A Prevention Method of Lightning Strikes to Aircrafts

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ABSTRACT: It is well known that lightning discharges from winter thunderclouds to aircraft and ground have frequently occurred around Komatsu Airport, Japan Sea coastal area. In winter over the Hokuriku coastal area including Komatsu Airport, an interesting statistical correlation is found between the lightning activity associated with the life cycle of radar echoes in winter convective cloud systems and altitude of the -10 degree of centigrade level over Komatsu Airport. Particularly, in midwinter (January and February, mainly) even if no natural lightning discharges occur, aircrafts invading thunderclouds or convective clouds can trigger lightning strikes to them. In winter time, especially in midwinter, it can be inferred that lightning strikes may occur when aircrafts invade the lower layer near -10 degree of centigrade level with a more intense electric field in the mature stage of thundercloud. But from our recent observational result, we cannot distinguish with the lightning strike to aircraft case and the safety take-off case. And most recent prevention method of lightning strikes to aircrafts will be presented in this paper.

INTRODUCTION

For about a century, studies concerning summer thunderstorms in the middle latitude zone have accumulated data both on their meteorological and electrical features. By contrast, winter thunderstorms have been studied only for the last few decades. In this paper, it will be presented that the nature of winter thunderstorms and recent several observational results and the latest prevention method of lightning strikes to aircrafts.

Study of winter thunderstorms in particular began with Takeuti and Nakano [1977], who reported that ground flashes which lowered positive charge to the earth accounted for nine out of every ten of the flashes they studied. Thereafter, international field studies were carried out by Japanese and U.S. scientists in Japan's Hokuriku coastal area. In these studies, Magono and his co-workers [1983; 1984] measured electric field and particle charges in clouds by means of balloon sounding. They found that the electrical structure of winter thunderclouds was about the same as that of summer thunderclouds, and that so-called positive pocket charges were sometimes located near cloud bases. The joint team of Brook, Krehbiel et al. [1982] and Takeuti, Nakano [1978] made simultaneous measurements of lightning electric field changes at seven stations scattered over the Hokuriku coastal area. They determined the amount and the positions of electric charges consumed by individual strokes of ground flashes and clarified the characteristic features of winter lightning discharges as well as the electrical structure of winter thunderclouds. Since then, numerous scientists have continued research work along this line [Takeuti and Nakano 1983].

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Meanwhile, Takahashi [1978; 1984; 1987] studied the charge separation mechanism of thunderclouds based on his numerical simulation and laboratory experiments, and determined that charge is separated between graupels and ice crystals, the mechanism being essentially the same both in summer and winter.

Lightning damage to aircrafts and electric power lines along the Sea of Japan coast has become a rather serious problem and the improvement of avoidance and protection against winter lightning has come to the fore as a task for meteorological researchers and electrical engineers working on aviation weather and electric power systems. Lightning measurements employing various techniques have been conducted at a number of electric power establishments along the Sea of Japan coast since 1980. In this way, studies on winter thunderstorms have become one of the focuses of lightning research.

