THUNDERSTORMS, CHARGES AND CURRENTS

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Abstract

In the early part of the twentieth century, the diurnal variations of the fair weather electric field as a function of universal time (UTC) were characterized by the Carnegie and Maud research ships [e.g.,Whipple, 1929; Torreson et al., 1946]. The source of these variations in the global electric circuit (GEC) was theorized to trace directly to the diurnal variations in thunderstorms and electrified shower clouds [Wilson, 1921; Williams, 2009]. Much subsequent research on the global electric circuit has focused on linking the fair weather field variation, commonly called the Carnegie curve, to worldwide variations in electrified weather by using the proxy of thunderstorm or lightning statistics [e.g., Mach et al., 2011discussion]. What resulted from this research was long standing, unresolved scientific riddle: the diurnal variation global thunderstorm (and lightning) activity was in phase with but nearly twice the amplitude of the Carnegie Curve! A necessary and important step needed to address and solve this long standing discrepancy was providing actual observations of the electric current output and associated electrical generator strength of thunderstorms.

Keywords: Atmosphere, Thunderstorms, Current, global electric circuit

Introduction

In fair weather, when there are no thunderstorms around, the electrical nature of the lower to middle atmosphere is in a state of quasi static equilibrium. Below the ionosphere, the atmosphere is weakly conducting with conductivity increasing exponentially with increasing altitude. A current flows from the lower ionosphere to the ground. The overall electrical structure of the atmosphere below the ionosphere is usually described as a spherical capacitor filled with slightly conductive medium. The outer shell of the capacitor is the highly conductive region or ionosphere of the upper atmosphere.

The Earth's surface, which is the inner shell of the spherical capacitor, is very conductive compared to the lower atmosphere. A resistance of 200 ohms (approximately) exists between the surface and the ionosphere. The capacitor is charged with roughly 5×10^5 C of negative charge on earth and an equal positive charge in the atmosphere. As the atmosphere is weakly conducting, there is a leakage current that would neutralize the charge on the earth and atmosphere within 10 minutes.

[Peltier, 1842] stated that the earth was negatively charged but he did not address how to maintain the charge in the presence of leakage current. [Wilson, 1920] proposed that thunderstorms are the generators in a global electric circuit that can sustain the leakage currents. Placing a thunderstorm in the atmosphere will produce so-called Wilson current, from the cloud top to the ionosphere. This in turn produces a current back down through the global atmosphere along the surface, and underneath the storm. Together these 'circuit elements' are known as the GEC, Global Electric Circuit (Fig. 1).

At the ground level, the GEC creates a variable electric field, averaging 100 V/m in fair weather [Bering, 1998]. According to the Wilson hypothesis, a global total electric current of 1kA flows from all the thunderstorms in the troposphere into the ionosphere, eventually returning to the ground through the fair weather atmosphere and closing via lightning activity.

I.

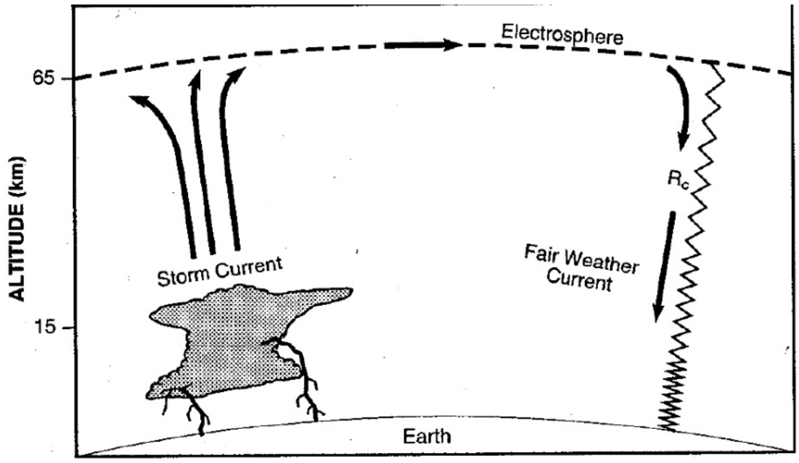

Figure:1 : Global Electric Circuit., From [MacGorman, 1998].The Wilson current is labeled "Storm current" and is represented by the three upward pointing lines with arrowheads.

The Electrical Structure of Thunderstorms

In the eighteenth century, Benjamin Franklin established that negative charge was usually present in the thunderstorm but sometimes positive charge was also observed. Around 1800's some investigators suggested that both positive and negative charge co-existed in thunderstorms. It was not possible to determine the charge structure until new instruments were developed. Based on ground field mill measurements and electric field changes, $\vec{E}$ changes from lightning [Wilson,1916] and [Wilson,1929] suggested that thunderstorms typically have a dipole structure. Recent balloon borne measurements have shown that these charge structures are almost always more complicated than an electric tripole. In particular, the work by [Stolzenburg, 1998c] has shown that the charge structure of a thundercloud is significantly more complex, with four charge regions (tripole structure, plus screening layer) within convective updrafts and six (or more) charge regions outside of these updrafts as seen in (Fig.2). The main positive (UP), main negative (MN), and lower positive (LP) charge regions within the convective updraft are most often associated with the lightning flashes.

