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CHARACTERISTICS OF LIGHTNING

PART I - ELECTRICAL FIELDS AND CHARGE SEPARATION

INTRODUCTION

The Western Region has been involved in the collection and dissemination of real-time lightning data since 1982. Due to the paucity of radar and manual observations in the region, the lightning data have proven to be a valuable tool in the detection of thunderstorms. As hardware and software advances have increased the utility of this information, we look forward to even more success in 1986. The BLM has installed more accurate and reliable direction finders which will also be able to detect positive strikes. Additionally, new software will detect "hot spots" and automatically alert the office of responsibility.

These two technical attachments (Part I this week and Part II next week) will review the global electrical field, charge separation, the mechanics of lightning strikes and investigations relating lightning strikes to thunderstorm evolution and severity. This information was obtained from many sources, including conversations with Ron Holle, Weather Research Program, Environmental Research Laboratory, NOAA, Boulder, Colorado.

GLOBAL ELECTRICAL FIELD

Under normal conditions, the earth is negatively charged with respect to the upper atmosphere (ionosphere). In many respects, the earth and ionosphere are analogous to a charged spherical capacitor (Figure 1). This charge is maintained by the estimated 2000 thunderstorms occurring simultaneously around the globe, at any given time. Since both the ionosphere and earth are excellent conductors, these charges are distributed evenly and rapidly. The atmosphere in between is nearly dielectric (poor conductor), although there is a weak continuous current, averaging 3×10^{-12} amp/m^2. This weak current, positive to negative, is called the "fair weather" field and has a distinct diurnal variation which correlates well with global thunderstorm activity (Figure 2). Additionally, empirical studies have shown that the electrical current generated by global thunderstorm activity, and interchanged with the earth and ionosphere, nearly balances the measured fair weather current.

The conductivity of the atmosphere depends on ion formation. Ions, positive and negative charged particles, are produced in the lower atmosphere by radioactive decay of elements, and in the upper atmosphere by solar ultraviolet light and cosmic rays. The degree of atmospheric conductivity is related to ion number, size, lifetime, and mobility. Ion mobility is limited in the lower atmosphere because of increased density and because ions frequently attach to large, slow moving aerosol particles. Ion mobility and atmospheric conductivity increase logrithmically with height as shown in Figure 3. The overriding factor in the increased conductivity (ion mobility) is due to decreased atmospheric density. As a result, the lower portions of the atmosphere are the least conductive, and it is this region where the greatest electric potentials develop.

THUNDERSTORM CHARGE SEPARATION

Although it is accepted that global thunderstorm activity maintains the earth-ionosphere potential, the method of charge separation within thunderstorms is still a fundamental problem, without definitive answers. Investigators have shown that various pockets of charge develop within a thunderstorm; however, there is a concentration of negative charges in the thunderstorm base and positive charges in the upper portions (Figure 4). The many competing theories of thunderstorm charge separation include selective ion capture, freezing effects involving impurities, induction by the fair weather field, and charge transfer during particle collisions. Discussion of these theories can be quite complex and will not be addressed here. However, several theories are based upon the phase-change relationships of water. Stow [1] has shown that when hail, ice crystals, and super-cooled droplets are present in the same region of a cloud, it often becomes very thermoelectrically active. One consequence of this mixture is that the relatively warm hail pellets acquire a negative charge while falling through ice crystals. There is little doubt that these phase change relationships play an important role in charge separation, especially in mid-latitude thunderstorms where the updrafts penetrate into the cold upper tropospheric air.

The electrical charges in a convective cell begin to polarize late in the growth stage of towering cumuli, as significant updrafts develop. As Holle and Maier [2] found over Florida, lightning activity began only after the development of deep cumuli with strong vertical motions, and hydrometeors in a mixed (ice and water) phase. As a result of convective and gravitational influences, the heavier negatively charged ice particles concentrate in the lower sections of the cloud while the lighter positively charged particles accumulate in the upper portions (Figure 4), resembling a positive dipole configuration. The largest concentration of negative charge is usually near the mid to lower sections of the storm, close to the updraft core. As the negative charge in the lower cloud increases, it effectively induces an equal positive charge in the earth below. This area of induced positive charge in the earth translates with the storm, like an invisible shadow. As the potential gradient increases between the earth and the base of the cloud, positive ions begin streaming into the higher points of the ground below (trees, towers, etc). As shown earlier, the electrical conductivity in the lower few kilometers of the atmosphere is very weak; therefore, a strong potential must develop before the electric field breaks down.

In addition to the primary concentrations of charge in the thunderstorm, there are many other pockets of lesser charge throughout the cell. For example, a small concentration of positive charge is often found in the base, near the strongest updraft/downdraft boundaries (Figure 4). This accumulation of charge is not completely understood, however, it may be the result of the stripping of positive ions from the earth by the increasing electrical field and the subsequent transport in the updraft.

