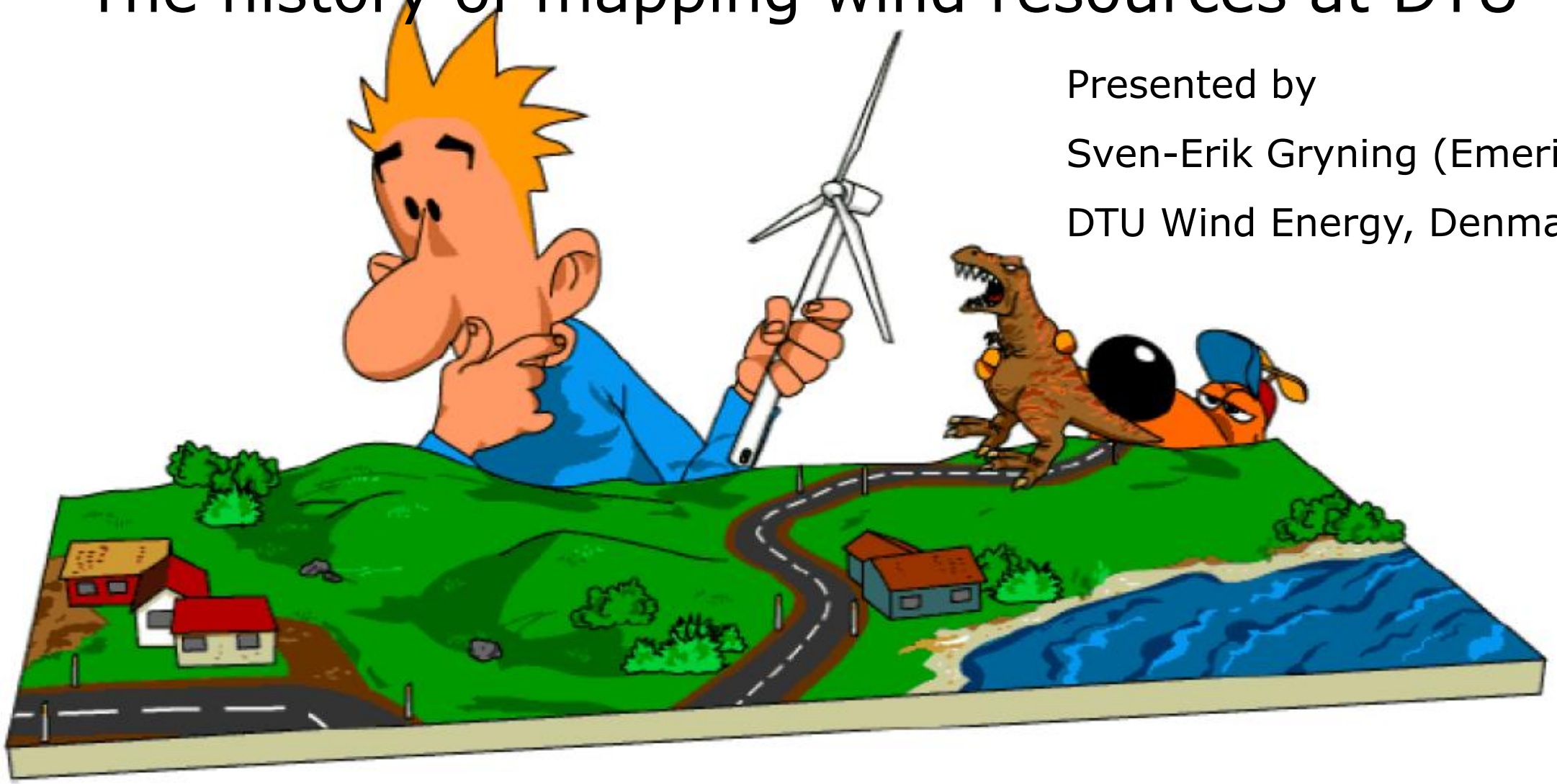
The history of mapping wind resources at DTU



Presented by

Sven-Erik Gryning (Emeritus),

DTU Wind Energy, Denmark

General:

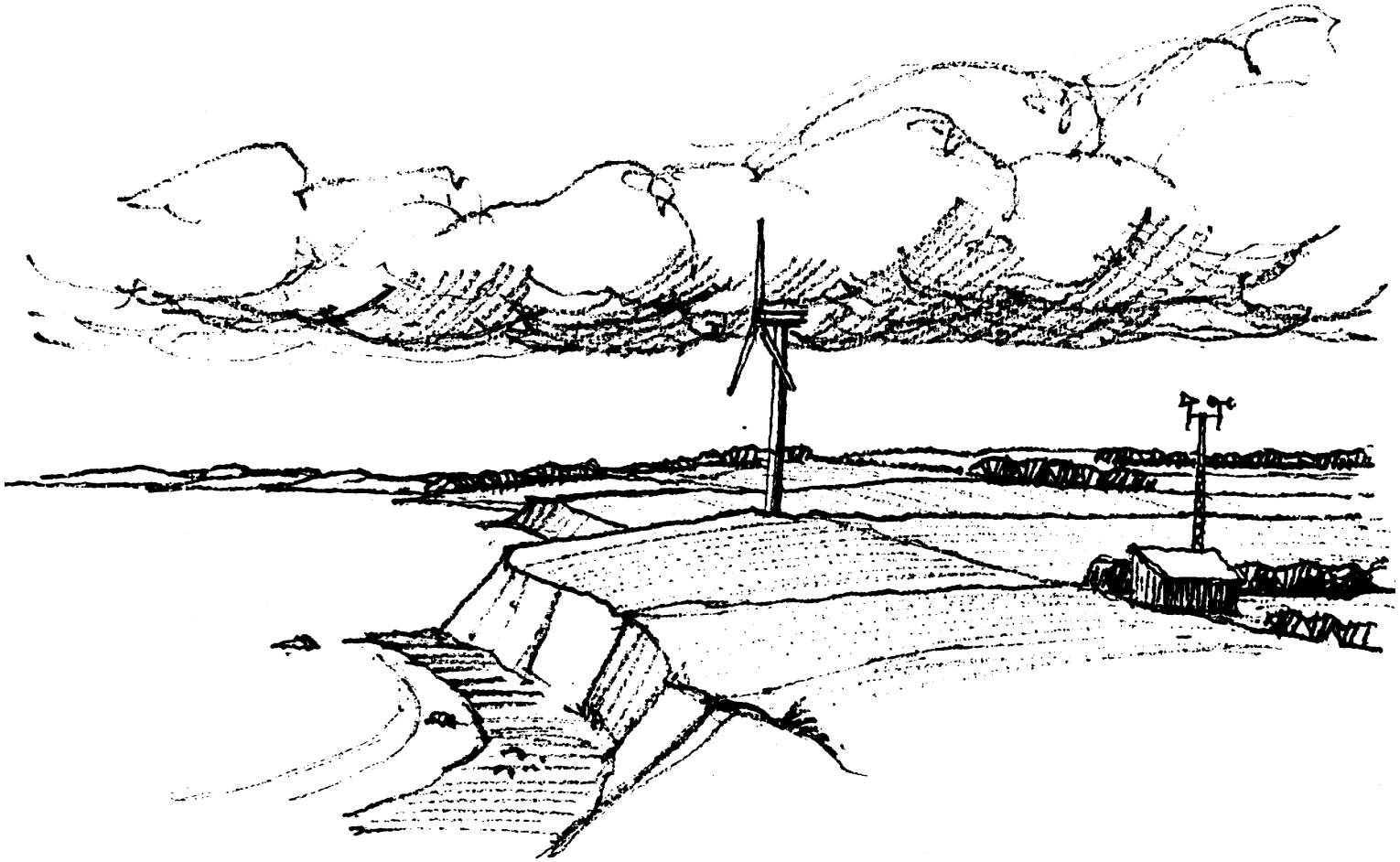
A wind atlas is a comprehensive collection of wind climate data.

DTU Wind Energy (original):

