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DEPENDENCE OF WIND ATLAS DATA ON THE EXTENT OF TOPOGRAPHIC MAPS AROUND A SITE

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ABSTRACT: Wind measurements in Denmark, Ireland, and Northern Portugal are analyzed with the Wind Atlas Analysis and Application Program WAsP. Wind atlas data is generated from the measurements using topographic maps, which were clipped in a circle around the observation sites. The dependence of the “cleaned” mean speed, energy flux density, mean direction, Weibull parameters, or upstream roughness on the diameter of the maps is investigated.
In order to obtain representative wind atlas data it is recommended that the distance from a site to the edge of the topographic maps should be 10 km or more.
Keywords: Terrain; Roughness; Siting

1 INTRODUCTION

The Wind Atlas Analysis and Application Program WAsP is used widely to calculate the wind resource around a site or region. It employs the wind atlas methodology [8] to “clean” wind measurements from local influences like orographic speed-up, roughness changes, or obstacles like buildings or trees in order to obtain the wind climate representative for the region around the observation site. However, non-hydrostatic orographic speed-up depends on terrain height variations with horizontal scales up to several kilometers around a site. Roughness changes can effect the wind field several kilometers downstream. Therefore, it is important to know how far a map should extend around a site in order to get reliable estimates of the general wind climate. The importance of the resolution of topographic maps was investigated by Mortensen and Petersen [5].

An introduction to the WAsP model is given by Mortensen et al. [4]. Troen [7] describes the flow model for orographic speed-up. WAsP employs the roughness change model of Sempreviva et al. [6].

2 METHOD

In order to investigate, how important the size of topographic maps is for a wind atlas, WAsP was run several times for a number of stations using maps of different size. The mean speed, energy flux density, annual energy production, mean direction, Weibull shape parameter, etc. of the wind atlas data was drawn as a function of map diameter.

To avoid any preferred axis the clipped maps were circular with the observation site in the center. Only the line segments within diameters of 2.5, 5, 10, and 20 km were taken. This is illustrated in Figure 1 for the mast at Risø. Circles indicating the extend of the clipped maps are shown overlaid on top of the original map

The main parameters affected by the size of the maps are the orographic speed-up on hills or valleys, and the upstream roughness [8, Chapter 8.3]. As WAsP is a neutrally stratified small-scale model the orographic speed-up depends mainly on hills with a half-width of less than a few kilometers. Therefore, only small speed-up can be expected for sites in Denmark.

The upstream roughness is used to transform the observed wind to different roughness classes of a wind atlas.

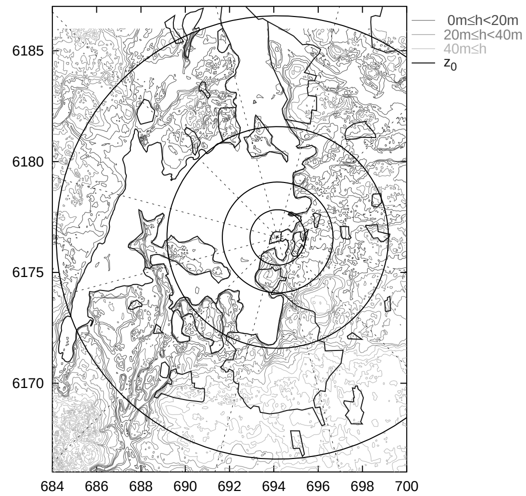

Figure 1: WAsP map of Risø. Circles with diameters 2.5, 5, 10, and 20 km are drawn around the position of the mast. Lines, z_0, are roughness change lines.

The decay length for the magnitude of roughness changes in WAsP is 10 km. Therefore, small maps can result in wrong upstream roughness values in WAsP. For example, in the circular map with diameter 10 km WAsP must assume that there is only water in the sector around 300°. This would yield an underestimation of the wind in the wind atlas from that sector. In reality the surface friction of the upstream land has reduced the wind speed compared to pure over-water conditions.

3 RESULTS

We shall concentrate here on the wind atlas values at 50 m height above a surface with roughness 3 cm. This is close to typical heights of many modern turbines and 3 cm roughness represents a good site on land.

