Low ozone in the Tropical Tropopause Layer (TTL) over the western tropical Pacific

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Background

- Low ozone has been previously observed over the tropical Pacific Ocean (Kley et al., 1996; Takashima et al., 2007, 2008).
- This has been hypothesized to lead to an “OH hole”, which could more easily allow short-lived ozone depleting substances to reach the stratosphere (Rex et al., 2014; Gao et al., 2014)

Data

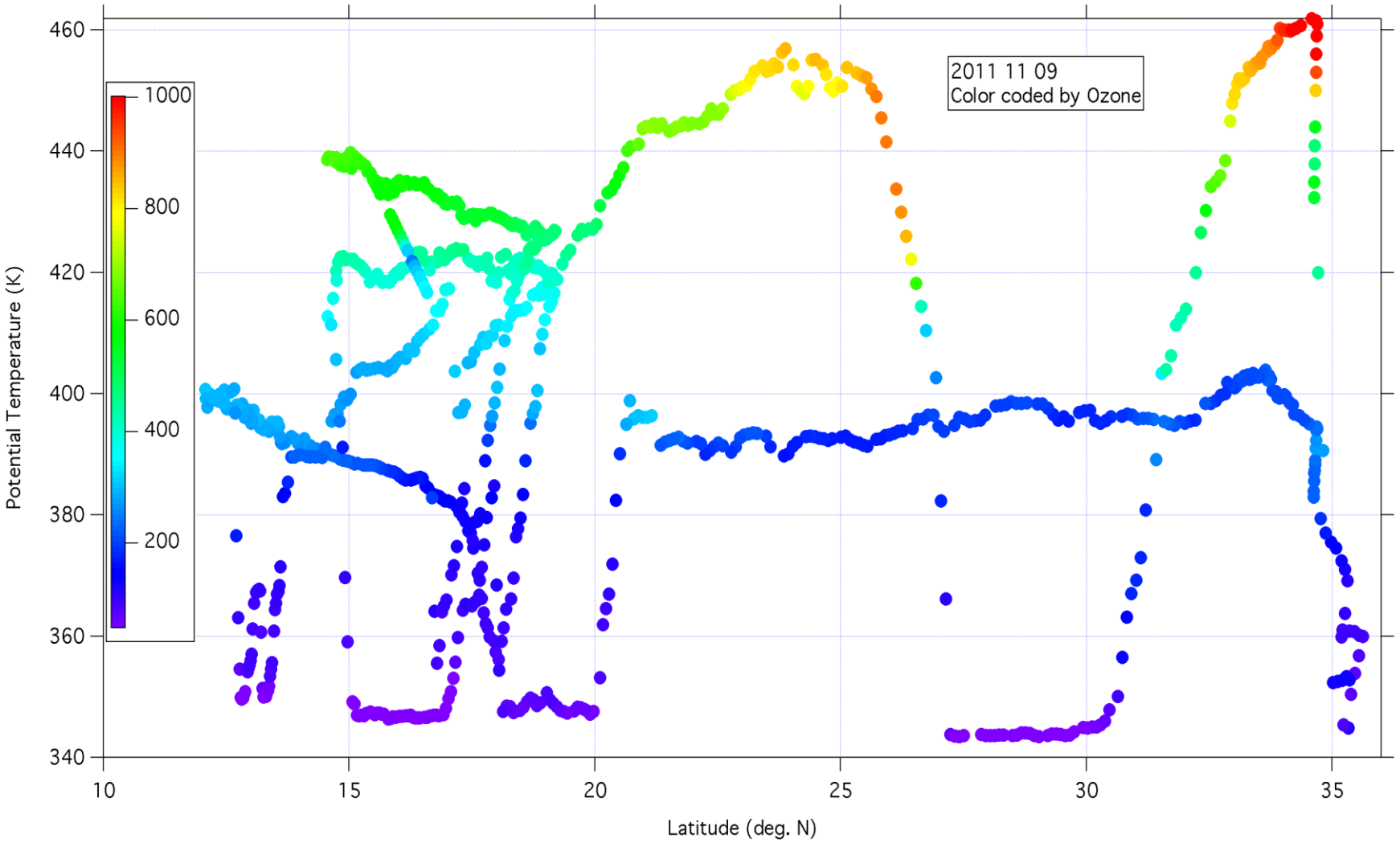
Ozone from NOAA/CSD photometer and UCATS 2B photometers (±5 ppb in TTL).

Tracers from UCATS (N_2O, SF_6, CH_4, CO), HUPCRS (CH_4, CO, CO_2), AWAS (Organic bromine).

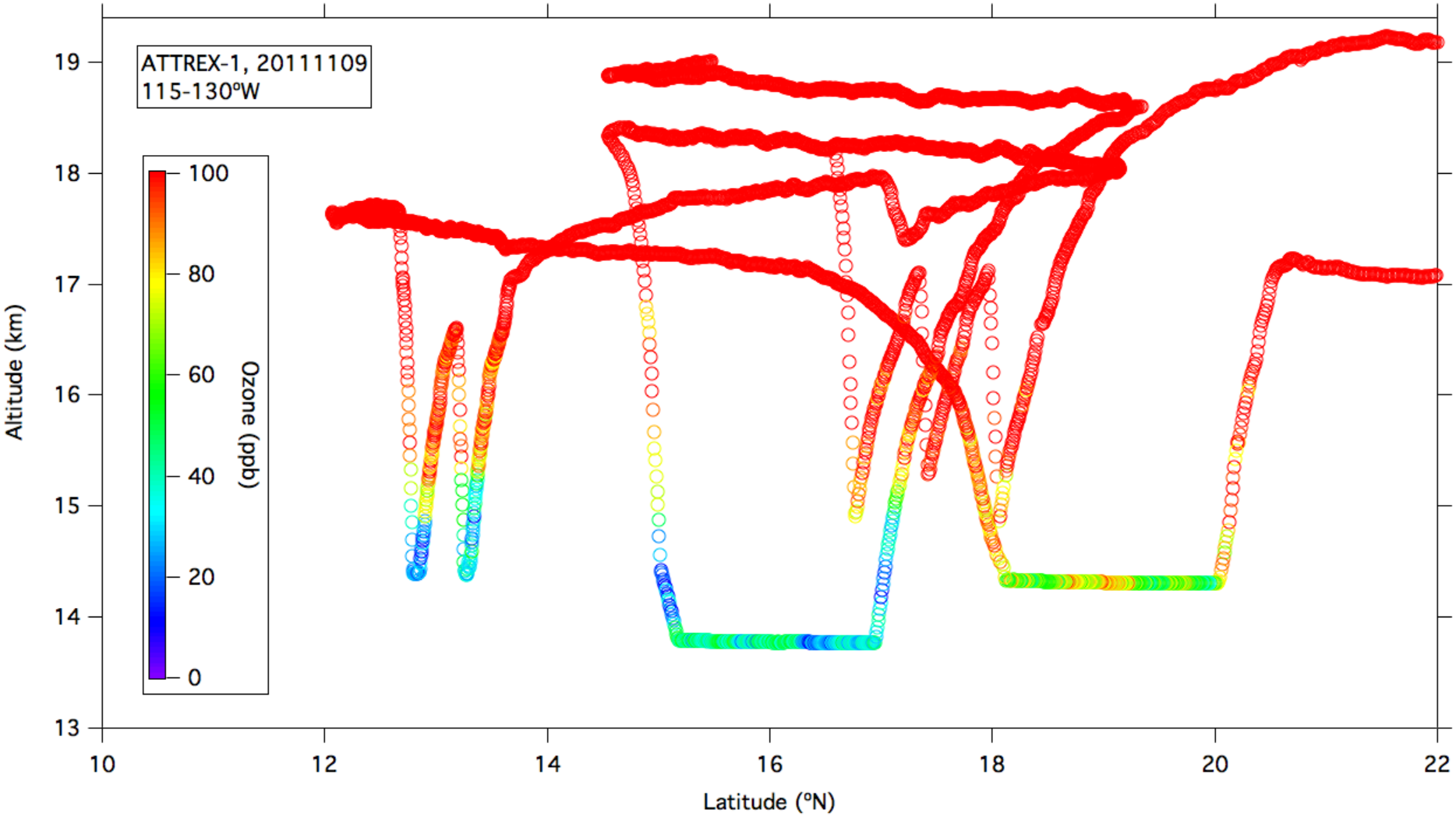
Meteorological data from MMS and MTP.

Back trajectory calculations.

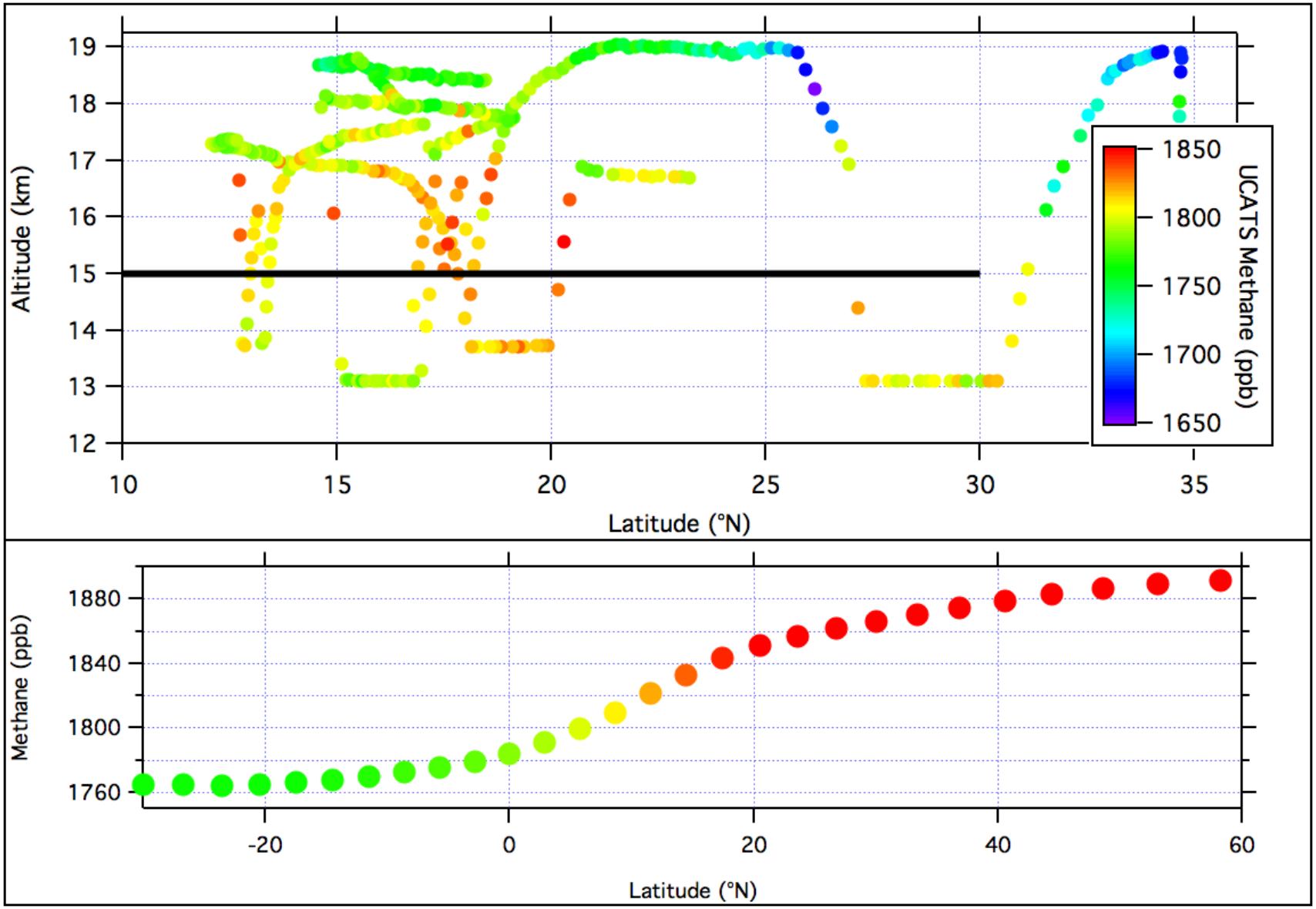
ATTREX-1 Ozone (November 9, 2011)



