Extreme wind speed mapping in Norwegian fjords using mesoscale meteorological models, scaled to 500 m x 500 m horizontal resolution

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WRF modelling

- The WRF (Weather Research and Forecasting) model is a state-of-the art mesoscale meteorological model used in numerical weather forecasting
- For climatic studies it is used in hindcast modus
- Forced by global model data, for instance from the Reading weather centre
- Nested to 4 km x 4 km or 6 km x 6 km from1979 and ongoing
- Nested to 500 m x 500 m from 2009 and ongoing for some project areas
- 500 m models are used to produce wind maps in complex terrain
- Validation are made to E39 wind project masts (KVT) and synoptic data from eklima (NMI)
- 500 m data are also used as a wind drive for wave (NMI) and sea current (IMR) models for the fjord basins

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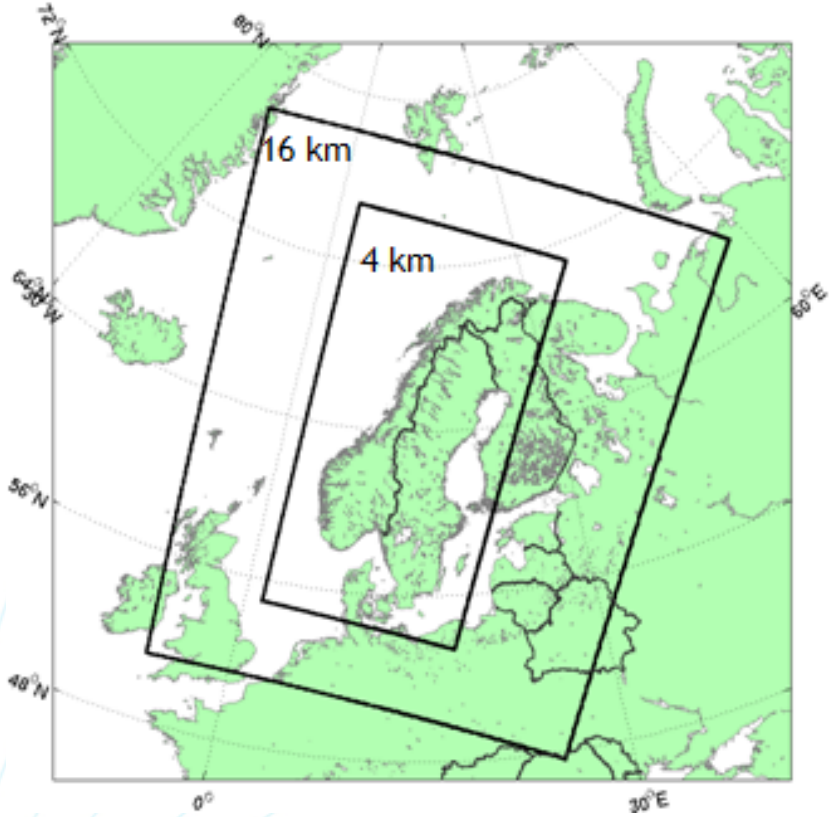
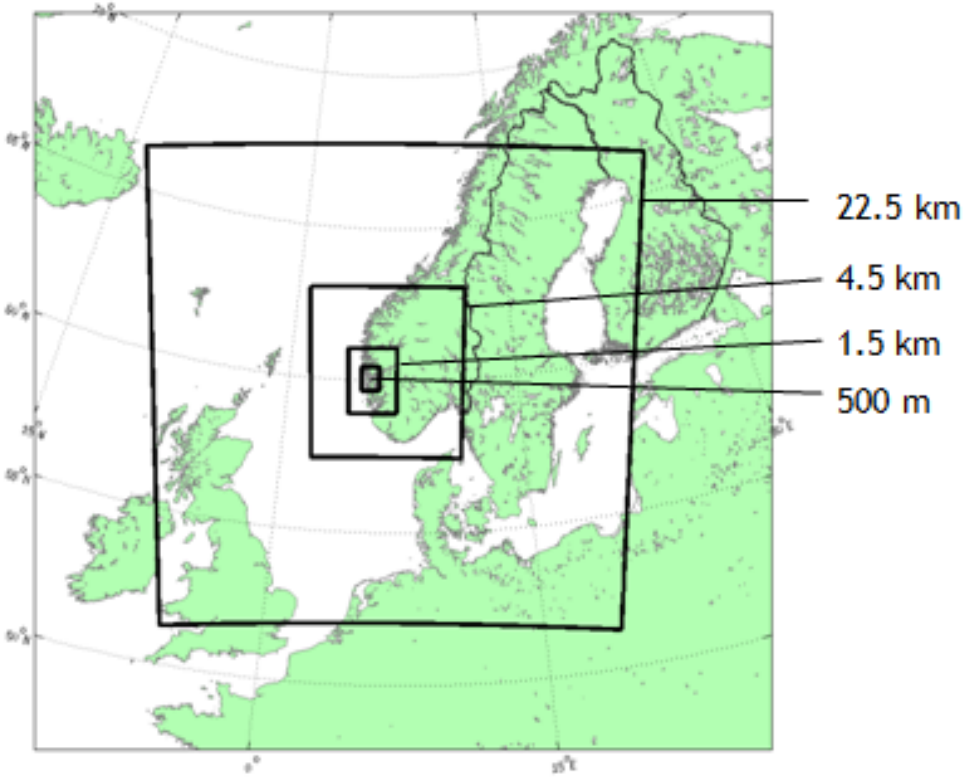
Model nesting to 500 x 500 m for the Bjønafjorden area





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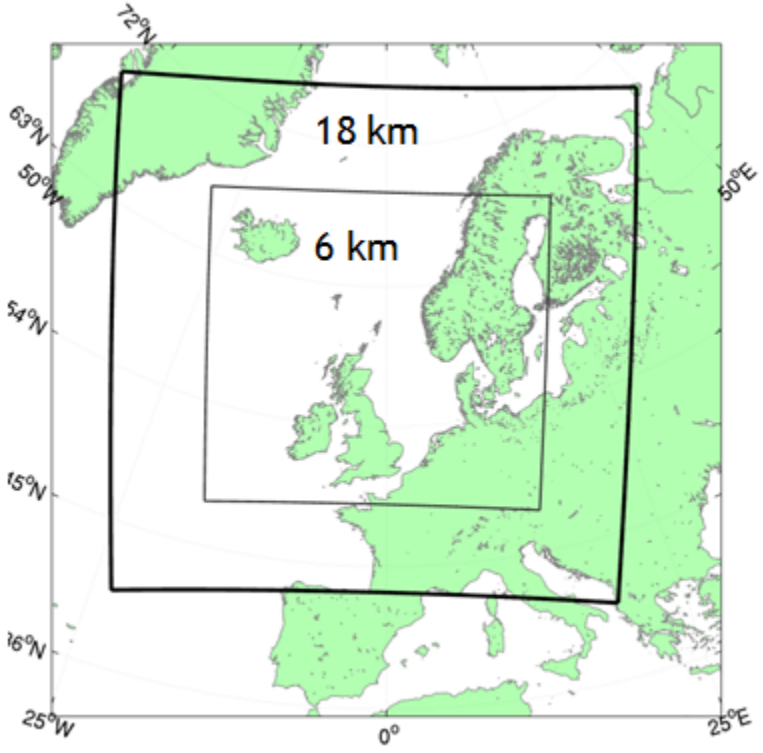
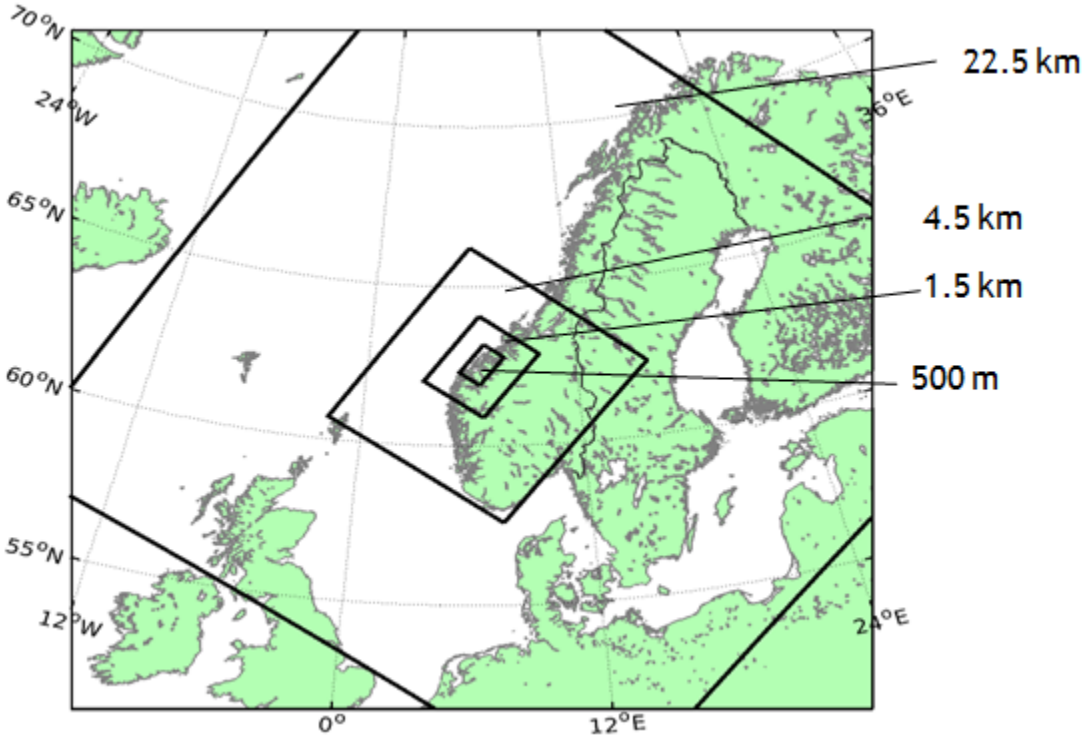
Model nesting to 500 x 500 m for the Sulafjorden area





