Danmarks Tekniske Universitet

From Trades to Turbines: The Art and Science of Wind Energy Resource Assessment

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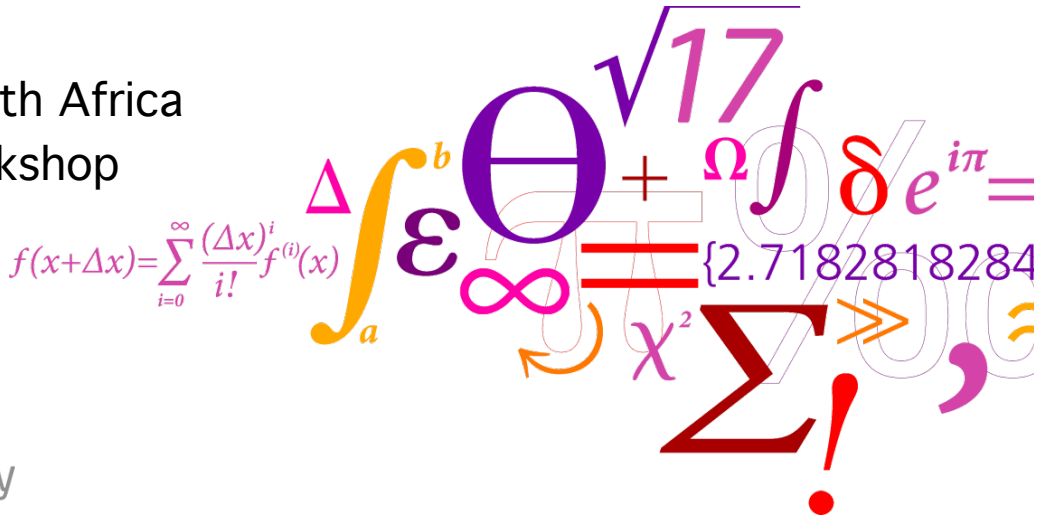
First Wind Atlas for South Africa
Project (WASA) Workshop



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Outline

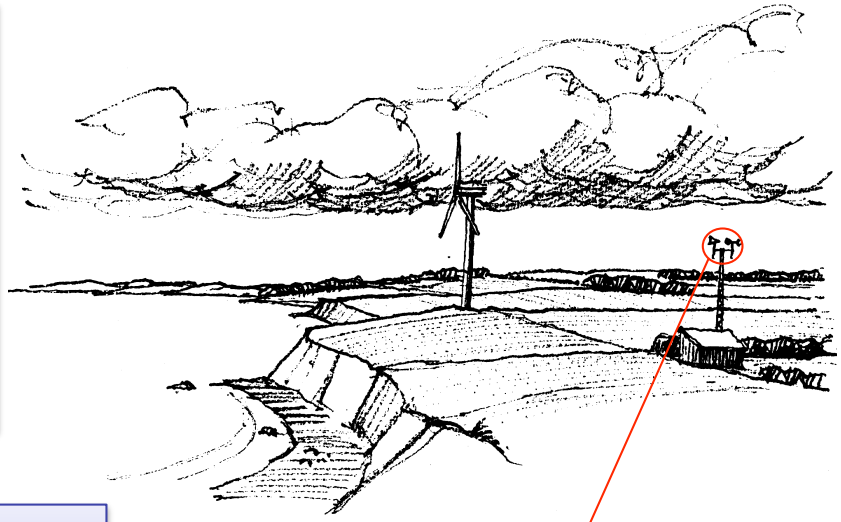
- Introduction
- Wind power resource assessment
- Observational wind atlases
- Numerical wind atlas – statistical-dynamical downscaling
- Examples of recent wind atlases – going the extra step
- Preview of future work: dynamical downscaling
- Final comments

The problem

Determining the wind resources accurately is important and difficult

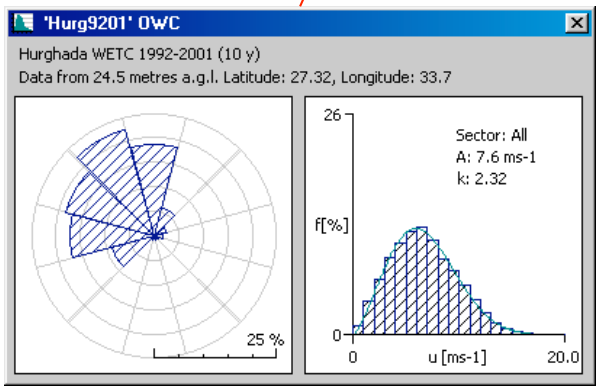
Main parameters governing wind power economics:

- Investment costs
- Operation and maintenance costs
- Electricity production / Wind resources
- Turbine lifetime
- Discount rate



- Wind speed, U [m/s]
- Kinetic energy flux, $P = \frac{1}{2}\rho U^3$ [W/m^2]
- ΔU of 5% (e.g. U=8.0+0.4m/s) ⟹ ΔP 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



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

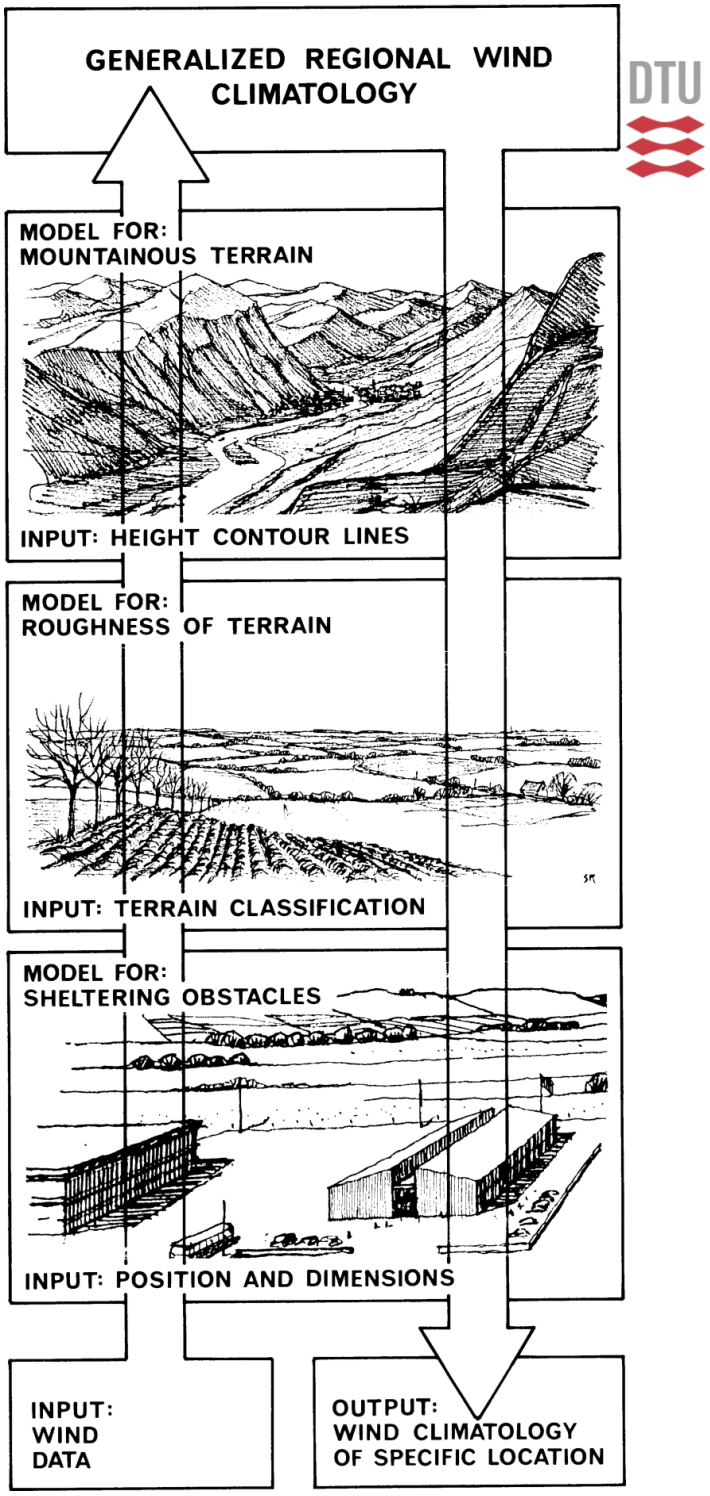
Outputs

- generalised *regional wind climate* for the specific location

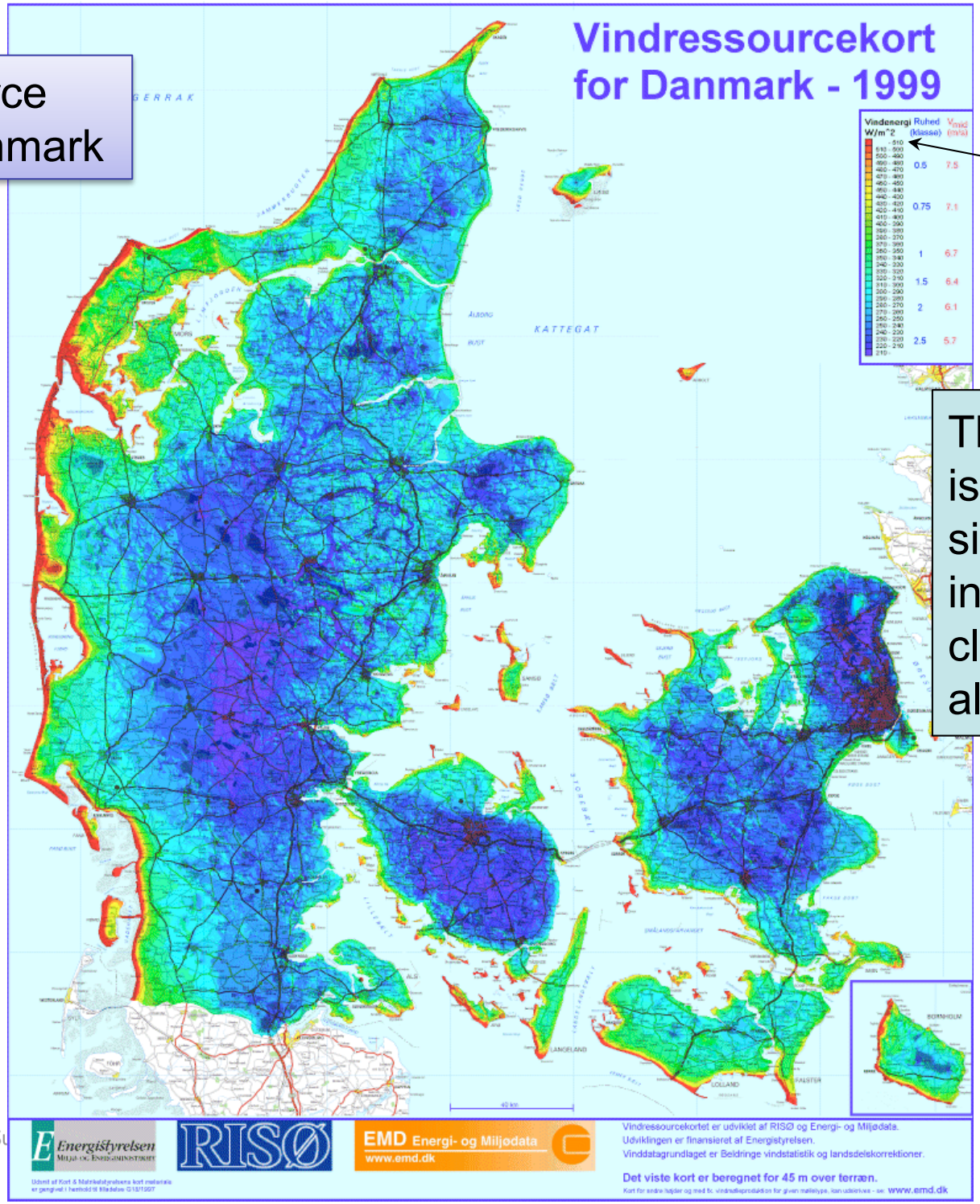
Applications

- 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.



Wind resource map for Denmark



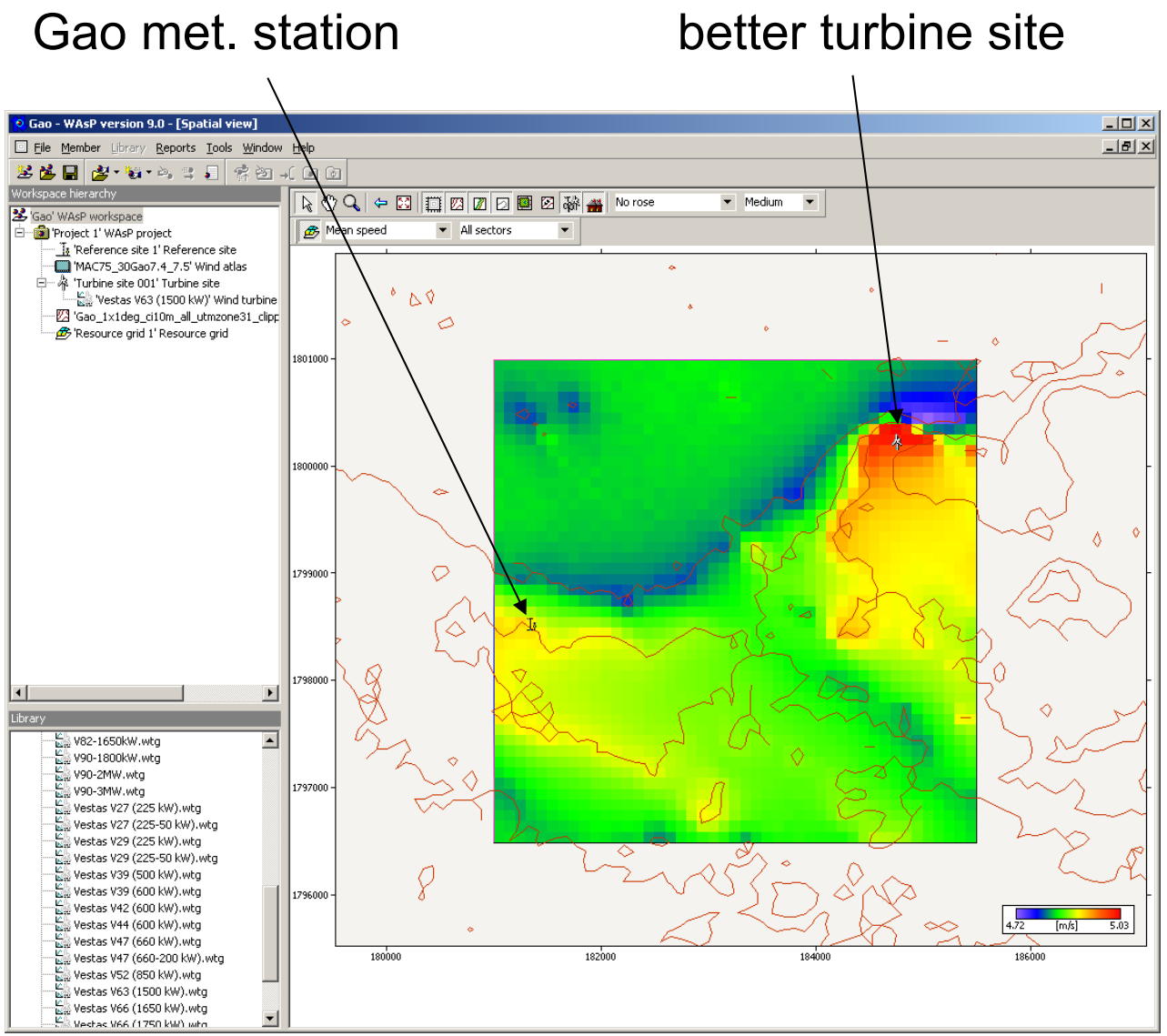
~500 W/m^2
Mean wind
~7.5 m/s

The wind atlas is more than a simple map – input “wind climate” files are also provided

Wind atlas study for Mali

WAsP showing a resource map for an area around the Gao measurement site at 100 m resolution.

