COST Action 727: Measuring and forecasting atmospheric icing on structures

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***Abstract*—The European Cooperation in the field of Scientific and Technical Research – COST – has established an Action on measuring and forecasting of atmospheric icing. It involves currently 10 European countries plus Japan. The background, objectives and current status of this Action is presented in the paper.**

I. What is COST?

COST was founded in 1971 as an intergovernmental framework for "European Cooperation in the field of Scientific and Technical Research". The goal of COST is to ensure that Europe holds a strong position in the field of scientific and technical research for peaceful purposes, by increasing European cooperation and action in this field.

COST has shown its strength in non-competitive research, in the pre-normative cooperation and in solving environmental and cross-border problems and problems of public utility. It has been used to maximize European synergy and added value in research cooperation and is a useful tool to further European integration.

Ease of access for institutions from non-COST member states also makes COST an interesting tool for tackling topics of a global nature.

To emphasize that the initiative came from the scientists and technical experts themselves and from those with a direct interest in furthering international collaboration, the funding fathers of COST opted for a flexible and pragmatic approach. COST activities have in the past paved the way for Community activities, and its flexibility allows COST Actions to be used as a testing and exploratory field for emerging topics.

The members states participate on an "à la carte" principle and activities are launched on a "bottom-up" approach. One of its main features is its built-in flexibility. COST has a scope beyond the EU and most of the Central and Eastern European countries are members. COST also welcomes the participation of interested institutions from non-COST Member States without any geographical restriction. Such partners must however be voted in an existing Action by the Action itself.

COST has developed into one of the largest frameworks for research cooperation in Europe and is a valuable mechanism coordinating national research activities in Europe. Today it has almost 200 Actions and involves nearly 30 000 scientists from 34 European Member States and more than 80 participating institutions from 11 non-COST Member States ad Non Governmental Organizations.

COST is based on Actions. These are networks of coordinated national research projects in the fields, which are of interest to a minimum of participants from different member states (at least 5). The Actions are defined by a Memorandum of Understanding (MoU) signed by the Governments of the COST states wishing to participate in the Action. The duration of the Action is generally 4 years.

Fig. 1. shows the general level of country participation of COST Member States.

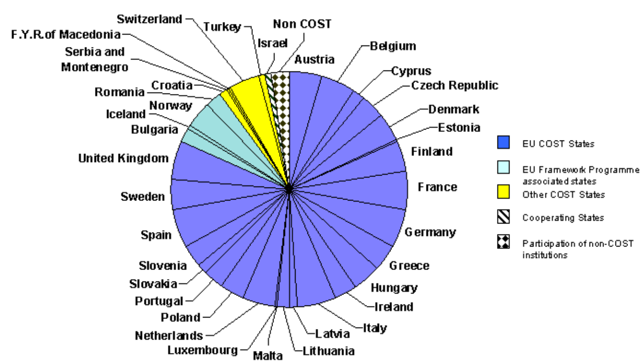

Fig. 1. General level of country participation of COST Member States.

COST covers a wide range of scientific and technological domains, one of these domains is Meteorology.

COST represents an estimated volume of national funding of more than € 2.0 billion/year. An average of € 80 000 per Action is available for coordination depending on size and activity of the Action. This funding is basically used to cover coordination costs such as contributions to workshops and conferences, travel costs for meetings, contributions to publications and short term scientific missions of researchers to visit other laboratories. COST does not fund research projects themselves, as its fundamental goal is to promote networking and collaboration.

COST is organized with a secretariat in Brussels. Each Member State has a COST National Coordinator (CNC) and also domain coordinators within the respective scientific and technical field of each domain. For more information about COST, see http://cost.cordis.lu/src/home.cfm.

II. COST ACTION 727

A. Memorandum of Understanding (MoU)

The Memorandum of Understanding for a suggested COST Action 727 "Measuring and forecasting atmospheric icing on structures" was circulated during 2003 and accepted by more than 5 countries early 2004. The initiative was taken within several European institutions involved in research and planning of wind turbine plants in icing exposed areas, especially in Finland, Germany, Austria, Switzerland, Norway and others.

