Towards the next generation integrated meteorology and atmospheric chemistry model

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A brief history of AQ modeling

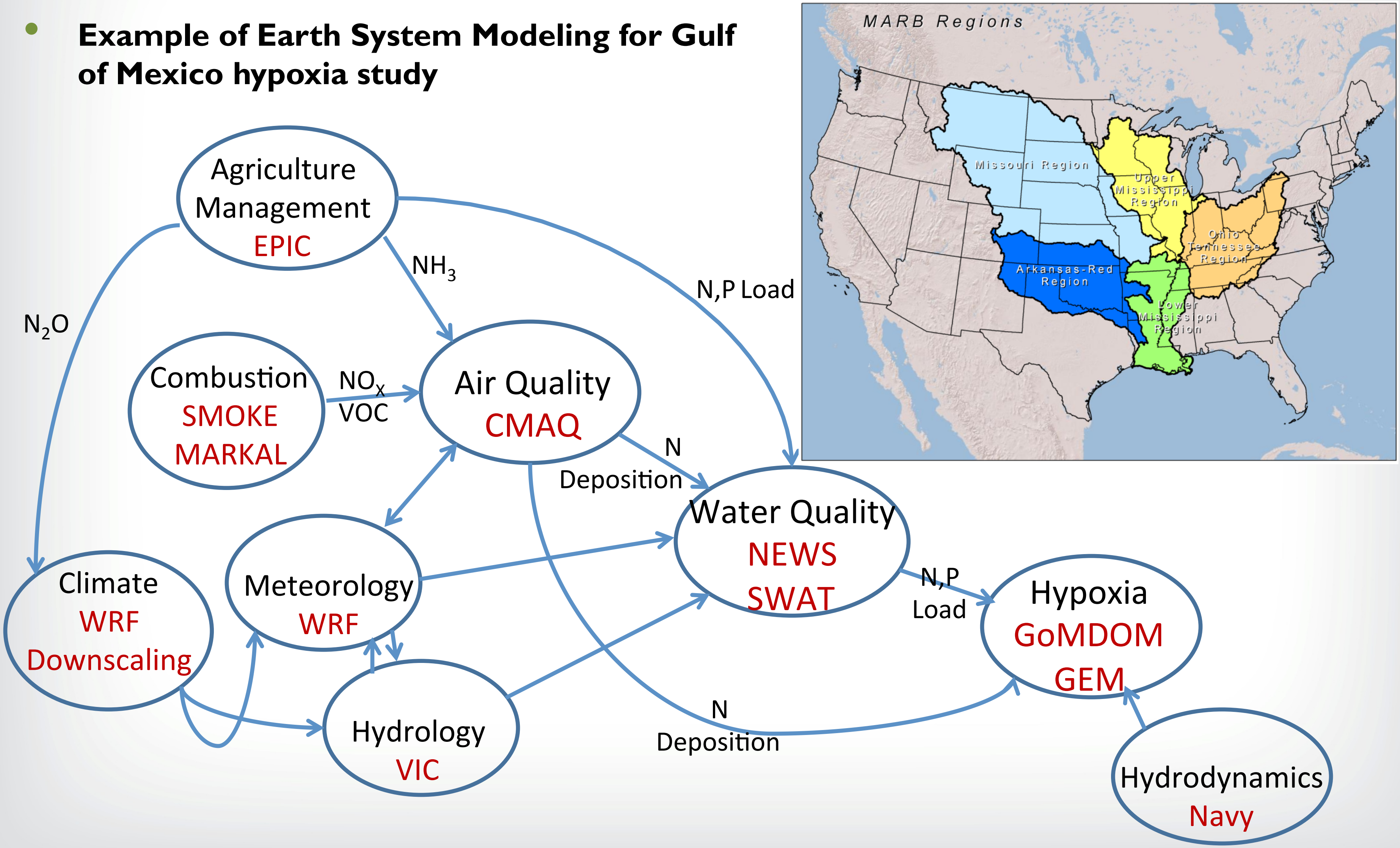
- **Eulerian grid chemical transport models**
  - Emission, advection, diffusion, chemistry, deposition
- **First generation AQ models - e.g. UAM, ROM**
  - Gas-phase photochemistry
  - Single mixed layer with diurnal evolution, another layer aloft
  - Meteorology interpolated from observations
- **Second generation – e.g. RADM, ADOM, STEM**
  - Multi-layer terrain following coordinates
  - Meteorology from prognostic model (e.g. MM4)
  - Include cloud processes – convective transport, aq chem, wet dep
- **Third generation – e.g. WRF-Chem, WRF-CMAQ, GEM-MACH**
  - Integrated or coupled Met – Chem
  - Include aerosol with feedback to meteorology

