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# Wind Atlas for South Africa (WASA): Project overview and current status

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**Abstract**
The goal of the South African Wind Energy Programme (SAWEP) is to reduce greenhouse gas emissions generated by thermal power in the national inter-connected system. SAWEP has six main expected outcomes: increased public sector incremental cost funding, initialising of green power funding, long-term policy and implementation framework for wind energy, assessment of wind resources, promotion of commercial wind energy development and the building of capacity and strengthened institutions. The wind resource assessment project is known as Wind Atlas for South Africa - WASA.

This paper will discuss the wind atlas method; provide an overview of the current understanding of the wind resource in South Africa; and describe the wind measurements that are currently being undertaken as well as the micro-scale modelling that is planned as part of the WASA project.

## 1. Introduction

South Africa needs capacity and skills development for methods and data that would enable the authorities, investors, power sector and industry to investigate and plan for large-scale exploitation of wind power for electricity generation. This requires a methodology for mapping the wind resources on national and regional scales, as well as tools for estimating reliably the annual energy production of proposed wind farms all over South Africa.

The development of a wind atlas would therefore accelerate the investment in wind energy. This is in line with government's objectives of reducing greenhouse gases and diversifying our energy supply and also developing human capacity to support the emerging industry. The wind atlas can find applications in at least two areas, namely to assist in the development of large grid-connected wind farms and to provide more accurate wind resource data to identify potential off-grid electrification opportunities.

The main objective of the new Wind Atlas for South Africa is to develop and employ numerical wind atlas methods and develop capacity to enable planning of large-scale exploitation of wind power in South Africa, including dedicated wind resource assessment and siting tools for planning purposes, i.e. the objective is the development of a numerical wind atlas and database for South Africa.

## 2. The Wind Atlas Method

The main parameters governing wind power economics are:
- Investment costs
- Operation and maintenance costs
- Turbine lifetime
- Discount rate
- Environmental benefits and
- Electricity production/wind resources

Wind resources and consequently electricity production is a key parameter; determining the wind resource accurately is important but also difficult. The power density ($P_a$) available in a cross-sectional area (A) perpendicular to the wind flowing at speed V is the kinetic energy flux, i.e. kinetic energy density x speed x area. Hence,

$$P_a = \frac{1}{2}\rho V^3 \text{ (W/m}^2\text{)} \ldots\ldots\ldots\ldots (1)$$

where ρ is the air density in kg/m$^3$ and V is the wind speed in m/s.

$P_a$ also refers to the theoretical amount of power available, determined by the kinetic energy of the wind. The cubic response of power to the instantaneous wind speed means that a small increase in wind speed results in a substantial increase in wind power. For example an increase in wind speed by a factor of 2 results in approximately 8 times as much wind power. Alternatively

$$\Delta V \text{ of } 5\% \text{ (e.g. } V=10.0+0.5\text{m/s)} \longrightarrow \Delta P_a \text{ of } 15\% \ldots (2)$$

Wind resources are in fact more about $P_a$ than V and V is measured at one point in space. However, V is needed in the entire atmospheric boundary layer and consequently modelling is necessary to develop a wind atlas.

The wind atlas methodology in its present form was developed for the analysis presented in the European Wind Atlas by Troen and Petersen, (1998). The methodology employs a comprehensive set of models for the horizontal and vertical extrapolation of wind data and the estimation of wind climate and wind resources. The actual implementation of the models is known as the *Wind Atlas Analysis and Application Program* (WAsP), which is the software package that has been applied by Mortensen et al, (1993) and (1998) for the study.

The WAsP models are based on the physical principles of flows in the atmospheric boundary layer and they take into account the effects of different surface roughness conditions, sheltering effects due to buildings and other obstacles, and the modification of the wind imposed by the specific terrain height variations around the meteorological station in question. Figure 1 illustrates the use of these models on measured wind data to calculate a regional wind climatology or wind atlas.

