Modeling the risk of icing in Switzerland

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Abstract—**Icing on structures is an important issue in many regions of the world. Unfortunately, information about icing conditions are often rare due to a lack of measurements. Icing simulations can be used to bridge this lack. The current study presents a method to simulate in-cloud icing by using an accretion model (Makkonen, 2000) driven by results of the mesoscale, non-hydrostatic weather forecast model WRF, or the results of the Swiss operational weather forecast model COSMO. Icing events measured at three sites in Switzerland during the winter 2008 / 2009 are simulated with different model set-ups and results are compared to ice load measurements. The evaluation results show that the model system is suitable to predict the occurrence of icing events and their duration. For the Jura and the Pre-Alps region, grid size of 2 – 3 km are sufficient to get a reasonable result, while in the Inner-Alps grid sizes around a few hundred meters are necessary. The prediction of the maximum ice load is less reliable than the prediction of frequency and duration of the icing event. Especially because it strongly depends on the cloud droplet number concentration which is a parameter that is not well known. The parameter is also used in microphysics schemes of weather models. First tests did not show a strong impact on the simulated icing. The accretion model driven by WRF and COSMO results seems a suitable tool to predict the frequency of icing.**

I. INTRODUCTION

Icing on structures is a key factor when planning infrastructures, such as overhead power lines, wind turbines, meteorological stations or cable cars in arctic or mountainous terrain. Still, the knowledge of icing risk is limited for most regions in the world since operational icing measurements are rare. Icing simulations are a possible tool to fill this gap and to create a three-dimensional picture of icing conditions.

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 generally used.

The Swiss project MEMFIS “Measuring, modelling and forecasting ice loads on structures” aims at providing more accurate information about icing conditions in Switzerland. The project is also part of the COST-727 action “Measuring and forecasting atmospheric icing on structures” which is striving for the same goal at the European level. For the purpose of improved knowledge about frequency and intensity of icing in Switzerland, ice load measurements at three sites in Switzerland are carried out. In addition, new methods for the simulation and forecast of ice loads on structures are implemented and tested. Beside WRF, output of the model COSMO of the Consortium for Small-Scale Modelling is used. The icing simulations have two focuses: one is to improve the methods for ice mapping and the second is to evaluate the potential to forecast icing.

II. DESCRIPTION OF THE METHOD

The icing simulations are based on an accretion model developed by Makkonen (2000) driven by results of two numerical weather forecast models: the weather forecast and research (WRF) model and the model of the consortium for small-scale modelling (COSMO). The accretion model, the numerical weather forecast models and the measurements used for evaluation are described in the following paragraphs.

A. *The accretion model by Makkonen (2000)*

The accretion model developed by Makkonen (2000) describes the ice accretion on a cylindric structure by in-cloud icing. Beside cloud droplets also freezing drizzle is taken into consideration. Freezing drizzle is not very frequent, but if it occurs it gives a strong contribution to the ice load. The ice load accumulating on a cylindric structure is simulated by using information about temperature, liquid water content (LWC) and wind speed, taken from the numerical weather model, as well as the volume number concentration of droplets. The latter is used to calculate the median volume droplet size (MVD).

The accretion model calculates the liquid water mass flux that hits the cylindric structure and the part of liquid water that contributes to icing. The latter is described by several coefficients:

Collision efficiency: ratio of droplets that actually hits the object, reduced because small particles are transported around the obstacle (Fig. 1).

Sticking efficiency: ratio of droplets that hit the object that is collected, reduced because some particles bounce from the surface.

Accretion efficiency: part of collected droplets that contributes to the rate of icing, reduced if the heat flux is too small to cause sufficient freezing.

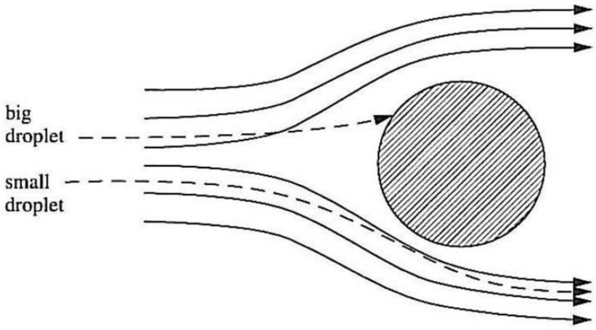

Fig. 1. Air streams and droplet trajectories around a cylindric object (sketch taken from Makkonen, 2000).

