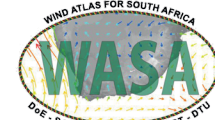
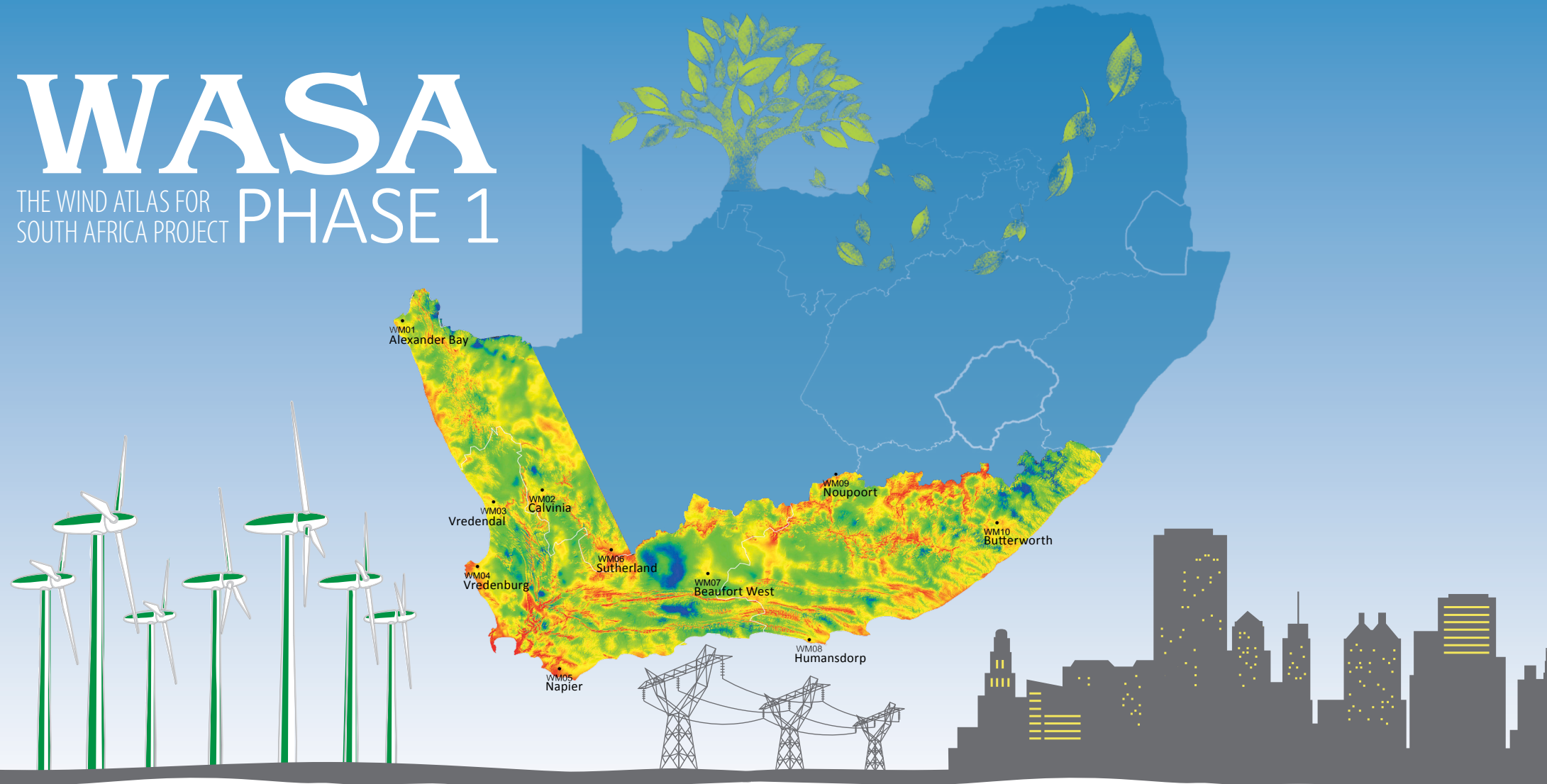




WASA

THE WIND ATLAS FOR SOUTH AFRICA PROJECT PHASE 1



PUBLISHED BY

South African National Energy Development Institute
Address: Second Floor, Block E, 150 Linden Street, Strathavon, Sandton 2146

PRINTED IN SOUTH AFRICA BY

Impumelelo Print Solutions (Pty) Ltd

WIND ATLAS FOR SOUTH AFRICA CONTACT DETAILS

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ISBN: 978-0-620-63781-7

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WIND ATLAS FOR SOUTH AFRICA



Phase 1

Compiled by André Otto
South African National Energy Development Institute
2015

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FOREWORD BY THE MINISTER OF THE DEPARTMENT OF ENERGY

“The Department is confident about the solid contribution of the entire WASA project to energy planning in South Africa.”

The Department of Energy (DoE) initiated the Wind Atlas for South Africa (WASA) project to update the old wind atlas with the latest wind measurement technologies that are designed to incorporate terrain obstacles including buildings and trees. This was done in parallel to the rollout of the Renewable Energy Independent Power Producers Programme (REIPPP). The WASA project was completed using 10 wind measurement masts of 62 m which were installed across the Western Cape and parts of the Northern and Eastern Cape. To this end, the renewable energy efforts reached another critical milestone in 2014 with the finalisation of the WASA Phase 1.

The WASA project is one of the major outputs of the South African Wind Energy Programme (SAWEP) which the DoE has implemented from 2008. Financial and technical assistance from the Global Environment Facility (GEF) through the United Nations Development Programme (UNDP) and the government of Denmark ensured that this initiative was successfully implemented while bringing on board key stakeholders from industry, universities and governments.

The WASA project is also being implemented as a research and capacity-building initiative, hence the appointment of the South African National Energy Development Institute (SANEDI) as the Executing Partner. Dedicated key Implementing Partners, namely the Council for Scientific and Industrial Research (CSIR), the South African Weather Service (SAWS), the University of Cape Town (UCT) Climate System Analysis Group (CSAG), the Technical University of Denmark (DTU), and the Department of Wind Energy worked with the SANEDI to strengthen South Africa’s capacity to undertake wind resource measurements. We are proud to have been able to anchor the development of this critical skill at South African public institutions for the long-term planning of the large-scale exploitation of our abundant wind

resources. We are inspired by the partnership with the Danish government where the twinning arrangement between our respective institutions has fostered the transfer of skills.

The WASA project has achieved many significant milestones and this book embodies the spirit of ensuring that the WASA outputs are publicly accessible in order to level the playing field between large and small industry players. We are encouraged by 90% data recovery from all 10 of the wind measurement masts which ensured that we were already able to share three years of high-quality measurements by 2013. The WASA project was completed through a combination of physical measurements, modelling tools and databases.

On 31 July 2013, we launched the first large-scale high-resolution (250 m x 250 m grid spacing) wind resource map made from the WASA database. This map identifies wind hot spots or the best suitable sites for the location of wind farms. To this end, the WASA project offers significant cost- and time-saving benefits to planners, policy makers, the Energy Supply Commission (Eskom) and the wind industry. The WASA project has also produced an innovative extreme wind atlas which estimates extreme wind speeds with a 50-year return period to assist wind energy developers to make informed decisions when selecting wind turbines and designing wind farms around areas with relatively strong winds. Outside the energy sector, the built environment has found the extreme wind atlas equally useful for informing national building standards, since wind loading is generally considered a key factor in structural design.

The DoE is grateful to the Danish government for further sponsoring the expansion of the WASA project to the remaining areas of the Eastern Cape, KwaZulu-Natal and parts of the Free State provinces. Additional funding is



also expected from the GEF which has approved the development of a full proposal for another US\$3.5 million for the development of a second phase of SAWEF. We are thankful for that.

The DoE is confident about the solid contribution the entire WASA project will make to energy planning in South Africa. Such a contribution includes enhancing the understanding of the quality of the wind resource, its spatial and temporal distribution as well as how to optimise the integration of wind power into the overall national energy supply mix for a more balanced and sustainable electricity provision over the medium to long term. We are also satisfied about the positive acceptance of the WASA results by the industry. The contribution and use of the WASA outputs by the International Renewable Energy Agency (IRENA) in the development of the global wind atlas as well as the World Bank's contribution and use through its Energy Sector Management Assistance Programme (ESMAP) stand out as significant affirmations of the importance of this project and South Africa's pivotal role in reinforcing the global renewable energy agenda.

A handwritten signature in black ink, appearing to read 'Tina Joemat-Pettersson'.

Hon. Tina Joemat-Pettersson (MP)
Minister of Energy



DANISH AMBASSADOR AND UNDP COUNTRY DIRECTOR PRELUDE

FOREWORD BY THE DANISH AMBASSADOR

• “Capacity building
• has been a key
• concept throughout
• this first phase of the
project.”

The main objective of the WASA was and is to enable South African authorities to do long-term planning of large-scale exploitation of wind power in South Africa. The development of the wind atlas was done by transferring knowledge from wind energy specialists at the DTU to their South African colleagues. In other words, capacity building has been a key concept throughout this first phase of the project.

The objective of the WASA Phase 1 has successfully been accomplished. Public data has since been downloaded more than 47 670 times by about 1 537 registered users. Furthermore, South Africa now has a group of wind resource modelling and measurement experts thanks to the WASA Phase 1.

The WASA now serves as a model for other countries and projects. The data and access are not monopolised by any company or institution. It is all in the public domain and free for all to use.

The WASA will thus assist all players in the wind energy market to obtain verifiable scientific data about the wind. It will assist Government in its long-term grid planning and it will offer important cost-saving benefits for large and small industry players that are developing their project sites.

The WASA Phase 1 can also serve as a reference in the ongoing review of the Integrated Resources Plan (IRP) which outlines how renewable energy will make up a large part of all the new additional energy capacity to be established until 2030.

In other words, the wind atlas is a very important input to the ambitious process of introducing wind energy to secure the green transformation of the South African energy profile.

South Africa has abundant coal resources and yet it has still embarked on an ambitious road toward renewable energy. I can only applaud and admire this policy of diversifying your energy sources and helping to combat climate change. I hope many other countries will continue to follow in your steps.

I would like to congratulate South Africa for the way the Government and the DoE has implemented the REIPPP. It has been very transparent and effective, setting new international standards in the field. This has made wind power a reality in South Africa and has demonstrated the feasibility of a model which could and ought to be exported and duplicated in other countries.

I see the green economy as one of the areas in which both Denmark and South Africa can benefit from further close co-operation. We already share a long history of collaboration on the Green Growth Agenda. The development of a Verified Numerical Wind Atlas (VNWA) is just one successful example. I hope we have seen other examples and continue to do so in the future.

Denmark is proud that we have been able to support the WASA Phase 1 in the first steps on the road toward a growing and sustainable wind industry in South Africa.



The Danish-South African energy co-operation will definitely continue in the years to come. During the visit of the Danish Prime Minister to South Africa in March 2013, the Danish government and the South African Government signed a co-operation agreement on a new Renewable Energy Programme with a budget of DKK40 million. Included in this agreement is the expansion of the wind atlas to cover the remaining areas of the Eastern Cape, KwaZulu-Natal and areas of the Free State provinces. The total budget for Phase 2 of the WASA is DKK12 million.

Mrs Trine Rask Thygesen
Ambassador of Denmark



FOREWORD BY THE UNITED NATIONS DEVELOPMENT PROGRAMME COUNTRY DIRECTOR

• **“Overnight, South Africa has become a global and regional leader in wind power deployment and wind is becoming a significant new sector in the South African economy.”**

I want to acknowledge, on behalf of the UNDP and the GEF, the leadership and commitment of a range of partners – including the South African DoE, the SANEDI, the South African CSIR, the SAWS, the UCT, the DTU Wind Energy Department and the government of Denmark – in the successful completion of the first WASA.

The story of the WASA and its success is intricately tied to the massive global emergence of wind power as a technology that has demonstrated that the world can turn this challenge into an opportunity and choose a different path to meeting its energy needs in a sustainable and climate-resilient manner.

Eight years ago, at the start of the SAWEPP Phase 1, South Africa had less than 10 MW of wind power. Today, because of the vision of Government and the REIPPP, if all goes well, the country will have some 2 GW of wind installed by 2018. Overnight, South Africa has become a global and regional leader in wind power deployment and wind is becoming a significant new sector in the South African economy. At the UNDP, we firmly believe that the WASA has played a key behind-the-scenes role in facilitating the growth of the South African wind sector, providing high-resolution wind resource data to all stakeholders that have, amongst others, the following benefits:

- allowed for a democratic levelling of the playing field between small and large industry players to identify and develop project sites for wind farms;
- assisted government planners to identify high-potential wind development zones in line with the strategic environmental framework and assessments studies; and
- facilitated short- and long-term grid planning for renewable energy rollout.

I also wish to highlight and commend the WASA’s involvement in the IRENA Global Atlas Initiative which is the largest initiative ever undertaken to assess renewable energy potential on a global scale. The WASA is helping to close the knowledge gap between nations with access to the necessary data sets, expertise and financial support to evaluate their national renewable energy potential and those countries lacking such elements or who wish to learn from the experiences of those nations that have already undertaken such work.

Looking forward, the UNDP is committed to continuing its support of South Africa’s wind sector and increased renewable energy deployment on a global level.

More specific to South Africa, in 2013, the GEF approved a project proposal concept for an additional funding allocation of US\$3.5 million for a second phase of the SAWEPP. Phase 2 is designed to assist Government and industry stakeholders to overcome strategic barriers to the successful attainment of South Africa’s IRP target of 2.8 GW new build wind power online by 2020. The second phase of the SAWEPP is intended to build on the achievements of the first phase, with regard to the removal of early-stage energy-related barriers, and focus efforts on creating the conditions for medium- and long-term wind power development in South Africa.

Components proposed under the second phase of the SAWEPP include, amongst others, providing additional support for resource mapping and wind corridor development, including the expansion of the WASA to additional provinces in conjunction with support from the government of

Denmark. Expanding the WASA to cover all of the Northern Cape, Eastern Cape, KwaZulu-Natal and parts of the Free State provinces would capture 80% and more of South Africa's wind resources. Opening up a bigger spread of wind energy industrial development across these provinces and different wind regimes contributes to a more predictable wind resource and allows for better planning for future procurement mechanisms.

