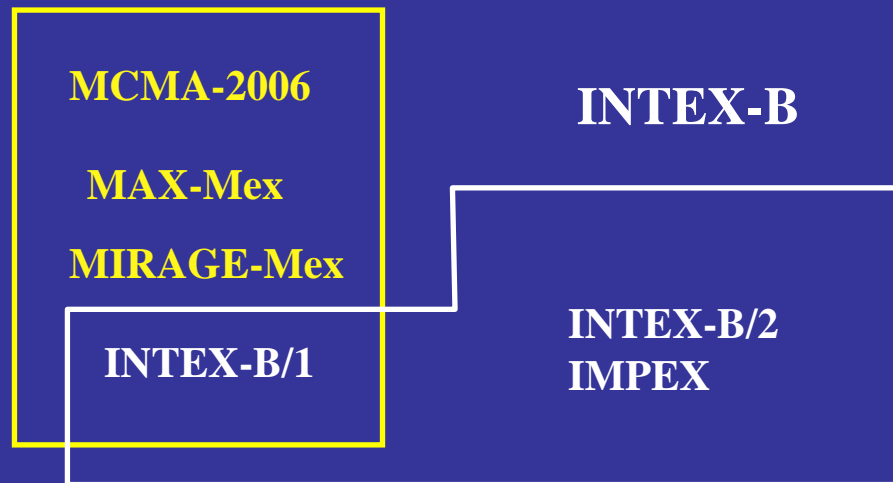


# *Trans-Pacific transport of pollution from Asia to North America*

## MILAGRO

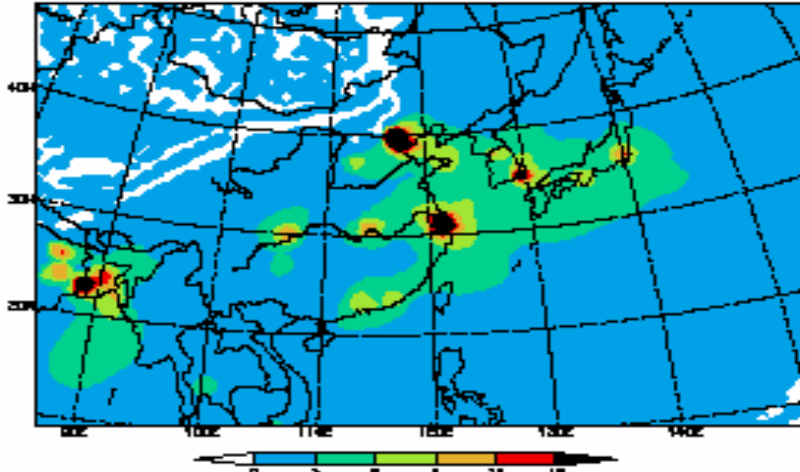


**Common Goal: To understand the transport, transformation, and impacts of gases and aerosols on air quality and climate from local to global scales**

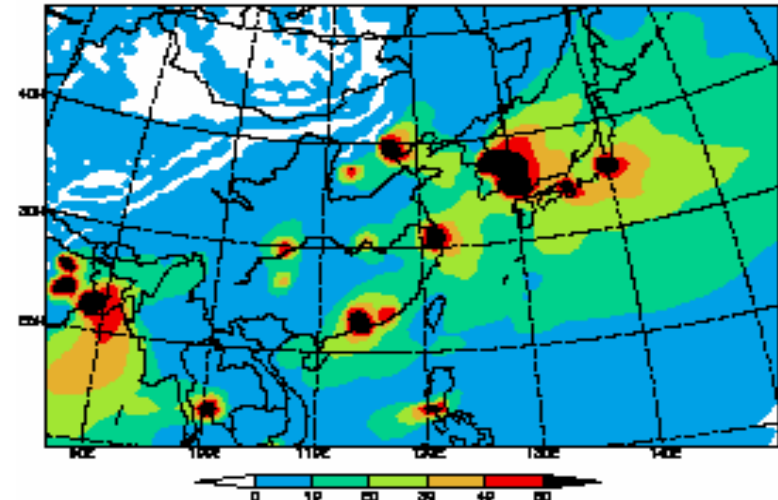
# Megacity Footprints (Spring 2001)

<1km

% Megacity

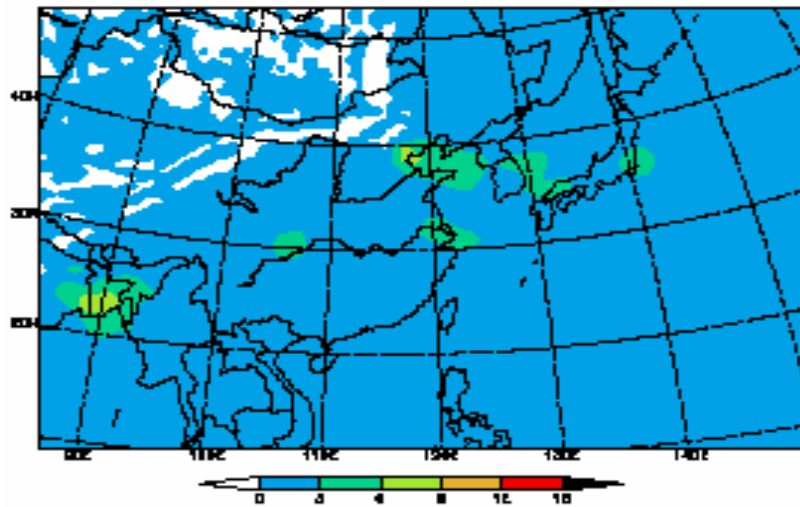


% Megacity

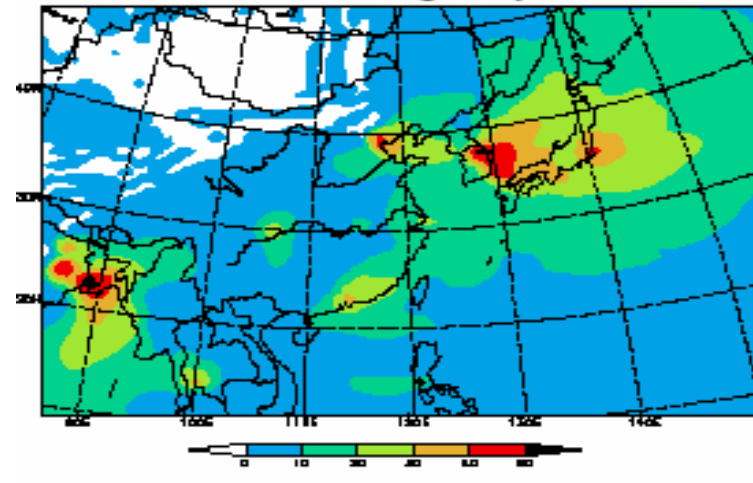


1-3 km

% Megacity



% Megacity

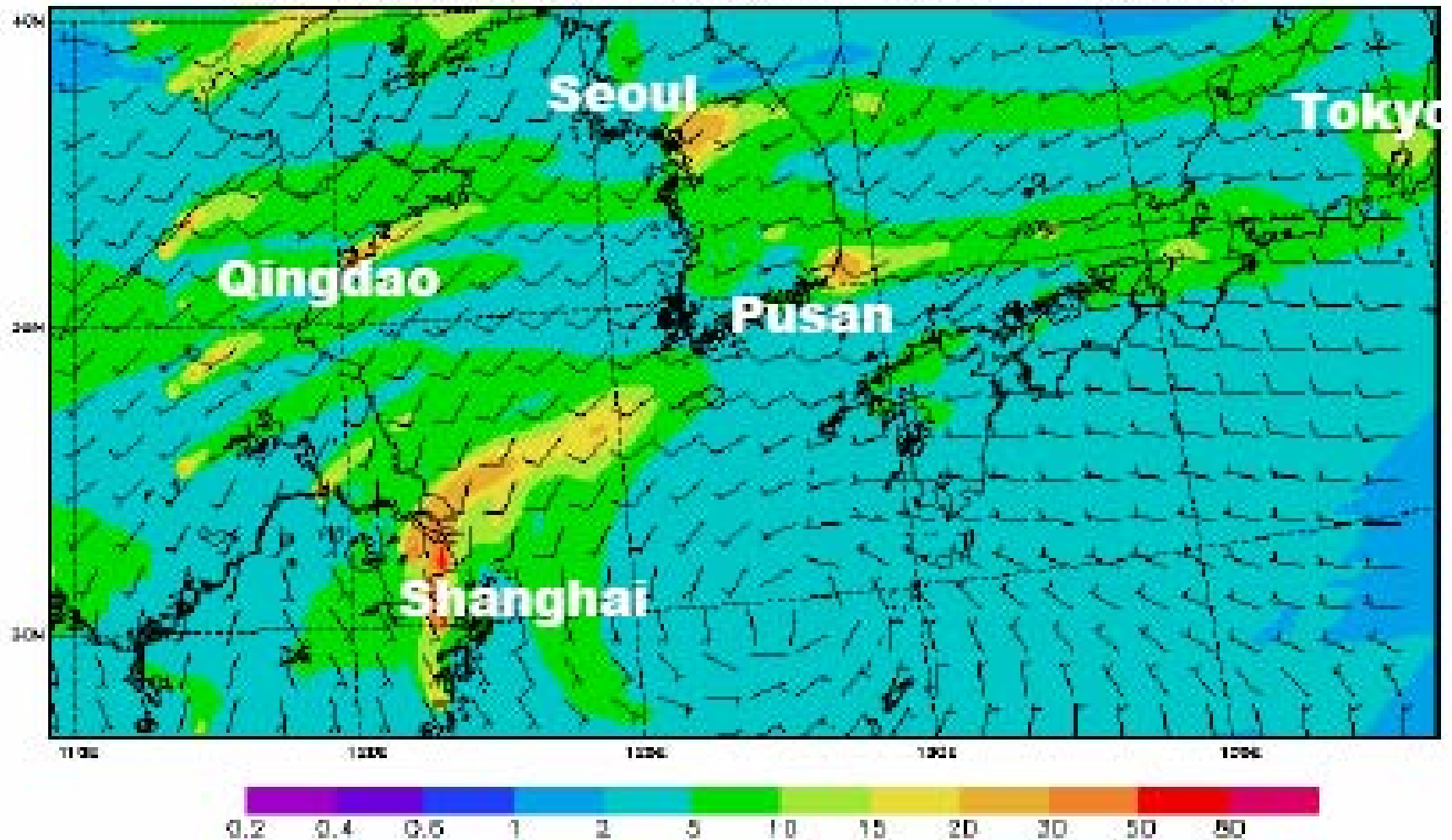


CO

NOz

# Simulated plumes of air pollution flowing out of Asian mega-cities

NO<sub>y</sub> Concentration (ppbv) at 9GMT, 4/15/2001



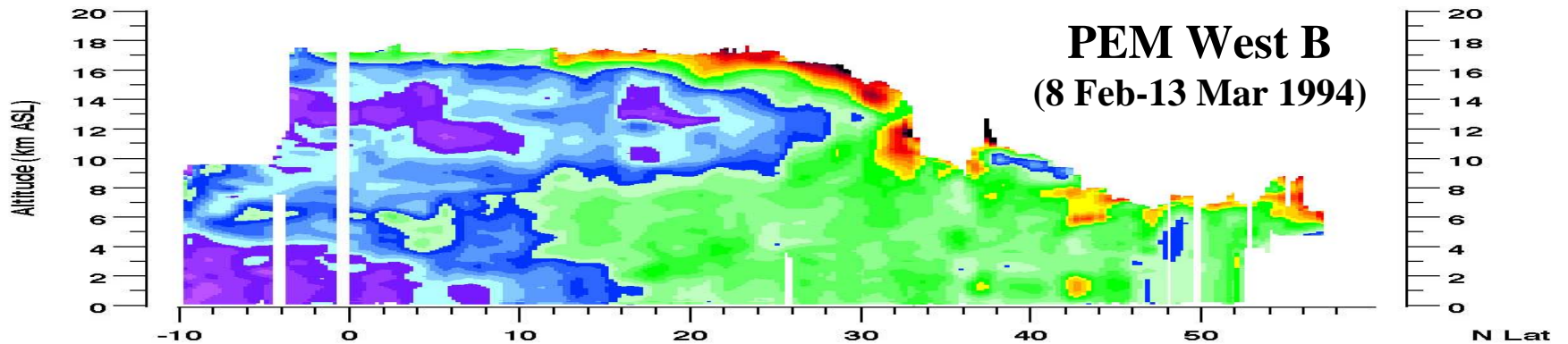
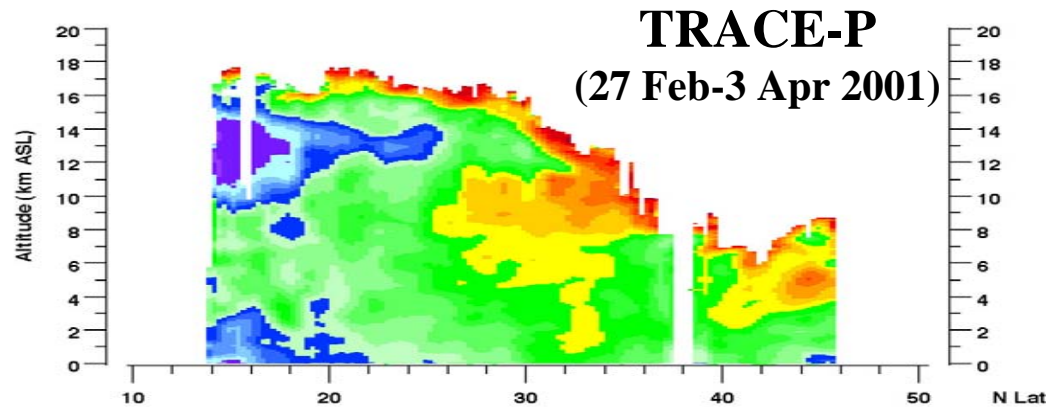
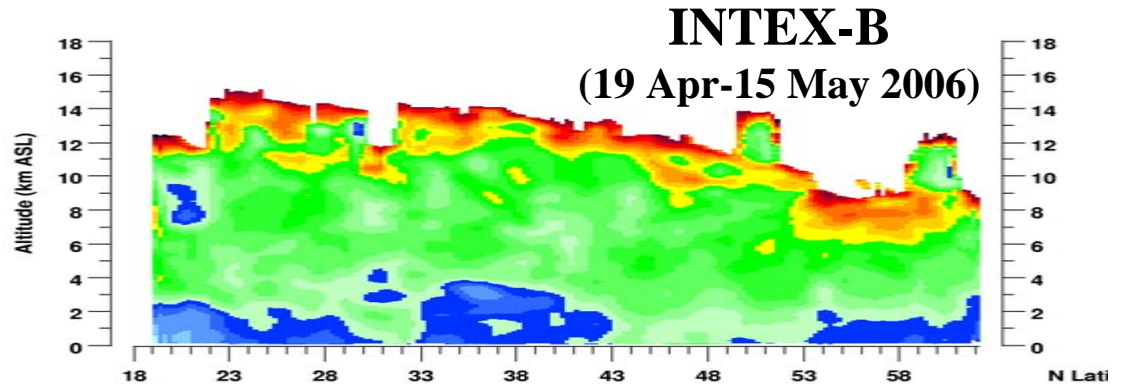
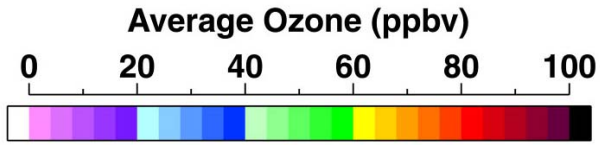
## **Asian outflow has been the focus of a number of airborne campaigns:**

- PEM-West A, Fall 1991 – Asian Pacific Rim during monsoon flow
  - PEM-West B, Spring 1994 – Asian Pacific Rim during maximum outflow
  - TRACE-P/ACE-Asia, Spring 2001 – Asian Pacific Rim during maximum outflow;  
first use of CTMs and satellites for planning
  - ITCT-2k2, Spring 2002 – North American inflow over eastern Pacific
  - INTEX-B, Spring 2006 – North American inflow over eastern Pacific
- \* Asian inflow has also been monitored from sites along the west coast, e.g.:  
Mt. Bachelor/Cheeka Peak, Whistler Peak, and Trinidad Head

