Implementing Lightning-NO_x Production For Studies Of Thunderstorms And Chemistry

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NCAR

Motivation

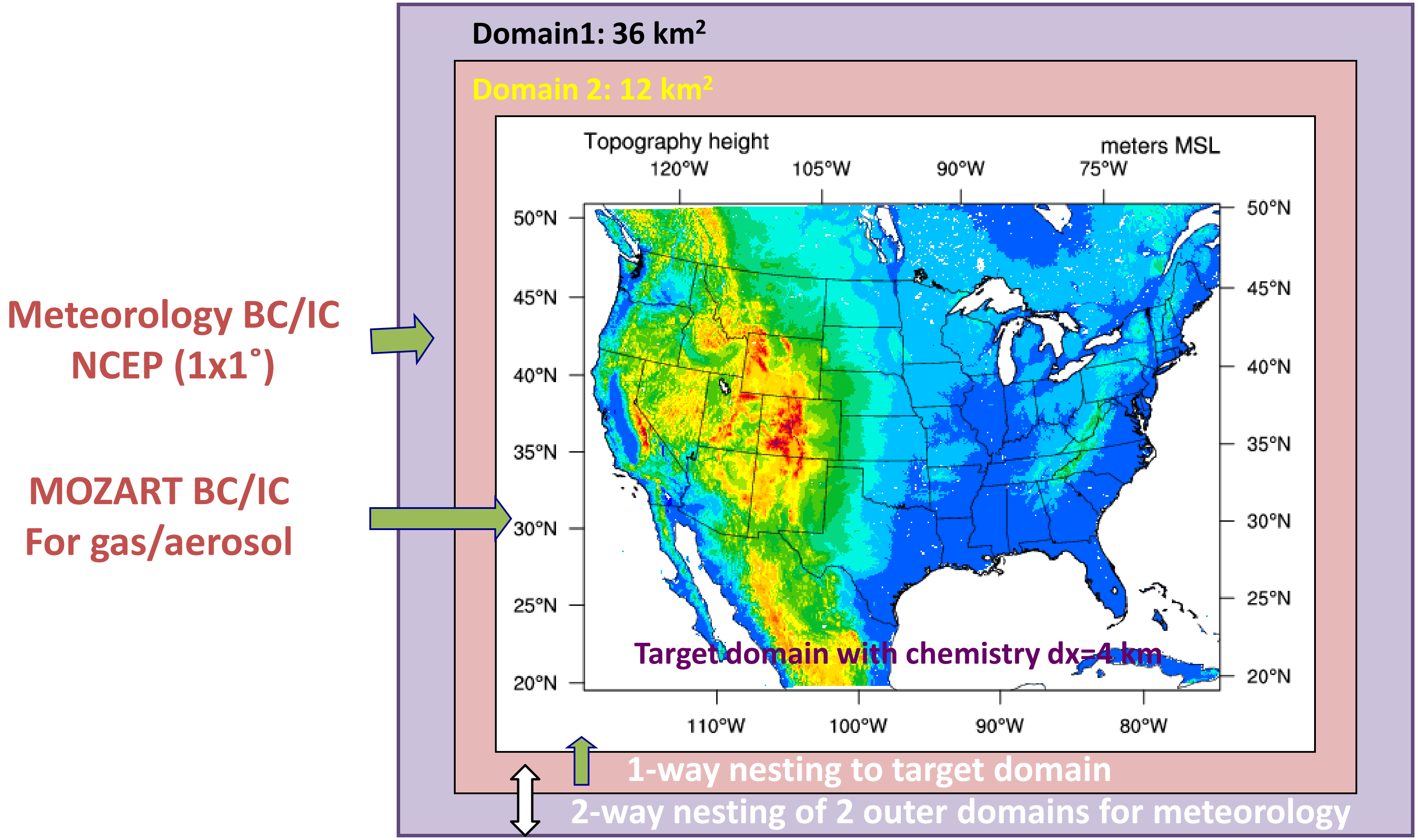
To understand the influence of convection on the chemistry and composition of the upper troposphere, representing convective transport and production of nitrogen oxides ($NO_x = NO + NO_2$) by lightning is important.

