Wind Ice and Snow Load Impacts on Infrastructure and the Natural Environment (WISLINE)

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***Abstract*: Atmospheric icing is a major weather hazard in many mid- to high-latitude locations in the winter, including Norway. There are mainly three types of atmospheric icing; in-cloud icing due to liquid cloud droplets at sub-freezing temperatures; icing due to supercooled rain droplets, and icing caused by wet snow or sleet at temperatures just above freezing point. In-cloud icing and icing caused by wet snow have together with strong wind caused damage to overhead power lines in Norway on several occasions, leaving people without electricity and the power companies with large expenses.**

The main objective of WISLINE is to quantify climate change impact on technical infrastructure and the natural environment caused by strong winds, icing and wet snow. In order to investigate future ice and snow loads, an extensive knowledge about such loads in the present climate is required. This will be provided by improving the description of the cloud microphysical processes of the AROME weather prediction model, which is run operationally by several European forecasting centres. The improved model will be combined with routines for ice accretion in order to produce an icing climatology for the present climate, which will be verified against measurements of ice loads on power lines as well as measurements of cloud water. The next step is then to apply the improved model to downscale data from climate models in order to produce a future icing climatology.

As damage is often caused by icing accompanied with heavy wind, wind loads in present as well as future climate will be investigated in the project. Techniques for downscaling wind data in complex terrain will be studied in order to provide a dataset for wind in both present and future climate. Wind and heavy snow may also cause damage to forests such as up-rooting and stem breakage, and we will hence combine wind, icing and snow damage data for forests with the datasets from WISLINE in order to produce a risk model for forest damage for both present and future climate. All datasets and results of the project will be open to end-users as well as the public.

Keywords: icing, snow loads, power lines, AROME, microphysics

Legend and Abbreviations

NWP	*Numerical Weather Prediction Model*
WRF	*Weather Research and Forecasting Model*
LAM	*Limited Area Model*

Introduction

Atmospheric icing is a major weather hazard in many mid- to high-latitude locations in the winter, including Norway. There are mainly three types of atmospheric icing; (1) 'freezing fog', i.e., in-cloud icing due to (supercooled) liquid cloud droplets at sub-freezing temperatures (Figure 1); (2) 'freezing rain', i.e., icing due to supercooled rain drops at sub-freezing temperatures; (3) 'wet-snow icing', which is caused by heavy precipitation in the form of of snow or sleet at temperatures just above freezing (Figure 2). All three types are common in central and northern Europe and North America, with (1) and especially (2) mainly occurring in continental air masses in inland regions, while (3) is most common in coastal regions, such as Iceland, the U.K., Japan and parts of Germany (Nygaard et al., 2013). Icing has been known to cause significant problems for many sectors of society, in particular for power transmission lines, wind turbines, aviation, telecommunication towers and road traffic. An extreme example of (2) is the ice storm that hit eastern North America in January 1998 with more than 100 mm of freezing rain observed in some areas (Gyakum and Roebber, 2001). This resulted in more than 4 million people in Canada and the United States losing power for days to weeks, or even months and a total economic damage estimated at 4.4 billion U.S. dollars.

Figure 1: In-cloud icing on a power line (Photo Ole Gustav Berg/Statnett)

A recent major icing event in Europe was the wet-snow event in Münsterland in Germany in November 2005, in which 82 transmission towers collapsed, leaving 250 000 people without electricity for several days (Frick and Wernli, 2012).

During the winter of 2013/2014 two 420 kV transmission lines in Southern Norway suffered severe damage due to ice loads exceeding their design values, i.e. observations indicated ice loads four to five times the design value at one location.

Values for extreme wind- , ice- and snow loads with corresponding return periods are used to design technical infrastructure such as bridges, telecommunication towers, and electricity transmission lines. Historically, the design estimation approach in Norway has been based on simple empirical relations developed from a limited number of in-situ observations, and therefore involves considerations that are subjective and based on individual experience. Recent damages on the electric grid show that the traditional approach has problems in predicting representative values in areas with rough and complex topography combined with the advection of warm and moist air masses in the winter season. There is therefore an urgent need to develop a methodology for estimation of such design values in a more objective and consistent way.

Preliminary studies within the frame of COST action 727 "Atmospheric Icing of Structures" showed that reasonable ice loads could be obtained by using the microphysical fields from an early version of the Weather Research and Forecasting (WRF) model (e.g. Harstveit et al. 2009; Nygaard 2009). Ice loads calculated from an updated WRF based model archive developed at Kjeller Vindteknikk have made it possible to reproduce and estimate the return periods of the 2013/2014 winter's icing events. There is however a large potential to further develop these objective methods, and use the tools within a consistent NWP model framework for quantification of changes in the icing climate in Norway.

