Global wind resources and meteorological challenges

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GLOBAL WIND RESOURCES & METEOROLOGICAL CHALLENGES

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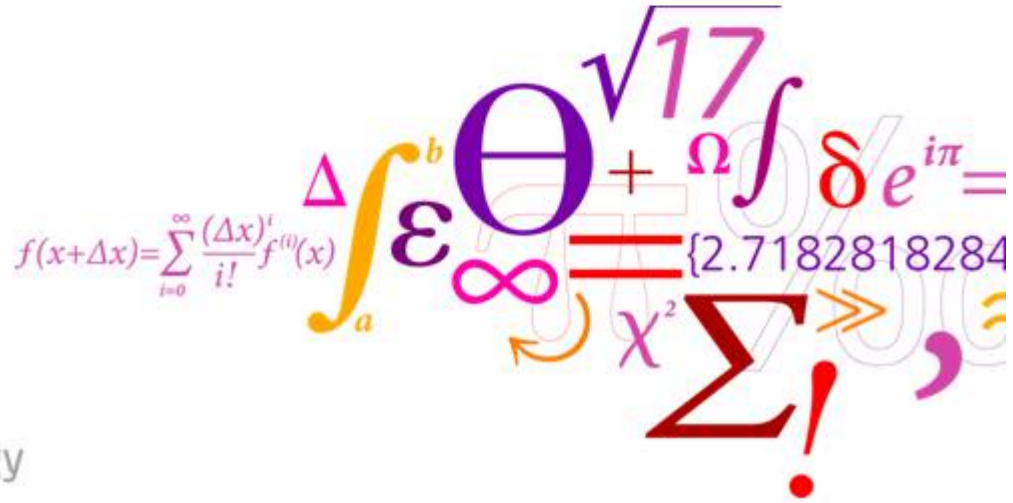
Wind Energy Division



Risø DTU
National Laboratory for Sustainable Energy

The atmosphere dissipates more than 30 times all the energy used by mankind

European Wind Energy Technology Platform

WG1
Wind energy resources

Implementing the plan:

Definition of the key project

3 % vision: 2030 Objectives

European Wind Energy Technology Platform

- Reduce the uncertainty of the estimated wind characteristics.

Current Techniques must be improved so that given the geographic coordinates of any wind farm predictions with an uncertainty of less than 3% can be made concerning:

I. The annual energy production
II. The wind conditions that will affect the design of the turbine
III. A short-term forecasting scheme for power production and wind conditions

3 % vision: Research Topics

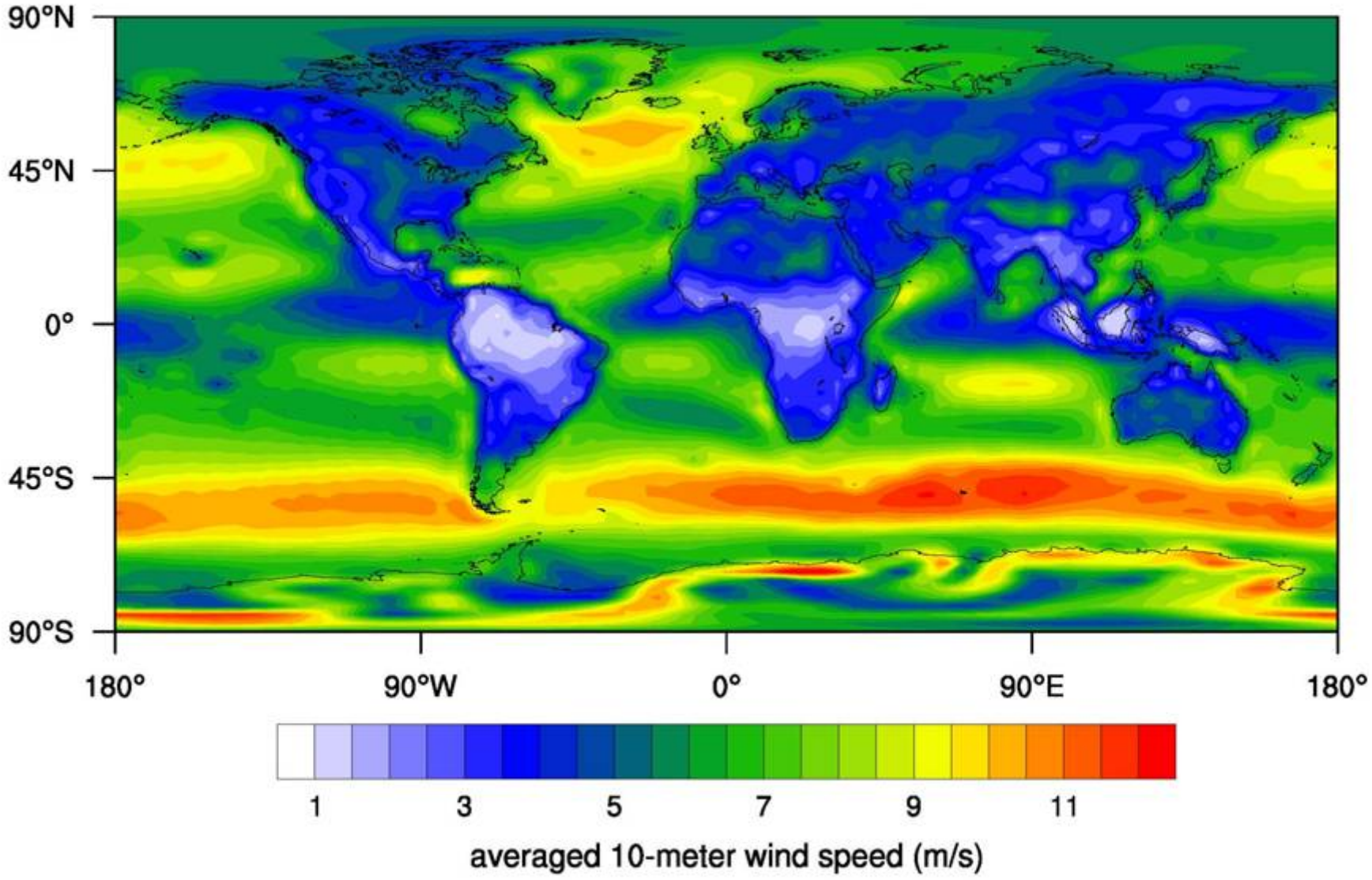
European Wind Energy Technology Platform

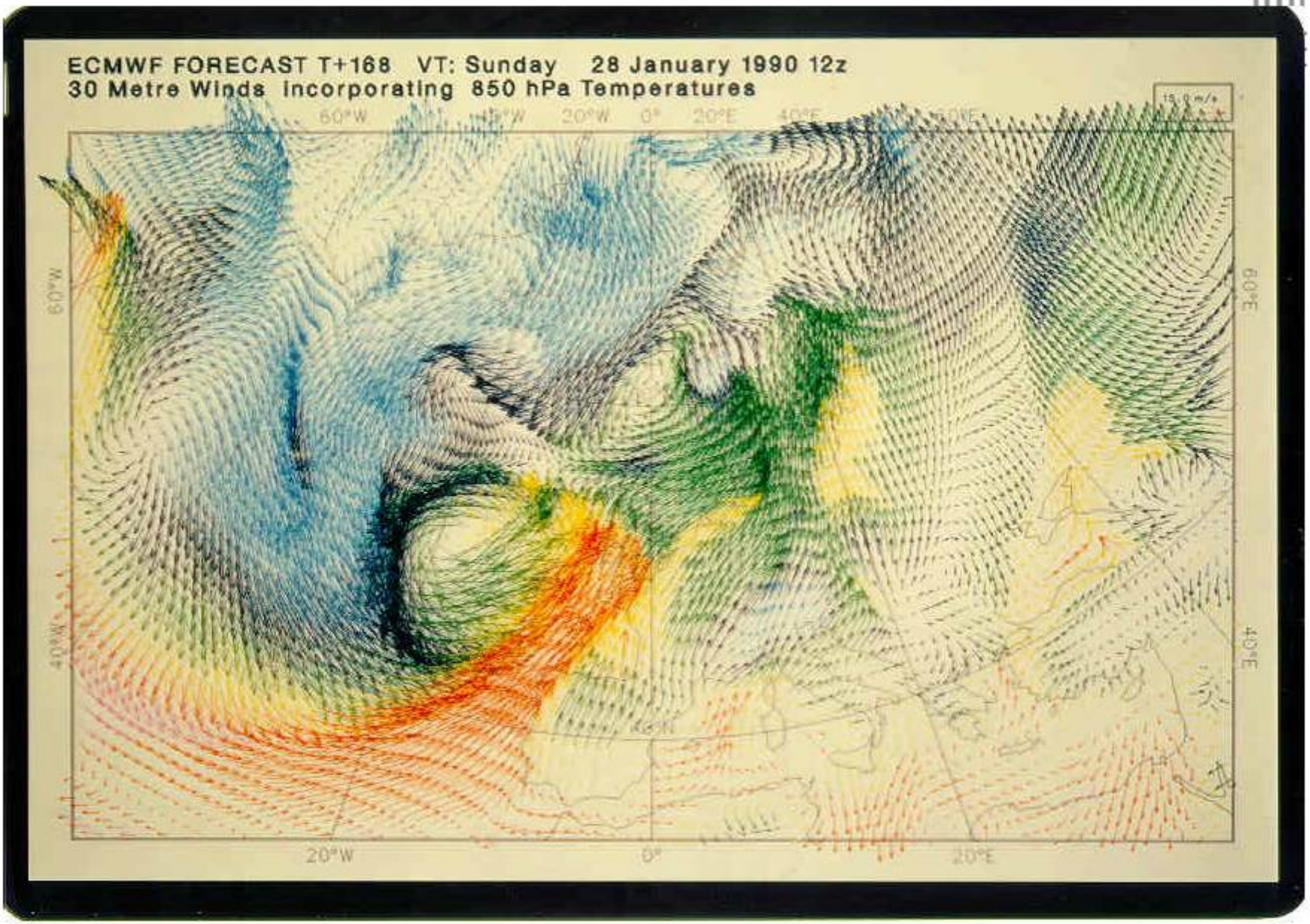
- Siting of WTs in complex terrain and forrested areas
- Wakes in and between wind farms
- Offshore meteorology
- Extreme wind speeds (reference Wind)
- Wind profiles at heights greater than 100m
- Short-term forecasting

Project SRA matrix

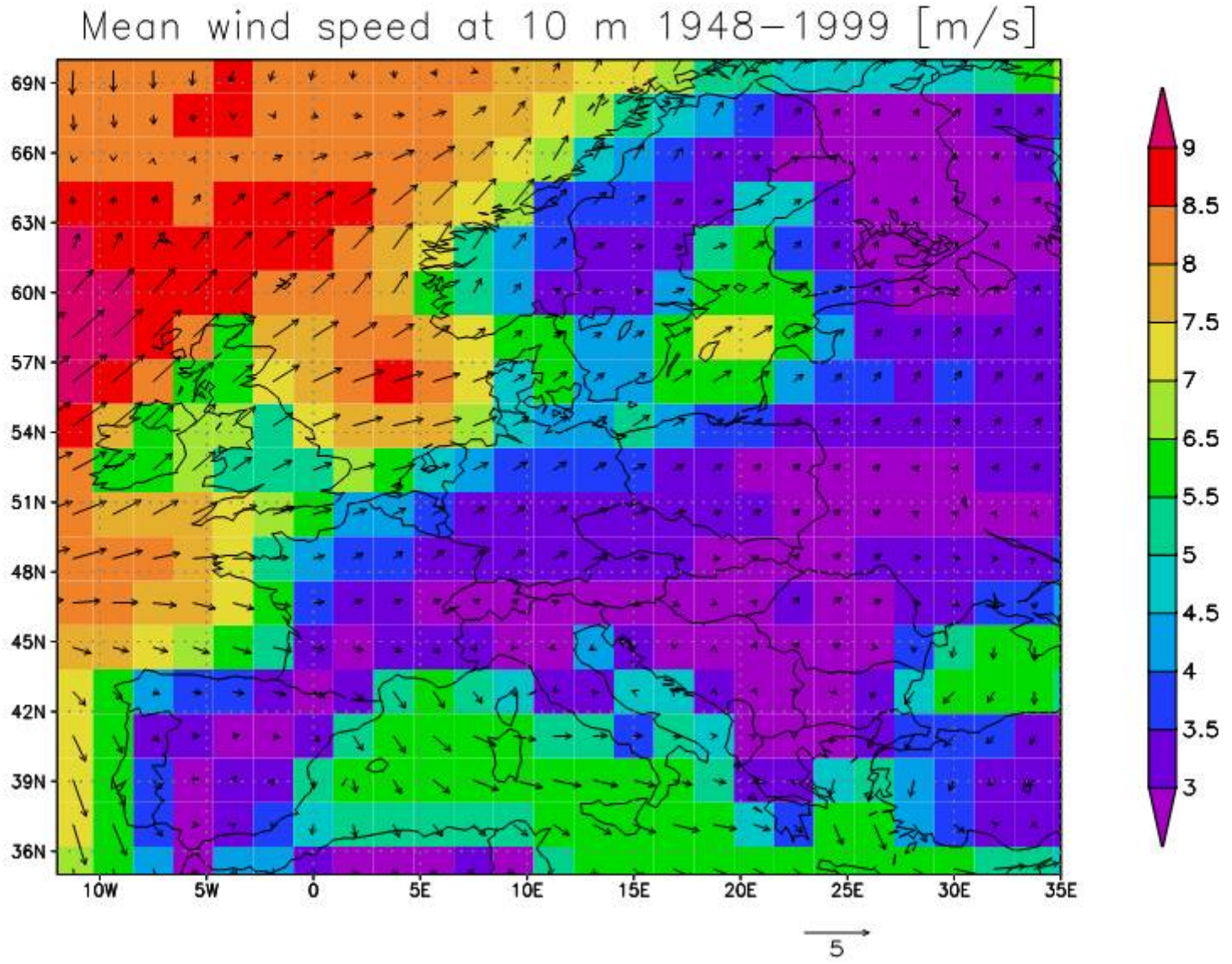
European Wind Energy Technology Platform

Description of experiments	BLM	Remote sensing	Advanced flow modeling	Vertical profiles (min 200m)	Turbulence/ short term gust (3 sec)	Wakes	Extreme wind	Short term prediction
Complex terrain		Xx	Xx	X	X		Xx	
Complex Terrain / wind farm		X	X		X	X		X
Forested Site / flat and complex	X	X	Xx	X	X		Xx	
Offshore/ wind farms	X	X	X	Xx	X	Xx	Xx	X
Costal / wind farms	XX	X	X	Xx	Xx	Xx	Xx	X

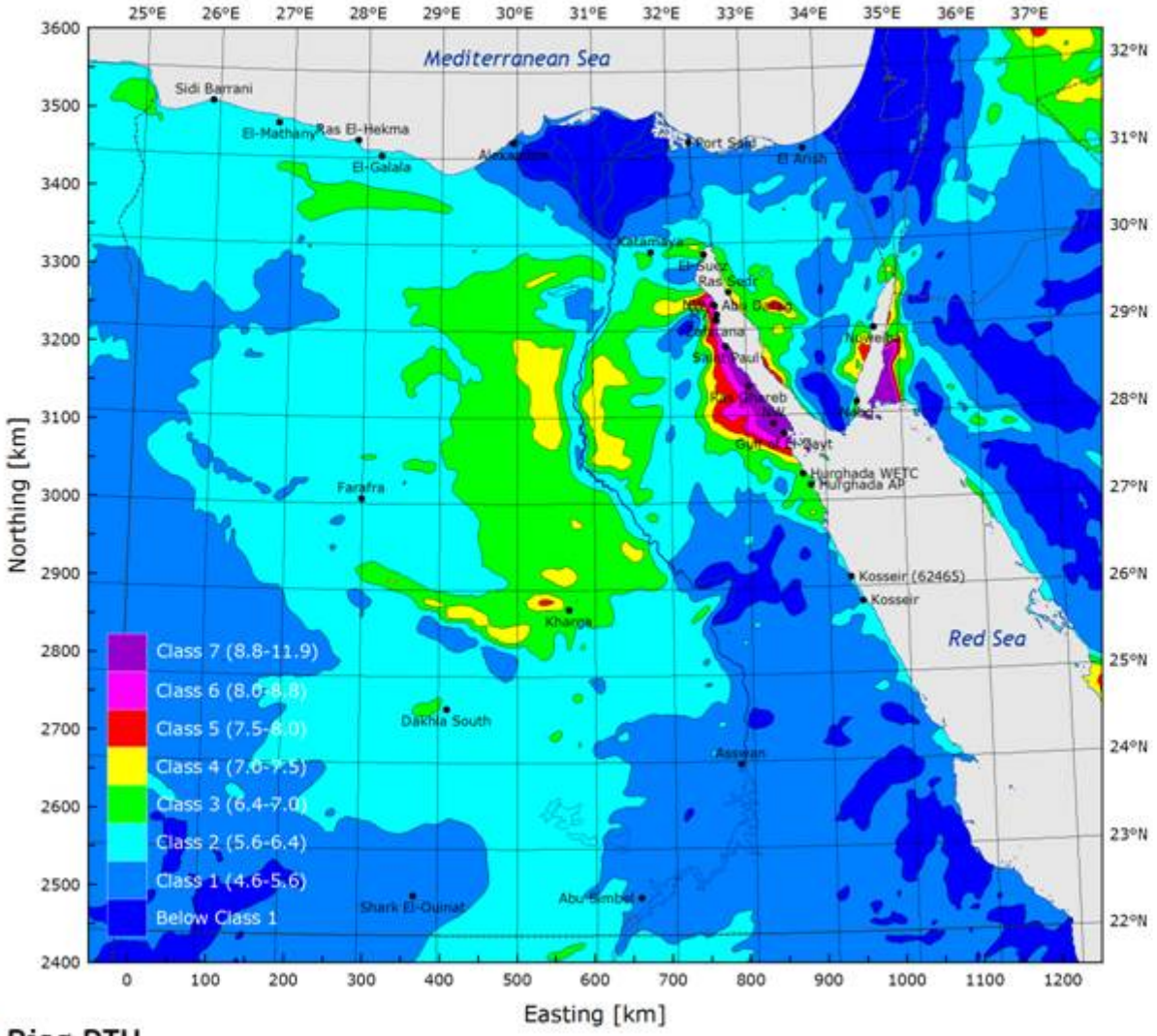

90°N
45°N
0°
45°S
90°S
180°
90°W
0°
90°E
180°
1
3
5
7
9
11
averaged 10-meter wind speed (m/s)
© RISØ DTU


