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Botnia-Atlantica WindCoE - Wind Center of Expertise Project

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PROJECT FINAL REPORT

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Nordland
COUNTY COUNCIL
Regional Council
of Ostrobothnia

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Introduction

The initial phase of a Botnia-Atlantica funded project called WindCoE (Wind Center of Excellence) approaches its end and the continuation is beginning. Academic centers within the Botnia-Atlantica region worked together in the first phase to engage the wind industry, local governments and ordinary citizens to implement the project. In the second phase, the partners continue the effort but now with some industry and municipality members joining the activity. This report highlights some of the first phase process.

Project main goal and purpose

The Botnia-Atlantica trans-national cooperation program supported this project to develop a permanent center of expertise to assure the possibility that industry, society and government could discuss the development of wind energy within the region with up-to-date and common knowledge. This new structure was created to solve and communicate problem solutions related to wind energy technologies in the Botnia-Atlantica region. This report summarizes the project phase efforts the members have carried out.

By identifying the research needs of the wind energy industry and addressing the bottlenecks in the wind energy development processes, the project partners have utilized their available academic research resources to promote the use of wind energy in the region and solve industry problems. The project partners lead and contributed-to the public discussion regarding the role and acceptance of wind energy in society.

The effort included work-package focus on domain specific research problems and networking with different stakeholders. The stakeholders consisted of companies, municipalities and governmental administrative units. Continuing activities include participating in wind turbine networking meetings of the administration office of the West-and Central-Finland and networking engagement of additional members.

With the project phase concluding, the center of expertise goals carry forward with the development of a registered association established in Finland, the “Nordic Forum for Wind Energy Research”. The spatial domain now expanded to bring interested parties from the full Finland/Norway/Sweden region. The forum is developing a space to foster discussion concerning wind energy in the region and identifying research topics, which act as friction slowing such development. The nature of the issues are in the political, social and technological realms.

Project partners

Luleå University of Technology

The Atmospheric Science Group at LTU conducts research on the following topics: atmospheric research including modelling and observations; in-situ and air-/space-borne instrument development; acquisition, processing, and interpretation of measurements and understanding of the relationships between the atmosphere and the environment, using models to understand the interaction between the electromagnetic radiation and components of the atmosphere.

Professor Javier Martín-Torres is Chaired Professor in Atmospheric Science at LTU. He has experience in space from concept idea to hardware development, science operations, atmospheric modelling and data exploitation. He is currently the principal investigator (PI) of the HABIT (HabitAbility: Brines, Irradiation and Temperature) instrument to be part of the European Space Agency (ESA)/Roscomos ExoMars 2018 mission. He has been co-investigator (co-I) of National Aeronautics and Space Administration (NASA) space missions and is currently co-I of the Mars Science Laboratory (MSL), Atmospheric Chemistry Suite/Trace Gas Orbiter (ESA/Roscomos) and the Infrated Spectrometer for ExoMars Rover (ESA/Roscomos). Prof. Martín-Torres has experience running and analyzing data from General Circulation Models, and interpreting them in the light of atmospheric observations. He has developed and validated radiative transfer algorithms for Earth observation missions from space and is the author of the radiative transfer code FUTBOLIN (Full Transfer by Optimized LINe by line) which has been adapted to the modelling of the atmosphere of the Earth and other planets. He has worked for the Institut für Meteorologie and Klimaforschung and Universität Karlsruhe, Germany (ESA External Fellowship); AS&M, Inc. at NASA/Langley Research Center, Hampton, USA; Jet Propulsion Laboratory, Pasadena, USA; Lunar and Planetary Institute, University of Arizona, Tucson, USA; California Institute of Technology (CalTech), Pasadena, USA, and Spanish Research Council.

Dr Ricardo Fonseca is a post-doctoral researcher in the field of atmospheric sciences at LTU. After completing his PhD in Atmosphere, Oceans and Climate at the University of Reading, United Kingdom, he went to the Earth Observatory of Singapore to do a postdoc on regional climate modelling with a focus on the tropics in particular on Southeast Asia. He has been working with the WRF model for more than 5 years and has applied it to both the tropics and Polar Regions.

Novia University of Applied Sciences R&D

Novia University of Applied Sciences is the largest Swedish speaking UAS in Finland. The Research and Development activities support a genuine joint effort between the UAS and the regional businesses and industries. The research and development activity is developed as a part of the Finnish innovation system through strategically chosen, long-term partners. The research and development areas within Novia R&D include Sustainable Energy Technology, Bioeconomy, Health and Welfare, Maritime Simulation, Culture and Entrepreneurship. The activities include research and development projects, services, investigations and consultant tasks. These varied research projects include national and international collaboration projects.

Kendall Rutledge is a Research Lead with experience in the fields of instrumentation, calibration, outdoor acoustics, environmental satellite ground-truth observations and system engineering. He has worked as a researcher in medical sciences (Eastern Virginia Medical School), and as a NASA support contractor for the Lockheed Engineering and Sciences Company, Analytical Services & Materials, Inc., and Science Systems and Applications at NASA/Langley Research Center, Hampton, USA.

Dennis Bengs is a computing specialist researcher with accomplished experience in database design, parallel programming, advanced visualizations, virtual reality and machine learning techniques.

Niklas Frände is a project manager with background in environmental engineering. He has over ten years of experience of development projects related to energy and environment, and experience in life cycle assessment modelling and methodology.

Seinäjoki University of Applied Sciences

Seinäjoki University of Applied Sciences (SeAMK) is a multidisciplinary institution of higher education and an efficient actor in education and research, development and innovation in the region of South Ostrobothnia in West Finland. The number of full-time students is 4800 and academic and other staff members 350. SeAMK has 19 Bachelor and 7 Master degree programs.

SEAMK has an extensive virtual reality laboratory including a CAVE room consisting five display walls of computer generated virtual reality. It is used for visualization of computer generated 3D worlds to in a virtual space where the viewer can move inside a virtual space. Laboratory is well equipped with virtual reality devices and software.

Tapio Hellman is head of SeAMK virtual reality laboratory. He has more than 10 years experience on virtual reality technology. He has conducted number of research projects applying virtual reality technology in various domains. He has done long-term co-operation with prof. Ellman in TUT.

Tampere University of Technology

Laboratory of Mechanical engineering and Industrial systems in Tampere University of Technology (TUT) performs the major part of the university level research and teaching in the field of mechanical engineering and industrial systems in Finland. Its main research topics are Product design and development, manufacturing and automation as well as product life cycle management. This laboratory has a research team in Seinäjoki University Colloquium, which is managed by prof. Asko Ellman.

Professor Asko Ellman is full professor in machine design and product development. His research team is developing design tools and methods that enable engineers to understand and design complex machine systems. This chain starts with elicitation and priorization of requirements and reach to co-design with stakeholders using virtual prototypes.
In product design, prototypes are generally used to ensure that the forthcoming product fulfils the design goals. Virtual reality technology enables studying of 3D models in real size and from real perspective. Due to this, all stakeholders can bring their expertise to the design process and enable effective co-design. Prof. Ellman has supervised several applied research projects co-funded by industry and various national and European funding agencies.

UiT The Arctic University of Norway

Arctic technology research team at UiT is focused on topics related to atmospheric ice accretion physics on structures such as wind turbines, power transmission lines, bridges and communication towers. One of their key research topic is wind energy in cold climate, with a particular focus of better understanding of ice accretion physics along wind turbine blades and its resultant effects on wind turbine performance and overall annual energy production. They also have good expertise of topics related to wind resource assessment & ice site classification for wind parks in ice prone cold regions. Below is a summary of the profiles of three main members of this group that were involved in WindCoE project:

Professor Muhammad Virk is a Professor in the Faculty of Engineering & Technology, University of Tromsø, Norway. He leads the Arctic technology research team within the Institute of Industrial Technology. The focus of his research activities is on various issues related to cold climate technology, wind energy in cold climate & atmospheric icing effects on both onshore and offshore structures. This includes the analytical, experimental & numerical analyses. He is engaged in various applied research projects co-funded by industry and various national and European funding agencies. During last 7 years, he has successfully managed and participated as principal & co-investigator in 9 different international research projects. In addition to cold climate technology, major part of his research work deals with the computational fluid dynamics, aerodynamics and heat transfer. With experience of numerical modeling of complex turbulent flow behaviors, he also has a good understanding of the aircraft design and aspects related to high-speed aerodynamics from his aerospace engineering background.

Jia Yi Jin is a PhD researcher at Arctic technology research team. She is working under supervision of Professor Virk. Miss Jia has good expertise in terms of numerical modelling of ice accretion on wind turbines and wind resource assessment.

Pavlo Sokolov is a PhD researcher at Arctic technology research team, working under supervision of Professor Virk. Mr Pavlo has mathematical background and has good expertise related to analytical and numerical modelling of ice accretion physics.

Umeå University

Umeå University contributes with broad knowledge in computing science and mathematical statistics. Computing Sciences contributes with expertise in AI, computational intelligence, decision modelling, information structures and ontology, many-valued logic and process modelling. Mathematical Statistics contributes with expertise in spatiotemporal statistical modelling and statistical learning with sparsity for big data, statistical methods for analysis of spatiotemporal data, functional data, and high dimensional data, uncertainty analysis, and advanced simulations and scenario analysis.

Jun Yu is Chaired Professor in Mathematical Statistics at Umeå University. He leads the spatio-temporal statistics group at the Department of Mathematics and Mathematical Statistics, which conducts research in spatial and spatio-temporal statistics, as well as signal-image analysis. The group works on tackling theoretical statistical problems and developing statistical methods for solving real-life problems, which originate from various application areas. Regarding the statistical inference studied, this group has particular interest in e.g. statistical compressive sensing, statistical learning with sparsity, nonparametric density estimation and smoothing techniques, classification and pattern recognition of remotely sensed imagery, statistical inference for stochastic processes, summary statistics for point processes, multiscale hidden Markov models, random fields and biomedical image analysis, tree growth model, and wavelet theory applied to statistical problems. In terms of data analysis (tools) the group also works on (tree) growth models, multimodal image processing, intelligent data sampling using compressive sensing, and general modelling of biological populations in space and time. Application areas of interest include atmospheric sciences, artificial intelligence, bioinformatics, conference telephony, criminology, epidemiology, forestry, geochemistry and hydrology, industrial quality control, medical engineering, population biology, radiation oncology, spatial ecology, and sports science.

Jianfeng Wang is a PhD student in Mathematical Statistics at Umeå University. He is working under supervision of Professor Yu. Jianfeng has good knowledge in spatiotemporal statistical modelling and uncertainty analysis for climate change estimation and prediction and big complexed structured data in general, and programming in R.

Patrik Eklund is a professor in computer science at Umeå University. His research interests include foundations, artificial intelligence, health informatics, distributed systems, and industrial information systems.

University of Vaasa

The renewable energies research group of University of Vaasa carries researchers wind, solar, geothermal energies and bio-fuels. The group has strong background in physics, machine learning and automation, which are applied to data driven research methods in various renewable energy research problems in cold climate conditions.

Associate Professor Petri Välisuo is the Vaasa Energy Business Innovation Centre research group leader and researcher in sustainable energy technologies. He is involved with research supporting new business opportunities due to energy transition, including synthetic fuels, energy storage, energy systems modelling and optimization, environmental assessments, new business cases, including public-private partnerships, and circular economy.

Work Package Highlights

WP-1: Wind Resource Assessment

Wind Resource Models

We have worked with the industry leading wind resource assessment company WindSim AS from Norway to improve the wind resource assessment method used by many actors within the industry. Improvement of the wind resource methods was highlighted by industry (to our project) as an important factor for progress in the Scandinavia region. This specific work is to be presented at the upcoming WindEurope 2018 Conference at the Global Wind Summit, Hamburg, Sept 2018 and at the5th International Conference Energy & Meteorology (ICEM) in Shanghai, China. WindSim's summary of the work follows.

Several wind resource modeling methods were used in the course of the project. In this work package we describe the use of a computational fluid dynamics (CFD) method and in the next work package we describe a numerical weather prediction method. Here we report on research aimed to improve the wind resource assessment process by providing more detailed initialization details to the CFD model. New wind farms may be developed in sites of high terrain complexity, where linear models (such as the Danish Technological University's WASP model) perform less well. Often in the Scandinavian case, improved wind energy can be found in these more complex environments. CFD models are used to assess the wind resources in such conditions given their better capability to physically represent the complex wind flow. While CFD is able to simulate more accurately the terrain induced flow field it lacks the simulation of the mesoscale flow features caused by thermal effects and pressure systems. In this project we start with a simpler terrain from a site in mid-Finland to demonstrate the methods perform properly in a simpler forested flatland regions.

Methods which use mesoscale simulated data as boundary and initial conditions in CFD modelling have been developed to generally improve the microscale results (CDF in this case). This technique is referred to as meso-microscale coupling. Mesoscale data can reproduce complex regional wind circulations like thermal winds and low-level jets and in the coming years, high resolution reanalysis data sets will be freely available for Europe. Using those data sets as boundary and initial conditions to the CFD modeling provides an opportunity to improve CFD modelling. Nevertheless, most of the development done on meso-microscale coupling has been focused on transient simulations, which are impractical for Annual Energy Production estimations.

In this work we use more realistic initial and boundary conditions for the steady state CFD modelling based on mesoscale data instead of just using simple analytical profiles, which is the standard today. We show how boundary conditions differ between the coupled and the default approach. The modelling of vertical wind speed profiles is improved when using a coupled approach, given its capability to include atmospheric stability effects into the CFD model.

The half-hourly results of the Weather Research Forecasting (WRF) model were first classified by wind direction and atmospheric stability, and then averaged accordingly. These fields were interpolated onto the CFD grid to generate the boundary and initial conditions to drive the simulations. Two methodologies were tested: one which only classifies and averages by wind direction and one which splits each wind direction into three atmospheric stability classes.

Two default simulations with analytical boundary conditions were conducted: One simulation with neutral atmosphere and one considering thermal effects. These are the common practice in wind resource assessment when using CFD models. For validation, the average vertical wind speed profile measured by Novia’s SODAR at the Honkajoki site in Finland was used.

When classifying the WRF by wind direction only, small improvements in the overall simulation results were obtained. For some main wind directions, the simulated wind speed profile has a very good match with the measured one. Nevertheless, in the overall vertical wind profile modelling, ***default simulations with thermal effects performed better***. When classifying the WRF and the measurements in 3 stability classes, **considerable improvements in the meso-microscale coupled simulation results were found** for unstable and neutral conditions. For stable conditions, the coupled simulation and the default simulation with thermal effects show similar performance. In general, the coupled simulation is delivering the best results for the main wind directions.

The meso-microscale coupling procedure improves the wind resource assessment, taking advantage of atmospheric stability information delivered by the mesoscale models.

This mesoscale-microscale coupling procedure produces more realistic wind profiles on the boundaries of the CFD domain. The CFD simulations using these profiles show improved results compared to standard simulations, especially for the main wind directions. Classifying the WRF and measurements by atmospheric stability provides the best results.

Observations for Validation

For the wind resource assessment methods used in the project, we made local weather observations to assess the quality of the modeled data. As described above, the observations were used to improve the assessment methods.

For a yearlong project at the Honkajoki site in Finland, weather observations were performed. These observations included at a single location, 2.8m, 10m and 50m to 200m, (with 5m steps, sodar wind profiling instrument) and 0m to 1000m, (with 50m steps, microwave radiometer temperature profiling instrument). All observations were summarized at 10 minute resolutions for the full year except the microwave radiometer which operated from September 2016 to March 2017. Daily, the previous day's weather elements were pushed to the project website (http://www.nordisktvindenergicenter.eu/weather-effects-on-wind-turbine-sound/ and http://www.nordisktvindenergicenter.eu/november-2016/) for public access. A summary of a small portion of the wind profile data in figure 1 demonstrates how the wind speed and directions change as a function of altitude within the lower atmosphere for the annual period at the site. The wind predominantly arrives from the SSW direction at lower levels and from the SW at higher altitudes. The wind speed distributions at the higher altitudes generally follow the Weibull distribution better than the lowest altitude.

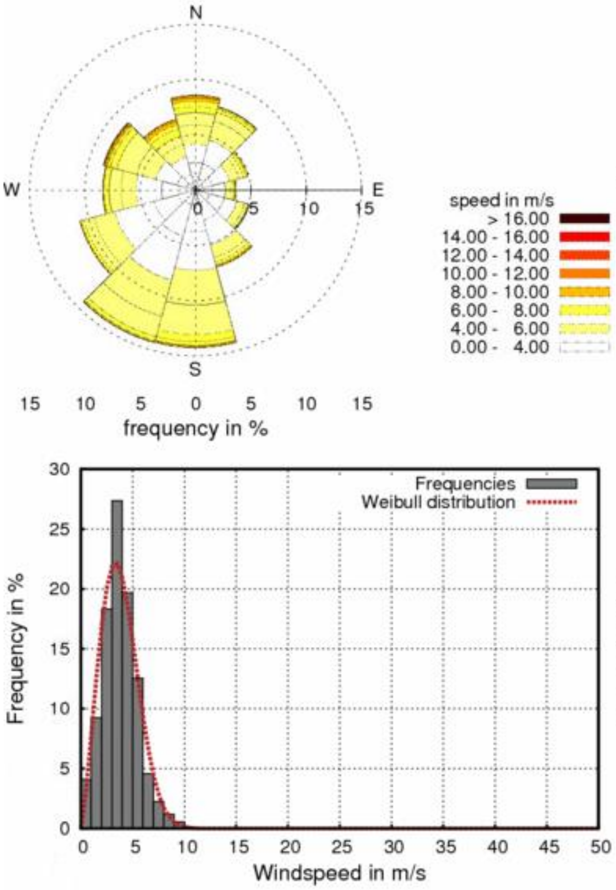

Figure 1a: Annual wind speed and direction summary from sodar at 50m altitude.