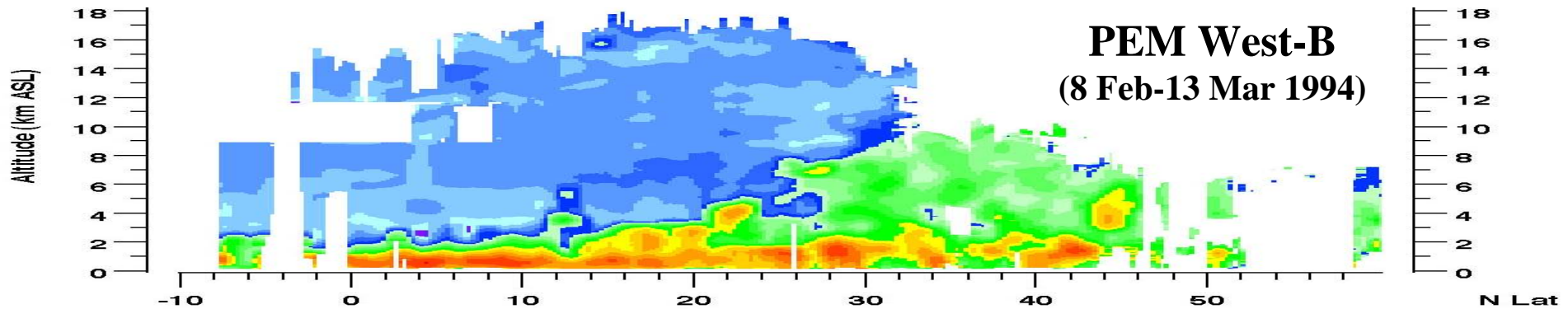
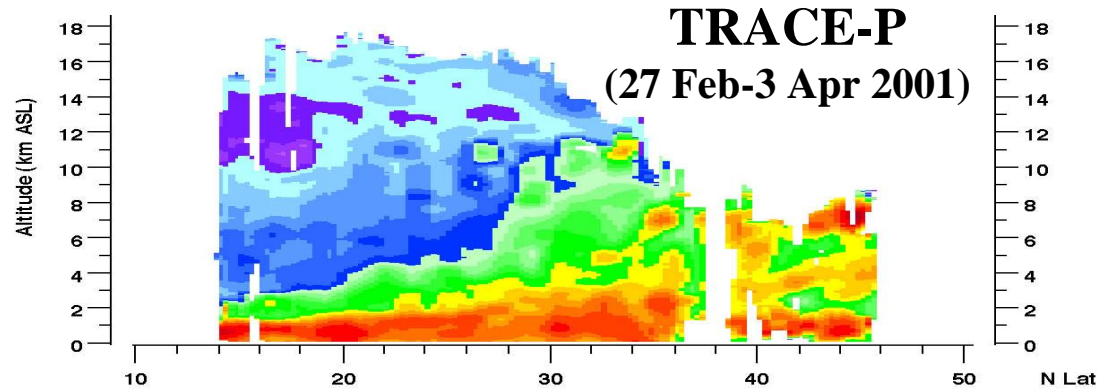
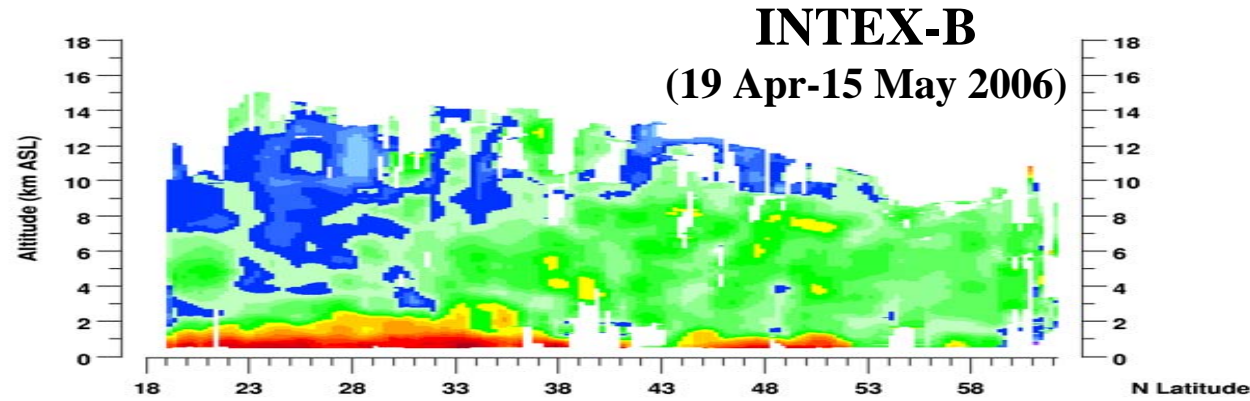
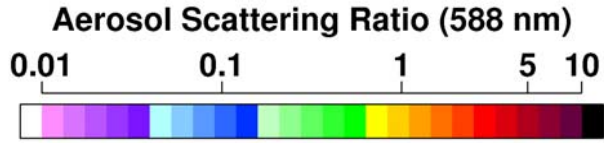
## **Why so much attention to Asian pollution and long-range transport?**

- Rapid economic growth and increase in associated emissions along Asian Pacific Rim (4 of top 10 megacities)
- The remote North Pacific is ideal for studying the long-range transport and transformation of pollution
- The North Pacific domain is too large to adequately probe in a single flight campaign

# Comparison of INTEX-B, TRACE-P & PEM West B Average Ozone Distributions



# Comparison of INTEX-B, TRACE-P & PEM West B Average Aerosol Distributions



# Understanding long-range transport requires the combination of in situ observations, satellite data, and models of atmospheric composition and climate

**Satellites:** CALIPSO, Cloudsat, OMI, TES, HIRDLS, MLS, MODIS, AIRS, MISR, MOPITT

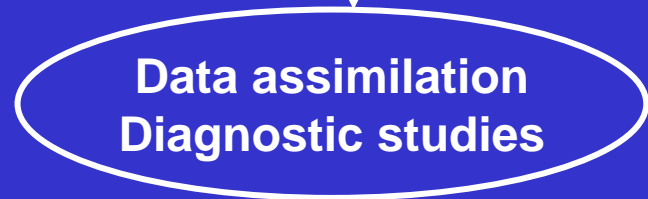
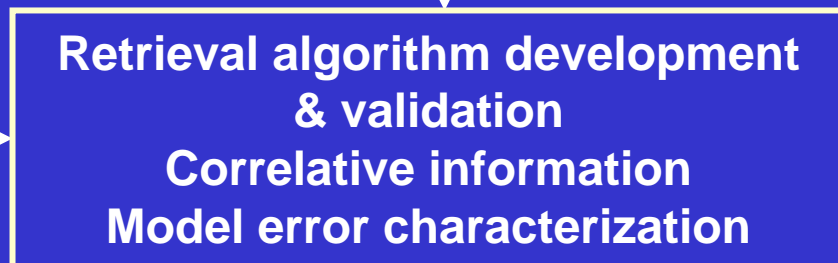
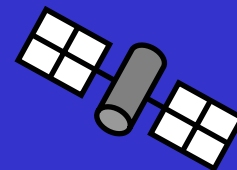
- CO, ozone, NO<sub>2</sub>, HCHO
- Aerosol optical depth, properties

**Aircraft, Sondes, Surface sites:**

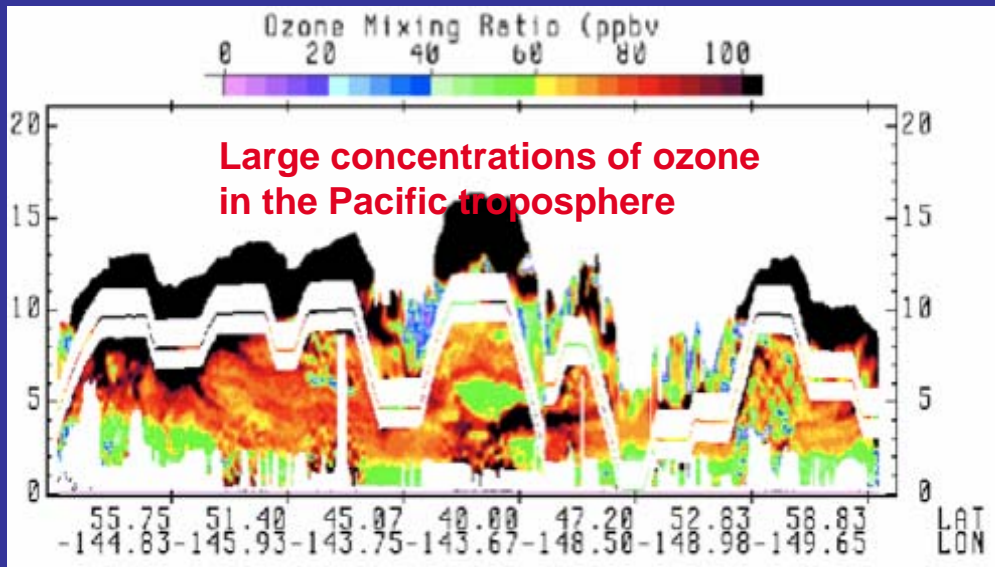
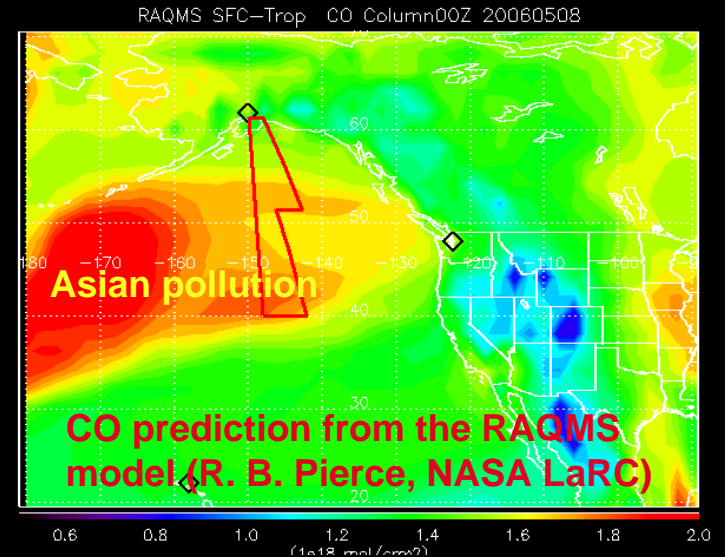
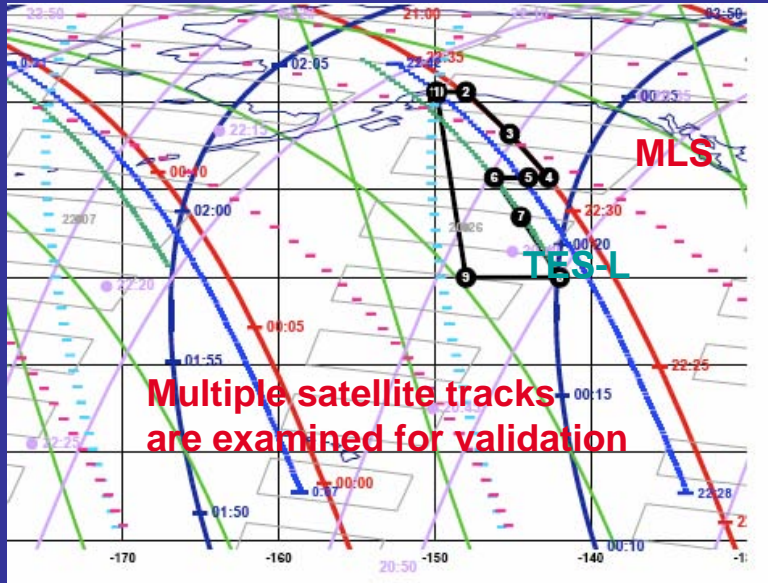
- Detailed in situ chemical and aerosol measurements
- Remote sensing of ozone, aerosol, surface properties

**Models:** CTMs, GCMs, ESMs

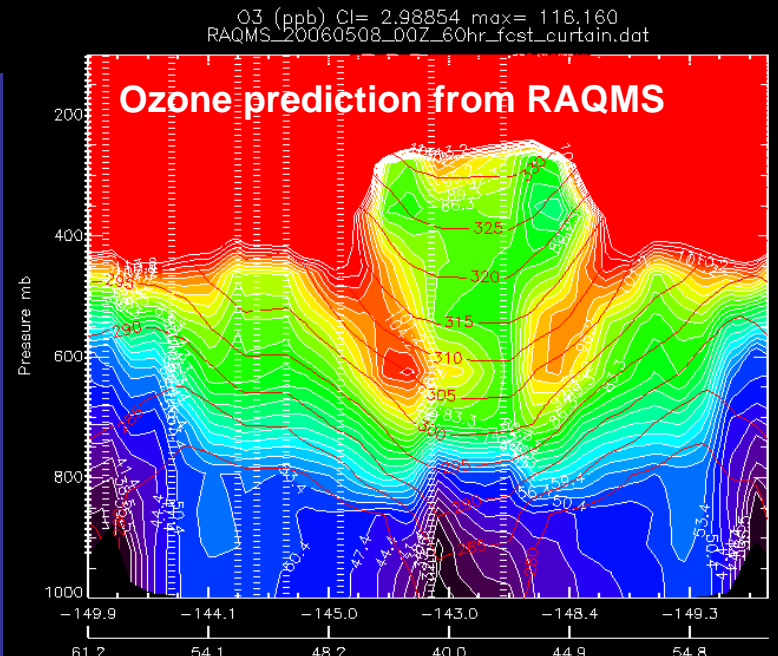
- Source-receptor relationships
- Chemical budgets
- Emissions verification
- Inverse modeling
- Data assimilation



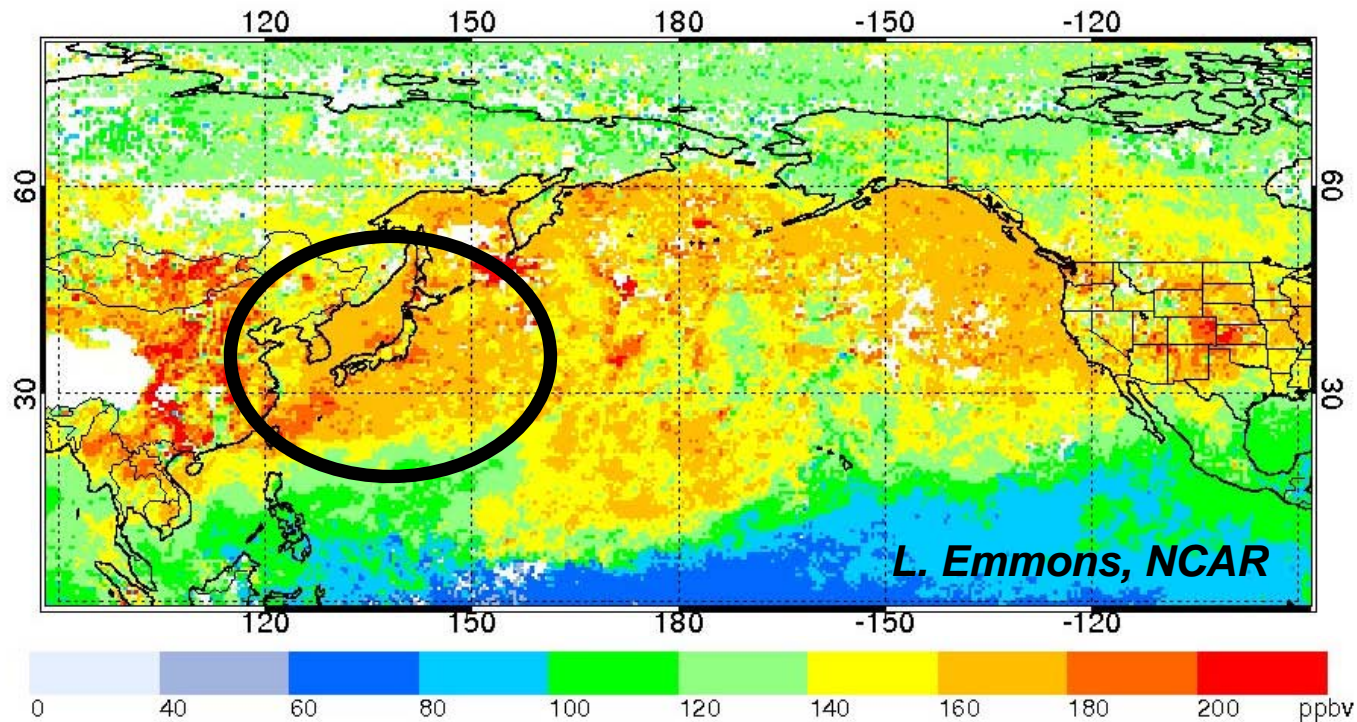
# INTEX-B Flights Provide Science-Focused Validation Opportunities: DC-8 Flight 16 from Anchorage



DIAL O3 (E. Browell, NASA LaRC)



