Thundercloud Features in Different Regions

Subjects: Remote Sensing

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A comparison of thundercloud characteristics in different regions of the world was conducted. The clouds studied developed in India, China and in two regions of Russia. Several field projects were discussed. Cloud characteristics were measured by weather radars, the SEVERI instrument installed on board of the Meteosat satellite, and lightning detection systems. The statistical characteristics of the clouds were tabulated from radar scans and correlated with lightning observations. Thunderclouds in India differ significantly from those observed in other regions. The relationships among lightning strike frequency, supercooled cloud volume, and precipitation intensity were analyzed. In most cases, high correlation was observed between lightning strike frequency and supercooled volume.

thundercloud radar cumulonimbus electrical strike lightning Meteosat

1. Introduction

The development of powerful cumulonimbus often leads to dangerous phenomena: heavy rainfall, squalls, tornadoes, hail, and lightning. The formation of these phenomena is closely related to the microphysical, dynamic, and electrical characteristics of clouds. The current understanding of cloud and precipitation formation should also include the role of electric fields and discharges on various scales in clouds, from corona to lightning [1][2][3][4][5].

Currently, most scientists consider the interaction among ice particles as the main mechanism of charge generation [6]. Taking into account the significance of the contact mechanism of electrification for charging cloud particles, a close correlation might be expected between the microphysical parameters of the cloud and the frequency of electric discharges. Correlation between the lightning flash rate and the cloud top height [7][8] were attempted, as well as with the maximum radar reflectivities observed at different heights [9][10][11][12], and also the number of ice crystals, estimated from radar data [13][14][15][16]. It is demonstrated in [17] that there are rather close relationships between the frequency of lightning and the total mass of particles in the upper part of the cloud, and also the mass of graupel and hailstones. These relationships are manifested in both supercell and multicell clouds. Other radar parameters were also examined, notably those which depend on: the number and size of ice particles in the cloud; the characteristics of precipitation in the form of ice particles [2][11][16]; the total mass of particles in the upper part of the cloud; the mass of graupel and hailstones [17]; the volume of the cloud containing mixed-phase hydrometeors [18]; among other characteristics [19][20][21][22]. Synchronous measurements using the radar and LIS instrument installed at the TRMM satellite were carried out during the period 1998–2010. These demonstrated that correlation between the cloud top height and the lightning frequency is insignificant but the lightning frequency depends more on the radar volume of the cloud that contains mixed-phase hydrometeors [18].

A significant correlation was obtained between the frequency of lightning flashes and ice-phase precipitation [2][11][14][15][23][24]. The rainfall volume per cloud-to-ground lightning flash was found to be from 0.7 × 10^4 to 6.4 × 10^4 m^3 [24]. In most cases, discharges preceded precipitation. All researchers note the regional and seasonal features of the revealed relationships.

It has been shown that the formation of the crystal fraction in convective clouds is accompanied by the increase in electric field strength [25][26], which is highly correlated with the integral characteristics of the supercooled part of the cloud defined by the number of rough ice particles in the cloud [27]. The importance of corona discharges in the process of cloud charge generation remains poorly explored, although there are hypotheses and experimental data which suggest that the contribution of these processes is significant [3].

Field experiments have demonstrated that the frequency of electric discharges in the cloud is proportional to the updraft speed to the sixth power [19], while the authors of [21][28] found that the lightning frequency was proportional to the updraft speed to the power of 4.55.

The presented brief review identifies Cb characteristics typical to the thundercloud-transition stage of Cu development, important for understanding cloud electrification physics. This also has practical implications for lightning prediction.

Attempts to establish relationships between lightning and the dynamic and microphysical cloud characteristics have primarily been made through remote sensing in recent years. Lightning characteristics, including lightning frequency, depend on Cb properties. It follows from the literature review that the crystal phase likely plays a role in lightning formation. Those specific habits of crystal phase which are most important for Cu electrification remain a challenge, and remain a topic for future investigations. At the same time, the varied conditions under which thunderclouds develop suggest that Cu electrification and hence lightning formation might result from differing mechanisms. This statement is supported by the regional variation in Cb properties when lightning is first observed.

The objectives of the present paper were to retrieve thundercloud characteristics and to quantify the interrelations between the parameters of lightning strikes and Cu characteristics during lightning events in different parts of the world. It is postulated that thundercloud properties differ significantly according to the varying climates under study: north and south Russia, India and China. Hence, one can expect that relations between lightning characteristics and Cu characteristics will also be different, suggesting that differences in Cu electrification play an important role in lightning initiation frequency. Special attention is paid to lightning formation in a supercell Cb, which developed in the north Caucasus of Russia.

