Anatomy of High Levels of Wintertime Photochemical Ozone in the Uintah Basin, UT 2013

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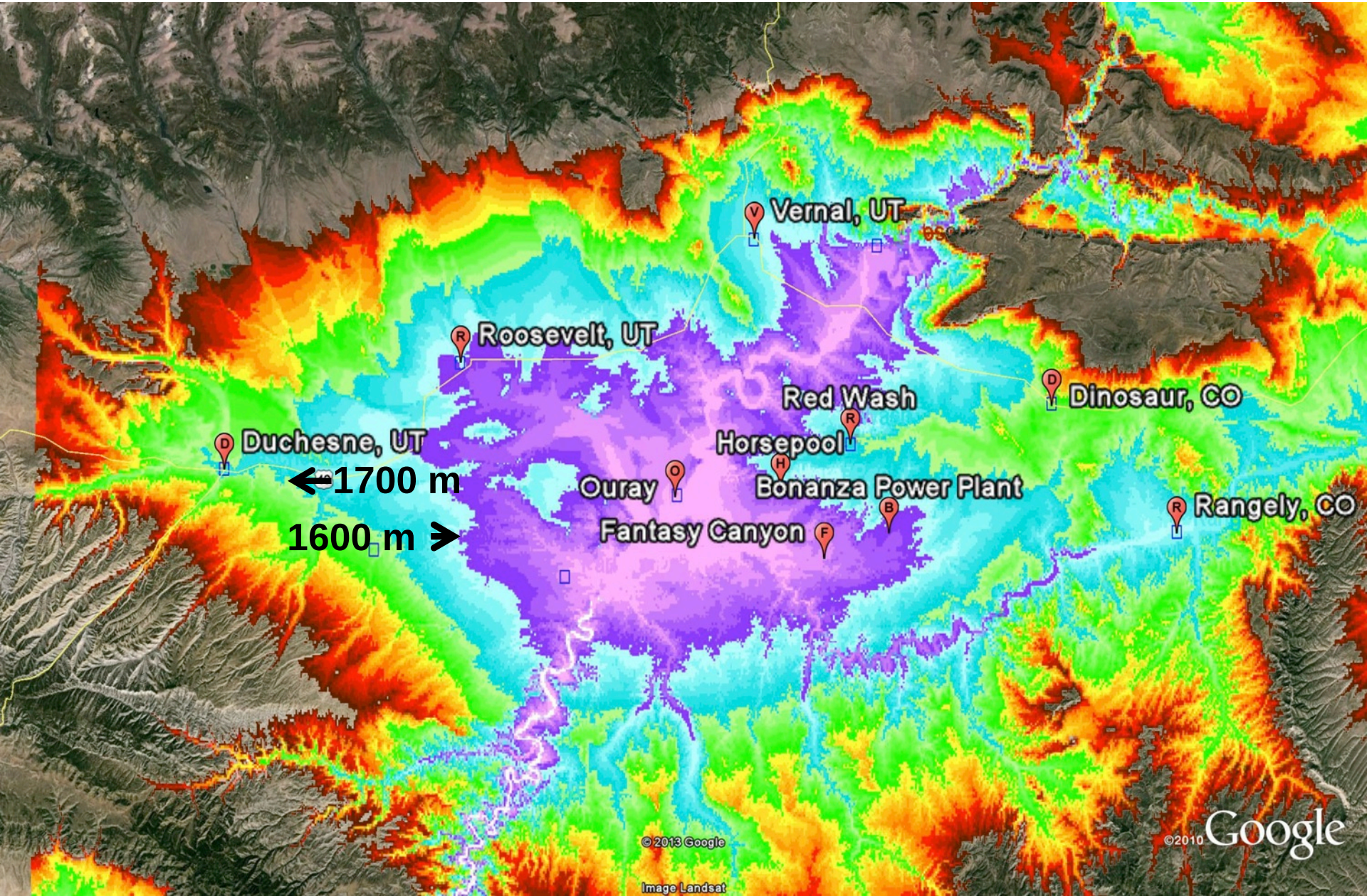
Boulder, CO 80305

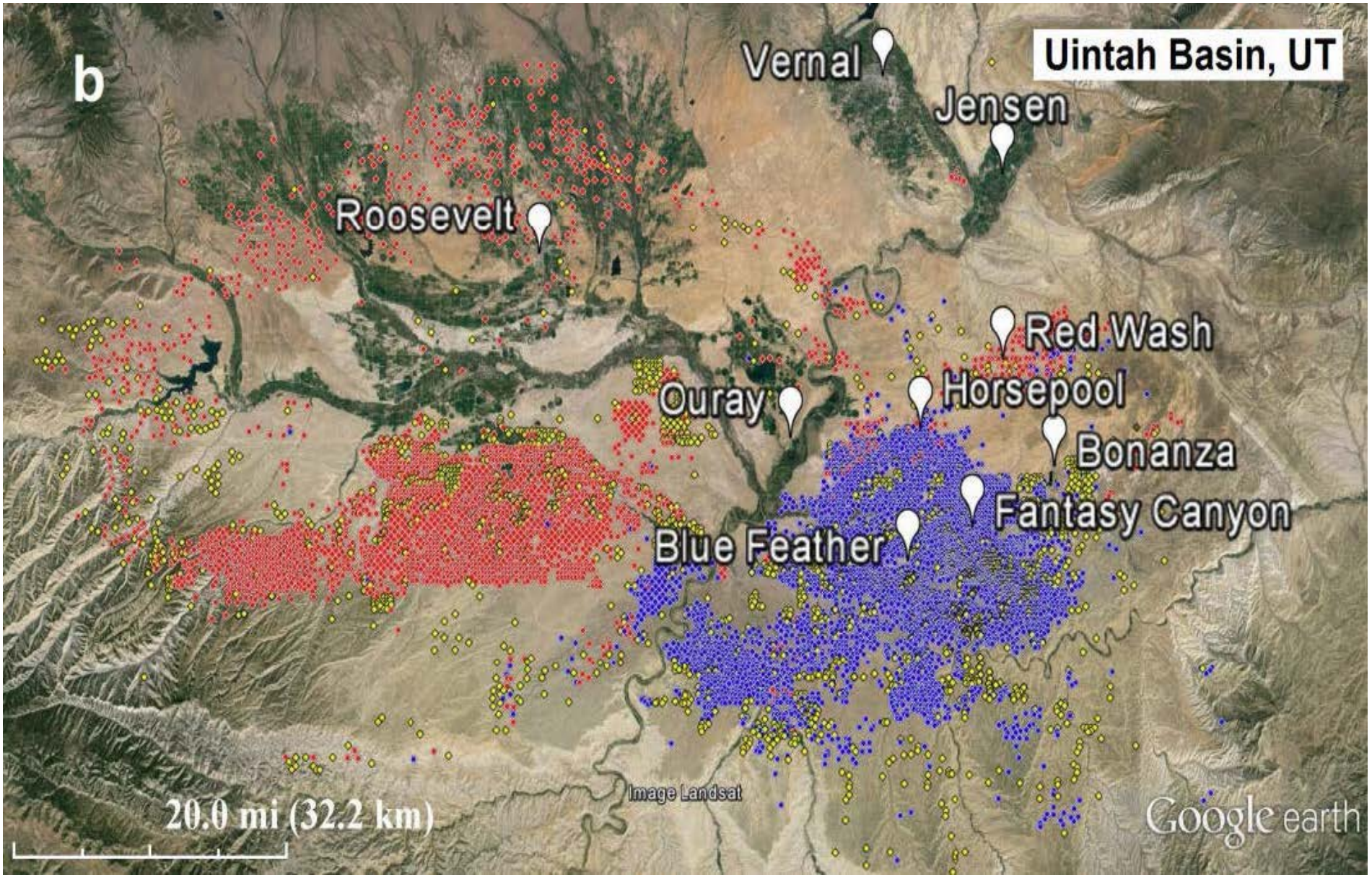
GMD GMAC

June, 2014

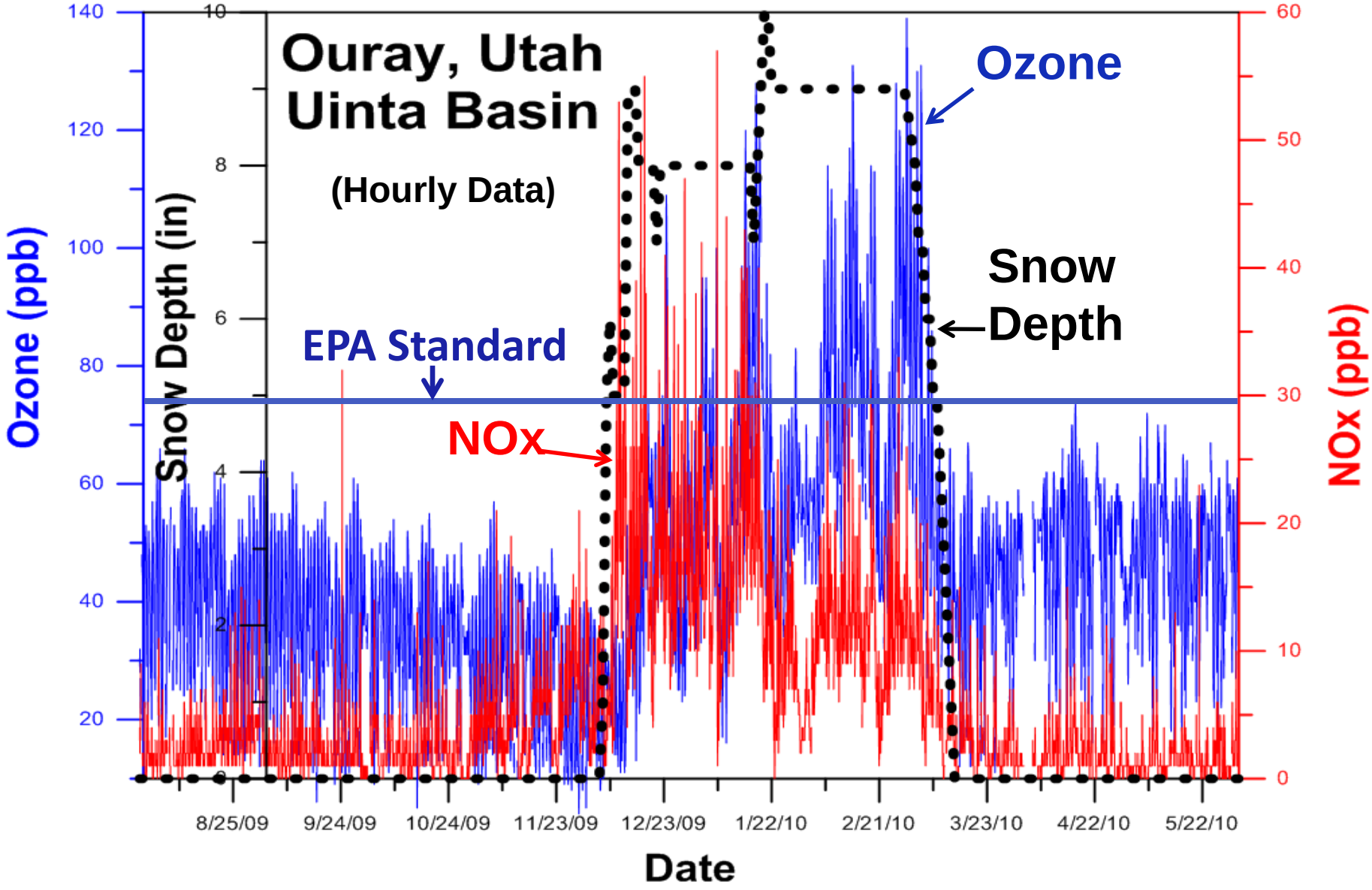
Surface Elevation Contours, Uintah Basin, Utah



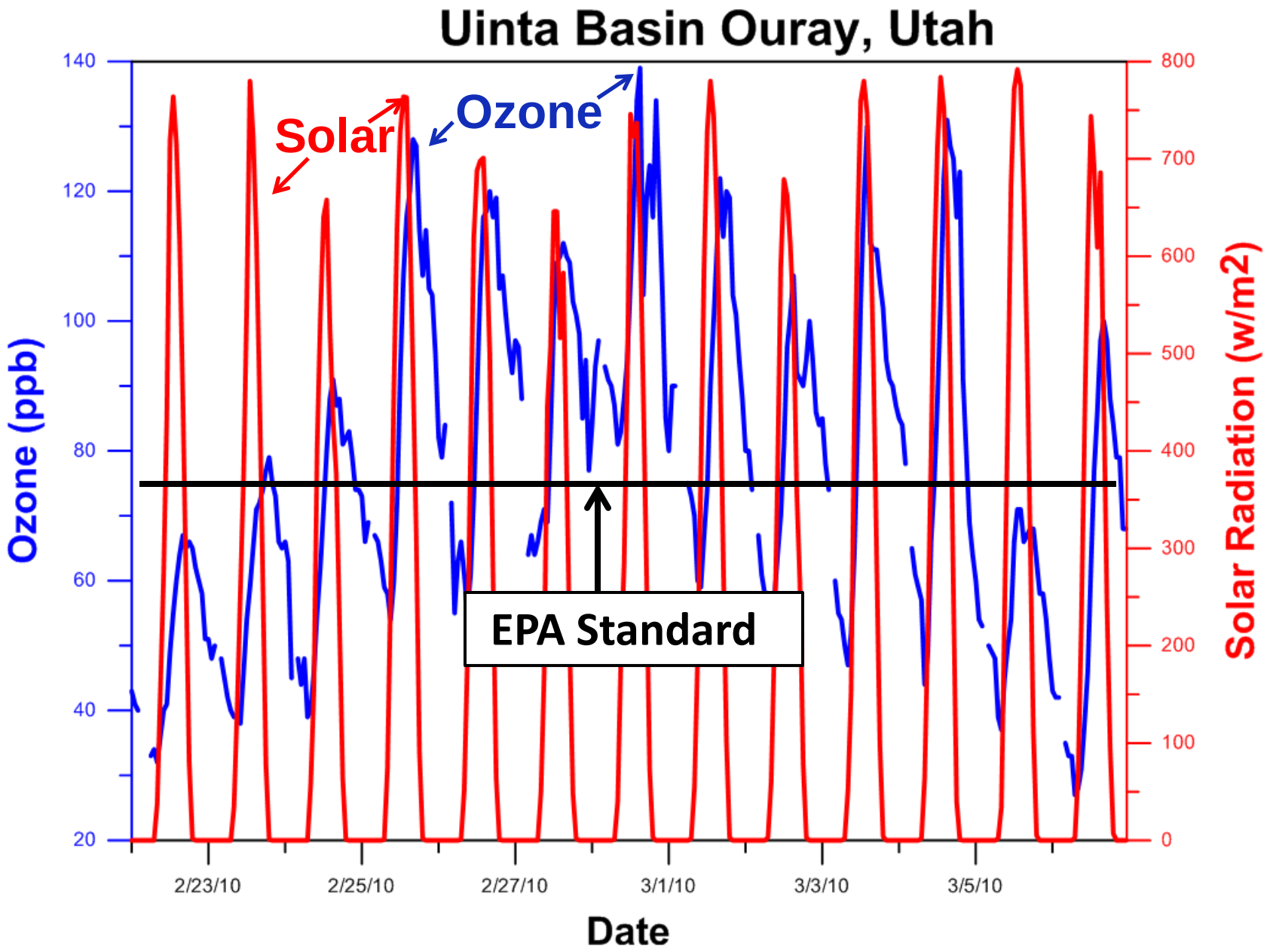
Oil (red) , Gas (blue) Wells and Measurement Sites, Uintah Basin, Utah



