August 27-31, 2023
FLORENCE - ITALY
ICWE 16
16th International Conference on Wind Engineering

Mapping future offshore wind resources in the South China Sea under climate change by dynamical downscaling

J.Y. He [1,2,#], Q.S. Li [1,2,*], H.W. Tong [3], P.W. Chan [1,3], X.D. Zhao [4]

[1] *Dept. of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong.*
[2] *Architecture and Civil Engineering Research Center, City University of Hong Kong Shenzhen Research Institute, Shenzhen, China.*
[3] *Hong Kong Observatory, Kowloon, Hong Kong.*
[4] *University of Hull, Hull, United Kingdom.*
[#] *First author. E-mail: junyihe3-c@my.cityu.edu.hk*
* *Corresponding author. E-mail: bcqsli@cityu.edu.hk*

SUMMARY:
Based on dynamical downscaling using a 25-km-resolution regional climate model, this paper investigates the future wind resources in the South China Sea under climate change. First, wind field simulations based on the regional climate model are validated using satellite wind observations and reanalysis dataset. It is confirmed that the regional climate model has a satisfactory performance in reproducing the wind fields in the South China Sea. Then, the spatial distribution of wind power density in the past and future climates are comprehensively analysed. It is found that for Representative Concentration Pathway 8.5, the wind power density will generally increase by 5-10% in the northern part of the South China Sea but decrease by 5-10% in the southern part of the South China Sea in 2046-2065 (relative to 1985-2004), and the wind power density will mostly increase by 10-20% in the northern part of the South China Sea but decrease by 10-20% in the southern part of the South China Sea in 2081-2100 (relative to 1985-2004).

Keywords: Wind energy; Wind resource map; Climate change

1. INTRODUCTION

The carbon dioxide emission from fossil fuel burning has led to the climate change crisis, which has fundamentally changed the global energy market. Renewable energy utilities, such as wind turbines and solar panels, are built across the globe at a remarkable pace. Due to the rich resources and relatively low costs, wind energy has been increasingly utilized for electricity generation over the last two decades. The cumulative installed capacity of wind turbines drastically increased from 24 GW in 2001 to 837 GW in 2021, with China (338 GW) and the United States (134 GW) having the highest installed capacity (GWEC, 2022).

Due to the evolving global temperature and atmospheric motion patterns under climate variability, substantial change may occur in spatiotemporal distributions of wind resources in the future. To quantify climate change impacts, global climate models (GCMs) have been utilized. Carvalho et al. (2021) projected a general decrease of wind potential in Europe by 10–20% in 2081-2100 relative to 1995-2014. Martinez and Iglesias (2022) predicted that North America will experience an overall 15% decrease in wind power density in 2091-2100 relative to 2005-2014.

To improve spatial resolution and facilitate regional assessment, downscaling approaches have been developed and employed, including statistical downscaling and dynamical downscaling. Statistical downscaling establishes a statistical relationship between the local and large-scale meteorological variables, while dynamical downscaling simulates the fine-scale meteorological fields using regional climate models (RCMs). Future wind resources under climate change have been assessed using statistical downscaling in Hong Kong (He et al., 2023), the United States (Wimhurst and Greene, 2019), Spain (Solaun and Cerdá, 2020), and using dynamical downscaling in Germany (Jung and Schindler, 2020), the United States (Costoya et al., 2020), India (Sherman et al., 2021), among other places.

However, there has been no study that focuses on the climate change impacts on future wind resources in the South China Sea (SCS). In light of the research gap, this study aims to investigate the future wind potential in the SCS under climate change based on dynamical downscaling. The outcomes of this study are expected to provide useful information for wind farm siting, wind turbine selection, and economic analysis of wind energy projects in the SCS.

2. MODEL AND VALIDATION

Hong Kong Observatory (HKO) carried out high-resolution regional climate simulation over the domain 100–140°E, 0–40°N and the period 1971–2100 using the RCM system RegCM4.7. The RCM simulates the four-dimensional variation (three-dimensional space and one-dimensional time) of climate variables by numerically solving the primitive dynamical equations governing the atmospheric motion, which include horizontal momentum, continuity, thermodynamic, and hydrostatic equations. The RCM has a horizontal resolution of 25 km. The initial and boundary conditions of the RCM are prescribed by 22 Coupled Model Intercomparison Project Phase 5 (CMIP5) GCMs. The study domain of SCS is shown in Figure 1. The scenario of Representative Concentration Pathway (RCP) 8.5 is considered in this study.

