



## Assessment of wind resources and annual energy production of wind farms

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# Assessment of wind resources and annual energy production of wind farms

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I acknowledge colleagues!

## Content

- Wind power in Europe – key numbers
- Assessment of wind resources
- Annual energy production (AEP) of wind farms
- Earth Observation data
- Summary

DTU Wind Energy has 240 employees since 1st January 2012.

Merger:

Former Risø DTU Wind Energy at the National Laboratory for Sustainable Energy merged with people from DTU MEK and Risø Material Science Department.

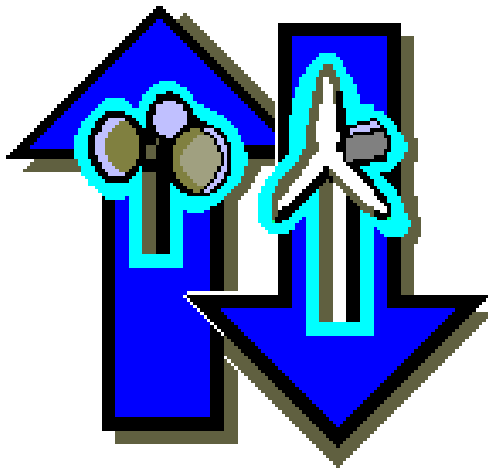
## Wind power in Europe – key numbers

- The total wind power capacity in Europe is 96 GW with 9 GW new onshore and 0.8 GW new offshore in 2011.
- Wind energy has an annual growth of 15.6% during the last 17 years.
- In EU 6.3% share of total electricity consumption is powered by wind energy (2011).
- Denmark plans to increase from 26% (2011) to 50% (2020) share of wind energy.

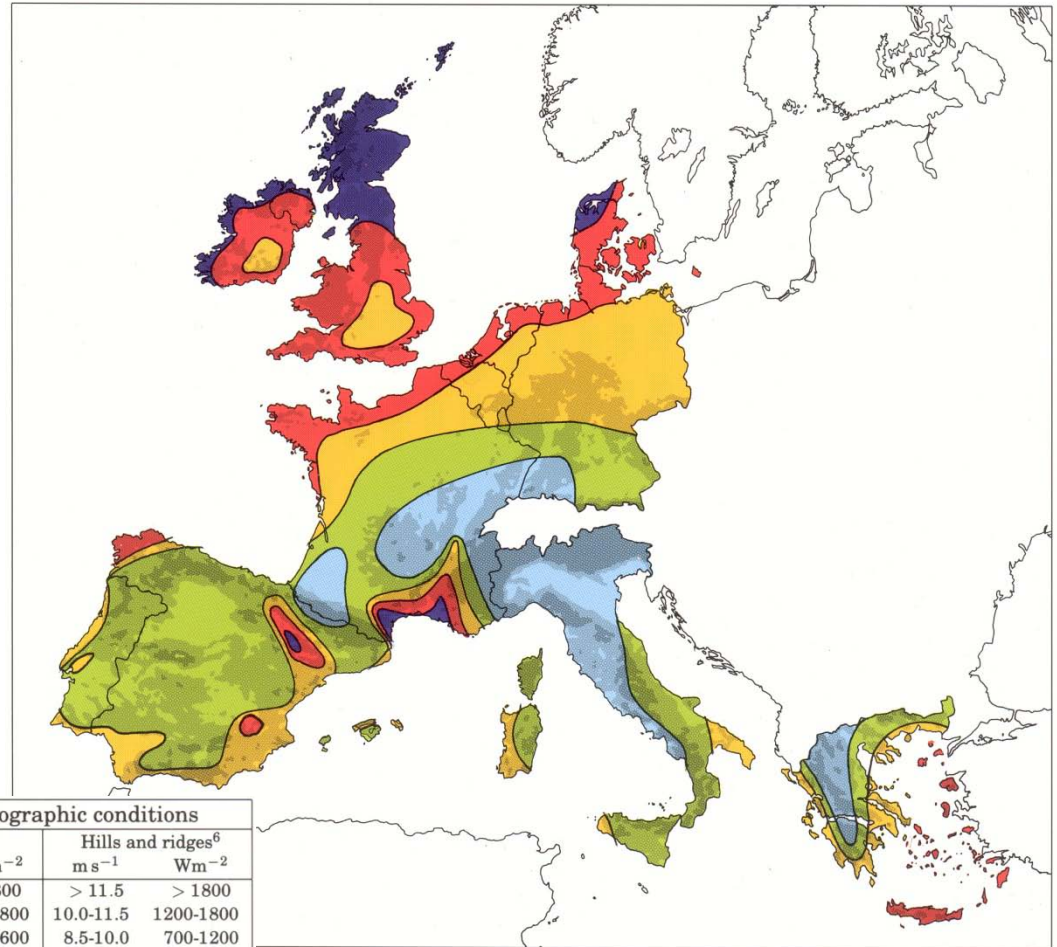
Source: EWEA

# Assessment of wind resources

## European Wind Atlas (1989)



WASP icon



Wind resources<sup>1</sup> at 50 metres above ground level for five different topographic conditions

	Sheltered terrain <sup>2</sup>		Open plain <sup>3</sup>		At a sea coast <sup>4</sup>		Open sea <sup>5</sup>		Hills and ridges <sup>6</sup>	
	ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>	ms <sup>-1</sup>	Wm <sup>-2</sup>
	> 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

# WAsP

- Analysis procedure (  $\uparrow$  )

## Observed Wind Climate

- + sheltering obstacles
- + roughness map
- + elevation map

## → Generalised Wind Climate

- Application procedure (  $\downarrow$  )

