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Lightning Strokes Observed by the JLDN and Height of -10 °C Air Layer

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***Abstract*—We investigated the relationship between lightning strokes observed by the JLDN and the height of -10 °C air layer above the cities in the coastal areas of the Sea of Japan and the Pacific Ocean. The height of-10 ℃ air layer was estimated by the numerical weather forecast based on Meso Scale Model (MSM) delivered by the Japan Meteorological Agency (JMA). As results, the polarity ratio of positive lightning strokes was less than 10 % when the height of -10 °C air layer was higher than 6000m. The ratio of that was constant at approximately 40 % in the coastal areas of the Sea of Japan in winter when the height of that was less than 4000m.**

Keywords—Porlarity; Height of -10 degree cetigrade air layer; Winter lightning; JLDN;

I. Introduction

Winter lightning has caused serious damage to the wind turbines [1], power facilities [2][3][4] and electronic devices in homes [5] in the coastal areas of the Sea of Japan. Approximately 66% of the number of failures at wind turbines caused by lightning occurred during winter [6]. The characteristics of winter lightning are that the ratio of positive lightning is quite higher than that in summer and lightning discharges were initiated and develop from high structures [7]. Therefore, it is very important for lightning protection design to clarify characteristics of winter lightning occurring in the coastal areas of the Sea of Japan. Most of the lightning discharges hitting the wind turbine and the tower for lightning protection was upward during winter [8]. Therefore, we assumed that there was a relationship between the height of electric charge associated with lightning discharges and the occurrence of positive lightning. It is said that electrical charge associated with lightning discharges is at height of air layer where the temperature of the atmosphere is -10 °C. According to [5], the damage caused by winter lightning occurred when the height of -10 °C was in the range between 1000 m and 4000 m. We investigated that the relations between them using the lightning data observed by the Japanese Lightning Detection Network (JLDN) and the height of the air layer estimated with Meso Scale Model (MSM) provided by the Japan Meteorology Agency (JMA) [9].

II. Data Source of Lightning Occurrence and Height Of -10 °C Air Layer

A. Japanese Lightning Detection Network to Analayze Lightning Occurrence

We analyzed lightning occurrence with the datasets derived from the JLDN. The JLDN is the largest lightning detection network in Japan. The JLDN has been owned and operated by the FJC (Franklin Japan Corporation) since 1998. FJC had operated a small lightning detection network with six sensors in the central area called "Kanto-Koshinnetsu" region of Japan before the JLDN was built. The FJC expanded lightning observation network in central and western areas of Japan in 1998. We added sensors to the network in the northern area of Japan in 1999 and in southwestern islands called "Ryukyu" in 2002. The sensor network to observe lightning discharges occurring in the whole area of Japan was named "JLDN (Japanese Lightning Detection Network)". As of the end of November 2018, the JLDN consists of thirty-one sensors. Fig.1 shows sensor allocation of the JLDN. The location accuracy of the JLDN has been improved year by year. It was reported that

