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SURFACE WIND DISTRIBUTIONS IN THAILAND

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Abstract

Published percentage frequencies of surface wind speeds and directions at 45 synoptic weather stations in Thailand for the period 1951-1961 have been used to determine the seasonal characteristics of the wind at height 10 m over the country for use in wind energy studies. Calm conditions occur generally from 10% to 50% of the time. The Weibull distribution shape parameters calculated for the wind speeds in the non-calm periods lie mostly between 1 and 2, while the scale parameters range from 1 m/s to 6 m/s The distrubutions of wind direction are characterized by a mean direction and a parameter indicating constancy of direction. The results show that there is some potential for harnessing the wind in the south, the centre and the north-east of the country.

Introduction

In order to assess the potential for the development of wind energy in a particular location one must know the characteristics of the wind regime there. Thailand is fortunate in having a considerable amount of readily available information on her winds in the publications of the Meteorological Department, Ministry of Communications. However, the information provided is not in a form convenient for wind energy studies and certain transformations of the data are necessary in order to reveal the parameters needed in practical work.

Some years ago a study by Heronemus[1] included rough estimates of the velocity-duration curves of the surface winds at several stations in the central plain and the north-eastern region. More recently, studies in the Asian Institute of Technology[2,3] have shown that the seasonal hourly wind speed distributions at four stations in Thailand are adequately represented by a statement containing (a) the percentage of time the air is calm, and (b) the two parameters giving respectively the shape and mean value of the Weibull functions[4] representing the wind speed distributions in the non-calm periods. One of the studies[3] also included a survey of the mean wind speeds and the resultant wind directions over the whole of Thailand, and the maximum wind velocities recorded, but did not contain an extensive geographical survey of wind speed distributions or of the constancy of the wind directions.

The present paper supplies this missing information, which, as the following sections show, is inherent in the climatological wind data published by the Meteorological Department, but which has not hitherto been extracted.

Data

The information used for this study was taken from a report by the Meteorological Department[5] summarizing the surface wind observations at 48 stations in Thailand for the period 1951 to 1960. The data published consist of the mean monthly percentage frequencies of occurrence at each station of the wind observations subdivided into five wind speed classes and sixteen wind directions. The five wind speed classes are: calm, < 4 knots, 4-16 knots, 17-27 knots, and > 27 knots. The sixteen wind directions are: N, NNE, NE, ..., WNW, NW, NNW. The height of the wind vane above the ground at each station is also given.

For the present study 45 stations were selected. To represent the winds near Bangkok the stations at Don Muang Airport and Pom Prachulachomklao were chosen because of their open locations, while Bangkok Metropolis was omitted because of its unfavorable location in the city. For the same reasons, at Phuket the station at the airport was chosen in preference to the one in the town.

In order to show seasonal variations in the wind regime, the monthly data were grouped into four three-month periods, namely February-April, May-July, August-October and November-January, representing the seasons of the spring equinox, the summer solstice, the autumn equinox and the winter solstice respectively.

This subdivision is convenient in corresponding to the major changes of seasonal weather over much of Thailand, although regional differences occur in some areas. Thus, the spring is the hot dry season with southerly winds over the central plain. the summer is the first part of the wet season when the south-westerly monsoon dominates. The autumn is the end of the wet season during which the intertropical convergence zone moves south across the country; and the winter is the cool season with a dry north-easterly air stream over most of the Kingdom, except the south where wet easterlies prevail.

Wind Speeds

The standard representation of wind speed variations in wind energy studies is through a cumulative distribution function F(V) of wind speeds V, defined to be the probability that the wind at any time has a speed less than V. Wind data generally conform to the Weibull distribution

$$F(V) = 1 - \exp(-(V/c)^k), \qquad (1)$$

where k and c are parameters. The parameter k is a dimensionless exponent that determines the shape of the distribution and generally has values from 1 to 2 in light irregular winds, while c is a scale factor proportional to the mean wind speed $\overline{V}$ in accordance with the equation

$$\overline{V} = c\Gamma(1 + 1/k) \qquad (2)$$

where Γ is the gamma function.

When a set of data finely divided with respect to wind speeds is available one determines k and c by plotting values of $\ln(-\ln(1 - F(V)))$ on the vertical axis of a graph versus values of $\ln V$ on the horizontal axis. Equation (1), recast into the form

$$\ln(-\ln(1 - F(V))) = k \ln V - k \ln c,$$

shows that a straight line is then obtained whose slope is k and whose intercept on the vertical axis is $-k \ln c$. The best straight line fitting the data points thus gives estimates of k and c.

