Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 831-834.

# DETERMINATION OF WIND FARMS FOR THE BAHIA STATE USING NUMERICAL SIMULATION OF THE ATMOSPHERIC FLOW

*Leanderson M. da Silva Paiva**, Almir V. Ferreira
Federal Center of Technological Education, Rio de Janeiro, Brazil

Guilherme O. Chagas, Ricardo M. da Silva
Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

## 1. Introduction

The accelerated development of the science and the technology nowadays allows the exploration of new sources of energy, mainly those that do not affect drastically the environment. Therefore, the energy acquired from wind farms plays an important role into generating energy from cleaner methods. The environmental impact generated by the wind turbine is much smaller if compared to the most usual methods of energy production, such as hydroelectric, thermoelectric and nuclear plants. Some of the few impacts that wind turbines cause are due to the noise generated by the helices, the visual contrast and the aggression caused in the habitat occupation and on the obstruction of bird migration routes.

The main factor to the development of projects in this field is the wind quantification near the surface. In countries into development, the problem becomes worse due to the shortage of regular measurements. Some studies (Silva *et al*. 2004) make use of mean data series, from conventional meteorological stations, for the very past periods, while others studies use the numerical modeling as a possible solution. This numerical simulation are realized by mesoscale and microscale atmospheric models. Another approach includes applications of mesoscale models coupled with microscale models. Therefore, the objective of this work is to calculate mean wind conditions in order to indicate accurate conditions to the creation of wind farms in the State of Bahia, Brazil.

## 2. Methodology and Data

The simulations are computed using the numerical model “Mesoscale Model 5” (MM5) that is largely used by the meteorological community for weather forecast and studies of atmospheric systems. The Penn State University (PSU) and the National Center for Atmospheric Research (NCAR) developed the MM5 code and it has been continually improved by contributors from several universities and government laboratories of the entire planet. This is a model that solves complicated equations that mainly includes mass, energy and moment conservation, in order to determine the dynamics and thermodynamics of the atmospheric flow for spatial limited areas. Moreover, the MM5 has non-hydrostatic equations, it uses the sigma vertical coordinate that follows the surface (Dudhia, 1993), and its solutions are for the transient flows. The numerical code is organized in modules, in order to facilitate the compilation and execution procedures. The fifth generation of NCAR/Penn State Mesoscale Model, based on the model used by Anthes (Anthes and Warner, 1978) and used in this study, is the most recent version, and allows to realize multiple nested numerical grids, data assimilation in three-dimensional space and time (Stauffer and Seaman, 1990) and to choose many parameterizations for the cloud microphysics, solar and terrestrial radiation, turbulence, vegetation, and others.

Seeking to execute the MM5 in parallel processing, four microcomputers were exclusively destined to this purpose. The internal network of the Meteorology Laboratory was configured in order to operate this cluster, regulating the data traffic between the main computer and the execution modules and/or ordinary modules (Chagas, *et al*., 2004).

In order to obtain a comprehensive and precise initial condition, the Reanalysis database from the National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP/NCAR) is used in the data ingestion procedure. The Reanalysis Project basic idea is to use an analysis and forecast system in order to perform the assimilation using data from the past, since 1948 until nowadays. This database also includes several special datasets from international sources that were not available operationally through the Global Telecommunications System (GTS).

The Reanalysis Project database includes global data from radiosounding, buoys, airships, surface and altitude meteorological stations and from Special Sensing Microwave/Imager (SSM/I). This data is interpolated to a 2,5° resolution grid approximately, and then classified in agreement with the acquisition reliability and their composition characteristics.

### *2.1 Analysis of the Wind Field at 10 Meters Height*

The initial analyses are based in the wind field at 10 m height from the ground, obtained from NCEP Reanalysis for an area that includes the Bahia State. The Bahia State is placed in the Brazil’s northeast area, approximately limited by 8,5° to 18,5° of west latitudes and by 38,5° to 46,5° of south longitudes. The State has differentiated characteristics in terms of the soil type, vegetation and topography. An extensive coast on the Atlantic Ocean constitutes the east area of the State. The Central area has mountains and plains regions that reach the order of 1 Km heights and on the west area there is a mountain located in the border of Tocantins and Goiás States.

According to Kalnay *et al*. (1996) the wind field at 10 m height is considered as information of A type for Reanalysis, which means that they are atmospheric variables strongly influenced by the

* Corresponding author address: Leanderson M. da Silva Paiva, Federal Center of Technological Education; e-mail: leanderson@cefet-rj.br

observed data and, therefore, they are quite reliable variables that compose Reanalysis.

