Evaluation of NHRCM Wind Speed Simulations over Northeastern Thailand for Energy Applications

Nipaporn Sanjaiwong, Assistant Professor Dr. Sujittra Ratjiranukool
Department of Physics and Materials Science, Faculty of Science, Chaing Mai University, Chaing Mai, Thailand

Abstract

Non-Hydrostatic Regional Climate Model (NHRCM), dynamically downscaled from global climate models (GCMs) to a regional climate model (RCM) with 5×5 km grid resolution, enhances spatial representation of meteorological variables across Southeast Asia. This study evaluates NHRCM performance in simulating historical wind speed patterns over a 20-year period (1980-2000) for climate and energy applications in northeastern Thailand. Seasonal analysis for summer (June–September, JJAS) and winter (December–February, DJF), comparing NHRCM outputs against the fifth-generation European Centre for Medium-Range Weather Forecasts reanalysis (ERA5) dataset. Model validation employed spatial wind distribution analysis, Weibull distribution modeling with cumulative distribution functions (CDF), and multiple statistical metrics including independent samples t-tests, Kolmogorov–Smirnov (KS) tests, bias, root mean square error (RMSE), and correlation coefficients. Results demonstrate that NHRCM successfully reproduces spatial wind distribution patterns consistent with ERA5, correctly identifying higher mean wind speeds during winter compared to summer. However, Weibull distribution analysis, CDF comparisons, and statistical indicators show a positive bias, with NHRCM overestimating wind speeds relative to ERA5. Despite this overestimation bias, NHRCM proves effective for identifying high wind-potential zones in northeastern Thailand. The quantified statistical relationships and Weibull parameters provide essential baseline information for wind energy resource assessment, supporting strategic planning of wind turbine installations and renewable energy management under future climate scenarios.

Introduction

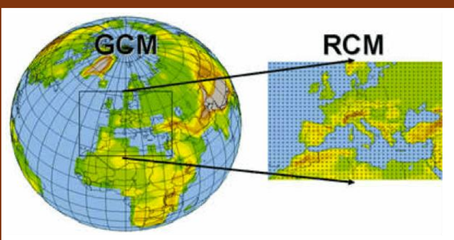


Figure 1: Downscaled from GCMs to RCM.

NHRCM (Non-hydrostatic Regional Climate Model) is a high-resolution regional climate model dynamically downscaled from global climate models (GCMs) to a regional climate model (RCM) with a 5 × 5 km grid resolution. This study evaluates NHRCM performance in simulating historical wind speed patterns over a 20-year period (1980-2000).

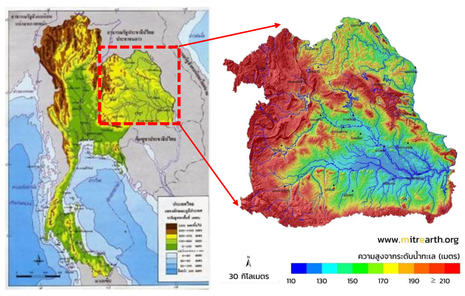


Figure 2: Northeastern Thailand.

