On the database of global reanalysis wind, terrain, land cover and observations

GASP Project Deliverable 1.1

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Preface

This report serves Deliverable 1.1 to the EUDP project GASP (Global Atlas for Siting Parameters). Here we introduce the global datasets that are needed for calculating the siting parameters.

Risø, July 2019

Xiaoli G. Larsén
Senior Scientist

Indhold

1. Introduction

For the workflow in GASP for providing the open data of global atlas for siting parameter at a resolution of 250 m, the following data need to be prepared first:

- Global elevation data
- Global land cover data
- Global wind data

This report introduces the datasets that have been considered, based on which decisions are made regarding what data are used eventually.

Section 2 to 4 introduce the datasets for elevation, land cover and wind, respectively.

Section 5 lists existing parameters that have been prepared by other projects, which can be used directly in GASP.

Two appendices are included, which contributed to some of the content of this report.

2. Elevation data

There are several available global or near global digital elevation datassets available today. These i include SRTM 1 arc-sec (approximately 30 m resolution)[1], Alos World 3D 1 arc-sec data (approximately 30 m) [2], SRTM void-filled 3 arc-sec (~ 90 m)[3], Viewfinder 3 arc-sec DEM[4], and several more.

The SRTM 3 arc-sec data along with the Viewfinder data were used in the Global Wind Atlas 3 (GWA3) project[5]. SRTM 3 arc-sec was generally used south of 60N, with Viewfinder used north of 60N. However, the Viewfinder data were not fully void-filled so a simple interpolation algorithm was used to fill regions that had missing data. Additionally there were approximately 20 SRTM tiles that had bad elevation data, which led the WAsP model used in GWA3 to crash. These were most common in areas of steep terrain, and around the islands in the Pacific Ocean. In steep terrain, the void-filling algorithm used for SRTM left some artifacts and non-natural looking features, most often Viewfinder had a better result in these regions, so the Viewfinder tiles were used in place of the SRTM data. In the Pacific Ocean, there were several cases of phantom islands in the SRTM data. These were most likely caused by cloud artifacts and these tiles were also replaced by Viewfinder data.

The same SRTM/Viewfinder data set used in the GWA3 were used in the New European Wind Atlas (NEWA). Upon viewing the results of the NEWA wind atlas, it was found that similar void-

1 https://doi.org/10.5066/F7PR7TFT

2 https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm

3 https://doi.org/10.5066/F7F76B1X

4 http://www.viewfinderpanoramas.org/dem3.html

5 https://globalwindatlas.info/about/dataset

filled artifacts were present in the Alps, which were not caught in the GWA3 processing because they did not cause the model to crash. Therefore, there is some uncertainty about the quality of the SRTM3 data in regions of steep terrain, however, our modelling is also more uncertain in these regions, so this was not considered a critical flaw.

Thøgersen (2019)[6] showed that for 1145 turbine locations, in the comparison with national elevation measurement campaigns, the lowest errors were found for SRTM 1 arc-sec and Alos World 3D data 1 arc-sec.The SRTM 1 arc-sec data are available for the entire globe between 50N and 50S, with 2 arc-sec resolution extending to 60N and 60S. However, these data have only been void-filled in the United States. Based on our experience using the void-filled SRTM 3 arc-second and viewfinder data, it would require several man months to void fill the 1 arc-sec data before using them.

Since GASP will use some derived parameters from GWA3 project (see section 5), the default choice of elevation data will be the SRTM 3 arc-sec/Viewfinder dataset used in that project. However, it should be noted that while all areas where WAsP crashed were fixed, there may be other regions that cause issues in the GASP modelling, which will need to be addressed. These data are ready to be used, despite some known limitations.

3. Land cover data

Land cover data are used to estimate the roughness length of the surface. To be consistent with GWA3, we will use the same land cover data and roughness translation table for GASP, namely the European Space Agency Climate Change Institute Land Cover Classification (ESA CCI-LC) 2015 land cover map[7]. New data products will be investigated and compared with calculations using this existing data.

The ESA CCI-LC dataset was created as part of the CCI program[8] to convert MERIS FR (Medium Resolution Imaging Spectrometer Instrument Fine Resolution) surface reflectance mosaics into land cover classes as defined by the United Nations Land Cover Classification System (LCCS). Efforts were made to retain the LCCS classifications of the Globcover 2009 product, however some classes were modified to better describe the land cover class. ESA CCI-LC 2015 has a 10 arc-second (300 m) resolution and was provided in the WGS 1984 coordinate system (EPSG: 4326). The data was converted to the UTM coordinates for each GWA tile, which had a dimension of 2° by 6° using gdalwarp[9], while retaining the spatial resolution of 300m.

6 Thøgersen, M.L., Svenningsen, L. and Sørensen, T.G. (2019) High Fidelity Elevation Models: What is the Value in Microscale Modelling? Resource Assessment Workshop 2019 WindEurope, June 2019, Brussels, Belgium

7 https://www.esa-landcover-cci.org/?q=node/158

8 https://www.esa-landcover-cci.org/

9 https://gdal.org/programs/gdalwarp.html

In the ESA CCI-LC data, one of the classification types is no-data, mostly in areas north of 60°. In GWA3, to void-fill these regions, the 0.5 km MODIS-based Global Land Cover Climatology[10] was used. The MODIS dataset was based on 10 years of data from 2001 to 2010, and had 17 land cover classes. These classes were mapped to the ESA CCI-LC classes to fill any no-data points. Afterwards, the hybrid ESA CCI-LC and MODIS data were converted to roughness length by defining a specific roughness length to each of the land use classes.

The data are ready in our cluster /mnt/ventus/MAP.

4. Reanalysis wind

It is needed to decide what reanalysis wind dataset to be used to calculate the generalized extreme wind, which later will be downscaled using microscale modelling to the site conditions of 250 m resolution, the same as the GWA3 resolution.

There are a number of options of reanalysis data, with e.g. ERA5 the latest products and MERRA the longest. In the report Appendix A, four most popular reanalysis data are compared and a final recommendation was made to choose the CFSR data as the candidate.

