Wind Atlas for South Africa (WASA)

Northern Cape Province

Observational Wind Atlas for Four Meteorological Masts in the Northern Cape Province

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WASA Observational Wind Atlas for four meteorological masts located in the Northern Cape Province

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1 Introduction

The Wind Atlas for South Africa (WASA) project is an initiative of the Government of South Africa (Department of Minerals Resources and Energy) and the project is co-funded by UNDP-GEF through the South African Wind Energy Programme (SAWEP) and by the Royal Danish Embassy.

The primary objective of the project is to develop and produce 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. a Numerical Wind Atlas and database for South Africa.

The present report describes the microscale modelling that has been carried out in Phase 3 of the WASA project, for four meteorological (met.) masts in the Northern Cape province, see Figure 1.1. It constitutes one of the main outputs of the projects Work Package 3: Observational Wind Atlas for the four sites in the WASA 3 domain in South Africa.

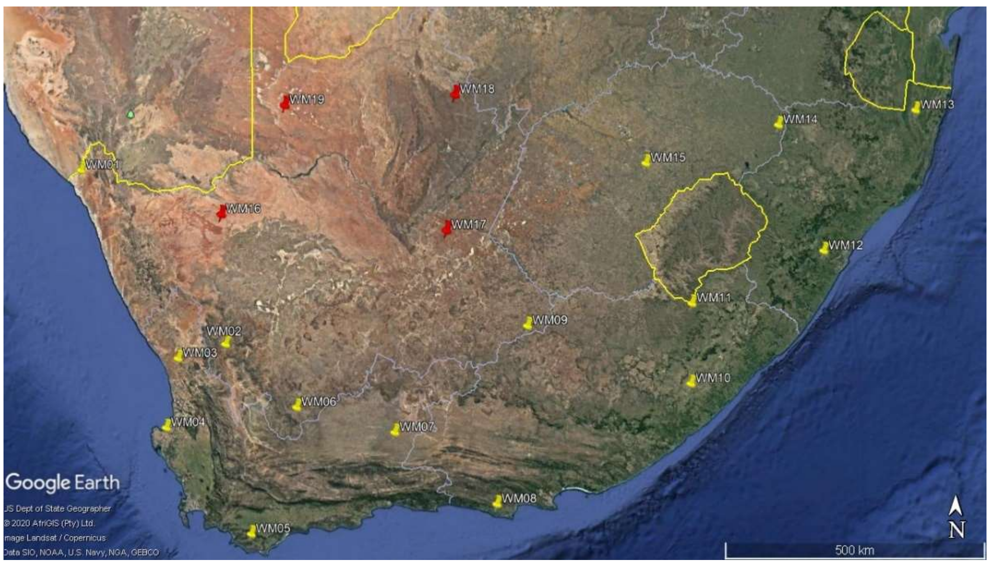

Figure 1.1: Overview map of the southern-most part of South Africa, showing the location of the 19 met. masts referred to in the text and the Wind Atlas for South Africa study area (Image © 2016 AfriGIS (Pty) Ltd., Data SIO, NOAA, US Navy, NGA, GEBCO, Image Landsat / Copernicus and Google Inc.).

The central study area for WASA Phase 3 is defined as 'Northern Cape province'. With reference to WASA Phases 1 and 2, the study area for Phase 3 comprises:

- The Northern Cape Province – all four districts

The present report contains similar information – and is edited along same lines – as the WASA Phase 1 (Mortensen *et al*., 2014, 2020) and Phase 2 (Julies *et al*., 2020) reports. The WAsP modelling results reported here were obtained using the most recent version of the Wind Atlas Analysis and Application Program, WAsP version 12.6 (2021).

2 Preliminary wind atlas analysis

The Wind Atlas for South Africa project is divided into three phases, based on ten, five and four met. masts, respectively. The overall purpose of the microscale modelling is three-fold:

- Validation of the mesoscale modelling at the met. mast sites
- Validation of the microscale modelling at the met. mast sites
- Establishment of an observational wind atlas for parts of South Africa

The validation activities also include study of modelling sensitivities and uncertainties, and possible adaptations of the methodology and models to South Africa. The main purpose of this version of the observational wind atlas for WASA Phase 3 is to provide validation data for the mesoscale modelling using the Weather Research and Forecasting (WRF) Model.

The main inputs to the microscale modelling are the observed wind climates from the 18 operational met. masts, see Figure 1.1. In addition to the purposes mentioned above, these masts may also serve as reference masts for wind resource calculations at wind farm sites in the vicinity of the masts, and as test beds for comparison of wind sensors and mounting arrangements.

2.1 Summary of measurements

More than twenty four months of data is available from the four Phase 3 met. masts. The period from 1 November 2018 to 31 October 2020 has been selected as the two-year reference period for the preliminary wind atlas analyses and modelling. **Error! Reference source not found.** provides a summary of some weather observations for this period and of some site characteristics at the masts.

Table 2.1: Summary of weather observations at the four met. masts for a 2-year period: absolute minimum air temperature (Tmin), absolute maximum air temperature (Tmax), mean air temperature (Tmean), mean barometric pressure (B), and mean relative humidity (RH).

Mast	T_{min} [°C]	T_{max} [°C]	T_{mean} [°C]	B [hPa]	RH [%]	z [m]	ρ* [kg/m^3]
WM16	- 1.68	39.53	18.93	894.00	35.15	1,079	1.063
WM17	- 1.91	38.63	20.26	881.44	31.88	1,201	1.043
WM18	- 2.88	34.80	19.52	853.38	36.44	1,478	1.012
WM19	0.53	40.8	22.68	917.29	27.77	844	1.077

**Air density estimations have been applied in wind power density calculations.*

2.2 Wind-climatological inputs

Observed wind climates, i.e. the wind rose and sector-wise wind speed distributions, were constructed for each mast using the WAsP Climate Analyst, version 3.01.0043.

Table 2.2 provides a summary of the wind observations at the masts, for the nominal top level (62 m) anemometer of the masts. Appendix A provides additional observed wind statistics in the form of wind-climatological fingerprints; as well as hourly, monthly and yearly wind statistics for the four Phase 3 masts.

Table 2.2: Summary of wind observations 62 m above ground level at the met. masts: data recovery rate (R), Weibull A- and k-parameters, Weibull-derived mean wind speed (U) and power density (E). The mast site ruggedness index is given in the right-most column.

Mast ID	***R***	***A***	***k***	***U***	***E***	***RIX****
	[%]	[m/s]	[ ]	[m/s]	[W/m^2]	[%]
WM16	99.99	8.0	2.78	7.12	328	0.0
WM17	99.99	7.8	2.58	6.90	311	0.0
WM18	99.99	7.20	2.50	6.41	256	0.0
WM19	99.99	6.4	2.78	5.71	169	0.0

** The site ruggedness index (RIX) is 0 % for all four of the masts and they are therefore within the operational envelope of the WAsP linearized IBZ model.*

2.3 Meteorological masts

The design and characteristics of the 60-m met. masts and instrumentation are described briefly in the Measurement report (2020) by Jody Julies *et al*. (2017). Photos taken during site inspection trips serve to verify that actual installations are done according to this master design. The *Station and Site Description report* (Mabille *et al*., 2019) contains information for each met. mast regarding

- Position and elevation of the mast site
- Boom and instrument heights above ground level
- Magnetic declination and meridian convergence at the site
- Sensor boom and lightning rod directions (bearings)
- Photographic documentation of mast design and installation
- Photographic documentation of mast surroundings (panoramic view)

The report, as well as the met. data measured at the masts, is available from the WASA web site wasadata.csir.co.za/wasa1/WASAData.

2.4 Topographical inputs

For a general impression of the setting, the terrain surrounding each mast are shown in panoramic photographs taken during the site inspection trip.

Elevation maps for each site were constructed from Shuttle Radar Topography Mission (SRTM) 3 arc-second data as described for Phase I, the maps used for the flow modelling are given in the accompanying WAsP workspaces.

Land cover maps are simple land/water classifications for this first version of the observational wind atlas; coastlines, lakes and rivers were derived from the SRTM Water Body Data set. Recent editions of the atlas have used GlobCover 2009 and ESACCI 2015 land cover data for the roughness maps.

2.5 Other resources

In addition to the present report, the following information, data and files are available:

- Station and site description report (Mabille *et al*., 2019)
- WAsP-compatible elevation and roughness maps for each mast
- WAsP Climate Analyst projects for each mast
- WAsP workspaces for each mast

The report *Planning and Development of Wind Farms: Wind resource assessment using the WAsP software* (Mortensen, 2020) provides general background information, guidelines and best practices for the WAsP microscale modelling.

2.6 Uncertainties in the wind atlas analysis

For reference, the uncertainty factors investigated and addressed in the present wind atlas analysis are described below. In general, we have tried to minimise or even eliminate the uncertainty factors involved.

1. **Cup anemometer calibration**. The anemometer type employed is the P2546A cup anemometer, see www.windsensor.dk for detailed specifications. Anemometers have been individually calibrated according to the MEASNET Cup Anemometer Calibration Procedure. The design of the masts and the mounting of anemometers and wind vanes follow international standards (IEC-61400-12: 2010) and best engineering practices as closely as possible.

