

First Verified Numerical Wind Atlas for South Africa

- Overview – results, verification, uncertainties and recommendations

Jake Badger

Andrea Hahmann

Niels Gylling Mortensen

DTU Wind Energy

Technical University of Denmark

DTU Wind Energy

Department of Wind Energy

Outline and objectives of the presentation

- Explain what a numerical wind atlas is
- Give motivations for verification
 - lets modellers know the modelling is on track
 - let the users know the appropriate application of data
 - adds value
- Give the background for the modelling process
- Give recommendations and points of discussion
- Illustrate first results from WRF and an alternative downscaling method

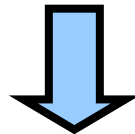
Motivation

A numerical wind atlas method is of great value

- when long-term measurement data unavailable
- when flow features are due to regional scale topography

It uses the principle of statistical dynamical downscaling

large-scale *meteorological conditions*



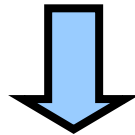
small-scale *meteorological conditions*

Numerical wind atlas

Need following ingredients:

- a tool to calculate how atmospheric flow is modified by terrain
 - mesoscale model downscaling

i.e. represented by



in previous slide.

We also need:

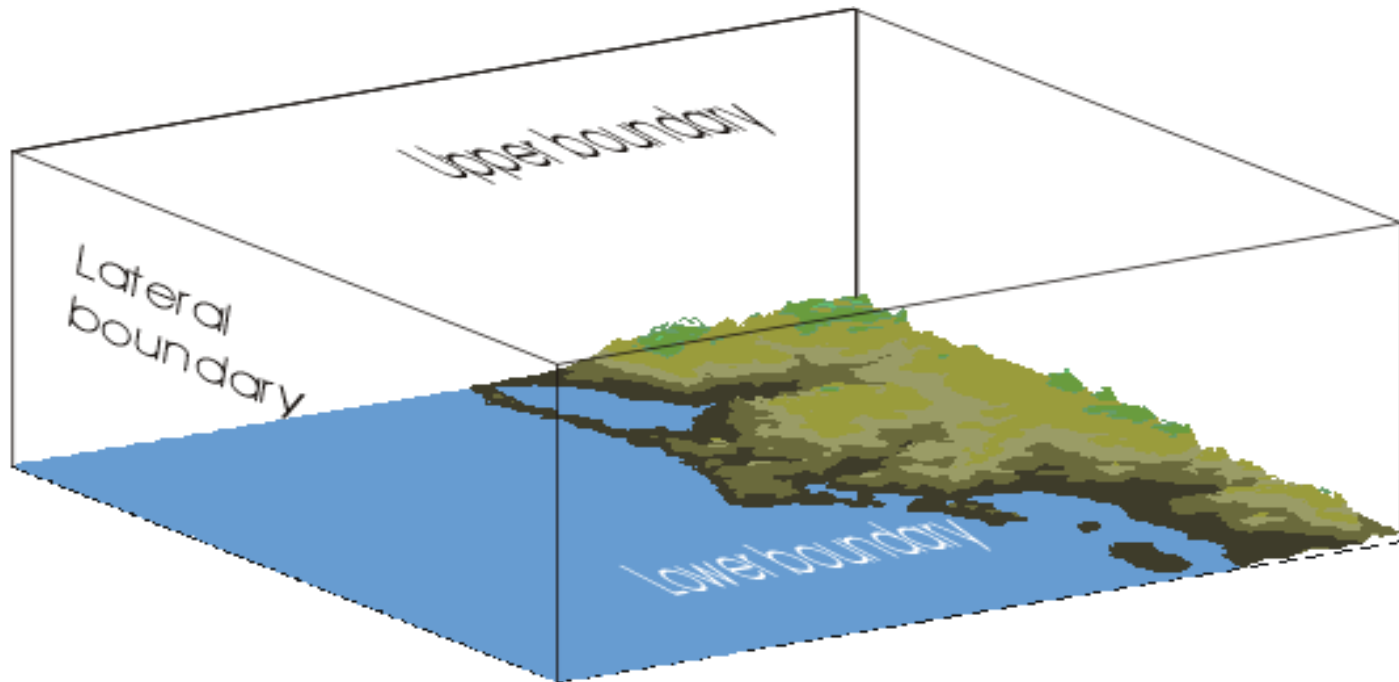
- information about large-scale meteorological conditions
- information about terrain
 - surface elevation (orography)
 - surface roughness

Numerical wind atlas

Mesoscale model

KAMM Karlsruhe Atmospheric Mesoscale Model

non-hydrostatic, regular horizontal grid, stretched vertical coordinate (terrain following)



Numerical wind atlas

Large-scale meteorological conditions

NCEP-DOE reanalysis II data provides large-scale, long-term atmospheric forcing.

- 2.5 x 2.5 degree resolution
- 4 times daily
- 1948 to present

NCEP-DOE reanalysis II data is used to calculate profiles of

- geostrophic wind
- potential temperature

Climatological period is 1980 – 2009.

Numerical wind atlas

Terrain description

Orography

- SRTM30 data – approx. 1km resolution.

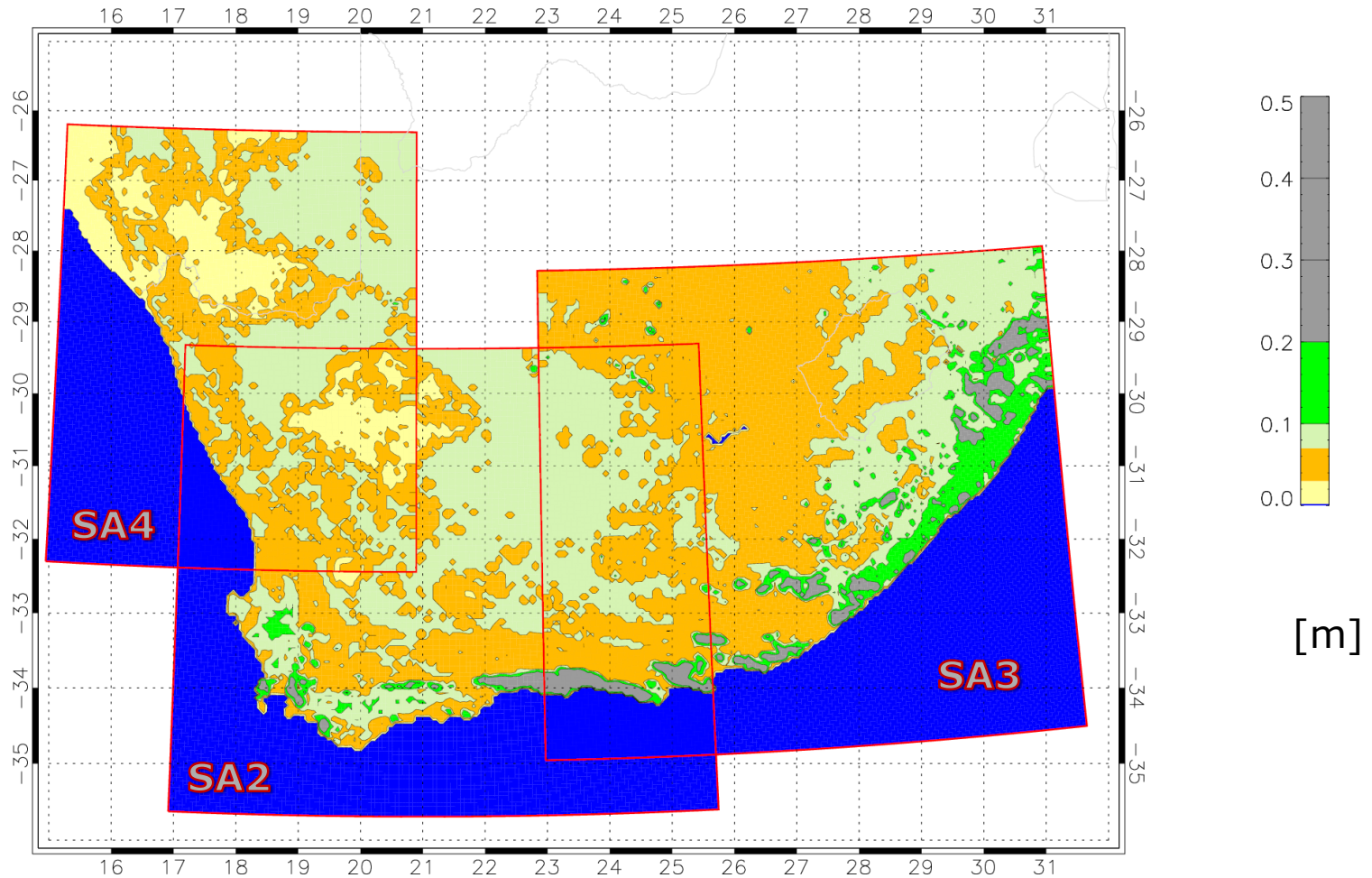
The Space Shuttle Radar Topographical Mission data is provide by the National (USA) Geospatial-Intelligence Agency (NGA) and the National (USA) Aeronautics and Space Administration (NASA).

Surface roughness

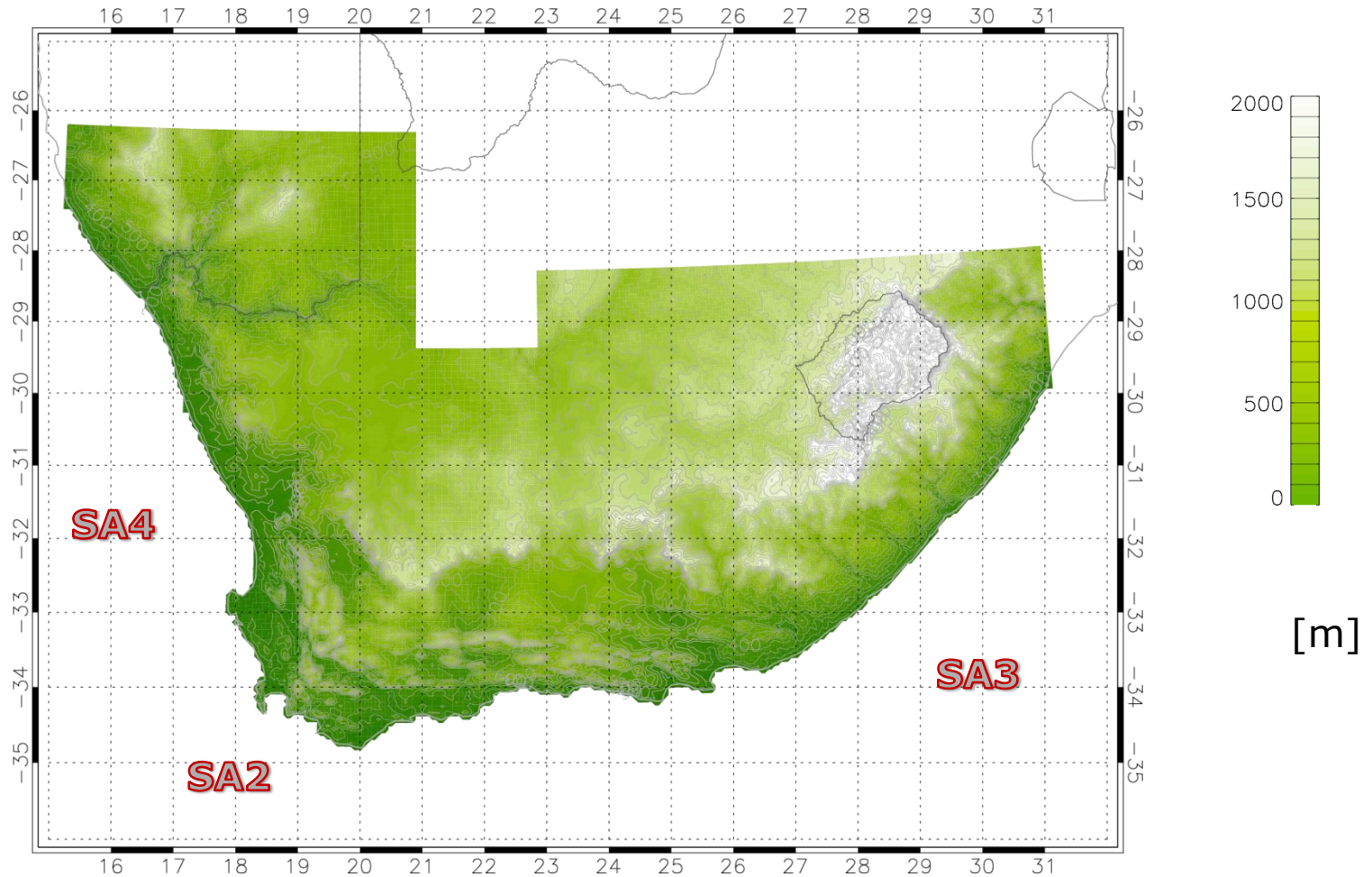
- USGS GLCC 30 dataset – approx. 1km resolution.
- Land use → surface roughness (via look-up table)

The Global Land Cover Classification (GLCC) is provided by the United States Geological Survey.