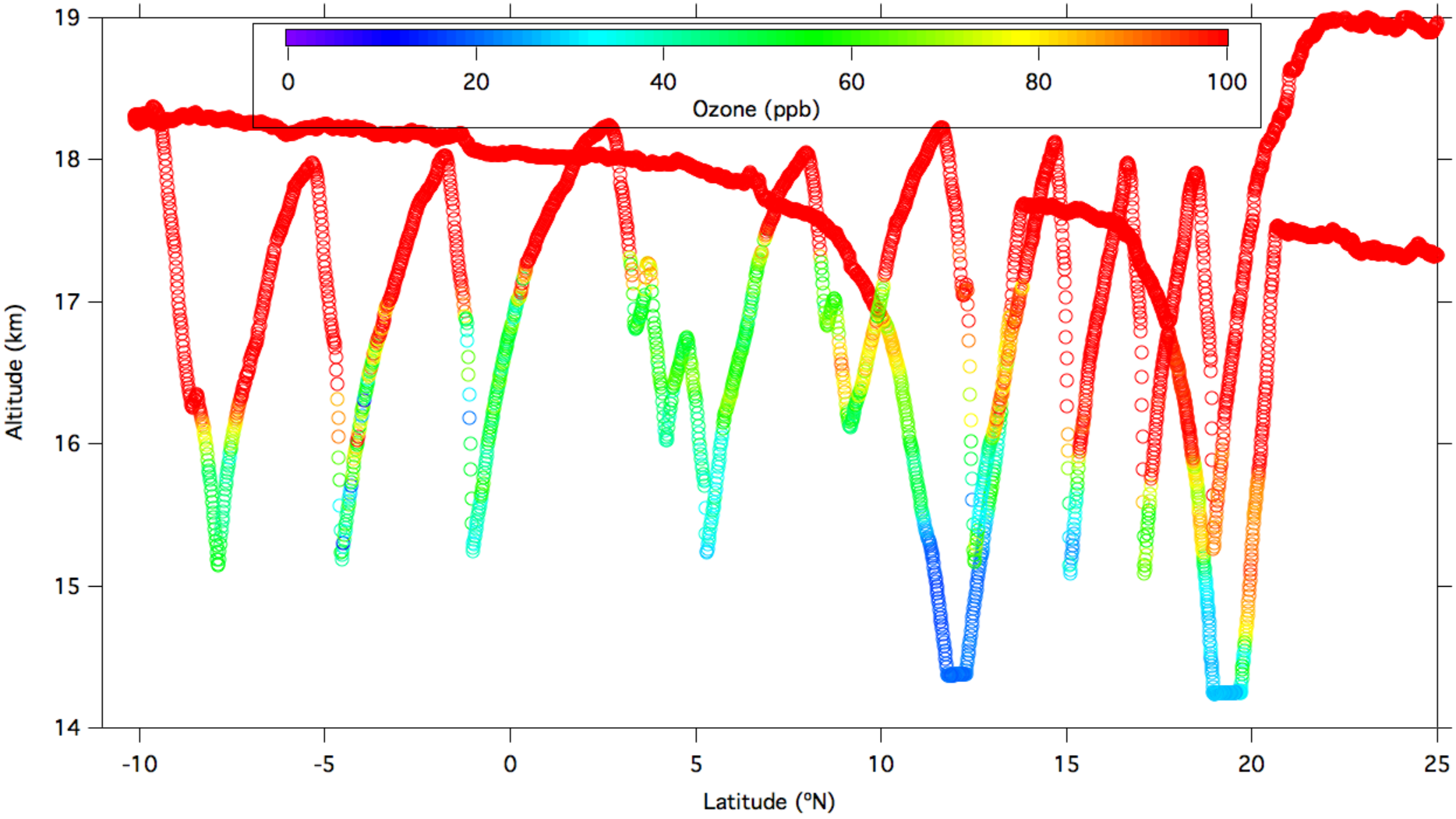
Flight curtain in tropics, low ozone



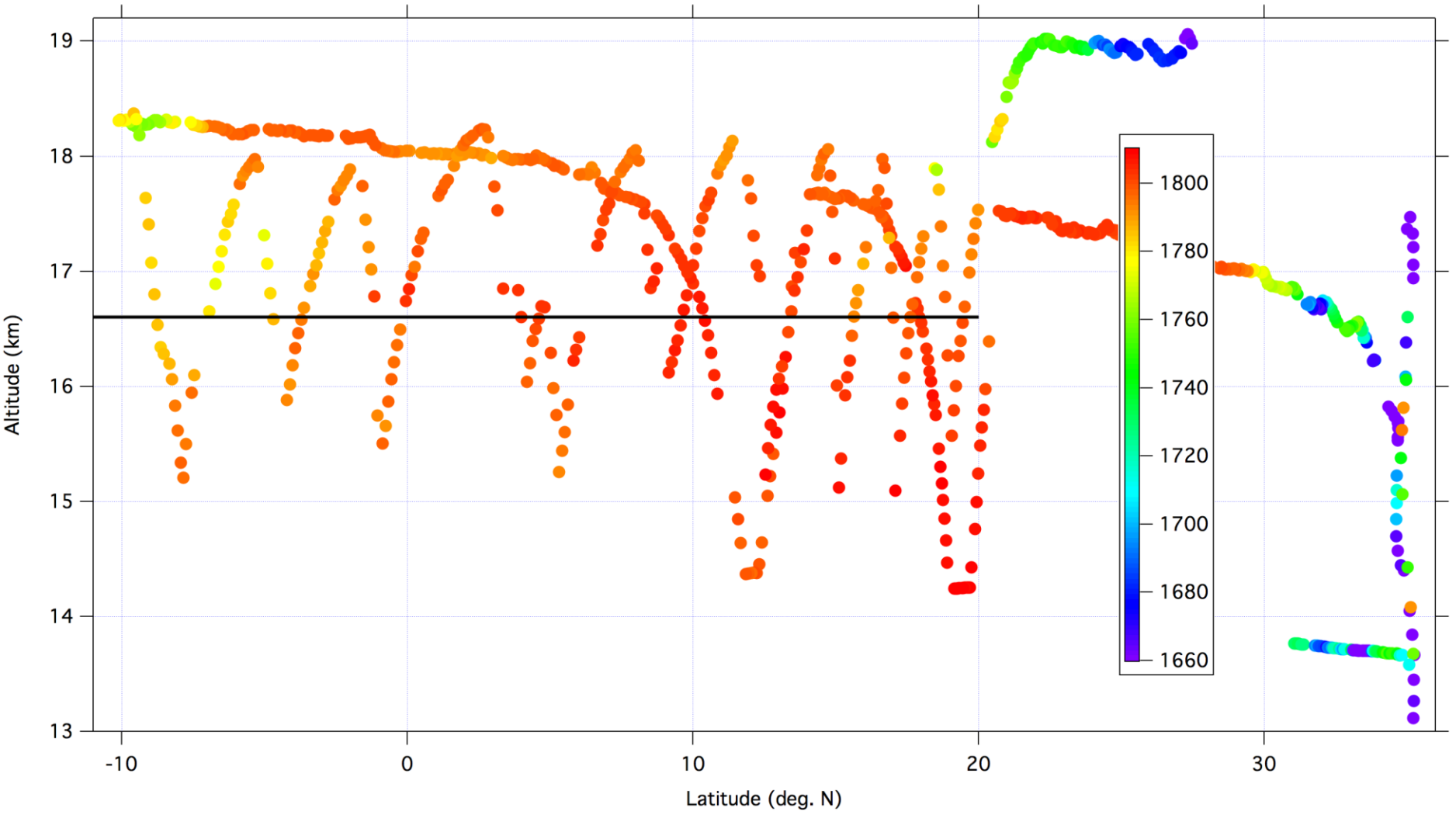
November 9, 2011; methane



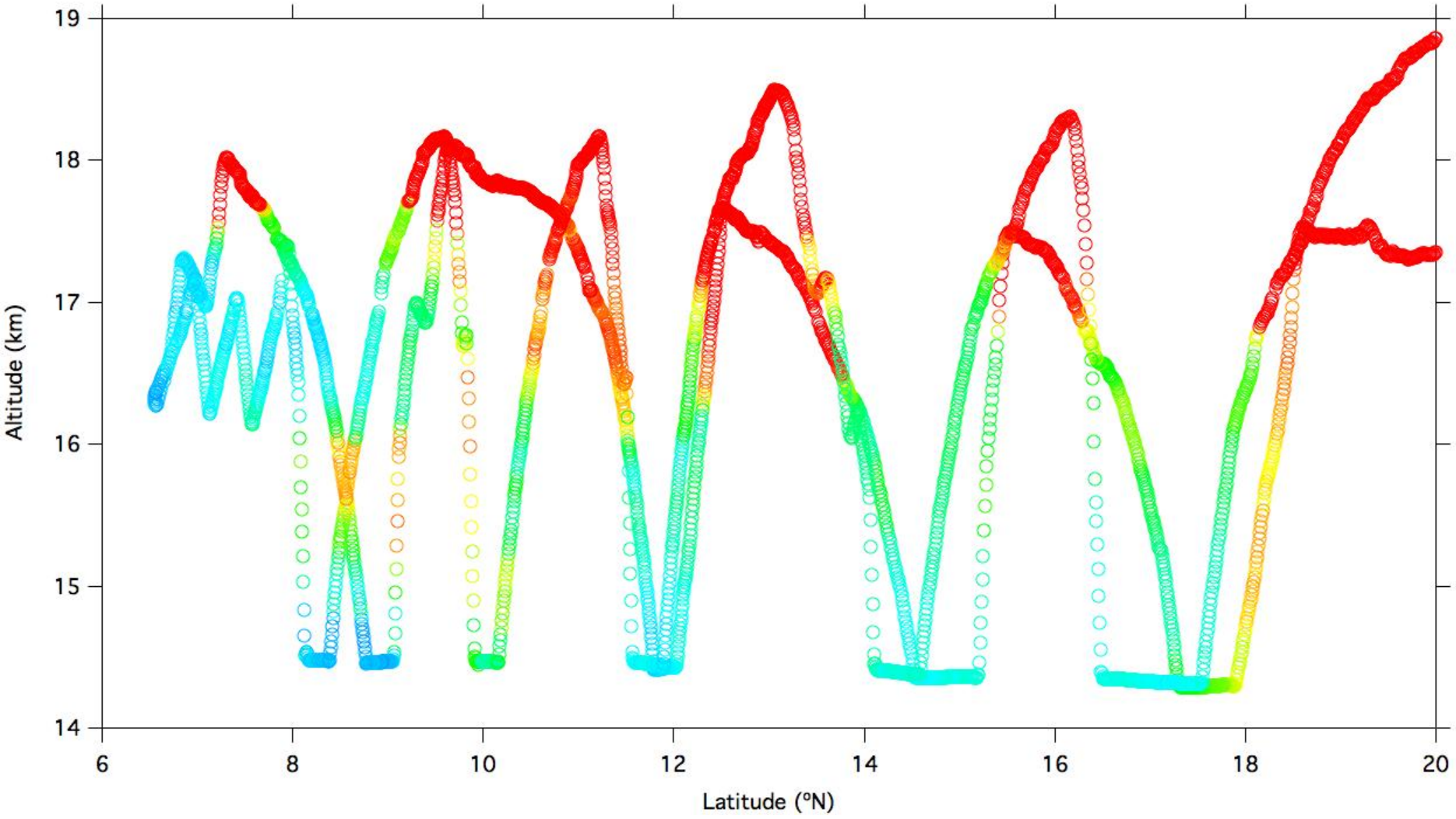
ATTREX-2 Ozone, February 9, 2013



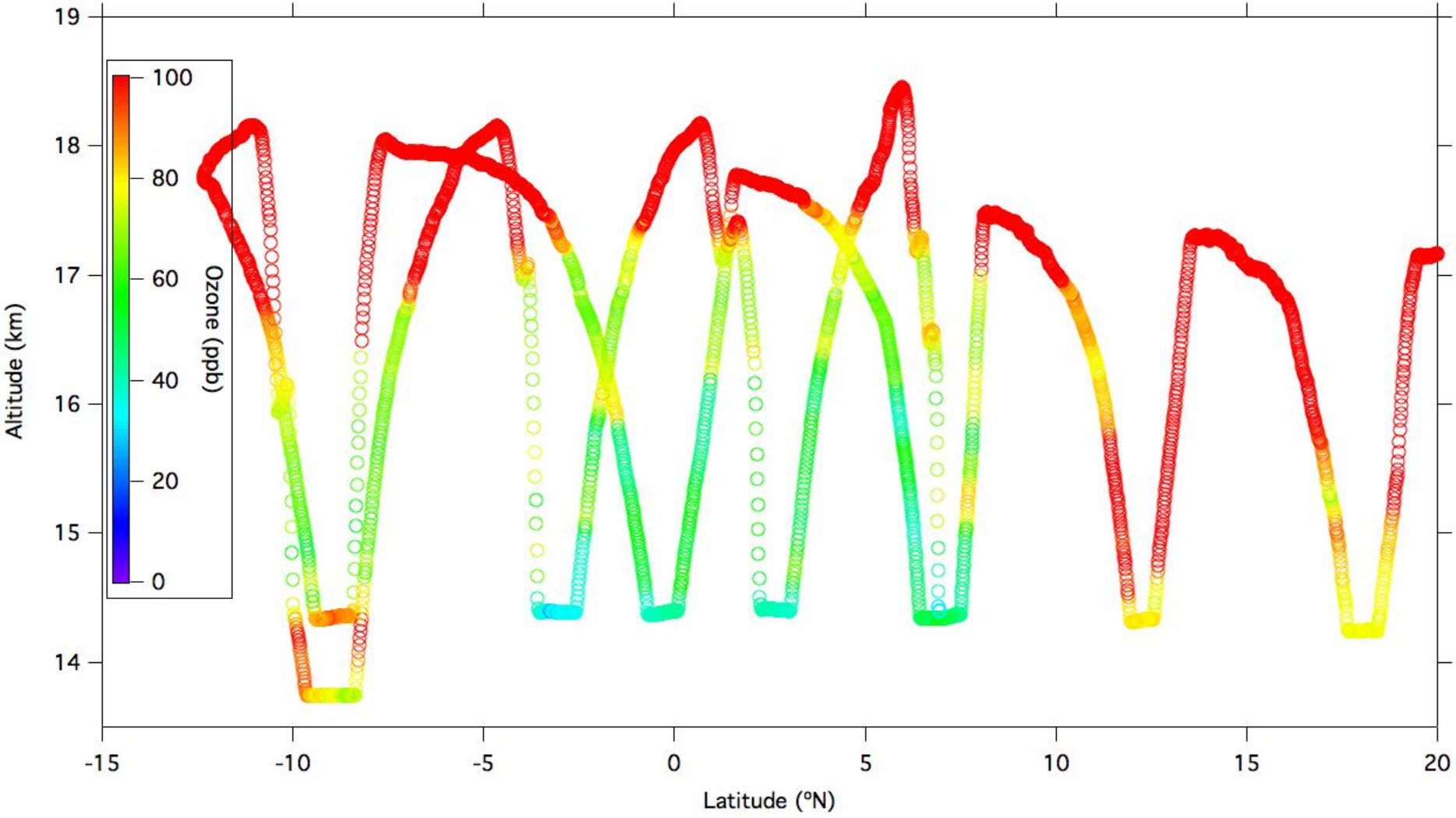
ATTREX-2 Methane, February 9, 2013



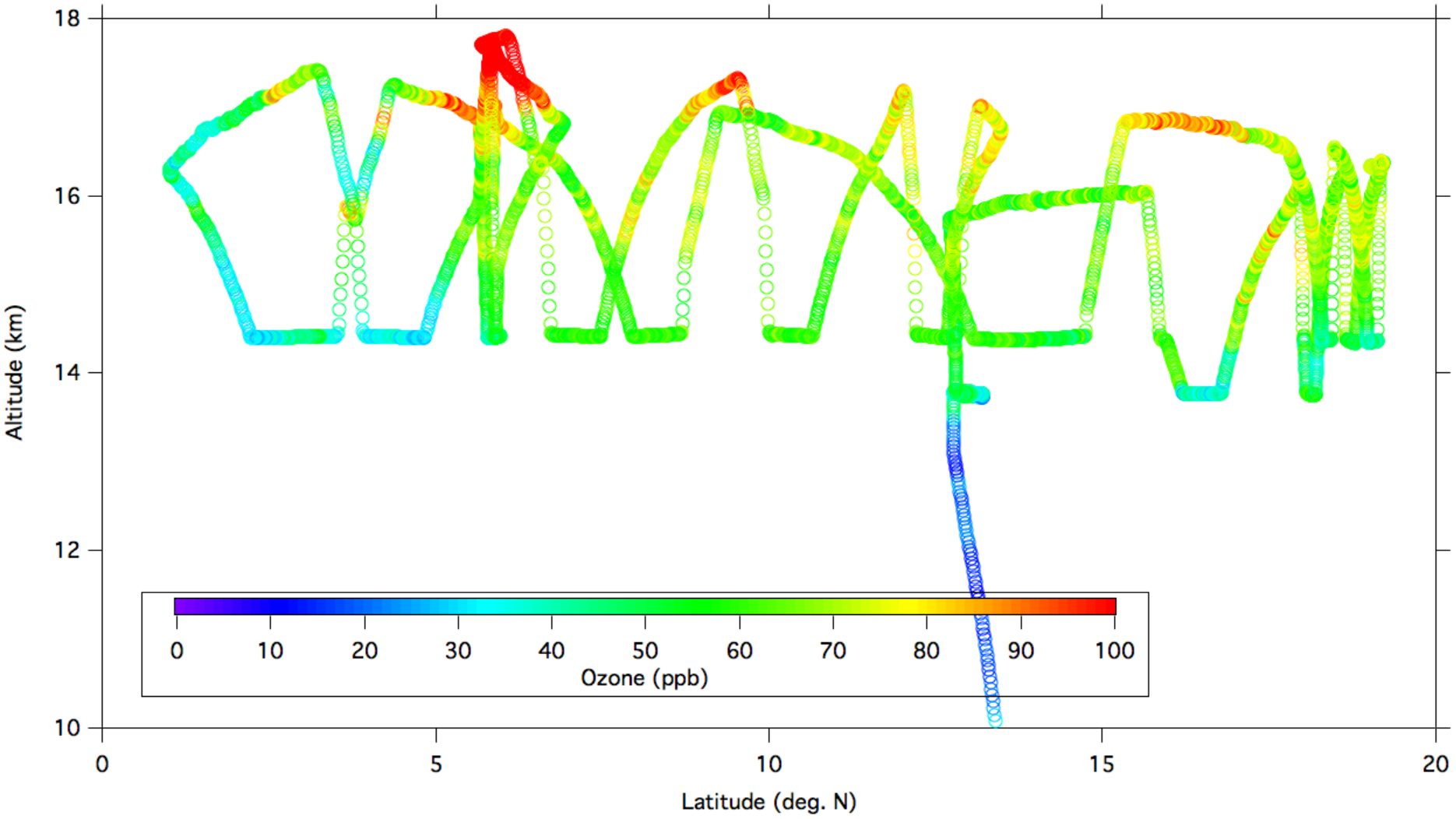
ATTREX-2 Ozone, February 26, 2013



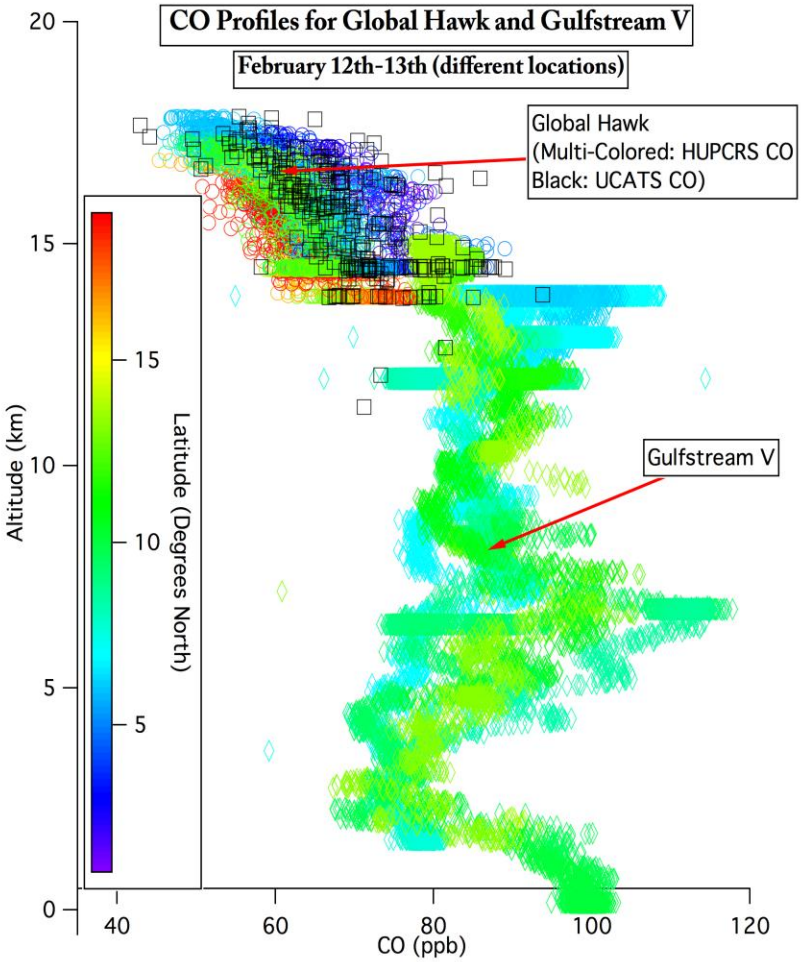
Eastern Pacific (100 W) Feb. 21, 2013

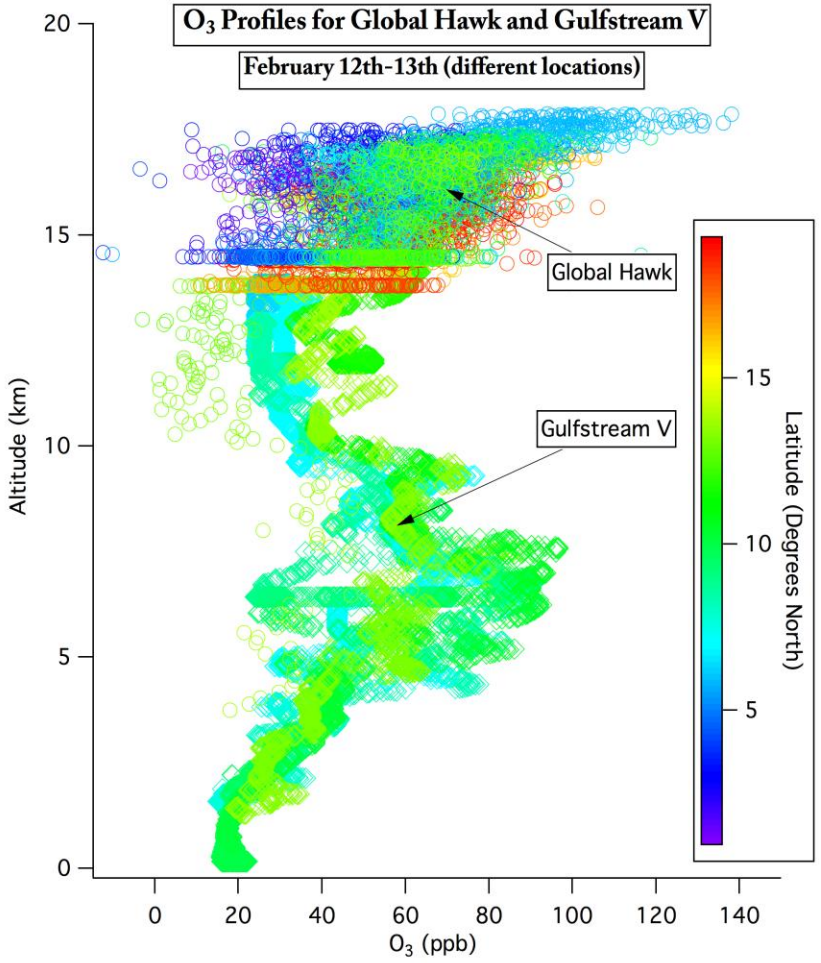


ATTREX-3 Ozone, February 12, 2014

