

WP1:

Mesoscale modeling for the second verified WASA numerical wind atlas

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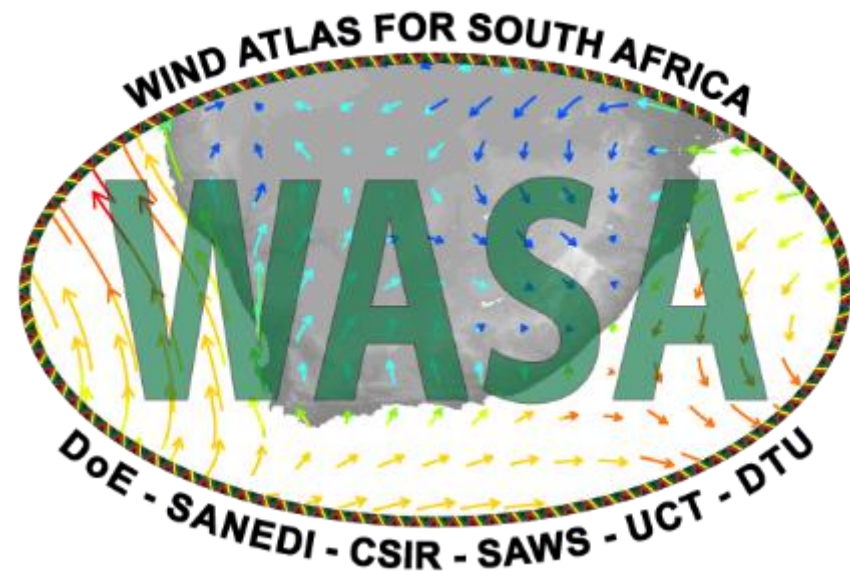
DTU Wind Energy, Risø Campus, Roskilde, Denmark

Chris Lennard and Brendan Argent

University of Cape Town, Cape Town, South Africa

Final WASA wind seminar

Cape Town, 8 April 2014



The following students at Univ. of Cape Town have been either direct or indirect beneficiaries of the WASA project and their work has helped in the understanding of the many aspects of wind climate of South Africa.

1. Graduated students

Christopher Broderick (B.Sc. Hons)

Using sodar for wind measurements: assessing the correlations of wind profiles from sodar, radiosonde and anemometer data.

Teboho Nchaba (M.Sc.)

Verification of gridded seasonal wind forecasts over South Africa.

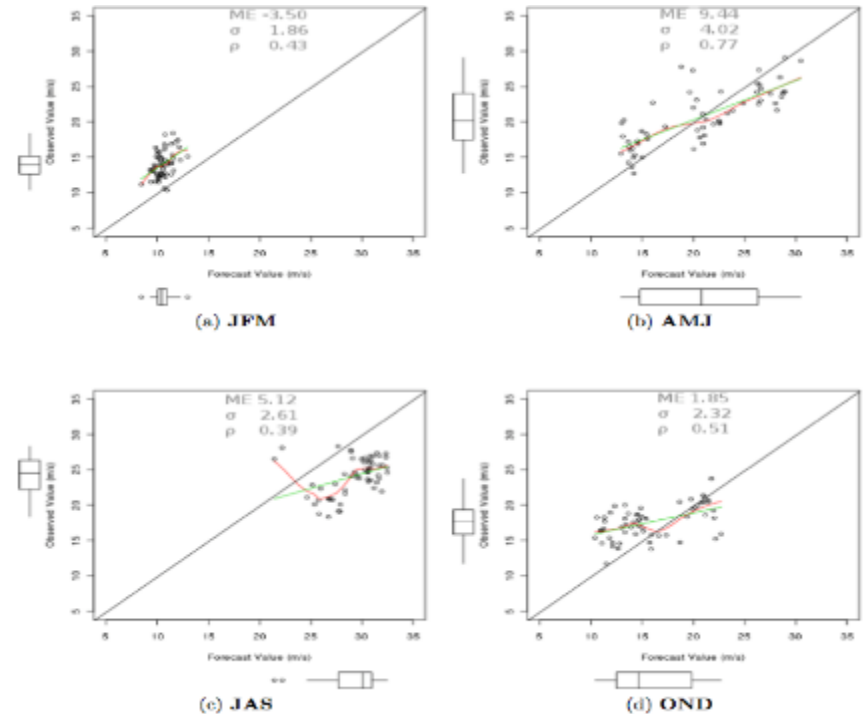
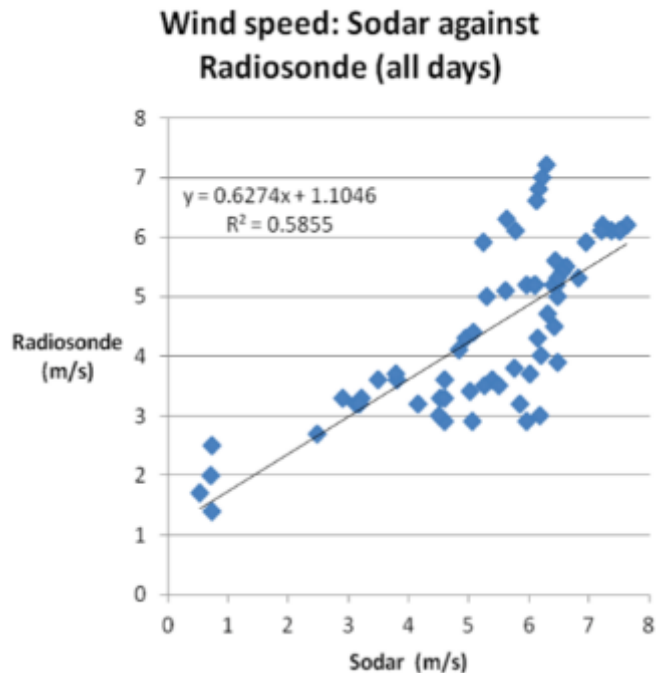


Figure 2. Distribution of wind speed forecasts and their matching observations over a 20 year period (1991 - 2010) at pressure level 100 hPa over the Western Cape.

2. Current Students

Brendan Argent (Ph.D., expected graduation end-2014)

Towards an Uncertainty Atlas for Wind Forecasts in South Africa

Teboho Nchaba (Ph.D., expected graduation end-2016)

Improved South African wind atlas from multi-model super-ensemble

Zaccheus Olaofe (Ph.D., expected graduation end-2017)

Assessment of offshore wind resource along the west coast of South Africa

Tich Mukunga (B.Sc. Hons, expected graduation end-2014)

Assessment of the wind power resource in the Sere region of the Western Cape

Outline

- Mesoscale modeling within the WASA project
- Brief introduction to downscaling methods
 - First verified wind atlas: KAMM/WAsP
 - Research-based: WRF modeling
- Generalization procedure
- Validation and comparisons of wind climate
- Validation of seasonal and diurnal cycles
- Available products
- Conclusions



The Wind Atlas for South Africa (WASA) Project

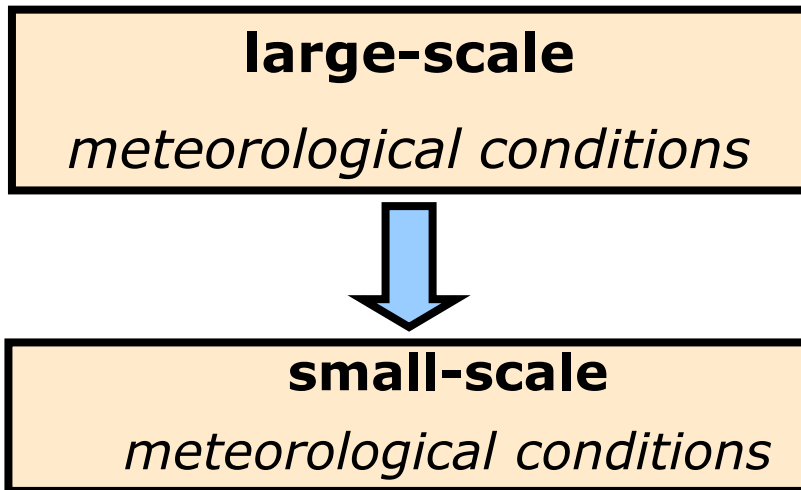
- Objectives: to develop, verify and employ numerical wind atlas methods and to develop capacity to enable large scale of exploitation of wind energy in South Africa.
- The project includes:
 - 10 measurement masts (top anemometer 62 meters); most sites operating September 2010 – present (data freely available: <http://wasadata.csir.co.za/wasa1/WASAData>)
 - Two numerical wind atlas; preliminary statistical-dynamical downscaling (KAMM/WAsP); final WRF-based dynamical downscaling
- Wind resource assessment and siting tools for planning purposes that can be used for feasibility studies in support of projects.
- First preliminary wind atlas made available in March 2012
- The (WRF-based) research-based wind atlas will be freely available to all interested parties on the completion of the project

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

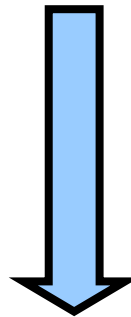
It uses the principle of **dynamical downscaling**



Dynamical downscaling

large-scale
meteorological conditions

Statistical-dynamical
downscaling:
KAMM/WAsP method
First Numerical Wind Atlas



Dynamical downscaling:
Weather Research and
Forecasting (WRF) model
New Research-based Wind Atlas

small-scale
meteorological conditions

What is the difference between the KAMM and WRF numerical wind atlases?

Statistical-dynamical method KAMM-based (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

