COST-727 ACTION: Measurements and Simulations

Cattin, René [1]
Dierer, Silke [1]
Nygaard, Bjørn Egil [2]
Säntti, Kristiina [3]
Wareing, Brian [4]

[1] Meteotest, Fabrikstrasse 14, 3012 Bern, Switzerland, rene.cattin@meteotest.ch, silke.dierer@meteotest.ch
[2] Norwegian Meteorological Institute, P.O.Box 43, Blindern, NO-0313 Oslo, Norway. Email: bjornen@met.no
[3] Finnish Meteorological Institute, Erik Palmenin aukio 1, 00560 Helsinki, Finland, kristiina.santti@fmi.fi
[4] Brian Wareing.Tech Ltd, Rosewood Cottage, Vounog Hill, Penyffordd, Chester, CH4 0EZ, UK, bwareing@theiet.org

Abstract

The COST-727 Action "measuring and forecasting atmospheric icing on structures" was defined to develop the understanding of icing (especially in-cloud icing), wet snow 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 second phase of the action is dedicated to in-situ measurements of atmospheric icing with selected reference icing sensors at six stations operated in Europe and to the modelling of selected icing events with an ice accretion model driven by the weather model WRF.
The first two test stations have been installed in Switzerland (Guetsch, 2'300 m a.s.l, co-located with the highest wind turbine in Europe) and Finland (Luosto, 515 m a.s.l). These stations have been used to perform tests with different types of icing sensors, resulting in the selection of two systems yielding information on the occurrence of meteorological icing periods (yes/no; Goodrich Rosemount ice monitor) and on the amount of accreted ice (kg/m; Combi-Tech IceMonitor). The other four stations in Sweden (Sveg), Germany (Zinnwald), United Kingdom (Deadwater Fell) and Czech Republic (Studnice) are equipped with those instruments for winter 2008/09.
First icing simulations for icing events at Guetsch and Deadwater Fell have been performed with very promising results. This was followed by an icing simulation of a wet snow event at the UK station which predicted accretion levels and extent successfully. Currently, simulations of selected icing events for all six test stations are underway in order to verify the model under different climatic conditions.

1. Introduction

Icing on structures is an important issue when planning infrastructures: overhead power lines, wind turbines, cable cars or meteorological stations. The risk of icing is gaining importance because human activities are increasingly extending to cold climate regions. At the same time there is not much information about icing risks, neither from measurements nor from modelling. The aim of the COST-727 Action is to deepen the understanding of icing (especially in-cloud icing) and to provide a framework to develop tools for monitoring and forecasting icing events.
Measurements with icing sensors are rarely performed at automatic weather stations. Main objective of the COST-727 Action is to perform joint icing measurement campaigns, to test and verify existing ice detectors and ice detecting methods and to collect a dataset of icing events and ice loads for verification of icing models. Since icing differs for various geographical regions regarding the dominance of in-cloud icing, wet snow or freezing rain, ice sensors are tested under different climatological conditions.
The six operational stations Luosto (Finland), Sveg (Sweden), Zinnwald (Germany), Deadwater Fell (UK), Studnice (CZ) and Guetsch (Switzerland) have been equipped with the Combitech Mk I Ice Monitor and the

Goodrich ice detector for the winter 2007-2008. The stations are additionally equipped with other icing sensors, which are compared to the reference sensors (Combitech and Goodrich). The test sites are described in section 2.
Icing modelling based on an accretion model (Makkonen, 2000) and driven by weather forecast models has not been an issue since recently. This is basically due to the fact that growing computing resources allow increased model resolutions and that microphysics parameterizations have been improved continuously. Within the COST 727 Action the mesoscale, non-hydrostatic Weather Research and Forecast (WRF) model is used. WRF is a state-of-the-art model for high resolution weather forecasts mainly developed by NCAR, NOAA und NCEP (USA). It includes a sophisticated microphysics scheme by Thompson et al. (2004) allowing a good description of humidity, liquid and frozen water components. The results of icing simulations for Deadwater Fell and Guetsch are presented in section 3.