Domains' surface roughness length



Domains, surface elevation

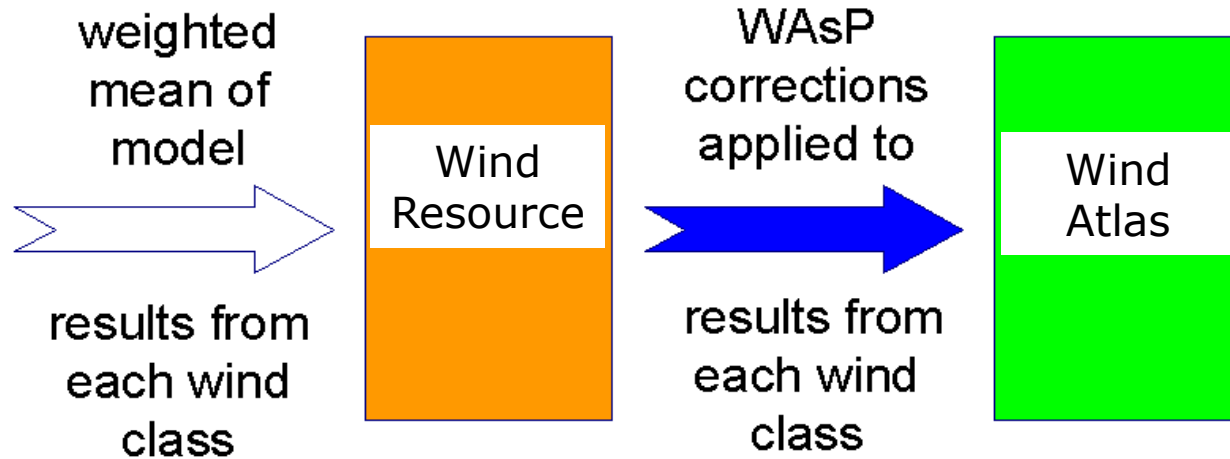
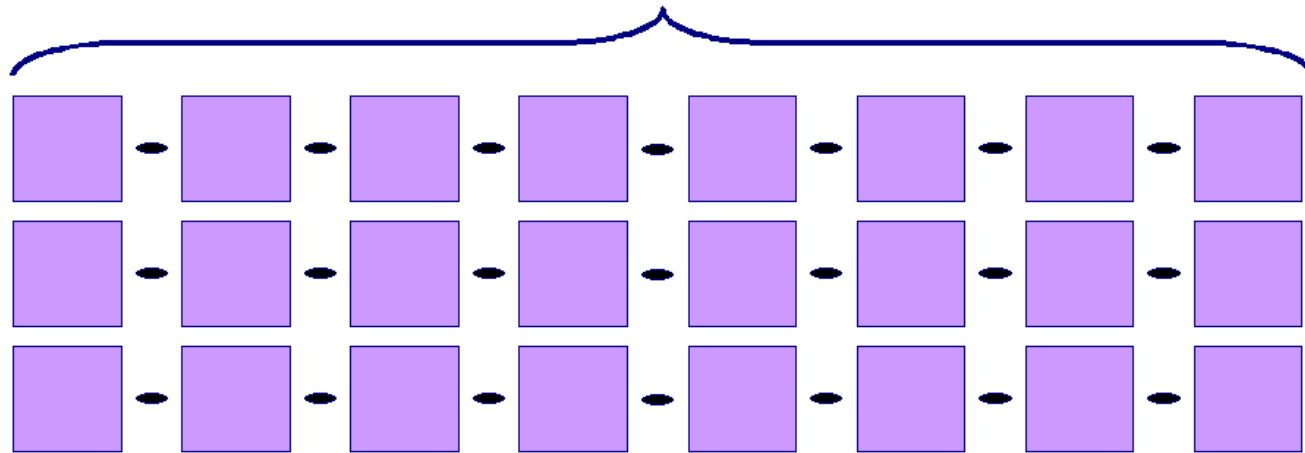


Numerical wind atlas

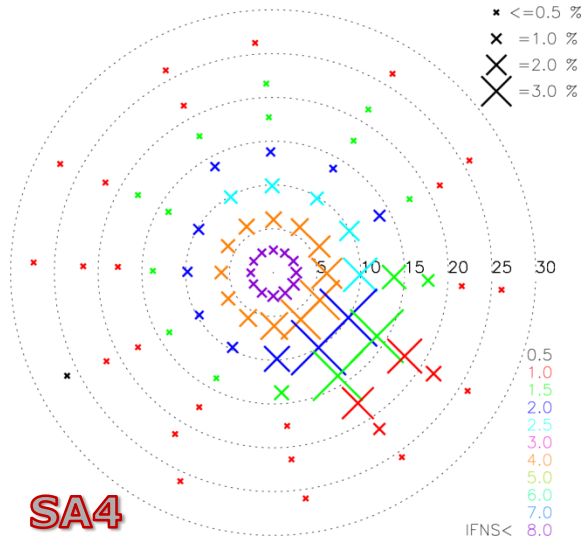
We have the terrain description, large-scale atmospheric conditions, and mesoscale scale model ready to run, so...

- We could run KAMM using 30 years of 4 times daily data as large-scale forcing conditions
 $30 \cdot 365 \cdot 4 = 43800$ integrations
A lot of work! ...and also repetition.
- Instead we select around 100 representative conditions, called wind classes profiles.
- ***"Statistical-dynamical downscaling"***

mesoscale model (KAMM) forced by N large-scale wind classes



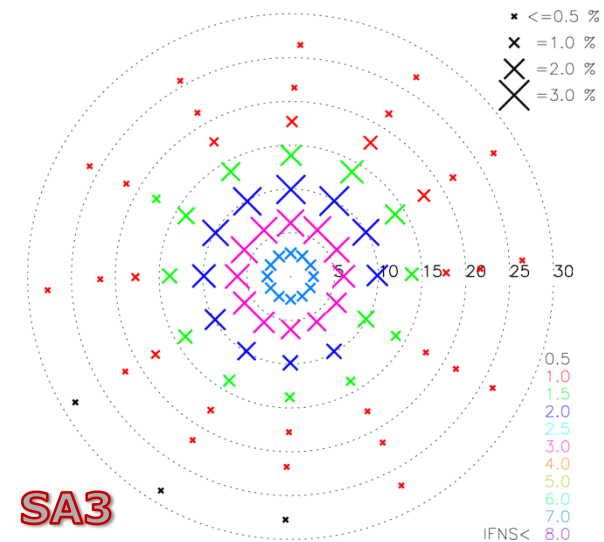
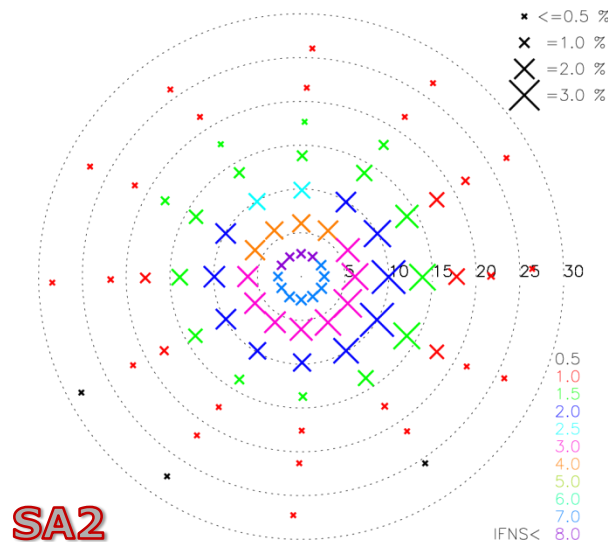
Meteorological forcing



Forcing profile described at
0 m, 1500 m, 3000 m, 5500 m

0 m winds shown

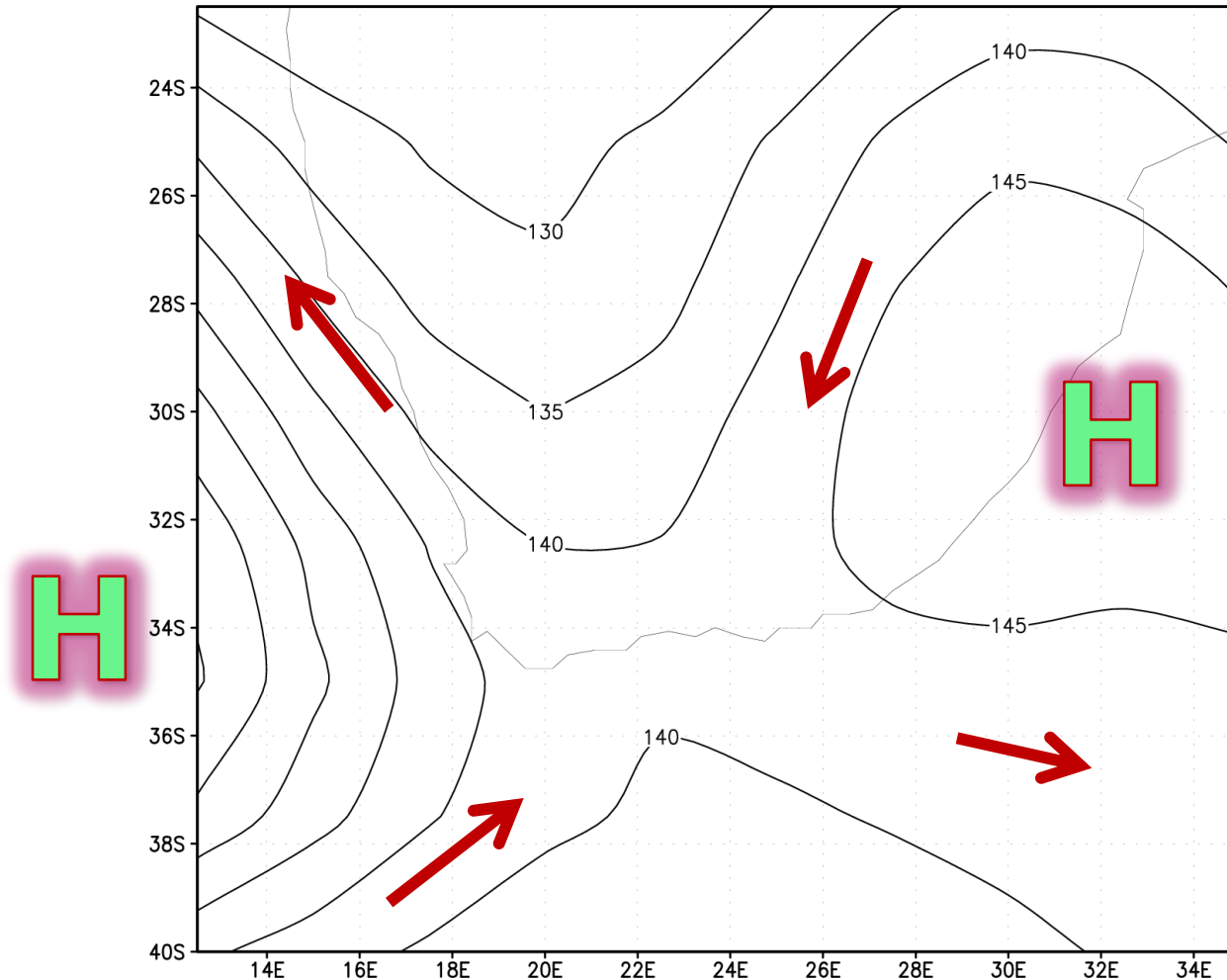
- each x indicates a different forcing of the mesoscale model
- frequency of occurrence of each wind varies within domain



