Wind Atlas for South Africa (WASA)

KwaZulu-Natal, Free State and parts of Eastern Cape

Station and Site Description Report

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Abstract As part of the “Wind Atlas for South Africa Phase 2” project, site inspection trips were carried out by the Council for Scientific and Industrial Research (CSIR) and DTU Wind Energy in April of 2016. Observers from the South African National Energy Development Institute (SANEDI) also attended. A total of 2 sites featuring instrumented 60-m masts were visited; the present report summarises the findings of the site inspection teams. The results from the other 3 sites were recorded during the mast instrumentation period. The main results are descriptions and documentation of the meteorological masts, instruments and site conditions. For each site, the location and magnetic declination have been determined, as well as the sensor boom directions on the mast. Elevation maps have been constructed to show the surrounding terrain and photos taken to document the land cover. The observed wind rose and wind speed distribution are given for one full year’s worth of data.

WASA 2 Station and Site Description Report.

Contents

1 Introduction

As part of the "Wind Atlas for South Africa Phase 2" project, a site inspection trip was carried out by the Council for Scientific and Industrial Research (CSIR) and DTU Wind Energy in April of 2016 to two of the five sites featuring instrumented 60-m masts; the results from the other three masts were obtained during the installation of the instrumentation. Figure 1 shows the positions and names of the nine WASA1 mast sites, with the new WASA2 mast positions featuring in the north-eastern part of the map below. Figure 2 shows the positions of the WASA2 masts in more detail.

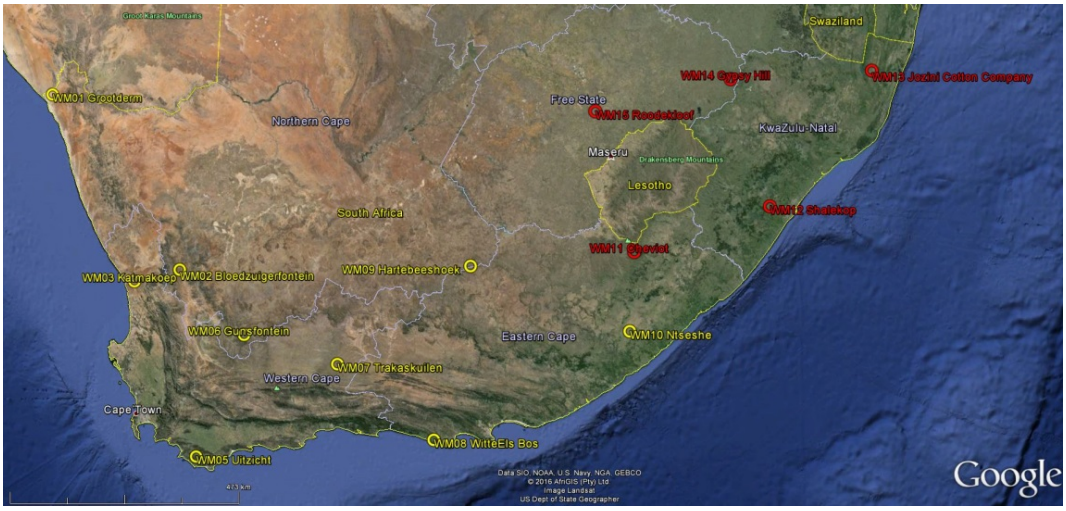


Figure 1. Overview map of the southernmost part of South Africa, showing the location of the nine meteorological masts referred to in the text as WASA 1, with the five new WASA 2 mast locations in the north-eastern part of the map (Image © 2011 AfriGIS (Pty) Ltd., US Dept. of State Geographer, Google Inc. and Europa Technologies).

Figure 2. Detailed map showing the five new meteorological masts referred to as WASA 2 (Image © 2011 AfriGIS (Pty) Ltd., US Dept. of State Geographer, Google Inc. and Europa Technologies).

The purpose of the site inspection trips is to assure the quality of the mast installations, as well as to provide those mast, site and land cover characteristics which are necessary for the subsequent analysis of the meteorological data. The main characteristics of each mast and site, which have been measured, calculated or recorded, are:

- 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
- Photographic documentation of mast design and installation
- Photographic documentation of mast surroundings (panoramic view)

In addition, elevation maps have been constructed for each site from SRTM 3 data and a summary of the wind observations have been compiled; these are presented in Appendix A below.

Photographic documentation of land cover types around and en route between the mast sites have also been recorded; this may aid in the interpretation of land cover codes and the construction of roughness length maps from databases of land cover.

2 Mast and site characteristics

The information presented in this section is necessary for the reliable data analysis and wind flow modelling at the five WASA 2 sites and in their surroundings.

2.1 Mast positions

The positions of the meteorological masts were determined using GPS receivers. One to three readings were taken (the latter corresponding approximately to the three legs of the mast) and averaged to find the position of the mast. Most positions have been determined on several occasions and the average is then used, see Table 1.

Table 1. Mast coordinates and elevations. The datum used is WGS 84; elevations are determined by the WAsP 11.5 flow model from SRTM 3 maps with 5-m height contours.

Mast ID	**Longitude**	**Latitude**	**Elevation**	**Easting**	**Northing**	**UTM**
	[°E]	[°S]	[m a.s.l.]	[m]	[m]	zone
WM 11	28.07351	30.81436	2575	602,685	6,590,479	35J
WM 12	30.52871	29.85026	770	261,255	6,695,243	36J
WM 13	32.16636	27.42605	80	417,602	6,966,098	36J
WM 14	29.54348	27.88169	2045	750,400	6,913,303	35J
WM 15	27.12303	28.62023	1505	512,026	6,834,082	35J

The terrain elevation of the mast sites were subsequently determined using height contour maps created for the WAsP flow modelling (Mortensen *et al*., 2014). The 5-m height contour elevation maps were derived from Shuttle Radar Topography Mission (SRTM) 3 arc-second data. Version 11.5 of WAsP was used which has an improved site elevation determination procedure.

2.2 Bearings and directions

The Universal Transverse Mercator coordinates of a mast site and of points around this site refers to the Cartesian grid coordinate system; this system is also used for the vector elevation and roughness length maps used for the microscale flow modelling. The local angle between the *y*-axes of the grid coordinate system (*G*) and of the geographical coordinate system (*T*) is called the meridian convergence (*C*); and $T = G + C$. For the UTM coordinate system, the convergence can be calculated from the latitude and longitude of the site, see Table 2.

The magnetic declination (*D*) at each mast site was determined by taking the compass bearing between two points; from a viewpoint looking towards the masts itself. Knowing the grid coordinates of these two points, the

geographical (true) bearing can be calculated by adding the convergence to the grid bearing (angle). Given the true bearing (*T*) and the compass bearing (*M*), the declination (*D*) can be calculated as $D = T - M$. This value may be compared to the value derived from topographical maps published by the Chief Directorate: Surveys and Mapping (now National Geo-spatial Information, NGI), see Table 2.

The magnetic declination at a site can also be estimated using the magnetic declination calculator provided by NOAA's National Geophysical Data Center (NGDC).

All compass (magnetic) bearings (*M*) have been transformed to true bearings (*T*) using $T = M + D$, where *D* is the magnetic declination. The magnetic declination is westerly (and therefore negative) for all the sites in South Africa, i.e. the magnetic north *M* lies to the west of geographic north *T* (when seen from the site).

Table 2. Convergence, magnetic declination, boom direction and lightning rod direction.

Mast ID	**Meridian conver-gence**	**Magnetic declination (measured)**	**Magnetic declination (NGI map)**	**Boom direction (measured)**	**Boom direction (logger)**	**Lightning rod direction**
	[°]	[°]	[°]	[°] (true)	[°] (true)	[°] (true)
WM11	−0.55	−27.68	−25.43	14.72 - 194.72	18.73	326.72
WM12	+1.23	−23.5	−25.16	0.98 - 180.98	25.87	53.98
WM13	+0.38	−23.9	−22.20	60m 113.93-293.93 20m 115.93-295.93	296.92	154.13
WM14	−1.19	−20.58	−21.81	11.32-191.32	12.32-192.32	244.3
WM15	−0.06	−21.86	−21.93	60m 136.1-316.1 20m 142.1-322.1º	143.87	±240

The alignment of the wind direction vanes during installation was done using a compass; the recorded wind directions are therefore initially referenced to magnetic north. During data calibration, the wind directions are converted and referenced to the geographical coordinate system. Table *2* lists the anemometer boom direction determined as described above, as well as the calibrated direction read from the data logger when aligning the wind vane along the boom. The anemometer boom direction is defined here as the direction in which the cup anemometer points.

Comparison of the two boom directions in see Table 2, provide an independent evaluation of the calibration expression used to transform the wind direction data measured at the mast. In general, the difference is small, i.e. 0-2 degrees. The stations WM11, WM13 and WM15 still require the logger directions of booms.

A lightning protection system has been installed at the top of each mast, as may be seen from the photographs in Appendix A. This system will distort the wind flow when the wind comes from the direction of the system. This direction, i.e. the bearing of a line from the top anemometer through the vertical part of the lightning protection system, is also given in Table 2.

2.3 Mast characteristics

The design and characteristics of the 60-m masts are described elsewhere; a sketch is shown in Figure 18. Photos taken during the site inspection trip may serve to verify that actual installations are done according to this master design. The actual anemometer heights have been determined in the field using laser distance meters, see Table 3.

Table 3 lists the anemometer heights on the 5 masts, i.e. the height of each cup anemometer rotor above the terrain next to the main concrete foundation of the mast. The top of the mast foundation is about 20-27 cm higher than the terrain surface, except for mast 15, which has a foundation of 97 cm, see Table 3.

Table 3. Cup anemometer heights above foundation level on the 5 masts. The boom heights were determined using laser distance meters; the heights listed below refer to the height of the cup anemometer rotor plane above the top of the terrain surface.

Mast ID	**Level '62'**	**Level '60'**	**Level '40'**	**Level '20'**	**Level '10'**	**∆Terrain**
	[m]	[m]	[m]	[m]	[m]	[m]
WM 11	61.70	60.80	40.68	19.84	10.38	0.20
WM 12	61.74	60.86	40.22	19.39	10.74	0.24
WM 13	61.75	60.84	40.80	19.72	10.22	0.25
WM 14	61.77	60.71	40.33	20.20	10.20	0.27
WM 15	62.47	61.34	39.94	21.88	10.10	0.97

3 Topographical characteristics

Some topographical information was prepared before, or recorded during, the site visits.

3.1 Surrounding terrain and mast photos

In Appendix A, the terrain surrounding each mast is shown in panoramic photographs; starting from 000°, photos were taken clockwise for every 45°. Note that the directions given in these figures refer to the magnetic north direction. Photos of the measurement levels and of the entire mast are also given in Appendix A.

3.2 Elevation maps

Elevation maps for each site were constructed from Shuttle Radar Topography Mission (SRTM) 3 arc-second data, using Surfer 12. Overview maps cover 20×20 km^2, with 20- or 10-m height contours; detailed site maps cover 4×4 km^2, with 5-m contours. These maps are shown for each station in the descriptions below. The maps are preliminary and will be verified against other elevation information – especially close to the masts.

