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Latest Development of the Lightning Location Network over the Pearl River Estuary and Data Analysis Related to Tropical Cyclone Monitoring

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Abstract

Since 2005, the Hong Kong Observatory (HKO) has established a lightning location network, in cooperation with the Guangdong Meteorological Bureau (GMB) and the Macao Meteorological and Geophysical Bureau (SMG), to provide real-time regional lightning location information for the Pearl River Estuary and its vicinity over southern China. In 2016, HKO's Lightning Location Information System (LLIS) underwent server and software upgrade. The new system was subsequently declared operational in mid-2017 after tuning and optimization. The new LLIS has stronger data processing power and is able to incorporate lightning data from similar lightning location systems of nearby meteorological services for lightning locating purpose.

In late 2017 and early 2018, some old model lightning sensors of HKO's network have been successively replaced by the latest model sensors. Implementation of two new lightning detection stations is also in the pipeline. After the hardware enhancements and further system software upgrade, it is expected that the lightning detection capability of LLIS, especially the detection of cloud-to-cloud lightning, will be further increased. This paper outlines the tuning, optimization and configuration parameter setting of the enhanced LLIS.

To facilitate the development of new-generation aviation meteorological services, HKO acquired real-time global lightning data from a service provider in 2016. The lightning data from both HKO's own network and the service provider allow forecasters to have a better grasp of convective weather especially over the adjacent South China Sea region. In August 2017, tropical cyclones Hato and Pakhar crossed the South China Sea and approached the Pearl River Estuary. During the rapid intensification of the two tropical cyclones, some interesting lightning characteristics were observed. This paper presents the relevant lightning data analysis, as well as a comparison of the lightning characteristics with some other tropical cyclones.

1. Introduction

The Lightning Location Network around the Pearl River Estuary in southern China was jointly established by the Hong Kong Observatory (HKO), the Guangdong Meteorological Bureau

(GMB) and the Macao Meteorological and Geophysical Bureau (SMG) in 2005. The network comprises two central processors and several lightning sensor stations located in Hong Kong, Guangdong and Macau. It started with 5 lightning stations installed at Chung Hom Kok, Tsim Bei Tsui and Sha Tau Kok in Hong Kong, Sanshui in Guangdong as well as Taipa in Macao (Figure 1). In 2007, Huidong lightning station was established. All the aforesaid stations were each equipped with an IMPACT ESP (Vaisala, 2004) lightning sensor. In 2012, the Yangjiang lightning station was also set up with a newer model LS7001 sensor installed. Due to recent drastic changes in the surrounding environment of Huidong lightning station, it became inadequate for the proper operation of the lightning sensor. The sensor was subsequently relocated to a new site at hillside about 9 km to the northeast of the old site in January 2018. The new site has better exposure and hence there is less interference to the operation of the lightning sensor. With a network of the aforesaid 7 sensors, the lightning detection covered a range of about 200 to 300 km from Hong Kong.

During the period from 2005 to 2016, the central processor of the lightning location network was of model LP2000 (Vaisala, 2003). LP2000 provided lightning information including the followings:

- time of occurrence
- location
- type (i.e. cloud-go-ground (CG) or cloud-to-cloud (CC))
- electrical polarity
- peak current
- rise time and peak-to-zero time of waveform
- number of sensors used to compute the lightning location

LP2000 used the time of arrival and direction of the electromagnetic waves generated by the lightning discharges as detected by the sensors to compute the lightning location. For LP2000, the uncertainty in determining the location of CG lightning strokes was about 500 m within the network when all stations were operative. The CG lightning detection efficiency, i.e. the probability that a stroke with peak current greater than a certain level can be detected by the network, was estimated to be around 90%. Since the primary function of the IMPACT sensors was to detect CG lightning, the efficiency of CC lightning detection was thus not high and estimated to range from 10% to 50%.

2. Enhancement of the central processor for lightning detection

In 2016, the Observatory enhanced the lightning location information system with new central processor of model TLP (Vaisala 2014). TLP provides the same type and amount of lightning information as LP2000 but the former features stronger processing capability compared with LP2000. In this connection, TLP can process data from several tens of sensors and allows ingestion of data from Vaisala lightning sensors operated by GMB and Shenzhen Meteorological Bureau (SZMB)

(Figure 1), thereby extending the spatial detection coverage of the lightning network from a range of around 200 to 300 km to about 300 to 500 km from Hong Kong. In addition, TLP is able to incorporate GMB and SZMB newer model LS series sensors which are more sensitive and can detect more CC lightning compared to older model IMPACT sensors.

TLP adopts a more advanced lightning detection algorithm which screens out poor quality lightning raw data to achieve higher lightning location accuracy. Furthermore, the new algorithm can better identify CG and CC and thereby increases the lightning detection efficiency of the network.

