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Surface Wind Regionalization Based on Similarity of Time-series Wind Vectors

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ABSTRACT

In the complex terrain where local wind systems are formed, accurate understanding of regional wind variability is required for wind resource assessment. In this paper, cluster analysis based on the similarity of time-series wind vector was applied to classify wind regions with similar wind characteristics and the meteorological validity of regionalization method was evaluated. Wind regions in Jeju Island and Busan were classified using the wind resource map of Korea created by a mesoscale numerical weather prediction modeling. The evaluation was performed by comparing wind speed, wind direction, and wind variability of each wind region. Wind characteristics, such as mean wind speed and prevailing wind direction, in the same wind region were similar and wind characteristics in different wind regions were meteor-statistically distinct. It was able to identify a singular wind region at the top area of Mt. Halla using the inconsistency of wind direction variability. Furthermore, it was found that the regionalization results correspond with the topographic features of Jeju Island and Busan, showing the validity.

Key words: Wind regionalization, Wind variability, Wind characteristics, Cluster analysis, Wind resource map of Korea

1. INTRODUCTION

Korea is a mountainous country wherein 70% of the land is stiffly inclined and bent. Under such geographic condition, wind variability is more complicated; thus, local wind systems are formed even in a small area (Jung *et al*., 2009).

Since the wind power business is characterized by economy of scale, it is more advantageous for it to be as large as possible. Currently, commercially available wind turbines have a capacity of 1.5 MW and blade diameter of 80 m or wider. To minimize the wake loss of such wind turbines, the turbines must be separated with at least 7 times blade diameter space between them along the prevailing wind direction. As such, a 100 MW capacity wind farm would require 14 km^2 or larger area on a flat land.

On a mountainous region, wind characteristics are generally not homogeneous in a 14 km^2 area. Therefore, it will be difficult to observe the entire wind farm with single meteorological tower for wind resource assessment, and multiple meteorological towers must be installed according to local wind regions to measure accurate wind variability corresponding to the geological and meteorological characteristics. As such, accurate understanding of local wind systems is mostly needed to assess the wind resources and to control the wind farm in a mountainous region by dividing the region into small areas with homogeneous wind characteristics.

Surface wind regionalization has been done by applying the principal component analysis (PCA) by Jimenez *et al*. (2008). They derived wind regions based on two different methods according to temporal variability. The first method groups the areas with similar PCA loading vector using cluster analysis and the second method applies the rotation of the selected principal components. Both methods led to similar wind regions. Previous studies on wind classification also include the classifications of wind fields. Wind field classification also has been done according to temporal variability by applying PCA. The loading vector extracted from PCA is compared to examine the similarity (Green *et al*., 1992). However, Weber and Kaufmann (1995) classified the wind fields using the similarity of wind vector itself. Jimenez *et al*. (2009) compared two methods using PCA loading vector and wind vector and confirmed that both methods led to very similar classification. Jung *et al*. (2007) and Jung *et al*. (2009) performed the wind regionalization in

South Korea using the similarity of wind vector. Jung *et al.* (2007) regionalized Busan into 9 sub-regions. 6 sub-regions were classified using 9 weather observation stations sites and 3 sub-regions were added considering the topographic features of study area. Jung *et al.* (2009) regionalized wind sectors of South Korea using meteorological simulation data of 10 km^2 spatial resolution. Note, however, that they used simple annual average wind vectors instead of hourly time-series wind vectors.

This study is to propose precise wind regionalization method based on similarity of wind vectors using hourly time-series data, reflecting temporal variability of wind vectors. First, Jeju Island, which has relatively simple terrain, is regionalized. Wind characteristics, such as wind speed, wind direction and temporal wind variability, of each sub-region is compared. Wind regionalization is also applied to Busan, which has complex terrain, and the result is compared to the topographic features. In this way, the validity of surface wind regionalization is evaluated from simple to complex terrain.

2. DATA

This study performs wind regionalization using KIER-WindMap^{TM}, the wind resource map of Korea drawn by the Korea Institute of Energy Research (KIER). The wind resource map of Korea is in surface spatial resolution of 1 km^2 and temporal resolution of 1 hour created by a mesoscale numerical weather prediction model, the Weather Research and Forecasting (WRF). Detail descriptions, such as domain dimensions, physical model schemes, initial and boundary conditions, data assimilations and validations comparing with the in-situ measurements of a numerical simulation framework to draw the wind resource map of Korea, are found in Lee *et al.* (2009a, b) and Kim *et al.* (2011).

In Iberian Peninsula, Jimenez *et al.* (2010) evaluated the performance of the WRF simulation over complex terrain by comparing the wind variability of observations and the model prediction. It was identified that the sub-regions derived from the simulation data are similar to those from observations. In the case of Jeju Island, the accuracy of KIER-WindMap^{TM} was proven by the comparison of the aforementioned wind resource measurement data and offshore wind speed retrieved from the satellite images of Synthetic Aperture Radar (Kim *et al.*, 2014). In this study, wind regionalization was applied to Jeju Island and Busan, two different characteristic regions.