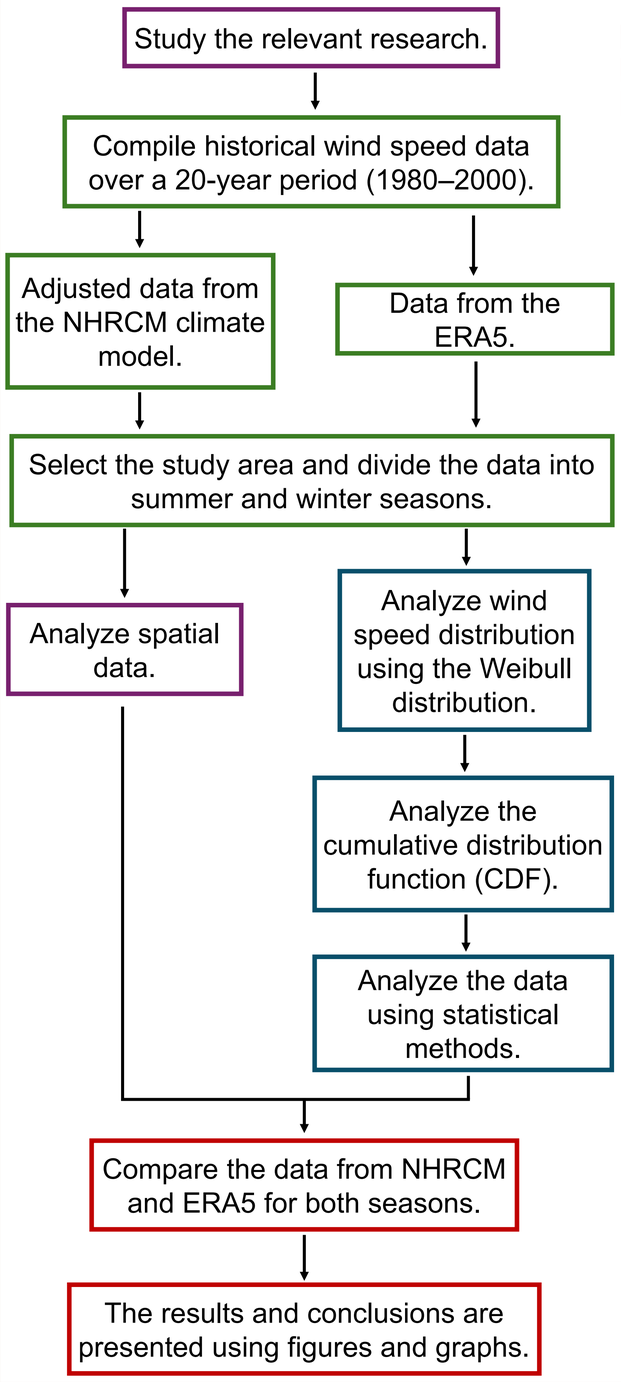
The study area

- Northeastern Thailand was selected as the study area.
- The landscape consists of plateaus and lowland areas.
- Has high potential for wind energy development.

Compare and estimate wind speeds using ERA5 data.

- ERA5 is a fifth-generation global reanalysis product.
- ERA5 is compiled from measurement data collected from multiple sources.
- The dataset is provided hourly with a spatial resolution of 31 km.

Methods



Horizontal Wind Speed is a combination of the zonal wind (u: west to east) and the meridional wind (v: south to north) components, as follows:

$$U = \sqrt{u^2 + v^2}$$

in units of m/s.

The Weibull distribution is a function used to describe wind speed distribution in an area. The probability density function (PDF) of the Weibull distribution is expressed as follows:

$$f(U) = \left(\frac{k}{\lambda}\right)\left(\frac{v}{\lambda}\right)^{k-1} \exp\left[-\left(\frac{v}{\lambda}\right)^{k}\right]$$

where v is the wind speed (m/s), k is the shape parameter, and λ is the scale parameter.

The cumulative distribution function (CDF) of the Weibull distribution is given by:

$$F(U) = 1 - \exp\left[-\left(\frac{v}{\lambda}\right)^{k}\right]$$

The parameters k and λ can be estimated using the Maximum Likelihood Method, as follows:

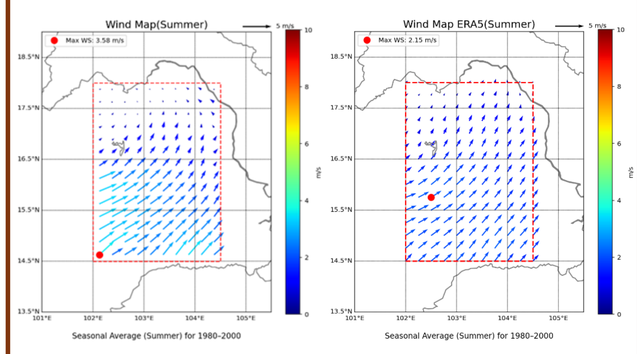
$$k = \left(\frac{\sum_{i=1}^{n} U_i^n \ln(V_i)}{\sum_{i=1}^{n} U_i^n} - \frac{\sum_{i=1}^{n} \ln(U_i)}{n}\right)^{-1}$$

$$\lambda = \left(\frac{1}{n}\sum_{i=1}^{n} U_i^k\right)^{\frac{1}{k}}$$

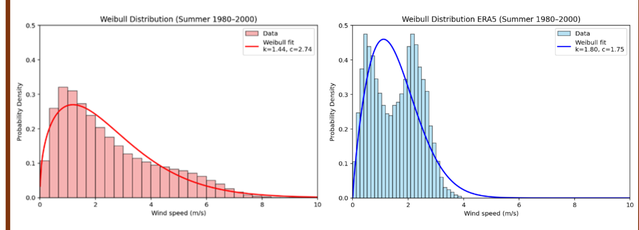
The Kolmogorov–Smirnov (K–S) test is a non-parametric statistical test used to compare the wind speed distributions between NHRCM and ERA5. At a significance level of 95%,
H_0: significant difference between NHRCM and ERA5.
H_1: no significant difference between NHRCM and ERA5.