3.3 Land cover maps

The land cover was checked against print-outs of Google Earth imagery and photos were taken of characteristic land cover types. Preliminary land cover maps may be constructed from this information, but these should be verified on basis of ordinary topographical maps and data bases of land cover.

4 Wind-climatological characteristics

The observed wind climate, i.e. the wind rose and wind speed distribution, is shown for each station in Appendix A. The observed wind climates were constructed using the WAsP Climate Analyst, version 3.1.

Table 4 shows the status of the meteorological measurements at the time of writing.

Table 4. Status of measurements as of 1 April 2017. The "%" column is the data recovery rate for the concurrent one year period from 2015-11-01 to 2016-11-01 which is used in Appendix A.

Mast ID	Mast name	Province	Data start	Days until	1-y recovery rate
			Date and time	1 April 2017	[%]
WM 11	Rhodes	Eastern Cape	27/10/2015 15:00	522	99.0
WM 12	Eston	KwaZulu-Natal	16/10/2015 14:20	533	100.0
WM 13	Jozini	KwaZulu-Natal	15/10/2015 11:20	534	100.0
WM 14	Memel	Free State	02/10/2015 15:50	547	100.0
WM 15	Winburg	Free State	30/09/2015 11:50	549	99.8

Meteorological data from the five measurement stations can be downloaded from the WASA download web site wasadata.csir.co.za/wasa1/WASAData.

5 Conclusions and recommendations

In general, the mast installations were found to be of a high standard and no changes other than regular maintenance were made to the installations during the visits.

The mast positions were generally confirmed to within a few tens of meters. The coordinates given in Table 1 refer to the coordinates obtained during the site inspection trips.

The boom directions – and thereby the calibration expressions used – were confirmed at most stations to within 0-2 degrees, and there is no need to change the calibration expressions. Repeat measurements will be done at all stations after the required checking and re-tensioning of mast guy wires after one year, are done by the mast contractor.

The boom and cup anemometer heights were mostly quite easy to determine; however, the top anemometer height could not be measured directly and is estimated from photos and the known dimensions of the associated hardware.

6 Acknowledgements

The Wind Atlas for South Africa project is an initiative of the Government of South Africa – Department of Minerals and Energy (now DoE) and the project is funded by the Royal Danish Embassy.

The South African National Energy Development Institute (SANEDI) is the Executing Partner, 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.

7 References

Mortensen, N.G., D.N. Heathfield, O. Rathmann and Morten Nielsen (2014). *Wind Atlas Analysis and Application Program: WAsP 11 Help Facility*. Department of Wind Energy, Technical University of Denmark, Roskilde, Denmark. 366 topics.

Mortensen, N.G., Hansen, J.C., Kelly, M.C., Prinsloo, E., Mabille, E., & Szewczuk, S. (2014). *Wind Atlas for South Africa (WASA) Station and Site Description Report*. Roskilde: DTU Wind Energy. (DTU Wind Energy E; No. 0071). 72 pp.

A. Station descriptions and photos

The following five sections list the mast and site characteristics for the five meteorological masts of WASA 2. Elevation maps of the surrounding terrain and the observed wind climates at 62 m above ground level are also shown. Finally, each section contains photographs of the surrounding terrain and of the mast installation. The stations are:

WM11 Rhodes

WM11	28.07351°E	30.81436°S	2575 m	E 602,685 m	N 6,590,479 m	UTM 35

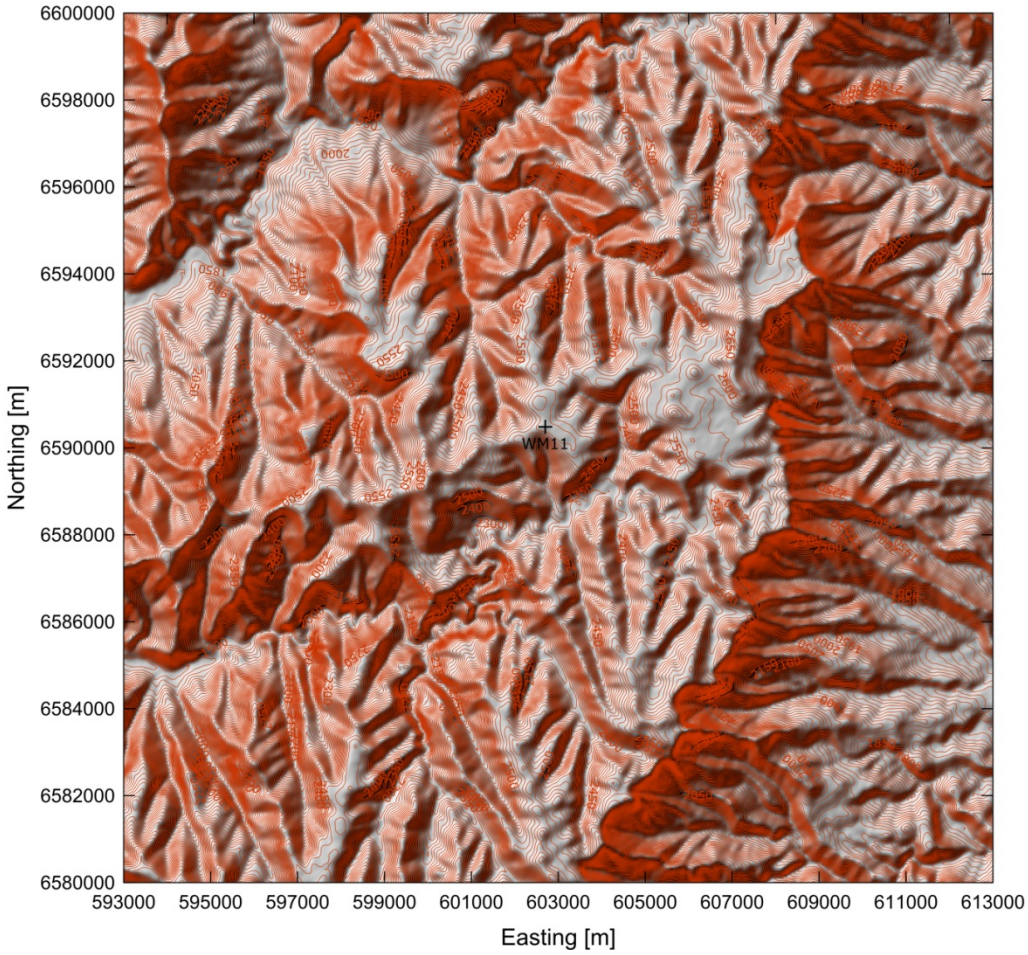


Figure 3. Elevation map from SRTM3 data, covering 20×20 km^2, with 10-m contours. The ruggedness index for the site is 11%.

Site and mast characteristics

Table 5. Convergence, magnetic declination, boom direction and lightning rod direction.

Mast ID	Meridian convergence	Declination (measured)	Declination (NGI)	Boom (measured)	Boom (logger)	Lightning rod
	[°]	[°]	[°]	[°] (true)	[°] (true)	[°] (true)
WM11	−0.55	−27.68	−25.43	14.72-194.72	18.73	326.72

Table 6. Anemometer heights above ground foundation and foundation height.

Mast ID	Level ‘62’	Level ‘60’	Level ‘40’	Level ‘20’	Level ‘10’	ΔTerrain
	[m]	[m]	[m]	[m]	[m]	[m]
WM 11	61.70	60.80	40.68	19.84	10.38	0.2

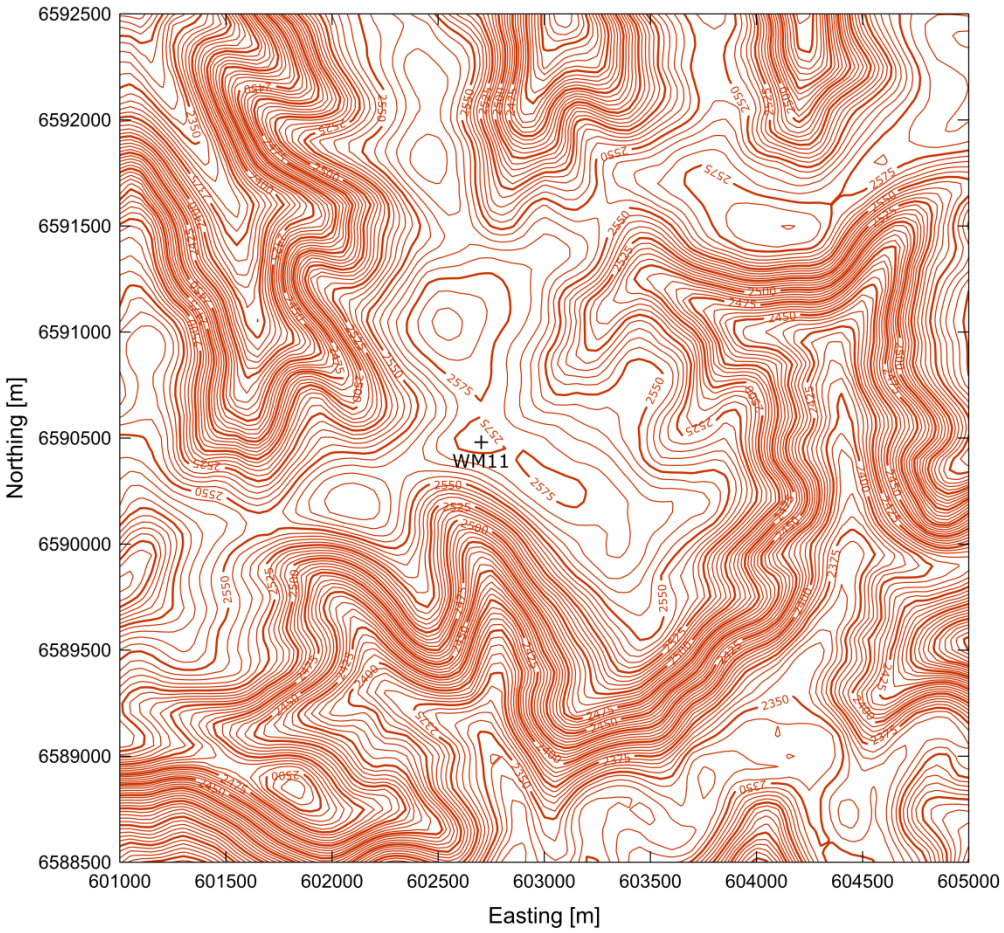


Figure 4. Elevation map from SRTM3 data, covering 4×4 km^2, with 5-m height contours.

