On recent development and challenges associated with the operation and utilization of renewable energy

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Fossil fuelled power plants in Norway

- Kårstø (Gas):
  - Put in operation in 2007
  - Energy capacity: 3.5 TWh per year
  - **Decommissioned in 2017**

- Mongstad (Gas):
  - Put in operation in 2010
  - Energy capacity: 2.3 TWh per year
  - **Will be shut down in 2018.**

Norge bygger rekordmye vindkraft

Det har aldri blitt bygget ut og satt i drift mer vindkraft i Norge enn i 2017, viser ferske tall fra NVE.

BYGGES MYE: Rekordmye vindkraft var under utbygging i 2017, ifølge tall fra NVE. Dette er Tellenes vindkraftverk i Rogaland, som ble satt i produksjon i fjor. Google har en 12-årig avtale om kjøp av strømmen fra anlegget. **FOTO:** ZEPHYR

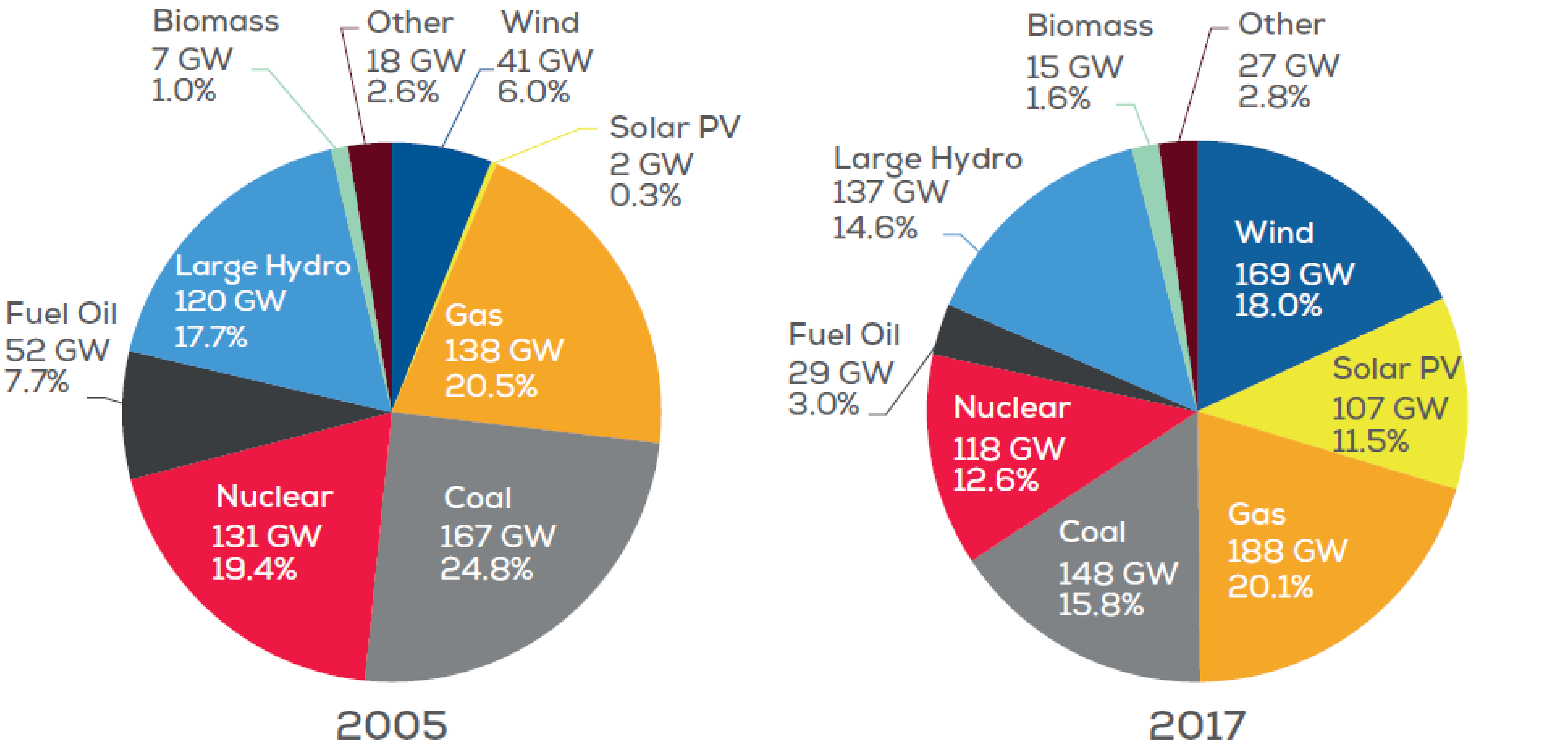
2017 was a record year for wind energy in Norway.