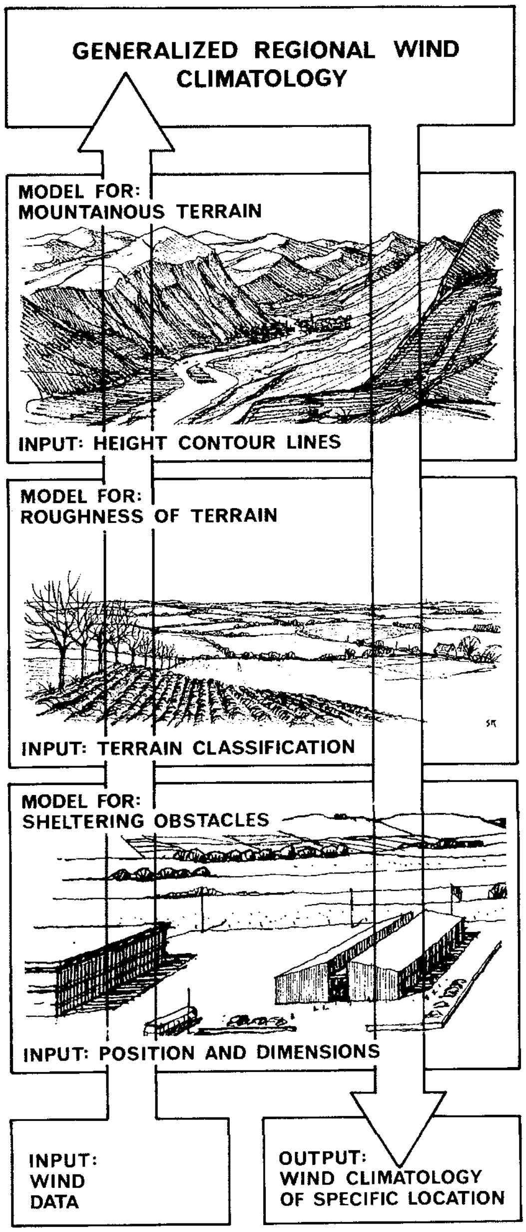


Figure 1: Diagrammatic summary of WAsP modelling procedure (after Troen and Petersen, 1989)

The WAsP program enables an analysis of any time-series of wind speed and direction measurements. The output is a wind rose and the wind speed distributions in the different sectors. A Weibull distribution function is then fitted to the measured histograms to provide scale and shape parameters *A* and *k* for each sector. The observed wind data are converted into a wind atlas data set by invoking the shelter, roughness and flow models in WAsP; using descriptions of the topography of the meteorological station as input. In a wind atlas data set the wind distributions have been “cleaned” with respect to the site-specific conditions and reduced to standard conditions, e.g. transformed into Weibull *A*- and *k*-parameters for 4 standard roughnesses, 5 standard heights above ground and 12 azimuth sectors.

Figure 1 also illustrates the so-called application part of the methodology, following a procedure in which the regional wind climatology is used as input to the same models to produce site-specific wind climatology and, given the power curve of a wind turbine, a production estimate. The *analysis* and *application* parts of the program can thus be summarised in the following way:

**Analysis**:
time-series of wind speed and direction → wind statistics
wind statistics + meteorological site description → wind atlas data

**Application**:
wind atlas data + site description → estimated wind climate
estimated wind climate + power curve → estimated power production

Using a wind atlas data set calculated as described above or one obtained from another source – e.g. the European Wind Atlas (Figure 2) – the program can estimate the wind climate at any particular point by performing the inverse calculation as is used to generate a wind atlas, i.e. by reintroducing the actual topographic conditions of the application or predicted site. Furthermore, the total energy content of the mean wind can be calculated from the predicted wind speed distributions and an estimate of the actual, yearly mean power production of a wind turbine can be obtained; given the power curve of the turbine in question.

