

# **The critical role of fine-grained atmospheric data in determining the rates of transport, sources, and sinks of greenhouse gases across the globe.**

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**Harvard University**

*Greenhouse gases in the Earth system: Setting the agenda to 2030*

*Discussion at the Royal Society, London Monday 22 to Tuesday 23 February 2010*

# HIAPER Pole-to-Pole Observations 2009 (“HIPPO”)



Brooks Range, AK

## **Science Objectives:**

**Use observed distributions of major greenhouse gases to help determine the continental-scale sources and sinks of major greenhouse gases.**

## **Motivation:**

Past, current, and future emission need to be understood in order to place our current situation in context, to intervene intelligently, and to monitor and verify greenhouse gas agreements.

Computer models are the basic tool for this application.

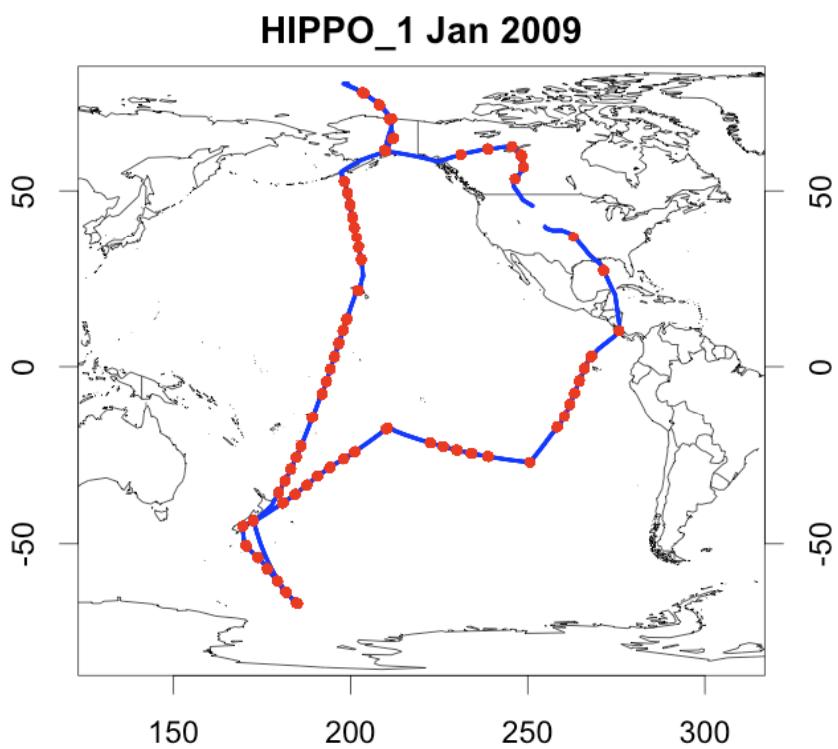
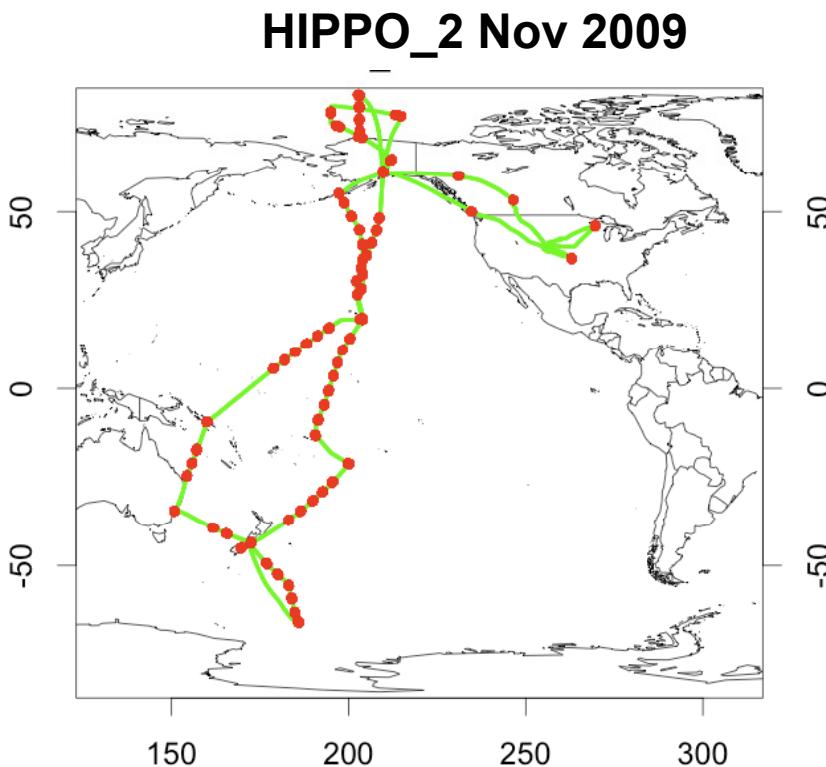
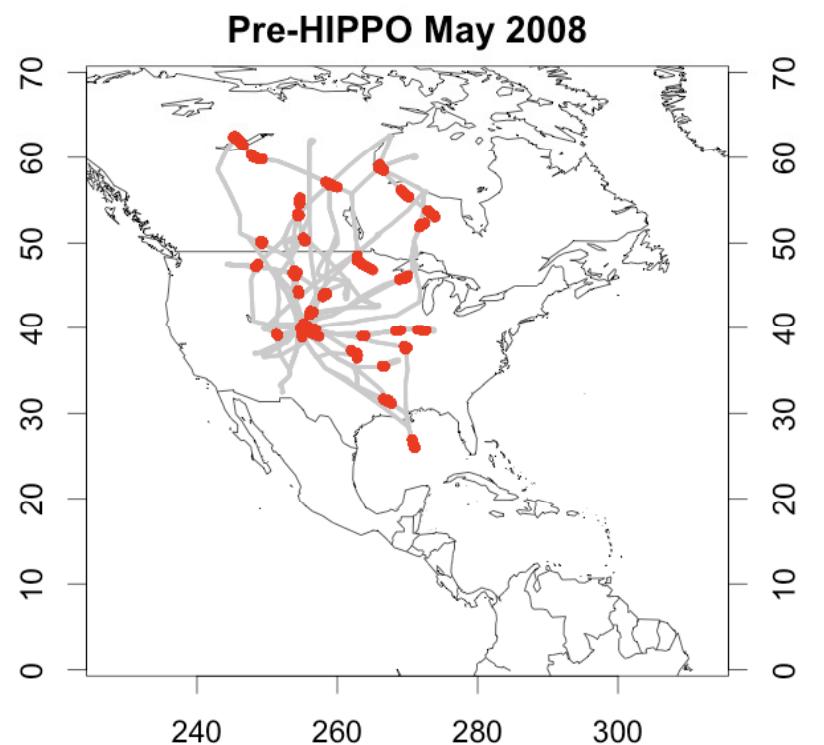
Models obtain the global distributions of surface fluxes for GHGs by optimizing *a priori* emission rates to match time series observations at surface stations.

**"HIPPO" is designed to challenge models by confronting them with a new type of data.**

**We wish to uncover and eliminate sources of bias and error that limit the application of models to assessment of source trends and distributions: to distinguish to model-data differences that tell us about sources and sinks from those arising due to deficiencies of transport, model aggregation, etc**

Fine-grained data for multiple species of different source/sink distributions, at the surface and in profile should provide critical tests of models.





> 400 vertical profiles, with 3 missions yet to go; nearly 1000 at HIPPO's conclusion.

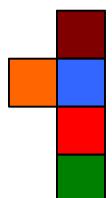
Shadow of the Earth  
visualized by ice  
crystals over the  
Alaska range.

Pago Pago, Samoa

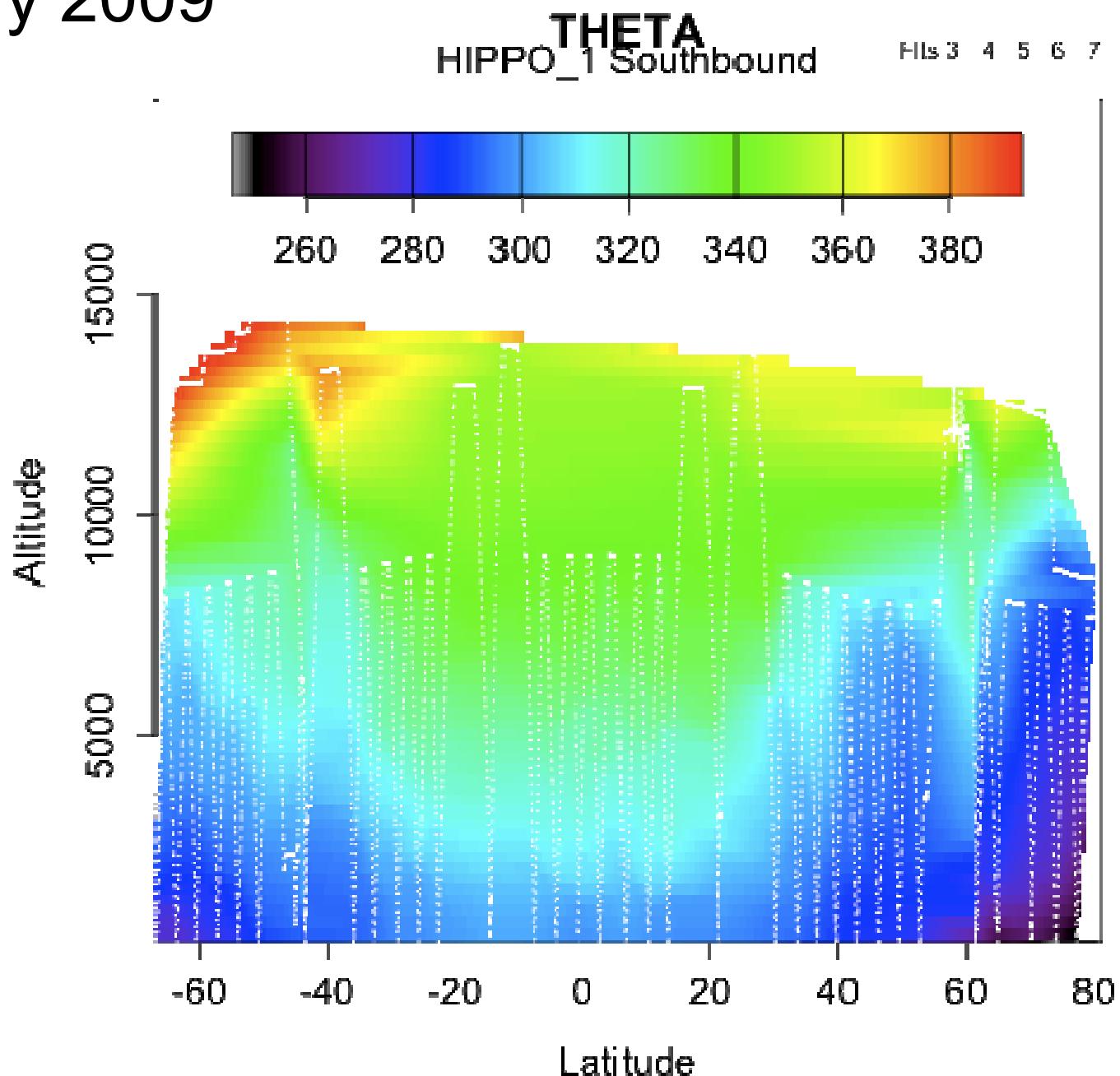


ITCZ

# HIPPO Aircraft Instrumentation

Harvard/Aerodyne—HAIS QCLS	$\text{CO}_2$ , $\text{CH}_4$ , CO, $\text{N}_2\text{O}$ (1 Hz)
NCAR AO2	$\text{O}_2:\text{N}_2$ , $\text{CO}_2$ (1 Hz)
Harvard OMS $\text{CO}_2$	$\text{CO}_2$ (1 Hz)
NOAA CSD $\text{O}_3$	$\text{O}_3$ (1 Hz)
NOAA GMD $\text{O}_3$	$\text{O}_3$ (1 Hz)
NCAR RAF CO	CO (1 Hz)
NOAA- UCATS, PANTHER GCs (1 per 70 – 200 s)	CO, $\text{CH}_4$ , $\text{N}_2\text{O}$ , CFCs, HCFCs, $\text{SF}_6$ , $\text{CH}_3\text{Br}$ , $\text{CH}_3\text{Cl}$ , $\text{H}_2$ , $\text{H}_2\text{O}$
Whole air sampling: NWAS (NOAA), AWAS (Miami), MEDUSA (NCAR/Scripps)	 $\text{O}_2:\text{N}_2$ , $\text{CO}_2$ , $\text{CH}_4$ , CO, $\text{N}_2\text{O}$ , other GHGs, $\text{COS}$ , halocarbons, solvent gases, marine emission species, many more
Princeton/SWS VCSEL	$\text{H}_2\text{O}$ (1 Hz)
NOAA SP2	Black Carbon (1 Hz)
MTP, wing stores, etc	T, P, winds, aerosols, cloud water

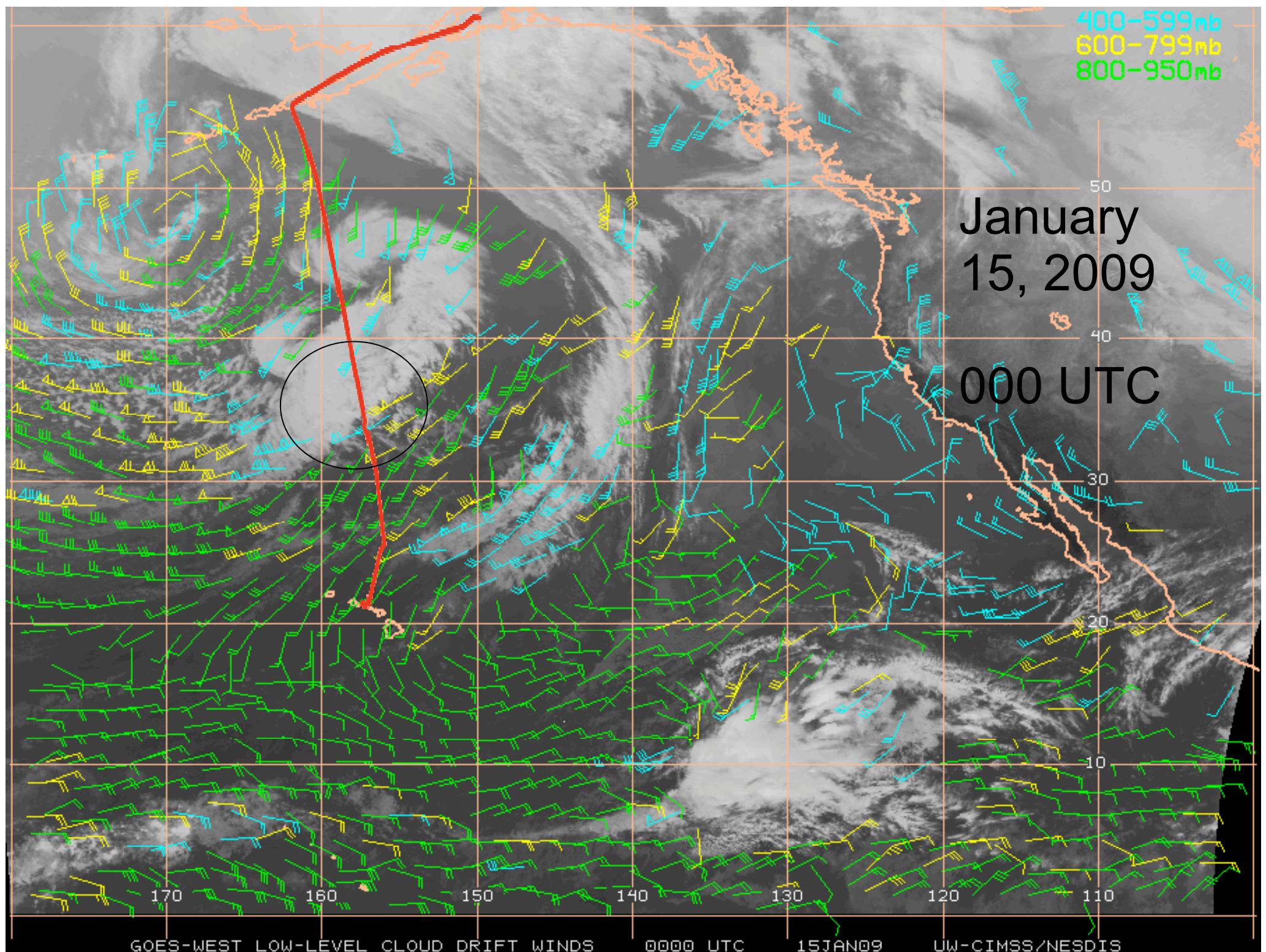
# Global distribution of potential temperature – January 2009

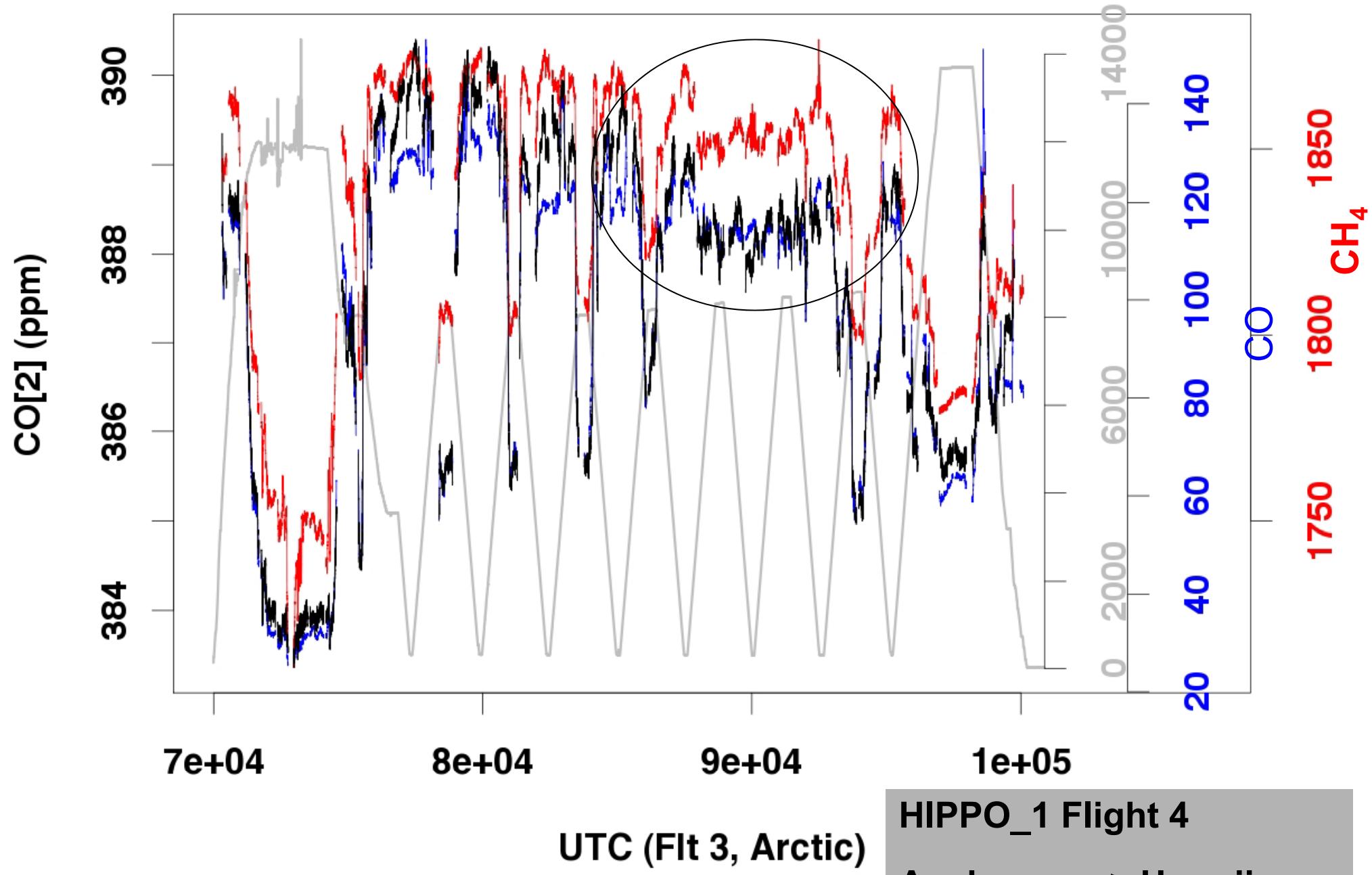


400-599mb  
600-799mb  
800-950mb

January  
15, 2009

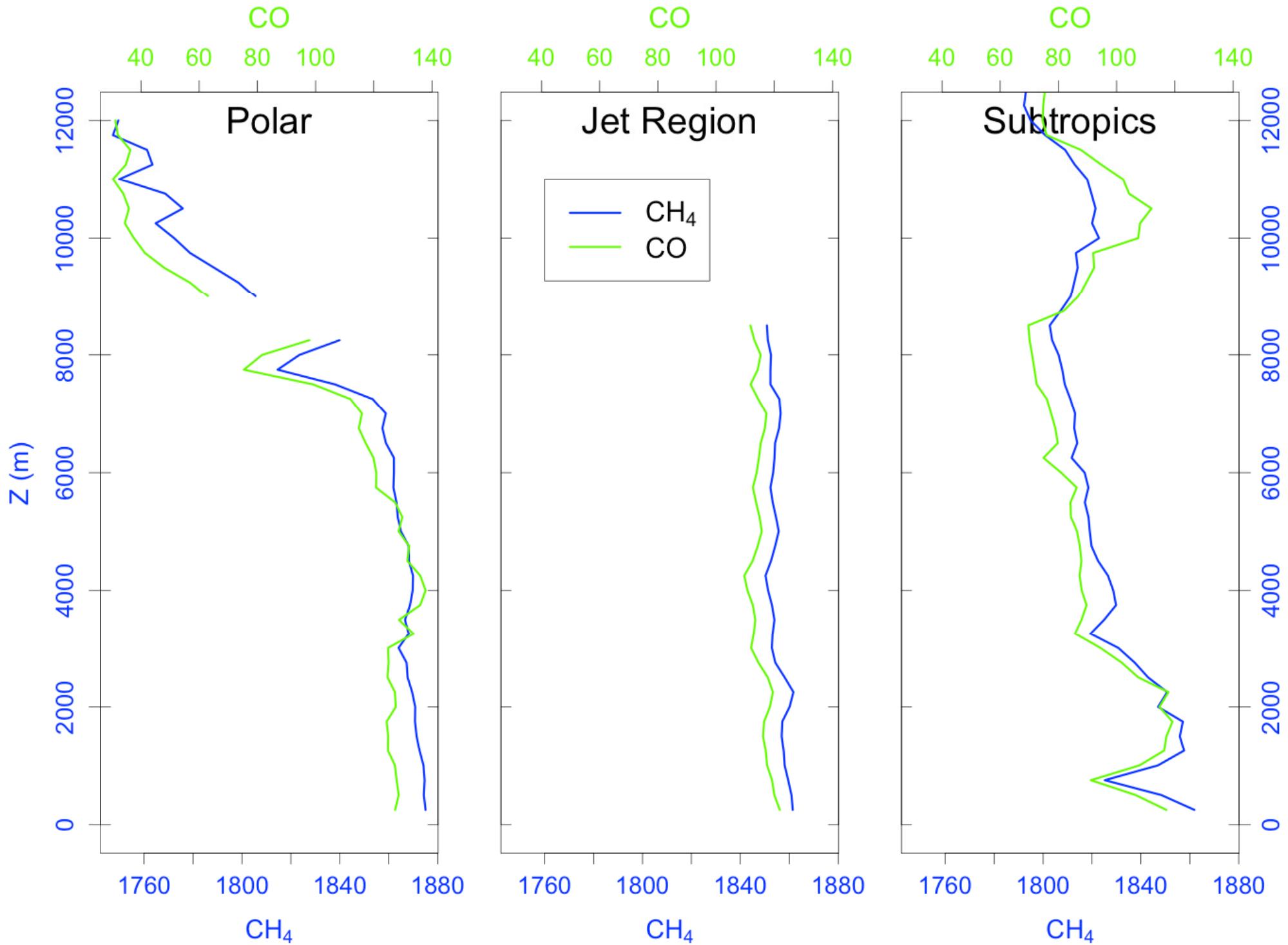
000 UTC

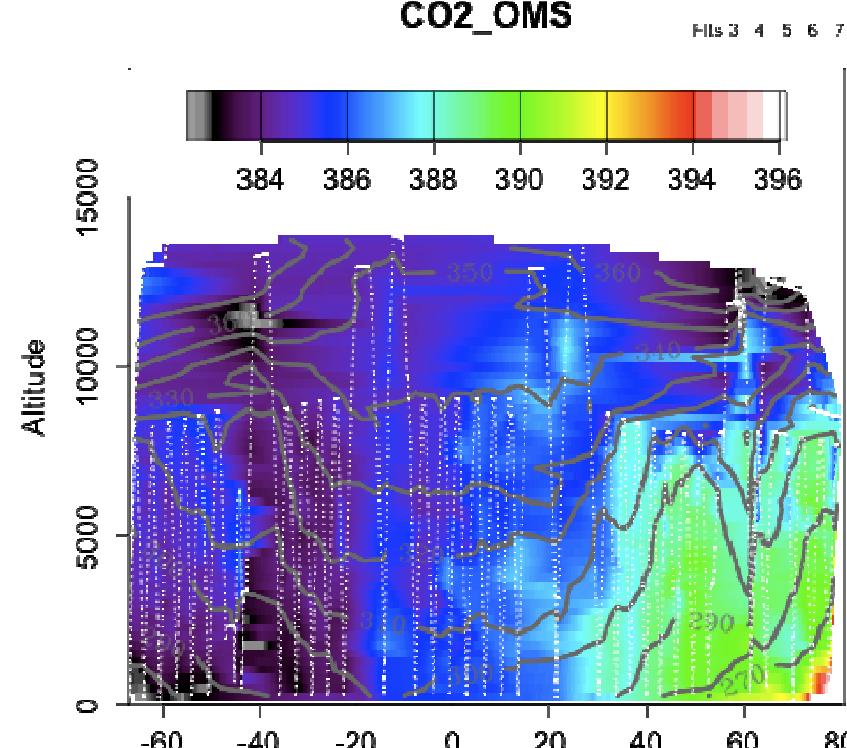
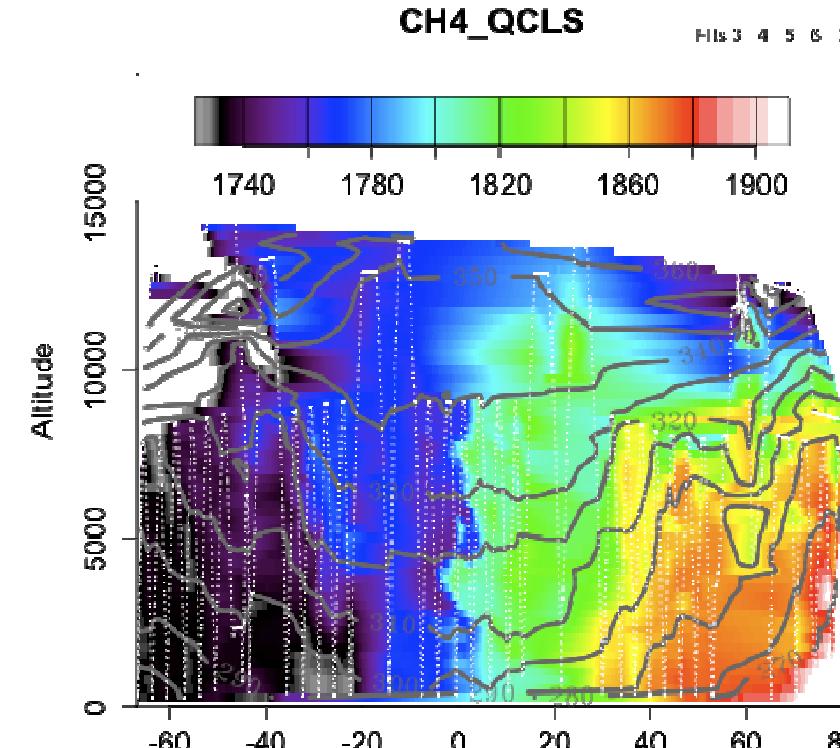




UTC (Flt 3, Arctic)

HIPPO\_1 Flight 4  
Anchorage -> Hawaii  
14 January 2009

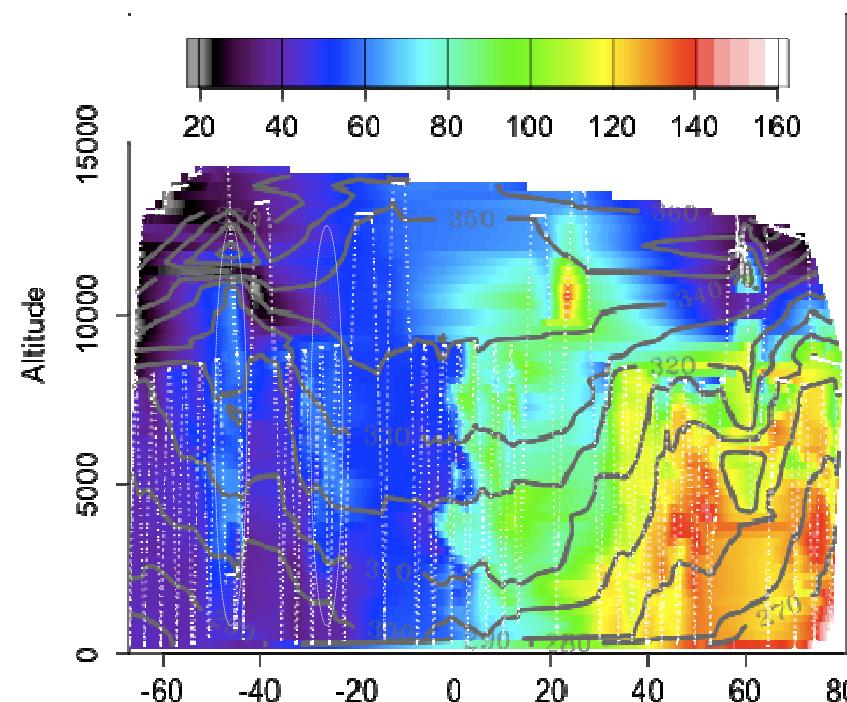
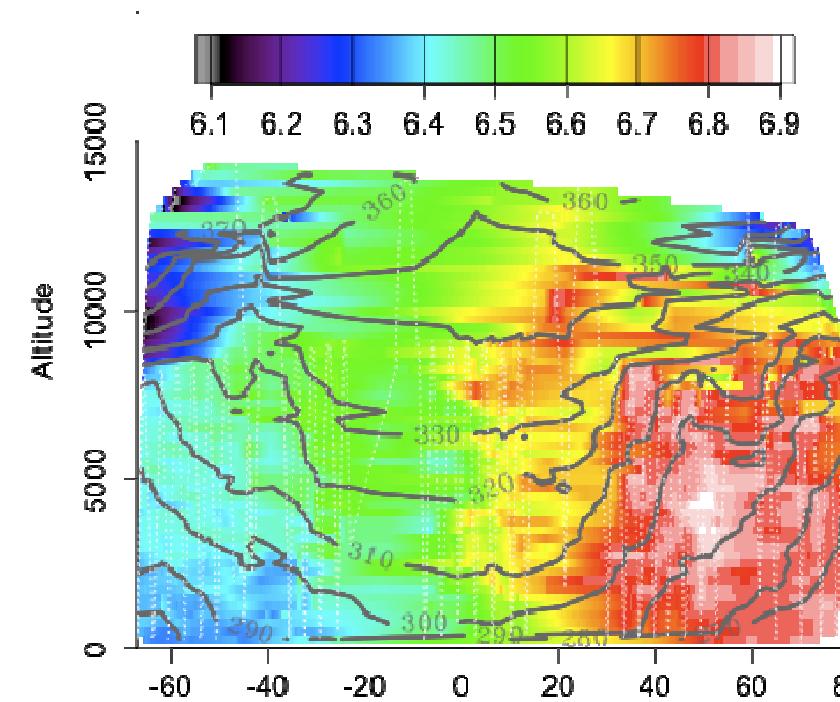


