TC^4 Atmospheric chemistry science goals and mission strategy

Paul Wennberg

Table 1 Major questions addressed by TC[4]

Scientific question
1. What mechanisms maintain the humidity of the stratosphere? What are the relative roles of large-scale transport and convective transport and how are these processes coupled?
2. What are the physical mechanisms that control (and cause) long-term changes in the humidity of the upper troposphere in the tropics and subtropics?
3. What controls the formation, maintenance and distribution of thin cirrus in the Tropical Tropopause layer, and what is the influence of thin cirrus on radiative heating and cooling rates, and on vertical transport?
4. What are the chemical fates of short-lived compounds transported from the tropical boundary layer into the Tropical Tropopause layer. (i.e., what is the chemical boundary condition for the stratosphere?)
5. What are the mechanisms that control ozone within and below the Tropical Tropopause Transition layer? What is the chemical nature of the outflow from the convective region of the Eastern Pacific?
6. How do convective intensity and aerosol properties affect cirrus anvil properties?
7. How do cirrus anvils, and tropical cirrus in general, evolve over their life cycle? How do they impact the radiation budget and ultimately the circulation?
8. How can space-based measurements of geophysical parameters, particularly those known to possess strong variations on small spatial scales (e.g., H_2O, cirrus), be validated in a meaningful fashion?

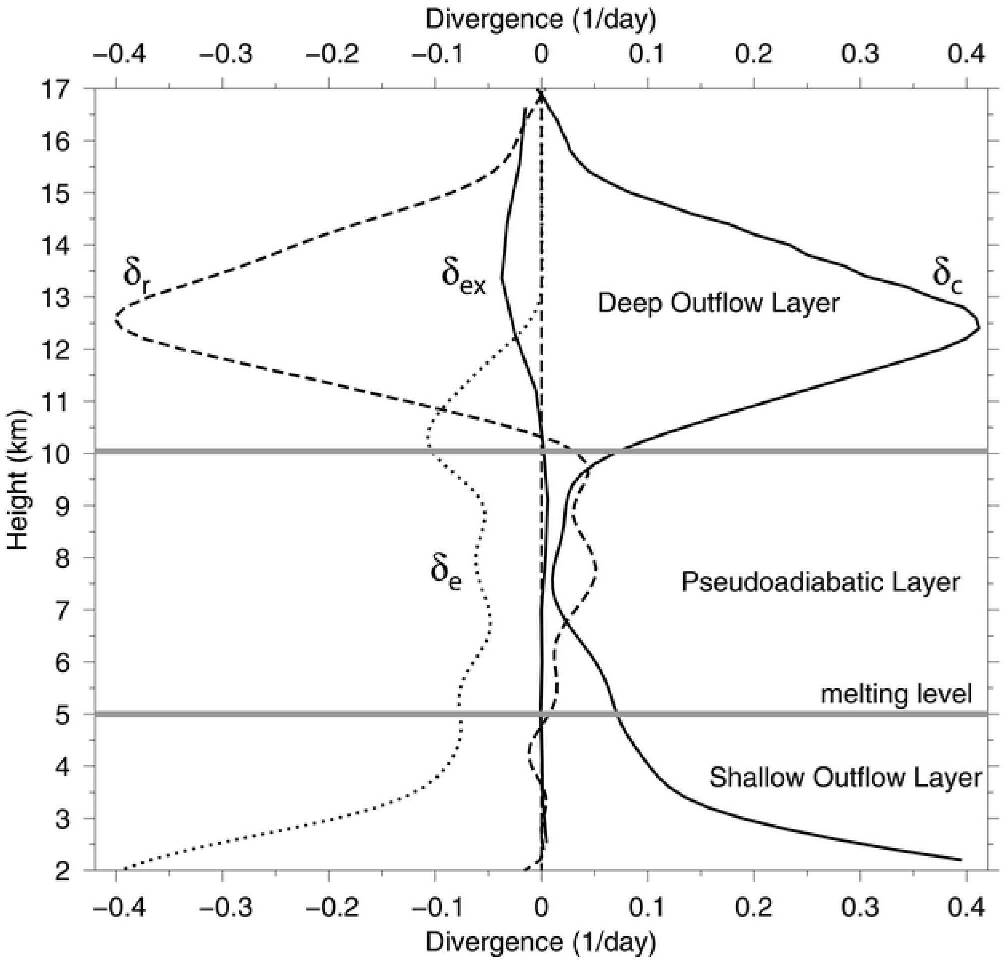
Chemistry and Convection Questions

- **Transport:** What is the chemical nature of the outflow of convection and how is it distinct from the air entrained into the convection? How does it vary with altitude and can cloud models accurately describe the chemical transport? Are lofted short lived bromocarbons associated more strongly with maritime convection than with continental convection?

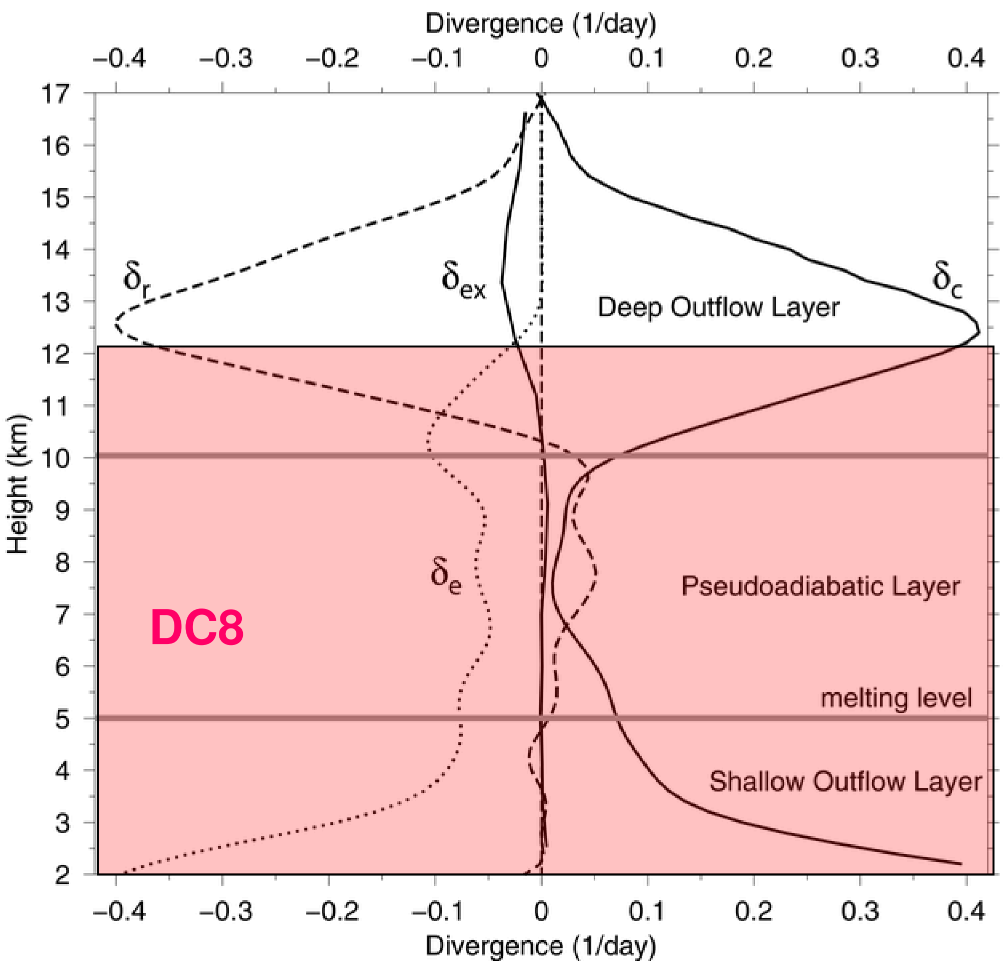
- **NOx:** What is the efficiency of NO_x production by lightning? Is it different for cloud-ground / cloud-cloud? Is it different for maritime convection?