2. **Cup anemometer heights**. The actual heights above ground level of most cup anemometers were determined with precision laser distance meters. The height of the top (reference) anemometer on each mast was determined from the design of the mounting arrangement and the mast dimensions. The uncertainties associated with the exact height of anemometers above ground level are therefore assumed to be negligible.

3. **Wind direction offset**. The wind vane alignment and wind direction calibration have been checked carefully using a handheld GPS and a sighting compass (Mortensen *et al*., 2012). During this procedure, the magnetic declination was also determined and compared to estimates derived from 1:50,000 topographical maps published by the South African Chief Directorate: Surveys and Mapping, and to estimates provided from the NOAA web site calculator. The standard deviation of the wind vane alignment procedure at the four masts is on the order of one degree, so the uncertainty associated with the wind direction measurements is assumed to be negligible.

4. **Wind atlas heights**. The calculation heights for generalised wind data sets (wind atlas heights) have been adapted to the measurement heights on the masts. The heights chosen here are 10, 20, 40, 62 and 100 (125) meters above ground level. The uncertainties associated with vertical interpolation in the wind atlas data sets are therefore assumed to be negligible. The 100-m level is used for validation of the mesoscale modelling. These settings should be changed for microscale modelling at heights larger than 100 (125) metres.

5. **Position of mast**. The exact positions of the masts were determined several times using hand-help GPS receivers. The accuracy of the positions is therefore likely to be on the order of 5-10 meters. Given the nature of the met. mast sites, this uncertainty is not likely to introduce any significant uncertainty in the wind speed and power predictions.

6. **Data conditioning.** Data conditioning includes the removal of sparse climate time series and the extrapolation of wind speeds in order to fill gaps in the 62 m wind speed series. Climate time series data was removed when:
   - the time stamp dataset has less than three wind speed measurements, or
   - both wind direction measurements (60 m and 20 m) are missing.

   The observed wind climate (OWC) is calculated from 62 m wind speed measurements. Occasionally, at certain time stamps the 62 m wind speed measurements were not recorded or measured. Possible explanations involve the occurrence of instrumentation icing, insufficient power supply to instrumentation or hardware malfunctioning.

7. **Air density**. As described elsewhere, air density can be calculated from temperature and atmospheric pressure measurements at the met. station sites, or estimated directly in WAsP 12. The performance tables for a wind turbine generator are given for discrete values of air density, but WAsP 12 can interpolate between these. Therefore, power

density and power production values may be different compared to previous versions of WAsP, where such interpolation was not possible.

8. **Elevation map source and detail**. Elevation maps are derived from SRTM data, and height contours have been constructed using intervals of 5, 10 and 20 metres, depending on the distance to the mast site. Based on experience from many other sites around the world, and given the topographical nature of the WASA met. mast sites, these maps are assumed to be adequate for WAsP modelling.
9. **Background roughness length (z_0)** Simple roughness maps are derived from SWBD data (water bodies) and the roughness lengths for land surfaces are determined from Google Earth imagery and based on site visits. In Phase II of the WASA project, more detailed land cover maps from a variety of sources (GlobCover 2009 and ESACCI 2015) have been tested and implemented. ESACCI 2015 is used here with a translation table suggested by EMD International (Hahmann et al., 2020).
10. **Heat flux offset value**. Given the elevation and roughness length maps described above, the WAsP offset heat flux value for over-land conditions will be adjusted at most sites in order to model the measured wind speed profile as accurately as possible. As part of Phase 3 of the WASA project, a more detailed investigation of the influence of the heat flux values will be carried out.

The current topographical and wind-climatological input data to the flow modelling are shown for each met. mast in Section 3. Likewise, any non-default modelling parameters are given and the wind profile modelling results are shown. The mean absolute percentage errors, comparing measured and modelled mean wind speeds, are very low for all the met. mast sites; mostly less than a few percent.

3 Observed and generalised wind climates

In this chapter, the topographical and climatological data for the met. masts used in the study are presented briefly in tables and graphs. For each mast, the tables give the calculated regionally representative wind climatology – the generalised wind climate – obtained from the mast data by applying the Wind Atlas analysis, together with a summary of the raw data – the observed wind climate – and the measuring conditions.

Each mast summary is printed on a pair of facing pages containing

- mast name, coordinates and elevation map
- observed wind climate at 62 metres above ground level
- observed and WAsP-modelled wind speed profiles
- calculated regionally representative Weibull parameters
- calculated generalised mean wind speeds and power densities

The presentation of the data is explained in more detail in the following sections. Note, that data and results are valid at the time of writing only and will likely change when the analyses are updated with more wind data, improved topographical inputs, etc.

3.1 The mast description

The mast description comprises the geographical location and a mast elevation map. The ruggedness index (RIX) for the met. mast site is given in the map caption.

Geographical coordinates

The longitude and latitude of each mast are given in decimal degrees referred to the World Geodetic System 1984 (WGS84) horizontal datum.

Elevation

The elevation of the mast is given in metres above mean sea level (m a.s.l.) referred to the WGS84 Earth Gravitational Model (EGM96) vertical datum.

Grid coordinates

The Cartesian grid coordinates consist of the Universal Transverse Mercator (UTM) Easting (E) and Northing (N) in integer metres. The number of the UTM zone is also given. The horizontal datum is World Geodetic System 1984 (WGS84).

Mast topographical map

The topographical map shows the terrain elevation contours in a 20 km by 20 km area around the met. mast, with the mast approximately in the middle of the map. The height contour interval is 10 or 20 metres. The contour lines used in the orographic flow model may be more detailed (say, 5-m contours close to the mast). Some areas of different land cover (roughness length) may be indicated as well; in particular land, sea, lake and river areas.

3.2 Observed wind climate

The observed wind climate comprises the distributions of the wind measurements at 62 m a.g.l. (nominal height) in the form of a wind rose and a histogram. The observed and modelled mean wind speed profiles at the mast are also shown.

The data time series specific to WM16 up to WM19 all cover two years, from 1 November 2018 to 31 October 2020.

Wind rose and histogram

The wind rose shows the distribution of wind directions in the processed time-series. Wind directions are divided into twelve 30°-sectors; the angular axis is given in degrees from 0° to 360° clockwise, the units on the radius axis is per cent. A calm threshold of 0.5 m/s has been applied in the analysis.

The histogram shows the total distribution of observed wind speeds (bar graph) in the processed time-series. A Weibull distribution function has been fitted to the data and is shown with a grey dashed line. Also shown (with a blue dashed line) is the emergent distribution, i.e. the distribution that emerges by adding together the 12 sector-wise Weibull distributions. The units on the *x*-axis is [m/s], on the *y*-axis [% per m/s].

Wind speed profiles

This graph shows the measured and Weibull-derived mean wind speeds at the nominal heights 10, 20, 40, 60 and 62 metres above ground level (a.g.l.); these values are shown using black and blue dots, respectively. The data points are plotted using the actual height above ground level of each anemometer.

WAsP-modelled wind profiles are shown with full lines, using the 62 m level as the predictor level. The modelled wind profile using default WAsP model parameter values is shown in blue; a profile using the geostrophic shear model is shown in red; a strictly neutral profile is shown in green for reference.

3.3 Generalised wind climate

The Wind Atlas table give the estimated (calculated) omni-directional Weibull *A*- and *k* parameters, the mean wind speed for each of five heights and five roughness length classes. Wind speed was calculated using the Weibull parameters of the Wind Atlas tables. The Weibull *A*-parameters and the mean wind speeds are given in [m/s].

Note that the five roughness classes correspond to uniform surfaces with a roughness length of 0.0 (0.0002) m, 0.03 m, 0.10 m, 0.40 m and 1.50 m, respectively. An extra class with z_0 = 1.50 m is used here, because of the possible occurrence of forest at some sites in South Africa. Below the wind atlas table are listed any non-default parameters values used in the calculation of the wind atlas; i.e. the site-specific air density and adapted atlas heights.

3.4 Mast statistics and climatologies

The mast statistics and climatologies given below were compiled and modelled in December 2020, using data collected in the period November 2018 to October 2020. The wind atlas data were calculated using the available information at the time of writing and the results will change in subsequent analyses and editions.

The 4 masts included in the report are listed in Table 3.1 below and their locations are shown on the sketch map in Figure 1.1. This map further shows typical land cover for South Africa, derived from the Shuttle Radar Topography Mission data set SRTM30, which contains spot heights of node points in grids with 30 arc-second resolutions (926 metres or less). More summaries of the wind measurements are given in Appendix A.

Table 3.1: Mast coordinates and elevations. The datum used is WGS 84; elevations are determined by the WAsP flow model from SRTM3 maps with 5-m height contours.

