COST Action 727 WG1– Review of results

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***Abstract*—This presentation reviews the results of Working Group 1 (WG1) "Icing Modeling" of COST Action 727. In phase II of the Action, Working Group 3 "Mapping and Forecasting of Atmospheric Icing" was combined with the modeling group to form a new WG1. This review, therefore, outlines the results of the former WG3 as well.**

I. INTRODUCTION

According to the Memorandum of Understanding of the COST Action 727 the activities of working group 1 (WG1) were to:

a) create an inventory about the knowledge base on icing

b) identify and summarise the gap in knowledge and data in order to be able to produce more accurate on-site predictions of icing climate

c) set up improved models and forecast schemes on the basis of available data

d) give recommendations on how to implement icing forecast schemes into the product chain of other forecast products on the basis of the given forecasted data stream.

Initially, in phase I of the Action a separate working group WG3, chaired by H. Dobesch, dealt with climatic icing mapping, prospects of icing forecasting and impacts of climate change on icing. However, already early in the action, the modeling work in WG1 started to focus towards the use of high-resolution atmospheric weather research and forecasting models (WRF). This brought the technical issues so close to those of WG3 that it was appropriate to join the two working groups. The roles of the working groups are shown in Figure 1.

This new focus also required increasing co-operation with the meteorological modeling community, and strengthened the joint work with WG2 in verification of modeling by measured icing events. Accordingly, many scientific papers produced during the action include several co-authors also from outside WG1 and the whole Action. This made the Action a truly international endeavor and produced significant advances in modeling and mapping of icing on various types of structures in different environments and on different types of structures..

The results of the research projects of WG1 have been published as book chapters, peer-reviewed journal papers and numerous conference papers during the entire Action. In addition, many oral presentations have been given and posters

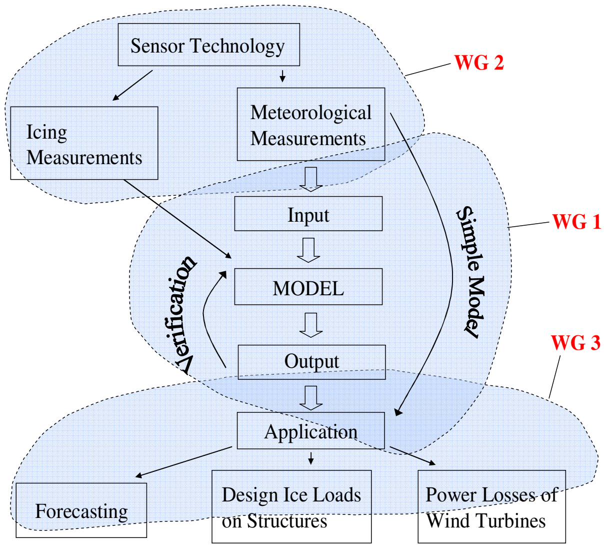

Fig. 1. Role of the initial working groups of COST 727. In phase II of the Action WG1 and WG3 were combined to form the new WG1

presented in conferences and workshops. The most recent results of WG1 are discussed in the individual papers presented in the Final Workshop as published in the IWAIS 2009 Proceedings. The reference list of this review may be considered as the publication list of WG1 of COST 727.

II. STATE-OF-THE-ART

The state-of-the-art report on icing modeling, prepared in co-operation with E.P. Lozowski from Canada, was presented and published as a conference key note paper [1], and as a comprehensive book chapter [2] that focused on icing problems on power transmission systems. Furthermore, a detailed review on the present and historical atmospheric icing studies in Europe was included in the extensive report of the initial WG3 [3].

These reviews together provide a significant knowledge base on the methods and data requirements of icing modeling. They formed the basis of focusing the subsequent modeling work in Phase II of the Action by emphasizing the lack of input data for numerical icing models, the lack of reliable data for model verification and the need for closer co-operation with the aircraft icing community. It was also concluded in these reviews that new icing models would benefit from attention given to standardization, interoperability and dissemination.

III. MODELING OF RIME

After phase I of the Action it was concluded that the theoretical accuracy of the existing rime icing models far exceeds that related to the uncertainty in the input parameters. In fact, the critical model parameters, the liquid water content (LWC) and median volume droplet diameter (MVD) of the icing cloud/fog are usually not know at all. This state of affairs left two routes to proceed: 1) Bypass the detailed numerical modeling entirely and use simple model schemes only, and 2) Try to model also the input parameters by theory and numerical methods.