The following data illustrate a significant difference between thundercloud characteristics in Russia and China, in comparison with India. Moreover, thundercloud characteristics also differ for northern and southern Russian regions. These features can be explained by differing troposphere depth, the height of a zero-degree isotherm, and other troposphere properties: temperature, humidity, aerosol content. The observations confirm the importance of a crystal phase in Cu electrification. A volume with strong radar reflectivity above the zero-degree isotherm, a prerequisite for lightning formation, is assessed.

2. Discussion

The clouds reviewed developed in India, China, and two regions of Russia—north Caucasus and northwestern Russia in the vicinity of St. Petersburg. It was believed that different physical, geographical, and climatic conditions would influence the development of thunderclouds. Several field projects were discussed. Five groups of clouds were analyzed, which were separated according to geographical position and cloud characteristics. Four groups corresponding to the geographical regions, and one special "group", a supercell in the north Caucasus, were expected to have extreme characteristics.

The atmosphere parameters were typical for the development of continental type clouds in Russia and China. India stands out from this series because of the monsoon circulation, which is typical for this region.

Cloud characteristics were obtained with the help of measurements by radars, the SEVERI instrument on the Meteosat satellite, and several lightning detection systems. Radar reflectivity depends on the presence of big particles to a great extent. Cu electrification also depends on the interaction of graupel with ice crystals; hence, it could be expected that intensive electrification and lightning flashes will be found in the cases with high reflectivity. This was based upon numerous observations, and referred to in the introduction. Regional peculiarities of lightning formation remain a subject of interest [29][30].

Cu characteristics during their initial stage of transition to thunderclouds were studied. Cloud characteristics were compared during two consecutive radar scans: just before any flashes were observed, and during the first occurrence of flashes (within 10 min).

In the Russian regions under study, the altitudes of the maximum reflectivity H_{Zm} generally decrease while clouds are transitioning to thunderstorms, which can be associated with the intensification of the precipitation process. This process was not observed in India. The maximum reflectivity, Z_m, increases during the transition to the thundercloud stage for the clouds analyzed in Russia, which may be associated with an increase in hydrometeor sizes. In post-monsoon clouds in India, no difference in Z_m distributions was noted. Lightning strikes were accompanied by a noticeable increase in dV35 in the Russian regions, while no changes were observed in India. One of the important distinctions between post-monsoon clouds in India and continental clouds in Russia was the rarity of large ice particles (in India), which to a large extent determined the reflectivity of a cloud above the zero-degree isotherm, as noted previously [31].

The cloud top height was the only characteristic of clouds which increased during their transition to the thundercloud stage in all regions. It is the highest (the median of distribution is 13.5 km) in India and the smallest (the median is 9.5 km) in northwestern Russia, corresponding to a general increase in the depth of clouds (height of the tropopause) with a decrease in latitude.

Statistical characteristics of the clouds were studied at the period of radar scans, when LF lightning was observed just during the scans. The frequency of lightning strikes f_{LF} differed greatly among the analyzed groups. The maximum frequency was registered in Super-Cau_Gr; the median was equal to 11 min^{-1}, and the maximum was 99 min^{-1}, which fits the published data on the frequency of flashes in such clouds, which can amount to hundreds of flashes per minute [4]. High correlation between lightning frequency f_{LF} and dV35, observed in most cases, made it possible to assess the supercooled cloud volume at the time lightning flashes begin; it was equal to ~200 km^3. High correlations between the radar reflectivity at altitudes above the 0 °C isotherm and the lightning flash rate may be informed by the non-inductive charging theory. This holds that collisions among radar-sensitive, precipitating ice particles, and smaller, cloud ice particles may separate the electric charge when supercooled liquid water is present. A strong correlation between flash frequency and the supercooled volume and cloud area for the temperatures less than −5 °C was also obtained in previous experiments [18][30].

Radar measurements of cloud top heights H_r demonstrated that they differ. On average, lightning flashes were observed if the cloud top height exceeded 9.5 km. Medians in top height distributions for the groups: Ind_Gr, N-Cauc_Gr, Chi_Gr were within 11–11.3 km. The biggest median value was registered for Super-Cau_Gr, that being 16.3 km, and the lowest, for the clouds of N–W_Gr, at 9.8 km. This could be expected due to decrease in tropopause heights at higher latitudes. The minimum top height for clouds producing lightning was ~7 km. In agreement with previous studies [18][29], these data show that the echo top height needed for Cu to transition to Cb differed depending on the region and cloud character, and can be used for simple flash rate assessments. The maximum cloud top temperature when lightning was recorded was equal to −34.5 °C for N–W_Gr, but in most cases, was <−45 °C.

Medians of the distribution of maximum cloud reflectivity Z_m differed greatly. The maximum value of 67 dBZ, as expected, was in Super-Cau_Gr. The minimum median of 48.2 dBZ was observed for Ind_Gr. Z_m is greater than 52 dBZ in most of the clouds studied. An exception is that of the clouds in Ind_Gr, where lightning was observed when maximum reflectivity in most clouds exceeded 45 dBZ. The minimum recorded reflectivity was 40.5 dBZ (Ind_Gr case). The difference in reflectivity for clouds over land and ocean was mentioned earlier, also in the investigations [7]. The relationship of lightning frequency to maximum precipitation intensity can characterize the role of precipitation in formation of lightning. For the cloud groupings under study here, this relationship changed six times among the groups.

