# POWER – A Methodology for Predicting Offshore Wind Energy Resources

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## SYNOPSIS

An accurate estimate of the long-term wind speed is essential to site an offshore wind park effectively. Unfortunately measured wind speed data at potential offshore wind farm sites are currently sparse. A major European Commission funded project called ‘POWER’ aims to develop a methodology for predicting the long-term wind resource that does not rely directly on offshore anemometry mast data.

Work on the POWER project began in August 1998 and is scheduled to finish in July 2001. This paper presents an overview of POWER and shows how the components of the prediction methodology fit together. It also reports on progress in the project to date and presents some preliminary results.

## 1. INTRODUCTION

There is an increasing interest in using offshore sites for wind farms, particularly in Europe. However, for economic siting of such developments, there needs to be an accurate estimate of the wind regime at the proposed site. Unfortunately, compared to sites on land, measured wind data at offshore locations are spatially and temporally sparse and of variable quality. Furthermore, installation of offshore anemometry masts is expensive and is likely to provide wind records over relatively short periods only.

A novel methodology has been developed which can produce long-term and spatially detailed estimates of the wind conditions at offshore sites covering a wide area. Within the POWER project, this methodology is being applied to European Union waters. The resulting wind resource estimates may subsequently be used to identify areas that are favourable for offshore wind power installations. More detailed monitoring studies can then be carried out at a particular site to refine the initial estimates.

## 2. THE POWER METHODOLOGY

### 2.1 Outline

The POWER methodology does not rely directly on anemometry mast data to predict wind conditions offshore. Instead, the estimates are based on grids of atmospheric pressure data at mean sea level covering the area of interest.

The methodology is built up of three basic steps:

1. The mean sea level pressure gradient is used to calculate the geostrophic wind.

2. The geostrophic wind is transformed to the sea surface layer by applying the Wind Atlas Analysis and Application Program (WA$^{s}$P).

3. In nearshore areas, a coastal discontinuity model (CDM) is used to transform the geostrophic wind to the surface layer, taking account of effects experienced in the land/sea transition zone.

The final wind resource estimates are refined using sea surface roughness values inferred from hindcast wind/wave datasets. In addition, the CDM is “fine-tuned” using both existing offshore mast data and coastal SODAR data.

A schematic flow diagram of the POWER methodology is shown in Figure 1.

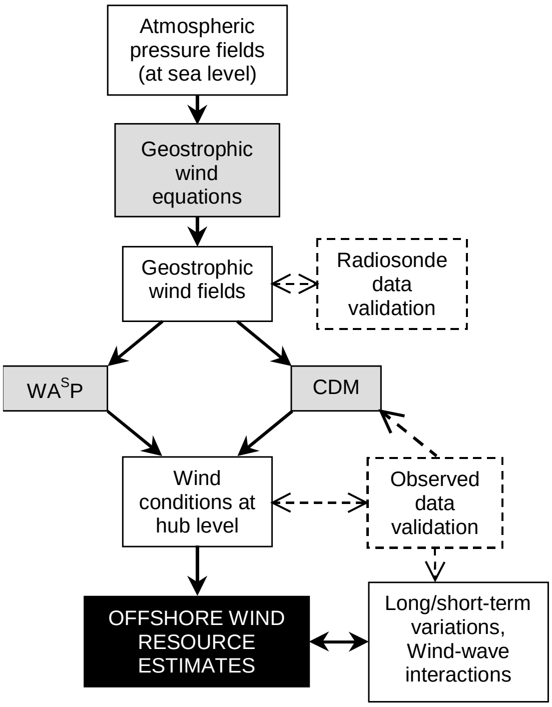

**Figure 1 Flow schematic of POWER methodology**

## 2.2 Calculation of geostrophic winds

Geostrophic wind theory is used to convert southerly and westerly components of sea level pressure gradient into their associated geostrophic wind values using equations 1 and 2:

$$U_g = -\frac{1}{f_c \rho}\frac{\partial p}{\partial y} \qquad 1.$$

$$V_g = +\frac{1}{f_c \rho}\frac{\partial p}{\partial x} \qquad 2.$$

Where $f_c$ is the local Coriolis parameter at latitude $\phi$ given by:

$$f_c = 2\Omega \sin\phi \qquad 3.$$

$U_g$ and $V_g$ are the westerly and southerly components of the geostrophic wind speed, respectively, $\Omega$ is the Earth’s angular velocity ($7.29\times10^{-5}$ rad s$^{-1}$), $\rho$ is the density of air, $\partial p/\partial x$ is the component of the pressure gradient from south to north and $\partial p/\partial y$ is the pressure gradient from west to east.