Meteorological situation

1000 hPa geopotential heights

2011 mean



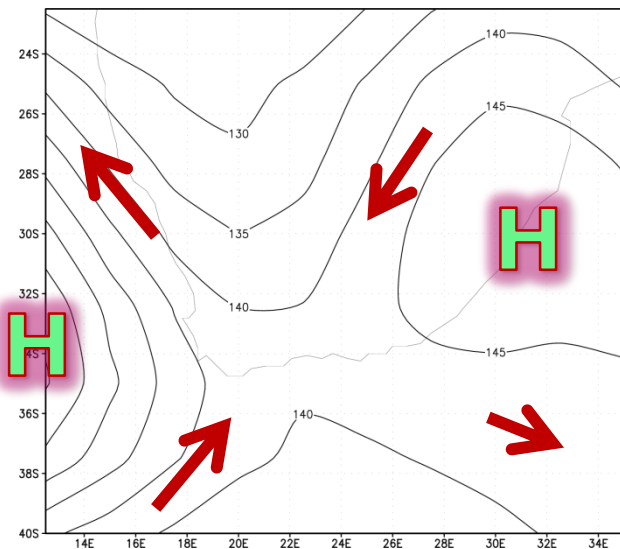
Indication of annual mean vector wind

Meteorological situation

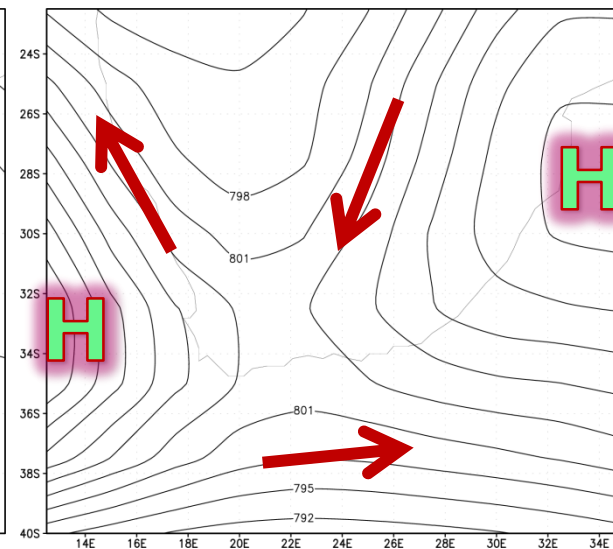
1000, 925, 850 hPa geopotential heights

2011 mean values

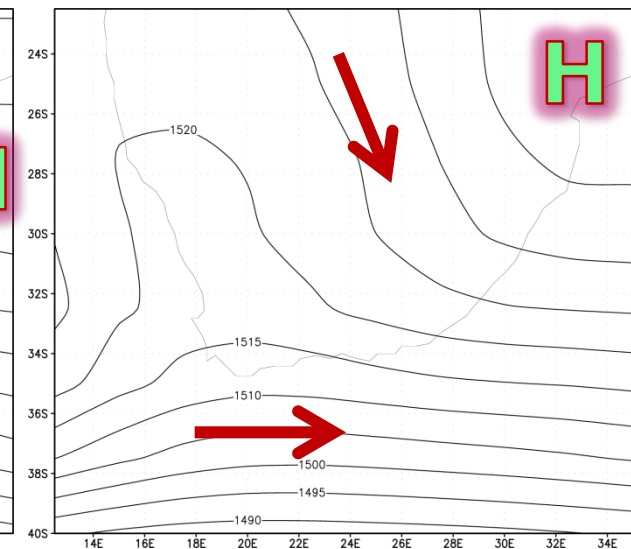
~ 0 m



~ 800 m

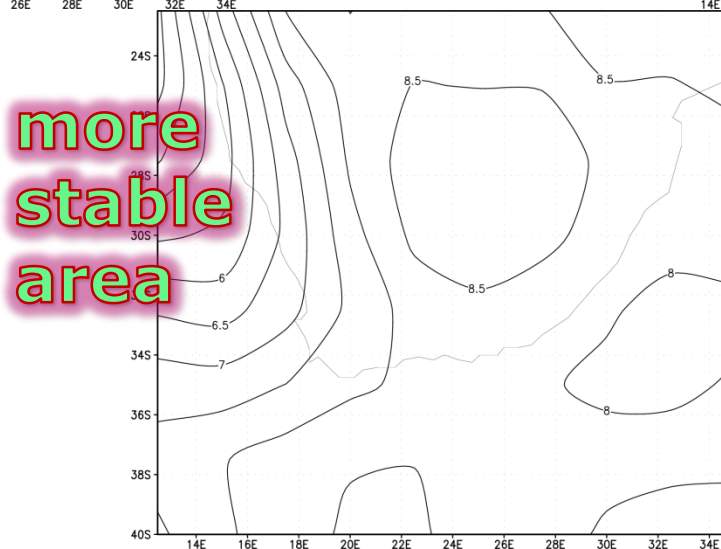
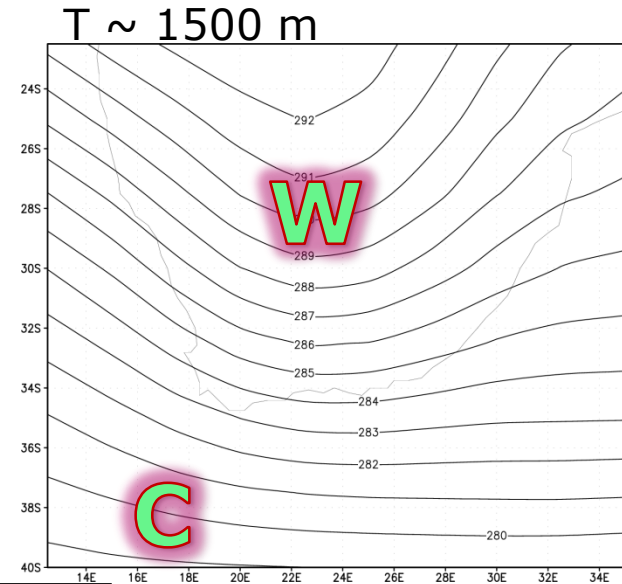
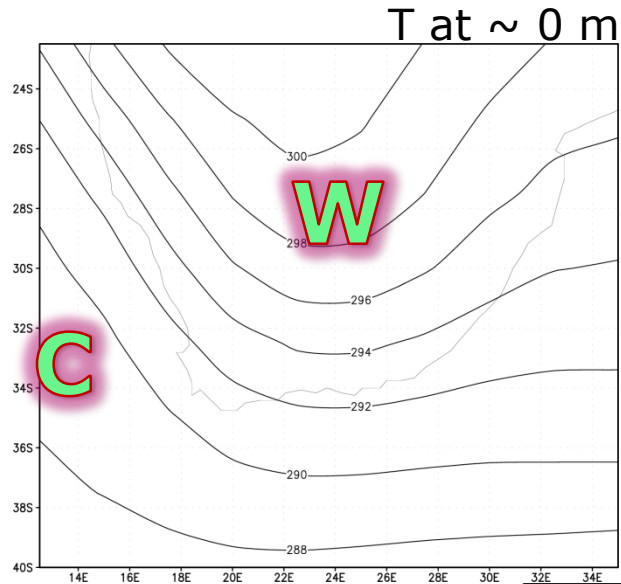


~ 1500 m



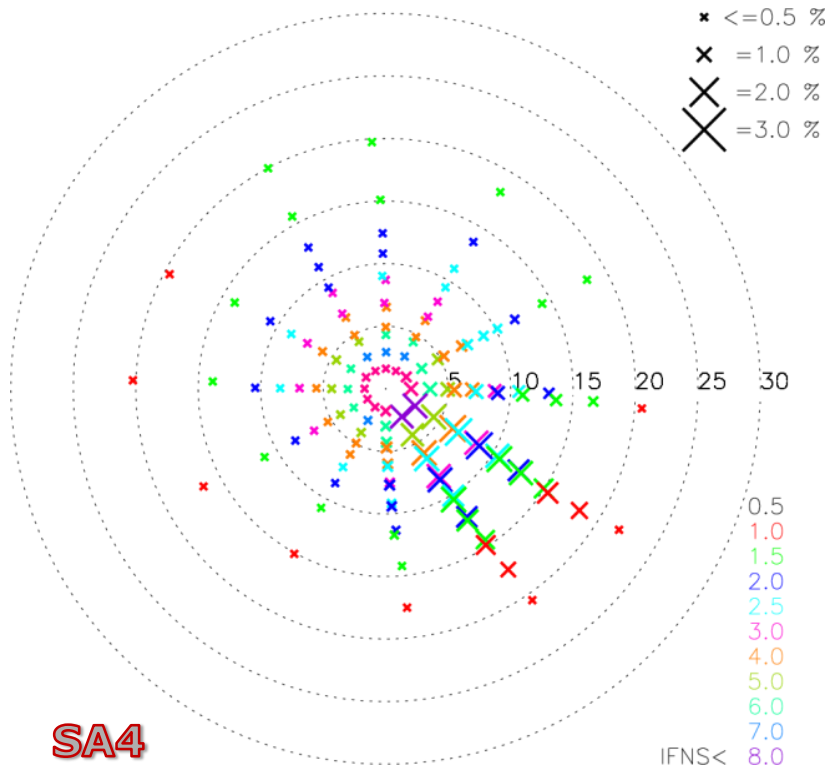
Indication of annual mean vector wind

Meteorological situation 1000 and 850 hPa temperature 2011 mean



$\Delta T \sim 0 \text{ m} - 1500 \text{ m}$

Special set-up for north-western domain (SA4)



Forcing profile described at
0 m, 800 m, 1500 m, 5500 m

0 m winds shown

This set of wind classes gave
much improved results.

However the wind climate in
this domain is still a challenge.

Calculating the mean simulated wind speed

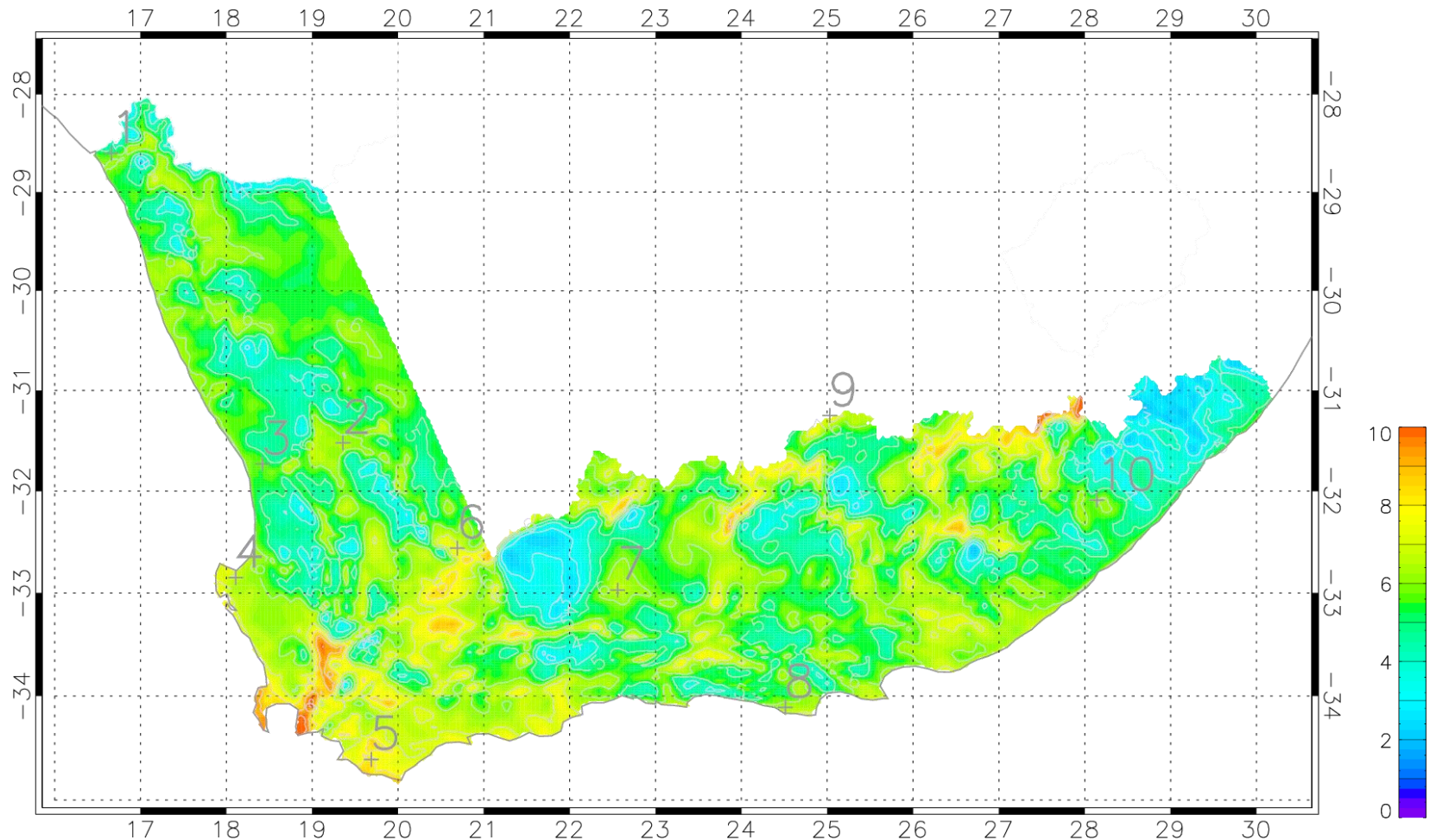
$$\bar{u}(x, y, z) = \frac{\sum f_i(x, y)u_i(x, y, z)}{\sum f_i(x, y)}$$

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

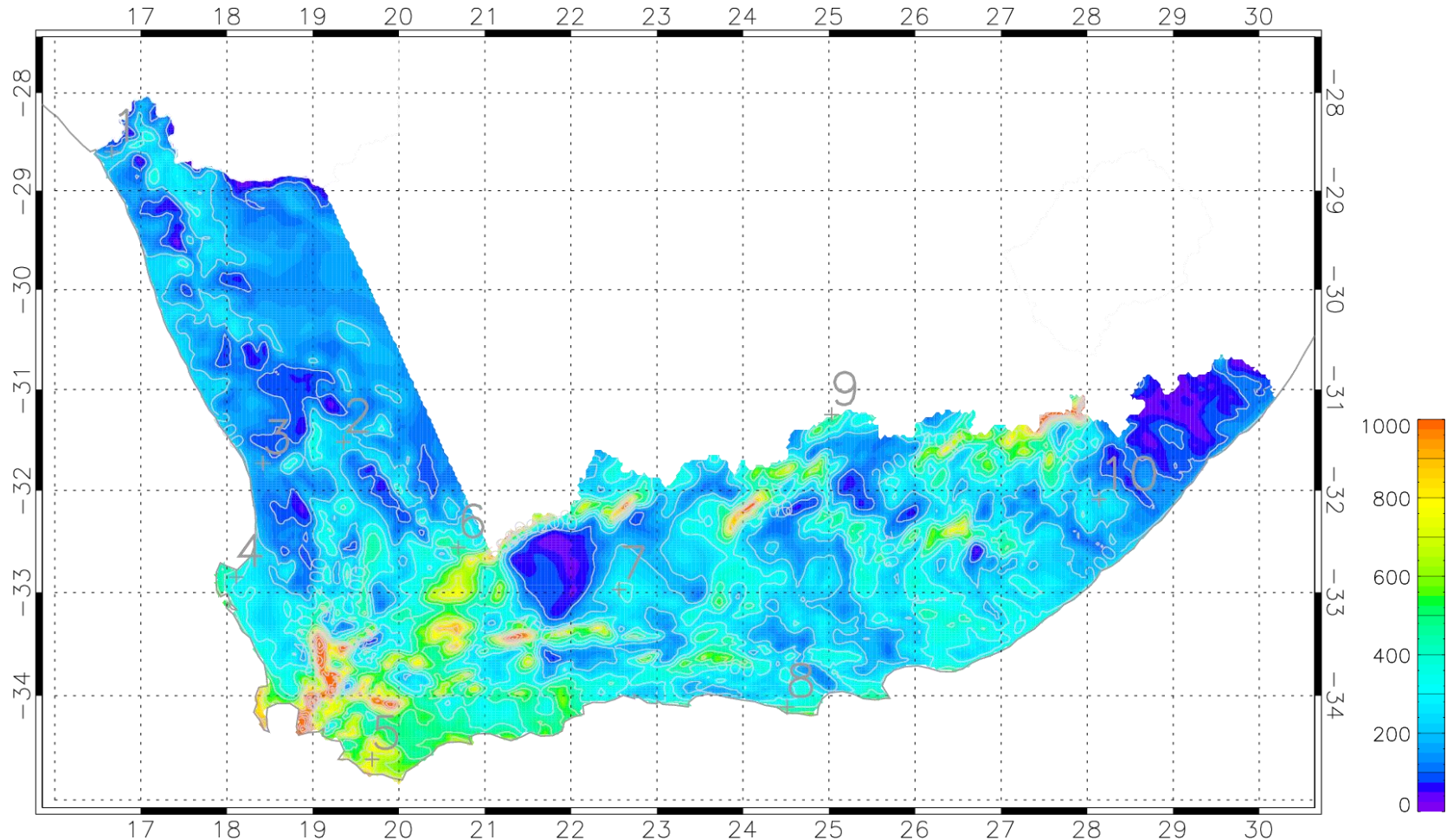
$f_i(x, y)$ = frequency of wind class i , a function of x and y .

