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Wind resource estimation – from local to global

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ABSTRACT: This paper will describe the different ways a region's or a site's wind climate can be estimated. The set of possibilities is limited only by the imagination of the authors! The ways differ in mainly the complexity and detail of the input data. The paper will describe each of seven ways and comment on advantages and disadvantages of each of them.

1 INTRODUCTION

One of the first actions needed when interest in wind energy from a region appears is to establish an overview of the available wind resource. This overview should make it possible to identify areas of high and low winds. It should also quantify these, making it possible to evaluate whether wind energy is economically viable in the area. The problem is that different areas will have very different sources of information about the wind. This is not a problem if one has the option of establishing a dense measuring network, wait for 5 to 10 years, and then evaluate the wind resource. In practice this is not possible, of course, so other methods must be applied.

In the following seven methods for estimating the wind resource of an area will be described. First, however, the term 'wind climate' will be defined.

2 DEFINING THE REGIONAL WIND CLIMATE

In Table I the definition of the regional wind climate is given. It is put into context by defining the wind resource and the wind atlas as well.

The regional climate is calculated from measurements by removing the *local effects*. Local effects are all effects being specific only to the specific site, viz.

- shelter from near-by obstacles
- effects of roughness, and changes in roughness
- effects of the orography, on scales less than ≈10 km
- thermally driven effects

The main advantage of using this definition is that it is virtually scale independent, ie small features in the landscape (hills, valleys, forests, lake etc) do not affect the regional wind climate.

3 METHODS FOR WIND RESOURCE ESTIMATION

In Table II the different methods are outlined and in the following sections each of the methods will be described and its applicability will also be discussed.

Table II: The seven different ways of wind resource estimation. 'Measurements' refers to traditional on-site measurements taken at eg airports. An example of a data base of geostrophic winds could be the global one of NCEP/NCAR, and an example of a data base of land-use (ie the roughness of an area) as eg the CORINE data base.

Method	1	2	3	4	5	6	7
Measurements		√	√		√		√
Data base geostrophic winds				√		√	√
Data base land-use						√	√
Data base orography						√	√
WAsP terrain					√		√
Meso-scale model						√	√
Micro-scale model					√		√
Geostrophic drag law				√			
Statistical models			√				
"Folklore"	√						

3.1 Method 1: Folklore

This method bases itself on interviews with local people, and the aim is to identify areas with high and/or low wind speeds. The method can be used if all else is not possible and has the advantage of being very cheap and fast. Of the large number of shortcomings this method has only two will be mentioned: there is almost always a tendency to overestimate the wind in windy areas, mainly – we speculate – because of the chill factor: when it is cold even moderate winds feel strong. The other problem with this method is that it is not certain that the entire area in question is traversed by humans. The reasons for this can be many, one could be high winds! Another inaccessibility. In conclusion this method should be used only if no other is available and important decisions should not be based on this evidence alone.

A derivative of this method is *onomatology* where areas with potentially high winds are located by finding geographical names indicating this. An example is 'Windy Standard' in Scotland, another 'Vindeby' in Denmark.

Another related method is locating high wind areas by studying the local vegetation; eg trees in very windy areas tend to take shape after the prevailing wind, the so-called 'flagging' of trees.

3.2 Method 2: Measurements only

Basing a regional study on measurements only is indeed possible. However, great risk exists of either severely over- or under-determining the resource. The resource will be under-determined if the study is based on mainly observations in build-up (or other high roughness or otherwise sheltered) areas. Conversely the resource will be over-determined if the observations are mainly from low roughness, very exposed areas.

Table I: The definition of the three wind resource terms. For each term some comments are also given, relating to scale and/or scope.

Term	Definition	Comments
Atlas*	Collection of regional wind climates for a large area	Scope: 100 – 10,000 km Scale: O(50 km)
Regional climate	Wind statistics, temporal and spatial variation. Reduced to standard conditions.	Scale: O(50 km) Regional validity Must be modelled
Resource	The actual long-term kinetic energy content of the wind at a specific location and height	Scale: O(1 m)

* 'Atlas' is also used as the term describing the WAsP `.LIB`-file.

3.3 Method 3: Measure-correlate-predict

A method often used in micro-siting is measure-correlate-predict (MCP). The idea is that the resource at a potential site can be determined using a short measuring campaign at the site and then correlating these measurements with an overlapping but climatologically representative (ie containing measurements over a 5–10 year period) time series. This method could also in principle be used for regional wind resource estimations, but it suffers from the same drawbacks as method 2: risk of either severe under-/over determination of the resource. Once the resource at the site has been determined, modelling is required to carry out the micro-siting