2. Testing of icing sensors at Deadwater Fell, Guetsch and Luosto

The Combitech IceMonitor uses a freely rotating vertical cylinder over a probe and measures the weight of ice accreted on the probe set up on the balance at the bottom of the sensor. It was installed at Deadwater Fell in December 2007 and its output was logged over the 2007/8 winter. There have been problems in the past at other sites with ice bridging the gap between the rod and the main body of the instrument but it was thought that the instrument would perform better under the relatively lighter icing expected at Deadwater Fell (compared with central Europe and Scandinavia).
In operation, the signal from the instrument was very noisy, but despite this, it was possible to pick out several of the icing incidents that occurred during the winter, although not all of them. There are also some false positives, where the IceMonitor indicated icing incidents which were clearly not present, as confirmed by site weather data and video footage. These are probably related to the high noise levels of the instrument. Results from the other test sites have shown that spurious oscillations were everywhere spotted in the measurements with the IceMonitor. The amplitude of the oscillations has been analyzed as function of the measurements' sampling frequency, of the wind speed, of the heating system, etc. without obvious conclusions. It was decided that all the instruments would be sent back to the manufacturer as soon as possible, in order to build in new electronics and to test all the instruments before sending them back to the stations for the next winter period. Combitech agreed to modify the instrument and extend the loan period so that it could undergo a second trial during winter 2008/09.
The Goodrich ice monitor has a probe that oscillates at 40 kHz and monitors the frequency change due to ice accretion on the probe. A heater melts the ice at regular intervals depending on the accretion rate. It is now distributed by Campbell Scientific. The Goodrich instrument should also be available for installation at all stations by September 2008 for testing over the 2008/09 winter.

2.1. Icing measurements at Deadwater Fell

The Deadwater Fell site is situated at a height of 580m on an isolated, exposed hill top near the Scottish/English border, equidistant between the East and West coasts of the UK. It consists of a 190m test span with intermediate single poles and terminal H-poles. The test spans are orientated North-South and suffer from severe winds as well as ice incidents and blizzards. Load cells and video cameras are mounted on a platform at the southern H-pole to measure ice loads (Fig. 1), and a weather station is mounted nearby to monitor meteorological parameters. All the data are collected and stored at the site and down-loaded automatically via a mobile telephone to EA Technology at Capenhurst where they are analyzed.

Fig. 1: The Southern H-pole on the Deadwater Fell test site.

Three instruments were identified as likely to provide icing data that could be fed back directly to utilities to enable them to monitor network performance and vulnerability:

- Combitech IceMonitor (Reference)
- Goodrich/Rosemount ice monitor (Reference)
- HoloOptics Icing Rate sensor (external)

The HoloOptics uses an infra red beam from the tip of probe and measures the amount reflected from a reflector on the central rod. The HoloOptics sensor was delivered too late for installation but an improved version will be available for testing by September, 2008. Three icing events were measured at Deadwater Fell.

2.2. Icing measurements at Guetsch

The test site Guetsch of MeteoSwiss is located on a ridge in highly complex terrain in the midst of the Swiss Alps at 2’300 m a.s.l. The prevailing wind directions are north and south (Foehn). Winds are very variable and during strong Föhn events, wind speeds can easily reach 120 km/h or more. The long term average monthly air temperature varies from -6.9℃ in February to 7.3℃ in July and drops below 0℃ from November to April. Icing can occur throughout the year, but the main icing periods are late autumn and early spring when the temperature often lies around 0℃.
The meteorological test station Guetsch is equipped with the Combitech IceMonitor and the Goodrich ice detector. Other instruments (HoloOptics T26, CZ ice monitor, Vibrometer prototype) were installed, but did not work properly. A web camera is installed on the wind mast to monitor the state of the instruments.
Two web cams were mounted at the nacelle of a wind turbine located at about 100 meters north east of the test station. They allow for the investigation of icing on the rotor blades and the performance of the blade heating. In summer 2007 a new, more sensitive camera was installed together with an infrared headlight which allows taking pictures of the rotor blades also during the night.
There were not many heavy icing events at the Guetsch station, two icing periods were measured. The Combitech IceMonitor and the Goodrich ice detector behaved to our satisfaction during a major icing event in the second part of November 2007 and during later, less intensive icing periods. Still, the oscillations observed at the Combitech IceMonitor e.g. at the Deadwater Fell station are confirmed.