Observed wind climate

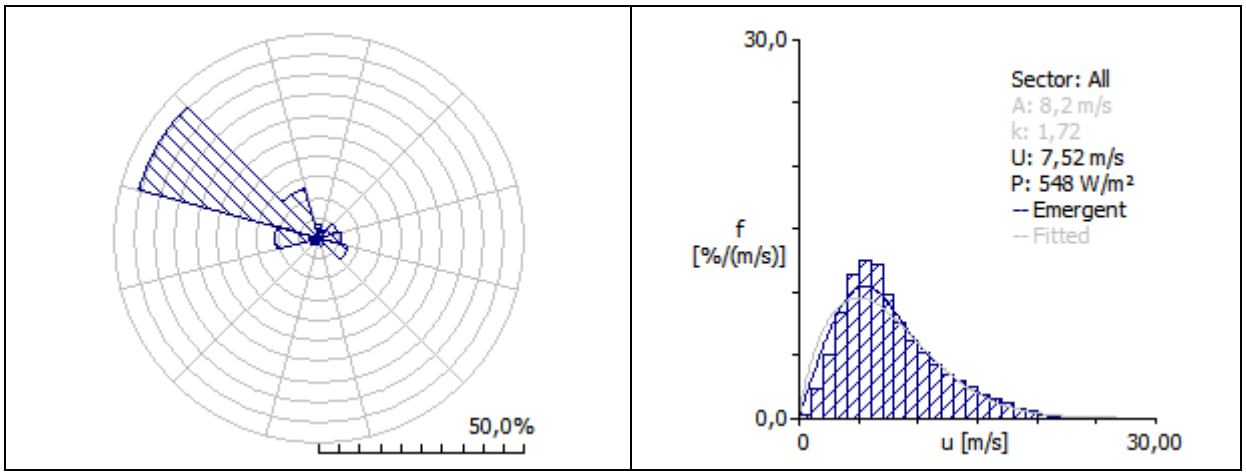
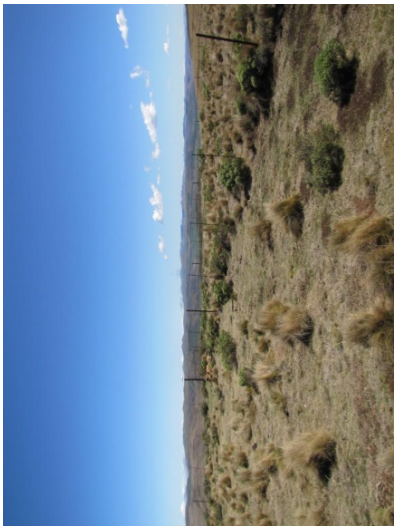
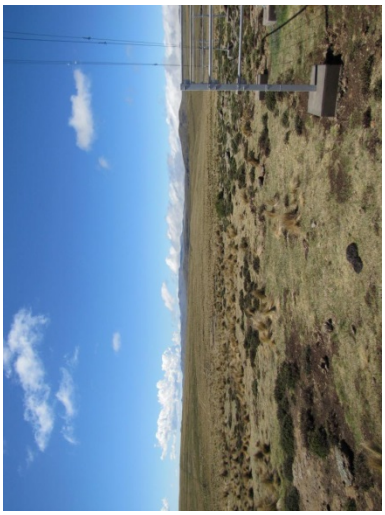
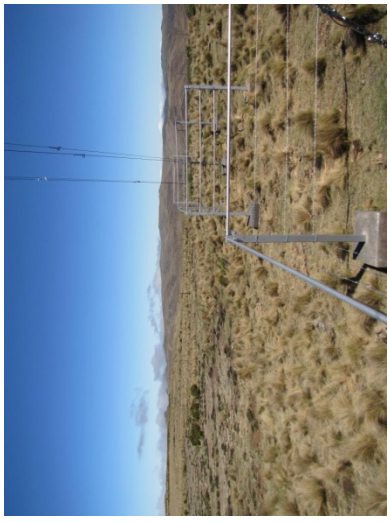
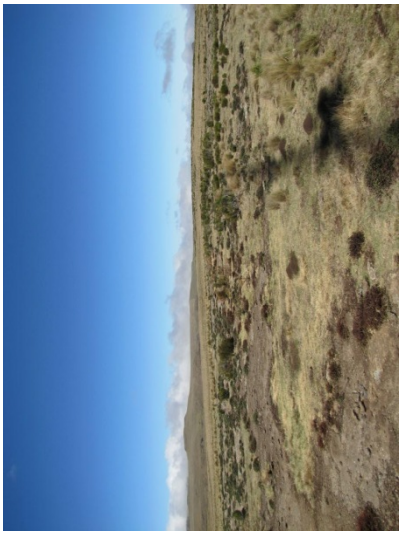


Figure 5. Wind rose and wind speed distribution for WM11 Rhodes at 62 m a.g.l. The data shown represent a period of one year, from 2015-11-01 to 2016-11-01.

Sector photographs

The sector photographs on the following two pages refer to magnetic directions, followed by photos of each of the boom levels.

 090	 225
 045	 180
 000	 135

270

315

2/4

4/4 (bottom)

1/4 (top)

3/4

Tower Full View

WM12 Eston

WM12	30.52871°E	29.85026°S	770 m	E 261,255 m	N 6,695,243 m	UTM 36

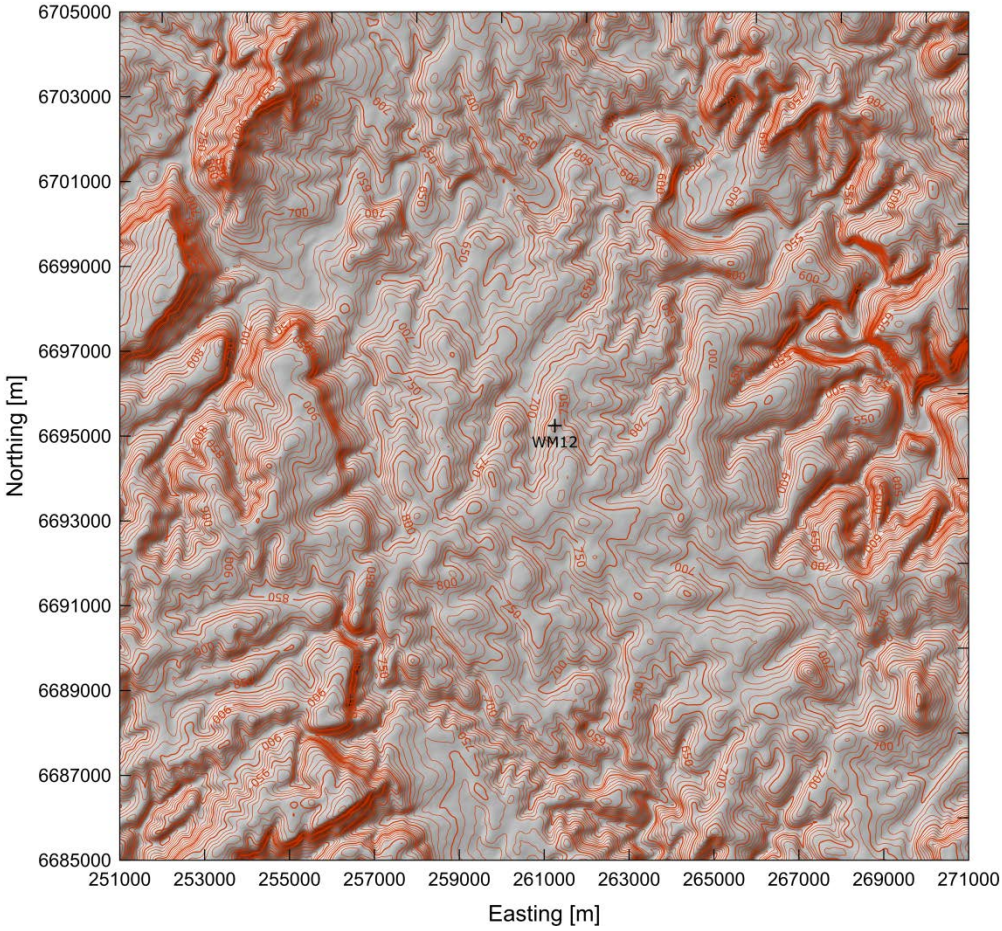


Figure 6. Elevation map from SRTM3 data, covering 20×20 km^2, with 10-m contours. The ruggedness index for the site is 0%.

Site and mast characteristics

Table 7. Convergence, magnetic declination, boom direction and lightning rod direction.

Mast ID	Meridian convergence	Declination (measured)	Declination (NGI)	Boom (measured)	Boom (logger)	Lightning rod
	[°]	[°]	[°]	[°] (true)	[°] (true)	[°] (true)
WM12	+1.23	–23.5	–25.16	0.98-180.98	25.87	53.98

Table 8. Anemometer heights above ground foundation and foundation height.

Mast ID	Level ‘62’	Level ‘60’	Level ‘40’	Level ‘20’	Level ‘10’	ΔTerrain
	[m]	[m]	[m]	[m]	[m]	[m]
WM 12	61.74	60.86	40.22	19.39	10.74	0.24

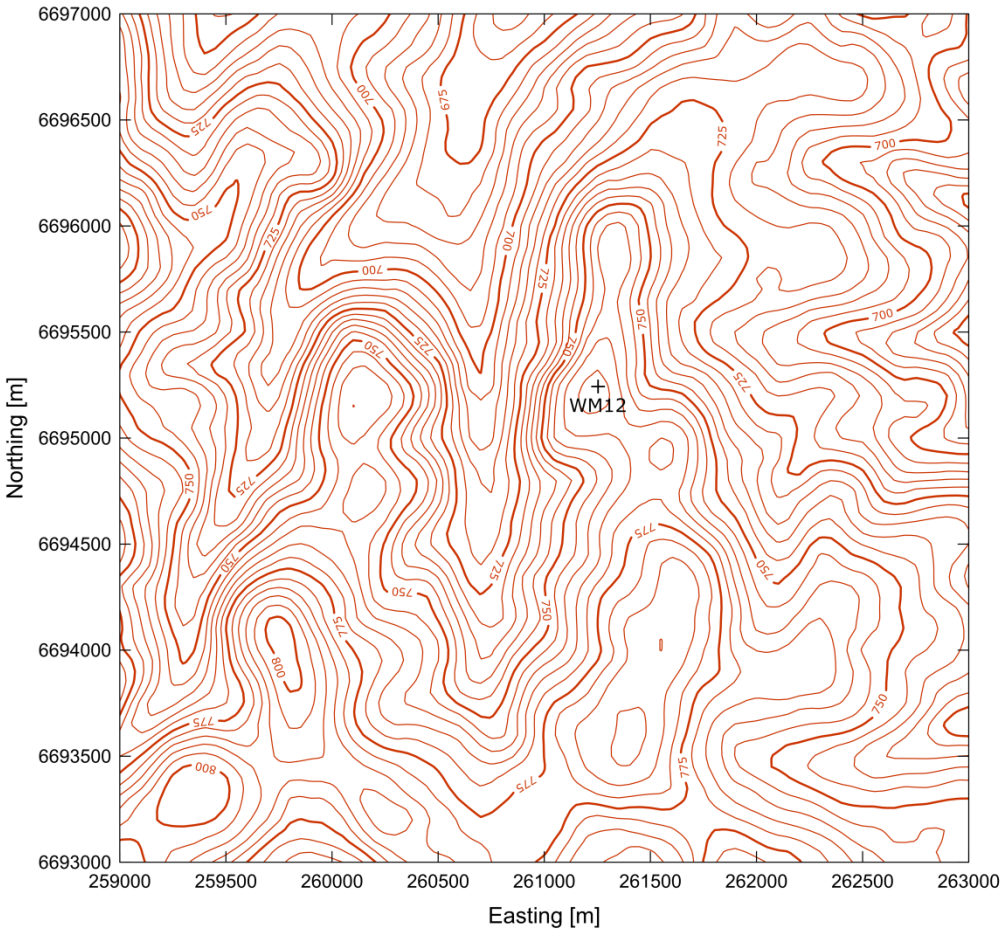


Figure 7. Elevation map from SRTM3 data, covering 4×4 km^2, with 5-m height contours.

