The Use of WRF for Wind Resource Mapping in Norway

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1. Introduction

Norway is a country of large potential for wind power. The Norwegian coastline, broken by fjords and thousands of islands, stretches over 2,500 km, bordering the North Sea and Norwegian Seas to the west. The coastal climate of western and northern Norway is dominated by the westerlies, the major weather pattern of the North Atlantic at this latitude.

The wind power potential for Norway has been calculated by Hofstad et al. (2005). By developing 0.5% of the land area of Norway an annual production of 250TWh from wind power could be generated. This amounts to more than twice the Norwegian consumption of electrical power. However to this date only a few wind farms are operational with a combined annual production of less than 1 TWh.

The WRF model makes a promising tool for wind resource mapping. Combined with wind measurements at various locations, we can use this tool to locate good sites to develop wind power.

Moisture combined with temperature below freezing during large periods of winter makes icing on wind turbines a potential problem in Norway. Icing on wind turbines reduces the power output at any wind speed, and is also be associated with larger wear/stress of the gearbox, generator and rotor blades. Ice that breaks off a wind turbine may also constitute a health risk for people and animals in the wind farm area.

Icing calculations have typically been done by evaluating cloud height observations from nearby airports (e.g. Harstveit 2002). Reliable measurements are not always available close to a potential wind farm site. Output from the WRF model can also be used to calculate the potential for icing. This methodology shows promising results.

2. Model setup

WRF v2.2 is set up with two 2-way nested model domains shown in Figure 1. We use a horizontal resolution of 5 km for the outer domain and 1 km for the inner domain. We use 32 layers vertically, with the lowest 4 model levels at 20 m, 60 m, 115 m and 190 m above the ground. The model is run for the complete year 2005.

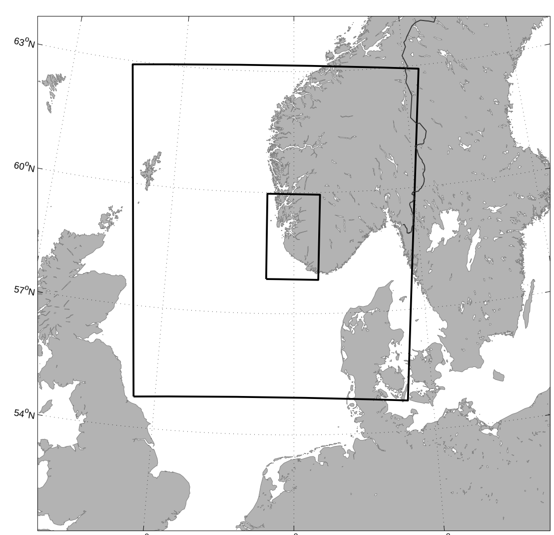


Figure 1 Setup of the domains for the simulation

The simulation is set up with Ferrier microphysics, the thermal diffusion scheme for the surface, the YSU scheme for BL physics and Runge-Kutta 3rd order time-integration scheme with a time step of 30s for the outer domain and 6 seconds for the inner domain. The model evaluates 2nd order diffusion term on coordinate surfaces for turbulence and mixing, and uses the horizontal Smagorinsky 1st order closure eddy coefficient option. No damping is used for the vertical velocities.

3. Wind climate

Model results from the nearest grid point to an observation site are used for validation purposes. The simulation has been evaluated for 9 sites within the inner model domain. Data from 5 sites are openly available. These are stations operated by the Norwegian Meteorological Institute (met.no). For the five sites wind speed is measured at 10m above ground level. Additional 4 sites are operated by Kjeller Vindteknikk on behalf of Norwegian power companies with interests in this region. Our agreement with the power companies does not allow us to publish the wind speed nor the location of these sites. The sites are therefore kept anonymous and referred to as Site 1-4. The measuring height for these sites ranges from 50-100m.

Table 1 shows the deviation in wind speed between WRF and observations and the correlation coefficient. The correlation coefficient for hourly data is typically in the range 0.8-0.9.

