Understanding how the North American Monsoon creates an ozone maximum in the upper troposphere

plans and activities (work in progress)

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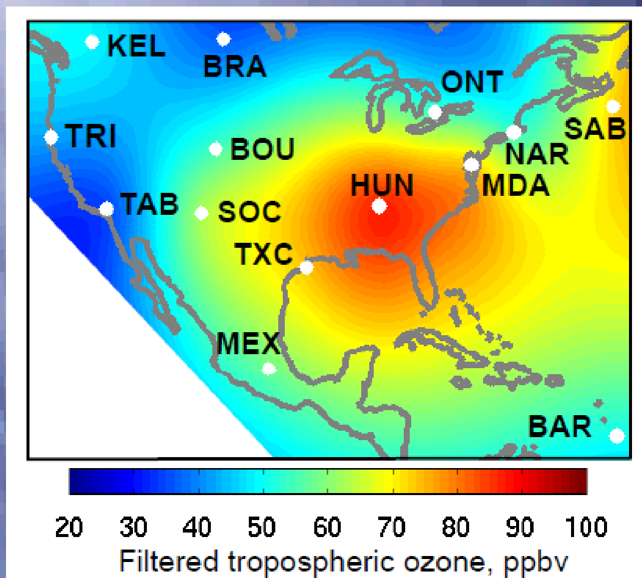
WRF collaborators: Bill Skamarock, Alma Hodzic, Jeff Lee, Gabi Pfister, Christine Wiedinmyer, Louisa Emmons

Motivation

- Recent papers* have documented the existence of an enhancement in upper troposphere (UT) ozone during July and/or August
- These studies have hypothesized that the ozone is a result of thunderstorms and chemistry occurring during the North American monsoon when an UT anti-cyclone traps the air

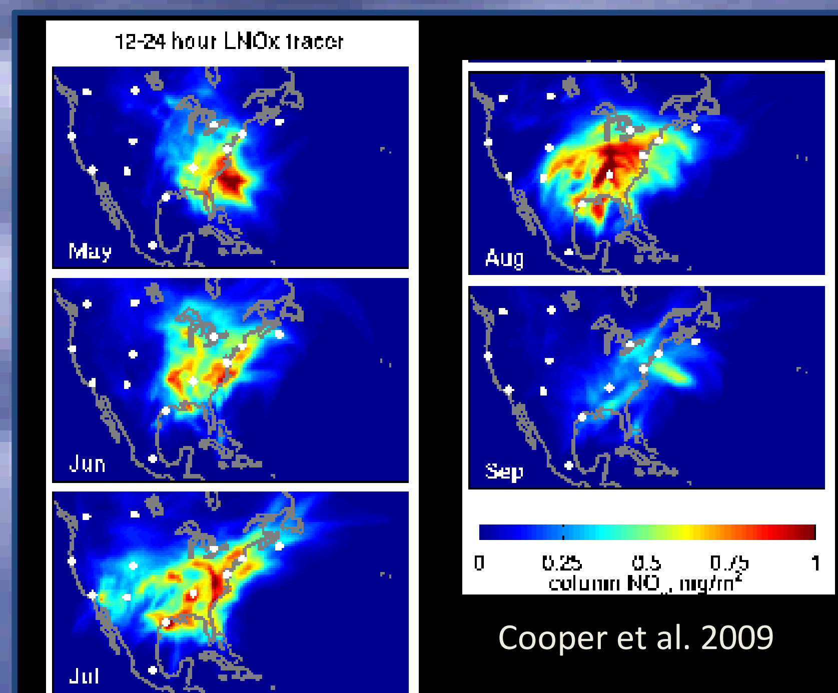
*Zhang et al. (2003); Li et al. (2005); Cooper et al. (2006, 2007, 2009); Choi et al., 2009

Examples



Observations (interpolated from ozonesondes during August 2006) show UT O_3 enhanced over SE USA. From Cooper et al., 2007.

Flexpart simulations of a lightning-NO_x tracer show that thunderstorms are likely source of enhanced UT O_3. From Cooper et al., 2009.