Observed wind climate

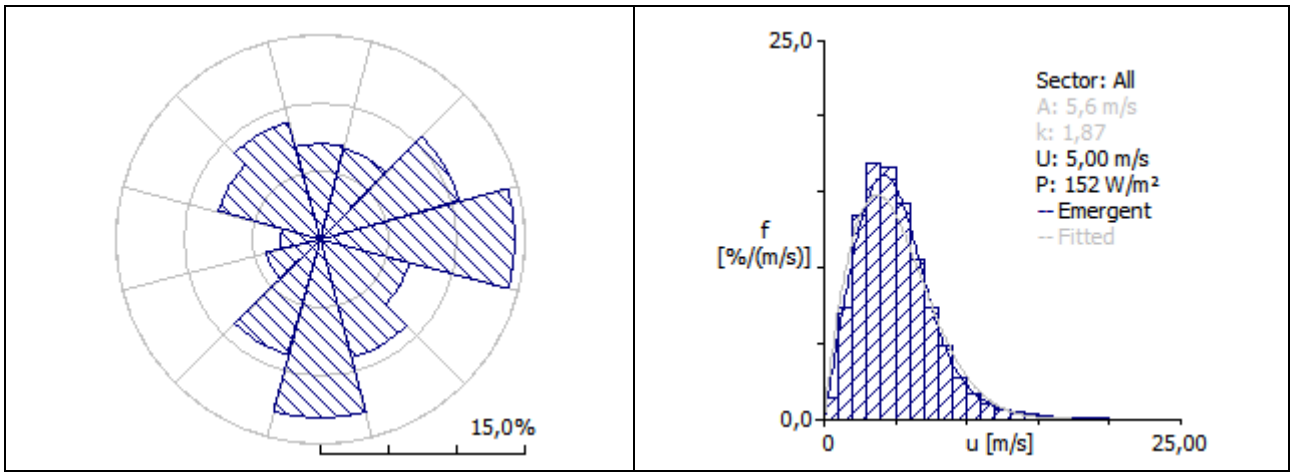


Figure 8. Wind rose and wind speed distribution for WM12 Eston 62 m a.g.l. The data shown represent a period of one year, from 2015-11-01 to 2016-11-01.

Sector photographs

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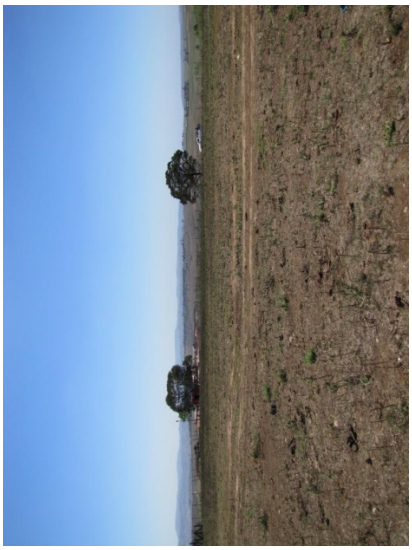
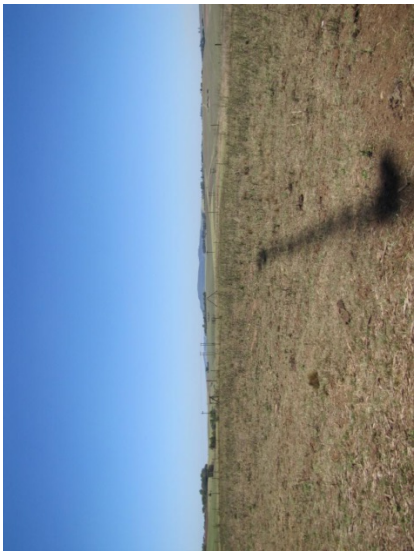
 090	 225
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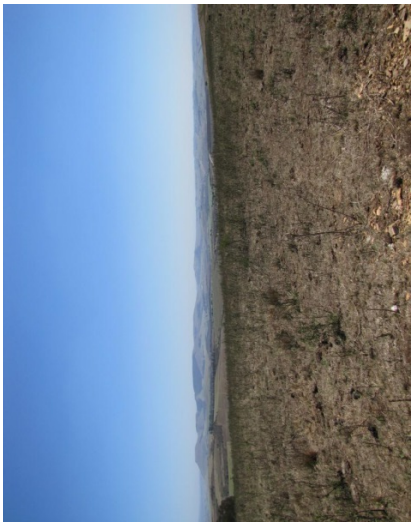
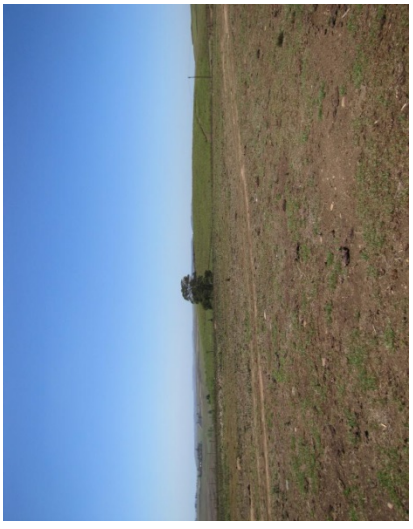
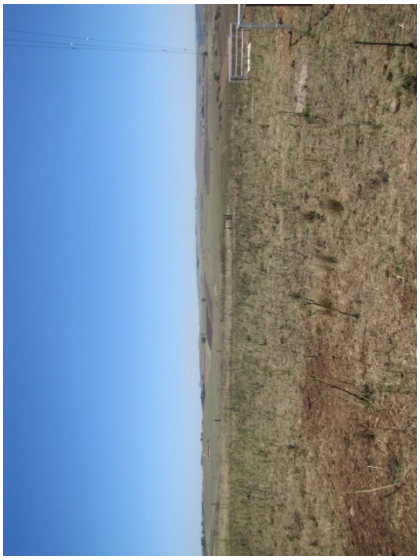
 000	 135



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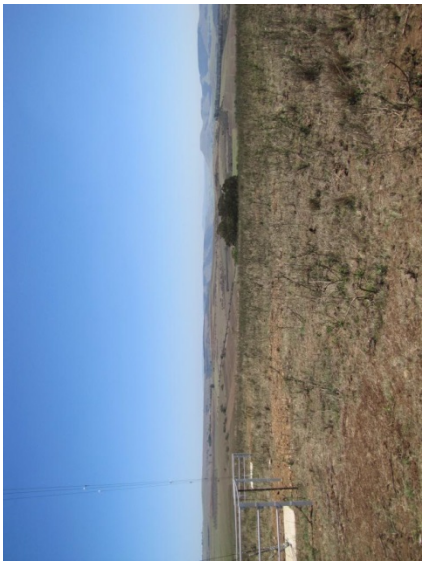

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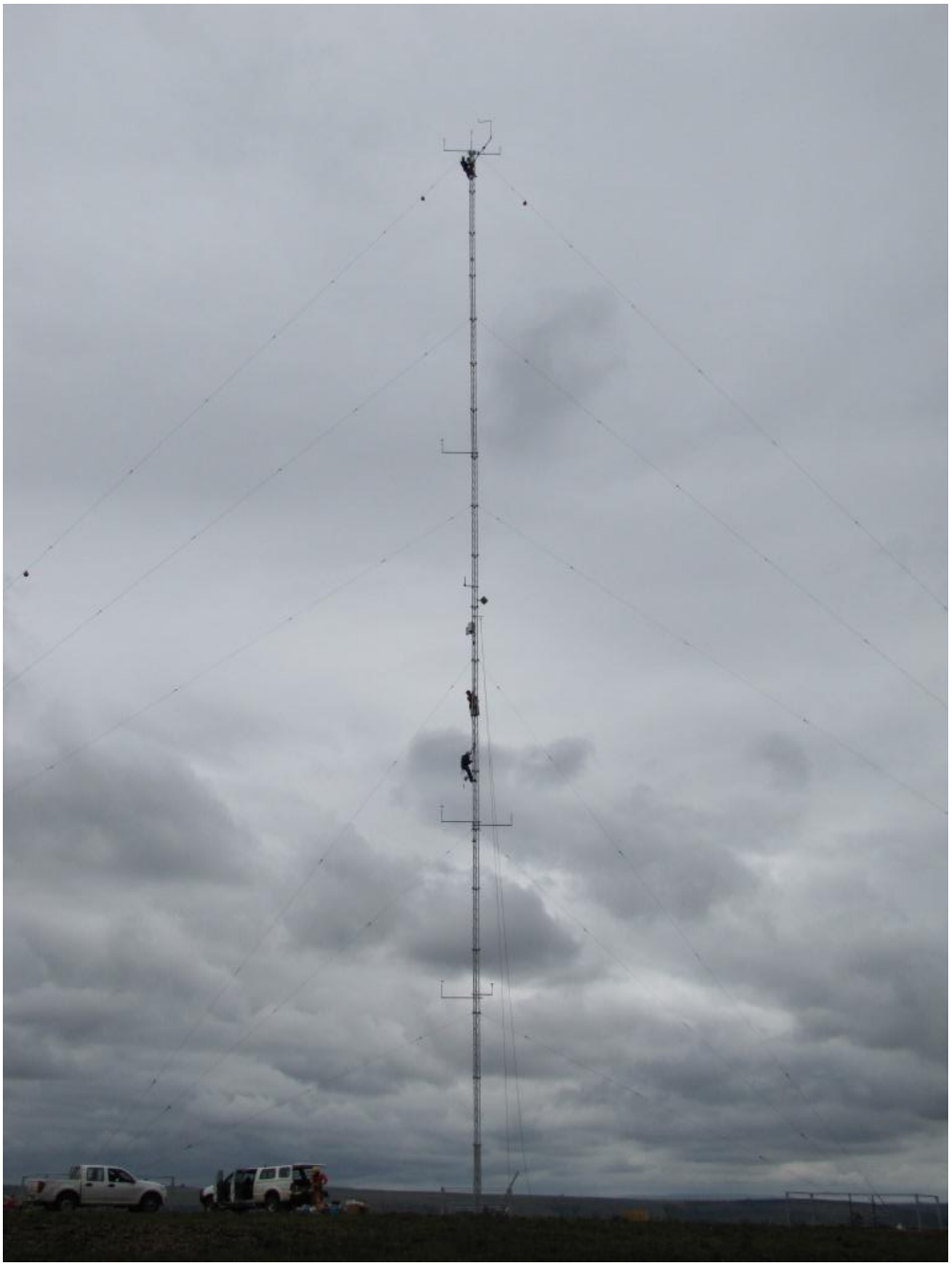
2/4

4/4 (bottom)

1/4 (top)