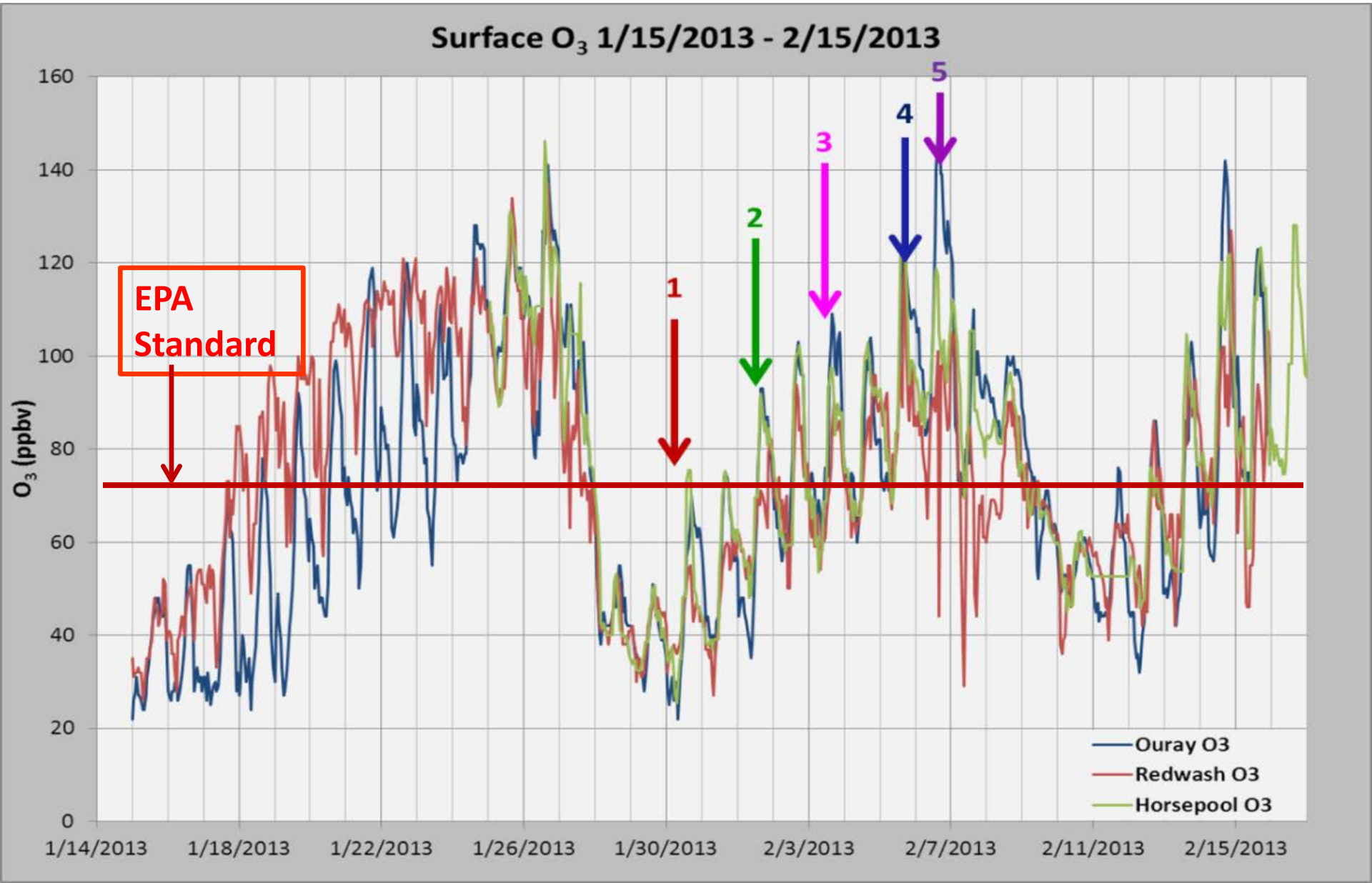
Ozone, NO_x and Snow Depth: Winter 2009/10



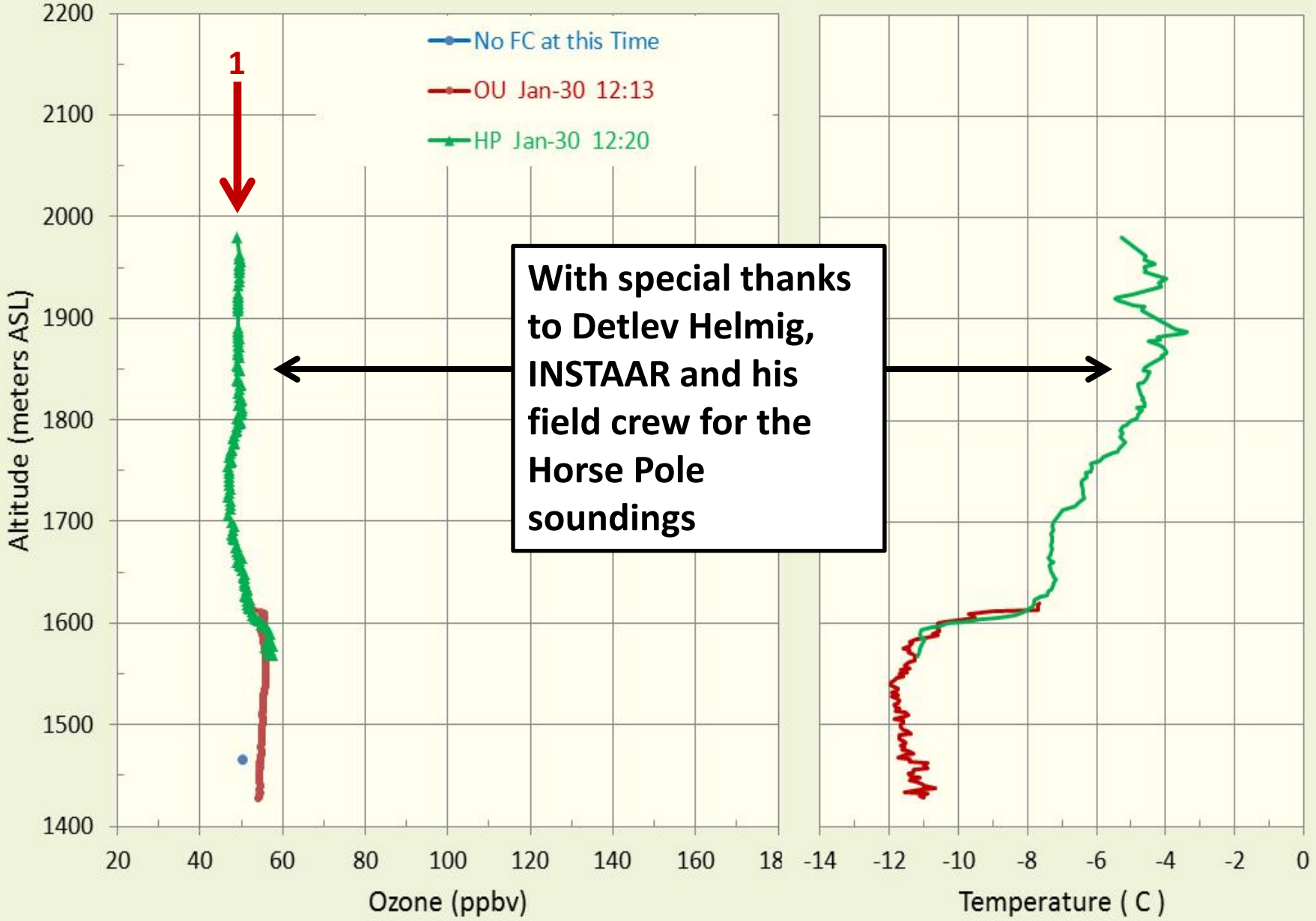
Ozone and Solar Radiation: Winter 2009/10



Surface Ozone Concentrations at Three Sites, Uinta Basin, Utah 2013 over Three Ozone Events