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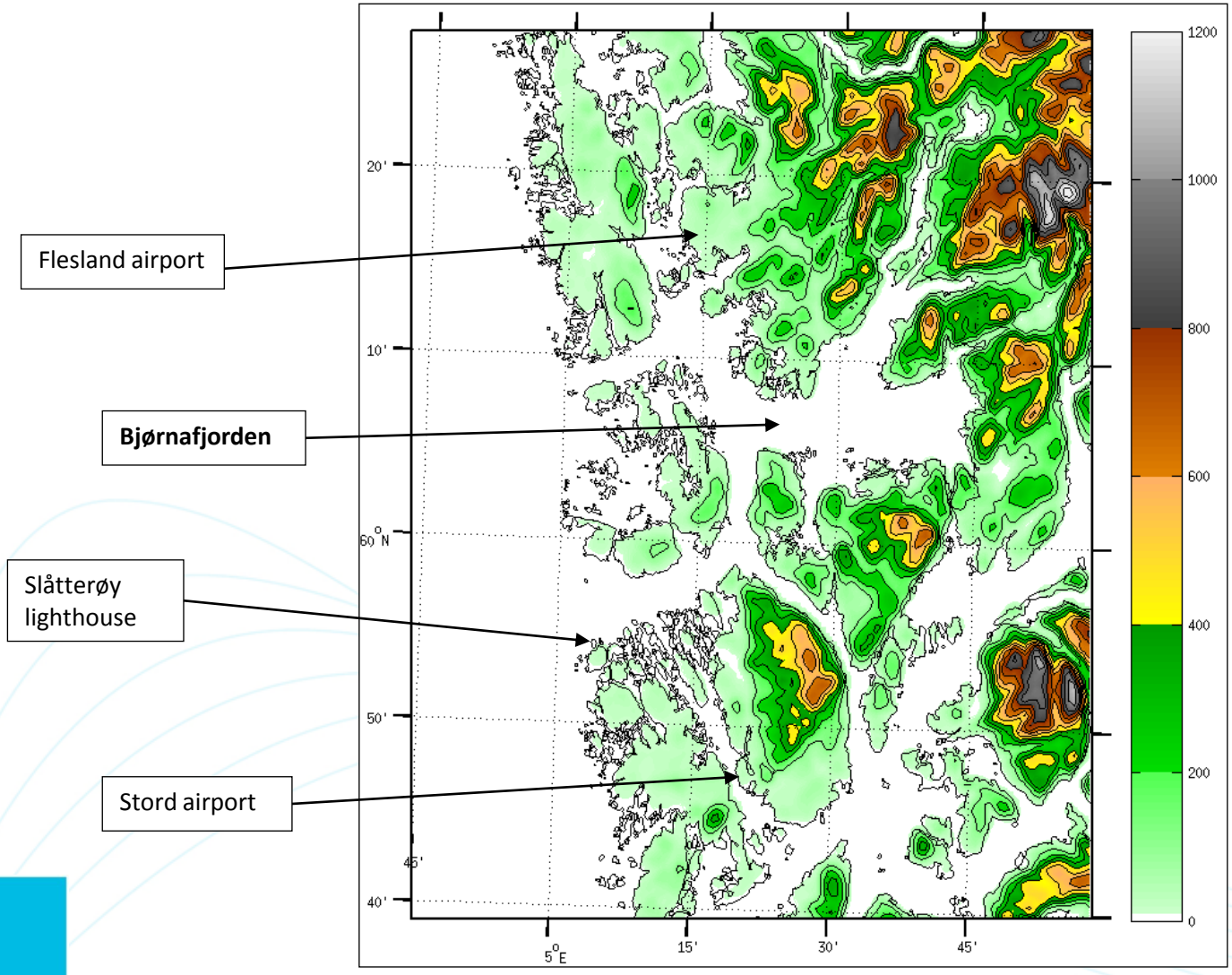
The 500 m x 500 m model terrain



Map of the 500 m model surface terrain for the Bjørnafjorden area

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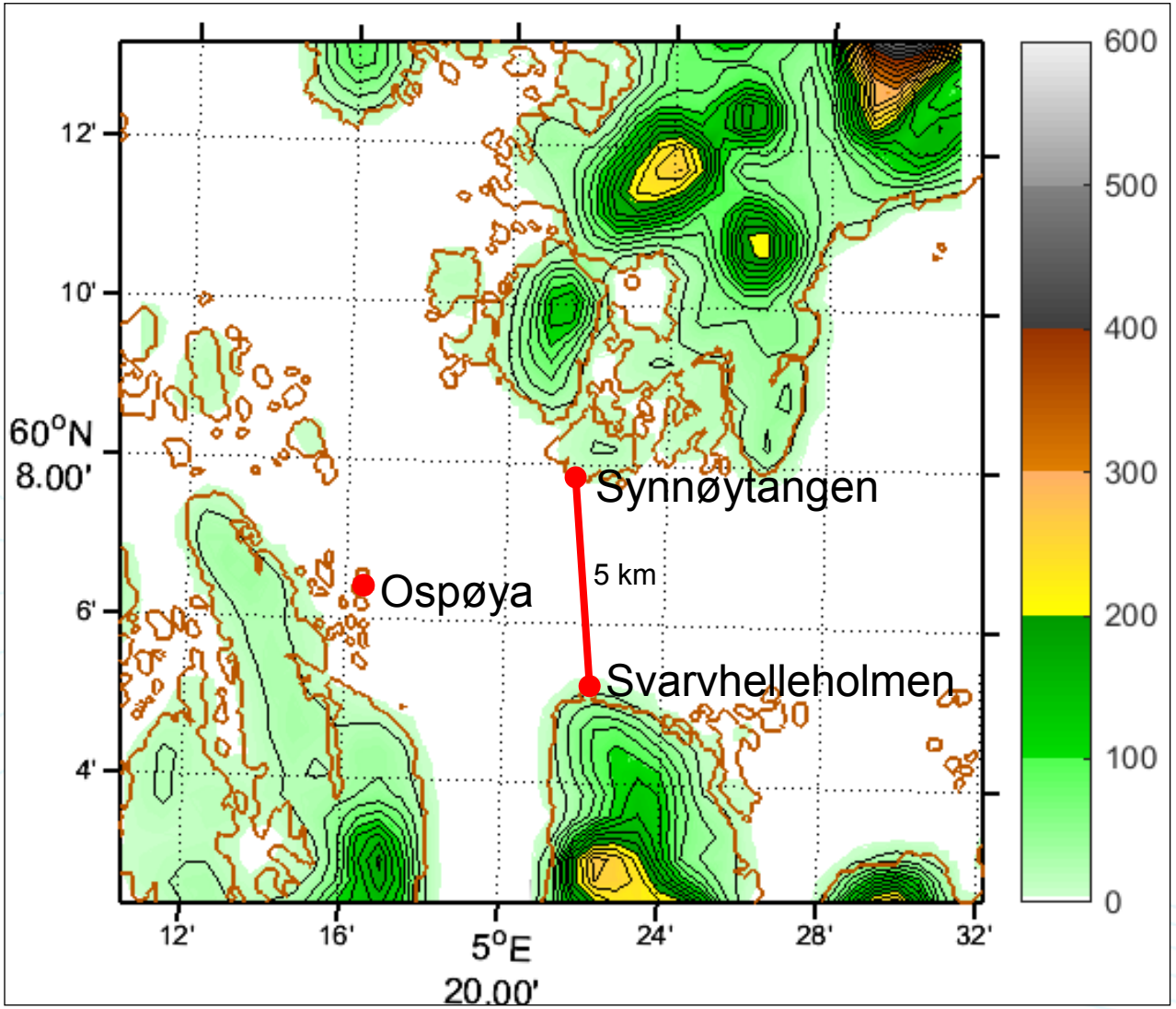
The 500 m x 500 m model terrain - focused on the bridge area



