A SUMMARY OF THE NASA LIGHTNING NITROGEN OXIDES MODEL (LNOM) AND RECENT RESULTS

William Koshak*
Earth Science Office, NASA Marshall Space Flight Center, Huntsville, AL, USA

Harold Peterson
National Space Science & Technology Center, Huntsville, AL, USA

1. INTRODUCTION

Making accurate estimates of lightning NOx (= NO_2 + NO) has proven difficult for several reasons: the variable nature of lightning, the difficulty in making direct measurements of the physical parameters of lightning that are important to NOx production, and an incomplete knowledge of all the physical mechanisms responsible for NOx production by lightning.

To help improve upon these limitations, the NASA Marshall Space Flight Center introduced the Lightning Nitrogen Oxides Model (LNOM; Koshak et al., 2009). The LNOM combines detailed, flash-specific measurements of lightning with empirical laboratory results of lightning NOx production. The measurements include VHF lightning source data [such as from the North Alabama Lightning Mapping Array (NALMA; Koshak et al., 2004)], and ground flash location, peak current, and stroke multiplicity data from the National Lightning Detection Network™ (NLDN). Following some initial runs of LNOM (Koshak et al., 2010), the model was updated to include several non-return stroke lightning NOx production mechanisms and was applied in Koshak et al. (2011) to examine the impact of lightning NOx on ozone forecasts for an August 2006 run of the Community Multiscale Air Quality (CMAQ) modeling system.

In this study, we briefly discuss the functionality of the LNOM and describe the model's latest upgrades and applications. Whereas previous applications were limited to five summer months of data for North Alabama thunderstorms, this most recent LNOM analysis covers all seasons of several years. The latest statistics of ground and cloud flash NOx production are provided.

**Corresponding author:* William J. Koshak, Earth Science Office, ZP11, NASA-MSFC, Robert E. Cramer Research Hall, 320 Sparkman Drive, Huntsville, AL, 35805-1912; e-mail: william.koshak@nasa.gov

2. LNOM FUNCTIONALITY

An overview of the basic functionality of the LNOM is provided in Figure 1. The LNOM ingests lightning VHF source location (and time-of-occurrence) data such as obtained from the NALMA. It also ingests location, time-of-occurrence, peak current, and stroke multiplicity data from the NLDN. Both the VHF and NLDN data are used to determine the flash type (ground or cloud) of each flash occurring within an analysis cylinder (height 0-21km, and radius 20.31km). This cylinder is the approximate volume equivalent of a 36km x 36km CMAQ grid cell, but is adjustable for other application purposes.

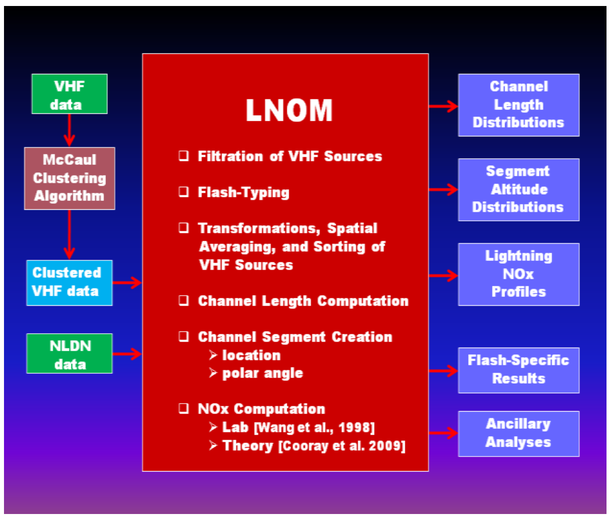

Figure 1. Functionality of the LNOM showing data inputs and product outputs.

The LNOM analyzes the VHF sources to estimate the total channel length of each flash. It also dices up the lightning channel into 10-m segments, and then tallies those segments (falling inside the analysis cylinder) as a function of altitude; this produces the Segment Altitude Distribution (SAD) product. Finally, using laboratory (Wang et al., 1998) and theoretical (Cooray et al., 2009) results, the LNOM interrogates all of the 10-m segments to compute the vertical lightning NOx profile inside the analysis cylinder and the total NOx produced by each flash. A summation of the NOx profiles produced inside the analysis cylinder by each flash gives the final lightning NOx profile product for the analysis period studied (typically a 1 month profile).