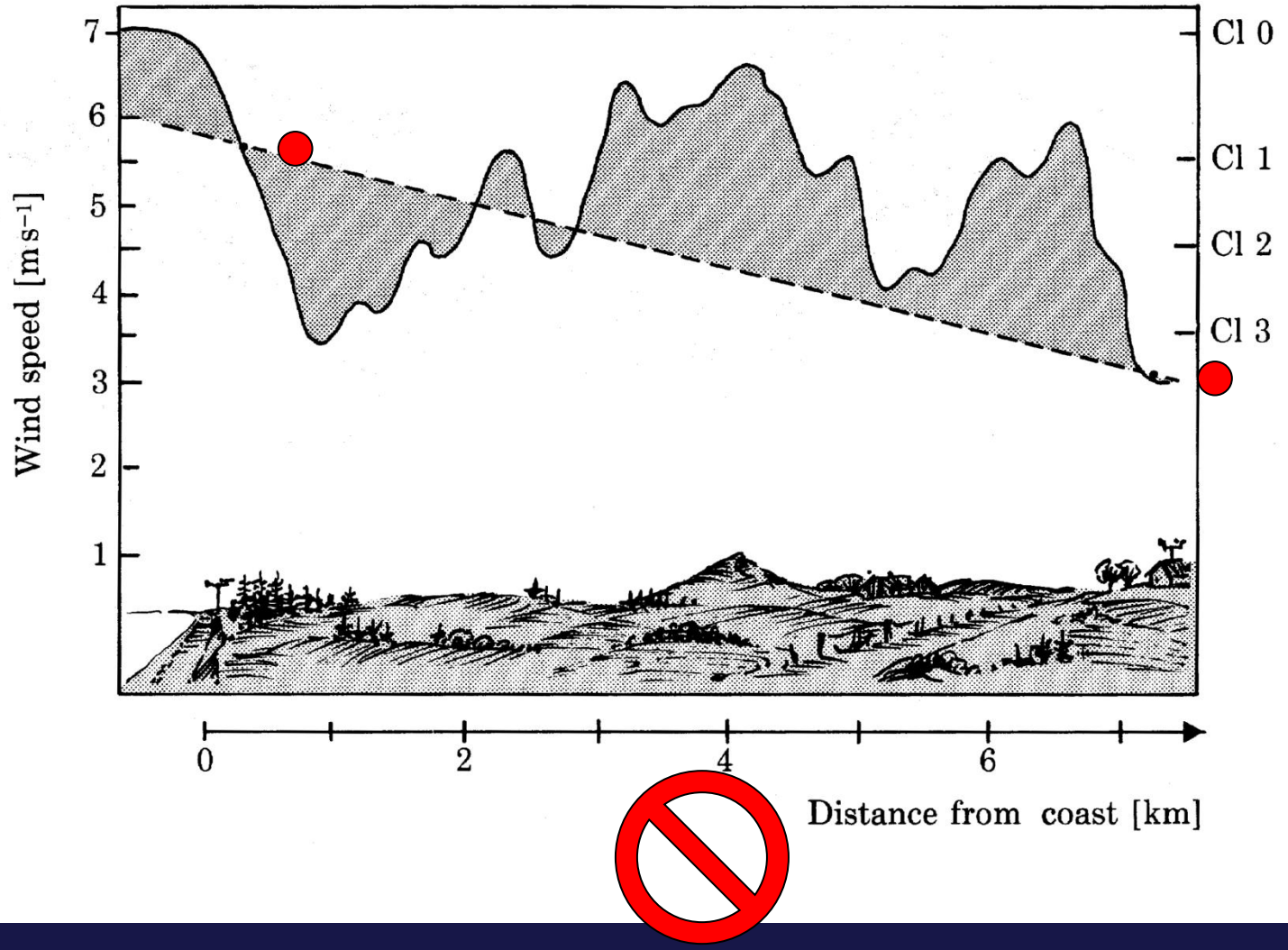
A wind atlas is a comprehensive collection of generalized wind climates (GWCs), derived by the wind atlas methodology.

A generalized wind climate and a topographical map are the two main inputs to wind resource assessment anywhere in the world.