ECMWF FORECAST T+168 VT: Sunday 28 January 1990 12z
30 Metre Winds Incorporating 850 hPa Temperatures
60°W
40°W
20°W
0°
20°E
40°E
60°E

Global Reanalysis data

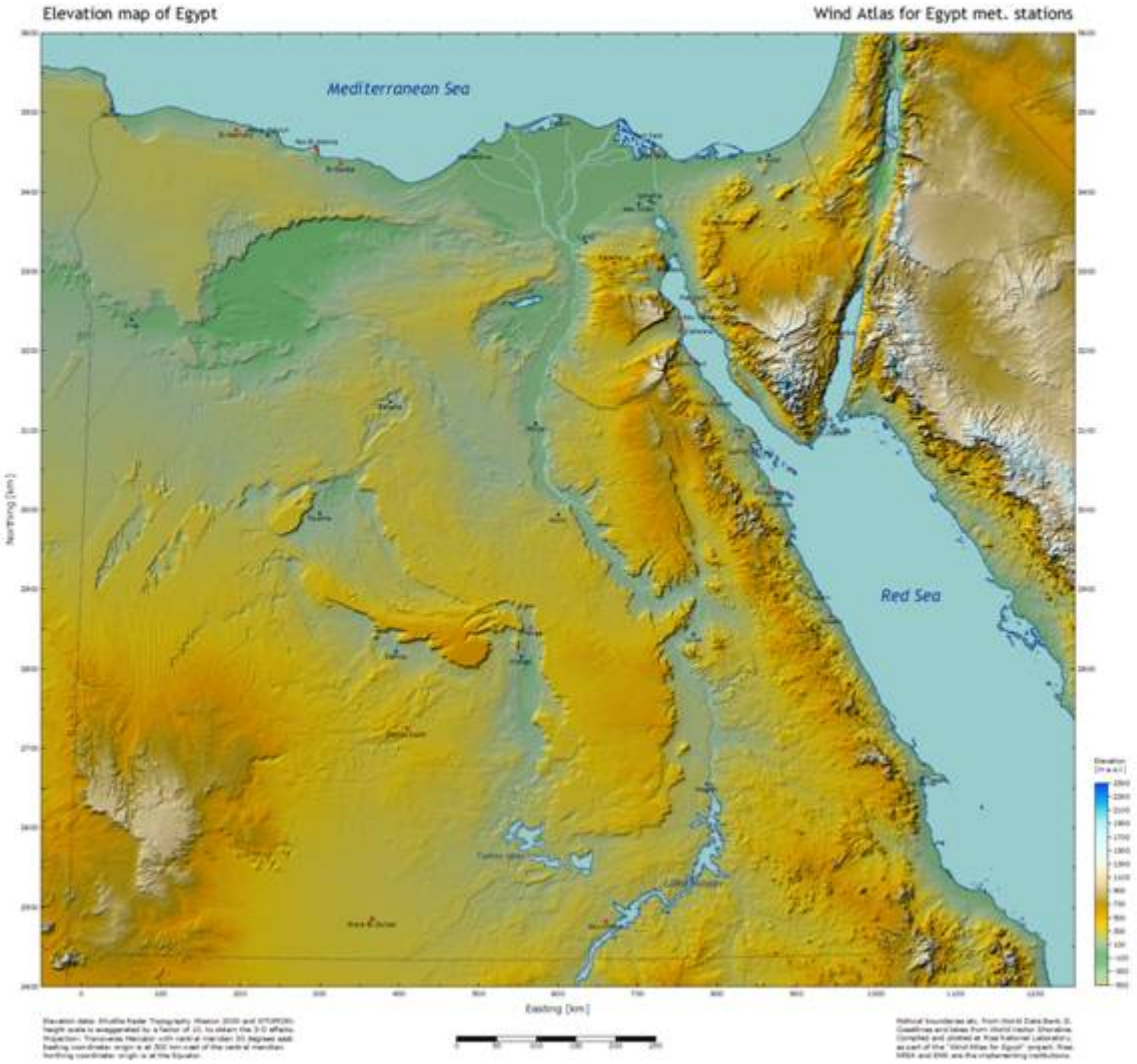


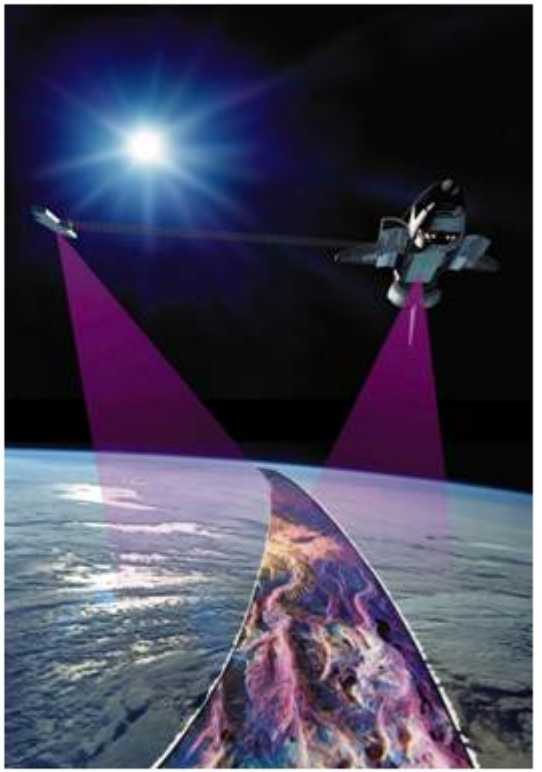
Wind Atlas for Egypt
New wind resource maps



- Predicted wind climate
- Mean wind speed 50 m a.g.l. [m s^{-1}]
- 7 speed classes
- KAMM modelling
- Resolution 7.5 km
- NCEP/NCAR data
- SRTM30 elevation
- GLCC land cover
- Terrain features may give higher wind speeds locally!
- Output formats:
  - map graphics
  - statistics, ...

Shuttle Radar Topography Mission





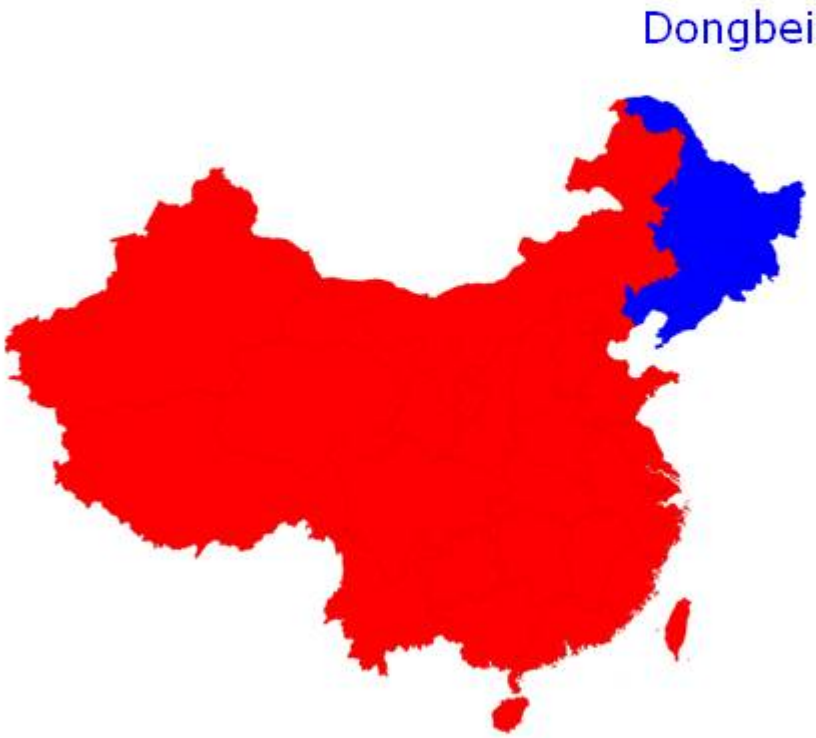
- Grid point elevations
- 3" (~90 m) resolution
- Vertical accuracy 5-10 m

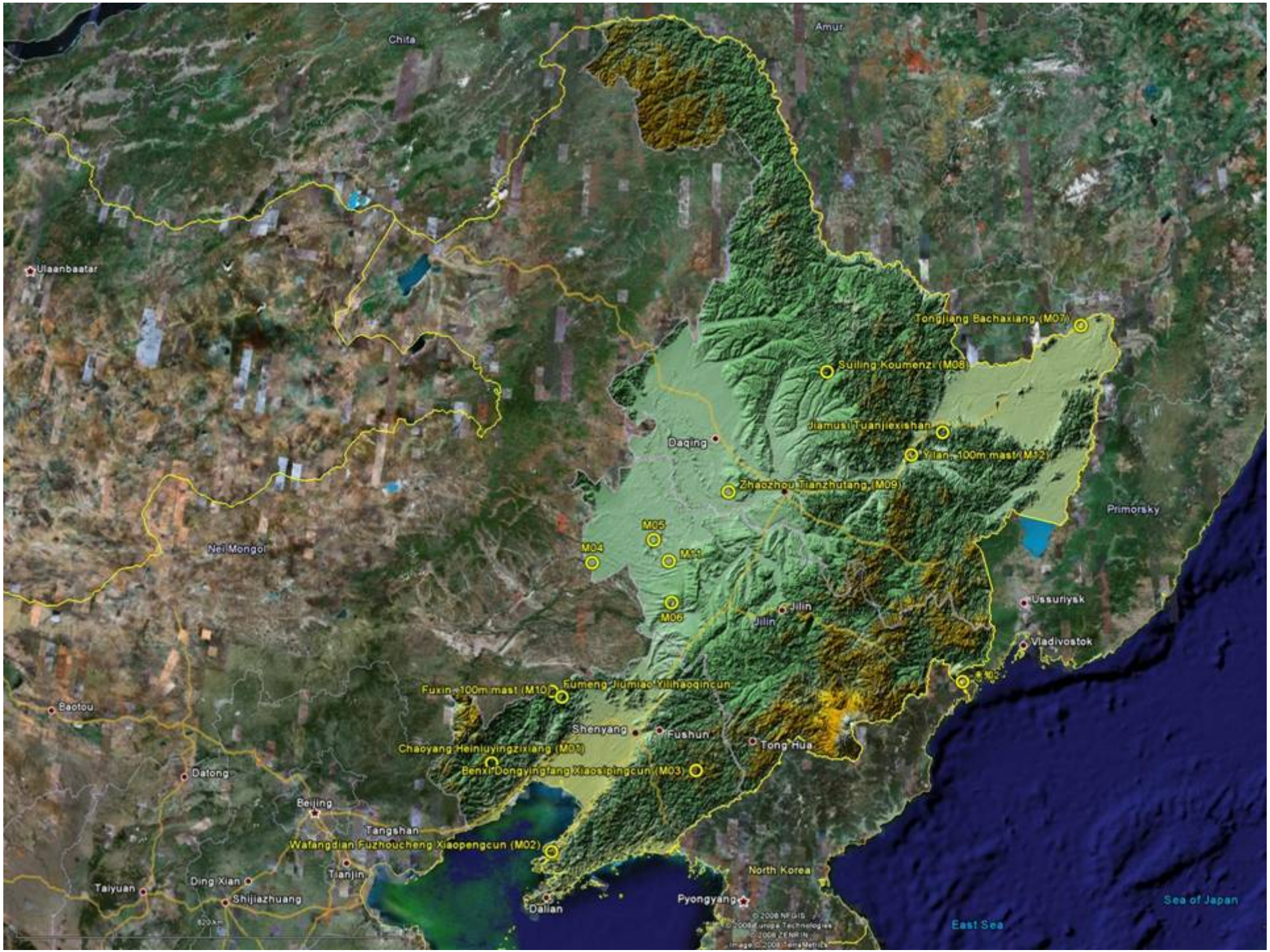
Mesoscale and microscale modelling in China

- Funded by the "Sino-Danish Wind Energy Development Programme"
- Project focuses on Dongbei
- Project period 2008-2009

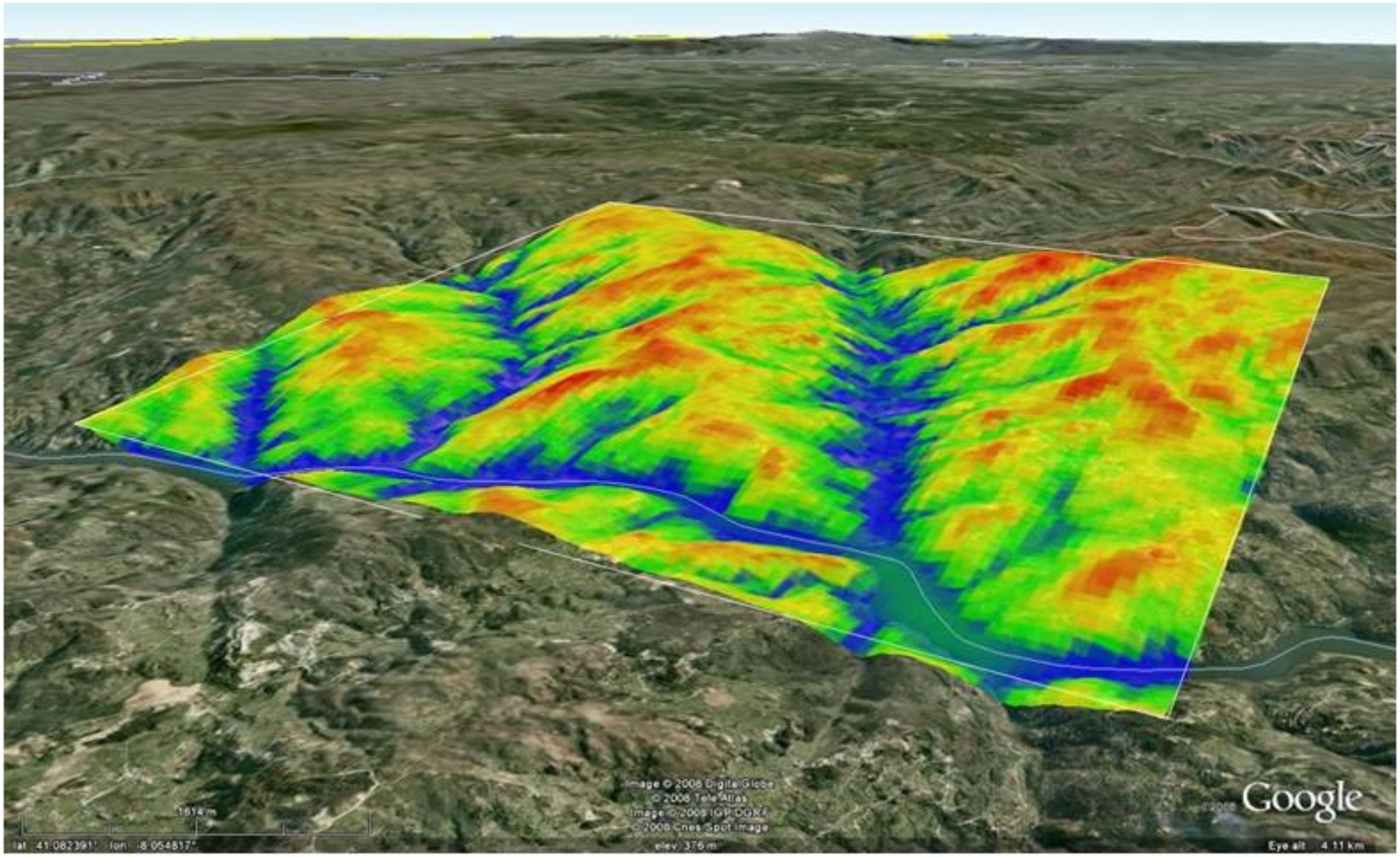
- Wind resource assessment in Dongbei
  - Measurements
  - Microscale modelling
  - Mesoscale modelling
  - Application

