

The Intra-Cloud Lightning Fraction in the Contiguous United States

Gina Medici¹, Kenneth L. Cummins¹, William J. Koshak², Scott D. Rudlosky³, Richard J. Blakeslee², Steven J. Goodman⁴, Daniel J. Cecil²

¹Department of Atmospheric Sciences, University of Arizona, Tucson, AZ

²NASA George C. Marshall Space Flight Center/NSSTC, Huntsville, AL

³NOAA/NESDIS/STAR, College Park, MD

⁴NOAA/NESDIS/GOES-R Program Office, Greenbelt, MD

Total Lightning Incidence, Cloud-to-ground Incidence, and Relative Occurrence

Abstract

The first satellite in the Geostationary Operational Environmental Satellite R-series (GOES-R) will be launched in 2016 and will include the world's first Geostationary Lightning Mapper (GLM). GLM will provide continuous, spatially uniform Total Lightning observations that are expected to significantly improve our ability to nowcast severe weather. However, optimal use of changes in Total Lightning flash rate for individual storms may require knowledge of long-term regional differences in the relative contribution of intra-cloud (IC) and cloud-to-ground (CG) flashes to the total flash rate, reflected in the IC:CG ratio (or equivalently the IC fraction). Additionally, Carey and Rutledge (Journal of Geophysical Research, 1998) found a strong correlation between very high IC:CG ratios and severe storms, including, heavy rain, large hail and tornados.

Given the potential value of understanding long-term regional variations in the IC:CG ratio, we have expanded upon an earlier analysis by Boccippio and collaborators (Monthly Weather Review, 2001). They created the original IC:CG ratio climatology for the Continental United States (CONUS) using datasets provided by the U.S. National Lightning Detection Network™ (NLDN) and the Optical Transient Detector (OTD). These data sets were for the period of May 1995 through April 1999. Since 1999, the duration of the NLDN historical data set has more than doubled, and OTD data can be supplemented with data from the Lightning Imaging Sensor (LIS) which is on the Tropical Rainfall Measuring Mission satellite in a precessing low earth orbit. The Total Lightning data set in this study includes the OTD data from May 1995 to March 2000 and LIS from 1998-2010 which is limited between 38°South to 38°North. Preliminary findings support earlier results indicating factor-of-10 variations in the IC:CG ratio throughout CONUS. High values are seen in the Pacific Northwest and the border of Colorado with Kansas, Oklahoma and Nebraska. This second location is strongly correlated with positive lightning flashes and a high percentage of severe storms. This paper will also include intermediate analyses that will help bound the uncertainty in the IC:CG ratio and IC fraction.

Background

- GOES-R is going to have a GLM which will provide Total Lightning through the day and night.
- It is expected to significantly improve our ability to nowcast severe weather over land and ocean.
- Optimal use of changes in Total Lightning flash rate for individual storms may require knowledge of long-term regional differences in the relative contribution of IC and CG flashes to the total flash rate, reflected in the IC:CG ratio.
 - Boccippio et al. 2001 did a 4 year climatology of ICCG ratio over CONUS using OTD and NLDN
 - We now have a lot more data!

Data and Methods

- Total Lightning** provided by the Optical Transient Detector (OTD), Lightning Imaging Sensor (LIS), and combined OTD/LIS

- OTD → May 1995 – March 2000
- LIS → 1998-2012
 - On the TRMM so only reaches 38° N
- Combined OTD/LIS
 - May 1995 – December 31st, 2012
 - Below 38 Degrees North climatology is 17.5 years
 - Above 38 degrees North climatology is 5 years (OTD only)

- CG Lightning** provided by the U.S. National Lightning Detection Network™

- Grid Size and Smoothing
 - 0.5 x 0.5 degree grid
- Gaussian smoothing with 1 grid (0.5°) Standard Deviation
 - Done before any arithmetic manipulations were made

Assess Spatial Difference between LIS and OTD

- “Signed” Spatial = $\frac{100 \cdot (OTD - LIS)}{(OTD + LIS)/2}$

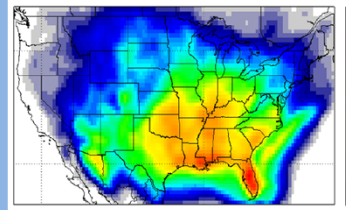
- Magnitude = $\frac{100 \cdot (OTD - LIS)}{(OTD + LIS)/2}$

Ratios

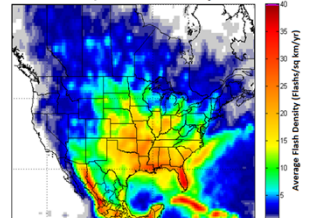
- IC:CG Ratio(Z): $Z = \frac{Total - CG}{CG}$

- Cloud Fraction(CF): $CF = \frac{Total - CG}{Total}$

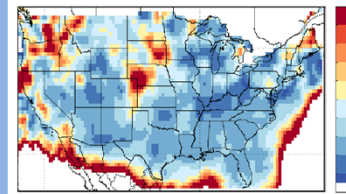
Modified NLDN for OTD and LIS 1995-2012



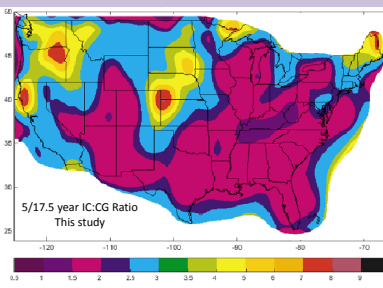
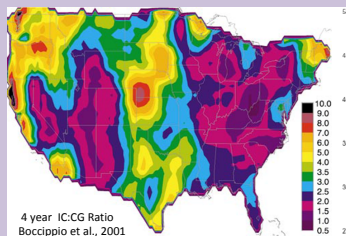
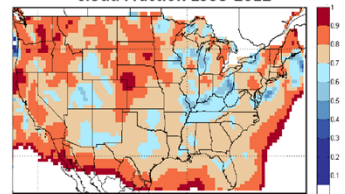
OTD/LIS Flash Density