2.3. Icing measurements at Luosto

The automatic (unmanned) Luosto test station (500 m asl) was set up during the winter 2000/2001 by Finnish Meteorological Institute. The main purpose of the Luosto test station is to monitor the behaviour of meteorological instruments icing as well as to perform specific icing measurements. The test station is located in northern Finland, north of the Arctic Circle, on the top of Luosto fell (N 67 08', E 26 54'). Luosto is at the northern end of a chain of arctic fells with open treeless caps and with height about 500 m a.s.l. The site is prone to heavy icing from clouds, typically something like 130 icing days in October-April. The measurement platform for the instruments with iron made grating floor is 3.5 m above the ground (Fig. 2). The poles for the wind sensors are 3 m high, while the other sensors are attached to shorter poles on the other side of the platform. The Luosto test sites represent an elevated site inland with harsh and frequent icing climate.

Figure 2: Measurement platform at the Luosto test side

During the winters 2006/2007 and 2007/2008 performance of three ice detectors has been examined: Rosemount 0872J (prototype) manufactured by BFGoodrich (icing/no icing status), IceMonitor manufactured by Combitech AB (automatic weighting, free rotation) and T26 icing sensor (prototype) manufactured by HoloOptics (icing/no icing status). Also data measured with temperature, humidity, dew point and wind sensors has been evaluated.

It is important to have also visual observations at the test sites, because at the moment only these types of observation can give sufficient information on icing events and operation of the tested sensors. At Luosto visual observations have been logged and documented with appropriate digital pictures taken by four cameras. Remote data reading (including camera observations) makes it also possible to get online information about device failures so that the site may be visited in proper time.

First results and experiences gathered during the winters 2006/2007 and 2007-2008 showed that performance of the tested ice detectors is not always reliable. The ice detectors are to some extent insensitive to icing under heavy icing conditions at Luosto. For instance, the HoloOptics (a prototype) did not work properly and did not produce reliable data during the test period. Anyway, it seems that the Rosemount/Goodrich ice detector and the Combitech IceMonitor are most feasible for field application. However, the availability for service of the Rosemount/Goodrich is not as good as it should be and the

Combitech IceMonitor still has to be improved on some details. For instance, the freely rotating cylinder was not really adequate in conditions with heavy ice loads, which restricted or even stopped the free rotation of the rod. Better results might be obtained with a motorised version (forced rotation). Combitech has announced that, in view of present experiences, they will - in parallel with the upgrade of the existing operational instruments – consider the development of a new version Mk II of the actual sensor with forced rotation and, possibly, turn the instrument upside down to prevent the accumulation of ice between the rotating element and the case of the sensor. Five icing events measured at the Luosto station were selected for simulation with an ice accretion model driven by the weather model WRF. The simulations are currently performed.

3. Icing simulations for Deadwater Fell and Guetsch

Simulation of icing is performed by using an accretion model and high-resolution results of the weather forecast model WRF. Air temperature, wind speed, Liquid Water Content (LWC) and Median Volume Diameter (MVD) for droplets are needed to integrate the ice accretion. LWC is an important input parameter but also very difficult to determine and - unfortunately - not measured automatically. Until recently, there was no way of adequately simulating it with a weather forecast model. Thanks to more sophisticated cloud microphysics in forecast models and increased computing power, it is nowadays possible to simulate LWC reasonably well. The MVD is an essential parameter when calculating the collision efficiency for cloud droplets. So far simple assumptions regarding droplet size distribution have to be made to calculate MVD, but in the near future even more advanced microphysics in forecasting models will predict MVD directly. The result of icing simulations is three-dimensional spatial and temporal information on ice accretion. The first simulations were performed for the sites Guetsch (Switzerland) and Deadwater Fell (UK) and showed promising results. Further studies for other test sites are currently performed. Examples of simulated icing events at Guetsch and Deadwater Fell are presented in the following.

3.1. Icing simulations for Deadwater Fell

An in-cloud icing event took place from 9 to 11 February 2007. The event was simulated using the WRF model with a horizontal grid size of 0.8 km and with 51 model layers below 100hPa, and results are used as input for the accretion model. The output of the model was focussed on predicting the ice loads on conductors strung at Deadwater Fell (in this case Hazel AAAC conductor).