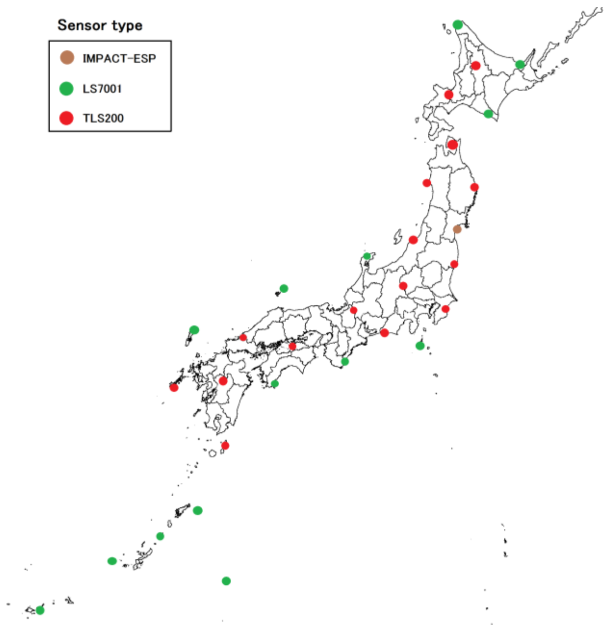


Fig.1 Sensor allocation of the JLDN as of the end of November 2018

average location accuracy for negative downward lightning strokes in summer was approximately 440 m [10] and that for lightning discharges initiated and developed from wind turbines in the coastal areas of the Sea of Japan was approximately 580 m in winter [11]. The Propagation Delay Correction (PDC) was applied to the JLDN in December 2015. As results of recalculation with the PDC, the average location error of [10] was improved from approximately 440 m to approximately 310m and that of lightning return strokes hit the wind turbine at Nikaho windfarm in the coastal area of the Sea of Japan was improved from approximately 790 m to approximately 120 m [12]. Above evaluations of location accuracy were recalculated raw data observed at the sensors in the past. The minimum peak current of lightning strokes hitting the wind turbine, detected by JLDN was -3.3 kA [13]. Matsui and Michishita [14] investigated the median location accuracy of the JLDN at the wind turbines in Nikaho and that was approximately 260 m in real-time calculation.

B. Meso Scale Model to Obtain Height of -10 ℃ Air Layer

In this paper, we used pressure surface data of Meso-Scale Model (MSM), which is distributed by the JMA to obtain heights of -10 ° C air layer. The datasets of MSM is distributed from the JMA every three hours. The forecasted contents are altitude, wind direction and speed, air temperature, updraft speed, relative humidity at each barometric pressure surface (1000, 975, 950, 925, 900, 850, 800, 700, 600, 500, 400, 300, 250, 200, 150, 100 [hPa]) with a grid spacing of 0.1 degree × 0.125 degree in Japan and its surrounding areas. Those datasets are forecasted every three hours, up to 15 hours ahead. MSM has been improved by the JMA. In comparison with the actual measurement by radiosonde, the average error of the temperature of each pressure surface at the altitude of 200 hPa or less predicted after 3 hours from the initial time in winter is within about 0.5 ° C (mean square error: maximum 0.7 ° C), within 3m of average error of height (mean square error: maximum 12m), the accuracy tends to decrease as time passes from the initial time [17]. In this paper, since the purpose is to estimate the past -10 ° C altitude, among the numerical forecasts of MSM, only the pressure surface prediction of the initial time was used to estimate the -10 ° C altitude of that time.

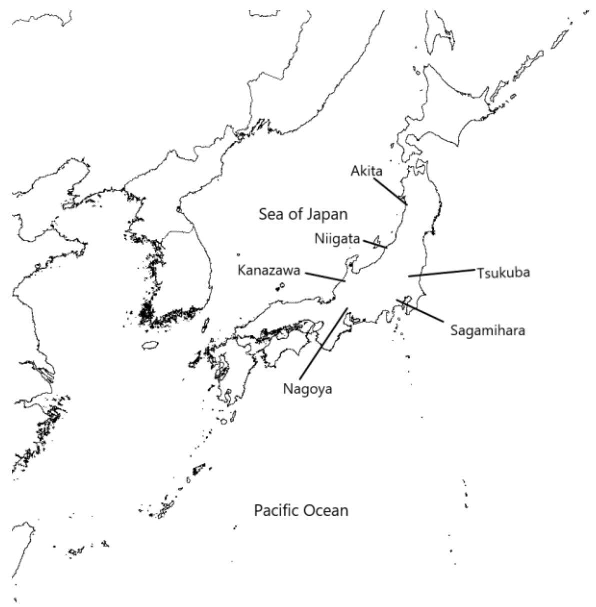


Fig.2 Cities investigated for this study

III. Dataset Observed by the JLDN

We investigated the lightning strokes observed in 2018 by the JLDN within a radius of 50 km from the six cities (Akita, Niigata, Kanazawa, Tsukuba, Sagamihara, and Nagoya) shown in Fig.2. Akita, Niigata, and Kanazawa are located in the coastal areas of the Sea of Japan. On the other hands, Tsukuba, Sagamihara and Nagoya are in those of the Pacific Ocean. We eliminated the lightning strokes shown in the following.

