Global Electric Circuit Diurnal Variation Derived From Storm Overflight and Satellite Optical Lightning Datasets

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ABSTRACT: We have combined analyses of over 1000 high altitude aircraft observations of electrified clouds with diurnal lightning statistics from the Lightning Imaging Sensor (LIS) and Optical Transient Detector (OTD) to produce an estimate of the diurnal variation in the global electric circuit. Using basic assumptions about the mean storm currents as a function of flash rate and location, and the global electric circuit, our estimate of the current in the global electric circuit matches the Carnegie curve diurnal variation to within 4% for all but two short periods of time. The agreement with the Carnegie curve was obtained without any tuning or adjustment of the satellite or aircraft data. Mean contributions to the global electric circuit from land and ocean thunderstorms are 1.1 kA (land) and 0.7 kA (ocean). Contributions to the global electric circuit from ESCs are 0.22 kA for ocean storms and 0.04 kA for land storms. Using our analysis, the mean total conduction current for the global electric circuit is 2.0 kA.

1. INTRODUCTION

We have been measuring the electric field and atmospheric conductivity over electrified clouds for many years [e.g., Blakeslee et al, 1989; Bailey et al., 1999; Bateman et al., 2010]. By combining the mean currents and flash rates associated with land/ocean storms derived from aircraft overflights [Mach et al., 2010] with the diurnal variations in global lightning rates derived from satellite observations [e.g., Bailey et al., 2007], we are able to estimate the total current and diurnal variation in the global electric circuit [Mach et al., 2011]. The resultant diurnal variation closely matches the Carnegie curve. The two datasets used to derive our estimate of the global electric circuit are totally independent and the analysis and results include the contributions from both thunderstorms and electrified shower clouds (ESCs).

2. INSTRUMENTATION

2.1 Overflight dataset

The 1040 overflights of electrified clouds were obtained by three different aircraft. The first was the NASA ER-2 aircraft [Heymsfield, et al., 2001], the second was the Altus unmanned aerial vehicle [Farrell et al., 2006], and the third was the NASA Global Hawk [Bateman et al., 2010]. All aircraft were directed to target storms based on mission objectives and remote sensing data.

The electric field vector (e.g., E_X, E_Y, E_Z, and Q) was determined by the analysis of observations from the field mills (electric field meters) [Bateman et al., 2007] on the aircraft. The conductivity data were derived

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from atmospheric model data [Blakeslee, personal communication, 2011] (Global Hawk) or from Gerdien capacitor conductivity probes [Mitchell et al., 1990; Bailey et al., 1999] (ER-2 and Altus). More detailed information about the instrumentation is contained in Mach et al. [2009; 2010].

*2.2 **Satellite Dataset***

The satellite-based data are from the Lightning Imaging Sensor (LIS) and Optical Transient Detector (OTD) instruments. Details of the instruments are contained in other studies [e.g., Christian et al. 1996; Koshak et al., 2000]. The global lightning diurnal variation (in UTC) from the LIS/OTD satellite data comes from Bailey et al. [2007].

3. RESULTS

*3.1 **Overflight data***

We analyzed 1040 overflights of electrified clouds collected over a 17 year period from 1993 to 2010 (Table 1). The overflights were divided into four groups depending on their location (land, ocean) or electrical activity (lightning, ESC). Land storms with lightning have a mean current of 0.95 A while ocean storms with lightning have a mean current of 1.7 A. The mean flash rate for land storms with lightning is 2.2 flashes min^{-1} and the mean flash rate for ocean storms with lightning is 0.8 flashes min^{-1} [Mach et al., 2010]. Land ESCs have a mean current of 0.17 A and ocean ESCs have a mean current of 0.41 A [Mach et al., 2010].

Table 1 Field program overflight statistics

Campaign (month, year)	Lightning	No Lightning	Land	Ocean
TOGA-COARE (Jan-Mar, 1993)	14	64	19	59
CAMEX-1 (Sep-Oct, 1993)	13	25	15	23
CAMEX-2 (Aug-Sep, 1995)	29	7	11	25
TEFLUN-A (Apr-May, 1998)	39	8	43	4
TEFLUN-B (Aug-Sep, 1998)	35	3	35	3
CAMEX-3 (Aug-Sep, 1998)	37	38	19	56
TRMM-LBA (Jan-Feb, 1999)	192	63	255	0
CAMEX-4 (Aug0Sep, 2001)	52	35	22	65
ACES (Aug, 2002)	76	22	80	18
TCSP (Jul, 2005)	55	43	15	83
GRIP (Aug-Sep, 2010)	65	125	14	176
Totals	607	433	528	512

*3.2 **Satellite data***

To create the diurnal lightning rate data, Bailey et al. [2007] analyzed 5 years (April 1995 to March 2000) of OTD data and 8 years (December 1997 to December 2005) of LIS data. Gridded flash products (2.5º x 2.5º resolution bins) are used in the analyses. The flash locations and rates were divided into the major continents (i.e., land) and ocean data. For our analysis, we combined the UTC diurnal variation of all continents into a single “land” diurnal variation and used the remaining ocean contribution as our “ocean” diurnal variation.

