

A Study on Long-term Variations in Wind Characteristics in Jeju island, Korea

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ABSTRACT: In order to clarify variability in wind energy over long-term period, an investigation was conducted on Jeju island, Korea. The 4 coastal areas and the 3 mountainous areas were selected and wind data for 8 to 11 years at the sites were collected for this work. Inter-annual variations, monthly variations and diurnal variations in wind characteristics were calculated from the long-term wind data. As a result, wind speed is high in winter season, while that is low in summer season. Wind at all sites blew strongly in the daytime and weakly at night. Also, wind energy and the range of variation in wind energy varied significantly from region to region on Jeju island. Inter-annual variations in wind energy on Jeju island occurred a little greater than the results of earlier works.

Keywords: Wind energy, Average wind speed, Average wind power density, Wind rose, Coefficient of variation

NOMENCLATURE

ρ Air density[kg/m³]
N Number of data
i Sample number
V Wind speed [m/s]
 σ Standard deviation
 $\bar{y}$ Mean

1. INTRODUCTION

Recently, oil price is becoming higher and higher, and environmental problem such as

global warming and pollutant coming from fossil fuel is being treated as a big issue in the world. Instead of fossil fuel, the use of new and renewable energy is essential for sustainable society. Of the new and renewable energy, wind energy is one of the fastest in their growth rates. The total capacity of global wind power is 94,000 MW by end of 2007, and it provides 1 % of the global electricity.[1] Wind energy scored the second most highly with an EU average of 71% in favour, and opposition to wind power was negligible at 4%.[2] Those mean wind

energy technology is deserve to be developed sufficiently.

About 85% of world wind energy capacity had a capacity factor of 22% in 2005, which is the ratio between the average power output of a wind turbine and its rated output.[3] However, it was reported that the capacity factor would be change in accordance with years and regions.[3] Earlier investigations have pointed out that the yearly average wind speed varies from year to year but within $\pm 10\%$ of the long term mean. Ramachandra et al.[4] had analyzed the wind data from meteorological observatories for a long time of 30-50 years to find out availability of wind energy. Linear regression analysis for wind speed for 36 years was done and modelled by Al-garni.[5] It was reported that variations in wind speed occurred diurnally as well as seasonally, and the power output from a wind turbine during daytime was about two times the output at night.[6] Besides those studies, there were some investigations on long-term variation in wind energy in Korea[7] and Japan[8].

In this study, long-term wind data were analyzed to clarify the characteristics of wind regime for harnessing wind energy in Jeju island, Korea. Fluctuation in yearly average wind speeds over 7 sites in Jeju island were revealed. Fluctuation in monthly and hourly average wind speed and the changes of wind roses were also obtained. Finally this investigation presents the coefficient of variation as well as the range of variations in wind speed and wind power density at each site.

2. SITES AND WIND DATA

The seven sites were selected for this investigation. The positions of the sites on Jeju island where is located in southern part of main land of Korea are shown in Figure 1. Of the selected regions, the four regions of Guja, Hallim, Mosulpo and Namwon were coastal area, while the three regions of Gasy, Seoguang and Seonhul were mountainous

area. The Halla mountain that is 1,950m in height is located in the center of Jeju island.

Table 1 shows measurement conditions for wind data which were recorded from automatic weather system (AWS) of meteorological observatories and measurement period. The wind data were recorded at 10m to 14m above ground level and collected for the period of 8 to 11 years.