Jeju Island located in the south sea is the largest island in Korea. With total area of 1,849 km^2, it has an ellipse shape spanning 73 km east to west and 41 km north to south. The island forms a gentle slope around the 2 km-high Mt. Halla located at the center of the island. Because of the conically shaped geography of the island, different wind systems appear according to the direction around Mt. Halla (Kim *et al.*, 2008). Hourly wind speed and wind direction data at 20 m above ground on 26 grid points east to west and 22 grid points north to south (total of 572 grid points in spatial resolution of 3 km^2) including the offshore territory around Jeju Island from 2005 to 2007 were extracted from the wind resource map of Korea and used for analysis.

Busan is the second biggest city in Korea, located in the southeastern corner of Korean Peninsula with a total area of 766 km^2. Southern and eastern side of Busan is bordering the sea with complex Rias coast. Inland is divided into mountainous areas on the eastern region and plains on the western region. 300 to 700 m high mountains are spread out on the eastern region as it is located in the end of Taebaek mountain ranges. Western region is flat because of Gimhae plain which is located at the mouth of Nakdong River. Various local wind systems appear in Busan according to their complex topography (Jung *et al.*, 2007). 46 grid points east to west and 53 grid points north to south (total of 2438 grid points in spatial resolution of 1 km^2) of 2007 hourly wind data at 20 m above ground were used including Yangsan, Gimhae and the offshore territory around Busan.

3. METHODOLOGY

3.1 Methodology of Wind Regionalization

Cluster analysis is a statistical technique of grouping a set of objects that are similar. For that, a measure representing the similarity or dissimilarity between objects is needed. Generally, Euclidean distance is defined as the measure of dissimilarity.

3.1.1 Similarity of Wind Conditions

Weber and Kaufmann (1995) defined the similarity of wind fields using the wind vector itself. The similarity of wind vectors at the point of time A and B was defined by Eq. (1). Here, i means the node of wind vector (measurement or analysis grid point), and M refers to the total number of nodes.

$$d_{AB} = \frac{1}{M}\sum_{i=1}^{M}[(\tilde{u}_{Ai} - \tilde{u}_{Bi})^2 + (\tilde{v}_{Ai} - \tilde{v}_{Bi})^2]^{1/2} \qquad (1)$$

In Eq. (1), the wind vector is normalized. In other words, the mean wind speed of a wind pattern is calculated according to Eq. (2), and the wind vector at each point of time is divided by the mean wind speed of the wind field by Eq. (3). Using normalization, the wind fields were classified according to the relative relationship of wind speed and wind direction in the wind field.

$$s = \frac{1}{M}\sum_{i=1}^{M}(u_i{}^2 + v_i{}^2)^{1/2} \tag{2}$$

$$\tilde{u}_i = \frac{u_i}{s}, \;\; \tilde{v}_i = \frac{v_i}{s} \tag{3}$$

In this study, the similarity of wind vectors on two nodes A and B was expressed by the Euclidean distance defined by Eq. (4). Here, j indicates the time stamp of time-series wind vector and N denotes the total number of time stamps used to classify the wind regions.

$$d_{AB} = \frac{1}{N}\sum_{j=1}^{N}[(\tilde{u}_{Aj} - \tilde{u}_{Bj})^2 + (\tilde{v}_{Aj} - \tilde{v}_{Bj})^2]^{1/2} \tag{4}$$

To calculate the difference in wind vectors between two nodes, hourly wind speed and direction for 3 years were decomposed to the wind speed in the east-west direction (u) and wind speed in the north-south direction (v). The data were then normalized. First, the mean wind speed of each node for the past 3 years was obtained using Eq. (5).

$$s = \frac{1}{N}\sum_{j=1}^{N}(u_j{}^2 + v_j{}^2)^{1/2} \tag{5}$$

The hourly wind speed components in the east-west direction and north-south direction were divided by the mean wind speed on each point (Eq. (6)).

$$\tilde{u}_j = \frac{u_j}{s}, \;\; \tilde{v}_i = \frac{v_j}{s} \tag{6}$$

The normalization reduces the distance between two nodes with different wind speeds but the same wind directions. Using the normalized wind vectors enables the wind regionalization using the wind direction and relative wind speed.

3.1.2 Two-step Cluster Analysis

Cluster analysis is generalized into a hierarchical and a non-hierarchical method according to how the clusters are divided. The hierarchical method merges the groups that are close to one another until all of the groups are merged into one, whereas the non-hierarchical method divides the objects into K clusters by measure of similarity. Davis and Kalkstein (1990) and Davis and Walker (1992) developed a two-step cluster analysis method to classify weather patterns, and it was applied and reviewed in many studies (Jimenez *et al.*, 2009; Jimenez *et al.*, 2008; Kaufmann and Whiteman, 1999; Kaufmann and Weber, 1996). Based on their study results, the present study also applied the two-step cluster analysis method to surface wind regionalization.

