# The National Wind Resource Assessment Project of Namibia

**EBJ Siepker[a] and TM Harms[b]**

Received 31 August 2017, in revised form 12 December 2017 and accepted 13 December 2017

***Abstract:** With eleven tall masts equipped with modern wind data acquisition systems, the National Wind Resource Assessment Project (NWRAP) of Namibia is the most comprehensive dedicated wind measurement project undertaken in the country to date. The objective of NWRAP is the provision of high-quality wind data from which reliable wind climates can be identified for relevant parts of the country. The article provides a brief background to the project and proceeds with a description of the development and location thereof, the equipment employed to produce wind data and the processes and methods used to analyse the data. The statistics pertaining to the observed wind climates as identified from wind speed data observed at two elevations at each of the masts are presented in the results section. The statistics include Weibull parameters and mean wind power density. It is inter alia shown that the best wind resource exists at the site located close to the Southern coastal town of Lüderitz where a resource of 411 W/m² at approximately 46 m above ground level was identified.*

## 1 Introduction

Wind data have been acquired in Namibia for agricultural and meteorological purposes from the early 1900s as first reported by Thomas [1] in 1903. These data are, however, in general not well suited for use in wind energy applications. The objectives of the measurements did not require the systems and processes that produced the data to be in conformance with the stringent requirements of international standards for accurate wind measurements for wind energy applications such as IEC61400-12-1:2005(E) [2]. The major deficiencies of the historic systems and processes in respect of this standard include:

- the poor positioning and low elevation of wind sensors that lead to the excessive interference of ground obstacles and support structures with the free flow of wind over the sensors,
- the employment of sensors of unknown or questionable calibration that causes uncertainties in the accuracy of recorded data and
- the excessively long data observation or averaging intervals that Siepker and Harms [3] show to be a major source of inaccuracies in the estimation of the power in the wind.

The unsuitability of the deficient data acquired thus is further exacerbated by poor system maintenance and data management procedures. These aspects in turn lead to unacceptably low data recovery and reporting rates as elaborated on by Wisse and Stigter [4] in their article on the rather bleak state of wind engineering in Africa as of 2007. The unavailability of wind data of sufficient quantity and quality in the past often led to the outright dismissal of wind energy technologies as possible contributors to optimum energy supply solutions at locations of interest in Namibia. In 2008 a number of Namibian stakeholders decided to co-operate on NWRAP in order to alleviate this undesirable situation through the provision of high-quality wind data from which reliable wind climate parameters can be identified for relevant parts of the country. These stakeholders are Gobabeb Research & Training Centre (GRTC), Mobile Telecommunications Limited (MTC), Namibia Power Corporation (NP) and Namibia University of Science and Technology (NUST). Between 2010 and 2012 the intended co-operation was formalized in a number of contracts in terms of which the parties agreed that:

- GRTC would permit the installation of NWRAP equipment on their existing meteorological research mast at Gobabeb,
- MTC would permit the installation of NWRAP equipment on a suitable selection of eight of their existing telecommunications masts,
- NP would finance the procurement and installation of two new wind masts and electronic equipment at Walvis Bay and Lüderitz and
- NUST would be responsible for the management of NWRAP as well as the technical and scientific work associated with the project.

The electronic wind measurement equipment and the new wind masts were procured via international tenders whereas the services associated with the installation thereof were secured via bidding processes restricted to Southern African contractors. Booms and mounting brackets required for the mounting of equipment on the GRTC and MTC masts were designed by the Department of Mechanical and Marine Engineering (DMME) of NUST and manufactured in the workshop of DMME by final year B Tech (Mech Eng) project students. The major advantages of utilizing the MTC telecommunication masts as mounting platform for wind measurement equipment are:

- the avoided costs associated with new masts and environmental impact assessment studies,
- the avoidance of applications for approval by civil aviation and other relevant authorities and
- the security of the equipment against vandalism and theft as the masts are generally located on stands that are protected by electrified palisade fencing and remotely observed alarm systems.

These advantages, however, come at the penalty of increased flow disturbances primarily caused by the fencing that surrounds the mast, the ancillary bulky telecommunications and power supply equipment in close proximity to the mast and indeed the bulky mast itself.

In NWRAP, the challenges associated with the flow disturbances caused by the ground based obstacles were addressed by the selection of telecommunications masts of a

a. Namibia University of Science and Technology, Windhoek, Namibia. bsiepker@nust.na
b. SAIMechE Fellow, Stellenbosch University, Stellenbosch, South Africa

height of 50 m or more where possible. This enables the mounting of two anemometers at nominal elevations of 20 m above ground level (AGL) and 50 m AGL, thereby limiting the effect of these flow disturbances on the lower anemometer and at the same time establishing a sound anemometer elevation ratio for the assessment of wind shear. The influence of flow disturbances caused by the mast structure was reduced by the mounting of wind sensors on booms that were designed in cognizance of the recommendations of Annex G of IEC61400-12-1:2005(E), as further expanded on by Pedersen *et al.* [5] and Orlando *et al.* [6]. Flow disturbances caused by telecommunications antennae were minimized by installing the booms at elevations suitably set off from the mounting elevations of the antennae. Due to the density and bulk of the telecommunication, aviation lighting and lightning arresting equipment installed close to the top of the MTC masts, top mounted anemometers could unfortunately not be employed at these masts of opportunity. The tubular masts at Lüderitz and Walvis Bay do, however, have top mounted anemometers. The NWRAP masts are generally located in areas of elevated wind activity as identified in a study by Bicon Namibia (Bicon) [7]. These areas include the Namibian coastal belt and the interior South West and North West of Namibia. Figure 1 shows the Bicon wind speed map for 14h00 in October, indicating strong wind activity in the described areas. Wind speed maps for the other months have similar patterns.

