikke 2000].

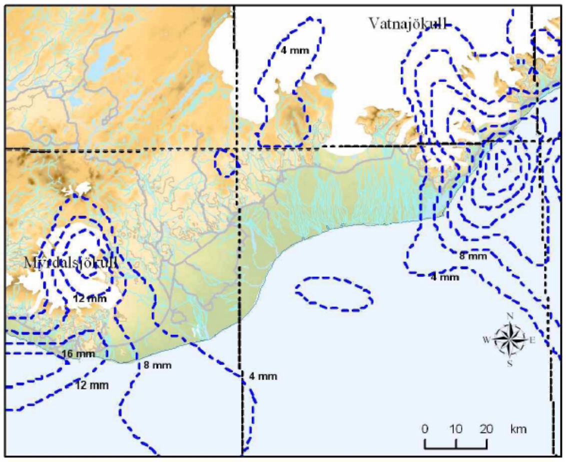

Fig. 8. Modeling of wet snow in southern Iceland by using a dynamic weather model. After [Olafsson IWAIS 2002].

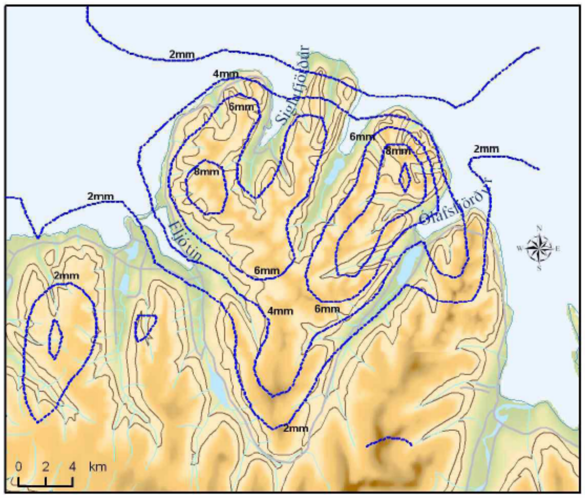

Fig. 9. Same as Fig. 8 for northern Iceland. After [Olafsson]

V. NESTING OF HIGH RESOLUTION MODELS

Dynamic models for the atmosphere are, as mentioned, of different size and resolutions. It is however indeed a long way from the overall model handling the global circulation of the atmosphere around the Earth to the weather I experience on my way to work. The former is analyzing the development and movement of individual high and low pressure systems around the world and the latter is dealing with the air temperature, wind speed, wind direction, sunshine, precipitation, etc. I observe about 1.7 m above ground. It is simply not possible to do all these calculations in time and space within one limited model, even with today's largest super-computers. The most common technique to solve this task is by nesting smaller and more detailed models into the larger ones. An HIRLAM mentioned above is an example of such a model which is nested within a global model. The latter is operated by only a few regional weather centers in the world. In Europe the only global models are run by the European Center for Medium Range Weather Forecasts (ECMWF) in Reading, UK. All European countries get their global data from this model and run their own models nested into this by inserting new parameters from the global model on the boarder surface of the local model for each time step in the integration procedure.

Fig.10 shows an illustration of such a model "box" where the grid values of wind, air pressure, temperature, etc. on the surfaces of the "box" is forcing the similar parameters inside the boarder. The grid size, both horizontally and vertically, and hence the representation of the ground, can be refined and the calculation result will represent much better the local conditions. In order to take care of the dynamic stability of such models it is common to nest several models, one into the other.

The HIRLAM mentioned above is nowadays substituted with the MM5 model (see: www.mmm.ucar.edu/mm5/mm5-home.html). This system appears with different horizontal resolutions and number of vertical layers. Fig.11. shows an

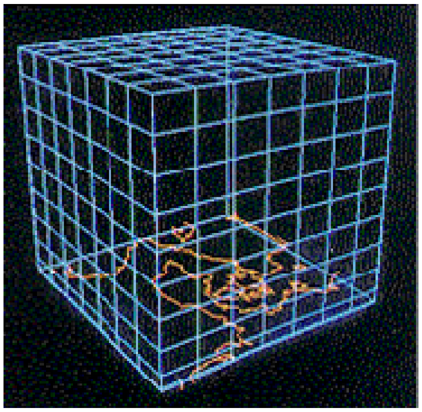

Fig. 10. An example of an atmospheric model "box". (From www.dmi.dk)

example of a model with 36 km horizontal resolution featuring the overall weather system with, in this case, a depression west of England and France. The isobars are shown in solid lines and the precipitation in yellow (week) and red (strong) colors. The model in Fig. 12 has a horizontal resolution of 12 km and shows the main features of Scandinavia and northern UK.