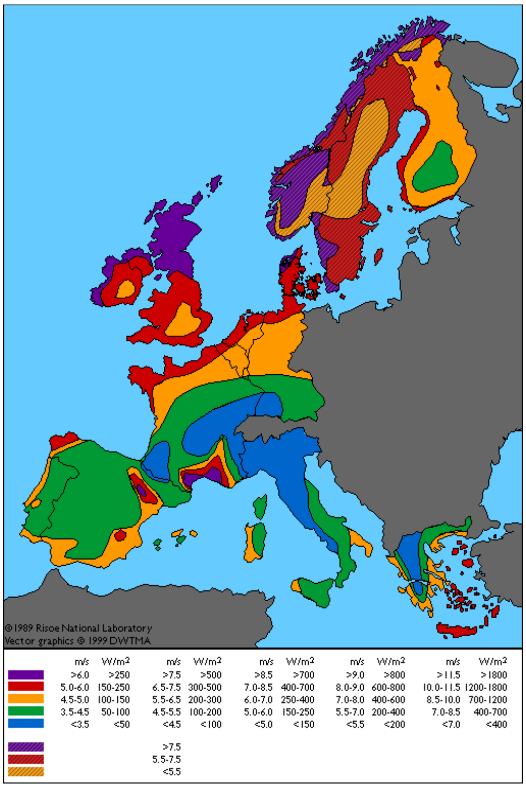


Figure 2: The European Wind Atlas

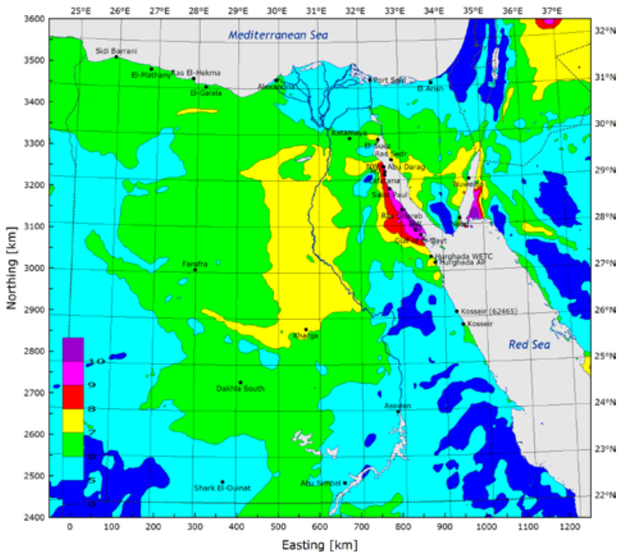


Figure 3: The Egyptian Wind Atlas

The European Wind Atlas was published in 1989 for the Commission of the European Communities by Risø National Laboratory. Figure 2 depicts the wind resources at 50 meters above ground level for five different topographic conditions:
1) Sheltered terrain, 2) Open plain, 3) At a coast, 4) Open sea, and 5) Hills and ridges.

The WAsP program was also used by Risø to develop the Wind Atlas for Egypt (Figure 3) and was made available in the beginning of 2006. The atlas is published by the New and Renewable Energy Authority (NREA) of Egypt, the Egyptian Meteorological Authority (EMA) and Risø DTU.

Similarly the WAsP program was used to develop the detailed Wind Atlas for Ireland (Figure 4).