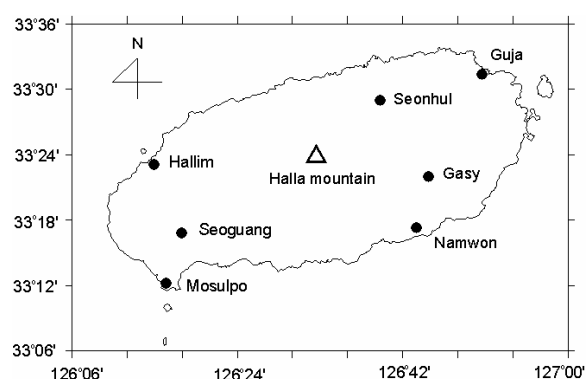


Figure 1: The selected sites in Jeju island, Korea

Table 1: Measurement conditions and periods

Site	Height of anemometer	Altitude	Topographical situation	Measurement period
Guja	14m	40m	Coastal area	1997~2007
Hallim	14m	48m	Coastal area	1997~2007
Mosulpo	14m	20m	Coastal area	1999~2007
Namwon	14m	73m	Coastal area	1997~2007
Gasy	10m	120m	Mountain area	2000~2007
Seoguang	14m	146m	Mountain area	1997~2007
Seonhul	11m	345m	Mountain area	1997~2007

3. ANALYSIS AND RESULTS

Yearly average wind speeds on coastal areas are presented in Figure 2. Wind speeds in Mosulpo site are higher than those in other sites, while wind speeds in Namwon site are the lowest. It can be seen that fluctuation in yearly average wind speed occurs in all sites. Figure 3 shows yearly average wind speeds on mountainous areas. Overall, wind speeds on mountainous areas are lower than those on coastal areas. From Figures 2 and 3, it is clear that wind speeds vary from region to region in spite of the same year.

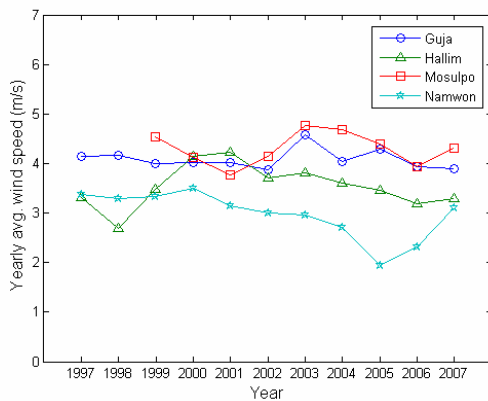


Figure 2: Yearly average wind speeds on coastal areas

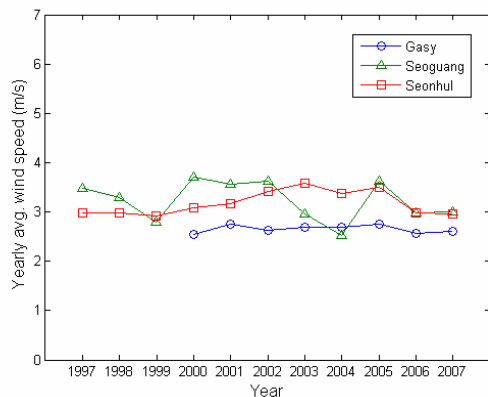


Figure 3: Yearly average wind speeds on mountainous areas

Wind characteristics for all sites were analyzed in detail. The results at Seonhul site and Hallim site were given representatively in this paper. Yearly wind characteristics at Seonhul site are listed in Table 2. Since one

wind datum per one hour is saved in main server of Korea meteorological administration, 8,760 of wind data should be collected. However the error data due to malfunction of AWS were excluded for accurate analysis. Since the data collection rate over 11 years is about 97.4%, reliable analysis results are expected. The calm data in the Table mean the data that have 0 m/s of wind speed. In Table 2, the average of the number of calm data for 11 years was 2.8% of total number of data. Yearly average wind power density (YAWPD), $\bar{P}/A$, is given by :

$$\bar{P}/A = \frac{1}{2} \rho \frac{1}{N} \sum_{i=1}^N V_i^3 \quad (1)$$

where ρ = air density (assumed 1.225 kg/m³ here), N = number of data, i = sample number, and V = wind speed.