The UNDP is hopeful that the SAWEF Phase 2 and its support for the expansion of the WASA will continue to help grow South Africa's wind industry in a way that provides green jobs and skills enhancement, particularly for rural communities living adjacent to emerging REIPPs in impoverished provinces like the Northern Cape.



Mr Walid Badawi
UNDP Country Director



• **“South Africa is one of
• 15 countries with the best
• wind resources in Africa.”**



1 SOUTH AFRICA AS A MAJOR WIND RESOURCE SITE



1.1 BACKGROUND

In 2003, the Department of Minerals and Energy's (DME^a) Capacity-Building Project in Energy Efficiency and Renewable Energy, which was funded by the Danish Government, commissioned the *Review of Wind Energy Resource Studies in South Africa*^b study. This study reviewed wind energy resource studies and estimated if the potential of the resources discussed in these studies are correct.

The conclusions drawn by this study include the following:

- There is a poor accuracy prediction rate of the wind energy resources at potential sites based on the present wind atlases. This is mainly because the locations of the weather measuring masts are too close to buildings and other obstacles. Therefore, the present wind atlases should not be used to predict the energy output at potential sites which are in turn used in feasibility studies.
- The accuracy of the resource estimates may be improved significantly by establishing a network of high-quality wind measurements, including masts of at least 30 m.

The study also revealed that South Africa has potential sites with wind resources that are equal to wind resources at sites around the world that have been exploited for large-scale wind power projects. This finding agrees with the findings of another study conducted for the African Development Bank, namely the *Strategic Study of Wind Energy Deployment in Africa*^c, which stated that South Africa is one of 15 countries with the best wind resources in Africa.

1.2 THE IMPORTANCE OF ASSESSING WIND RESOURCES FOR SOUTH AFRICA

It is very important to assess the wind resources correctly, because if the wind data is, for example, only 10% incorrect, the calculation of the amount of energy produced would be incorrect – up to the order of 30%. An error of such magnitude could result in cost-benefits being incorrectly determined for:

- investment costs;
- operation and maintenance costs;
- electricity production;
- turbine lifetime; and
- environmental benefits.

Incorrectly assessing the wind resources will also result in the modelling output being incorrect.

It is also important to assess the wind resources as:

- energy, electricity and sustainable solutions are needed;
- the development of power systems are long-term efforts;
- we need to look for the best place for wind resources;
- we need to plan, implement and operate the power systems for timely and well-placed wind power distributions;
- traditional climatology models do not give the required answers for wind resources; and
- data on wind is not adequately available and/or is of poor quality^d.

Fast Facts

Wind speed determines the amount of power in the wind.

Wind power (P) is directly proportional to the wind speed cubed (U³).

$$P \propto U^3$$

$$P = \frac{1}{2}\rho U^3 \text{ [W/m}^2\text{]}, \rho = \text{air density.}$$

The amount of energy a wind turbine produces depends on the power (P) in the wind and the efficiency of the wind turbine (C_p).

The efficiency of the wind turbine is specified as a function of the wind speed at hub height (the distance from the ground to the hub which connects the wind turbine blades to its main shaft). It is therefore very important that we can determine the wind speed accurately at the hub heights of wind turbines.

^a Currently the Department of Energy. ^b See Reference 1. ^c See Reference 2. ^d See Reference 3.

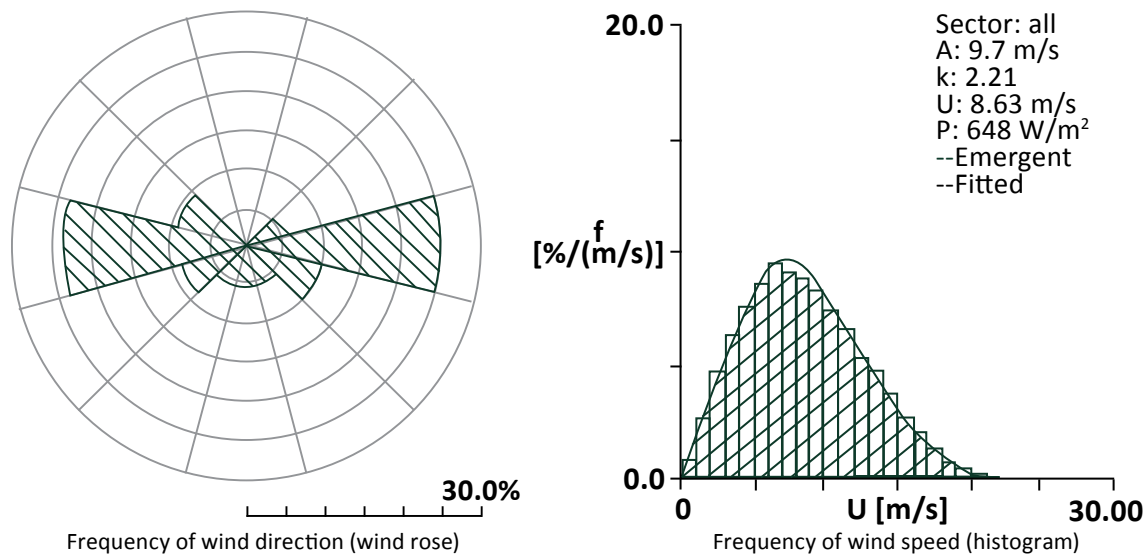


Figure 1: Wind rose and wind speed distribution U for WM05 Napier at 62 m AGL

1.3 DEFINING THE PROJECT AREA

The WASA Phase 1 project covers the Western Cape province and parts of the Northern Cape and Eastern Cape provinces.

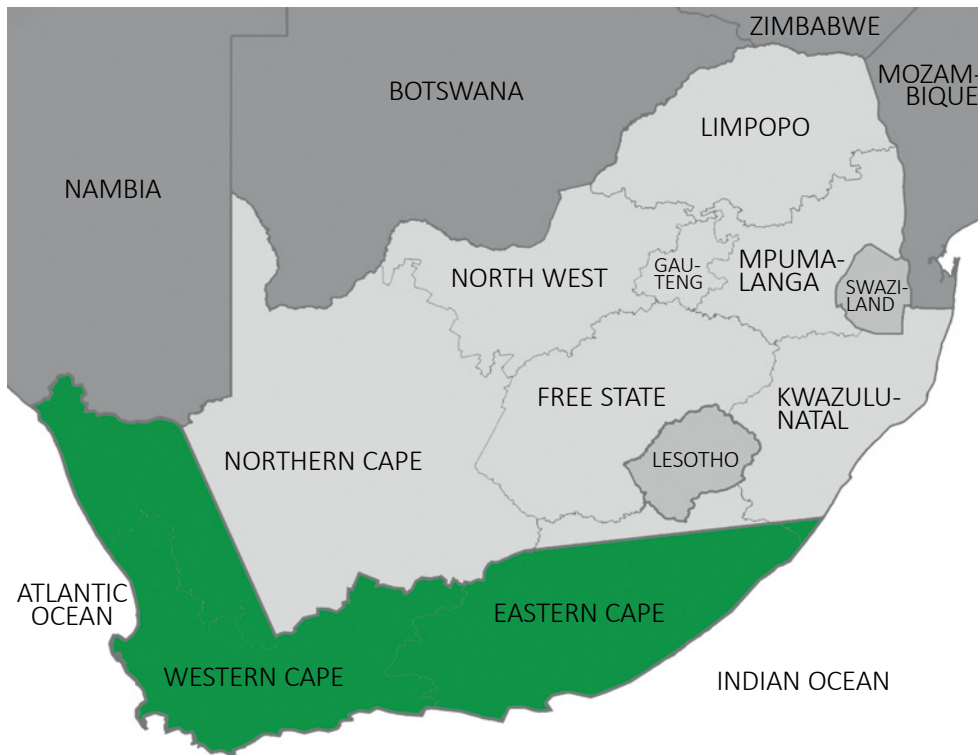
The criteria for selecting the wind measurement sites were based on the needs to best possibly serve for verification of the wind modelling and the following^e:

- Topography: such as mountains, escarpments, hills, the slope of hills, and the distance to mountain ranges and valleys;
- Roughness: such as vegetation, forests, agricultural land, and the distance to towns and cities;
- Communication: such as a Global System for Mobile Communications (GSM) network, a radio modem and a satellite;
- Infrastructure: such as access, roads, building material and concrete.
- The distance to the power grid;
- Sensitive areas: such as airports, nature reserves, game parks, bird migration routes and bats;
- Land ownership: such as private, trust, Government, local authority and tribal land; and
- Land classification: such as industrial or agricultural land.

The positions were carefully chosen to cover all of the WASA domain terrain types and climatology for the modelling to be representative of the WASA domain. They were not chosen because they were the windiest or the best locations for wind farms^f.

The end result of this WASA project is to support the large-scale utilisation of wind energy in South Africa.

^e See Reference 4. ^f See Reference 5.



- “The end result of this WASA project is to
- support the large-scale utilisation of wind
- energy in South Africa.”

Figure 2: WASA Phase 1 project area: Western Cape and parts of the Northern Cape and Eastern Cape provinces

2 BEHIND THE SCENES



The WASA project commenced in 2009 as an initiative of the South African DME. The principal funders were the GEF (R8 million), through the SAWEP with UNDP support, and the Royal Danish Embassy (DKK9 985 441).

The project's Executing Partner is the SANEDI, and the project's Implementation Partners are:

- the CSIR;
- the UCT CSAG;
- the SAWS; and
- the DTU Wind Energy (Technical University of Denmark).

The Project Steering Committee guiding the project's implementation comprise the DoE (Chair), the UNDP, the Danish Embassy, the SANEDI, the South African Department of Science and Technology (DST) and the South African Department of Environmental Affairs (DEA).

The Project Implementation Unit (PIU) consists of the SANEDI (Chair) and the various implementation partners. Together, they are responsible for implementing the project. The PIU Chair (SANEDI) reports to, and is a member of, the Project Steering Committee.

• **“The WASA project commenced in 2009**
• **as an initiative of the South African DME**
• **(now the DoE).”**



3 A SET OBJECTIVE



Through capacity development and research co-operation, the WASA project's main objective is to develop and employ numerical (modelled) wind atlas methods. In using these methods, the project also aims to develop capacity in support of long-term planning for large-scale wind power to take place in South Africa. This includes dedicated wind resource assessment and siting tools for planning purposes. The siting tools used when planning are:

- physical wind measurements;
- numerical (modelled) wind atlases; and
- South African databases.

• **“The WASA project’s main objective is to develop and employ numerical (modelled) and verified wind atlas methods.”**



4 ABOUT THE WIND ATLAS FOR SOUTH AFRICA PROJECT

The following are the six WPs of the WASA project:

- WP1 – Mesoscale Wind Modelling
- WP2 – Wind Measurements
- WP3 – Microscale Wind Modelling
- WP4 – Application for Wind Resource Assessment
- WP5 – Extreme Wind Atlas
- WP6 – Documentation and Dissemination

The WASA project consists of six Work Packages (WPs). The outcomes for each package are summarised in this chapter.

4.1 WORK PACKAGE 1 – MESOSCALE WIND MODELLING

The initial model setup and the preliminary calculations formed part of the first WP. This involved downscaling from global data sets to regional data with the Karlsruhe Atmospheric Mesoscale Model (KAMM) method and the Weather Research and Forecasting (WRF) model.

The outcomes of WP1 include:

- KAMM and WRF model configurations;
- statistical and dynamic downscaling (using KAMM and WRF coupled to the Wind Atlas and Application Programme (WASP));
- dynamical downscaling using WRF;
- methods for satellite data input to mesoscale models;
- the post-processing of mesoscale outputs which are coupled to microscale models;
- the analysis of the mesoscale results versus the measured data;
- the creation of a Numerical Wind Atlas (NWA) for the Western Cape and selected areas of the Northern and Eastern Cape provinces; and
- training, including the exchange of PhD theses.

4.2 WORK PACKAGE 2 – WIND MEASUREMENTS

The most important objective of the second WP was to get high-quality wind measurements over three years from the 10 masts in order to verify the mesoscale modelling.

The outcomes of WP2 include:

- the design of a wind measuring system;
- the design of data acquisitions by GSM;
- the procurement, shipment, customs clearance, tax and Value Added Tax (VAT) exemption and necessary import permits;
- survey, screening and selection (if appropriate) of the existing data from private measurements, agreement and confidentiality and the value of the data;
- siting and necessary approvals attained;
- consideration of an appropriate mast design;
- construction and installation;
- recalibration;
- operation, security and data collection;
- data analyses; and
- technical training on upgrading to wind energy-related measurement systems.

4.3 WORK PACKAGE 3 – MICROSCALE WIND MODELLING

During this WP, microscale modelling was carried out for the 10 chosen meteorological stations to create an observational wind atlas for each of the 10 masts.

The outcomes of WP3 include:

- wind speed and the distribution of the direction of the wind;
- terrain elevation;
- terrain roughness;
- sheltering obstacles;
- WASP modelling;



- the analysis of the microscale results versus the measured data;
- the creation of observational wind atlases for selected measurement sites in South Africa; and
- WAsP training which will consist of Training of Trainers (ToT).

4.4 WORK PACKAGE 4 – APPLICATION FOR WIND RESOURCE ASSESSMENT

This WP concerned the use of the results for actual applications particularly for those parties that are not part of the project.

The outcomes of WP4 include:

- mid-term workshops for invited stakeholders from authorities, planners, developers, banks, scientists, etc.;
- the development of tools, such as guidelines and training materials on how to use the NWA for wind resource assessment;
- a course for trainers;
- microscale High-Resolution Wind Resource Map for the modelled areas in the three provinces, including integration as a Geographic Information System (GIS) layer;
- the seasonal variation of wind resources at the mast locations; and
- final workshops and Training of Trainers (ToT) for invited stakeholders, including opportunities for application in determining extreme wind climate, seasonal forecasting and applications, which are not wind energy related.