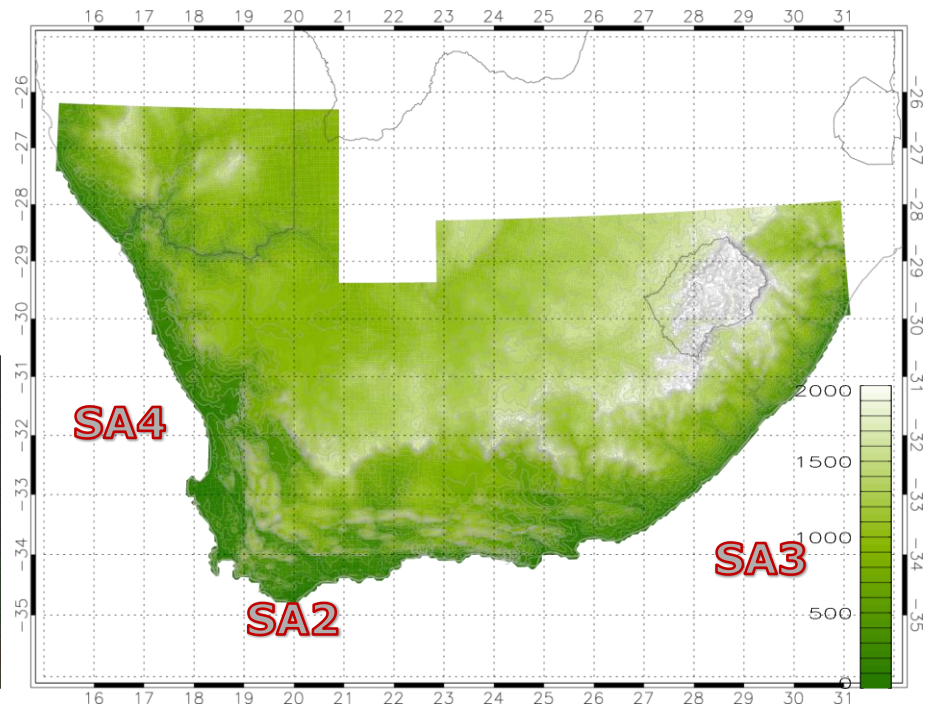
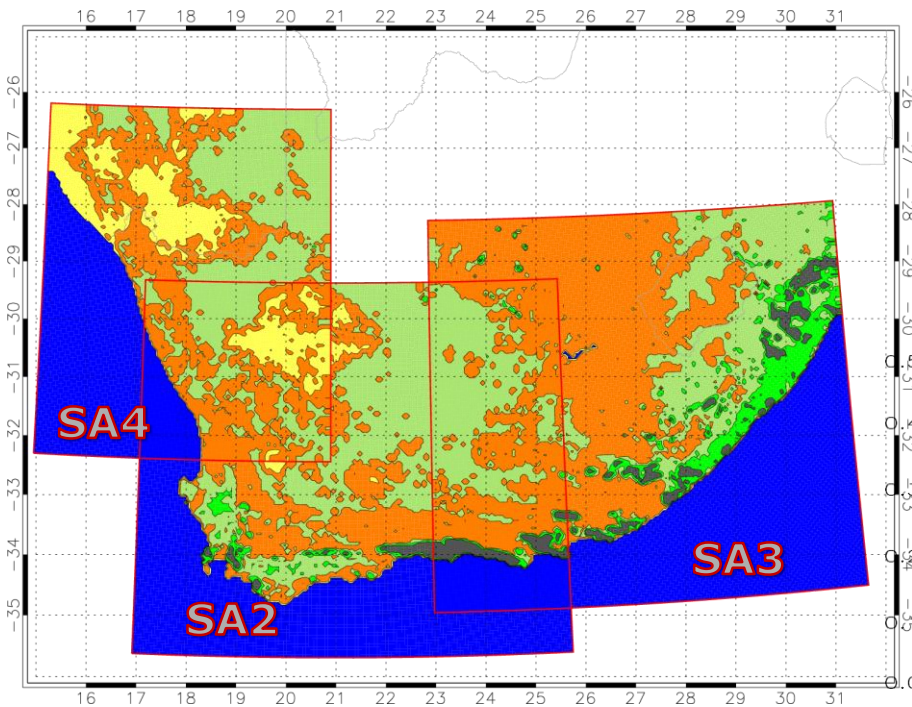
Dynamical downscaling WRF-based (WASA phase 2)

- “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

KAMM-based simulations

surface roughness

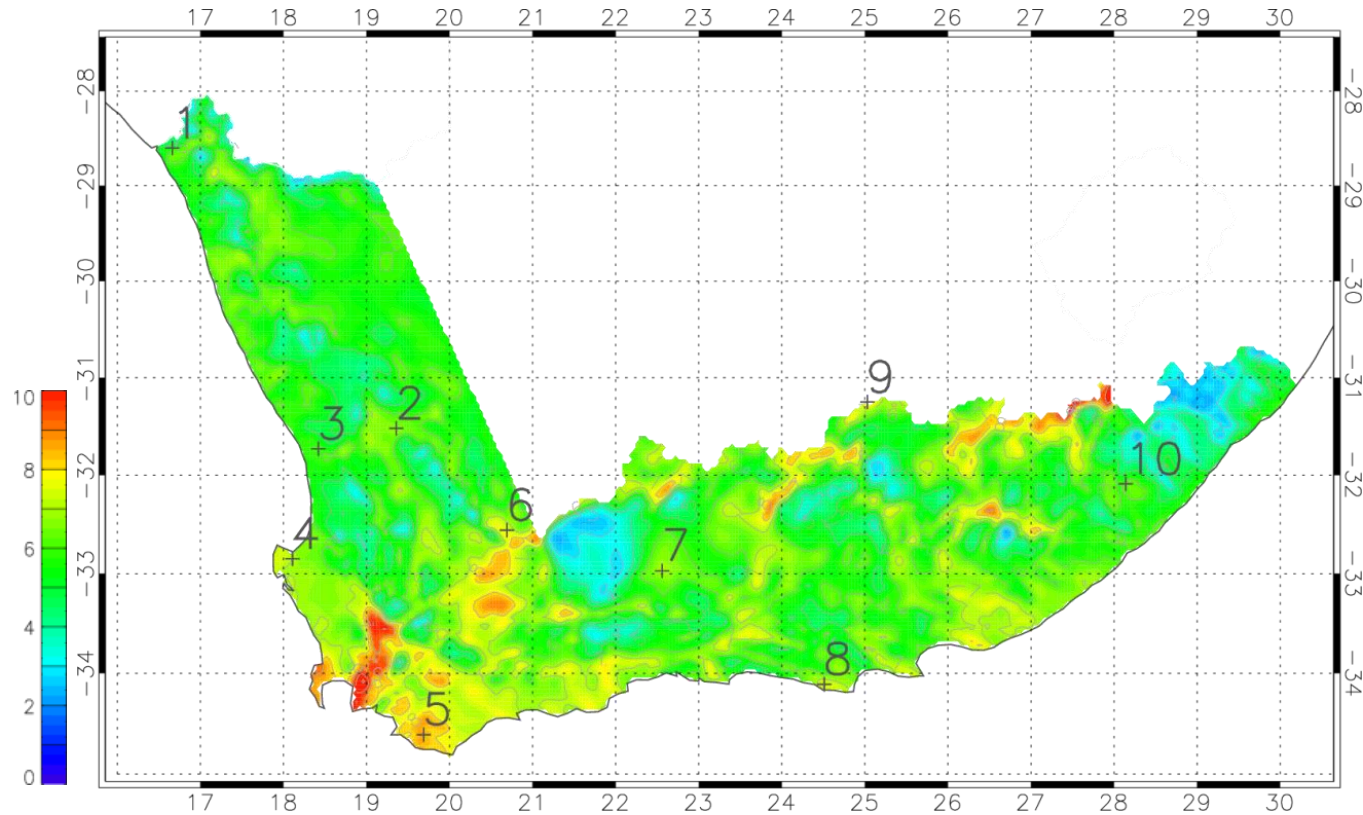
surface elevation



3 separate domains, 5 km grid spacing
 Simulations are run for each wind class until equilibrium
 is found between large-scale flow and detailed
 topography and roughness

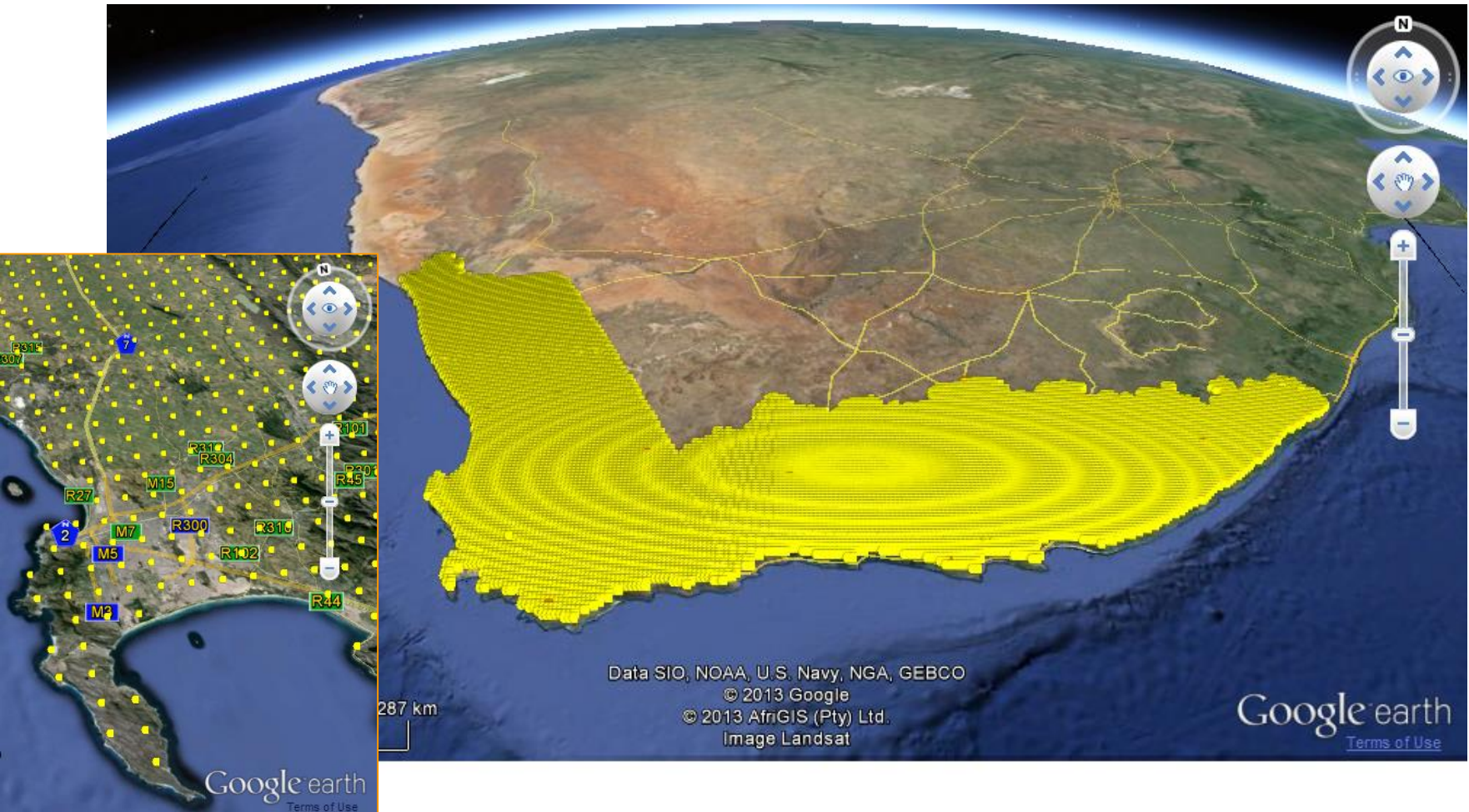
Verified Numerical Wind Atlas for South Africa VNWA launched March 2012

- the KAMM/WAsP method
- verified against 1 year of data
- a map – and much more



Generalized climatological (30-year) annual mean wind speed [m/s] 100 m above ground level, flat terrain, 3 cm roughness everywhere