Next Gen AQ model

- **Need AQ modeling at Global to Continental to Regional to Urban scales**
  - Current systems using cascading nests is cumbersome
  - Duplicative modeling in overlap regions
  - Interpolation errors at boundaries
- **Tighter AQ standards require global modeling:**
  - Inter-continental transport, important for both Ozone and PM
  - Stratospheric ozone
  - Marine chemistry
- **Earth system Linkages**
  - Greenhouse gases
  - Nitrogen, carbon cycling
  - AQ – Climate interactions
  - Eco, hydro linkages

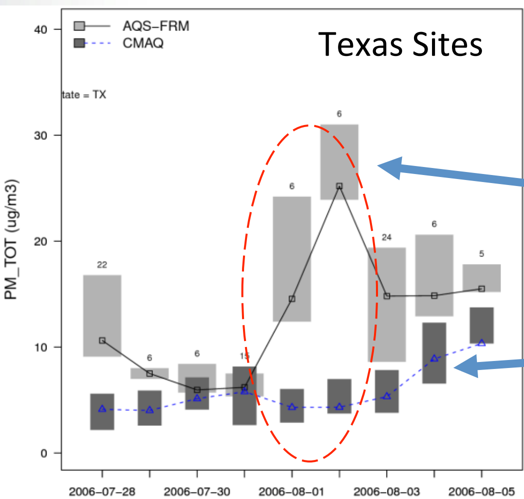
Link to Ecosystem Models

- **Example of Earth System Modeling for Gulf of Mexico hypoxia study**



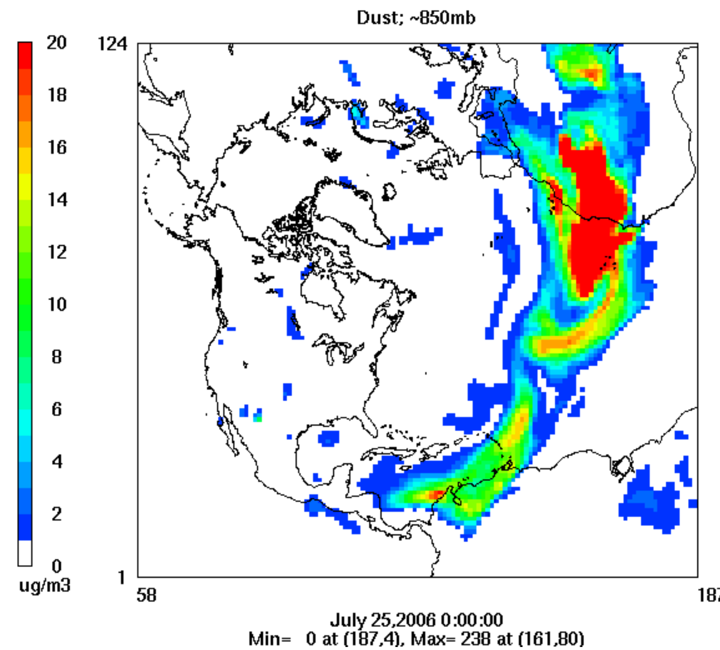
Saharan dust impacts in US

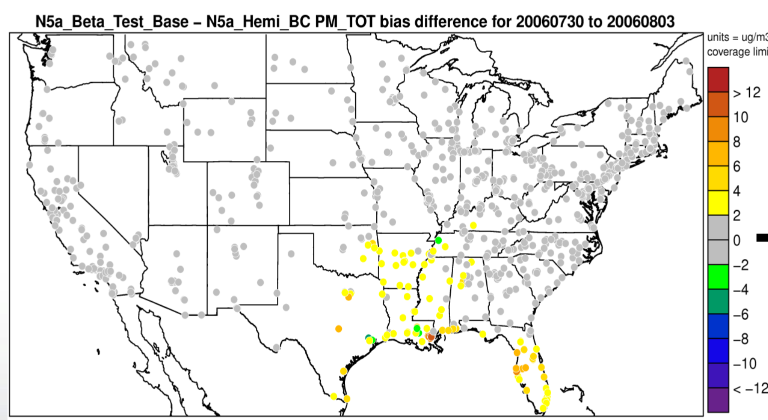
Impacts of LRT during July 30-Aug 3, 2006



Measured surface PM concentration at Texas AQS sites

Base model w/ fixed LBCs





Lower bias in Hemis.