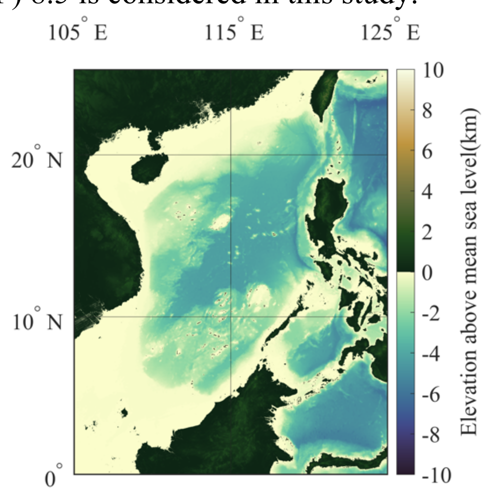
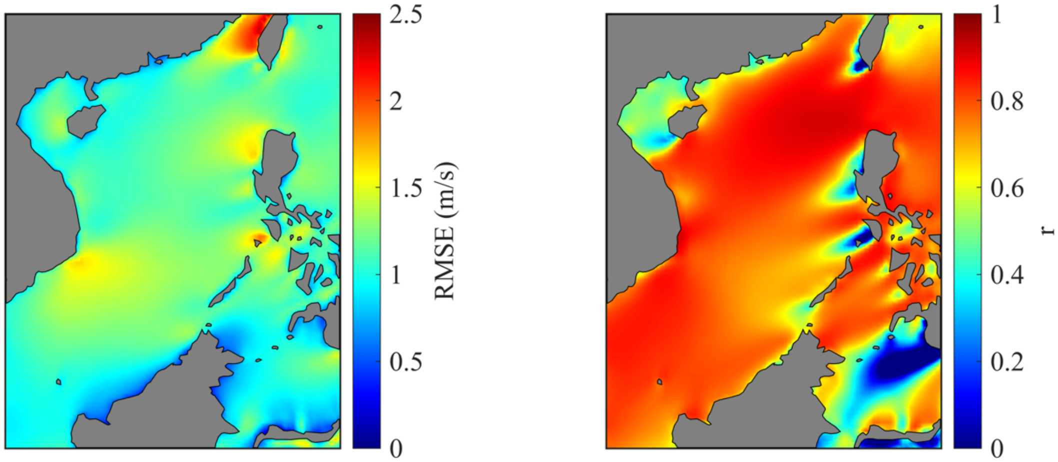


Figure 1. The study domain of the SCS. The elevation data is from GEBCO (https://www.gebco.net/).

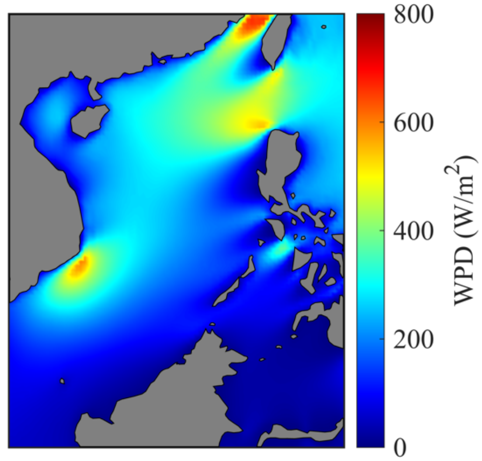
To validate the RCM, a satellite-based wind dataset named Cross-Calibrated Multi-Platform (CCMP) wind vector analysis product is utilized. The wind speed at 10-m height from the RCM is compared with that from the CCMP dataset. Moreover, a reanalysis dataset named ERA5 is also employed for validation purposes. The wind speed at 100-m height from the RCM is compared with that from the ERA5 reanalysis dataset. The CCMP data are available from https://www.remss.com/measurements/ccmp/, and the ERA5 data are available from https://climate.copernicus.eu/climate-reanalysis.