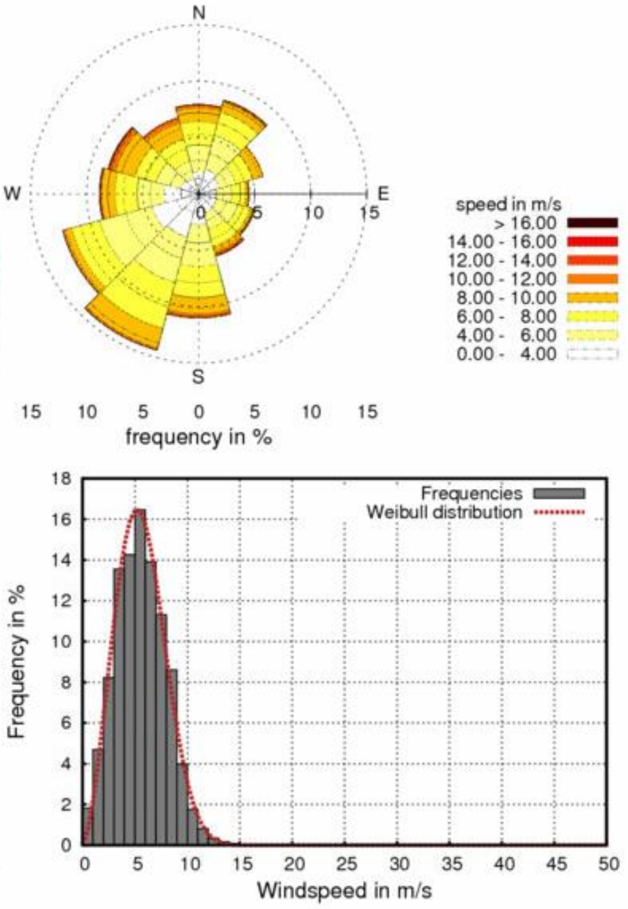

Figure 1b: Annual wind speed and direction summary from sodar at 100m altitude

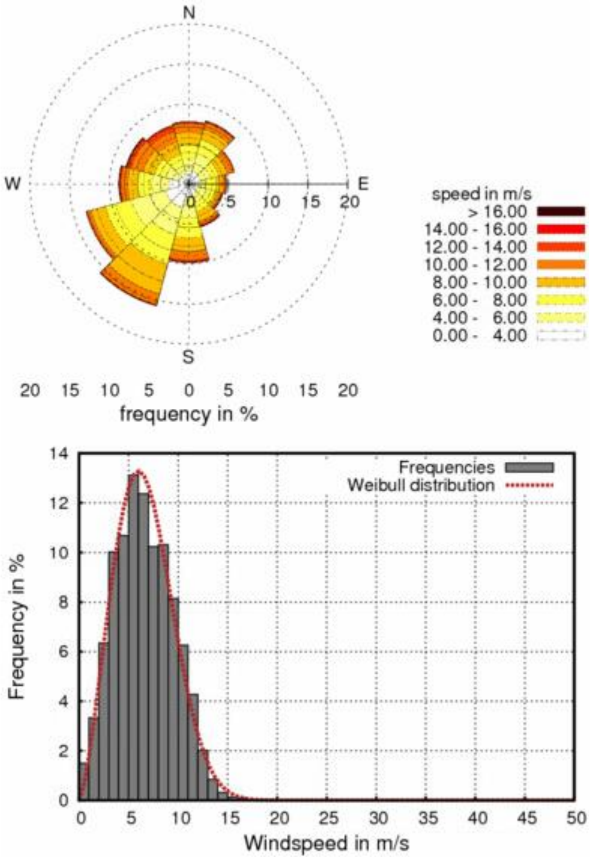

Figure 1c: Annual wind speed and direction summary from sodar at 150m altitude

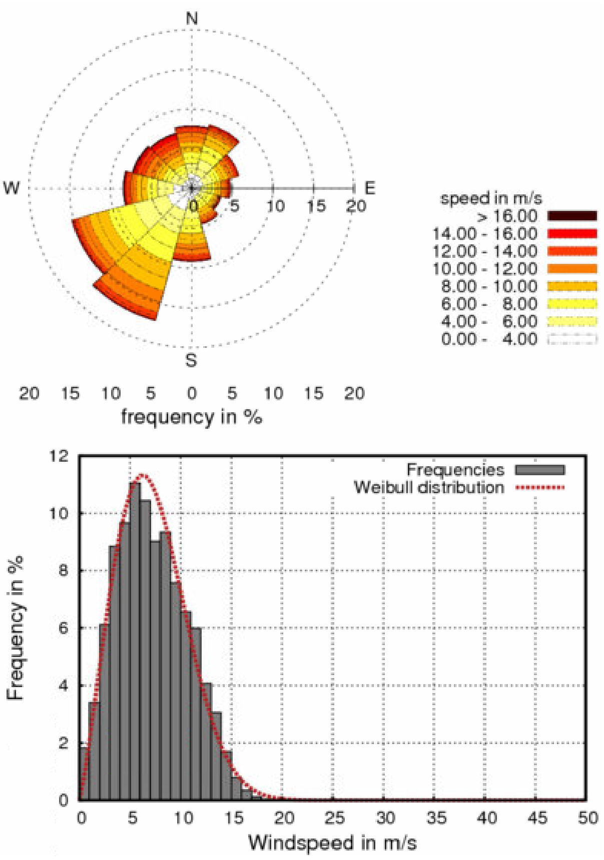

Figure 1d: Annual wind speed and direction summary from sodar at 200m altitude

Temperature profiles in the atmosphere (figure 2) demonstrated the presence of strong thermal inversions during the winter months. The temperature and wind profile data was used to characterize the sound propagation environment and to verify the simulated outputs from the mesoscale model, WRF. For the temperature profile observations, the thermal inversion analyses identified times when thermal inversions were present. This situation is especially important to outdoor acoustic propagation since the inhomogeneous density gradients associated with the inversions bends the propagation paths of acoustic wave fronts compared to isothermal atmospheres. The strengths of the inversions ranged from just a few degrees to 22 degrees C. From analyzing these data, systematic errors in the WRF simulations were identified based on comparison to the microwave radiometer observations.

Statistical summaries and graphical comparisons were made for all available simulated and observed weather variables. Figure 3 and 4 show examples of such summaries giving the opportunity to get both qualitative and quantitative assessments of the accuracy of the WRF weather simulation method. In figure 3 an example of a meteorological event called a “low level jet” shows the skill of the WRF model to capture complex three dimensional wind flow. These events can be important for the wind energy sector since they provide improved resources to the wind turbine systems. Figure 4 shows the results of a statistical summary of seasonal wind

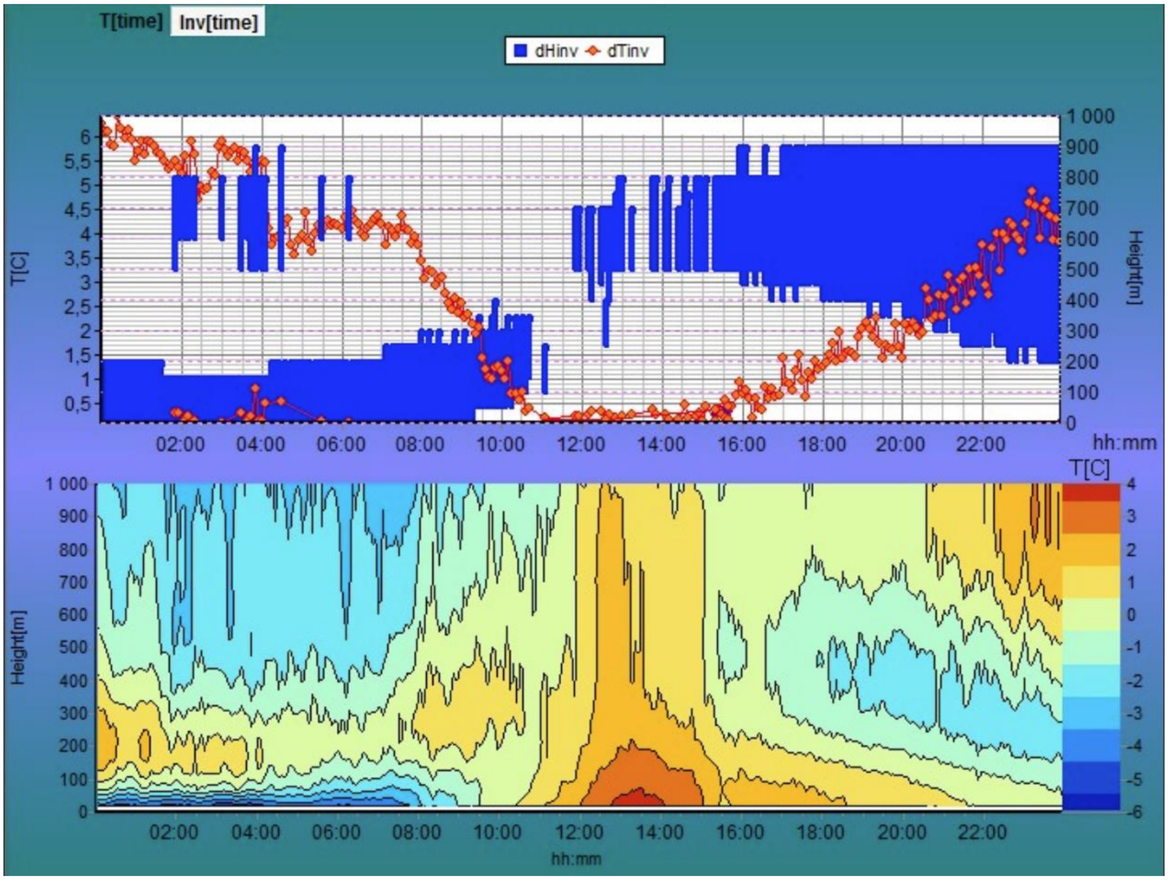

Figure 2: Example temperature profile observations (bottom) and inversion analyis (top) from a single day (Feb 15, 2017).

speed profiles from the WRF model and the observations taken at the Honkajoki site. The variance-similarity results indicate the WRF model has lower skill at the lower atmosphere heights near the surface while the winds at higher heights are well simulated. Specifically, the WRF's winter, summer, and autumn skill is somewhat similar with poorer skill being associated with the spring season. The overall skill of the WRF system indicates good performance as indicated by the variance-similarity statistical summary.

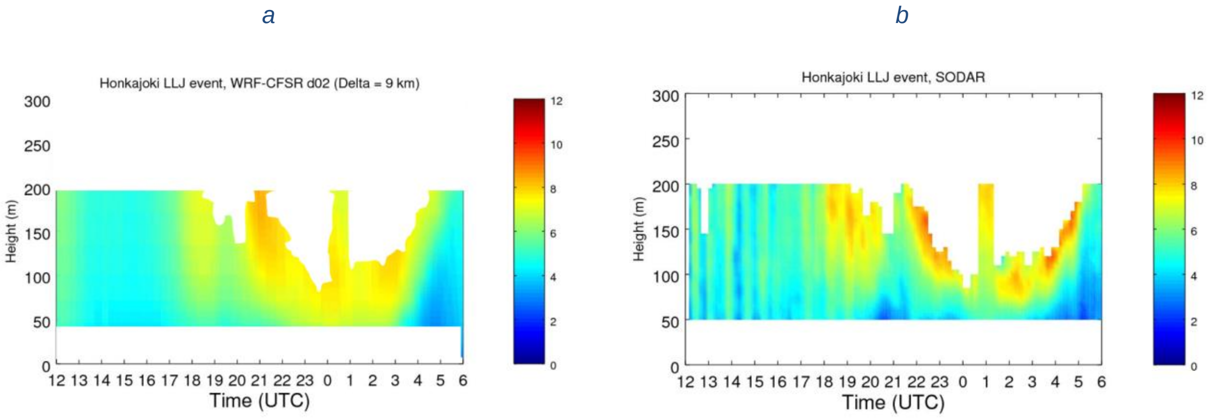

Figure 3: WRF simulated (a) and observed (b) wind fields within the lower atmosphere over the Honkajoki area for a specific eighteen hour period. The missing data characteristic of the sodar instrument during extreme turbulent wind periods was excised from the simulated data for visual comparison purposes.

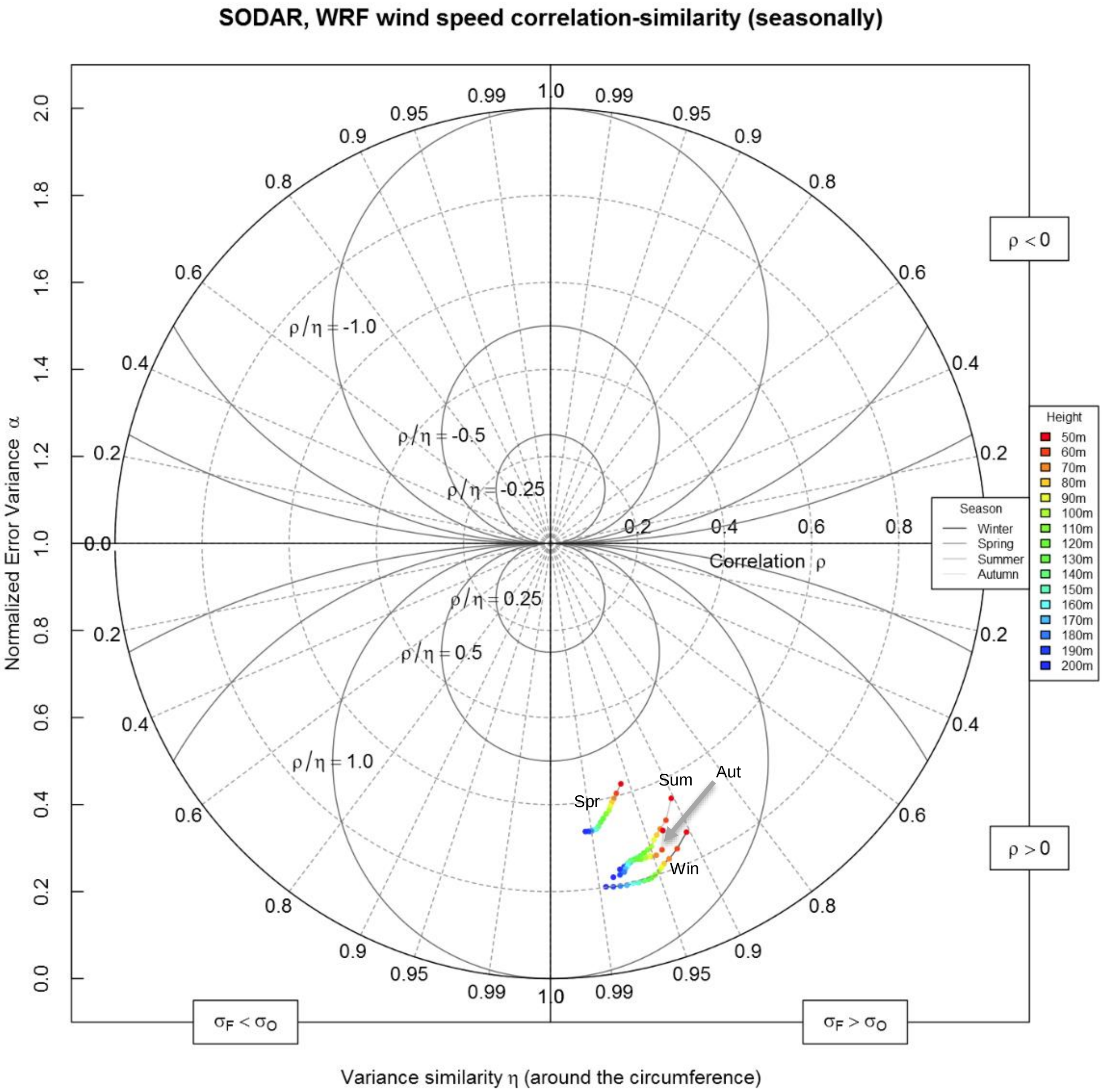

Figure 4: Correlation-similarity statistical comparison of wind speed profiles for seasons of the year (as a function of altitude) comparing WRF simulations and sodar observations for the Honkajoki experiment.

Including Atmospheric Stability

The state of the atmospheric stability in the lower atmosphere can be estimated from measured weather variables and is calculated by the WRF weather simulation process. The year-long availability of observation and simulation parameters associated with this turbulence characterization in our project showed the stability class for the Scandinavion region to have a large proportion of stably stratified conditions. The available observation and simulation results from the project allowed the data to be subsetted according to atmospheric stability classes permitting the opportunity to test the simulation system (CFD WindSIM) relative to this sensitive atmospheric characteristic.