Mast ID	Longitude [°E]	Latitude [°S]	Elevation [m a.s.l.]	Easting [m]	Northing [m]	UTM zone
WM 16	19.357042	29.444360	1,073	340,654	6,741,658	34J
WM 17	23.519533	29.757876	1,196	743,631	6,705,384	34J
WM 18	23.655421	27.597376	1,478	762,101	6,944,582	34J
WM 19	20.568330	27.726700	848	457,450	6,932,997	34J

3.5 WM16 – Pofadder

WM16	19.357042°E	29.444360°S	1,073 m	E 340,654 m	N 6,741,659 m	UTM 34J

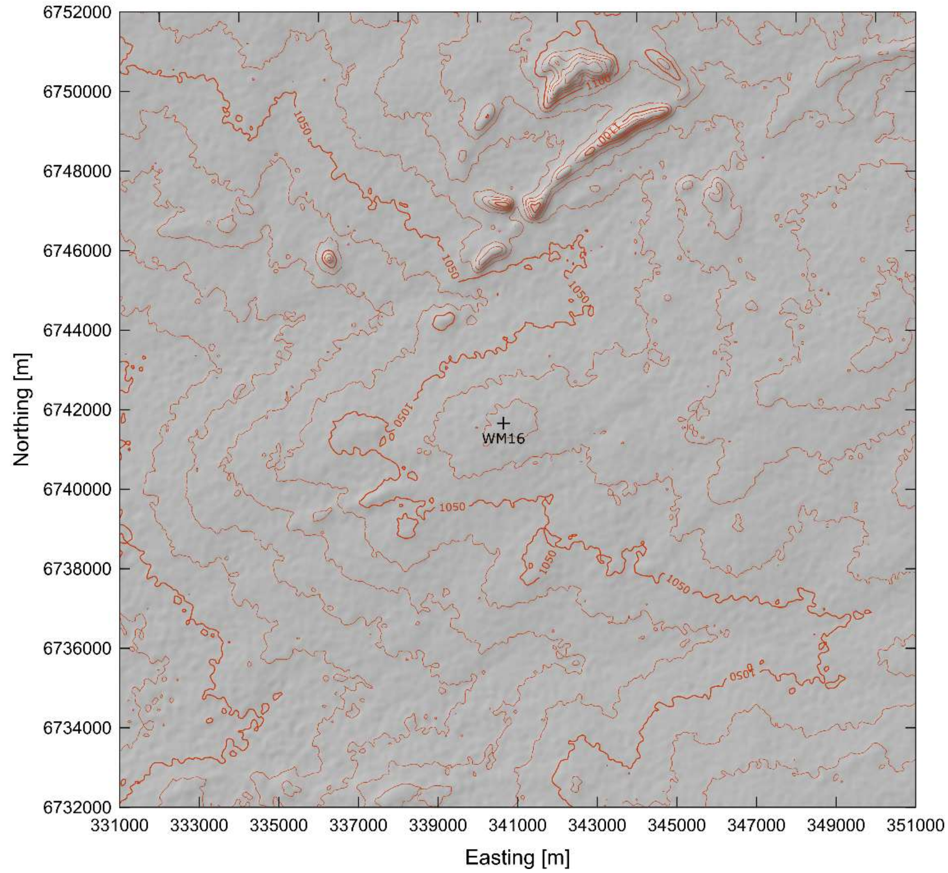

Figure 3.1: Elevation map from SRTM3 data that covers a 20 km by 20 km area with 10 m elevation contours. The ruggedness index for the site is 0 %.

3.5.1 Observed wind climate

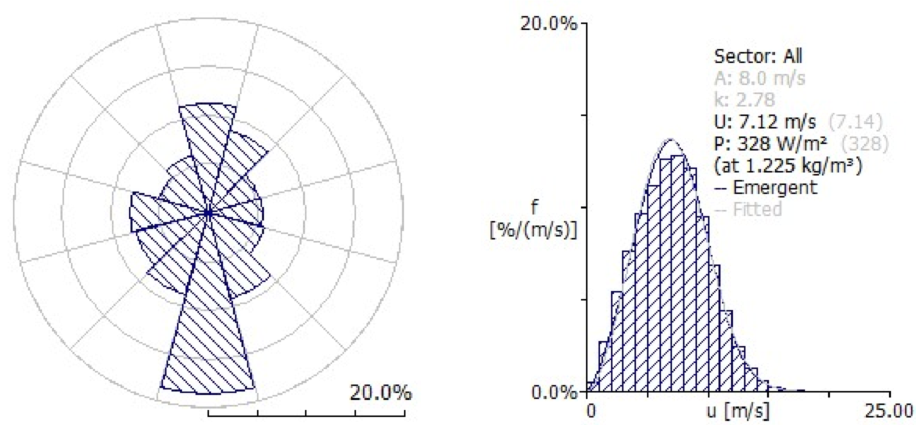

Figure 3.2: Wind rose and wind speed distribution for WM16 (Pofadder) at 62 m a.g.l. The data shown represent a period of two~~one~~ years, from 2018-11-01 to ~~2019~~2020-10-31.

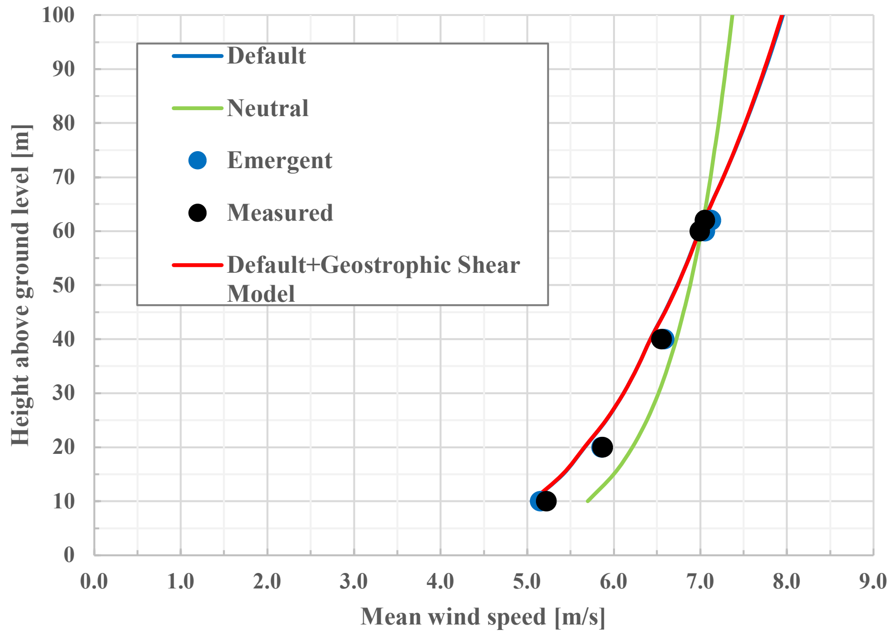

Figure 3.3: Measured and WAsP-modelled wind profiles for WM16 (Pofadder)

3.5.2 Generalised wind climate

Table 3.2: Generalised wind climate for WM16 (Pofadder). Non-default parameters are the reference heights with the air density estimated in WAsP 12.6.

Height [m]	**Parameters**	**Surface roughness lengths [m]**				
		0.00	**0.03**	**0.10**	**0.40**	**1.50**
10.0 m	Weibull *A* [m/s]	7.01	5.05	4.41	3.49	2.33
	Weibull *k*	2.36	2.10	2.15	2.22	2.29
	Mean speed [m/s]	6.21	4.47	3.91	3.09	2.07
20.0 m	Weibull *A* [m/s]	7.52	5.78	5.18	4.31	3.23
	Weibull k	2.42	2.22	2.26	2.32	2.39
	Mean speed [m/s]	6.66	5.12	4.59	3.82	2.86
40.0 m	Weibull *A* [m/s]	8.08	6.66	6.07	5.22	4.20
	Weibull *k*	2.52	2.44	2.46	2.50	2.56
	Mean speed [m/s]	7.17	5.91	5.38	4.64	3.73
62.0 m	Weibull *A* [m/s]	8.48	7.34	6.73	5.88	4.86
	Weibull *k*	2.63	2.70	2.69	2.70	2.74
	Mean speed [m/s]	7.53	6.53	5.98	5.23	4.33
125.0 m	Weibull *A* [m/s]	9.27	8.82	8.10	7.18	6.14
	Weibull *k*	2.55	2.74	2.73	2.71	2.67
	Mean speed [m/s]	8.23	7.85	7.21	6.38	5.45