Never before has so much wind energy capacity been installed

Installed capacity in EU

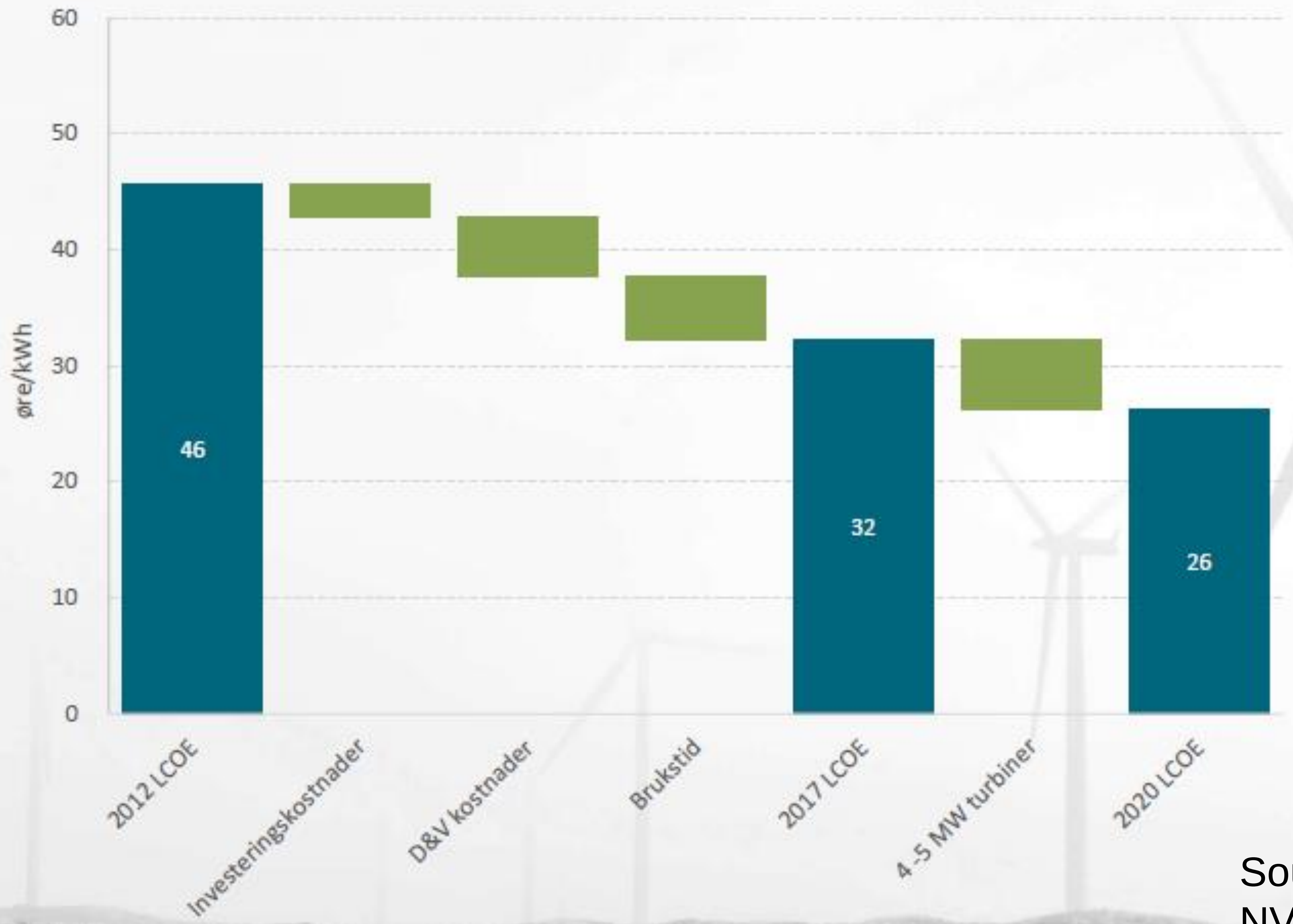
FIGURE 8

Share in installed capacity in 2005 and 2017



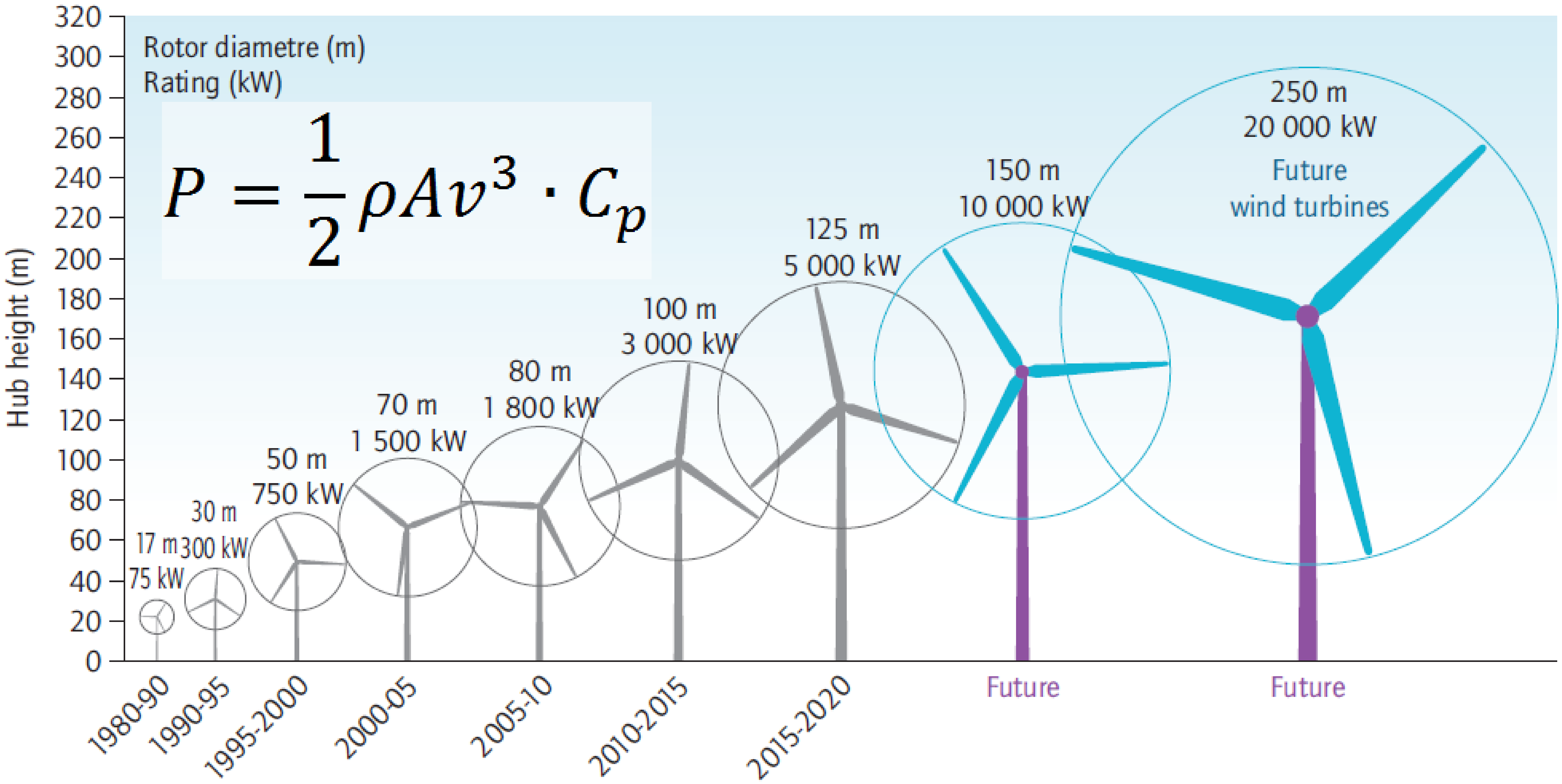
Source: WindEurope

Vindkraftkostnader faller raskt



Source: Per Sanderud,
NVE vindkraftseminar 2018

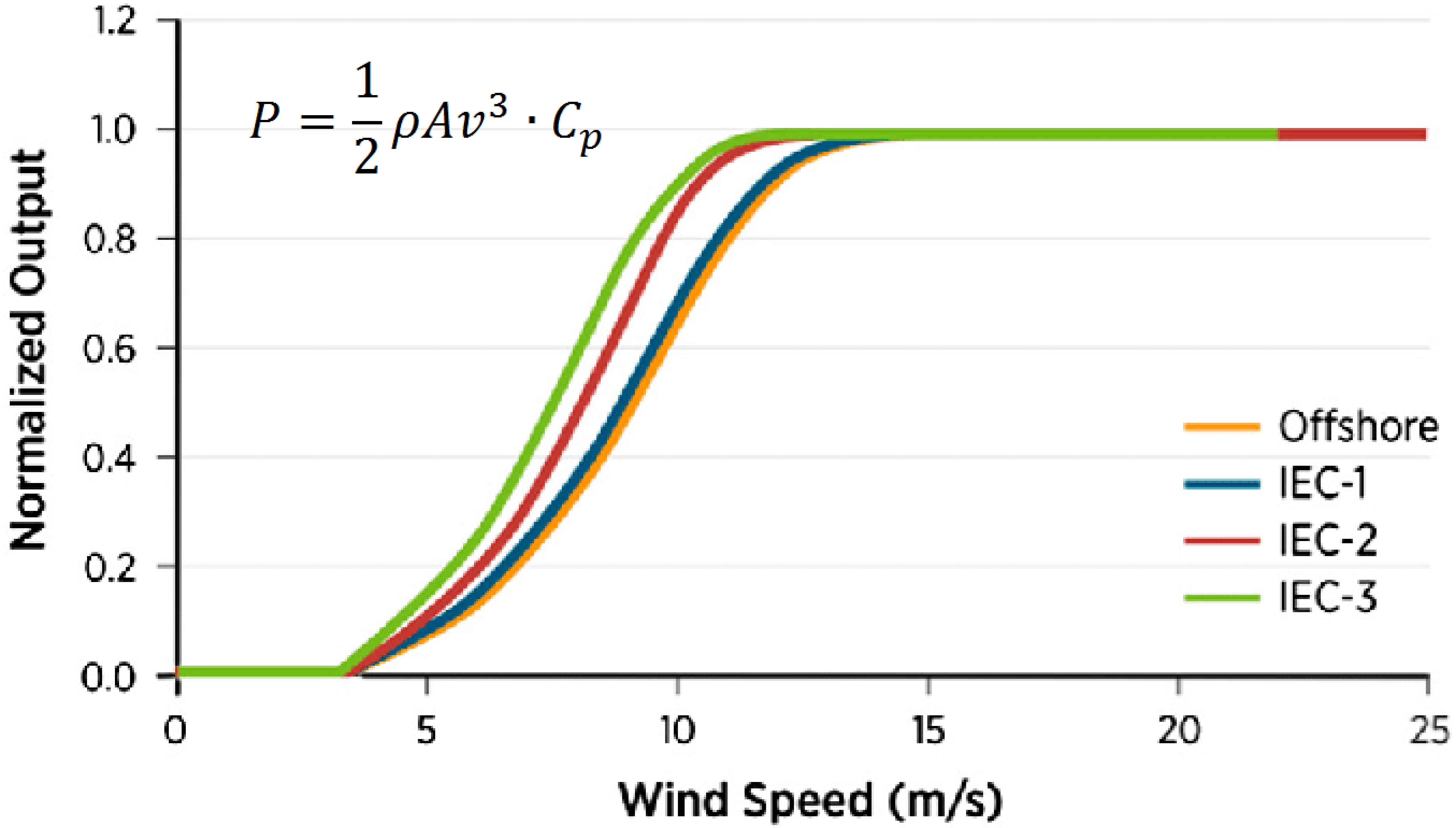
$$P = \frac{1}{2}\rho A v^3 \cdot C_p$$



Source: adapted from EWEA, 2009.

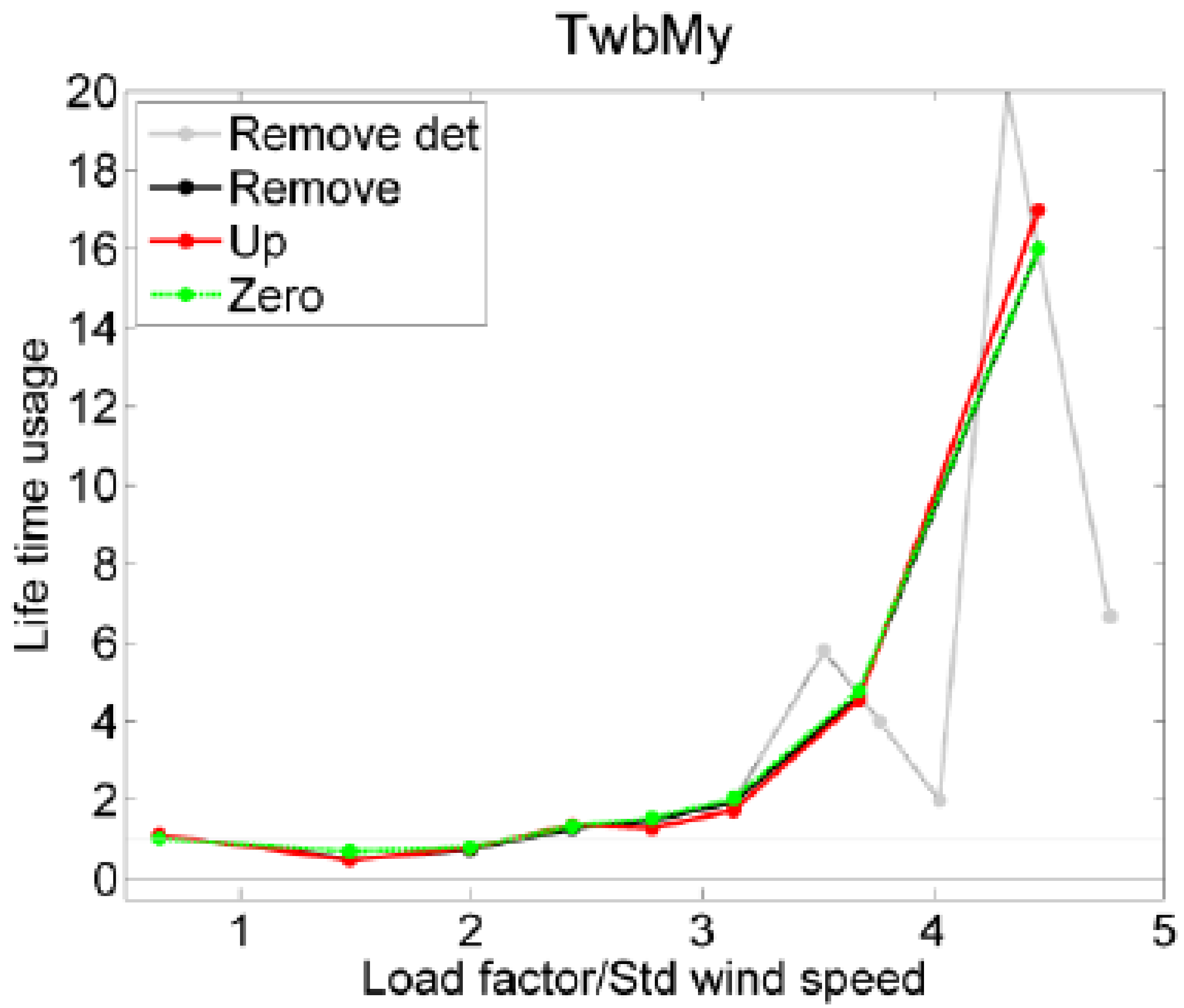
Wind turbine power curves

$$P = \frac{1}{2}\rho A v^3 \cdot C_p$$



Turbine lifetime

- The turbines are designed for a lifetime of 20 years.
- Every hour of production will contribute to a shortening of the remaining life time of the turbine:
  - Large wind vertical wind shear (or negative wind shear)
  - Turbulence
  - Vertical wind component
  - High wind speeds



