Recommendations for Meteorological Measurements under Icing Conditions

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Abstract— **At present time, the WMO/CIMO has scarce guidelines for measurements under harsh environmental conditions, including icing, though there is a requirement for such specifications. Therefore, it was decided to expand the WMO/CIMO Guide by including a chapter dedicated to meteorological measurements under harsh environment, including icing.**
One of the objectives of the COST 727 Action was precisely to fulfill the WMO/CIMO request to provide guidance for performing measurements under harsh icing conditions. A set of definitions concerning meteorological and instrumental icing is proposed, together with a site classification related to the local icing severity to be expected. With these tools, a method for characterizing a meteorological instruments in relationship with the site – icing - environment is presented, which should allow meteorological stations' or network managers to select sensors according to the required availability of the final data.

I. Introduction

THERE is an increasing demand of accurate meteorological measurements and measurements of icing in cold climate and mountainous regions worldwide for the benefit of various human activities such as construction, recreation, utilization of natural resources – e.g. wind energy - and energy distribution which require good weather forecasts. This includes also the improvement of meteorological measurements in networks for synoptic and climate applications together with more reliable data for numerical weather prediction models. Providing specific climatic weather information from given sites is also requested for economical and safe design of structures sensitive to harsh environments.

From the meteorological measurements point of view, icing events may result in more or less severe degradation of the measurement system up to the destruction of the sensor itself. This kind of situation is difficult to assess, especially for remote, stand-alone stations leading to often unnoticed perturbation of the data, as usually no icing sensors are available on the site.

The Commission for Instruments and Methods of Observations (CIMO) of the World Meteorological Organization (WMO) has published the Guide to Meteorological Instruments and Methods of Observations ([1]) that includes specifications (meteorological requirements, accuracy, etc.) for various instruments that are used for manned synoptic as well as for automatic weather stations. These specifications are applied by the manufacturers producing meteorological instruments and by National Weather Services and institutes involved in applied meteorology. However, they provide only scarce information concerning guidance for measurements under harsh (icing) conditions. Recognizing this situation, it was recently decided to extend the WMO/CIMO Guide with a chapter specifically dealing with measurements under harsh conditions, including mountainous/arctic, desert, tropical, marine and urban environments.

In parallel, recent experiments dealing with comparisons of instruments and their respective behavior under harsh icing conditions have been performed and it has been recognized that there is a lack of knowledge and practically no guidance for performing meteorological measurement under harsh conditions (e.g. the EUMETNET SWS II experiment: more details in [2],[3],[4],[5],[6],[7],[8],[9],[10] and[11]).

In April 2004, the COST 727 Action "Measuring and Forecasting Atmospheric Icing on Structures" was launched to develop the understanding of atmospheric icing (in cloud icing, wet snow and freezing rain) events in the atmospheric boundary layer including their distribution over Europe as well as to improve the potential to observe, monitor and forecast them. The results obtained show that at present time no operational ice detector is available on the market: the few available sensors will need more developments which could be best achieved only in the framework of further international projects. It was also recognized that unlike for other meteorological parameters, there are still very limited data available about ice accretion and scarce resources in the National Weather Services to extend meteorological networks with such specific instruments.
The goal of the present paper is therefore to fulfill the WMO/CIMO request to provide guidance for performing measurements under harsh icing conditions.

II. Present State of Research

The expression "atmospheric icing" comprises all processes where drifting or falling water droplets, rain, drizzle or wet snow in the atmosphere freeze or stick to any object exposed to the weather.

Due to different processes taking place in different climatic conditions, it is difficult to standardize the effects of ice accretion. Therefore local (regional, national) experiments have to be performed, and such activities should be based on the existing International Standards ISO 12494 ([12]). Detailed information about icing frequency, intensity etc. has to be collected applying different methods such as:

- Collecting existing experiences,
- Direct measurements of icing over periods of many years,
- Icing modeling based on known meteorological data.

The first method is widely based on existing field activities such as telecommunication, power transmission, road and airport safety, wind turbine operation etc.

Meteorological Services are more specifically fitted for the second method which implies operational activities upon a long period of time: standardized measuring devices (if available) must be operated in the areas representative of the site of interest following established procedures and measurements should be taken for a sufficient long period of time to form a reliable basis for extreme value analysis. The time period could last a few years to several decades, depending on the local conditions. However, shorter series may be of valuable help and may also be connected to longer records of meteorological data, either statistically or (better) physically, in combination with theoretical icing models.