**CO<sub>2</sub>\_OMS****CH<sub>4</sub>\_QCLS**

**HIPPO\_1**

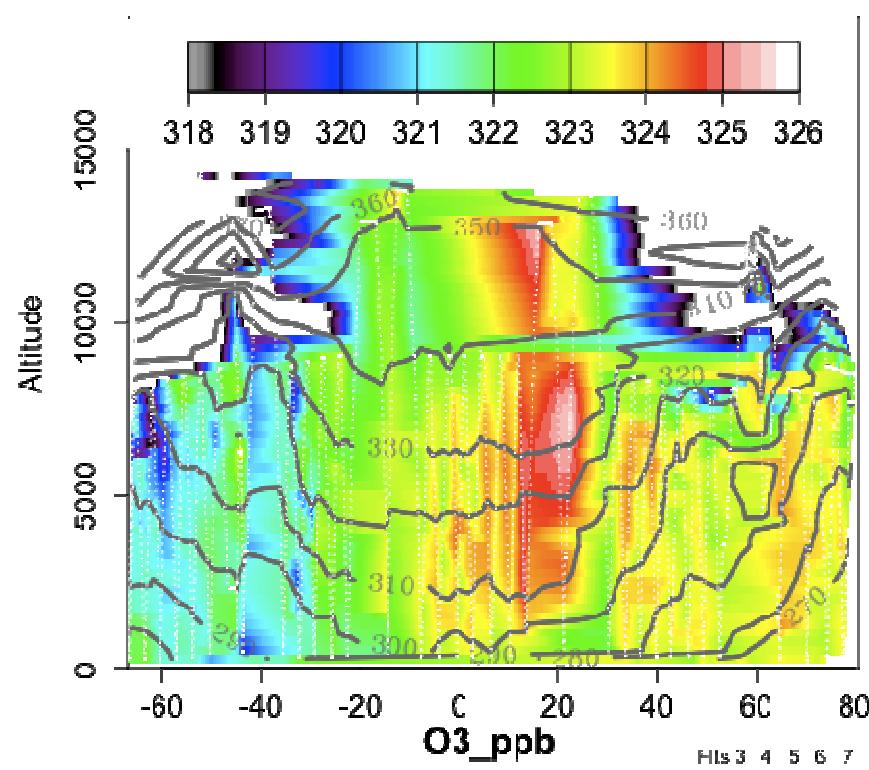
Xsects along  
the Dateline

Jan 2009

**CO\_QCLS****SF6\_UCATS**

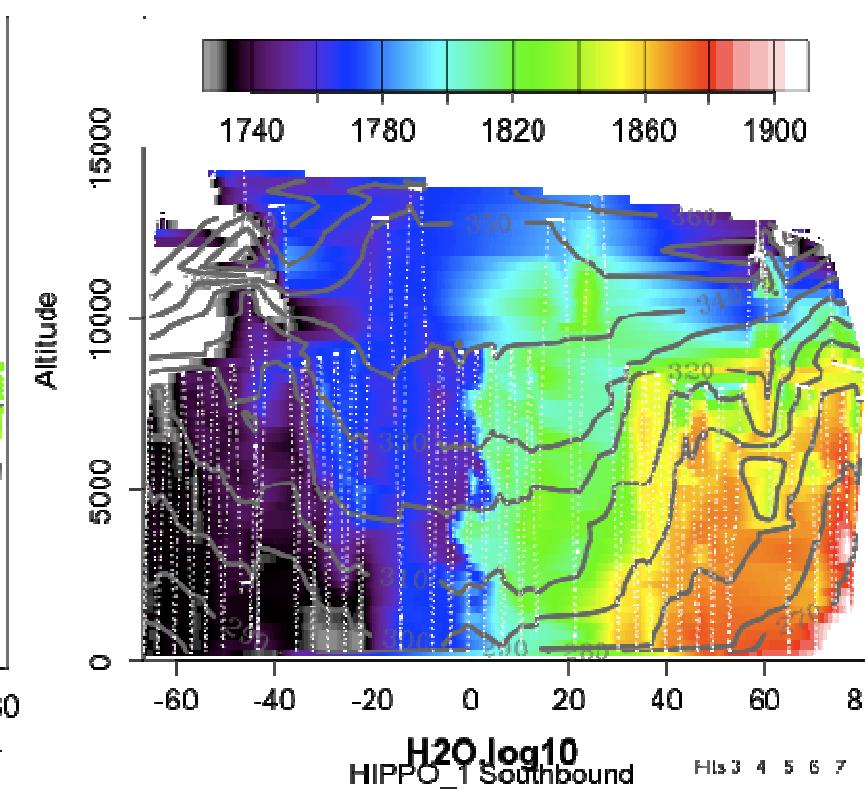
### N2O\_QCLS

Hls 3 4 5 6 7



### CH4\_QCLS

Hls 3 4 5 6 7



**HIPPO\_1**

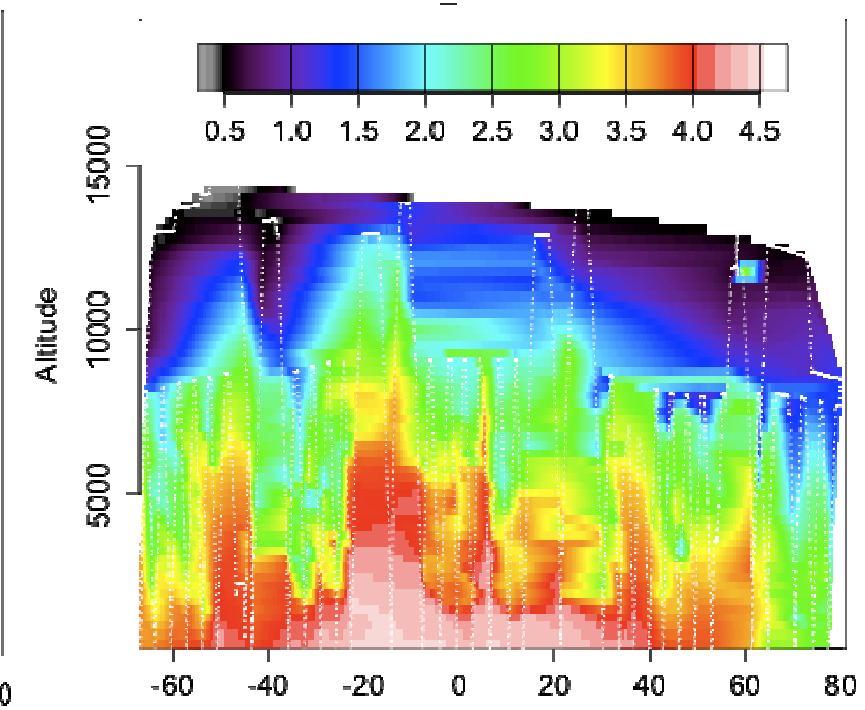
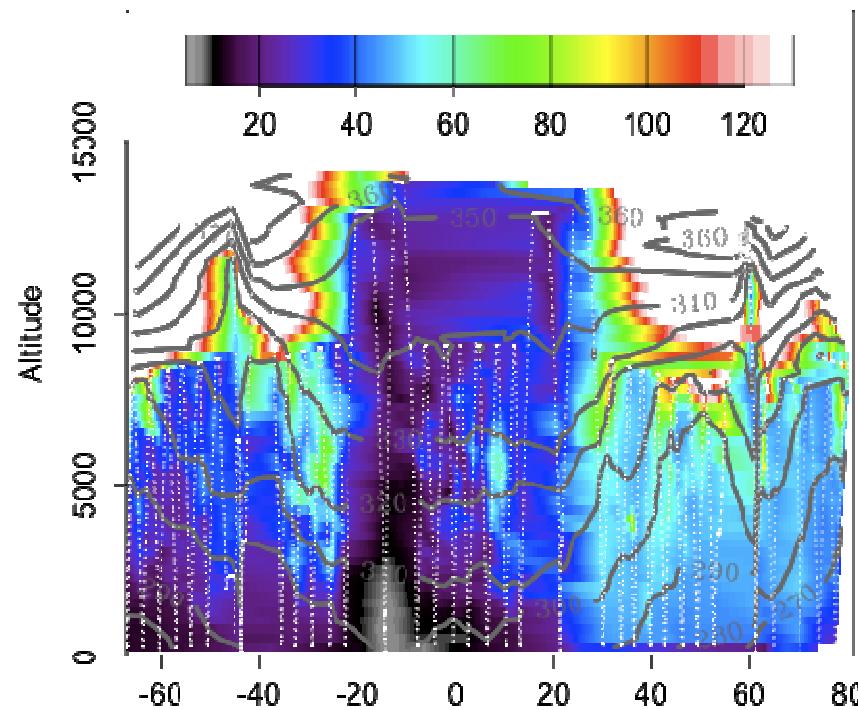
Xsects along  
the Dateline

Jan 2009

### H2O\_log10

HIPPO\_1 Southbound

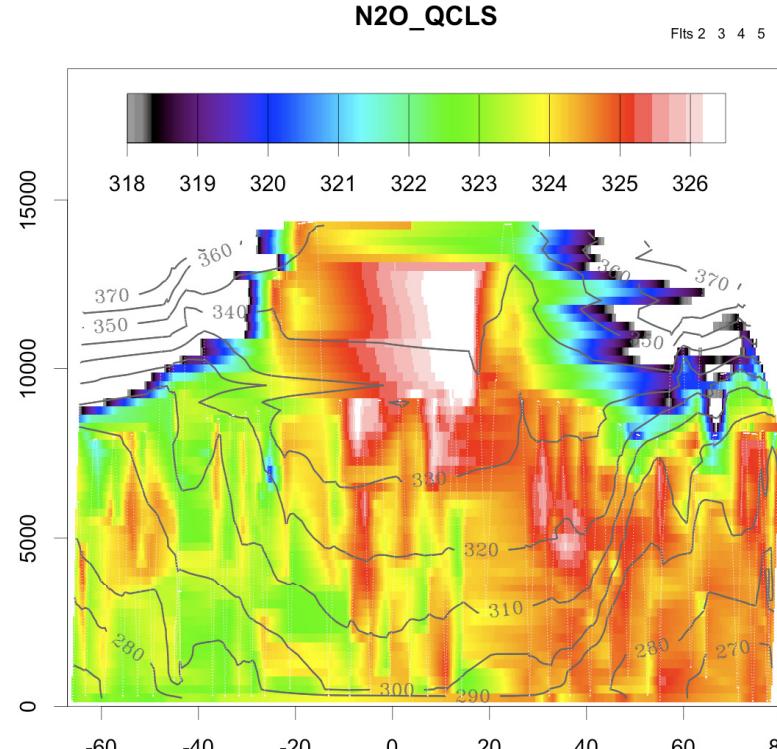
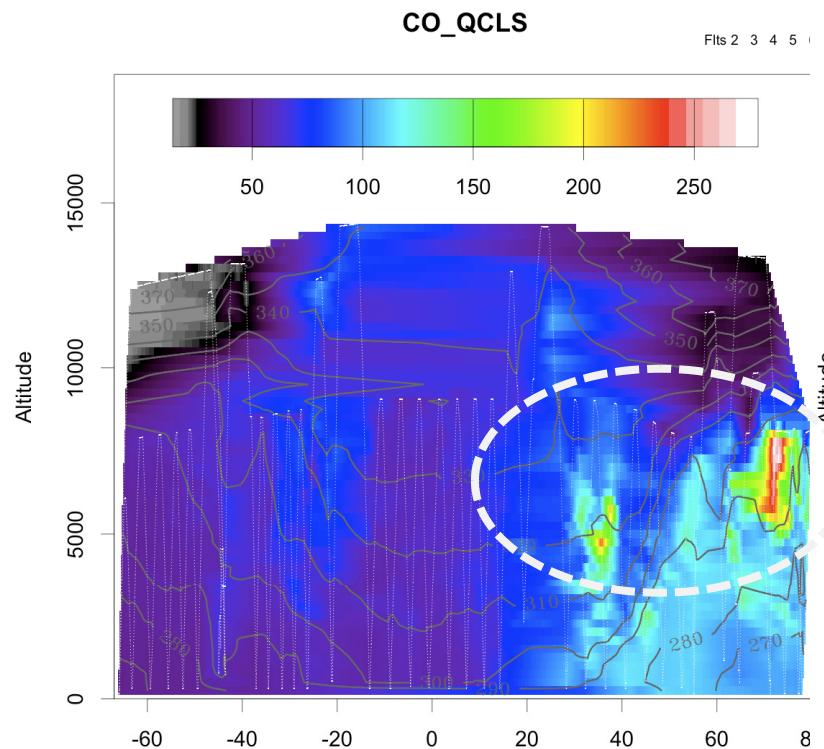
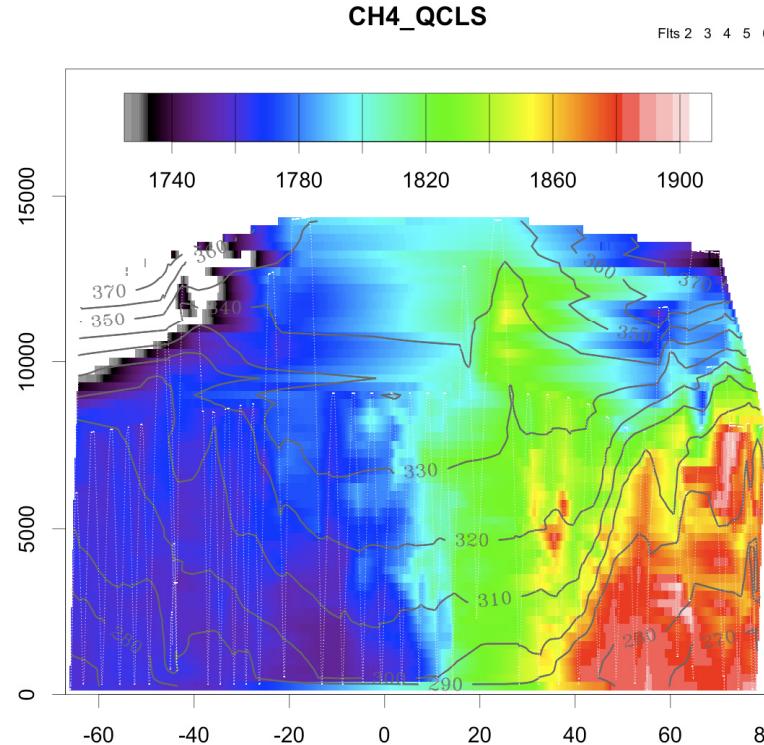
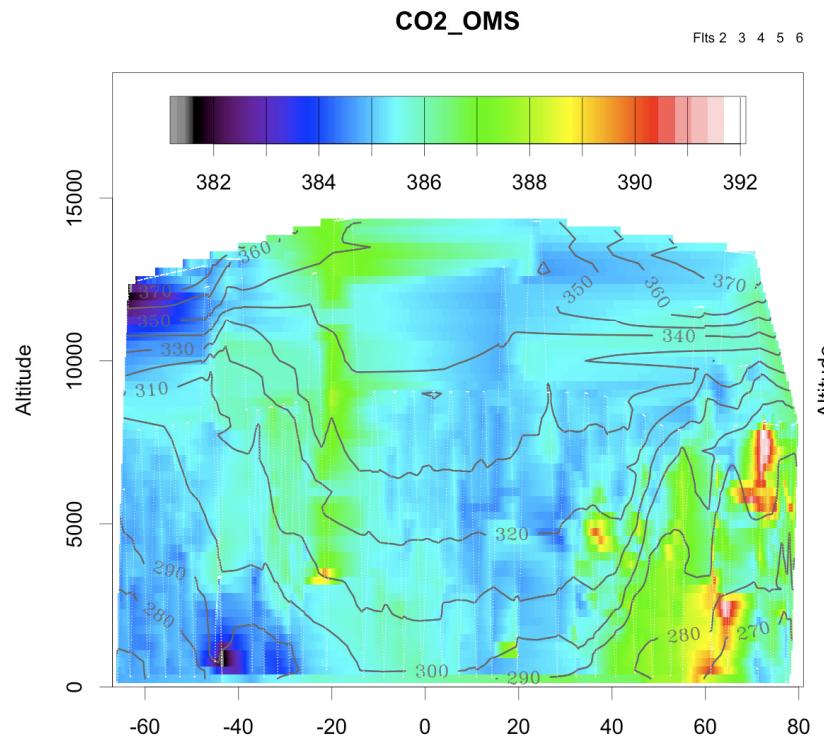
Hls 3 4 5 6 7



# HIPPO\_2

Xsects along  
the Dateline

Nov 2009



*upside down*

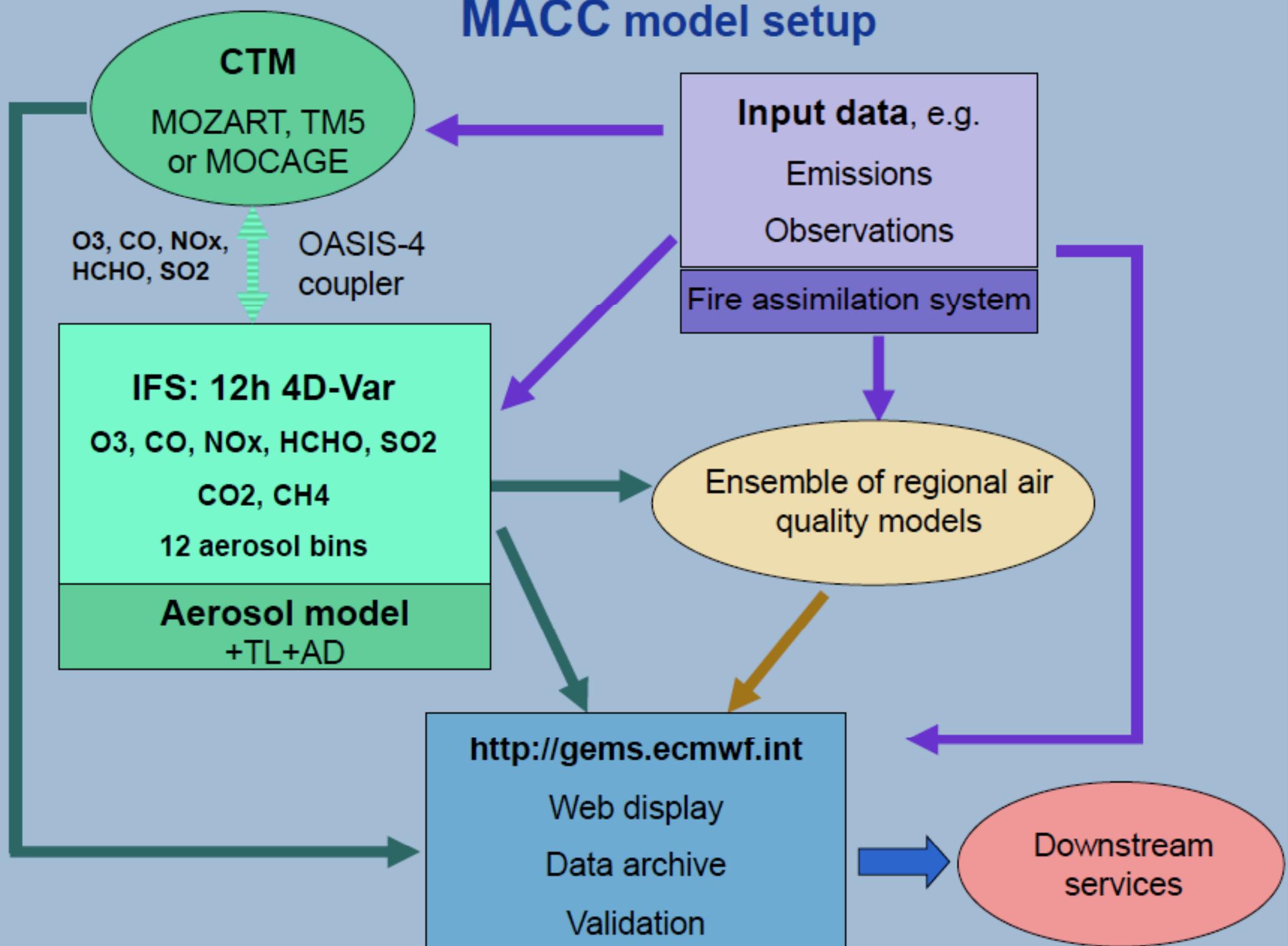
# Models with detailed simulations of HIPPO\_1 or Pre-HIPPO Data

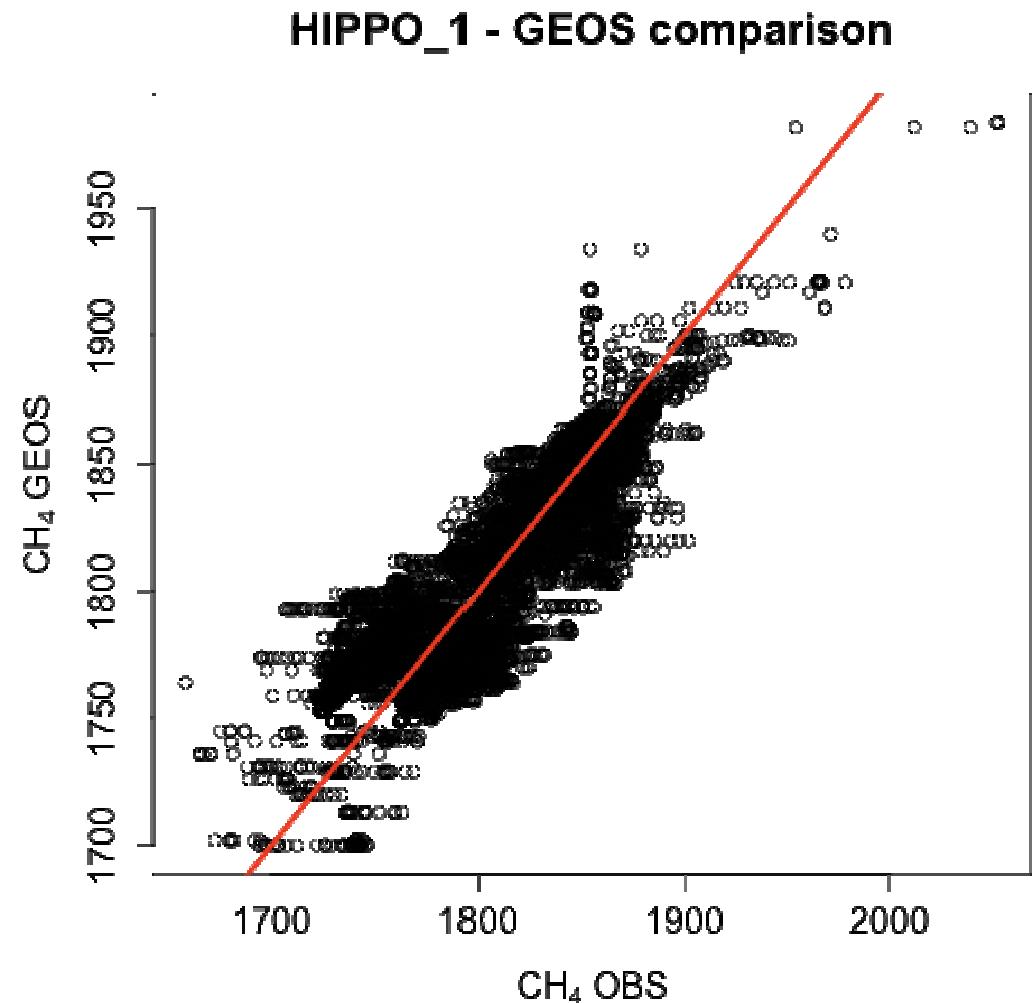
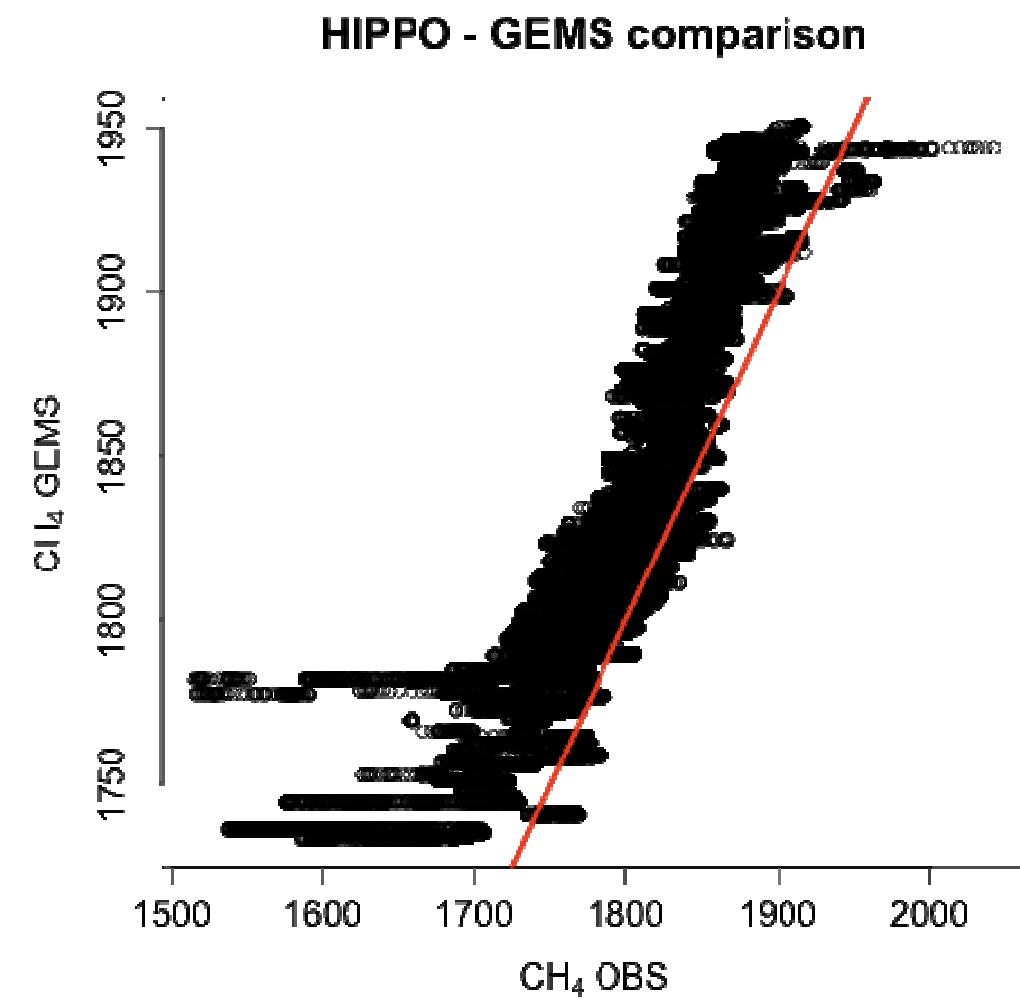
- Earth Simulator – ACTM cCSR/NIES/FRCGC AGCM
- GEOS-CHEM (NASA DAO) Harvard
- MACC-GEMS ECMWF Air Quality and Air chemistry model

Detailed Model results for HIPPO\_1:

	CO2	SF6	C2H6	CO	N2O	CH4	O3	PAN	NOx	HCHO	BkC
GEOS_C	1	1	1	1	0	1	0	0	0	0	*
ACTM	1	1	0	0	1	1	0	0	0	0	
MACC	0	0	1	1, Fcst	0	1	1	1	1	1	
TOTALS	2	2	2	2, Fcst	1	3	1	1	1	1	