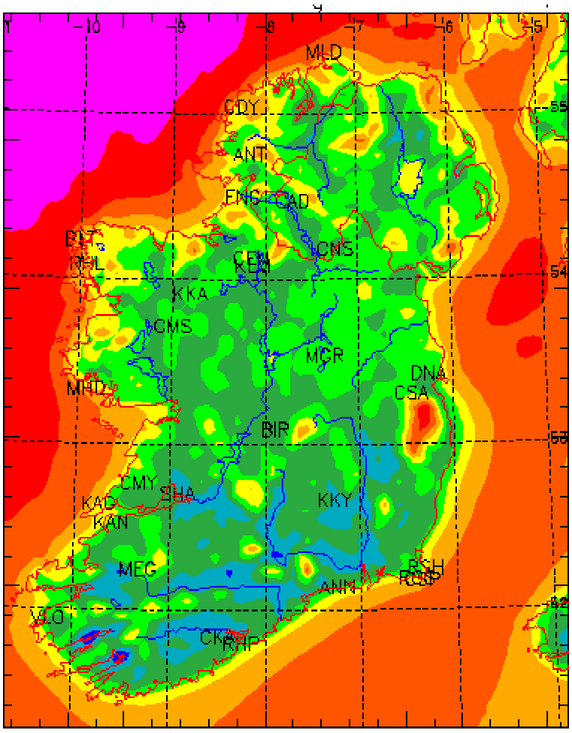


Figure 4: The Irish Wind Atlas

The WAsP micro-scale modelling program will be used to develop the Wind Atlas for South Africa.

## 3. The South African Wind Resource Potential

Several studies have been carried out to assess the wind energy potential of South Africa and the estimates range from a very low 500 MW to an extremely high estimate of 56,000 MW.

Currently only 0.05 % of the annual electricity production is derived from wind energy, mainly supplied by the Darling wind farm and the ESKOM Klipheuwel demonstration plant. Two hybrid mini-grid energy systems in the Eastern Cape add a small fraction to that, as do other isolated off-grid turbines. A number of small wind turbines have been installed in the country on premises connected to the grid, for example the three Kestrel turbines at the Pick 'n Pay regional centre in Port Elizabeth, but these are typically installed behind the electricity meter and do not feed in to the national grid.

In sharp contrast to the currently installed capacity is the very large figure of 8000 MW of wind capacity for which grid connection requests have been received by ESKOM.

South Africa's wind resources are influenced by the large-scale weather patterns that have distinct characteristics between summer and winter.

### 3.1 Summer Winds

In summer, the "Westerlies" are situated well to the south of the continent (Figure 5). The south-eastern trade winds (A) influence the north-eastern part of the region. These winds can be strong, curving sometimes from the Limpopo Province (N) into the Free State Province (F), or moving over far northern areas, such as Zimbabwe and Zambia (Z).

In the west, the south-eastern trade winds (B) caused by ridging of South Atlantic High, are often strong and persistent. The strong "Westerlies" are only able to influence the western, southern and south-eastern coastal areas and adjacent interior.

### 3.2 Winter Winds

In winter all the circulation features (Figure 6) are situated more to the north than in summer. Strong winds and gusts during winter are usually caused by strong cold fronts, moving mostly over the southern half of South Africa, and also by the ridging of the high-pressure systems behind the fronts.

The "Westerlies" influence the weather of the southern and central parts of the subcontinent to a large degree. Cold fronts often move over these areas and may reach far to the north. The strong "Westerlies" are only able to influence the western, southern and south-eastern coastal areas and adjacent interior. When the Atlantic high-pressure system moves more eastwards and stays strong, gale-force winds can spread to the KwaZulu-Natal coast and as far north as the Mozambique Channel.