4.5 WORK PACKAGE 5 – EXTREME WIND ATLAS

During this WP, an estimation of the extreme wind climate of South Africa was also achieved.

The outcomes of WP5 include:

- the development of tools and guidelines;
- a course for trainers;
- workshops as technical working sessions and progress reporting for PIU;
- a better understanding of the estimation of extreme winds;
- capacity development of the theoretical aspects of extreme wind estimation;
- the application of mesoscale modelling results to the estimation of an extreme wind climate of the project area; and
- database and maps for extreme winds.

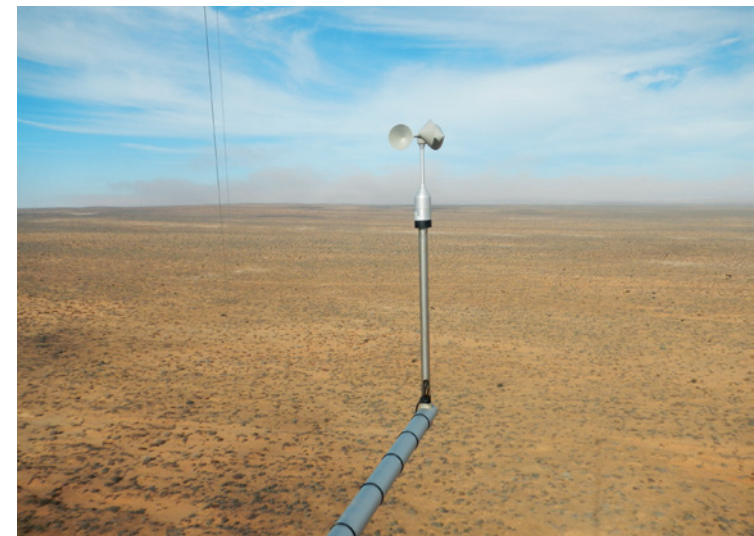
4.6 WORK PACKAGE 6 – DOCUMENTATION AND DISSEMINATION

During the last WP, the WASA project has been presented at conferences and seminars and published and distributed through websites for Phase 1.

The outcomes of WP6 include:

- the preparation and dissemination of research publications of the results of the project, including the final book and homepage publication;
- the preparation of national wind seminars for dissemination of the results of the project; and
- the establishment and documentation of research co-operation between South African and international wind research partners.

• “The WASA project
• consists of six work
• packages.”



Erection of the WASA wind measurement masts.

5 EXPECTED OUTCOMES



The expected project outcomes can be summarised as follows:

- A Numerical Wind Atlas (NWA) and database for the Western Cape Province and parts of the Northern Cape and Eastern Cape provinces, including seasonal variations and resource maps prepared for introduction as a GIS layer;
- A microscale High-Resolution Resource Map and database for the modelled areas in the three provinces;
- A map and database of extreme wind climates of the modelled areas in the three provinces;
- Ten high-quality wind measurement masts and data collection that are operational;
- A minimum of two mid-term and two end-term workshops for invited participants in the application of the NWA and database;
- The CSIR established as a resource centre for microscale modelling;
- The UCT established as a resource centre for mesoscale modelling;
- Training tools and software;
- Research publications of the results of the Twinning Programme, including the final book and homepage publication;
- A minimum of one national wind seminar for dissemination of the results of the Twinning Programme; and
- The establishment and documentation of research co-operation between South African and international research partners.

• “One of the expected project outcomes is a microscale High-Resolution Resource Map and database for the modelled areas in the three provinces.”



6 A SOLID METHODOLOGY

Mesoscale models were developed for numerical weather prediction and have been used more and more since the 1990s. The calculation of these models has also been refined and validated and numerical (modelled) wind atlases have been developed for Europe, Egypt, Canada, the United States, China, India and other countries.

Studies have shown that if appropriate mesoscale and microscale models are used, wind atlases which cover large geographical areas can be calculated and developed in much less time and with less cost than when these models are not used. This is because it extends the wind atlas beyond physical wind monitoring. However, physical wind monitoring is still required to verify the wind atlas.

The mesoscale model uses a variety of global, geophysical and meteorological databases such as the reanalysis database. This database is a gridded historical weather data set produced by many weather bureaus or research centres across the globe.

Microscale modelling (high resolution), incorporating surface effects such as local topography, roughness and obstacles, enables you to estimate the local wind climates and to identify wind hot spots for wind farm planning, layout and wind resource assessment.

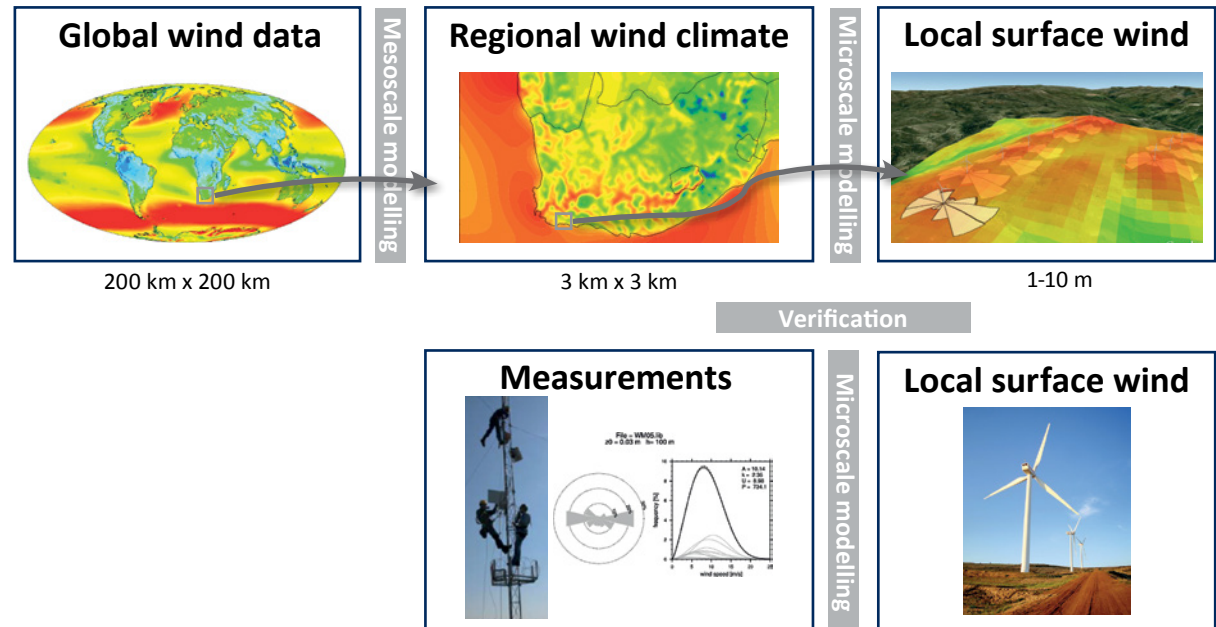
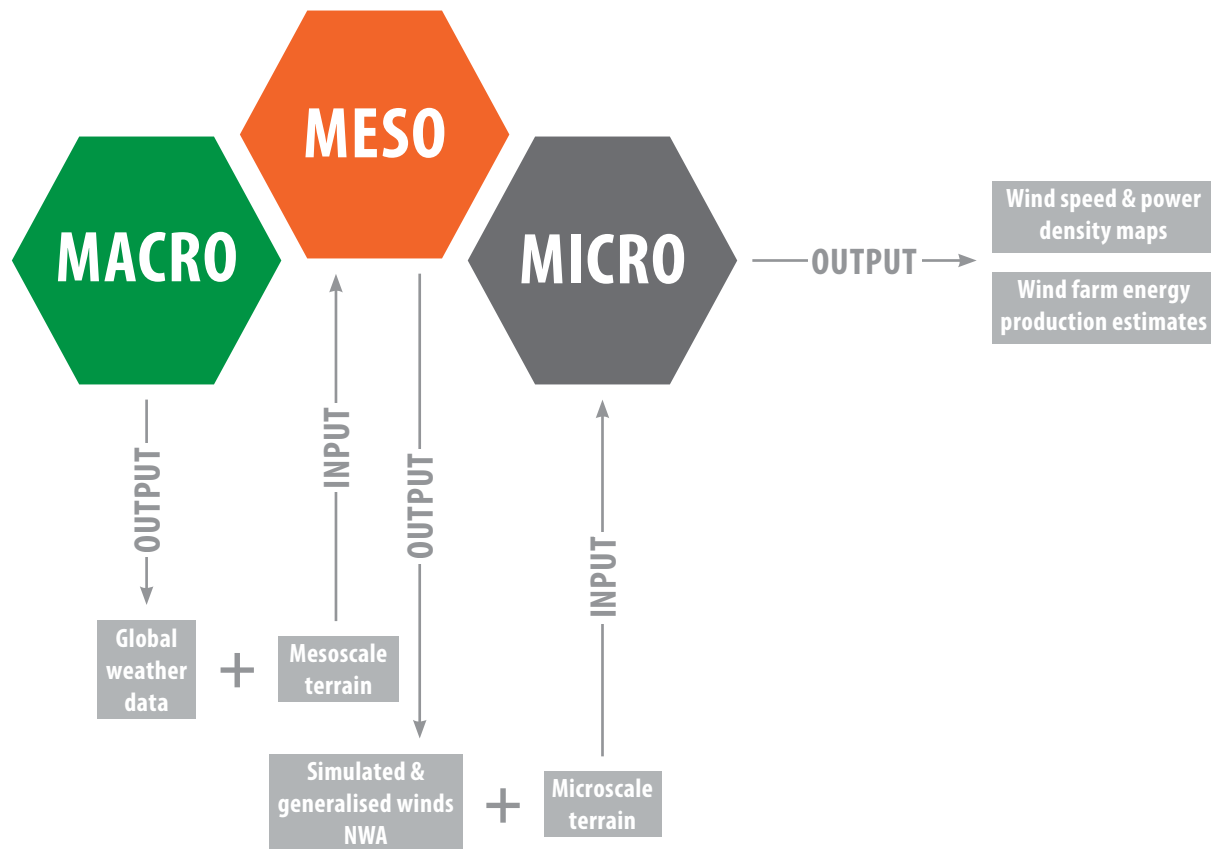


Figure 3: The WASA methodology



“Microscale modelling, incorporating surface effects, enables the estimation of the local wind climate and the identification of wind hot spot areas.”

Figure 4: Modelling scales and the making of a wind atlas

7 IT IS ALL ABOUT THE RESULTS

The Deputy Minister of Energy launched the first VNWA that was based on the KAMM method at the WASA workshop in March 2012.

The WRF-based NWA verification compared to measurements at the 10 WASA sites show that the generalised mean wind speeds have a mean absolute error* of only 4.4%.

*Average of the absolute errors of the annual mean wind speed at the 10 sites.

The WASA results are divided into six WPs as well as capacity building and human development. These WASA results are summarised below according to these divisions. The original reports can be downloaded by following the links provided:

- <http://www.wasa.csir.co.za>
- <http://wasadata.csir.co.za/wasa1/WASAData> (register for free and log in)
- The WASA website at <http://www.wasaproject.info/>
- <http://veaonline.risoe.dk/wasa>

Final reports, maps, guides and data can be accessed online (register for free and log in): <http://wasadata.csir.co.za/wasa1/WASAData>

7.1 WORK PACKAGE 1 – MESOSCALE MODELLING

The Numerical Wind Atlas (NWA) is the main result of the mesoscale modelling based on the WRF model in April 2014. The responsible parties for WP1 are the UCT CSAG and the DTU Wind Energy.

The measured data from the 10 WASA wind measurement stations was used to verify the result which resulted in a Verified Numerical Wind Atlas (VNWA) (see Figure 5).

This VNWA can be applied to more than the 10 WASA mast areas; it can be applied to the whole WASA modelling domain with data available every 3 km x 3 km which correspond to about 40 000 points of data (or “virtual masts”) covering the WASA area. This VNWA data can be directly used with most of the standard software that is used to assess wind resources, such as the WAsP. The information on wind resources is used for the planning of wind farms.



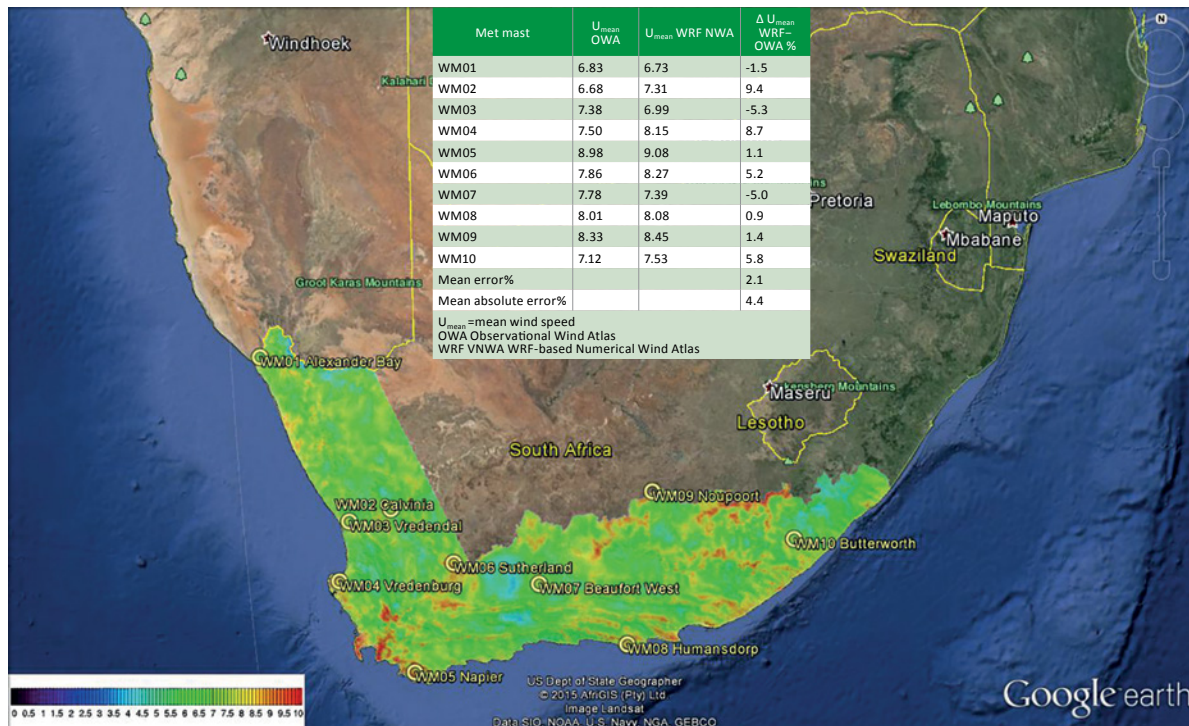


Figure 5: VNWA for South Africa, based on WRF, launched in April 2014 (generalised wind climate – flat terrain, 3 km x 3 km grid spacing)

“This VNWA can be applied to more than the 10 WASA mast areas; it can be applied to the whole WASA modelling domain with data available every 3 km x 3 km which correspond to about 40 000 points of data (or ‘virtual masts’) covering the WASA area.”