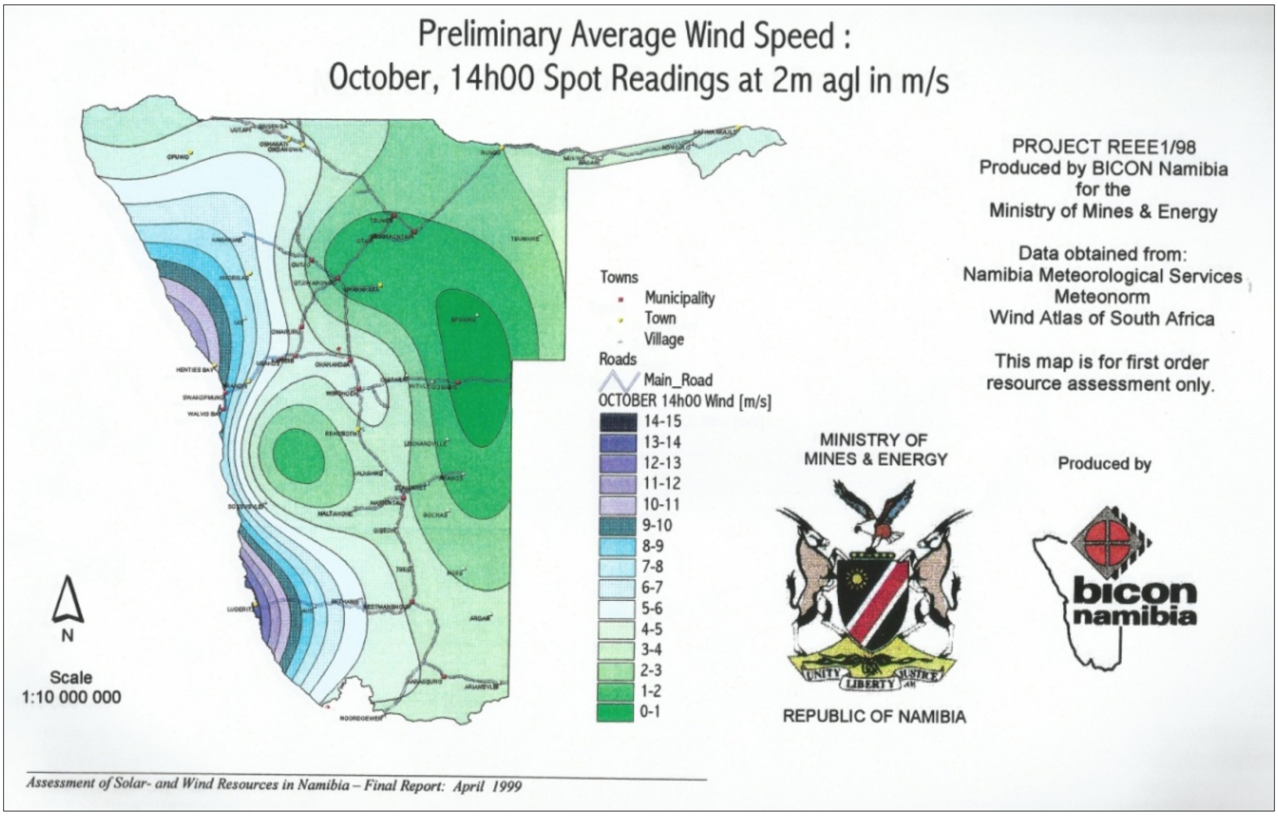


Figure 1 Interpolated wind speeds in Namibia at 2 m AGL at 14h00 Central African Time in October (Bicon - with permission: Dr Detlof von Oertzen)

Bicon reports that the maps are interpolations of monthly means of spot observations of wind speed at 14h00 Central African Time at 2 m AGL at amongst others twelve Namibian sites presumably equipped with mechanical wind sensing devices such as pressure plates and Dines anemometers. The data used in the Bicon analysis cover the period 1989 to 1998 and were digitized by Bicon themselves, as digitized data for this period were reportedly not obtainable from Namibia Meteorological Services (NMS), the Namibian authority responsible for the acquisition and management of meteorological data. As the Bicon study does not indicate that wind shear calculations were performed to determine the monthly mean wind speeds at 2 m AGL, it is probable that Bicon merely assumed that the observations were in fact made at 2 m AGL at all sites. Such an assumption is, however, at variance with evidence provided in annual reports by the Weather Bureau of South Africa (a predecessor of South African Weather Services and NMS) [8] in which wind statistics for at least seven of the Namibian sites covered in the Bicon report is presented and the actual observation elevations for these sites given as varying between 5 m AGL and 15 m AGL. It is highly unlikely that the observation elevations were lowered from the indicated heights to 2 m AGL between the last year (1977) covered by the Weather Bureau reports and 1989. The Bicon study also does not describe the interpolation scheme used in the development of the wind maps, or indicate if the maps reflect interpolations of observed or regional wind climates. In the absence of this information, it is probable that the maps simply are interpolations of observed wind climates, a procedure that is bound to produce inaccuracies, as the effects of orography and roughness amongst others are completely ignored. In view of the strong sensitivity of wind speed with observation elevation particularly at low levels AGL and rough terrain, the Bicon maps therefore probably are not accurate in absolute terms, even if the observation sites were located on level plains and if the wind data rendered by the mechanical wind sensing devices were accurate. Nevertheless, whatever the shortcomings of the Bicon maps may be, the authors considered these to be the most reliable information source based on in-situ measurements available to aid in the selection of suitable MTC masts to be utilized in NWRAP. The location of the NWRAP masts and the details of the construction of the masts and wind sensor booms are presented in section 2, whereas the details of the employed instrumentation and the analysed wind data are described in section 3. The procedures employed in the analysis of the data and the identification of Weibull parameters are described in section 4. The results of the data analysis are given in section 5, in which the findings of the study are also summarized and an outlook provided on further research that is required.

## 2 Mast Location and Construction Details

The locations of the eleven NWRAP masts are shown as the place markers in the Google Earth image presented in figure 2. Black dots inside the markers identify the dedicated wind masts at Walvis Bay, Gobabeb and Lüderitz. The other markers indicate the eight telecommunication masts of MTC. Most masts are located in flat terrain of gentle orography that meets the requirements of class A terrain as described in Annex B of IEC61400-12-1:2005(E). Figure 2 also shows the close proximity of the Alexander Bay mast of the Wind Atlas of South Africa project to the NWRAP masts at Korabib and Warmbad. With the exception of the tubular masts installed at Walvis Bay and Lüderitz, all masts are lattice masts with triangular footprints. Except for the free-standing masts at Helmeringhausen and Warmbad, all masts are guyed. The free-standing masts are tapered while all other masts are cylindrical with a constant face width (L), L varying from mast to mast. Figure 3 is a perpendicular view onto one of the three faces of a typical triangular footprint guyed lattice mast used in NWRAP. The figure shows the three round section uprights and the sharp edges of the structural members connecting the uprights, as well as the concrete footing onto which the mast is bolted and the 2.5 m high electrified perimeter fencing that encloses the stand. Slightly visible behind the fence is a guy cable that is anchored to a concrete footing located outside the perimeter fencing. Table 1 is an exposition of the details of the NWRAP masts of which the locations are shown in figure 2. The details include the owner of the mast, the latitude φ [°South] and longitude λ [°East] of the location of each mast, the elevation H [m] above sea level (ASL) of the top of the concrete footing onto which the mast is mounted, the nominal mast height h* [m], the mast face width (L) [m] and whether the mast has round or sharp edged upright and bracing sections.


Figure 2 Location of NWRAP masts

In the case of the free standing lattice masts at Helmeringhausen and Warmbad, the higher and lower values in the face width (L) column of table 1 refer to the face width as measured at the bottom and the top of the mast respectively. At Lüderitz and Walvis Bay these refer to the outer diameters of the bottom and top sections of the tubular masts.