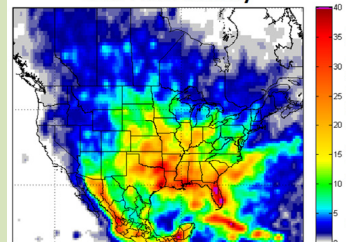
ICCG Ratio 1995-2012



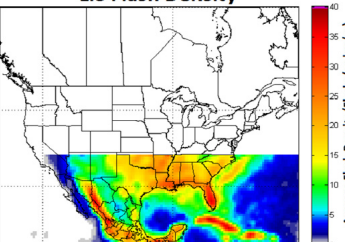
Cloud Fraction 1995-2012



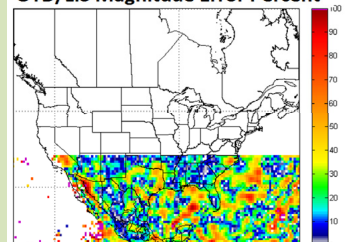
OTD Flash Density



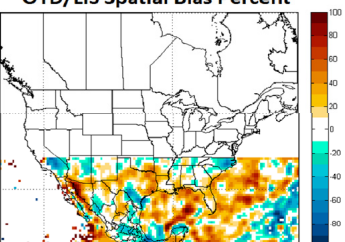
LIS Flash Density



OTD/LIS Magnitude Error Percent



OTD/LIS Spatial Bias Percent



Results

NLDN and OTD/LIS – highest flash densities in:

- Florida
 - Differential heating from thermal contrasts between land-water
- Gulf Coast
 - Deep moisture from the very warm ocean waters helps create strong convection
 - Correlated with large sea-breezes
- Gulf Stream
 - Consists of warm waters that favor deep convection
 - Stationary convective clouds and precipitation
- Front Range of the Rocky Mountains (Relative to its surroundings)
- West Coast of Mexico

Nearly steady fall-off of density to the west, northwest and north of Florida and the Gulf Coast

Regions of High IC:CG and Cloud Fraction:

- NW Texas, W Kansas, Nebraska, S. Dakota
 - High percent of positive CG lightning
 - Large Fraction of severe storms are ‘positive dominant’
 - 30-90% of all severe storms are positive storms
 - Typically less than 10-20% positive in southern and eastern United States storms
- Northwest and west coast
 - Low lightning incidence due to cold water and large-scale sinking
 - This results to weak convection

4-yr vs. 17.5 year IC:CG Climatologies

Similarities

- Maximum over Kansas Nebraska and South Dakota
- High values over Washington, Idaho and Oregon
- Maximum in Northern California
- Similar patterns over the Rocky Mountains
- Follows same patterns in over Eastern United States

Differences (due to much longer observation period in southern latitudes)

- Better Spatial Continuity
- Texas values decreased

This work provides the first assessment of the IC:CG ratio over coastal waters. Both the NLDN and satellite dataset perceived enhanced lightning over the Gulf Stream but there was no variation in the IC:CG ratio.

OTD and LIS Satellite Variability

- Spatial = $\frac{100 \cdot (OTD - LIS)}{(OTD + LIS)/2}$
 - Negative (green/blue) values represent a bias towards LIS
 - Positive (orange/red) values represent a bias towards OTD
 - Mostly vary between ± 40%
 - Highest variation in parts of the Gulf of Mexico, along the west coast of the Gulf of California, and east of the Gulf Stream off the east coast
- Magnitude = $\frac{100 \cdot (OTD - LIS)}{(OTD + LIS)/2}$
 - Similar patterns seen in the spatial plots
 - Larger variations of roughly 50% in south-central and eastern Texas
- Overall variability
 - Differences due to orbital sampling and year-to-year variations in storm locations
 - They only overlap for 2 years
 - LIS has a stable 14 year climatology
 - Dominant variability likely from OTD (5 year climatology)

Future work

Future work will employ three years of Global Lightning Dataset (GLD360) to produce a global IC:CG ratio to improve our understanding of lightning behavior throughout the world.

References :

- Boccippio, D. J., K. L. Cummins, H. J. Christian, and S. J. Goodman, 2001: Combined Satellite- and Surface- Based Estimation of the Intracloud-Cloud-to-Ground Lightning Ratio over the Continental United States. *Monthly Weather Rev.*, **129**, 108–122.
- Cecil, D. J., D. E. Buechler, and R. J. Blakeslee, 2014: Gridded lightning climatology from TRMM-LIS and OTD: Dataset description. *Atmos. Res.*, **135**, 136–404–414.
- Carry, L. D., and K. M. Buffalo, 2007: Environmental Control of Cloud-to-Ground Lightning Polarity in Severe Storms. *Monthly Weather Rev.*, **135**, 1327–1353.
- Holle, R. L., 2014: Diurnal Variations of NLDN-Reported Cloud-to-Ground Lightning in the United States. *Monthly Weather Rev.*, **142**, 1037–1052.