TC^4 Opportunity – Convection

- Take advantage of the physical description of the convection provided by the satellite observations and the remote sensing instruments to define the mass (and moisture / precipitation) flux and lightning flash rate.
- Chemically describe the entrainment and detrainment from the convection from the boundary layer to the top of the convective event.
- Propagation of easterly jet carrying biomass burning tracers through the convective region offers significant test of entrainment / detrainment parameterizations



Tropical mean (20 °S–20 °N) vertical profiles of cloud-mass divergence δc, clear-sky radiative mass divergence δr, and evaporative mass divergence δe. δex refers to the tropical mean divergence associated with transport between the tropics and extratropics. A positive mass divergence refers to a source of mass to the clear-sky atmosphere while a negative mass divergence refers to a sink of mass from the clear-sky atmosphere. Folkins and Martin, 2005.



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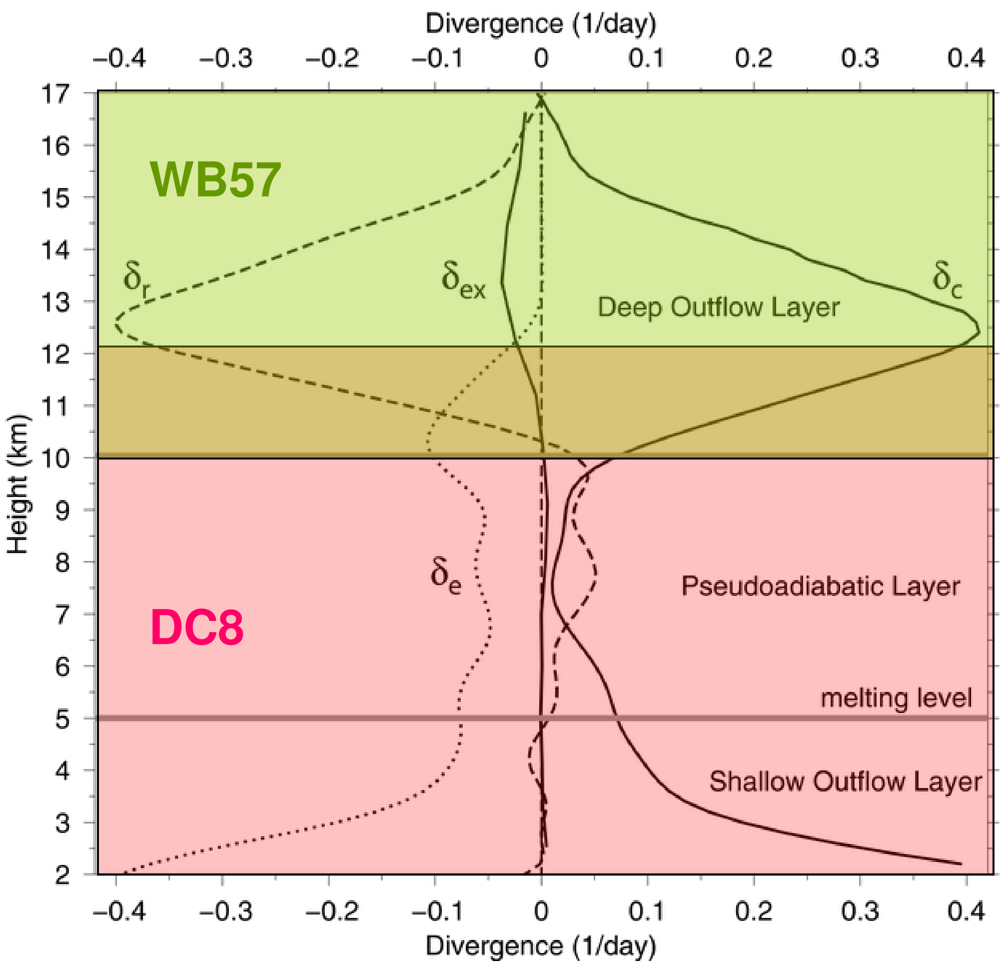

