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# Understanding the role of baroclinity on the wind in the northern seas' coastal areas

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## Introduction

Coastal areas are challenging for flow modeling, perhaps even more than complex terrain "traditional" areas like mountainous terrain and forested areas, as different atmospheric and marine phenomena are taking place at different scales. Abrupt changes in surface roughness, interaction between wind and waves, high horizontal and vertical temperature gradients are just few examples of such phenomena, which in many cases are unique for this type of areas. Coastal areas are however very attractive for wind energy because the wind resource is generally higher than that over land and the cost of energy is much lower compared to that of "more offshore" projects.

Our idea is to look at one particular physical phenomenon, baroclinity, which often occurs in coastal areas. Baroclinity is normally regarded to the change of geostrophic wind with height and so the strength of baroclinity is related to the strength of the horizontal temperature gradients (thermal wind). This phenomenon is commonly neglected in microscale flow modelling as at such scales other effects are generally more important when predicting winds close to the surface. At coastal areas, baroclinity can indeed have a stronger effect on both wind shear and wind veer already at heights where turbines are operating.

## Theoretical background

Large-scale winds, such as the surface geostrophic and the thermal winds, can be determined from the horizontal pressure and the difference between geopotential gradients between two vertical levels. We use results from simulations performed with the WRF model (see below) to derive such winds. The surface geostrophic winds in the north-south and west-east components, respectively, are given as

$$Go_x = -\frac{1}{\rho f}\frac{\partial Po}{\partial y}, \qquad Go_y = -\frac{1}{\rho f}\frac{\partial Po}{\partial x},$$

where $\rho$ is the air density, $f$ is the Coriolis parameter, and $Po$ the mean sea level pressure. The thermal winds are estimated as

$$Gt_x = -\frac{1}{f}\frac{\partial\Phi z - \partial\Phi o}{\partial y}, \qquad Gt_y = \frac{1}{f}\frac{\partial\Phi z - \partial\Phi o}{\partial x},$$

where $\Phi$ is the geopotential. The procedure is well-explained in Floors et al. (2014)

## WRF modelling

Simulations were performed using initial and boundary conditions from the NCEP/NCAR reanalysis and the SSTs are obtained at 0.25º horizontal resolution and temporal resolution of 1 day. Here the results are for the year 2000 with hourly outputs. The model has 41 vertical levels and two domains (here we use the outer one which has horizontal grid spacing of 45 km). The model setup uses the Yonsei University PBL scheme. More details on the model setup and configuration can be found in Peña and Hahmann (2012).