Since the data for the present study were divided into only four wind speed classes, and observations of wind speeds greater than 27 knots were rare, it was decided to add together the frequencies in the two highest classes and use only values of $F(V_1)$ and $F(V_2)$, where V_1 = 4 knots and V_2 = 16 knots. The values of k and c were then calculated with the help of the equations

$$k = (N_1 - N_2)/(\ln V_1 - \ln V_2),$$

and

$$c = \exp((N_1 \ln V_2 - N_2 \ln V_1)/(N_1 - N_2)),$$

where

$$N_1 = \ln(-\ln F(V_1)),$$

and $$N_2 = \ln(-\ln F(V_2)).$$

This method is equivalent to plotting only two points on the graph described above and joining them to obtain the straight line giving k and c.

Although this method was somewhat crude, the fact that the data represented long term average values, and the fact that the applicability of the Weibull function had already been tested[2], made the parameters obtained fairly reliable. This conclusion was supported by the consistency of the results.

Since friction between the wind and the ground causes surface wind speeds to increase with height, the results from the various stations were adjusted to the standard height of 10 m for comparison purposes. A study by Justus and others[4] has shown that the Weibull parameter k at a particular location does not vary appreciably with height, but the wind speed at height z is proportional to z^n, where n depends on the roughness of the surface and is close to 0.2 over open terrain. Therefore, in the present study scale factors c_z for observations at height z were adjusted by means of the equation

$$c_{10} = c_z(10/z)^{0.2}$$

to values c_{10} applicable at height 10 m.

Wind Direction

The seasonal wind directions at each station are represented in this study by two parameters: the bearing Θ of the mean wind direction, measured eastwards from north, and parameter r representing the constancy of the wind direction.

To calculate these parameters the percentage frequencies of occurrence of the different directions were used. An examination of the data showed that the reported directions contained a strong bias in favor of the eight main directions N, NE, E, SE, S, SW, W and NW, while the frequencies of the eight intermediate directions NNE, ENE, etc., were almost invariably small. It was therefore possible to reduce the labour of computation by using only the frequencies of the eight main directions. Simple checks showed that the omission of the data for the intermediate directions had insignificant effects on the results.

The method of calculating the parameters Θ and r was as follows. Let the eight directions N, NE, ..., NW be represented by eight equally spaced points on the circumference of the unit circle with polar coordinate angles Θ_i, and let each point be weighted by the frequency of occurrence f_i of the corresponding wind direction. Next calculate the centroid (r, Θ) of these weighted points by means of the equations

$$X = \sum_{i=1}^{8} f_i \cos \Theta_i \Big/ \sum_{i=1}^{8} f_i,$$

$$Y = \sum_{i=1}^{8} f_i \sin \Theta_i \Big/ \sum_{i=1}^{8} f_i,$$

$$r^2 = X^2 + Y^2,$$

$$\cos \Theta = X, \quad \sin \Theta = Y.$$

Then Θ represents the desired mean wind direction, and the value of r, which lies between 0 and 1, is a measure of the constancy of the wind direction. Large values of r represent winds with a relatively constant direction, while small values represent winds that are variable in direction.

The vector (r, Θ) is not the same as the resultant wind often quoted in climatological work because wind speeds do not enter into the calculation of r and Θ.

Results and Discussion

The results are listed in Table 1 for each station in the four seasons. The percentage frequencies of calm s were taken directly from the published data, while the parameters k and c of the Weibull distributions, and the parameters Θ and r of the distributions of wind directions, were calculated by the methods described above.

The frequencies of calm vary widely from over 70% in very unfavorable locations in the north (such as Chiang Mai and Nan) to less than 10% at well exposed coastal stations (such as Pom Prachulachomklao). The hourly records from inland stations having pressure-tube anemometers show that calms are indeed frequent[3]. They occur mainly at night when stability of the lower air layers prevents the exchange of momentum between the surface and the wind aloft.

Some uncertainty may exist as to the distinction between "calm" and "wind speed < 4 knots". Officially, "calm" is defined as a wind speed less than 1 knot, and in practice there is a bias against reporting a 1 knot wind. Such winds, if reported as calm, would distort the distributions calculated in this paper. However, errors at this end of the wind speed scale, where windmills do not operate, are of little practical importance in wind energy studies.

