APPLICATION OF DIFFERENT INDICES OF PERFORMANCE EVALUATION OF FORECAST FOR WIND SPEEDS

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Summary. In this study, firstly, we’ll see an introduction about wind energy and its current use in Brazil, giving an overview of the development of the treatment of wind forecasting through two techniques for forecasting. One of the data sources available are predictions from numerical models, due to the large volume of information, it were saved only prediction’s images made. Worked these images you can retrieve a value of wind speed forecast for a specific city.

We’ll show the used methodology, seeing how processed data were taken, we’ll also see the accumulator’s installations, which will contain for the same date, actual values and projected wind speeds, and we’ll conclude with the indexes’ calculations for evaluating performance working with three indexes: “MAPE”, “RMSE”, “MAE”, in the range of a year in four quarters and 45 samples in each quarter. Then we’ll see according to several articles, the most used indexes evaluation, which are “MAPE”, “RMSE” and “MAE”, that’s the reason in this study we’re also going to work with these ones. Finally, we’ll proceed to the analysis of the results. In the rainy season and the dry season, we will see what was the numerical model that best approached to the reality.

Key words forecast, performance evaluation, prediction error, numerical weather prediction model.

1. Introduction

The world capacity for generating electricity through wind power has been increasing year by year. To get an idea of the magnitude of the expansion of wind energy in the world. In 2010 was approximately 153.1 GW, in 2011 was 175.48 GW, in 2012, 198.39 GW, and in 2013 is estimated to reach this magnitude of 222.79 GW. [1]

The production capacity of wind power in Brazil has been increasing year by year also. In 2008 was 341MW, in 2010 was 920MW spent in 2012 amounted to 1200 MW. [2]. To take full advantage of this generating capacity of wind power, a good prediction of the wind speed is required. These wind forecasts are realized by mathematical models of the climate. Begins with some initial conditions measured by satellites and thousands of stations and weather balloons located around the world.

The quality of these measures is essential for a correct prediction of forecasts. The mathematical formulation of the model of evolution of the atmosphere is based on a partial differentials equations, which due to its huge size doesn’t have an analytical solution system. That's why we need to use numerical tools to solve the system.

There’s a lot of numerical models that have been developed by various agencies and organizations meteorological. In this study, we’ll pay attention in specifics numerical models: NWP (Numerical Weather Prediction), with two forecasting techniques: Regional Atmospheric Modeling System (RAMS) and Weather Research and Forecasting (WRF). With the speeds’ wind’s predictions of these two techniques, we evaluate which moved closer to reality by applying of several indices of performance evaluation of forecasts

2. OBJETIVES

Evaluate the performance of forecasts of wind speed according to different evaluation criteria

Specifics objectives.
- Development of indexes of performance analysis of forecasts of wind speed
- Compare the performance of different configurations of the methods in different seasons, to the town of Catarina city in the state of Ceará Brazil, for the year 2010/2011
- Quantify the use of indexes of performance analysis forecasts of wind speed.
- Apply different indexes of performance for analyzing the predictions of RAMS and WRF models simulated by FUNCEME to the same city 2010/2011.

3 State of art

3.1 Wind forecast

The wind forecast can also be defined as an estimate of future values of wind speed and direction at different heights with an estimation of the error in its output. The
research in the area of wind forecasting began in the 1980s. Thereafter numerous research centers have invested in developing methods and tools that have generated a wide variety of forecasting models. Some of them are commercial, and offer their services to companies operating wind resources.

3.2 Forecasting techniques

There are three types of forecasting techniques constrained by the available data:
- "Delphi Method": qualitative data and measurements
- Statistical Algorithms and / or simplified physical methods:
- Weather forecast model. [3]

According [4] the prediction of the weather conditions may be accomplished by numerical climate models called NWP ("Numerical Weather Prediction"), which as already mentioned, this is the model that will be used in this present study.

Within the numerical model NWP two forecasting techniques, RAMS and WRF will be used, from which are obtained from the different evaluation indices and compared with other comparative graphs and tables mediants ones.

