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Seasonal variations in the lightning diurnal cycle and implications for the global electric circuit

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ABSTRACT

Data obtained from the Optical Transient Detector and the Lightning Imaging Sensor satellites (70° and 35° inclination low earth orbits, respectively) are used to statistically determine the number of flashes in the seasonal diurnal cycle as a function of local and universal time. These data include corrections for detection efficiency and instrument view time. They are further subdivided by season, land versus ocean, and other spatial (e.g., continents) and temporal (e.g., time of peak diurnal amplitude) categories. These statistics are then combined with analyses of high altitude aircraft observations of electrified clouds to produce the seasonal diurnal variation in the global electric circuit. Continental results display strong diurnal variation, with a lightning peak in the late afternoon and a minimum in late morning. In geographical regions dominated by large mesoscale convective systems, the peak in the diurnal curve shifts toward late evening or early morning hours. The maximum seasonal diurnal flash rate occurs in June–August, corresponding to the Northern Hemisphere summer, while the minimum occurs in December–February. Summer lightning dominates over winter activity and springtime lightning dominates over fall activity at most continental locations. Oceanic lightning exhibits minimal diurnal variation, but morning hours are slightly enhanced over afternoon. As was found earlier, for the annual diurnal variation, using basic assumptions about the mean storm currents as a function of flash rate and location (i.e., land/ocean), our seasonal estimates of the current in the global electric circuit provide an excellent match with independent measurements of the seasonal Carnegie curve diurnal variations. The maximum (minimum) total mean current of 2.4 kA (1.7 kA) is found during Northern Hemisphere summer (winter). Land thunderstorms supply about one half (52%) of the total global current. Ocean thunderstorms contribute about one third (31%) and the non-lightning producing ocean electrified shower clouds (ESCs) supply one sixth (15%) of the total global current. Land ESCs make only a small contribution (2%).

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1. Introduction

Starting with the Optical Transient Detector (OTD) in April 1995, and continuing with the Lightning Imaging Sensor (LIS) in November 1997, we have been monitoring global lightning activity with high detection efficiencies from low Earth orbit for over 17 years. We have used fifteen years of observations from these sensors (1995–2000 for OTD, 1998–2010 for LIS) to provide quantitative data on the annual and seasonal

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worldwide lightning occurrences (Christian et al., 2003; Boccippio et al., 2000a,b). Our prior and current work with this ever expanding dataset has provided insights into the global spatial and temporal distribution of lightning, including the diurnal variation in flash rates (e.g., Boccippio et al., 2000b; Christian et al., 2003; Mach et al., 2011).

Also spanning a period of more than fifteen years (1993–2010), our observations from high altitude aircraft missions (e.g., Blakeslee et al., 1989; Mach et al., 2009; Hood et al., 2006) provide a varied atmospheric electrical data set, which are complementary to the satellite lightning observations. The aircraft measurements include electric fields, flash rates, and electrical conductivities. We have used the data from the overflights of electrified clouds and thunderstorms to determine storm-level atmospheric electrical parameters such as current densities, flash rates, and total current output, often called the Wilson current (Mach et al., 2009, 2010, 2011). The overflight observations and analyses have also been combined with the satellite-based data to produce results unobtainable with either dataset alone (Mach et al., 2011).

Current flowing in the global electric circuit can be calculated by combining the high altitude aircraft observations of electrified clouds (storm flash rates, electric fields, and conductivities) with the annual diurnal lightning statistics derived from OTD and LIS, and making basic assumptions about the storm current as a function of flash rate and location (i.e., land/ocean). Using this approach, Mach et al. (2011) reproduced the diurnal variations in the global electric circuit that closely matched independent measurements of the diurnal variations of the fair weather electric field obtained by the Carnegie and Maud research ships (e.g., Whipple, 1929; Torreson et al., 1946) and other subsequent measurements (e.g., Markson, 1976, 1977; Burns et al., 2005). The significance of Mach et al. (2011), and also Liu et al. (2010), which applied an alternate approach, is that these papers appear to finally confirm the long held hypothesis that thunderstorms and other electrified clouds (e.g., Wilson, 1921; Williams, 2009) are the source of the fair weather electric field variations, commonly called the Carnegie curve. These results finally overcome the long observed amplitude overestimation discrepancy that arises when using thunderday-only or lightning-only statistics (Whipple, 1929; Whipple and Scrase, 1936; Williams and Heckman, 1993; Blakeslee et al., 1999; Bailey et al., 2007).