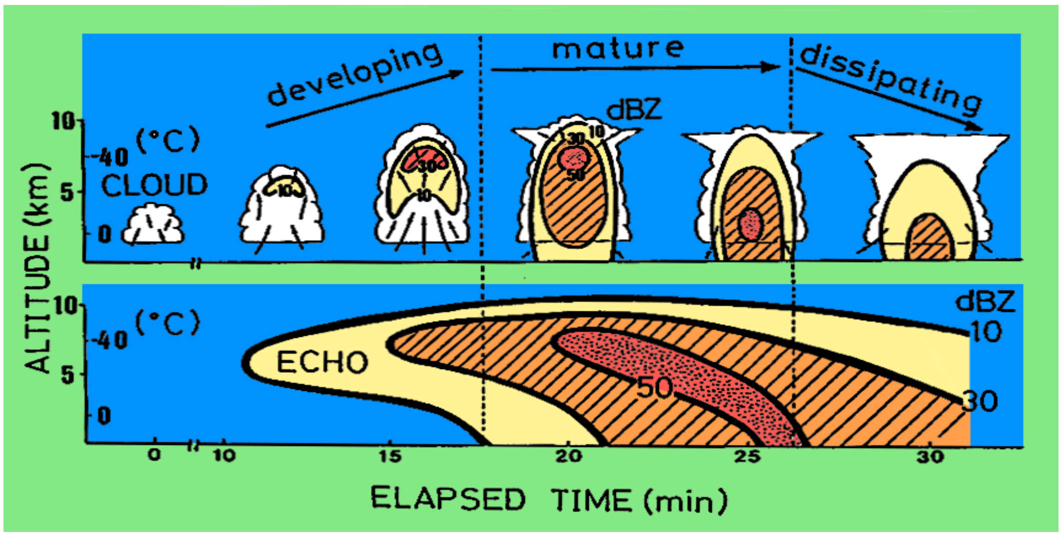


Figure 1 Schematic chart illustrating radar echoes stages associated with the life cycle of a thundercloud. In the lower part of this figure, the temporal variation of each radar echo reflectivity in convective clouds is illustrated in correspondence with the echo life stages. (Michimoto [1991; 1993a])

CHARACTERISTICS OF WINTER THUNDERSTORMS

The characteristic features of electrical activity of winter thunderclouds have been extensively investigated. The main results may be summarized as follows:

(1) The duration of the lightning activity of an individual storm is short (usually less than 30 minutes) and the frequency of lightning flashes is very low (Fig. 1). Thunderstorms of a low electrical activity, exhibiting only a few flashes throughout their existence, are the most common. This type of thunderstorm is called a “single-flash storm” (“Ippatsu-rai”) in Japanese [Michimoto 1993a].

(2) About 33 percent of all flashes are ground flashes which lower cloud positive charge. This percentage is remarkably high compared with that of a few percent for summer thunderclouds [Takeuti and Nakano 1983].

(3) Ground flashes of more than 100 C (coulomb) are occasionally observed [Brook et al. 1982]. Turman [1977] recognized flashes of the same nature based on his analyses of the lightning records obtained by DMS (Defense and Meteorology Satellite).

(4) The number of strokes in one flash is usually one or just a few. Almost all flashes involve continuing current [Brook et al. 1982; Takeuti and Nakano 1983].

Concerning the meteorological aspects of winter thunderclouds, Kitagawa [1989] analyzed both surface and aerological data for thunderstorms along the whole Sea of Japan coast. Goto and Narita [1991] also surveyed the meteorological conditions at Maki in Niigata Prefecture. The main results they obtained are summarized as follows:

(5) Winter thunderclouds in this area are formed by the advection of Siberian air masses, which are dry polar air masses, over the relatively warm Sea of Japan. About 60 percent are formed purely by advection. Thunderstorms formed by the combination of advection and frontal activity and those formed by the combination of advection and cyclonic conversion, account for about 20 percent each.

(6) The thunderstorms occur when the 500 hPa air temperature over the coastline decreases at a rate of 10 degree of centigrade per day or more.

To advance the study of winter thunderstorms, it was necessary to investigate more closely the relationship between the meteorological structure of clouds and their electrical activity. For this purpose, Tomine et al. [1986] and Michimoto [1988; 1989] carried out three-dimensional radar observations of thunderstorms as well as the lightning detection using the sferics direction-finder system around Komatsu Airport (Fig. 2).

The results which they obtained are summarized as follows:

(7) The echo top of thunderclouds necessarily develops higher than -20 degree of centigrade temperature level in summer. In winter, however, active convective clouds with the same echo top height frequently generate no lightning activity.

(8) The clouds with lightning activity necessarily involve strong echo cells 40-to-50 dBZ, and the occurrence of lightning discharges is associated with the vertical motion of these strong echo cells both in summer and winter (Fig. 1).

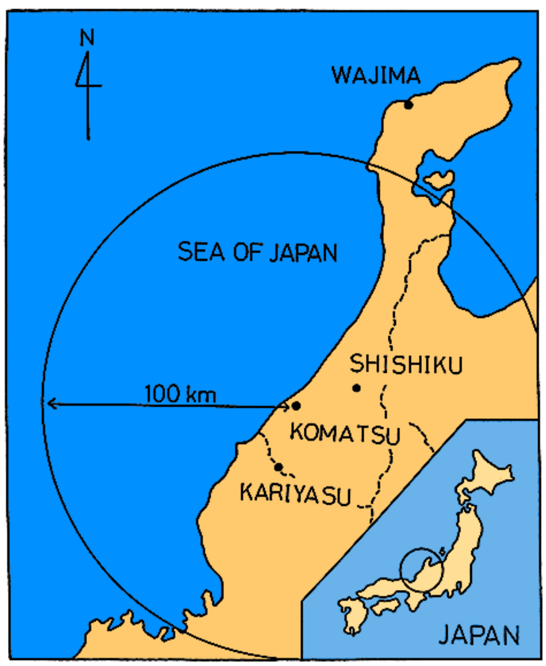


Figure 2 Observation sites in the Hokuriku district.

