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Validation of Regional In-Cloud Icing Maps in Norway

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The meso – scale numerical model, WRF (Weather Research and Forecasting) is used to produce vertical profiles of wind, temperature and cloud water content in a 1x1 km horizontal grid. These data are further processed by an ice accretion model to calculate vertical profiles of in-cloud icing on a reference object.

At airports high – quality cloud data can be taken from airport metar - data. Use of an adiabatic cloud water gradient together with extrapolated values of surface temperature and wind speed can be used to calculate corresponding in-cloud icing profiles. There is excellent coincidence between the results from the two methods above 500 masl. On the basis of this, regional icing maps (number of hours per year >10g/h) is produced. Results for the Nordland County, Norway, are presented.

I. INTRODUCTION

THE WRF model is a promising tool in icing prediction, and the model is used to produce in-cloud ice maps [1], [2]. A model using airport cloud observations, temperature, and wind speed has been validated to icing observations in maritime climate [3]. In this paper, the model outputs will be compared at airports in a Norwegian region.

II. MODELS

A. The WRF model and setup

The Weather Research and Forecast (WRF) model is a next generation meso-scale numerical weather prediction system, aiming at both operational forecasting and atmospheric research needs. A description of the modeling system can be found at the home page http://www.wrf-model.org/. Details about the modeling structure, numerical routines and physical packages available can be found in for example [4] and [5].

WRF solves coupled equations for all important physical processes (such as winds, temperatures, stability, clouds, radiation etc.) in the atmosphere based on the initial fields and the lateral boundary values derived from the global data. This version of the model presumes that all cloud water is in the liquid phase. The WRF-model calculates the change in the meteorological fields for each grid-cell for a time step of five seconds. Thus a realistic temporal development of the meteorological variables is achieved.

The model is set up with two 2-way nested model domains shown in Fig. 1. We use a horizontal resolution of 5 km for the outer domain and 1 km for the inner domain. We use 32 layers vertically, with the lowest 4 model levels at 20 m, 60 m, 115 m and 190 m above the ground. The model is run for one full year, the period 01.01.2005 – 31.12.2005.

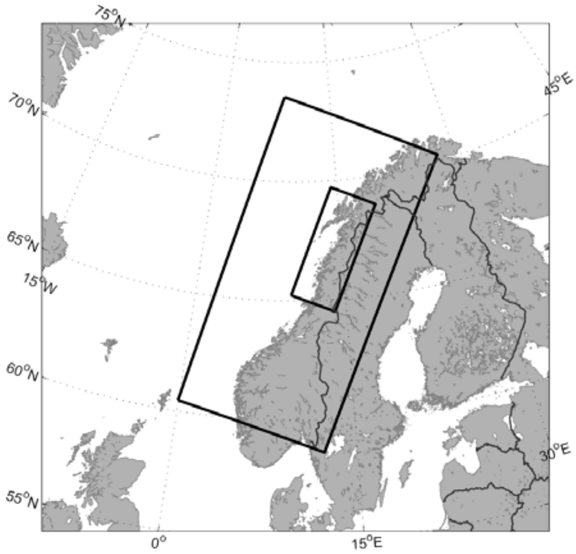

Fig. 1. Inner and outer domain of the WRF-calculations for Nordland

B. Icing calculations

According to [6] icing has been calculated from:

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \cdot w \cdot A \cdot V \qquad (1)$$

Here dM/dt is the icing rate on a standard body (defined by [6] as a cylinder of 1m length and diameter 30mm). w is the liquid water content, A is the collision area perpendicular to the flow of air. V is the collision speed. α_1, α_2 and α_3 are the collision efficiency, sticking efficiency and accretion efficiency.

The collision efficiency, α_1, is an estimate of the number of droplets that collide with the object. The value is given as a ratio in the range 0 to 1. α_1 depends on the collision speed, collision area, shape of the object and the size of the droplets. α_1 is described by an empiric formulation as given in [6]. A fixed droplet number, 79 cm^{-3} [7] is used.