Lower bias in Base

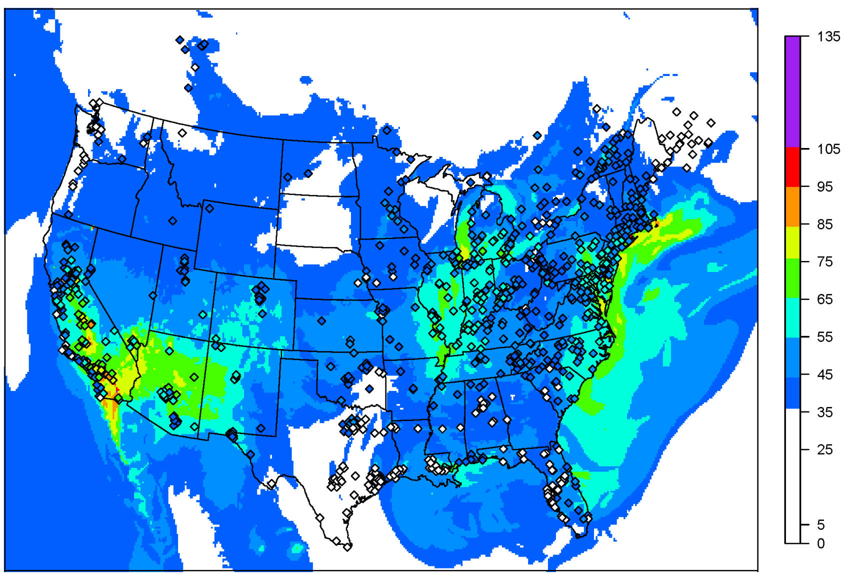
- **Intercontinental transport has impacts on US air quality**
  - Global or hemispheric modeling is necessary to capture these events

Hemi as LBC for CONUS 12 km

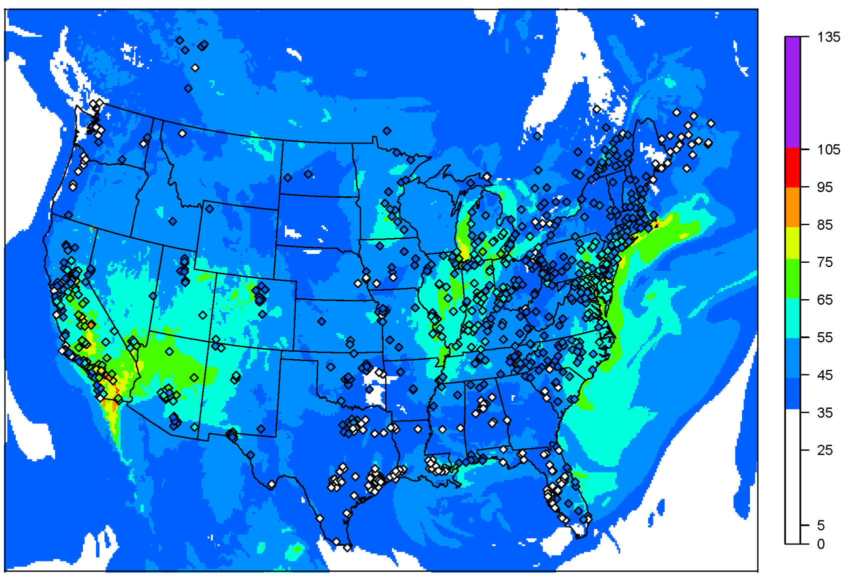
WRF-CMAQ max 8-hr average ozone on June 8, 2014

Daily M

3 (ppb): 20140608



Domain size: 299x459, Max=105.4 at (69, 96)



Domain size: 299x459, Max=103.8 at (69, 96)

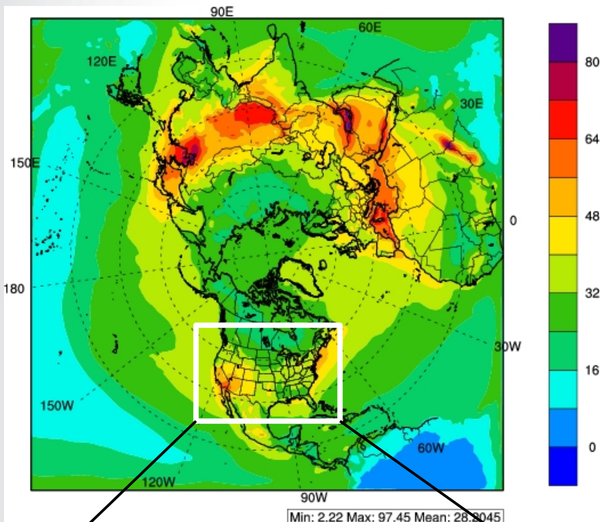
Hourly LBCs from WRF-CMAQ Hemispheric run