Result

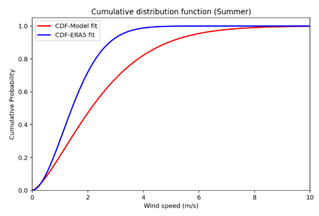
Summer



Graph 1: Mean wind speed map for the summer season. The left panel shows NHRCM, and the right panel shows ERA5.

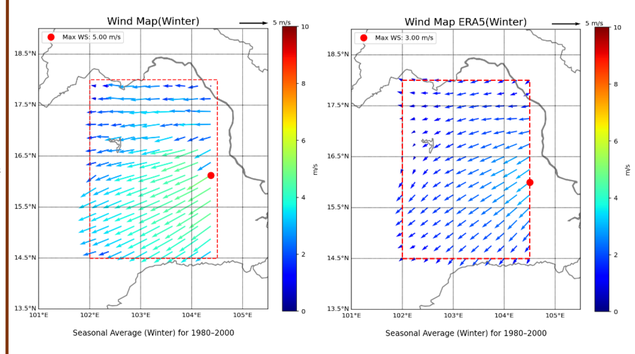


Graph 2: Weibull distribution of wind speed for the summer season. The left panel shows NHRCM, and the right panel shows ERA5.

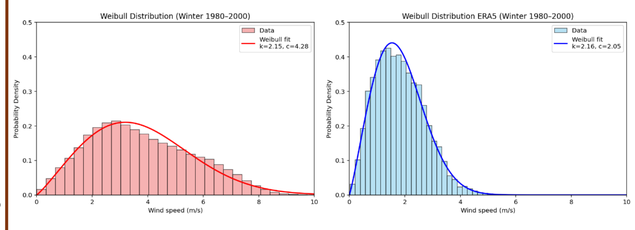


Graph 2: Cumulative distribution function for the summer season. The left panel shows NHRCM, and the right panel shows ERA5.

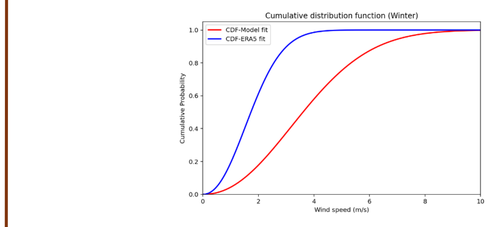
Winter



Graph 4: Mean wind speed map for the winter season. The left panel shows NHRCM, and the right panel shows ERA5.



Graph 5: Weibull distribution of wind speed for the winter season. The left panel shows NHRCM, and the right panel shows ERA5.



Graph 2: Cumulative distribution function for the summer season. The left panel shows NHRCM, and the right panel shows ERA5.

Table 1: Statistical values of wind speed from NHRCM and ERA5.

Stat		Summer		Winter	
		NHRCM	ERA5	NHRCM	ERA5
Weibull distribution	k	1.44	1.80	2.15	2.16
	c	2.74	1.75	4.28	2.05
Mean		2.62	1.56	3.79	1.82
SD		1.12	0.647	1.40	0.617
T-test		7.4607944		10.08211	
p-value		9.94e-12		4.09e-16	
K-S test		0.32		0.52	
Bias		1.06		1.98	
RMSE		1.43		2.51	
Correlation		0.504		-0.0196	

Conclusion

The results show that the NHRCM model can reproduce the spatial distribution patterns of wind speed consistent with ERA5 and correctly indicate that the mean wind speed in winter is higher than in summer. However, Weibull distribution analysis, cumulative distribution function (CDF) comparisons, and statistical indicators reveal a positive bias, with NHRCM tending to overestimate wind speeds compared with ERA5. Despite this overestimation bias, NHRCM remains effective in identifying areas with high wind energy potential in northeastern Thailand. Furthermore, the quantified statistical relationships and Weibull parameters provide essential baseline information for wind energy resource assessment and support strategic planning for wind turbine installations and renewable energy management under future climate scenarios.

References

[1] M. Ranthodsang and J. Waewsak, “The Comparative of the Wind Speed Distribution in Pakpanang District of Nakhon Si Thammarat Province,” Thaksin University Journal, vol. 18, no. 3, 2015.
[2] W. Fan et al., “Evaluation of Global Reanalysis Land Surface Wind Speed Trends to Support Wind Energy Development Using In Situ Observations,” Jan. 2021.
[3] P. Ratjiranukool and S. Ratjiranukool, “Evaluation of projected decadal wind energy potential in Chiang Mai,” J. Phys.: Conf. Ser., vol. 2145, art. no. 012048, 2022.
[4] X.-Y. An, Z. Yan, and J.-M. Jia, “A new distribution for modeling wind speed characteristics and evaluating wind power potential in Xinjiang, China,” Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, vol. 46, no. 1, pp. 7644–7662, 2024.