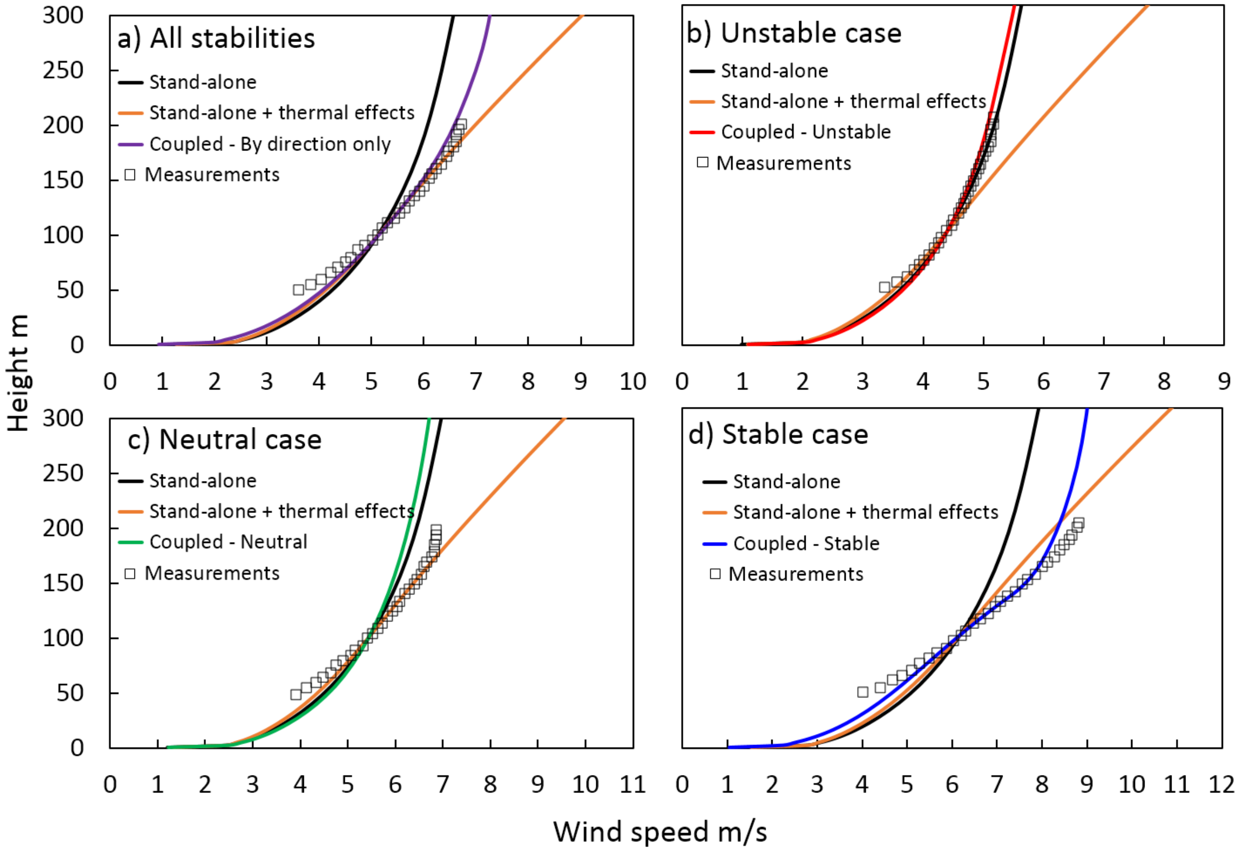

Figure 5: Observed and simulated (CFD WindSIM wind profiles as a function of atmospheric stability classes.

Figure 5 indicates that the technique used to initialize the CFD simulation model using WRF mesoscale weather details improved the results relative to the industry standard method. Better agreement between measurements and the “coupled” procedure is demonstrated for the stable and unstable atmospheres but not so for the neutral stability case. This level of detail can only be accomplished using long-term simulations and observations as were collected during this project. The normal scenario is demonstrated in figure 5a where all stabilities are grouped together when compared to the simulation results.

In this project, the modeling method which includes thermal effects and analytical definitions for the initialization of the atmosphere at simulation start up performed better in the neutral stability grouping of data. The method mesoscale-microscale coupling has been demonstrated to improve the skill of the CFD WindSim wind resource assessment model. The company accomplished the needed verification testing of this method that only long term weather simulation and observations can provide.

This work has highlighted the complexity of the near surface atmosphere in the cold-climate region. We have initiated work to improve the WRF model to better simulate this situation.

WP-2: Meso-Scale

Estimation of model uncertainty

In this work package we investigated the issues of uncertainty associated with wind resource assessment products. This issue was identified, as an important one, by one of the wind energy industry leaders (from our steering committee). A common approach to estimate the uncertainty associated with weather and climate projections is to perform an ensemble of simulations. This can be achieved in different ways such as by changing the model physics and/or dynamics configuration (e.g. Evans et al., 2012), perturbing the initial and/or boundary conditions (e.g. Torn et al., 2009), or even by considering different models (e.g. Salazar et al., 2016). These methods are not only time-consuming but very computationally demanding, slowing down the progression into higher resolutions needed for a better representation of the surface fields and consequently the local atmospheric conditions (e.g. Prein et al., 2015). At the same time, providing the uncertainty of a field like the 2-meter temperature is crucial for the majority of weather and climate applications, not least for climate change projections as it will help guide policy makers and stakeholders responsible for developing mitigation strategies. A novel approach is developed that only requires one model simulation: fitting a Bayesian Hierarchical Model (BHM; Cressi and Wikle, 2011) to the output data and from it estimating the uncertainty of a given variable.

The WRF model is run at 3km spatial resolution over the Botnia-Atlantica region for one month in the winter (January 2017) and summer (July 2016) seasons. In addition, an ensemble of simulations is generated with 10 different model configurations for the first 10 days of January 2017 and July 2016 with a 1-day spin-up before. These periods are chosen as they comprise weather conditions typical of the region: i.e. milder and rather cold days in the winter period, and rather warm and cooler days in the summer period. In the BHM the 2-meter temperature, at a given time and spatial location, is assumed to follow a normal distribution with mean μ and standard deviation σ_e. While σ_e is assumed to be constant in time (for each month considered), four assumptions are made to explore its spatial heterogeneity ranging from spatial homogeneity to largest possible heterogeneity. The predicted 2-meter temperature is evaluated against station data given by the National Oceanic and Atmospheric Administration (NOAA) Global Surface Summary of the Day (GSOD; available online at https://data.noaa.gov/dataset/dataset/global-surface-summary-of-the-day-gsod) dataset.

For both seasons, the uncertainty estimated using the WRF-BHM is comparable to that obtained from an ensemble of simulations with the best agreement achieved with a spatially uniform σ_e. In addition, the WRF-BHM is found to predict well the observed temperature at the locations of the GSOD stations with biases generally below 2 K except in the winter season in cold and stably stratified environments where they can exceed 5 K. These larger discrepancies are not so much the failure of the WRF-BHM but are mostly a result of the referred WRF deficiencies in these environments (e.g. Kilpeläinen et al., 2011; García-Díez et al., 2013). The methodology developed is fully general and can easily be extended to any other variable and numerical model. This work has been submitted as an article (Wang et al., 2018).

WRF Simulations

The Weather Research and Forecasting (WRF; Skamarock et al., 2008) model version 3.7.1 is set up over the Scandinavian Peninsula at 15 km horizontal resolution with a 3 km grid that covers the full Botnia-Atlantica region and a 600 m grid centered over the Honkajoki wind farm. The initial and boundary conditions for the WRF simulations are provided by the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR; Saha et al., 2010) 6-hourly data (horizontal resolution of 0.5° × 0.5°), freely available online in near-real time at https://rda.ucar.edu/. In all model grids a simple wind farm parameterization scheme, based on Fitch et al. (2012), which assumes that wind turbines act as a momentum sink on the mean flow transferring a fraction of the kinetic energy into electricity and into turbulent kinetic energy (the latter representing the stirring of the ambient flow by the turbines), is employed. This scheme is configured for the Honkajoki wind farm using data provided by the manufacturer. The WRF version used here contains most of the improvements made in Polar WRF (Hines et al., 2008; http://polarmet.osu.edu/PWRF/), a modified version of the model optimized for the polar regions, and therefore suitable for this work. In particular, the fractional sea-ice coverage and sea-ice depth are read in from CFSR every 6 h, the sea-ice albedo is a function of air temperature, skin temperature and snow (Mills, 2011), and an optimal surface energy balance and heat transfer over sea ice and permanent ice surfaces is employed in the simulations. In addition, a simple interactive prognostic scheme for the sea surface skin temperature (SSKT) based on Zeng and Beljaars (2005), which takes into account the effects of the sensible, latent and radiative fluxes as well as molecular diffusion and turbulent mixing, is added to the model to capture the diurnal variation of the SSKT and allows its feedback to the atmosphere. The lower boundary condition to the SSKT-scheme comes from the 6-hourly Sea Surface Temperature (SST) data from CFSR, linearly interpolated in time in order to have a continuous-varying forcing on the skin layer. The model is set up with 60 levels in the vertical with about 20 levels in the lowest 200 m. This increased vertical resolution in the Planetary Boundary Layer (PBL) allows for a proper representation of the low-level flow and evaluation of temperature and wind vertical profiles. These two fields are needed to generate speed of sound profiles that are used to study the propagation of acoustics from the wind turbines.

After determining the optimal model configuration in sensitivity experiments for April 2016, WRF is run for the period March 2016 – March 2017 inclusive. In order to minimize the accumulation of integration errors, and following Lo et al. (2008), each month’s run is broken into three overlapping 11/12-day periods (e.g. for March 2016 the model is run from 29th February 00UTC - 11th March 00UTC, 10th March 00UTC - 21st March 00UTC and 20th March 00UTC - 1st April 00UTC) with the first day regarded as model spin-up. The 1-hourly post-processed output from the 3 km grid and the 10-minute post-processed output data from the 600 m grid have been stored and used for analysis. The model runs were performed at the Abisko cluster, a High Performance Computing (HPC) cluster at the High Performance Computing Center North (HPC2N), one of the six national centers funded by the Swedish National Infrastructure for Computing (SNIC).

The output of the 3 km grid is evaluated using station data from the GSOD and radiosonde profiles from the Integrated Global Radiosonde Archive (IGRA; Durre et al., 2006, 2008), both datasets developed and maintained by NOAA. The output of the 600 m grid output is evaluated using observational measurements from the different sensors available near the wind farm which include horizontal wind measurements from 50 to 200 m above ground level from a sodar, temperature measurements from the surface to 1 km from a microwave radiometer and 10-meter horizontal wind, temperature, relative humidity and surface pressure measurements from a weather mast.

The verification diagnostics proposed by Koh et al. (2012) are used to evaluate the model's performance in particular the correlation, variance similarity and normalized error variance. The correlation (ρ) is a measure of the phase agreement between the modelled and observed signal variations. The variance similarity (η) indicates how well the signal variation amplitude given by the model agrees with that observed and is defined as the ratio of the geometric mean to the arithmetic mean of the modelled and observed variances. The normalized error variance (α) is the variance of the error arising from the disagreements in phase and amplitude, normalized by the combined modelled and observed signal variances. The optimal performance corresponds to $\rho = 1$ and $\eta = 1$ and $\alpha = 0$ (a model forecast is deemed useful if $\alpha < 1$ as in this case it is more skillful than a random forecast). These three diagnostics are non-dimensional, symmetric with respect to the observation and forecast and applicable to both scalar and vector variables allowing therefore for a direct comparison of the performance of different fields and WRF configurations. This diagnostic suite is more robust and powerful than other commonly used diagnostics such as the Root Mean Square Error (RMSE). As discussed in Koh and Ng (2009), the RMSE has a few drawbacks when compared to α such as a strong dependence on the observation variability and, as a scalar, it does not capture the full set of error information for two-dimensional variables such as the wind vector.

The WRF performance of both grids 2 (3 km spatial resolution) and 3 (600 m spatial resolution) is found to be rather good with generally high correlations and variance similarities and low normalized error variances. Focusing on grid 3 which is centered on the wind farm, a comparison with the weather mast, sodar and microwave radiometer data revealed that ρ is mostly in the range 0.75-1.0 (no lower than 0.55), and α values that do not exceed 0.45 and are typically about 0.1 - 0.3. A more in-depth evaluation indicated two main deficiencies: (i) lower skill in the surface layer (lowest 10% of the boundary layer where the winds and temperature change rapidly with height; Jiménez et al., 2012) mostly from amplitude errors (i.e. higher values of α come mainly from lower η than lower ρ) and (ii) lower skill in cold and stable environments in which a strong low-level temperature inversion is present, a type of environment commonly found in Scandinavia in particular in the cold season (e.g. Pepin et al., 2009).

In an attempt to address problem (i), and for a 3-day period (4th - 6th January 2017) with a 1-day spin-up before, the model is run with two additional grids: one at 120 m spatial resolution and another at 40 m resolution which is run in Large-Eddy Simulation (LES) mode (i.e., at this spatial resolution the model is expected to explicitly resolve the larger-scale eddies, with the effects of smaller-scale eddies still parameterized). A comparison with the sodar and microwave radiometer measurements revealed that statistically the performance of grids 2 (3 km spatial resolution) to 4 (120 m resolution) is similar with a general deterioration of the performance for grid 5 (40 m resolution). As discussed in the literature (e.g. Pagowski, 2004), the WRF model is known to have difficulties in simulating the flow in the surface layer and using static fields (which include topography, albedo and vegetation fraction, among others) interpolated from a ~900 m resolution dataset may also prevent the model from capturing the observed smaller-scale features.

Regarding problem (ii), and for the same 3-day period, the model is run with 10 different configurations and none is found to outperform another. In order to determine from which scales the lower skill is mostly coming from, the Lanczos filter (Duchon, 1979) is employed with the verification diagnostics re-computed for the data with the synoptic-scales (2-8 days) and higher-frequency variability (<2 days) removed. It is concluded that the WRF model simulates well the mid-latitude synoptic-scale transients but generally fails to capture the higher-frequency variability. This lower performance can be tied to the referred coarse resolution static fields as well as to the known deficiencies of the parameterization schemes used in WRF in cold and stably stratified environments (e.g. Kilpeläinen et al., 2011; García-Díez et al., 2013).

Recent work has shown that a significant increase in the model performance can be obtained by optimizing the some of the tunable parameters used in the physics parameterization schemes employed in the model (e.g. Quan et al., 2016; Duan et al., 2017). This work is currently being done for this region with the aim of developing a version of the model optimized for the Scandinavian Peninsula. This WRF version will then be used for different research studies within the Nordic Forum for Wind Energy Research (NFWER).

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WP-3: Cold Climate/Icing Effects

The ice forming on the aerodynamic surfaces of wind turbine blades change the physics of the “wing” and moving fluid system. In this work package we look at these effects.

Cold regions have good wind resources but icing affects the wind turbine performance and power production. Such losses have been reported to lead up to a 17% decrease in Annual Energy Production (AEP) and 20-50% in aerodynamic performance/power coefficient. Worldwide, installed wind energy capacity in ice prone regions in 2015 was 86.5 GW, which is expected to reach 123 GW in year 2020. Northern Europe has good wind resources but cold climate causes environmental and operational issues mainly due to icing in harvesting wind energy such as: *complete loss of power production, reduction of power due to the disrupted aerodynamics, overloading due to delayed stall, increased fatigue of components due to imbalance in the ice load and damage or harm caused by the uncontrolled shedding of large ice chunks etc*. The International Energy Agency (IEA) Annex XIX: *‘Wind energy in cold climates’*, also calls for developing new methods to better predict the effects of ice accretion on energy production. Ice accretion on different components of wind turbines creates multiple problems, which shorten the life expectancy of a wind turbine operating in icing conditions. Icing has resulted in up to 17% loss in annual energy production (AEP) and can reduce wind turbine performance in the range of 20-50%. *WindCoE project aimed to develop a better understanding of ice accretion physics along wind turbine blade and its resultant effects on performance.* The knowledge gained in this project will help to improve the understanding of wind flow physics and the effects of ice accretion on aerodynamic performance of wind turbines.

Numerical Modelling of Ice Accretion on Wind Turbine

Ice Accretion along blade profile and its effects on aerodynamics

A numerical study was carried out to understand the effect of wind turbine blade profile symmetry on resultant ice accretion. Two symmetric (*NACA 0006 & 0012*) and two asymmetric airfoils (*NACA 23012 & N-22*) were used for this study. Based upon the flow field calculations and the super cooled water droplet collision efficiency, the rate and shape of accreted ice was simulated for rime ice conditions on each airfoil. Analysis showed a higher air velocity along top surface of the asymmetric airfoils as compared to symmetrical airfoils that also effects the droplet behavior and resultant ice growth. Results show that change in blade profile symmetry effects the ice accretions. For symmetric airfoils, more streamlines ice shapes were observed at leading edge as compared to asymmetric airfoils.