First Verified Numerical Wind Atlas 2012

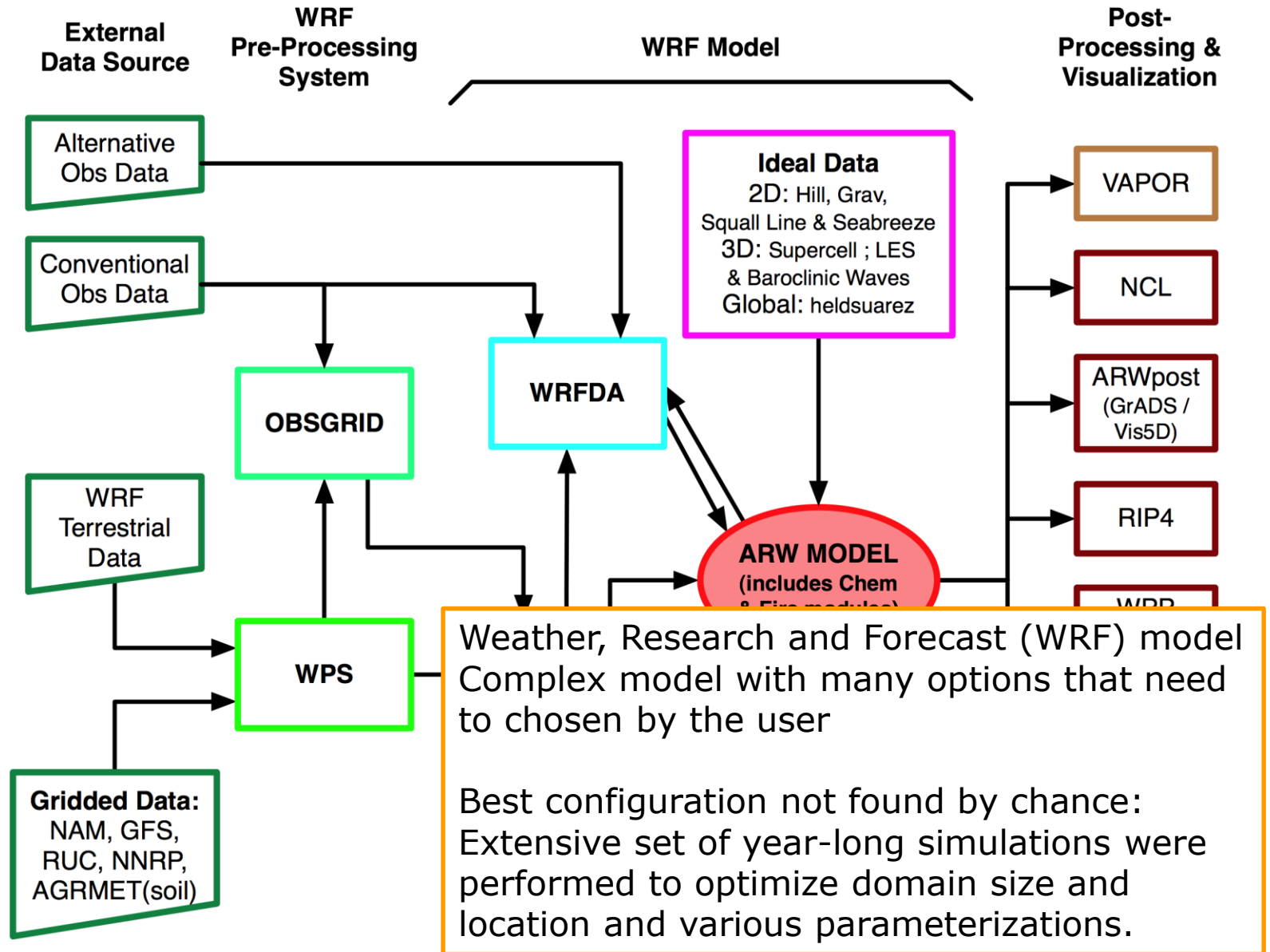


WRF-based simulations

Steps towards the new research-based new numerical wind atlas

- Determine optimal model configuration (some learned from previous wind atlases), others are new to WASA project
- Run simulations (18 days on a almost fully dedicated cluster; a total of 293 runs; each 6 hours, on 8 nodes)
- Data processing – output from simulations are 8Tb!
- Generalization and validation
- Generation of data products – still underway

WRF Modeling System Flow Chart

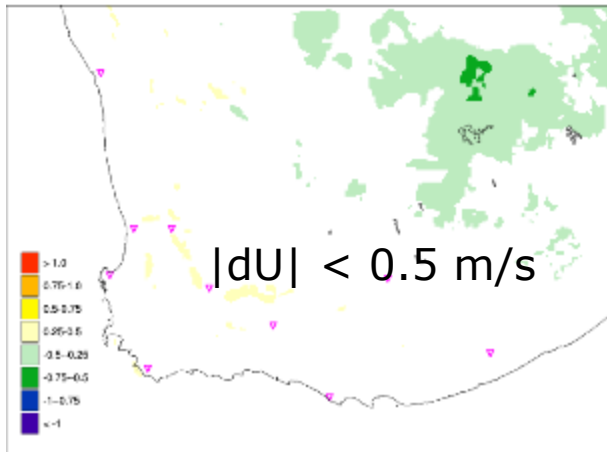


Sensitivity Experiments

One year-long (Oct 2010 – Sep 2011) simulations (5 km x 5 km grid)
 Compare mean annual wind speed (m/s) at 100 meters