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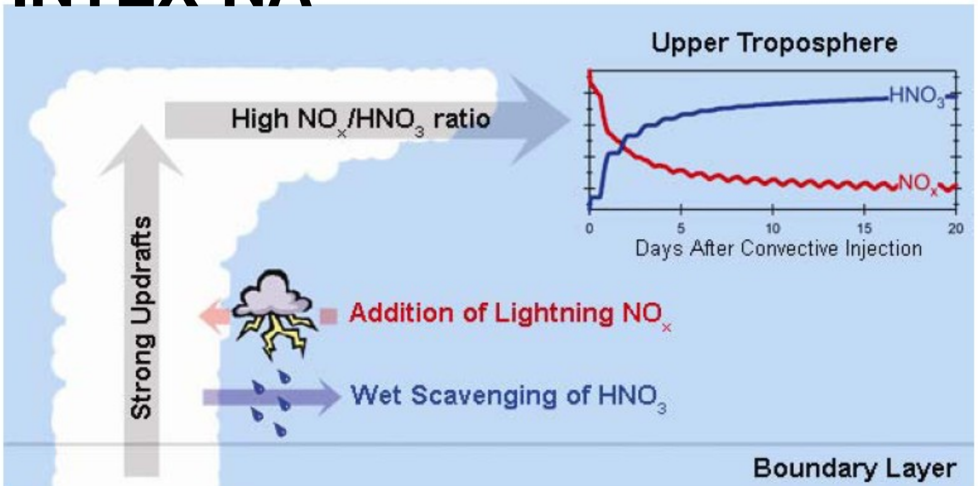
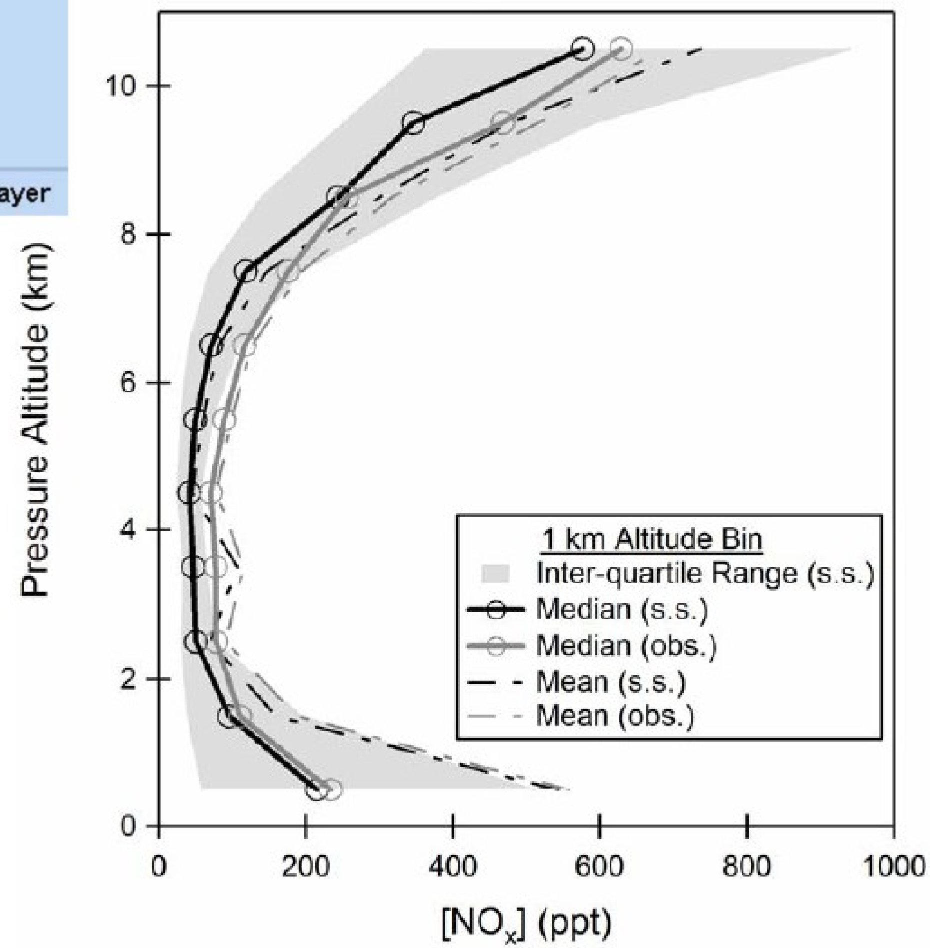
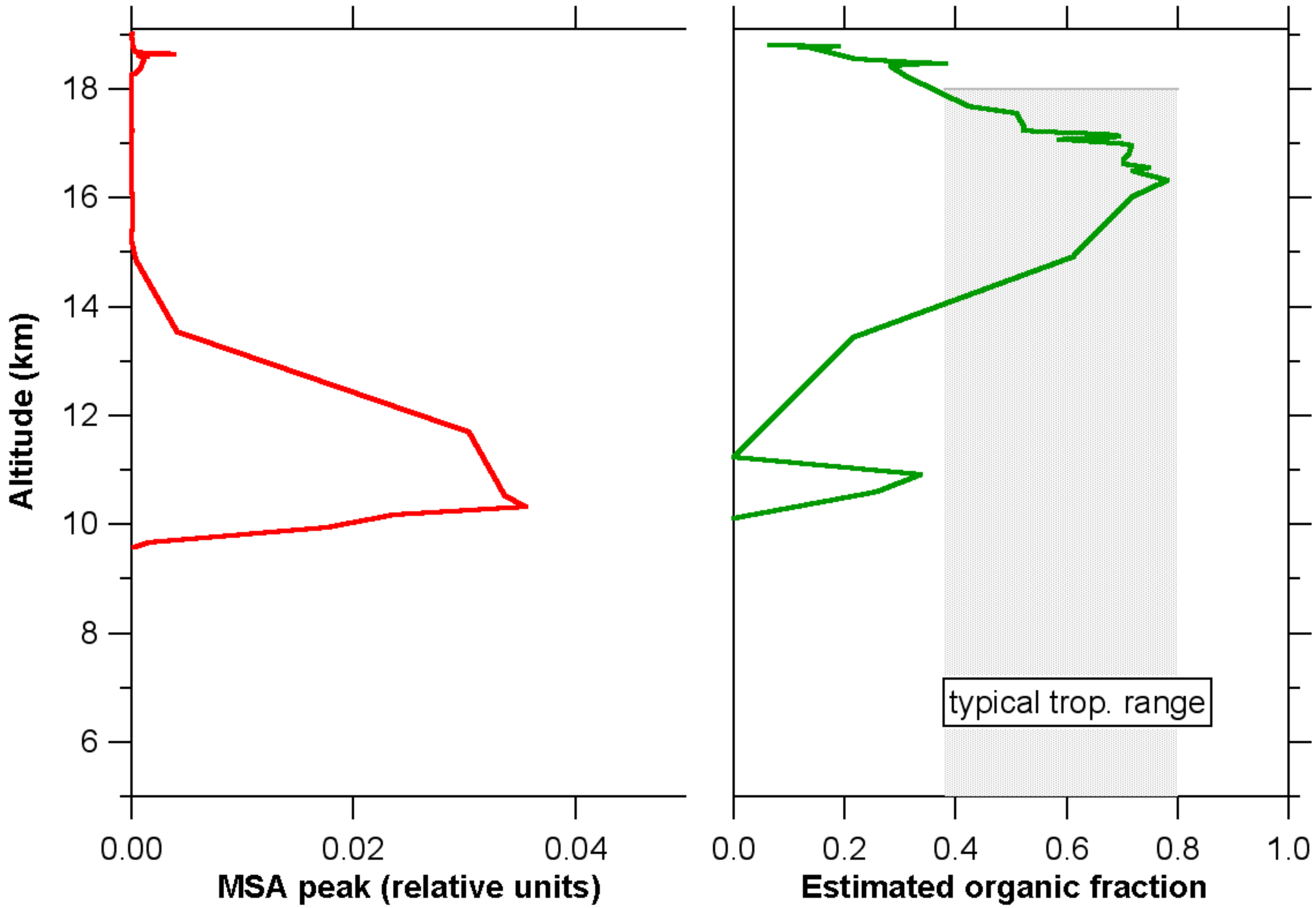
Efficient NOx production from Lightning observed during INTEX-NA