3.6 WM17 – Strydenburg

WM17	23.519533°E	29.757876°S	1,196 m	E 743,631 m	N 6,705,384 m	34J

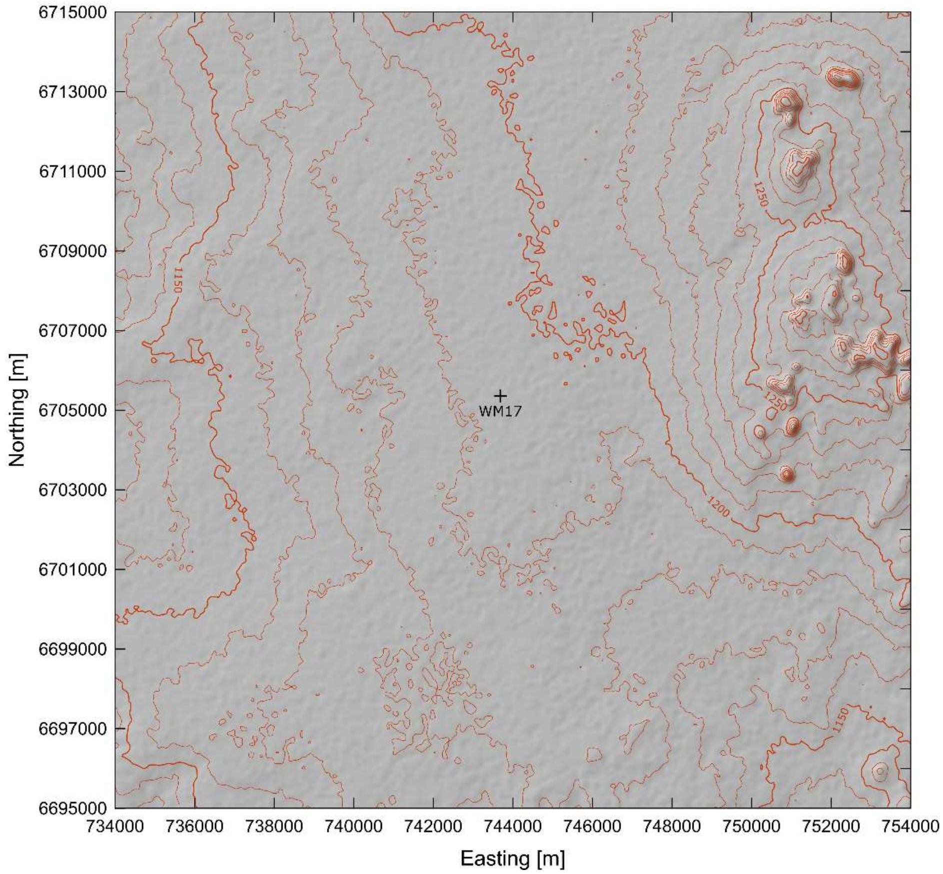

Figure 3.4: Elevation map from SRTM3 data that covers a 20 km by 20 km area with 10 m contours. The ruggedness index for the site is 0.0 %.

3.6.1 Observed wind climate

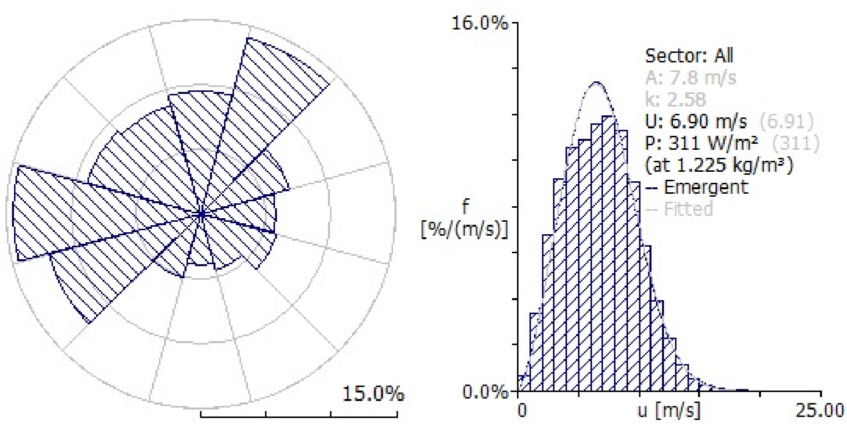

Figure 3.5: Wind rose and wind speed distribution for WM17 (Strydenburg) 62 m a.g.l. The data shown represent a period of ~~one~~ two year, from 2018-11-01 to ~~2019~~2020-10-31.

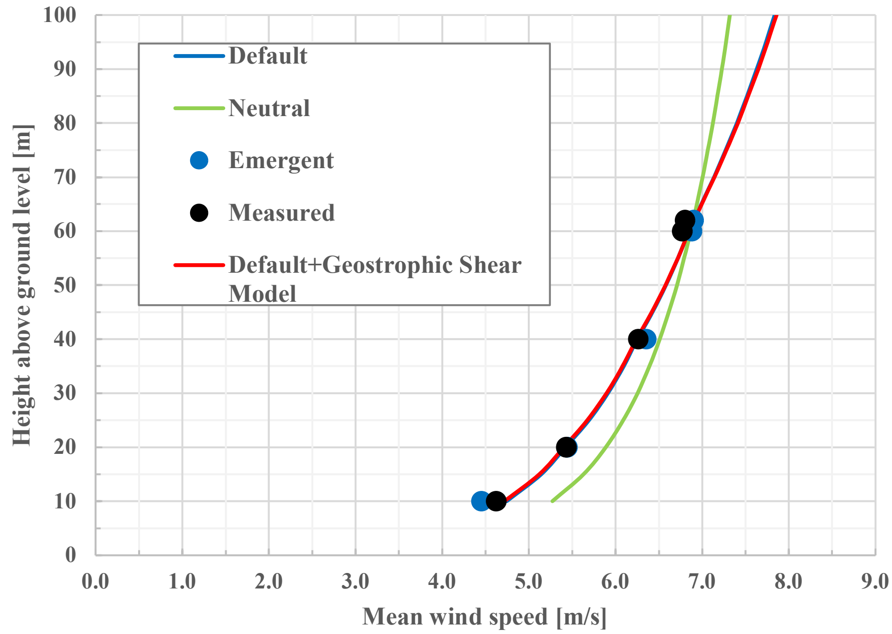

Figure 3.6: Measured and WAsP-modelled wind profiles for WM17 (Strydenburg).

3.6.2 Generalised wind climate

Table 3.3: Generalised wind climate for WM17 (Strydenburg). Non-default parameters are the reference heights with the air density estimated in WAsP 12.6.

Height [m]	Parameters	Surface roughness lengths [m]				
		0.00	0.03	0.10	0.40	1.50
10.0 m	Weibull *A* [m/s]	7.29	5.26	4.61	3.66	2.47
	Weibull *k*	2.24	2	2.03	2.07	2.1
	Mean speed [m/s]	6.46	4.66	4.09	3.24	2.19
20.0 m	Weibull *A* [m/s]	7.82	6.04	5.42	4.53	3.43
	Weibull *k*	2.29	2.12	2.14	2.17	2.19
	Mean speed [m/s]	6.93	5.35	4.8	4.02	3.03
40.0 m	Weibull *A* [m/s]	8.41	6.98	6.37	5.51	4.46
	Weibull *k*	2.39	2.35	2.35	2.35	2.35
	Mean speed [m/s]	7.45	6.18	5.64	4.88	3.95
62.0 m	Weibull *A* [m/s]	8.83	7.71	7.08	6.21	5.19
	Weibull *k*	2.46	2.56	2.52	2.48	2.42
	Mean speed [m/s]	7.84	6.84	6.28	5.51	4.6
125.0 m	Weibull *A* [m/s]	9.67	9.3	8.56	7.61	6.56
	Weibull *k*	2.39	2.54	2.53	2.49	2.43
	Mean speed [m/s]	8.58	8.26	7.6	6.75	5.81

3.7 WM18 – Kuruman

WM18	20.568330°E	27.591376°S	1,478 m	E 762,106 m	N 6,944,582 m	UTM 34J

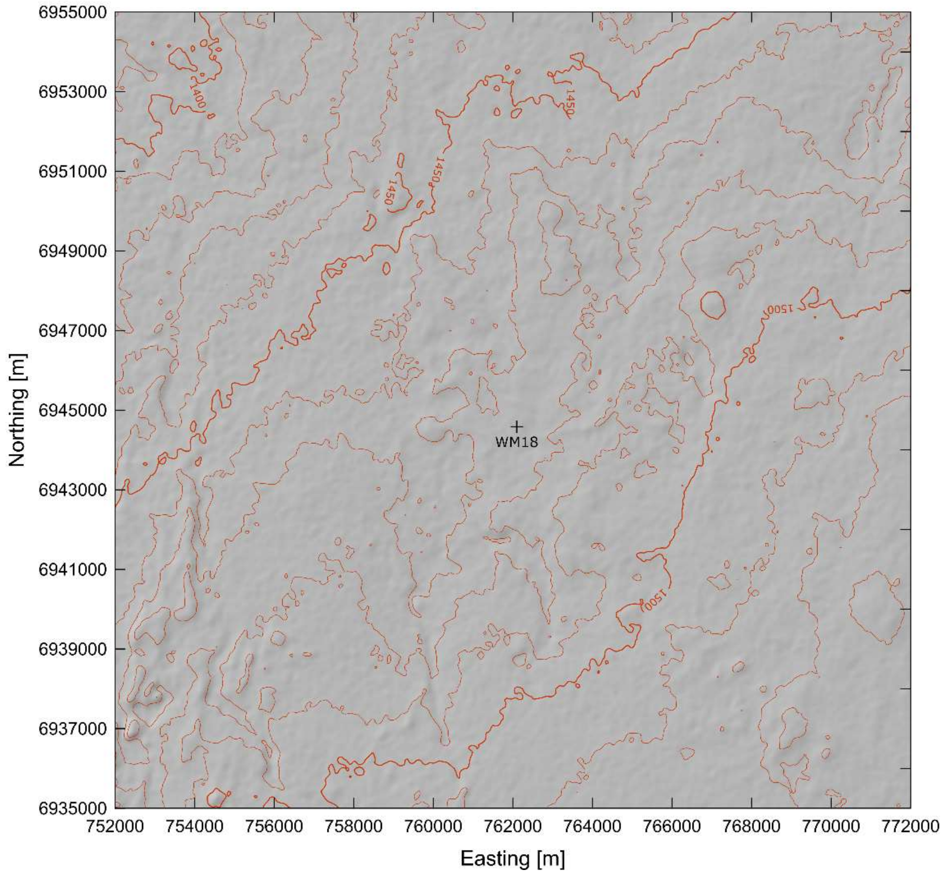

Figure 3.7: Elevation map from SRTM3 data that covers a 20 km by 20 km area with 10-m contours. The ruggedness index for the site is 0.0 %.

