LNOx Influence on Upper Tropospheric Ozone

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Introduction

Lightning is a particularly significant NO_x source (LNO_x) in the middle and upper troposphere where NO_x is long-lived, typically at more dilute concentrations, and consequently more efficient at producing ozone than in the boundary layer where the majority of NO_x is emitted.

Currently, the CMAQ model does not count for NO_x emission from lightning.

However, it's important to quantify the effect of LNO_x on tropospheric ozone concentration in order to make our model simulation more realistic, particularly in regions/periods with frequent lightning events.

In this study, we will apply the National Lightning Detection Network (NLDN) lightning data as an extra NO_x emission sources to the CMAQ model and then quantify the contributions of LNO_x to tropospheric ozone. These quantitative values will be useful for parameterization in future modeling studies.

NLDN

The U.S. National Lightning Detection Network (NLDN) has been providing real-time, continental-scale information on cloud-to-ground (CG) lightning since 1989 (Cummins et al., 1998). After its most-recent system-wide upgrade in 2002, the CG flash detection efficiency (DE) has been improved into the range of 90-95% throughout the continental U.S. (Cummins et al., 2006).

Parameterization

We adjust CG flash counts for NLDN detection efficiency (DE) of ~95%.

Scale up the CG flash counts to total flashes using a fixed IC:CG ratio value (3) which is close to the Boccippio et al. (2001) 4-yr mean IC:CG ratio value (2.94).

Assume each flash produces 500 moles of NOx; 75% of LNOx as LNO and 25% as LNO_2.

Vertically distribute LNO_x amounts into 39 layers of CMAQ model according to the mid-latitude continental profile specified in Pickering et al. (1998).

(a) (b)

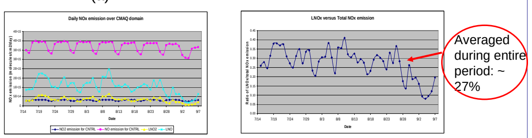


Figure 1. (a) Daily NO_x emissions (molecules/cm2/day) over CMAQ domain for the CNTRL run as well as LNO_x emission. (b) Ratio of daily LNO_x production versus daily total NO_x emission (including LNO_x).

•Two model runs are made:

•CNTRL: NOx emission only from the boundary layer;
•CNTRL_LNOx: NOx emission from the boundary layer and lightning.

(Both runs use pre-defined boundary conditions that may not represent the real atmosphere well)

NO_2 emission modified by LNO_x

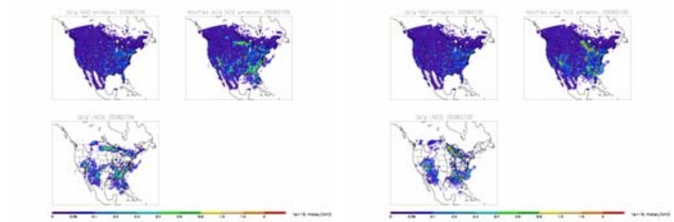


Figure 2. NO_2 emission during 0 GMT ~ 24 GMT, (a) July 29, 2006; (b) July 30, 2006. Upper left: NO_2 emission from CNTRL; Upper right: NO_2 emission for CNTRL_LNO_x; Bottom: LNO_2.

LNO_x impacts on model NO_2 prediction

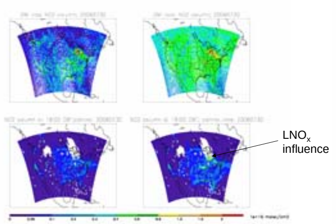


Figure 3. NO_2 column from OMI and CMAQ model. Upper: OMI tropospheric (left) and total (right) NO_2 column. Bottom: Tropospheric NO_2 at 19:00 GMT, from two CMAQ simulations: CNTRL (left) and CNTRL_LNO_x (right). The CMAQ tropospheric NO_2 is calculated based on the tropopause pressure from OMI O_3 data.