Previous work

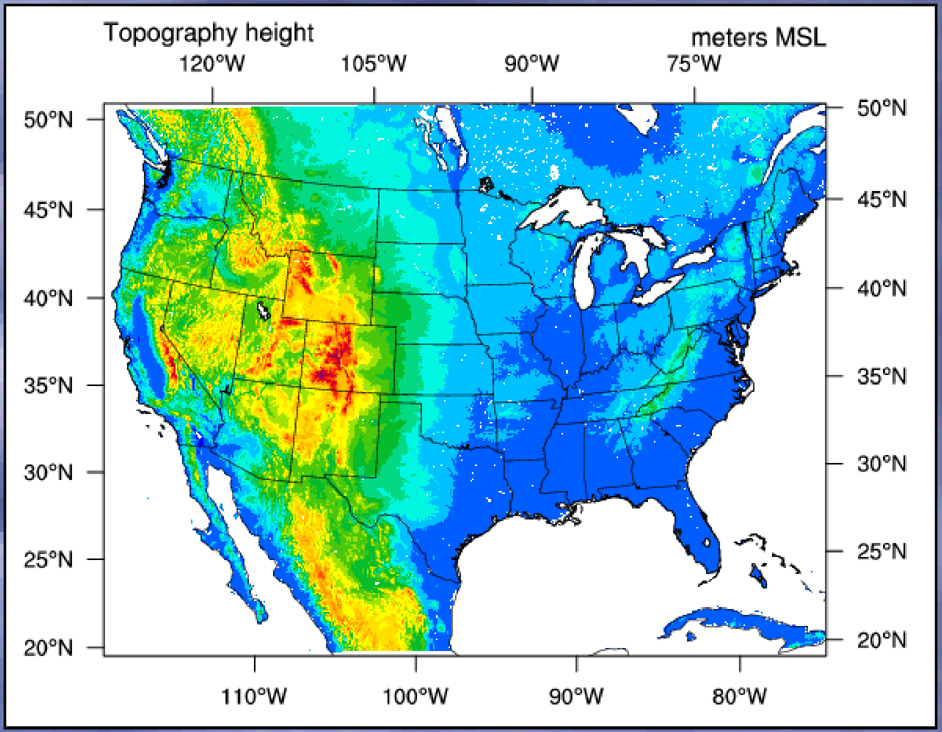
- Zhang et al., 2003; Li et al., 2005; Hudman et al., 2007 results:
  - Widespread UT ozone enhancement over southern US due to convective transport of O_3 and its precursors coincident with lightning-produced NO_x
  - The location of maximum O_3 values is anywhere from northern Mexico to Florida

Previous work

- Model studies aimed at examining NOx from lightning and UT chemistry, have been done at coarse resolution
  - Convection is parameterized
  - Convective transport is parameterized
  - Production of NOx from lightning parameterized
- Ability to represent the convection well in these model studies is limited

