Comparing observed and modelled cloud base height for ice assessment

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TECHNOLOGY FOR BUSINESS

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Introduction

According to BTM, nearly 100 GW of wind power is currently installed in low temperature and icing climates making it one of the largest "non-standard" markets in the world today [1]. Ice accretion on wind turbine blades is one of the largest challenges when operating wind turbines in low temperatures and icing climates. Ice changes the aerodynamics of the turbine blade and causes production losses, potential increase in turbine vibration, increased noise emissions and falling ice present a health and safety risk in the vicinity of the turbine.

Ice accretion on an object requires the presence of liquid water and freezing temperatures. The most typical form of icing in Europe is rime icing as a result of low level clouds below freezing temperatures. If the cloud height is below the level of wind turbine rotor, ice will be collected on the turbine blades.

For assessing icing risks in pre-construction phase for a wind farm, mainly two different methods exist: 1) use icing measurements from a location nearby (turbine production data, on-site ice measurements or nearby met station measurements) or 2) perform meteorological modelling of site icing conditions. Often on-site or nearby icing measurements are not available because icing measurements are not systematically part of frequently meteorological measurements. As a result, weather modelling is often solely used to evaluate icing risks.

Objectives

Market potential in low temperature and icing climate wind power is huge and icing severity has to be known when building or operating wind farms in icing climate. It is important to understand how different methods can be used for icing estimation without icing measurements. Cloud base height (CBH) of mesoscale weather simulations and weather observations have not been compared with each other at this extent before.

Methods

In order to evaluate icing risks for wind turbines, measurements of CBH provide a good proxy. If the cloud base is in the area of the wind turbine rotor and temperature is below freezing, the conditions are suitable for meteorological icing and ice to form on the rotor blades. In this study, 149 met stations in Scandinavia from time period 2000-2015 are selected and observed and modelled CBHs are compared. Only CBH is compared in order to limit the potential sources of errors in the comparisons. CBH observations are primarily from long-term weather stations and airports. Using the CBH observations in combination with temperature measurements has shown promising results as a meteorological icing proxy for wind power applications. [2] [3] [4].

Based on mesoscale weather simulations using the Weather Research and Forecast model (www.wrfmodel.org) a wind and icing map for Norway was produced by Byrkjedal & Åkervik (2009) [5] and compared against icing calculations based on airport data in Harstveit (2009) [8]. The methodology for using airport data to calculate in cloud icing is further described in WECO project (2000) [11], NEWICETOOLS project (2005) [12] Harstveit (2002, 2009) [6][7][9][10] and Bernstein (2009) [13]. Wind and icing maps have later also been produced for Sweden and Finland using a similar methodology [14]. In this poster, modelled time series of CBH are retrieved from Kjeller Vindteknikk's hindcast archives of meteorological simulations. Statistical methods are used to evaluate Mean Absolut Errors (MAE) and bias of observed and modelled results.

As sample rate is variable in different meteorological stations observations was interpolated to one hour resolution. The data was filtered and it includes only timestamps where both observed and modelled CBH is available. A CBH frequency histogram was calculated for various elevations for every location with both datasets. Example histograms are seen in Figure 1. Measurement method and quality varies on different stations. In some stations certain cloud heights occur more frequently than others which indicates that CBH is a visual estimation or resolution of measurement is really coarse. Example of low quality measurement data is seen in right hand side in Figure 1.

Several filters was used in analysis:

- Country
- Histogram spikiness (mean absolute difference of adjacent bins)
- Terrain flatness (Standard deviation on terrain elevation in 10 km radius)
- Local elevation (difference between station elevation and average elevation in 10 km radius)

Histogram spikiness was used to remove low quality observations from dataset and country to find out regional differences in correlation. Used filter values are presented in Table 1.

