The NASA Lightning Nitrogen Oxides Model (LNOM): Application to Air Quality Modeling

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ABSTRACT: Recent improvements to the NASA Marshall Space Flight Center Lightning Nitrogen Oxides Model (LNOM) and its application to the Community Multiscale Air Quality (CMAQ) modeling system are discussed. The LNOM analyzes Lightning Mapping Array (LMA) and National Lightning Detection Network™ (NLDN) data to estimate the raw (i.e., unmixed and otherwise environmentally unmodified) vertical profile of lightning NOx (= NO + NO_2). The latest LNOM estimates of lightning channel length distributions, lightning 10-m segment altitude distributions, and the vertical profile of lightning NOx are obtained. The primary improvement to the LNOM is the inclusion of non-return stroke lightning NOx production due to: hot core stepped and dart leaders, stepped leader corona sheath, K-changes, continuing currents, and M-components. The impact of including LNOM-estimates of lightning NOx for an August 2006 run of CMAQ is discussed. Global estimates of lightning NOx are also provided using the NASA satellite global lightning climatology.

1. INTRODUCTION

The methodologies for estimating lightning NOx have involved theoretical and laboratory studies, studies that attempt to combine aircraft measurements with modeling results, and studies that are based on satellite observations. Unfortunately, there has been considerable variability in the estimates of lightning NOx production per flash; see for example the summary table in Labrador et al. (2005) and the review paper by Schumann and Huntrieser (2007). The variability in these estimates is linked to the differences in the measurements and estimation methods employed, and the natural variability of lightning. Recently, the NASA Marshall Space Flight Center introduced the Lightning Nitrogen Oxides Model (LNOM; Koshak et al., 2010) to combine routine and accurate measurements of lightning with Wang et al. (1998) lightning NOx laboratory results.

In the present study, we implement important upgrades to the LNOM, and apply it to analyze thunderstorms occurring over North Alabama for the following months: August 2005, August 2006, August 2007, August 2008, and August 2009. The LNOM-derived lightning NOx profiles are then used to assess the impact of lightning NOx on an August 2006 run of the Community Multiscale Air Quality (CMAQ) modeling system. Global estimates of lightning NOx production are also provided using the NASA Optical Transient Detector (OTD) and Lightning Imaging Sensor (LIS) global lightning climatology.

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2. THE LNOM

2.1 Basic Functionality

The LNOM ingests lightning VHF source location (and time-of-occurrence) data such as obtained from the North Alabama Lightning Mapping Array (NALMA). It also ingests location, time-of-occurrence, peak current, and stroke multiplicity data from the National Lightning Detection Network™ (NLDN). These data are used to determine the flash type (ground or cloud) of each flash occurring within an analysis cylinder (height 0-20km, and radius 20.31km). This cylinder is the approximate volume equivalent of a 36km x 36km CMAQ grid cell. The LNOM analyzes the VHF sources to estimate the total channel length of each flash. It also chops each portion of a flash contained in the analysis cylinder into 10-m segments to determine the Segment Altitude Distribution (SAD) within the cylinder. Finally, it computes the vertical lightning NOx profile in the cylinder; see Figure 1.