B. The WRF model

WRF is a state-of-the-art model for high resolution weather forecasts mainly developed by NCAR, NOAA und NCEP (USA). It is a non-hydrostatic, mesoscale numerical weather forecast model developed for research purposes as well as for operational weather forecasts. Its application field is wide ranging from large-eddy simulations with grid sizes of 100 m to regional climate simulations at 100 km grid size. Prognostic variables are horizontal and vertical wind components, pressure perturbation, temperature, specific humidity, cloud water and ice content, specific water content of rain and snow and turbulent kinetic energy. Three nested model domains with grid sizes of 12.8 km, 3.2 km and 800 m are set up. The high resolution of the innermost domain (800 m) forces very small time steps (~2s in the innermost domain) and makes the simulations quite computing time consuming. Initial and boundary conditions are derived from GFS 0.5° data.

A detailed model description is given by Skamarock et al. (2008). The simulations for the current study are performed with WRF ARW version 3.1. Turbulence is calculated with the Yonsei University scheme which uses a K-closure with counter-gradient terms. The surface layer is parameterized using a Monin-Obukov scheme. The land surface is calculated with the unified Noah land surface scheme. Cumulus convection is not parameterized in all three domains and microphysics is parameterized by a sophisticated microphysics scheme by Thompson et al. (2004) allowing a good description of humidity, liquid and frozen water components. It is a two moment (mass and number concentration) scheme, which is considered to be important for the prediction of supercooled water in the atmosphere. Radiation is simulated using the RRTM longwave radiation scheme and the Dudhia shortwave radiation scheme.

C. The COSMO model

The COSMO model is a non-hydrostatic limited-area atmospheric model developed within the Consortium for Small-scale Modelling (COSMO) for applications on the meso-ß and meso-γ scale (Steppeler et al., 2003). The model is based on non-hydrostatic, fully compressible hydro-thermodynamical equations. Prognostic variables are horizontal and vertical wind components, pressure perturbation, temperature, specific humidity, cloud water and ice content, specific water content of rain and snow and turbulent kinetic energy. The simulations for the current study are taken from the operational forecasts of COSMO-2 at 2.2 km grid size of the Federal Office of Meteorology and Climatology, MeteoSwiss. Initial and boundary data are taken from ECMWF forecasts to drive a first version with grid size of 6.6km in which COSMO-2 is nested. Data assimilation is used to provide realistic initial conditions.

The model equations are solved on an Arakawa C-grid with user-defined vertical grid staggering. Data at the lateral boundaries are prescribed using a Davies-type one-way nesting. Subgrid-scale turbulence is parameterized by a prognostic turbulent kinetic energy closure at level 2.5 including effects from subgrid-scale condensation and thermal circulations. The surface layer parameterization is based on turbulent kinetic energy and includes a laminar-turbulent roughness layer. The formation of precipitation is described by a bulk microphysics parameterization including water vapour, cloud water and ice, rain and snow with a fully prognostic treatment of precipitation, i.e. three-dimensional transport of rain and snow is calculated; in COSMO-2 the graupel is treated as an additional prognostic variable (Reinert and Seifert, 2006). Condensation and evaporation of cloud water are parameterized by saturation adjustment while depositional growth/sublimation of cloud ice is calculated using an explicit non-equilibrium growth equation. Subgrid-scale cloudiness used for radiation calculations is parameterized by an empirical function depending on relative humidity, pressure and ice content. Radiation is calculated using a two-stream scheme for short- and longwave fluxes (eight spectral intervals) including a full cloud-radiation feedback. A multi-layer version of the soil model solving the heat conduction equation is applied. Convection is not parameterized.

D. Measurements for evaluation

Icing measurements are performed at three sites in Switzerland using the Saab Security (former Combitech) IceMonitor. The three sites are situated in different parts of Switzerland: Matzendoerfer Stierenberg (Jura), Schwyberg (Pre-Alps) and Guetsch (Inner Alps). The measurement sites are shown in Fig. 2. During winter 2008 / 2009 16 icing episodes took place at the three sites.

Fig. 2. Sites with CombiTech IceMonitor measurements.

The Combitech IceMonitor is measuring the amount of accreted ice [kg/m] on a vertically installed, freely rotating cyclindric structure. The instrument behaved satisfactorily. Still, oscillations were observed at the Guetsch and Schwyberg station. Thus, the accuracy of the measured amount of ice mass is uncertain at those positions. The uncertainty is in the range of 0.5 kg/m. Oscillations are less pronounced at Matzendoerfer Stierenberg.