Figure 6: A screenshot of the VNWA database interface – Tadpole – using a Google Earth plug-in that can be accessed here: <http://wasaclimates.eu/Tadpole/Viewer?gid=08aee5e5-e31f-416a-ad12-9a7a4d26f92e>

“The NWA that is based on the WRF method agrees excellently with the average measured wind speed and the measured wind speed and direction distributions of the measurement mast sites.”

The *South African Wind Atlas (WASA) Guide*⁹ provides:

- a step-by-step instruction on how you can access the database’s assumptions, usage and limitations; and
- instructions on why the microscale resource modelling is important for assessing detailed wind resources and for planning wind farms.

7.1.1 THE NUMERICAL WIND ATLAS EXPLAINED

The VNW that is based on the WRF method agrees excellently with the average measured wind speed and the measured wind speed and direction distributions of the measurement mast sites. This is shown in Figure 7, which compares the observed and simulated wind atlases at WM05.

7.1.2 SEASONAL AND DAILY CYCLES

The WRF regional model gives data on wind that occurs at the same time as the data from the 10 WASA wind measurement masts. For most masts, the period during which the data were collected overlaps for three years.

The WRF wind modelling results are verified at each of the 10 WASA measurement masts for winds at 62 m height above ground level (AGL). The daily and yearly distributions of the wind speed at each of the masts are compared with the data collected from the corresponding WRF-based grid cell in which that mast would be situated.

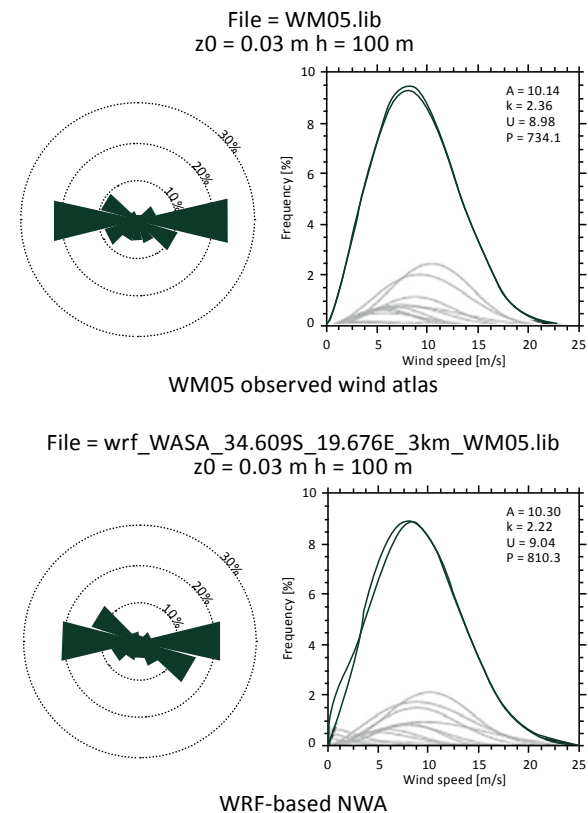


Figure 7: The WRF-based NWA shows good agreement with the wind speeds and wind direction distributions

⁹ See Reference 10.

For each of the 10 masts, the following assessments were made:

- a histogram of the wind speed, seasonal cycle and daily cycle (see Figure 8); and
- summary statistics:
 - mean bias;
 - root mean squared error (RMSE);
 - mean absolute cycle bias (this is the mean absolute difference between the daily cycles across the seasonal cycles); and
 - a Pearson's correlation coefficient (namely a linear correlation coefficient).

Figure 8 shows:

- the wind speed distribution (top left); the mean seasonal cycle (top centre) and the mean daily cycle (top right) in the mast measurements (blue) and in the WRF model simulations (green); and
- the mean wind speed (ms^{-1}) at 62 m AGL as a function of the time of the day and the month of the year for the mast observations (bottom left) and the WRF simulations (bottom right).

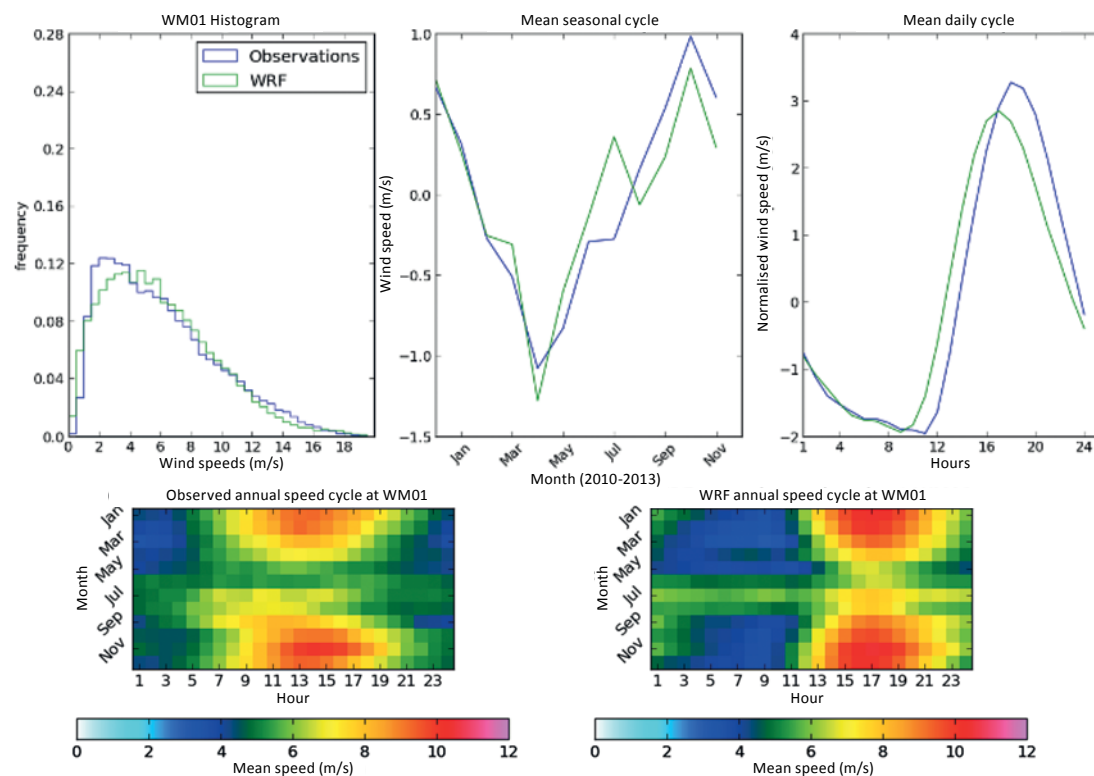


Figure 8: Comparison of the wind speed at 62 m AGL for WM01

“The WRF model agrees excellently with the daily and seasonal wind cycles at the wind mast sites.”

The tenth mast was completed on 17 September 2010. The three-year measurement period started once this mast was completed.

The CSIR indicated that the time to install instruments on a mast was improved, from taking two days to only taking five hours at the tenth mast.

Wind data is stored in the Rodeo MySQL database management system after which it is displayed on the website. A stringent quality assurance process was applied to the WASA data before being published on the website.

The preferred mast type for the WASA measurements was a narrow, triangular, lattice mast.

The WRF model data agrees excellently (near unity 1.0 Pearson correlation coefficients) with the hourly, daily and monthly measured wind speed averages.

7.1.3 WIND TIME SERIES DATA

The WRF model simulated the wind time series data (hourly mean wind speed and direction) from 1 September 1990 to 31 December 2012.

The wind time series are particularly useful:

- to study the annual, seasonal and diurnal variations in wind resources;
- as input to power system modelling;
- to study the geographical cross correlation of wind across South Africa; and
- for long-term corrections of the wind resources given by the WRF wind climate files.

7.1.4 FINAL REPORTS AND DATA FOR WORK PACKAGE 1

A final report was created for the first WP, named the *Mesoscale Modelling for the Wind Atlas of South Africa (WASA) Project*^h.

7.2 WORK PACKAGE 2 – WIND MEASUREMENTS

The main result of WP2 was to collect quality measurements from the 10 installed wind masts. WP2 was carried out by the CSIR and the DTU Wind Energy.

The Minister of the DoE launched 10 wind measurement masts (WM01 to WM10) (see Figure 9) at the second Annual Wind Energy Seminar in September 2010, after they were installed according to the International Electrotechnical Commission (IEC) and Measnet standards. These masts have been operational since their launch.

Features of WASA wind measurement masts include the following:

- instrumentation is arranged to minimise errors and uncertainties due to flow distortion;
- proven sensors are of high quality that are individually calibrated;
- regular inspection and maintenance;
- anemometers at five different heights: 10 m, 20 m, 40 m, 60 m and 62 m;
- wind vanes at two heights: 20 m and 60 m;
- temperature and pressure sensors;
- data recovered at 10 minute average intervals;
- turbulence calculated and recorded; and
- data downloaded and checked regularly to minimise loss of data or data gaps.

Risø Online Database for Environmental Observations (Rodeo) has been installed and is operational at the CSIR branch in Stellenbosch. It is a system which manages data and stores online measurement data in a MySQL database. The data are automatically displayed on a website from the MySQL database. The online graphs on this website can be viewed on the WASA website and you can access and download the data from the website once quality checks have been done.

^h See Reference 9.

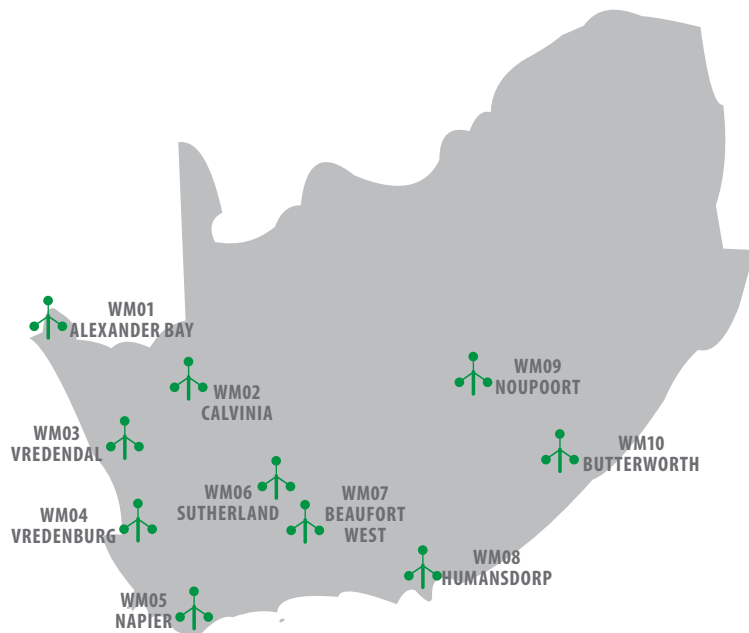


Figure 9: The 10 wind masts launched in September 2010

Table 1: WASA wind measurement masts data recovery

WASA	U_{mean} at 61.9 m - Year	U_{mean} at 61.9 m - Year 3 Years*	ΔU	Data Recovery
	[m/s]	[m/s]	[%]	[%]
WM01	5.86	6.06	3.3	100
WM02	6.21	6.14	-1.1	93.4
WM03	7.09	7.14	0.7	100
WM04	6.59	6.71	1.8	100
WM05	8.64	8.56	-0.9	98.6
WM06	7.02	7.36	4.6	99.9
WM07	6.85	6.93	1.2	97.0
WM08	7.36	7.34	-0.3	100
WM09*	7.58	8.22	7.8	99.7
WM10*	6.55	6.55	0	98.8

U_{mean} = mean wind speed

ΔU difference = U_{mean} 1 year & U_{mean} 3 years

*2-year periods for WM09 & WM10:

WM09: 2010-10 to 2013-09 minus the year 2011.

WM10: 2011-03 to 2012-02 plus 2012-10 to 2013-09.

Table 1 shows the percentage difference in mean wind speed for some of the WASA sites for the first year and after three years' measurements with an excellent data recovery rate. The measured wind data is used to create the statistics of the wind at each of the WASA meteorological stations that are used to verify the NWA.



7.2.1 FINAL REPORTS AND DATA FOR WORK PACKAGE 2

Three final reports were created for the second WP. These were:

- *WP2 Report on Trainingⁱ*
- *Report on Measurements^j*
- *Station and Site Description Report^k*

The *WP2 Report on Trainingⁱ* covers the training which was required as part of WP2 and which was provided by the DTU. Training was provided on the correct methods for setting up and installing the hardware on the mast to ensure the measurements are of a high quality on the Rodeo database and quality control system.

The *Report on Measurements^m* concerns the importance of quality data as this is essential to a good and accurate wind atlas. It documents the three-year measurement campaign and includes all the aspects related to the measurements, including the mast positions, design of the masts, the instruments to be used and the layout. The best practices for the measurements are also provided.

