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Atmospheric Modelling and Weather Forecasting for Cold Climate Regions

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General Circulation Models (GCMs) are run at very coarse spatial resolutions, typically 100 to 200 km, and therefore cannot simulate many of the processes that are important on a local scale. This is particularly true in wind farms that are of a relatively small size and where the wind turbines strongly interact with the low-level atmospheric flow. Using the Weather Research and Forecasting (WRF) model, a general circulation "community model" that can be used for both large- and small-scale applications, we have conducted a high-resolution simulation for 1 year over Scandinavia with a 3-km resolution grid that includes the full Botnia-Atlantica region and a 600-m resolution grid over the Honkajoki wind farm in western Finland. In this simulation a simple representation of the wind farm and the interaction of the turbines with the atmospheric flow is added to the model. The WRF predictions for the 600 m grid are evaluated against the observations from a set of weather sensors located near the wind park whereas those of the 3-km resolution grid are compared against the available station and radiosonde data. For both domains a good agreement is found between the model predictions and available observations highlighting the suitability of the model product for acoustic and dynamic studies.

Wind Turbine Icing- Progress & Challenges

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Northern Europe has good wind resources but cold climate/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. This highlights the importance of finding innovative/disruptive technological solutions for wind turbine operations in icing conditions to reduce the Capital Expenditure (CAPEX) and the Operational Expenditure (OPEX). The International Energy Agency (IEA) Task 19: *'Wind energy in cold climates'*[3] has also urged the development of new methods to enable better prediction of the effects of ice accretion on wind energy production.

Icing on wind turbines causes environmental and operational issues such as: *complete loss of power production [2], reduction of power due to the disrupted aerodynamics, overloading due to delayed stall, increased fatigue of components due to imbalance in the ice load [3] and damage or harm caused by the uncontrolled shedding of large ice chunks etc*. Therefore, it is important to better understand the ice accretion physics on wind turbine and find the solutions to minimize its effects on wind turbine performance.

Statistical learning in wind power production and weather prediction

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A. Climate varies over a wide range of spatial and temporal domain. Large scale climate determines the environment of mesoscale, while microscale processes govern the local climate. The regional climate models (RCMs) are developed from the large scale climate model to simulate local scale climate. The resolution of large scale model, e.g. global general circulation model, is around 100-200km, while the resolution of RCMs could be as small as hundreds meter.
   - How to understand the relationship between climate from RCMs and local scale climate, which could guide human activities in future?
   - How to improve the accuracy of downscaling?
   - How to estimate the uncertainty of RCM's model output fields (e.g. 2-meter temperature, surface radiation fluxes or wind speed) in an efficient and fast way?

B. Wind power is a renewable energy resource, that has relatively cheap installation costs and it is highly possible that will become the main energy resource in the near future. Wind power needs to be integrated efficiently into electricity grids, and to optimize the power dispatch, techniques to predict the level of wind power and the associated variability are critical.
   - How to obtain reliable forecasts for the wind power distributions to account for the propagation of weather fronts
   - How to make multi-step ahead probability predictions for wind power generated at both locations where wind farms already exist but also to nearby locations.

To answer the above-mentioned questions, statistical learning and spatiotemporal modeling for big data are of key importance.

Wind turbine noise characteristics: Infrasound and amplitude modulation

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The standard wind turbine noise measurements is mainly concentrated on average sound pressure level. There are however, many other noise characteristics which are frequently under discussion. Particularly, the pulsating nature of wind turbine sound, so called amplitude modulation, and the existence and possible adverse health effects due to infrasound have been often discussed. One goal of our research was to measure these phenomenon.

The results show the prevalence of amplitude modulation and it's depth in the target wind parks. The measurements extended in the infrasound range, and the amplitude and waveform of the infrasound pulses were also analyzed. According to our experience, the amplitude modulation is rather common, existing up to 30% of time in some locations, but the detection and measurement of it is not yet unambiguous.

Wind turbine causes infrasound pulses with blade-tower interaction mechanism. The pulses can be detected with measurement instrument sometimes even from several kilometer's distance, but the pulse amplitude is so small that people are exposed with similar infrasound levels from many natural sources. The amplitude modulation may increase the annoyance of the wind turbine noise.

How weather is affecting acoustic propagation in cold climate regions

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A good characterization of the atmosphere is important for understanding how sound travels outdoors (acoustic propagation). Further, the atmosphere in colder climates is different from its warmer cousins because heat is important in so many processes within the atmospheres. Problematically, it is difficult to measure all the variables in the atmosphere which are important to the sound propagation over large spaces and long periods of time. Here, we present results from a year-long study where we measured and simulated some of the variables describing the atmosphere and also measured sound (from wind turbines). We attempt to characterize the physical environment and have these data show how acoustics are propagated and affected by the atmosphere. By analyzing these data, we demonstrate how:

- to specifically detect wind turbine signatures in the acoustic data, and also birds, cars, etc.
- nature provides a continuum response in the detected signatures.
- the characteristics of the atmosphere are associated with the detected wind turbine acoustics.
- well the simulated atmosphere results characterize the atmospheric environment
- these type of data are used in acoustic propagation models to see the sound propagation characteristics