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CHARACTERISTICS OF LIGHTNING

PART II - THE DISCHARGE AND ITS RELATIONSHIP TO THUNDERSTORM CHARACTERISTICS

In PART I (WRTA 86-16) last week, the thunderstorm's electrical field and charge separation were addressed. This week, the lightning discharge, the significance of positive strikes, and relationships between lightning and thunderstorm structure/severity will be discussed.

THE LIGHTNING DISCHARGE

As detailed in PART I, positive charge accumulates in the upper portions of the thunderstorm, and negative charge concentrates in the lower portions. As the cell approaches maturity (Figure 1), an increasing electrical potential develops between the cloud base and the positive charge induced in the earth below. However, the first breakdown in the potential likely occurs between pockets of less charge within the cloud mass. For example, intracloud lightning may develop between the negative center and the small positive area in the base, effectively transferring even more negative charge to this area. Once the breakdown potential of approximately 10^6V/m is achieved between the cloud base and the earth, a step leader is launched from the base of the cloud (Figure 2a). The step leader is a core of negatively charged particles which carries the potential of the initiating point in the cloud. The step leader movement is fast (2×10^5m/s), but not continuous, moving in 50-100 meter steps. The brief hesitation may be due to the recharging of the tip with charged particles from the base of the cloud. The luminosity of this leader is low and usually not visible to the unaided eye. By seeking a path of least resistance, it may branch several times. When the main branch of the leader approaches close to the ground (~50m), the electrical field is so strong that an upward streamer of positive ions is triggered. When this streamer meets the leader, the circuit is complete (Figure 2b). The highly luminous return stroke, carrying positive charge, shoots up the ionized channel at 5×10^7 m/s, attaining temperatures of 3×10^4 C. Negative charge is immediately lowered to the ground in the wake of the return stroke. The result is a net negative charge lowered to the ground, a negative cloud-to-ground (CG) strike. At this point, the ionized channel is at ground potential. Positive streamers, at the top of the channel, probe the cloud for additional concentrations of negative charge. If found, a dart leader races back down the ionized channel and another return stroke is triggered. Depending on the concentration of negative charge in the cloud, several return strokes may occur. The BLM directional finders (DF) count each return stroke. The time between return strokes varies from 20 to 200 milliseconds, sufficiently long that the unaided eye can detect the flicker. The most return strokes recorded by a DF is 23 at Cape Canaveral. It should be noted that many of the step leaders never complete the circuit with the ground; however, they still effectively lower negative charge towards the ground in the ionized channel.

An analogous electrical field also develops between the positively charged upper cloud and the upper atmosphere. Owing to the superior conductivity of the upper atmosphere (see PART I), this field is usually kept in check by general ion conduction. Occasionally, however, lightning has been observed between the top of a high thunderstorm and the ionosphere.

POSTIVE LIGHTNING STRIKES

This year, for the first time, positive strikes will be detected by the BLM DFs, and their locations will be made available to the users. Positive strikes, in contrast to negative strikes, transfer a net positive charge to the earth. Of all the CG strikes, only 2-3% are positive. It should be emphasized that out of all lightning strikes involving the ground (positive and negative), over 99% are cloud-to-ground (CG); only a few are ground-to-cloud. The less than 1% of ground-to-cloud strikes are usually triggered from tall structures such as towers or high buildings.

There are some important differences between negative and positive strikes. It is estimated that positive strikes are several times more powerful than negative strikes and longer in duration, which has important implications to be discussed later. Since CG positive strikes transfer a net positive charge to the ground, they usually originate from the upper portions of a cloud where the charge is concentrated. Furthermore, since there is an induced positive charge in the ground directly beneath the cloud base, positive strikes often branch to the negatively charged earth, away from the thunderstorm base. In contrast to negative strikes, positive strikes usually have just one return stroke, but of longer duration. Rust et al [1] provides photographic evidence of continuing current after a single return stroke from a positive strike.

Three situations in which positive strikes will most likely occur, according to Holle of the Weather Research Program, are explained below.