# MACC model setup

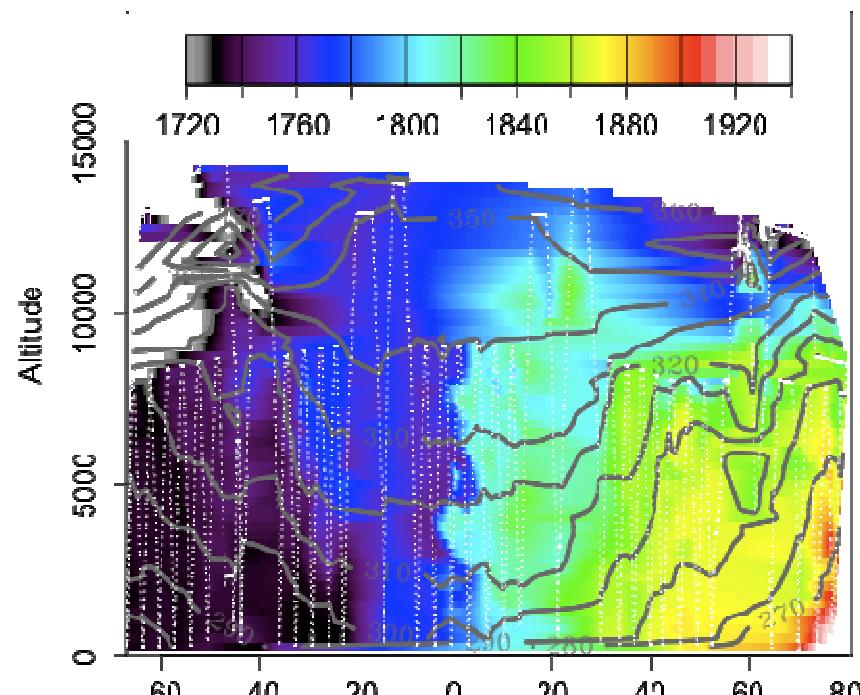




**CH<sub>4</sub> HIPPO**

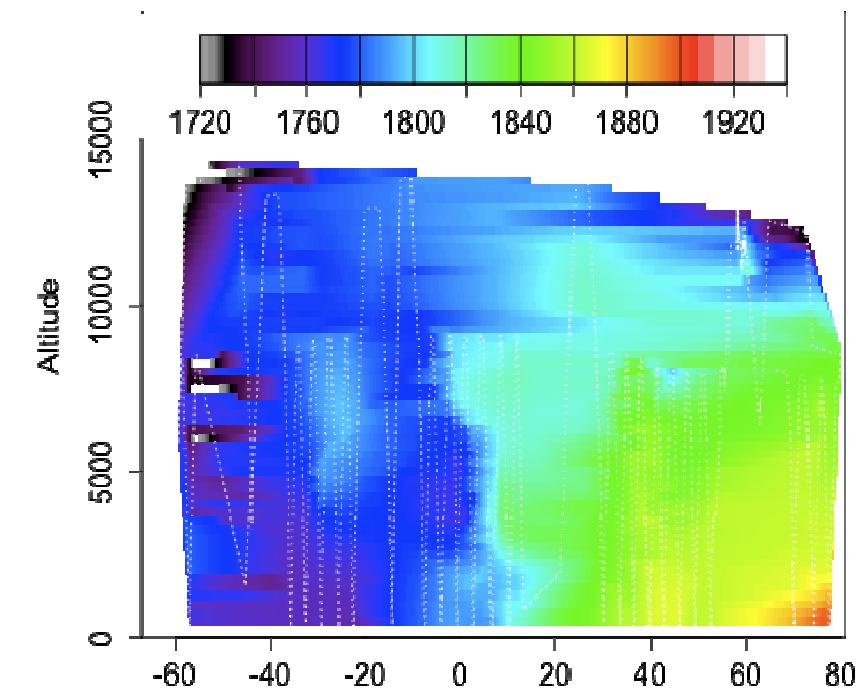
**CH<sub>4</sub>\_QCLS**

Hls 3 4 5 6 7



**CH<sub>4</sub>\_GEOS**

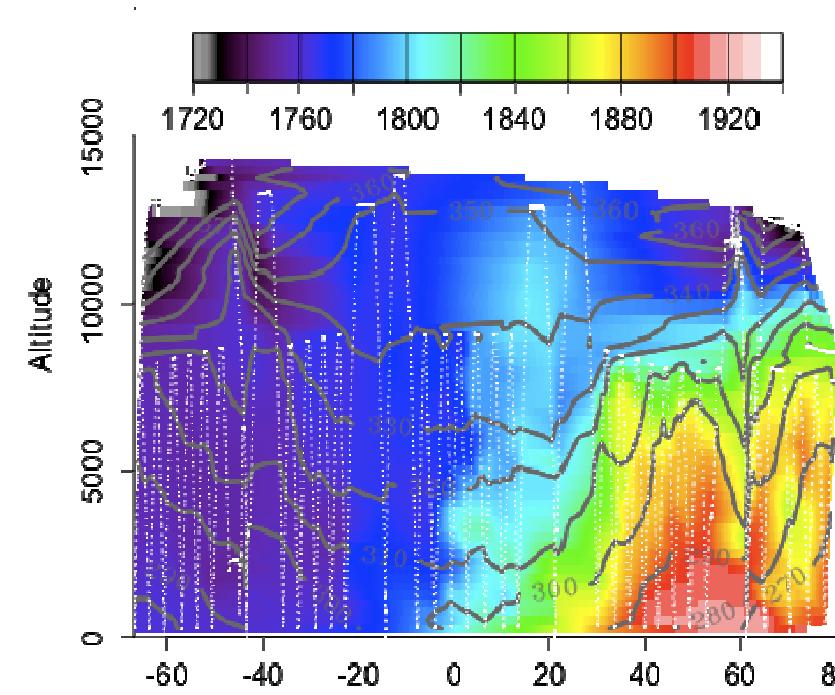
Hls 3 4 5 6 7



**CH<sub>4</sub>.gems**

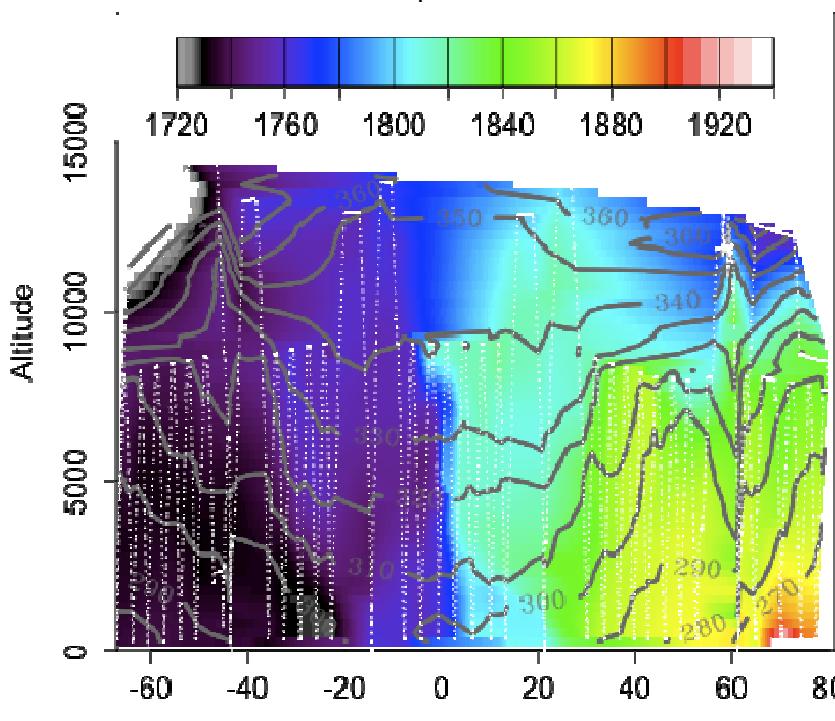
**offset 31 ppb**

Hls 3 4 5 6 7



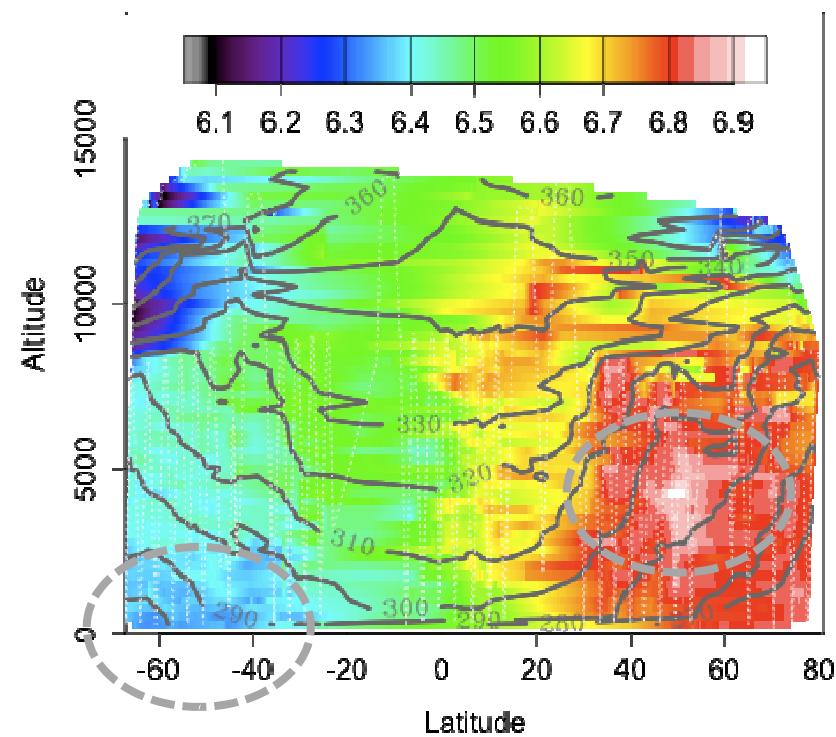
**CH<sub>4</sub> ACTM**

Hls 3 4 5 6 7



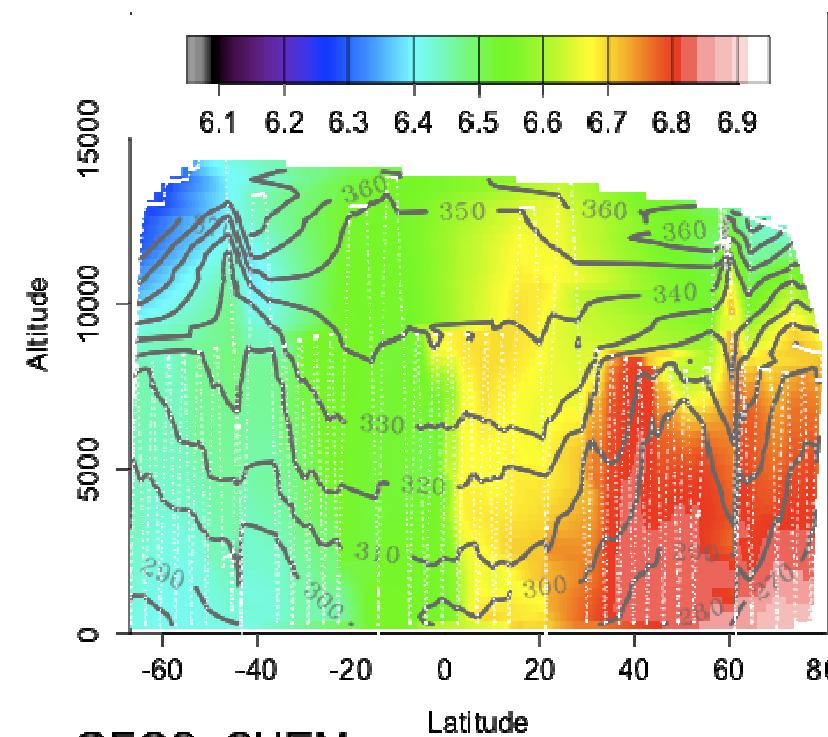
*sources  
and vertical  
and  
horizontal  
transport*

SF6\_UCATS OBS/HIPPO

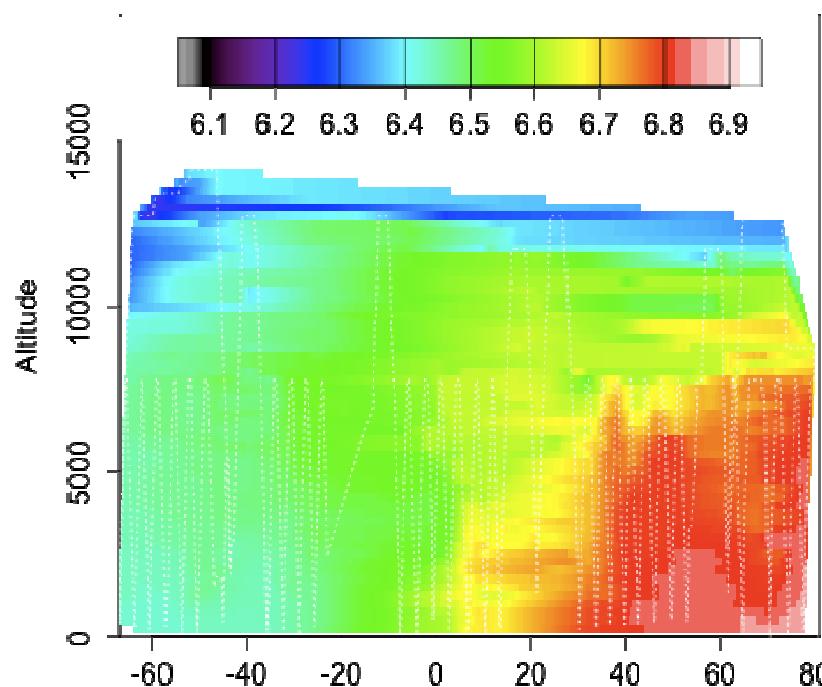


SF6.ppt.

ACTM

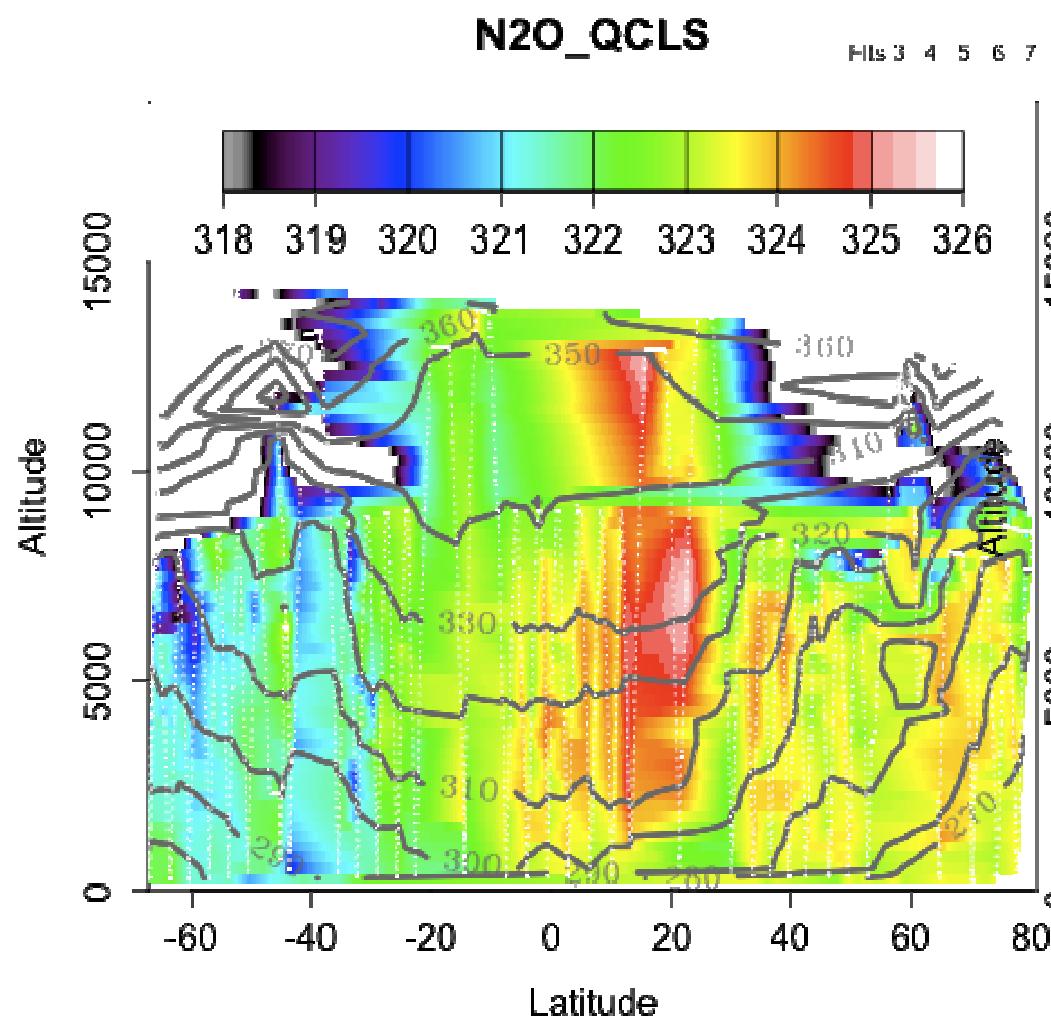


SF6\_GEO\$GEOS\_CHEM

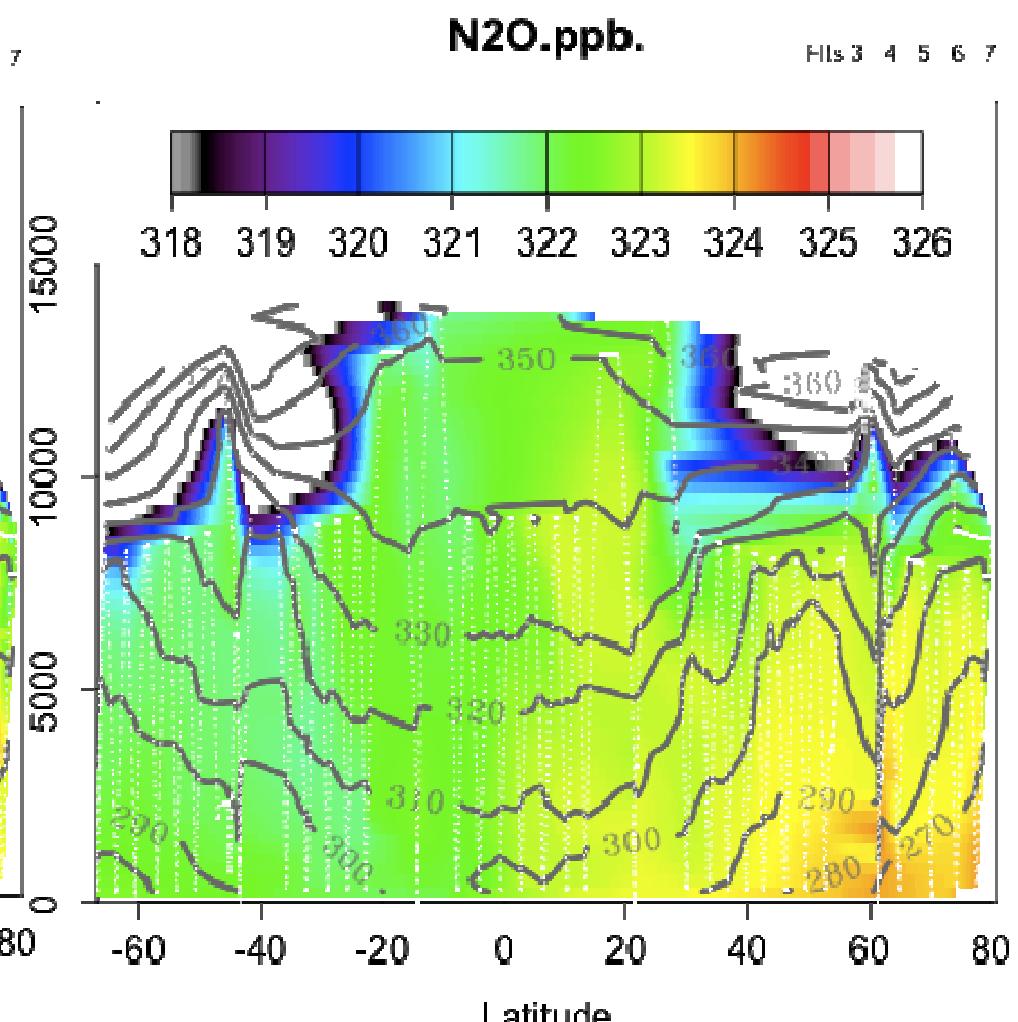


*sources  
and vertical  
and  
horizontal  
transport*

# Jan 2009 Observed

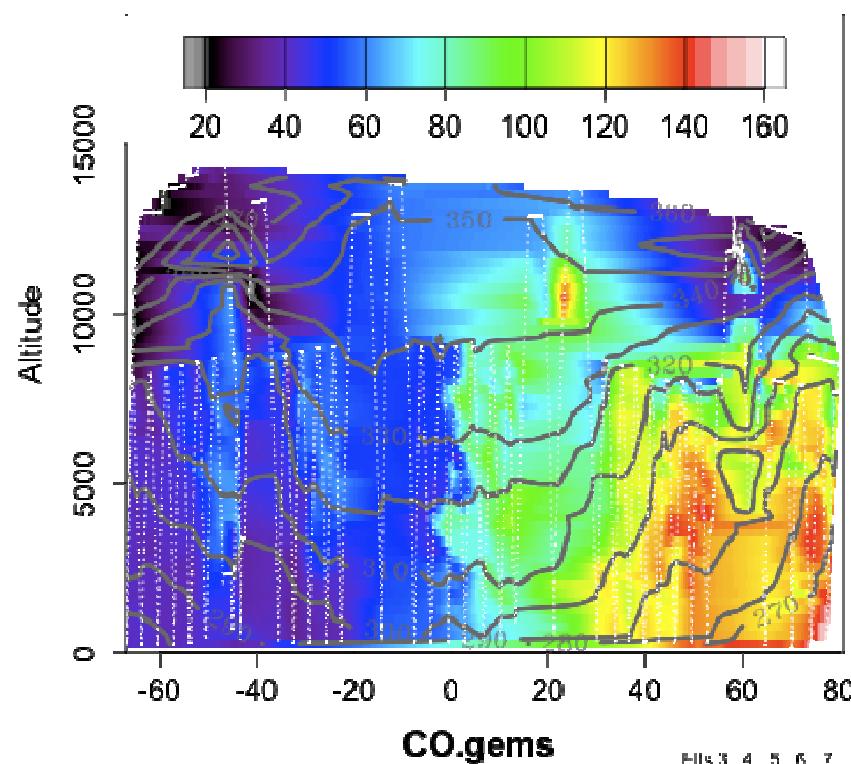
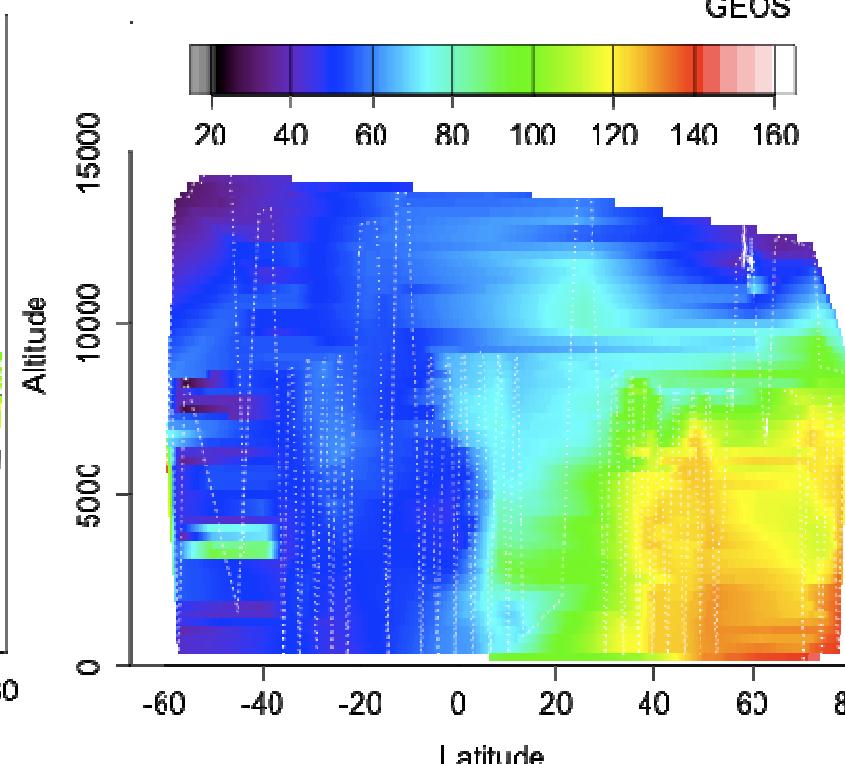
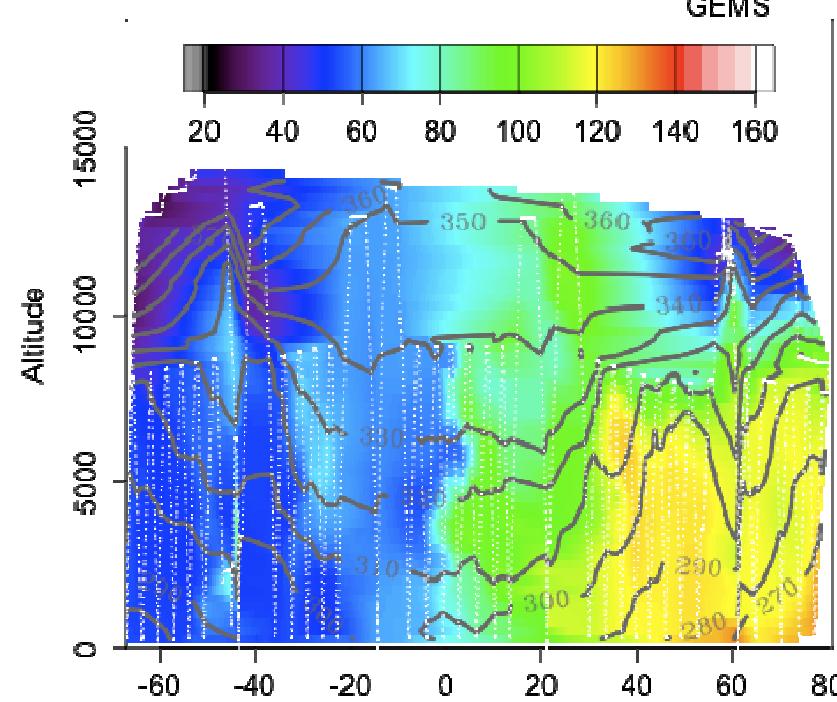