Table 1 lists briefly the four reanalysis products. Appendix A compared the four data in the orography, roughness length, and the 50-year wind, with and without generalization over two areas: Europe and South Africa. Both places have been studied earlier and there are measurements for validation.

It was found that over water, different products are consistent with each other and the generalization is not needed.

Large differences was found between the products over land sometimes. For instance, ERA5 provide too low wind speeds over Southwest of South Africa, with the other datasets comparable with each other. CFDDA data underestimates significantly the extreme wind in general over South Africa, when compared with CFSR, MERRA and measurements. MERRA also underestimates many places in South Africa and Europe, in comparison with CFSR data.

Following the study in Appendix A, we use CFSR data as the default choice. The other datasets can be considered to form an ensemble later in the project, if there is enough resources.

5. Derived parameters

There are a number of parameters calculated in other projects that can be used directly in GASP, thus saving considerable amount of resources. These data include (see details in Appendix B):

- Sector-wise Weibull parameters *A* and *k*, and frequencies *f*, which were created with WAsP12 worker in Frogfoot. The data are saved in NetCDF files at 250 m resolution in UTM projection.

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[10] https://modis.gsfc.nasa.gov/data/dataprod/mod12.php

- The RIX are also available at 250 m resolution.
- Wind shear. GWA has sectorwise wind speeds at 5 heights: 10, 50, 100, 150 and 200 m.
- Air density. GWA3 calculation was based on frogfoot calculator from WIAB[11].

6. Observations

Observations will be used to validate the calculations. Measurements from other projects will be used, directly (from time series) or indirectly (from estimates). The projects include GWA, New European Wind Atlas, OffshoreWake, XWiWa, WASA etc. These data are already in our database.

[11] To get higher accuracy air density, we can consider using higher resolution reanalysis data, e.g. ERA5 and include the effects of varying lapse rate, following the methodology in Floors (2019): Estimating air density using observations and reanalysis outputs for wind energy purposes. Energies. Published..

7. Appendix-A: Finding the suitable reanalysis data for GASP

Prepared by Xiaoli Guo Larsén 2019-05-10

7.1 Introduction

The purpose of the study behind of this report is to find out which reanalysis data we start with, or use, in connection with creating the global atlas of siting parameters using the GASP project concept.

Currently, in WEng 4.0, the CFDDA reanalysis data is used in connection with the extreme wind estimation. CFDDA data are hourly, available 1985 – 2005. Both as suggested by the calculation over South Africa (through the WASA project) and some individual commercial work, the estimates using CFDDA data are not as good as the those from CFSR or MERRA data. This is seen as a motivation to look into the newer reanalysis data and their suitability in the GASP application.

The detailed use of the reanalysis data can be found in e.g. report by Hansen (2016) or Larsén (2014). Briefly, we need wind speed, wind direction, topography and roughness length for the calculation. The orography and roughness length are used to calculate the speedup correction factors using the LINCOM model. The speedup correction factors will be applied to the wind speed, with direction information, to the generalized condition (at 10 m, over a roughness length of 5 cm). To the generalized model time series, the spectral correction method is applied when calculating the 50-year wind.

7.2 The various reanalysis data

The following reanalysis data are investigated: CFDDA, CFSR, MERRA and ERA5. The 50-year wind atlas, as well as the generalized 50-year wind atlas, over South Africa and Europe are calculated using these data. The results are compared between the various data. The results include the extreme wind atlases and the maps of roughness length. The maps of extreme wind are particularly (1) the 50-year wind at 10 m from the reanalysis wind time series directly, with no generalization, and no spectral correction. (2) the 50-year wind at 10 m over a roughness length of 5 cm (generalization), using a simple spectral correction factor of 1.08, approximately correcting the reanalysis 1 h resolution to the “actual” 1 h temporal resolution. This simplification is applied, first of all, to verify the estimates for South Africa case, where the 1 h resolution map from measurements is available. Secondly, it is used to have a qualitative comparison between different reanalysis and we do not need to wait until the spectral correction calculation is done. An additional 8% to account for the reanalysis smoothing effect is an approximation, which is roughly the mean value we observed in previous tests. The actual value will need to be obtained for particular areas and particular reanalysis data.

All the four data are hourly. The CFDDA data are from 1985 to 2005, with a spatial resolution about 40 km in the mid-latitude. The data length is not so long and they are frozen. They are currently the data in WEng 4. They were chosen at that time for WEng because the data were available through GWA project and the roughness length calculated from the wind profile method has shown to be less problematic than several other options we had.

The CFSR data have two phases, one is from 1979 – 2010 and one is from 2011 and now. The two have different spatial resolutions, with the first a resolution of about 39 km and the second 25 km. The CFSR-I 10 m wind has been applied in the South Africa project and the result has shown to be promising.

The MERRA2 data is from 1980 to now, with the longest record available. The spatial resolution is about 45 km in the mid-latitude.

The ERA5 data is the new comer with its high spatial resolution (about 30 km). Together with corresponding wave data, they have caught tremendous attention in wind energy section. The available data on the same Portal as the other three data cover so far only 2002 – 2017, but they are expected to be extended. Even so, it is sufficient for us to investigate a number of elements related to this data set in the context of GASP calculations.

The orography data from the four data are used directly. The roughness length has though been calculated in various ways. The reason of not using the roughness length data from the reanalysis is that the calculation of generalized wind has shown to be very sensitive to the given roughness length data, causing discontinuity in the spatial distribution. It is then decided to calculate the roughness length from the wind field, so that the two parameters are better corresponded. For CFDDA data in WEng 4, the roughness length was calculated from mean annual maximum wind speed at 10 m, 50 m and 100 m using profile method. For CFSR data, the 10 m wind speed and the frictional velocity are used to obtain the roughness length through Monin-Obukhov similarity theory. For MERRA data, again the profile method is applied to mean annual maximum wind speed at 2 m, 10 m and 50 m. For ERA5 data, the stress and wind speed at 10 m are used.