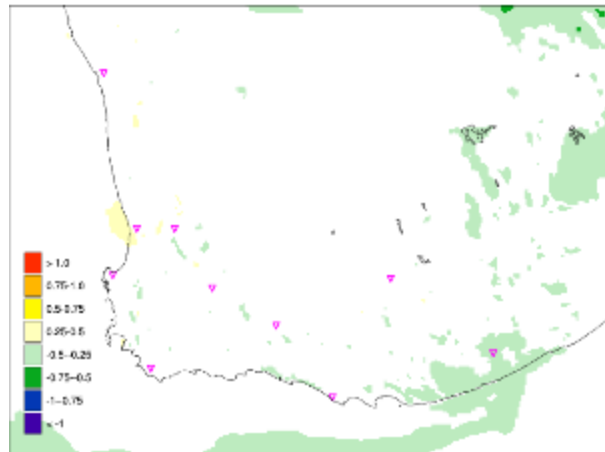
Forcing reanalysis

Mean wind speed (m/s) at 100 m Min:-0.53 Max: 0.39



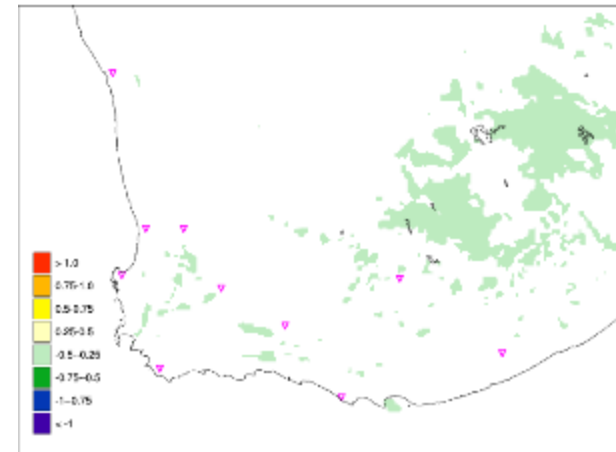
Boundary layer scheme

Mean wind speed (m/s) at 100 m Min:-0.55 Max: 0.49



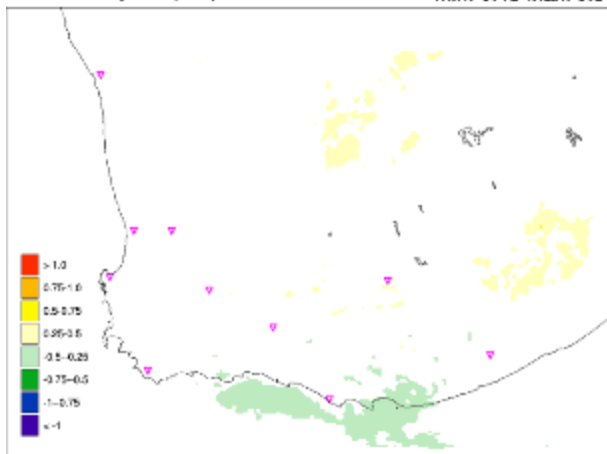
Radiative param

Mean wind speed (m/s) at 100 m Min:-0.42 Max: 0.22



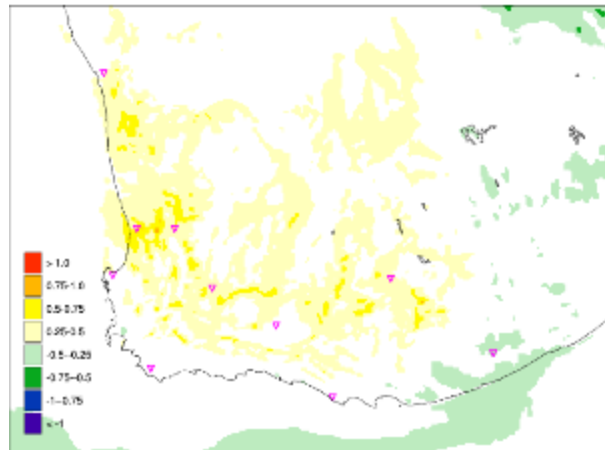
Convective param

Mean wind speed (m/s) at 100 m Min:-0.43 Max: 0.51



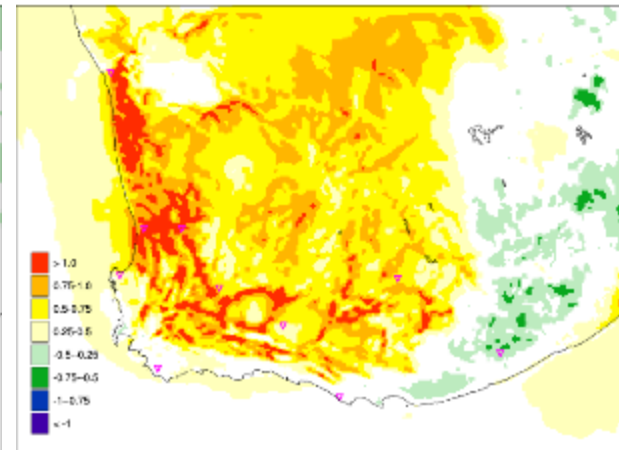
Land use class

Mean wind speed (m/s) at 100 m Min:-0.55 Max: 0.81



Land surface model

Mean wind speed (m/s) at 100 m Min:-0.75 Max: 2.07

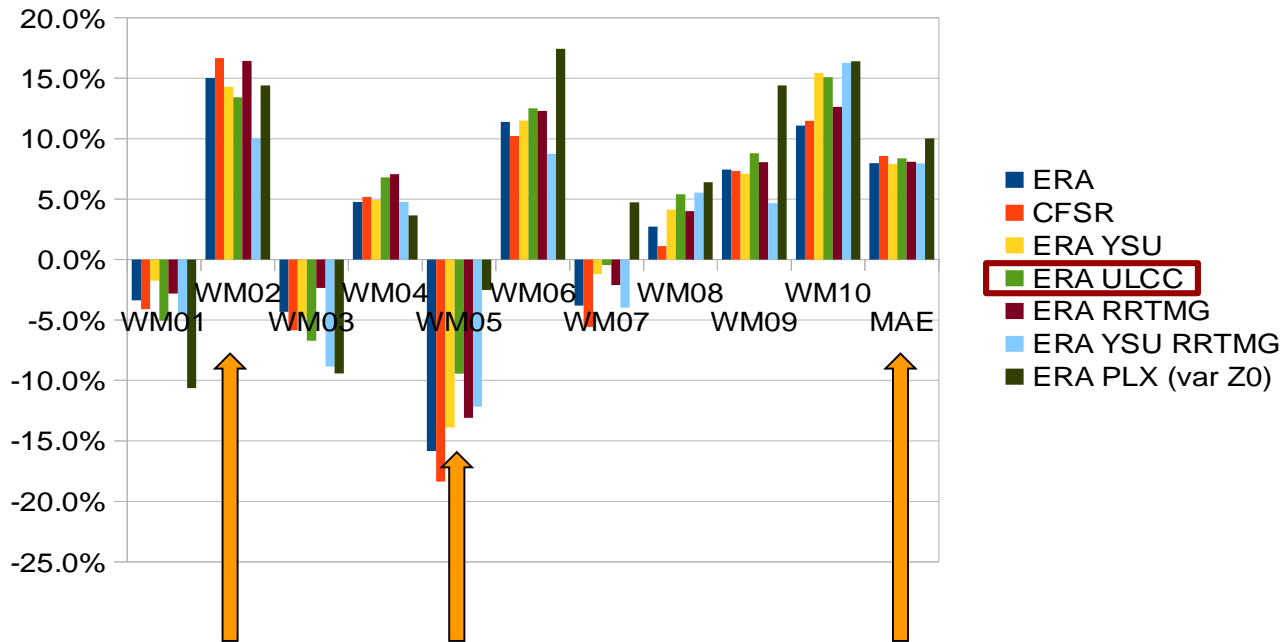


Results from the various sensitivity experiments

5 km x 5 km grid spacing

$$\text{Error} = (U_{\text{model}} - U_{\text{obs}}) / U_{\text{obs}}$$

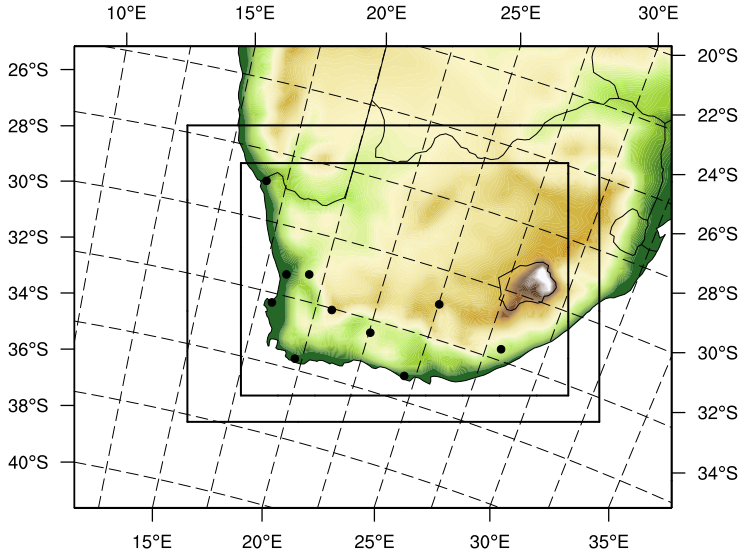
U = year-long mean generalized wind speed



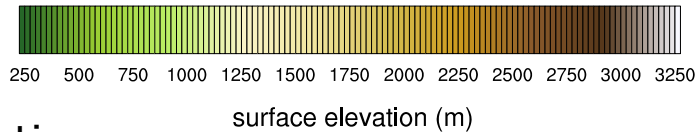
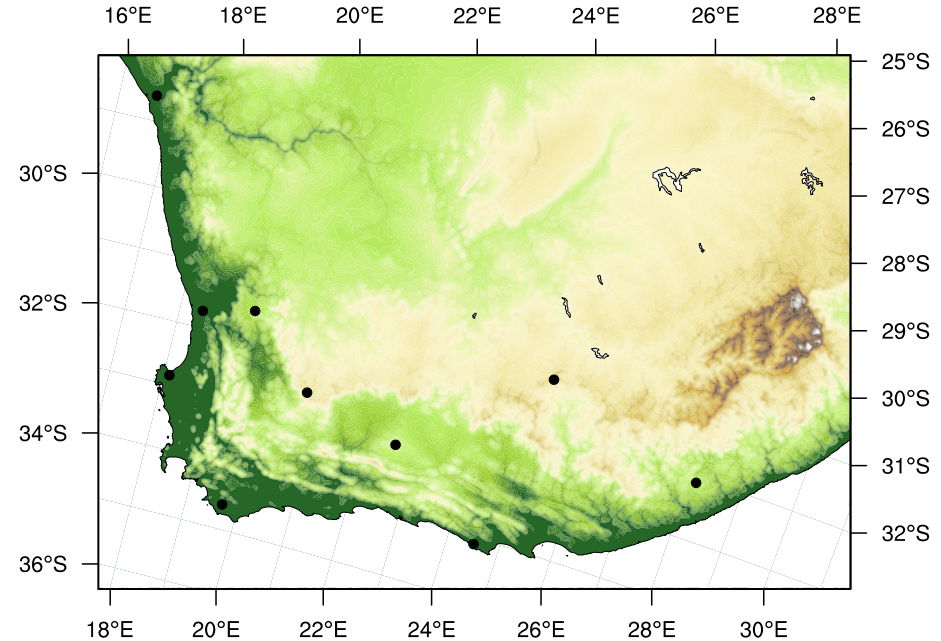
Error reduction
by using high-resolution

New research wind atlas: WRF Model Configuration

WRF, DOMAIN 1, $\Delta x=27.0$ km



WRF, DOMAIN 3, $\Delta x= 3.0$ km



Very large (309 x 435) inner grid (3km grid spacing)

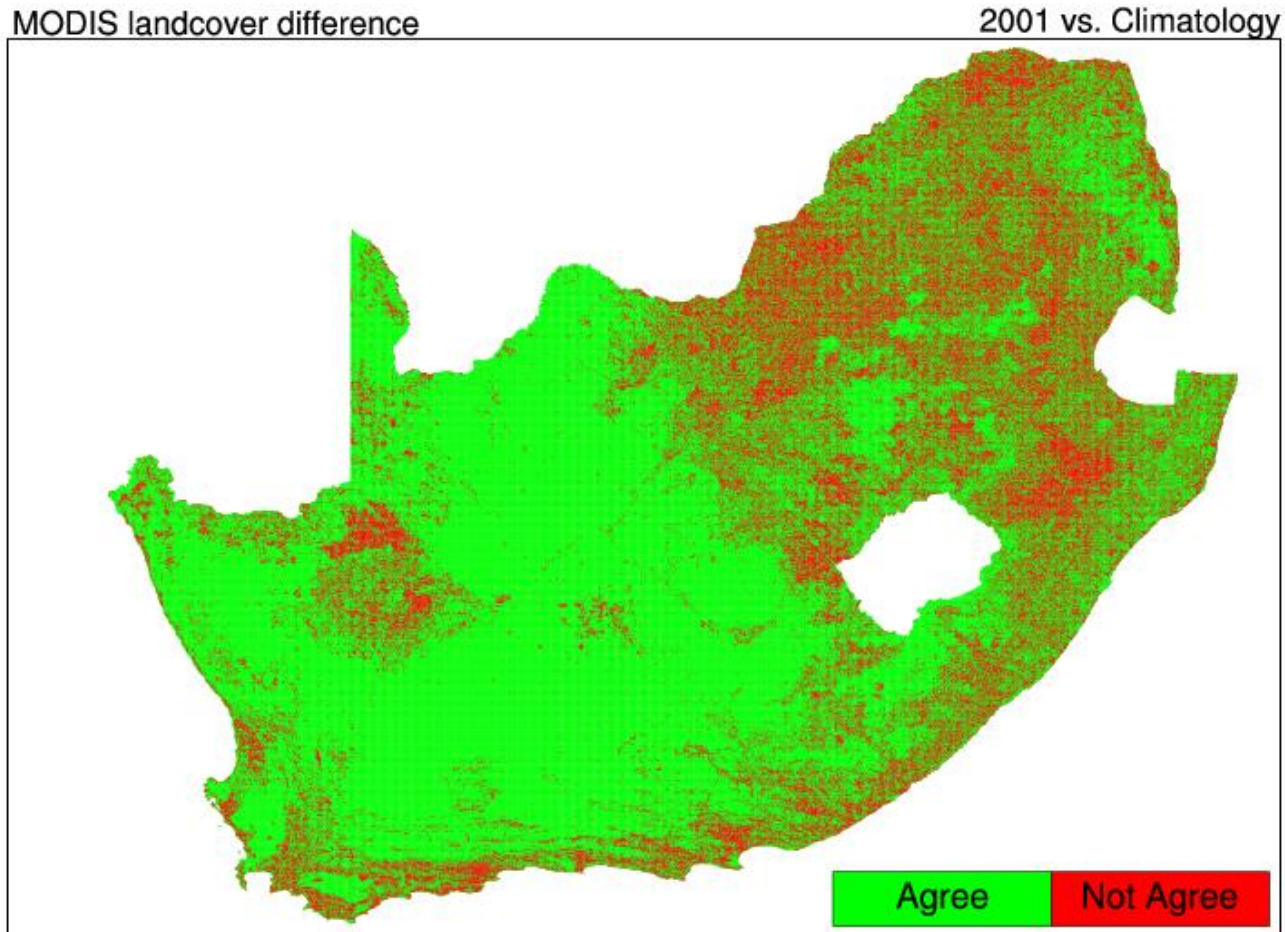
Changes to standard WRF land use and roughness

ERA-Interim forcing, 1/12 degree SSTs; MYJ PBL; 41 vertical levels (further details in incoming report)

Simulations:

8 years for (27/9/3 km) – 2005-2013; High-resolution SSTs;
24 years (27/9 km) – 1990-2013;

Difference in MODIS Landcover



Difference in land cover classes between what is currently used in WRF (1 year) and the new MODIS climatology (2001-2012)