# ACTM (GEIA)

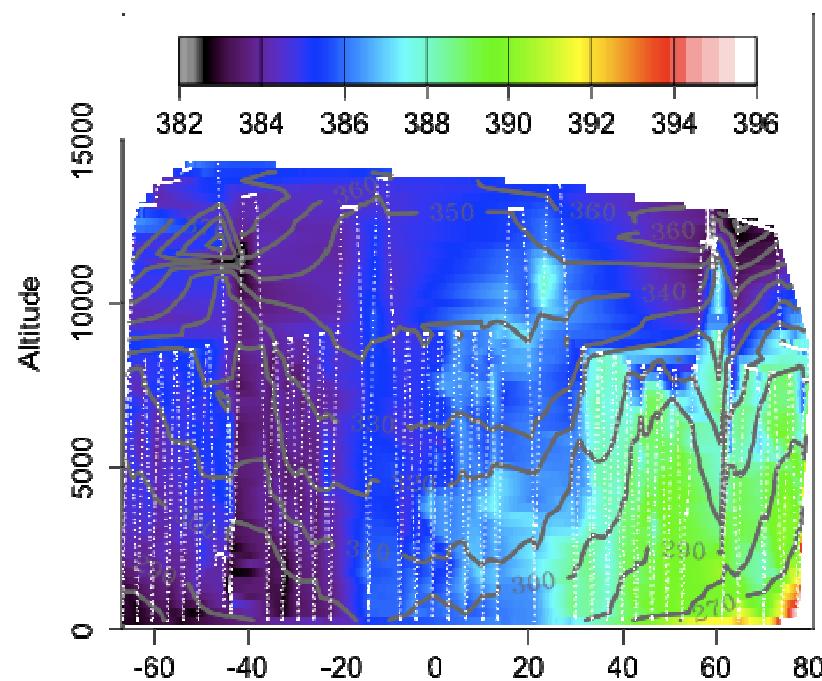


**CO\_QCLS**

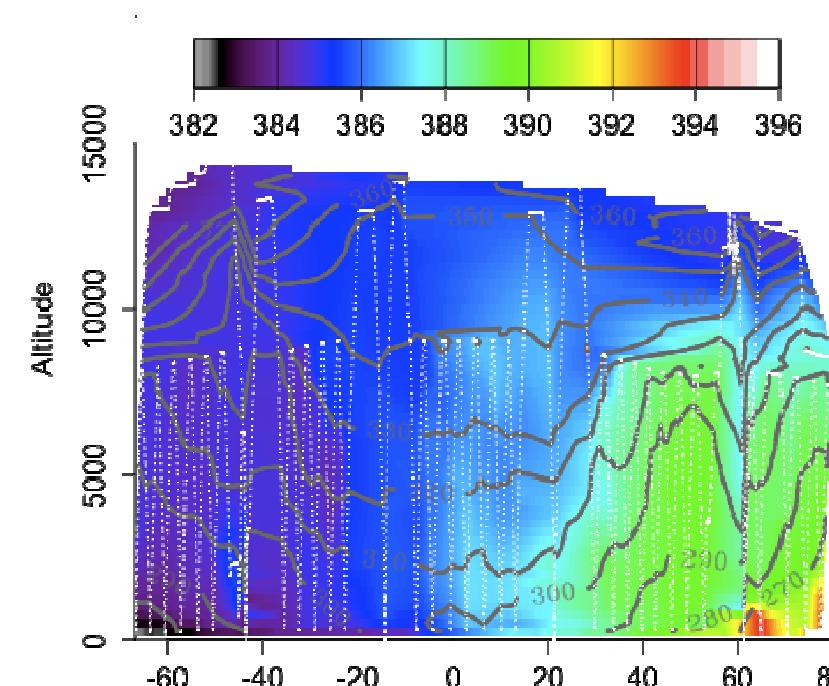
Fls 3 4 5 G 7

**CO\_GEOS**Fls 3 4 5 6 7  
GEOS**CO.gems**Fls 3 4 5 6 7  
GEMS

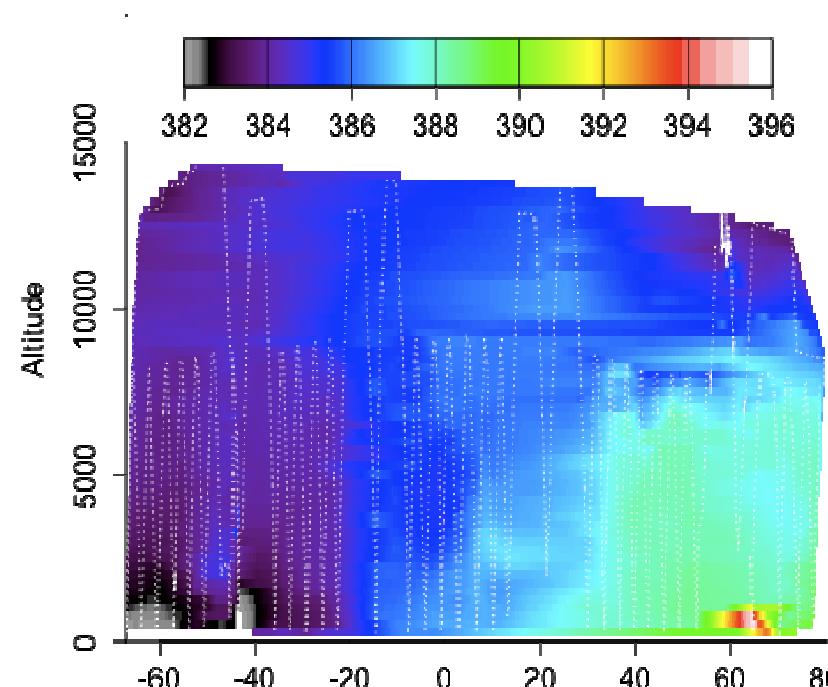
**CO<sub>2</sub>.composite OBS/HIPPO**

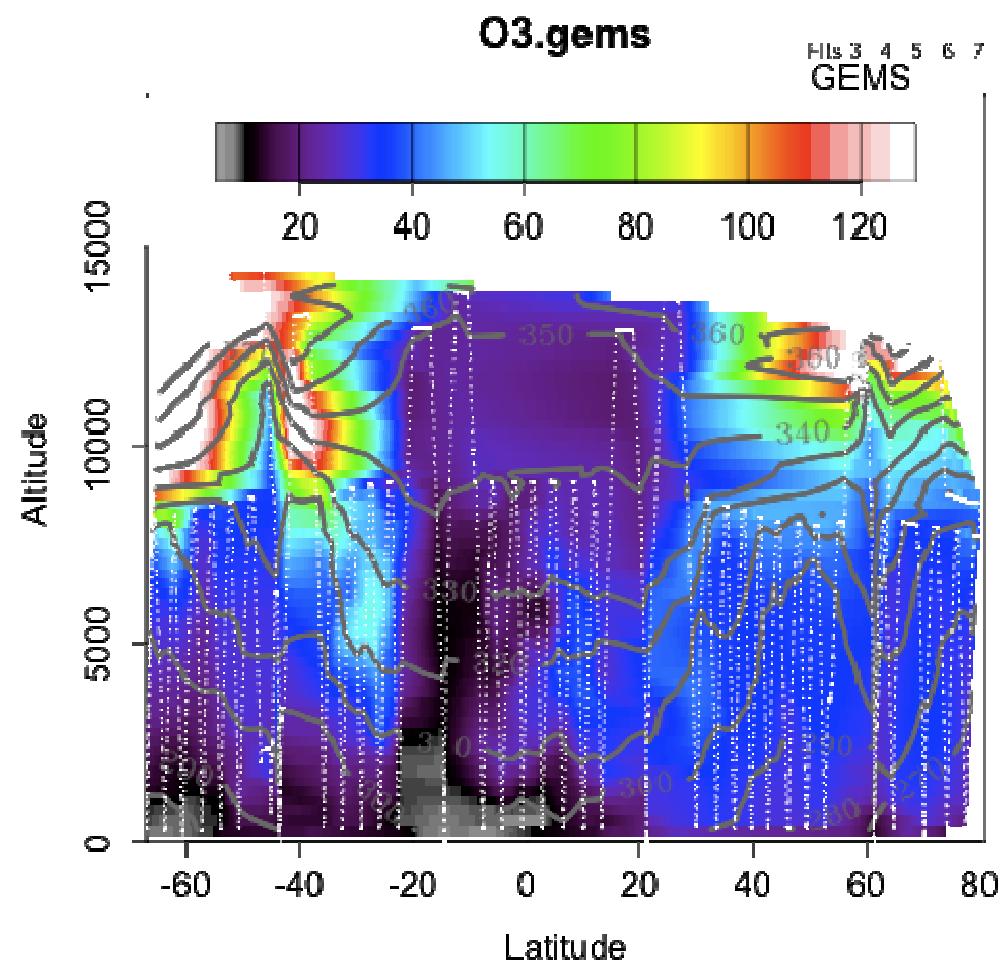
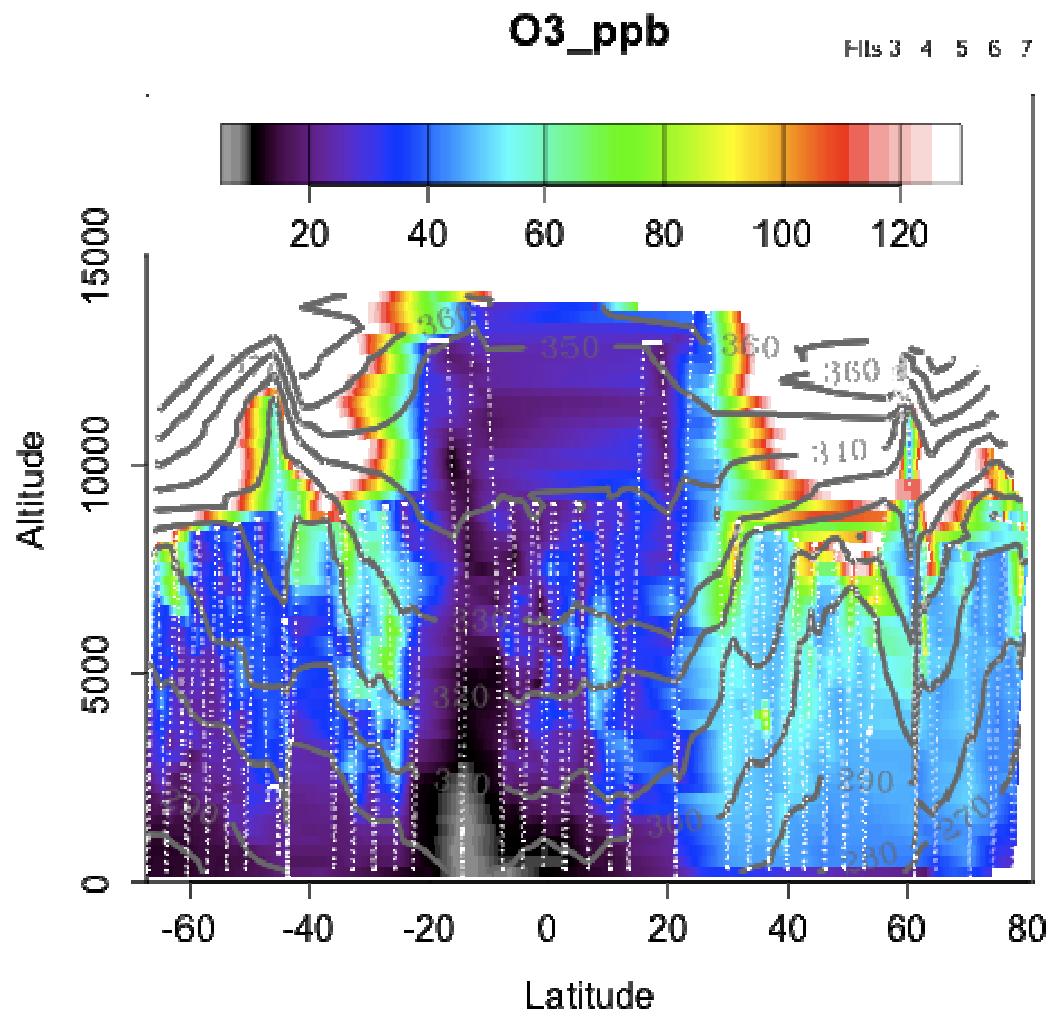


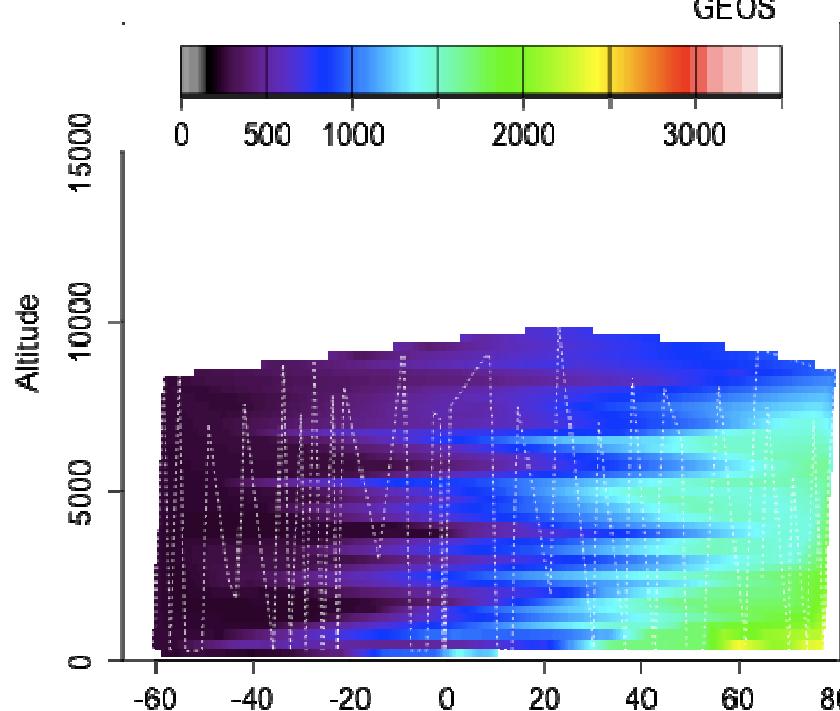
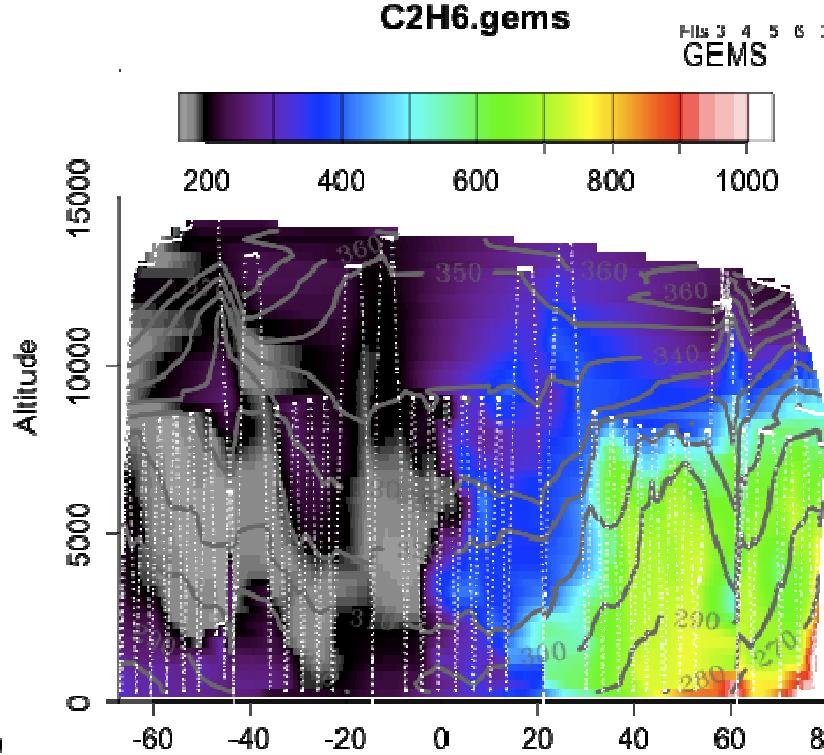
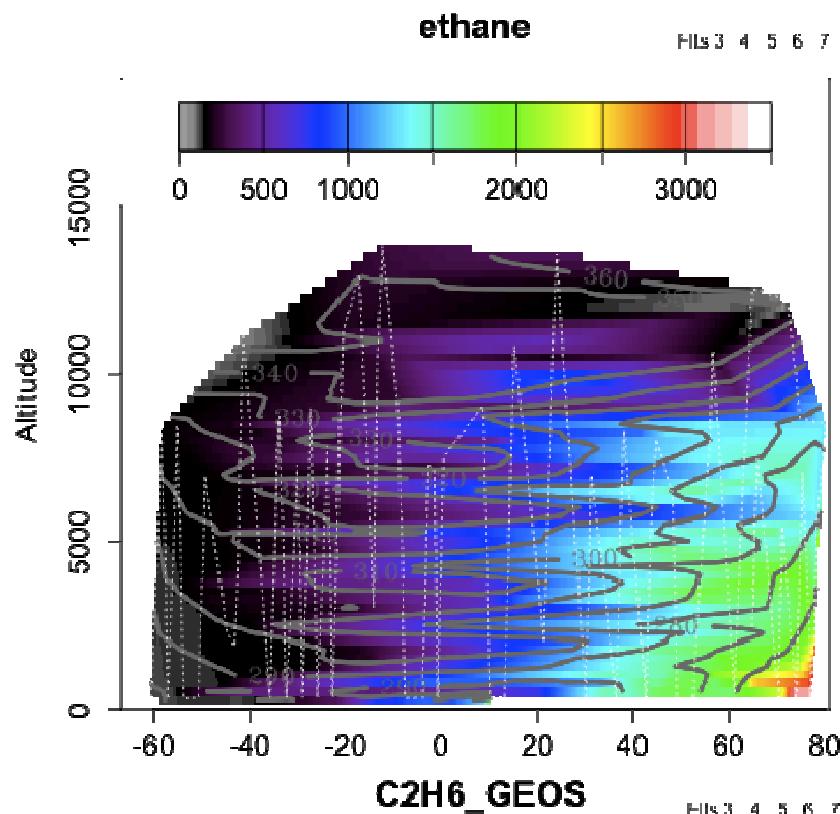
**CO<sub>2</sub>.ppm. ACTM**



**CO<sub>2</sub>\_GEOSEOS\_CHEM**





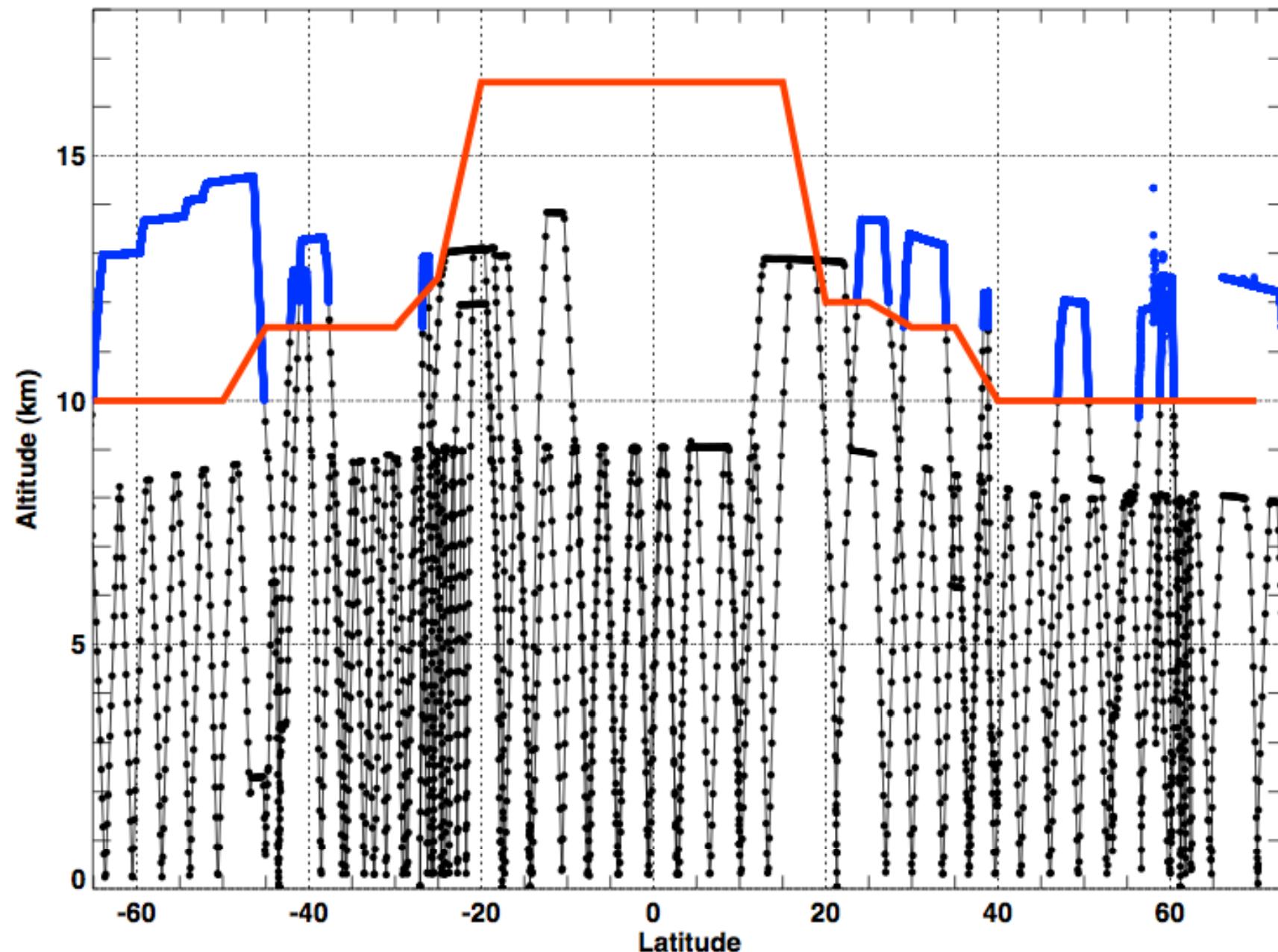


note scale change for GEMS

# **Using multiple tracers to help solve the model-measurement conundrum**

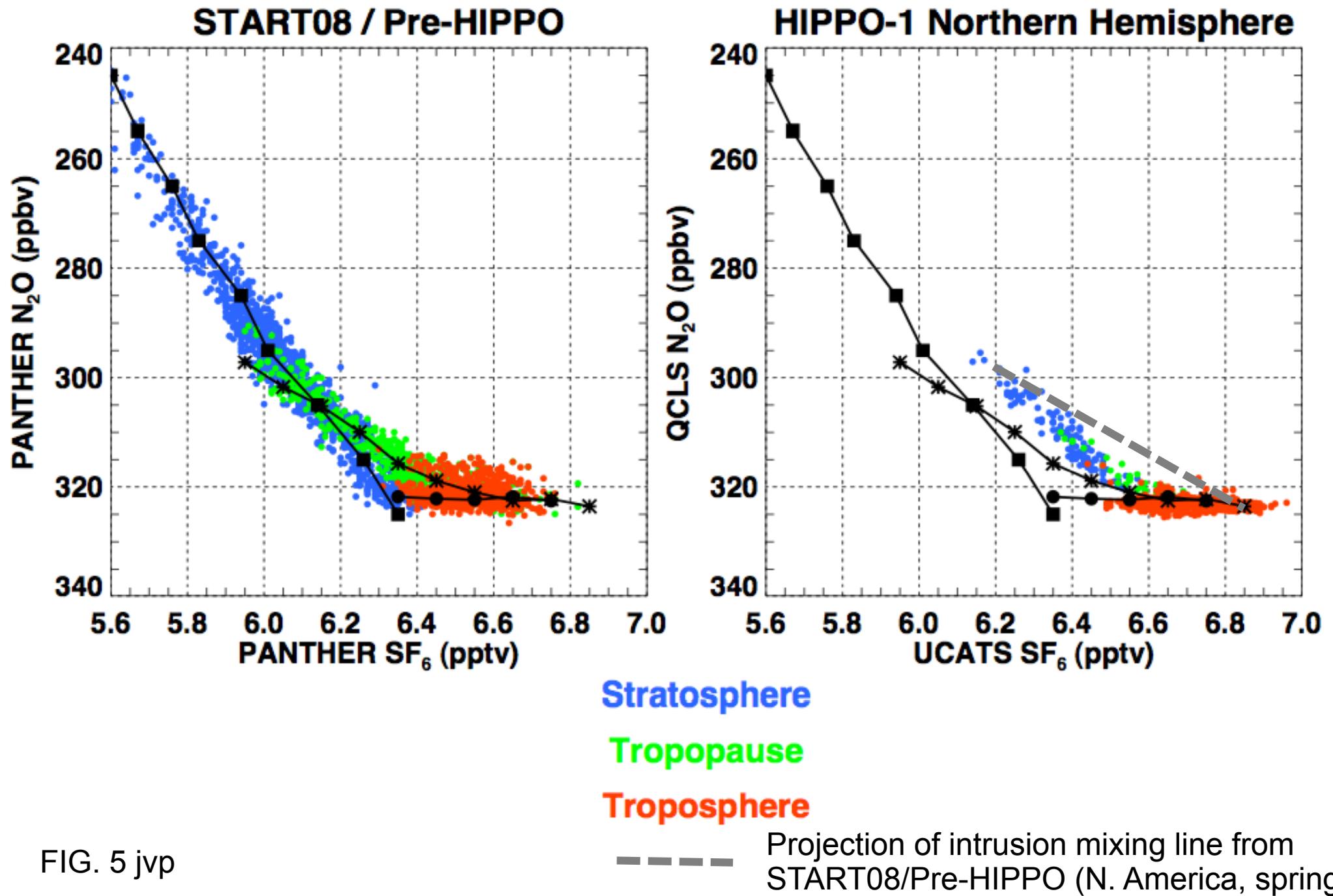
- The stratosphere has a major influence on the concentrations of tracers distributed through the troposphere. How well is this feature captured by models ?
- What do we learn about sources, versus transport, from latitude and altitude profiles ?

# HIPPO-1



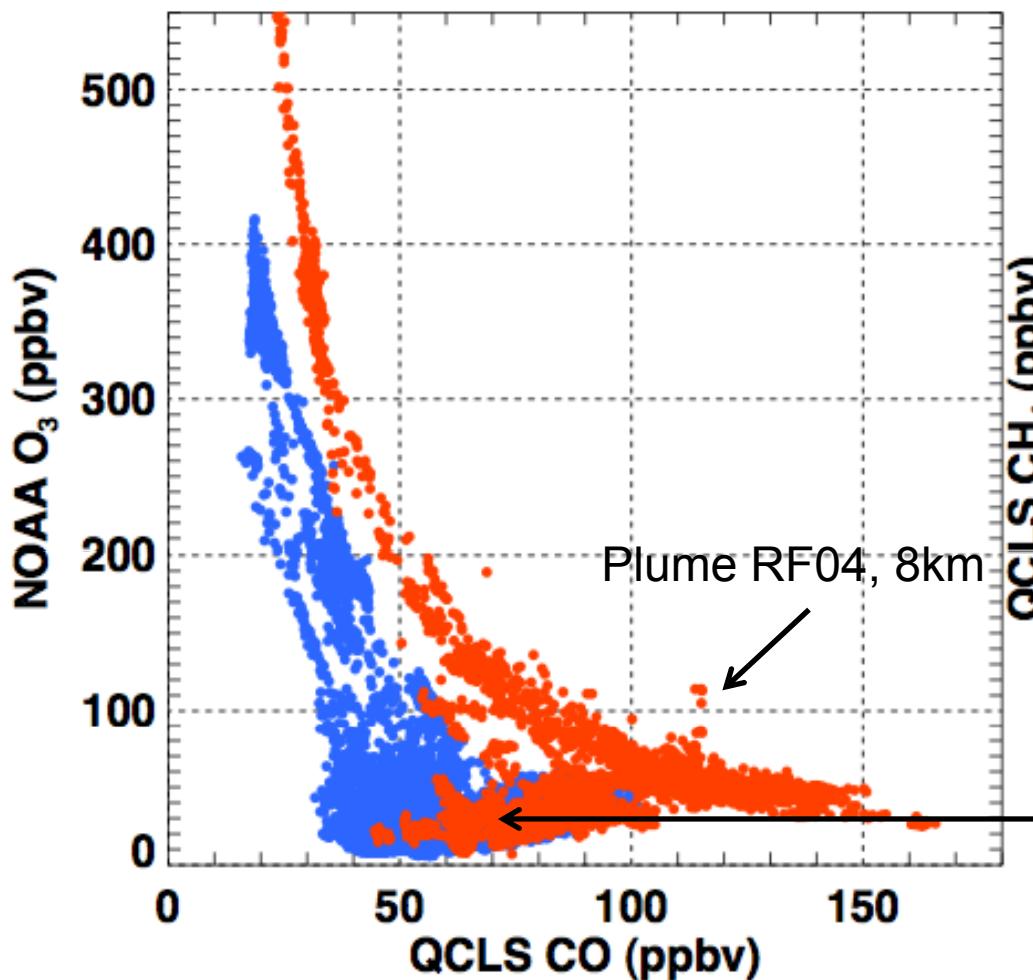
*HIPPO-1 spent ~13% of the campaign in the stratosphere;  
START08/Pre-HIPPO spent ~ 44%*