A high resolution WRF-Chem simulation (Δx=4km) 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

North American Monsoon Simulation – WRF-Chem model setup

- WRF-Chem simulation performed for the time period of July 10 to July 23, 2006, at 4 x 4 km^2 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

Lightning NO_x Parameterization for the North American Monsoon simulation

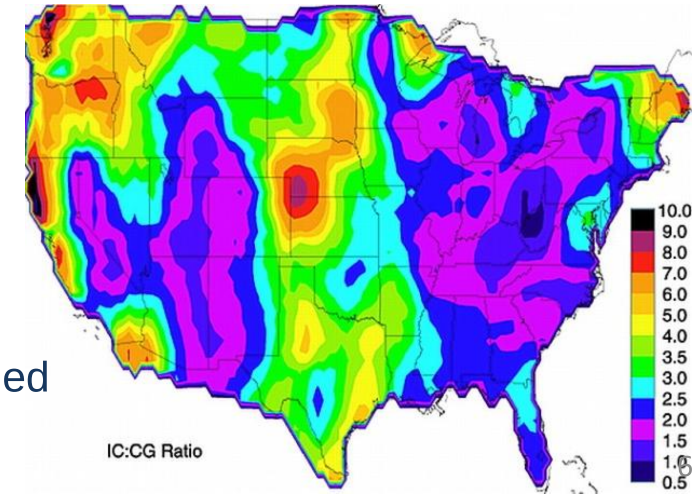
1) Lightning flash rate is predicted:

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

     Note: w_{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



Ratio of IC to CG flashes averaged over the 1995-1999 period (from Boccippio et al., 2001).

Lightning NO_x Parameterization for the North American Monsoon simulation

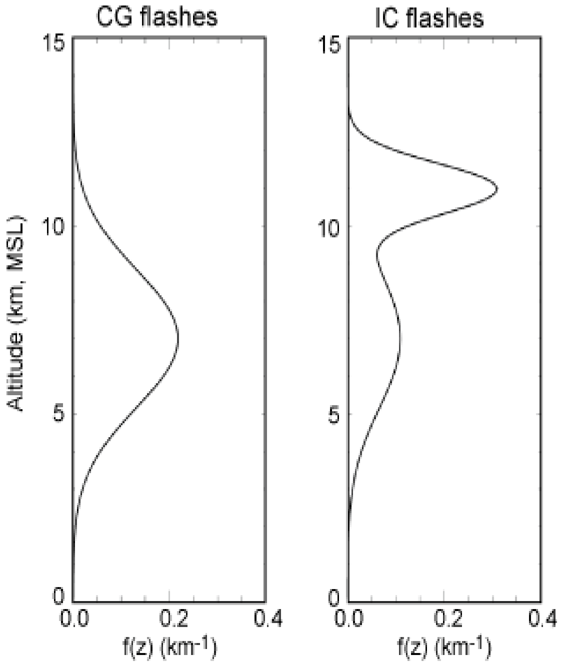
3) Find region of reflectivity > 20 dBZ (DeCaria et al., 2000)