MODIS – satellite-derived land cover

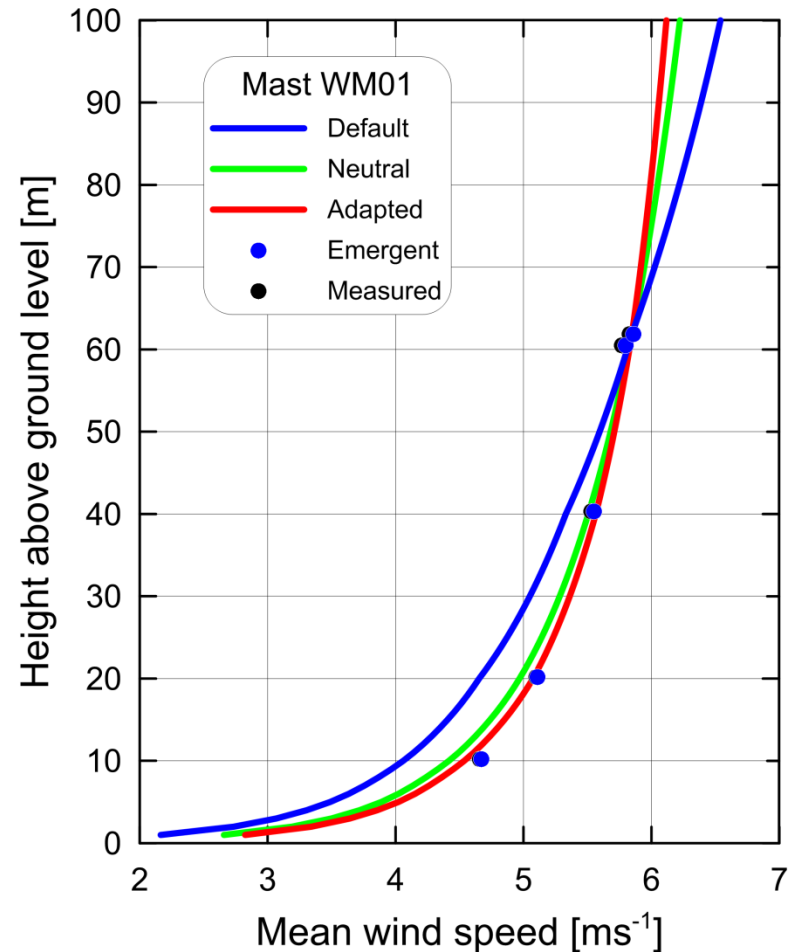
Microscale modelling at the 10 WASA masts

Some background

- Wind-climatological inputs
 - Three-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



This data was used to verify the numerical wind atlas, but **not** to create them

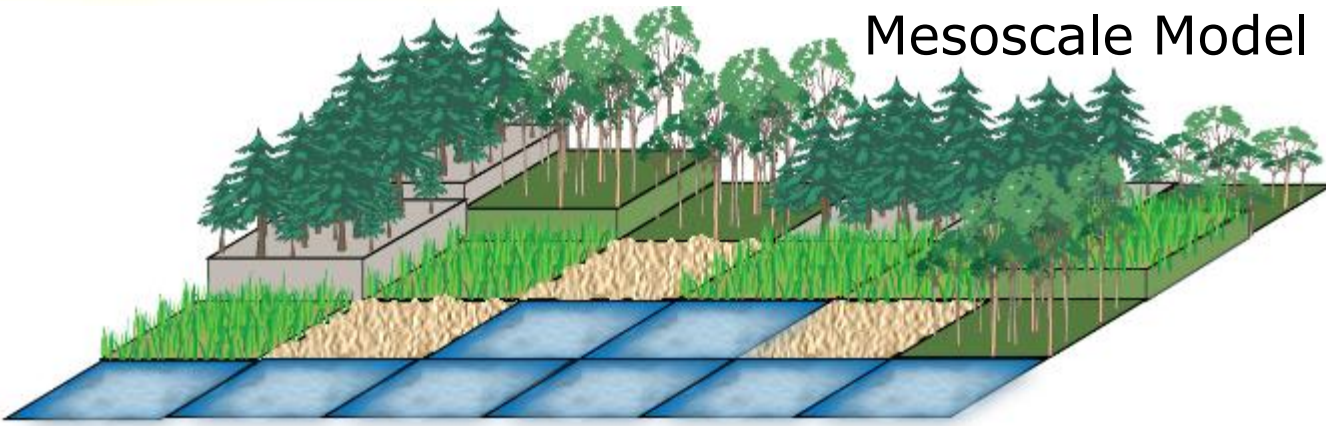
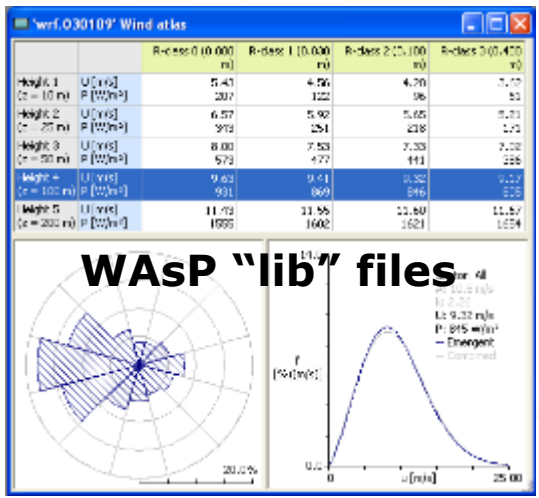
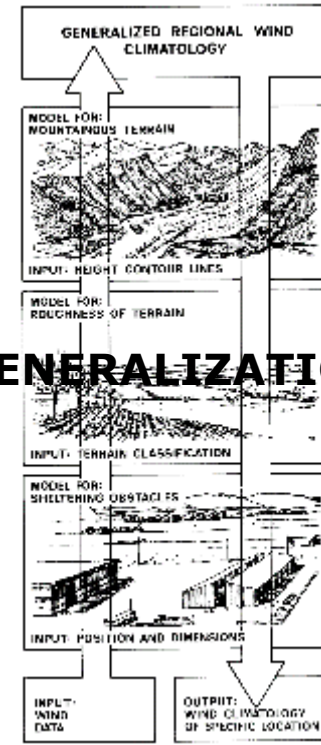
Analysis show prevalence of non-neutral conditions at the sites.

Validation after generalization

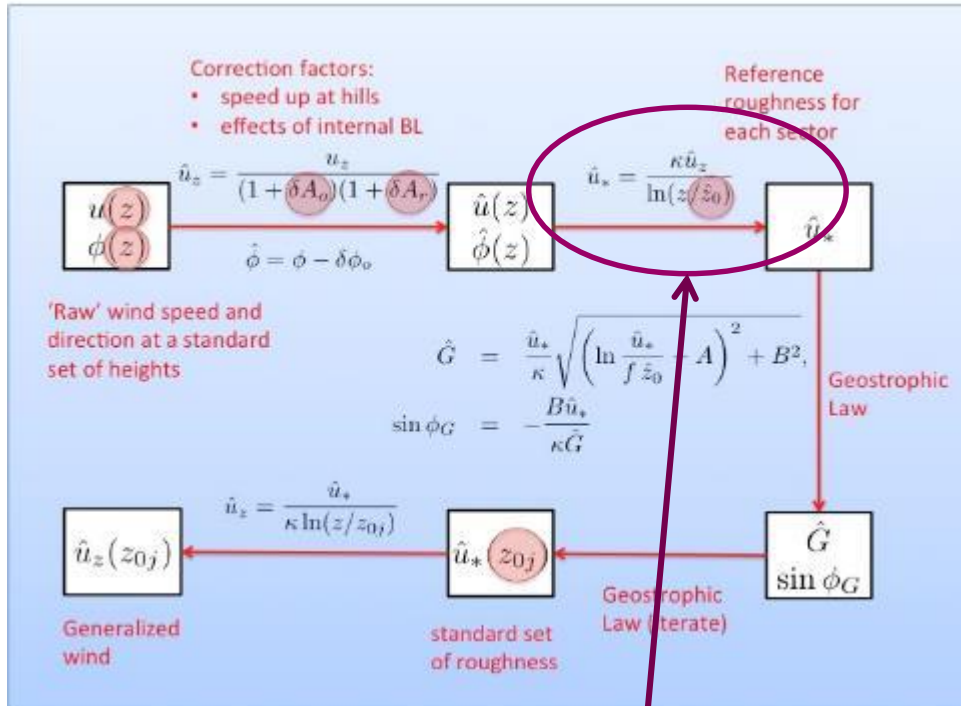


Photo: Forskningscenter Risø

GENERALIZATION



Mesoscale generalization procedure



Term modified to account for non-neutral conditions.

Similar generalization procedure for KAMM and WRF simulations.

In KAMM – generalization applied to the results of the simulations for each wind class (under neutral assumption)

In WRF – results from simulations are binned according to wind direction, wind speed, and stability (1/L).

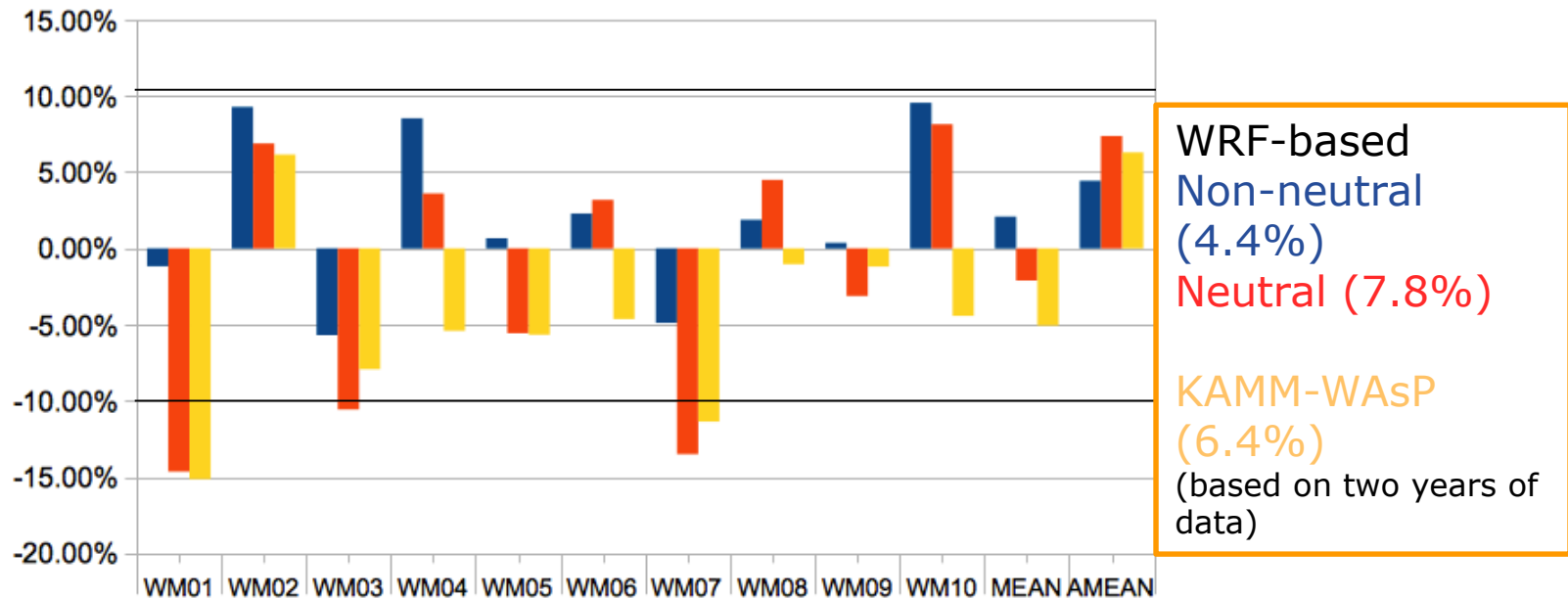
Each binned wind class is then generalized and aggregated using their frequency of occurrence

Neutral or non-neutral assumption was tested

Verification at WASA Masts

Numerical wind atlas (NWA) compared to observational wind atlas (OWA) Generalized annual mean wind speed at 100 m, $z_0 = 3$ cm [m/s]

$$\text{Error} = (U_{\text{model}} - U_{\text{obs}}) / U_{\text{obs}}, \quad U = \text{long-term mean wind speed}$$