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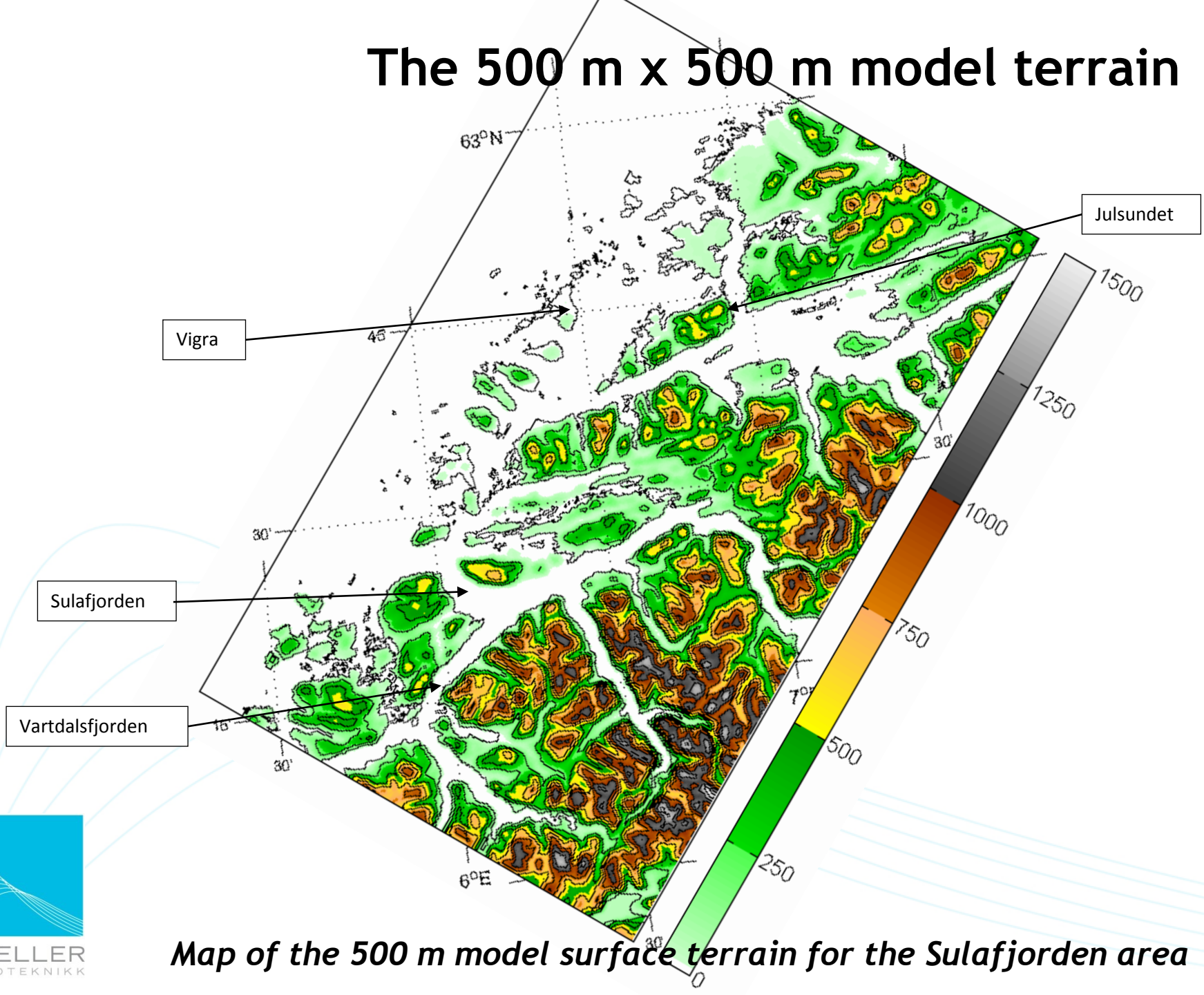
The 500 m x 500 m model terrain



Map of the 500 m model surface terrain for the Sulafjorden area

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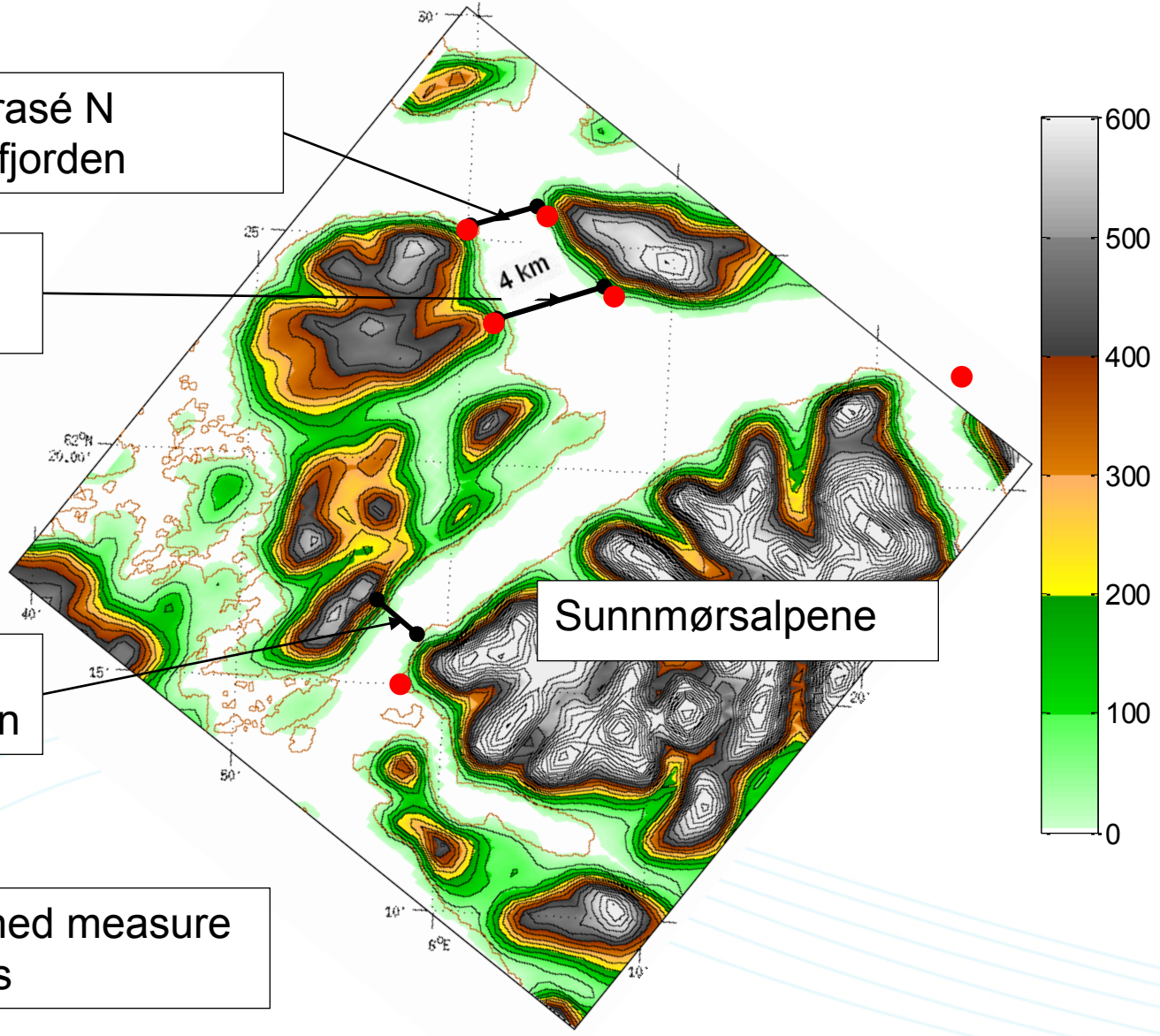
The 500 m x 500 m model terrain



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Map of the 500 m model surface terrain for the bridge area in Sulafjorden

Data postprossessing - Syntesized data sets

1. Nesting WRF down to 500 m x 500 m modeling is very time-consuming, especially for complex areas covering some fjords. Therefore the 500 m data are covering max 10 years
2. The mast series from the bridge areas are short (1 - 3 years)
3. Both of the series above is therefore extended to hourly series from the period 1979 - 2015 using statistical downscaling of the WRF 6 x 6 km data set.
4. The down-scaled data set is referred to as a synthetic data set, valid for 500 m x 500 m
5. Correspondingly, synthetic data sets from measurement campaigns are created

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Data post prossessing – statistical downscaling - the method of quantile regression

- The statistical downscaling is made using the method of quantile regression, customized for wind data by Undheim and Nyhammer, KVT (U&N method)
- In this method the wind direction and the velocity are treated separately
- The direction correction is carried out by first finding the direction difference between site (500 m data) and ref (6 km data) for the main wind direction at ref
- The simultaneous data are then corrected according to the difference, and sorted individually in ascending order
- The correction for each direction is found from the relation between the two sorted datasets (QQ methodology)
- This method is effective also for rather low regression coefficients, which are typical when comparing hourly values for different scaled data sets in complex terrain

