ANOTHER LOOK AT THE DEPENDENCE OF LIGHTNING FLASH RATE ON THE TEMPERATURE OF BOUNDARY LAYER AIR IN THE PRESENT CLIMATE

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ABSTRACT: Satellite observations of lightning flash rate are merged with proximal surface station thermodynamic observations toward understanding the response of the global circuit to temperature. These comparisons support an important role for cloud base height in regulating the transfer of Convective Available Potential Energy (CAPE) to updraft kinetic energy in thunderstorms. This role for cloud base height gives preference to dry bulb temperature over wet bulb temperature as the lightning-regulating temperature in regions characterized by moist convection.

INTRODUCTION

The global electrical circuit has long been recognized as a natural global integrator of electrified weather [Whipple, 1929]. In this study, “global circuit” is construed to include both the traditional ‘DC’ global circuit as well as the Schumann resonances (SR) in the ELF range. The growing interest in global warming in the 1990’s spurred ideas linking the global circuit with global temperature and the accumulation of a large body of supporting empirical evidence [Williams, 1992, 1994, 1999; Price, 1993; Fullekrug and Fraser-Smith, 1998; Reeve and Toumi, 1999; Markson and Price, 1999; Moore and Idone, 1999; Markson, 2003]. More recently, connections between SR and upper tropospheric water vapor have been investigated [Price, 2000]. The linkage between the global circuit and temperature/water vapor is complicated by two incompletely understood phenomena that resist analytical treatment: tropospheric convection and charge separation in electrified clouds. This study is concerned with a re-examination of the physical linkage between temperature and the global circuit, based primarily on new observations linking thermodynamics and lightning activity at the cloud scale.

Perhaps the most important variable linking temperature and the global circuit response is the vertical air motion. Numerous field experiments [Williams et al., 1992; Rutledge et al., 1992] underscore the sensitive relationship between updraft speed and lightning activity, and recent model results [Baker et al., 1999] indicate lightning flash rate is proportional to the forth power of vertical velocity. At the outset it should be emphasized that vertical air motions are caused by temperature gradients, not by temperature, but one expects these quantities to be correlated. One idealization in which such a correlation is absent is the moist neutral troposphere [Xu and Emanuel, 1989], but numerous subsequent observations [Williams and Renno, 1993] cast doubt on this condition.

In assessing vertical air motion in moist convection, appeal is often made to the thermodynamic quantity Convective Available Potential Energy (CAPE). The initial hypothesis [Williams, 1992, 1994] linking the global circuit with temperature invoked a temperature-dependent CAPE [Williams and Renno, 1993], but in which the temperature variable was wet bulb potential temperature, $\theta_w$. This hypothesis is based on tightly correlated relationships between CAPE and $\theta_w$ throughout the tropics in the present climate.

Two problems have been identified that weaken the CAPE-based hypothesis. The first is that CAPE over warm tropical oceans is of comparable magnitude as over the land [Williams and Renno, 1993; Lucas et al., 1996], yet the lightning activity differs by more than an order of magnitude [Williams and Stanfill, 2002]. At the same time, the mean maximum $\theta_w$ values over land exceed those over the ocean by 1-2°C, equivalent to 1000-2000 joules/kg in CAPE, if CAPE-$\theta_w$ correlations are considered [Williams and Renno, 1993]. This is indirect evidence that the air temperature over land (ocean) has already adjusted to the surface conditions over land (ocean).

The second problem is an older one: parcel theory, on which any evaluation of CAPE is based, is flawed by the nature of turbulent convection: mixing is highly prevalent. The maximum air speeds predicted on the basis of CAPE and parcel theory are substantially greater than observations, in all but the largest supercells [Williams and Stanfill, 2002]. If parcel theory is unreliable, then any hypothesis based on it for which vertical velocity is a key variable may also be unreliable.
The two problems cited above led Williams and Stanfill [2002] to consider ways in which differences in updraft speed between land and ocean could be achieved with essentially the same CAPE. They re-examined the idea [Lucas et al., 1994] that both the width of boundary layer thermals and the width of the ensuing moist convection scale with cloud base height (CBH). The working hypothesis then holds that oceanic convection with typical 500 meter CBH’s will exhibit narrower updrafts, smaller convective ‘bubbles’, and smaller conversion efficiency of CAPE to updraft kinetic energy. Continental convection with CBH’s 2-5 times larger will exhibit stronger updrafts on this basis.