1. Positive strikes are frequently observed from thunderstorms which develop in a moderate to strong vertical wind shear. In an analysis of an outbreak of thunderstorms with an unusually high percentage of postive CG strikes, Rust, et al, [2] found that the only discriminating parameter was vertical wind shear. The thunderstorms which formed in the region of stronger vertical wind shear (850-300mb) exhibited a much higher percentage of postive CG strikes.

2. Thunderstorms which develop as cold air moves over warm water develop a high percentage of positive strikes. This has been observed over the Sea of Japan during the winter months. An analogous situation may occur in the West during spring and fall as very cold upper troughs move inland over relatively warmer ground.

3. Positive strikes are most frequently observed during the later stages of a thunderstorm as the accumulation of positive charge in the upper portions of the cloud extends downstream in the anvil.

SIGNIFICANCE OF VERTICAL DEVELOPMENT

Goodman, et al [3], in an analysis of the 3-dimensional locations of lightning during the mature stage of a severe thunderstorm in Oklahoma, found that the mean height of lightning-generated electromagnetic impulses was 6.9km, which corresponded to an environmental temperature of -20°C. This was supported by Holle and Maier [4], who determined relationships between vertical cloud dimensions and CG lightning involving thunderstorms over Florida. CG lightning strikes were coordinated with hourly radar-determined echo height observations (Figure 3). The analysis of 553 cases revealed that the minimum echo height associated with a CG strike was 7.8 km, corresponding to an environmental temperature of -18°C. These data were further filtered by plotting only those thunderstorms with more than one CG strike during a 10-minute interval against echo height (Figure 4). This graphic clearly demonstrates a strong relationship between CG lightning rates and vertical storm development. Those thunderstorms with greater than 2 CG strikes/minute had tops above 12 km. While it can be argued that there are significant differences between Florida thunderstorms and those in the western U.S., the point here is that there is an apparent relationship between CG rates and the degree of updraft penetration through approximately the -20°C level. For example, in the northern portions of the Western Region during the spring and fall, it's not unusual for migratory cold upper troughs (low -20°C level) to trigger moderate thunderstorms with frequent lightning, even though thunderstorm tops average below 6km.

In an Eastern Region Technical Attachment [5], a correlation was found between radar echo tops above the -20°C level and reported lightning. Most investigators believe that the penetration of updrafts through the -20°C environmental temperature is a key threshold in the charge separation process. More research is needed in this area; however, it can be hypothesized that as more water is transported through the -20°C isotherm, lightning activity will intensify. If this is the case, this transport of water will be dependent upon the strength of the updrafts, which in turn, is well-correlated with thunderstorm severity.

TEMPORAL AND SPATIAL RELATIONSHIPS

The temporal and spatial relationships of CG strikes have been researched more frequently in recent years. It's been observed that negative CG strikes are most prevalent during the late development to mature stage of a convective cell and are generally concentrated near the updraft core. Positive CG strikes are most common during the dissipation stage of a cell and usually originate from the upshear or downshear anvil region (Figure 5). Several investigators have found correlations between lightning and storm reflectivity and updrafts. Goodman 3 , in an analysis of a severe thunderstorm, found that lightning impulses were concentrated near the mesocyclone core and zone of high reflectivity, as shown in Figure 6. This concentration of impulses decreased as soon as the mesocyclone began to decay. Fuquay [6] in a study of positive CG lightning in western Montana, found that positive flashes usually occurred during the final 30 minutes of a thunderstorm. While intracloud flashes may have occurred with the positive CG strikes during this period, negative CG strikes were noticeably absent. Fuquay also observed that the positive CG flashes often extend horizonatally away from the cloud, before branching to the ground. During 3 summer seasons in western Montana, only 3% of the total CG strikes were positive.

LIGHTNING ACTIVITY AND SEVERE WEATHER

The relationship between lightning intensity and severe thunderstorm is much more dubious. Maier and Krider [7] compared lightning characteristics of Florida air mass thunderstorms with severe thunderstorms in Oklahoma, and found the following:

1. In general, the CG lightning rate for severe thunderstorms was greater. Severe thunderstorm CG rates averaged 2-6/minute while the air mass thunderstorms averaged 1/minute.