## MOPITT CO 700 hPa – 1-31 March, 2006

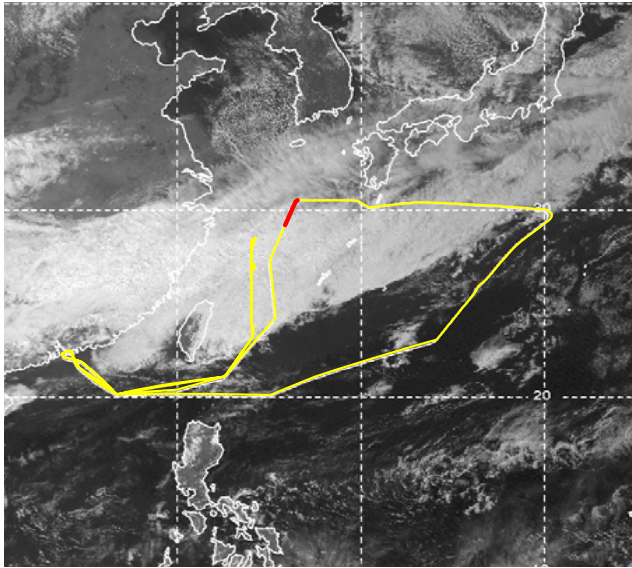


**The majority of field studies have focused on near-field observations which have demonstrated the seasonal and episodic nature of Asian outflow.**

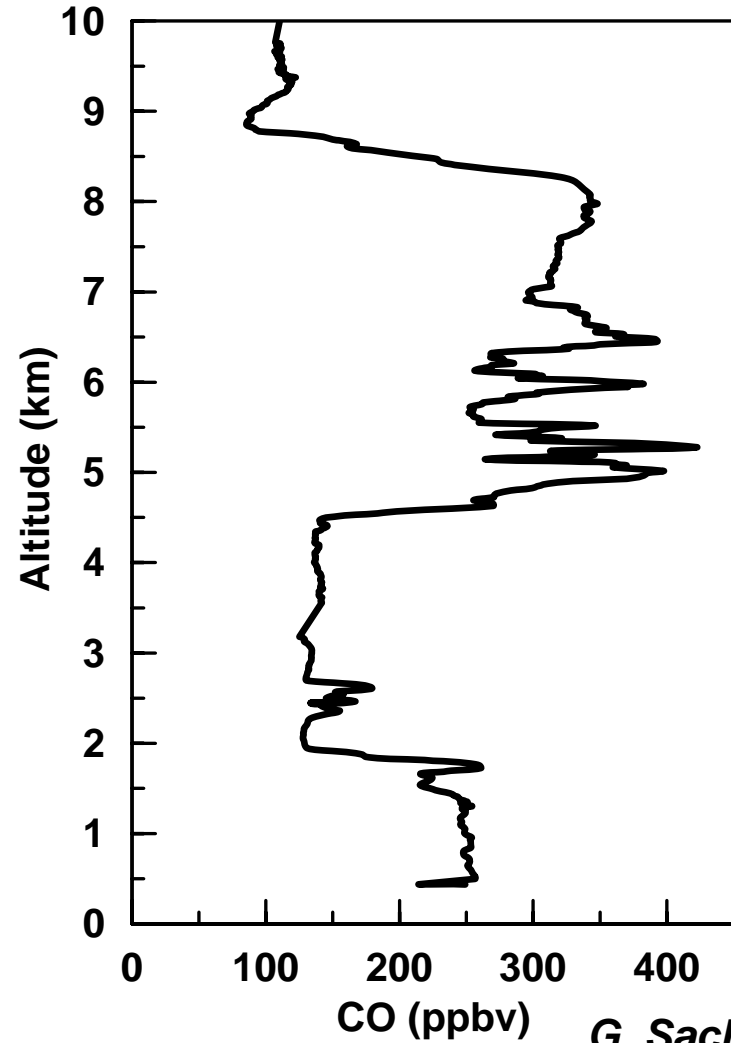
**These observations have been used to – characterize the chemical composition of outflow, quantify outflow using models, reconcile CO emissions through inverse modeling, and examine chemical evolution and the intermingling of sources (e.g., anthropogenic pollution, biomass burning, and dust).**

# *Example of Frontal Outflow of Asian pollution during TRACE-P*

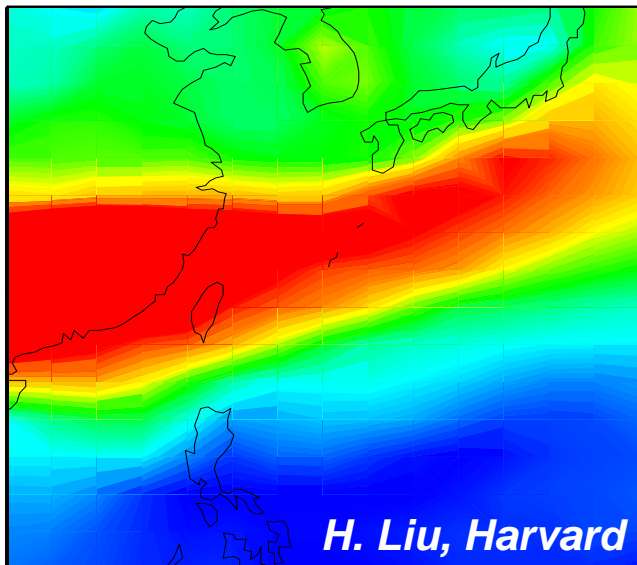
**DC-8 Flight 7 March 2001**



**DC-8 CO Profile in Frontal Cloud**

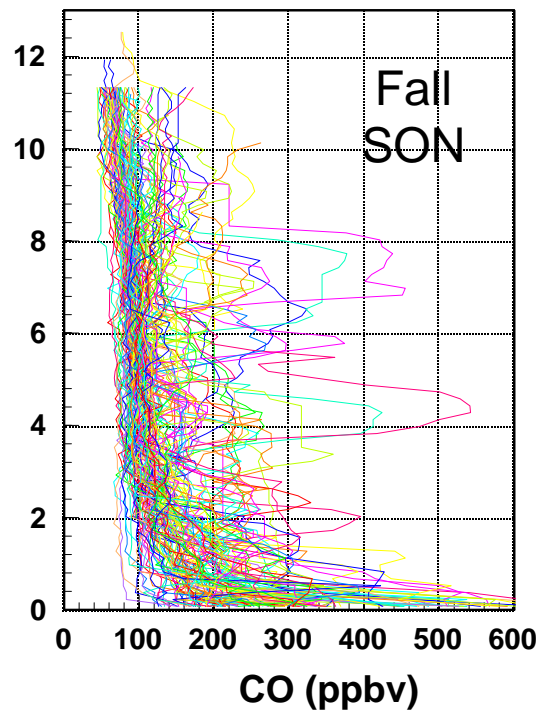
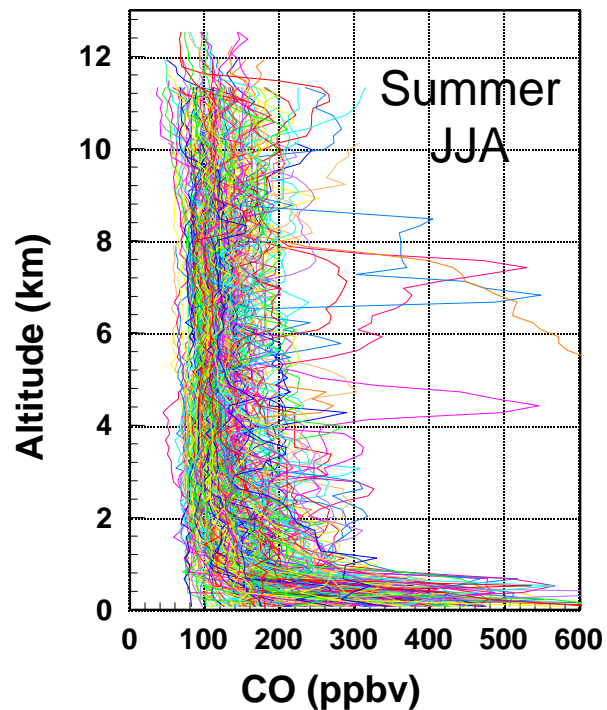
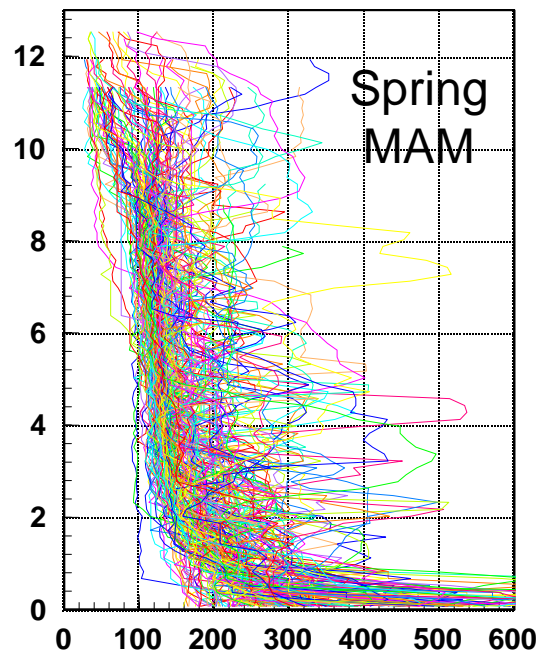
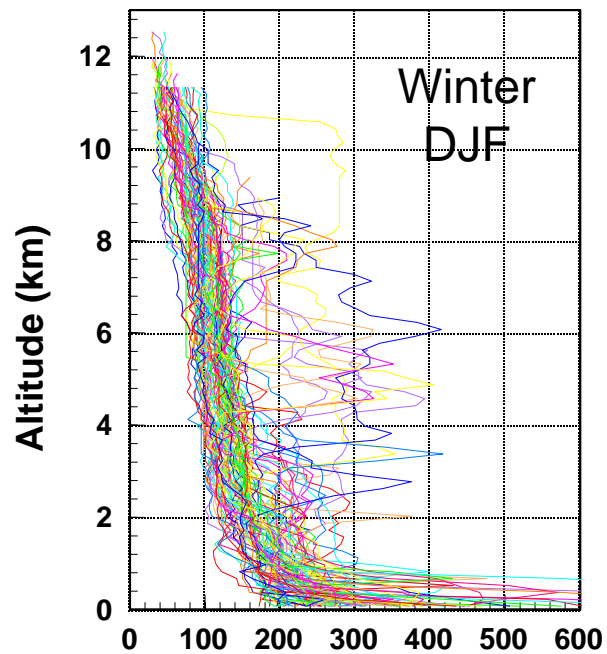


**GEOS-Chem CO Column**



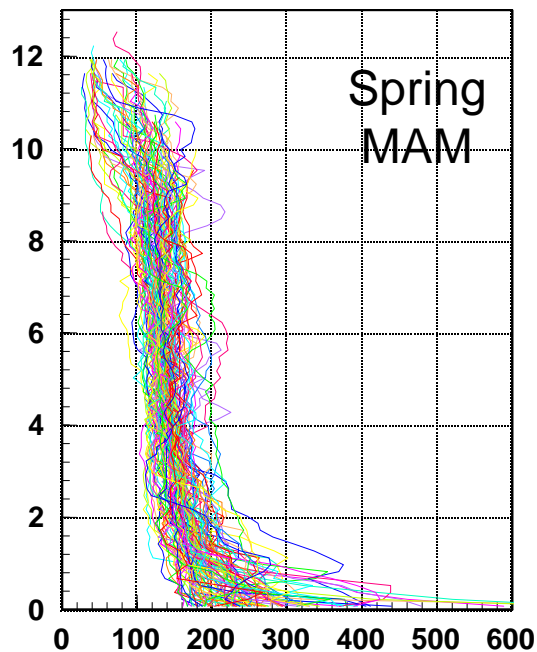
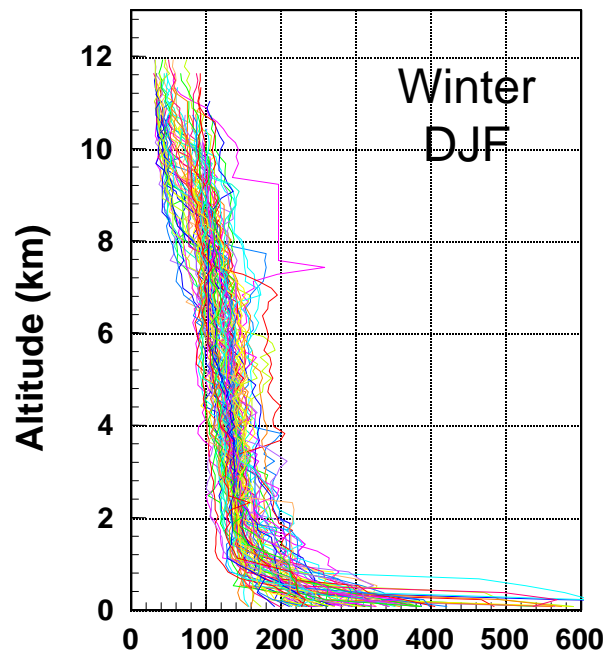
*H. Liu, Harvard*

*G. Sachse, NASA*



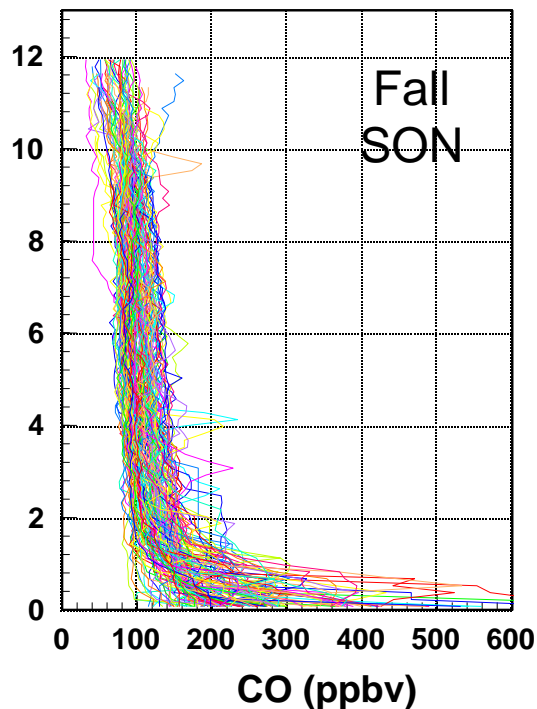
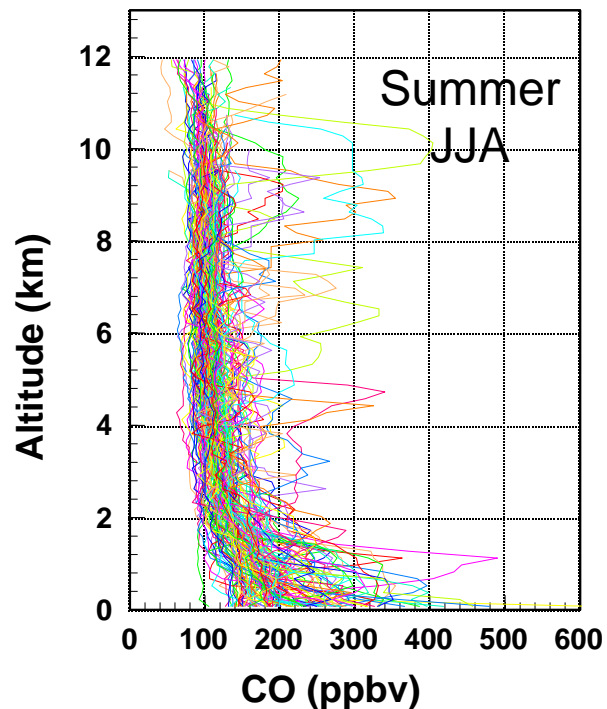
## Seasonal MOZAIC profiles of Carbon Monoxide: Tokyo-Osaka-Nagoya

**These Asian Pacific Rim sites exhibit high variability in all seasons with greatest variability in spring. This is consistent with large-scale outflow in springtime associated with cold fronts lifting and transporting pollution from Asia to the North Pacific. Clouds associated with this frontal lifting present a complication for satellite observations.**