The sticking efficiency, α_2, estimates the number of droplets that collide with the object that will stick to the object given as a ratio. For super cooled droplets the sticking efficiency will be close to 1.

When a droplet hits the object and freezes, latent freezing energy is released from the droplet. For temperatures close to 0°C there may be too little cooling of the water before it is blown off. The accretion efficiency, α_3, can be reduced from 1 for temperatures close to 0°C. The formulation of α_3 is given in [6].

An icing episode is identified from the model data when the icing rate (dM/dt) comes above 10g/hour, which is equivalent to a 0.5mm layer of ice on the standard body.

In [1] there was presented a validation between the icing model results and icing estimates based on cloud data. There was found reasonable good agreement, but it was difficult to draw a precise conclusion due to the simplified ice estimation method from cloud data.

In [3], there was concluded that a model based on (1) and metar data from airports using adiabatic cloud water gradients, produced results in nice agreement with icing observations at exposed hills at the Norwegian Coast and the border between Scotland and England. This gives confidence to the metar data model. The metar data used is cloud height and cloud amounts in up to three layers, air temperature, and wind speed. The model presumes, like the actual WRF model, presumes that all cloud water is in the liquid phase, and the same, fixed droplet density of 79 cm^{-3}.

III. VALIDATION

Modelled data from the eight airports in Nordland where there are hills of 600 masl and higher (horizontal scale 1 km) in reasonable vicinity were compared using the two methods. The number of hours where dM/dt > 10g/hr were counted for the period Jan 1 – April 30 and Nov 1 to Dec 31, 2005. WRF output data from all 1 km points within 20 km at 80 m height above model surface where plotted, given masl and number of icing hours as axes (Fig. 2 – Fig. 9).

In the metar model, the wind gradient representing exposed terrain [6] were used to extrapolate the airport wind data to the different heights above the airport. The metar modelled output icing data then represent sites exposed in the same way as the airport. For some of the airports, the plotted WRF values may represent more sheltered areas or less sheltered areas than the airport. In areas with large variation in the sheltering within the 20 km radius, the WRF-results will show a large variation in the number of icing hours within the same level, most typical illustrated for Narvik airport (Fig. 7). Also the other airports in the inner fjord areas show rather high variation within given levels (Mosjøen (Fig. 4), Mo i Rana (Fig. 5), and Evenes (Fig. 8)). The position of the airport can be found in Fig. 10 and Fig.11.

For the airport metar data, model outputs were given for each 100 m level from 300 to 1200 m above the airport. To compare the results, it should be commented that the actual version of the WRF model tends to over predict the number of hours of icing for heights below 500 masl [1]. Fig. 2 – Fig. 7 clearly show the same tendency.

There is excellent agreement between the two model outputs for heights between 500 and 1200 masl. Due to the variability in the representativity between the two data sets, some deviations are to be expected. Bodø airport (Fig. 6) is in many ways atypical because most of the high terrain represented by the WRF data is sheltered by the high mountains south of the airport, so the two model outputs represents very different icing conditions.

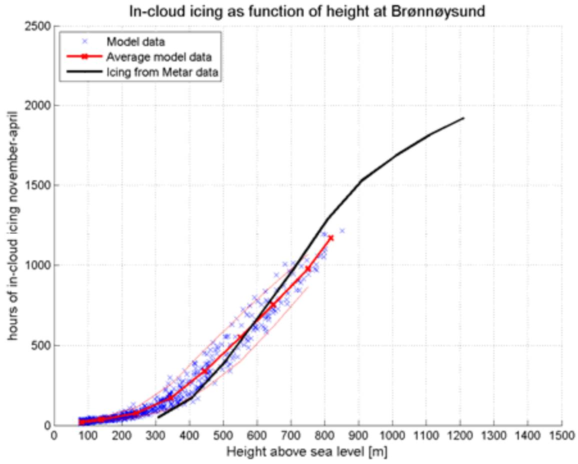

Fig. 2. Model outputs at Brønnøysund airport.