Adaptive turbine operating systems

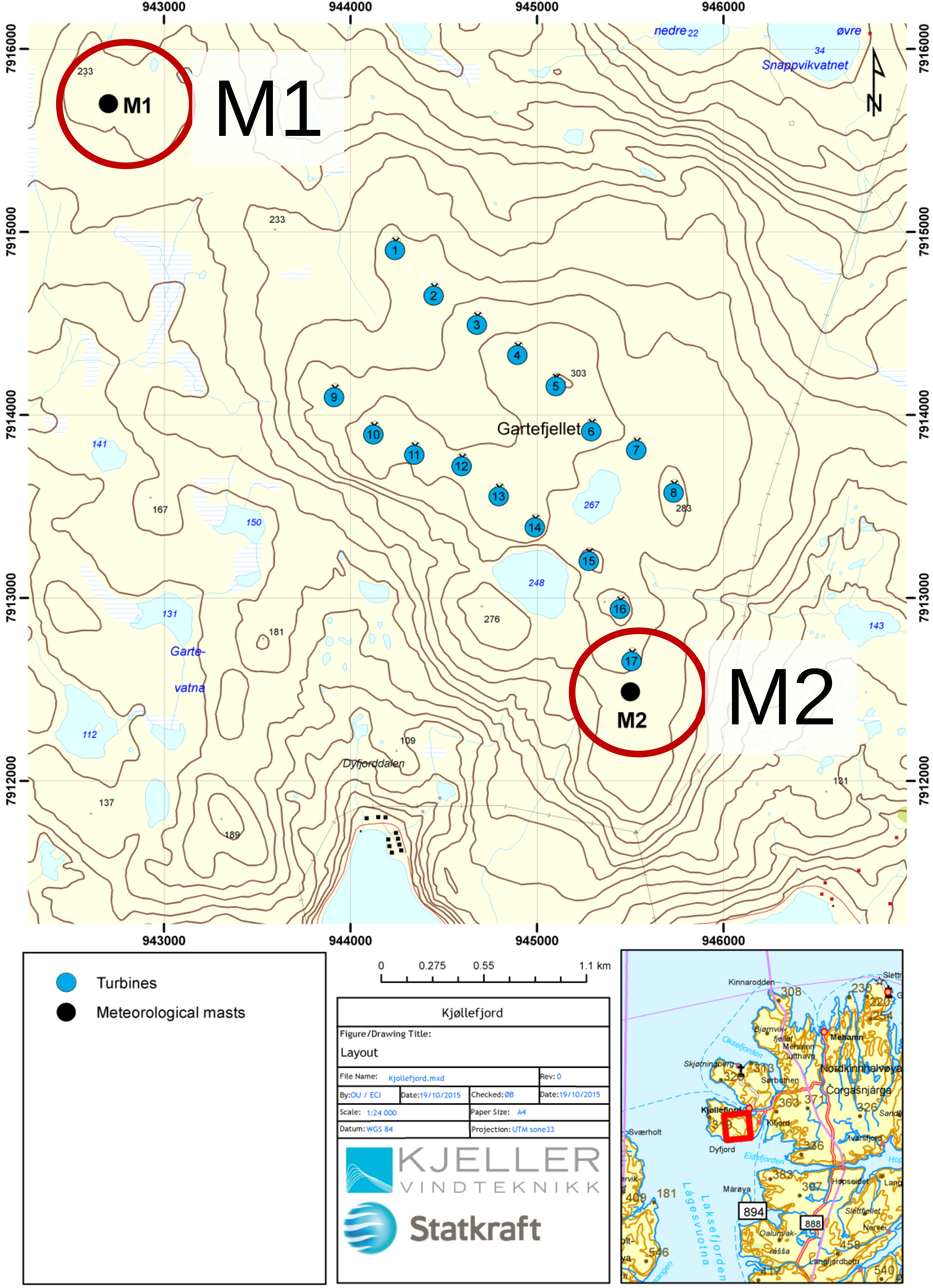
- Allow turbines to operate differently under different meteorological conditions.
- Increase the lifetime of components:
  - If we avoid 1% of the highest load cases the turbine lifetime can be extended by 1 year.
- Allow the use of more efficient turbines with longer blades at exposed sites (IEC classificaitons)

More detailed knowledge about the meteorological conditions will be needed!

Case study: Kjøllefjord

Kjøllefjord wind farm

- Location: 70°56’ North
- Wind energy data
  - 17 Siemens 2.3 MW turbines
  - In operation since 2006
- Two masts:
  - M1 - 50 m tall mast located at 230 m.a.s.l.
  - M2 - 70 m tall mast located at 250 m.a.s.l.
  - The distance between the masts is ~4 km

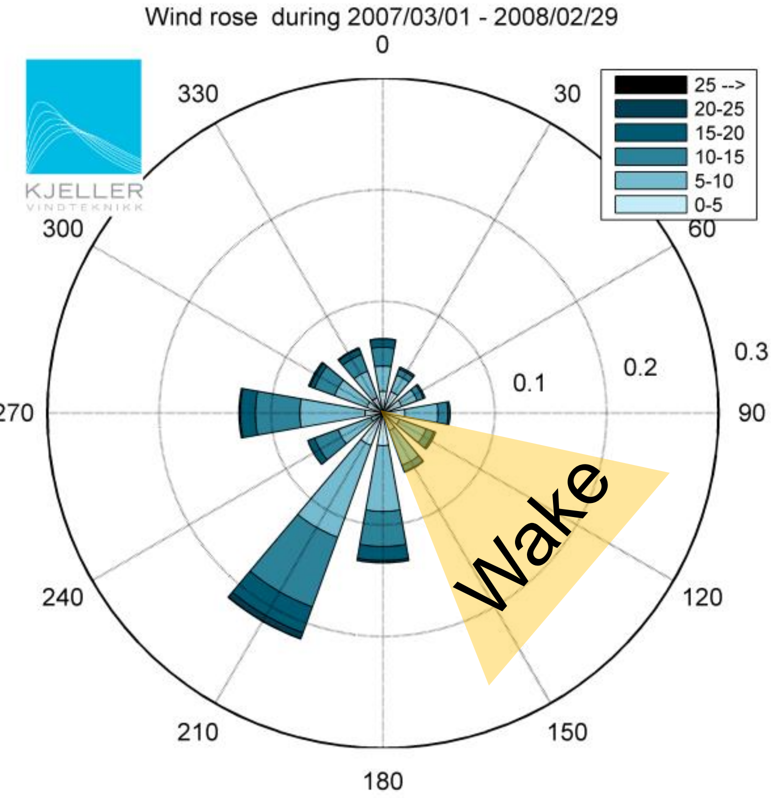


Measurements

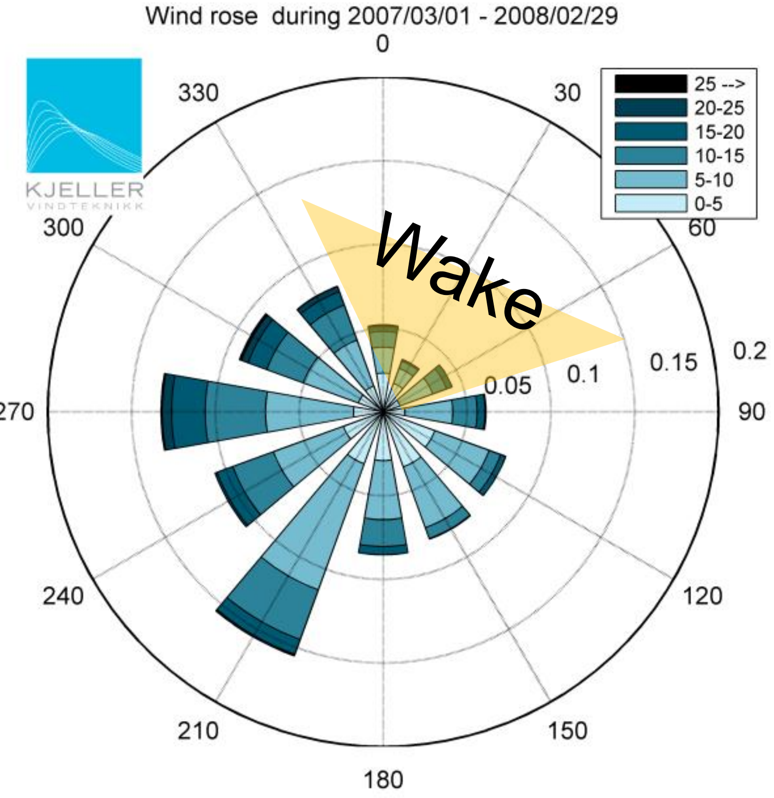
- 1 year analysis period:
  - March 2007 – February 2008

- Wind farm influence:
  - The wind farm influences are adjusted for in the analysis by a wake model, but concerns sectors of minor interest to the analysis.