7.3 Results and discussions

The results presented here include: (1) the derived roughness length that will be used for generalization, (2) the 50-year wind at 10 m from the original reanalysis wind time series, without generalization, without spectral correction and (3) the generalized 50-year wind, corrected to an equivalent 1 h resolution. Fig. 1 is provided to help reading the maps of roughness length (z_0), which has been presented through $\log_{10} z_0$.

Results for two areas are presented: (1) South Africa (2) Europe. South Africa is chosen for investigation because the calculations here have been verified with more than 72 measurement stations across the country (Kruger et al. 2011). Europe is chosen because there have been evaluations done using site measurements here.

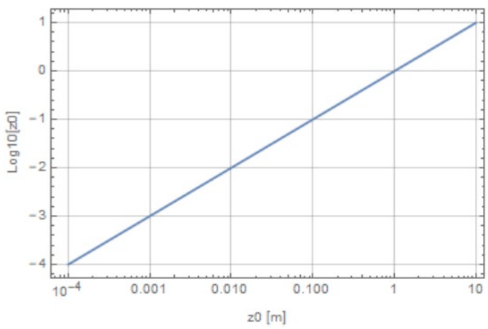
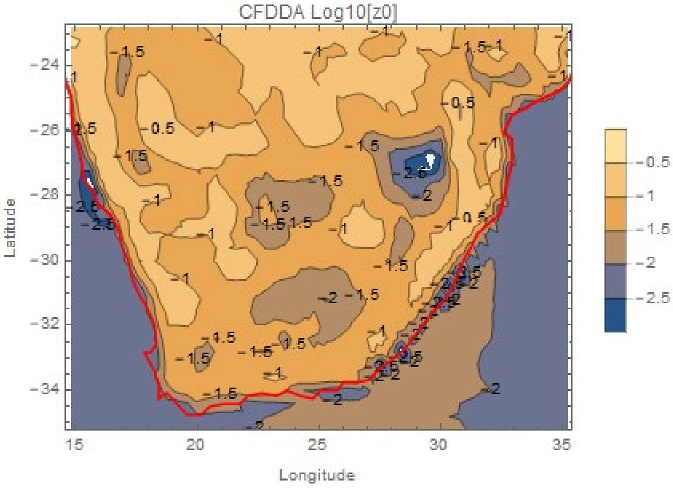
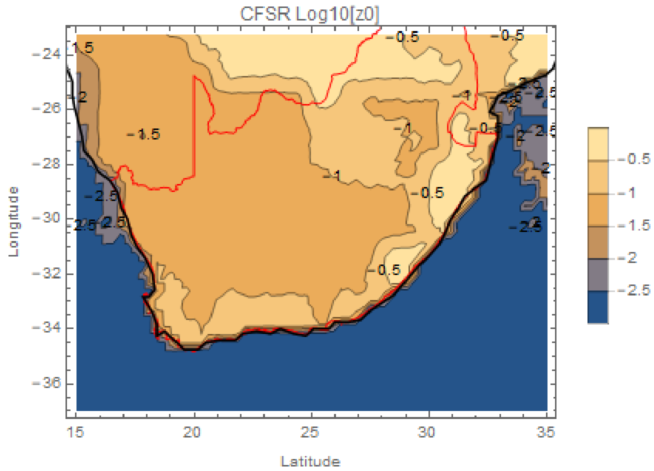


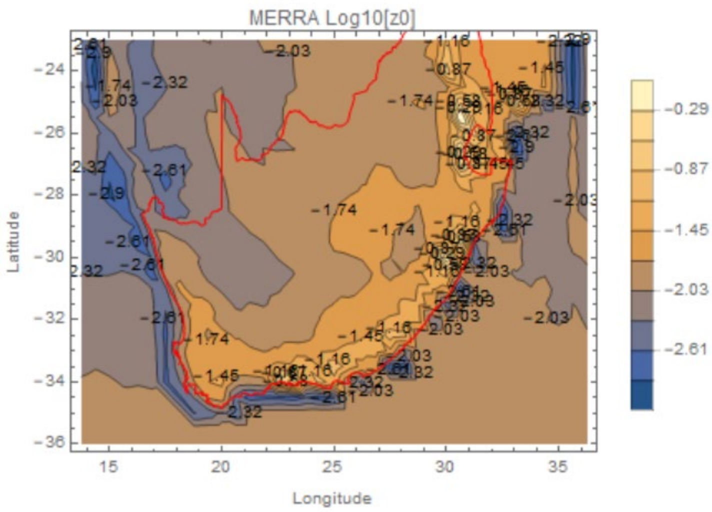
Fig. 1. z_0 vs $\log_{10} z_0$, for readability of the following maps of $\log_{10} z_0$