The most interesting quantity for wind energy applications is the annual energy production, AEP. Therefore, we present the effect of the map size on the AEP, i.e. the wind distribution is folded with a power curve. We chose the power curve of the Vestas V47 (660 kW) turbine for standard air density. The AEP is calculated with the wind distribution from the wind atlas data for height

50 m above 3 cm, i.e. as if the hub height were 50 m and the turbine would stand on a plane with uniform surface roughness. Other quantities are presented in Frank et al. [3].

3.1 Sites in Denmark and Ireland

The AEP as functions of map diameter for sites in Denmark and Ireland. is shown in Figure 2 The important result is that even using maps with diameters 10 km, i.e. 5 km distance to a site, errors greater than 10 % in annual energy production can occur in wind atlas data. For the energy flux density the error can be greater than 15 %. At sites within a few kilometers from a coast line, which lies upwind in the dominant wind direction, it is very important to include the coast line in the map. Examples are the stations Klemensker Ø on Bornholm, and Tystofte on Zealand. Comparing Figure 2 with Figure 3 it can be recognized, that to a great extent the mean energy of the wind atlas data follows the upstream roughness used by WAsP. The strength of the variation of AEP is not directly proportional to the variation of z_0. This depends also on how much of the total energy is concentrated in the sector with the highest energy flux density.

Denmark has no steep mountains, and Ireland only a few. Consequently, the orographic speed-up is relatively small. The orographic speed-up in WAsP acts on smaller scales than roughness change effects. Good examples are the stations Corrie Mountain, Kilronan Mountain, or Mount Eagle in Ireland. If the map gets so small that it does not encompass the full mountain, the orographic speed-up can be seriously underestimated. However, already for map diameters of 5 km the errors for the orographic speed are less than 5 % for almost all the stations in Denmark and Ireland.

The Weibull shape parameter k does not change much with varying map size. If the map diameter is 10 km or greater, the mean wind direction deviates less than 5 degrees from the value obtained with the full map.

3.2 Sites in Portugal

Northern Portugal is very mountainous and the mountains are steep. Hence, the orographic speed-up is big. On the other hand, the surface roughness is quite uniform. Only one station, Murtosa, lies on the flat coast where the land-sea roughness change is important. RIX approximately less than 10.

The dependence of annual energy production, AEP, on map diameter for the Portuguese stations is shown in Figure 5. The available maps are smaller than in Denmark or Ireland. Some maps have an irregular shape because they were set together from several smaller maps. Diameters from 2 km to 15 km are chosen. Obviously, maps with diameters of 5 km are far to small to get a reliable estimate of the annual energy production. Errors greater than 10 % must be expected in this type of terrain.

For most sites the orographic speed-up is seriously underestimated when using small maps (Figure 6). For maps with diameters 5 km, the error of the mean wind speed can be over 5 %. The errors might be even greater if bigger maps were available because there might be weak speed-ups at greater scales than the total map size. Errors in mean wind direction are less than 3°. The Weibull shape parameter, k, differs by less than 3 % from the value with the full map.