Figure 2: Snow load on power line (Photo Hallingdal Kraftnett)

In forests wind and heavy loads of snow, rime and ice can cause wind-throw or stem breakage (Figure 3). Wind-throw has been the most damaging agent in Europe's forests during the last 150 years, and it has increased considerably during the last 50 years in Europe (Schelhaas et al. 2003), mainly driven by changes in forest management (Nilsson et al. 2004, Bengtsson and Nilsson 2007). The risk for such damage is expected to increase further with climate change due to a slight increase in windiness, reduced root anchorage due to more rain and wetter soils during the storm season (Kamimura et al. 2012), a reduction in the depth and extent of frozen soil (Kellomaki et al. 2010) and increased frequency of heavy snow fall (Gregow et al. 2011). The Gudrun storm may serve as an illustration of possible future damage events. When it hit Sweden on 8th January 2005, it followed a period of 2 weeks with heavy rain.

Increased attacks by the spruce bark beetle can be expected after wind and snow damage, in particular with increasing temperatures (Schlyter et al. 2006). Falling trees or tree tops generate considerable damage on infrastructure, mainly roads, railways and power lines. The damage risk can be decreased through appropriate forest management, and scenarios make up an important basis for decisions on altered management. This includes changing tree species, providing the trees generous space at low age (increasing 'single tree stability'), avoidance of late and heavy thinning (increasing 'social stability'), and careful placement of stand edges after clear-cut in the landscape (Nielsen 2001, Albrecht et al. 2012).

Figure 3: Wind damage from the storm Dagmar in 2011 (Photo Jon Eivind Vollen/Skogkurs)

Design of robust infrastructure and management of natural resources require quantitative information about climate loads in the future. In order to investigate future ice, snow and wind loads, an extensive knowledge about such loads in the present climate is required. The basic idea of the WISLINE project is to improve the methods for calculating ice and wind loads, apply these methods for the present climate and verify the data against observations. When this is done successfully, we will have methods that are capable of simulating climate loads at high resolution, and the next step is then to downscale data from climate models in order to produce wind and ice datasets for a future climate. We can then fulfil the main objective of WISLINE: <u>To quantify climate change impact on technical infrastructure and the natural environment caused by strong winds, icing and wet snow.</u>

I. THE PROJECT

The Research Council of Norway has granted the project Wind Ice and Snow Load Impacts on Infrastructure and the Natural Environment 6.5 millions Norwegian kroner for the period 2015 – 2018. In addition to the previously mentioned main objective, they also stated the following sub objectives for the project:

-To improve the description of cloud microphysical processes of importance for simulating atmospheric icing.

-To quantitatively assess future wind and ice design loads on electric transmission lines in different geographical regions in Norway.

-To establish risk assessment models for weather hazard induced damages on forests.

The grant from the Research Council and the stated objectives are a result of a proposal from The Norwegian

Meteorological Institute and several partners. These are The Department of Geosciences at The University of Oslo, National Center for Atmospheric Research (NCAR) in Colorado, Kjeller Vindteknikk (KVT), Norwegian Forest and Landscape Institute (NFLI) and Swedish University of Agricultural Sciences (SLU). These different institutions have competence in various fields such as cloud micro physics, wind modelling, downscaling of climate data and forestry, which is necessary to fulfil the ambitious objectives of the project. The project also has a user group consisting of Skogbrand (insurance company owned by Norwegian forest owners), Statnett (system operator, the Norwegian energy system) and the Directorate for Emergency Communication (agency for public safety network) who conveyed their support for project proposal to the Research Council, contributing to it's success. In addition to this Statskog (The Norwegian state-owned land and forest enterprise) has joined the user group, and it might be extended further.

A. *The partners*

The Norwegian Meteorological Institute (MET Norway) is the meteorological service for both The Military and the Civil Services in Norway, as well as the public. The mission of the institute is to contribute to protection of life, property and the environment as well to provide the meteorological services required by society. MET Norway operates an extensive network of meteorological observations in Norway, its adjacent seas and the polar areas and performs research for both private and public sector.

Founded in 1811 as the first in Norway, the University of Oslo is the country's leading public institution of research and higher learning with 27 000 students and 6000 employees. Department of Geosciences at the University of Oslo was formed in 2003 as a merger between the three earth sciences departments: the Geology Department, the Department of Physical Geography and the Department of Geophysics. The merger resulted in the widest ranging earth sciences department in Norway, covering a wide range of disciplines from deep mantle processes to atmospheric sciences.