- Project emphasis
  - research and development
  - measurement practices
  - numerical wind atlas methodologies
  - verification and uncertainties
  - application aspects for wind energy planning and project preparation

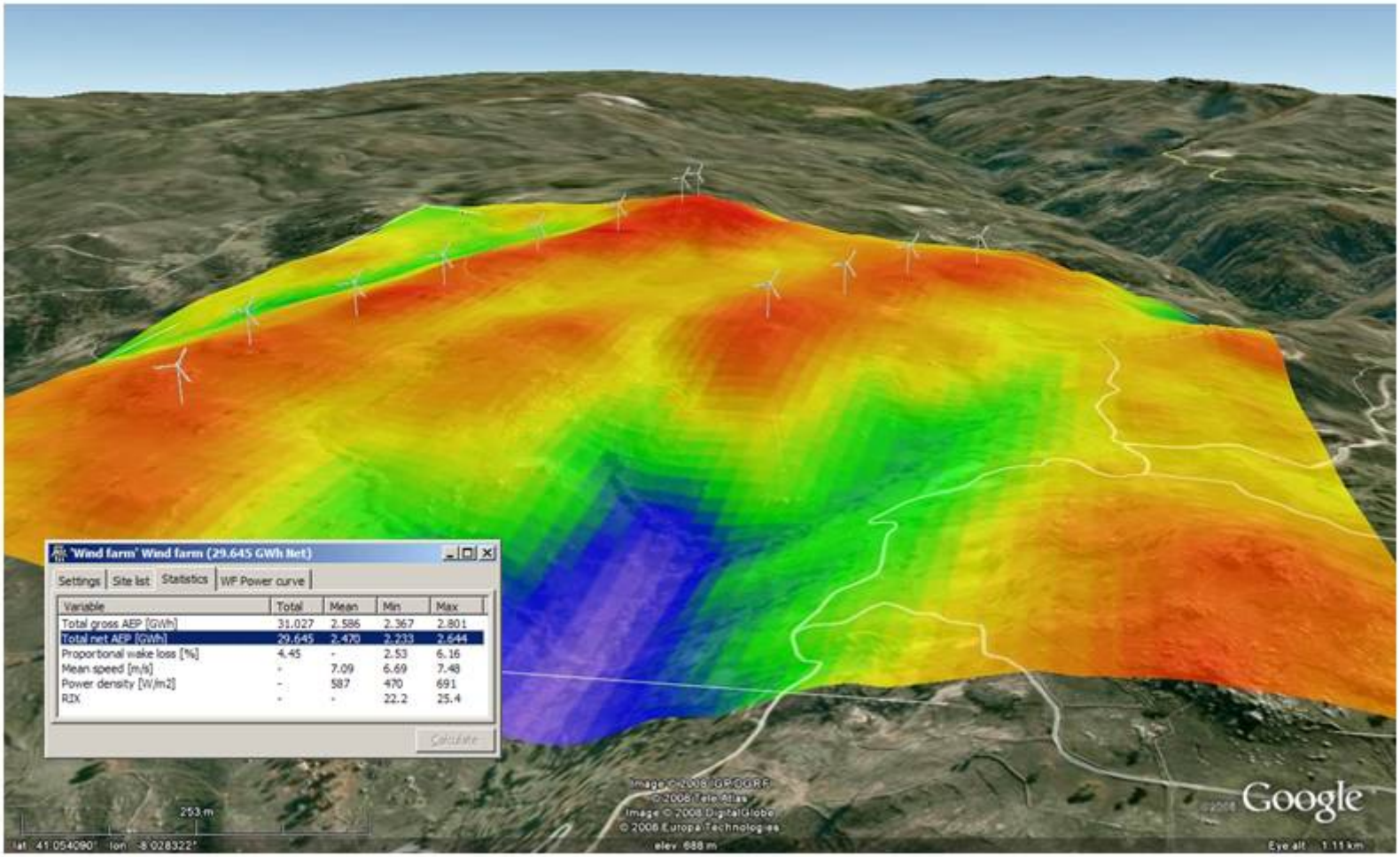



Chita
Amur
Ulaanbaatar
Tongjiang Bachaxiang (M07)
Suiling Koumenzi (M08)
Jiamusi Tuanjiexishan
Daqing
Yilan, 100m mast (M12)
Zhaozhou Tianzhutang, (M09)
Primorsky
M05
M04
M11
Nei Mongol
M06
Jilin
Jilin
Ussuriysk
Vladivostok
Fuxin, 100m mast (M10)
Fumeng Jiumiao Yilihaoqincun
Baotou
Shenyang
Fushun
Tong Hua
Chaoyang Heiniuyingzixiang (M01)
Benxi Dengyingfang Xiaosipingcun (M03)
Datong
Beijing
Tangshan
Wafangdian Fuzhoucheng Xiaopengcun (M02)
Tianjin
North Korea
Taiyuan
Ding Xian
Shijiazhuang
Dalian
Pyongyang
Sea of Japan
East Sea

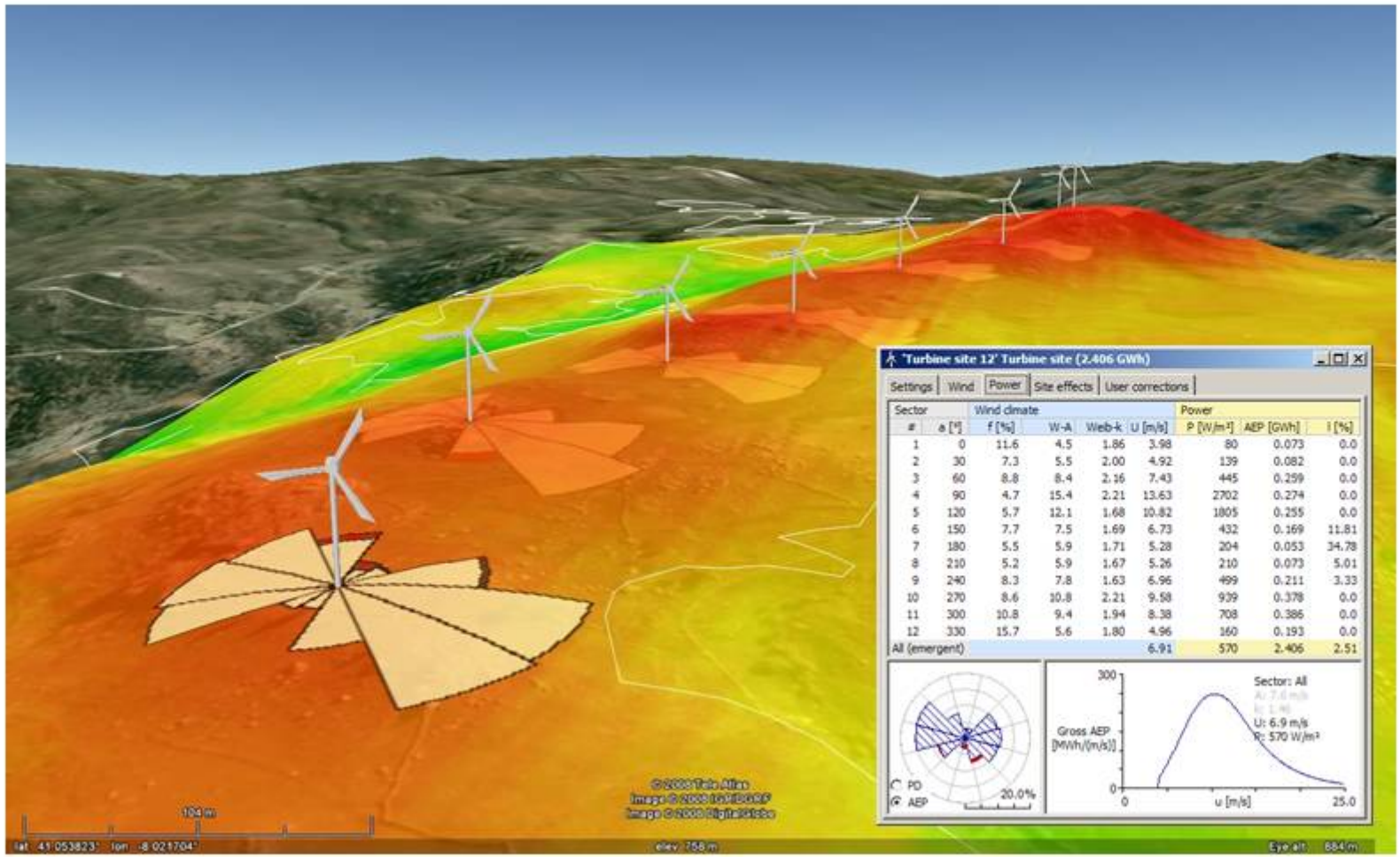
Sample wind resource map



Sample wind farm layout and estimated production



Sample wind turbine characteristics



Mesoscale modelling for wind resource assessment

Twinning project with Chinese Meteorological Adminstration (CMA)

Topographic map

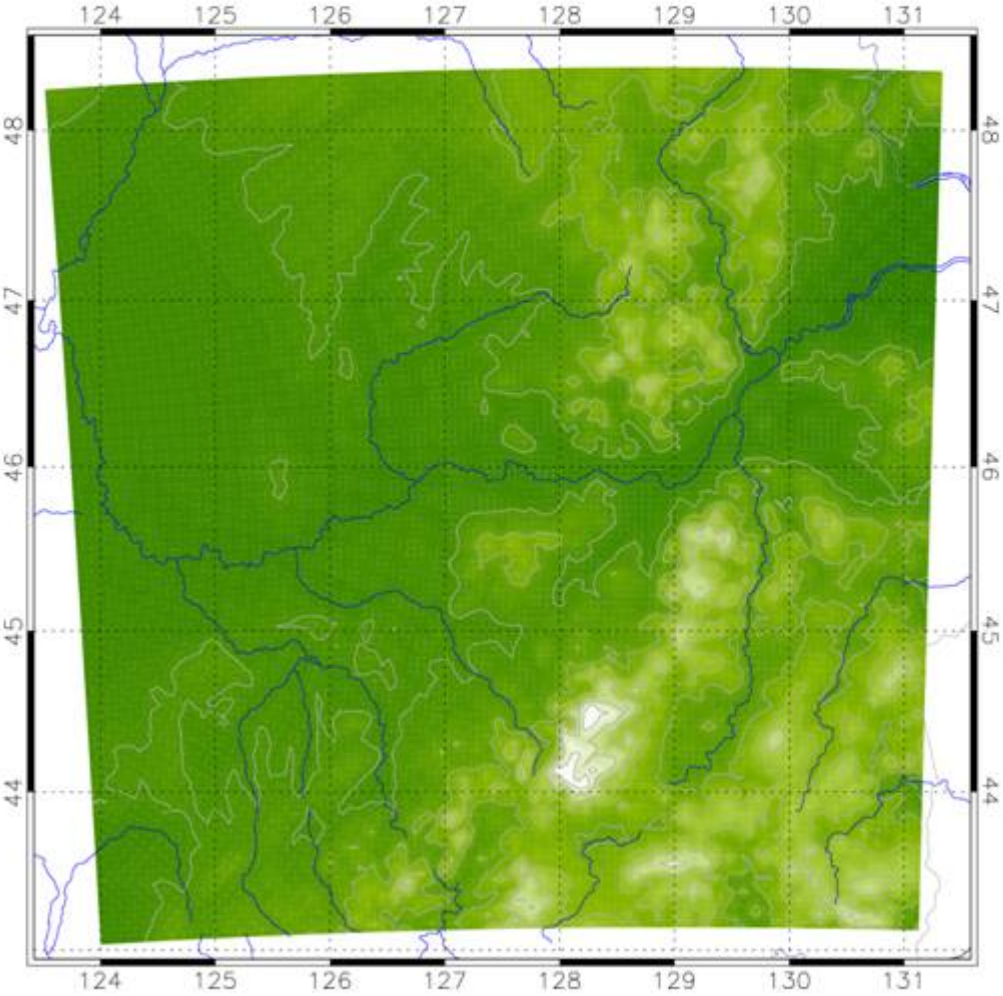
Mesoscale modelling domain located around Harbin in Dongbei.

600 x 600 km region.

5km resolution.

Contour interval 100 m.

Notice elevated terrain running north-south, with gap and passsage of one major river system.



Mesoscale modelling for wind resource assessment

Twinning project with Chinese Meteorological Adminstration (CMA)

Wind resource map

Annual mean wind speed at 50 m a.g.l. given by 121 simulations (wind classes).

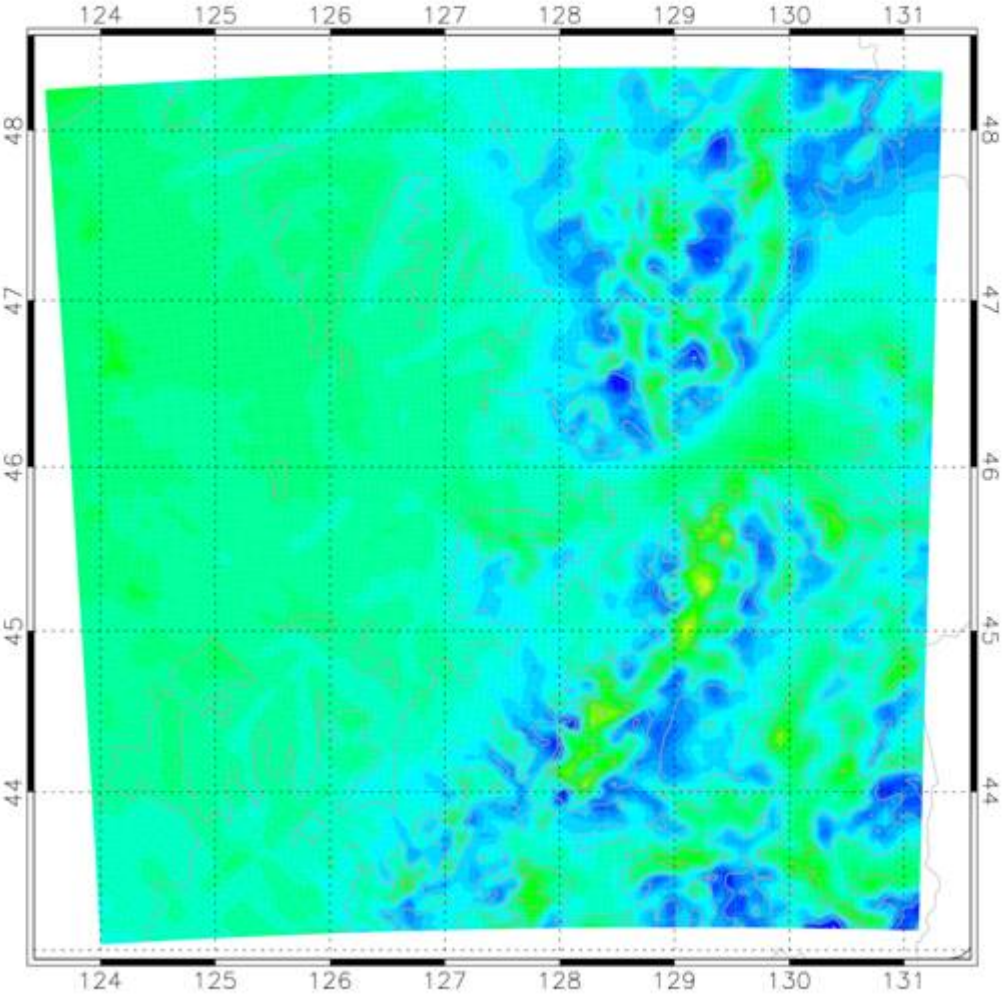
Wind classes capture scale forcing in terms of direction, speed and stability.

Maximum of 7.6 m/s.

Notice highest winds located on exposed elevated terrain, in gap, and parts of plane area.

Credit: simulations shown

Zhu Rong, Yuan Chunhong, Xiaoli Larsen



Mesoscale modelling for wind resource assessment

DTU

Twinning project with Chinese Meteorological Adminstration (CMA)

Ensemble wind resource map

Annual mean wind speed at 50 m a.g.l. given by 345 simulations (wind classes).