3. RECENT LNOM UPGRADES

The LNOM continues to evolve in order to improve its accuracy, speed, practicality, and ease of operation. The subsections below highlight the major LNOM upgrades that have occurred since early February of 2011.

3.1 Channel Length Computation

Early versions of the LNOM [i.e., as provided in Koshak et al. (2010) and earlier] did not have sufficient spatial resolution for computing lightning flash channel length. On March 9, 2011, the LNOM was upgraded so that spatial averaging of VHF sources was performed over $(100\ m)^3$ grid cells rather than the $(1\ km)^3$ grid cells previously used. This upgrade has allowed the LNOM to better account for the tortuous nature of lightning, and has resulted in more realistic (longer) channel length estimates, hence more NOx production.

3.2 Negative Charge Layer Height

The LNOM needs the height of the lower negative charge layer, or so called "N-region" of the thundercloud, in order to properly calculate NOx from individual lightning channel segments. Previously, the lower relative maximum of the SAD was manually analyzed to estimate the N-region altitude. This was time consuming, and required extra LNOM runs. On March 23, 2011, this process was removed and replaced with a more accurate method that sets the N-region altitude at the height of the -15^oC isotherm, which is where charging occurs. The average sea-level temperature (for the particular month analyzed and for the particular location of the VHF network employed) is combined with a prescribed atmospheric lapse rate to compute the height of the -15^oC isotherm.

3.3 Leader Currents

Certain lightning current values provided in the older literature have been adjusted as discussed in Rakov and Uman (2003; pgs. 126, 168, 331) and Cooray (2003; pgs. 151-152). As such, the following upgrades to assumed currents in the LNOM were made on March 23, 2011: (1) stepped leader current was increased from 100A to 1.3 kA, (2) dart leader current was increased from 1kA to 1.7kA, and (3) cloud flash hot core leader current was increased from 100A to 130A.

3.4 Flash-Typing

According to Cummins and Murphy (2009), NLDN-detected flashes with positive peak currents between 10-20 kA are in reality a mixture of ground and cloud flashes. Hence, flashes in the positive 10-20 kA range (which are relatively few) are deemed an "ambiguous" flash type by LNOM and are removed from further LNOM analyses. This upgrade was implemented on July 15, 2011.

3.5 Continuing Currents

Previously, the LNOM randomly assigned continuing currents (CCs) to 30% of the ground flashes. But, CCs are actually more frequent in positive polarity ground flashes. Even though positive ground flashes are only about 10% of all ground flashes, the LNOM now randomly assigns CC to 75% of the positive ground flashes. This change was implemented on August 18, 2011. In addition, a complicated "wave propagation" model for determining the duration of CCs was replaced by a simpler, and more realistic 100 ms duration; this change was implemented on August 22, 2011.

4. LNOM RUNS FOR 2005-2007

In this study, the latest version of the LNOM was applied to analyze substantially more flashes from North Alabama thunderstorms than has previously ever been analyzed. In total, we have obtained lightning NOx profiles for each month in the three years 2005-2007 (see Figures 2-4). Since the LNOM analysis cylinder is rather narrow in horizontal extent, two months had no flashes captured by the cylinder.

Each profile provided in Figures 2-4 shows three rows of information in red. The first row is the number of ground flashes and the associated average NOx per ground flash. The second row is the number of cloud flashes and the average NOx per cloud flash. Finally, the third row is the total number of flashes and the average NOx per flash (i.e., the sum of the NOx from all flashes divided by the total number of flashes).