The two-step cluster analysis is performed in two steps. The first step selects the appropriate number of clusters and initial clusters to be used in the next step through hierarchical cluster analysis. In hierarchical cluster analysis, there are several ways to merge the clusters according to how the distance between two clusters is defined. Davis and Walker (1992) applied the average linkage method. Weber and Kaufmann (1995) compared five linkage methods and confirmed that the complete linkage method was most appropriate. Jimenez *et al.* (2008) applied the complete linkage method for wind regionalization. The complete linkage method defines the distance between two clusters as the distance between two observations values with the longest distance in each cluster. This study defined the distance between two clusters using the complete linkage method and similarity defined at Eq. (4).

In this study, appropriate number of clusters was determined using the distance between two merged clusters, which was applied in the previous studies using the same similarity (Kaufmann and Whiteman, 1999; Kaufmann and Weber, 1996; Weber and Kaufmann, 1995). Generally, the appropriate number of clusters is determined using cluster validity indices in cluster analysis. There are several advanced indices that can be used, however, it is important to use appropriate indices depending on the kind of clustering method, similarity and data (Guerra *et al.*, 2012). Meanwhile, a simple index is sufficient to evaluate our surface wind regionalization method. In hierarchical cluster analysis, the distance between two merged clusters keep increases as it merges two clusters with the minimum distance. If the distance greatly increases, it indicates that those two merged clusters are dissimilar; thus, merging must be terminated. The initial cluster is set to the clusters when the merging has to be terminated. The second step classifies the wind regions through non-hierarchical cluster analysis. It uses K-means cluster analysis, which is most widely used for non-hierarchical analysis. The distance between two sub-regions is defined with Eq. (4). The cluster count and initial clusters that must be set for K-means cluster analysis were set in the first step.

3.2 Evaluation of the Regionalization Method

Wind regionalization method is first evaluated over Jeju Island, which has relatively simple topography, by comparing wind characteristics of each sub-region. Wind speed and wind direction of each node in the same sub-region are compared to examine the similarity within the sub-region and the wind characteristics of a sub-region are compared to other sub-regions to identify the differences among them.

Temporal wind variability is examined by analyzing the time series of wind speed and wind direction. Surface wind regionalization method based on PCA divides wind regions according to temporal variability. However, since our wind regionalization method uses the similarity of hourly wind vector for several years, the temporal wind variability of each sub-region has to be examined.

Second approach evaluates the ability of the regionalization to replicate the topographic features. For example, wind regions derived in Jimenez *et al.* (2008) and Jimenez *et al.* (2010) agree with the topographic features. Surface wind regionalization is then applied to Busan, which has complex terrain, and compared to the topographic features of the terrain. In this way, the validity of surface wind regionalization is to be evaluated.

4. RESULTS

4. 1 Jeju Island

4. 1. 1 Wind Regionalization

The first step sets the appropriate sub-region count through hierarchical cluster analysis. The distance between two clusters tends to be larger when two close clusters are grouped (Fig. 1). The points showing greater increase than the general trend are those with three clusters and eight clusters. Since the verification of the analysis result becomes much more complex when the wind regions are segmented into eight, this study derived three wind regions in Jeju Island, considering the intermediate wind system.

The second step derives the wind regions through K-means cluster analysis. On Jeju Island, three wind regions are classified around Mt. Halla at the center (Fig. 2). Different sub-regions appear in the south and north of Mt. Halla, with another sub-regions appearing from east to west. Such is consistent with the wind system on Jeju Island (Kim *et al.*, 2008).

The three wind regions, numbered as [1], [2] and [3] in Fig. 2, contain 161, 310, and 101 nodes (grid cell size of 3 km^2), respectively. Fig. 3 shows the wind roses at each sub-region. Although east-northeast is the prevailing wind direction of the sub-region [1] located north of Mt. Halla, various wind directions also appear. The eastern part of the sub-region [2], located east of Mt. Halla, has two prevailing wind directions, north and east, whereas the western part has one prevailing wind direction, *i.e.*, north-northwest. Therefore, the prevailing wind direction of the sub-region [2] is north. The sub-region [3] located south of Mt. Halla has northeast as the prevailing wind direction.

4. 1. 2 Evaluation: Comparison of Wind Characteristics

To evaluate the meteorological validity of the regionalization method, similarity of wind characteristics under the same sub-region and difference of wind characteristics between different sub-regions were verified. Fig. 4, a box plot of mean wind speed by sub-regions, was presented to show the similarity and difference among sub-regions. The range of mean wind speed of each regions overlaps, but the sub-region [2] has a higher mean wind speed than the other sub-regions [1] and [3]. This can be interpreted that wind speeds of the sub-regions [1] and [3] are slowed down due to the existence of big topographic object, Mt. Halla, while wind speed spread of the sub-region [3] is wider than [2] due to a lee-side effect.

