LATITUDINAL VARIATIONS OF CLOUD BASE HEIGHT AND LIGHTNING PARAMETERS IN THE TROPICS

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ABSTRACT: The observed reduction in cloud-to-ground lightning in the near-equatorial zone is examined from the perspective of the width of the main negative charge region. Thermodynamic observations of cloud base height also show a minimum value in the near-equatorial region. The association of low cloud bases with both narrow updrafts and narrow charging zones may impede the bridging of the large air gap to ground.

INTRODUCTION

This study is concerned with the latitudinal variation of lightning characteristics and with a simple meteorological interpretation. Certain observations have long been recognized, most notably that the ratio of intracloud (IC) to cloud-to-ground (CG) lightning is declining generally with latitude away from the equatorial zone *[Pierce*, 1970; *Prentice and Mackerras*, 1977]. More recent work [*Williams et al.*, 1996] has shown that an important contribution from this decline is the increase in cloud-to-ground lightning flash density away from the equatorial zone, as suggested by the results from several stations in Figure 1. Contemporary meteorological explanations for the latitudinal dependence of the IC/CG ratio [*Rutledge et al*., 1992; *Price and Rind*, 1993] have emphasized the enhancement of IC lightning rather than the suppression of CG lightning in the near equatorial zone.

New insights on this issue have come from recent progress in understanding the land-ocean lightning contrast [*Williams and Stanfill*, 2002] and the distinction between maritime and continental convection [*Williams et al.*, 2002]. The key result from the present study is the role of cloud base height in influencing the updraft width and the efficiency with which Convective Available Potential Energy (CAPE) is converted to updraft kinetic energy. This role is also evident in the dependence of global lightning activity on temperature, as discussed in a companion paper [*Williams et al.*, 2003]. The working hypothesis here is that higher cloud base height is associated with a wider updraft, a broader main negative charge region, and hence a greater tendency for cloud-to-ground lightning. The demonstration that the cloud base height has a systematic mean latitudinal dependence is hence a primary goal in this study.

METHODOLOGY

To correlate lightning activity in the near-equatorial zone with local thermodynamic conditions, two customized databases were organized. Information about the spatial-temporal positions of thunderstorm areas and flash rates was extracted from observations of the Lightning Imaging Sensor (LIS) on board the NASA TRMM satellite. Thermodynamic information was adopted from the Surface ADP File (NCAR) of synoptic reports from more than two thousand meteorological stations throughout the tropics and subtropics. For a more profound insight into lightning-meteorological relationships, this database contains direct synoptic observations (dry bulb T and dew point T_d temperatures, pressure, cloudiness, etc.) that enable calculations of other pertinent thermodynamic variables (potential θ and wet bulb potential θ_w temperatures as well estimates of cloud base height (CBH)). The potential temperatures were computed on the basis of *Bolton* [1980], and CBH was estimated from the dew point depression $T-T_d$ [*Bradbury*, 2000].

The comparative analysis revealed a significant number (about 1500 per month) of intersection scenarios when a LIS area was within a 50 km radius from a surface station presented in the thermodynamic database. Due to highly uneven quality of synoptic reports, especially from African region, a thorough selection was necessary to identify scenarios without observation gaps preventing the reliable determination of thermodynamic parameters prior to and during a corresponding LIS event. As a result, about 1800 quality afternoon scenarios have been selected for the six-month period (January to June, 2000) covered in this paper.

RESULTS AND DISCUSSION

Figure 2 shows the latitudinal variation of total (zonally-integrated) lightning activity observed by the LIS for 2000. Consistent with numerous other results, both ground- and satellite-based, the total lightning activity shows a broad maximum in the near-equatorial zone and declines with latitude. This total activity is influenced by the latitudinal variation of thunderstorms, and by the flash rate per thunderstorm.

Figure 3 shows the latitudinal variation of the number of LIS 'areas', where 'area' is interpreted as an individual thunderstorm, consistent with earlier work [*Williams et al.*, 2000]. This quantity also shows a broad maximum in the near-equatorial zone and declines with latitude, and is the main contributor to the total lightning activity in the previous Figure 2.

