

# SAWEP Workshop Wind Atlas for South Africa (WASA)



Cape Town, 4<sup>th</sup> March 2010

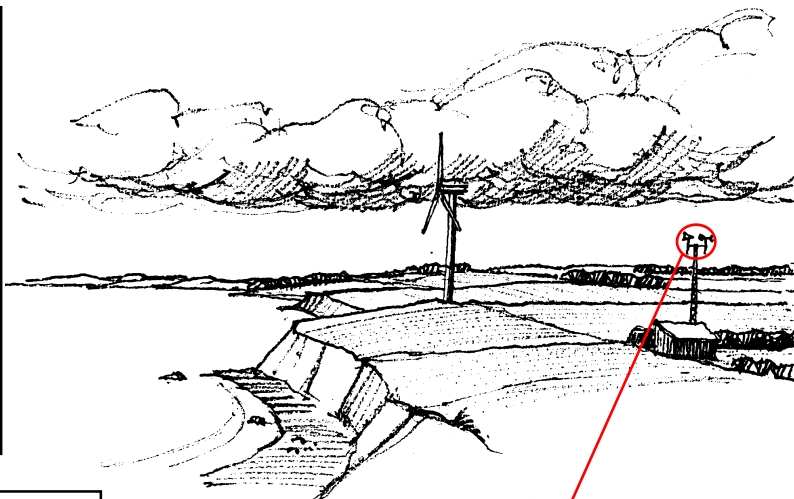
Presentation and demonstration of  
the Wind Atlas Method and the WAsP software

Micro-scale modelling and wind resource mapping

# Wind resources - the problem

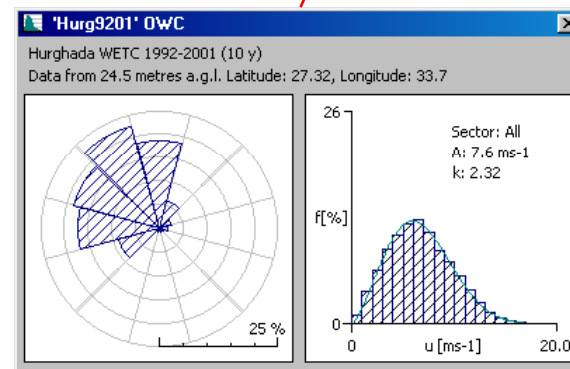
Determining the wind resources accurately is important and difficult

- Main parameters governing wind power economics:
- Investment costs
  - Operation and maintenance costs
  - Electricity production / **Wind resources**
  - Turbine lifetime
  - Discount rate
  - **Environmental benefits**

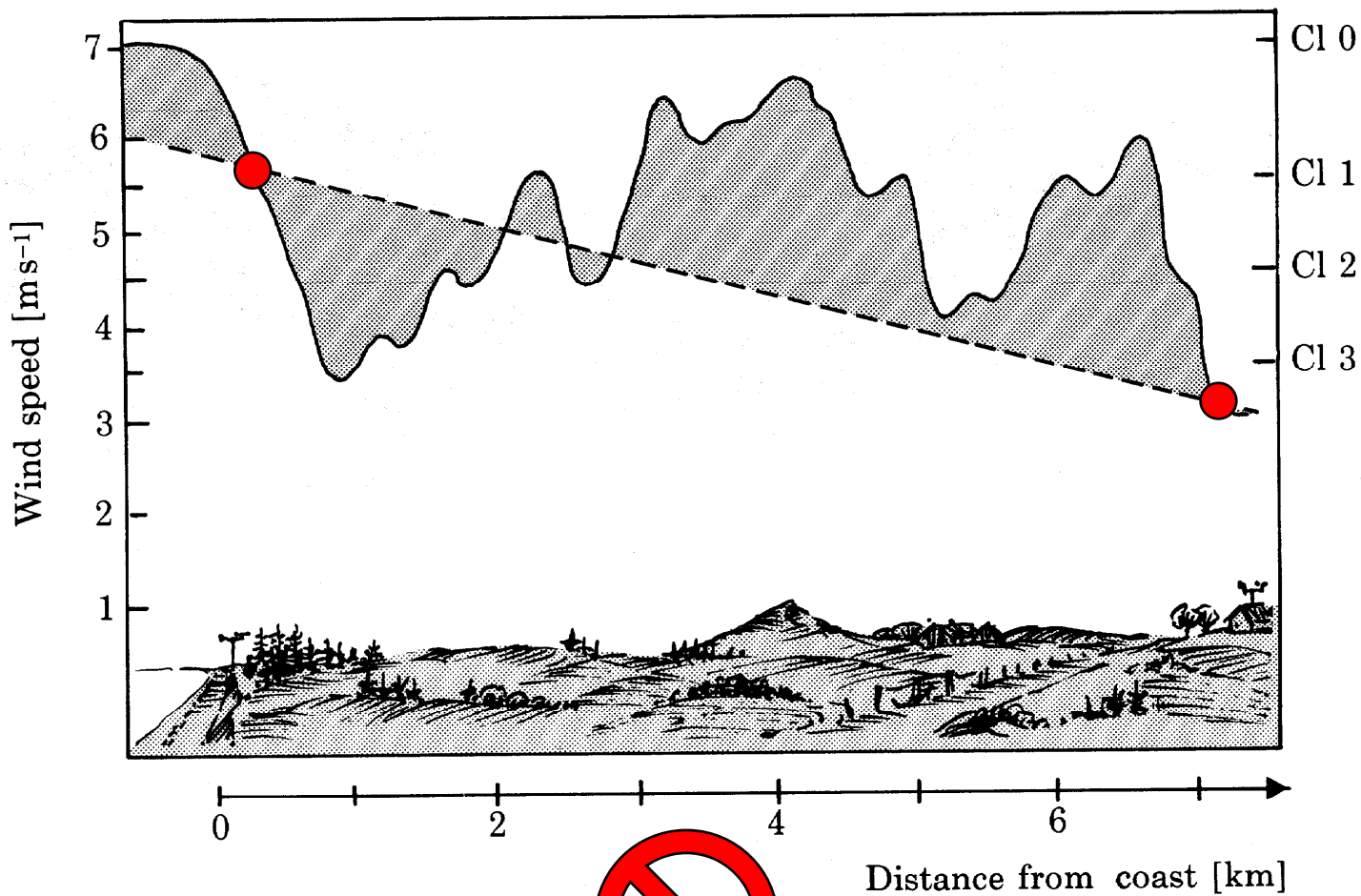


- Wind speed, **U** [m/s]
- Kinetic Energy flux, **P** =  $\frac{1}{2}\rho U^3$  [W/ m<sup>2</sup>]
- $\Delta U$  of 5% (e.g. U=10.0+0.5m/s)  $\longrightarrow$   $\Delta P$  of 15%

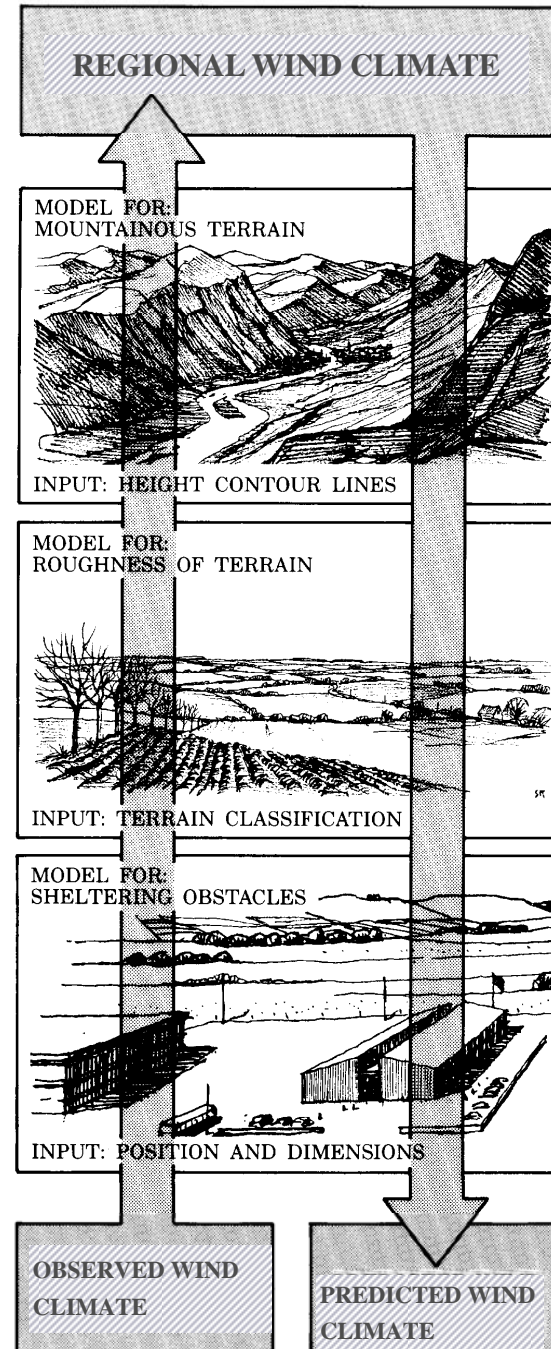
- Wind resources are in fact more P than U
- Both U and P are statistical distributions
- We measure U (and D) in one point in space, but need it in the entire atmospheric boundary layer