The Reanalysis database is acquired from the Internet, and their analysis started with the pattern behavior of the available kinetic energy in the Bahia State region. The kinetic energy *K* is defined as

$$K = \frac{1}{2}\sqrt{u^2 + v^2}\ , \qquad (1)$$

where *u* and *v* are the magnitudes of the zonal and meridian components of the wind speed, respectively. Initially the kinetic energy is calculated based in the wind field at 10 m height and, later on, the mean of these is computed on the area shown in Pic. 1. Consequently, it was obtained a temporary series of the kinetic energy for the area of interest.

Picture 1: The numerical grid and the studied region. The small circles indicate points where there is available information from Reanalysis.

It is important to remind that on the Reanalysis composition the obtained observations are irregularly spaced on the terrestrial globe, and as the information density vary in function of the position, they pass into mathematical filters and interpolation methods. Consequently NCEP Reanalysis are not considered as *in situ* data, however, they are an acceptable data source for the numerical modeling studies. The parameters from Reanalysis don't have information about the energy involved in the meso and microscale processes, what means that their representation just embraces the large scale, involving processes that characterize, for example, the occurrence of frontal systems and location of air masses. For a reasonable representation of the physical processes of meso and microscale, that would involve, for example, local winds, mostly started due of the differentiated heating and topographical variation, there is a need of generating a new database that has the representation of the energy involved in these scales. In these cases, the use of mesoscale atmospheric models as the MM5 can satisfy these needs, since its boundary conditions are imposed by the larger scale conditions, and its physics and dynamics includes meso and some microscale effects. By using this approach the Reanalysis database can be used together with mesoscale numerical models, in the attempt of representing those local effects and generating a new database that includes them. However, considering that generating such database for the whole period of Reanalysis (1948 to 2003), would demand a massive computational infrastructure, it is needed a detailed analysis of a representative period, to optimize the use of such tools. The Reanalysis data serves for that proposal, as they can supply a general result of the energy behavior of the area for a certain period.

Facing the general objective of this work, it's interesting to obtain objective parameters for determination of the periods in which the data groups would be generated and not to determinate major or minor energy generation potential. An analysis of the annual kinetic energy's variation on one year basis will display the behavior of the annual kinetic energy amplitude.

Ideally, it would be interesting that there were conditions of realizing simulations for three different periods, one of them with the kinetic energy by the mean value, another with the kinetic energy above it and the other with the kinetic energy below, seeking, in this approach, the use of years in which the extremes don't exceed the standard deviation. An approach of this type would bring to the energy generation process the extreme and average conditions. Besides, it can be found, in situations of low and extreme energy, maintainable conditions of wind energy generation in function of the meso and microscale effects, which could be more evident during some periods.

Considering that many past years had climatic occurrences such as El Niño and La Niña, the analysis must be calculated for more recent periods. It's important to remember that in recent years we had a technological evolution of the meteorological instruments, and consequently an improvement in the measures and observations, as well as in the number of observation points, and a modification of the climatologically behavior that was provoked, for example, by anthropogenic influences. In this case, the analysis is realized for the year of 2002.

*2.2 Numerical Configuration*

An analysis considering the relation between the performance and the computational workload was accomplished for the simulations. A numerical grid was structured with spatial resolution of 15 Km, with 82 x 100 horizontal points, and time resolution of 30 seconds, consisting of a physical domain of 1230 x 1500 Km. In the vertical orientation a resolution of 100 m is used, associated with topographical data with resolution of 9 Km. The evaluated simulation time is 4 minutes for every real hour of the simulation period. In this case, a simulation of 3 months results in 6 days of computational time uninterruptedly simulated.

3. Results and Discussion

From the resultant analysis, the average values of wind fields for the seasonal and annual periods are computed, according to the following equation

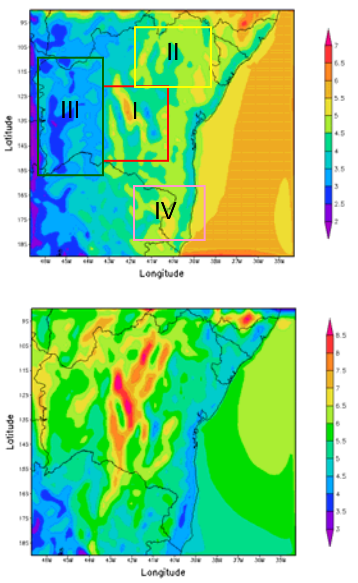
$$\overline{V} = \frac{\int_0^T V dt}{T}\ , \qquad (2)$$

where $\overline{V}$ is the field of horizontal speeds of the wind and *T* it is the total period calculated. The global analysis indicates that the most intense speeds on the terrestrial surface are in the areas of the center, center-south and center-north of the Bahia State. On the coastline surfaces the speeds are relatively more intense when compared to the speeds on terrestrial surfaces at the mean sea level, due to the low effectiveness of the friction on the wind flow. On terrestrial surfaces the speeds are influenced strongly by friction generated inside of the atmosphere boundary layer. It is noticed that the mean wind direction is predominantly from east.