2. CG lightning associated with severe thunderstorms was much more organized and exhibited tighter clusters, which translated with the storm.

3. During three Oklahoma thunderstorms which produced tornadoes, CG rates were quite low during periods of tornadic activity, but increased and peaked after the tornadoes dissipated. This suggests that the CG lightning data has little predictive value for tornadic activity.

Rust, et al [8] have also compiled characteristics comparing lightning in non-severe air mass thunderstorms and severe storms (Figure 7). The lightning data are consistent with those found by Maier above. Mazur and Rust [9], in an analysis of multicelled thunderstorms, found a positive correlation between maximum lightning density and the merging of two cells, a known indicator of potential severe weather.

In the Western Region, flash flooding is an important problem during the convective season; however, no definitive relationships between lightning frequency and rainfall have been established. In a few undocumented cases in 1985, post analyses of flash flood events correlated well with negative CG clusters in the Western Region. We hope to catologue more of these events during the 1986 season. Another important consideration for the Western Region this year is the identificaton and location of positive CG strikes. Since positive strikes are stronger and impact away from the heavier rains near the storm center, these strikes are potential fire starters.

SUMMARY

In these two technical attachments, information was presented to familiarize the forecaster with the characteristics of lightning and recent investigations relating lightning to storm structure/severity. There are still many unanswered questions which investigators continue to pursue. From the data presented, positive correlations have been shown between the degree of lightning activity and vertical storm structure, updraft strength/penetration and radar reflectivity. Although there is evidence supporting relationships between lightning activity and severe weather, it cannot be assumed that observed intense lightning activity implies a severe weather event. Particularly in the West, intense and spectacular lightning displays often accompany high-based, non-severe thunderstorms. However, well-organized and frequent CG strikes, as displayed on AFOS and alphanumeric-type graphics, should alert the forecaster to the possible existence of significant convective weather.

With the new software available to the users this year, offices can define rectangular areas and set lightning count threshold values for a 30-minute period. If this threshold is exceeded, an alarm will automatically be sent to the office with warning responsibility. We encourage all offices to make use of this new tool to identity "hot spots" which may be related to significant convection and possibly heavy rainfall.

References:

[1] Rust, W.D., D.R. MacGorman, and W.L. Taylor, 1985: "Photographic Verification of Continuing Current in Positive Cloud-to-Ground Flashes", Journal of Geosphysical Res., Vol. 90, pp. 6144-6146.

[2] Rust, W.D. and D. R. MacGorman, 1985: "Unusual Positive Cloud-to-Ground Lightning in Oklahoma Storms on 13 May 1983", Preprints: 14th Conference on Severe Local Storms, pp. 372-375.

[3] Goodman, S.J., R.J. Doviak, and D.R. MacGorman, 1983: "Lightning Location in a Severe Oklahoma Thunderstorm", Preprints: 12th Conference on Severe Local Storms, pp. 326-329.

[4] Holle, R.L. and M.W. Maier, 1983: "Radar Echo Height Related to Cloud-to-Ground Lightning in South Florida", Preprints: 12th Conference on Severe Local Storms, pp. 330-333.

[5] Kieltyka, F. and J. Torrence, 1985: "20 Below Celsius...A Number to Remember", Eastern Region Technical Attachment, July 1985.

[6] Fuquay, D.M., 1982: "Positive Cloud-to-Ground Lightning in Summer Thunderstorms", Journal of Geophysical Res., Vol. 87, pp. 7131-7140.

[7] Maier, N.W. and E.P. Krider, 1983: "A Comparative Study of Cloud-to-Ground Lightning Characteristics in Florida and Oklahoma Thunderstorms", Preprints: 12th Conference on Severe Local Storms, pp. 334-337.

[8] Rust, W.D. and D.R. MacGorman, and R.T. Arnold, 1981: "Positive Cloud-to-Ground Lightning Flashes in Severe Storms", Geophysical Res. Letter 8, pp. 791-794.

