EUROPEAN WIND ENERGY CONFERENCE, OCTOBER 1997, DUBLIN CASTLE, IRELAND.

NUMERICAL SIMULATION OF THE IRISH WIND CLIMATE AND COMPARISON WITH WIND ATLAS DATA

Helmut P. Frank and Lars Landberg
Wind Energy and Atmospheric Physics, Risø National Laboratory, P.O. Box 49, 4000 Roskilde, Denmark

ABSTRACT

The wind climate of Ireland has been calculated with the Karlsruhe Atmospheric Mesoscale Model KAMM using the statistical-dynamical method. The large-scale climatology is represented by 65 classes of geostrophic wind. From the frequency of the classes and the simulations the climatology of the surface wind is determined. The simulated winds are processed similar to observed data to obtain LIB-files for the Wind Atlas Analysis and Application Program WA^{S}P. Comparisons are made with mast observations which have been analyzed by WA^{S}P. Sites with high wind power potential are well predicted. Places with low observed wind power are overpredicted.

1 INTRODUCTION

The Wind Atlas Analysis and Application Program, WA^{S}P [7, 8] is a standard tool for the siting of wind turbines. It allows to extrapolate measurements of wind speed and direction from one place to other places in the same climate region in not too complex terrain. However, carefull measurements are costly, and to obtain a reasonable climatology requires several years of observation. Simultaniously, data archives of upper air or geostrophic wind from many years of numerical weather prediction do already exist.

To supplement WA^{S}P in regions of poor data coverage and to use the upper air data archives a method is presented which uses numerical simulations with an atmospheric mesoscale model to predict the wind climate near the surface. We employ the statistical-dynamical downscaling approach [11, 5, 4] together with the Karlsruhe Atmospheric Mesoscale Model KAMM [2, 1].

This paper presents a detailed comparison between a wind atlas obtained from observations and an atlas based on numerical simulations for Ireland. Previous studies appeared in [3, 4].

2 DATA DESCRIPTION

Most of the measurements are from 14 synoptic stations of the Irish Meteorological Service. They have been taken every hour and cover a period of 20 years (1974-93). In addition four masts have been operated by the University College Dublin and the Electricity Supply Board for three years (1992-94). They are typically equipped with wind speed and direction sensors at 10 and/or 30 meters. The masts collect 10 min averages every hour. See [4, 10] for more information.

To see the uncertainties in the climatological mean wind or mean power density, data which has been employed in the European Wind Atlas [8] is included in some figures. These measurements cover only 10 years. At most stations it is the period 1970-79.

A wind atlas is determined from this data using the Wind Atlas Analysis and Application Program, WA^{S}P [8, 7, 9]. WA^{S}P is the link from the local site to the regional scale which is resolved in the simulations. This processing of the observations will introduce additional errors. However, we think a comparison of simulations to processed observations is better than to real observations because the simulations represent only idealized conditions and local effects on scales of less than a few kilometres cannot be simulated for this big area. WA^{S}P is also used to calculate the expected energy production of a wind turbine at the sites.

The geostrophic wind, which is the large-scale forcing of the simulations, has been determined from 9 years (1983-91) analysis of the wind at 850 mb by ECMWF. The spatial resolution is 1.5°, approximately 100×160 km^2. A map of the third moment of wind speed at 850 mb, which is proportional to the power density of the wind, is shown in Figure 1. The speed and power increases from the south-east towards the north-west of the island.

3 METHOD AND DATA PROCESSING

3.1 The statistical-dynamical method

To calculate the surface wind climate we use the statistical dynamical approach of regionalization of large-scale climatology [5]. It rests on the assumption that the local surface layer climate is determined uniquely by a few parameters of the larger, synoptic scale and parameters of the surface. This parameter space is decomposed into several representative situations. Numerical simulations of these situations are performed with a meso-scale model to calculate the meso-scale state of the atmosphere. Then, the meso-scale climatology is calculated from the results of the simulations together with the frequency of the typical situations.

