Atmospheric Chemical Composition, Climate, and Societal Implications

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Abstract

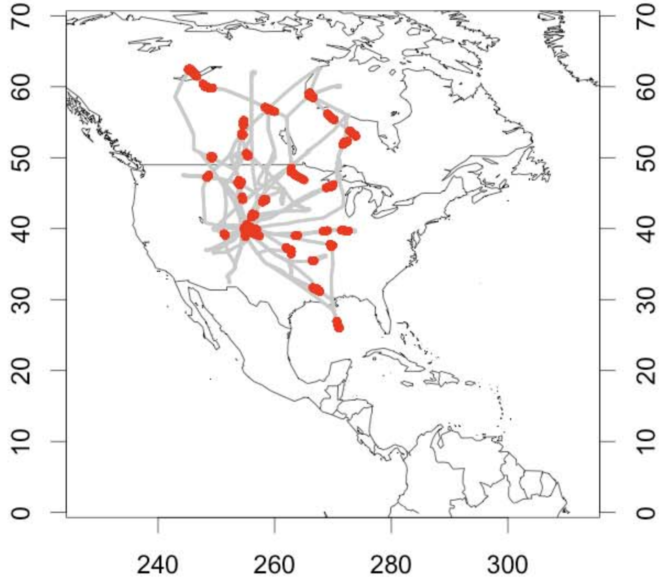
Global atmospheric concentrations of CO_2, CH_4 and N_2O are largely under human control, affecting climate and global atmospheric chemical processes. This talk discusses measurements of these gases in two major aircraft campaigns: HIAPER Pole-to-Pole Observations program ("HIPPO", sponsored by NSF and NOAA) and CalNEX (sponsored by NOAA and CARB), and their synergy with measurements at NOAA surface, tower, and aircraft profile stations. New information on the drivers of long-term changes in the global atmosphere are explored, emphasizing interpretation of data for CO_2 and other GHGs from the NOAA network, and new information on CH_4 emissions in the Arctic region.

HIPPO: NCAR Gulfstream V "HIAPER"

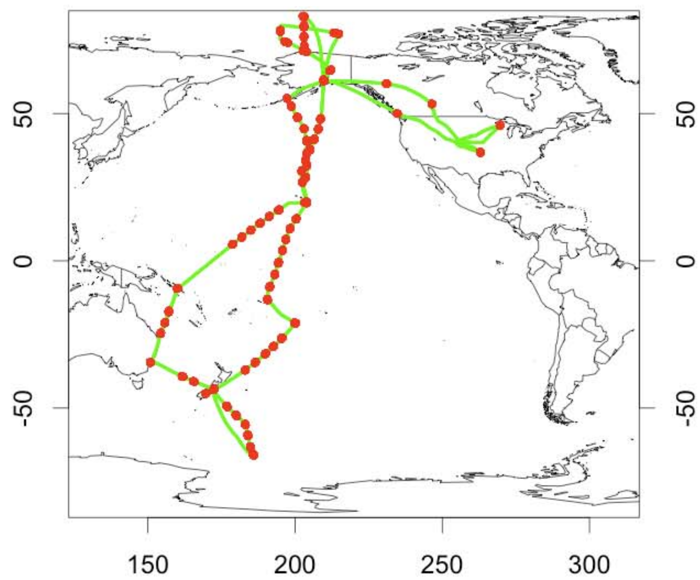
GV launch in the rain, Anchorage, January, 2009 (HIPPO-1)

HIPPO itinerary

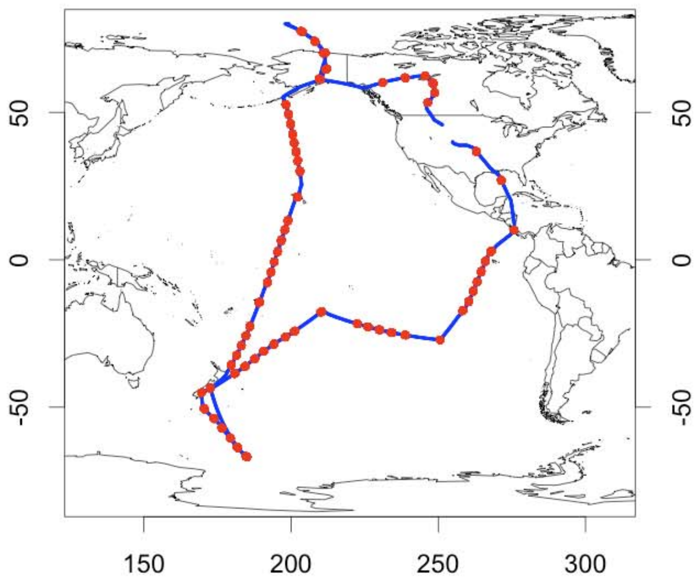
preHIPPO Apr-Jun 2008



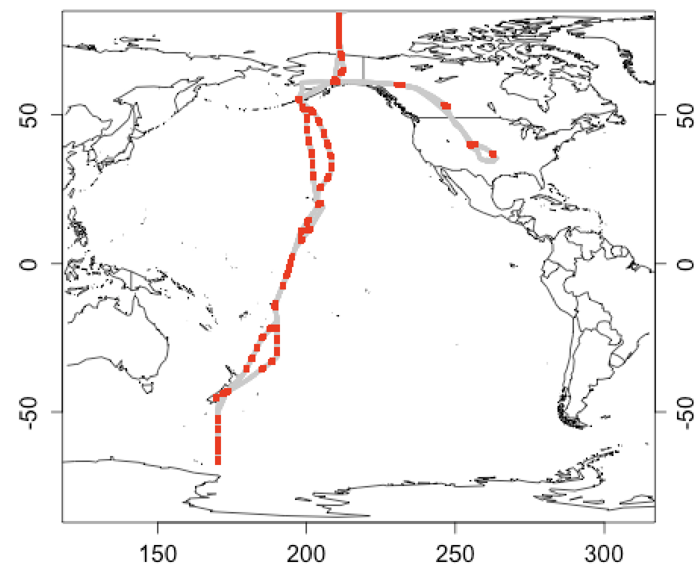
HIPPO_2 Nov 2009

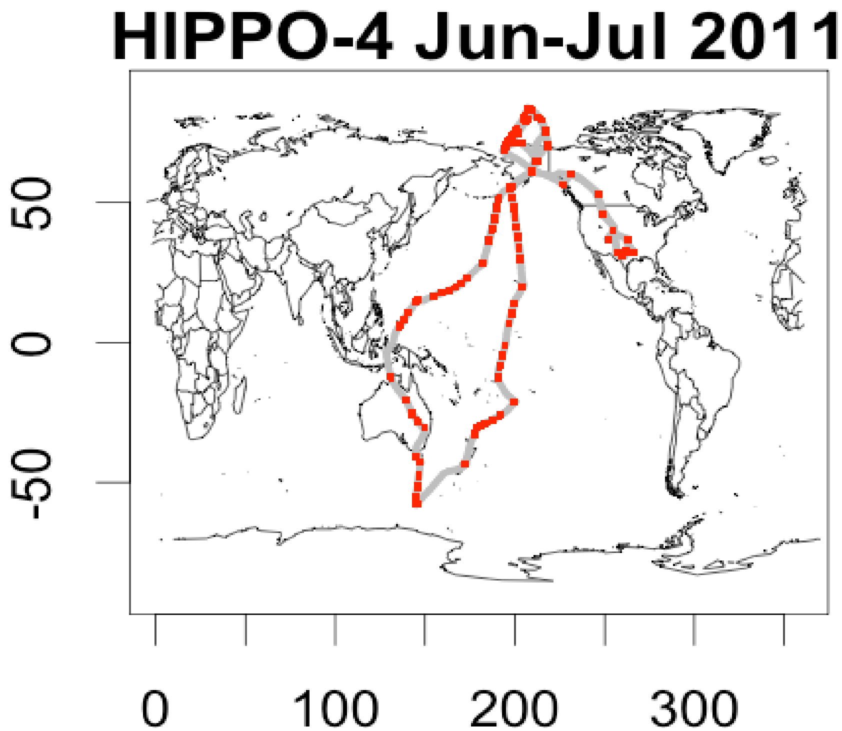


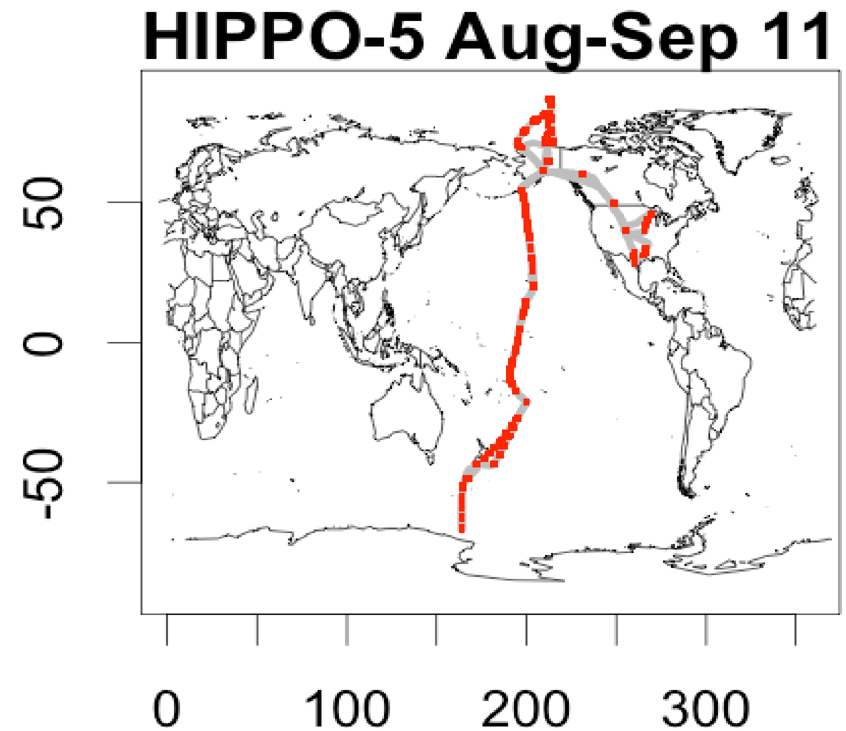
HIPPO_1 Jan 2009



HIPPO_3 Mar-Apr 2010




HIPPO-4 Jun-Jul 2011
50
0
-50
0
100
200
300

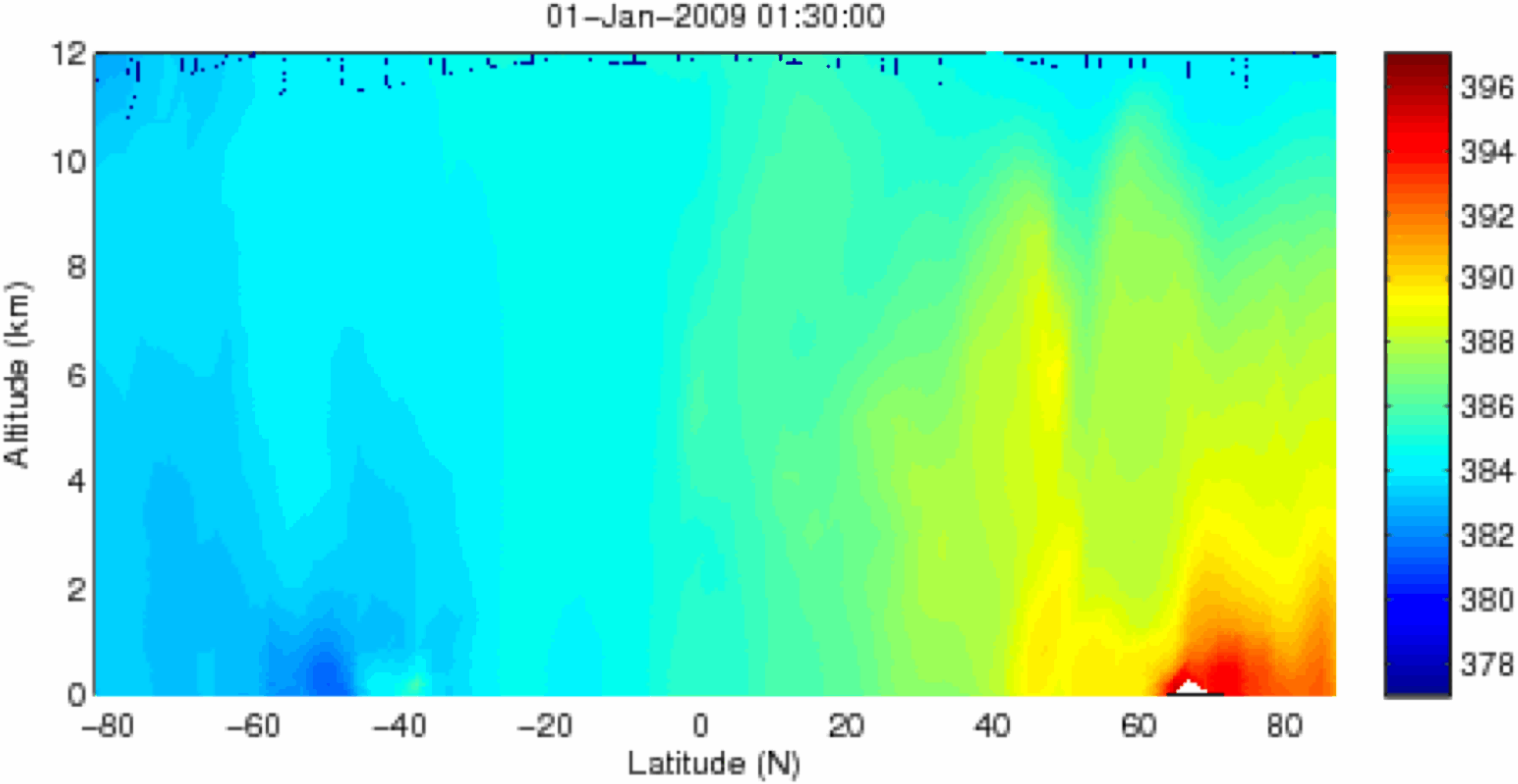

HIPPO-5 Aug-Sep 11
50
0
-50
0
100
200
300

Part 1.

CO_2 at the global scale:
The Network, CarbonTracker, and atmospheric "global fine structure"

CO_2

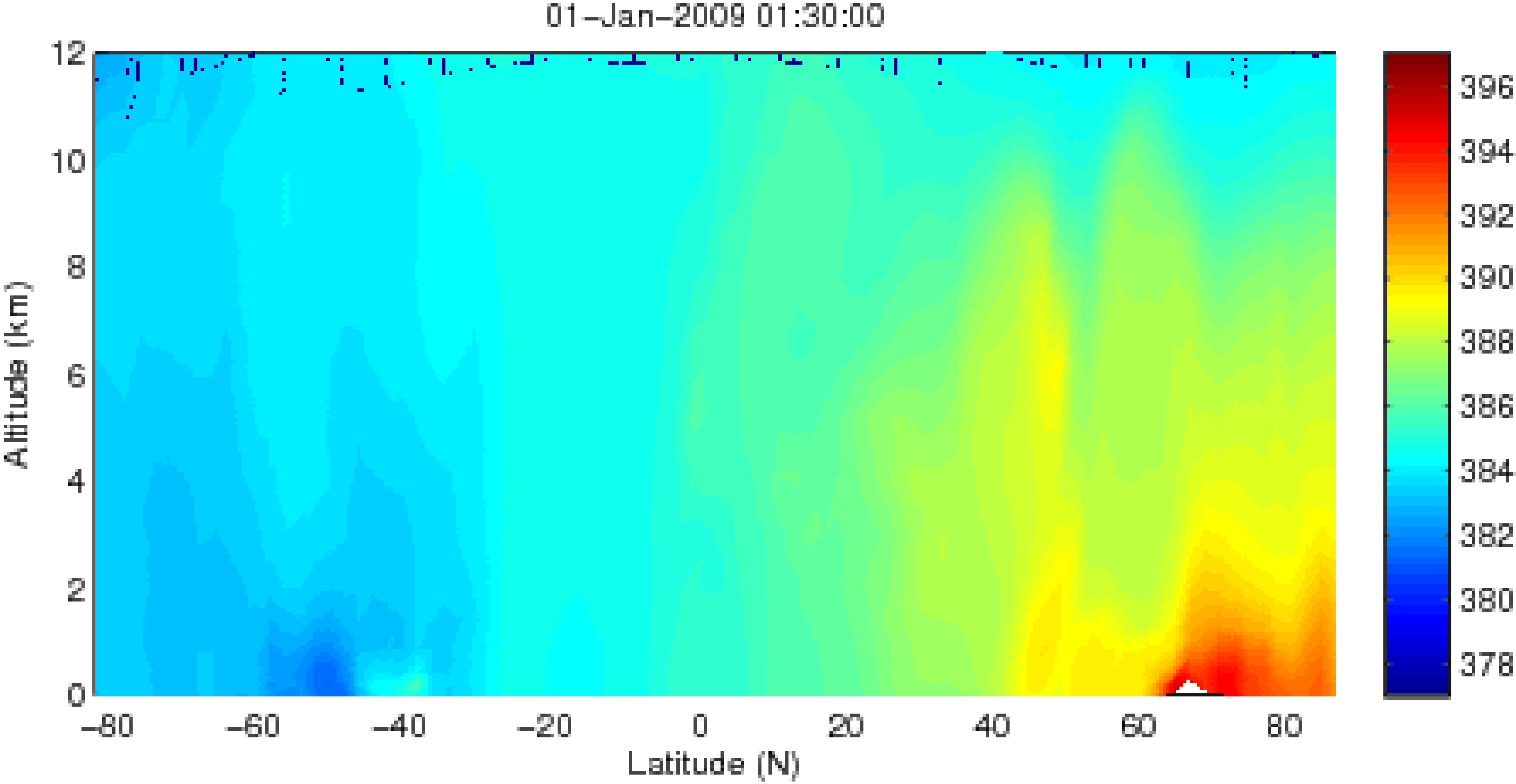
CarbonTracker along the HIPPO flight track



