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Relationship between cloud-to-ground discharge and penetrative clouds: A multi-channel satellite application

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ABSTRACT

This work presents a relationship between atmospheric cloud-to-ground discharges and penetrative convective clouds. It combines Infrared and Water Vapor channels from the GOES-12 geostationary satellite with cloud-to-ground discharge data from the Brazilian Integrated Lightning Detection Network (RINDAT) during the period from January to February 2005. The difference between water vapor and infrared brightness temperature is a tracer penetrating clouds. Due to the water vapor channel's strong absorption, this difference is positive only during overshooting cases, when convective clouds penetrate the stratosphere. From this difference and the cloud-to-ground, discharge measured on the ground by RINDAT, it was possible to adjust exponential curves that relate the brightness temperature difference from these two channels to the probability of occurrence of cloud-to-ground discharges, with a very large coefficient of determination. If WV-IR brightness temperature difference is greater than −15 K there is a large potential for cloud-to-ground discharge activity. As this difference increases the cloud-to-ground discharge probably increases, for example: if this difference is equal to zero, the probability of having at least one cloud-to-ground discharge is 10.9%, 7.0% for two, 4.4% for four, 2.7% for eight and 1.5% for sixteen cloud-to-ground discharges. Through this process, was developed a scheme that estimates the probability of occurrence of cloud-to-ground discharge over all the continental region of South America.

1. Introduction

Multispectral satellite analysis has demonstrated its ability to depict cloud top features. The combination of water vapor and infrared window channels to describe deep convective clouds has been largely used; for instance, Medaglia et al. (2005) used these channels from geostationary satellites to develop the Global Convective Diagnostic. Schmetz et al. (1997) noted through simultaneous observation of the METEOSAT infrared window and water vapor channels and a line-by-line radiative transfer model that differences greater than zero degrees between both channels are related to convective clouds with high vertical extension. The simulations show that the larger brightness temperatures in the water vapor channel are due to stratospheric water vapor, which absorbs radiation from overshooting tops and emits radiation at a higher stratospheric temperature. Adler and Mack (1986) studying the cloud top dynamics also found storm tops above the tropopause. Fritz and Laszlo (1993) also noted a brightness temperature from the water vapor channel warmer than from the infrared window channel over a region associated with deep convection. Kurino (1997) showed that the difference between both brightness temperatures can be very useful in defining heavy precipitation related to deep convection. Reudenbach et al. 2001 use this difference to discriminate deep convection from thick Cirrus clouds. Stevak et al. (2007) used the higher spatial resolution images from the MODIS sensor to investigate the correlation between

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cloud top temperature and the water vapor-infrared window difference. They consider that a positive difference is possible if each storm top generates some amount of moisture in the stratosphere, or by pre-existent stratospheric moisture in a layer above the cloud top. They found some cases that agree with the previous results, where the positive difference is well correlated with the minimal cloud top temperature. However, one case did not agree; the larger difference was not correlated with the minimal temperature. They also suggest that different ice emissivity for each channel can in some cases explain these differences. Wang (2007), using a three-dimensional non-hydrostatic cloud model studied penetrating convective clouds. He suggests that moisture plumes in the stratosphere above convective clouds are generated by gravity waves and large instability over the cloud top due to convection inside the storm.

The main goal of this study is to test the hypotheses that the difference between the water vapor and infrared channel can be used as a tracer of penetrative clouds, and those clouds are related to cloud-to-ground discharge.

Section 2 describes the data and the methodology employed in this study. Section 3 presents the results obtained, comparing satellite data and cloud-to-ground discharge occurrence, and finally Section 4 presents the conclusion.