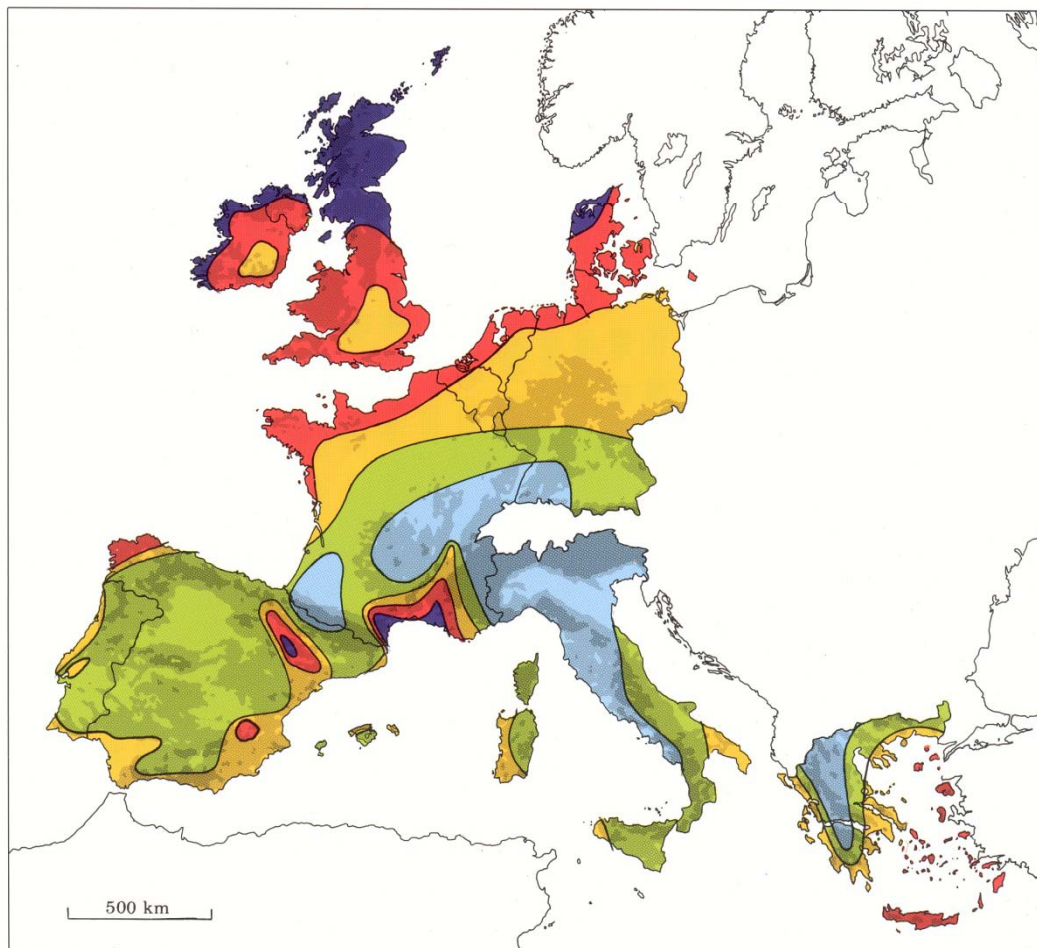
# Linear interpolation



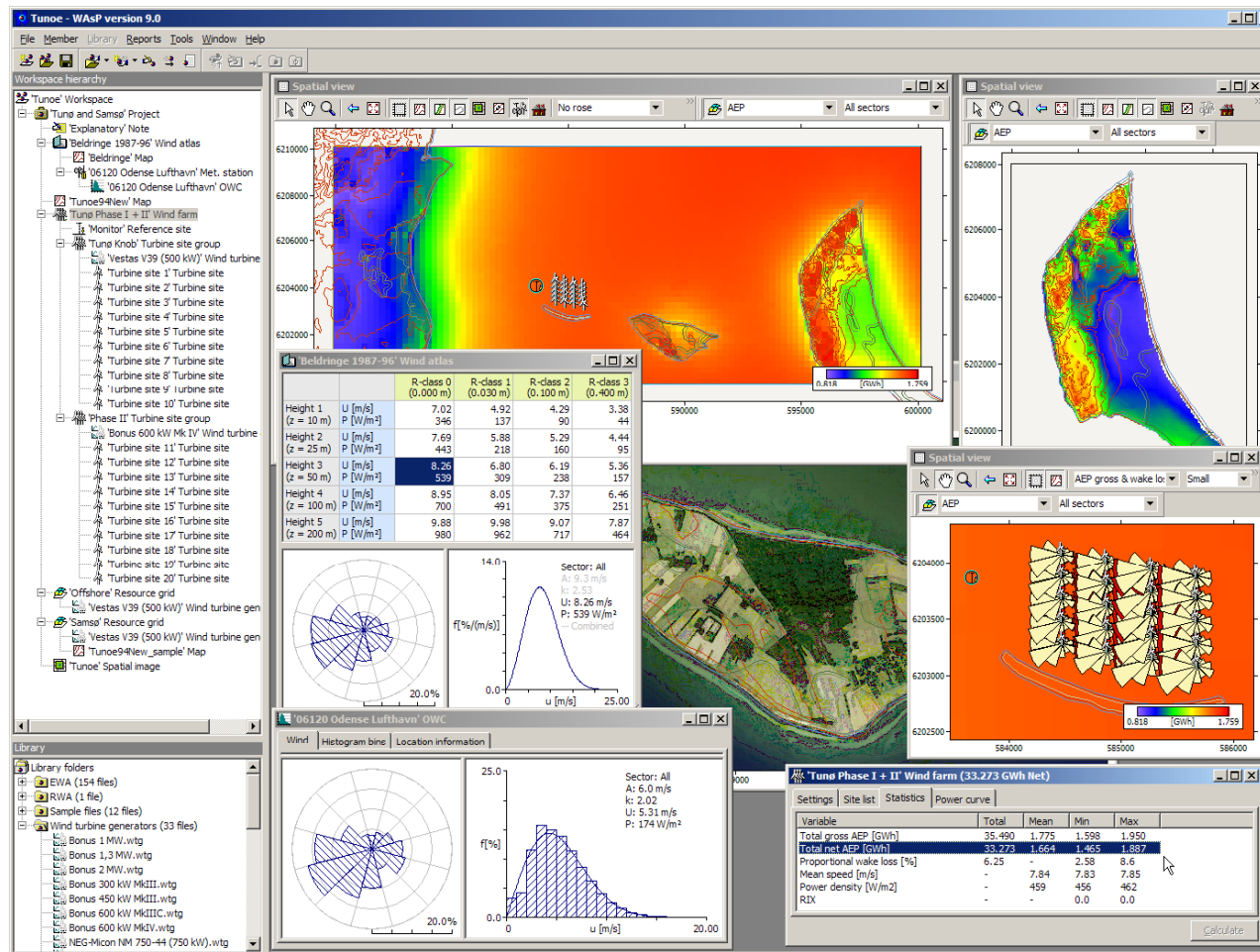
# The Wind Atlas Method



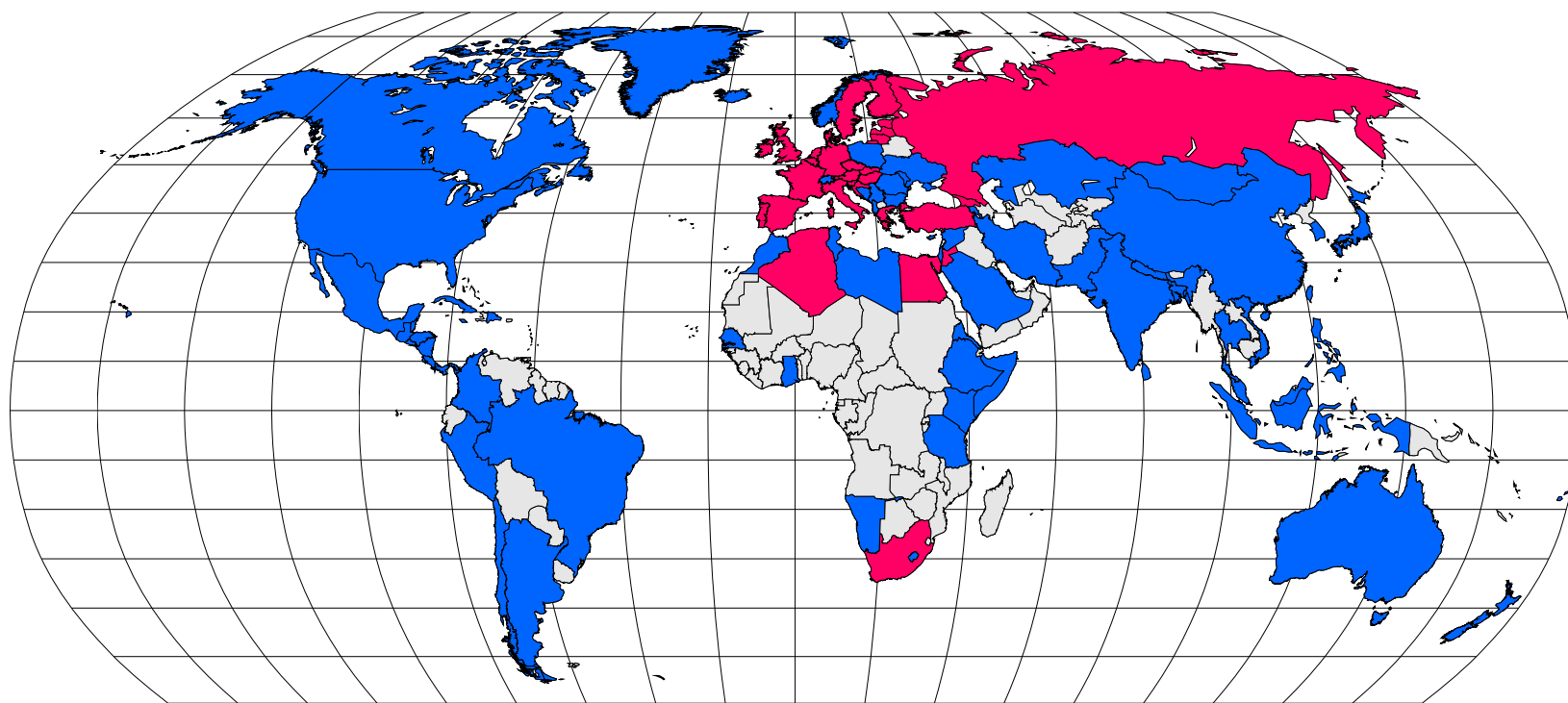
# European Wind Atlas



# Wind Atlas Analysis and Application Program (WAsP)



## The world according to WAsP



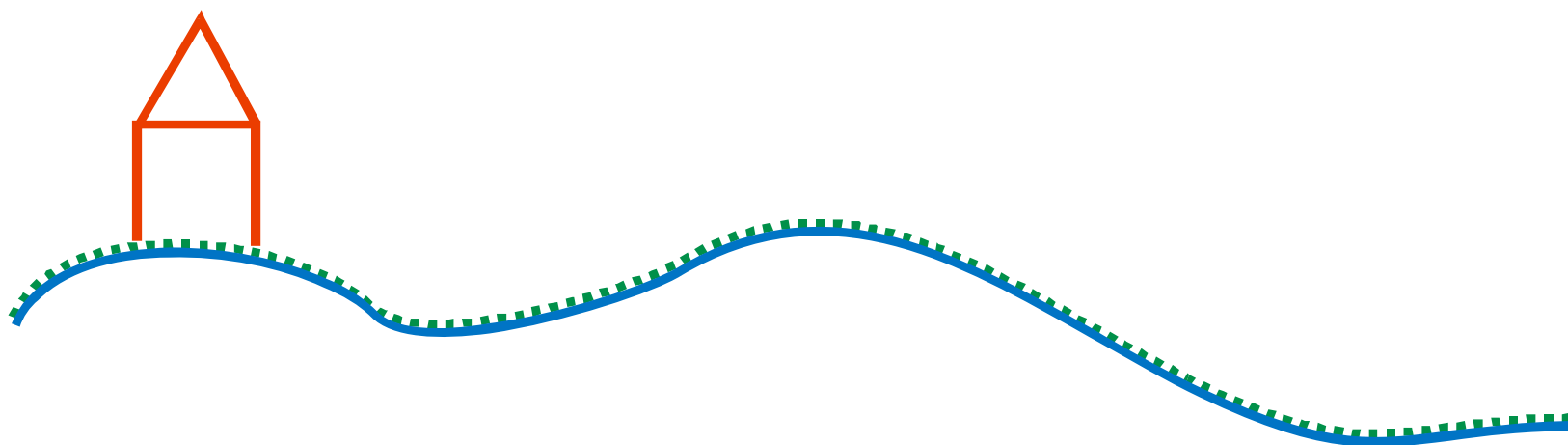
Political boundaries according to Golden Software's WORLD.GSB

- WAsP software since 1987
- 2800 licensed users by now
- 105 countries and territories
- National wind atlases... ■
- Regional and local studies... ■
- No information available... ■

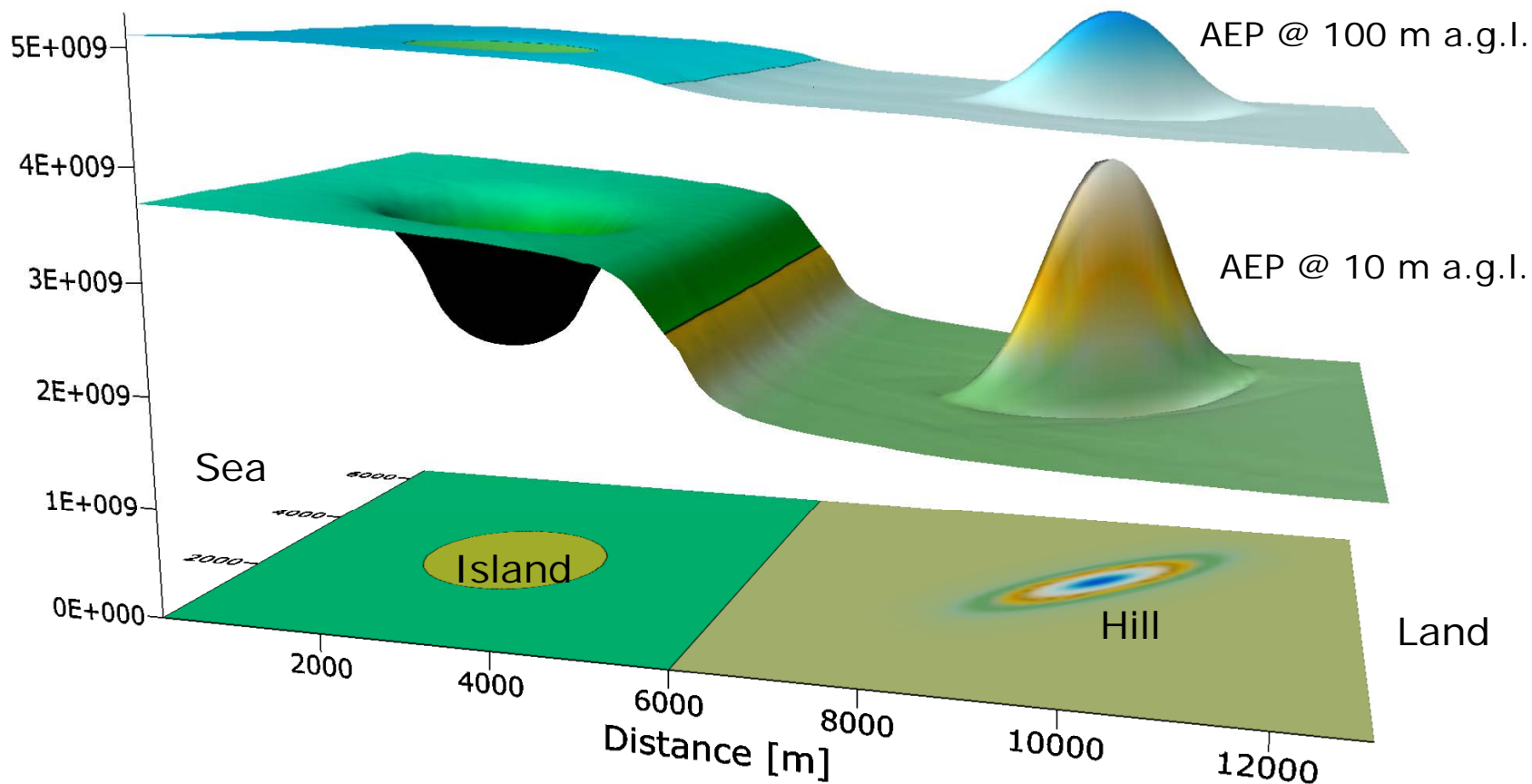
WAsP arithmetic



$$\text{WAsP} = \text{ROU} + \text{ORO} + \text{OBST}$$

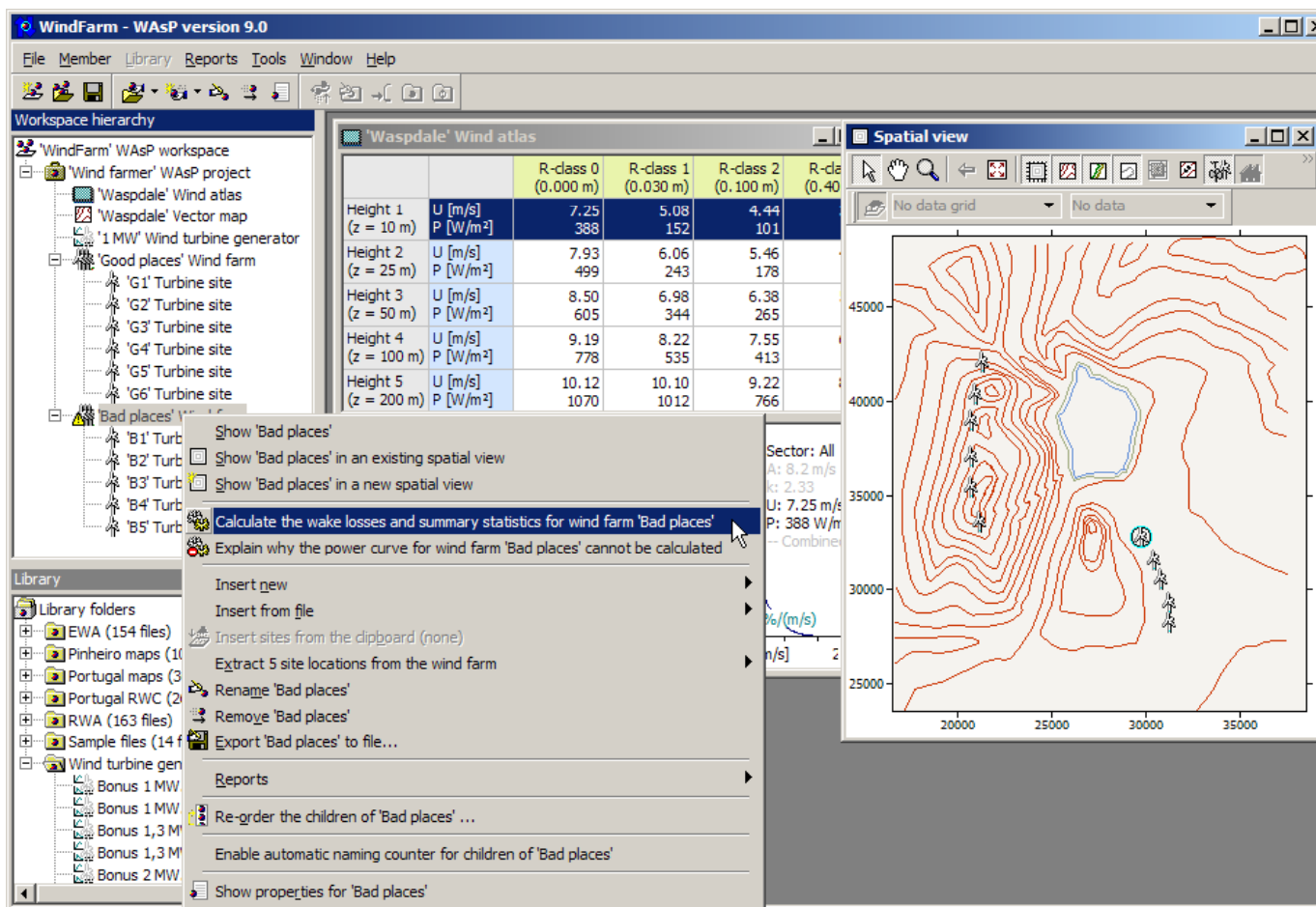


# Terrain effects



Power production at 10 & 100 m a.g.l.  
 Uniform wind rose, hill is 100 m high.