Statistics of Weibull scale and shape factors representing wind speed distribution characteristics were compared by sub-regions to verify how these factors

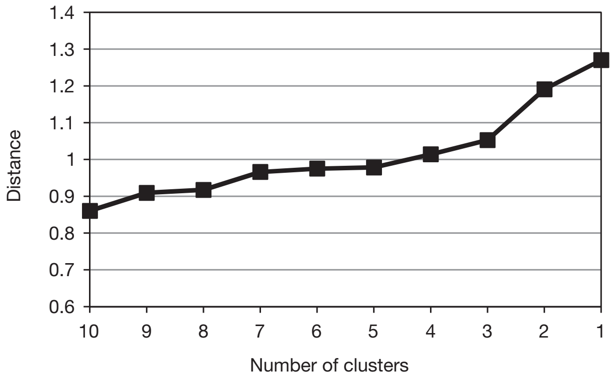


Fig. 1. Distance measure for each number of clusters in Jeju Island.

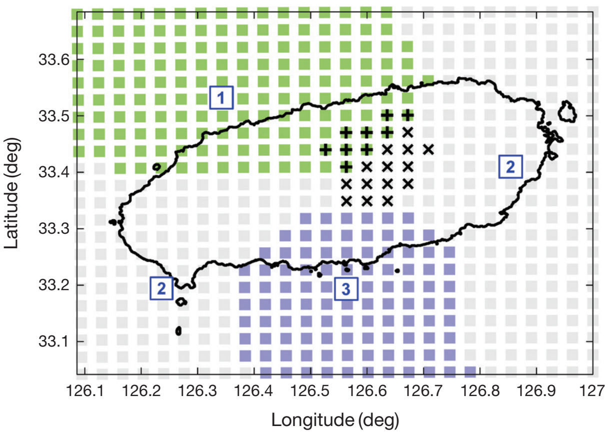
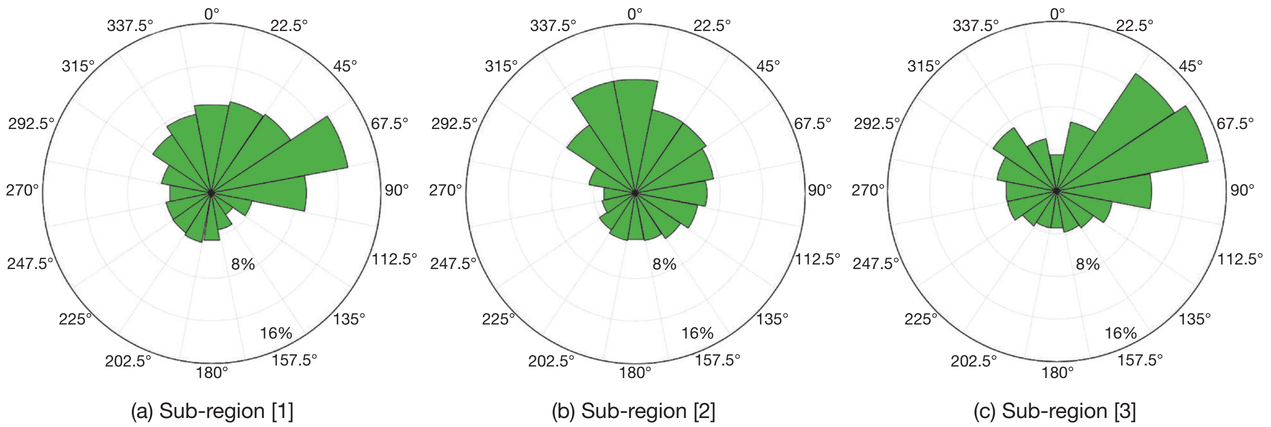


Fig. 2. Wind regions in Jeju island (cross symbols represent negative correlation of wind direction pattern over time with other nodes).



(a) Sub-region [1] (b) Sub-region [2] (c) Sub-region [3]

Fig. 3. Wind roses of each wind region in Jeju Island.

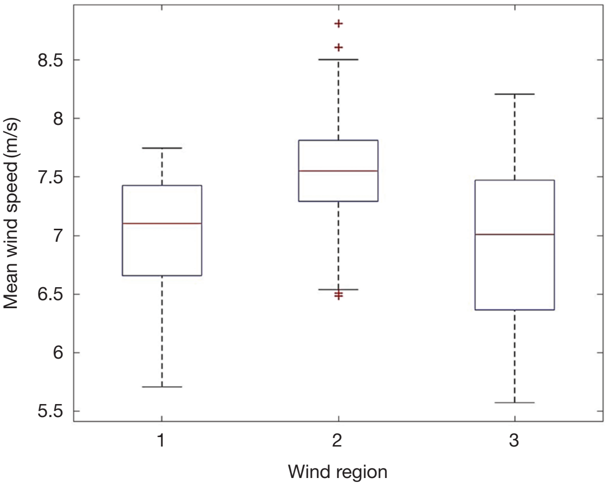


Fig. 4. Box plot of mean wind speed by wind regions.

