

A Finite Mixture Von Mises Distribution for Wind Direction Analysis in Kuala Terengganu, Malaysia

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Abstract

The complexity of its circular nature of data has limited research on wind direction compared to the linear form of wind speed. Nevertheless, the important role of wind direction is undisputable. This study is purposely to distinguish the best fit probability distribution for Kuala Terengganu's wind direction data. Then, this probability distribution can be used in determining the best direction that able to capture the highest wind speed in that area. The numerical and graphical presentation of the wind direction will be discussed throughout this paper. Next, the coefficient determination, R^2 is examined to ensure the appropriateness of this probability distribution. Finally, the analysis reveals that the wind direction data of Kuala Terengganu fits best with the four number of components ($H=4$) mixture model of von Mises.

Keywords: Finite mixture model; Von Mises distribution; Wind direction; Wind power. by Semicolon .

1. Introduction

As one of the renewable energy resources, wind energy is expected to be an alternative to fossil fuel. Among all, the wind is the most readily available source. This energy comes from the wind that blows around us which is clean, environment-friendly and unlimited. Knowledge of wind resources and the potential in generating energy is very important to avoid worthless findings. Study on the nature of wind particularly of its speed and wind direction, its probability distribution and the best model to represent such data could be beneficial not only to the researchers but the most important is to the investors and stockholders. Any relevant information will be very helpful in the decision-making process.

Research of wind has extensively studied especially on the importance of wind speed including the appropriateness of probability distribution [1]-[3], the relevance of producing energy [4]-[10] and study of mapping of the promising areas [11]-[12]. The wind speed was known as the main variable that affecting the potential of generating wind energy in an area. However, studies on wind direction are still limited due to its circular nature of data. This circular type of data should be treated differently compared to a linear data. For example, if a normal distribution is known as the important and most common distribution to represent linear data, then a Circular Normal (CS) or a von Mises distribution do the same role for circular data [13]. Nevertheless, there are still numerous options of probability distributions for circular data for example cardioid, wrapped normal (WN), wrapped Cauchy (WC) and circular Beta model distribution that has been studied by researchers.

In this paper, the data of wind direction will be analyzed using a finite mixture of von Mises as it is believed to be the most appropriate

distribution that can best describe the circular with multi-modal data [14]-[16]. Next, the dominant direction will be determined so that the amount of wind capture can be optimized. Finally, the significance of wind direction to maximize the energy production will be resolved.

2. Study Area and Data

Kuala Terengganu is located at the eastern part of Peninsular Malaysia (as shown in Figure 1). At $5^{\circ} 20' 0''$ north latitude and $103^{\circ} 8' 0''$ east longitude, Kuala Terengganu experience a wet and humid climate throughout the year just like other places in Malaysia. Kuala Terengganu exposes to a major monsoon season which is northeast monsoon that occurs from November until March every year. This northeast monsoon usually brings heavy rainfall to Peninsular Malaysia and Kuala Terengganu is among the most affected area. Besides, Kuala Terengganu also exposes to short inter-monsoons with the land and sea breezes effect.

Hourly data of wind direction (in degree, $^{\circ}$) at 10 metres height for Kuala Terengganu is provided by Department of Environment, Malaysia. The data recorded from January 2007 until December 2013. However, the analysis in this paper only focuses on wind data for 2007.



Fig 1: Location of Kuala Terengganu, Malaysia.

3. Methodology

The suitability of finite mixture von Mises (FMvM) distribution will be investigated in this paper. The distribution is then to be used in determining the best direction with high wind speed in Kuala Terengganu. The procedure begins with the parameter estimation and followed by the equation solving for FMvM. The data is presented in the graphical and numerical presentation. MATLAB R2014a software is used throughout the analysis of the study.