3.7.1 Observed wind climate

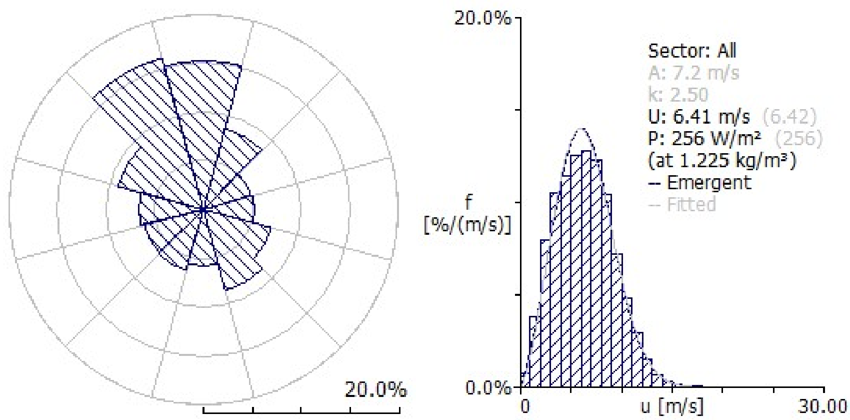

Figure 3.8: Wind rose and wind speed distribution for WM18 (Kuruman) at 62 m a.g.l. The data shown represent a period of ~~one~~ two year, from 2018-11-01 to ~~2019~~2020-10-31.

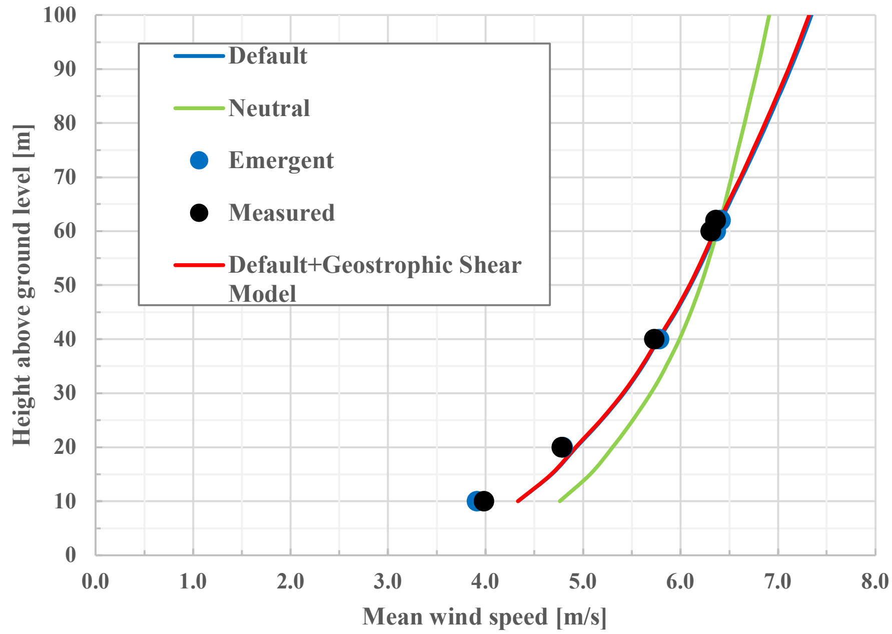

Figure 3.9: Measured and WAsP-modelled wind profiles for WM18 (Kuruman).

3.7.2 Generalised wind climate

Table 3.4: Generalised wind climate for WM18 (Kuruman). Non-default parameters are the reference heights with the air density estimated in WAsP 12.6.

Height [m]	**Parameters**	**Surface roughness lengths [m]**				
		0.00	**0.03**	**0.10**	**0.40**	**1.50**
10.0 m	Weibull *A* [m/s]	7.5	5.37	4.7	3.71	2.48
	Weibull *k*	2.18	1.94	1.98	2.04	2.12
	Mean speed [m/s]	6.64	4.77	4.17	3.29	2.2
20.0 m	Weibull *A* [m/s]	8.04	6.17	5.52	4.59	3.44
	Weibull *k*	2.23	2.04	2.08	2.13	2.2
	Mean speed [m/s]	7.12	5.46	4.89	4.07	3.05
40.0 m	Weibull *A* [m/s]	8.64	7.12	6.47	5.57	4.47
	Weibull *k*	2.33	2.26	2.27	2.3	2.36
	Mean speed [m/s]	7.66	6.3	5.73	4.93	3.96
62.0 m	Weibull *A* [m/s]	9.08	7.85	7.18	6.27	5.19
	Weibull *k*	2.43	2.49	2.48	2.49	2.53
	Mean speed [m/s]	8.05	6.96	6.37	5.56	4.6
125.0 m	Weibull *A* [m/s]	9.93	9.43	8.66	7.66	6.54
	Weibull *k*	2.35	2.53	2.52	2.49	2.46
	Mean speed [m/s]	8.8	8.37	7.68	6.79	5.8

3.8 WM19 – Upington

WM19	29.54348°E	27.726700°S	848 m	E 457,450 m	N 6,932,997 m	UTM 34J

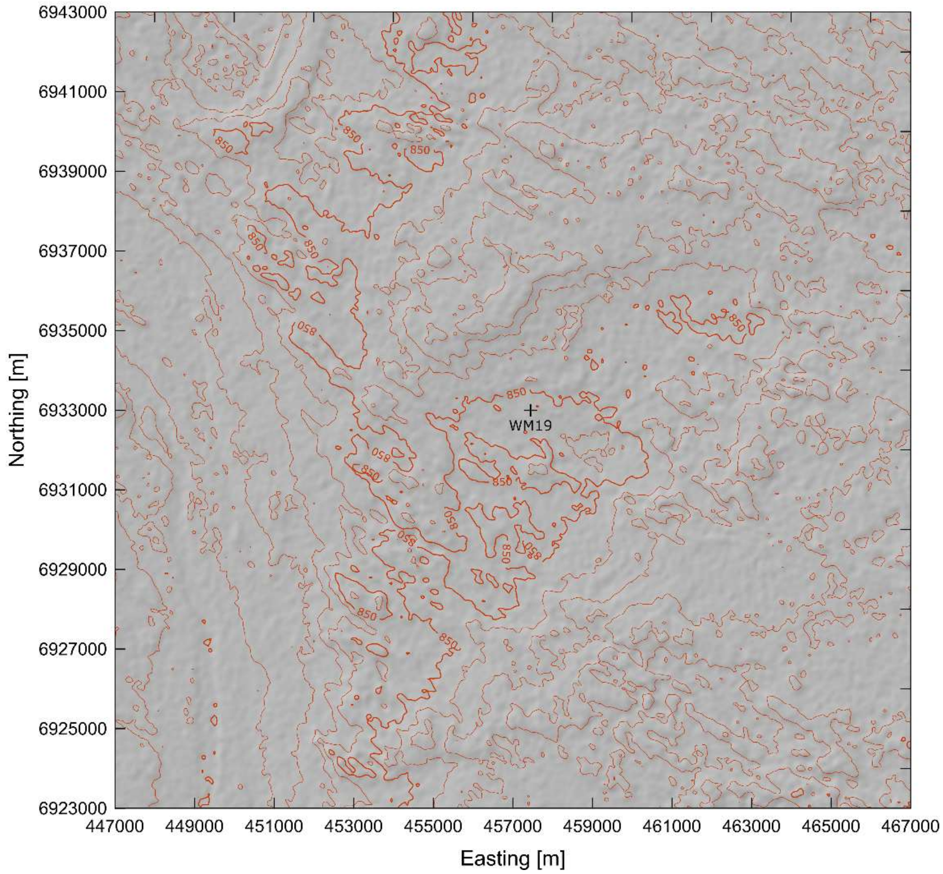

Figure 3.10: Elevation map from SRTM3 data that covers a 20 km by 20 km area with 10 m contours. The ruggedness index for the site is 0.0 %.

3.8.1 Observed wind climate

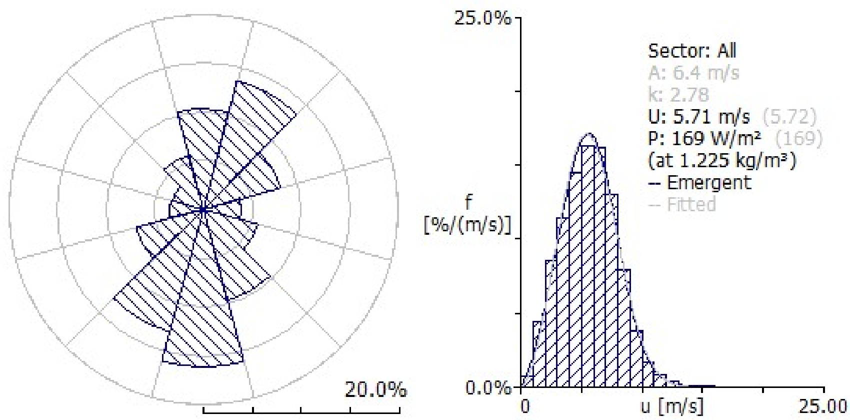

Figure 3.11: Wind rose and wind speed distribution for WM19 (Upington) at 62 m a.g.l. The data shown represent a period of two~~one~~ year, from 2018-11-01 to ~~2019~~2020-10-31.

