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Project 14-025
Development and Evaluation of an Interactive Sub-Grid Cloud Framework for the CAMx Photochemical Model

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Project 14-025 - Development and Evaluation of an Interactive Sub-Grid Cloud Framework for the CAMx Photochemical Model

Today:

- Summarize convective processes and model limitations
- Project objectives
- Introduce EPA's convection updates in the Weather Research and Forecasting (WRF) meteorological model
- Summarize the new CAMx convective model framework – Cloud in Grid (CiG)
- Summarize evaluation of WRF + CAMx/CiG to date
- Discuss project status and next steps

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Importance of convection for atmospheric processes

- Daily convective cloudiness and rainfall is common during the ozone season
- Clouds are often small scale, but ubiquity and abundance are important for vertical exchange, chemical processing, and wet removal

Meteorology

- Boundary layer mixing and ventilation
- Deep transport of heat and moisture
- Radiative transfer and surface energy budgets
- Precipitation patterns

Example of scattered shallow and deep convection over Texas

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Importance of convection for atmospheric processes

Air quality

- Boundary layer mixing and ventilation
- Deep vertical transport of chemical tracers
- Radiative transfer and photolysis rates
- Aqueous chemistry
- Patterns and intensity of wet scavenging
- Certain environmentally-sensitive emission sectors (e.g., biogenics)

A typical summer afternoon with scattered shallow cumulus over Texas

Meteorological models

- Most clouds are not explicitly resolved by model grid scales
  - "Sub-grid" clouds /convection (SGC)
  - Develop and propagate via stochastic processes
  - Physical effects are difficult to characterize accurately
- Sub-grid parameterizations adjust grid-resolved vertical profiles of heat and moisture
  - Typically ignore other effects; e.g, radiative transfer

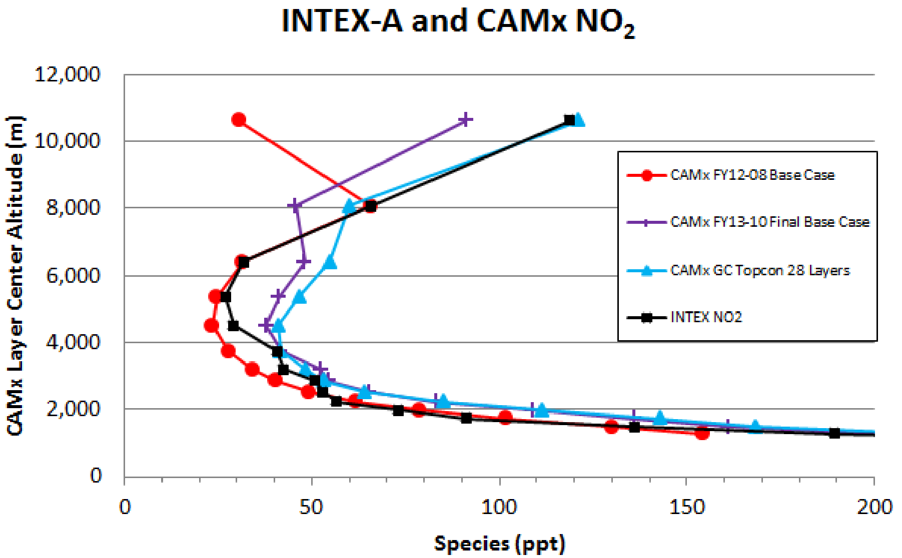
Modeling limitations

Off-line photochemical grid models (PGM)

- Met models do not export SGC data
  - SGC must be re-diagnosed
- Effects of SGC are addressed to varying degrees
  - Potentially large inconsistencies between models
- CAMx implicitly treats effects of SGC at grid scale
  - Diagnoses from resolved met model output
  - Blends SGC properties into the resolved cloud fields
  - Applies total cloud fields to photolysis rates, aqueous chemistry, and wet scavenging at grid scale
  - **No cloud convective mixing treatment**

Modeling limitations

- Comparing CAMx NOy profiles against aircraft and satellite data (Kemball-Cook et al., 2012; 2013, 2014):
  - Large underestimates above 8 km
  - Add NOx sources aloft (aircraft, lightning) and set arbitrary top BC's
  - Add explicit top BC's from global models
- These improve average profiles over large areas
- Convective mixing is important at local scales