- The lightning strokes classified as cloud discharges by the JLDN because the JLDN might double count those ones associated with preliminary breakdown in summer [15].
- The positive lightning strokes whose peak currents were less than 10 kA because the JLDN recognizes a cloud discharge as a cloud-to-ground stroke [16].
- The lightning strokes whose interval time with previous one was less than 300 microseconds because the JLDN count a lightning stroke as multiple ones.

We defined lightning strokes occurred between April and October as "summer lightning" and those occurred between November and March as "winter lightning" in this study.

IV. Characteristics of Lightning Strokes Observed by the JLDN in the Coastal area of the Sea of Japan and the Pacific Ocean

Fig.3 shows a monthly variation of the number of positive and negative lightning strokes observed by the JLDN in the cities in the coastal areas of the Sea of Japan and in those in the Pacific Ocean. The number of lightning strokes in the coastal

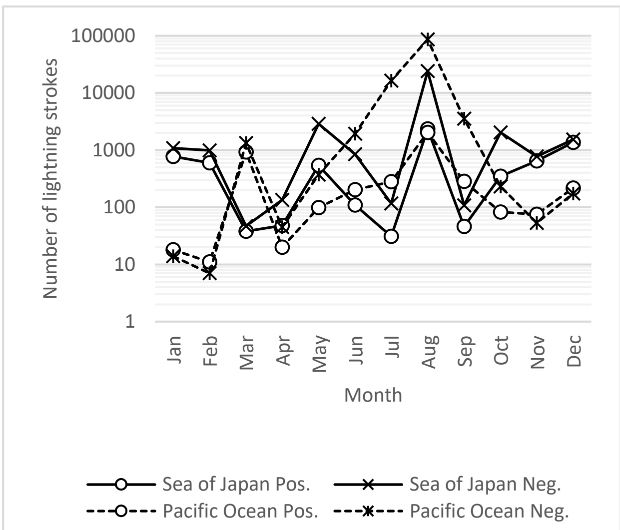
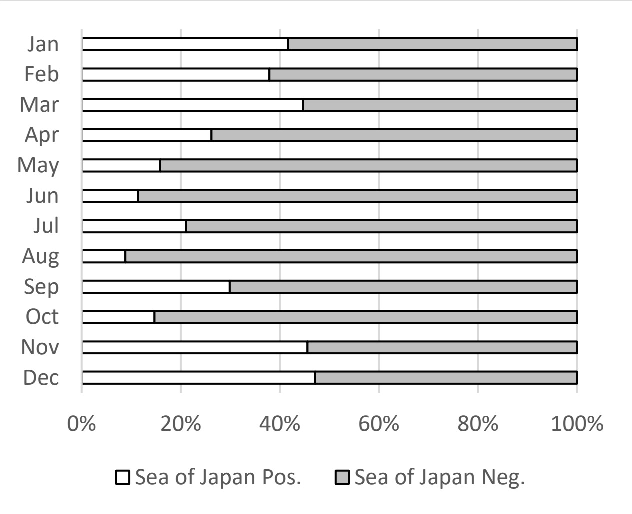
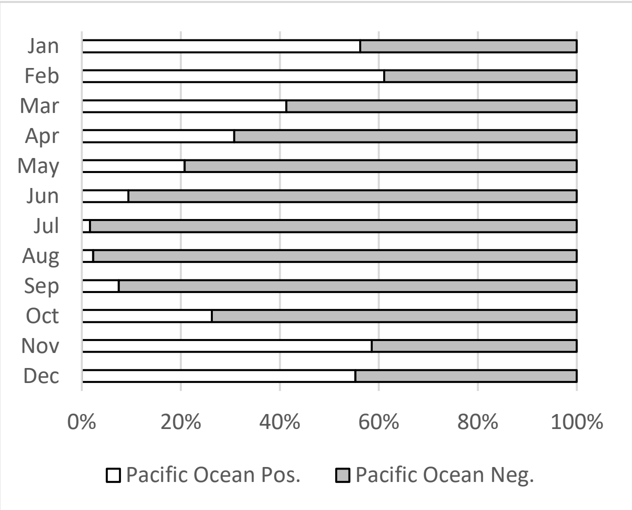


Fig. 3 Monthly variation of number of lightning strokes observed by the JLDN in the cites in the coastal areas of the Sea of Japan and those in the Pacific Ocean.