Comprises of 3 sets of wind classes, each set using a different breakdown of stability:

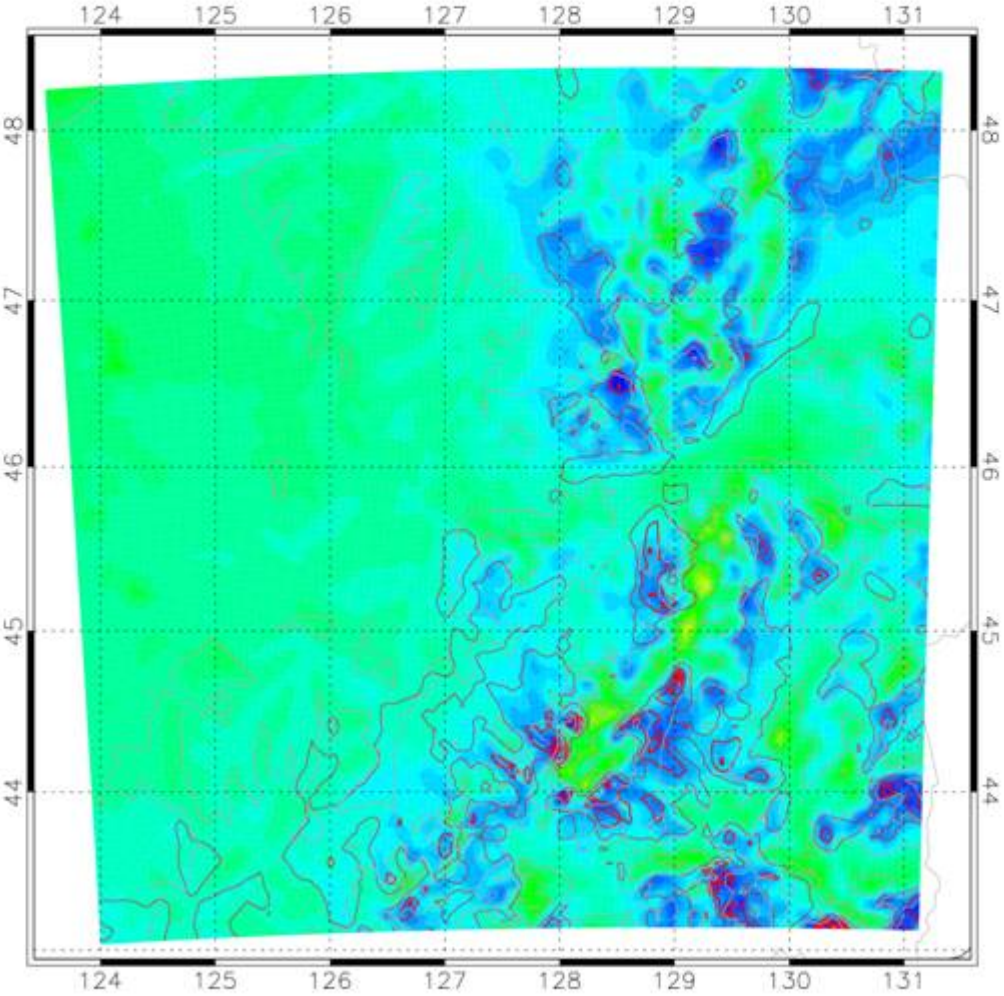
set 1: no stability classes

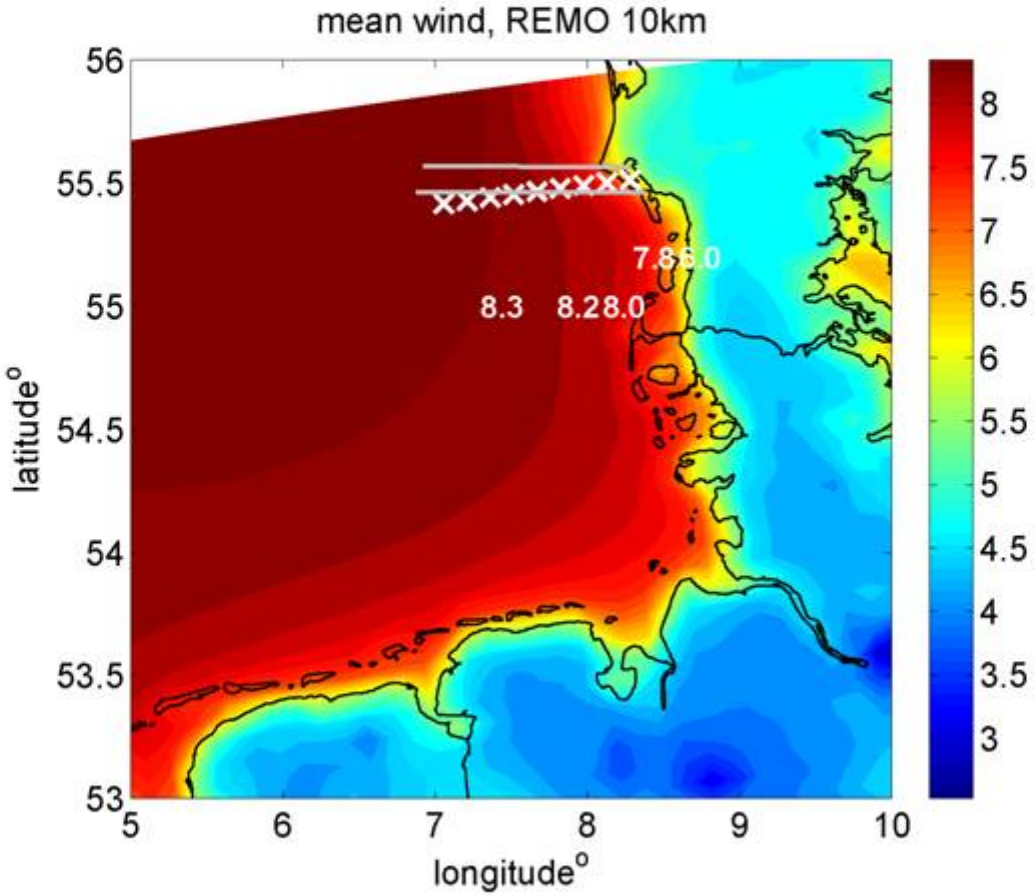
set 2: 2 stability classes

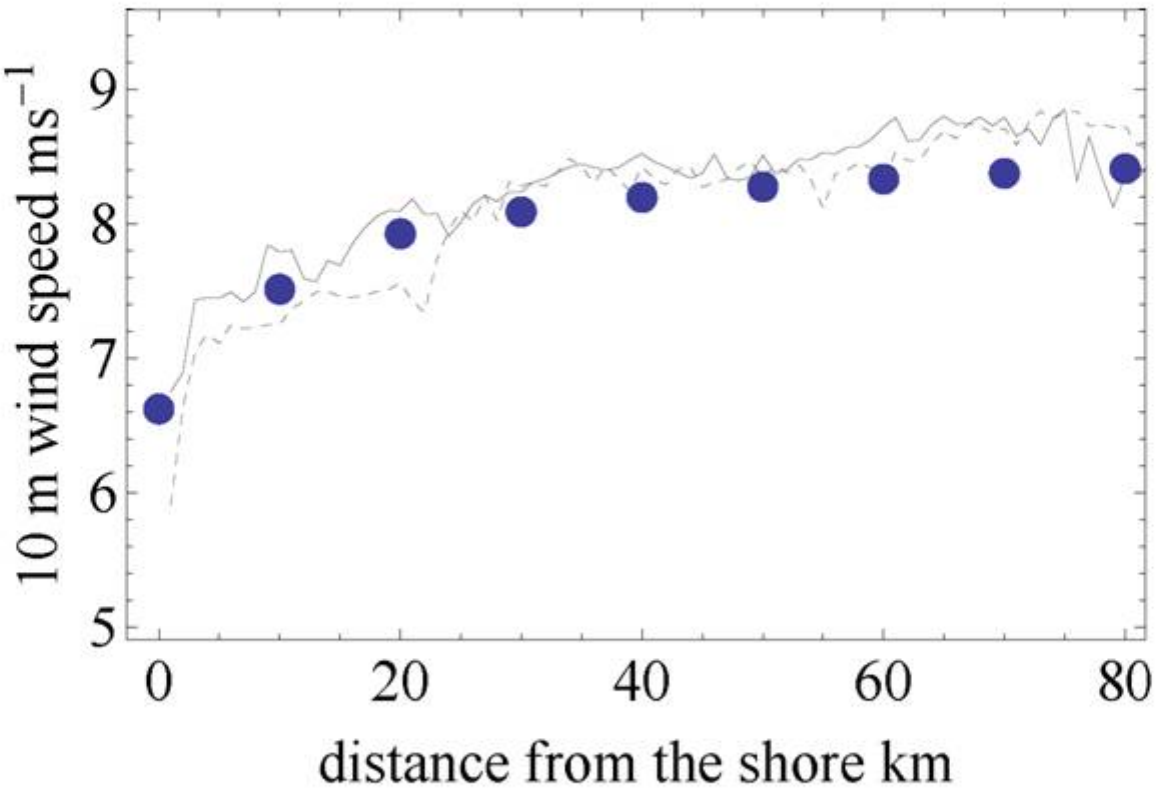
set 3: 3 stability classes

Red contours show ensemble spread (1.5%, 3%, 6%)

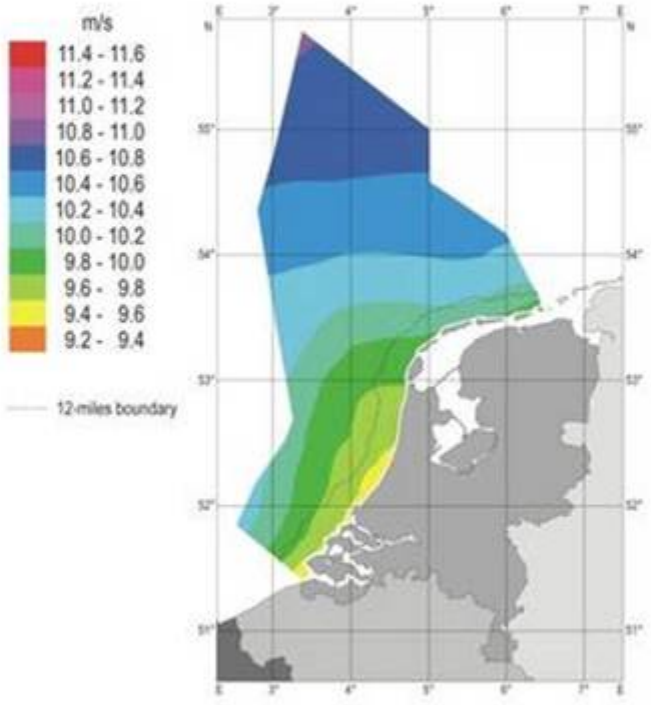
Q: Relationship between sensitivity to stability and uncertainty in wind resource estimate?




mean wind, REMO 10km
56
55.5
55
54.5
54
53.5
53
5
6
7
8
9
10
latitude°
longitude°
8.3
8.28.0
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3


10 m wind speed ms^{-1}
9
8
7
6
5
0
20
40
60
80
distance from the shore km

Mean Wind Speed at the Netherlands' Exclusive Economic Zone (NEEZ)
Period: 1997 - 2002
Height: 90 m above mean sea level

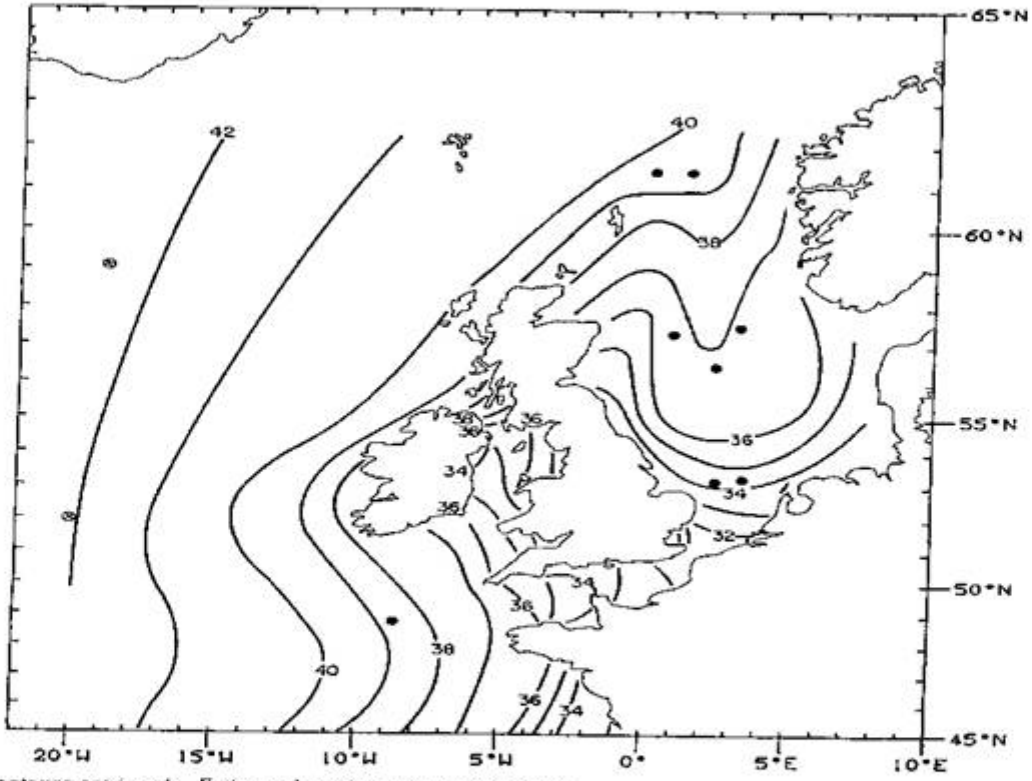


Supported by the Programme 'Duurzame Energie in Nederland' as operated by SenterNovem for the Dutch Ministry of Economic Affairs

3.3 INDICATIVE VALUES (WINDS)

a) Hourly wind speeds at 10m above sea level

Estimates of 50-year return hourly wind speeds are shown in Figure 1. The speeds are appropriate for a height of 10 m above still water level. The map gives no indication of the direction of the extreme wind.



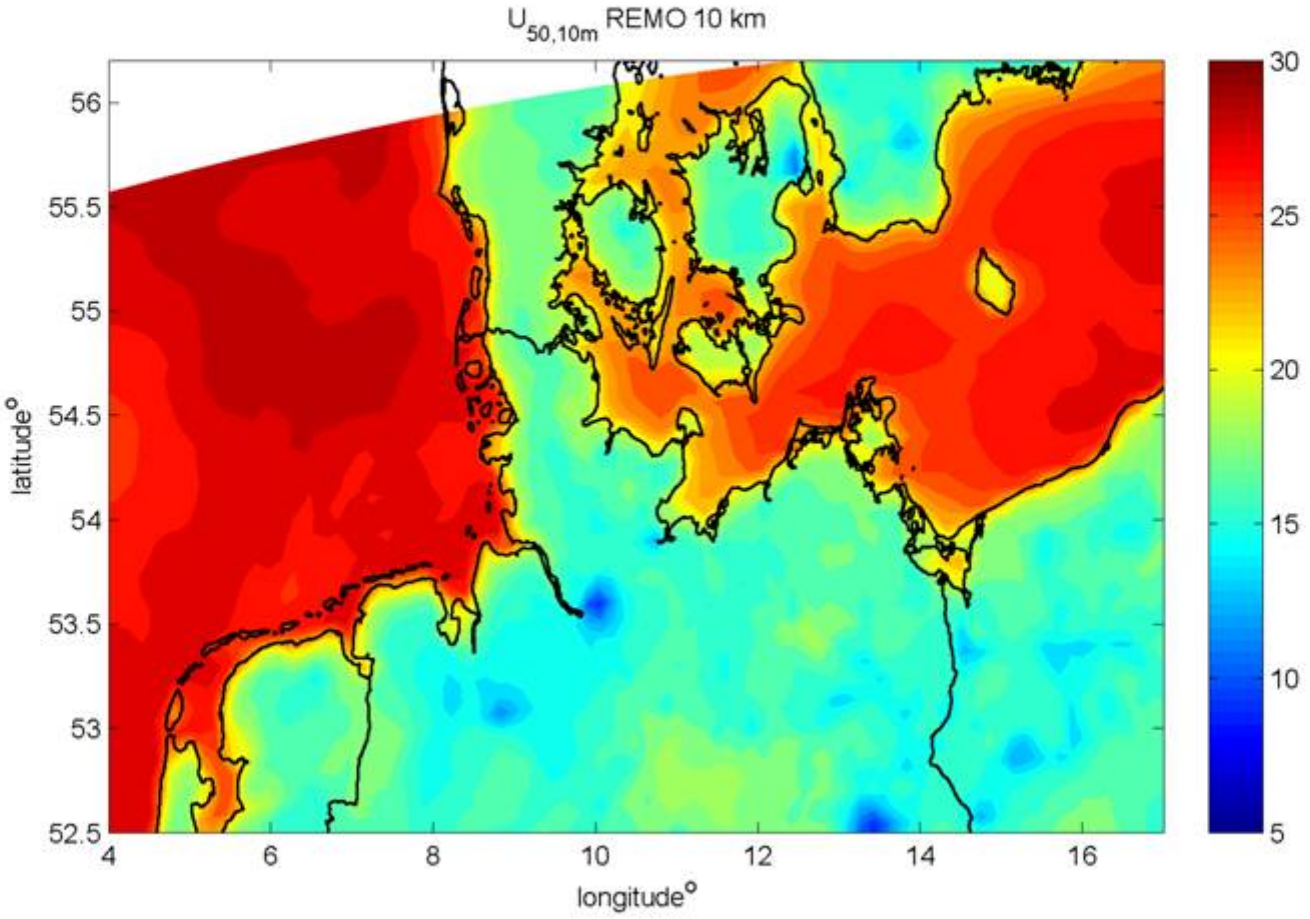
Contours are in m/s. Estimated maximum error is ± 2 m/s.

