SEVERE STORM LIGHTNING EVOLUTION PATTERN AND ASSOCIATED WEATHER HAZARDS

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ABSTRACT. Close interconnection of microphysic, dynamic and electrical properties of a cloud, owing to appropriate physical mechanisms (need further study and clarification), leads to the certain time and space sequence of the above processes during severe storm evolution. An integration of satellite, radar, DFs data makes it possible to identify lead times of the upcoming severe weather what is of great importance for timely warning. As access to more information increases, information management will become a major factor. Expert system can be developed and implemented to provide guidance for decision–making by disaster managers or in guiding on appropriate response for specific types of hazards.

INTRODUCTION

Thunderstorms become electrified shortly after they produce actively riming graupel and during this period lightning production is affected by such storm characteristics as updraft speed, rainfall rate and the interaction of storm cells. The complexity of convective cloud evolution dominated by different synoptic regimes complicates the understanding of lightning – weather hazards relationship.

Weather forecast offices began using cloud-to-ground (CG) strike locations to detect thunderstorms and to delineate storm configuration and motion. However further understanding of lightning activity and finding out reliable forecast scheme for convective cloud severity were confronted by the lack of information on its behavior as the sequence of well organized updraft and downdraft (what we name convective cell).

Evidently, the single-cell cloud is the object where such a relationship would be delineated. However the most of weather hazards are associated with multi-cell or super-cell clouds lasted for hours and produced plenty of troubles. Convective cells juxtaposition, cell development and dissipation rates (with corresponding updrafts and downdrafts), liquid water content (LWC) and vertical profile of the latent heat release (LHR) cause the impact of severe weather.

CONVECTIVE CELL DYNAMICS

Since more than 80% of thunderstorms in the S.Petersburg area are multi-cell, weather extremity diagnostics and nowcasting depend on the knowledge of convective cloud evolution. That is why multi-cell cloud dynamics investigation began with individual cell tracking during the whole lifetime based on cloud volume radar scanning every 5 minutes. Data set of 465 internal and frontal convective cells was analyzed in view of isolated or merged status. To assess the difference, these types of cells were considered separately. The cell reflectivity maximum – Z max, distance between Z max of adjacent cells – R, height of Z max – Hz max and cloud top – H were monitored during 6-8 hours of continuous observation. Convective cell lifetime – T, growth time until Z max – t_{1}, dissipation time – t_{2} were measured also.

Typical convective cell maturates within 16-24 minutes, what is 0,3 – 0,4 T, and the growth stages comes quickly to dissipation. New cell appear at distances of 13 – 15 km from the parent cloud and merge with it within 5 – 10 minutes. Importantly, the higher cloud motion speed and non-stability of the atmosphere, the more compact and dynamic cell cluster is. Then an average distance R decreases to 8 – 10 km. Cells developed within multi-cell cloud have radar parameters 1,5 – 3 times larger than that of isolated cells. This means that multi-cell clouds, being a superposition of convective elements, are more dangerous and persistent.

Updraft location and intensity are important for forecasting hazardous conditions. All dangerous thunderstorm conditions are created in updraft, these include severe turbulence, supercooled water (icing), hail, heavy rain and LF.

THUNDERSTORM EVOLUTION CHARACTERISTICS

In the absence of lighting flash (LF) sensors potential thunderstorms can be detected by weather radar. To explore the utility of accurately nowcasting CG lightning using MRL – 1 weather radar, reflectivity criterion $Y = H \cdot \lg Z_3$ was applied ($\lg Z_3$ is measured at the 4,5-5 km height). The data set of 62 thunderstorm cells (16 belong to single-cell and 46 to multi-cell thunderclouds) with 4500 lightnings was analyzed. LFs in every cell of thundercloud were detected by the P-12 (λ = 2 m) radar from the very beginning and till the end of thunderstorm [*Stasenko et.al., 1996*]. The meter band radar is able to locate and size up LF echo amplitude maxima which correspond to the cloud charge volumes incorporating to the flash, as it was stated by *Hewitt* [*1957*]. It may be possible to use amplitude maxima to track the movement of charged regions of cloud or changes in cloud charge distribution that may accompany the progression of storms from non-severe to severe stages.

Typical (average) LF rate was about 2–10 fpm, however intensifications up 30 - 60 fpm were observed. To find out reasons of such flash rate variations, vertical profiles of reflectivity Z(H) of convective cell in initial and final stage of thunderstorm were compared, as well as location and dimension of flashes relative to cloud cell structure. With respect to the above periods, the following main results were obtained:

- there is an obvious asymmetry in the cell radar characteristics at the beginning of lightning activity: Z max, Z_3, dZ/dR, H are 1,2 – 1,6 times larger on average than that of final stage. So if radar criterion is still valid for the first CG, the second half of thunderstorm is out of reliable radar identification;
- distance between adjacent cells (between Z max) in the moving thundercloud can be as small as 6–8 km what leads to the rapid LF rate intensification. Seemingly, total lightning activity during this event is dominated by intra-cloud (IC) discharges;
- an average LF radar (λ=2 m) echo dimension (projection of a flash on radial direction) during initial stage of thunderstorm is of 2-3 km and grows 2-3 times in the final stage;
- LF penetrates 2-3 km upwind of the center of a moving cell (Z max) and spreads up to 10-15 km in downwind direction;
- LF frequency distribution maximum shifted 2-4 km to the rear side of a moving cell and the faster cell moves the larger this space shift to the rear;
- horizontal dimension of LF radar echo may reach up to 50-70 km as a result of some kind of a “chain reaction” when discharge in one cell triggers the same in the adjacent cell and so on. Remarkable feature is a step-wise LF progression along the line of frontal cells (with space 6-8 km and time 0,27-0,3 sec increments).