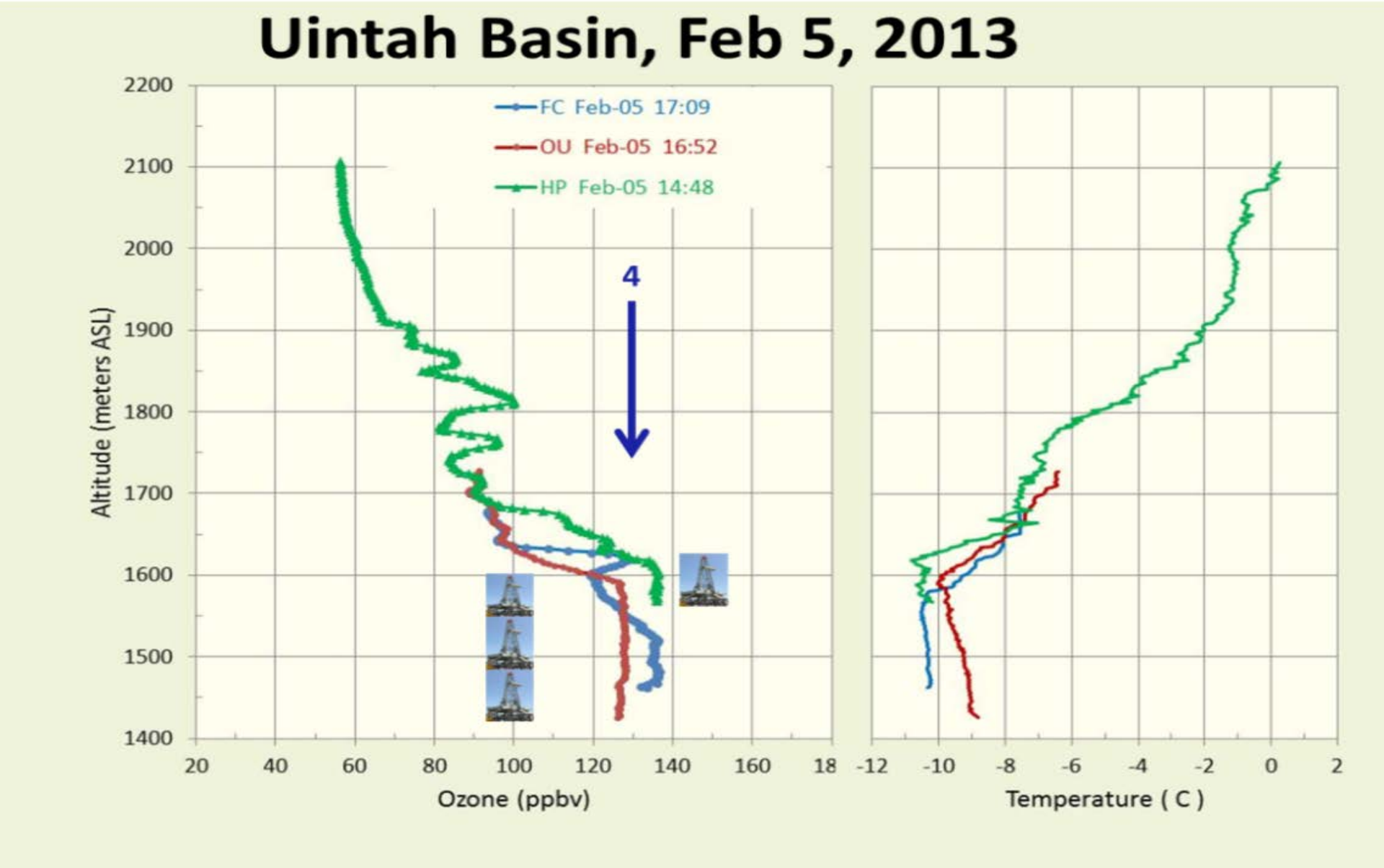


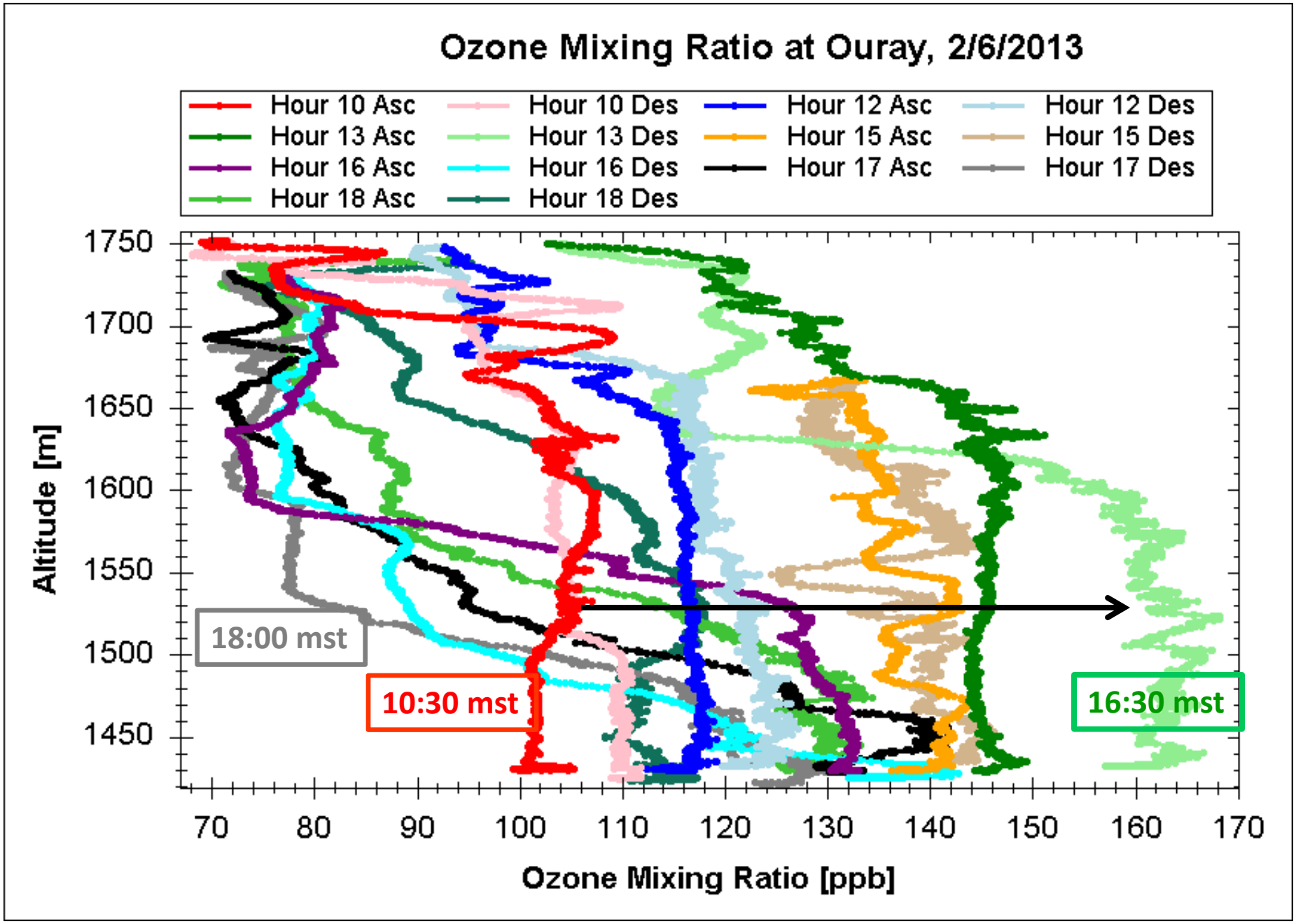
Uintah Basin, Jan 30, 2013



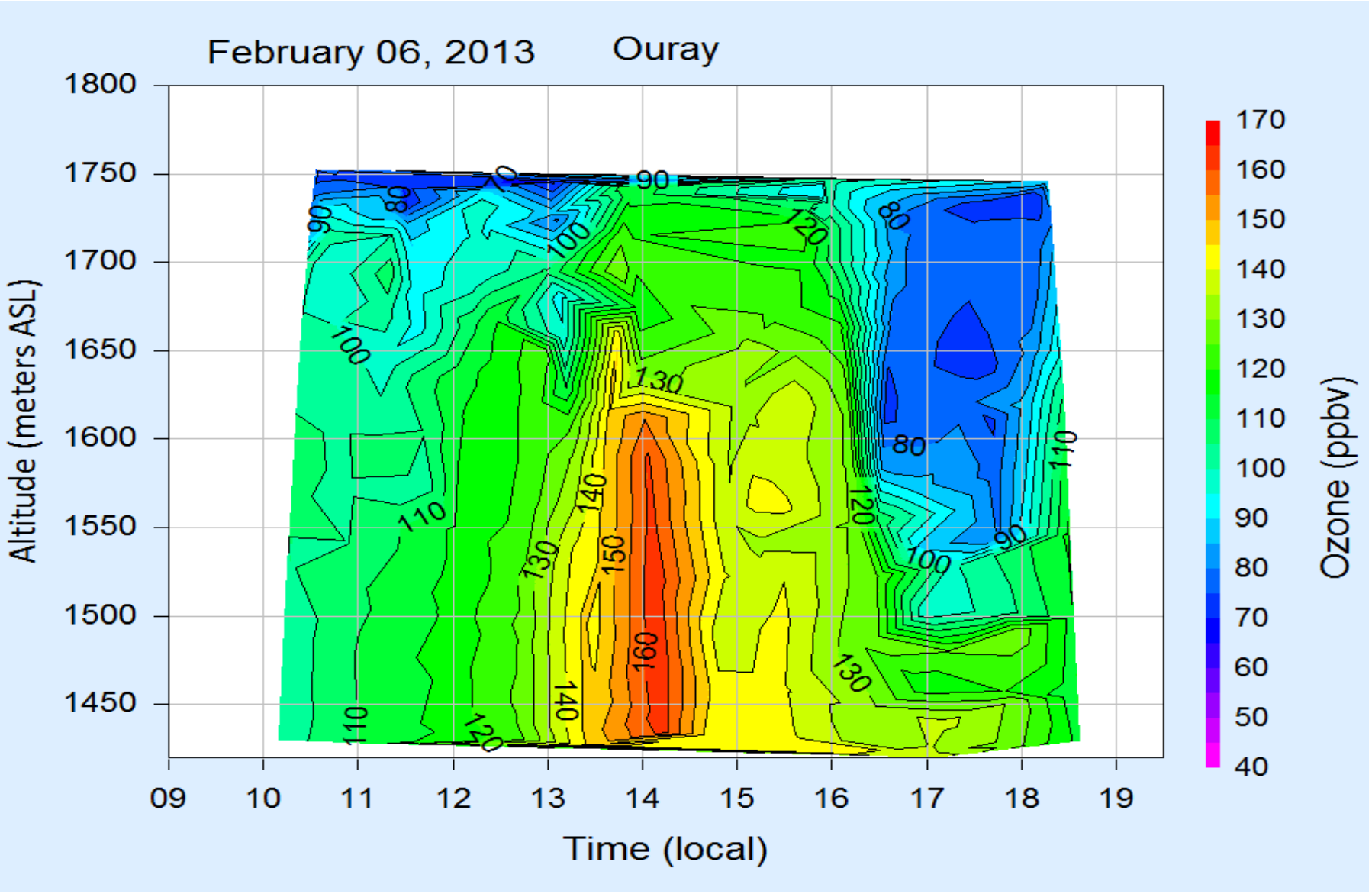
With special thanks to Detlev Helmig, INSTAAR and his field crew for the Horse Pole soundings

Ozone and Temperature Profiles

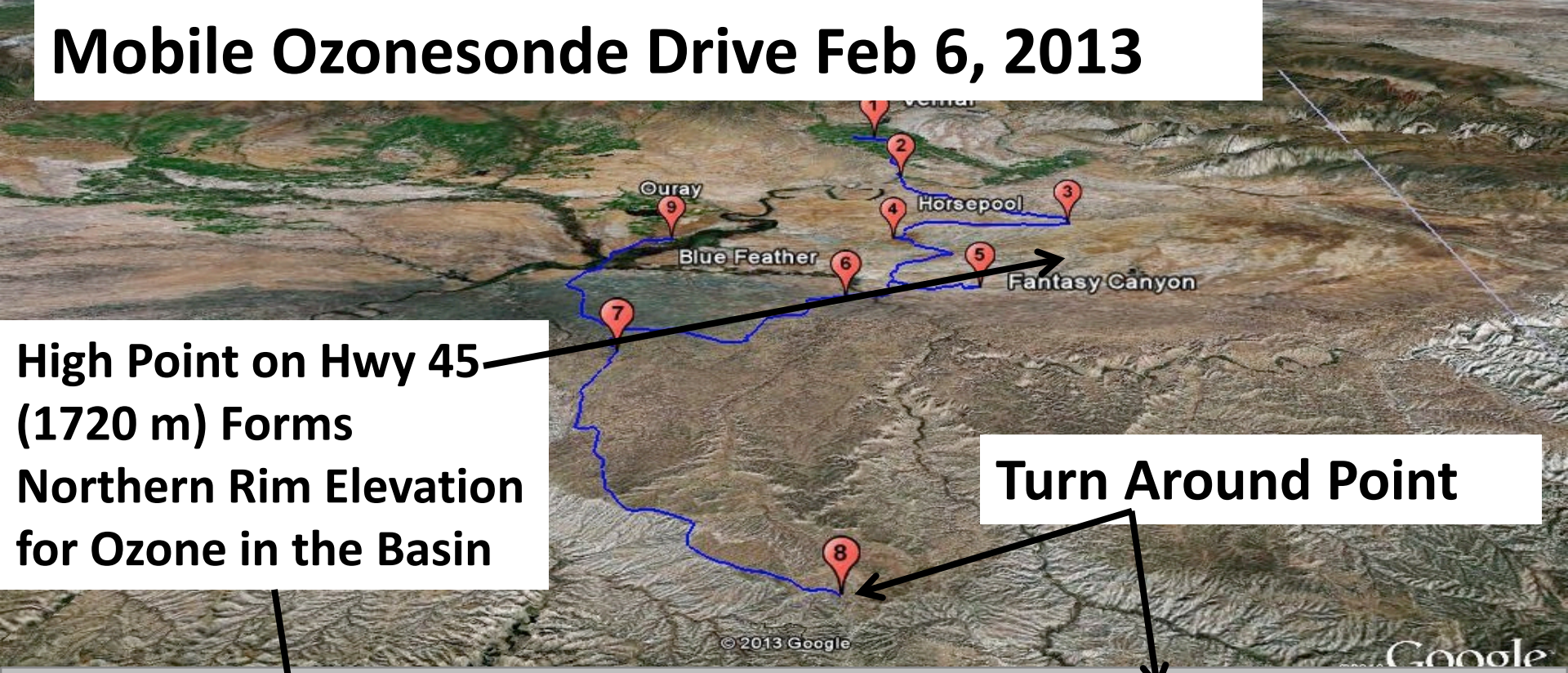



Ozone Mixing Ratio at Ouray, 2/6/2013
Hour 10 Asc
Hour 10 Des
Hour 12 Asc
Hour 12 Des
Hour 13 Asc
Hour 13 Des
Hour 15 Asc
Hour 15 Des
Hour 16 Asc
Hour 16 Des
Hour 17 Asc
Hour 17 Des
Hour 18 Asc
Hour 18 Des
Altitude [m]
1750
1700
1650
1600
1550
1500
1450
70
80
90
100
110
120
130
140
150
160
170
Ozone Mixing Ratio [ppb]
18:00 mst
10:30 mst
16:30 mst

Contour Plot of Ozone Over Ouray, Uintah Basin, Utah, February 6, 2013

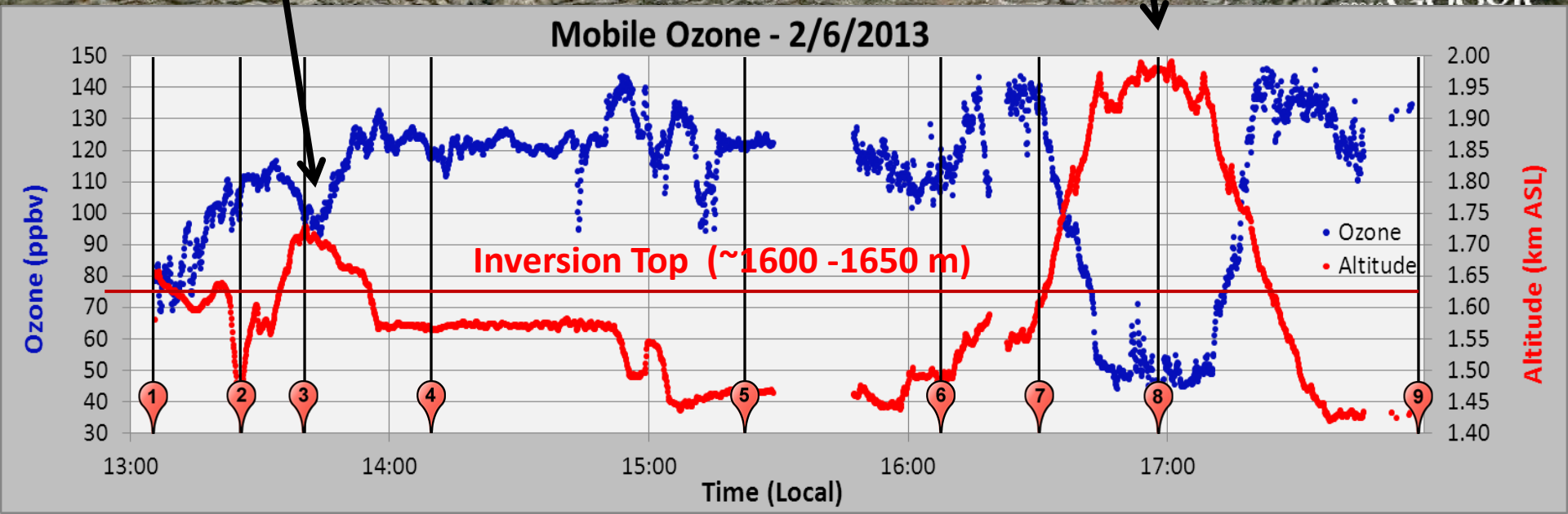


Mobile Ozonesonde Drive Feb 6, 2013



High Point on Hwy 45 (1720 m) Forms Northern Rim Elevation for Ozone in the Basin

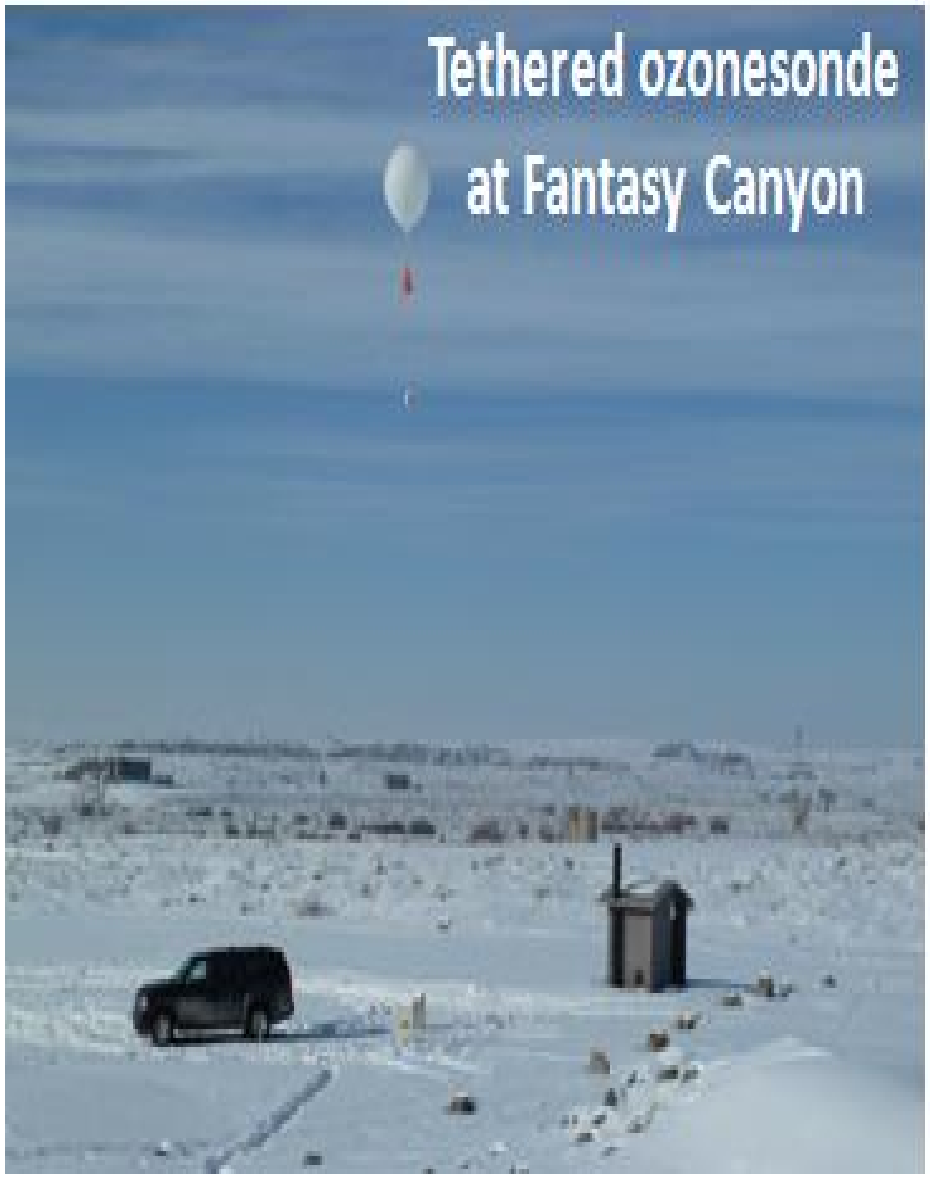
Turn Around Point



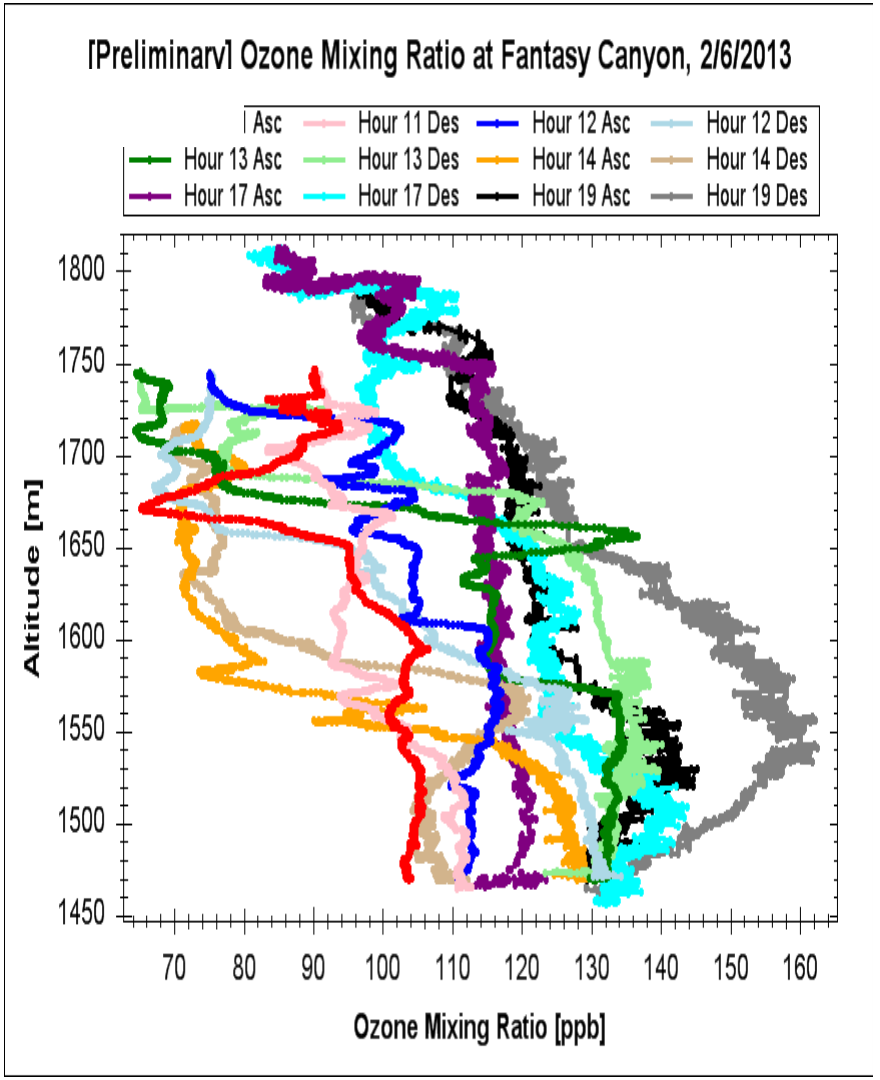
Thank You for Hanging in Until the End!

Thank you for your time and attention.