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

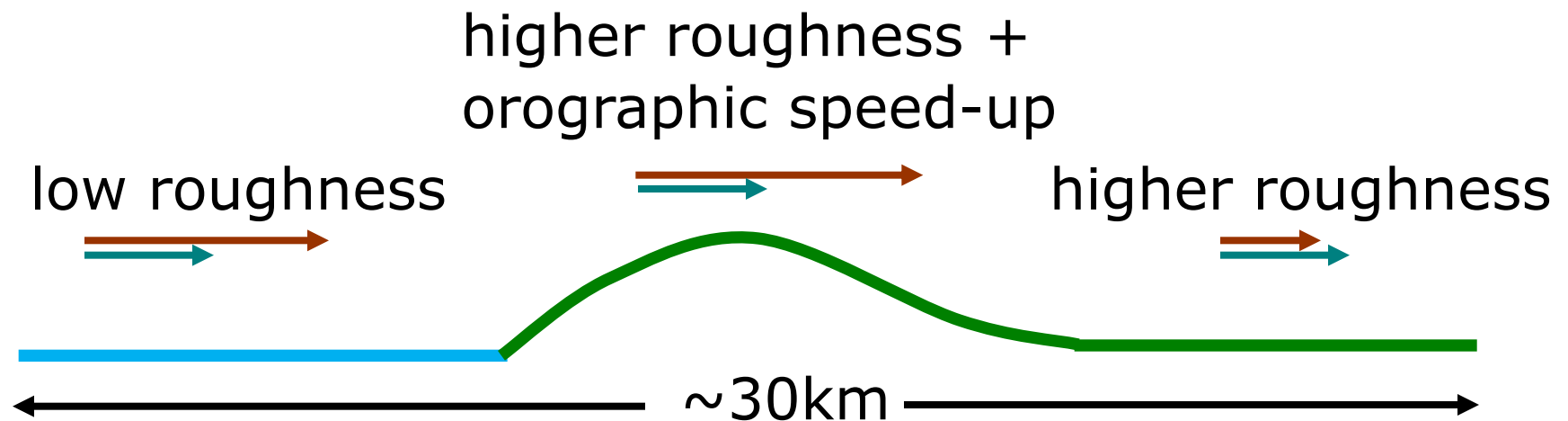
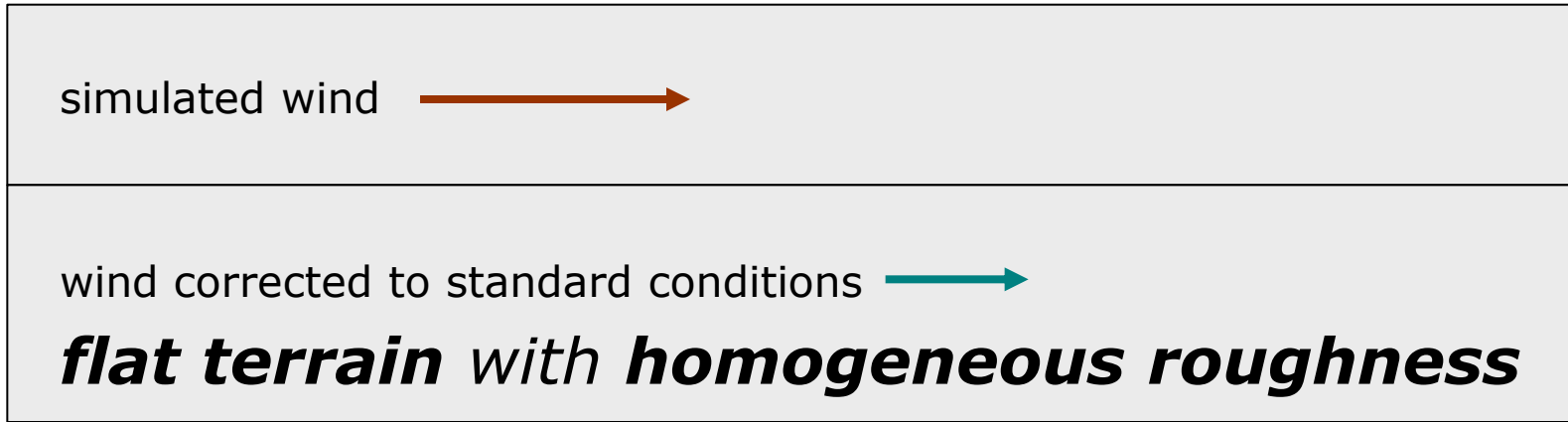
Simulated annual mean wind speed [m/s] (30-year climatology)



Simulated annual mean wind power density [W/m^2] (30-year climatology)



The WAsP part in KAMM/WAsP



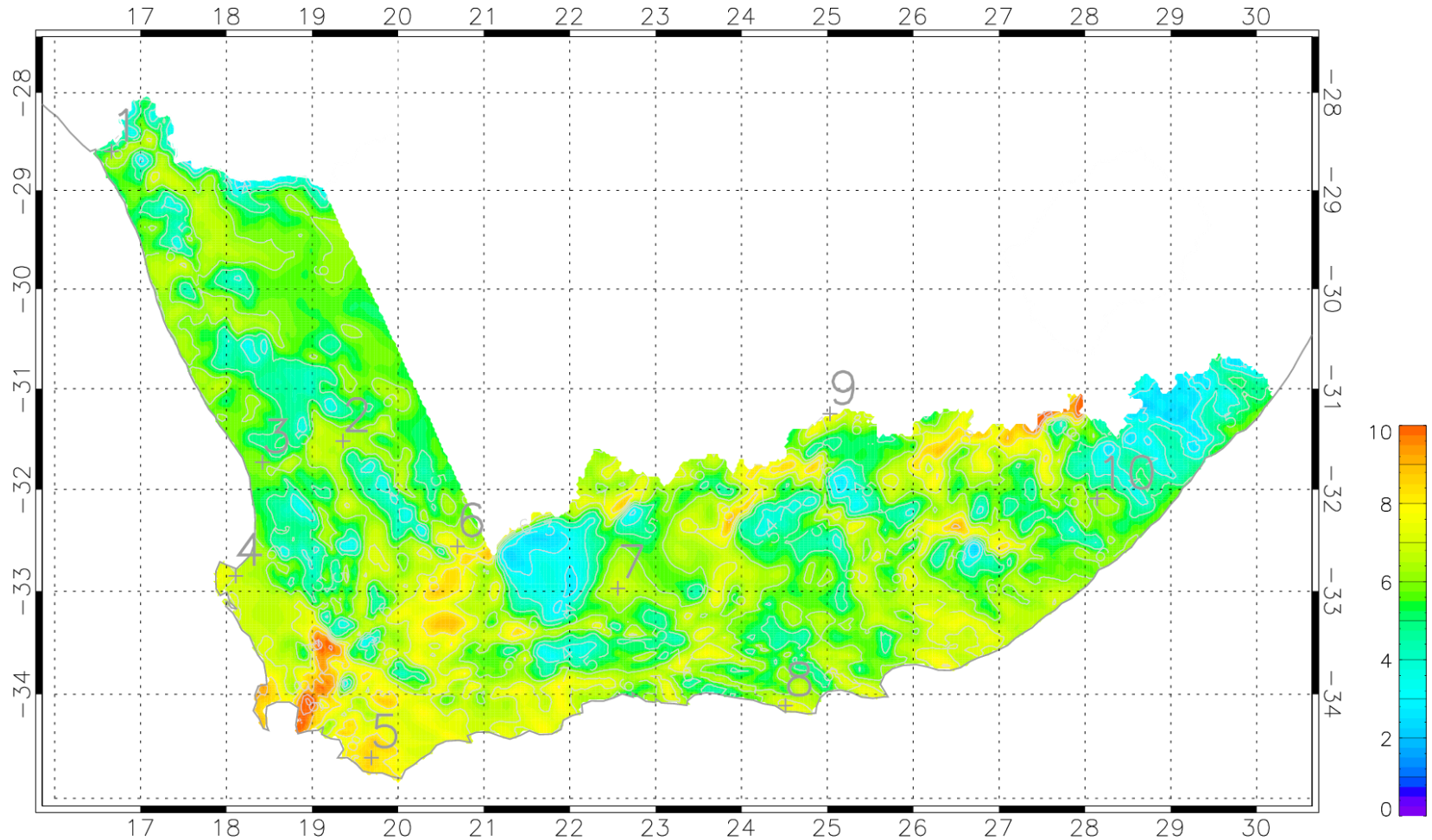
Calculating the mean generalized wind speed

$$\bar{u}_{Atlas}(x, y, z) = \frac{\sum f_i(x, y)W[u_i(x, y, z)]}{\sum f_i(x, y)}$$

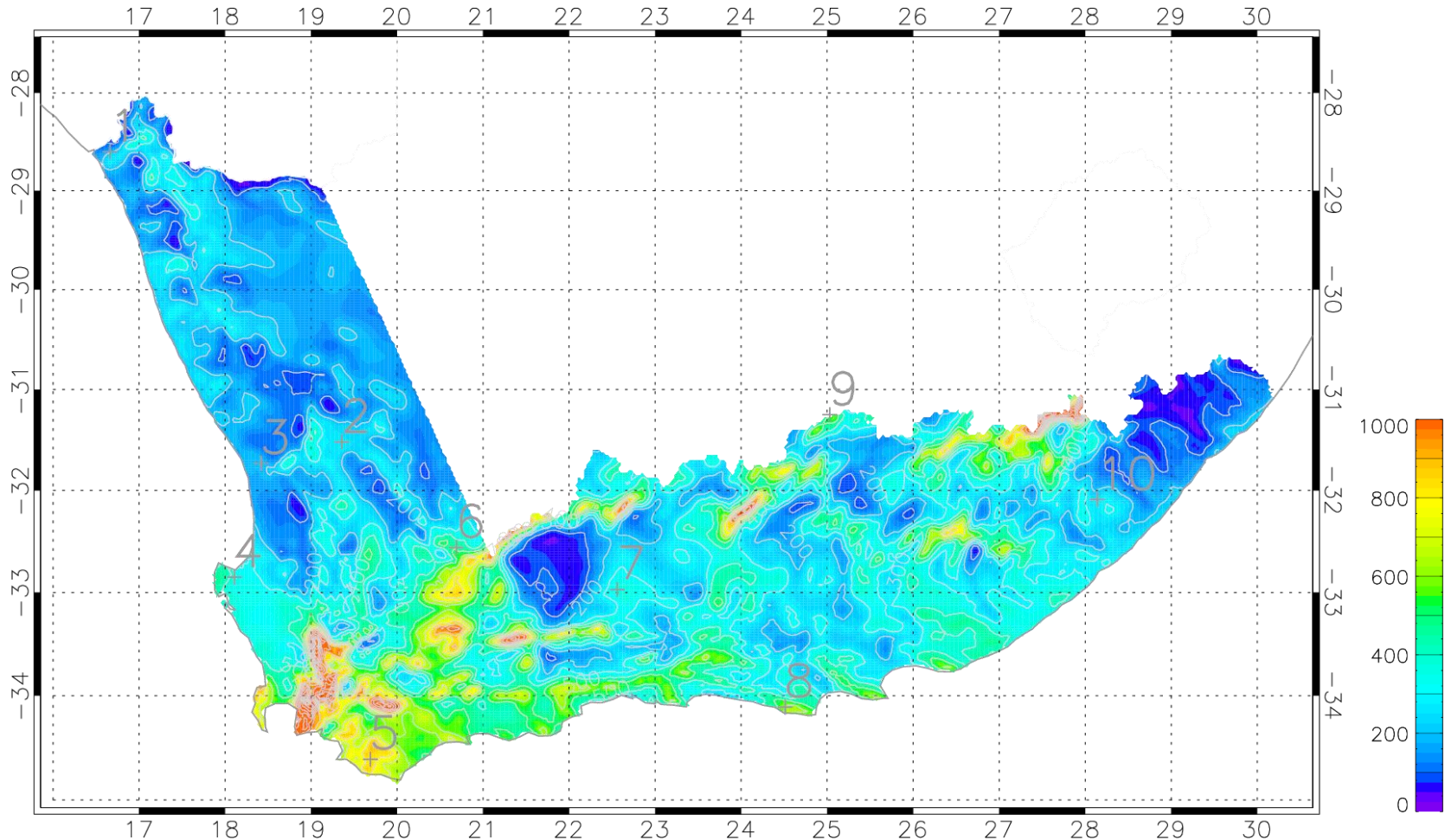
$W[u_i(x, y, z)]$ represents the WASP standardization operation on the simulated wind

$\bar{u}_{Atlas}(x, y, z)$ = mean wind speed at z m a.g.l. above flat terrain of uniform roughness length