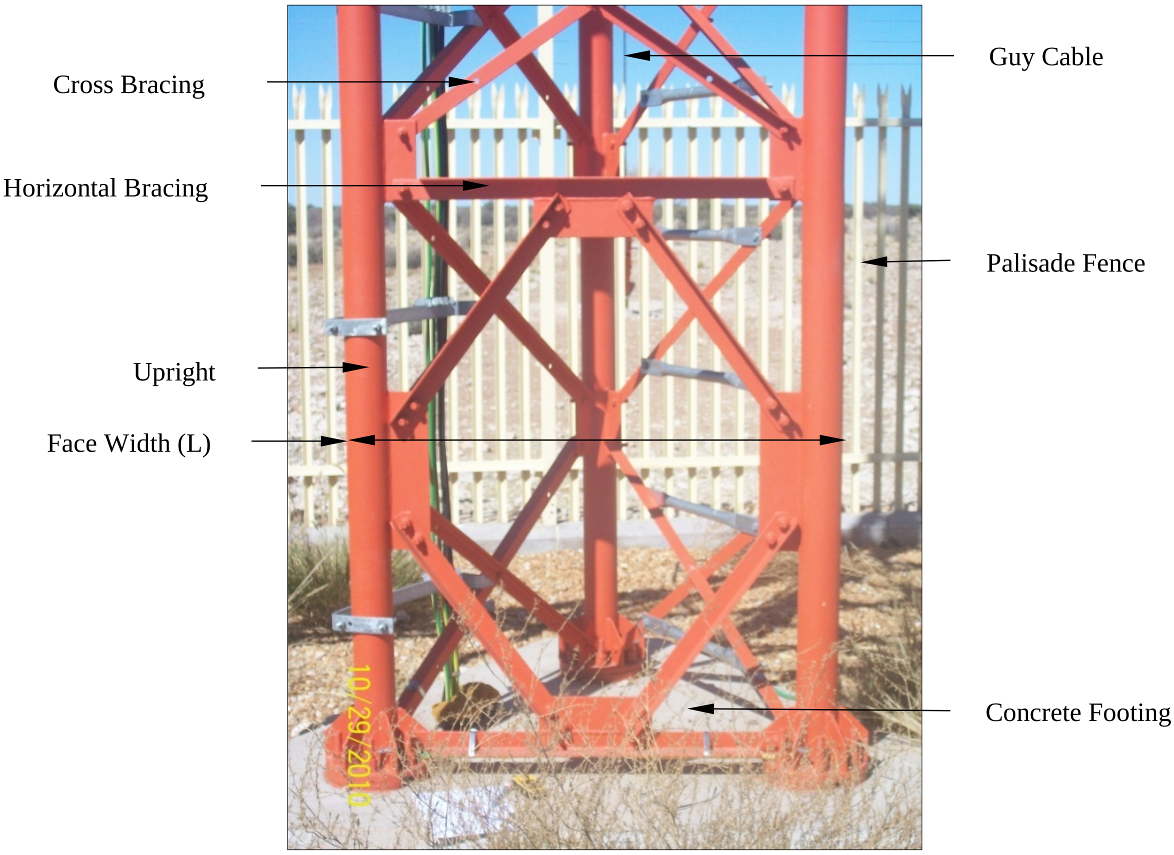


Figure 3 Construction details of a typical triangular footprint guyed lattice mast

Table 1 NWRAP mast details

| Site | Owner | Location | | H | h* | L | Upright | Bracing |
|---|---|---|---|---|---|---|---|---|
| | | φ [ºS] | λ [ºE] | [m ASL] | [m] | [m] | | |
| Terrace Bay | MTC | 19.993 | 13.040 | 37 | 48 | 1.16 | sharp | sharp |
| Okanapehuri | MTC | 21.888 | 16.496 | 1140 | 80 | 1.10 | round | sharp |
| Walvis Bay | NP | 23.041 | 14.677 | 141 | 45 | 0.22 - 0.15 | round | - |
| Gobabeb | GRTC | 23.551 | 15.051 | 422 | 30 | 0.49 | round | round |
| Schlip | MTC | 24.030 | 17.131 | 1381 | 60 | 1.10 | round | sharp |
| Amperbo | MTC | 25.354 | 18.313 | 1152 | 120 | 1.10 | round | sharp |
| Helmeringhausen | MTC | 25.880 | 16.828 | 1412 | 42.5 | 4.83 - 1.32 | sharp | sharp |
| Lüderitz | NP | 26.709 | 15.368 | 261 | 45 | 0.22 - 0.15 | round | - |
| Kanas | MTC | 26.775 | 17.473 | 1067 | 80 | 1.32 | sharp | sharp |
| Warmbad | MTC | 28.472 | 18.767 | 790 | 48 | 4.83 - 1.32 | sharp | sharp |
| Korabib | MTC | 28.548 | 17.820 | 625 | 120 | 1.32 | sharp | sharp |

The wind sensors of the dedicated tubular wind masts at Walvis Bay and Lüderitz are mounted on boom-stub arrangements supplied with the masts. These booms conform to the recommendations of IEC61400-12-1:2005(E) and are clamped to the mast via a mounting plate and U-bolts. In the case of the masts of opportunity, the wind sensors are carried on custom-made boom-stub arrangements. The booms have a nominal length of 3 m and are manufactured from relatively inexpensive 6 m stock lengths of mild steel pipe of 50 mm outside diameter (d) and 2 mm wall thickness. The booms separate the geometric centres of the triangular footprint of the cylindrical lattice masts and the vertical axes of rotation of the wind sensors by a distance R [m] such that the ratio R/L is better than 2.45 in all cases, that for an estimated maximum mast thrust coefficient $C_T$ of approximately 0.7 corresponds to a centreline relative wind of about 97.5 %, 1.5 % shy of the 99 % recommendation of IEC61400-12-1:2005(E). Solid mild steel boom stubs of outer diameter 13 mm separate the centres of the wind sensors and the top of the booms by a ratio r/d of approximately 12 boom diameters. This r/d ratio is slightly less than the ratio of 15 required for a 0.5 % flow distortion in terms of the IEC standard, but it is in agreement with Recommendation 11 of the International Energy Agency [9] for the same amount of flow distortion. For the sake of simplicity of manufacturing and installation, the NWRAP booms are cantilever devices that are bolted and/or clamped to the masts, the interface design varying between different mast types. In order to preserve the structural integrity of the masts, no additional holes were drilled into the masts to accommodate the booms. With the 3 m long steel boom providing sufficient rigidity, no additional boom supports are provided, thereby eliminating any further flow obstructions. Figure 4 shows an example of one of designs of an anemometer boom mast interface used in NWRAP. Using the existing holes in the cross-bracing of the mast, the non-sensor end of the boom is bolted to the centres of the cross bracing through a tube spacer that is welded into the boom. The centrelines of the spacer, boom and stub are orthogonal, the latter two intersecting the boom centreline. The length of the spacer is matched to the mast construction details so as to ensure that the centreline of the boom is installed parallel to the mast face. At a horizontal distance of about 0.5 m away from the non-sensor end, the boom is clamped to the mast upright via a vertical mounting plate and U-bolts. The position of the clamping device may be adjusted vertically along the upright which allows the boom to rotate about the spacer, ensuring that the boom is installed horizontally as indicated by a spirit level placed on the top surface of the boom. A 10 cm long 8 mm diameter solid steel pilot stub, welded into the centre of the boom parallel to the wind sensor stub and which may be observed protruding from the top of the boom about 0.3 m away from the non-sensor end as shown in figure 4 serves as angular reference line to confirm that the wind sensor stub is vertical. Inherent warping of the mast cross bracing may require small adjustments to be made by the forced rotation of the spacer about the centreline of the boom until the pilot stub is perfectly vertical. The ends of the booms are closed by plastic plugs to protect against ingress of dust and water. The sensor wiring is tied to the leeward side of the stub by means of cable ties. The wiring enters the inside of the boom through a rubber grommet installed on the leeward side of the boom closest to the stub. A second rubber grommet installed in the centre of the plastic plug at the non-sensor end of the boom serves as exit point of the wiring. The wiring fits tightly through the grommet holes ensuring a seal against the elements. The booms and stubs are covered by a coat of Zinc Chromate anti-corrosive primer and two coats of enamel paint that match the red and white colours of the mast.

Figure 4 A typical mast boom interface

## 3 Instrumentation and analysed Data

Except for the GRTC mast at Gobabeb that NWRAP shares with the University of Basel (UoB) as mounting platform for micro-meteorological research conducted by UoB and for that purpose is equipped with a Campbell Scientific (CS) CR3000 data logger, all NWRAP masts are equipped with Second Wind (SW) Nomad 2 wind energy data loggers. The sensors installed at the MTC masts at Terrace Bay, Okanapehuri, Schlip, Helmeringhausen, Kanas, Warmbad and Korabib are two SW C3 cup anemometers, one SW PV-1 wind vane and one SW SWI thermistor. The GRTC mast is equipped with two NRG #40C cup anemometers that belong to NWRAP, as well as other micro-meteorological instrumentation owned by UoB. The latter instrumentation includes a Vaisala WAV15 wind vane and a CS ASPTC aspirated dry bulb air temperature sensor. The MTC mast at Amperbo is instrumented for a detailed study of wind shear and has seven NRG #40C cup anemometers, four NRG PV-1 wind vanes and one SW SWI thermistor. The sensors of the dedicated wind masts at Walvis Bay and Lüderitz are seven SW C3 cup anemometers, two SW PV-1 wind vanes, one SW SWI thermistor, one Setra 276 barometric pressure transducer and one Vaisala HMP50 relative humidity sensor. With the exception of the wind vanes, all NWRAP sensors are individually calibrated and have supporting calibration certificates.