WAsP calculates wind resource for new sites and heights above ground level.



Numerical wind atlas – mesoscale

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

Inputs

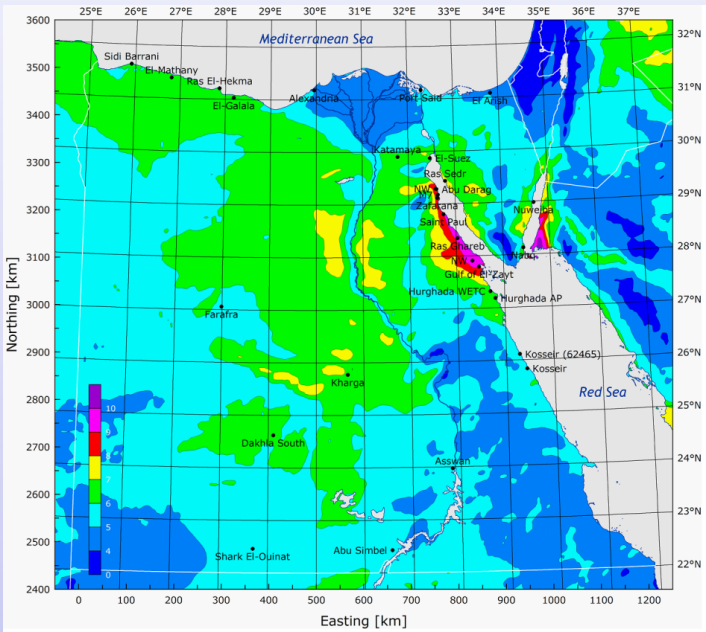
- NCEP/NCAR global reanalysis data-set
- terrain topography – elevation and roughness – satellite and SRTM data

Outputs

- generalised *regional wind climate* for large domains

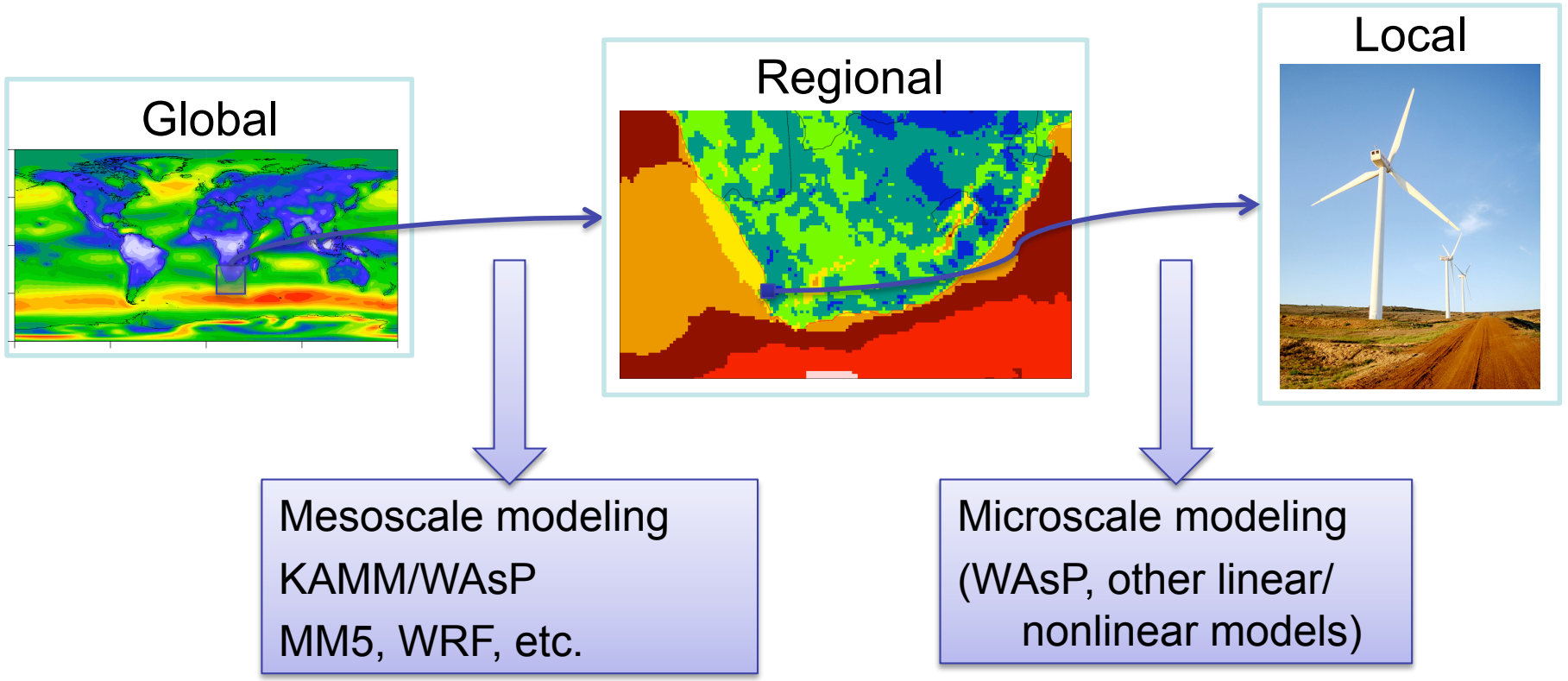
Applications

- planning
- assessment of mesoscale effects at wind farm projects



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

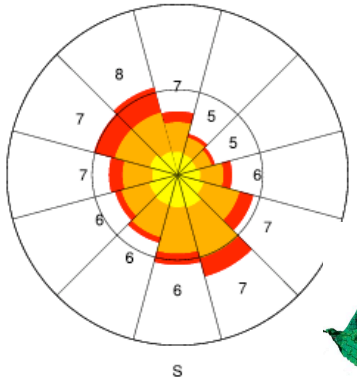
Numerical Wind Atlas - Downscaling steps

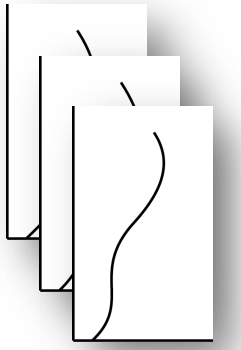


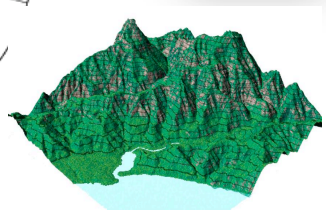
KAMM: Karlsruher non-hydrostatic mesoscale model
WAsP: Wind Atlas Analysis and Application (widely used wind resource tool)

wind profiles
atmos stab.

wind classes
from large
pressure field



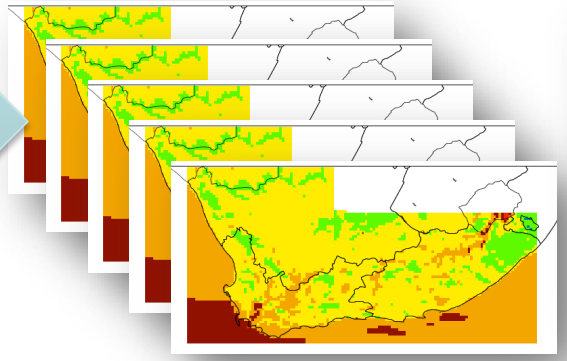




terrain elevation
surface roughness

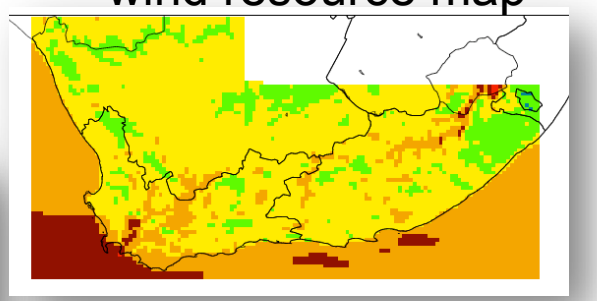
Mesoscale Model

wind maps for each
wind class



+ frequency
distributions of
wind classes

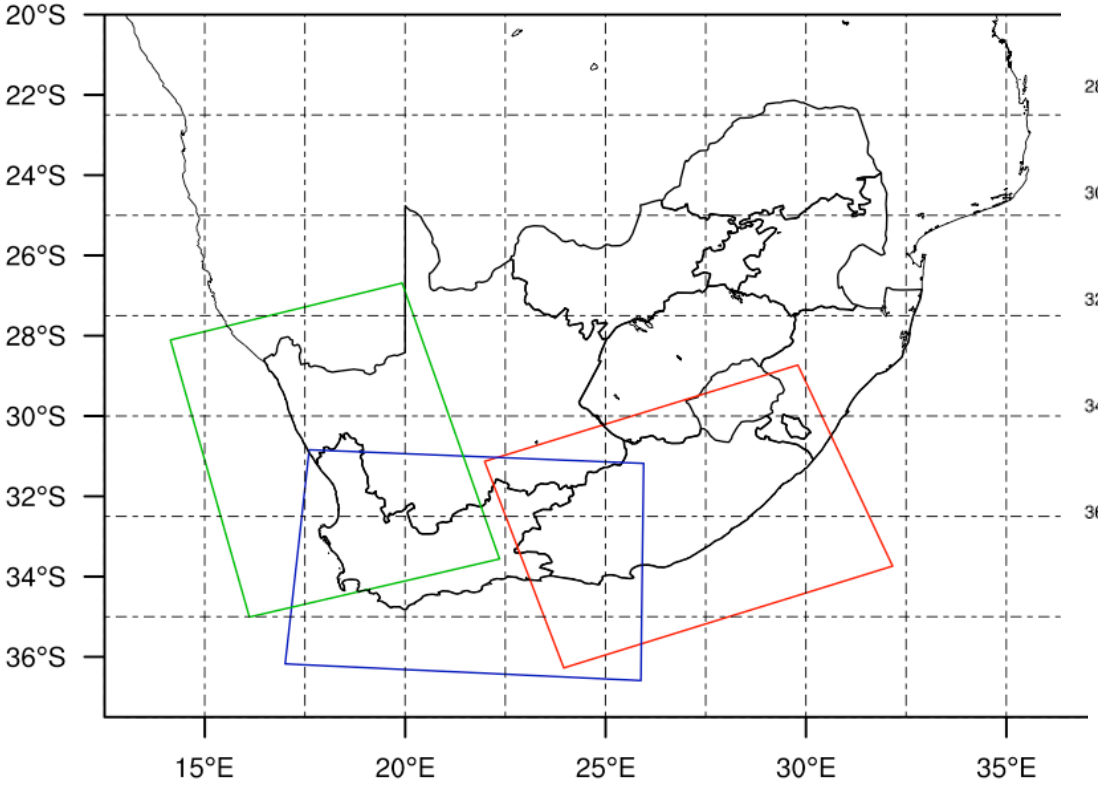
wind resource map

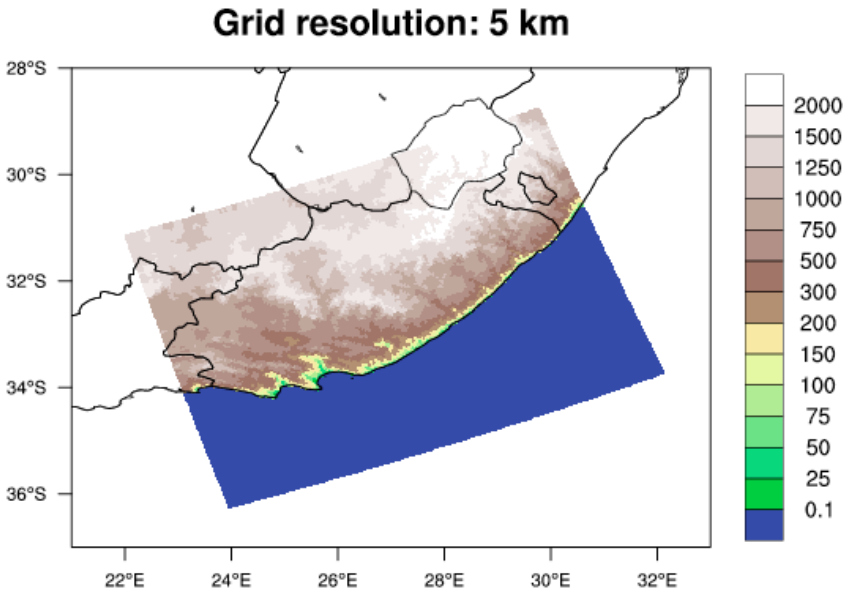


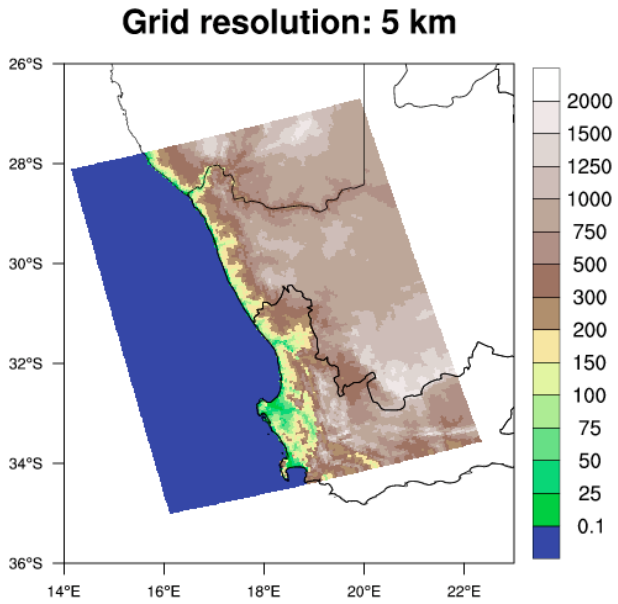
Simple/Fast/Cheap — Complex/Slow/Expensive