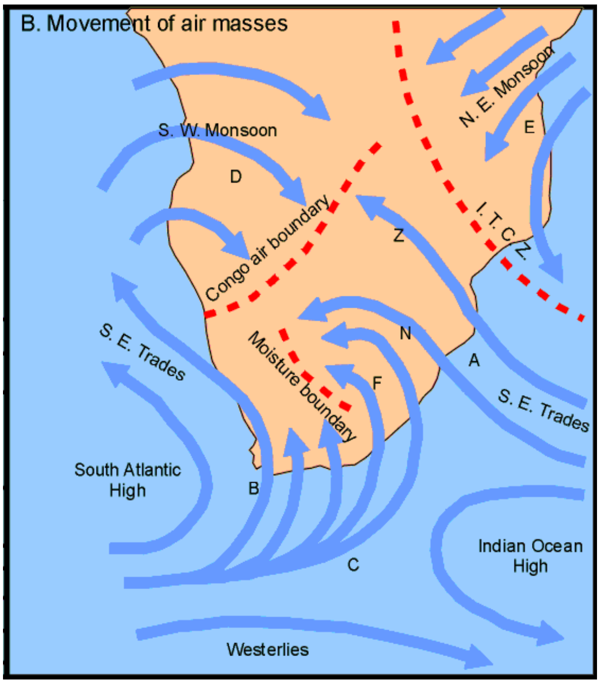


Figure 5: Summer winds over South Africa

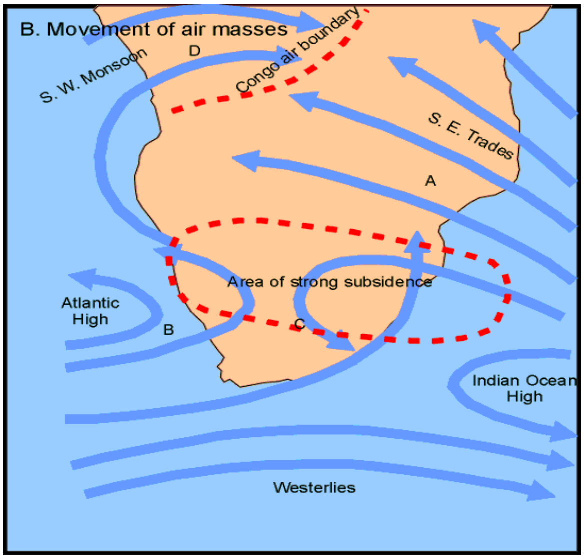


Figure 6: Winter winds over South Africa

**3.3 Diab's wind atlas**

The first estimates of wind power potential for South Africa were done by Diab (1995), who concluded that (Figure 7):

- Wind power potential is generally good along the entire coast with localised areas, such as the coastal promontories, where potential is very good, i.e., mean annual speeds are above 6 m/s and power exceeds 200 W/m$^2$;
- Moderate wind power potential areas include the Eastern Highveld Plateau, Bushmanland, the Drakensberg foothills in the Eastern Cape and KwaZulu-Natal; and
- Areas with low wind power potential include the folded mountain belt (vast region of very complex and diverse terrain), the Western and Southern Highveld Plateau, the Bushveld basin, the Lowveld, the Northern Plateau, the Limpopo basin, Kalahari basin, the Cape Middleveld and the KwaZulu-Natal interior.

**3.4 Kilian Hagemann's wind atlas**

A mesoscale wind map of South Africa was produced by Hagemann (2008) as part of his PhD research at the University of Cape Town. His thesis explores the utility of what is known as the MM5 regional climate model and the use of the MM5 model in producing a detailed wind climatology for South Africa in the context of wind power applications.

In terms of the resultant mesoscale wind atlas of South Africa (Figure 8), a significant inland wind resource was discovered over the Northern, Western and Eastern Cape Provinces, which was previously unknown. Hagemann puts forward the case that South Africa's wind resource is higher than some previous studies have suggested and is comparable to some of the windiest markets in the world.

The study modelled wind speeds across the country at various heights above ground and carried out the GIS-based scenario analysis for South African wind power penetration as per Table 1 below.