   ➢ Distribute NO horizontally within this region

4) Distribute NO vertically using a curve

   ➢ CG flash: Gaussian distribution

   ➢ IC flash: Bimodal distribution



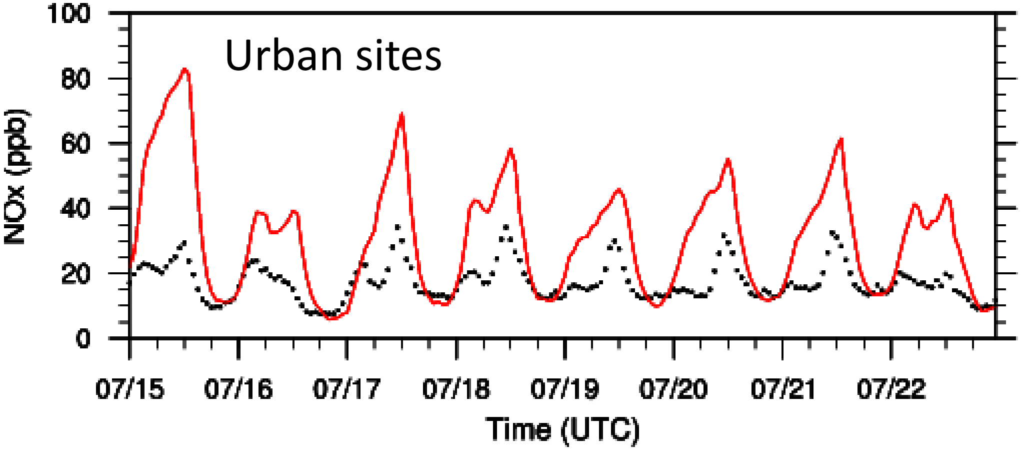
5) Amount of NO produced per flash

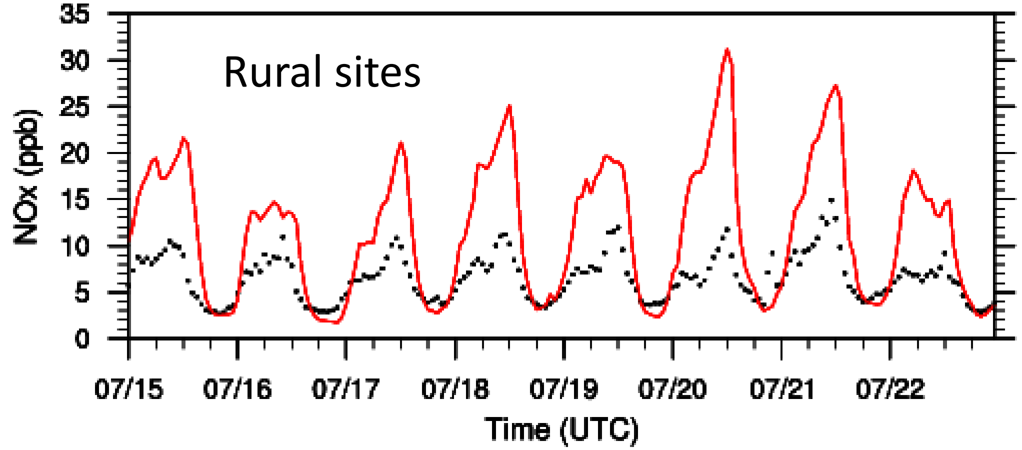
   ➢ 330 moles NO/flash (both CG and IC flashes)