All anemometer booms are installed at optimum angles relative to the direction of the prevalent wind as stipulated in IEC 61400-12-1:2005(E), which is 90° for lattice masts and 45° for tubular masts. The direction of the prevalent wind was obtained from discussions with the owners of the land on which the masts are located, as well as with reference to the Weather Bureau reports [8]. Table 2 presents the installed sensor configurations at the indicated MTC and GRTC masts. The elevations h of the wind sensors (WSi and WD denoting anemometers and wind vanes respectively) and the ambient drybulb air temperature sensors (DB) are indicated, as well as the R/L ratios and azimuth angles ψ of the wind sensor booms, where ψ is the direction in which the sensor end of the boom centreline points. Table 3 presents the installed sensor configurations for the NP masts at Walvis Bay and Lüderitz. RH and BP refer to relative humidity and barometric pressure sensors respectively. Table 4 provides the installed sensor configuration for the MTC mast at Amperbo.

In March 2014, the lower two anemometers of the NWRAP system installed at Amperbo in August 2012 were removed from their initial positions and re-installed as redundant anemometers at 16.88 m AGL and 64.92 m AGL as indicated in table 4. This change was required in terms of a co-operation agreement that was signed between NUST and the Masdar Institute of Science and Technology of the United Arab Emirates in December 2013 which provides for the installation of a Lidar system at Amperbo to enable an evaluation of the influence of the mast on the wind speeds measured by the NWRAP sensors. In tables 2, 3 and 4, the WS and WD sensors are labeled with a numerical suffix that increases with increasing installation elevation. Redundant WS sensors located at approximately the same nominal elevation are indicated by additional suffices A and B. The boom orientations ψ indicated in tables 2 to 4 were determined from GPS readings of the positions of waypoints that are located at the intersection of a circle of a radius of approximately 50 m centred on the mast centre and the forward and rearward extensions of the centrelines of the installed booms as determined by line of sight and parallax. The elevations h indicated in the tables were determined by survey students of NUST using a total survey station.

The digital count integration intervals employed for wind speed measurements by the CR3000 and Nomad 2 data loggers are 2 s and 1 s respectively. The sampling interval for the PV-1 wind vanes and SWI thermistors is 1 minute, whereas the output of the barometric pressure transducers and relative humidity sensors is sampled once every 10 minutes. The sampling intervals of the WAV15 wind vane and the ASPTC aspirated dry bulb air temperature sensor at Gobabeb are 2 s and 1 s respectively. The recording interval of all Nomad 2 loggers is 10 minutes, while that of the CR3000 data logger at Gobabeb is 1 minute in order to accommodate the requirements of UoB in respect of their micro-meteorological research activities. Table 5 identifies the statistics that the loggers are configured to calculate from the sampled readings of the indicated sensors and that are recorded for every recording interval i.

Table 2 Installed sensor configurations at MTC and GRTC masts

| Site | WS1 | | | WS2 | | | WD | | | DB |
|---|---|---|---|---|---|---|---|---|---|---|
| | h | ψ | R/L | h | ψ | R/L | h | ψ | R/L | h |
| | [m] | [°] | [1] | [m] | [°] | [1] | [m] | [°] | [1] | [m] |
| Terrace Bay | 21.20 | 154 | 2.72 | 48.46 | 153 | 2.72 | 48.46 | 273 | 2.72 | 2.4 |
| Okanapehuri | 23.60 | 267 | 2.47 | 50.60 | 265 | 2.47 | 50.60 | 28 | 2.47 | 3.1 |
| Gobabeb | 11.66 | 250 | 3.08 | 27.53 | 250 | 3.08 | 27.25 | 88 | 3.24 | 2.9 |
| Schlip | 20.63 | 161 | 2.47 | 49.90 | 163 | 2.47 | 49.90 | 283 | 2.47 | 3.9 |
| Helmeringhausen | 20.81 | 267 | 1.27 | 43.31 | 268 | 2.45 | 43.31 | 26 | 2.45 | 2.7 |
| Kanas | 20.93 | 130 | 2.45 | 52.18 | 130 | 2.45 | 52.18 | 249 | 2.45 | 2.6 |
| Warmbad | 18.55 | 181 | 1.27 | 50.85 | 185 | 2.45 | 50.85 | 301 | 2.45 | 2.7 |
| Korabib | 19.86 | 168 | 2.45 | 51.11 | 164 | 2.45 | 51.11 | 287 | 2.45 | 2.8 |

Table 3 Installed sensor configurations at NP masts

| Sensor | Walvis Bay | | | Lüderitz | | |
|---|---|---|---|---|---|---|
| | h | ψ | R/L | h | ψ | R/L |
| | [m] | [°] | [1] | [m] | [°] | [1] |
| WS1 | 10.63 | 235 | 8.49 | 11.28 | 231 | 8.49 |
| WS2B | 25.37 | 146 | 12.01 | 30.77 | 141 | 12.01 |
| WS2A | 25.77 | 234 | 12.01 | 31.43 | 233 | 12.01 |
| WS3B | 34.06 | 145 | 12.01 | 39.88 | 142 | 12.01 |
| WS3A | 39.91 | 234 | 12.01 | 40.58 | 233 | 12.01 |
| WS4B | 44.32 | 146 | 12.01 | 45.53 | 138 | 12.01 |
| WS4A | 45.46 | na | 12.01 | 45.96 | na | 12.01 |
| WD1 | 34.08 | 101 | 12.01 | 40.25 | | 12.01 |
| WD2 | 44.97 | 280 | 12.01 | 45.45 | | 12.01 |
| DB | ~ 6 | - | - | ~ 6 | - | - |
| RH | ~ 6 | - | - | ~ 6 | - | - |
| BP | ~ 6 | - | - | ~ 6 | - | - |

Table 4 Installed sensor configurations at Amperbo

| Sensor | August 2012 | | March 2014 | |
|---|---|---|---|---|
| | h | ψ | h | ψ |
| | [m] | [°] | [m] | [°] |
| WS1 | 3.38 | 159 | - | - |
| WS2 | 4.88 | 159 | - | - |
| WS3 | 8.68 | 159 | 8.68 | 159 |
| WS4 | 16.88 | 159 | 16.88 | 159 |
| WS4B | - | - | 16.88 | 278 |
| WS5 | 32.68 | 160 | 32.68 | 160 |
| WS6 | 64.92 | 160 | 64.92 | 160 |
| WS6B | - | - | 64.92 | 278 |
| WS7 | 120.38 | 159 | 120.38 | 159 |
| WD1 | 4.88 | 38 | 4.88 | 38 |
| WD2 | 16.88 | 38 | 16.88 | 38 |
| WD3 | 64.92 | 38 | 64.92 | 38 |
| WD4 | 120.38 | 279 | 120.38 | 279 |
| DB | ~ 2 | na | ~ 2 | na |

