Thunderstorm activity in typhoon Lionrock (2016)

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Abstract. On Aug. 29, 2016, the tropical cyclone Lionrock was reported to turn into an extra-tropical storm and go to the shore of the Primorsky Region as monitoring shows, which brought about significant precipitation growth recorded in the north of the coast. Many surveys show the tropical cyclones in this area to transform into extra-tropical ones and become powerful mid-latitude storms with significant damage to coastal and maritime areas. The paper uses WWLLN (World Wide Lightning Location Network) data to study the thunderstorm activity while the tropical cyclone reaches the typhoon level with the maximum wind velocity. This made it possible to identify parameters’ variations of thunderstorm activity during atmospheric vortex phenomena. It also enabled us to determine the emergency probability due to a thunderstorm.

1. Introduction

Currently, more and more attention is paid to the study of the dependence between hazardous weather phenomena with thunderstorm activity. A tropical cyclone is an atmospheric disturbance with lower air pressure and storm wind speeds arisen in tropical latitudes. Most tropical cyclones originate in the Pacific Ocean to the south of 25˚N, between 100˚E and 180˚E in the northern hemisphere. In [1], 69 tropical cyclones over the northwestern Pacific were studied from 2005 to 2009. It is noted that over 80% of them were formed from May to November in the northwestern Pacific. As far as tropical cyclones are concerned, lightning activity over the northwestern part of the Pacific Ocean is more likely at the stages of development such as tropical depression and tropical storms. In work [2], it is believed that tropical cyclones in the northwestern part of the Pacific Ocean, which turning into extra-tropical ones, can develop into powerful mid-latitude storms that can significantly damage coastal and marine areas.

In [3] it is noted that in some remote tropical oceanic regions, the proportion of lightning resulted from tropical cyclones may exceed 75%. The results show that the main thunderstorm season in the northeastern Pacific Ocean begins in May and lasts until October. The highest lightning activity is observed in July, August and September, and the lowest one is recorded in February. It is explained by fluctuations in monthly precipitation. At the same time, in the oceanic region to the east of Japan, the highest lightning activity is observed in winter [3]. Lightning is observed in form of stripes connected with the tracks of winter storms. In winter, synoptic-scale cyclones, as a rule, are formed in the western part of ocean currents. Most of the lightning above the northern part of the Pacific Ocean in winter depends on cold fronts of mid-latitude cyclones. Another factor for the winter lightning emergence to the east of Japan is the Kuroshio flow [3]. Thus, the occurrence of a tropical cyclone is always accompanied by the formation of dense convective cumulus clouds and extremely fast winds.
The Japan Meteorological Administration classifies tropical cyclones according to its stages of development. The main separating feature is the value of the maximum constant wind speed in a 10-minute period. A tropical depression is characterized by a maximum constant wind speed of up to 17 m/s. During a tropical storm, speeds vary from 17 to 23 m/s, during a strong tropical storm velocities vary from 24 to 32 m/s; and when a wind value exceeds 33 m/s, the tropical cyclone passes to the typhoon stage.

An alternative classification making the physical features of the process pronounced in the work of Minina [4]. She divides a tropical cyclone into five stages: tropical disturbance, tropical depression, tropical storm, typhoon, and a decaying tropical cyclone, the last one in some cases turning into an extratropical storm (ex-typhoon) [5].

The main sign of the initial stage i.e. a tropical disturbance in the zone of a cloud band or cloud masses is enough to be higher number and thickness of cumulonimbus clouds and their gradual concentration in a certain area [4]. Convection increases in the area of disturbance. The most frequent tropical disturbance is observed in the zone of cloud bands [4].

At the stage of tropical depression, a dense cloud massif is separated from the main cloud band by a few clouds or a cloudless space. It is oriented along the line of convergence. With further development, the cloudiness of the tropical depression continues bending, taking the form of a spiral, and, in the northern tropics, resembling a comma in shape. The form of clouds in the shape of a comma reflects a certain stage in the development of depression. At the point where the cloud ridges meet, there is an increased development of convective clouds, the center of depression is usually located here [6].

The tropical storm is characterized in [4] by the fact that the cloudiness of a tropical storm is formed from a system of powerful convective clouds in the shape of a single turn of a spiral. Cirrus clouds appear in a tropical system in a tropical storm. Its appearance is a sign of the rapid deepening of the emerging tropical cyclone. This cirrus cloud cover disguises the center of the cyclone and cumulonimbus clouds [7].

The main identifying features of tropical cyclones at the typhoon stages of its development and its maximum point are the formation of compact continuous cloud arrays in the shape of a circular zone or a disk with smoothed edges, as well as the formation of spiral bands of cumulonimbus clouds extending from the main massif. Among them, there may be two main bands located diametrically opposite. In the center of a cloudy massif a dark spot or a point are often seen, it is the eye of a storm in front of a tropical cyclone, a ridge of cumulonimbus clouds, a squall line [8]. At the typhoon stage, a tropical cyclone has a maximum wind speed of 33 m/s and even more. This stage is the most specific for a tropical cyclone and the longest one (5-7 days) [9].

The main reasons leading to the destruction of a tropical cyclone at the final stage are the changes of thermodynamic conditions that are specific for the cyclone stages considered above, i.e., the change of synoptic conditions, the transition to the colder ocean surface, the convergence of the typhoon with the polar front and cyclone or typhoon coming to land. The transition from a tropical cyclone to an extratropical cyclone has not been fully studied yet.