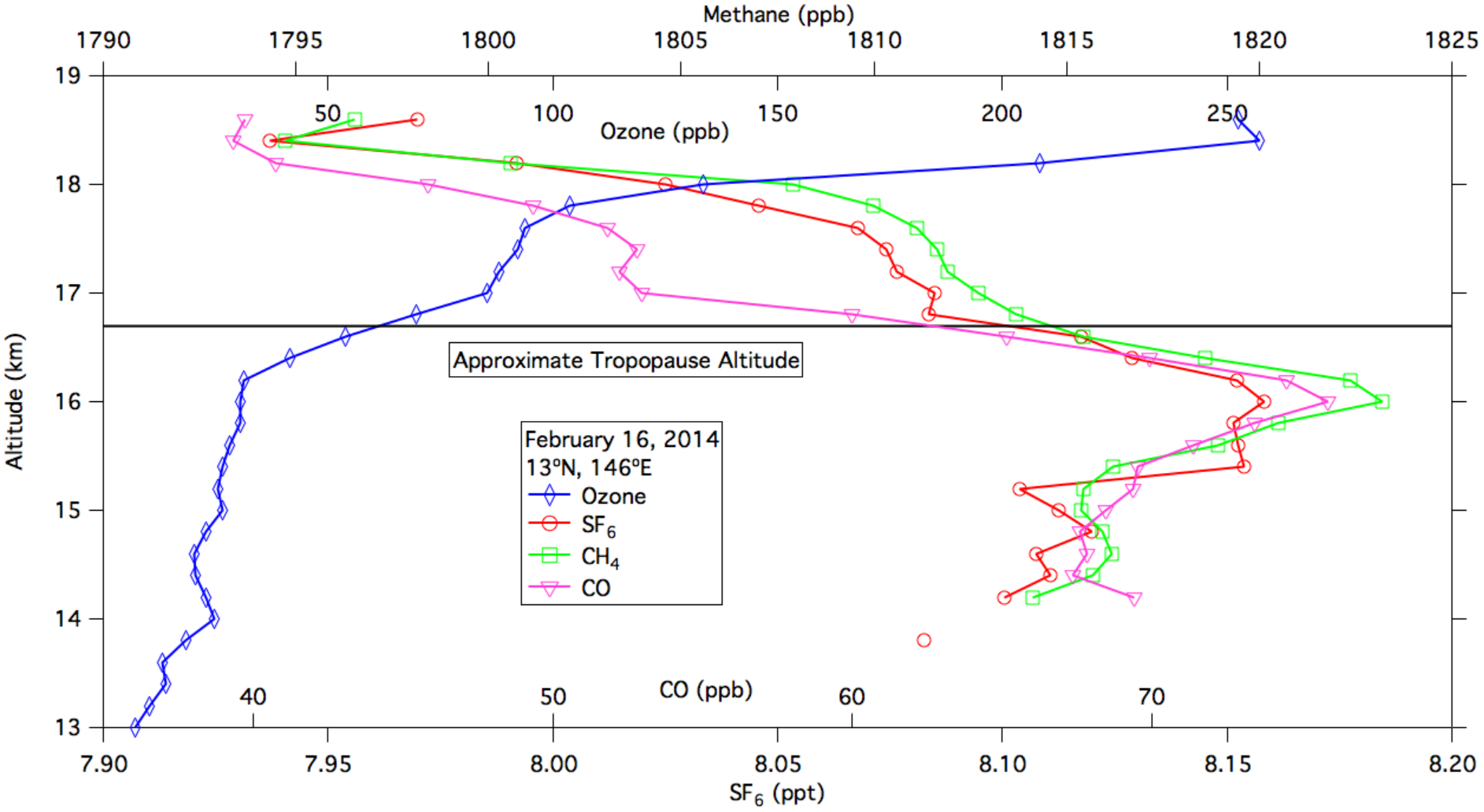


Combined ATTREX and CONTRAST data

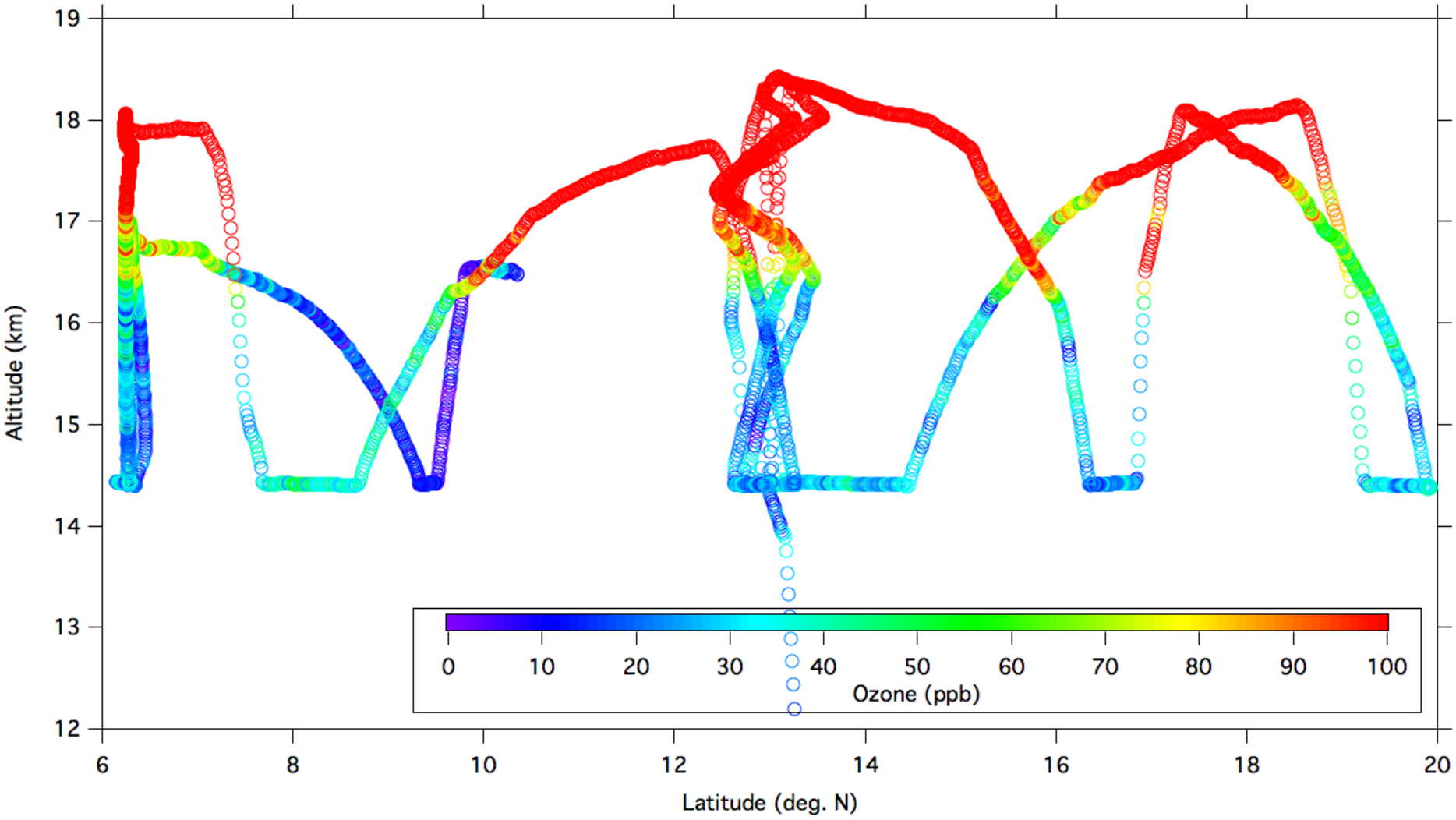




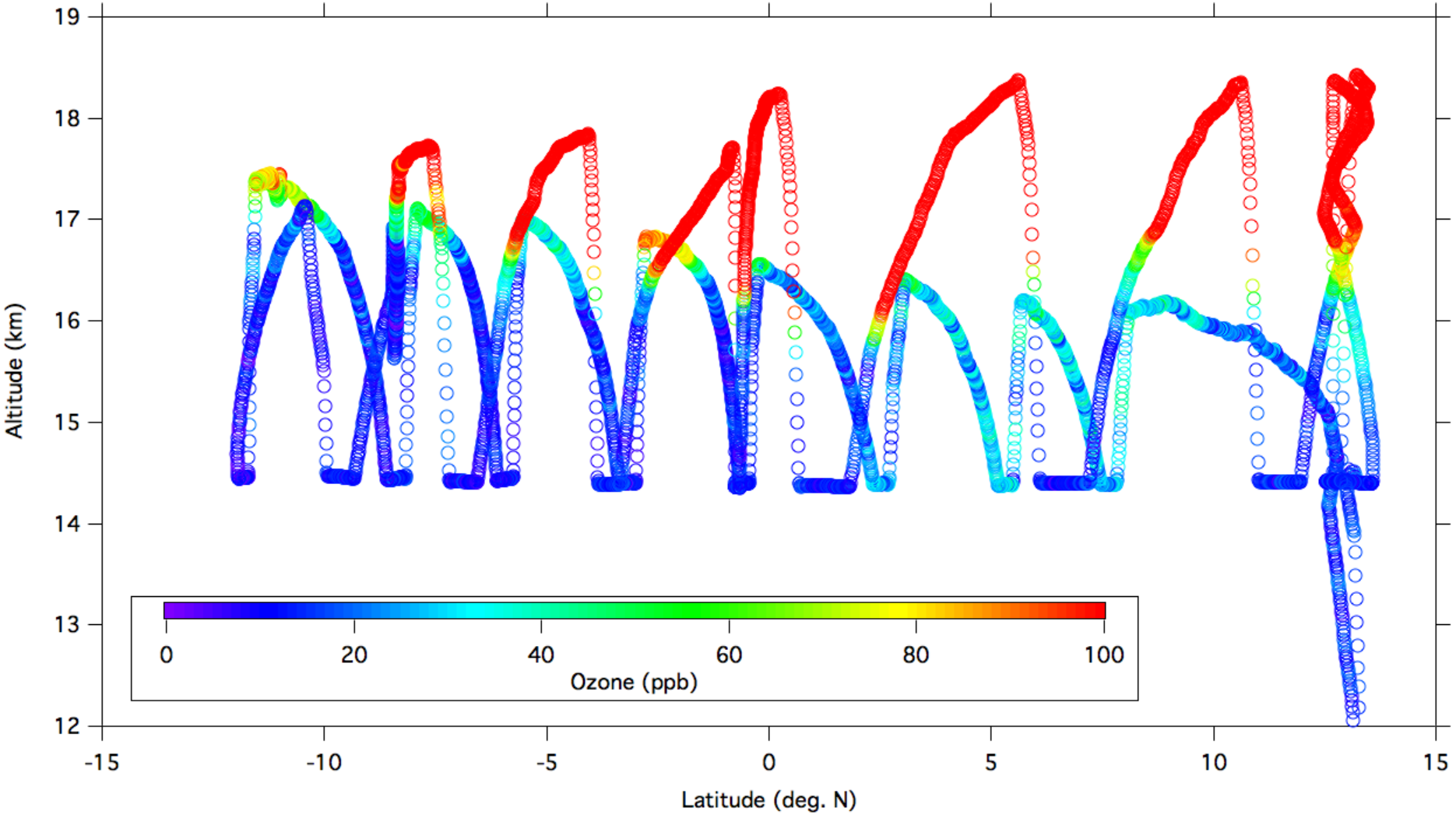
Local Guam flight, February 16, 2014



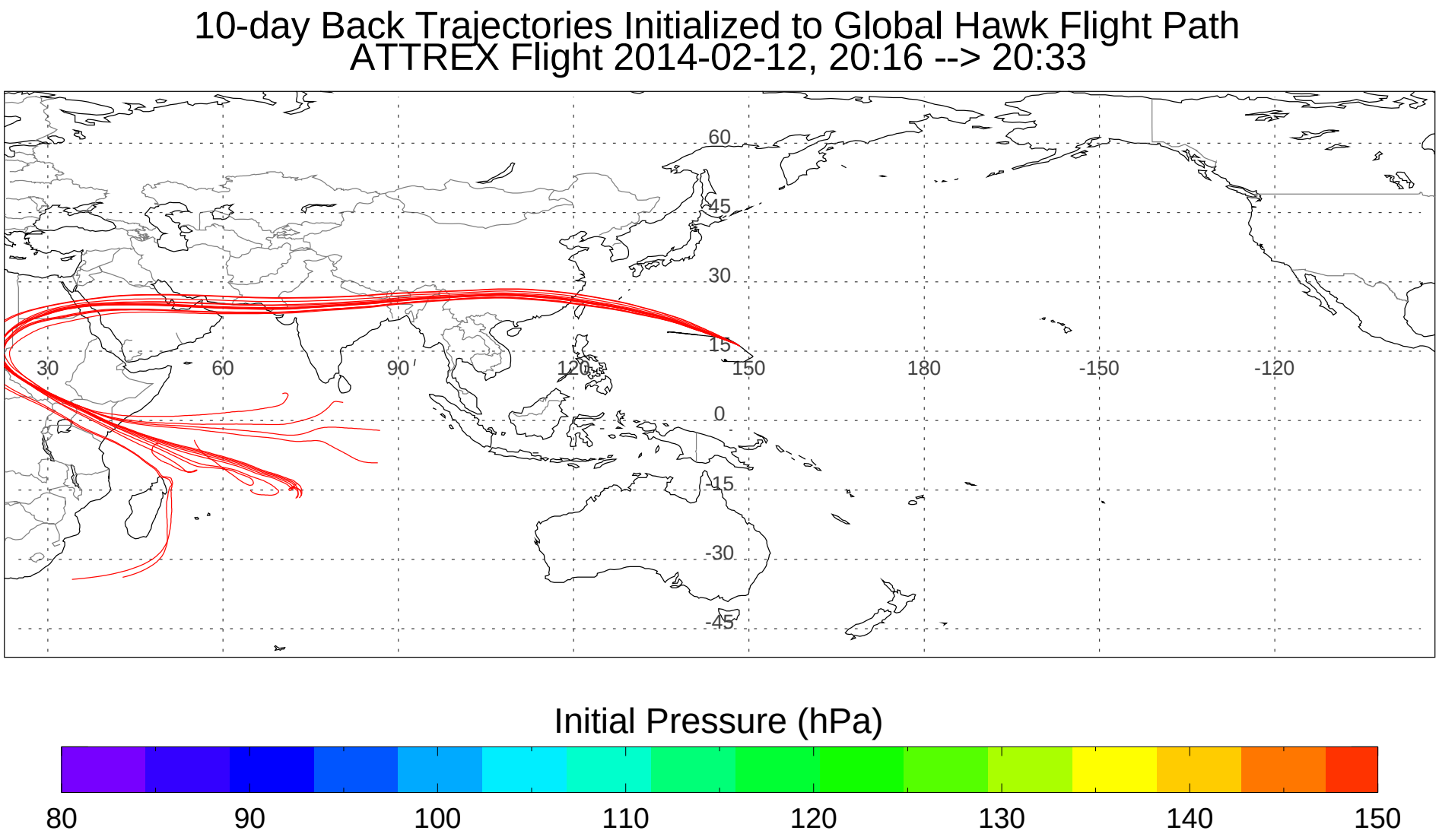
ATTREX-3 Ozone, March 6, 2014



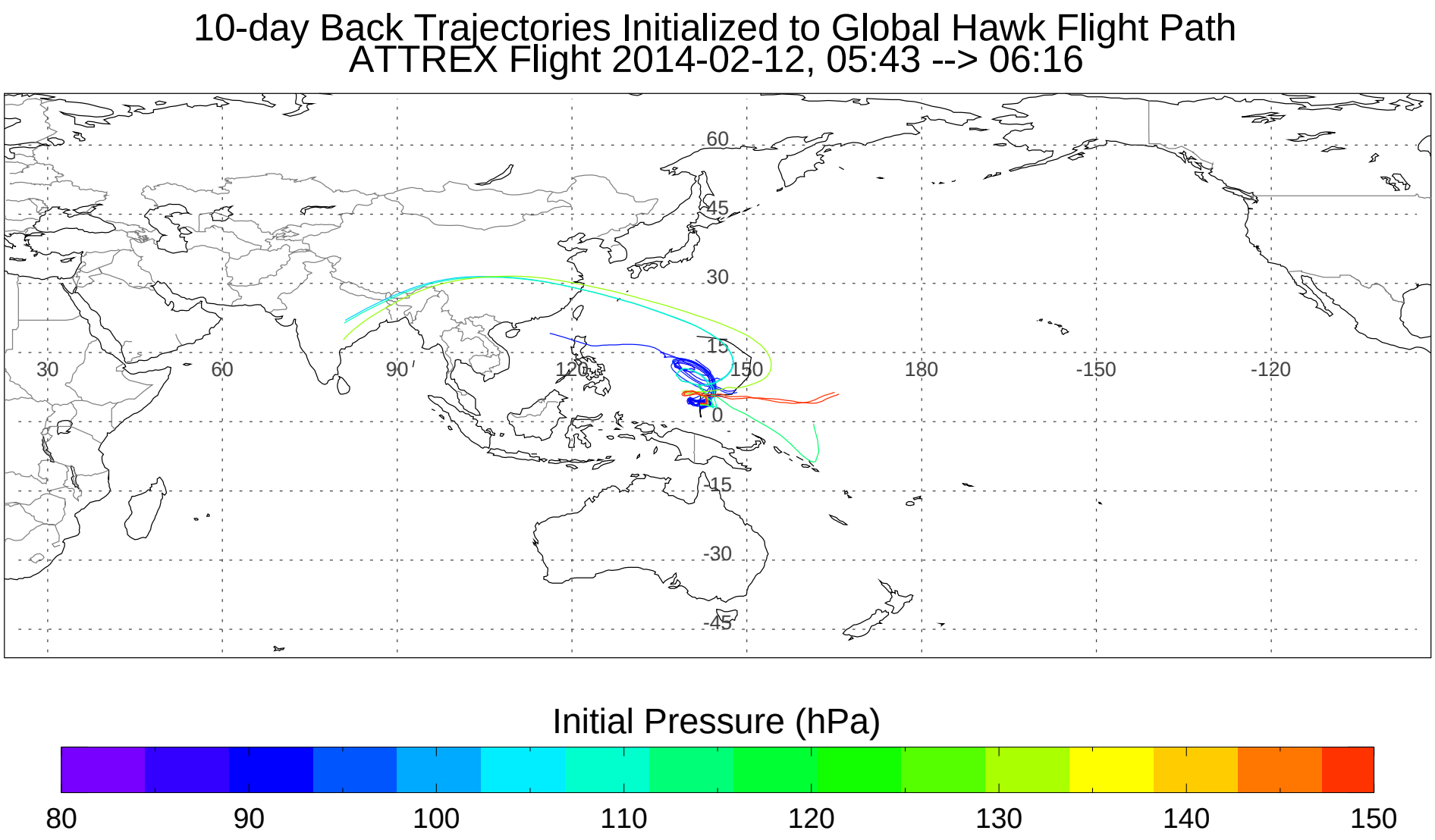
ATTREX-3 Ozone, March 9, 2014



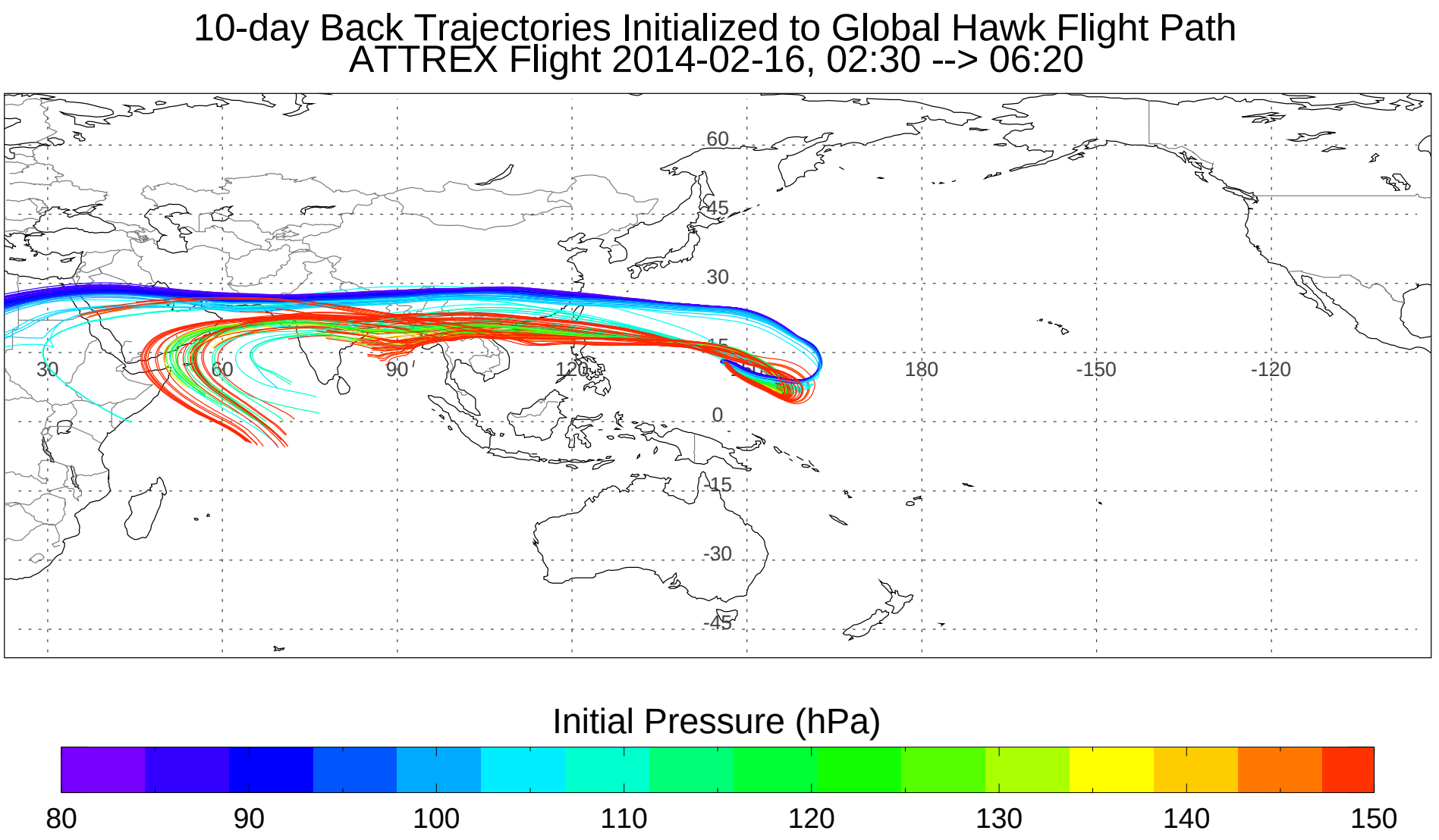
Back Trajectories from Tao Wang



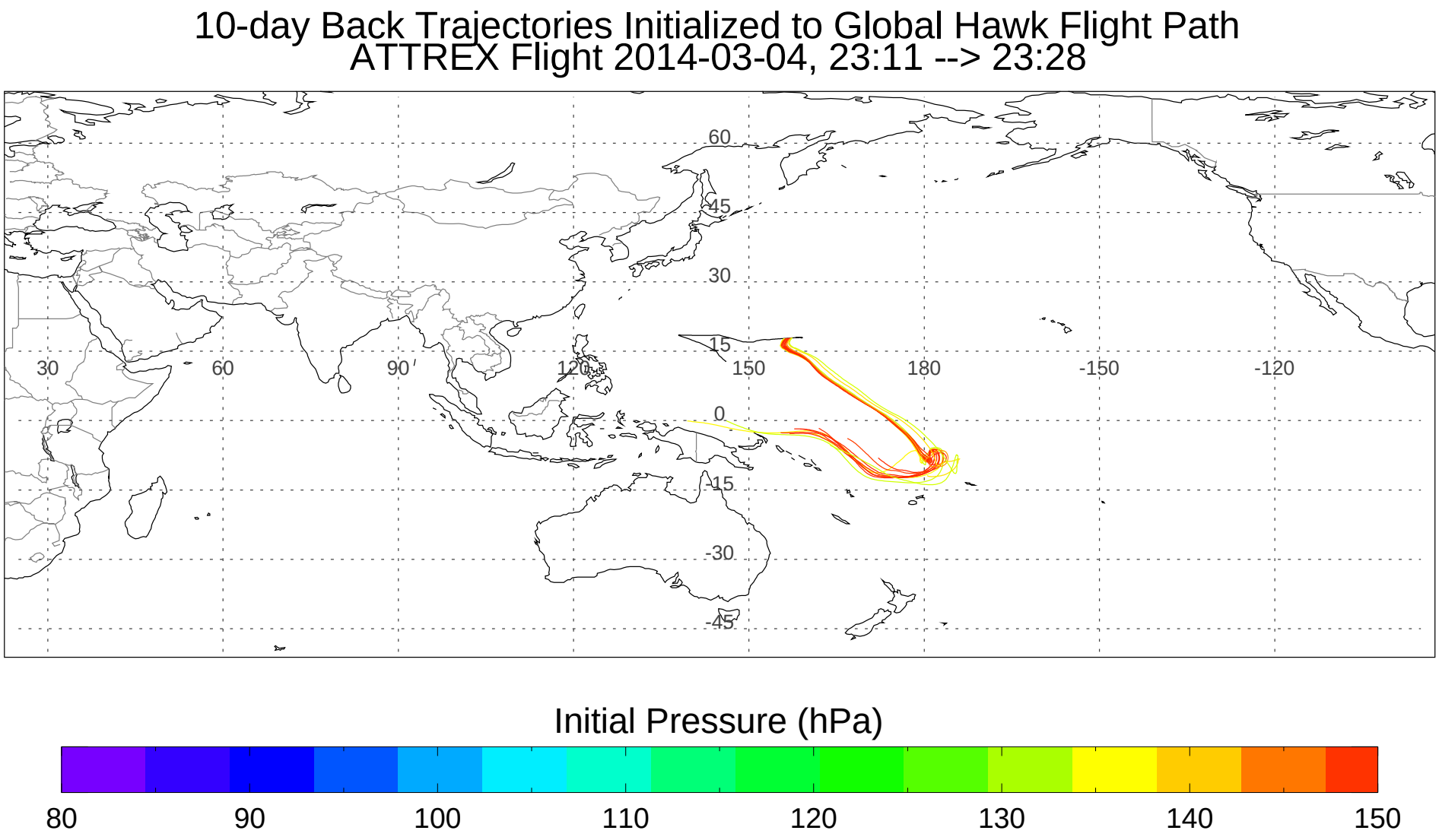
February 12, 2014; 3.5-5°N



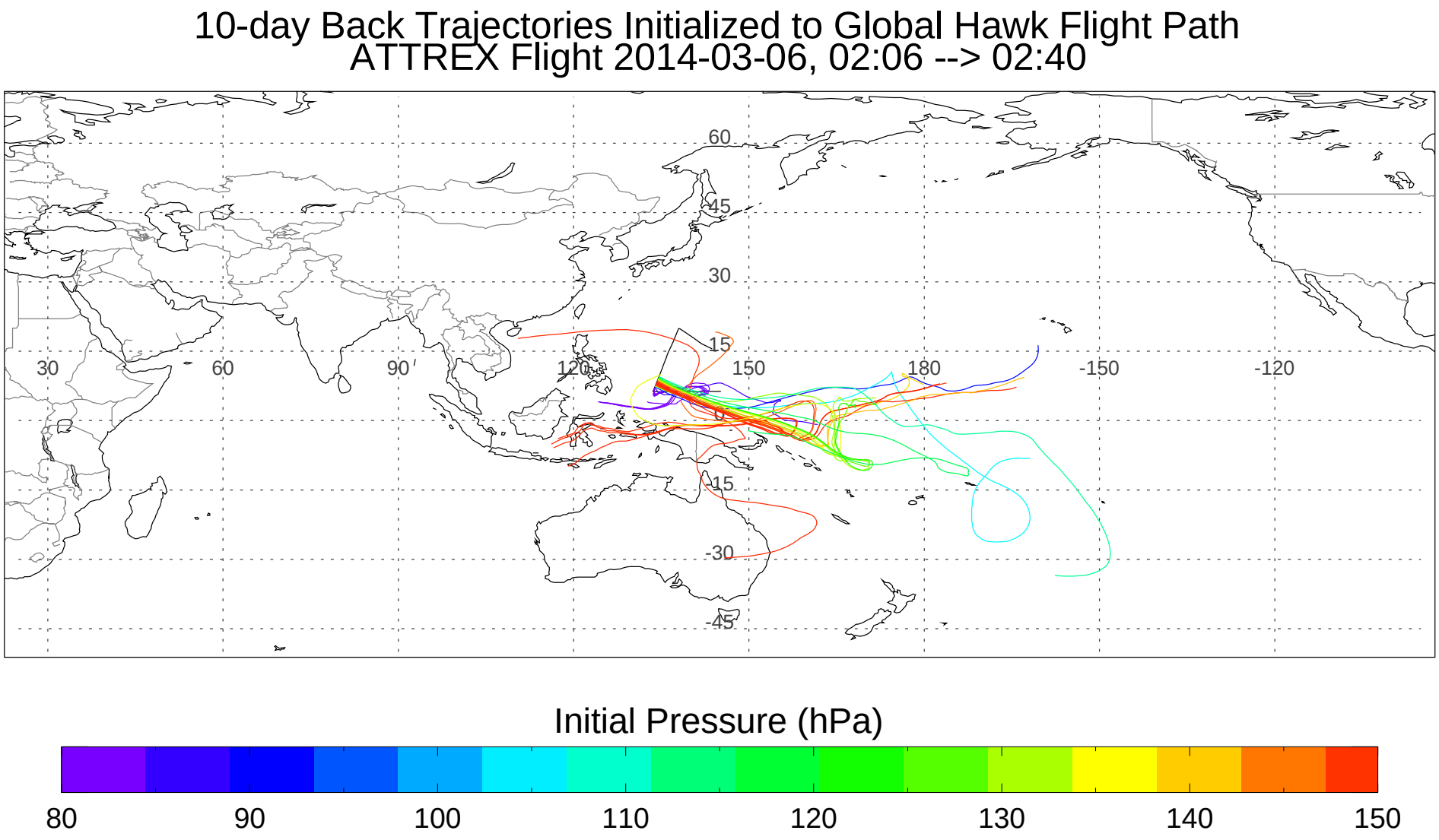
February 16, 2014; “in the box”