3. RESULTS AND DISCUSSION

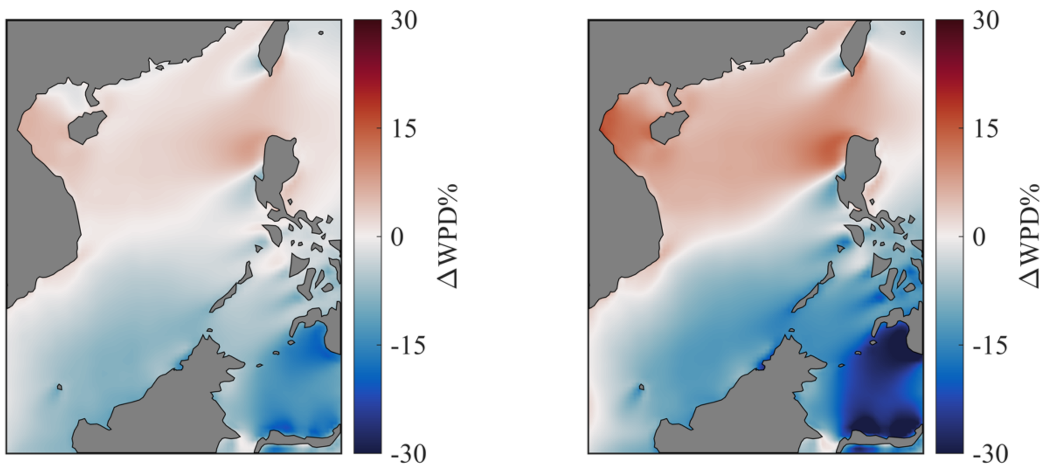


(a) Root mean square error (b) Correlation coefficient

Figure 2. Spatial distribution of root mean square error *RMSE* and correlation coefficient *r* between the monthly mean wind speeds from the RCM and the reanalysis dataset.



(a) WPD in baseline period 1985-2004



(b) Change in WPD in 2046-2065 (c) Change in WPD in 2081-2100

Figure 3. Spatial distribution of values and percentage changes in wind power density *WPD*.

Figure 2 shows the spatial distribution of root mean square error *RMSE* and correlation coefficient *r* between the monthly mean wind speeds from the RCM and the reanalysis dataset. It is observed that in most parts of the SCS, *RMSE* is lower than 1.5 m/s, and *r* is higher than 0.8. This indicates that the RCM has a satisfactory performance in simulating the wind fields over the SCS. However, in some regions close to the coastline and near the equator, *r* is noticeably low (< 0.2). This indicates that the RCM may not be adequate in reproducing the wind resources near the coastlines and the equator.

Figure 3 depicts the spatial distribution of wind power density *WPD* in the baseline period 1985-2004 and the percentage change in *WPD* in the mid-future 2046-2065 and far-future 2081-2100. It can be identified that the region with the highest wind potential is located in the northern and southwestern parts of the SCS, where *WPD* is greater than 400 W/m^2. In the mid-future (2046-2065), *WPD* will generally increase by about 5-10% in the northern part of the SCS but decrease by about 5-10% in the southern part of the SCS (relative to 1985-2004). In the far-future (2081-2100), *WPD* will mostly increase by about 10-20% in the northern part of the SCS but decrease by about 10-20% in the southern part of the SCS (relative to 1985-2004).

4. CONCLUSION

Based on a 25-km-resolution RCM, this study investigates the climate change impacts on future wind resources in the SCS. The RCM is validated by the CCMP satellite wind observations and ERA5 reanalysis dataset. Generally, the RCM has a satisfactory performance in simulating the wind fields in the SCS, with *RMSE* lower than 1.5 m/s and *r* higher than 0.8. The RCM predicts that the *WPD* will generally increase by 10-20% in the northern part of the SCS but decrease by 10-20% in the southern part of the SCS in 2081-2100 (relative to 1985-2004) in the scenario of RCP8.5.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Hong Kong Observatory for the provision of the RegCM4.7 data and the permission of using the data in this study. The work described in this paper was fully supported by grants from the Science, Technology and Innovation Commission of Shenzhen Municipality (Project No: SGDX2020110309300301), the National Natural Science Foundation of China (Project No: 51978593), and the Research Grants Council of Hong Kong (Project No: CityU 11204020).

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