Gesellschaft für Umweltmeteorologie mbH

Documentation

on the anemos wind atlas

for France 3 km

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1. Introduction

The new **anemos wind atlas** for France 3 km (**F-3km.M2**) represents a database containing long-term time series for the atmospheric parameters wind speed, wind direction, air temperature, air pressure, relative humidity, air density, precipitation, long- and shortwave radiation. The temporal resolution of the wind atlas is 10 minutes, the horizontal resolution is 3 x 3 km². It covers whole France, Switzerland, Belgium and Corsica as well as the coastal areas of the Atlantic Ocean and Mediterranean Sea. Fig. 1 shows the process chain of the development of the anemos wind atlas. The three main issues are:

- Optimization of the model settings with subsequent WRF main simulation (Downscaling)
- Wind atlas remodelling (Optimization of the WRF main simulation)
- Verification of the WRF main simulation with wind measurements

More detailed explanations of these three issues can be found in chapters 4 - 7.

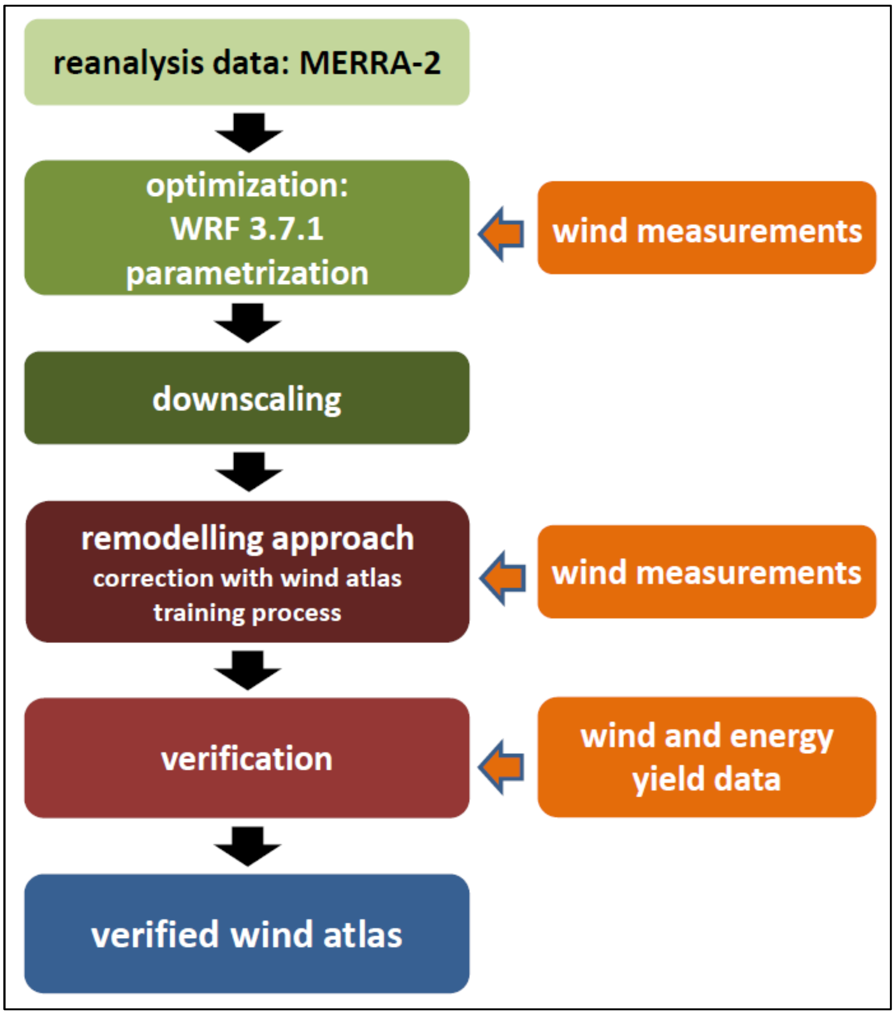

Fig. 1: Developmental steps of the new anemos wind atlas for France 3 km.