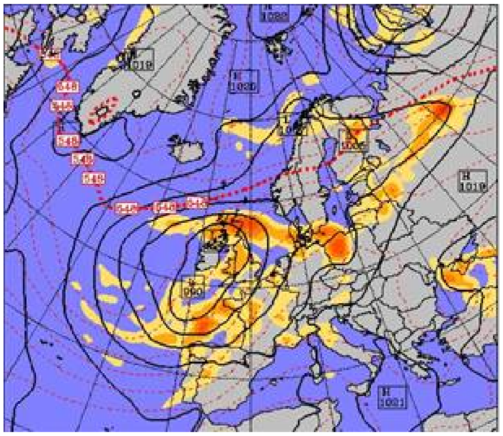

Fig. 11. Example of the MM5 model with 36 km grid for Europe.

Many countries now run models of 10-12 km horizontal resolution operationally. The next generation will probably be a 3 km model like the one now running on an experimental basis by UK Met. Office.

Below 10 km resolution a Canadian model called MC2 [22] is currently used for smaller areas, down to 1 km horizontal grid size. Fig. 13 shows an example of this. Here detailed features of an archipelago where hills with height less than 100 m asl can be seen clearly.

Regardless of scale, each grid point on the earth's surface of these models have information on average height of the grid square as well as surface characteristics like water, soil type, farmland, forest, rock, inhabited areas, etc. Hence parameters like surface friction, surface heat exchange, water evaporation or condensation, etc. may be included in the model. It is easy to understand that it is often the limited knowledge of many of these parameters, as well as the amount and quality of observations and data you can put into the models from regular and automatic weather stations, satellites, radars, ships and buoys in the oceans, etc., that will limit the quality of the weather forecast for your planned Sunday excursion.

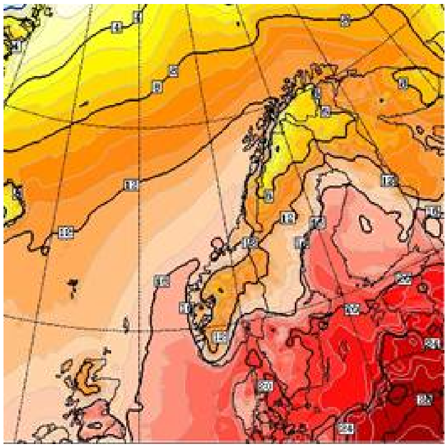

Fig. 12. An example of the MM5 model with 12 km horizontal resolution.

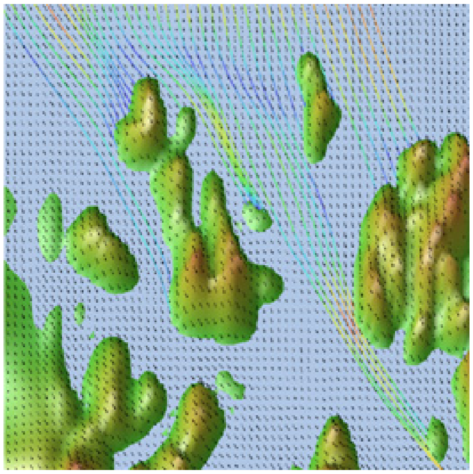

Fig. 13. Example of the Canadian MC2 model where each arrow represents the wind in a 1 km grid.

As mentioned, the MM5 models are used for regular forecasting purposes. The MC2 may be used likewise for limited areas, often for forecasts of air quality in cities during inversion periods. But they are also used for scientific purposes, including case studies of local weather and particular phenomena. Below the lower limit of 1 km resolution for MC2, super-fine models may be nested into MC2 for even more detailed studies. Fig. 14 shows an example of a model with 100 m grid size.

