Results of RAIJIN, the intensive observation program to relax the triggered lightning launch commit criteria

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ABSTRACT: Lightning triggering to launch vehicle can cause system failures and total loss of the rocket and payload. The current Japanese criteria to delay launch is "Thick cloud rule", which is applied when 1.8km or more thick cloud with the temperature between -20 and 0 degree Celius is observed. Of all H2A launches during the past ten years, half have experienced delays due to weather. So, we initiated a research to change the thick cloud rule from outside parameter to inside parameter of the cloud, three years ago.
We herein present the overall results of the observation campaign (RAIJIN*) in Feb/2012, Jan-Feb/2013 and Jan/2014, using air-born field mill on airplane, X-band dual polarization radar, ground based field mill and Videosonde. Also, the new criteria could be proposed.
*) Raijin is the name of Thunder god of Japanese mythology and stands for Rocket launch Atmospheric electricity Investigation by Jaxa IN cooperation with academia

INTRODUCTION

Concerning triggered lightning by flying rockets, the threshold of electric field to create insulation breakdown is lower than that of natural lightning. However, the exact triggering threshold is difficult to determine. The Lightning Advisory Panel (LAP) of top American scientists in the field of atmospheric electricity [Willet et al., 2010] has set a threshold of 3kV/m as conservative triggering threshold. Unfortunately, the airborne electric field cannot be determined remotely. Therefore, it is important to link the electric field to some parameter that can be remotely determined, such as radar reflectivity.

JAXA has been using the prior NASA thick cloud rule [Merceret et al., 2010]. JAXA will not allow a vehicle to fly through a cloud which is

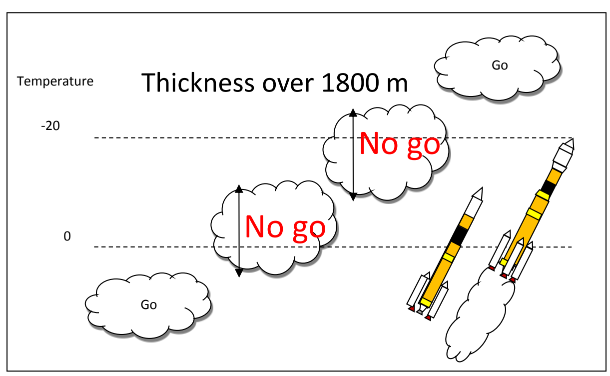

Fig 1 Schematic of thick cloud rule

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thicker than 1.8km and is between the -20 and 0° C levels. We call this rule the "Thick cloud rule" (Figure 1). This rule often causes launch delays which is costly in both time and money. However, during the rule violations, the triggering risk seems very low as there is often no enhanced fields detected at the ground and the radar reflectivity of the clouds are very low.

To conduct optimal operations, with enhanced safety and launch opportunities, three years research was planned. The goal of this research is to relax current thick cloud rule by setting an appropriate new threshold based not only on the thickness and temperature distribution of a cloud but on cloud electrification processes.

OBSERVATION CAMPAIGN : RAIJIN

To acquire the necessary data to understand the in-cloud condition around Tanegashima space center, intensive observation campaigns were conducted. As shown in Figure 2, RAIJIN is operated in accordance with the lightning process. At the initial cloud growth stage, X-band dual polarization radar identifies the cloud particle distribution. At the stage of generation of electric charge, Videosonde captures the particles' images and electric charge and estimates particle spatial density. At the stage of evolution of the electric field, airborne field mills and filed mills on the ground detect electric field intensity.

The observation campaign RAIJIN were conducted for the three periods in Feb/2012 (RAIJIN2012), Jan-Feb/2013 (RAIJIN2013) and Jan/2014 (RAIJIN2014). The observed hours and numbers are shown in Table 1.