3/4



Tower Full View

WM13 Jozini

WM13	32.16636°E	27.42605°S	80 m	E 417,602 m	N 6,966,098 m	UTM 36

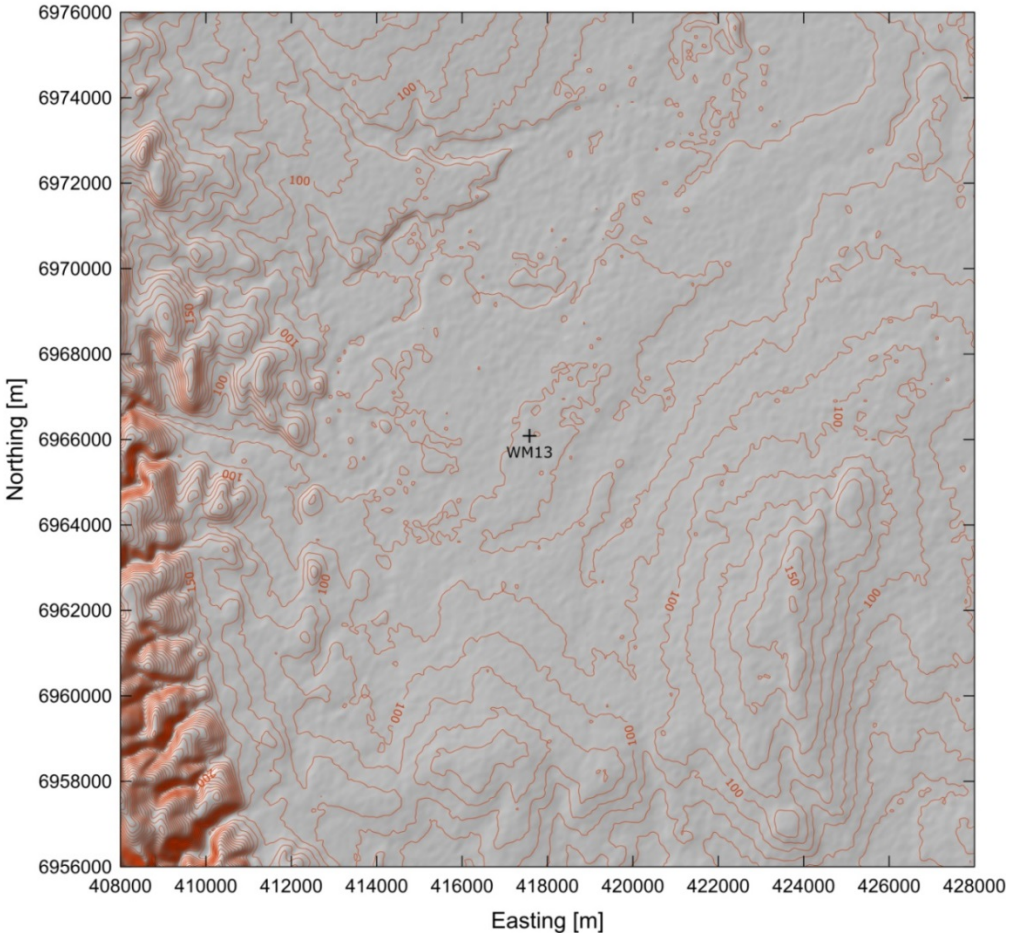


Figure 9. Elevation map from SRTM3 data, covering 20×20 km^2, with 10-m contours. The ruggedness index for the site is 0%.

Site and mast characteristics

Table 9. Convergence, magnetic declination, boom direction and lightning rod direction.

Mast ID	Meridian convergence [°]	Declination (measured) [°]	Declination (NGI) [°]	Boom (measured) [°] (true)	Boom (logger) [°] (true)	Lightning rod [°] (true)
WM13	+0.38	–23.9	22.20	60 m 113.93-293.93 20 m 115.93-295.93	296.92	154.13

Table 10. Anemometer heights above ground foundation and foundation height.

Mast ID	Level ‘62’ [m]	Level ‘60’ [m]	Level ‘40’ [m]	Level ‘20’ [m]	Level ‘10’ [m]	ΔTerrain [m]
WM 13	61.75	60.84	40.80	19.72	10.22	0.25

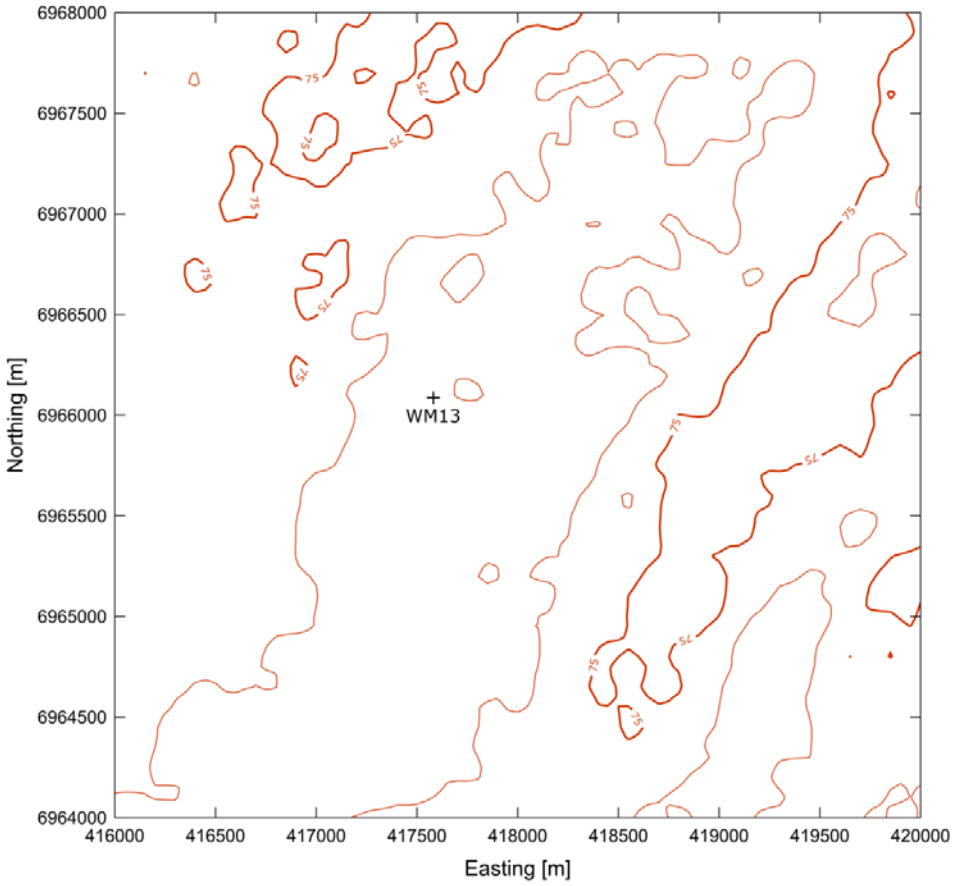


Figure 10. Elevation map from SRTM3 data, covering 4×4 km^2, with 5-m height contours.

Observed wind climate

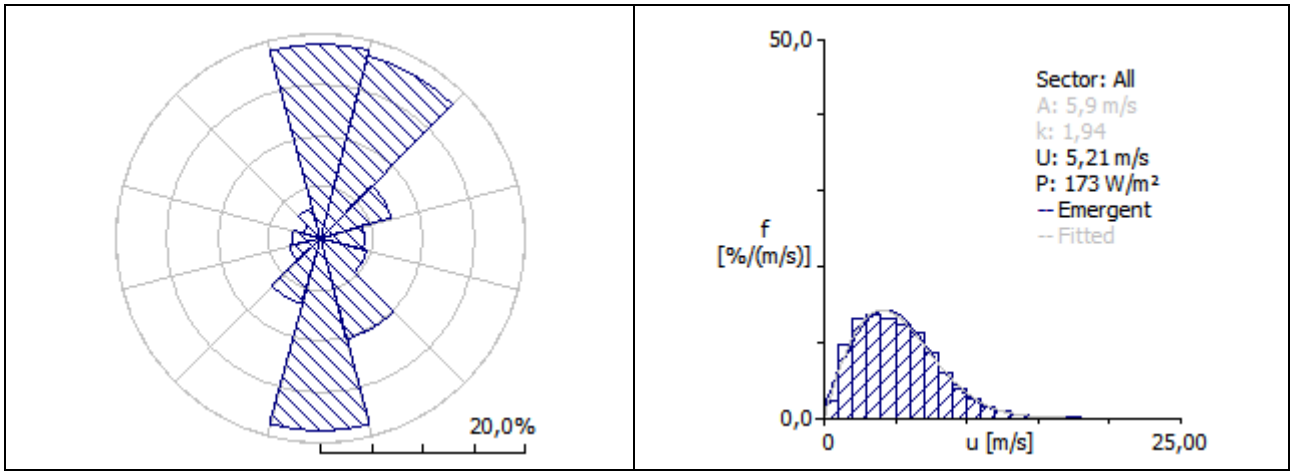


Figure 11. Wind rose and wind speed distribution for WM13 Jozini at 62 m a.g.l. The data shown represent a period of one year, from 2015-11-01 to 2016-11-01.

Sector photographs

The sector photographs on the following two pages refer to magnetic directions, followed by photos of each of the boom levels.

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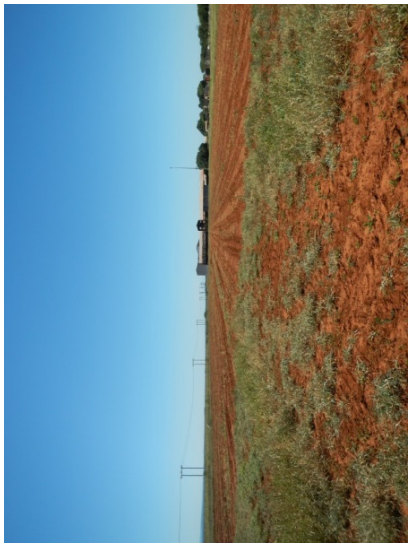 045	 180
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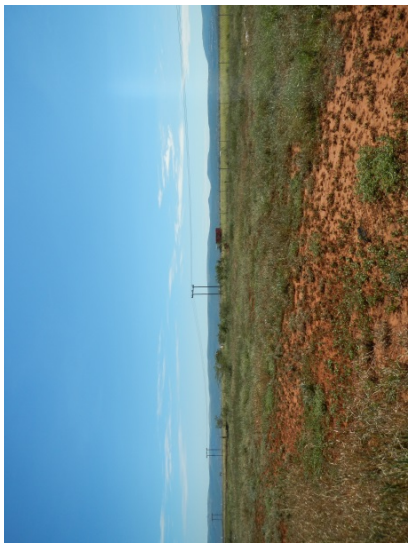
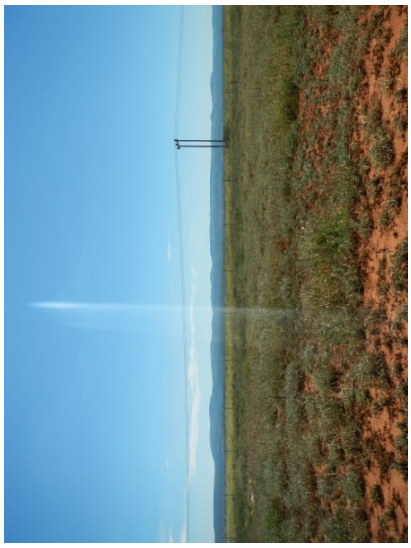


