Examination of the Feasibility of Area-Specific Criteria of Special Weather Report by Estimation of the Threshold Value of Disaster-Causing Strong Winds

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Abstract

Strong winds are one of the several factors contributing to natural disasters. Although in recent years, the intensity and frequency of strong winds has decreased, different areas are differently affected by such winds; these winds still have the potential to cause adverse impacts on life and property. In Korea, strong winds are also responsible for the incidence of increased number of accidents and forest fires. Therefore, in this study, the relationship between wind speed and damage was analyzed, and the threshold value of damage-causing wind speed was estimated. We first analyzed the relationship between wind speed and damage occurrences based on the daily maximum wind speed and daily maximum instantaneous wind speed data, and data on damage related to strong winds. Second, we examined the validity regarding the regional segmentation of the Korean criteria of special weather report for strong winds using the critical success index and cumulative percentile distributions to estimate the damage-causing threshold value for each region. We found that damage resulting from very strong wind speeds in Korea had not occurred in recent times. In addition, considerable damage had occurred because of low-speed wind compared to the current criteria for high wind advisory. However, the incidence of damage was higher when wind speed was stronger than the current criteria for high wind advisory. Based on threshold estimation, the study areas were categorized into areas with high threshold values (coastal, mountainous, and island) and those with low threshold values (inland areas). A notable difference was observed between the threshold values of the two categories of areas. This necessitated the regional segmentation of the criteria of special weather report on strong winds.

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1. Introduction

Changes in global wind are evident in several studies (Kim et al. 2020; Kim and Kim 2013; Wu et al. 2018). In particular, the causes and characteristics of each region vary because ground wind is greatly affected by topographic features and synoptic circulations (Baltaci et al. 2015; Baltaci et al. 2017). In addition, natural disasters caused by strong winds and meteorological features differ in frequency and scale of damage according to region. Categorizing these varying features and classifying areas experiencing similar characteristics is an effective way of reducing damage (Jun et al. 2008). To this end, estimating the threshold that causes damage is important. Many previous studies have analyzed regional classification and threshold estimation related to natural disasters; however, most studies have focused on rainfall.

In recent years, the frequency and intensity of strong winds has decreased, resulting in reduced interest in strong winds. However, the damage caused by strong winds continues to occur, necessitating appropriate preparation. In Korea particularly, there are large regional differences in the frequency of strong winds, and agriculture and greenhouses are clearly vulnerable facilities (MOIS 2018). In addition, during strong winds, relatively more traffic and railroad accidents occur, and the risk of forest fires increases (Kang et al. 2016; Lee 2007, 2010; Park et al. 2010). Therefore, management of the criteria of special weather reports classified according to region is necessary.

Accordingly, in this study, the relationship between wind speed and resulting damage in Korea is first identified. Second, the probable classification criteria of special weather report for strong winds is validated by estimating the disaster-causing threshold and analyzing regional differences.

2. Data and study method

2.1 Data

In this study, complementary data on weather and damage were used. Weather data included the daily maximum wind speed and the daily maximum instantaneous wind speed recorded in 61 Automated Synoptic Observing System (ASOS) units operated by the Korea Meteorological Administration (KMA) from 1988 to 2017 (Fig. 1a). Generally, wind speed means the average wind speed for 10 min before the observation time. The daily maximum wind speed means the maximum value of the 10 min average wind speed, observed during the day. Instantaneous wind speed means the wind speed observed at a specific time. The daily maximum instantaneous wind speed means the maximum value of the instantaneous wind speed, observed during the day (KMA 2016). Data that were collected by many observation stations before 1993 did not include daily maximum instantaneous wind speeds. However, these data were used to estimate the detailed threshold of the location of the data (Fig. 2b). Observation stations that lacked data for a period of time were analyzed using available data only. According to the ground weather observation guidelines, standard wind speed is that which is measured 10 m above the ground. As the height of the anemometer for each observation station varied, the following equation was used for height correction (Jiang et al. 2010; Pryor et al. 2005; Wan et al. 2010).

\[
\frac{U(Z_m)}{U(Z_a)} = \left(\frac{Z_m}{Z_a}\right)^{\alpha}
\]

where \(U\) represents the wind speed, \(Z_m\) represents a height of 10 m, \(Z_a\) represents the actual observation height, and \(\alpha\) is generally set at 1/7 (Kim and Kim 2013; Peterson and Hennessey 1978; Weisser and Foxon 2003).