For both TLP and LP2000, lightning location is calculated using the time of arrival and direction of the electromagnetic waves generated by the lightning discharges as detected by the sensors. In order to achieve accurate time of arrival and direction finding, network optimization has to be performed to implement the necessary propagation and angle offset to each sensor in the network. Initial network optimization of TLP was carried out using HKO, GMB and SZMB sensor raw data in the summer of 2015. Afterwards, lightning raw data from 1 January 2016 to 31 March 2017 was reprocessed using different configuration parameter settings to further optimize the TLP lightning detection algorithm.

During the optimization process of TLP algorithm, it was discovered that if the direction information of the LS series sensors (i.e. Yangjiang, GMB and SZMB sensors, Figure 1) was not employed, false alarms in lightning detections could be effectively minimized (Figure 2). It was probably due to the higher sensitivity of LS sensors capturing weak or noisy signals, resulting in a larger uncertainty in direction information which led to more false alarms.

The algorithm of TLP also features a new module “Grid Filter”. During the algorithm optimization process of TLP, it was found that by tuning the configuration setting parameters (Table 1) and turning on the Grid Filter, isolated false alarms of lightning detection caused by noise signals from sensors could be removed (Figure 3).

TLP was put into operation at end May 2017 after the above optimization. With improved lightning detection algorithm, the CG location accuracy and detection efficiency of TLP are higher than those of LP2000, reaching about 200 to 300 m and more than 90% respectively. Furthermore, as LS series sensors are designed to detect more CC lightning and TLP can ingest data from LS sensors of GMB and SZMB, the CC lightning detection efficiency of TLP is also higher at roughly 50%.

3. Installation of new model lightning sensors

From December 2017 to January 2018, latest model sensors LS7002 (Vaisala, 2016) were implemented in Chung Hom Kok, Tsim Bei Tsui, Sha Tau Kok and Taipa to replace the old IMPACT sensors. In April and July 2018, LS7002 sensors were installed in two more new stations, one at Dongao Island, Zhuhai and another one at Chek Lap Kok, Hong Kong respectively (Figure 1).

Since installation of the six aforesaid new LS7002 sensors, further network optimization has to be carried out to implement the necessary propagation and angle offset to each sensor for achieving accurate time of arrival and direction finding. In particular, in this network optimization, emphasis will also be put on adjusting the angle offset of Yangjiang, GMB and SZMB LS sensors to improve their direction finding, with a view to re-adopting the angle information of these sensors. The optimization will be carried out using lightning raw data collected in the whole summer of 2018. Before completion of this network optimization, direction information from the new LS7002 sensors will more likely be susceptible to errors and therefore should be ignored in lightning detection meanwhile. Nonetheless, the LS7002 sensor is designed for CC detection as well as high precision CG detection. After the network optimization, it is expected that the TLP, with LS7002 sensors, will achieve CG location accuracy of 250 m, CG detection efficiency up to 95% and CC detection efficiency of more than 50%.

4. Global Lightning Dataset (GLD360)

To further the development of new-generation aviation meteorological services, HKO started to acquire real-time global lightning dataset, GLD360, from Vaisala Oyj in 2016 (Vaisala, 2015). GLD360 data serves as a useful reference for aviation weather forecasters in issuing Significant Weather Information (SIGMET) to aircrafts.

GLD360 provides lightning information like time and location of occurrence, electrical polarity and current. However, GLD360 cannot differentiate between CG and CC lightning. Despite this, it has a much larger spatial coverage compared to TLP, providing real-time global lightning data useful for long-distance weather monitoring. GLD360 achieves a lightning location accuracy of about 2 to 3 km and detection efficiency of over 80% in the Northern Hemisphere.

5. Lightning characteristics associated with tropical cyclones affecting South China coast in 2017

In August 2017, tropical cyclone Hato crossed the South China Sea and approached the South China coastal area. When it edged nearer to the Pearl River Estuary, both TLP and GLD360 registered dense lightning with large magnitude current, especially positive current of over 100 kA magnitude, near the centre of Hato (Figure 4(a)). In fact, Hato was undergoing intensification during the period that these high density, large current lightning were observed, as revealed by Doppler velocity images (Figure 4(b)). The intense lightning might probably be related to strong convection near the intensifying tropical cyclone.

Three other tropical cyclones approaching the Pearl River Estuary in 2017 also showed similar lightning characteristics. They were Roke (Figure 5), Pakhar (Figure 6) and Khanun (Figure 7) affecting the coastal area in June, September and October 2017 respectively. In all the three cases, dense lightning, with some strong positive current, were found near an intensifying tropical cyclone.

6. Conclusion

In recent years, HKO has enhanced the lightning location network over the Pearl River Estuary with latest model central processor TLP and new LS7002 lightning sensors. Global lightning dataset, GLD360, is also available for use by weather forecasters. TLP and GLD360 provide precise lightning information with large spatial coverage and the lightning data are also useful in monitoring of tropical cyclones.

Dense lightning with strong current were observed near the centre of some tropical cyclones affecting the South China coastal areas in 2017. The lightning characteristics may be associated with intensification of tropical cyclones. Further study of tropical cyclone lightning should be carried out to find out the relationship between lightning occurrence and tropical cyclone intensity.