[9] Mazur, V. and W.D. Rust, 1985: "Evolution of Lightning Flash Density and Reflectivity Structure in a Multicell Thunderstorm", Preprints: 14th Conference on Severe Local Storms, pp. 363-367.

[10] Doswell, C.A., 1985: "The Operational Meteorology of Convective Weather, Vol. II", NOAA Technical Memorandum ERL ESG-15, pp. 193-203.

[11] Pierce, E.T., 1982: "Storm Electricity and Lightning", Thundertorm Morphology and Dynamics, Vol. II, NOAA, pp. 447-463.

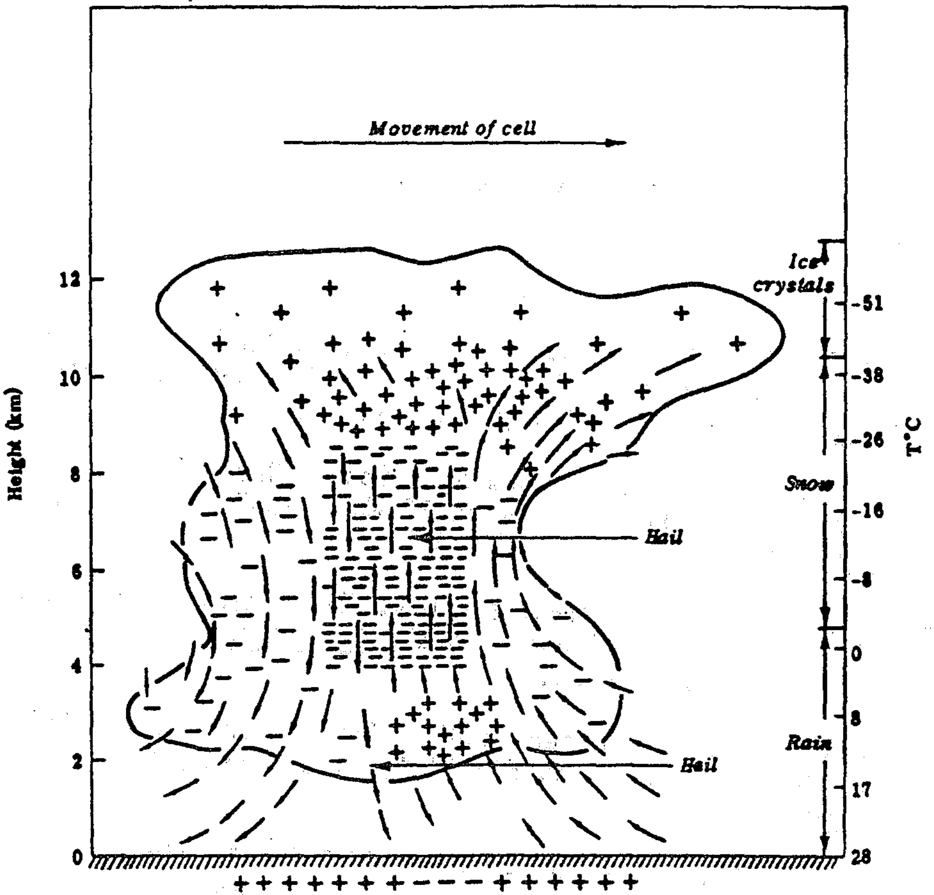

FIGURE 1. Cross section through very active convection cell showing temperature, vertical air velocity and charge distribution (after L. B. Loeb, *Modern Physics for the Engineer*, p. 330. McGraw-Hill, New York, 1954).