The third method has been intensively tested during the COST 727 Action as presented in a number of papers during the IWAIS-2009 Conference: numerous model simulations were performed at six available test stations in Europe and the results compared with the local validation measurements. The results proved promising, comforting the fact that a breakthrough has been achieved by the use of the numerical weather prediction model WRF together with the ice accretion formula as post-processing. This could be achieved thanks to the close collaboration with the developer of the cloud physics and precipitation scheme in the WRF model (Greg Thompson, NCAR, USA). The WRF model and the post-processing algorithm are presently operated successfully in different other projects by the Norwegian Meteorological Institute and Meteotest in Switzerland among others. Finally, tentative mapping of the whole European region containing the test stations could also be obtained for a given icing period, opening the way to mapping and forecasting of icing over large regions. The results can be summarized in more details as follows:

- The WRF model together with the Makkonen icing formula [13] is able to simulate icing events. Icing periods were reproduced relatively accurately whereas the ice load remains inaccurate due to the lack of information concerning the Liquid Water Content LWC and the Particle Size Distribution PSD at the stations' height (there are presently no operational instruments able to measure these parameters).
- Complex topography puts high requirements on numerical weather prediction models. For icing simulation, the use of high resolution topographical data is crucial.
- Extensive computer resources are needed to carry out such simulations.

Modeling of wet snow has also been developed and verified with events that have been taken place in UK, Germany and Hungary.

However, improvements may be achieved more simply through better knowledge of the relative humidity, temperature and dew point temperature: in order to give information about icing potential – also at sites not equipped with an ice detector – a simple approach for early ice detection is presently being developed and tested with promising results. First applications of these methods have proved positive [14].

More information concerning standards, definitions of the different types of icing and past activities may be found in the status report prepared by the COST 727 Action ([15]).

III. Proposal for combined site and instrument specifications

During the experiments mentioned in the preceding section, it was possible to setup/adapt the following definitions which can used to characterize existing sites or select new adequate locations for Automatic Weather Stations (AWS) and to describe the behavior of meteorological instruments under harsh conditions.

A. *Definitions*

Meteorological icing M_{icing} is defined as the duration of the meteorological event or perturbation which causes icing [unit: time].

Meteorological icing can be characterized by the duration of the icing event, and/or the actual meteorological conditions together with information such as the total amount of ice accreted during the icing event or the average and maximum accretion rate (Figure 1).

However, it must be noted that meteorological icing is not easy to define: it is today widely accepted that it is dependant on the following factors: wind speed, air temperature, liquid water content LWC, droplet size distribution, the latter two being difficult to measure in operational mode. New development may improve this situation.

Today, ice accretion can be more or less measured under specific conditions by instruments measuring the changes of a vibrating frequency (e.g. Goodrich Ice detector) or the load of ice following the ISO 12494 standard (SSE/Combitech IceMonitor MK I).

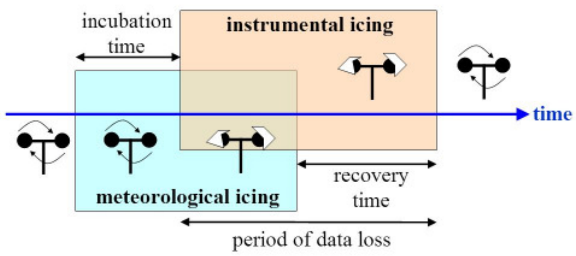

Fig. 1. Schematic representation of the different icing durations.

Instrumental icing I_{icing} is defined as the duration of the technical perturbation of the instrument due to icing [unit: time].

Instrumental icing is the effect of icing on the quality (e.g. degradation) of the measurements, depending on icing conditions as well as the design of the instrument. It can be today only recorded by analyses of video recordings and/or regular visual observations.

This definition is valid for all objects and it can be easily generalized to "structural icing".

Finally, further definitions can be useful:

- **Incubation time [time]:** delay between the beginning of the meteorological icing and of the instrumental icing.
- **Recovery time [time]:** delay between the end of the meteorological icing and the full recovery of the performance of the instrument.

Instrumental icing can be smaller, equal or longer than meteorological icing. The incubation time indicates how quickly the instrument reacts to icing while the recovery time may be much longer that the meteorological icing, especially in northern countries with low solar irradiance in winter.