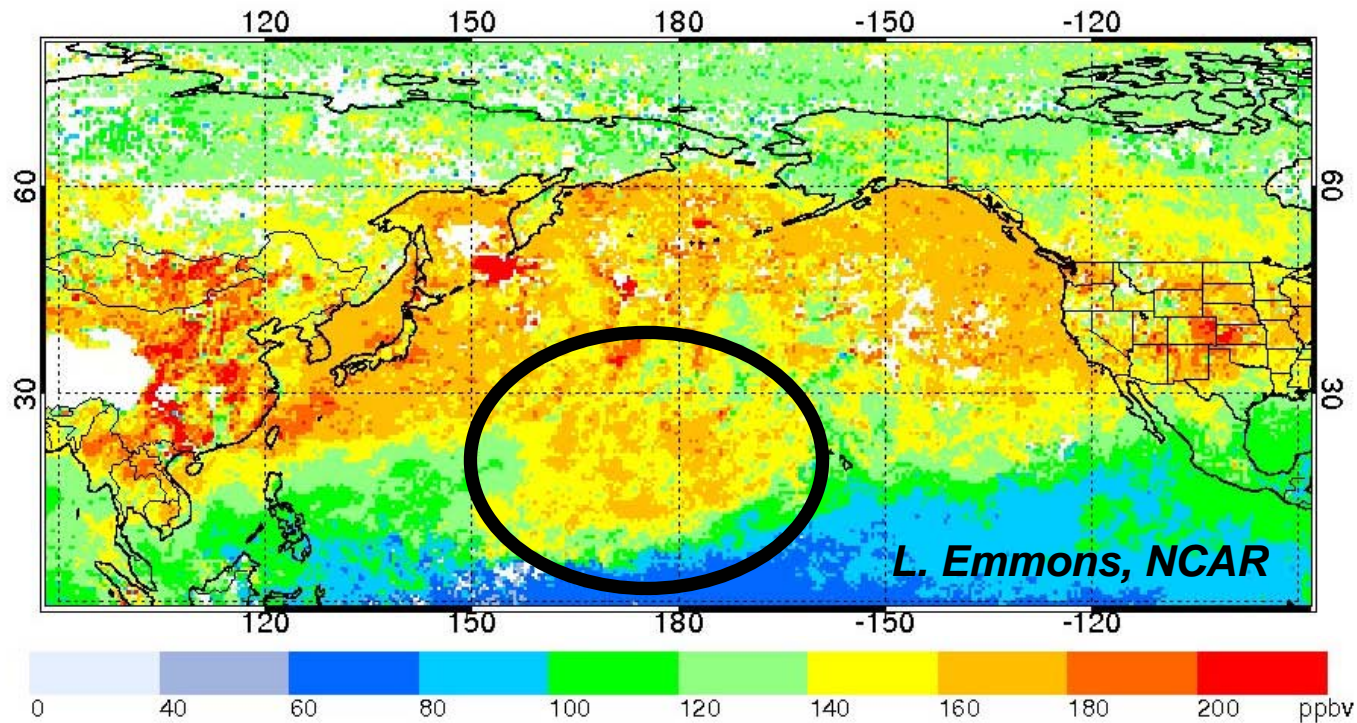
## Seasonal MOZAIC profiles of Carbon Monoxide: New York-Philadelphia-Washington DC

CO variability in the free troposphere for these North American sites is minimal in all seasons except summer.



Summertime perturbations are consistent with the influence of deep convection and forest fires during this time of year.

# MOPITT CO 700 hPa – 1-31 March, 2006

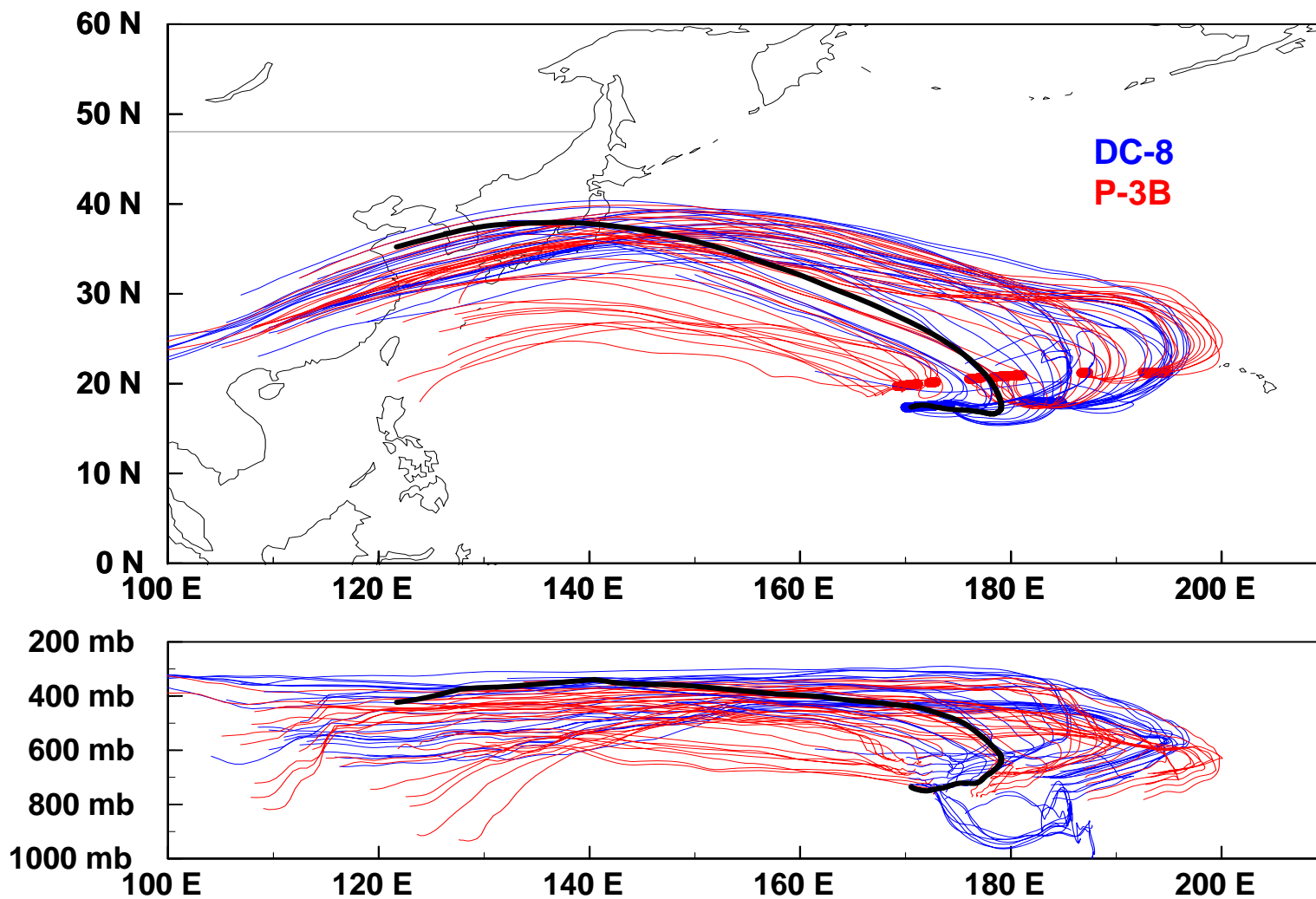


**A significant fraction of Asian outflow subsides over the central Pacific. These air masses may undergo minimal dilution and can sustain strong ozone production as NO<sub>x</sub> is replenished through PAN degradation.**

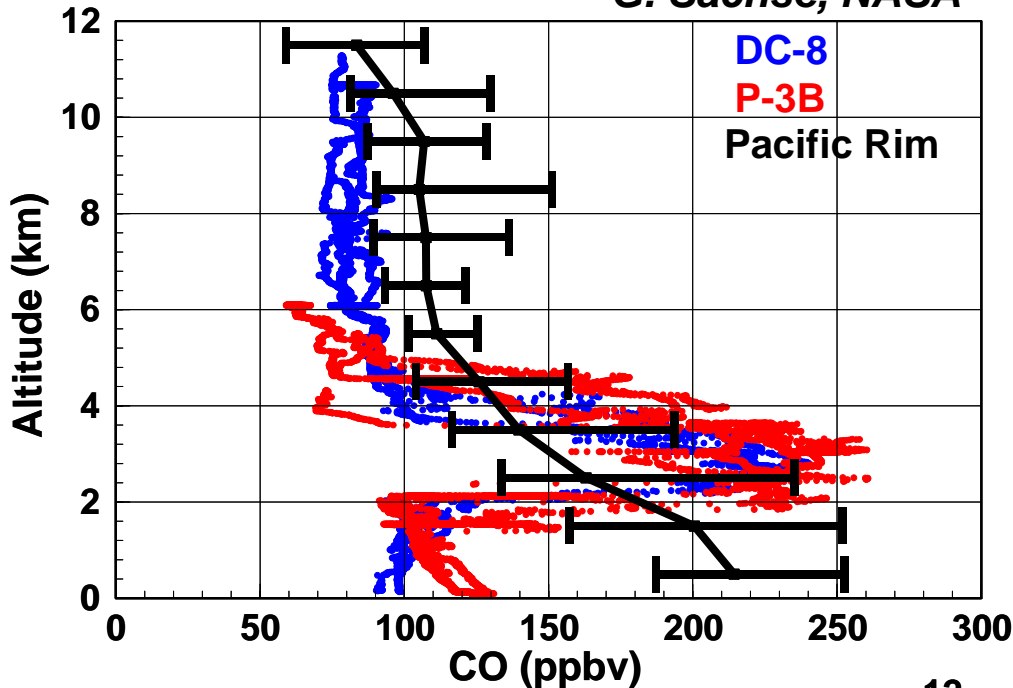
**These conditions have been observed during transit flights across the Pacific.**

**A widespread pollution layer of Asian origin was observed by the NASA DC-8 and P-3B aircraft extending from Hawaii to Wake Island**

**Trajectories show outflow at high altitude followed by subsidence**



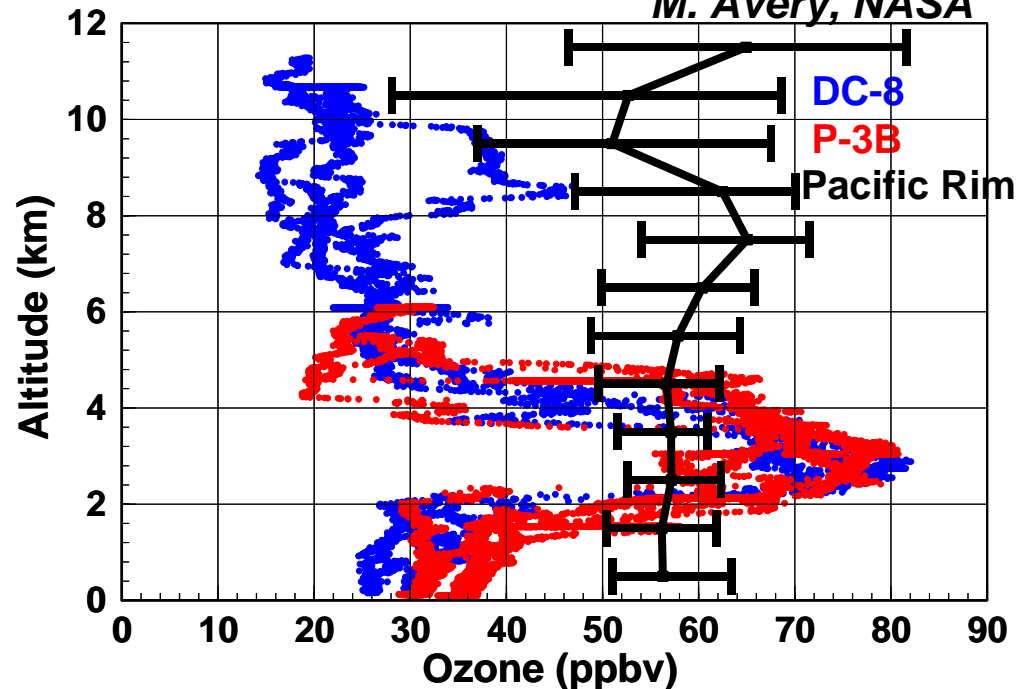
G. Sachse, NASA



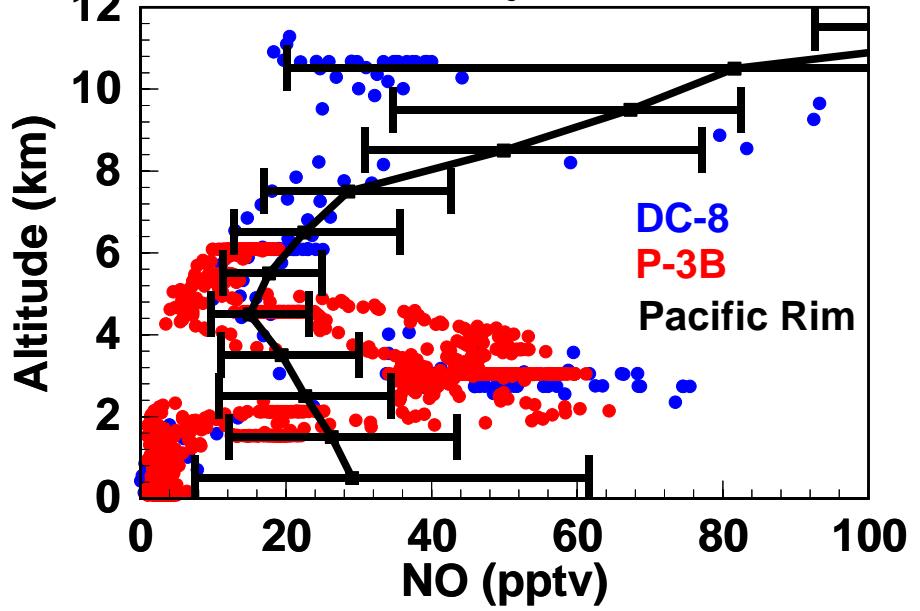
Carbon Monoxide values in the pollution layer equal upper quartile values observed along the Asian Pacific Rim

Ozone values in the pollution layer exceed upper quartile values observed along the Asian Pacific Rim, demonstrating substantial chemical production during transport.

