Comparison of Reanalysis, Analysis and Forecast datasets with measured wind data for a Wind Power Project in Jhimpir, Pakistan

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Abstract. This study aims to evaluate reanalysis, analysis and forecast data of wind speed and direction with the surface measured data at a site in Jhimpir region of Pakistan. Five datasets (reanalysis, analysis and forecast), NCEP-NCAR, 20th Century Reanalysis v2c (20C), CFSR, GFS and NCEP-FNL have been used for this study. The comparison has been made on six hourly and daily bases. The statistical parameters used are Mean Bias Error (MBE), Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and correlation coefficient (R). The Weibull probability distribution has been drawn, the shape and the scale factors have been calculated. The CFSR data shows significantly good results for lower temporal resolution (daily) with a high correlation coefficient for a wind speed of 0.898 while at a higher temporal resolution of 20C shows significantly lower values of MBE of -0.87 m/s and CFSR shows lower values of RMSE of 2.09 m/s. CSFR wind direction data show good agreement with measured data in terms of statistical parameters The wind industry in Pakistan is under development stages with the possible potential of the offshore wind farm and expansion of land wind farms in other areas of the country, this study will be an initiative toward the initial wind resource assessment for potential sites in the wind corridor.

1. Introduction
Pakistan has been facing a shortage of about 4000 MW in the supply and demand of electricity over the past decade, so looking for alternative resources of energy, the wind is a good sustainable option. There was not a single grid-connected wind farm exists in Pakistan until 2007, but progress is being made in this regard in the past decade. The total capacity of operational wind projects at various locations is 308.2 MW according to the Alternate Energy Development Board (AEDB), 477MW projects are under construction and 663MW projects are in the pipeline. Pakistan Metrological Department (PMD) with financial assistance from the Ministry of Science and Technology brought about the Wind Power Potential Survey of Coastal Areas of Pakistan in June 2005, the estimated wind potential to be of 43000 MW in the Gharo-Jhimpir wind corridor \cite{1}, Jhimpir region has been identified as the most lucrative site for wind power plants in Pakistan by PMD.

The NCEP-NCAR reanalysis dataset \cite{2, 3} jointly produced by the National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) in the mid-nineties and this was the first generation of reanalysis datasets. The spatial resolution of wind speed data
is 1.905°×1.875° (latitude × longitude) and temporal resolutions six hours (00, 06, 12, 18 UTC). The Twentieth Century Reanalysis Project (20C) was developed by the Physical Sciences Division of the Earth System Research Laboratory from NOAA and the CIERs/Climate Diagnostics Center of the University of Colorado [4]. The wind data of the 20th Century Reanalysis version 2c was used which has a temporal resolution of three hours with a spatial resolution of 1.905°×1.875°.

The Climate Forecast System Reanalysis (CFSR) is a third-generation reanalysis product by NCEP in released in 2010, which is available for from January 1979 [5]. The wind data of CFSR has a spatial resolution of 0.5°×0.5° and a temporal resolution of six hours. The Global forecast system (GFS) is a forecast data product prepared by NCEP [6, 7] available from December 2002. This wind data has a spatial resolution of 0.5°×0.5° and a temporal resolution of six hours. The NCEP FNL (Final) is global operational analysis data produced by the Global Data Assimilation System (GDAS) [8]. This wind data has a spatial resolution of 1°×1° and a temporal resolution of six hours and available from 1999.

The wind data measured by a private company at Jhimpir region is being compared data from reanalysis, analysis and forecast datasets (all termed in this paper as datasets) to analyze the resource potential. The site is located 114 km from Karachi and has been identified as a potential region for the wind power generation according to a resource potential estimation survey of Pakistan Meteorological Department. The geographical location of the site where the mast was installed is 25.134° N and 67.996° E. The mast consists of five anemometers at measurement levels of 85 m, 60 m, 30m, and 10m to measure wind speed and two wind vanes at 83.5 m and 28.5 m to measured wind direction. The data for the duration of 36 months, from 1st January 2009 to 31st December 2011, was used to evaluate wind data from the datasets for this study.