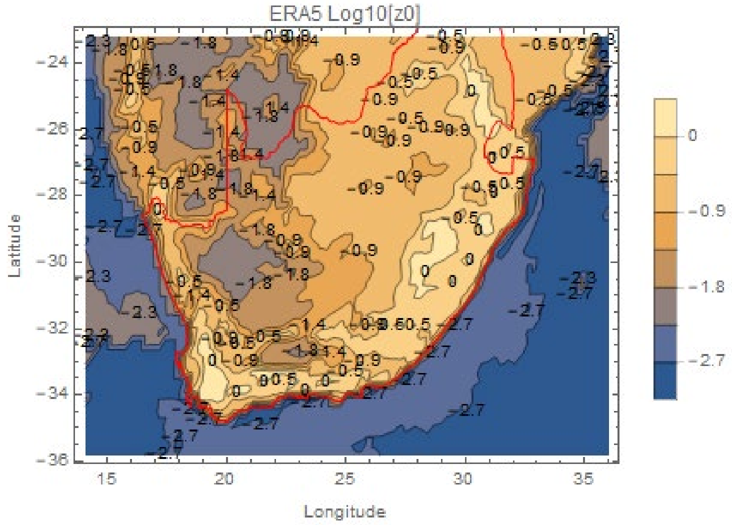
7.3.1 Comparison over South Africa

Roughness length used for generalization

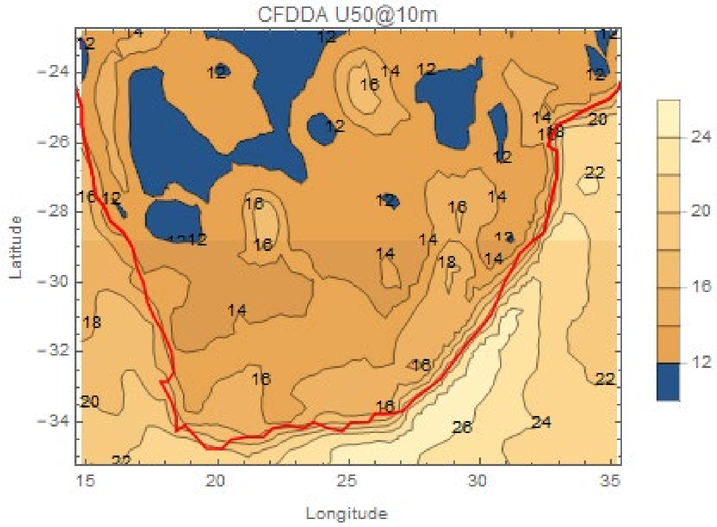


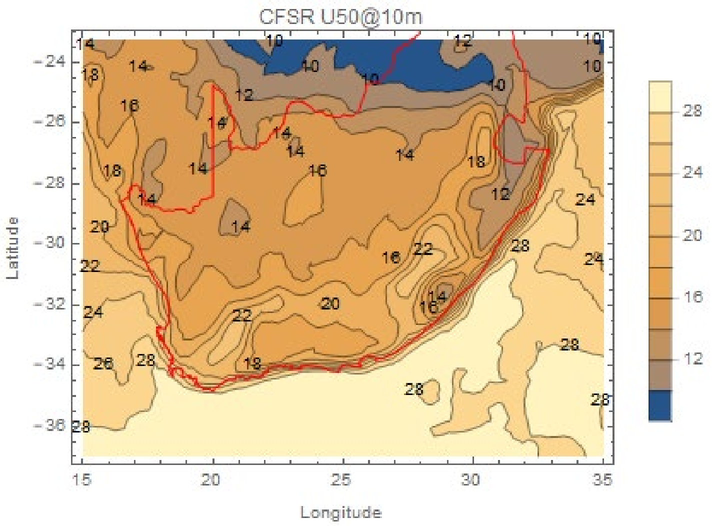


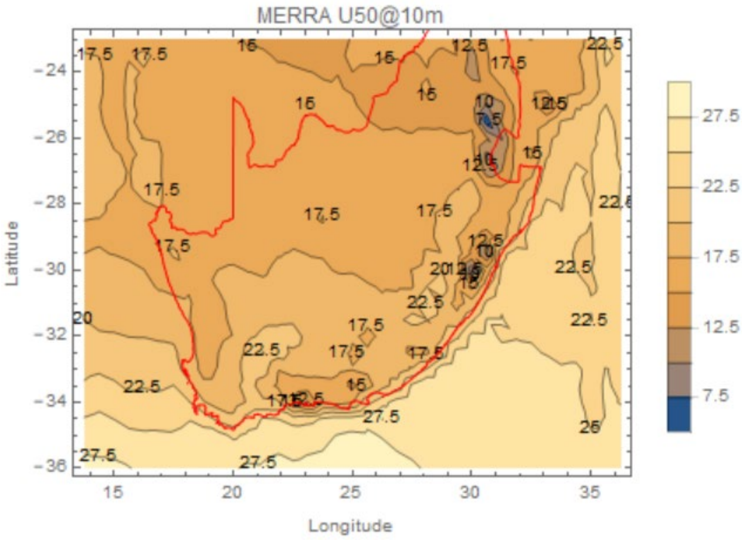


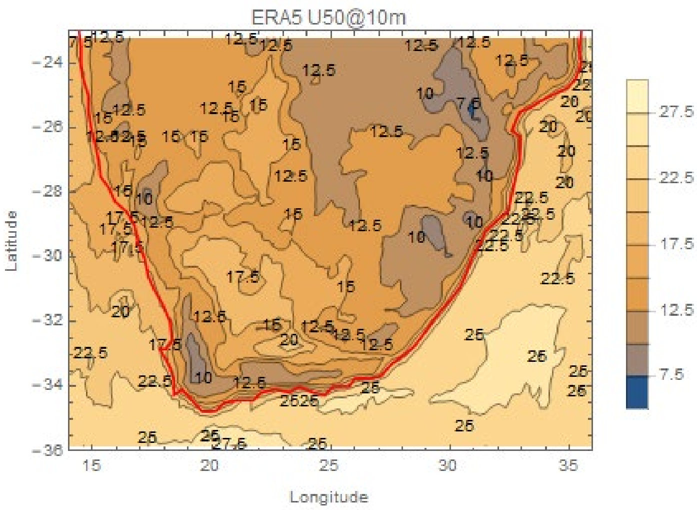


U50, hourly value, no spectral correction









Generalized U50, at a resolution of 1 h

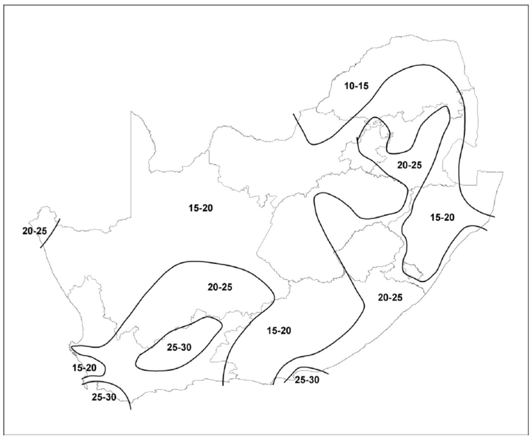


Fig. A. The atlas of the generalized 50-year wind (at 10 m, over roughness length of 5 cm) for South Africa using standard meteorological measurements, one-hour resolution (Kruger et al. 2011).