270



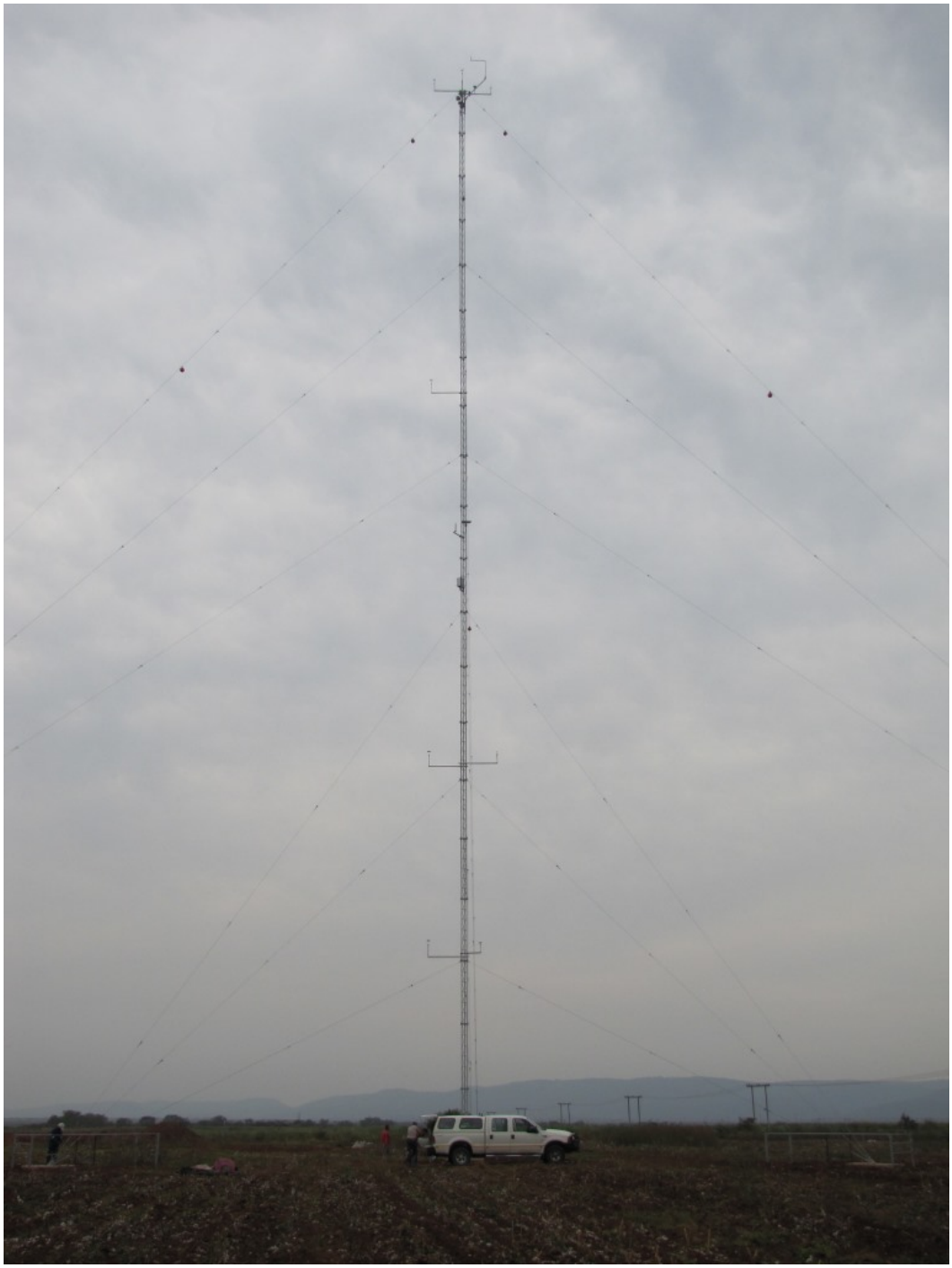
315

2/4

4/4 (bottom)

1/4 (top)

3/4



Tower Full View

WM14 Memel

WM14	29.54348°E	27.88169°S	2045 m	E 750,400 m	N 6,913,303 m	UTM 35

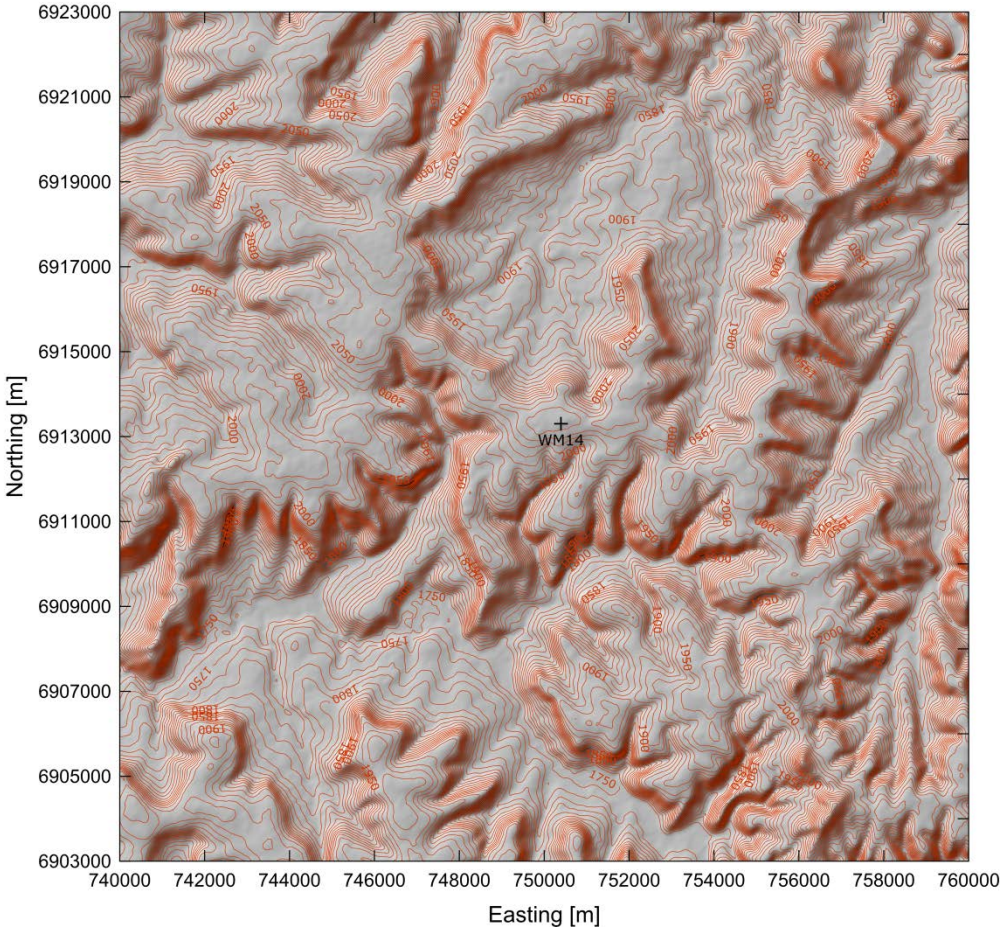


Figure 12. Elevation map from SRTM3 data, covering 20×20 km^2, with 10-m contours. The ruggedness index for the site is 1.6%.

Site and mast characteristics

Table 11. Convergence, magnetic declination, boom and lightning rod directions.

Mast ID	Meridian convergence [°]	Declination (measured) [°]	Declination (NGI) [°]	Boom (measured) [°] (true)	Boom (logger) [°] (true)	Lightning rod [°] (true)
WM14	−1.19	−20.48	21.81	11.32-191.32	12.32-192.32	244.3

Table 12. Anemometer heights above mast foundation and foundation height.

Mast ID	Level ‘62’ [m]	Level ‘60’ [m]	Level ‘40’ [m]	Level ‘20’ [m]	Level ‘10’ [m]	ΔTerrain [m]
WM 14	61.77	60.71	40.33	20.20	10.20	0.27

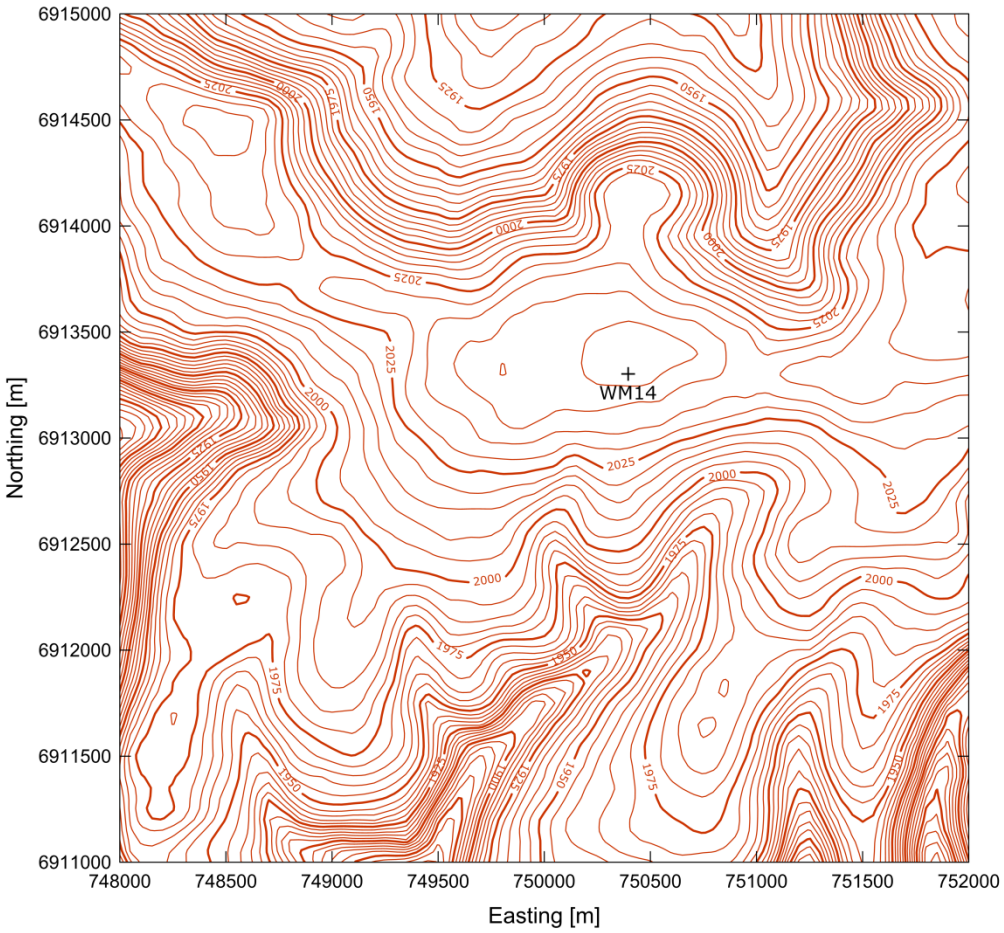


Figure 13. Elevation map from SRTM3 data, covering 4×4 km^2, with 5-m contours.