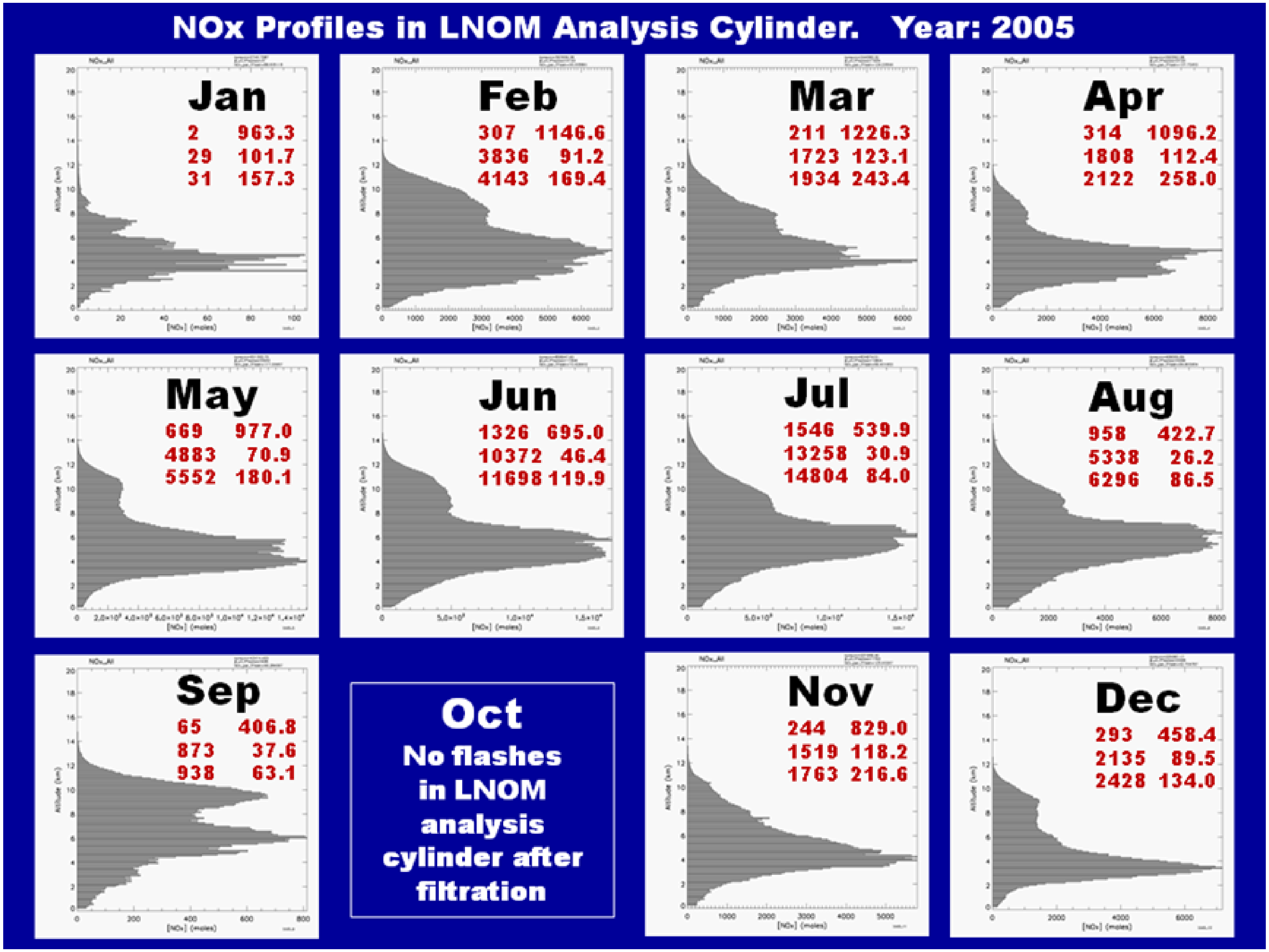

Figure 2. The monthly lightning NOx profiles (altitude vs. [NOx] in moles) within the LNOM analysis cylinder for North Alabama storms in the year 2005; see main text for a description of the information in red.