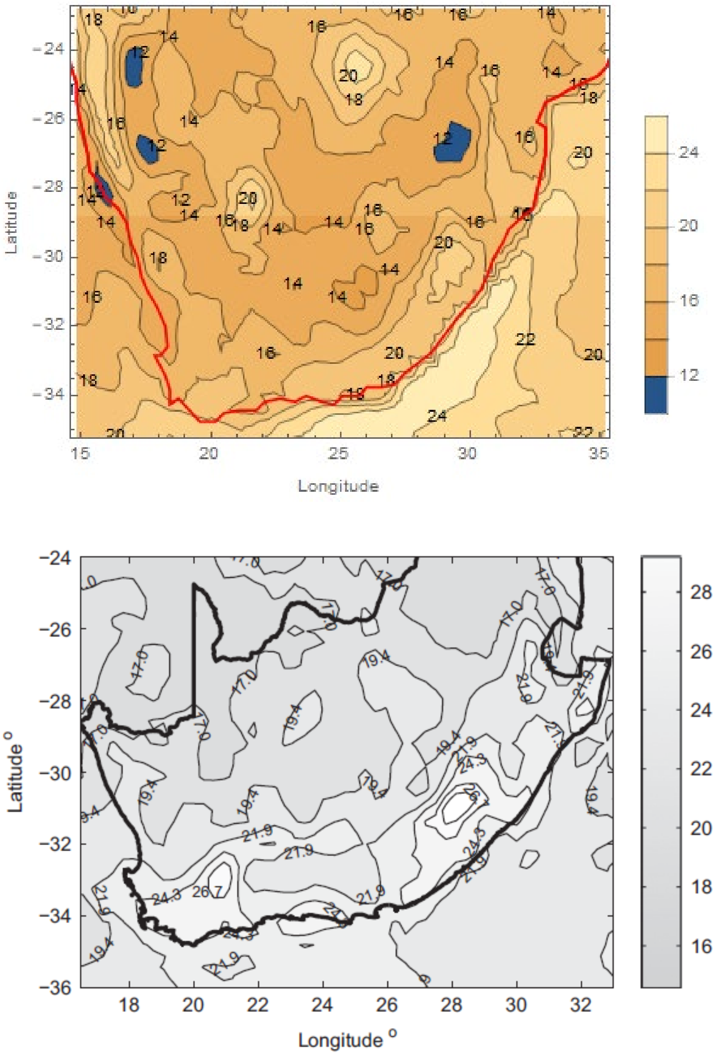
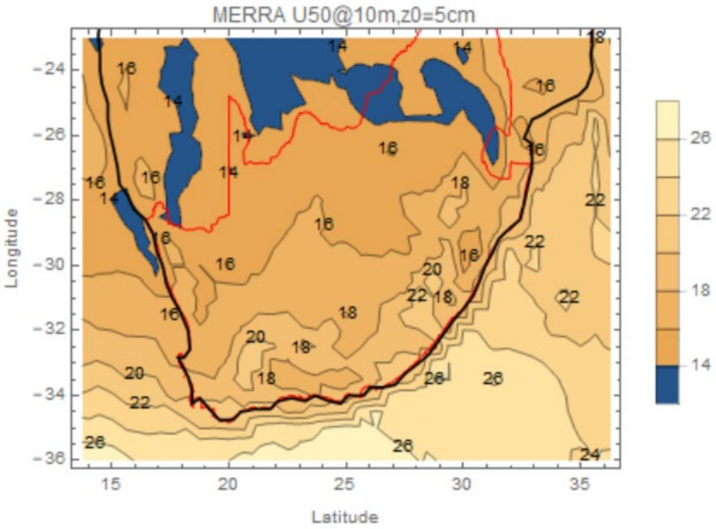
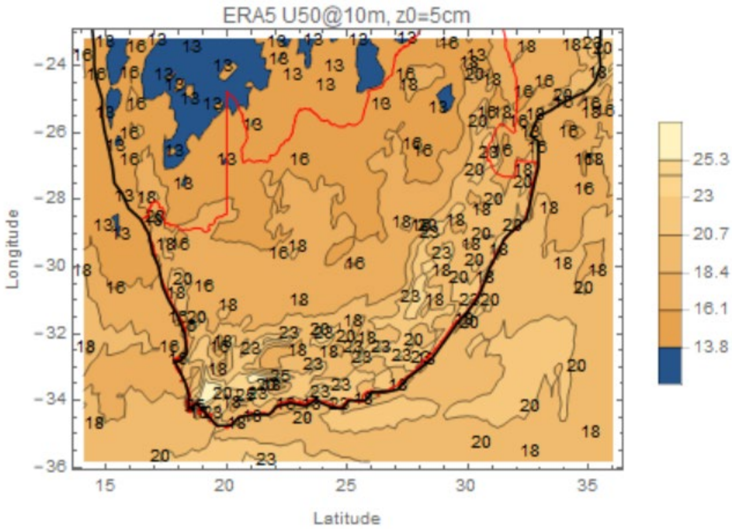


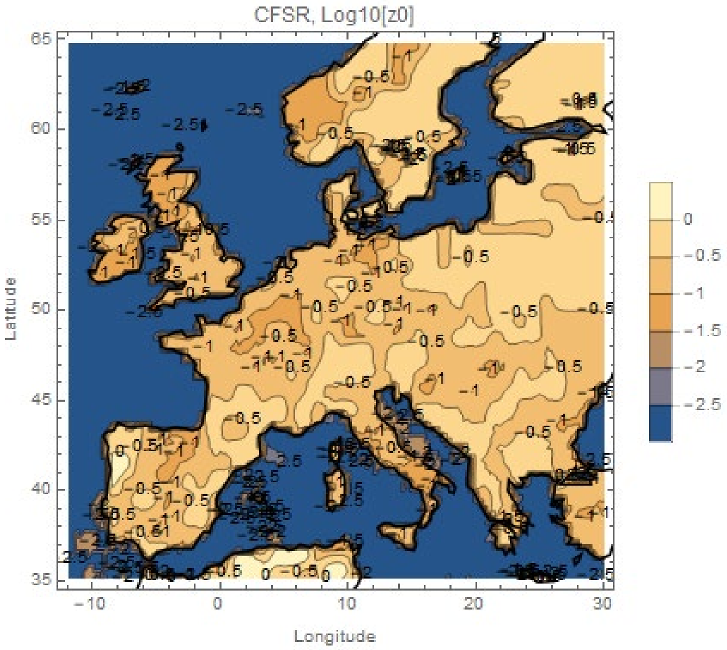
Fig. B. The atlas of the generalized 50-year wind (at 10 m, over roughness length of 5 cm) for South Africa using CFSR data, spectral correction to equivalent 1-h resolution. This is a copy from Larsén and Kruger (2015)