2. The WRF model

The wind atlas **F-3km.M2** is created by means of the meteorological mesoscale model **WRF** (**W**eather **R**esearch & **F**orecasting model with the version 3.7.1). The WRF model is a state-of-the-art weather forecast system (coupled atmospheric-land surface model) of the next generation which was developed in the 1990s at **NCAR** (**N**ational **C**enter for **A**tmospheric **R**esearch).

WRF is a non-hydrostatic model (explicit calculation of the vertical velocity) and estimates for each time step the Navier-Stokes equations, which describe the atmospheric flow. Mesoscale processes such as the land-sea wind circulation or deep convection (thunderstorms) can be sufficiently resolved by the model. However, microphysical processes as well as shallow convection, radiation or planetary boundary processes have to be parameterized.

The WRF model with its so-called multi-nesting ability allows for a simultaneous calculation of several model domains with different grid resolutions (Fig. 2). This way, regional high-resolution simulations of the atmospheric circulation are possible, which employ detailed ground level information in order to take into account the impact of vegetation, roughness and orography.

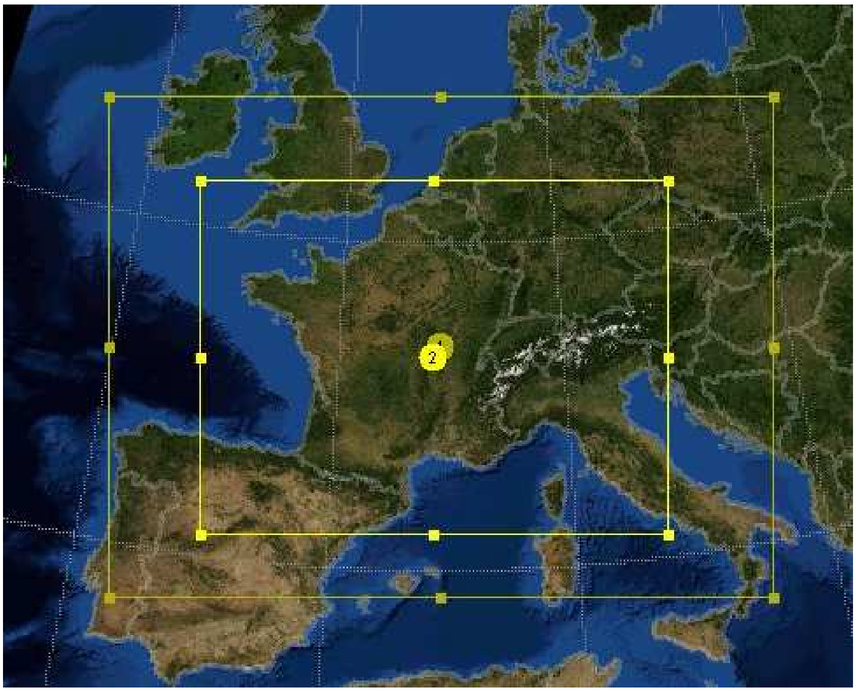

Fig. 2: Multi-nesting process with two domains of the anemos wind atlas France 3 km. Domain 1 with 15 x 15 km² and domain 2 (Nest) with 3 x 3 km².

For the wind atlas **F-3km.M2** a nest with two domains is applied (Fig. 2). The simulation area consists of a coarser exterior domain inside which a high-resolution interior domain is nested. The exterior domain covers great parts of Europe and has a spatial resolution of 15 x 15 km². The interior domain covers France and the Alpine Region with a spatial resolution of 3 x 3 km². During the simulation process, both domains communicate with each other. The exterior domain supplies the boundary conditions for the interior domain, while latter feeds the exterior domain with high-resolution calculations.

During the simulation, new input data are assimilated into the WRF model every three hours, which forces the model into the right direction (nudging process). The atmospheric state variables are stored every 10 minutes for each grid point on a grid. The simulation covers the period 2007 up to date and is continuously extended. The vertical model structure of the atmosphere has a high resolution with 25 vertical layers. The lower heights, which are relevant for wind turbines (up to 250 m) contain already 8 of the 25 vertical layers.