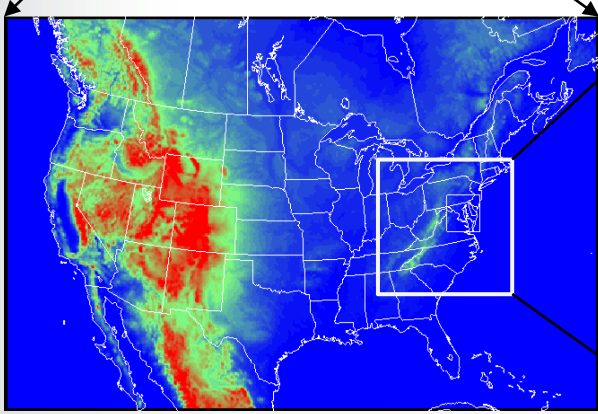
Monthly average LBCs from GEOS-Chem

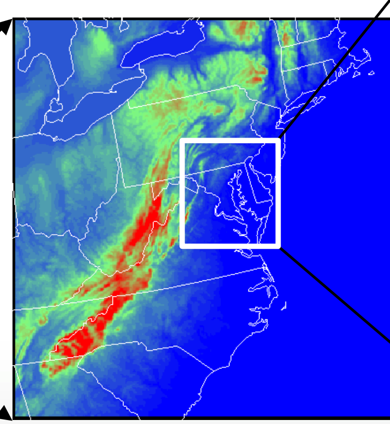
Using 108 km hemispheric WRF-CMAQ improves ozone simulation especially in Texas and Canada compared to monthly average static LBCs derived from global model (GEOS-Chem)

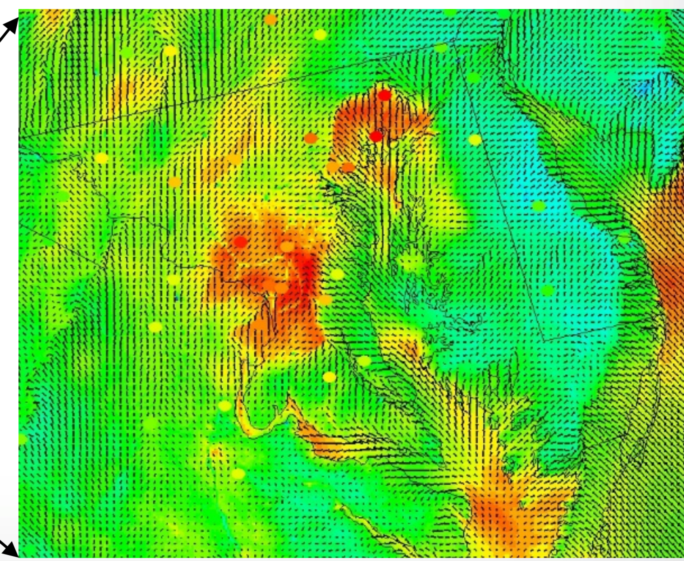
Multi-scale modeling

- Hemispheric model at 108 km provides LBCs for 12 km CONUS with nests to 4 km and 1 km
  - Multi-step process
  - Many opportunities for user mistakes
  - Interpolation errors on boundaries
  - Resolution discontinuities
  - No upscale feedback



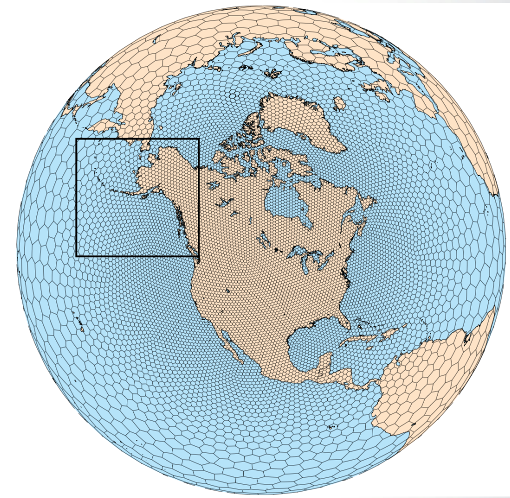


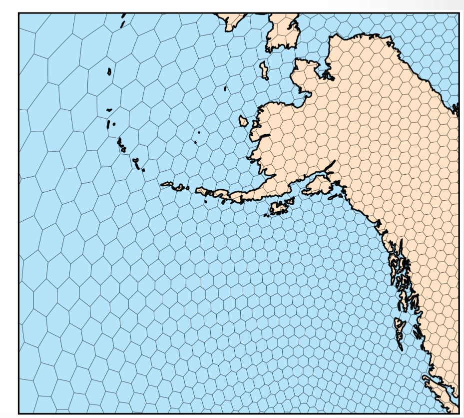




Vision

- **Extend to global scales**
  - Single global mesh with seamless refinement to local scales
  - Integrated chemistry, dynamics, physics
- **Three configurations of flexible systems:**
  - On-line global variable grid (e.g. MPAS, OLAM)
  - Online regional (WRF-AQ)
  - Offline regional (redesigned CMAQ)
- **Interoperability of as much model code as possible**
  - Gas, aerosol, aqueous in modular box
  - Modules for biogenic emissions, dry dep/bidi, wind-blown dust, photolysis, etc
- **Transport in met models for online systems (adv, diffusion)**
  - Ensure mass conservation
  - Consistency with met parameters
  - Minimize numerical diffusion and dispersion