3.4 Method 4: Global databases

Using global databases of winds has first been possible within the past 2–5 years with the appearance of databases like the ones from NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research, [5]) and ECMWF (European Centre for Medium-range Weather Forecasting, [4]) (cf Figure 1). These databases are the result of the huge reanalysis effort carried out by these institutions. The databases typically contain wind at several heights, temperature, pressure etc in a grid covering the entire Globe. To ensure that local effects on the measurements are avoided to the greatest extend wind in the free atmosphere are used. To extrapolate these winds to the surface the geostrophic drag law is employed. The geostrophic drag law connects the geostrophic wind to the friction velocity at the surface according to

$$G = \frac{u_*}{\kappa}\sqrt{\left(\frac{u_*}{fz_0} + A\right)^2 + B^2} \qquad (1)$$

where G is the geostrophic wind (ie the wind derived from the balance between the pressure force and the Coriolis force), u_* is the friction velocity, κ (=0.4) the von Karman constant, f the Coriolis parameter, z_0 the surface roughness, and A and B are constants, equal to 1.8 and 4.5, respectively.

The geostrophic drag law is used to extrapolate the wind to different roughness and landscape conditions.

This method has several advantages. Firstly, since the databases are globe-spanning the method can be applied to any area. Secondly, since high-level winds are used the local effects are not introduced in the first place, Thirdly, since the database contains typically around 10 years or more of measurements the estimates are climatologically stable. This, potentially, makes the estimates very close to the actual wind resource. The method has also some drawbacks, the main one is the resolution, typically on the order of degrees (ie 100's of km), and the fact that not all wind climates near the ground are determined by the winds aloft.

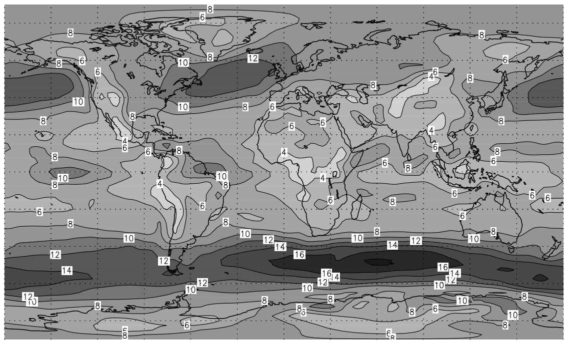

Figure 1: Mean wind speed at 850 mb for the years 1976-1995 from the NCEP/NCAR reanalysis database.

3.5 Method 5: Wind Atlas Methodology

For countries with a tradition of long records and dense networks of observations of the wind, the wind atlas methodology (Troen and Petersen, 1989) is the preferred method for wind resource studies. The method has been applied to a large number of counties (all of EU-Europe, Russia, countries in northern Africa) making it the de-facto standard, see Figure 2. The method directly corrects existing long-term measurements for three of the four local effects listed in Section 2 (cf Figure 3). The fourth (thermally driven winds) is not very dominant in many areas of the world. In areas where they do occur, the wind atlas methodology can be applied – as long as care is taken to only use wind climate datasets for areas of similar thermal influence.

The advantages are many: firstly, by being the de-facto standard different wind atlases can be compared and understood directly by a large community. Secondly, by using the method in reverse (the so-called application part) makes it possible to determine the specific winds at a site to a very high accuracy.

3.6 Method 6: Meso-scale modelling

With the increasing speed of computers during the last years, it has become possible to use atmospheric meso-scale models to estimate the wind resource of a region. The grid size of the models is of the order of a few kilometres. A region of a few hundred by hundred kilometres is typically modelled, see Figure 4.

Mostly, a statistical dynamical approach of regionalization of large-scale climatology [3] is used to calculate the regional surface wind climate. It is assumed that the regional

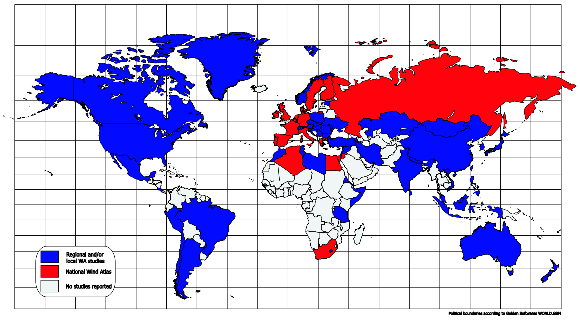

Figure 2: World-wide status of the Wind Atlas methodology by the beginning of 2002. National wind atlases have been published for the countries marked in black and regional and/or local studies exist in the countries marked in dark grey. No wind atlas studies have been reported so far for countries marked in light grey.

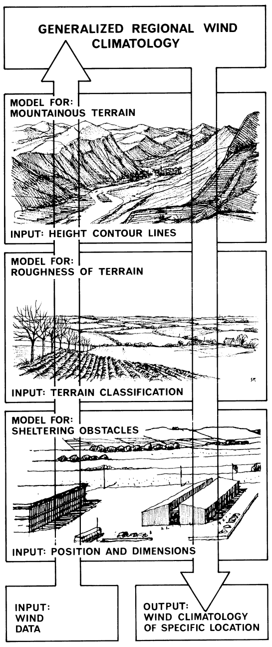

Figure 3: The Wind Atlas Methodology. From Troen and Petersen, 1989.

surface layer climate is determined uniquely by a few parameters of the larger, synoptic scale and parameters of the surface. Representative combinations of the parameters are found and simulations of these situations are performed with the meso-scale model. Then, the meso-scale climatology is calculated from the results of the simulations together with the frequency of the situations.