# Central Pacific flights, January 2009

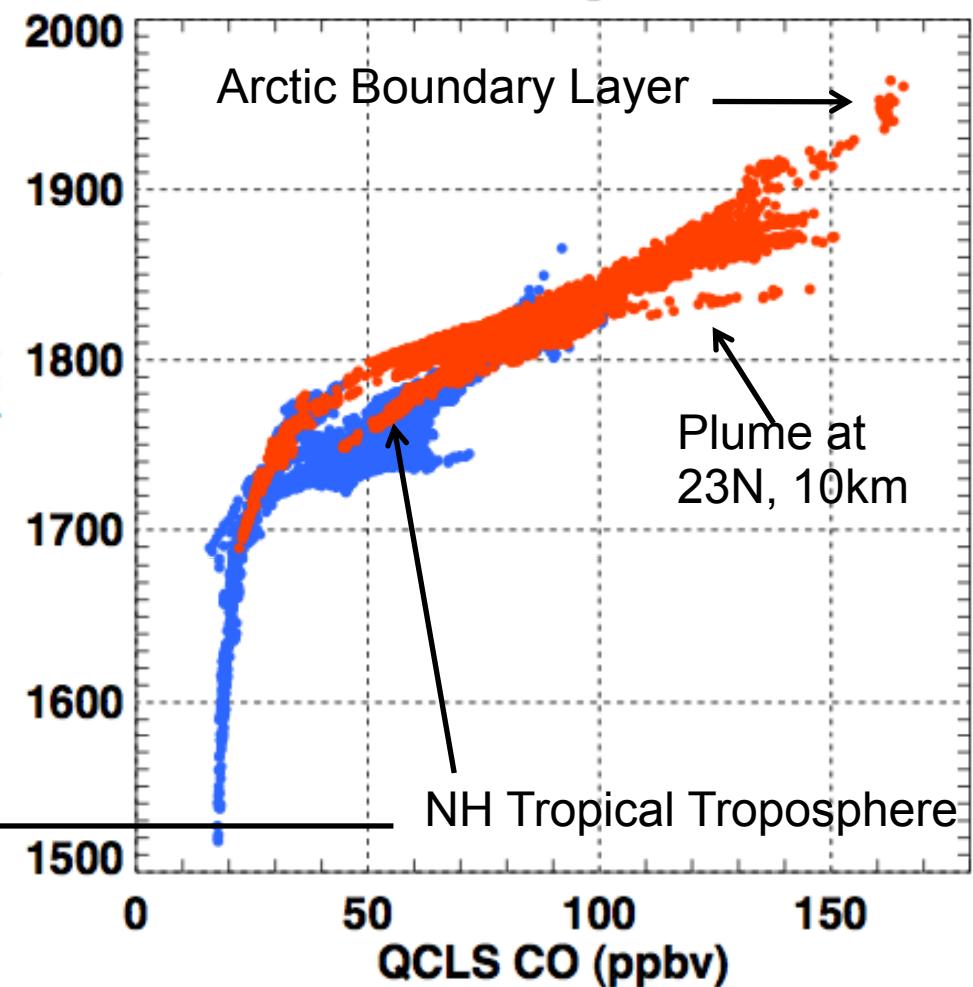


# Profiles over Ocean

HIPPO-1



HIPPO-1

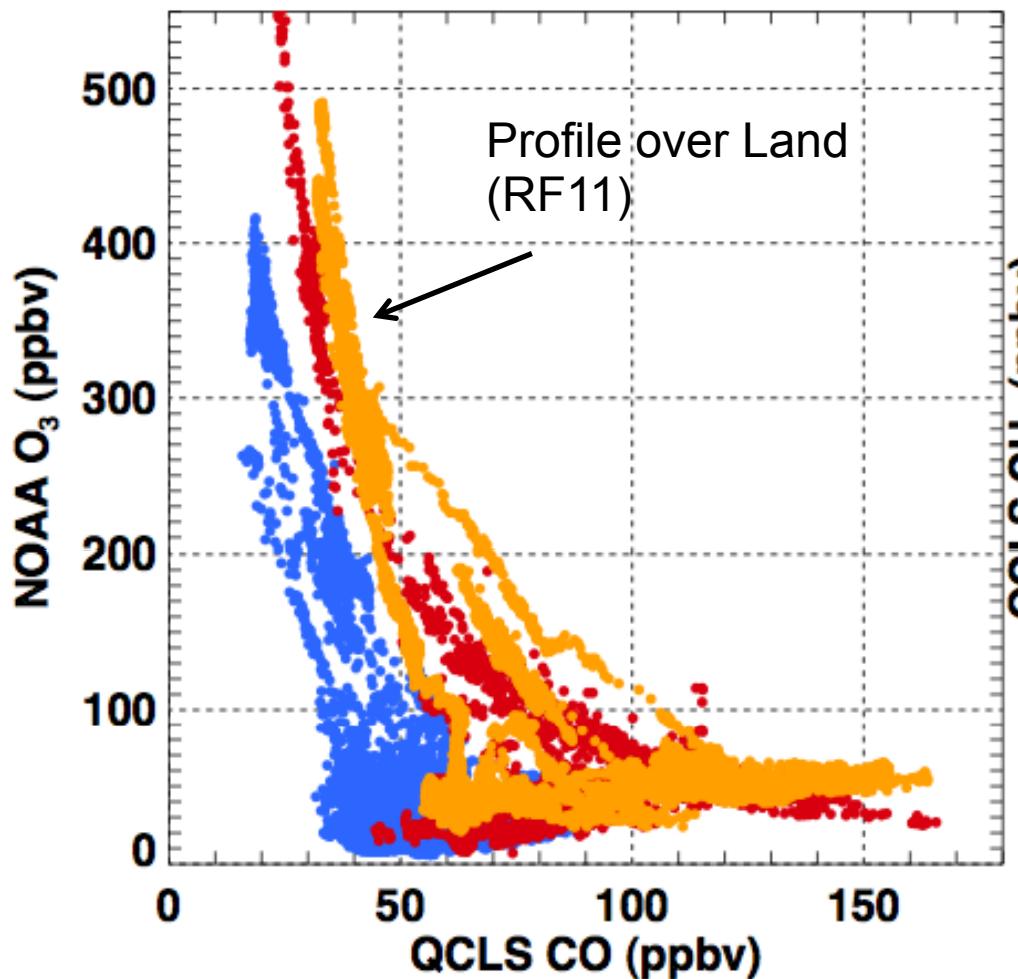


Northern Hemisphere  
Southern Hemisphere

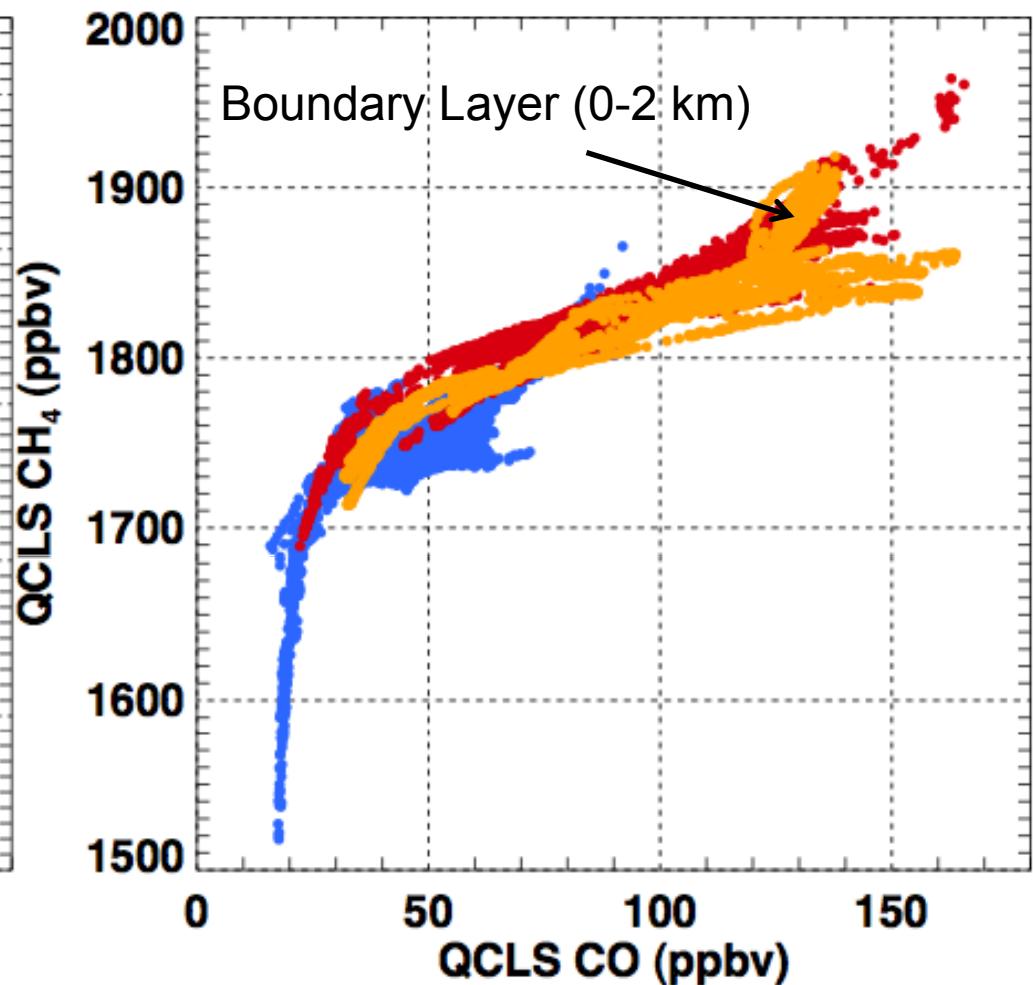
FIG. 7 jvp

# Profiles over Ocean and Land

HIPPO-1



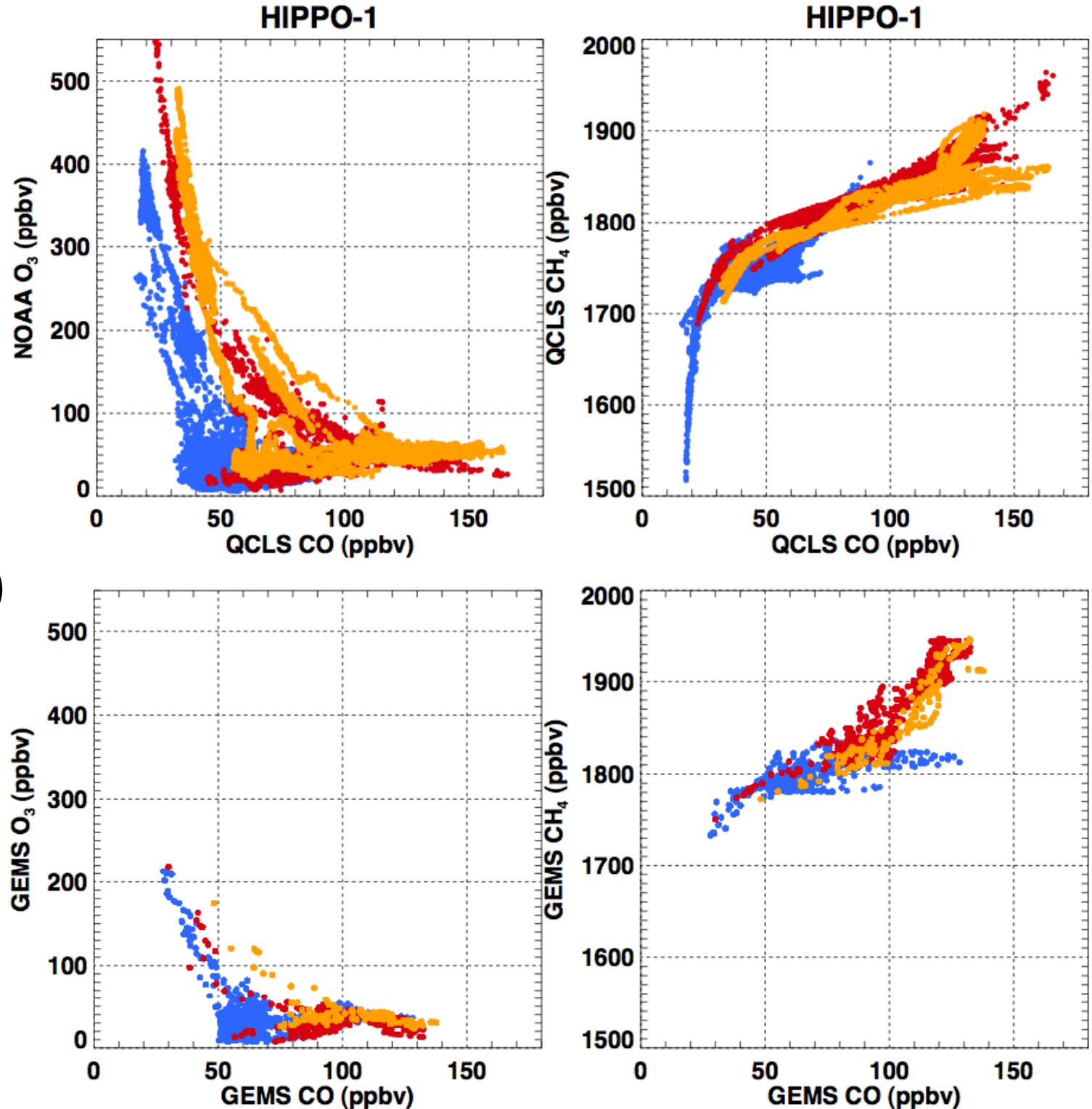
HIPPO-1



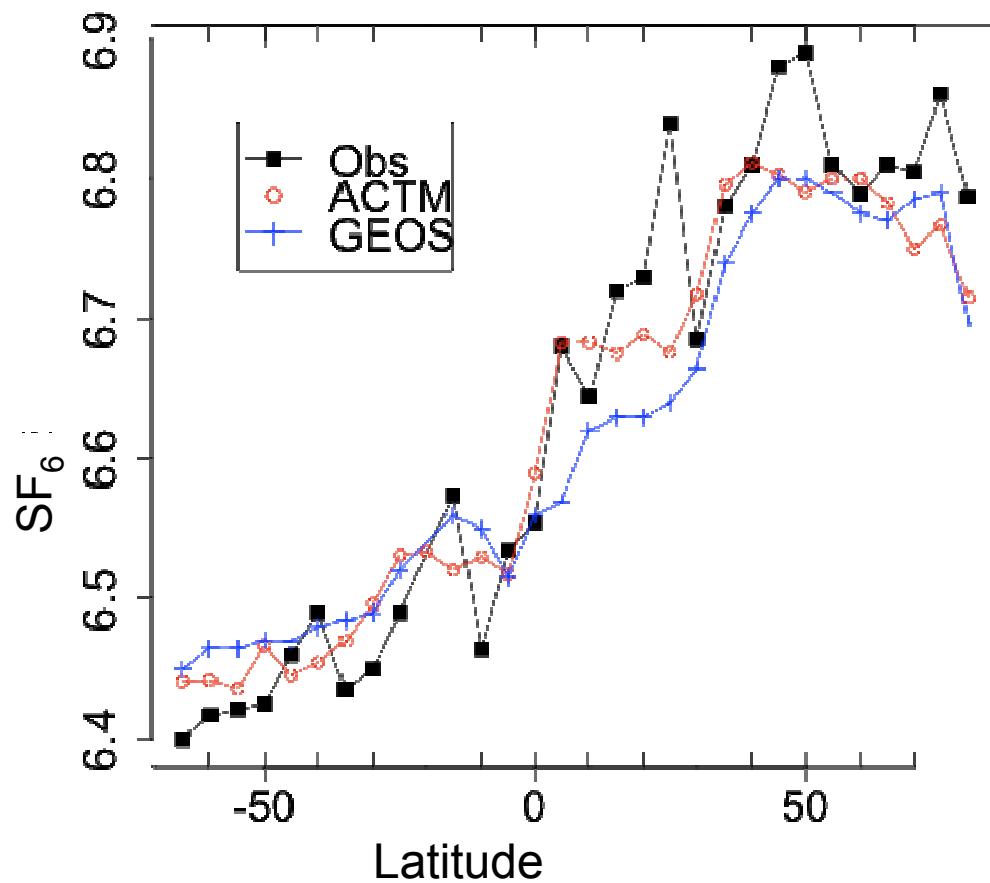
Northern Hemisphere  
Southern Hemisphere

Aircraft  
VS  
MACC (GEMS)  
Model  
(long-lived tracers)

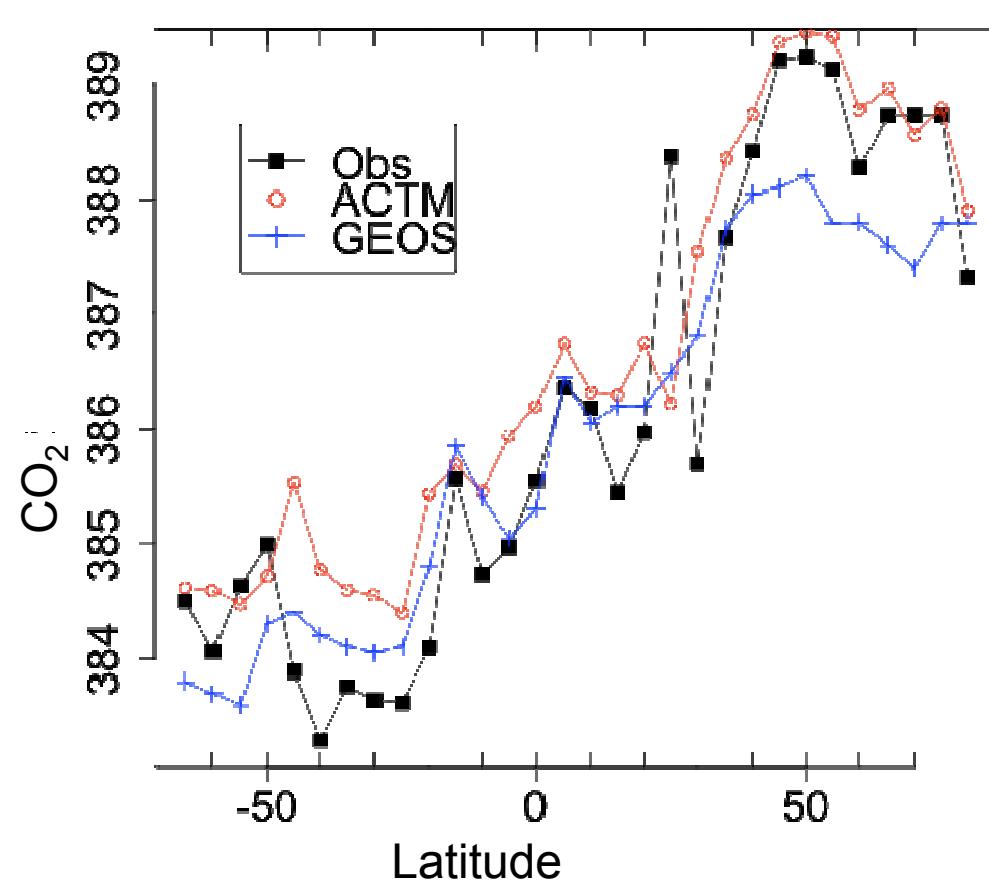
FIG. 9 jvp



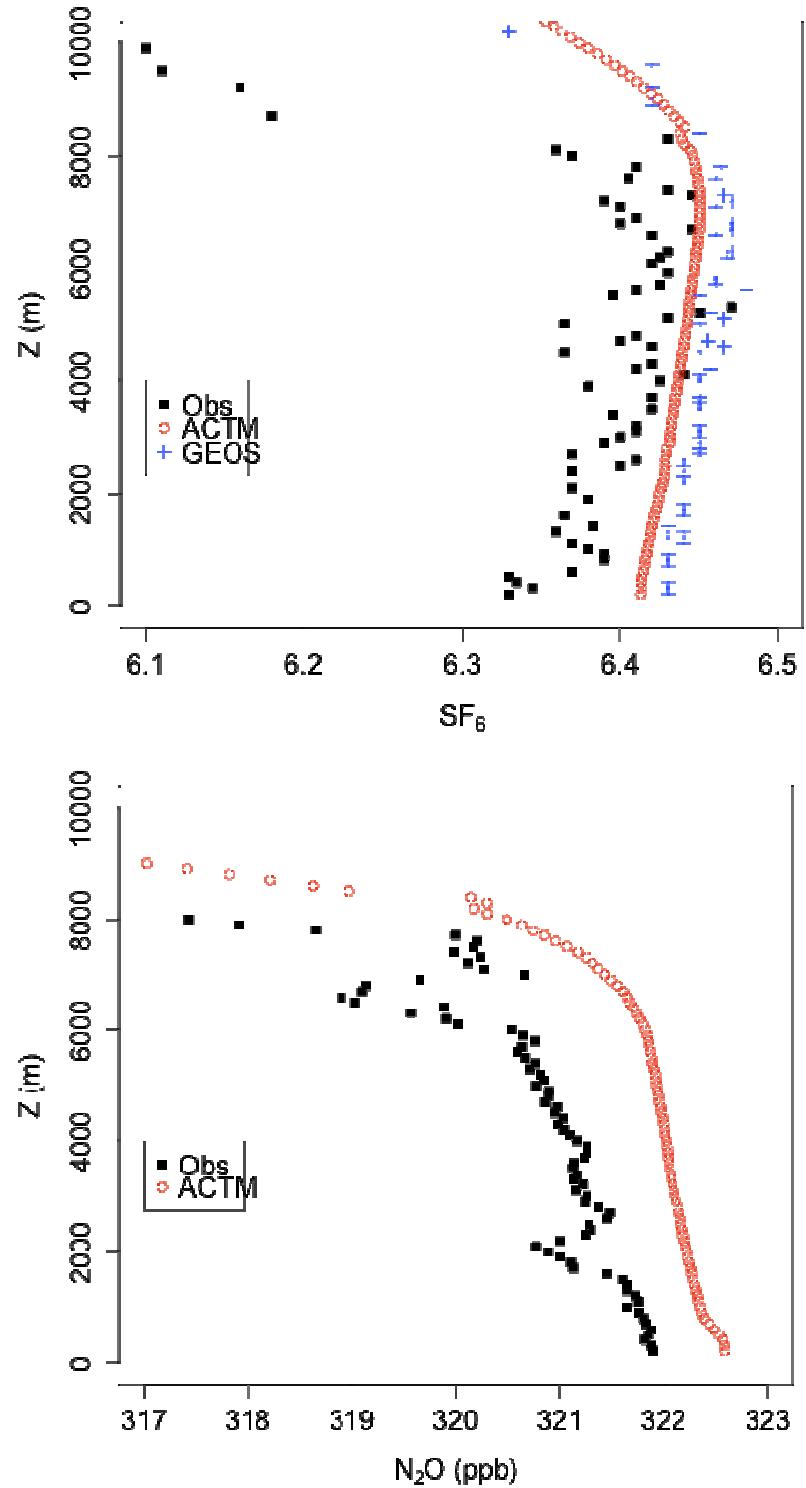
SF6\_UCATS P-weighted Tropospheric Mean



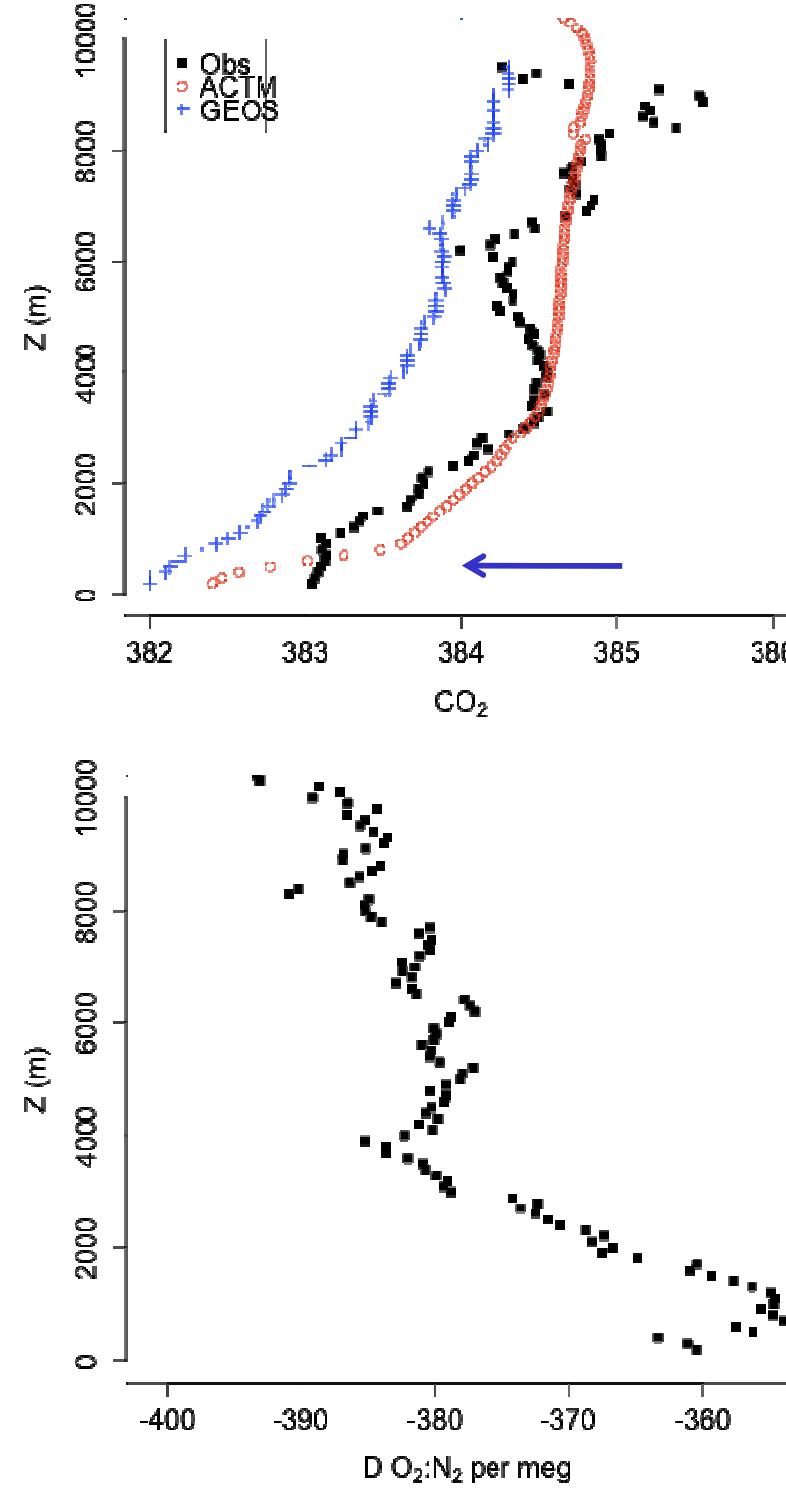
CO2\_QCLS P-weighted Tropospheric Mean



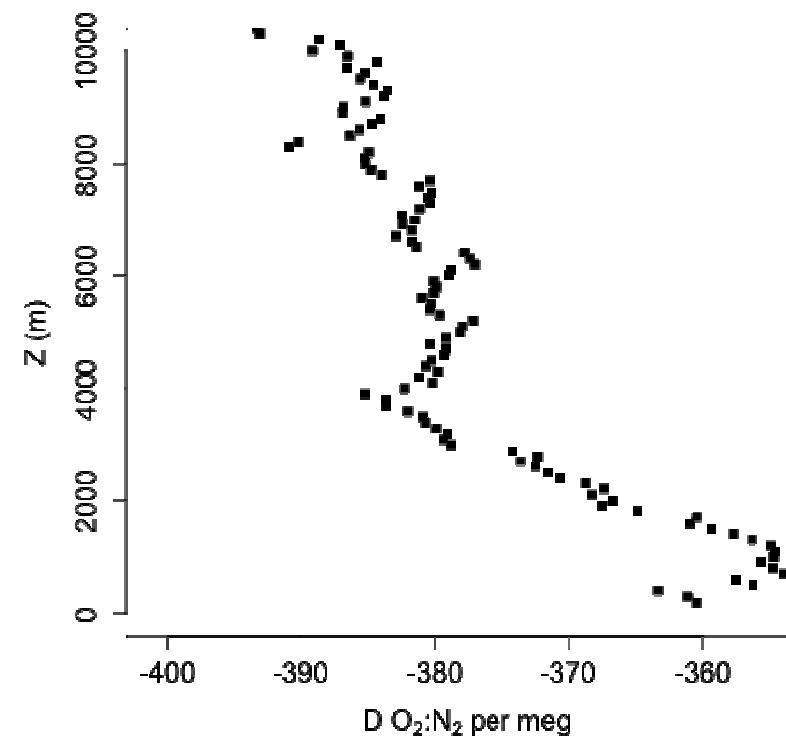
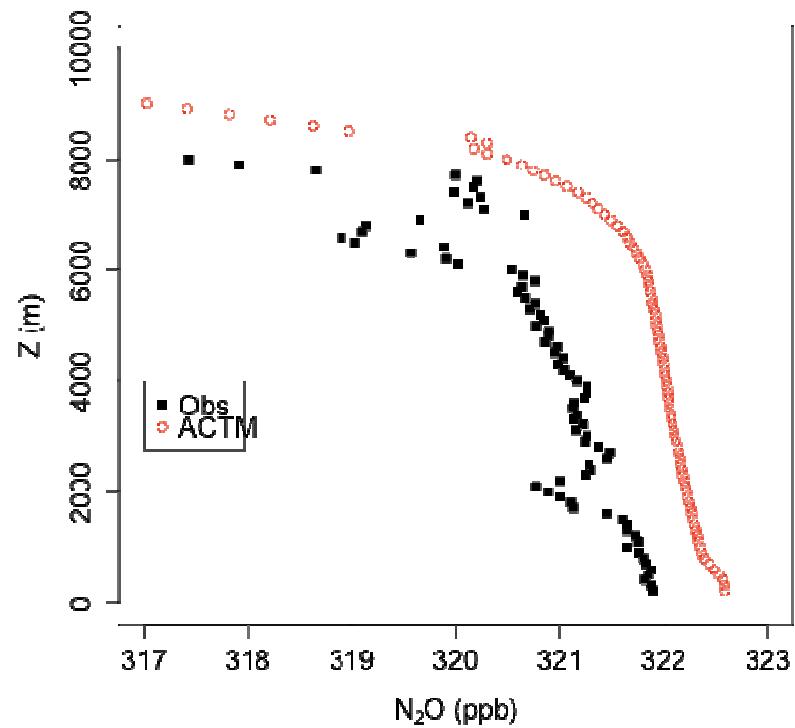
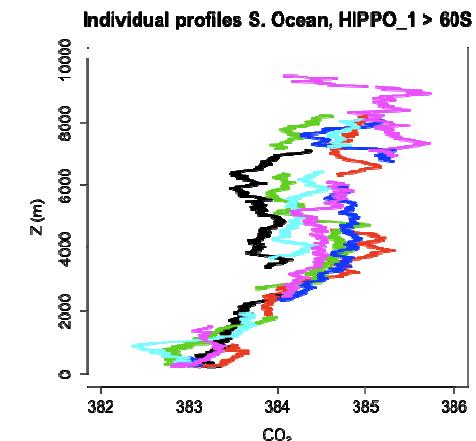
Mean of 6 S. Ocean Profiles



Mean of 6 S. Ocean Profiles

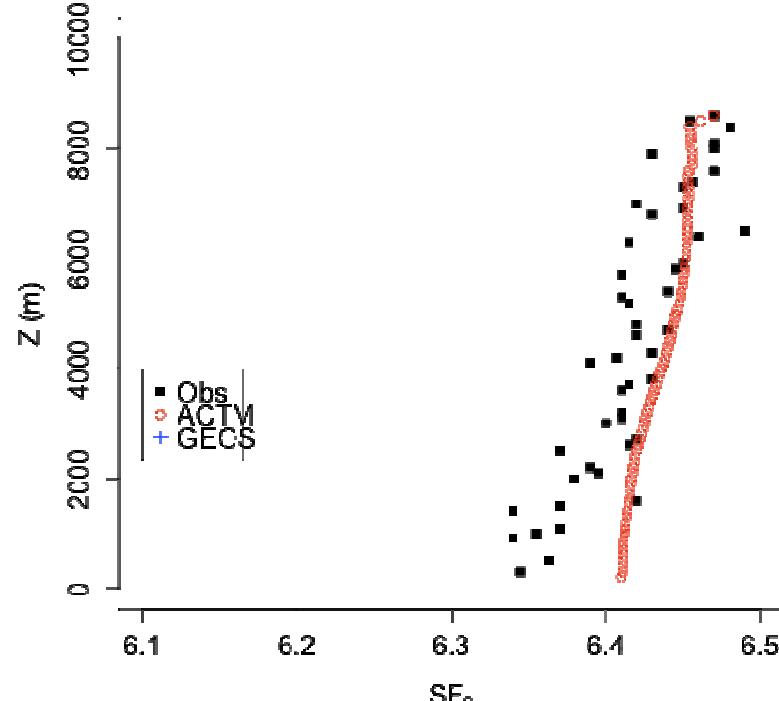


lat -60 to -70

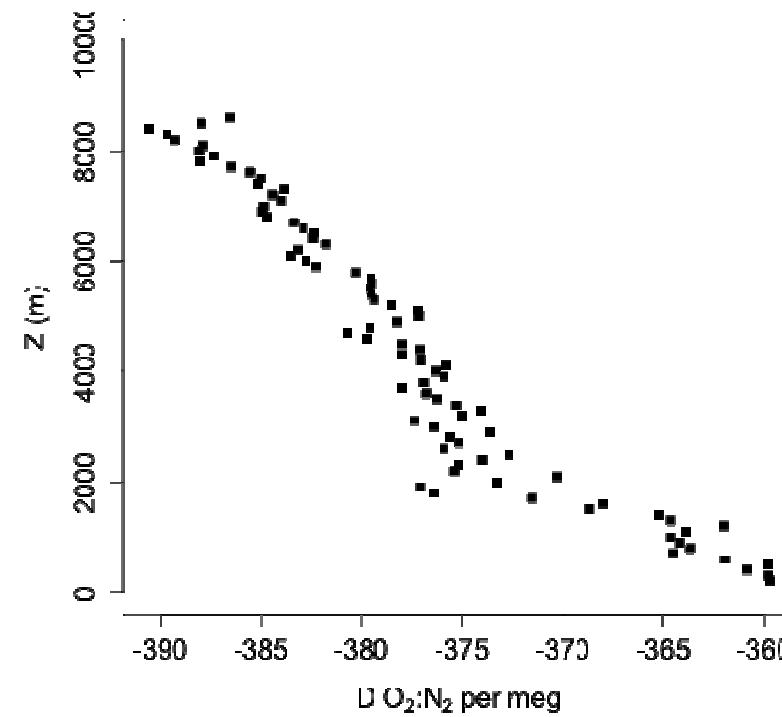
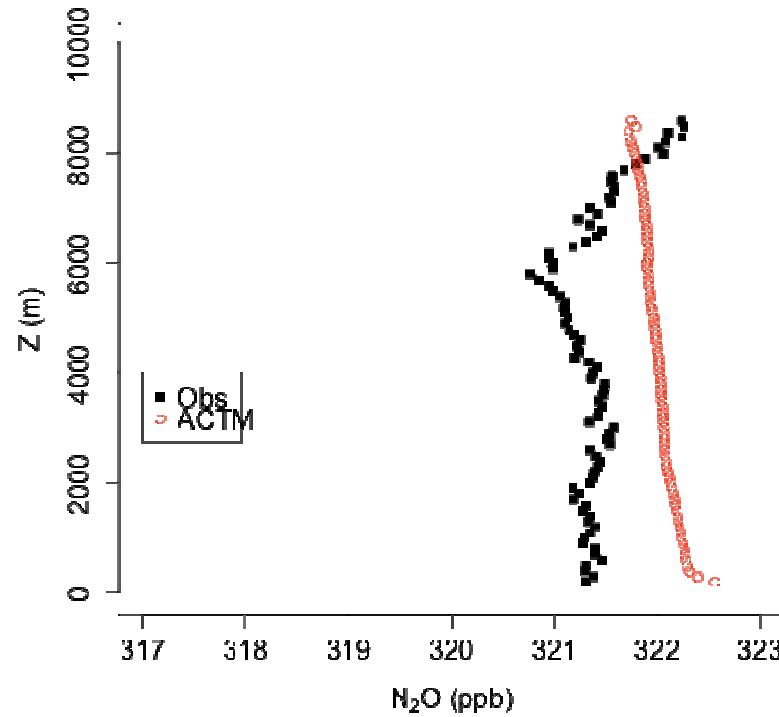
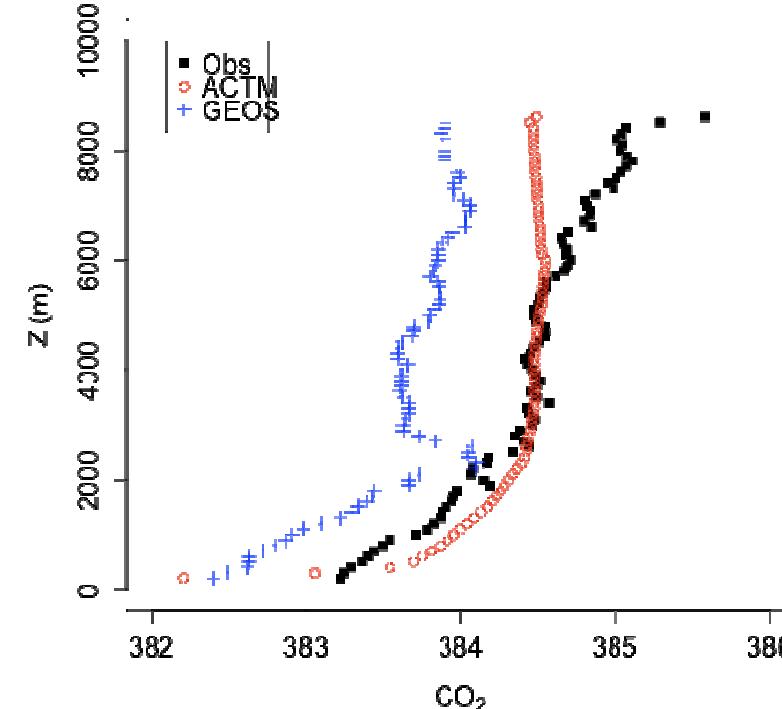