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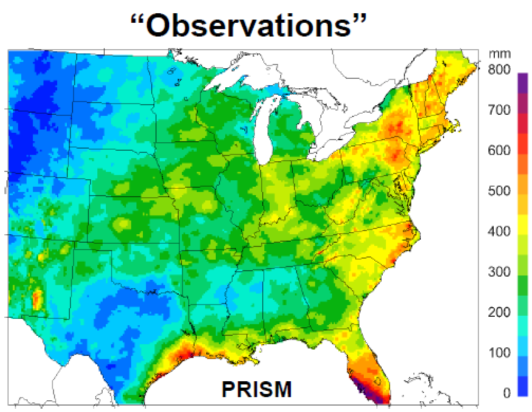
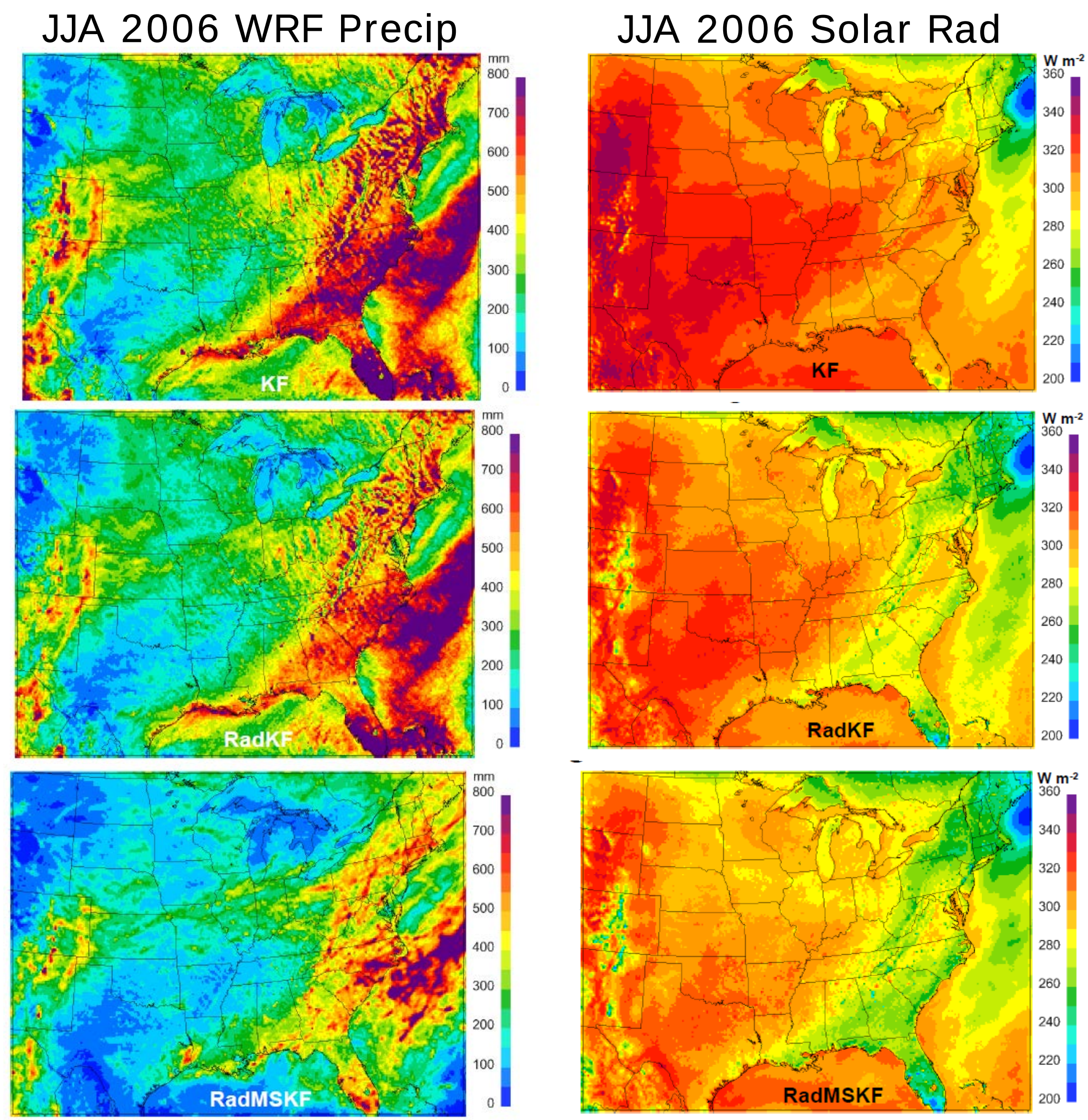
Project 14-025: Objectives

- Add sub-grid convective module to CAMx
  - Vertical transport
  - Aqueous chemistry
  - Wet deposition
- Tie into recent EPA/NREL updates to WRF convection (KF)
  - Add KF cloud information to WRF output files
  - Consistent cloud systems among WRF and CAMx
- Test for two aircraft field study episodes:
  - September 2013 Houston DISCOVER-AQ (Pickering et al., 2013)
  - Spring 2008 START08 (Pan et al., 2010)

EPA's WRF updates to convection (Alapaty et al, 2012; 2014)





- 2012: Link WRF KF cumulus scheme to WRF radiation scheme (RadKF)
  - RadKF shades ground: reduces convective PE and rain
- 2014: Generalize RadKF to multi-scale (MSKF)
  - MSKF generates more SGC: more shading, less rain