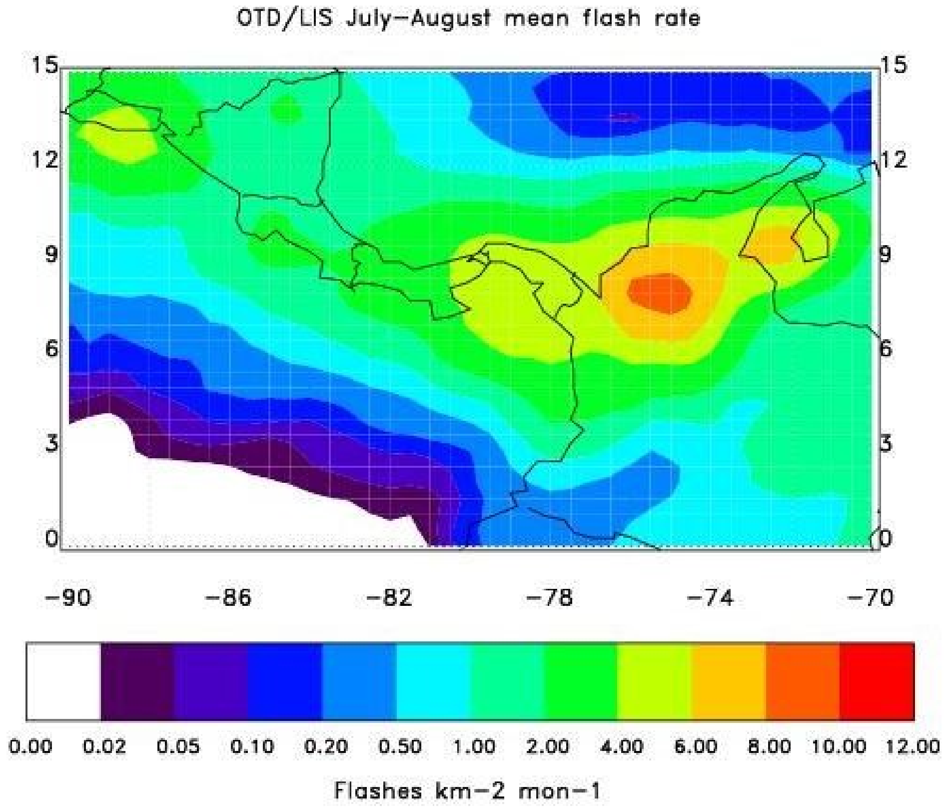




Bertram et al., Science, 2007

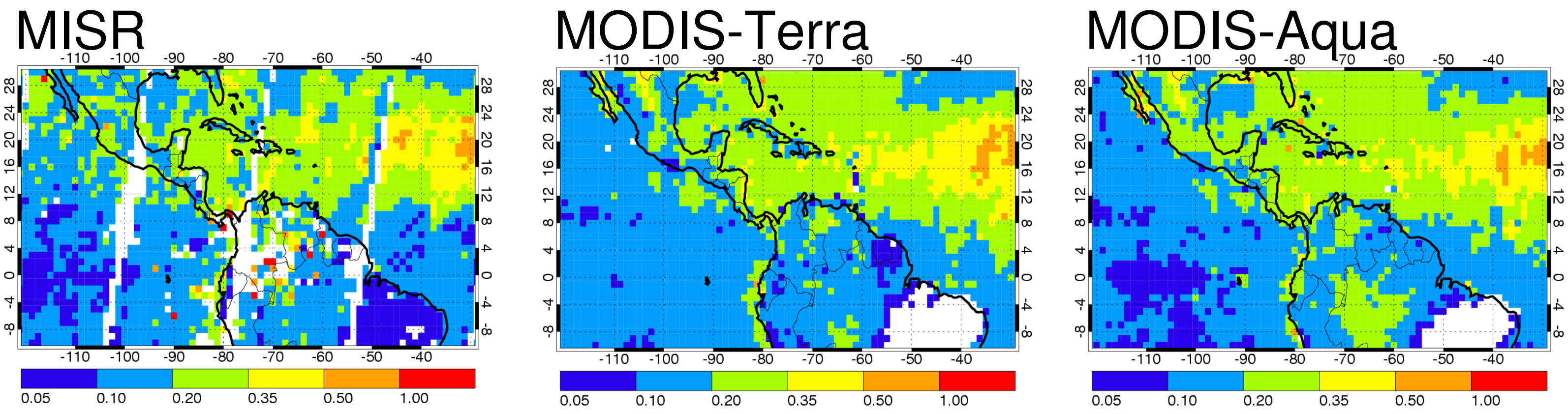


Murphy – WB57 Observations

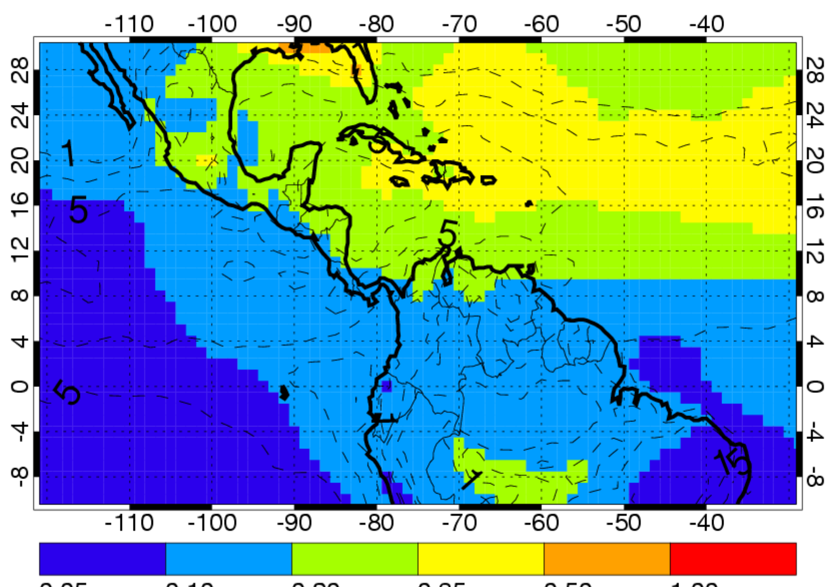


- TC4 region is near one of the several global lightning “hot spots”.
- TC4 should provide an opportunity for OMI tropospheric NO_2 validation in a region where lightning is the dominant source.
- Production per midlatitude summertime flash averages 500 moles NO based on cloud-resolved (STERAO and CRYSTAL-FACE) and larger-scale CTMs (ICARTT). Are tropical flashes equally productive?