M1 mast - northwest

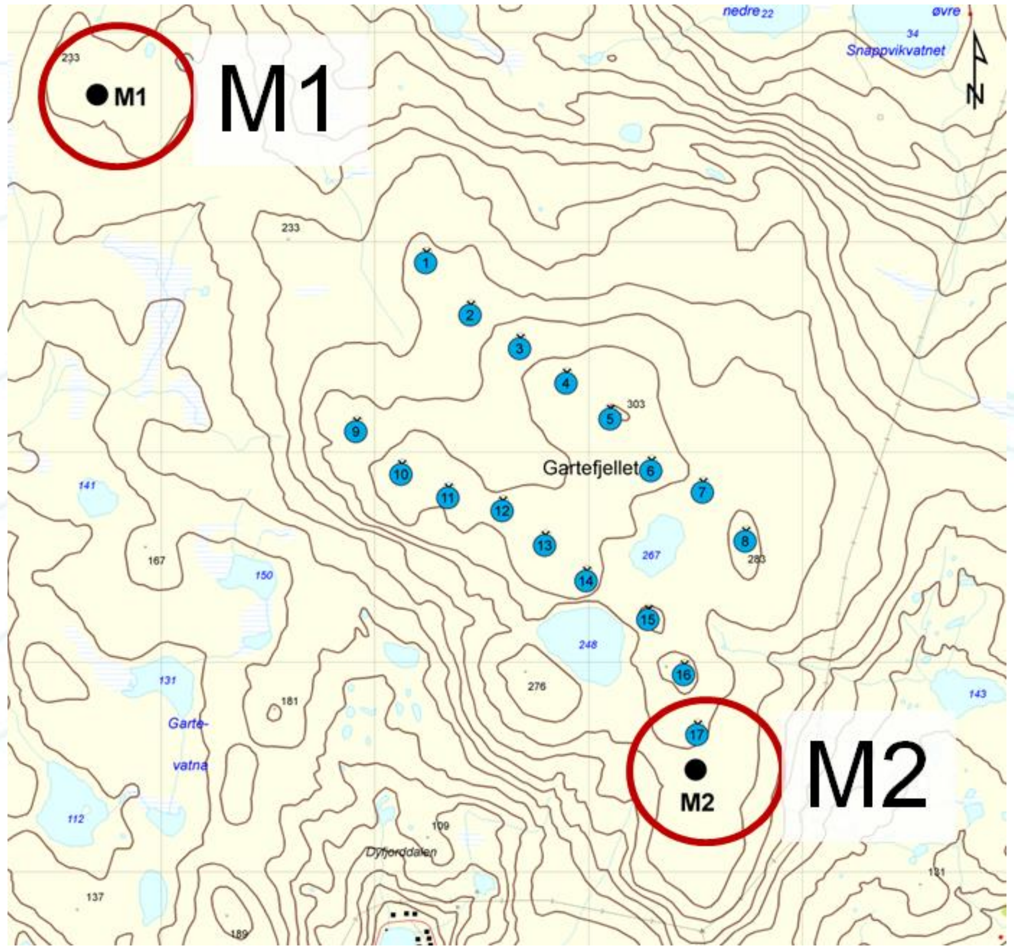


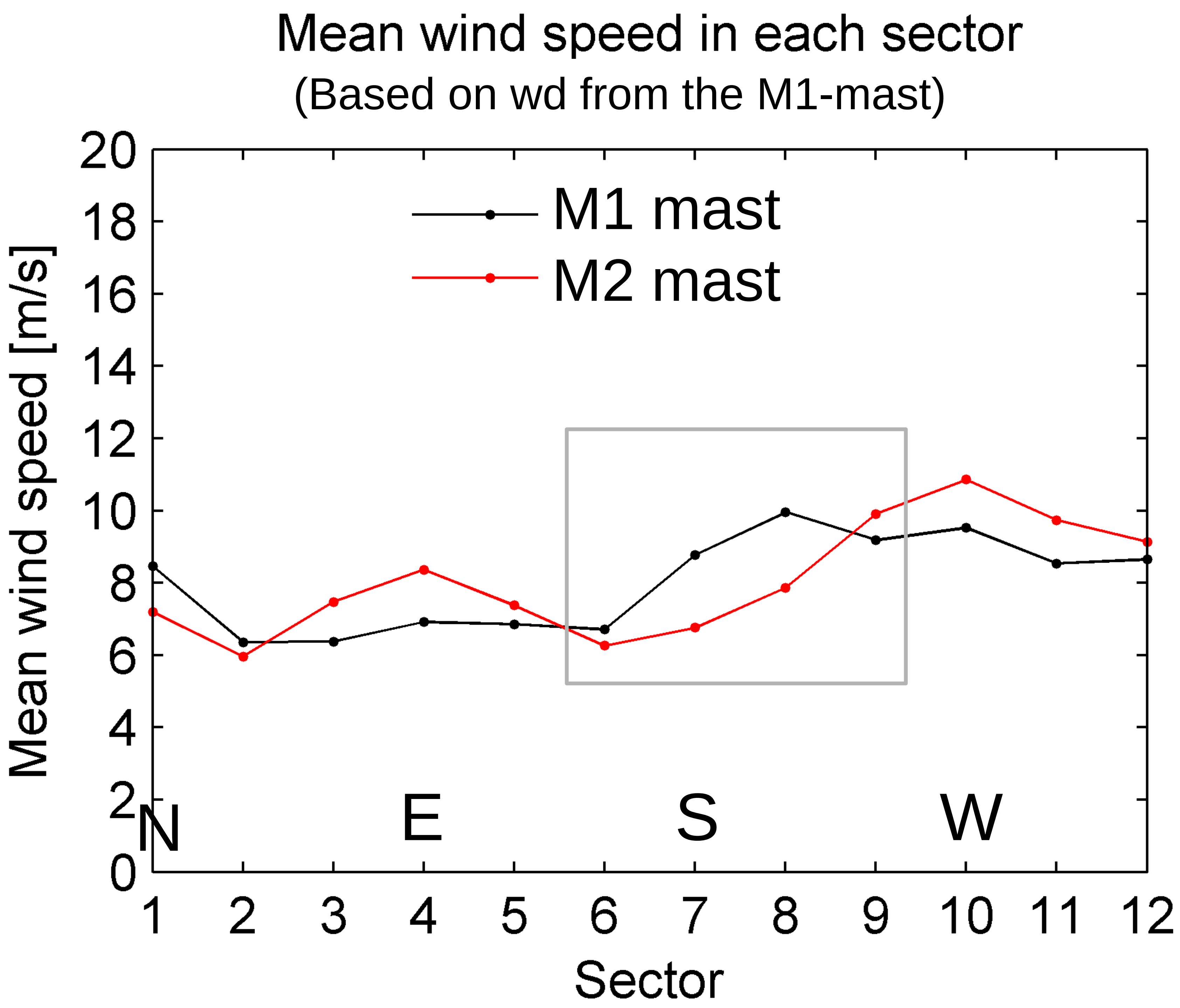
M2 mast - southeast



Measurements

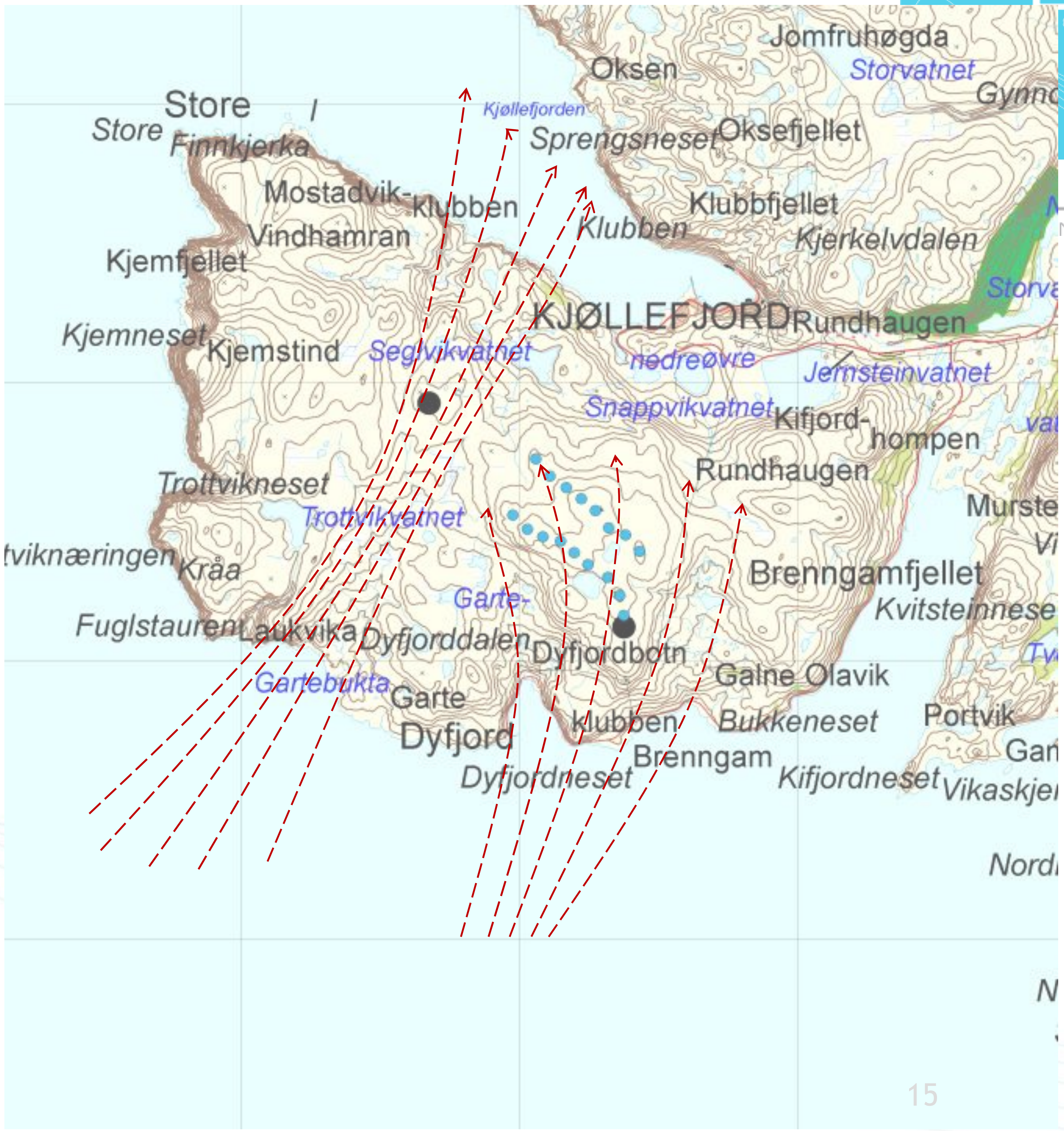
	elevation	height	average wind speed
M1 – mast	230 m.a.s.l.	50 m	8.65 m/s
M2 – mast	250 m.a.s.l.	70 m	8.35 m/s





- The wind speed in M1 is higher than M2 in relation with winds in sector 7 and 8 (main wind directions)

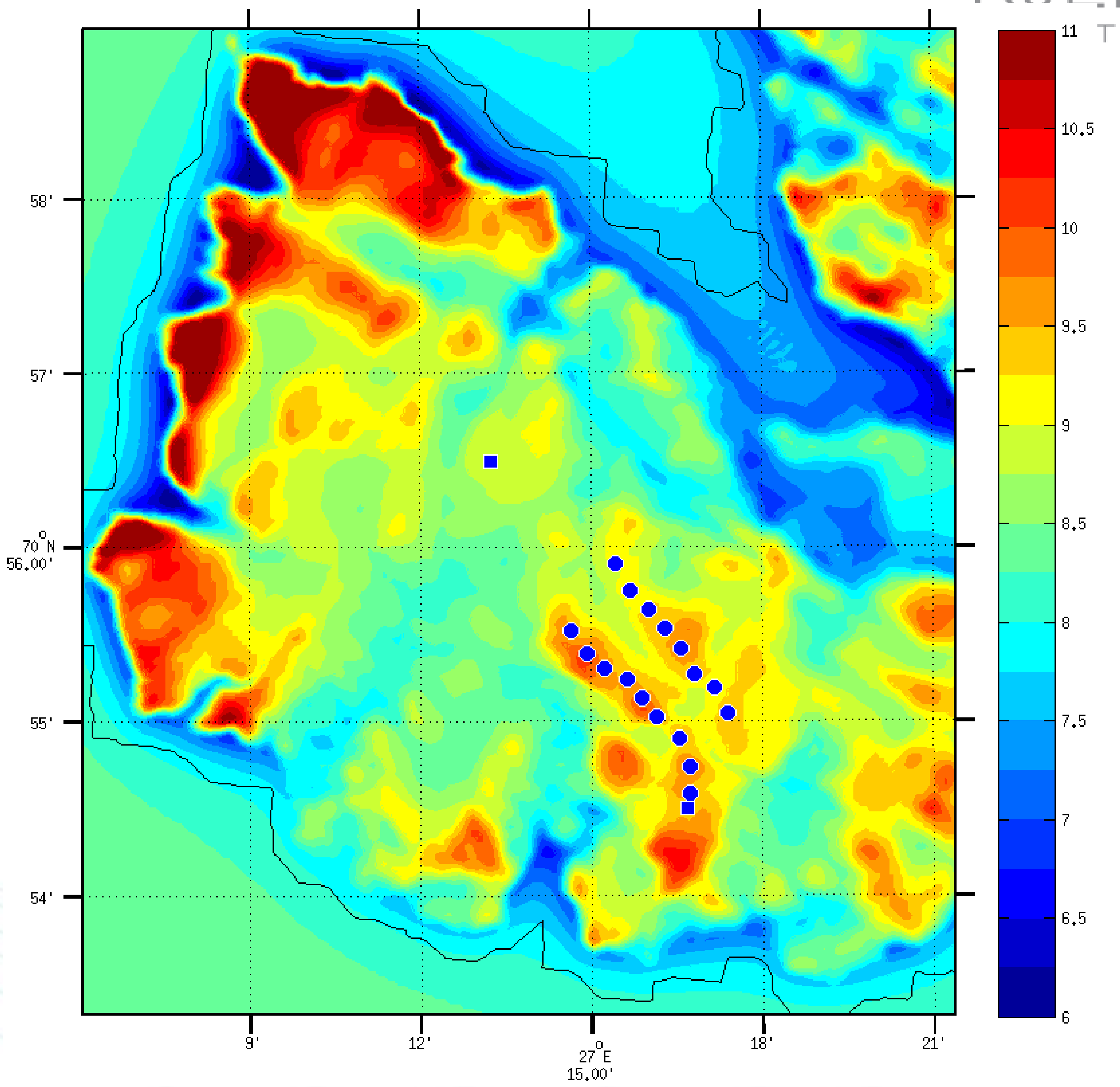
- M1 location:
  - Saddlepoint
  - Speedup
  - Convergence of wind
- M2 location:
  - Southern edge of a platau
  - Tendency of the wind to flow around under stable conditions
  - Divergence of wind



Modelling the wind conditions (I)

Traditional wind energy approach:

- Linear modelling (Wasp).
- Based on a mast calculate a wind atlas:
  - Represent the geostrophic wind
- The wind atlas is transfered to all points in the terrain:
  - Topography and surface roughness
- Calculations
  - Wind speed distibution for 12 wind directions
  - Neutral stability