The statistical characteristics of the clouds at the moment of the occurrence of VHF flashes were considered. The median value of the distributions of lightning frequency f_{VHF} varied very significantly. It exceeded 100 min^{-1} for the clouds observed at the N-Cauc_Gr and Super-Cau_Gr, was 27.6 min^{-1} at the Chi_Grn, but was less than 1 min^{-1} for the clouds in Ind_Gr. A maximum f_{VHF}, observed during radar scans, was 725 min^{-1} at Super-Cau_Gr. The "normalized" frequency f_{VHF}/dV35 also significantly differed among the groups; some cloud volumes with high reflectivity were not the source of significant cloud electrification. Wide variations in the f_{VHF}/I and f_{LF}/I relationships show that these do not provide as much insight regarding the role of precipitation in lightning formation. Precipitation flux may be more reasonable for this task.

Relations of the frequency of LF discharges with supercooled volume and precipitation intensity were analyzed. The averaged equation between f_{LF} and dV35 was derived and can be used for f_{LF} assessments. No consistent relationships between f_{VHF} and dV35 or *I* were discovered.

Lightning currents and transferred charges were measured and assessed. Maximum currents were observed in Super-Cau_Gr. A maximum negative current was −67 kA, and positive current was +140 kA. The currents are rather big and exceed those recorded in China by 2–4 times [32]. The observed currents in the VHF range were less than those in the LF range. This is because the current in VHF flashes characterize mostly intra-cloud discharges. Transferred charges were assessed in the LF range for the lightning observed in Pyatigorsk. The charges transferred from the cloud by negative lightning totaled 387.4 C, with an average charge per flash of 0.44 C. Similarly, the charge transferred by positive lightning was 72.6 and 0.60 C, respectively.

3. Conclusions

A comparison of thundercloud characteristics in different regions of the world was conducted. The clouds studied developed in India, China, and in two regions of Russia.

Cu characteristics during their initial stage of transition to thunderclouds were analyzed. The cloud top height was the only characteristic of the clouds which increased during their transition to the thundercloud stage in all the regions. The maximum reflectivity, Z_m, and the volume, dV35, increased during the transition to the thundercloud stage for the clouds analyzed in Russia. In the post-monsoon clouds in India, no difference in Z_m and dV35 distributions was noted.

The statistical characteristics of the clouds were also studied during radar scans, when LF lightning discharges were observed. The frequency of lightning strikes f_{LF} differed greatly among the analyzed groups. The maximum frequency was registered in a supercell Cb, which developed in the Caucasus; the median of distribution was −11 min^{-1} and the maximum was 99 min^{-1}. Measurements of cloud top heights showed that the echo top height needed for Cu to transition to Cb differ, depending on the region and cloud character. On average, lightning was observed if the height of cloud top exceeded 9.5 km. Medians in top height distributions for clouds in India, North Caucasus, and China were nearly the same and fall between 11 and 11.3 km. The biggest median was registered for Super-Cau_Gr, 16.3 km, and the lowest for the clouds of N–W_Gr at 9.8 km. On average, lightning flashes were observed if the cloud top height exceeded 9.5 km.

The medians of the distribution of maximum cloud reflectivity Z_m differed greatly. The minimum median of maximum cloud reflectivity Z_m of 48.2 dBZ was observed for clouds in India. Z_m was greater than 52 dBZ in most of the other clouds studied. Post-monsoon clouds in India differ from those of other regions. Lightning strikes are accompanied by a noticeable increase in dV35 in the Russian regions, while no changes were observed in India. One of the important distinctions between post-monsoon clouds in India and continental clouds in Russia is the rarity of large ice particles (in India), which determine to a large extent the reflectivity of a cloud above the zero-degree isotherm.

Statistical characteristics of the clouds when VHF flashes occurred were considered. The median value of the distributions of lightning frequency f_{VHF} varied very significantly. It exceeded 100 min^{-1} for the clouds observed at the north Caucasus, is 27.6 min^{-1} in the Cb in China, but it is less than 1 min^{-1} for the clouds in India.

The relationships between the frequency of LF discharges and supercooled volume were analyzed. An equation describing the relationship between f_{LF} and dV35 was derived and can be used for f_{LF} assessments. On average, one lightning strike is formed per minute when a supercooled volume with a reflectivity greater than 35 dBZ is equal to ~200 km^3.

Lightning currents were measured. Maximum currents were observed in the one supercell Cb. The maximum negative current was −67 kA, and the maximum positive current was +140 kA.

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