The difference between minimum and maximum of yearly average wind speed (YAWS) was 0.67 m/s, which occurred in the year 1999 and the year 2003. The average wind speed for the years 1997-2007 at Seonhul site was 3.18 m/s. Yearly average wind power densities also vary from year to year and range from 37.46 W/m² for 1997 to 66.04 W/m² for 2003. The maximum wind speed (MWS) and the month occurred in each year are also listed in Table 2.

Figure 4 shows monthly variations in wind speed for 11 years at Seonhul site. Wind speed is high during the period December to April. It ranges from 2.58 m/s during October and reaches a peak of 3.87 m/s during January. For all sites in this study, winter season had higher wind speed, while summer season had lower wind speed. Wind characteristics like this are different from those in India, which has the opposite trend on seasonal variation.[4] Significant variations in monthly average wind speed occurs over all months. In general, since significant wind variation can occur on seasonal or monthly time scale over most of the world[9], variations in monthly average

wind speed in Figure 4 are seemed to be common.

Table 2: Yearly wind characteristics at Seonhul site

Year	No. of data	No. of calm data	MWS (m/s) /month	YAWS (m/s)	YAWPD (W/m ²)
1997	7918	128	13.5/11	2.98	37.46
1998	8401	80	15.1/3	2.98	38.81
1999	8255	552	15.4/8	2.92	39.74
2000	8663	199	13.7/8	3.08	42.61
2001	8718	520	14.4/6	3.17	46.31
2002	8683	252	16.4/4	3.42	64.32
2003	8701	175	19.9/9	3.59	66.04
2004	8738	223	18.4/7	3.38	62.19
2005	8577	207	15.0/5	3.49	63.11
2006	8525	212	15.6/7	2.99	42.64
2007	8644	131	13.5/9	2.96	37.76
Avg.	8529	244	15.54/-	3.18	49.18

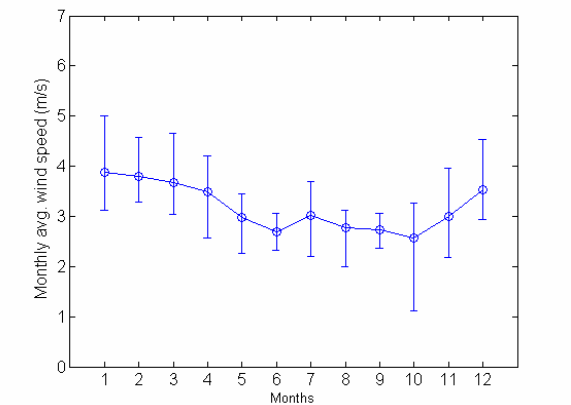


Figure 4: Monthly variations in wind speed at Seonhul site

Diurnal variations in wind speed for 11 years at Seonhul site are shown in Figure 5. It is seen that wind speeds during 9 o'clock to 18 o'clock are higher than average wind speed for 11 years. The maximum occurs during 13 o'clock to 15 o'clock. The difference between the maximum and the minimum for each time is around 0.7 m/s.

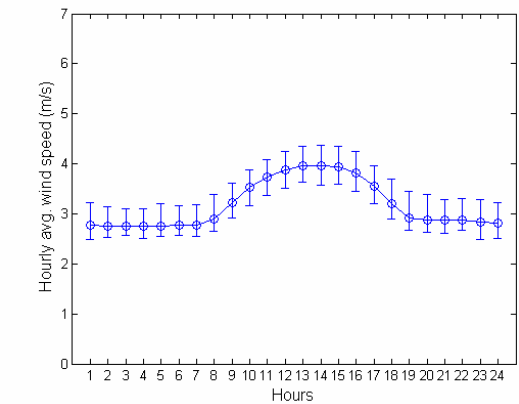


Figure 5: Diurnal variation in wind speed at Seonhul site

Figure 6 represents some wind roses, which is frequency distribution of wind direction for a given period, at Seonhul site. The prevailing wind direction is not evident in the year 1999 that the lowest wind blew for 11 years. On the other hand, in 2001 and 2003, the prevailing wind directions are from the north, which accounts for 19% to 26% of total wind direction distribution. From Figure 6, it can be seen that frequency distribution of wind direction also varies from year to year.

