Wind resources in CMIP6 models for the North Sea

Work in progress…

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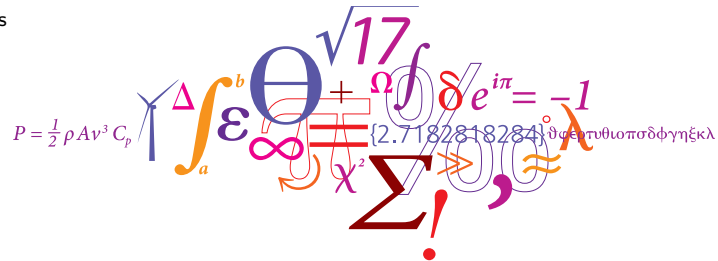

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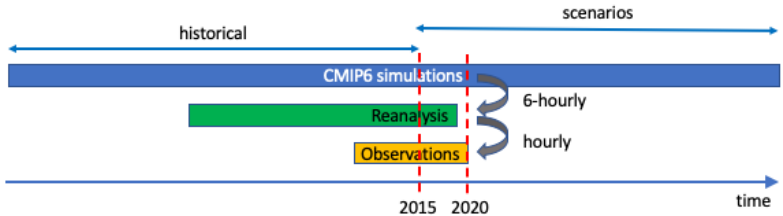
Outline

- Introduction
- Atmospheric reanalysis
- CMIP6
- Methods
- Results
- Future work

Objectives

1. Examine the spatial and temporal distribution of wind speed in various recent reanalysis over the North Sea.
   Question: What reanalysis should one use to assess climate model simulations?
2. Compare the wind climate simulated by the CMIP6 models over N. Europe and Scandinavia to that from atmospheric reanalysis.
3. Part of a step-by-step approach for validation:



4. What changes in wind climate do the CMIP6 models predict for the North Sea in near future? (Preliminary evaluation; power density and AEP are forthcoming)

Summary of modern atmospheric reanalysis

reanalysis product; release year	resolution	frequency	period	advantages	disadvantages
ECMWF ERA5 (2016)	$0.25° \times 0.25°$ 137 levels	hourly	1979–	high resolution; U100 directly available	sub-grid orographic drag
NOAA 20CRv3 (2019)	$1° \times 1°$ 28 levels	3-hourly	1850–	long duration; consistent assimilated data	low resolution
NASA MERRA2 (2015)	$0.5° \times 0.625°$ 72 levels	hourly	1980–	updated often	medium resolution; only U50 available

A bit too low for wind energy applications

Comparison of atmospheric reanalysis

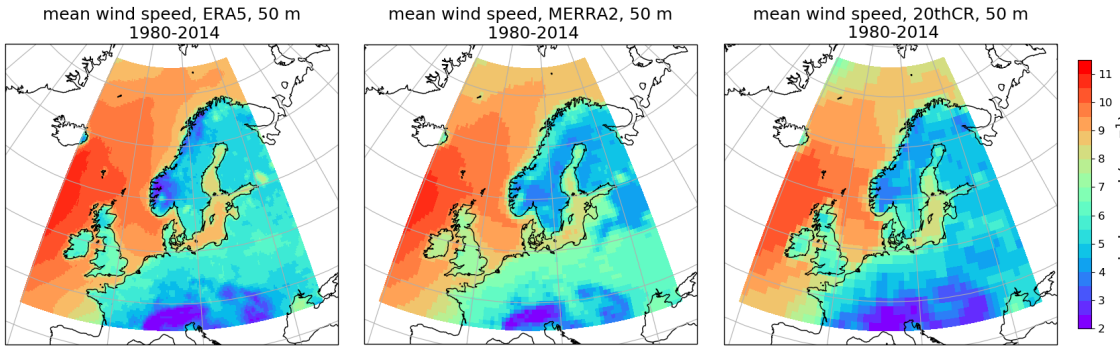


Figure: Mean wind speed (1980–2014) at 50 m, 1980–2014, ERA5, MERRA2 and 20thCR V3