3.3 Numerical forecasting models.

According [4] a numerical prediction model attempts to establish the relationship between the historical values and a series of variables that may be related to this value, as the NWP forecast of the meteorological variables surrounding areas. There are many techniques of numerical models to predict, but we’ll pay attention on: RAMS, and WRF, because they are provided by the Ceará Foundation of Meteorology and Water Management (FUNCEME), daily predictions.

3.4 Indexes of performance evaluation of forecasts

In this section we will define a series of techniques to be considered when evaluating the errors committed by the forecasts. The main indexes of the performance evaluation of the predictions are shown in Table 1:

4 Theoretical foundation

According to [5], one of the sources of data available for the state of Ceará - Brazil are the predictions from numerical models, where the FUNCEME due to the large volume of information, were saved only images of the predictions made. Worked these images you can retrieve a value of wind speed forecast for a specific city. The focus of interest are the images of speed and wind direction at 10 meters height equivalent to the height of the meteorological towers FUNCEME. Images are transferred in the form of compressed files according to the daily simulations.

<table>
<thead>
<tr>
<th>Evaluation Index</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MSE</strong> (mean squared error)</td>
<td>[ \text{MSE}<em>k = \frac{1}{N_T} \sum</em>{t=1}^{N} (e_{t+k})^2 ] (1)</td>
</tr>
<tr>
<td><strong>MAE</strong> (mean absolute error)</td>
<td>[ \text{MAE} = \frac{1}{N} \sum_{t=1}^{N}</td>
</tr>
<tr>
<td><strong>RMSE</strong> (root mean squared error)</td>
<td>[ \text{RMSE}<em>k = \sqrt{\text{MSE}<em>k} = \left( \frac{1}{N_T} \sum</em>{t=1}^{N} (e</em>{t+k})^2 \right)^{1/2} ] (3)</td>
</tr>
<tr>
<td><strong>MARE</strong> (mean absolute relative error)</td>
<td>[ \text{MARE} = \frac{1}{N} \sum_{t=1}^{N} \frac{</td>
</tr>
<tr>
<td><strong>MSRE</strong> (mean squared relative error)</td>
<td>[ \text{MSRE} = \frac{1}{N} \sum_{t=1}^{N} \left( \frac{e_t - y_t}{y_t} \right)^2 ] (5)</td>
</tr>
<tr>
<td><strong>RMSRE</strong> (root mean squared relative error)</td>
<td>[ \text{RMSRE} = \sqrt{\frac{1}{N} \sum_{t=1}^{N} \left( \frac{e_t - y_t}{y_t} \right)^2} ] (6)</td>
</tr>
<tr>
<td><strong>MAPE</strong> (mean absolute percentage error)</td>
<td>[ \text{MAPE} = \frac{100}{N} \sum_{t=1}^{N} \left</td>
</tr>
<tr>
<td><strong>MSPE</strong> (mean squared percentage error)</td>
<td>[ \text{MSPE} = \frac{1}{N} \sum_{t=1}^{N} \left( \frac{e_t - y_t}{y_t} \right)^2 ] (8)</td>
</tr>
<tr>
<td><strong>RMSPE</strong> (root mean squared percentage error)</td>
<td>[ \text{RMSPE} = \sqrt{\frac{1}{N} \sum_{t=1}^{N} \left( \frac{e_t - y_t}{y_t} \right)^2} ] (9)</td>
</tr>
</tbody>
</table>

Initially a code image processing speed of the wind, which decompresses these files sequentially preparing a directory with images related to the speed and wind direction at 10 m was generated.

Images are maps with colors relating to greatness in the study and follow a pattern, there are references in this map latitude and longitude axes of the image, so it was possible to relate a coordinated equivalent pixel, as shown in Figure 1, points A, B, C and D are the pixel coordinates of the vertices of the grid simulation, zero latitude is equivalent to the pixel.

![Figure 1 Identification of the pixels compared with Latitude and Longitude](https://example.com/image.png)

In section 6 an analysis of different articles by various authors will be held and conclude that the three most commonly used indexes are: "ASM", "MAE" and "RMSE". That is why this work will be used to review these three indexes.