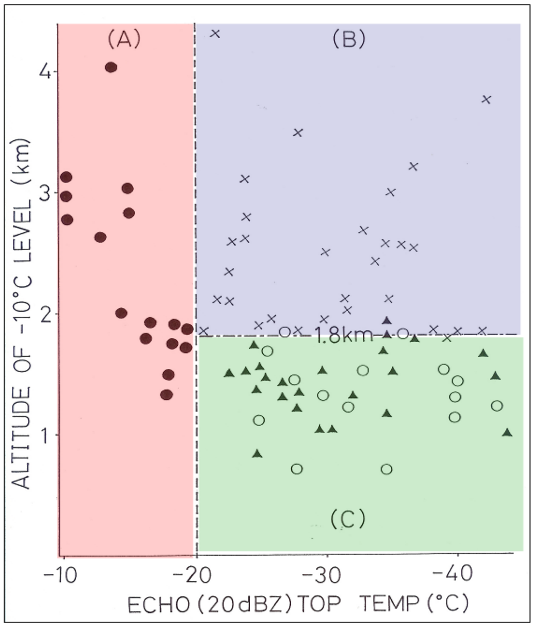


Figure 3 Lightning activity classified by the altitude of -10 degree of centigrade level in the vicinity of Komatsu Airport. (Black open circles : no L/A, crosses : strong L/A, black triangles : weak L/A, white open circles : no L/A, respectively) [Michimoto 1991; 1993b]

(9) When the altitude of -10 degree of centigrade temperature level is higher than 1.8 km, active convective clouds generate rather strong lightning activity. When it is lower than 1.8 km, active convective clouds exhibit either weak or no lightning activity, even if their echo top exceeds the -20 degree of centigrade temperature level (Fig. 3).

Building upon the aforementioned research, the author continued his field work using radars with CAPPI performance and the sferics direction-finder system around Komatsu Airport. Suzukawa et al. [1987] compared three-dimensional radar echoes with the temporal variation of surface electric field and investigated the electrical structure of winter thunderclouds in the Hokuriku district. They tried to observationally verify Takahashi's thundercloud model. However, they operated the radar at 30-minute intervals, and more detailed radar observations were needed to obtain conclusive results on this subject. As such, the present author carried out more field work, with the addition of simultaneous surface electric field recording at 27 sites mutually separated by about 10 km around Komatsu Airport (Fig. 4). Based on this field work, he clarified the electrical structure of winter active convective clouds in relation to the subsequent stages of their development.

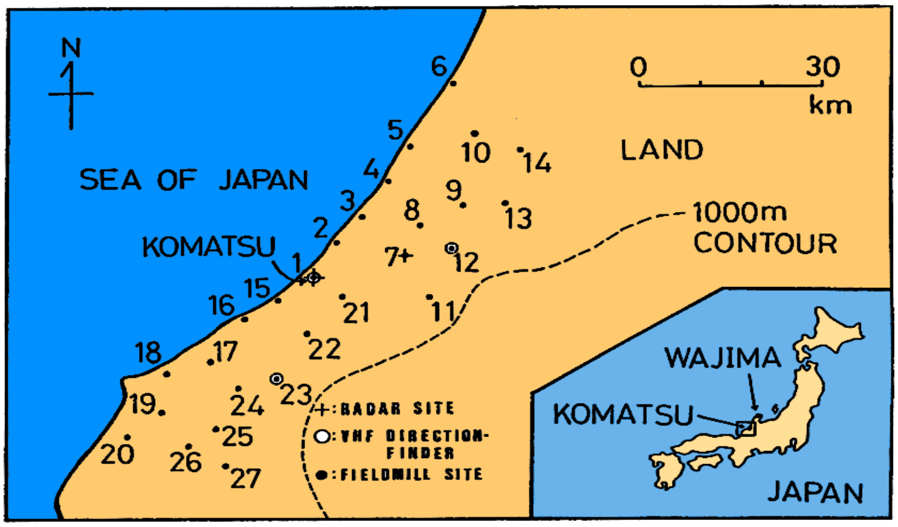


Figure 4 Location of the network of 27 field mills, weather radar, and direction-finder antenna.