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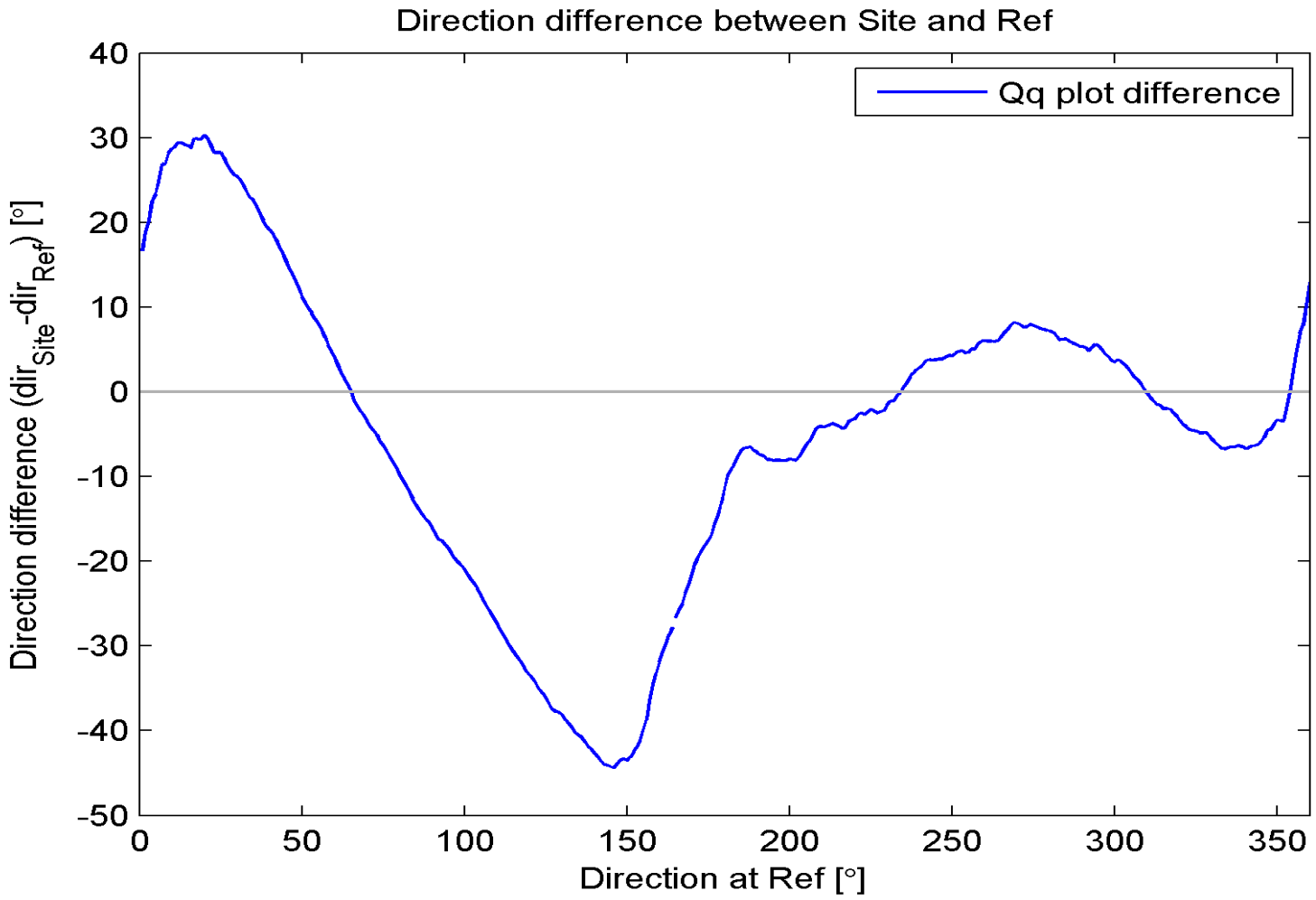
Wind direction correction in the U &N method



Example of the direction difference between the 500m series (Site) and the 6 km data series (ref) for a grid point in the central part of Bjørnafjorden

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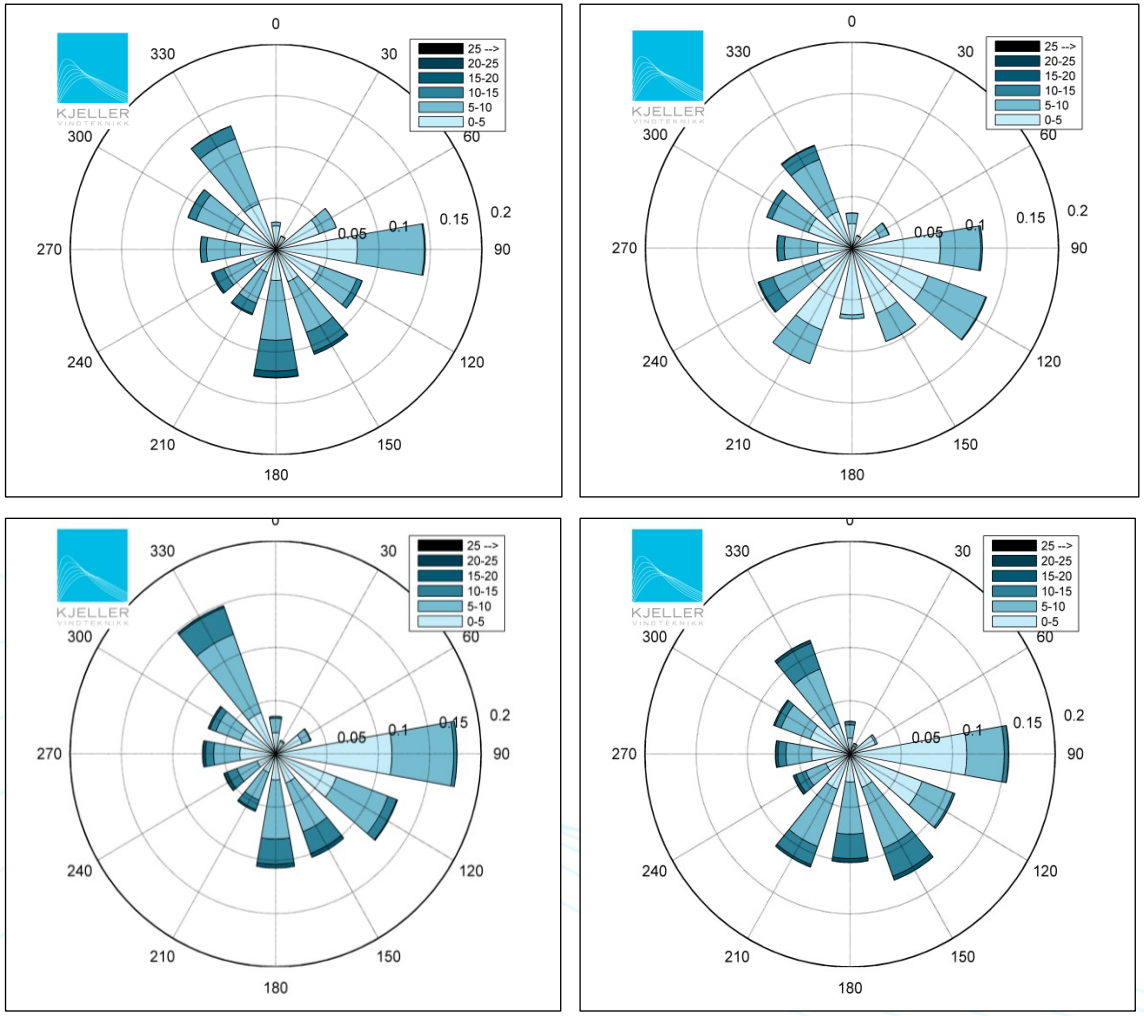
Model validation - Bjørnafjorden



Long-term adjusted wind roses from Synnøytangen (left panel) and Svarvehelleholmen (right panel). The wind roses are based on observational data (upper panel) and WRF 500 model data (lower panel). All data from 50 m agl.

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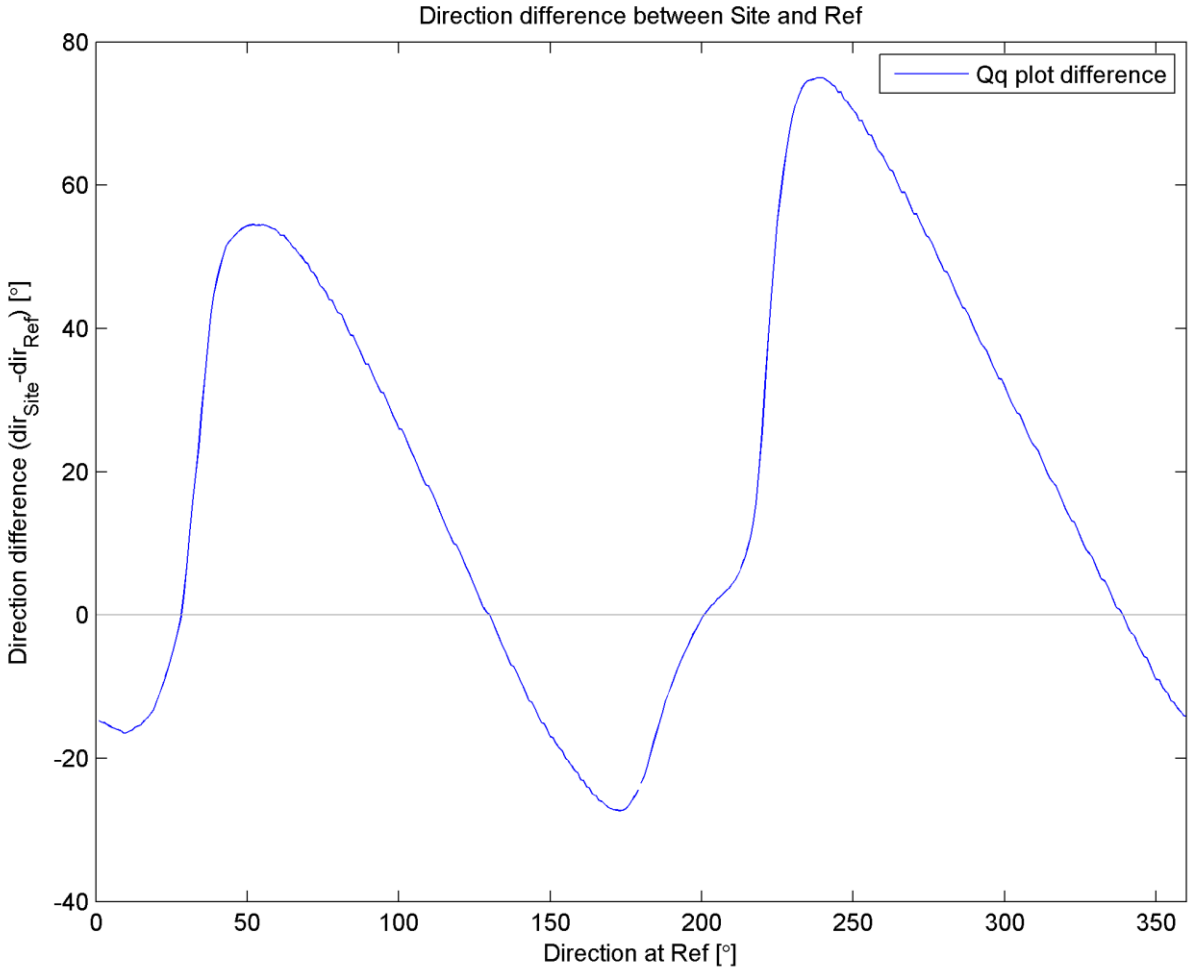
Wind direction correction in the U &N method