# User interface

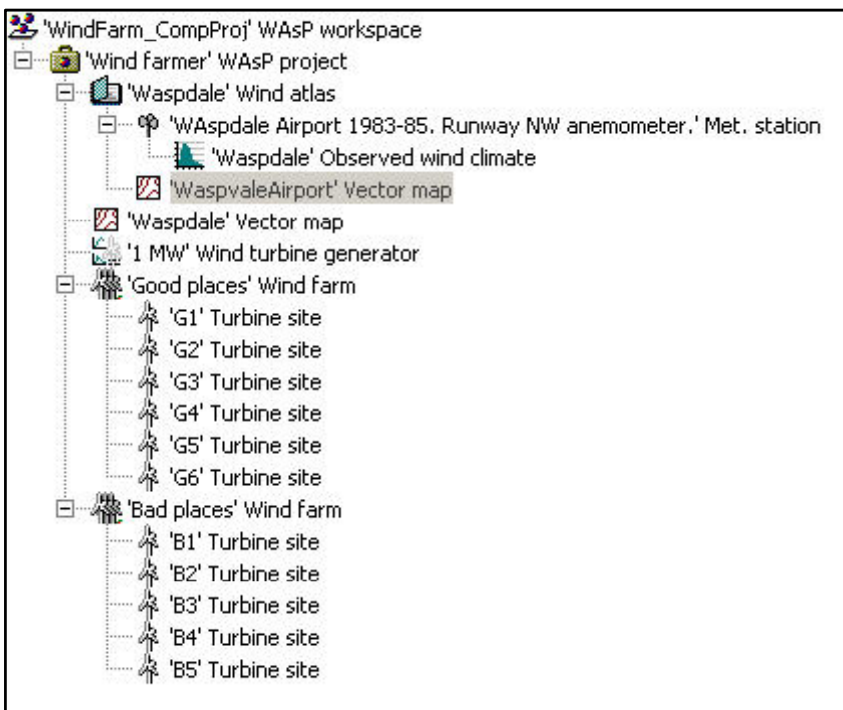


The screenshot displays the WindFarm - WAsP version 9.0 software interface. The main window is divided into several panes:

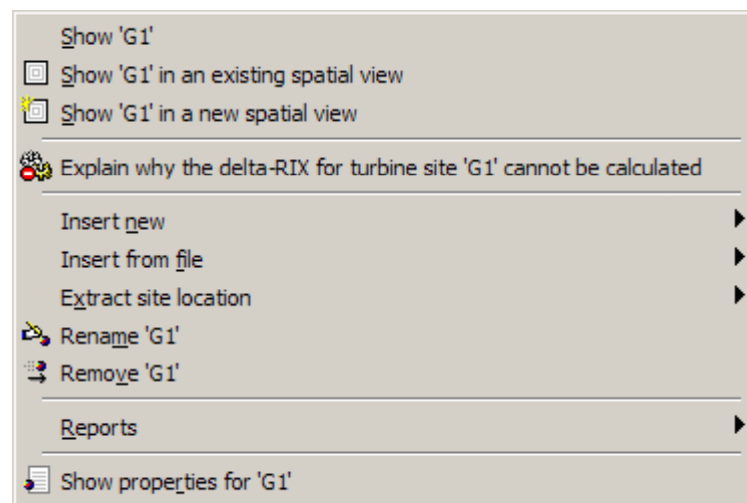
- Workspace hierarchy:** A tree view on the left showing the project structure, including 'Waspdale' Wind atlas, '1 MW' Wind turbine generator, and 'Good places' Wind farm with six turbine sites (G1-G6) and 'Bad places' with five turbine sites (B1-B5).
- Data Table:** A table in the center showing wind speed (U) and power (P) for different heights and R-classes.
 

		R-class 0 (0.000 m)	R-class 1 (0.030 m)	R-class 2 (0.100 m)	R-class 3 (0.400 m)
Height 1 (z = 10 m)	U [m/s]	7.25	5.08	4.44	
	P [W/m <sup>2</sup> ]	388	152	101	
Height 2 (z = 25 m)	U [m/s]	7.93	6.06	5.46	
	P [W/m <sup>2</sup> ]	499	243	178	
Height 3 (z = 50 m)	U [m/s]	8.50	6.98	6.38	
	P [W/m <sup>2</sup> ]	605	344	265	
Height 4 (z = 100 m)	U [m/s]	9.19	8.22	7.55	
	P [W/m <sup>2</sup> ]	778	535	413	
Height 5 (z = 200 m)	U [m/s]	10.12	10.10	9.22	
	P [W/m <sup>2</sup> ]	1070	1012	766	
- Spatial view:** A topographic map on the right showing terrain contours and turbine locations. A context menu is open over the 'Bad places' turbine sites, with the option 'Calculate the wake losses and summary statistics for wind farm 'Bad places'' selected.
- Library:** A pane on the bottom left showing a list of library folders and files, including 'EWA (154 files)', 'Pinheiro maps (10)', 'Portugal maps (3)', 'Portugal RWC (2)', 'RWA (163 files)', and 'Sample files (14 files)'.

# Hierarchy



context-sensitive menus, e.g. 'G1' Turbine site:

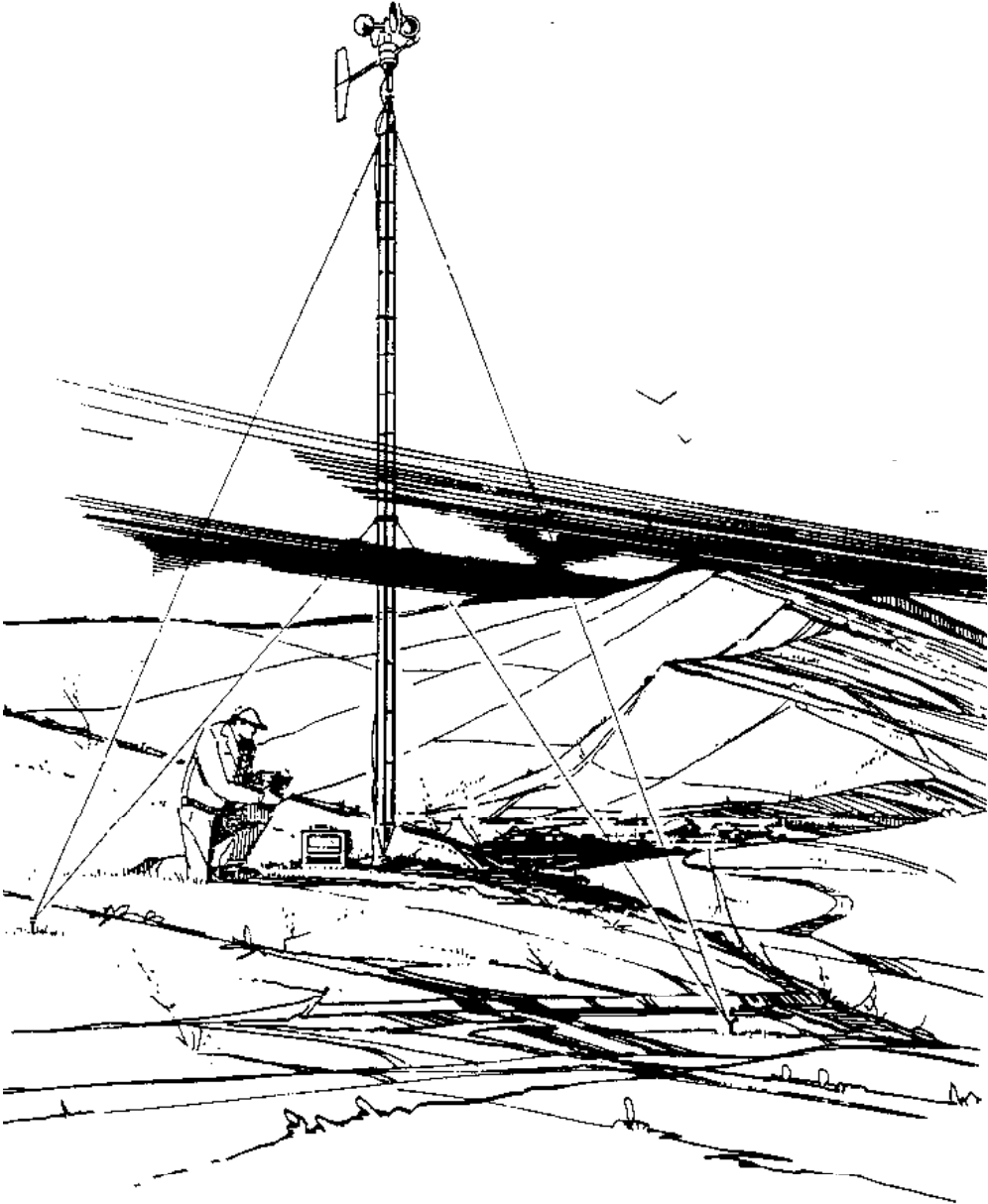


Modelling scenario is defined by the hierarchy set-up!

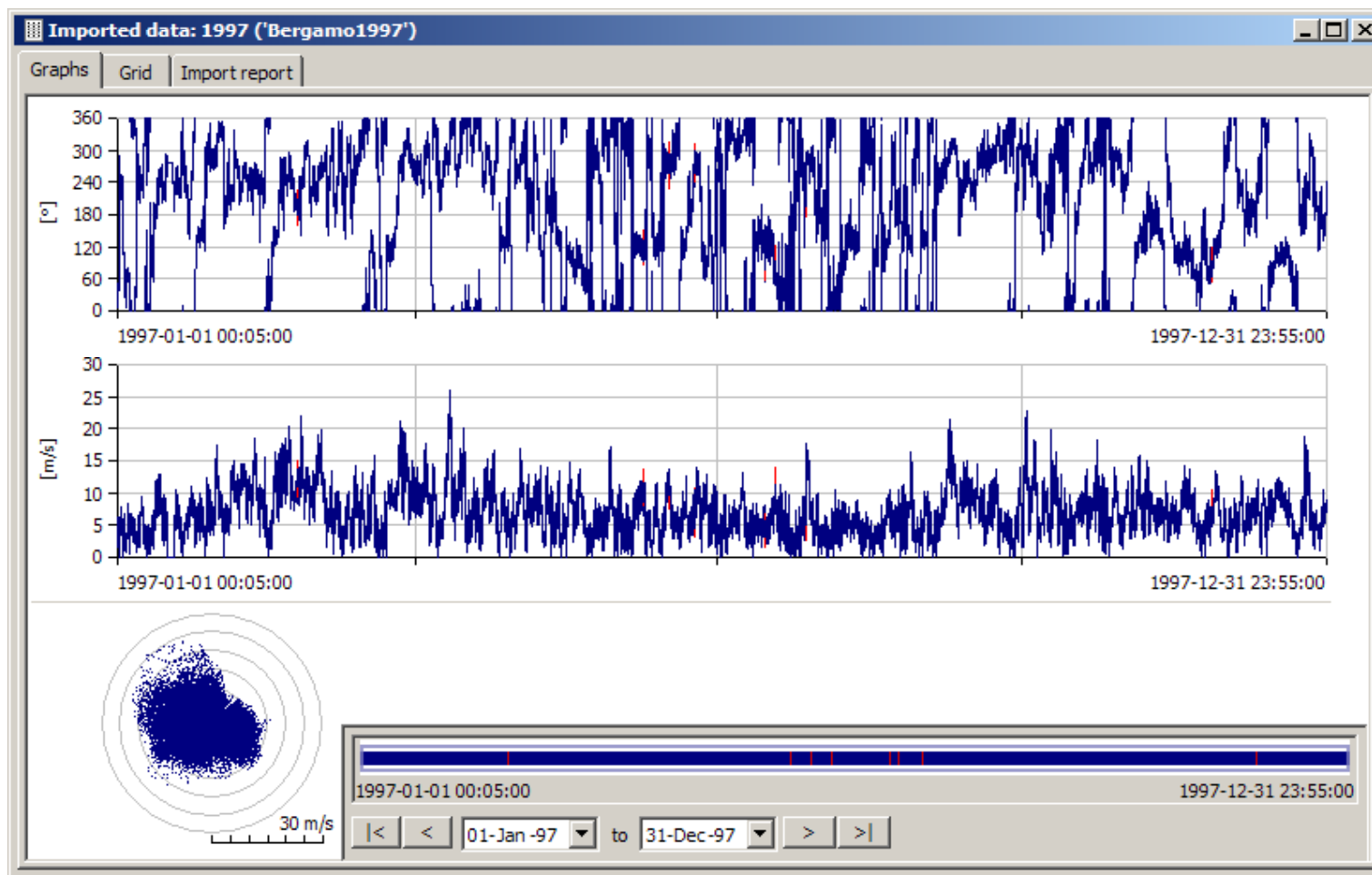
## But first input data

- Wind data
- Terrain data

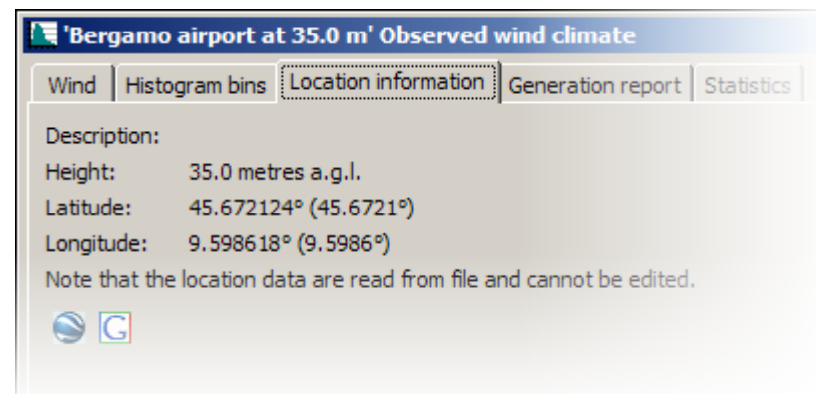
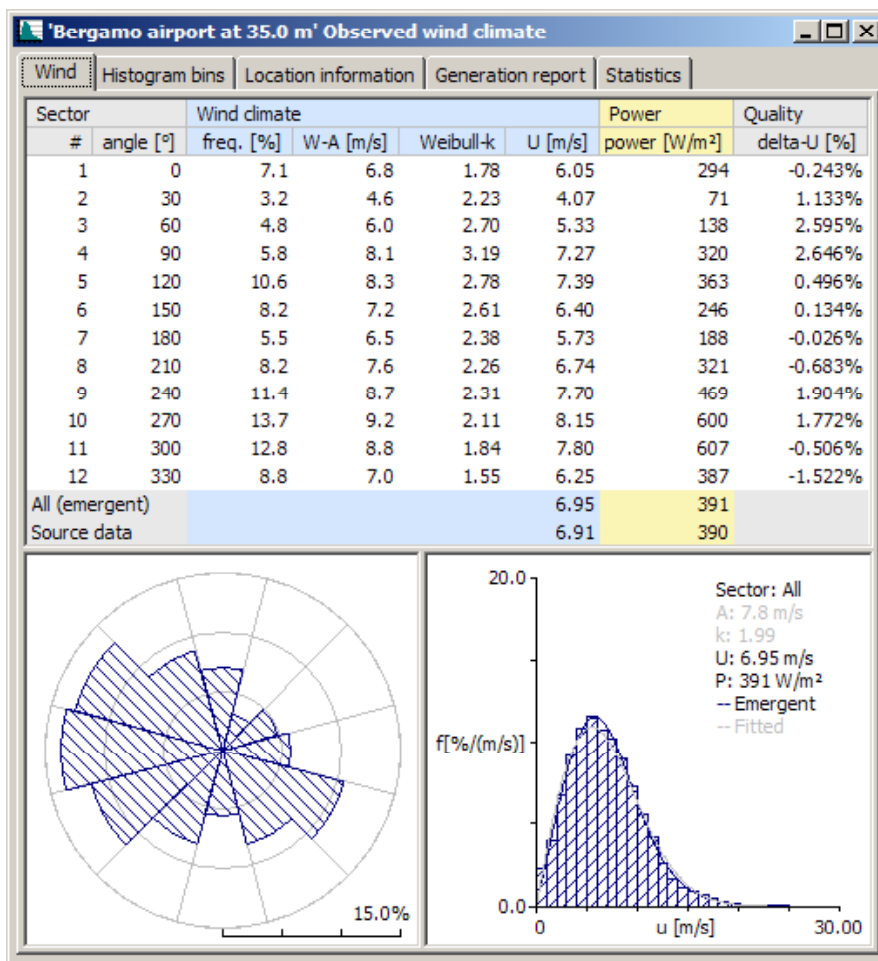
# Wind data