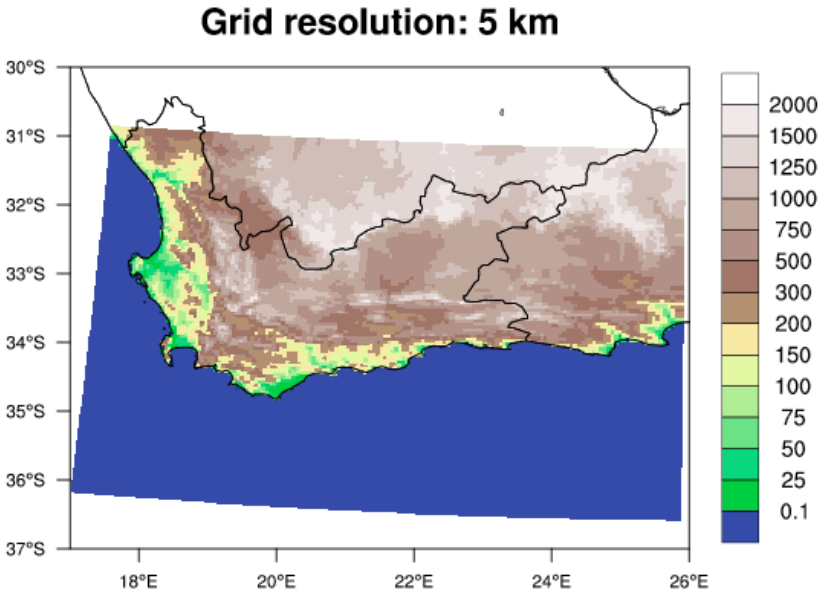
Interpolation	Risø Wind Atlas	Statistical-dynamical	Fully dynamical

Original mesoscale model domains









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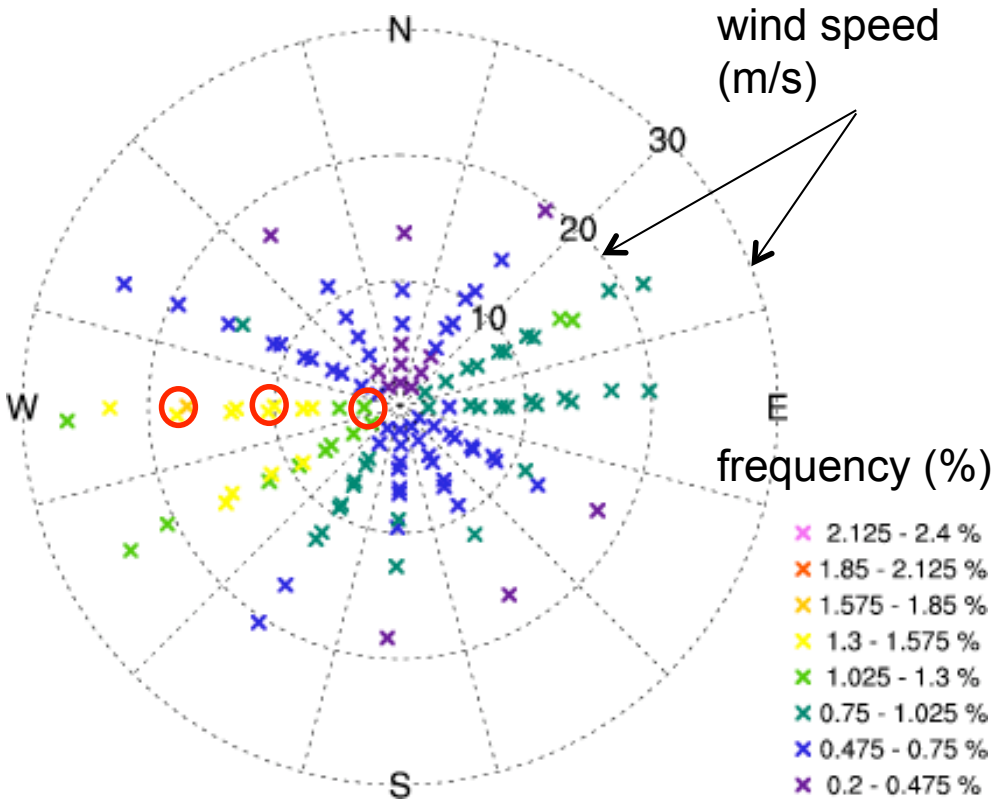
The Wind Atlas Method

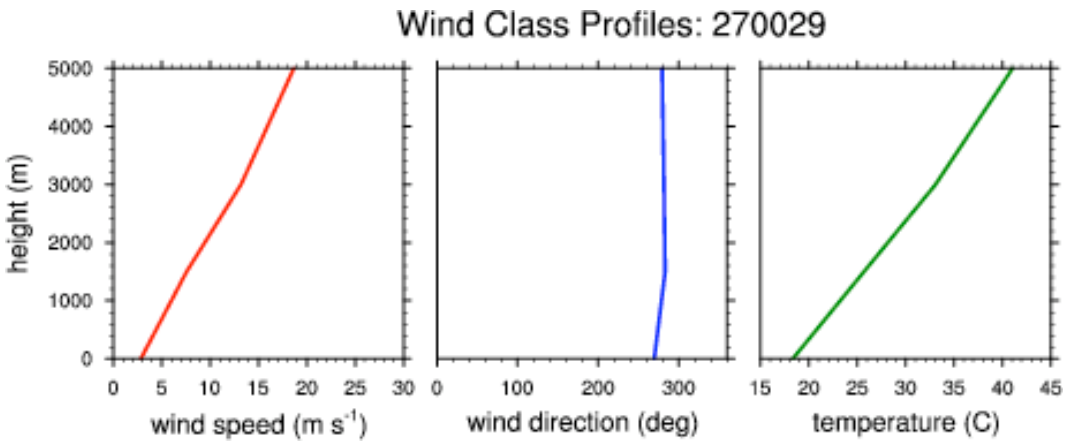
- Determine the large-scale wind forcing of a region based on long-term, but spatially coarse, dataset.
- Classify the geostrophic wind (and stability) time-series into wind classes
- Use a mesoscale model (KAMM) to determine how topography modifies the large-scale wind defined by each wind class.

125 wind classes for Southern S. Africa
– mean sea level geostrophic wind
(NCEP/NCAR reanalysis)

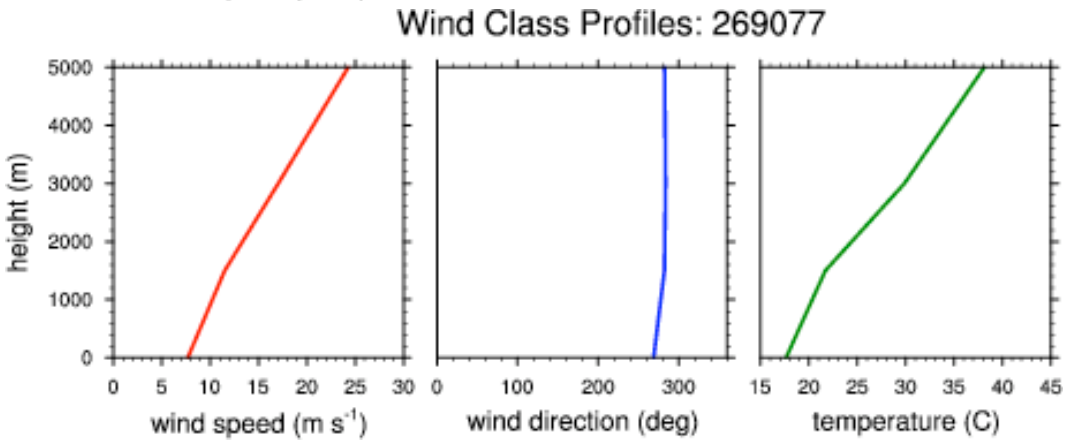


Example wind class profiles

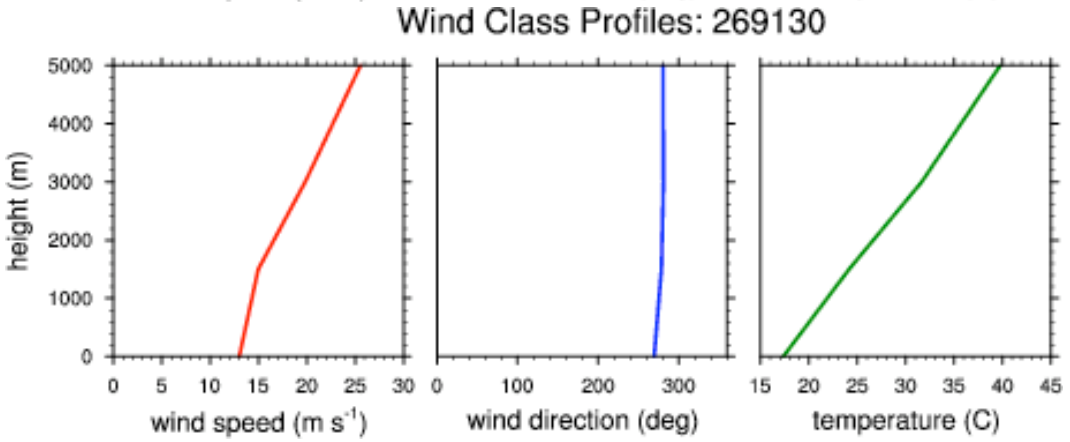
Wind Class: 095
Frequency: 1.17%
Wind speed 2.9 m/s
Wind direction: 270°



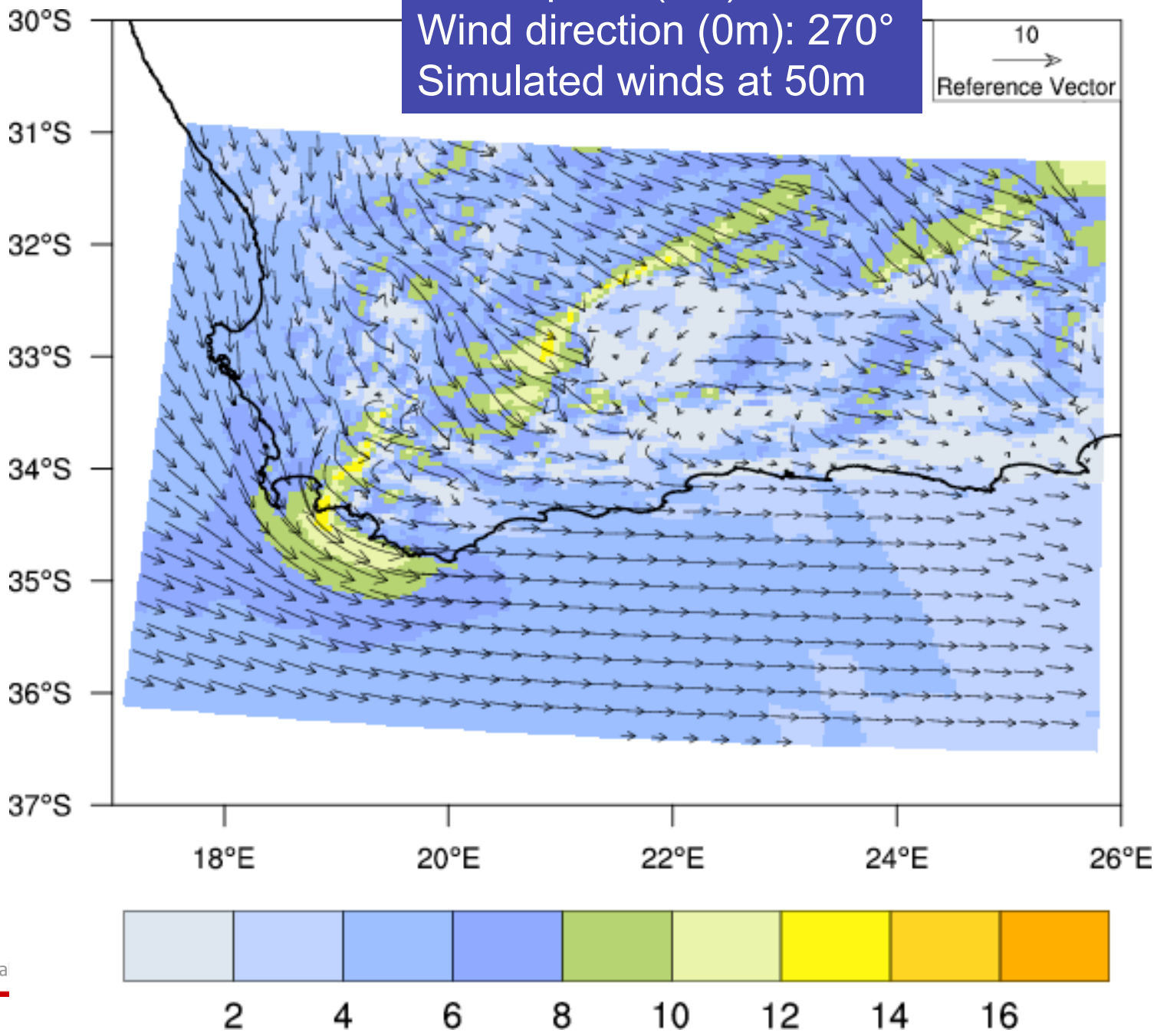
Wind Class: 098
Frequency: 1.33%
Wind speed 7.7 m/s
Wind direction: 269°