ERA5 versus MERRA2

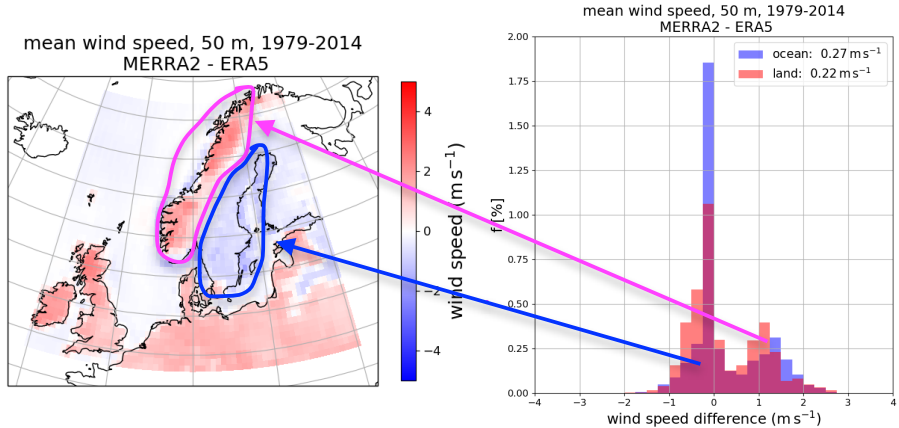
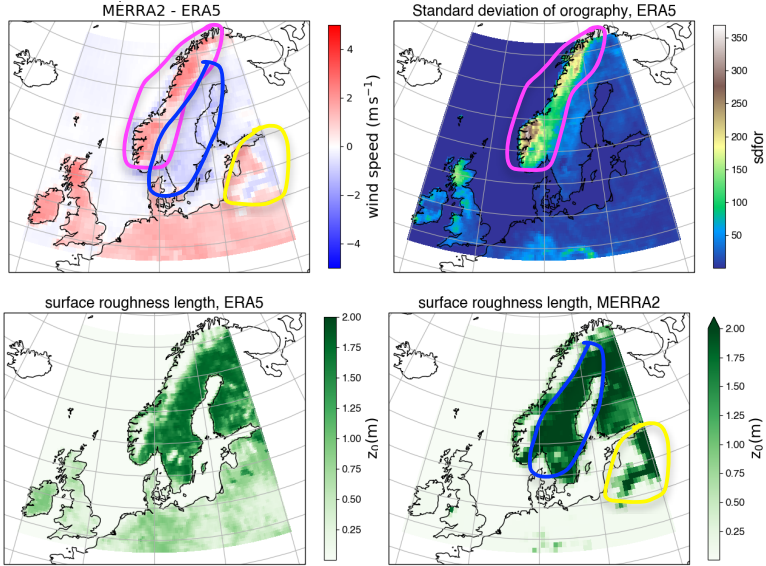


Figure: Differences in mean wind speed (1979–2014) at 50 m between MERRA2 and ERA5 reanalysis. [ERA5 data aggregated to MERRA2 grid]

ERA5 versus MERRA2



NOAA 20thC V3 versus ERA5

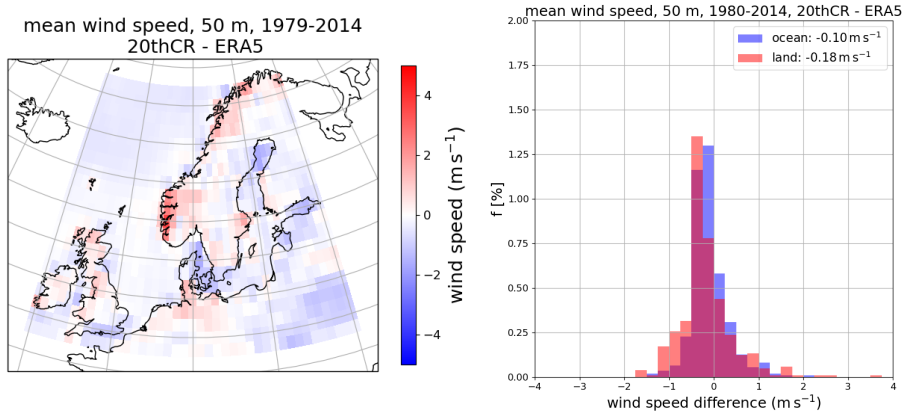


Figure: Differences in mean wind speed at 50 m between 20thCR and ERA5 reanalysis. [ERA5 data aggregated to 20thC grid]