The study is aimed to evaluate the reanalysis, analysis and forecast datasets for the site located Jhimpir region of Sind province. The evaluation or comparison of the datasets for wind resource assessment for South Asia has been performed to a very limited extent for few regions in Iran [9]. Amjad et al. [10] evaluated NCEP-NCAR data Gharo region using WRF simulated model at 10m and 30m heights using statistical parameters and time series. In this study, for the first time an extensive evaluation of five datasets: NCEP-NCAR, 20C, CFSR, GFS and NCEP-FNL against measured wind data at 10 m height has been performed using statistical parameters: MBE, MAE, RMSE and R. A comparison of these results with previously published results have been reported thus validating results and identifying the datasets variations for the South Asian region. The recent exponential increase in renewable energy projects especially wind projects are attracting attention and for the installation of such projects accurate potential estimate is of key importance. Since installing a wind mast and to measure surface data is a costly and time-consuming process, the datasets can be used as an alternative to surface measured data. This study is an initiative towards wind resource assessment of potential sites based on wind data from the datasets in Pakistan so that it can be sued to estimate the potential of the site without measured data.

2. Methodology
The quantitative comparison between the mast measured data and data datasets, and is of key importance to assess the potential of a site for the installation of a project and this comparison goes beyond having some graphs. Several methods had been used by researchers in literature for evaluation of the datasets against mast measured data. A comparison between the mast measured data and the datasets in literature has been made on the basis of daily time series [11], monthly mean wind speed [9, 11], sub-daily time series [12], annual average series [13], statistical analysis [14, 15], and probability distribution function[16, 17]. For evaluation of wind speed and direction from datasets, four methods have been used in this study. The evaluation of wind data from dataset against measured data was performed based on statistical analysis of wind speed and wind direction, monthly mean time series of wind speed, wind direction frequency in terms of wind rose and Weibull probability distribution function. Statistical analysis includes calculating several parameters which provide an idea of how much a wind data from datasets is comparable. The statistical parameters include MBE (mean bias error), MAE (mean absolute error), RMSE (root mean square error), and correlation coefficient R, the details of
calculations of these errors are presented in the Ref [17]. The wind rose represents the percentage of wind direction in sectors and for each sector and relative frequency of wind speed for each sector. The Weibull Probability Density Function (PDF) is an important tool to determine the resource probability density, cumulative frequency functions and subsequently to plot their respective graphs [18].

The datasets are available at a temporal resolution of three hours (20C) and six hours (NCEP-NCAR, CFSR, GFS and NCEP-FNL), 20th Century data had been converted to six hours. The reanalysis wind speed data at the mast location was calculated from the four nearby grid locations using bilinear interpolation. The data from datasets have been converted to daily mean as well for comparison. The surface measured data had a temporal resolution of ten minutes, so six hourly and daily mean data was calculated.

3. Results

In this section, results are presented in the form of statistical analysis, monthly mean time series of wind speed, the wind rose for wind direction and Weibull probability density function.

3.1. Statistical Analysis

MAE, MBE, RMSE and R computed from data from datasets and measured data of wind speed and wind direction for a temporal resolution of six hours and one day are presented in Table 1. A positive bias or error in the wind speed represents the data from datasets is overestimated and vice versa, whereas for wind direction a positive bias represents a clockwise deviation and vice versa. The lower values of errors and considerably higher value of correlation coefficient for wind speed and direction are of greater importance.