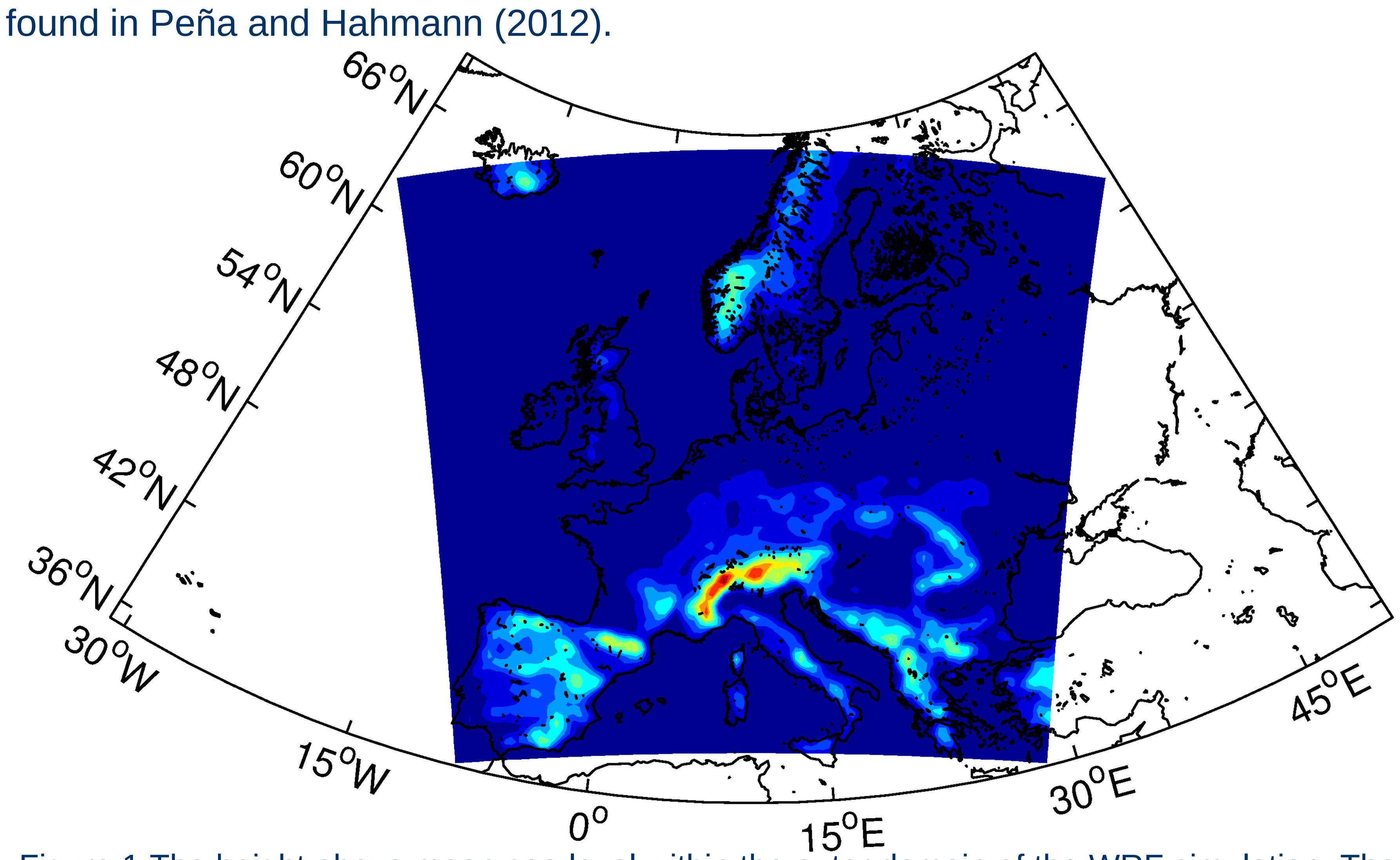


Figure 1 The height above mean sea level within the outer domain of the WRF simulation. The less blue the color the higher above the sea.

## Results

The mean surface geostrophic wind is illustrated in Fig. 2. By comparison with the results from the European wind atlas in Fig. 3 (Troen and Petersen, 1989) and by the elevation map in Fig. 1 we can see (qualitatively) that the methodology to derive large-scale winds from the WRF outputs generally works well for the northern