Courtesy Colm Sweeney/Anna Karion

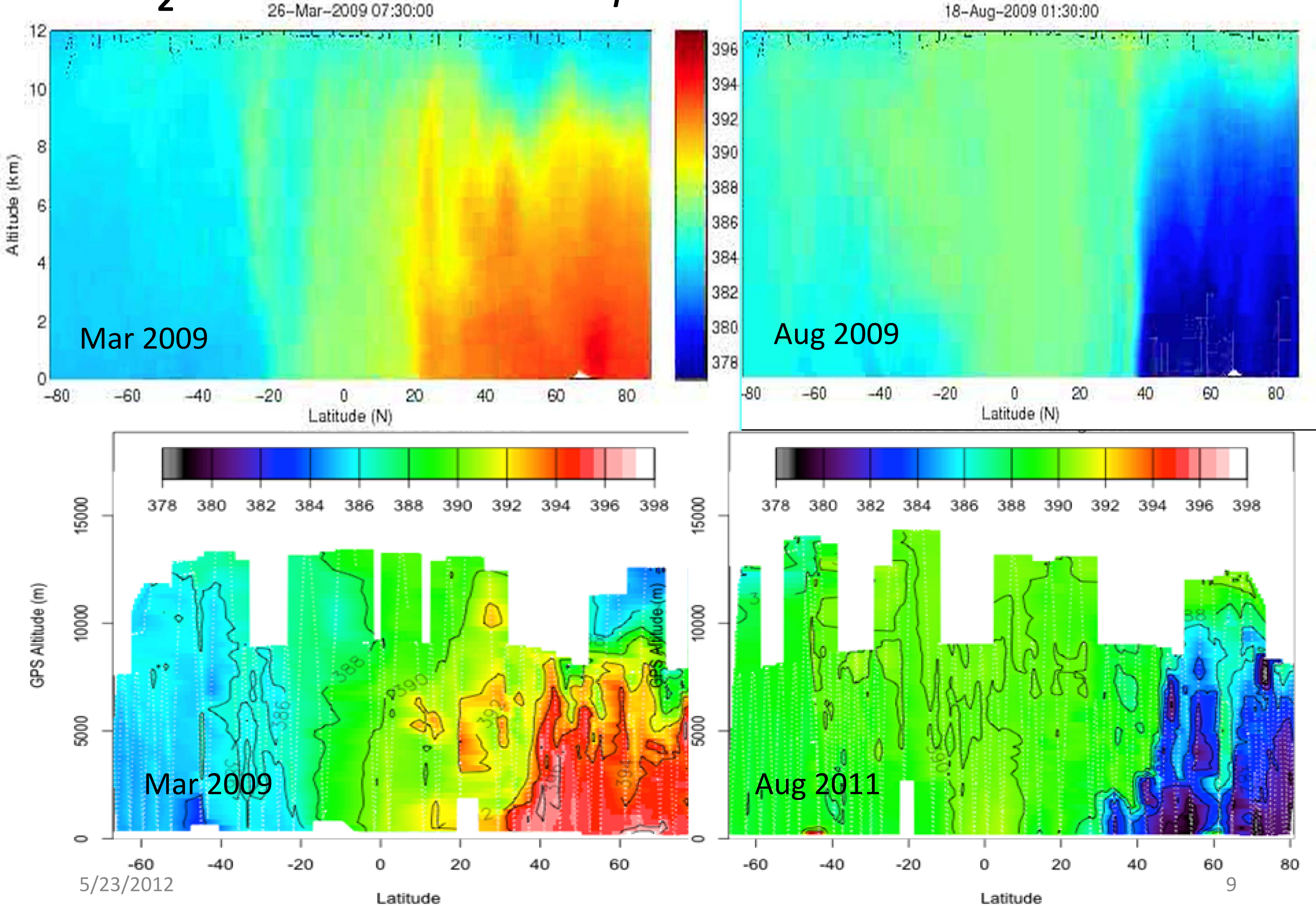
CO_2

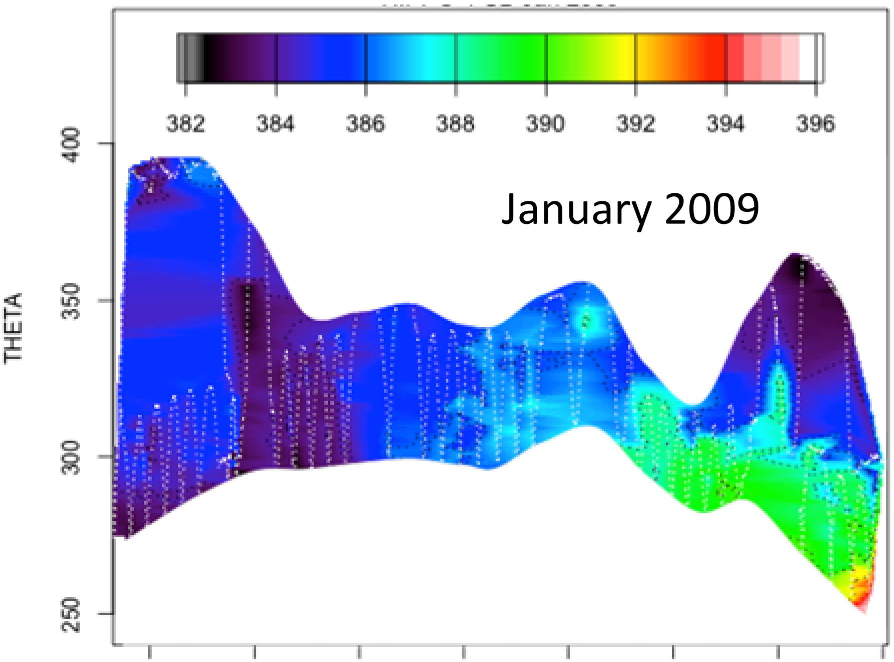
CarbonTracker along the HIPPO flight track

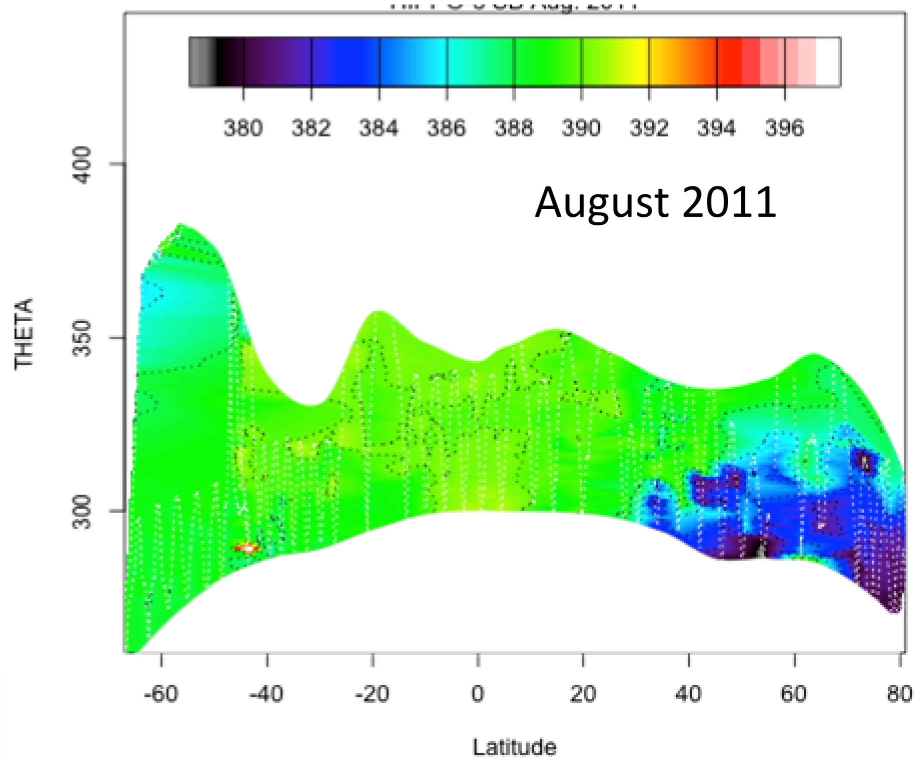


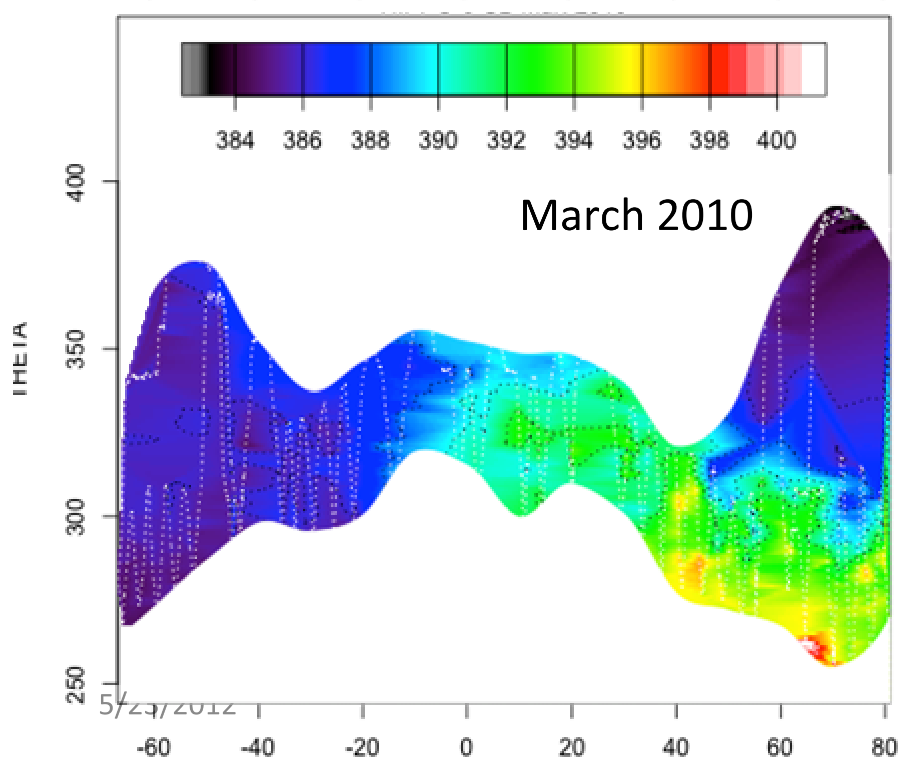
Courtesy Colm Sweeney/Anna Karion

CO_2 *CarbonTracker compared to HIPPO cross section*







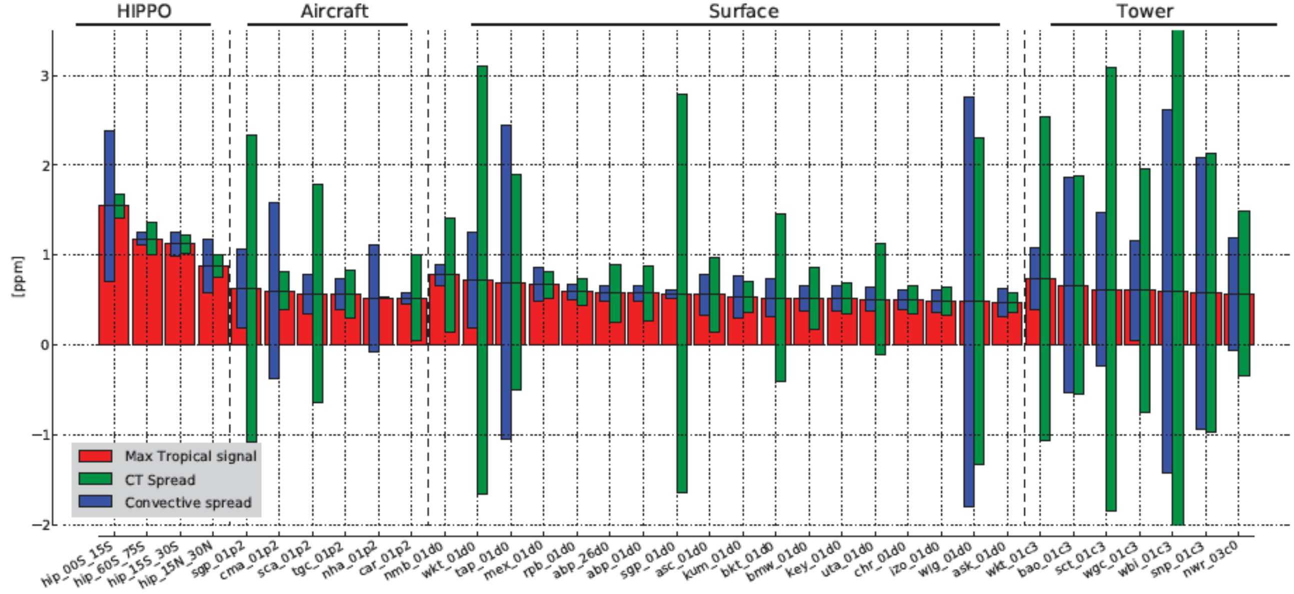


Seasonal transport of CO_2 through the middle and high latitude troposphere has strong isentropic character, and in winter, a jet stream component. (*B. Stephens, H1 science team meeting*).

Why the tropical carbon balance cannot be constrained from the current atmospheric CO_2 monitoring network

W. Peters[1] and G.R. van der Werf[2]

Network design study using Carbon Tracker



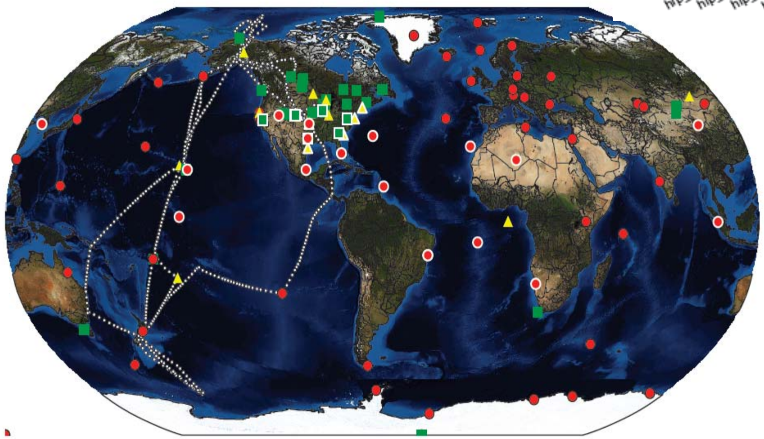
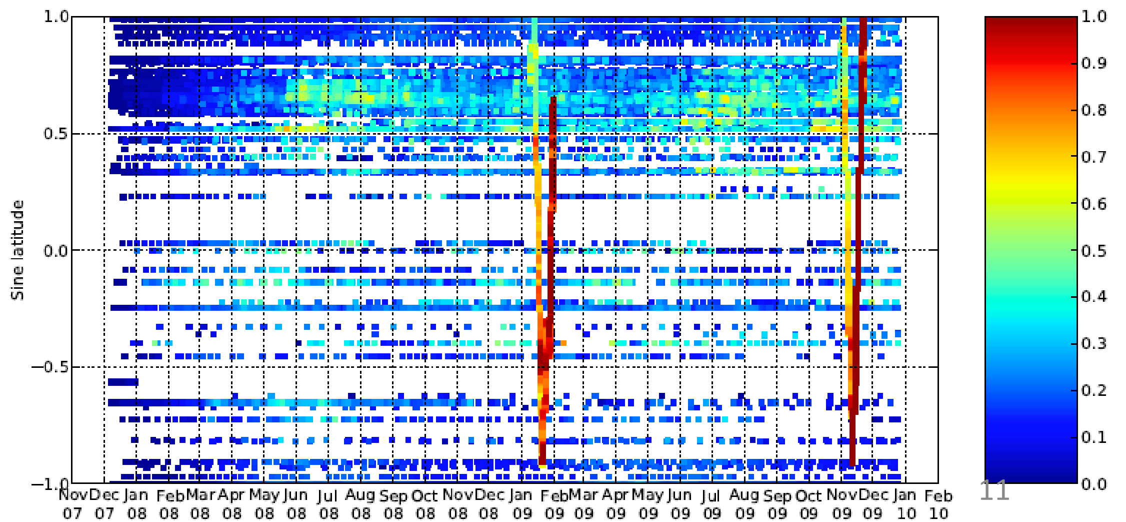


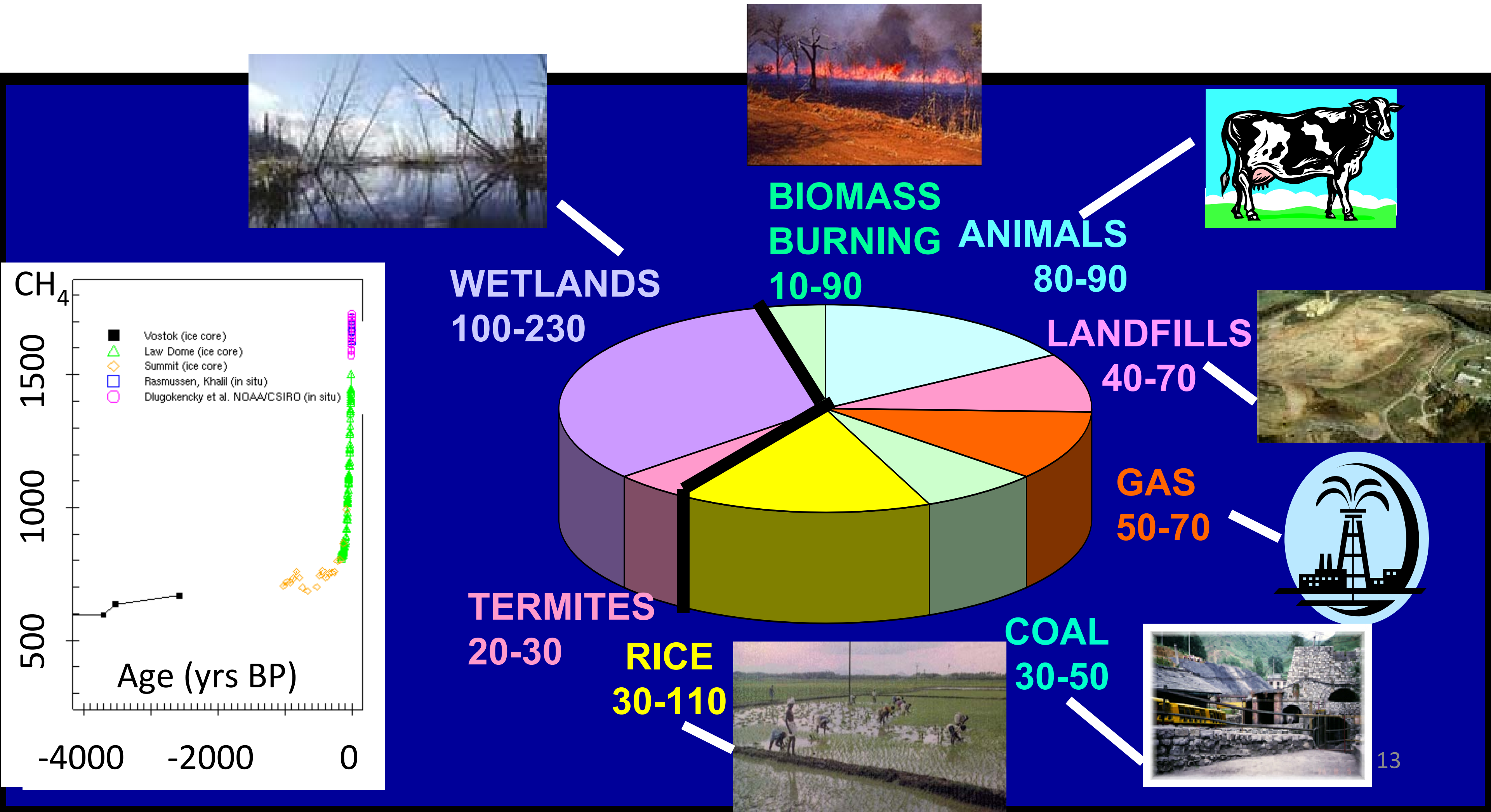
Figure 1: Locations of the monitoring sites considered in this study, corresponding to the 2009-2010 sites from several programs including, but not limited to the NOAA ESRL Collaborative Air Sampling program, the Environment Canada measurement network, the HIPPO campaign, and the CarboEurope/ICOS-EU observing network. Red dots are locations where