Models like the one in Fig. 14 are often used in regular computer fluid dynamics (CFD). However, the conventional CFD models have significant limitations as to reliable descriptions of small scale weather phenomena. There are several reasons why nested atmospheric models have better performance than conventional CFD models. The most important ones are:

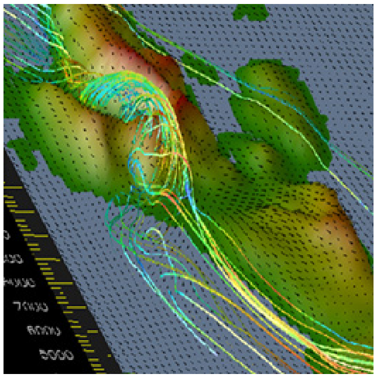

Fig. 14. A superfine model with 100 m grid size. Arrows show wind direction and wind speed in each grid point. Colored lines show trajectories of the turbulent flow. (Courtesy of Storm Weather Center AS.)

- The parameter fields are forced by external models and thus by the time dependent weather development.
- The physical characteristics of the atmosphere are preserved consistently from global to local scales.
- Wind shear, both vertically and horizontally, is handled on all scales simultaneously.
- Stratification has a dramatic influence on the airflow pattern. This means that upstream characteristics of topography and temperature distributions must be incorporated dynamically. (Extremely important for freezing rain!)
- Resources with respect to both man-power and computers are much less than for conventional CFD studies. Nested MC2 and fine-scale models run very efficient together with global atmospheric models.
- Historical meteorological data are available for many years back, and can be used for case studies of historical events.

It should also be noted that many countries now have digital topographical "maps" or geographical data with a grid size down to 25 m. These may be provided by governmental mapping agencies at reasonable costs, and can easily be implemented in the models. For such reasons we can look forward to local weather descriptions which are representative for the span of an overhead power line, at reasonable costs and manual efforts.

VI. APPLICATIONS FOR OVERHEAD LINE PURPOSES

The title of this paper is "Modern meteorology and atmospheric icing". It may seem that this perspective was lost for a while. But that is not really true. Although icing is very much a matter of water in the air, it is also a matter of wind speed, wind direction and air temperature. The water available for icing is also depending on clouds, precipitation, adiabatic cooling (condensation) or heating (evaporation), etc. Therefore the picture of icing cannot be complete unless we take the complete weather situation into account too – and we can describe the relevant parameters with a spatial resolution which is comparable with the overhead line itself.

Except for the Icelandic studies for wet snow mentioned above, there is probably no dedicated icing studies based on this kind of atmospheric models so far. It is the opinion of the author that probably the most significant progress in the understanding of atmospheric icing can be obtained along these lines in the near future.

In order to demonstrate applications for overhead line purposes I will mention two studies in Norway. The first was related to local wind in a very complex terrain. Two parallel 132 kV lines (double circuit) were planned to feed a new aluminum factory located in the bottom of a fjord in mid-Norway. The location is known to have very special wind conditions. Long time local measurements of wind and the regular design code, told us to design for a wind speed of 75 m/s at 30 m height for these lines. The lines should cross a flat area at the mouth of two valleys, one to the south and the other towards ESE. The mountains around this place reach up to more than 1 800 m asl and very strong and turbulent winds are generated from these mountains and also forced out the valleys. A model study, confirmed by local measurements up to 50 m above ground, could justify that the design gust wind speed at 30 m height could be reduced to 65 m/s. Fig.15 shows an example from this model. The grid size in this case was down to 250 m and the model size was 15 km x 15 km. [23]

In another study [24] a similar model was used to evaluate wind conditions over a 3,5 km long fjord crossing of a new 132 kV line in western Norway.

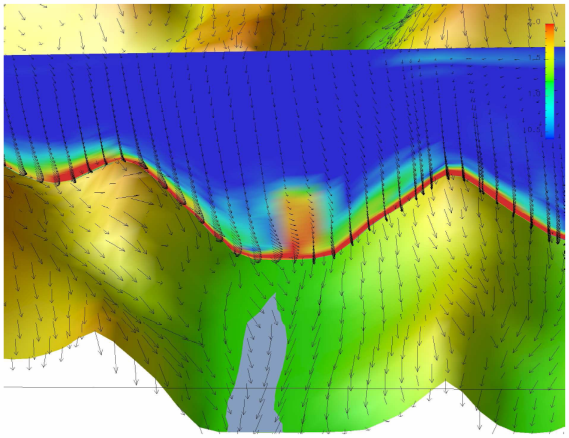

Fig. 15. Model output from Sunndalsøra, Norway. Arrows show wind speed and direction over the surface and in a vertical plane, approximately where the 132 kV lines cross in the valley bottom. Colors in the cross section represents turbulent kinetic energy. [23]