# Wind observations

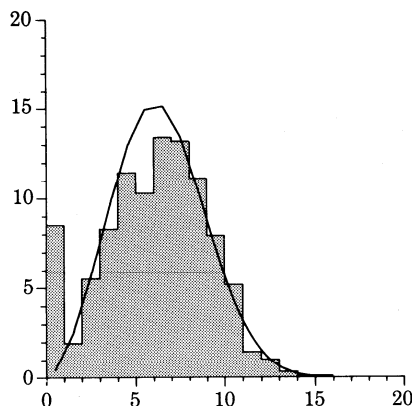


# Wind distributions

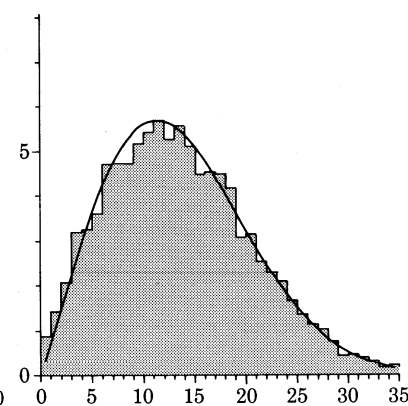


# Weibull distributions

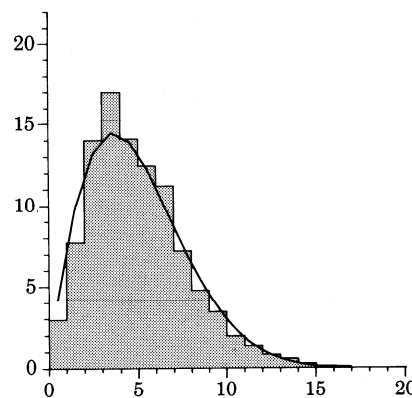
Fuerteventura Canary Islands, Spain  
 $A = 7.2 \text{ ms}^{-1}$ ,  $k = 2.78$



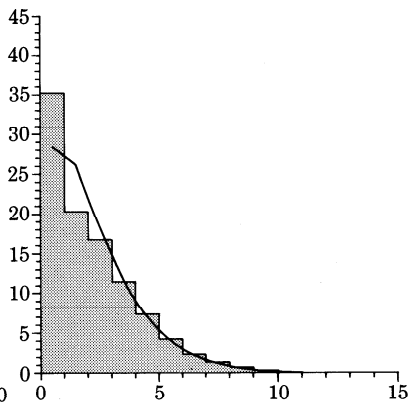
Snaefell, UK  
 $A = 15.4 \text{ ms}^{-1}$ ,  $k = 2.08$



Schiphol, The Netherlands  
 $A = 5.6 \text{ ms}^{-1}$ ,  $k = 1.83$



Mont de Marsan, France  
 $A = 2.4 \text{ ms}^{-1}$ ,  $k = 1.24$



Weibull distribution

$$f(u) = \frac{k}{A} \left(\frac{u}{A}\right)^{k-1} \text{Exp}\left(-\left(\frac{u}{A}\right)^k\right)$$

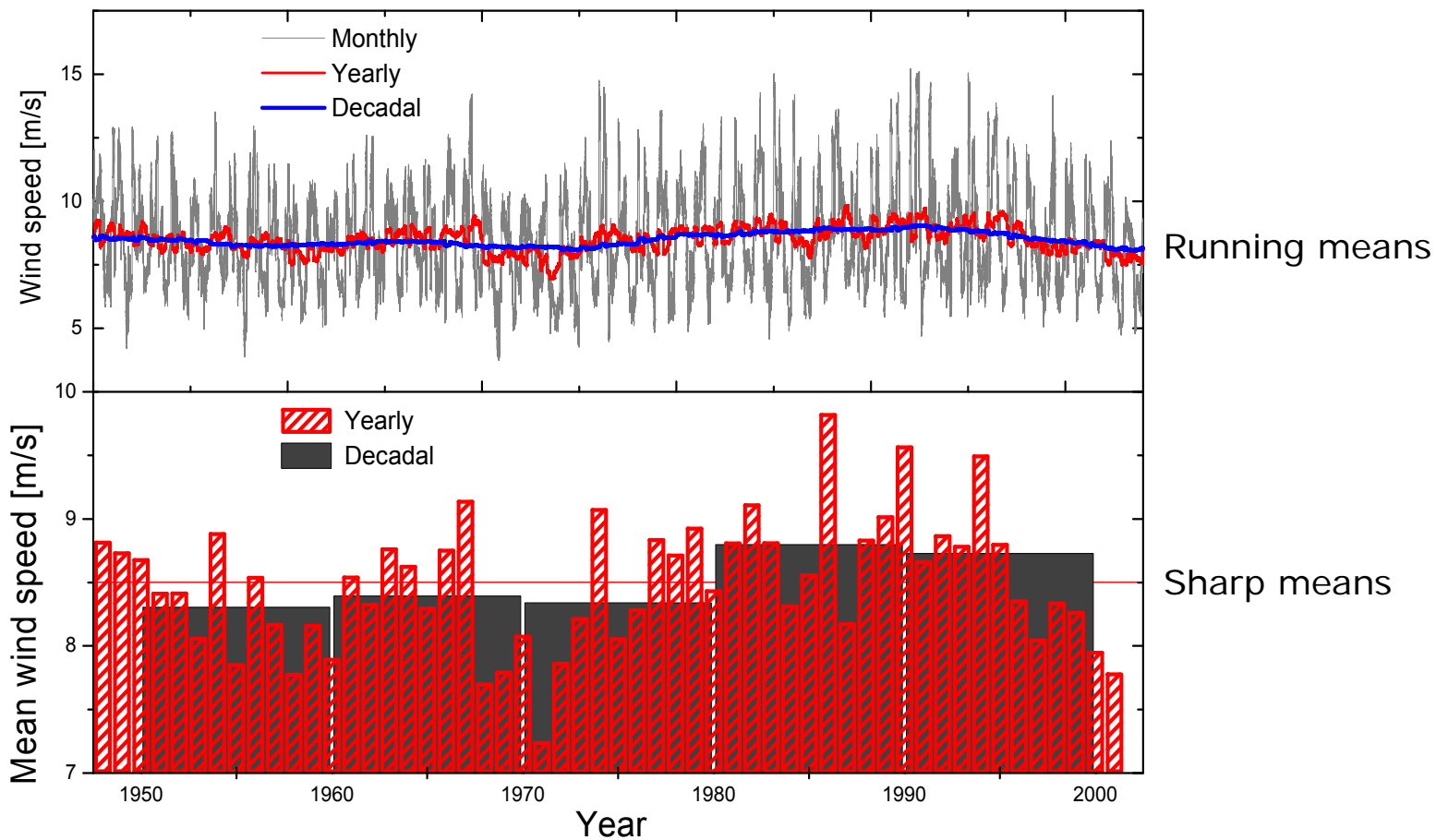
$f$  : frequency (probability) of occurrence

$u$  : wind speed

$k$  : shape parameter

$A$  : scale parameter

# Annual variation



Data from NCEP/NCAR reanalysis for a site in Ireland

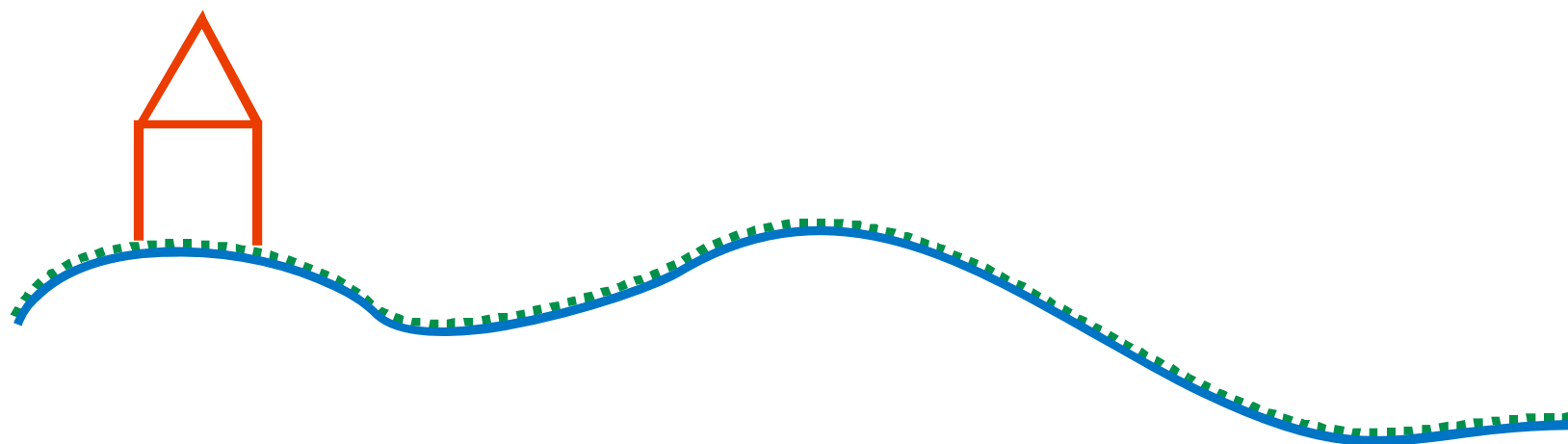
## Terrain data - description in WAsP



## Roughness and Orography

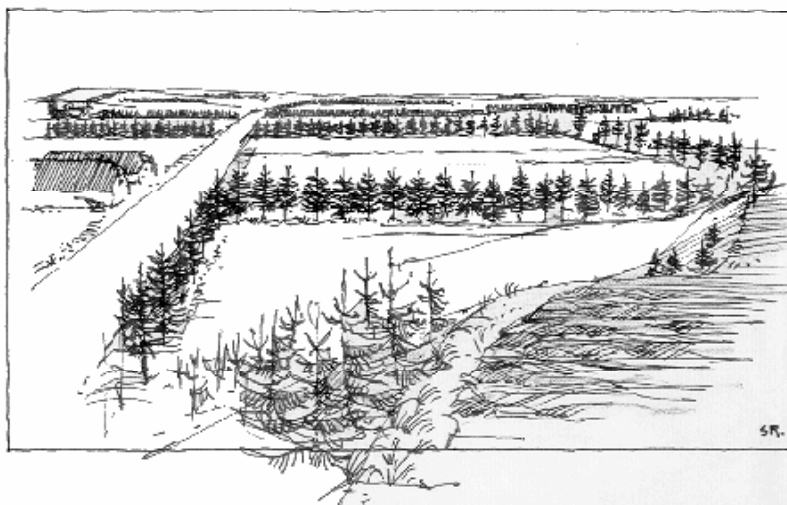
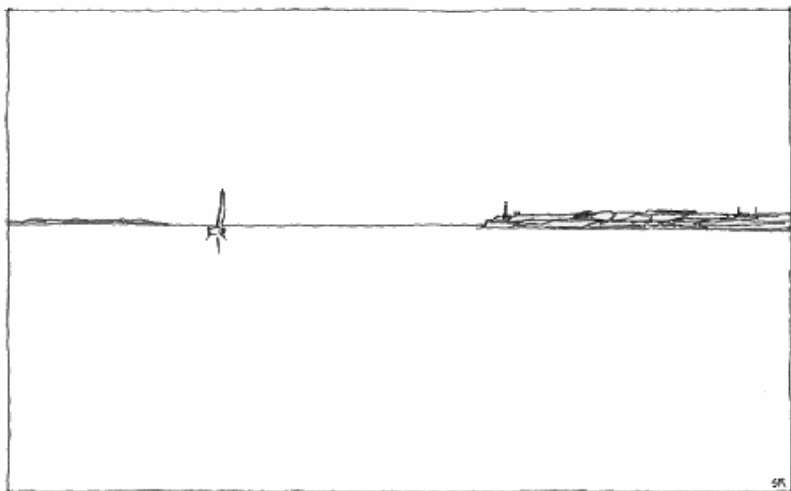
- Roughness = terrain surface characteristics
  - vegetation, buildings etc. on small scale (land-use)
  - from “smooth as silk” (water, snow, sand, soil) to the high roughness of a forest or a city
- Orography = terrain height (elevation) variations
  - large-scale geometry of terrain surface
  - from plains and low smooth hills and valleys to complex, rugged terrain and mountains

# ROU



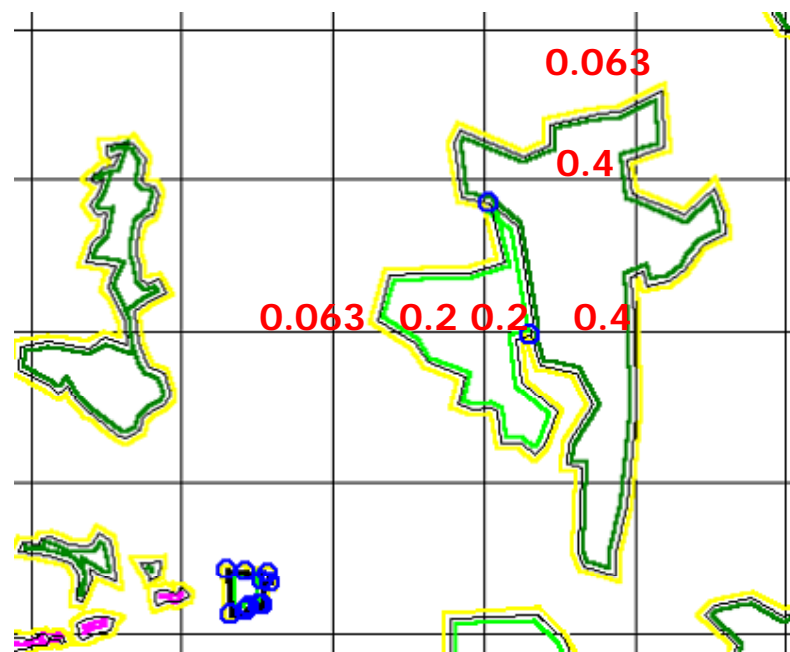
## Roughness examples

- Water surface  
 $z_0 = 0.0$  (0.0002) m
- Many shelter belts, forest  
 $z_0 = 0.4$  m (or more)