7. Acknowledgement

The author would like to thank Mr. K.C. Tsui for his invaluable advice and comments.

8. References

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Table 1 Configuration parameters of Grid Filter in TLP lightning detection algorithm

Parameter	**Value**
<Grid Point Setting>	
Latitude Minimum (degrees)	-90.0
Latitude Maximum (degrees)	+90.0
Longitude Minimum (degrees)	-180.0
Longitude Maximum (degrees)	+180.0
Rows	1000
Columns	2000
<Effective time of lightning detected in grid>	
Active Duration (minutes)	10.0
<Threshold for exemption from Grid Filter>	
Location Accuracy (km)	5.0
Degrees Of Freedom	4

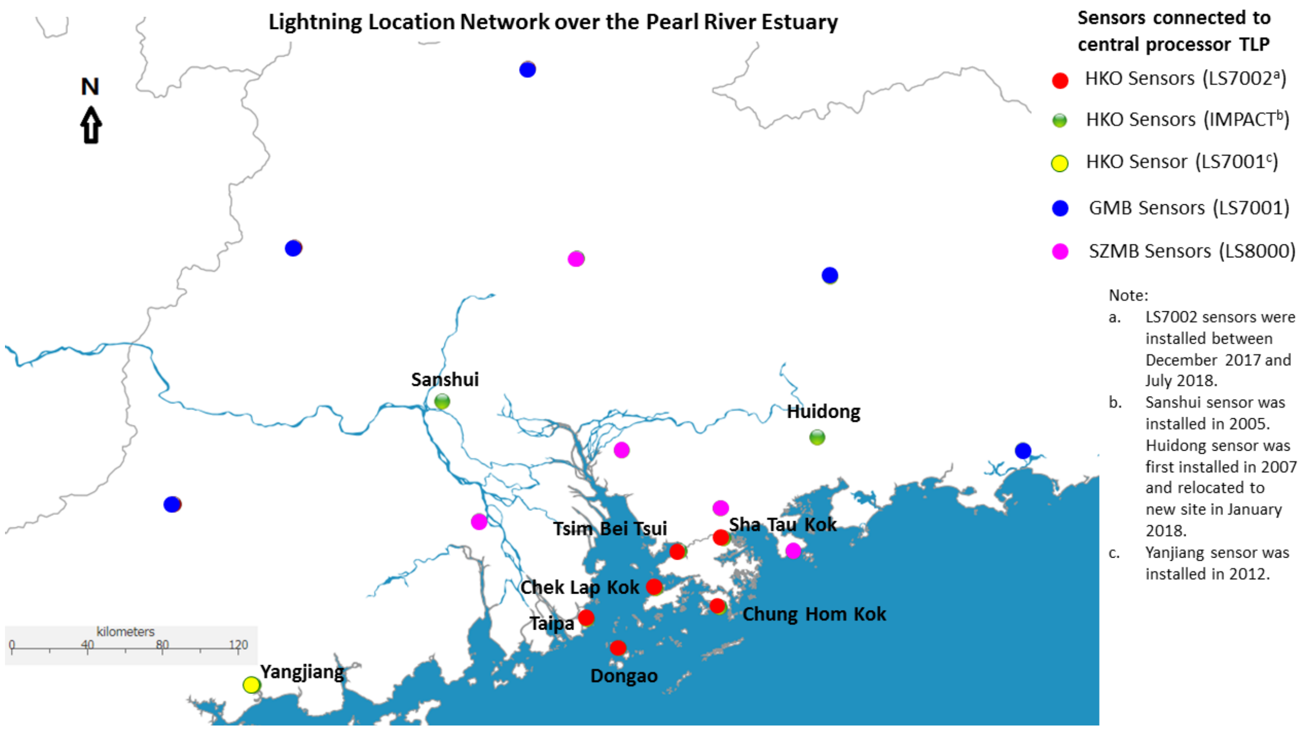

Figure 1 Lightning sensors of the Lightning Location Networks around the Pearl River Estuary