VII. AN OVERALL MODEL FOR THE DESIGN AND OPERATION OF POWER LINES

As a conclusion, we may consider all aspects of planning, designing and operating of power line networks with respect to any weather impact within a complete system where any type of field data relevant to the line could be combined with operational weather observations and models. This could include ice loads on conductors, galloping of conductors, pollution on insulators, vibration, thermal rating, etc. as shown in Fig.16 [25]. This concept has an "online" side where field data from power networks is incorporated in the operational model for local weather forecasts. If an adverse weather dependent incidence is identified, alarms can be generated automatically to various recipients like dispatch centers, field crew, etc. The other side is “historical” where data is collected from field and assimilated in similar models to generate for instance design parameters. In both cases the validity range of field data from the lines is expanded very significantly.

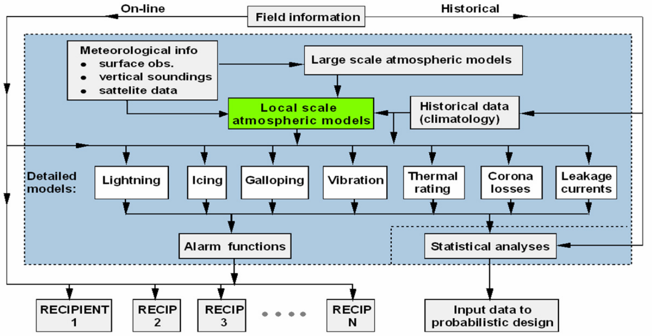

Fig. 16. A comprehensive model for design and operation of power line networks with respect to adverse weather impacts [25].

As shown above, the weather models perform very well in high wind situations already. This is because these weather systems are driven by pressure gradients on a large scale. When the horizontal pressure gradients are small, the thermodynamic processes are dominating, and they are not at all easy to model in a deterministic way. Therefore it is not yet possible to model for instance thermal rating accurately enough, unless you are within an environment of significant diurnal variations like land and sea breeze.

Ice accretion is also an important element for other phenomena on power lines such as galloping and corona losses. Examples on how long range transportation of airborne pollution combined with icing can lead to extensive flashovers on line insulation are shown in [26].

An operational system as sketched in Fig. 16, also have the potential of calculating load histories for a particular line. This could be a useful tool to manage condition based line maintenance with less efforts on the line condition analyzes.

VIII. ACKNOWLEDGMENT

The author is grateful to F. Ortega Conde (Iberinco) and P. Marais (Eskom) for icing pictures from Spain (Fig.2) and South Africa (Fig. 3), respectively. Dr Ivar Lie, Storm Weather Center AS, has very generously provided Figures 11-15 as well as information on recent advancements of fine-scale modeling technologies for the atmosphere.

IX. REFERENCES

[1] *Overhead lines – Meteorological data for assessing climatic loads,* IEC Technical Report 61774, First edition, Aug 1997.

[2] *Atmospheric icing of structures,* ISO 12494, First edition Aug 2001.

[3] A. B. Peabody, “Snow loads on transmission and distribution lines in Alaska,” presented at the 6th IWAIS, Budapest, Hungary, 1993.

[4] E.P. Lozowski and L. Makkonen, “Progress in modeling the accumulation of atmospheric ice on power line network equipment”, presented at the 11th IWAIS , Montreal, Canada, 2005

[5] L. Makkonen, "Models for growth of rime, glaze, icicles and wet snow on structures", Philosphical Transactions of The Royal Society, Ed. G. Poots, London, (2000) 358, pp. 2913-2940.

[6] M. L. Lu, N. Popplewell and A. H. Shah, “Predicting a power line’s extreme ice load from weather records”, in Proc. 2000 9th IWAIS, Chester, UK, June 2000.

[7] V. Kakos, J. Stekl, J. Jez and J. Cermak, ”On synoptic conditions supporting the appearance of heavy icing”, in Proc. 2002 10th IWAIS, Brno, Check Republic, June 2002. Paper 2-1.