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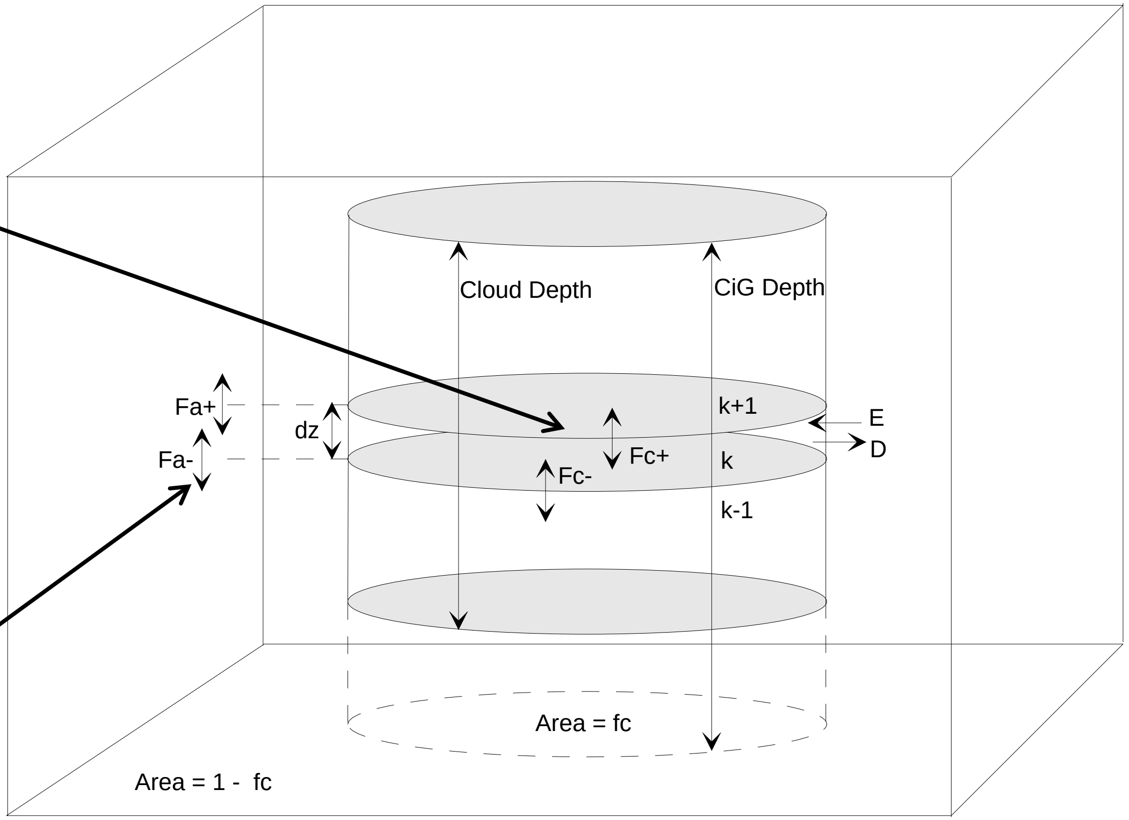
CAMx Cloud-in-Grid (CiG) framework

- CiG defines a multi-layer cloud volume per grid column according to WRF KF output
- Stationary steady-state SGC environment between met updates (e.g., 1 hour)
- Grid-scale pollutant profiles are split to cloud and ambient volumes
- Convective transport uses a first-order upstream approach
  - Solves transport for a matrix of air mass tracer per grid column
  - Tracer matrix is algebraically applied to pollutant profiles
- Aqueous chemistry and wet scavenging separately processed on in-cloud and ambient profiles
- Cloud/ambient profiles are linearly combined to yield final profiles
- Rigorously checked to ensure mass conservation

Schematic of CAMx CiG

- Up/downdrafts (Fc) balanced by lateral en/detrainment (E,D) by layer (dz)
- Compensating vertical motion (Fa) in ambient air is a function of –(E,D) and cloud fractional area (fc)