The main objective of the Action is to "develop the understanding of icing (especially in-cloud icing) and freezing rain events in the atmospheric boundary layer and their distribution over Europe as well as to improve the potential to observe, monitor and forecast them". The MoU will remain in force for a period of five years from the date of the first meeting of the Management Committee (held on 27 April 2004 in Brussels).

As a background for the Action it is emphasized that the potential for icing of structures is an important design parameter in the sectors of, e.g., building industry (TV towers and ski lifts), energy distribution, maritime activities, aviation conditions on the ground and meteorological observations. It has also recently become a relevant issue in activities related to wind energy production, where the icing of blades and control wind gauges significantly reduces the power production and causes a severe environmental safety problem. Furthermore, as human activities are increasingly extending to cold climate regions affected by icing problems, there is also a need to increase robust meteorological measurements under cold climate conditions.

Freezing rain may be a significant factor at some sites. Freezing rain is a meteorological parameter which is routinely observed as occurrences by national meteorological networks. In recent years there has also been considerable research effort by electricity companies in the study of ice and wet-snow accretion on overhead transmission lines. This research has also involved the participation of several European research centers and institutes.

In many cases the most severe form of icing is in-cloud icing. It occurs when super-cooled cloud droplets collide with cold surface. As the intensity of ice accretion is strongly related to wind speed, it is a severe problem especially at elevated sites such as high towers and structures built in mountains or upon hills.

There are some theories available on in-cloud ice accretion upon structures, but so far there are not enough statistics or measurements available to be able to predict icing and impacts of ice accretion, or to assess the geographical distribution of ice accretion intensity. Very sophisticated icing models based on spectrum of particle size, mass of particles and their thermodynamic state, and description of the airflow are available. However, there is little information on input parameters required for the modelling of ice accretion as well as under which exact atmospheric conditions in-cloud icing occurs.

At the same time, relevant economic sectors have a growing need to start to produce (meteorological) forecasts on icing, ice accretion and duration of icing for various end-users based on a sound scientific parameterisation of relevant processes. Typically, so far, icing expectance is simply forecasted when the temperature is below 0°C and relative humidity over 95%, or when the target structure is within a cloud.

At the EU level, in-cloud icing and cold climate problems with respect to wind turbines and meteorological observations have been studied within the "Icing of Wind Turbines" and "Wind Energy production in Cold Climates" projects, as well as within the current "New Icetools" project (ref: www.fmi.fi/research). In these projects however, icing as a phenomenon, parameterisation of icing or development of proper icing sensors were not really addressed. The impact of icing upon meteorological sensors was studied within the "EUMETNET Severe Weather Sensors" (the SWS II) - project. Common to all these projects is a lack of proper observation of icing, icing rate and duration of icing, and low participation of persons/institutes with dedicated interest in the icing phenomenon.

According to preliminary statistics produced within EU wind energy projects, severe icing occurs over large regions in Europe from Northern Spain and the Italian Apennines to hills in northern UK, in the Alps and the Nordic countries. Unfortunately, these frequency distribution estimates are based on very simple parameterisation of icing (cloud, T<0°C, wind speed >0 m/s), and do not give actual climatological distribution of icing over Europe nor can they be used for, e.g., specification of ice prevention systems (e.g. blade heating systems for wind turbines) or for the ISO standard for atmospheric icing [1].

The preliminary icing map (icing from supercooled cloud droplets) over Europe produced within the EU/WECO project (Wind Energy production in COld climate) is based on synoptic measurements on temperature, wind and clouds from 100 weather stations. The estimate on intensity of ice accretion is based on empirical data from measurements with a Finnish Meteorological Institute (FMI) ice cylinder. The cloud data include only synoptic values of the cloud height and the cloud amount. It gives a rough estimation about possible in-cloud icing events at different altitudes, but it cannot be used for icing climatology over Europe. However, this work can be significantly improved by adopting new information produced by this COST Action and by also taking meteorological data from upper air sounding stations and other synoptic stations. There are also large differences in in-cloud icing due to topography; the isolated hills or hilly terrain typical in northern UK or the Scandinavian countries are usually affected only with the lowest clouds, whereas in the Alps middle clouds also affect icing while climatological conditions change from valley to valley.