III. ICING SIMULATIONS USING WRF AND COSMO INPUT

Case studies are performed for 16 icing periods during winter 2008 / 2009 at the three different test sites. Until now, WRF simulations are performed for eight cases, the COSMO results are available for all periods. Results of the numerical weather forecast models are used to drive the accretion model. The WRF and COSMO model results at 800 m and 2.2 km grid size, respectively, are taken at the model grid box that corresponds to the measurement location and at the model level that is approximately at the real height of the measurement. This, of course, leads to some questions, since the vertical profile of wind is strongly affected by the distance from the ground. And, thus, there is a good chance that at a higher level higher wind speeds are found. Still, for cloud water and temperature, especially in mountainous regions, it's more valuable to be at the real height. This is why it was decided to take the model values at the real height.

The comparison of model results and measurements suffers from the different spatial representativeness of both. Measurements are point values, while the model results represent a volume corresponding to the grid box size, e.g. for the WRF model 800m length and 10 – 20 m height. The temporal representativeness is 10 min for the measurements and one hour for the model results. This difference needs to be kept in mind when comparing the results.

A. *Icing simulations for Matzendoerfer Stierenberg, Schwyberg and Guetsch*

Examples of icing simulations for the three sites in Switzerland are shown in Fig 3 to 5. The icing periods at Matzendoerfer Stierenberg and Schwyberg are captured by the simulations using WRF and COSMO results.

The timing for the event at Matzendoerfer Stierenberg is not very well: the icing starts 20 hours too early with the WRF and 10 hours too early with the COSMO results. The duration of the icing event is overestimated by both models. The maximum ice load of 0.75 kg/m is underestimated with the WRF results (0.15 kg/m) and overestimated with the COSMO results (2.5 kg/m).

The timing for the Schwyberg icing event is slightly better: the results using WRF show the icing event about 5 hours too early and the results using COSMO about 10 hours too early. The simulation with WRF overestimates the duration, while the simulation with COSMO captures the length of the event quite good. Both results overestimate the maximum ice load of 1.75 kg/m. The results with WRF predict 2.5 kg/m and the results with COSMO strongly overestimate with 4.5 kg/m.

The simulation using WRF predicts the icing event at Guetsch very well with just a slight time shift of about 3 hours. The simulation using COSMO results misses the icing event. The probable reason is that 2.2 km grid size is still not small enough to represent the orographic conditions in a region with very complex terrain like at Guetsch (Section IV A). Altogether, the icing simulations show that the model system has a good potential to simulate icing events.

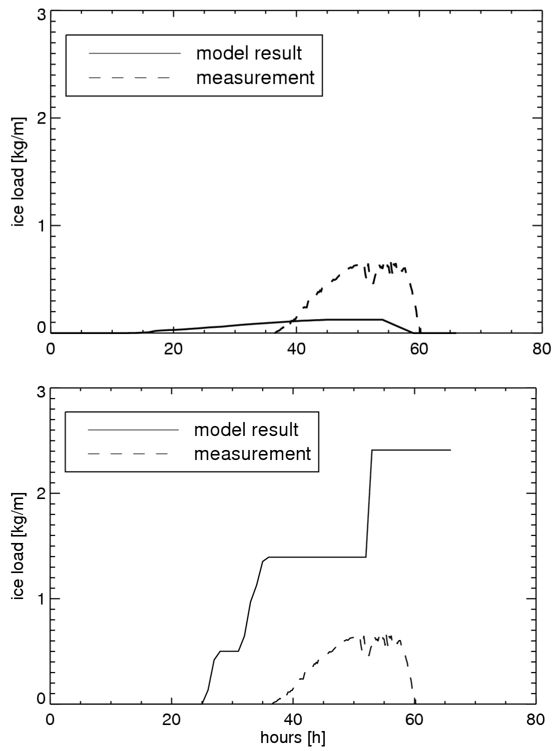

Fig. 3. Time series of simulated ice load at the position of Matzendoerfer Stierenberg for a simulation starting on 5.1.2009, 12 UTC using WRF (upper panel) and COSMO results (lower panel) as input. Measurements are shown as dashed line, the model results as continuous line.