*3.3 **Combined data***

Combining our mean flash rates for all ocean and land storms with the global diurnal flash rate statistics from LIS/OTD, we can estimate the number and total currents produced by land and ocean storms with and without lightning (Figure 1). The mean conduction current from lightning producing land storms is 1.1 kA while the mean conduction current from lightning producing ocean storms is 0.7 kA. The mean current from ocean ESCs is 0.22 kA and the mean current from land ESCs is 0.04 kA. The total mean conduction current is 2.0 kA. Our analysis indicates that the largest contributing group of storms is land thunderstorms which have an average count of about 1100. The next largest group of storms is ocean ESCs (mean storm count of 530). This is followed by ocean thunderstorms (mean storm count of 390). The smallest group is land ESCs (mean storm count of 330).

3.4 Comparison to Carnegie curve

Comparing the relative magnitudes of the Carnegie curve with the total current diurnal variations produces an interesting result (Figure 1). The two diurnal variations agree to within 4% except during two brief periods. We assume that the diurnal variation of ESCs (not measured by LIS/OTD) follows the diurnal variation of lightning storms (measured by LIS/OTD) and that the relative occurrence of lightning storms and ESCs are close to what we found in our overflight data.

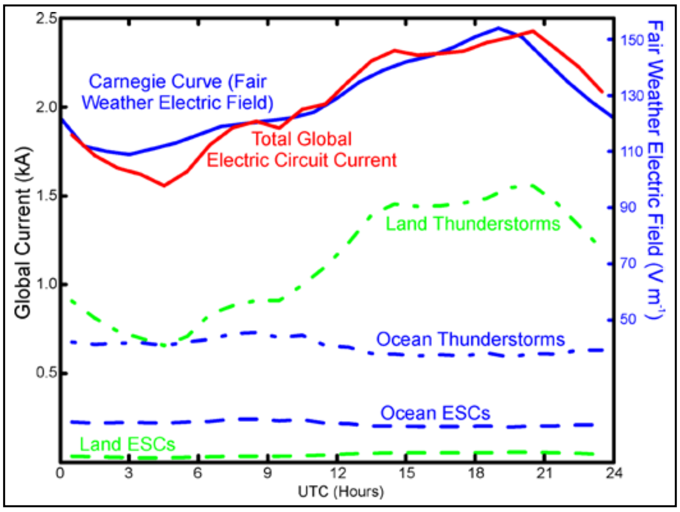

Figure 1. Global electric circuit total generator current (left axis) plus Fair Weather Electric Field (Carnegie curve, right axis).

4. DISCUSSION

Using these data sets (LIS/OTD land/ocean lightning diurnal variations and storm overflight mean currents and lightning rates) alone, we are able to create an estimate of the diurnal variation in the global electric circuit generator that is mostly within 4% of the Carnegie curve without any ad hoc assumptions or other datasets. As past studies have demonstrated [e.g., Whipple, 1929; Bailey et al. 2007; Williams, 2009], lightning alone is a poor proxy for the global electric circuit, producing a diurnal variation (35%) that is much greater than the variation in the fair weather field (10-20%). However, as our results show, most of the observed amplitude variation of the Carnegie curve is accounted for by correctly including the differences that exist in the mean currents and flash rates between land and ocean thunderstorms [e.g., Mach et al., 2009; 2010; 2011].

Although the mean current values from electrified storms without lightning are much less than either land or ocean thunderstorms, the mean current from ESCs is still significantly different than zero (0.13 A for land storm and 0.41 A for ocean storms). Overall, ESCs contribute 13% of the total current, with 11% due to ocean storms and only 2% from land-based storms. When we rank the contributions of the four categories (land with lightning, ocean with lightning, ocean without lightning, land without lightning), the dominant source of current is from land thunderstorms, which can explain why prior estimations of the global circuit using only lightning producing land storms matched the phase of the Carnegie curve but not the amplitude variation.

5. CONCLUSIONS

To reconcile the past differences found between the diurnal variations in the fair weather electric field (i.e., Carnegie curve) and lightning based estimates of the global electric circuit [e.g., Whipple, 1929; Williams, 2009], we included the differences between land and ocean storms and the contributions from ESCs. Ocean storms have less lightning than land storms, but have greater currents on a storm-by-storm basis. The differences between land and ocean storms account for nearly all of the amplitude differences between the Carnegie curve and the purely lightning-based diurnal variation. ESCs account for the rest of the amplitude variation between the Carnegie curve and single parameter lightning based diurnal variations. We found that ESCs produce mean currents one-fourth to one-fifth the amplitude of the mean current of storms with lightning [Mach et al., 2010]. Once these storms are included in the global electric circuit estimation, the resultant global circuit diurnal variation derived from the combined aircraft storm electric current measurements and the satellite-based diurnal lightning statistics is mostly within 4% of the Carnegie curve. When we increase the ESC contribution by a factor of between 3 and 4, our diurnal curve has a slightly better match to the Carnegie curve than our "untuned" data. One thrust of any future work will be in the area of determining the distribution and diurnal variation in ESCs.

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