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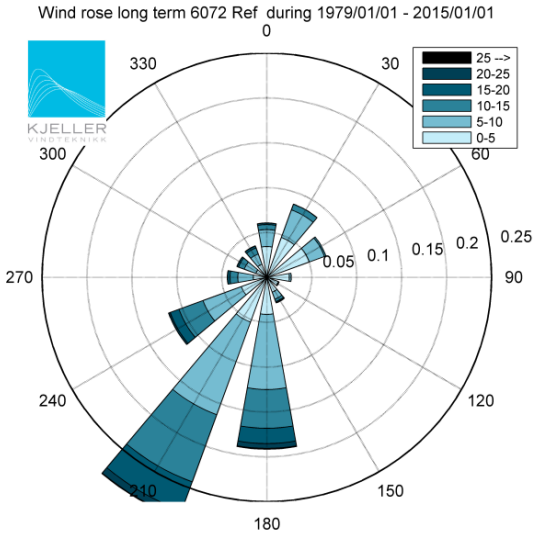
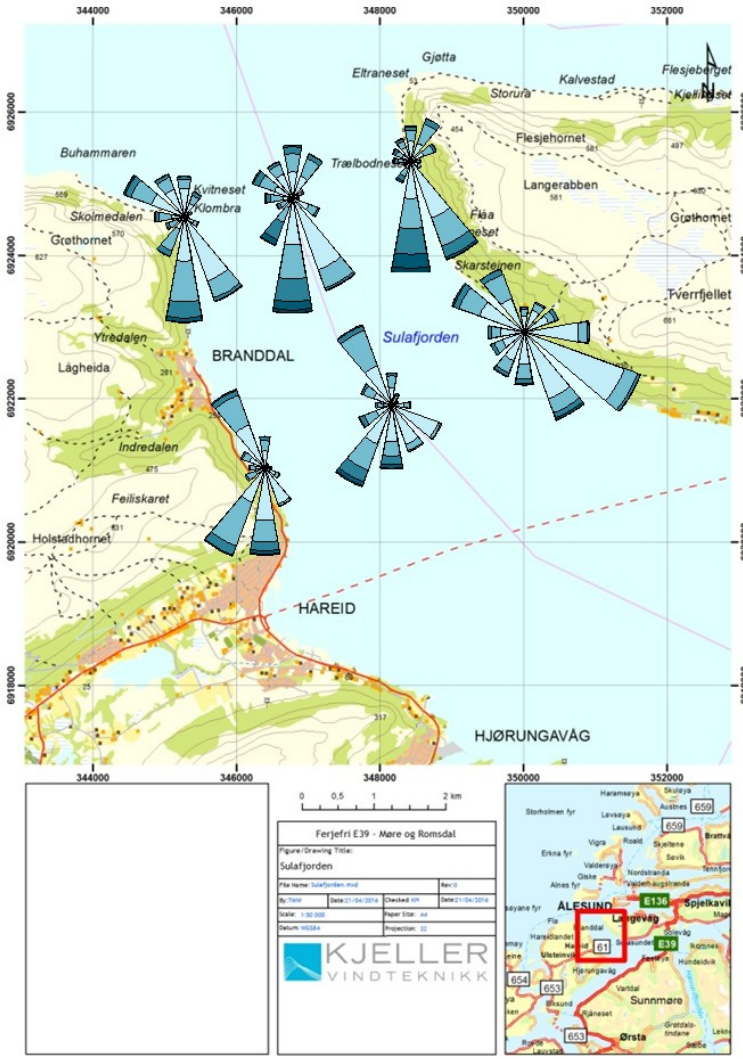
Modelled wind roses 1979 - 2014



Modelled wind rose (6km x 6 km) for a site in central Sulafjorden, 60 m asl



Modelled wind roses (500 m x 500 m) for six sites in Sulafjorden, 60 m asl

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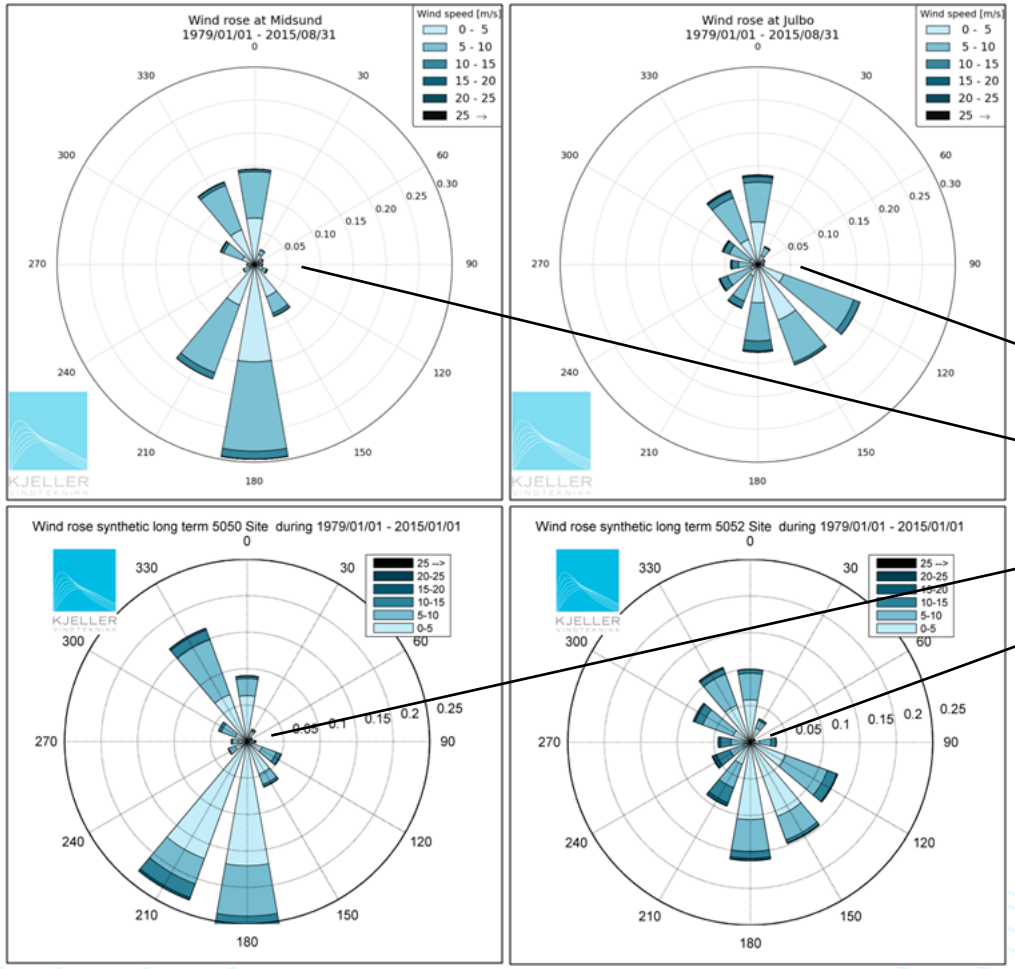
Model validation - Julsundet



Long-term adjusted wind roses from Midsund (left panel) and Julbø (right panel). The wind roses are based on observational data (upper panel) and WRF 500 model data (lower panel). All data from 60 m agl.