The statistical parameters for daily data are better compared to six hourly data. For six hourly wind speed data the lowest bias is for 20C but it shows worst value of R, CFSR has the lowest MAE, RMSE and the highest value of R. The six hourly wind direction data of CFSR has lowest MBE, MAE and RMSE and the highest value of R. The best values, higher correlation coefficient and lower errors for both six hourly and daily for all the datasets, are highlighted in bold. The overall wind speed biases are negative which indicate the underestimate of wind speed by satellite. The negative biases of wind direction indicate anticlockwise wind rotation from datasets compared to measured data. For the site under study, CFSR data shows overall good comparison of both six hourly and daily data.

| Temporal Resolution | Satellite Data | MBE Speed (m/s) | MBE Dir’n (°) | MAE Speed (m/s) | MAE Dir’n (°) | RMSE Speed (m/s) | RMSE Dir’n (°) | R Speed (m/s) | R Dir’n (°) |
|---------------------|----------------|----------------|--------------|----------------|--------------|----------------|--------------|--------------|------------|
| Six Hourly          | NCEP-NCAR      | -1.52          | -15.06       | 1.86           | 43.11        | 2.34           | 58.83        | 0.700        | 0.529      |
|                     | 20C            | -0.87          | -26.66       | 1.72           | 53.22        | 2.18           | 68.28        | 0.644        | 0.387      |
|                     | CFSR           | -1.44          | -11.13       | 1.69           | 33.65        | 2.09           | 51.85        | 0.785        | 0.689      |
|                     | GFS            | -1.60          | -19.25       | 1.92           | 37.45        | 2.41           | 54.56        | 0.683        | 0.593      |
|                     | NCEP-FNL       | -1.73          | -19.57       | 1.99           | 37.63        | 2.49           | 54.52        | 0.679        | 0.579      |
| Daily               | NCEP-NCAR      | -1.52          | -21.18       | 1.61           | 39.45        | 1.96           | 53.14        | 0.824        | 0.565      |
|                     | 20C            | -0.87          | -32.78       | 1.44           | 50.99        | 1.83           | 66.18        | 0.718        | 0.464      |
|                     | CFSR           | -1.44          | -11.86       | 1.48           | 27.51        | 1.77           | 43.15        | 0.898        | 0.728      |
|                     | GFS            | -1.60          | -19.97       | 1.65           | 33.02        | 2.04           | 50.13        | 0.821        | 0.721      |
|                     | NCEP-FNL       | -1.73          | -20.25       | 1.76           | 33.02        | 2.15           | 49.89        | 0.824        | 0.703      |
Figure 1. Correlation between surface measured and the datasets wind speed
The correlation between the measured data and data from the dataset mean daily wind speeds at 10 m height is shown in Figure 1. The horizontal axis in the scatter plot is measured wind speed and the vertical axis is wind speed estimated by satellite. The best-fit line of correlation between both datasets along with 1:1 line is presented in Figure 1; the equation of the best-fit line is also presented. The equation of best-fit line has gradient close to one and intercept close to zero for better comparison. The highest gradient is for 20C and second best is for CFSR, the highest value of intercept is for 20C and lowest for CFSR. The CFSR data is in good agreement with measured data based on the equation of best fit and correlation coefficient.

3.2. Monthly Mean Time Series and Wind Rose

The monthly mean wind speed from measured and data from datasets for the duration of three years is presented in Figure 2. The general trends of the wind speeds for NCEP-CNAR and CFSR, GFS and NCEP-FNL are similar and closely related to each other. The trend of 20C is different from other satellites and measured data sets. The overall trend of all satellites except 20C is like measured with a consistent bias. All datasets underestimate wind speed in summer while only 20C overestimates from mid-August to mid-October. From April to October, 20C shows the least biased results while CFSR data represents the same trend as of surface measured data with a considerable non-varying bias, so its correlation coefficient has the highest value. Both NCEP-FNL and GFS show almost identical trend and that is the most biased from March to October. Although 20C shows overall good trend yet from November to February, it shows the most biased trends.

![Figure 2. Measured and the datasets monthly mean wind speed](image)

![Figure 3. Measured and the datasets wind direction frequency](image)
The wind rose in terms of wind direction frequency for measured data and data from the datasets for 12 sectors is presented in Figure 3. The dominant wind direction is southwest for measured data with 60% of wind. The dominant measured wind direction from March to October is towards southwest whereas form November to February (winter season) is towards the northeast. The wind rose shows that wind direction of CFSR, GFS and NCEP-FNL data has less rotation towards anticlockwise direction whereas NCEP-NCAR and 20C have a more anticlockwise rotation. The wind direction frequency for CFSR is closely related to measured data among all datasets.