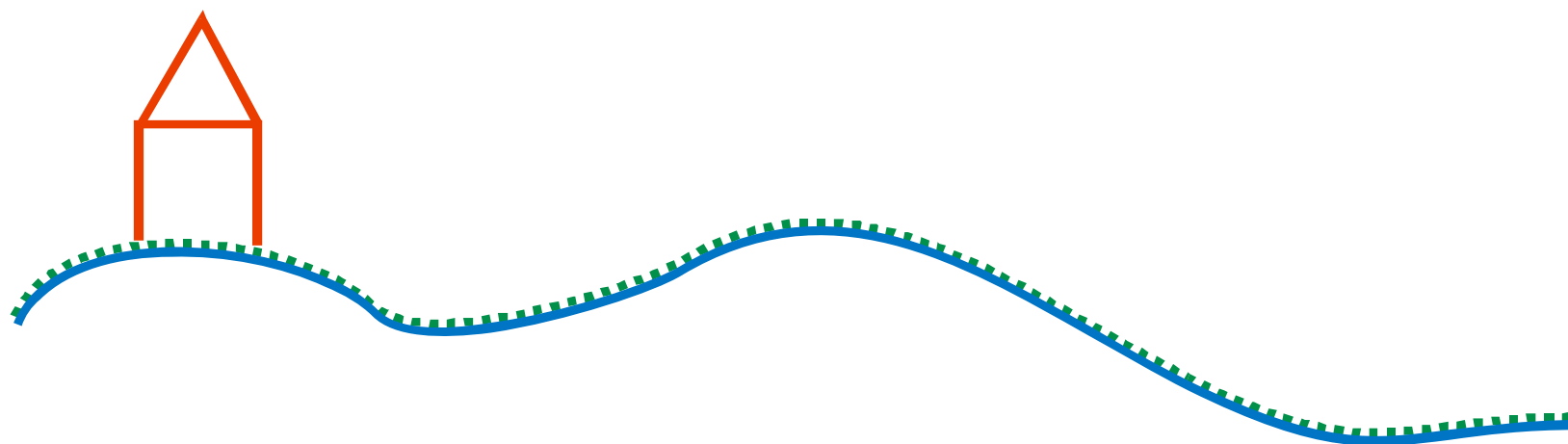


## How is roughness represented?

- Roughness is represented by roughness-change-lines.
- Each line has a pair of right- and left-hand roughness lengths (m) as attributes.
- Roughness change lines are also represented by a number of points:
  - connected line segments
  - polygon
- Combined elevation and roughness-change lines are allowed (coastline)

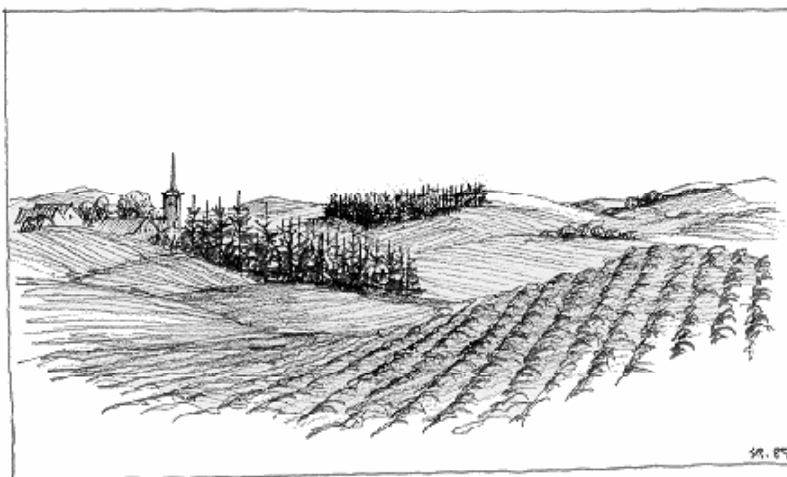


# ORO



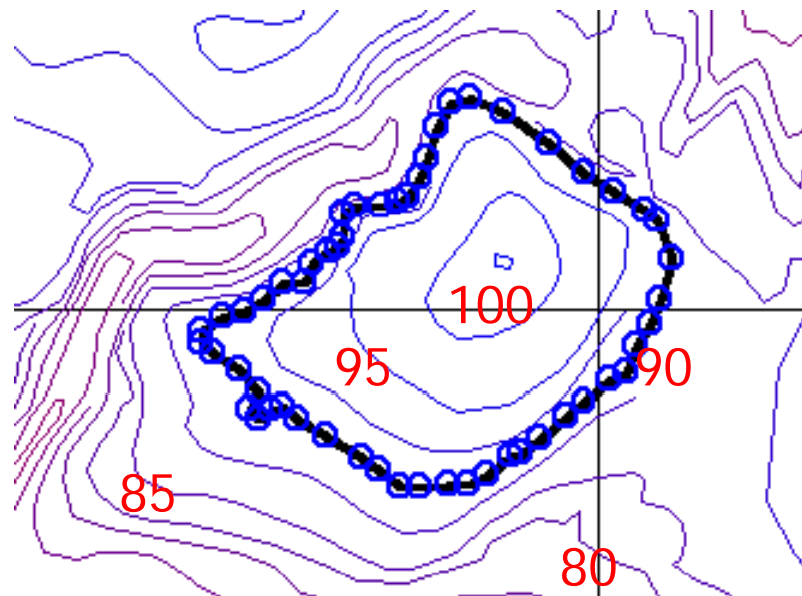
## Orography examples

- Low, smooth hills  
Relative height variations are small
- Mountainous terrain  
Relative height variations are large

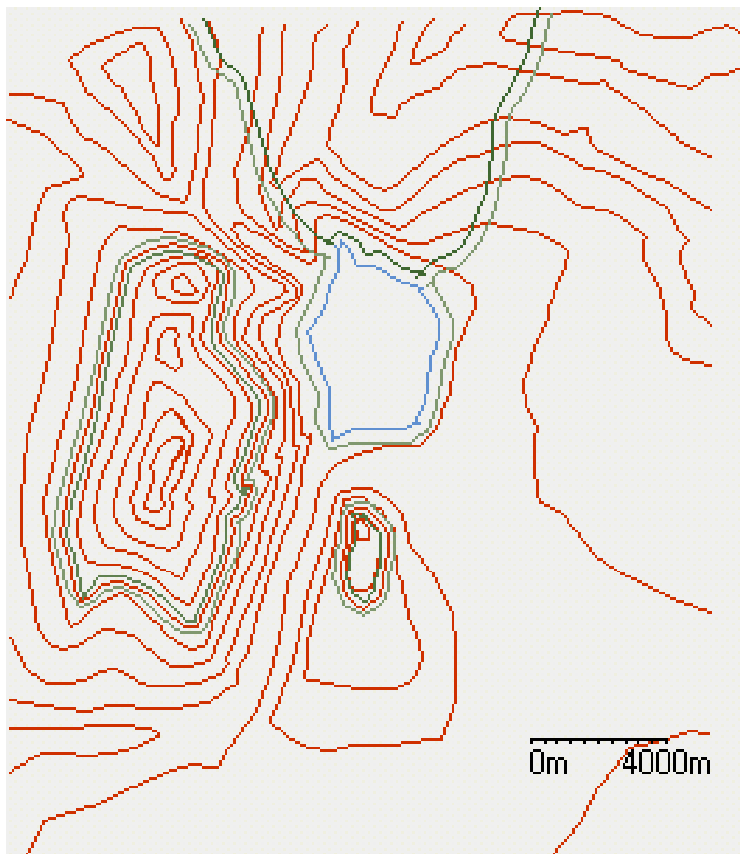


## How is orography represented?

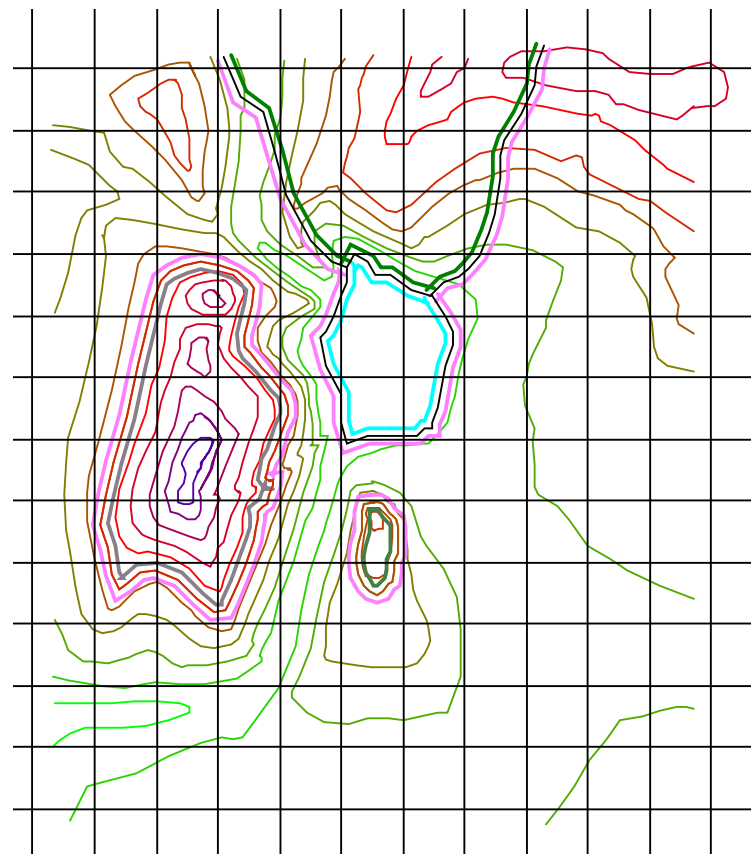
- Orography is represented by height contour lines – as on a paper map.
- Each contour has the elevation above mean sea level (m a.s.l.) as attribute.
- Each contour is represented by a number of points:
  - connected line segments
  - polygon



## Digital height contour maps

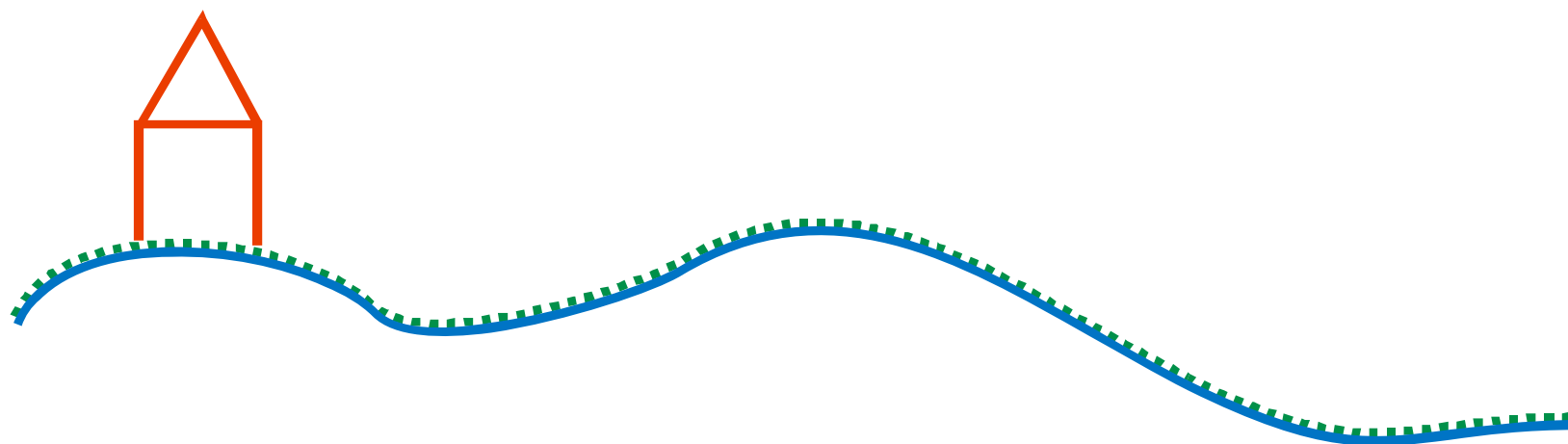


- WASP spatial view window

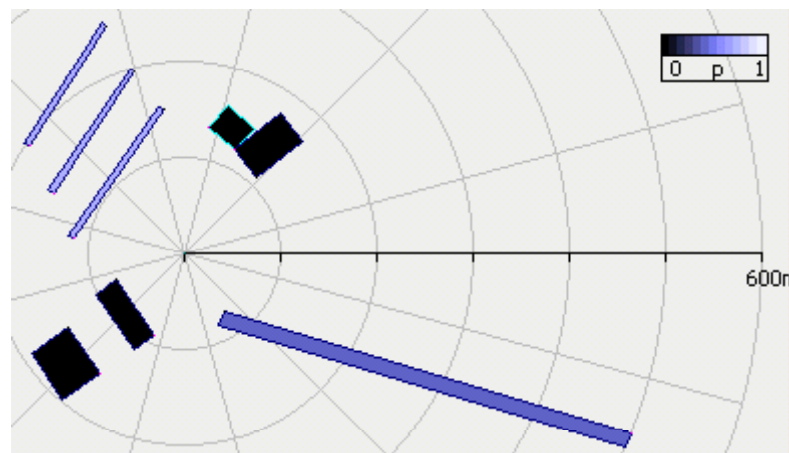
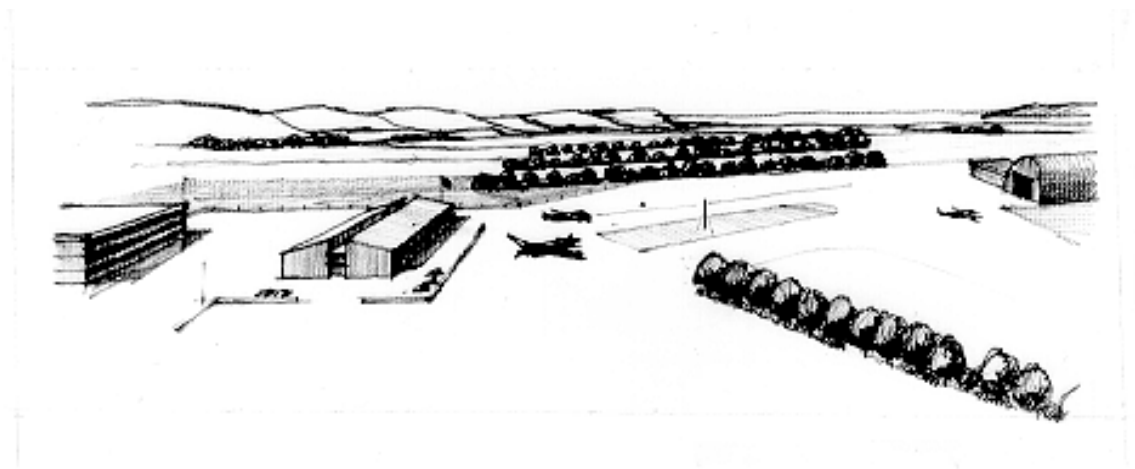