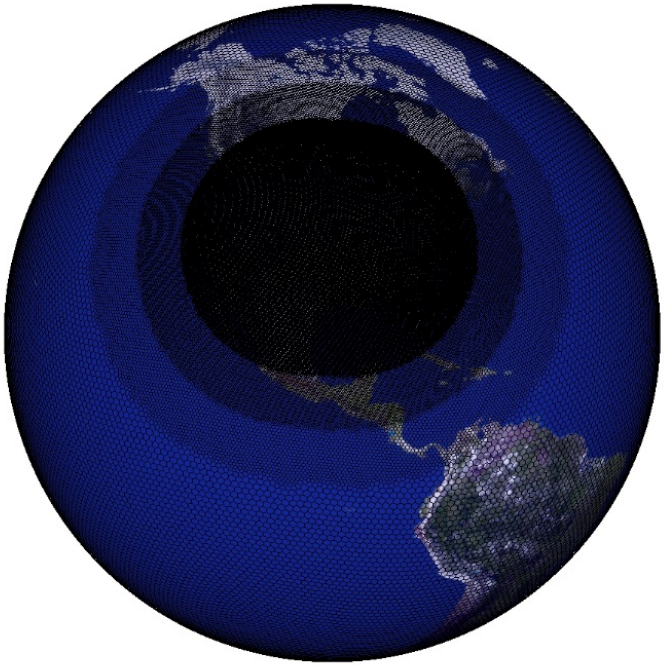




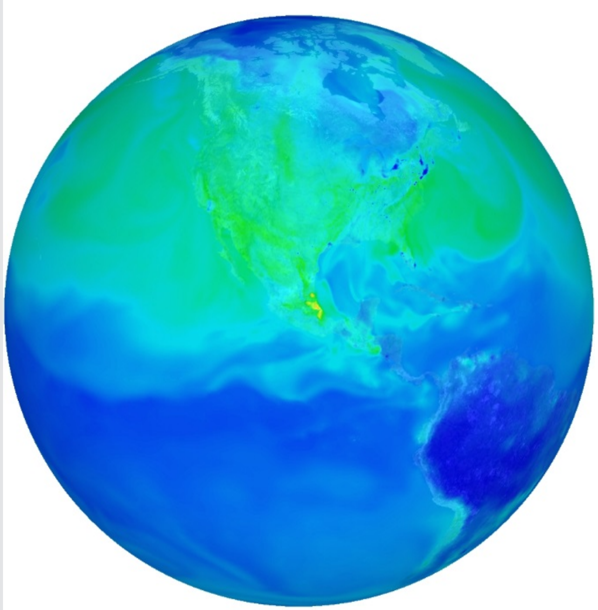
MPAS

Prototype: OLAM-Chem

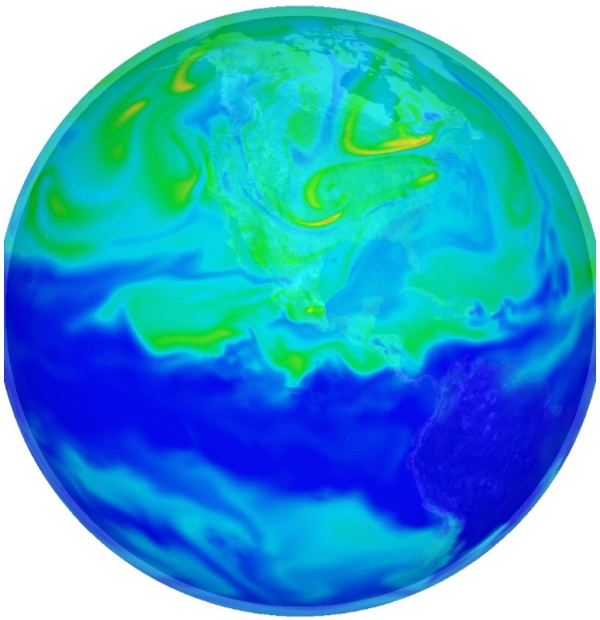
- **The Ocean Land Atmosphere Model (OLAM)**
  – A global general circulation/climate model with flexible mesh refinement technique that works on either triangular or hexagonal grids
- **OLAM-Chem**
  – Martin Otte has added CMAQ gas-phase chemistry, photolysis, emissions, plume rise, deposition, and convective cloud mixing
- **Initial testing of OLAM-Chem**
  – Simulation starting on April 1, 2006
  – Hexagonal grid from 108 km to 12.5 km
  – 46 vertical layers
  – Emissions from EDGAR
  – CB05 chemical mechanism
  – Kain-Fritsch convective clouds
  – ACM2 PBL for met and chem
  – RRTMG Radiation