7.3.2 Comparison over Europe

Roughness length used for generalization


CFSR, Log10[z0]
Latitude
Longitude
65
60
55
50
45
40
35
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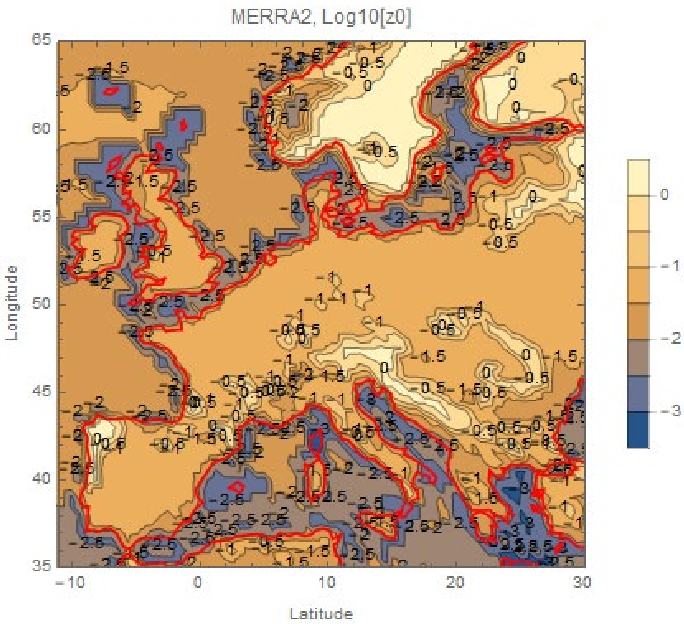
0
10
20
30
0
−0.5
−1
−1.5
−2
−2.5


MERRA2, Log10[z0]
Longitude
Latitude
65
60
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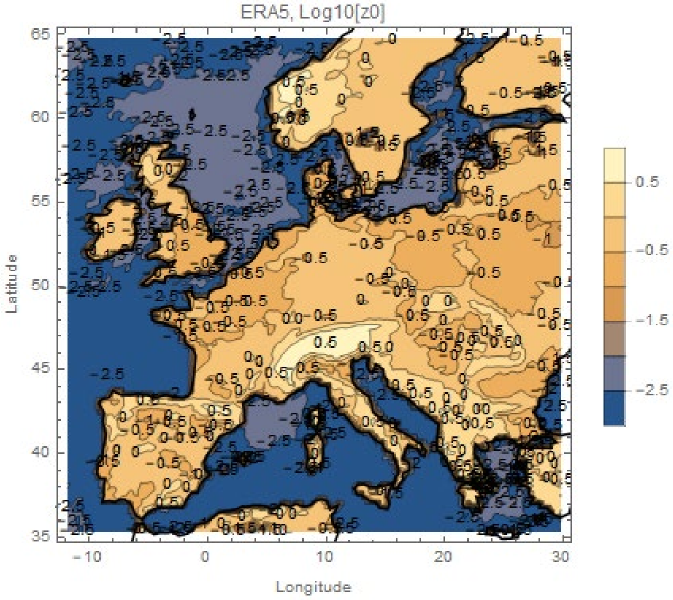
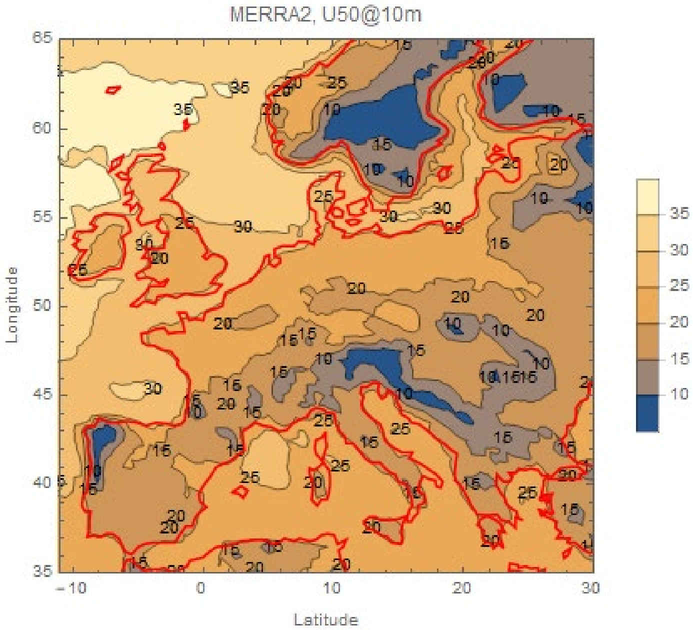
50
45
40
35
−10
0
10
20
30
0
−1
−2
−3



U50 at 10 m, without generalization nor spectral correction


MERRA2, U50@10m
Longitude
Latitude
65
60
55
50
45
40
35
−10
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20
30
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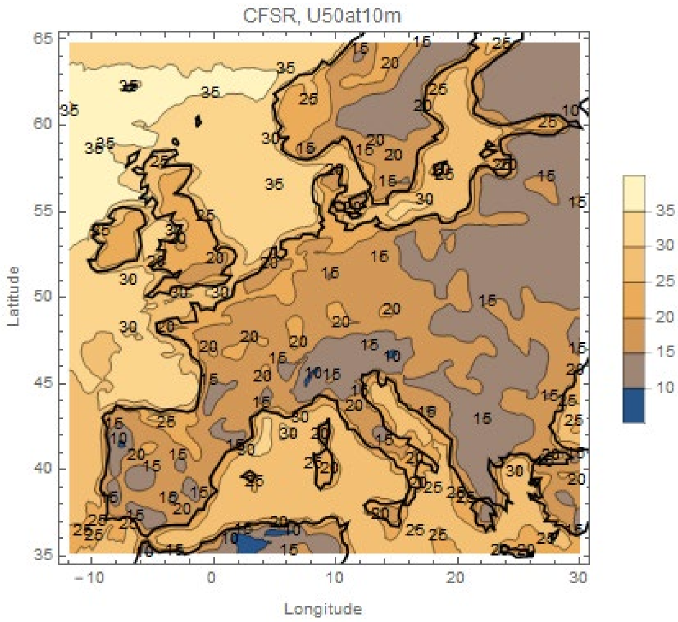
30
25
20
15
10