Structures for which icing is a significant hazard includes lattice towers (TV and communication towers, high voltage power line towers), airplanes on the ground and wind turbines. When severely iced, these objects become large bodies for which the droplet collision efficiency is very small. For such small values of the collision efficiency, the aerodynamic theory that describes it fails, and the theoretical model results become excessively sensitive to the input parameters (droplet size, wind speed). Therefore, empirical methods need to be developed in order to estimate ice loads for lattice towers and other large bodies. Data from full-scale measurements of ice loads on towers (Ylläs, Finland; Akkanalke, Sweden) need to be analyzed in order to verify and validate the models.

Another important problem area related to in-cloud icing is the dependence of ice load on the elevation above ground level. This problem severely hampers estimation, and thus the design of tall structures, such as TV-towers and large wind turbines. Efforts to model the height dependence of ice loads need to be done by both theoretical and empirical modeling, as well as to be supported by direct measurements.

The EUMETNET SWS II project proved that at present reliable equipment to measure atmospheric icing (freezing rain and in-cloud icing) do not exist. There are currently a few sensors available to detect icing, but there is a need to improve them, to inform manufacturers about requirements for icing measurements as well as occurrence and distribution of icing intensity. A very important result would be to produce verifications of representativity of sensors under typical icing conditions. There is also a need to include WMO's (World Meteorological Organisation) measurement requirements for icing measurements and acknowledge them in the Guide to Meteorological Instruments and Methods of Observation. It is important to produce definitions and specifications for measurement of icing and for ice sensors. This information is also required e.g. for safety standards of wind turbines.

Forecast of rime accretion and freezing rain is needed by many sectors of activities and responsible bodies. However, at present icing forecasts are not produced by national meteorological services (NMS). Therefore, there is a need to design a forecast scheme based on available parameters.

The required research is multidisciplinary and has wide applications for various sectors of activity in various regions of Europe. Therefore, this COST Action is very appropriate in terms of addressing the mentioned issues, since it will draw together the scattered national activities in the field. It is also obvious that this COST Action will act as a stimulator to some EU research projects and also to some national R&D projects. This Action will not directly address upper air icing of aircraft and splash water icing of ships as applications. However, these issues will also benefit from the better understanding of the physics and climatology of icing developed in this Action.

Currently the COST Action 727 is supported by 11 European countries:

- Austria
- Bulgaria
- Czech Republic
- Finland
- Germany
- Hungary
- Norway
- Spain
- Sweden
- Switzerland
- United Kingdom

In addition to several governmental and private institutions within these countries, the Kaganawa Institute of Technology in Japan takes part in the Action.

B. Objectives and benefits

The main objective of the Action is to develop the understanding of icing (especially in-cloud icing) and freezing rain events in the atmospheric boundary layer and their distribution over Europe as well as to improve the potential to observe, monitor and forecast them.

The means by which this objective will be achieved include:

- To undertake scientific research of the processes relevant for atmospheric icing of structures and instruments.
- To support the development of icing climatologies and occurrence thresholds for validation purposes and to establish its relationship with boundary layer icing forecasting.
- To regularly assess the requirements from the operators and planners of TV/towers, power lines, wind turbines and meteorological services.
- To develop methods that is suitable for operational implementation taking into account users' needs.
- To produce detailed documentation on the various methods and models, their quality and applicability.
- To recommend measurement requirements and to introduce specifications for ice detectors.
- To disseminate existing expertise and the results of the Action to a wide range of users and scientists.
- To provide preliminary estimates on potential icing conditions under a changing climate (ref. IPCC reports, NEFP Climate & Energy project[1]).
- To enhance a more active and sustained co-operation in research & development in the field, and to foster exchange of knowledge, of data and methods between participants across Europe.