## 2.3 WA$^S$P transformation

WA$^S$P (1) is a linear flow model that can be used to transform geostrophic winds to wind turbine hub levels in the surface layer. The model calculations are based on the geostrophic drag law combined with models of stability and development of an internal boundary layer (IBL). WA$^S$P makes adjustments to the wind speed profile offshore based on the assumption that the wind speed profile in the surface layer (up to approximately 100m) is slightly stable.

## 2.4 Coastal Discontinuity Model (CDM)

CDM (2) is based on similar principles to WA$^S$P although it models the IBL and stability in a different manner.

If the fetch to a point is uniformly land or sea, a neutral wind speed profile is used to transform geostrophic winds to the surface layer. Alternatively, if there is a mixed fetch over which an IBL can develop, a three-layer IBL model based on Bergstrom’s formula (3) is used to calculate the neutral IBL height at that location. Beneath this height, the equilibrium neutral sea wind speed profile is used; above this height the equilibrium land wind speed profile is used.

Stability is modelled by the Monin-Obukhov Length anaLYsis (MOLLY) model (which uses routines from (4)). The Monin-Obukhov length stability parameter is calculated according to the sea surface temperature, an air temperature and the wind speed and direction.

In addition, CDM can account for variable roughness offshore, which is dependent on the wind speed.

# 3. APPLICATION OF THE POWER METHODOLOGY TO EUROPEAN WATERS

## 3.1 Introduction

The POWER methodology outlined above is being applied to the region 30ºN to 70ºN and 15ºW to 30ºE. As figure 2 shows, this area covers the major sea areas bordering European Union countries – the North Sea, the Baltic, the Mediterranean and the eastern North Atlantic.

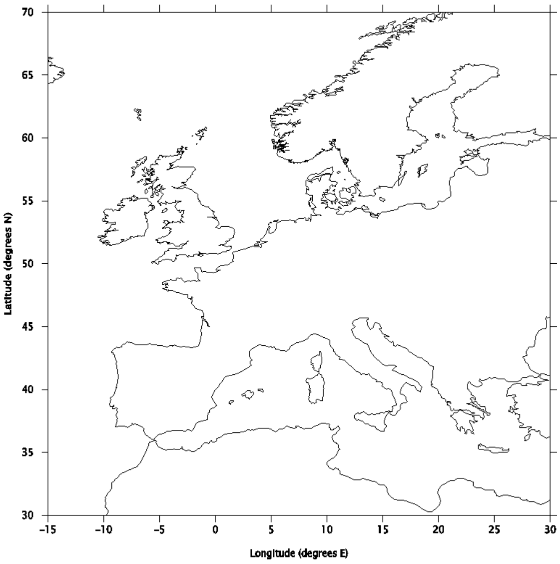

**Figure 2 Map showing the European sea area where the POWER methodology is being applied**

There follows a report of progress to date, together with some preliminary results.

## 3.2 Calculation of geostrophic winds

Six-hourly atmospheric pressure data on a 2.5º x 2.5º latitude/longitude grid were obtained from the US National Centers for Environmental Prediction (NCEP). The pressure data for the period 1985 to 1997 were interpolated onto a 0.5º x 0.5º latitude/longitude grid using bi-cubic spline interpolation. The associated geostrophic winds for this period have been calculated using equations 1 and 2.

Figure 3 presents a contour plot of the mean annual geostrophic winds calculated from the NCEP pressure data in the period 1985 to 1997.