Table 1. Statistics of wind speed distribution by sub-regions.

Sub-region number	No. of node	Weibull scale factor (m/s)		Weibull shape factor	
		Mean	Standard deviation	Mean	Standard deviation
[1]	161	7.82	0.64	1.69	0.19
[2]	310	8.48	0.44	1.89	0.16
[3]	101	7.78	0.82	1.73	0.21

Table 2. T-test results of wind speed distributions between two sub-regions.

Compared sub-region numbers		*t*-value of Weibull scale factor	*t*-value of Weibull shape factor
[1]	[2]	−13.1	−12.4
[2]	[3]	11.0	8.0
[3]	[1]	−0.5	1.9

are uniform in a same sub-region. Thus, its mean and standard deviation were calculated by sub-regions (Table 1). The Weibull scale factor represents the mean value of wind speed distribution. Since the standard deviation of the Weibull scale factor was as fairly low as less than 1.0 m/s in all wind regions, the mean wind speed of the nodes in each sub-region can be judged to be similar. This is exactly corresponding to Fig. 4. The Weibull shape factor represents the dispersion of wind speed distribution from its mean value. A higher Weibull shape factor value means low dispersion of wind speed distribution from the Weibull scale factor which is the area mean of wind speed distribution. Because the ratio of standard deviation to its mean of the Weibull shape factor was less than 12% in all sub-regions, the wind speed variance of the nodes in each sub-region can be judged to be similar.

T-test was performed to check the statistical difference in mean values of Weibull scale factor in each sub-region at significance level of 5% (Table 2). The *t*-values between the sub-region [1] and [2] was −13.1 and the sub-region [2] and [3] was +11.0, indicating clear difference in wind speed distributions. It should be noted that the sub-region [2] had much higher mean wind speed than those of the sub-regions [1] or [3] (see Table 1). However, the mean wind speed in the sub-region [1] and [3] was similar with *t*-value of −0.5. In case of Weibull shape factor, the *t*-values between the sub-region [1] and [2] was −12.4 and the sub-region [2] and [3] was 8.0, indicating clear difference in its distribution shape. Dispersion from the mean wind speed was lowest in the nodes of the sub-region [2] (see Table 1). Note, however, that the *t*-value between the sub-region [1] and [3] was 1.9, the lowest value, showing similar Weibull shape parameter. As such, the sub-region [1] and [3] has similar dispersion shape of wind speed distribution.

Table 3 summarizes the mean and standard deviations of wind direction in each sub-region. The calculation applied the method of obtaining mean value of wind direction and its standard deviation considering the circular (or cyclic) characteristics of angle (Berrens, 2009). According to the calculation, the prevailing wind directions of each sub-region [1], [2] and [3] were northeastern wind close to the east-northeastern wind, northern wind, and northeastern wind, respectively. Such is in accord with the wind rose of the center node in each sub-region as shown in Fig. 3. The standard deviations from the prevailing wind directions in the sub-regions [1], [2] and [3] were 31.3°, 37.6° and 18.9°, respectively, suggesting that the wind direction distribution in each sub-region was almost uniform. Table 4 shows the *t*-test results of wind direction distributions between sub-regions at significance level of 5% meaning that all three sub-regions showed different wind direction distribution statistically.

It is verified that the nodes regionalized in the same sub-region have similar wind characteristics but all sub-regions have different wind characteristics. No difference of mean wind speed between the sub-region [1] and [3] is attributed to the use of normalized wind vectors.

4.1.3 Identification of a Singular Region

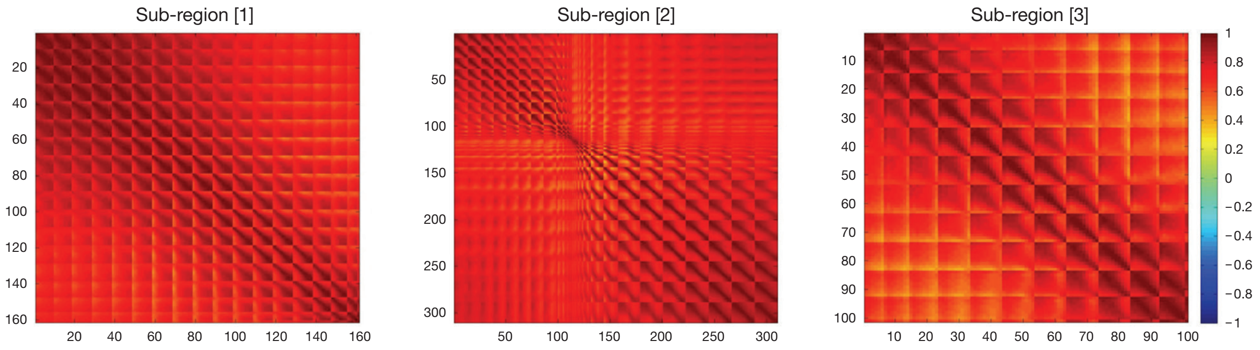
The correlation matrix of the time-series wind data in each sub-region is graphically depicted in Fig. 5. The

Table 3. Statistics of wind direction distribution by sub-regions.