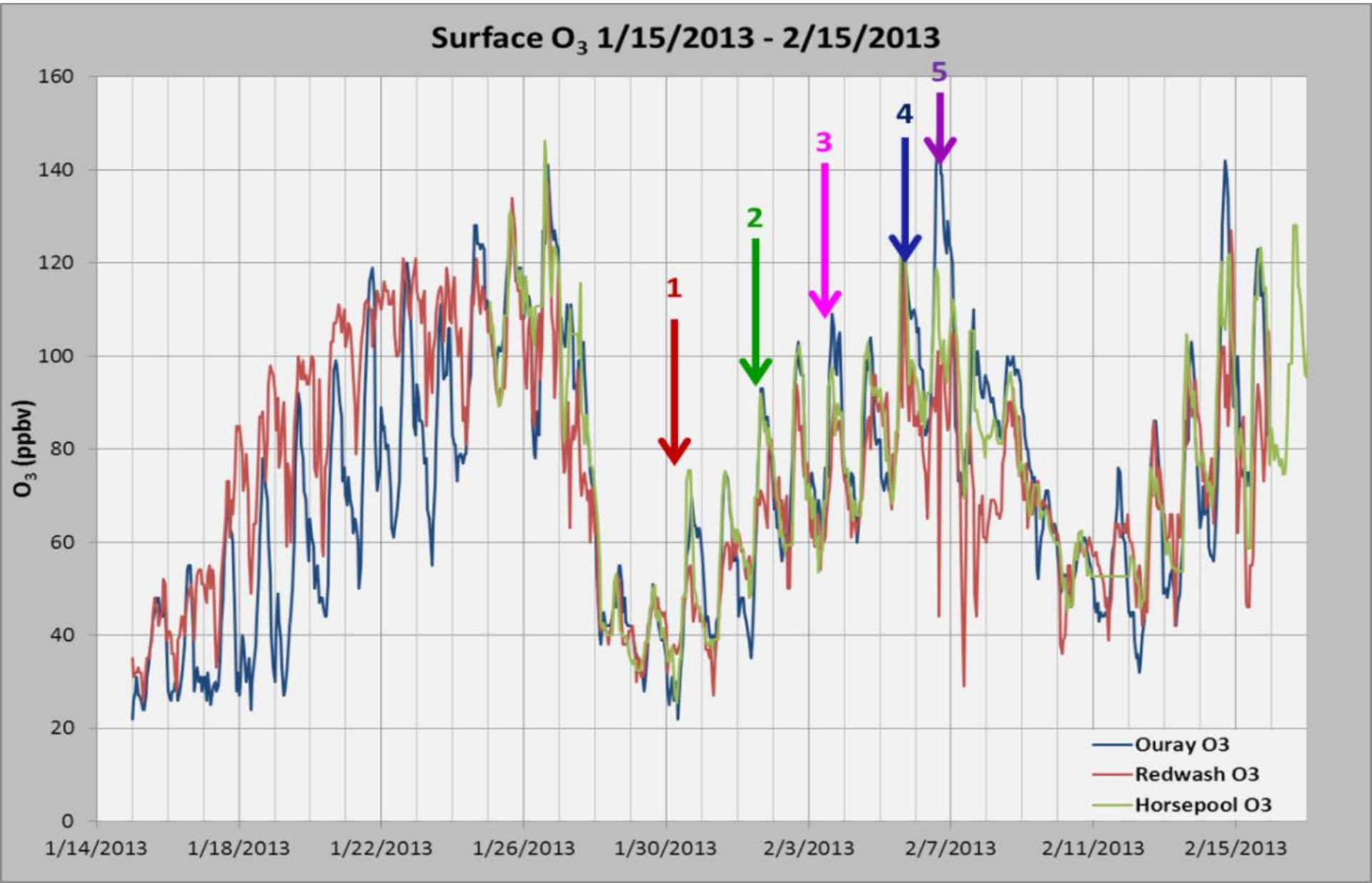
Ozone in the Uintah Basin, Utah: Winter 2012-13



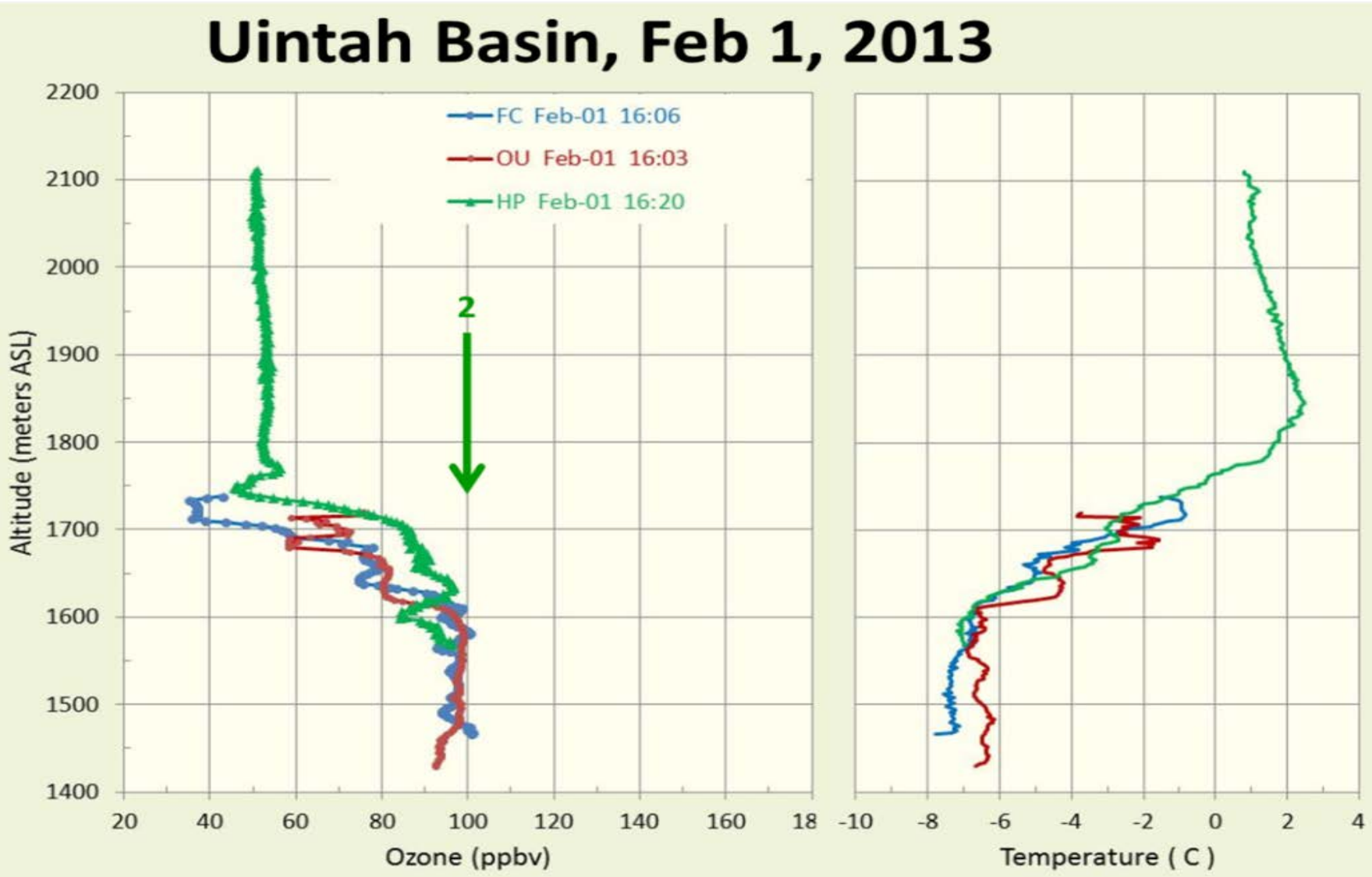
Ozone profiles, Fantasy Canyon, Feb 6, 2013



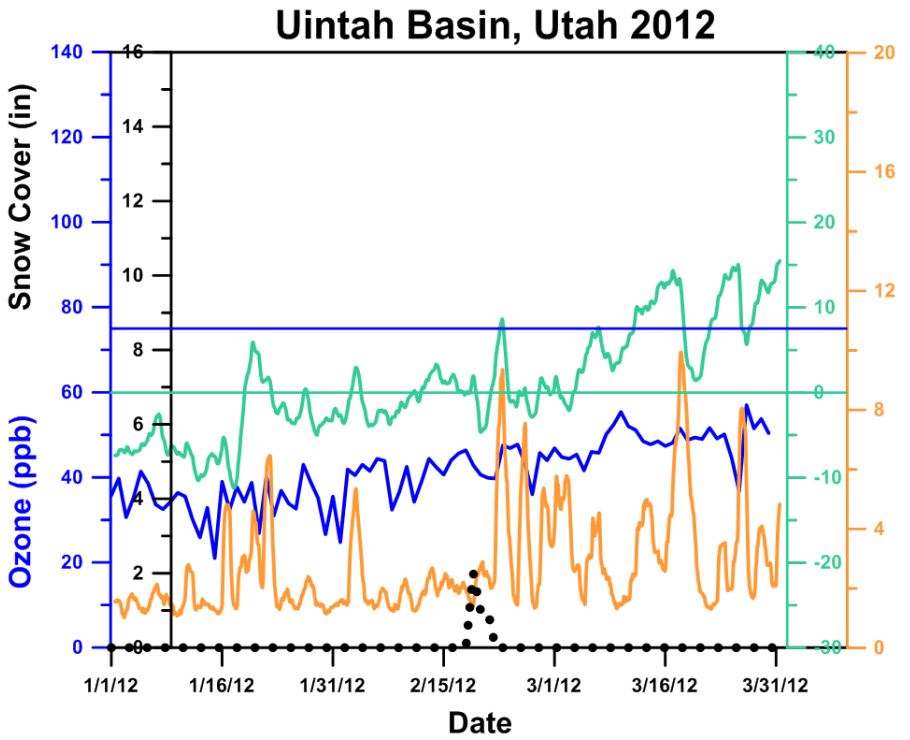
Surface Ozone Concentrations at Three Sites, Uinta Basin, Utah 2013 over Three Ozone Events

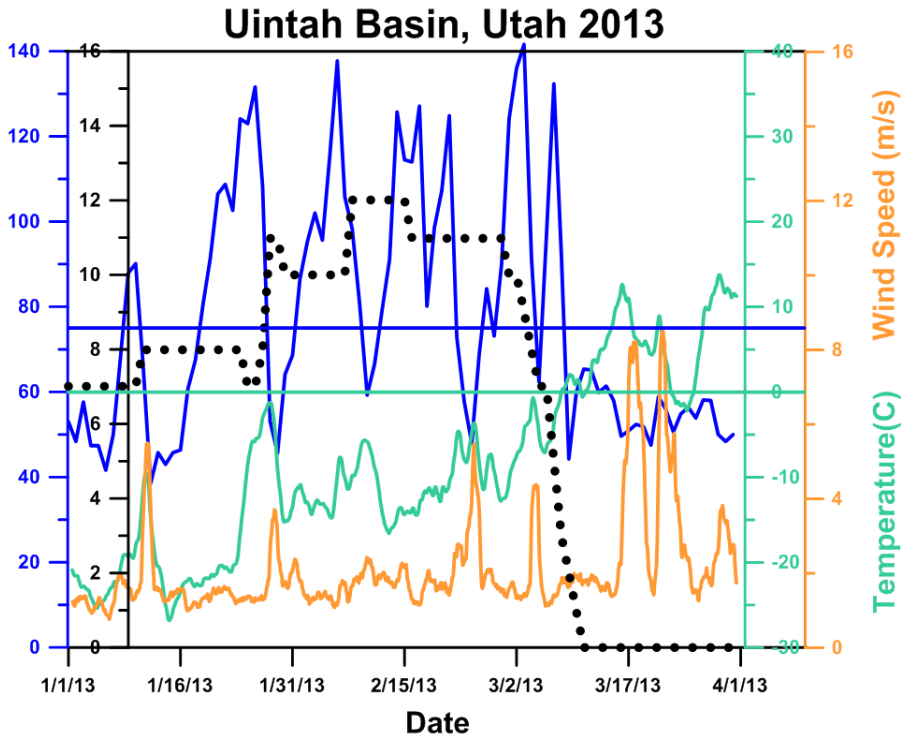


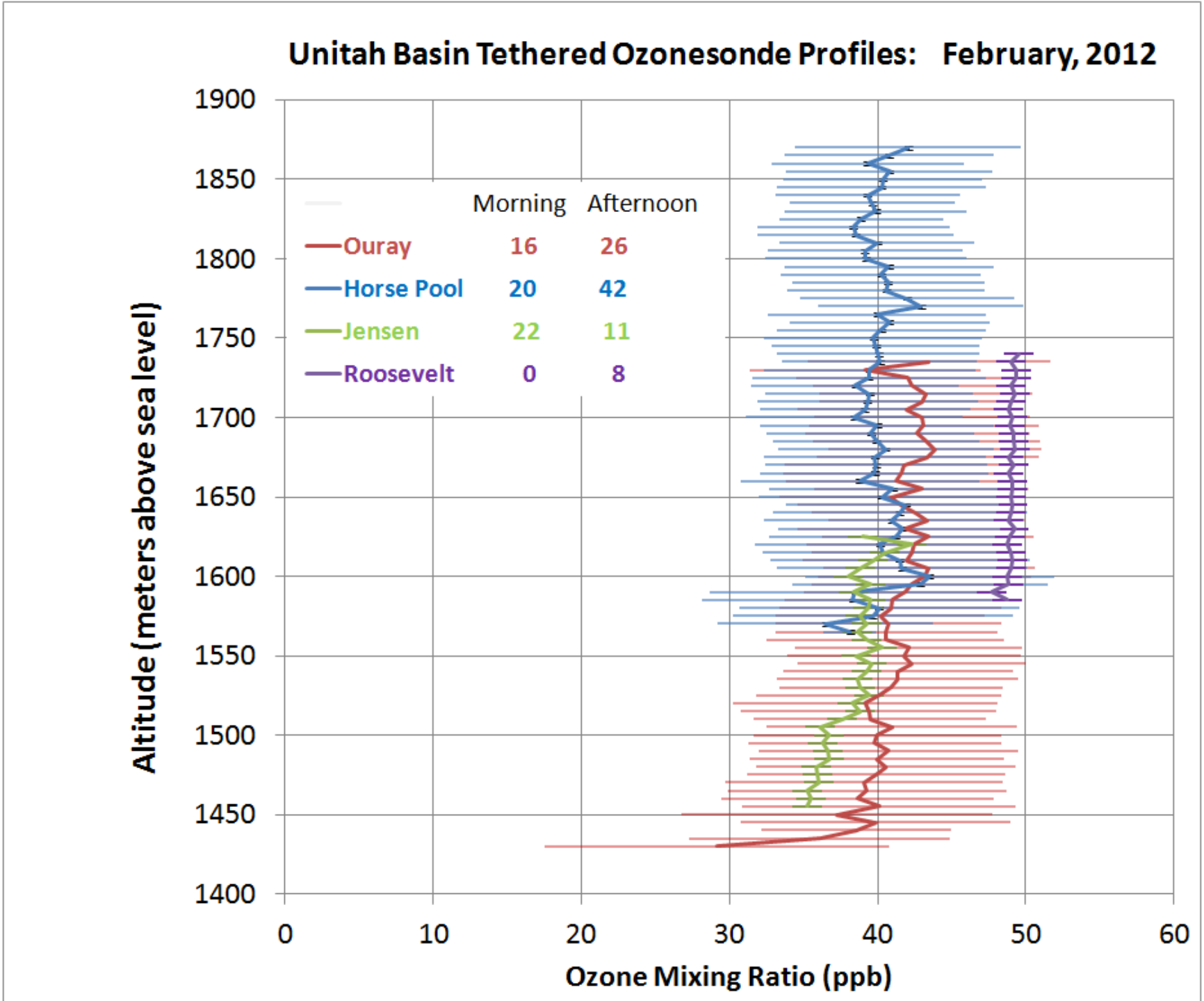
Ozone and Temperature Profiles at Three Sites in the Uintah, Basin