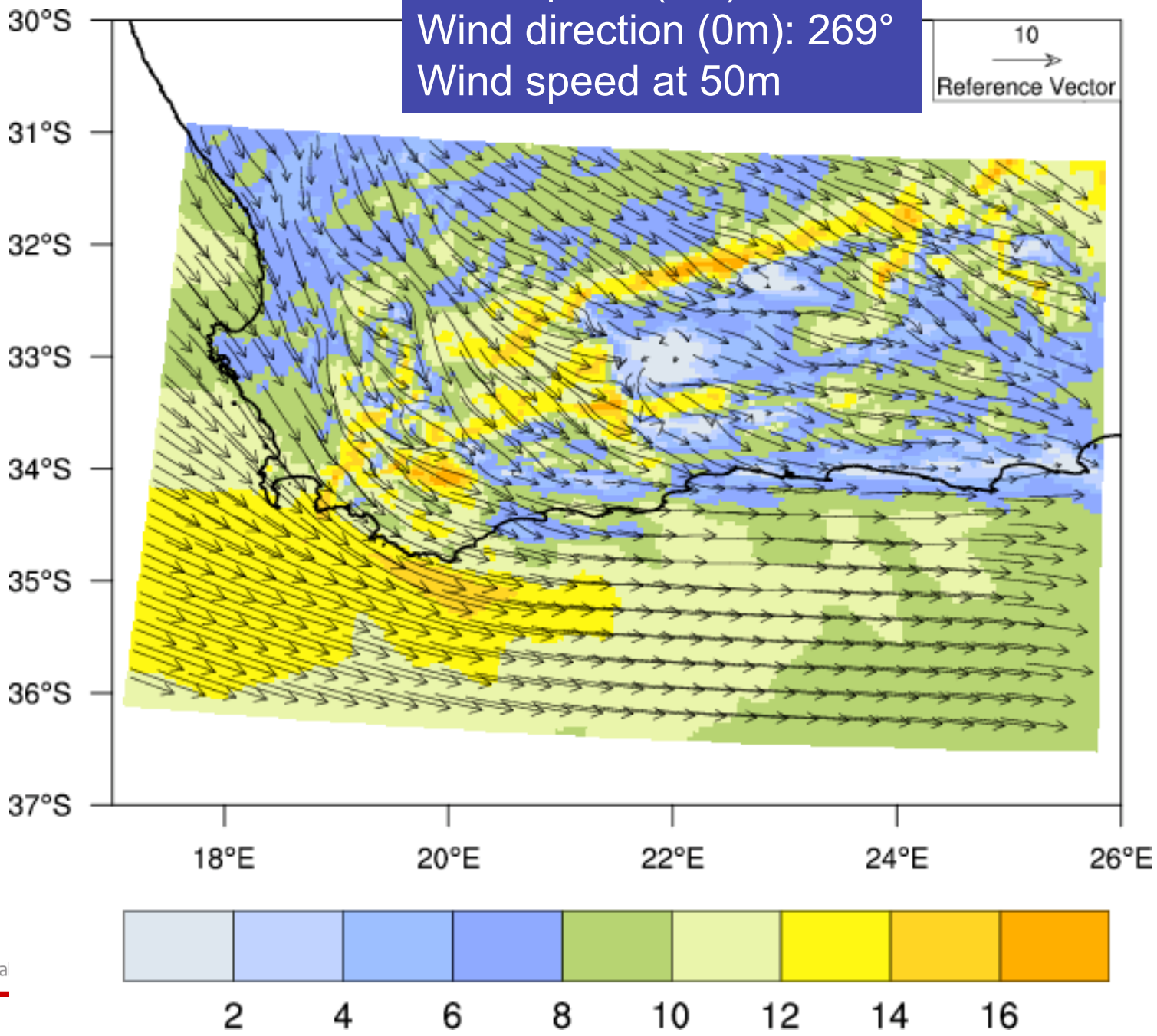
Wind Class: 101
Frequency: 1.51%
Wind speed 13.0 m/s
Wind direction: 269°

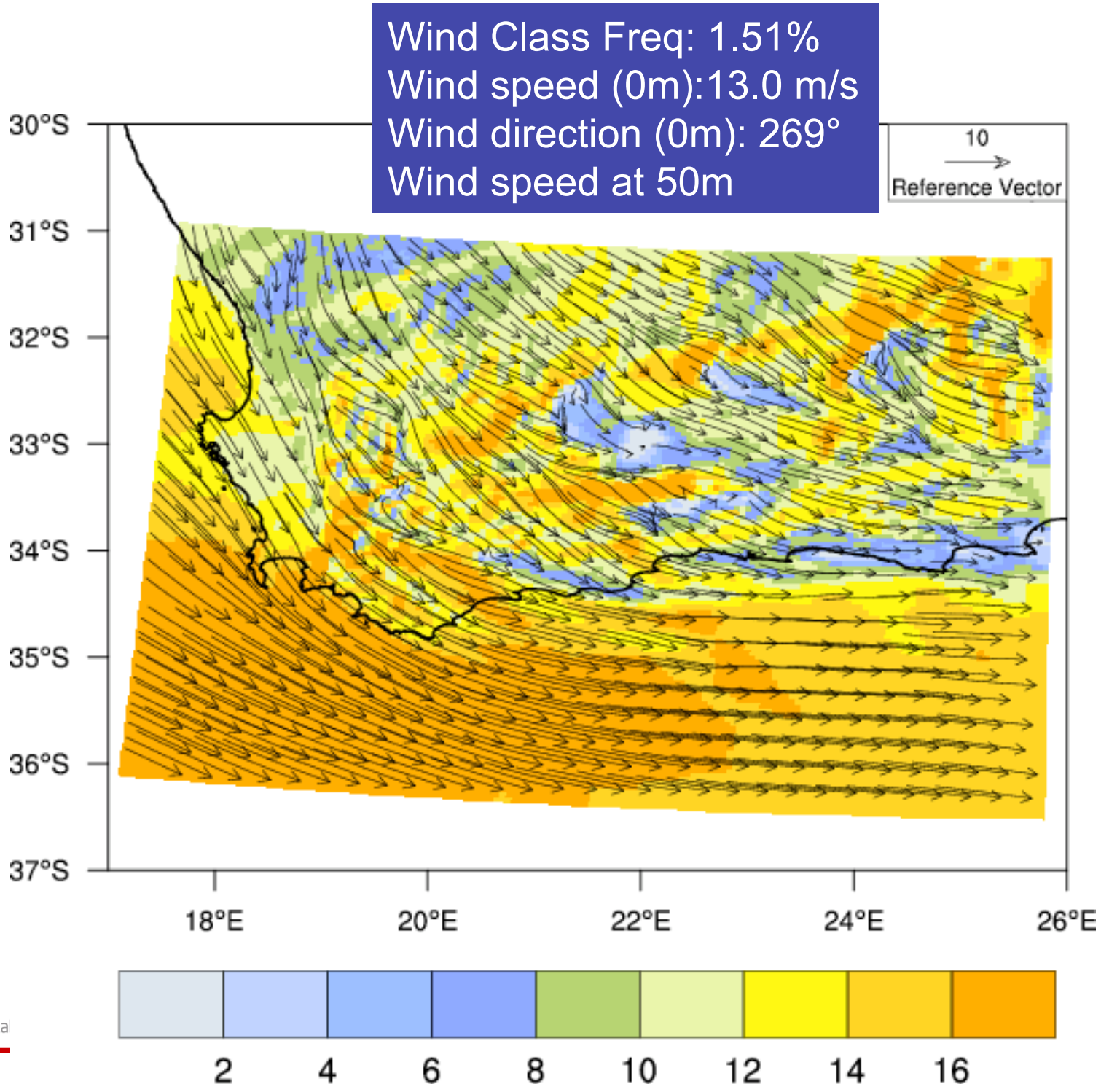


Wind Class Freq: 1.17%
Wind speed (0m): 2.9 m/s
Wind direction (0m): 270°
Simulated winds at 50m



Wind Class Freq: 1.33%
Wind speed (0m): 7.7 m/s
Wind direction (0m): 269°
Wind speed at 50m





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Simulated wind climate

$$\overline{u}(x,y,z) = \frac{\sum f_i(x,y)\, u_i(x,y,z)}{\sum f_i(x,y)}$$

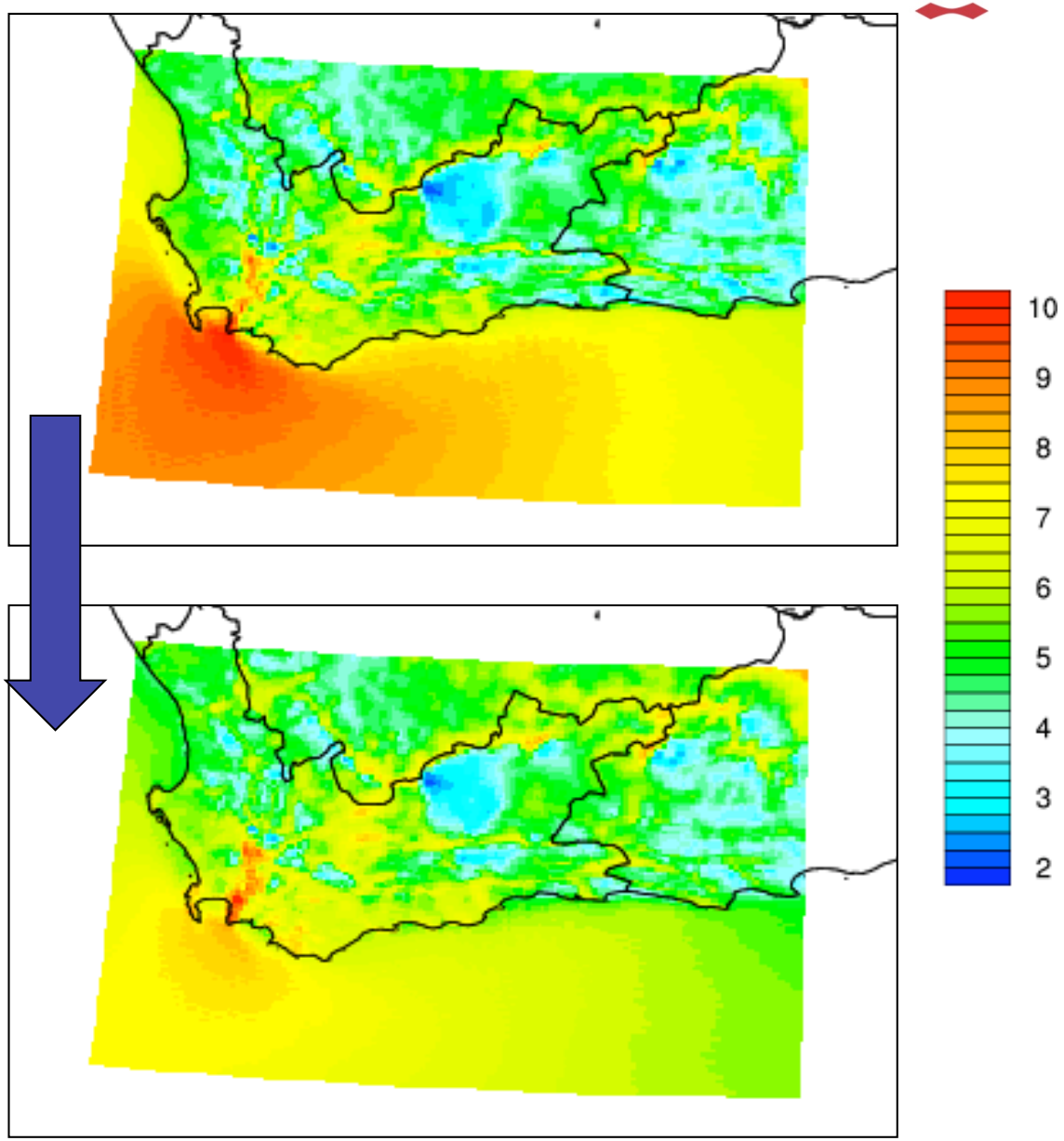
$u_i(x,y,z)$ = wind speed at *z* m a.g.l. for wind class i.

$f_i(x,y)$ = frequency of wind class i, a function of *x* and *y*.

$\overline{u}(x,y,z)$ = mean wind speed at *z* m a.g.l.

Simulated wind climate
mean wind speed [m/s] at 50m

Generalized wind climate
mean corrected wind speed [m/s] at 50m flat terrain z0=3cm