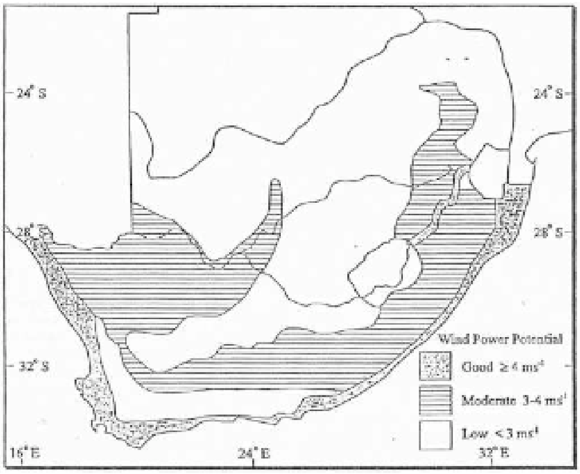


Figure 7: Diab's wind atlas

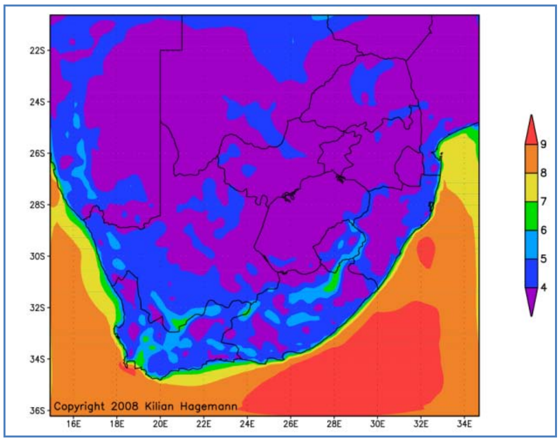


Figure 8: Hagemann's wind atlas

Table 1. Scenarios for wind development by Hagemann (2008)

| Case | Assumptions | Result |
|---|---|---|
| Low case | All sites within 3 km of existing infrastructure (66+ kV grid, roads); 60 m hub height; minimum of 35% capacity factor | 20 TWh of feasible annual electricity generation corresponding to approx. 6 GW of installed wind power capacity |
| Central Case | All sites within 4 km from existing infrastructure; 60 m hub height; minimum of 30% capacity factor | 80 TWh of feasible annual electricity generation, corresponding to approx. 26 GW of capacity |
| High Case | All sites within 5 km from infrastructure; 100 m hub height; minimum of 25% capacity factor | 157 TWh of feasible annual electricity generation corresponding to approx. 56 GW of capacity |

All of the scenarios show that South Africa has a very high wind resource and that even under the low case, substantial wind energy generation is feasible. Based on the work done by Hagemann a map of average annual wind speeds at 10 m above ground level for South Africa is given in Figure 8.

### 3.5 Department of Energy/Eskom/CSIR wind atlas for South Africa

The Department of Energy (DoE), Eskom and CSIR are jointly funding the development of an off-grid electrification planning tool based on harnessing renewable energy resources. However, this off-grid electrification planning tool is dependent on good quality resource data and inputs. The current South African wind energy resource database is inadequate and a more accurate and reliable wind energy resource database will enhance the value of the off-grid electrification planning tool.

The current wind atlas, Figure 9, also a joint DoE, Eskom and CSIR initiative, is far from being adequate and is compiled from modelling that was done under two separate projects. The wind resource assessment that covers the bulk of South Africa and is represented by a number of circles is described by Ragoonanthun et al (no date given). The wind resource assessment that covers the Eastern Cape Province was done as part of collaborative project between the CSIR and EU-based organisations, Szewczuk et al (2000). Figure 10 shows the details of the wind resource assessment that was done for the Eastern Cape province.