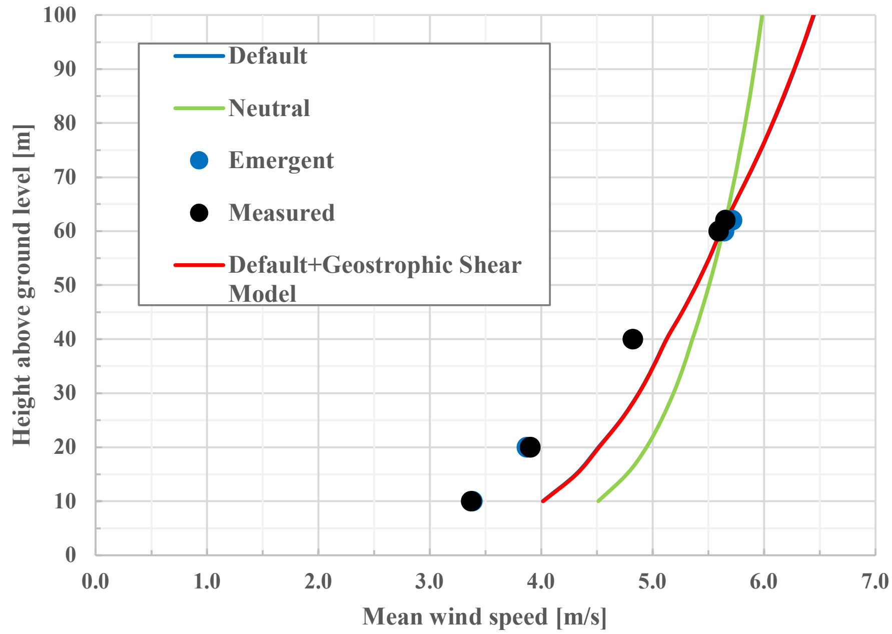

Figure 3.12: Measured and WAsP-modelled wind profiles for WM19 (Upington).

3.8.2 Generalised wind climate

Table 3.5: Generalised wind climate for WM19 (Upington). Non-default parameters are the reference heights with the air density estimated in WAsP 12.6.

Height [m]	**Parameters**	**Surface roughness lengths [m]**				
		0.00	**0.03**	**0.10**	**0.40**	**1.50**
10.0 m	Weibull *A* [m/s]	5.85	4.22	3.69	2.92	1.96
	Weibull *k*	2.36	2.1	2.15	2.22	2.3
	Mean speed [m/s]	5.18	3.74	3.27	2.59	1.73
20.0 m	Weibull *A* [m/s]	6.27	4.84	4.34	3.61	2.71
	Weibull *k*	2.41	2.22	2.26	2.31	2.39
	Mean speed [m/s]	5.56	4.28	3.84	3.2	2.4
40.0 m	Weibull *A* [m/s]	6.74	5.57	5.08	4.38	3.52
	Weibull *k*	2.51	2.44	2.46	2.5	2.56
	Mean speed [m/s]	5.98	4.94	4.5	3.88	3.12
62.0 m	Weibull *A* [m/s]	7.07	6.14	5.63	4.92	4.08
	Weibull *k*	2.62	2.69	2.68	2.69	2.74
	Mean speed [m/s]	6.28	5.46	5	4.38	3.63
125.0 m	Weibull *A* [m/s]	7.74	7.38	6.78	6.01	5.15
	Weibull *k*	2.54	2.73	2.72	2.7	2.67
	Mean speed [m/s]	6.87	6.56	6.03	5.35	4.57

3.9 Summary of generalised wind climates

This section summarises the main characteristics of the *generalised wind climates* from the 4 masts, see Table 3.6.

Table 3.6: Summary of the generalised wind climates at 100 m a.g.l. over roughness class 2 (roughness length z_0 = 0.03 m) at the met. masts: Data-collecting period, Weibull A- and k-parameters, mean wind speed (U).

Mast ID	**Period [years]**	***A* [m/s]**	***k* [ ]**	***U* [m/s]**
WM16	2	8.30	2.78	7.37
WM17	2	8.70	2.58	7.75
WM18	2	8.90	2.57	7.86
WM19	2	6.90	2.77	6.17

4 Concluding remarks

With this report, the observational wind atlas for the WASA 3 domain in South Africa has been established, based on data and analyses from 4 met. masts in the Northern Cape province. The main results of the wind atlas analysis are reported in Chapter 3, but much more data and information are available in the Climate Analyst projects and WAsP workspaces that accompany this report. Based on this work, it will be straightforward to update the observational wind atlas if and when more data becomes available. It should be borne in mind that the present atlas is based on two years only and that long-term data from near-by met. masts or mesoscale data sets are not included here.

The generalised wind climates determined in the wind atlas analysis can be used for validation of the mesoscale modelling close to the met. mast sites; this validation is described on the WASA web pages and reports.

The observed wind climates established during the wind atlas analysis can also be used for validation of the microscale modelling, in particular how well the vertical wind profile can be modelled from 0-62 metres above the terrain. The main results of such a preliminary comparison are shown in Chapter 3.

The preliminary wind profile analyses suggest that modelling of the vertical wind profiles can be improved significantly by adjusting the land cover (roughness) descriptions and heat flux settings in WAsP.

Based on the work reported here, it is strongly recommended to follow the general *WAsP Best Practices* closely when applying WAsP and similar models in South Africa; the current version of these is given in Appendix B. Since the modelling of the vertical wind profile seems to be particularly challenging, the deployment of tall met. masts or remote sensing devices (comparable to the hub height of the wind turbine) is strongly recommended. It is also strongly recommended to design and instrument such masts according to international standards and best practices, and to independently inspect the installations when they are in operation (Mortensen *et al*., 2012).

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- Royal Danish Embassy

The South African National Energy Development Institute (SANEDI) is the Executing Agency, coordinating and contracting contributions from the implementing partners: Council for Scientific and Industrial Research (CSIR), University of Cape Town (UCT), South African Weather Service (SAWS) and DTU Wind Energy (formerly Risø DTU).

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Appendix A Additional observed wind statistics

A.1 Hourly, monthly and yearly wind statistics

Mean wind speeds by hour of day and month of year, as well as monthly mean wind speeds for the year 1 November 2018 to 31 October 2019 are given in the tables below.

A.1.1 WM16 - Pofadder

Table A.1.1: Hourly and monthly mean wind speeds in [m/s] at 62 m a.g.l at WM16 (Pofadder) for the two year period, from 2018-11-01 to 2020-10-31.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	8.2	6.99	7.1	7.38	6.57	7.98	8.34	7.27	8.06	7.19	8.07	7.2	7.53
1	7.56	6.84	6.87	7.5	6.56	7.96	8.45	7.37	8.09	7.21	7.93	6.99	7.45
2	7.06	6.77	6.7	7.38	6.71	8.11	8.54	7.3	8.31	7.44	7.96	6.67	7.41
3	6.87	6.92	6.24	7.4	6.86	8.07	8.57	7.52	8.44	7.39	7.88	6.58	7.39
4	6.97	7.06	6.36	7.53	7.13	8.16	8.56	7.68	8.43	7.2	7.71	6.71	7.46
5	7.04	7.19	6.58	7.55	7.24	8.21	8.49	7.48	8.56	7.26	7.66	6.78	7.5
6	6.77	7.48	6.44	7.57	7.28	8.36	8.23	7.38	8.17	7.47	7.58	6.39	7.43
7	5.92	6.83	6.28	7.65	7.55	8.53	8.12	7.23	7.8	6.97	6.54	5.59	7.08
8	5.5	6.27	5.61	7.15	7.53	8.48	8.01	7.09	7.41	6.44	6.03	5.45	6.75
9	5.09	6.32	4.98	6.66	6.75	7.89	7.64	6.48	7.08	6.34	5.7	5.23	6.35
10	4.56	6.06	4.92	6.8	6.72	7.58	7.58	6.31	7.34	6.01	5.41	5.12	6.2
11	4.52	5.72	4.98	6.48	7.09	8.04	7.79	6.43	7.41	5.83	5.03	5.3	6.22
12	4.87	5.5	5.16	6.23	7.08	8.02	7.92	6.55	7.45	5.86	5.19	5.63	6.29
13	5.26	5.57	5.47	6	6.85	7.87	7.93	6.77	7.34	6.04	5.5	5.94	6.38
14	5.63	5.65	5.88	5.95	6.6	7.71	8.03	6.81	7.19	6.23	6.08	6.33	6.51
15	6.29	5.93	6.17	5.91	6.19	7.32	7.72	6.85	7.09	6.32	6.39	6.73	6.58
16	6.77	5.98	6.44	5.86	5.77	6.83	7.29	6.79	6.97	6.5	6.64	7.13	6.58
17	7.13	6.46	6.52	5.98	5.45	6.52	6.79	6.57	7.1	6.83	6.94	7.66	6.66
18	7.93	7.03	6.96	5.8	5.39	6.68	6.36	6.7	7.02	7.22	7.54	8.19	6.9
19	9.44	8.02	7.68	6.01	5.67	6.94	6.58	6.66	7.31	7.6	8.65	8.83	7.45
20	10.2	8.72	7.99	6.39	6.12	7.1	7.05	6.77	7.57	7.76	9.05	9.69	7.87
21	10	8.99	7.85	6.61	6.2	7.47	7.49	6.85	7.75	7.59	8.68	9.59	7.92
22	9.24	8.28	7.22	6.6	6.4	7.86	8	7.09	8.02	7.44	8.51	8.61	7.77
23	8.57	7.38	7.08	7.12	6.59	8.14	8.05	7.48	8.16	7.29	8.07	7.8	7.64
	6.97	6.83	6.39	6.73	6.6	7.74	7.81	6.98	7.67	6.89	7.11	6.92	7.05

