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# Climate Change Impacts on Wind Climatology

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***Abstract-*** Apart from all other important aspects, from the environmental point of view, the wind and wave have a significant impact on pollution transport and dispersion through the coastal areas. Indeed, the height and the energy of the wave are influenced by wind characteristics such as wind speed, wind duration, fetch length and etc. Among these characteristics, wind speed has the most important role; that is, the greater wind speed results in greater waves. The main objective of this study is to project the wind speed and wave height under the climate change scenarios. For this aim, the outputs of a General Circulation Model (GCM) are used to project the monthly probability distribution of wind speed. Two statistical downscaling methods, namely, the Quantile – Quantile transformation and Nearest Neighbour search methods are used to downscale the wind speed data. To have a better perception of extreme wind events in the future, then, the monthly 100-year wind speed extracted from the downscaled wind speeds probability distribution. The projected wind climatology may be implemented as an input for various practical applications through the coastal areas. In order to show the utility of the developed model, it is applied to the Qatar coast as a case study.

***Keywords*:** Statistical downscaling, wind speed downscaling, wave height projection, Quantile – Quantile transformation, nearest neighbour search.

## 1. Introduction

The plausible changes in statistical distribution of climate variables over several decades to longer time period is referred to as climate change (Wetterhall, 2005). General Circulation Models (GCMs) are climate models widely applied for understanding and projections of climate variables. Even with remarkable progress in computer and numerical modelling, GCMs are not able to provide the details of climate variables on very small spatial scales due to the incomplete scientific understanding and limitations of available observations (Jolley and Wheater, 1996). Therefore, small-scale features cannot be represented, even though they may significantly impact the local, regional, or even global climate (Horvath et al., 2011, Legates, 2002). In most of the practical applications such as hydrological models and marine pollutant transportation, the climate variables are needed at the much more finer both spatial and temporal resolution than GCMs outputs provided (Carter et al., 1994). Among all climate variables, near-surface wind speeds have particular importance for climate change impacts on different aspects such as society, coastal erosion and wind energy resource estimation (Pryor et al., 2005), (Viles and Goudie, 2003). Ocean circulation and wind-drift models used to detect derelict nets and other debris in the open ocean (U.S. Environmental Protection Agency, 2011). As shown by Lin et al. (2003) when there exists wind, waves and storm surges as well as their coupling interaction will change tidal current field, thus affecting material transport and diffusion, and when there exists large wind, the stirring action of waves will become stronger and their coupling background current may play a decisive role on the material transport and diffusion of coastal area.

Statistical downscaling methods aim to establish empirical relationships between GCM output and local climate variables. Statistical downscaling, first, develops quantitative relationships between observed small-scale (often station level) variables (predictands) and larger (GCM) scale variables (predictors), using one of the available approaches. Then, future values of the large scale variables obtained from GCM projections of future climate are used to drive the statistical relationships and to estimate the smaller-scale details of future climate (Wilby and Wigley, 1997). In Shirkhani et al. (2013), a regression-based downscaling technique was used to downscale wind speed at the Agadez city located in Niger, West Africa. Results indicated that both linear and non-linear regression techniques are not capable in predicting the wind speeds variation even when bias correction is applied. Some methods have been proposed to implement regression models for downscaling the GCMs output in the probabilistic approach. In fact, instead of direct using of GSMs output and local scale values as predictors and predictands, the mean and standard deviation of large and local scales data are used (Pryor et al., 2005).

In the current study, the station-level daily surface wind speed is selected as the predictand and the GCM-output wind speed and, maximum and minimum temperature as the predictors. The Quantile-Quantile and Nearest Neighbour methods are then employed to determine the probability distribution of the wind speed through the study area.

## 2. Study Area and Data

The observation data (1973-2012) was downloaded from the National Climatic Data Center of the National Oceanic and Atmospheric Administration (Web-2). The study area is located through the Qatar coast and the observation is available at the Doha International Airport situated at 25.25° and 51.57° longitude and latitude, respectively.

The outputs of the ESM2M model will be used as GCM data in this study. The ESM2M was developed CMIP5 by the Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration. The outputs were generated as a contribution to the CMIP5 experiment (Web-1). They include simulations of the historical period (1971 to 2005) and future periods (2006 to 2100).