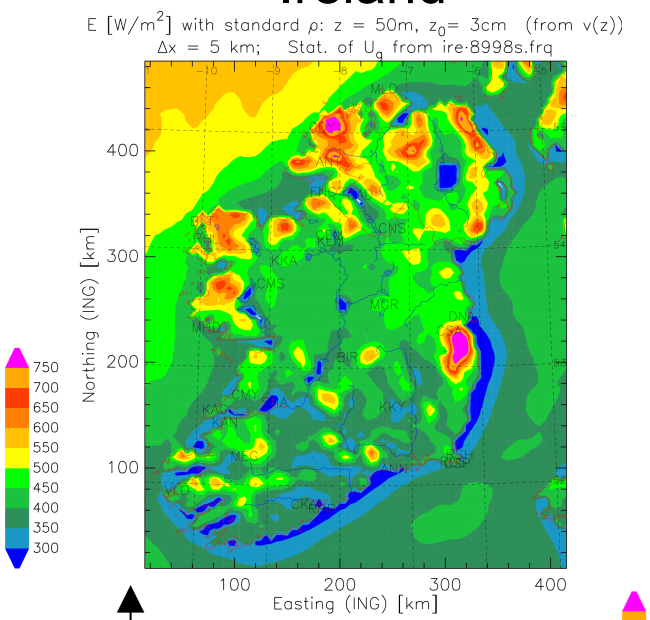


Validation against observations

Errors at 50m computed from all available observations

U = wind; P = power density

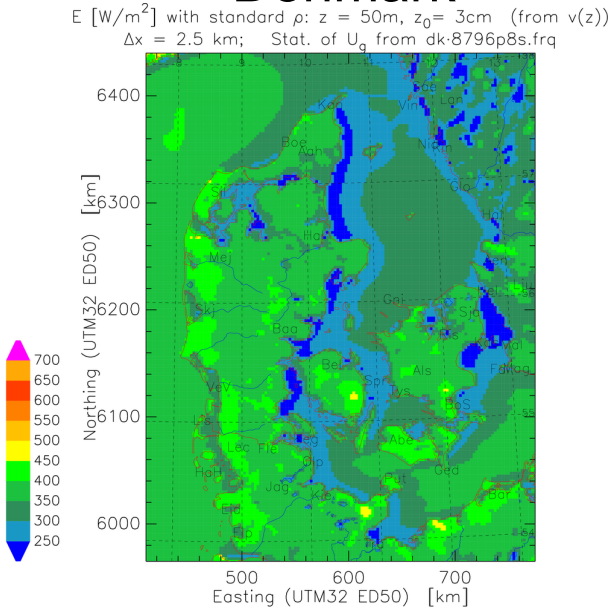
Ireland



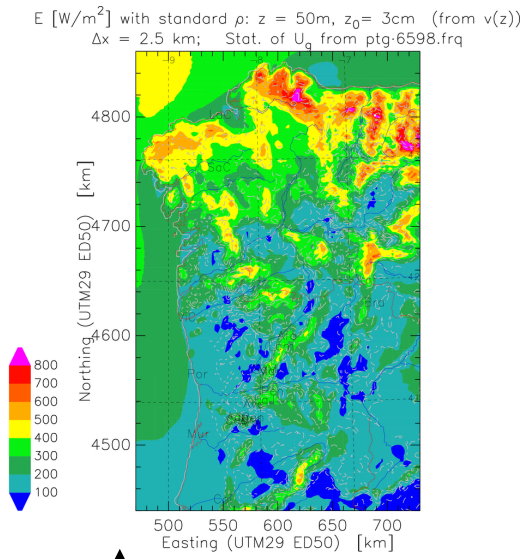
U rms 7%
P rms 17%
dx = 5km

U rms 5%
P rms 16%
dx = 5km

Denmark



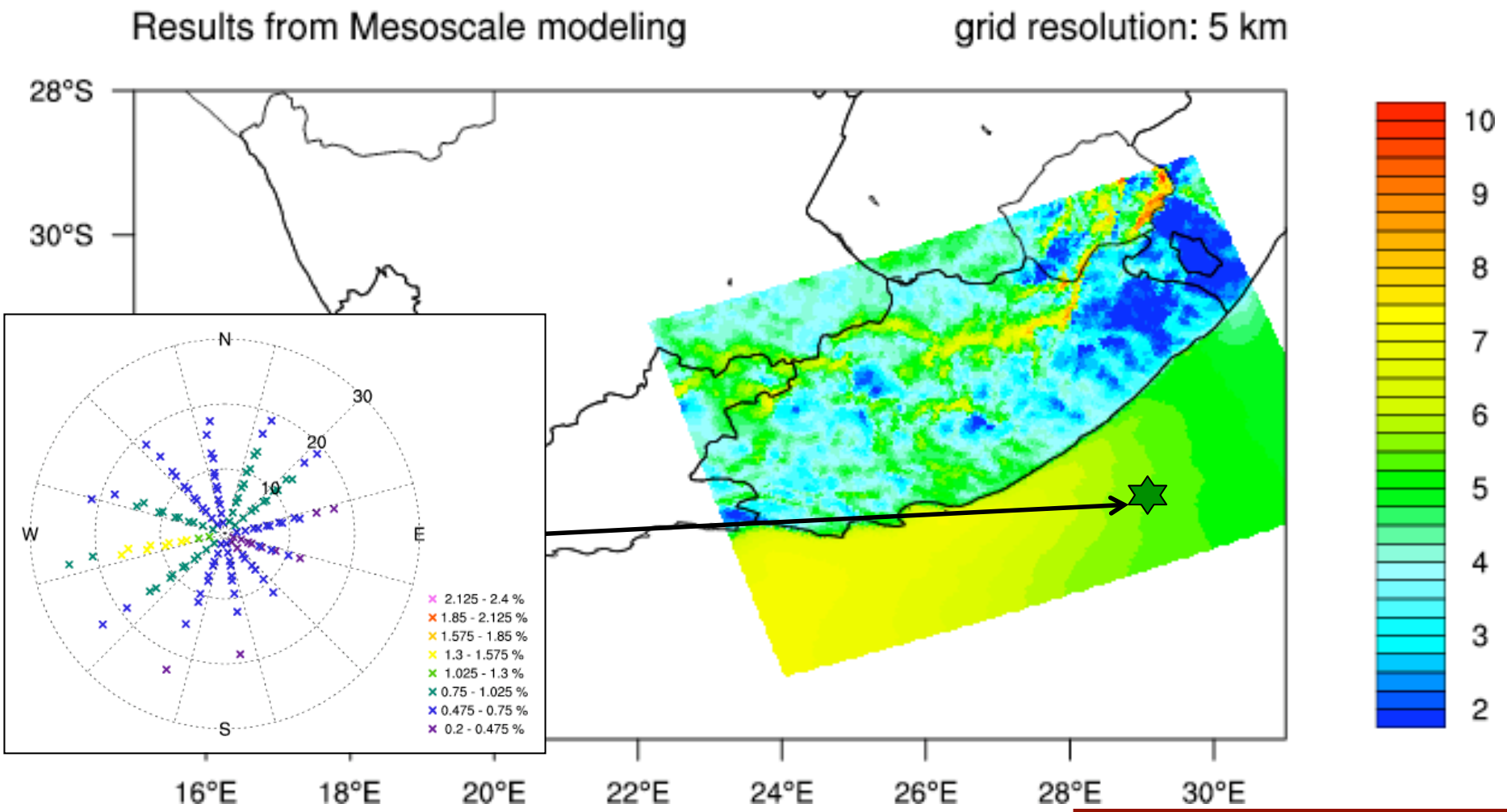
Portugal



U rms 10%
P rms 34%
dx = 2.5km

Frank, H. P., O. Rathmann, N. G. Mortensen, L. Landberg: The Numerical Wind Atlas – The KAMM/ WAsP Method. (2001)

Preliminary calculations for South Africa
Mean wind speed (m/s) at 50 m



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unverified output, do not use these numbers

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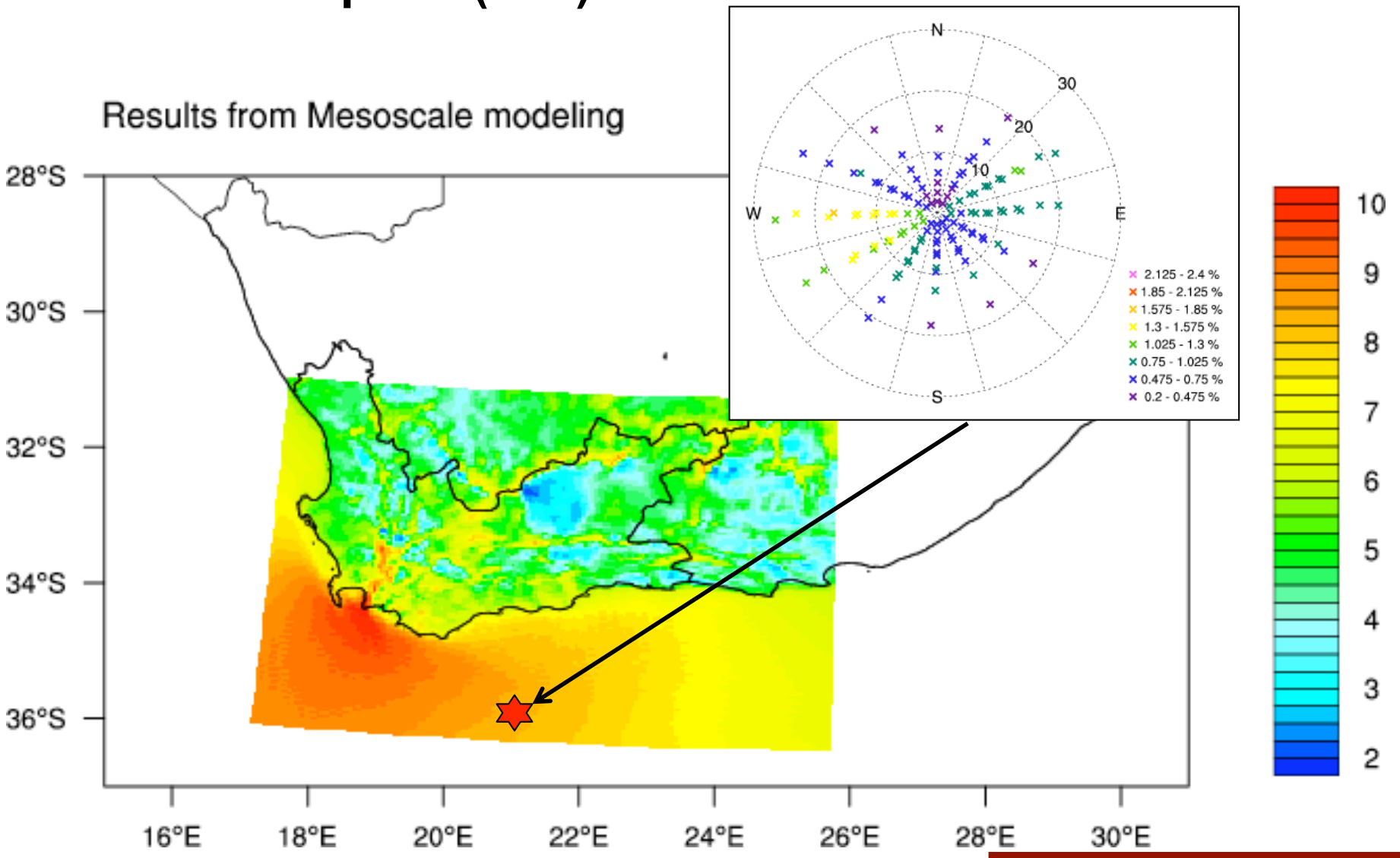

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Preliminary calculations for South Africa
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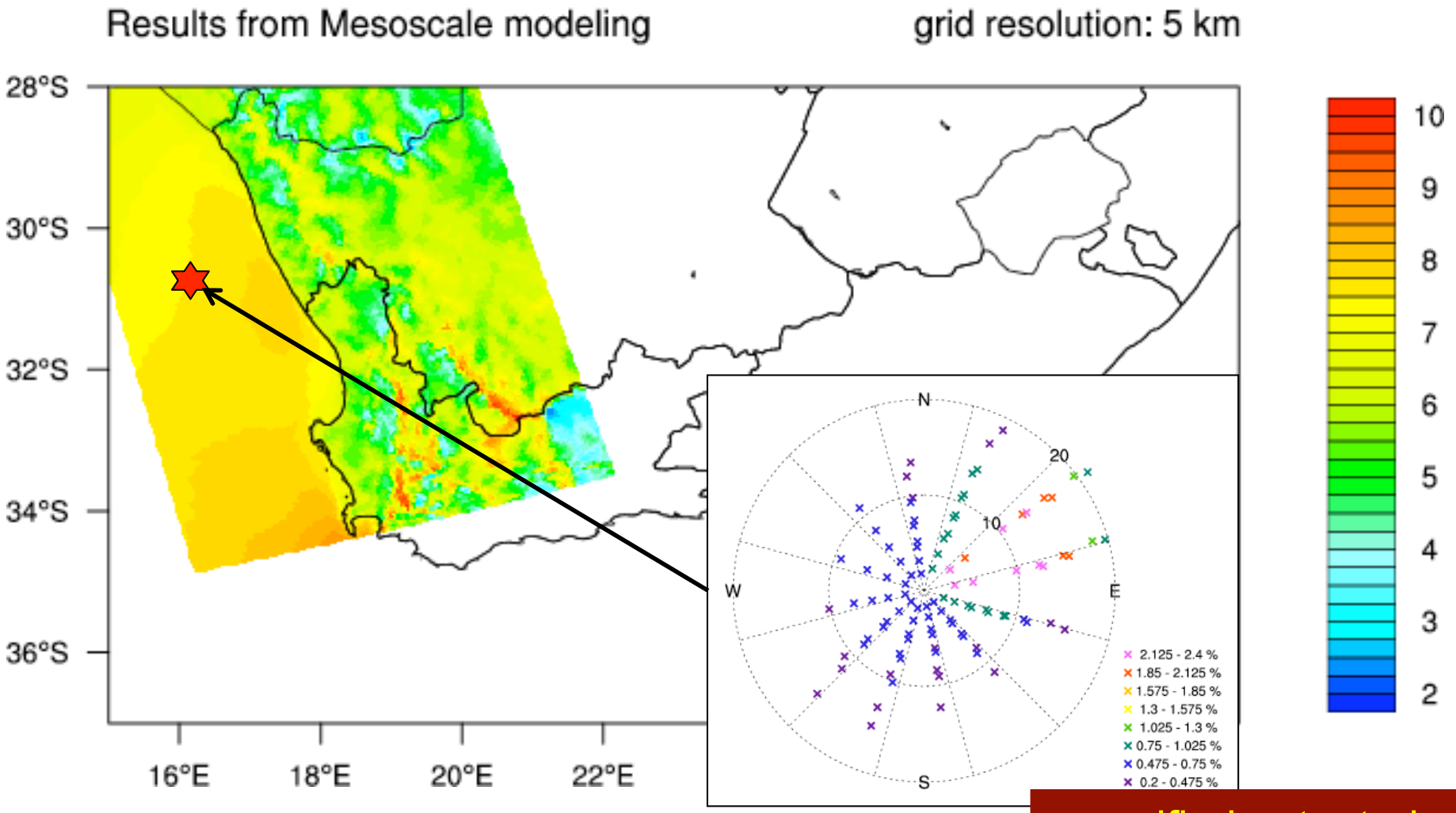
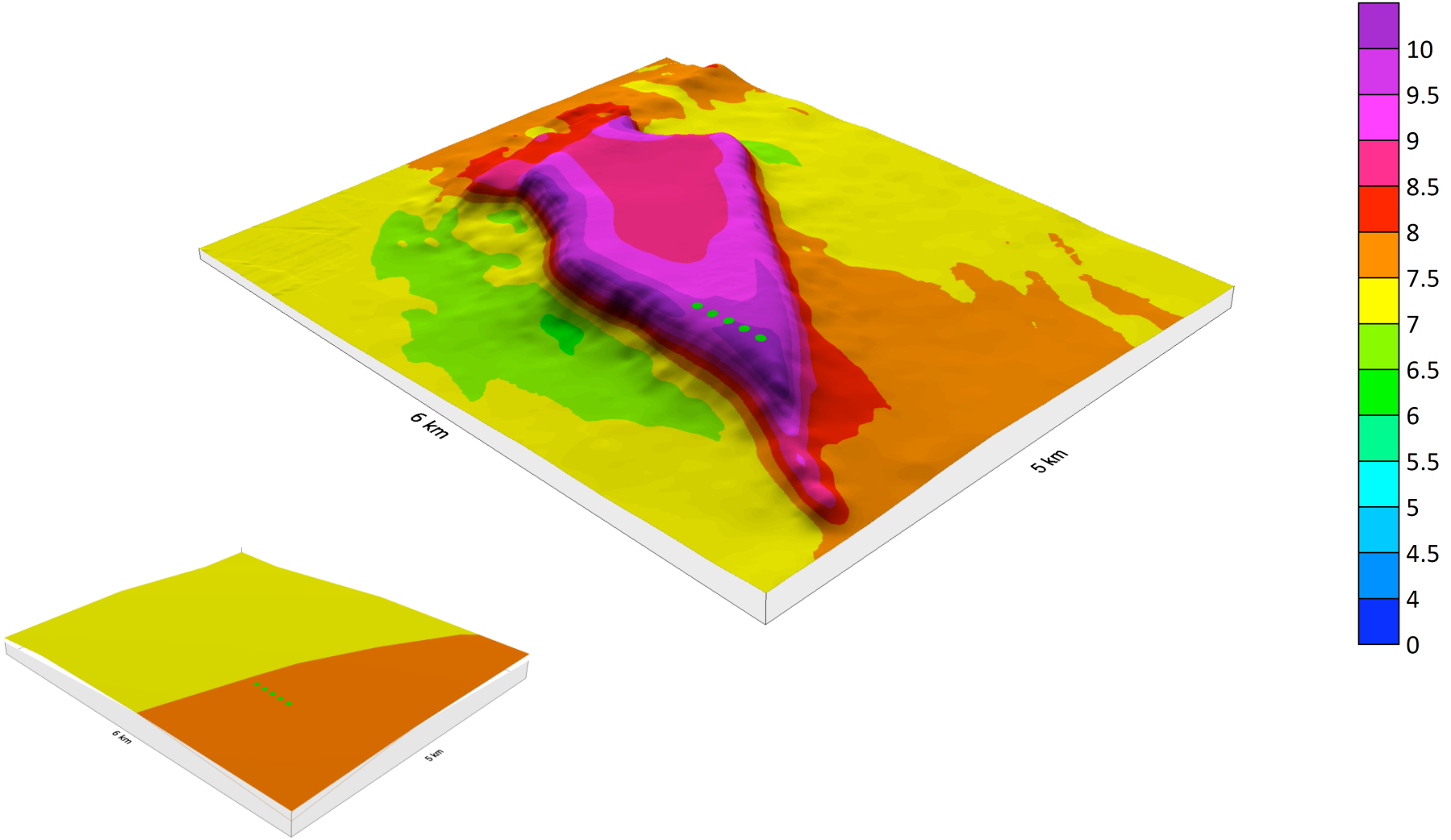