A thunderstorm becomes so electromagnetically active by the time it reaches the mature stage, that it's very difficult to measure the electrical field. Figure 5 illustrates the approach and passage of a very weak thunderstorm. Before the approach of the storm, the fair weather field exhibits a positive potential gradient of 900 V/m. As the negatively charged base moves closer to the sensing site, the gradient reverses, becoming strongly negative. The sharp spikes in the graph represent lightning strikes attempting to neutralize the strong electrical field.

In Part II, next week, the lightning discharge, positive lightning strikes and relationships between lightning and thunderstorm structure/severity will be discussed.

References:

[1] Stow, C.D., 1969: "Atmospheric Electricity," Rep. Prog. Phys., 32:1-67.

[2] 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, January, pp 330-333.

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

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

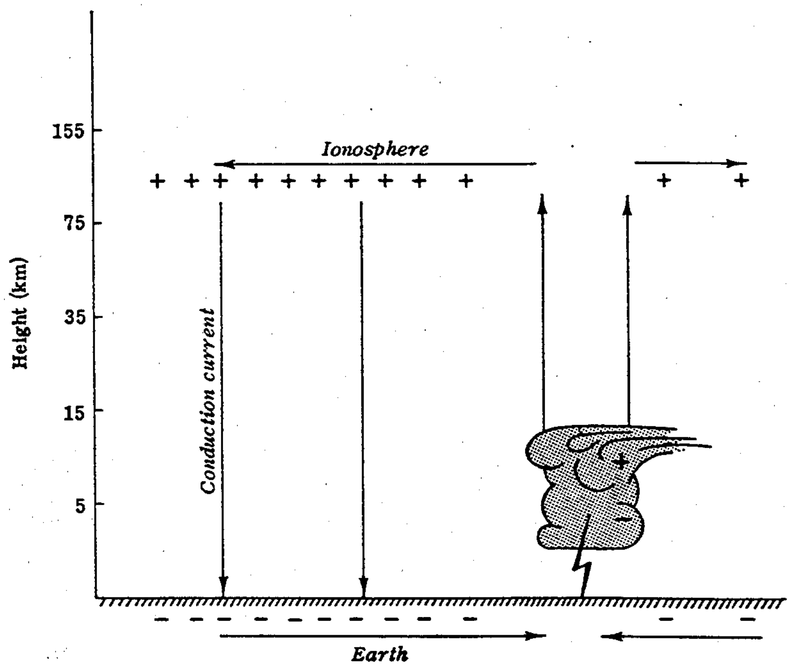

FIG. 1. Charge generation by thunderstorms, the charge distribution in the earth and ionosphere and the positive conduction current.

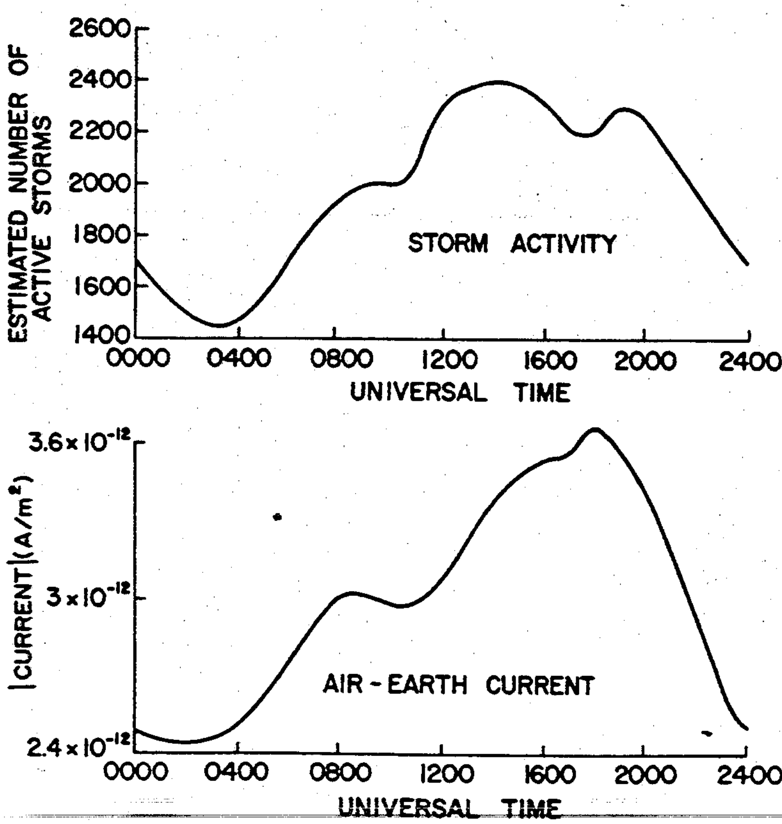

Figure 2.--Comparison of diurnal variations with Universal Time of global thunderstorm activity and of the fair-weather, air-Earth current.