2. Methodology

Schmetz et al. (1997) suggested that positive differences between water vapor and infrared brightness temperature are only possible when deep convective clouds penetrate in the tropopause, moistening the stratosphere. The infrared is located in the window channel; a region of the electromagnetic spectrum where the earth atmosphere's slightly absorbs terrestrial radiation. However, the water vapor channel has strong absorption features and the brightness temperature reported by this channel is nearly always colder than that measured in the infrared channel. Therefore, the difference between the water vapor and infrared window channels is normally negative, except if penetrating clouds go through the tropopause, moistening the stratosphere and then, as the temperature increases in this layer, the difference can be positive. In these cases, these positive differences are related to overshooting, which is normally associated with high deep convective cloud tops with a large amount of ice, chiefly responsible for the development of an electrical field inside the clouds. The atmospheric cloud-to-ground discharges are the response of the accumulated charges inside the cloud that can breakdown the dielectric air (Pinto et al., 2004). The center of charges (positive and negative) is formed by several cloud microphysical processes that transfer positive and negative charges during the formation of cloud droplets, rain drops and ice particles (MacGorman and Rust, 1998). Moreover, observational studies revealed that lightning is associated with glaciation, and the flash rate increases as the volume of precipitation-sized ice particles in the mixed-phase region increases and updraft strengthens (Baker et al., 1995; Petersen and Rutledge, 1998). The mixed phase clouds were observed to occur occasionally up to the homogeneous ice nucleation and cloud electrification processes can extend up to the higher levels of the clouds (Heymsfield and Miloshevich, 1993).

Therefore, these very deep and high extended clouds are responsible for a very large rate of cloud-to-ground discharges (Abdoulaev et al., 2001). The difference between these two brightness temperatures can be used as a proxy for very deep convection clouds (overshooting cases) associated with frequent lightning. Considering these features, we will

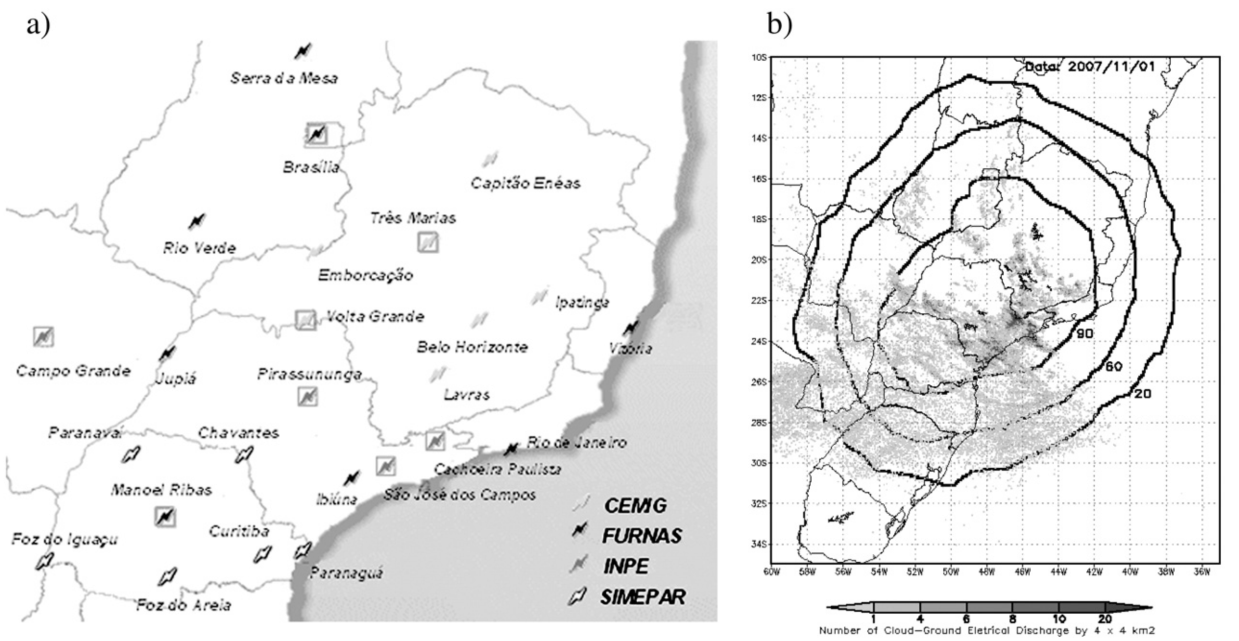

Fig. 1. a) Location of RINDAT sensors and the institution responsible for each sensor. b) Number of cloud-to-ground discharges per day on November 1st 2007, and lightning detection efficiency contour lines within the 20, 60, and 90%.