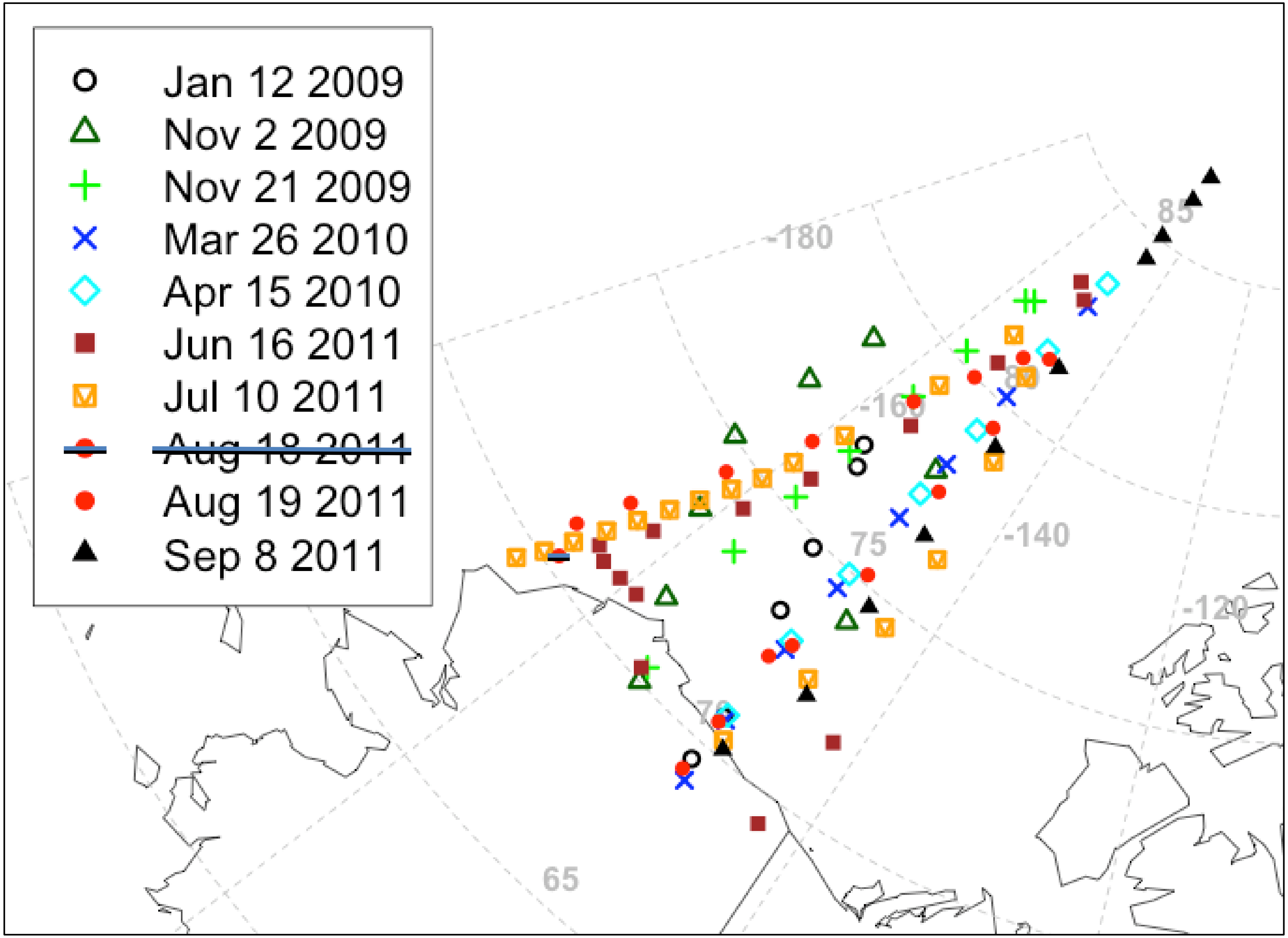
Part 2.
CH_4 (and other stuff) in the Arctic

GLOBAL METHANE SOURCES, Tg a^{-1} [IPCC, 2007]

Sink: oxidation by OH (lifetime of 10 years)



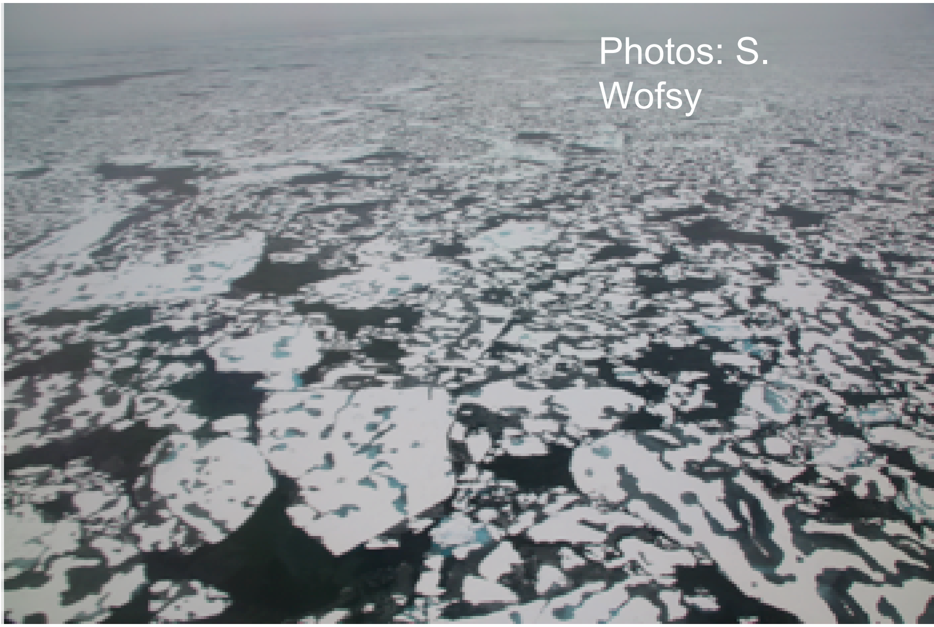
HIPPO Profiles over the Arctic Ocean and North Slope (*n* = 96)



UT	NN	GGLAT	GGLON	ALT m	T° C
79860	1535	81.51841	-149.4505	161.296	-3.766

UT	NN	GGLAT	GGLON	ALT m	T° C
79980	1541	81.63584	-149.0444	161.634	-3.626

UT	NN	GGLAT	GGLON	ALT m	T° C
79920	1539	81.57697	-149.2495	162.370	-3.758



UT	NN	GGLAT	GGLON	ALT m	T° C
82800	1546	78.57906	-147.7003	163.884	-3.904

UT	NN	GGLAT	GGLON	ALT m	T° C
74520	1467	75.04469	-161.5916	653.708	-4.736278

UT	NN	GGLAT	GGLON	ALT m	T° C
74640	1473	75.17651	-161.4241	257.740	-3.14

UT	NN	GGLAT	GGLON	ALT m	T° C
74580	1469	75.11114	-161.5076	403.508	-3.894623

UT	NN	GGLAT	GGLON	ALT m	T° C
77280	1481	78.70973	-156.4544	3854.904	-25.08

UT	NN	GGLAT	GGLON	ALT m	T° C
85740	1568	74.42879	-147.7220	247.620	-3.278

UT	NN	GGLAT	GGLON	ALT m	T° C
85800	1576	74.36211	-147.7852	161.070	-2.737

UT	NN	GGLAT	GGLON	ALT m	T° C
85740	1572	74.42879	-147.7220	247.620	-3.27

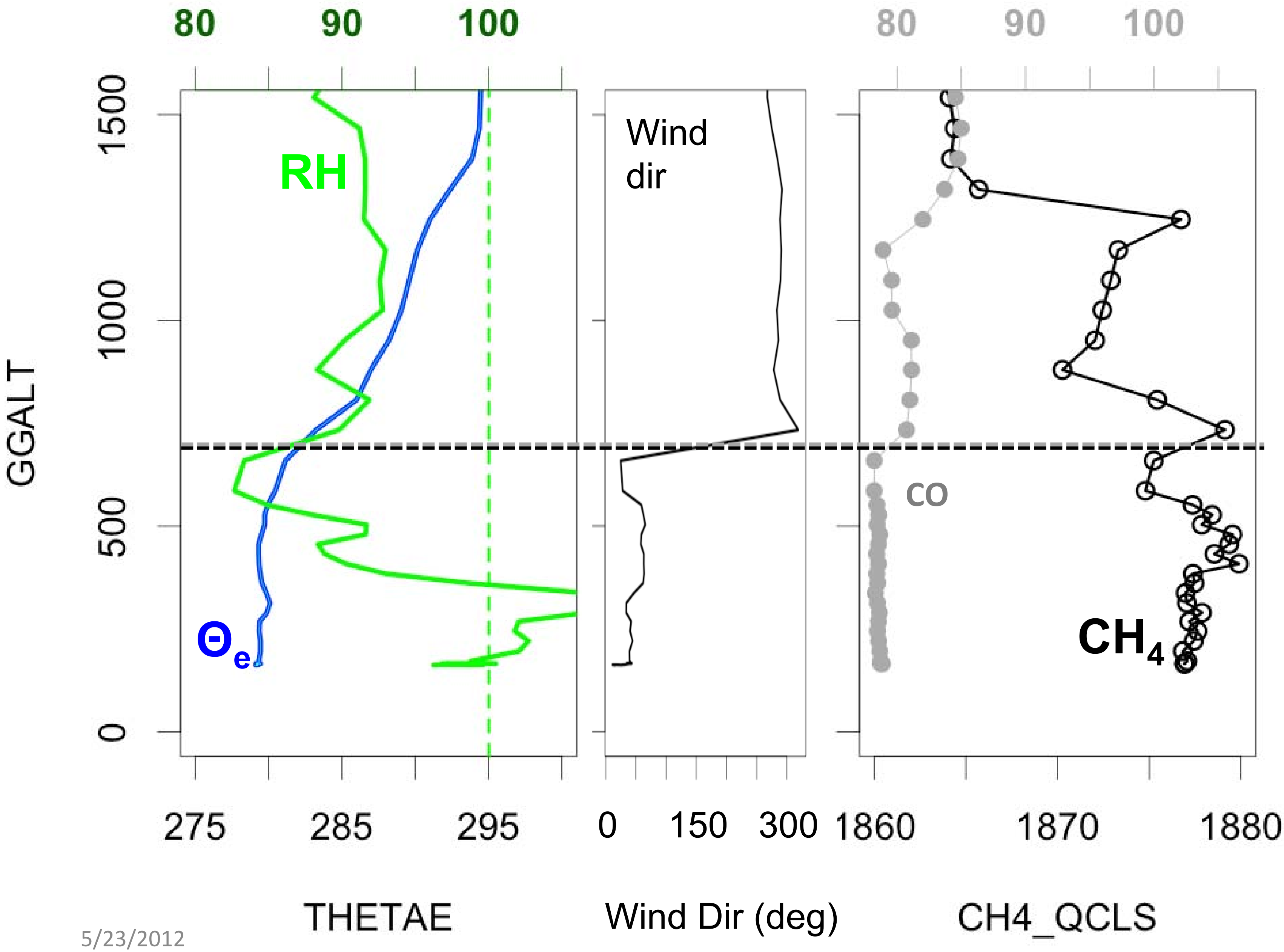
UT	NN	GGLAT	GGLON	ALT m	T° C
85800	1577	74.36211	-147.7852	161.070	-2.737

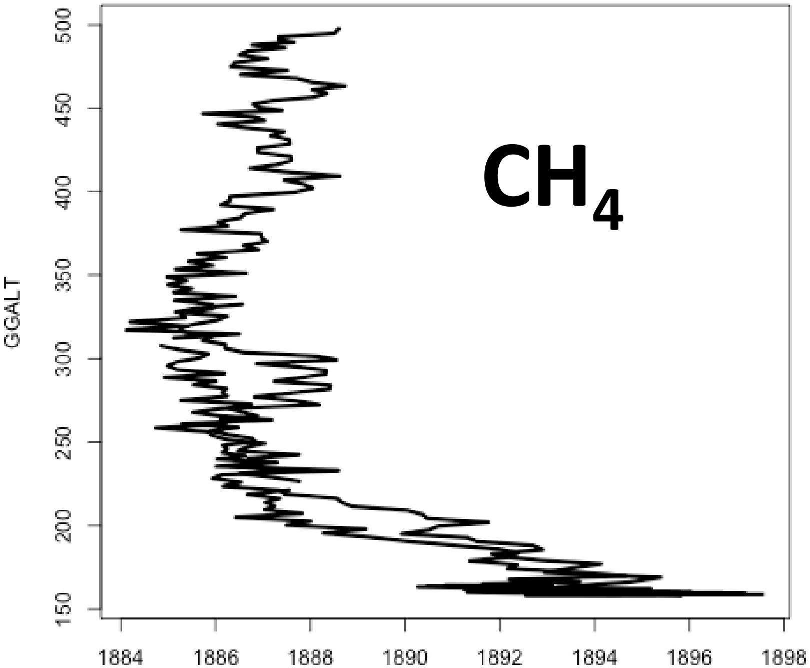
UT	NN	GGLAT	GGLON	ALT m	T° C
87720	1596	72.05512	-149.6590	274.496	-0.063

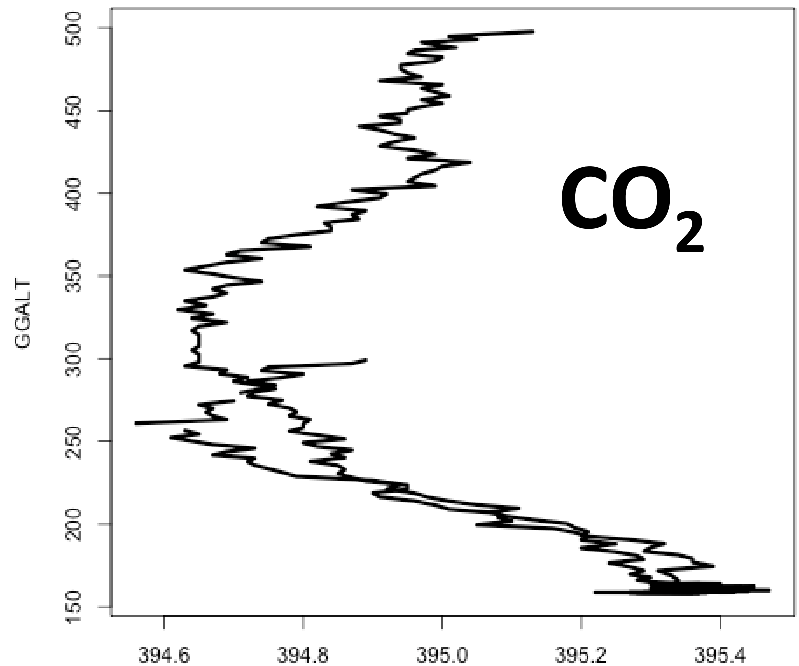
UT	NN	GGLAT	GGLON	ALT m	T° C
87900	1606	71.85716	-149.7977	133.362	0.73 ←

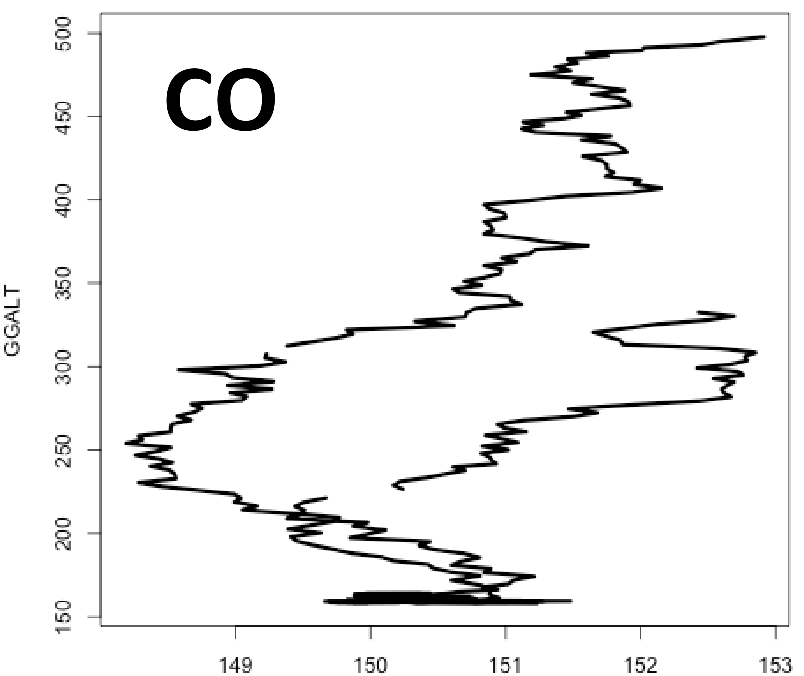
UT	NN	GGLAT	GGLON	ALT m	T° C
88680	1611	70.99602	-149.1112	4739.594	-17.84