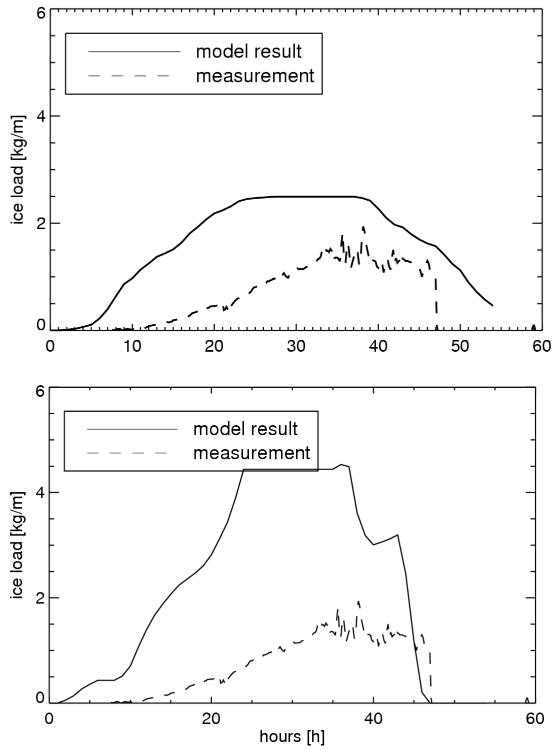

Fig. 4. Time series of simulated ice load at the position of Schwyberg for a simulation starting on 13.11..2008, 00 UTC using WRF (upper panel) and COSMO results (lower panel) as input. Measurements are shown as dashed line, the model results as continuous line.

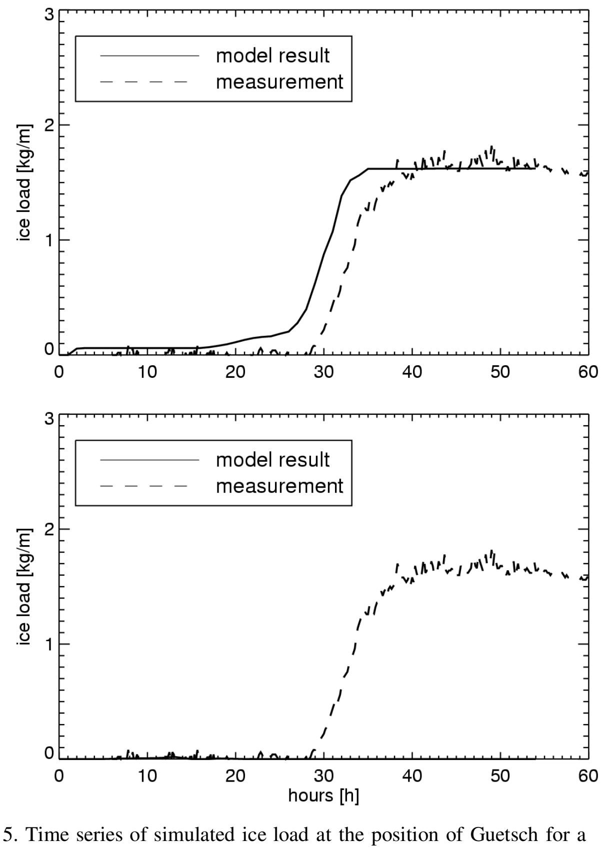

Fig. 5. Time series of simulated ice load at the position of Guetsch for a simulation starting on 22.11.2007, 00 UTC using WRF (upper panel) and COSMO results (lower panel) as input. Measurements are shown as dashed line, the model results as continuous line.

IV. SENSITIVITY STUDIES

The impact of different parameters for the simulated icing is investigated by performing sensitivity studies.

A. Horizontal grid size

The differences between icing simulations driven by WRF and by COSMO results for the Guetsch site suggest that for some regions in Switzerland a horizontal grid size of about 2 km is not enough to resolve relevant orographic features. Simulation results using WRF results at 800 m and 3.2 km grid size are compared for Schwyberg and Guetsch (Fig. 6 and 7). The comparison shows that for the Schwyberg site, grid sizes around 3 km are sufficient to describe the orographic and meteorological conditions that are important to capture an icing event. Different from that, grid sizes around 3 km are not sufficient for the very complex site Guetsch. There are indications that for complex terrain, grid sizes in the range of few hundred meters are needed for the successful simulation of icing events.