5 Methodology Used

Steps of the methodology:
1) Data processing of numerical models: RAMS and WRF.
2) Creation of accumulators, which will contain the wind speeds predicted and actual, for all days of the year, for each numerical model.
3) Calculation of the index of performance evaluation.

5.1 Processed Data

Each of the five numerical model has two rounds of daily forecasts for each of the variables. Considering the first round at zero hour and the second one at 12 hours, each of these rounds makes 14 predictions. The first round gives forecasts 3 to 81 hours ahead, with a step of 6 hours. The second round gives forecasts 15 to 93 hours ahead, also with a step of 6 hours (Table 2).

Table 2. Scales for each round of prediction.

<table>
<thead>
<tr>
<th>Date</th>
<th>Hour</th>
<th>forecast 0h</th>
<th>Forecast 12h</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/02/2009</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>05/02/2009</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>05/02/2009</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>05/02/2009</td>
<td>21</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>06/02/2009</td>
<td>3</td>
<td>27</td>
<td>15</td>
</tr>
<tr>
<td>06/02/2009</td>
<td>9</td>
<td>33</td>
<td>21</td>
</tr>
<tr>
<td>06/02/2009</td>
<td>15</td>
<td>39</td>
<td>27</td>
</tr>
<tr>
<td>06/02/2009</td>
<td>21</td>
<td>45</td>
<td>33</td>
</tr>
<tr>
<td>07/02/2009</td>
<td>3</td>
<td>51</td>
<td>39</td>
</tr>
<tr>
<td>07/02/2009</td>
<td>9</td>
<td>57</td>
<td>45</td>
</tr>
<tr>
<td>07/02/2009</td>
<td>15</td>
<td>63</td>
<td>51</td>
</tr>
<tr>
<td>07/02/2009</td>
<td>21</td>
<td>69</td>
<td>57</td>
</tr>
<tr>
<td>08/02/2009</td>
<td>3</td>
<td>75</td>
<td>63</td>
</tr>
<tr>
<td>08/02/2009</td>
<td>9</td>
<td>81</td>
<td>69</td>
</tr>
<tr>
<td>08/02/2009</td>
<td>15</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>08/02/2009</td>
<td>21</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>09/02/2009</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09/02/2009</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this way, after five days of predictions, each parameterization has accumulated predictions for a same moment (Table 3).

Table 3. Wind speed forecasts accumulated for a same moment.

<table>
<thead>
<tr>
<th>Days</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>date</td>
<td>hour</td>
<td>0h</td>
<td>12h</td>
<td>0h</td>
<td>12h</td>
</tr>
<tr>
<td>08/12/09</td>
<td>15</td>
<td>6,7</td>
<td>6,7</td>
<td>6,2</td>
<td>6,2</td>
</tr>
<tr>
<td>08/12/09</td>
<td>21</td>
<td>6,2</td>
<td>6,2</td>
<td>6,2</td>
<td>6,2</td>
</tr>
<tr>
<td>09/12/09</td>
<td>3</td>
<td>6,2</td>
<td>6,2</td>
<td>6,2</td>
<td>6,2</td>
</tr>
<tr>
<td>09/12/09</td>
<td>9</td>
<td>6,2</td>
<td>6,2</td>
<td>6,2</td>
<td>6,2</td>
</tr>
<tr>
<td>09/12/09</td>
<td>15</td>
<td>6,2</td>
<td>6,2</td>
<td>6,2</td>
<td>6,2</td>
</tr>
<tr>
<td>09/12/09</td>
<td>21</td>
<td>6,2</td>
<td>6,2</td>
<td>6,2</td>
<td>6,2</td>
</tr>
</tbody>
</table>

5.2 Mounting of Accumulators

Accumulators were created to group the predictions of each scale prediction. We then have 28 accumulators: acum300h, acum1512h, acum2700h, acum3912h, acum5100h, acum6312h, acum57500h, acum8712h, acum900h, acum2112h, acum3300h, acum4512h, acum6912h, acum8100h, acum9312h, acum1500h, acum2712h, acum3900h, acum5112h, acum6300h, acum7512h, acum2100h, acum2100h, acum3312h, acum4500h, acum5712h, acum6900h, acum8112h. Each accumulator will save the set of all predictions to the same scale prediction, later to be compared with the values of real measurements. This procedure will evaluate how each scale prediction by the numerical model is closer to the actual value measured by an anemometer.