Our present analysis has two primary objectives. First, we investigate the occurrence and distribution of lightning flashes in the annual and seasonal diurnal cycles as a function of local and universal time using reprocessed combined OTD/LIS observations to extend the prior data set (e.g., Bailey et al., 2007) by five additional years through December 2010 (now providing 15 years of OTD/LIS data in place of the previous 10 years). The results from these analyses provide new insights into the timing and distribution of lightning on a regional and seasonal basis, while continuing to confirm earlier results on mean global flash rate (Christian et al., 2003; Bailey et al., 2007). Second, we extend the work of Mach et al. (2011) by combining our reprocessed satellite-based global lightning statistics with analyses of high altitude aircraft observations of electrified clouds (Mach et al., 2009, 2010) to produce the seasonal diurnal variation in the global electric circuit. In support of this present effort, we have added storm overflight data from the Genesis and Rapid Intensification Processes (GRIP) field program (Braun et al., 2012), which has increased our storm overflight database by 25% from 850 to 1063 overflights. As in Mach et al. (2011), the seasonal diurnal variations of the global current derived from the combined satellite and airborne data analyses of thunderstorms and non-lightning producing electrified shower clouds (ESCs) closely match direct measurements of fair weather electric field variations (e.g., Torreson et al., 1946; Burns et al., 2005). This result, now shown on shorter seasonal time scales, strengthens the evidence for thunderstorms and ESCs being the source of the global electric circuit and the quantitative explanation presented in Mach et al. (2011) on how these storms contribute current into the circuit. Following the operational definition used in our prior papers (Mach et al., 2009, 2010, 2011), an ESC is defined as any storm in the dataset that had no lightning during an aircraft overpass. No other criteria, such as minimum cloud height or minimum electric field amplitude, were applied. Note that the time span of the overpass was the time when the aircraft was close enough to the storm to detect lightning. Across the various aircraft platforms, this “view time” was on the order of 1–2 min. Self consistency in this definition exists between the aircraft and low Earth orbit lightning observations used in this paper, since the satellite view time was also on the order of 1 to 2 min (e.g., Mach et al., 2009, 2010, 2011; Boccippio et al., 2002).

2. Instrumentation and measurements

2.1. Satellite observations

For global lightning statistics, we use the satellite-based total lightning dataset derived from the OTD and LIS instruments. OTD and LIS detect lightning during both day and night with a detection efficiency ranging from 44 ± 9% (OTD daytime) to greater than 93 ± 9% (LIS nighttime), storm scale location accuracy (10 km for OTD, 4 km for LIS), and small regional bias (Boccippio et al., 2002). The OTD (Christian et al., 1996) was launched in April 1995 into a 70° inclination (detects lightning to ~±75° latitude), 735 km altitude orbit on the MicroLab-1 satellite (later renamed OV-1). OTD collected observations for a 5-year period that ended March 2000. The LIS, launched in November 1997 on-board the Tropical Rainfall Measuring Mission (TRMM) (Kummerow et al., 1998, 2000) satellite into a 35° inclination (detects lightning to ~±38° latitude), 350 km altitude orbit (raised to 402 km in August 2001), remains operational (as of 2012). In this paper, we analyze LIS data from launch through 2010, which includes 5 additional years of LIS data from that used in Mach et al. (2011). Poleward of ±37.5° latitude, only the 5 years of OTD data contribute to the combined OTD/LIS lightning climatology, which essentially is a full global climatology as there is very little lightning beyond ±75° latitude (e.g., Orville and Henderson, 1986; Orville et al., 2011; Virts et al., submitted for publication). On an annual basis, LIS detects 90% of the lightning in the Northern Hemisphere (NH) and 98.6% in the Southern Hemisphere (SH), but this is seasonally dependent (maximum missed by LIS is 28% in NH in July, 3% in SH in January, minimum missed by LIS is 1% in both hemispheres). Several studies (e.g., Christian et al., 1996, 1999, 2003; Boccippio et al., 2000a,b; Koshak et al., 2000; Cecil et al., 2014–this issue) discuss the details of the OTD and LIS instruments and the orbital