Sorry, but the roughness length for 20thCR is not available

Temporal variability

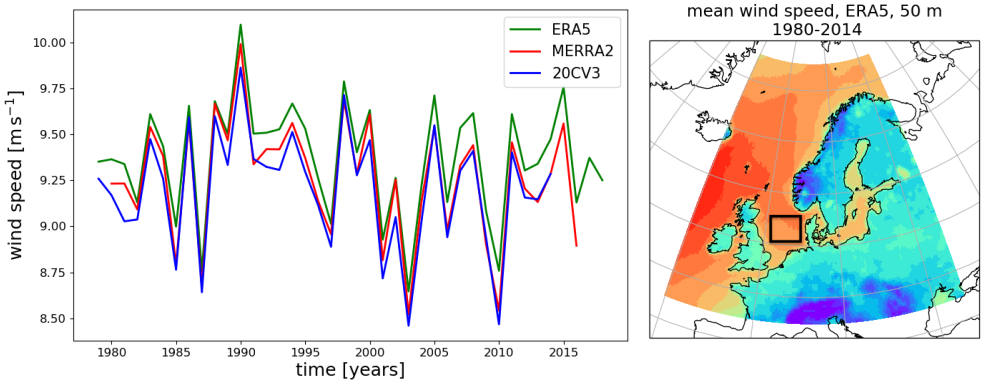


Figure: Annual mean wind speed over an area (54–57°N, 1.5–7.5°E) in the North Sea.

In summary...

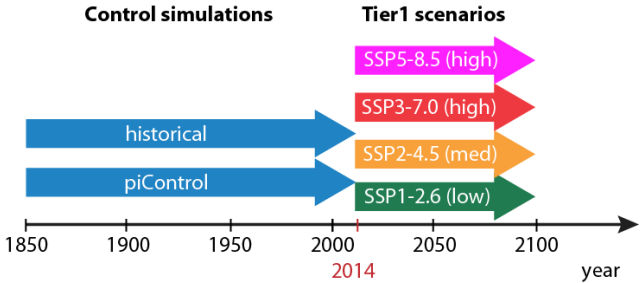
- The three reanalysis are very similar over this region
- Differences in the long-term mean wind speed are a mainly linked to the model representation of the aerodynamic surface properties
- Over the sea, ERA5 winds speeds at 50 m are slighly larger than in MERRA2 and 20thC V3.
- In the time domain, the interannual variability in the three reanalysis is nearly identical for the North Sea
- Concentrate future analysis to offshore resources in the North Sea, where other complications can be ignored

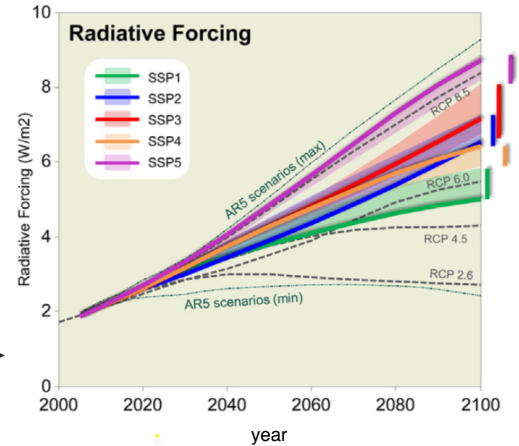
CMIP6 (Coupled Model Intercomparison – version 6)

- WCRP fosters development and review of coupled climate models
- Various CMIPs aimed at understanding natural climate variability and predictability on decadal to centennial time scales, and predicting the response of the climate system to changes in natural and anthropogenic forcing
- CMIP6 simulations are forced by evolving, externally imposed forcings such as solar variability, volcanic aerosols, and changes in atmospheric composition (greenhouse gases and aerosols) caused by human activities.

CMIP6 scenarios

Shared Socioeconomical Pathways (SSP) in CMIP6 — called Representative Concentration Pathways (RCP) in CMIP5.