As to the first option, significant efforts were made in the Action to improve and test simple modeling schemes of rime icing [4-8]. These provided interesting perspectives in utilizing simple icing indexes used in aviation, for example.

Regarding the second option, significant steps were made during the Action by the meteorological modeling community, including WG1 members, towards modeling the cloud physical parameters by basic meteorological ground data [9,10] and numerical WRF models [11,12].

Accordingly, it was decided to focus strongly on comprehensive icing modeling: First to model the input parameters by numerical WRF models and then to model icing by those data as input of a theoretical icing model. This approach seemed to open the door for short-term icing forecasting as well. For developing this idea effectively contacts were made with the key people outside the Action, in particular G. Thompson and B. Bernstein working in the field of aviation meteorology in the USA. WG1 also organized one of its meetings in connection with the SAE Aircraft and Engine Icing Conference, thus pioneering close co-operation between structural icing and aviation icing communities of the world.

The sharpened focus and co-operation produced a significant amount of efforts of rime icing modeling and verification by various parties of the Action and other experts. The use of high resolution numerical meteorological boundary-layer models in predicting icing conditions was developed and the models improved in this regard. Icing models were implemented in WRF-models and sensitivity studies [13] and comparisons with observations [12-17] were made with considerable success. Most comprehensive comparisons were made by utilizing the COST 727 icing station data of WG2 and are summarized in reference [18].

IV. MODELING OF GLAZE

No new theoretical developments were attempted in modeling the physics of glaze icing as the present models were considered adequate noting the limitations of input data. Instead, WRF models were utilized also in modeling icing due to freezing precipitation. The methodology was basically the same as for rime, but the icing models used in this case included the treatment of the heat balance of the icing surface [19-22].

Simple glaze icing models were also used in identifying freezing precipitation events by ground data and creating various statistics of them for glaze icing mapping [23,24].

V. MODELING OF WET SNOW

There is no comprehensive theory for wet snow accretion due to the lack of understanding of the details of the snow flake collision and impinging processes. Only empirical models can therefore be used. This would seem to suggest that developing a theoretical wet snow model should have been a primary task of WG1 of COST 727.

However, it was understood early in the Action that verification of wet snow accretion modeling was missing to the extent that further development of the models appeared fruitless prior to proper means of verification.

Severe wet snow events are rare, so that measurement campaigns provide results for this phenomenon very slowly. Therefore, there was no hope that the efforts of WG2 in measuring wet snow during the four-year Action would provide much help in this regard. Accordingly, emphasize in wet snow modeling in the Action was put on verifying the existing wet snow models by historical severe events, although well documented cases are scarce. A new disastrous wet snow event in Munsterland, Germany “fortunately” occurred during the Action, in fact, during one of the Action meetings, and could be effectively utilized in verification and model development [25].

Verification studies were made both by improving and utilizing the simple model based on visibility [25,26] and by wet snow detection made by WRF simulations [27,28]. The results were surprisingly promising, and were, consequently, immediately applied to wet snow risk analysis and mapping [25,26,28].

VI. MODELING OF HOARFROST

Hoarfrost is formed when water vapour sublimates directly into solid ice and it causes problems on high voltage power lines due to corona discharges which result in losses in electricity transmission. Hoarfrost also forms combined with rime icing. The rate of hoarfrost formation is approximately proportional to the surface area whereas the rate of rime icing decreases with the object size. Therefore, for ice load modelling on very large objects, hoarfrost needs to be taken into account.

As no model for atmospheric hoarfrost formation existed, an effort towards numerical modeling of hoarfrost formation was made in connection with COST727. This produced a model [29] which can be used by basic meteorological data as input.

It is noteworthy that it was also revealed during the Action that the present methods to measure high humidity values at cold temperatures are inadequate [30]. It was shown both theoretically and by empirical data that conventional humidity measurements fail in icing conditions. A method to detect icing based on humidity of air, as measured by a heated humidity sensor was also identified and verified [30].

An improvement to the accuracy of modeling hoarfrost by the model developed [29] may thus be possible only when the humidity sensors at weather stations are replaced by the type that is adequate for arctic conditions.

