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Analysis of Ground Network Lightning Data Relative to OTD/LIS to Derive Flash Rates for Use in Determining Lightning NO_x Production from Satellite Observation

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***Abstract*. Reactive odd nitrogen (NO_x) with a lightning source affects local air quality, atmospheric photochemistry and global climate through its influence on ozone, an atmospheric pollutant and greenhouse gas, and the hydroxyl radical (OH), the troposphere's "detergent". As part of a project designed to evaluate the production of NO_x per lightning flash, we are using information from the GLD360 and WWLLN networks to estimate the total number of flashes contributing to satellite-retrieved nitrogen dioxide (NO_2) columns from the Ozone Monitoring Instrument (OMI) aboard the NASA Aura satellite. As part of this analysis, we estimated the detection efficiency of these networks relative to the Optical Transient Detector/Lightning Imaging Sensor (OTD/LIS). We then compared detection-efficiency adjusted flash rates from these networks for convection over central Africa and the Gulf of Mexico. Our goal is to determine the uncertainty in total flash rate for each storm and the contribution of that uncertainty to uncertainty in lightning-NO production per flash. In this presentation, we discuss the detection efficiency adjustment and then compare WWLLN and GLD360 flashes for a storm over western Africa on June 24, 2012. We then examine if the NO_x produced by this storm can be seen from OMI. A following talk will discuss the method used to extract the lightning-NO signal from OMI.**

Keywords—nitrogen dioxide, GLD360, WWLLN, OMI, OTD/LIS

I. INTRODUCTION

Reactive odd nitrogen (NO_x) with a lightning source affects local air quality, tropospheric photochemistry, and global climate through its influence on ozone, an atmospheric pollutant and greenhouse gas, and the hydroxyl radical (OH), the troposphere's "detergent".

As part of a project designed to evaluate the production of NO_x per lightning flash, we are using information from the World Wide Lightning Location Network (WWLLN) [*Virts et al*., 2013] and Vaisala GLD360 networks to estimate the total number of flashes contributing to lightning-NO perturbations of satellite-retrieved nitrogen dioxide (NO_2) columns from the Ozone Monitoring Instrument (OMI) aboard the NASA Aura satellite.

In this proof-of-concept paper we describe how we estimate the detection efficiency of these networks relative to the Optical Transient Detector/Lightning Imaging Sensor (OTD/LIS) [*Mach et al*., 2007]. We then compare detection-efficiency adjusted flash rates from these networks over western and central Africa. Finally, we examine the contribution of June 24, 2012 thunderstorms to the tropospheric NO_2 column over western Africa.

II. DETERMINATION AND APPLICATION OF RELATIVE DETECTION EFFICIENCIES

The Optical Transient Detector (OTD) was launched with the MicroLab-I satellite in April 1995 and had a lifetime of ~5 years. It had a 1300 x 1300 km field of view and measured flashes occurring between ±70° with a detection efficiency of 45-55%. It passed over any one location 400 times per year with each observation lasting 2 minutes [*Christian et al*., 2003]. The Lightning Imaging Sensor (LIS) was launched aboard the TRMM satellite in November 1997. It has a 600 x 600 km field of view, storm-scale resolution, and measures flashes occurring between ±35° with a detection efficiency of ~70%. The LIS detects lightning with storm-scale resolution (4 x 7 km) over a large region (600 x 600 km). It sees any one location ~0.1% of the time. The ground-based WWLLN network was formed in 2003 and consisted of ~70 very low frequency sensors as of late 2012. It observes continuously with a detection efficiency that varies with time-of-day, location, and date. While its detection efficiency (~10% globally) is less than that of the LIS, it samples ~100 times as many lightning strokes/flashes per year due to its much greater temporal coverage [*Virts et al.*, 2013]. Therefore with detection efficiency information, it can be used to estimate the flashes associated with individual storms. The ground-based Vaisala GLD360 network was formed in early 2011. It is most sensitive to cloud-to-ground flashes and has detection efficiencies of greater than 50% in much of the Northern Hemisphere and 10-50% in the tropics and Southern Hemisphere [*Demetriades et al*., 2010; *Said et al*., 2013].