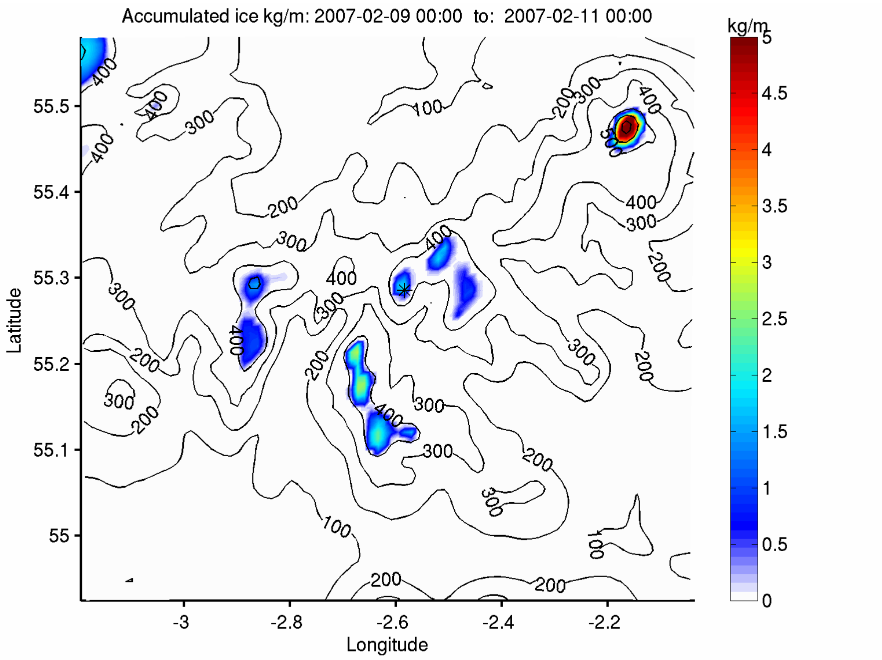

Figure 3: Simulated accumulated ice on Hazel conductor (kg/m) in the area around Deadwater Fell (marked with a star) for the icing event from 9th to 11th of February 2007 [kg/m].

The results of the icing simulation (Fig. 3) show that a Hazel conductor strung at the site (marked by a star in Fig. 3) would attract around 1.2 kg/m ice load. Lines down to 400m in land height would also attract ice loads (400m height would receive around 0.5kg/m) but below this level temperatures would be too high and LWC too low for any accretion to occur.

Time series of simulated LWC (w), wind speed, temperature and ice load for Deadwater are shown in Fig. 4. It can be seen that the initial ice accretion is not correct but the general picture is. At the end of the period the actual measured temperature (Fig. 4, blue) can be seen to be slightly above the modelled value and this is why the model predicted the melting period a few hours too late.

Besides in-cloud icing, wet snow events are considered. These are difficult to simulate due to the narrow range of temperatures (0.5 to 1.5ºC) at which wet snow accretion on structures occurs and a high resolution is therefore required. Wet snow modelling is performed using the French Admirat model (Admirat et al., 1988) for the accretion process.

First experiences in wet snow modelling were gained simulating a wet snow storm of 8 December, 1990, in the central midlands area of the UK. Conductor ice loads are simulated with the Admirat model from CIGRE driven by precipitation intensity, wetness of snow particles, wind speed, temperature and humidity from the WRF model. The simulation was performed for 3 days from 7 to 9 December using a 16km grid size for the UK and a 1 km grid size for the area around Nottingham. The WRF model and weather data provided by Brian Wareing and the UK Met Office were used to predict the location, type, amount and timing of the precipitation caused by the weather patterns of 7/8 December, 2008 in the UK.