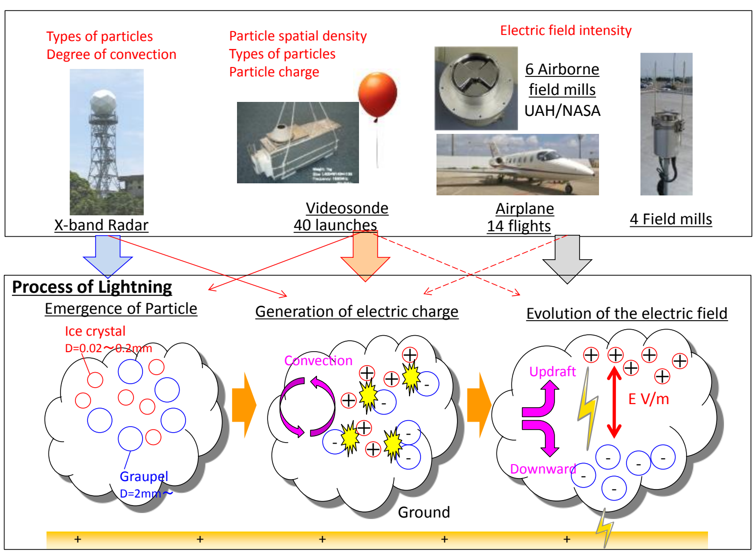

Figure 2 Intensive observation RAIJIN

Table 1 RAIJIN project summary

	Period	Flight hours	Video sonde
RAIJIN2012	10/Feb~28/Feb (19days)	17h	20
RAIJIN2013	15/Jan-21/Jan, 4/Feb~12/Feb (16days)	16h	20
RAIJIN2014	10/Jan-26/Jan (17days)	16h	13

DATA ANALYSIS

We intended to find a radar parameter that we could use to determine a less than 1 in 10,000 chance of producing a lightning strike during a launch[Willet et al., 2010]. We consider the probability of lightning strike is negligible for in situ electric fields aloft below 3 kV/m[1]. There is at least a factor of which is 2 built into that threshold, but we lack data to formally reduce that margin. Therefore, we are trying to estimate the probability of a >= 3kV/m field from RAIJIN data for a given radar-based launch commit criterion.

We are faced with several challenges. Our RAIJIN sample sizes will not allow direct calculation of the probability of >= 3kV/m fields because we have chose launch criteria that make such fields extremely rare (1 in 10,000 far exceeds the effective RAIJIN sample size). Therefore, we must perform some kind of extrapolation. The RAIJIN data are serially correlated because they are taken along an aircraft flight trajectory through a cloud, and adjacent time points in the series are not enough apart spatially for the RAIJIN data to be considered as independent cases. Serial correlation further reduces our sample size and sometimes distorts the apparent shape of the statistical distributions we are working on. Finally, the radar data are imperfect, e.g., due to scan gaps. Also, because of the attenuation, X-band radar has only 15dBZ sensitivity within 60km, display range (Figure 3). So, we also used JMA (Japan Meteorological Agency) C-band radar to use the aircraft data efficiently.

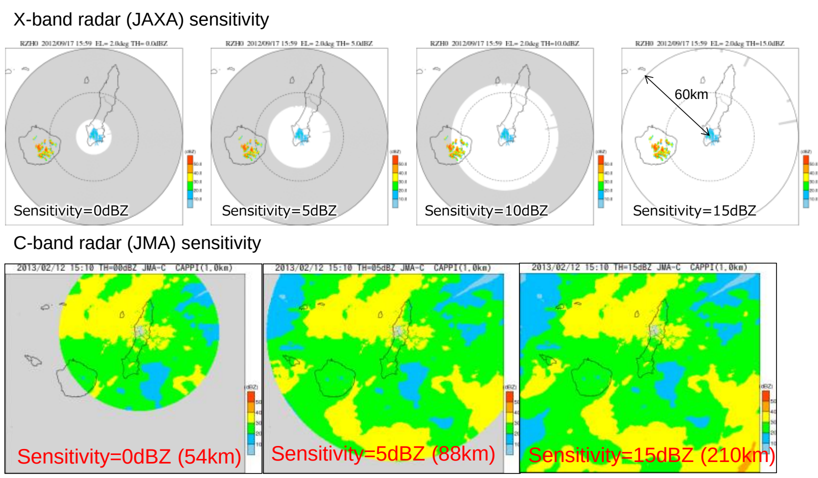

Figure 3 Radar reflectivity sensitivity

Next, we use a variety of scatter plots to examine the data for some radar parameter (Figure 4).