73.6 N, Aug 2011 HIPPO-5







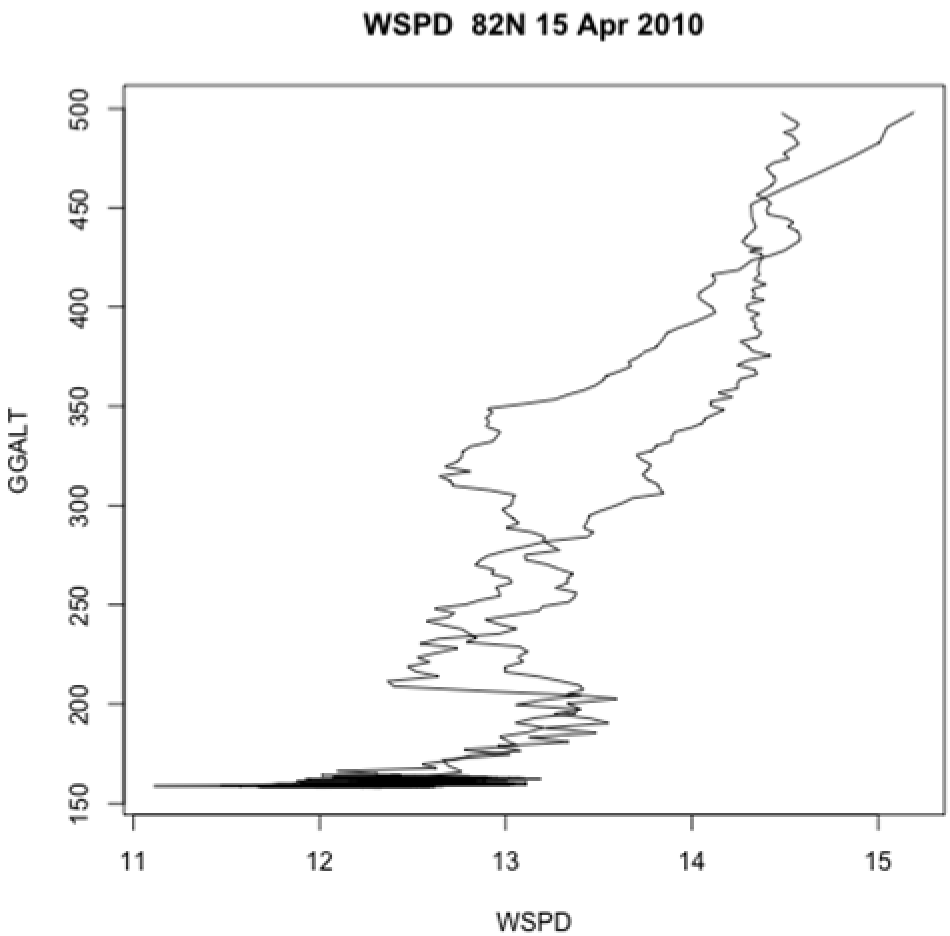


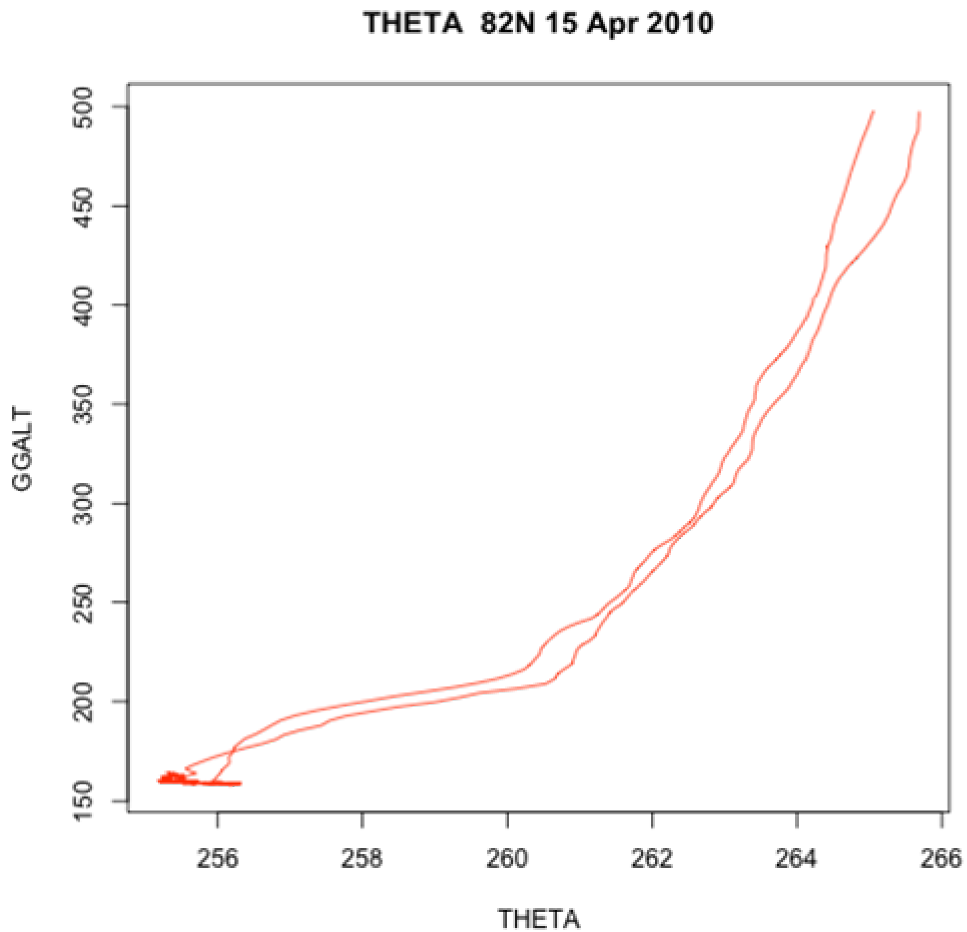
82N 15 April 2010

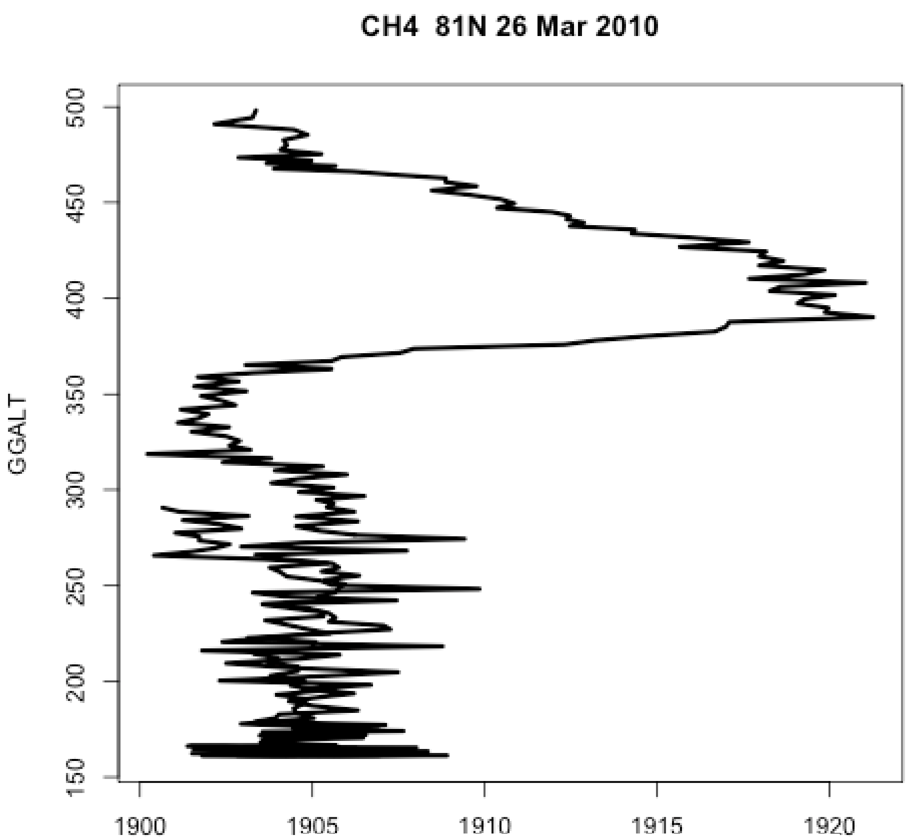
$\Delta CH_4 = 0.15 \times \Delta CO_2$ $r^2=.83$

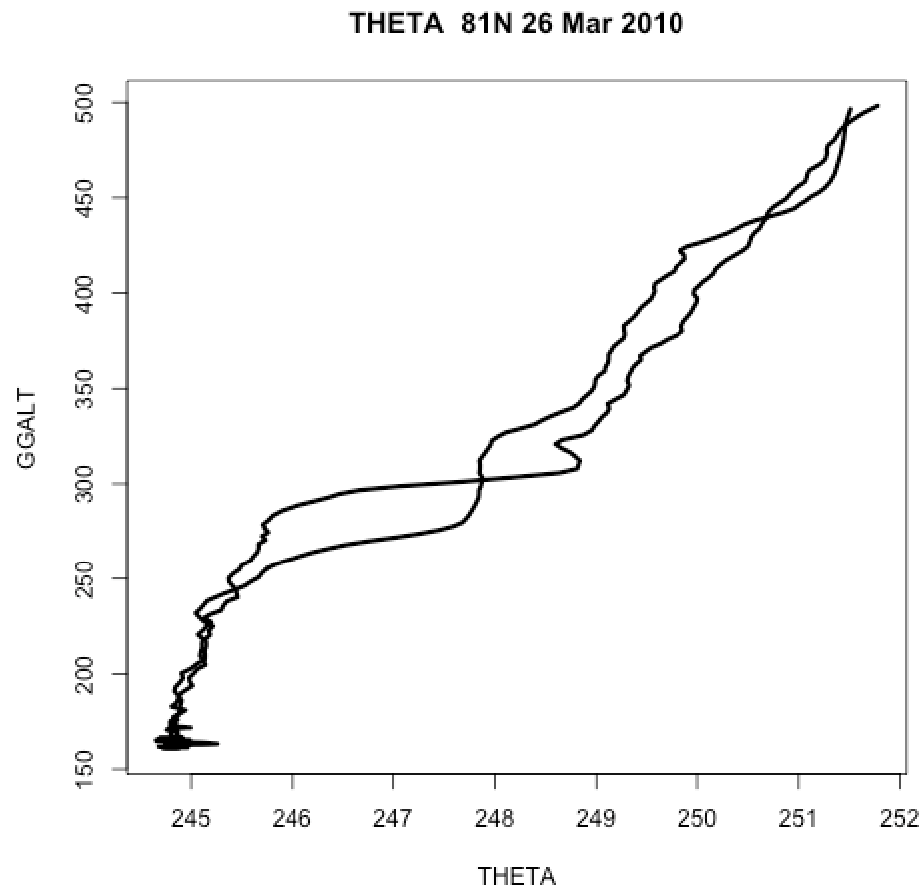
pollution: 0.3 ppb CH_4/ppb CO

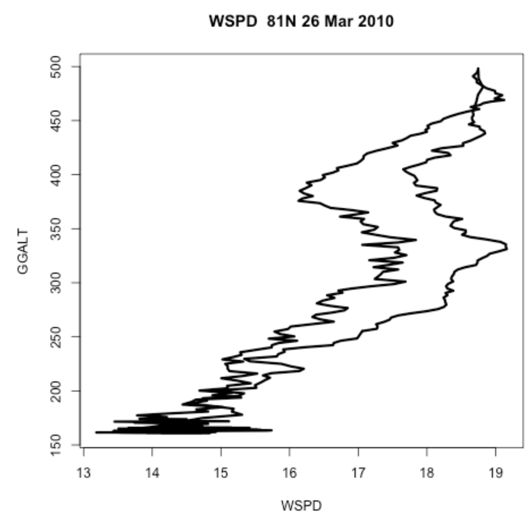
could account for at most ~0.6 ppb ΔCH_4