   This is based on average found in Schumann and Huntrieser (2007) review.

Evaluation of NO_x at monitoring sites located between 22-50N and 120-65W

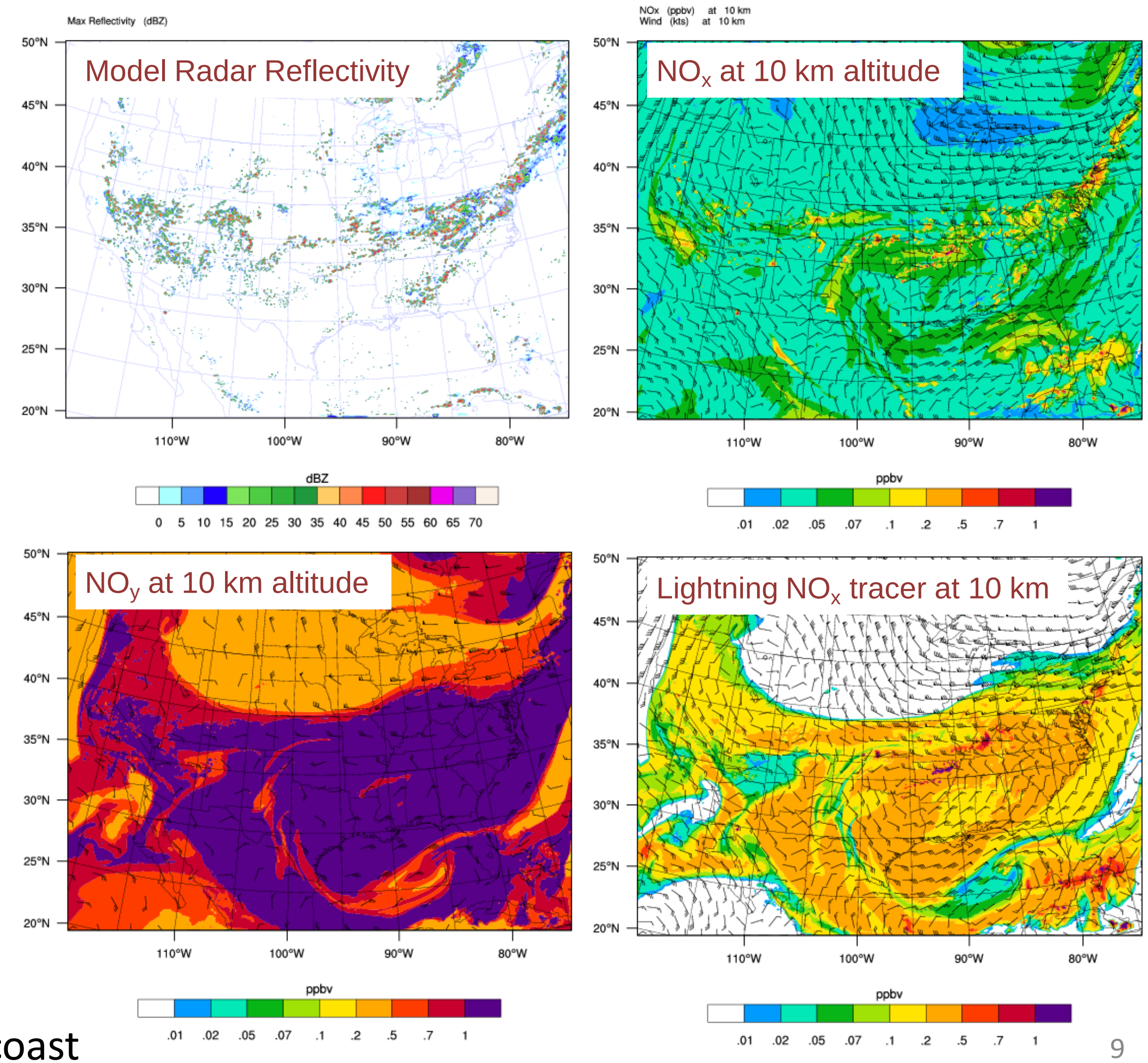
WRF-Chem reproduces nighttime observations well, but overpredicts observations during daytime.