The classic problem

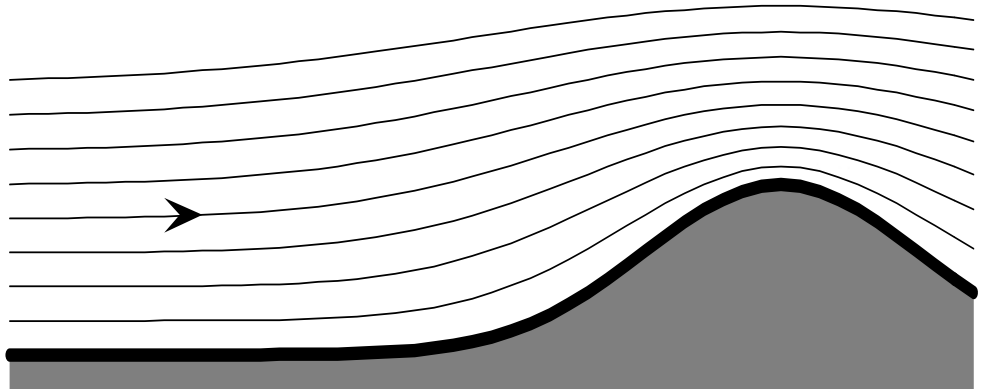


Linear interpolation…



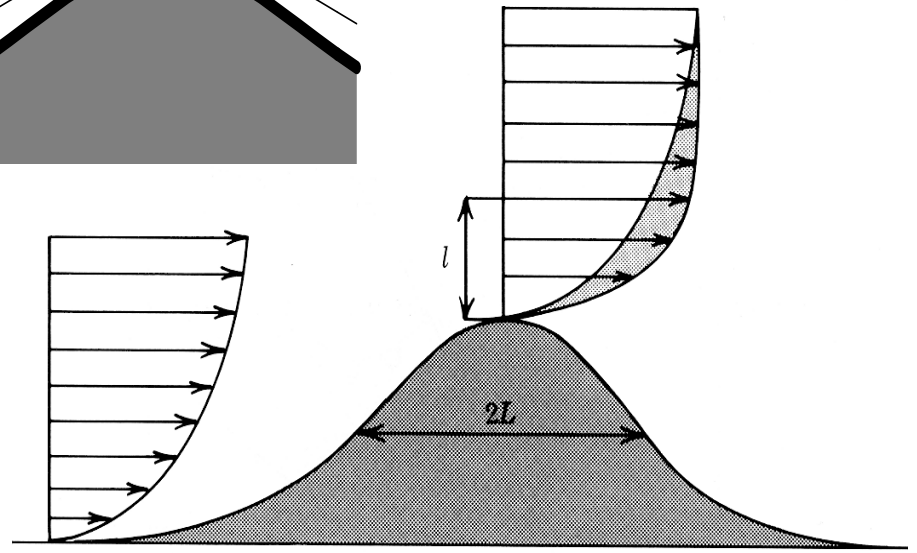
Microscale
Orographic speed-up

Handled by WAsP modelling



Winds speed up on hills

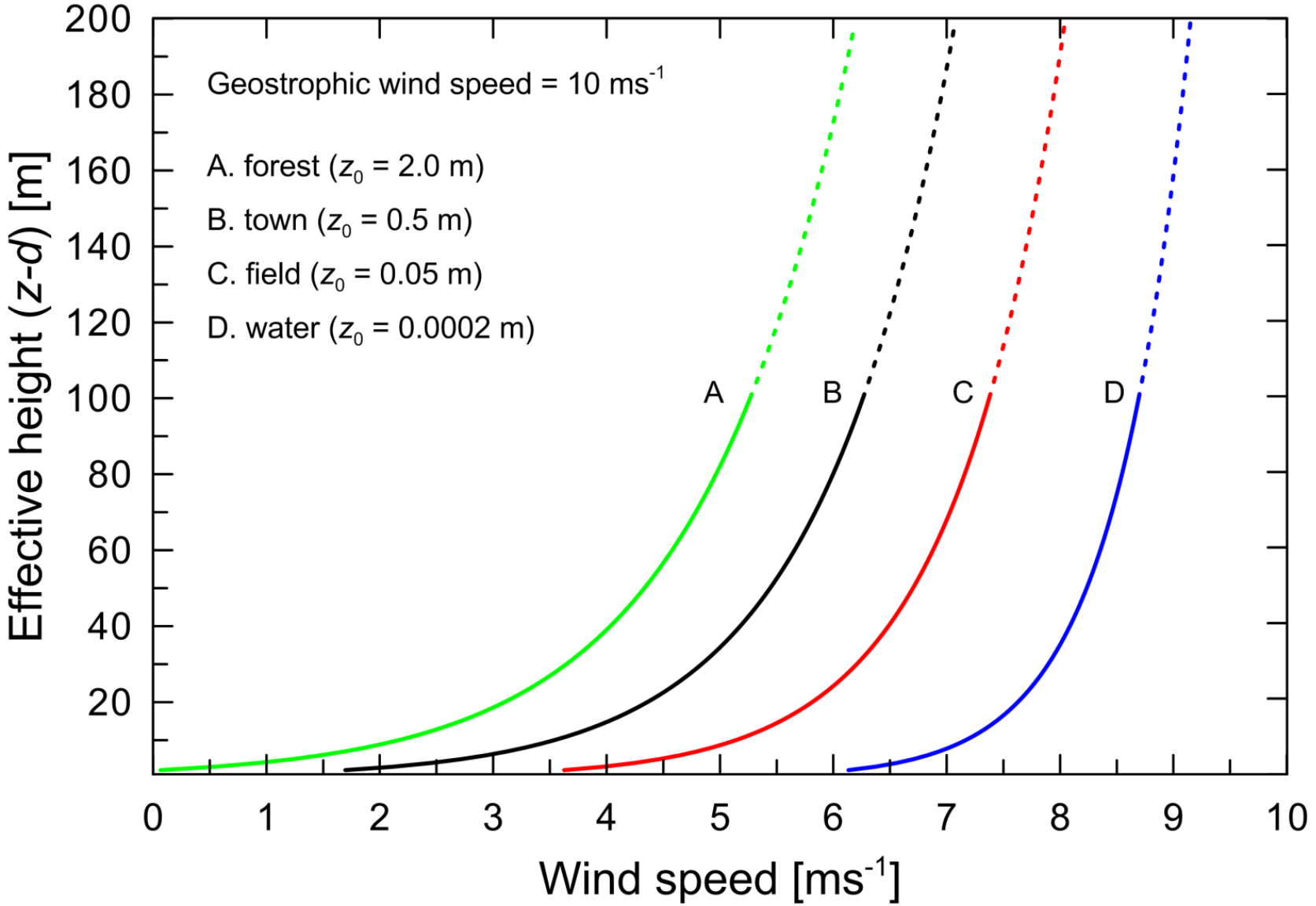
Winds slow down in valleys



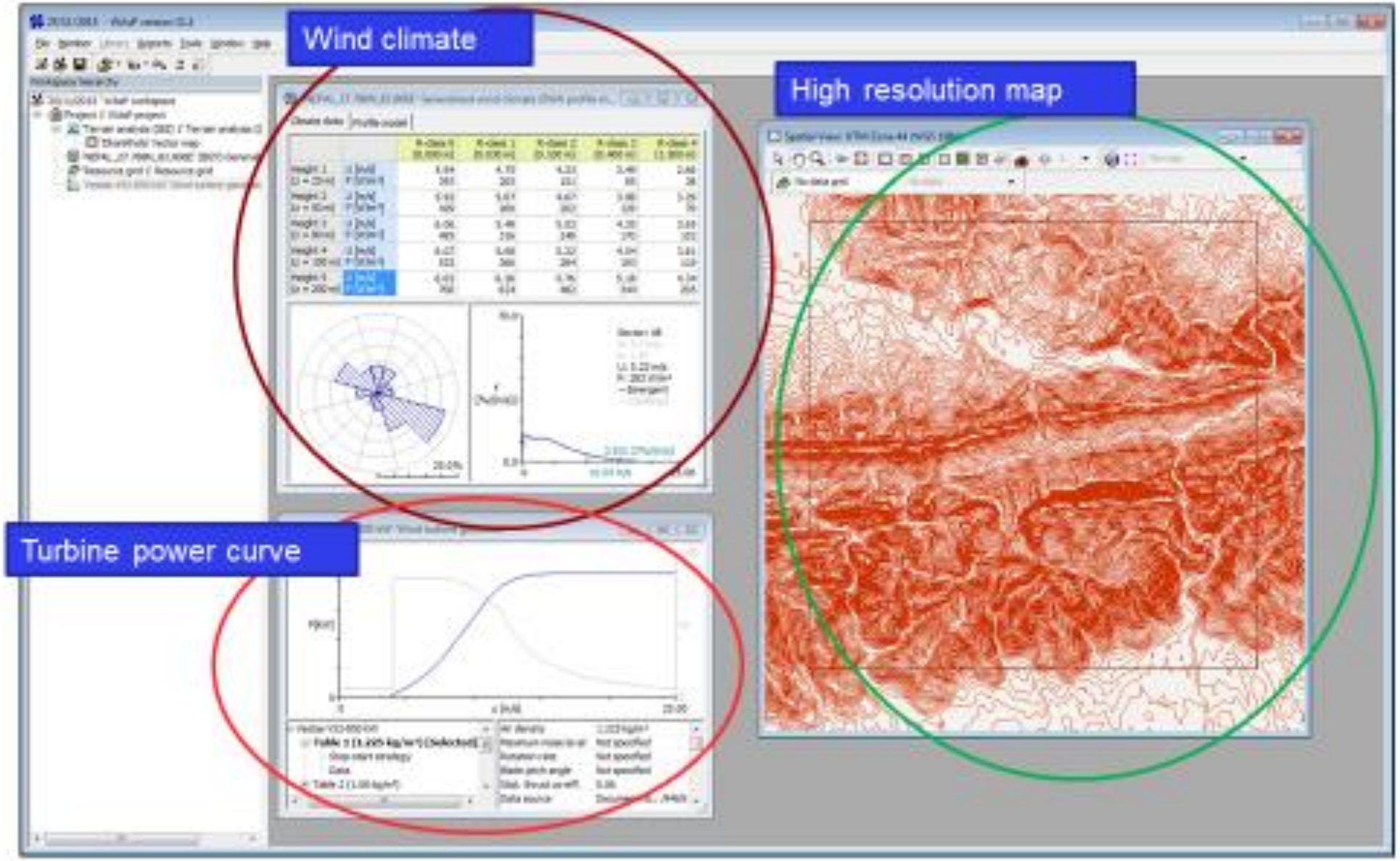
Modification of the wind profile

Microscale
Surface roughness length

Handled by WAsP modelling



Microscale modelling (with WAsP software)



Observational wind atlas

Inputs

- measured time-series of wind speed and direction – observed wind climate
- terrain topography – elevation, roughness and obstacles – digitised maps, SRTM, Google Earth

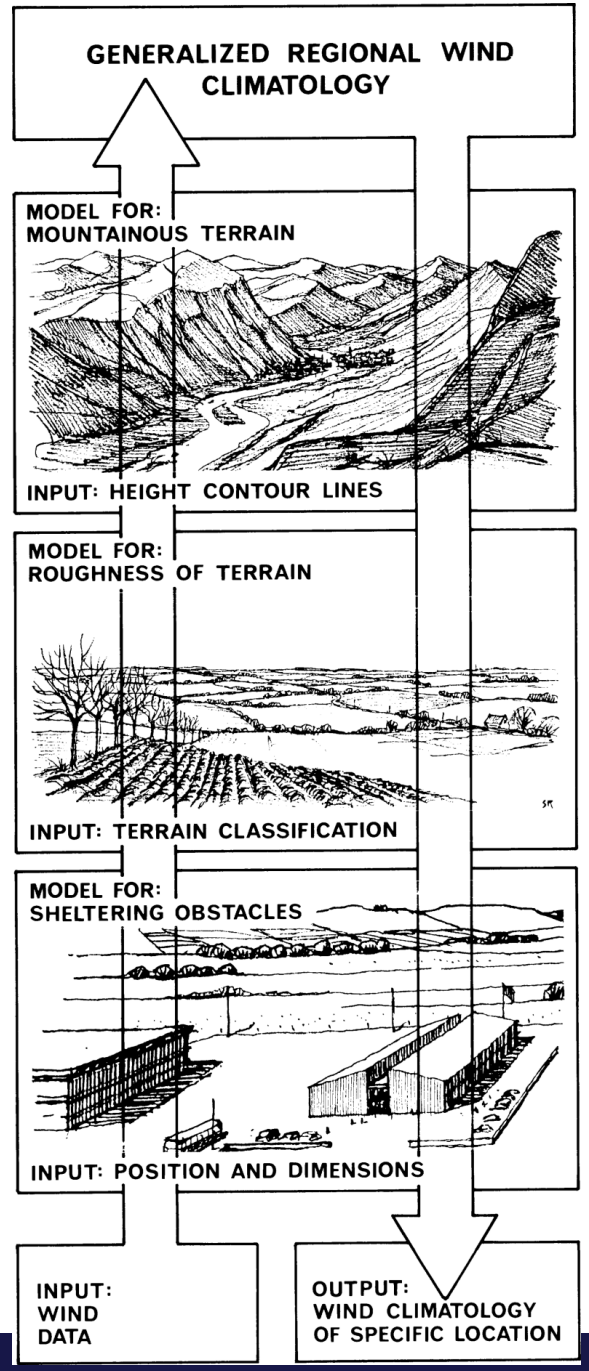
Outputs

- generalised *regional wind climate* for the specific location

Applications

- energy production estimate for wind farms in the region near the meteorological station

- This Regional Wind Climate is the hypothetical wind climate for an ideal, featureless and completely flat terrain with a uniform surface roughness, assuming the same overall atmospheric conditions as those of the measuring position.

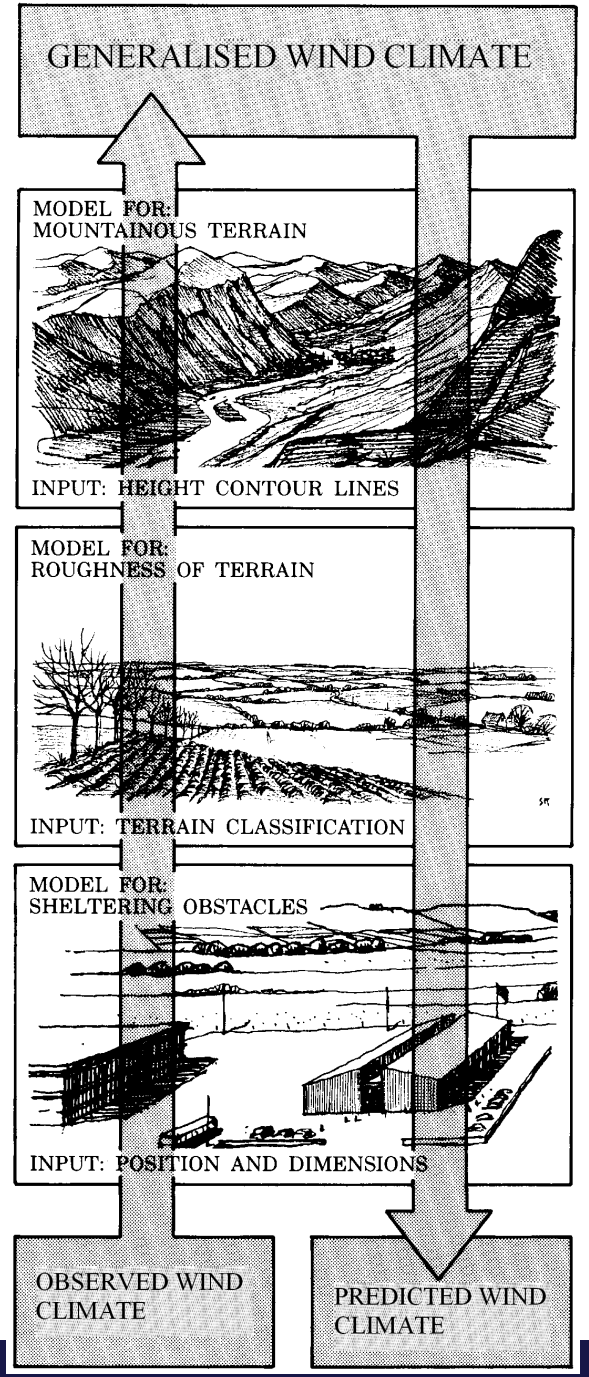


“WAsP-ology”…

- Analysis procedure (⇑)
  Observed Wind Climate
  + elevation map
  + roughness map
  + sheltering obstacles
  ⟶ **Generalised Wind Climate**

- Application procedure (⇓)
  Generalised Wind Climate
  + elevation map
  + roughness map
  + sheltering obstacles
  ⟶ **Predicted Wind Climate**