The Weibull shape parameters lie for the most part between the values $k = 1$ and $k = 2$, while the scale parameters c vary from 1 m/s to values in the neighbourhood of 6 m/s. These parameters show a remarkable internal consistency, in view of the simplicity of the method used to obtain them. The Weibull parameters are also consistent with those found for Chiang Mai, Ubon, Bangkok and Hat Yai in the previous study[3], where hourly data over a period of one year were used.

The high values of k and c at the inland station of Phetchabun are unusual. It seems that the location of the station between high mountains in a straight level valley aligned along the direction of the prevailing winds may be the reason. Although the frequencies of calm are rather high (about 50%), it would be interesting to investigate more closely the possibilities for harnessing the wind in this area.

The wind direction parameters $\underline{\Theta}$ and r vary widely with geographical location and seasonal changes. In most places the mean direction lies between south and west during the summer, and between north and east during the winter. These two seasons also have the most constant wind directions.

Figure 1 gives a visual impression of the winds over the country in summer and winter. The maps indicate that the most promising areas for the development of wind energy are the southern provinces on the peninsula, the part of the central plain near the Gulf of Thailand, and a broad band stretching across the north-eastern region.

The amount of energy in the wind in Thailand is not large. Since the Weibull parameters k are mostly greater than unity, the mean wind speeds $\overline{V}$ of the distributions are usually a little less than c. A knowledge of these mean wind speeds is important for the selection of windmill designs for individual sites, but the occurrence of calms makes the overall average wind speed less than $\overline{V}$. On the other hand the data used here have been taken from ordinary synoptic weather stations, whose locations were chosen to represent the weather over the surrounding area as a whole. Windmills at sites especially chosen with respect to the surrounding terrain could extract more energy from the wind than the results of this study indicate.

TABLE 1. FREQUENCIES OF CALM s (%), WEIBULL PARAMETERS k AND c (m/s), MEAN DIRECTION θ (DEGREES) AND CONSTANCY OF DIRECTION r

Station		Feb – Apr	May – Jul	Aug – Oct	Nov – Jan
Chiang Rai	s	28	24	23	29
	k	1.2	1.5	1.5	1.4
	c	2.7	2.8	2.6	2.3
	θ	50	160	60	40
	r	0.2	0.3	0.3	0.6
Mae Hong Son	s	51	50	60	64
	k	1.1	1.0	1.0	1.1
	c	2.2	1.8	1.5	1.2
	θ	100	170	150	60
	r	0.2	0.3	0.2	0.5
Chiang Mai	s	60	58	67	74
	k	1.2	1.2	1.1	1.1
	c	2.0	2.0	1.8	1.7
	θ	180	200	200	180
	r	0.4	0.6	0.3	0.1
Nan	s	65	61	72	77
	k	1.1	1.2	1.2	1.2
	c	1.8	1.7	1.4	1.6
	θ	160	180	170	110
	r	0.6	0.8	0.6	0.4
Lampang	s	25	22	32	37
	k	1.1	1.2	1.1	1.1
	c	1.9	2.1	1.7	1.4
	θ	210	220	210	20
	r	0.3	0.4	0.2	0.1
Phrae	s	35	20	36	47
	k	1.2	1.3	1.1	1.2
	c	2.4	2.3	1.9	1.9
	θ	190	200	210	10
	r	0.6	0.8	0.4	0.4

TABLE 1 (Continued)

Mae Sariang	s	36	36	35	46
	k	1.2	1.2	1.3	1.0
	c	2.8	3.0	2.5	2.2
	Θ	190	190	190	0
	r	0.5	0.7	0.3	0.3
Uttaradit	s	29	31	33	26
	k	1.1	1.0	1.0	1.2
	c	1.5	1.5	1.4	1.5
	Θ	130	160	130	80
	r	0.6	0.7	0.6	0.7
Loei	s	9	11	12	14
	k	0.9	1.0	1.1	1.3
	c	1.4	1.5	1.4	1.6
	Θ	330	300	340	0
	r	0.1	0.2	0.2	0.3
Nakhon Phanom	s	36	37	41	34
	k	1.2	1.2	1.1	1.1
	c	2.3	1.8	2.0	2.8
	Θ	100	110	90	80
	r	0.7	0.4	0.5	0.8
Udon Thani	s	36	34	37	49
	k	1.0	1.0	1.0	1.4
	c	2.0	1.6	1.7	2.3
	Θ	100	160	110	70
	r	0.4	0.3	0.2	0.6
Sakon Nakhon	s	28	33	36	33
	k	1.3	1.4	1.3	1.5
	c	2.4	2.0	2.2	2.5
	Θ	100	200	130	60
	r	0.4	0.4	0.1	0.8