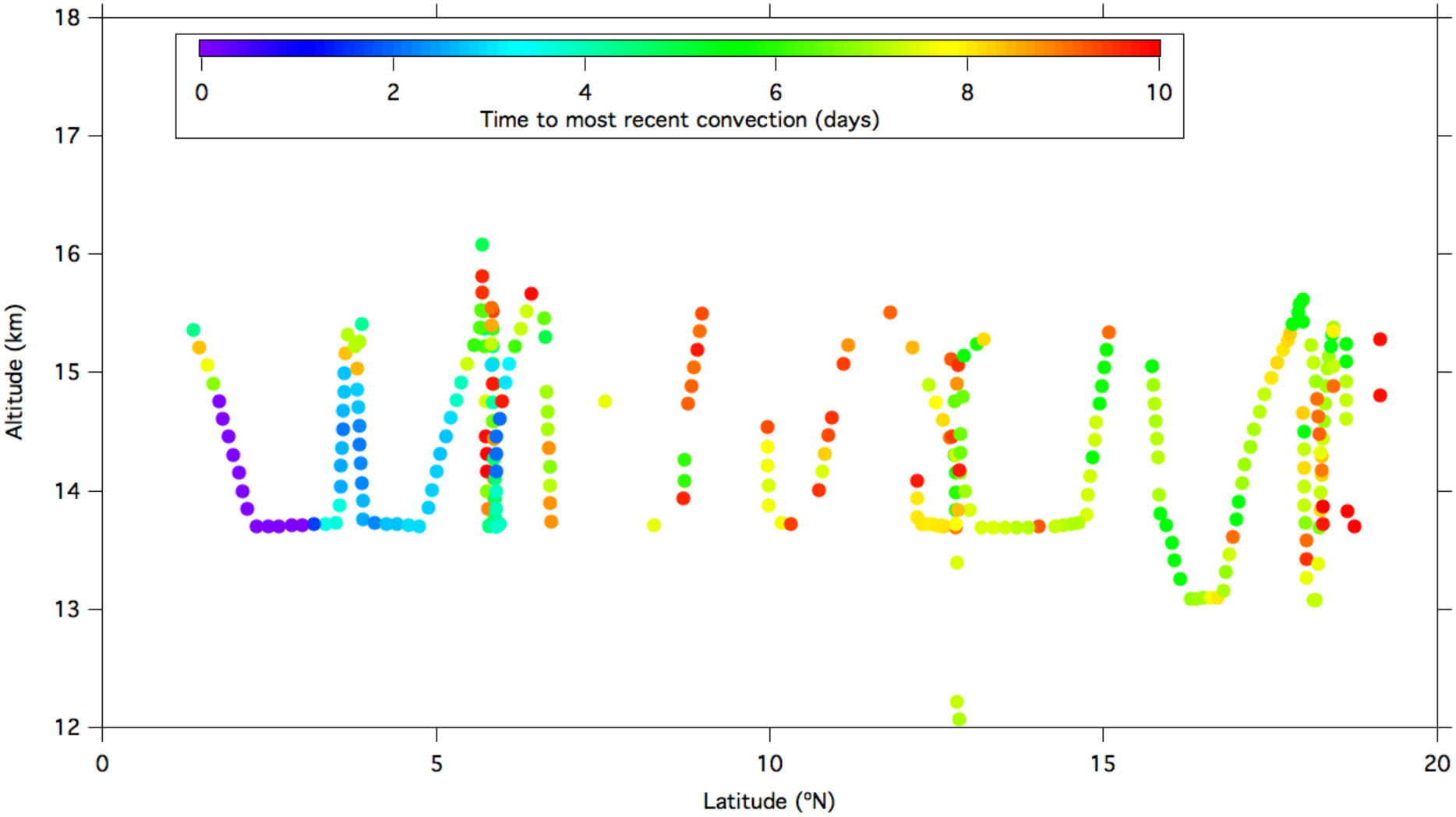
March 4, 2014; 17-18°N



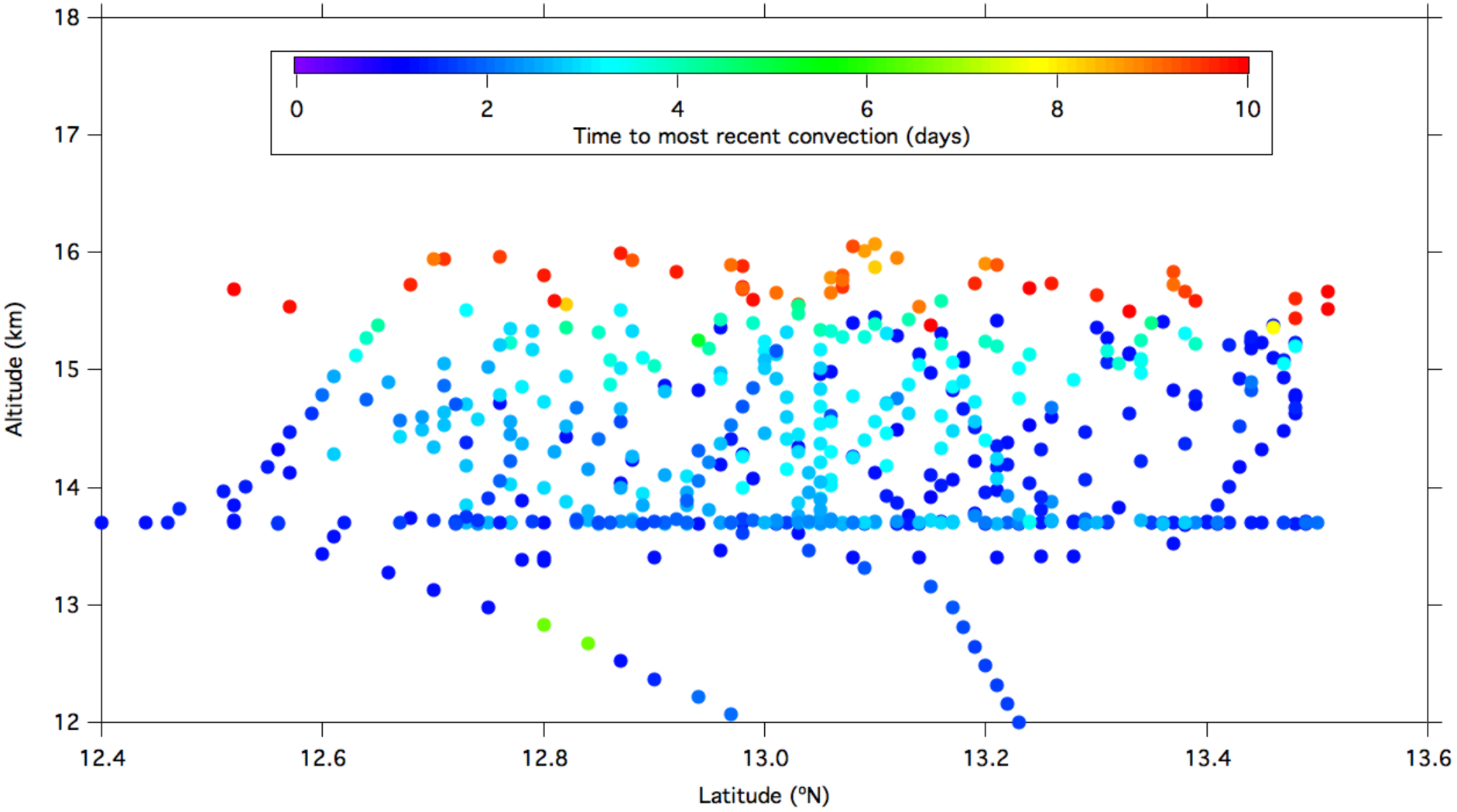
March 6, 2014; 8°N



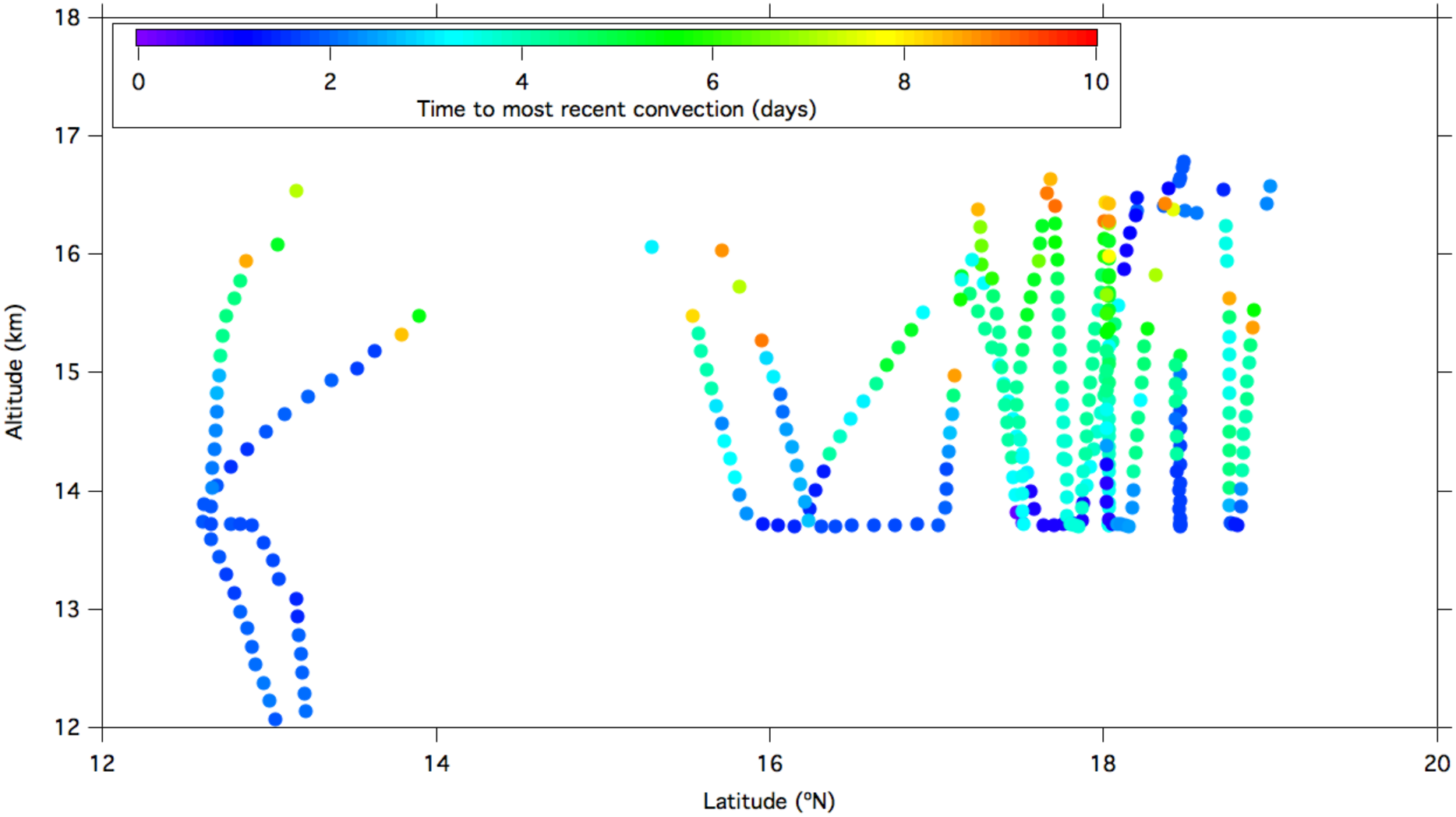
Time since convection, Feb. 12, 2014



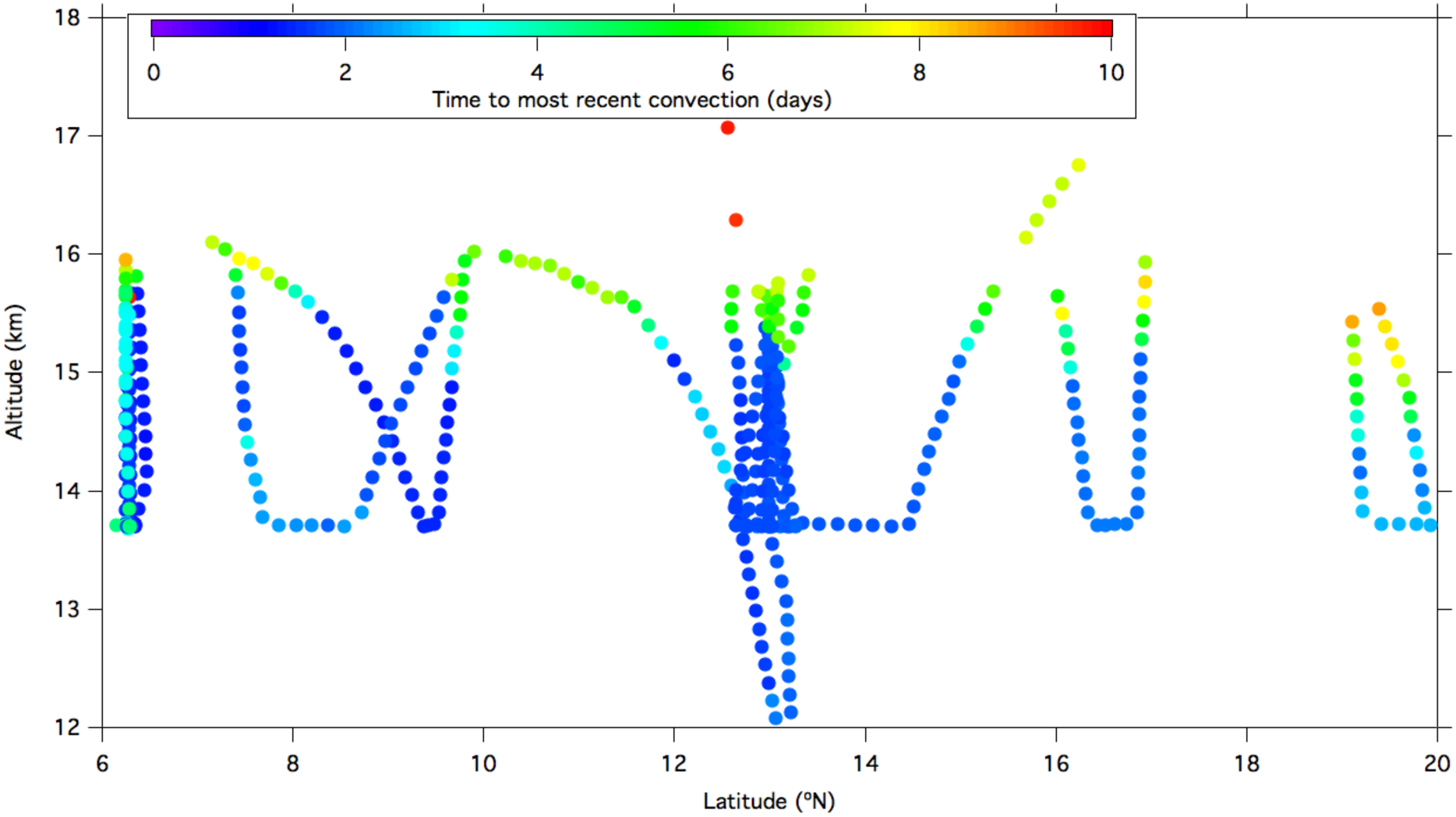
Time since convection, Feb. 16, 2014



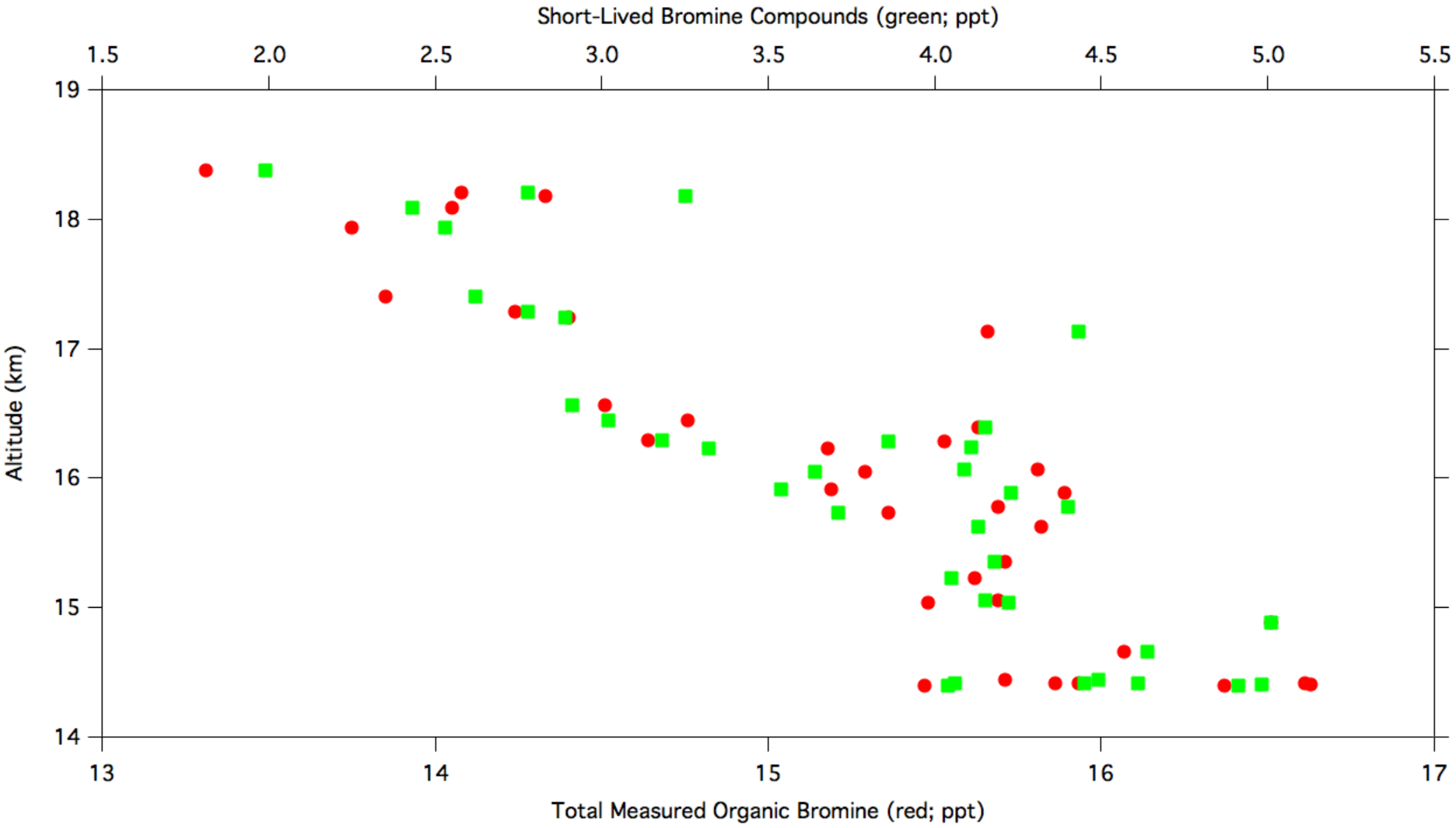
Time since convection, March 4, 2014



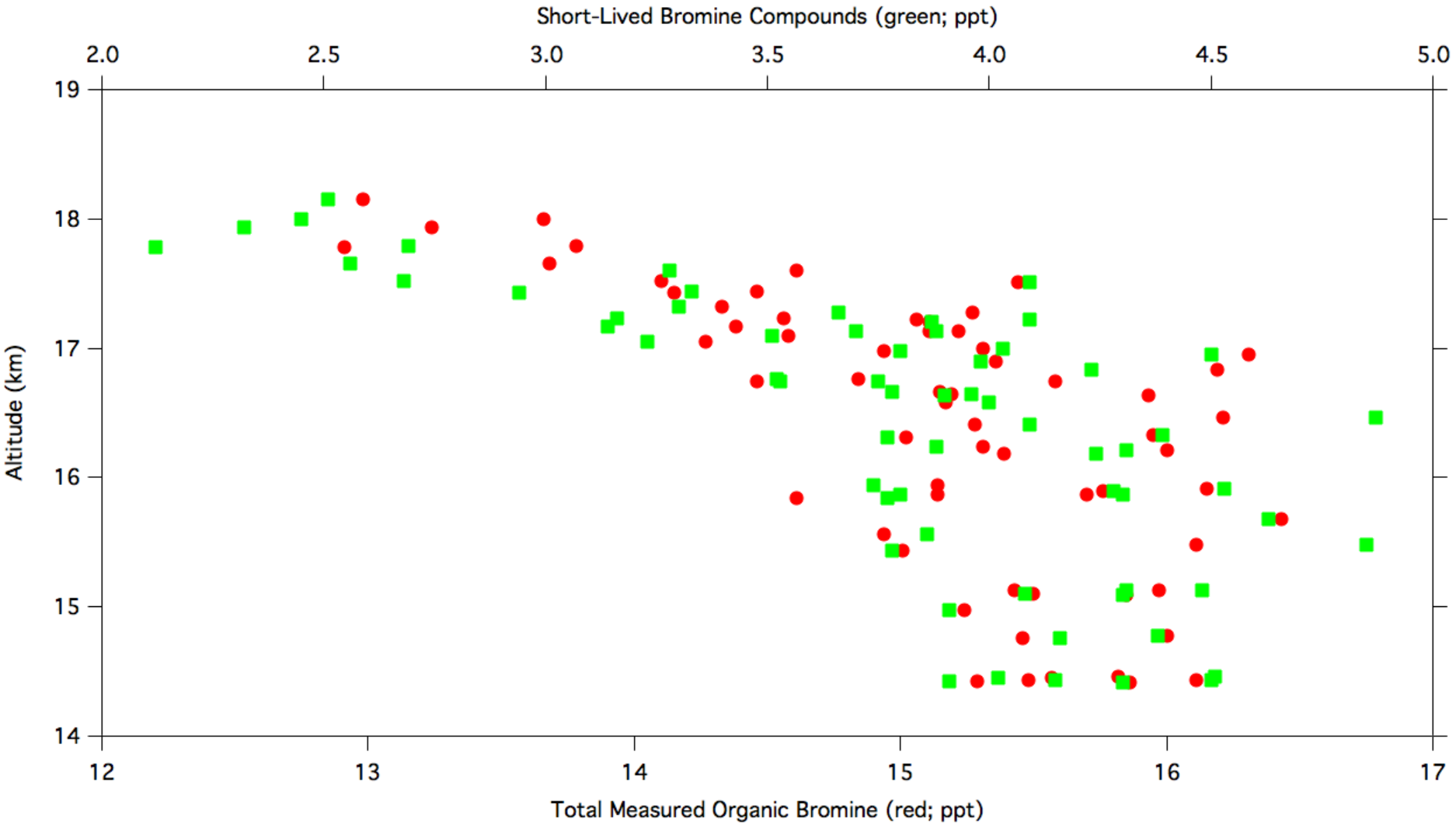
Time since convection, March 6, 2014



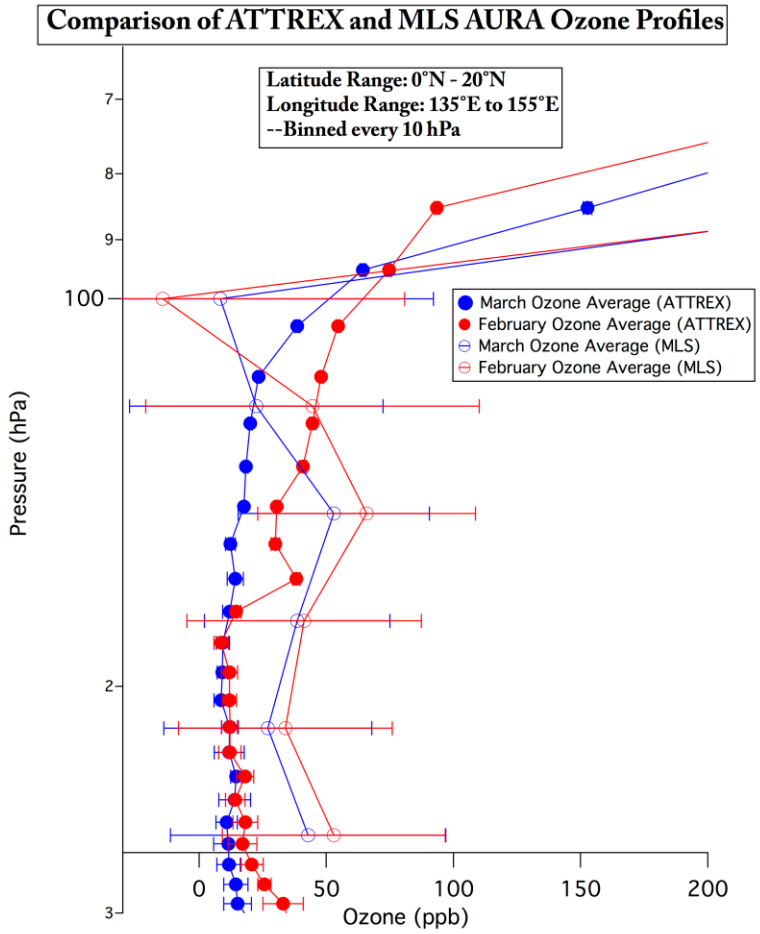
WAS data; February 16, 2014



WAS data; March 4, 2014



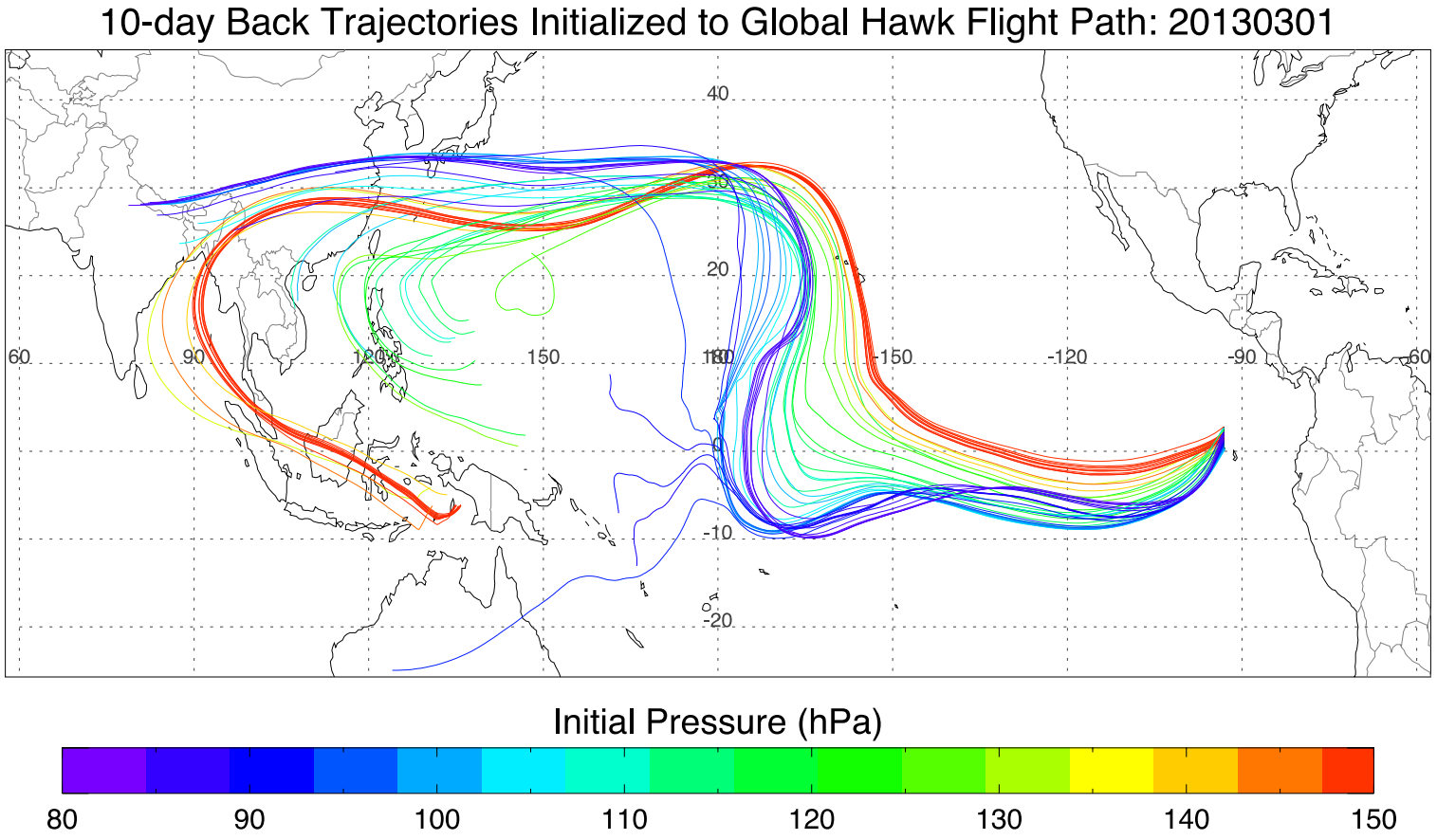
ATTREX-3 Satellite Comparison



- MLS uncertainty overlaps UCATS ozone data
  - Large Error Bars
  - ~3 km vert. resolution
  - UCATS lower than MLS
- March vs. February
  - Lower in TTL
  - Higher in stratosphere

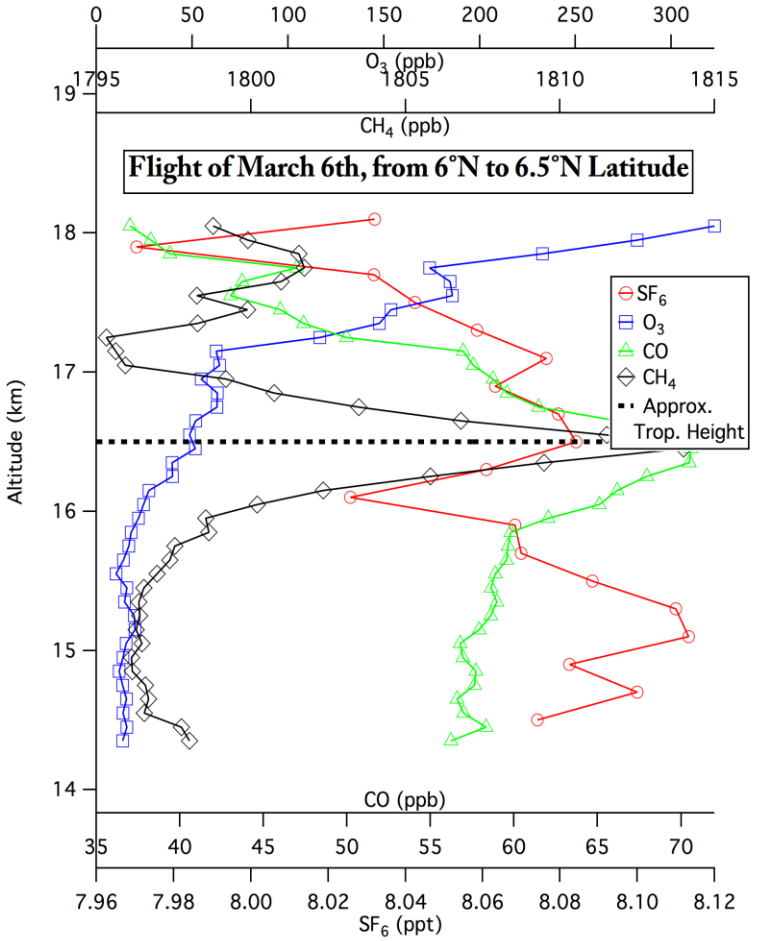
Summary

- Ozone was lower in ATTREX-3, particularly in March 2014, compared to ATTREX-1 and 2.
- Long-lived tracers were relatively uniform in the TTL over the western tropical Pacific.
- Tracers and back trajectory calculations suggest deep convection reaching into the TTL.
- Organic bromine begins to decline (and ozone increases) above 16 km, which is also the approximate highest altitude influenced by recent convection.
- Data are consistent with deep convection bringing air with low ozone up to the tropopause.

