Lightning Distribution in Tropical Cyclones observed by the TRMM/LIS

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***Abstract*— Typhoon is one of the severe weather phenomena which consists almost entirely of thunderstorms. However, the lightning activity in typhoon is a remarkable low compared to that in typical thunderstorms. It is important to know the feature of lightning flashes in typhoons to solve this problem.**

In this paper, we analyze the lightning data by the Lightning Imaging Sensor (LIS) on board Tropical Rainfall Measuring Mission(TRMM) satellite in terms of the storm-relative and radial distribution, the seasonal variation, and the dependency on typhoon's life stages (, namely the developing, the mature, and the dissipating stages). The lightning flashes in 218 typhoons from January 1998 to December 2007 were examined.

Remarkable features of lightning flashes in typhoon are the following: (a) High flash rate regions in typhoons are most commonly found in the left side to the direction of storm motion. (b) A radial distribution of lightning flashes in the peak season (July-September) has two peaks. One appears in the outer rainband region and the other is in the eyewall region. (c) Most vigorous lightning activity occurred in the dissipating stage.

These results suggested that the distribution of lightning flashes in peak season shows the typical pattern of lightning in typhoons.

Key words: typhoon, lightning, LIS, TRMM

I. INTRODUCTION

The studies about lightning discharge in tropical cyclones, namely hurricanes, typhoons, and cyclones are still not enough. Just some ancestors focused on lightning flashes in hurricanes (e.g., [1]-[5]).

A radial variation was observed in flash rate in Hurricane Andrew (1992), with a weak maximum in the eyewall region, and a steady increase to a larger maximum in the outer rainband region of 190km away from the storm center [1]. Hurricane Jerry (1989) was accompanied by more lightning activity than Hurricane Hugo (1989). During 18-h observing period, more than half of the 33 cloud-to-ground (CG) lightning flashes in Hurricane Hugo occurred in or near the eyewall region, and 691 CG lightning flashes in Hurricane Jerry occurred exclusively in the outer rainband region. One of the reasons for the large difference in the number of lightning flashes between the two hurricanes is the presence of many convective rainbands in Jerry [2]. Several case studies confirm that lightning flashes are rather common within the outer rainband region. CG lightning flashes within the eyewall region of mature tropical cyclones are generally low [3]. Using data from National Lightning Detection Network (NLDN), [4] examined CG lightning flash locations of nine Atlantic basin hurricanes. A common radial distribution in CG lightning flash rate was a weak maximum in the eyewall region, a clear minimum 80-100km outside of the eyewall region, and a strong maximum in the vicinity of the outer rainband region (210-290 km radius). The outer rainband region contains the vast majority of CG lightning flashes in hurricanes [4]. The outer rainband region produces more lightning flashes than the other regions of the hurricane or nonhurricane tropical oceanic systems [5].

On these previous studies of lightning in hurricanes, a radial distribution of lightning flashes was mainly clarified, but no work has focused on the comparison with the meteorological element, such as the central pressure. And also, the seasonal variation in the distribution of lightning flashes was not clarified. Furthermore, a considerable amount of uncertainty still exists as to the mechanism of lightning flashes in typhoons. In this paper, we investigate the storm-relative and radial distribution of lightning flashes, the seasonal variation of lightning flashes, and the lightning activity per typhoon's life stage.

II. DATA AND METHOD

A. Data

In this study, we used data sets of the LIS, tropical cyclone database, and the best track data provided by the Global Hydrology and Climate Center (GHCC), the Japan Aerospace Exploration Agency (JAXA) / Earth Observation Research Center (EORC), and the Regional Specialized Meteorological Center (RSMC),respectively. The LIS is carried on the TRMM satellite. To investigate the global scale rainfall including tropical ocean region, the TRMM satellite launched into a 35 degree inclination orbit on November 28, 1997. The LIS observes lightning flashes (CG lightning flashes and intracloud (CC) lightning flashes) by recording optical pulses in the near-infrared region (777.4nm). The LIS has an approximately 600 km × 600 km field of view. Any point in this field of view is observed per about 80s. The resolutions

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are 5km at nadir in spatially and 2ms in temporally. The orbit number of typhoons observed by the TRMM satellite and the Visible InfraRed Scanner (VIRS) data in this orbit number are obtained from the tropical cyclone database in JAXA/EORC. The VIRS is also one of the TRMM instruments.