The entries identified by single asterisks are only recorded at the NP masts and those identified by the double asterisk not at Gobabeb. From left to right in table 5, the abbreviated column headings refer to scalar mean, scalar standard deviation, scalar maximum, vector mean and vector standard deviation, the latter two calculated from the sampled unit wind direction vectors. All NWRAP Nomad 2 data loggers were configured to allow remote data download protocols between the loggers and the base station computer via the GSM modems installed in the loggers and base station computer. Unfortunately, however, the GPRS protocol which allows for data to be sent to the base station by the logger as e-mail attachments via the Internet could for a variety of reasons not be brought into full operation. As a result, data were initially downloaded to the base station by placing monthly prepaid GSM circuit-switched data (CSD) calls to the loggers, during which time the system status was also observed in real time in order to identify possible equipment malfunctions. In view of the high costs of the CSD calls, data are presently downloaded directly from the compact flash memory cards of the loggers during maintenance visits to NWRAP sites that take place on average once every six months. Although excellent gross data recovery rates (GDRR - ratio of the number of recovered data records to the total number of recoverable data records in the data assessment period) were recorded at many NWRAP sites, the inability to always access data remotely and the irregularity of costly site visits caused a reduction in GDRR at some sites due to system malfunctions, acts of vandalism and cases of corrosion damage that were not discovered in time. The effects of the described occurrences are presented in table 6 that gives an exposition of the status of the data acquired at each NWRAP site since the first full month after installation until the last full month of data in the NWRAP data base by the end of March 2015. Table 6 refers to fully functional complete systems as presented in tables 2 to 4 and the complete recording of all the statistics as presented in table 5. The heading *Recovered* indicates the number of full months for which all (better than 99.87 %) recoverable data were recovered. *GDRRM* is the gross data recovery rate based on the number of full months for which all recoverable data were recovered. *Full Years Recovered* indicates the start and end

Table 5 Statistics recorded by NWRAP loggers

| Sensor | Unit | S Ave | S St D | S Max | V Ave | V St D | Sample |
|---|---|---|---|---|---|---|---|
| WS | m/s | $u_i$ | $\sigma_i$ | $\hat{u}_i$ | | | |
| WD | ° | | | | $\Psi_i$ | $\sigma_{\Psi,i}$ | |
| DB | °C | $T_i$ | $\sigma_{T,i}$** | | | | |
| RH | % | | | | | | $\phi_i$* |
| BP | Pa | | | | | | $p_i$* |

Table 6 Status of data acquired at NWRAP sites

| Site | Start [mmyy] | End [mmyy] | Total [months] | Recovered [months] | GDRRM [%] | Full Years Recovered Start [mmyy] | End [mmyy] |
|---|---|---|---|---|---|---|---|
| Terrace Bay | 0912 | 0714 | 23 | 21 | 91.3 | 0113 | 1213 |
| Okanapehuri | 0912 | 0315 | 31 | 28 | 90.3 | 0113 | 1213 |
| Walvis Bay | 0112 | 0315 | 39 | 31 | 79.5 | 0113 | 1213 |
| Gobabeb | 0113 | 0315 | 27 | 27 | 100 | 0113 | 1214 |
| Schlip | 0712 | 0315 | 33 | 33 | 100 | 0113 | 1214 |
| Amperbo | 0912 | 0214 | 17 | 2 | 11.8 | - | - |
| Amperbo 1 | 0414 | 1214 | 9 | 0 | 0 | - | - |
| Helmeringhausen | 0912 | 0315 | 31 | 31 | 100 | 0113 | 1214 |
| Lüderitz | 0312 | 0315 | 37 | 20 | 54.1 | - | - |
| Kanas | 0912 | 0315 | 31 | 31 | 100 | 0113 | 1214 |
| Warmbad | 0912 | 0315 | 31 | 31 | 100 | 0113 | 1214 |
| Korabib | 0912 | 1214 | 28 | 28 | 100 | 0113 | 1214 |

Table 7 Improved GDRRM at indicated sites

| Site | Start [mmyy] | End [mmyy] | Total [months] | Recovered [months] | GDRRM [%] | Years [1] |
|---|---|---|---|---|---|---|
| Walvis Bay* | 0112 | 0912 | 9 | 9 | | |
| | 0113 | 1213 | 12 | 12 | | |
| | 1014 | 1214 | 3 | 3 | 100 | 2 |
| Amperbo* | 0114 | 1214 | 12 | 12 | 100 | 1 |
| Lüderitz* | 0312 | 1112 | 9 | 9 | | |
| | 1214 | 0215 | 3 | 3 | 100 | 1 |

dates of full calendar years with complete data sets (better than 99.99 %) for each month during the indicated period. The site Amperbo 1 refers to the re-configuration of the instrumentation in March 2014 as indicated in table 4. If a selection of equal numbers of full months with fully recovered data is made from different years, the GDRR at Walvis Bay and Lüderitz improves to 100 % for two and one complete years' worth of data at the former and latter site respectively. If anemometers WS1, WS2, WS6B and WS7 at Amperbo are omitted from the systems presented in table 4, one full calendar year of data are available for analysis at a GDRR of 100 %. The described situation is presented in table 7, where the special conditions are indicated by an asterisk behind the names of these sites.

## 4 Data Analysis and Identification of Weibull Parameters

Raw data files were exported from the NWRAP wind data base and converted into MS Excel files, one file per year per site for each full year presented in table 6, as well as for the sites and periods indicated in table 7. The MS Excel files were then subjected to data quality check procedures involving inspection and evaluation of a set of summary statistics followed by standard range, trend and relational tests and the subsequent removal of data records that violated the quality control parameter settings that were employed. In the process, the GDRRs presented in tables 6 and 7 were reduced to the net data recovery rates (NDRR) shown in table 8. In the present analysis, the small differences between the GDRR and NDRR are purely the result of a few occurrences of dry bulb temperature data records that exceeded the maximum specified value. The high NDRR values imply that the seasonal representativeness of the choice of analysis periods as presented in tables 6 and 7 is preserved after the completion of all the quality control procedures. The heading *All* in table 8 and subsequent tables refer to both indicated years or the total period covered as indicated in table 7.

The wind resource at any particular site, elevation and assessment interval may be characterized by wind parameters that are constants in a mathematical function called a probability density function (PDF). One of the PDFs often used to characterize wind resources is the Weibull PDF. The wind parameters of this PDF are two Weibull parameters. The Weibull parameters are the scale factor A [m/s] and shape factor k [1] as they appear in the PDF $f(u)$ [1] of the Weibull distribution that is given by:

Table 8 Net data recovery rate

| Site | NDRR [%] 2013 | 2014 | All |
|---|---|---|---|
| Terrace Bay | 99.99 | - | - |
| Okanapehuri | 99.89 | - | - |
| Walvis Bay | 99.47 | - | - |
| Walvis Bay* | - | - | 99.65 |
| Gobabeb | 97.52 | 98.96 | 98.38 |
| Schlip | 99.95 | 99.93 | 99.94 |
| Amperbo* | - | 99.93 | - |
| Helmeringhausen | 99.50 | 99.39 | 99.44 |
| Lüderitz* | - | - | 99.76 |
| Kanas | 99.95 | 99.99 | 99.97 |
| Warmbad | 99.93 | 99.95 | 99.94 |
| Korabib | 99.85 | 99.89 | 99.87 |

$$f(u) = \left(\frac{k}{A}\right)\left(\frac{u}{A}\right)^{k-1} exp\left\{-\left(\frac{u}{A}\right)^{k}\right\} \quad (1)$$

where $f(u)$ is the probability of observing wind speed u at the site and elevation that has the Weibull factors $k$ and $A$. The expected value $E(u)$ is the mean $(\mu)$ of the wind speed $u$. CRES [10] shows that for the Weibull PDF $\mu$ is:

$$\mu = E(u) = A\Gamma\left(1 + \frac{1}{k}\right) \quad (2)$$

Where $\Gamma$ is the Gamma function. From equation (2) follows that:

$$\mu^2 = A^2\Gamma^2\left(1 + \frac{1}{k}\right) \quad (3)$$

The expected value $E(u^2)$ is the mean of the square of the wind speed $u$. For the Weibull PDF, Troen and Lundtang Petersen [11] show that:

$$E(u^2) = A^2\Gamma\left(1 + \frac{2}{k}\right) \quad (4)$$

The variance $Var(u)$ of wind speed is the expected value or mean of the squared deviation of wind speed from the mean wind speed. From the properties of expected values and equations (3) and (4), it follows that $Var(u)$ for the Weibull PDF is given by:

$$Var(u) \equiv \sigma_u^2 = E\{(u-\mu)^2\} = E(u^2) - \mu^2$$
$$= A^2\left\{\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right\} \quad (5)$$