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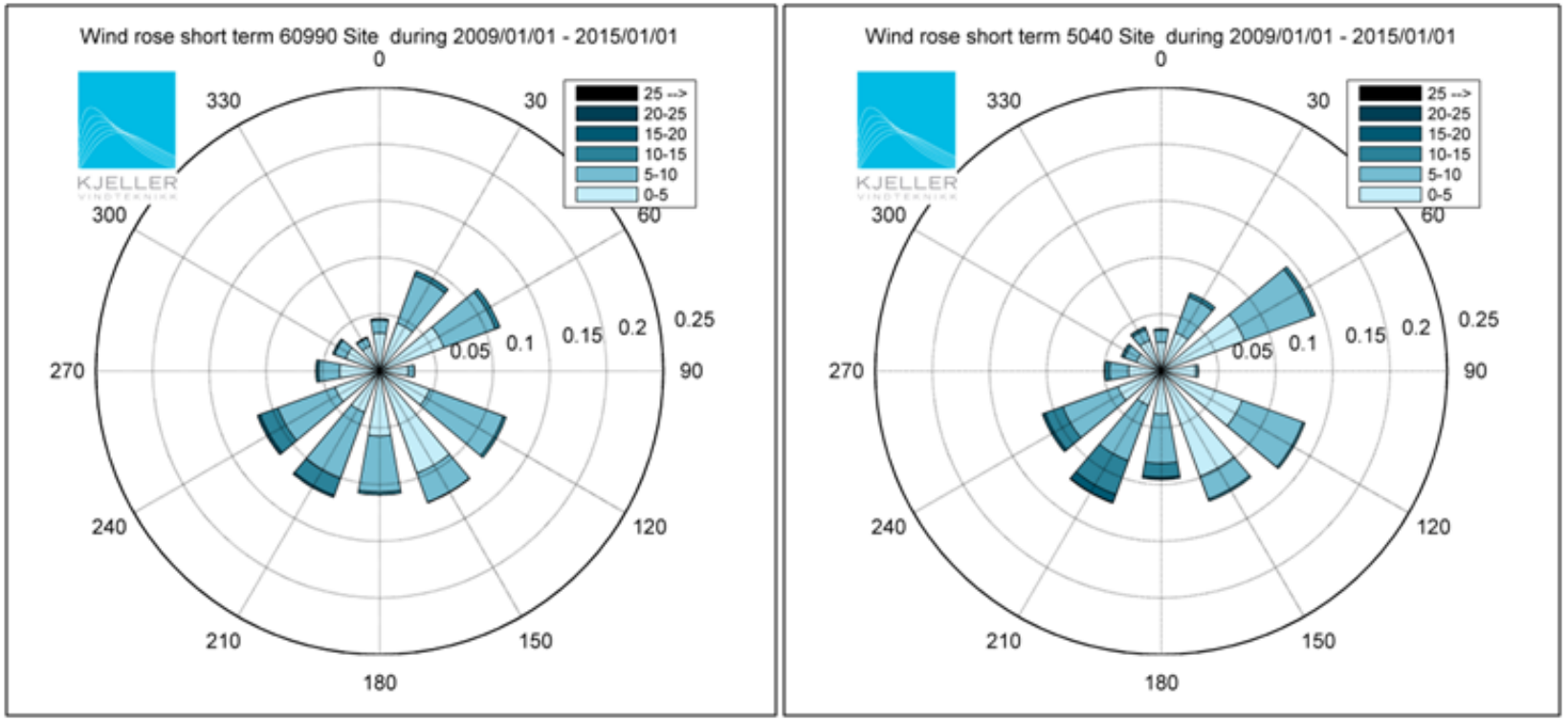
Model validation Vigra airport



Wind roses from the met mast (12 m agl) at Vigra (left panel) and WRF 500 m model data from 10 m (right panel). Data from 2009 – 2014.

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Model validation

Long-term mean wind speed from observations and 500 m data

Area	Data	Observations	500 m data	Deviation
B	Slåtterøy lighthouse (10 m)*	6.30	6.45	2.4 %
B	Stord airport (10 m)*	4.44	4.51	1.6 %
B	Haugesund airport (10 m)*	5.80	5.73	-1.2 %
B	Bergen airport, Flesland (10 m)*	3.85	3.93	2.1 %
S	Vigra (10 m)*, 2009 - 2014	5.12	5.16	0.8 %
B	Ospøya N (50 m)**	6.37	6.55	2.8 %
B	Ospøya S (50 m)**	6.64	6.55	-1.4 %
B	Synnøytangen (50 m)**	5.92	6.08	2.7 %
B	Svarvhelleholmen (50 m)**	4.73	5.99	26.6 %
S	Julbø (50 m)**	5.31	5.48	3.2 %
S	Midsund (50 m)**	4.46	4.32	-3.2 %

*Official weather stations operated by Norwegian Meteorological Institute
**Project masts

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Data postprossessing – Extreme wind calculations

- The 1979 – 2015 synthesized data set is used for general wind statistics and for extreme wind calculations
- The extreme wind method used is the Gumbel – Lieblein method at the series of yearly maxima of U^2
- This method is robust for errors in the tails, which is very important when analysing model data series
- 50 year extreme wind maps are created using every 500 x 500 m horizontal point value, and a convolute smoothing filter are used to remove noise
- Maps are given for hourly extreme values for different heights (10 m, 60 m most typical)
- Transfer to 10 minute values are made using factors from met masts (North Sea mast, synoptic stations, E39 masts). Factor 1.07 is now used

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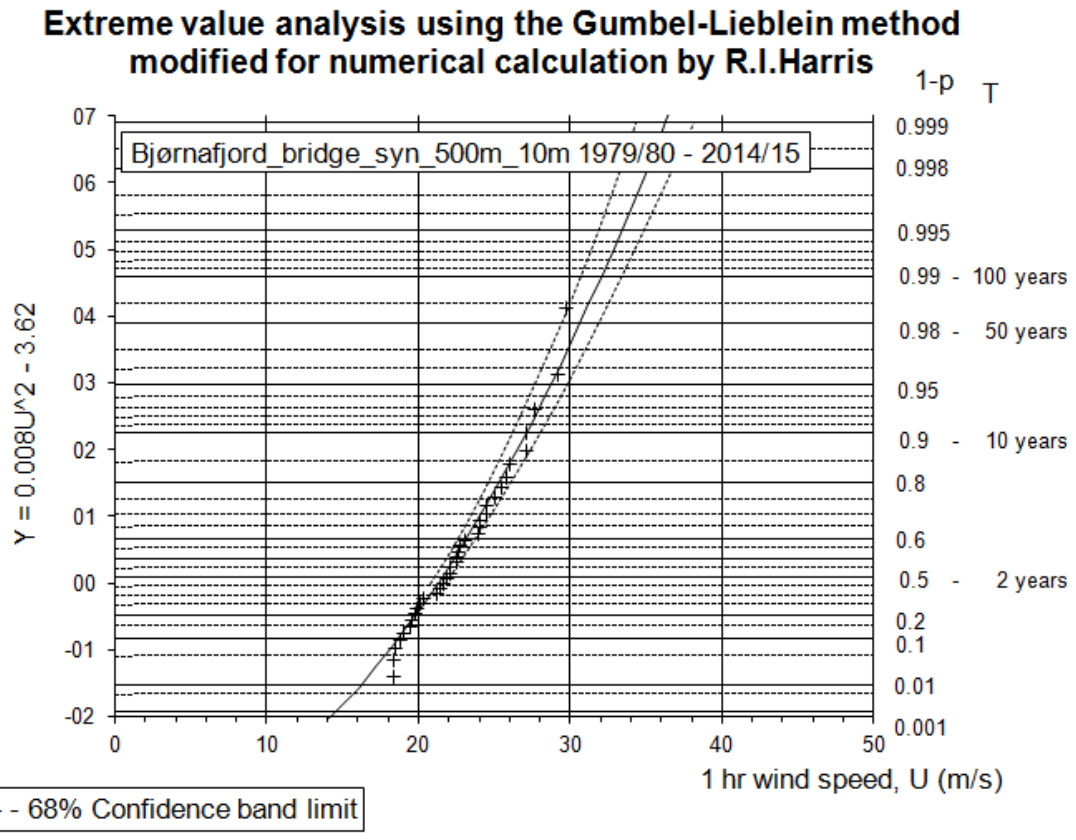
Extreme wind calculations



p	0.5	0.2	0.1	0.05	0.04	0.02	0.01	
T	2	5	10	20	25	50	100	years
U	22.3	25.3	27.1	28.7	29.2	30.7	32.1	m/s

Gumbel-Liebein plot of extreme wind speed from yearly maximum synthetic wind speed.