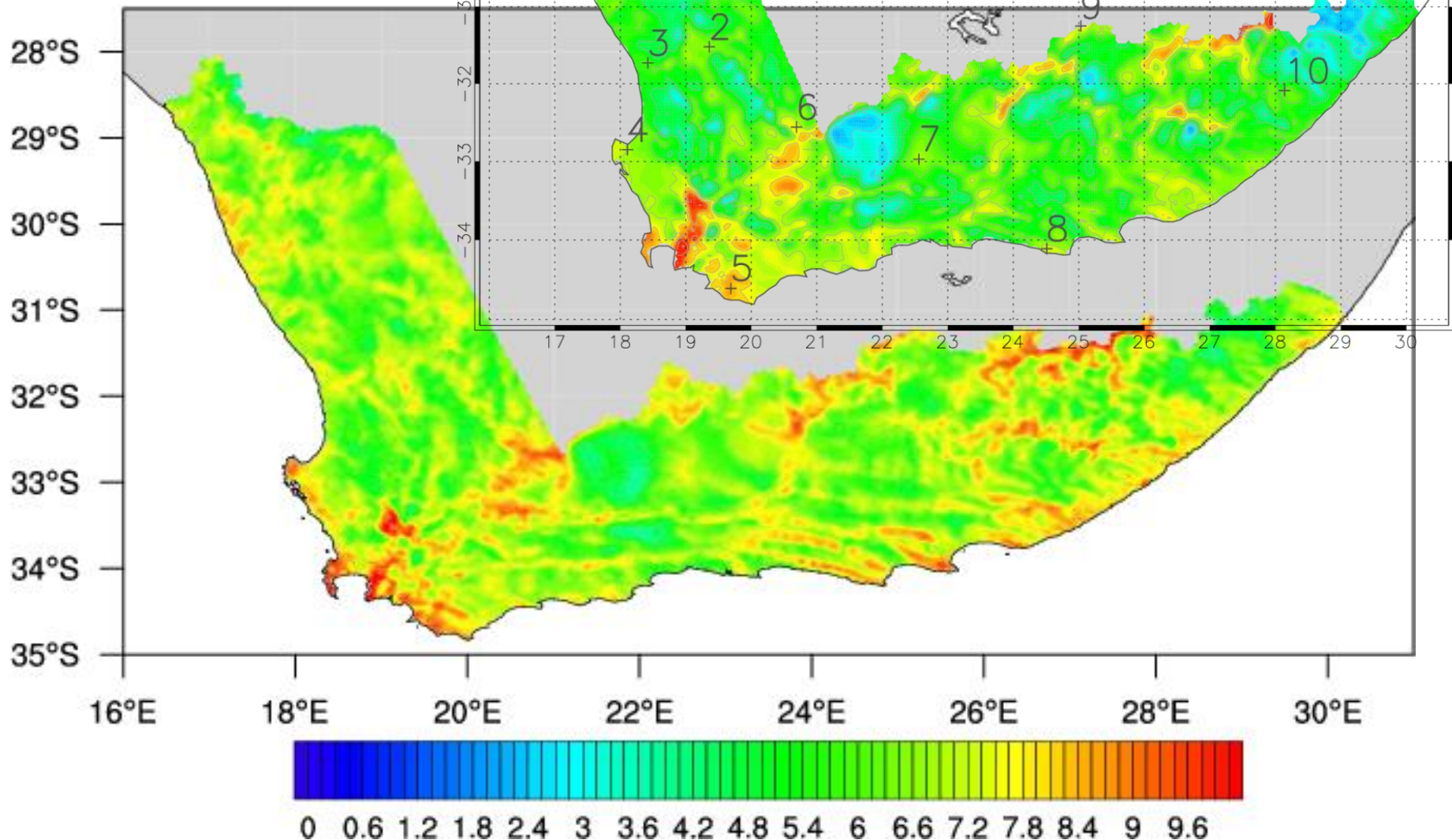
Verification site

Mean Absolute Error

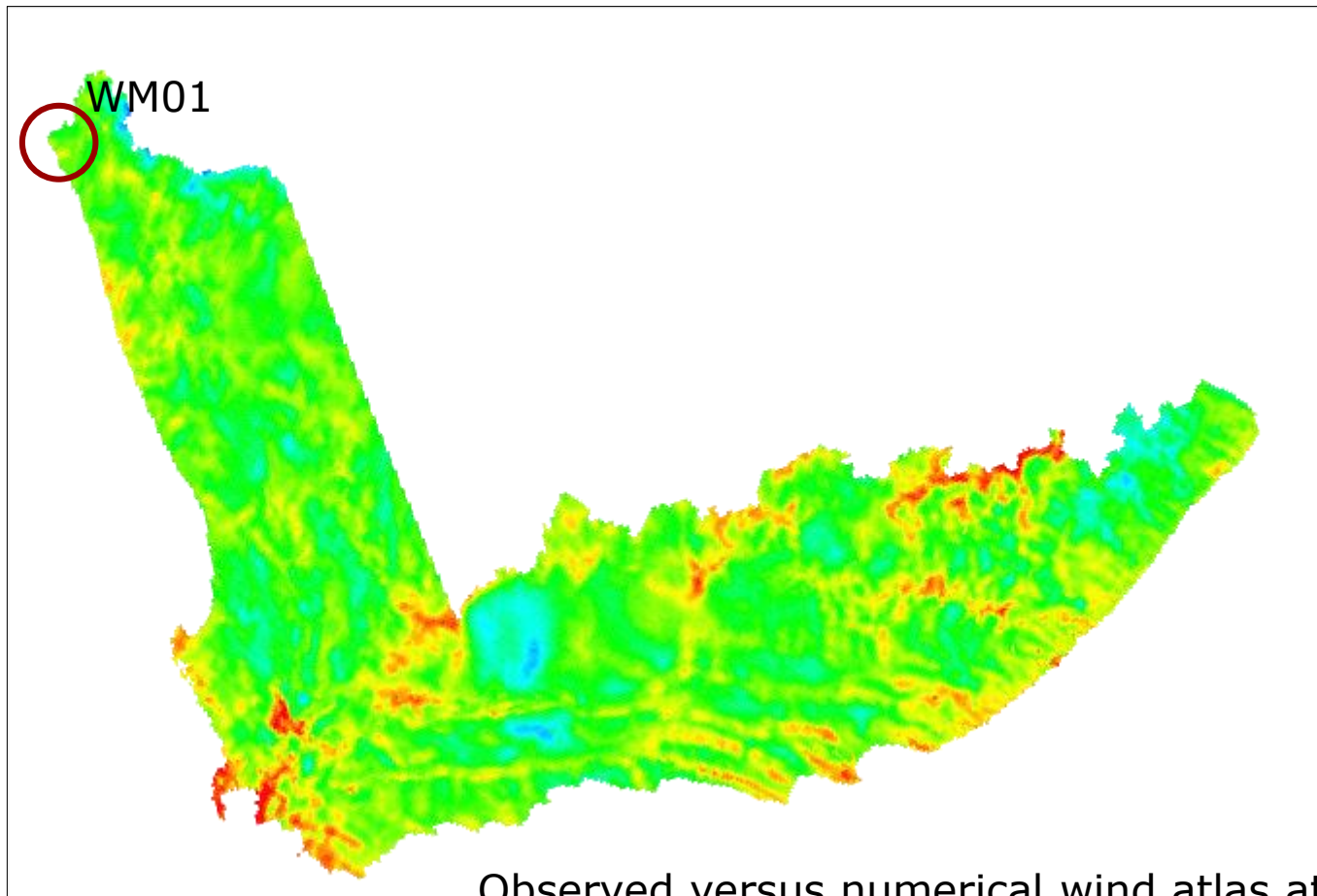
Numerical wind atlas - WRF 3km simulation



Generalized wind speed, $h=10=0.03$ m



Comparison at specific sites

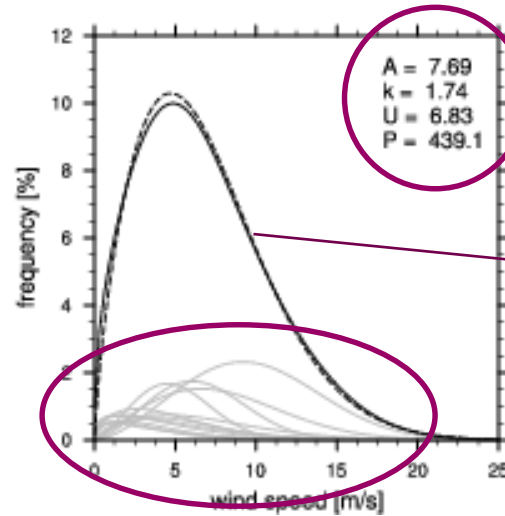


Observed versus numerical wind atlas at 3 sites
h=100 meters, z0=0.03 m
October 2010-September 2013

Example: WASA site 1, far northwest

File = WM01.lib
z0 = 0.03 m h = 100 m

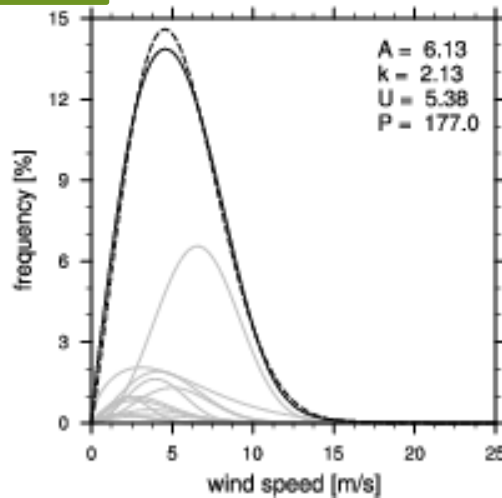
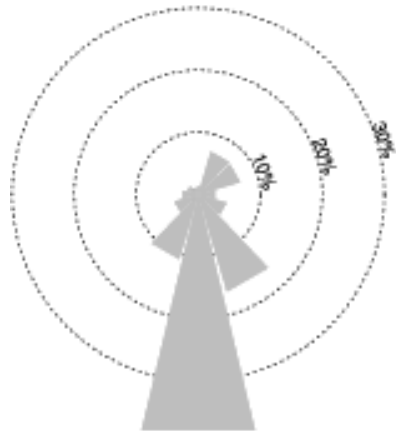
Observed
wind atlas



Weighted (solid)
Re-fit (dashed)