## Generalised Wind Climate

- + sheltering obstacles
- + roughness map
- + elevation map

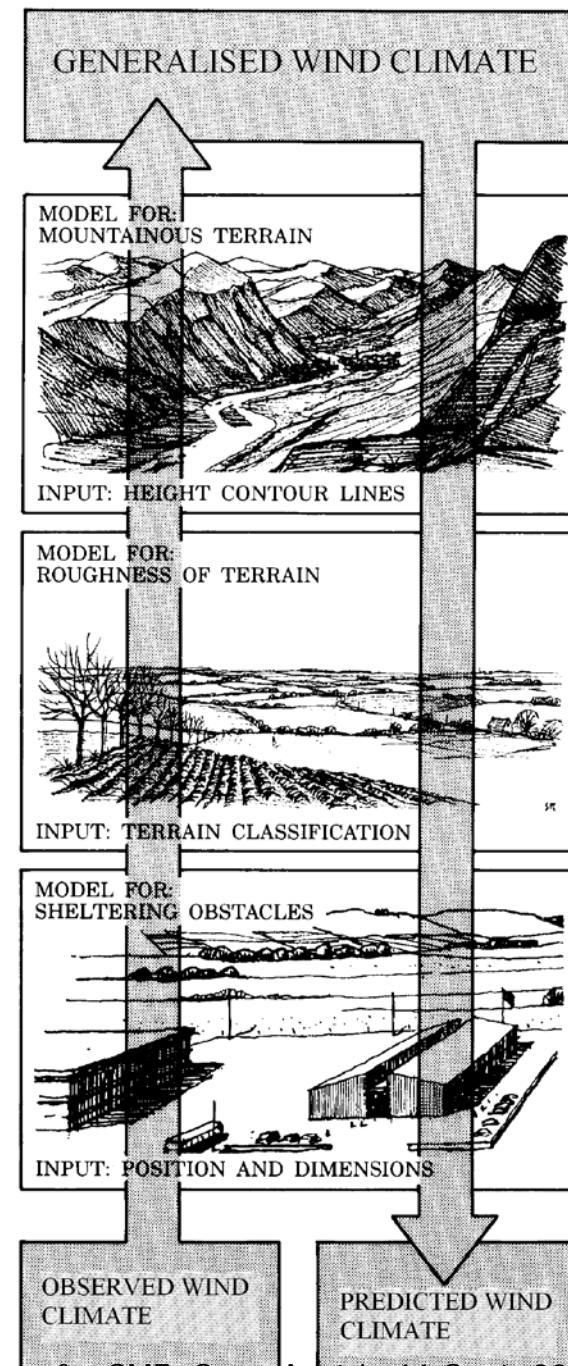
## → Predicted Wind Climate

- Wind farm production

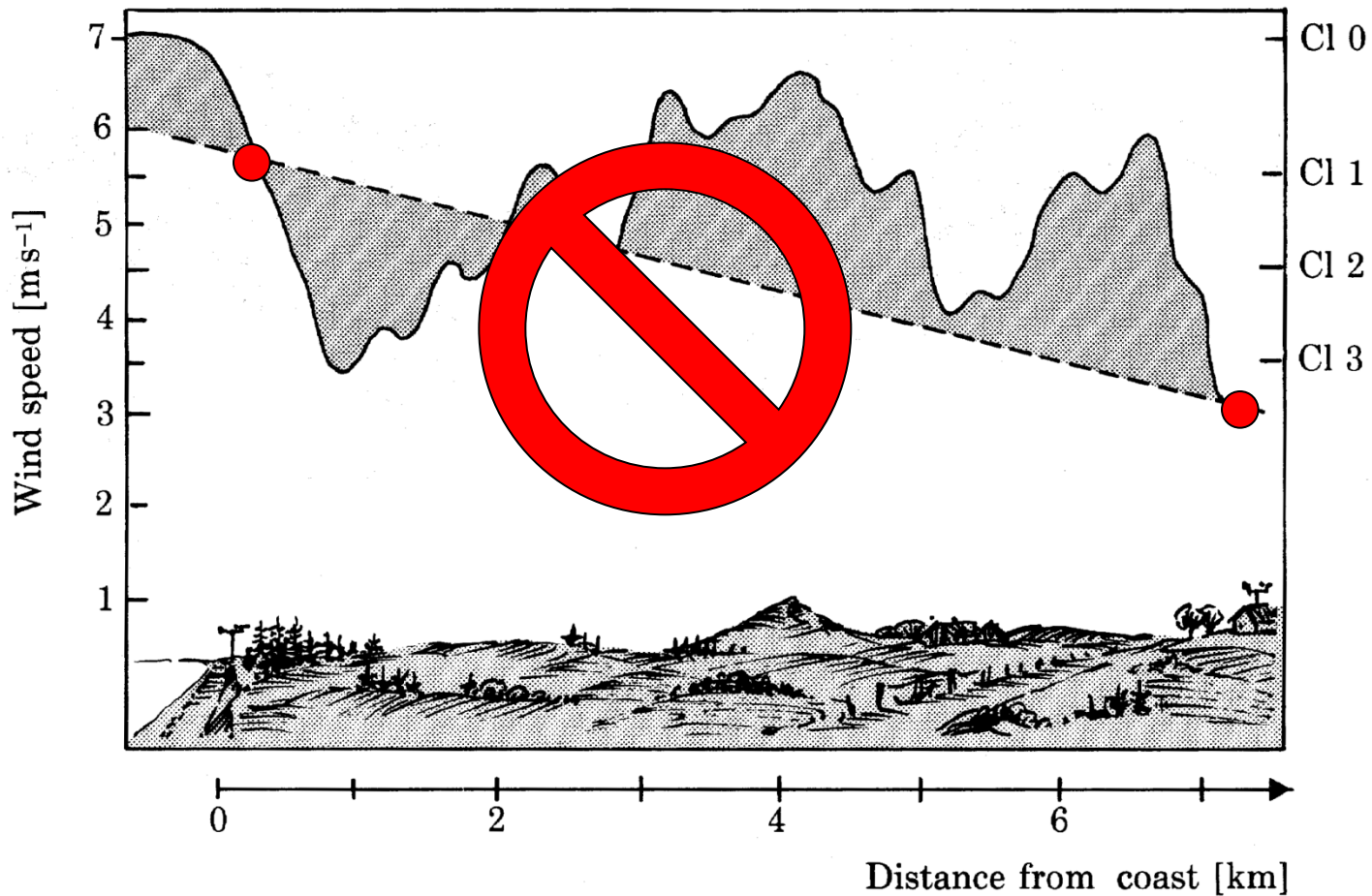
## Predicted Wind Climate

- + power and thrust curves
- + wind farm layout

## → Predicted wind farm AEP

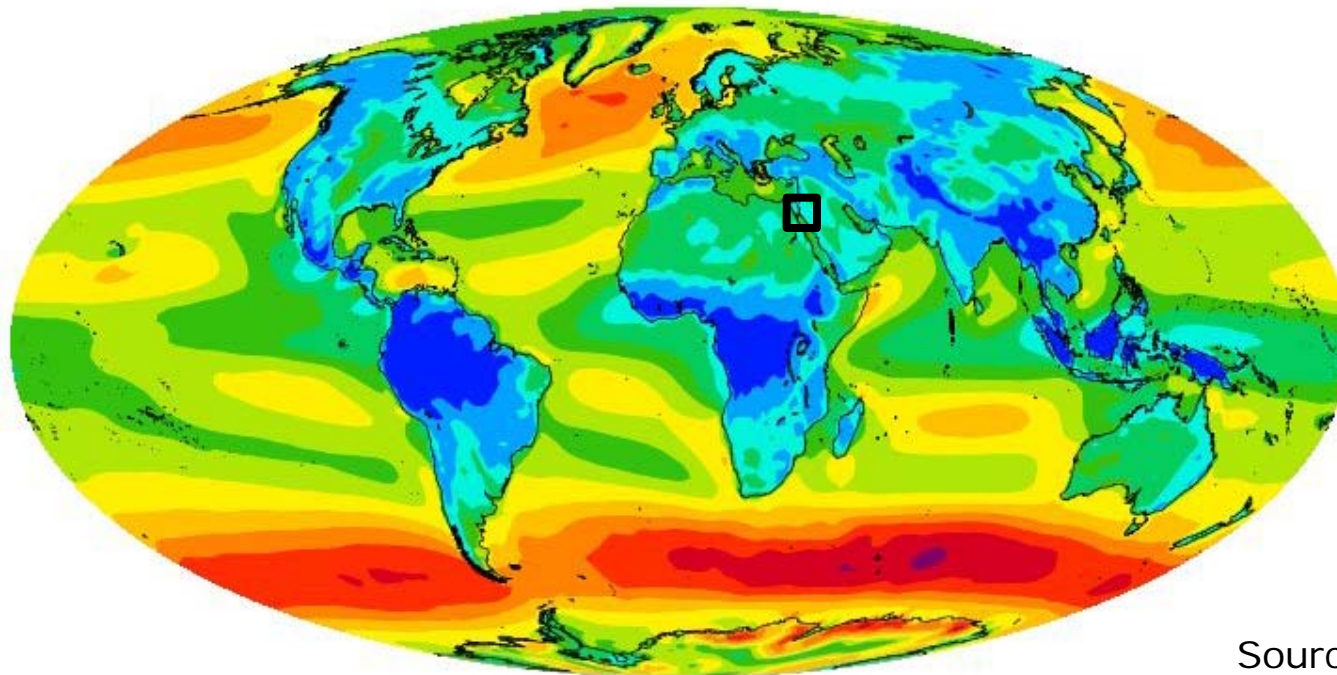


# Linear interpolation...





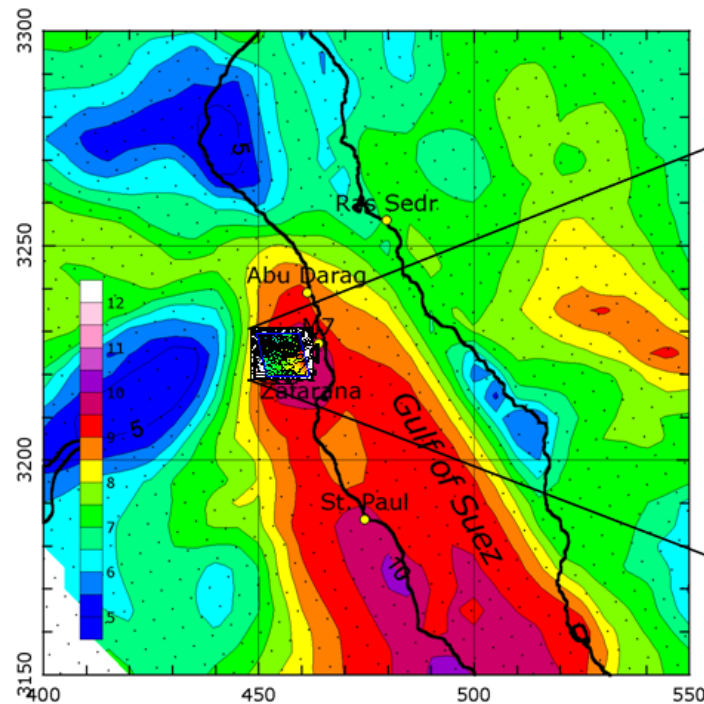
# Global annually averaged 10-meter wind map



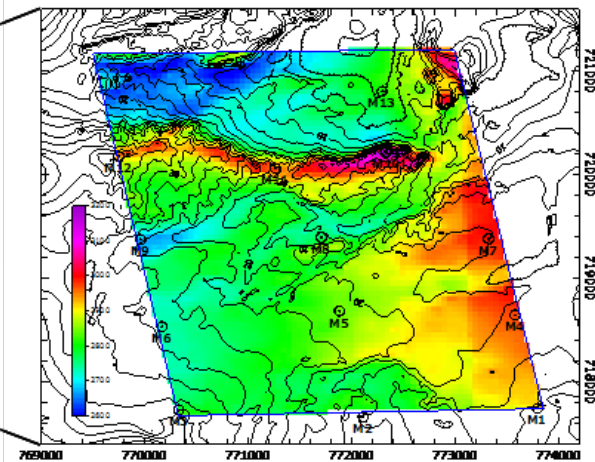
Source: European  
Center for Medium  
Range Weather  
Forecasting  
(ECMWF) - ERA  
Interim reanalysis