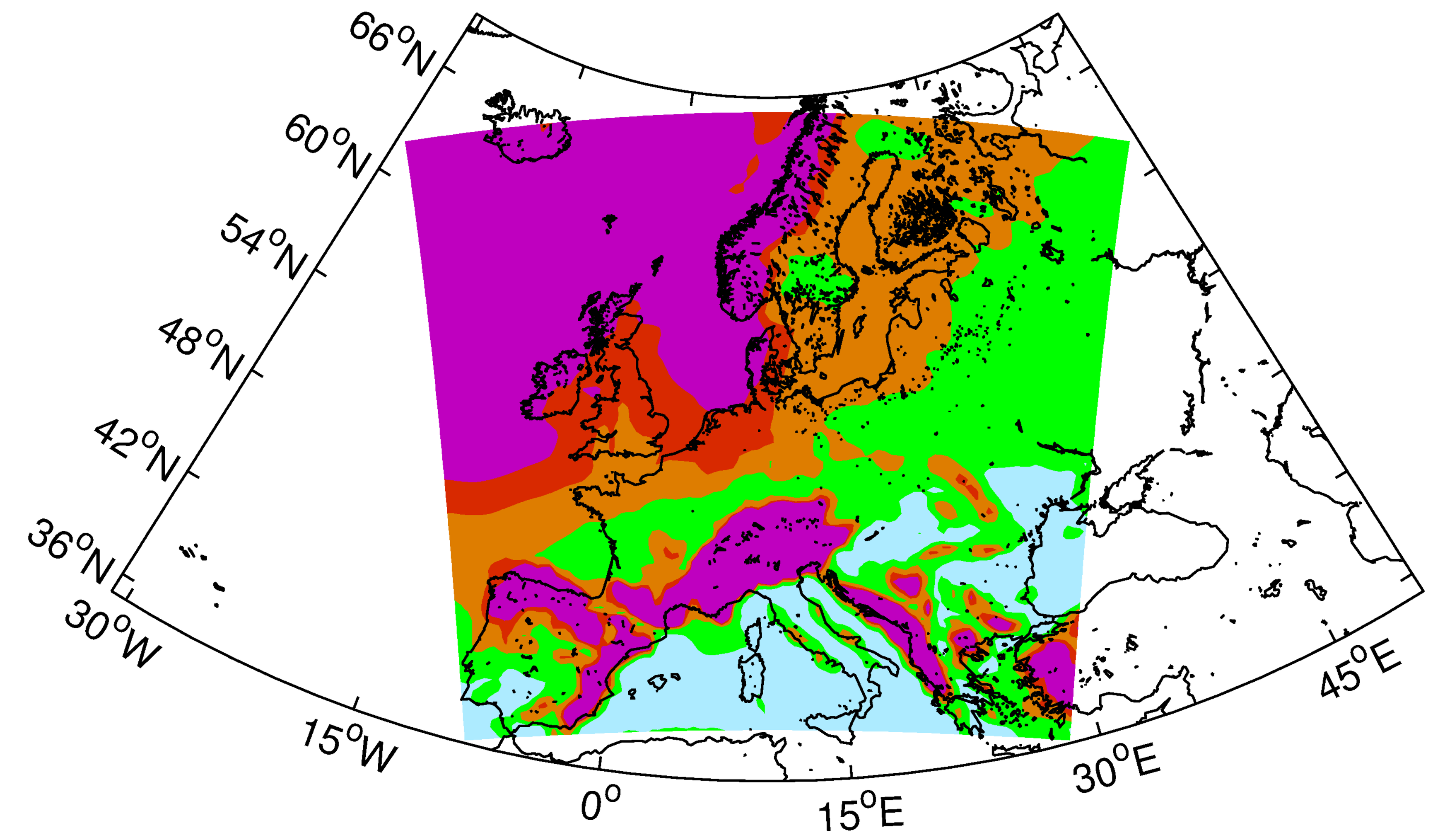


Figure 2 The mean surface geostrophic wind from WRF simulations for the year 2000. The colormap was adapted to be compared with that in Fig. 3

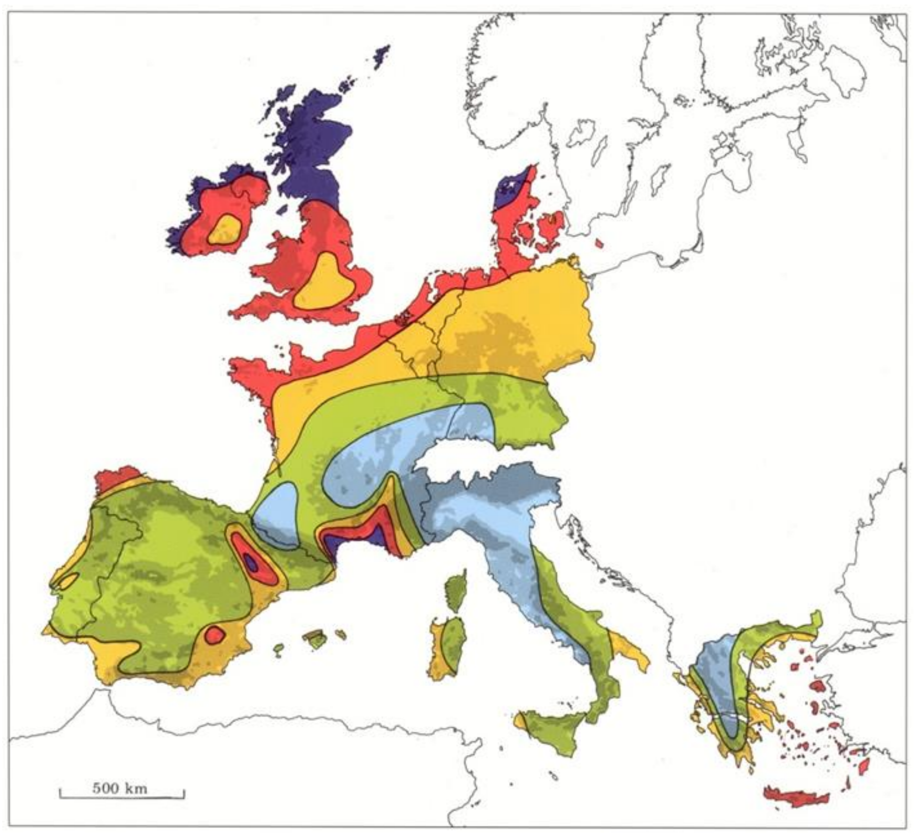

Figure 3 European wind atlas from Troen and Petersen (1989)

European countries where the terrain is flat, whereas for regions with complex orography such as the Alps, north and east Spain and the Balkan coast the estimations of the large-scale winds seem to be too high as also shown from the baroclinity map in Fig. 4. For the estimations of the horizontal gradients we use a squared area around the point of interest of 450 km x 450 km, which seems to be too large at the complex terrain sites. However the resemblance between Figs. 2 and 3 in the United Kingdom, north of France, Germany and Denmark, where most of the coastal wind projects take place is encouraging.