Our work

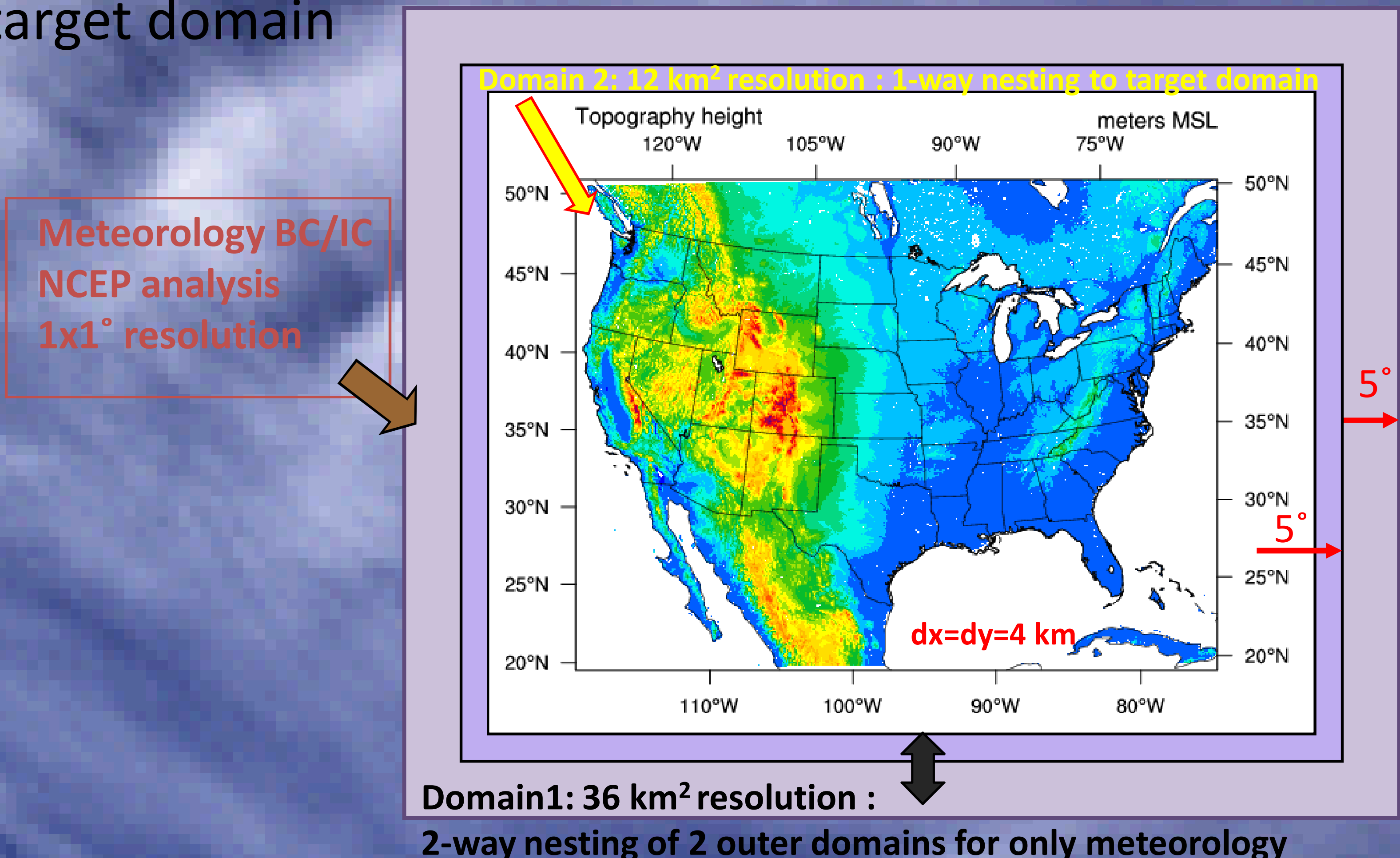
- Use the Weather Research and Forecasting (WRF) model coupled with chemistry (WRF-Chem) to simulate a 2 month period over the US and northern Mexico



- Horizontal resolution is 4 km
  - Convective systems are resolved, therefore convective transport is explicit
- Parameterization of NO_x production from lightning is based on maximum updraft speed

Model Configuration – Meteorology

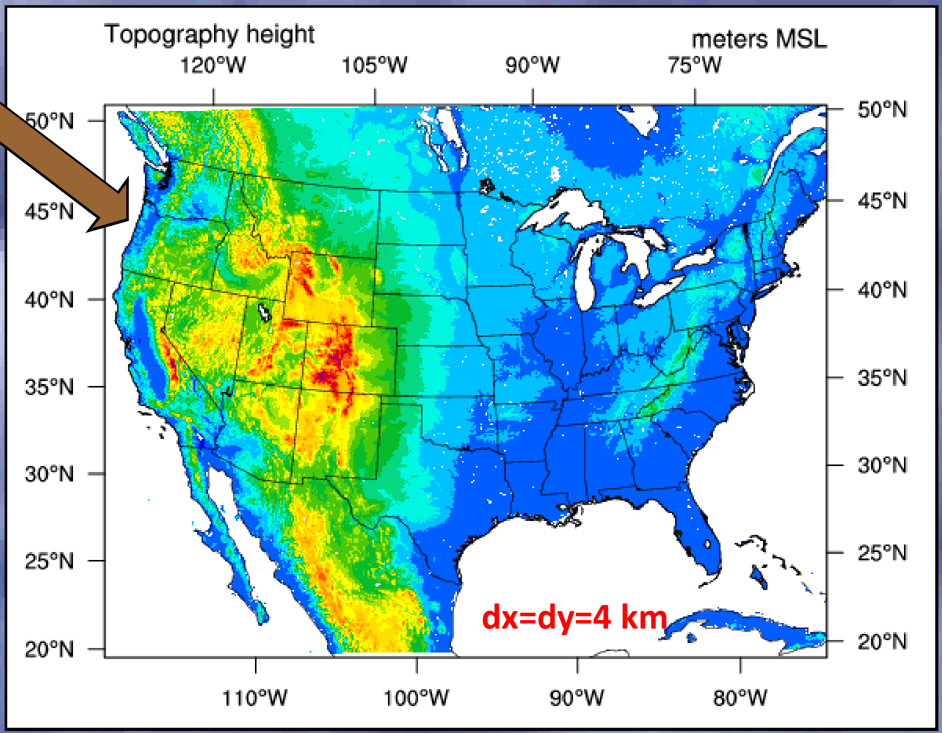
- NCEP Global Analyses on 1x1° grid are input and boundary conditions for 2 outer domains
- 2 outer domains used to bring coarse resolution analysis to target domain