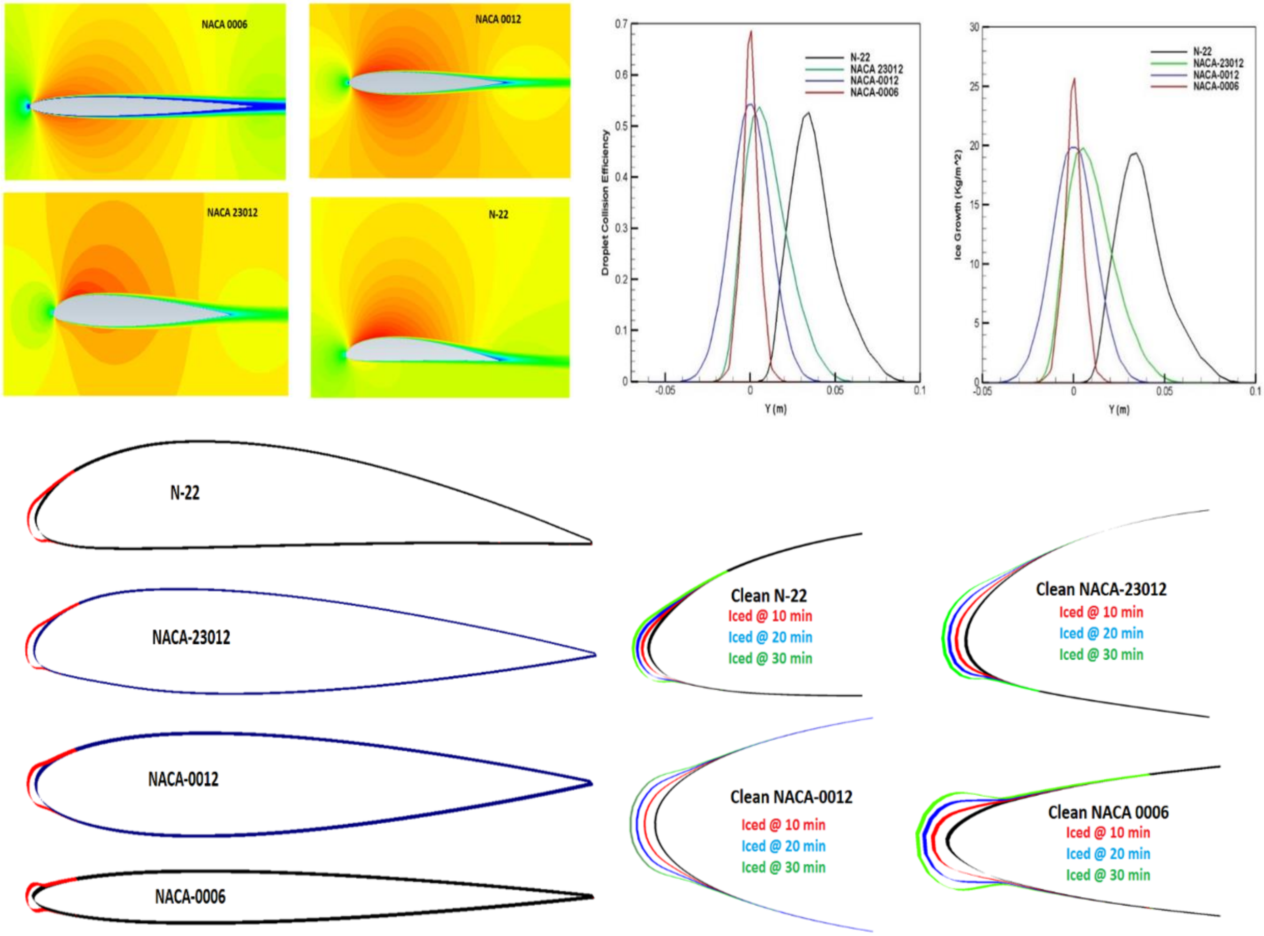


Figure 6: Ice accretion along symmetric and asymmetric blade profiles.

A study has also been carried out to understand the effect of ice accretion on aerodynamic characteristics of NACA 0012 and NACA 23012 airfoils. For the iced profiles, simulated ice shapes at an AOA of 0 degrees are used. A comparison is made between aerodynamic performance of clean and iced profiles. All these analyses were carried out at Re = 3 X 10^6. For clean airfoils results are also compared with the experimental data.

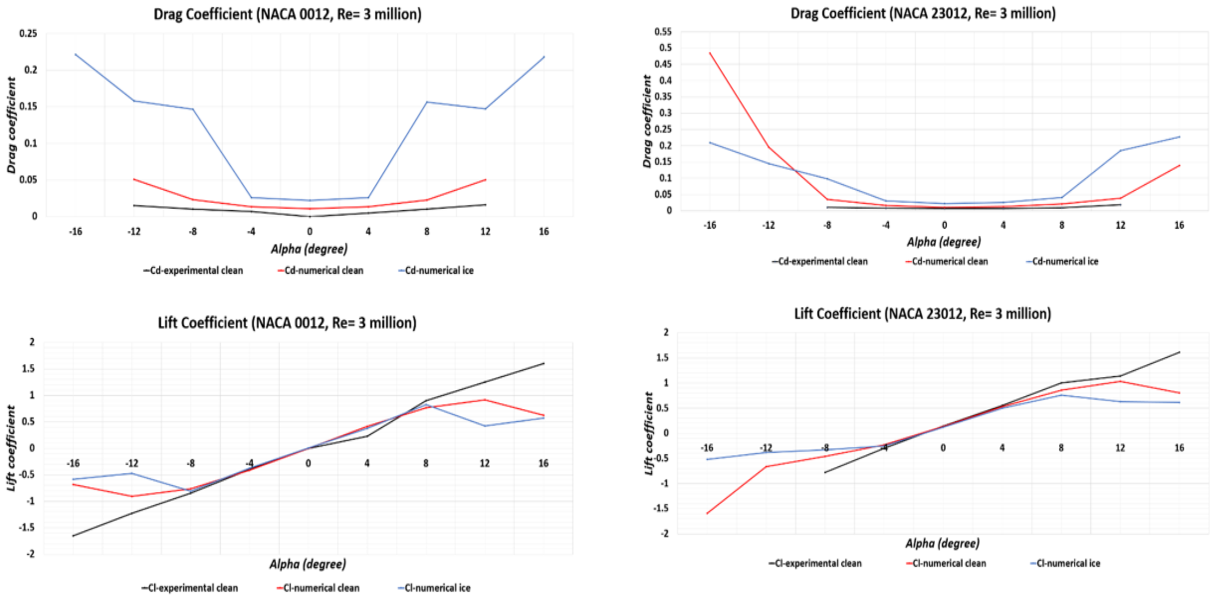


Figure 7: Aerodynamic coefficient comparison at different angles of attack.

The analysis shows a decrease in the aerodynamic characteristics of the iced airfoils when it is compared to the clean airfoil. This change in the aerodynamic characteristics is mainly due to a change in the iced airfoil shape and surface roughness, which affects the flow behavior. From an aerodynamic properties analysis, it is clear that the iced shapes have a significant influence on the airfoil aerodynamic characteristics when the absolute value of the angle of attack is increased. The analysis of the flow behavior shows a significant change in the velocity and pressure distribution along the iced airfoils. A shift in position of the stagnation point is observed to affects the velocity and pressure distribution. Results show that for the different positive angles of attack a high velocity zone appears along the upper surface of the iced profiles near the leading edge, whereas a flow recirculation zone is found near the trailing edge along the upper surface of the iced profiles. For negative angles of attack, the flow separation zone appears along the pressure side of the iced airfoils.

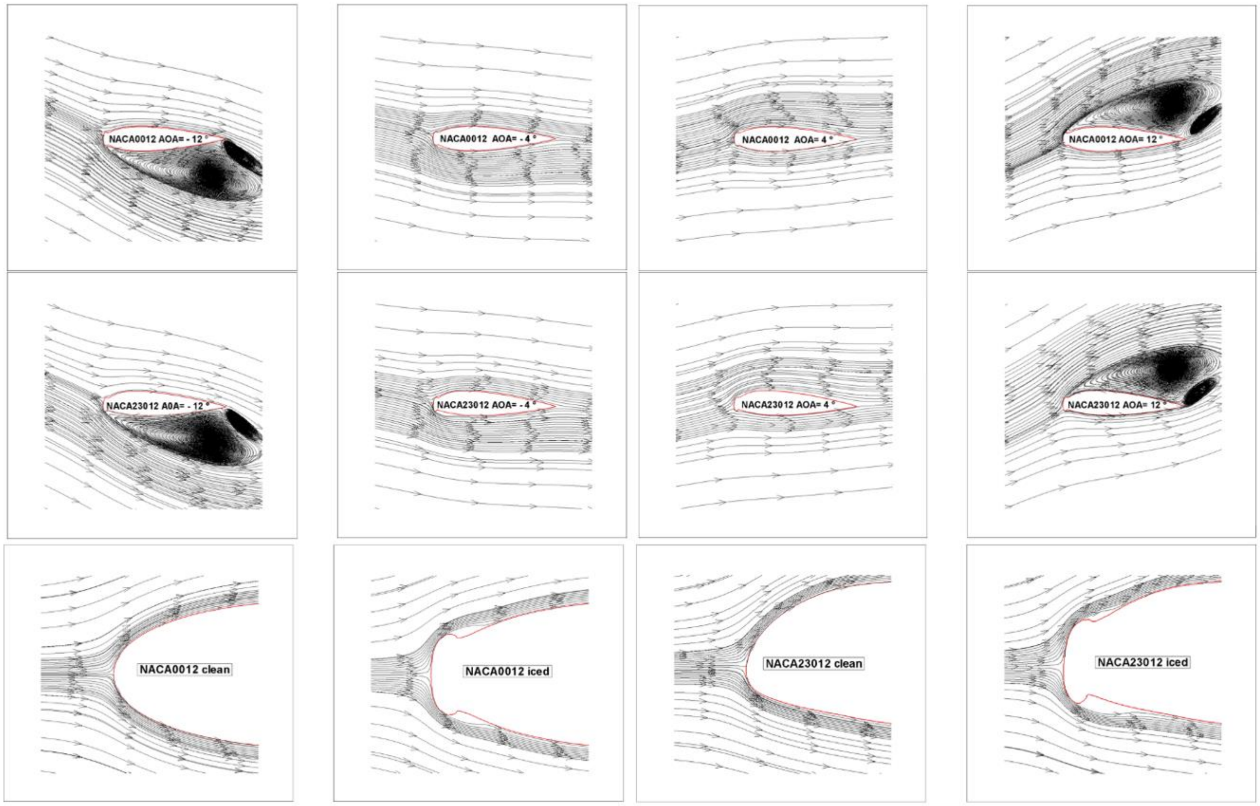


Figure 8: Velocity streamlines at different angles of attack (-12°, -4°, 0°, 4°, 12°).

Ice accretion on large scaled wind turbine blade

Ice accretion on the wind turbine blades is caused by the impingement of super cooled water droplets. Most of these liquid water droplets freeze immediately upon impact due to rapid heat dissipation leading to ice accretion. The location and intensity of water impingement can be numerically determined by solving the air-water multiphase flow in proximity of the blade. The shape of the accreted ice depends upon many variables such as point of operation, the geometry of wind turbine blade, relative wind velocity, temperature, droplet diameter and the liquid water content. Atmospheric icing on the wind turbine blades has been numerically simulated for a variety of cases in the past. During WindCoE project, multiphase computational fluid dynamics based numerical analyses were carried out to study the rate and shape of ice growth on a large wind turbine blade. NREL 5MW wind turbine blade was selected as test case for this study, mainly because of its geometric size and the availability of test data. Analyses were carried out at different atmospheric icing temperatures. Main objective of this study was to simulate the atmospheric ice along a large wind turbine blade and analyses the ice distribution to identify the most affected areas due to icing.

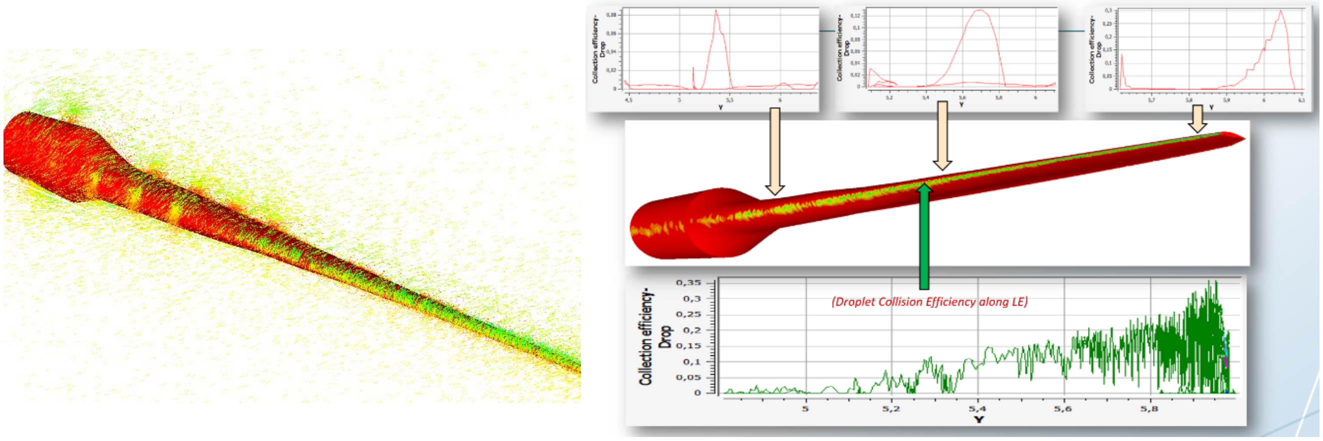


Figure 9: Airflow and droplet behavior along a large wind turbine blade.

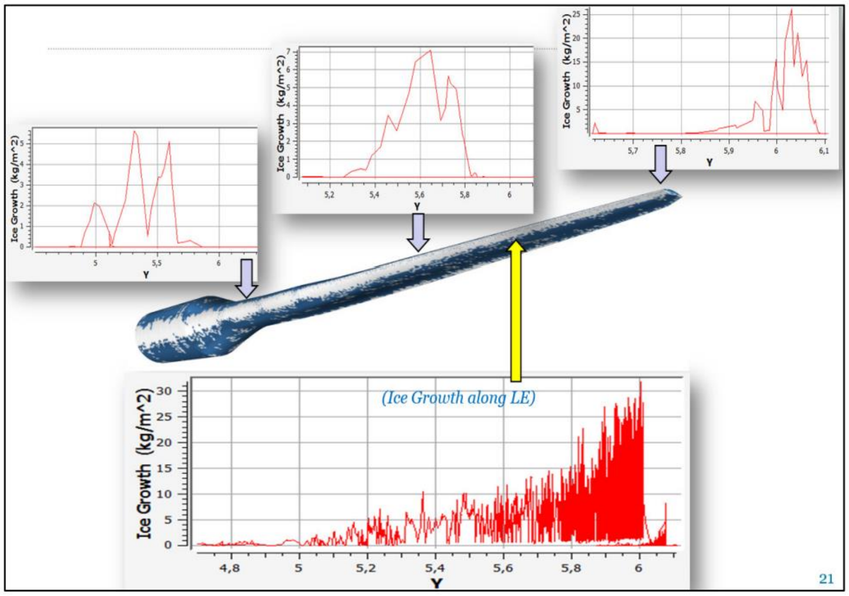
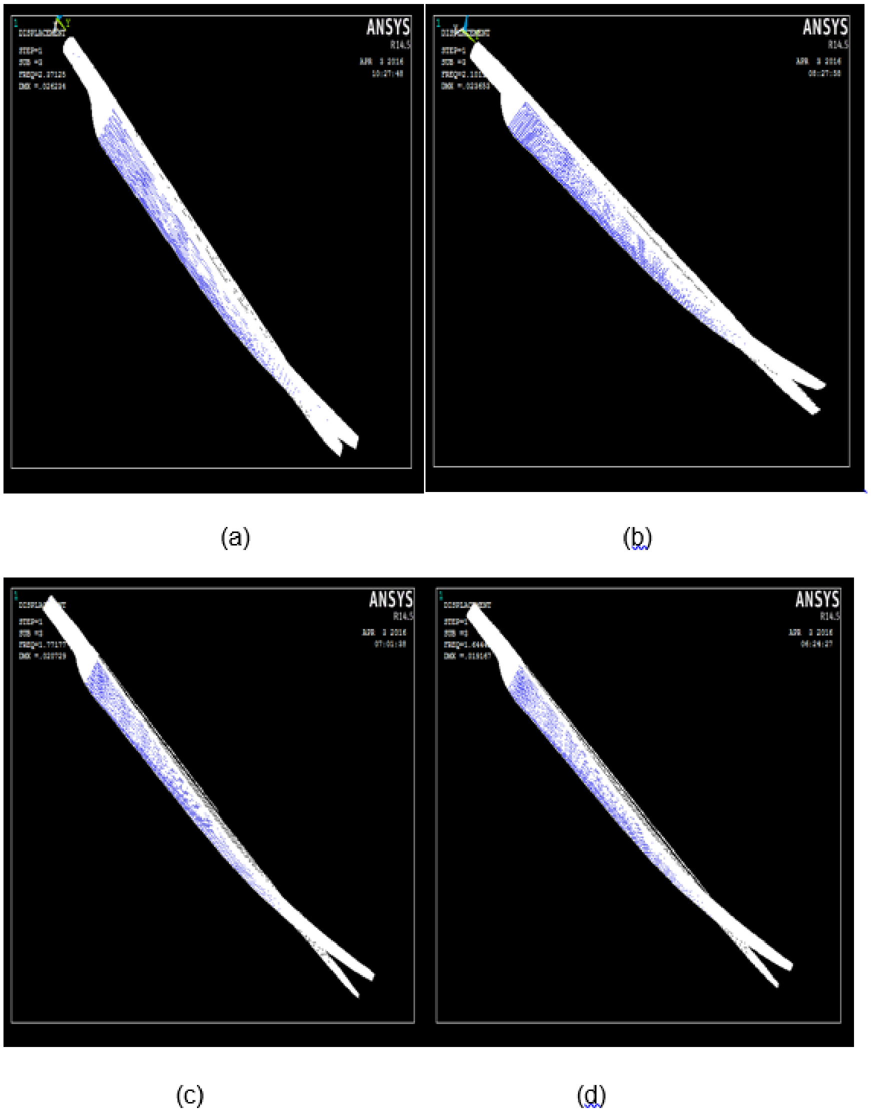


Figure 10: Atmospheric ice growth rate along a wind turbine blade.

Structural behavior of iced wind turbine blade

A 5-MW NREL (National Renewable Energy Laboratory) wind turbine blade was selected for this study, due to availability of required geometric design parameters and experimental data for verification. The turbine rotor and its three blades were modelled and numerically simulated with commercial finite element software ANSYS. Three icing scenarios were chosen according to the ISO Standard and the corresponding icing profiles were developed to investigate their influence on vibrational behaviors of the wind turbine blade and rotor under different weather conditions. Icing loads were applied on the leading edge of the blade and natural frequency results were compared between clean and iced blades. It was found that harsh icing weather drove the natural frequency down to the near resonance limit, which could lead to significant issue on structural integrity of the wind turbine. The effect of atmospheric ice accretion with additional load due to varying wind speeds on the fatigue life of the wind turbine blade has been investigated. Significant reduction of fatigue life was found due to the increase of the von Mises stresses.