CO<sub>2</sub> and  
other gases  
in S. Polar  
regions

Mean of 5 Ocean Profiles -51 to -58

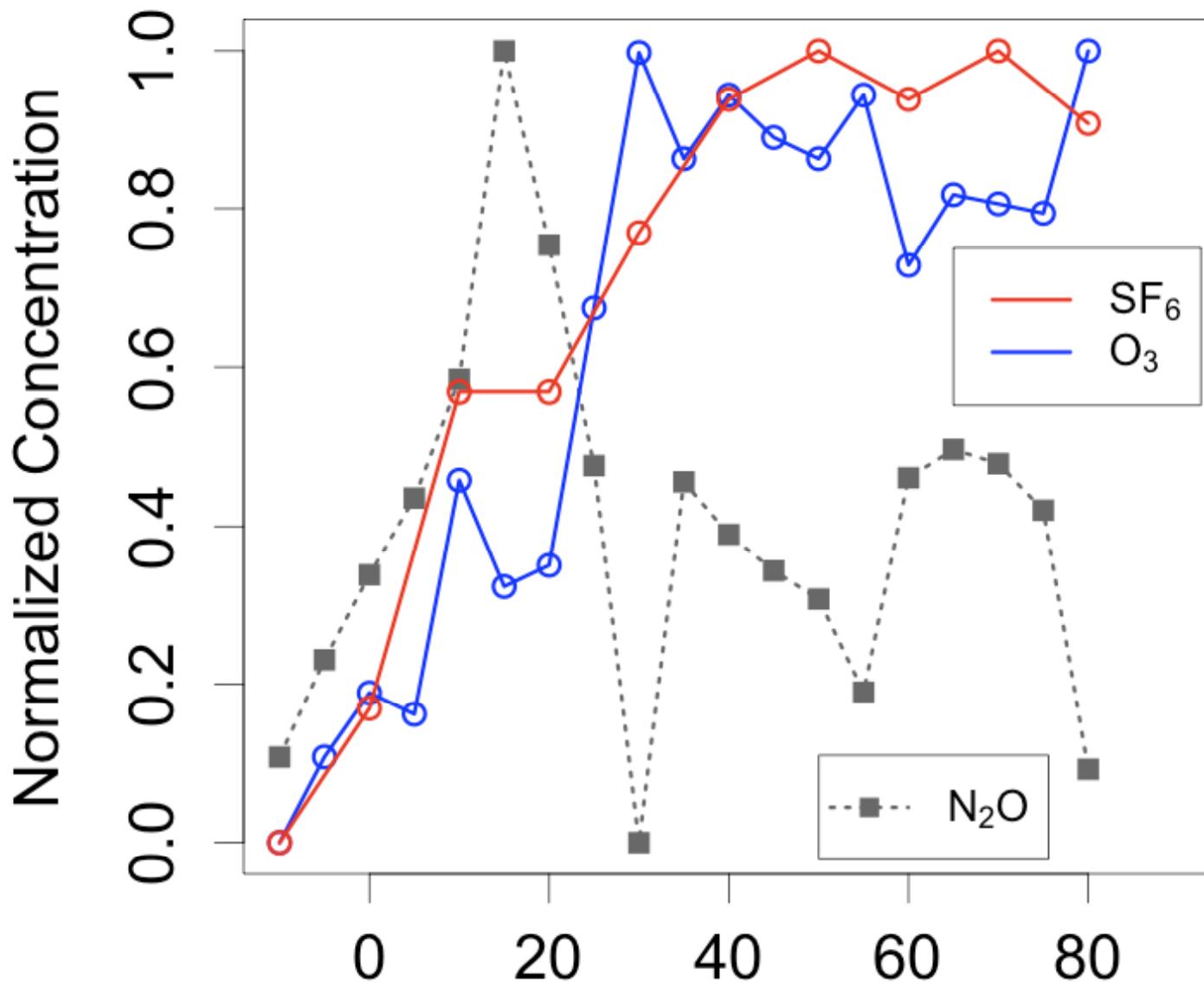


Mean of 5 Ocean Profiles -51 to -58



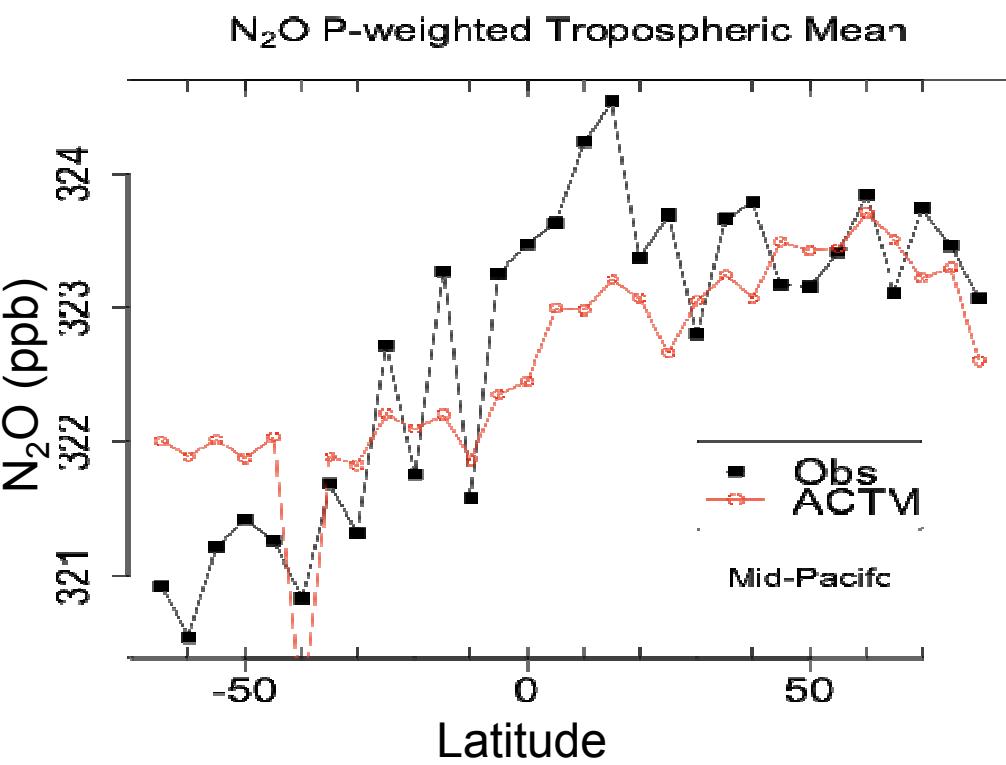
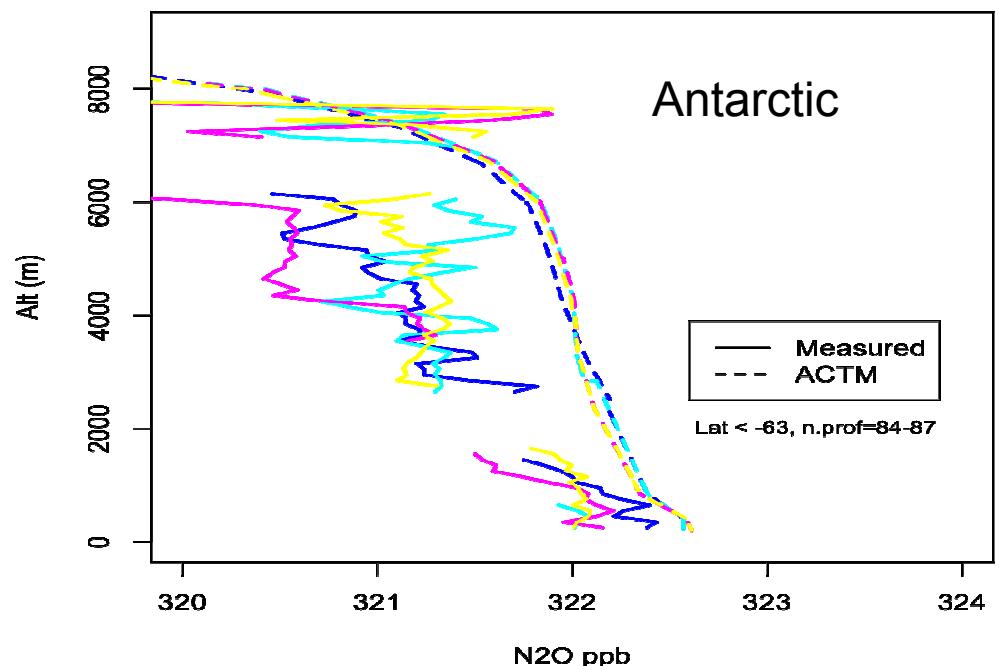
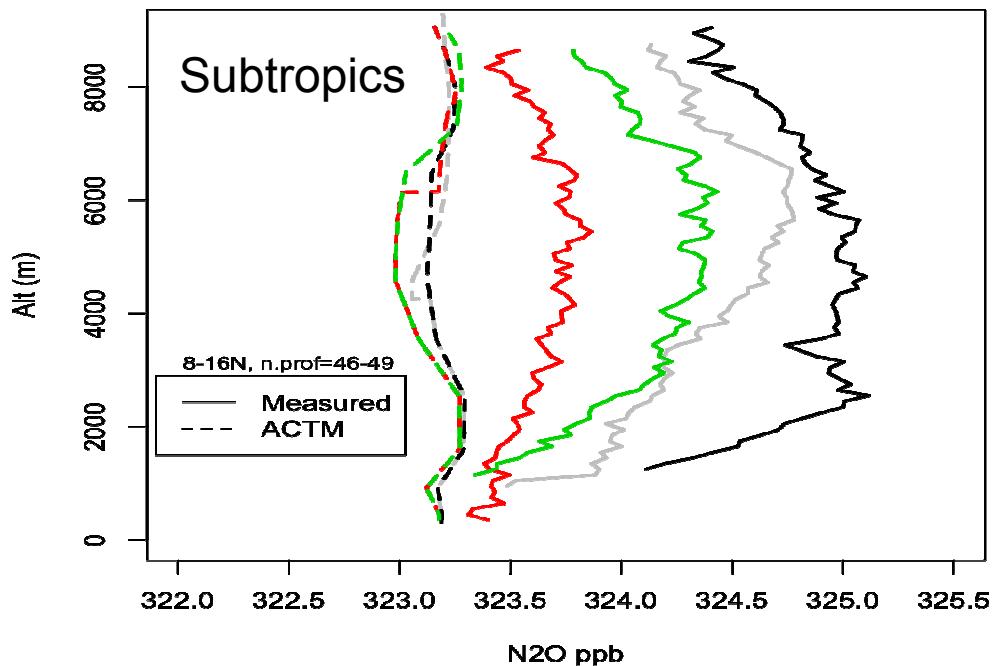
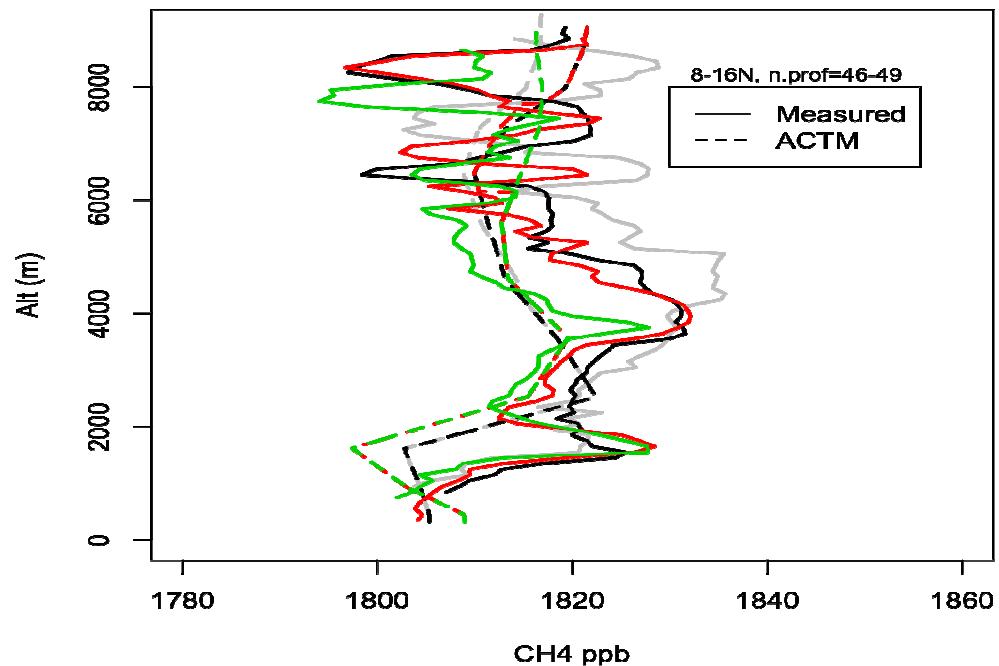
CO<sub>2</sub> and  
other gases  
in Southern  
Ocean area

# Northern Hemisphere Tropospheric Tracers of Strat/Trop Exchange

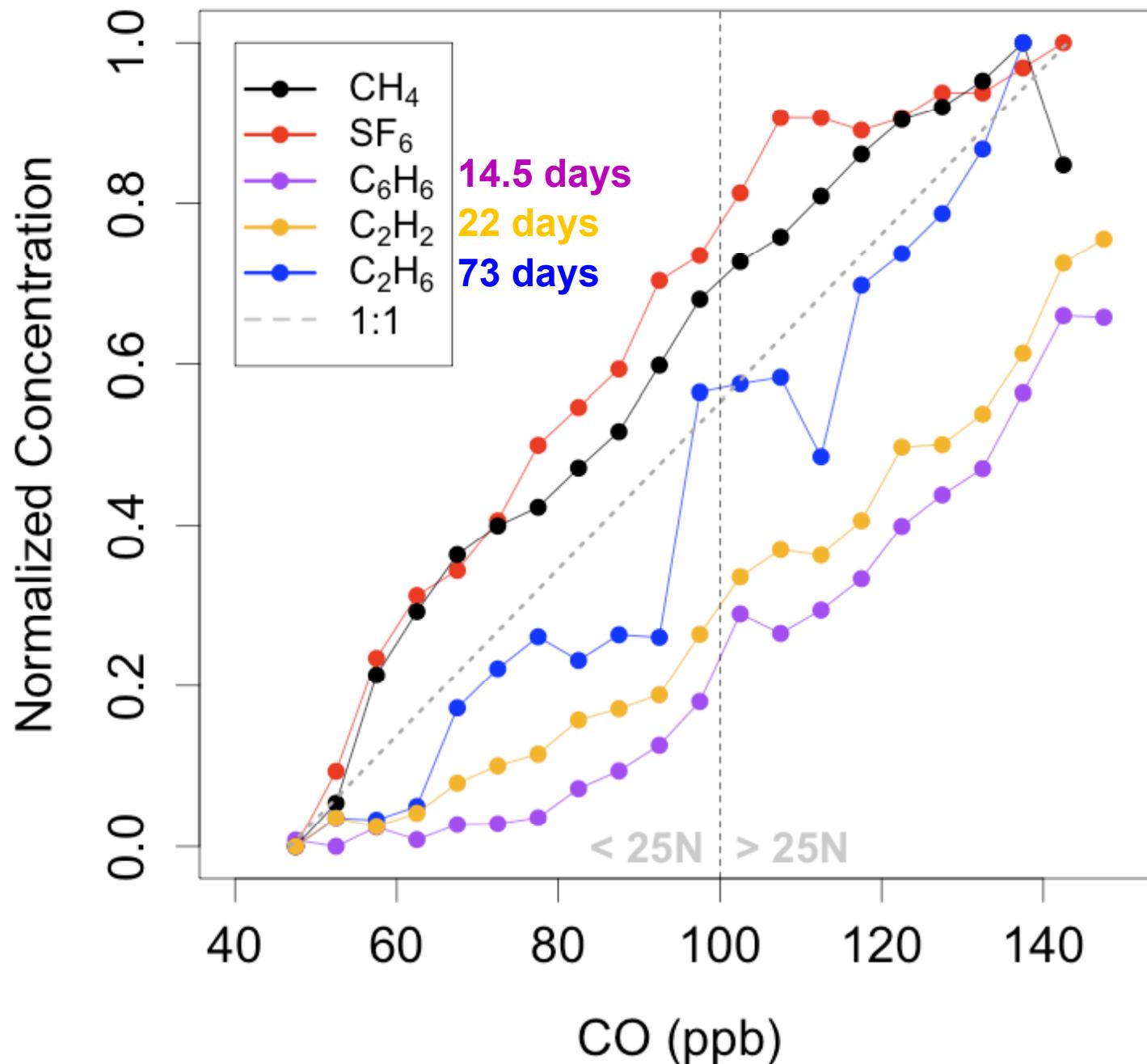


$$(\bar{X} - \bar{X}_{\min}) / (\bar{X}_{\max} - \bar{X}_{\min})$$

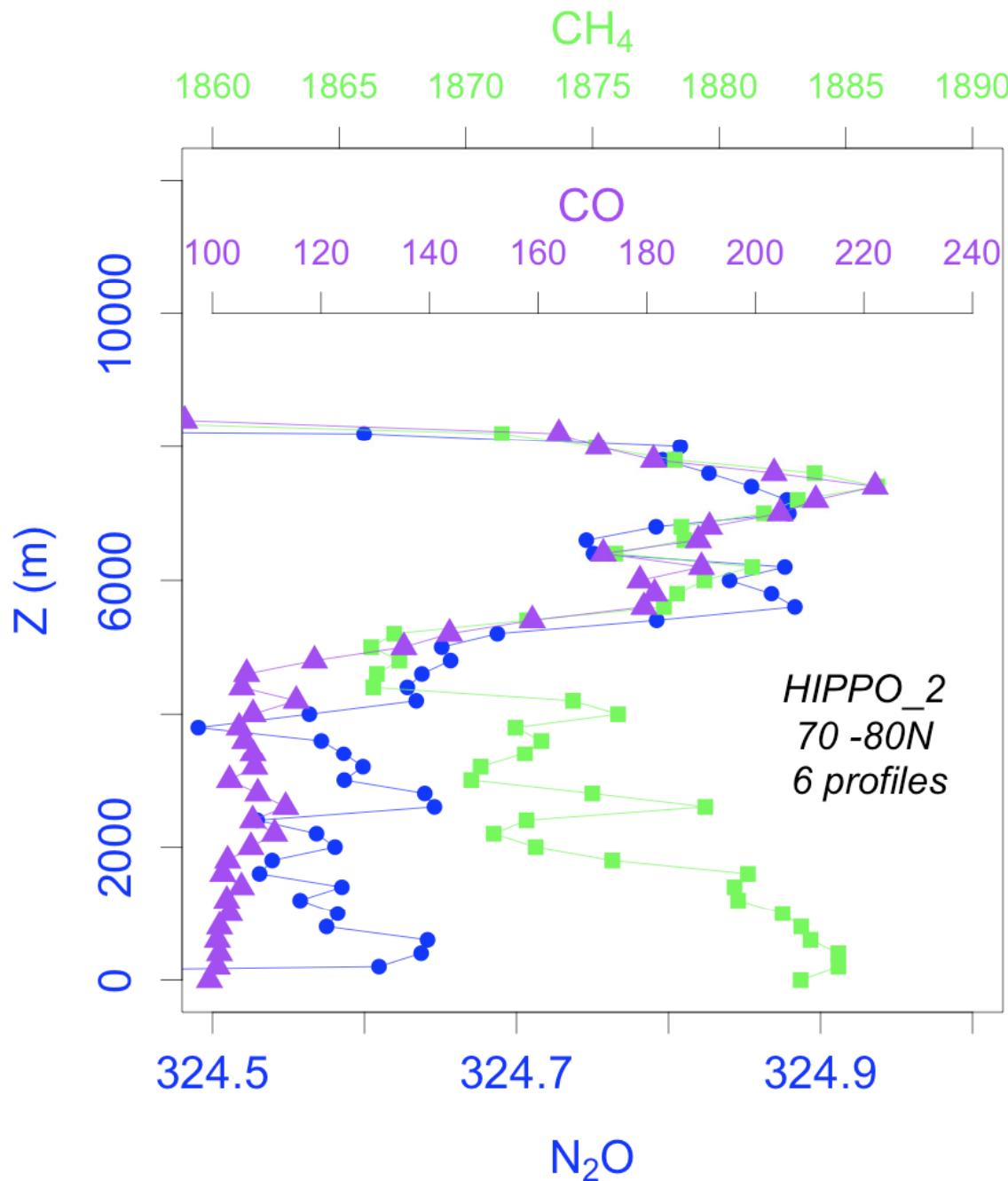
Latitude



# Northern Hemisphere Tropospheric Tracers of Non-Conservative Transport



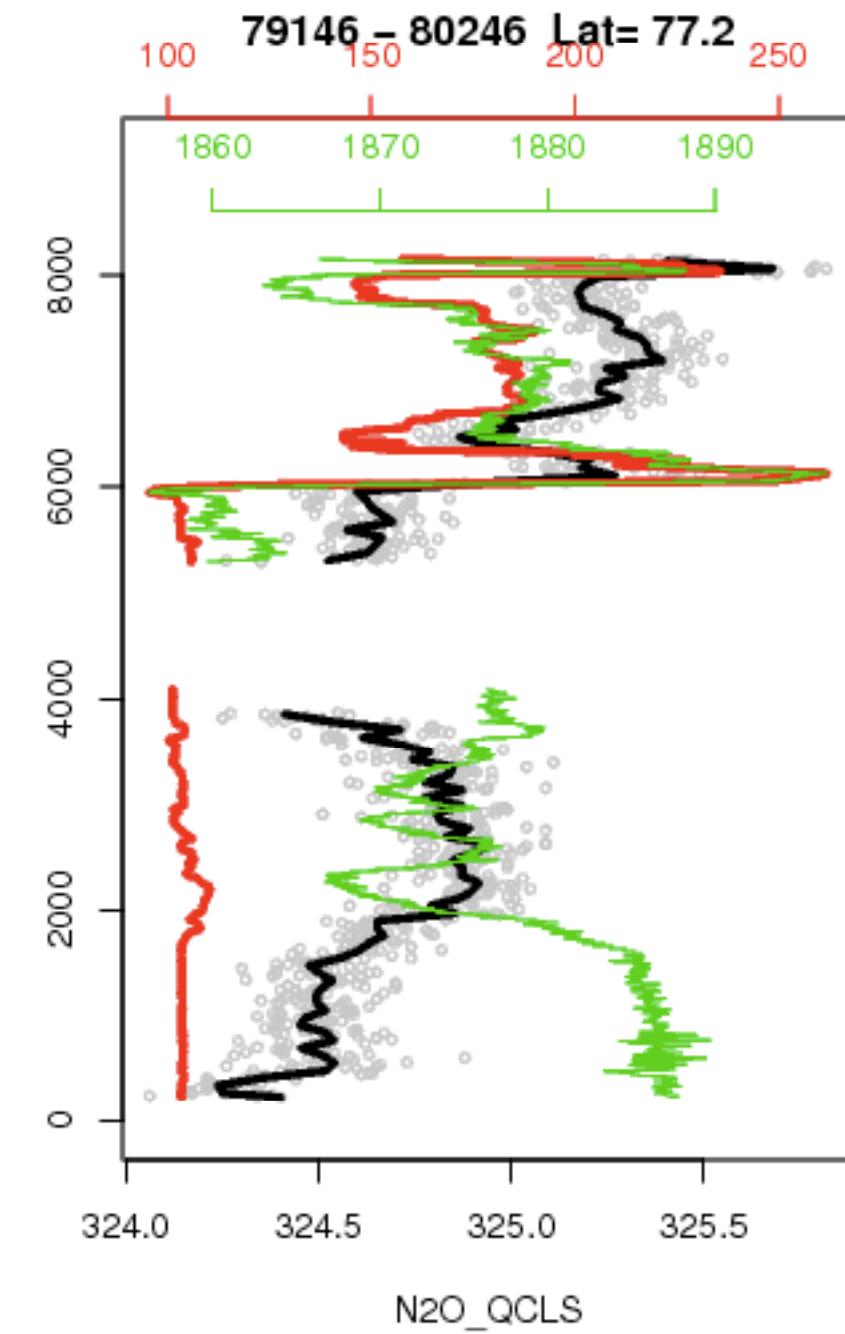
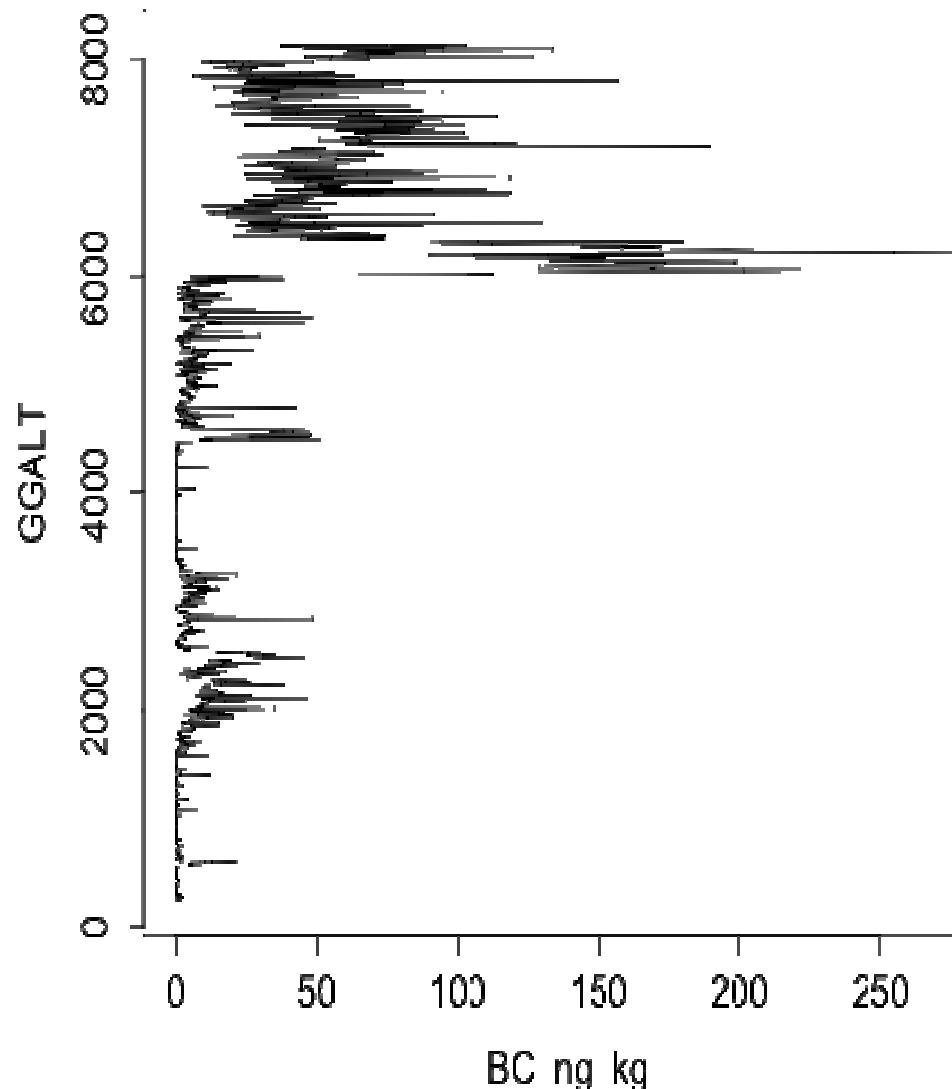
# HIPPO\_2: High-altitude pollution phenomena in the Arctic



78N latitude, 160W (north of Barrow) 04 Nov 2009  
*moonrise, haze, black carbon*

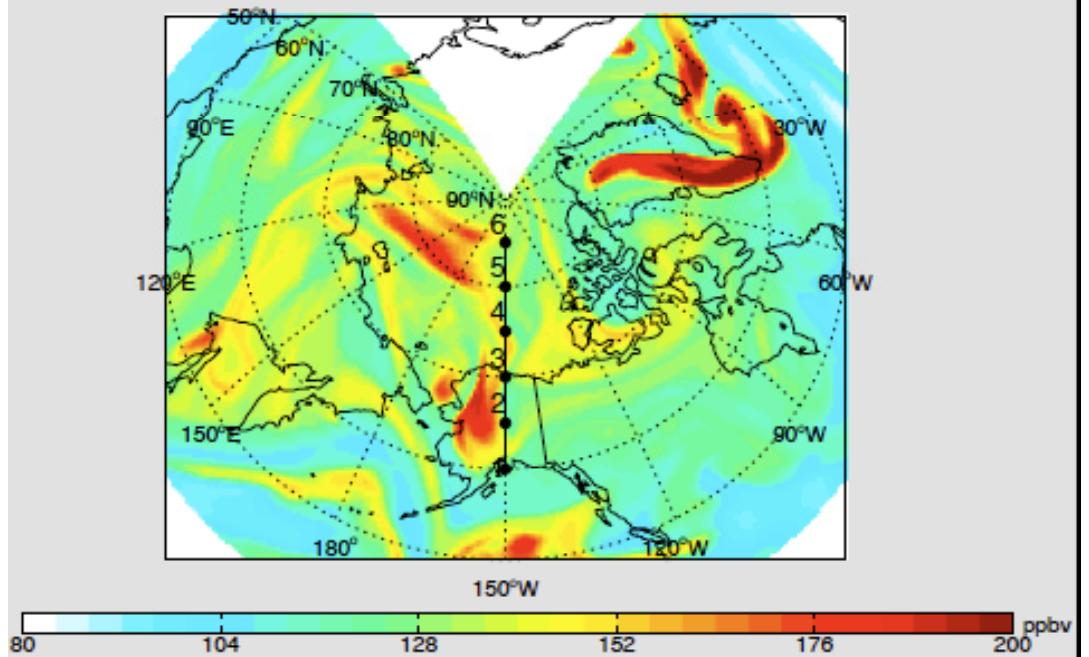


**20091102 NOAA SP2 Black Carbon Loading  
77.2 N Lat**

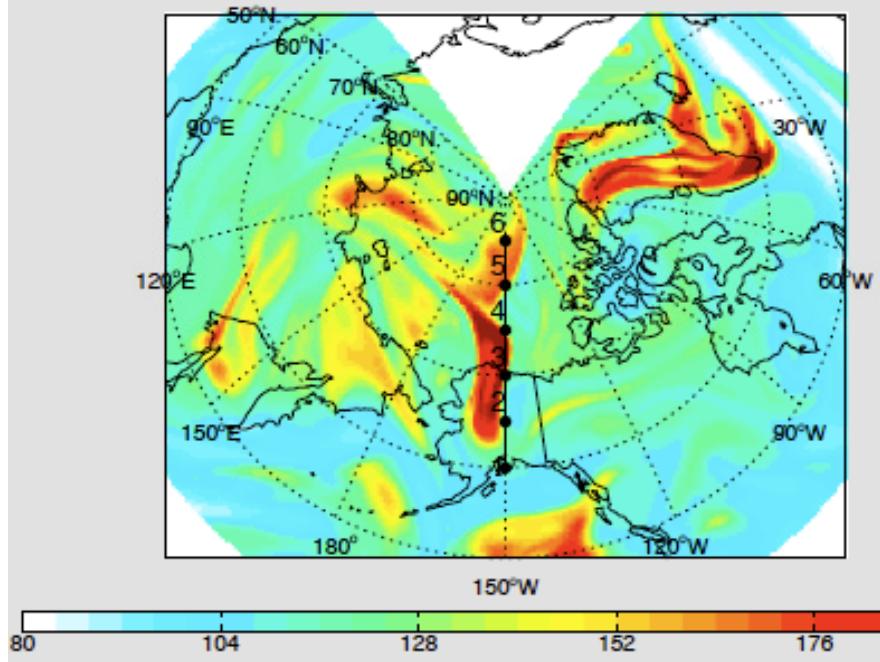


Urban plumes (Dallas, Houston): 500-600 ng/kg  
Texas non-urban: 50-100 (USA) (Schwartz et al., 2008)