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Model validation - extreme wind speed

50 year wind speed [m/s] from measurements and model data

Area	Data	Observations (10min)	500 m data (1 hr)
B	Synnøytangen (50 m)**	32.5	32.0
B	Svarvhelleholmen (50 m)**	31.5	32.3
S	Vigra (10 m)*	32.0	31.1
S	Julbø (50 m)**	28.8	32.6
S	Midsund (50 m)**	27.2	30.3

*Based on true observation series
**Based on synthetic series

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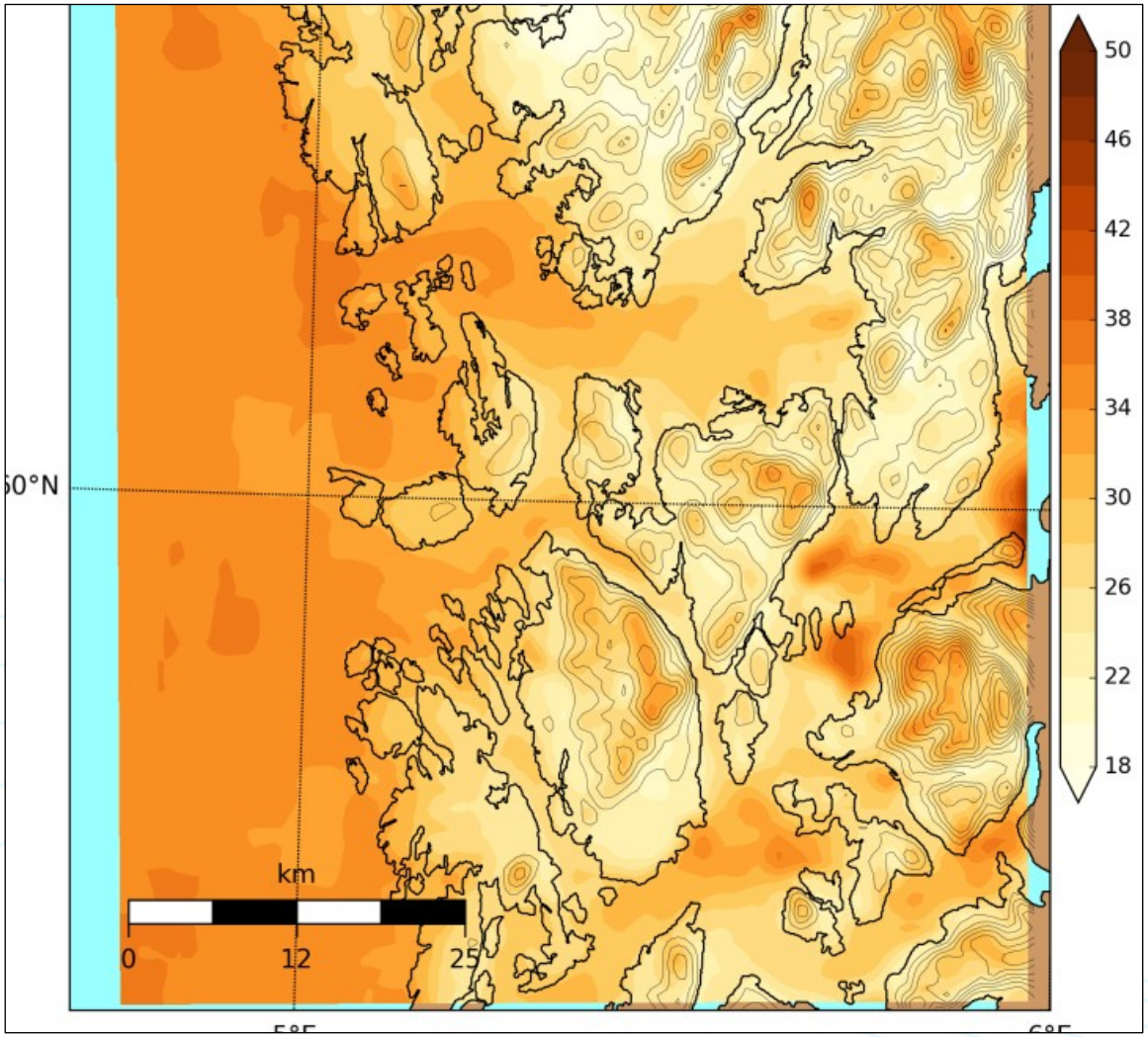
Extreme wind calculations



Map of the 10 minute 50 year wind speed at Bjørnafjorden area calculated at 10 m agl using WRF synthesized data series (1979 - 2014).

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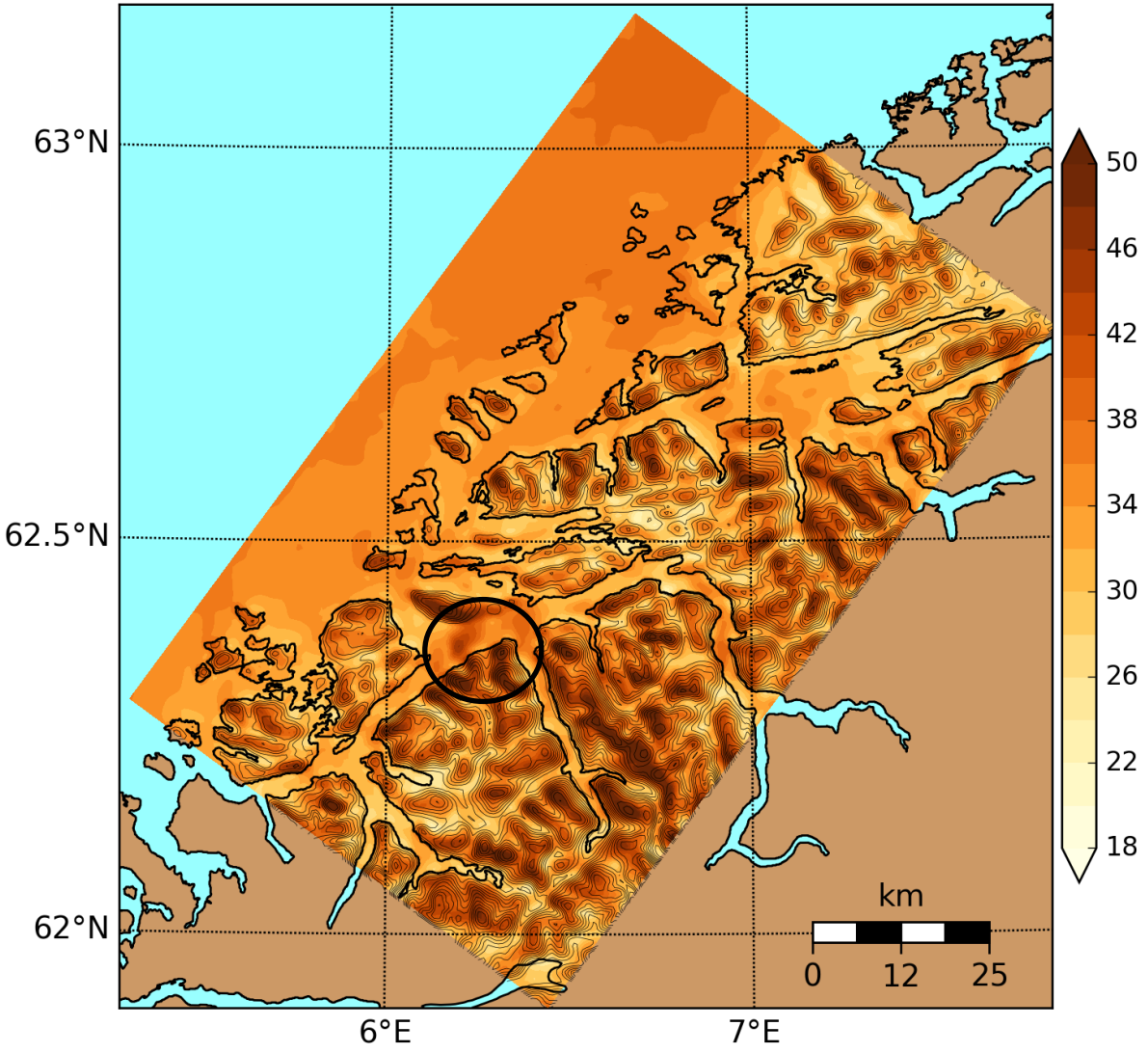
Extreme wind calculations