In order to determine the total number of flashes contributing to observed lightning-NO perturbations to tropospheric NO_2 columns we gridded the WWLLN and GLD360 flashes hourly as a function of local and universal time onto a 2°x2.5° grid. The time periods gridded were January 1, 2007 through December 31, 2012 for WWLLN and May 5, 2011 through September 30, 2013 for GLD360. The regions gridded were global for WWLLN and central Africa and the Gulf of Mexico for GLD360. We then determined the detection efficiencies (DEs) of each network relative to OTD/LIS as follows:

1. WWLLN and GLD360 srokes/flashes read in and gridded hourly as a f(UT) and f((LT).

2.Gridded stroke/flash rates were smoothed via the sequential application of a 31-day moving average, a 3-hour moving average, and a 3-point x-y boxcar average.

3. For each of the 61 (18) 12-month time periods during the January 2007-December 2012 (May 2011 – September 2013) time period, the mean DE of WWLLN strokes (GLD360 flashes) relative to the OTD/LIS was determined by dividing the number of ground-network flashes during the 12-month time period at each grid box by the number of v2.3 OTD/LIS flashes during the same time period at the same grid box.

4. The DE for individual months was then determined by averaging DEs from the twelve 12-month periods containing the month of interest. The result was a temporally weighted DE with the month of interest having the highest weighting.

5. The resulting WWLLN DEs were smoothed via the 3x application of a 7-point boxcar average. The results DEs were then multiplied by a scaling factor to ensure that the mean six-year average flash rate matches v2.3 OTD/LIS climatology. This smoothing step was not taken with the GLD360 product as it had a higher DE and we did not have global fields

6. Finally, an OTD/LIS based diel adjustment was applied to the WWLLN DEs. This step was not taken with the GLD360 product, although we may do so in the future.

Figure 1 shows the mean DE of WWLLN and GLD360 relative to OTD/LIS over central and western Africa (20°W to 35°E, 10°S to 20°N) for June through August 2012. For this region and time period, the mean DE of WWLLN strokes relative to OTD/LIS flashes is 3.2%, while the mean DE of GLD360 flashes relative to OTD/LIS is 25.7%. Clearly, ground-network detection efficiencies in this region of plentiful lightning are low relative to most locations of the globe.

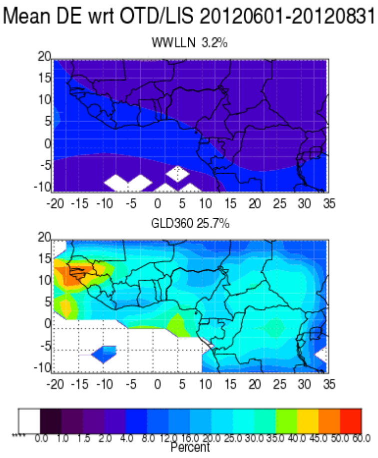

Figure 1. Mean DE of WWLLN strokes and GLD360 flashes relative to OTD/LIS for June through August 2012.

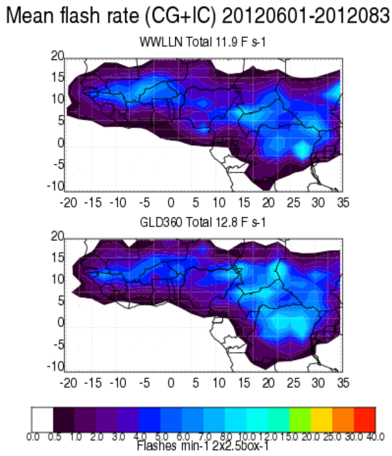

Figure 2. DE-adjusted mean flash rate for June – August 2012. WWLLN (GLD360) is shown on top (bottom).

Figure 2 shows the mean detection-efficiency adjusted flash rates from WWLLN and GLD360 for the same region and time period. The mean flash rates (11.9 and 12.8 Flashes s^{-1} for WWLLN and GLD360 are nearly the same with WWLLN showing larger flash rates over western Africa and GLD360 showing larger flash rates over central Africa. The temporal correlation of daily flash rates between WWLLN and GLD360 for this time period and region was 0.56 (not shown).

III. CASE STUDY ANALYSIS

The Ozone Monitoring Instrument (OMI) aboard the NASA Aura satellite passes overhead at ~1:30 PM local time, which is ~3 hours before lightning activity peaks at many continental locations. This diel cycle is prominent in our region of interest too with June-August 2012 flashes in the six-hour time period preceding OMI overpass averaging 4.2 (7.5) flashes s^{-1} and flashes in the six-hour time period following OMI overpass averaging 22.6 (30.7) flashes s^{-1} for WWLLN (GLD360). Clearly, the overpass time is not ideal for LNO_x

estimation. We look forward to the launch of geostationary satellites that include lightning sensors.