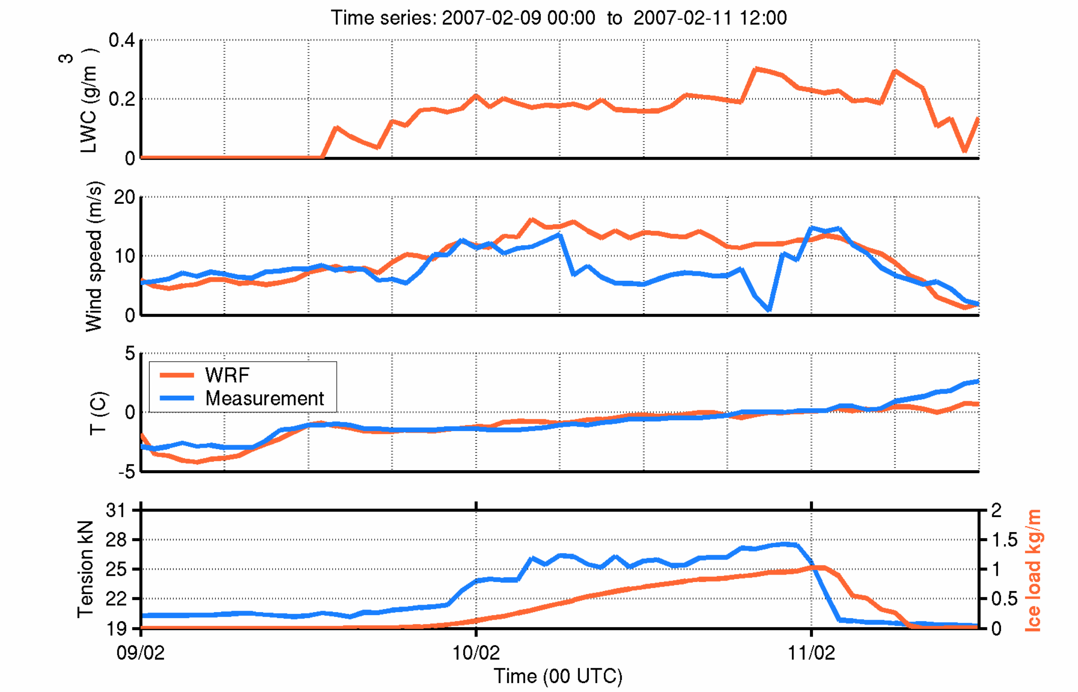

Figure 4: Time series of measured (red) and simulated (blue) LWC, wind speed, temperature and ice load for Deadwater for the icing event from 9th to 11th of February 2007.

The precipitation type was determined by the water content of the snow particles. Below 15% the snow will be too dry to adhere to any OHL conductor and above 40% the precipitation will be sleet and will tend to slide off the conductors. It is therefore possible within the model to further delineate the areas where precipitation is of specific types e.g. rime ice, dry snow, wet snow, sleet and rain. The results were very promising: the timing and geographical extent of the occurrence of the icing periods was remarkably well reproduced, whilst the amount of ice accreted still showed some deviations (slight underestimates of ice loads on the small conductors) which were probably induced by the selected values of the chosen constants like LWC of snow particles or from equation for accretion efficiency. The results therefore picked out the wet snow depth and the actual accretion of wet snow on the conductors (Fig. 5). Considerably lower accretion levels were simulated at greater land heights as the accretion type turned to dry snow and rime ice and also the well defined edges of the affected area. This was confirmed by actual data.

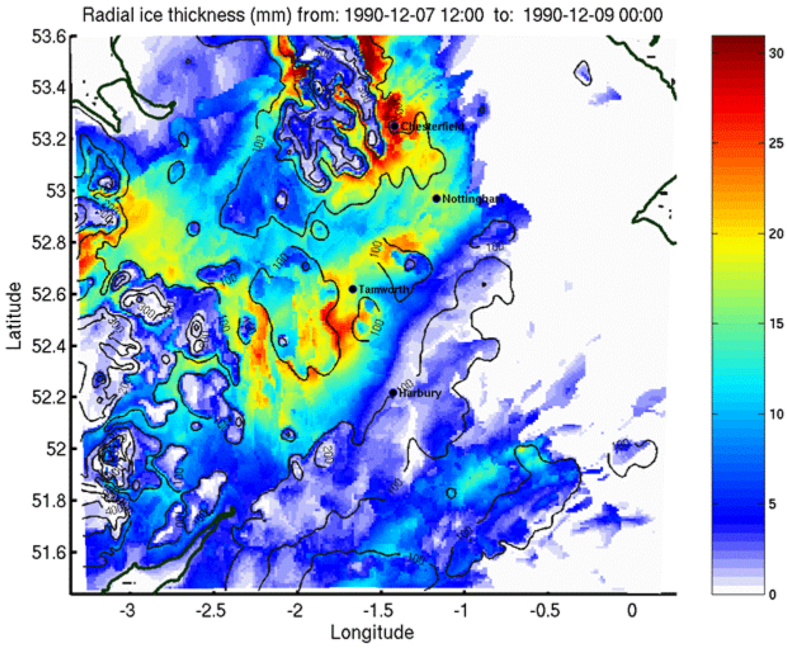

Figure 5: Wet snow accretion on small conductors in the December storm in the Nottingham area.