The authors also investigated lightning strikes to aircraft around Komatsu Airport. They dealt with 255 cases, 236 of which occurred in winter season (November through March). They analyzed all of these cases with reference to the surrounding aerological conditions, the radar echoes of the clouds, and the meteorological and electrical conditions on the surface.

Table 1 Position if lightning strikes in relation to cloud

IN CLOUD	93
BELOW CLOUD	11
BETWEEN CLOUD	1
TOTAL	105

Tables 1 and 2 show the position of lightning strikes in relation to clouds and the precipitation types for the 105 cases occurring from November to March. These tables were prepared from the captain reports, which completely elucidated the relation with clouds and the precipitation types. Almost all cases were in cloud, and over 90 percent were in solid and/or liquid precipitation. [Michimoto 1993c]

Table 2 Precipitation types during lightning strikes

SNOW SHOWER	37
GRAUPEL	12
RAIN & SNOW	24
RAIN SHOWER	21
NONE	11
TOTAL	105

OBSERVATIONS

December 18, 2009: 0945JST(Japan Standard Time), safety taking-off was observed at the runway direction 240 degree, and 1236JST, B-777 was struck by thunderbolt just after take-off at the runway direction 240, same direction in the morning.

Figure 5 show the map of Komatsu Airport, runway, RVR measurement instruments, special observational field mill.

Figure 5 Map of Komatsu Airport, runway directions are NE, 060 degrees and SW, 240 degrees, respectively.

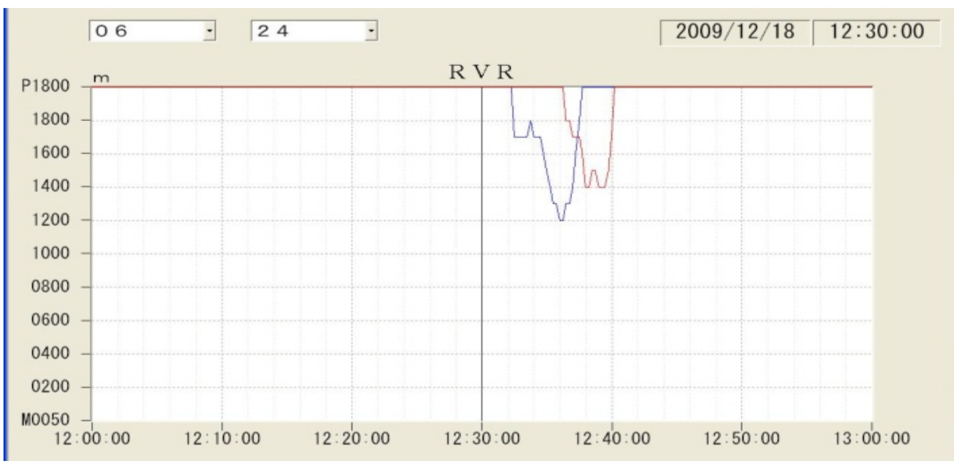
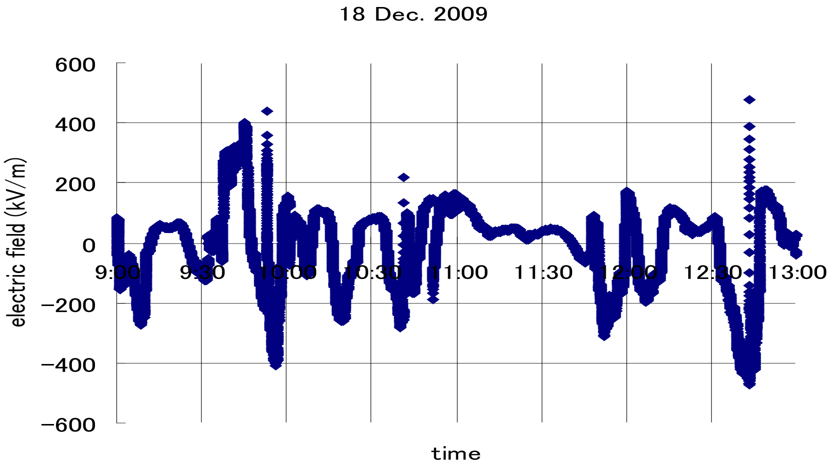


Fig 6 Runway visual ranges time variations, 060 direction (red line), and 240 direction (blue line), respectively.

Figure 6 presents two RVR observations 060 and 240 directions, respectively.