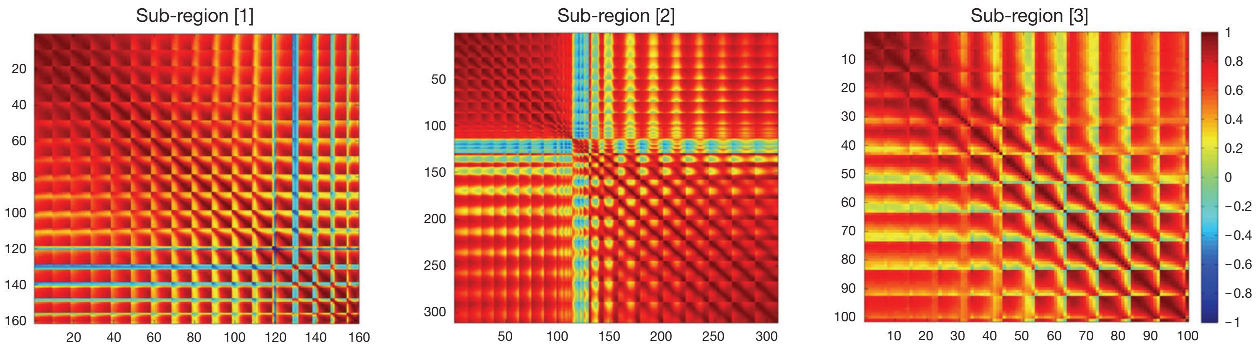
Sub-region number	No. of node	Wind direction (degree)	
		Circular mean	Circular standard deviation
[1]	161	70.3	31.3
[2]	310	359.6	37.6
[3]	101	49.7	18.9

Table 4. T-test results of wind direction distributions between two sub-regions.

Compared sub-region numbers		*t*-value of wind direction
[1]	[2]	−12.7
[2]	[3]	12.3
[3]	[1]	−4.0



(a) Correlation matrices of wind speed



(b) Correlation matrices of wind direction

Fig. 5. Graphical depiction of correlation matrices by sub-regions.

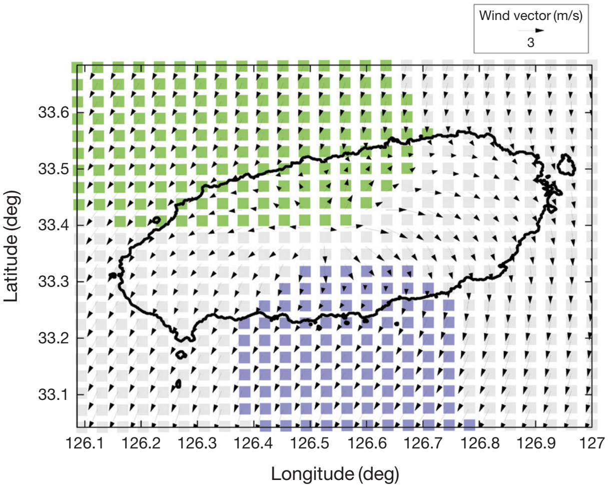


Fig. 6. Mean wind vector field in Jeju island.

columns and rows of unit correlation matrix become the nodes of each sub-region; different colors were painted according to the cross-correlation coefficient between the wind speed and direction of the nodes of the columns and rows. Red means strong positive correlation, whereas orange and yellow denote low correlation; blue means strong negative correlation. The circularity of the wind direction was reflected by applying the circular correlation coefficient formula suggested by Berens (2009).

Fig. 5 shows that most of the nodes exhibit strong positive correlation in the variation of time-series wind speed, but there are some areas of low or even negative correlation in the variation of time-series wind direction. Areas showing strong negative correlation with other regions are mostly located at the center part where the wind direction is diverging because of the conical shape of Mt. Halla and particularly such area in sub-region [2] is located at the east side of Jeju Island, indicating difference between east side and west side of Jeju Island (Fig. 2). This meteorological characteristic is clearly shown as the wind vector field in Fig. 6 which are three-year averaged mean wind vectors. Due to the orographic characteristics of Jeju Island, mean wind vectors dispersing to four directions of north, east, west, and south centered on Mt. Halla peak. The central area of Mt. Halla can be considered a singular and unusual region.