a) VAHIRR : Based on modern U.S rule [Merceret et al., 2010]. But it has a operational difficulty not to measure the real thickness of cloud, using radar system for the scan gap.
b) MAX reflectivity (h>0℃) : Alternative of a) in U.S rule, for the good launch availability and risk
c) MAX reflectivity (all altitude) : Include below 0℃ altitude
d) AVE reflectivity (h>0℃) : Average of some volume above 0℃

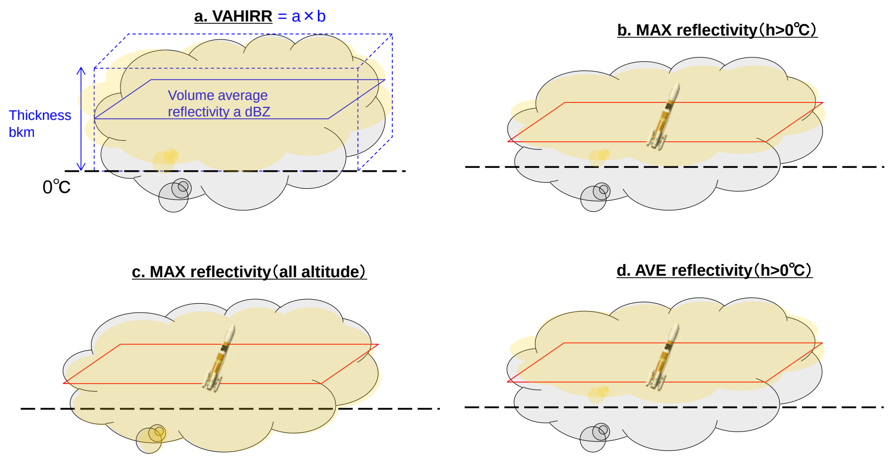

Figure 4 Radar parameter candidates

Figure 5 shows the examples of scatter plots for the each criteria. Examining such scatter plots, we determine that no 3 kV/m fields are observed for all radar parameter less than some dBZ. That defines the region we will explore for a launch commit rule based on this four parameter.