The main large-scale parameters to influence the surface wind at the mid-latitudes are the geostrophic wind and the stratification of the atmosphere. The main surface parameters are surface elevation and roughness, and soil or sea surface temperature.

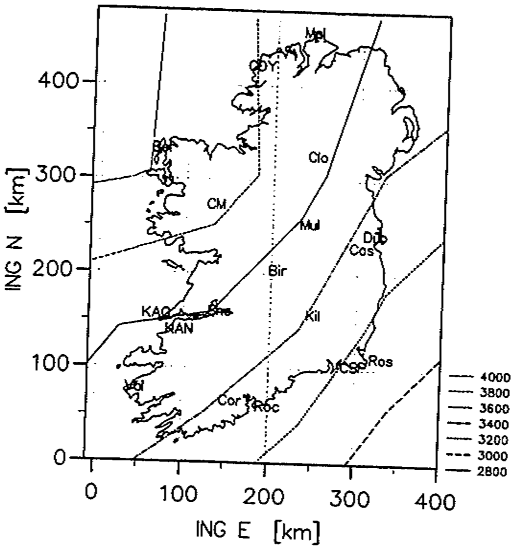

Fig 1. Third moment of wind speed (in $m^3 s^{-3}$) at 850 mb from the analysis of ECMWF for 1983-91. The position of the measurement sites is indicated by 3 letters.

We assume the dominating influence over Ireland is the geostrophic wind. The mean stratification is assumed not to vary significantly because Ireland has a moderate, oceanic climate. Also, it is assumed that thermally forced circulations are less important than those driven by the large-scale pressure gradient. Therefore, only steady states with no daily cycle of insolation are simulated. Soil and sea surface temperature are kept constant during a simulation.

The assumptions are influenced by the goal to reduce the number of simulations which are necessary to yield a good representation of the original parameter space. We ended up with 65 classes of geostrophic wind in 12 sectors of 30° (see also [3, 4]).

3.2 The simulations

The numerical simulations were done with the non-hydrostatic Karlsruhe Atmospheric Mesoscale Model KAMM [2, 1]. The model is initialized with a hydrostatic and geostrophic basic state. The large-scale pressure gradient and the daily cycle of radiation represent the external forcing of the model.

The model domain consisted of 50×60 points in the horizontal with a resolution of 10 km. In the vertical direction 30 levels were used up to 5000 m height with finer resolution near the surface. The orography was generated from a 1:625,000 scale map (Ordnance Survey, 1972) The roughness has been generated from the CORINE land-use database [6]. See [4] for details on the simulations.

During one simulation the geostrophic wind was constant and uniform throughout the model domain. The wind climate was constructed from the different simulations by calculating the weighted mean of the simulated wind after 6 h simulation time when the the atmospheric model is considered to be in equilibrium. The weights are the frequencies assigned to the geostrophic wind classes.

3.3 Data processing

The simulations are processed in a similar way to the measurements. The geostrophic drag law is used to transform the simulated friction velocity u_*, temperature scale θ_*, and local roughness length z_0 to a logarithmic wind profile in a neutrally stratified atmosphere over a given standard roughness z_{0r}. This wind profile is modified to account for the climatological mean stratification as in WAsP (see [8], Ch. 8).

The non-uniformity of the geostrophic wind (Figure 1) was accounted for by using different frequencies of the classes at each individual grid point of KAMM. They had been calculated separately for each grid point of the ECMWF analysis, and were interpolated to the KAMM grid.

In Figures 4-6 results from the simulation are compared with the WAsP-analysis. There, the KAMM value is the weighted mean of the four nearest grid points. The weights are $\exp(-r/(0.25\Delta x))$, where r is the distance from the observation site to a grid point and Δx is the grid size. Only grid points over land are included in the interpolation.