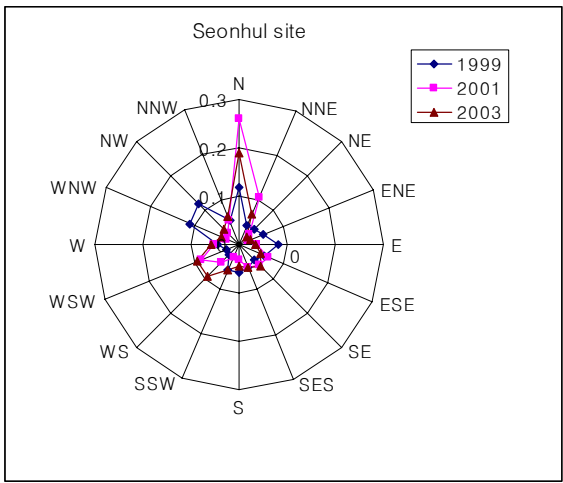


Figure 6: Wind roses at Seonhul site

Yearly wind characteristics at Hallim site are listed in Table 3. The data collection rate over 11 years is 98.3% and the rate of calm data for 11 years is 3.4%. Maximum wind speeds occurred mostly in July, August and September. The reason comes from typhoon

blowing in summer in Korea. The yearly average wind speed varies from a minimum of 2.68 m/s for 1998 to a maximum of 4.23 m/s for 2001. The average of wind speeds over 11 years is 3.54 m/s that is comparatively high wind speed. The yearly average wind power density also varies from year to year and the difference between the maximum and the minimum is 57.53 W/m².

Table 3: Yearly wind characteristics at Hallim site

Year	No. of data	No. of calm data	MWS (m/s) /month	YAWS (m/s)	YAWPD (W/m ²)
1997	8068	799	13.5/9	3.32	63.54
1998	8419	641	13.1/3	2.68	37.18
1999	8482	427	18.0/8	3.47	67.11
2000	8714	102	18.4/8	4.15	94.71
2001	8728	29	19.6/6	4.23	91.24
2002	8733	316	15.7/8	3.7	82.64
2003	8727	175	22.5/9	3.82	82.51
2004	8762	278	15.3/7	3.6	68.85
2005	8697	369	13.5/12	3.45	61.94
2006	8687	33	12.4/7	3.19	46.77
2007	8664	55	21.2/9	3.3	54.62
Avg.	8607	293	16.65/-	3.54	68.28

Figure 7 shows monthly variations in wind speed for 11 years at Hallim site. Wind speeds in winter are higher than those in summer, which is the same trend as wind speed at Seonhul, as shown in Figure 4. However the range of the error bar for each month at Hallim site is wider than that at Seonhul site. This means that inter-annual variations in wind speed at Hallim site occurred greater than that at Seonhul site.

Diurnal variations in wind speed for 11 years at Hallim site are given in Figure 8. Wind at the site blows strongly in the daytime and weakly at night, which is the same trend as wind speed at Seonhul site. The range of the error bar for each hour at Hallim site is broader than that at Seonhul site. The reason is the same as described above.

Figure 9 shows wind roses for some years at Hallim site. The prevailing wind direction in 1998 is from the north, which accounts for about 20 % of total time. However in the year 2001, the wind mainly blew from the east, whose wind comprised almost the same percentage with the prevailing wind direction in 1998. However the prevailing wind direction returned to the north in 2005. Therefore, since wind direction also varies from year to year, variations in wind direction need to be considered in wind turbine siting.