Aerosol Optical Thickness
July 15 - August 15, 2006



GEOS-4 Model τ_{550} July 15 - August 15, 2006

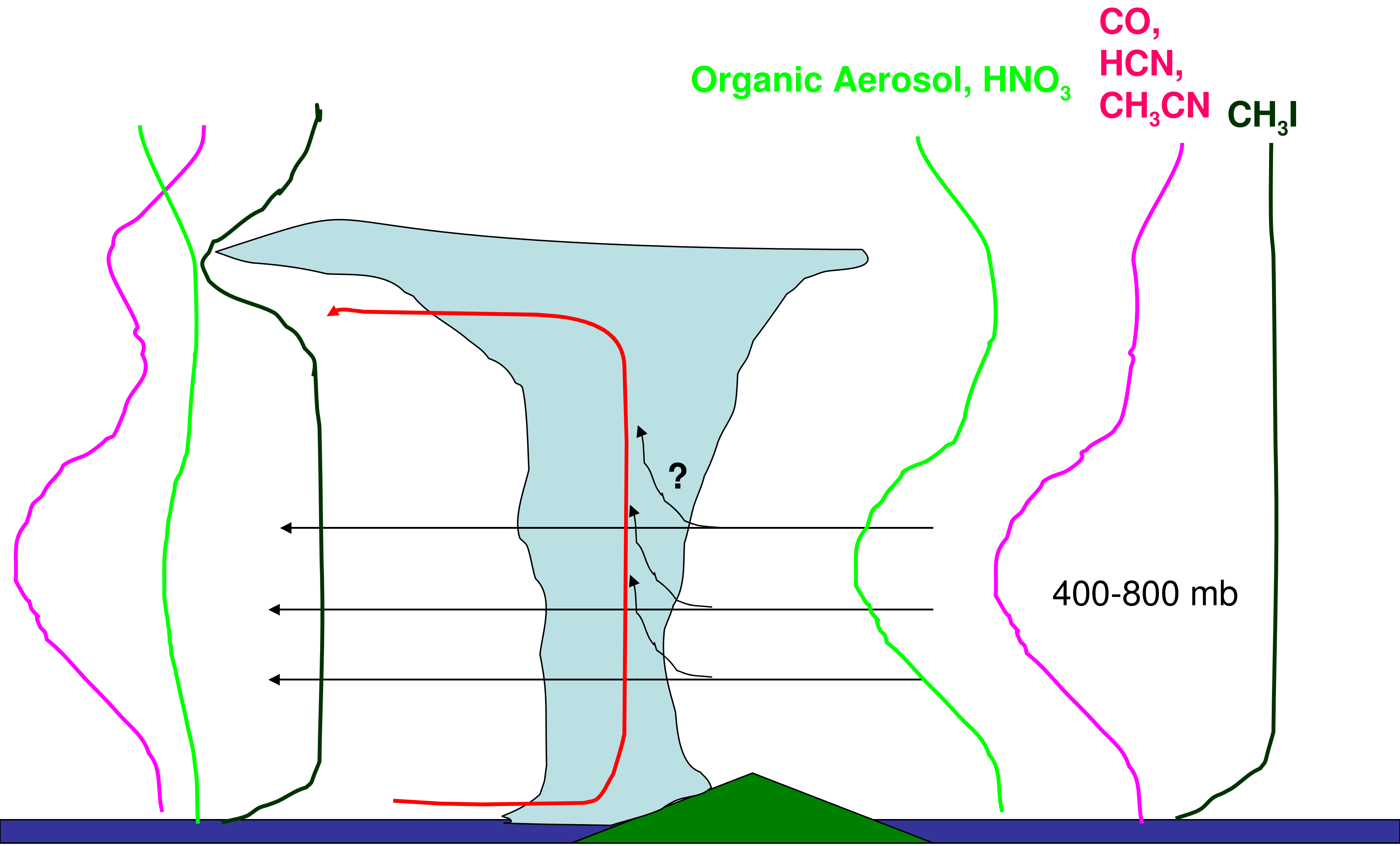


Contours: GEOS-4 Analysis Total Precipitation [mm/day]

Aerosols for the same period from the online GOCART model running inside GEOS operational DAS

For TC4 will run in new GEOS-5 system at global 0.5° x 0.5° resolution

Peter Colarco


Organic Aerosol, HNO_3
CO,
HCN,
CH_3CN
CH_3I
?
400-800 mb

Flight Plan

Case Studies:

- Coordinated flights of the WB57 and DC8 to profile the entrainment and outflow of convection.

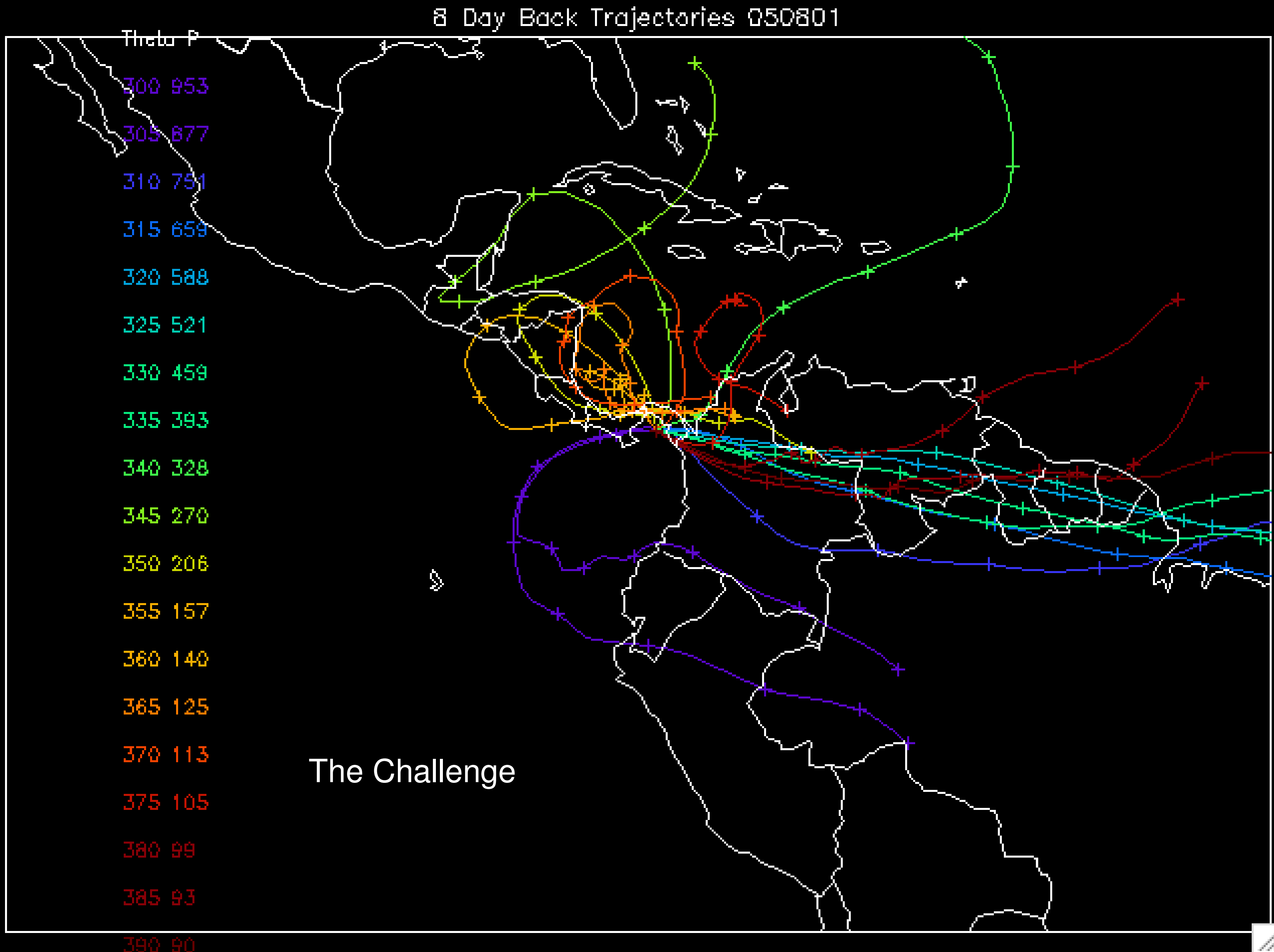
- Need to profile from boundary layer to 15 km.
- Need accurate count of cloud-to-ground and cloud-to-cloud lightning.