Observed wind climate

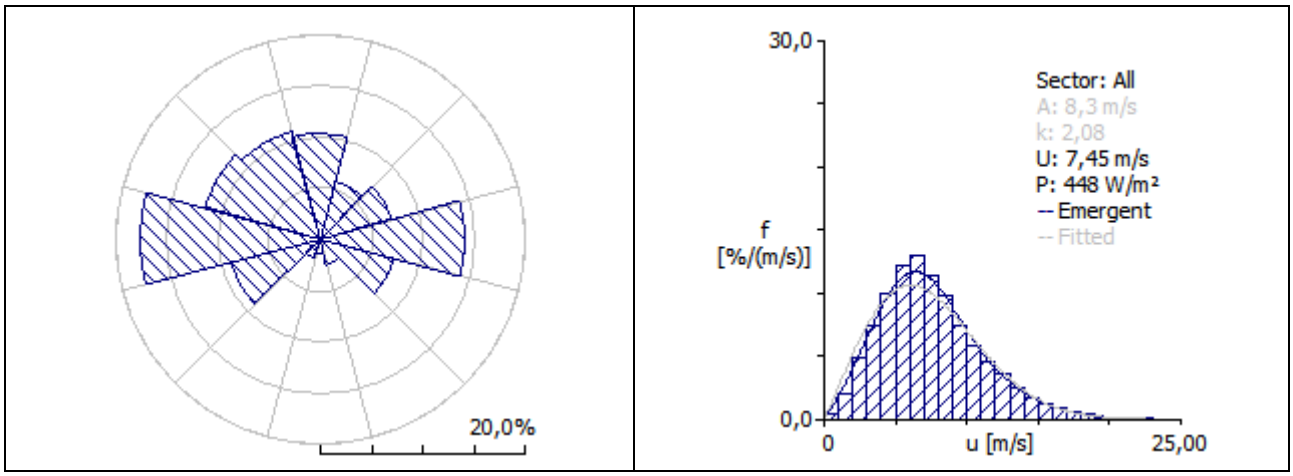
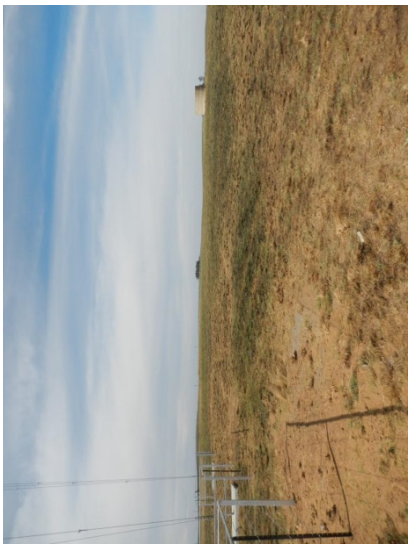
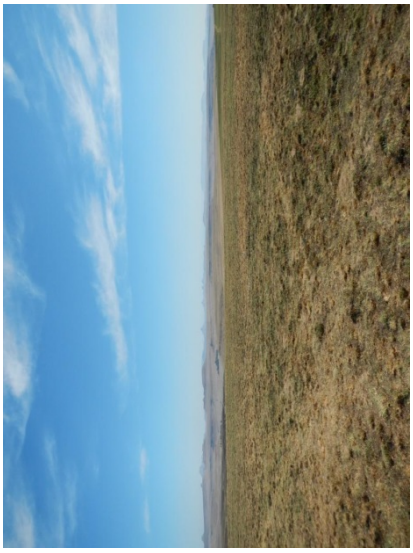
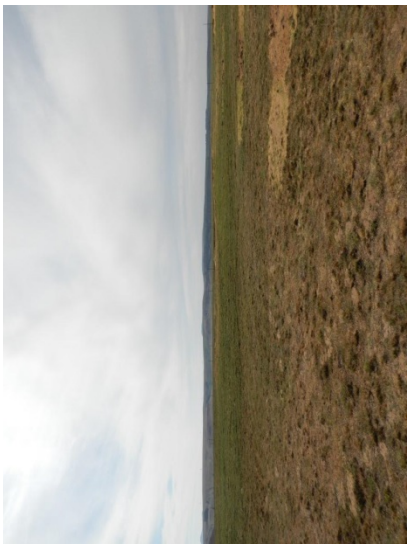
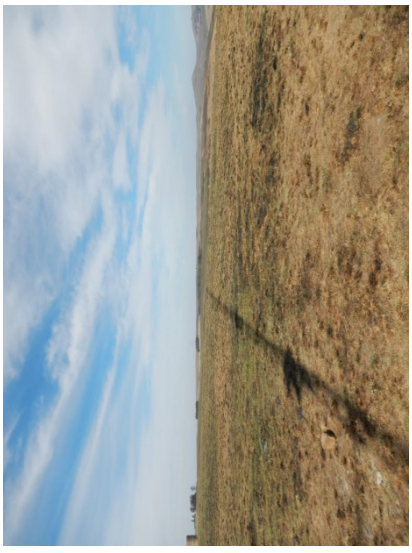
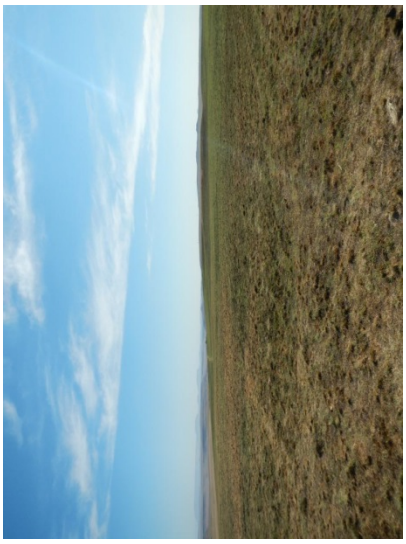


Figure 14. Wind rose and wind speed distribution for WM14 Memel at 62 m a.g.l. The data shown represent a period of one year, from 2015-11-01 to 2016-11-01.

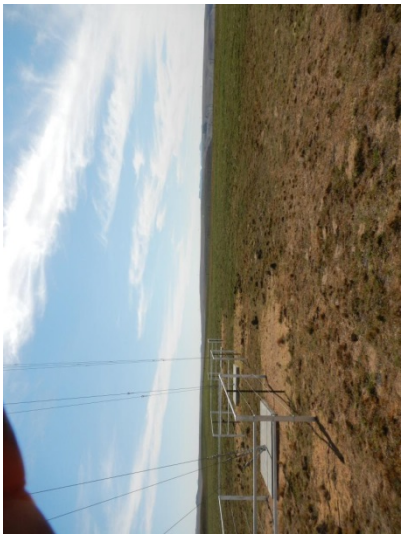
Sector photographs

The sector photographs on the following two pages refer to magnetic directions, followed by photos of each of the boom levels.

 090	 225
 045	 180
 000	 135



270



315

2/4

4/4 (bottom)

1/4 (top)

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Tower Full View

WM15 Winburg

WM15	27.12303°E	28.62023°N	1505 m	E 512,026 m	N 6,834,082 m	UTM 35

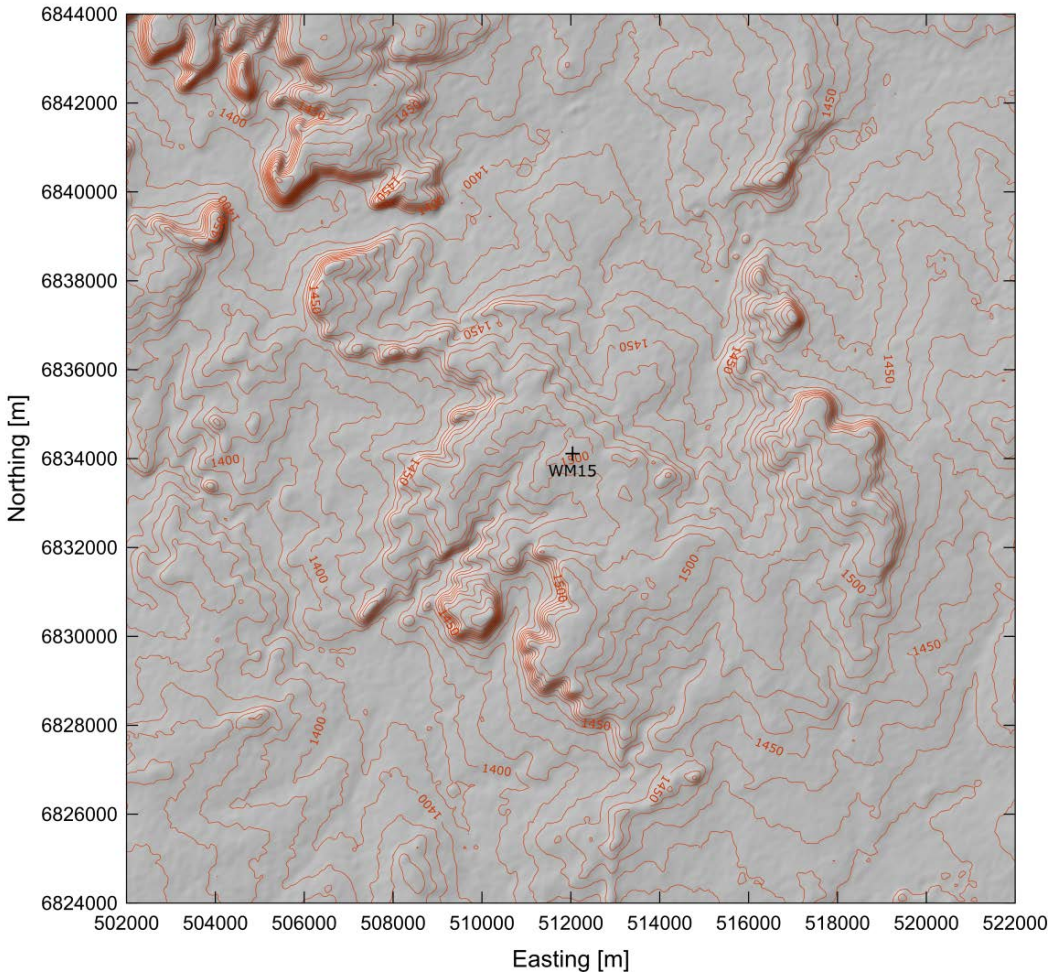


Figure 15. Elevation map from SRTM3 data, covering 20×20 km², with 10-m contours. The ruggedness index for the site is 0%.

Site and mast characteristics

Table 13. Convergence, magnetic declination, boom and lightning rod directions.

Mast ID	Meridian convergence [°]	Declination (measured) [°]	Declination (NGI) [°]	Boom (measured) [°] (true)	Boom (logger) [°] (true)	Lightning rod [°] (true)
WM15	−0.06	−21.86	−21.93	60m 136.1-316.1 20m 142.1-322.1	143.87	±240

Table 14. Anemometer heights above mast foundation and foundation height.