(a) (b)

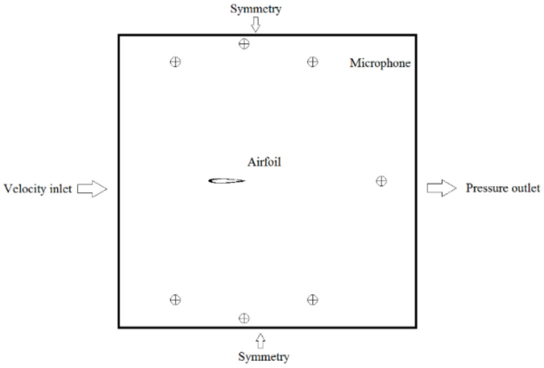
(c) (d)

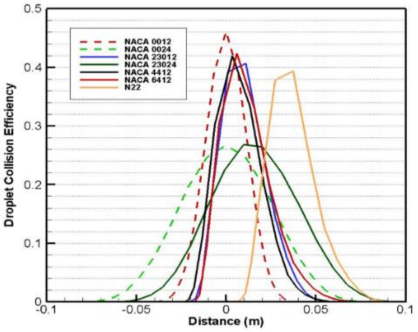
Figure 11: Third mode shape of vibration , (a) clean blade, (b) moderate icing, (c,d) heavy icing.

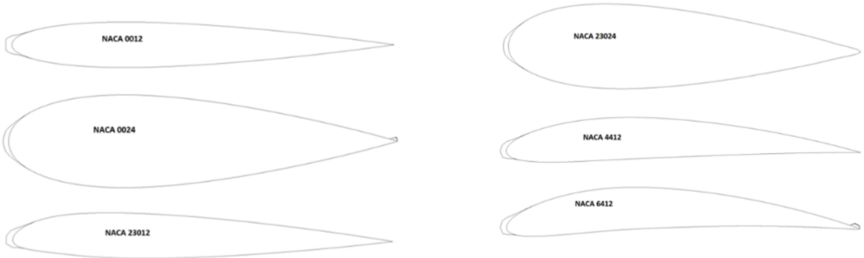
Aeroacoustics of iced wind turbine blade profiles

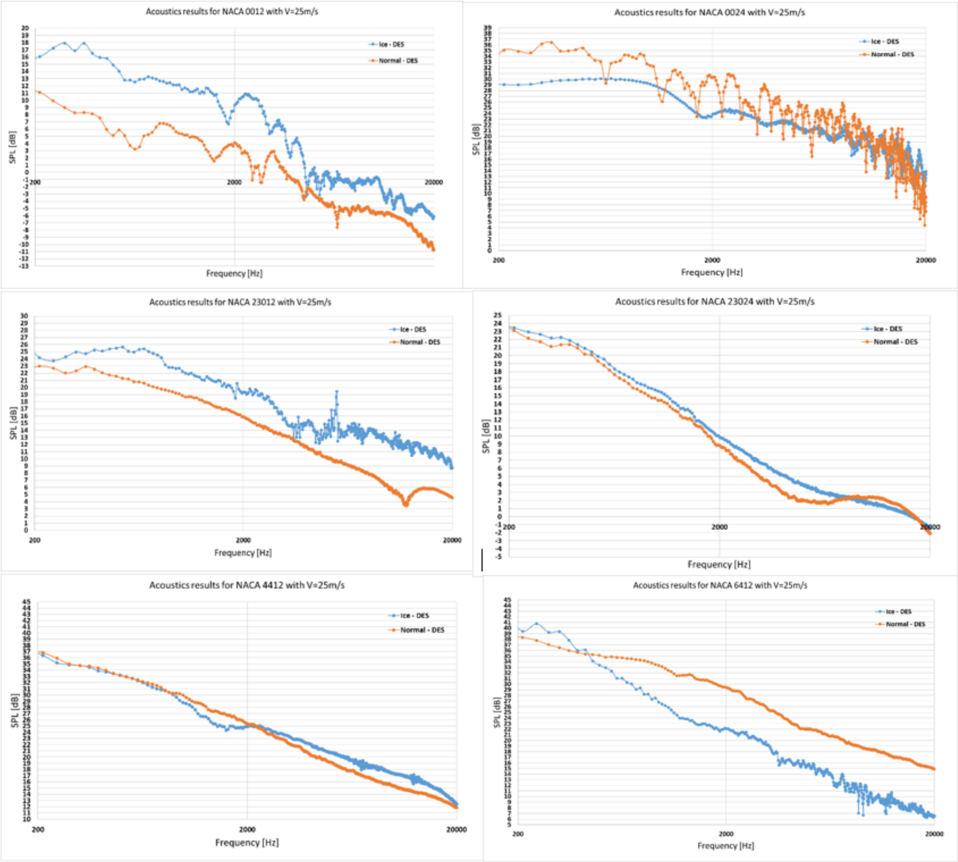
Wind turbines have certain aeroacoustics behaviors that show unique characteristics. Noise generated from wind turbine blades directly affects nearby residents. Noise associated with wind turbine can be influenced by the climate they are operating in. The aerodynamic noise generated by blade and tower interaction of an upwind turbine is significantly lower when compared with downwind turbine. Out of all the aerodynamic noise mechanisms, airfoil self-noise is the one which is affected the most by accretion of ice on the blades of wind turbines. Airfoil self-noise is dependent on turbine rotor blade specifications (*airfoil geometry, angle-of attack etc.*) and atmospheric conditions. In ice prone cold regions, wind turbine operations become more challenging, as ice accretion on wind turbine blades changes its aerodynamics and effects the aeroacoustics that can possibly exceed the allowed noise limits by the regulators. Aeroacoustics of wind turbine blade is linked with the blade profiles (airfoil) geometry therefore; aeroacoustics response of wind turbine blade can be different along the root and tip sections.

To study the effect of ice accretion on aeroacoustics response of wind turbine blade profiles in icing conditions, multiphase CFD based numerical study of the aeroacoustics response of symmetric and asymmetric airfoils for both normal and icing conditions was carried out. Three difference turbulence models (RANS, DES & LES) were used to make a comparison of numerical results with the experimental data. A good agreement is found between numerical and experimental result in normal conditions. Detached eddy simulation (DES) turbulence approach is found best for this study because it is more appropriate to capture the dynamics of the acoustic sources. Later an extended CFD study is carried out for iced profiles, where the results indicate a significant increase in sound level for iced profile as compared to un-iced blade profiles.








Acoustics results for NACA 0012 with V=25m/s

Acoustics results for NACA 0024 with V=25m/s

Acoustics results for NACA 23012 with V=25m/s

Acoustics results for NACA 23024 with V=25m/s

Acoustics results for NACA 4412 with V=25m/s

Acoustics results for NACA 6412 with V=25m/s

Figure 12: Comparison of acoustics response of iced and un-iced blade profiles.

Wind Resource assessment in Cold region

Improvement in estimation of icing related power production losses is the significant need both for the proper operation of wind parks and to provide more accurate wind energy production forecasts. During WindCoE project, a detailed case study of a wind park SCADA data analyses has been carried out to better understand the seasonal effects on wind power production & identify icing events. To better understand the wind turbine wake effects on flow behaviour and resultant power production computational fluid dynamic (CFD) based numerical approach has also been used in addition to statistical analysis of SCADA data. For this study a wind park located in a complex terrain in an ice prone region is selected. In this study, One year (2014) SCADA data from Wind Park is sorted in three seasonal categories; 1) Winter 1 (*January to April*), 2) Winter 2 (*October to December*) & 3) Summer (*May to September*). The purpose of this categorization is to better understand the seasonal effects on the power production. The comparison for each wind turbine is done by seasonal sorting and between two function forms: time & wind power production and average wind velocity & wind power production.

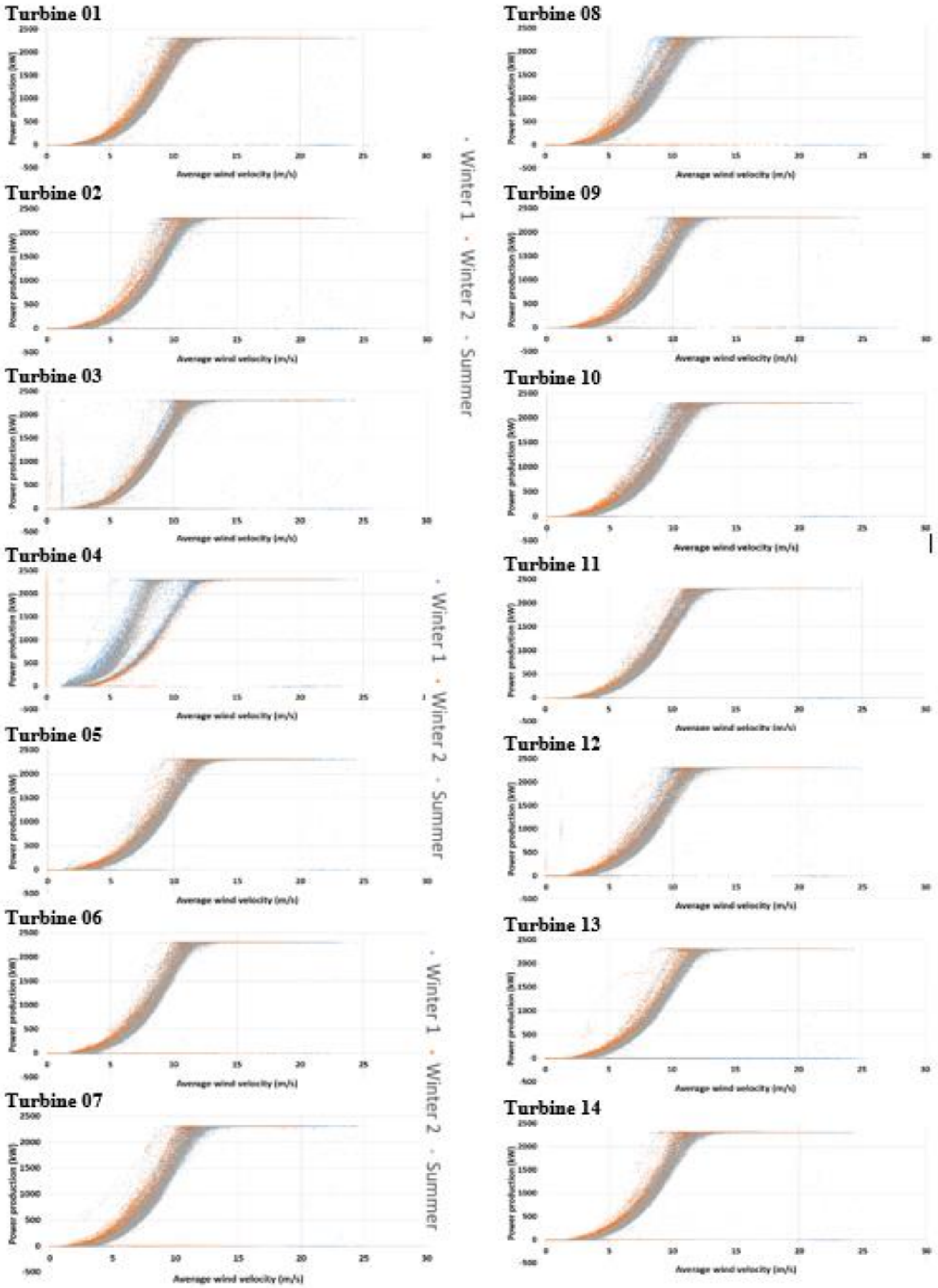


Figure 13: Seasonal wind power production analysis using SCADA data,

Analysis shows that the average temperature during winter 1 was less than winter 2. Analysis about icing type shows that most of time during winter 1 the meteorological conditions were in favour of soft rime ice, whereas during winter 2 was hard rime. To further identify the icing events from SCADA data; detailed analysis were carried out. For these analysis the icing events occurrence criteria is selected assuming these conditions: *temperature below 0* ^{0}*C; wind velocity more than 20m/s, as well as the power production between 600–2200 kW*. The occurrence frequency of these conditions selected to be at least 3 times in a row for same day to confirm an icing event. Results show that duration and timing of icing event is different for different wind turbines, which clearly indicate that icing event depends upon the meteorological conditions, wind flow behaviour and also the location of wind turbine. Even in same wind park, it is not compulsory that ice accretes on all wind turbines. The wind park layout and change in flow behaviour effects the occurrence of ice accretion, despite the favourable conditions for icing events. This is clear from results presented in following figure, where "1" means icing events occurred, "0" means no icing event.

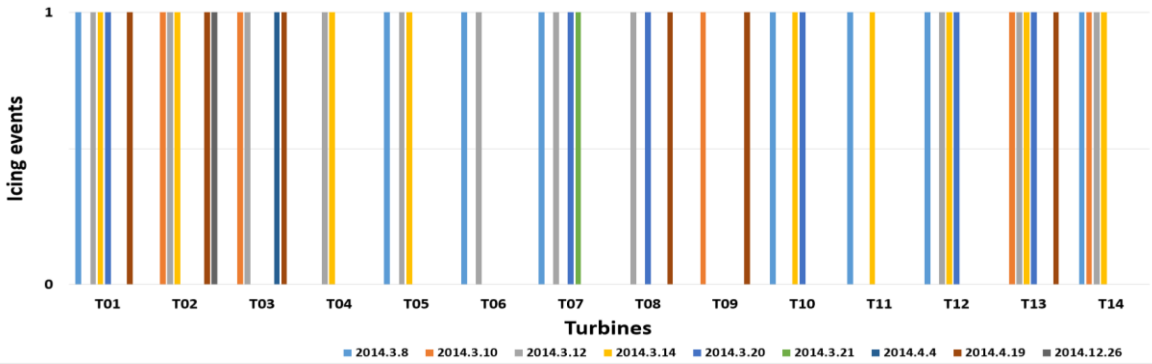


Figure 14: Indications of icing events for different wind turbines on different days.

To study the wake effect three wake models were used in CFD simulations and a comparative results among them in addition to gross AEP from SCADA data is shown in following figure. Results show that AEP with wake model 2 (*Larsen et al. model*) have the best annual power production estimation. Detailed analysis showed that the real production from SCADA analysis is 95.90% thus giving an annual energy loss of 4.10%, when compared to the idealized model in CFD. The AEP with wake models included has the annual energy loss of around 7.0% for the case of Jensen et al. model, 3.3% for Larsen et al. model and around 6.7% for Ishihara et al. model. Thus, one can conclude that real power production is optimized sufficiently well, when compared to CFD simulation results with and without wake models included, and, in general, wake models tend to overestimate the energy losses, though Larsen et al. model has a decent agreement with the AEP from SCADA data.

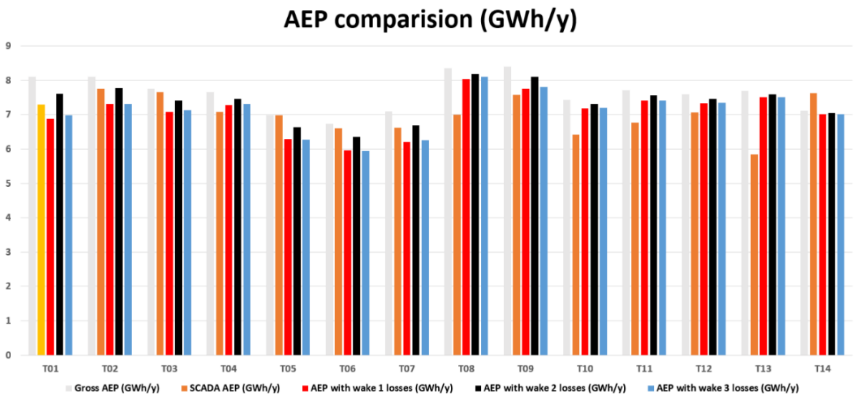


Figure 15a: Annual energy production comparison between SCADA data and three CFD wake models.

Ice detection on wind turbines using thermal IR approach

One of the difficulties of atmospheric ice detection on wind turbines is how to accurately detect and analyze the intensity of accreted ice on its rotating blade surface. Most ice detectors are point devices and measure required icing parameters only at one particular location, while the interest of operators is often to detect ice accretion over a large surface area. At the same time, ice detector technology must not interfere with the ice accretion process, so that the measurements are accurate, nor should it be affected by icing event itself, which is one of the problems with the present point based ice detection methods. A system based on the processing of thermal images acquired in the infrared spectra can be a possible way to monitor the ice accretion on wind turbine blade in non-intrusive manner, while covering all these areas of interest. The infrared spectrum lies below the visible band. Infrared (IR) imaging can divided into two main categories: *active imaging and passive imaging*. Active imaging techniques use artificial IR lighting source to illuminate the target image in which there may be icing present, then an infrared sensor collect the reflecting signal. Many successive images over a number of sub-bands are collected, which are then processed to determine whether ice is present. Passive thermal infrared image captures the naturally radiated infrared from the target to construct an image. In this technique, a thermal image is constructed using a *Focal Plan Array* (FPA) sensor that captures the radiated IR energy from the object. The FPA is designed to sense a certain band of IR radiation depending on the application for which the thermal image camera will be used. Every object in the world emits thermal radiations, which are mainly the function of object temperature and surface emissivity. When the object's temperature increases, the radiation also increases. Thermal imaging devices capture these thermal radiations and allow one, to study variations in surface temperature. During ice accretion process, the region where ice accretion occurs, become warmer than the surrounding surface due to release of latent heat of fusion while water freeze. In case of already ice covered area, the iced surface will have low temperature as compared to the un-iced surface area. By measuring the intensity of thermal radiation from the surface material and emissivity, it then become possible to infer the surface temperature in icing conditions.