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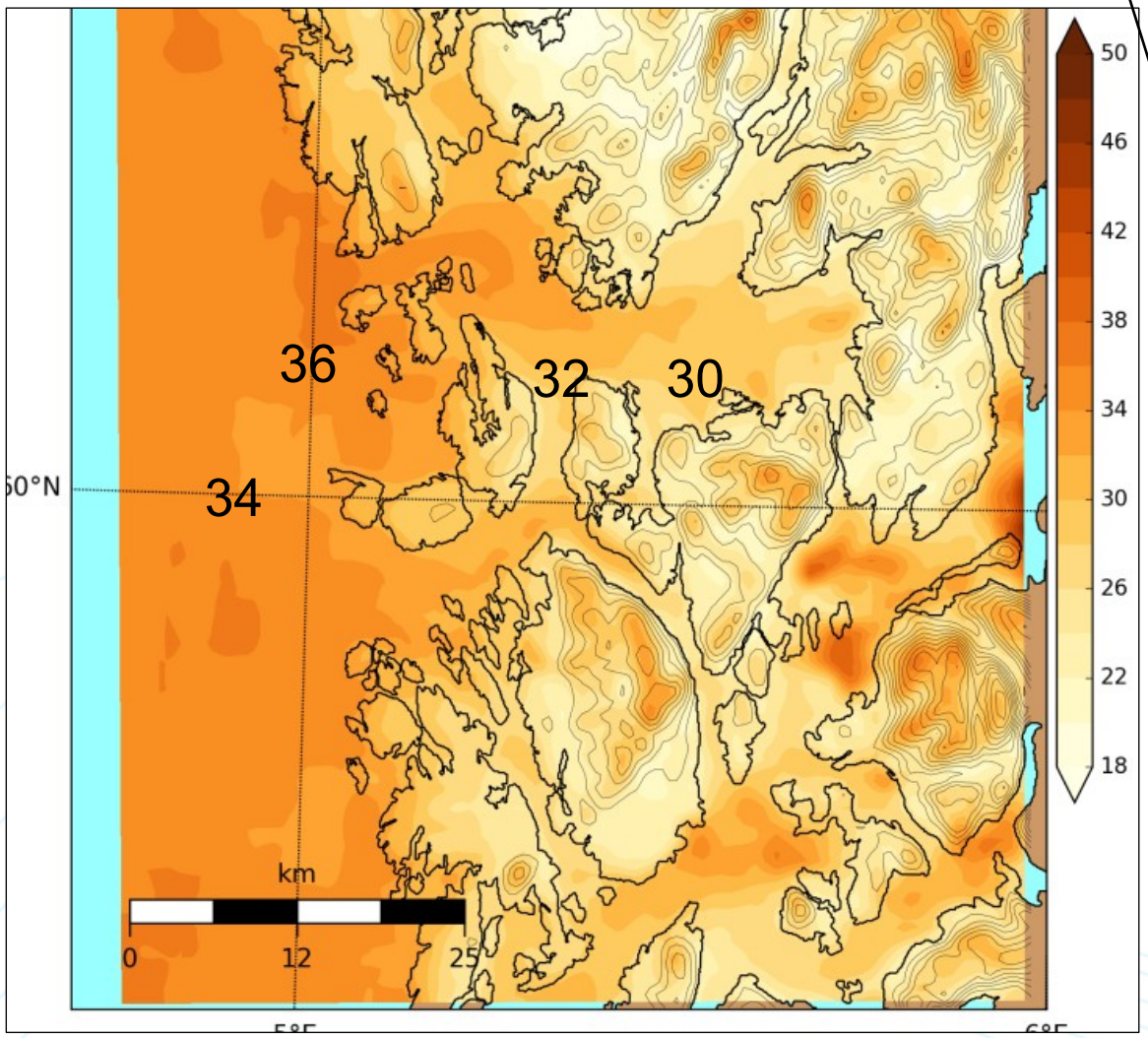
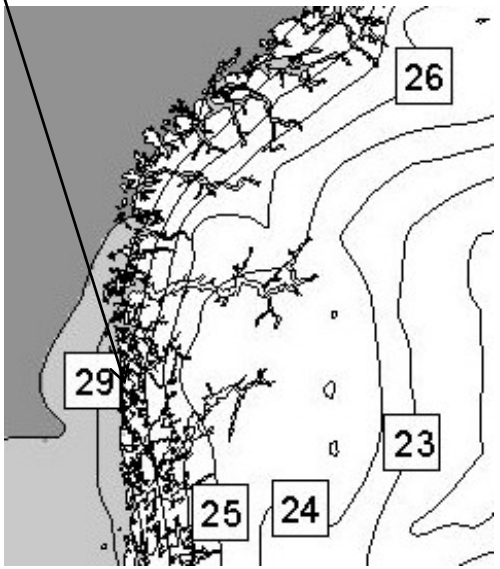
Comparing to NS-EN 1991-1-4:2005+NA:2009





$U_{50yr;\ 10m;10min;\ 0.003m}$
$= 1.27 \times U_{50yr;\ 10m;10min;\ 0.05m}$
$U_{50yr;\ 10m;10min;\ 0.01m}$
$= 1.17 \times U_{50yr;\ 10m;10min;\ 0.05m}$
=>30 – 35 – 38 m/s as 50 yr values

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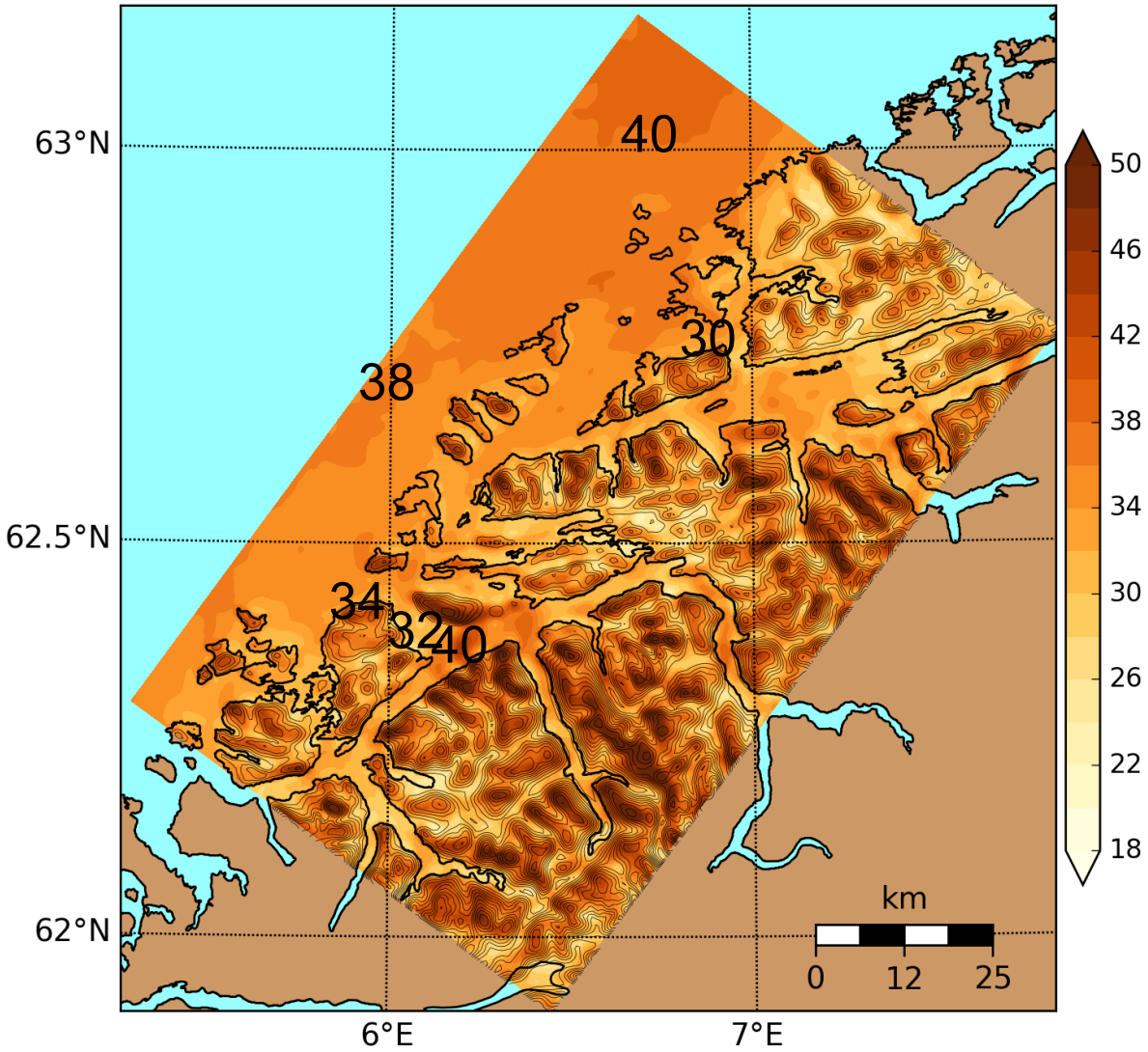
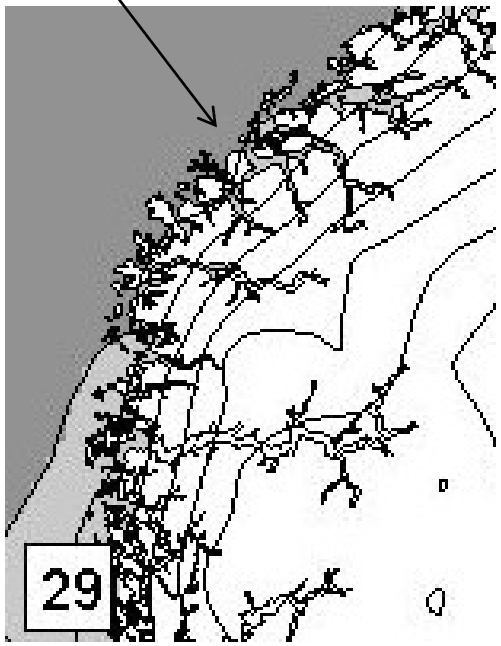
Comparing to NS-EN 1991-1-4:2005+NA:2009





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Conclusion remarks

- The WRF model is nested down to 500 m x 500 m for a period of ~ 5 to 10 years
- The period covering 500 m x 500 m data is extended to a long period (~ 30 years) using statistical downscaling of 6 km x 6 km WRF data
- General wind statistics and extreme wind statistics can be extracted from the synthetic data sets
- The results are very good at open landscape at a scale of few kilometers, even if this landscape is surrounded by complex mountain terrain
- Near steep terrain the model may overestimate the hourly wind speed. However, such sites may be characterized by strong wind gusts
- The model data may give more representative results at open fjord areas than data based on masts at shore close to steep or irregular terrain
- The model data sets are suitable for different kinds of maps (average wind speed, extreme wind speed, …….)
- The statistical downscaling method is suitable also for observation campaign data

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Further work

- From all masts continues 3 D data in 3 heights are continously sampled with a frequency of 10 Hz. Turbulence spectra and coherence analysis are carried out
- There is planned several Lidar campaigns to measure horizontal and vertical wind and turbulence profiles
- Different kinds of CFD – models will be tested to the data, especially in the Møre and Romsdal region where the terrain is more complex, steeper and higher. We will try CFD models with high resolute mesoscale timeseries as input profiles

NS-EN 1991-1-4:2005+NA:2009

Time to take a step further?

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