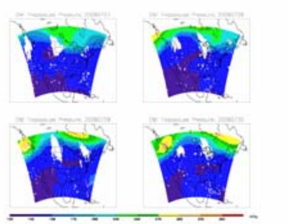


Figure 4. Tropopause pressure field from OMI O_3 data. CMAQ tropospheric columns of NO_2 and O_3 are calculated according to these pressures. Blank areas indicate failure of obtaining tropopause pressure from OMI O_3 data set.

LNO_x influence on CMAQ O_3 (compared with OMI O_3)

(19:00 GMT, 7/30/2006) **(19:00 GMT, 8/10/2006)**

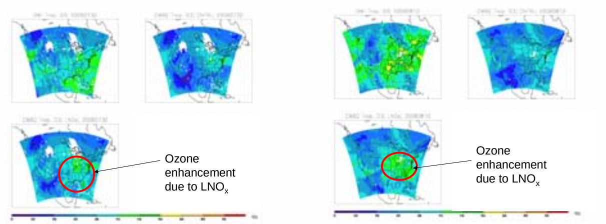


Figure 5. Tropospheric ozone column from OMI and CMAQ model (CNTRL and CNTRL_LNO_x runs).

Evaluating LNO_x influence on Ozone Prediction using ozonesonde measurements (Aug. 2006)

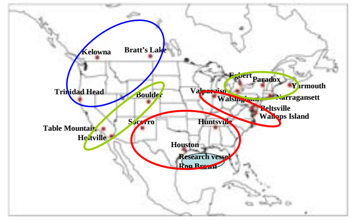


Figure 6. LNO_x influenced O_3 at IONS06 stations.

Three groups are divided:

Not influenced: Kelowna(26), Bratt's Lake(28), Trinidad Head(29)

Improved: Table Mountain(25), Holtville(10), Boulder(27), Egbert(15), Paradox(5), Yarmouth(13), Walsingham(19), Narragansett(27)

Significantly improved: Socorro(25), Houston(16), Ron Brown(23), Huntsville(29), Valparaiso(5), Beltsville(9), Wallops Island(10)

Note: Digits indicate number of ozonesonde measurements within 15:00 ~ 23:00 GMT at each station.

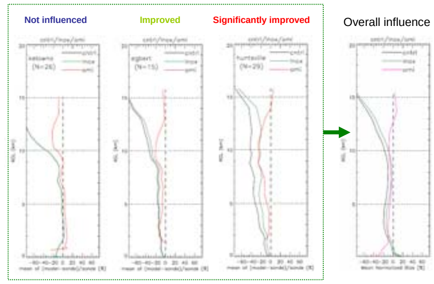
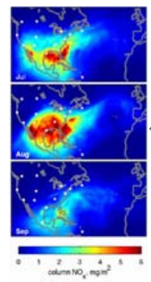


Figure 7. Mean normalized bias when model predicted O_3 (CNTRL and LNO_x runs) and OMI O_3 are evaluated by ozonesonde measurements.

Consistent with Cooper et al., 2009



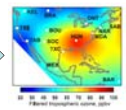


Figure 9: Median filtered tropospheric ozone (FTO_3) mixing ratios during August 2006 at all 14 IONS06 measurement sites between 10 and 11 km. FTO_3 is the measured ozone within the troposphere with the model calculated stratospheric ozone contribution removed. Details on the methodology are given by Cooper et al. [2007]. Figure adapted from Cooper et al. [2007].

Figure 8. Monthly average location of a 20-day passive LNO_x tracer that has been allowed to decay with a 4-day e-folding lifetime, indicating the regions where LNO_x would most likely be found, as well as the regions where ozone production would most likely occur, for July through September 2006.

Conclusions

We estimate total lightning NO_x amount from NLDN CG flashes based on a set of assumptions (DE~95%, IC:CG ratio ~ 3, LNO_x production rate ~ 500 moles N per flash), and put them into 39 CMAQ model layers according to Pickering's vertical distribution profile.

LNO_x contributes 27% to total NO_x emission during July 15 ~ Sept. 7, 2006.

Model prediction shows significant enhancement in upper tropospheric ozone concentration due to lightning-produced NO_x above southeastern and eastern U.S.

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