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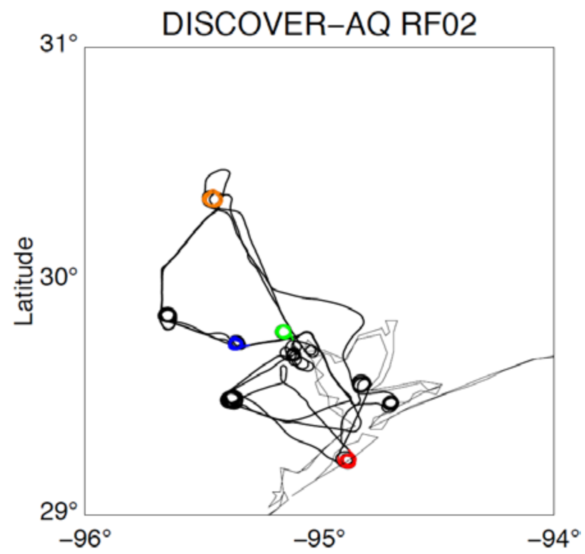
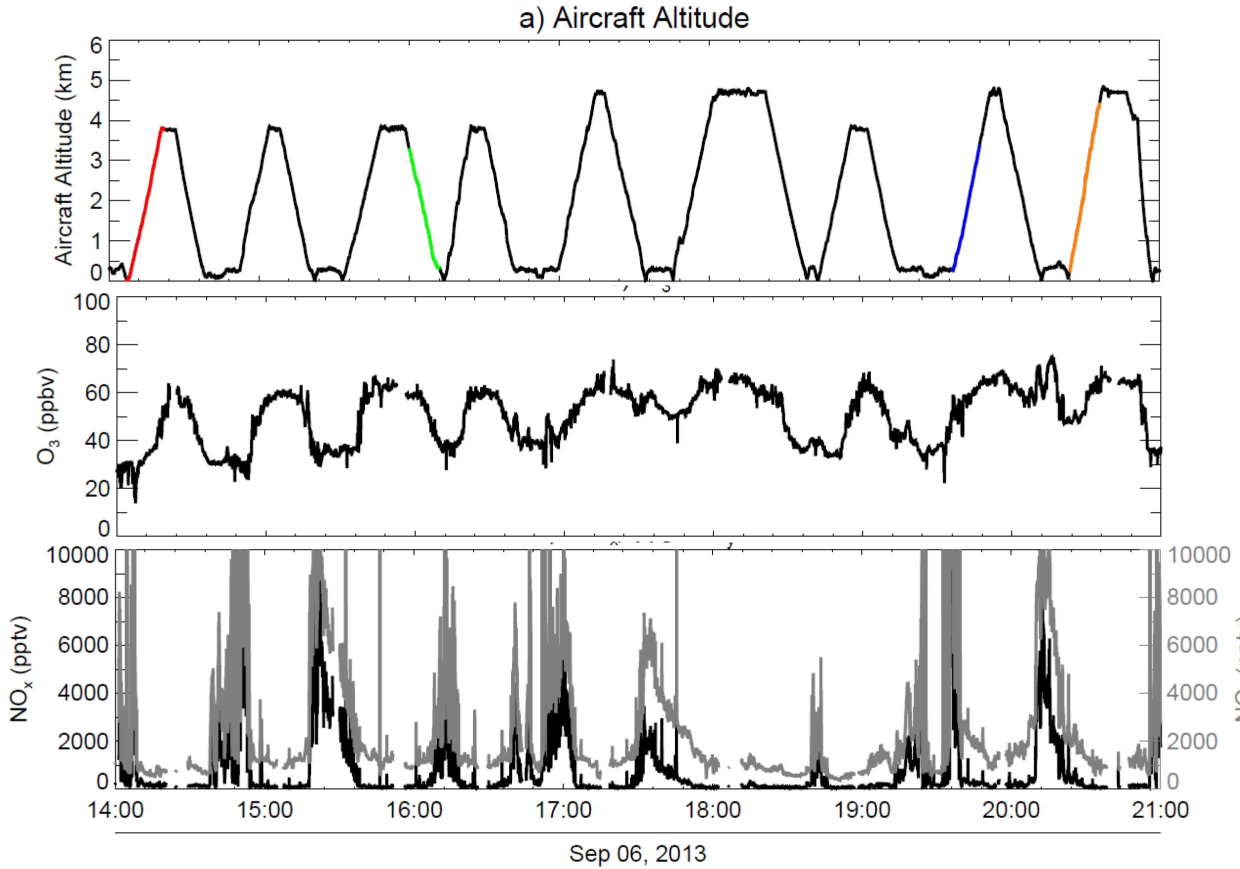
DISCOVER-AQ

- September 1-6, 2013: convective period in Houston and Gulf Coast area
- NASA P-3 flights during September 4 & 6, boundary layer spirals
- O_3: 20-40 ppb surface to 60 ppb aloft
- NOy: 0-5 ppb NOx + 1-5+ ppb NOz





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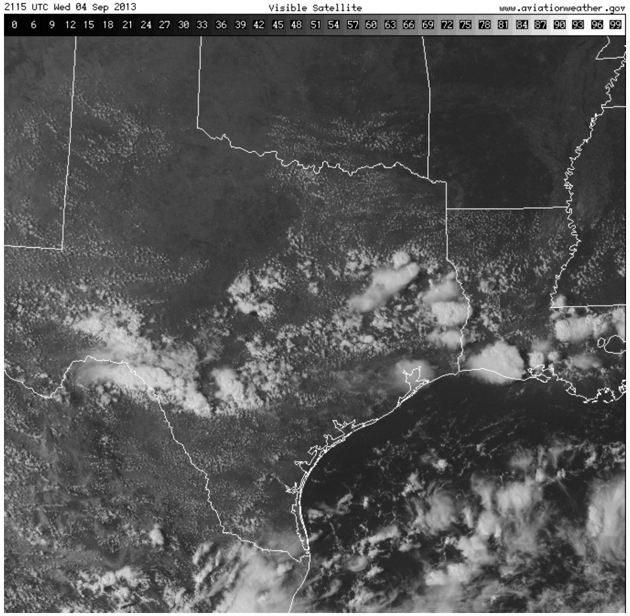
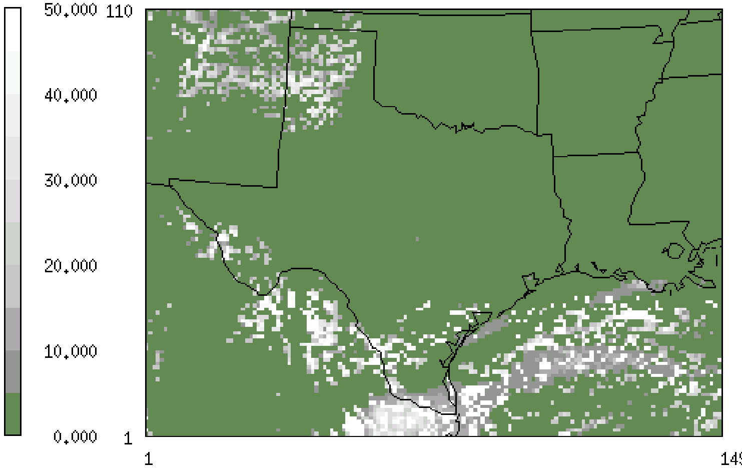
DISCOVER-AQ: September 4, 2013

- RadKF (WRF v3.6.1) and MSKF (WRF v3.7) lead to very different cloud patterns
  - **And** different wind, temperature, humidity patterns
  - Purely a result of MSKF? Or other changes in WRF v3.7?
- MSKF seems to be a better simulation – serendipitous?