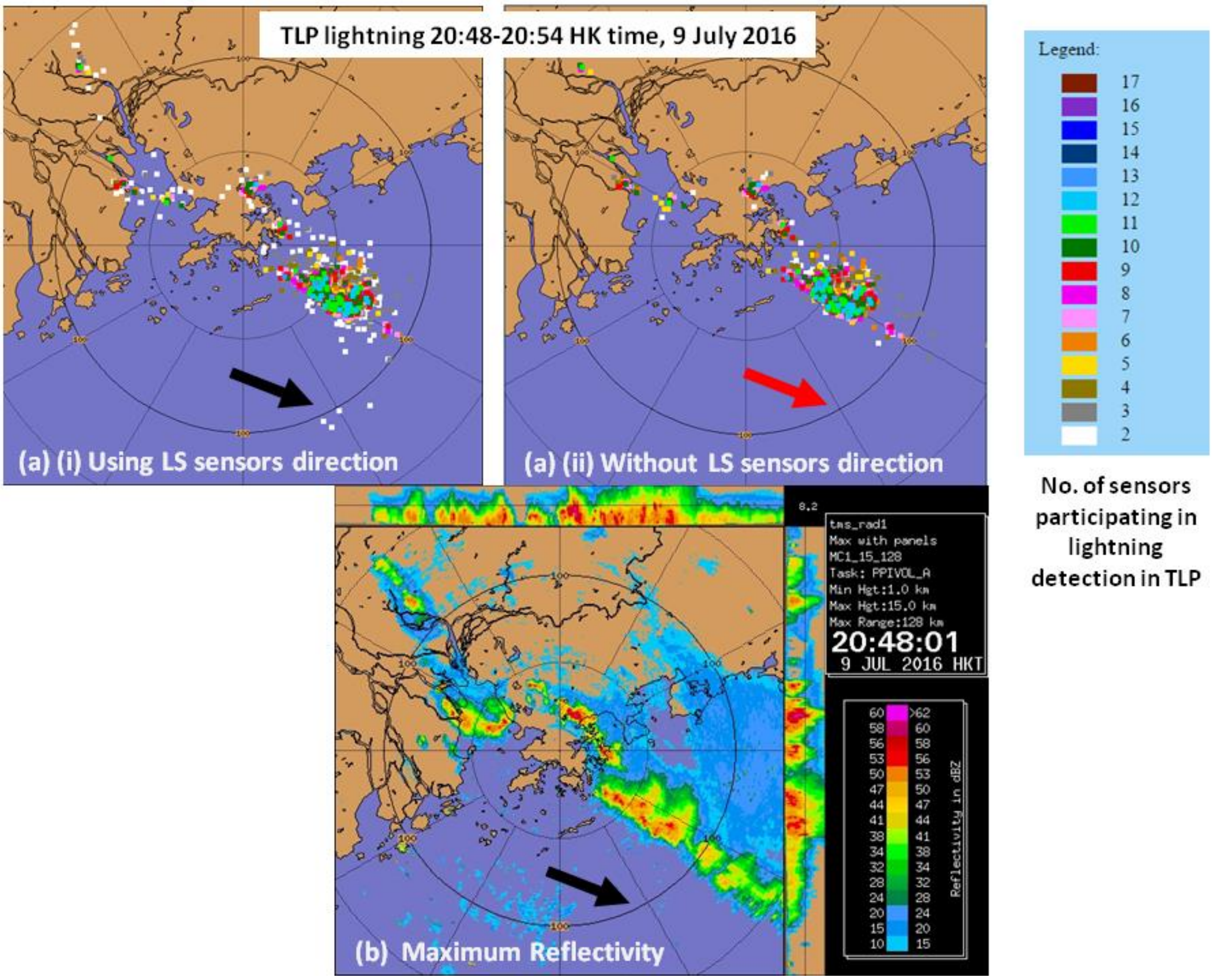

Figure 2 Effects of direction information of lightning sensors on performance of TLP lightning detection algorithm

(a) Lightning locations detected by TLP at 20:48-20:54 HK time on 9 July 2016 (i) using direction information from LS series sensors; and (ii) without using direction information from LS series sensors. If direction information from all LS series sensors were enabled, false lightning locations were detected in radar echo-free area (black arrow). On the other hand, if direction information from all LS series sensors were disabled, false lightning detections were removed (red arrow).

(b) Vertical maximum reflectivity image of HKO's Tai Mo Shan Doppler Radar at 20:48-20:54 HK time on 9 July 2016. Black arrow shows echo free area where TLP registered false lightning if direction information from LS series sensors were used in lightning detection.