2. Material and methods

In Russia in 2016, the impact of the tropical cyclone Lionrock on the Primorsky Region was the most ambitious at the stage of a collapsing cyclone (ex-typhoon stage). In this work, we studied the parameters of thunderstorm cells based on the analysis of data from the thunderstorm registration system WWLLN. One of the reception points of this scientific network for the registration of lightning discharges is located in Yakutsk. In [10], it was proposed to convert the WWLLN data into a grid with a node spacing of 8 km. The study analyzed the lightning discharges obtained by the WWLLN recording system, on the territory of 10°–35°N, 125°–145°E with grid spacing of 2.5 km in the period of maximum development of typhoon Lionrock from August 23, 0:00:00 LT to August 28, 23:59:59 LT.

As far as the analysis is concerned, the methods of cluster analysis, implemented in the software package, were used. Clustering was performed similarly to the method presented in [11].
According to the site http://agora.ex.nii.ac.jp/digital-typhoon, the tropical cyclone originated on August 16, 2016 at a point of 26.4°N and 159.1°E at the stage of tropical disturbance and reached the typhoon stage by August 24 at 3:00 LT with a wind speed of about 36 m/s.

3. Results
As a result of the analysis, it was established that in the zone of a cyclone in the territory of 10°–35°N, 125°–145°E from 23.08 to 28.08, the average atmospheric flux per minute during the daytime is of greater importance than at night. In the diurnal course (Figure 1), there are two maximum, approximately equal peaks at 11–12 LT and at 21–22 LT (up to 42 discharge/min). At the typhoon stage, when the wind speed reaches its maximum value, the level of thunderstorm activity practically did not exceed the background level, according to the studies [12].

Figure 1. The density of the flow of pulses per minute in the registration area from 08.23.2016 to 08.28.2016

It was noted in [13] that many lightning discharges are produced in large turbulent eddies. Scaling up of lightning discharges occurs as the frequency of their occurrence decreases. In a thundercloud, zones with a lower frequency of discharges are gradually formed. The largest lightning occurs between them.

A sharp increase in thunderstorm activity occurred during the transformation of a tropical cyclone from a tropical storm stage (wind speed 23–27 m/s) to a typhoon stage (wind speed up to 38 m/s) from August 23 to August 24 LT. At the same time, wind speed stabilization begins on August 25 (in average up to 43 m/s).

According to studies of lightning activity in the northwest Pacific [3], the highest density of lightning appears in cyclones within the next 24 hours after reaching a wind speed of 15–25 m/s. During the period of typhoon formation, lightning discharges are distributed relatively chaotically. On the day of maximum development on August 24, 2016, spiral bands coinciding with the cloud boundaries were also observed in the field of the distribution of the density of lightning discharges.

Analysis of the WWLLN registration system data showed that in the area of typhoon Lionrock from 23.08 to 28.08, from nine to forty-two cells are allocated per hour, with an average value of 23, the mode is 16. The largest number of cells is recorded at the maximum steady wind at a speed of 43 m/s. At the same time, at the moment of a tropical storm transition to a typhoon stage, the number of allocated cells in the registration area do not exceed 25 (on the background level).
At the same time, the intensity of lightning discharges in a single cell had reached its maximum on August 25, 9:00 LT and reached a value of 0.19 (Figure 2). The median intensity value is equal to mode and equal to 0.03. In general, for the period under review, the intensity values ranged from 0.01 to 0.19.

Figure 2. Discharge density per minute per unit area of a single cell in the registration area from 08.23.2016 to 08.28.2016

The analysis of the lifetime of the cells selected by means of a cluster analysis showed that the average lifetime is 41 minutes. This time coincides with the median (41 min), with mode equal to 50 min.

The average cell area during their lifetime peaked at 8 p.m. LT on August 24. The next day, the intensity of lightning discharges in a single cell increased with a small number of short-living (up to 16 minutes) cells. When the maximum wind speed stabilized to 43 m/s, the intensity of discharges in the cell began falling, but the number of cells and their lifetime increased. At the same time, an increase was recorded in the wind speed. At this stage, the tropical cyclone goes into the typhoon phase from the phase of the tropical depression.

Thus, up to the typhoon stage, the area of each cell monotonously increased taking into account the daily course of the density of the flow of thunderstorm discharges. Furthermore, the number of cells as well as the intensity of lightning discharges in each cell increased, while the lifetime and area decreased.

In [14], the area of enhanced convective activity associated with powerful thunderstorm activity is proposed to be contoured with an ellipse. Consideration of the shape of the cells showed that the maximum value of the eccentricity of the ellipse to 0.8 is characterized by the conditioned (Figure 3) when the wind stabilizes and reaches a value of 43.7 m/s, and is observed in short-living cells of a thunderstorm cell. At the same time, the intensity of atmospheric flux per minute per area unit in the registration zone is 10°–35°N, 125°–145°E decreased after a sharp increase. The intensity of discharges in the cell on that day reached a maximum and then began to subside. In August 27, thunderstorm cells become less dense, their shape becomes less elongated (eccentricity decreases to 0.3). Note that during the time from August 23 to August 28 the median value of eccentricity coincides with the mode and is equal to 0.6, with a minimum value of 0.32 and a maximum value of 0.8.
Figure 3. The change in the eccentricity of a single cell in the registration area from 08.23.2016 to 08.28.2016

4. Conclusions
Spatial and temporal characteristics of thunderstorm activity have been analyzed in the paper, which has allowed us to come up with the correspondence between the anomalous changes in the model ellipse eccentricity under vortex and atmospheric radiation. Given the results obtained, we have introduced the ellipse eccentricity estimate in the model as a risk parameter related to thunderstorm emergency. With the eccentricity level and wind velocity higher than 0.6 threshold and 17 m/s, respectively, an increased lightning discharges density is recorded inside the thunderstorm. Such situations require obligatory protective steps.

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