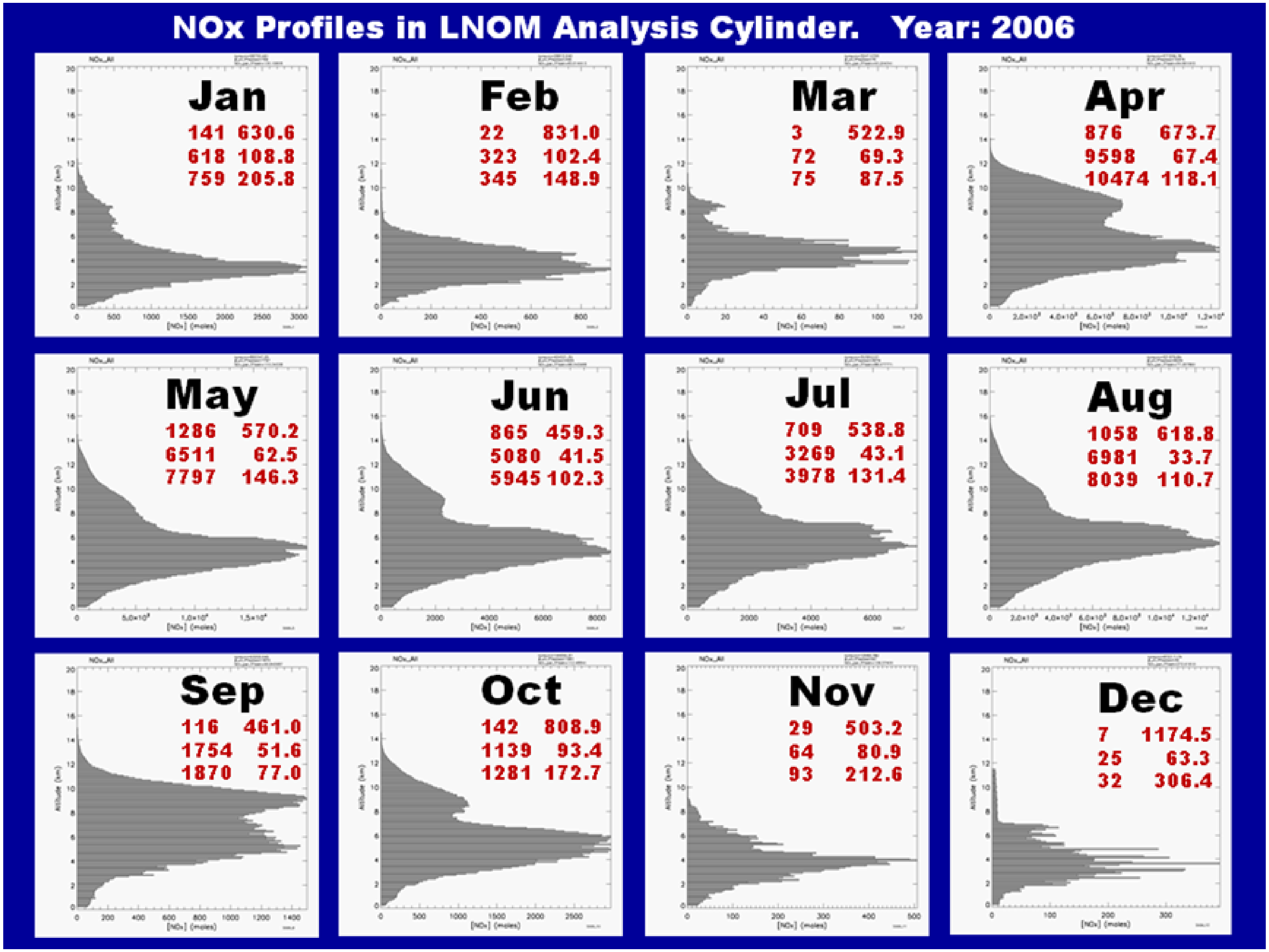

Figure 3. The monthly lightning NOx profiles (altitude vs. [NOx] in moles) within the LNOM analysis cylinder for North Alabama storms in the year 2006; see main text for a description of the information in red.