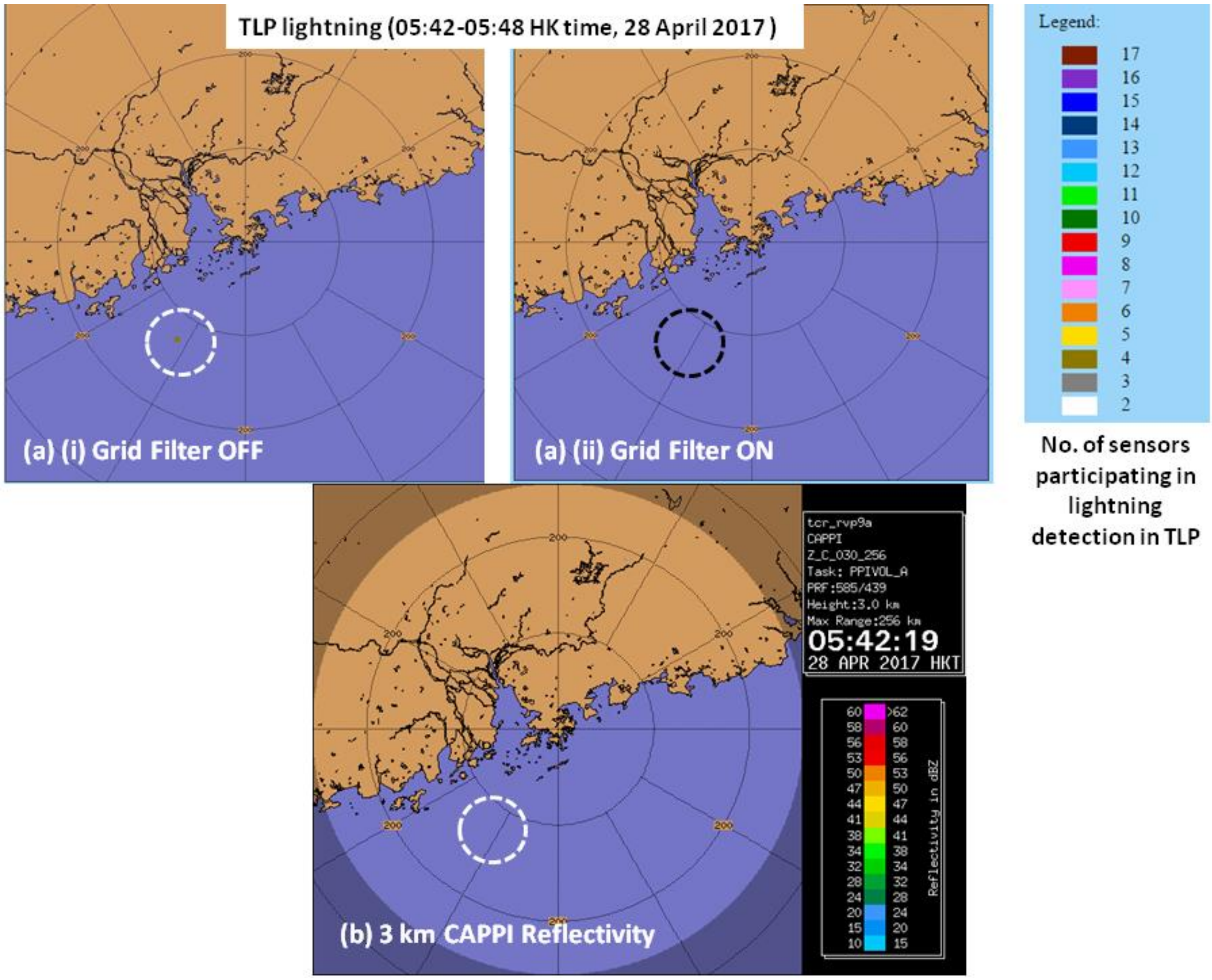

Figure 3 Effects of Grid Filter on performance of TLP lightning detection algorithm

(a) Lightning locations detected by TLP at 05:42-05:48 HK time on 28 April 2017 with (i) Grid Filter off and (ii) Grid Filter on. If Grid Filter is turned off, isolated false lightning over radar echo free area was detected by TLP (white circle). If Grid Filter is turned on, false lightning was removed (black circle).

(b) 3 km CAPPI reflectivity image of HKO's Tai Mo Shan Doppler Radar at 05:42-05:48 HK time on 28 April 2017. White circle shows echo free area where TLP registered false lightning if Grid Filter is off.