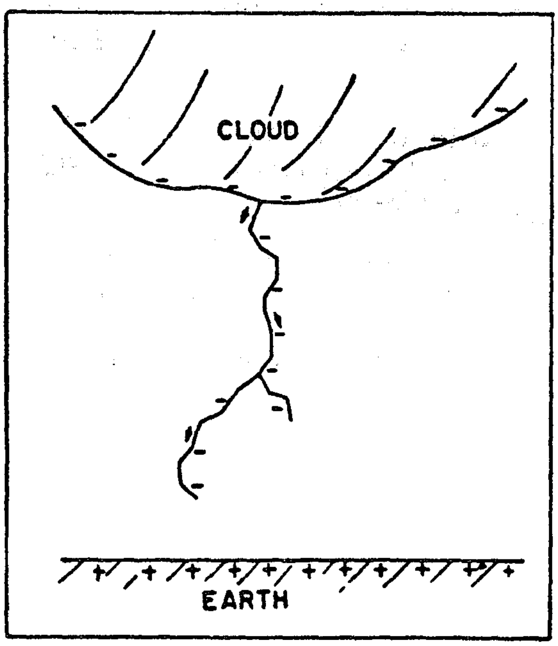

FIGURE 2A

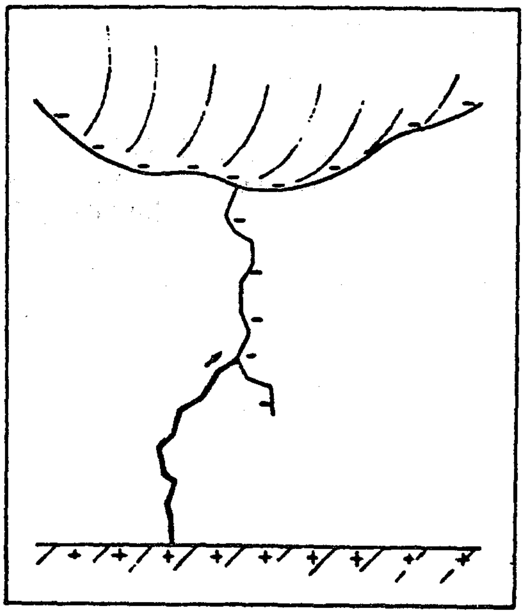

FIGURE 2B

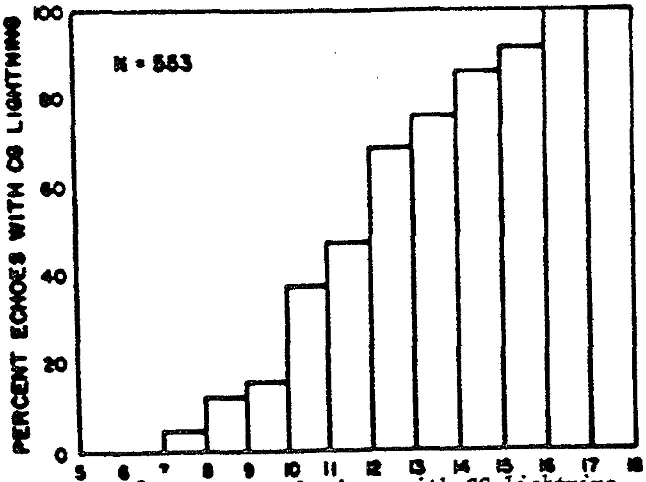

Figure 3. Percent of echoes with CG lightning within ± 5 min of the radar observation time as a function of radar-observed echo height.

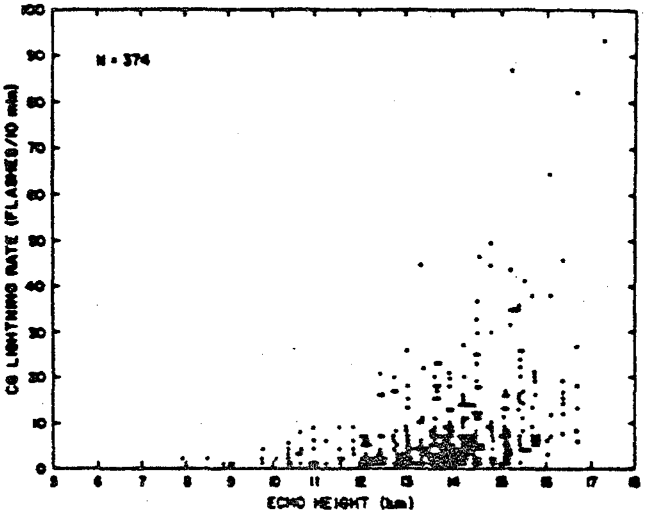

FIGURE 4. *Mean CG lightning rate during the 10-min period centered on the radar observation time as a function of the radar-observed echo height. Storms with one flash are not plotted.*