- Wind farm production
  Predicted Wind Climate
  + power and thrust curves
  + wind farm layout
  ⟶ **Predicted wind farm AEP**



Motivation: The GIGO principle

- This universal principle for computer models (and many other aspects of life ;-) states:

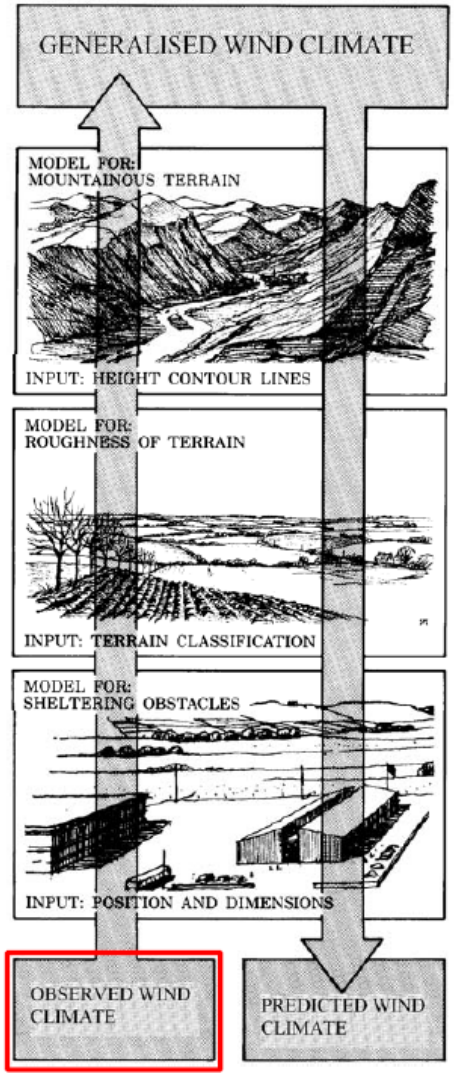
  $$\text{Garbage Out} = (\text{Garbage In})^n$$

- Since power in the wind, $P = \frac{1}{2}\rho A U^3$, the exponent for wind energy models is:

  $$n = 1 \text{ to } 3$$

- 'Garbage' or not – it's difficult to make accurate, reliable, long-term wind measurements.

- The good WAsP user should know how!

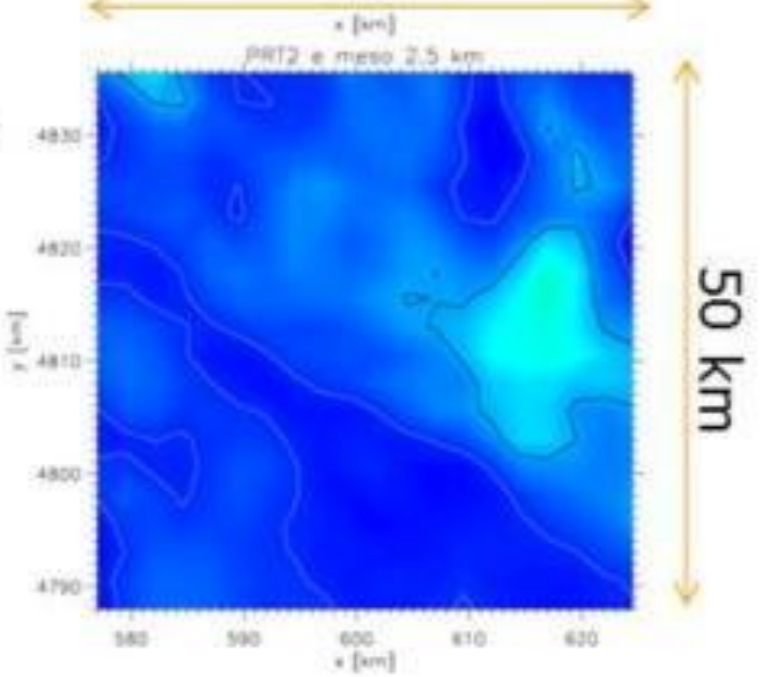


Wakes at Horns Rev wind farm

Mesoscale

50 km

2.5 km



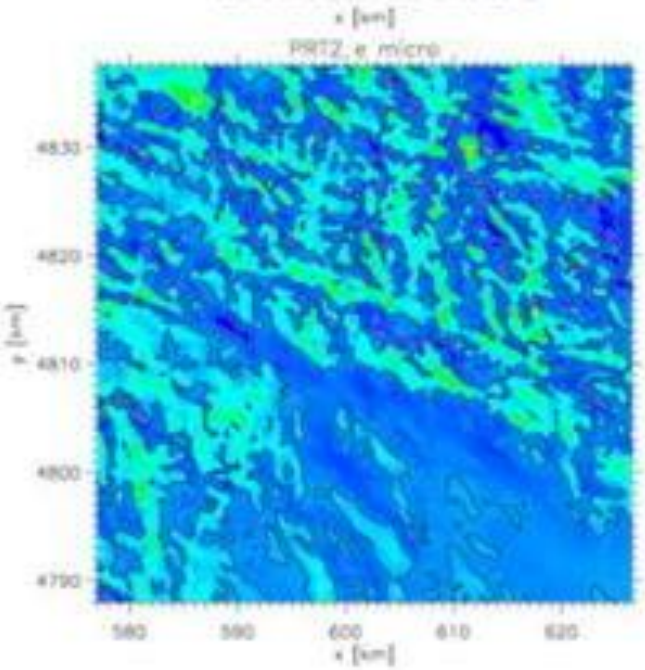
50 km

323 W/m²

410 W/m²

mean power density of total area

Mesoscale + microscale



100 m

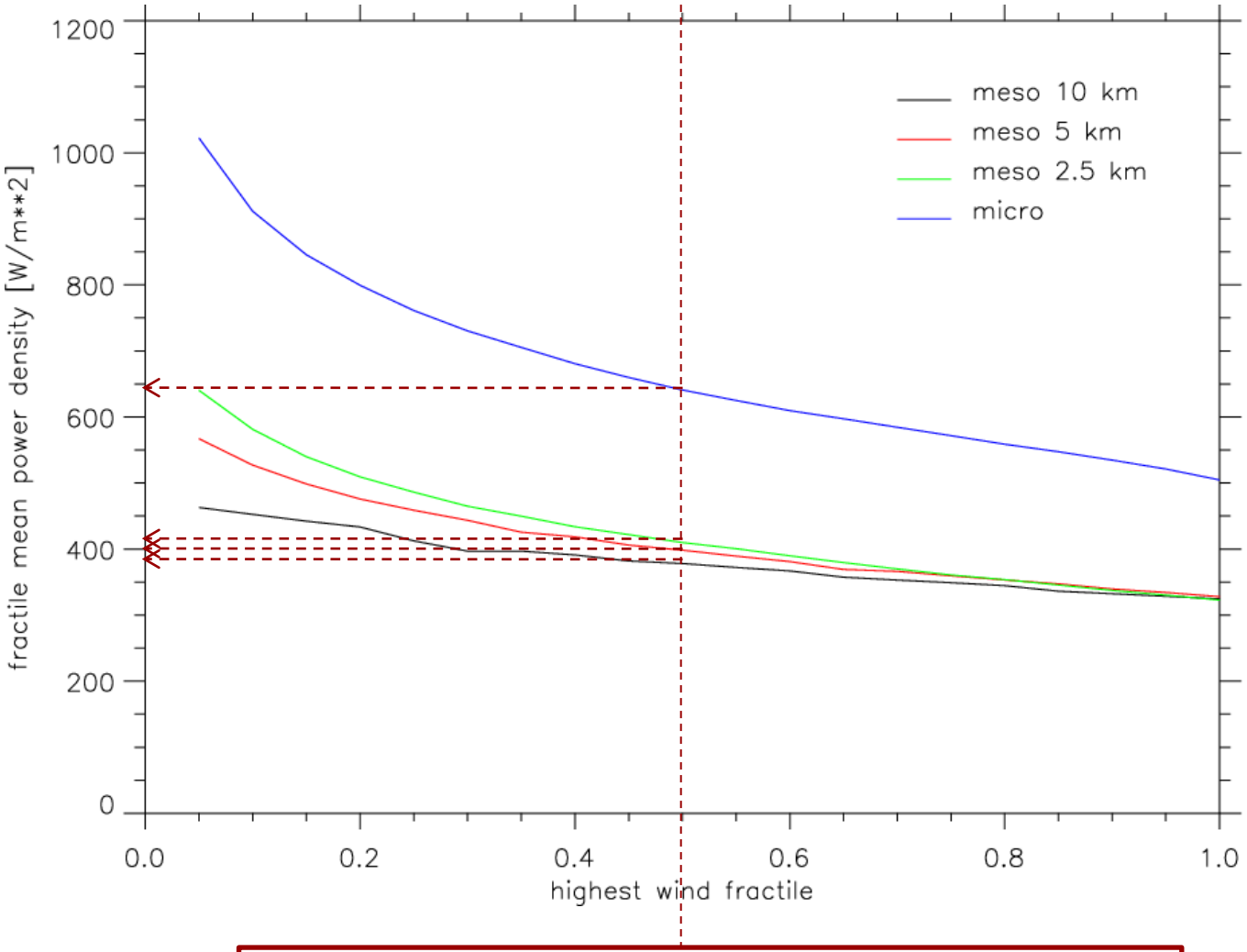
505 W/m²

641 W/m²

mean power density for windiest 50% of area

Importance of resolution

Note: this area exhibits very large topography effects. Even for Danish landscape effect can give 25 % boast in wind resource at the windiest 5 percentile.