If time series wind data are available, the Weibull parameters $k$ and $A$ may be identified from the sample mean $\bar{u}$ [m/s] and variance $s_u^2$ [m$^2$/s$^2$] of the time series data over the assessment period, as follows:

$$\bar{u} = \frac{1}{n}\sum_{i=1}^{i=n} u_i \quad (5)$$

$$s_u^2 = \frac{1}{n-1}\sum_{i=1}^{i=n}(u_i - \bar{u})^2 \Rightarrow s_u = \sqrt{\frac{1}{n-1}\sum_{i=1}^{i=n}(u_i - \bar{u})^2} \quad (6)$$

where $u_i$ [m/s] the mean wind speed for data record $i$ and $n$ the total number of data records in the time series. Although not used in the derivation of Weibull parameters in the present study, the observed mean wind power density $\bar{P}$ [W/m$^2$] is:

$$\bar{P} = \frac{1}{n}\sum_{i=1}^{i=n}\frac{1}{2}\rho_i u_i^3 = \frac{1}{2n}\sum_{i=1}^{i=n}\rho_i u_i^3 \quad (7)$$

where $\rho_i$ [kg/m$^3$] is the air density for data record $i$ as calculated from the observed ambient dry bulb air temperature $T_i$ [°C] as:

$$\rho_i = \rho_0 \frac{T_0}{T_i^*}\left(1 - \frac{T_{z,0}z}{T_0}\right)^{\frac{g}{T_{z,0}R}} \quad (8)$$

where subscript 0 refers to the conditions of the International Standard Atmosphere which are given by Kröger [12] as $T_0$=288.15 K, $T_{z,0}$=6.5 K/km and $\rho_0$=1.255 kg/m$^3$. In equation (8), $T_i^*$ is $T_i$ expressed in [K], $z$ [m] is the elevation of the DB sensor above sea level, $g$=9.81 m/s$^2$ the acceleration of gravity and R=287.08 J/kgK the gas constant. If barometric pressure $p_i$ [Pa] and/or relative humidity $\phi_i$ [%] data series are also recorded in addition to $T_i$ [°C] - like in the case of Walvis Bay and Lüderitz -, more accurate values for $\rho_i$ may be determined, but in the present analysis only equation (8) was employed for all locations. The values of $\bar{u}$ and $s_u^2$ recorded over an assessment period of a whole number of full years are used as estimators of $\mu$ and $\sigma_u^2$ so that from equation (3):

$$\bar{u}^2 \doteq \mu^2 = A^2\Gamma^2\left(1 + \frac{1}{k}\right) \Rightarrow \frac{A}{\bar{u}} \doteq \Gamma^{-1}\left(1 + \frac{1}{k}\right) \quad (9)$$

$$s_u^2 \doteq \sigma_u^2 = A^2\left\{\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right\} \quad (10)$$

From equations (9) and (10) it follows that:

$$\left(\frac{s_u}{\bar{u}}\right)^2 \doteq \left(\frac{\sigma_u}{\bar{u}}\right)^2 = \frac{\Gamma\left(1+\frac{2}{k}\right)}{\Gamma^2\left(1+\frac{1}{k}\right)} - 1 \quad (11)$$

Equation (11) can be written as:

$$g(y) = \frac{\Gamma(1+2y)}{\Gamma^2(1+y)} - \left(\frac{s_u}{\bar{u}}\right)^2 - 1 = 0 \quad (12)$$

where $y = k^{-1}$

In the present study, the iterative Generalized Reduced Gradient Nonlinear option of the SOLVER function of MS Excel was employed to solve equation (12) for the value of $y$ and thus $k$ that satisfies the equality. With $k$ known, $A$ is calculated from equation (9).

## 5 Results of Analysis and Discussion

The mean value $\bar{u}$ [m/s] of the wind speed data records as calculated from equation (5) is given in table 9. In table 9 and all subsequent tables, $WS_b$ and $WS^t$ refer to the bottom and top anemometer of which the wind data were used in the calculations. As expected from the characteristics of wind shear, the mean wind speed at the higher elevations exceeds that at the lower elevations. The wind speed standard deviations $s_u$ [m/s] as calculated from equation (6) are presented in table 10. The standard deviation of wind speed at higher elevations exceeds that at the lower elevations. The maximum value $\hat{u}$ [m/s] of all the wind speed data records $u_i$ is presented in table 11. With the exception of Warmbad $WS_b$, all values are lower than the cut-out wind speed of commercial wind turbines for electricity generation, whereas all values are considerably greater than the cut-out wind speed of commercial wind pumps. The mean mechanical power $\bar{P}$ [W/m$^2$] in the wind as calculated from equations (7) and (8) is presented in table 12. The values recorded at the Southern and Northern coastal towns of Lüderitz and Terrace Bay far exceed the values recorded at the other sites, including - quite surprisingly - the central coastal town of Walvis Bay. The Weibull shape parameters $k$ [1] as calculated from equations (9) to **Error! Reference source not found.** are given in table 13. In general, there is little difference between the shape parameters for lower and higher elevations and different analysis periods at the same site. Table 14 presents the Weibull scale parameter $A$ [m/s] as calculated from equation (9). All scale parameters are bigger than the corresponding values of mean wind speed. Like the mean wind speed, scale parameters at higher elevations exceed those at lower elevations.