Model Configuration – Chemistry

- CAM-Chem 6-hourly model output

Chemistry BC/IC
CAM-Chem
2.5x1.9˚ resolution



Model Configuration

- Simulation dates: July 10 – September 10, 2006
  - Δt = 20 s; output every 3 hours
  - 1200 x 900 x 51 grid points; p_top = 10 mb
- Physics
  - Single moment cloud physics (Lin et al. 1983)
  - No convective parameterization
  - Mellor-Yamada-Janjic PBL parameterization
  - NOAH land surface model
  - Rapid Radiative Transfer Model for long wave radiation
  - Dudhia scheme for short wave radiation
- Dynamics
  - Runge-Kutta time integration method
  - Positive definite advection for water, scalars, and chemistry species

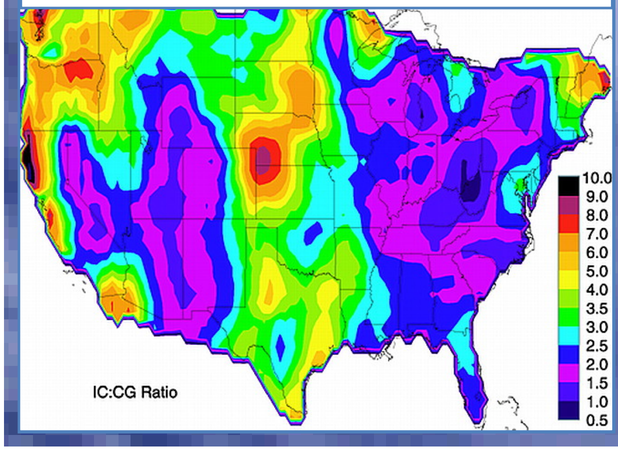
Model Configuration

- Chemistry
  - RACM (Stockwell et al., 1997) gas-phase chemistry
  - MADE/SORGAM aerosols – modal approach
  - Emissions:
    - Anthropogenic emissions: US EPA NEI-05 + Mexico NEI
    - Biogenic emissions: MEGAN – online calculation based on T, PAR
    - Wildfire emissions: MODIS locations (Wiedinmyer et al., 2006);
      Plume-rise of fires: Freitas et al. (2005) methodology
    - Aircraft emissions: 1999, 1x1° annual average (Baughcum, Boeing)
  - Photolysis rates: fast-TUV (Tie et al., 2003)
  - Wet deposition (Easter et al., 2004)
  - Dry deposition (Wesely, 1989)
  - Aerosols feed back to radiation heating in meteorology