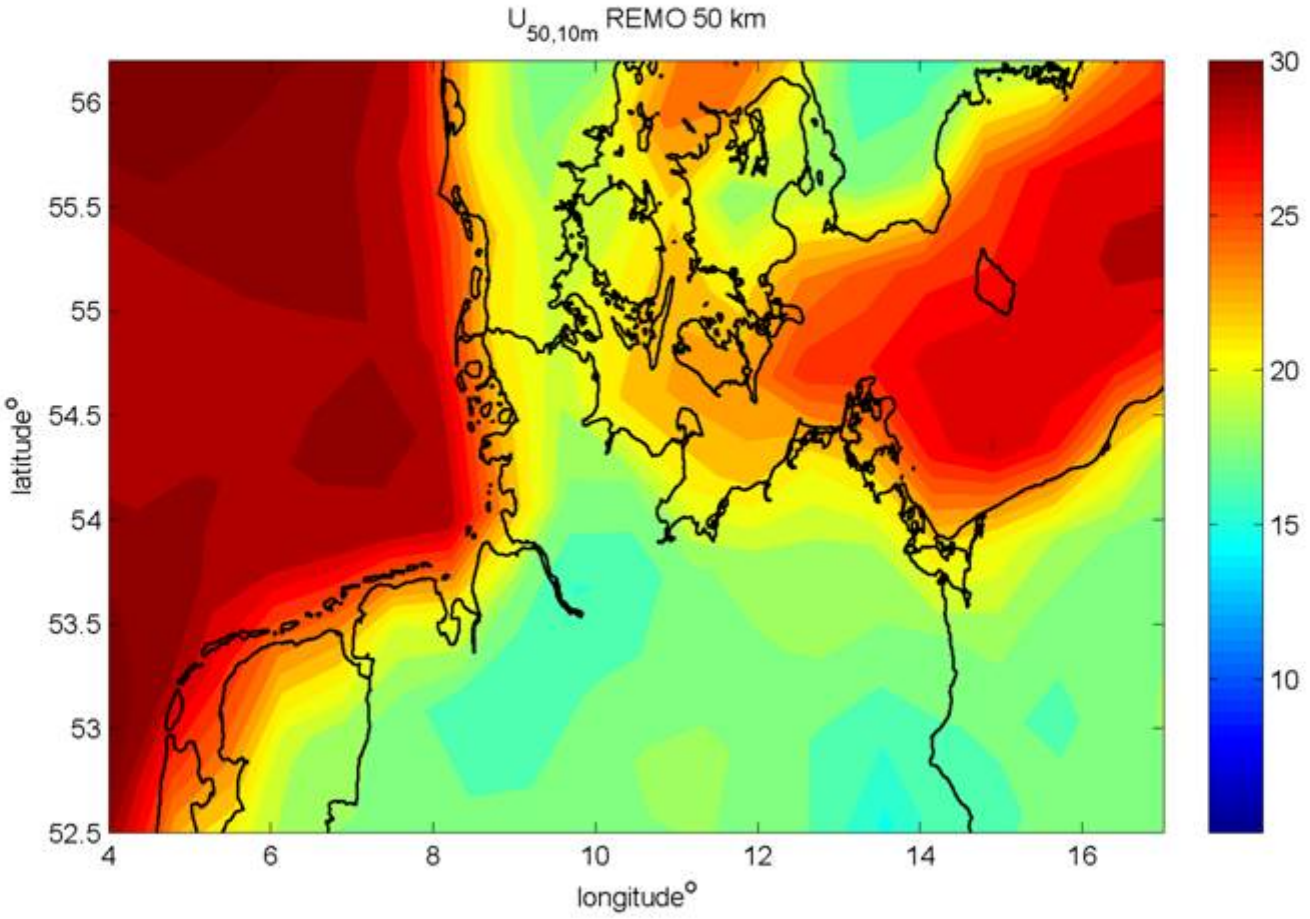
Ocean Weather Stations, where wind speeds have been measured for many years at fixed locations, are shown ⊕. Sites used for verification purposes are shown ▪ (see OTH 89 299)[4].

Source: Analysis of VOF and instrumental data (OTH 89 299)[4]. Details of the analysis method used are to be found in this reference.

Figure 1 Estimates of 50-year return omnidirectional hourly-mean wind speeds at 10 m above still water level

Estimates from Figure 1 are likely to be subject to a maximum error of ±2m/s.

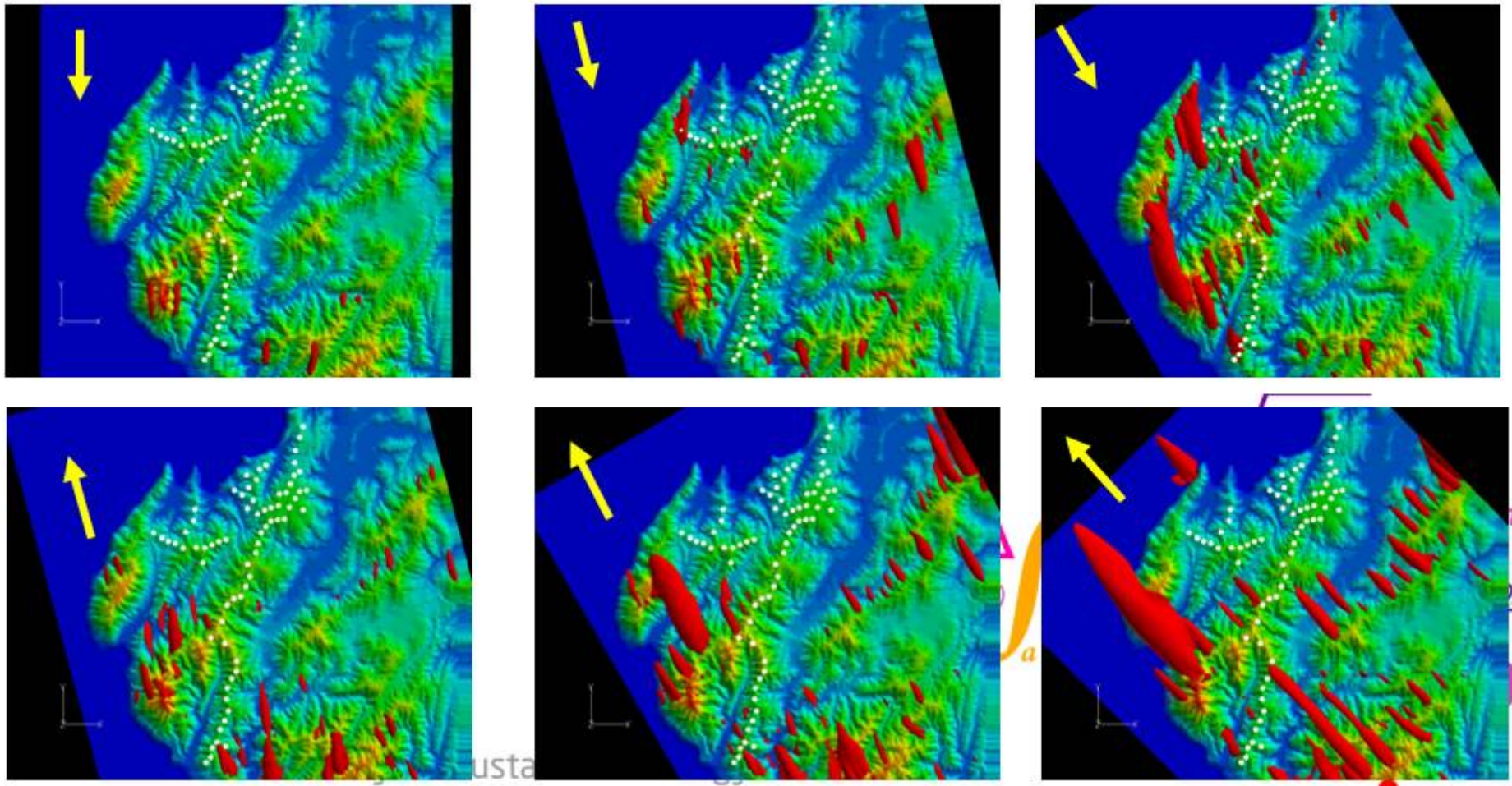

$U_{50,10m}$ REMO 10 km
56
55.5
55
54.5
54
53.5
53
52.5
latitude°
4
6
8
10
12
14
16
longitude°
30
25
20
15
10
5


$U_{50,10m}$ REMO 50 km
56
55.5
55
54.5
54
53.5
53
52.5
latitude°
4
6
8
10
12
14
16
longitude°
30
25
20
15
10

RANS computations from a complex terrain in New Zealand

Six wind directions

Iso-contour of turbulent kinetic energy clearly indicating areas where problems may arise

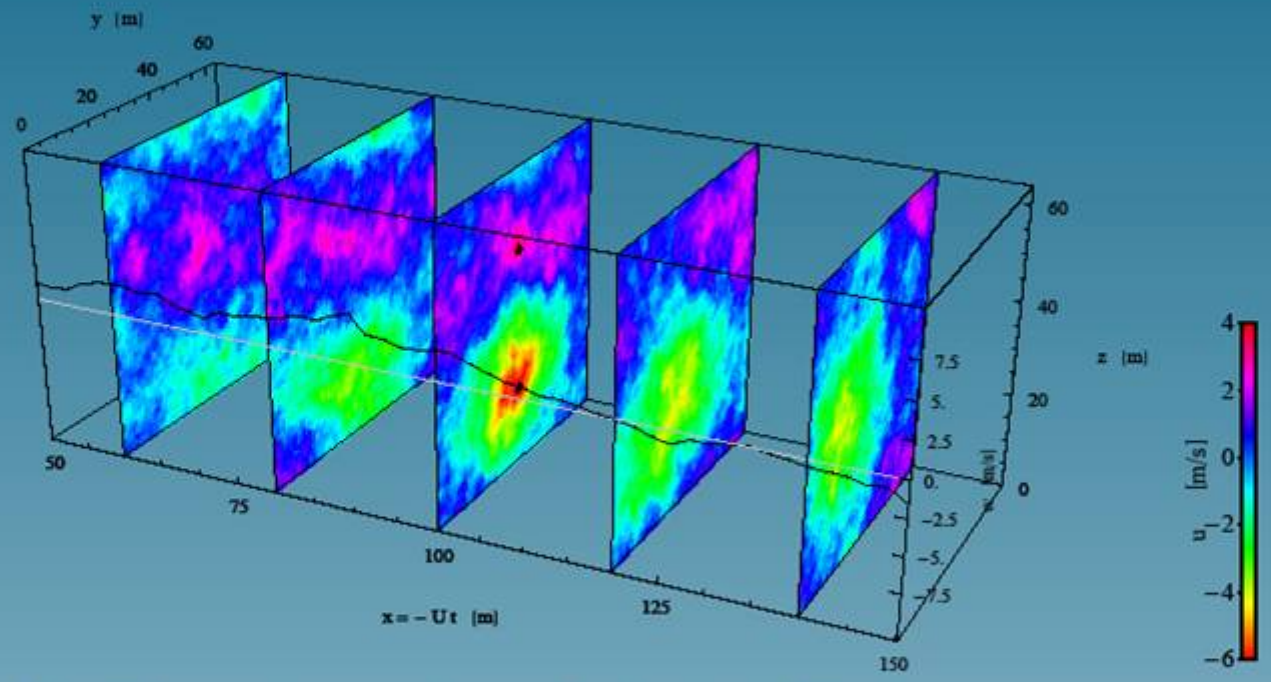


ATMOSPHERIC TURBULENCE

The complete description of turbulence remains one of the unsolved problems in physics.

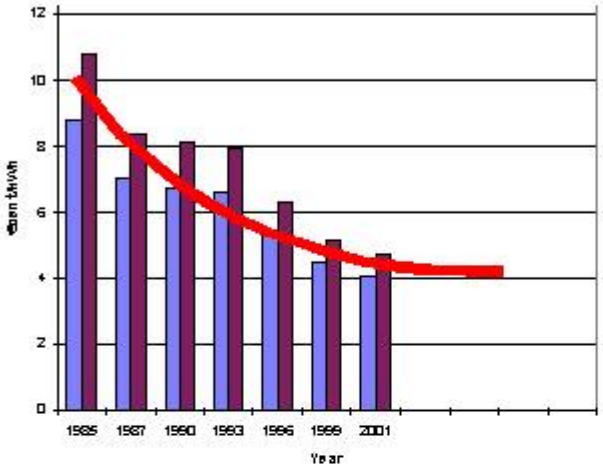
Werner Heisenberg was once asked what he would ask God, given the opportunity. His reply was: "When I meet God, I am going to ask him two questions: Why relativity? And why turbulence? I really believe he will have an answer for the first."

Example: "Strong velocity shear" (2:2)



The difference in u at the two black point is 10 m/s.

Size of Wind Turbines



Wind turbine blades are large

- examples

LM 38.8 m

LM 61.5 m (17.7 tons)

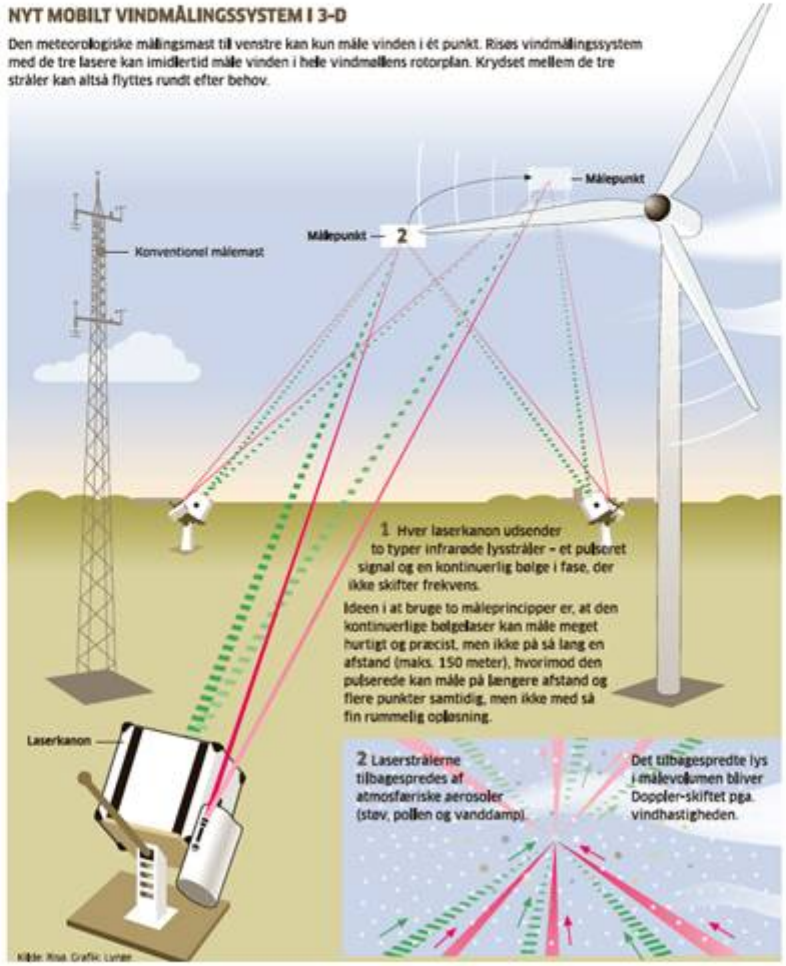
National Test Station for Large Wind Turbines - 2007