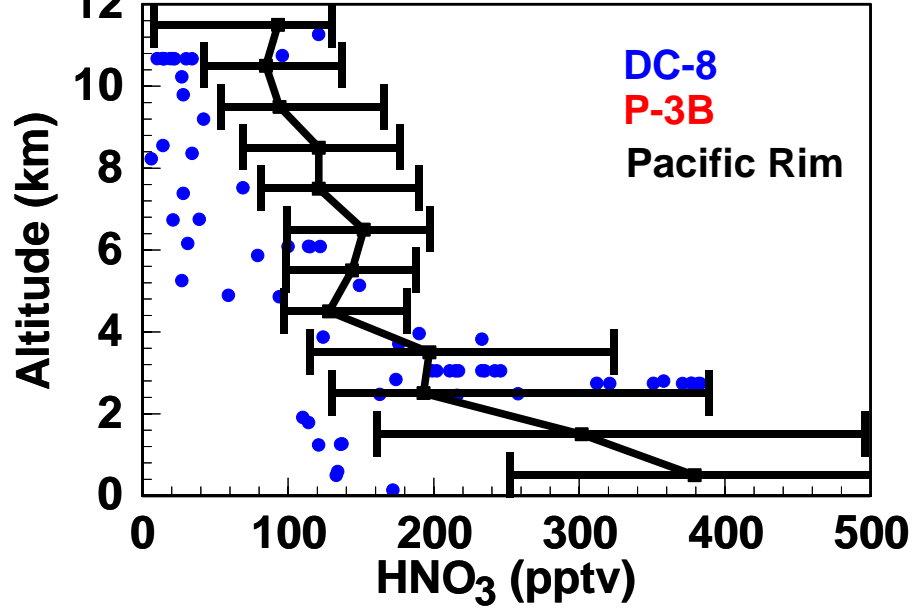
M. Avery, NASA



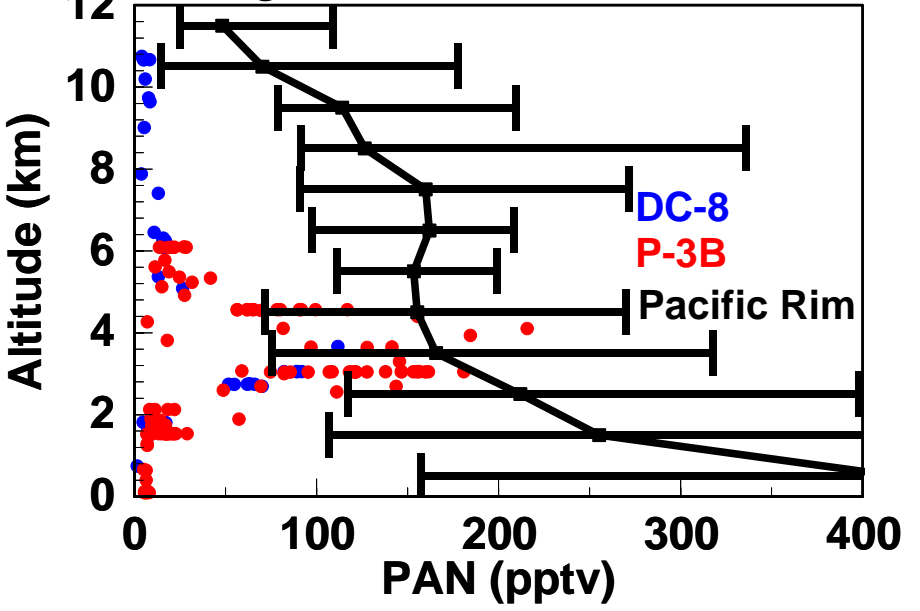
*Y. Kondo, U. Tokyo and D. Tan, GIT*



*R. Talbot, UNH*

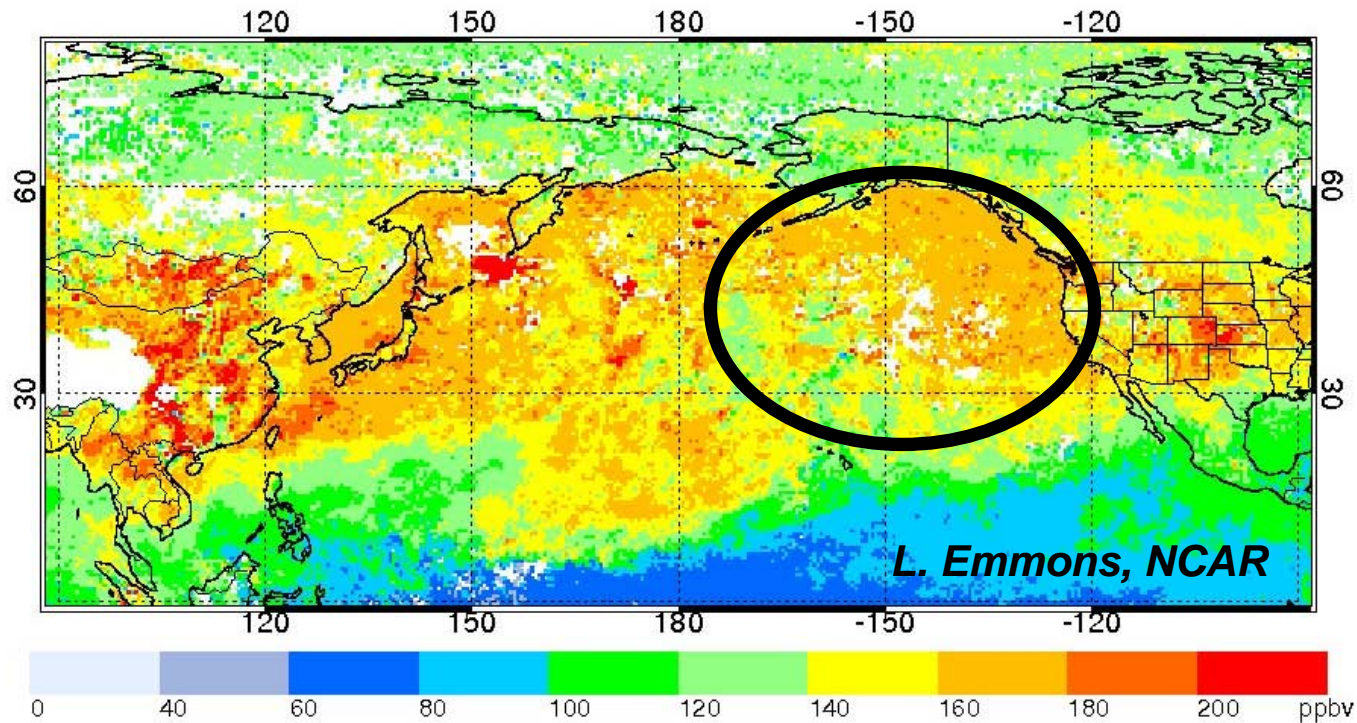


*H. Singh, NASA and F. Flocke, NCAR*



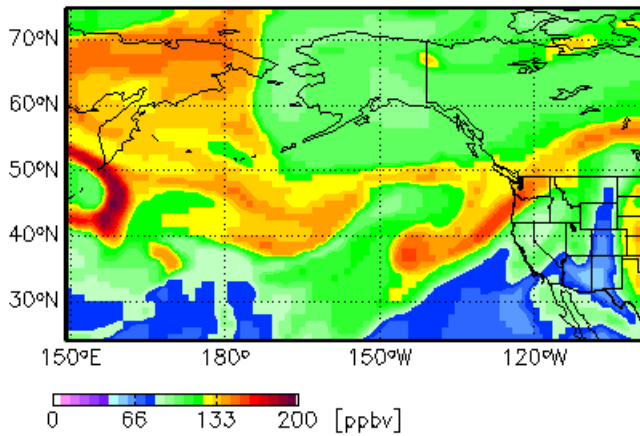
Reactive nitrogen measurements show PAN in the polluted layer is able to support NO levels well in excess of those observed along the Asian Pacific Rim

# MOPITT CO 700 hPa – 1-31 March, 2006

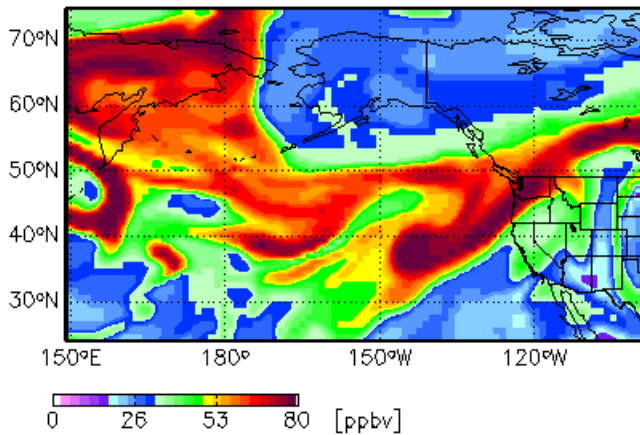


**Outflow crossing the Pacific at altitude can remain highly concentrated due to rapid transport and extended lifetimes for short-lived species. The dominance of PAN in the reactive nitrogen budget allows for the release of NO<sub>x</sub> and substantial ozone production far downwind.**

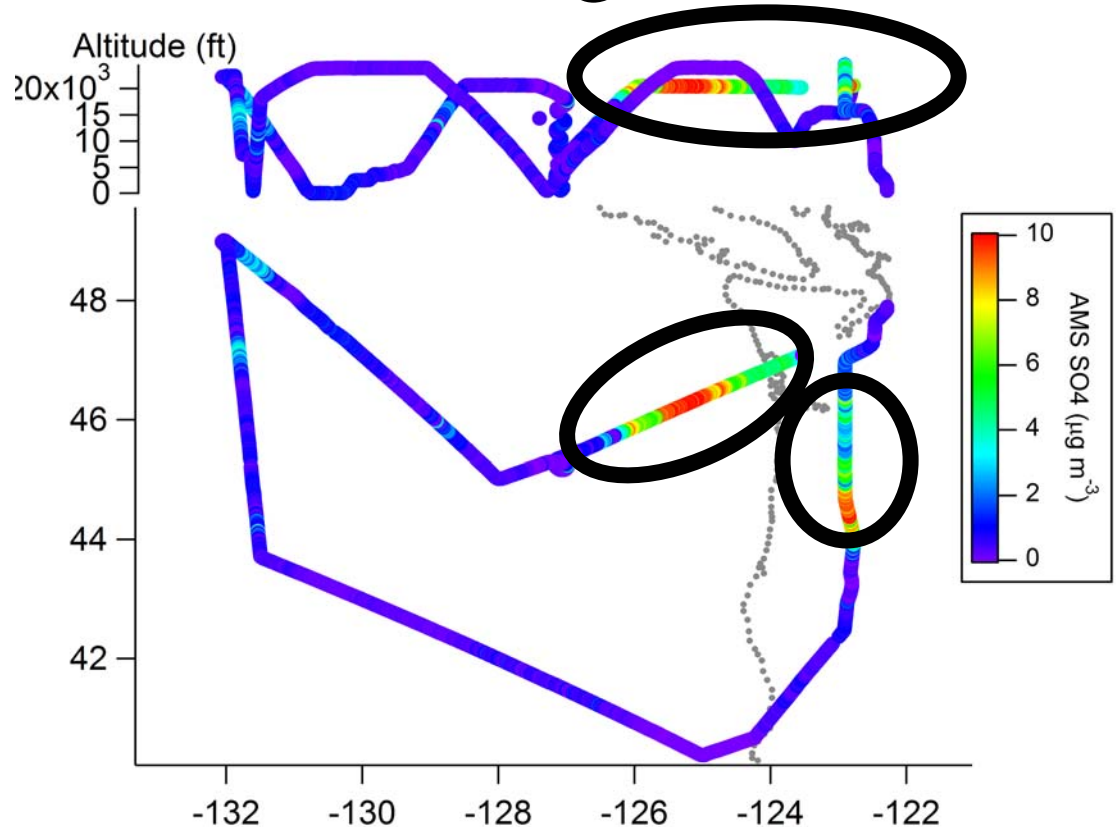
CO 20060501 18 GMT at 600 hPa (4.2 km)



Asian CO 20060501 18 GMT at 600 hPa (4.2 km)



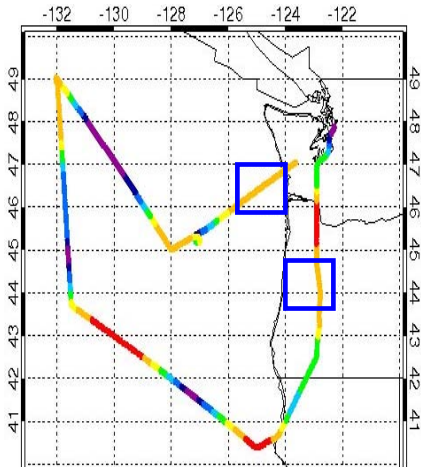
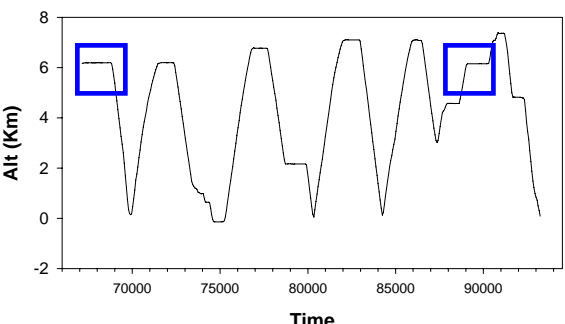
# 5/1/2006 Flight (RF 06)



*J. Jimenez, CU-Boulder*

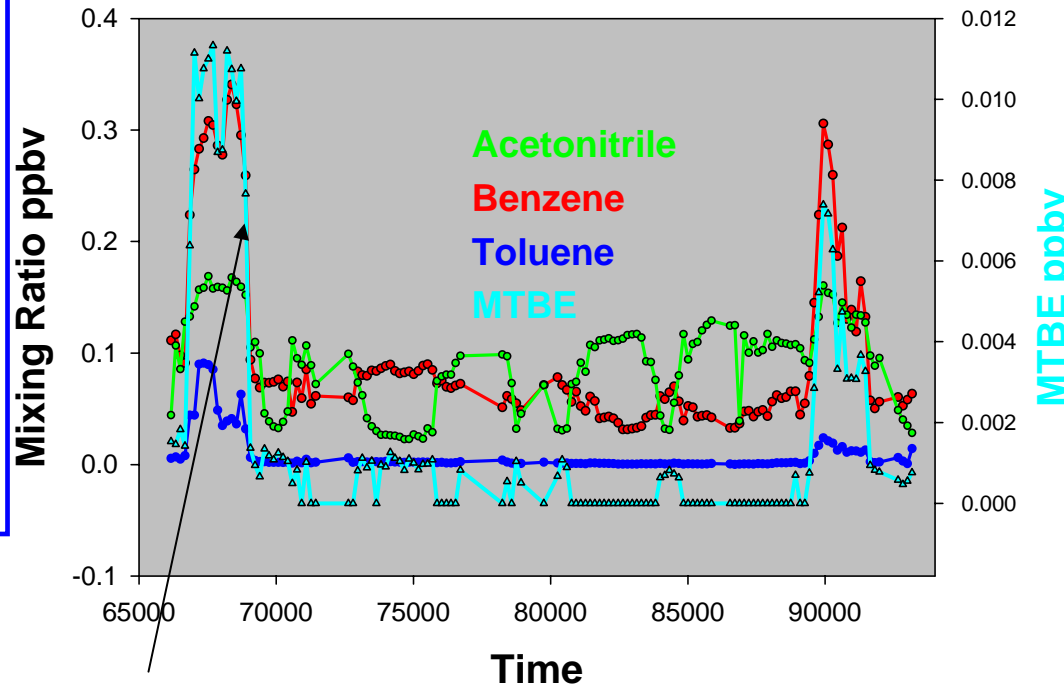
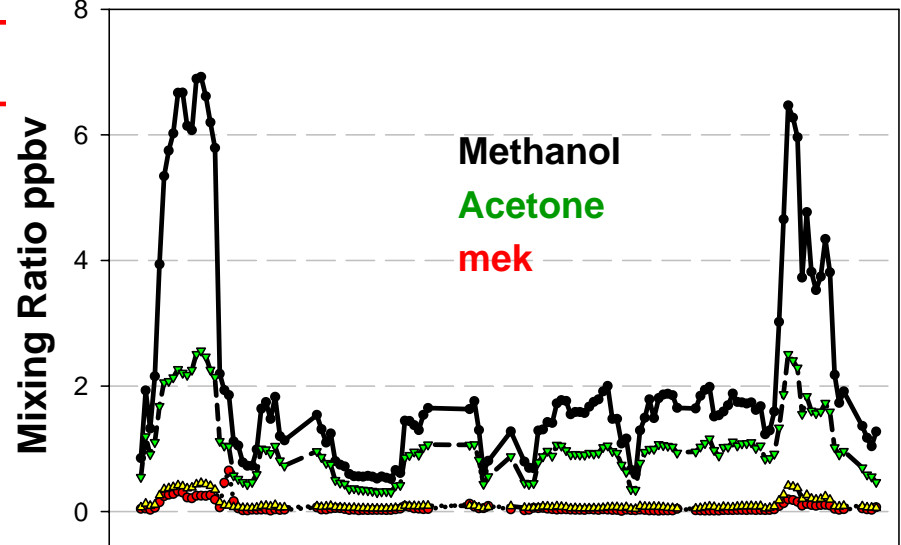
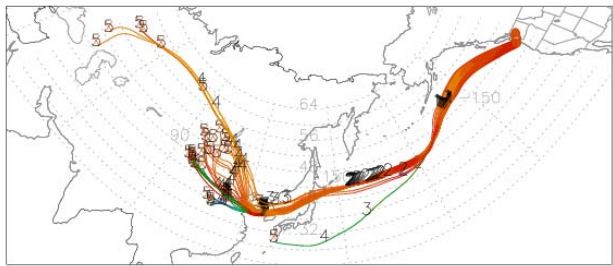
- Pre-flight modeling showed Asian influenced air mass off coast of Northwest U.S.
  - Flight plan chosen to intercept it
- Pollution seen in layer at 20,000 ft early and late in flight

# May 1 Plume: Rapid transport from Asia



**PAN/PPN ~ 8 (1)  
8.9 (2)  
High methanol,  
Benzene  
Benz/tol = ~ 6 (1),  
13 (2)  
 $\Delta\text{CH}_3\text{CN}/\Delta\text{MeOH}$   
= 40 (1), 30 (2)  
Anthropogenic  
w/possible BB**