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- CMIP6 simulations are forced by **evolving**, **externally imposed forcings** such as solar variability, volcanic aerosols, and changes in atmospheric composition (greenhouse gases and aerosols) caused by human activities.
- I have used data from:
  - **historical**: 1850–2014 (1981–2010 is used here)
  - **ssp585**: 2015–2100 (2021–2050 used here), analogous to RCP8.5 in CMIP5

CMIP6 models

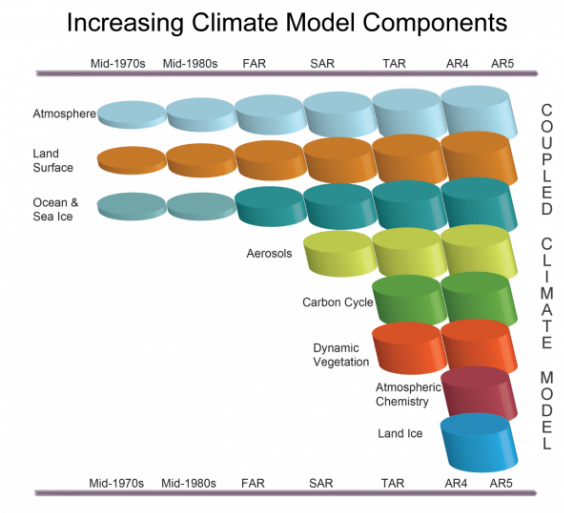

Figure source: adapted from Cubasch et al. (2013).

Two (main) types of models used here:

- Atmosphere-Ocean-Land coupled models (CMs) – **prescribed** time-varying land use
- Earth System Models (ESMs) can calculate atmospheric CO_2 concentration – often include **interactive vegetation** (fraction of various LU changes in time)

CMIP6 models – data download

- Well coordinated system of data naming and download servers
- Most data available from OpenDAP servers, with search (web and python) and direct read https://esgf-pyclient.readthedocs.io/en/latest/quickstart.html
- In python, files can be opened directly with Xarray (otherwise data analysis will be nearly impossible because files are enormous)

```
du =
xr.open_dataset("http://esg.lasg.ac.cn/thredds/dodsC/esg_dataroot/CMIP6/...")
u = du.ua.sel(lat=slice(50.,70.),lon=slice(350.,360.),time=t)
```

- Still process is slow on some servers

CMIP6 models – data processing

- Data frequency every six hours (mostly 00:00, 06:00,..., but sometimes 03:00, 09:00,...), number of samples in each file varies from model to model and sometimes field to field (from monthly to 20 years);
- Model fields on pressure-sigma coordinates, $p(i,j,k) = a(k) * p_0 + b(k) * ps(i,j)$. Exact definition of a, b can vary slightly from model to model (i.e. full versus half-level);
- Thickness (height) of layers determined by integrating hypsometric equation:

$$h = z_2 - z_1 = \frac{R_d \overline{T_v}}{g} \log \frac{p_1}{p_2}$$

  $\overline{T_v}$ needs temperature and specific humidity. Thus u, v, T, q, p_s are needed every 6 hours;
- Derived fields: wind speed (log interpolation) and wind direction (from linear interpolation of U and V) at $h = 50, 100, 200$ m above model terrain, also surface air density;
- The fields are computed in the python script and **only the derived fields** are written to local server.

CMIP6 models – available models

Table: Models with U,V available at model levels and 6-hourly output in the **historical** and **ssp585** simulations. Data forthcoming.

Model name	Center (Country)	grid spacing (lat x lon)
ACCESS-CM2	CSIRO (Australia)	1.25°x 1.875°
CNRM-CM6-1	CNRM (France)	1.4°x 1.4°
CNRM-ESM2-1	CNRM (France)	1.4°x 1.4°
IPSL-CM6A-LR	IPSL (France)	1.27°x 2.5°
MPI-ESM1-2-LR	MPI (Germany)	1.875°x 1.875°
MPI-ESM1-2-HR	MPI (Germany)	0.9375°x 0.9375°
NESM3	NUIST (China)	1.875°x 1.875°

Interesting set of models: (1) Same atmospheric core and resolution (CNRM), but CM and ESM simulations. (2) Same model (MPI-ESM1-2), but two (LR and HR) resolutions.