## 3. Methods

The Quantile-Quantile transformation (Jakob Themeßl et al., 2011), makes the statistical distribution of a given climate variable as close as possible to the statistical distribution of the observed variable. Corrected GCM simulations are generated on the validation period and future periods using the following Equation:

$$XCORR = (FOBS)-1\ (FGCM(XGCM)) \quad (1)$$

Where, XGCM is the variable extracted from the raw GCM simulation and XCORR is the corrected climate variable.

In nearest neighbour approach for each day in the future period, a day is selected in the historical period from the same month while it tries to minimize the absolute temperature difference between the historical and GCM-output value. Then, this day in the historical period is linked to the day in the future to extract the downscaled value of the wind speed.

## 4. Results

The calibration and validation results for both Quantile-Quantile transformation and Nearest Neighbour method are presented on Figures 1 and 2. In these figures, the empirical probability density function of wind speed is plotted for each month within both calibration and validation periods for all RCPs. It can be visually assessed that the distribution of the projected data is almost identical to the distribution of the observation

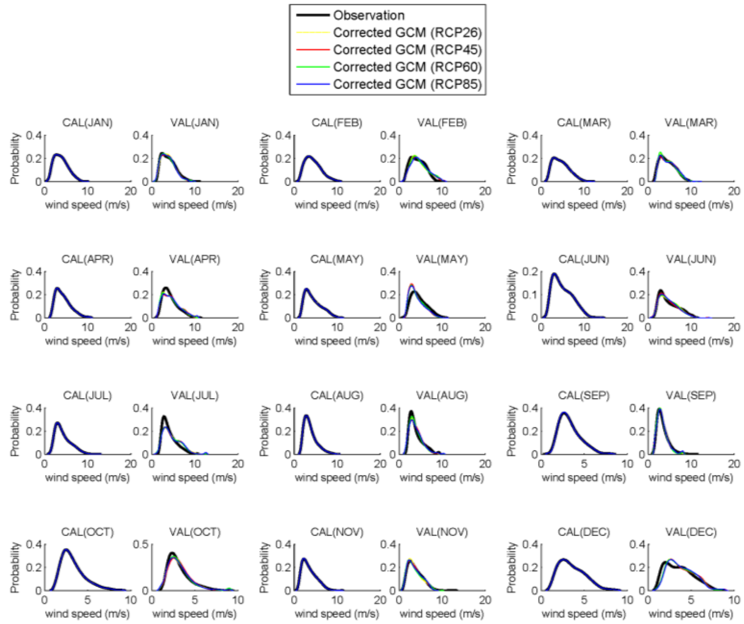


Fig. 1. Monthly distribution of observed and projected daily mean wind speed using Quantile-Quantile transformation for Calibration and Validation period.

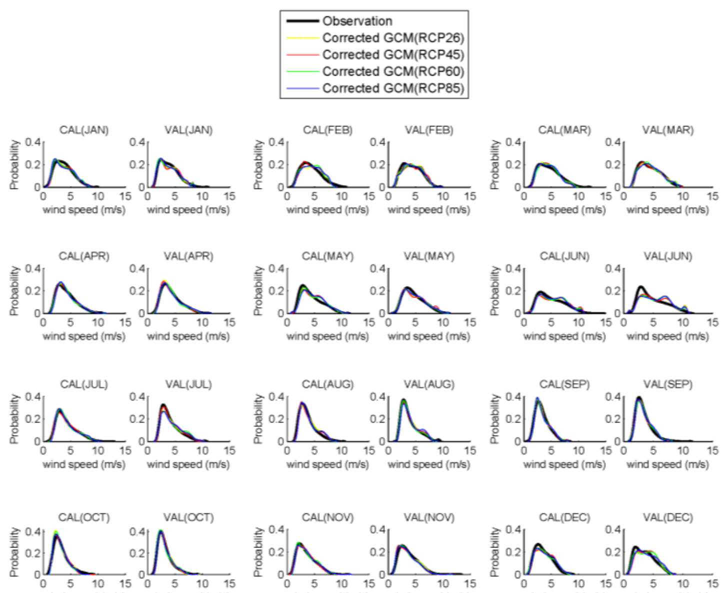


Fig. 2. Monthly distribution of observed and projected daily mean wind speed using Nearest Neighbour method for Calibration and Validation period.