CBH is a quantity extractable from thermodynamics [Betts, 1997; Bradbury, 2000], and is proportional to the dew point depression, $T - T_d$, where $T$ is the dry bulb temperature and $T_d$ is the dew point temperature of surface air. CBH is a quantity not considered in the evaluation of CAPE, and therefore of no importance in the initial hypothesis linking the global circuit with temperature. The availability of simultaneous values of CBH and lightning flash rate provides an opportunity to test this alternative idea for temperature control of lightning activity. This study is concerned with such a test.

**METHODOLOGY**

Unlike previous studies linking lightning activity with temperature on a global basis, this study seeks to relate lightning flash rate and thermodynamic quantities pertaining to the same storm, for many storms. This goal is achieved through comparisons of satellite observations of lightning flash rate and surface thermodynamic observations of the air ingested by the same thunderstorms.

Lightning flash rate for thunderstorms throughout the latitude range 35° S to 35° N are recorded with the Lightning Imaging Sensor (LIS) on board the NASA TRMM (Tropical Rainfall Measuring Mission) satellite. This flash rate is representative of the observation periods (of the order of 80 sec) typically afforded by the satellite’s low earth orbit. Flash rates are determinable in day and night conditions, but in this study, the daytime storms were targeted.

Routine surface observations of $T$, $T_d$, and pressure recorded at intervals varying from 1 to 3 to 6 hours at stations worldwide were obtained as a global data set from NCAR as the Surface ADP File. Stations were selected on the basis of their proximity in space and time to those thunderstorms documented by the LIS. Only stations within 50 km of the thunderstorm of interest were queried for thermodynamic information. Maximum values of temperature, CBH and $\theta_w$ were then extracted from the raw station data. For storms in close proximity to stations it was fairly typical to see the values of all these quantities rising prior to the storm, and then dropping fairly abruptly at the time of the storm.

Connected satellite (flash rate) and ground station ($T$, CBH, $\theta_w$ ) scenarios were identified for the entire period January-June, 2000.

**RESULTS**

Figure 1 shows the results of thunderstorm flash rate (flashes/min) versus thunderstorm cloud base height (meters) for all thunderstorms within 50 km of a corresponding ground station. The data were grouped in 100-meter intervals of CBH with standard deviations about the mean flash rates also included. Despite considerable scatter, the results show a quasi-exponential increase of mean flash rate with CBH and an order-of-magnitude increase from the 500 m typical of tropical oceanic convection to the 3000 m typical of strongly continental convection. (Note however that while the full range of...

![Flash Rate vs. CBH (Tropics, Jan-Jun 2000)](image-url)
CBH is captured, the great majority of thunderstorms examined were continental storms on account of the need for corresponding surface station data.) These results clearly support the hypothesis that CBH may influence updraft strength by modulating effective parcel size.

Figure 2 shows thunderstorm flash rate versus maximum dry bulb temperature T of surface air, recorded in advance of the observed flash rate. Again, a quasi-exponential temperature dependence is noted, with an e-folding in flash rate of approximately 5°C. This result is consistent with an important role for the dry component of convection in invigorating the subsequent moist component at higher altitudes.

Multiple thermodynamic parameters are shown in Figure 3 with an aim toward distinguishing the roles of T, T_d, θ_w and CBH in determining lightning flash rate. Here the horizontal and vertical axes are T_d and T, respectively. The rightward sloping lines are isolines of CBH (0 to 3000 m spaced by 500 m) and the leftward sloping lines represent isolines of θ_w (spaced by 1°C). The circle diameters are proportional to the logarithm of the mean flash rate. The most pronounced gradient in flash rate is apparent with respect to dry bulb temperature T, in marked contrast with θ_w. It is also important to note that the very largest flash rates are associated with less moisture and higher CBH.

CONCLUSIONS
Based on local comparisons between lightning flash rate and thermodynamic quantities, dry bulb temperature and cloud base height are shown to be important indicators of lightning activity. These results are consistent with the idea that the efficiency with which CAPE is transferred to updraft kinetic energy is controlled by CBH. These results are consistent with correlations between global circuit and dry bulb temperature as well as upper tropospheric water vapor on short time scales. Further work should be directed at quantifying global changes in CBH on longer time scales—notably the ENSO time scale.

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