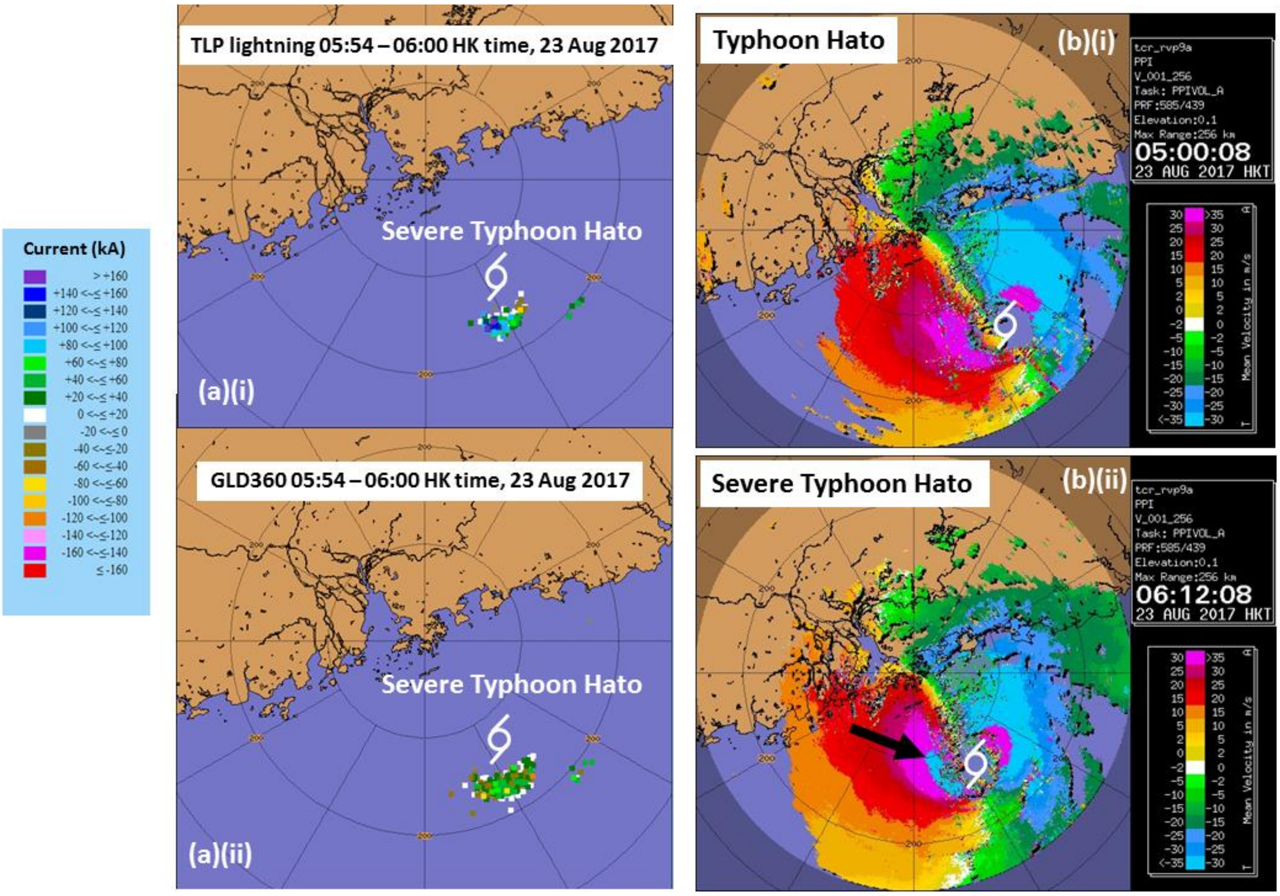

Figure 4 Lightning characteristics of tropical cyclone Hato

(a) Lightning locations detected by (i) TLP (05:54-06:00 HK time and (ii) GLD360 (05:55-06:00 HK time) on 23 August 2017). Lightning with large positive current (over 120 kA) was detected by TLP near centre of Hato.

(b) 0.1 degree PPI Doppler velocity images of HKO's Tate's Cairn Doppler Radar at (i) 05:00 HK Time and (ii) 06:12 HK Time on 23 August 2017. As revealed by velocity folding near centre of Hato shortly after 06:00 HK time (black arrow), Hato was intensifying when dense lightning with strong current was observed around that time.