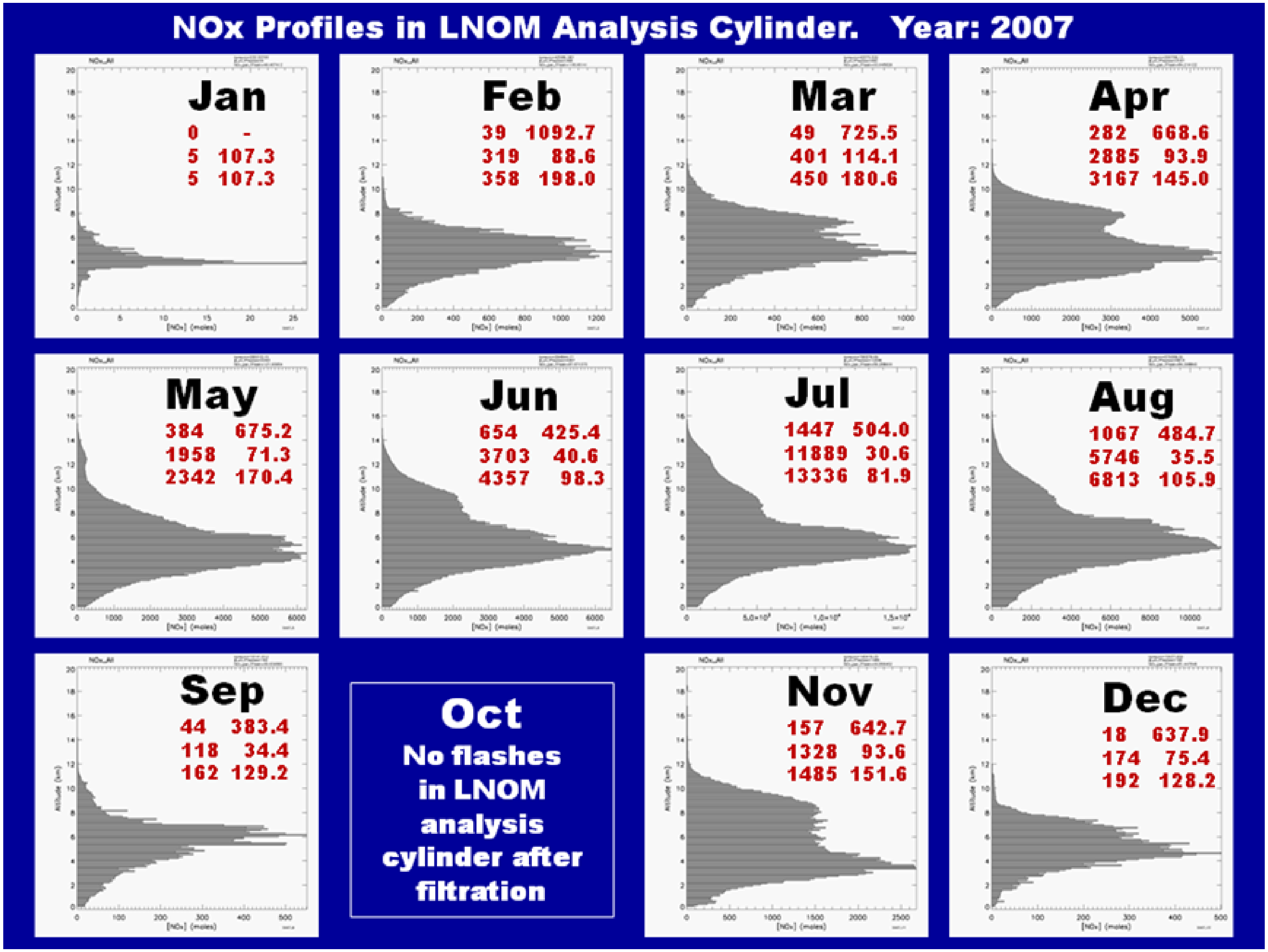

Figure 4. The monthly lightning NOx profiles (altitude vs. [NOx] in moles) within the LNOM analysis cylinder for North Alabama storms in the year 2007; see main text for a description of the information in red.