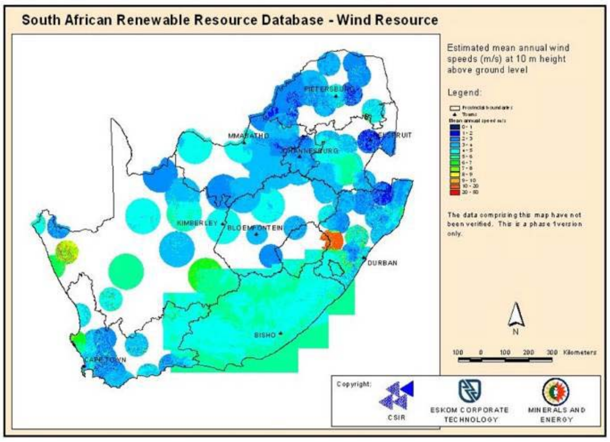


Figure 9: Current Wind Atlas for South Africa

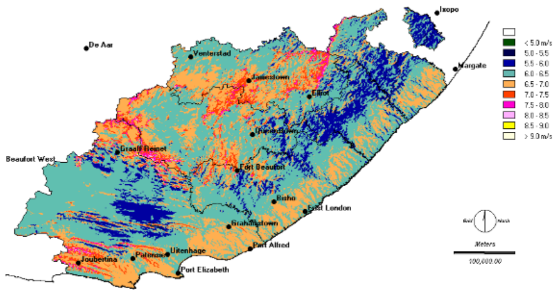

Figure 10: Wind resource for Eastern Cape province

## 4. Wind Atlas for South Africa (WASA) overview

### 4.1 Introduction

The goal of South African Wind Energy Programme (SAWEP) is to reduce greenhouse gas emissions generated by thermal power in the national inter-connected system. SAWEP has six main expected outcomes:

- Increased public sector incremental cost funding
- Initialising of green power funding
- Long-term policy and implementation framework for wind energy
- Assessment of wind resource
- Promotion of commercial wind energy development
- Building of capacity and strengthening of institutions.

The CSIR, the Department of Energy (DoE), University of Cape Town (UCT), South African Weather Services (SAWS), South African National Energy Research Institute (SANERI) and Risø-Danish Technical University (Risø-DTU) are jointly working on the wind resource assessment outcome of SAWEP.

The wind resource assessment project, known as Wind Atlas for South Africa (WASA), has six work packages that cover the work to be done. The headings of the work packages, as well as the South African organisations working on these packages, are as follows (Risø-DTU is the technical expert partner in each of these work packages):
WP1- Meso-scale modelling, UCT
WP2 - Measurements, CSIR
WP3 – Micro-scale modelling, CSIR
WP4 – Application, CSIR
WP5 – Extreme wind atlas, SAWS
WP6 – Documentation and dissemination, SANERI

Objectives are to also develop capacity and to develop the CSIR into a national competence centre for high-quality wind measurements and micro-scale modelling.

### 4.2 Micro-scale modelling and wind measurements status

The Global Environmental Facility (GEF) and the Danish Government are funding a three-year project to develop an accurate wind resource map for the coastal regions of South Africa. Figure 11 shows the area in blue that is currently planned to be assessed to form the basis of the new wind atlas. Using meso-scale data and information, including Hagemann's (2008) meso-scale results, site selection criteria were developed as to the locations where the 10 wind measurement masts were to be erected. These sites are representative of terrain types, suitable for meso- and micro-scale modelling and geographically spread out evenly over the project area.

Site visits have been undertaken and interactions have taken place with the various land owners, and the relevant agreements to erect the masts have been completed. The 10 sites where the masts are to be erected are near Alexander Bay, Calvinia, Vredendal, Vredenburg, Napier, Sutherland, Prince Albert/Beaufort West, Humansdorp, Hartebeeshoek and Ntshe.


Figure 11 Area, in blue, to be modelled for the new wind atlas

The wind measurement stations were designed to meet IEC standards and MEASNET guidelines. The sensors are of high quality and individually calibrated and the instrumentation is arranged on the masts to minimise errors and uncertainties caused by flow distortions. The 60-meter masts have been designed, procured and manufactured. The measurement equipment and data acquisition system, designed by and delivered from Risø-DTU in Denmark, have been installed on a trial mast and training to operate the system has been completed.

In accordance with environmental impact assessment procedures, basic assessment procedures were negotiated and an application document submitted. The basic assessments approvals have been obtained, site preparations initiated and the construction of the foundations undertaken. The masts have been transported to the 10 sites and erected with all the instrumentation installed as per Risø-DTU specifications and training, and are due to start collecting real time data.

The entire wind measuring system and the transmission of wind data to the CSIR's Stellenbosch campus is expected to be fully commissioned during September 2010. The data will then be able to be monitored on [www.wasa.csir.co.za](http://www.wasa.csir.co.za)

Figure 12, courtesy of Risø-DTU, shows the 60-meter mast with the configuration and heights of the various sensors.