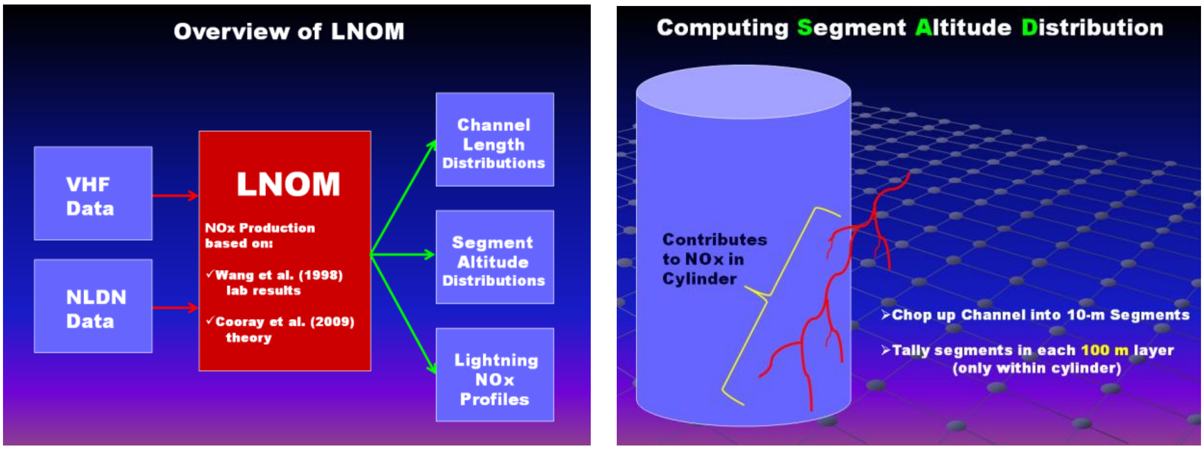

Figure 1. Functionality of the LNOM showing (left) inputs & outputs, and (right) the analysis cylinder and details of channel segment altitude distribution computation.

2.2 Recent Upgrades

Upgrades to LNOM involve the addition of several important non-return stroke processes that produce NOx (see Cooray et al., 2009), but are often neglected by other investigators. Specifically, the LNOM upgrades include NOx contributions from: hot core stepped leader, hot core dart leaders, stepped leader corona sheath, K-changes, continuing currents, and M-components.

2.3 Examples of LNOM Output

Examples of the LNOM output for the August 2006 analysis period in Northern Alabama are provided in Figure 2. The LNOM also provides the component NOx profiles due to each separate production mechanism (i.e., return strokes, hot core stepped leaders, hot core dart leaders, stepped leader corona sheaths, K-changes, continuing currents, and M-components). The sum of these components gives the final result shown in the right-side plot of Figure 2. The average channel length of a flash (across all five Augusts) ranged from 38.9 km to 69.6 km.

3. LIGHTNING NOx STATISTICS

The LNOM analysis of the five Augusts (2005-2009) has provided statistics of the amount of NOx produced by ground and cloud flashes, and by all flashes overall as shown in Table 1.

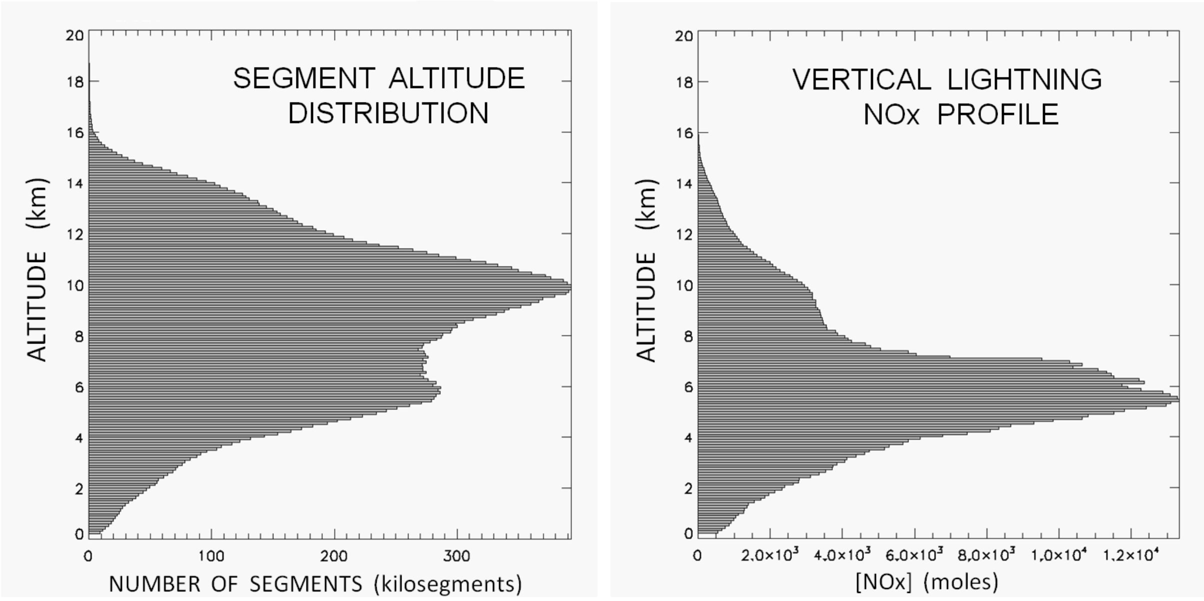

Figure 2. Example of two LNOM output products for the August 2006 analysis period.