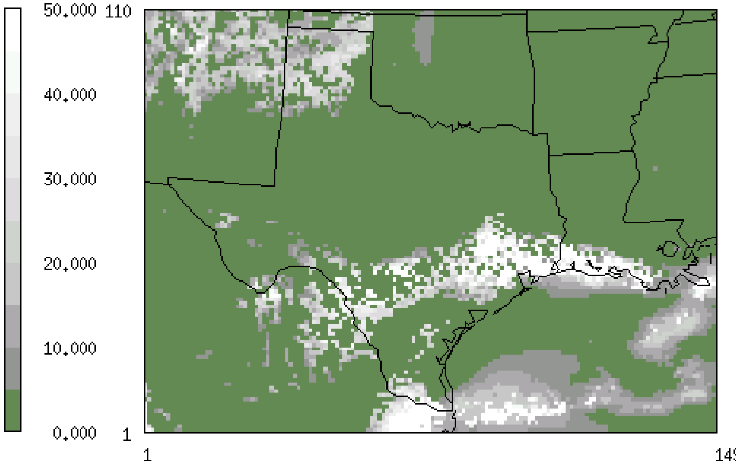


12 km CAMx grid

Resolved + RadKF Clouds



Resolved + MSKF Clouds



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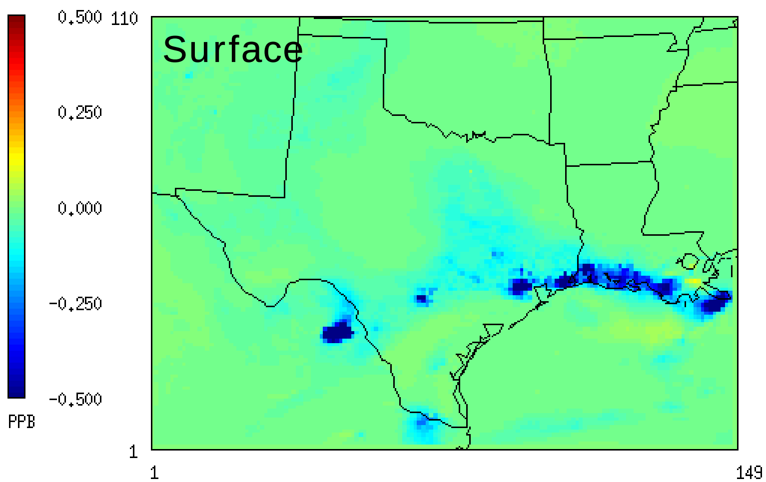
DISCOVER-AQ: September 4, 2013

- NO_2 vertical transport from surface to free troposphere (MSKF meteorology)
- Reductions near surface, increases aloft
  - Agrees with conceptual model for surface sources
  - Patterns reflect local net influence of up/downdrafts among clouds and ambient volumes
- O_3 is more complicated; inverted gradient