TABLE 1 (Continued)

Tak	s	24	24	36	48
	k	1.4	1.2	1.2	1.3
	c	3.4	2.9	2.7	2.1
	Θ	240	250	250	100
	r	0.4	0.4	0.3	0.3
Phitsanulok	s	42	38	48	61
	k	1.1	1.0	1.0	1.0
	c	1.7	1.5	1.2	1.1
	Θ	180	180	180	340
	r	0.6	0.7	0.3	0.2
Mae Sot	s	27	25	25	35
	k	1.4	1.4	1.4	1.1
	c	3.1	2.5	2.1	2.4
	Θ	250	250	260	50
	r	0.5	0.6	0.2	0.3
Mukdahan	s	20	16	18	18
	k	1.3	1.6	1.5	1.5
	c	3.0	2.7	2.8	4.1
	Θ	90	220	70	60
	r	0.4	0.4	0.2	0.8
Phetchabun	s	52	46	50	47
	k	2.3	2.4	2.4	2.4
	c	4.0	3.9	3.6	3.5
	Θ	190	200	200	30
	r	0.3	0.8	0.3	0.8
Khon Kaen	s	33	30	34	33
	k	1.7	1.7	1.7	2.0
	c	2.5	2.5	2.5	2.7
	Θ	30	230	310	40
	r	0.1	0.6	0.1	0.9

TABLE 1 (Continued)

Roi Et	s	24	15	21	27
	k	1.4	1.4	1.3	1.5
	c	2.8	2.6	2.4	3.1
	Θ	150	200	170	60
	r	0.4	0.8	0.3	0.8
Nakhon Sawan	s	24	21	33	37
	k	1.2	1.1	1.0	1.2
	c	2.8	2.4	1.9	2.5
	Θ	180	190	180	60
	r	0.8	0.9	0.7	0.3
Chaiyaphum	s	27	25	27	28
	k	1.9	1.9	1.9	2.1
	c	3.3	3.2	3.4	3.5
	Θ	160	250	290	60
	r	0	0.8	0.1	0.9
Ubon	s	51	52	48	35
	k	1.1	1.3	1.3	1.4
	c	2.3	2.4	2.8	3.6
	Θ	70	220	300	30
	r	0.1	0.5	0.2	0.8
Korat	s	49	44	50	53
	k	1.3	1.4	1.6	1.6
	c	2.6	3.1	2.9	3.0
	Θ	310	240	280	50
	r	0	0.6	0.3	0.7
Surin	s	13	6	10	16
	k	1.0	1.1	1.0	1.1
	c	1.3	1.4	1.4	1.8
	Θ	120	180	180	30
	r	0.3	0.8	0.2	0.8

TABLE 1 (Continued)

Lopburi	s	23	23	31	34
	k	1.7	1.8	1.8	1.6
	c	3.8	3.4	3.3	4.1
	Θ	160	180	180	40
	r	0.7	0.9	0.5	0.5
Suphanburi	s	15	7	10	20
	k	1.7	1.8	1.8	1.6
	c	2.8	2.9	2.7	2.8
	Θ	200	220	240	30
	r	0.5	0.7	0.3	0.7
Prachinburi	s	27	31	32	18
	k	2.1	2.0	2.0	2.1
	c	4.0	3.5	3.5	4.6
	Θ	140	170	190	60
	r	0.3	0.3	0.1	0.8
Kanchanaburi	s	26	26	31	37
	k	1.1	1.2	1.2	1.2
	c	1.7	1.8	1.8	1.8
	Θ	180	260	270	60
	r	0.2	0.8	0.6	0.6
Don Muang	s	6	8	12	15
	k	1.6	1.6	1.6	1.5
	c	3.6	3.4	3.0	2.5
	Θ	160	200	230	20
	r	0.6	0.6	0.3	0.4
Aranyaprathet	s	24	26	26	31
	k	0.8	0.8	0.7	1.0
	c	1.2	1.3	0.8	1.6
	Θ	280	270	280	40
	r	0.6	0.9	0.6	0.8