Generalized annual mean wind speed [m/s] (30-year climatology)



Generalized annual mean wind power density [W/m^2] (30-year climatology)



Verification

Requires high-quality measure wind speed and direction data

and

Proper analysis of measurements for a correct comparison

Compare:

Observational wind atlas (OWA)

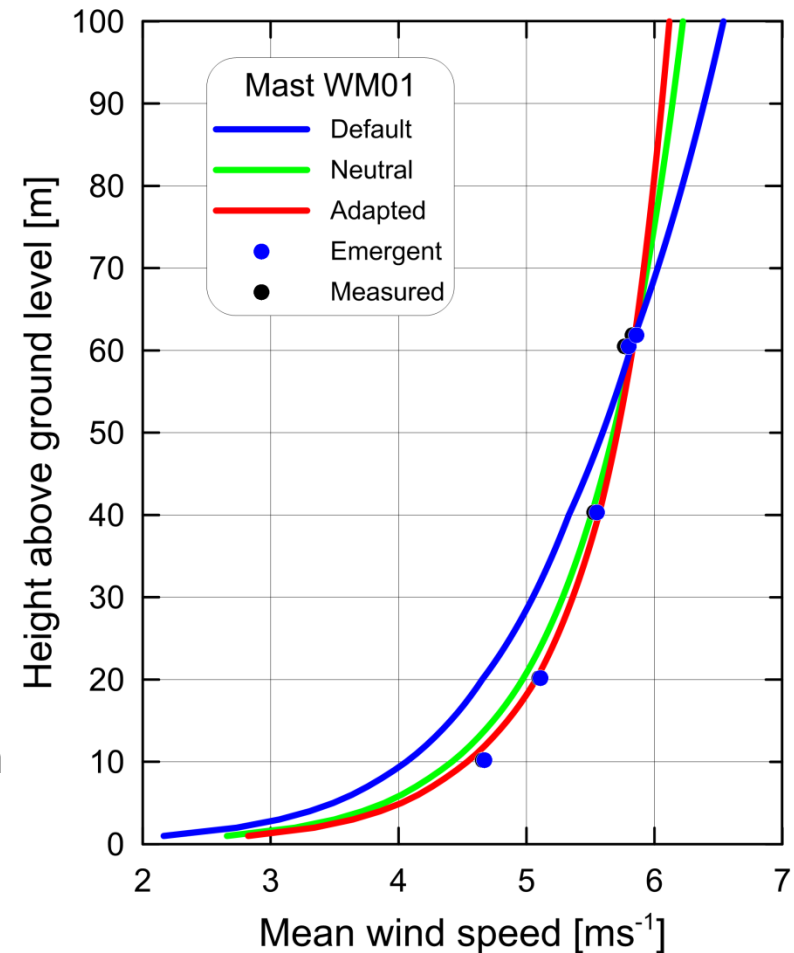
V

Numerical wind atlas (NWA)

In this way we compare “apples with apples”

Some background

- Wind-climatological inputs
 - One-years-worth of wind data
 - Five levels of anemometry
- Topographical inputs
 - Elevation maps (SRTM 3 data)
 - Simple land cover maps (SWBD + Google Earth); water + land
- Preliminary results
 - Microscale modelling verification
 - Site and station inspection
 - Simple land cover classification
 - Adapted heat flux values
 - Wind atlas data sets from 10 sites



Terrain characteristics and over-land heat fluxes

Station	Terrain	z_0	Heat flux	Neutral	Default	Adapted
		[m]	[Wm ⁻²]	[%]	[%]	[%]
WM01	coastal	0.03	+40	2.4	6.6	0.8
WM02	inland	0.03	-20	3.8	1.7	0.6
WM03	coastal	0.03	-20	3.3	1.7	0.5
WM04	coastal	0.03	-30	3.7	0.7	0.7
WM05	coastal	0.07	-40	3.0	0.7	0.6
WM06	inland	0.03	-20	2.6	1.8	0.5
WM07	inland	0.03	-10	1.8	2.9	0.5
WM08	coastal	0.03	-10	0.9	2.7	0.4
WM09	inland	0.03	-10	1.0	3.3	0.3
WM10	inland	0.01	+20	1.6	5.8	0.6

Sensitivity and uncertainty on WAsP

Not sensitive / low uncertainty

- Cup anemometer calibration
- Mast site coordinates
- Cup anemometer heights
- Wind vane alignment
- Wind atlas heights
- Elevation map

Sensitive / higher uncertainty

- Roughness length assignment
- Heat flux (how to determine?)
- Air density (discrete tables)

Verification

Observation period is not a climatological period.

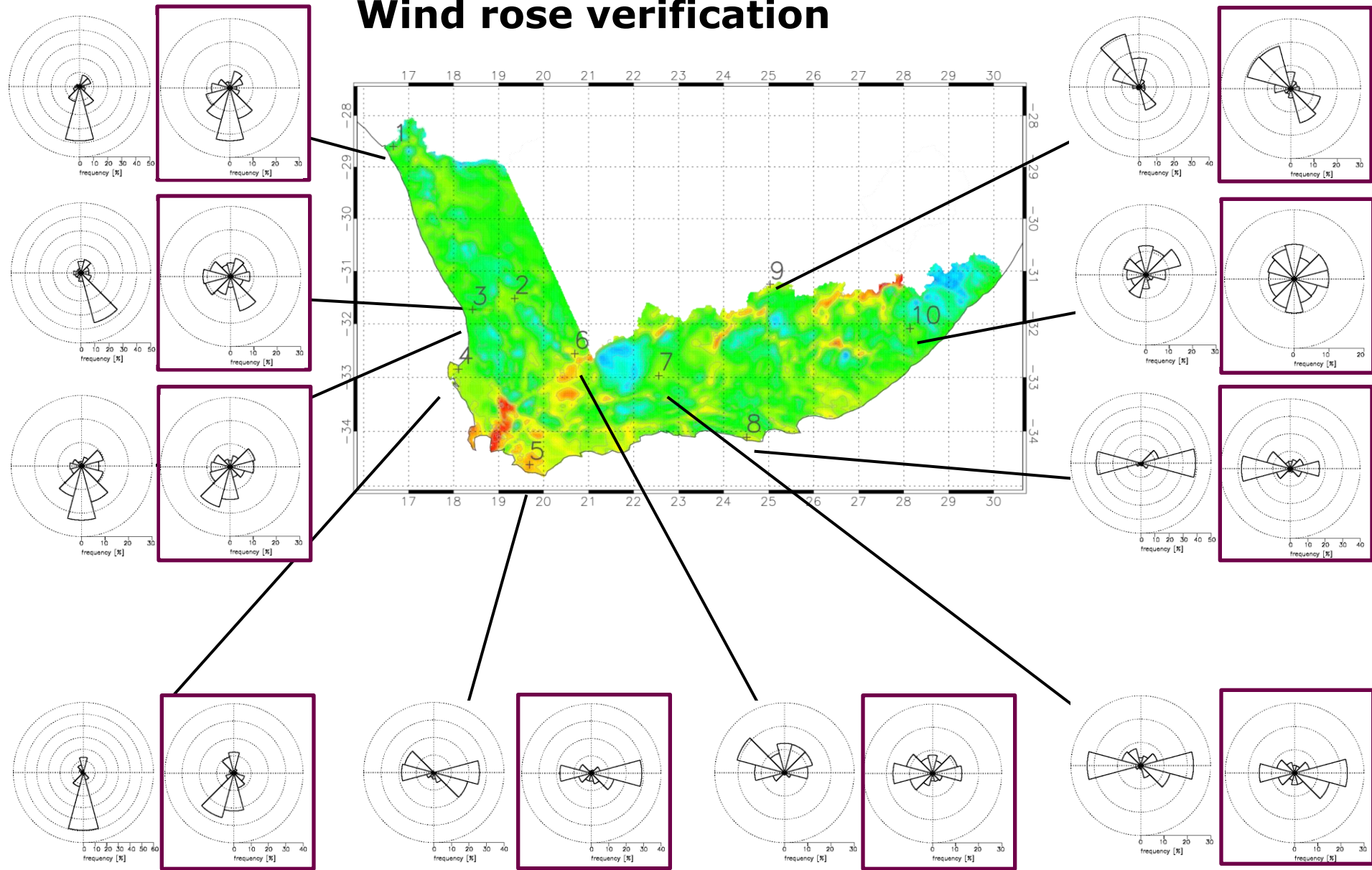
Comparing mean of observation period will not give climatological mean.

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

$f_i^{\text{obs period}}(x, y)$ = frequency of wind class i , a function of x and y for measurement period.

$\bar{u}^{\text{obs period}}(x, y, z)$ = mean wind for observation period.

Wind rose verification



Boxed wind roses derived from observation, unboxed derived from KAMM/WASP.

Wind speed verification

generalized annual mean wind speed at 100 m, z0 = 3 cm [m/s]				
Met mast	OBS Wind Climate	NUM Wind Climate	Error [%]	Configuration
1	6.16	5.33	-13.47	SA5050_m7
2	6.62	7.01	5.89	SA5050_m7
3	7.19	6.63	-7.79	SA5050_m7
4	7.33	7.19	-1.91	SA2050_02
5	8.99	8.35	-7.12	SA2050_02
6	7.44	7.24	-2.69	SA2050_02
7	7.45	6.61	-11.28	SA2050_02
8	7.71	7.66	-0.65	SA2050_02
9	7.5	7.58	1.07	SA3050_03
10	6.32	6.09	-3.64	SA3050_03
		mean error	-4.16	
		mean absolute error	5.55	

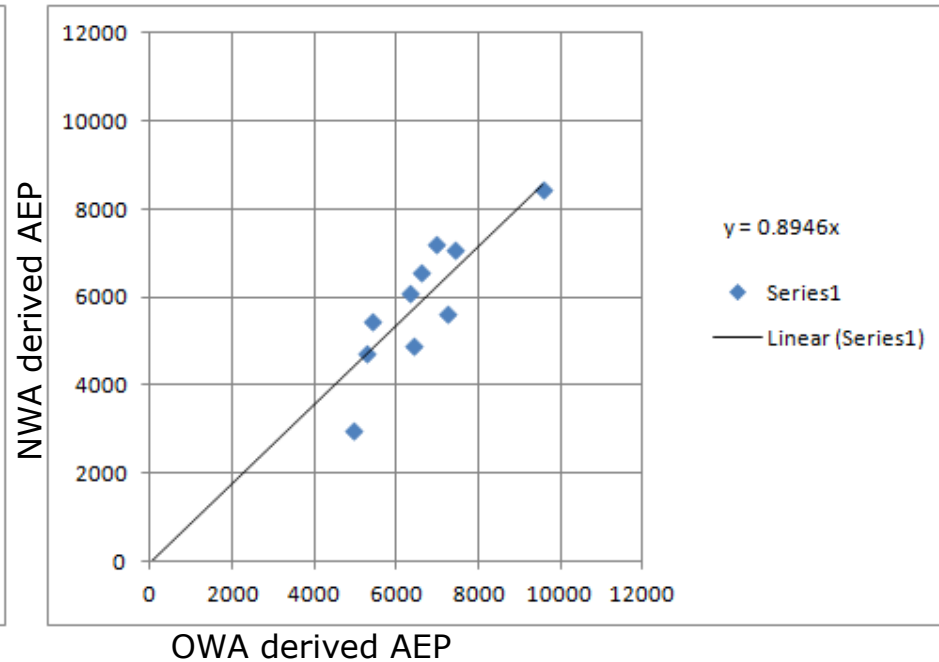
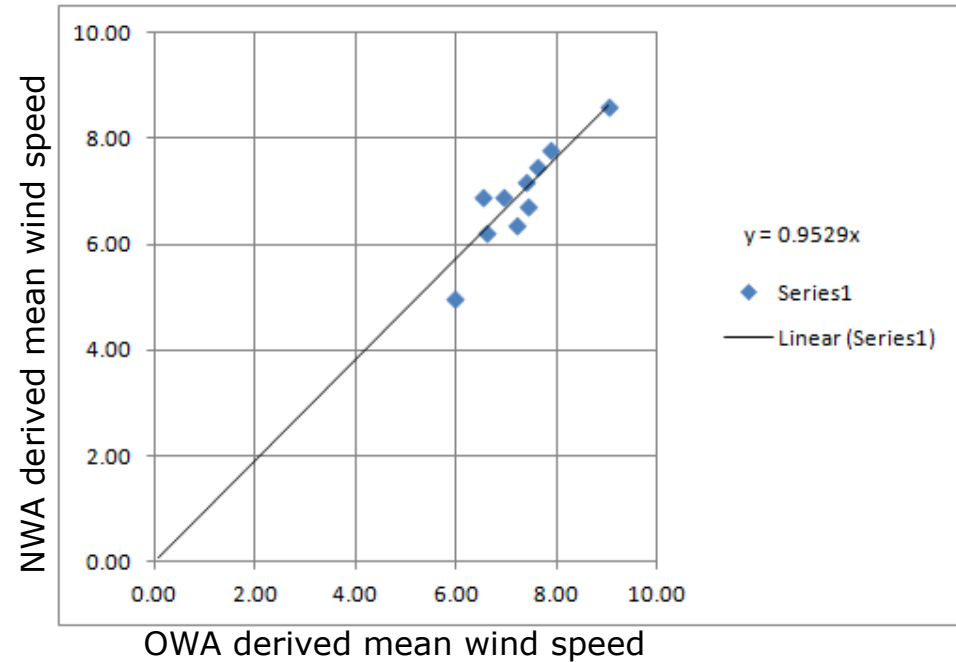
Uncertainty characteristics are in line with state-of-art.