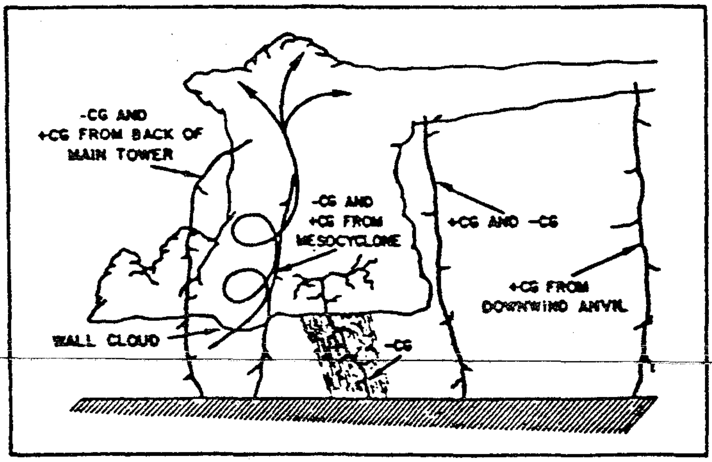

FIGURE 5. *Sketch of observed locations and polarities of CG flashes from severe thunderstorms. The spiral denotes the region of intense updraft and rotation. Only negative CG flashes have been observed in the precipitation core. The +CG flashes seem to constitute only a very small percentage of the total flashes to ground (from Rust et al., 1981).*