Finally, the *Station and Site Description Reportⁿ* discusses findings of the site inspections of the 10 mast sites which were carried out by the CSIR and DTU in 2011. These site inspections considered the quality of the mast installations and collected the data needed for the analysis. The report concludes, amongst others, that the mast installations were mostly of a high standard and no changes were made to the installations during the site visits.

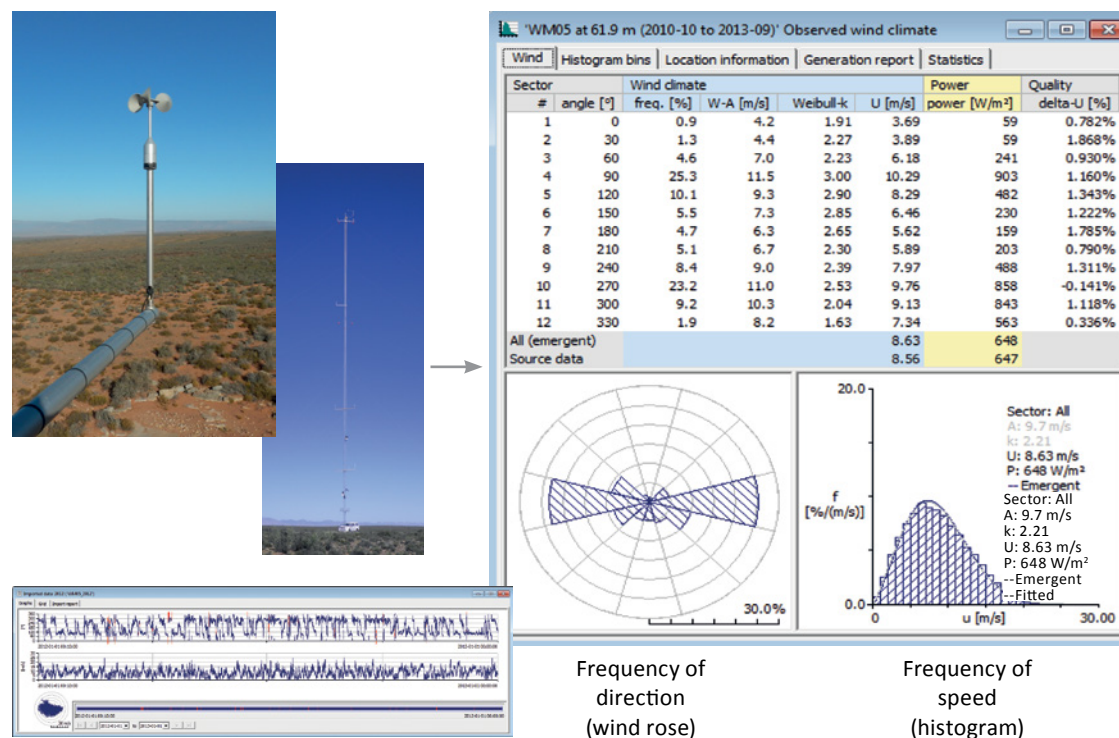


Figure 10: The measured wind data is used to create the wind statistics

ⁱSee Reference 12. ^jSee Reference 11. ^kSee Reference 13. ^lSee Reference 12. ^mSee Reference 11. ⁿSee Reference 13.

7.3 WORK PACKAGE 3 AND WORK PACKAGE 4 – MICROSCALE MODELLING AND APPLICATION FOR WIND RESOURCE ASSESSMENT

The main result of WP3 was 10 observational wind atlases while WP4 mainly resulted in ways to apply the maps and data. These WPs were carried out by the CSIR and the DTU Wind Energy.

7.3.1 IMPORTANCE OF MAP RESOLUTION

The highest resolution – obtained through micro-scale modelling using the wind atlases as input climate information – is important to resolve the real wind energy potential and create the High-Resolution Wind Resource Maps. This is illustrated in Figure 11.

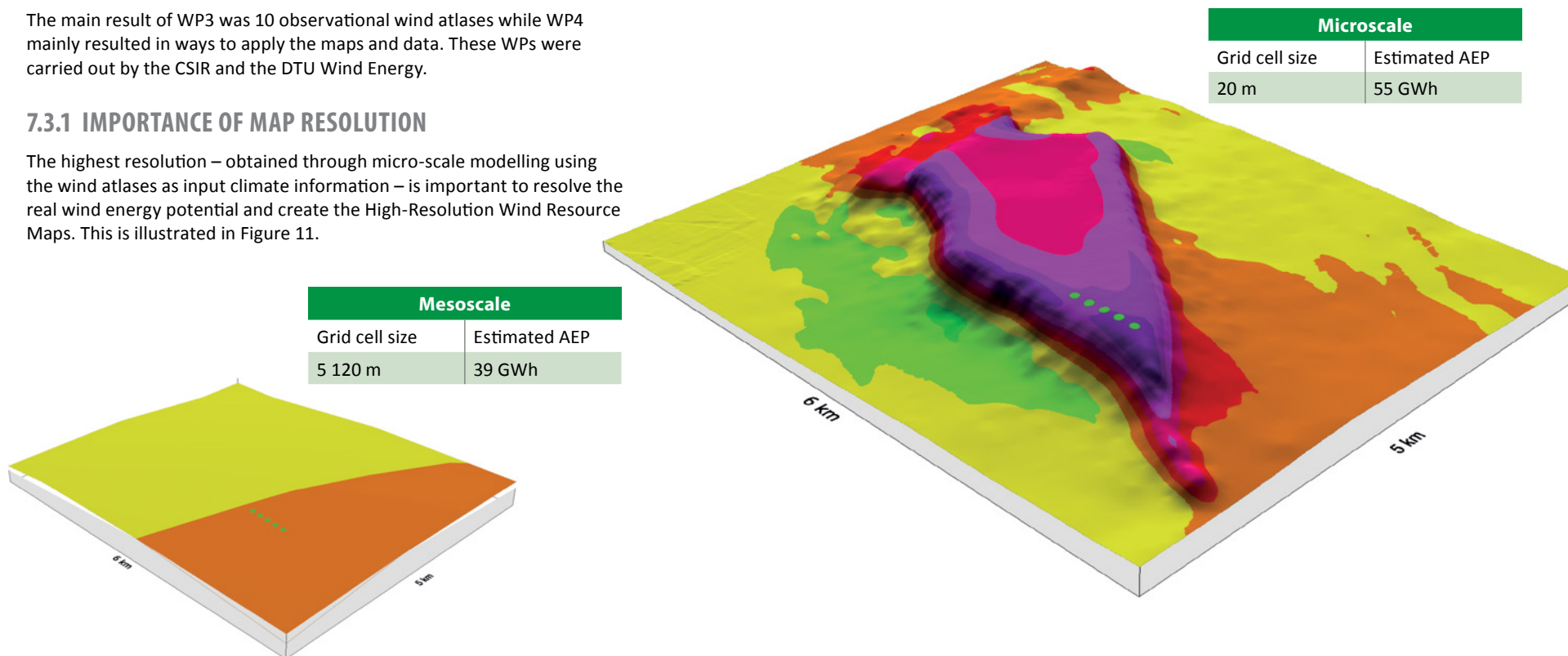


Figure 11: Resolution is important for the real wind energy potential, as shown in the study by DTU Wind Energy (N.G. Mortensen)

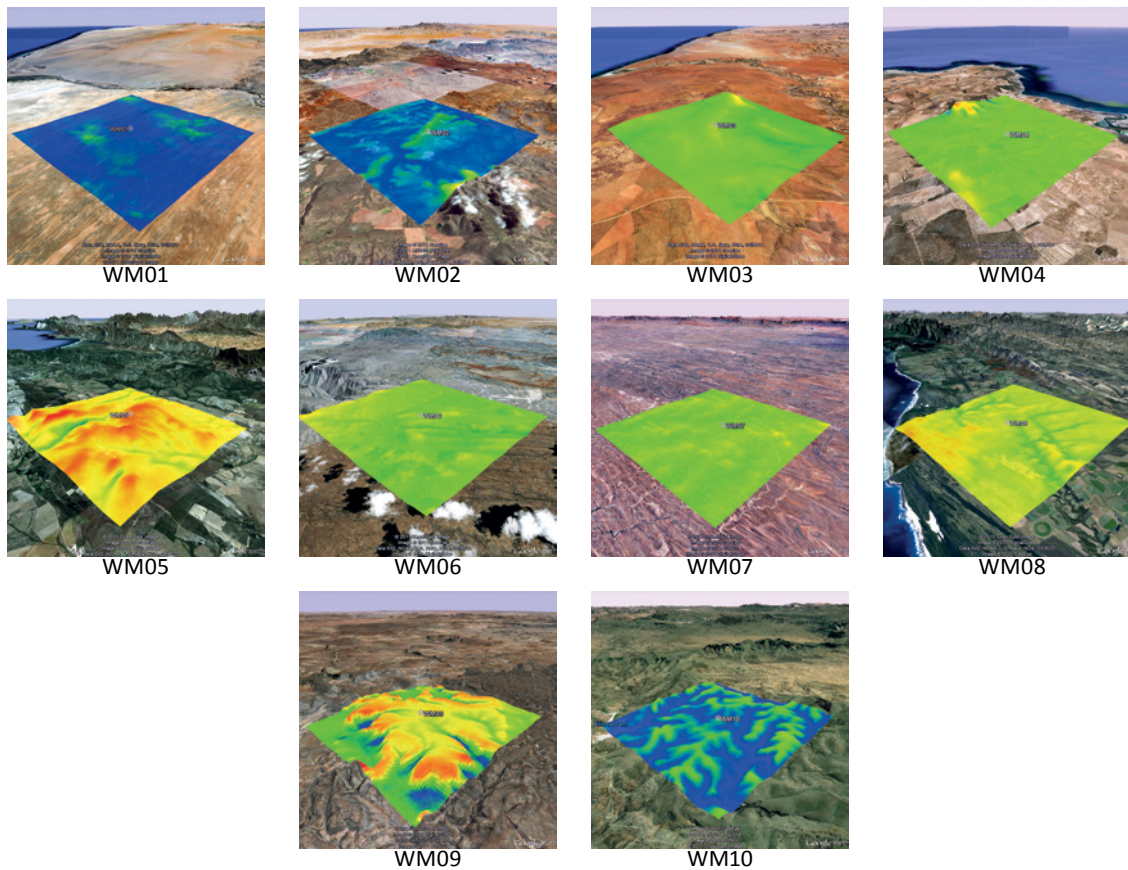


Figure 12: The microscale modelling at the WASA meteorological masts

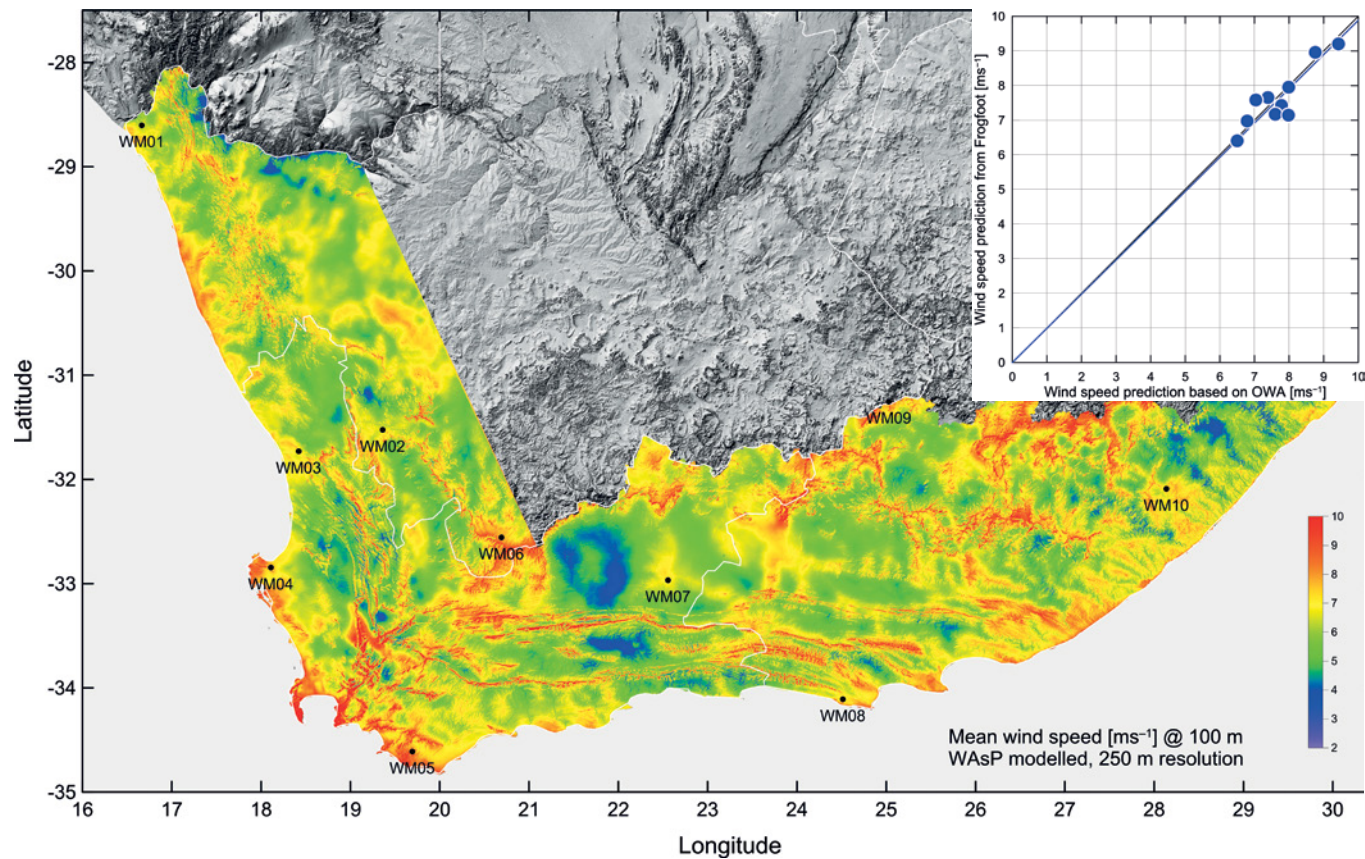
The VNWA and the local terrain topography are used with the DTU WAsP Wind Resource Mapping Tool, Frogfoot, to create large-scale high-resolution (250 m grid spacing) wind resource maps.