Figure 7 shows the time variation of special observational field mill (FM), one or two hundred meters below the strike point of aircraft. Safety take-off was 0945JST, and lightning strikes to aircraft (B-777) was 1236JST, respectively, strong electric field and change from negative to positive, and repeatedly negative patterns, each other cases.



(JST)

↑ (safety T/O)　　　　　　　　　↑ (L/S)

Figure 7 Electric field variation of special observational FM installed near runway.

Both cases are similar situation for meteorological observation data from Komatsu air weather service squadron. For example, there are temperature, visibility, and so on. Furthermore, electric field data are same for each case of take-off time (see Fig.7).

But runway visual range (RVR) data were different from each other, AM case was plus 2000 meter, and PM case was below 2000 meter.

DISCUSSIONS

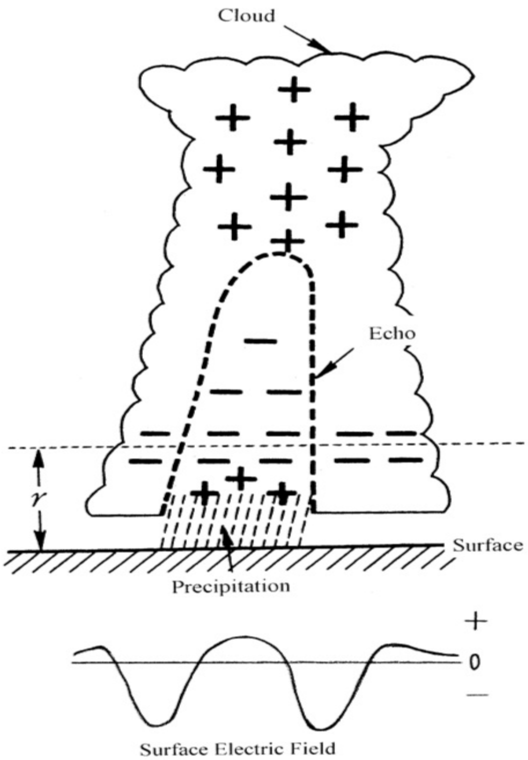


Fig 8 Schematic chart of thundercloud. (Michimoto [2012])

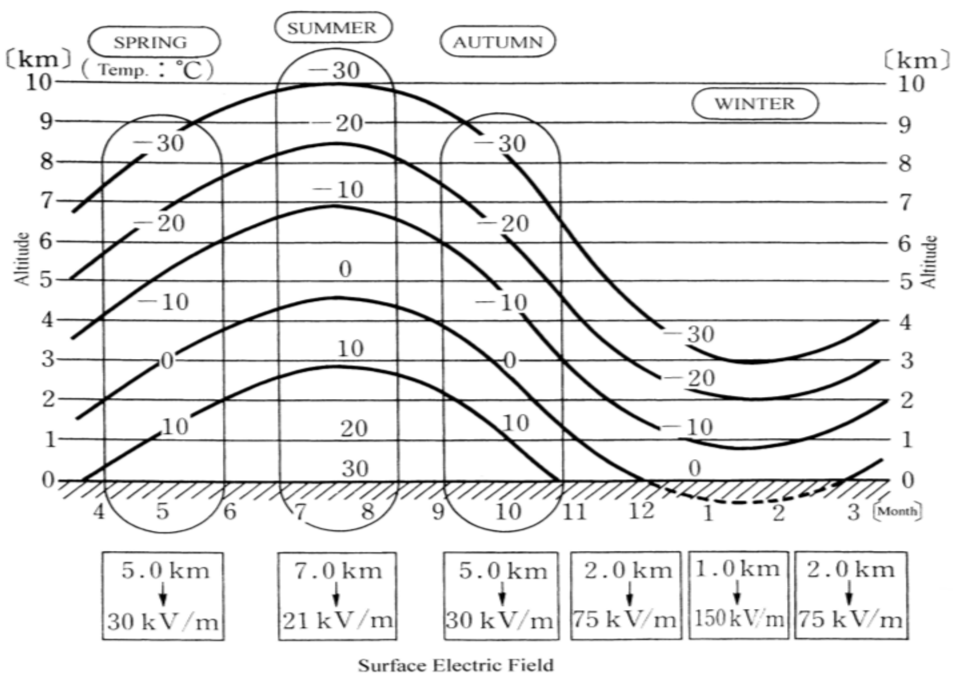


Fig 9 Seasonal variation of upper air temperature per 10 degree. [Michimoto 2012]
(Wajima, Japan Meteorological Agency sonde site in Fig. 2)

Figure 8 indicates a schematic chart illustrating surface electric field (lower part of this figure) associated with the radar echo pattern and electric charge distribution (upper part of this figure) at a mature stage of thundercloud (Michimoto [2012]).