3. Input data

The WRF model requires surface data (soil temperature, soil moisture, snow, etc.) as well as all important atmospheric parameters (wind, temperature, pressure, relative humidity, etc.) as input data. For the wind atlas **F-3km.M2** the worldwide available MERRA-2 reanalysis data are used as input and driving data. The MERRA-2 reanalysis data are of higher quality than the former MERRA reanalysis data regarding consistency and correlation. Therefore, the advantages of the MERRA-2 reanalysis data such as consistency, homogeneity, length of time series, continuous updates, onshore as well as offshore availability can be preserved or even amplified by the WRF model. In addition, the disadvantages of relatively low spatial (0.5° latitude, 0.625° longitude, corresponding to approx. 50 x 50 km²) and temporal resolution (3 h) of MERRA-2 reanalysis data are surmounted by the anemos wind atlas **F-3km.M2**.

The surface data are taken from the **CFS** data set (NCEP **C**limate **F**orecast **S**ystem). It consists of four surface levels and contains soil moisture, soil temperature and snow. The CFS data have a temporal resolution of six hours and a horizontal resolution of 0.2° latitude and 0.2° longitude.

The ground level elevations are taken from the **SRTM** data set (**S**huttle **R**adar **T**opography **M**ission, USGS EROS Data Center) and interpolated onto the model grid. These data were collected in the year 2000 and are available with a spatial resolution of about 90 m. The vertical resolution is 1 m. Any information about vegetation or roughness conditions within the boundaries of the simulation area are derived from the **CORINE** data set of the European Environment Agency (**EEA**). This information is based on data of the satellite LANDSAT 7 scaled 1:100.000. The grid data are available in a spatial resolution of 100 m.

4. Optimization of the model settings

The model settings and parameterizations (e.g. planetary boundary scheme, surface scheme, radiation scheme) were tested prior to the main simulation and optimized for the relevant atmospheric parameters (wind speed and wind direction). The model settings were compared with the Germany wind atlas (**D-3km.M2**) and were verified with wind measurements (met masts and LiDAR, see Fig. 1). These tests show how the wind field near the ground reacts to different parameterizations and schemes (sensitivity tests). After that, the setting which yields the smallest deviations between model and observations was used for simulating the entire time period (> 10 years).

5. Statistical verification with wind measurements as preparation for remodelling

The most important task after running the main simulation is its intensive verification with a variety of wind measurements. 24 measurements were used for verifying the **F-3km.M2**.

Through the verification the quality of the main simulation is determined. In the next step, systematic errors are identified and removed (remodeling, ch.6) and consequently, the quality of the wind atlas is greatly improved. The verification includes statistical key parameters such as mean values, coefficient of determination (R^2) or correlation (R), bias, root mean squared error (RMSE) and extreme values (QQ-plot). Additionally, vertical profiles, diurnal cycles, wind roses, and frequency distributions with Weibull parameters are checked.

6. Remodelling

After the complete verification of the main simulation with all available wind measurements, the wind atlas is optimized by a remodelling process. Based on the results of the verification in chap. 5, a sectorial training with 18 wind measurements is realized. The remaining measurements are used for the subsequent independent verification of the remodelling process.

During the training process, scale parameters are developed by a multiple linear regression analysis, which are then applied to the wind atlas time series. Dependencies between the scaling parameters and the sub grid topography are identified and applied if they are significant. Consequently, all grid cells can be corrected with the developed scaling parameters based on the sub grid information (orography, roughness, etc.). Eventually, remodelling improves the statistical key parameters as well as the frequency distribution with Weibull parameters and the vertical wind profile.

7. Site-specific time series of wind speed

Within the frame of the remodelling process, a site-specific elevation correction was developed based on CFD simulations at several complex measurement sites. The CFD model Meteodyn WT simulates the 3 km x 3 km grid cells of the test sites with a high spatial resolution. The orographic information is taken from the SRTM data set (3 arcsec ~ 90 m).

Since the elevation correction considers the difference in elevation between the grid cell and the measurement, the site-specific correction leads to improvements in mean wind speed and all derived variables especially in complex regions. In flat terrain, the elevation correction has no significant impact because of the small height variations. The height correction function is applied to each time step of the time series.