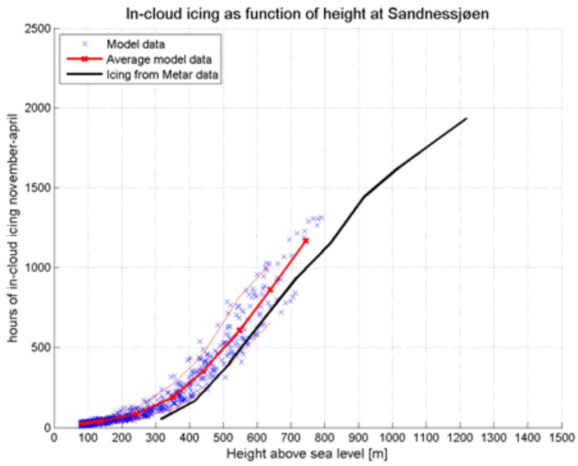

Fig. 3. Model outputs at Sandnessjøen airport.

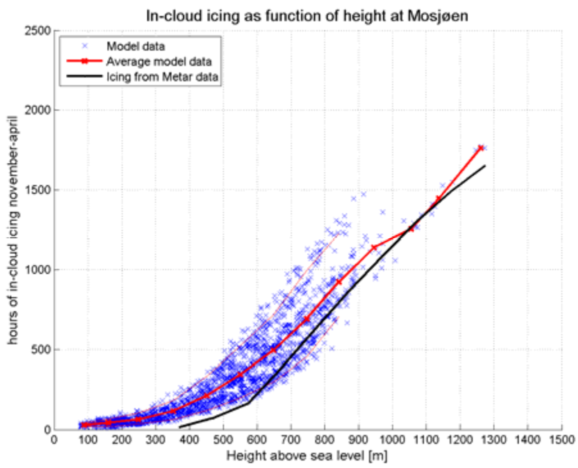

Fig. 4. Model outputs at Mosjøen airport.

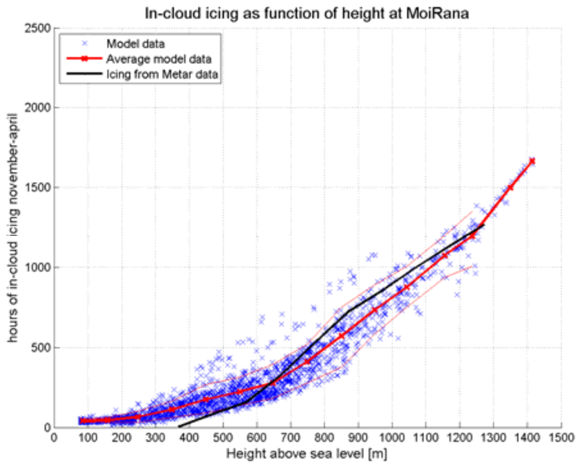

Fig. 5. Model outputs at Mo i Rana airport.

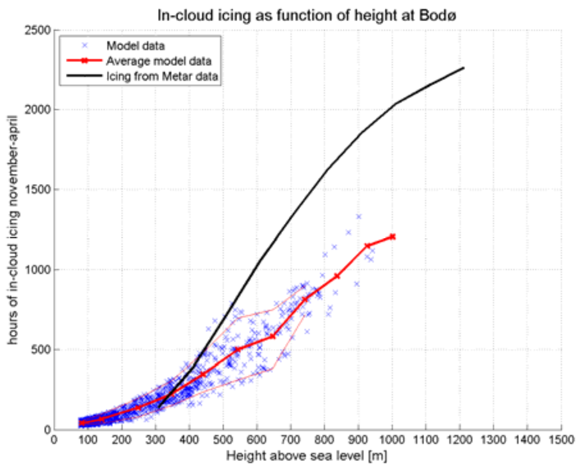

Fig. 6. Model outputs at Bodø airport.