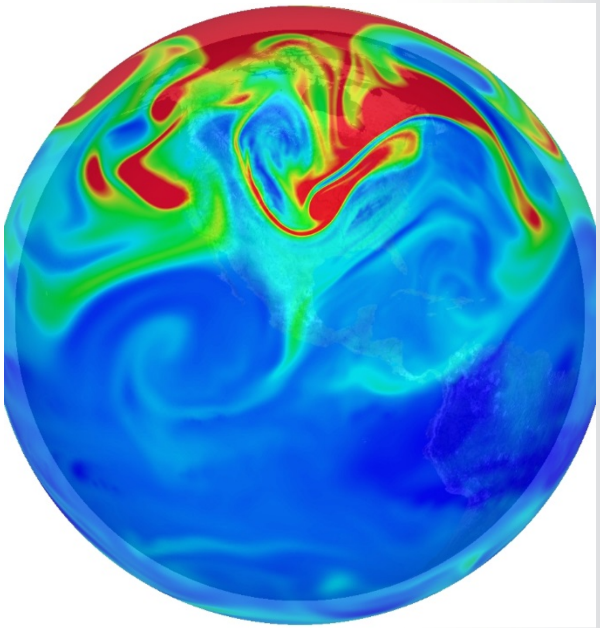
Ozone at 00Z on April 29, 2006



Surface
0 – 120 ppb



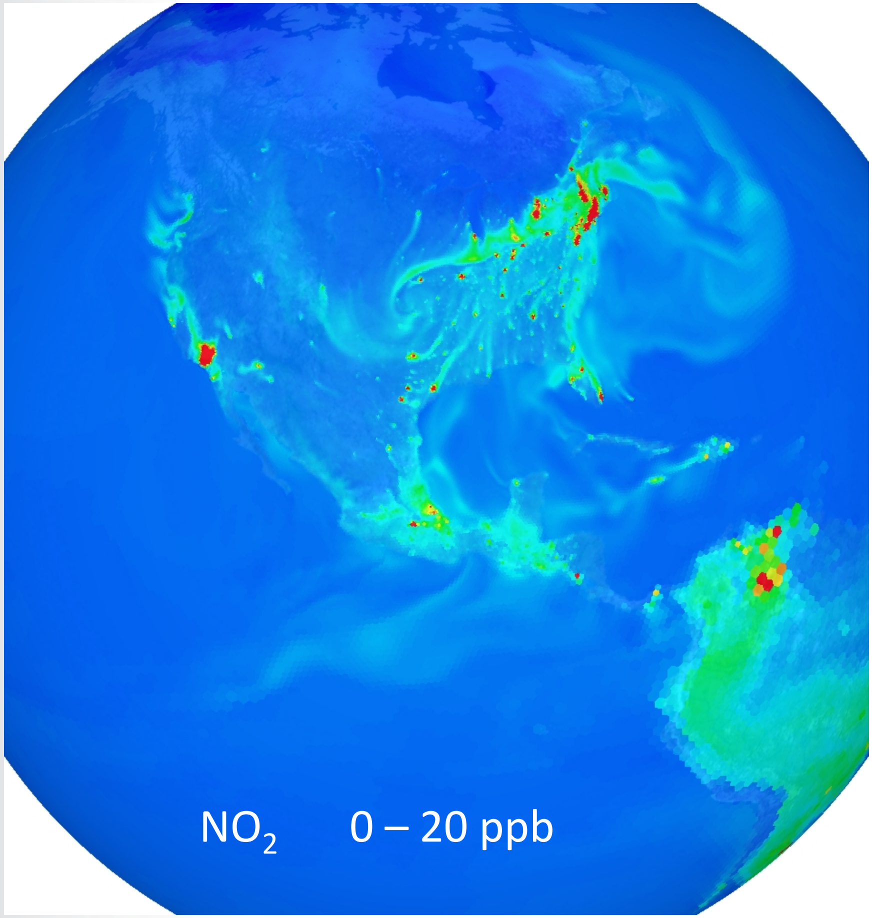
3 km altitude
0 – 140 ppb

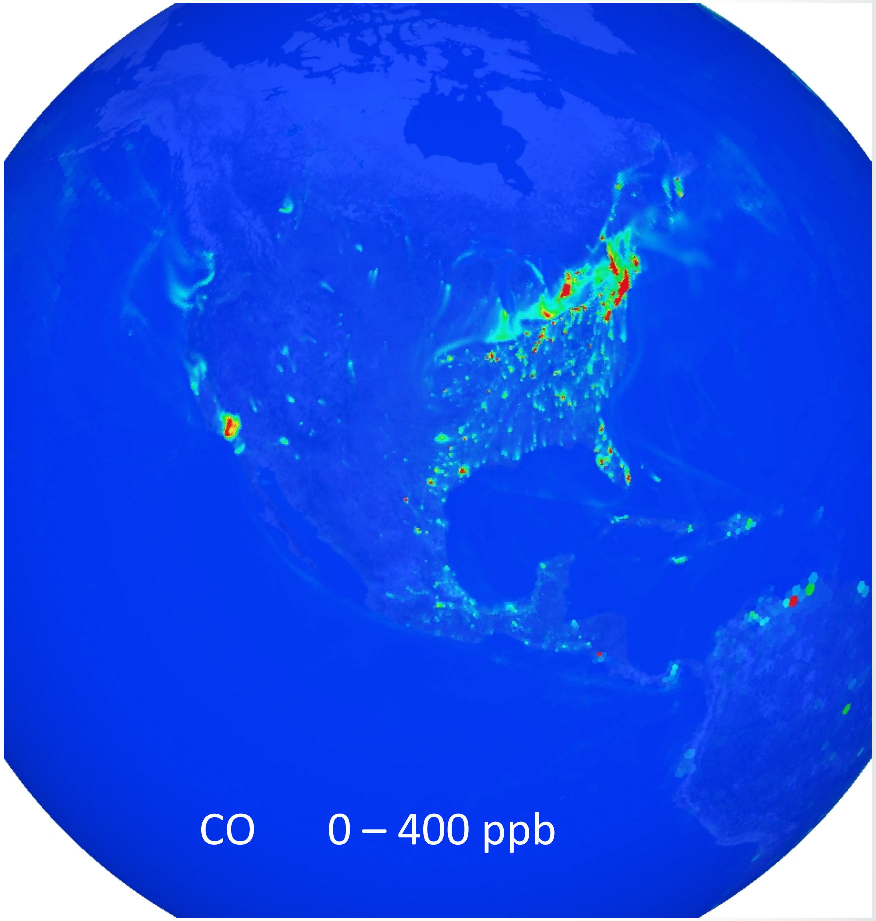


8 km altitude
0 – 240 ppb

- **Example of ozone concentrations at three altitudes**
  - Top ozone BC from CFSR analysis

Surface level NO_2 and CO





- **Note the coarse resolution in South America and much finer resolution in North America**

Community development

- **Initial discussions among EPA, NCAR, NOAA, DOE**
  - Leverage diverse expertise across community
- **Multiple purposes:**
  - Air quality policy development and regulation
  - Air quality forecasting
  - Atmospheric chemistry research
  - Climate modeling with short-lived climate forcers
  - Earth system applications: coupled system for air, hydro, eco, ag, energy, etc…