The outputs of the high-resolution maps are given in Figures 13 and 14:

- Mean wind speed and mean power density at 100 m AGL and a grid spacing of 250 m.
- Terrain ruggedness index and more are also available on the download site.

These high-resolution maps based on the WRF model are traceable to the wind measurements that were used to verify the NWA.

• “The VNWA and the local terrain topography
• are used to create large scale high-resolution
• wind resource maps.”



• “On average, the
 • WRF-based wind
 • resource map (see
 • Figure 13) estimates
 the wind speed
 accurately at the
 WASA mast sites
 with an uncertainty
 of less than 2.2%.”

Figure 13: Large-scale high-resolution wind resource map launched in April 2014 (local wind climate, 250 m grid spacing) with the mean wind speed

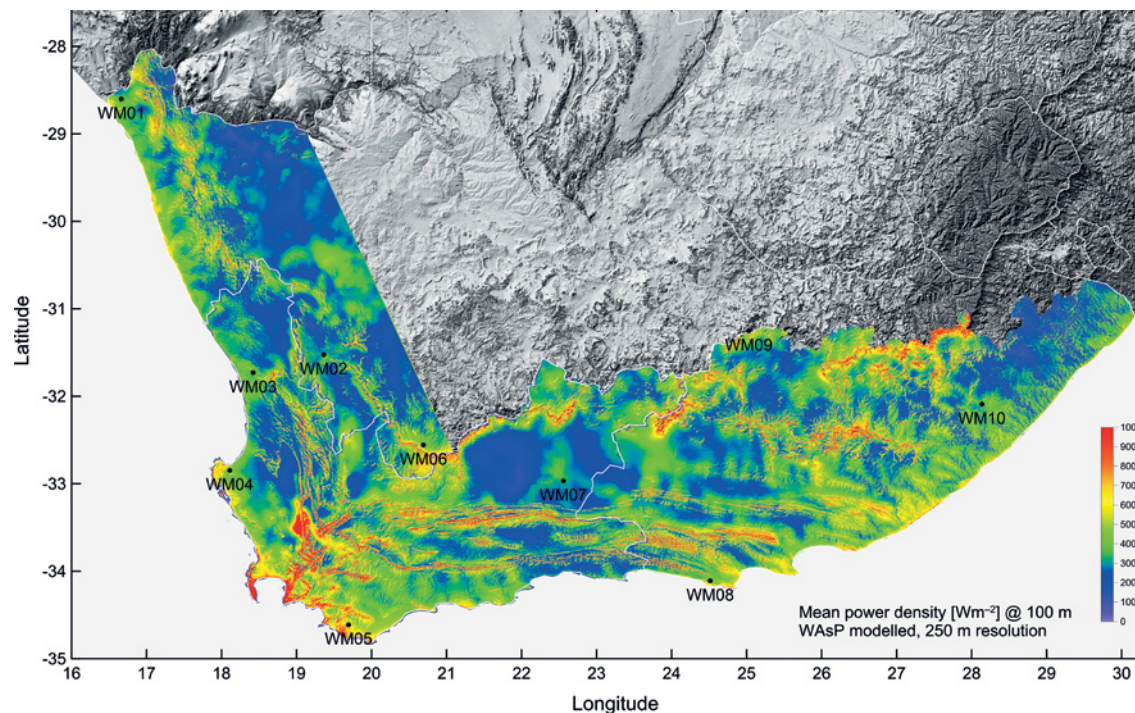


Figure 14: Large-scale high-resolution wind resource map launched in April 2014 (local wind climate, 250 m grid spacing) with the mean wind power density

^aSee Reference 15. ^bSee Reference 14.

7.3.2 METADATA

The high-resolution wind resource map depicts the local wind climate that a wind turbine would encounter. It also offers important benefits for developers, policy makers, utilities and the industry, including the following:

- Saves time and costs as the bankability of a potential wind farm site can now be estimated and physical wind measurements are only undertaken for bankable wind sites.
- Levels the playing field between small and large industry players to identify and develop wind hot spots.
- Assists Government in estimating the real wind resource potential.
- Identifies possible wind development zones in line with the strategic environmental assessment (SEA) studies or in line with frameworks. The DEA's SEA for solar photovoltaic and wind is an example of such an SEA study and is available at <http://www.csir.co.za/nationalwindsolaresea/>
- Long-term grid planning to connect with high-potential wind development areas.
- Wind farm planning in positioning (micrositing) the wind turbines for optimal wind exposures.

7.3.3 REPORTS, DATA AND TRAINING MATERIAL FOR WORK PACKAGE 3 AND WORK PACKAGE 4

For the third WP, the *Observational Wind Atlas for 10 Met Masts in Northern, Western and Eastern Cape Provinces^a* report was developed.

This report describes the microscale modelling that was done for the 10 meteorological masts, using the latest version of the WAsP. This modelling was done to create the first observational wind atlas and it was concluded that the WAsP works well where the sites are within its operational

Extreme winds are strong winds that can damage a turbine, but do not frequently occur. So, it is a wind speed that is, on average, exceeded only once in 50 years.

The origins of strong winds are dominated by thunderstorms, cold fronts and a mixed, strong wind climate.

envelope and to follow the general WASP best practices closely when applying WASP and similar models in South Africa.

The fourth WP resulted in the reports, training and maps listed below:

- *Brief Introduction to Working with WASA Files*⁹
- A training course in applying the products of the WASA project
- Detailed High-Resolution Wind Resource Maps

The *Brief Introduction to Working with WASA Files*⁹ provides step-by-step instructions on how to use the NWA with the topography data to do microscale wind resource mapping.

The training course in applying the products of the WASA project concerned the planning and review of potential wind farm production and education for the purposes of teaching planners, assessors and students about wind atlases and, specifically, the WASA project. The course was divided into three themes:

- Theme 1: Wind Atlases
- Theme 2: the Wind Industry Sector
- Theme 3: the WASA project

7.4 WORK PACKAGE 5 – EXTREME WIND ATLAS

WP5 mainly resulted in an Extreme Wind Atlas and was carried out by the SAWS and the DTU Wind Energy.

Wind makes up most of the essential environmental loading that affects the structural design of South Africa’s built environment. It follows that you also need information on extreme winds when you design wind farms, which are usually situated in places where there are relatively strong winds.

The Extreme Wind Atlas provides maps of the 1:50 years gust and 10-minute average wind speed which, together with turbulence, define the wind turbine class according to the IEC standard 61400-1. It is important that the appropriate wind turbine class is known for a particular site to ensure the optimal selection of a turbine in a particular strong wind climate.

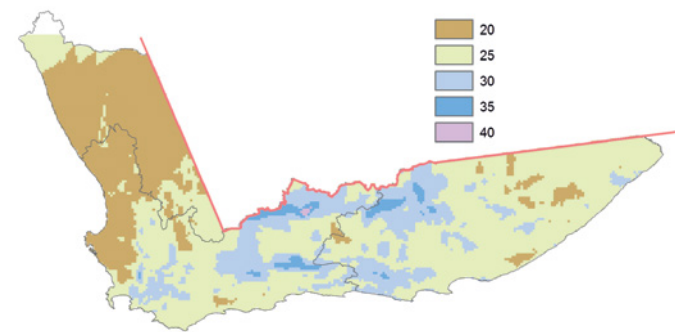


Figure 15: 1:50 years 10-minute wind speed (m/s) at 10 m AGL (standard conditions)

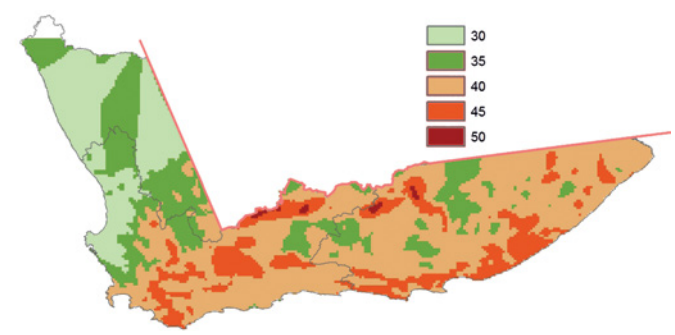


Figure 16: 1:50 years 2-3 s gust speed (m/s) at 10 m AGL (standard conditions)

⁹ See Reference 15. ¹⁰ See Reference 15.

7.4.1 FINAL REPORTS AND DATA FOR WORK PACKAGE 5

For this WP, the metadata for the Extreme Wind Atlas has been created. The *Guidelines for Using the Extreme Wind Data from the Selective Dynamical Downscaling Method*⁵ from April 2014 was also created. This guideline was created to obtain the design parameters required in the IEC standard and provides instructions to use the WASP Engineering (WEng) software to estimate the 1:50-year wind at a particular site at the hub height.

7.5 WORK PACKAGE 6 – DOCUMENTATION AND DISSEMINATION

The main results of the sixth WP is to create awareness of the WASA project and its results. This WP was carried out by the SANEDI.

Awareness of the WASA project is created through websites, workshops, WASA briefs, Windaba presentations, wind seminars, press releases, the IRENA Global Solar and Wind Atlas and other projects that reference the WASA project. These forms of communication are also used to share the information gathered by the WASA project.

7.5.1 WEB PRESENCE SINCE SEPTEMBER 2010

The WASA project has had a web presence since September 2010. The websites that make use of information from the WASA project is listed below:

- To view the online graphs, go to <http://www.wasa.csir.co.za>
- Go to <http://wasadata.csir.co.za/wasa1/WASAData> to download the final reports, maps, guides and data (register for free and log in)

- To view the WASA information on the WASA website, go to <http://www.wasaproject.info/>
- To read about the WRF model which forecasts wind speed, power density and direction of the wind over South Africa, go to <http://veaonline.risoe.dk/wasa> This model is the basis of the research-based NWA.



⁵See Reference 16.

7.5.2 WEBSITE USER STATISTICS (MAY 2014)

The latest user statistics of the WASA website can be found below, in Figure 17.

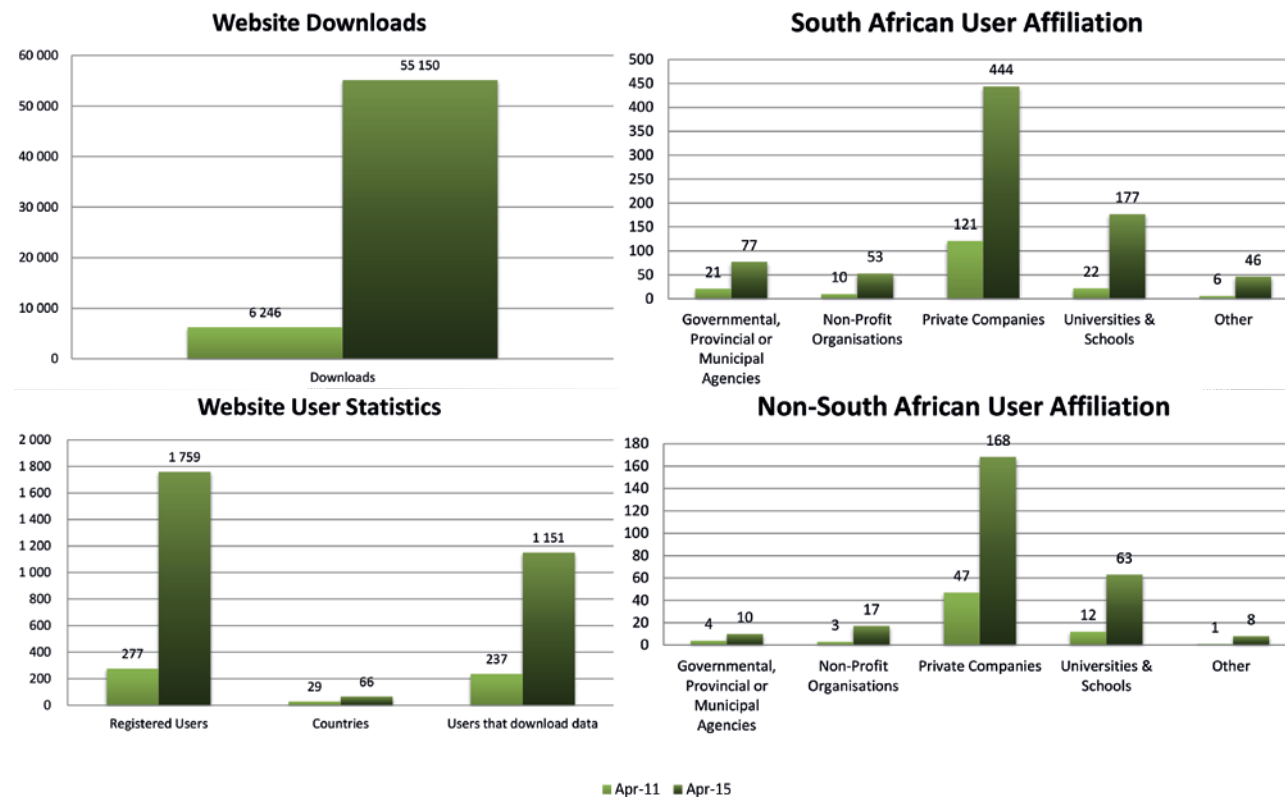


Figure 17: User statistics of the WASA websites

“SAWEA would also like to congratulate the WASA team on further developing an internationally-recognised methodology for compiling such a wind map that is already being adopted by other countries.”
 Frank Spencer on behalf of SAWEA Technical Working Group, June 2014.



7.5.3 WORKSHOPS

Four workshops were completed since 2010 in order to distribute the information from the WASA project and to make people aware of the project. These were:

- SAWEP Wind Atlas Workshop (completed on 4 March 2010);
- WASA Mid-Term Workshop (completed on 14 to 16 March 2012);
- DoE WASA Workshop (completed on 11 December 2012); and
- SANEDI WASA Workshop (completed on 10 April 2014).