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

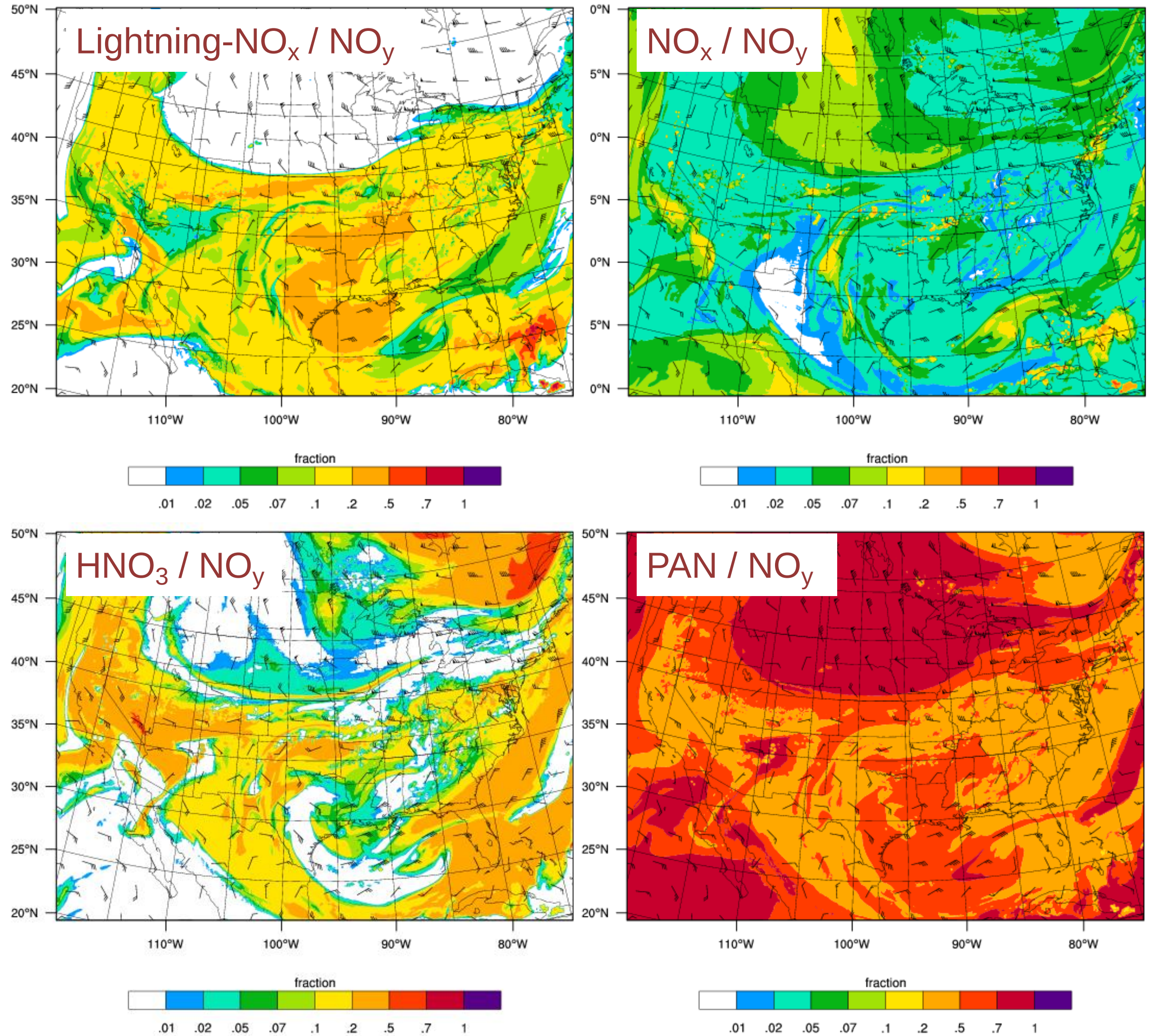
Much of the high NO_x concentrations in the upper troposphere is due to lightning