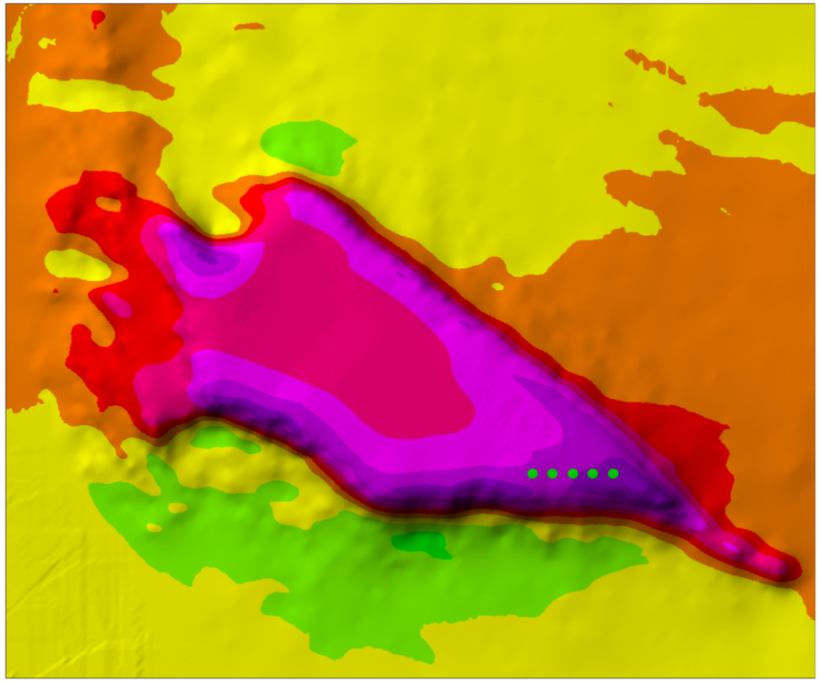
unverified output, do not use these numbers

Resolution is key in applications



Mesoscale vs. Microscale – effect of model resolution

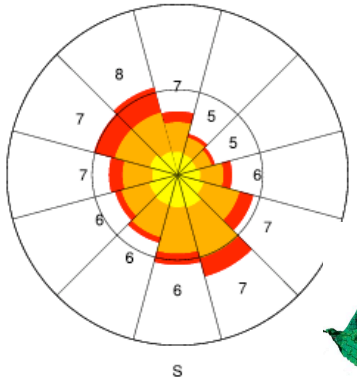
- KAMM wind resource map only
- Grid cell size 5120 m
- Wind farm of five 2 MW turbines
- Estimated AEP = 39 GWh

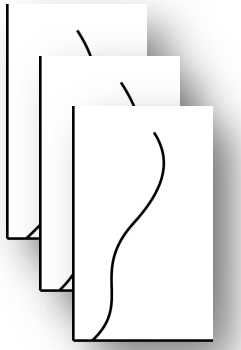


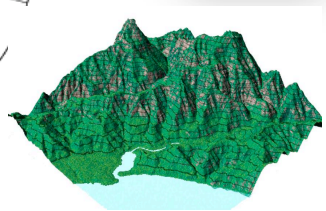
- KAMM/WAsP wind resource map
- Grid cell size 20 m
- Wind farm of five 2 MW turbines
- Estimated AEP = 55 GWh

wind profiles
atmos stab.

wind classes
from large
scale wind



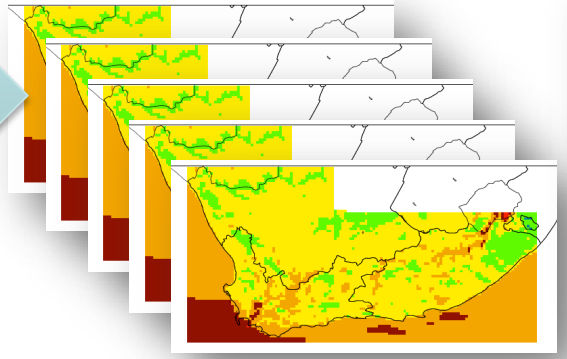




terrain elevation
surface roughness

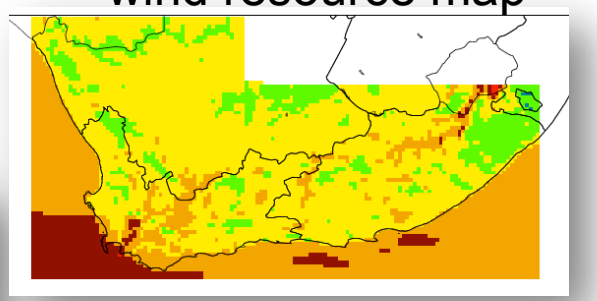
Mesoscale Model

wind maps for each
wind class



+ frequency
distributions of
wind classes

wind resource map

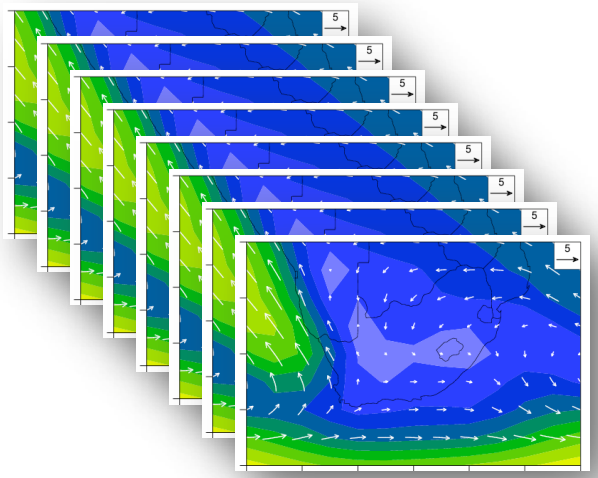


Simple/Fast/Cheap → Complex/Slow/Expensive

Interpolation	Risø Wind Atlas	Statistical-dynamical	Fully dynamical

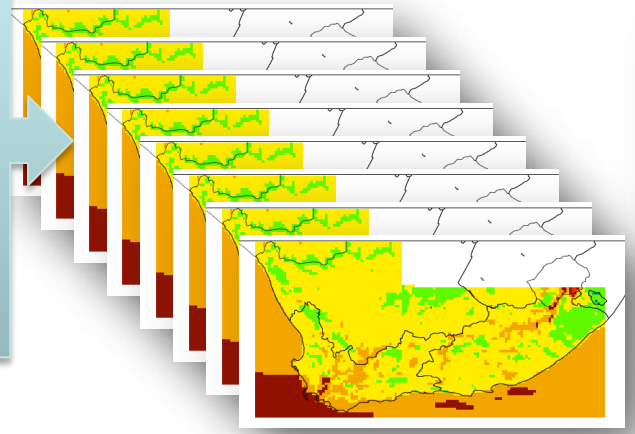
Dynamical downscaling

entire collection of
large-scale atmos. conditions

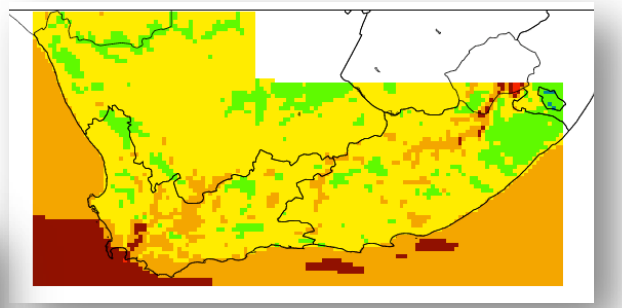


MODEL

wind maps for every
large-scale day



wind resource map



Simple/Fast/Cheap → Complex/Slow/Expensive

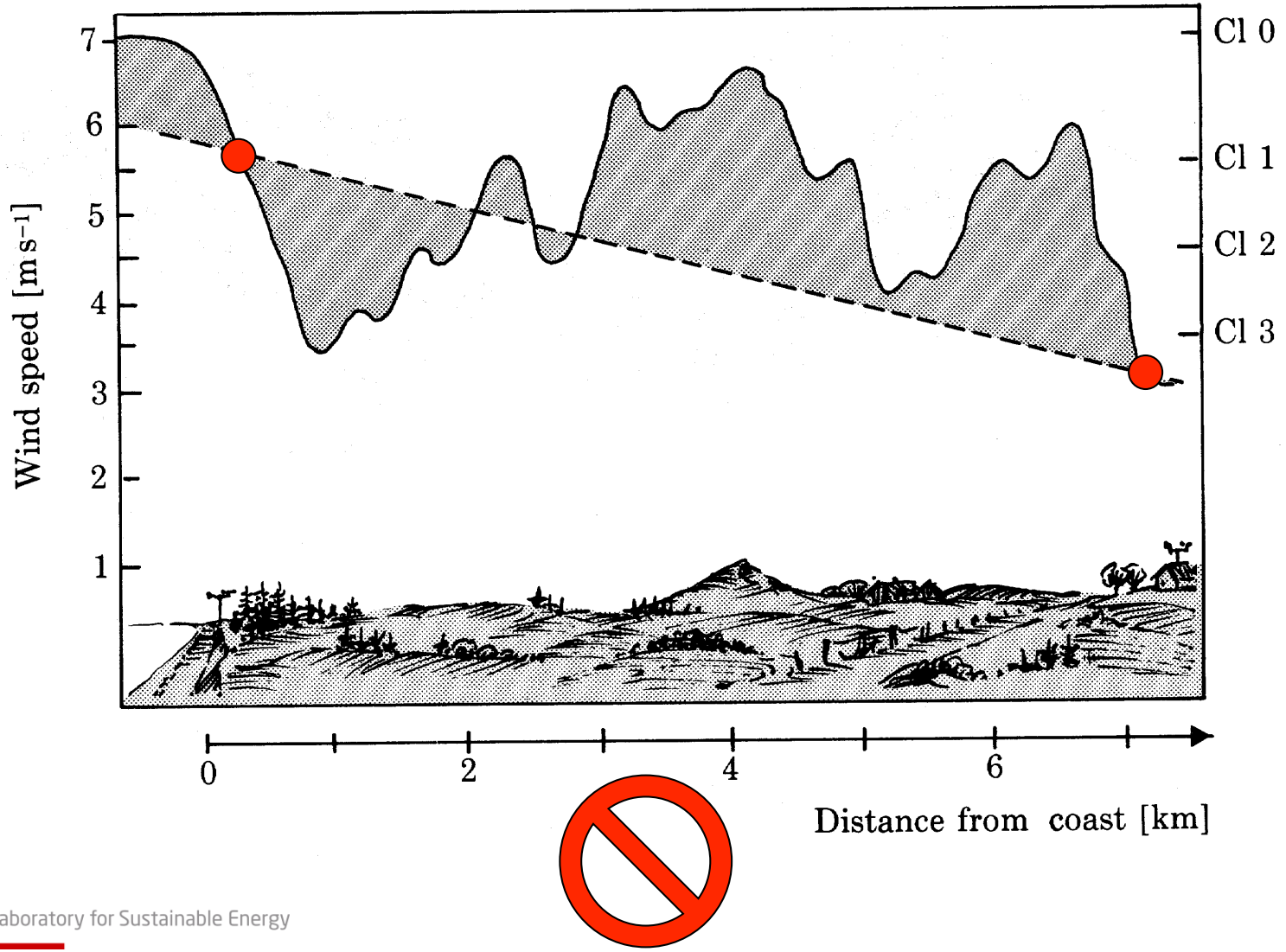
~~Interpolation~~

Risø Wind Atlas

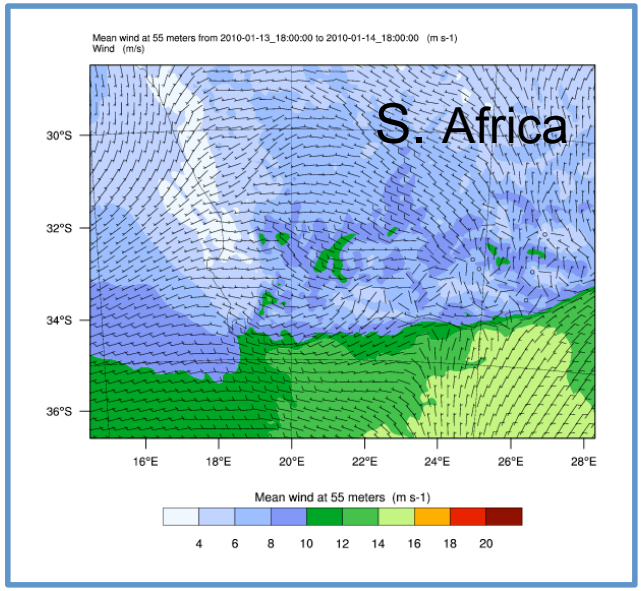
Statistical-dynamical

Fully dynamical

Linear interpolation



Developed a real-time wind (weather) forecast system for Denmark. System operational since March 2009 running twice daily