Site verification on speed and power production at measurement masts

Numerical wind atlas (NWA) derived plotted against observational wind atlas (OWA) derived

Wind speed at 80m
[m/s]

Power production
2 MW turbine V90 80 m hub height
[MWh per year]



Recommendations and discussion

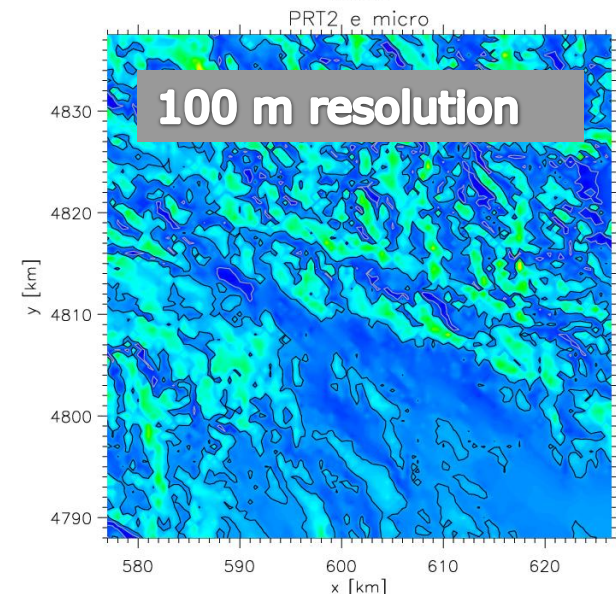
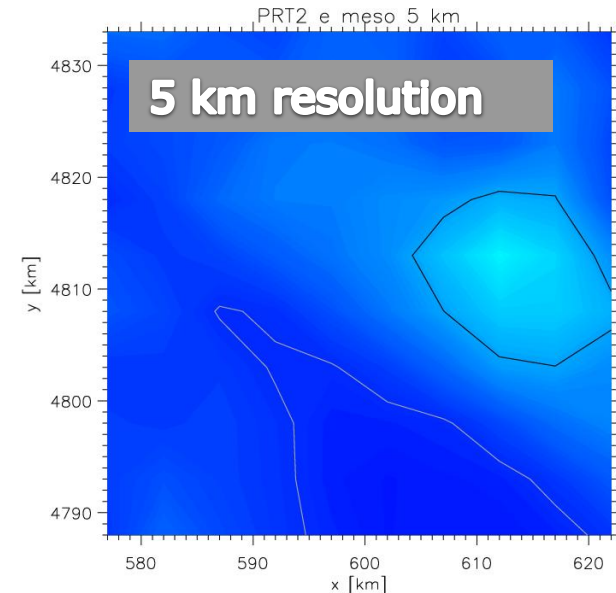
Application of numerical wind atlas

The generalized wind climate information is contained in files that can be used by WAsP to calculate resource information at microscale.

The application of WAsP is necessary for most complete assessment of wind resource, due to strong influence of orography and roughness features of wind power density.

Use of WAsP requires all appropriate considerations and cautions for WAsP application

e.g. Complex terrain, stability correction.

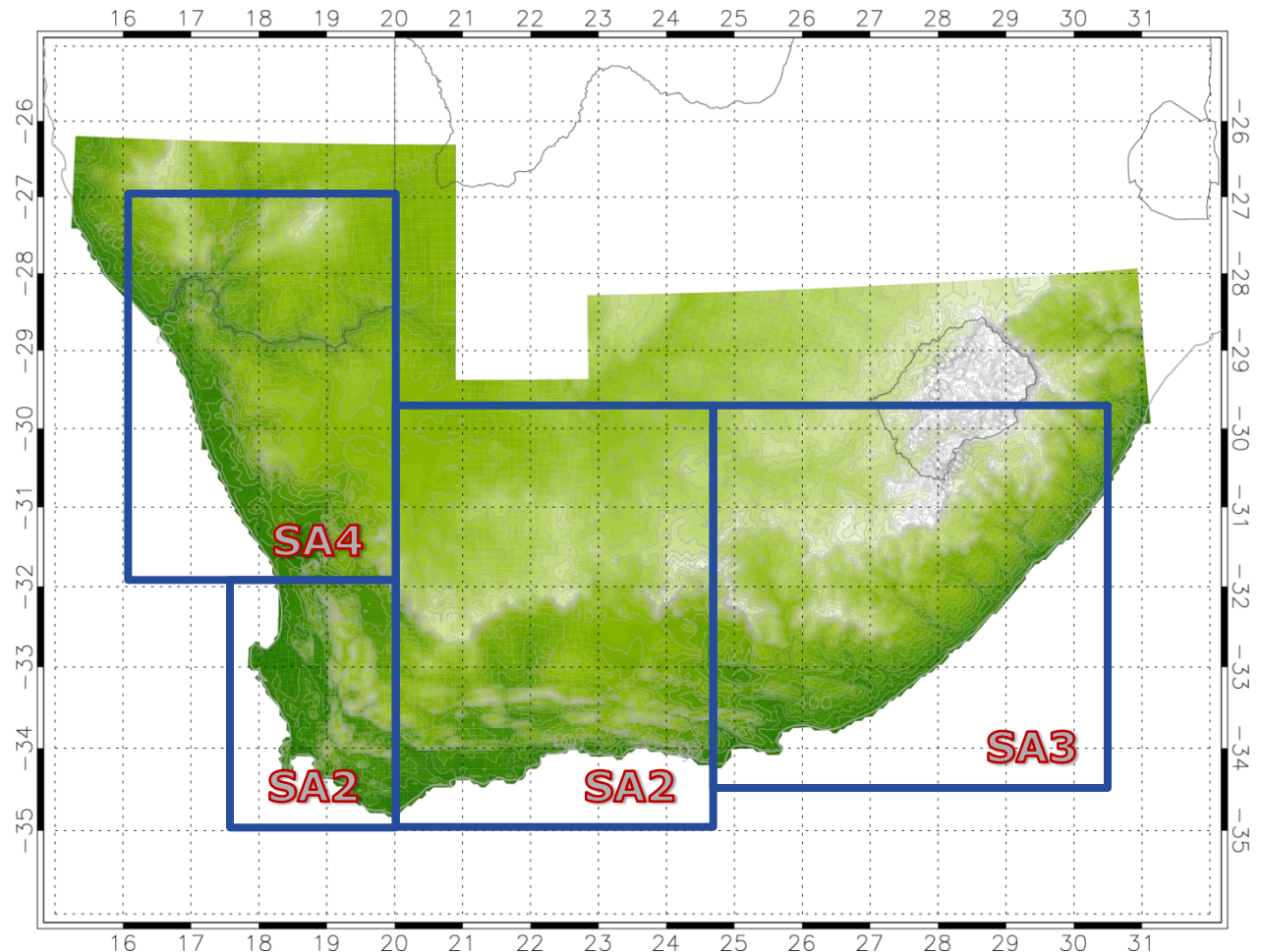


Recommendations and discussion

Issue: overlapping domains

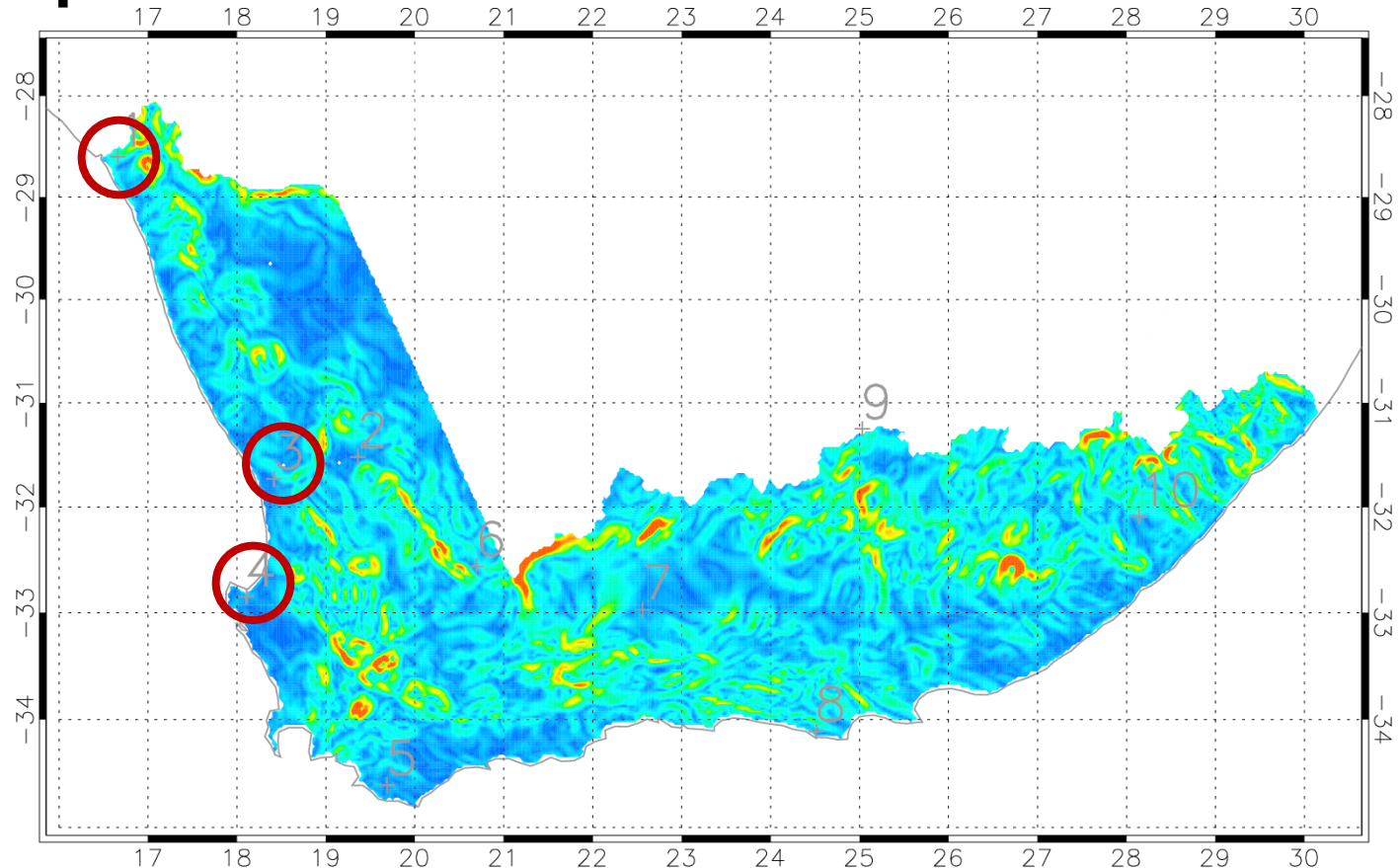
Presently, the generalized wind atlas files are available from the 3 modelling domains on Tadpole

For user-friendliness, Tadpole also gives, within a single dataset, libfiles selected from the modelling domains according to the figure.



Uncertainty and relation to horizontal gradients of mean wind speed

Mast	Error %
1	-13
7	-11
3	-8
5	-7
2	6
10	-4
6	-3
4	-2
9	1
8	-1



Gradient of mean wind speed can be a indicator of uncertainty

Recommendations and discussion

Comparison with WRF

On average WRF gives a higher annual mean wind speed.

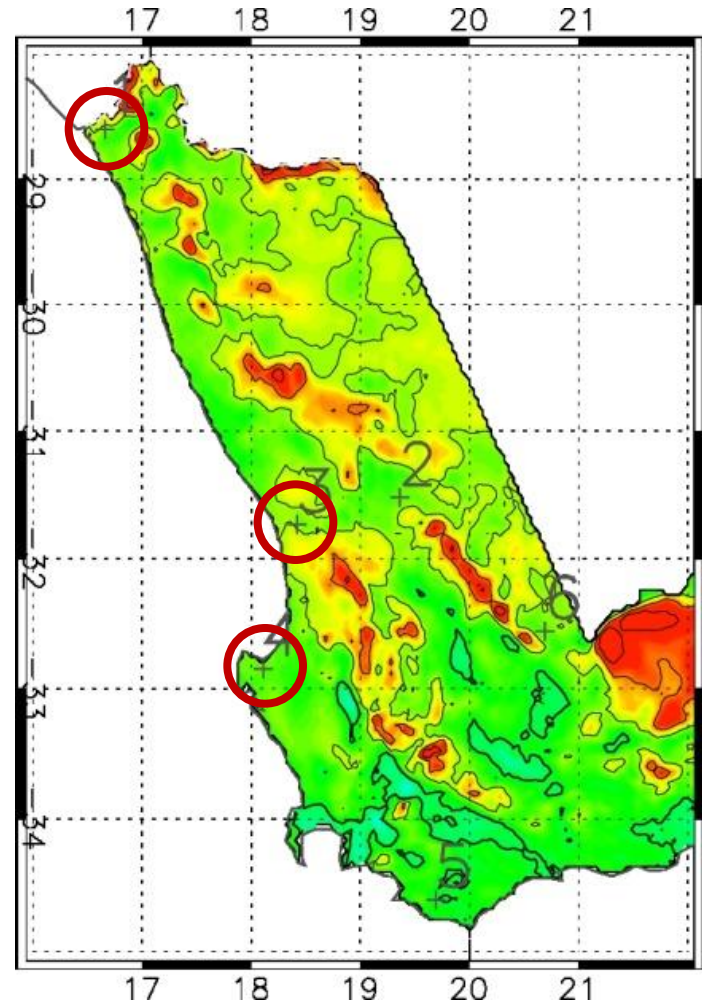
Difference in annual mean wind speed is not uniform.

Need to investigate the causes of these differences.

Some the difference are due to different downscaling method.

Differences in WRF and KAMM results can be an indicator of uncertainty.