The position of typhoons, the central pressure, and the radius of the gale force wind are obtained from the best track data in RSMC. The time resolution of the best track data is 6 hours. In this paper, we adopt linearly- interpolated the best track data.

233 typhoons occurred in the western North Pacific (WNP) from January 1998 to December 2007. The LIS observes 13308 lightning flashes from 218 typhoons during this period and we examined these lightning flashes. Table 1 shows these 15 typhoon’s name. Table 2 shows the numbers of occurred, missed, analyzed typhoons, and the number of typhoons observed by the TRMM satellite.

TABLE 1
THE EXCLUDED TYPHOON NUMBER

The typhoon number that was excluded by the analysis data	T9911,T9919,T0110,T0111,T0217, T0218,T0219,T0221,T0224,T0319 T0426,T0601,T0612,T0716,T0717

TABLE 2
THE ANALYZED DATA INFORMATION

Years	Occurred typhoons	Lack of observations	Analyzed typhoons	TRMM observations
1998	16	0	16	107
1999	22	2	20	97
2000	23	0	23	173
2001	26	2	24	192
2002	26	5	21	188
2003	21	1	20	169
2004	29	1	28	268
2005	23	0	23	193
2006	23	2	21	181
2007	24	2	22	170
Total	233	15	218	1738

B. Methods

Lighting flashes and view times (unit minute) obtain from the LIS data for every 0.5 deg × 0.5 deg grid area. Lightning flash data is one of the science data of the LIS. The TRMM/LIS orbit product version is 4.1. The distance between the center of typhoons and lightning location is calculated with the best track data and lightning flash locations. In this study, it is necessary to define the influenced range of typhoon. In general, the sizes of typhoon are decided with the size of the gale force wind area. If it is assumed that the gale force wind area is a sampling area of lightning flashes, when there are thunderclouds with lighting flashes on the boundary line of the radius of the gale force wind area, lightning flashes of thunderclouds may be separated. Therefore, we think that it is necessary to consider the outside circulation of typhoons called Outer Circulation in [6]. If 300 km away from the gale force wind area, the average tangential wind velocity of the near surface becomes 10 m/s. Thus, we define the size of typhoons as the radius of the gale force wind plus 300 km. We assume this the influence range of typhoons. We call this Typhoon Circulation Filed (TCF).

The gale force wind area is either the circle or an ellipse. If the gale force wind area in typhoon is an ellipse, the average oblateness is 0.3. Since the oblateness is a small value, we approximate circle by an ellipse. And the size of the gale force wind area is different per typhoon’s life stage. Thus, the size of TCF is not the same. In order to clarify that how far are the lightning flash locations from the typhoon center, we normalized by the size of TCF. Furthermore, in order to examine the number of lightning flashes per a quadrant of the typhoon circle, we do transformation of coordinate system and the direction of movement of typhoons is rotated in the same direction.

(a) (b)

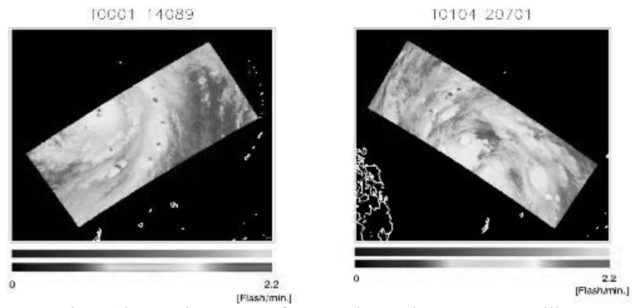

Fig.1 Observation cases of two typhoons by TRMM satellite
Asterisks are represent the locations of lightning flashes that observed by the LIS. Diamonds are the center of typhoon. (a) TRMM observation orbit (orbit number: 14089) of Typhoon DAMREY (T0001) (b) TRMM observation orbit (orbit number: 20701) of Typhoon UTOR (T0104).