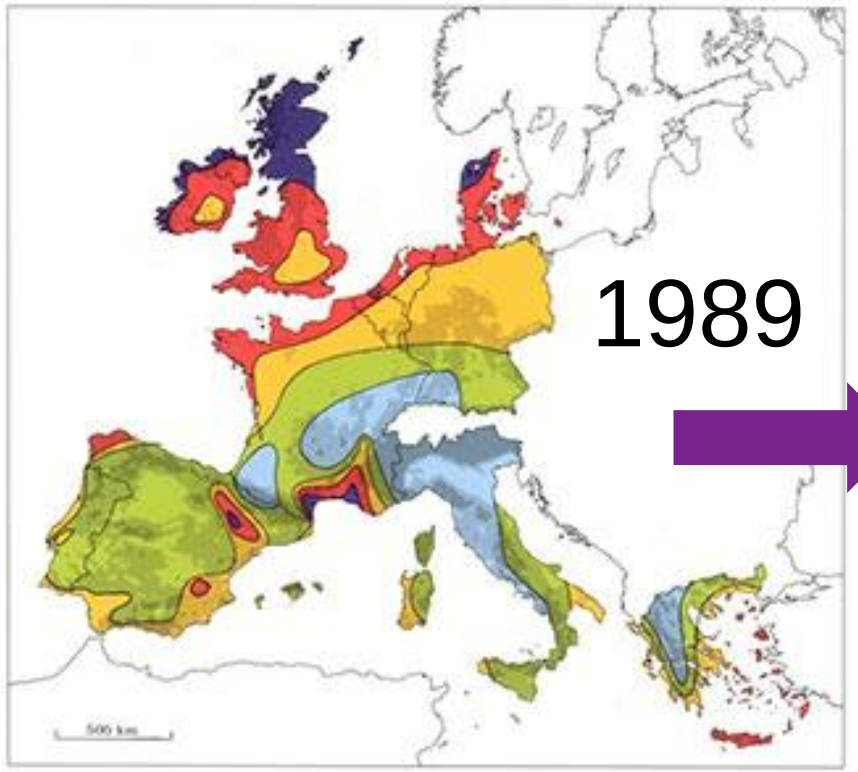


Mean wind power density for windiest half of area

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]	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-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

European Wind Atlas to Global Wind Atlas



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

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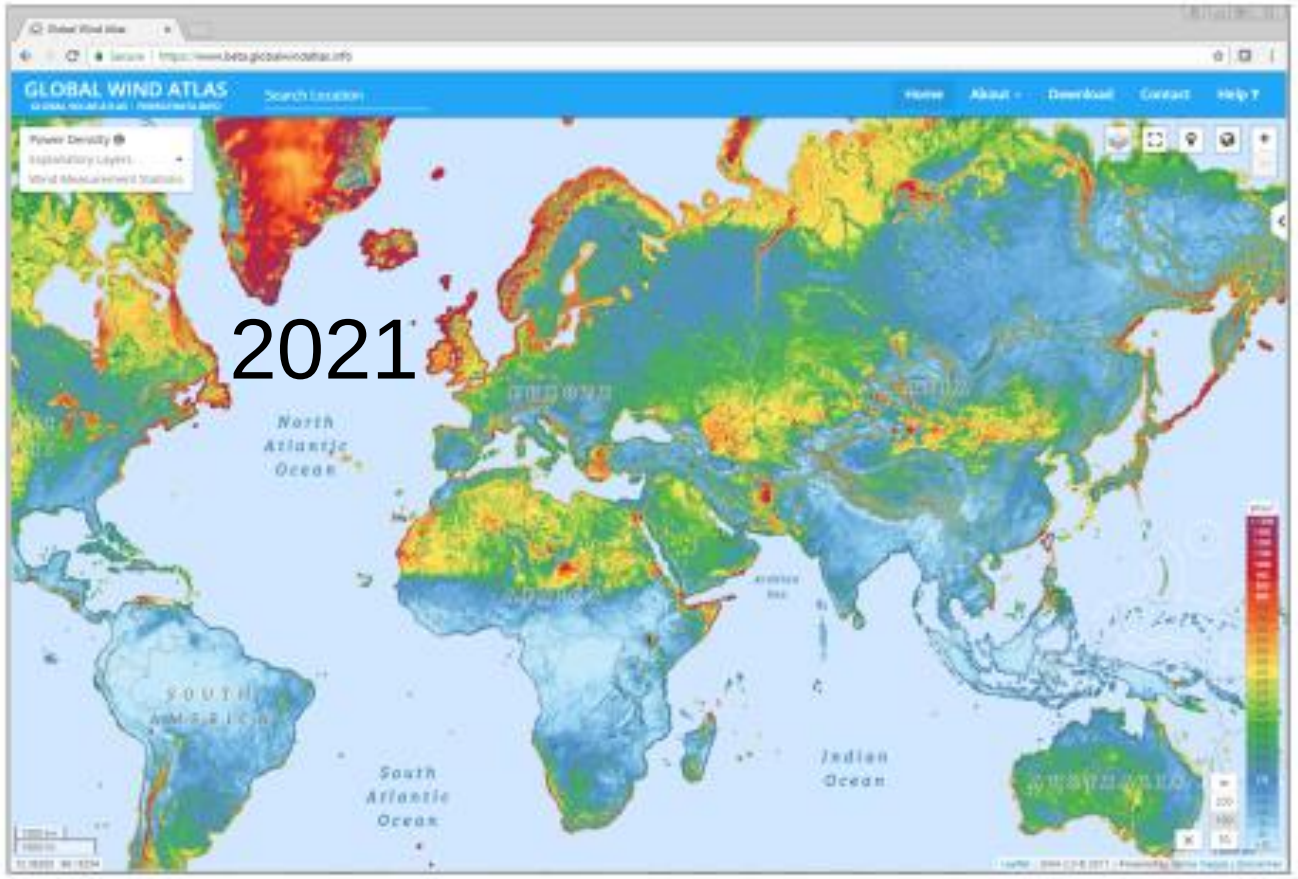
	m s^{-1}	W m^{-2}	m s^{-1}	W m^{-2}	m s^{-1}	W m^{-2}	m s^{-1}	W m^{-2}	m s^{-1}	W m^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	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



Long-term mean wind speed (m/s) at 100 m, 1989-2018

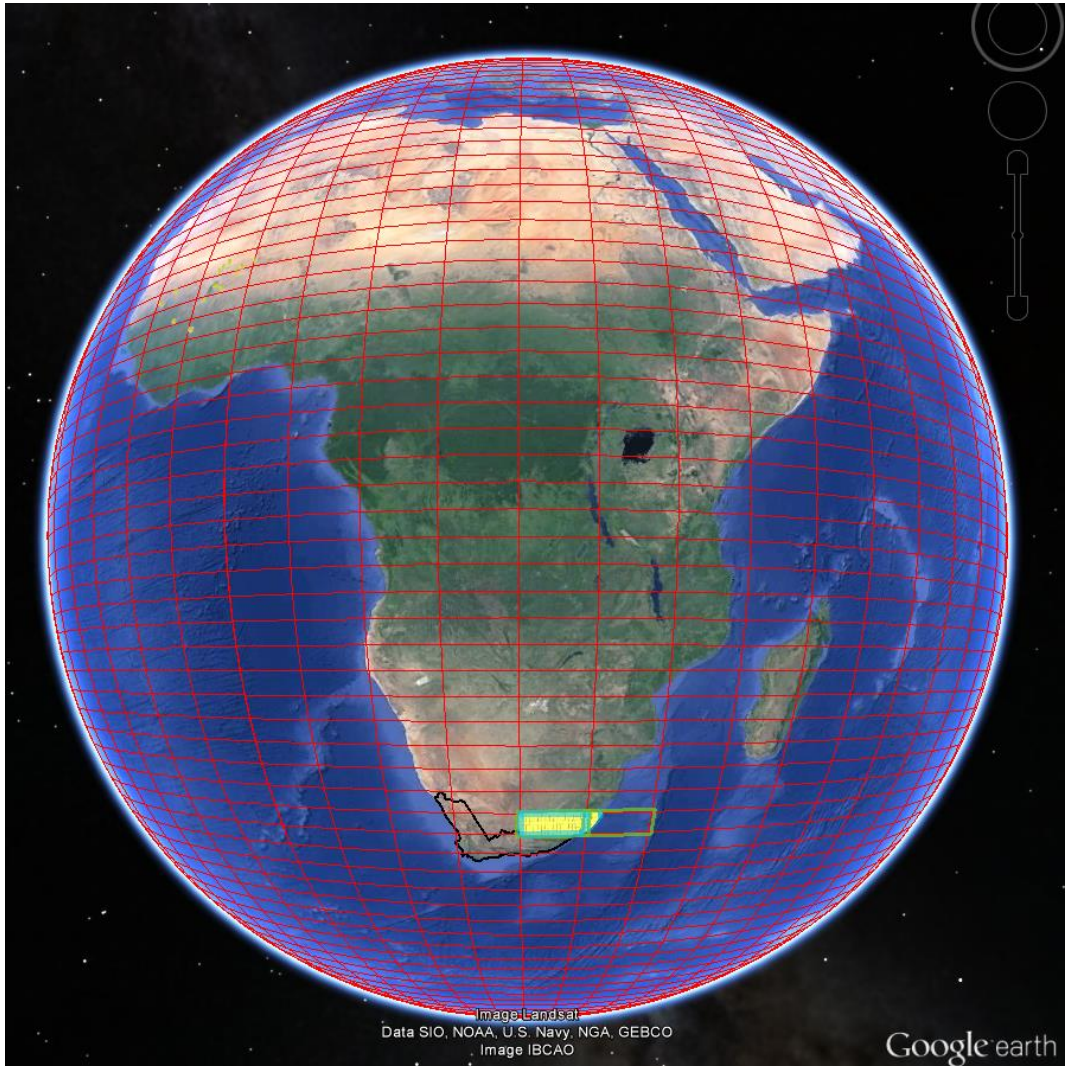
Global Wind Atlas model chain
Microscale modelling