The correlation of the time-series wind speed was positively high, presenting that sub-regions are grouped with homogenous temporal wind speed variability. However, the correlation matrix of the time-series wind direction indicated that the temporal variability of wind direction is not homogeneous in the same sub-region. Although the wind regionalization method used in this study only reflected the variation of time-series wind speed but not that of time-series wind direction, the top of Mt. Halla could be separately regionalized from the correlation matrix of the wind direction. Also, east side and west side of Jeju Island could be separately regionalized. In this study, wind regionalization was done using 3 years of annual wind data, but by performing wind regionalization seasonally this division could be apparent.

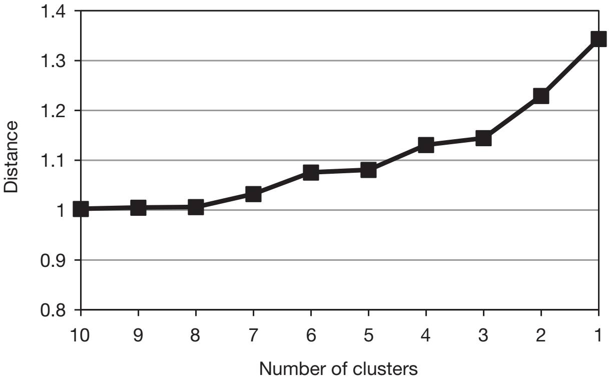


Fig. 7. Distance measure for each number of clusters in Busan.

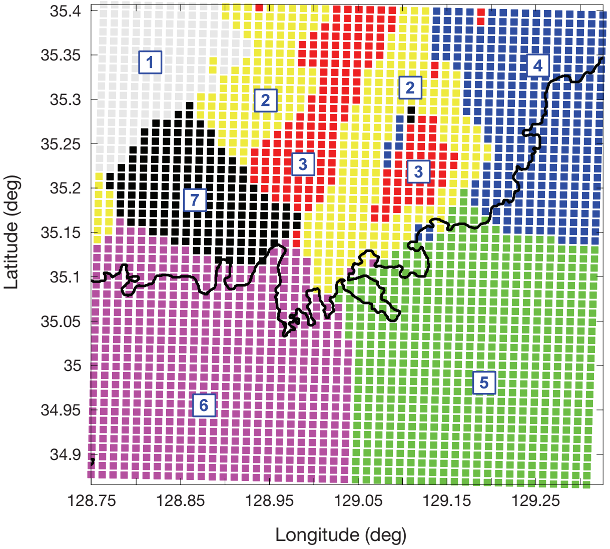


Fig. 8. Wind regions in Busan.

4. 2 Busan

4. 2. 1 Wind Regionalization

At the first step, the value of distance measure at each number of clusters was examined to determine the appropriate number of wind regions (Fig. 7). A sudden and big increase appears when the number of clusters

Fig. 9. Wind roses of each wind region in Busan.

were five and seven. Fig. 8 shows the wind regions in Busan when it is divided into seven sub-regions. Considering the topographic complexity of Busan, seven wind regions would be appropriate rather than five.

Fig. 9 shows the wind roses of each sub-region. The prevailing wind directions at the sub-region [1] and [7] are north-west, while it is north-northeast and south-southwest at the sub-region [3]. The sub-region [2] in the high elevation has higher wind speed than sub-regions in the low elevation on inland such as [1]. Similar to the adjacent regions, the prevailing wind direction is northwest and north-northeast. The highest wind speed appears at the wind regions [5] and [6] located on the offshore. In the sub-region [4], including the Taebaek mountain ranges and the offshore, northerly wind is dominant. The rest of the sub-regions in the offshore have three prevailing wind directions, northeast, northwest and southwest.

4.2.2 Evaluation: Comparison to Topographic Features

A comparison of the wind regionalization result and topographic features depicted as terrain elevation is suggested in Fig. 10. Along the regions with high elevation, homogeneous wind characteristics appear in the sub-region [2]. Valley and basin located between the high elevation regions have similar wind characteristics as the sub-region [3]. The sub-regions [1] and [7] presenting plains are divided by the mountains. The sub-region [4], including mountainous areas and off-

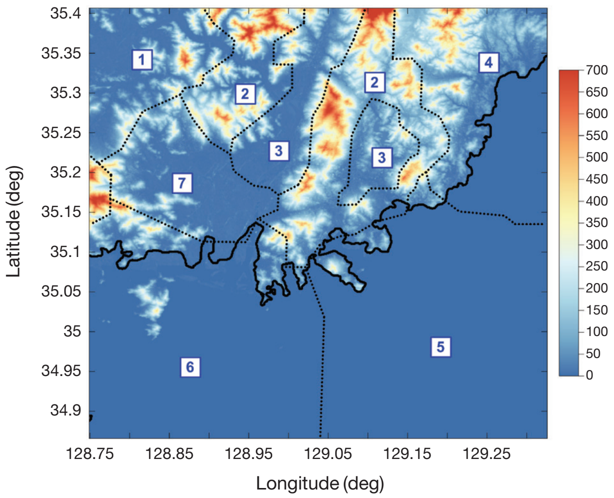


Fig. 10. Comparison of wind regions and terrain elevation (m) in Busan.