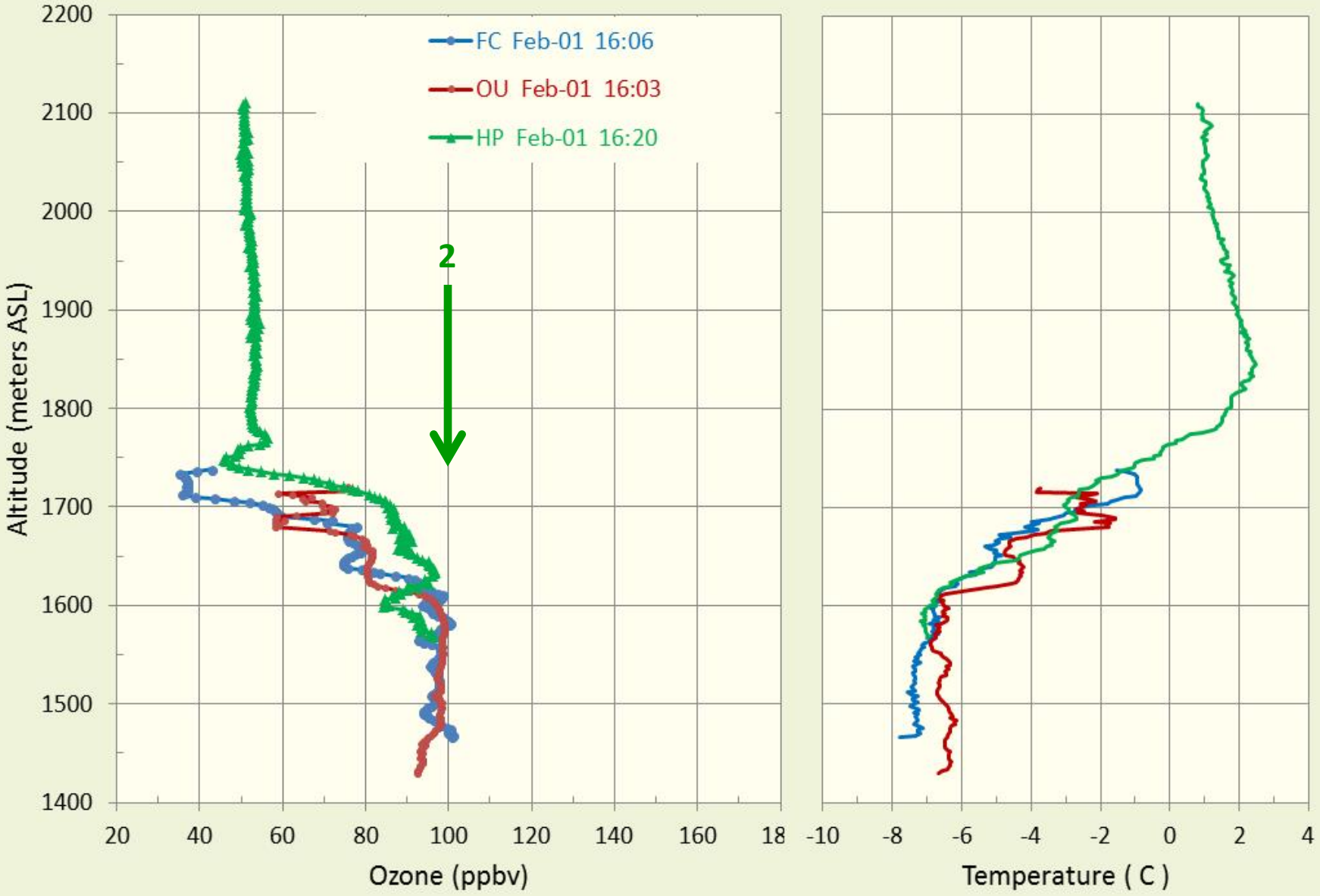
Ozone in the Unita Basin of Utah in Winter 2012 and 2013



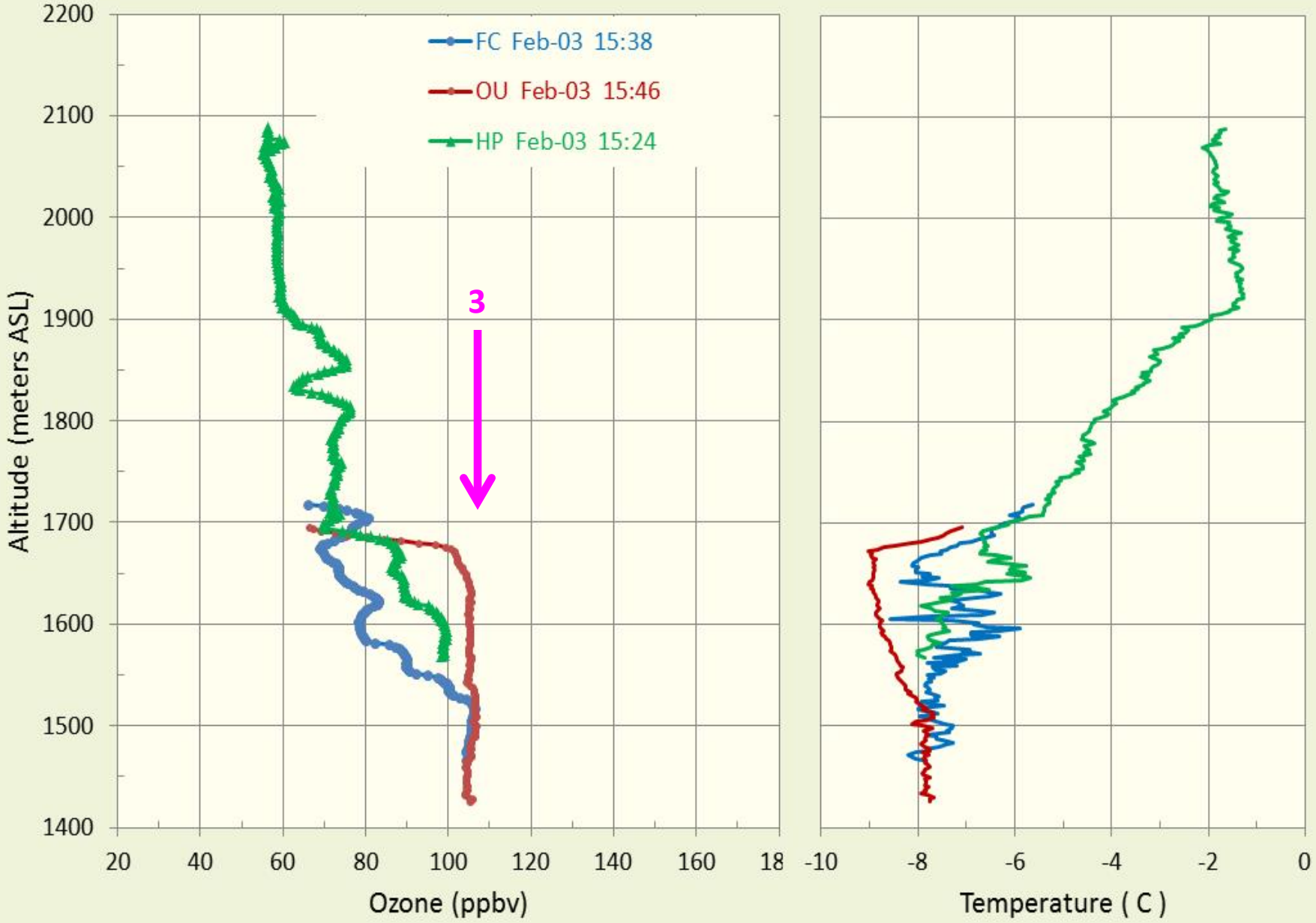



Unitah Basin Tethered Ozonesonde Profiles: February, 2012
Altitude (meters above sea level)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
0
10
20
30
40
50
60
Ozone Mixing Ratio (ppb)
Morning Afternoon
Ouray 16 26
Horse Pool 20 42
Jensen 22 11
Roosevelt 0 8