3.2. Icing simulations for Guetsch

The in-cloud icing event from 22 to 25 November 2007 at the Guetsch station was simulated with the accretion model driven by WRF model results at 800 m grid size. The high horizontal resolution was used in order to capture the complex terrain around the station, but the grid size of 800 m is still not sufficient to describe the details. Therefore, the uncertainty linked to the orography probably plays an important role. The results of the icing simulation are shown in Fig. 6. The model simulation describes the temporal development of the ice load very well. The simulated and the measured maximum ice load are reached at about 12 UTC on the 23 November. The simulated maximum ice load of 1 kg/m underestimates the measured ice load of 1.6 kg/m by about 40%. A simulation using measured temperature and wind is performed in order to investigate if the underestimation of ice load is due to errors in simulated temperature or wind speed. Since LWC measurements are not available, LWC is taken from the simulation. The simulated ice load increases to 1.2 kg/m, reducing the underestimation to 25%. The remaining underestimation might be caused by inaccuracies of the accretion model or of LWC or by the orography.
A sensitivity study regarding the impact of the size of the cloud droplets on simulated ice load was performed. In the model used for ice accretion the median volume droplet diameter (MVD) is an essential parameter, but the MVD is not very well known from measurements. The results of the sensitivity study are shown in Fig. 7. The simulation using a lower droplet concentration results in increased MVD and increased ice load. The results show that the impact of droplet concentration on simulated ice load is quite high: increasing the concentration results in a decrease of ice load of about 50%. Since little is known about typical cloud droplet concentrations, further investigations are necessary to specify this critical number.

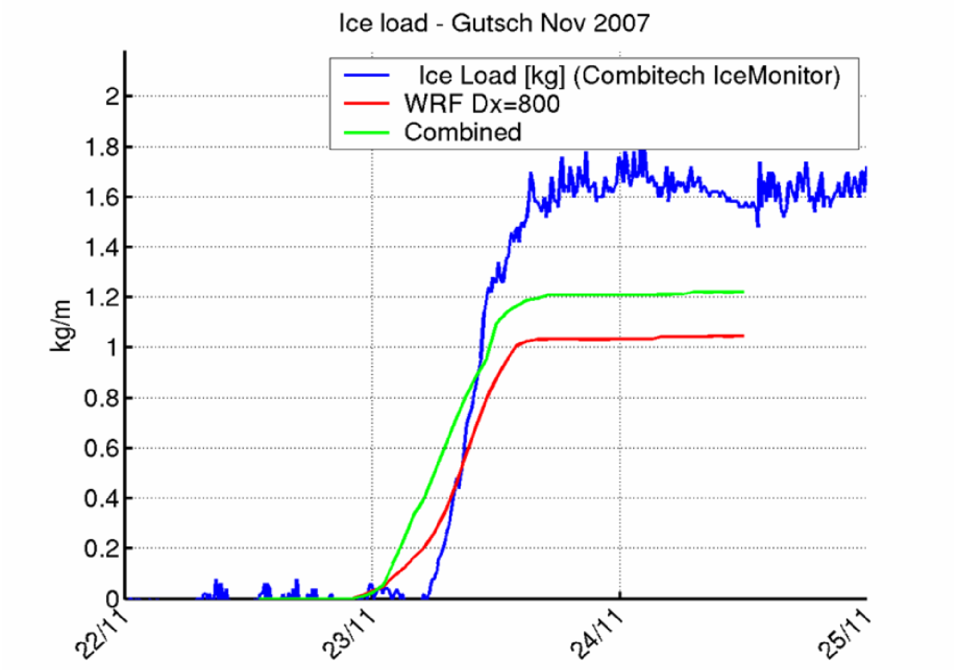

Figure 6: Time series of measured (blue) and simulated (red and green) ice load at the Guetsch station between 22 and 25 November 2007. The red curve shows the results of the accretion model driven by WRF model output. The green curve shows the results of the accretion model driven by temperature and wind speed from measurements and LWC from WRF results.