- **Standardize model engineering for coupling chemical components to different dynamics models**
- **Initial steps: add chemistry to existing global models**
  - For example: MPAS-Chem, OLAM-Chem
- **Involve grant programs to foster development**
  - EPA STAR grants
  - DOE Model development grants

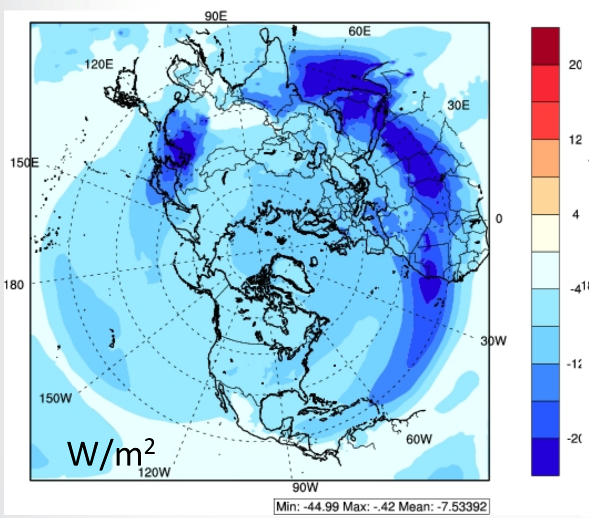
Opportunities at EPA

- NRC Postdoc open until August 1
- New Federal position soon
- Pleim.jon@epa.gov

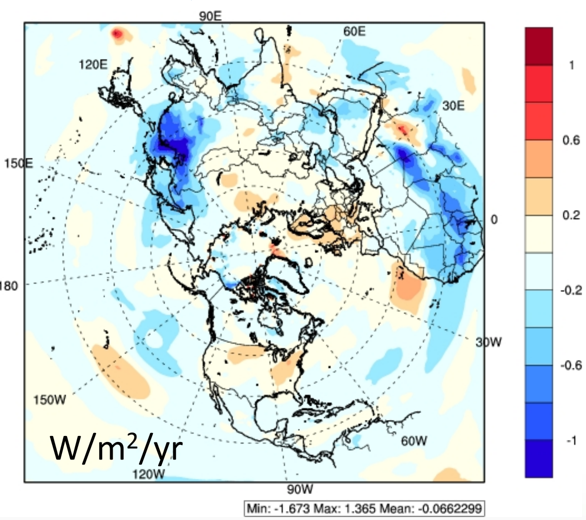
Extras

Hemispheric modeling

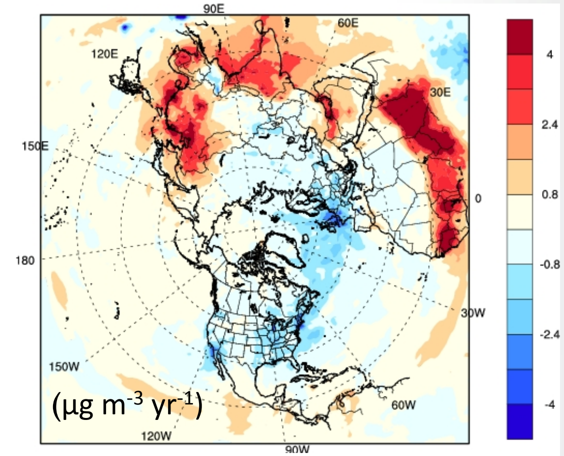
- **Typically we run hemispheric WRF-CMAQ at 108 km grid resolution**
  - Hemispheric runs useful for global AQ analysis including regional trends in concentrations
  - Coupled Met–Chem model can also be used to assess aerosol radiative effects and their trends