The National Center for Atmospheric Research (NCAR) is a federally funded research and development center devoted to service, research and education in the atmospheric and related sciences. NCAR's mission is to understand the behavior of the atmosphere and related physical, biological and social systems; to support, enhance and extend the capabilities of the university community and the broader scientific community – nationally and internationally; and to foster transfer of knowledge and technology for the betterment of life on Earth. The National Science Foundation is NCAR's primary sponsor, with significant additional support provided by other U.S. government agencies, other national governments and the private sector.

Kjeller Vindteknikk (KVT) was established in 1998 in Kjeller, Norway, as a spin-off from the Institute for Energy Technology (IFE). With the increasing number of customers in Sweden, a subsidiary was open in Stockholm in 2009. Today, KVT is one of the leading companies in wind measurement and analysis in Norway and Sweden. The staff consists of meteorologists, physicists, engineers and technicians. Kjeller Vindteknikk has extensive experience from a large number of wind power projects in Sweden, Norway and other countries such as Iceland, Bulgaria and Macedonia.

The Norwegian Forest and Landscape Institute (NFLI) is one of Norway's foremost scientific institutions regarding the use of forest resources, forest ecology and the environment. The institute is also responsible for a range of national mapping programs and resource inventories related to land cover, forestry, agriculture, landscape and the environment. The institute provides knowledge to the authorities, the business community and the general public in order to contribute to the sustainable management of and value creation based on land resources through research and data management.

The Swedish University of Agricultural Sciences (SLU) is a university focusing on the sustainable use of biological natural resources, as well as on environmental and life sciences. The activities span from genes and molecules to biodiversity, animal health, bioenergy and food supply. Urban and regional planning, sustainable urban and rural development and global issues such as climate change are also on the agenda.

B. *How the project is organised*

A project involving a variety of competence from different institutions should be divided into sub projects addressing the different fields, and for WISLINE we identified 5 sub projects or work packages (WPs). These are presented in Figure 4, which shows the project structure. While WP1 mainly addresses the microphysics of the AROME model, and hence the scientific basis of the project, WP2 will together with WP3 apply the results from WP1 by simulating climate loads such as ice, snow and wind, and produce datasets for both present and future climate. As WP4 addresses forest damage from wind and snow, it will apply data from WP2 and WP3 directly by combining wind and snow data with forest damage data. The activities of WP5 are related to data storage and availability, which is essential as WISLINE is under obligation to provide open access to data. The different WPs will be described more in detail below.

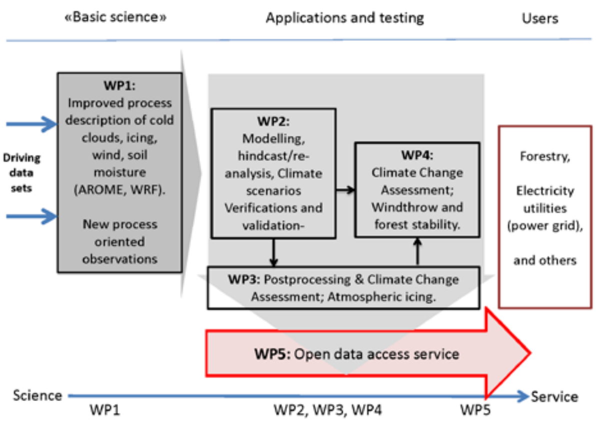

Figure 4: The project structure

The end users of the methods and data from WISLINE will be agencies and private companies connected to forestry, power supply, telecommunication and aviation. The user group will be invited to take active part in the project in order to assure that the results of WISLINE will benefit planning of robust infrastructure and protection of natural environment in a changing climate.

II. THE WORK PACAKGES OF WISLINE

The activities that are necessary in order to meet the objectives of WISLINE have been placed under the different WPs according to academic field and need for competence. This section provides a brief presentation of each WP.

A. WP1 – Improved predictions of atmospheric icing by upgrading the cloud microphysics scheme in the AROME NWP model

The NWP model AROME is a LAM run operationally at MET Norway as well as several other European forecasting centers. The current AROME cloud microphysics scheme is based upon Cohard and Pinty (2000), which when followed backward through the literature, has physical processes similar to Ferrier (1994), Rutledge and Hobbs (1984), and Lin et al (1983). The recent study by Liu et al. (2011) showed how the schemes with roots in Lin et al. (1983) all predicted too much ice and too little liquid and resulted in too much surface precipitation compared to observations. In contrast, the Thompson et al (2008) and Morrison et al (2009) schemes predicted much more liquid and less ice with surface precipitation that very closely matched the observations. The objective of WP1 is to improve the microphysics scheme of AROME and hence its ability to simulate cloud droplet distribution and precipitation processes.