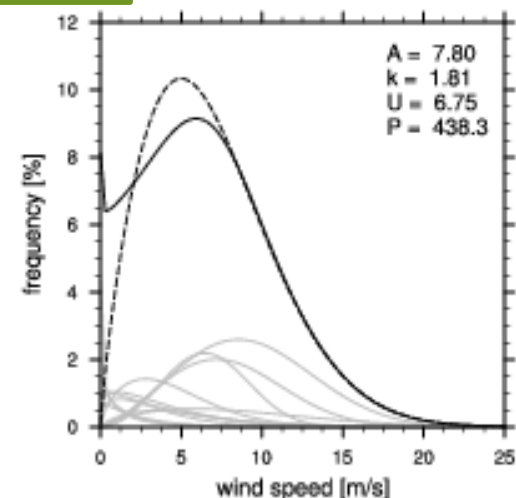
Numerical wind atlas
KAMM

WM01.4_5.lib

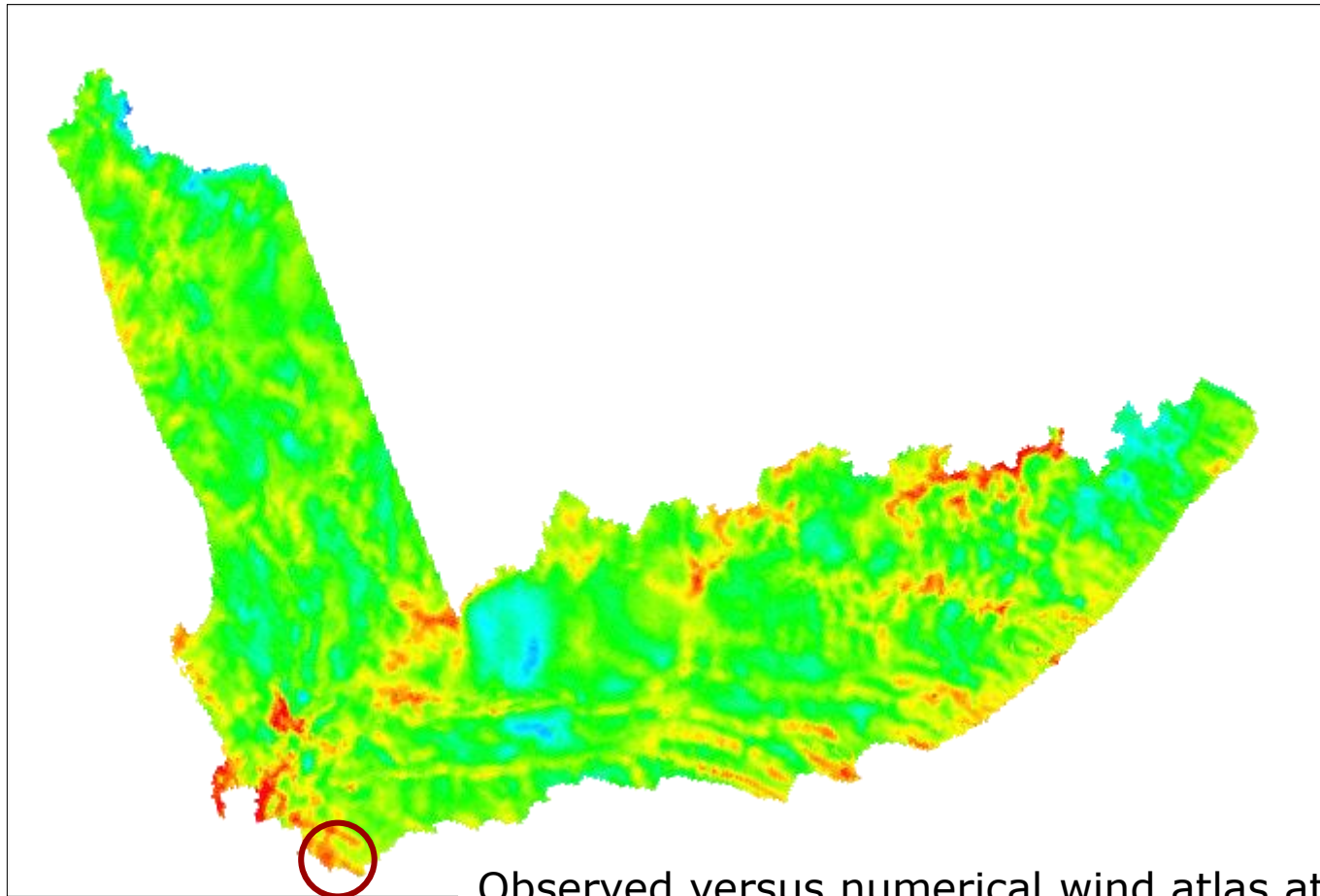


Numerical wind atlas
WRF

m_WM01.lib



Comparison at specific sites



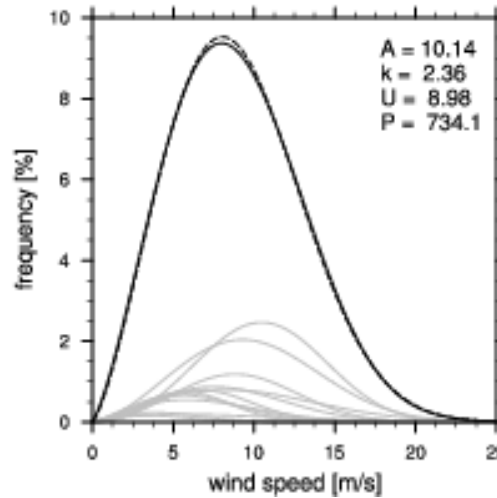
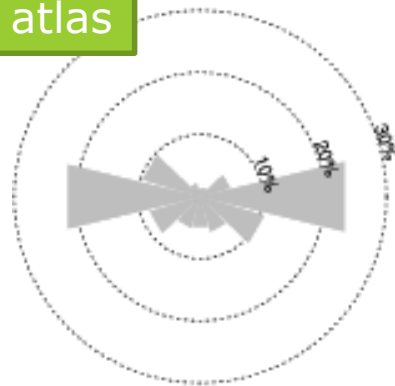
WM05

Observed versus numerical wind atlas at 3 sites
h=100 meters, z0=0.03 m
October 2010-September 2013

Example: WM05, southern coast

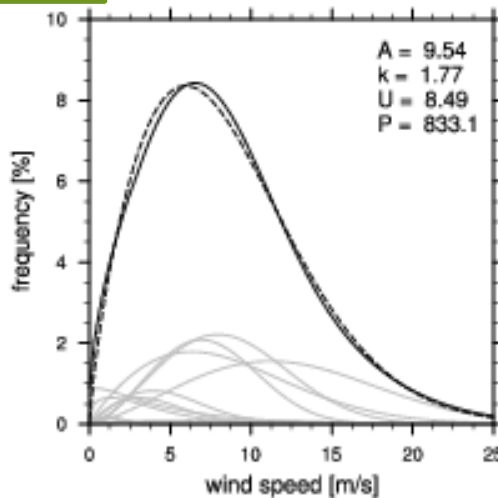
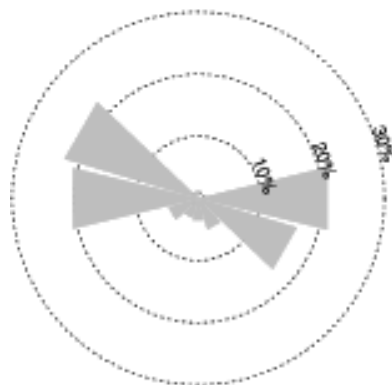
File = WM05.lib
z0 = 0.03 m h = 100 m

Observed
wind atlas



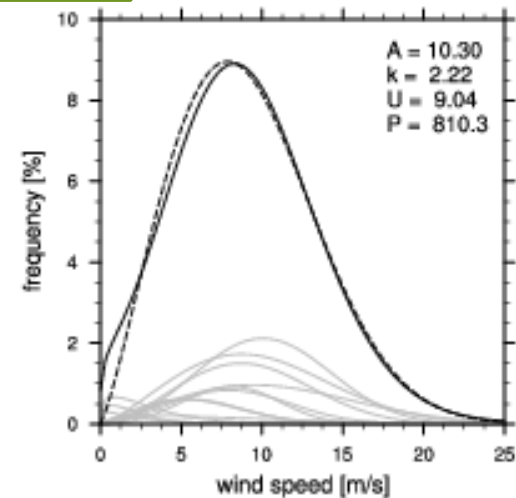
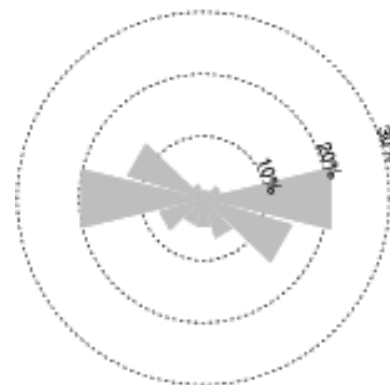
Numerical wind atlas
KAMM