CMIP6 model comparison to ERA5

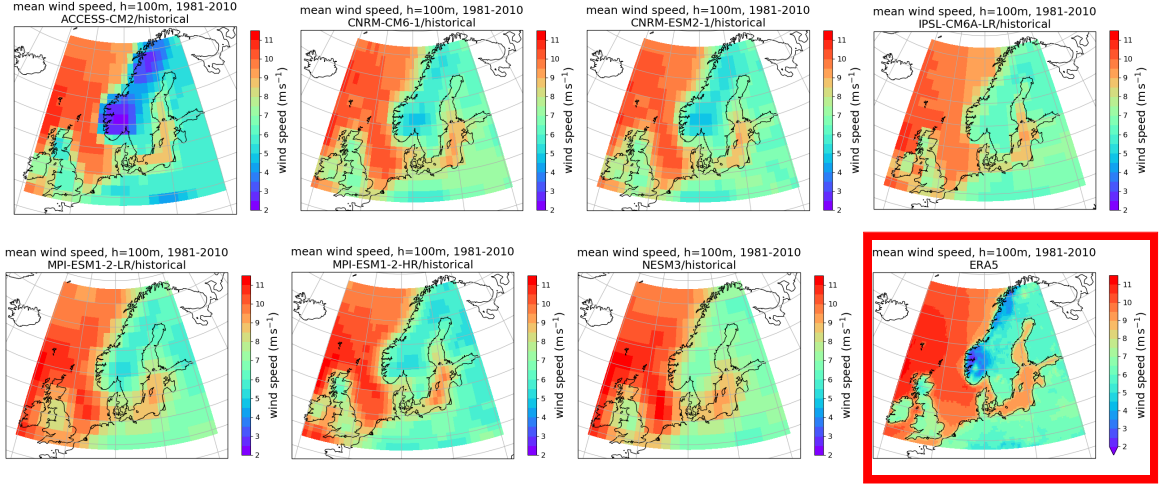

Figure: Mean wind speed (1981–2010) at 100 m in CMIP6 historical simulations and in the ERA5.

CMIP6 predictions of the future wind: ssp585 minus historical

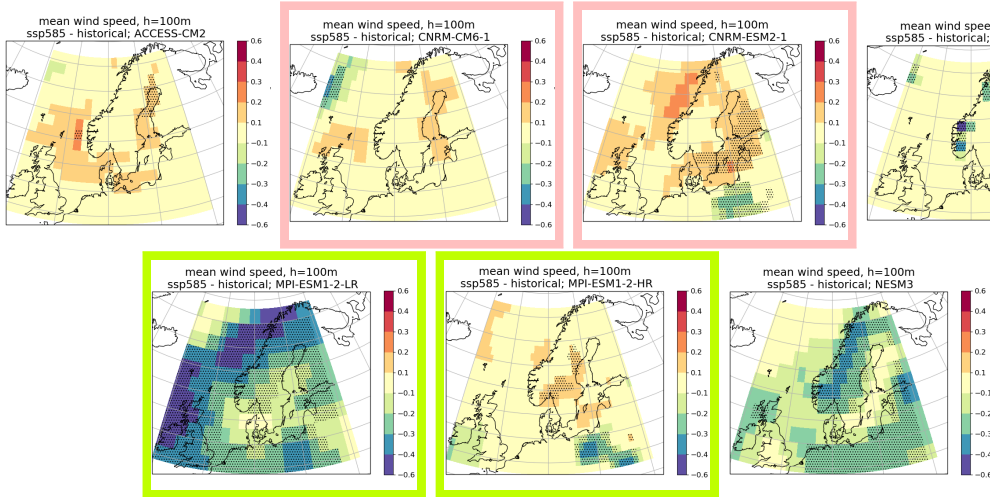

Figure: Mean wind speed difference (m/s) between ssp585 (2021–2050) and historical (1981–2010) periods. Dotted: changes are significant at the 95% level.

In summary...

- The mean wind in all CMIP6 historical simulations resembles that of the ERA5 reanalysis. Not surprising since in this region the land-ocean distribution and the orography (e.g. Norway) play an important role controlling the flow (much more work is needed here)
- The change in mean wind speed over northern Europe for the **so-far** available CMIP6 climate models is very varied
- Model resolution can give different results — see MPI model at low and high resolution
- The changes in mean wind speed in some models could be a consequence of land use changes and not changes in atmospheric circulation

Future perspectives

Many unresolved issues...

- How to deal with the different height in CMIP simulations? 100 meters AGL is a different height in the atmosphere in the different models...
- What constitutes a "good" model? What metrics should be used?
  - ✓ Smaller long-term bias in historical period?
  - ✓ Realistic wind direction distribution?
  - ✓ Realistic representation of the annual cycle?
  - ✓ Realistic inter-annual variability?

Future work

- Continue validation and understanding future changes in wind resources
- Examine the details of the landuse representation (what is land changes and/or circulation changes?)
- Python xarray + Fortran could be used to prepare CMIP6 forcing data for WRF simulations (data does not need to be downloaded)