5.3 Calculation of indices for evaluating performance

We will work in the range of one year, beginning in June 2010 and ending in May 2011, we will divide the year into four quarters: June to August (quarter 1), September to November (quarter 2), December to February (quarter 3), and from March to May (quarter 4). The first two quarters are considered dry season, and the last two quarters of the rainy season. For each quarter we have 45 samples of forecasts of wind speed and their actual values of the velocities for each numerical model. With these predicted values and the actual index of MAPE error was calculated. So it was evaluated the numerical model that will best approached reality for each quarter.

6 Index Performance Evaluation Of Numerical Model Forecasts

In this section a survey of the use of indexes of the performance evaluation was conducted to identify the most common indices in the literature, this study is presented in Table 4.

Table 4 - Survey of the use of indices for evaluating performance.

<table>
<thead>
<tr>
<th>Index Performance</th>
<th>FREQUENCY</th>
<th>AUTHOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MSE (mean squared error)</td>
<td>5</td>
<td>[11], [14], [33], [38], [40]</td>
</tr>
<tr>
<td>2 root-mean-square deviation (RMSD) or root-mean-square error (RMSE)</td>
<td>19</td>
<td>[6], [7], [8], [10], [11], [12], [13], [18], [19], [20], [21], [22], [24], [26], [29], [36], [41], [42], [50]</td>
</tr>
<tr>
<td>3 MAPE (mean absolute percentage error)</td>
<td>13</td>
<td>[5], [6], [13], [14], [23], [25], [38], [40], [44], [46], [47], [48], [49]</td>
</tr>
<tr>
<td>7 MAD</td>
<td>4</td>
<td>[12], [37], [38], [43]</td>
</tr>
<tr>
<td>10 % prediction accuracy</td>
<td>2</td>
<td>[39], [45]</td>
</tr>
<tr>
<td>16 NRMSE</td>
<td>3</td>
<td>[18], [30], [31]</td>
</tr>
<tr>
<td>17 NMAE</td>
<td>3</td>
<td>[9], [21], [32]</td>
</tr>
<tr>
<td>18 MAE</td>
<td>11</td>
<td>[7], [11], [14], [15], [16], [17], [21], [25]</td>
</tr>
</tbody>
</table>

This analysis found a wide variety of indices used and the most common were RMSE, MAE and MAPE.
### 7 Comparative Results

In this section, we graphically present the evaluation results for each quarter, identifying the behavior of each numerical model in each quarter. In this study, the forecasts were evaluated using the MAPE index, where, the closer to zero the index, the more the prediction approached the actual value. We compared the MAPE of 45 samples of each expected range, 3-93 hours ahead, for RAMS and WRF models for two daily rounds, the round noon (12h), and round midnight (00h):

For the quarter June to August of 2010 we have:

For the quarter March to May of 2010 we have:

In the fourth quarter the same behavior was observed oscillation between performance and better performance of RAMS model.

### 8 Conclusion

In the present study, we determined the wide variety of performance indices used, standing out as the three most widely used indexes: "MAE", "MAPE" and "RMSE" or (RMSD). We can also say that in this study the dry season and in the rainy numerical model that best approached to reality was: "RAMS". Also notable was a cyclical and complementary behavior between the results of the predictions made at 00h and 12h, usually when one is bad the other is better. The present study is an analysis tool for users and developers of numerical models, it demonstrates their behavior in different seasons. These results serve as indicative of adjustments in parameterization of models, trying to adapt them to regional conditions, specifically wind variable.

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