(a) Sea of Japan



(b) Pacific Ocean

Fig. 4 Monthly variation of the ratio of lightning polarity observed by the JLDN in the cities in the Sea of Japan and the Pacific Ocean

areas of the Sea of Japan is the total number of lightning strokes observed in Akita, Niigata and Kanazawa, and that in the Pacific Ocean is the total one in Tsukuba, Sagamihara, and Nagoya. This figure indicated the number of lightning strokes in August was the largest in the cities in both coastal areas. The number of negative lightning was overwhelmingly larger than that of positive one in summer. The numbers of both polarities lightning strokes in the cities of the Sea of Japan were larger than that in the Pacific Ocean. According to [6], the lightning ground flash density in the coastal areas of the Sea of Japan in winter was higher than that in those of the Pacific Ocean. Fig.4 shows the monthly variation of the ratio of lightning polarity in cities of both coasts. In those cities, the ratio of positive lightning stroke in summer was lower than that in winter. According to [7], the ratio of positive lightning occurring in the coastal areas of the Sea of Japan in winter was higher than that in summer. However, nobody has discussed winter lightning in other areas. even though the number of lightning strokes was small, Fig.4 (b) shows the ratio of positive lightning in the coastal cities in the Pacific Ocean was as high as those in the Sea of Japan in winter. Therefore, we assumed the ratio of positive lightning did not depend on the region, but on the season.

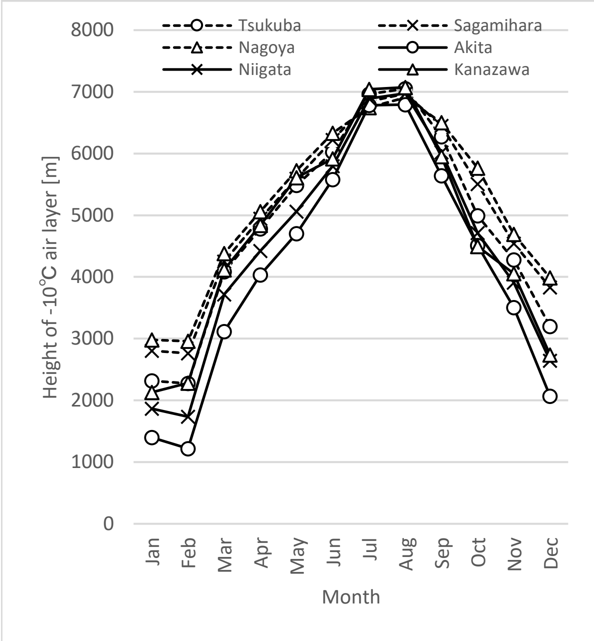
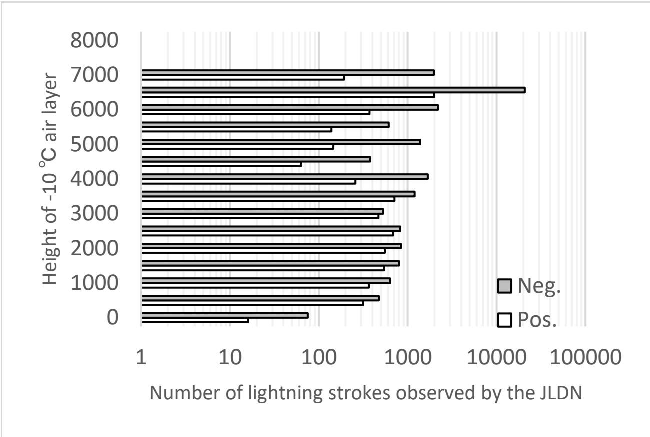


Fig.5 Monthly variation of height of -10 ℃ air layer estimated with MSM for the six cities shown in Fig.2