A realistic distribution of cloud ice and supercooled droplets is essential if the model is used for simulating cloud icing on infrastructure such as power lines, and the model will be verified against icing observation from Statnett's test span at Ålvikfjellet in Western Norway. We also plan to purchase a Thies distrometer for validation purposes, and place it at Gaustatoppen (Figure 5), which is a mountain in Eastern Norway, 1883 m above sea level. As part of the project Development of a toolbox for assessing Frost and Rime ice impact on overhead Transmission Lines (FRonTLINES), Kjeller Vindteknikk and Statnett plan to set up a second test span, which will be available for WISLINE for validation purposes. Furthermore FRonTLINES activities on forecasting atmospheric icing and hoar frost will benefit from the improvements of AROME's microphysics.

Figure 5: Gaustatoppen (Photo Ole Jørgen Østby / MET)

WP1 will be led by Jón Egill Kristjánsson from The University of Oslo, and the co leader will be Roy Rasmussen from NCAR. Greg Thompson from NCAR will also contribute to this work. Major parts of WP1 will be carried out as a PhD project by Bjørg Jenny K. Engdahl at the Norwegian Meteorological Institute, supervised by professor Kristjánsson. The activities of WP1 will increase AROME's ability to predict precipitation and icing events, which will benefit both planning and operation of infrastructure such as power lines, public roads and air ports. This will also make the AROME a robust tool for downscaling data from climate models to investigate ice and snow loads in a future climate.

B. WP2 –Establish high-resolution datasets for present and future climate

The design of infrastructure with respect to climate loads not only requires adequate modelling tools but also datasets of sufficient length. The objective of WP2 is to establish both a high resolution hindcast archive and a dataset for future climate based on the AROME model with the improved micro physics scheme from WP1. Design values are mainly based on extreme value analysis e.g. one need to design for ice loads that have a return period of 150 years, which means that the length of the dataset should be three to four decades. To provide datasets of such lengths is beyond the scope of WISLINE, which will demonstrate the use of AROME to produce high resolution datasets of approximately one decade for present and future climate. The datasets from AROME will have a spatial resolution of 2.5 km, but we also plan to apply a surface model to downscale data further to 1 km.

WP2 will be led by Jan Erik Haugen at The Norwegian Meteorological Institute with contribution from at least three other scientists from MET Norway. The work will be done in close collaborations with WP3, which will focus on wind and icing climatology and WP4, which addresses forest damage.

C. WP3– Climate change influence on the geographical distribution of wind and icing design loads in Norway

Ice loads on infrastructure such as power lines are calculated by applying a postprocessor on data from NWP models. The postprocessor will calculate ice load (kg ice per meter line) based on variables such as precipitation, wind speed, temperature, liquid water content and droplet distribution. We plan to develop existing postprocessors further and apply these on data from WP2 in order to create datasets for atmospheric icing in both present and future climate. Theses activities will be carried out in collaboration with FRonTLINES.

Although WP2 will provide wind data, further work on the data is required since a horizontal resolution of 2.5 km is not sufficient to describe wind loads in complex terrain. Methods for further downscaling will be tested and validated against observations, and recommended methods will be demonstrated and applied to both hindcast data as well as data from climate projections.

WP3 will be led by Bjørn Egil K. Nygaard from KVT, and Greg Thompson from NCAR as well as scientists from MET will contribute to the work. The work on wind in complex terrain will be supervised by Knut Harstveit from KVT.

D. WP4– Forest damage from wind and snow

Damage to forest by wind and snow occurs if the load from wind and/or snow exceeds the resistance of the forest to this load. The vulnerability of the forest to this kind of damage also depend on soil wetness and the surrounding topography as this strongly influences the local wind conditions, and we plan to estimate an index for wind speed by combining downscaled wind data with an elevation model. We will then fit a statistical model for forest damage based on wind, snow and soil data and validate it against a forest damage database. Based on this model and datasets from WP2 and WP3, a risk map for weather induced forest damage in both present and future climate will be created.

WP4 will be led by Svein Solberg at NFLI with contributions from scientists at NFLI and MET as well as Kristina Blennow from SLU.

E. WP5– Data Services

According to the conditions for R&D projects issued by the Research Council, we are under obligation to provide open access to the datasets produced by WISLINE. During the project period WP5 will prepare, manage and publish the data sets through relevant portals and servers, assuring that end user will benefit from the datasets as soon as they are considered suitable for publication. WP5 will be led by Harold Mc Innes at MET Norway.

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