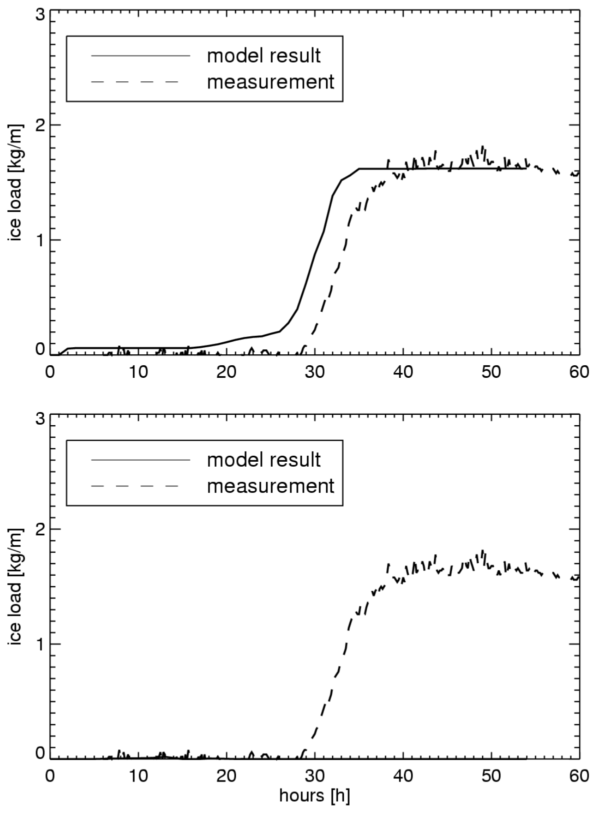

Fig. 6. Time series of simulated ice load at the position of Guetsch for a simulation starting on 22.11.2007, 00 UTC using WRF results at 800 m grid size (upper panel) and at 3.2 km grid size (lower panel) as input. Measurements are shown as dashed line, the model results as continuous line.

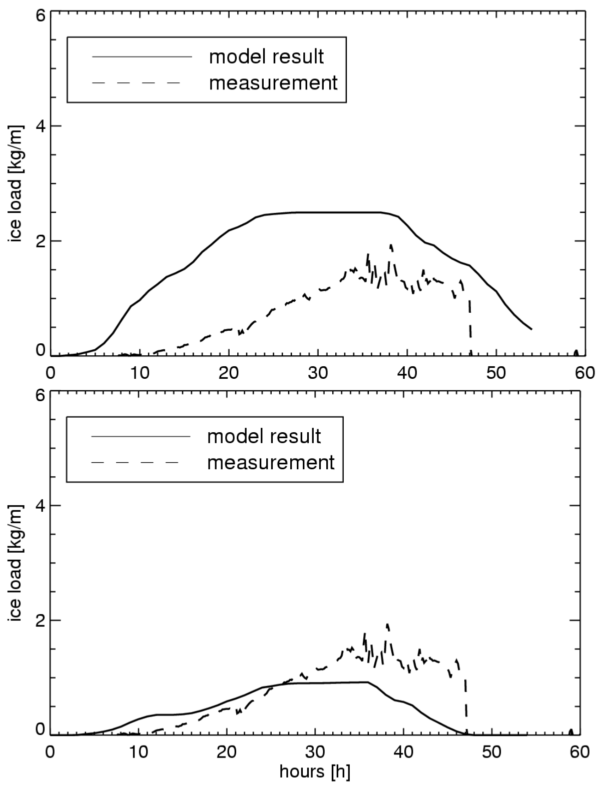

Fig. 7. Time series of simulated ice load at the position of Schwyberg for a simulation starting on 13.11..2008, 00 UTC using WRF results at 800 m grid size (upper panel) and at 3.2 km grid size (lower panel) as input. Measurements are shown as dashed line, the model results as continuous line.

B. Volume number concentration of droplets in the accretion model

The volume number concentration of droplets, that is one of the input parameter of the accretion model, is highly uncertain, since there are few measurements available. A sensitivity study investigates the impact of the volume number concentration of droplets in the accretion model. If the number of droplets is increased and the LWC remains constant, the MVD of droplets is decreased. Sticking and accretion efficiency are basically independent of MVD, but it is expected that the number of droplets hitting the cylinder is decreased resulting in decreased icing rates. The sensitivity studies confirm a decrease of the icing rate and show that there is a significant impact on the simulated maximum ice load. The example of an icing period at Schwyberg is shown in Fig. 8. In this sensitivity study the concentration is reduced from 300 to 100 cm^{-3} droplets with 300 cm^{-3} being a realistic number for Schwyberg while 100 cm^{-3} is typical for maritime conditions. The results of the sensitivity study show that the maximum ice load is increased from 2.5 kg/m to a maximum ice load of 4.25 kg/m. Thus, selecting a suitable volume number concentration of droplets is very difficult due to a lack of measurements but essential for a good simulation of ice load.