7.5.4 WINDABA PRESENTATIONS

Since 2011, three Windaba presentations were done every year, as shown below:

- In 2011, the Windaba was held in Cape Town on a comparative and quantitative assessment of South Africa's wind resource – the WASA project.
- In 2012, the Windaba presentation concerned quantifying South Africa's wind resource – an update on the WASA project and verification against two years of measurements.
- In 2013, the Windaba presented on large-scale high-resolution wind resource mapping for SEA and wind farm planning and development.

7.5.5 FINAL WIND SEMINAR 8 APRIL 2014

A final wind seminar was presented on 8 April 2014 and was divided into three sections. The three sessions concerned:

- the WASA results;
- an overview of the WASA project and the first two WPs; and
- WP3 to WP5, including case studies.

7.5.6 PRESS RELEASES

Two press releases were created to make people aware of the project. The first press release¹ announced the launch of South Africa's first large-scale high-resolution wind resource map and notified people that the map would boost renewable energy efforts.

This press release can be read in its entirety at <http://www.sanews.gov.za/south-africa/wind-resource-map-boost-renewable-energy-efforts>

The second press release² was released on 8 April 2014 and notified the public about the completion of the project with the final seminar of the WASA Phase 1 taking place.

You can read this press release in its entirety at <http://www.energy.gov.za/files/media/pr/2014/PressRelease-WASA-Seminar-08April2014.pdf>

7.5.7 INTERNATIONAL RENEWABLE ENERGY AGENCY GLOBAL SOLAR AND WIND ATLAS

The WASA supports the DoE and the DoE Minister with the Clean Energy Ministerial and is a technical partner in the IRENA Global Solar and Wind Atlas initiative.

You can find out more about the other partners of the IRENA Global Solar and Wind Atlas initiative by visiting <http://globalatlas.irena.org/Partnership.aspx>
The WASA is also included in the catalogue of this initiative, as can be seen at <http://irena.masdar.ac.ae/?map=405>
as well as the initiative's booklet at http://www.irena.org/DocumentDownloads/Publications/GA_Booklet_Web.pdf

¹ See Reference 19. ² See Reference 20.

7.5.8 PROJECTS REFERENCING THE WIND ATLAS FOR SOUTH AFRICA

The WASA project has also been referenced by other projects, increasing awareness of the project and distributing information to the public.

The Terms of Reference for Renewable Energy Mapping: Wind Pakistan, 2013 of the World Bank ESMAP Renewable Energy Resource Mapping initiative²¹ referred to the WASA project as:

“In the numerical wind atlas supplied by the bidder, each cell shall provide downloadable directional Weibull distributions in WASP lib-file format, applicable to a generalised wind climate with flat terrain and a uniform roughness of 0.03 m. (See, for example, the Wind Atlas for South Africa [WASA] project.)”

You can visit http://www.esmap.org/RE_Mapping for more information on the World Bank ESMAP Programme.

The Palestinian Energy Authority also made reference to the WASA project in their Request for Proposal in June 2013²² for the Energy Sector Assistance in Palestine, Phase V project which was to produce a comprehensive, validated atlas for wind energy resource based on satellite data. They referenced the WASA project as follows:

“The consultant must supply all wind maps and data for the same heights above ground level as in the Wind Atlas for South Africa (WASA).”

“Directional Weibull distributions for each cell is the most important data, cf. the WASA model data online.”

7.6 CAPACITY BUILDING AND HUMAN DEVELOPMENT

Capacity building, human development and skills transfer, as this WASA project is uncharted territory for South Africa, are the cornerstones of the WASA project and are encouraged and promoted. The public has shown their interest in participating in this capacity building and human development of the WASA project.

7.6.1 SOUTH AFRICAN WEATHER SERVICE CAPACITY BUILDING AND HUMAN DEVELOPMENT

The WASA supported the doctoral thesis of Dr Andries Kruger, a SAWS WASA team member, entitled *Wind Climatology of South Africa Relevant to the Design of the Built Environment*²³. This thesis is relevant for extreme winds.

“SAWS refined the quality control procedures of its wind climate data in view of the information obtained through the measured wind data analysis in the WASA project. This included the training of SAWS Climate Service personnel in the optimal quality control of wind data.”

The development of the revised map of the South Africa Wind Loading Code will now take into account the South African mixed wind climate and other uncertainties. It will also be based on a more comprehensive set of wind statistics from a much larger set of wind data compared to the data that were available previously. This was presented at two wind seminars on the provisions of South African National Standards (SANS) 10160-3, organised by the Stellenbosch University.



²¹See Reference 21. ²²See Reference 22. ²³See Reference 23.

“Capacity building, human development and skills transfer are the cornerstones of the WASA project.”

7.6.2 UNIVERSITY OF CAPE TOWN CLIMATE SYSTEMS ANALYSIS GROUP CAPACITY BUILDING AND HUMAN DEVELOPMENT

Students have directly or indirectly benefited from the WASA project. How we understand the many aspects of the wind climate of South Africa has been aided by these students’ work. Certain students have already graduated, while others are still studying.

7.6.2.1 GRADUATED STUDENTS

- Christopher Broderick (BSc Hons) used sonic detection and ranging (sodar) for wind measurements to assess the correlations of wind profiles from sodar, radiosonde and anemometer data.
- Teboho Nchaba (MSc) verified gridded seasonal wind forecasts over South Africa.
- Tich Mukunga (BSc Hons) graduated at the end of 2014 with an assessment of the wind power resource in the Sere region of the Western Cape.

7.6.2.2 CURRENT STUDENTS

- Brendan Argent (PhD) is expected to graduate in July 2015 with a look at *Towards an Uncertainty Atlas for Wind Forecasts in South Africa*.
- Teboho Nchaba (PhD) is expected to graduate at the end of 2016 with an improved South African wind atlas from a multi-model super-ensemble.
- Zaccheus Olaofe (PhD) is expected to graduate at the end of 2017 with an assessment of the offshore wind resources along the West Coast of South Africa.

7.6.3 COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH CAPACITY BUILDING AND HUMAN DEVELOPMENT

The capacity and expertise of the CSIR can be divided into three main themes: measurements, data management and microscale modelling.

A number of staff members received training in various aspects of the project which ensured the final outcomes of the second, third and fourth WPs.

7.6.4 TECHNICAL UNIVERSITY OF DENMARK WIND ENERGY CAPACITY BUILDING AND HUMAN DEVELOPMENT

Jens Carsten Hansen, the DTU project leader, has stated the following regarding the WASA project’s contribution to research and training at the DTU:

“The WASA project is an applied research project for DTU through which we get an opportunity to pilot new models and methods in a real application and collect feedback for further developments and research. Depending on the definition of the term ‘capacity building’, this has certainly happened here at DTU, i.e. as we see it, WASA has contributed to building capacity at DTU, including teaching students and applied research.”

Xiaoli Guo Larsén (from the DTU) gave the below statement about WASA’s contribution to creating the background for further WASP Engineering development:

“WASA has contributed to creating the background necessary for DTU decisions regarding how to further develop WASP Engineering.”

7.6.5 CAPACITY BUILDING AND HUMAN DEVELOPMENT IN MEASUREMENTS

The WASA project has also provided other valuable training for measurements:

- Prinsloo, E. and Mabile, E. were trained in site selection to ensure conformity with the WASP criteria. The training was provided by DTU.
- Truter, P., Hendricks, T., Prinsloo, E. and Mabile, E. were trained in installing measurement sensors on the masts according to the Measnet and IEC standards. The training was provided by DTU.
- Prinsloo, E., Truter, P., Hendricks, T., Kieviet, J., Mashabala, S. and Connor, P.O. attended a Working at Heights course in June 2010 in Cape Town so they could comply with Safety, Health, Environmental and Quality (SHEQ) requirements.
- Prinsloo, E., Connor, P.O., Kieviet, J. and Hendricks, T. attended a course in August 2013 to be SHEQ certified again.
- Jelbert, H., Haasbroek, S. and Mabile, E. also completed the full SHEQ course for the WASA Phase 2.
- Von St Ange, U., August, M., Prinsloo, E. and Pietersen, S. were trained on the Rodeo Data Management System by DTU.
- Prinsloo, E. was trained in data quality control that enabled him to eventually take over the 10 stations' data quality control from the DTU.

Both the Working at Heights and SHEQ recertification courses were conducted by Alpinist Safety Consultants at their premises in Montague Gardens.

7.6.6 CAPACITY BUILDING AND HUMAN DEVELOPMENT IN MICROSCALE MODELLING

Prinsloo, E., Mabile, E., Szewczuk, S. and other CSIR staff members were trained on the WASP microscale modelling software at the Pretoria campus by experts from DTU. Eugene Mabile became actively involved in the microscale modelling in WP3.



Artistic impression of South African Renewable Energy Technology Centre (SARETEC), Cape Town.

“There are numerous publications which have made use of the WASA project.”

7.6.7 INTERNATIONAL CONFERENCES, PRESENTATIONS AND PUBLISHED PAPERS FOR CAPACITY BUILDING AND HUMAN DEVELOPMENT

7.6.7.1 PUBLICATION PRESENTED AT AN INTERNATIONAL CONFERENCE

Hahmann, A.N., Badger, J., Volker, P., Nielsen, J.R., Lennard, C., Hansen, J.C. & Mortensen, N.G. 2014. *Validation and Comparison of Numerical Wind Atlas Methods: the South African Example*. Presented to European Wind Energy Association, European Wind Energy Conference and Exhibition 2014, Barcelona, Spain, 10 March 2014.

7.6.7.2 REFERENCE OF THE WIND ATLAS FOR SOUTH AFRICA PROJECT IN CONFERENCE PAPERS

Kruger, A.C., Goliger, A.M. & Retief, J.V. 2011. *Integration and Implications of Strong Wind Producing Mechanisms in South Africa*. Presented to ICWE 13, Amsterdam, Netherlands, 10-15 July 2011.

Kruger, A.C., Goliger, A.M. & Retief, J.V. 2011. *An Updated Description of the Strong-Wind Climate of South Africa*. Presented to ICWE 13, Amsterdam, Netherlands, 10-15 July 2011.

Kruger, A.C., Goliger, A.M. & Retief, J.V. 2013. *Directional Analysis of Extreme Winds under Mixed Climate Conditions*. Presented to EACWE 2013, Cambridge, United Kingdom, 7-11 July 2013.

Kruger, A.C., Goliger, A.M. & Retief, J.V. 2013. *Representivity of Wind Measurements for Design Wind Speed Estimations*. Presented to EACWE 2013, Cambridge, United Kingdom, 7-11 July 2013.

Larsén, X.G., Kruger, A.C., Badger, J. & Jørgensen, H.E. 2013. *Extreme Wind Atlases of South Africa from Global Reanalysis Data*. Presented to EACWE 2013, Cambridge, United Kingdom, 7-11 July 2013.

Kruger, A.C., Goliger, A.M., Larsén, X.G. & Retief, J.V. 2014. *Optimal Application of Climate Data to the Development of Design Wind Speeds*. Presented to 26th Conference on Climate Variability and Change (Annual Meeting of the American Meteorological Society), Atlanta, United States of America, February 2014.

Larsén, X.G., Kruger, A.C., Badger, J. & Jørgensen, H.E. 2014. *Dynamical and Statistical Downscaling Approaches for Extreme Wind Atlas of South Africa*. Presented to EMS conference, Reading, United Kingdom, February 2014.

7.6.8 PUBLICATIONS PUBLISHED FOR CAPACITY BUILDING AND HUMAN DEVELOPMENT

There are also numerous publications which have made use of the WASA project, including the following:

- Hansen, J.C., Hahmann, A.N., Mortensen, N.G. & Badger, J. 2011. *How Can Denmark Support Wind Mapping in Africa? Third Wind Energy Seminar between South Africa and Denmark*. Presented to Side Event at COP17, Durban, South Africa, 8 December 2011.
- Mortensen, N.G., Hansen, J.C., Kelly, M.C., Prinsloo, E., Mabilie, E. & Szewczuk, S. 2012. *Wind Atlas for South Africa (WASA) Station and Site Description Report*. Presented to Danmarks Tekniske Universitet, Risø Nationallaboratoriet for Bæredygtig Energi. p70. (Risø-I; No. 3271 [ed.3][EN]).
- Mortensen, N.G., Hansen, J.C., Kelly, M.C., Szewczuk, S., Mabilie, E. & Prinsloo, E. 2012. *Wind Atlas for South Africa (WASA) Observational Wind Atlas for 10 Met Stations in Northern, Western and Eastern Cape Provinces*. Presented to Danmarks Tekniske Universitet, Risø Nationallaboratoriet for Bæredygtig Energi. p42. (Risø-I; No. 3273 [ed.2][EN]).
- Mortensen, N.G., Hansen, J.C., Mabilie, E. & Spamer, Y. 2013. *Large-Scale, High-Resolution Wind Resource Mapping for Strategic Environmental Assessment and Wind Farm Planning and*

- *Development*. Presented to Windaba 2013, Cape Town, South Africa, 25 September 2013.
- Hahmann, A.N., Badger, J., Volker, P., Nielsen, J.R., Lennard, C., Hansen, J.C. & Mortensen, N.G. 2014. *Validation and Comparison of Numerical Wind Atlas Methods: the South African Example*. Presented to European Wind Energy Association, European Wind Energy Conference and Exhibition 2014, Barcelona, Spain, 10 March 2014.
- Mortensen, N.G., Badger, J., Hansen, J.C., Mabilile, E. & Spamer, Y. 2014. *Large-Scale, High-Resolution Wind Resource Mapping for Wind Farm Planning and Development in South Africa*. Presented to Proceedings of EWEA 2014, European Wind Energy Association, 2014.
- Goliger, A.M., Retief, J.V., Dunaïski, P.E. & Kruger, A.C. 2009. Revised Wind-Loading Procedures for SANS 10160. In Retief, J.V. & Dunaïski, P.E. (eds). *Background to SANS 10160. Basis of Structural Design and Actions for Buildings and Industrial Structures*. SunMedia, Stellenbosch.