TABLE 1 (Continued)

Pom Prachulachomklao	s	5	5	11	7
	k	1.8	1.9	1.7	1.5
	c	3.5	4.1	3.6	3.0
	Θ	170	180	180	30
	r	0.7	0.8	0.3	0.7
Chonburi	s	9	12	13	15
	k	1.5	1.4	1.3	1.5
	c	4.1	3.7	3.3	3.6
	Θ	190	190	190	60
	r	0.5	0.7	0.4	0.5
Sattahip	s	17	12	23	25
	k	2.0	1.8	1.6	2.0
	c	3.1	4.3	4.0	3.2
	Θ	190	220	250	350
	r	0.7	0.7	0.5	0.6
Chantaburi	s	54	51	52	35
	k	1.4	1.3	1.3	1.4
	c	3.3	2.9	3.2	5.4
	Θ	220	220	230	30
	r	0.3	0.6	0.3	0.7
Hua Hin	s	21	26	26	16
	k	1.3	1.3	1.3	1.3
	c	3.1	2.6	2.2	3.1
	Θ	140	210	250	20
	r	0.5	0.5	0.2	0.6
Prachuab	s	10	6	7	8
	k	1.5	1.5	1.4	1.3
	c	3.5	3.4	3.5	5.4
	Θ	160	240	270	10
	r	0.4	0.6	0.5	0.7

TABLE 1 (Continued)

Khlong Yai	s	26	32	32	22
	k	1.3	1.3	1.2	1.3
	c	2.4	2.2	2.5	2.9
	Θ	310	300	290	10
	r	0.2	0.5	0.5	0.4
Chumphon	s	29	25	22	27
	k	1.4	1.4	1.3	1.2
	c	3.3	3.0	3.0	4.0
	Θ	130	220	220	90
	r	0.5	0.5	0.4	0.7
Ranong	s	19	26	29	21
	k	1.9	1.9	1.7	
	c	3.9	4.6	4.5	4.1
	Θ	60	240	230	70
	r	0.4	0.5	0.4	0.8
Bandon	s	55	36	42	57
	k	1.4	1.4	1.3	1.4
	c	2.8	3.1	2.7	2.9
	Θ	50	220	220	40
	r	0.5	0.9	0.8	0.7
Nakhon Si Thammarat	s	26	19	21	21
	k	1.7	1.3	1.4	1.9
	c	3.2	3.3	3.2	2.9
	Θ	80	230	250	20
	r	0.5	0.4	0.3	0.5
Phuket Airport	s	44	35	35	46
	k	1.9	1.8	1.6	1.6
	c	3.3	3.8	4.0	3.3
	Θ	40	270	280	80
	r	0.3	0.8	0.8	0.6

TABLE 1 (Continued)

Trang	s	33	41	39	20
	k	1.5	1.5	1.6	1.5
	c	5.0	3.1	3.7	5.7
	Θ	80	230	250	70
	r	0.5	0.4	0.5	0.8
Songkhla	s	19	34	33	14
	k	1.9	1.7	1.7	1.8
	c	5.5	3.7	4.2	6.7
	Θ	90	230	240	80
	r	0.7	0.4	0.4	0.7
Narathiwat	s	14	26	27	19
	k	1.6	1.7	1.6	1.7
	c	5.3	4.6	4.9	5.6
	Θ	60	340	330	40
	r	0.7	0.1	0.1	0.7