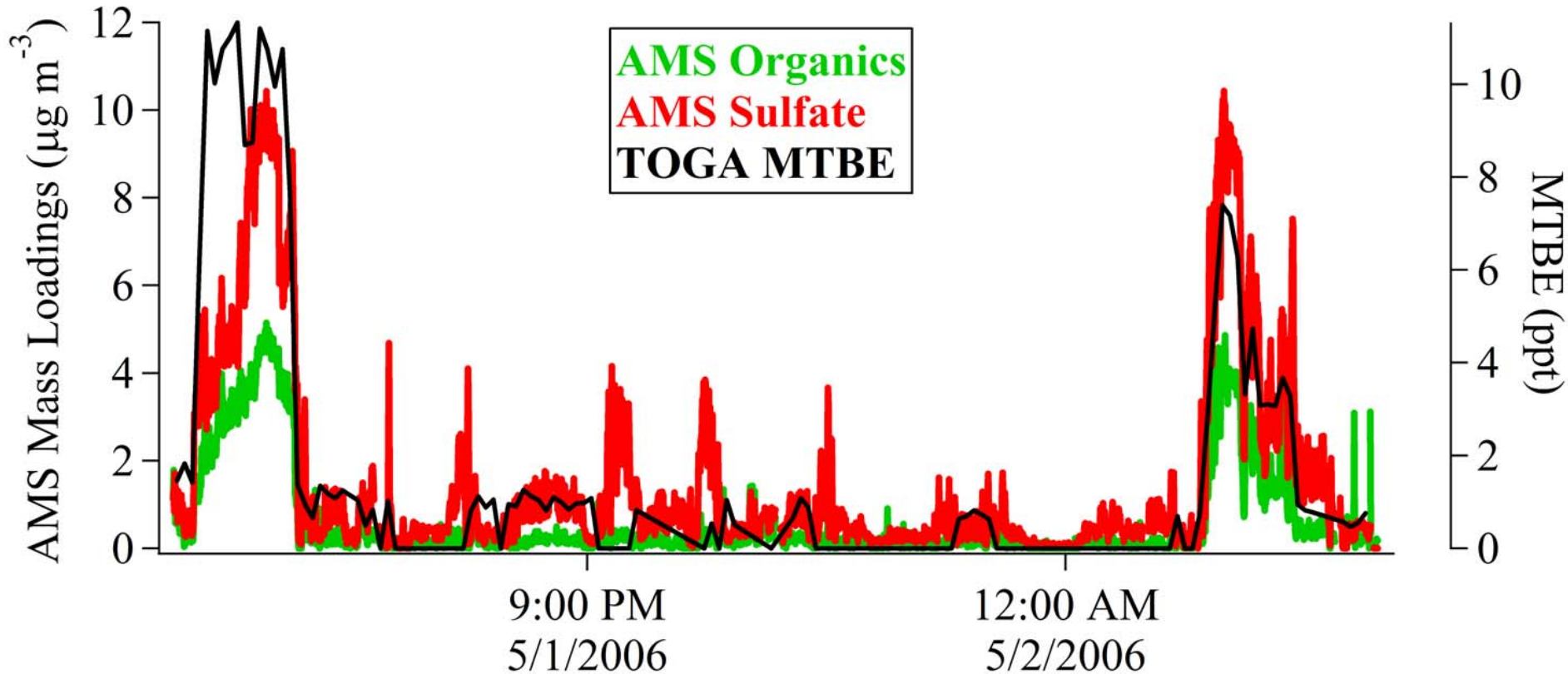
**Plume 1 Trajectory**



**Clear mtbe signature bt also  $\text{CH}_3\text{CN}$**

# 5/1/2006 Flight

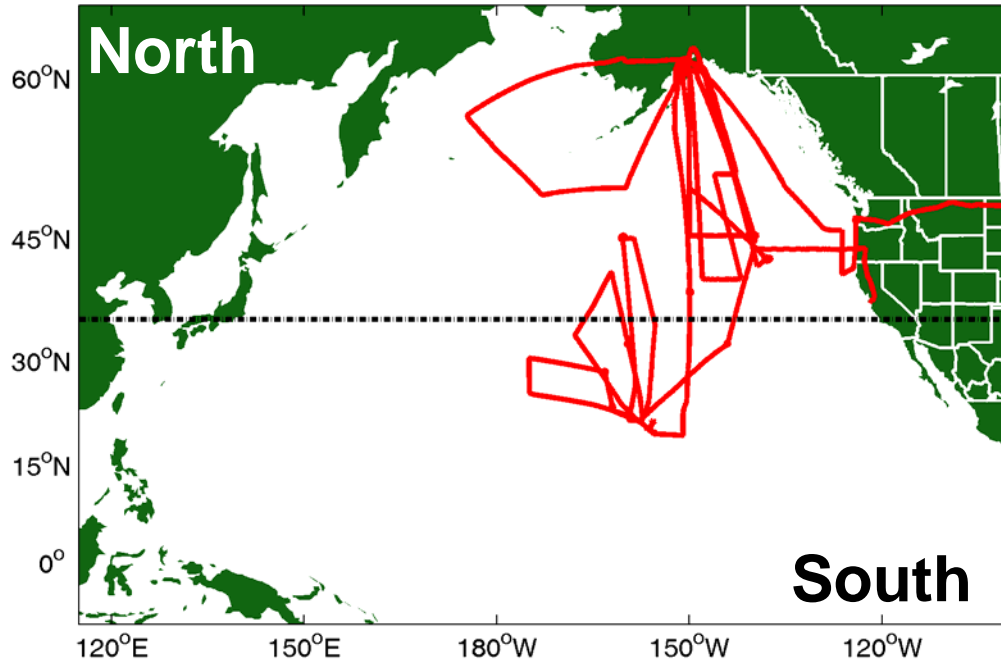
AMS observes high  $\text{SO}_4$  loading with some Organics



E.Apel et al. (TOGA)  $\rightarrow$  MTBE as tracer for Asian pollution  
MTBE used in gasoline in Asia, no longer in U.S. gas  
This appears to be best Asian transport event

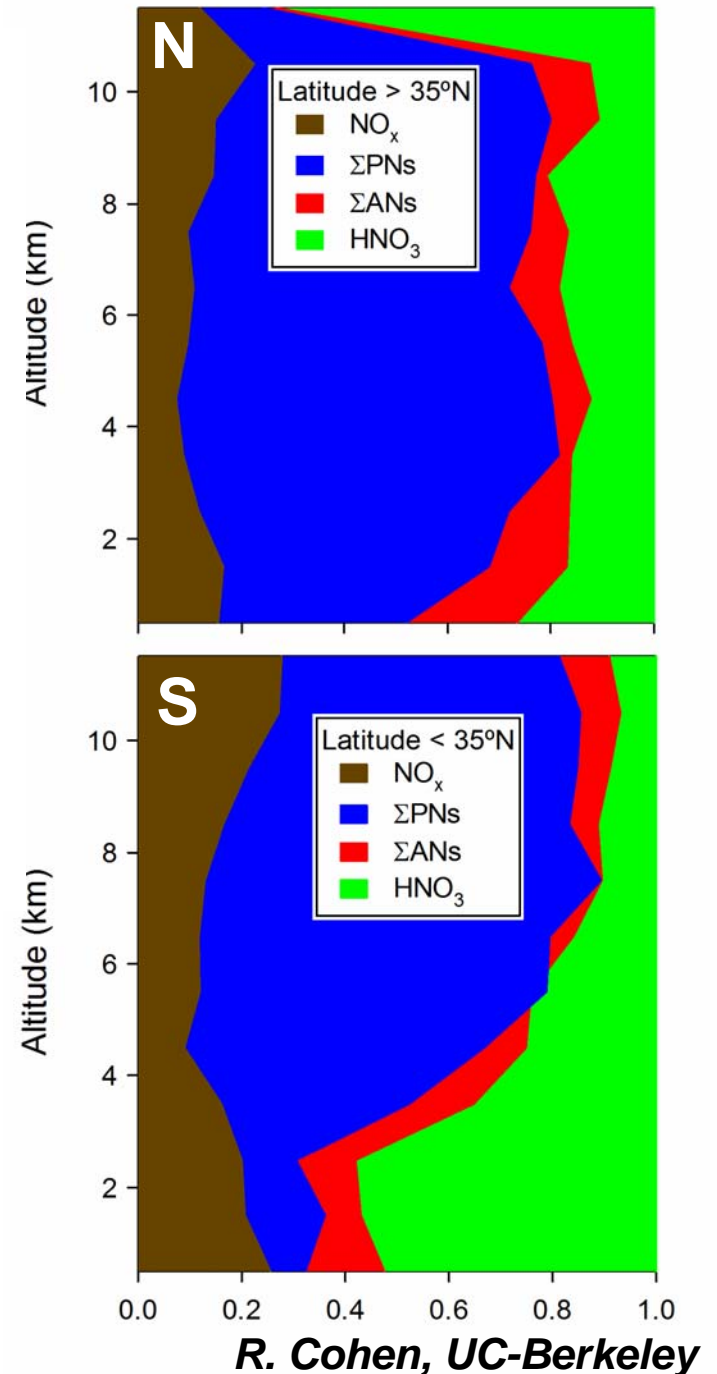
# NO<sub>y</sub> Partitioning: Remote Pacific

Flight Tracks During INTEX-B



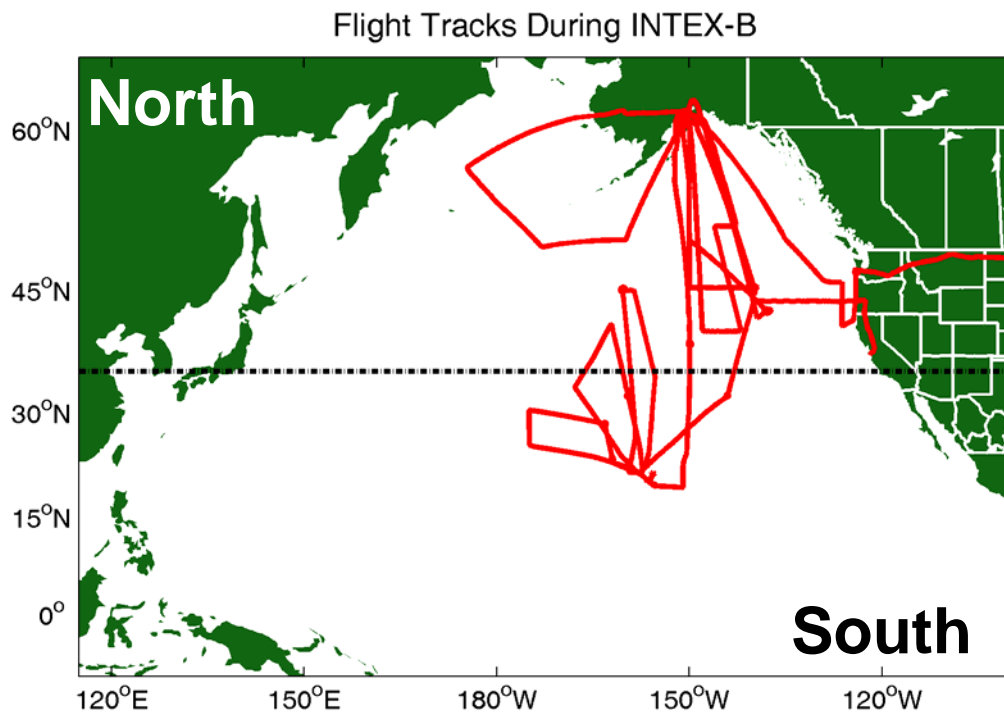
**PANs comprise the dominant fraction of reactive nitrogen in the free troposphere over the eastern Pacific.**

**Observations from earlier campaigns suggest that these PANs are largely formed during the initial lifting of pollution outflow along the Asian coast.**

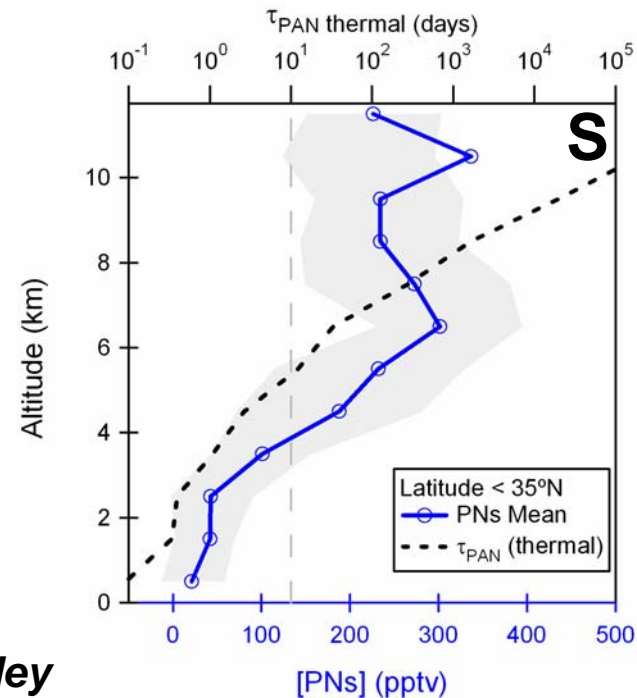
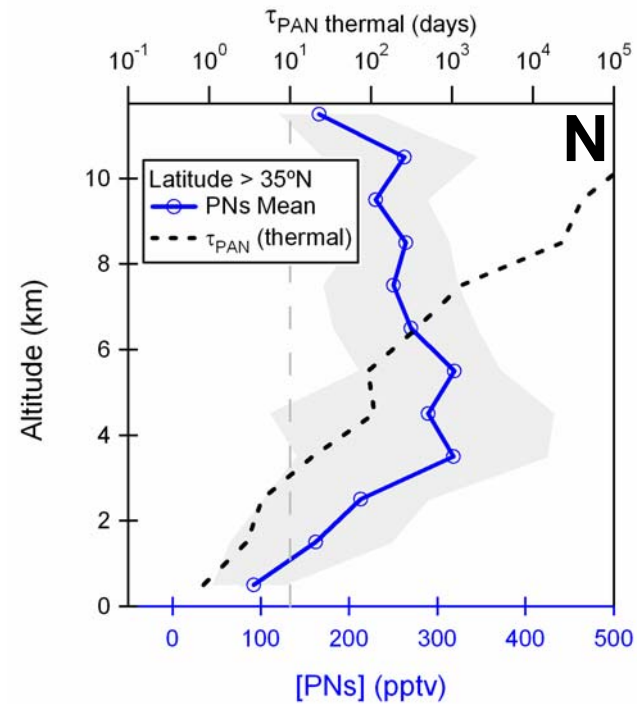


*R. Cohen, UC-Berkeley*

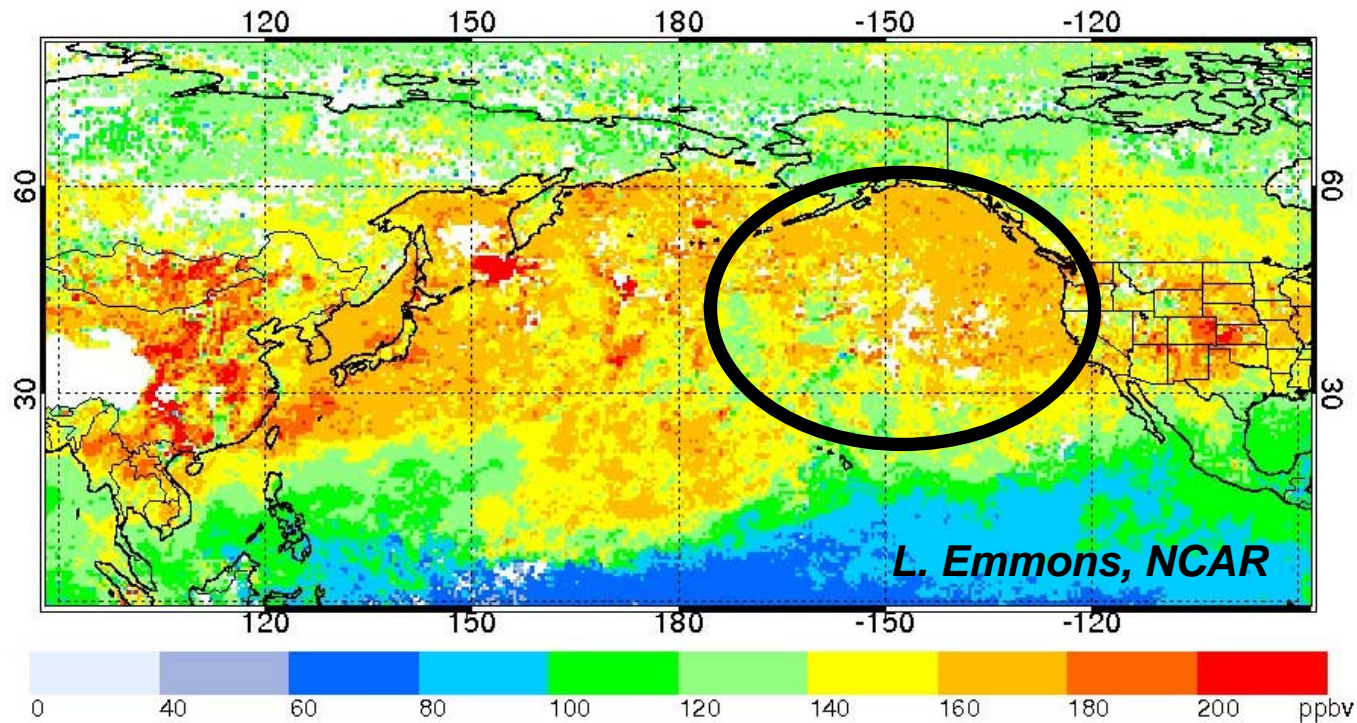
# PAN Thermal Dissociation: Remote Pacific