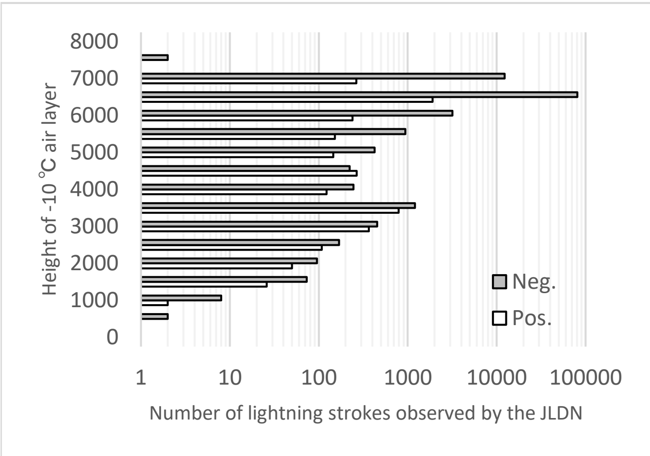
V. LIGHTNING STROKES AND HEIGHT OF -10 ℃AIR LAYER

A. Monthly Variation of Height of -10 ℃ Air Layer

Fig.5 shows the monthly variation of the average height of -10 ℃ air layer in the six cities shown in Fig.2. We estimated the height of -10 ℃with the MSM provided by the JMA. Fig.5 indicates there were no significant differences in the heights of -10 ℃ above the six cities in summer. However, the difference between those heights in the six cities was larger in winter. Fig.4 and Fig.5 indicate that the ratio of positive lightning strokes tended to be less than 10% when the height of -10 ℃ air layer was higher than 5500 m. Akita (N.39.72, E.140.10) is located the most north of those cities. Therefore, the height of -10 ℃ in Akita is the lowest. We compared the height of that in Kanazawa (N.36.59, E.136.63) with that in Akita. The both Akita and Kanazawa are located in the coastal areas of the Sea of Japan, famous for winter lightning area. The difference in the height of -10℃ air layer between those cities was between approximately 700 m to 1000 m in winter. A report [18] said the height of -10 ℃ air layer was higher and median electric charge of lightning in Hokuriku region (included Kanazawa) was larger than those in Tohoku region (included Akita) during a typical winter pressure pattern (High pressure is on the west side of Japan and Low one on the east side). Therefore, the height of -10 ℃ air layer is one of the factors affect the characteristics of lightning occurring in the area.

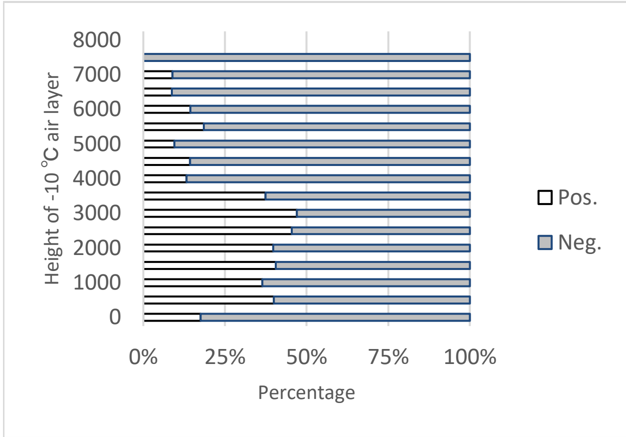


(a) Sea of Japan

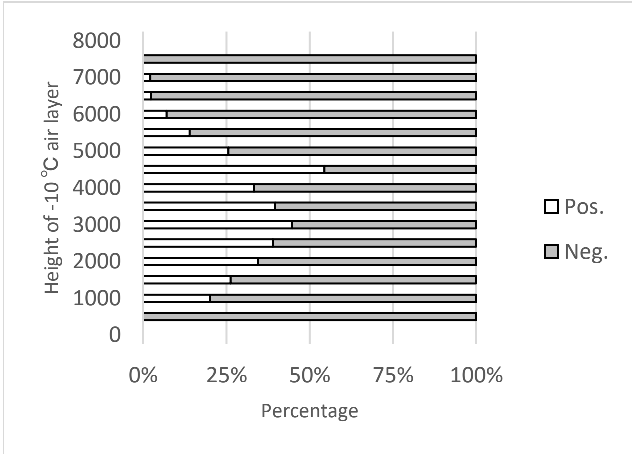


(b) Pacific Ocean

Fig. 6 Relationship between number of lightning strokes and height of -10 ℃ air layer above cities in the coastal areas of the Sea of Japan and the Pacific Ocean