Key chemical observables:

- H_2O, HDO, CO, O_3, NO_x, H_2O_2, CH_3OOH, $C_xCl_yBr_z$, CH_3I

Key dynamical observables:

- Precipitation, thermal structure



The Challenge

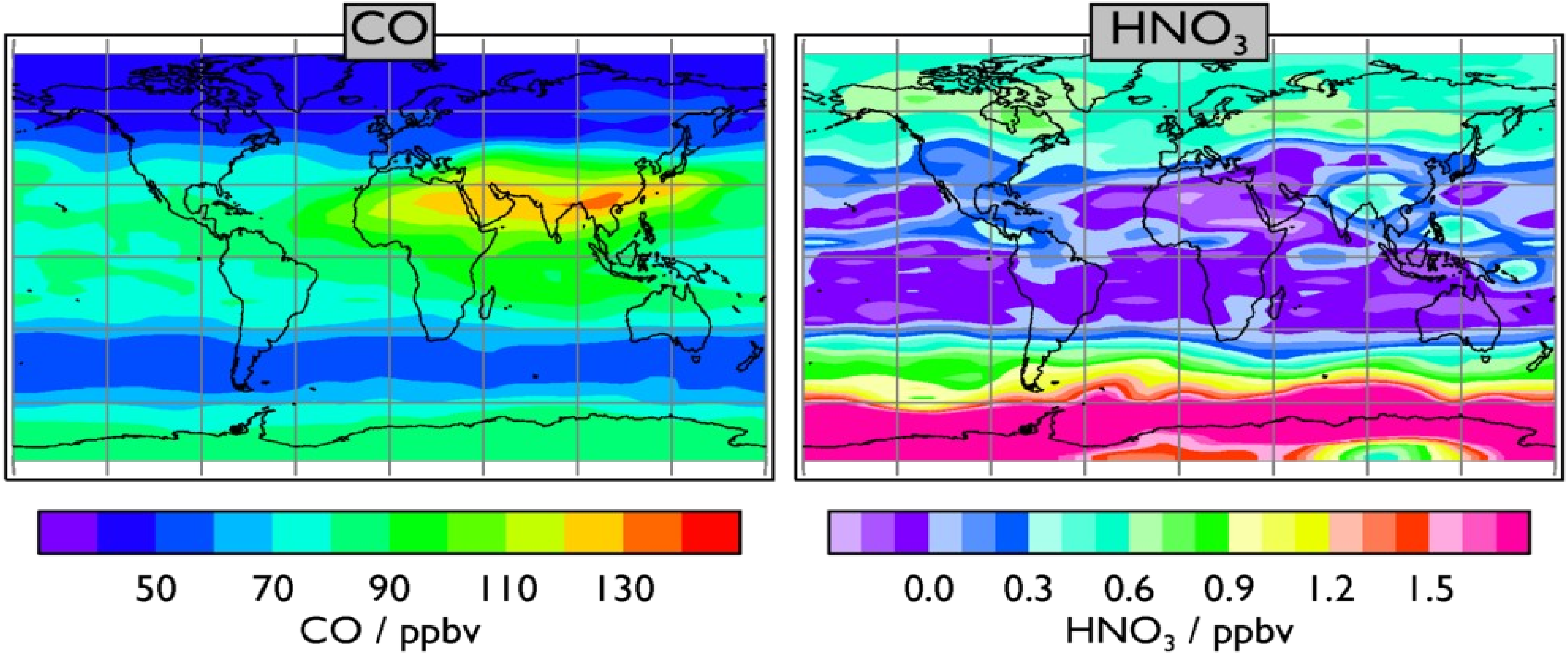
Chemistry 'Downwind' of Convection Questions

High NO_x, peroxides, and low ozone in the outflow should produce copious amounts of ozone downwind.

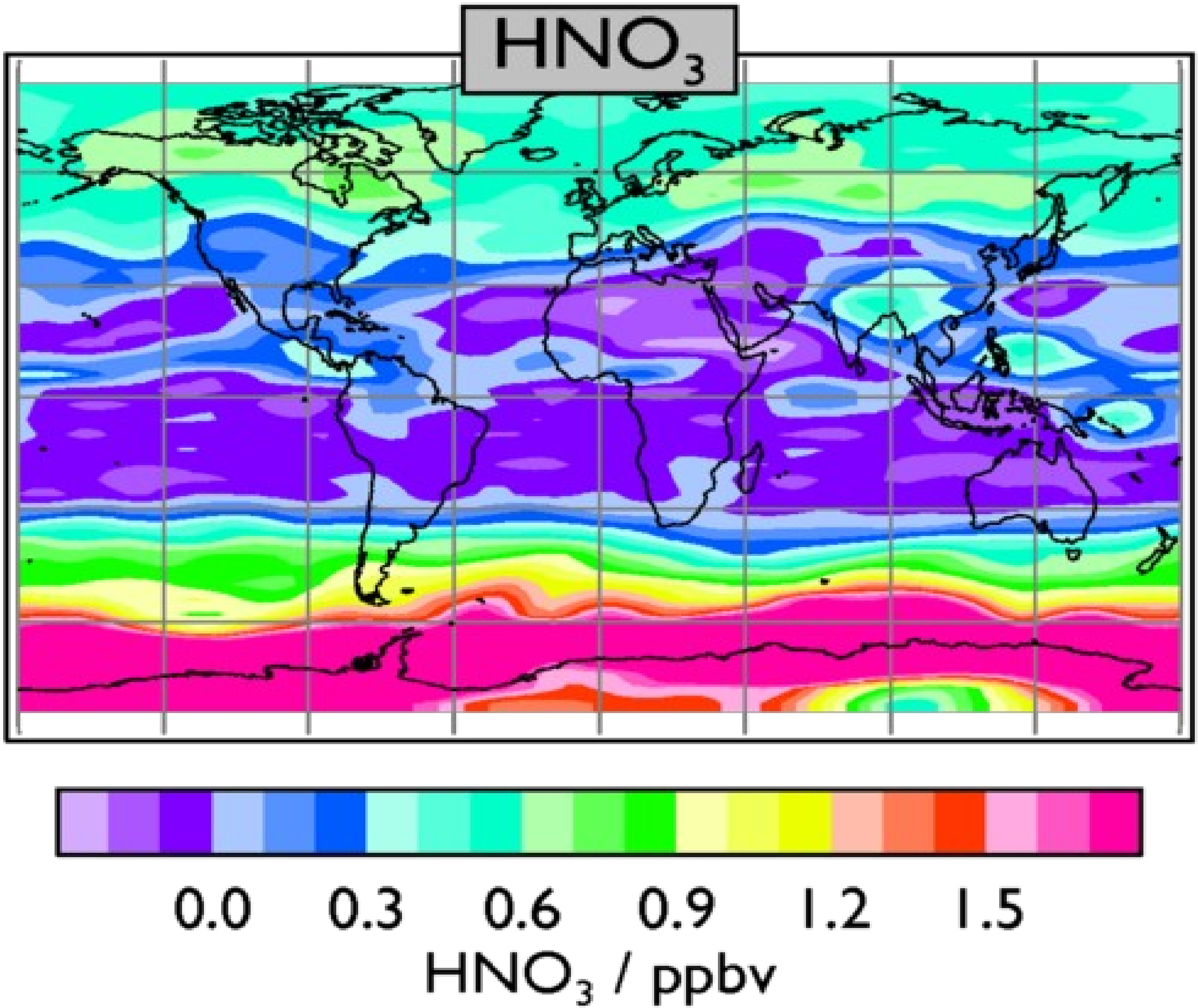
- How fast is the ozone production rate?
- Is it consistent with the initial conditions?
- Is ozone production in the tropical upper troposphere significant for the budget of the tropospheric column?