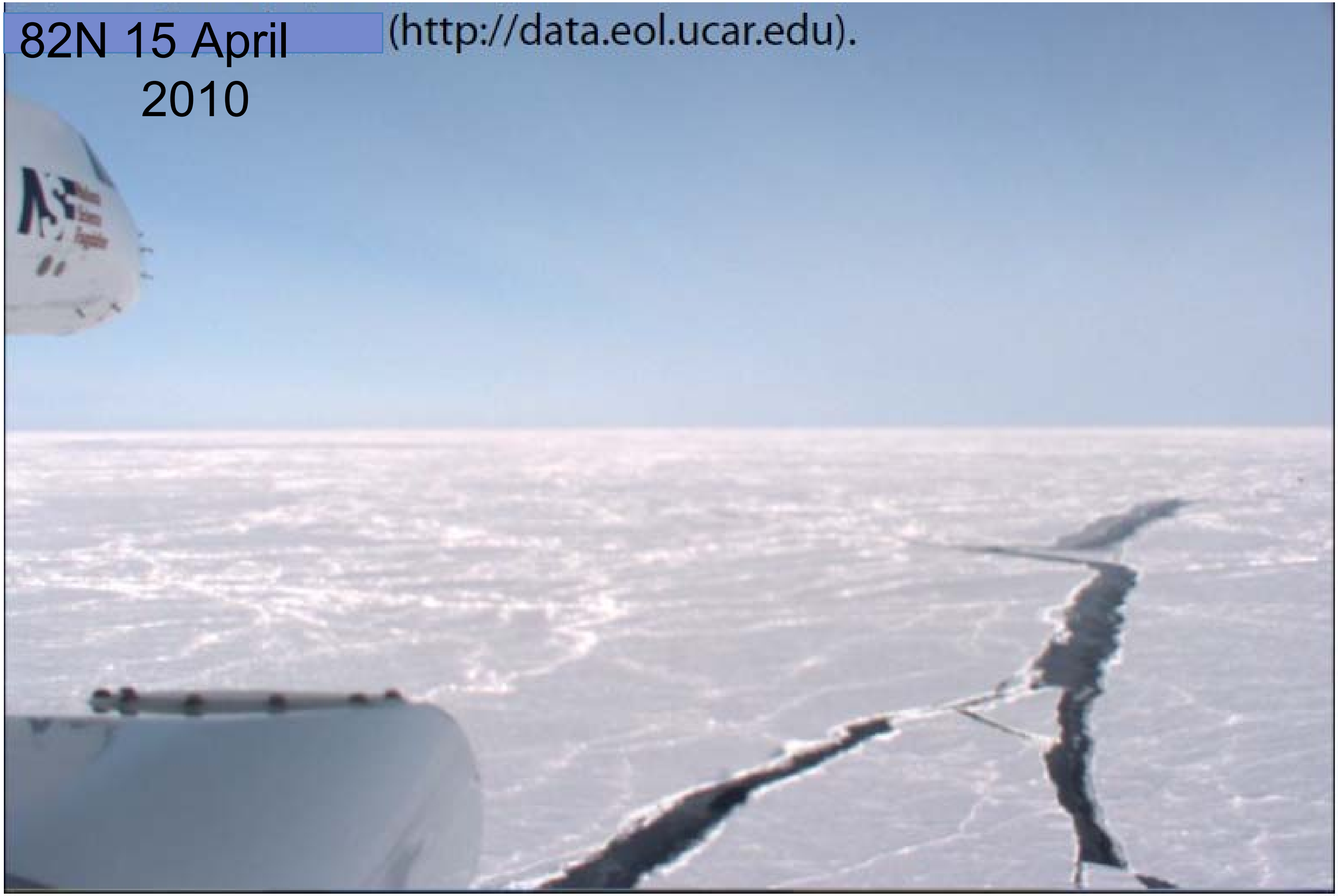

WSPD 82N 15 Apr 2010
GGALT
500
450
400
350
300
250
200
150
11
12
13
14
15
WSPD


THETA 82N 15 Apr 2010
GGALT
500
450
400
350
300
250
200
150
256
258
260
262
264
266
THETA

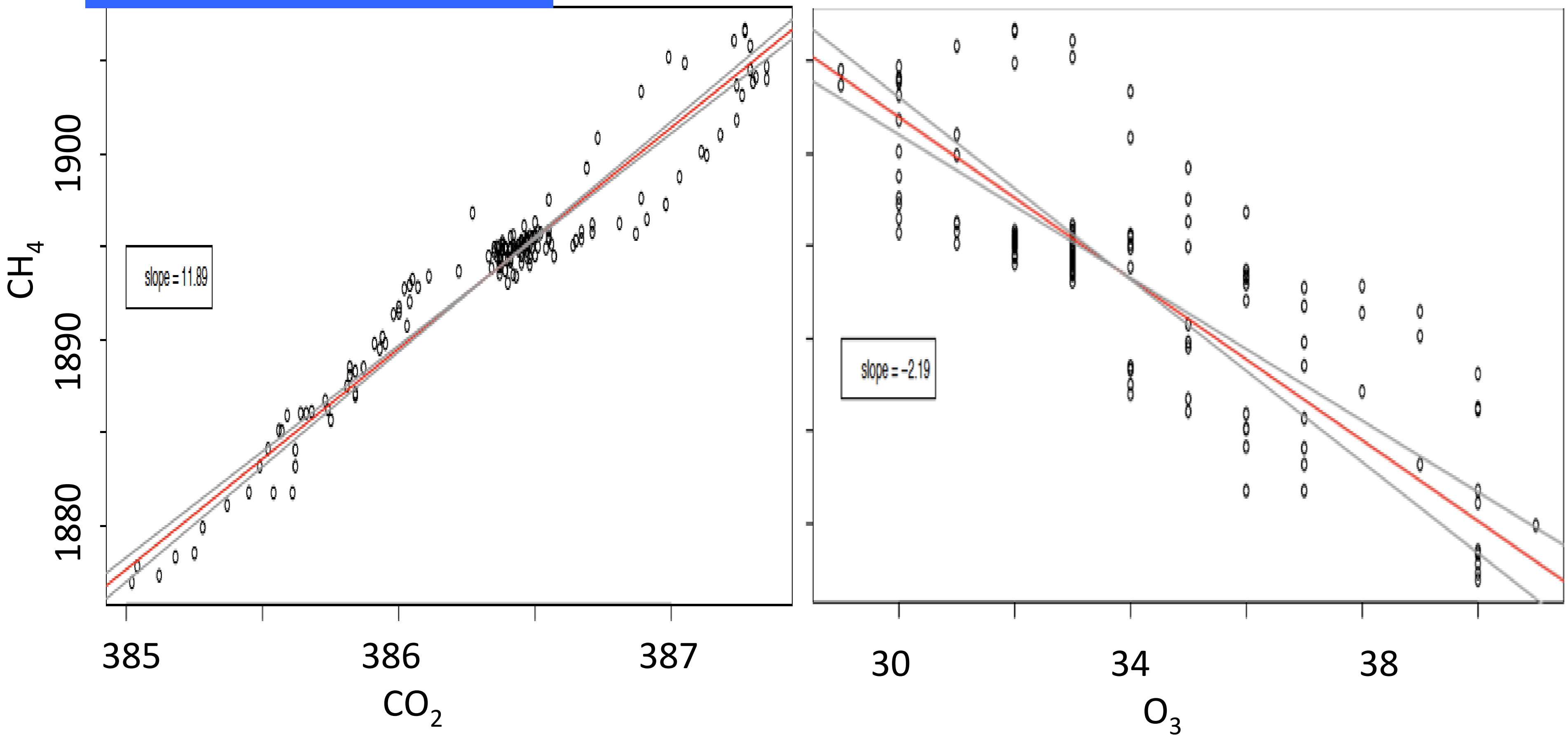

CH4 81N 26 Mar 2010
GGALT
500
450
400
350
300
250
200
150
1900
1905
1910
1915
1920


THETA 81N 26 Mar 2010
GGALT
500
450
400
350
300
250
200
150
245
246
247
248
249
250
251
252
THETA

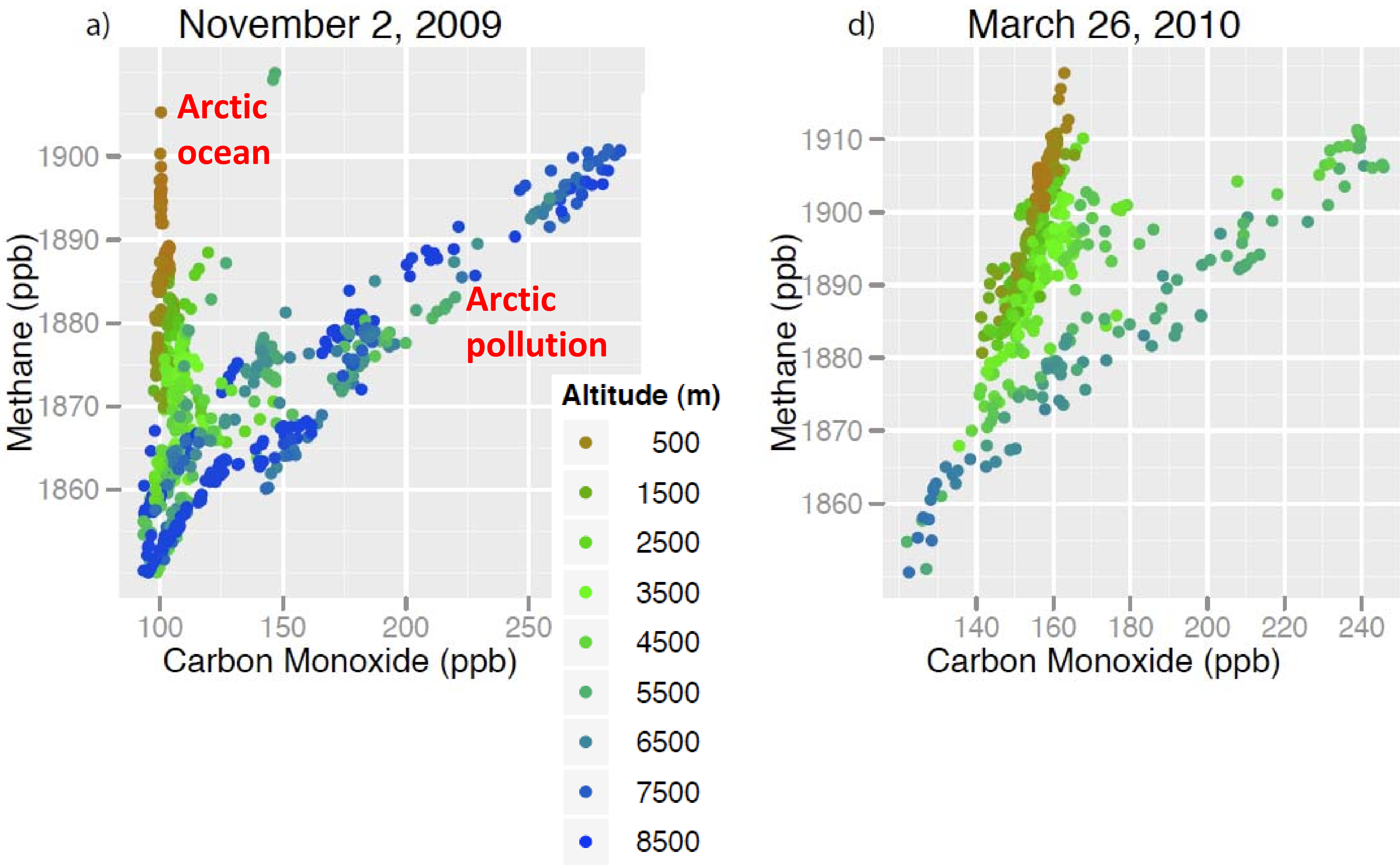

WSPD 81N 26 Mar 2010
GGALT
500
450
400
350
300
250
200
150
13
14
15
16
17
18
19
WSPD


82N 15 April 2010
(http://data.eol.ucar.edu).

$\Delta CH_4 = 0.12 \times \Delta CO_2$

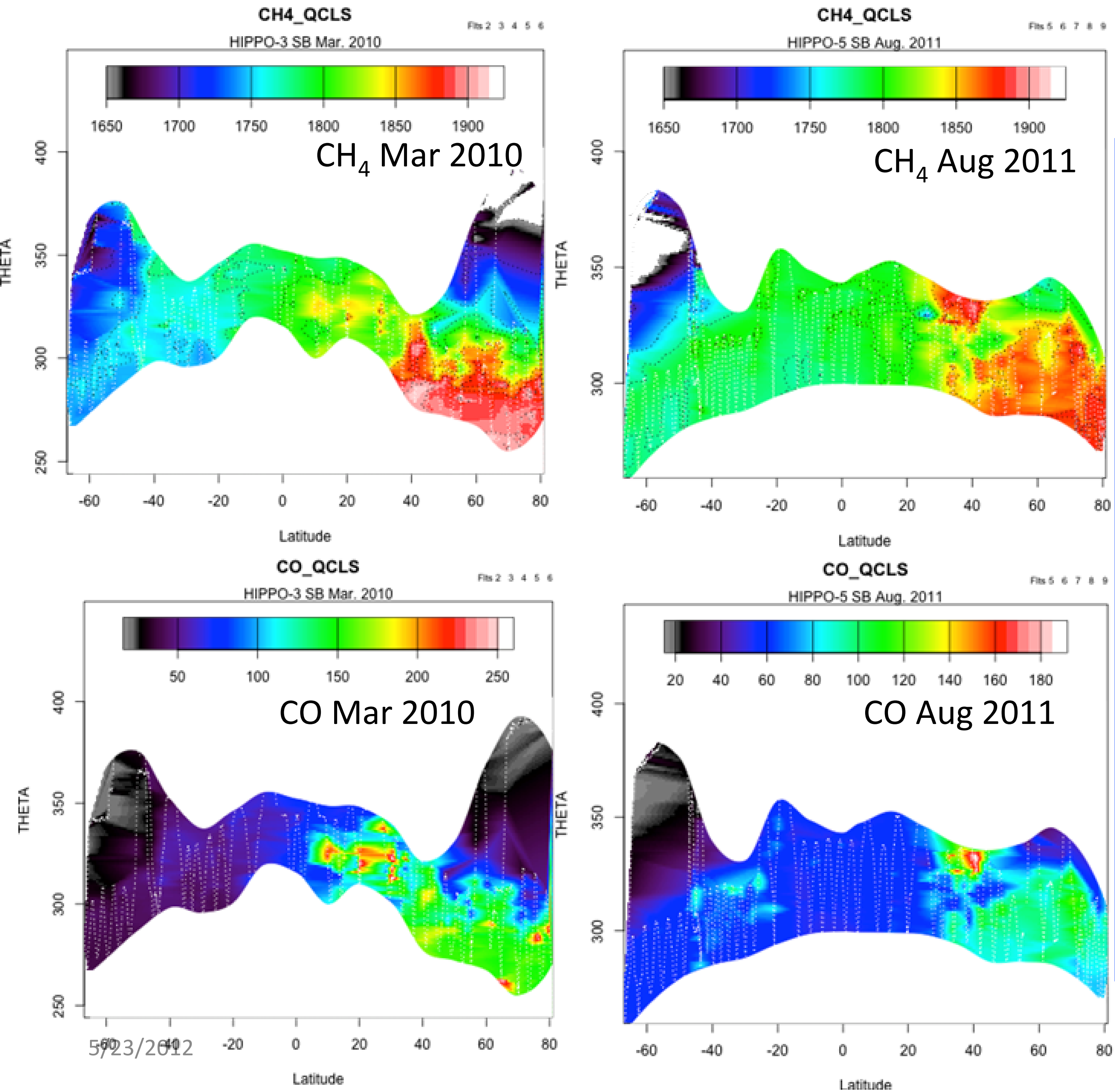


Supplementary Figure 2: Multi-species correlations. Data from below 600 m for a profile observed on Nov. 2, 2009 at 78° N.



Relationships between tracers with distinct sources: A tool for understanding large scale sources and sinks of GHGs.

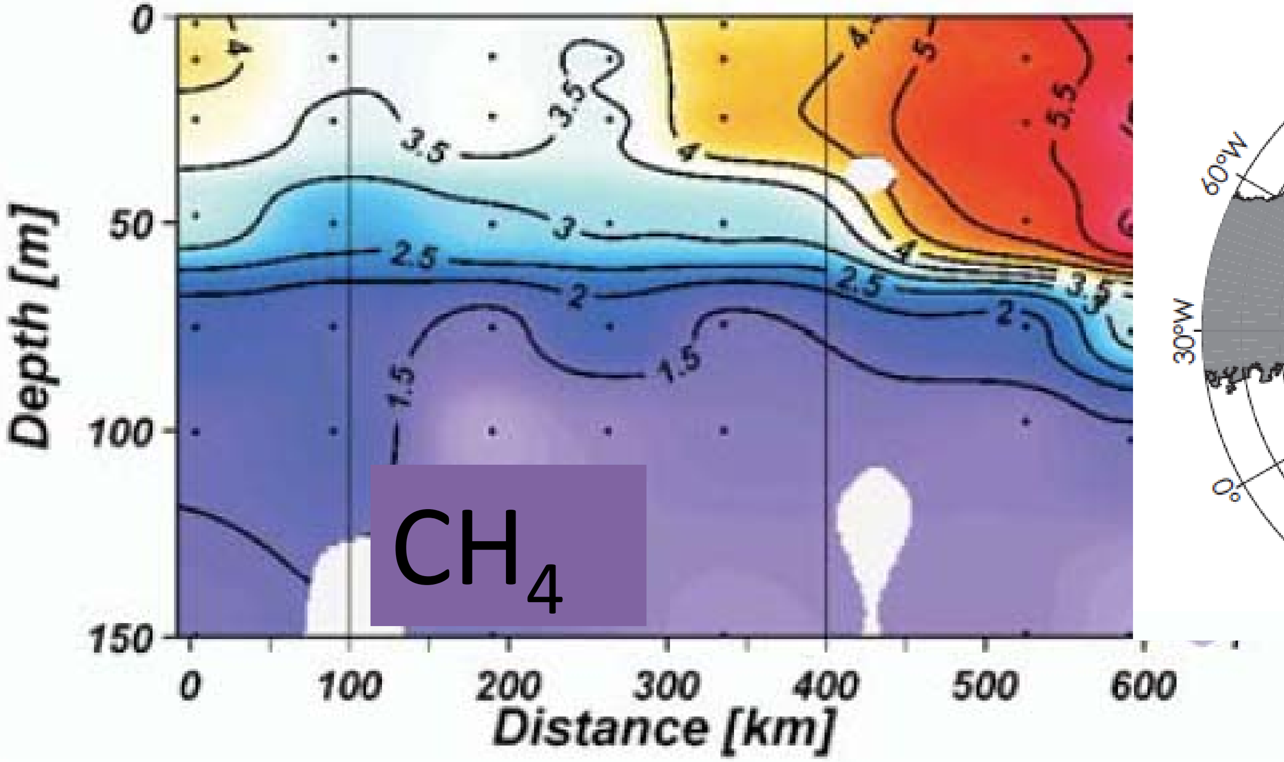
Slide from: E. A. Kort

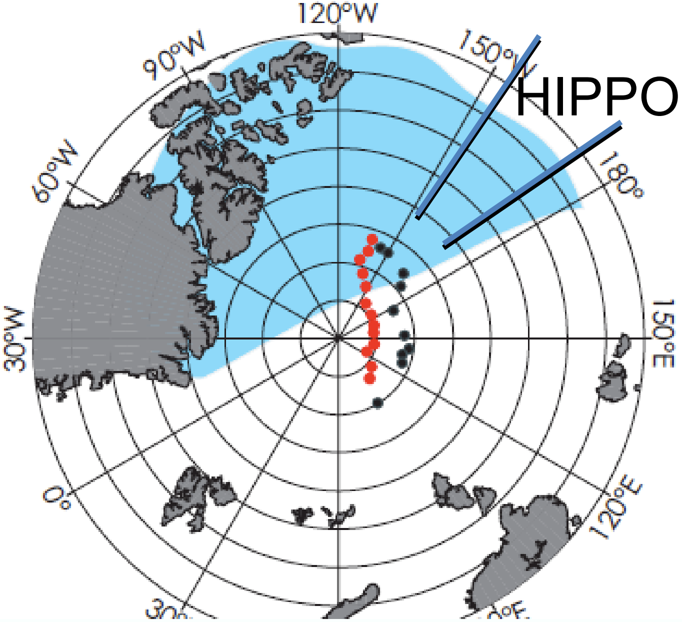


Non-pollution sources of CH_4 fill the whole Arctic…

Is this excess due to marine emissions?

Do ocean sources respond to changes in ice cover?

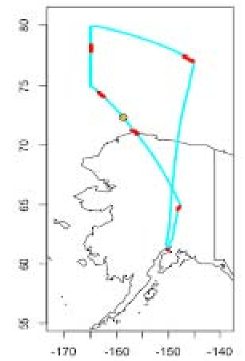




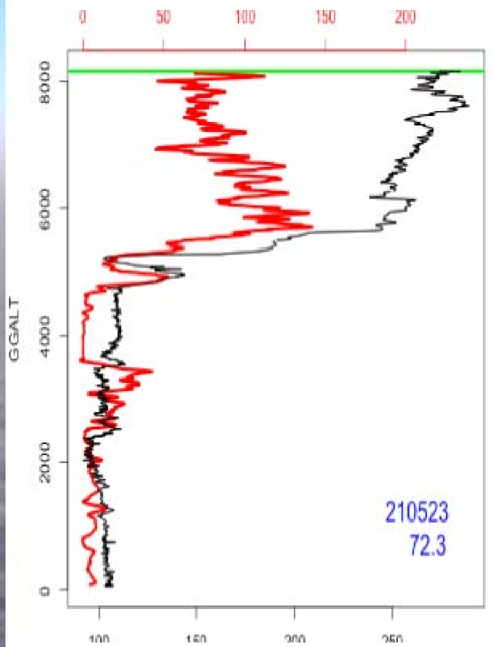
E. Damm et al.: Methane production in aerobic oligotrophic surface water
Biogeosciences, 7, 1099–1108, 2010

Arctic Pollution

6-8 km, all year round…



Black C (NOAA SP2)



CO (Harv/Aerodyne/NCAR)

Summary: The Arctic

The HIPPO data show:

•**Dense pollution** at both very high and low altitudes in the Arctic. Unexpected distributions of **Black Carbon** (NOAA SP-2; radiative forcing?). **(*Not shown here*)**.

•Sources of CH_4 in the Arctic from from the ocean surface, significant compared to fossil fuel extraction and land surface.

… and a lot more

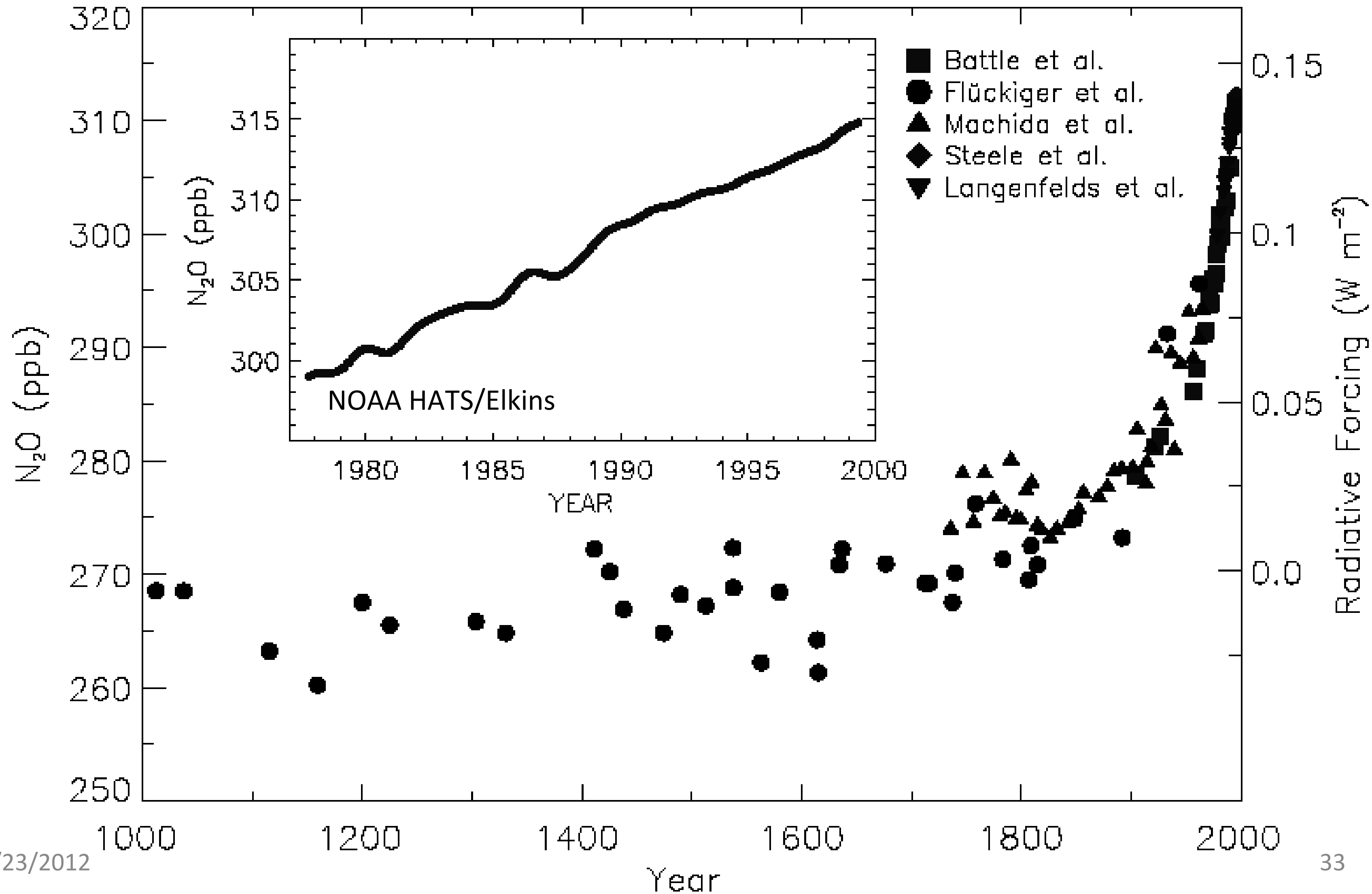
Photos: by; B. C. Daube
& J. V. Pittman

Stepping back:

If you set the goal to monitor the atmosphere, globally or regionally, for science and policy, what are the considerations for science strategy and design of networks?