To validate the concept a lab based study was performed using cold room chamber of UiT. The experimental study was carried out using a small scaled wind turbine model [blade length (radius) = 11.5 cm; max chord length = 1 cm; min chord length = 0.1 cm]. The wind turbine model was static (no rotation) during the test). The cold room chamber was equipped with a very long wavelength (17 µm) FLIR A615 thermal infrared camera, a CCTV camera, low speed frequency controlled ice generator, high pressure air regulated water spray gun, thermocouples, weather station, data acquisition system and a computer for data storage and image processing. Icing clouds (super cooled water droplets) were generated using the ice generator in cold room chamber, where the temperature can be well maintained in the range of (−30°C to + 10°C). Low speed frequency controlled ice generator, used for this study can generate the wind velocities up to 5 m/s, where wind velocity is operated by a variable frequency drive.

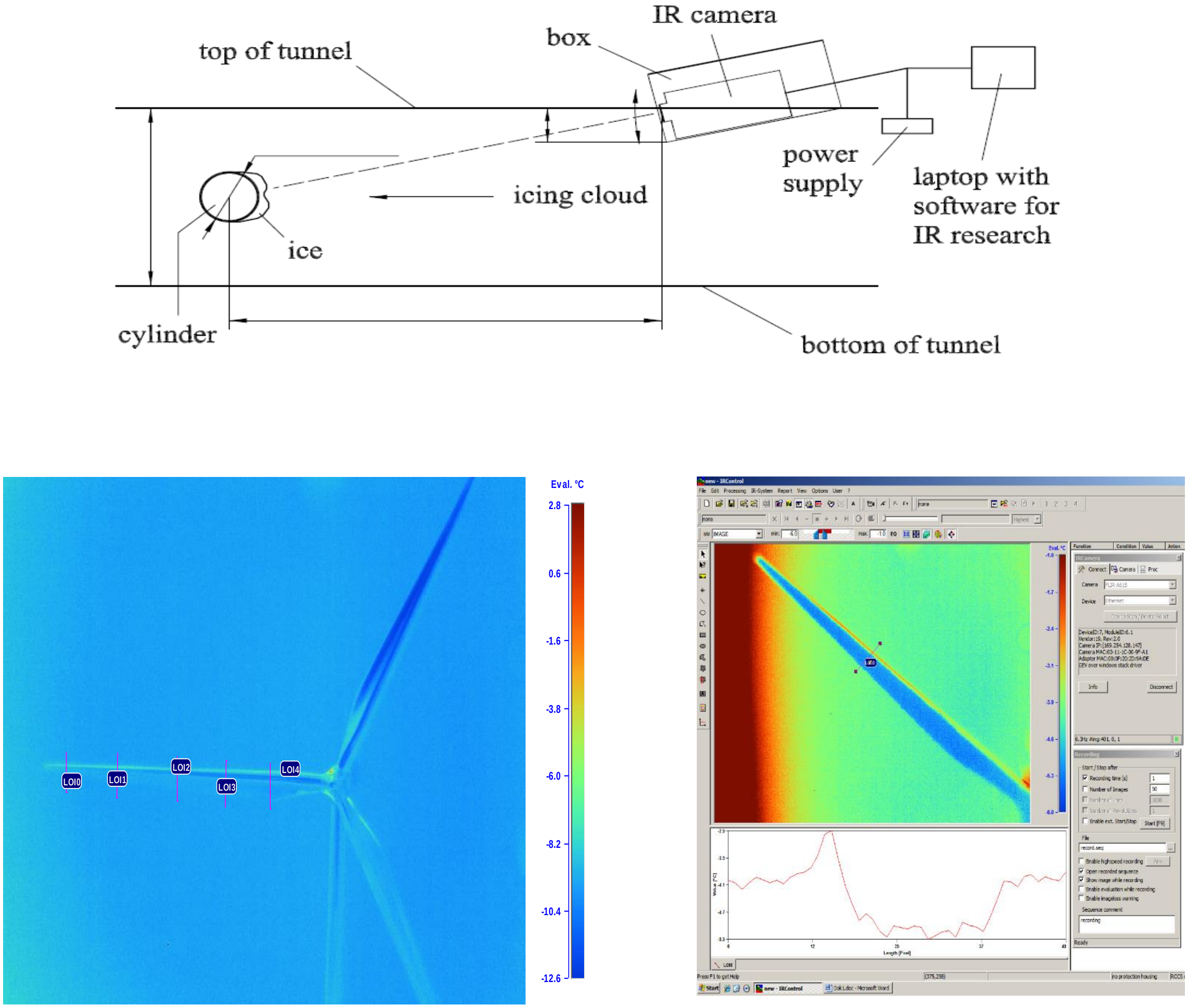


Figure 15b: Experimental setup and image analysis results of model wind turbine blade icing using the UIT facilities.

Scientific Publications resulting from WP3 (UiT)

International Journal Papers:

1. E.H. Caisedo & Muhammad S Virk,’ Numerical study of NACA 0012 aeroacoustics response for normal and icing conditions’, (2018), Applied mechanics and materials, vol 875, pp. 89-93.
2. J. Y. Jin ,Pavel Sokolov & Muhammad S.Virk "Wind Resource Assessment in Cold Regions - A Numerical Case Study", (2018), Applied Mechanics and Materials, Vol. 875, pp. 94-99.
3. E.H. Caisedo & Muhammad S.Virk,’ Aeroacoustic response of wind turbine blade profiles in normal and icing conditions, (2018), *Wind Engineering : The International Journal of Wind Power* , https://doi.org/10.1177/0309524X17751260
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WP-4: Wind turbine acoustics

Participation with society, government and industry

A large part of the work has been networking with different stakeholders, mainly with municipalities, and governmental administration units. One on-going activity has been to participate in the wind turbine network meetings of the administration office of the West-and Central-Finland.

The most important meetings and seminars are listed below:

1. Participation in Kuortane wind energy evening in 15.1.2016 to learn opinions of different stakeholders for wind energy. More than 100 citizens took part in the event..
2. Dr. Välisuo was an invited panelist in SataWind's wind energy project discussion event in Ahlainen 3.5.2016. Topic was especially wind energy noise. More than 100 citizens participated in the event.
3. Participation in public Ilmajoki city planning review event, to learn stakeholder’s views. It had also more than 100 participants.
4. Participated in a meeting for national coordination on wind energy research in Finland, organized by VTT, to inform about WindCoE’s results and learn other research activities in Finland.
5. In 25.4.2016, participated in a visit to Santavuori wind park in Ilmajoki by EPV energy, to find out the wind developer view on wind energy planning.

6. Working in LSS-AVI wind energy network. Participation in the meeting 8.11.2016 to learn stakeholder’s opinion and to deliver scientific knowledge to stakeholders.
7. 25.4.2017 Taking part in off-shore wind seminar in Pori to learn the wind energy potential of the Baltic Sea and the effect of the wind industry to other sectors of the industry.
8. 21.5.2017 Invited to Ilmajoki by the Suupohja health inspector to deliver research knowledge of wind turbine noise, based on our own measurements in WindSoMe and WindCoE projects. We learned about the knowledge gaps and information demands in the municipalities.
9. 2.6.2017 LSS-AVI: Discussions about wind turbine noise from the viewpoint of authorities, citizens and researchers, to be able to break the discussion bubbles and to make common ground.
10. 21.6.2017, Meeting of the wind energy network of ELY centers, which had participants from 6 centers and from the Ministry of Environment. The purpose was to communicate research results to the all regions of Finland.
11. 8.3.2018, Presentation in Ilmajoki wind energy seminar to the public servants and the public.

Regional collaboration

We have contacted to the municipalities in Finland belonging to the Botnia-Atlantica area, including Vaasa, Kokkola, Kristiinankaupunki and Seinäjoki regions. We explained the project purpose and asked how it can help the municipalities in city planning. We have participated in several public city planning and discussion events to find out what are the main topics what citizens are discussing and to spread information about the wind energy research done in Botnia-Atlantica region and about our projects, including WindCoE.

Public opinion on wind turbine noise

The discussion in Ilmajoki wind turbine event was analyzed. During the two hours event, 26 statements were used. We have found out that the citizens were mostly worried about the health effects of noise and infrasound, and if the turbines can affect animals, reducing for example hunting possibilities. Noise and infrasound was mentioned about 23% of the statements, adverse health effects in 17% of statements and affect to animals in 22% of the statements. In similar event, organized in Ahlainen, the noise and infrasound were the dominant topics. In an event in Kuortane, the discussion was quite similar.

We have recognized some very active non-govermental organizations (NGO) which are catalyzing the discussion of adverse health effects of wind turbine noise and infrasound. This information is sometimes rather colored. On the other hand, the sites providing scientific information are scarce. According to these findings, it seems very important to provide more scientific information to dwellers.

The wind power company SataWind found it to be very important that the scientific facts about wind power noise, infrasound and health effects are distributed. These kind of statements will help us to target the resources of competence center to right directions. EPV wind energy has shared this view, and they have asked us to share our research results to municipalities and to the public. The co-oeration with EPV wind energy, Nordex and Taaleritehdas have helped us to get wind energy production data, so that we can compare the noise levels with energy production.

Knowledge can be a discriminating factor, for example in wind energy development, since the companies have knowledge about wind energy, it's benefits and disadvantages, whereas the public does not often have as much knowledge. Our activities in gaining and sharing the knowledge with the public makes it easier for everyone to participate in wind energy discussion more equally.

Wind turbine noise measurements

Wind turbine noise measurements continued in Santavuori wind parks and the measurement period covers now 10 months period. These measurements together with measurements from two other wind parks: Kirkkokallio and Torkkola were used in studying typical noise levels and characteristics in different distances and weather conditions. The aim is to advance responsible development of renewable wind energy, to reduce carbon footprint of the society. More information about sound generation and propagation helps developing more efficient wind farms with higher acceptability.

Noise propagation

The goals were to estimate wind turbine noise model parameter uncertainties to wind turbine acoustics and to assess performance of noise propagation methods in cold climate.

Long term acoustic measurements have been carried out and they have been compared with the acoustic spreading models given by the wind park developers. The average sound pressure levels (SPL) are summarized as well as SPL dependency on wind speed, direction, season and time of the day. Other wind turbine noise characteristics have been also carried out, especially the spectrum and amplitude modulation (AM).

Calculations of wind turbine noise propagation over an annual cycle, compared with the spreading models reveals that the background level corrected average noise level in Kirkkokallio wind park is 31.3 dBA while the sound spread model used in city planning estimated it to be 34.7 dBA. The measurements in Santavuori do not allow the background level correction, but it seems that the wind turbine noise together with the background noise level is close to what was estimated. Therefore the measurements do not reveal big discrepancies in between measured and modelled sound pressure levels. Weather seems to affect to sound levels a lot.

Noise classification

Work was carried out to find methods to automatically classify noise sources. Automatic classification is important for separating wind turbine noise from other noise sources and to help understanding wind turbine acoustics. The classification is traditionally made manually, but it is not possible for long time measurements.

A new, more robust wind turbine noise classification method, which can be applied to many wind parks, have been designed and tested in three wind parks. With this method, it is now possible to separate bird calls, engine noise and other severe external noise sources from the noise created by the wind turbines.

Noise characteristics

Amplitude modulation (the pulsation of the noise level) is one of the most dominant characteristics of wind turbine noise, and it is probably one of the most important reasons why noise often perceived as annoying. At the moment, there is no standard method for assessing amplitude modulation. British amplitude modulation working group (AMWG) has proposed a method for estimating the amplitude modulation. We applied their method to our measurements in three wind parks (three in total). The results show that the prevalence of high amplitude modulation levels is different in each wind park, and it changes according to weather conditions. However, we also found out that the method is not entirely reliable: The highest amplitude modulation level was found to be caused by external noise sources and not the wind turbines after all.

WP-5: Virtual Wind Energy Environment

Introduction

The social acceptance is one of the main obstacles for planning wind power in Finland as well as in many other countries. Wind power parks are often resisted by public due their overestimated harm for scenery and harmony of nature. This resistance easily makes design and realization process very long and expensive. In UK, about 80% of the population supports wind energy, but only 25% of the wind power plant projects are actually commissioned. In Sweden, the public has felt that they have only a little possibilities in influencing the wind power planning and decision processes. Wind energy is distributed to wide areas and therefore affects large number of people. The visual impact of the wind turbines to the landscape is the main course of negative attitudes in Sweden. Therefore, it would be essential for wind power plant design to find more powerful methods in co-operating with local inhabitants in wind power design.

Virtual reality (VR) technology can be one tool for gaining social acceptance at preliminary design phase of a wind power park. By using Virtual Reality technology, inhabitants of the neighborhood of a planned wind power park can see and hear how their landscape would be changed due to the future Wind Power Park. The research question of this WP is if using of Virtual prototypes can influence on inhabitant’s attitudes in pre-design phase of a Wind Power Park.

Virtual reality studies are mainly performed in sophisticated virtual reality laboratories, which facilitate high-fidelity immersion and feeling on being inside of a 3D virtual world. SeAMK has an outstanding virtual reality laboratory with Cave-like virtual environment including five-sided projection walls as shown in figure 16. However based on our recent study (Kaapu et al, 2014) we discovered importance of place when performing perception assessment. Furthermore, due to rapid technological development several advanced head-mounted displays became available such as Oculus Rift and Microsoft Hololenses. These VR-devices make it possible to do perception studies with VR technology in field, figure 17.

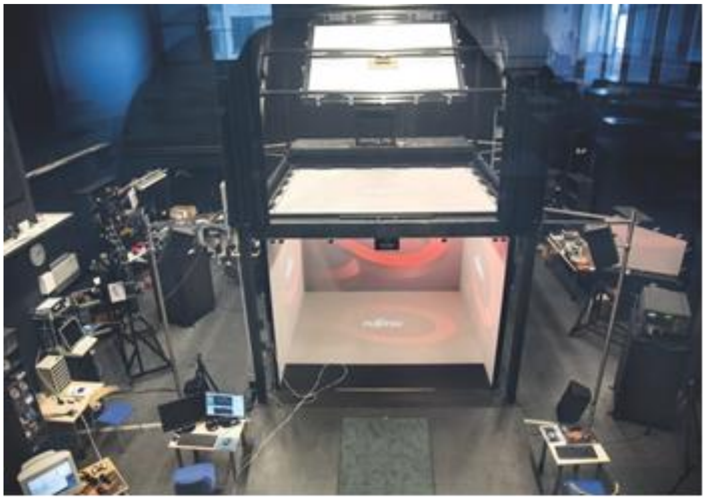


Figure 156: CAVE-like virtual environment at Seinäjoki University of Applied Sciences.

Figure 17: Test setup with VR technology in the field.

Portable VR devices open new possibilities because perception studies can be done in practice in the field. This is a notable advance for several reasons.

VR studies can be performed in a natural environment. Instead of modelling large entities of the surrounding environment, it is possible to focus only on those parts of the environment where the topic of interest is, such as the sector of the wind power park in our case. Furthermore, we can reach the identity of the place more easily. Many places, such as the churchyard in our case, have special emotional impact on people. This kind of emotion is hard to reach in a laboratory.

Informants are more focused on the virtual content in the field. In our previous studies, we have noticed that in laboratory studies informants tend to focus on VR technology instead of the actual content (Kaapu et al, 2014). This observation was strengthened in this study also: Informants did not discuss the technological features of VR during the test.

It is easier to reach relevant informants to VR studies. It is significant to reach a representative sample of that group of people that you are focusing on. In our case, the best test users were people who live in the village or near it. It would have been highly unlikely to get this kind of informant group to come to our VR laboratory that is located at a distance of 100 km. In many VR studies, the test users are students, as it is too hard to get other kind of test users (Tiainen and Ellman, 2014). When portable VR devices are used, the test usage can be performed in such a place that makes it easy for test users to participate.

VR Model Techniques

Since perception testing with VR devices need to be performed in the field, we decided to use a laptop computer with high performance graphics card and an Oculus Rift head mounted display. Scenery around the churchyard is presented with game engine Unity. This software has become a meaningful tool for high-quality modelling of different environments that contains functionalities such as the effect of the angle of the sun, weather etc. Unity software also includes a number of add-ons that can be used for detailed landscape modelling such as trees and grass. Also sound models can be included in virtual models. This software is well supported in new head-mounted display devices such as Oculus Rift and Microsoft HoloLens.

The scenery around the churchyard was modelled with Blender based on photographs taken from the test place. We used game engine Unity for presenting this model in Oculus Rift head mounted display. Windmills were modelled based on their dimensions and geographical positions. The rotors were expected to rotate with the same speed. The real and virtual landscape is presented in figure 18.

Figure 18: Real and virtual landscape in the test place.

In addition to visual image, we decided to include an audio model as well. This was due to the fact that wind turbine noise is considered an issue in public discussions. We used an experimental audio model that was recorded from a similar kind of wind power park and from the same distance as in our test case.

The test setup is shown in Figure 17. Besides of IT devices the setup consists of a table for the laptop and VR devices, two chairs and a tent. Chairs were needed because the test persons were allowed to either sit or stand during the test. Furthermore, a tent roof was needed to give shelter to VR devices due to changeable weather.

Photogrammetric 3D modelling for virtual reality

The test model was made by manual modelling using Unity software and its add-ons for detailed landscape modelling such as trees and grass. However, manual 3D modelling of real object and worlds is labor-intensive work, which will reduce its future use for wind power pre-design. As an alternative we studied photogrammetric 3D modelling, which is relatively new way to create realistic 3D structures using ordinary two-dimensional (2D) photographs by an automated software process.

There are several software programs for the creation of 3D models using photographs. The workflow is generally the same for all, but there are features that make them distinct from each other.

The first phase is always loading the photo set. Depending on the amount of photos and their resolution, this phase usually takes from a few seconds to some minutes. Photos may include Global Positioning System (GPS) information, but it is not required. If they include longitude, latitude and height information from the GPS satellite system, it will provide the software with important information for calculation of camera locations.