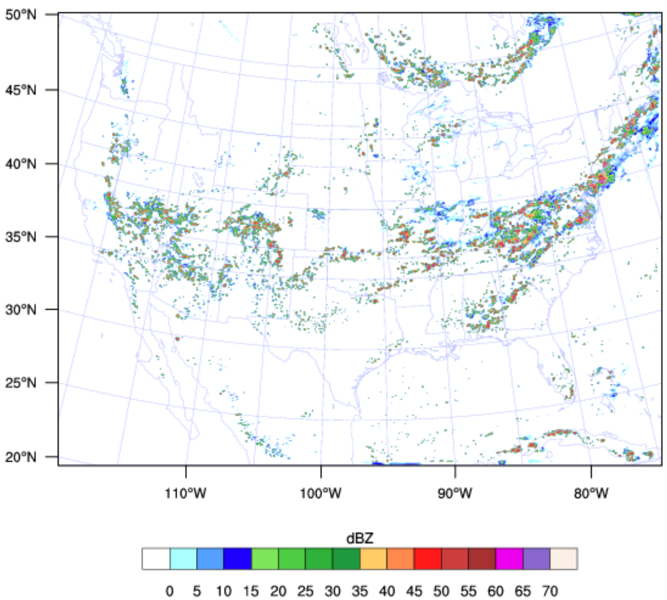
*All results for:
21 July 2006 at 2100 UTC
(2 pm west coast, 5 pm east coast