### 3.3. Probability Distribution Function

The Weibull probability distribution function is widely used to represent wind speed distribution due to its flexibility and simplicity. The scale factor $A$ is related to mean wind speed while shape factor $k$ is equivalent to the standard deviation [19]. The Weibull probability distribution function (PDF) of measured data and data from datasets for the six hourly duration is presented in Figure 4. The datasets PDF’s are shifted towards the left side of the wind speed axis relative to the measured PDF, this means low wind speed frequencies are overestimated whereas strong wind speed frequencies are underestimated by the datasets, which originates the overall wind speed underestimation. It is evident from the Figure 4 that data from 20C shows the closest trend to the surface measured data (underestimation of 16.34% in $A$) while on the other hand, NCEP-FNL shows the most deviated trend with the highest deviation in mean wind speed (underestimation of 32.20% in $A$). All datasets show a similar trend for Weibull scale factor except 20C. All datasets overestimate the lower speed wind frequencies and underestimate the higher speed wind frequencies.

![Figure 4. The Weibull probability distribution function of measured and the datasets wind speed](image)

| Wind Data | Mean wind speed (m/s) | Mean wind direction (°) | Weibull Scale Factor $A$ (m/s) | Weibull Shape Factor $k$ |
|-----------|-----------------------|-------------------------|-------------------------------|-------------------------|
| Measured  | 5.366                 | 271.2                   | 6.075                         | 2.366                   |
| NCEP-NCAR | 3.843 (-28.38)        | 233.2 (-14.01)          | 4.340 (-28.56)                | 1.979 (-16.36)          |
| 20C       | **4.492 (-16.29)**    | 223.5 (-17.59)          | **5.063 (-16.34)**            | 2.036 (-22.44)          |
| CFSR      | 3.923 (-26.89)        | **257.5 (-5.05)**       | 4.428 (-26.83)                | **2.186 (-16.72)**      |
| GFS       | 3.762 (-29.89)        | 253.4 (-6.56)           | 4.246 (-29.84)                | 2.095 (-20.19)          |
| NCEP-FNL  | 3.634 (-32.28)        | 252.8 (-6.78)           | 4.103 (-32.20)                | 2.154 (-17.94)          |
The measured mean wind speed, direction, Weibull scale factor $\lambda$ and Weibull shape factor $k$ are presented in Table 2. The mean wind speed and direction from datasets for three years duration with percentage error from measured speed is presented in parenthesis in Table 2. Mean wind speed from 20C is best with least percentage error and CFSR is the second best, mean wind direction from CFSR is best with least percentage error and GFS is second best. The Weibull scale factor for 20C is best with least percentage error and CFSR is the second best whereas the Weibull shape factor is best for CFSR and NCEP-FNL is the second best.

4. Discussion
The results of the statistical analysis between measured data and data from datasets are presented in Table 1. The MBE, RMSE and $R$ for six hourly wind speeds from NCEP-NCAR are -1.52 m/s, 1.86 m/s and 0.700 respectively. A comparison of NCEP-NCAR wind speed data for five sites along the Iberian Peninsula coast was reported by Carvalho et al. [12], the MBE, RMSE and $R$ for wind speed ranges from 0.03 m/s to 0.70 m/s, 2.28 m/s to 2.62 m/s and 0.73 to 0.82. Abderrahim et al. [20] compared NCEP-NCAR for five site in France, the MBE, RMSE and $R$ for wind speed ranges from 1.49 m/s to 2.54 m/s, -0.62 m/s to -0.08 m/s and 0.71 to 0.84. A comparative study of present results with previous results revealed that for Pakistan the values of MBE, RMSE and correlation coefficient are in slight disagreement with the values obtained from the global analysis. However, the correlation coefficient is showing a relatively good estimate for Pakistan region. The MBE, RMSE and $R$ for six hourly wind speeds from 20C are -0.87 m/s, 1.72 m/s and 0.644 respectively. A general observation about 20C is that there is a small MBE compared to other datasets but still the value of the correlation coefficient is not good.