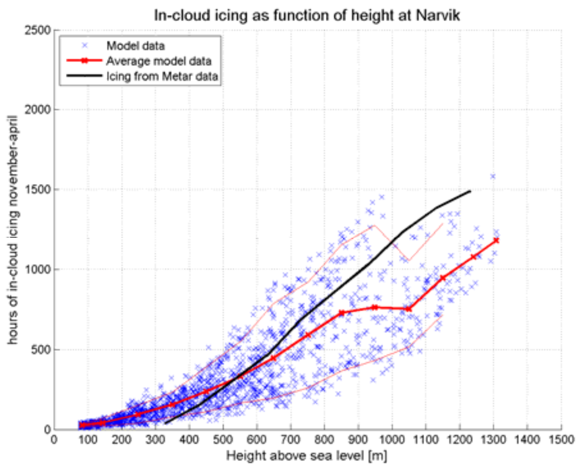

Fig. 7. Model outputs at Narvik airport.

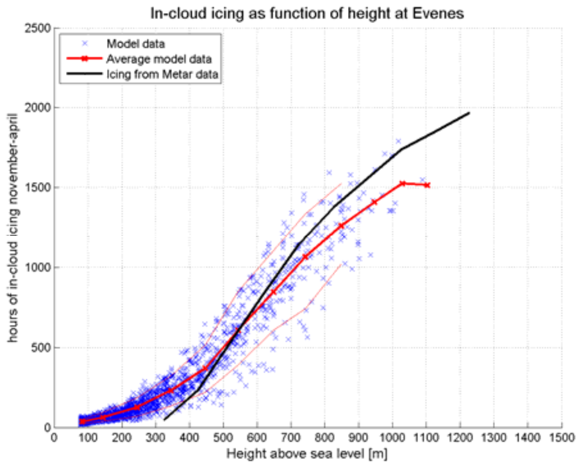

Fig. 8. Model outputs at Evenes airport.

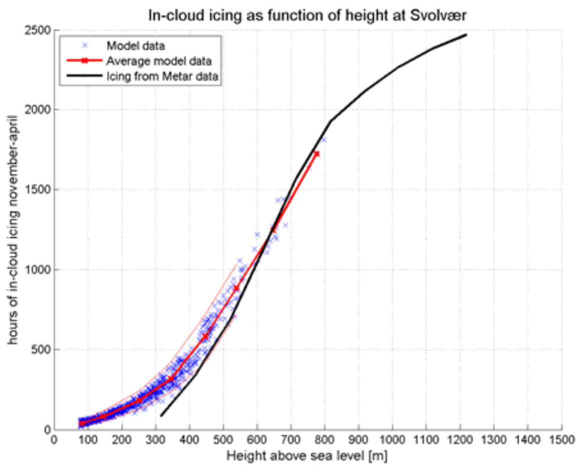

Fig. 9. Model outputs at Svolvær airport.

IV. ICING MAPS

A map showing the icing conditions calculated from the model results using (1) is presented in Fig. 10 and Fig. 11. The map shows the number of occurrences when we find $dM/dt > 10 g/hr$ during 1 year of model data. Icing has been calculated for the WRF grid at all model levels. The icing amounts are very dependent on height. Therefore the icing levels have been adjusted by employing a fine scale topography mesh with horizontal resolution of 25m (N50 topography) to adjust for the smoothed WRF topography (1km).

Due to the over prediction of icing risk below 500 m, no attempt is done to resolve the maps at low levels which have icing risks below 100 hours per year.