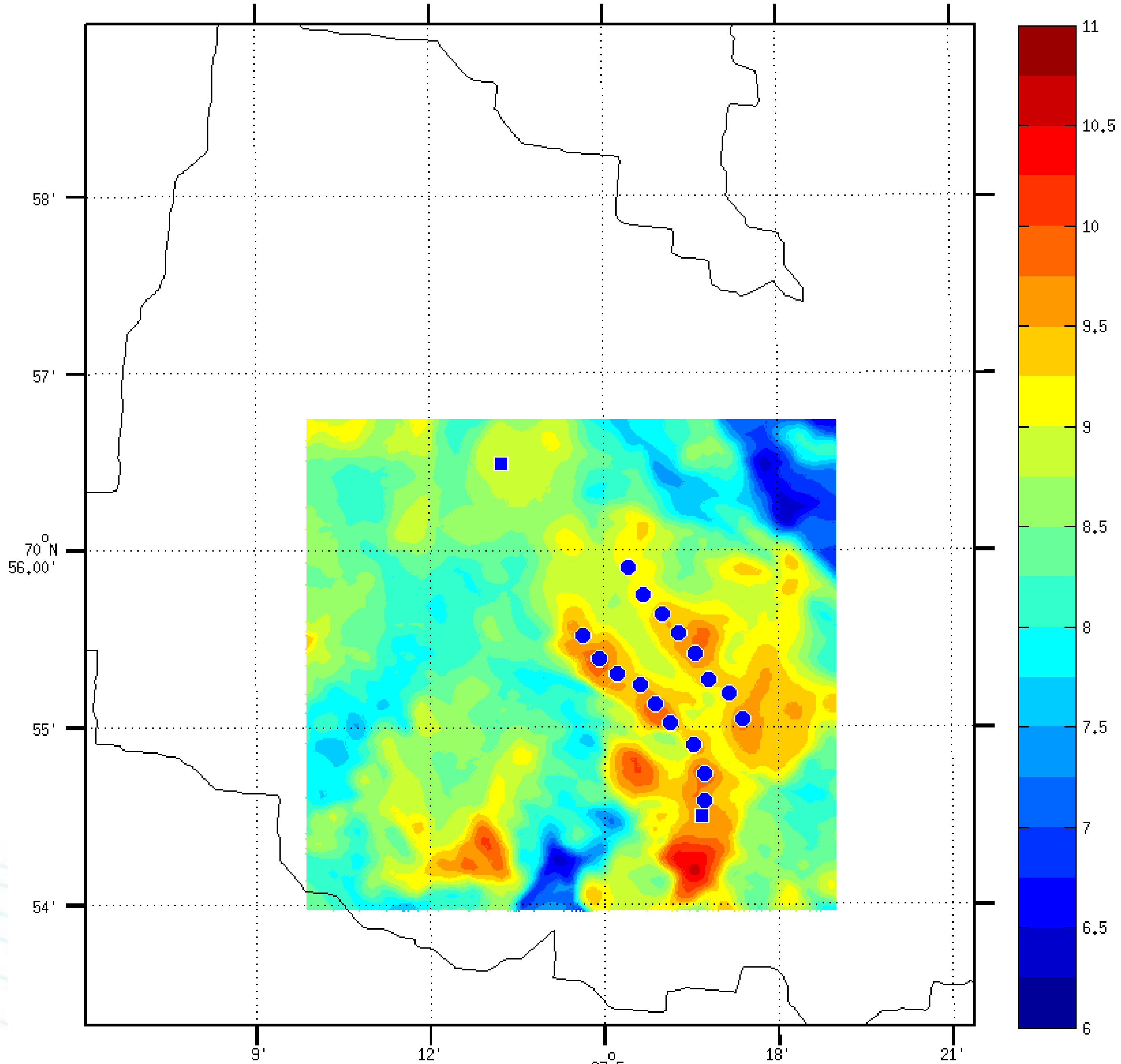


Wasp map based on M1-mast

Modelling the wind conditions (II)

Enginering approach:

- Computational fluid dynamics (WindSim)
- Reynolds averaged Navier Stokes (RANS)
- Pure flow modelling:
  - Topography and surface roughness
- Run until convergence for a number of inflow cases:
  - 12 wind directions
  - Neutral stability
- Typical grid resolution: 20 m x 20 m

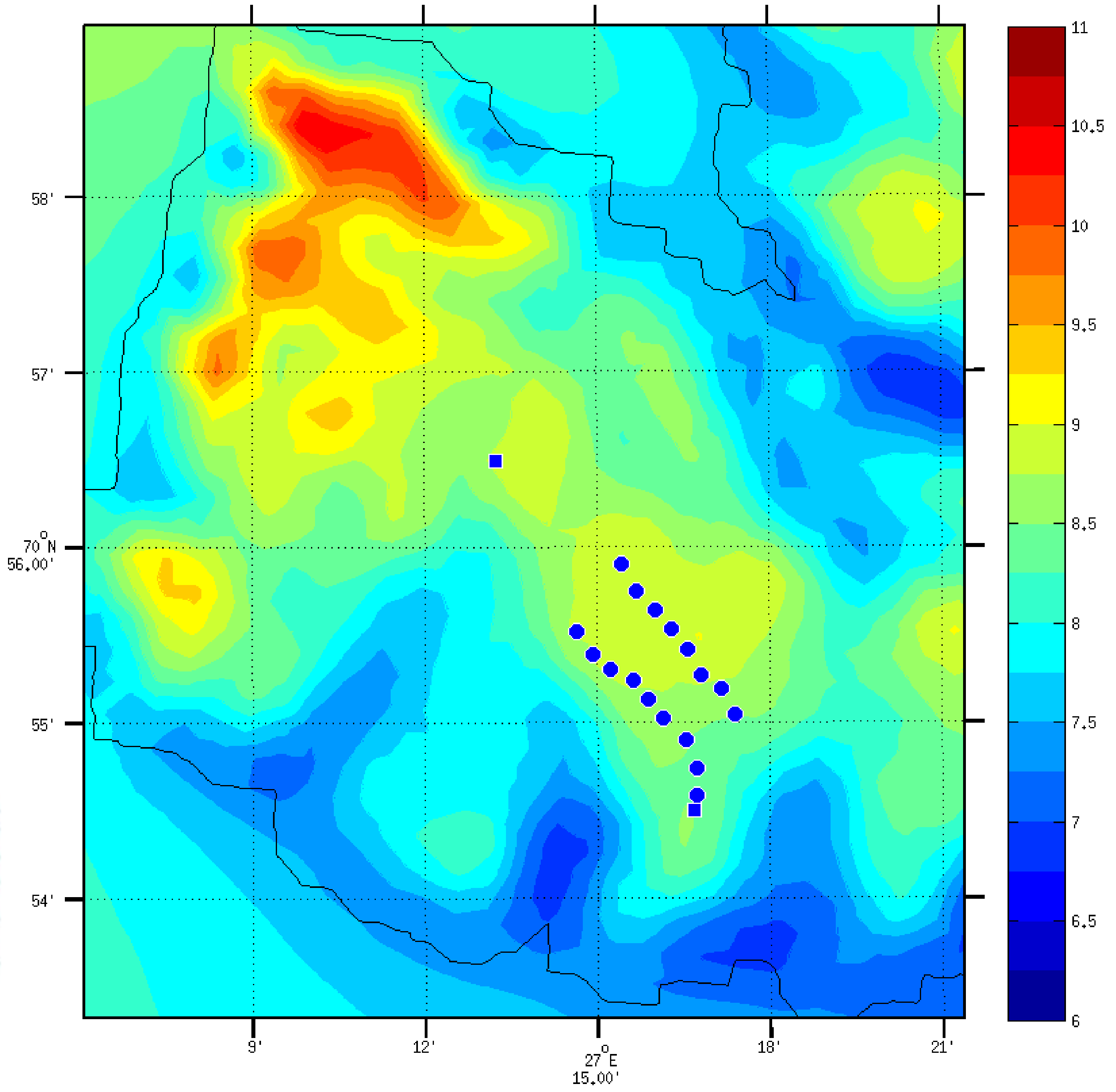


CFD map based on M1-mast

Modelling the wind conditions

Meteorological approach:

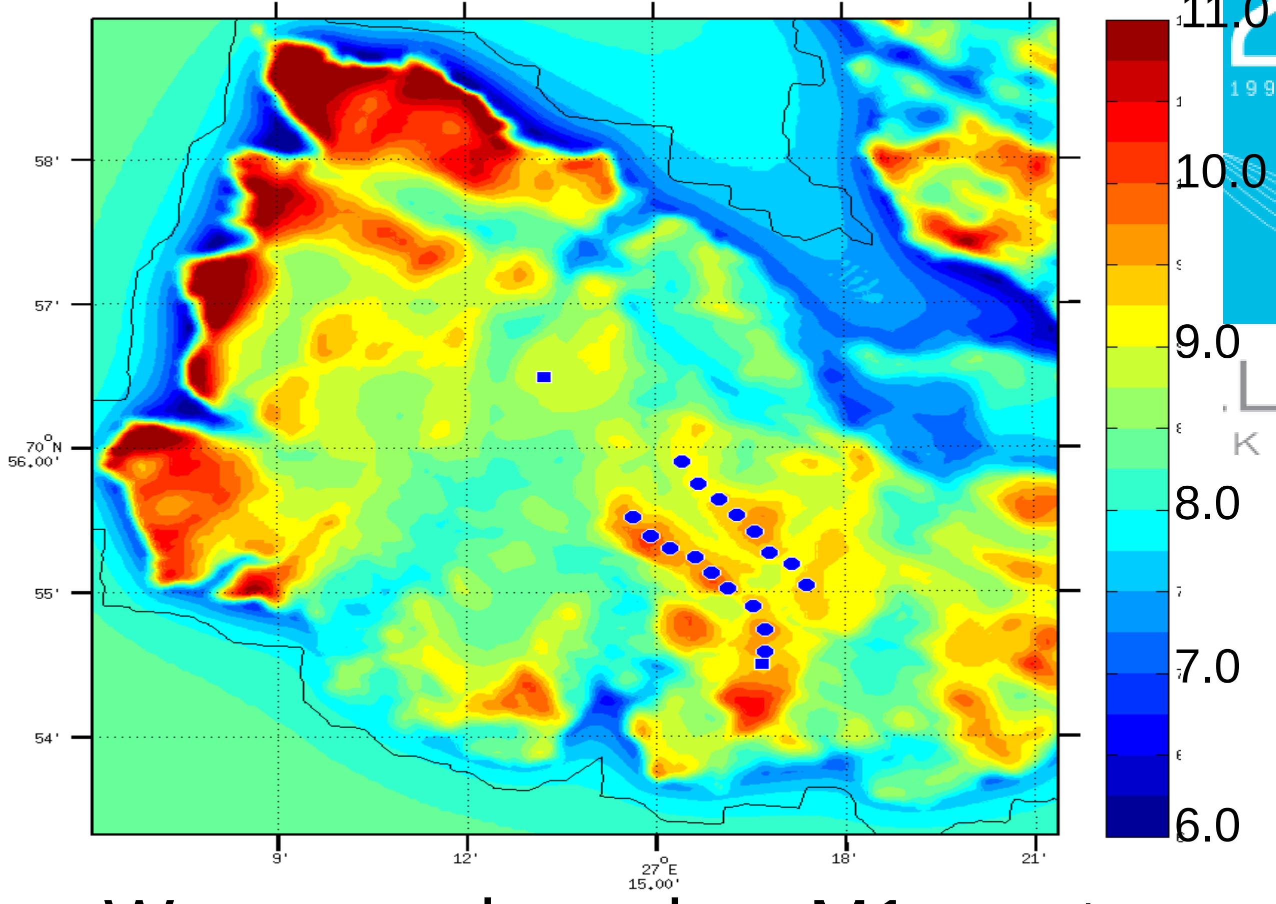
- Meteorological model (WRF)
- Coupled dynamics and physics:
    - Solar radiation, clouds, moisture, temperature, stability,
- Time dependent calculations
- Simulations carried out for one year.
- Horizontal resolution: 333m x 333m