CO MIXING RATIO  
500 hPa ( 5.6 km) 20091102 22:30Z



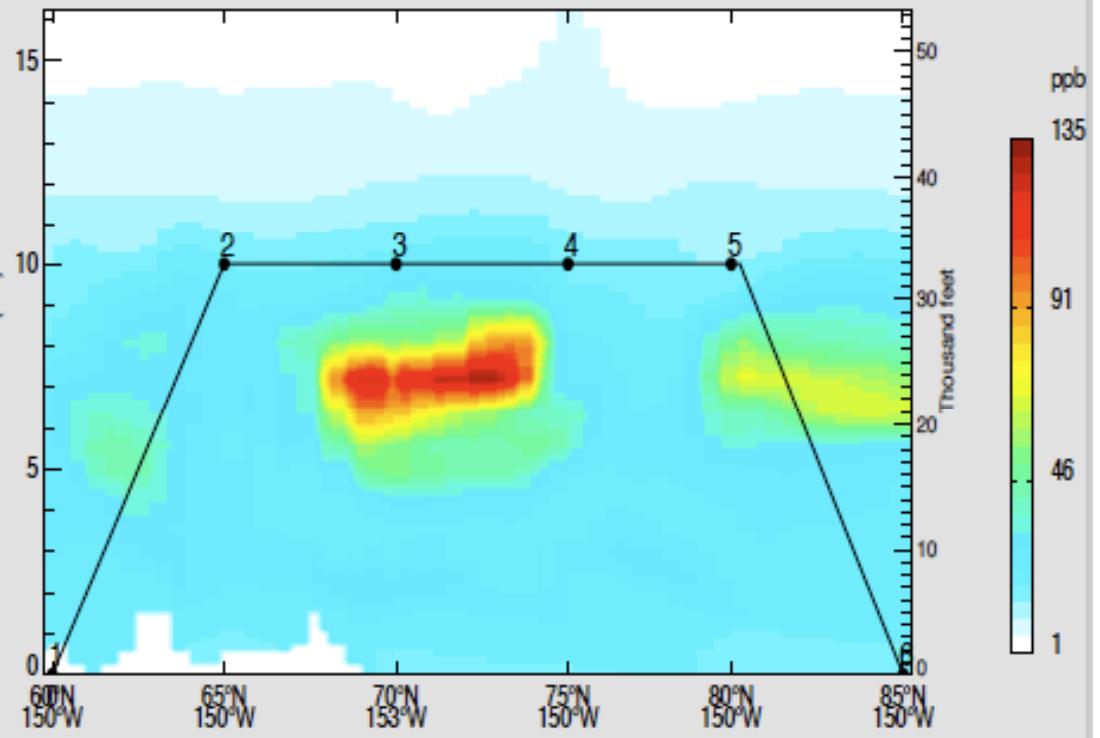
CO MIXING RATIO  
400 hPa ( 7.2 km) 20091102 22:30Z



# HIPPO\_2:

Pollution from Asia  
covered a vast area of  
the Arctic on 02 Nov  
2009

Curtain plot  
CO - ANTHROPOGENIC (ASIA) 20091102 22:30Z

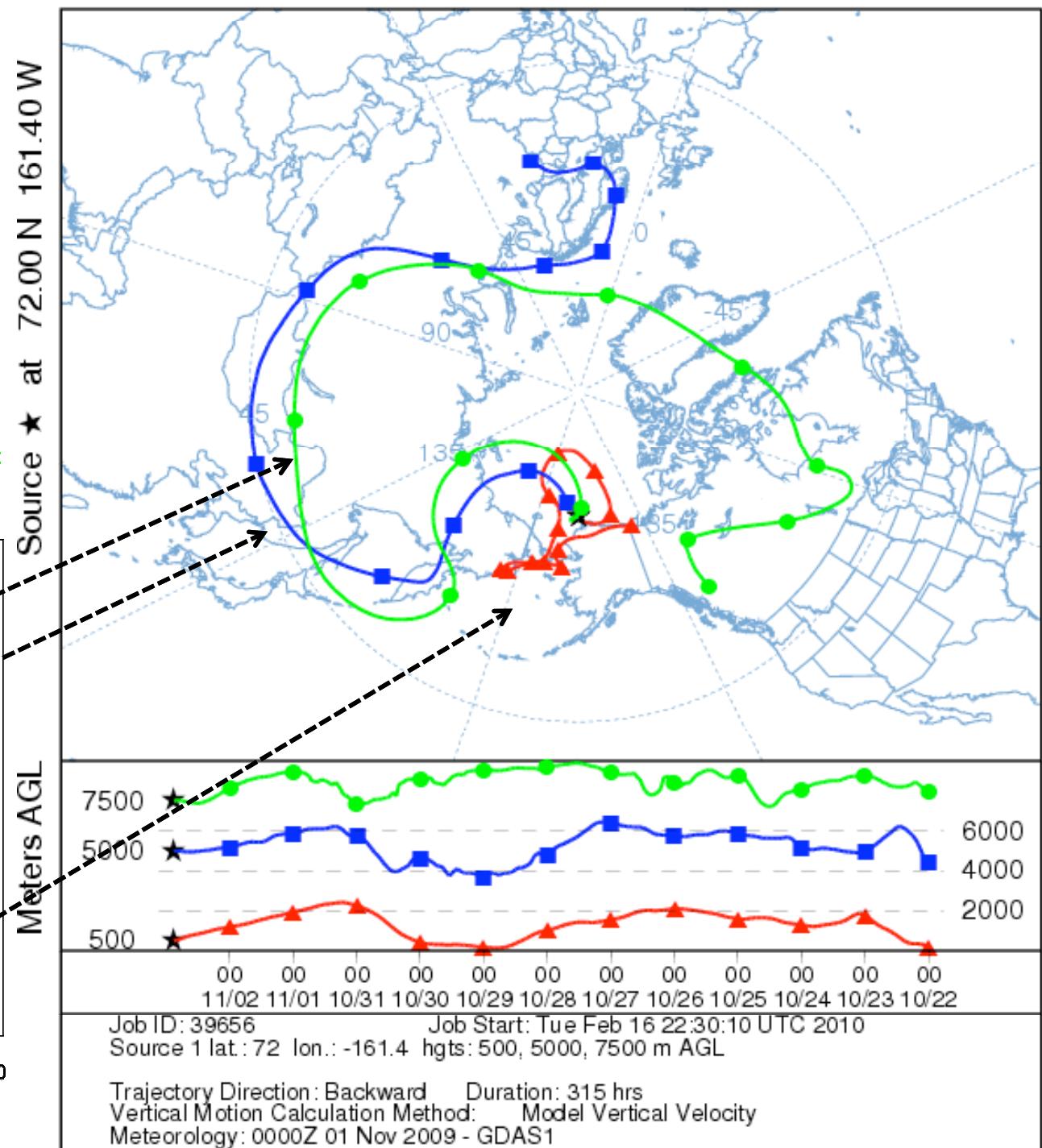
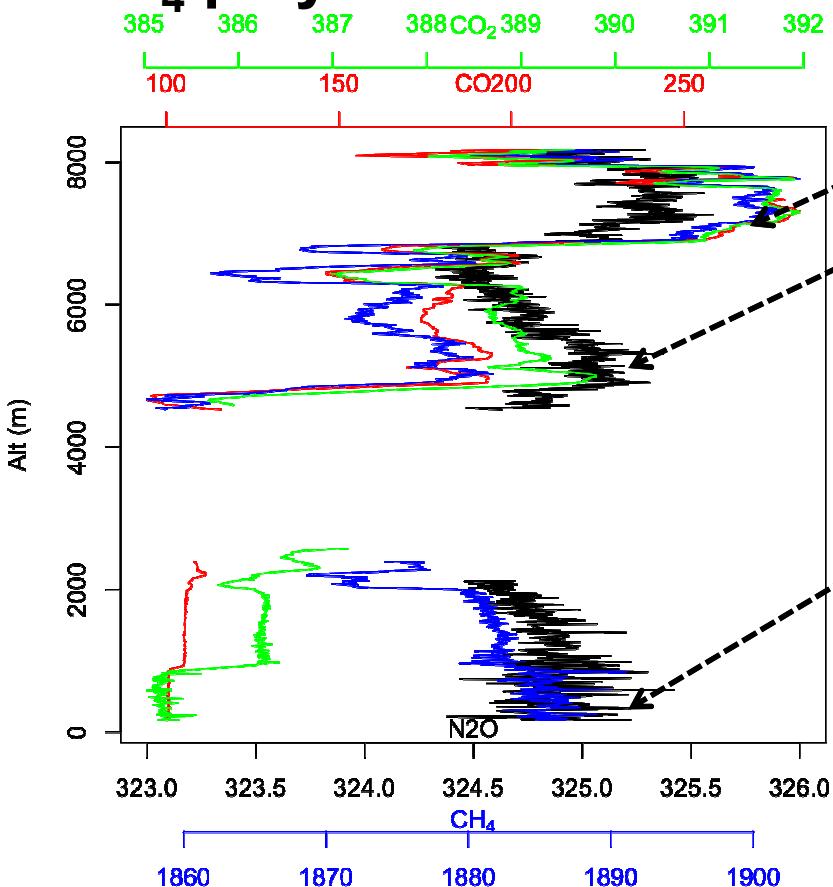


## H2 Profile 19

NOAA HYSPLIT MODEL  
Backward trajectories ending at 2100 UTC 02 Nov 09  
GDAS Meteorological Data

How do anomalies arise? How is a profile composed?

Arctic, very dense high-altitude pollution juxtaposed with "a pure CH<sub>4</sub> play"

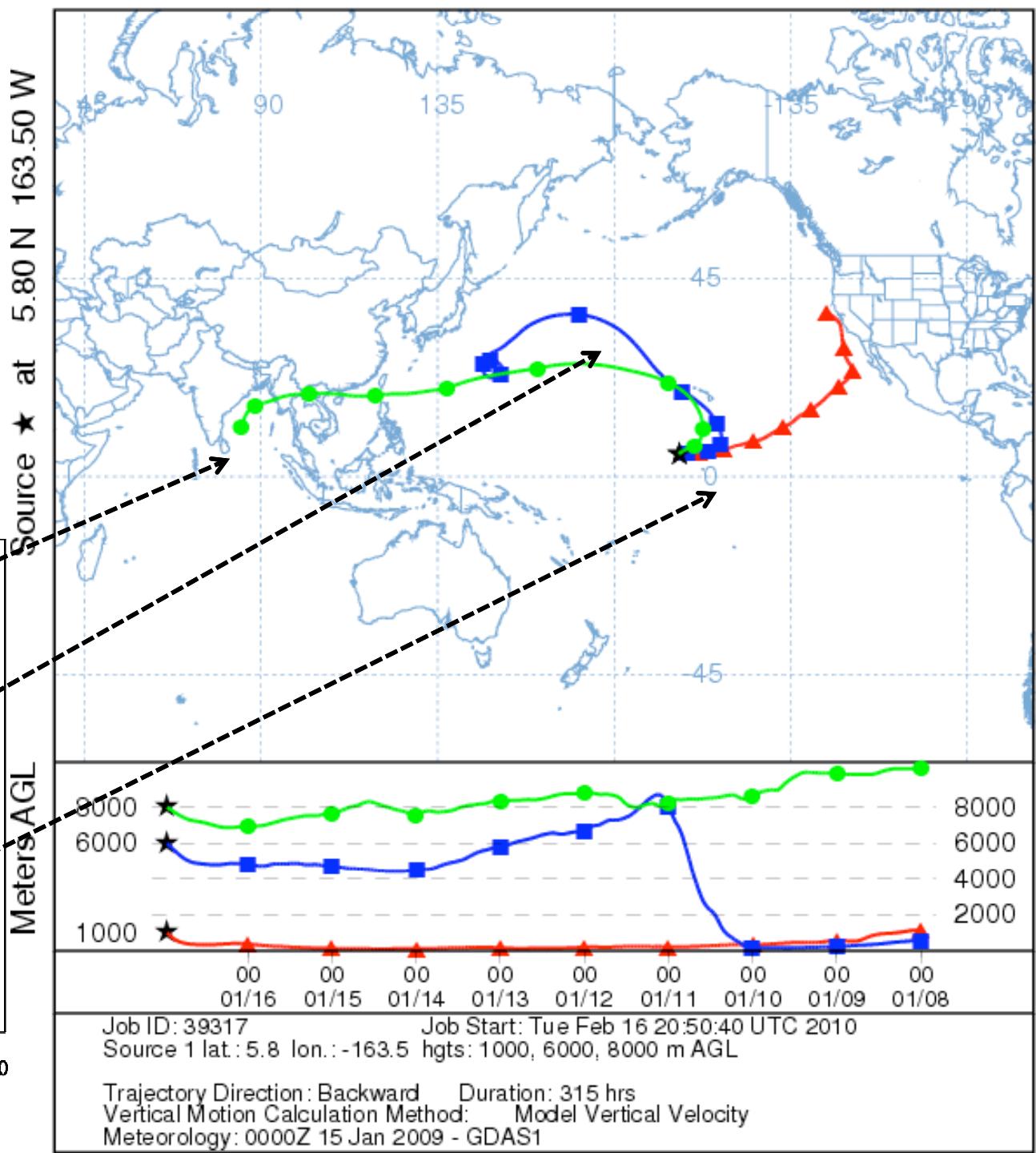
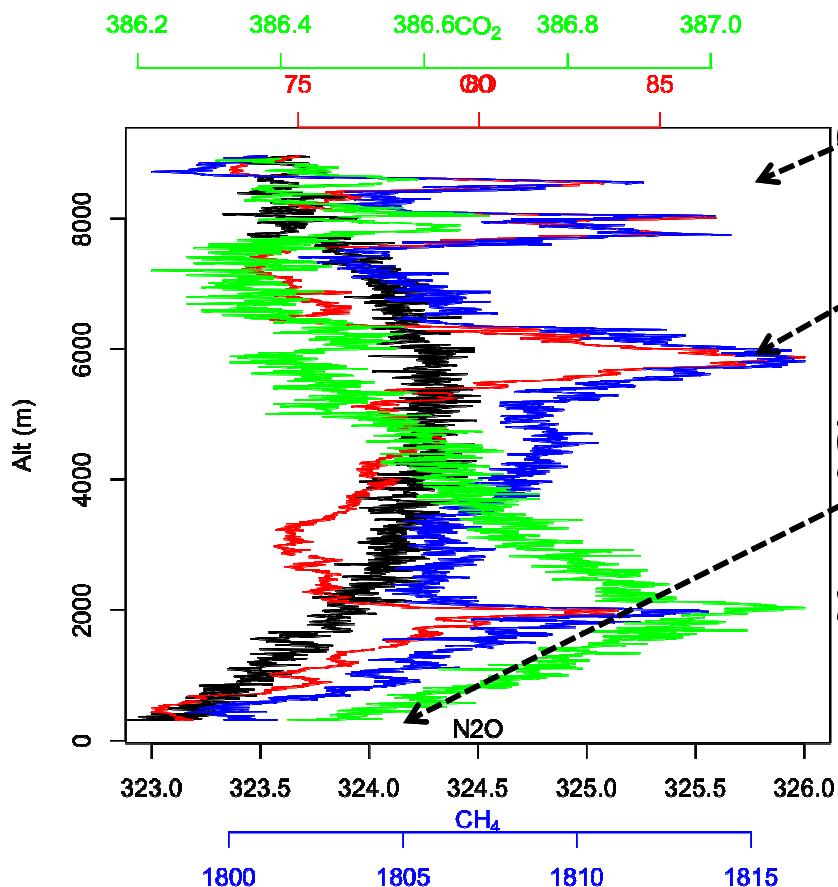


NOAA HYSPLIT MODEL  
Backward trajectories ending at 2300 UTC 16 Jan 09  
GDAS Meteorological Data

H1 Profile 51

How do anomalies arise? How is a profile composed?

Central Pacific

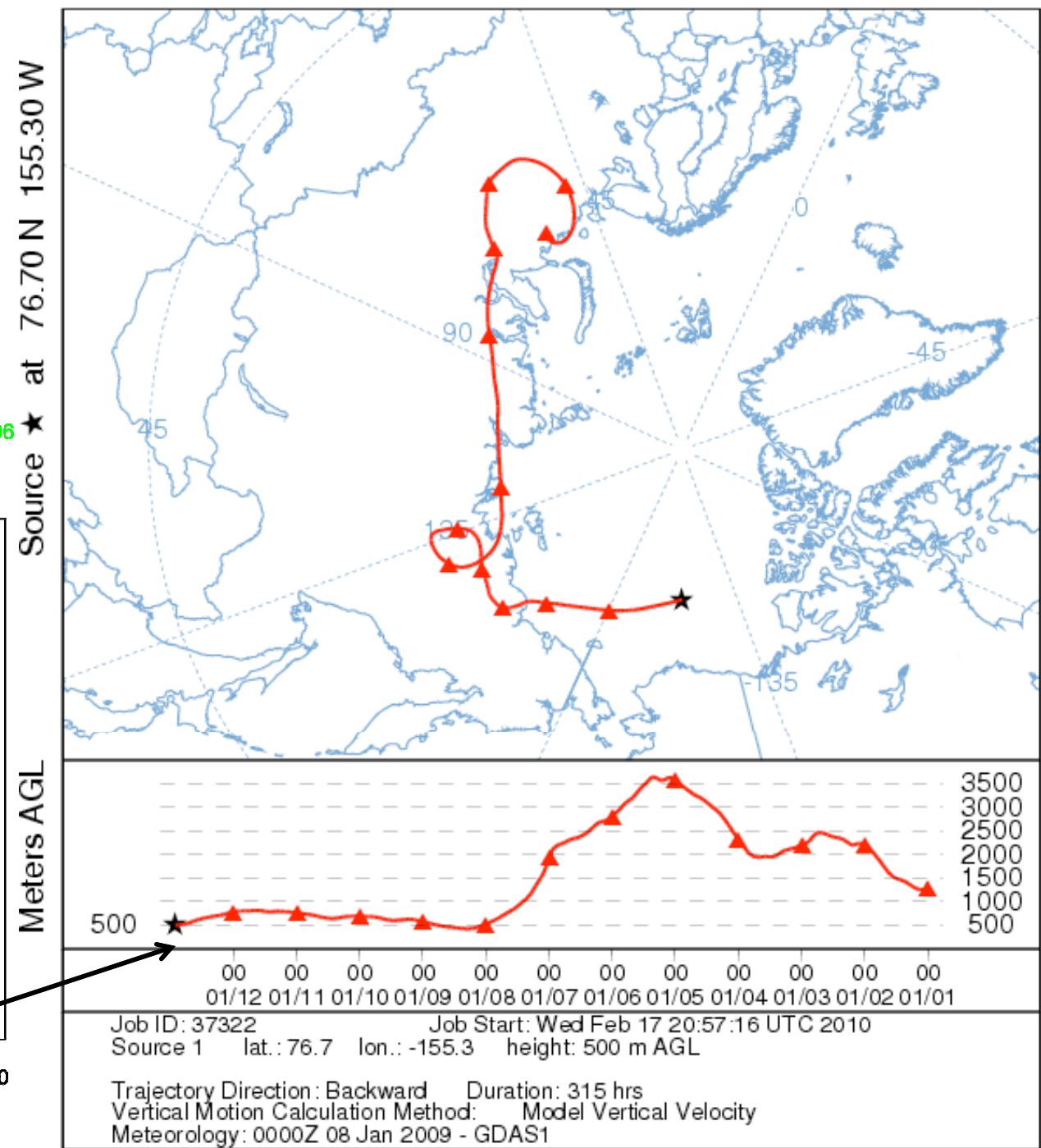
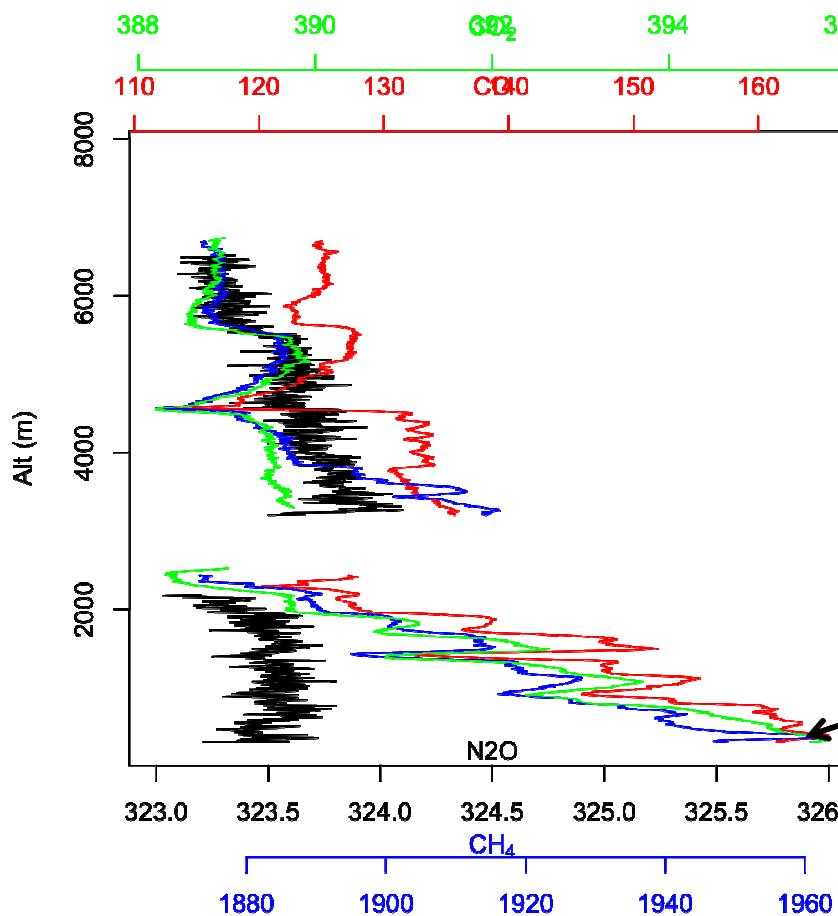


NOAA HYSPLIT MODEL  
Backward trajectory ending at 2200 UTC 12 Jan 09  
GDAS Meteorological Data

H1 Profile 24

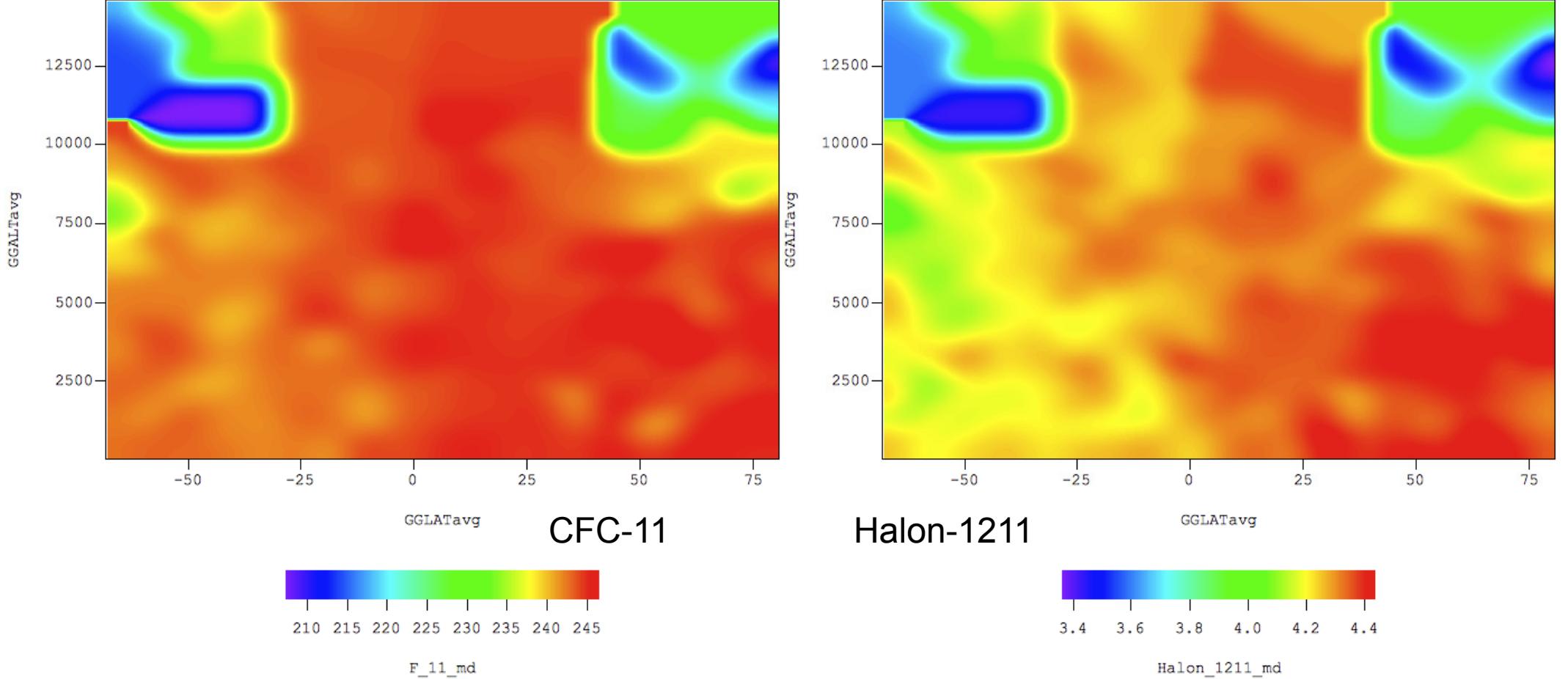
How do anomalies arise? How is a profile composed?