Achieving the above means will lead to the following direct benefits:

- Increased scientific understanding of processes and conditions leading to icing.
- Increased knowledge of the requirements for various applications (energy transport, tourism, wind power production etc.)
- Pre-normative data for certification bodies to improve

[1] A Nordic project "Impact of the Climate Change on Renewable Energy Sources and their role in the Nordic Energy System" partially funded by the Nordic Energy Research; http://www.os.is/ce/

safety and probabilistically optimized economical design of structures.
- Statistical data on prevailing icing conditions and occurrence.
- Basis for planning future needs on the issue of icing; measurements, parameterisation, prediction and forecasting.
- Basis for development of better devices or methods to prevent icing of structure and instruments.
- Effective advanced models and methods for processing observational data and forecasting ground icing occurrence.
- More synergetic co-operation between European countries in the development of forecasting methods of atmospheric icing and for the exchange of forecasting tools.
- Better estimate of measurements bias under icing conditions.
- Wider distribution of knowledge about risks of icing among various sectors of activity and economy
- Strengthening of the European scientific community devoted to icing and related investigations.

Consequential benefits will arise from the operational implementation of the results of this Action:
- Planning aids for energy networks, manufacturers and maintainers of wind energy turbines, tourism, and meteorological forecasters.
- Reduction of costs due to interruption of communication or energy supply, material damage and traffic congestion.
- Possibility to develop new observation systems and devices based on the recommendations for standard measurement equipment.
- Improved safety in traffic following from ability to assess and predict airfield and road slipperiness.

C. Scientific Program and Organization

The scientific program is divided into two phases: 1) a preparatory phase, and 2) a research and development phase.

The goal of the preparatory phase is to:
- produce statistics on icing events and duration of icing at any site desired
- predict ice loads on structures
- forecast icing or rime accretion (time, duration, intensity of icing)
- measure icing and available data
- model ice accretion on structures.

The deliverables of phase 1 are:
- Reports on the state-of-the-art
- Inventory of users' needs based in analyses
- Establishment of web sited for the Action
- Working plan for the second phase of the Action.

The second phase of the Action will focus on current research and developments within this field. A lot of theoretical work on ice and snow accretion on structures is available. However, there is very little knowledge and data about the parameters needed to use the produced formulas in the most proper way. There is also a lack of data on occurrence of atmospheric icing. It is obvious from preliminary data available from various parts of Europe that atmospheric icing occurs during a much wider range of temperature and humidity than usually expected. Thus, for instance, predictions of loads provided in many countries may lead to 1-2 decade errors at present.

Forecast of rime accretion and freezing rain is needed by many sectors of activities and responsible bodies. In principle the icing forecast can be a part of a Limited Area Weather Forecast Model System (e.g. HIRLAM or MM5, see [2]). On the other hand, experimental data and observations are needed to verify the accuracy of the forecasting models. Possibilities for more accurate forecasting systems will be assessed and tested in the framework of the more general weather forecast systems.

Obtaining sufficiently accurate input data for icing models is a significant problem that needs to be solved. The cloud droplet size distribution and liquid water content are not routinely measured and the anemometers supposed to provide correct wind data are often iced up. High temporal resolution determination of the air temperature is critical in the ice disappearance phase of the modeling effort. Proper measurement and extrapolation of these input parameters to often remote sites of interest is extremely difficult. Consequently the future usefulness of theoretical icing modeling will essentially depend on the progress made in this area. Making the measurements by the rotating multi-cylinder automatic could be attempted, which would enable the validation of the icing theories in the field (e.g. at the existing test sites at Deadwater, U.K., Olos, Finland and at the EUMETNET SWS sites).

The empirical data on icing obtained within the EUMETNET SWS II project, actually studying ice-free sensors in harsh conditions at three sites (Mont Aigoual/France, Mont Säntis/Switzerland, and Luosto fell/Finland) during the winter 2001/02, will be used and applied in this Action.

Several new wind energy plants located at high latitude and high altitude sites in Europe will also provide some empirical data that will be used for this COST Action. Also some TV masts in various countries are capable of measuring total ice loads on the mast. Such data are available at several broadcasting companies and research centers. The available data can also increase the knowledge on the frequency of super-cooled clouds in various parts of Europe.