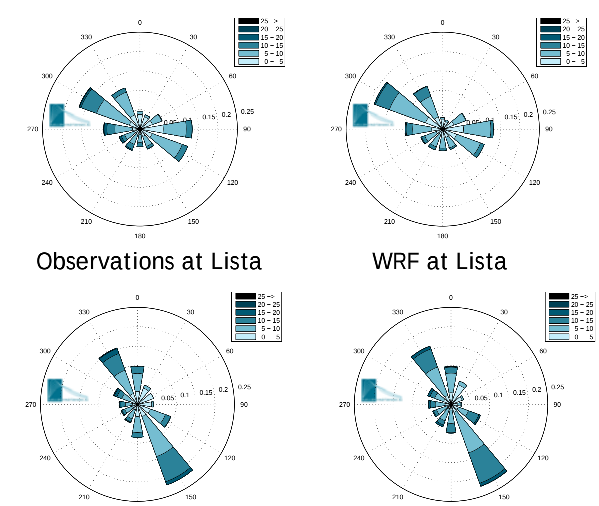
Station	Observed 2005	WRF 2005		ρ
Lista	6.6 m/s	6.4 m/s	- 3 %	0.80
Obrestad	7.2 m/s	7.9 m/s	+ 10 %	0.83
Utsira	8.8 m/s	8.7 m/s	- 1 %	0.87
Haugesund	6.0 m/s	7.5 m/s	+ 25%	0.83
Sola	4.8 m/s	4.5 m/s	- 7%	0.81
Site 1			+ 5%	0.89
Site 2			- 8%	0.91
Site 3			- 6%	0.80
Site 4			+ 22%	0.78

Table 1 Average wind speed (2005) for 5 observation sites and the nearest WRF point. Percentage deviation of the WRF model compared to observations at 9 sites. Correlation coefficient (ρ) between hourly data from WRF and observations.

In general we find deviation in wind speed between WRF and observations within ±10%. For Haugesund we find larger deviations, this may partly be explained be sheltering effects at this site that is not captured by the model. Site 4 shows also a large deviation from model climate. A typical feature of the terrain at this site is sub-grid topographical variations that are smoothed by the model. This adds to the surface roughness and is not accounted for in the model.

Micro scale steady state models (e.g. WAsP, 1993) is typically used for wind resource mapping for smaller model domains (less than 400km^2 area). By using WRF data as input to micro scale models we are able to adjust for finer variations in topography and surface roughness. By combining WRF with WAsP we generally accomplish to reduce the deviations in observed and modeled average wind speeds (Berge et al 2007).

Wind roses for the some of the sites and their corresponding WRF point are shown in figure 3. The distribution in wind direction for these sites is captured very well by the model.



Observations at Lista — WRF at Lista

Observations at Obrestad — WRF at Obrestad

Figure 2 Observed and simulated wind roses for Lista and Obrestad

The data are finally compiled to generate a map showing annual wind speed for the region. The annual value of 2005 has been adjusted to long term climate by reducing the wind speed by 4.5%. The wind map is shown in Figure 3. The best wind resources are found along the coast. High annual wind speed is also found in the mountainous part farther from the coast. These locations are typically higher, and less suited for wind power due to icing and turbulence.

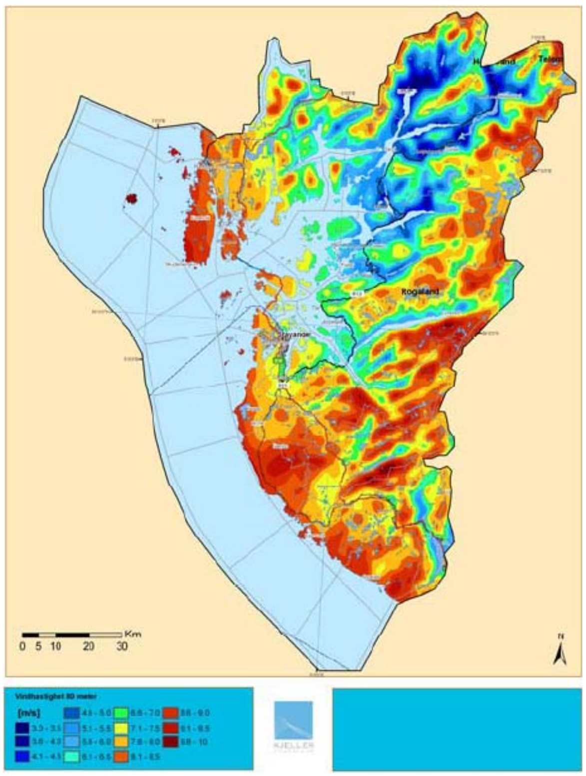


Figure 3 Expected annual wind speed for Rogaland at 80 m.a.g.l.