# Regional and local wind map Egypt

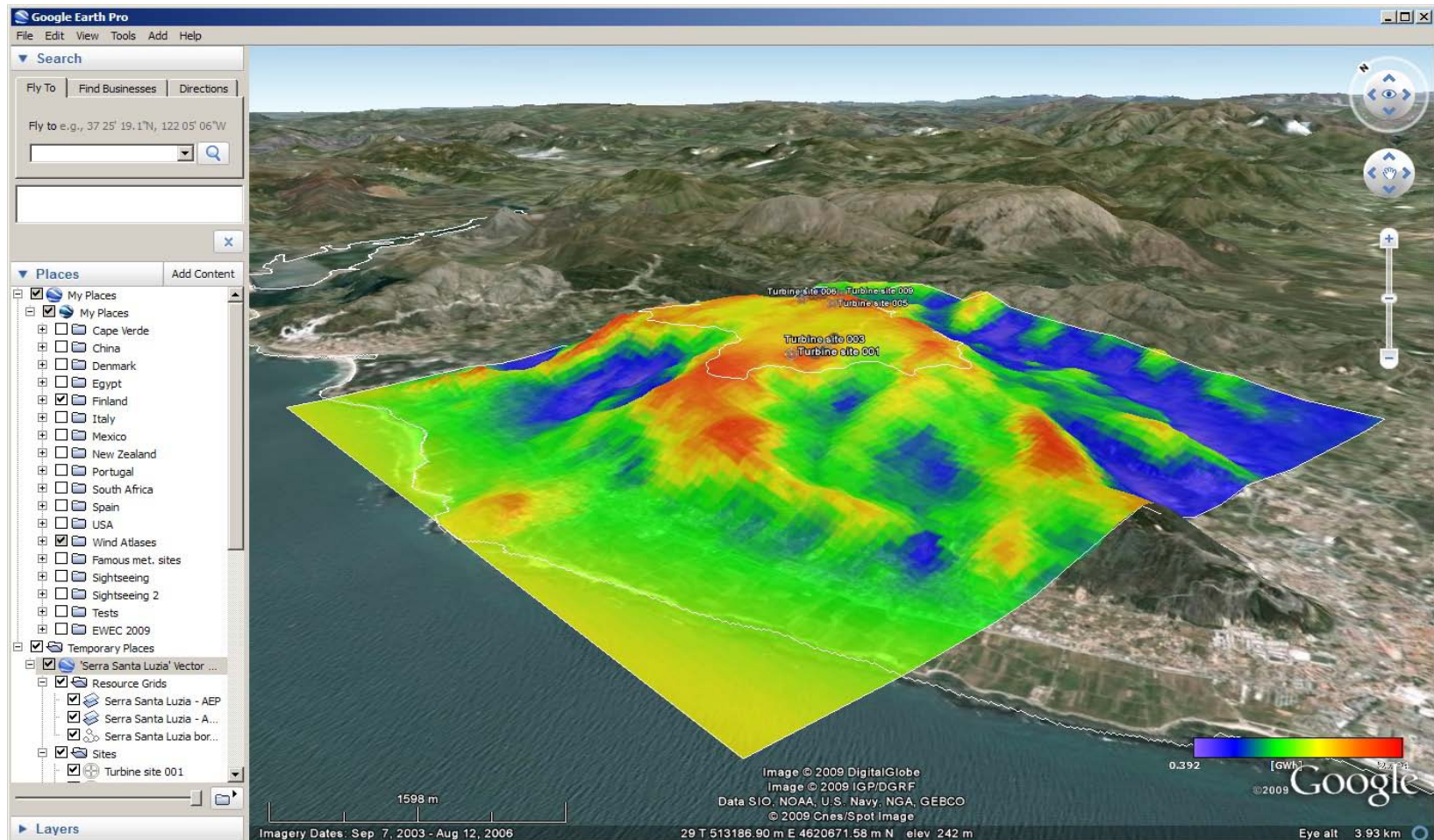


Mesoscale wind map

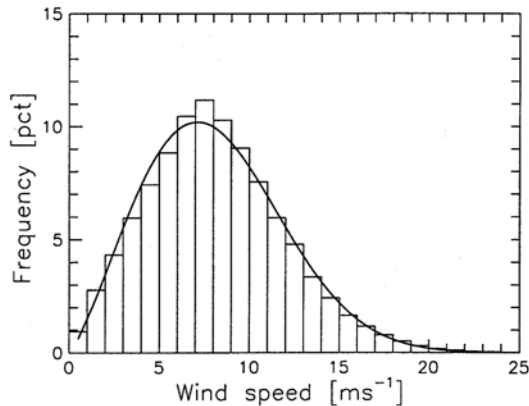


Microscale wind map

# Example winds in mountains

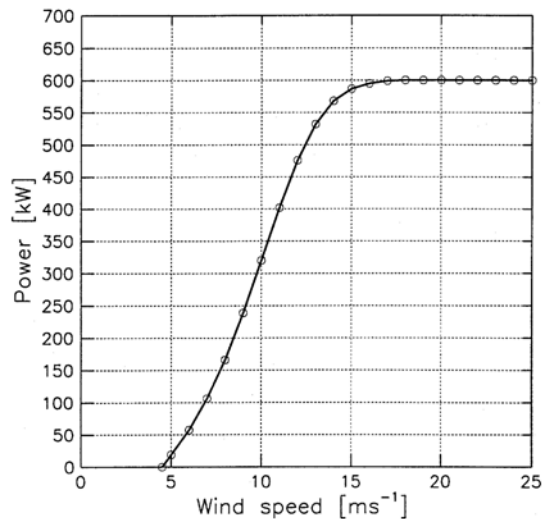


# Annual energy production (AEP) of wind farm



**Wind speed distribution at hub height**