WM05.4_5.lib

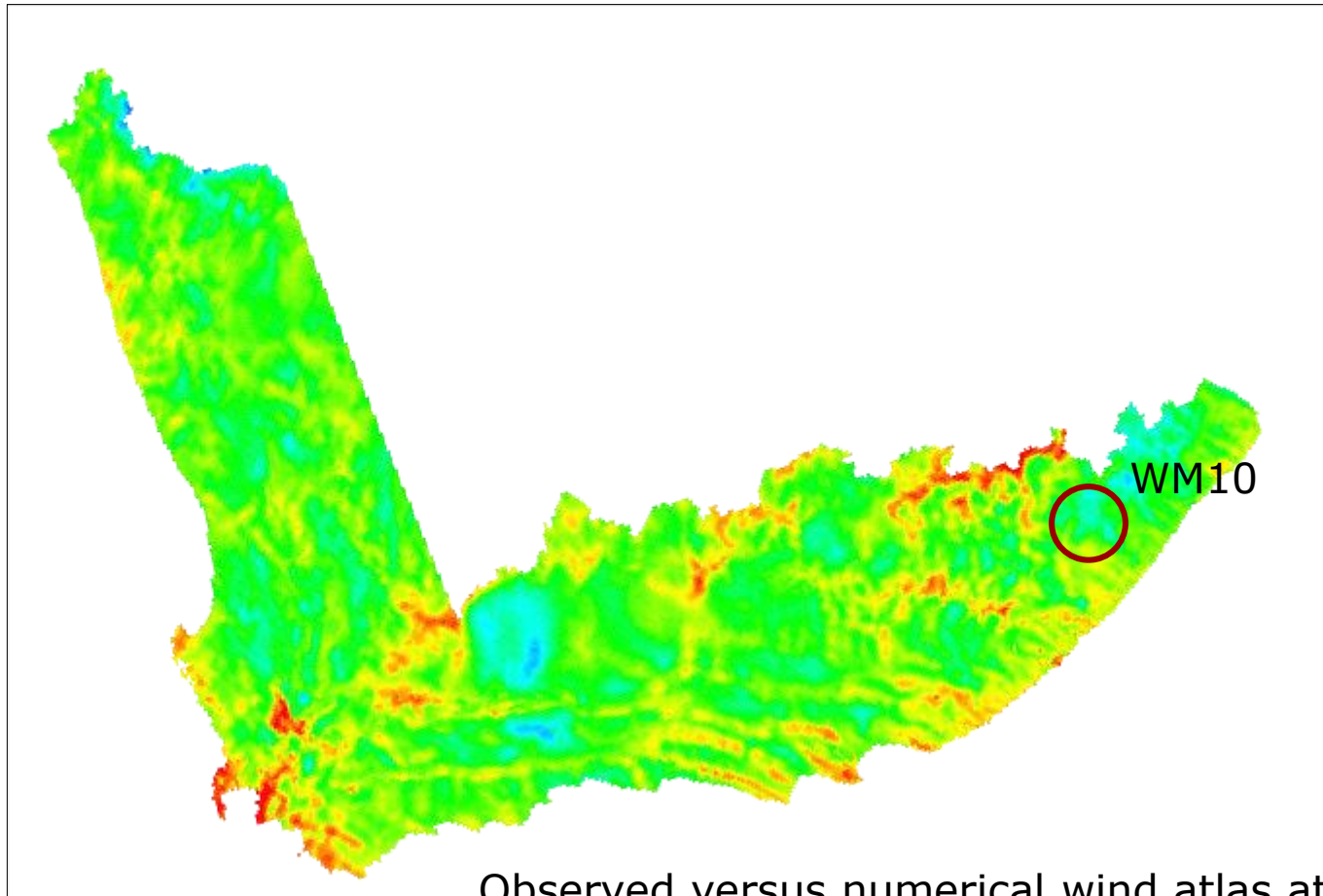


Numerical wind atlas
WRF

m_WM05.lib



Comparison at specific sites

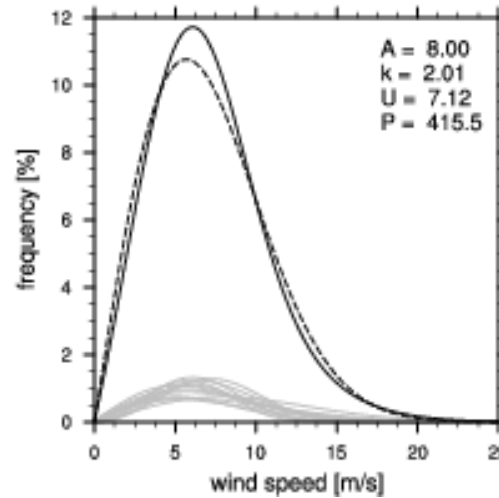
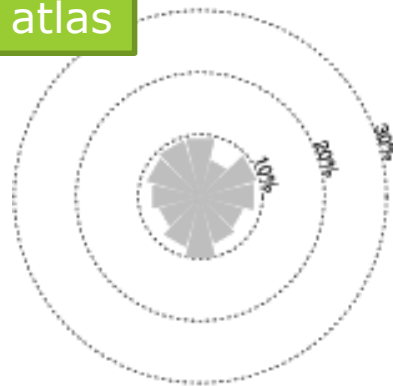


Observed versus numerical wind atlas at 3 sites
 $h=100$ meters, $z_0=0.03$ m

Example: WM10, Eastern cape

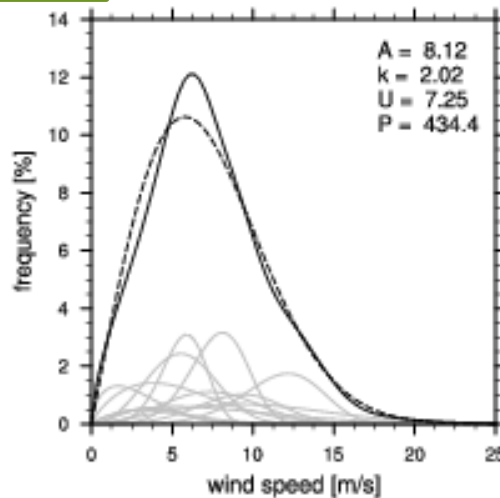
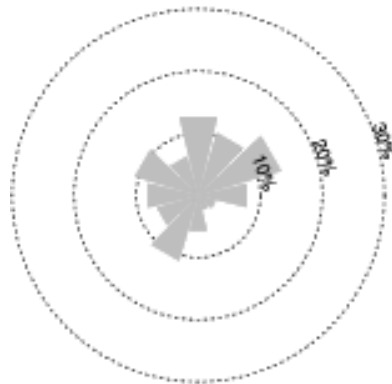
File = WM10.lib
z0 = 0.03 m h = 100 m

Observed
wind atlas



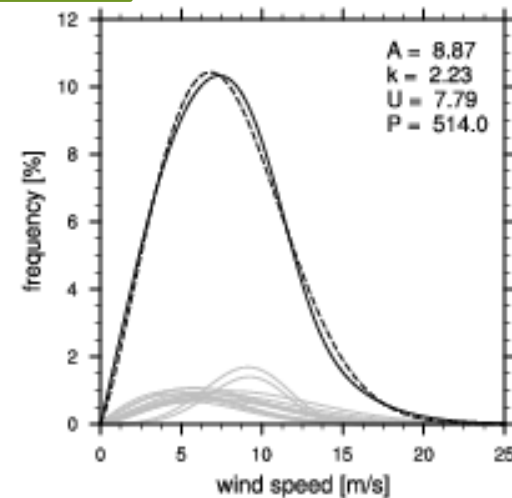
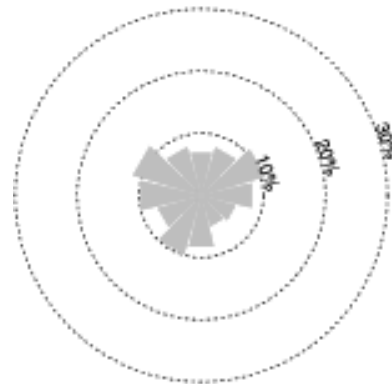
Numerical wind atlas
KAMM

VM10.4_5.lib



Numerical wind atlas
WRF

m_WM10.lib



Long-term corrections

- KAMM/WAsP numerical wind atlas – past of the method (30 years)
- WRF numerical wind atlas in based on 8 years of data
- But most wind farm projects require long-term wind climate assessments
- ERA-reanalysis seems to indicate a trend towards higher wind speeds over South Africa but result is most likely reanalysis dependent
- Input from users regarding what is needed

Freely available products derived from the numerical wind atlases



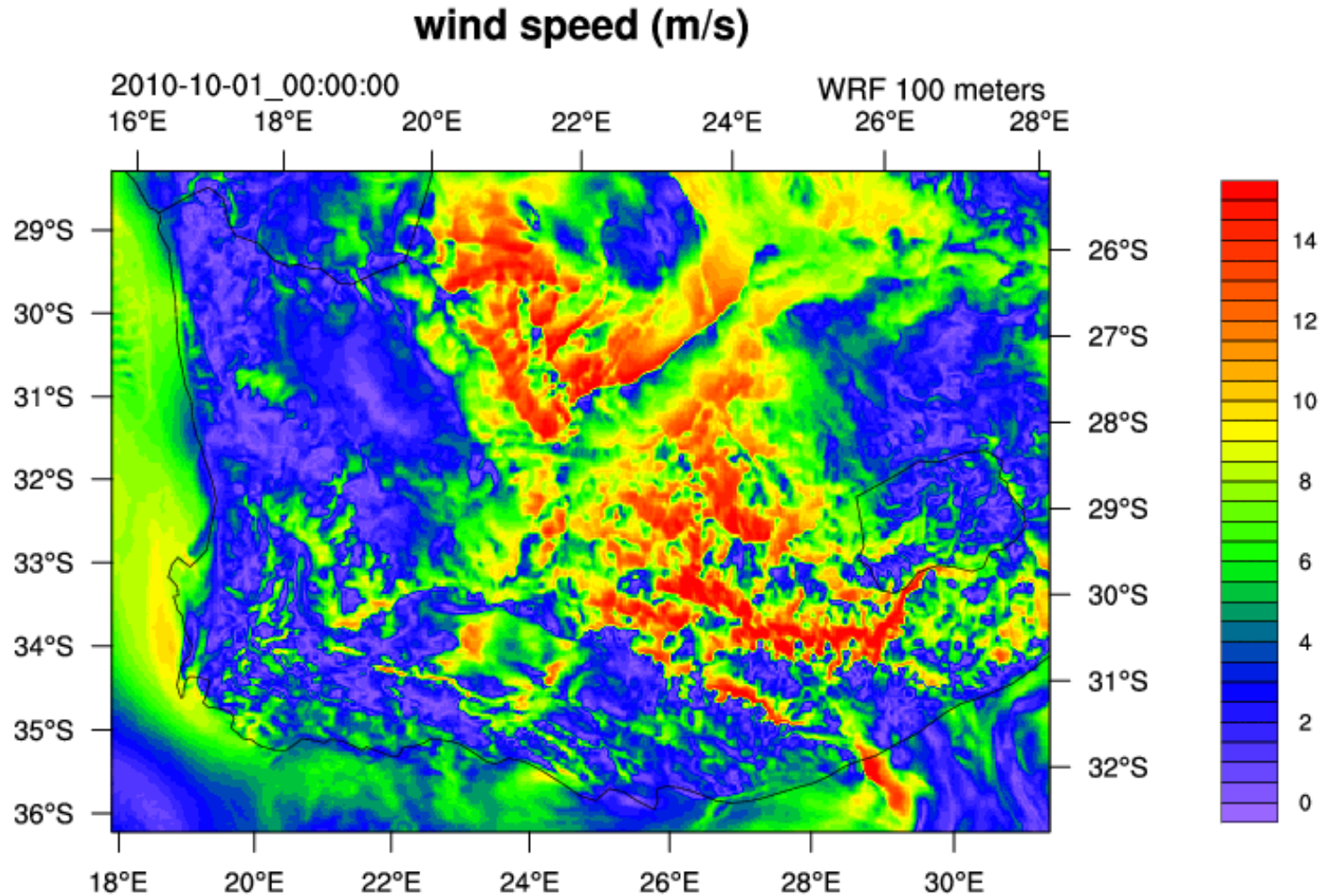
KAMM/WAsP			WRF-based		
Product	horizontal resolution	time resolution	Product	horizontal resolution	time resolution
GIS layers	5 km x 5 km	climate	GIS layers	3 km x 3 km	climate
WAsP lib files (5 levels)	5 km x 5 km horizontal resolution	long-term (30 year) climate	WAsP lib files (5 levels)	3 km x 3 km horizontal resolution	8 years climate
			Time series (1 vertical level)	27 km x 27 km (based on 9 km x 9 km)	Hourly 24 years
			Long-term correction	to be determined	climate

Available May 2014
from WASA web site

Summary and conclusions

- Results from a new verified numerical wind atlas for South Africa are presented and compared to the first verified wind atlas
- Production of the new wind atlas required a large amount of work – many knowledge and software was not available at the inset of the project
- KAMM/WAsP method, numerically very cheap, gives good results
 - underestimation of mean wind speed at most sites; specially at sites influenced by thermal processes
 - resulted in a quite conservative wind resource atlas
- WRF method, numerically very expensive, gives excellent results
 - Excellent comparison between wind roses in model and observations
 - Stability conditions should be taken into account at generalization
 - Stability conditions should be taken into account when applying WRF-derived wind atlas – where should this come from? How to verify?

WRF Simulations for the WASA project



Acknowledgements

The Wind Atlas for South Africa (WASA) project is an initiative of the South African Government - Department of Energy (DoE) and the project is co-funded by

- UNDP-GEF through South African Wind Energy Programme (SAWEP)
- Royal Danish Embassy

WASA Project Steering Committee:

DoE (chair), DEA, DST, UNDP, Danish Embassy, SANEDI



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