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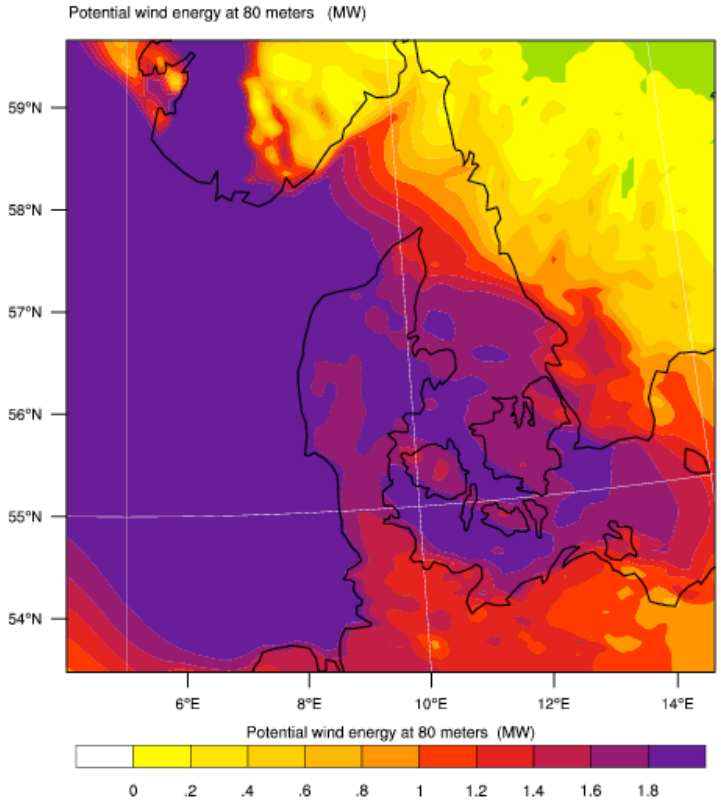
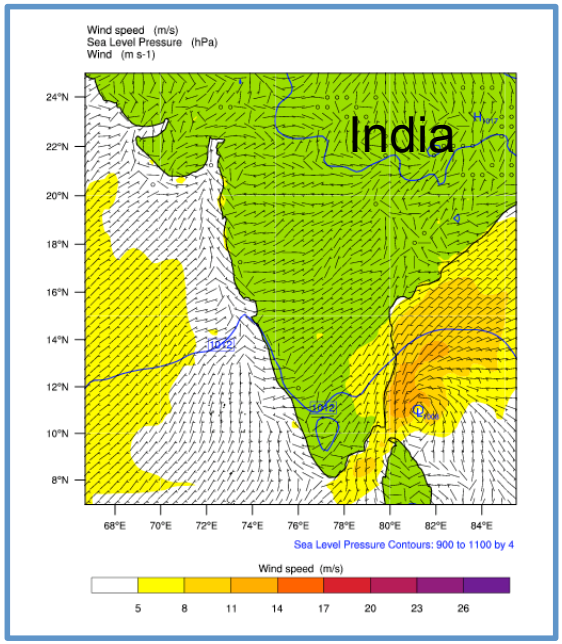
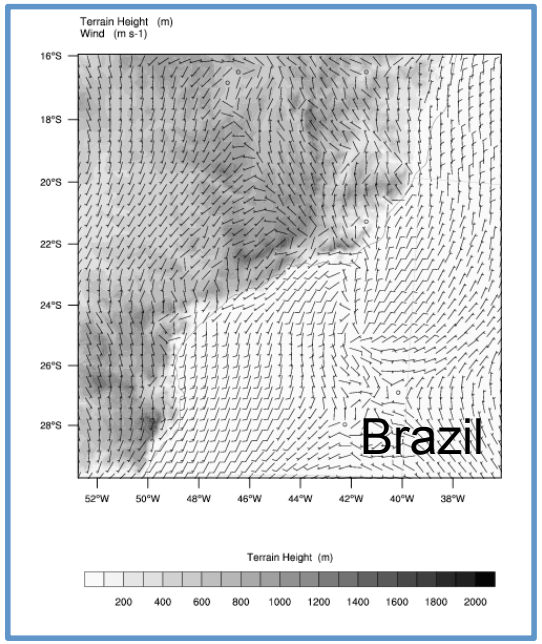
Forecast potential wind energy at 80 meters

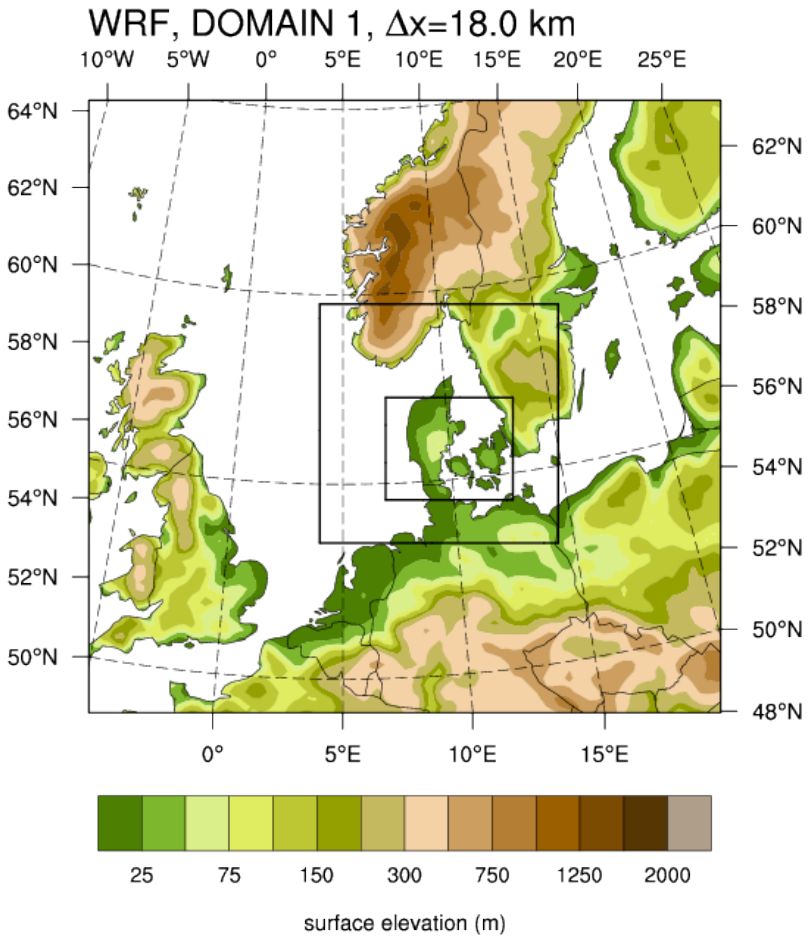




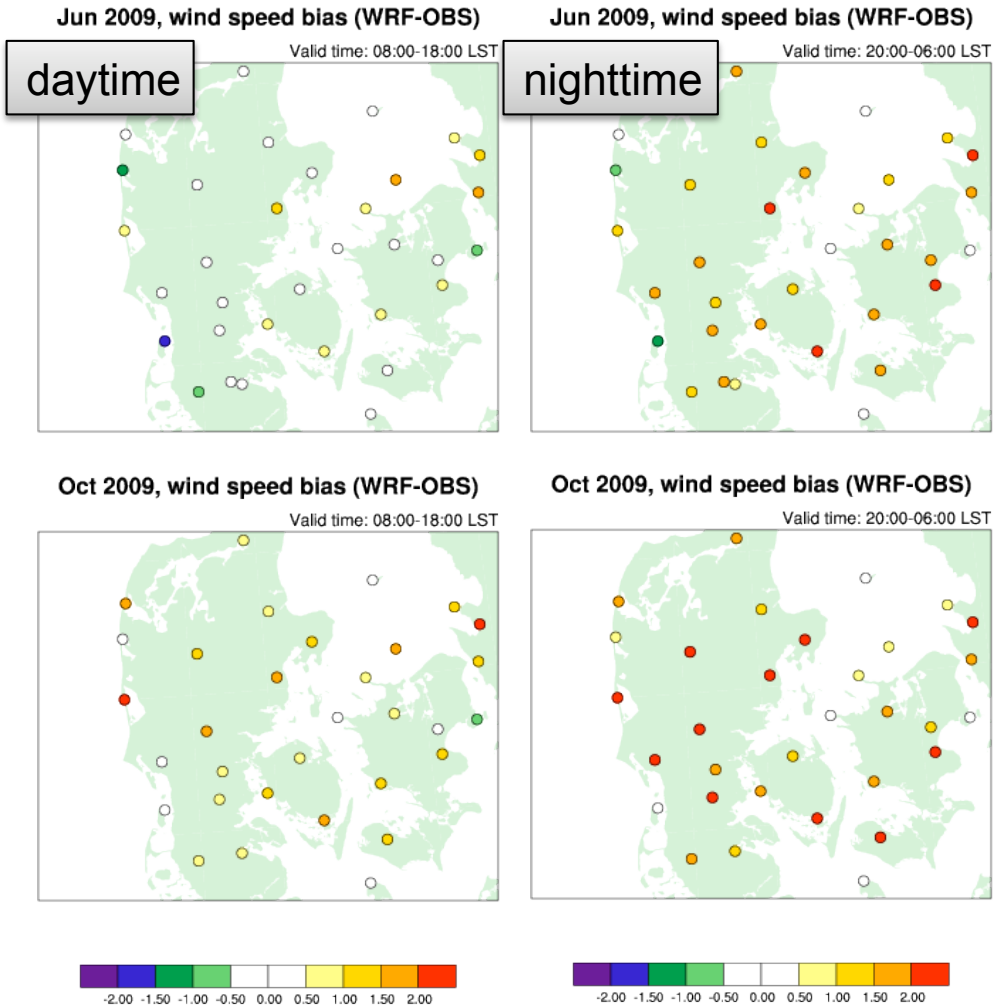


Similar systems for South Africa, Brazil, and India

Verification of WRF real-time wind forecast system over Denmark

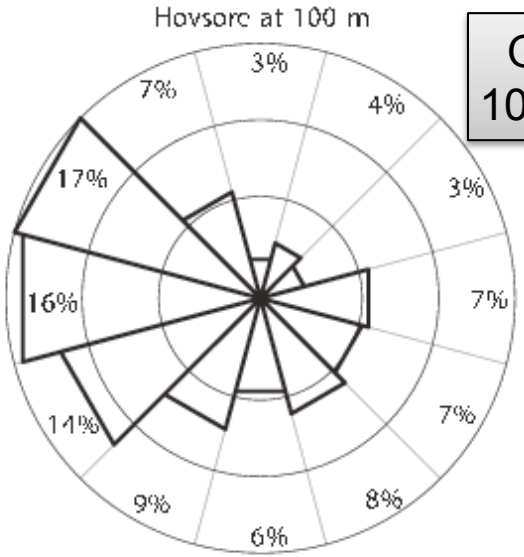


WRF topography and configuration
Δx = 18, 6 and 2km

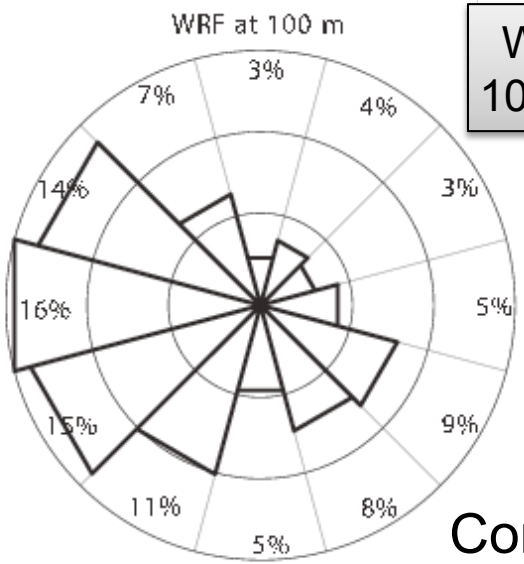


10-meter wind speed mean error (WRF-OBS) for the months of June and October 2009

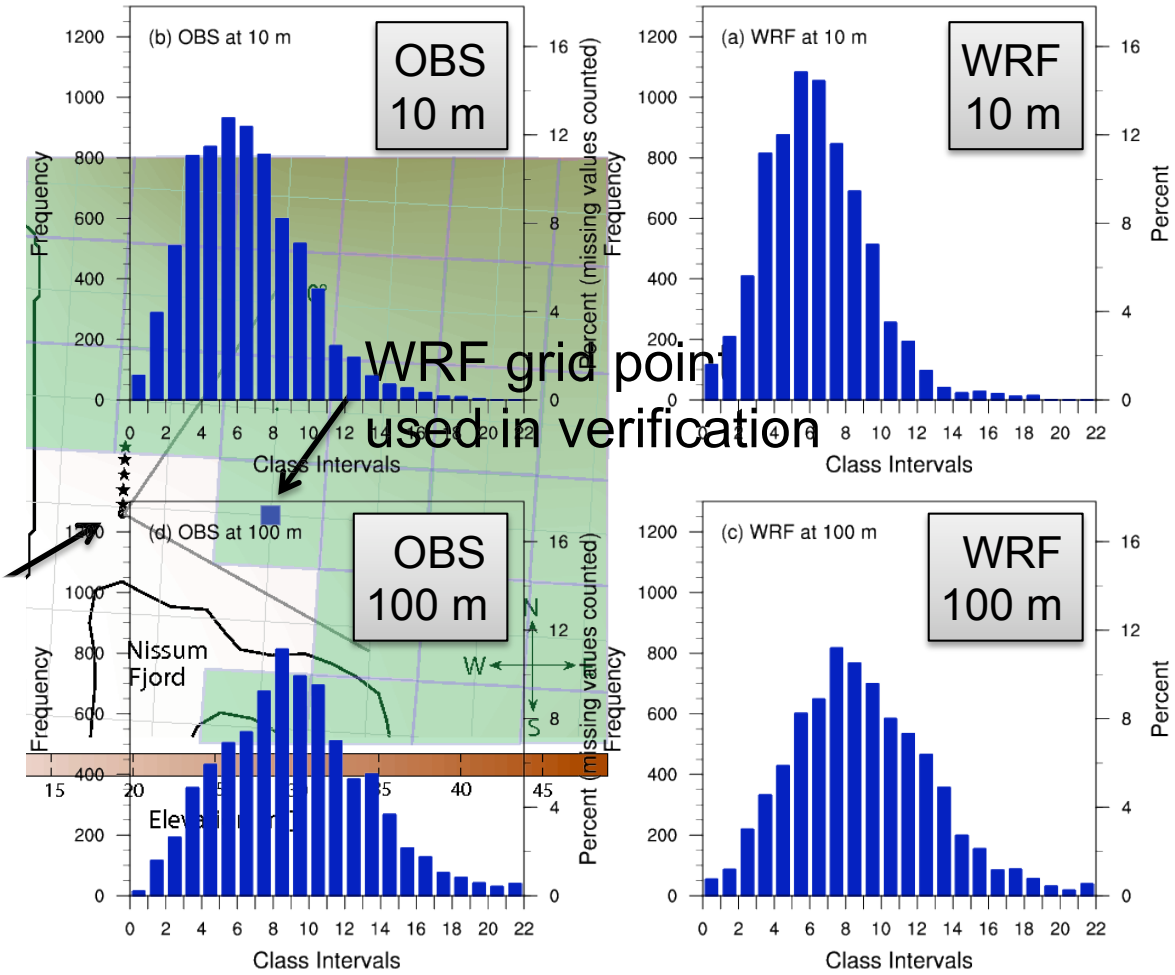
Verification at Høvsøre test site, 116 m mast