Damage data include the duration and amount of damage recorded by the disaster yearbook published by the Ministry of Interior and Safety. The damage amount was converted to using the 2017 consumer price index of the Bank of Korea’s Economic Statistics System. The duration of damage recorded in the disaster yearbook was defined as the period during which the damage occurred.
condition; among them, wind speed values with an index close to 1 were estimated to be thresholds. The thresholds for each section were determined using CSI at intervals of 2 m s\(^{-1}\). As there were few incidences of strong wind damage in every region, the damage cases in each wind speed section were set to overlap the damage cases in the previous section. For comparison with the threshold estimated using the CSI, the equation proposed in a policy study on the criteria of special weather reporting was used (KMA 2008; KMA 2017).

\[
\text{Threshold} = \text{Weather occurrence value} \times 0.5 + \text{Disaster-causing wind speed value} \times 0.5
\]

where the weather occurrence value is the top 5% of the CPD among wind speed values during the study period. Disaster-causing wind speed value is the wind speed value corresponding to 50% of the CPD among wind speed values over the duration of the damage.

3. Results and discussion

Figure 2 shows the damage characteristics according to the intensity of daily maximum wind speed and daily maximum instantaneous wind speed for the period of strong wind damage from 1988 to 2017. Figures 2a and 2b show the annual damage caused by high-intensity wind speeds. Figures 2c and 2d show the number of damage occurrences caused by the high wind speed. Over the past 30 years, the average degree of damage caused by the intensity of the daily maximum wind speed was found to be approximately 32.9 times more than that in the preceding years. In addition, above-average damage caused by strong winds occurred at wind speeds that were below the criteria for high wind advisory. The
intensity of wind speed with damage that is above average and the number of damage occurrences according to intensity were observed 96 times within the range of 10 to 12 m s$^{-1}$, 86 times within the range of 8 to 10 m s$^{-1}$, 79 times within the range of 6 to 8 m s$^{-1}$, 63 times within the range of 12 to 14 m s$^{-1}$, and 36 times within the range of 4 to 6 m s$^{-1}$. The average number of damage occurrences caused by the daily maximum instantaneous wind speed during the day and according to intensity was observed approximately 46.1 times. Above-average damage occurred at a strength that was similar to that of the criteria for high wind advisory. In addition, a substantial damage occurred even as a result of a wind strength measuring 30 m s$^{-1}$ or higher. The intensity of wind speed with above-average damage as well as the number of damage occurrences according to intensity were observed 69 times at 30 m s$^{-1}$ or higher, 561 times within the range of 18 to 20 m s$^{-1}$, 60 times within the range of 20 to 22 m s$^{-1}$, and 51 times within the range of 16 to 18 m s$^{-1}$. This is because the frequency of weak wind speed is high. Figures 2e and 2f show the extent and incidence of damage caused by wind speed intensity. The scale and incidence of damage increased as wind speed increased. The inconsistency in the increasing trend resulted from the inclusion of all regions whose strong wind and infrastructure features varied. Damage caused by strong wind were found to occur more frequently when the wind speed was weaker than that of the criteria for high wind advisory. However, the incidences of damage were more frequent when the wind speed was stronger than that of the criteria for high wind advisory. These incidences are considered to be the result of the decrease in the wind speed of high-intensity and the increase in the wind speed of low-intensity, as revealed in previous studies (Kim et al. 2020; Kim and Kim 2013; Wu et al. 2018).