4. Icing

In-cloud icing is a challenge for wind power in Norway. In-cloud icing describes the process where liquid supercooled droplets (typically cloud droplets) collide with structures and momentarily freezes to the structure. In-cloud icing is known to accumulate thick layers of ice. (More than 100kg of ice per meter has been observed on power lines in western Norway). For locations with a height lower than ~ 400 m.a.s.l. the problems due to icing is assumed to be minimal.

Icing has been calculated from:

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \cdot w \cdot A \cdot V$$

Here dM/dt is the icing rate on a standard object (defined by ISO 12494, 2001, as a cylinder of 1m length and diameter 30mm). w is the liquid water content, A is the collision area perpendicular to the flow of air. V is the collision speed. α_1, α_2 and α_3 are the collision efficiency, sticking efficiency and accretion efficiency.

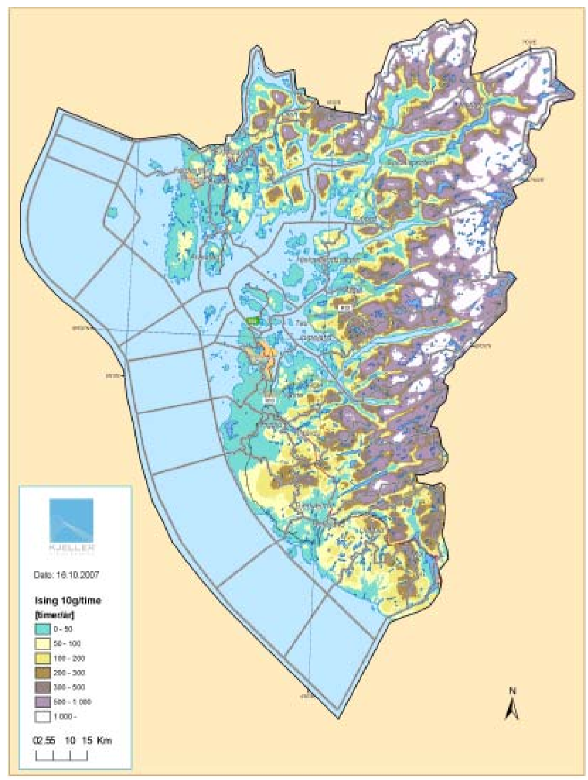


Figure 4 Number of hours with icing rate larger than 10 g/hr.

Icing has been calculated for the WRF grid at all model levels. The icing amounts are very dependent on height. Therefore the icing levels have been adjusted by employing a fine scale topography mesh with horizontal resolution of 25m (N50 topography) to adjust for the smoothed

WRF topography (1km). Icing at 80m above ground level is shown in Figure 4.

The map shows the number of hours where icing is predicted to occur during 2005. We define icing to occur when the icing rate (dM/dt) exceeds 10g/h. This is equivalent to form a 0.5mm layer of ice on the standard object.

Icing calculated from WRF data is compared to icing calculated from observations of cloud height from the airports at Sola and Haugesund (not shown). The model tends to overpredict number of hours of icing for heights 200-500 m.a.s.l and underpredict icing at heights above 1000 m.

5. Conclusions

We find good correlation between observations and the WRF model. But the absolute wind climate and the vertical wind speed profile at a certain height is very sensible to local surface roughness and topography of sub-grid scale. The model thus seems to overestimate wind speed in areas with large sub-grid topographic variations. While the smoothed model-terrain often leads to underestimated wind speed at hilltops. The uncertainty of predicting the absolute wind speed at 100m above ground is in the order of 10%. But for areas with smoother terrain, the uncertainty is in general less than this. We have experienced that the uncertainty in the predicted wind climate can be further reduced by combining WRF with microscale models.

Icing can be calculated by the model, but icing is typically overestimated in the lower 200-400m of the atmosphere. This bias is probably related to biases in the vertical mixing processes and the relatively simple microphysics parameterization scheme used in this simulation.

Acknowledgement

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