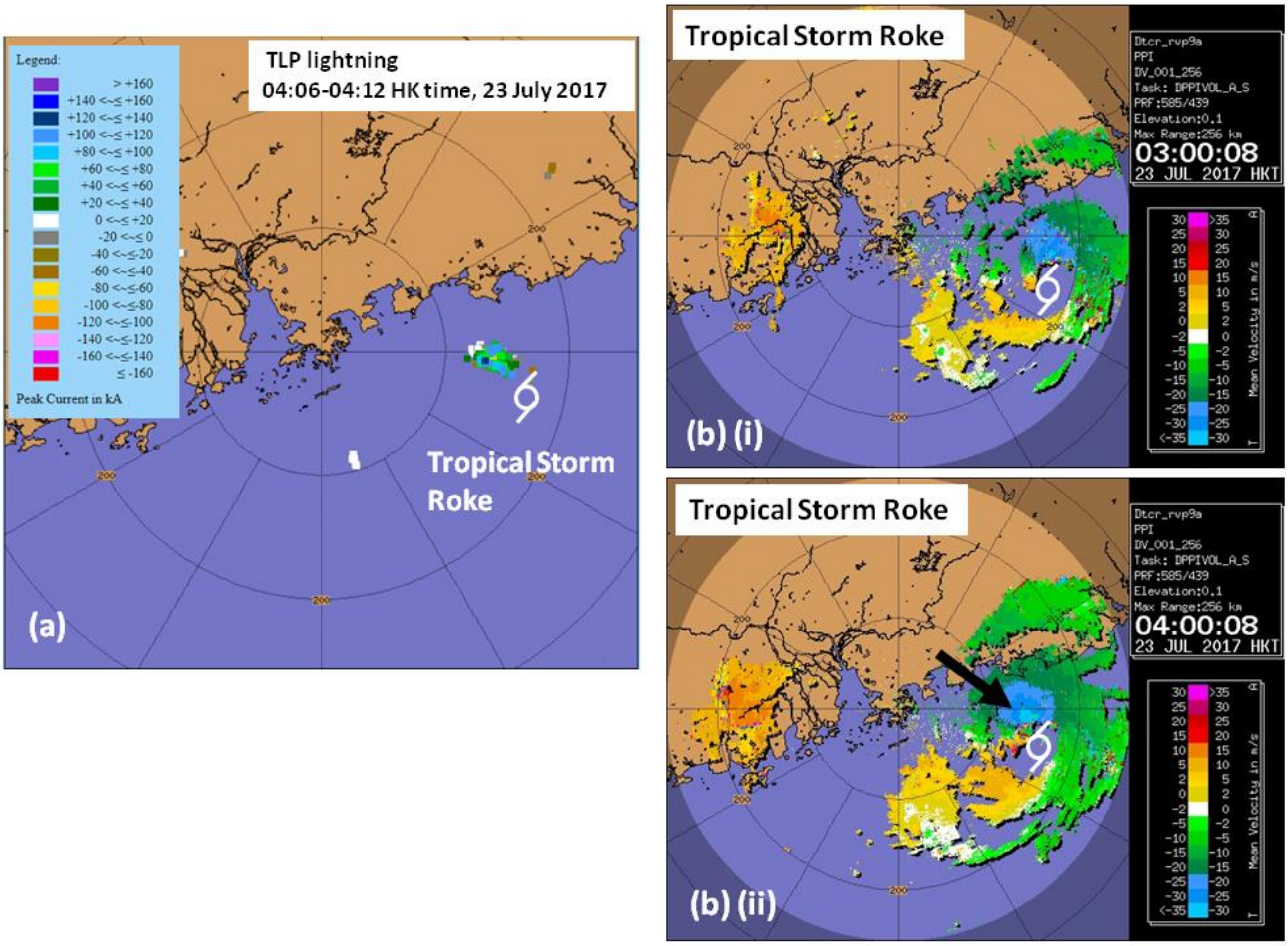

Figure 5 Lightning characteristics of tropical cyclone Roke

(a) Lightning locations detected by TLP at 04:06-04:12 HK time on 23 July 2017. Lightning with large positive current (over 120 kA) was observed near centre of Roke.

(b) 0.1 degree PPI Doppler velocity images of HKO's Tate's Cairn Doppler Radar at (i) 03:00 HK time and (ii) 04:00 HK time on 23 July 2017. Higher Doppler velocity (over 30 m/s) appeared near centre of Roke starting 04:00 HK time (black arrow), indicating that it was intensifying at that time. It was also around this time when dense lightning with strong current was observed near Roke's centre.