N_2O in the atmosphere: where does it really come from?

Concentrations of atmospheric N_2O have been increasing since the end of the 18th Century

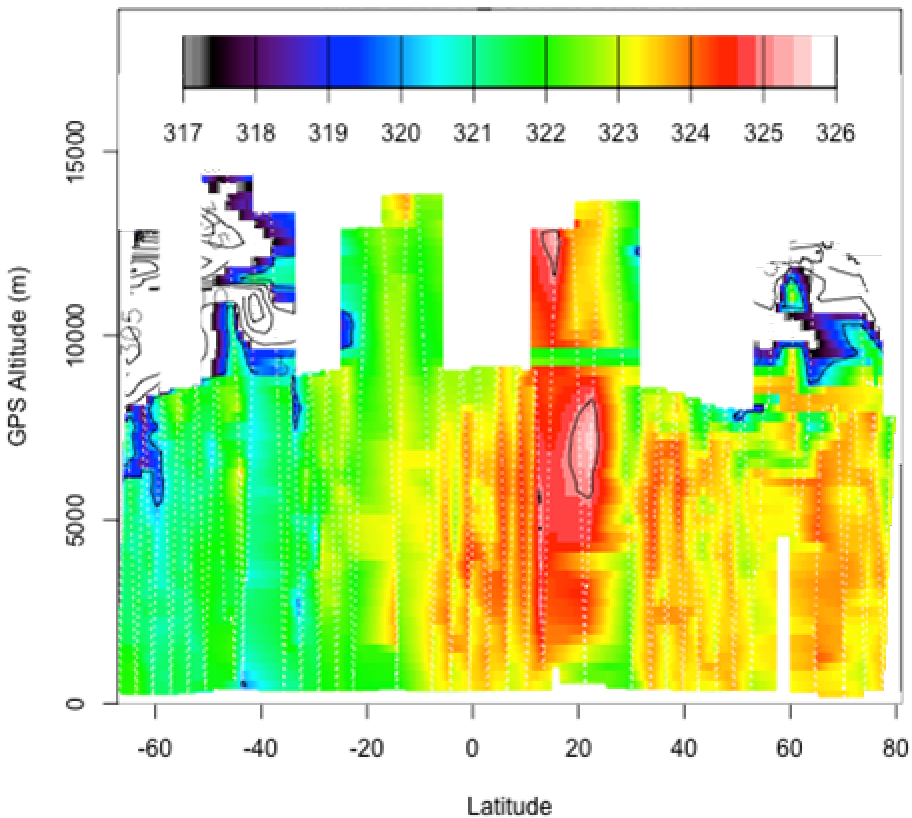


PRESENT-DAY GLOBAL BUDGET OF ATMOSPHERIC N_2O (1535 TgN)

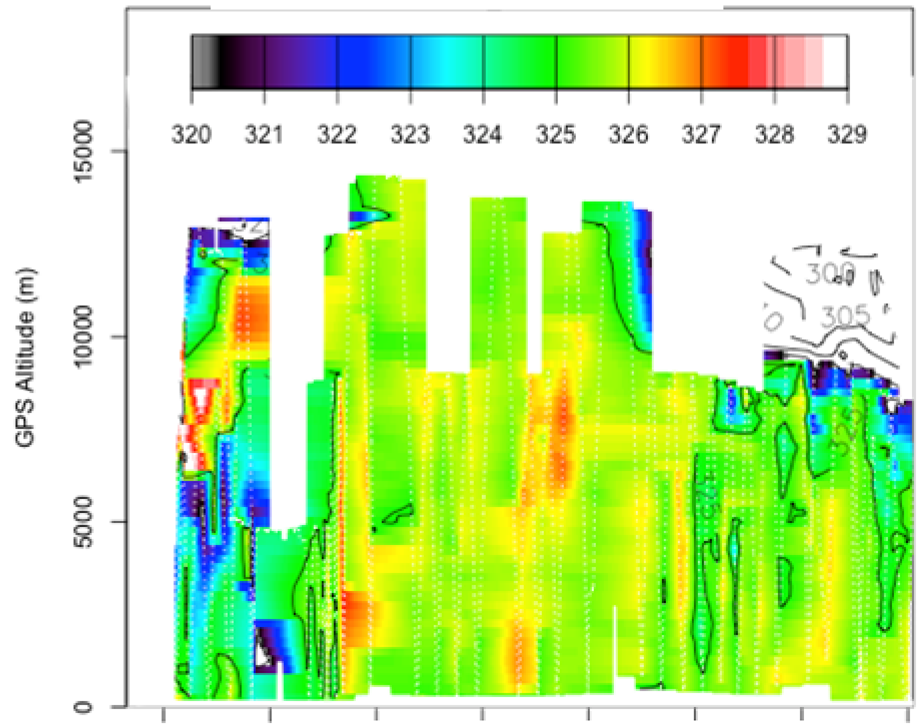
SOURCES (Tg N yr^{-1})	16 (13 - 19)
Natural	10 (5 – 16)
Ocean	3 (1 - 5)
Tropical soils	4 (3 – 6)
Temperate soils	2 (1 – 4)
Anthropogenic	8 (2 – 21)
Agricultural soils	4 (1 – 15)
Livestock	2 (1 – 3)
Industrial	1 (1 – 2)
SINK (Tg N yr^{-1}) Photolysis and oxidation in stratosphere (τ = 127 yr)	12 (10 - 14)
ACCUMULATION (Tg N yr^{-1})	4 (3 – 5)

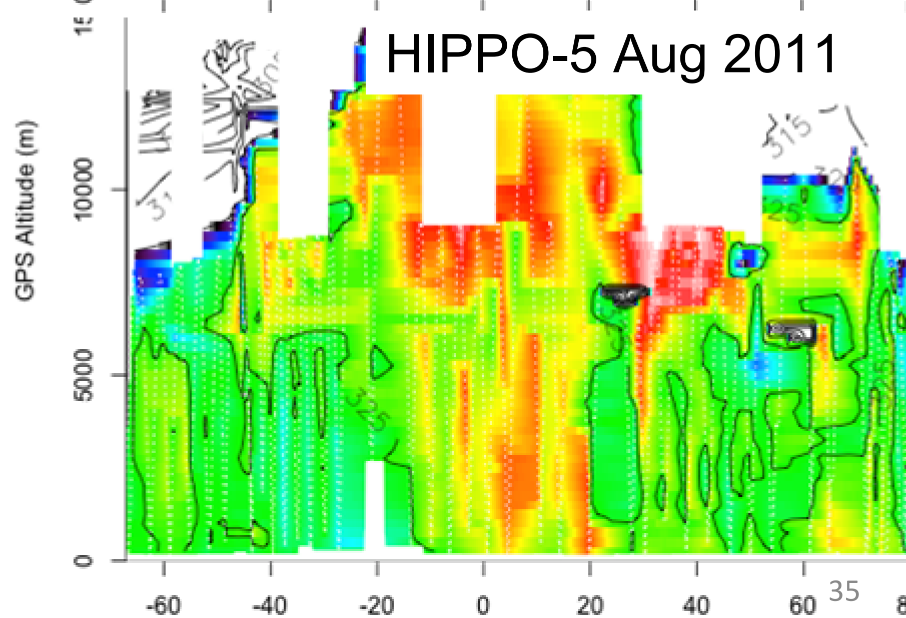
A budget can be constructed, but uncertainties in sources are large !

HIPPO-1 Jan 2009

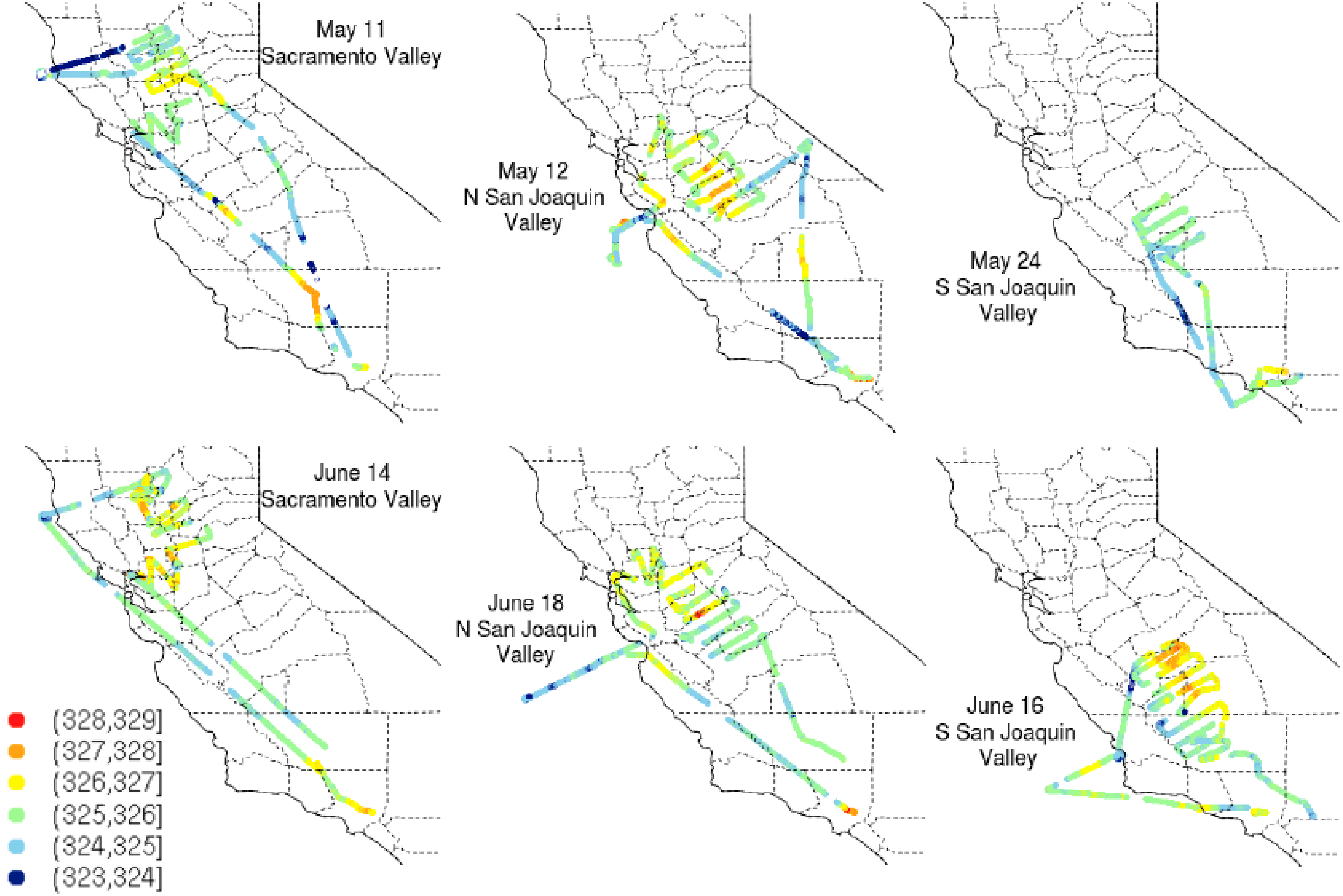


HIPPO-4 Jun 2011





CalNEX NOAA P-3 at Ontario, CA June 2010



Examples of CalNEX flights and N_2O data (NOAA P3, 2010)