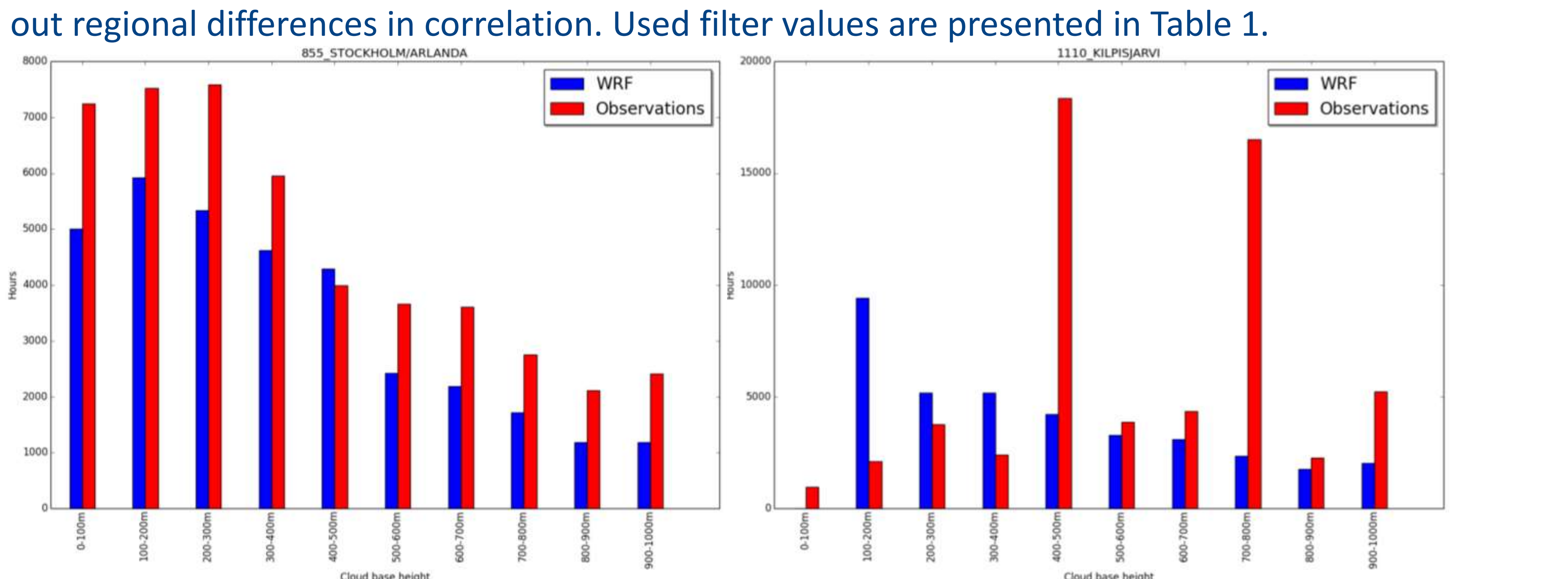

Figure 1. Example histograms. On right hand side there is an example of high quality cloud height measurement and on left hand side cloud height distribution is uneven which indicates poor measurement quality or coarse resolution. Histogram spikiness value for Stockholm (SE) is 611 and for Kilpisjärvi (FI) 6438.

Results

Histograms were compared by adding histograms from all stations together and calculating bin-vise linear (Pearson product-moment) correlation between observed and modelled histograms using. Method was selected to minimize temporal differences in comparison. Correlation coefficients are presented in Table 1. From this table clear elevation dependency in correlations can be seen. Elevation dependency in selected cases is illustrated in Figure 3.

Table 1. Filters and correlations between observations and numerical model.

	Filters					Correlations R^2						
Case	country	Histogram spikiness	Terrain flatness stdev(h_{R10km})	Local elevation h - mean(h_{R10km})	N	0-100m	100-200m	200-300m	300-400m	400-500m	500-600m	average
1	All	-	-	-	149	0.28	0.63	0.32	0.61	0.15	0.37	0.39
2	All	<1500	-	-	74	0.35	0.92	0.88	0.83	0.63	0.72	0.72
3	All	<2500	-	-	106	0.30	0.90	0.84	0.80	0.47	0.66	0.66
4	All	-	<=20 (flat)	-	67	0.24	0.64	0.81	0.75	0.07	0.68	0.53
5	All	-	>20 (complex)	-	82	0.29	0.61	0.16	0.48	0.27	0.18	0.33
6	All	-	-	<0 (valley)	111	0.42	0.55	0.25	0.57	0.25	0.32	0.39
7	All	-	-	>=0 (hill)	38	0.16	0.88	0.80	0.71	0.01	0.59	0.52
8	FI	-		-	40	0.13	0.42	0.73	0.79	0.16	0.62	0.47
9	NO	-		-	58	0.44	0.43	0.06	0.37	0.19	0.35	0.31
10	SE	-		-	51	0.10	0.74	0.13	0.62	0.24	0.26	0.35
11	FI	<1500	-	-	11	0.19	0.97	0.97	0.96	0.85	0.84	0.80
12	NO	<1500	-	-	22	0.35	0.63	0.62	0.71	0.62	0.71	0.61
13	SE	<1500	-	-	41	0.04	0.85	0.75	0.67	0.50	0.57	0.56
14	All	<1500	<=20 (flat)	>=0 (hill)	13	0.25	0.98	0.94	0.87	0.56	0.51	0.69
15	All	<1500	<=20 (flat)	-	40	0.31	0.93	0.92	0.91	0.71	0.78	0.76