Table 1. LNOM summary statistics [NOx is in moles; NOx values are flash-count-weighted means].						
Period	# Ground Flashes	# Cloud Flashes	Total # of Flashes	NOx per Ground Flash	NOx per Cloud Flash	NOx per Flash
August 2005	1023	5306	6329	403.26	26.34	87.27
August 2006	1067	6986	8053	601.41	34.03	109.21
August 2007	1058	5766	6824	450.17	37.22	101.24
August 2008	1237	7563	8800	380.70	33.52	82.32
August 2009	447	2252	2699	756.08	54.97	171.09
Totals/Means	4832	27,873	32,705	**484.15**	**34.78**	101.17

4. IMPACT ON AUGUST 2006 CMAQ RUN

We summed the August 2005-2009 lightning NOx profiles and divided by the number of flashes (to obtain per flash NOx profiles). The August 2006 NLDN data was then used to find the number of ground flashes in each

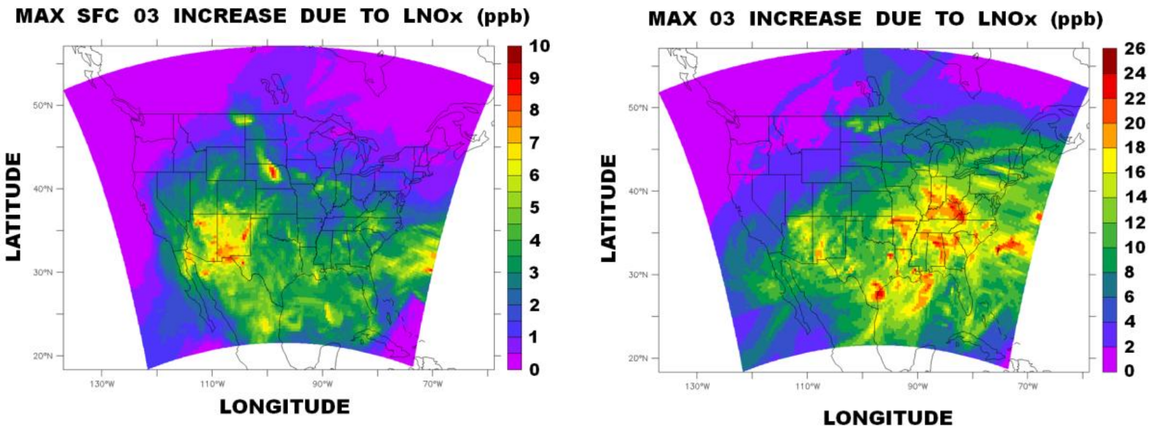

Figure 3. Impact of lightning NOx on ozone (left) at surface, and (right) at all levels.

CMAQ grid cell; climatological Z-ratio data was used to estimate the associated number of cloud flashes. The ground and cloud flash counts were then multiplied by the respective per ground and per cloud flash lightning NOx profiles to estimate the lightning NOx profile within each CMAQ grid cell. The August 2006 CMAQ run was then completed. Figure 3 shows the impact of LNOM-derived lightning NOx on CMAQ ozone predictions.

5. GLOBAL LIGHTNING NOx

Using the statistics in Table 1, an estimate of global lightning NOx can be obtained. Christian et al. (2003) gives a global annual total of about N = 1,387,584,000 flashes. Mackerras et al. (1998) estimates a global ground flash fraction range of between 0.154-0.215, which has a midpoint m = 0.1845. Using the weighted means from Table 1 give a total annual lightning NOx of: $mN(484.15) + (1-m)N(34.78)$ = 1.633E11 moles = 2.287 Tg(N).

6. CONCLUSIONS

It is feasible to combine LMA/NLDN data, laboratory measurements, and theory to make estimates of lightning NOx that are useful in air quality and global climate studies. The fixed 250 or 500 moles/flash values customarily assumed in the literature, with production by ground and cloud flashes set equal, is not optimal given the results in Table 1. The impact of lightning on air quality is significant (Figure 3). Finally, our 2.287 Tg(N) estimate of global annual lightning NOx is regarded as a lower bound since most lightning occurs in the tropics where the tropopause is higher, leading to longer channel lengths and hence more lightning NOx production.

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