B. The Performance Index

During a meteorological icing event, the relationship between meteorological and instrumental icing can be expressed in the following way: An instrument which remains free of ice during a meteorological icing period (good heating, good coating, etc.) may be considered as well adapted for the station's climatology. On the other side, an instrument which gets frozen during a meteorological icing period and remains in that state after the meteorological icing period must be classified as poorly adapted to the site's environmental conditions. This leads to the following definition:

The Performance Index PI is the ratio of the duration of the instrumental icing to the duration of the meteorological icing (both expressed in the same time unit).

$$PI = I_{icing} / M_{icing}$$

The Performance Index PI can be used for the selection of the instrument as function of some station's classification. A value of PI near 0 reflects a good behavior of the instrument in terms of icing (e.g. good heating). Values of PI between 0 and 1 may be acceptable as long as ice detectors (or other methods) are available to "flag" dubious periods of measurements. Values of PI higher than 1 indicate a sensor which is sensitive to icing (e.g. poor heating) for a time period (much) longer than the meteorological icing.

C. Influence of the climatic conditions

As seen in the preceding section, meteorological icing is different than instrumental icing, the latter being the consequence of the former, but with different effects depending on the characteristics of the prevailing meteorological conditions and of the instrumental design.

Instruments (or structures) will behave differently depending on the location of their installation. Sensors operated in cold climate (polar) conditions may get frozen at the beginning of the winter and remain as such for a long period due to the low temperatures and the lack of sunshine. On the contrary, such instruments may be installed in temperate climate environment and work more or less undisturbed under milder, sunnier conditions. Therefore, the instruments availability must be evaluated as a function of the site of installation **in terms of local icing conditions**.

D. Site Ice classes

To be able to express the expected amount of accreted ice at a certain site, the term ICE CLASS (IC) is introduced in the ISO 12494 standards. This definition is adapted for meteorological purposes as presented in the following.

The station's **Local Icing Index LII** is the parameter proposed to the meteorological community to determine how severe the ice accretion is expected to be at the particular site.

Climatology may provide information about LII, which (in general terms) tells how much icing can be expected at a given location for designing purposes. Measurements and/or model studies such as the WRF model – with adequate post-processing developed during the COST-727 Action – are necessary to obtain the information needed for a specific site, unless measurements, resp. visual observations can supply the same information. The LII class may vary within rather short distances of a specific area. Measuring should be carried out where ice accretion is expected to be most severe, or at the precise station site, or both.

Therefore, it is recommended that a classification of sites such as presented in Table 1 is introduced in the metadata of the station indicating the degree of severity of local icing conditions. This information could be added to the site classification as proposed by the WMO/CIMO for the characterization of AWSs.

TABLE I

CLASSIFICATION OF SITES ACCORDING TO SEVERITY OF ICING. IT IS ASSUMED THAT THE SENSORS OPERATE AT THE EXPECTED ACCURACY (WMO OR MANUFACTURER) MINIMUM 95% OF THE TIME PER MONTH (FROM EUMETNET/SWS II EXPERIMENT).

LII class	**Days with meteorological icing / year**	**Duration of meteorological icing %/year**	**Hourly intensity of icing g/100 cm² (95%)**	**Icing type**
LII=5	> 60	> 16	> 50	Heavy
LII=4	31-60	8-16	25	Strong
LII=3	10-30	3-8	10	Moderate
LII=2	3-10	0.05-3	5	Light
LII=1	0-2	0 – 0.5	0-5	Occasional

E. Instrument Class Index

A classification for meteorological sensors taking into account accuracy and required reliability of data combined with climatic conditions will be difficult to achieve. Therefore, the goal is now to build a common indicator by combining the Performance Index PI defined above together with the site classification through the Local Icing Index LII.

A potential indicator for the mean availability of instruments under icing conditions may be given by the **Instrument Class Index IC** which links the PI values ranging from 0 → ∞ ∞ to the different site classes LII as indicated tentatively in Table 2. The range of this classification extends from IC=5 (PI = 0; availability = 100 % for all LII values → perfect ice-free instruments) to IC=1 (PI = very high values; availability < 39 % → instruments which could remain frozen for a very long period after the meteorological icing period, e.g. long recovery time for high latitude stations without sun during whole seasons).