The MBE, RMSE and $R$ for six hourly wind speeds from CFSR are -1.44 m/s, 1.69 m/s and 0.785 respectively. A comparison of CFSR wind speed data was performed by Carvalho et al. [17] for five locations, the MBE and RMSE ranges from 0.42 m/s to 0.41 m/s and 2.06 m/s to 2.51 m/s respectively. When location of Portugal was taken for analysis and evaluation purpose, it was seen that CFSR data shows ad results compared to NCEP FNL dataset with the values of MBE and RMSE for CFSR data range from 0.42 m/s to 0.41 m/s and 2.06 m/s to 2.51 m/s respectively [17]. In another similar study for the Iberian Peninsula [12] the values of MBE, RMSE and $R$ for range from 0.38 m/s to 0.82 m/s, 1.77 m/s to 2.33 m/s and from 0.83 to 0.90 respectively for wind speed. A comparison shows CFSR gives better estimation in Europe compared to Pakistan, the wind speed is mostly overestimated with higher values of correlation coefficients in Europe whereas in Pakistan it is underestimated with a comparatively lower value of correlation coefficient.

The MBE, RMSE and $R$ for six hourly wind speeds from GFS are -1.60 m/s, 2.41 m/s and 0.683 respectively. Carvalho et al. [21, 22] compared GFS wind speed for five sites along the Iberian Peninsula coast at 10 m height, the MBE, RMSE and $R$ ranging from 0.12 m/s to 0.4 m/s, 1.65 m/s to 2.26 m/s, and 0.81 to 0.90. The results obtained from the site in this study are comparable with data reported in the literature.

The MBE, RMSE and $R$ for six hourly wind speeds from NCEP-FNL are -1.73 m/s, 2.49 m/s and 0.679 respectively. A comparison of NCEP-FNL with measured data reported in [23] had values of MBE, RMSE and $R$ range from 0.24 m/s to 0.82 m/s, 1.70 m/s to 2.24 m/s and from 0.83 to 0.90 respectively. A similar study [21] reported had values of MBE, RMSE and $R$ ranges from -2.02 m/s to 0.90 m/s, 1.82 m/s to 3.07 m/s and from 0.84 to 0.89 respectively. It is clear from above that statistical results of NCEP-FNL that for selected site in Pakistan are comparable with the previous studies, the values of correlation coefficients are higher for previous studies compared to the site for this study.

5. Conclusions
The evaluation of the NCEP-NCAR, 20C, CFSR, GFS and NCEP FNL datasets against the measured wind data has been presented for the first time for Pakistan. The wind industry in Pakistan is under development stages with the possible potential of the offshore wind farm and expansion of land wind
farms in other areas of Pakistan, this study will be an initiative toward the initial wind resource assessment for potential sites in Pakistan.

The evaluation of datasets wind speed and direction data was performed in four ways; statistical analysis, monthly mean wind speed, wind direction frequency as the wind rose and Weibull probability distribution function. Based on MBE, MAE and RMSE CFSR data shows overall good agreement. CFSR data is in good agreement with the measured data based on scatter plot and value of correlation coefficient.

A comparison of monthly mean time series shows that 20C reanalysis data is good among all datasets. The wind direction frequency for CFSR is closely related to measured data among all datasets using wind rose comparison. A comparison of probability distribution function curves shows that 20C reanalysis data is good in terms of Weibull scale factor and CFSR is good in term of Weibull shape factor. Overall based on all parameters, CSFR reanalysis data gave good approximation and can be used as an alternative to surface measured data for initial site assessment for a wind farm.

6. References

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