[8] H. Olafsson, A.J. Eliasson and E. Thorsteins, “Orographic influence on wet snow icing. Part I: Upstream of mountains”, in Proc. 2002 10th IWAIS, Brno, Check Republic, June 2002. Paper 2-2.

[9] H. Olafsson, A.J. Eliasson and E. Thorsteins, “Orographic influence on wet snow icing. Part II: Downstream of mountains”, in Proc. 2002 10th IWAIS, Brno, Check Republic, June 2002. Paper 2-3.

[10] L. Latinov, D. Nikolov, “Study of the synoptic situation during the heavy icing in north Bulgaria for the period 20-30.XI.1998”, in Proc. 2002 10th IWAIS, Brno, Check Republic, June 2002. Paper 2-4.

[11] F. Popolansky, “Historical survey of ice investigation on the territory of the Czech Republic”, in Proc. 2002 10th IWAIS, Brno, Check Republic, June 2002. Paper 3-5.

[12] J. Stekl, J. Cermak, and R. Brazdil, “Icing phenomena on Milesovka in the period 1905-2000”, in Proc. 2002 10th IWAIS, Brno, Check Republic, June 2002. Paper 3-8.

[13] J. N. Lott and K. F. Jones, “Using US weather data for modeling ice loads from freezing rain”, in Proc. 1998 8th IWAIS, Reykjavik, Iceland, June 1998.

[14] J. N. Laflamme, “A few alternatives to ice load modeling from meteorological data and to direct ice load measurements”, in Proc. 2000 9th IWAIS, Chester, UK, June 2000.

[15] K. Ahti and L. Makkonen, "Observations on rime formation in relation to routinely measured meteorological parameters", Geophysica, 1982, Vol. 19 (1), pp. 77-85.

[16] K. Harstveit, “Using routine meteorological data from airfields to produce a map of ice risk zones in Norway”, in Proc. 2002 10th IWAIS, Brno, Check Republic, June 2002. Paper 8-1.

[17] W. Fuchs, “Forecast of aircraft icing by use of boundary layer model products”, in Proc. 2002 10th IWAIS, Brno, Check Republic, June 2002. Paper 4-2.

[18] A. Veal, B. Wareing and S.M. Fikke, “Using meteorological data to predict ice loads on overhead line conductors and structures”, presented at the Cigre Study Committee B2 colloquium UK transmission & distribution – An area of change, Edinburgh, UK, September 2003.

[19] J.B. Wareing, A. Veal and A. Skea, “Validation of ice models from meteorological models”, in Proc. BOREAS VII, Saarisalkä, Finland, March 2005.

[20] K. Finstad, “Visibility as an indicator of snowfall concentration in wet snow accretion modeling”, in Proc. 1998 8th IWAIS, Reykjavik, Iceland, June 1998.

[21] S. Krishnasamy, S. M. Fikke and O. E. Tveito, “Estimation of extreme wet snow loads in southern Norway”, in Proc. 2000 9th IWAIS, Chester, UK, June 2000.

[22] R. Benoit, M. Desgagné, P. Pellerin, S. Pellerin, Y. Chartier, ”The Canadian MC: A semi-Lagrangian, semi-implicit wideband atmospheric model suited for fine scale process studies and simulation”, *Monthly Weather Review, 125 (1997), pp. 2382-2415.*

[23] A. Holstad, I. Lie, T. Utnes and V. Ødegaard, ”Wind conditions in Sunndalsøra: A study using fine-scale models”, Res. Rep. No 125, The Norwegian Meteorological Institute, July 2001.

[24] I. Lie, “Wind conditions in Fjærlandsfjorden”, Res. Rep. No 129, The Norwegian Meteorological Institute, November 2001.

[25] S. M. Fikke, L. Rolfseng, I. Lie, L. Sidselrud, ”Meteorological models and remote monitoring technology for overhead line purposes”, JUKO Cigré Colloquium on overhead lines revitalization, Belgrade, May 2003.

[26] S.M. Fikke, T.M.Telstad, H. Förster and L. Rolfseng, ”Effect of long range airborne pollution on outdoor insulation”, in Proc. Nordic Insulation Symposium, Vaasa, Finland, June 1994, paper 1.6, pp.103-113.