**+ wind turbine power curve**

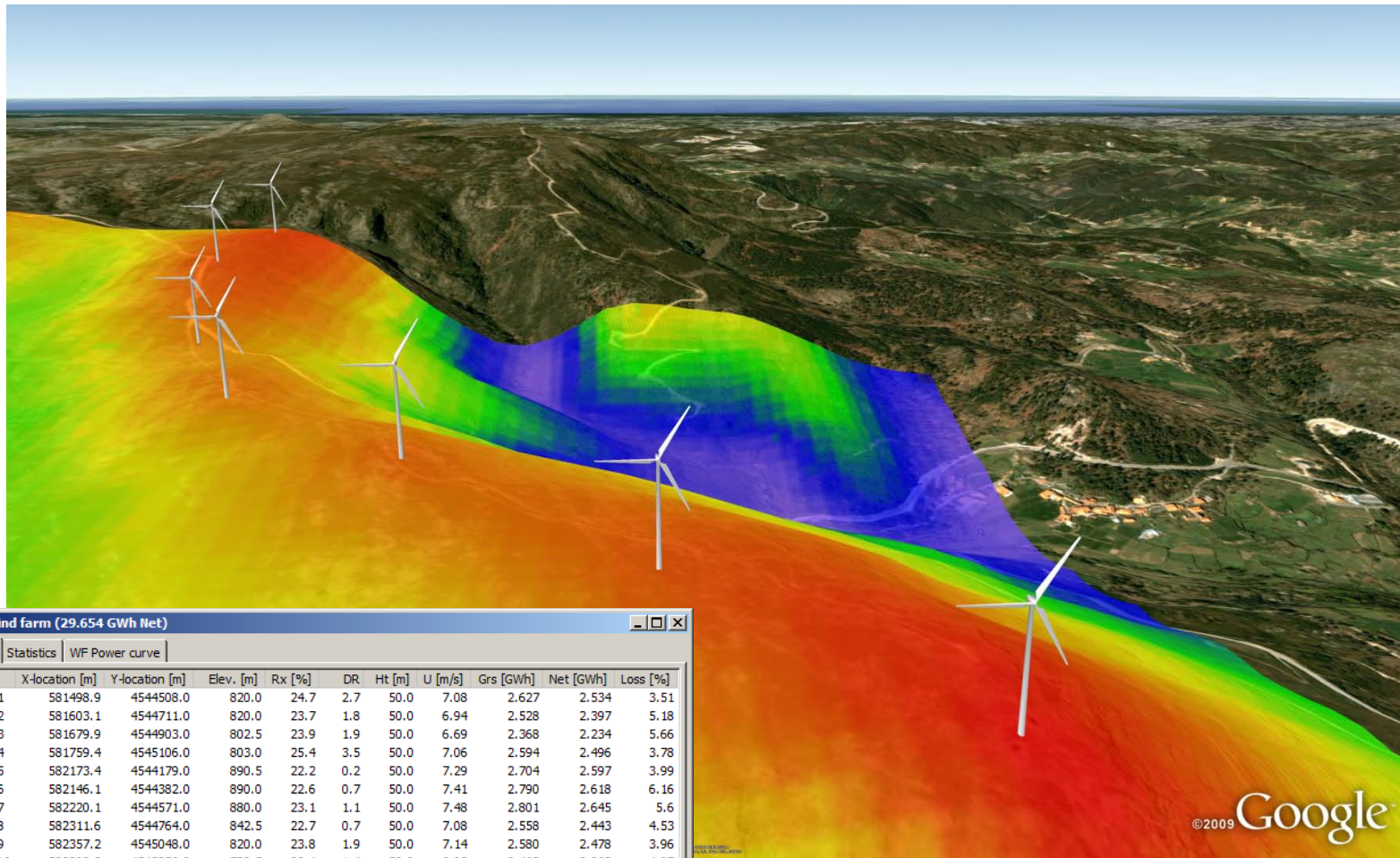


**= AEP calculation and prediction**

- Based on  $n$  previous years
- Valid for wind turbine lifetime (20 year)



# Annual Energy Production (AEP) of wind farm



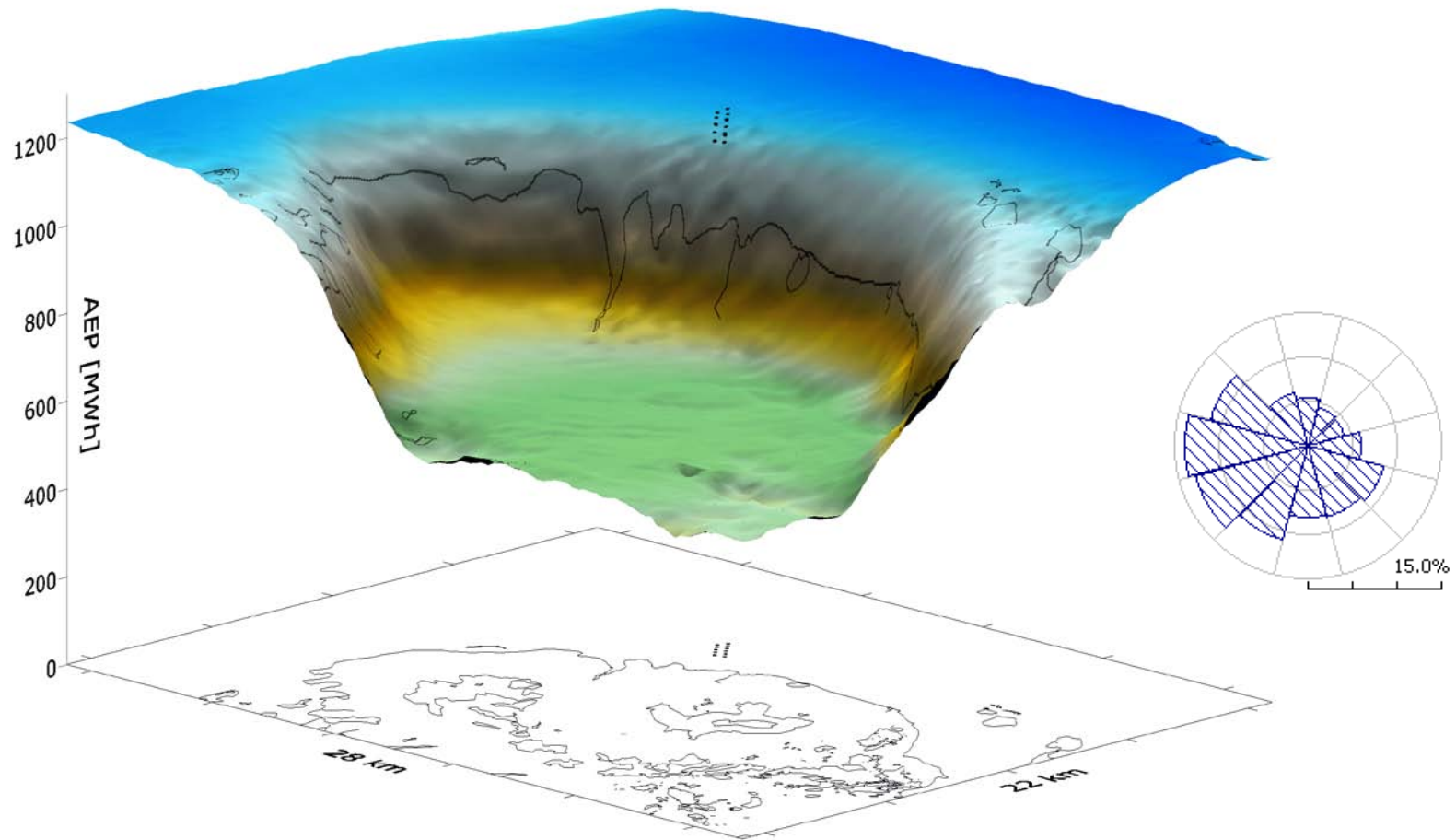
**'Wind farm' Wind farm (29.654 GWh Net)**