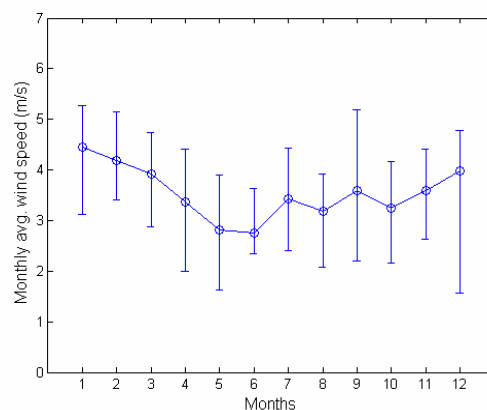


Figure 7: Monthly variations in wind speed at Hallim site

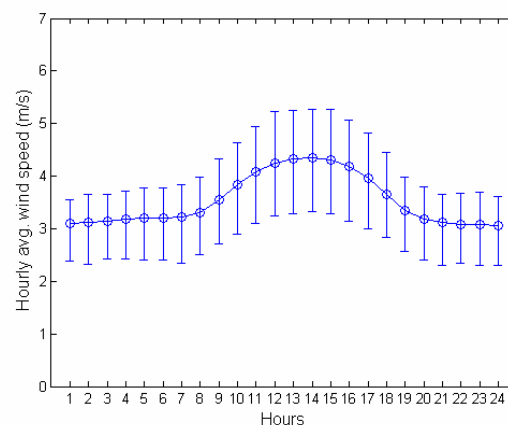


Figure 8: Diurnal variations in wind speed at Hallim site

Regional variations in wind speed for each data collection period are shown in Figure 10. It can be seen from this Figure that wind speed relies on local topographical variation. Inter-annual variations in wind

speed can be checked regionally from this Figure. Hallim site and Namwon site have wide range of the error bar for yearly average wind speed, while Gasy site and Seonhul site have narrow range of the error bar. Accordingly, inter-annual variations in wind speed are greater in Hallim site and Namwon site than in the other sites.

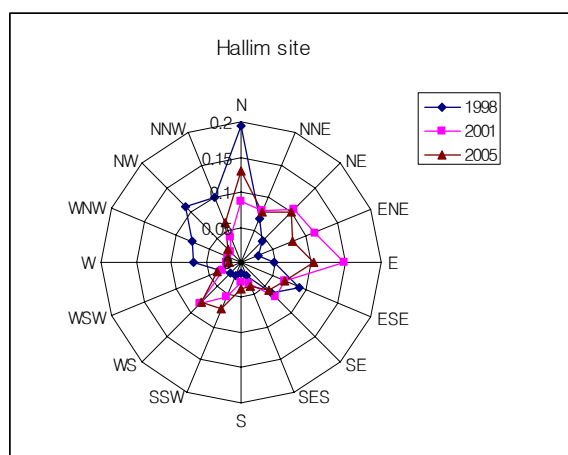


Figure 9: Wind roses at Hallim site

In an aspect of harnessing wind energy, variations in wind power density are more important than those in wind speed. Thus, we had calculated regional variations in wind power density for each data collection period. The results are shown in Figure 11. Since wind power density is proportional to the cube of wind speed, the range of the error bar of wind power density for each site became wider compared with that of wind speed. In the case of Mosulpo site, though the range of error bar of yearly average wind speed is average level from Figure 10, variations in wind power density are the greatest in all sites. From Figures 10 and 11, it is concluded that on Jeju island, there are regional variations in wind energy, and some regions have a wide range of inter-annual variations in wind energy, while others do not. That is, wind energy and the range of variation in wind energy vary significantly from region to region on Jeju island. It seems to be because Jeju island has lots of complex terrain.