(a) Sea of Japan



(b) Pacific Ocean

Fig.7 -10 ℃ air layer height variation of the ratio of lightning polarity observed by the JLDN in the cities in the Sea of Japan and the Pacific Ocean

B. The Number of Lightning Strokes and Height of -10 ℃ Air Layer

Fig 6 shows relations between the number of lightning strokes observed by the JLDN and the height of -10 ℃ air layer in the coastal area of the Sea of Japan and the Pacific Ocean. The numbers of both negative lightning strokes and positive ones were the largest when the height of -10 ℃ air layer was between 6500 m and 7000 m in the areas of both coastal areas. The number of lightning strokes on the Pacific Ocean side was more than three times larger than that in the Sea of Japan in the height between 6500 m and 7000 m because the Pacific Ocean side included Tsukuba with particularly high number of lightning strokes in summer. Fig.6 shows lightning stroke rarely occurred when the height of -10℃ was less than 1500 m in the Pacific Ocean side. Comparing both coastal sides, the number of lightning strokes in the Sea of Japan side was larger than that in the Pacific Ocean side when the height of -10 ℃ air layer was less than 4000 m because winter lightning occurred only in the Sea of Japan side. Authors [5] have already investigated the relationship between the damage by winter lightning and the height of -10 height air layer during winter lightning season in the coastal area of the Sea of Japan and reported the damage due to winter lightning has occurred when the height of that varied between 1000 m to 4000 m [5]. The result of this study was similar to that of our previous study.

C. The Ratio of Positive Lightning Strokes and Height of -10 ℃ Air Layer

Fig.7 shows the relation between the height of -10℃ air layer and the ratio of lightning polarity observed by the JLDN in the cities in the Sea of Japan and the Pacific Ocean. Fig.7 indicates the ratio of positive lightning strokes was less than 10% when the height of that was more than 6000 m in the cities in the coastal area of the Sea of Japan and in those in the Pacific Ocean, respectively. Shindo et. al. [19] reported that most of the lightning strokes hitting Tokyo SkyTree located in the Pacific Ocean side was downward ones when the height of -10 ℃ air layer was more than 6000 m. We assume that the ratio of negative lightning strokes became higher in summer. Fig. 7 (a) shows the ratio of positive lightning strokes was constant at approximately 40 % in the cities in the Sea of Japan side when the height of that was between 500 m and 4000 m in winter lightning season. On the other hand, Fig. 7 (b) shows the ratio of positive lightning strokes varied between 20% and 55%

when the height of -10°C air layer was between 1000m and 5500 m in those in the Pacific Ocean side.

VI. Summary

We investigated the relationship between lightning strokes observed by the JLDN and -10°C air layer. Authors found out the followings.

(1) According to previous studies, the electric charges of lightning strokes in Kanazawa where is located in lower latitude than Akita tended to be larger than in Akita because there were differences in the height of -10 °C air layer in those cities. Therefore, the height of that affects the characteristics of lightning strokes. The ratio of positive lightning strokes was lower in summer than in winter in the coastal areas of the Sea of Japan and in those of the Pacific Ocean. In the coastal areas of the Sea of Japan (winter lightning area), the height of -10 °C air layer in Akita was lower than that in Kanazawa.

(2) The number of lightning strokes was the largest when the monthly average height of -10 °C air layer was at the range between 6500 m and 7000 m the cities along the coast of the Sea of Japan and in those of the Pacific Ocean. The number of those in the coastal areas of the Sea of Japan was larger than in those of the Pacific Ocean when the -10 ℃ air layer was less than 4000 m in winter because winter lightning rarely occurred in those of the Pacific Ocean.

(3) The ratio of positive lightning strokes was less than 10 % when the height of -10 ℃ air layer was higher than 6000 m in coastal areas of the Sea of Japan and those of the Pacific Ocean. The ratio of that was constant approximately 40% in the coastal areas of the Sea of Japan when the height of that was less than 4000 m.

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