The second phase would yield:
- research activities on in-cloud icing
- measurement activities on atmospheric icing
- modeling of icing processes
- improved forecasting systems

- verification of existing icing sensors
- mapping of icing occurrences and potentials in Europe.

The deliverables are expected to be:

- Scientific and technical publications on measurements and predictions of in-cloud icing
- Publications on verification of icing forecasts
- European icing map
- Recommendations for WMO observations and further work.

Each of the COST 727 Member States are entitled according to COST rules to have two members of the Management Committee (MC). The MC is responsible for the implementation of the Technical Annex of the MoU by developing a Work Program that will take into account the expertise and the interest of the participating institutions and results from earlier work connected to this topic.

According to the above scientific program, it is envisaged that the basic activity will be carried out within 3 Working Groups (WG) representing three clear lines of activity:

1. Development of the scientific understanding of icing processes, their occurrence and their forecast (including verifications), and modeling of ice loads (ice accretion and melting; duration of ice load).
2. Icing observations, measurements, field campaigns at different climatic regions and under different types of icing conditions, verification of sensors and development of ice detectors (sensors).
3. Establishment of frequency distribution maps of icing potential in Europe based on the new knowledge of WG 1 and existing climatological data. This would also necessitate use of GIS-methodologies (cooperation with COST-719 is to be established).

1) WG1: Icing Modeling

WG1's activities will be to:

- create an inventory about the knowledge base on icing (physics, models,…)
- identify and summarize the gap in knowledge in order to be able to produce more accurate on-site predictions of icing (number of icing days, distribution on rates of icing, melting processes, etc.)
- set up improved models and forecast schemes on the basis of available data
- 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.

2) WG2: Measurements and Data Collection on Icing

Measurements over a specific period of time on ice accretion and testing of icing sensors will be based on existing test sites in the far north (Luosto/Finland), Alpine region (Switzerland) and in southern Europe (Mont Aigoual/France). Additional experimental data from other ongoing activities will be used for this Action.

WG2's activities will be to:

- create an inventory and collect available experimental data on icing as well as ancillary data
- review and assess existing ice detectors and their performance
- review and assess existing verification data from different sources
- contribute to the set up of icing measurements at different locations in Europe and to the development of existing test sites
- set up a data quality control scheme for measured icing data
- establish a basic data set for icing modeling and verification
- provide recommendations to set up a long-term icing measuring network and data base (to be submitted to WMO)
- establish an icing monitoring core group for collecting and maintaining data on icing during and especially after the course of the Action
- develop the scientific and technical bases of specifications of ice detectors
- set up recommendations for testing/approving ice detectors and ice/free sensors.

3) WG3: Mapping and Forecasting of Atmospheric Icing

WG3's activities will be to:

- harmonize the pre-processing methods using relevant meteorological and ancillary input data
- map icing in Europe on the basis of the data obtained from the previous item as well as other measured and modeled data
- establish a European Icing Atlas (in cooperation with COST 719)
- assess the possible influence of climate variability and climate change on icing effects (together with WG1)
- produce climatological data on icing using data from numerical forecast models
- adapt the recommendations of WG1 on icing forecast to study feasibility of implementation and usability of such a forecast scheme
- set up and run a test implementation in one or more of the participants' NMS
- final recommendation on icing forecast for NMSs and WMO

4) Current Status

The Action 727 was formally established 27 April 2004. The Chairmen of the Action were appointed as follows:

- Management Committee: Dr Bengt Tammelin, Finnish Meteorological Institute, Finland.
- WG1: Dr Lasse Makkonen, VTT, Finland.
- WG2: Mr Svein M. Fikke, Consultant, Norway.

- WG3: Dr Hartwig Dobesch, ZAMG, Austria.

Each WG is currently in the process of consolidating their working procedures according to the scientific program described above. Most of the participating countries have at least one (maximum is two) member in each WG. In total, more than 30 researchers and technical experts are taking active part in this work (January 2004).

III. References

[1] *Atmospheric icing of structures*, ISO 12494, First edition Aug 2001.
[2] S.M. Fikke, "Modern meteorology and atmospheric icing", in Proc. 2005 11th IWAIS, Montreal, Canada, June 2005, paper IW-73.