Global Lightning Activity and the Hiatus in Global Warming

Earle Williams Anirban Guha Robert Boldi Hugh Christian and Dennis Buechler

***Abstract*---**Multiple records of global temperature contain periods of decadal length with flat or declining temperature trend, often termed ‘hiatus’. Towards assessing the physical reality of two such periods (1940-1972 and 1998-2014), lightning data are examined. Lightning activity is of particular interest because on many different time scales, it has been shown to be non-linearly dependent on temperature. During the earlier hiatus, declining trends in regional thunder days have been documented. During the more recent hiatus, lightning observations from the Lightning Imaging Sensor in space show no trend. Future measurements are needed to capture the total global lightning activity on a continuous basis.

I. INTRODUCTION

This study is concerned with the response of global lightning to temperature on decadal time scales, with a focus on two time intervals when the global temperature has been flat or declining with time. The two intervals are 1940-1972 and 1998-2014. The selection of periods has been dictated fortuitously by data availability on lightning, but a focus of attention on such periods is especially important in understanding the behavior of the climate system.

II. EVIDENCE FOR THE RESPONSIVENESS OF LIGHTNING TO TEMPERATURE

It is a matter of common experience that lightning activity is responsive to atmospheric temperature. That is to say that lightning is more prevalent in the hot afternoon than the cooler night, and more prevalent in the hot summer than the cold winter. The global response of lightning to temperature is a more subtle issue, because where it is daytime in some longitudes it is nighttime in others, and where it is summer in one hemisphere, it is winter in the other. These compensating aspects serve to dilute the sensitivity of global lightning to temperature. On still longer time scales, when one transitions from ‘weather’ to ‘climate’, other subtleties arise, most notably the issue of global convective adjustment to climate forcing (Xu and Emanuel, 1989; Emanuel et al., 1994) involving changes in the entire temperature profile in the atmosphere.

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The response of lightning to temperature rests on the responsiveness of the cloud microphysical basis for thunderstorm electrification to temperature. This involves the thunderstorm ice factory production of graupel particles and ice crystals from water vapor. The two key temperature-dependent factors here are the Clausius-Clapeyron relation and the Convective Available Potential Energy (CAPE) (Williams, 2012). Clausius-Clapeyron represents the temperature control on the availability of the working substance for thunderstorms—water vapor, and amounts to about 7% per ^{o}C at a mean temperature of 20^{o}C. This represents an approximate doubling of equilibrium water vapor concentration for every ten degrees of temperature increase, and is largely responsible for the fact that thunderstorms are prevalent in equatorial regions and generally absent from the polar regions. The other key factor is the energy available to drive updrafts in thunderstorms. According to parcel theory, CAPE sets an upper limit to updraft speed. It is now well established by observations (Williams et al., 1991) and in cloud models (Baker et al., 1995; 1999) that the lightning activity in thunderstorms is non-linearly dependent on the updraft speed. The dependence of CAPE on temperature, involving convective adjustment on longer time scales, has been a matter of some debate. Early speculation supposed that CAPE is a climate invariant (Emanuel et al., 1994). The weight of the evidence today is that CAPE increases with temperature (Williams, 2012; Romps et al., 2014; Singh and O’Gorman, 2015; Seeley et al., 2016). Though the Clausius-Clapeyron relation and CAPE are inter-dependent, it is likely that the CAPE dependence on temperature will predominate in setting the sensitivity of global lightning to temperature.

With growing interest in climate change, much progress has been made over the last few decades in quantifying the global response of lightning to temperature on many different time scales. The use of the global electrical circuit (both DC and AC manifestations) is increasingly considered as a natural means to quantify this response (Markson, 2007; Williams and Mareev, 2014; Williams et al., 2014). The global diurnal response of lightning to temperature, associated with the longitudinal progression of solar heating of the continental zones, has been explored and verified by Price (1993), Markson and Price (1999), Williams (1999) and Markson (2003; 2007). On the semiannual time scale, discernible variations in surface air temperature are caused by the changes in insolation as the Sun crosses the equator twice annually. The lightning response to these nominal 1C temperature changes are documented in Williams (1994), Sátori and Zieger (1996) and Fullekrug and Fraser-Smith (1997). On the annual time scale, the asymmetric hemispheric distribution of land mass and corresponding albedo are important, resulting in a global 3-4 C temperature swing in mean temperature. Lightning follows suit, with nearly a factor-of-two variation (Christian et al., 2003), and with maximum in August. The most conspicuous interannual mode of global temperature variability is the ENSO phenomenon, and in the warm El Nino phase, the entire tropical atmosphere is warmed by about 1C. The responsiveness of lightning to that change has been documented by Williams (1992), Sátori and Zieger (1999), Sátori et al. (2009) and Williams and Mareev (2014). On the still longer time scale, Romps et al. (2014) have predicted increases in lightning activity in the United States in response to a global warming on the basis of GCM results.