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2018	---	---	---	---	---	---	---	---	---	---	7.32	6.69	7
2019	7.22	6.37	6.5	6.92	6.79	7.28	7.36	6.83	8.09	7.07	6.91	7.16	7.04
2020	6.72	7.27	6.29	6.54	6.4	8.2	8.27	7.13	7.25	6.72	11.9	---	7.52
	6.97	6.82	6.39	6.73	6.6	7.74	7.81	6.98	7.67	6.89	8.72	6.92	7.19

Wind speed [m/s]: 3 – 10

A.1.2 WM17 - Strydenburg

Table A.1.2: Hourly and monthly mean wind speeds in [m/s] at 62 m a.g.l at WM17 (Strydenburg) for the two year period, from 2018-11-01 to 2020-10-31.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	8.39	8.28	7.93	7.63	7.19	6.86	7.35	6.69	7.43	7.24	7.65	8	7.55
1	8.41	8.06	7.6	7.43	7.07	6.74	7.47	6.75	7.58	7.37	7.61	7.66	7.48
2	8.22	7.82	7.73	7.43	6.87	6.9	7.64	6.86	7.52	7.23	7.52	7.87	7.47
3	7.95	7.88	7.44	7.19	6.98	7.13	7.64	6.63	7.3	7.22	7.36	7.7	7.37
4	7.82	7.76	7.26	7.13	6.89	7.1	7.34	6.58	7.07	7.25	7.09	7.34	7.22
5	7.68	7.68	7.35	7.11	6.81	7.16	7.25	6.68	7.28	7.47	7.22	7.38	7.26
6	7.17	7.37	7.25	7.21	6.55	7.39	7.33	6.53	7.42	7.11	6.7	6.82	7.07
7	6.84	6.66	6.87	7.09	6.51	7.41	7.68	6.49	7.18	6.3	5.99	6.38	6.78
8	6.84	6.8	6.29	6.4	6.2	7.28	7.51	6	6.39	6.2	5.59	6.21	6.48
9	6.36	6.66	6.1	5.85	5.23	6.23	6.42	5.4	6.6	6.03	5.25	5.85	6
10	6.12	6.45	5.81	5.86	4.96	6.04	6.57	5.43	6.75	6.13	5.55	5.86	5.96
11	6.06	5.87	5.59	5.75	5.23	6.06	6.78	5.71	6.54	6.37	5.83	5.91	5.98
12	6.27	5.62	5.73	5.37	5.39	6.01	6.79	6.11	6.48	6.61	6.34	6.4	6.09
13	6.67	5.72	5.92	5.27	5.54	5.96	6.69	6.28	6.43	6.87	6.75	6.98	6.26
14	6.96	5.86	6.1	5.14	5.5	5.86	6.5	6.6	6.71	7.26	7	7.38	6.41
15	7.4	5.98	6.45	5.38	5.41	5.65	6.33	6.7	6.67	7.47	7.59	7.76	6.57
16	7.74	6.17	6.88	5.11	5.03	5.53	6.04	6.58	6.67	7.63	7.91	8	6.61
17	7.91	6.36	6.73	5.3	4.67	5.15	5.44	6.26	6.61	7.53	7.61	8.28	6.49
18	8.14	6.69	6.75	5.61	4.88	5.17	5.37	5.9	6.52	7.21	7.54	8.61	6.53
19	7.78	6.94	7.38	6.21	5.33	5.6	5.63	5.86	6.61	6.85	7.33	8.48	6.67
20	8.01	7.37	7.4	6.77	5.83	6.19	5.95	5.85	6.99	6.86	7.3	8.18	6.89
21	8.03	8.12	7.5	7.27	6.53	6.48	6.44	6.12	7.43	7.1	7.28	8.27	7.21
22	8.1	8.47	7.49	7.52	6.84	6.64	6.86	6.56	7.43	7.2	7.45	8.27	7.4
23	8.44	8.65	7.78	7.74	7.13	6.79	7.01	6.75	7.47	7.27	7.65	8	7.56
	7.47	7.05	6.89	6.45	6.02	6.39	6.75	6.31	6.96	6.99	6.96	7.4	6.8

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2018	---	---	---	---	---	---	---	---	---	---	7.05	7.75	7.4
2019	7.5	7.07	6.87	6.57	6.91	6.48	6.97	5.88	6.96	7.31	6.9	7.05	6.87
2020	7.44	7.03	6.9	6.33	5.14	6.29	6.53	6.73	6.96	6.67	8.93	---	6.82
	7.47	7.05	6.89	6.45	6.02	6.39	6.75	6.31	6.96	6.99	7.63	7.4	7.03

Wind speed [m/s]: 3 10

A.1.3 WM18 - Kuruman

Table A.1.3: Hourly and monthly mean wind speeds in [m/s] at 62 m a.g.l at WM18 (Kuruman) for the two year period, from 2018-11-01 to 2020-10-31.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	7.38	6.57	6.26	6.47	5.37	5.95	6.43	6.55	6.86	7.26	6.89	6.89	6.57
1	7.07	6.42	6.37	6.17	5.25	6.06	6.4	6.42	6.62	7.04	6.93	6.75	6.46
2	6.93	6.11	6.31	6.02	5.3	6.16	6.28	6.1	6.7	7.29	6.98	6.36	6.38
3	7.01	6.22	6.33	6.19	5.2	6.11	6.13	6.52	6.87	7.12	7.05	6.13	6.41
4	6.9	6.26	6.15	6.24	5.09	5.94	6.11	6.89	6.65	7.27	7.4	6.24	6.43
5	6.81	6.3	6.17	6.01	5.08	5.79	5.8	7	6.67	7.1	7.75	6.2	6.39
6	6.52	6.13	5.96	6.03	5.07	5.38	5.59	6.92	6.54	7.08	7.37	6.13	6.23
7	6.33	5.67	5.63	5.71	5.3	5.08	5.61	6.57	6.04	6.55	7.04	6.39	5.99
8	6.57	5.78	5.55	5.17	4.48	4.95	5.41	5.62	5.94	6.78	7.47	6.74	5.87
9	6.47	6.02	6.3	5.53	4.59	4.72	5.34	5.93	6.21	6.63	7.26	6.69	5.97
10	6.38	5.99	6.59	5.83	5.09	5.67	5.98	6.49	6.42	6.44	7.11	6.84	6.24
11	6.16	5.99	6.59	6	5.16	5.96	5.88	6.38	6.56	6.72	6.89	7	6.27
12	6.25	6.02	6.53	6.32	5.25	5.97	5.78	6.46	6.67	7.1	6.95	7.28	6.38
13	6.47	6.16	6.69	6.33	5.23	5.86	5.78	6.69	6.79	7.23	7.02	7.55	6.49
14	6.79	6.29	6.64	6.32	5.1	5.65	5.76	6.74	6.78	7.37	7.24	7.78	6.54
15	7.08	6.04	6.25	6.24	5	5.41	5.64	6.68	6.6	7.23	7.35	7.9	6.45
16	7.24	6.27	6.13	6.27	4.79	5.18	5.5	6.38	6.45	7.21	7.33	8.09	6.4
17	7.13	6.56	5.9	5.96	4.84	5.07	5.29	5.99	6.42	7.03	6.94	7.96	6.26
18	7.27	6.23	5.69	5.73	5.16	5.38	5.48	6.06	6.39	6.83	6.95	7.82	6.25
19	7.39	6.12	5.77	5.61	5.39	5.46	5.77	6.24	6.65	7.09	7.07	7.42	6.33
20	7.57	6.62	6.13	5.63	5.5	5.84	6.01	6.35	6.82	7.17	7.06	7.17	6.49
21	7.53	6.66	6.17	6.26	5.6	6.06	6.25	6.68	6.93	7.23	7.09	6.97	6.62
22	7.44	6.95	6.29	6.54	5.54	6.31	6.29	6.79	7.07	7.21	7	7.04	6.71
23	7.27	6.69	6.35	6.67	5.37	6.42	6.24	6.55	7.02	7.03	6.77	7.01	6.62
	6.92	6.25	6.2	6.05	5.16	5.68	5.86	6.46	6.61	7.04	7.12	7.01	6.36

`	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2018	---	---	---	---	---	---	---	---	---	---	7.01	7.56	7.28
2019	7.25	6.66	6.72	6.18	5.97	6.11	5.82	6.45	6.34	7.16	7.2	6.47	6.53
2020	6.58	5.86	5.68	5.93	4.35	5.26	5.9	6.46	6.88	6.92	12	---	6.53
	6.92	6.26	6.2	6.05	5.16	5.68	5.86	6.46	6.61	7.04	8.74	7.01	6.78