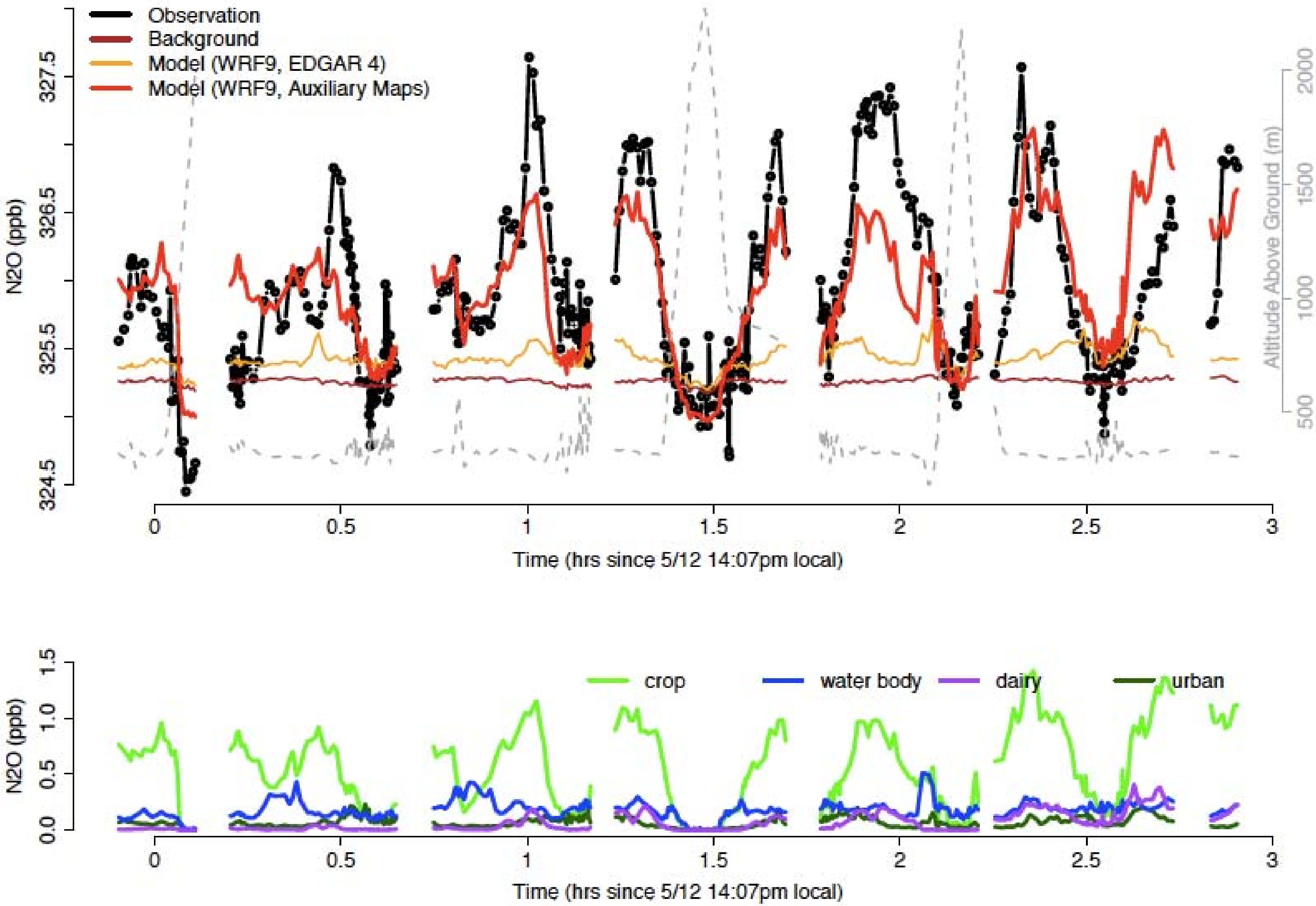
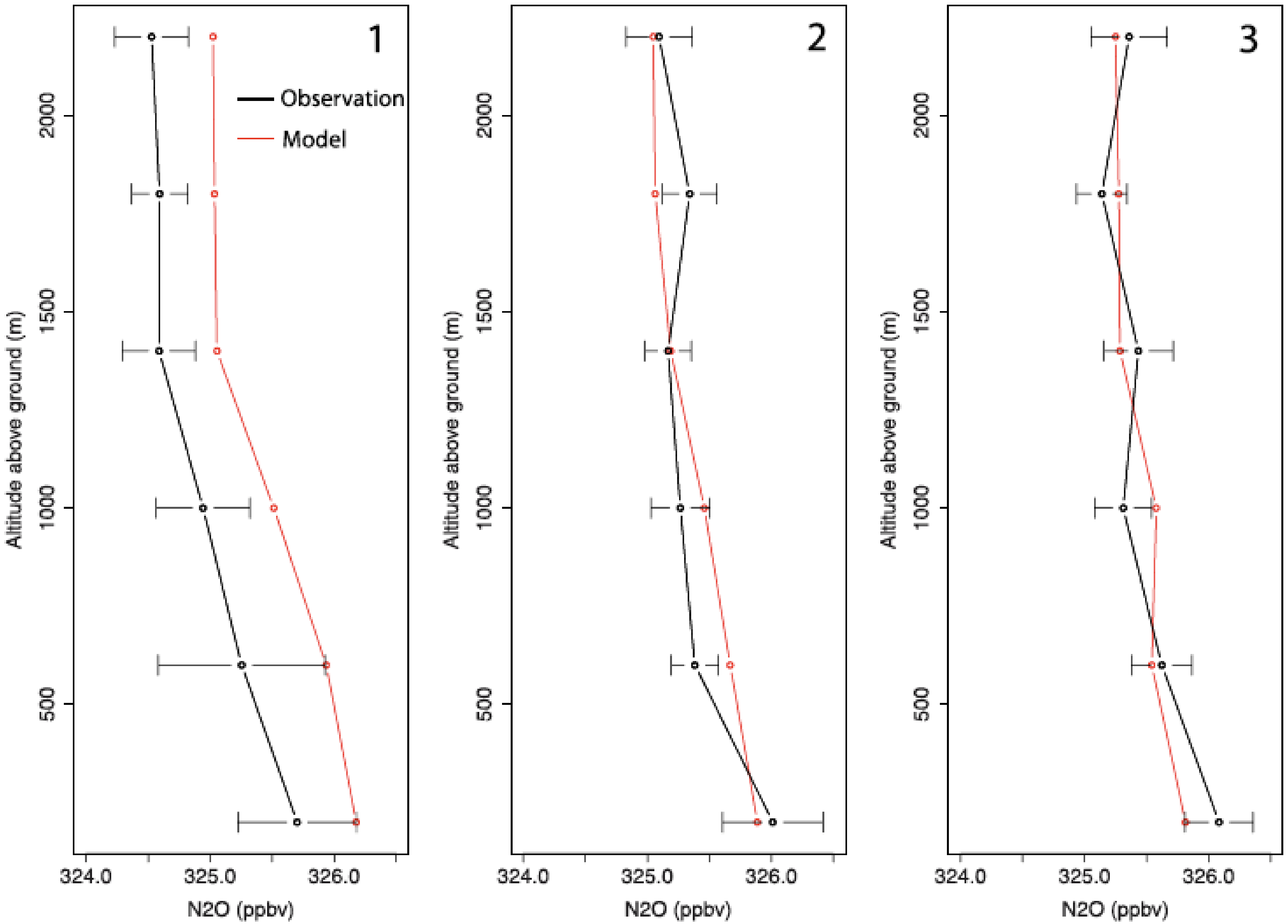
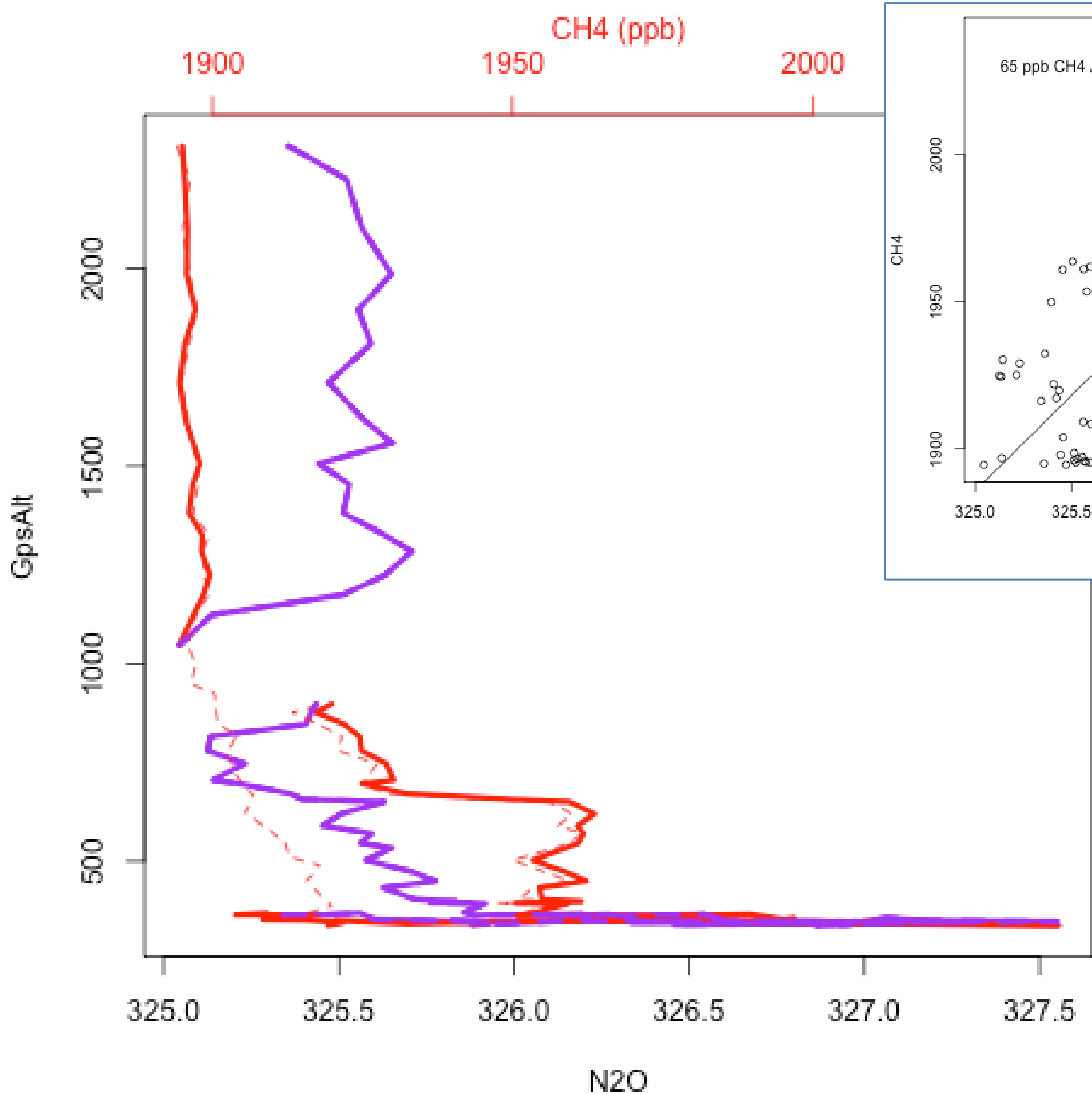
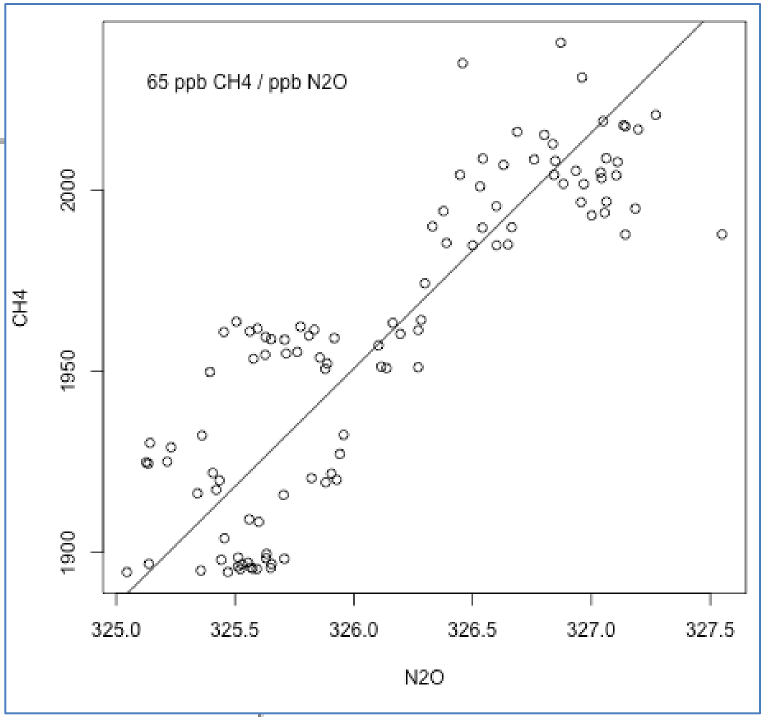

Observation
Background
Model (WRF9, EDGAR 4)
Model (WRF9, Auxiliary Maps)
N2O (ppb)
324.5
325.5
326.5
327.5
Altitude Above Ground (m)
500
1000
1500
2000
0
0.5
1
1.5
2
2.5
3
Time (hrs since 5/12 14:07pm local)
crop
water body
dairy
urban
N2O (ppb)
0.0
0.5
1.0
1.5
0
0.5
1
1.5
2
2.5
3
Time (hrs since 5/12 14:07pm local)

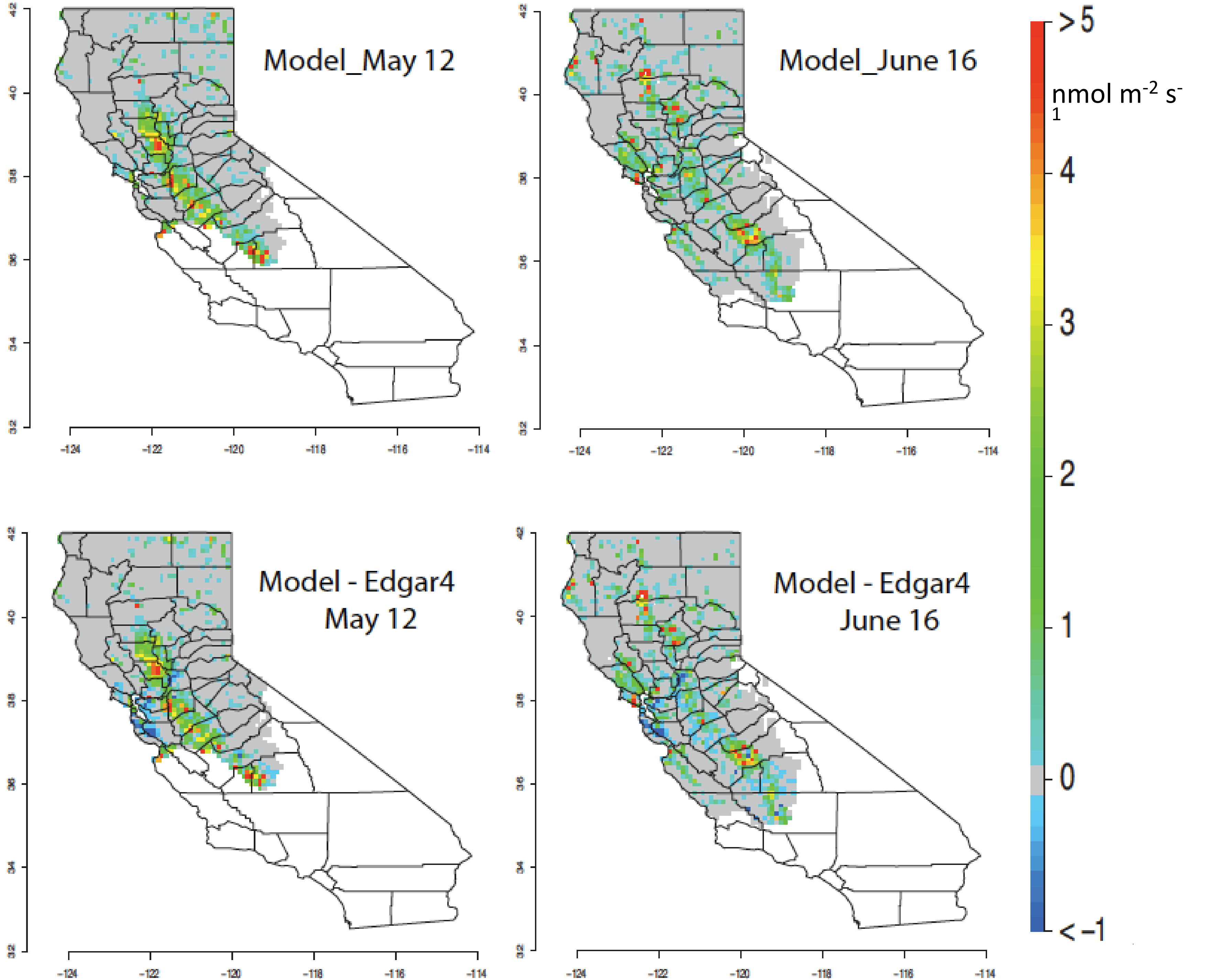
Figure 5. Vertical profiles of observed and modeled N_2O over: 1.Walnut Grove Tower (38.3N, 121.5W); 2. corn field (37.3N, 121.0W); 3. San Luis Reservoir (37.1N, 121.1W). Observations are averaged within 400 m bins.




CH4 (ppb)
1900
1950
2000
GpsAlt
500
1000
1500
2000
325.0
325.5
326.0
326.5
327.0
327.5
N2O

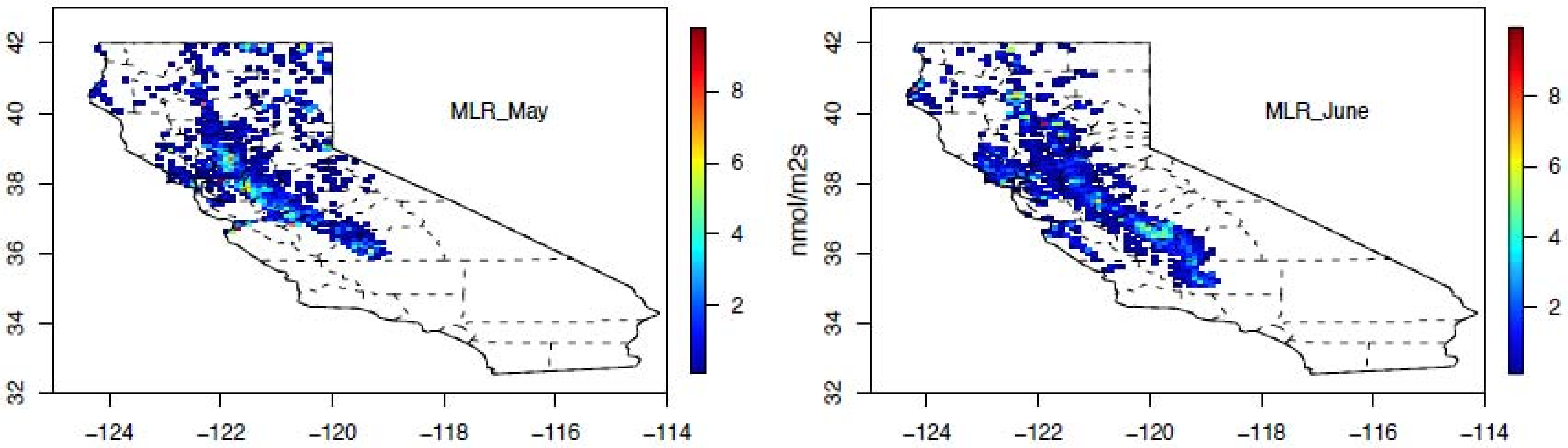

65 ppb CH4 / ppb N2O
CH4
1900
1950
2000
325.0
325.5
326.0
326.5
327.0
327.5
N2O


Merced

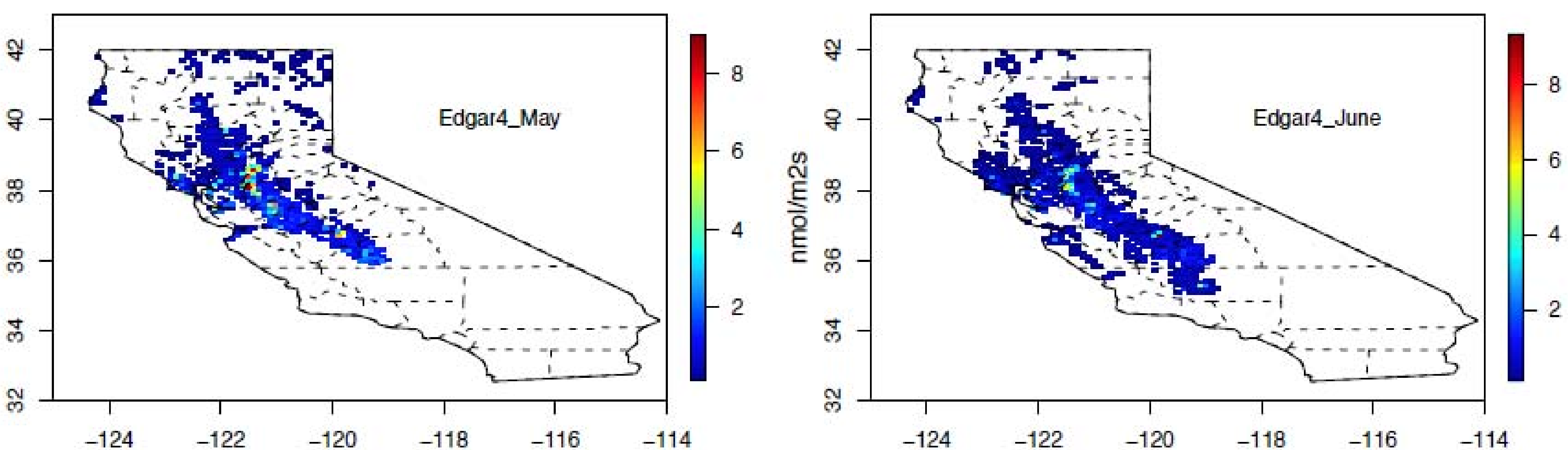


Model_May 12
Model_June 16
Model - Edgar4
May 12
Model - Edgar4
June 16
nmol m-2 s-1
>5
4
3
2
1
0
<-1
-124
-122
-120
-118
-116
-114
32
34
36
38
40
42

Flux Model Results (Optimized using CalNEX aircraft data) Total (est) = 0.12 TgN/yr



Edgar 4.0 Flux Model Total = 0.026 TgN/yr



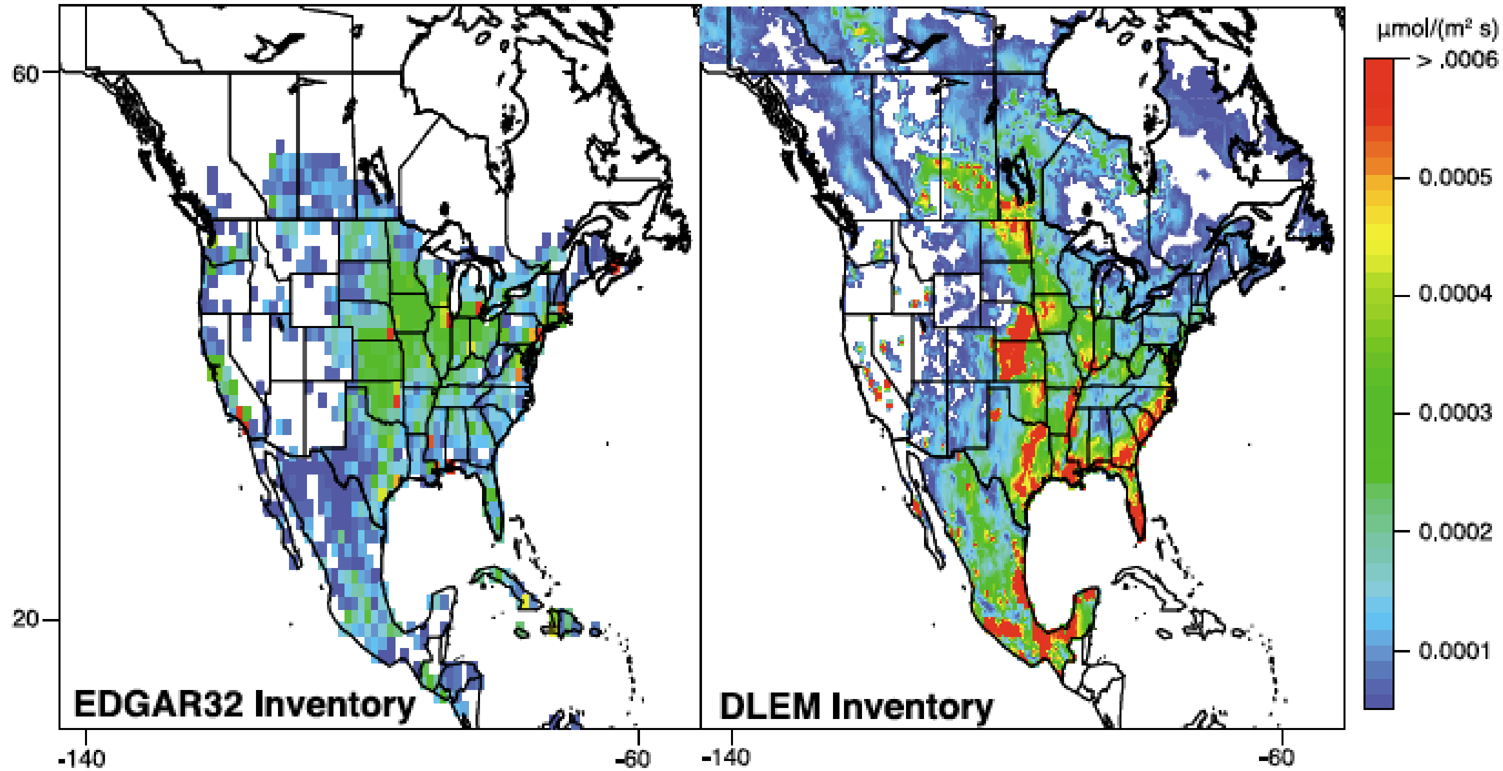


Figure 1. Graphical plots of the different N_2O emissions inventories for 2000. Because DLEM is a daily inventory, the plot above shows average fluxes for May–August 2000. EDGAR v.4 and GEIA (not shown) have similar distributions to EDGAR32 but smaller magnitude (particularly EDGAR v.4).