3.1. Finite Mixture of Von Mises (FMvM)

$$f_{\theta}(\theta) = \sum_{j=1}^H \frac{\omega_j}{2\pi I_0(\kappa_j)} \exp(\kappa_j \cos(\theta - \mu_j))$$

where,

$$0 \leq \theta < 2\pi, \quad 0 \leq \mu_j < 2\pi, \quad \kappa_j \geq 0,$$

$$0 \leq \omega_j < 1 \quad \text{for } j=1,2,\dots,H \quad \text{and} \quad \sum_{j=1}^H \omega_j = 1$$

$$I_0(\kappa_j) = \frac{1}{\sqrt{2\pi}} \int_0^{2\pi} \exp(\kappa_j \cos \theta) d\theta$$

$$= \sum_{k=0}^{\infty} \frac{1}{(\kappa_j!)^2} \left(\frac{\kappa_j}{2} \right)^{2k}$$

3.2. Goodness of Fit Test

The suitability of FMvM to model the wind direction data in Kuala Terengganu is measured by using R^2 determination correlation. It is a type of distribution fitting test which measures the appropriateness of a mathematical model. (José A. Carta, Bueno, and Ramírez 2008; José Antonio Carta and Ramírez 2007) has proven that the R^2 determination coefficient is best in assessing goodness of fit for a circular probability distribution. Equation for R^2 determination coefficient:

$$R^2 = \frac{\sum_{i=1}^n (\hat{F}_i - \bar{F})^2}{\sum_{i=1}^n (\hat{F}_i - \bar{F})^2 + \sum_{i=1}^n (F_i - \bar{F})^2}$$

where,

F_i is a cumulative data function

$\hat{F}_i$ is the estimate cumulative distribution function

$$\bar{F} = \frac{\sum_{i=1}^n \hat{F}_i}{n}$$

3.3. Wind Rose

The graphical presentation that uses to present the frequency and percentage of winds blowing is called wind rose. The direction from each of the leading eight points of the compass is shown by this presentation. It also shows the dominant direction of the wind. Figure 2 shows an example of wind rose.

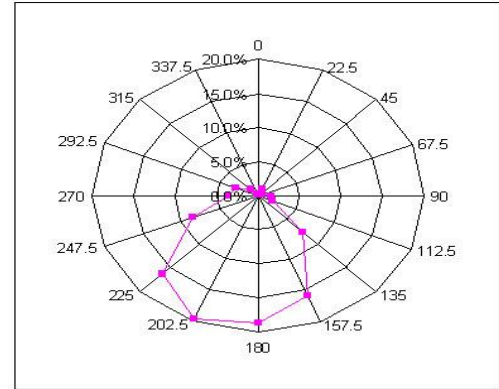


Fig 2: Wind rose.

4. Result and Discussion

- (1) The best fit and appropriate distribution will best explain the prevailing wind direction in that study area which is Kuala Terengganu, Malaysia. Parameter estimation is a vital initial step in a model fitting process. Table 1 shows the parameter estimation values for each component in FMvM distribution ($H=1,2,\dots,8$) at Kuala Terengganu.

Table 1: Parameter Estimates

FMvM	Parameter estimates			
	μ_1		κ	ω
H = 1	-0.98309	-0.18313	0.38973	1.00000
H = 2	0.36496	0.93102	1.72525	0.36706
	-0.69182	-0.72207	2.61702	0.63294
H = 3	0.62850	0.77781	4.10217	0.33209
	0.29205	-0.95640	2.92384	0.10934
H = 4	0.29205	-0.95640	2.92384	0.10934
	0.73084	0.68255	7.30861	0.31500
H = 5	-0.78842	0.61513	5.04408	0.10690
	-0.81116	-0.58483	7.93437	0.50691
H = 6	0.69763	-0.71646	5.04408	0.07119
	0.77857	0.62755	9.73148	0.25828
H = 7	-0.27274	0.96209	7.80525	0.09269
	-0.97158	-0.23672	12.79867	0.36270
H = 8	-0.52125	-0.85340	10.40707	0.23082
	0.81445	-0.58024	7.80525	0.05551
H = 9	0.83116	0.55604	13.59250	0.24537
	0.06497	0.99789	10.94528	0.10175
H = 10	-0.93094	0.36517	9.48706	0.08518
	-0.86572	-0.50053	13.81694	0.42325
H = 11	-0.12149	-0.99259	11.48548	0.09227
	0.87169	-0.49006	10.94528	0.05218

A numerical evaluation should be presented to determine the suitability of the finite FMvM model towards data. This study uses R^2 determination coefficient as the numerical evaluation. Table 2 shows the values of R^2 for each fitted components of finite mixture von Mises. The values of R^2 increase significantly as the increases in the number of components, H . Nonetheless, the value becomes closer and closer as H approaching four and larger. It concludes that the FMvM ($H=4$) can best explain 99 percent of the variation in Kuala Terengganu wind direction data.