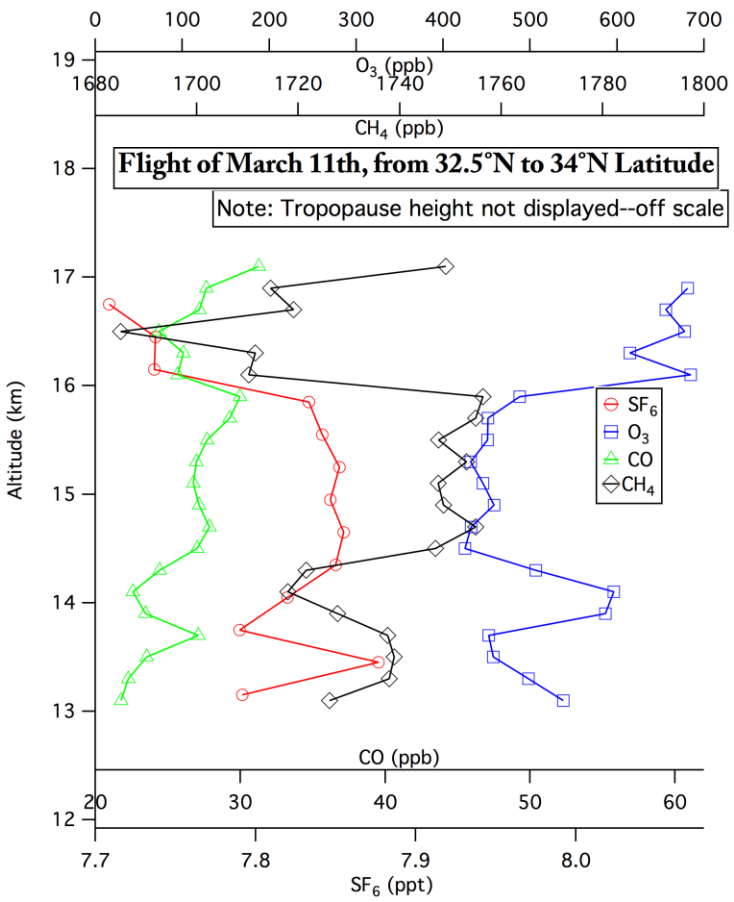

10-day Back Trajectories Initialized to Global Hawk Flight Path: 20130301
40
30
20
60
90
120
150
180
-150
-120
-90
-60
0
-10
-20
Initial Pressure (hPa)
80
90
100
110
120
130
140
150

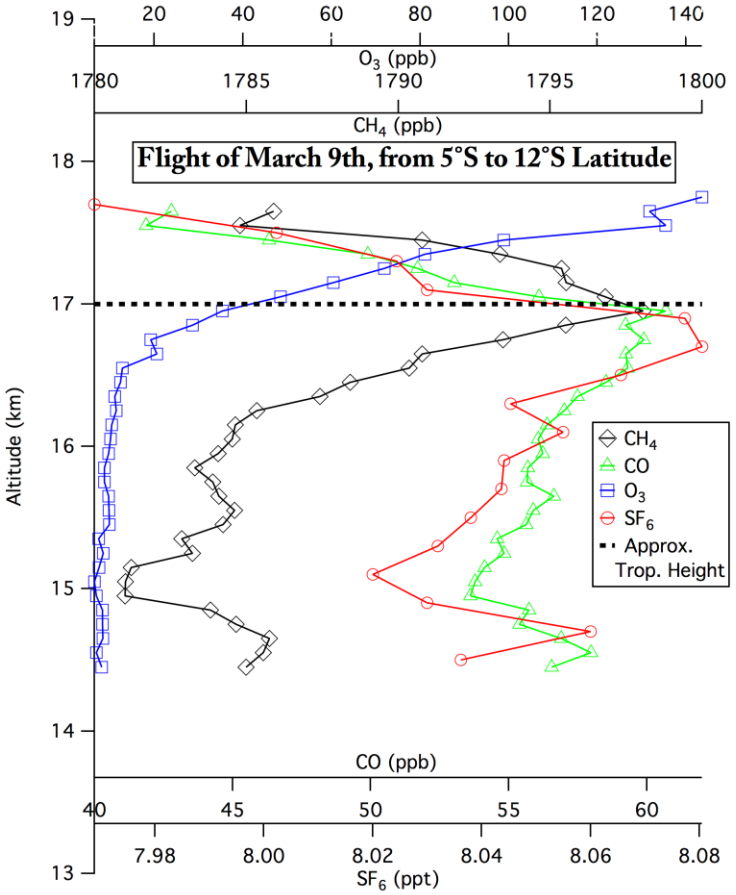
Results: Binned Profiles

- Near tropopause, spike in CH_4 and CO, low values of ozone above
  - Implies deep convective mixing
- SF_6 ~8.08 ppt
  - Mauna Loa Observatory (MLO) (19.5° N): SF_6 ~ 8.21 ppt
  - American Samoa (SMO)(14.2° S): SF_6 ~ 8.01 ppt
- CH_4: (1795-1815 ppb)
  - MLO: 1839 ppb
  - SMO: 1767 ppb



Other Binned Profiles



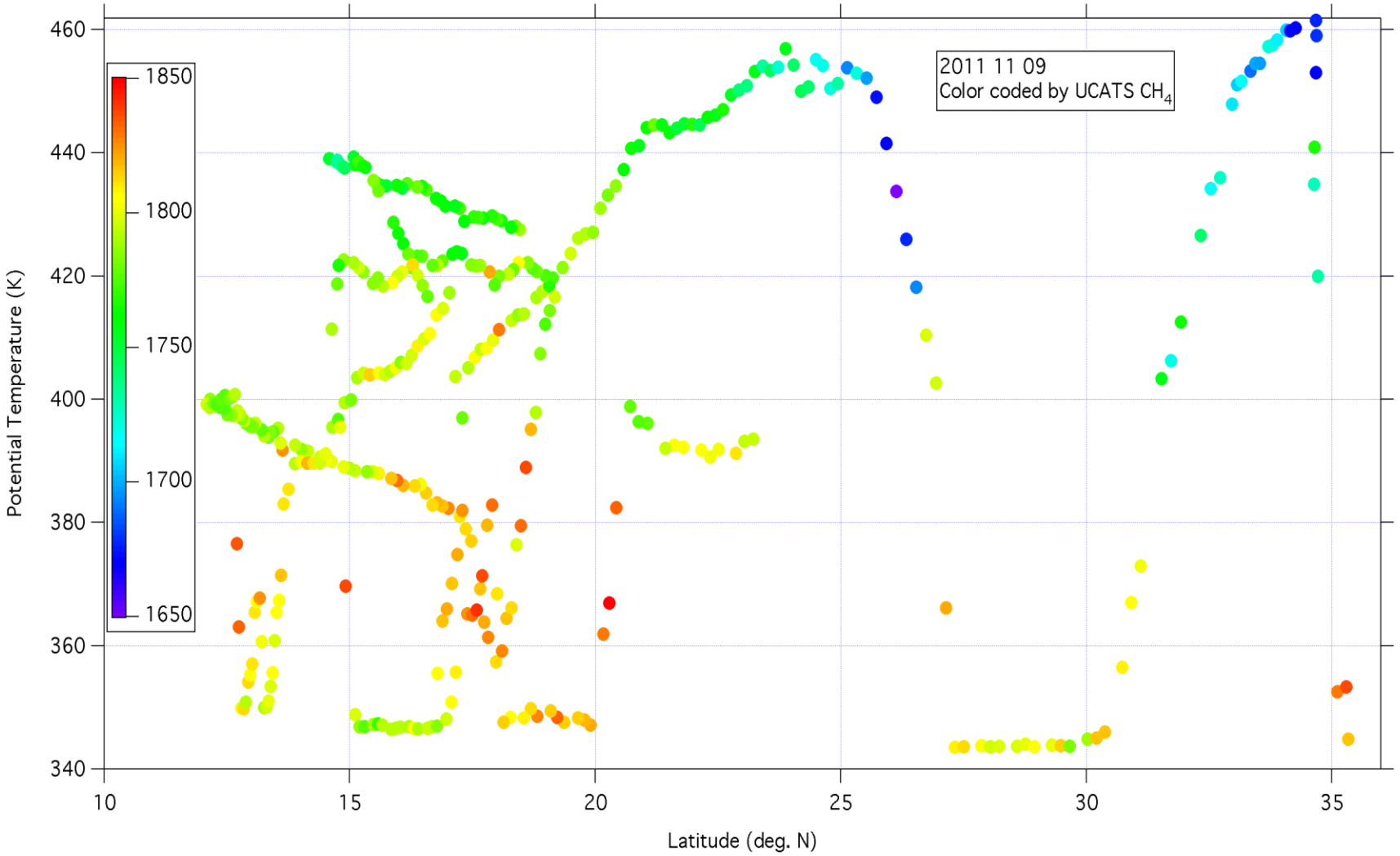


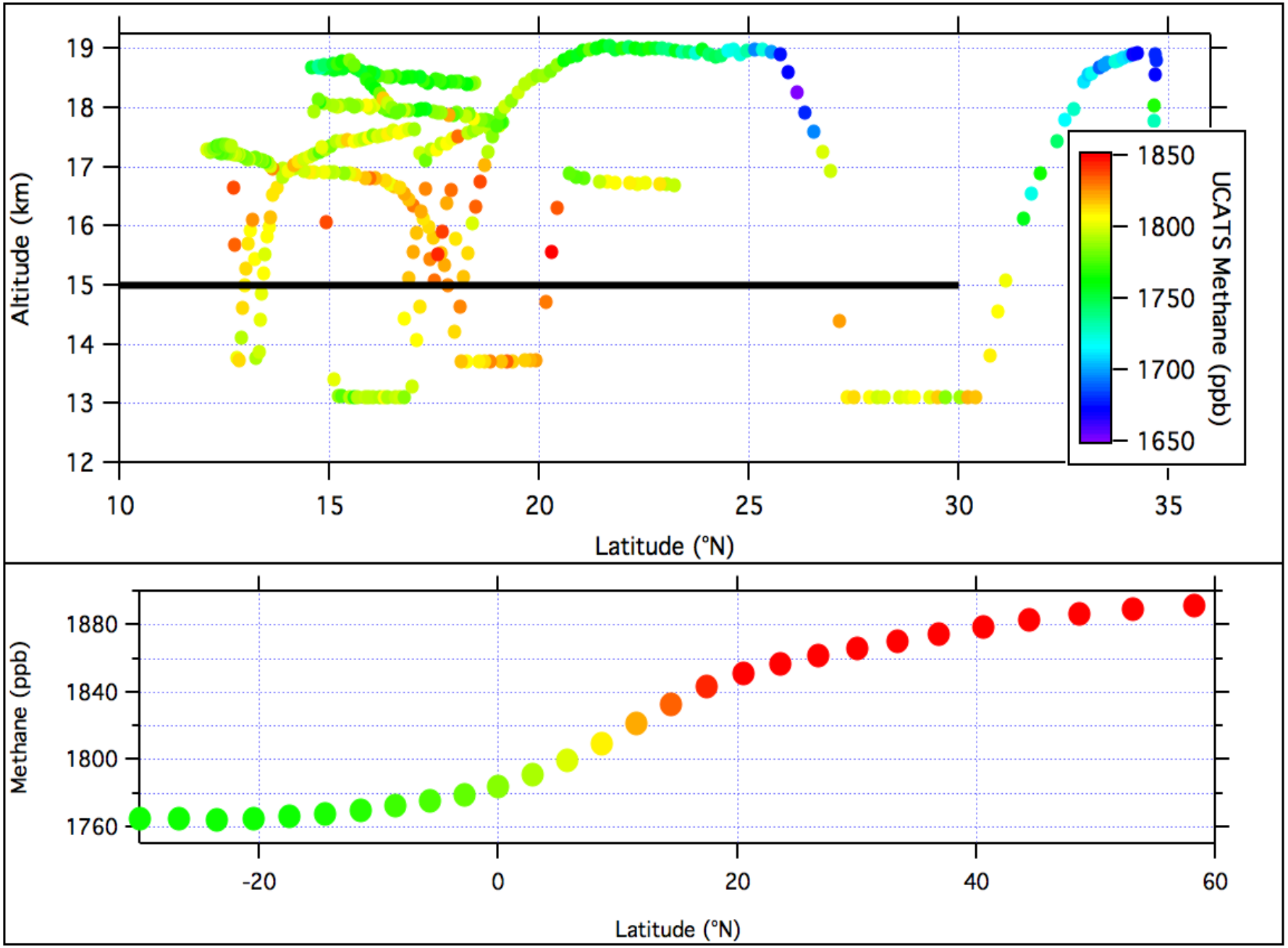
- Left: March 11th (crossed subtropical jet into mid-latitudes)
- Right: March 9th (crossed equator)

The Main Points

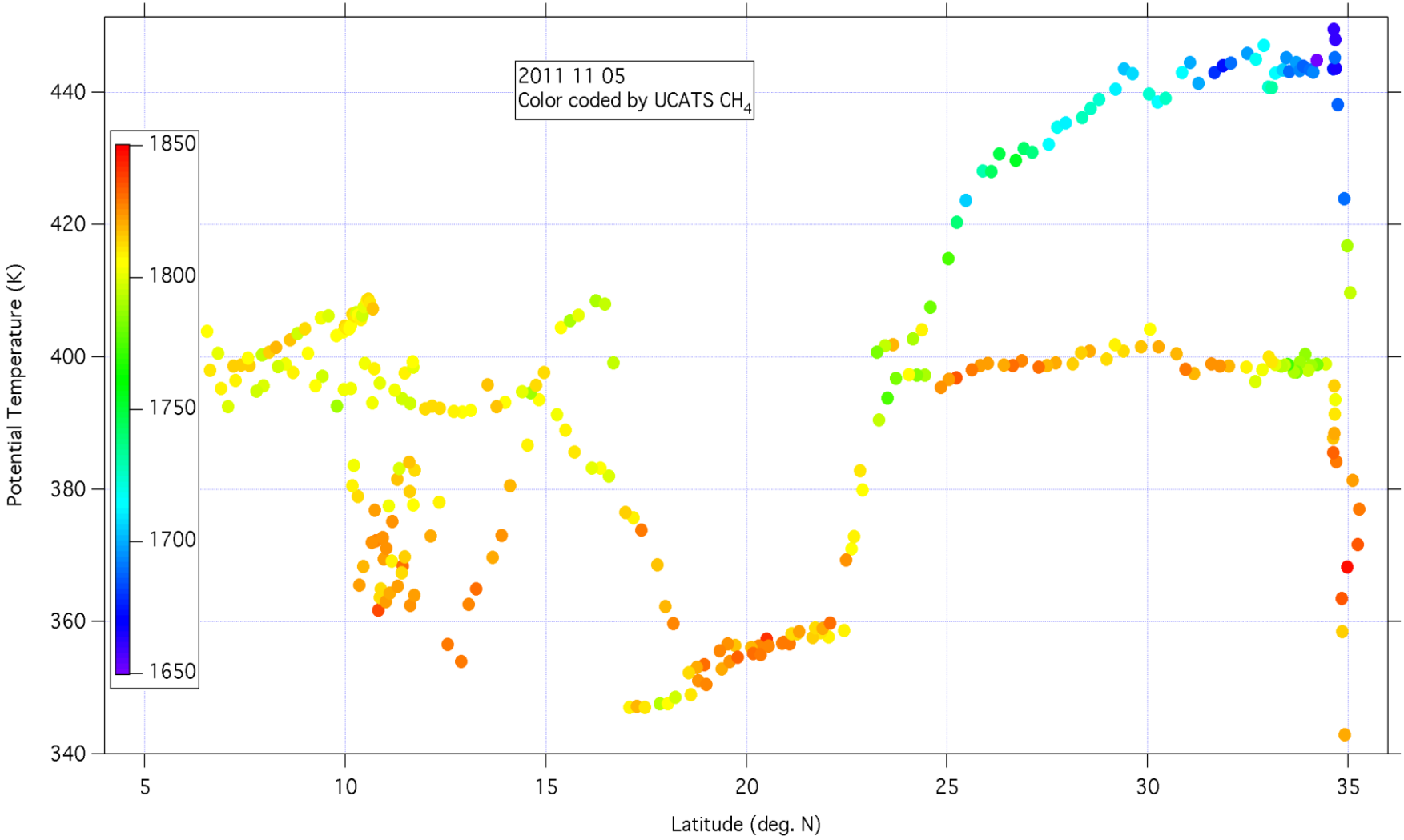
- The parts of the TTL sampled by the Global Hawk during ATTREX-2 (February 2013) had young and relatively uniform air.
- Small variations in tracer mixing ratios show that there was some mixing in of extratropical or older air.
- TTL air sampled in ATTREX-1 (November 2011) had much more extratropical character.

ATTREX-1: Possible intrusions of extratropical air into the tropical tropopause region (115-135°W)

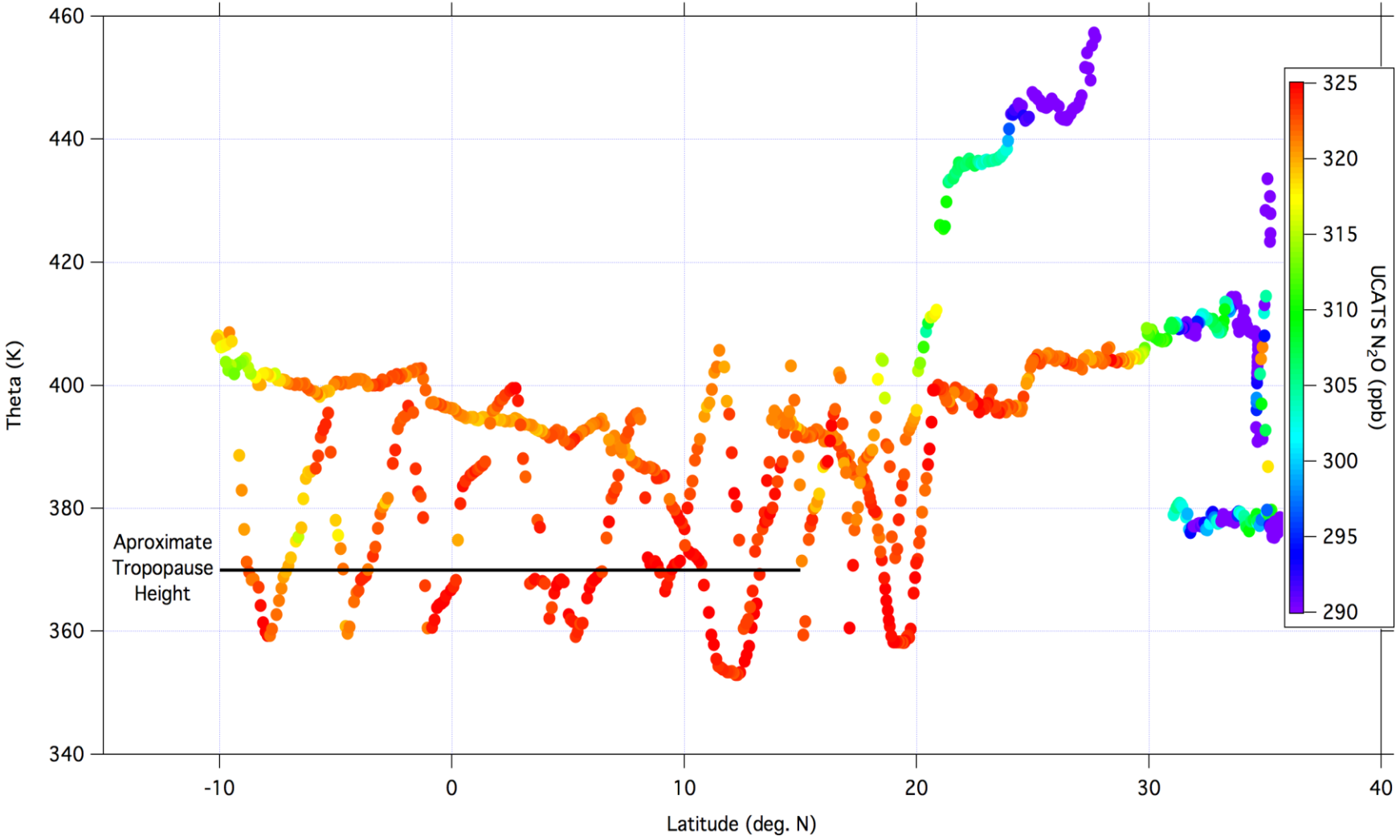



Altitude (km)
19
18
17
16
15
14
13
12
10
15
20
25
30
35
Latitude (°N)
UCATS Methane (ppb)
1850
1800
1750
1700
1650
Methane (ppb)
1880
1840
1800
1760
-20
0
20
40
60
Latitude (°N)