Shortlived bromine containing compounds introduce additional bromine into the TTL.

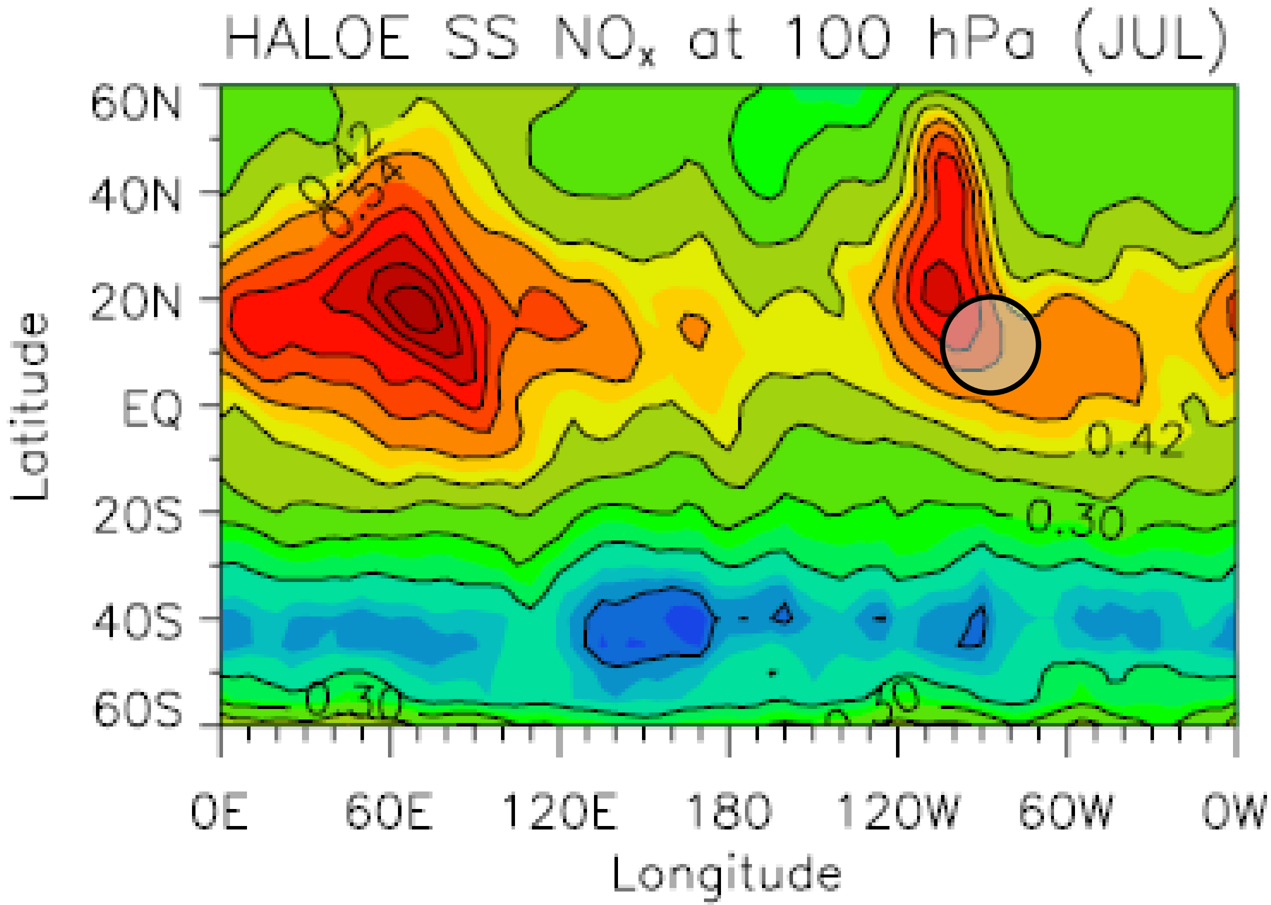
- Can we observe the decay of these shortlived halogen containing organics? Are the loss rates consistent with expectation?



Aura MLS July 2006 observations at 147 hPa



HNO_3
0.0
0.3
0.6
0.9
1.2
1.5
HNO_3 / ppbv



Combined climatology for HALOE sunset NO_x (derived by adding together the individual NO and NO_2 climatologies) for July at 100 hPa. The NO_x data show relative maxima of ~0.5-0.8 ppmv centered over the regions of maximum convection. Very large gradients are observed in the vicinity of Costa Rica. (*Park et al.*, 2004)

Does convection of shortlived bromine containing organic compounds carry significant Br to the stratosphere?