Table 2: The R^2 Determination Coefficient for each Component FMvM

H	1	2	3	4	5	6
R^2 value	0.92387	0.98564	0.99822	0.99841	0.99853	0.99875

The estimation for the density probability function of FMvM ($H=4$) model is then can be derived as:

$$f_0(\theta) = \frac{0.31500}{2\pi I_0(7.30861)} \exp(7.30861 \cos(\theta - \mu_1)) + \frac{0.10690}{2\pi I_0(5.04408)} \exp(5.04408 \cos(\theta - \mu_2)) + \frac{0.50691}{2\pi I_0(7.393437)} \exp(7.393437 \cos(\theta - \mu_3)) + \frac{0.07119}{2\pi I_0(5.04408)} \exp(5.04408 \cos(\theta - \mu_4)) \quad (4)$$

$$\begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \end{bmatrix}^T = \begin{bmatrix} 0.73084 & 0.68255 \\ -0.78842 & 0.61513 \\ -0.81116 & -0.58483 \\ 0.69763 & -0.71646 \end{bmatrix}^T \quad (5)$$

The parameter of mean directions refer to mean for circular data in rectangular coordinates:

$$X^T = [\cos \theta \quad \sin \theta] \quad (6)$$

Wind rose is selected for describing wind direction data in Kuala Terengganu via graphical presentation. The diagram is presented in circular type and shows the frequency or percentage of winds blowing from a specific direction and determine the dominant wind direction for that area. Figure 3 and 4 show the wind rose for Kuala Terengganu. The dominant direction for wind is towards East-North-East point. However, in Figure 4, the highest wind speed is also pointing towards East-North-East. The wind speed values in Figure 4 are converted to mile per hour unit.

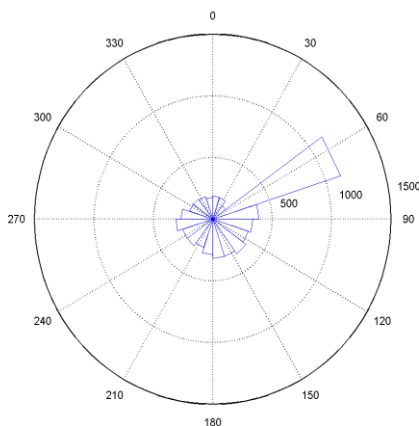


Fig 3: Wind direction for Kuala Terengganu.

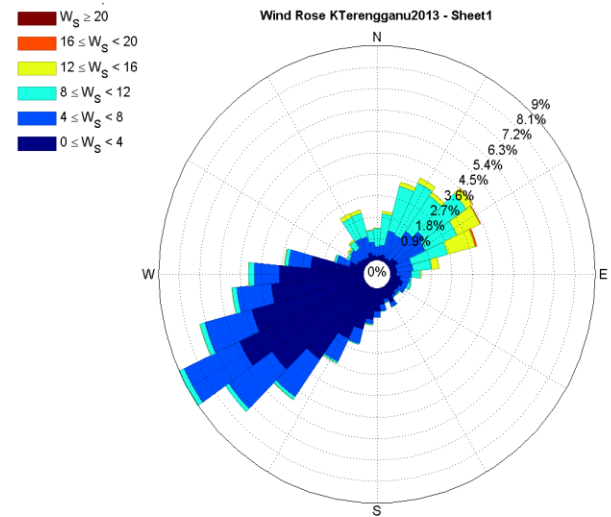


Fig 4: Wind speed for Kuala Terengganu.