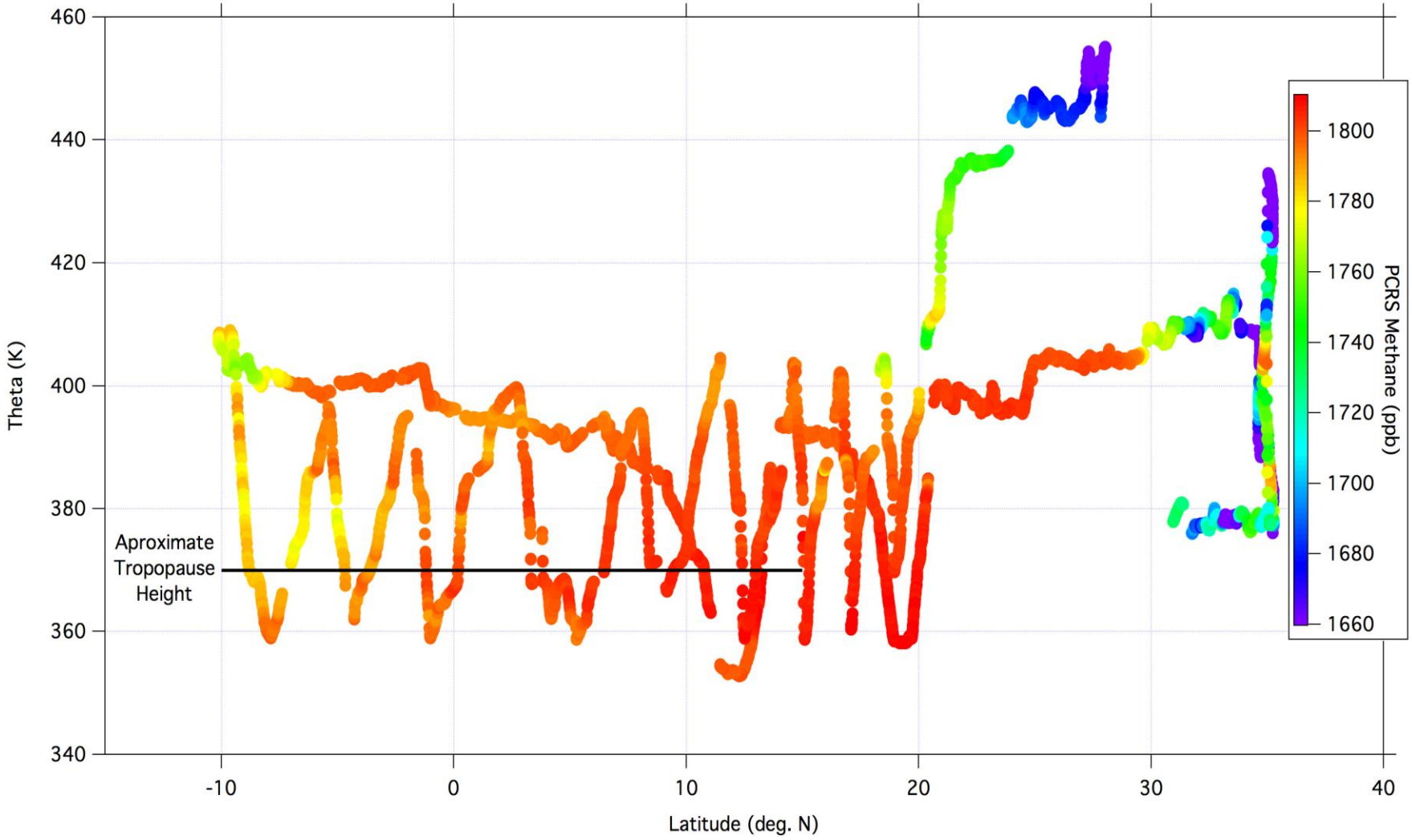
Variations in methane distribution on November 5, 2011 (Latitude-theta slice along 118-128°W)



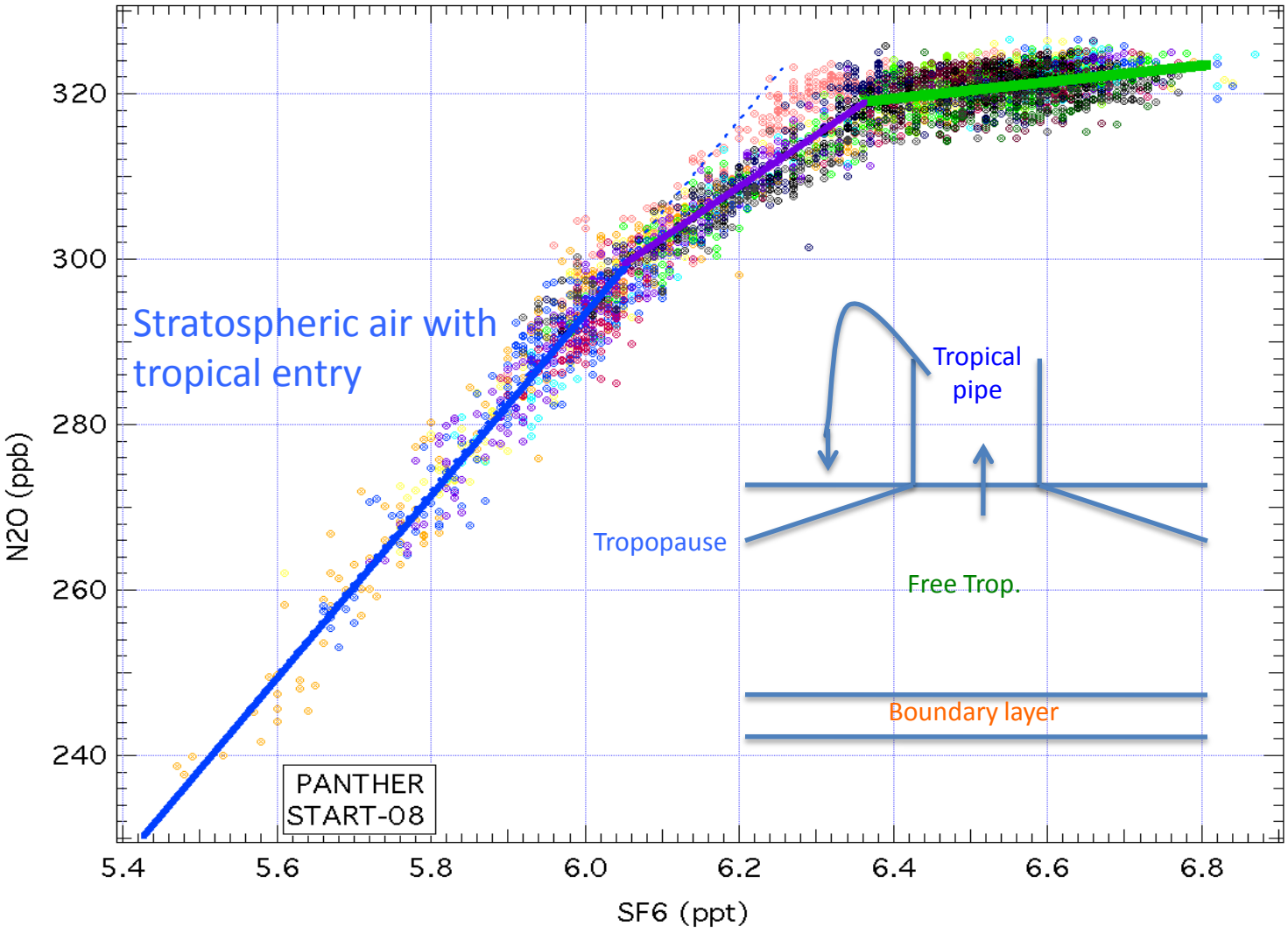
Potential Temperature – Latitude Cross-section, February 9, 2013



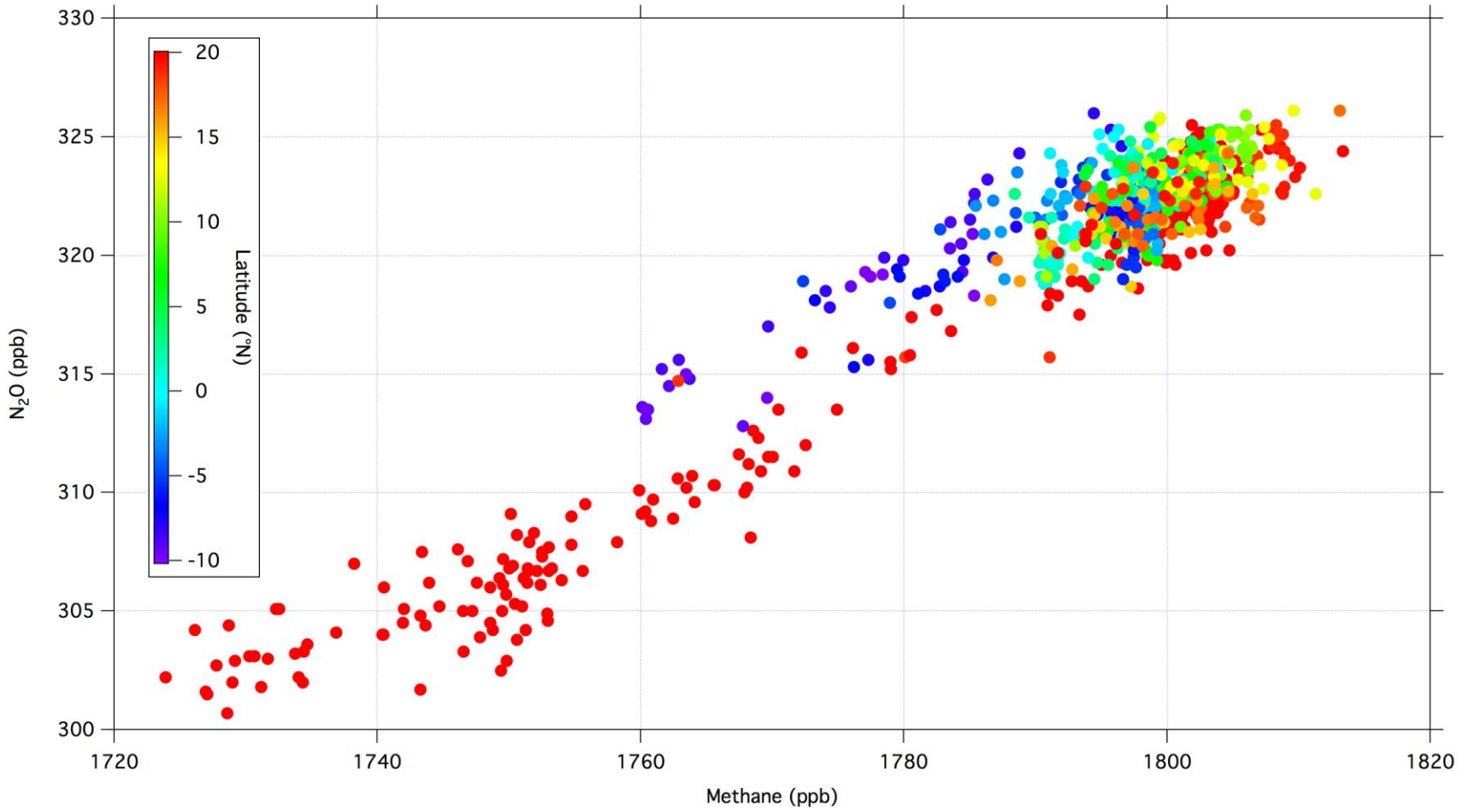
Feb. 9, 2013, Color-coded by Methane



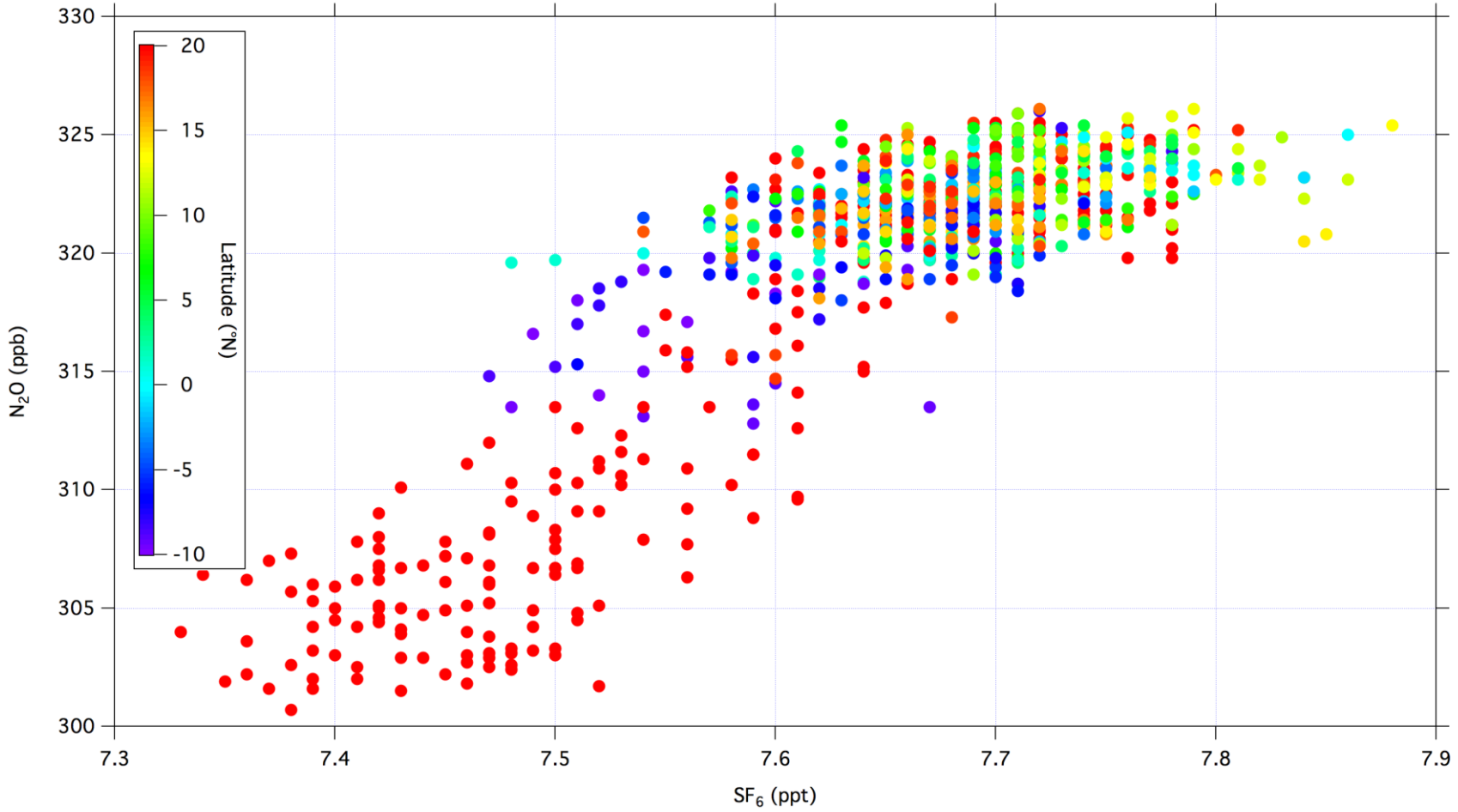
START-08 Data – GV flights in NH midlatitudes



Feb. 9, 2013, Color-coded by Latitude



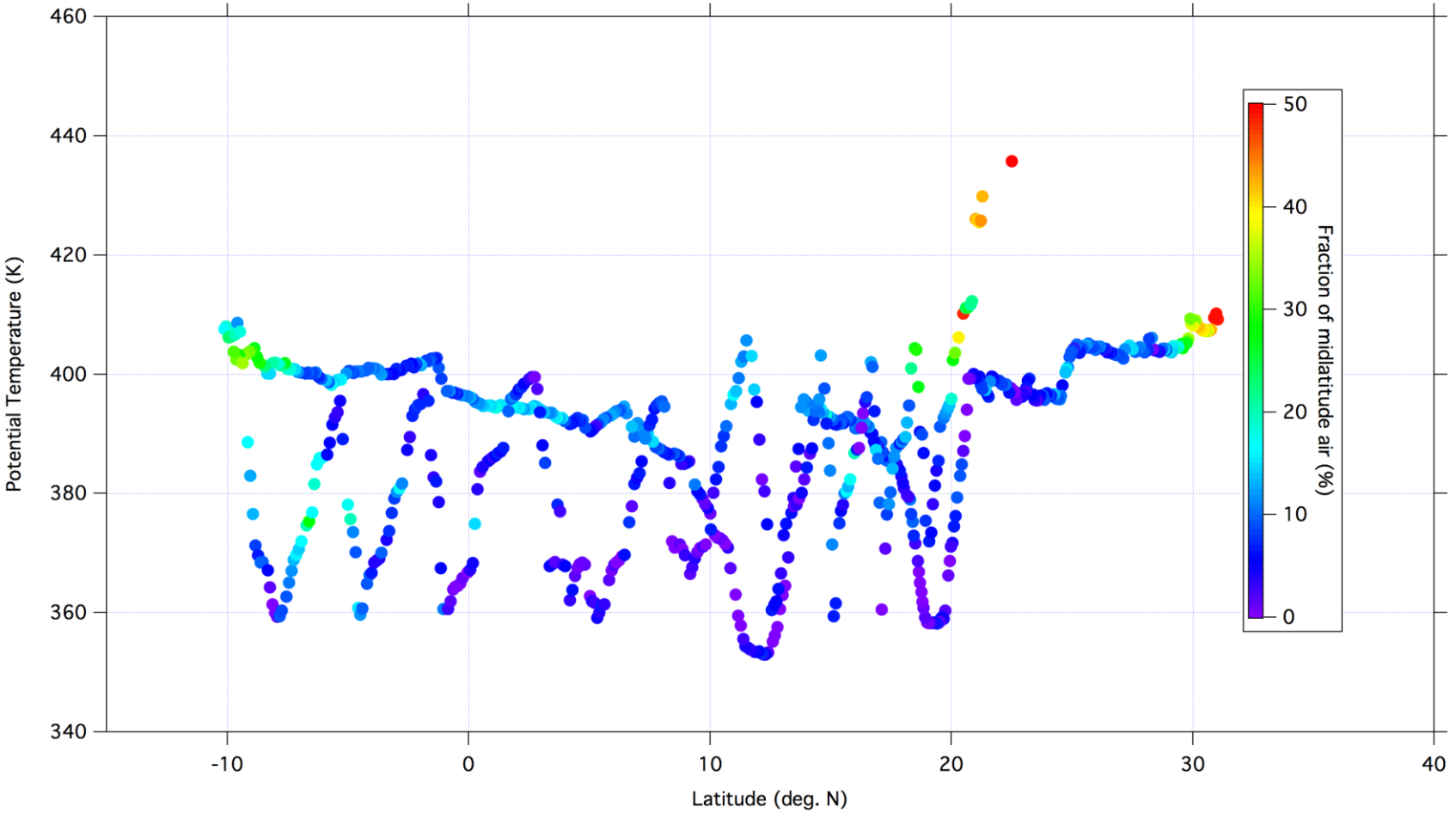
Feb. 9, 2013, Color-coded by Latitude



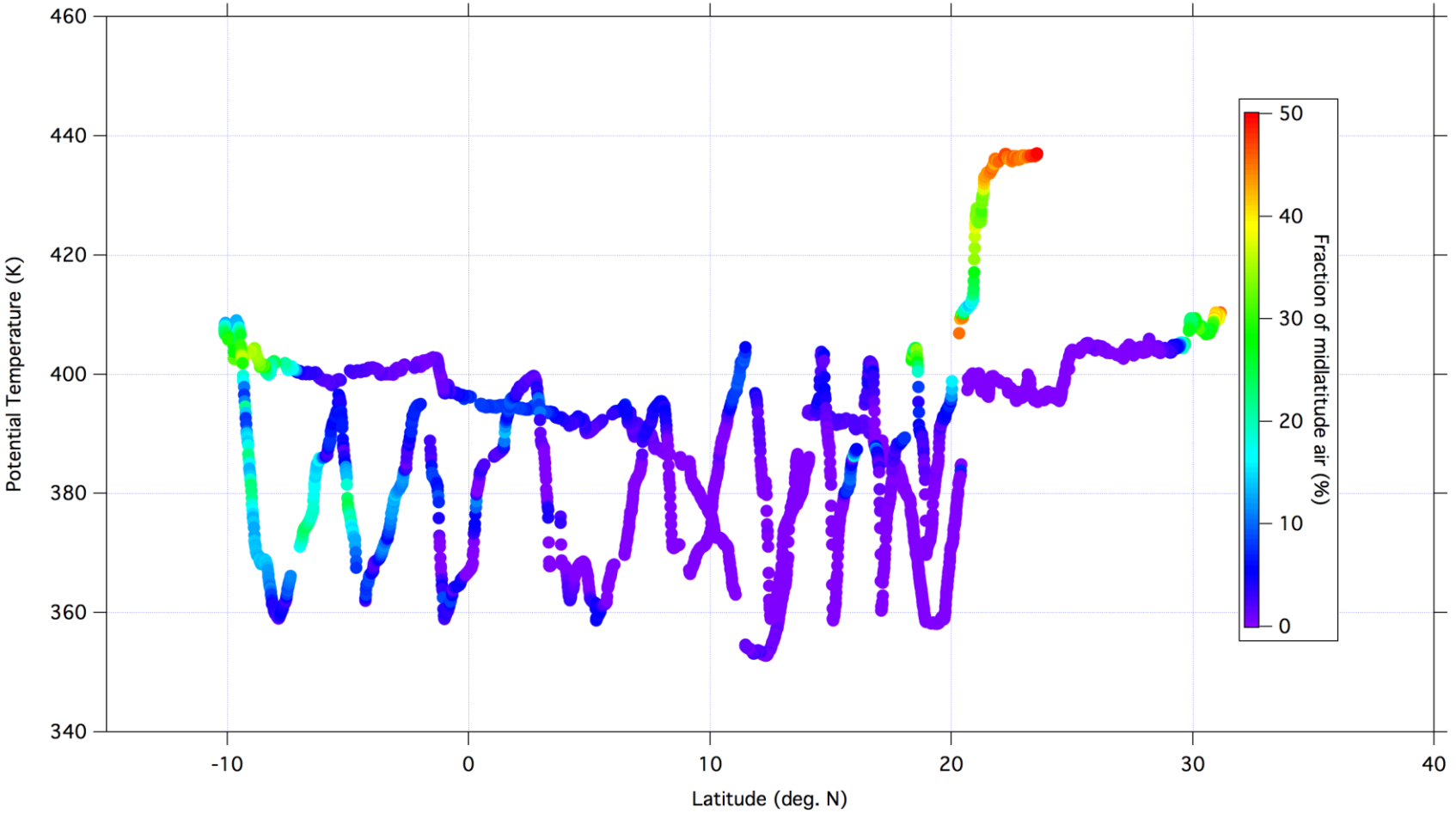
Simple model for mixing

- Measured mixing ratio = x*(mixing ratio of midlatitude air) + (1-x)*(mixing ratio of tropospheric air)
- x = fraction of midlatitude (or older) air
- Tropospheric values from NOAA ground sites
- Mixing ratios for midlatitude air from Global Hawk measurements: N_2O = 290 ppb and CH_4 = 1805 ppb
- x_{N2O} = (325 ppb – measured)/(325-290 ppb)