**PAN abundances are enough to provide several hundred pptv of NO<sub>x</sub> in subsiding conditions.**



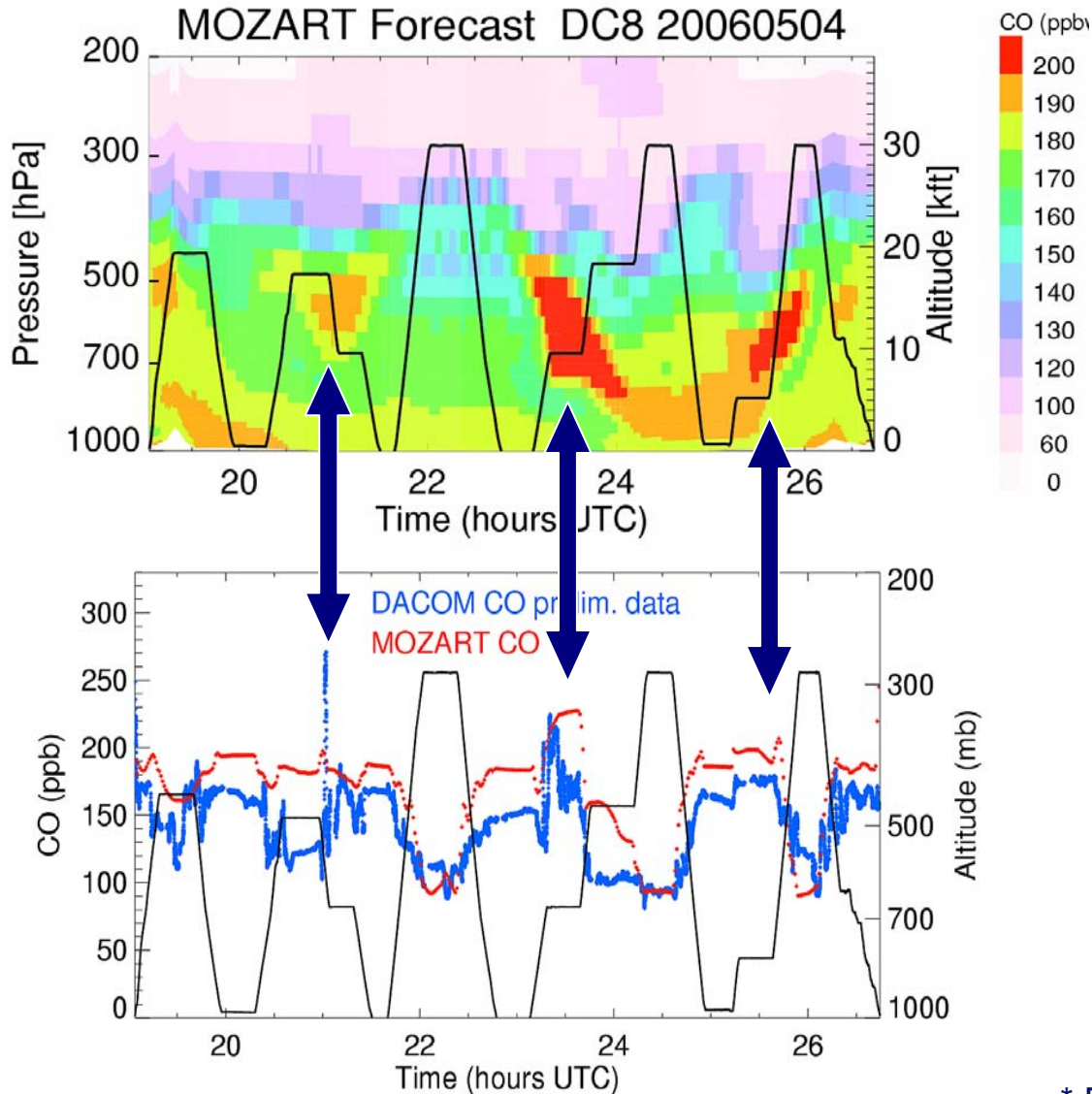
# MOPITT CO 700 hPa – 1-31 March, 2006



**Outflow crossing the Pacific across a broad range of altitudes provides the best situation for evaluating model transport and chemical evolution.**

**Such an event was observed by the DC-8 and C-130 on subsequent days during INTEX-B.**

# Forecast Evaluation - May 4 - DC8



MOZART Forecast CO  
along flight track  
(Fx initialized 0502 12UTC)

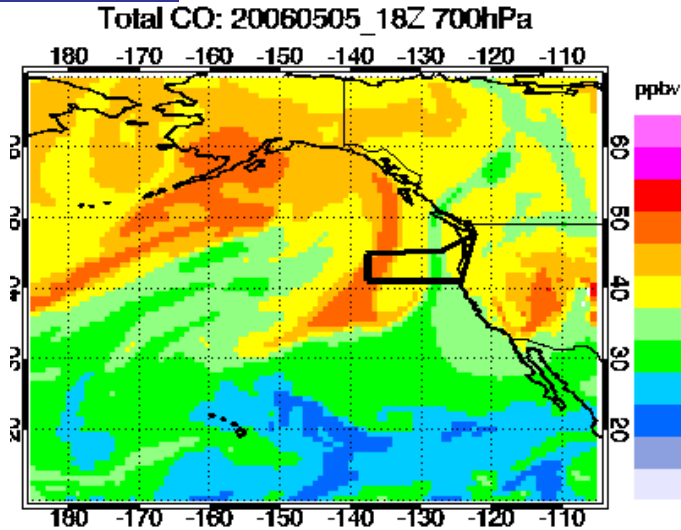
MOZART Forecast CO  
interpolated to flight track  
*compared to preliminary*  
data from DACOM\*

\* Data from Glen Sachse, NASA Langley

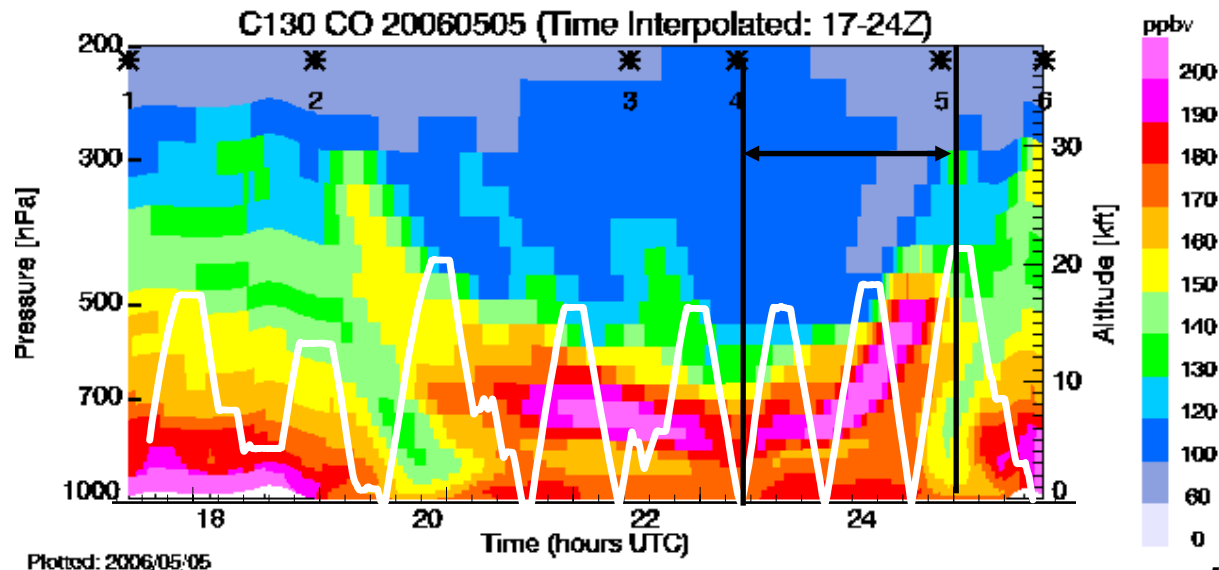
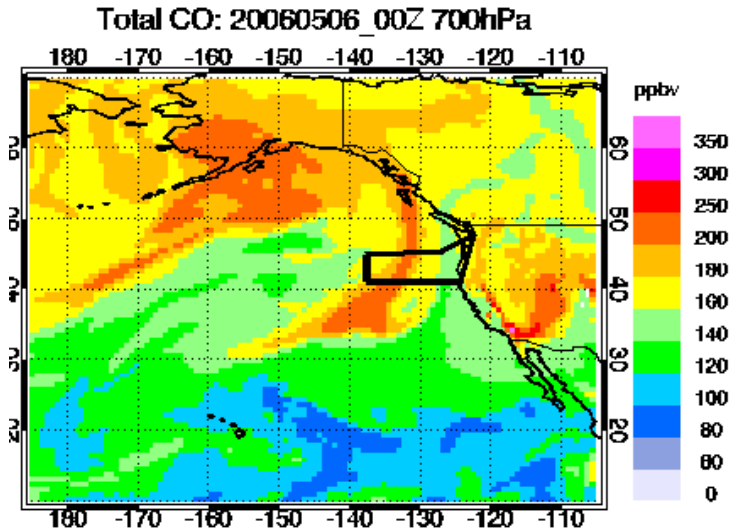


# 05/04 12Z Forecast: Valid for 05/05 18-24Z

18Z: 700 hPa



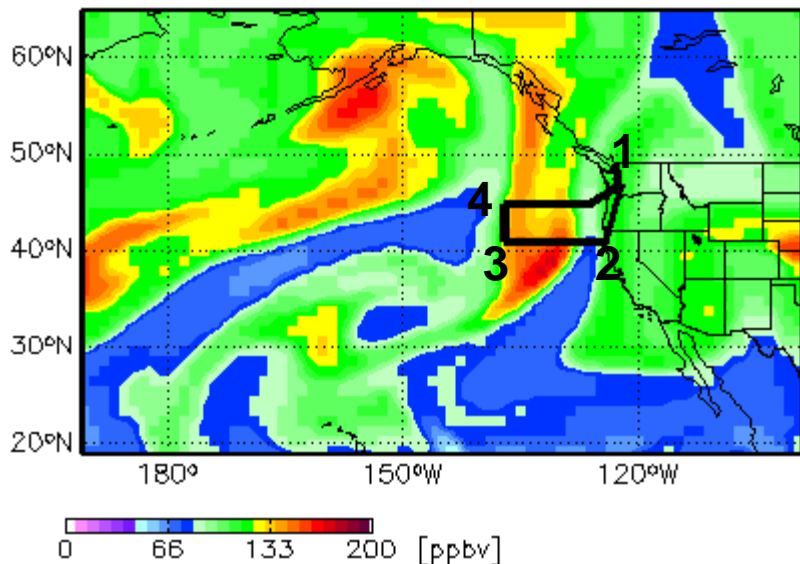
24Z: 700 hPa



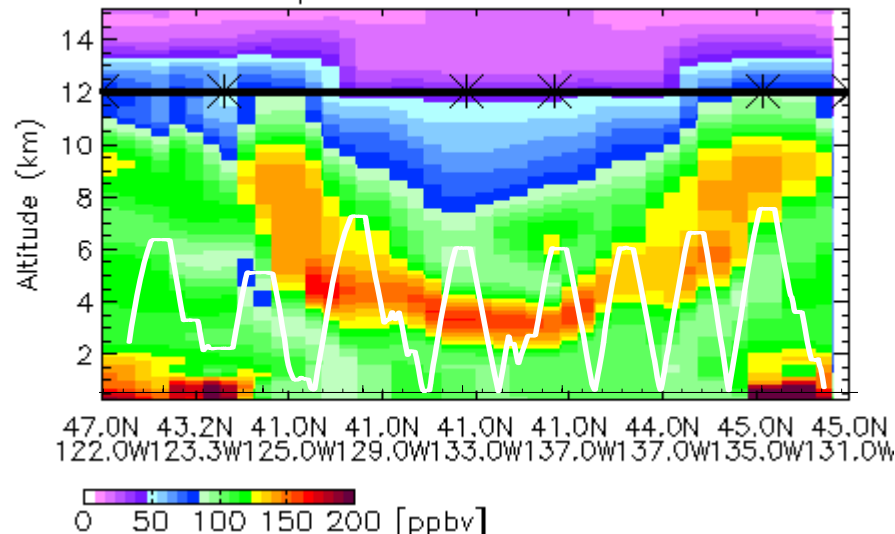
# 5/5 00Z forecast

# Friday, 5/5, 18Z

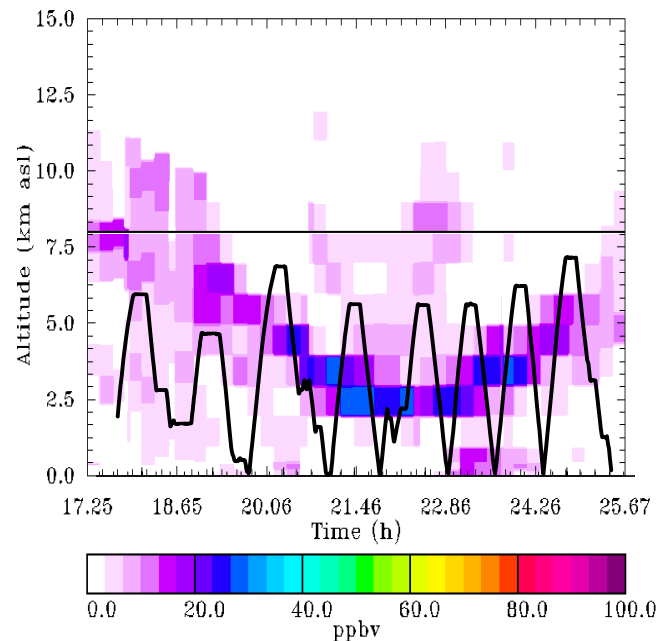
**CO** CO 20060505 18 GMT at 600 hPa (4.2 km)