Required input data are orographic and land-use grid maps. The surface roughness is determined from the land-use. The external forcing of the model are boundary conditions from the larger scale, e.g. the large-scale pressure gradient or geostrophic wind. It is either determined from radiosoundings [6], or from large-scale models, e.g. re-analysis data [5, 4].

In principle, the method can be applied worldwide as global data coverage is now available.

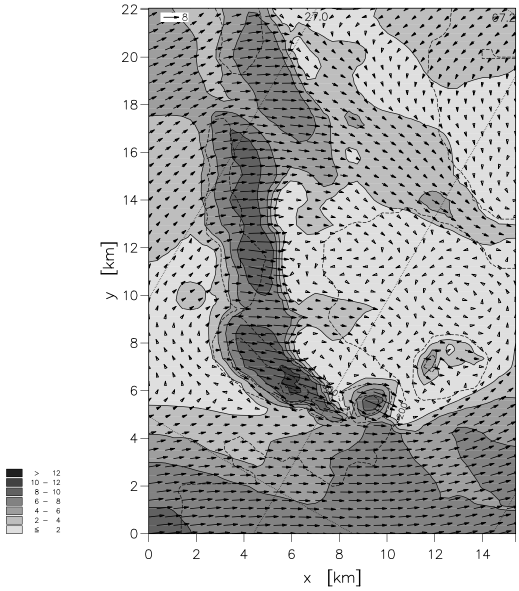

Figure 4: Simulated wind field at 61 m a.g.l. around Pyhätunturi Fell in northern Finland for a geostrophic wind of 10 m s^{-1} from the left under conditions of a very strong inversion. The contours show wind speed. Height lines are dashed. Note the eddies in the wake of the mountains which are approximately 300 m higher than the surroundings.

Major problems are the determinations of the important external parameters and the definition of the most representative situations. Also, a resolution of several kilometres cannot resolve the micro-scale terrain features which influence the surface wind. Resolutions of one kilometre or less require a tremendous amount of computing.

3.7 Method 7: Combined meso-/micro-scale modelling

A slightly different use of meso-scale modeling is done in combining a meso-scale model with a micro-scale model like WAsP. Instead of trying to resolve all small-scale terrain features the meso-scale modeling stops at a resolution of approximately 5 km. Local predictions are made with a micro-scale model like WAsP using output from the meso-scale model as input to the small-scale model. This approach is followed by [1, 2].

The method produces wind atlases like method 5 which makes comparisons between regions possible. Also, many people, who gained experience in wind resource estimation with WAsP, can readily use the output from the meso-scale model. An example of the application of the method is shown in Figure 5.

4 ESTIMATING THE GLOBAL WIND RESOURCE

In this section a sketch plan is laid out, describing one approach to attacking the rather large task of estimating the wind resource world-wide.

The first step is to realise that it will be impossible to apply the same method to all areas of the globe: the data coverage and the availability will vary considerably from region to region. Therefore, an approach must be taken where different levels of sophistication can be applied.

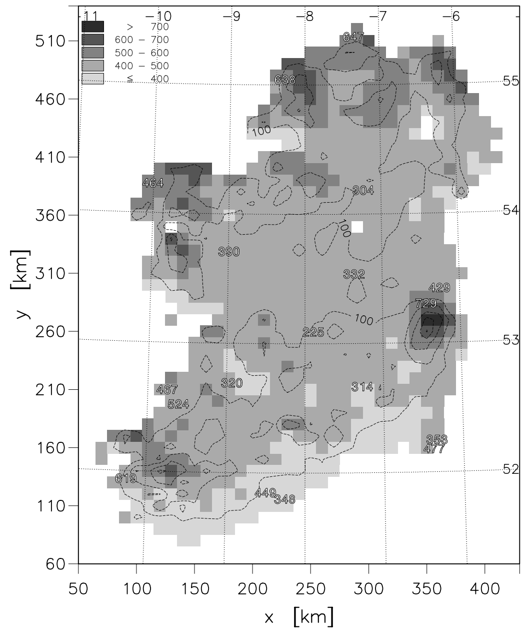

Figure 5: Simulated mean wind power density E in W m^{-2} at 50 m above a surface with roughness length $z_0 = 3$ cm for Ireland. Numbers show values determined from observations with WA$^{\mathrm{S}}$P. Height contours are dashed.

The lowest level is to use data bases of the geostrophic wind and then project the wind down to different roughness and landscape classes (method 4). Next step up is the wind atlas methodology (method 5) and the final step is the combined meso-/micro-scale modelling (method 7).

5 ACKNOWLEDGEMENTS

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Helmut Frank is now with the German Weather Service, DWD.

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