8. Verification after remodelling

After remodelling, the wind atlas times series are verified with 39 wind measurements, which are roughly displayed with red dots in Fig. 3. The measurements are concentrated in the northern and central parts of France and in southwest Germany. In Fig. 4 the results of the verification are shown for a measurement height between 40 m and 120 m. The bias of wind speed is calculated and shown for 3 offshore- and 36 onshore-sites.

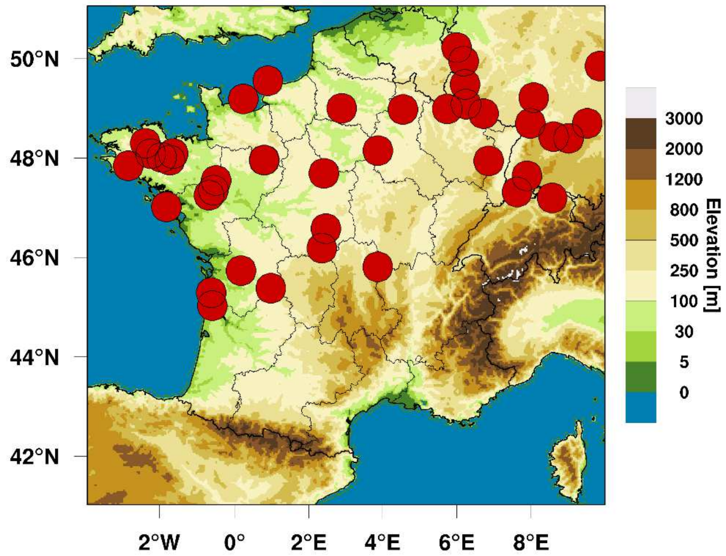

Fig. 3: Final model domain of anemos wind atlas France 3 km (compare with Fig. 2). The color bar shows the model elevation. Red circles mark roughly (± 50 km) the 39 measurement sites.

Fig. 4 shows the percentage deviations for each measurement in comparison to the wind atlas after remodelling and site-specific downscaling (F-3km.M2, green bar). Most sites exhibit a bias in the range of ± 7 % (87 % of the measurements) after remodelling, which is a significant improvement. The mean hourly correlation (R) is 84.9 % and the mean bias is -0.03 %. The standard deviation is 4.66 %.

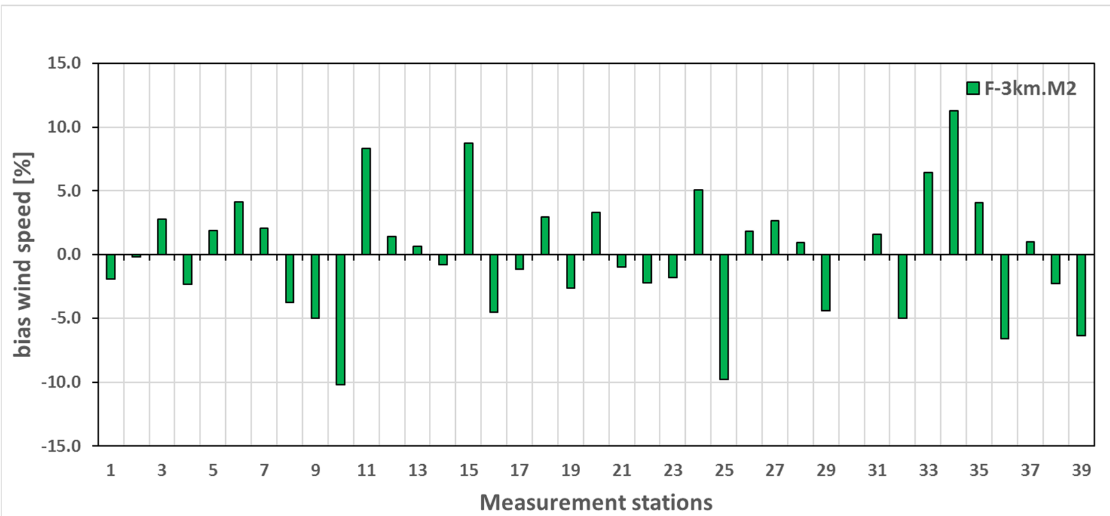

Fig. 4: Bias in mean wind speed between 39 internal wind measurements and the F-3km.M2 wind atlas (green). The measurement height is between 40 - 120 m.