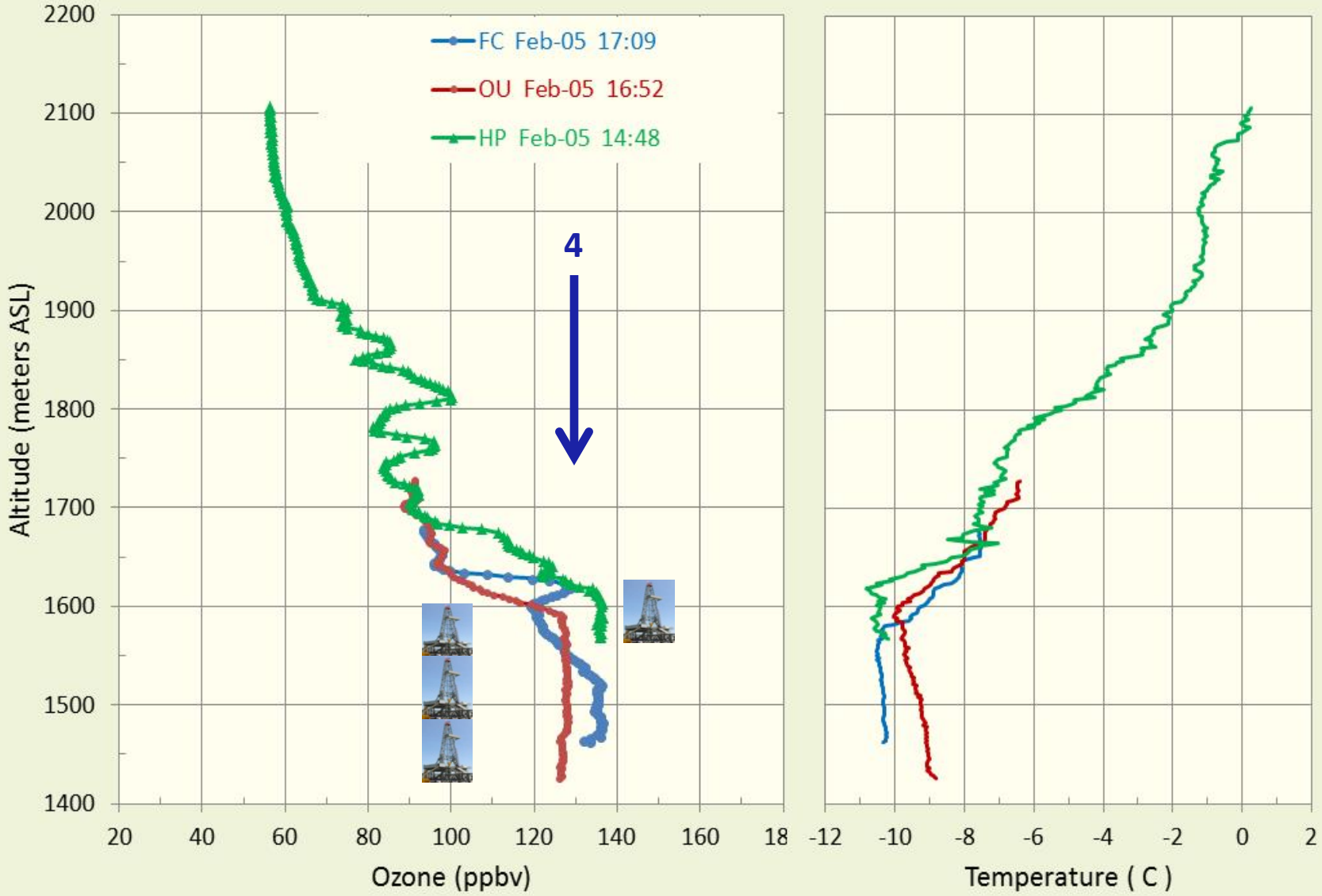
Uintah Basin, Feb 1, 2013



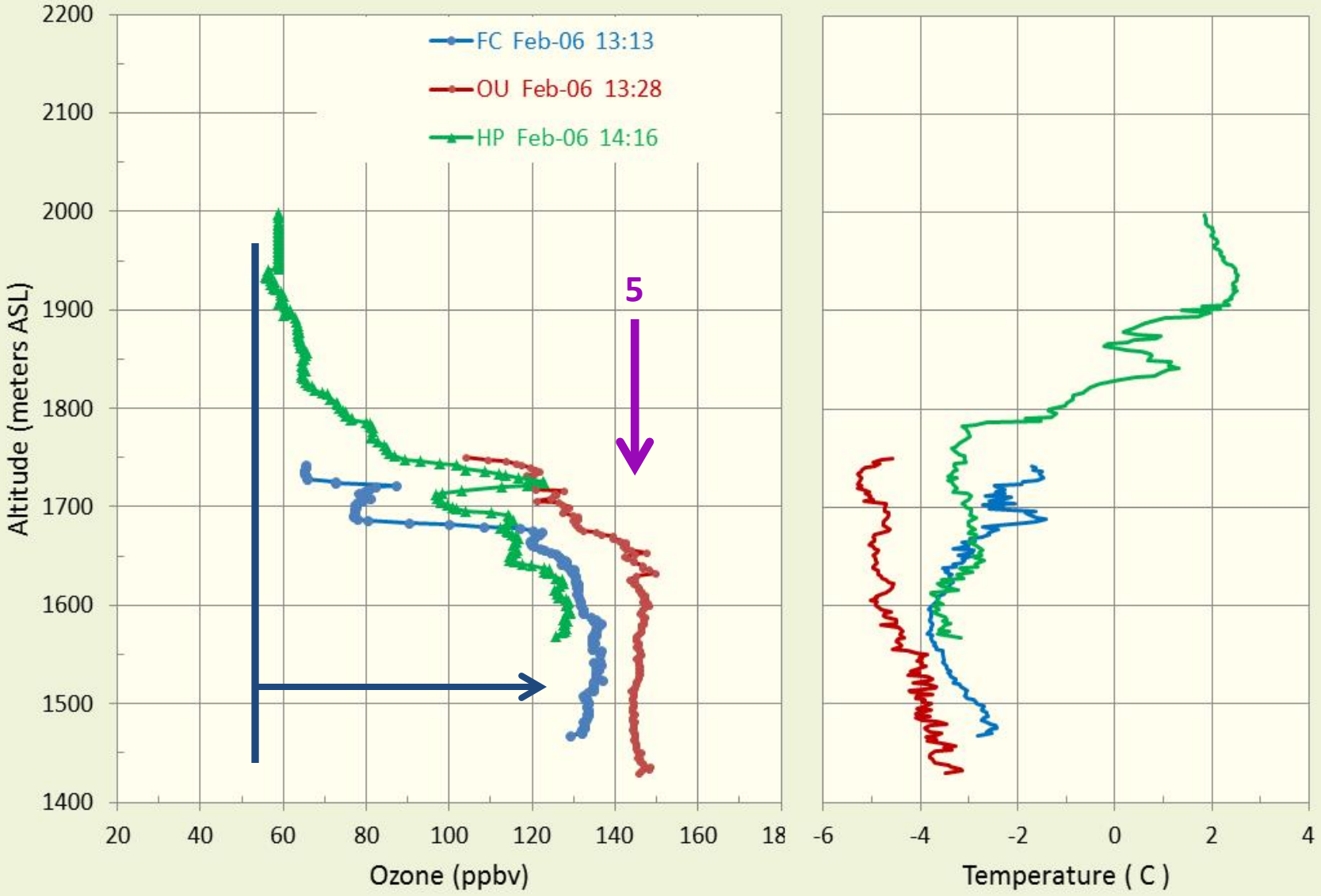
Uintah Basin, Feb 3, 2013



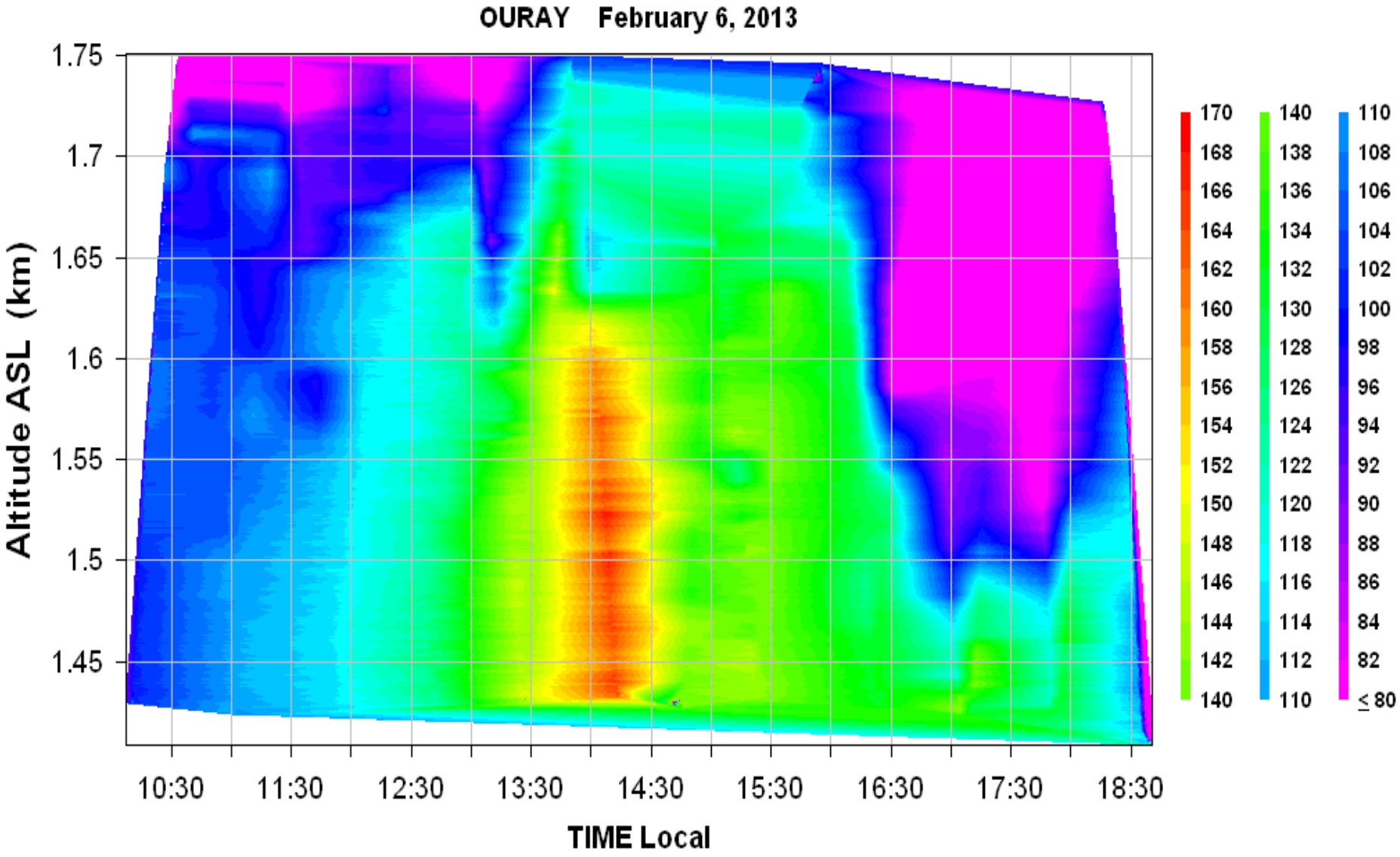
Uintah Basin, Feb 5, 2013

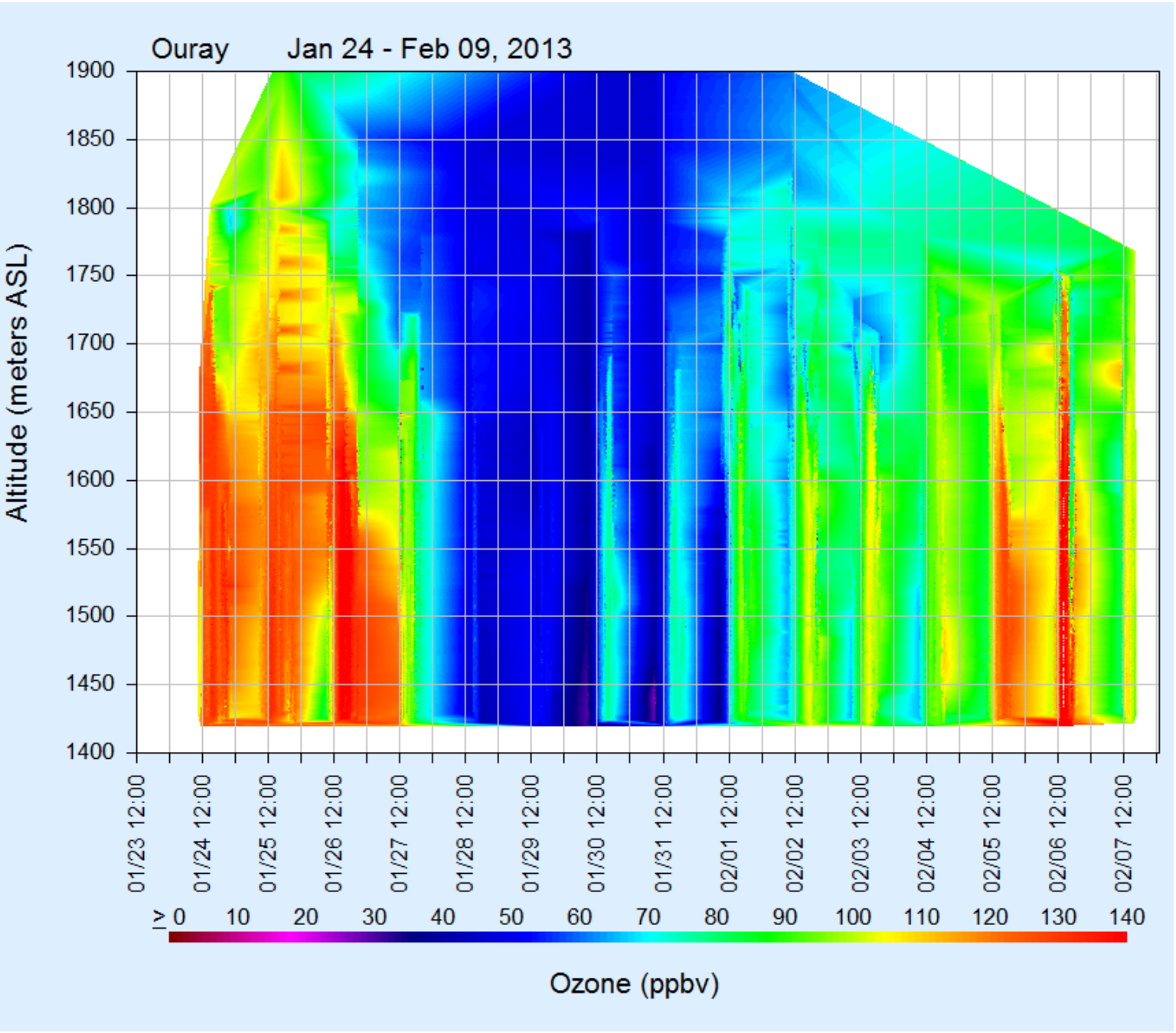


Uintah Basin, Feb 6, 2013



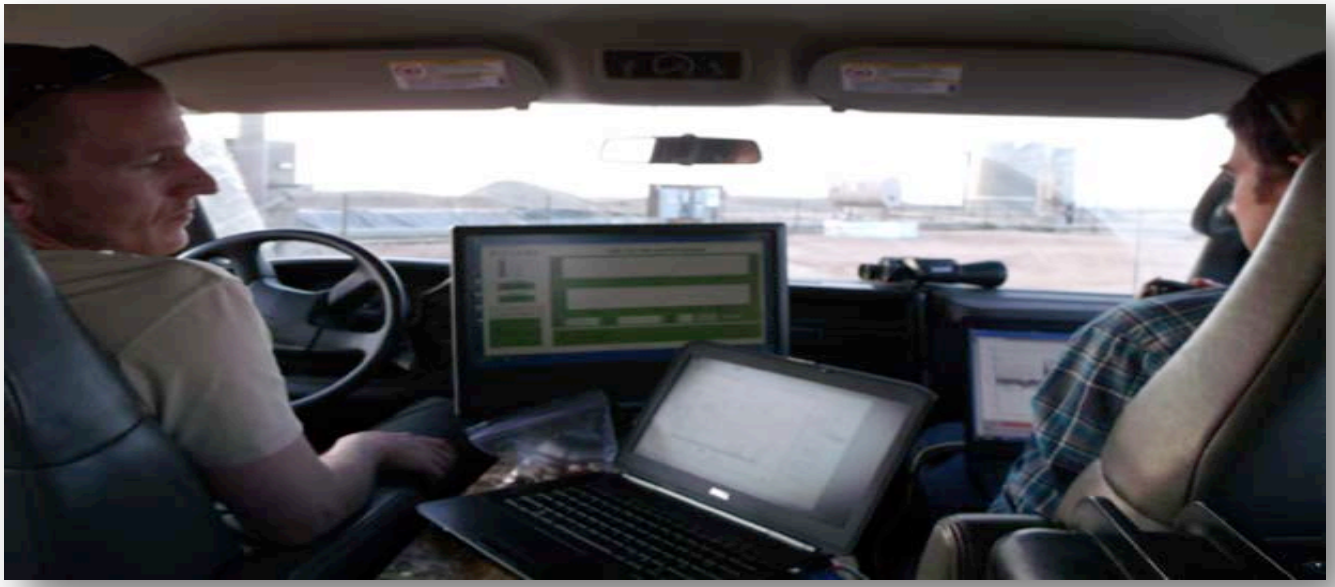
Ozone Time/Height/Concentration Plot, February 6, 2013, Ouray Site




Ouray
Jan 24 - Feb 09, 2013
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
01/23 12:00
01/24 12:00
01/25 12:00
01/26 12:00
01/27 12:00
01/28 12:00
01/29 12:00
01/30 12:00
01/31 12:00
02/01 12:00
02/02 12:00
02/03 12:00
02/04 12:00
02/05 12:00
02/06 12:00
02/07 12:00
< 0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Ozone (ppbv)