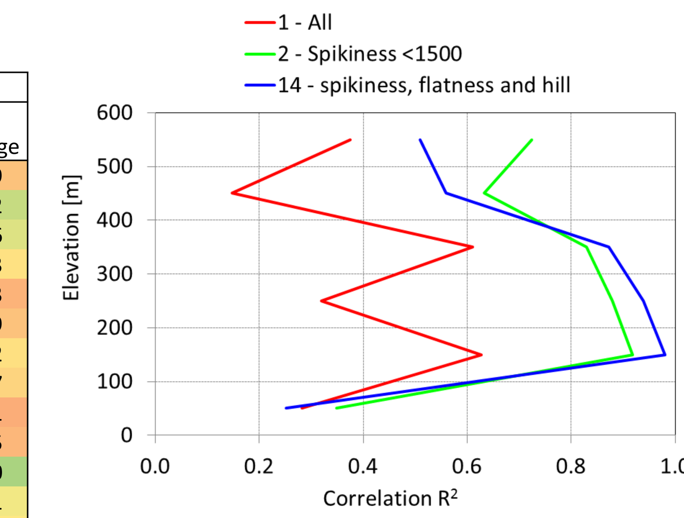

Figure 3. Correlation R^2 at different heights.

Usually only CBH is observed and cloud thickness is unknown. A cumulative cloud height distribution (which is the same as unlimited cloud thickness) have been used in CBH based icing assessment [2] [3] [4]. It is obvious that this assumption is not working at very high altitudes. In Figure 4 cumulative cloud distribution is calculated from observation with 100 m resolution. Cumulative distribution is compared to modelled data with cloud thickness. The difference increases at higher elevations.

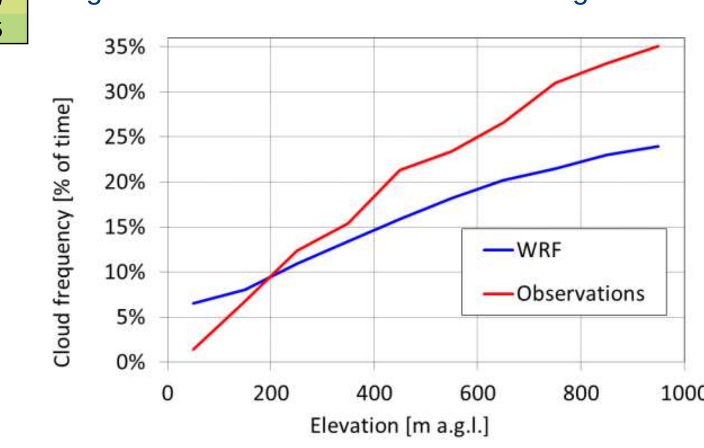

Figure 4. Cumulative observed cloud distribution and modelled cloud distribution with cloud thickness. Both are averages of all stations.

Conclusions & discussion

Quality of cloud base height (CBH) measurements is the largest individual factor which decreases the correlations in this study. The cloud height measurement method was not known in this study but assumably old observations are visual and more recent automatically detected with ceilometers. A possible reason for observed spiky cloud height distribution is poor measurement resolution. Data may include visually estimated cloud heights which means that cloud height can be rounded to nearest 100 m. By filtering stations where observed cloud height distribution is spiky, correlations improve significantly. However, filtering is not improving correlations in lowest elevation bin. In modelled data there is a lot of moisture in lowest model layer near ground level, which is not seen in observations. It is possible that CBH measurements are not performed during fog. Mist and fog observations were not studied in this analysis.

Effect of different filters on correlation was studied. Correlations are best in simple, flat terrain areas and if stations are located higher than average elevation in region. Regional differences were also found. In Finland correlations are better than in Sweden and Norway. The most probable reason for this result is the more flat terrain in Finland. The best correlations were found in 100-200 m elevation which is the most important altitude in wind power production. Filtered correlations were good between 100-400 m agl. Cumulative cloud distribution overestimates slightly cloudiness in higher elevations. Unlimited cloud thickness assumption works well at elevations between 150-350 m agl.

Observed and modelled CBH agree well when appropriate filters are applied. The results give confidence that both observed and modelled CBH can be used to estimate in-cloud icing conditions for wind power applications.

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