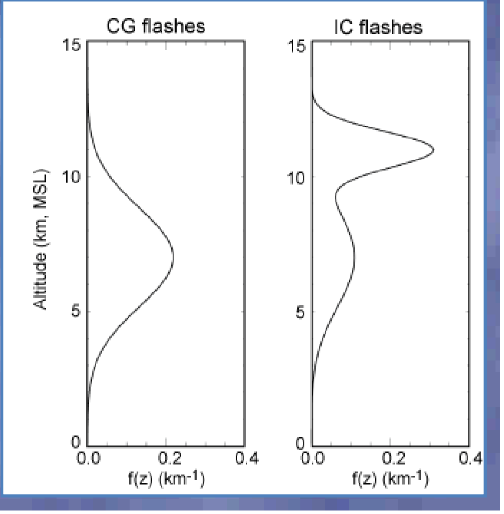
Model Configuration

- Lightning-NO_x parameterization
  - Lightning flashes predicted by maximum updraft speed (Price and Rind, 1992) within a tile of the domain
  - Intracloud to cloud-to-ground flash ratio based on climatology (Boccippio et al., 2001)
  - Location of NO_x source is within 20 dBZ region, following DeCaria et al. (2000) vertical distribution
  - NO_x produced: 330 moles NO per flash (both IC and CG flashes)

IC to CG Ratio (Boccippio et al., 2001)



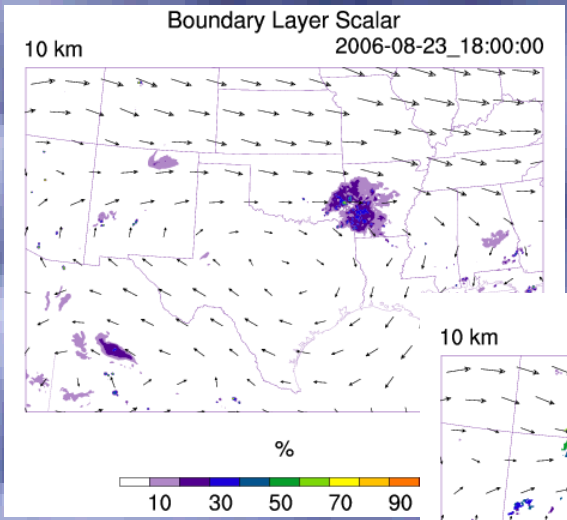
Vertical Distribution of NO Source (DeCaria et al., 2000)

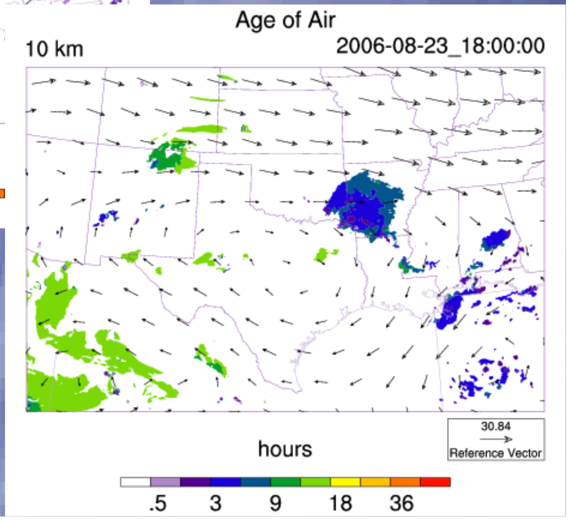


Model Configuration

- Scalars – 6 tracers are included
  - Tracers from the horizontal boundary (tracer = 1 at boundary)
  - Tracers from the boundary layer (tracer = 1 from sfc to PBL top)
  - Tracers from the stratosphere (tracer = 1 from $z(T_{min})$ to 10 mb)
  - Two types of tracers:
    - Passive tracer
    - Decaying tracer with time scale of 1 day