III. BEHAVIOR OF THUNDER DAYS DURING AN EARLIER HIATUS IN GLOBAL WARMING

The most pronounced hiatus in global warming during the 20th century occurred in the period 1940-1972. Hansen et al. (2007) refer to this period as the "peak warmth near 1940". In the more recent literature it has been called the "big hiatus". This occurred during the pre-satellite era and so all global documentation of this event is by surface thermometers. All temperature data sets (Hansen and Lebedeff, 1987; Jones et al., 1999; Vose et al., 2012) show this period of flat or declining global temperature. Attempts to match this feature with climate models have met with only limited success (Hansen et al., 2007). Unlike periods characterized by strong global warming (i.e., in the 1980s and 90s) (Hansen et al., 2010), both this hiatus and the more recent one show stronger increases in oceanic temperature than land temperature (Karl et al., 2015), a behavior inconsistent with external forcing (by increasing CO_2 for example).

The response of global lightning to temperature during this earlier hiatus is unknown because no uniform global lightning data set was available in this period. One can resort to observations of thunder days as a proxy measure for lightning activity in climate studies (Williams, 1994; Williams, 2012; Pinto et al., 2013). Thunder day observations have been organized on a regional basis in two earlier studies over the period of this hiatus, one for North America (Changnon and Hsu, 1984; Changnon, 1985) and for Siberia and central Asia (Gorbatenko and Dulzon, 2001). A total of 90 stations (72 in the U.S. and 18 in Canada) for the period 1905-1980 were used in the former study and 20 stations for the period 1936-1995 in the latter. The comparisons between trends in thunder days and global temperature are reproduced in Figure 1. The observations in North America show a systematic decline in thunder days when the global temperature is also decreasing. The steep decline from 1945 to 1970 amounts to 11%.

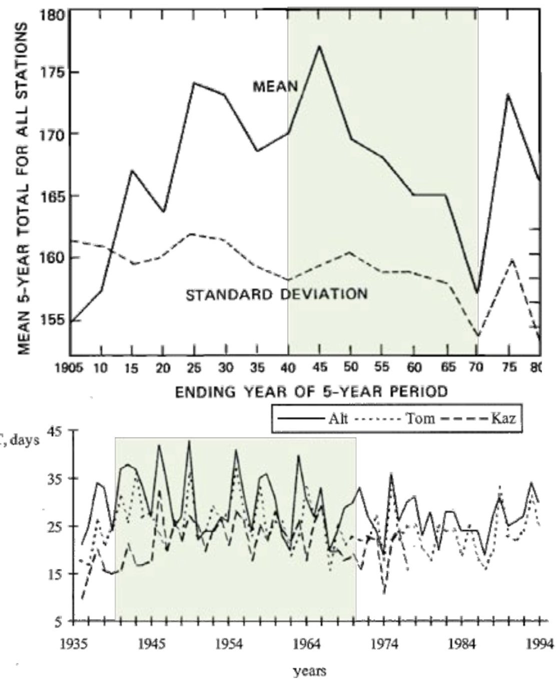

Figure 1 Trends in thunder days during the hiatus in global warming from 1940-1972 (grey-shaded), including analysis for North America by Changnon (1985) and for Siberia by Gorbatenko and Dulzon (2001).

IV. THE RECENT HIATUS IN GLOBAL WARMING

A marked diminishment in the rate of global warming in the 1980s and 90s was identified in the recent period 1998-2014, and has been the subject of much debate in the climate community. Hansen et al. (2010) maintained on the basis of data then in hand that "the global warming is continuing unabated". However, his analysis included an 11-year running mean (for the solar cycle) that shared the rapid increase in the 1990s with the more recent temperature data. Later Hansen et al. (2013) dubbed this period the 'standstill in global warming' and speculated about a solar influence for that standstill. The currently favored explanation for the hiatus in surface air temperature has been increased heat uptake by the ocean (Hansen et al., 2011; Trenberth et al., 2014). However, the uncertainty in the total oceanic heat content is larger than generally acknowledged in studies of this kind (Wunsch, 2016). More recently, Kyle et al. (2015) have claimed that the 'hiatus' is an artefact of errors in the analysis of the oceanic contribution to global temperature. Fyfe et al. (2016) reaffirm the existence of a hiatus. Here additional data sets are examined to shed light on the hiatus, and the response of global lightning to temperature in the same time interval.