Andrea N.H. (DTU Wind Energy) said the following:

“The DTU wind atlas method is based on the generalisation of the wind climatologies derived from the mesoscale modelling. This generalisation post-processing method has been used extensively in a number of wind resource assessment studies within the KAMM-WAsP method. The WRF- based WASA wind atlas is the first wind atlas study where the generalisation has been carried out on the WRF-model output with excellent results.”

7.6.9 JOURNAL ARTICLES PUBLISHED FOR CAPACITY BUILDING AND HUMAN DEVELOPMENT

The following journal articles have referenced the WASA project or referenced methodologies developed or results obtained during the course of the WASA project:

- Goliger, A.M. & Kruger, A.C., *et al.* 2013. Comparative Study between Poland and South Africa: Wind Climates, the Related Damage and Implications of Adopting the Eurocode for Wind Action on Buildings. *Archives of Civil Engineering*.
- Kruger, A.C., Retief, J.V. & Goliger, A.M. 2013. Strong Winds in South Africa: Part I – Application of Estimation Methods. *Journal of the South African Institution of Civil Engineering*.
- Kruger A.C., Retief, J.V. & Goliger, A.M. 2013. Strong Winds in South Africa: Part II – Mapping of Updated Statistics. *Journal of the South African Institution of Civil Engineering*.
- Kruger, A.C., Goliger, A.M., Retief, J.V. & Sekele, S. 2012. Clustering of Extreme Winds in the Mixed Climate of South Africa. *Wind and Structures*.
- Kruger, A.C., Goliger, A.M., Retief, J.V. & Sekele, S. 2010. Strong Wind Climatic Zones in South Africa. *Wind and Structures*.
- Larsén, X.G., Mann, J., Rathmann, O. & Jørgensen, H. 2013. Uncertainties of the 50-Year Wind from Short Time Series Using Generalized Extreme Value Distribution and Generalized Pareto Distribution. *Wind Energy*.

7.6.10 DISSEMINATION OF WIND ATLAS FOR SOUTH AFRICA RESULTS FOR CAPACITY BUILDING AND HUMAN DEVELOPMENT

WASA results have also been disseminated through:

- Hahmann, A.N., Badger, J., Morgensen, N.G. & Hansen, J.C. 2009. *From Trades to Turbines: The Art and Science of Wind Energy Resource Assessment*. Presented to WASA Mesoscale Workshop, Pretoria, South Africa, 24 September 2009.
- Hahmann, A.N. & Kruger, A. 2010. *What is the Large-Scale Wind Regime in South Africa?* Presented to SAWEP Wind Atlas Workshop, Cape Town, South Africa, 4 March 2010.
- Hahmann, A.N., Badger, J., Mortensen, N.G. & Hansen, J.C. 2010.



“All WASA data and analyses are in the public domain.”

Wind Atlas Introduction. Presented to SAWEP Wind Atlas Workshop, Cape Town, South Africa, 4 March 2010.

- Hahmann, A.N., Badger, J., Vincent, C.L., Kelly, M., Volker, P., Refslund, J., Hansen, J.C., Mortensen, N., Lennard, C. & Argent, B. 2014. *WP1: Mesoscale Modelling for the Second Verified WASA Numerical Wind Atlas*. Presented to Final WASA wind seminar, Cape Town, South Africa, 8 April 2014.
- Hahmann, A.N. 2014. *The Wind Atlas of South Africa*. Presented to DTU Wind Energy Internal Seminar, Roskilde, Denmark, 4 May 2014.

7.6.11 OTHER CAPACITY DEVELOPMENT ACTIVITIES

Further capacity development activities that have been performed by the WASA project are given below:

- Brendan Argent was able to attend the 2012 European Wind Energy Association meeting and present his work there.
- Teboho Nchaba, Brendan Argent and Christopher Broderick presented their work at the annual meetings of the South African Society of Atmospheric Sciences.
- Dr Chris Lennard has learned advanced techniques related to the WRF model in his work with Dr Andrea Hahmann at DTU and is also trained in the use of the WASP microscale model.
- Assessment of the WASA forecast using SAWS wind data was carried out.



Cookhouse Wind Farm. Image by Stefanie de Beer – Line of Sight.

8 CONCLUDING REMARKS



All the project objectives and expected project outcomes have been met and exceeded within the budget for the WASA project. For example, the WASA wind resource map based on both the KAMM method and the WRF model could be done without making any changes to the project budget for the entire (100%) WASA domain and with the time series data being available from 1 September 1990 to 31 December 2012.

The WASA project, while under implementation, could help the SIP 8: Green Energy SEA initiative Strategic Environmental Impact Assessment study for PV and wind that was implemented by the DEA. The WASA project could also help the revision of the South African Building Load Codes for wind.

The WASA generates much more than data with in-depth analysis, tools (for example the “Tadpole”) and guides. Of particular importance were the setup, customisation and validation (measurements, wind speed and direction distributions, and seasonal and daily cycles) of the WRF model for wind resource assessment.

Minister of Energy, Tina Joemat-Pettersson, stated (speech delivered by Acting DG at the Windaba 2014):

“I am now happy to say the key results of the First Phase that have been independently verified by a team of scientists working on the Wind Atlas project of South Africa using both numerically modelled data and practical observational methods and analysis, confirm that South Africa has an excellent wind resource.”

The project helped with capacity building and human development both in South Africa, for example the six UCT students that benefitted and contributed to the WASA project, and overseas and other projects, for example the World Bank ESMAP Renewable Energy Resource Mapping initiative, are using the WASA project’s information. The amount of

governmental, public and private people using the WASA project’s website also indicates how useful its information is.

The WASA is the first project that used the wind resource mapping tool, Frogfoot, successfully at a large scale when it created the large-scale high-resolution WASA resource maps.

The results of the WASA Phase 1 form a good basis to use for the WASA Phase 2 which will use the WRF modelling as it was set up, customised and verified during the WASA Phase 1.

Finally, the WASA data and access are not monopolised by any company or institution. It is all in the public domain, thereby levelling the playing field as it is free for all to check and use.

• “The results of the
• WASA Phase 1 form
• a good basis to use
• for the WASA
Phase 2.”



Darling National Demonstration Wind Farm – South Africa’s first commercial independent power producer wind farm.



“The WASA initiative came at a critical time in the development of the wind industry in South Africa. The extremely robust affirmation it provided of the excellent wind resource in the country and its wide geographical distribution served to enhance developer interest and urgency and to reassure policy makers that wind is an energy source they can bank on. These aspects have been instrumental in the rapid growth and the success of our wind industry. The opportunity exists now with private sector continuing measuring the exact wind regime and WASA expanding to map the remainder of the country, together confirming and unlocking South Africa’s excellent wind resource. The future relevance of WASA looks as unequivocal as the historical relevance.”

Johan van den Berg
CEO, SAWEA, 2015

APPENDICES



Acronyms

Acronym	Description
AGL	Above ground level
CSAG	Climate System Analysis Group
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DME	Department of Minerals and Energy
DoE	Department of Energy
DST	Department of Science and Technology
DTU	Technical University of Denmark
Eskom	Electricity Supply Commission
ESMAP	Energy Sector Management Assistance Programme
EWEA	European Wind Energy Association
GEF	Global Environment Facility
GIS	Geographic Information System
GSM	Global System for Mobile Communications
GW	Gigawatt
GWh	Gigawatt hour
IEC	International Electrotechnical Commission
IRENA	International Renewable Energy Agency
IRP	Integrated Resources Plan
KAMM	Karlsruhe Atmospheric Mesoscale Model
m	Metre
ms ⁻¹	Metres per second
MW	Megawatt

Acronym	Description
NWA	Numerical Wind Atlas
PIU	Project Implementation Unit
REIPPP	Renewable Energy Independent Power Producers Programme
RMSE	Root mean square error
Rodeo	Risø Online Database for Environmental Observations
SANEDI	South African National Energy Development Institute
SANS	South African National Standards
SAWEA	South African Wind Energy Association
SAWEP	South African Wind Energy Programme
SAWS	South African Weather Service
SEA	Strategic Environmental Assessment
SHEQ	Safety, Health, Environmental and Quality
ToT	Training of Trainers
UCT	University of Cape Town
UNDP	United Nations Development Programme
VAT	Value Added Tax
VNWA	Verified Numerical Wind Atlas
WASA	Wind Atlas for South Africa
WAsP	Wind Atlas Analysis and Application Programme
WM	Wind mast
WP	Work package
WRF	Weather Research and Forecasting

Endnotes/References and Further Reading

ENDNOTES/REFERENCES

1. 2003. *Review of Wind Energy Resource Studies in South Africa*.
2. Africa Development Bank. 2004. *Strategic Study of Wind Energy Deployment in Africa*.
3. Mid-term workshop, 14 & 16 March 2012. *Wind Atlas Methodology – The Why and The How?*
4. Hansen, J.C. & Mortensen, N.G. 2014. *Report on Measurements*.
5. 2014. WASA Training Presentation Slides Final.
6. 2010. Project Brief September 2010 at Official Opening of Data Display and Download Websites.
7. 2014. Project Brief.
8. International Renewable Energy Agency. 2012. *IRENA Case Study 2013 Wind Atlas for South Africa*.
9. Hahmann, A.N., Badger, J., Vincent, C.L., Kelly, M.C., Volker, P.J.H., Refslund, J., Lennard, C. & Argent, B. 2014. *Mesoscale Modelling for the Wind Atlas for South Africa (WASA) Project*.
10. Mabilie, E. 2014. *South African Wind Atlas (WASA) Guide*.
11. Mabilie, E., Prinsloo, E., Mortensen, N.G. & Hansen, J.C. 2014. *Report on Measurements*.
12. Mabilie, E. & Prinsloo, E. 2014. *WP2 Report on Training*.
13. Mortenses, N.G., Hansen, J.C., Kelly, M.C., Prinsloo, E., Mabilie, E. & Szewczuk, S. 2014. *Station and Site Description Report*.
14. Mortensen, N.G., Hansen, J.C., Kelly, M.C., Szewczuk, S., Mabilie, E. & Prinsloo, E. 2014. *Observational Wind Atlas for 10 Met Masts in Northern, Western and Eastern Cape Provinces*.
15. Mabilie, E. 2014. *Brief Introduction to Working with WASA Files*.
16. Larsén, X.G., Kruger, A. & Cronin, T. 2014. *Guidelines for Using the Extreme Wind Data from the Selective Dynamical Downscaling Method*.
17. Hansen, J.C. & Lennard, C. 2011. *A Comparative and Quantitative Assessment of South Africa's Wind Resource – the WASA Project*. Presented to Windaba 2011. Cape Town, South Africa.
18. 2014. *Wind Atlas for South Africa (WASA) Phase 1 Project Final Wind Seminar*. Cape Town, South Africa. 8 April 2014.
19. SAnews.gov.za. 2013. *Wind Resource Map to Boost Renewable Energy Efforts Press Release*.
20. Department of Energy. 2014. *Wind Atlas for South Africa (WASA) Phase 1 – Final Seminar Press Release*.
21. World Bank Energy Sector Management Assistance Programme Renewable Energy Resource Mapping Initiative. 2013. Renewable Energy Mapping: Wind in Pakistan, South Asia Region, Project ID: P146140, Selection: 1118422.
22. Palestinian Energy Authority. 2013. *Request for Proposal for the Energy Section Assistance in Palestine, Phase V (RFP No. Phase V-PEA/CS-W)*.
23. Kruger A.C. 2010. *Wind Climatology of South Africa Relevant to the Design of the Built Environment*. PhD dissertation Stellenbosch University <http://hdl.handle.net/10019.1/6847>

FURTHER READING

It is advised that you visit the following WASA websites for further reading:

- To view the online graphs, go to <http://www.wasa.csir.co.za>
- Go to <http://wasadata.csir.co.za/wasa1/WASAData> to download the final reports, maps, guides and data (register for free and log in)
- To view the WASA project information, presentations, etc., go to <http://www.wasaproject.info/>
- To read about the WRF model which forecasts wind speed, power density and direction of the wind over South Africa, go to <http://veaonline.risoe.dk/wasa>

Acknowledgements and Implementation Partners

The WASA project is an initiative of the Government of South Africa – the DME (now the DoE) – and the project is co-funded by the UNDP-GEF through the SAWEP with UNDP support; and the Royal Danish Embassy.

The SANEDI is the executing agency, coordinating and contracting with the implementing partners: the CSIR, the UCT CSAG, the SAWS and the DTU Wind Energy (formerly Risø DTU).



SOUTH AFRICAN NATIONAL ENERGY DEVELOPMENT INSTITUTE

The SANEDI is a Schedule 3A state-owned entity. The main function of the SANEDI is to direct, monitor and conduct applied energy research and development, demonstration and deployment as well to undertake specific measures to promote the uptake of green energy and energy efficiency in South Africa.



COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

The CSIR improves the competitiveness of industry and the quality of life of the people of the country. South Africa's CSIR was established in 1945 as a science council by an act of Parliament. It has a proud track record and a bright and challenging future through science, engineering and technology, undertaken by its innovative individuals and teams.



UNIVERSITY OF CAPE TOWN

The UCT is a public research university located in Cape Town in the Western Cape province of South Africa. UCT was founded in 1820 as the South African College and is the oldest university in South Africa and the second oldest extant university in Africa.



SOUTH AFRICAN WEATHER SERVICE

The SAWS is a Section 3(A) public entity under the Department of Environmental Affairs. It is the authoritative voice for weather and climate forecasting in South Africa. The company became a public entity on 15 July 2001 in terms of the South African Weather Service Act, 2001 (Act No. 8 of 2001).



TECHNICAL UNIVERSITY OF DENMARK WIND ENERGY

The DTU Department of Wind Energy is a globally leading centre for wind energy research and development with technical-scientific competences in the international front and with a unique integration of research, education and public as well as private sector consulting.



www.wasaproject.info