VII. STATISTICS AND MAPPING

It was found prior to the Action that the statistical methods that are widely used in estimating and mapping the frequency and return period of extreme meteorological events are partly inappropriate. This rather striking finding was outlined in a journal paper [31] and, as a consequence, the problem was reported by the American Meteorological Society in a Press Release on 21 March 2006.

An improved method to estimate the return periods of extreme events, such as icing, was subsequently developed and published in two journal papers [32,33]. The study [33] showed, in particular, that the risks have typically been severely underestimated. As a result, estimates of icing risk in many areas of the world need to be re-evaluated. The new method was utilized in the Action when estimating the return periods of hazardous wet snow loads on power lines [25].

The complicated statistical problems, mentioned above, are related to estimating the probability of *extreme ice loads* for e.g. structural design. Icing maps are required for other purposes too, most typically to estimate the frequency of the *occurrence of icing* in order to asses icing related power losses of wind turbines. Several methods were used in the Action to assess the frequency of various types of icing conditions in Europe [3,19,21-23,26,28,34-36]. For example, the global airport weather data archives by NOAA were utilized and statistics were made both for the ground level and the typical height of a tower or a wind turbine. Studies of this type were made in the Action based on direct observer's records as well as indirect calculations [23].

The effect of *climate change* on the rime icing frequency of wind turbines was also studied in the Action by combining a simple icing model with regional numerical climate model simulations [24].

VIII. SUMMARY/CONCLUSIONS

In summary, the most significant achievements of COST 727, WG1 were the following

- Existing scattered literature on icing was thoroughly reviewed, previous icing models conceptually evaluated and historical data sets identified.
- An improved method to estimate the return periods of extreme events, such as icing storms, was developed.
- Theory was developed for estimating cloud parameters at high elevations based on ground data.
- A physical-numerical model of the growth of hoarfrost on a cable was developed
- Modeling of wet snow accretion was improved and successfully verified.
- The use of high resolution numerical meteorological boundary-layer models (WRF) in indicating icing conditions was introduced. Icing models were implemented into WRF models and comparisons with observations were made with promising results.
- It was shown that meteorological observations are unreliable as far as icing related parameters are concerned. Tools to deal with this fact were introduced.
- Several methods were developed to assess the frequency of icing conditions in Europe. Icing maps were created for Europe. The results can be used in practical estimation of icing, e.g. in assessing tower safety and the profitability of wind energy projects.
- First steps were taken towards short-term prediction of icing events by utilizing WRF models.
- The possibility to evaluate the effects of global climate change on the icing frequency by regional climate model simulations was demonstrated.

These results mark a significant improvement in understanding icing phenomena and open the door for detailed on-site icing estimates and icing prediction. They also provide results that can be directly used in assessing icing risk and frequency in Europe. One of the users of these data is the rapidly growing wind power industry which is moving towards sites at higher elevations in its search for higher winds – and there faces the icing problem. The impact of COST 727 on solving these problems in outlined separately in reference [37]. The work of the Action has implications in the field of meteorological measurements as well [38].

As always, obtaining new results reveals new questions and needs for further research. In this case, we can be quite impressed about the sophistication of the models and the power of numerical simulation using vast amounts of observed or simulated data. The resolution of WRF models is improving still, so that it seems that in the near future we will be able to model icing in almost any scale. But are the results correct?

We lack verification, although this aspect too was significantly advanced in the Action. The problem is largely due to difficulties in measuring icing – the issue dealt with WG2. Another fundamental problem is that in many applications, e.g. in structural design, it is only the extreme conditions that are of interest, and they are rarely observed by definition. We may not necessarily expect that the models which work well under common conditions do the same under extreme conditions.

As the use of WRF models, significantly developed by the Action, will provide almost unlimited possibilities in regional icing modeling, the problem of verification has become a real bottleneck. When we use the LWC and MVD given by a WRF model as input for an icing model, we would ideally wish to verify the WRF output first. Unfortunately, LWC and MVD are even more difficult to measure than icing – or must be measured by icing. On the other hand, this state of affairs provides an indirect method to verify the WRF output by icing measurements. This is a unique opportunity and should be heavily utilized in further development of WRF models to be used in cold as well as warm climates.

IX. ACKNOWLEDGEMENTS

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