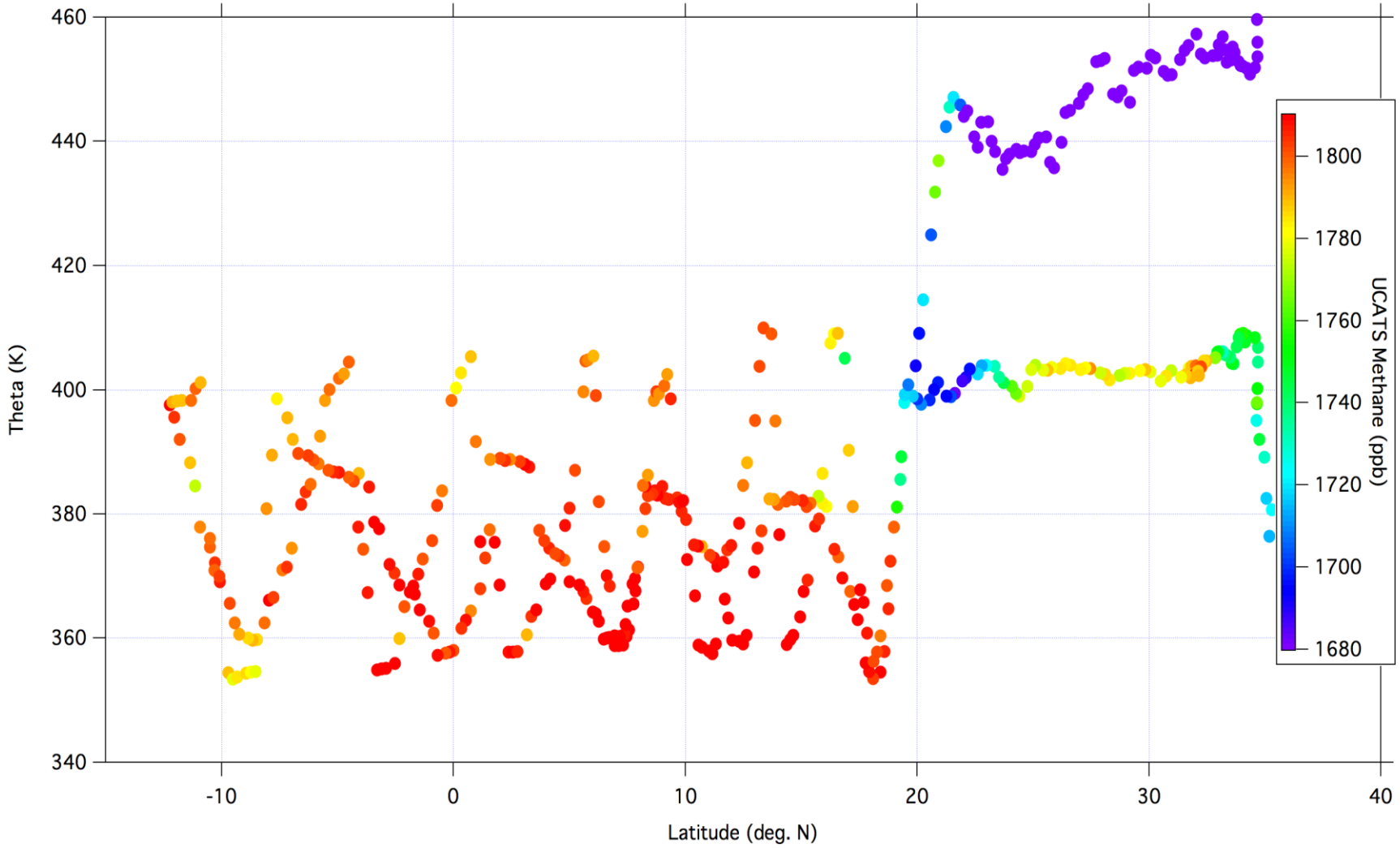
Percent of midlatitude or older air based on N_2O, February 9, 2013



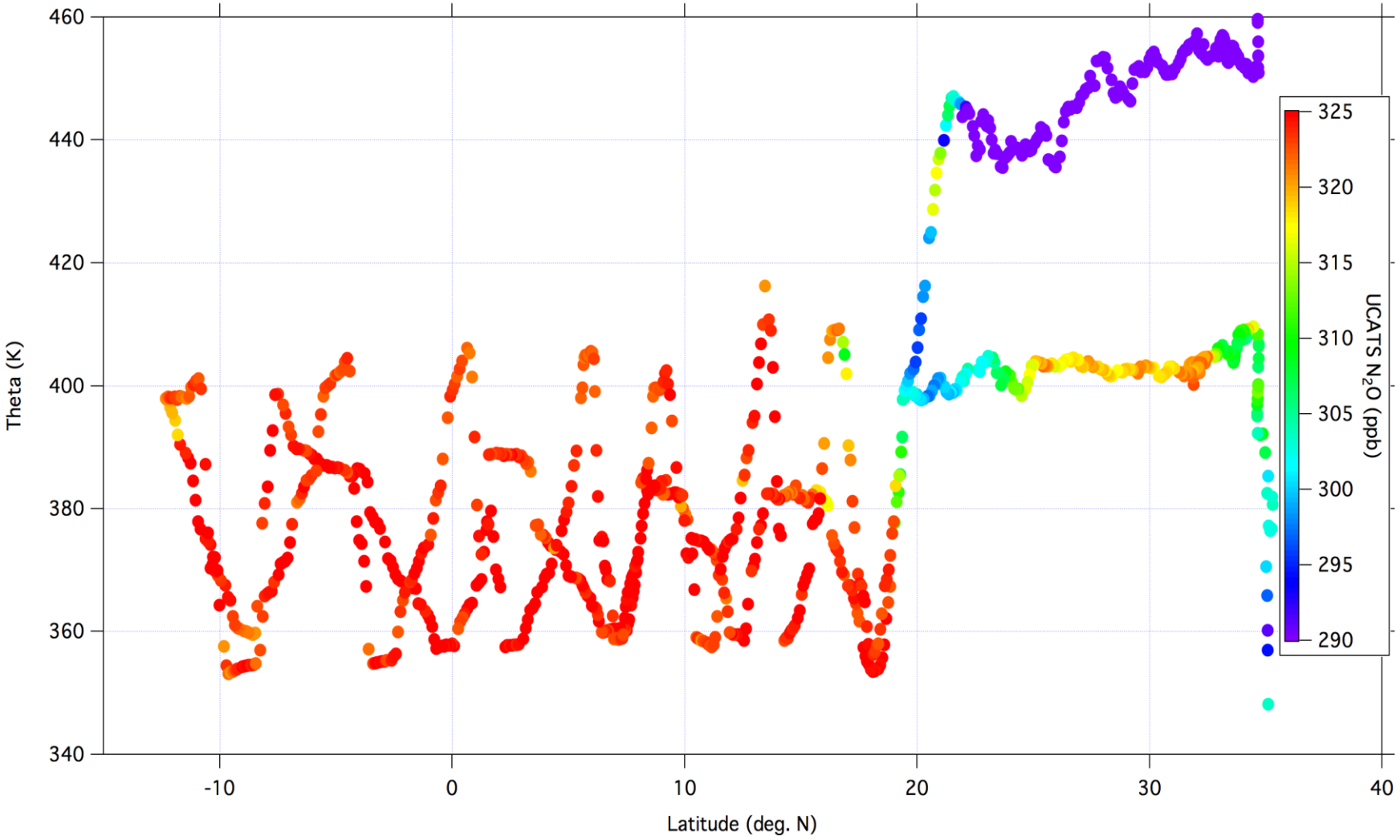
Percent of midlatitude or older air based on methane, February 9, 2013



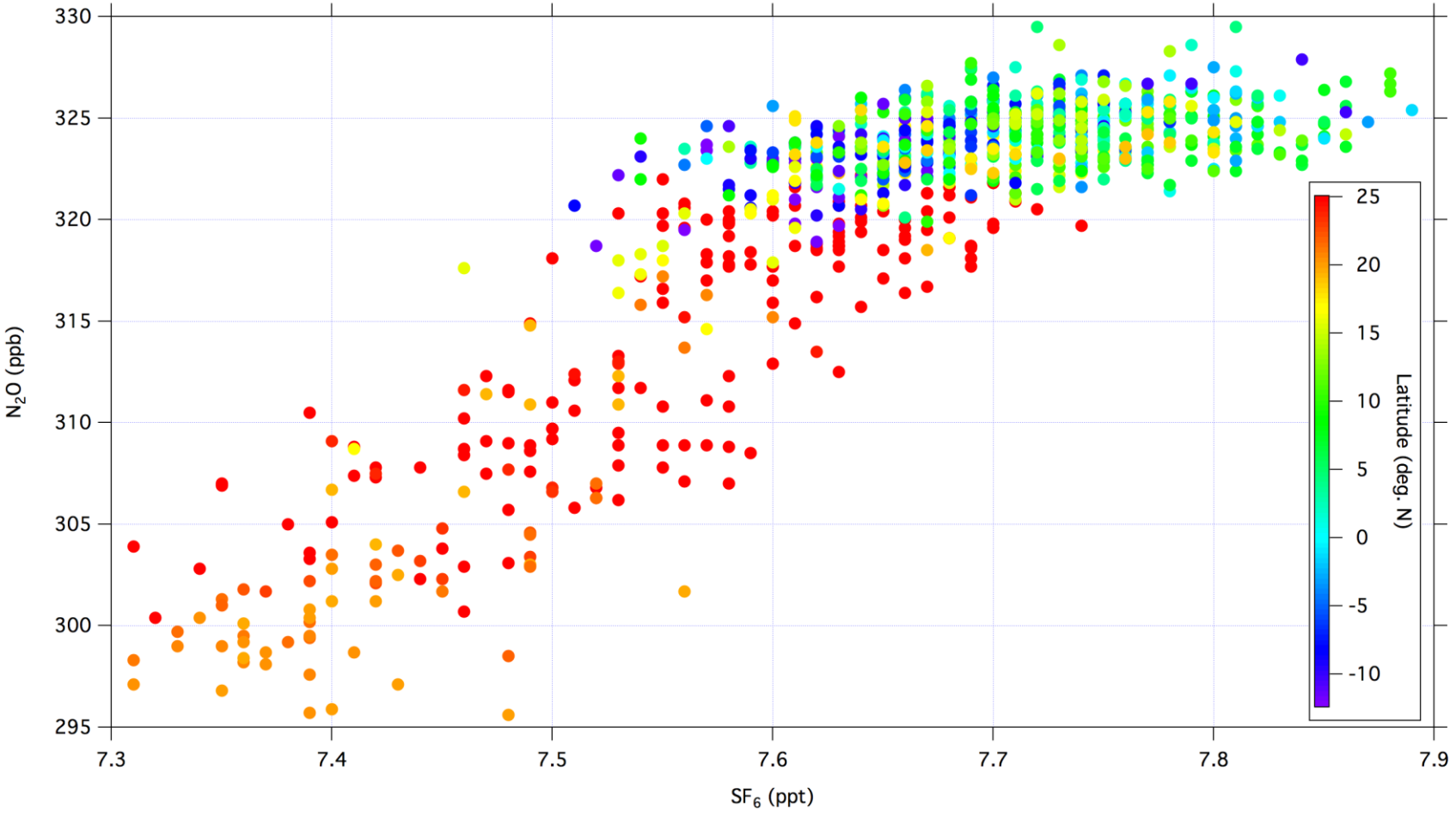
Feb. 21, 2013; UCATS Methane



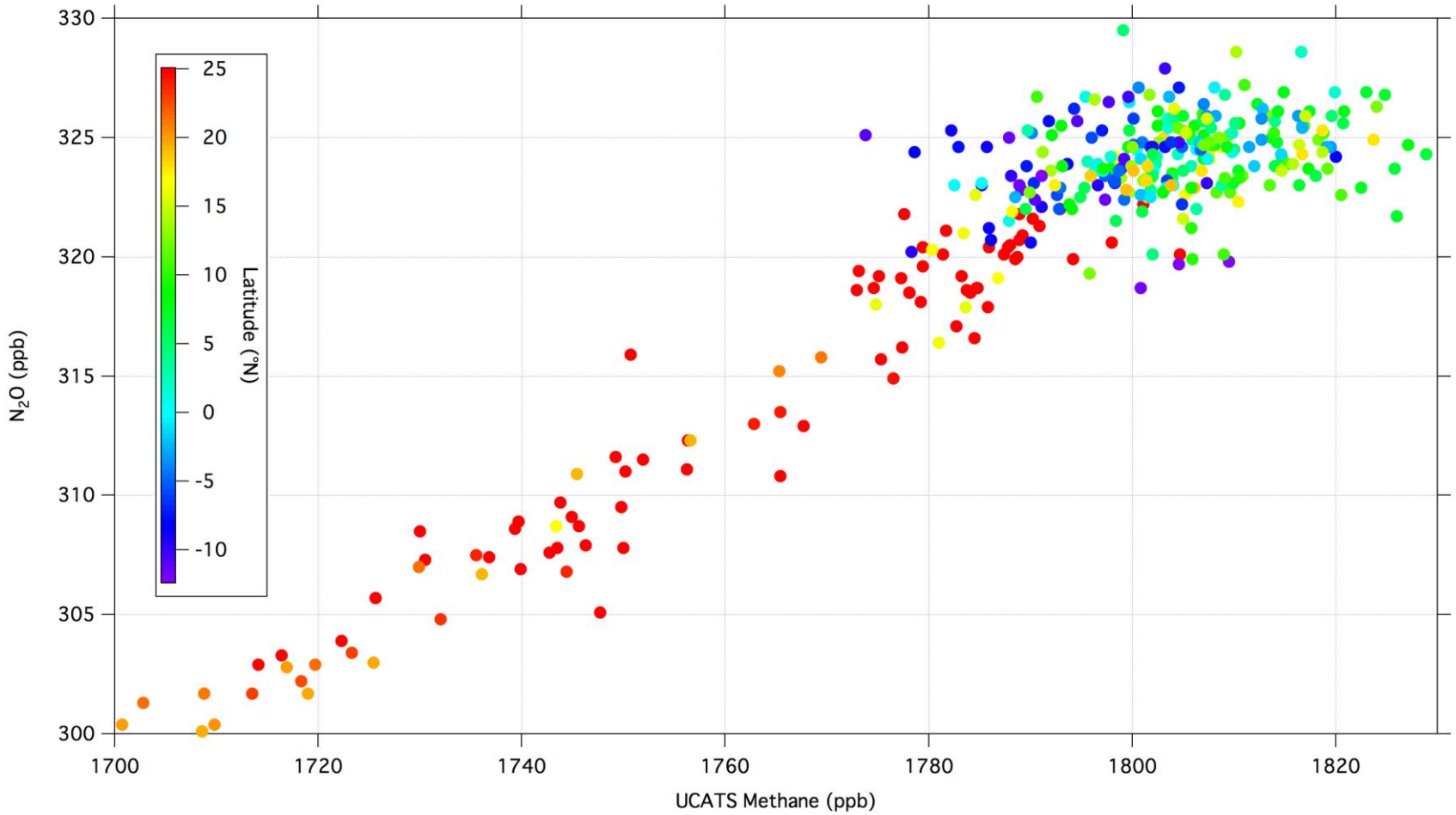
Feb. 21, 2013, Color-coded by N_2O



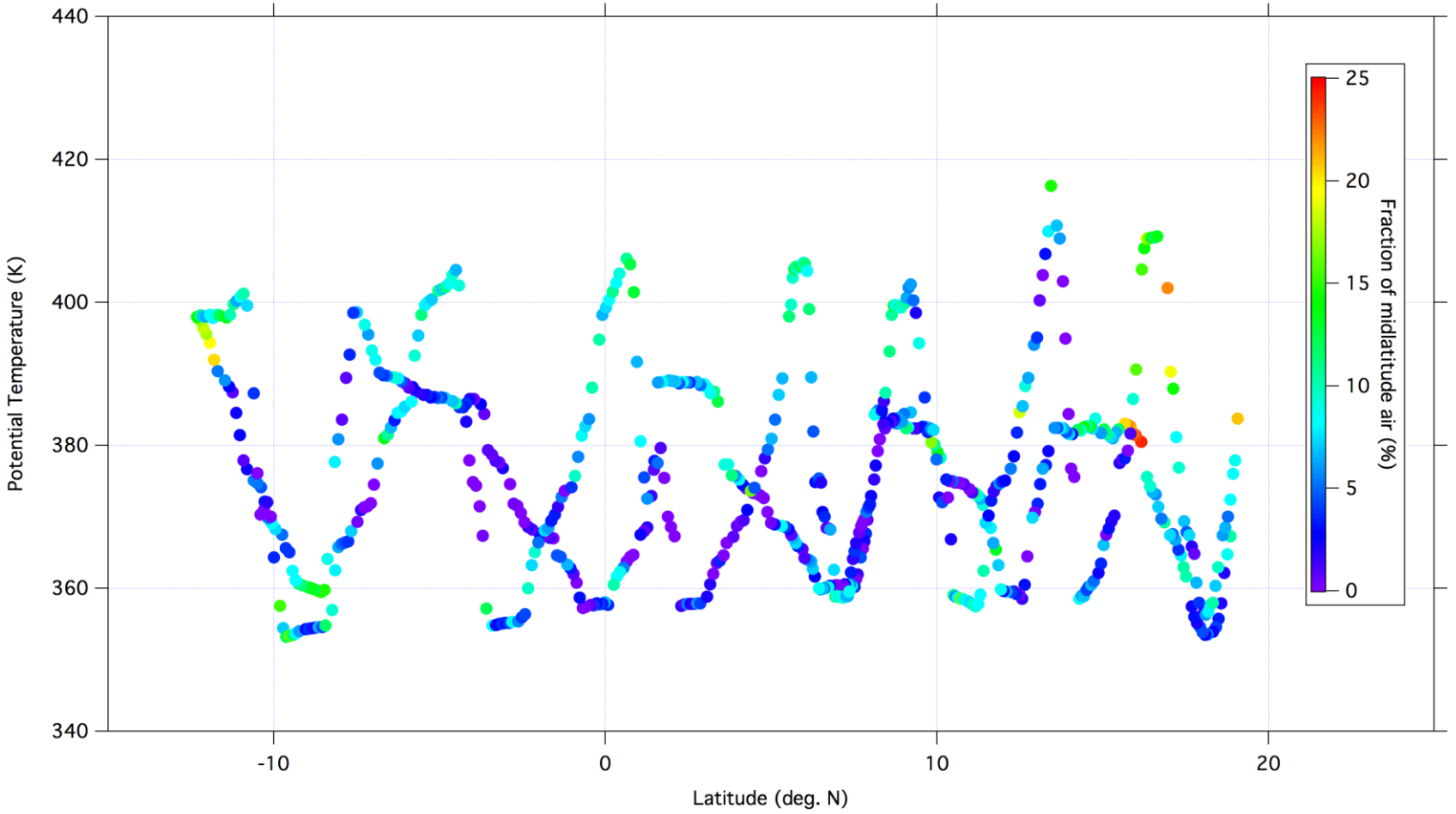
Feb. 21, 2013, Color-coded by Latitude



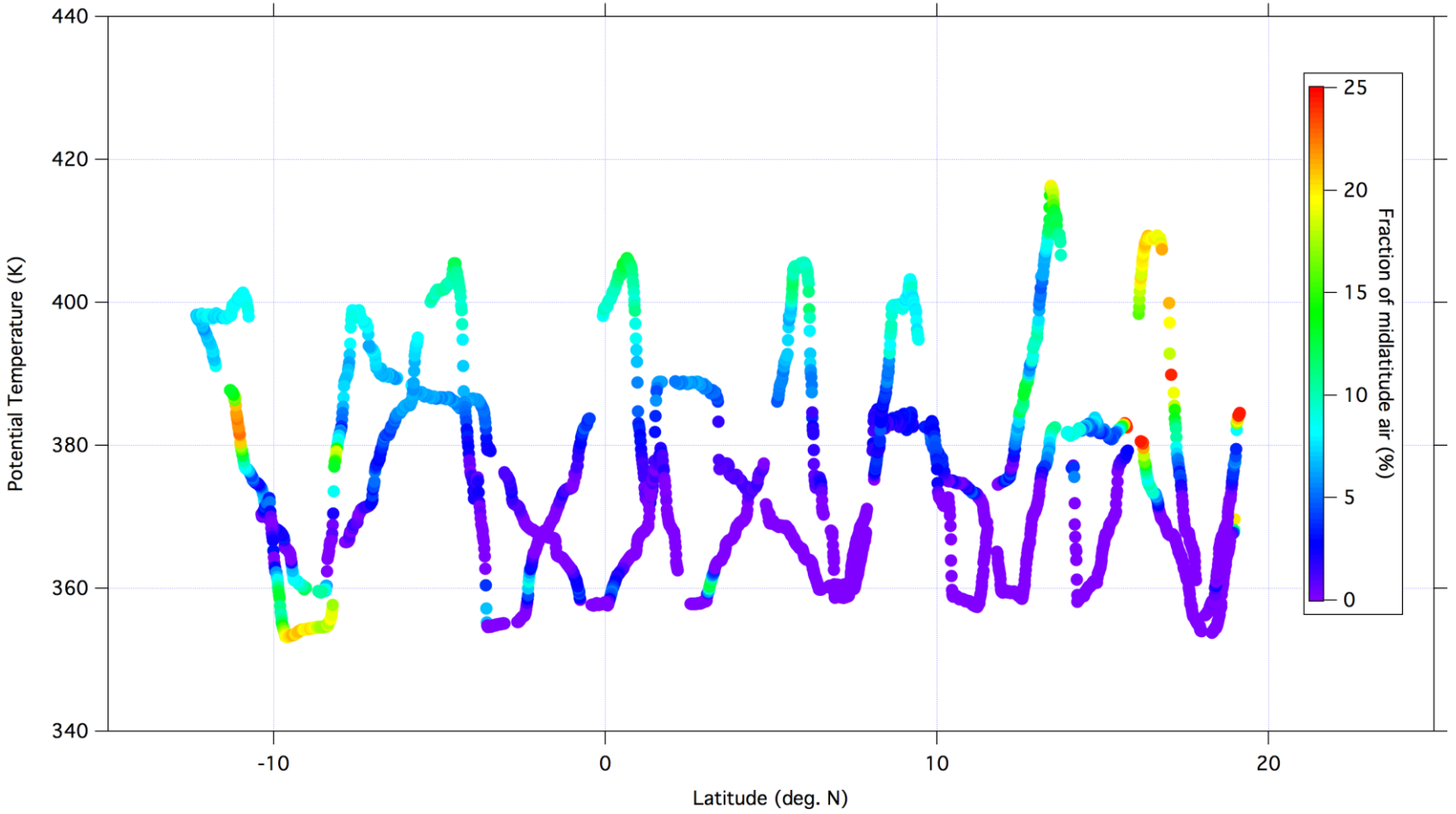
Feb. 21, 2013, Color-coded by Latitude



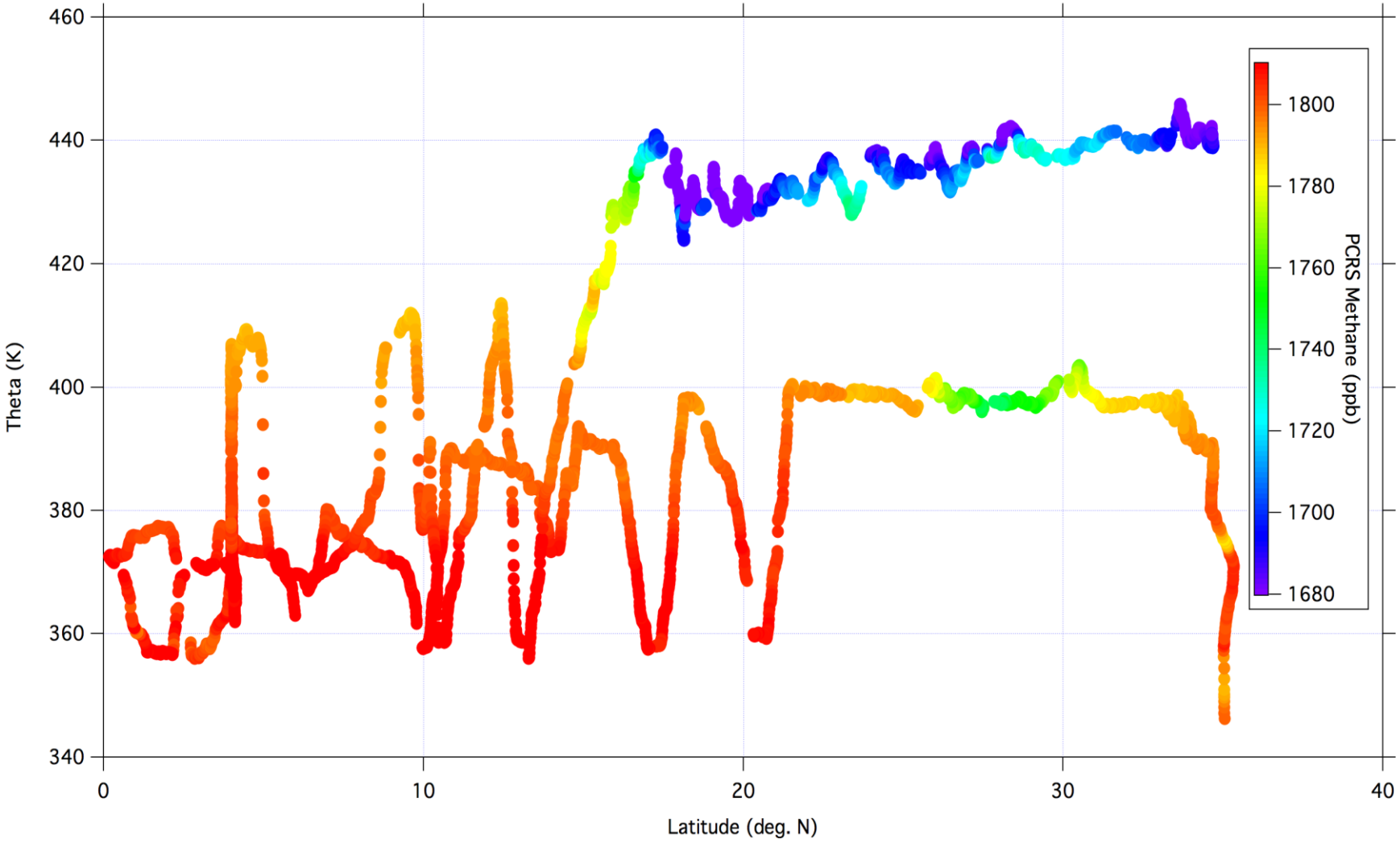
Percent of midlatitude or older air based on N_2O, February 21, 2013