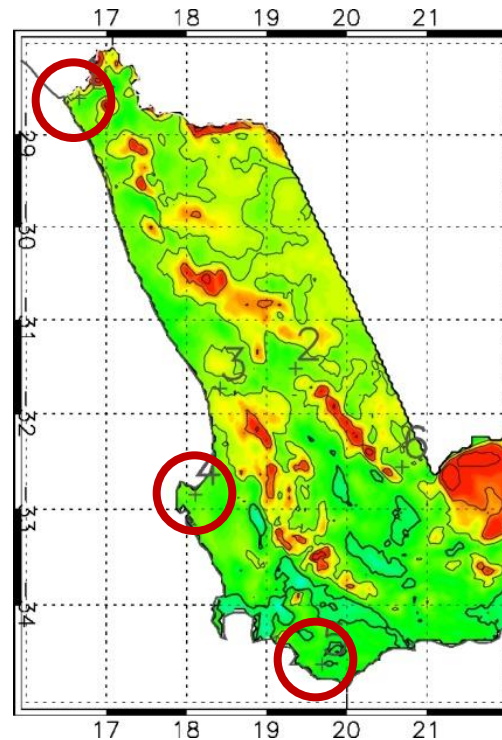
Relative difference between WRF and KAMM atlas winds at 100m



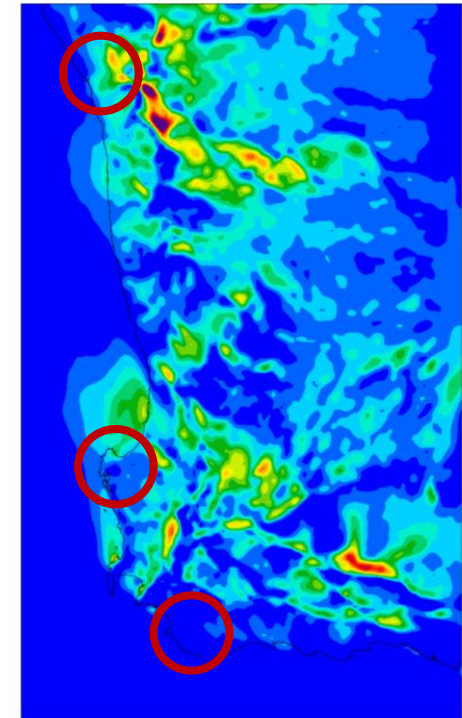
Recommendations and discussion

Comparison with WRF

Mast	Error %
1	-13
3	-8
5	-7
2	6
6	-3
4	-2



2011-01-01 to 2011-01-31



Diurnal variation given by WRF can be an indicator of uncertainty on KAMM.



2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
kinetic energy
power [m^2/s^2] in
the diurnal range
(22-26 hours)

Conclusions

- Numerical wind atlas method presented
- Special set-up required for South Africa
- Uncertainty assessed
- Uncertainty is in line with expectation using this method
- Public domain
 - Everyone can access and use the data
- Output is compatible with industry standard tools
- Traceable and transparent
- This is the first phase
- It is the basis for further development
 - WRF
 - Deeper analysis of uncertainty and recommendations
 - Downscaling to microscale



Appendix

First results from WRF and an alternative downscaling method

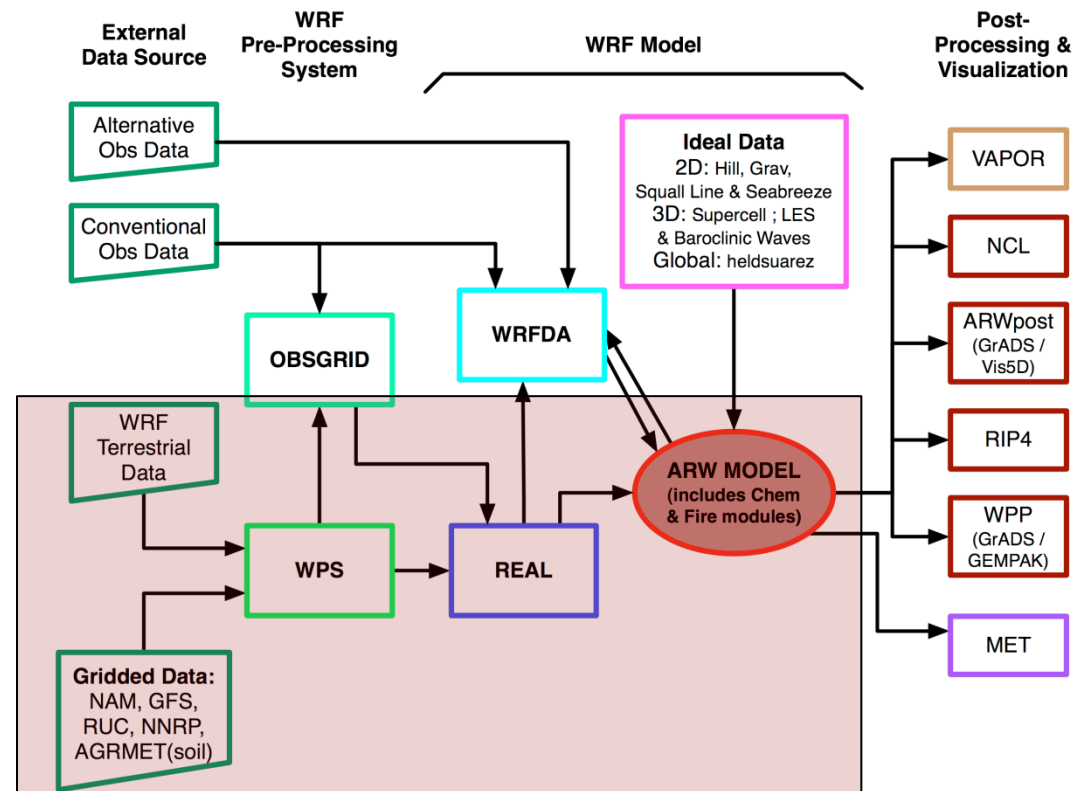
Dynamical downscaling using WRF

- To get a handle on the strength of thermally driven circulations (not represented in KAMM/WAsP method) along the west coast of South Africa we use simulation with a fully dynamical mesoscale model
- These simulations will be the base of the work on WASA Phase 2

The Weather Research and Forecasting model

The Weather Research and Forecasting (WRF) model is a numerical weather prediction (NWP) and atmospheric simulation system designed for both research and operational applications. The WRF model is open source, and reflects flexible, state-of-the-art, portable code that is efficient in computing environments ranging from massively-parallel supercomputers to laptops.

WRF Modeling System Flow Chart



What is the difference between KAMM and WRF

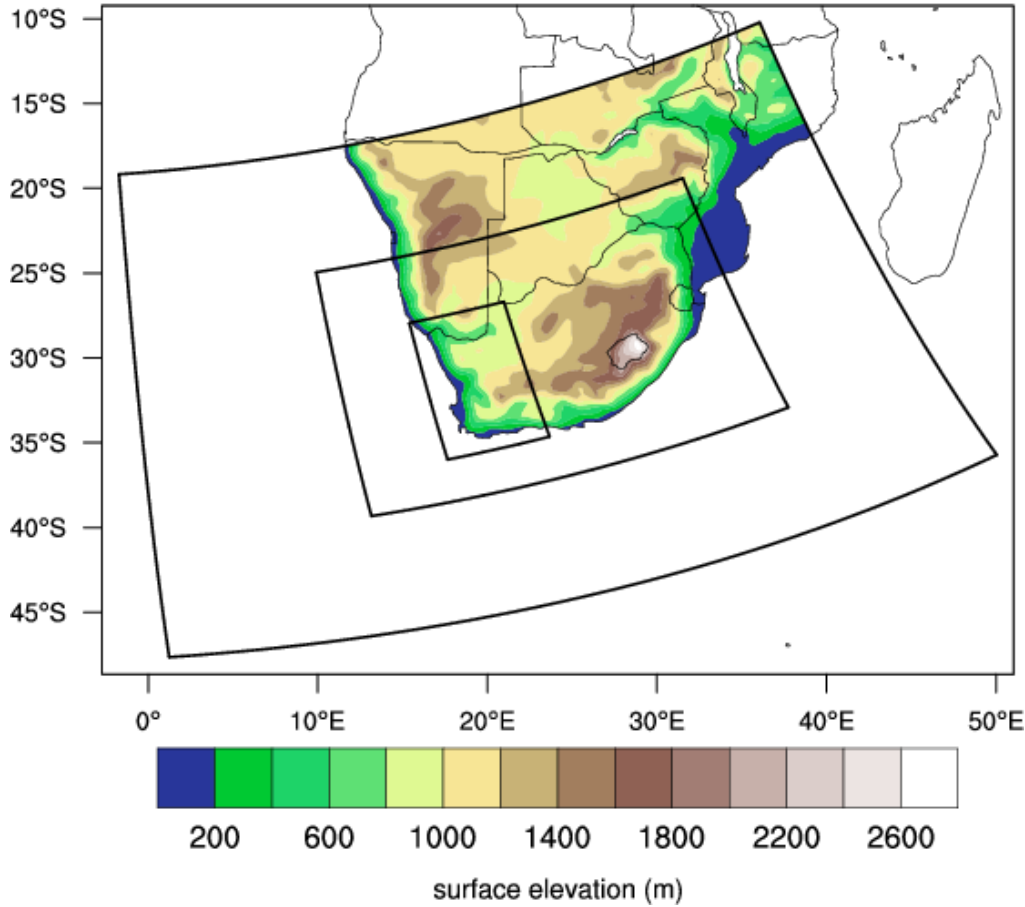
KAMM (1st wind atlas)

- “steady-state” simulations from 100+ wind situations (sets of initial conditions)
- each initialized with a single vertical representation of the atmosphere
- lower boundary conditions: uniform land and sea temperatures

WRF (WASA phase 2)

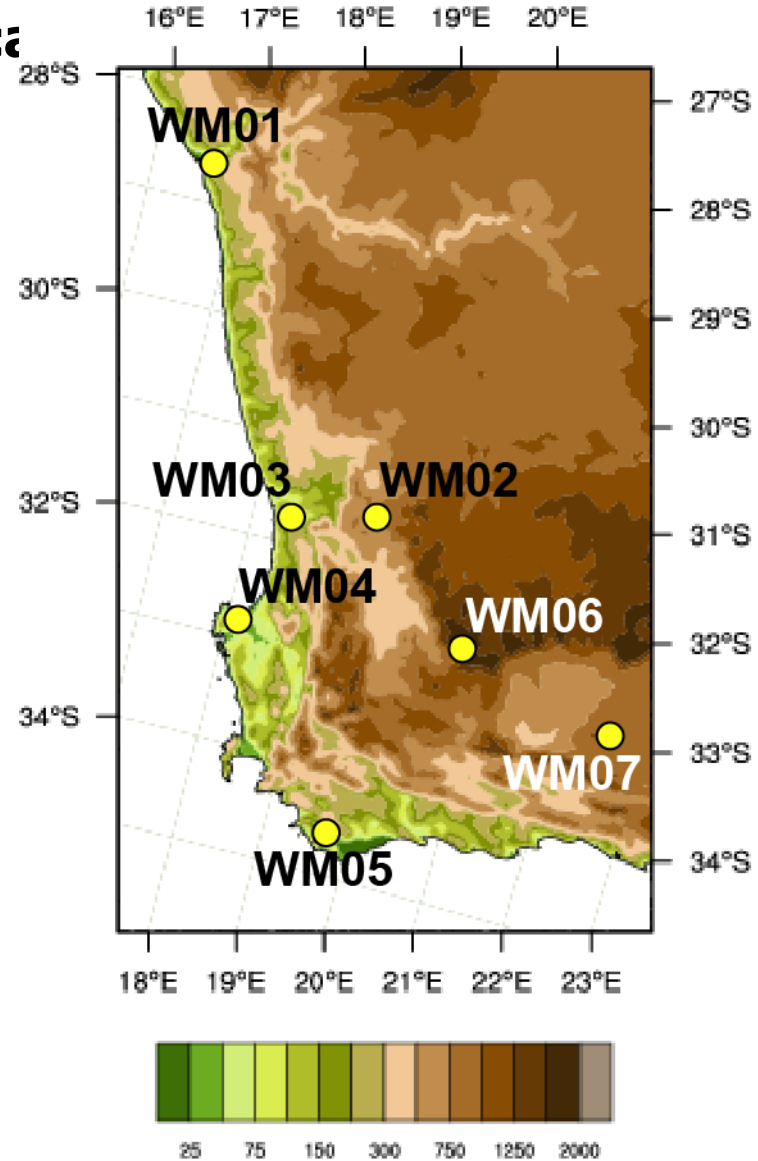
- “sequential” simulation that provides time-series for each grid point in the domain
- initialized with a 3 dimensional state of the atmosphere
- lower boundary conditions: interactive land + time-varying sea surface temperatures

