



Gesellschaft für Umweltmeteorologie mbH

Preliminary documentation on the anemos wind atlas for Scandinavia 10 km

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1. Introduction

The new **anemos wind atlas** for Scandinavia 10 km (**SK-10km.E5**) 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 10 x 10 km². It covers whole Northern Europe (Scandinavia, Baltic Sea and the Baltic countries). 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 in process!* (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 the following chapters.

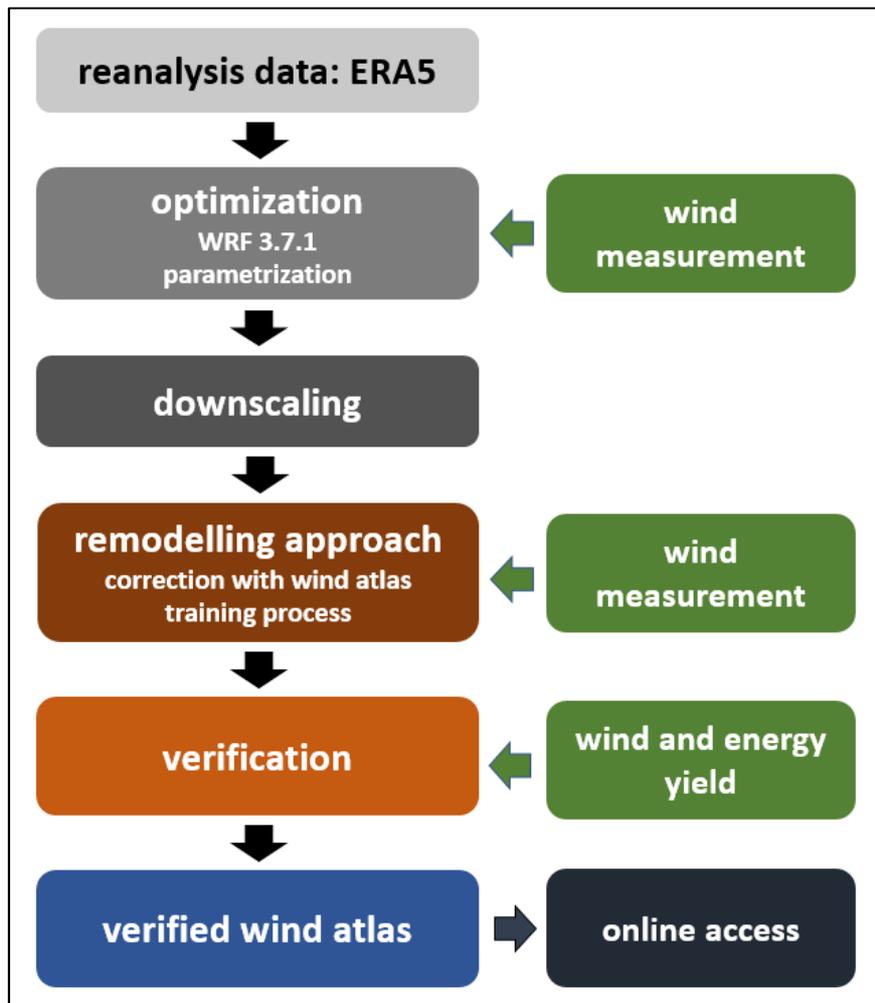


Fig. 1: Developmental steps of the new anemos wind atlas for Scandinavia 10 km.

2. The WRF model

The wind atlas **SK-10km.E5** is created by means of the meteorological mesoscale model **WRF** (**Weather Research & Forecasting** 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** (**National Center for Atmospheric Research**).

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 can be sufficiently resolved by the model. However, microphysical processes as well as 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: Domain of the anemos wind atlas Scandinavia 10 km. Domain with 10 x 10 km².

For the wind atlas **SK-10km.E5** one domain is applied (Fig. 2). The domain covers great parts of Northern Europe and has a spatial resolution of 10 x 10 km².

During the simulation, new input data are assimilated into the WRF model every hour, 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 300 m) contain already nine 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 **SK-10km.E5** the new worldwide available ERA5 reanalysis data are used as input and driving data. The ERA5 reanalysis data are of higher quality than the former ERA-Interim reanalysis data regarding consistency and correlation. Therefore, the advantages of the ERA5 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 (approx. 30 x 30 km²) and temporal resolution (1 h) of ERA5 reanalysis data are surmounted by the anemos wind atlas **SK-10km.E5**.

The surface data are taken from the ERA5 data set as well. Thus, consistency of the radiation- and heat flow between surface and atmosphere is given. The surface data consists of four surface levels and contains i.a. soil moisture, soil temperature and snow.

The ground level elevations are taken from the SRTM data set (Shuttle Radar Topography Mission, 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 USGS data set (United States Geological Survey). The grid data are available in a spatial resolution of 1 km.