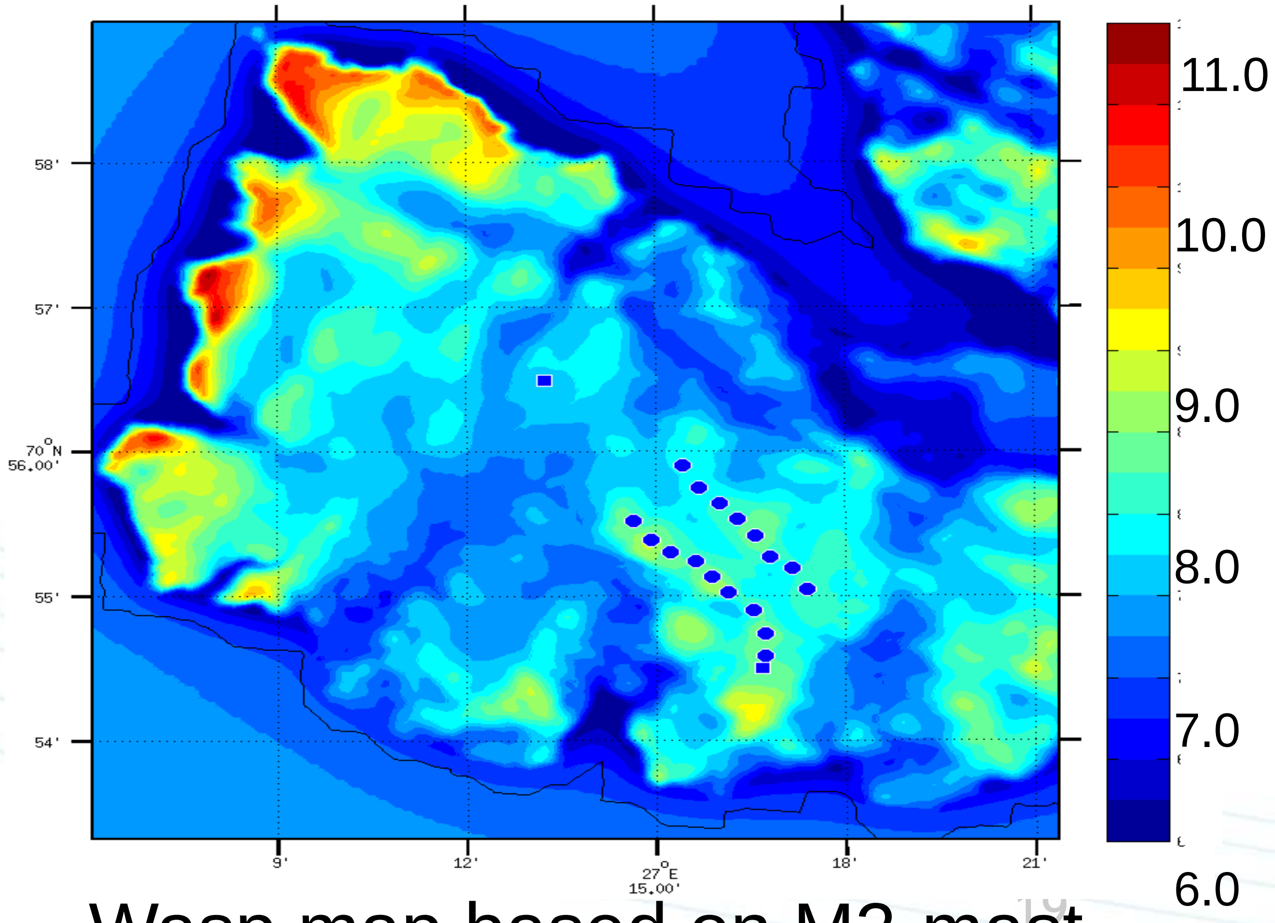
Microscale simulations

- Large difference in the wind maps:
  - M1 or M2 ?
  - 1.0-1.5 m/s
  - Similar results for CFD and Wasp

- Both microscale models expect the average windspeed to be higher at M2 than on M1



Wasp map based on M1-mast



Wasp map based on M2-mast

Cross prediction errors

	Mast data	Wasp	WindSim	WRF 333m
M1	- 7 %	- 14 %	- 16 %	- 3 %
M2	+ 7 %	+ 14 %	+ 17 %	+ 3 %

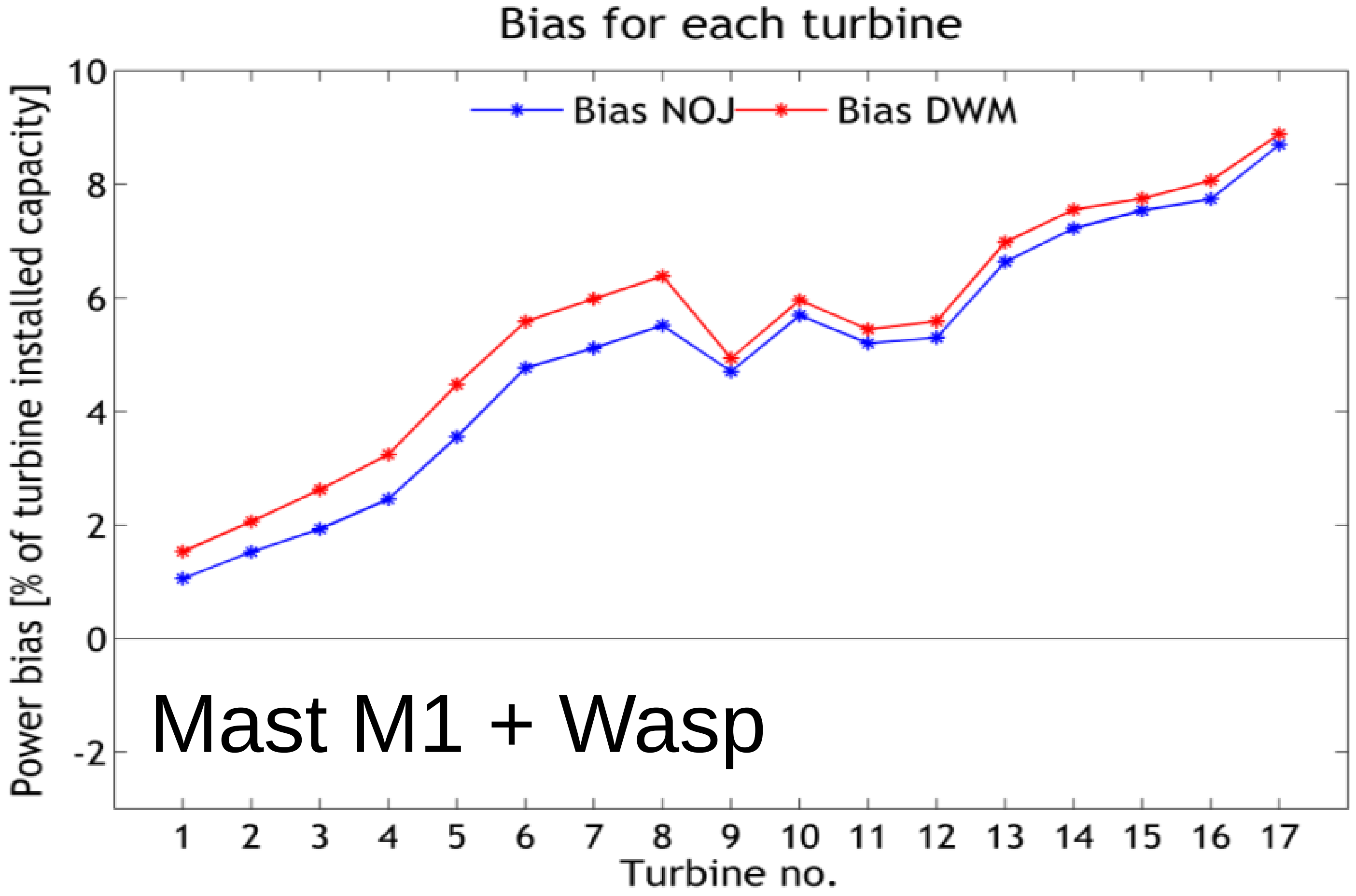
- Wasp and WindSim:
  - The largest cross prediction errors are found for sectors 5-10
  - The cross prediction errors is >20 % for the main wind direction
- WRF (333m):
  - Largest cross prediction errors in sector 2 and 5 of around 10%
  - Low cross prediction error in the main wind directions