We note that DE-adjusted GLD360 flashes exceed DE-adjusted WWLLN flashes during daytime hours. This bias exists despite the fact that total flashes detected are similar. Therefore, day-night differences in detection efficiency add uncertainty and will need to be re-examined.

Flashes that occur during the six-hour time period prior to OMI overpass are assumed to contribute to the LNO_x perturbation to the OMI NO_2 column. Figure 3 compares WWLLN and GLD360 flash rates for 08-13 LT on June 24, 2012.

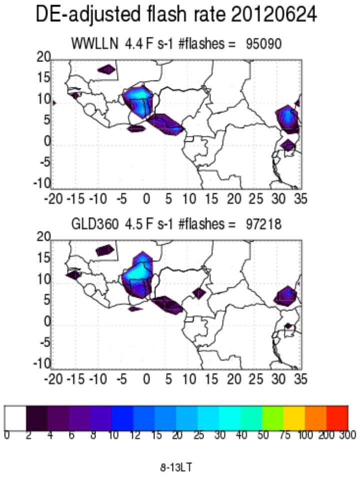

Figure 3. Detection-efficiency flash rate for 08-13 UT June 24, 2012.

Flashes are concentrated over western Africa (Burkina Faso) with perhaps 90000 flashes occurring over western Africa during this six-hour period. Figure 4 shows the OMI tropospheric NO_2 column on the 24th of June. Elevated amounts of NO_2 are seen over western Africa in vicinity of the the lightning strikes. Possible sources for this NO_2 include soil-NO emissions, biomass burning, anthropogenic emissions, and of course lightning-NO. Figure 5 shows the 550 nm aerosol optical depth from MODIS aboard Aqua [*Levy et al.*, 2010] at approximately the same time. While data are missing over the center of the convection, it does show larger than background AOD over central Africa. This biomass burning signal is additional noise that must be considered when estimating LNO_x production per flash using satellite data. The method used to isolate the LNO_x signal from the tropospheric background is described in a companion paper by K. Pickering.

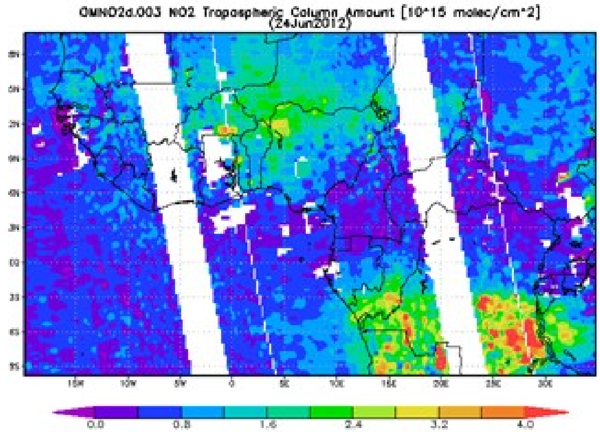

Figure 4. Tropospheric NO_2 column (petamolecules cm^{-2}) from OMI on June 24, 2012. All pixels are included regardless of cloud cover. Plot prepared using Giovanni http://disc.sci.gsfc.nasa.gov/giovanni] a product developed and maintained by NASA GES DISC [Acker and Leptoukh, 2010]. The NO_2 fields are based on version 2 of the OMI standard product [*Bucsela et al*., 2013].

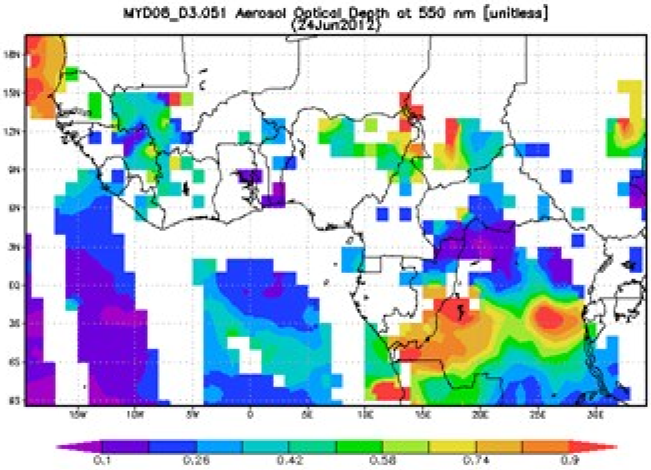

Figure 5. Aerosol optical depth at 550 nm from MODIS on June 24, 2012. Plot prepared using Giovanni. The AOD is from v5.1 of MODIS-Aqua.

A. Authors and Affiliations

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