WRF, DOMAIN 1, $\Delta x=36.0$ km



Africa

WRF, DOMAIN 3, $\Delta x=4.0$ km



WRF V3.2.1 – 36/12/4km domains
October 2010 - September 2011

Preliminary validation

Oct 2010-Sep 2011

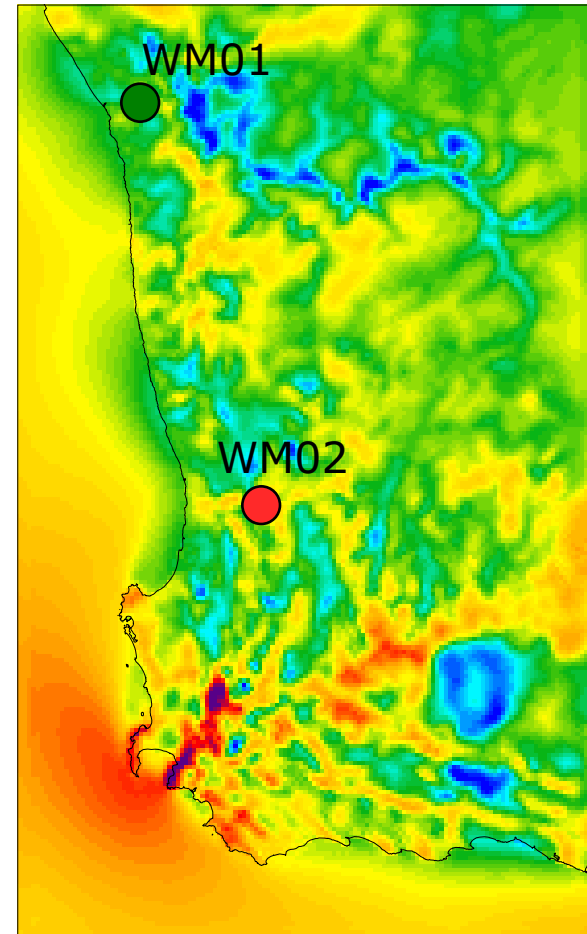
Comparison of measured and simulated generalized 100 meter wind speed - October 2010 to September 2011

	U Obs (m/s)	U WRF (m/s)	U bias (m/s)	Absolute Error
WM01	6.59	6.39	3%	3%
WM02	6.74	7.82	-16%	16%
WM03	7.32	6.99	5%	5%
WM04	7.40	7.77	-5%	5%
WM05	8.82	8.50	4%	4%
WM06	7.56	8.25	-9%	9%
WM07	7.67	7.00	9%	9%
Mean Absolute Error:				7%

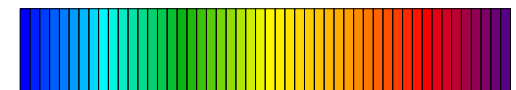
Oct 2010-Sep 2011 time-mean wind speed (m/s) at 100 meters

Oct 2010-Sep 2011

Height: 100 meters



mean wind speed (m/s)



4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5

Comparison of measured and simulated 62 meter winds at WM01 - Oct 2010 to Sep 2011 (1 year)

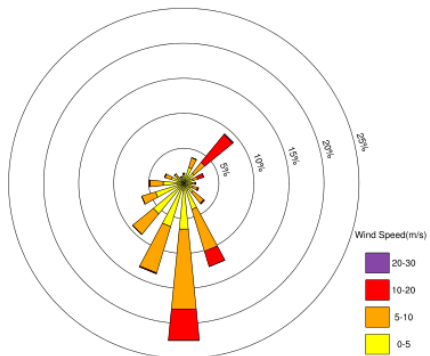
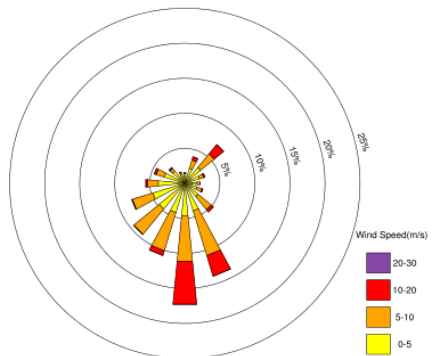
Averaged diurnal cycle
October 2010 - WM01



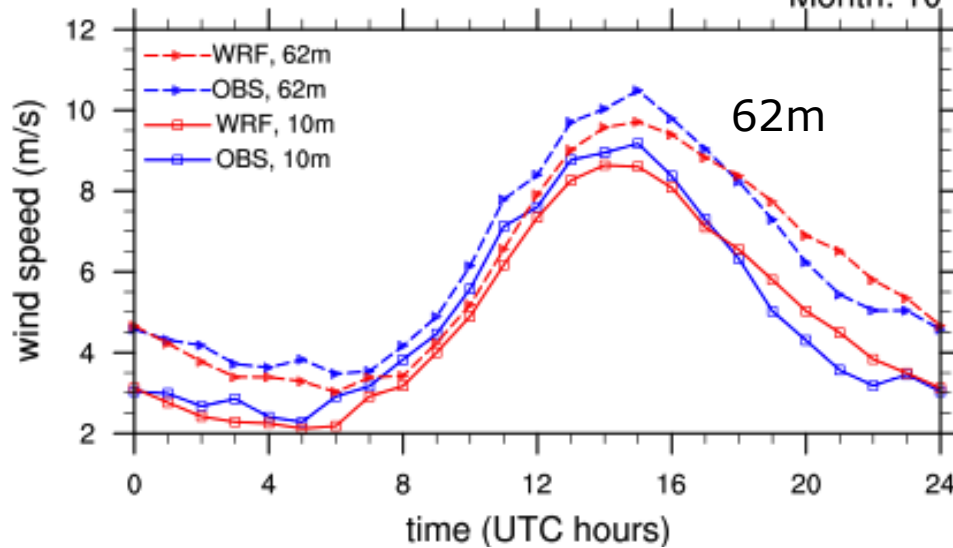
Month: 10

Winds at 62m - OBS

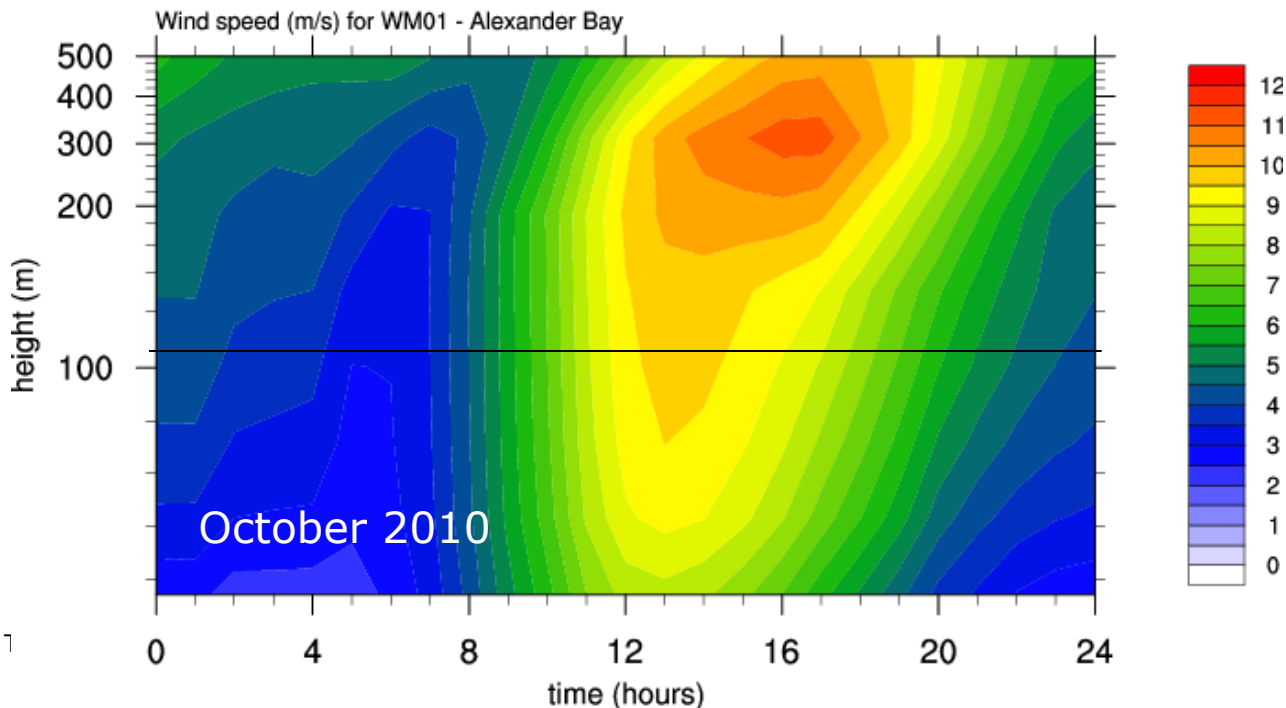
Winds at 62m - WRF



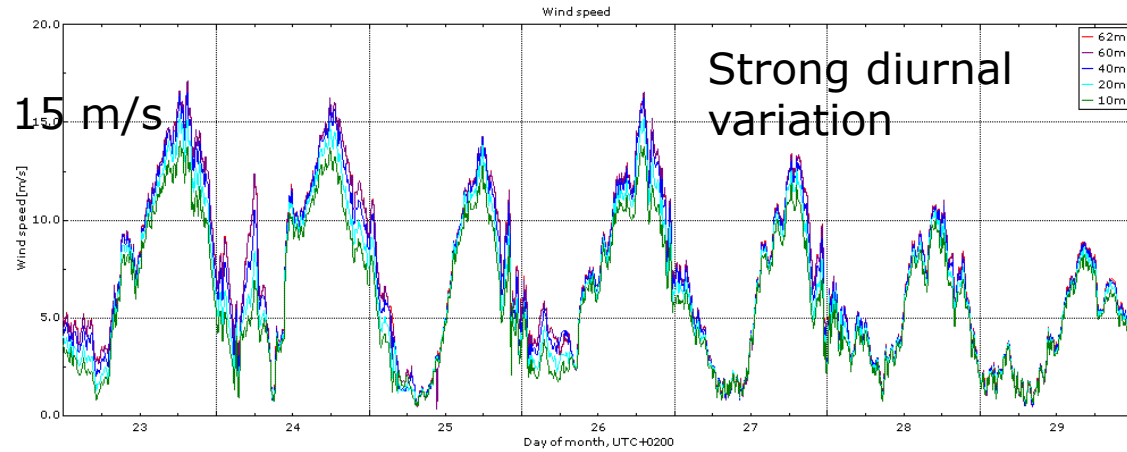
Excellent representation of the wind climatology



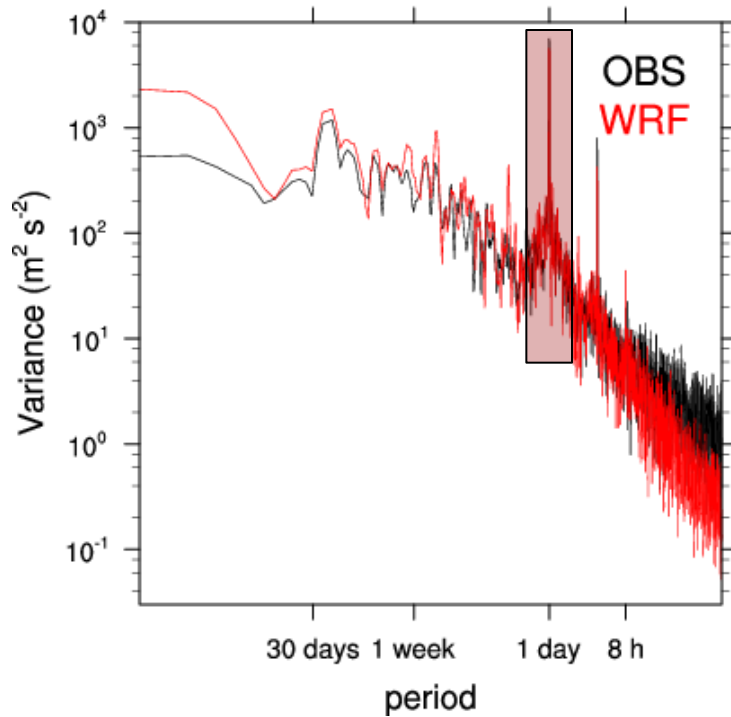
What mechanism(s) generates the strong diurnal cycle?



A week of measured wind speeds at WM01

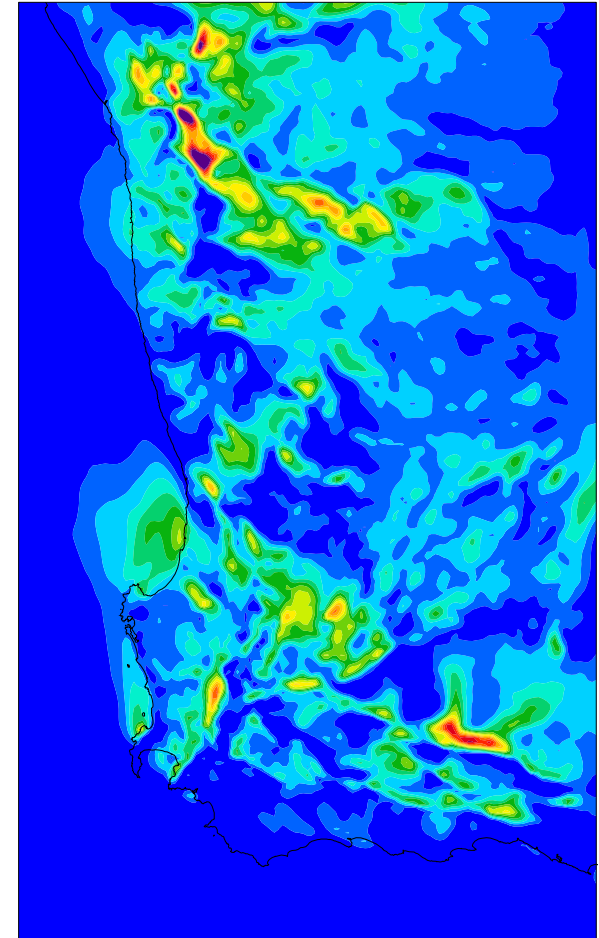


Wind speed - Spectra: WM01

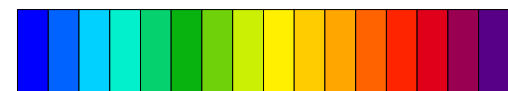


WRF simulation during January 2011

2011-01-01 to 2011-01-31



kinetic energy power (m^2/s^2) in the diurnal range (22-26 hours)



2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

THANK YOU FOR YOUR ATTENTION