CFSR, U50at10m
Latitude
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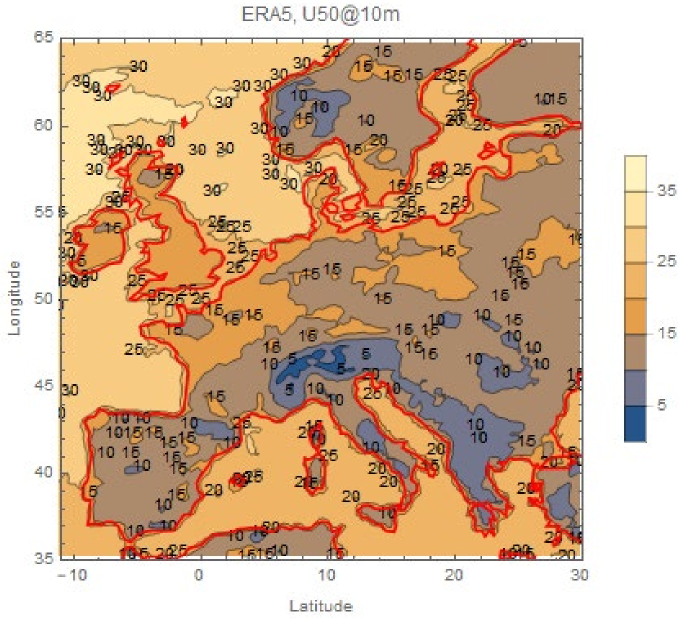
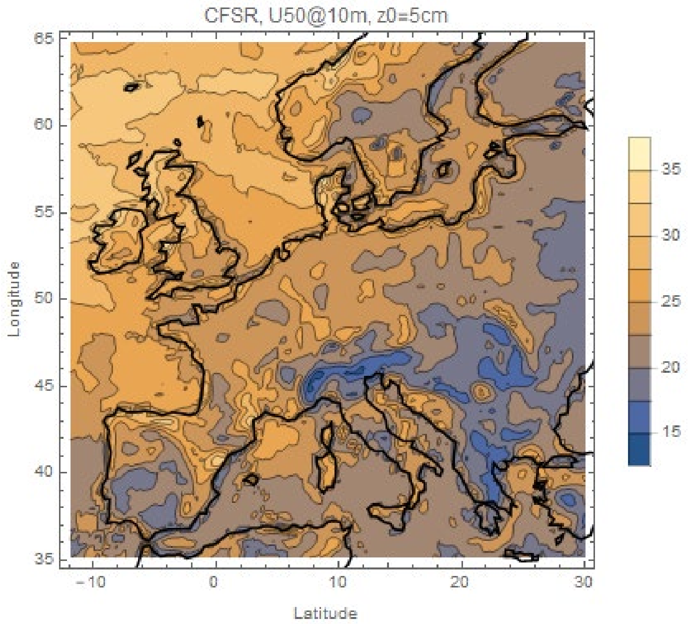
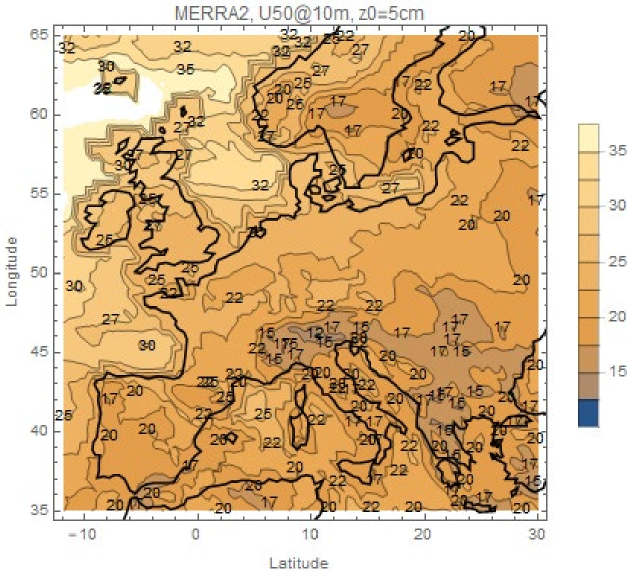
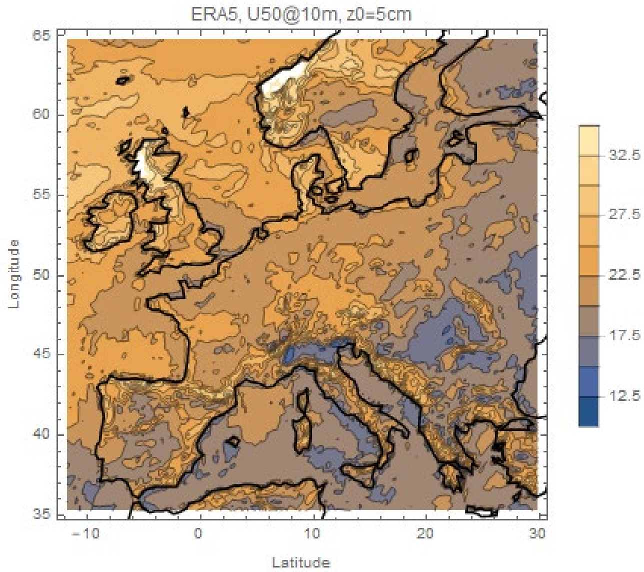


U50 of generalization with spectral correction







7.4 Conclusions

Over land, the direct wind time series give very different estimate of the 50-year wind (Figures in section 3.1.2), regarding mostly the magnitude. This seems to be related to the values of roughness length from these reanalysis data. The generalization brings the estimates to a more comparable level, though the differences are sometimes still not negligible. We use the map from measurements as the reference.