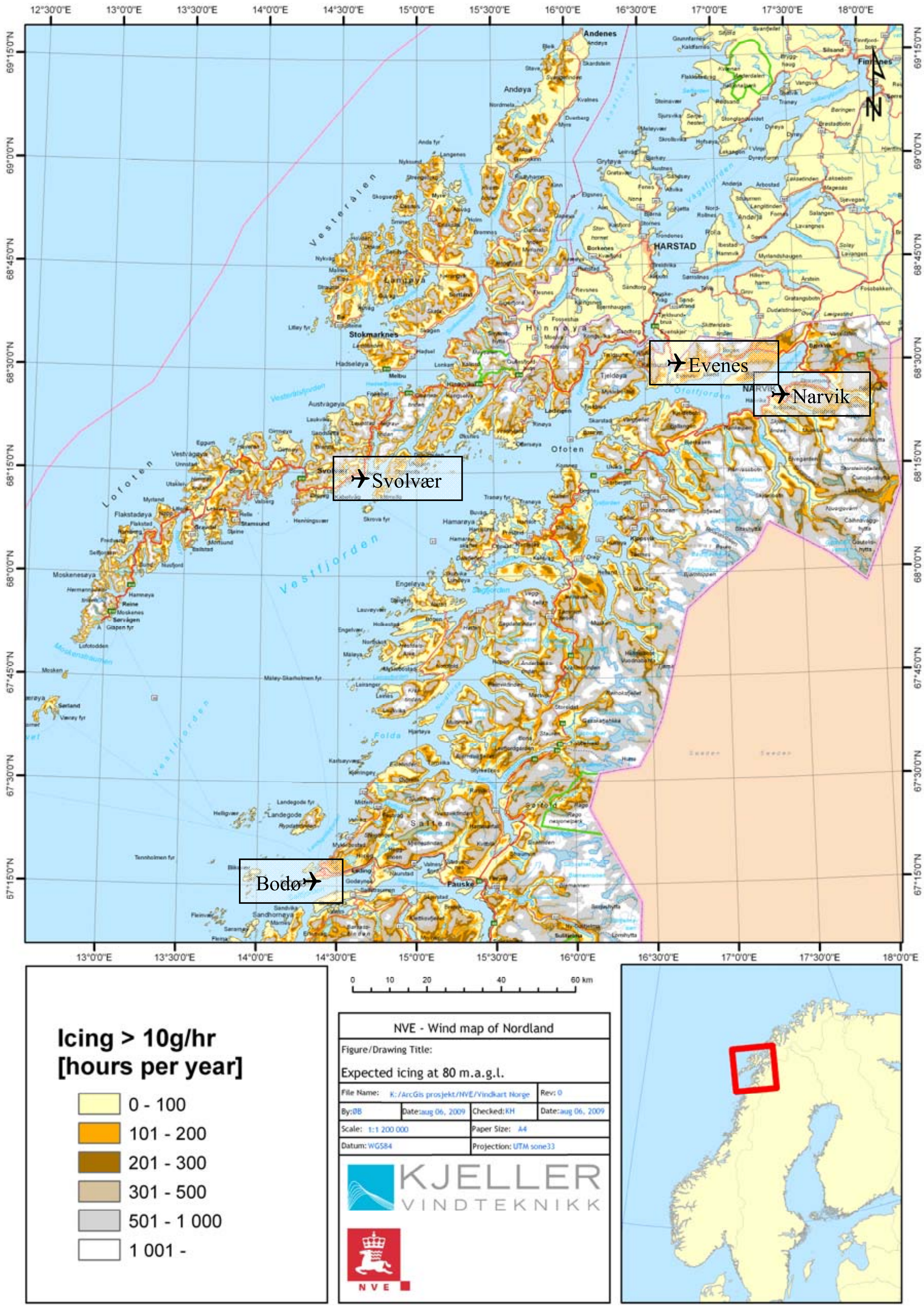

Fig. 10. Number of hours per year with ice accumulation, southern part of Nordland.