    → Age of air

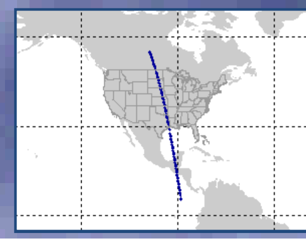


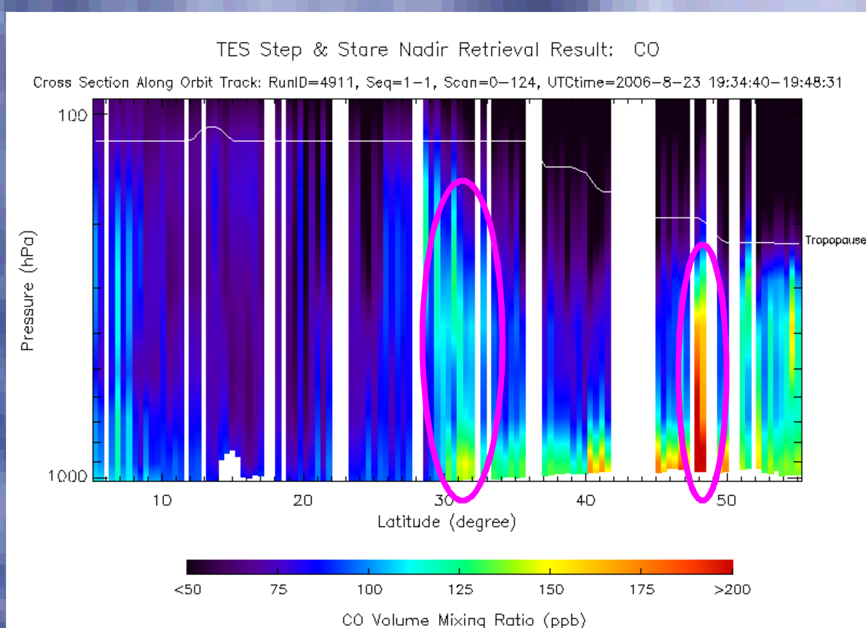


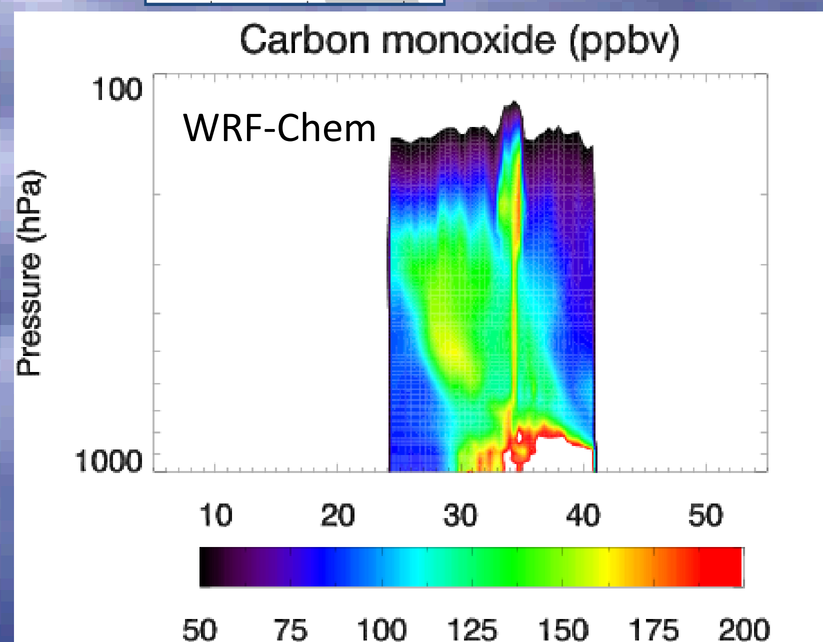
Evaluation of Results

- Satellite data: TES, and hopefully others
- Field campaign: TEXAQS 2006 data
- monitoring sites: AIRNOW, IMPROVE, etc

Example of data that can be compared:
TES data on 23 August 2006







Science Questions to Address

with respect to enhanced O_3 in UT

1. How soon after the NA monsoon sets up does the upper troposphere ozone substantially increase?
2. What is the lifetime of ozone in the UT anti-cyclone?
3. How quickly does the ozone decrease after the anti-cyclone dissipate?
4. How much do ozone sources and sinks depend on photolysis rates versus replenishment of ozone precursors via convective transport in order to maintain high UT ozone mixing ratios?
5. What role do non-methane hydrocarbons play in ozone formation in the UT?

Conclusions

- Simulation is just beginning production run
  - Running on bluefire: IBM Power 575
  - Expect simulation will take 2-3 months to run
- Welcome feed back
  - Mary Barth barthm@ucar.edu for UT ozone studies
  - Alma Hodzic alma@ucar.edu for air quality studies
- Welcome those interested in analyzing model results