In relative terms, the mean wind speeds observed at the NWRAP sites largely echo the Bicon map presented in figure 1, which inter alia indicates good wind regimes at the Northern - and Southern coastal sites of Terrace Bay and Lüderitz and surprising lulls at the central coastal site of Walvis Bay. This notion indicates that wind resource assessments of reduced sophistication including those employing pressure plate devices that produced the data on which the Bicon maps are based should not be dismissed as being meaningless and that they indeed can serve as a good first indication of available wind resources in countries for which only similar data are available. Further evidence of the value of wind resource assessments of reduced sophistication is provided by Agüera-Pérez *et al.* [13] who present evidence that a regional wind climate derived via basic interpolation methods and shear calculations performed on the statistics of long term wind data recorded as daily means at 2 m AGL at a relatively dense grid of agricultural automatic weather stations in the South of Spain compare favourably with two advanced mesoscale computer simulations in the characterization of wind roses for test sites located in the identified wind climate. The interpolated regional wind climate of Agüera-Pérez was derived without any consideration of the orography of the region and the shear coefficients were estimated from published values of roughness classes. The mesoscale computer simulations are driven by the output of the Mesoscale Model (MM5) of the National Center for Atmospheric Research, which in turn utilizes so-called re-analysis data generated by numerical models of the global atmospheric state. From the observations of Agüera-Pérez it therefore seems that even reduced quality in-situ wind measurements may be a suitable substitute for mesoscale computer simulations of wind climates in Namibia, provided the former is sufficiently representative in spatial and temporal terms. In the absence of reliable numerical wind simulations for Namibia (until the very recent launching of the Global Wind Atlas), this notion makes for the interesting prospect of generating regional wind climates for relevant parts of Namibia through the augmentation of the NWRAP results with those derived from measurements made at lower quality Namibian wind assessment stations, such as those of the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL). In Namibia, SASSCAL presently operates 56 automatic weather stations each equipped with an anemometer and a wind vane at 10 m AGL, as well as a dry bulb air temperature sensor at 3 m AGL. The recording interval is one hour. The stations conform to the specifications of the World Meteorological Organisation for synoptic stations. The quality of the stations is therefore superior to that of the agricultural stations employed in the study of Agüera-Pérez. The combined spatial density of the SASSCAL stations is approximately 14 700 km$^2$/station based on the surface area of Namibia and the majority of these stations came into operation in 2012. The results of the analysis presented in this article are only representative of the observed wind climates at the NWRAP sites and should not be used directly to predict the expected annual energy production (AEP) of a wind turbine or wind farm installed at sites removed from the measurement sites. Same can only be determined once the regional wind climates are identified and the physical parameters of the site where the turbines will be installed are known, provided the installation site is located in the relevant wind climate. With the observed wind climates known, the regional wind climates around the measurement sites can be determined through the use of computational fluid dynamics simulation software, such as WAsP, which can also be used to determine the AEP at prospective turbine installation sites. The procedure is as described by Mortensen *et al.* [14].

Table 9 Observed mean wind speed

| Site | h [m AGL] | | $\bar{u}$ [m/s] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $WS_b$ | $WS^t$ | | $WS_b$ | | | $WS^t$ | |
| | | | 2013 | 2014 | All | 2013 | 2014 | All |
| Terrace Bay | 21.20 | 48.46 | 5.903 | - | - | 6.136 | - | - |
| Okanapehuri | 23.60 | 50.60 | 3.995 | - | - | 4.799 | - | - |
| Walvis Bay | 10.63 | 45.46 | 3.816 | - | - | 4.517 | - | - |
| Walvis Bay* | 10.63 | 45.46 | - | - | 3.853 | - | - | 4.534 |
| Gobabeb | 11.66 | 27.53 | 4.146 | 4.150 | 4.149 | 4.381 | 4.481 | 4.433 |
| Schlip | 20.63 | 49.90 | 4.651 | 4.658 | 4.655 | 5.491 | 5.316 | 5.403 |
| Amperbo* | 8.68 | 64.92 | - | 3.550 | - | - | 5.912 | - |
| Helmeringhausen | 20.81 | 43.31 | 4.162 | 4.236 | 4.198 | 4.729 | 4.853 | 4.790 |
| Lüderitz* | 11.28 | 45.96 | - | - | 5.969 | - | - | 6.664 |
| Kanas | 20.93 | 52.18 | 4.941 | 5.098 | 5.019 | 5.777 | 5.886 | 5.830 |
| Warmbad | 18.55 | 50.85 | 4.849 | 4.875 | 4.861 | 5.620 | 5.709 | 5.663 |
| Korabib | 19.86 | 51.11 | 3.696 | 3.728 | 3.714 | 4.413 | 4.506 | 4.462 |

Table 10 Observed standard deviation of wind speed

| Site | h [m AGL] | | $s_u$ [m/s] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $WS_b$ | $WS^t$ | | $WS_b$ | | | $WS^t$ | |
| | | | 2013 | 2014 | All | 2013 | 2014 | All |
| Terrace Bay | 21.20 | 48.46 | 2.878 | - | - | 3.000 | - | - |
| Okanapehuri | 23.60 | 50.60 | 2.127 | - | - | 2.551 | - | - |
| Walvis Bay | 10.63 | 45.46 | 2.224 | - | - | 2.808 | - | - |
| Walvis Bay* | 10.63 | 45.46 | - | - | 2.241 | - | - | 2.867 |
| Gobabeb | 11.66 | 27.53 | 2.417 | 2.400 | 2.408 | 2.563 | 2.484 | 2.524 |
| Schlip | 20.63 | 49.90 | 2.240 | 2.385 | 2.314 | 2.611 | 2.616 | 2.615 |
| Amperbo* | 8.68 | 64.92 | - | 1.743 | - | - | 2.771 | - |
| Helmeringhausen | 20.81 | 43.31 | 2.300 | 2.401 | 2.351 | 2.551 | 2.646 | 2.599 |
| Lüderitz* | 11.28 | 45.96 | - | - | 3.672 | - | - | 4.281 |
| Kanas | 20.93 | 52.18 | 2.458 | 2.531 | 2.496 | 2.786 | 2.823 | 2.805 |
| Warmbad | 18.55 | 50.85 | 2.658 | 2.559 | 2.609 | 3.080 | 3.031 | 3.056 |
| Korabib | 19.86 | 51.11 | 2.345 | 2.409 | 2.377 | 2.730 | 2.732 | 2.731 |

Table 11 Observed maximum ten[1] minute mean wind speed

| Site | h [m AGL] | | $\hat{u}$ [m/s] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $WS_b$ | $WS^t$ | $WS_b$ | | | $WS^t$ | | |
| | | | 2013 | 2014 | All | 2013 | 2014 | All |
| Terrace Bay | 21.20 | 48.46 | 21.677 | - | - | 21.945 | - | - |
| Okanapehuri | 23.60 | 50.60 | 14.153 | - | - | 16.317 | - | - |
| Walvis Bay | 10.63 | 45.46 | 16.159 | - | - | 20.905 | - | - |
| Walvis Bay* | 10.63 | 45.46 | - | - | 17.495 | - | - | 21.546 |
| Gobabeb | 11.66 | 27.53 | 18.620 | 18.900 | 18.900 | 19.500 | 19.650 | 19.650 |
| Schlip | 20.63 | 49.90 | 19.764 | 17.030 | 19.764 | 20.648 | 18.085 | 20.648 |
| Amperbo* | 8.68 | 64.92 | - | 15.098 | - | - | 22.585 | - |
| Helmeringhausen | 20.81 | 43.31 | 18.971 | 15.708 | 18.971 | 20.665 | 17.527 | 20.665 |
| Lüderitz* | 11.28 | 45.96 | - | - | 18.191 | - | - | 20.466 |
| Kanas | 20.93 | 52.18 | 16.257 | 18.266 | 18.266 | 18.613 | 20.461 | 20.461 |
| Warmbad | 18.55 | 50.85 | 22.837 | 21.402 | 22.837 | 23.761 | 25.607 | 25.607 |
| Korabib | 19.86 | 51.11 | 14.622 | 20.707 | 20.707 | 16.418 | 22.397 | 22.397 |