The Pic. 2, which encloses the patterns of wind at 10m, reveals that the speeds are relatively weak in the entire Bahia State during the summer and they tend to intensify their values as the winter comes. In the central area of the Bahia State (Area I, Pic. 2(a)), that includes the Espinhaço Mountain and the Diamantina Plated, a decrease of speed is verified in the upstream of the mountainous areas, an increase of speed in the mountains tops and again a decrease of speeds close to the downstream. This is a pattern found in practically all the simulated periods. Such pattern is determined by the Espinhaço Mountain aerodynamics and by mass conservation. In the Area II of Pic. 2(a) some signs can be noticed on the northwest of the State, next to the Chapéu Hill and Sobradinho Dam. In this case, it's possible that the topography and the dam will establish a thermodynamic mechanism of breezes, capable of amplifying the speeds in certain points of this area. In the Area III, in spite of the weak signs, the pattern of decreasing speeds in the upstream and in the downstream of the plated and the increasing speeds in the top it happens as in the Area I. On the other hand, in the Area IV, that includes Eunápolis, Guaratinga, Teixeira of Freitas, among others cities, a small sign is computed, probably due to the proximity with the coast, capable of creating sea-land breezes.

(a)

(b)

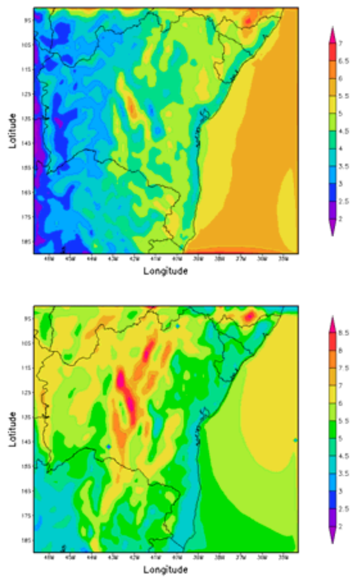



Picture 2: Mean fields of magnitude wind (m/s), to 10 m of height, for the periods ranging from (a) December – February and (b) June - August.

In Pic. 3, which refers to the wind field at 50m, the pattern found is similar to the Pic. 2. Despite of different heights, the differences in the speeds are small. In this case, the areas that have signs of relatively high speeds expands, reaching 7 m/s. Heights of 50 to 70 m are typical for wind turbines.

(a)

(b)

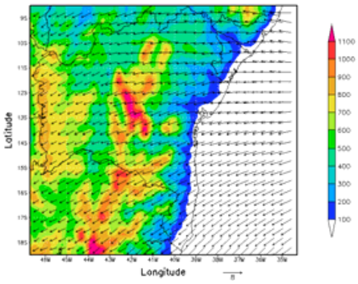



Picture 3: Mean fields of magnitude wind (m/s), to 50 m of height, for the periods ranging from (a) December – February, and (b) June – August.

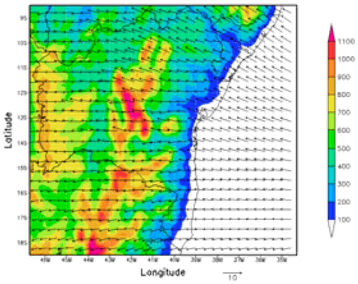
The predominant direction of the wind is east, with small deviations during the year that oscillate from northeast to southeast (Pic. 4). It is observed that in the summer the winds tend to east and northeast directions, turning counter-clockwise, determined by the circulation pattern of the permanent high-pressure system, that is, the South Atlantic Subtropical High. This flow tends to turn from east to southeast as the winter approaches. Such fact happens because the occurrence of frontal systems increases in this area during the winter. Generally, the winds are perpendicular to the direction of the larger axis of the Espinhaço Mountain. In this case, the mountain acts as a true flow barrier, capable to turn the flow into a bi-dimensional flow, amplifying, therefore, its intensity due to the mass conservation. A more detailed study in this area is needed, in order to identify three-dimensional effects in the flow, associated with the generation of turbulent wake zones, recirculating and separating the flow, and in the determination of the potential to build wind farms.