Figure 3 shows the distribution of the estimated threshold values for each observation station using the CSI and CPD. The distribution of the left panel represents the threshold that is estimated using the CSI, while the distribution of the right panel represents the threshold that is estimated using the CPD. In addition, the distribution of the upper panel represents the threshold value of the daily maximum wind speed, while the distribution of the bottom panel represents the threshold value of the daily maximum instantaneous wind speed. In the distribution chart, the black and
gray triangles represent the area where the estimated threshold is higher and lower than the criteria for high wind advisory, respectively, while the circle represents the same area whose threshold is similar to the estimated one. Overall, a lower threshold than that of the existing criteria for high wind advisory was estimated. In particular, the threshold value estimated using the CPD was found to be lower than that estimated using the CSI as well as the existing criteria for high wind advisory. These results are considered to reflect the occurrence frequency of wind speed, which is not related to disaster, and the recent decrease in the occurrence frequency of strong winds. Considering previous findings showing the decreasing occurrence frequency of strong wind and the low incidence of damage at weak wind speeds, the threshold using CPD can be deemed to be overestimated. However, the Seoul area was identified as an unusual area with a threshold that was higher than the CSI. These results are considered to be a combination of various variables such as infrastructure, topography, and geography.

Regions are categorized into those with high and low thresholds using the estimated threshold determined by the CSI. Among the threshold values calculated on the basis of the daily maximum wind speed, the lowest and highest threshold values were 6 m s\(^{-1}\) and 21 m s\(^{-1}\) respectively. The difference between the two threshold values was 15 m s\(^{-1}\). The average threshold values that were lower and higher than the criteria for high wind advisory were approximately 9.5 m s\(^{-1}\) and 17.6 m s\(^{-1}\), respectively. The differ-
ence between the two threshold values was 8.1 m s\(^{-1}\). Among the threshold values that were calculated on the basis of daily maximum instantaneous wind speed, the lowest and highest threshold values were 12 m s\(^{-1}\) and 29 m s\(^{-1}\). The difference between the two threshold values was 17 m s\(^{-1}\). The average threshold values that were lower and higher than the criteria for high wind advisory were approximately 12.5 m s\(^{-1}\) and 20.3 m s\(^{-1}\), respectively. The difference between the two threshold values was 7.8 m s\(^{-1}\). High thresholds mostly featured in coastal areas including islands and mountains. Areas with low thresholds were mostly inland areas. The difference between the threshold values of the two regions was found to be large. These results are similar to those of the study conducted by Kim et al. (2020). Areas with high thresholds have a high occurrence frequency of strong winds. For this reason, disaster prevention measures are considered to have been well established in these regions. Areas with low thresholds are those that do not feature a lot of strong wind. In these areas, damage is thought to occur only in aging buildings.

### 4. Summary and conclusions

In this study, the relationship between wind speed and damage was analyzed based on weather and damage data, and the damage-causing threshold was estimated using the CSI and CPD. The results are as follows:

1. Damage caused by strong winds occurred mainly in the past. In addition, considerable damage occurred at low-intensity wind speed compared to the criteria for high wind advisory.

2. The number of damage occurrences was greater at wind speeds that were lower than that of the criteria for high wind advisory, but the incidence of damage was more frequent at wind speeds that were higher than the criteria for high wind advisory.

3. As a result of comparing the estimated thresholds using the CSI and CPD, the CPD reflecting the weather phenomenon values overestimated the threshold.

4. The threshold estimated using the CSI was divided into coastal, mountainous, and island areas, where the thresholds were estimated to be higher than the current criteria for high wind advisory and inland areas where the thresholds were estimated to be low. A large difference was observed between the threshold values of the two regions.

Setting a threshold value for the disaster-causing wind speeds based solely on the results of this study is impractical. However, it possibly raises the need for regional criteria for special weather reports for strong winds. In addition, considering the number of damage occurrences and incidences of each wind speed, there is an increasing need to subdivide threshold values. The results of this study are likely to be used as a basis for policy decisions regarding the establishment of detailed criteria for each region in the future.

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