Settings Site list Statistics WF Power curve

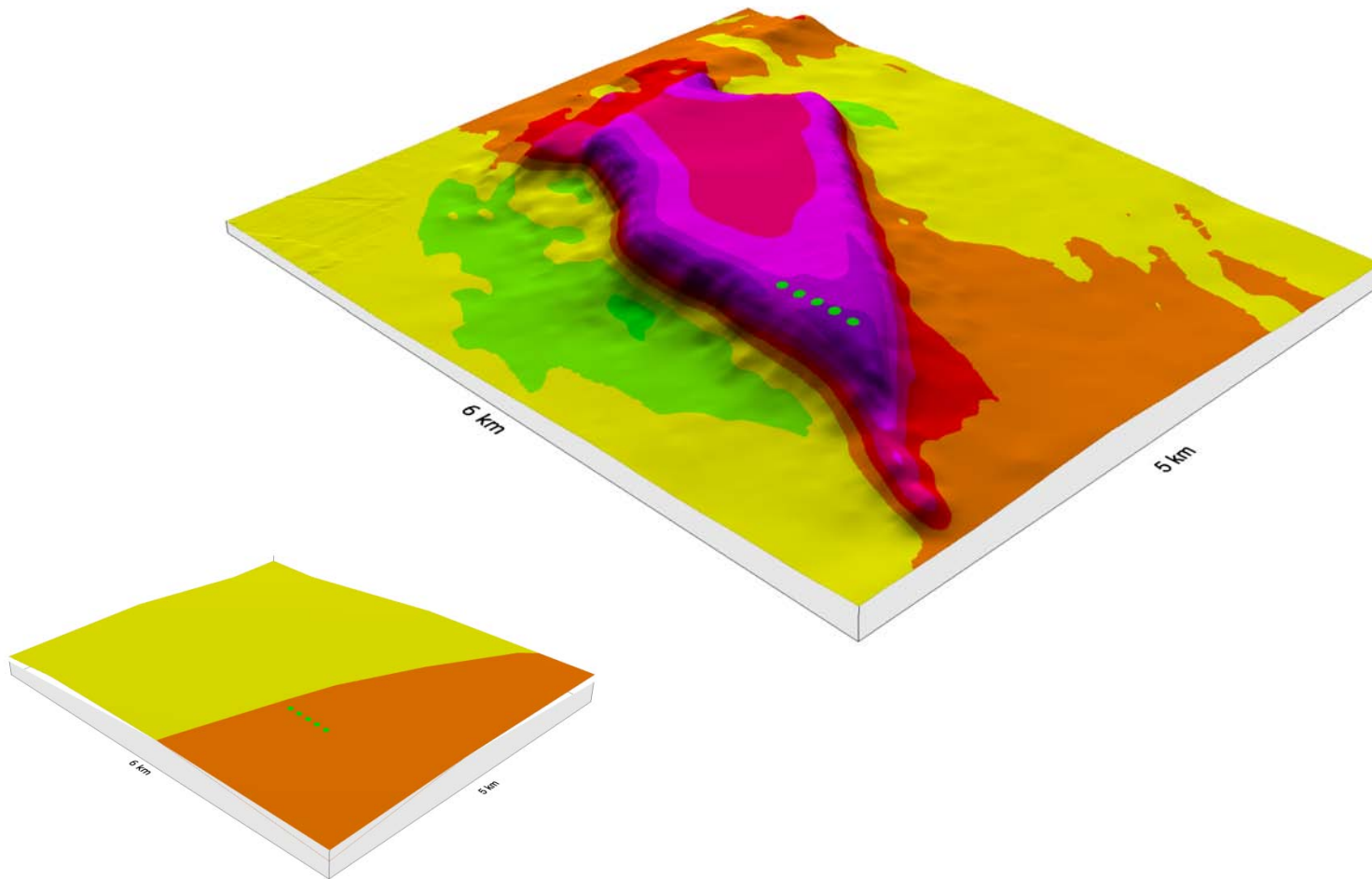
Site ID	X-location [m]	Y-location [m]	Elev. [m]	Rx [%]	DR	Ht [m]	U [m/s]	Grs [GWh]	Net [GWh]	Loss [%]
Turbine site 1	581498.9	4544508.0	820.0	24.7	2.7	50.0	7.08	2.627	2.534	3.51
Turbine site 2	581603.1	4544711.0	820.0	23.7	1.8	50.0	6.94	2.528	2.397	5.18
Turbine site 3	581679.9	4544903.0	802.5	23.9	1.9	50.0	6.69	2.368	2.234	5.66
Turbine site 4	581759.4	4545106.0	803.0	25.4	3.5	50.0	7.06	2.594	2.496	3.78
Turbine site 5	582173.4	4544179.0	890.5	22.2	0.2	50.0	7.29	2.704	2.597	3.99
Turbine site 6	582146.1	4544382.0	890.0	22.6	0.7	50.0	7.41	2.790	2.618	6.16
Turbine site 7	582220.1	4544571.0	880.0	23.1	1.1	50.0	7.48	2.801	2.645	5.6
Turbine site 8	582311.6	4544764.0	842.5	22.7	0.7	50.0	7.08	2.558	2.443	4.53
Turbine site 9	582357.2	4545048.0	820.0	23.8	1.9	50.0	7.14	2.580	2.478	3.96
Turbine site 10	582398.3	4545256.0	788.5	23.4	1.4	50.0	6.93	2.463	2.363	4.07
Turbine site 11	582453.1	4545448.0	769.8	24.4	2.4	50.0	7.04	2.529	2.419	4.32
Turbine site 12	582398.3	4545660.0	741.7	25.1	3.2	50.0	6.96	2.494	2.431	2.53