Arctic low altitude pollution



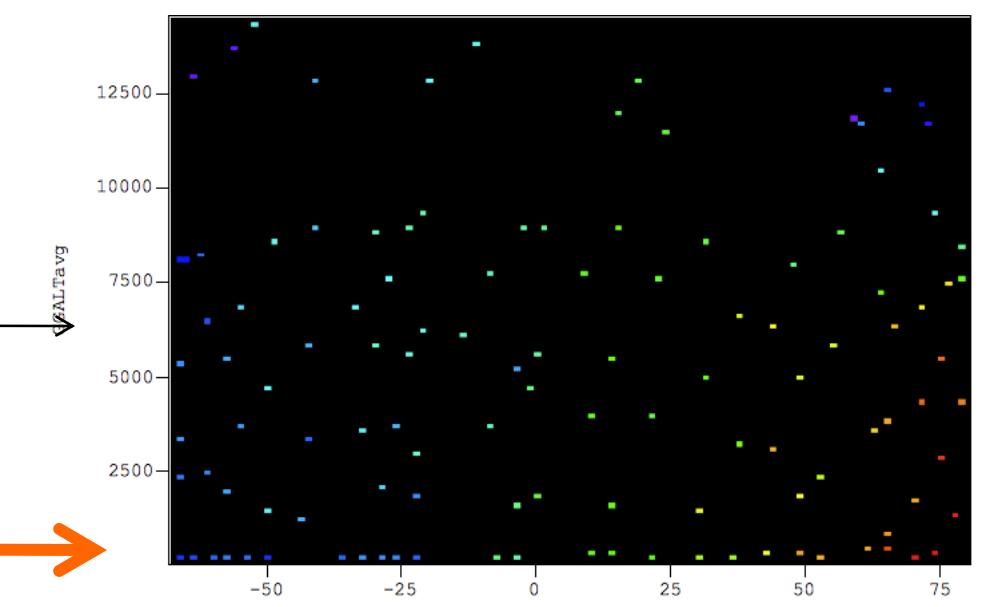
# Reactive species in the atmosphere:

*A movie... (not in 3-D)*

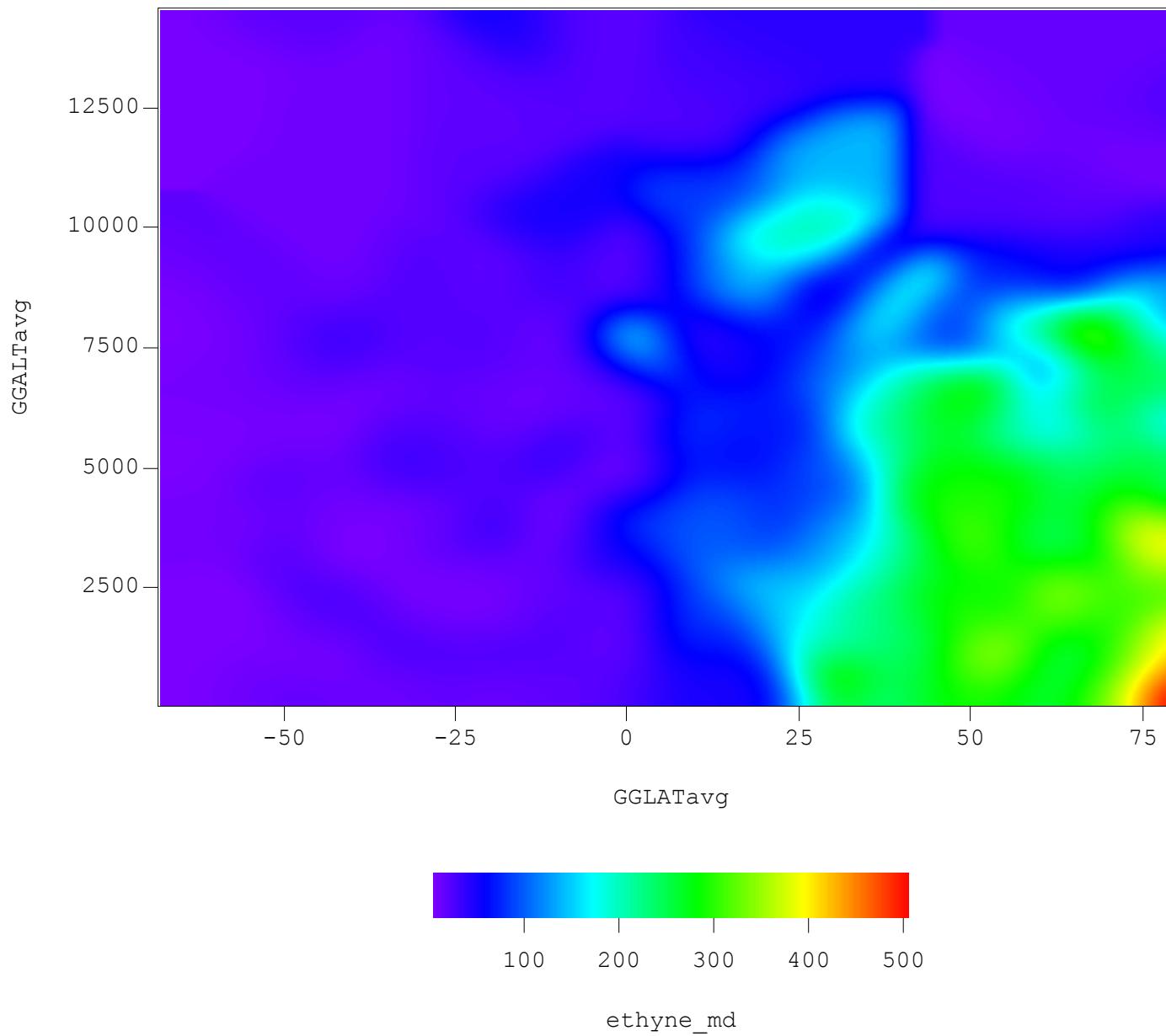


Whole-Air Sampling NWAS /  
AWAS (E. Atlas, S. Montzka)

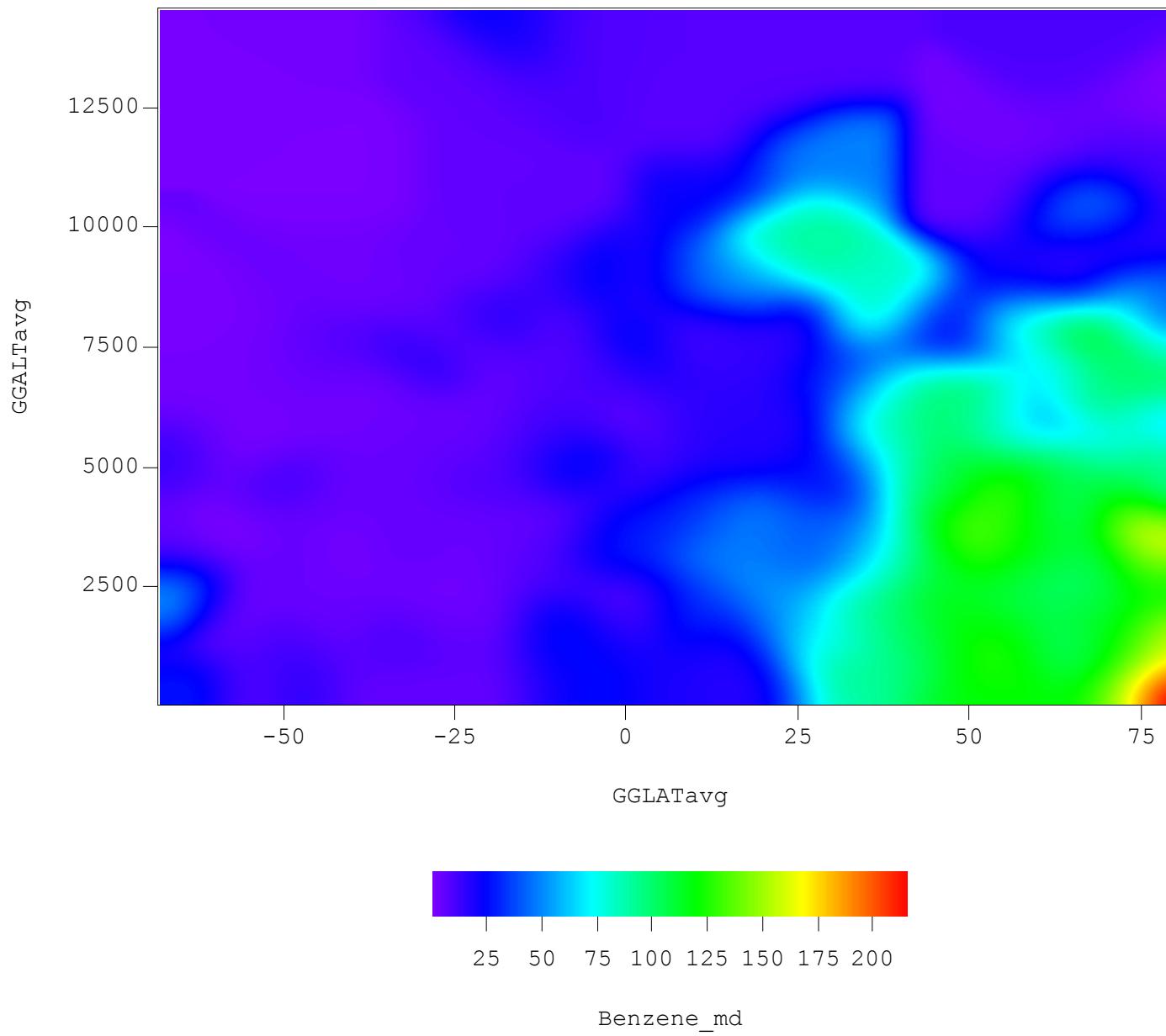
Mid-Pacific Sample coverage



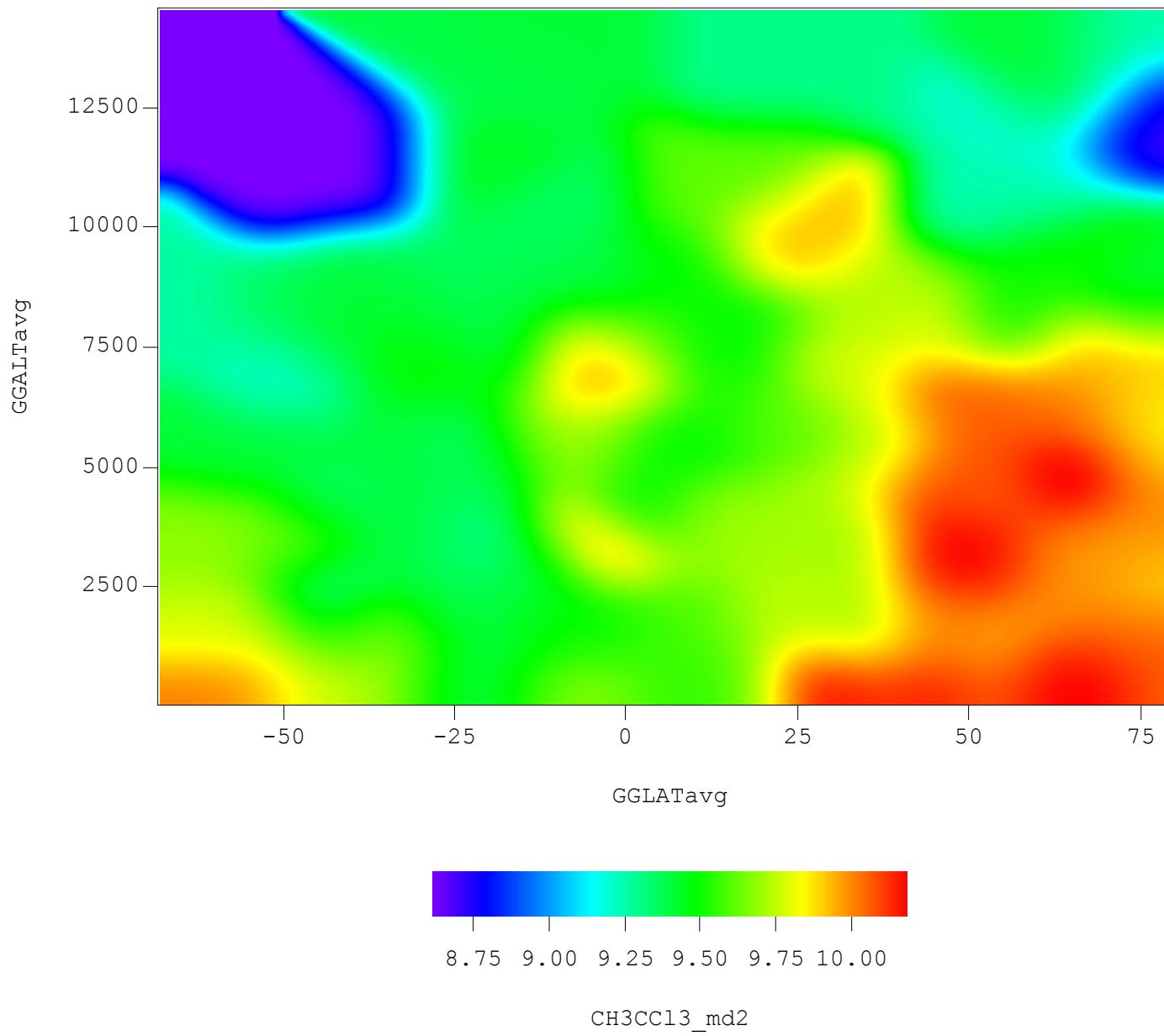
Ethyne



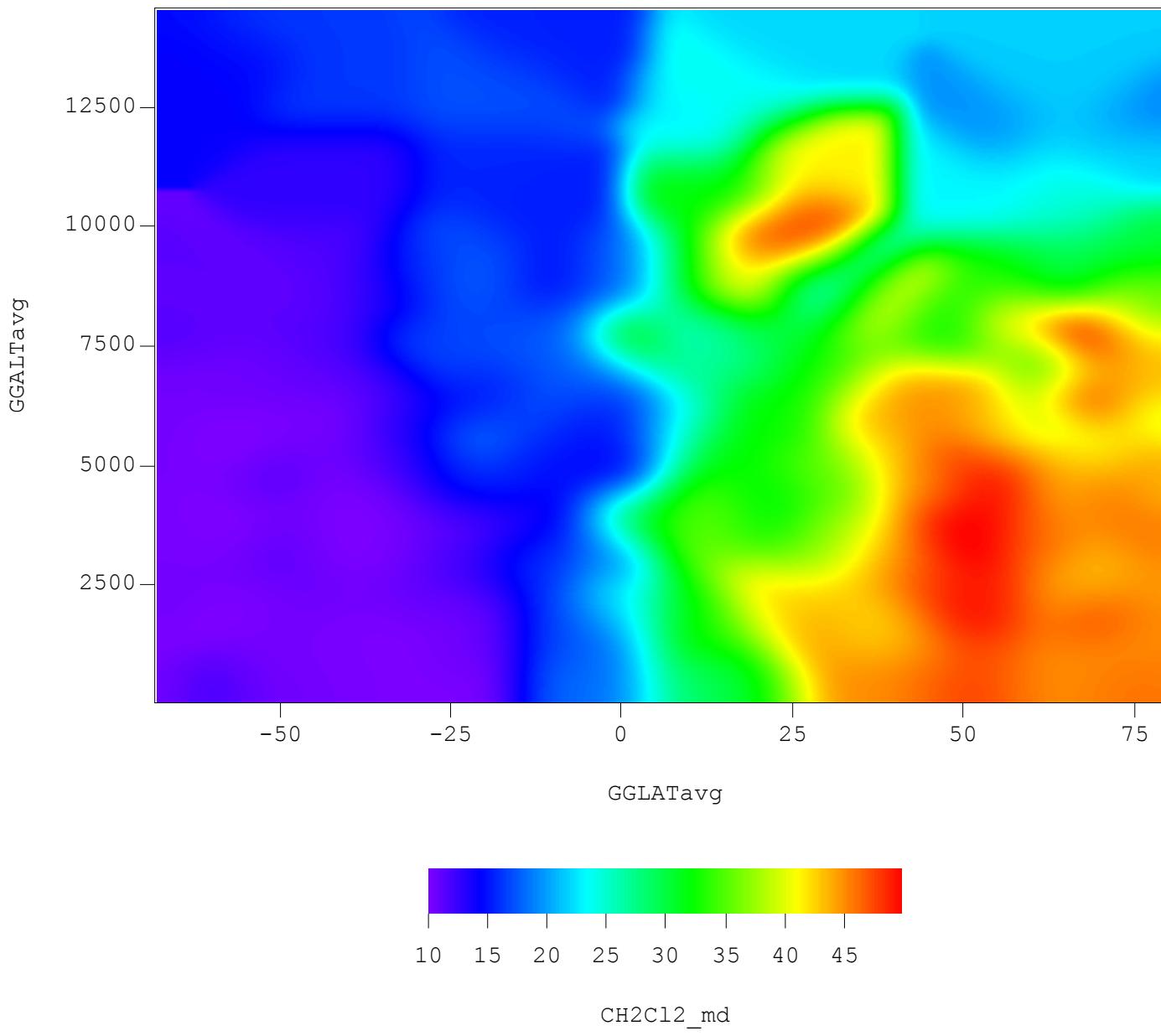
# Benzene



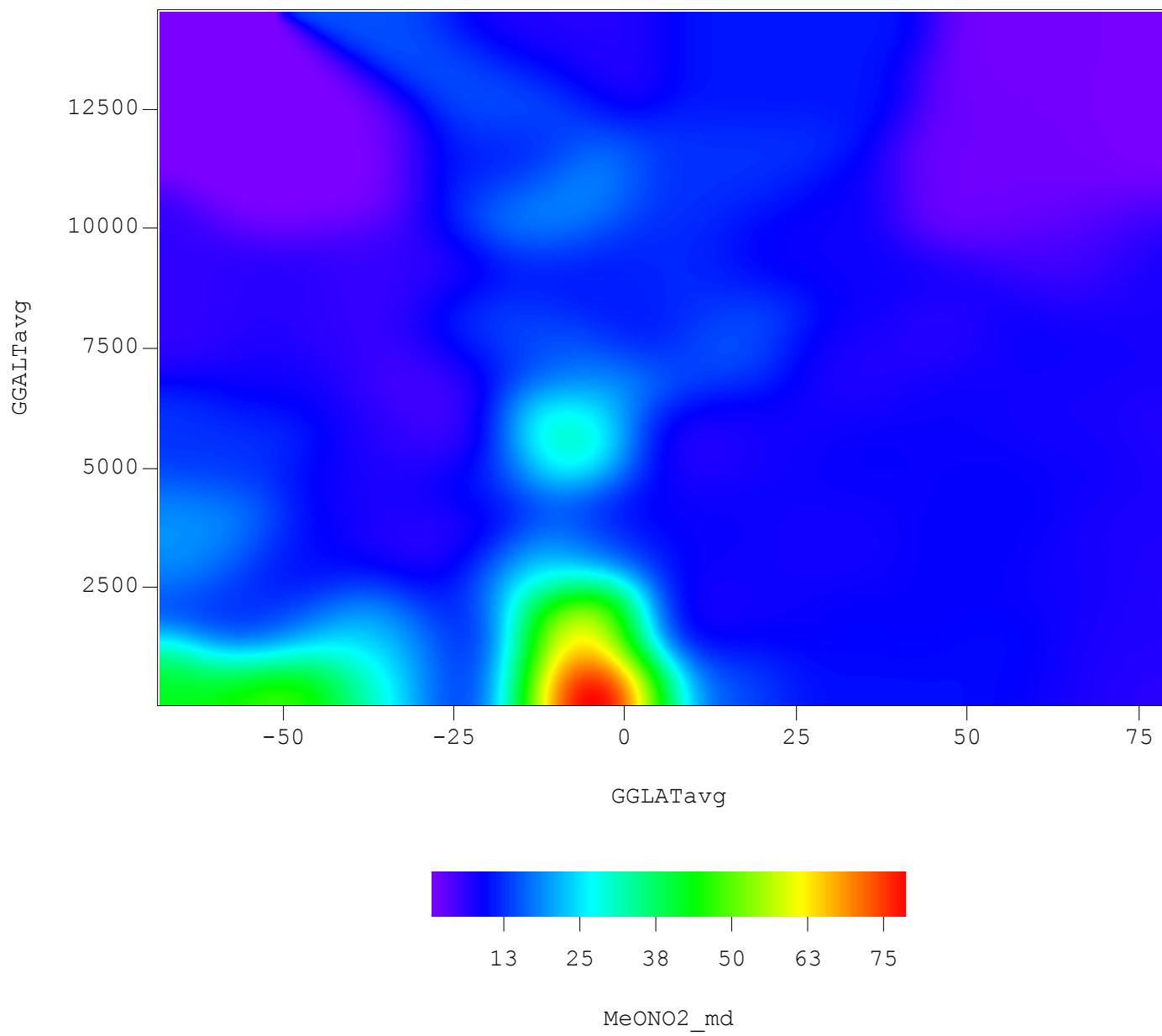
# Methyl chloroform



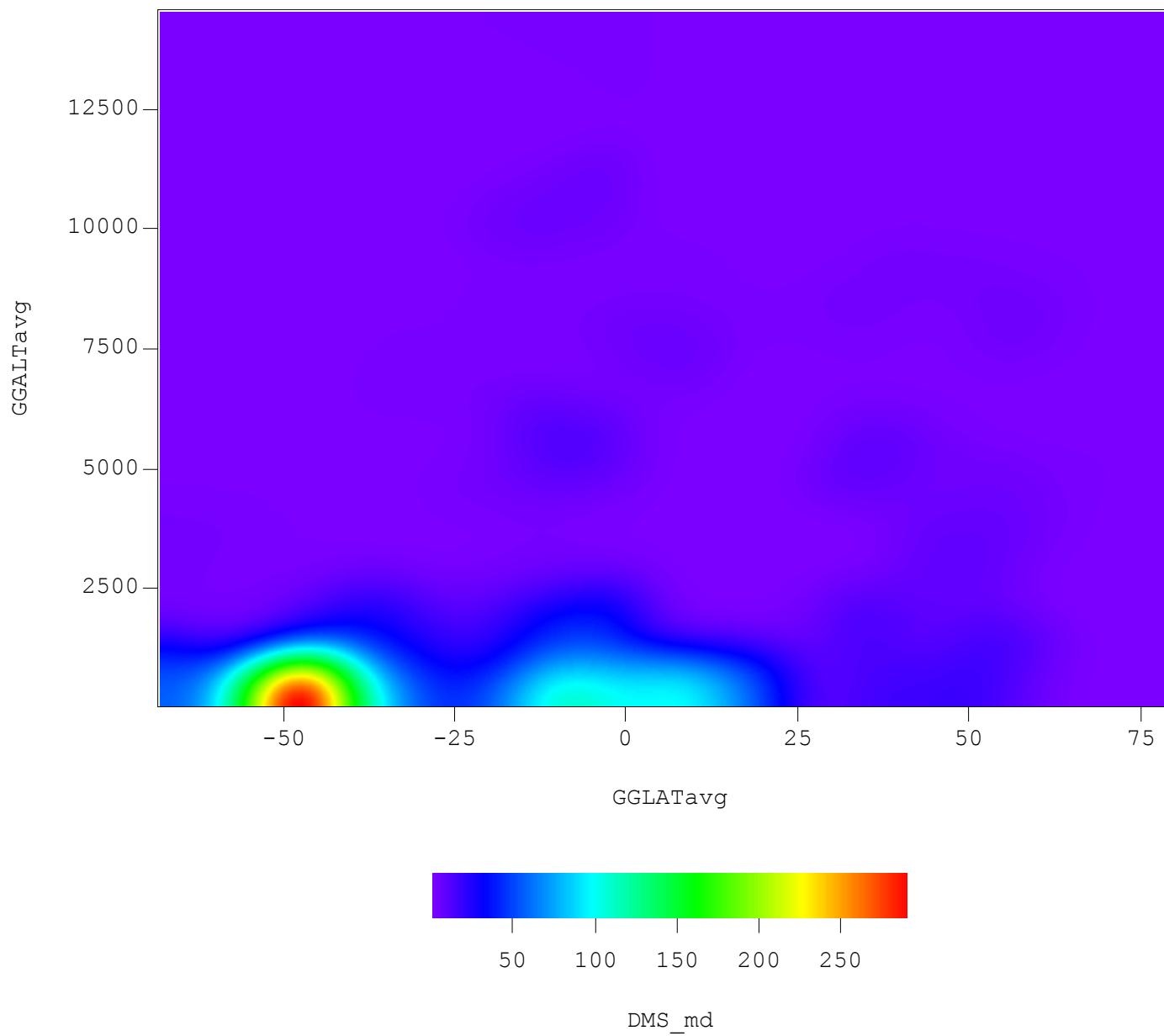
# Dichloromethane



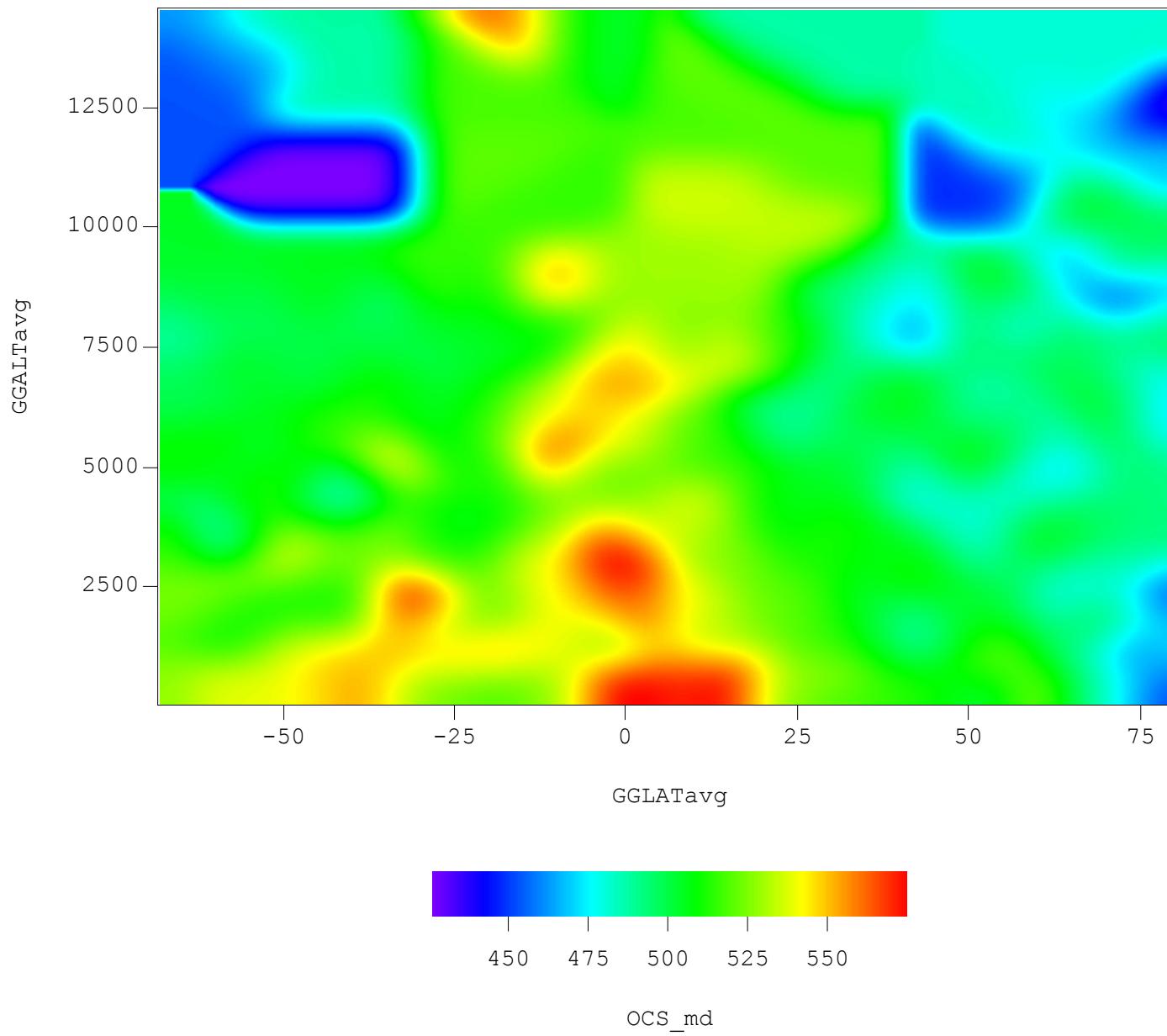
# Methyl Nitrate



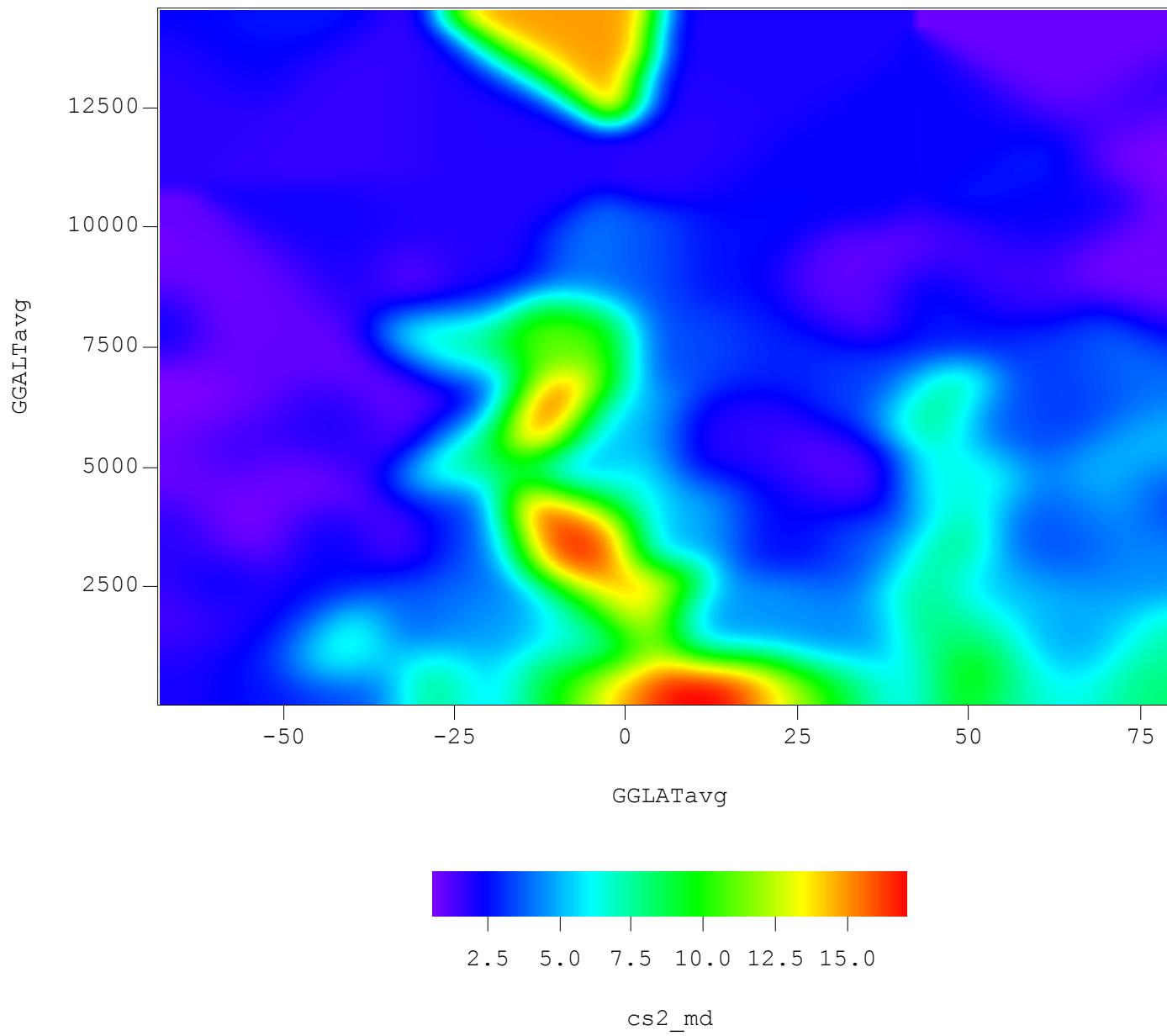
# Dimethyl Sulfide



# Carbonyl Sulfide



# Carbon Disulfide



**\* HIPPO and Pre-HIPPO Teams \***

Harvard: *PI: S. Wofsy; Measurement, data team: R. Jimenez, S. Park, B. Daube, E. Gottlieb, E. Kort, J. Pittman, R. Commane, Bin Xiang, G. Santoni; GEOS-CHEM team: D. Jacob, J. Fisher, C. Pickett-Heaps, H. Wang, J. V. Pittman, K. Wecht, Q.-Q. Wang*

NCAR and NCAR-RAF: B. Stephens, P. Romanshkin, T. Campos, Laura Pan, J. Haggerty, S. Schertz, GV Crew (*Henry Boynton, Ed Ringleman, pilots*)

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Princeton: M. Zondlo    JPL: *M. J. Mahoney*

UCSD/Scripps: R. Keeling, J. Bent

U. Miami: E. A. Atlas, R. Lueb

Cooperating modeling groups: ACTM (*Prabir Patra, Kentaro Ishijima*), GEMS-MACC (*Richard Engelen*), ...others soon.

## Summary/ conclusions: for the Royal Society Discussion paper

- HIPPO provides a new type of data for CO<sub>2</sub> and GHG studies: global, extremely fine grained, many tracers.
- Major transport processes: ; Stratosphere [sets the stage; Pre-HIPPO connection]; **warm conveyor belt** (intense, persistent, ensemble of small scale processes)—**mixes the whole atmosphere** [CO<sub>2</sub>, CH<sub>4</sub>, CO: QCLS, RAF; *all models*]; **Arctic Cold Dome**—brings strong pollution to high altitudes in pivotal season [BC, CH<sub>4</sub>, N<sub>2</sub>O: QCLS, SP2; □ GEMS, ACTM and GEOS] and **Antarctic marine PBL** —distortion of surface observations used in models [CO<sub>2</sub>, CH<sub>4</sub>, O<sub>2</sub>, SF<sub>6</sub> : QCLS, UCATS; *all models*].
- Source/sink regions are revealed and impacts quantified—**N<sub>2</sub>O in the tropics and Antarctic**—a major finding [N<sub>2</sub>O: QCLS; ACTM] □; **marine reactive species**—obvious implications for source regions [COS, CS2, DMS; ALLWAS]; **O<sub>2</sub> and CO<sub>2</sub> Antarctic and S. Ocean**.—source strength, relate to PBL [CO<sub>2</sub>, O<sub>2</sub>: QCLS, AO2; GEOS-CHEM].