9. Literature

Christoffer, J. und M. Ulbricht-Eissing, 1989: Die bodennahen Windverhältnisse in der Bundesrepublik Deutschland, Bericht des DWD, Nr. 147

Farr, T. G., et al., 2007: The Shuttle Radar Topography Mission, Rev. Geophys., 45, RG2004, doi:10.1029/2005RG000183; http://www2.jpl.nasa.gov/srtm/srtmBibliography.html

Gelaro, R. et al.,2017: The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2), AMS, doi: 10.1175/JCLI-D-16-0758.1

Howard, Tom and Clark Peter, 2007: Correction and downscaling of NWP wind speed forecasts, Meteorol. Appl. 14: 105-116

Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, Gandin L, Iredell M, Saha S, White G, Woollen J, Zhu Y, Chelliah MW, Ebisuzaki W, Higgins J Janowiak KC, Mo C, Ropelewski A, Leetmaa R, Reynolds, Jenne R (1996) The NCEP/NCAR reanalysis project. Bull. Am. Meteorol. Soc., 77:437–471

Keil, M., M. Bock, T. Esch, A. Metz, S. Nieland, A. Pfitzner, 2010: CORINE Land Cover Aktualisierung 2006 für Deutschland. Abschlussbericht zu den F+E Vorhaben UBA FKZ 3707 12 200 und FKZ 3708 12 200, Deutsches Zentrum für Luft- und Raumfahrt e.V., Deutsches Fernerkundungsdatenzentrum Oberpfaffenhofen, Januar 2010

Mengelkamp, H.-T., 2015: Wind-, Ertrags- und Erlösgutachten für Windenergieanlagen, promet – meteorologische Fortbildung, Hrsg. Deutscher Wetterdienst, Jahrg. 39, Nr. 3/4, 193-202

Mengelkamp, H.-T., 1988: On the energy output estimation of wind turbines, Int. Journal of Energy Research, 12, 113-123

Mengelkamp, H.-T., 1999: Wind Climate Simulation over Complex Terrain and Wind Turbine Energy Output Estimation, Theor. Appl. Climatol, 63, 129-139

Mengelkamp, H.-T., H. Kapitza und U. Pflüger, 1997: Statistical-dynamical downscaling of wind climatologies, Journal of Wind Engineering and Industrial Aerodynamics, 67&68, 449-457

Mengelkamp, H.-T., T. Sperling, 2005: Windindizes werden von Produktionsdaten unabhängig, Erneuerbare Energien, 2, 25-27

Rienecker, M.M., M.J. Suarez, R. Gelaro, R. Todling, J. Bacmeister, E. Liu, M.G. Bosilovich, S.D. Schubert, L. Takacs, G.-K. Kim, S. Bloom, J. Chen, D. Collins, A. Conaty, A. da Silva, et al., 2011: MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications. J. Climate, 24, 3624-3648, doi:10.1175/JCLI-D-11-00015.1

Schneider, M., J. Bethke, A. Glücksmann, H.-T. Mengelkamp, 2016: Der neue anemos Windatlas für Deutschland – Korrektur und Verifikation mit Windmessungen und Ertragsdaten, 25. Spreewindtage, 09. November, Potsdam

Staffell, Iain and Pfenninger Stefan, 2016: Using bias-corrected reanalysis to simulate current and future wind power output, Energy 114, 1224-1239

Thogersen, M.L. et. al., Measure-Correlate-Predict Methods: Case Studies and Software Implementation, EMD International A/S

Traup,S. und B. Kruse, 1996: Winddaten für Windenergienutzer, Selbstverlag des Deutschen Wetterdienstes

Troen, I. und E.L. Petersen, 1989: European Wind Atlas. Risø National Laboratory, Roskilde. 656 pp. ISBN 87-550-1482-8

WRF, 2017, User's Guides for the Advanced Research WRF (ARW) Modeling System, Version 3, WRF users page, http://www2.mmm.ucar.edu/wrf/users/docs/user_guide_V3/contents.html