Measuring Effluents from Oil and Gas Field: Uintah Basin

Instrumentation and Displays



NO NO_2

flasks

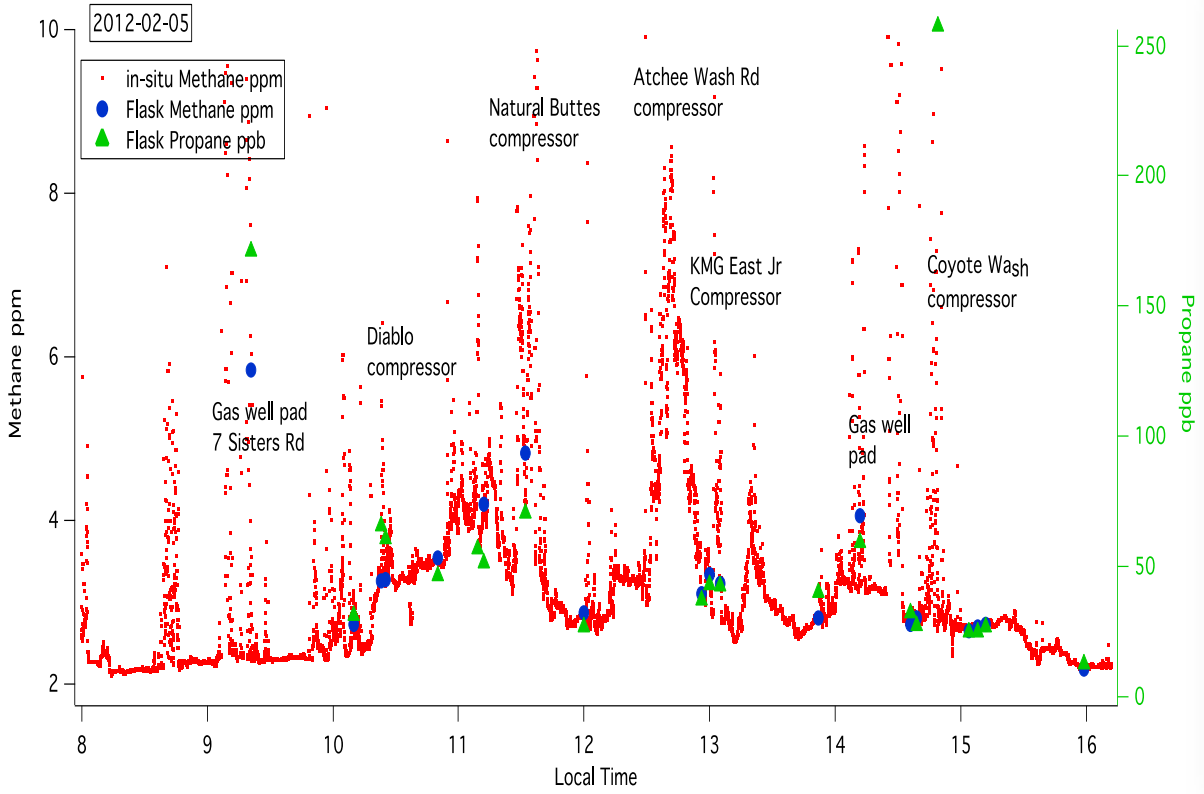
VOCs

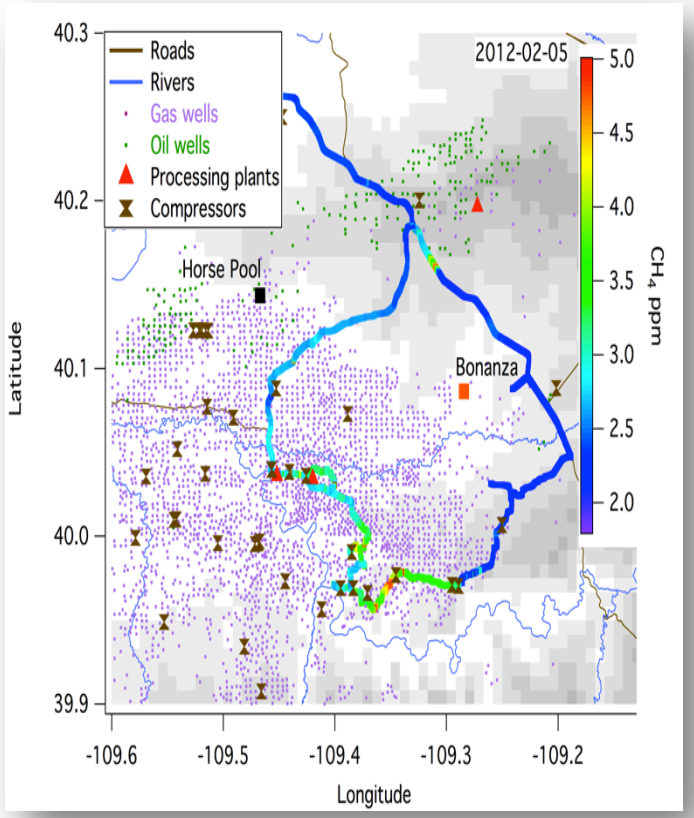
CH_4 CO

CO_2

Example of local sources in the gas field: large fugitive emissions

Compressor Stations in the gas field in the Uintah Basin

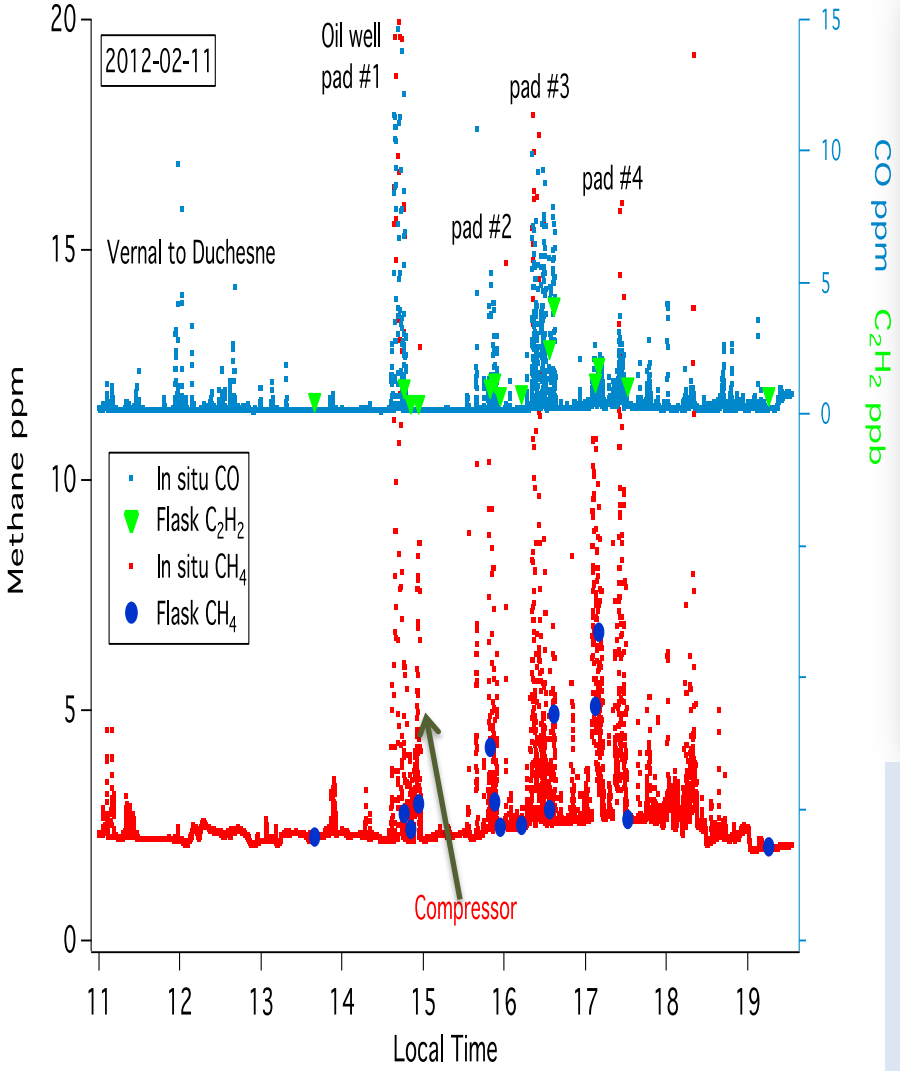


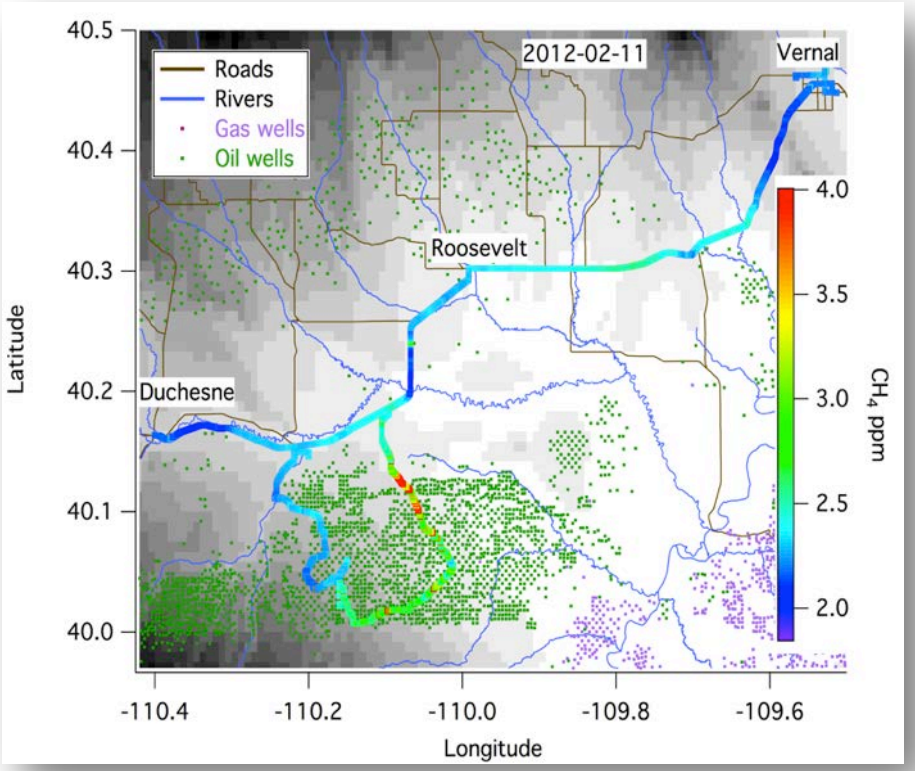


- **Overall methane levels are very high (often > 2,500 ppb) in the gas field especially under stagnant conditions.**
- **Fugitive emissions of natural gas are substantial at several locations in the oil & gas fields such as at compressor stations.**
- **C2+ alkanes are also elevated (> 10s of ppbs) and correlate well with methane.**
- **Levels are higher at night. They most likely are high under inversion conditions.**

Example of local sources in the oil field: Poor engine performance

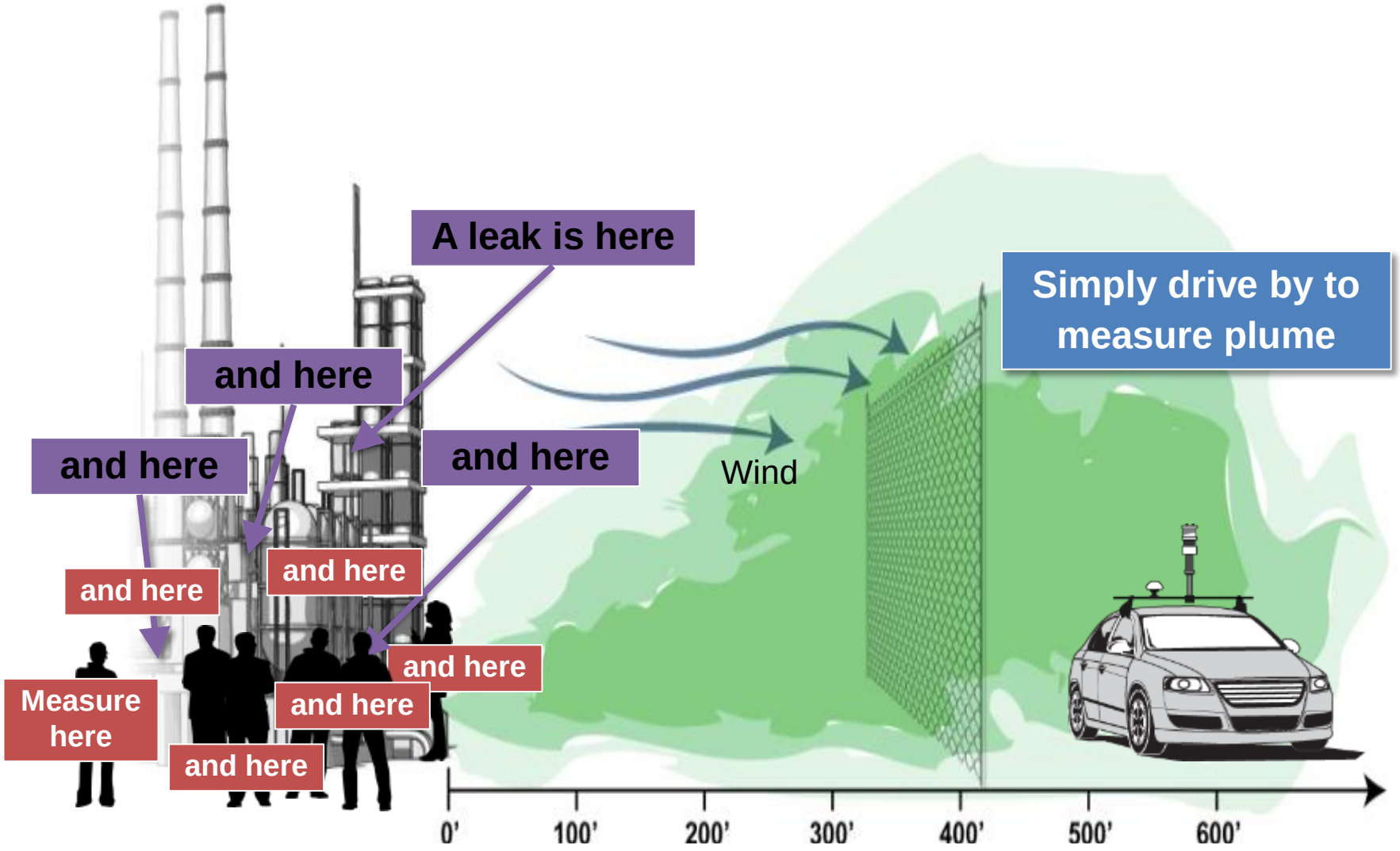
Natural gas powered artificial lifts & their emission products in the Gilsonite Draw field





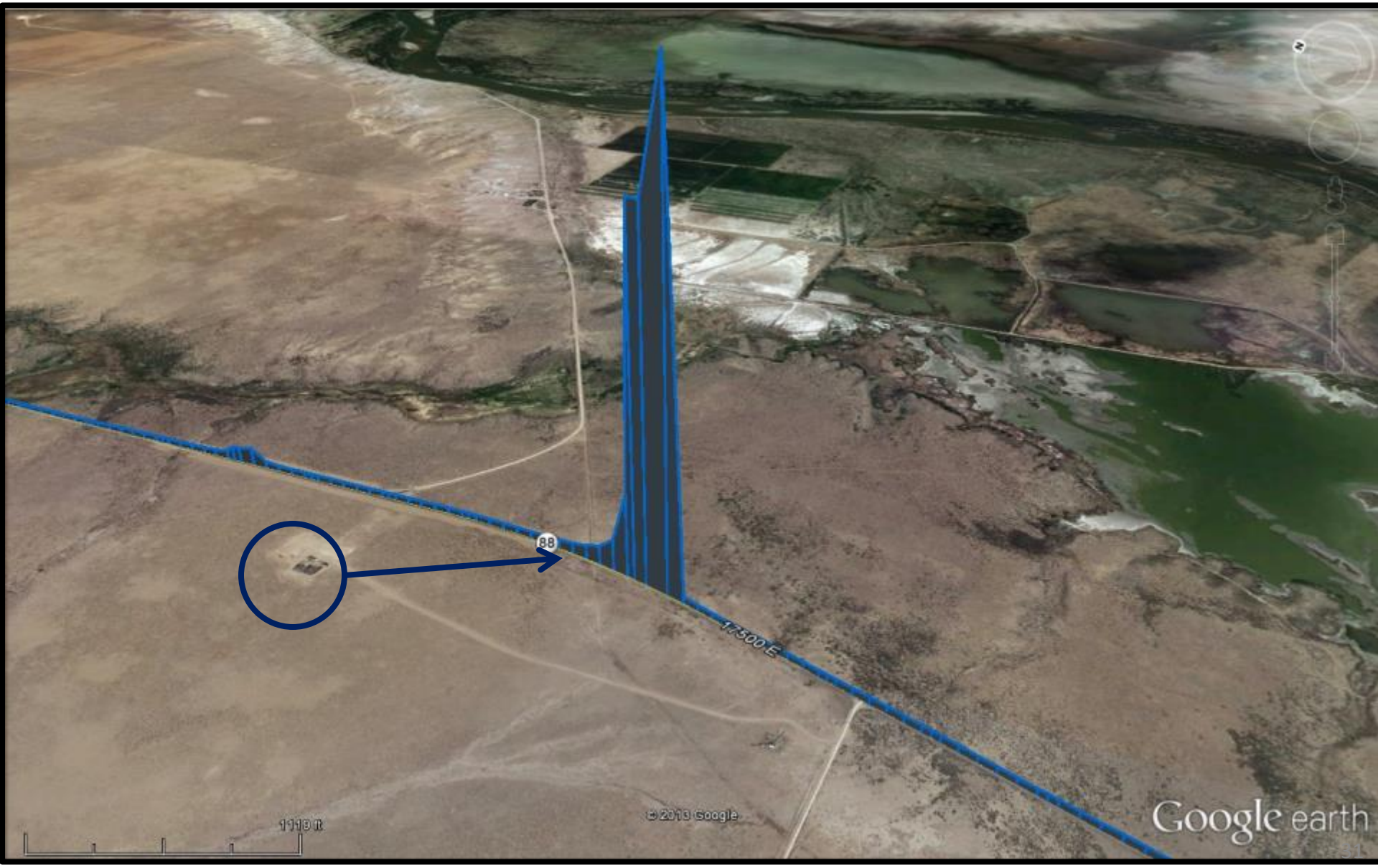
- **Pumpjack engines in the oil field seem to be very dirty.**
- **An appreciable percentage of the natural gas used to power these engines can leak to the atmosphere.**

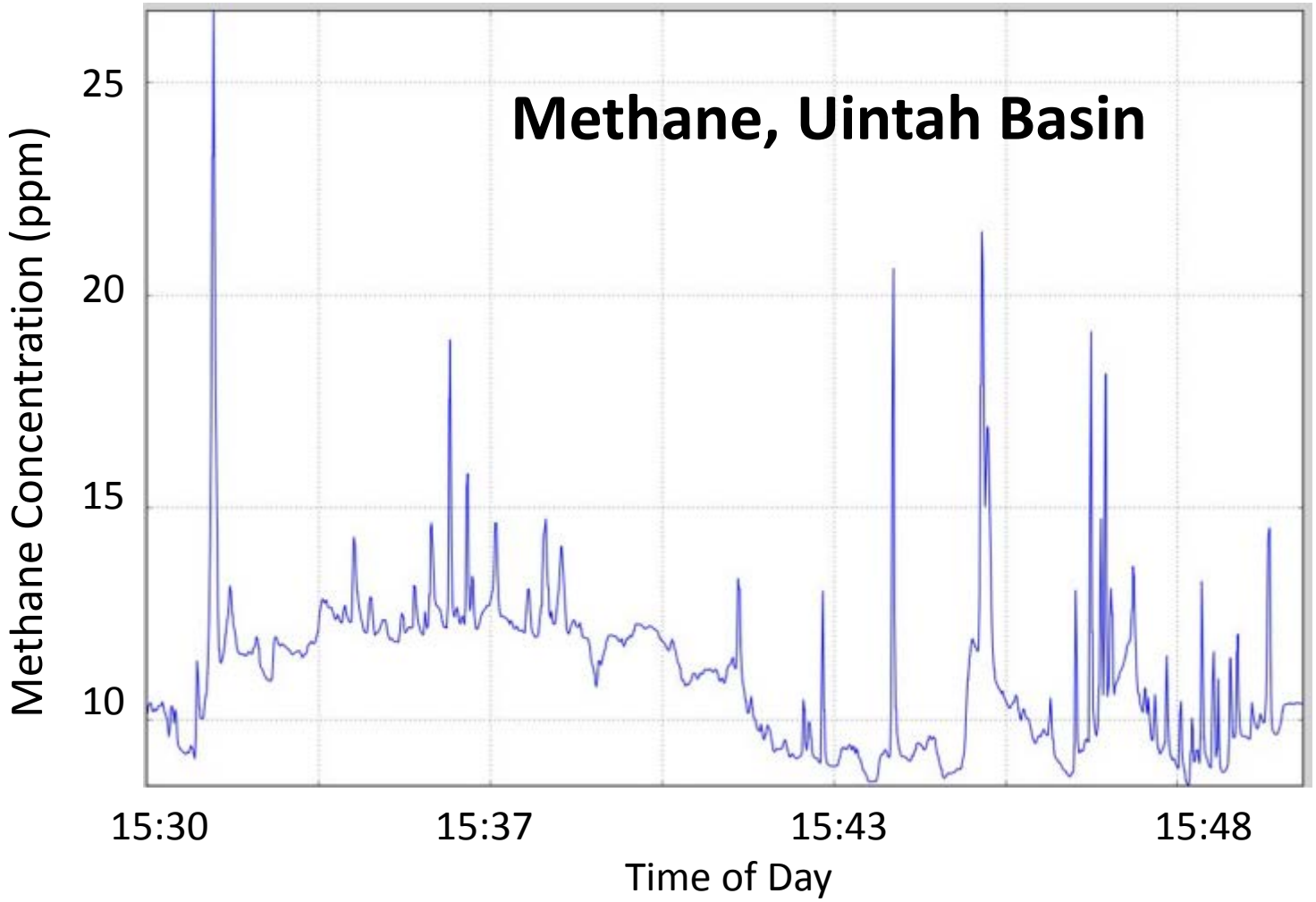
Measuring methane leak rates by driving through the plume



An example of a plume in the Uintah Basin

(Peak of 25 ppm)