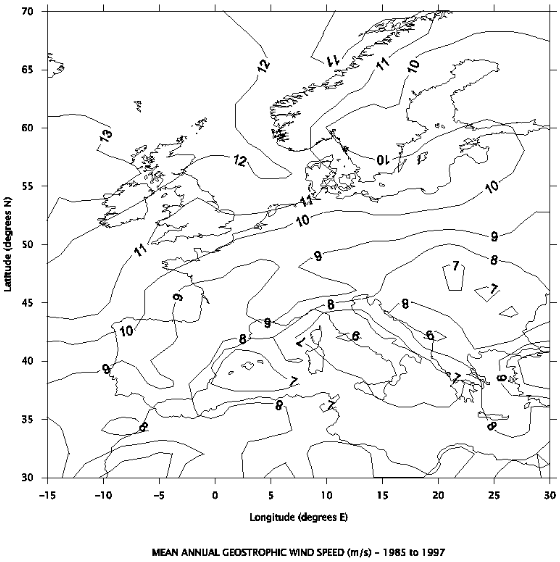

**Figure 3 Calculated mean annual geostrophic wind speeds (m $s^{-1}$) – 1985 to 1997**

## 3.3 Validation of geostrophic winds against radiosonde data

Radiosonde data were obtained from the British Atmospheric Data Centre (BADC) for the period 1990 to mid-1998 from an extensive network of European stations. Observations from the radiosonde ascents at selected sites were used to compare the observed wind speeds and directions in the region of frictionless flow above the friction layer with the calculated geostrophic winds.

Two types of comparison were undertaken. First, the wind speeds and directions occurring at particular timesteps were compared for dates representing severe storm conditions as well as more typical winter and summer days with relatively light winds. Figures 4 and 5 show charts of geostrophic wind speed and direction, superimposed with the corresponding radiosonde observations, for one of the timesteps monitored. The overall correspondence between the observed wind speed and direction and the geostrophic values is good.

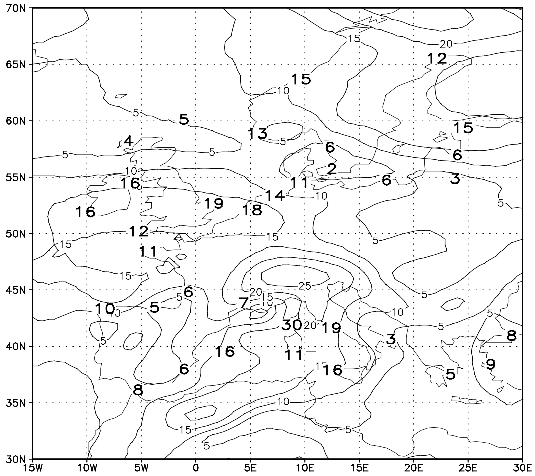

**Figure 4 Example comparison of calculated geostrophic wind speeds (m s$^{-1}$) (contours) and radiosonde observations (bold numerals)**

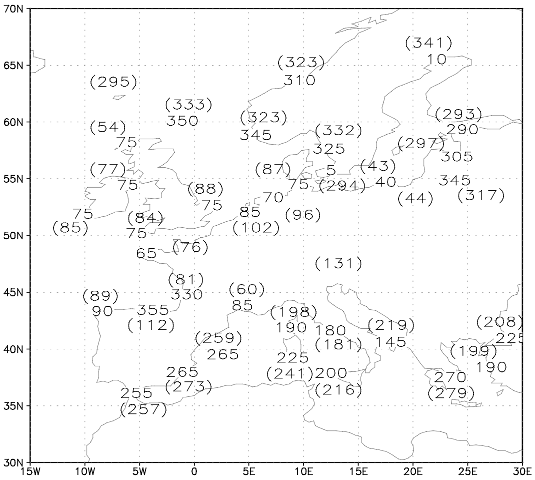

**Figure 5 Example comparison of calculated geostrophic wind directions (ºN) (values bracketed) and radiosonde observations (values not bracketed)**

Second, although the charts above provide a detailed overview of the relationship between the geostrophic wind and the observed frictionless wind, it is only practicable to consider a small number of timesteps in this way. Therefore, a comparison of the long-term summary statistics of the calculated geostrophic wind speeds and the radiosonde observations was also made. Once again there was an overall good agreement between the data sets.

### 3.4 WA$^{S}$P modelling

The WA$^{S}$P model is being used to transform geostrophic winds to the surface layer, at each point in the 0.5º x 0.5º latitude/longitude grid that lies over the sea. In practice, this means that WA$^{S}$P analyses are being performed at over 3700 grid locations.

Where a grid point is situated far offshore (>10km), a constant roughness value of 0.0001m is assumed. Alternatively, where a grid point is close to the coast (<10km) a roughness value of 0.0001m is assumed over the sea area and 0.03m over the land.

The WA$^{S}$P modelling is currently on-going. Wind conditions are being predicted at eight heights above mean sea level between 10m and 150m in order to cover the range of expected hub height levels of wind turbines that are likely to be sited offshore in the coming years.

### 3.5 CDM modelling

Development and application of the CDM in European waters is also on-going. Development and evaluation of the CDM model to date is described in (2).

Refinement of the CDM will be achieved using various data observed at coastal and offshore sites. Some of this data comes from existing masts and platforms, however within the POWER project additional data are being collected for this purpose using a mini-SODAR device.