- **More than 2400 jobs required to cover land**
  - **200 km offshore (GWA3)**

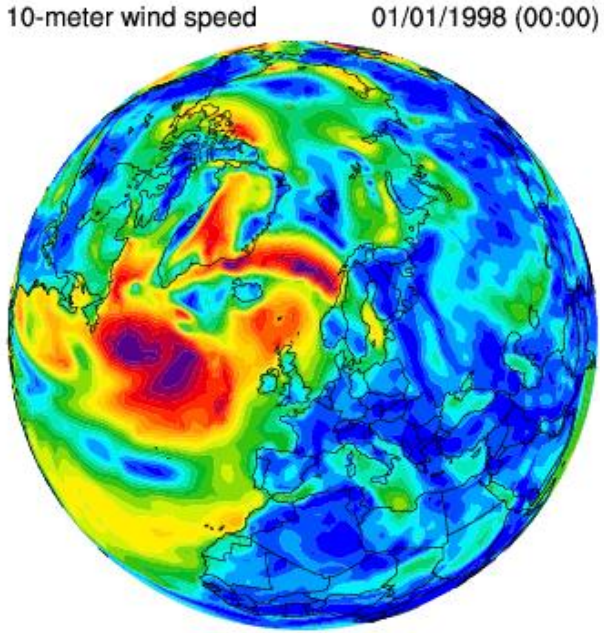
- Calculation system runs WAsP-like microscale modelling over vast areas using many computer nodes.

- It manages and despatches inputs
  - Generalized reanalysis winds
  - High resolution elevation and surface roughness data

- Wind climate calculation spacing 250 m

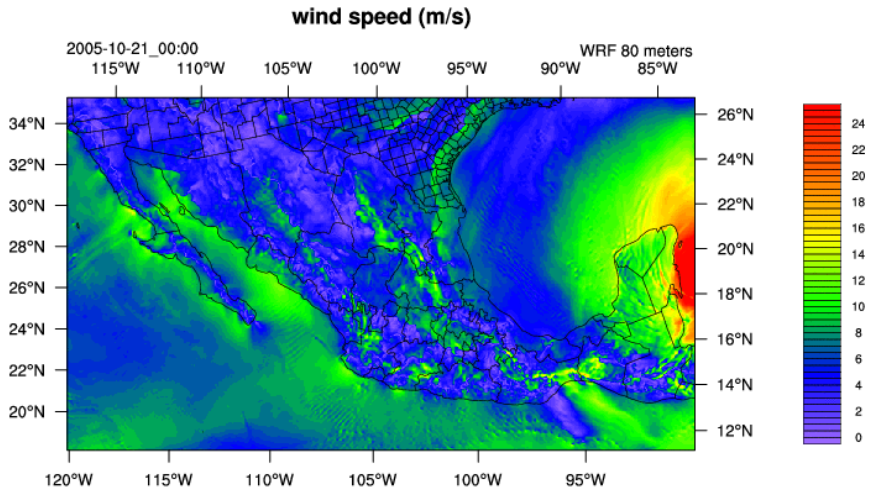


Meteorology at different scales: modelling chain

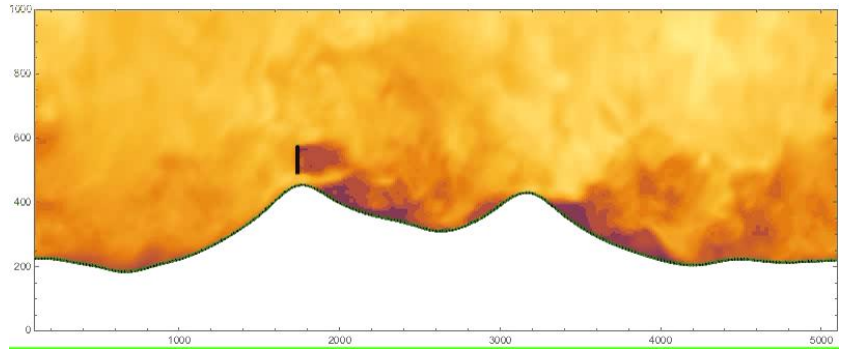


Global

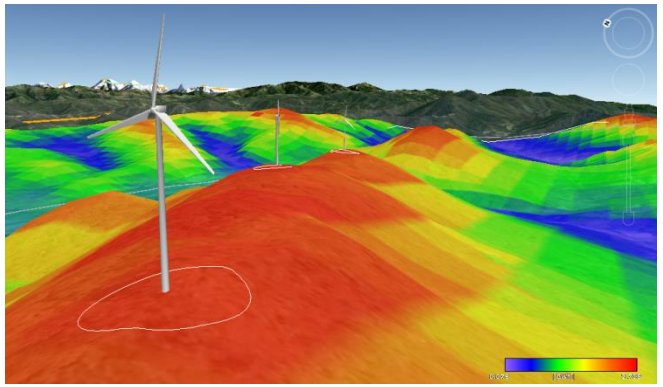
MESOSCALE MODELLING



Source: Hahmann (2016)



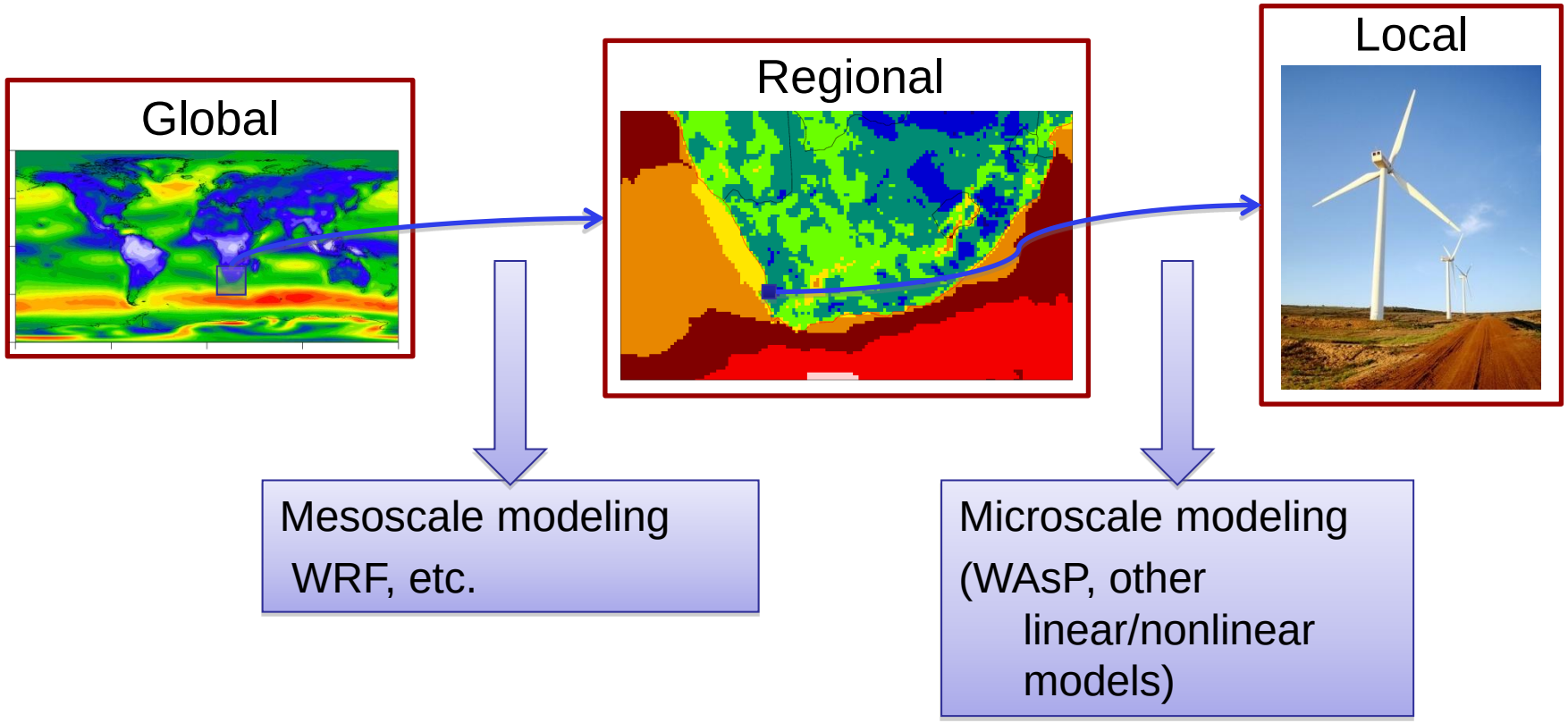
MICROSCALE MODELLING



Regional Downscaling

Site

Numerical Wind Atlas - Downscaling steps



KAMM: Karlsruher non-hydrostatic mesoscale model

WAsP: Wind Atlas Analysis and Application (widely used wind resource tool)

Numerical wind atlas – mesoscale

When good quality long-term wind observations are not available, the numerical wind atlas method is used.