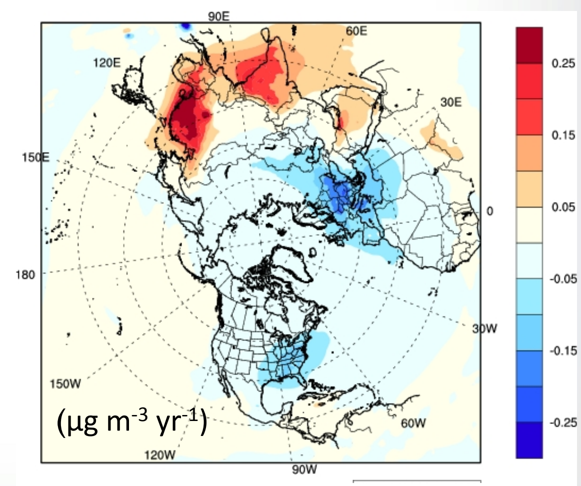
Direct radiative effects



DRE trend 2000-2010



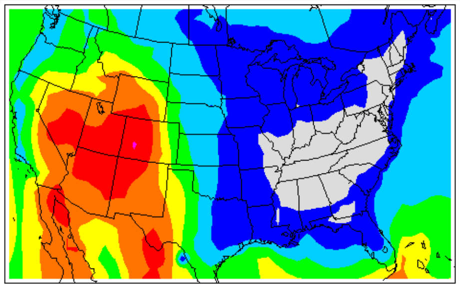
O_3 max 8-hr trends 1990-2010



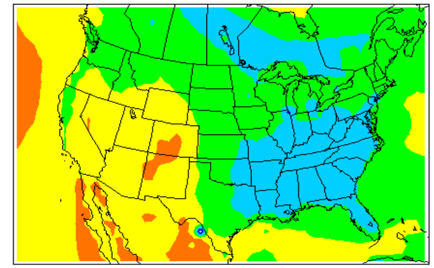
SO_4 annual trend1990-2010

Background O_3 and Source Contributions

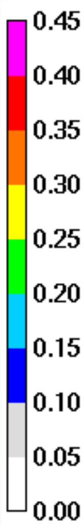
Background O_3 Summer (June 2006)

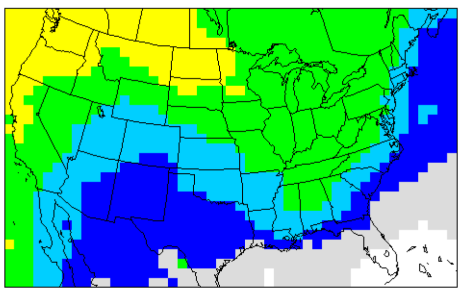


Background O_3 Spring (March-April 2006)



East Asia Contribution





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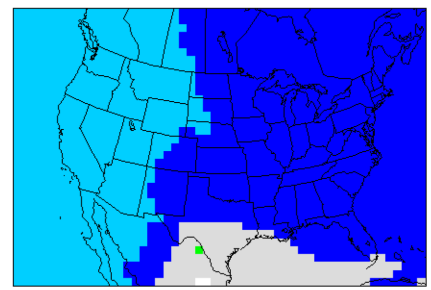
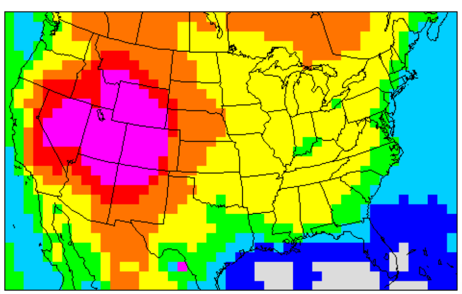


Stratospheric Contribution



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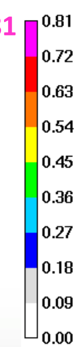
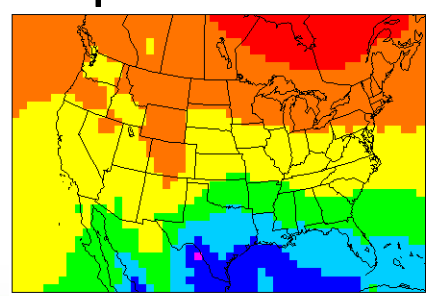


Stratospheric Contribution (note: scale)



Background levels (and relative contributions of sources) varies seasonally and spatially