Calculate

## Example offshore

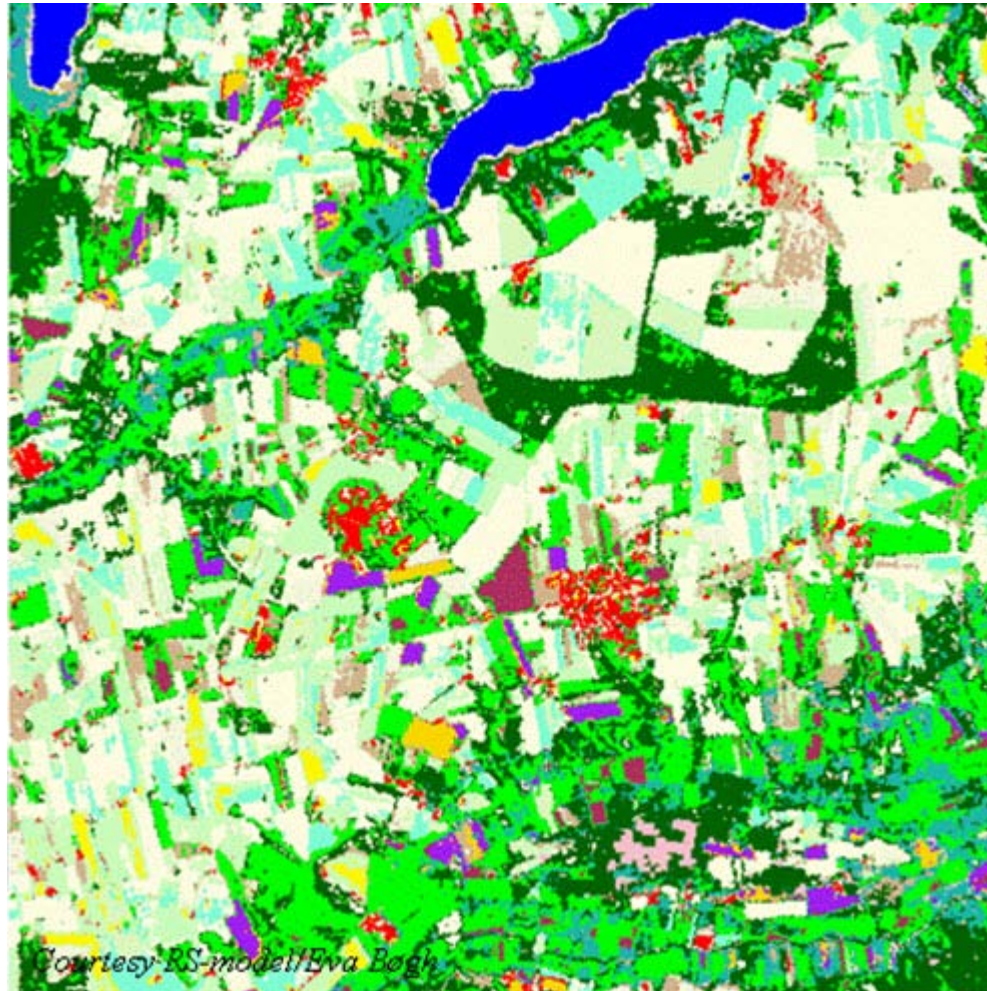


## Land information at sufficient scale

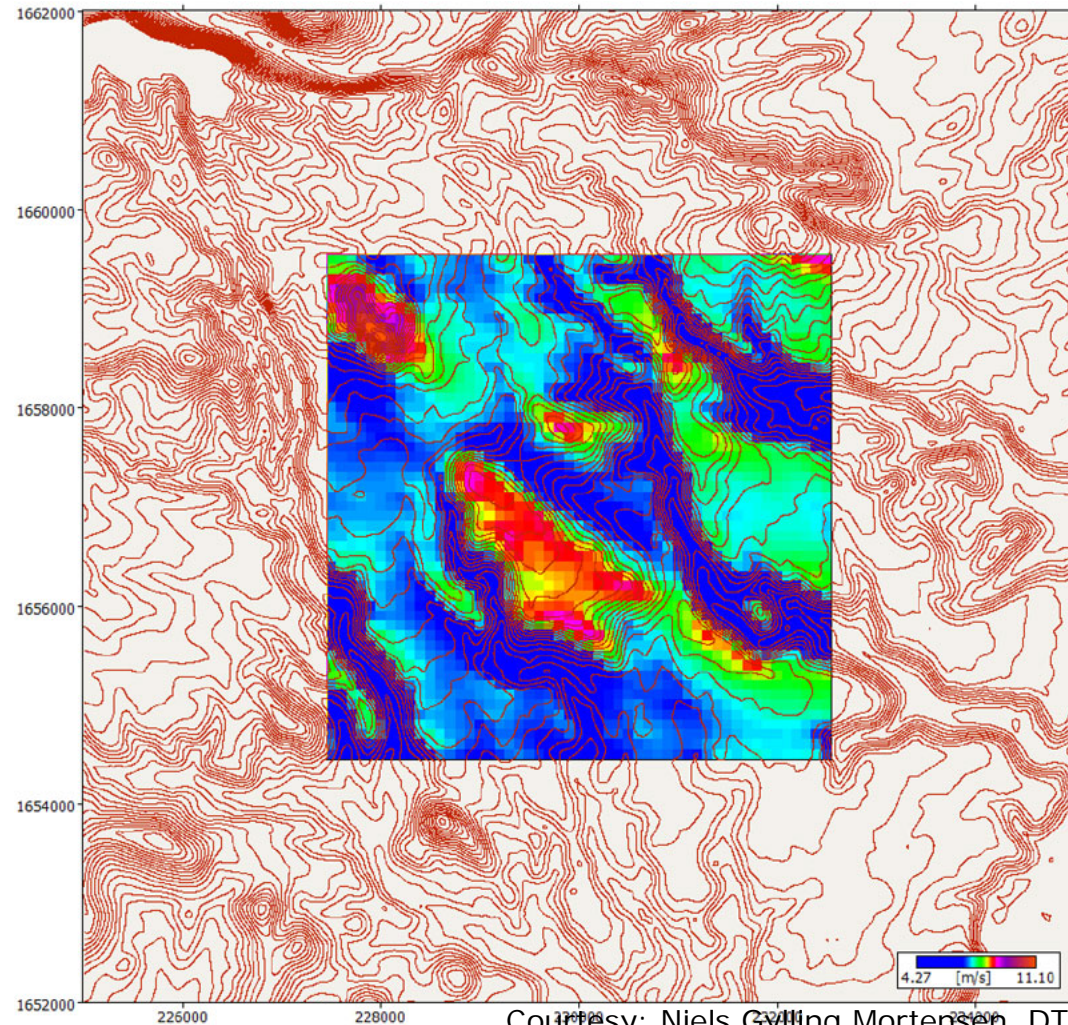




## Earth Observation – roughness from land cover



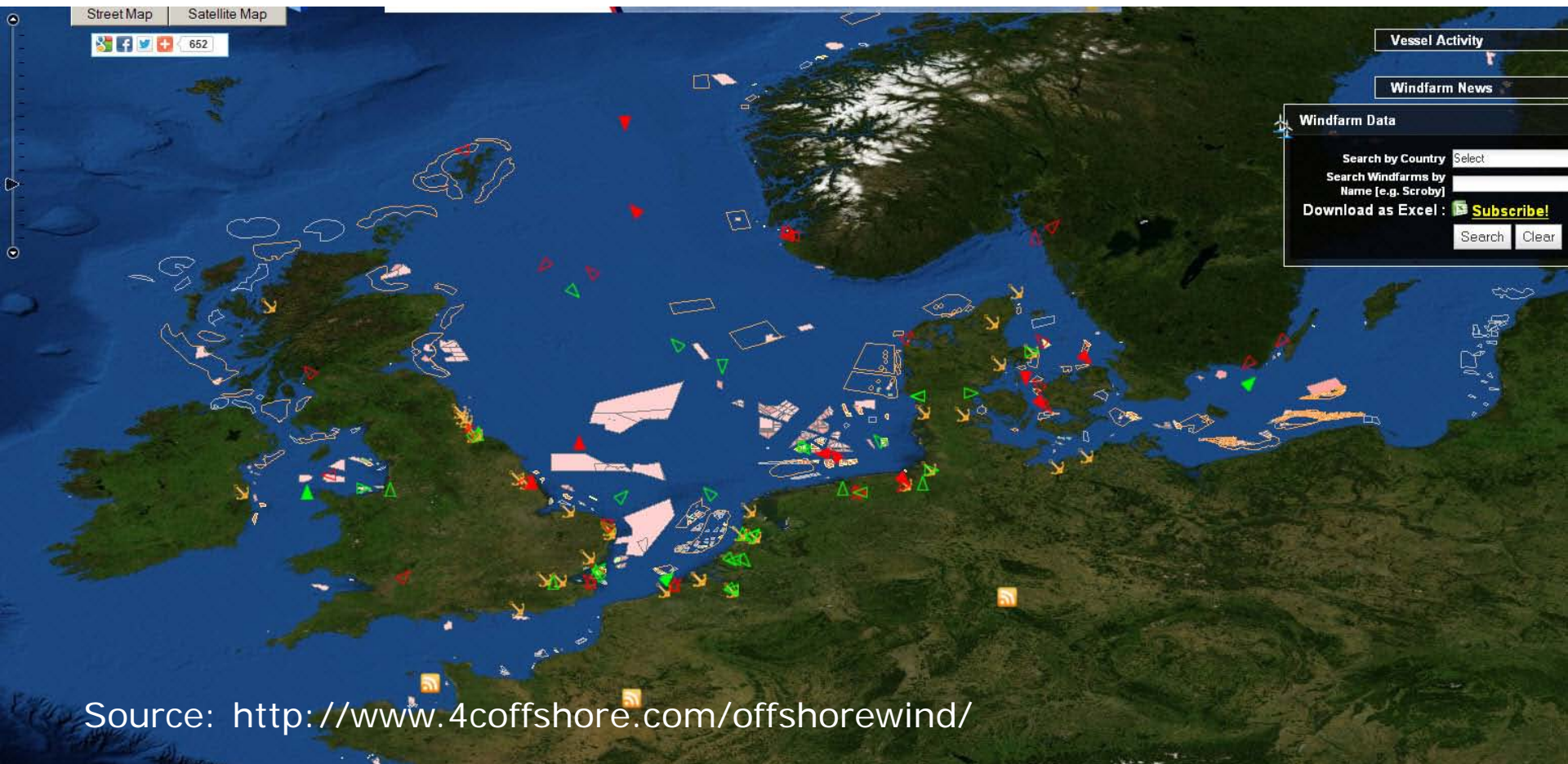
# Elevation – using Shuttle Radar Topography Mission