Inputs

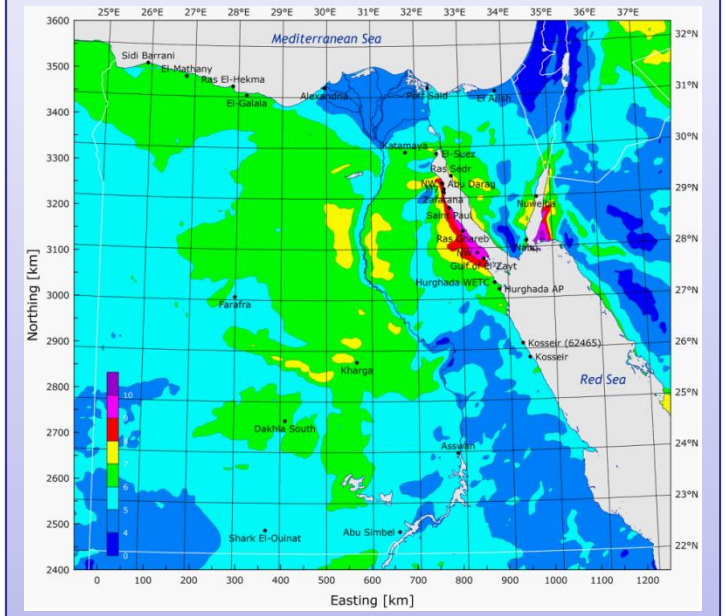
- NCEP/NCAR global reanalysis data-set
- terrain topography – elevation and roughness – satellite and SRTM data

Outputs

- generalised *regional wind climate* for large domains

Applications

- planning
- assessment of mesoscale effects at wind farm projects



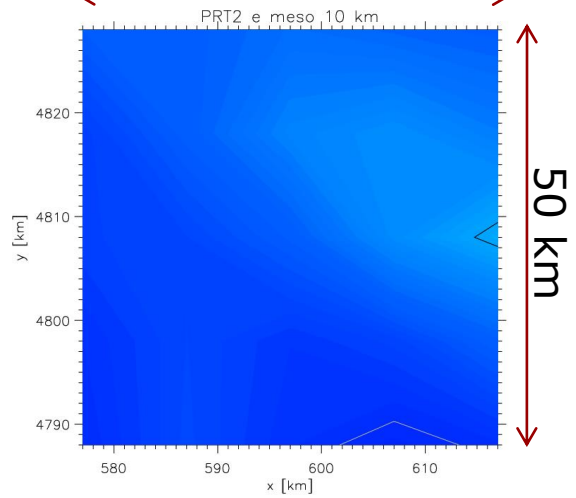
wind resource map for Egypt: mean wind at 50m AGL