Fig.1 is examples of the observations. The locations of lightning flashes are superimposed on the VIRS data. Fig.1a displays a southeastern part of a typhoon. On the other hand, Fig.1b displays a northeast part of a typhoon. In this way, the different quadrant of the typhoon circle was observed. The range of the observations and the number of the TRMM observations are different per typhoons. Therefore, we used the flash rate (unit minute) to solve non-uniform of the TRMM observations. The flash rate is calculated by dividing the number of lightning flashes by the view times.

III. RESULTS AND DISCUSSION

Fig.2 shows the storm-relative distribution of lightning flashes in TCF. It is composite of the flash rate in 218 typhoons. The center of the coordinate represents the typhoon center. The upward direction of the coordinate is the direction of typhoon movements.

(a) (b)

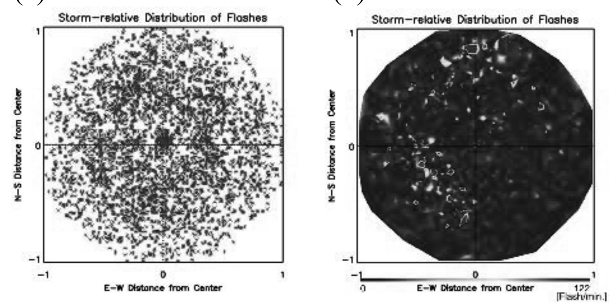

Fig.2 Storm-relative distribution of lightning flashes in TCF

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We normalized by the size of TCF. The center of the coordinate represents the typhoon center. The upward direction of the coordinate is the direction of typhoon movements. (a) The distribution of lightning flashes in typhoon. Blue asterisks show the flash rate≦10. Red asterisks show the flash rate>10. (b) Contour line indication of (a).

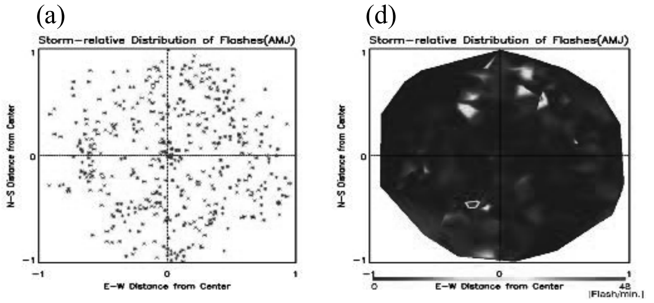
Since the size of the average of TCF was about 700km, the eyewall, the inner rainband, and the outer rainband regions correspond to the axis of from 0 to 0.1, from 0.1 to 0.3, and more than 0.3, respectively. The eyewall and the outer rainband regions have a high frequency. On the other hand, the inner rainband region has a low frequency (Fig.2a). This distribution of lightning flashes in typhoons is consistent with that in hurricanes. Lightning flashes occurred in any quadrant of the typhoon circle. However, flash rate is 10 and less in many lightning locations. Therefore, from the viewpoint of lightning activity, the lightning activity in typhoons was a very weak.

The vigorous lightning activity is most commonly found in the left of the direction of typhoon movements (Fig.2b). These places correspond to the locations more than 10 flash rates (Fig.2a) In order to clarify the seasonal dependency of lighting flashes in typhoons, we divide a twelvemonth into three seasons by means of an occurred frequency of typhoons [7]. That is to say, they are the early season (April-June), the peak season (July-September), and the late season (October-December). Table 3 shows the occurred typhoons and the lightning flash locations per seasons.