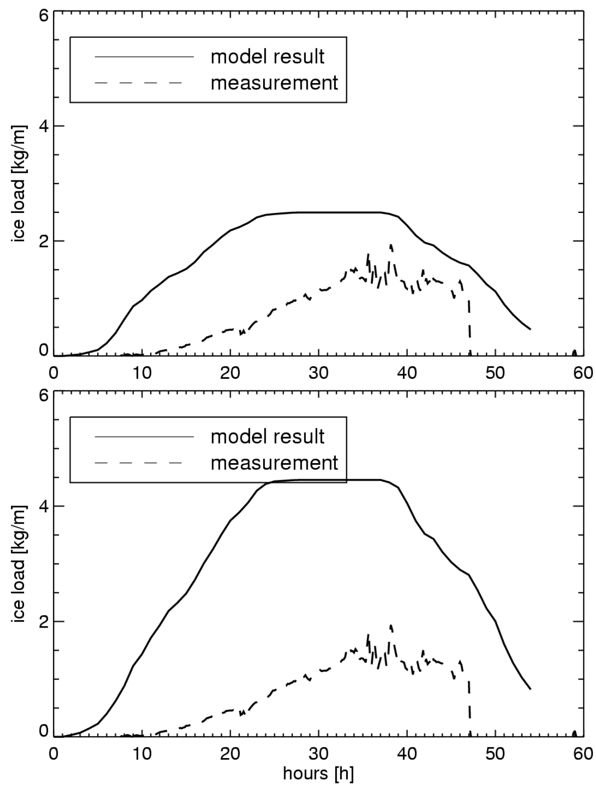

Fig. 8. Time series of simulated ice load at the position of Schwyberg for a simulation starting on 13.11..2008, 00 UTC using a volume number concentration of droplets of 300 cm^{-3} in the accretion model (upper panel) and a volume number concentration of droplets of 100 cm^{-3} in the accretion model (lower panel). Measurements are shown as dashed line, the model results as continuous line.

C. Volume number concentration of droplets in the WRF microphysics scheme

The volume number concentration of droplets is also a parameter in the microphysics scheme of the WRF model. It affects the growth of cloud droplets and their conversion to rain and, thus, might affect LWC and lifetime of clouds. The default volume number concentration of droplets is 100 cm^{-3} which is characteristic for a maritime environment, while for continental regions like Switzerland a number of 300 cm^{-3} is more realistic. All simulations are performed with the default value of 100 cm^{-3}. A sensitivity study is performed in order to investigate how the volume number concentration of droplets in the WRF microphysics scheme affects the icing simulation.

Fig 9 shows an example cross section of simulated hydrometeors for an icing event at Schwyberg. The result corresponds to the theoretical expectation: lower cloud droplet numbers with the same LWC cause the droplets to be bigger. A higher amount of cloud droplets reaches the critical radius becoming rain drops. Thus, more rain is created and cloud water is reduced (Fig 9, upper panel). Still, for this situation, the impact of an increased volume number concentration of droplets on the icing simulation remains small, reducing the simulated ice load by about 10% (Fig. 10). Further studies are necessary in order to understand if the impact on simulated icing might be stronger in other situations.