The second phase is aligning the images. The purpose is to calculate the position and orientation of the camera when the photo was shot. This is done by comparing the digital RGB (Red, Green and Blue) color values of selected pixels between adjacent photos. Since the pixel count is very high, only a certain amount of pixels is chosen for the comparison. Usually the amount of corresponding pixels is parametrized and the 3D points are usually called tie points, since they tie different images together by their pixel values.

The third phase is the calculation of a sparse point cloud by a trigonometric algorithm using the tie points and camera locations and the lens data. A point cloud is a set of points in a three dimensional space, where every point has X, Y and Z coordinates and a color value. Usually, after the creation of a sparse point cloud, the user is able to define the volume to be modeled more precisely, leaving out unnecessary slices of the final volume.

The fourth phase is the calculation of the dense point cloud, and in this phase a significantly larger amount of image, pixels are used. This usually takes the longest time in the process. Depending of the algorithm, if the software uses all the pixel values in the reconstruction process, it has to process millions of pixels hundreds of times. The finesse of this algorithm makes a significant difference between programs.

The fifth phase of the process is to create a three dimensional polygonal geometry, a mesh, matching the point cloud. Different feature detection algorithms allow finding planes and straight corners in the 3D geometry.

The sixth phase is creating one or more 2D images, called texture maps, which are used to cover the 3D model with a texture adopted from the photographs. This process is also time consuming since if we are about to create a 3D environment which is to be explored in a game engine, at least one or preferably, several 8K texture maps are required. 8K map is a square image of 8192 pixels in length and height. It occupies 64 megapixels. In computer graphics, texture map images are usually powers of two on the sides, since the computer loads and renders them most efficiently.

The seventh and final phase is saving of the texture mapped 3D geometry as a file in one of the formats supported by the software. Usually, FBX is the best photogrammetric 3D model choice. This is the generic workflow, but there are significant differences between the algorithms, post processing abilities and features of the different programs, such as reporting, video production of the resulting 3D model, etc. Example of photogrammetric 3D model is shown in figure 19.

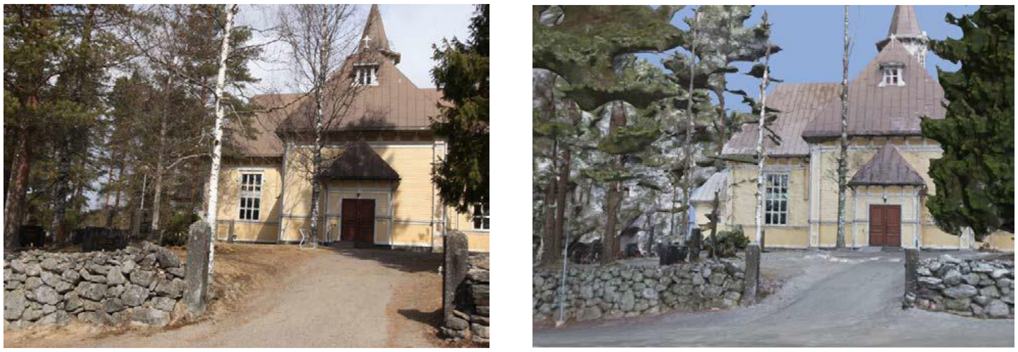


Figure 19: Real photograph and photogrammetric 3D model of Töysä church.

Photogrammetric modeling is developing fast and it is very promising method for modeling 3D worlds in near future. The VR modelling WP was done by SeAMK in co-operation with TUT.

Perception Assessment

When we selected the research method, we consider the essence of the research question. First, it is needed a method with focuses on the informants' interpretations, as the research question deals with how they perceive a wind power park in their local area. Second, we needed a research method, which makes change visible. Phenomenography fulfils these criteria. It is a method, which is created for educational research for making visible how students view things and how their views change within teaching. The aim of phenomenographic study is to find out about the diversity of people's understandings. The results of it are presented as a categorization of alternative conceptions. Phenomenographic data collection is usually based on open-ended interviews. As both data collection and its analysis are time-consuming, the number of informants is typically kept low: 20 or so is a common number of individuals interviewed in phenomenography. This number of informants is usually enough for reaching saturation: new categories are not found any more (Kaapu and Tiainen, 2012). The perception assessment WP was done by TUT in co-operation with SeAMK.

Selection of field test place

In our earlier studies, we have acknowledged importance of testing place (Kaapu et al, 2014). Furthermore, we have acknowledged importance of place identity. The test place was in the center of the village at Churchyard in front of a parish center. We considered this place having highest identity in the village. In addition, from this location it was possible to get local people to attend the test. Therefore, we want to make this testing in field with portable VR devices in a place which identity is important to the community members. We defined requirements for the field test place:

- It should be a village centrum due to identity of the place and availability of informants.
- It should be village which is earlier been free from Wind Power but which neighborhood is targeted with future Wind Power Park.
- Future Wind Power Park should be close enough (max 5 km) to the village centrum to cause a real visual of audio harm.

A suitable test place was found in Töysä. It is a small countryside village (3100 inhabitants) in South Ostrobothnia in Finland, Figure 20.

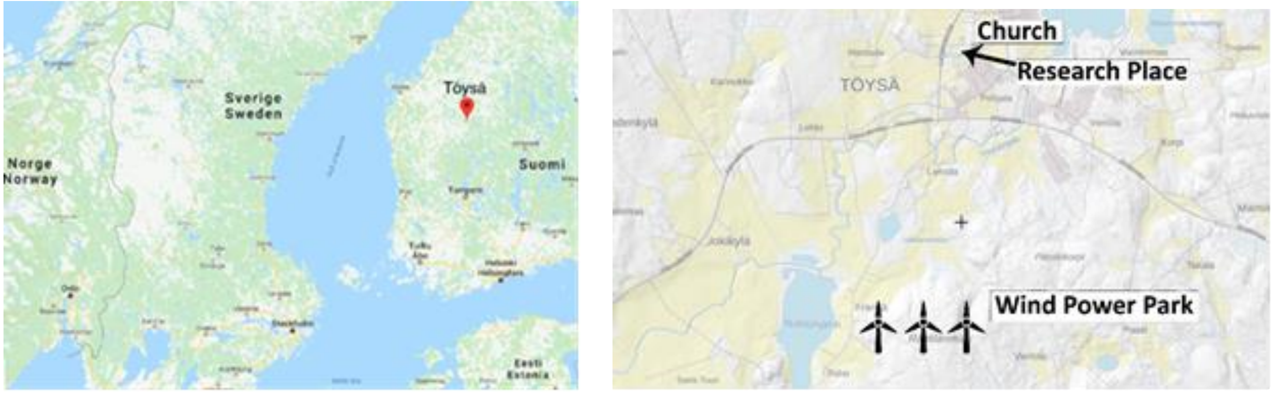


Figure 20. The test place and Wind Power Park in Töysä village.

Töysä is a feasible place for this study because it is a uniform village community and there is a wind park planned for the neighborhood. The village has no previous wind parks. The Wind Park is planned to be consisting of three wind turbines of 3 MW with 140 m pylon and 120 m rotor diameter. Distance from Wind Power Park to village center is only 2.0 km (Figure 2).

The test place was in the center of the village at a churchyard in front of a parish center. We considered this place having the highest identity in the village. In addition, from this location it was possible to get local people to attend the test.

Acquisition of informants and interview material

For this study, we wanted to find local adult people. Therefore, informants were searched by contacting the local village community and the local radio station. In addition, people passing by were asked to participate in the test. Finally, we got 18 people participating in the test. There were nine women and nine men. Their average age was 41.5 years. The oldest test person was 77 and the youngest one was 17.

In the test, there was an operator who took care of VR devices and an interviewer who took care of conducting the test with the informants. The test uses were performed in 14th - 18th of August 2017.

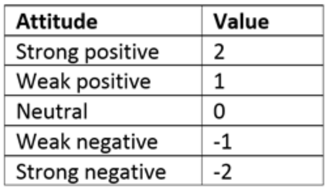
Besides of watching virtual prototypes, the informants were interviewed. The interviews consisted of three parts:

1. Before the VR-experiment we asked some advance information about the informants and their opinions on wind power.
2. VR-glasses were put on for the informant. In this section, the informants described how they experienced the VR. The informants were asked to describe both the virtual landscape and the virtual soundscape. Informants were asked to tell about their feelings and why they were experiencing positive or negative feelings.
3. After the VR-experiment the interviews focused on how informants' opinions might have changed.

Analysis of interview material

All the interviews were recorded for the analysis. Based on the interview material, informants' attitudes were categorized on five levels as shown in Table 1.

Table 1: Categorization of informants' attitudes.



Attitude	Value
Strong positive	2
Weak positive	1
Neutral	0
Weak negative	-1
Strong negative	-2

Results

The results of the interview material are classified into four topics based on the three parts of the interviews. The categorization of informants' attitudes (table 1) is used in all the topics. The results are presented in table 2.

The first topic is focused on informants' opinions towards wind power in initial situation before the virtual inspection. This is the same as the first part of the interviews.

The second and third topics are based on the second part of the interviews, which consists on informants' experience in VR. The second result topic focuses on virtual landscape, especially how informants perceive the landscape of the future wind power park. The third topic focuses on virtual soundscape, especially how informants perceive noise from the future wind power park.

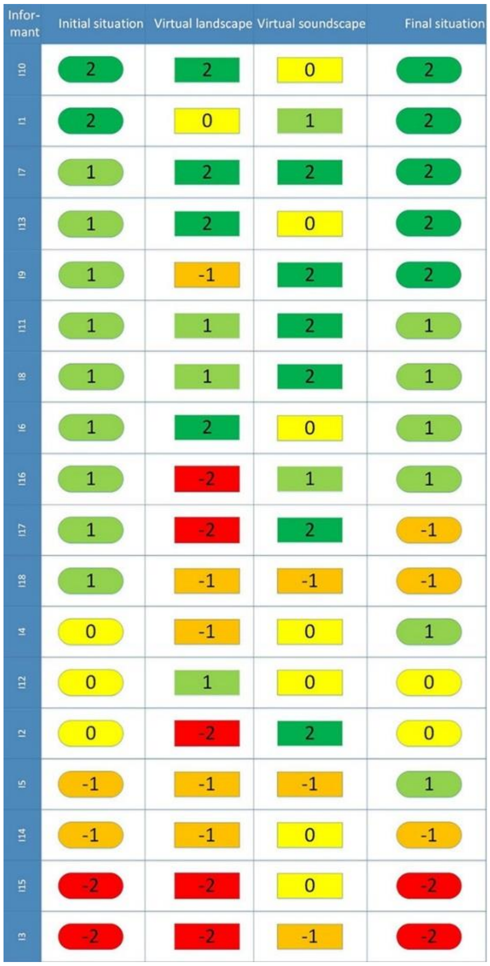
The last part of the interview focuses on the informants' attitudes after the test use. The fourth topic of the results deals with the same theme, i.e. informants' opinions on wind power in general after the virtual inspection.

Table 2 presents the results of informants' attitudes by all four topics (the columns of the Table). The attitude is presented in five categories from strong positive (green 2) to strong negative (red -2). Some extracts how the informants presented their attitudes:

- Strong positive (green 2) on initial situation (1. topic): "Wind power sounds like an ecological solution. It is great that wind can be used for energy production."
- Weak positive (light green 1) on virtual landscape (2. topic): "Well, they clearly change this landscape. But it is not so ugly."
- Neutral (yellow 0) on final situation (4. topic): "I have rather neutral ideas about wind power. I am not so sure about this, but maybe it is worth to try."
- Weak negative (orange -1) on virtual soundscape (3. topic): "I don't feel that the noise is so disturbing. However, if I had I would have my house right here, I it might think differently."
- Strong negative (red -2) on virtual landscape (2. topic): "They (wind turbines) are not suitable for being so close to houses and to this kind of a village center. They need to be built somewhere else."

From table 2 it can be seen that people with strong preconception do not change their opinions. However, people with mild preconception may change their opinion. Actually, 37 % of informants changed their attitude in the virtual inspection. It is noteworthy that the change can take place into both directions (Figure 21).

Table 2: Informants' opinions on wind power.



Infor-mant	Initial situation	Virtual landscape	Virtual soundscape	Final situation
I10	2	2	0	2
I1	2	0	1	2
I7	1	2	2	2
I13	1	2	0	2
I9	1	-1	2	2
I11	1	1	2	1
I8	1	1	2	1
I6	1	2	0	1
I16	1	-2	1	1
I17	1	-2	2	-1
I18	1	-1	-1	-1
I4	0	-1	0	1
I12	0	1	0	0
I2	0	-2	2	0
I5	-1	-1	-1	1
I14	-1	-1	0	-1
I15	-2	-2	0	-2
I3	-2	-2	-1	-2

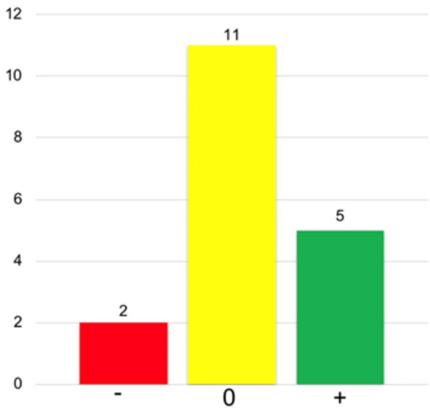


Figure 21. Change of informant's attitude in the study.

Conclusion

This perception study focused on the case of pre-design of a wind power park in Finland. This case is especially suitable for our study as wind power is rather new technology in the Finnish countryside and there are plenty of prejudices against it. We studied if inhabitant's attitudes towards future wind power park can be affected with virtual prototyping. We used a portable VR device for enabling evaluation of audio-visual impact of a future wind park in the field. We found out that people with strong preconception did not change their opinions. However, people with mild preconception may change their opinion. Actually, 37 % of informants changed their attitude in the virtual inspection. It is noteworthy that the change can take place in both directions.

Findings of this study are planned be published in a future conference (Ellman et al., 2018).

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WP-6: Data platform and Models

Stakeholders and information sources

Logic and many-valuedness enables to describe underlying logical structures of information as represented within industrial processes, and as part of their respective markets. WP6 underlines the importance of introducing classification structures in order to enable management of information granularity within and across subsystems in a system-of-systems (SoS). The logic of information and process, in combination and as integrated, is a main contribution within our illumination of a system-of-systems in the field of energy. In our process view we look closer into the power market with all its stakeholders, and in particular as related to renewable energy. Supply, demand and pricing models are further subjected to logical considerations. Information structures build upon our many-valued logic modelling, and for process modelling we adopt the BPMN (Business Process Modeling Notation) paradigm.

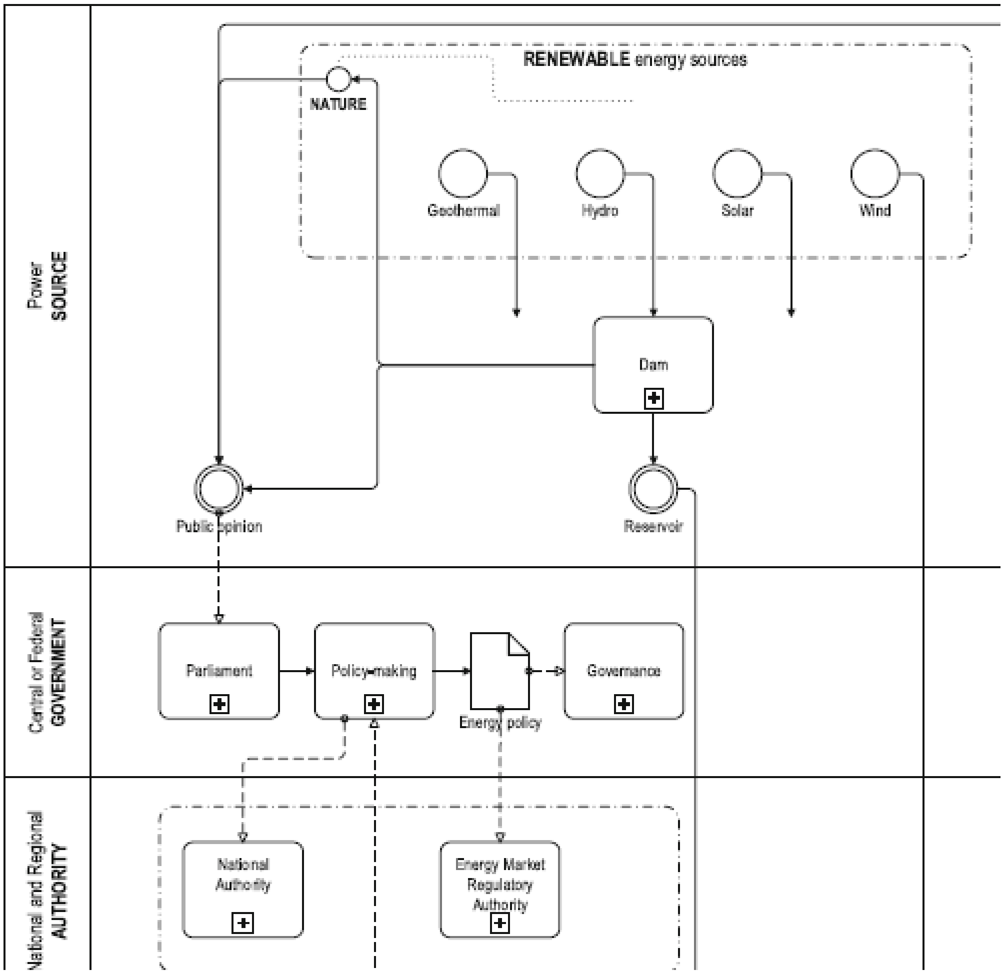

Figure 22 Policy making and public opinion in dialog.

Opinion, policymaking and governance, in dialogue and interaction over time, are important parts of the energy market SoS. Those dialogues and interactions obviously involve political and policymaking type of consensus, consensus reaching among a variety of stakeholders, and negotiation in various form, as representatives in BPMN swimlanes try to meet their respective objectives.