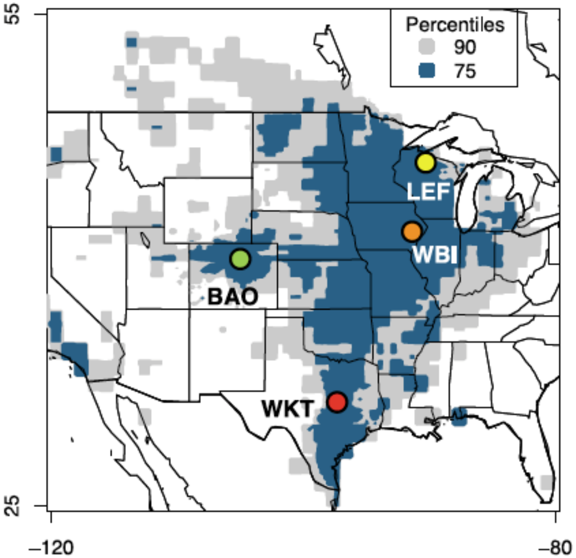


Figure 2. The contour lines indicate the regions that contribute 75 and 90% of the mixing ratio signal seen at each of the tall tower sites. The plot reflects the months of May through August, 2008, and was constructed using the EDGAR32FT2000 emissions inventory. The tall tower ensemble sees influence from N_2O sources over much of the central US.

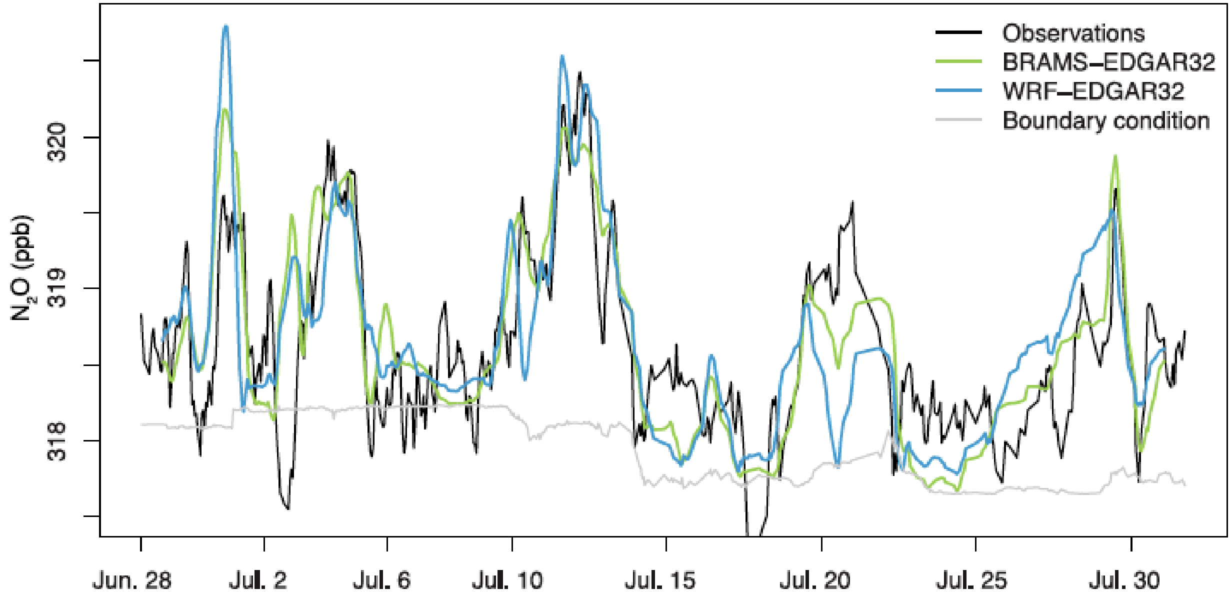


Figure 3. STILT model results for hourly observations at LEF Tower in Park Falls, WI, with two different meteorological drivers. Each result is optimized with a reduced major axis regression and smoothed with a Savitsky-Golay filter.

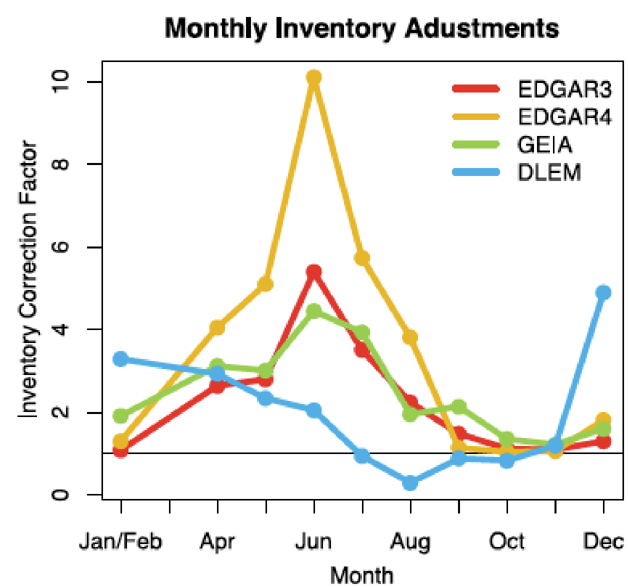


Figure 5. Corrective emissions inventory scaling factors produced by the RMA regression for the ensemble of 2008 tall tower data.

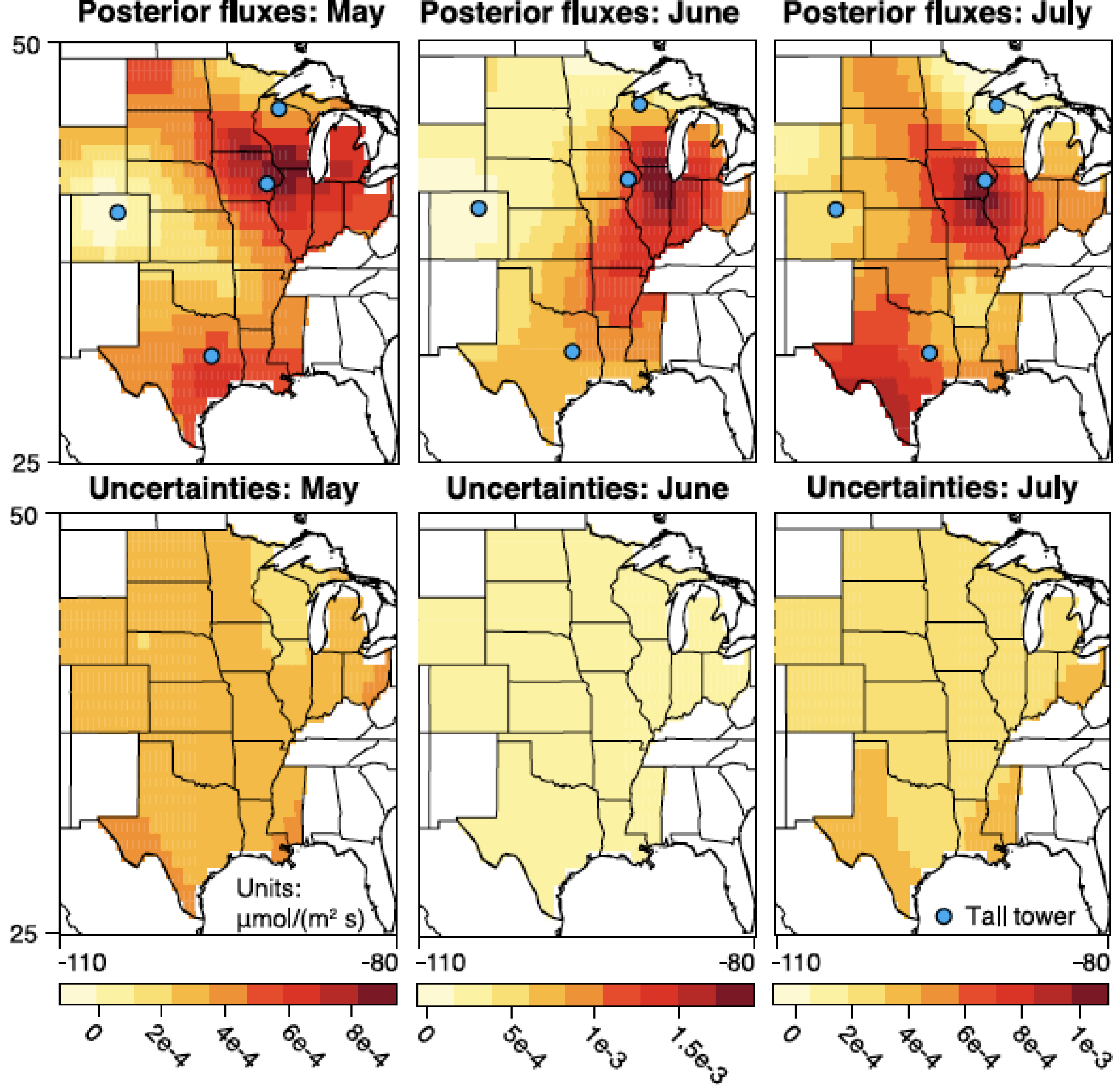


Figure 6. Monthly a posteriori fluxes and associated uncertainties (a posteriori standard deviations) estimated for the geostatistical inversion. This plot is made using different colors from Figure 1 and on different scales to better highlight spatial trends.

[47] The inversions and regressions suggest sources that are significantly larger than in either EDGAR or GEIA for nearly all geographic regions and times of year. Interestingly, estimated emissions in the newest release of EDGAR (v. 4) are lower than previous releases, requiring even larger modification. Table 4 displays monthly N_2O budgets from the inversions and RMA regressions for both 2004 and 2008. Using the RMA regression for the 2008 ensemble of tall tower sites, we estimate an annual N_2O budget of 1.0–1.2 TgN/yr for the inversion region. If we divide these results by the percentage of fluxes in the inversion region (see Table 5), we can extrapolate to the entire US and Canada. The resulting budget estimate for the United States and Canada is 2.4–2.6 TgN/yr. This range of estimates reflects the results of different starting inventories (the EDGAR and GEIA inventories). The different methods produce slightly

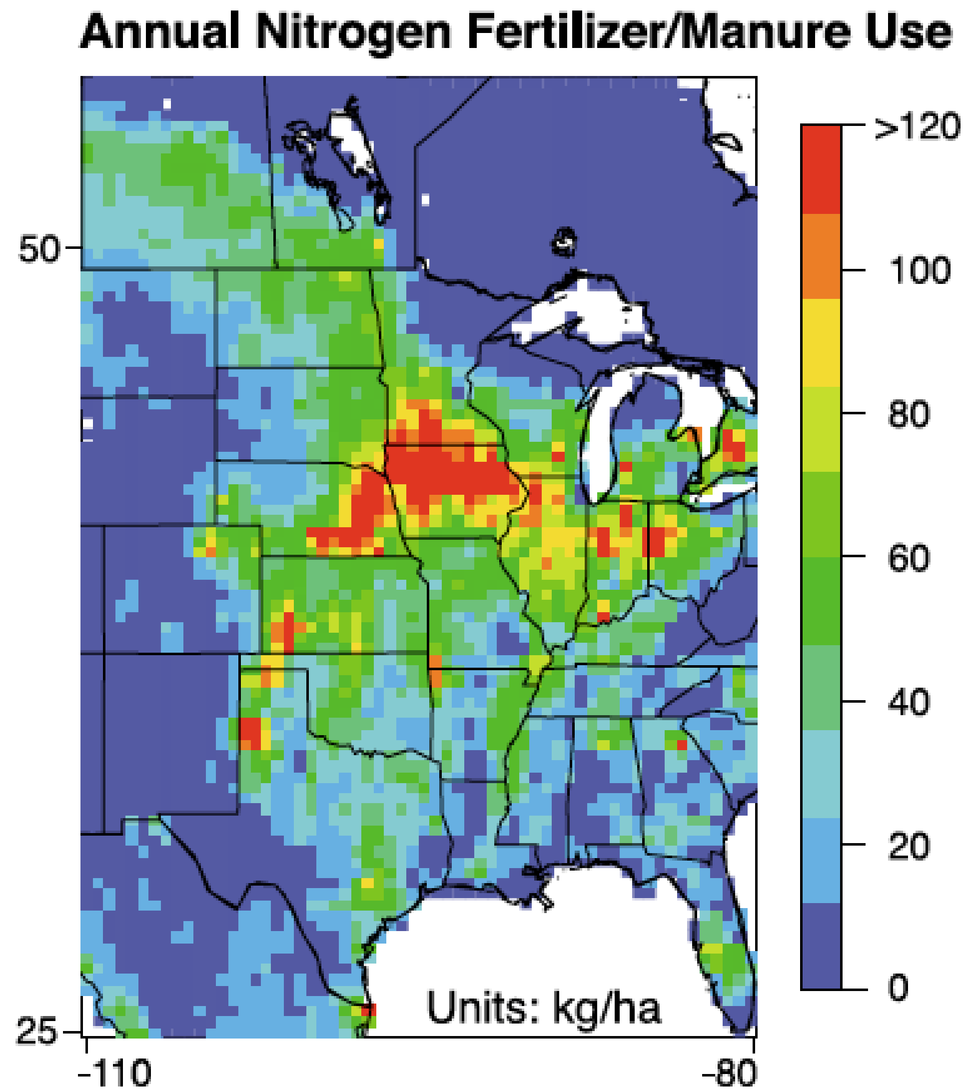


Figure 9. An estimate of annual fertilizer use taken from *Potter et al.* [2010]. The a posteriori N_2O fluxes from both the geostatistical and Bayesian inversions are strongly similar to the spatial distribution of nitrogen fertilizer. *Potter et al.* [2010] estimate manure application for 2007 and synthetic fertilizer for 2000.

Do you want greenhouse gases with that, sir?

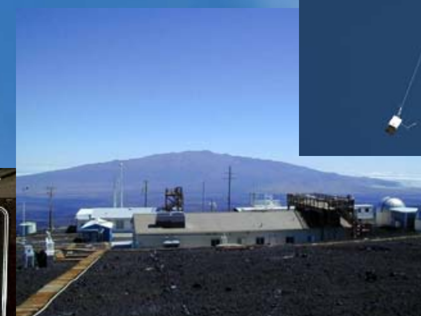
Summary: N_2O

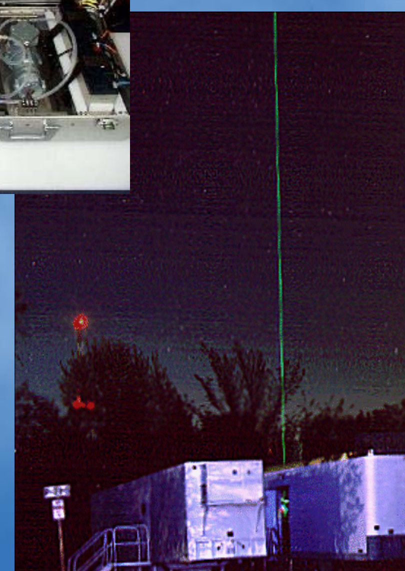
Analysis of data from HIPPO and CalNEX flights, and NOAA surface stations and tall towers, shows:

• Global sources are stronger (2x) in the tropics than given in inventories, and the influence is invisible to surface stations (see next slide for CO_2).

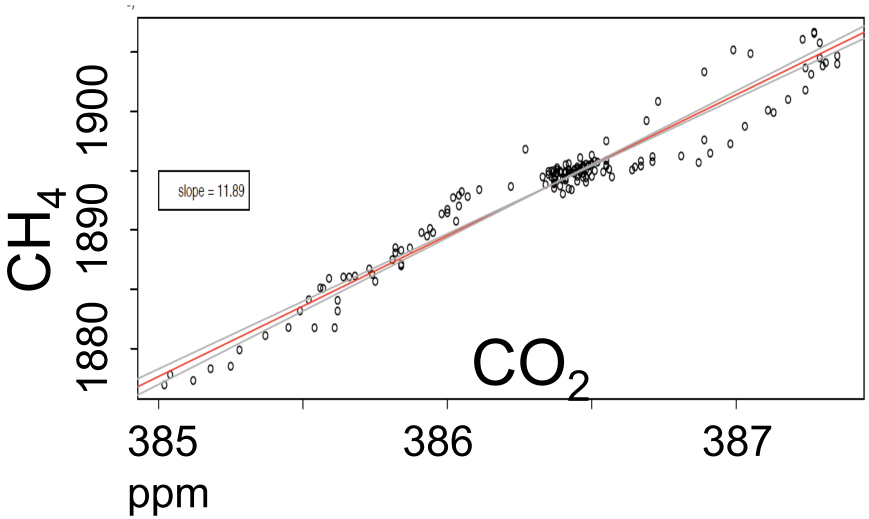
• Agricultural sources in the US are 2x to 4x bigger than in current inventories.

An optimal Earth observing system includes a diversity of data types and very tight control of data quality.





Courtesy: Arlyn E. Andrews



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CH_4:CO_2 = .0085