OBS 100 m



WRF 100 m

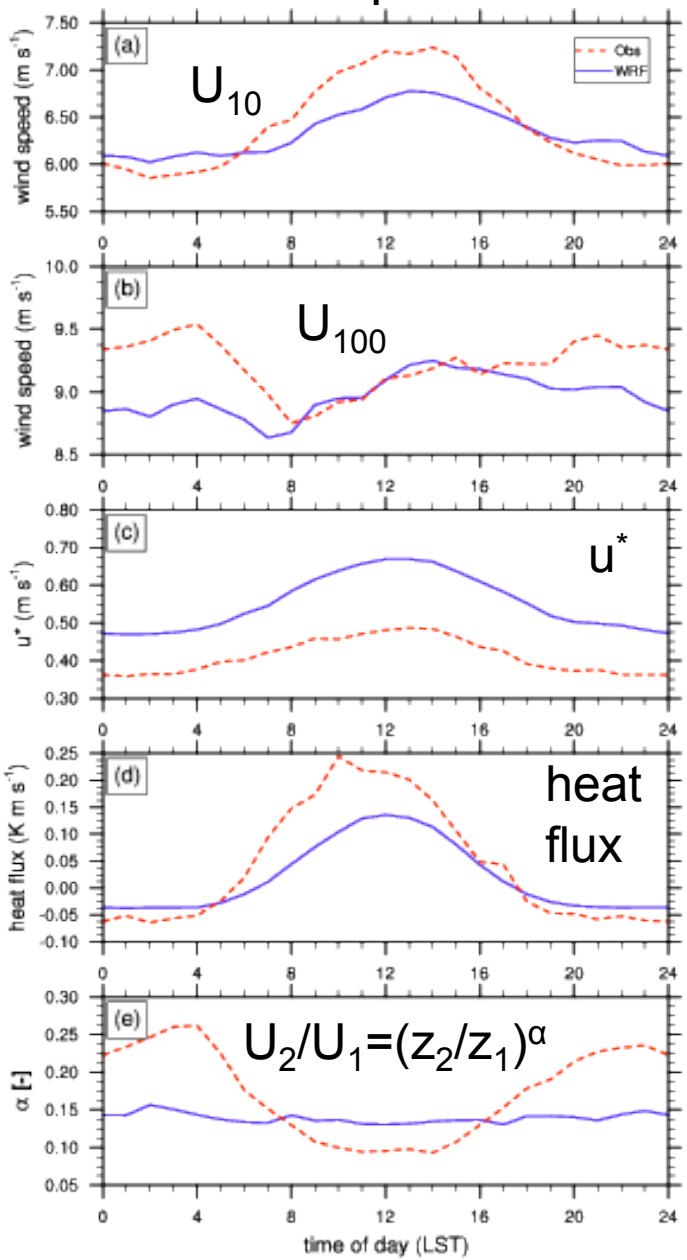


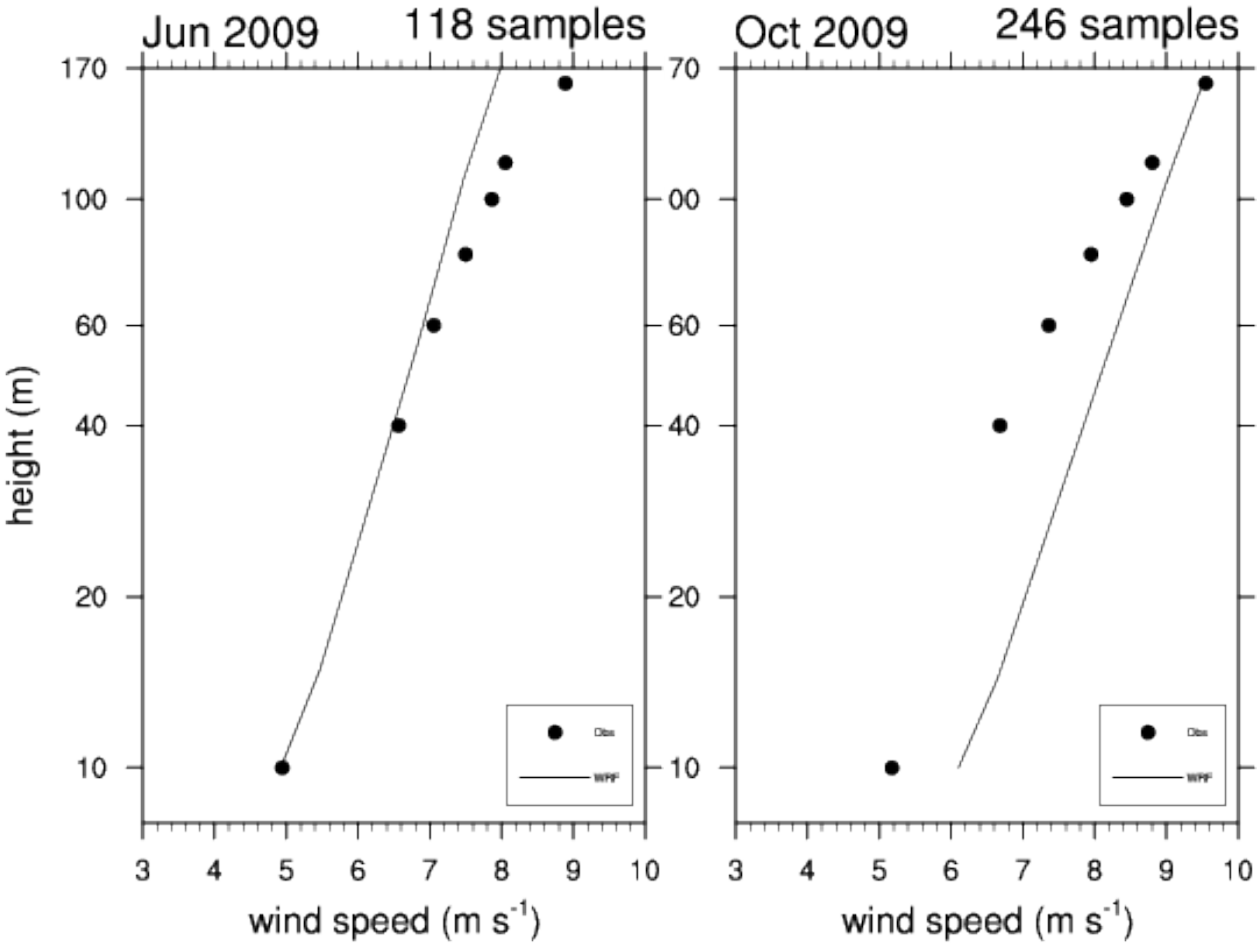
Wind speed distributions at 10 and 100 meters

Computed from all 4-27 hour forecasts (1200 UTC run)
May – October 2009

Verification at Høvsøre test site

Averaged diurnal cycle of various quantities



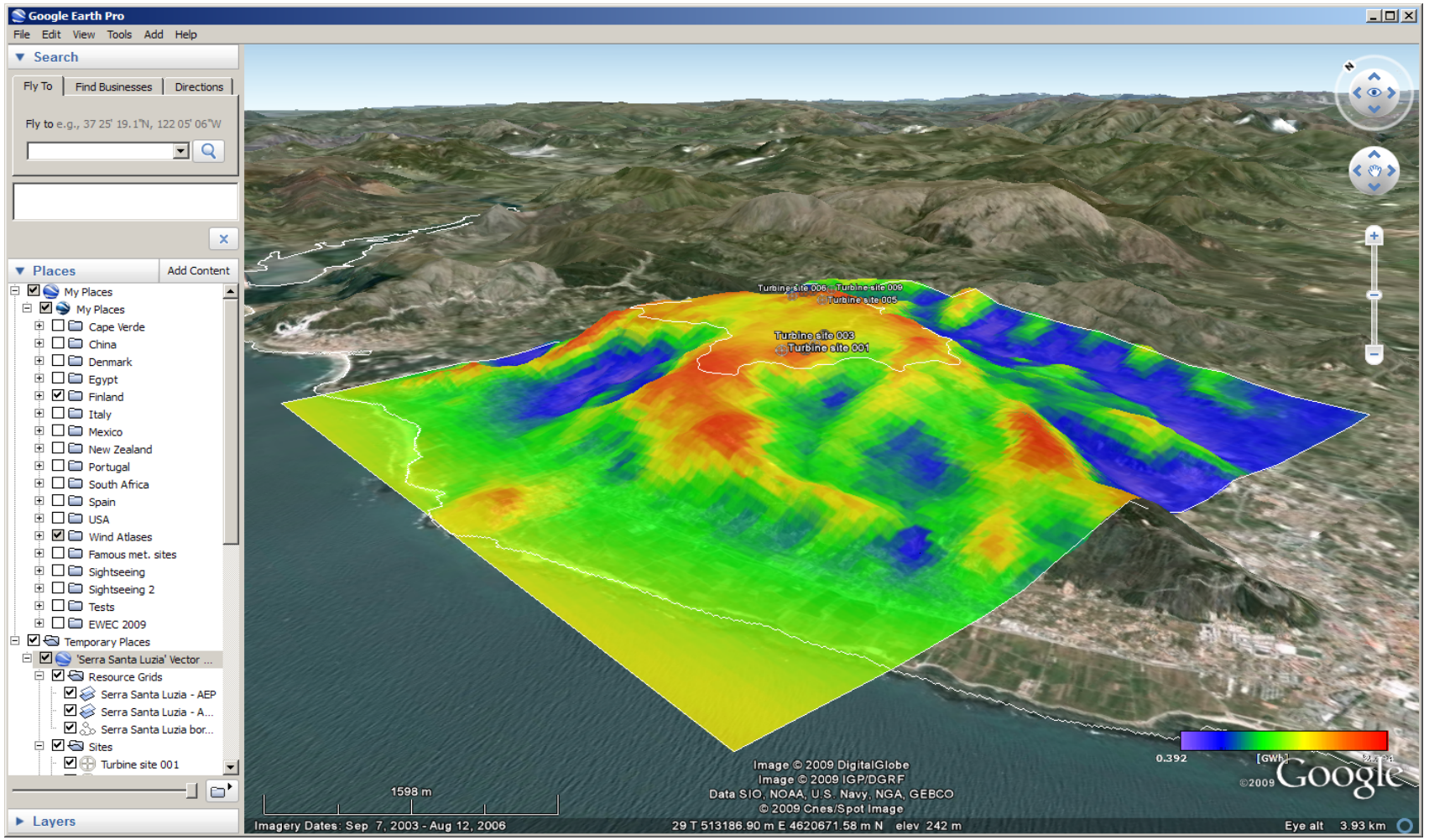


Comparison of profiles from the flat and homogeneous sector (minimize site effects) at Høvsøre

Conclusions

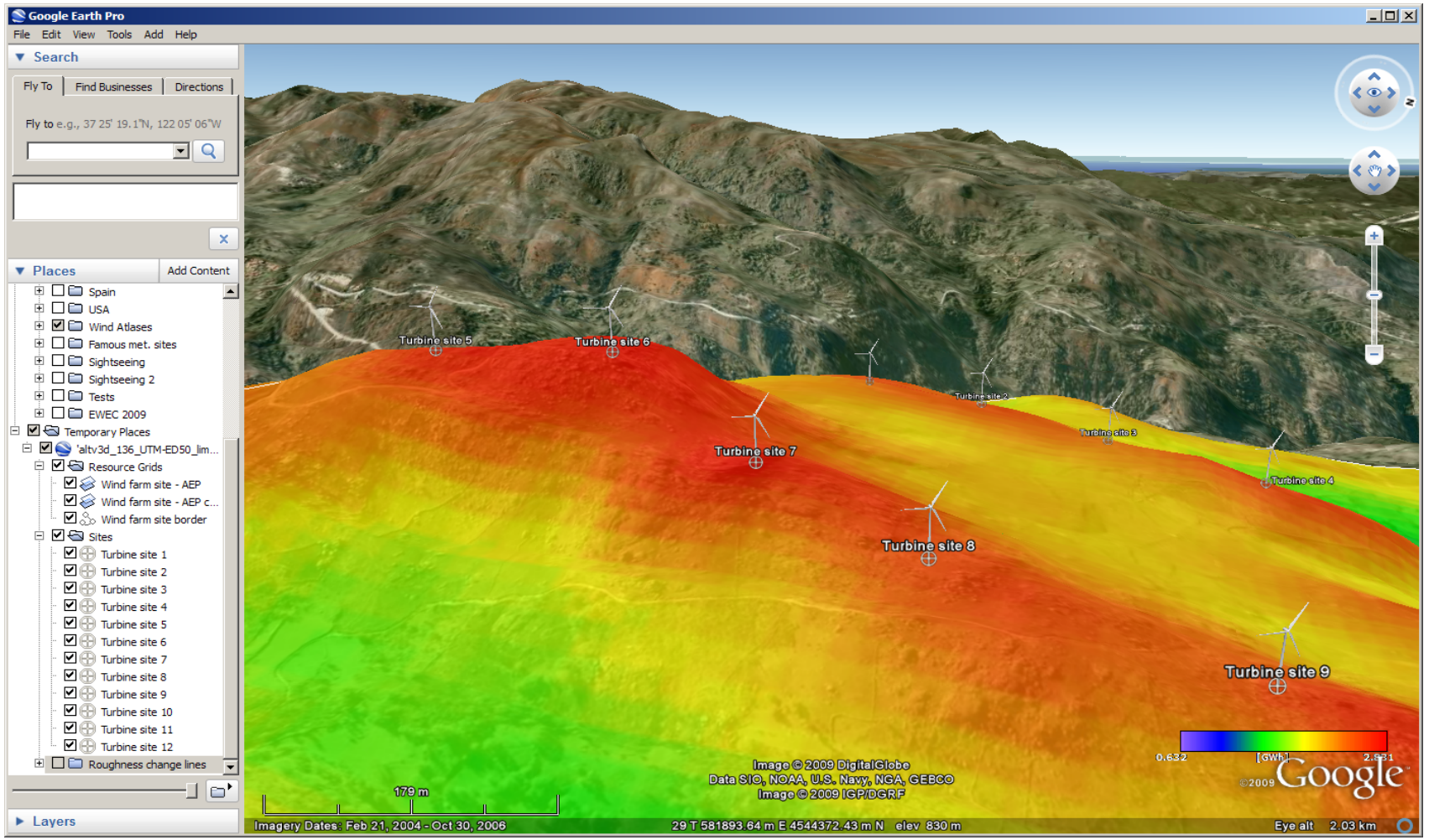
- The method used to generate mesoscale wind atlas is presented.
- Preliminary, unverified modeling results for South Africa are presented.
- The importance of downscaling mesoscale results to the microscale is emphasized.
- The dynamical downscaling method is introduced
- Validation results of mesoscale weather forecasts for Denmark illustrate the difficulties in modeling the vertical wind profile.

The goal…



Thanks to Niels Mortensen

End of story (and yet another pretty picture…)



Thanks to Niels Mortensen