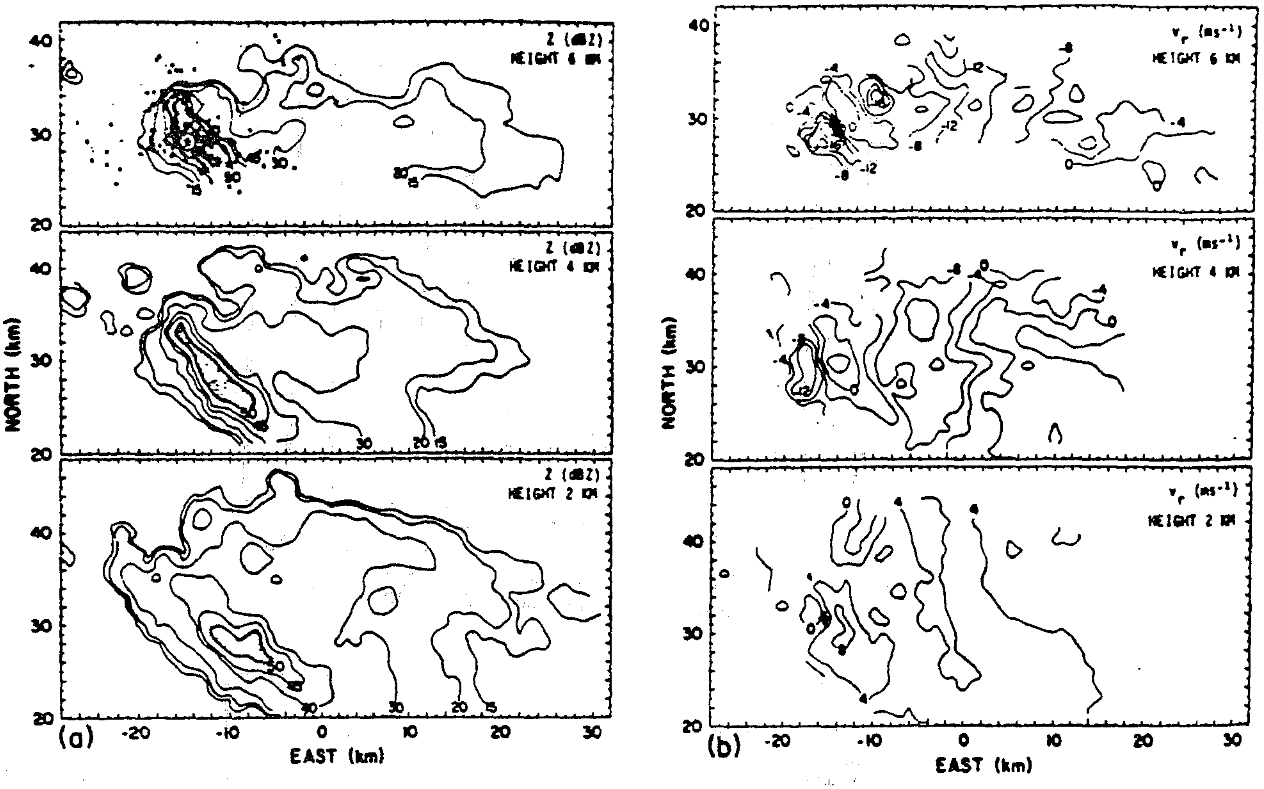

FIGURE 6. *Plot of radar data at the 2, 4, and 6 km levels from 190212-191408 CST. Distances are north and east of the Norman Doppler radar. (a) Reflectivity contours Z > 50 dBZ is stippled. The VHF impulses produced by 3 IC and 2 CG flashes superimposed on the 6 km level are indicated by small dots and large dots, respectively. The mesocyclone vortex core is indicated by a star on the 6 km level plot. (b) Radial velocity (m·s^{-1}).*

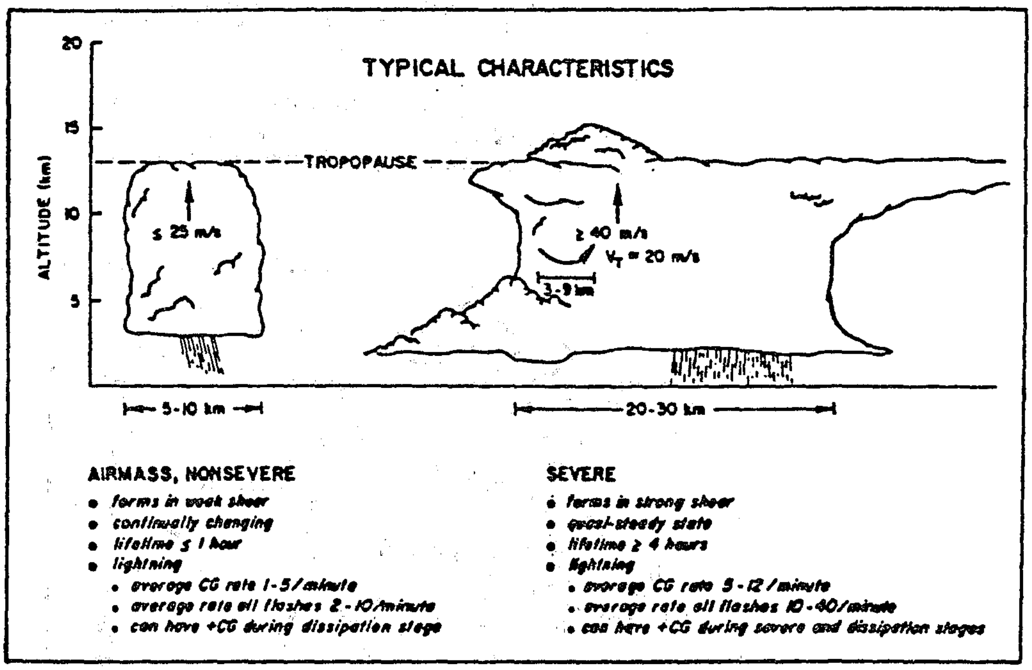

FIGURE 7. *Oversimplified depiction of apparent differences between very small ("airmass", nonsevere) storms and supercell, severe storms. Other differences are likely (from Rust et al., 1981).*