a. VAHIRR

b. MAX reflectivity（h>0℃）

c. MAX reflectivity（all altitude）

d. AVE reflectivity（h>0℃）

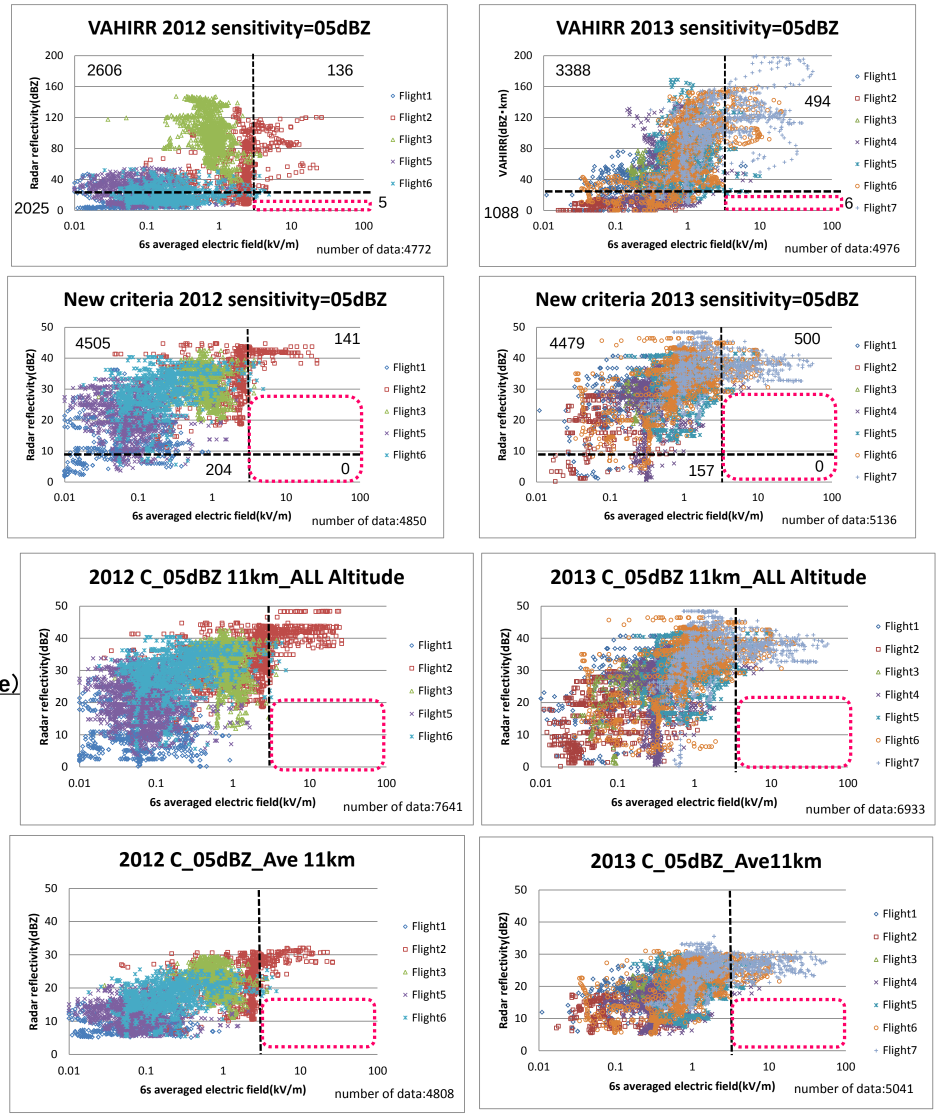

Figure 5 Scatter plots : electric field at the aircraft versus each radar parameter a~d

Next, we compare the coverage of radar reflectivity. The electric field is influenced by some electric charge with some distance from airplane and we have to set the appropriate region which has good correlation with the electric field. With the candidate “b. MAX reflectivity（h>0℃）”, parameter study for 3, 5, 7, 11, 21km was performed (Figure 6).