Table 12 Observed mean wind power

| Site | h [m AGL] | | $\bar{P}$ [W/m$^2$] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $WS_b$ | $WS^t$ | $WS_b$ | | | $WS^t$ | | |
| | | | 2013 | 2014 | All | 2013 | 2014 | All |
| Terrace Bay | 21.20 | 48.46 | 219.4 | - | - | 246.2 | - | - |
| Okanapehuri | 23.60 | 50.60 | 63.7 | - | - | 109.8 | - | - |
| Walvis Bay | 10.63 | 45.46 | 73.7 | - | - | 137.8 | - | - |
| Walvis Bay* | 10.63 | 45.46 | - | - | 75.1 | - | - | 141.3 |
| Gobabeb | 11.66 | 27.53 | 87.7 | 86.8 | 87.2 | 105.1 | 105.9 | 105.5 |
| Schlip | 20.63 | 49.90 | 90.6 | 96.4 | 93.5 | 145.4 | 137.0 | 141.2 |
| Amperbo* | 8.68 | 64.92 | - | 42.6 | - | - | 181.6 | - |
| Helmeringhausen | 20.81 | 43.31 | 74.0 | 80.9 | 77.4 | 105.6 | 115.6 | 110.6 |
| Lüderitz* | 11.28 | 45.96 | - | - | 281.7 | - | - | 411.0 |
| Kanas | 20.93 | 52.18 | 115.5 | 126.9 | 121.2 | 178.0 | 188.0 | 183.0 |
| Warmbad | 18.55 | 50.85 | 125.0 | 122.3 | 123.6 | 193.1 | 195.4 | 194.3 |
| Korabib | 19.86 | 51.11 | 66.2 | 69.6 | 67.9 | 109.1 | 113.4 | 111.3 |

Table 13 Derived Weibull shape factors

| Site | h [m AGL] | | $k$ [1] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $WS_b$ | $WS^t$ | $WS_b$ | | | $WS^t$ | | |
| | | | 2013 | 2014 | All | 2013 | 2014 | All |
| Terrace Bay | 21.20 | 48.46 | 2.159 | - | - | 2.153 | - | - |
| Okanapehuri | 23.60 | 50.60 | 1.958 | - | - | 1.962 | - | - |
| Walvis Bay | 10.63 | 45.46 | 1.771 | - | - | 1.650 | - | - |
| Walvis Bay* | 10.63 | 45.46 | - | - | 1.776 | - | - | 1.621 |
| Gobabeb | 11.66 | 27.53 | 1.771 | 1.787 | 1.779 | 1.764 | 1.873 | 1.817 |
| Schlip | 20.63 | 49.90 | 2.188 | 2.045 | 2.113 | 2.220 | 2.137 | 2.177 |
| Amperbo* | 8.68 | 64.92 | - | 2.143 | - | - | 2.257 | - |
| Helmeringhausen | 20.81 | 43.31 | 1.879 | 1.827 | 1.852 | 1.930 | 1.907 | 1.918 |
| Lüderitz* | 11.28 | 45.96 | - | - | 1.669 | - | - | 1.592 |
| Kanas | 20.93 | 52.18 | 2.112 | 2.116 | 2.113 | 2.186 | 2.199 | 2.192 |
| Warmbad | 18.55 | 50.85 | 1.896 | 1.989 | 1.941 | 1.896 | 1.964 | 1.930 |
| Korabib | 19.86 | 51.11 | 1.614 | 1.582 | 1.597 | 1.660 | 1.696 | 1.678 |

[1] One minute in the case of Gobabeb

Table 14 Derived Weibull scale factors

| Site | h [m AGL] | | $A$ [m/s] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $WS_b$ | $WS^t$ | $WS_b$ | | | $WS^t$ | | |
| | | | 2013 | 2014 | All | 2013 | 2014 | All |
| Terrace Bay | 21.20 | 48.46 | 6.661 | - | - | 6.924 | - | - |
| Okanapehuri | 23.60 | 50.60 | 4.503 | - | - | 5.409 | - | - |
| Walvis Bay | 10.63 | 45.46 | 4.285 | - | - | 5.048 | - | - |
| Walvis Bay* | 10.63 | 45.46 | - | - | 4.327 | - | - | 5.062 |
| Gobabeb | 11.66 | 27.53 | 4.655 | 4.662 | 4.658 | 4.918 | 5.044 | 4.982 |
| Schlip | 20.63 | 49.90 | 5.248 | 5.254 | 5.252 | 6.195 | 5.998 | 6.096 |
| Amperbo* | 8.68 | 64.92 | - | 4.006 | - | - | 6.669 | - |
| Helmeringhausen | 20.81 | 43.31 | 4.686 | 4.764 | 4.725 | 5.329 | 5.466 | 5.397 |
| Lüderitz* | 11.28 | 45.96 | - | - | 6.677 | - | - | 7.425 |
| Kanas | 20.93 | 52.18 | 5.575 | 5.752 | 5.663 | 6.518 | 6.641 | 6.580 |
| Warmbad | 18.55 | 50.85 | 5.461 | 5.497 | 5.479 | 6.329 | 6.436 | 6.383 |
| Korabib | 19.86 | 51.11 | 4.123 | 4.151 | 4.137 | 4.935 | 5.047 | 4.991 |

## Acknowledgements

The work is funded by Ministry of Foreign Affairs of Denmark, Ministry of Foreign Affairs of Finland, United Kingdom Department for International Development, Austrian Development Agency and Namibia Power Corporation. In-kind support is provided by University of Basel and Namibia University of Science and Technology.

## References

1. *Thomas,* Resultate der Meteorologischen Beobachtungen in Deutsch-Südwestafrika für das Jahr Juli 1901 bis Juni 1902, Berlin, 1903.
2. IEC, International Standard IEC 61400-12-1 First Edition 2005-12 Wind Turbines - Part 12-1: Power performance measurements of electricity producing wind turbines, IEC, Geneva, 2005.
3. *Siepker EBJ and Harms TM*, On the Potential Value of Interval Deficient Wind Data, *Journal of Wind Engineering and Industrial Aerodynamics*, 165, 100 - 114, 2017.
4. *Wisse JA and Stigter K*, Wind Engineering in Africa, *Journal of Wind Engineering and Industrial Aerodynamics*, 95(9), 908 - 927, 2007.
5. *Pedersen BM, Hansen KS, Øye S, Brinch M and Fabian O,* Some Experimental Investigations on the Influence of the Mounting Arrangements on the Accuracy of Cup-anemometer Measurements, *Journal of Wind Engineering and Industrial Aerodynamic*, 39(1-3), 373 - 383, 1992.
6. *Orlando S, Bale A and Johnson DA*, Experimental Study of the Effect of Tower Shadow on Anemometer Readings, *Journal of Wind Engineering and Industrial Aerodynamics*, 99(1), 1 - 6, 2011.
7. Bicon Namibia, Final Report - REEE1/98 - Assessment of Solar and Wind Resources in Namibia, Unpublished Report, 1999.
8. Weather Bureau (South Africa), Report on Meteorological Data of the Year 19xy, Pretoria, Various reports from 1956 - 1977.
9. *Pedersen BM, Pedersen TF, Klug H, Van der Borg N, Kelley N and Dahlberg J-Å*, Expert Group Study on Recommended Practices for Wind Turbine Testing and Evaluation 11. *Wind Speed Measurement and Use of Cup Anemometry*, Hunter RS, Ed., International Energy Agency, 1999.
10. Centre for Renewable Energy Sources, WindRose - A wind data analysis tool - User's Guide, Pikermi: Centre for Renewable Energy Sources, 2009.
11. *Troen I and Lundtang Petersen E*, European Wind Atlas, Roskilde: Risø National Laboratory, 1989.
12. Kröger DG, *Air-cooled Heat Exchangers and Cooling Towers, Thermal-flow Performance Evaluation and Design*, University of Stellenbosch, Stellenbosch, 1998.
13. *Agüera-Pérez A, Palomares-Salas JC, De la Rosa JJ, Ramiro-Leo JG and Moreno-Muñoz A,* Basic Meteorological Stations as Wind Data Source: A Mesoscalar Test, *Journal of Wind Engineering and Industrial Aerodynamics*, 107, 48-56, 2012.
14. *Mortensen NG*, Wind Atlas for Egypt: Measurements, Micro - and Mesoscale Modelling, European Wind Energy Conference and Exhibition, January, 2006.