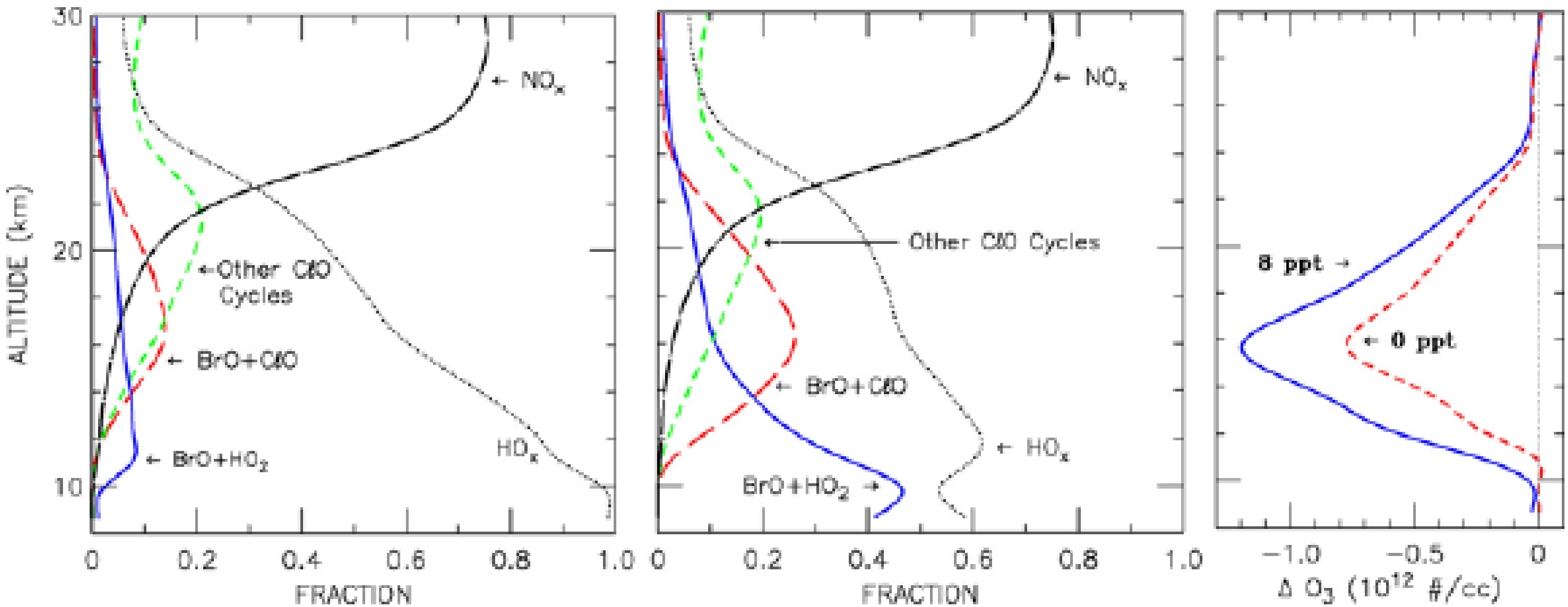


Figure 4. Fraction of odd oxygen loss by various catalytic cycles within the AER model at 47ºN, March 1993, for model runs with contributions to Bry from VSL halocarbons of 0 ppt (left panel) and 8 ppt (middle panel). Difference between the ozone profile at 47ºN, March 1993 and the profile at 47ºN, March 1980 for runs with 0 and 8 ppt of Br_y from VSL bromocarbons (left panel). From Salawitch *et al.*, 2005.

TC[4] Opportunity – Outflow Chemistry

- Take advantage of the range of the aircraft to observe the chemical aging of air following convection. Use chemical clocks to define the time scale. Trajectory approach unlikely to be successful.
- Use the large scale characterization of the chemical environment defined by the satellite and remote sensing observations on the aircraft to evaluate the significance of this downstream chemistry on the large scale fields.

Flight Plan

Case Studies:

- Coordinated flights of the WB57 and DC8 to profile the chemical fields east and west of the broad regional convection.
- Need to profile from 8 to 15 km.

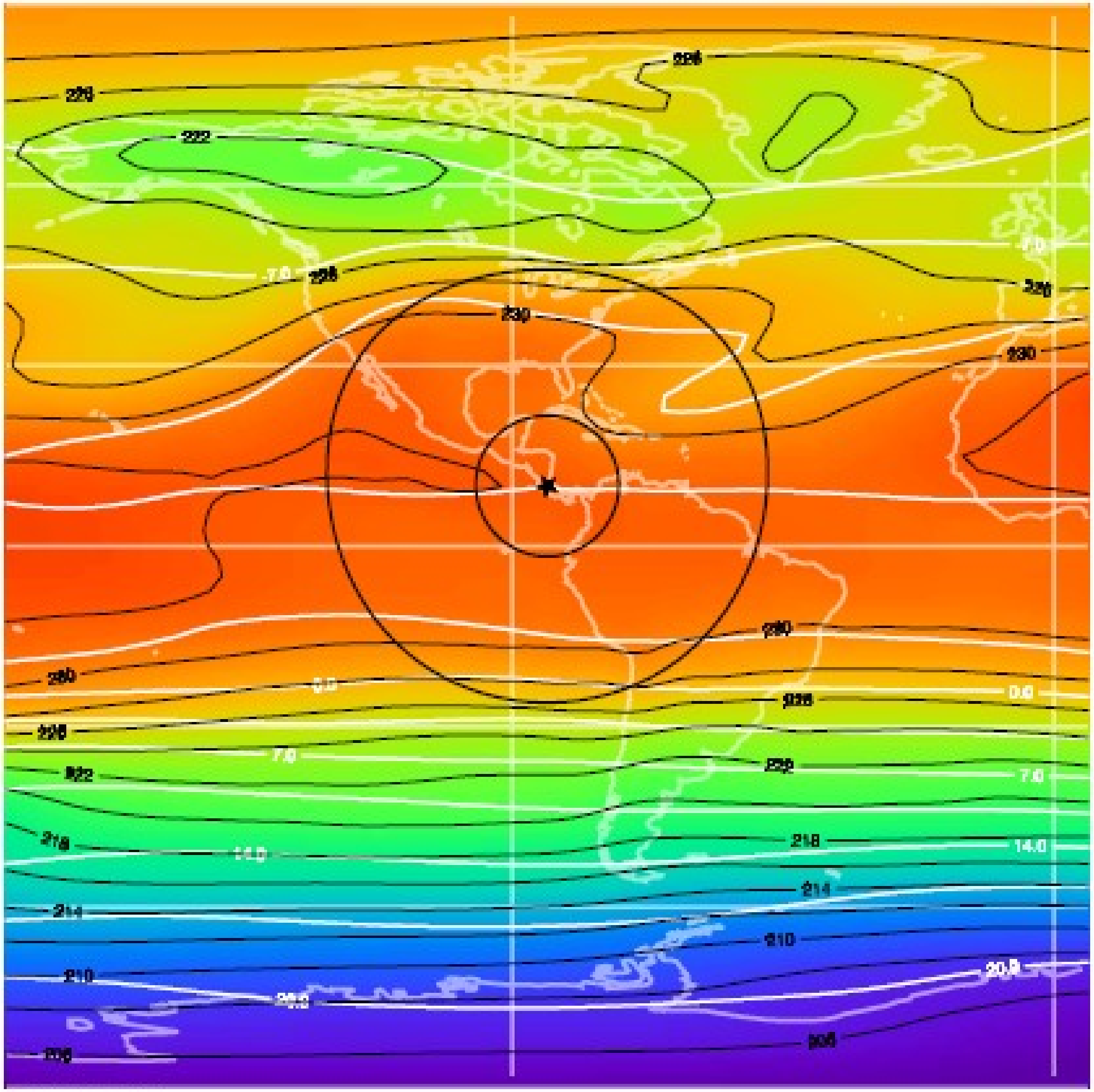
Key chemical observables:

- H_2O, HDO, CO, O_3, NO_x, H_2O_2, CH_3OOH, $C_xCl_yBr_z$, CH_3I

Key dynamical observables:

- 3-d wind field

Temperature (K) July 1979-2006



250 hPa