In what refers to the coastal area, the winds are relatively calm, but such fact requests a greater analysis. The causes can be associated to the mean positioning of the center of the South Atlantic Subtropical High that is located in this area. The center of a high pressure system is associated with conditions of clear sky with winds varying in intensity from weak to moderate. The Bahia State founds itself in an area next to the center of the high pressure system and far away from the boundaries, where more intense winds are likely to be found. The coastal area of Bahia State presents considerable variations on the movement during the diurnal hours. This means that the area doesn't present a quasi-stationary flow, generating a transient behavior, differently of what happens with the trade winds that blow on north Brazil areas. Therefore, it can be concluded that this region doesn't seem to be an adequate area for the use of wind energy. The analysis realized by Silva *et al*. (2004) and the mean data of the Brazilian Institute of Meteorology corroborate these results.

(a)




(b)




Picture 4: Mean fields of wind direction, to 50 m of height, and topography (m) for the periods ranging from (a) December – February and (b) June - August.

The estimated profile for other heights can be obtained analytically by logarithmic laws. However, it is necessary the knowledge of flow's parameters as much as the roughness length and the friction velocity for the lands studied. It is noticed that on the average, the winds blow to east with speeds below 4 m/s.

4. Conclusions and Final Considerations

To have a better precision in the simulations, it is necessary a certain precaution with the boundary conditions being imposed and with the resolution of numerical grids that is defined in the model. This causes greater difficulties to the simulation, requiring a higher computational performance. Thus, a detailed study should be elaborated to establish the relationship cost/benefit of the results that are generated.

The analyses indicate that just the central area of Bahia State, mainly on Diamantina Flatted, presents values of speeds adapted for the use of wind energy. However, it is important to point out that the mean wind doesn't reveal extreme conditions and conditions do not supply indications of stationary regime during long periods of the day. That is important because, it is preferred to consider the wind energy as the first generating matrix of energy, followed by the hydroelectric, nuclear and finally the thermoelectrical. The intermittence of the wind field is not favorable to the wind farms installation; consequently, a more detailed study that includes daily analyses of the wind behavior is required.

These numerically simulated results represent a acceptable standard when compared to others consulted in the literature and available for national centers of research in Internet (Research Center of Electric Energy - CEPEL and Electricity Company of the Bahia State - COELBA). The controversies are just observed for the coastal area. The relatively weakest speeds found are a result of the mean position of the center of South Atlantic Subtropical High, according to the climatologic of the permanent pressure systems. The mean data computed of the meteorological stations of INMET corroborate the results numerically simulated.

We suggest a re-simulation with more refined numerical grids and the accomplishment of experimental fields research to validation model.

*Acknowledgments*

The authors thank to the Mr. Manfredo Pires Cardoso, director of Superintendence of Hydrological Resources (SRH) and, especially to Meteorologist Heráclio Alves Araújo for providing the wind data in situ from the automatic stations of SRH. We especially thanks to the colleagues Engineer Fábio Souza, Profs. Geraldo Martins Tavares and Nelson Francisco Favilla Ebecken for financial support.

References

Anthes, R. A., Warner, T. T., 1978, Development of hydrodynamic models suitable for air pollution and other mesometeorological studies. Mon. Wea. Rev., 106, 1045 – 1078.

Chagas, G. O., Silva Paiva, L. M., Silva, R. M., Ferreira, A. V., 2004, "Implementation of treatment system of satellite images and numerical modeling for weather forecast". In: *Annals of XIII Brazilian Congress of Meteorology*, The Meteorology and the Energy Management, SBMET, Mabu Hotel, Fortaleza – CE.

Dudhia, J., 1993, A nonhydrostatic version of the Penn State-NCAR mesoscale model: Validation test and simulation of an Atlantic cyclone and cold front, Mon. Wea. Rev., 121, 1493-1513.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K. C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R., Joseph, D., 1996, "The NCEP/NCAR 40-Year Reanalysis Project". Bulletin of the American Meteorological Society, v. 77, n 3, 437 – 470.

Silva, B. B., Alves, J. J A., Cavalcanti, E. P., Ventura, E. D., 2004, "Space and time variability of the wind potential of the predominant direction of the wind in the northeast of Brazil". Brazilian Rev. of Meteorology, vol. 19, n° 2, agosto 2004.

Stauffer, D. R., N. L. Seaman, 1990, Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic-scale data. *Mon. Wea. Rev.*, 118, 1250-1277.