A. Global Lightning Measurements from the Lightning Imaging Sensor

A record of monthly counts of lightning flashes recorded with the Lightning Imaging Sensor on the NASATRMM satellite is available at http://thunder.msfc.nasa.gov/data/data_lis.html. The low earth orbit of this optical sensor provides coverage from +/- 35 degrees latitude. While this coverage falls short of being global, half the global area lies between +/- 30 degrees latitude, and approximately two of every three lightning flashes are found within the tropics (Williams, 1992). A great virtue of the LIS measurements for global lightning is the verification that the optical sensor has maintained stability over the entire TRMM mission (1998-2014) (Buechler et al., 2014), with measured radiances varying by less than 0.8% over full period. Figure 2 shows the monthly flash counts for the 11-year period 2002 (after the orbital boost in August 2001) to 2013. The most conspicuous variation is the systematic annual variation with maximum in northern hemisphere summer (Christian et al., 2003), consistent with the 3-4 C annual variation in global temperature (Williams, 1994). On the long time (decadal) time scale however, the trend in LIS-measured lightning is statistically flat.

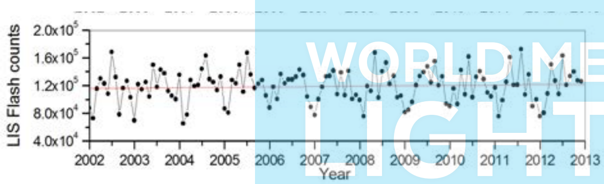

Figure 2 Monthly flash counts from the Lightning Imaging Sensor for the period 2002 to 2013.

B. Global Land surface Temperature Measurements

Given the evidence that lightning is a land-based phenomenon, with more than 10:1 contrast with the ocean (Christian et al., 2003), it is appropriate to consider land temperature alone when considering the lightning response to temperature on a global scale. Accordingly, we have made use of land-based temperature measurements to examine the behavior of global temperature in the hiatus period. Figure 3 shows the temperature anomaly time series for the +/-70 deg latitude range, for the period 1998-2014. The meaning of 'anomaly' is that a climatological mean annual temperature variation (for the period 1989-1998) has been removed from the original time series (Simmons et al., 2010). Further analysis of the trend in the temperature anomaly for an end time ranging from 2012 to 2015 shows that the hiatus ends in 2014. If true, this hiatus is bounded by two substantial El Nino events.

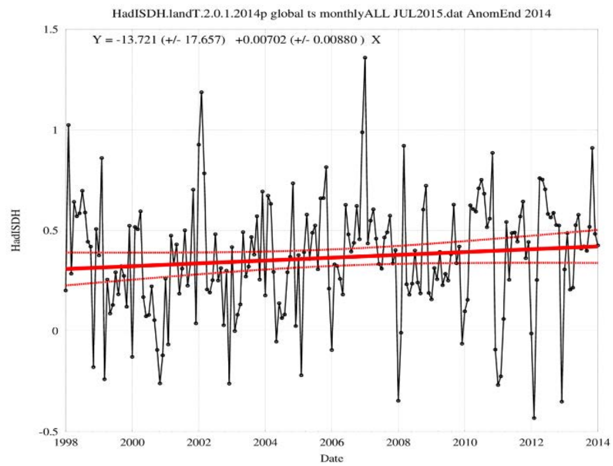

Figure 3 Monthly values of the global land temperature anomaly for the period 1998-2014, based on the UK Met. Office Hadley Center (Willett et al., 2014). The trend in temperature over this time interval is statistically flat.

C. Global Tropospheric Temperature Measurements from the MSU Satellite

Estimates of the global temperature have also been obtained from the Microwave Sounding Unit in space (Christy et al., 2007). Figure 4 shows both the mean (Fig. 4b) and the anomaly (Fig. 4a, with annual cycle removed) can be obtained, and are shown for the hiatus period 1998-2012 in Figure 4. The record of temperature anomaly strongly resembles the land temperature anomaly shown earlier in Figure 3, though the latter record exhibits greater variance. Like the LIS lightning time series repeated in Figure 4c, the annual temperature variation is the prominent feature in the MSU data record (Figure 4b). Analysis of the trend over this time period shows a statistically flat behavior, the same situation as for the land temperature.