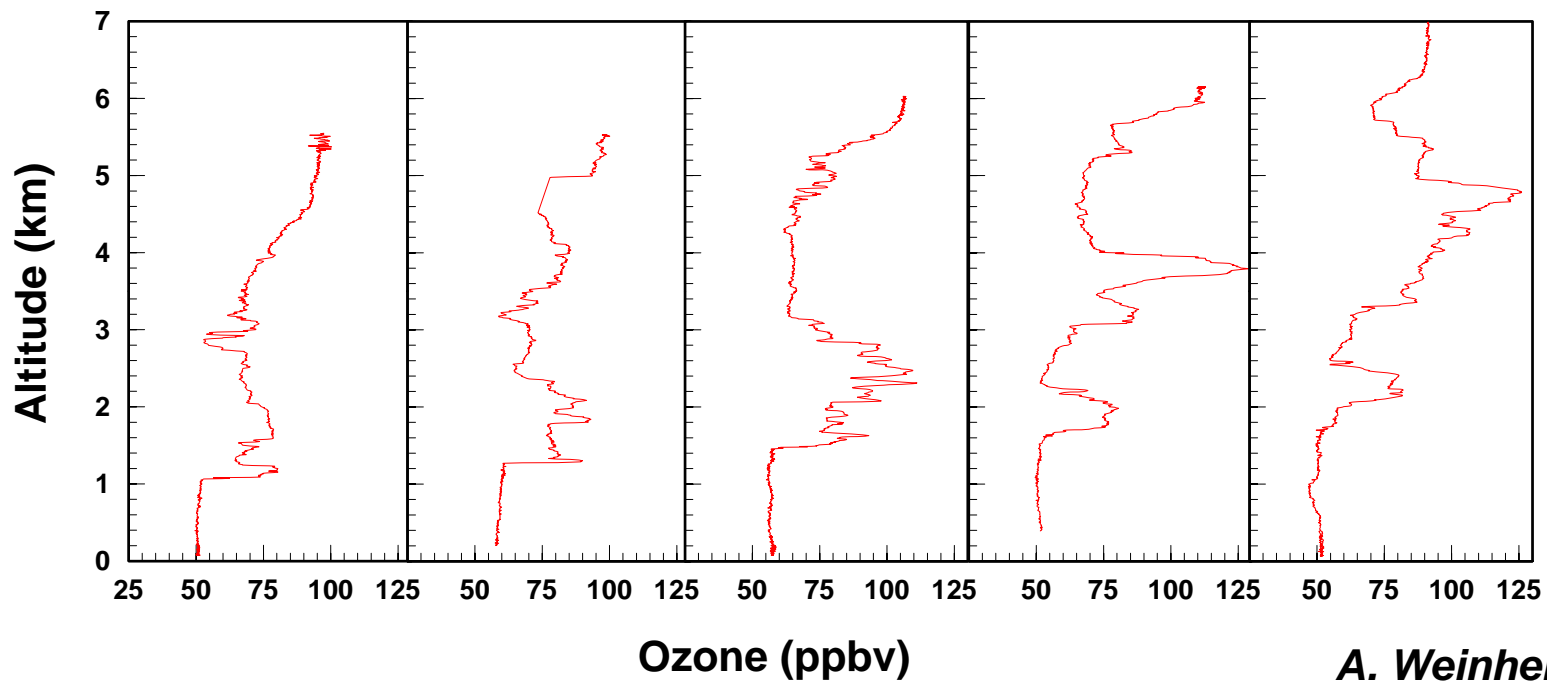
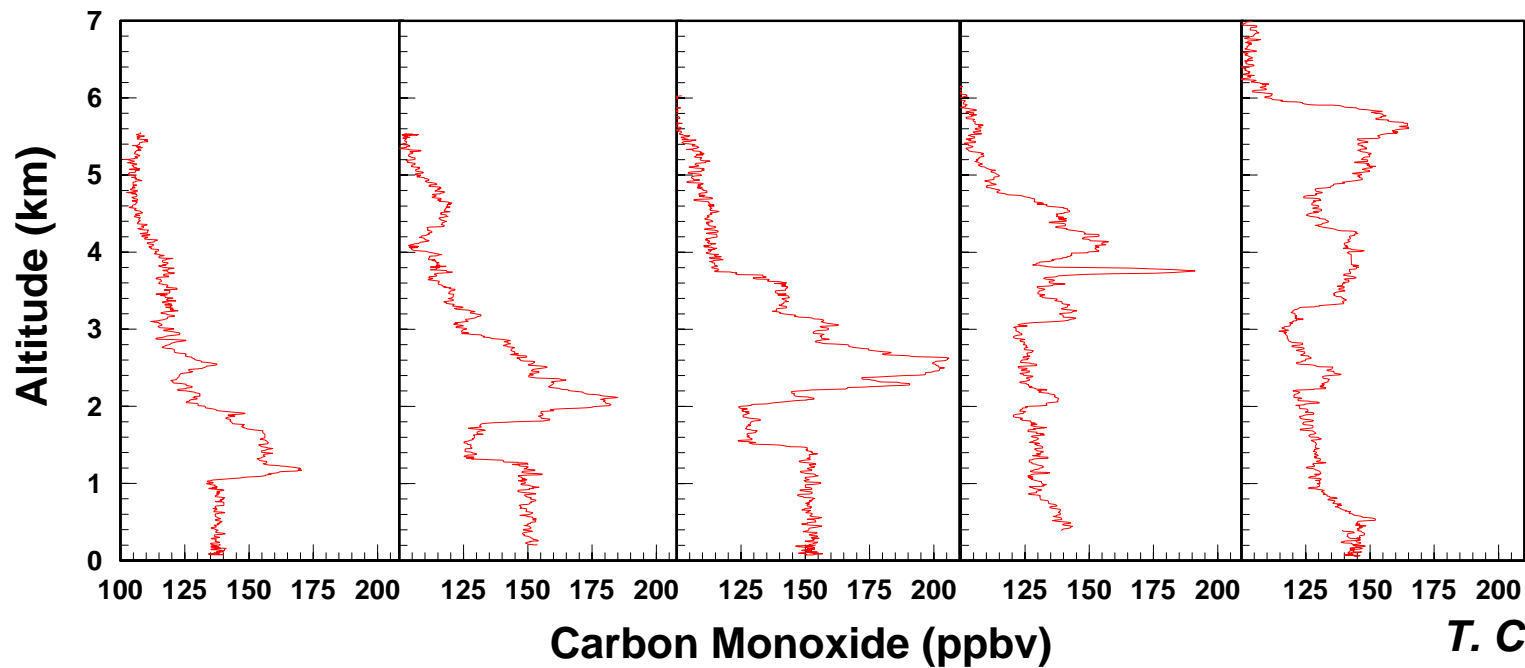


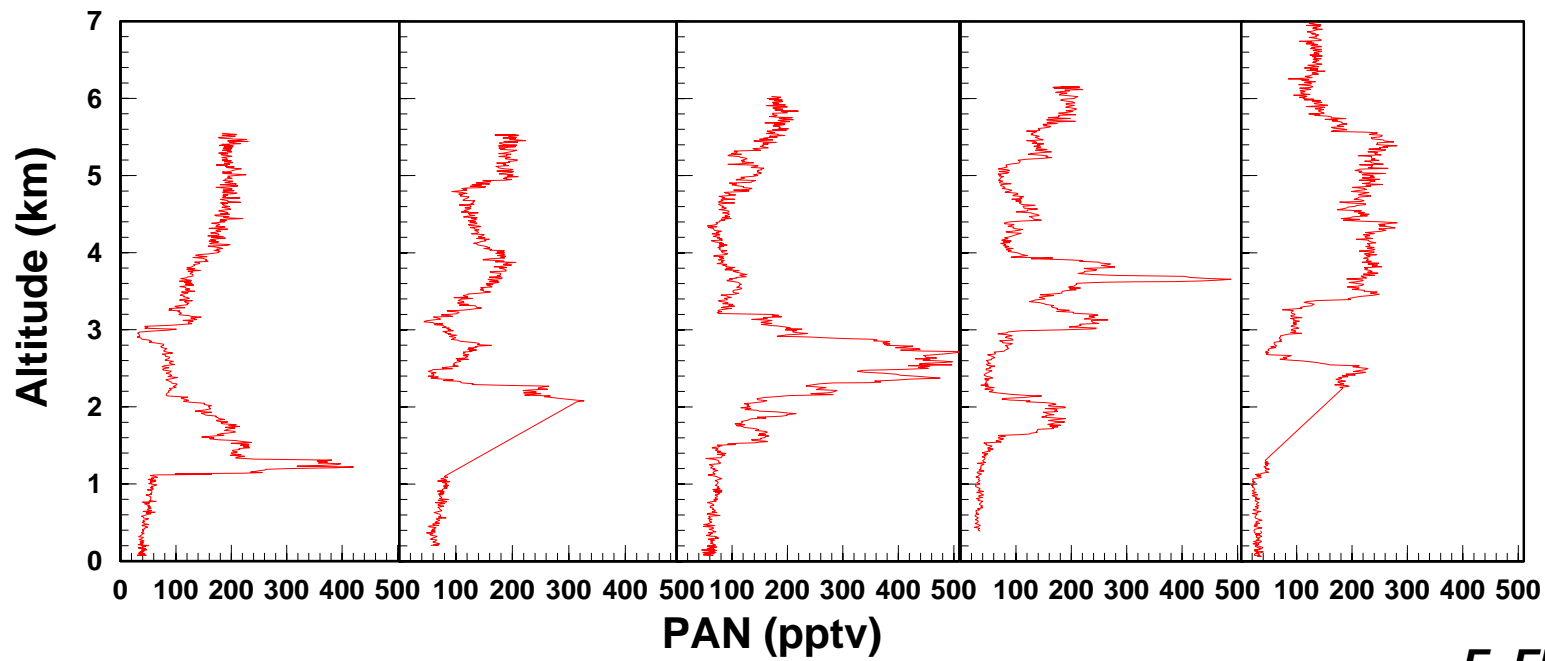
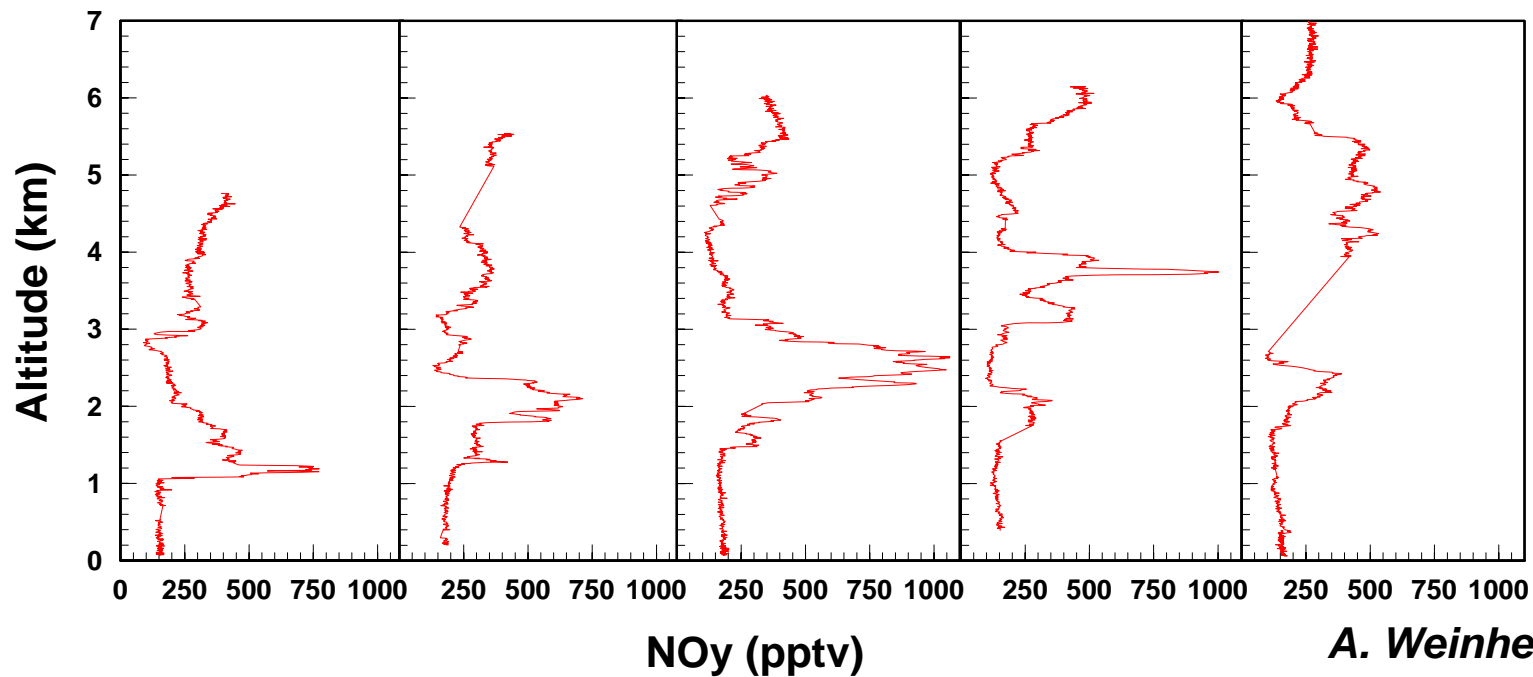
Curtain plot – CO 20060505 18 GMT

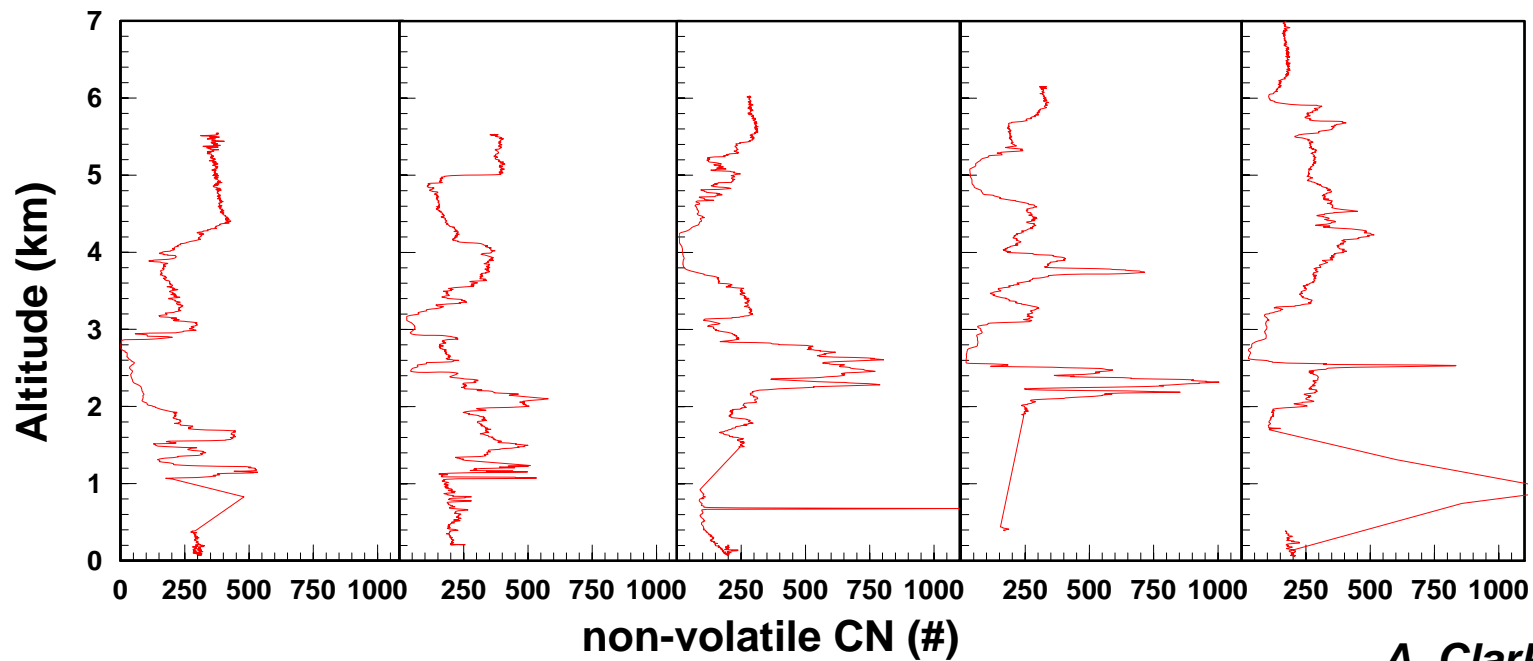
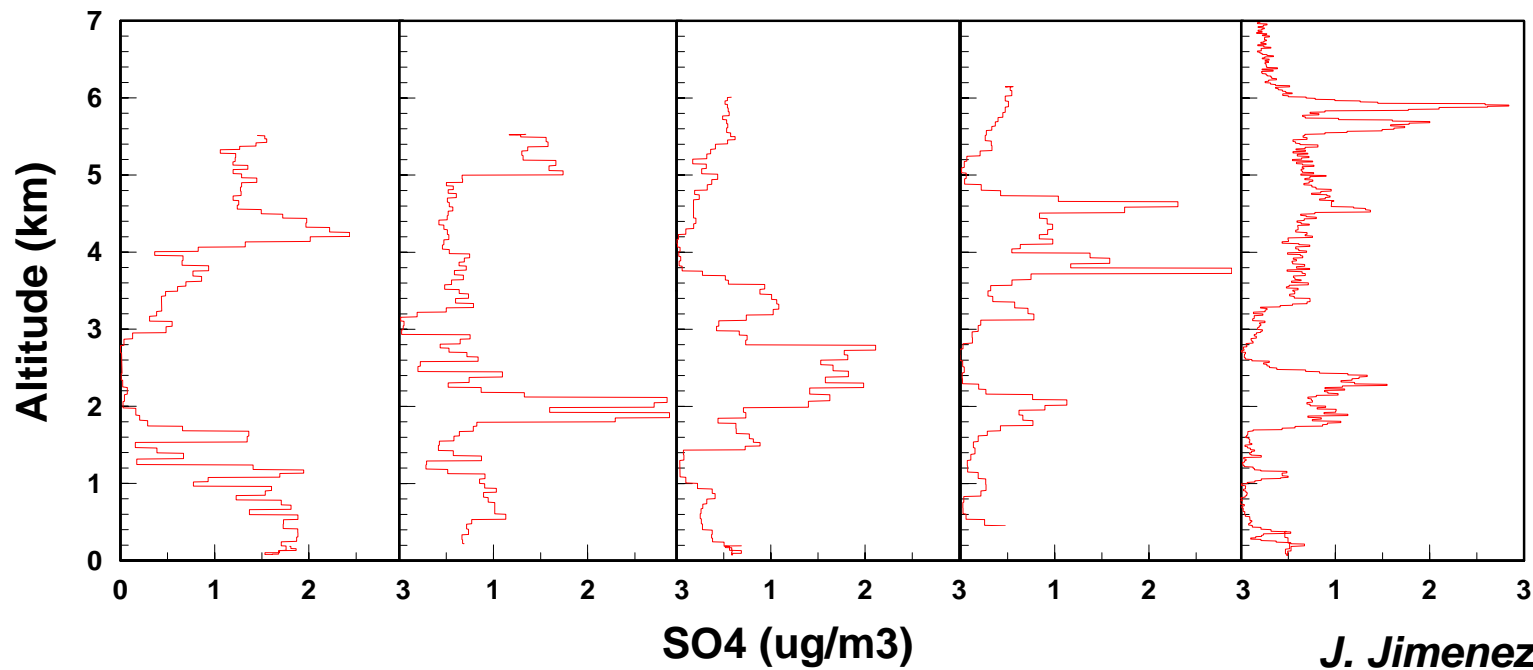


***GEOS-Chem and FLEXPART forecasts were very similar to MOZART for this flight...***









## **Two important challenges:**

**To what degree can observations be used to demonstrate or verify increases in emissions from Asia?**

**Can the impact of Asian emissions at the surface over North America be reliably observed or predicted?**