If we start with one reanalysis data, CFSR data seems to be a reasonable choice. Depending on the calculation cost, it would be an attractive idea for WEng to use several data sets, so that the user can either choose a “conservative” or an “ensemble” value for their final calculation.

Over water, please note that the roughness lengths are artificial and they were derived from extreme wind values in order to secure a smooth transition of land-sea roughness length change as used in the generalization. Over water, generalization should NOT be applied and the direct calculation from the time series is recommended. Apart from that, over water, the 50-

year winds from the original wind time series are actually quite similar, even though the picture is different for land grid points.

7.5 References

Hansen et al. (2016): Extreme wind calculation applying spectral correction method – test and validation. DTU Wind Energy E, vol. 0098

Kruger,A.C., Retief,J.V. and Goliger,A.M. (2011): An updated description of the strong wind climate of South Africa. Proceedings, 13th International Conference on Wind Engineering, 9–11 July 2011, Amsterdam.

Larsén X.G. 2014: Guidelines for applying the spectral correction method to modelled data to obtain REWC. DTU WIND RAM Internal report.

8. Appendix-B: Data requirements for IEC site assessment

Prepared by Rogier Floors, July 2019

Site assessment is described in chapter 11 of IEC 61400-1. The following list is read from edition 4.

8.1 Topographical complexity

- Turbine hub height
  - Is there a fixed hub height already for GasP?
- Terrain elevation map with min 50m resolution[12] extending 20 hub heights from all turbine positions
  - Thøgersen (2019) showed that for 1145 turbine locations the lowest errors compared with national height campaigns was achieved using the SRTM 1 arcsecond (approx. 30 m) data and the new AlosWorld 1 arcsecond data. The resolution is close to the recommended value of 20 m. SRTM 1 arcsecond data are available at */mnt/ventus/MAP*
  - We could use SRTM 1 arcsec but we need to voidfill. Neil has a script to do that and estimates this to take 1-2 person months. Alternatively we can use the dataset from GWA3 based on SRTM 3 arcsec patched with Viewfinder which is voidfilled to some extent. In the Alpes there is still some regions that are not very good, all areas where WasP crashed were fixed but might still be poor.
- Turbine positions in the same coordinate system as the map

8.2 Turbulence structure

Two *alternative* classification methods

a) Ratios of the standard deviations of *measured*[13] turbulent components σ_v/σ_u and σ_w/σ_u or
b) The above-mentioned topographical complexity

8.3 Wind conditions

These wind conditions are needed at hub height

- Extreme 10-min average wind speed with a recurrence period of 50 years, U50[14]
- COV of U50[15]
- Mean wind speed probability distribution[16]
  - GWA3 has netcdf files at 250 m resolution in UTM projection: A,k,f, sectorwise created with wasp12 worker in frogfoot. The roughness is based on the CCI2015 database and the elevation on SRTMv3 60 degrees away from the

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[12] Higher resolutions, say 20m, would be better
[13] We normally use *modelled* turbulence from the Mann model
[14] Caution for areas prone to tropical storms, optional annex suggests a method based on Holland model + MCP
[15] New requirement in edition 4, can be calculated by the Gumbel fit slope parameter
[16] Maybe simplified to sector-wise Weibull distributions. Long-term correction is recommended

equator and viewfinder for latitudes poleward of that. Nazka mapps might have a info about new landuse product that could be interesting. The elevation and RIX are available at this resolution as well, but no mesoscale roughness are speedup-factors.

- Turbulence intensity[17], based on longitudinal velocity fluctuations in 10 min periods
    - Potentially we could use the new landcover data from Copernicus available here. It is not clear to me what this dataset is referred to, but it is available here http://lcviewer.vito.be
    - In flat terrain, the better the roughness is estimated, the better we can probably estimate turbulence intensity.
- Climatological variability of turbulence intensity
- Extreme turbulence intensity[18]
- Flow inclination from horizontal
    - A easy and probably reasonable assumption is to assume that there is now flow separation and that the flow inclination follows the terrain. The difference between the linearized models that could be used (WasP/LINCOM) and this assumption should be small.
- Wind shear[19]
    - GWA has sectorwise wind speeds at 5 heights: 10, 50, 100, 150, 200 m. These could be used to find a wind shear. Potentially we could improve shear by using directly mesoscale sectorwise wind shear or using sectorwise heatfluxes from reanalysis or mesoscale model.
- Air density
    - There was a bug in PyWAsP which caused computations to be using a dry atmosphere. The calculations from GWA3 were not affected by this bug, because they are based on the frogfoot calculator from WIAB. To get higher accuracy air density it would take little computational effort to recalculate with different elevation and reanalysis data (ERA5?) and including the effects of varying lapse rate (Floors,2019).

The information is needed in 30-degree sectors and 2 m/s wind speed bins

8.4 Wake turbulence

The standard says that you have to consider this as part of the site assessment, and suggest the effective turbulence intensity[20] or the dynamic wake meander model[21] as two optional ways to handle the problems. In either case you will need

- Ambient turbulence intensity (mean and variability) as above
- Wind farm layout
- Thrust-coefficient curve of turbine
- Turbine hub height and rotor diameter

8.5 Other environmental conditions

- Temperature

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17 Preferably de-trended

18 New requirement in edition 4, can either be calculated by IFORM or a simple formula given in the standard

19 Preferably measured

20 Implemented in WAT

21 Implemented in HAWC2

- Humidity
- Ice, hail and snow[22]
- Lightning
- Solar radiation
- Chemicals
- Salinity
- Earthquakes[23]
- Soil properties

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[22] Heavy rain is not mentioned yet but maybe it should

[23] The standard has an optional annex describing a simplified earthquake analysis.

Acknowledgements

This report summarizes inputs from project meeting notes, preliminary reports and informal email discussions.