Wind speed [m/s]: 3 – 10

A.1.4 WM19 - Upington

Table A.1.4: Hourly and monthly mean wind speeds in [m/s] at 62 m a.g.l at WM19 (Upington) for the two year period, from 2018-11-01 to 2020-10-31.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	7.13	6.59	6.16	6.41	6.65	6.25	6.19	6.38	6.64	6.89	7.19	7.41	6.66
1	6.85	6.58	5.82	6.21	6.38	6.13	6.1	6.29	6.71	6.85	6.95	6.96	6.49
2	6.68	6.41	5.55	5.82	6.19	6.4	6.15	6.22	6.72	6.7	6.63	6.66	6.34
3	6.12	5.85	5.31	5.51	6.07	6.32	6.15	6.06	6.42	6.13	6.35	6.47	6.06
4	5.68	5.36	5.35	5.58	6.05	6.54	6.23	6.15	6.19	5.85	6.25	6.12	5.95
5	5.53	5.14	5.07	5.51	6.26	6.74	6.29	5.86	6.43	5.64	6.02	5.79	5.86
6	5.21	5.04	5.06	5.45	6.15	6.61	6.12	5.76	6.4	5.6	5.46	5.31	5.68
7	4.73	4.66	4.92	5.21	5.89	6.47	6.28	5.65	5.78	4.91	5.09	5.34	5.41
8	4.92	4.56	4.51	4.98	5.29	5.96	6.19	5.1	5.54	4.8	5.25	5.46	5.21
9	4.73	4.89	4.67	4.78	4.77	5.06	5.33	4.47	5.56	4.86	5.1	5.47	4.97
10	4.39	4.79	4.64	4.98	4.98	4.95	5.02	4.69	5.69	4.85	4.67	5.09	4.9
11	4.37	4.81	4.7	4.91	5.14	5.19	5.4	4.72	5.67	4.67	4.53	4.7	4.9
12	4.45	4.86	4.87	4.74	5.34	5.43	5.64	4.65	5.68	4.59	4.53	4.74	4.96
13	4.65	4.8	4.83	4.65	5.37	5.56	5.74	4.74	5.6	4.76	4.72	4.92	5.03
14	4.87	4.78	4.83	4.74	5.38	5.31	5.71	4.88	5.54	4.98	5.01	5.26	5.11
15	5.12	4.81	4.94	4.68	5.15	5.06	5.54	5.05	5.47	5.19	5.27	5.48	5.15
16	5.29	4.8	5.11	4.6	4.81	4.72	5.19	5.07	5.4	5.49	5.43	5.72	5.14
17	5.64	5.21	5.08	4.83	4.39	4.35	4.72	4.95	5.49	5.45	5.54	6.24	5.16
18	6.11	5.5	5.36	4.64	4.5	4.55	4.6	4.89	5.3	5.19	5.5	6.58	5.23
19	6.32	5.86	5.43	4.82	5.15	5.07	5.05	5.17	5.62	5.29	5.62	6.67	5.51
20	6.5	6.22	6.04	5.26	5.7	5.8	5.4	5.5	6.24	5.74	6.65	6.97	6
21	7.16	6.65	6.37	5.93	6.04	6.28	5.75	5.97	6.61	6.64	7.23	7.15	6.48
22	7.35	6.41	6.54	5.96	6.37	6.65	6.2	6.36	6.79	7.08	7.35	7.44	6.71
23	6.97	6.42	6.51	6.04	6.63	6.57	6.06	6.48	6.92	7.06	7.14	7.49	6.69
	5.7	5.46	5.32	5.26	5.61	5.75	5.71	5.46	6.02	5.63	5.81	6.06	5.65

`	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2018	---	---	---	---	---	---	---	---	---	---	5.93	6.06	5.99
2019	6.02	5.3	5.29	5.35	6.19	5.59	5.39	5.23	6.37	5.73	5.7	6.06	5.69
2020	5.37	5.61	5.35	5.17	5.03	5.91	6.03	5.7	5.66	5.54	6.79	---	5.65
	5.7	5.46	5.32	5.26	5.61	5.75	5.71	5.46	6.02	5.63	6.14	6.06	5.78

Wind speed [m/s]: 3 … 10

Appendix B WAsP best practices and checklist

This following list of requirements, best practices and recommendations for microscale modelling using the WAsP software is not exhaustive, but is meant to provide a brief summary of some important considerations regarding WAsP modelling. More information is available in the WAsP help system and at www.wasp.dk.

Measurement programme

- ❑ Design measurement programme based on preliminary WAsP analysis o Use SRTM elevation and water body data + land cover from Google Earth
- ❑ Follow WAsP similarity principle as much as possible when siting the mast(s)
- ❑ Height of reference anemometer(s) similar to hub height (preferably > 2/3 h_{hub})
- ❑ Optimum boom direction is @ 90° (lattice) or @ 45° (tubular) to prevailing wind direction
- ❑ Deploy 2 or more masts for horizontal extrapolation analyses
- ❑ Deploy 2 or more masts if RIX and ΔRIX analyses are required
- ❑ Deploy 2 or more levels on masts for vertical wind profile analyses
- ❑ Deploy 2 or more levels on masts for redundancy in instrumentation Measure temperature (@ hub height) and pressure for air density calculations Are anemometers calibrated according to international/traceable standards?

Wind data analysis

- ❑ Collect required information, e.g. by filling out the WAsP Data Description Form
- ❑ All fields in Climate Analyst protocol editor should correspond to data spec's
- ❑ Plot and inspect time traces of all meteorological measurements
- ❑ Visual inspection of time-series – in particular reference wind speed and direction
- ❑ Visual inspection of polar scatter plot – any patterns or gaps?

Observed wind climate

- ❑ Use an integer number of whole years when calculating the OWC Check Weibull fit: is power density discrepancy < 1%?
- ❑ Check Weibull fit: is mean wind speed discrepancy < a few per cent?
- ❑ Check within context of long-term wind climate (MCP)

Elevation map(s)

- ❑ Size of map: should extend at least several (2-3) times the horizontal scale of significant terrain features from any site – meteorological mast, reference site, wind turbine site or resource grid point. This is typically 5-10 km.
- ❑ Coordinates and elevations must be in meters
- ❑ Set map projection and datum in the Map Editor
- ❑ Add spot heights within wind farm site; interpolate contours if necessary
- ❑ High-resolution contours around calculation sites (contour interval ≤ 10 m)
- ❑ Low-resolution contours away from calculation sites (contour interval ≥ 10 m)
- ❑ Non-rectangular maps are allowed (circular, elliptic, etc.)
- ❑ Check range of elevations in final map

Roughness/land cover map(s)

- ❑ Size: map should extend <u>at least</u> max(150×*h*, 10 km) from any site – meteorological mast, reference site, turbine site or resource grid point.
- ❑ Coordinates and roughness lengths must be in meters
- ❑ Set map projection and datum in the Map Editor
- ❑ Set roughness length of water surfaces to 0.0 m!
- ❑ Check range of roughness length values in final map
- ❑ Map date should correspond to modelling scenario (met. mast or wind farm) Check for dead ends and cross points – and edit map as needed Check consistency of roughness values – there must be no LFR-errors!

Sheltering obstacles

- ❑ Is site closer to obstacle than 50 obs. heights and height lower than about 3 obs. heights?
- ❑ If yes to both, treat as sheltering obstacle; if no, treat as *roughness element*

WAsP modelling – site visit

- ❑ Go on a site visit! Use e.g. the WAsP Site/Station Inspection Checklists
- ❑ Print and bring the WAsP forms for recording the necessary information
- ❑ Bring GPS and note projection and datum settings – change if required
- ❑ Determine coordinates of all masts, sites, landmarks and other characteristic points on site
- ❑ Bring sighting compass and determine boom directions and wind vane calibration
- ❑ Take photos of station and surroundings (12 × 30°-sector panorama)
- ❑ Download GPS data and photographs to PC as soon as possible (daily)

WAsP modelling – parameters

- ❑ Wind atlas structure: roughness classes should span and represent site conditions
- ❑ Wind atlas structure: standard heights should span and represent project conditions
- ❑ Adjust off- & on-shore mean- and RMS-heat fluxes values to site conditions (*caution!*)
- ❑ Ambient climate: Set air density to site-specific value (WAsP 10+ only)

WAsP modelling – analysis and application

- ❑ Get site-specific (density, noise, …) wind turbine generator data from manufacturer
- ❑ Within forest: effective height = nominal height minus displacement length
- ❑ Complex or steep terrain is when RIX > 0 for one or more sites (terrain angles > 17° or 30%)
- ❑ Make RIX and ΔRIX analyses if RIX > 0 for any calculation site

WAsP modelling – offshore

- ❑ Roughness length of sea (and other water) surfaces: set to 0.0 m in WAsP!
- ❑ Add combined elevation/roughness change line around wind farm site
- ❑ Change wake decay constant to offshore conditions

WAsP modelling – sensitivity analyses and uncertainties

- ❑ Identify and try to estimate the main uncertainties
- ❑ Sensitivity of results to background roughness value and other important parameters