Coastal, flat terrain
5 test positions
Max. 10 MW
Max. height 165 m

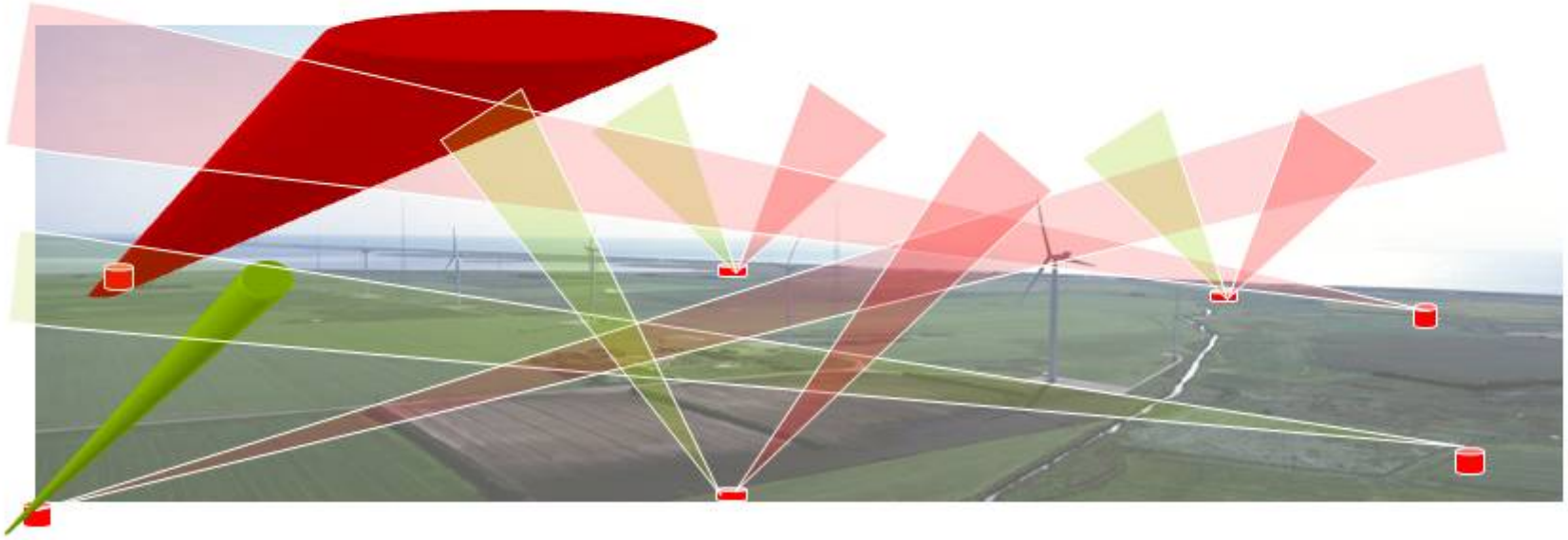
Small wind turbines at Risø - 1979

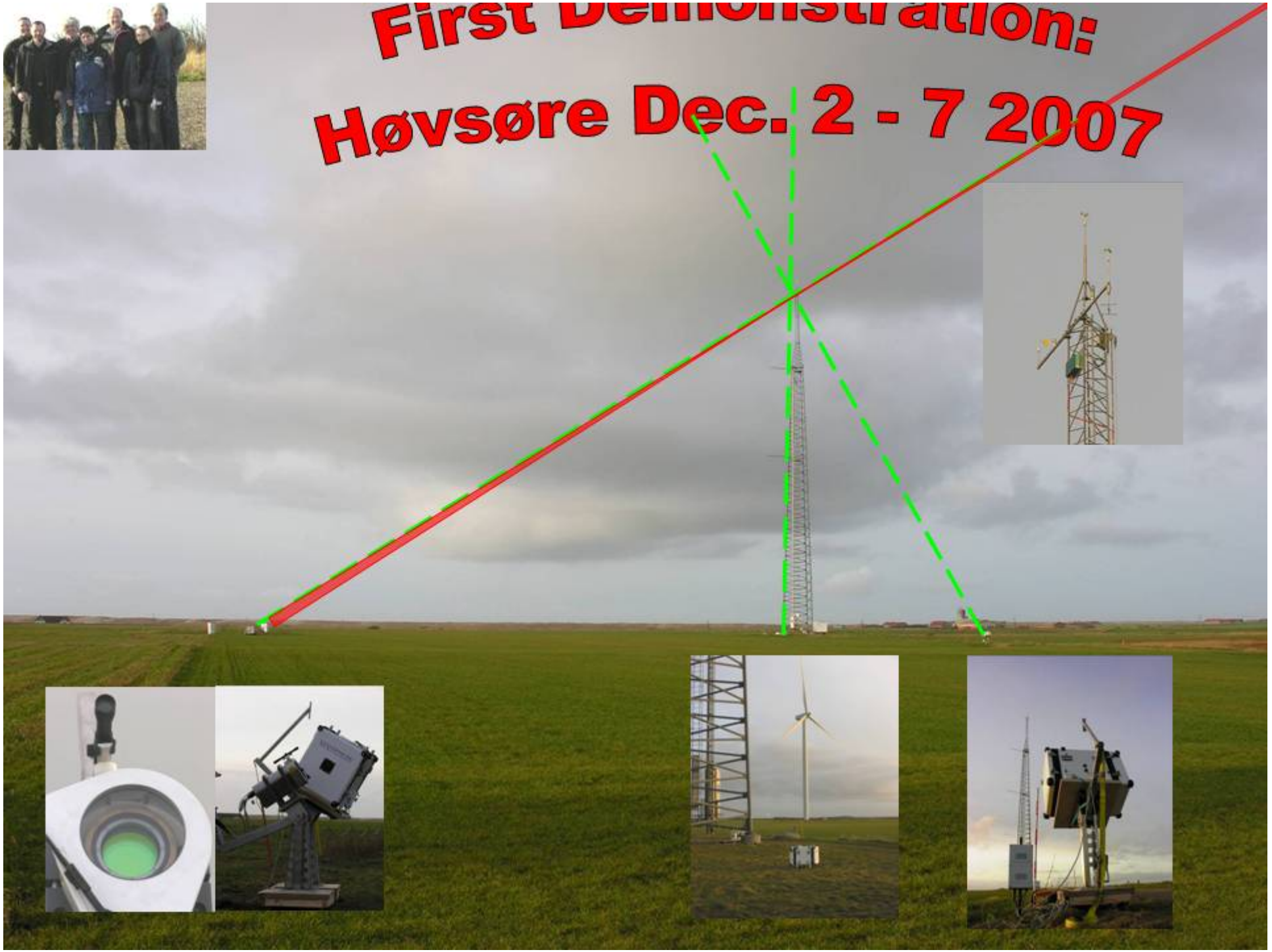
Since 2005:
Tall met-masts now replaceable by wind Lidars…

A new research facility for WT research based on 3-D Wind scanning:



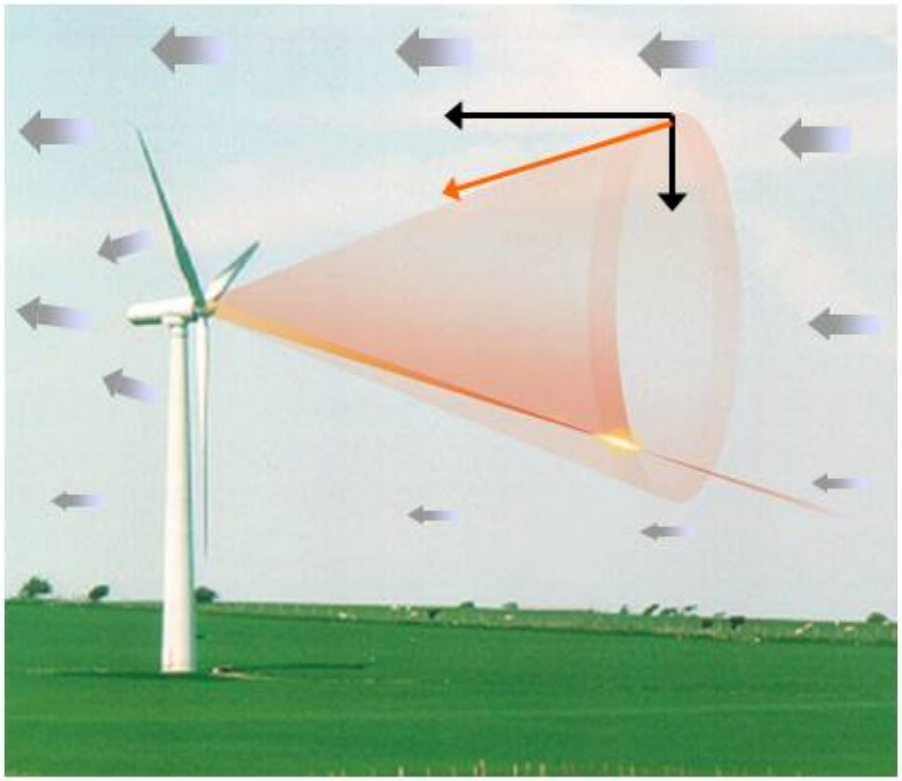
Artist's impression of a Wind scanner research facility in operation at Høvsøre DK



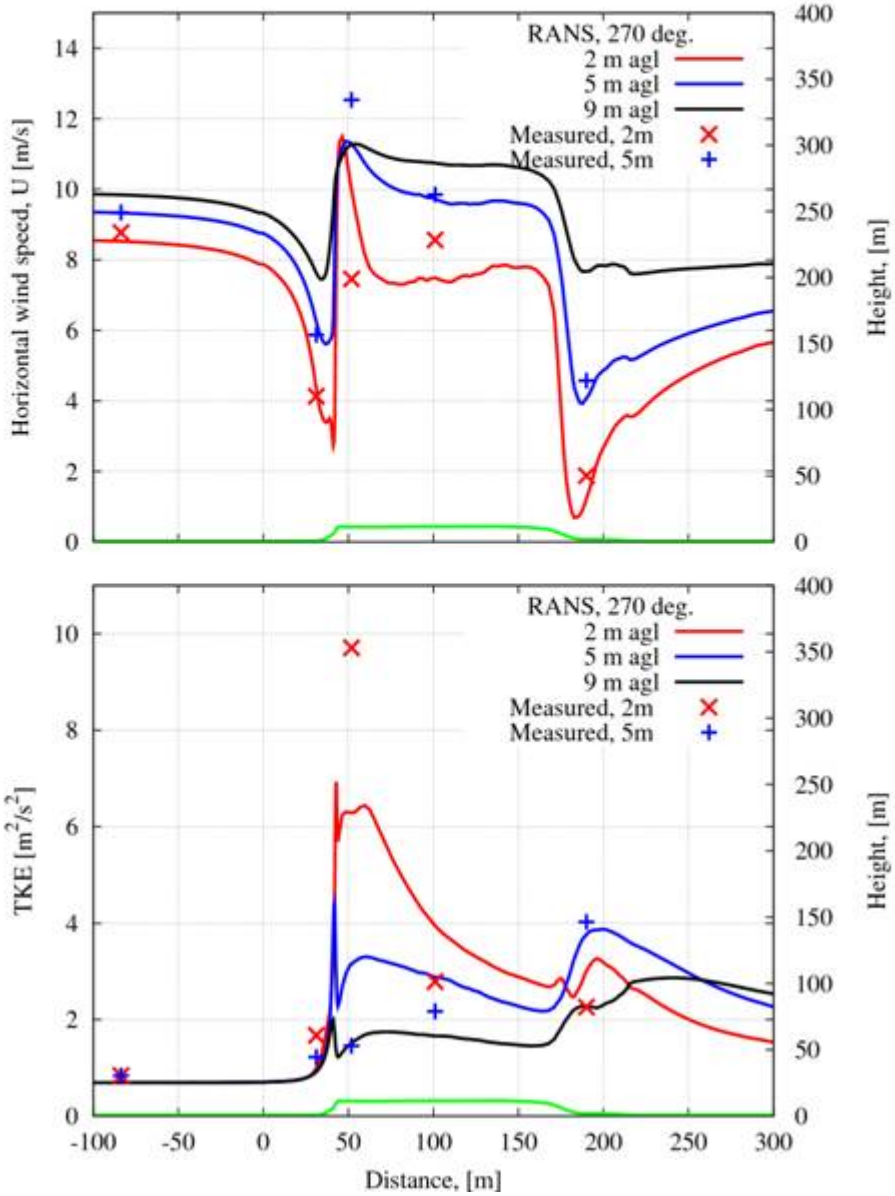

First Demonstration:
Høvsøre Dec. 2 - 7 2007

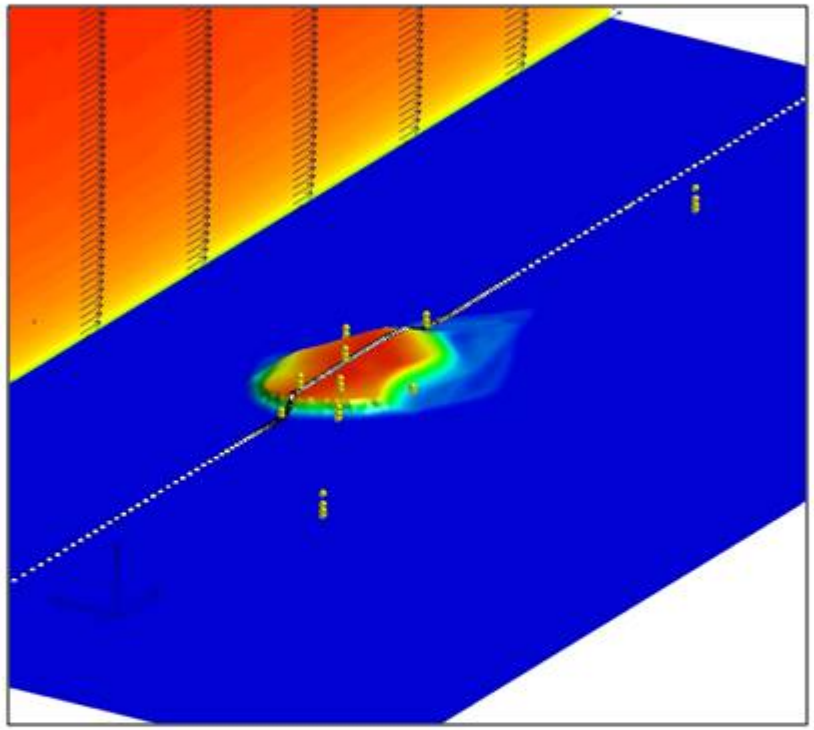
VISION

2. Active "proactive" WT control:



Bolund Experiment (Vestas), Profiles of U and TKE, 270°





VISION:

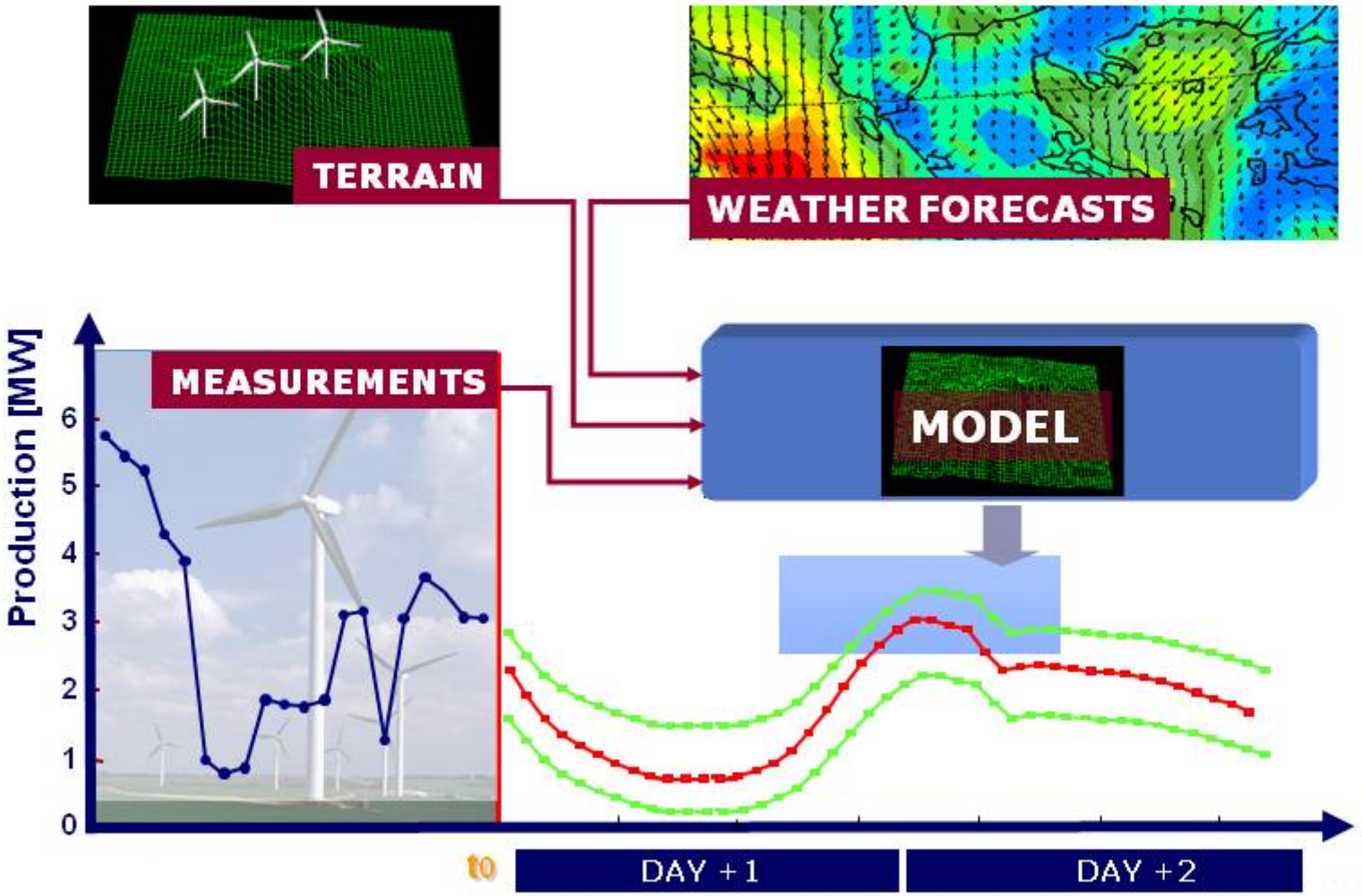
Wake Measurements On and Offshore...

(Horns Rev wind farm)

Horns Reef - 80 turbines 160 MW

Photos: ELSAM A/S

Short Term Prediction: The Principle



New Needs:

New information on wind and turbulence is required by the Wind Energy industry to move ahead:

Better and improved insight into

1. Wind profiles aloft
2. Turbulence and wakes around huge WT's – on shore & off-shore
3. Devastating strong wind gusts and wind-shear phenomena's

is required in 3-dimensional space and time, and at heights up to ~200-250 m height above ground/sea level.