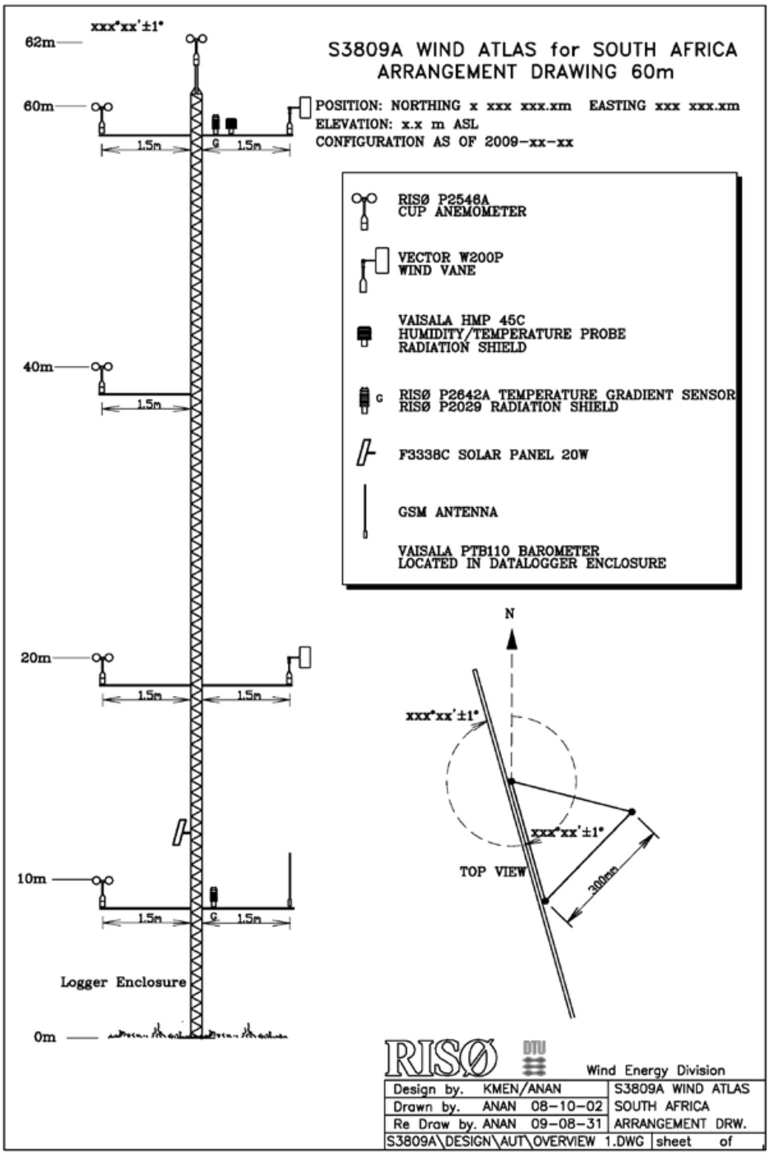


Figure 12: Configuration of the 60-meter masts

## 5. Discussion

Wind atlases are a useful tool to assist in the identification of wind energy-based projects. Examples of wind atlases that were referenced in this paper are the European Wind Atlas, the Irish Wind Atlas and the Egyptian Wind Atlas. These atlases were derived using the WAsP programme that was developed by Risø-DTU of Denmark.

Prior to micro-scale modelling, wind measurements need to be done and the methodology to undertake the measurements at the 10 South African sites was discussed. Every effort is being made to ensure that the wind data are accurate, representative and reliable.

Wind measurements are expected to start in late August, early September 2010. Once the entire system has been operating for a year, a draft wind atlas will be compiled. Since wind measurements will be done over a period of three years, regular updates on progress will be published. Furthermore the data will be available to the public on the following website: www.wasa.csir.co.za

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- Ms Andrea Hahmann - Risø-DTU of Denmark
- Mr Hans E. Jørgensen - Risø-DTU of Denmark

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