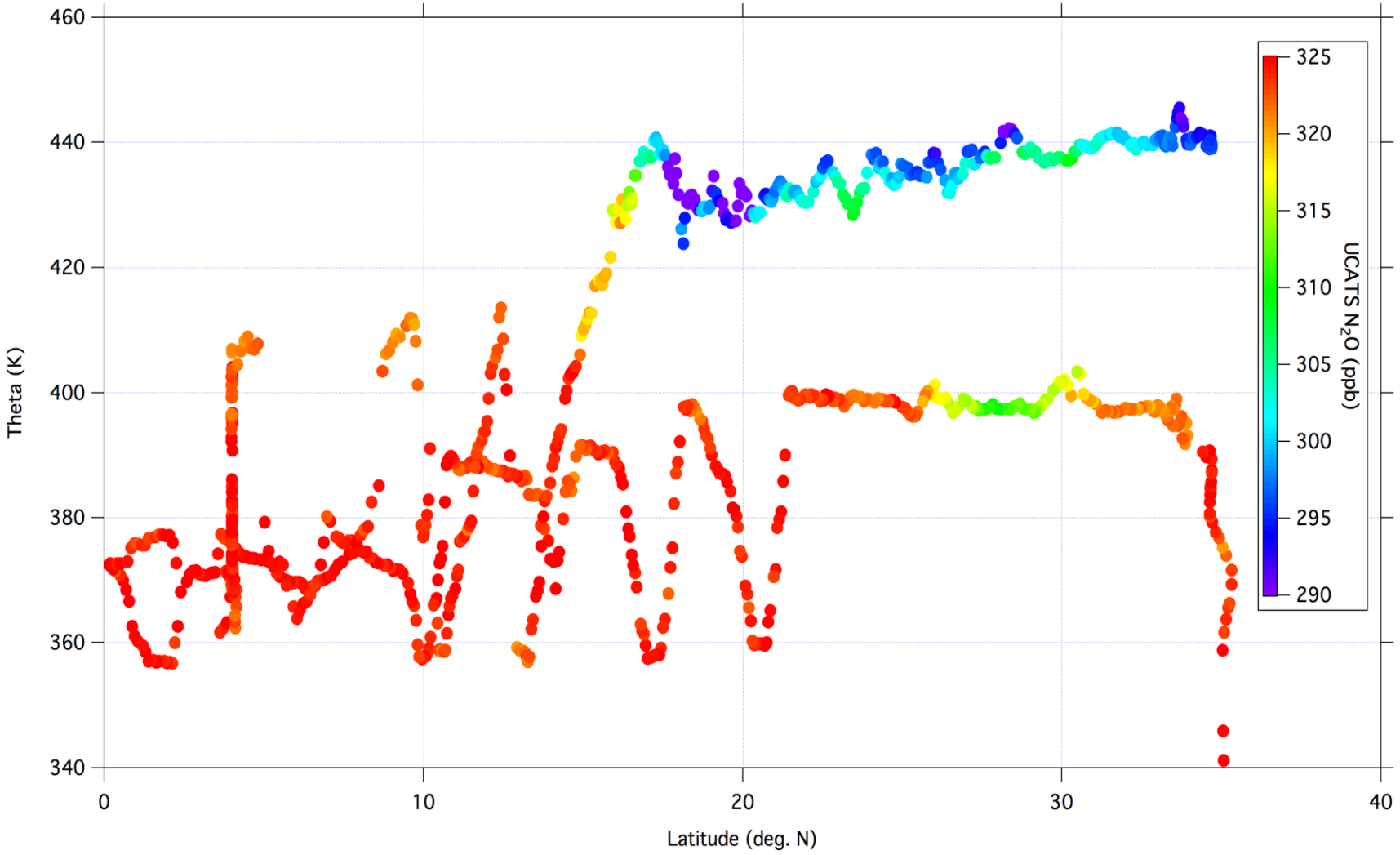
Percent of midlatitude or older air based on methane, February 21, 2013

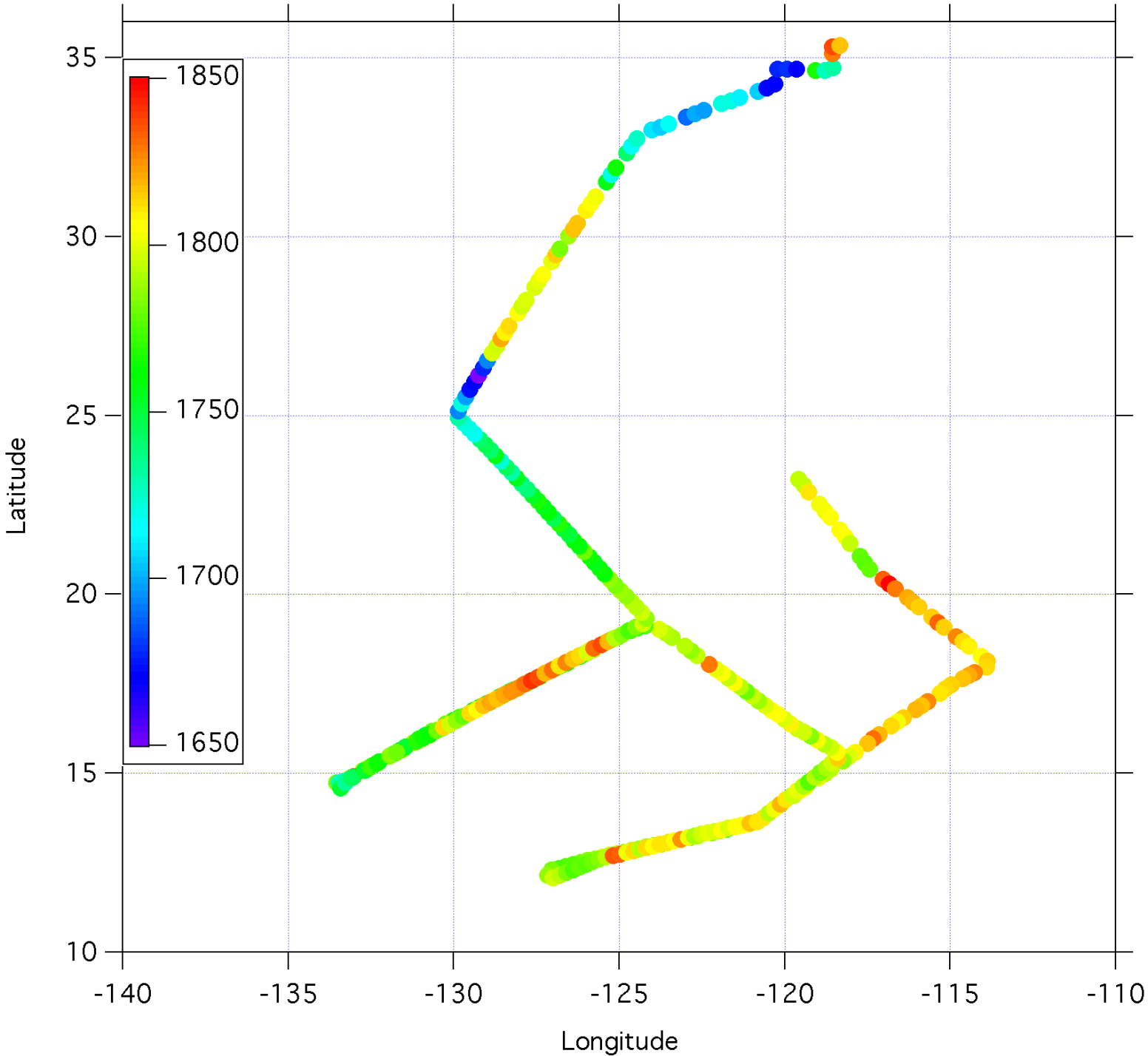


March 1, 2013, Color-coded by Methane

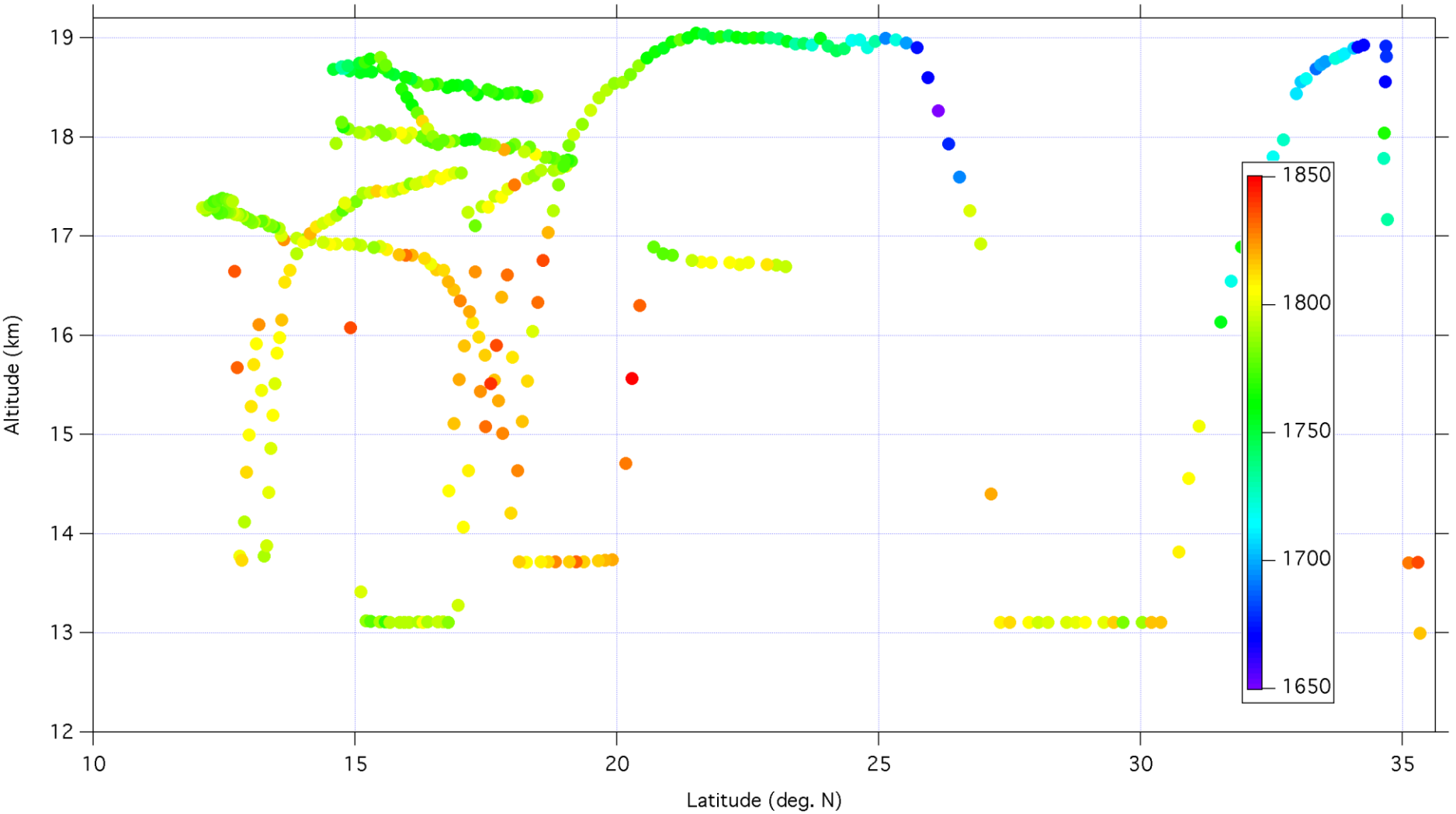


March 1, 2013, Color-coded by N_2O

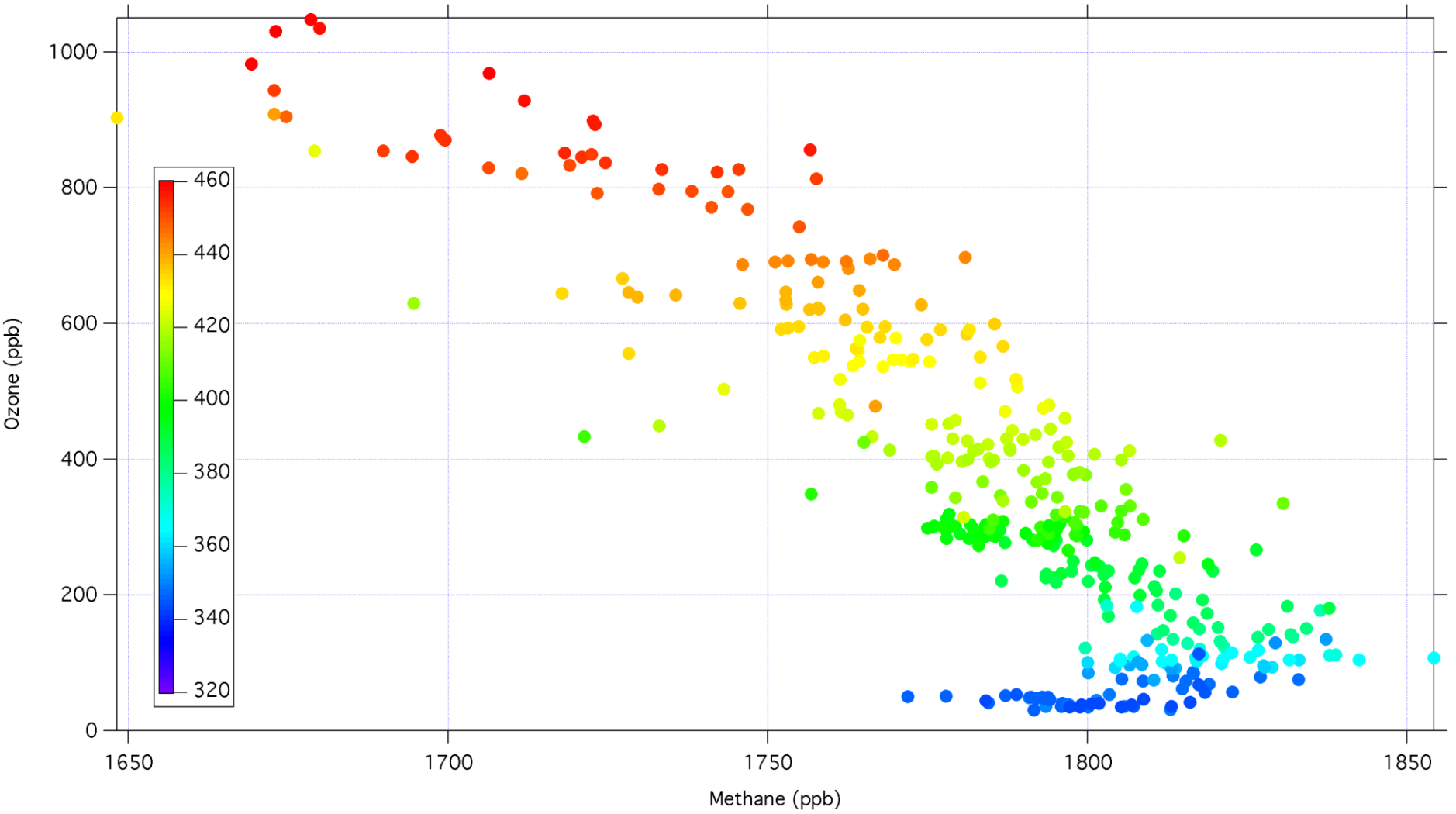



1850
1800
1750
1700
1650
35
30
25
20
15
10
Latitude
-140
-135
-130
-125
-120
-115
-110
Longitude

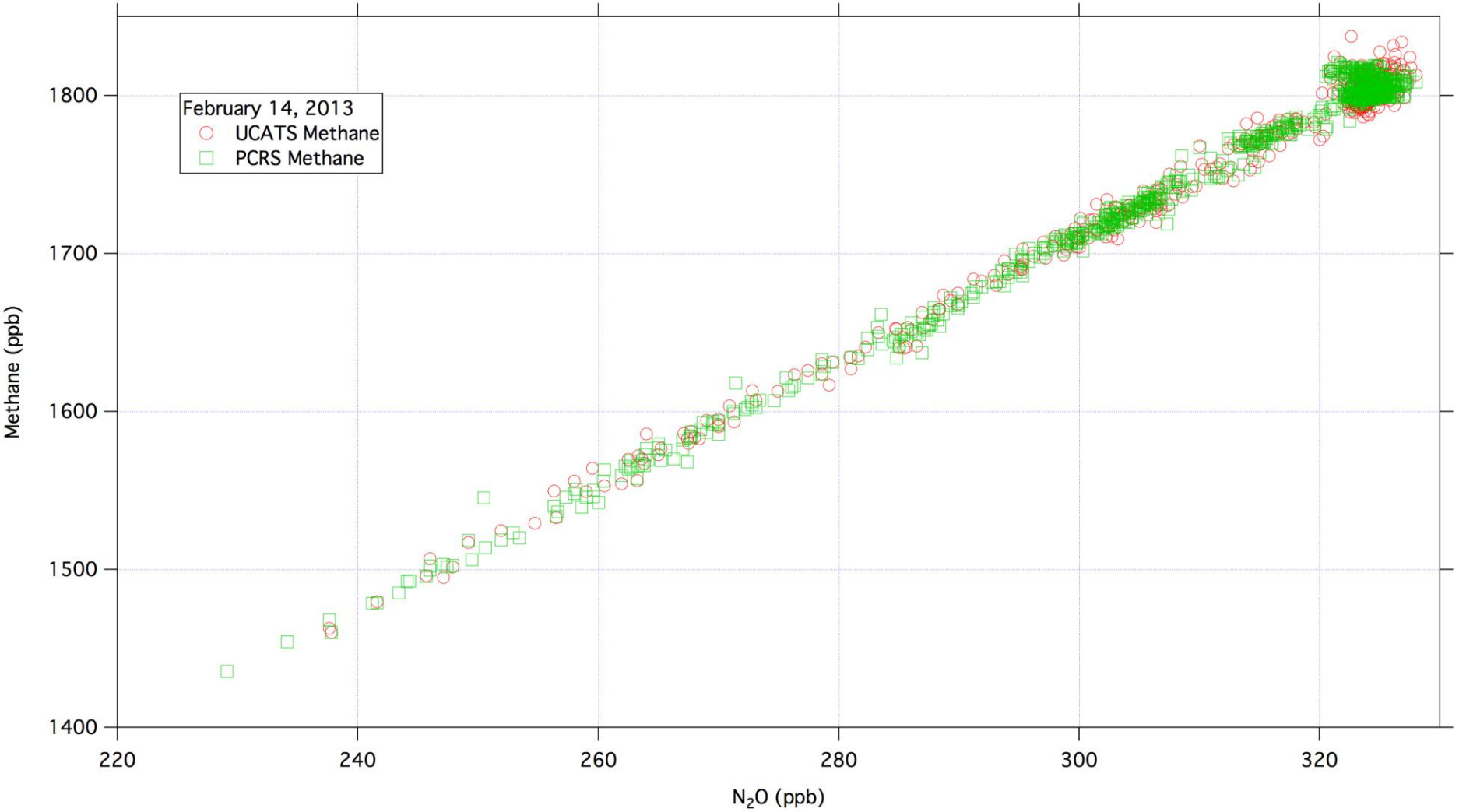
Altitude vs. latitude, color-coded by methane, Nov. 9



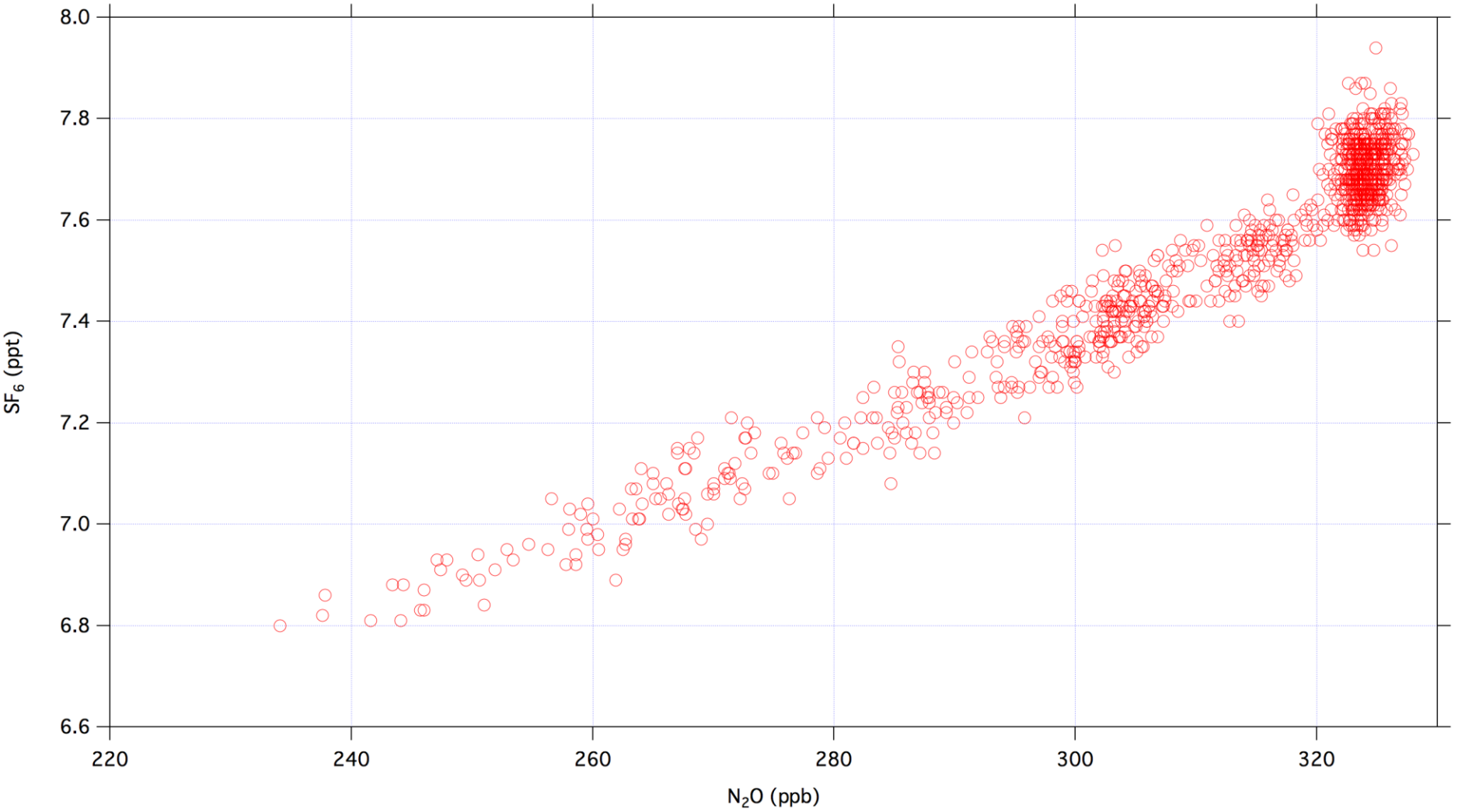
Ozone vs. Methane, binned by theta, November 9, 2011



Methane-N_2O Correlation Plot



SF_6 vs. N_2O, February 14, 2013



UCATS CO data sorted by Ozone