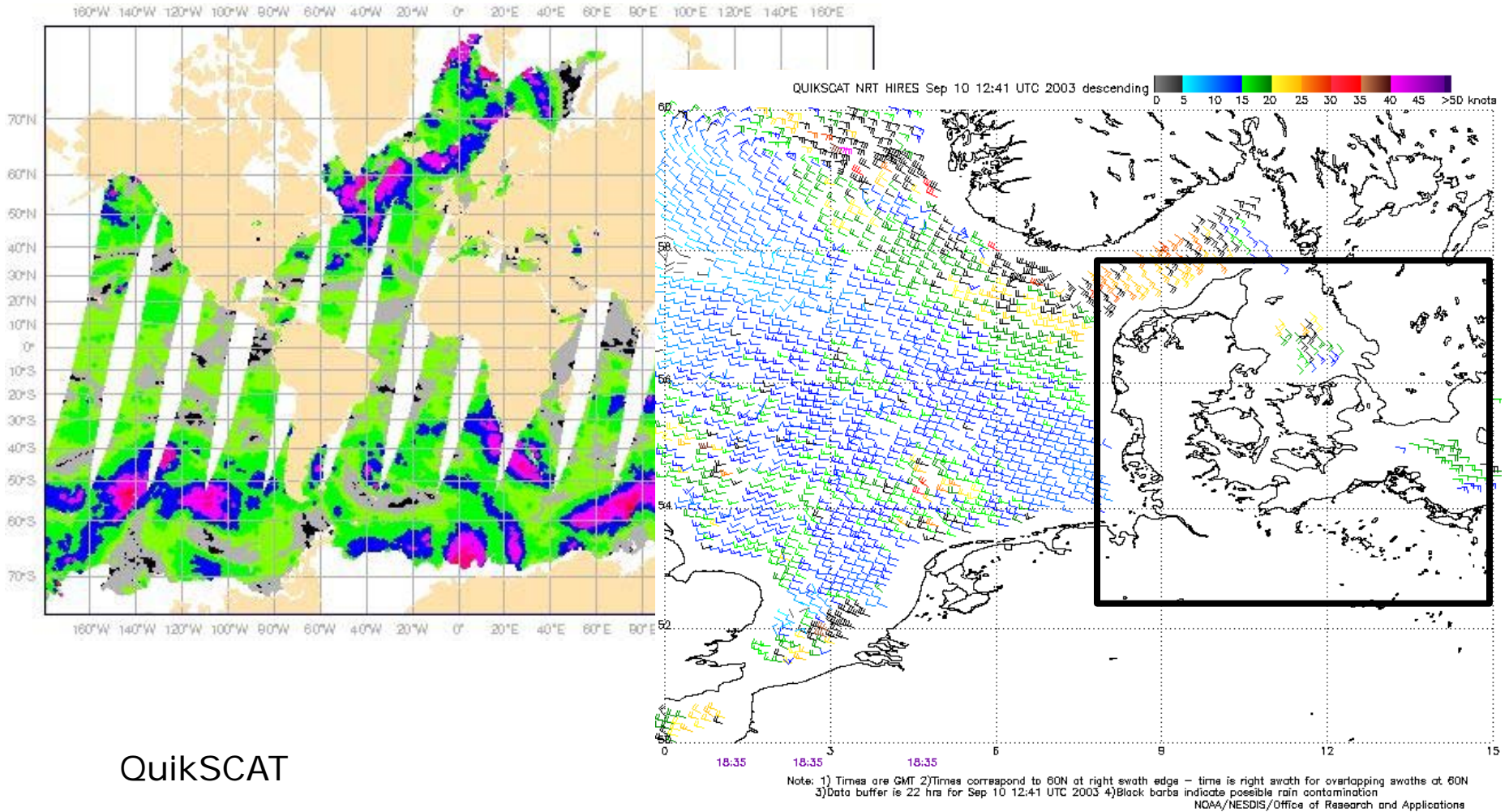
Courtesy: Niels Gylling Mortensen, DTU Wind Energy



# Offshore



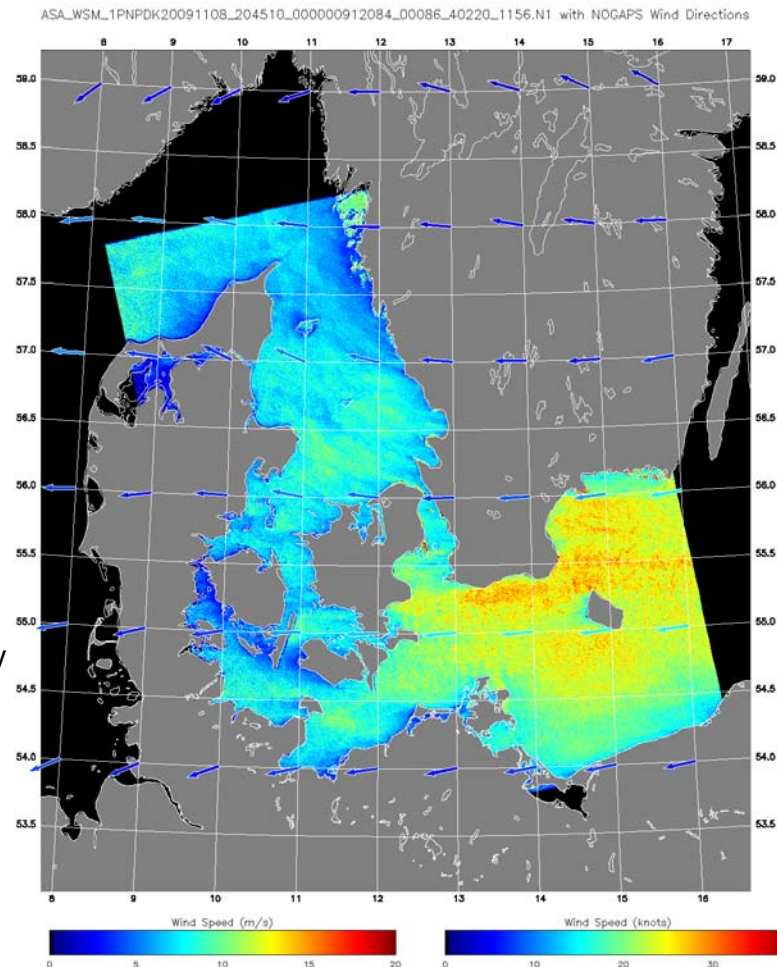
# Satellite SAR wind ocean surface wind maps



QuikSCAT



# Satellite SAR wind ocean surface wind maps



DTU Wind Energy  
Johns Hopkins University

FP7 project  
NORSEWIND at  
[www.norsewind.eu](http://www.norsewind.eu)  
contains offshore  
wind atlas for  
Northern European  
Seas based on 9000  
Envisat ASAR wind  
maps valid at 10 m.