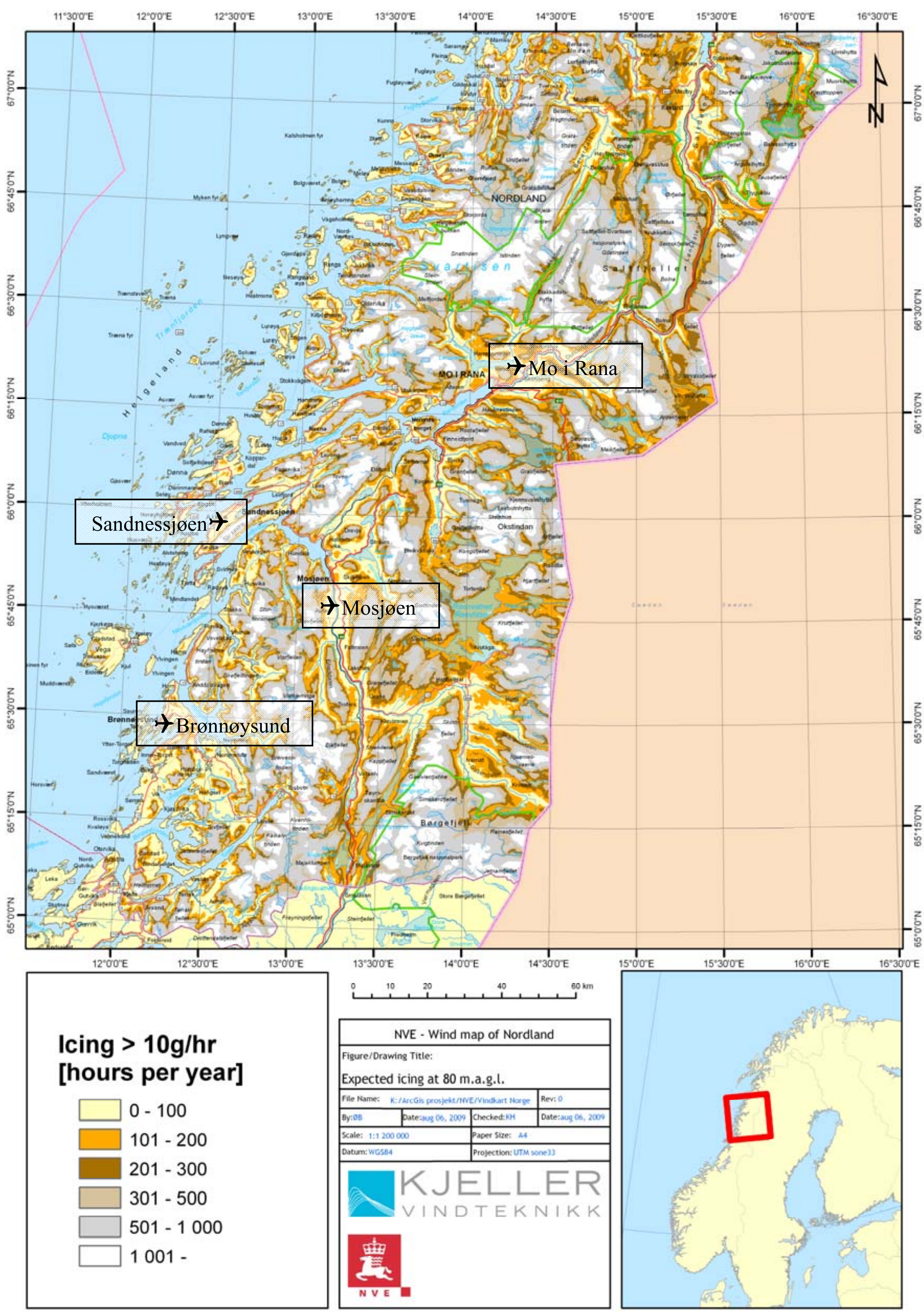

Fig. 11. Number of hours per year with ice accumulation, northern part of Nordland.

V. CONCLUSION

The WRF model with a simplified cloud water description presuming all cloud water to be in the liquid phase may be used to produce reliable maps of icing in typical Norwegian maritime areas for heights above 500 masl. For lower values, the model over predicts the icing risk.

The model is validated to an icing model using airport data of cloud observations, temperature, and wind speed. This metar model is tested with good results in icing situations against icing observations at coastal mountains at the Norwegian coast and the border between Scotland and England.

VI. ACKNOWLEDGMENT

The WRF model simulation has been supported by the Norwegian Water Resource and Energy Directorate (NVE). The simulations have been performed at the linux cluster Titan at University of Oslo.

VII. REFERENCES

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