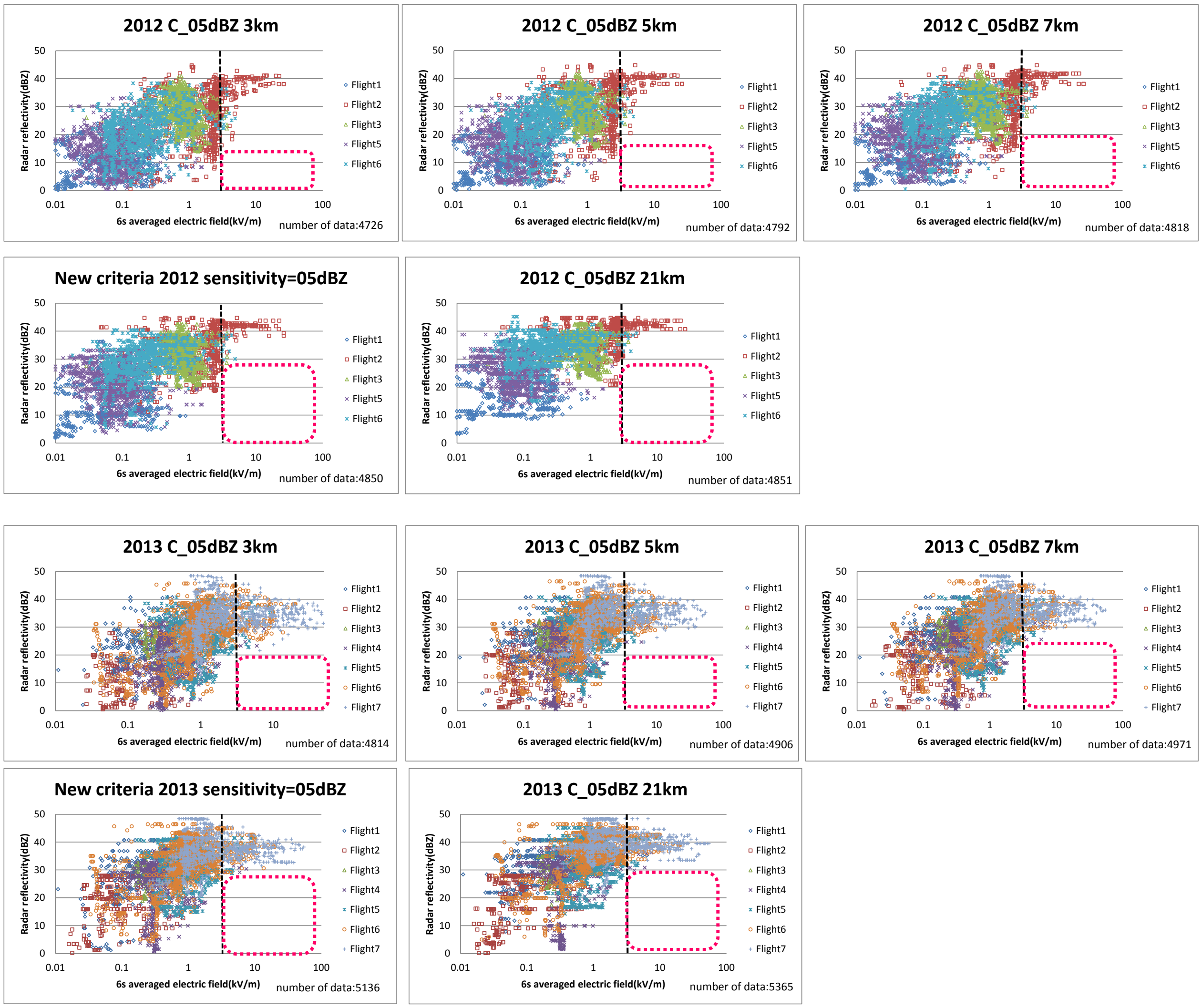

Figure 6 Scatter plots : parameter study to decide the radar coverage region of “b.”

Once the scatter plots suggest that a given parameter is promising, we make a preliminary selection of a rule threshold for the radar parameter. In this case, we select two dBZ for a,b,d as candidate rules. We set the data for this bin and several more permissive bins to examine how the probability of large electric fields depends on the radar parameter. Within each bin, we fit the electric field magnitude to a 2-parameter Weibull distribution.

NEW CRITERIA

We explore the trade-off between launch availability (data number) and risk. Also, the operability at launch campaign is one of the important factors.

With these considerations, we propose to set 20dBZ at “b. MAX reflectivity (base>0℃) in 11km square” as new criteria to replace the existing thick cloud rule. But we still have some discussions about the space of radar parameter and the base with Task Force Advisory Panel for Lightning Research of JAXA (JLAP). We will continue to update the data of RAIJIN2014 and review them with JLAP. Also operation systems with C-band and X-band radar need to be prepared

SUMMARY

With the in-cloud observation (RAIJIN) data, “Thick cloud rule”, which is applied when 1.8km or more thick cloud with the temperature between -20 and 0 degree Celsius is observed, could be changed to radar based new criteria. That would increase the launch opportunity. We will decide the criteria in this year

But there are some concerns. The applicable season, reliability of the criteria and other criteria of lightning must be studied soon.

ACKNOWLEDGMENTS

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