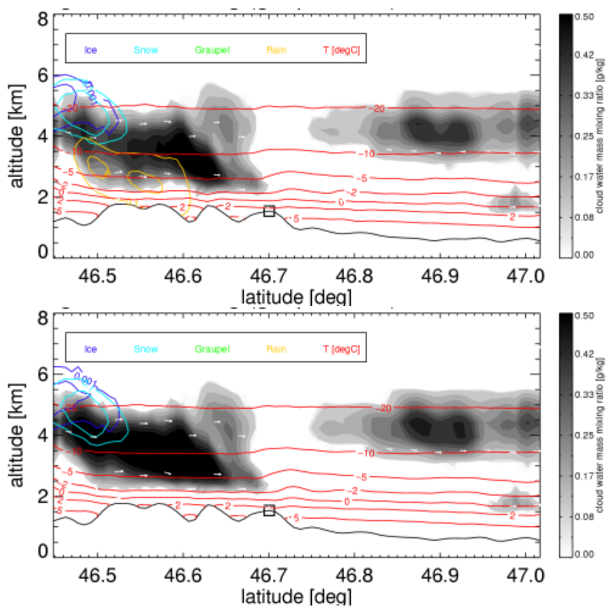

Fig. 9. North-South cross section at the position of Schwyberg for a simulation starting on 27.03.2009, 12 UTC after 17 hours simulation time using a volume number concentration of droplets of 100 cm^{-3} in the accretion model (upper panel) and a volume number concentration of droplets of 300 cm^{-3} in the accretion model (lower panel). The position of Schwyberg is marked by a black square. The black shading shows cloud water, the other hydrometeors are indicated in the figure.

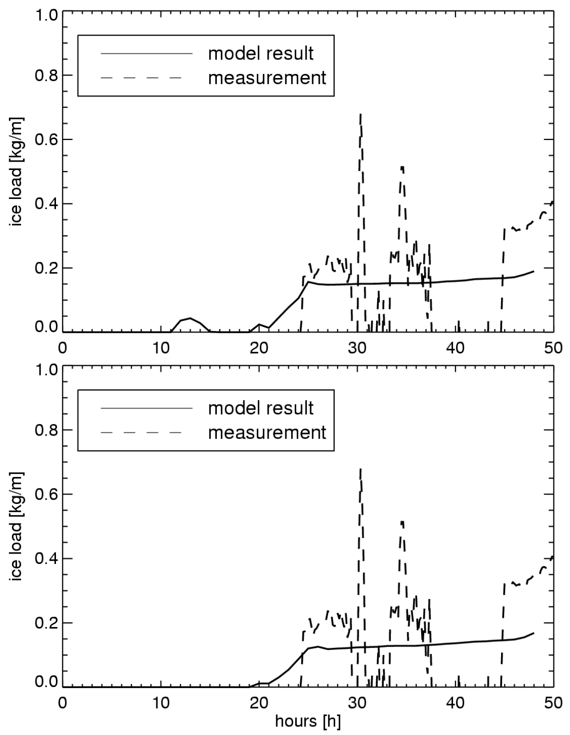

Fig. 10. Time series of simulated ice load at the position of Schwyberg for a simulation starting on 27.03..2009, 12 UTC using a volume number concentration of droplets of 100 cm^{-3} in the WRF model (upper panel) and a volume number concentration of droplets of 300 cm^{-3} in the WRF model (lower panel). Measurements are shown as dashed line, the model results as continuous line.

V. Summary and Conclusions

Icing simulations are performed for the winter 2008 / 2009 for three different sites in Switzerland using an accretion model driven by results of the weather forecast models WRF and COSMO. The simulated ice load is compared to ice load measurements.

Preliminary evaluation results show that the model system has a good potential to describe the frequency of icing. The simulated ice load is less precise. Still, for many cases, the simulated ice load roughly hits the measured ice load which possibly allows classifying light and strong icing events. The insufficient simulation of maximum ice load might be connected to the lack of knowledge about the volume number concentration of droplets. Sensitivity studies show that this parameter strongly affects the amount of ice that is simulated. Additionally, the icing measurements itself are uncertain because the Combitech IceMonitor is not yet fully developed. The effect of the volume number concentration of droplets in the microphysics scheme of WRF was also investigated. One sensitivity study was performed that shows the expected effect on rain and cloud water, but the effect on the simulated ice load remains small. Further studies for different situations are necessary. Sensitivity studies show that for the Jura and the Pre-Alps grid sizes around 2-3 km are sufficient, while grid size around a few 100 m are needed in very complex terrain in the Inner Alps.

The case studies suggest that the model system consisting of an accretion model and a weather forecast model is a suitable tool for ice mapping as well as icing forecasts if the main interest is on icing frequency and, maybe, a rough classification of icing strength. If the main interest is maximum ice load the model results are still too uncertain. The preliminary results presented in this paper are based on eight case studies of icing events at three stations in Switzerland. Thus, the findings need to be checked considering a wider set of simulations and more sites in different geographical regions. Further investigations are necessary to optimize the model system, e.g. defining the most representative grid point of the weather forecast model (see also Nygaard, 2009).

VI. Acknowledgment

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VII. References

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