5. SUMMARY

The computations for lightning channel length and negative charge altitude (“N-region” height), the values of leader and continuing current, and the flash-typing algorithm have all been updated within the LNOM. In addition, the LNOM now produces flash-specific output files that provide: details of the NOx profile (within the LNOM analysis cylinder) for each flash, the length of the flash channel, the total NOx produced by the flash, and other flash characteristics (e.g., time stamp, flash location, and the multiplicity and peak current if a ground flash).

This updated version of the LNOM was applied to analyze three consecutive years (2005-2007) of thunderstorms in North Alabama. In this period, the LNOM calculated the NOx for 125,064 flashes (15,330 ground flashes, and 109,734 cloud flashes). The average NOx produced by ground flashes was 611.3 moles, and the average produced by cloud flashes was 53.2 moles.

The LNOM continues to be an increasingly important tool for obtaining realistic estimates of lightning NOx emission inventories for regional air quality models and global chemistry/climate models. Because of the unique and detailed “bottom-up” estimates of lightning NOx offered by the LNOM on a flash-by-flash basis, the era of employing oversimplified “vertical stick” models of lightning, or assumptions of constant NOx per flash, can be replaced with parameterizations that depend on LNOM results.

6. ACKNOWLEDGEMENTS

This work supported under ROSES NRA NNH08ZDA001N (A.18 Decisions; PI Arastoo Biazar of the University of Alabama in Huntsville), ROSES NRA NNH09ZDA001N-ACMA (A.15 Atmospheric Composition Modeling and Analysis; PI Yuhang Wang of the Georgia Institute of Technology), and the NASA Post-doctoral Program (NPP).

7. REFERENCES

Cooray, V., M. Rahman, V. Rakov, 2009: On the NOx production by laboratory electrical discharges and lightning, *J. of Atmo. Solar-Terres. Phys.,* **71**, 1877-1889.

Cooray, V., The Lightning Flash, IEE Power & Energy Series, The Institution of Electrical Engineers, 2003, London, United Kingdom, ISBN 0-85296-780-2, 574 pp.

Cummins, K. L., M. J. Murphy, 2009: An overview of lightning locating systems: history, techniques, and data uses, with an in-depth look at the U.S. NLDN, IEEE Transactions on Electromagnetic Compatibility, **51**, No. 3, 499-518.

Koshak, W. J., R. J. Solakiewicz, R. J. Blakeslee, S. J. Goodman, , H. J. Christian, J. M. Hall, J. C. Bailey, E. P. Krider, M. G. Bateman, D. J. Boccippio, D. M. Mach, E. W. McCaul, M. F. Stewart, D. E. Buechler, W. A. Petersen, D. J. Cecil, North Alabama Lightning Mapping Array (LMA): VHF source retrieval algorithm and error analyses, J. Atmos. Oceanic Technol., **21**, 543-558, 2004.

Koshak, W., H. Peterson, M. Khan, A. Biazar, L. Wang, The NASA Lightning Nitrogen Oxides Model (LNOM): Application to Air Quality Modeling, XIV International Conference on Atmospheric Electricity, Rio de Janeiro, Brazil, August 8-12, 2011.

Koshak, W. J., H. S. Peterson, E. W. McCaul, A. Biazar, Estimates of the lightning NO_x profile in the vicinity of the North Alabama Lightning Mapping Array, International Lightning Detection Conference, Orlando, FL, April 19-20, 2010.

Koshak, W. J., M. N. Khan, A. P. Biazar, M. Newchurch, R. T. McNider, A NASA model for improving the lightning NOx emission inventory for CMAQ, Joint Session: 4th Conference on the Meteorological Applications of Lightning Data and and the 11th Conference on Atmospheric Chemistry; 89th Annual AMS Conference, Phoenix, AZ, January 11-15, 2009.

Rakov, V. A., and M. A. Uman, Lightning: Physics and Effects, Cambridge University Press, 2003 Cambridge CG2 2RU, UK, ISBN 0-521-58327-6, 687 pp.

Wang, Y., A. W. DeSilva, and G. C. Goldenbaum, 1998: Nitric oxide production by simulated lightning: dependence on current, energy, and pressure, *J. Geophys. Res.*, **103**, 19149-19159.