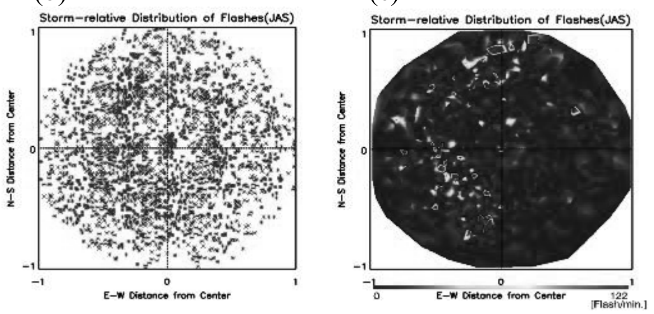
TABLE 3
THE OCCURRED TYPHOON AND LIGHTNING FLASH LOCATIONS PER SEASON

Seasons	Occurred typhoons	Lightning flash locations
Early season	31 (14%)	448 (13%)
Peak season	125 (57%)	2528 (71%)
Late season	57 (26%)	558 (16%)

(a) (d)



(b) (e)



(c) (f)

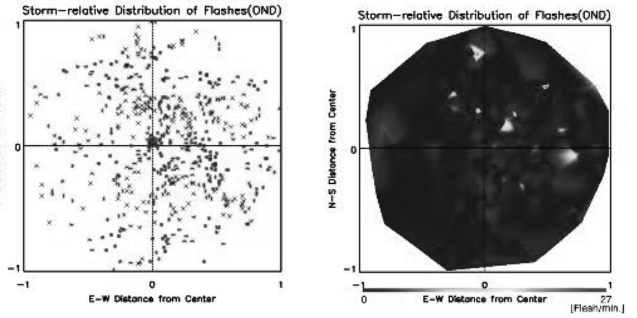
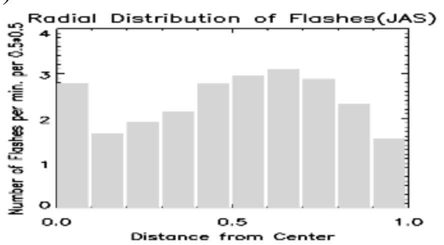


Fig.3 The storm-relative distribution of lightning flashes in TCP per seasons The distribution of lightning flashes in (a) the early season, (b) the peak season, and (c) the late season. (d), (e) and (f) show contour line indication of (a), (b) and (c), respectively.

Fig.3 shows the seasonal dependency of the storm-relative distribution of lightning flashes in TCF. In the early season, 31 typhoons occurred and lightning flash locations were 448 (Table 3). Lightning flashes occurred in any quadrant of typhoon circle (Fig.3a). The vigorous lightning activity locations (flash rate >10) had a few locations (Fig.3d). Lightning flashes had a uniform distribution. In the peak season, 125 typhoons occurred and lightning flash locations were 2528 (Table 3). On lightning flashes in peak season, the eyewall region and the outer rainband region had a high frequency, and the inner region had a low frequency (Fig. 3b). The vigorous lightning activity was remarkable in the third quadrant of the typhoon circle (Fig.3e). In the peak season, the ratio of the number of the occurred typhoons to the total was 57%, and the ratio of the lightning flash locations to the total was 71%. Thus, we suggested that the features of lightning flashes in the peak season are thought the typical pattern of lightning flashes in typhoons. In the late season, 57 typhoons occurred and the lightning flash locations were 558 (Table 3). Unlike the peak season, lightning flashes had a high frequency in the eyewall region (Fig.3c). The vigorous lightning activity was seen in the first quadrant (Fig.3f). This difference in between the peak season and the late season appears the radial distribution of lightning flashes in typhoons, too.

(a)



(b)

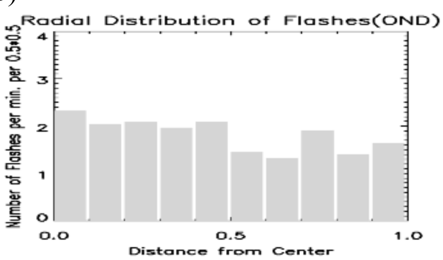


Fig.4 Radial distribution of lightning flashes in TCF per seasons.

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The horizontal axis shows the distance from the typhoon center in TCF.
The vertical axis shows the averaged flash rate per the distance of 0.1.
The radial distribution of lightning flashes in (a) the peak season, and (b) the late season.