TABLE 2:

CLASSIFICATION OF INSTRUMENTS IN TERMS OF MEAN PERFORMANCE DEPENDING ON THE PERFORMANCE INDEX AND THE STATION'S CLASSIFICATION LII (THE MEAN AVAILABILITY VALUES DISPLAYED IN ITALIC ARE PURELY HYPOTHETICAL AND WILL HAVE TO BE SPECIFIED IN FUTURE WITH DEDICATED MEASUREMENTS).

Instrument Class index	PI range	Mean availability [%] for LII=1 to 5	Conclusions
IC=5	0	*100 %*	Excellent instrument not sensitive to icing
IC=4	0..1	*99% to 90 %*	Good instrument, little sensitivity to icing
IC=3	1..5	*89% to 70 %*	Medium sensitivity to icing
IC=2	5..20	*69% to 40 %*	Instrument to be used only with separate icing detection
IC=1	20+	*<39 %*	Instrument not recommended for such applications

The interpretation of the IC index is strongly dependant on the Station Class LII and the effect of icing on the results' quality. This leads to the following graphical tentative representation (Figure 2) where the user can select the class of instruments needed to fulfill his requirements depending on the location (e.g. classification) of his station and his requirements.

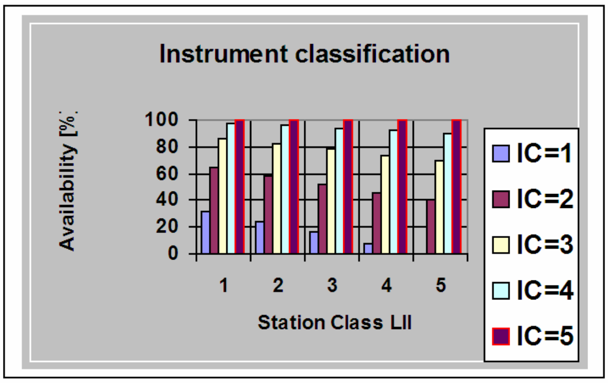

Fig. 2. Graphical display of the instruments' classification presented in Tables 1 & 2 (hypothetical values).

F. Consequences

The measurements' availability and accuracy is dependent on the instrument type (anemometer, thermometer, etc.), design (e.g. rotating parts), heating (power, design/geometry), but also on the meteorological conditions prevailing at the selected site (Metadata, AWS classification).

The sensors' characteristics should be determined independently of the site's meteorological characteristics, e.g. under laboratory conditions and/or at selected regional centers (RICs) representative of the stations' classification. The ultimate goal is that the user can determine approximately if the selected instruments fulfils the required specifications for his station.

For example, a potential user is located at a station classified LII=4 (strong icing) and intends to perform wind measurements of high quality. By choosing an instrument of class IC=3, the measurements will be performed correctly around 74% of the time for his station. However, when installing the same instrument at a station of type LII=2 (light icing), the mean availability of the instrument would increase to around 82%. As mentioned earlier, the availability percentages indicated in Table 2 will have to be adjusted with more accurate measurements in the future.

Two conditions must be met to achieve this goal:

- Adapting the above tables and diagram with values corresponding to the reality means that the development of reliable reference sensors to measure the duration and loads of icing is mandatory. The model developments achieved during the COST 727 Action will be very useful to determine the Station Class (icing maps) and, to some extent, the PI of sensors with simulations of selected icing events.
- Test sites for icing research must be promoted and

equipped for the determination of the meteorological icing periods as well as for the characterization of the instrumental icing.

IV. Conclusions

Recent international measurement campaigns as well as activities in the field of road safety and energy production/transport have shown quite clearly that there is a lack of adequate method for the determination of icing events and for the observation of the state of an instrument (or structures).

Following the recommendations expressed in the final report of the EUMETNET/SWS II project, the WMO/CIMO has recognized the need of better guidance for measurements performed under harsh conditions and has decided to extend the WMO/CIMO Guide with a specific chapter dedicated to meteorological

The COST 727 Action has contributed to the achievement of new advances in this field concerning the development of reference instruments, the characterization of sites in terms of local icing climatology and the modeling of icing.

Considering that meteorological icing can be determined with reference instruments which are to be further developed, the present paper proposes a method to classify instruments in terms of icing sensitivity based on the characteristics of the installation/operational site. To achieve this and to provide manufacturers with adequate specifications, the following developments on international level should be considered on the long term:

- The deployment of regional test centers with well defined icing characterization. It is recommended to start tentatively such activities at the test stations which have been installed and operated in Europe in relationship with the COST 727 Action.
- The definition of a certification procedure for meteorological instruments depending on the design of the sensors and the site location where it will be operated.