Research on lifting  
winds to hub-height  
is in progress.

Envisat

# Wind farm wake observed from satellite

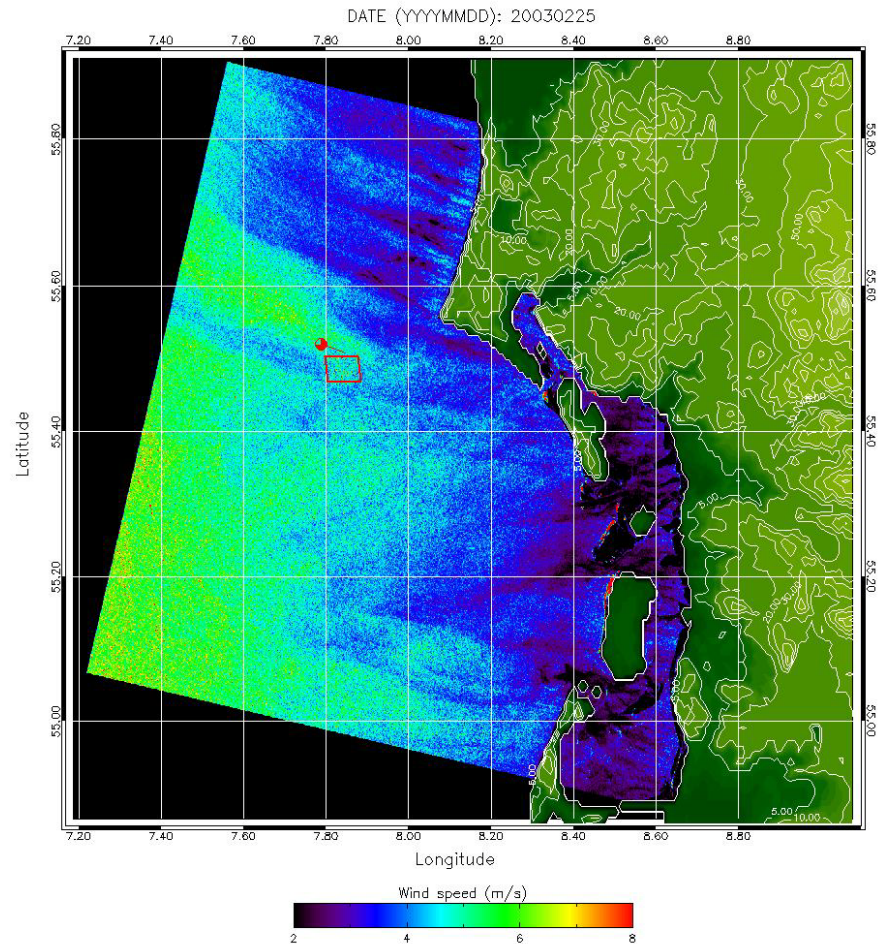
## EERA DTOC

European Energy Research  
Alliance -  
Design Tools for Offshore  
Wind Farm Clusters

[www.eera-dtoc.eu](http://www.eera-dtoc.eu)

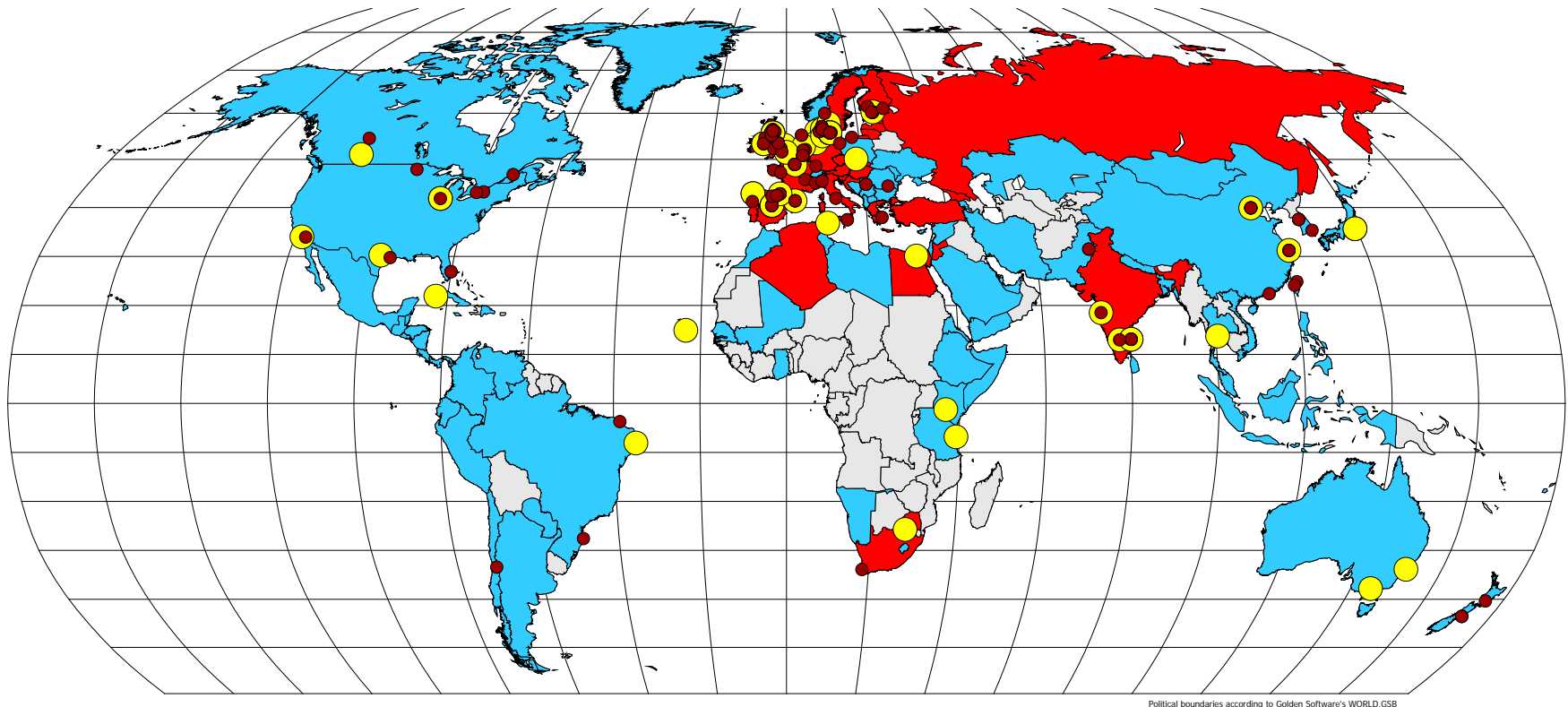
FP7 project on wake and grid  
issues

Courtesy: Merete Badger,  
DTU Wind Energy





# DTU Wind Energy: WAsP & WAsP Engineering



- WAsP/WEng software since 1987/2001
- More than 4000 licensed users
- Used in 110+ countries and territories
- WAsP/WEng courses since 1991/2001
- More than 100 courses in 25 countries ●
- 186 certified WAsP users in 27 countries ●

## Summary

- Earth Observation data can be useful for the input to WAsP onshore.
- Earth Observation data can be useful for the offshore.