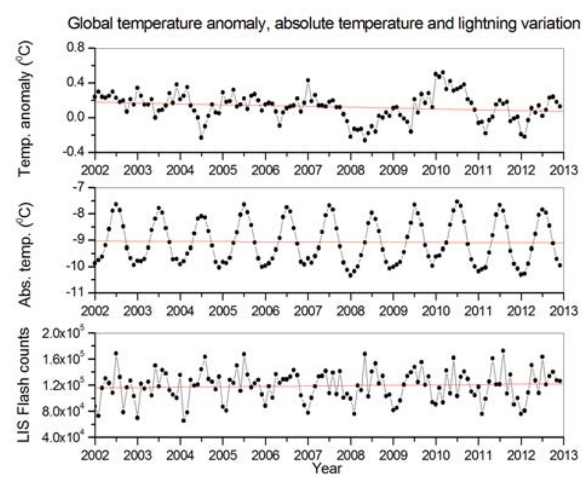

Figure 4 Monthly values of global (+/-90 deg latitude) tropospheric temperature from the MSU satellite (Christy

et al., 2007). Both the temperature (b) and the temperature anomaly (annual cycle removed (a)) are shown for the period 1998-2012. The LIS monthly flash counts are included in (c) for comparison.

The response of lightning to temperature can be obtained by plotting the LIS monthly lightning counts (Figure 2 and 4c) versus the corresponding MSU monthly global temperatures. The result is shown in Figure 5. The sensitivity from this plot is 16,500 flashes per ^{o}C, or a 14% increase in flash count per ^{o}C. Most of the signal here is linked with the annual variations of lightning and temperature. Little correlation is noted between the monthly lightning (4c) variation and the temperature anomaly (4a).

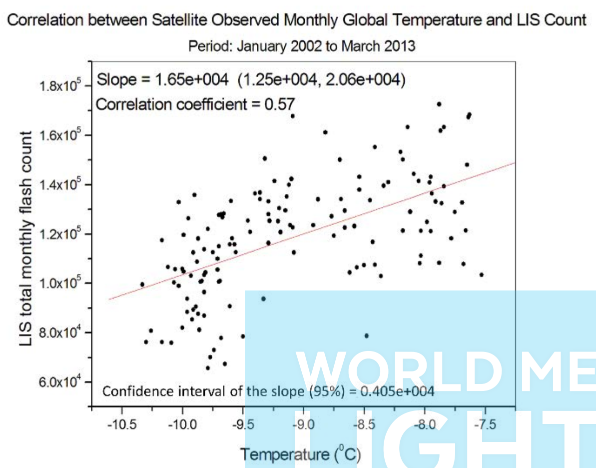

Figure 5 Scatter plot of LIS monthly flash totals versus MSU global temperature values (Christy et al., 2007) for the period 2002-2013.

V. DISCUSSION AND CONCLUSION

Two periods have been selected in global temperature records in which the temperature is either flat or declining with time. During the "big hiatus" from 1940-1972, the regional thunder day records show a clear decrease with time, along with the temperature. During the more recent hiatus (1998-2014), both the monthly temperature records and the monthly lightning counts from space are statistically flat with time, and therefore consistent with each other. The flatness of another global variable (lightning) which has been shown in earlier studies to be non-linearly dependent on temperature underlines the evidence that the global land temperature trend is also flat in the period 1998-2012 and that the 'hiatus' in warming therein is genuine.

Global lightning and global temperature are well correlated on the annual time scale. The reasons for the lack of correlation between the monthly lightning and the monthly temperature anomaly are not well understood. One possibility is that the global lightning is inadequately sampled by the LIS in low earth orbit.

The statistical analyses on the monthly temperature anomalies (e.g., Figure 3) also emphasizes that the identification of successive maxima in a statistically flat record as the warmest months on record, or the warmest year on record, is meaningless.

The responsiveness of lightning to temperature on still longer time scales motivates the use of (1) global lightning observations from geostationary orbit (GOES-R and other appropriately placed satellites) and (2) the natural framework of Schumann resonances to monitor the global activity on a continuous basis and on all time scales.

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