Importance of resolution

Wind resource (power density) calculated at different resolutions

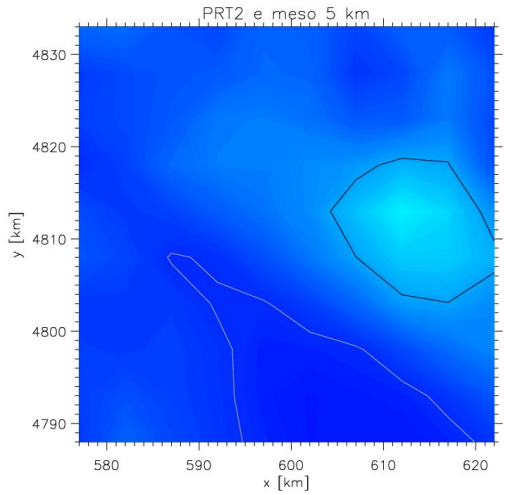
50 km

10 km



324 W/m²

378 W/m²

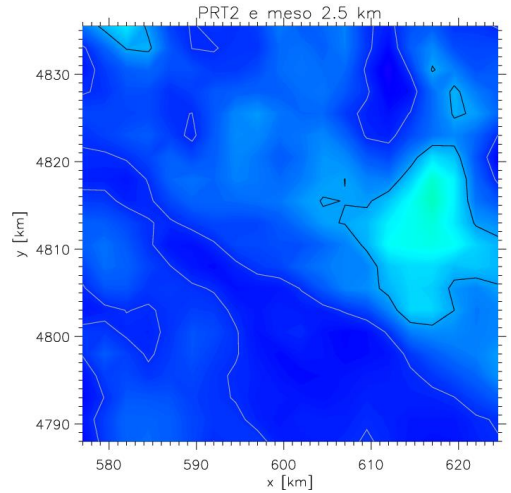


5 km

328 W/m²

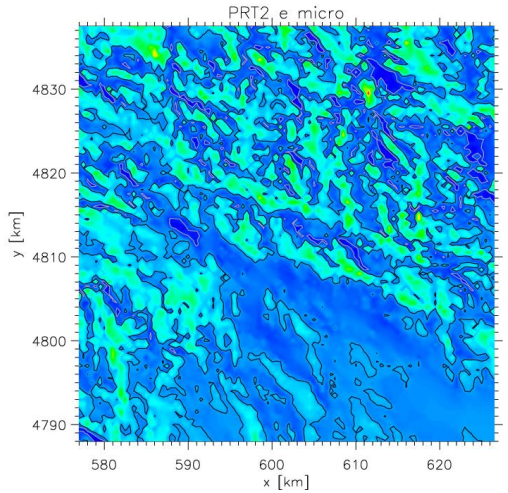
398 W/m²

2.5 km



323 W/m²

410 W/m²



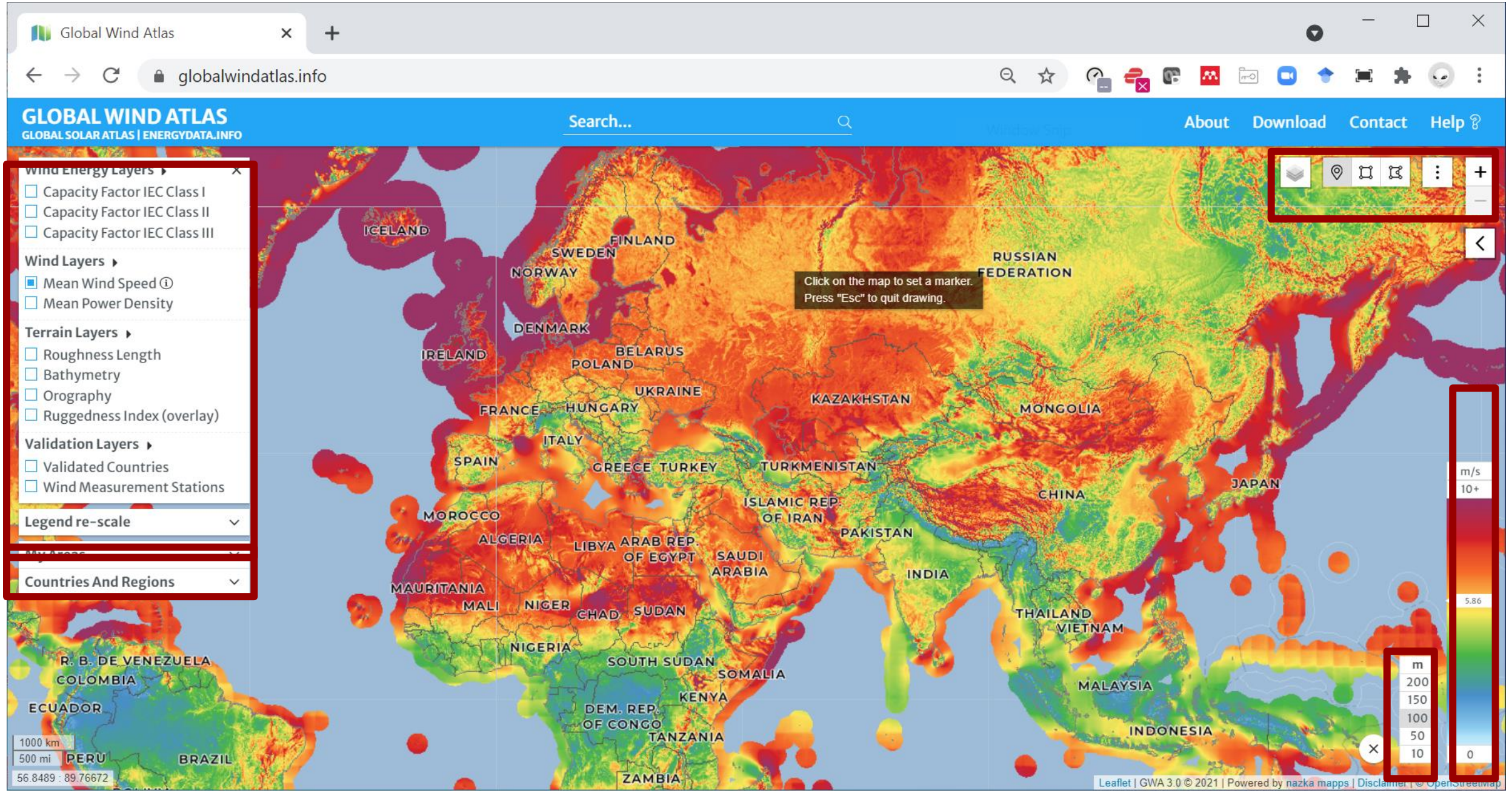
0.1 km

505 W/m²

641 W/m²

mean power density of total area

mean power density for windiest 50% of area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Orography
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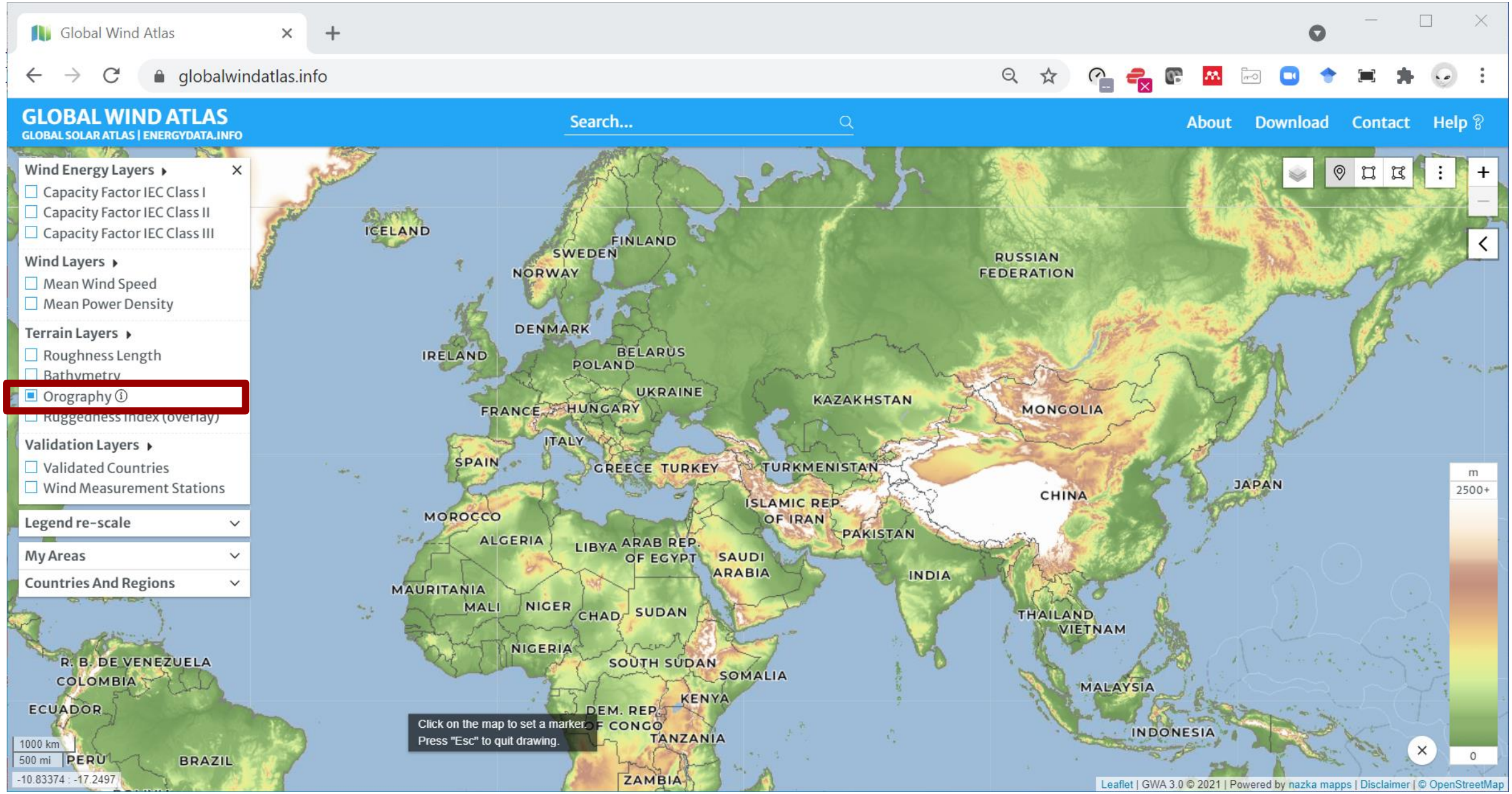
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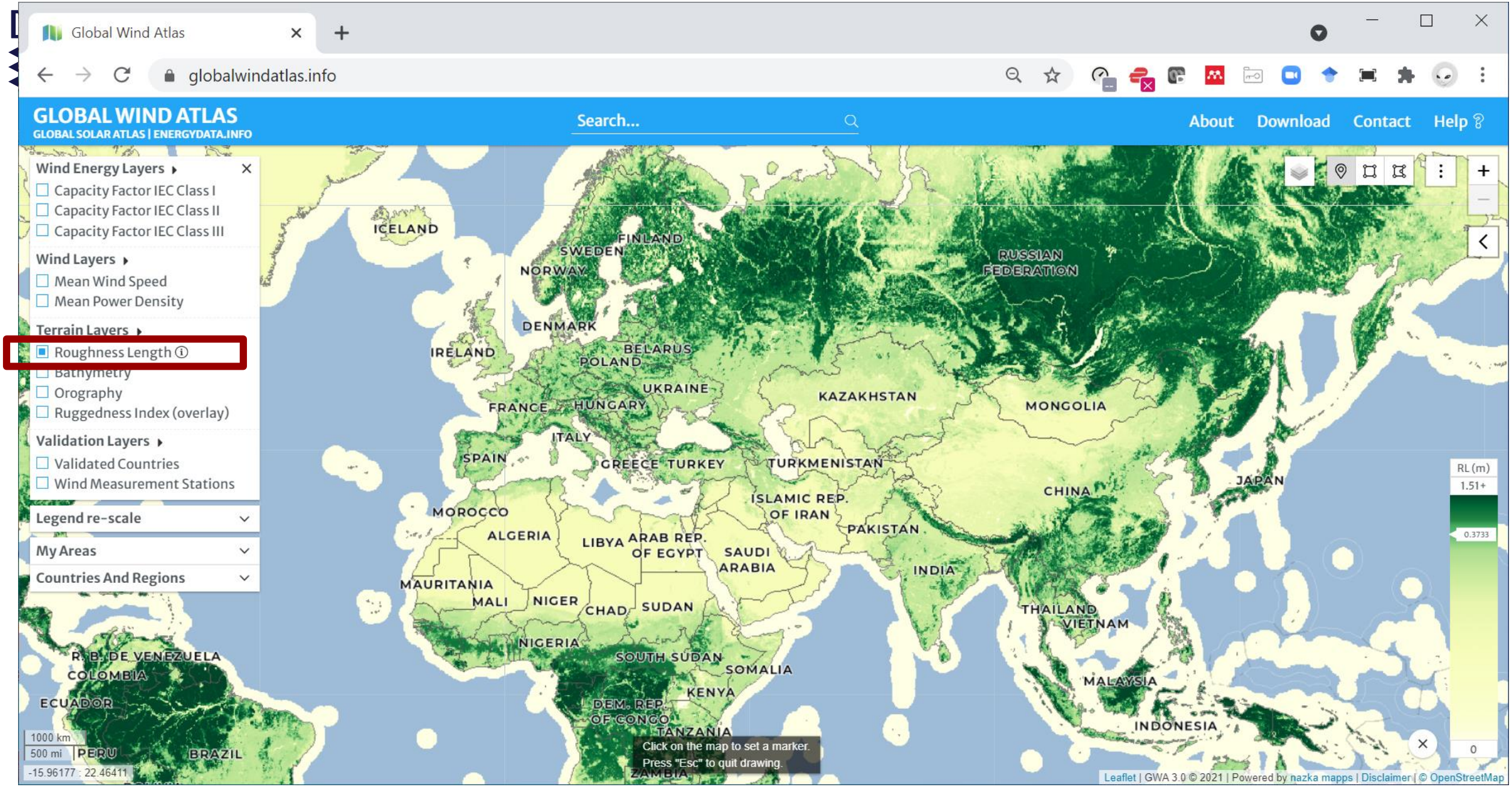
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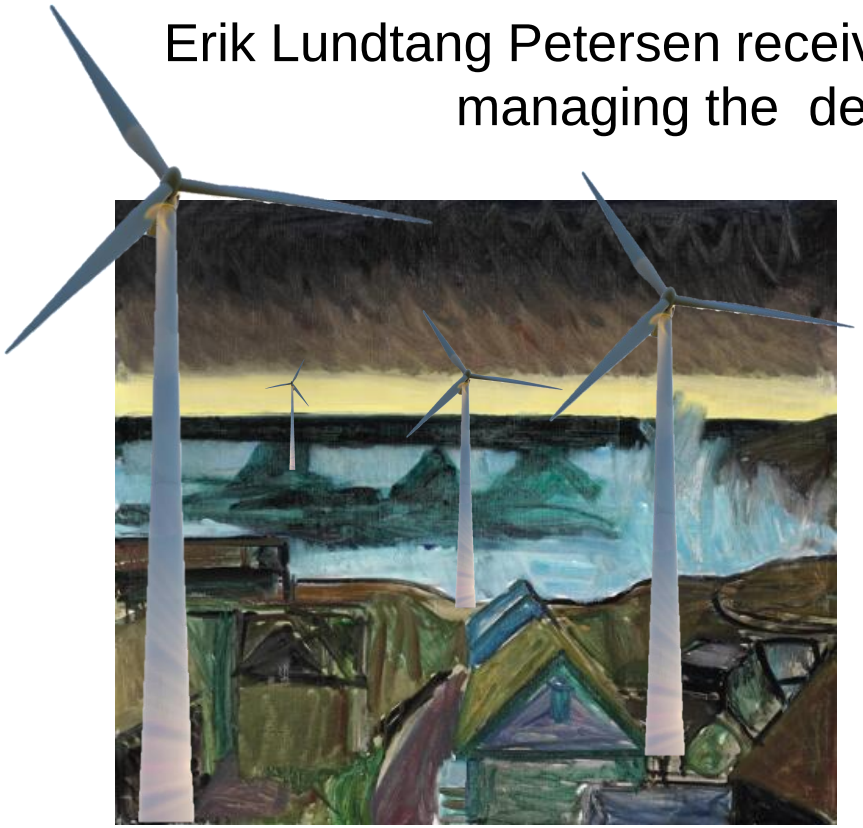
This talk describes ongoing developments since 1980 with contributions from numerous people.

Erik Lundtang Petersen received in 2021 the EMS silver medal for initiating and managing the developments that led to the wind atlas.



For further information please contact

Jake Badger at jaba@dtu.dk

Thanks for your attention