Figure 4 shows the mean lightning flash rate for afternoon thunderstorm 'area's for the period January-June, 2000. Now a different behavior is noted, with a general minimum in the near equatorial zone and a systematic increase with latitude. This behavior will contribute to a modest latitudinal flattening of the total lightning activity shown in Figure 2. A plausible meteorological explanation for this behavior is rooted in the latitudinal trends in cloud base height.

Figure 5 shows the mean cloud base height derived from surface station thermodynamic observations, for all those stations paired with afternoon thunderstorms documented by the LIS in January-June, 2000. As with the behavior for mean thunderstorm flash rate, the cloud base height is minimum in the near-equatorial zone and increases generally with latitude. The minimum cloud base heights in the near-equatorial zone are more maritime-like, even though the majority of the storms examined and the majority of lightning flashes are land-based. The climatological interpretation of these results is that the continental version of the Inter Tropical Convergence Zone (ITCZ) has a strong tendency to be equatorial, with a declining probability as latitude increases. Previous studies of 'monsoon' style convection over land [*Williams et al.*, 1992; *Rutledge et al.*, 1992; *Williams et al.*, 2002; *Cifeli* et al., 2002] have all shown reduced lightning activity in this more maritime regime. The monsoon regimes over land are the continental versions of the ITCZ.

The final Figure 6 encapsulates the interpretation of results in this study. Shown here are two thunderstorms, one with a low cloud base (representative of the near-equatorial zone) and an intracloud flash, and the other with a high cloud base (representative of regions north and south of the equator), a broader main negative charge region, and a cloud-to-ground lightning flash. A strong contrast is drawn between conditions necessary for intracloud lightning and cloud-to-ground lightning. The latter event requires the bridging of a gap between the main negative charge region and ground that is typically 6-8 km [*Krehbiel*, 1986; *Koshak and Krider*, 1989]. Such a discharge is expected to require substantial field energy on a large scale, a situation favored by a laterally extensive negative charge region. In contrast, no such large gap need be bridged for an intracloud flash between main negative charge and upper positive charge. A local breakdown field is of course required, but the vertical extent of an IC flash could be an order of magnitude less than for a cloud-to-ground flash. Based on Figure 6 and the foregoing qualitative arguments, intracloud flashes are expected to be favored relative to cloud-to-ground flashes in thunderstorms with narrower updrafts. Narrow updrafts are more prevalent in thunderstorms with lower cloud base heights [*Williams and Stanfill*, 2002]. Lower cloud base heights are more prevalent in the more maritime equatorial zone (Figure 5). This situation favors a reduction in the ground flash density (Figure 1) and the declining ratio of intracloud and cloud-to-ground lightning with latitude documented in earlier work [*Pierce*, 1970; *Prentice and Mackerras*, 1977].