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 (**D-3km.M2**) and France wind atlas (**F-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

The most important task after running the main simulation is its intensive verification with a variety of wind measurements. 18 measurements were used for verifying the **SK-10km.E5**.

Through the verification the quality of the main simulation is determined. 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.

The distribution of the measurement sites is roughly displayed with red dots in Fig. 3. 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 4 offshore- and 14 onshore-sites. Fig. 4 shows the percentage deviations for each measurement in comparison to the wind atlas (raw data). The mean daily correlation (R) is 94.3 % and the mean bias is +2.5 %. The standard deviation is 5.92 %.

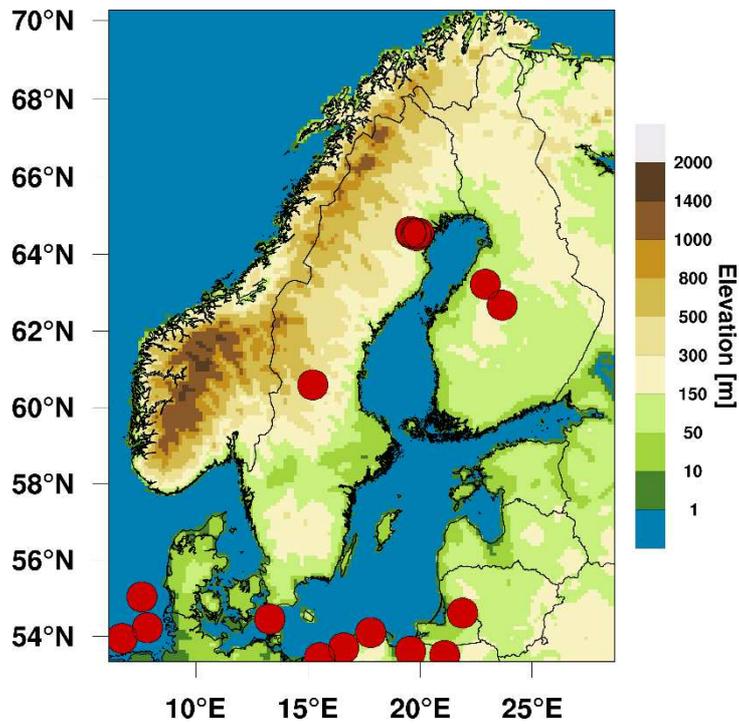


Fig. 3: Final model domain of anemos wind atlas Scandinavia 10 km. The color bar shows the model elevation. Red circles mark roughly (± 50 km) the 18 measurement sites.

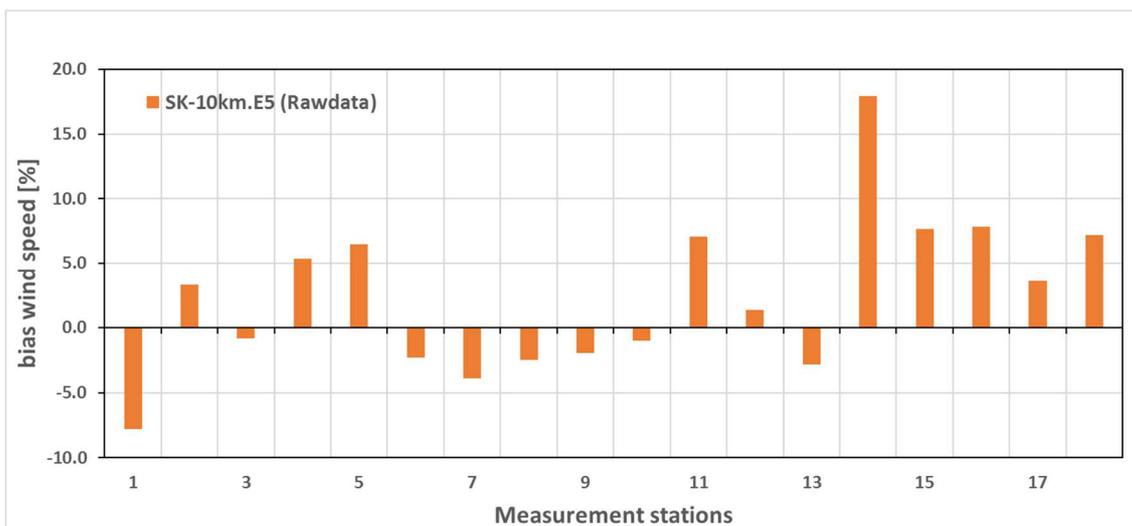


Fig. 4: Bias of mean wind speed between 18 internal wind measurements and the SK-10km.E5 wind atlas (orange). The measurement height is between 40 - 120 m above surface level.

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