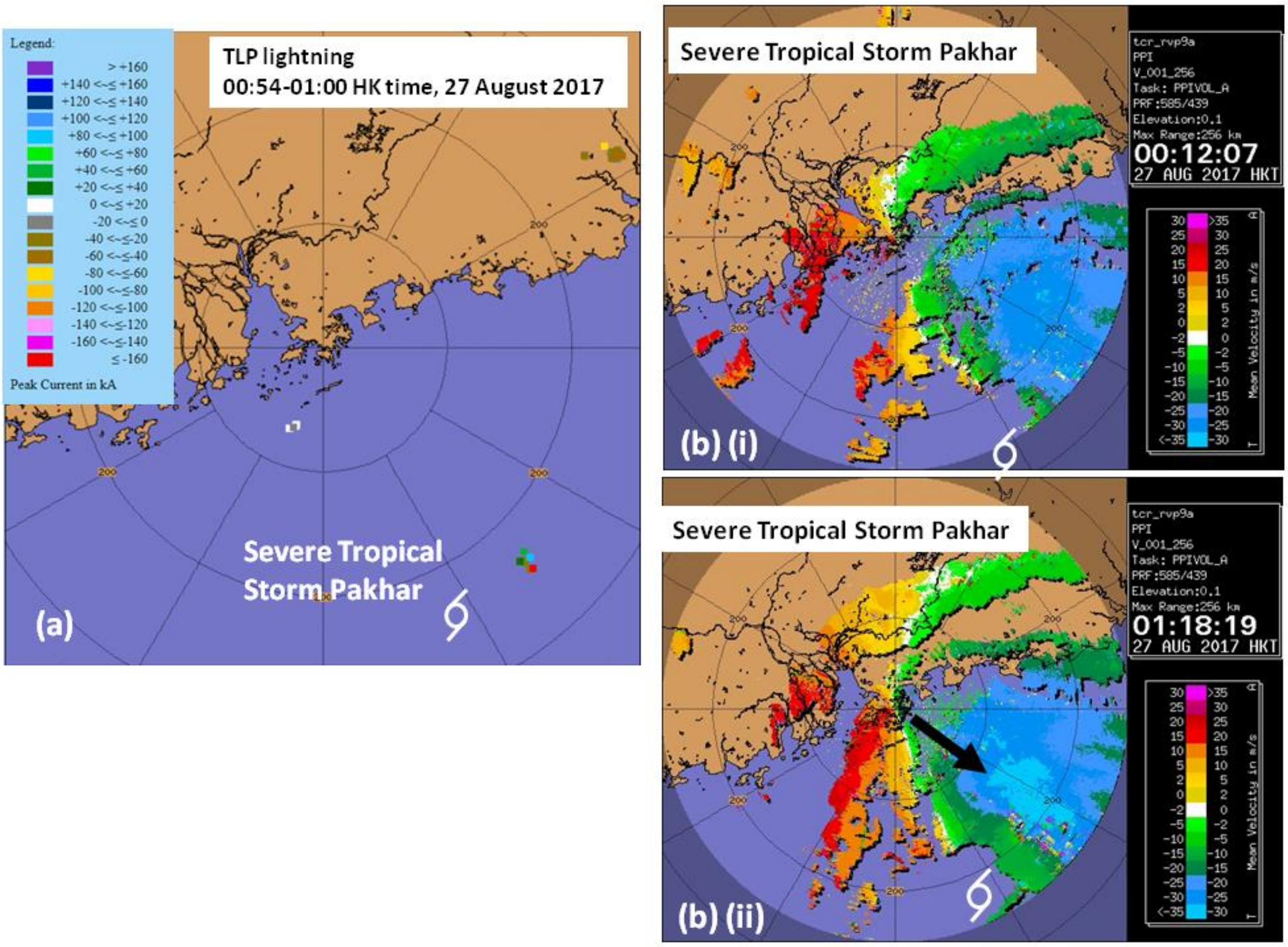

Figure 6 Lightning characteristics of tropical cyclone Pakhar

(a) Lightning locations detected by TLP at 00:54-01:00 HK time on 27 August 2017. Lightning with large positive current (over 100 kA) was observed near centre of Pakhar

(b) 0.1 degree PPI Doppler velocity images of HKO's Tate's Cairn Doppler Radar at (i) 00:12 HK Time and (ii) 01:18 HK time on 27 August 2017. Higher Doppler velocity (over 30 m/s) appeared near centre of starting around 01:00 HK time (black arrow), indicating that it was intensifying at that time. It was also around this time when dense lightning with strong current was observed near Pakhar's centre.

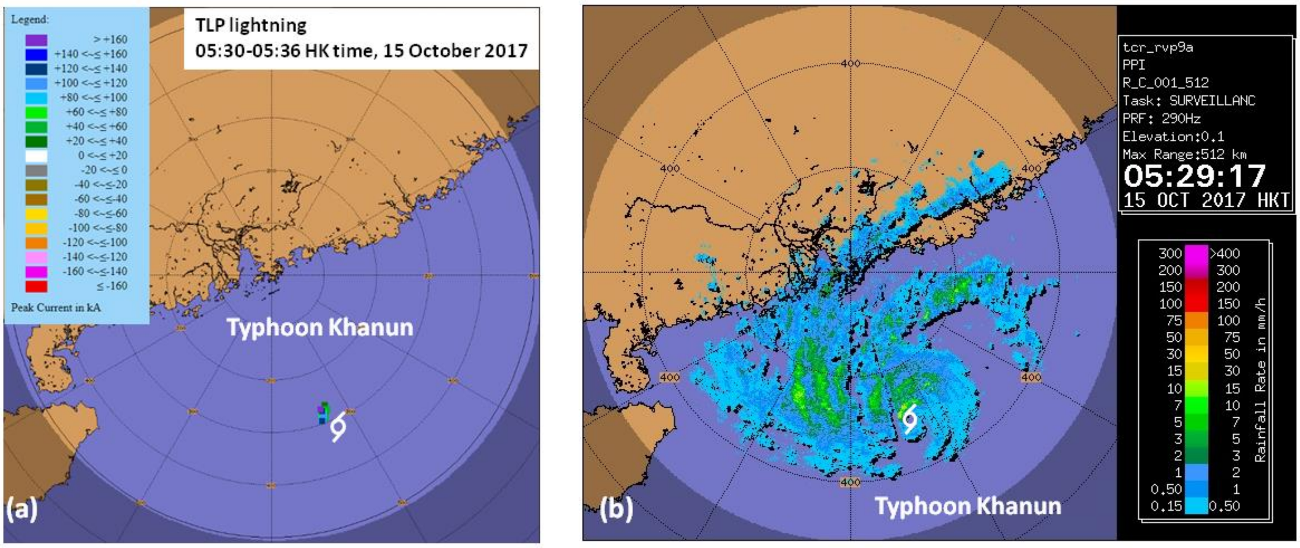

Figure 7 Lightning characteristics of tropical cyclone Khanun

(a) Lightning locations detected by TLP at 05:30-05:36 HK time on 15 October 2017. Lightning with large positive current (over 120 kA) was observed near centre of Khanun.

(b) 0.1 degree PPI reflectivity image of HKO's Tate's Cairn Doppler Radar at 05:29 HK time on 15 October 2017. During the period from 05:00 to 08:00 HK time, Khanun was intensifying from a typhoon to a severe typhoon. It was around that period when dense lightning with strong current was observed near Khanun's centre.