Figure 9 indicates seasonal variation of upper air temperature near Komatsu Airport, and the lower part of this figure indicates surface electric field below thundercloud (Michimoto [2012]).

For example, the -10 degree of centigrade line is 7 km in summer season, but in winter season, especially in midwinter, that line is near 1 km. If minus charges are distributed in pan-cake shape at the lower part of thundercloud (see Fig. 8), the distance from ground surface to -10 degree of centigrade altitude (r), in winter, the value of surface electric field is assumed at 150 kV/m, in summer, that value of surface electric field is estimated about 21 kV/m (1/7 small against winter value 150 kV/m).

We must consider for the seasonal variation of upper air temperature, because -10 degree of centigrade level is very important altitude for charge separation and charge accumulation of plus and/or minus graupel particles falling down from upper cold level to lower warm level in a thundercloud (Takahashi [1984]).

In winter time, especially in midwinter, it can be inferred that lightning strikes may occur when aircrafts invade the lower layer near -10 degree of centigrade level with a more intense electric field in the mature stage of thundercloud.

But from our recent observational result, we cannot distinguish with the lightning strike to aircraft case and the safety take-off case. Certainly, from runway visual range data, we can distinguish with both cases difference, but that is only one case datum.

After this event, we corrected many same data for several years and researched them. We cannot distinguish with many lightning strike cases and the safety take-off cases yet, by using field mills data.

However, we can obtain several useful thresh hold values of surface electric field and radar echo intensity of convective clouds and thunderclouds. These thresh hold values are, for example, plus and minus 5, 10, 15 kV/m, each of surface electric field, and are, for example, minus 10, 15, 20 degree of centigrade of radar echo top temperatures.

Precisely prevention method of lightning strikes to aircrafts will be presented at the conference and opened in discussions.

CONCLUSIONS

Winter thunderstorms have been very much studied since the discovery of peculiarity of them. Consequently, many characteristics have been revealed. The nature of winter thunderstorms was summarized as follows. (Kitagawa and Michimoto [1994]; Michimoto [2007])

Meteorological aspects of winter thunderstorms are summarized as follows:

(1) About 60 percent of winter thunderstorms are formed by cold air mass advection. Others formed by the combination of advection and frontal activity and cyclonic conversion, account for about 20 percent each.

(2) The thunderstorms occur when the 500 hPa air temperature over the coastline decreases at a rate of 10 degree of centigrade per day or more.

(3) When the altitude of the -10 degree of centigrade temperature level is higher than 1.8 km, active convective clouds generate rather strong lightning activity. When it is lower than 1.8 km, active

convective clouds exhibit either weak or no lightning activity, even if their echo top exceeds the -20 degree of centigrade temperature level.

(4) Convective clouds with lightning activity necessarily involve strong echo cells of 40-to-50 dBZ, and the occurrence of lightning discharges is associated with the vertical motion of these strong echo cells both in summer and winter.

(5) Almost all lightning to aircraft occurred in cloud and over 90 percent of precipitation types in the cloud were solid and/or liquid.

Electrical aspects of winter thunderstorms are summarized as follows:

(1) In midwinter, lightning strikes to aircraft may be triggered by aircrafts invading the region of intense electric field.

(2) Strong negative and positive electric fields may be generated by precipitation particles associated with radar echoes in low altitude below thundercloud.

(3) At the present time, we cannot distinguish with the lightning strike to aircraft case and the safety take-off case by using field mill data and another meteorological observation data.

We will present new prevention method of lightning strikes to aircrafts in this conference. This new method is coordinate of field mills data, radar echoes life cycle data and cloud type (convective or stratus type) data and upper air temperature profiles data, and after then, we predict the dangerous regions of lightning strikes to aircrafts by using those several useful data.

Now, we are using our WS (Weather Service Co. Ltd.) numerical aviation hazard prediction model, named “WS Airlines”, which is predict hazards of turbulences, icings, and thunderstorms, and soon we have been preparing for the new prevention method of lightning strikes to aircrafts to our “Airlines”. We will prepare for new numerical prediction model, such as named “New WS Airlines” near future.

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