The calculation of Weibull parameters for individual sectors is complicated because each simulation represents a 30° sector of geostrophic wind directions, and the rotation of the surface wind relative to the geostrophic wind is different for each simulation. If a modeled surface wind lies close to the boundaries of one sector than it should be weighted partly in this sector and partly in the neighboring sector. This was achieved by randomizing the simulated surface winds using a Weibull distribution for speed and uniform distributions for direction in one class. The shape and scale parameters for randomization were calculated from the mean speed and mean power of surface wind corresponding to a geostrophic sector. The maximum and minimum directions were linearly interpolated between the simulated direction and those of the neighboring geostrophic sectors depending on the random speed. Half of the random directions were distributed uniformly to the right of the simulated direction and the other half lay to the left of it. 40000 random surface winds were generated for a grid point. Histograms with 1 ms^{-1} bins were created from which the Weibull parameters for each sector were calculated.

A map of the modeled wind power density at 50 m height above the ground and roughness length $z_0 = 3$ cm is shown in Figure 2. At each grid point of the model the mean power is shown by a small square. For comparison the values from the analysis of the new data by WAsP are written at the position of the stations. The terrain height is indicated by isolines at 100 m intervals.

As can be expected the highest power production is predicted near the north and west coast and in the Wicklow Mountains south of Dublin. The picture changes somewhat if we normalize the predicted wind with the speed which would be expected from the drag law for a flat, uniform surface using the geostrophic wind and roughness 3 cm (Figure 3). This removes the effect of the non-uniformity of the geostrophic

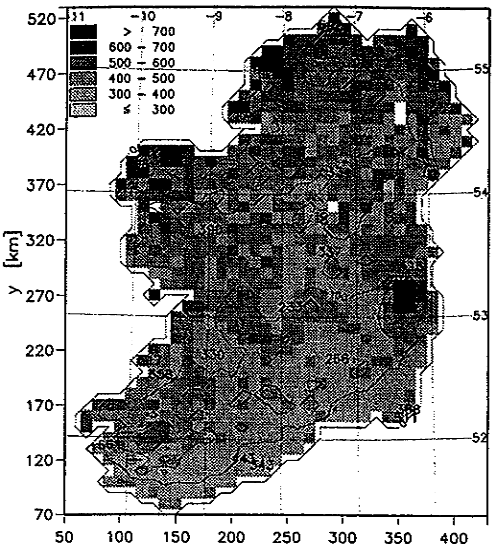

Fig 2. Wind power density in Wm^{-2} at a height of 50 m and roughness length $z_0 = 3$ cm over Ireland calculated by KAMM. The values from the wind atlas analysis of WA^{S}P are written at the position of the stations.

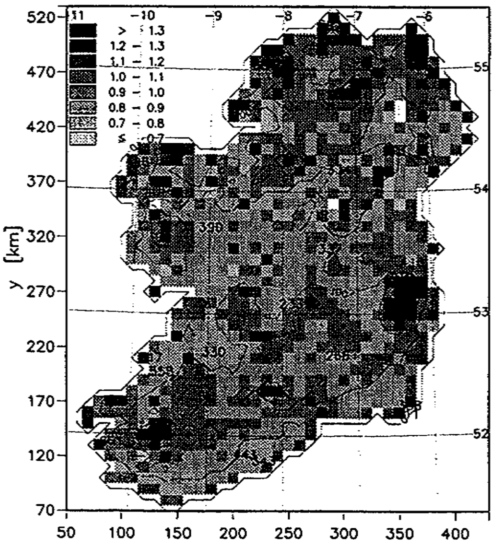

Fig 3. Normalized wind power at a height of 50 m and roughness length $z_0 = 3$ cm over Ireland calculated by KAMM.

wind. Everywhere, the normalized power is close to one. In general, it is less than one in the interior. Owing to the predominance of westerly winds the west coast tends to greater normalized power than the east coast.