Fig.4 shows the radial distribution of lightning flashes in TCF per seasons. The radial distribution of lightning flashes in peak season had two maximums. The first maximum appears the outer rainband region. The second maximum appears the eyewall region. The minimum appears the inner rainband region (Fig. 4a). However, in the late season, the radial distribution of lightning flashes has maximum in the eyewall region (Fig. 4b). It should be noted that lightning flashes in the outer rainband region decreased remarkably. This radial distribution of lightning flashes in the peak season and the late season are similar to that of two hurricanes reported by [2]. The outer rainband region occurs in the atmosphere with the convective instability, and it is necessary that the low-level of the typhoons have the equivalent potential temperature (EPT) of 350K or more. In general, the outer rainband region has the vigorous convective activity.

Fig.5 shows the lightning flashes per typhoon's life stages. We normalized by the correspondence relationship between lightning flashes and the central pressure. The center of coordinate shows the mature stage of typhoons. The left side of the center shows the developing stage of typhoons. The light side of the center shows the dissipating stage of typhoons. It should be noted that most vigorous lightning activity occurred in the dissipating stage. On the other hand, lightning flashes had a low frequency in the mature stage. Therefore, the number of lightning flashes in typhoons tended to be in inverse proportion to typhoon strength.

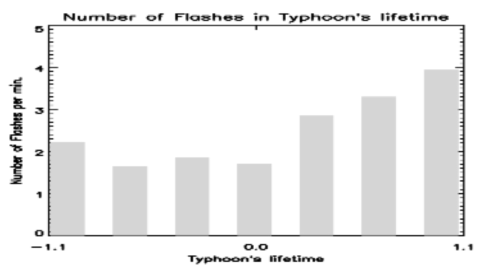

Fig.5 Lightning flashes per typhoon's life stage
The center of the horizontal axis shows the mature stage of typhoons. The left side of the center shows the developing stage, and the light side of the center shows the dissipating stage. The vertical axis shows the average flash rate per 0.3.

IV. CONCLUSION

In this paper, we investigated that lighting flashes in typhoon by the LIS on board TRMM. Remarkable features of lightning flashes in typhoons are the following: (a) The vigorous lighting activity is most commonly found in the left of the storm motion. (b) The outer rainband region has the high flash rate on a radial distribution of lightning flashes in the peak season. (c) Most vigorous lightning activity occurred in the dissipating stage. It is suggested that the distribution of lightning flashes in the peak season shows the typical pattern of lightning flashes in typhoons.

ACKNOWLEDGMENTS

The datasets used for this study are provided from GHCC LIS Data, JAXA/EORC Tropical Cyclone Database, RSMC Best Track Data. This work was supported by a grant of TRMM 5th RA. We express acknowledgment for TRMM/GDM Science Team.

REFERENCES

[1] Molinari, J., P. K. Moore, V. P. Idone, R. W. Henderson, and A. B. Saljoughy, 1994 : Cloud-to-ground lightning in Hurricane Andrew. *J. Geophys. Res.*, **99**, 16665-16676.

[2] Samsury, C. E., and R. E. Orville, 1994 : Cloud-to-ground lightning in tropical cyclones : A study of Hurricanes Hugo (1989) and Jerry (1989). *Mon. Wea. Rev.*, **122**, 1887-1896.

[3] Lyons, W. A., and C. S. Keen, 1994 : Observations of lightning in convective supercells within tropical stroms and hurricanes. *Mon. Wea. Rev.*, **122**, 1897-1916.

[4] Molinari, J., P. Moore, and V. Idone, 1999 : Convective structure of hurricanes as revealed by lightning location. *Mon. Wea. Rev.*, **127**, 520-534.

[5] Cecle, D. J., E. J. Zipser, and S. W. Nesbitt, 2002 : Reflectivity, ice scattering, and lightning characteristics of hurricanes eyewalls and rainbands. Part I : Quantitative description. *Mon. Wea. Rev.*, **130**, 762-784.

[6] Frank, W. M., 1977 : The structure and energetics of the tropical cyclones, I . Strom Structure. *Mon. Wea. Rev.*, **105**, 1119-1134.

[7] Wang, B., and J. C. L. Chan, 2002 : How strong ENSO events affect tropical storm activity over the Western North Pacific. *J. Climate*, **15**, 1643-1658.

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