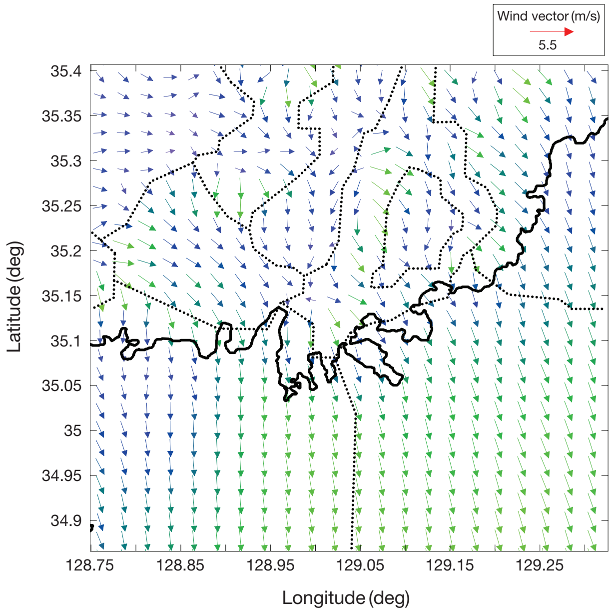


Fig. 11. Comparison of wind regions and mean wind vectors in Busan.

shore, show a local wind system, while the offshore area in the south of Busan is divided into two sub-regions [5] and [6]. Classifying wind regions based on hourly wind vectors improved on previous studies. The number of wind regions were smaller than previous study (Jung *et al*., 2007), *i.e*. 7 sub-regions instead of 9 sub-regions, but became more correlated to topographic features.

Fig. 11 displays mean wind vector field over Busan. Western wind is dominant in the sub-region [1]. The sub-region [7], Gimhae plane, adjacent to the sub-region [1] but blocked by the mountains so that it shows different wind direction to the sub-region [1] (see also Fig. 9). South east wind is dominant in the sub-region [7]. The sub-region [6], including offshore area, is adjacent to the sub-region [7] but also partially blocked by the mountains. Different from the sub-region [7], prevailing wind direction is south. Another offshore region, the sub-region [5], has north-northwest as a prevailing wind direction and has higher wind speed than the sub-region [6]. This is because of the wind coming from the sub-region [2]. North-northwest wind is also dominant in the sub-region [2]. Wind direction in the sub-region [3] corresponds to the direction of valley and wind towards to the side that the elevation gets lower in the sub-region [4], *i.e*., southeast.

5. CONCLUSION

The wind regions were divided based on the similarity of wind vectors using the hourly wind speed and wind direction data extracted from the wind resources map of Korea. It is anticipated that the method used in this study provides a precise wind regionalization but simpler method than the PCA method.

The followings are main conclusions deduced from this study:

1) Wind speed and wind direction of each node in the same wind region are similar and wind characteristics, specifically prevailing wind direction, of each sub-region are different. Also, Weibull distribution factors and prevailing wind direction had low standard deviation in the same wind region. The statistical difference of the wind characteristics in each sub-region was clarified by *t*-test. Therefore, the wind regionalization was deemed meteorologically relevant.
2) Temporal wind variability was examined using time-series of wind speed and wind direction. Surface wind regionalization based on similarity of wind vectors provides wind regions having similar temporal wind speed variability. However, temporal wind direction variability was not successfully reflected in regionalization according to the analysis case of Jeju Island.
3) Analyzing the temporal wind direction variability can identify a singular wind region. Based on the correlation matrix of wind directions, the top area of Mt. Halla, which has wind system characteristics of diverging wind directions, was identified as a separate unusual wind region. Also, correlation matrix of wind directions shows that east side and west side of Jeju Island can be divided from seasonal wind re-

gionalization.

4) Wind regions that agree with the topographic feature were divided. Sub-regions were divided around Mt. Halla at the center in Juju Island. Also in Busan, which has complex terrain, sub-regions were divided according with the mountain ridge, valley, basin, plain and offshore.
5) In this study, 3 years of annual wind data was used to derive wind regions. Accordingly, seasonal wind characteristics were not fully reflected. To improve this limit of wind regionalization method, other variables should be additionally considered to define the similarity of wind conditions. Also, determining appropriate number of wind regions is very important for precise wind regionalization. Applying and comparing other advanced indices to find appropriate number of wind region are needed.
6) If the wind regions of the area are known during the wind resource assessment, the appropriate size of wind farm and the appropriate number of meteorological towers to be installed for the wind resource assessment can be decided. For this, the wind regions must be divided into more segmented areas. It will need a reliable wind resource map that is much more precise than the 3 or 1 km^2 spatial resolutions used in this study.

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