5. Conclusion

This study reveals that finite mixture von Mises (FMvM) with four components ($H=4$) found to be the best-fitted model for Kuala Terengganu data. The variation in the data can be explained by the selected model where more than ninety-nine percent value stated in its R^2 determination coefficient. This study also discloses that East-North-East is the best point that the dominant direction for wind flow. Likewise, the highest speed of wind is also found in this East-North-East point. In a nutshell, this study gives the idea of how the regime of wind direction in Kuala Terengganu. The outcomes from this study might encourage further advance researches in the future. Hence, it is possible that Kuala Terengganu can be one of the potential areas of producing wind power. With the cooperation of all parties which are government, private sectors and researchers, this mission would not be impossible to realize.

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References

- [1] S. K. Najid, A. Zaharim, A. M. Razali, M. S. Zainol, K. Ibrahim, and K. Sopian, "Analyzing the East Coast Malaysia Wind Speed Data," *International Journal of Energy and Environment* (3), 53-60 (2009).
- [2] A. Zaharim, S. K. Najid, A. Mahir, and K. Sopian, "The Suitability Of Statistical Distribution In Fitting Wind Speed Data," *WSEAS Transaction on Mathematics* (7), 718-727 (2008).
- [3] A. Zaharim, S. K. Najid, A. M. Razali, and K. Sopian, "Analyzing Malaysian Wind Speed Data Using Statistical Distribution," *IASME/WSEAS International Conference on Energy & Environment (EE'09)*, 363-370 (2009).
- [4] M. R. . Siti, M. Norizah, and M. Syafrudin, "The Evaluation of Wind Energy Potential in Peninsular Malaysia," *Journal of Environmental Chemical Engineering* (2), 284-291 (2011).
- [5] N. Rosly, Y. Ohya, and T. Uchida, "Micro Siting and Wind Energy Potential in Mersing, Malaysia Using RIAM-Compact," *The Asian Conference on Sustainability, Energy and the Environment Official Conference Proceeding*, (2012).
- [6] M. Irwanto, N. Gomes, M. R. Mamat, and Y. M. Yusoff, "Assessment of wind power generation potential in Perlis, Malaysia," *Renewable & Sustainable Energy Reviews* (38), 296-308 (2014).

- [7] K. Sopian, "The wind energy potential of Malaysia," *Renewable Energy* (6), 4–6 (1995).
- [8] M. R. Islam, R. Saidur, and N. a. Rahim, "Assessment of wind energy potentiality at Kudat and Labuan, Malaysia using Weibull distribution function," *Energy* (36), 985–992 (2011).
- [9] K. M. Nor, M. Shaaban, and H. Abdul Rahman, "Feasibility assessment of wind energy resources in Malaysia based on NWP models," *Renewable Energy* (62), 147–154 (2014).
- [10] N. Sanusi, A. Zaharim, and S. Mat, "Wind energy potential: a case study of Mersing, Malaysia," *Journal of Engineering and Applied Sciences* (11), 7712–7716 (2016).
- [11] K. H. Yong, M. Z. Ibrahim, M. Ismail, A. Albani, and A. M. Muza-thik, "Wind Mapping in Malaysia Using Inverse Distance Weighted Method," *UMT International Annual Symposium (UMTAS 2011)*, 60–67 (2011).
- [12] N. Masseran, A. M. Razali, K. Ibrahim, W. A. N. Zawiah, and W. A. N. Zin, "On spatial analysis of wind energy potential in Malaysia," *WSEAS Transactions on Mathematics* (11), 467–477 (2012).
- [13] S. R. Jammalamadaka and A. SenGupta, "Topics in Circular Statistics. Singapore," World Scientific Publishing Co.Pte.Ltd, (2001).
- [14] N. A. B. Kamisan, A. G. Hussin, and Y. Z. Zubairi, "Finding the best circular distribution for southwesterly monsoon wind direction in Malaysia," *Sains Malaysiana* (39), 387–393 (2010).
- [15] N. A. B. Kamisan, A. G. Hussin, Y. Z. Zubairi, and S. F. Hassan, "Distribution of wind direction recorded at maximum wind speed : A case study of Malaysian wind data for," *International Journal of Physical Sciences* (6), 1840–1850 (2011).
- [16] N. Masseran, A. M. Razali, K. Ibrahim, and M. T. Latif, "Fitting a mixture of von Mises distributions in order to model data on wind direction in Peninsular Malaysia," *Energy Conversion and Management* (72), 94–102 (2013).