Mast ID	Level ‘62’ [m]	Level ‘60’ [m]	Level ‘40’ [m]	Level ‘20’ [m]	Level ‘10’ [m]	ΔTerrain [m]
WM 15	62.47	61.34	39.94	21.88	10.10	0.97

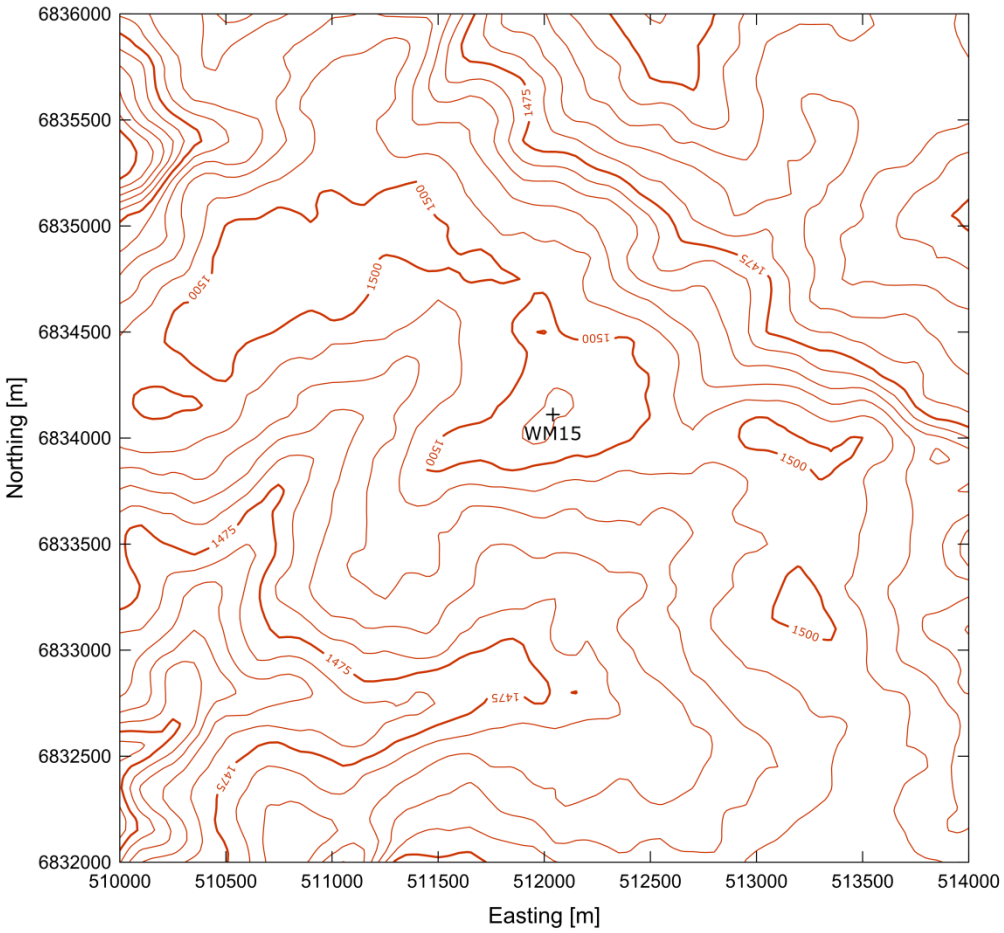


Figure 16. Elevation map from SRTM3 data, covering 4×4 km^2, with 5-m contours.

Observed wind climate

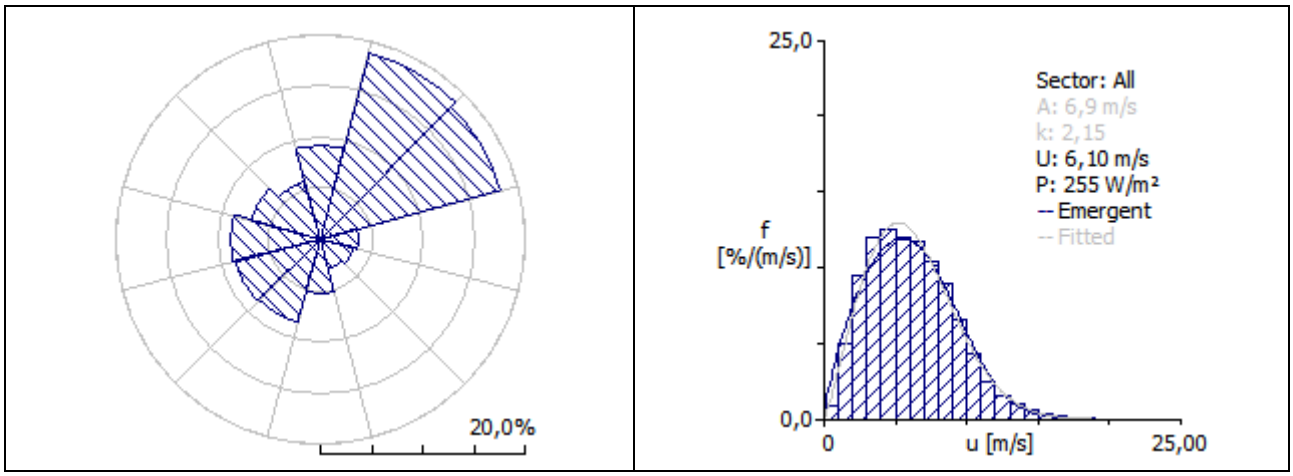
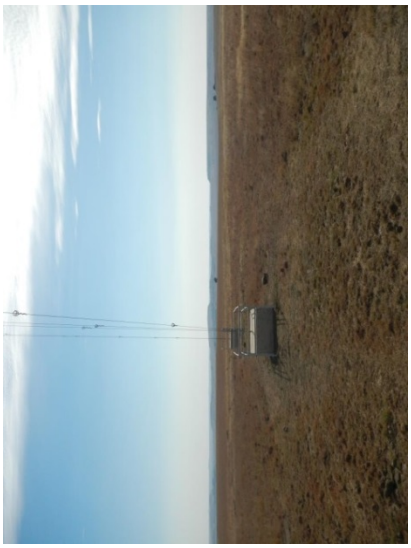
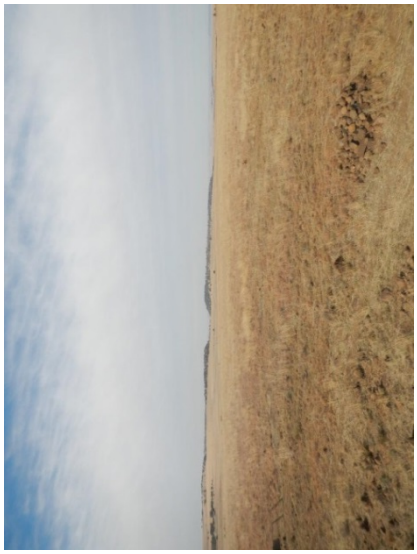
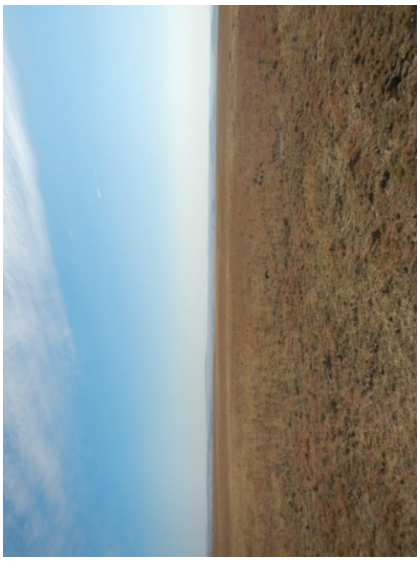
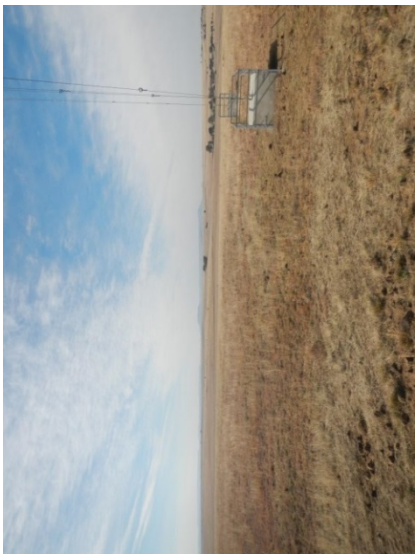
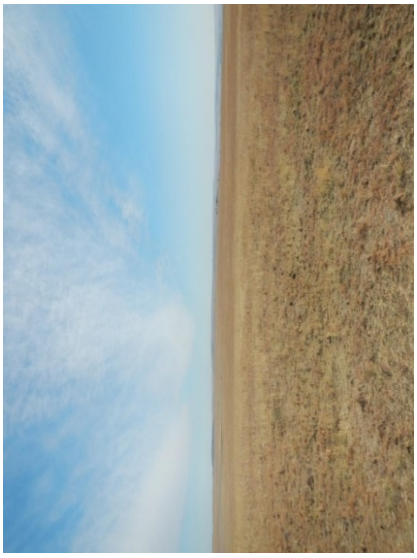
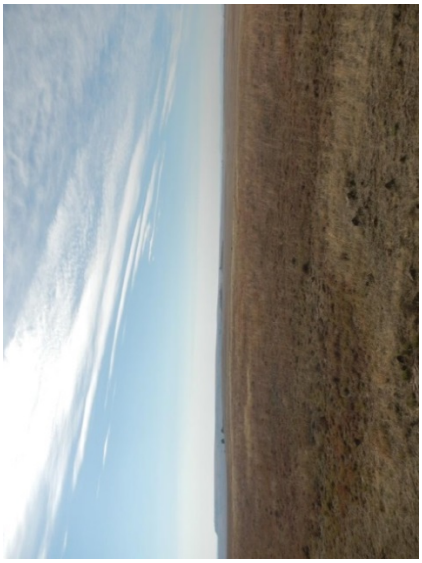
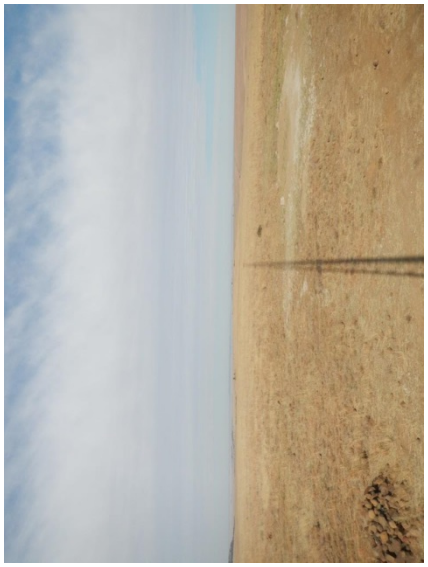


Figure 17. Wind rose and wind speed distribution for WM15 Winburg at 62 m a.g.l. The data shown represent a period of one year, from 2015-11-01 to 2016-11-01.

Sector photographs

The sector photographs on the following two pages refer to magnetic directions, followed by photos of each of the boom levels.

 090	 225
 045	 180
 000	 135



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4/4 (bottom)

1/4 (top)

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Tower Full View

B. Mast design

The original mast design and arrangement of instruments is shown in Figure 18. The actual dimensions and characteristics of each mast are given in the present report.

Figure 18. Mast design and arrangement drawing.