Example Results – Upper Troposphere

Lightning-NO_x contributes up to 50% of NO_y in the upper troposphere



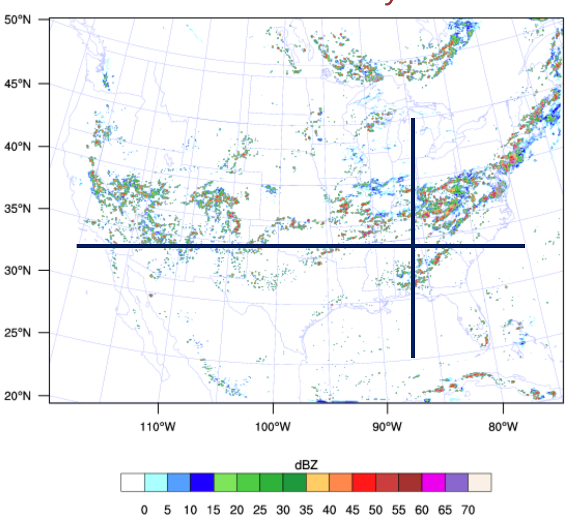
Model Radar Reflectivity

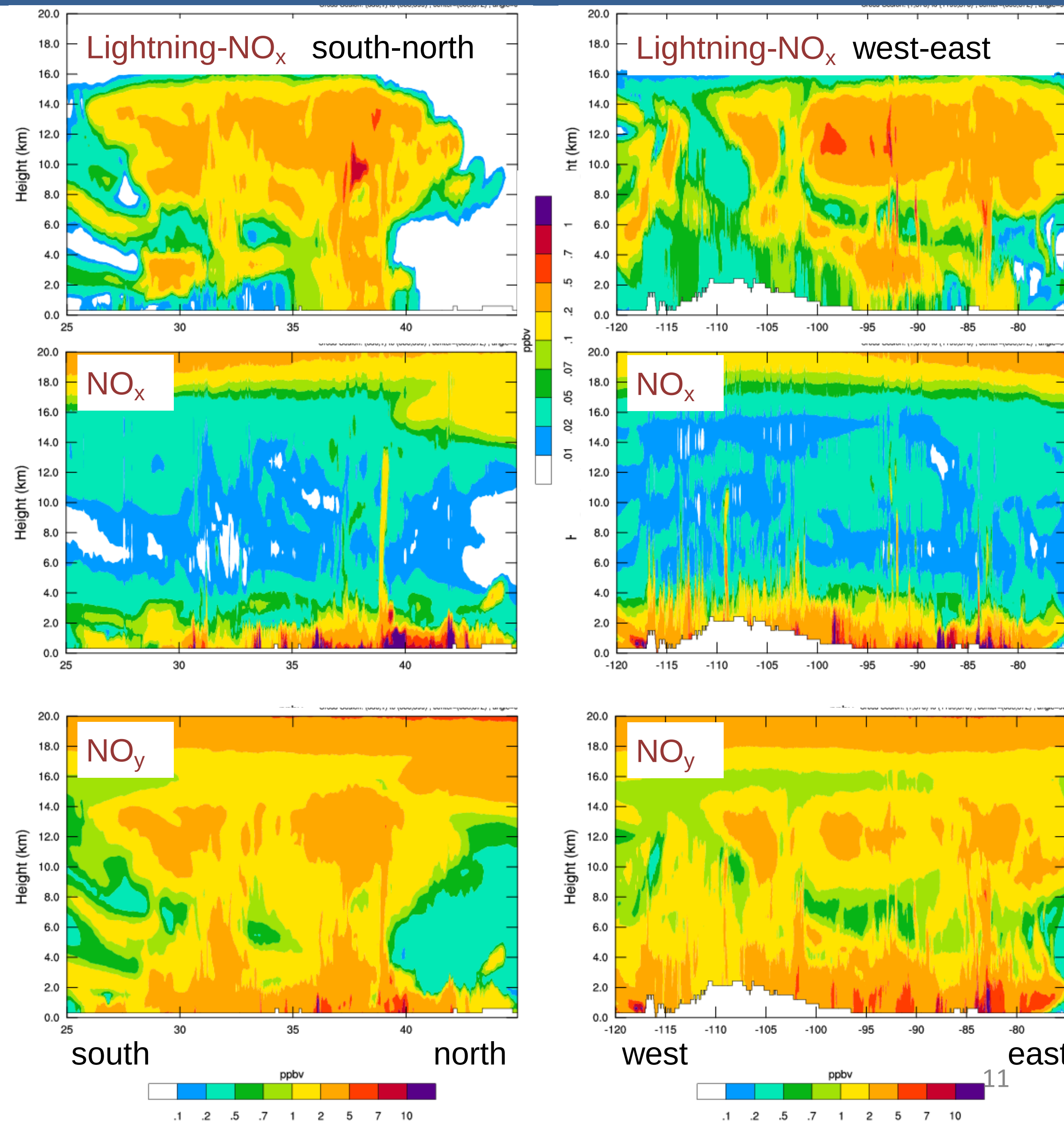


Example Results – Vertical Cross-Sections

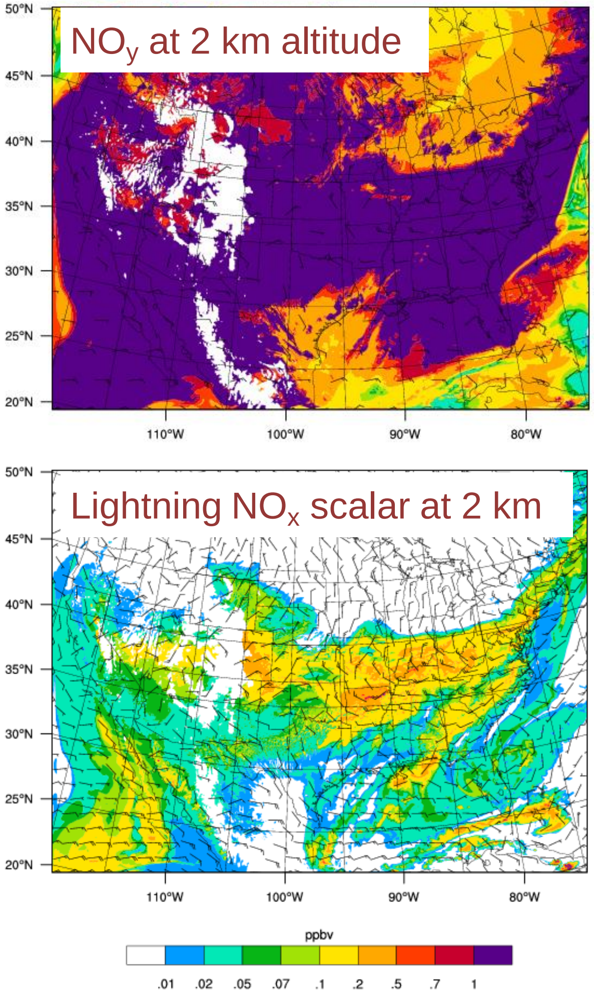
- Lightning-NO_x important in the UT, which contributes to NO_y
- Clean air from Canada moving southward behind front