Figure 4 illustrates the results for the thermal wind maxima in 2000 at 145 m, where one can see a very clear pattern of relatively high thermal winds along the coasts of Europe. This is mainly due to the temperature contrast between the land and sea in Europe. For a wind farm planned close to the coast, a mean wind speed difference of 0.5 m/s translates into a difference of ~20 M€/year for a 100 turbines array.

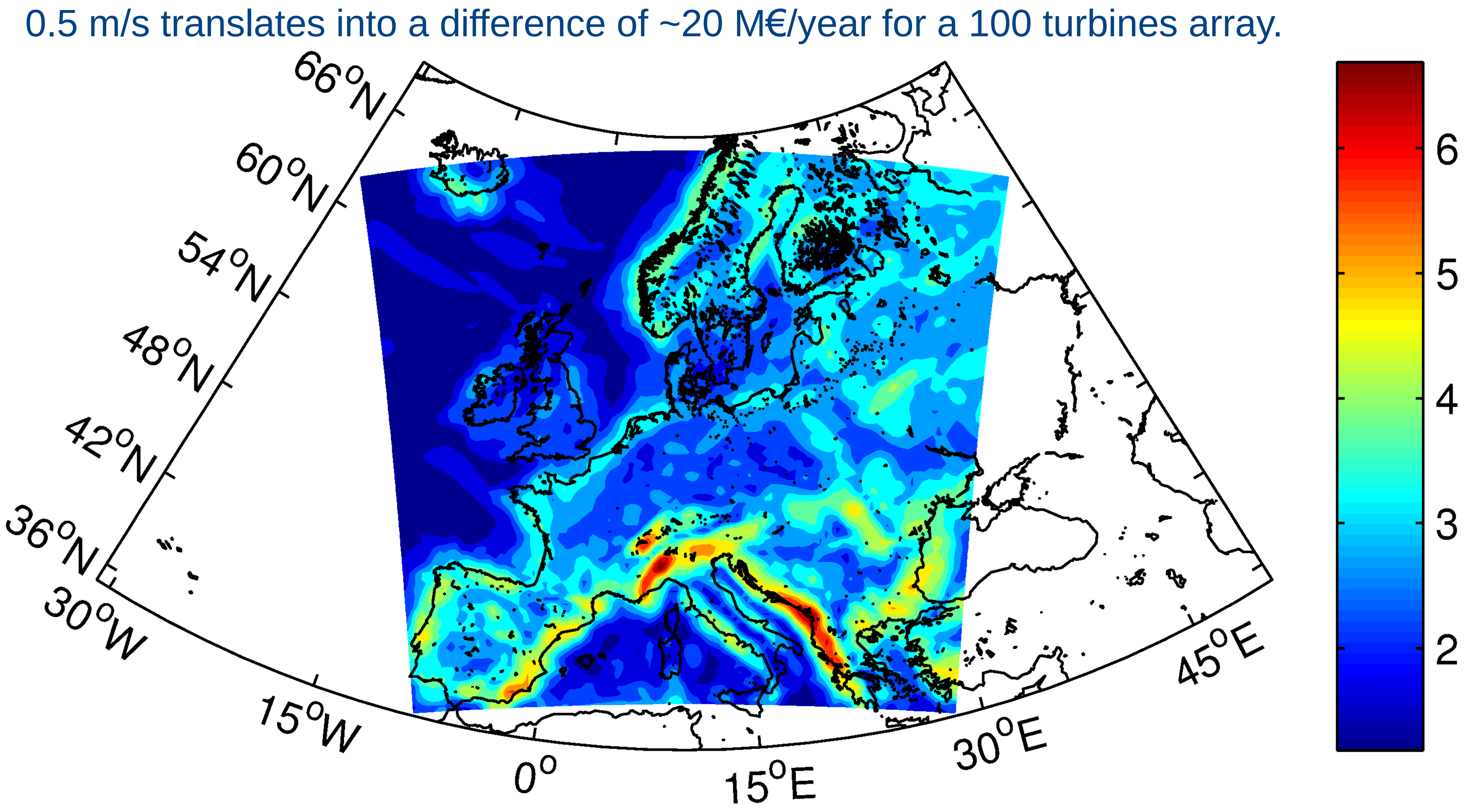


Figure 4 Thermal wind maxima in m/s from WRF simulations at 145 m for the year 2000

## Conclusions

1. The mesoscale model simulations can be used to derive the thermal wind and thus its effect on the boundary-layer wind

2. The thermal wind is an important component especially looking at coastal areas where horizontal temperature gradients can be large

3. Baroclinity needs to be accounted for in microscale models if we want to accurate predict winds at coastal sites where many offshore wind projects are being designed

## References

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3. Troen and Petersen (1989) European wind atlas. Risø National Laboratory, Roskilde