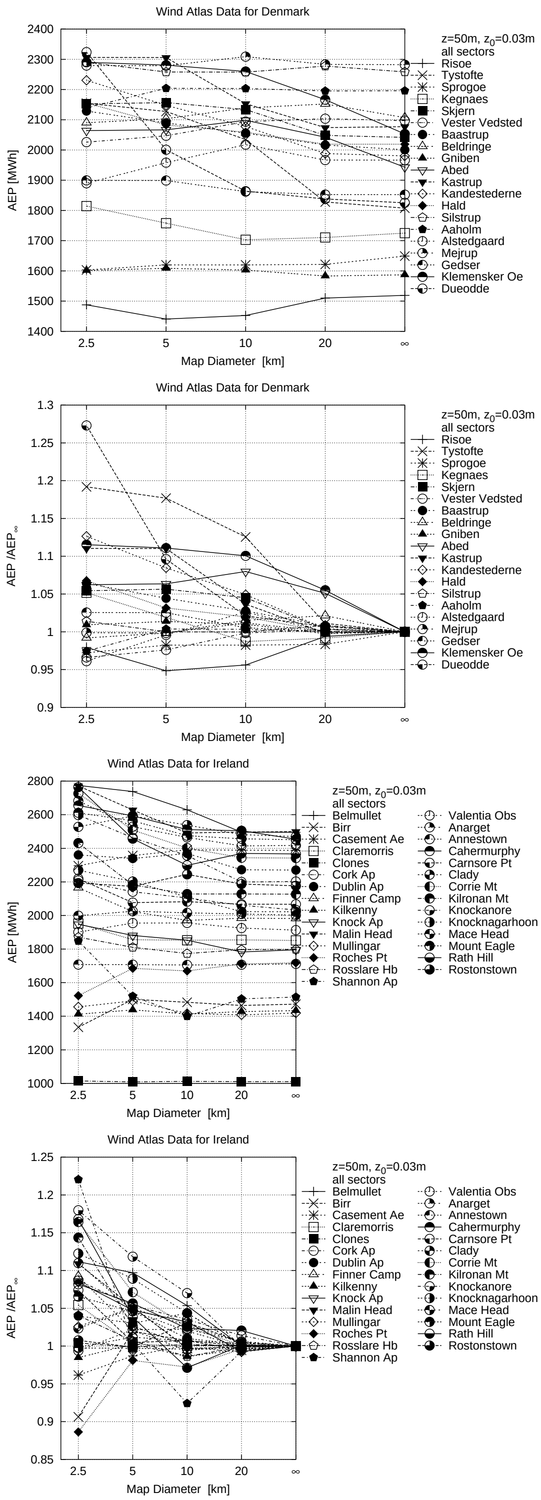

Figure 2: Annual energy production of a Vestas V47 (660 kW) turbine if it had a hub height of 50 m above a flat surface with roughness length 3 cm. Shown are the absolute values and the relative changes AEP_D/AEP_∞, where ∞ represents the full map. Sites in Denmark are at the top, and sites in Ireland at bottom.

4 CONCLUSIONS

In order to produce wind atlas data, i.e. a description of the regional wind climate independent of local disturbances, it is recommended that topographic maps around a site should extend 10 km out from it. Otherwise the error of the expected annual energy production of a typical wind turbine can be greater than 10 %. If there is a major roughness change like a coast line further away in a

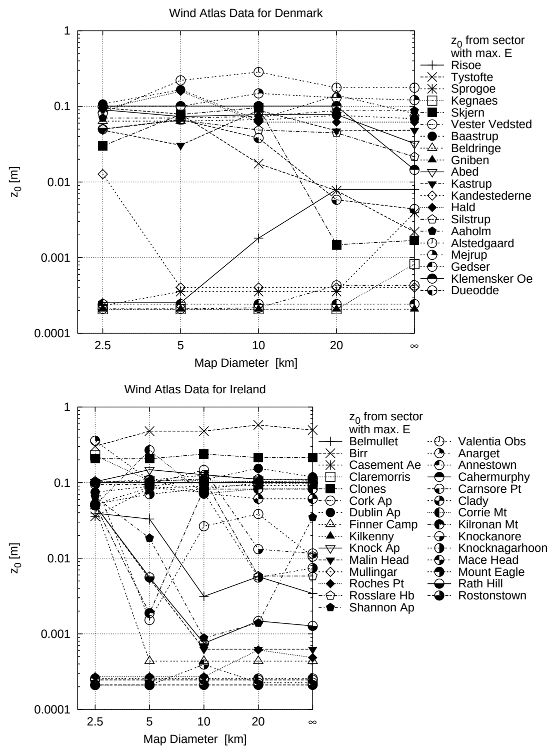

Figure 3: The upstream roughness length in the sector where most of the energy flux density is observed as a function of map diameter; sites in Denmark on top, Irish sites at bottom.