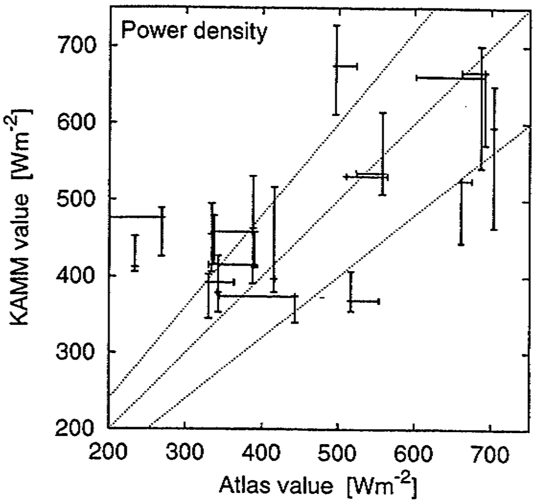

Fig 4. Comparison of the wind power density in Wm^{-2} at $z = 50$ m, $z_0 = 3$ cm at 18 stations in Ireland calculated with WA^{S}P from observations (atlas value) and by KAMM. See the text for an explanation of the error bars.

4 COMPARISON OF OBSERVED AND SIMULATED DATA

In Figure 4 the power density at height $z = 50$ m over a flat, uniform surface with roughness $z_0 = 3$ cm as analyzed with WA^{S}P is compared with the simulated values by KAMM. The range of wind power at the four nearest grid points is show by vertical error bars. This can be interpreted as a range of uncertainty. The horizontal error bar shows the difference between the 20 years of new data and the 10 years for the European Wind Atlas, or between the data measured at 30 m and 10 m. The dotted lines are the perfect agreement and deviations of ±20 %. KAMM overpredicts the sites with low wind power. Sites with great wind power potential seem to be better predicted.

The shape parameters k of the Weibull distributions are compared in Figure 5. KAMM predicts greater values which means that the predicted distribution is narrower than that analyzed by WA^{S}P. This is not astonishing because all simulations were with stationary forcing. Therefore, the variability of transient phenomena like fronts is not present. Considering this, the predictions of KAMM are remarkably good.

To show how the data can be used we calculated the expected yearly energy production of a Vestas V42-600 wind turbine at the position of the observations with WA^{S}P using the LIB-files from the analysis of the measurements and those from the simulations. The turbine has a hub height of 40.5 m and a rated power of 600 kW. This comparison is very good (Figure 6). However, the strongest influence is by the local terrain and roughness. Again, the sites with low energy production are overpredicted by KAMM.

5 SUMMARY

A wind atlas has been made for Ireland from numerical simulations using the statistical-dynmaical method with the Karlsruhe Atmospheric Mesoscale Model KAMM. The results are compared with measurements which were processed by the Wind Atlas Analysis and Application Program WA^{S}P. The comparison is only fair. Regions of high wind power density

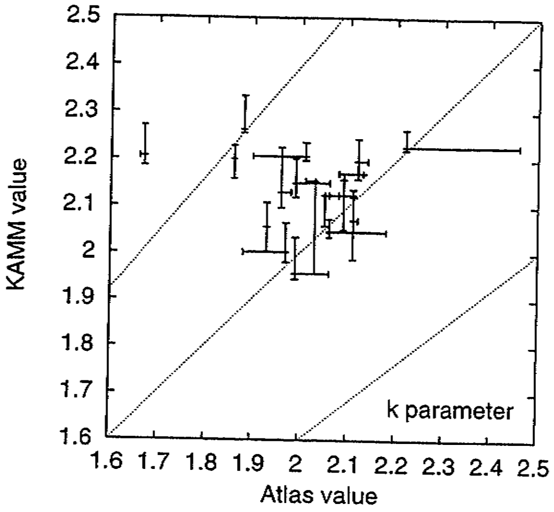

Fig 5. Comparison of the shape parameter k of the Weibull distribution for all sectors for $z = 50$ m, $z_0 = 3$ cm at 18 stations in Ireland calculated with WA^{S}P from observations (atlas value) and by KAMM. The errorbars have the same meaning as in Figure 4.