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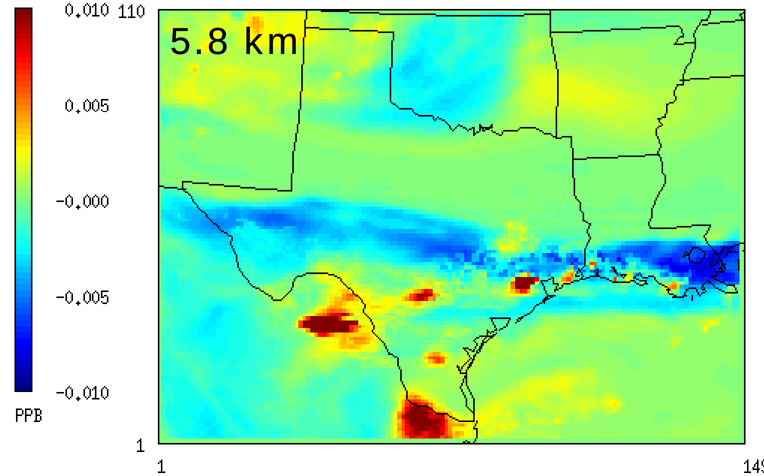
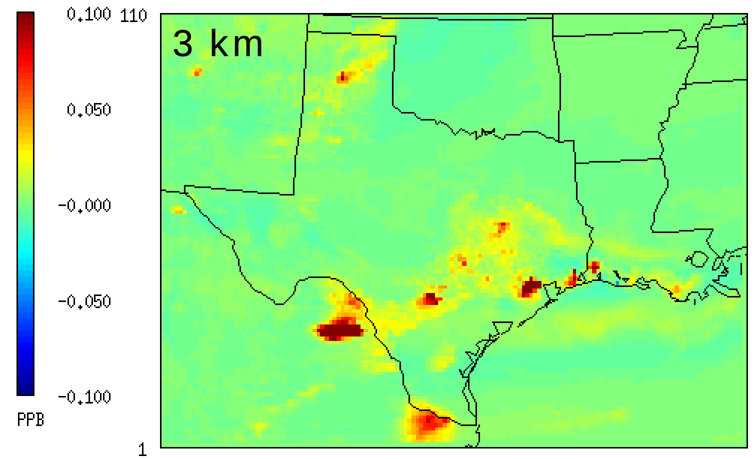
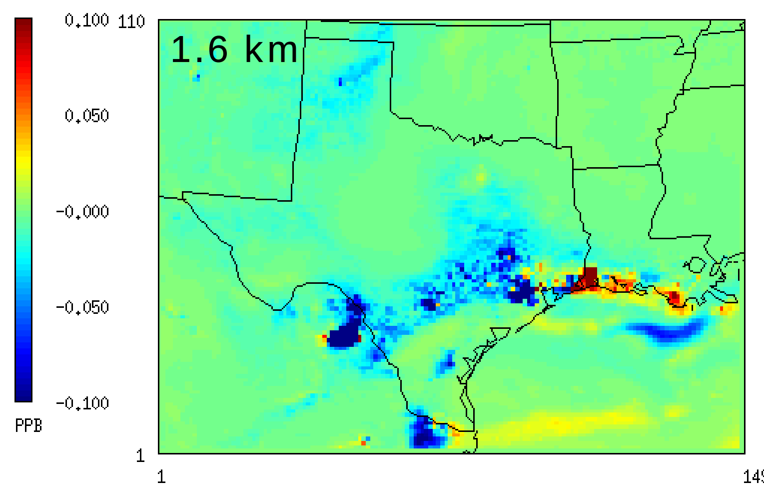
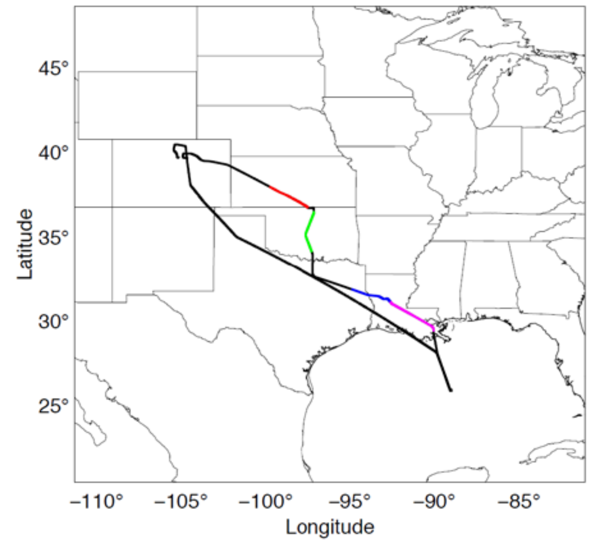