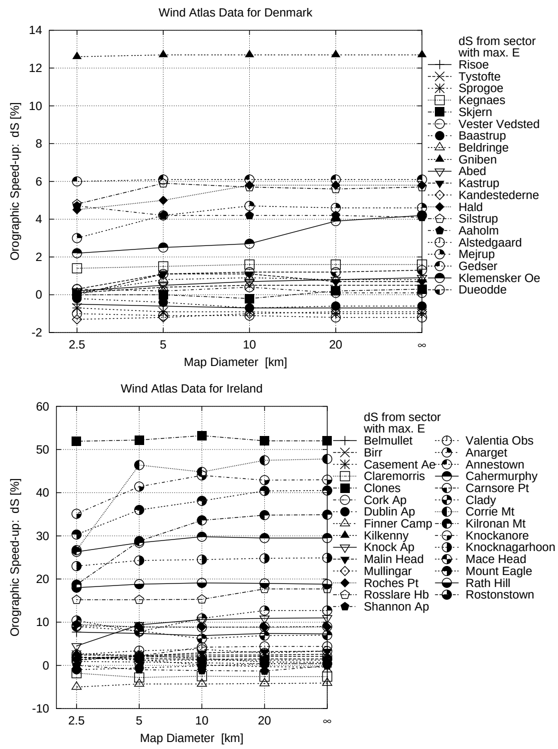

Figure 4: Orographic speed-up in the sector where most of the energy flux density is observed as a function of map diameter. The top row shows sites in Denmark, the bottom row sites in Ireland.

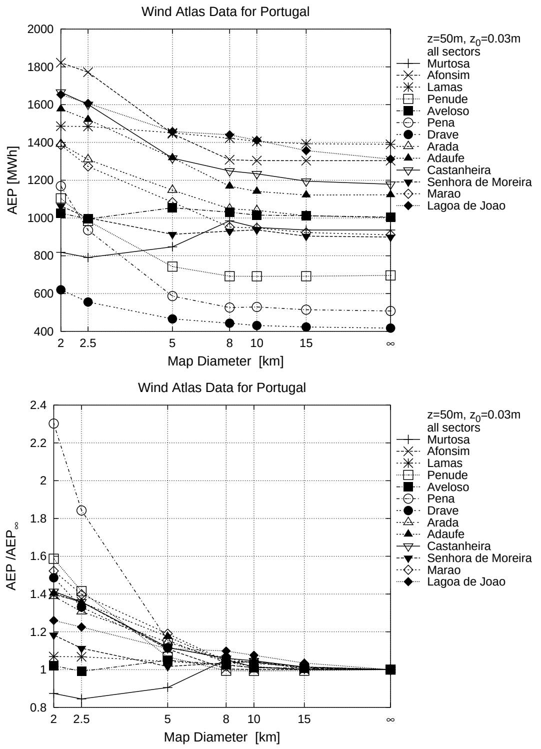

Figure 5: Annual energy production of a Vestas V47 (660 kW) turbine for sites in Portugal from wind atlas data at 50 m above a flat surface with roughness length 3 cm.

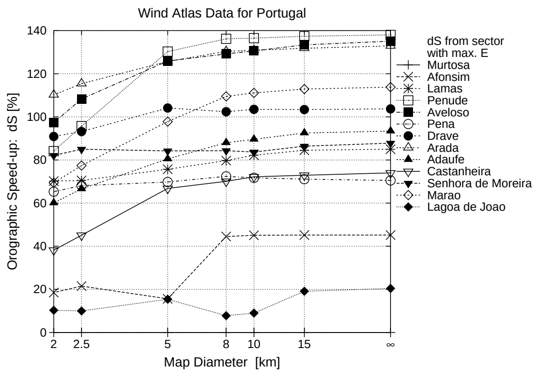

Figure 6: Orographic speed-up in the sector where most of the energy flux density is observed as a function of map diameter at sites in Portugal. The difference to the value for the total map, $\Delta S_D - \Delta S_\infty$, is shown at the bottom.

frequent wind direction this should be included at even greater distances, perhaps up to 20 km away. In mountainous terrain without major roughness changes somewhat smaller maps might be possible because the orographic flow model of WAsP reacts on terrain variations on smaller scale than the roughness change model.

Big maps are critical when a wind atlas for a region shall be made. For predictions close to a measurement site — say one or 2 kilometer away — smaller maps might be used because the errors in the analysis of the predictor site and the predicted site will almost cancel. This cancellation of errors explains why WAsP can be used in mountainous terrain of similar ruggedness [see 1, 2].

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