Model Radar Reflectivity

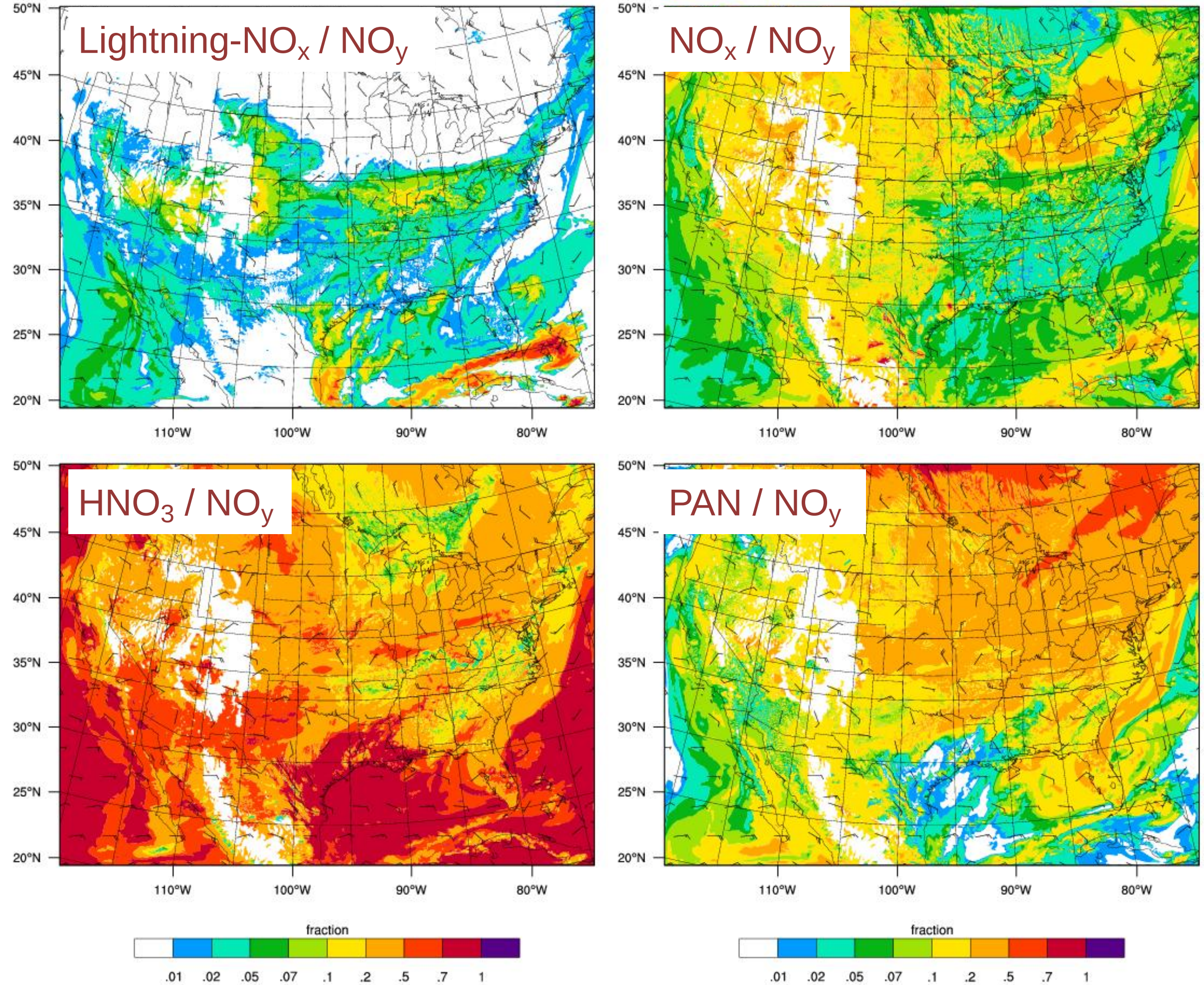




Example Results – 2 km Altitude



Fraction of NO_y

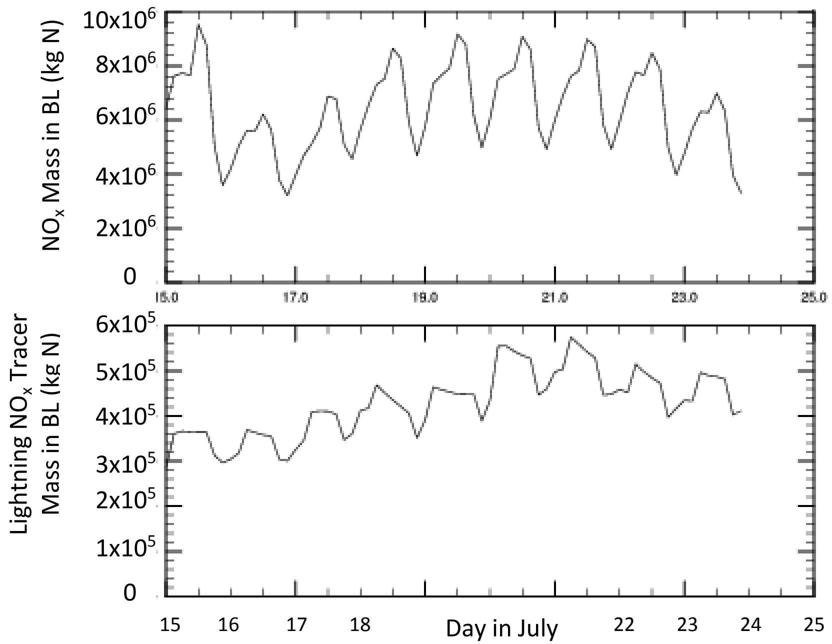


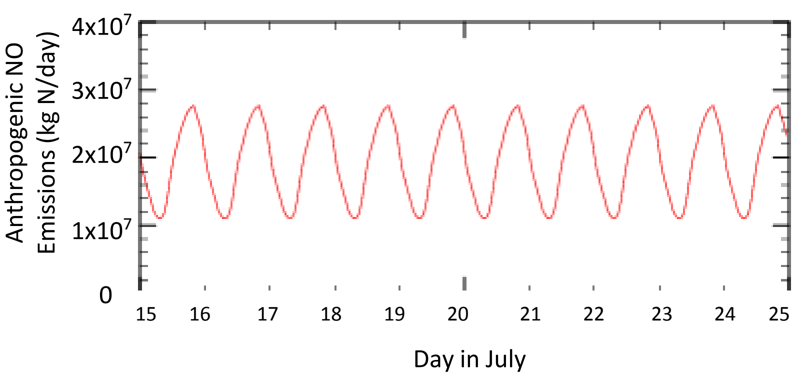
Lightning NO_x tracer is <10% of NO_y near top of BL

Example Results –
Amount of Lightning NO_x in 0-2 km altitude range

Average daily input of N into 0-2 km altitude range	
Anthropogenic Emissions	4.665×10^{8} kg N/day
Lightning Production	3.4×10^{4} kg N/day

Mass of Nitrogen in 0-2 km range





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

Summary

- 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)