V. Acknowledgments

The authors wish to thank the WMO/CIMO for their past, present and future outstanding collaboration with the COST 727 Action, hoping to have contributed to the establishment of guidelines for meteorological measurements performed under harsh conditions.

VI. References

[1] World Meteorological Organization (WMO), 1996. Guide to Meteorological Instruments and Methods of Observation. WMO-No 8, sixth edition. Secretariat of the World Meteorological Organization - Geneva – Switzerland

[2] Tammelin, B., Heimo, A., Leroy, M., Rast, J. and Säntti, K., 2001. Meteorological measurements under icing conditions - EUMETNET SWS II project. Reports 2001:6. Finnish Meteorological Institute, Helsinki. 52 p.

[3] Tammelin, B., Heimo, A., Leroy, M., Rast, J., Säntti, K., Bellevaux, C., Dal Cin, Bruno, Musa, M. and Peltomaa, A., 2003. Improvements of severe weather measurements and sensors – EUMETNET SWS II project, final report. Finnish Meteorological Institute, CD-ROM, p. 167.

[4] Tammelin, B., Heimo, A. and Leroy, M., 2002. Ice-free sensors - THE EUMETNET SWS II Project. In: the proceedings of WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2002). Report No 75, WMO/TD-No. 1123

[5] Leroy, L., Tammelin, B., Hyvönen, R., Rast, J., Musa, M., 2002. Temperature and humidity measurements during icing conditions. In the proceedings of WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2002). Report No 75, WMO/TD-No. 1123, 4p.

[6] Rast, J., Heimo, A., Tammelin, B., Leroy,. M., 2002. Solar Radiation Measurements under Icing Conditions. In the proceeding of WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2002). Report No 75, WMO/TD- No 1123, 5 p.

[7] Musa, M., Suter, S., Hyvönen, R., Leroy, M., Rast, J. and Tammelin, B.; 2002. Measurement of temperature with wind sensors during severe weather conditions. In: proceedings of the WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO 2002). Instruments and observing methods, report No 75, WMO/TD-No 1123.

[8] Tammelin, B., Heimo, A., Leroy, M., Peltomaa, A., Rast, J., 2003. Ice-Free Wind Sensors. 3th International Conference on Experiences with Automatic Weather Station ICEAWS, Torremolinos (Malaga) -19th-20th & 1th February 2003. CD-ROM.

[9] Tammelin, B., Heimo, A., Leroy, M., Peltomaa, A., and Rast, J, 2003. Ice-free wind sensors. In: Tammelin, B. et al (eds.) BOREAS VI proceeding, 9-11 April 2003, Pyhätunturi, Finland. Finnish Meteorological Institute, CD-ROM

[10] Säntti, K., Tammelin, B., Laakso, T. and Peltola, E., 2003. Experiences from measurements of atmospheric icing. In: Tammelin, B. et al (eds.) BOREAS VI proceeding, 9-11 April 2003, Pyhätunturi, Finland. Finnish Meteorological Institute, CD-ROM.

[11] Improvements of severe weather measurements and sensors – EUMETNET SWS II project – Final Report – Finnish Meteorological Institute, Helsinki, 2003

[12] ISO/TC 98/SC3 ISO 12494, 2000. Atmospheric Icing on Structures.

[13] Makkonen L., "Models for the growth of rime, glaze, icicles and wet snow on structures", Phil. Trans. R. Soc. Lond A., vol. 358, pp. 2913 - 2939, 2000.

[14] Rast J., Cattin R., Heimo A. "Icing Indices: a good solution?", XIII International Workshop on Atmospheric Icing of Structures (IWAIS), 8-11 September 2009, Andermatt, Switzerland, Proceedings (this volume).

[15] Fikke S., Ronsten G., Heimo A., Kunz S., Ostrozlik M., Persson P.-E., Sabata J., Wareing B., Wichura B., Chum J., Laakso T., Säntti K., Makkonen l.: 2006, COST-727 - Atmospheric Icing on Structures, Measurements and data collection on icing: State of the Art, Publication of MeteoSwiss, 75, 110 pp.