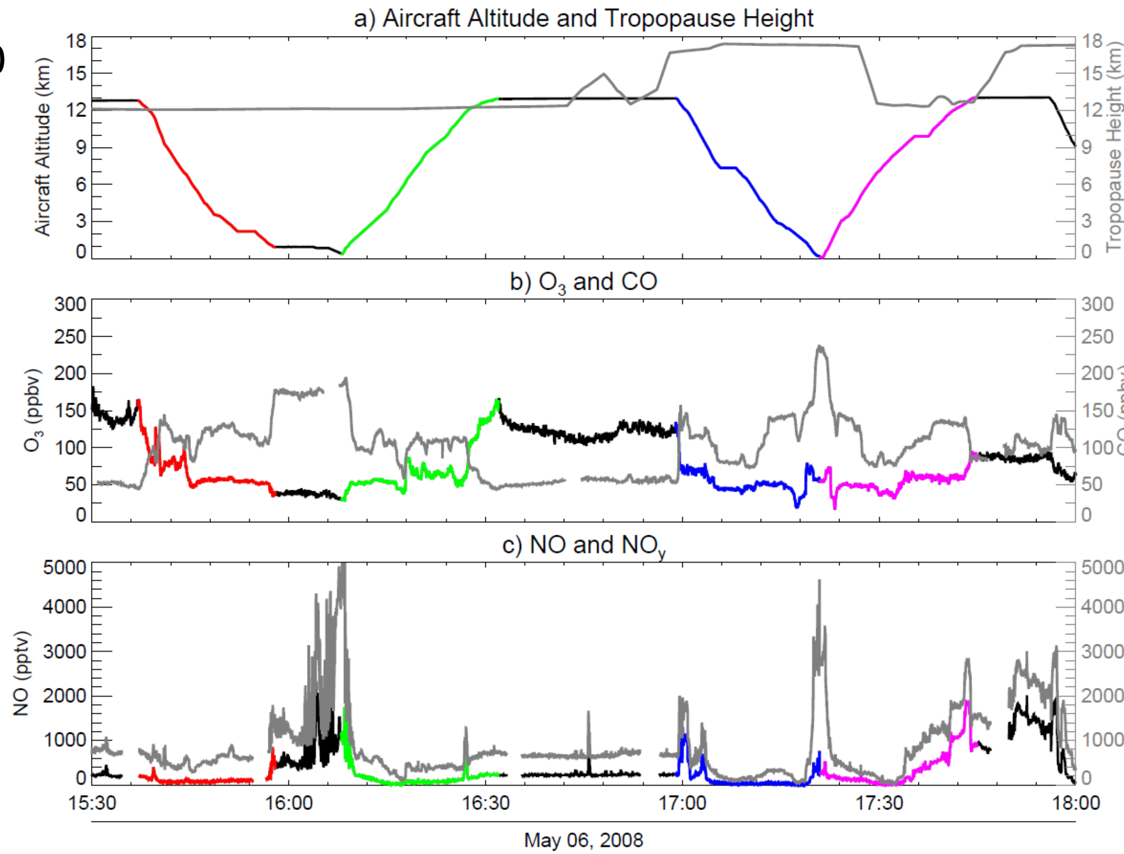


SOCAT08

- May 4-6, 2008: convective period in south-central US
- NCAR G-V flights during May 6, tropospheric profiles up/downwind of convective activity



- O_3: ~50 ppb surface to ~150 ppb 12 km
- NOy: 0-2 ppb NOx + 1-3+ ppb NOz



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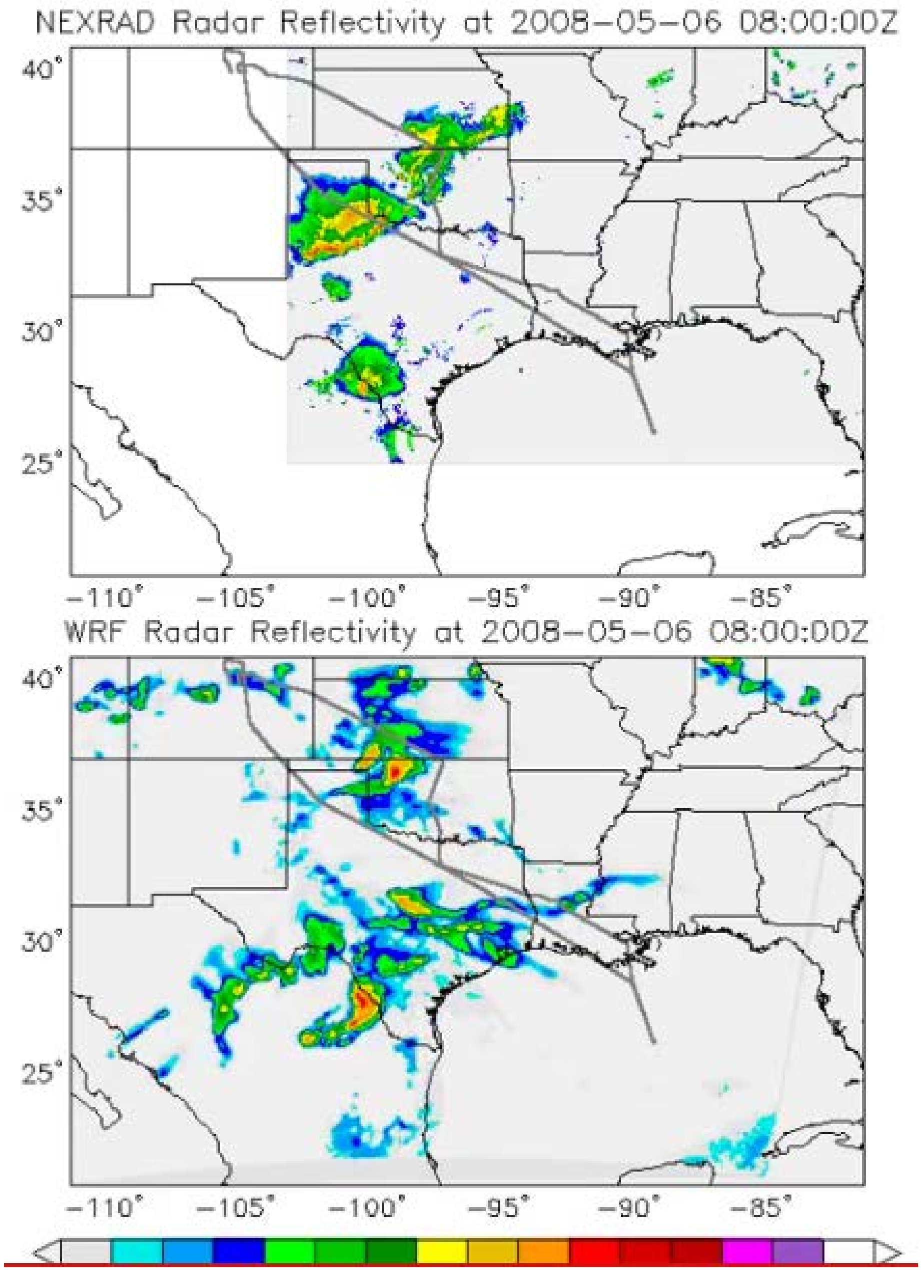
SOCAT08: May 6, 2008