… ambitious? …yes, but:

European Wind Atlas

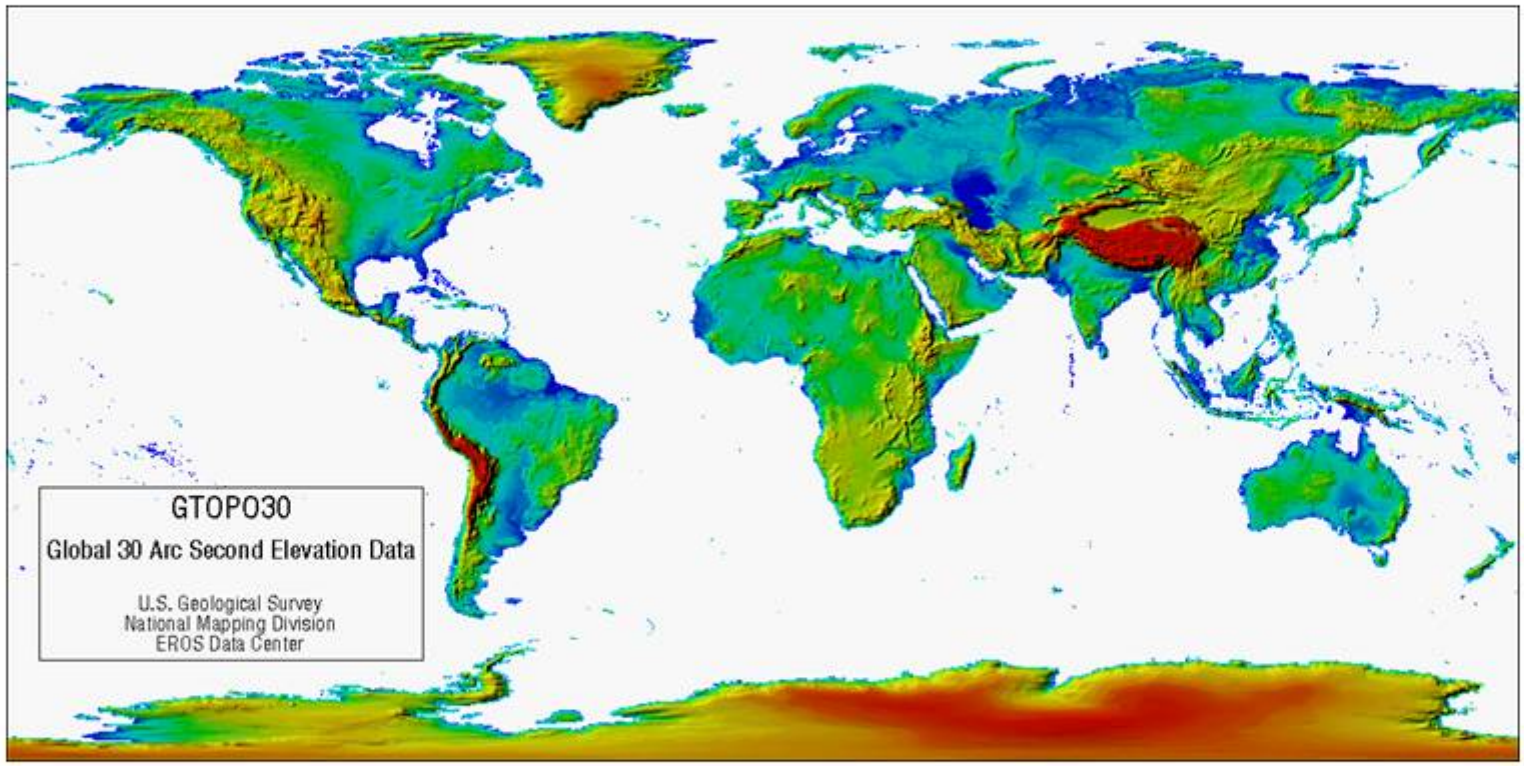
Wind resources[1] at 50 metres above ground level for five different topographic conditions

	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m\,s^{-1}$	$W\,m^{-2}$	$m\,s^{-1}$	$W\,m^{-2}$	$m\,s^{-1}$	$W\,m^{-2}$	$m\,s^{-1}$	$W\,m^{-2}$	$m\,s^{-1}$	$W\,m^{-2}$
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

1. The resources refer to the power present in the wind. A wind turbine can utilize between 20 and 30% of the available resource. The resources are calculated for an air density of 1.23 $kg\,m^{-3}$, corresponding to standard sea level pressure and a temperature of 15°C. Air density decreases with height but up to 1000 m a.s.l. the resulting reduction of the power densities is less than 10%.
2. Urban districts, forest and farm land with many windbreaks (roughness class 3).
3. Open landscapes with few windbreaks (roughness class 1). In general, the most favourable inland sites on level land are found here.
4. The classes pertain to a straight coastline, a uniform wind rose and a land surface with few windbreaks (roughness class 1). Resources will be higher, and closer to open sea values, if winds from the sea occur more frequently, i.e. the wind rose is not uniform and/or the land protrudes into the sea. Conversely, resources will generally be smaller, and closer to land values, if winds from land occur more frequently.
5. More than 10 km offshore (roughness class 0).
6. The classes correspond to 50% overspeeding and were calculated for a site on the summit of a single axisymmetric hill with a height of 400 metres and a base diameter of 4 km. The overspeeding depends on the height, length and specific setting of the hill.

Figure 2. Distribution of wind resources in Europe. By means of the legend the available wind energy at a height of 50 metres can be estimated for five topographical conditions. (Source: European Wind Atlas)

GTOPO30 global elevation data



Grid-point elevations

Resolution: 30 sec. (~900 m)

Meteorological Challenges

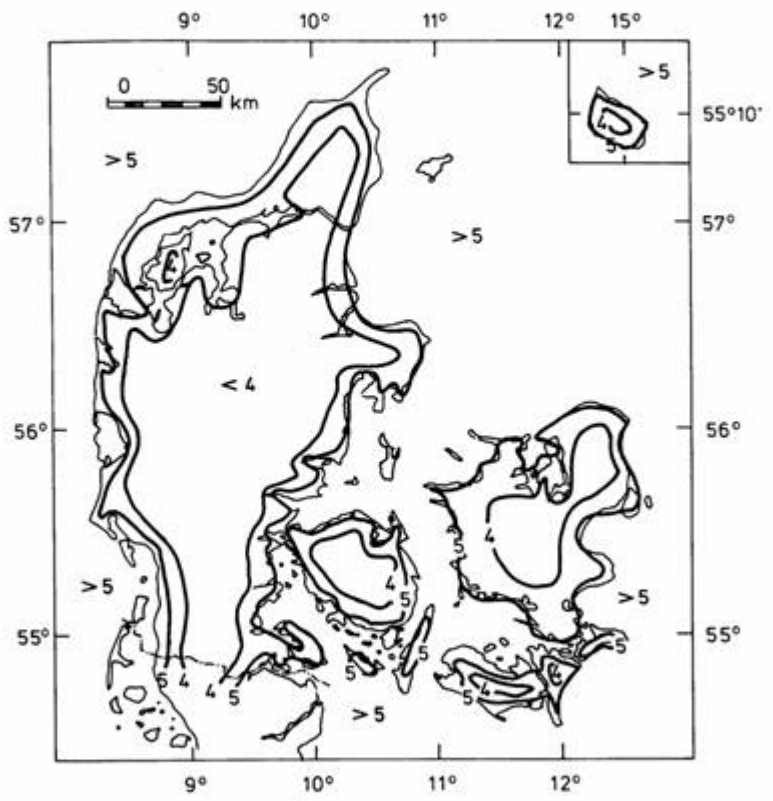
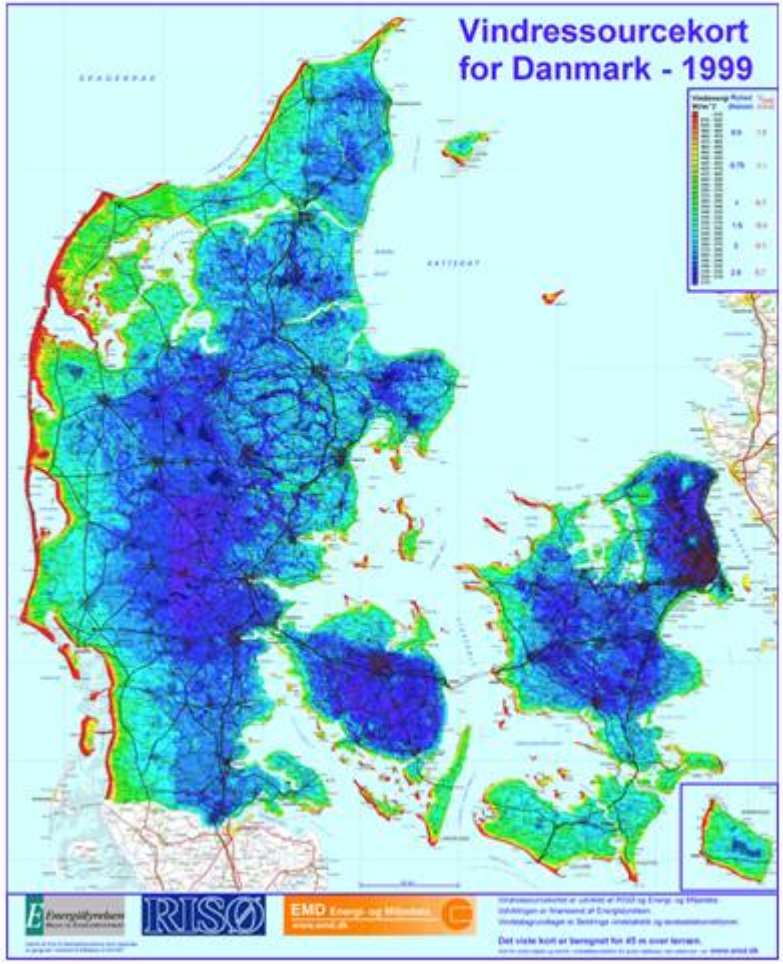
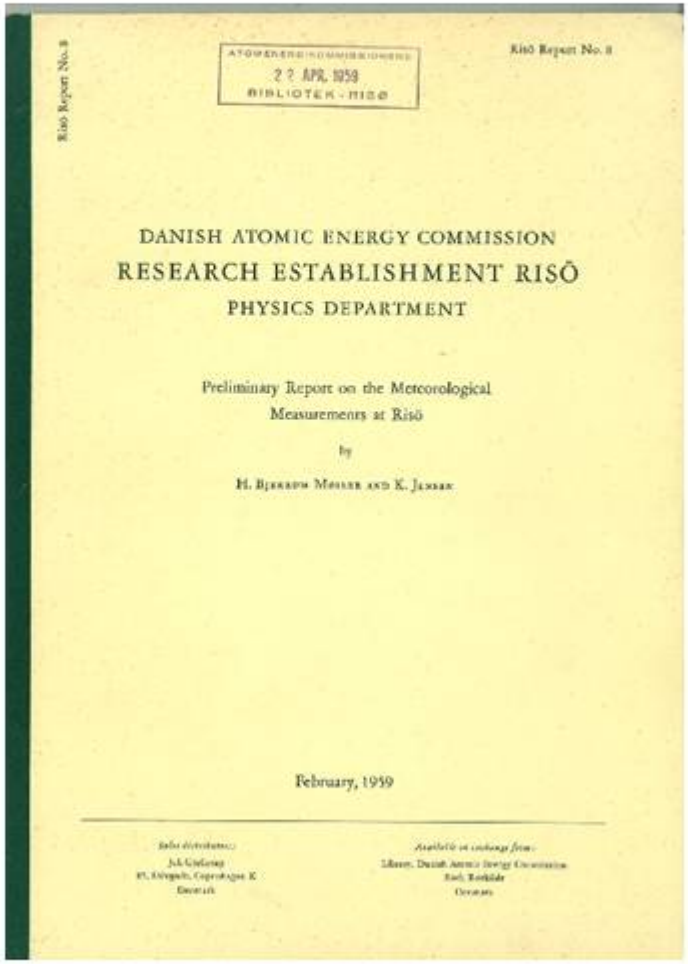


Figure 5.4. Isolines for wind speeds [m/s] in Denmark at 10 meter above the ground, based on data from 1931-60, compiled by Frydendahl (personal communication).





Risö Report No. 8

Risö Report No. 8

DANISH ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT RISÖ

PHYSICS DEPARTMENT

Preliminary Report on the Meteorological Measurements at Risö

by

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February, 1959

3 % vision

- Reduce the uncertainty of the estimated wind characteristics.

Current Techniques must be improved so that given the geographic coordinates of any wind farm predictions with an uncertainty of less than 3% can be made concerning:

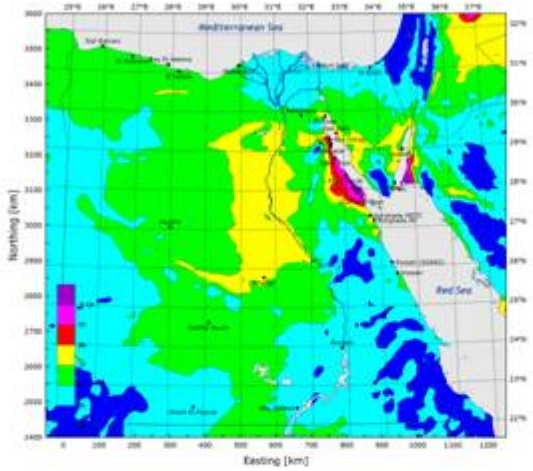
I. The annual energy production

II. The wind conditions that will affect the design of the turbine

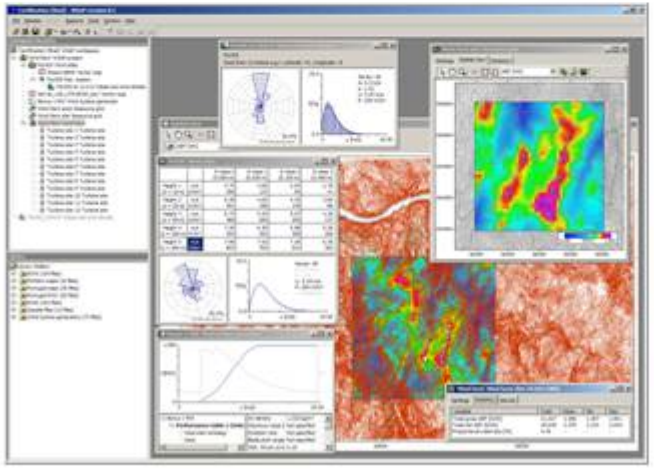
III. A short-term forecasting scheme for power production and wind conditions

Conceptual design – modelling

- **Mesoscale modelling**
  - KAMM/WAsP numerical wind atlas
  - covers large areas
  - fast and cost-effective
  - regional wind climate @ grid points
  - provides inputs for microscale
  - comparisons of several models: KAMM, WRF, MM5 and MC2



- **Microscale modelling**
  - analysis of 12 met. towers
  - analysis of CMA met. stations
  - WAsP observational wind atlas
  - regional wind climate @ tower
  - parameter studies used for localisation of model setup
  - same model as for applications



By the end of 2009

- **12 measurement stations** in operation
  - nine 70-m + three 100-m masts
  - double instrumentations: Risø and CMA

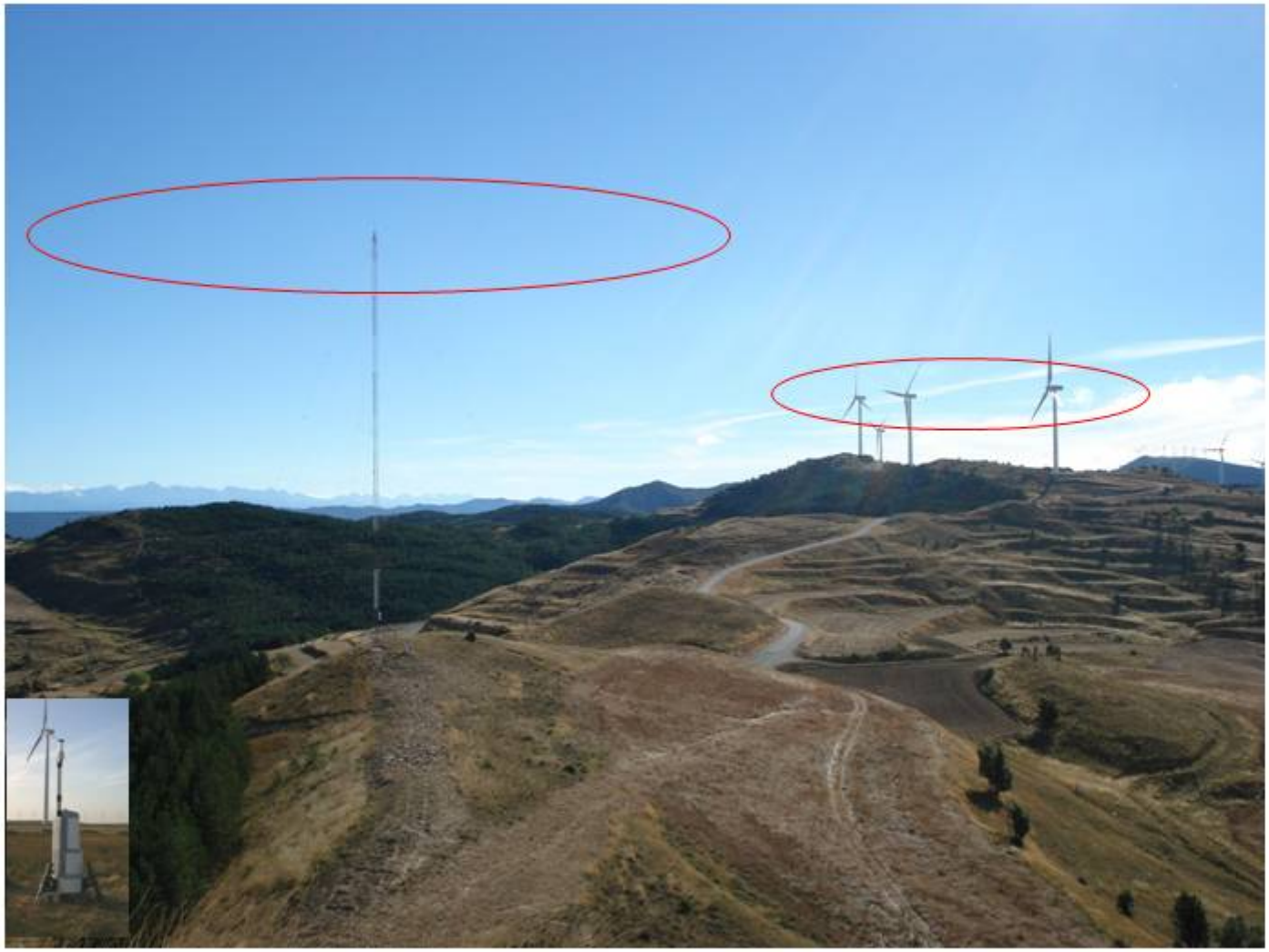
- **Observational Wind Atlas**
  - measurements and microscale modelling
  - for regions close to the towers and met. stations