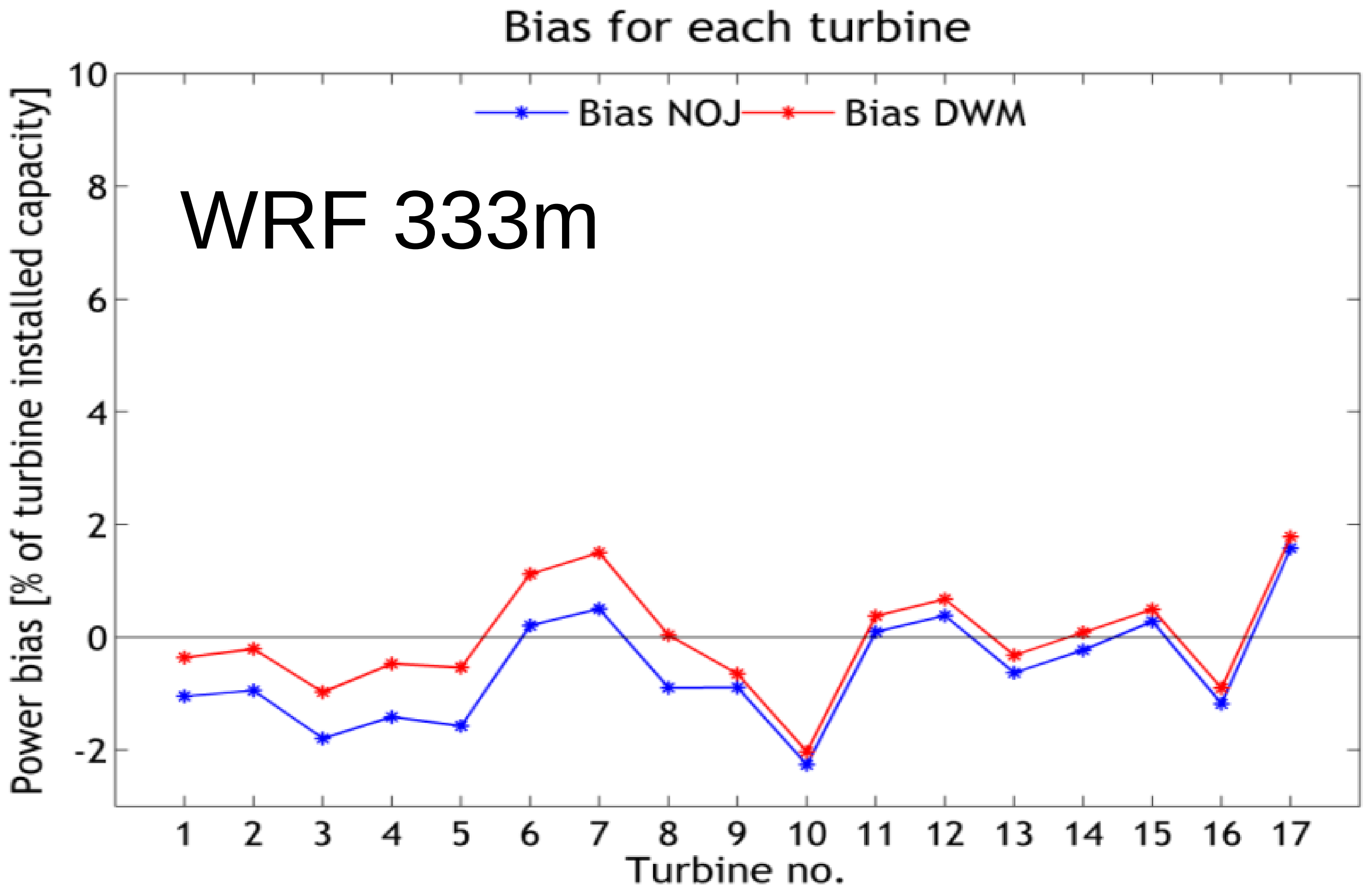
Bias in energy calculation per turbine

- Energy calculations using Wasp:
  - Average bias: 5 %
  - Individual bias: 1-9 %

- Energy calculations using WRF (333m):
  - Average bias close to 0 %
  - Individual bias +/- 2 %

The energy calculations were performed with the **Wind Farm Simulator** (Undheim et al, 2014) using two different wake models:
NOJ – N.O.Jensen
DWM – Dynamic Wake Meandering





Conclusions

- Large benefits of using meteorlogical methods to calculate wind energy
- Larger accuracy in the calculations is needed to develop new cost effective wind energy projects.
- Smarter turbines will have more complex operating systems with the need for more meterological data and more detailed forecasts.
- The cost of windpower have reduced largely over recent years and is expected to be further reduced

Thank you for your attention!

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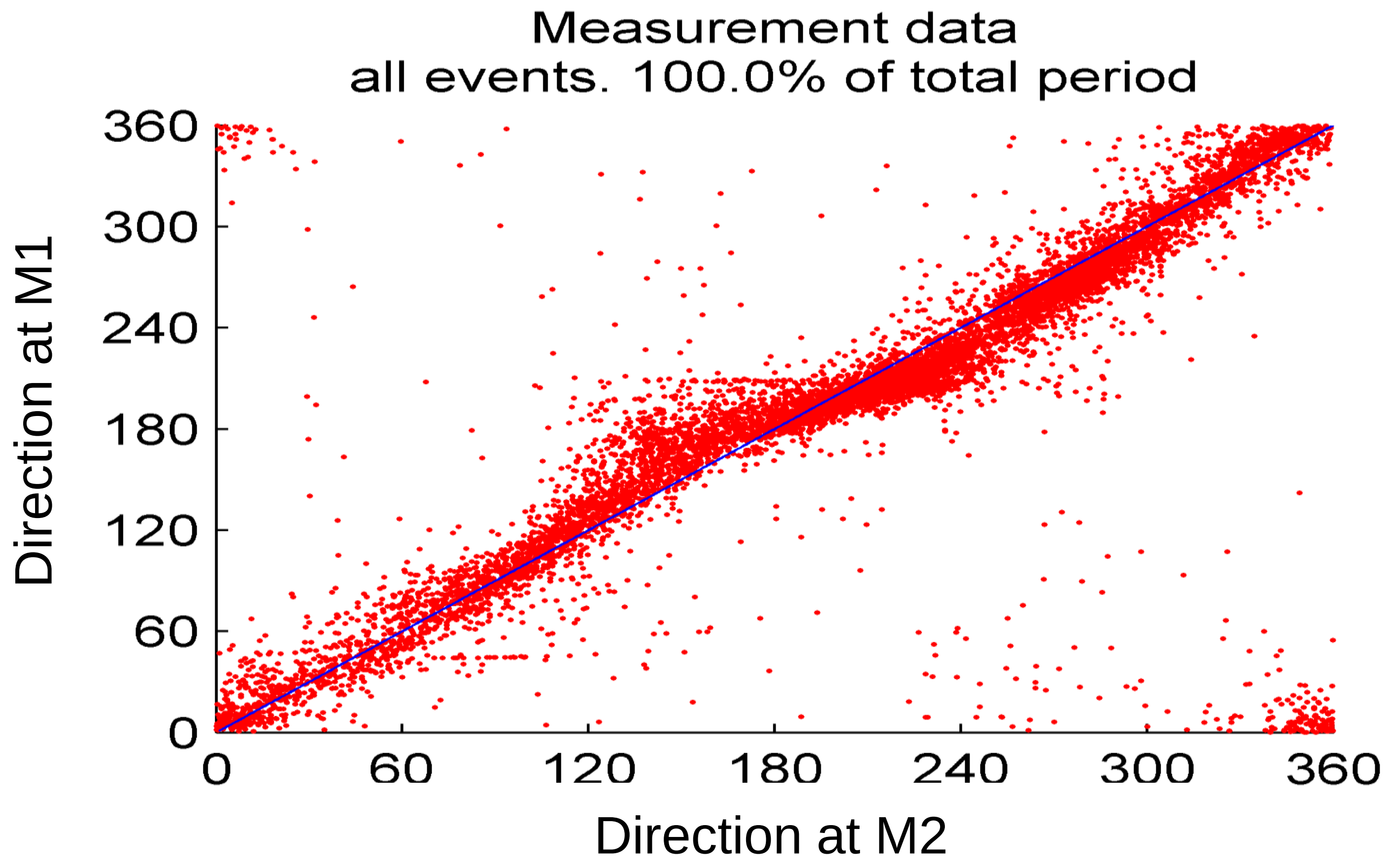
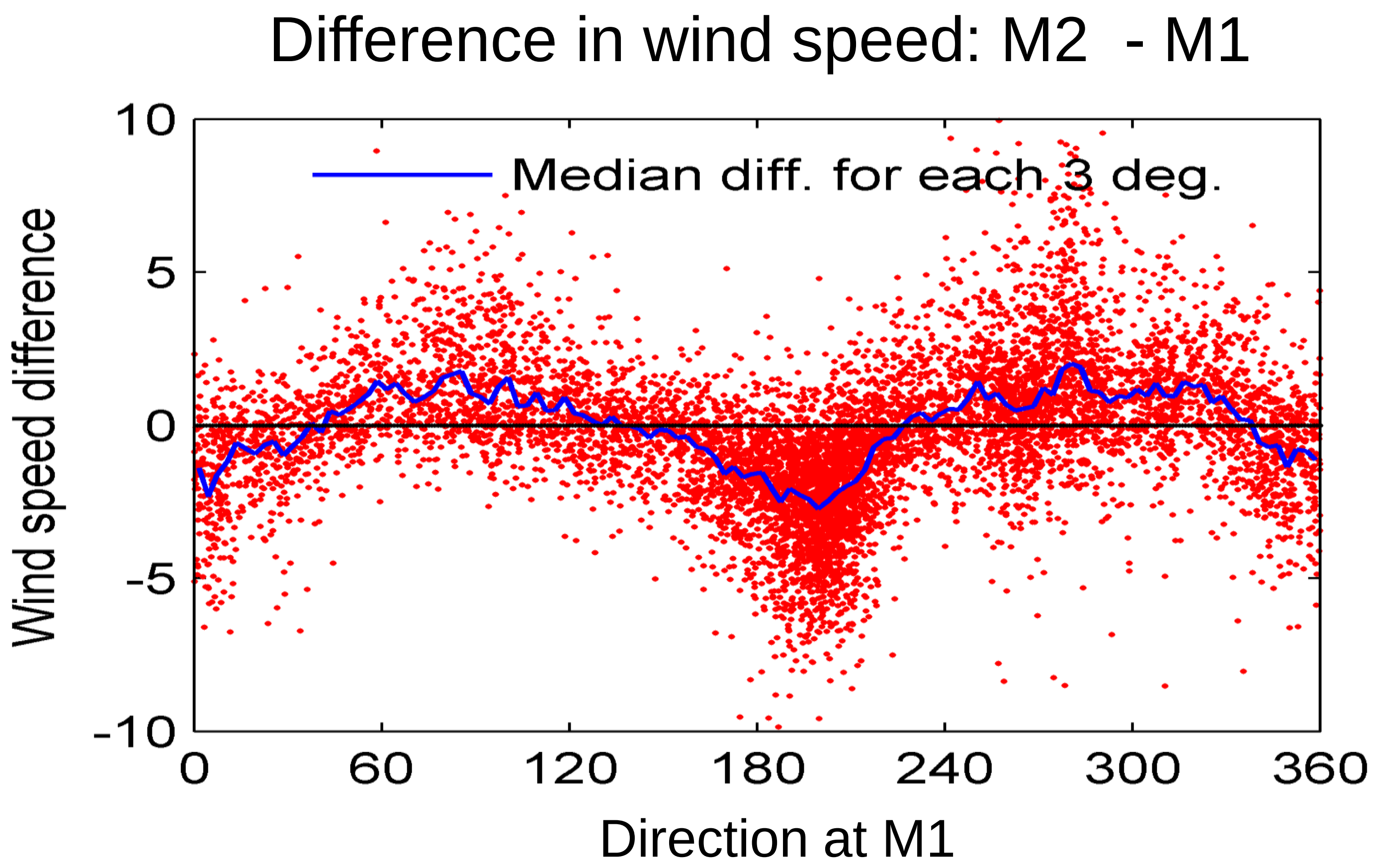
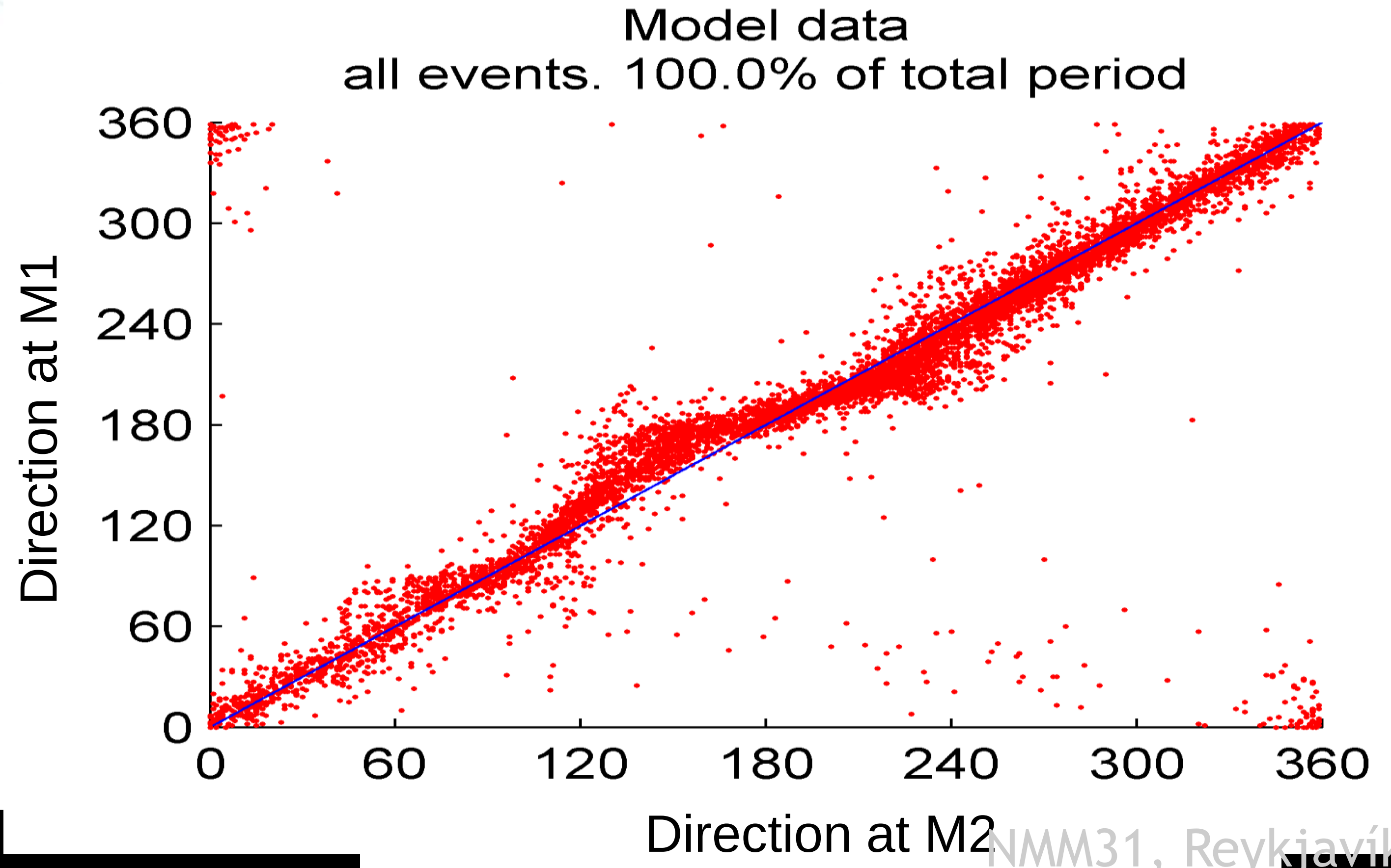
WRF333m vs observations