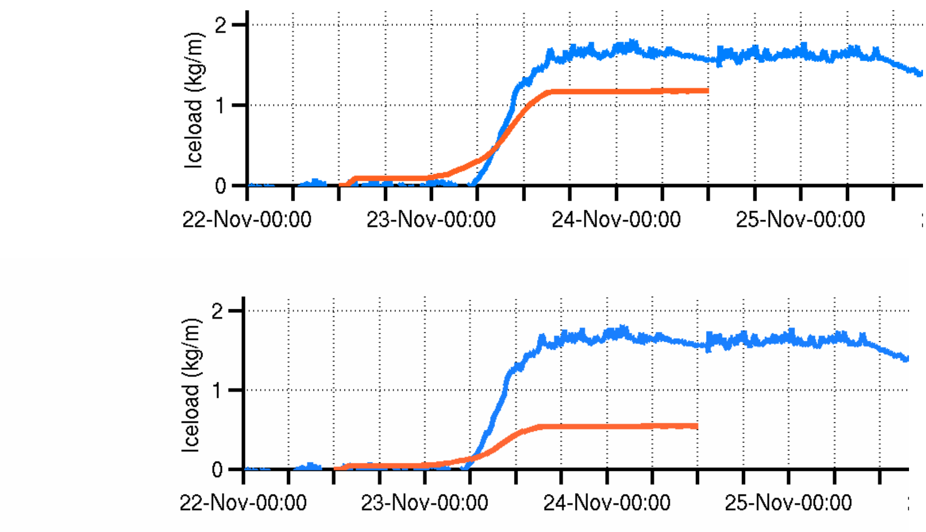

Figure 7: Measured (blue) and simulated (orange) ice load using a cloud droplet concentration of 35 cm^{-3} (upper panel) and of 100 cm^{-3} (lower panel).

4. Conclusions

Icing sensors were tested at Deadwater Fell, Guetsch and Luosto. The measurements performed with the Combitech IceMonitor have shown spurious oscillations at all stations. The amplitude of the oscillations has been analyzed without obvious conclusion. This effect was discussed with the manufacturer and it was decided that all the instruments would be sent back to the manufacturer as soon as possible, in order to build in a new electronic. Additionally, measurements at Luosto showed that the present design concept of a freely rotating cylinder was not really suitable for conditions of high levels of accretion since ice tends to creep up on the body of the instrument and finally restrict or even stop the rod's free movement. Therefore, in connection with the manufacturer, a new prototype was designed (Mk II) with forced rotation and hanging cylinder. Prototypes of this new sensor should be available for the winter 2008-2009. For the winter 2008/09, another 2 stations with icing measurements (Combitech IceMonitor) will be setup in Switzerland, in the pre-Alps and Jura regions.

In spite of the difficulties experienced with the icing sensors, a unique data set of icing measurements was collected, containing measurements performed with operational icing sensors at 5 (6) stations located in Europe. This first data set contains icing period cases for all the stations: Luosto: 5 icing periods, Sveg: 1 icing period, Zinnwald: 4 icing cases, Deadwater Fell: 3 icing periods, Studnice: 6 icing periods, Guetsch: 2 icing periods (Schwyberg: 2 icing periods).

The first results from in-cloud icing simulations using an accretion model driven by WRF results show very promising results. The icing events at Guetsch and Deadwater Fell are well captured by the model and the timing is predicted very well. The maximum ice load for the Guetsch case is underestimated by the model by about 40%. A possible explanation is that the spatial resolution is not high enough to resolve all details of the surrounding terrain. Additionally, sensitivity studies showed that inaccurate LWC might be one of the reasons for the underestimation and the simulated ice load strongly depends on the droplet concentration. Thus, measurements of LWC and size distribution would be of great help for evaluation and development of the icing model. The first study of a wet snow event in the area of Nottingham, UK also showed very good results. The timing was predicted very well, but the amount of ice accreted was slightly underestimated. Further investigations are necessary in order to understand the deviation of amount of accreted ice. Therefore, even if there are small deficiencies in the quantitative prediction of ice amount, the coupling of accretion models and weather forecast models is a suitable approach for icing simulations and gives good results for in-cloud icing events as well as wet snow events.

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