These findings prove us that beyond the evident updraft effect on convective cell development, dynamic interaction within multi-cell thundercloud multiplies electrification process and charge accumulation zones which lead to the high flashing rate.

Some facts which are hardly explainable in the frames of a “classic approach” still need for the corresponding microphysic interpretation, for example, unusually high LF rate over 60 fpm. Uncertain is the process responsible for the effective charge supply for the every-second LF that is quite different from 8-10 sec typical time needed for charge regeneration. Seemingly, these flashes are mainly IC.

To address this very interesting feature, concurrent radiometric measurements of the cloud brightness temperature on 0.8, 1.4 and 3,2 cm were organized and revealed that:

- there are small scale (around a few km) maxima of LWC at 7-9 km height which lasted for 5-6 minutes. Space and time variations of these maxima have no tight correlation with the cell reflectivity pattern. Aircraft observations conducted in Mendoza, Argentina documented several cases when highly supercooled water of 4 g/m^3 was found at – 38^{0}C [*Rosenfeld et.al., 2000*]. The discovery that in some clouds condensed cloud water remains liquid until point of homogeneous freezing requires a major revision in cloud simulating rain, hail and cloud electrification;
- there is no time coincidence between maxima of LF rate and LWC, moreover, LF rate peak occurs upon relatively low values of cloud water content (0.2-0.3 g/m^3). That means that the regions of intensive electrization contain mainly crystal and polycrystal cloud particles. Furthermore, model and observational studies have suggested that total LF rates are correlated with the total graupel, hail mass of storms.

The most active thunderstorms are accompanied also by the unique radar phenomenon – slowly fluctuating reflection of 15-20 dB on λ = 2 m, which lasts for 30-40 minutes. No precipitation particles for such a reflection, except small-scale and persistent corona discharges. Microphysics of such events is not well known and they serve as an indicator of storm severity.

SOME RATIONALES FOR THUNDERSTORM DANGER EXPERT SYSTEM

Severe storm lightning evolution pattern correlate apparently well with weather hazards produced by this storm. However LF sensors of different design exploring the same storm will portray clouds of different severity. Growing number of LF sensors assist to physical understanding, however requirements of operative use may differ from the rest since thunderstorm is dangerous for various services and productions in different ways. For example, electric power lines suffer of ground discharges, low voltage systems (PC networks) are affected by IC lightning also, aircraft can trigger LF in a cloud which does not contain the immediate threat. So early warning criteria for different consumers should be formulated and respective techniques of sufficient POD and lead time reduced to practice.

When natural variability of thunderstorms in the local area will be investigated, an expert system can be developed and implemented to provide guidance for decision-makers in emergency situations or planning the response to hazards of specific type. Main possible capabilities of the system would be:

- knowledge of the local meteorological, orographic etc. conditions critical for convective cloud development and associated severe weather;
- comprehension of convective cloud dynamics and organization in mesoscale upon typical synoptic regimes, likelihood of severe weather or natural disaster;
- typical LF scenario for single-, multi- and super-cell clouds, LF – hail, tornado, excessive precipitation, microbursts and other violent weather events;
- thunderstorm danger relevant to specific services, productions and population (elements of danger, safety criteria);
- early warning system based on the safety criteria developed;
- protective measures (technical, organizational etc.);
- assessment of potential damage to consumer, action scenario during thundery period to minimize the losses, service and production recovery scenario;
- staff training, modeling of preventive actions.

CONCLUSIONS

1. Comprehensive study the variety of electric phenomena associated with thundercloud upon a different synoptic regimes in relation to microphysics and dynamics of the parent storm will give us predictors for weather hazards timely warning.

2. Lightning mapping system data in combination with multi wavelength radar products can gain new insight to the problem. Evidently, cloud particles of various size, concentration and physical properties contribute to charge separation and growth, and finally to LF release. LF illuminates the charge structure of a cloud. Assuming low enough conductivity inside of a thundercloud, h.e. low probability of charge supply from other cloud volumes, we can consider LF as the volume where particles of different physical properties are concentrated and charge generation process maximized. This assumption most probably holds true for places of LF origin (active electric zones) so far as further LF branching is influenced by the superposition of electric fields of the main cloud charges.

REFERENCES

Stasenko V.N., S.M.Galperin, V.I.Frolov, G.G.Shchukin, I.A.Tarabukin. Investigation of Electric and Microphysic Properties of a Thundercloud using Active-Passive Multi-wave Radar System. Proc. 10th Intern. Conf. on Atmos. Electricity, Osaka, Japan, pp.200-204, 1996.

Hewitt F.J. Radar echoes from inter-stroke processes in lightning. Proc. Phys. Soc., London, B 70, p. 961-979, 1957.

Rosenfeld D. and W.L.Woodley. Convective clouds with sustained highly supercooled liquid water until -38^0C. Proc. 13th Intern. Conf. on Clouds and Precipitation, Reno, USA, pp. 661-664, 2000.