- Map editor window, grid size 2 km

# OBST



# Obstacles viewed in WAsP



# Maps - Scanned, Google Earth, SRTM and Map Editor



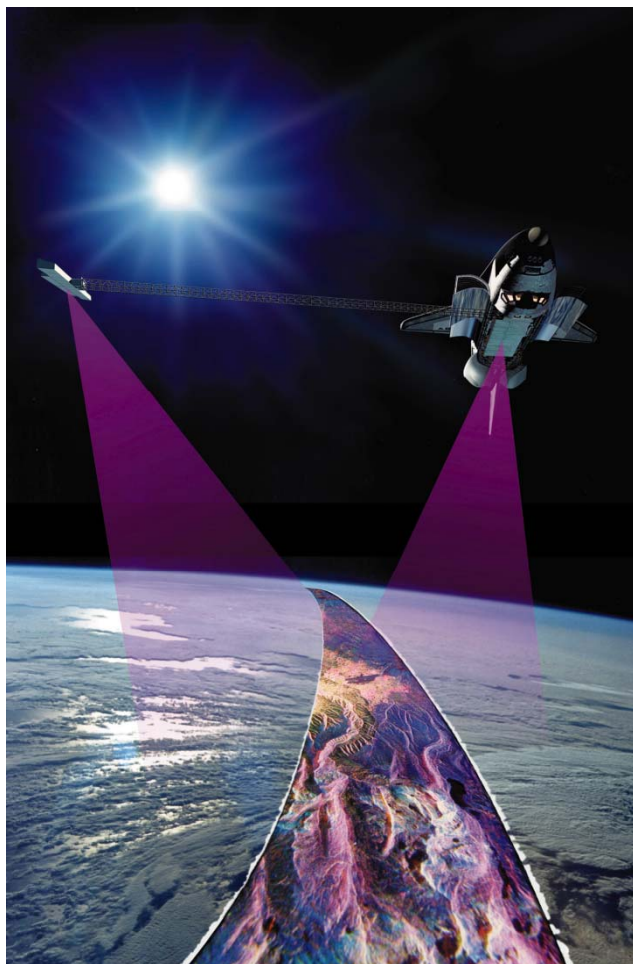
## Map files

- The entire terrain description is contained in a digital \*.map-file (binary or ASCII format)
- The map may contain three types of lines:
  - height contours ( $z$ )
  - roughness change lines ( $z_{01}, z_{02}$ )
  - no-attribute lines (NA-lines) for area boundaries etc.
- The Map Editor tool is provided for the digitization and editing of \*.map file(s) that can then be loaded into WASP.
- In case a terrain map contains no roughness-change lines, a default roughness length of 0.03 m (3 cm) is assumed.

## How to acquire digital maps

- Manual on-screen digitisation (WAsP Map Editor) using as background...
  - scanned bitmap images of paper maps
  - satellite imagery (Google Earth)
- Buy vector digital maps from e.g. the national survey
  - Map Editor can handle a number of standard formats: MAP, DXF, BNA, NTF, XYZ, ...
- Create from a raster DEM (Digital Elevation Model) using e.g. Surfer, GIS or similar
  - SRTM (Shuttle Radar Topography Mission) elevation data
    - 3 arc-sec (~90 m) grid point spacing
    - 1 arc-sec (~30 m) spacing in USA

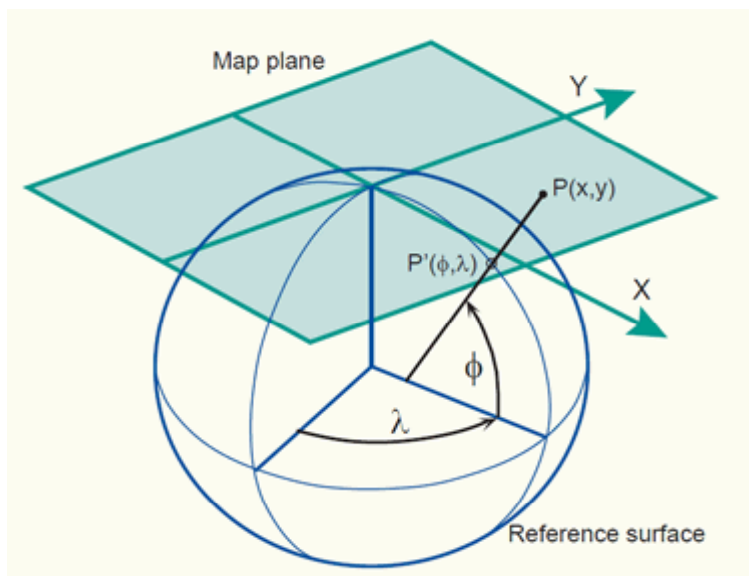
## Shuttle Radar Topography Mission



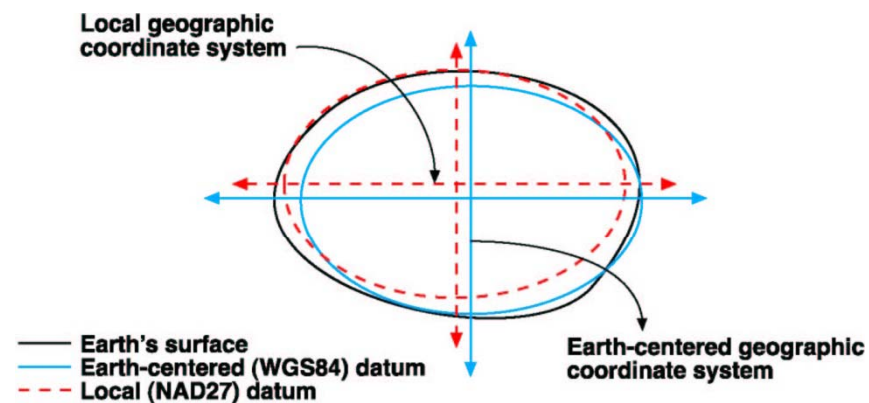
- Space Shuttle February 2000
- Radar interferometry technique
  - Resolution  $\sim 25 \times 25 \text{ m}^2$
- 80% of the Earth's land mass
- 9 terabytes of raw data
- Grid point elevations for every
  - 1 arc-sec ( $\sim 30 \text{ m}$ ) for USA
  - 3 arc-sec ( $\sim 90 \text{ m}$ ) outside
- Vertical accuracy 5-10 m ( $\sigma_z$ )
- Unedited and finished data
- Digital Surface Model rather than Digital Elevation Model
  
- For more information, visit <http://www2.jpl.nasa.gov/srtm/>

# Map coordinate systems

## Map projection



## Map datum



## Three 20-MW wind farms

Turbine type	Gamesa G47	Nordex N62	Enercon E66
Rated power	30×660 kW	16×1300 kW	11×1800 kW
Hub height	50 m a.g.l.	69 m a.g.l.	67 m a.g.l.
Total net AEP	<b>57.7 GWh</b>	<b>56.8 GWh</b>	<b>58.3 GWh</b>
Range [GWh]	1.77-2.17	3.10-3.99	5.11-5.43
SRTM maps*	$\Delta = -0.9\%$	$\Delta = -0.4\%$	$\Delta = -1.7\%$
Total net AEP	<b>57.2 GWh</b>	<b>56.6 GWh</b>	<b>57.3 GWh</b>
Range [GWh]	1.76-2.18	3.19-4.07	5.17-5.44

\* Details only added around the met. station – not the turbine sites!

## WAsP analysis: wind atlas generation

– from **observed** to **regional** wind climate



## Ingredients

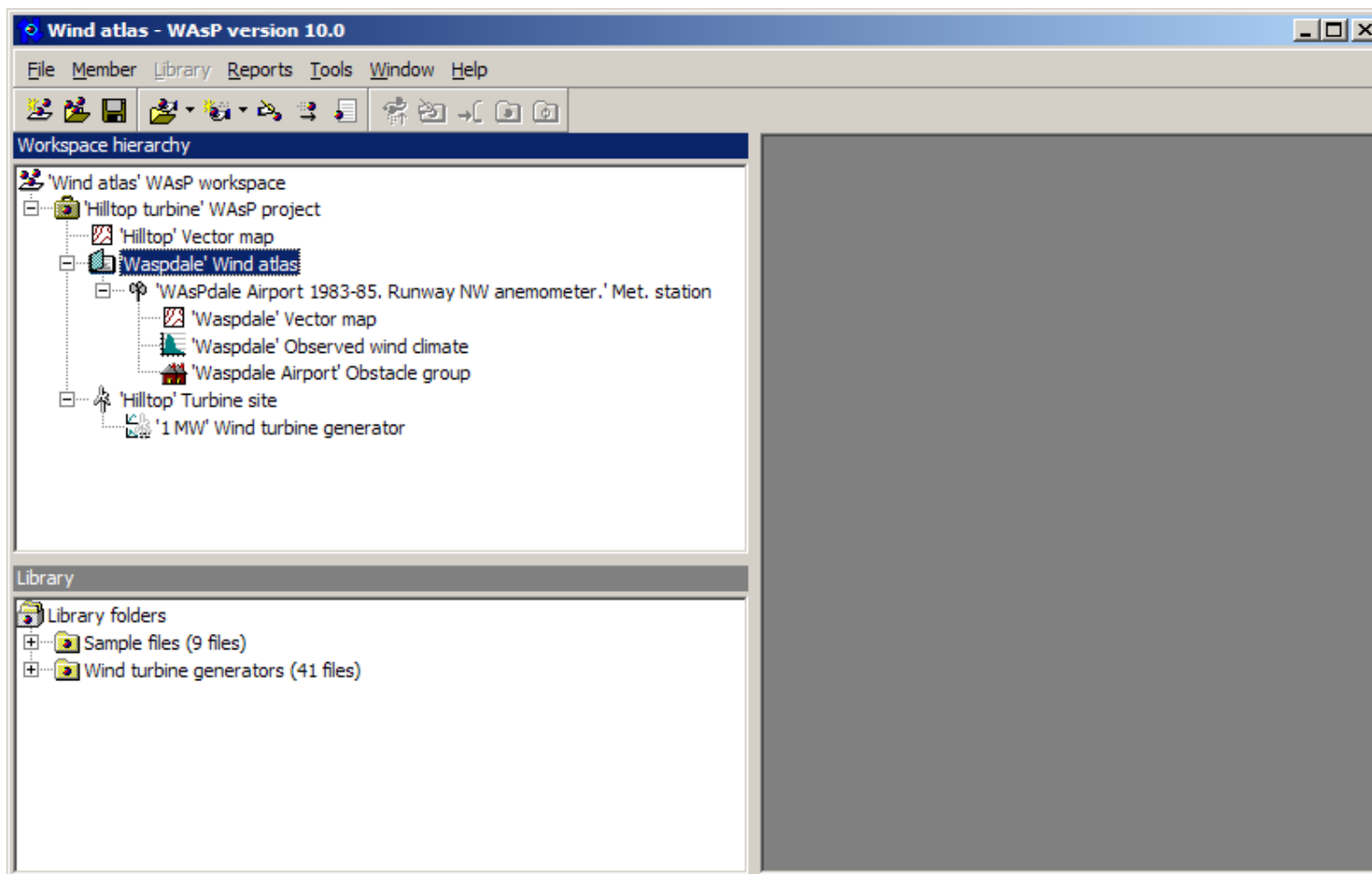
To calculate a regional wind climate one needs:

- Observed wind climate (\*.owc or \*.tab)
  - measured time-series of wind speed and direction
  - statistical summary of wind measurements
- Local (met. station) terrain descriptions:
  - roughness
  - orography
  - obstacles

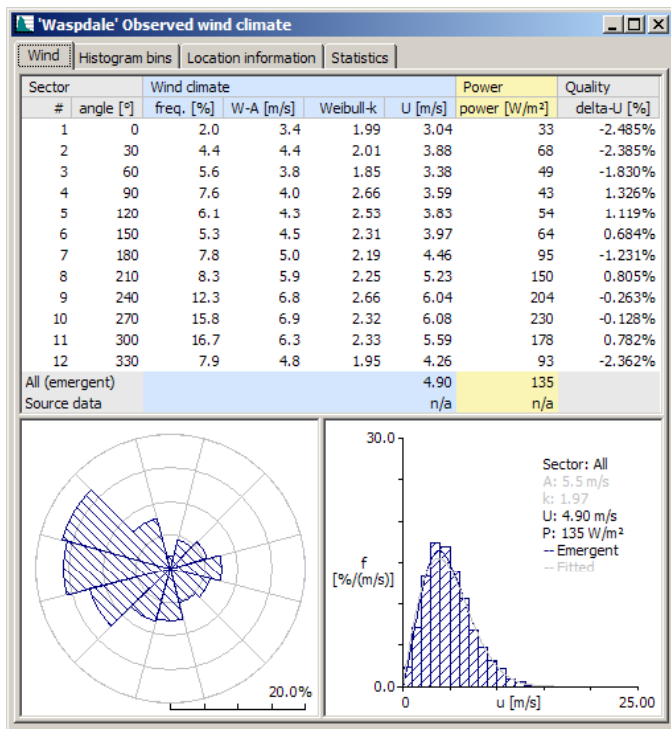
The regional wind climate or wind atlas (\*.rwc or \*.lib)

- is reduced to certain standard conditions
- can be compared to other wind atlas data sets
- is the basis for the wind resource predictions

# Generating a wind atlas

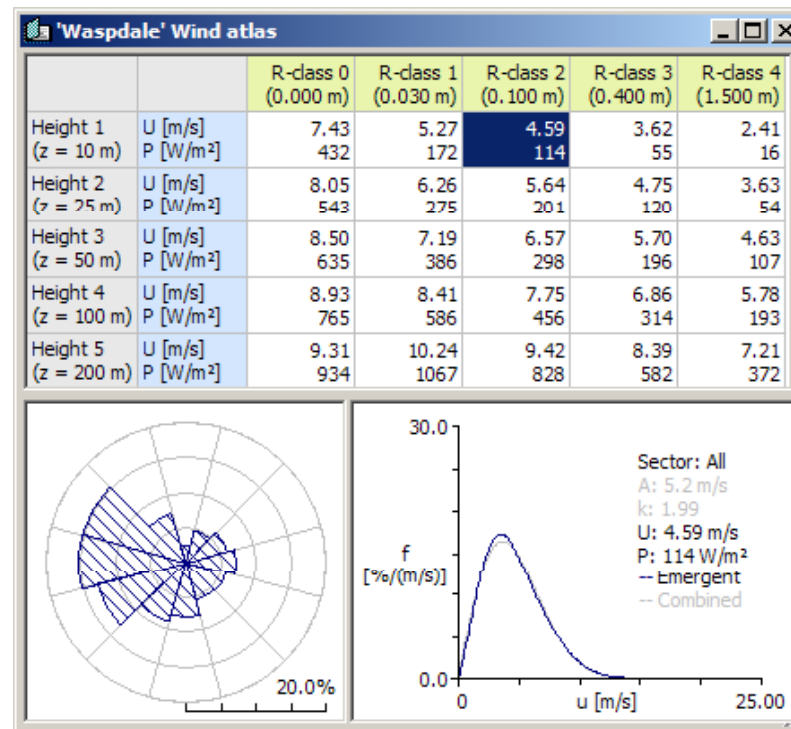


# Observed and regional wind climates



Observed wind climate (\*.owc)