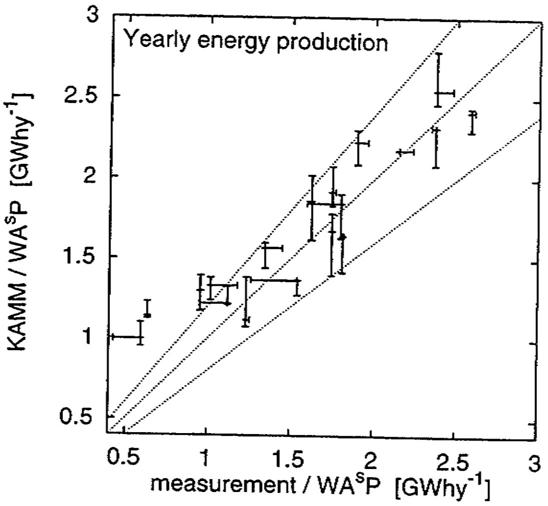

Fig 6. Comparison of the predicted yearly energy production in GWhy^{-1} of a Vestas V42-600 wind turbine at the measurement sites. The errorbars have the same meaning as in Figure 4.

are well predicted, but regions with low power density are overpredicted. A comparison of the expected annual energy production by a large wind turbine at the sites of the measurments is very good.

REFERENCES

[1] G. Adrian. Zur Dynamik des Windfeldes über orographisch gegliedertem Gelände. *Ber. Deutscher Wetterdienst*, 188:142 pp, 1994.

[2] G. Adrian and F. Fiedler. Simulation of unstationary wind and temperature fields over complex terrain and comparison with observations. *Beitr. Phys. Atmosph.*, 64:27–48, 1991.

[3] H. P. Frank and L. Landberg. Modeling the wind climate over Ireland. In A. Zervos, H. Ehmann, and P. Helm, editors, *Proc. EUWEC'96, Göteborg 1996*, pages 631–634. H. S. Stephens & Associates, 1996.

[4] H. P. Frank and L. Landberg. Modelling the wind climate of Ireland. *accepted by Boundary-Layer Meteorol.*, 1997.

[5] F. Frey-Buness, D. Heimann, and R. Sausen. A statistical-dynamical downscaling procedure for global climate simulations. *Theor. Appl. Climatol.*, 50:117–131, 1995.

[6] L. Landberg and R. Watson. The new Irish Wind Resource Atlas. In *Proc. from the European Wind Energy Association Conference and Exhibition, Thessaloniki, Greece*, volume I, pages 233–237, 1994.

[7] N. G. Mortensen, L. Landberg, I. Troen, and E. L. Petersen. *Wind Atlas Analysis and Application Program (WA^{S}P) Vol. 2: User's Guide.* Risø National Laboratory, Roskilde, Jan 1993.

[8] I. Troen and E. L. Petersen. *European Wind Atlas.* Risø National Laboratory for the Commission of the European Communities, Roskilde, Denmark, 1989. ISBN 87-550-1482-8.

[9] J. L. Walmsley, I. Troen, D. P. Lalas, and P. J. Mason. Surface layer flow in complex terrain: Comparison of models and full-scale observations. *Boundary-Layer Meteorol.*, 52:259–281, 1990.

[10] R. Watson. Wind measurement and modelling in Ireland. In *European Community Wind Energy Conference, Lübeck-Travemünde, Germany*, pages 607–610, 1993.

[11] F. Wippermann and G. Gross. On the construction of orographically influenced wind roses for given distributions of the large-scale wind. *Beitr. Phys. Atmosph.*, 54:492–501, 1981.

ACKNOWLEDGEMENTS

We thank E. L. Petersen and N. G. Mortensen from Risø National Laboratory, and A. J. Bowen from the University of Canterbury, New Zealand, for discussions about this work. The Irish Meteorological Service provided the wind data at the synoptic stations. Rick Watson from University College Dublin operated the other masts and checked the positions of the stations. F. Fiedler and G. Adrian allowed us to use KAMM. This research is funded in part by the JOULE program of the EU. HPF is supported by the European Commission through the program "Training and Mobility of Researchers".