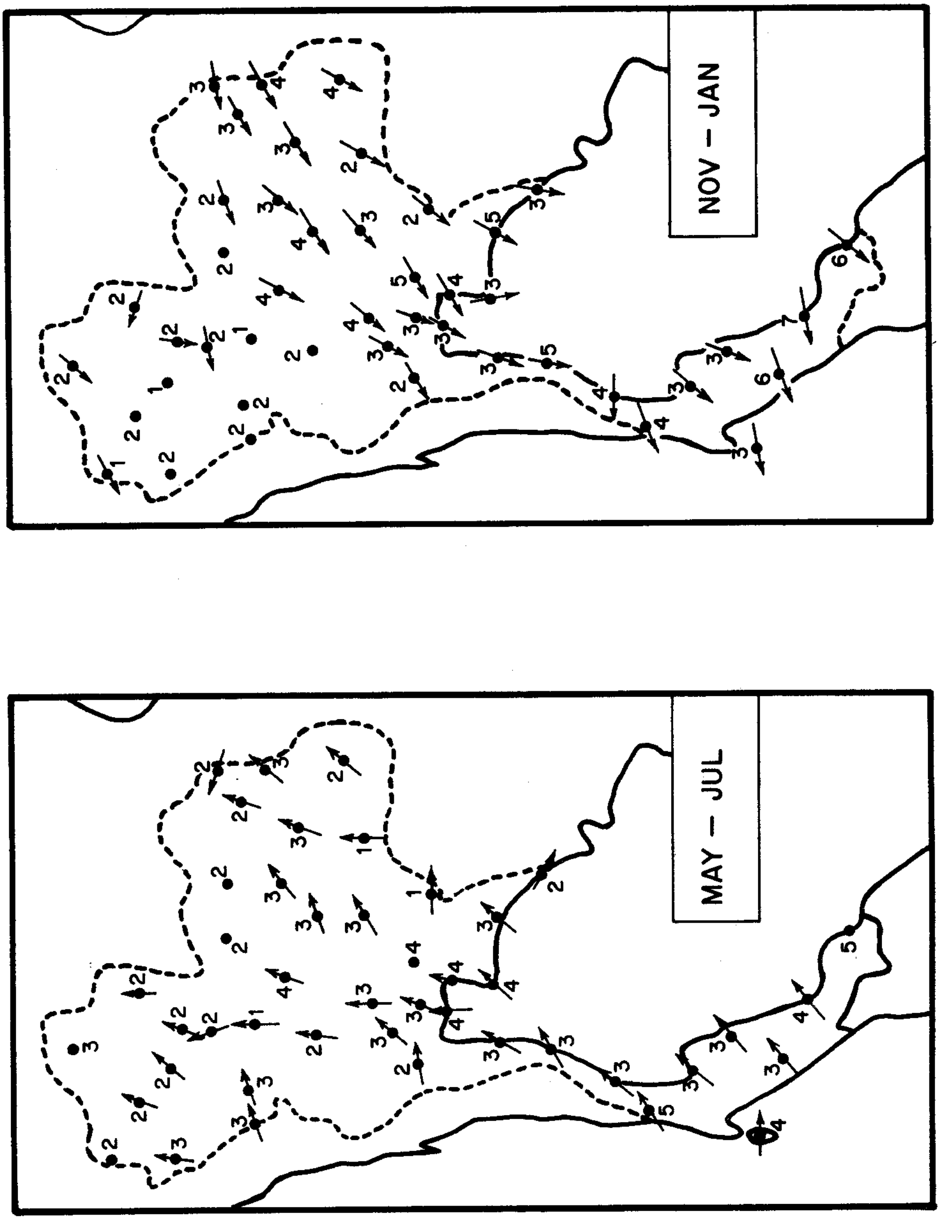

Fig. 1. Summer and winter winds. Numbers show approximate Weibull parameter c (m/s). Arrows show mean wind direction θ when $r \overline{<} 0.3$.

The use of simple windmills for low lift water pumping is traditional near the coast in the provinces of Samut Songkhram, Chachoengsao and Chonburi. The results presented in this paper show that there are many other places in Thailand where the same potential for the use of windmills exists.

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บทคัดย่อ

ได้ใช้เปอร์เซนต์ความถี่ซึ่งได้ตีพิมพ์แล้วของความเร็วและทิศทางของลมที่สถานีตรวจอากาศ 45 แห่งในประเทศไทยในช่วง พ.ศ. 2494-2504 เพื่อกำหนดลักษณะตามฤดูกาลของลมที่ความสูง 10 เมตร ทั่วประเทศ ในการศึกษาพลังงานลม สภาพลมโดยทั่วไปสงบ 10-50% ของเวลา ตัวแปรรูปร่างของ Weibull ที่คำนวณสำหรับความเร็วลมในช่วงที่ไม่สงบมีค่าระหว่าง 1 ถึง 2 และตัวแปรมาตราส่วนมีค่าระหว่าง 1 ถึง 6 m/s การกระจายของทิศทางลมถูกกำหนดลักษณะได้โดยทิศทางเฉลี่ย และตัวแปรที่บอกความคงที่ของทิศทาง ผลที่ได้แสดงว่าพอมีศักยภาพในการพัฒนาพลังงานลมในภาคใต้ ภาคกลาง และภาคตะวันออกเฉียงเหนือของประเทศ