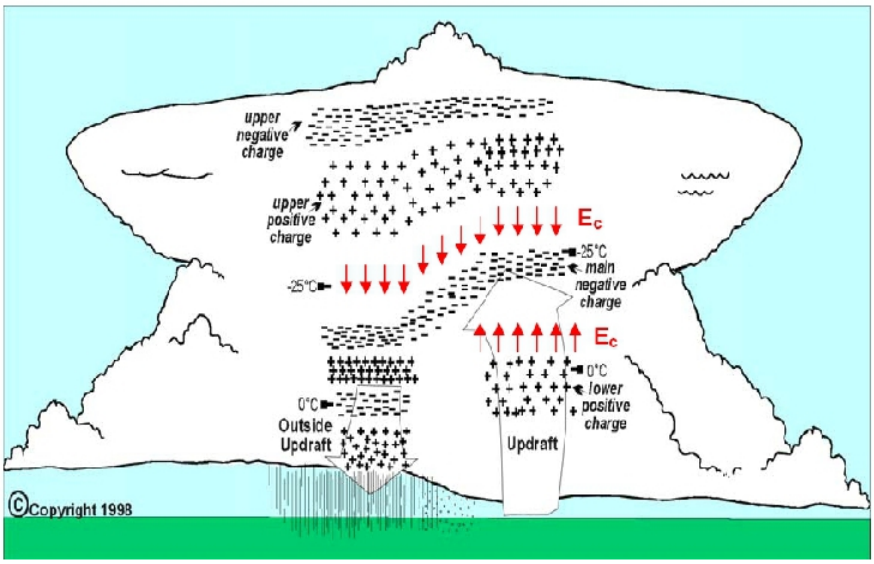

Figure: 2: Structure Of a thunderstorm with updrafts. Modified from Stolzenburg, 1998c.

Thundercloud Charges and Lightning

It is often assumed that lightning travels through the charge regions of the storm (e.g. [Reynolds, 1955], [Krehbiel, 1979]). Studies show that storms typically exhibit three layers of lightning activity with two regions of negative polarity breakdown indicating the presence of the UP and LP charge regions and one region of positive polarity breakdown interpreted as occurring in the MN charge region. In particular intra-cloud (IC) flashes effectively move negative charge from the MN charge region to the UP charge region, while cloud-to-ground(CG) flashes effectively move negative charge from the MN charge region to the earth and usually to the LP charge region (e.g. [Coleman,2003]).

Measurements of the Generator and Wilson Current

Currents in the storm environment include those in the internal generator, those from the storm top (Wilson current), cloud flashes, ground flashes, precipitation, corona, and convective air flow (both vertical and horizontal) near and in the cloud. Until recently, strategies aimed at determining the total current budget of a thunderstorm were mostly attempts to measure every conceivable current source, to estimate those not easily measurable and to total them all to derive the net current from a single storm to get a grand total. Integrating the vertical component of , z measured during a balloon soundings with height, a vertical electric potential profile of the storm can be made. *Marshall and Stolzenburg* [1995] presented electric potential profiles through 13 storms and found that voltages relative to the ground within thunderstorms ranged approximately between ±100 MV.

The internal generator current that exists between the different charge regions of a thunderstorm is also known as the charge separation current. A lightning flash temporarily reduces the magnitude of the in-cloud electric field. The recovery of the electric field after the flash indicates that charging mechanisms within the storm regenerate the charges neutralized by lightning. The in-cloud electric field may not be a necessary factor for thunderstorm charge generation mechanisms, the value of the electric field plays a greater role in influencing how, where, and when a lightning flash initiates. Also, the generator should be able to replenish the charge taken away by lightning between two consecutive flashes. As stated earlier, the Wilson current flows from the top of the thunderstorm to the upper atmosphere to the ionosphere to charge the global circuit and thereby supply the fair weather current. Wilson currents above thunderstorms have been estimated with aircraft measurements by [Gish, 1950] to be 0.5 A at 12 km over 21 storms. [Stergis, 1957] determined an average current of 1.3 A from 25 balloon flights. Also another study by [Blakeslee, 1989] showed the Wilson current varied between 0.09A and 3.7A above storms with an average of 1.7A for 15 flights. The modeling used by *Davydenko et al.* [2009] uses a set of steady state horizontal layers of external currents for two storms one in the great plains and the other in New Mexico.The Wilson current calculated from those two storms were 0.53A and 0.16A. These numbers are in reasonable agreement with the observed discharging current in fair weather regions of about 1000 A over the entire globe. *Bering et al.* [1998] measured the total current over the top of a single thunderstorm and found a value of 2.5 A from a balloon borne storm observation. Very recently, *Mach et al.* [2009] using aircrafts, measured the total upward current flow from storms. The mean peak current density was 1.9 nA/m2, and the median value was 0.6 nA/m2. Assuming the cylindrical symmetry of the storm they calculated the Wilson current to be ranging from -1.3 to 9.4 A with a mean value of 0.8 A. The amount of current flowing to the ionosphere can be directly be measured at locations above thunderstorms *Blakeslee and Vonnegut* [1989], but these measurements alone do not indicate how thunderstorms act as generators in the global electric circuit.

Conclusion

Some of the most intriguing and pressing questions that scientists are facing in the 21st century are whether or not the global climate is changing, and if so, by what factor and by what primary cause? To adequately address these questions, we must perform reliable and in-depth studies over a broad range of global systems. Of particular interest are those systems associated with the planet's equilibrium processes. One such equilibrium process is referred to as the global electric circuit.An accurate measurement of the area where charges are enclosed and an accurate value of in-cloud conductivity would give us a better value of the generator current and hence help us understand the global electric circuit.

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