Figure 1

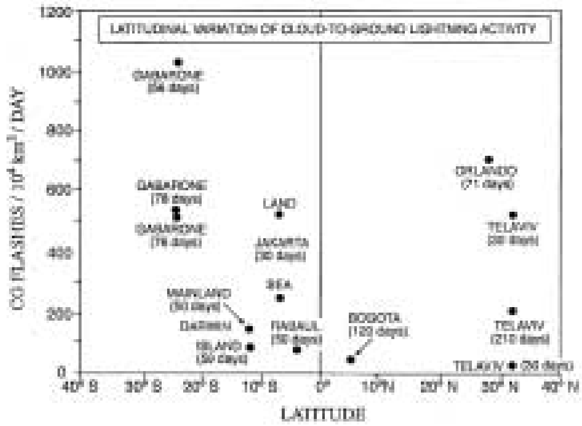


Figure 4

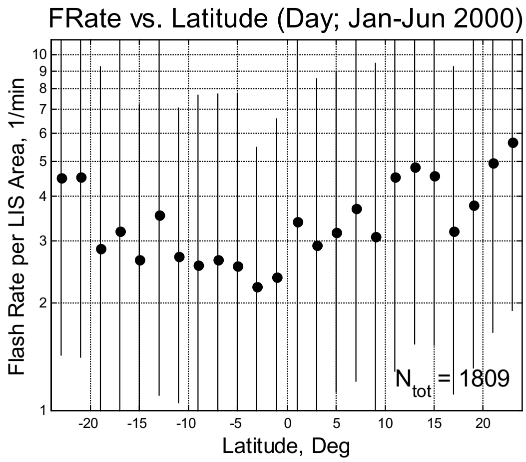


Figure 2

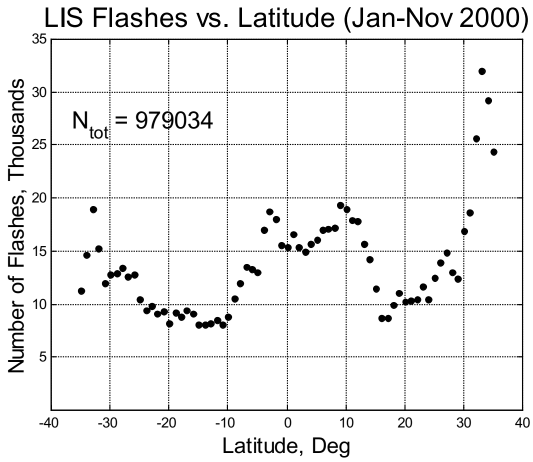


Figure 5

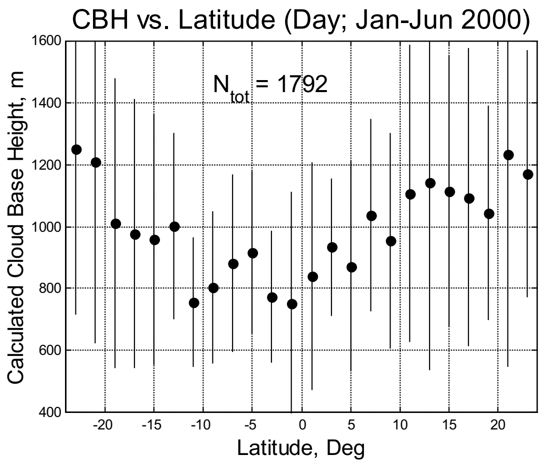


Figure 3

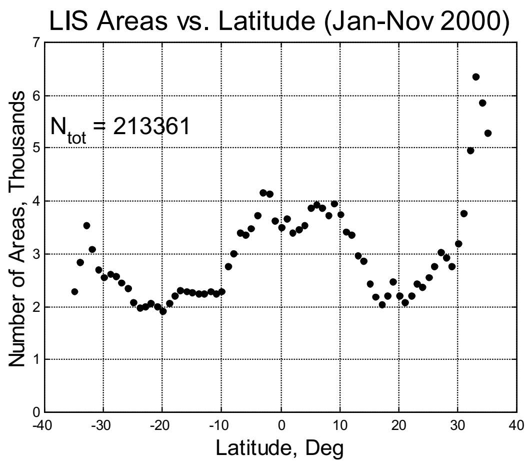
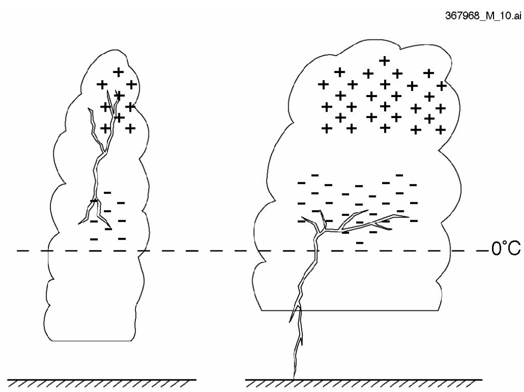


Figure 6



CONCLUSION

The reduction of ground flash density in the near-equatorial zone is plausibly explained by a tendency for cloud base heights and negative charge layer widths to be minimum in the same region. Intracloud lightning activity in the large number of near-equatorial thunderstorms can account for the latitudinal variation of total activity.

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