Implementing Lightning-NO$_x$ Production For Studies Of Thunderstorms And Chemistry

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Motivation

To understand the influence of convection on the chemistry and composition of the upper troposphere, representing convective transport and production of nitrogen oxides (NO$_x$ = NO + NO$_2$) by lightning is important. A high resolution WRF-Chem simulation ($\Delta x=4$km) is being conducted to investigate the role of the North American monsoon in affecting ozone and its precursors. Here we focus on the production of NO$_x$ from lightning and its contribution to NO$_y$ in the troposphere.
WRF-Chem simulation performed for the time period of July 10 to July 23, 2006, at 4 x 4 km² horizontal resolution over US.
Model Description

• **Physics**
  – Single moment cloud physics (Lin et al. 1983)
  – Mellor-Yamada-Janjic PBL parameterization
  – NOAH land surface model
  – Rapid Radiative Transfer Model for long wave radiation
  – Goddard scheme for short wave radiation
    ➢ Allows aerosols to feed back to radiation heating and meteorology

• **Dynamics**
  – Runge-Kutta time integration method
  – Positive definite, monotonic advection for water, scalars, and chemistry species
Model Description

• **Chemistry**
  - RACM (fast-TUV) gas-phase chemistry & MADE/SORGAM aerosols
  - Anthropogenic emissions: US EPA NEI-05 + Mexico NEI
  - Biogenic emissions: MEGAN online calculation
  - Wildfire emissions (Wiedinmyer et al. 2006): MODIS locations and Plume-rise (Freitas et al. 2005).
  - Aircraft emissions: 1999, 1x1 annual average
  - Wet and dry deposition
  - Aerosols feed back to radiation heating in meteorology
  - Lightning-generated nitrogen oxides
1) Lightning flash rate is predicted:

- \( FR = 5.7 \times 10^{-6} \, w_{\text{max}}^{4.5} \) (Price and Rind, 1992)

Note: \( w_{\text{max}} \) is meant to be for each storm; we calculate it for each WRF tile, which is ~172 km x 128 km sized regions

2) Partition between intracloud (IC) and cloud-to-ground (CG) flashes based on Boccippio et al. (2001) climatology

That is, region between 90W and 105W has IC:CG = 3.5; other regions IC:CG = 1.5
3) Find region of reflectivity > 20 dBZ (DeCaria et al., 2000)
   - Distribute NO horizontally within this region

4) Distribute NO vertically using a curve
   - CG flash: Gaussian distribution
   - IC flash: Bimodal distribution

5) Amount of NO produced per flash
   - 330 moles NO/flash (both CG and IC flashes)
     This is based on average found in Schumann and Huntrieser (2007) review.
Evaluation of NO\textsubscript{x} at monitoring sites located between 22-50N and 120-65W

WRF-Chem reproduces nighttime observations well, but overpredicts observations during daytime.
Much of the high NO$_x$ concentrations in the upper troposphere is due to lightning.

Example Results* from North American Monsoon (NAM) 2006 Case – **Upper Troposphere**

*All results for:
21 July 2006 at 2100 UTC
(2 pm west coast, 5 pm east coast)
Lightning-NO_x contributes up to 50% of NO_y in the upper troposphere.
• Lightning-NO$_x$ important in the UT, which contributes to NO$_y$

• Clean air from Canada moving southward behind front

Model Radar Reflectivity
Example Results – 2 km Altitude

NO$_y$ at 2 km altitude

Fraction of NO$_y$

Lightning NO$_x$ scalar at 2 km

Lightning-NO$_x$ / NO$_y$

NO$_x$ / NO$_y$

HNO$_3$ / NO$_y$

PAN / NO$_y$

Lightning NO$_x$ tracer is <10% of NO$_y$ near top of BL
Example Results – Amount of Lightning NO\textsubscript{x} in 0-2 km altitude range

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<tr>
<td><strong>Average daily input of N into 0-2 km altitude range</strong></td>
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<tr>
<td><strong>Anthropogenic Emissions</strong></td>
<td>4.665x10\textsuperscript{8} kg N/day</td>
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<tr>
<td><strong>Lightning Production</strong></td>
<td>3.4x10\textsuperscript{4} kg N/day</td>
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Over a 9 day period, the influx of nitrogen oxides from lightning into the lowest 2 km of the atmosphere is negligible compared to the anthropogenic emissions.
• Production of NO$_x$ from lightning is now included in WRF-Chem for cloud resolving scales
• The Lightning NO$_x$ primarily affects the upper troposphere – this is in agreement with Kaynak et al. (2008) *ACP* who found that the impact of lightning NO$_x$ on surface O$_3$ was small (<2 ppbv for 71% of cases)