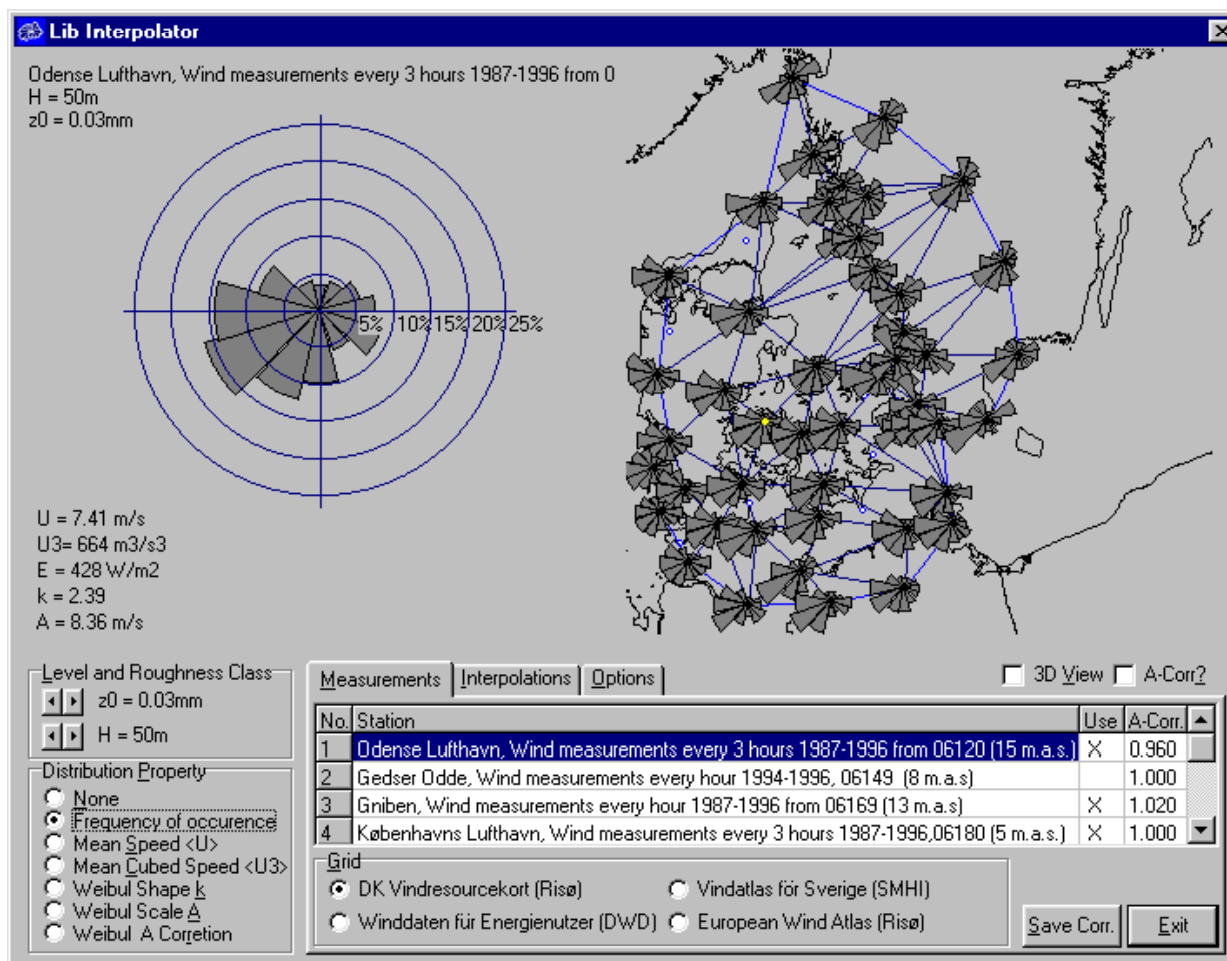
- local terrain effects
- emergent and fitted Weibull distributions are shown



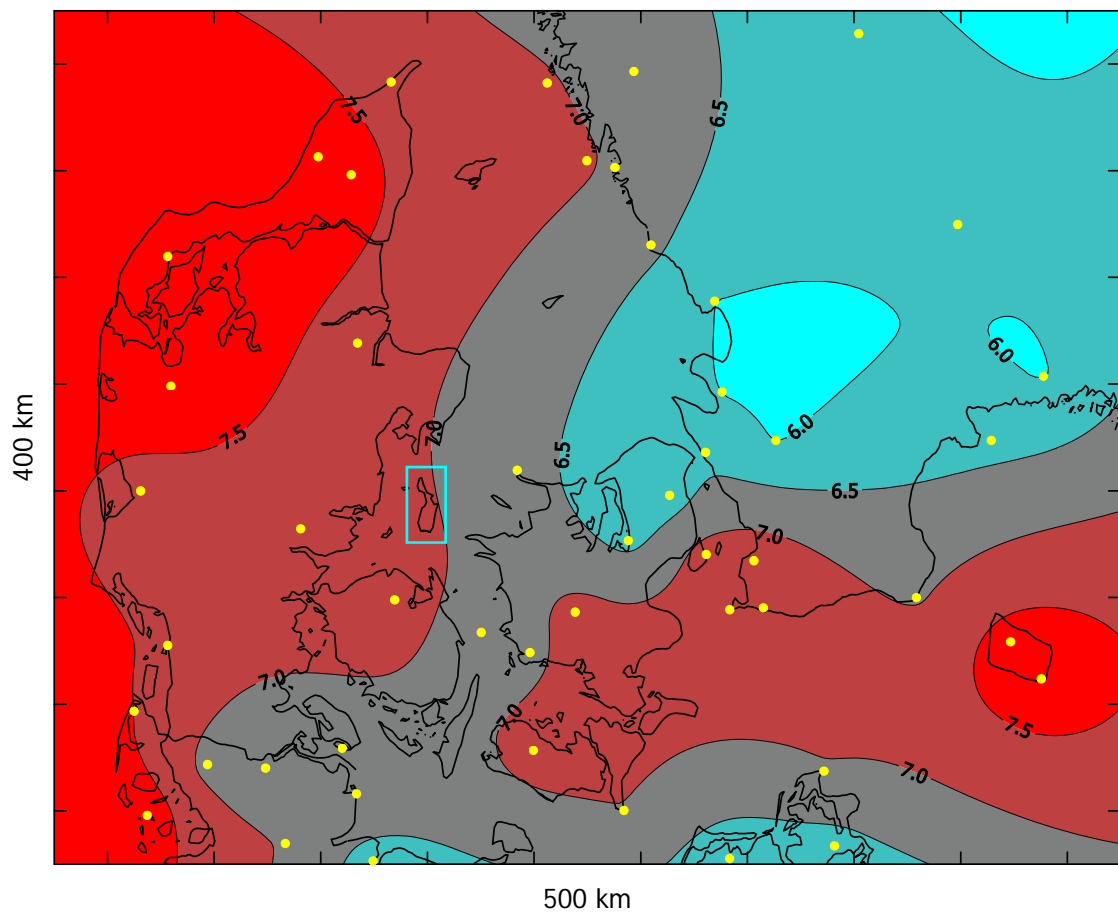
Regional wind climate (\*.rwc)

- no local terrain effects
- emergent and combined Weibull distributions

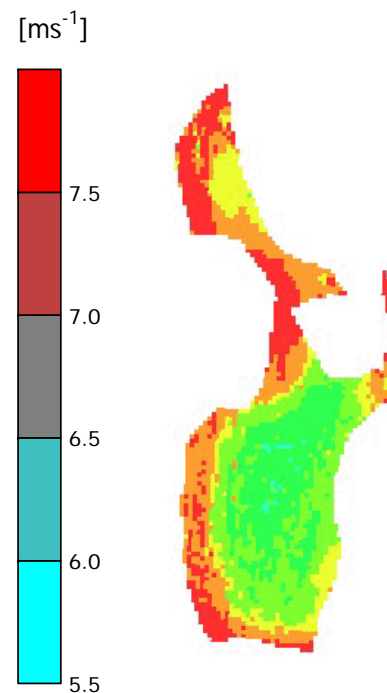
# Wind Atlas for Denmark 1987-96



# Regional wind climate of Denmark

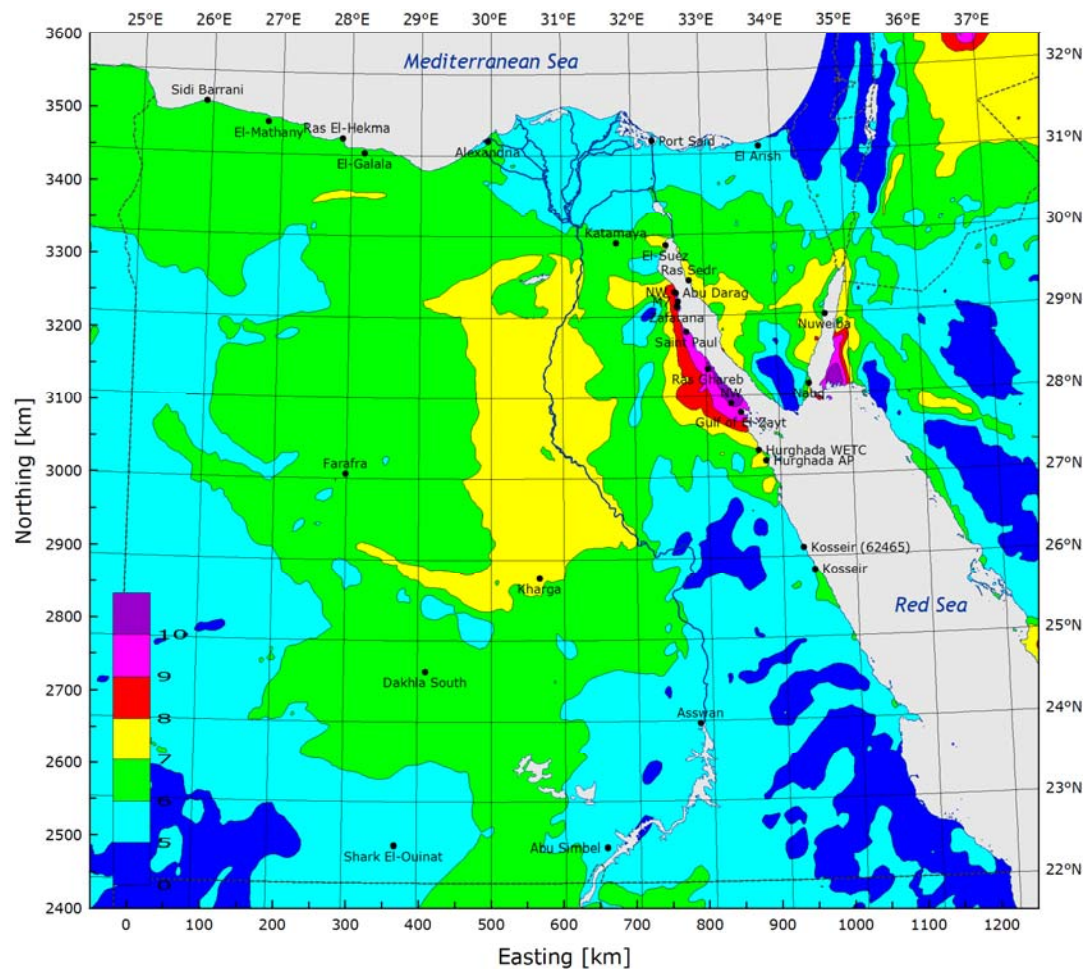


Mean wind speed [ $\text{ms}^{-1}$ ] at 50 m over  $z_0 = 0.03$  m



Samsø PWC!

# Numerical wind atlas



- Mesoscale modelling
- Wind climate over flat, uniform terrain (RWC)
- Resolution 7.5 km
- Map shows mean wind speed 50 m a.g.l. [ $\text{ms}^{-1}$ ]
- Output format: WASP wind atlas \*.lib files
  - Weibull  $A$  and  $k$
  - standard heights
  - standard  $z_0$
  - database of > 50,000 \*.lib files!

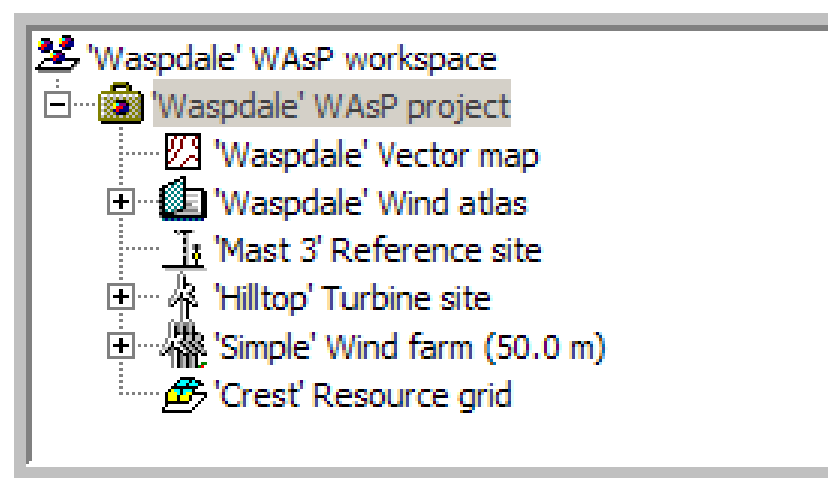
## WAsP wind resource predictions

– from **regional** to **predicted** wind climate







## Ingredients

- Regional wind climate (wind atlas data set)
- Roughness map
- Height contour map
- [Obstacle list]
- [Power curve]