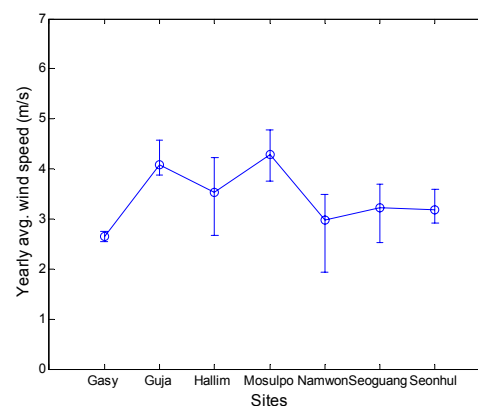


Figure 10: Regional variations in wind speed

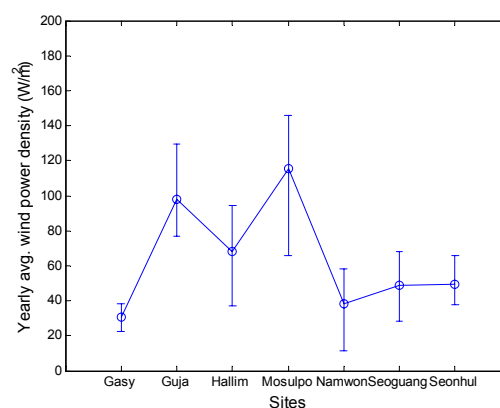


Figure 11: Regional variations in wind power density

Above results are needed to be quantified, if possible. So the coefficient of variation, CV, and the range of variation, RV, were calculated for yearly average wind speeds and yearly average wind power densities. The CV is expressed in the form of a percent :

$$CV = \frac{\sigma}{\bar{y}} 100\% \quad (2)$$

where, σ is the standard deviation and $\bar{y}$ is the mean.

The RV is given by :

$$RV = \frac{\max. \text{ or } \min. - \bar{y}}{\bar{y}} 100\% \quad (3)$$

Table 4 represents the coefficient of variation and the range of variation for each site. Overall, it can be seen that variations in average wind speed and average wind power density are greater at Namwon site than any other sites, while those are slightest at Gasy site. The average of the coefficient of variation for 7 sites is 9.2% for yearly average wind speed and 24.3% for yearly average wind power density. As for the average of all sites, from 13.1% to -15.8% variation in average wind speed occurred, and the variation in average wind speed resulted in a variation in average wind power density of between 35.6% to -38.8%. Earlier investigations reported that the yearly average wind speed varied within $\pm 10\%$ of the long term mean. On Jeju island, it can be seen that inter-annual variations in wind energy occur a little greater than the results of earlier works.

4. CONCLUSIONS

Long-term wind data in Jeju island, Korea were collected and analyzed in detail to reveal variations for each time scale in wind energy. Wind data for 8 to 11 years were collected from 7 sites in Jeju island, of which 4 sites are located in coastal areas and 3 sites mountainous areas. The anemometer and the wind vane of AWS were from 10m- to 14m-height above ground level. The results are as follows.

- (1) Wind energy and the range of variation in wind energy varied significantly from

region to region on Jeju island.

- (2) Inter-annual variations in wind energy on Jeju island occurred a little greater than the results of earlier works. Yearly average wind speed varied within +13.1% to -15.8% of the long-term mean. This resulted in a variation in average wind power density of between 35.6% to -38.8%.
- (3) Since wind direction as well as wind speed varied from year to year, this should be considered in wind turbine siting.

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Table 4: Coefficient of variation and range of variation for each site

Site	Coefficient of variation (%)		Range of variation (%)	
	YAWS(m/s)	YAWPD(W/m ²)	YAWS(m/s)	YAWPD(W/m ²)
Gasy	3.0	19.0	4.0~-4.3	25.8~-25.3
Guja	4.9	15.1	11.9~-5.0	32.4 ~ -21.4
Hallim	12.4	26.7	19.6~-24.2	38.7~-45.6
Mosulpo	7.9	21.8	11.0~-12.5	26.6~-43.2
Namwon	16.1	34.6	17.7~-34.7	51.3~-71.0
Seoguang	12.3	28.2	14.5~-22.0	39.9~-41.5
Sunhul	7.7	24.4	13.0~-8.1	34.3~-23.8
Avg.	9.2	24.3	13.1~-15.8	35.6~-38.8

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