Information Modelling

For process modelling, BPMN (Business Process Modeling Notation) diagrams build syntactically upon four basic categories of elements, namely Flow Objects, Connecting Objects, Artifacts and Lanes. Flow Objects, represented by Events, Activities and Gateways, define the behaviour of processes. Start and End are typical Event elements. Task and Sub-Process are the most common Activities. There are three Connecting Objects, namely Sequence Flow, Message Flow and Association. Gateways, as Event elements, handle branching, forking, merging, and joining of paths.

A Data Object, embracing an information model, is an Artifact, and having no effect on Sequence Flow or Message Flow. Data Objects are indeed seen to “represent” data, even if BPMN does not at all specify these representation formats or rules for such representations. However, Data Objects are expected to provide information about what activities require to be performed and/or what they produce. Information produced is in our sense the result of a reduction or inference, with related substitutions.

Notion like ‘service provision’ or ‘failure report’ in terms of their content and data formats is often well understood but this is not the case when considering provision and reports as structured documents, as a whole. To better understand the documents as a whole we must consider in detail the notions of documents, document structures, and document templates. In the categorical framework outlined above we can indeed identify a document over a logical structure which builds upon an algebraic foundation of many-valuedness.

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Dependency Modelling

Uncertainty estimation and temperature prediction:

We have submitted a paper for publication (Wang et al., 2018), in which a new method based on Bayesian Hierarchical Models (BHM) is proposed to estimate uncertainty of a weather research and forecasting (WRF) variable. It is applied to the WRF model's 2-meter temperature in the Botnia-Atlantica region of Scandinavia for a 20-day period in the winter and summer seasons, respectively. For both seasons, the estimated uncertainty using BHM is found to be comparable to that obtained from an ensemble of simulations in which different Planetary Boundary Layer (PBL) schemes are employed. In addition, the WRF-BHM can successfully predict the 2-meter temperature at locations given by the National Oceanic and Atmospheric Administration's (NOAA) global surface summary of the day (GSOD) dataset, for both seasons. The model accuracy is mostly within 2K for the summer period, but can exceed 5K in cold and stably stratified environments in winter mainly because of the inherent WRF deficiencies in the simulation of the boundary layer flow in such challenging environments. The methodology proposed here is fully general and can easily be extended to any other output variable and numerical model.

The BHM provides a framework to account for spatial or spatio-temporal data (Cressie, 2011). It is a statistical model consisting of multiple layers, typically three. The top layer is devoted to the data vector $\boldsymbol{y}$ modelled by a certain distribution $[\boldsymbol{y}|\boldsymbol{\theta},\boldsymbol{\Psi}]$, conditional on the latent variables $\boldsymbol{\theta}$ and the parameters $\boldsymbol{\Psi}$. In the second layer, often called latent or process model, the latent variables are modelled by the distribution $[\boldsymbol{\theta}|\boldsymbol{\Psi}]$, conditional on the parameters $\boldsymbol{\Psi}$, in order to characterize the complex spatio-temporal dependencies in the data that are unobservable. In the last layer, the prior distributions for the parameters, $[\boldsymbol{\Psi}]$, are provided. Through the product of the three (conditional) distributions above, one can obtain the joint distribution and make inference on $\boldsymbol{\theta}$ and $\boldsymbol{\Psi}$ based on $\boldsymbol{y}$, i.e. $[\boldsymbol{\theta},\boldsymbol{\Psi}|\boldsymbol{y}] \propto [\boldsymbol{y}|\boldsymbol{\theta},\boldsymbol{\Psi}][\boldsymbol{\theta}|\boldsymbol{\Psi}][\boldsymbol{\Psi}]$**.**

In the submitted paper (Wang et al., 2018), the three layers are specifically modeled as follow:

$$Layer\ 1\colon y_{\boldsymbol{s}_i t}|\mu_{\boldsymbol{s}_i t},\sigma_e = \mu_{\boldsymbol{s}_i t} + \varepsilon,$$

where $\boldsymbol{s_i}$ and t are location and time index with $i = 1,2,\dots N; t = 1,2,\dots T$, respectively, $\mu_{\boldsymbol{s}_i t}$ is the mean of $y_{\boldsymbol{s}_i t}$, and ε is a Gaussian noise with mean 0 and standard deviation σ_e accounting for measurement error. The $y_{\boldsymbol{s}_i t}$'s are also assumed to be conditionally independent.

$$Layer\ 2\colon \mu_{\boldsymbol{s}_i t}|\beta_0,\boldsymbol{\beta},\zeta_{\boldsymbol{s}_i t} = \beta_0 + \sum_{m=1}^{M} \beta_m x_{m\boldsymbol{s}_i} + \zeta_{\boldsymbol{s}_i t},$$

where β_0 is the intercept term, $x_{m\boldsymbol{s}_i}$ is the mth covariate, $\boldsymbol{\beta} = (\beta_1,\dots,\beta_M)$, β_m is the coefficient of $x_{m\boldsymbol{s}_i}$, M is the number of covariates, and $\zeta_{\boldsymbol{s}_i t}$ is a spatio-temporal term, which is modelled through its first-order neighbor in time and neighbors in space as

$\zeta_{\boldsymbol{s}_i t} = \rho\zeta_{\boldsymbol{s}_i(t-1)} + \varphi_{\boldsymbol{s}_i t}$,

where ρ characterizes the temporal correlation between $\zeta_{\boldsymbol{s}_i t}$ and $\zeta_{\boldsymbol{s}_i(t-1)}$, and $\varphi_{\boldsymbol{s}_i t}$ represents the spatial effect specified by a Gaussian Markov random field with Matérn covariance.

$$Layer\ 3: Prior\ distributions\ for\ the\ parameters\ in\ \boldsymbol{\Psi}.$$

Statistical and dynamical downscaling over Sweden:

In this scientific report, a simple and easy to apply statistical downscaling technique (CDF-t; Michelangeli (2009)) is applied to a 3km WRF data over Sweden to investigate whether, when combined with a dynamical downscaling product, it can give a better simulation of the observed station data as given by the NOAA GSOD dataset.

The Weather Research and Forecasting (WRF) model is used to dynamically downscale 1-year of the Climate Forecast System Reanalysis (CFSR) data over Scandinavia at 3km spatial resolution. The cumulative distribution function-transform (CDF-t), a quantile matching method, is applied to the dynamically downscaled data with the WRF-only and WRF+CDF-t evaluated against station data as given by the National Oceanic and Atmospheric Administration (NOAA) Global Surface Summary of the Day (GSOD) dataset. The performance of the two methods is assessed qualitatively by visual inspection of the Quantile-Quantile (Q-Q) plots and quantitatively through the Cramer-von Mises (CvM) diagnostic. It is concluded that while for the daily-mean air and dew-point temperatures, the WRF+CDF-t technique does not give a statistically significant improvement when compared to the WRF-downscaled data, for surface pressure the use of the statistical downscaling approach is found to partially correct the systematic bias that arises from an incorrect representation of the surface topography. For the daily minimum and maximum temperatures, WRF+CDF-t clearly outperforms the WRF-only downscaling. Given its simplicity and easiness to apply, the CDF-t technique may be used in conjunction with the traditional dynamical downscaling from regional climate models for both past and future climate simulations. Possible extensions of this work include a longer WRF simulation lasting several years, which will allow for longer training and forecast periods, and future climate change runs with the CDF-t developed for the past climate and applied to the future climate, which may yield more accurate local-scale predictions of crucial fields such as temperature and precipitation.

The CDF-t technique was introduced by Michelangeli et al. (2009). For a given variable, the CDF-t relates the CDF obtained from a large-scale model or dataset (e.g. WRF model or CFSR data) to that observed at a specific location (e.g. GSOD station). In order to apply this technique, for the training period (e.g. past climate) the relation between the large-scale and local-scale CDFs is computed and, assuming that the transform T between the two is invariant over time, the local-scale CDF for the forecast period (e.g. future climate) can be estimated. The transform T is defined as

$$T\left(F_{Wp}(x)\right) = F_{Gp}(x), \qquad (1)$$

where the subscript W denotes WRF data, G denotes GSOD data and p denotes the training (past) period. The same relation can be obtained for the forecast (future) period, f:

$$T\left(F_{Wf}(x)\right) = F_{Gf}(x). \qquad (2)$$

Substituting (1) in (2) gives

$$F_{Gf}(x) = F_{Gp}(F_{Wp}^{-1}(F_{Wf}(x))),$$

where F_{Gp}, F_{Wp}^{-1} and F_{Wf} can be estimated by the empirical CDFs. Afterwards, a quantile matching approach is performed between the estimated large-scale CDF $\hat{F}_{Wf}(x)$ and the estimated local-scale CDF $\hat{F}_{Gf}(x)$ to generate the statistically downscaled local climate data.

Analytics Competition

Considerable effort to implement an analytics competition resulted in little progress. The company we intended to use for this process (Kaggle) was bought by Google during the period of the project and a new emphasis was placed on the owner of the data (WindCoE) to offer prize money for the winner of the competition. (https://techcrunch.com/2017/03/07/google-is-acquiring-data-science-community-kaggle/) We worked with the Kaggle representatives to accomplish a pro-bono contest but still moving the process forward was not possible. During this process, we communicated with Kaggle representatives many times about using our data in their competitions but Kaggle expressed reluctance because of their perceived apparent complexity of the data. The Kaggle representative expressed that the project acoustics data from the wind turbines combined with simulated weather data would yield insufficient complexity.

Center Continuation

The overarching goal of the WindCoE project was to create a long lasting Center of Excellence for the wind power sector in the Botnia Atlantica region. The function of the center would be to bring together academia, industry and the public to a platform, where a discussion on how to implement renewable energy into the society in a sustainable way.

The discussion on how to achieve this goal was started at an early stage in the project, on project meetings and in the steering committee meetings. The project group could all agree on that the research network established within the project was a valuable asset, and that the contacts and cooperation relations created would remain after the project. This established network would however need to be maintained and managed, in order for it to prevail and flourish. In order for the network to best serve the different interest groups, it needed to be assembled into a structure. After discussions between the project personnel, and in the steering committee meetings, a association was determined to be the best form of organization structure for the center of excellence. An association has the flexibility to operate under very limited budget, as well as large volumes. It promotes working as non-profit organization while still maintaining the legal capacities for upholding a economical functionality.

Nordic Forum for Wind Energy Research rf

At a project meeting held in Luleå, Sweden in the early winter of 2017, a decision was made to go forward with the plans to establish an association, and different suggestions for names were discussed. The suggestion for name that came as a result from the meeting was 'Nordic Association for Wind Energy Research". The name 'Nordic' would imply an organization operating in countries with cold climate, and thus having capabilities to address research topics related to cold climate. The name 'Research' would imply an organization with academic interests, and specifically in topics related to 'Wind Energy'. It was at a later stage decided to change the name 'Association' to 'Forum', this was done to announce that the organization considers itself a community-type organization, where we promote an open discussion, open for anyone interested.

An association named the "Nordic Forum for Wind Energy Research rf" (abbreviated as NFWER) was officially registered in Finland (February 21, 2018), with its home specified as the city of Vasa. The working language of the association is English, the official language is however Swedish, since the Finnish patent and registration office only accepts Swedish or Finnish as the official language of an association, and the association bylaws have to be in either Finnish or Swedish. The association has the official bylaws in Swedish, and have made an English version of them, to be used internally.

Organization structure

The founders of the association wanted to create an environment, where the threshold to join the association/network/discussions was not burdensome. To do this an organizational structure with an open, “public” part was established, as well as a more structured “administrative” part. The figure 23 shows the suggested structure for the whole “center of excellence”.

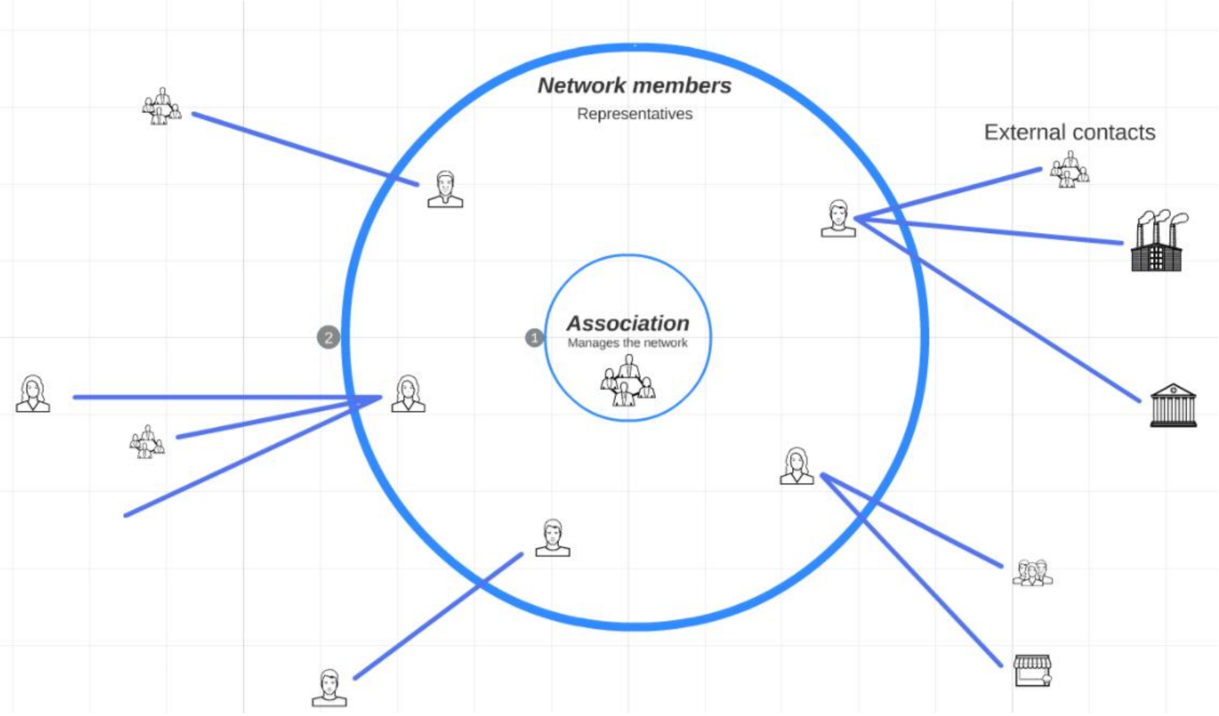

Figure 23: Organizational structure of the Nordic Forum for Wind Energy Research rf association and network.

In figure 23, you can observe the outer circle of network members, who are welcomed to take part of the information sharing activities of the network, can pose questions to the network and give or receive answers. The inner circle consists of members of the association, and the purpose of the association is to administer, uphold and expand the network. The association is administered by a board of up to 5 ordinary members and up to 4 substitutes. A chairperson is leading the board. Each member of the association is considered a member of the information network, and all members of the network have external contacts from their professional or personal life whom they can involve in the network activities, or even invite to become a member of the network.

Association activities

As mentioned earlier the main purpose of the association is information sharing. This can be achieved by newsletters, online discussion forums, e-mail services, online meetings, seminars, webinars, etc. The association plans to develop income streams from appropriate sources and keep the activity levels according to available funds. The association bylaws require that an annual meeting shall be held, and during those meetings, activities for the upcoming year can be planned and decided upon.

Association Strategy

The association's vision for the future is to establish itself as a reputable network that can be used and consulted for various types of research related information activities regarding wind power in cold climates. Possible subgroups of the network can be formed that specializes on different research and discussion topics. The association is currently focusing on expanding and getting more members to the network, and looking for possible sources for funding.

Conclusion

Work packages within the WindCoE project have brought together industry and university efforts to solve old and identify new problems that need addressing for continued sustainable wind energy development in the Fennoscandic region. Focus in two of the work packages on microscale wind resource assessment improvements and mesoscale wind simulation improvements have brought a quantitative weather-centric approach to the industry's environmental understanding. By convincingly demonstrating that virtual reality methods can be incorporated into the public assessment/polling process the efforts of the project specifically connected technology to assist the developing industry. Statistical analyses and system process models were performed by applying formal methods to address spatio-temporal descriptions of the fundamental data and process network systems making up the wind energy sector. Numerous connections with municipality groups and governmental health assessment sectors permitted the contributions from the project to provide inputs to evolving governmental processes. Finally, the cold climate effects on wind power production, blade aerodynamics and source acoustics were addressed and clarified for the industry's review.

We learned about the speed at which non-governmental organizations adapt their positions to impede individual wind park development processes. We learned about concerns of un-preparedness by health care workers to answer questions related to acoustic exposure / health effects. We learned that there is interest by the industry in basic research specifically in improving short-term predictive capabilities for wind power predictions and blockchain methods (both for future process control and transactive management). We learned the current acoustic regulations are not always effective for excluding wind turbine noise from some distant locations. We learned some of the assumptions made by acoustic regulation models in Finland with respect to the atmospheric boundary layer need adjustment. We learned the nature of the atmospheric stability effects the propagation of noise. We learned that for high latitude locations, improvements in numerical weather simulation processes to account for the stable atmosphere conditions are warranted. We learned than gender seems to affect attitudes associated with wind energy issues and perceptions. We learned that VR techniques have the possibility of improving concepts associated with acceptance of wind energy development in new areas.

During interactions with government officials, municipality representatives, NGOs and wind energy company representatives, the project members have worked to give equal information to each group. The societal debate concerning wind energy development in the Botnia-Atlantica region has now to respond to the attempt to level the knowledge playing field amongst the players.

The new Nordic Forum for Wind Energy Research begins it work as a permanent structure in the three countries. The organization is building and networking to increase its members representing academia, industry, organizations and private individuals working and/or interested within the wind energy industry.