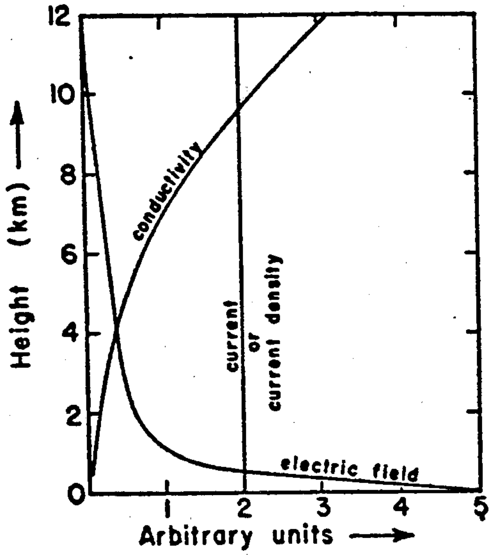

FIGURE 3.

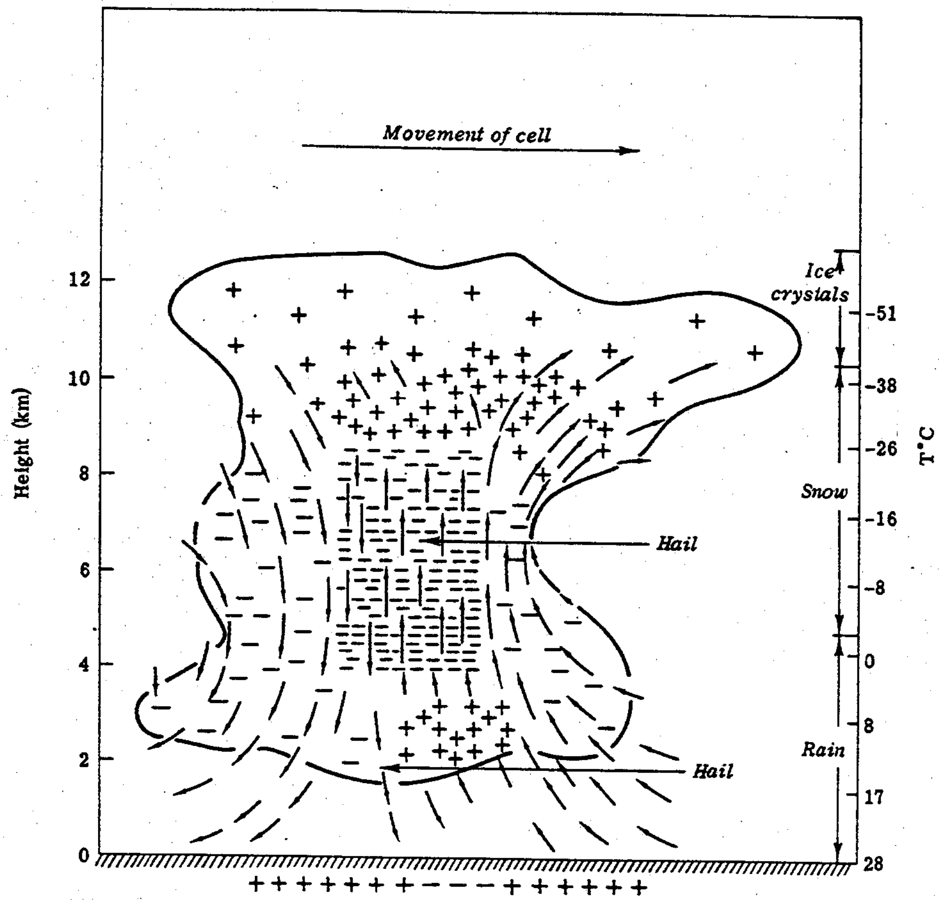

FIGURE 4. Cross section through very active convection cell showing temperature, vertical air velocity and charge distribution (after L. B. Loeb, *Modern Physics for the Engineer*, p. 330. McGraw-Hill, New York, 1954).

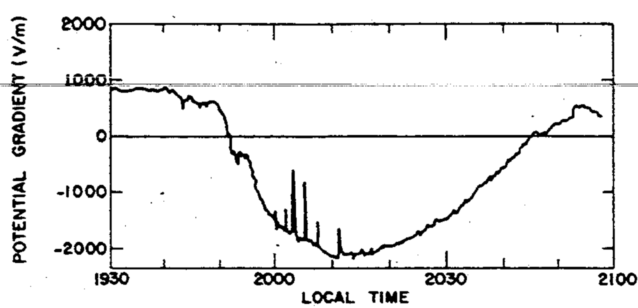

FIGURE 5.--**Potential-gradient variation during approach and retreat of a very weak thunderstorm.**