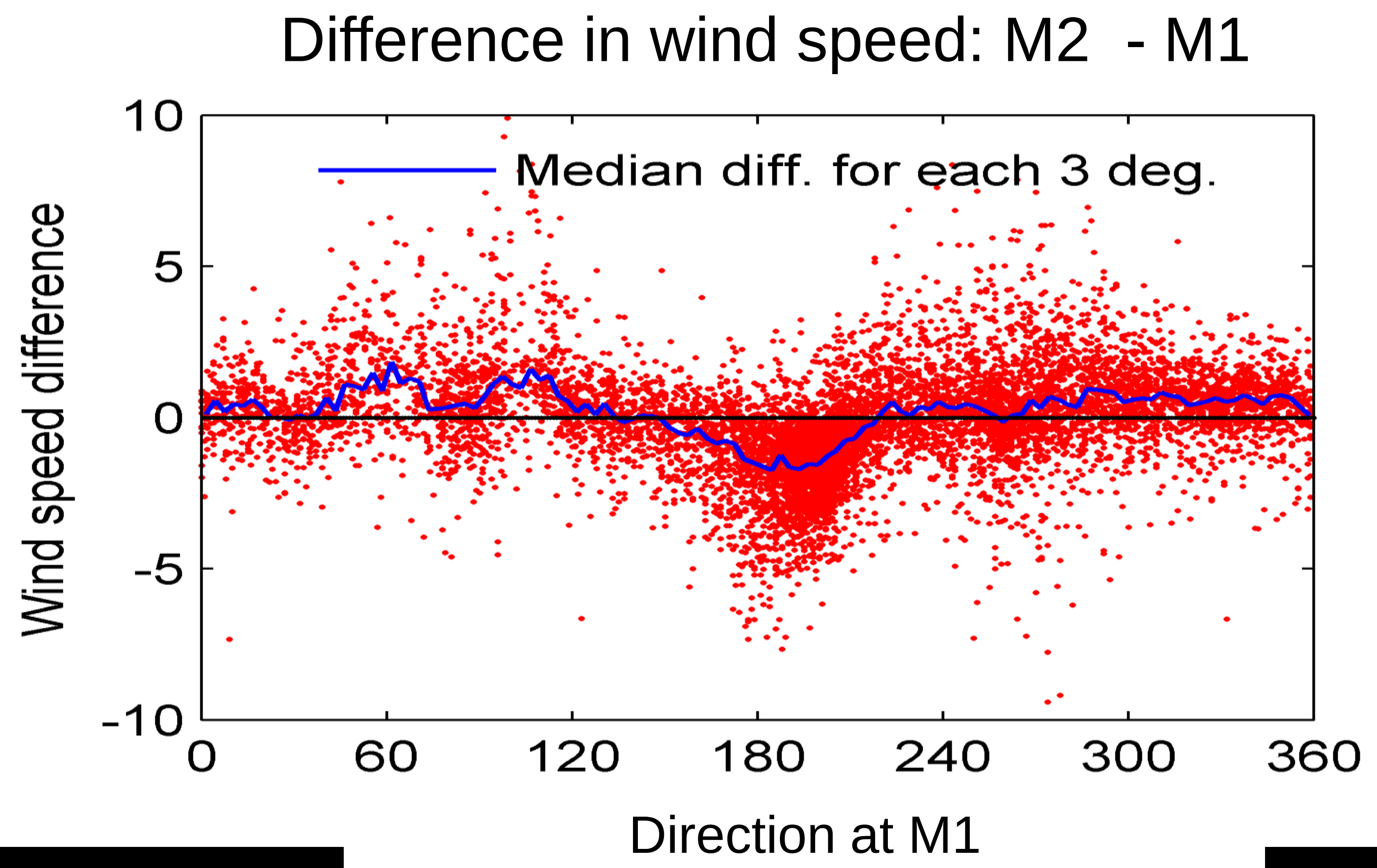
Observations:





WRF 333m:





Flow over a hill

Neutral stratification:

- The air will flow over the hill

Very stable:

- The air will flow around the hill

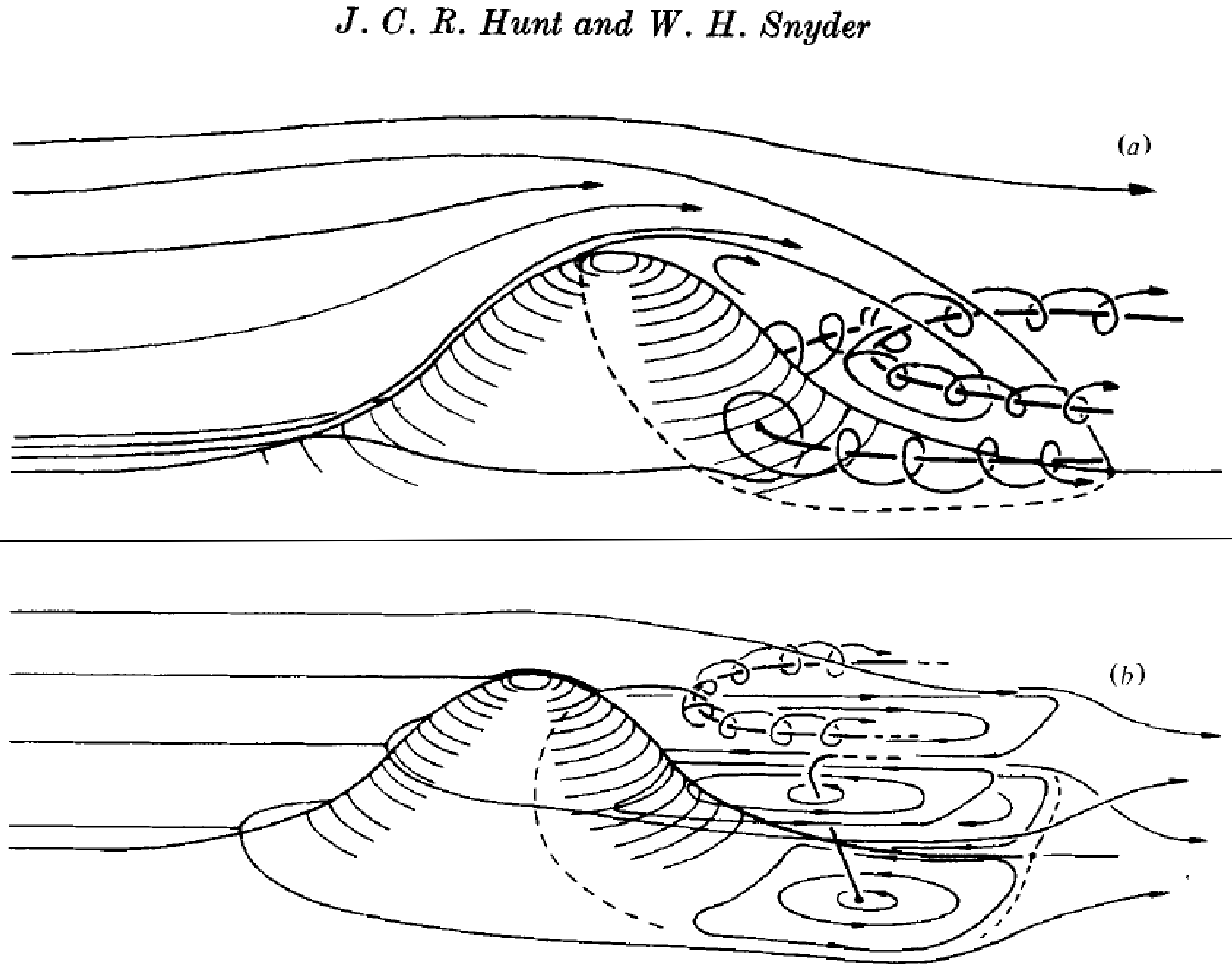


FIGURE 1. Sketch of flows over a three-dimensional hill in (a) neutral and (b) very stable stratification.

Hunt, J. C. R., & Snyder, W. H. (1980). Experiments on stably and neutrally stratified flow over a model three-dimensional hill. *Journal of Fluid Mechanics,96(04), 671-704.*

IEC wind turbine classes

Wind turbine class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37,5	Values specified by the designer
A	I_{ref} (-)	0,16			
B	I_{ref} (-)	0,14			
C	I_{ref} (-)	0,12			

- V_{ref} – maximum extreme 10 min average with a 50-year recurrence period; V_{ave} = 0.2 V_{ref}
- $I_{ref} = \frac{u'}{U}$ – reference turbulence intensity
  - u' – turbulent velocity fluctuations root-mean-square