- WRF produces organized convection with appropriate structures
- **But** spatially displaced, not enough in the area sampled by aircraft
- CAMx profiles collocated with aircraft ascents/descents tend to show little effect from convection
  - Lack of model-simulated convection rather than deficiency in CAMx CIG
- Shift focus to qualitative assessment against aircraft observations in nearby locations and similar times



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Summary:

- Convection is locally important for pollutant ventilation, transport and removal, but is difficult to model
- New CAMx/CiG framework includes sub-scale vertical transport and wet removal of gases & PM, plus in-cloud PM chemistry
- CiG is operating as designed, but model-measurement comparisons are hindered by WRF's SGC predictions

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Work to be done in this project:

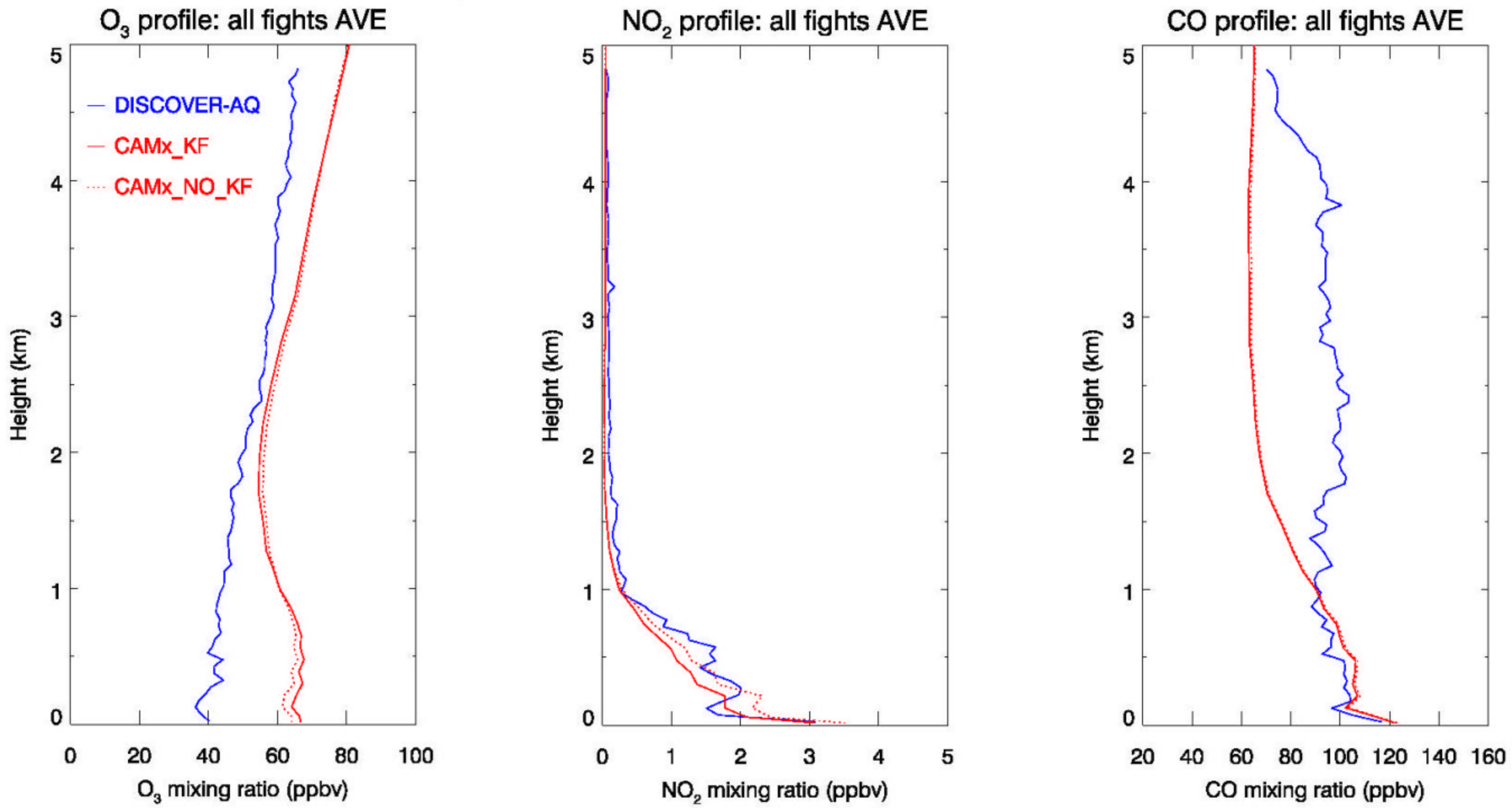
- Complete CAMx/CiG ozone/precursor evaluation for May 2008 START08 and September 2013 DISCOVER-AQ periods

Future steps:

- Evaluate impacts to PM, deposition
- Tie in Probing Tools (SA, DDM, RTRAC)

DISCOVER-AQ (extra slides)

- Model vs. aircraft ozone profiles
- September 6, 2013 (TAMU runs)



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DISCOVER-AQ (extra slides)

- Ozone difference (MSKF – RadKF)
- 2 PM September 4, 2013 (same as slide 14)