## Wind resource objects

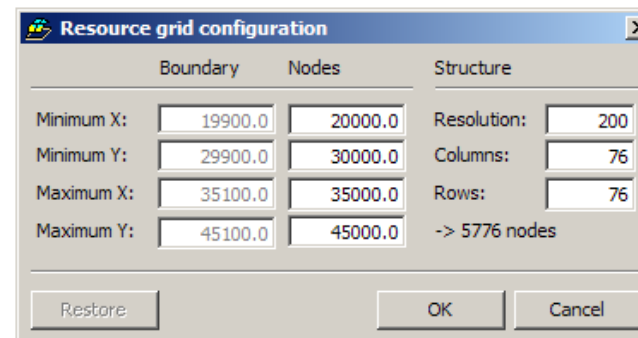
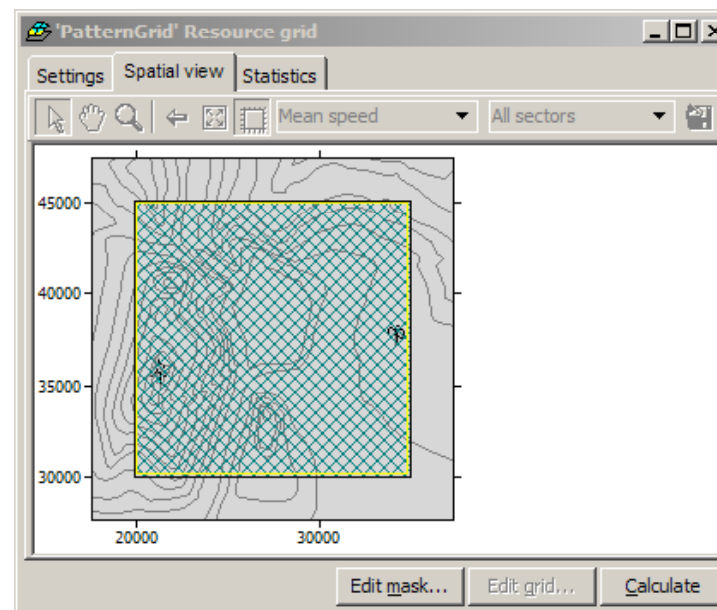
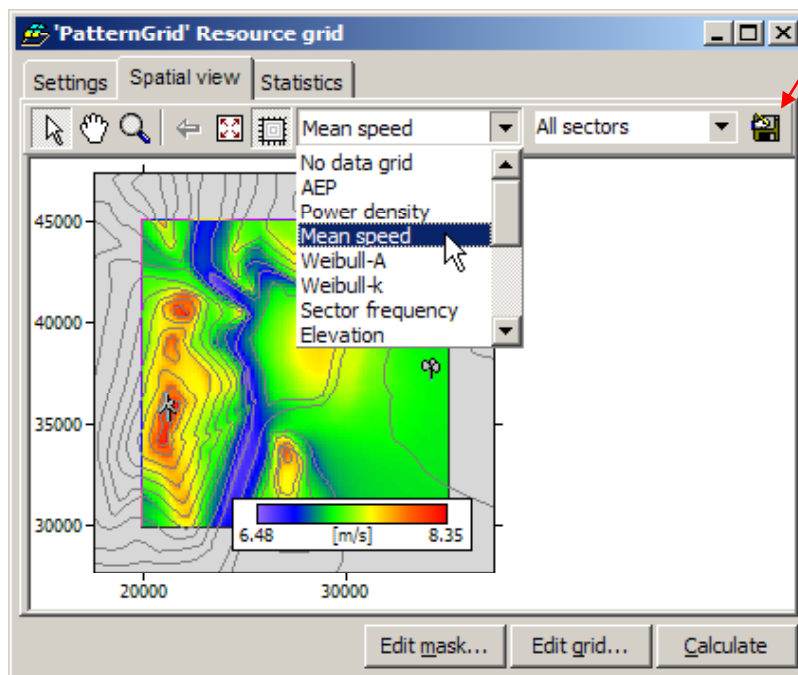
-  • Reference site: single site and height specified by user
  - comprehensive wind climate results + model outputs #)
-  • Turbine site: single site and height specified by user
  - comprehensive wind and power results + model outputs #)
-  • Wind farm: collection of turbine sites, arbitrarily placed within the map, includes wind farm wake effects
  - turbine site results for each turbine + wake model outputs \*)
-  • Resource grid: multiple sites, regularly spaced in an area, and one height specified by user
  - summary results and no model outputs #)

#) *No site-site interference*

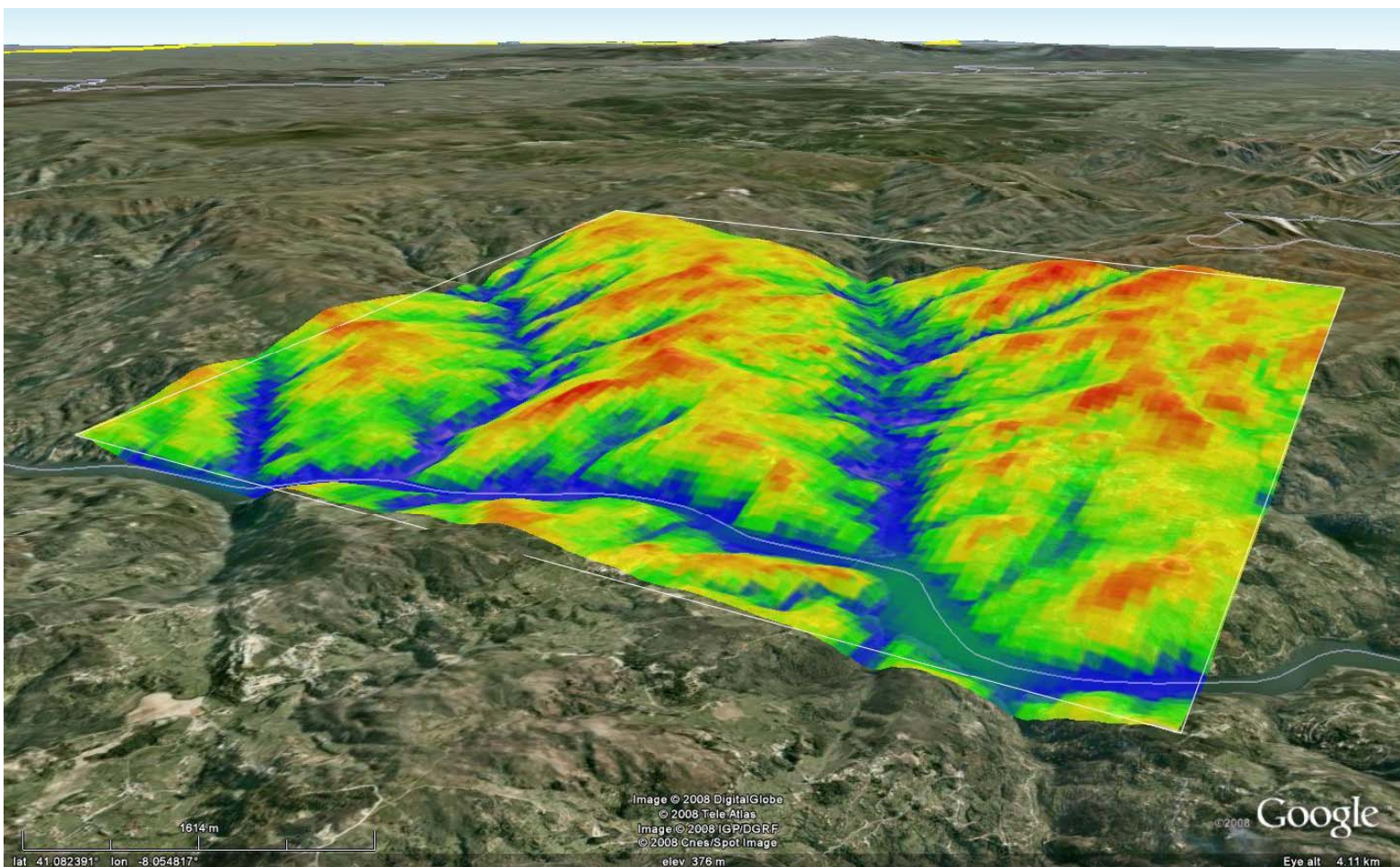
\*) *Only site-site interference within wind farm*

# Resource grid

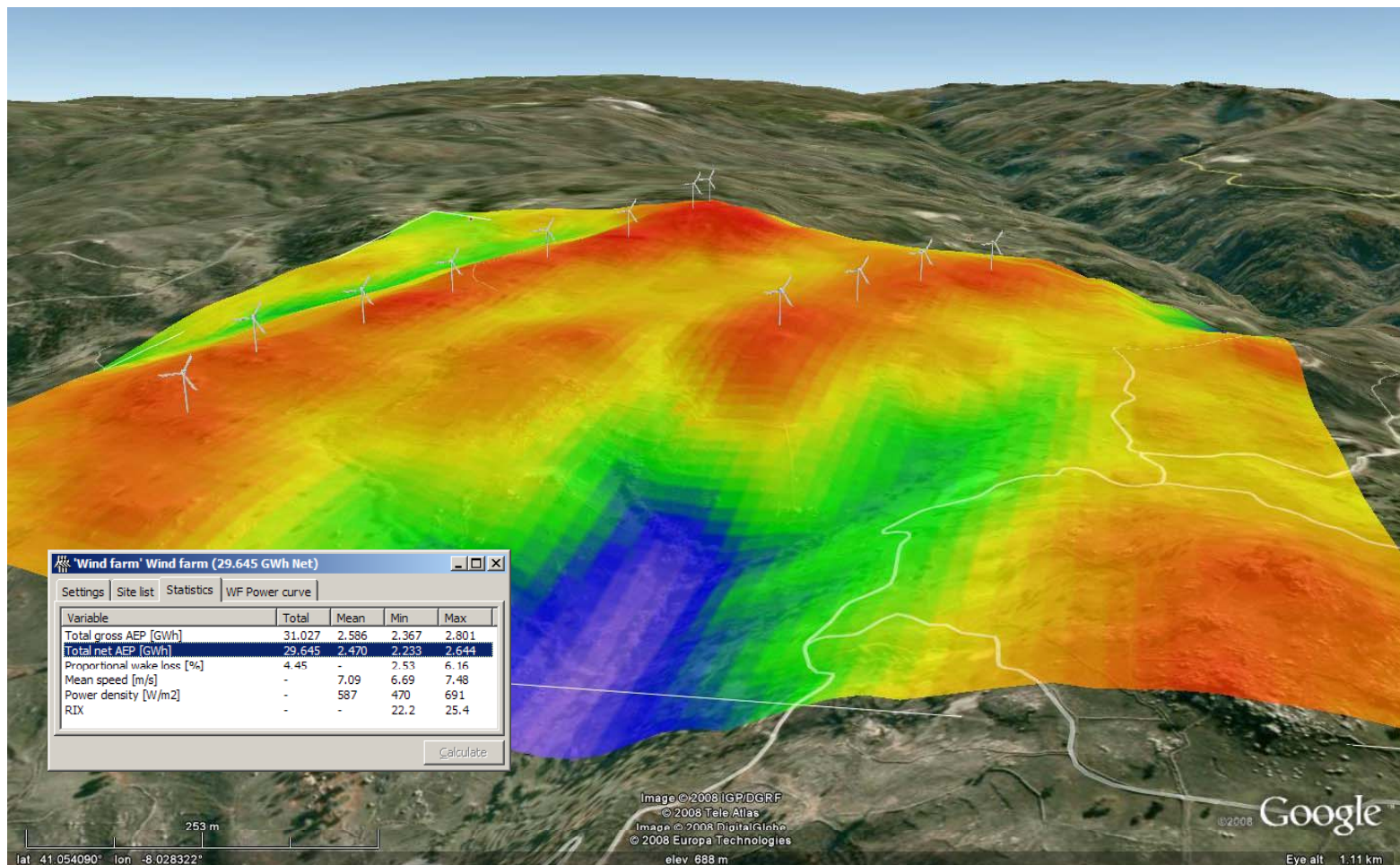
Export selected grid to .grid file



# Sample wind resource map

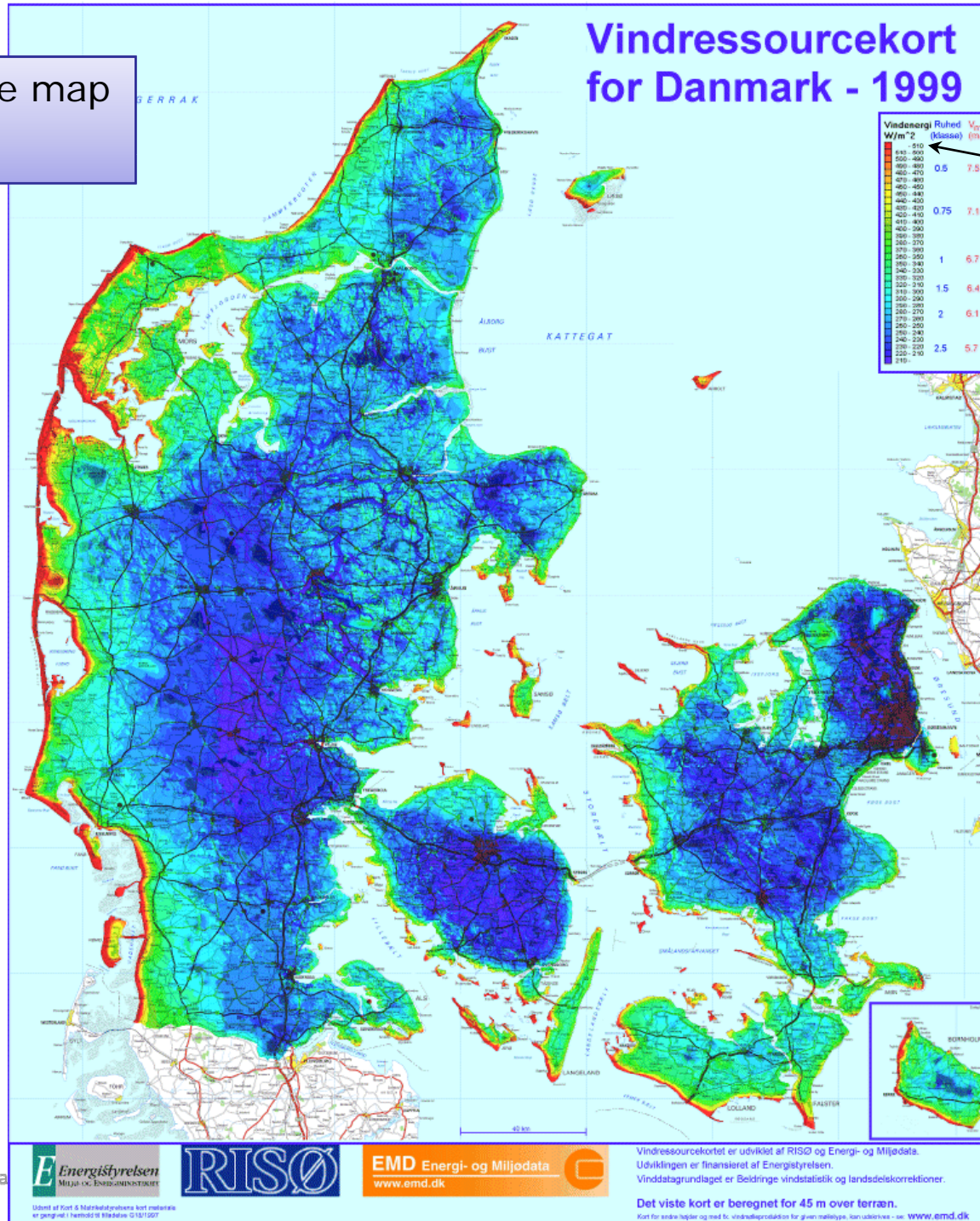


# Sample wind farm layout and estimated production



Wind resource map for Denmark

# Vindressourcekort for Danmark - 1999



~500 W/m<sup>2</sup>

Mean wind

~7.5 m/s

## The WAsP elements

- Interface
  - WAsP workspace
  - Projects
  - Hierarchy
- Inputs
  - Map
    - Digital map (elevation & roughness)
    - Digital obstacle description
  - Wind data
    - Raw data (time-series)
    - OWC, \*.tab
  - Wind turbine specifications
- WAsP Analysis
  - Generating the Wind Atlas
- WAsP Application
  - Wind resource prediction
- Wind resource grid and map
- Wind farm
  - Annual Energy Production (AEP)