- **Numerical Wind Atlas**
  - reanalysis data and mesoscale modelling
  - covering all of Dongbei with a resolution of 5 km

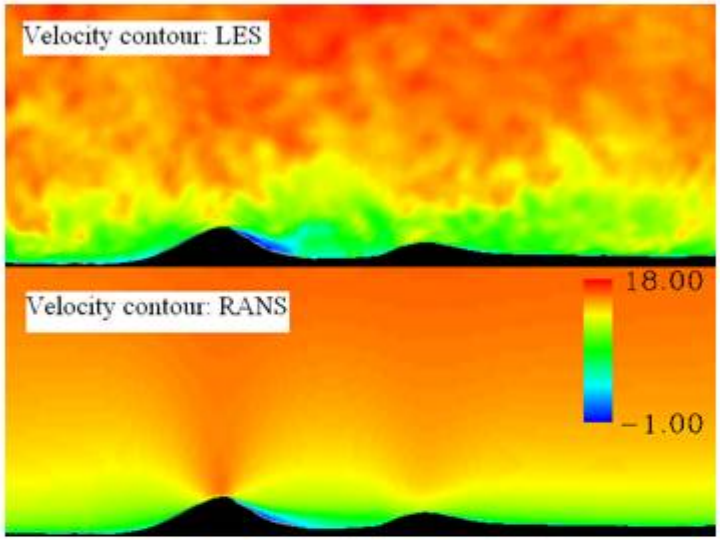
- **Verification** of numerical wind atlas against towers and met. stations

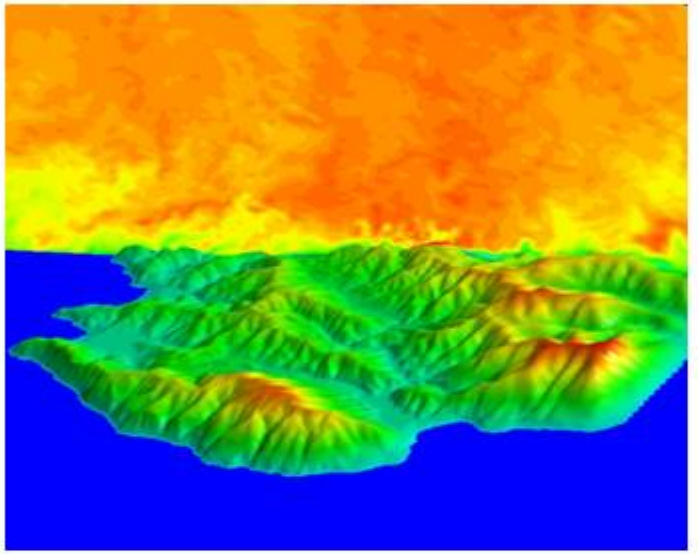
- **Databases, tools and guidelines** for applications

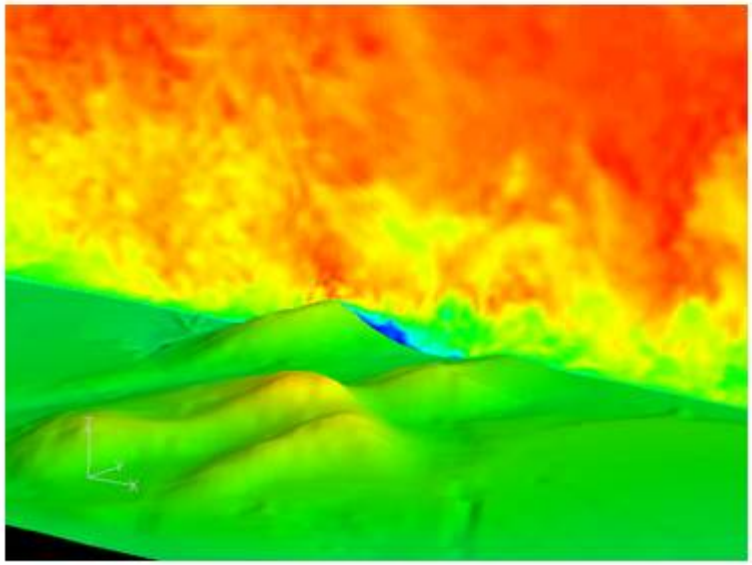
Windscanning also needed for secure WT siting in e.g. complex terrain…

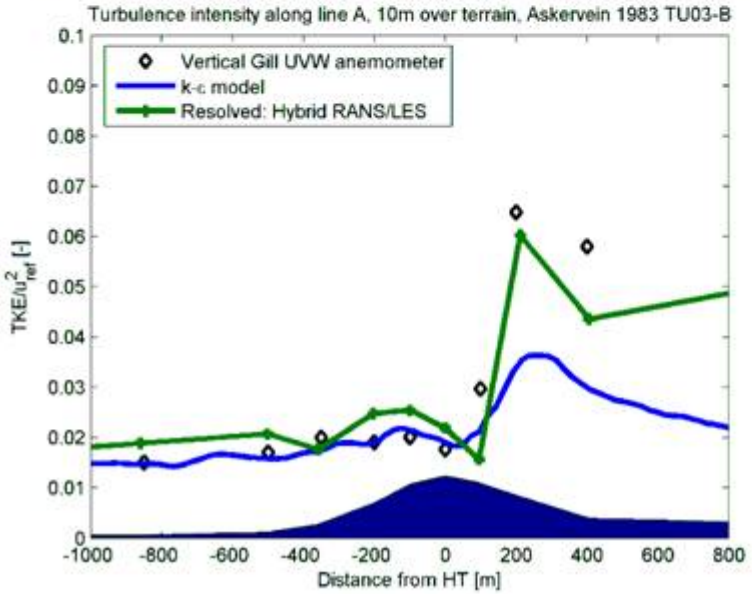


CFD computations of wind over complex terrain

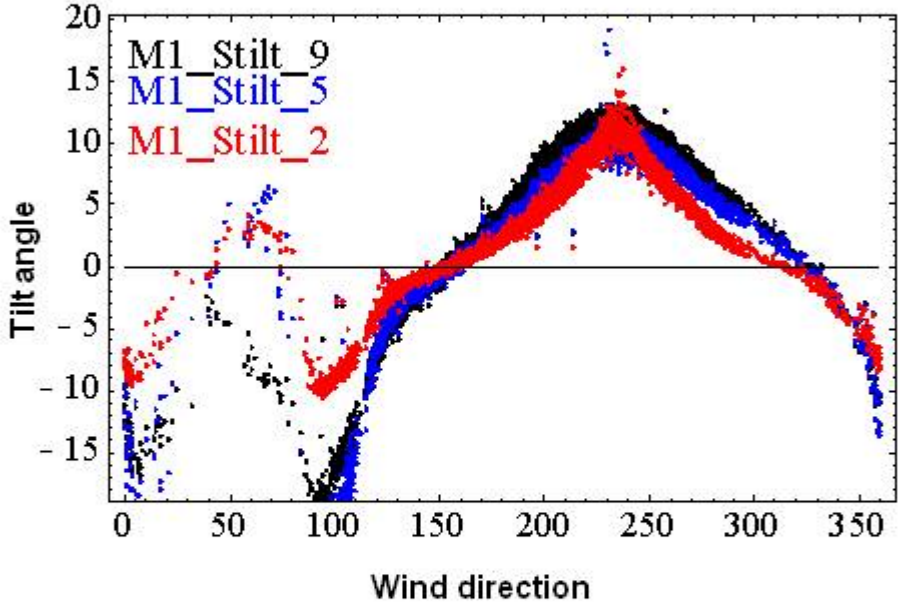


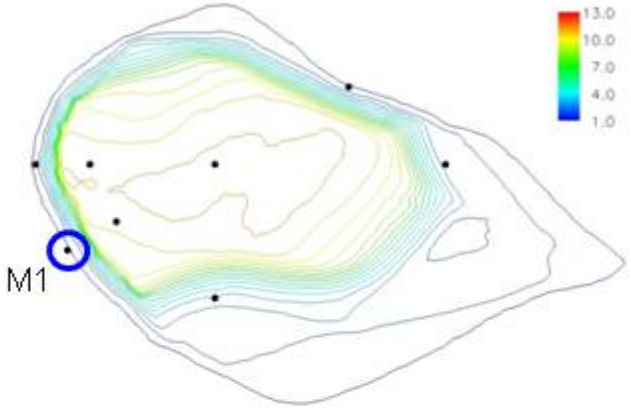


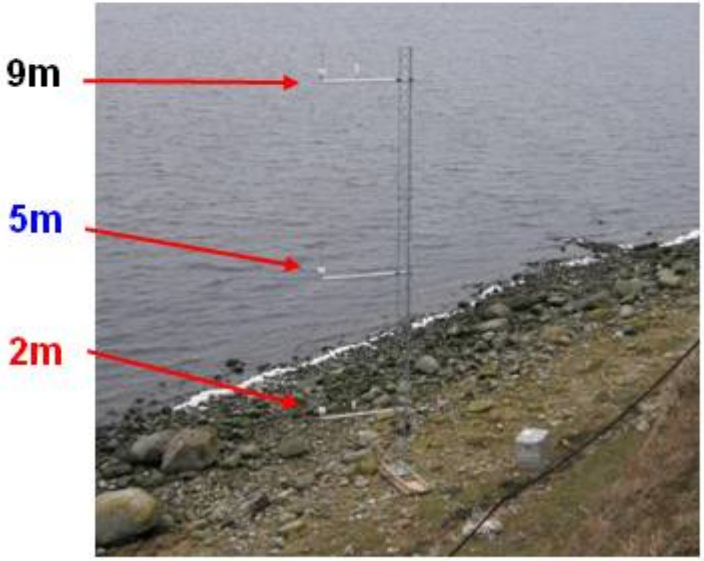




Tilt angle at M1







Summary:

DK's proposed large scale infrastructure

"Windscanning.eu"

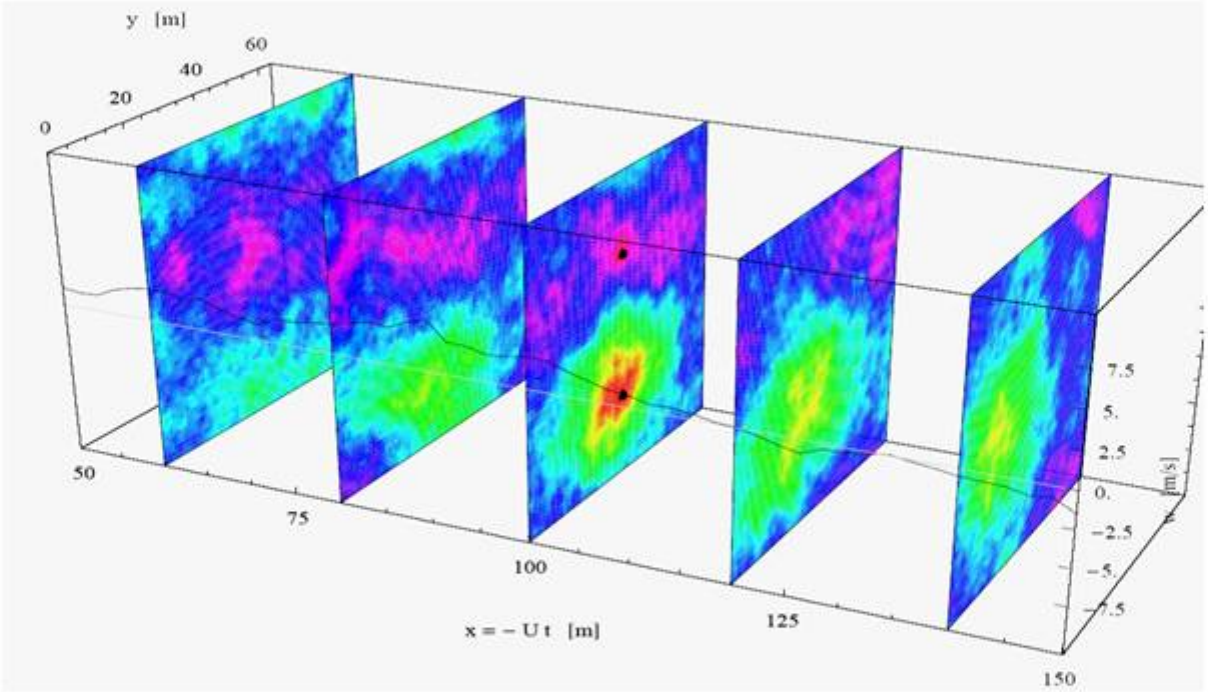
is a new mobile experimental research facility, that will improve:

1. Secure WT "Siting" - particular in complex terrain..
2. Optimal WT Design (gives more power and less wake effects...)
3. Proactive upwind WT control

and will spur research within wind energy society to provide:

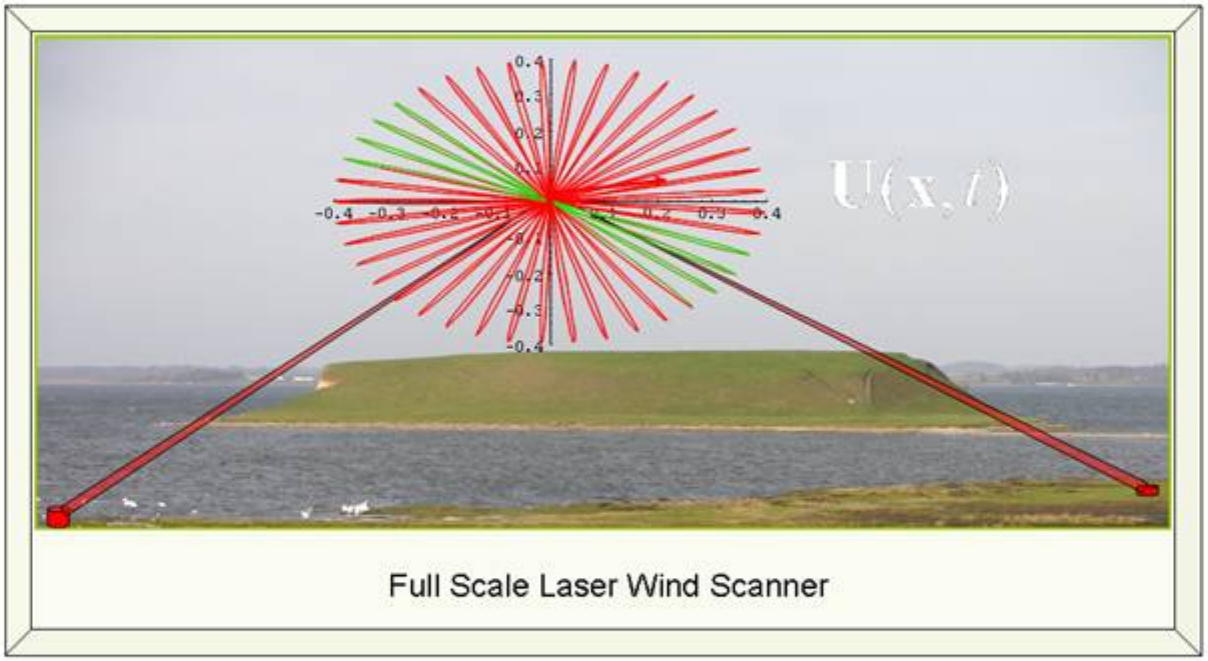
4. enhanced WT power performance and control
5. higher WT longevity

Simulated Wind scanner measurements of 3-D turbulence in high space & time resolution…



(1)

Vision New 3-D Windscanners...



Full Scale Laser Wind Scanner