Then, the developed model is employed to project the wind speed through the future period. The results for average and 100-year wind speeds are shown in the Table1 for each month. Table1 shows the possibility of increasing and decreasing of wind speeds up to +6.5% and -8.0% in mean wind speed and up to 29% increase in 100-year wind speeds in the future. The knowledge of the wind speed may help to have a better perception of the wave climatology and; they can be used as an input for various practical applications such as marina and coastal pollutant transport.

## 5. Conclusion

In this paper, the impact of climate change on the wind speed was studied through the Qatar Coast. Near-surface wind speed has an essential role in many practical applications specially the wave climatology as well as marine and coastal pollutant transport. The results showed that the wind speed can significantly decrees or increase in the future which may affect various aspects at the coastal areas.

Table 1. Comparison of observed and downscaled mean [100-year] wind speed, and future change in wind speed (m/s) for RCP85 scenario using Quantile-Quantile transformation (QQ).

| Month | Historical Period (1981-2010) | | Relative Error | Downscaled | | | Change (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Observation | Downscaled | (%) | 2026-2050 | 2051-2075 | 2076-2100 | 2026-2050 | 2051-2075 | 2076-2100 |
| Jan | 3.9 [8.0] | 3.8 [8.0] | 1.5 [0.7] | 3.7 [7.6] | 4.0 [7.7] | 4.0 [8.0] | -1.7 [-4.8] | 4.2 [-2.9] | 4.6 [0.0] |
| Feb | 4.4 [8.9] | 4.6 [9.5] | 5.4 [7.9] | 4.7 [9.8] | 4.6 [9.5] | 4.6 [9.8] | 1.4 [2.4] | -0.2 [0.0] | -1.2 [2.4] |
| Mar | 4.6 [9.2] | 4.7 [9.4] | 2.5 [2.5] | 4.4 [8.9] | 4.6 [9.5] | 4.6 [9.4] | -5.7 [-5.7] | -2.6 [1.2] | -2.4 [0.6] |
| Apr | 4.3 [9.5] | 4.5 [10.1] | 3.9 [5.9] | 4.4 [10.3] | 4.4 [9.6] | 4.6 [10.6] | -0.9 [2.0] | -0.6 [-4.4] | 2.9 [5.1] |
| May | 4.6 [9.5] | 4.3 [9.4] | 5.7 [1.6] | 4.3 [9.1] | 4.3 [9.2] | 4.3 [9.5] | 1.2 [-3.0] | 0.3 [-1.9] | 0.8 [1.7] |
| Jun | 5.0 [10.3] | 5.0 [10.4] | 1.0 [0.7] | 4.9 [13.5] | 5.1 [13.5] | 4.8 [10.4] | -2.0 [29.2] | 1.8 [29.2] | -3.9 [0.2] |
| Jul | 4.2 [9.3] | 4.5 [10.2] | 7.9 [9.9] | 4.4 [10.2] | 4.2 [9.1] | 4.2 [9.1] | -3.5 [0.0] | -8.0 [-11.0] | -7.3 [-11.0] |
| Aug | 3.8 [8.9] | 3.8 [8.9] | 0.1 [0.9] | 3.7 [8.5] | 3.7 [8.2] | 3.7 [8.2] | -3.1 [-4.9] | -3.3 [-8.1] | -2.0 [-8.1] |
| Sep | 3.4 [7.5] | 3.4 [7.7] | 0.4 [2.7] | 3.1 [7.2] | 3.1 [7.7] | 3.2 [7.7] | -6.9 [-7.0] | -7.3 [0.0] | -5.2 [0.0] |
| Oct | 3.2 [7.6] | 3.3 [7.9] | 0.5 [4.8] | 3.2 [7.4] | 3.2 [7.2] | 3.2 [7.4] | -2.0 [-6.8] | -2.3 [-9.7] | -2.6 [-6.8] |
| Nov | 3.7 [8.2] | 3.6 [7.7] | 1.4 [5.4] | 3.8 [7.9] | 3.8 [7.7] | 3.6 [8.1] | 4.2 [2.6] | 6.5 [0.0] | -0.2 [4.0] |
| Dec | 3.6 [7.7] | 3.7 [8.1] | 3.3 [6.0] | 3.6 [7.6] | 3.6 [8.1] | 3.7 [7.7] | -4.1 [-6.0] | -2.8 [0.0] | -1.8 [-5.0] |

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Web-2: NOAA's National Climatic Data Center (NCDC), United States Department of Commerce, http://www.ncdc.noaa.gov/