Cloud-to-Ground Lightning Estimates Derived From SSM/I Microwave Remote Sensing and NLDN

1. Abstract

A physically based correlation exists between passive microwave brightness temperatures and lightning flash rates (Li et al. 2011). Current lightning observations are made on land (NLDN, Figure 1a, Orville et al. 2011) and from space (TRMM LIS, Figure 2, Ceci et al. 2012). Each lightning detection system has fundamental limitations. TRMM satellite coverage is limited to the tropics and subtropics between 30°S and 30°N, so lightning at the higher latitudes in the southern and northern hemispheres is not observed. The detection efficiency of NLDN sensors is at least 90%, but the sensors are only operational over land. Previous research on satellite-based lightning sensors (World Wide Lightning Location Network, the European Cooperation for Lightning Detection, and Lightning Detection Network on the TRMM and NLDN, there would be enormous spatial gaps in present-day coverage of lightning. In addition, a globally-complete time history of observed lightning activity is currently not available either, with network coverage and detection efficiencies varying through the years. This study focuses on using DMAP SSM/I microwave brightness temperature data to estimate cloud-to-ground (CG) lightning with NLDN as ground verification. The potential exists for a complete global CG lightning-climatology using data of DMAP.

2. Introduction

Lightning observations from ground- and satellite-based sensors. The National Lightning Detection Network (NLDN) is a United States multipole ground sensor system (Liu et al. 2011). Satellite-based lightning observations have been made from 1998 to present using the TRMM Microwave Imager (TMI) from 1997 to 2011 and the Microwave Imager (TMI) from 1995 to 2005 using the Tropical Rainfall Measurement (TMI) on the Microsattellite satellite (Sunway et al. 1998 and Li et al. 2011). Both LFI and OITF = solar illumination that detects lightning as momentary changes in optical scenes. Passive microwave remote-sensing (SSM/I and 37 GHz brightness temperatures) from the TRMM Microwave Imager (TMI) has also been used to quantify characteristics of thunderstorms related to lightning (Li et al. 2011 and Ceci et al. 2012).

Previous research by Li et al. (2011) using the TRMM LIS and Microwave Imager (TMI) showed that there is a statistically significant correlation between lightning flash rates and passive microwave brightness temperatures. The physical basis for this correlation emerges because lightning in a thunderstorm occurs when ion is first present in the cloud and electric charge separation occurs. These ice particles efficiently scatter the microwave radiation at the 85 and 37 GHz frequencies, thus leading to high brightness temperatures. Lightning flash rate is related to the total amount of charge within the interior of the mesocyclones. Confirmation of the relationship using LIS and TMI data, however, remains constrained to TRMM observational limits of the tropics and subtropics.

Satellites from the Defense Meteorology Satellite Program (DMSP) have global coverage and are equipped with a passive microwave imager (called the Special Sensor Microwave Imager (SSMI) or SSM/I, SSM/I) also observes brightness at 85 and 37 GHz. Unlike the TRMM satellite, however, DMAP datasets do not have a lightning sensor, and SSM/I has never been used to review global lightning.

3. Research Objective

We investigate how microwave brightness temperatures from DMSP SSM/I and ground-based cloud-to-ground lightning data from NLDN are related. Our goal is to derive a spatially-complete time history of CG lightning for the USA.

4. Methods

The strongest thunderstorms generally have minimum 85-GHz Polarized Corrected brightness temperatures (PCT) less than 150 K (Li et al. 2011). A complete years of DMAP data was used from 2005 to 2013 from the F13, F14, and F15 DMSP satellites, as this is when the most complete NLDN data is available due to network upgrades and improvements (Ferraro et al. 2010). Archival radar data was used to resolve the spatial extent of a subset of individual storms (Figures 3, 4). NLDN data for each storm’s respective spatial extent defined by radar data was used to calculate the CG flash rate density for the storm. The CG flash rates calculated were then compared to the area of 85 GHz PCT below 150 K. A linear model is used to correlate the ratio between storm-specific CG flash rates and area of 85 GHz PCT below 150 K (Figure 5).

To extend the results to weaker storms, the probability of CG lightning (instead of the flash rate) was calculated for all storms from the total scene CG lightning from SSM/I versus NLDN. NLDN data was used to determine if a CG strike occurred for a storm based on different temporal and spatial criteria. The probability of CG lightning was plotted as a function of 85 GHz PCT and received a CG flash rates (Li et al. 2011). These probabilities were used in conjunction with the linear model from Figure 5 to estimate the CG flash rate for weaker storms with minimum 85 GHz PCT greater than 10K.

5. Results

The dependence of lightning on 85 GHz brightness temperatures, NLDN and SSM/I were identified in a grid of rectangular latitudinal-longitudinal grid (5.1 degrees by 5.1 degrees). NLDN data was extracted during the 7-minute temporal window of the SSM/I overpass time from southern to northern USA in order to obtain more accurate comparison between the brightness temperatures and ground verification at a grid pixel by pixel basis. The grid analysis revealed that the CG maximum is not always geographically co-located with the brightest brightness temperatures, therefore the NLDN CG strikes were simulated and averaged in increments of 25 K from 50 to 300 K (Figure 8).

Event NLDN Lightning showing the spatial distribution of NLDN CG strikes and a subset of individual storms. Scene - CG flash rates and lightning data for each storm’s respective spatial extent defined by radar data was used to calculate the CG flash rate for the storm. The CG flash rates calculated were then compared to the area of 85 GHz PCT below 150 K (Figure 5). A linear model is used to correlate the ratio between storm-specific CG flash rates and area of 85 GHz PCT below 150 K (Figure 5).

6. Conclusions and Future Work

Global maps of lightning are only beginning to be collected using ground-based networks of sensors (WWLN, GLD360), for example Rudolka and Forbes (2010). Orville et al. (2011) used SMMR data to obtain estimates of the global CG lightning from 1979 to 2006 and estimated that about 15% of the global CG lightning was collected using this method. The maps depicted in Figures 9 and 10 show the potential for future studies using the SSM/I data.

DMP SSM/I microwave remote-sensing data has been collected from a network of satellites starting in 1992 and currently continue to collect data. We used SSM/I data from the SSM/I F13 (1987-2005), F14 (1997-2006), and F15 (2001-2006) satellites and NLDN data to test whether brightness temperature values could be used to derive CG lightning. Our results show great promise for the majority of lightning features (Figure 10), although underestimate for extreme lightning events is a problem (Figure 9).

The methods in this research (Figures 8-12) have been derived using specific thunderstorm cases, but could be applied to all DMP SSM/I data for the USA, creating a high level of confidence such as those of TRMM LIS (see only for CG) and comparable to LIS. Furthermore, the methods could be extended to the global scales captured by SSM/I (SMAP). Global verification will be more challenging since ground-based networks are most established in the USA (Orville et al. 2011), but initial estimate could be compared against TRMM LIS for the subtropics and tropical regions after making assumptions about the latitudinal-dependent ratio of CG to total lightning (e.g., Freesten et al. 1997).

The most important potential in this research is that SSM/I could provide a global time history of CG lightning derived from microwave remote-sensing. This time history would be coincident with the period associated with the on-going climate change (e.g., Hartmann et al. 2013), could be used to test recent claims about increasing lightning rates as a function of temperature (Bomgard et al. 2014), and would also cover parts of the world (e.g., the northern hemisphere boreal shield and Arctic) that are experiencing rapid observed climate change.

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