### 3.6 SODAR measurements

SODAR (SOund Detection And Ranging) is a remote sensing technique for making wind speed and direction measurements at various heights. The technique is based on the reflection of sound pulses from turbulence in the atmosphere. The time taken for a reflection to be detected is used to determine the range (height) and the Doppler shift in the reflected signal is used to determine the wind speed and direction at that height.

In the POWER project, SODAR measurements of wind profiles are being made in the coastal transition zone. The resulting data sets will be used to refine the CDM. This work is on-going and is described in more detail in (5). Figure 6 shows examples of wind profiles measured by the SODAR at five different times in one day.

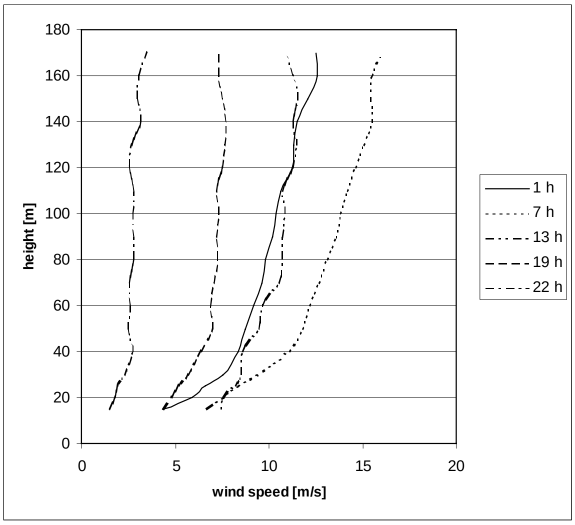

**Figure 6 Examples of wind profiles measured by SODAR**

## 4. PLANNED FUTURE WORK

### 4.1 Introduction

This paper was written at the end of the first year in the three year POWER project schedule. Once the sections of the project described above have been completed, there are plans to undertake several more associated tasks. These components of the POWER project will be presented in future papers, but in the meantime they are briefly outlined below.

### 4.2 Refinement and validation of the resource estimates

Predictions of wind conditions at hub height levels produced by WA$^{s}$P and CDM will need to be further refined and validated against existing offshore data sets. There are several possible sources of offshore data being considered including ship-borne observations, hindcast model archives and offshore mast and platform records.

Simultaneous wind and wave data will be used to infer surface roughness variability with wind strength. This will be used to modify the WAsP model estimates. In addition, wind and wave data may be used to highlight regions where extreme environmental loading on support structures may be encountered.

### 4.3 Short-term variability

An understanding of the daily variation in wind speed in offshore areas is important for the effective integration of offshore wind power into the mainland power grid.

Existing offshore data sets with a high temporal resolution will be used to assess the diurnal variability of offshore wind speed at several locations.

### 4.4 Long-term variability

A major advantage of POWER methodology is that historical records of sea level pressure extend back as far as 1880. This means that POWER estimates of offshore wind resource can be used to assess the long-term (decade to decade) variability of the offshore wind resource. This analysis will allow the expected uncertainty on the wind resource values due to long-term variability to be calculated. Similar assessments of long-term variability on land have been made in (6) and (7).

### 4.5 Case study

A final validation of the POWER methodology in European waters will be to perform a case study. The refined wind speed values will be compared with measurements taken at the planned location of a real offshore wind park.

### 4.6 Dissemination of the results

It is intended that once the implementation of the POWER methodology in EU waters is completed, the 0.5° x 0.5° latitude/longitude grid point values will be packaged as a database. There will be an interface for easy retrieval of the data by potential offshore wind farm developers.

## CONCLUSIONS

- This paper has presented an outline of the newly developed POWER methodology for assessing wind power resources in offshore waters.

- The POWER methodology does not rely directly on offshore wind speed measurements. Instead, offshore wind resource estimates are based on atmospheric pressure data.

- Since historical atmospheric pressure records date back several decades, POWER estimates of wind resources may have a truly long-term basis.
- The POWER methodology is being applied throughout European Union waters on a 0.5º x 0.5º latitude/longitude grid.
- Preliminary results from early stages of the application of the methodology have been presented.
- The project results indicate that the geostrophic wind speeds and directions calculated from interpolated pressure data are an excellent representation of frictionless flow in the coastal regions of Europe.
- Finally, this paper has also outlined future work to be carried out within the POWER project.

## ACKNOWLEDGEMENTS

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