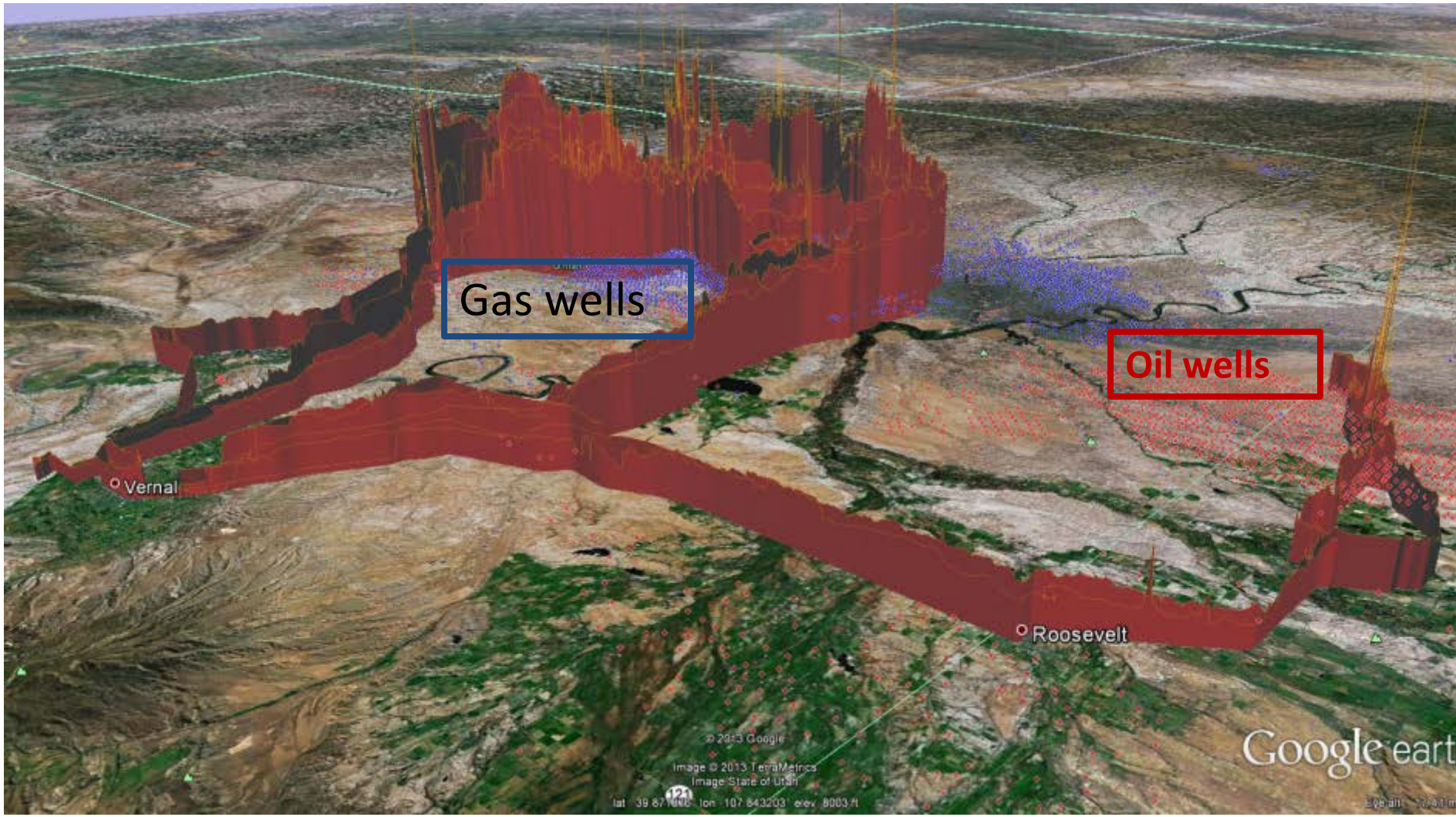




- ~10 miles of road in 15 minutes of driving.
- 23 leaks greater than 10 ppm, 34 leaks greater than 50 ppb (3 per mile traveled)

Methane concentrations in the Uintah Basin

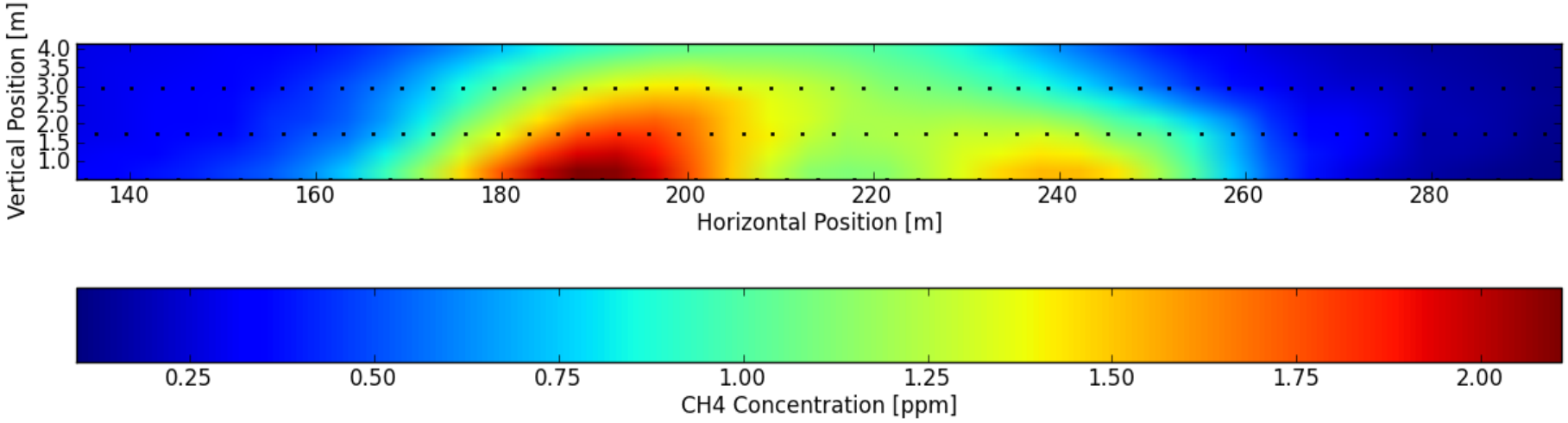
(maximum concentrations >25,000ppb)



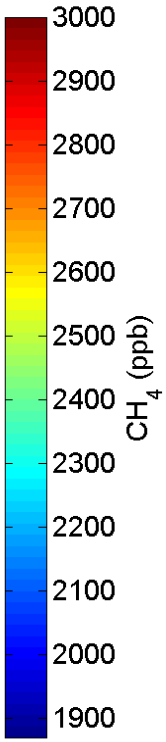
Methane concentrations 3x-12x above background levels over 100's of square mile from natural gas extraction. Two days.

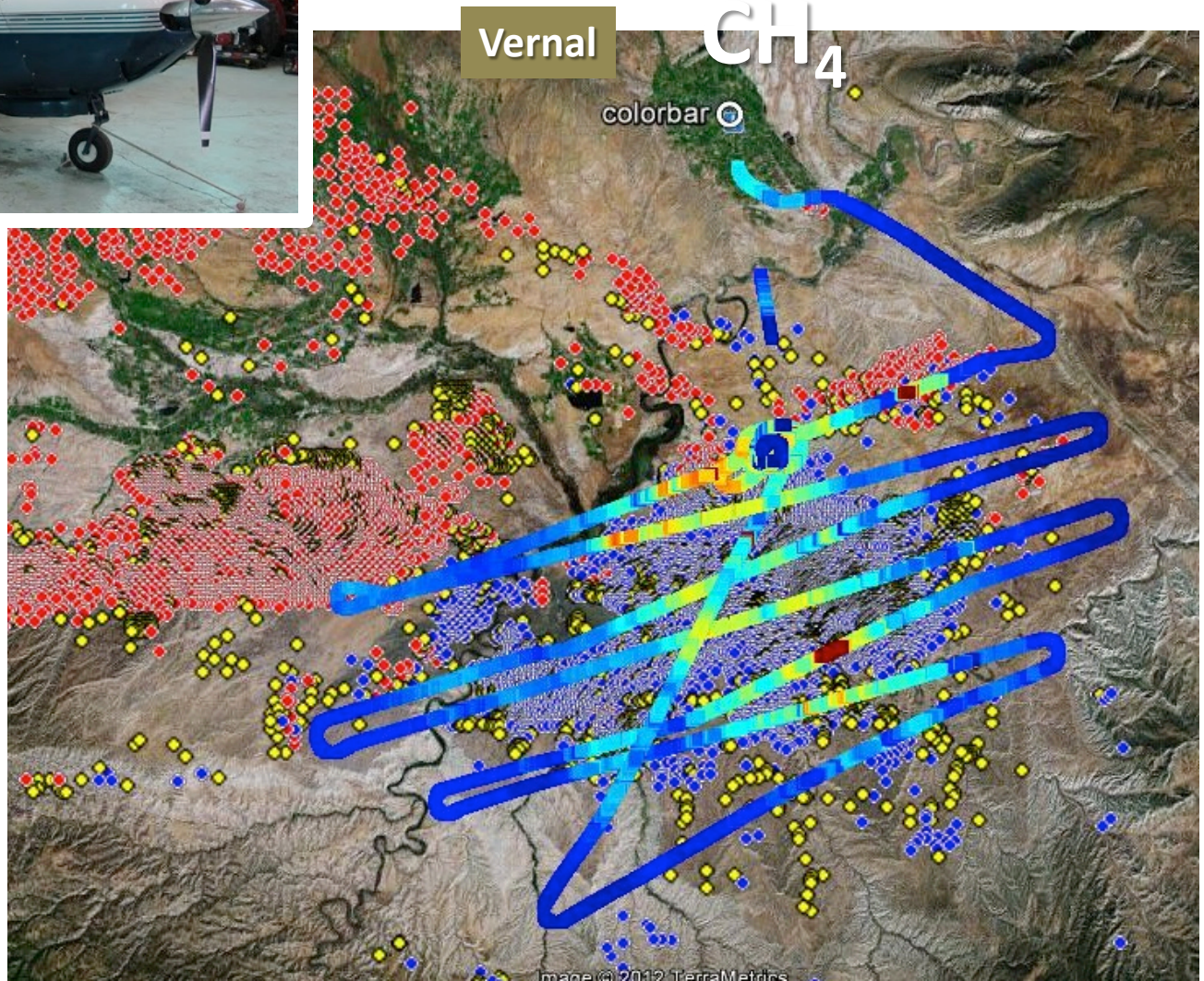
Uintah Basin

CH4 Plume Observed 4 Feb 2013 16:27	
Car Speed	18.7 m/s
Lateral Wind Speed	0.54 m/s
Flux Estimate	**>0.34 L/s**

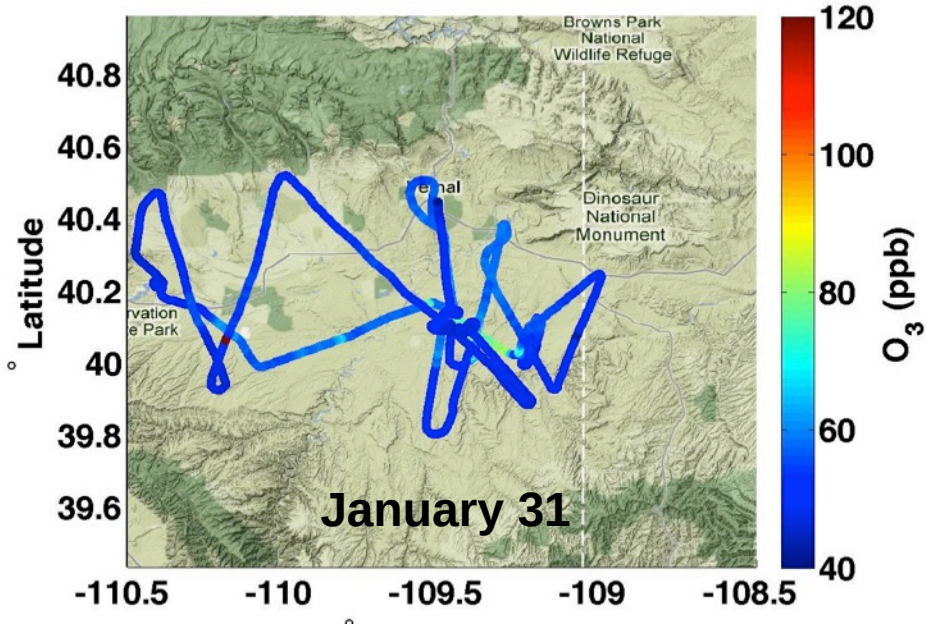


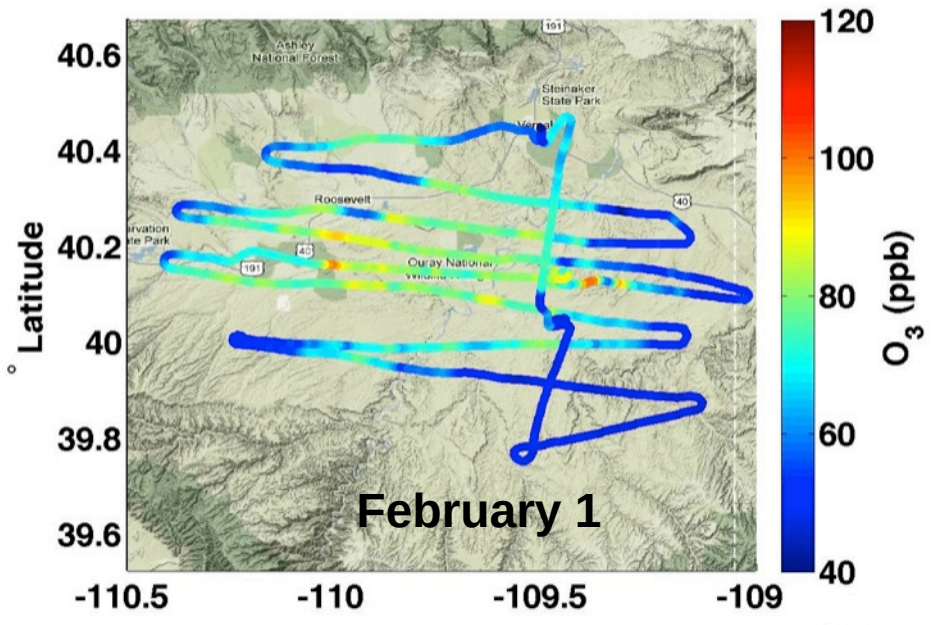
Feb 7, 2012: Low Wind Conditions

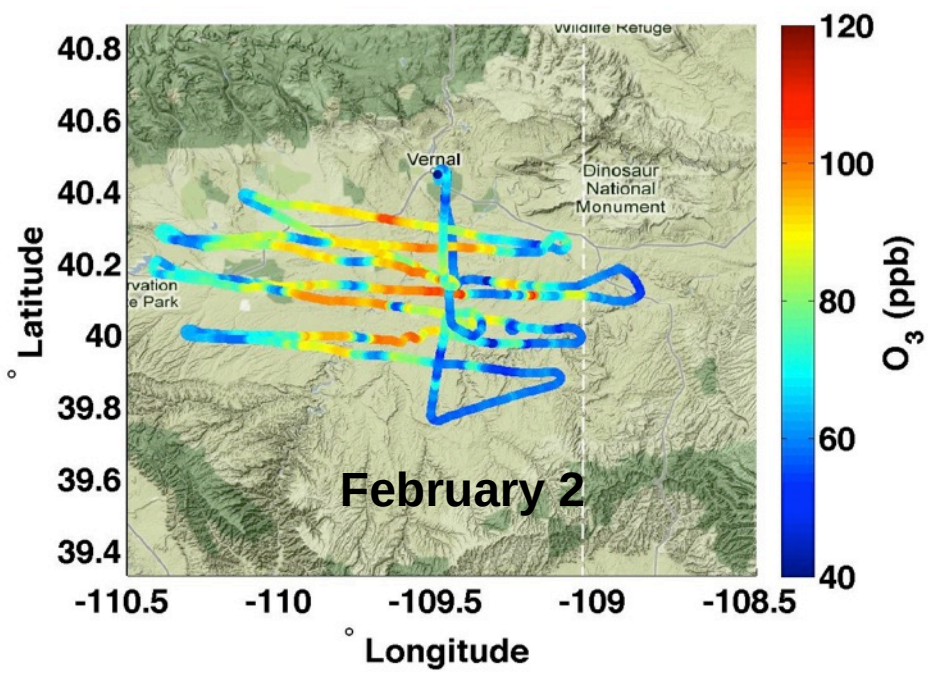


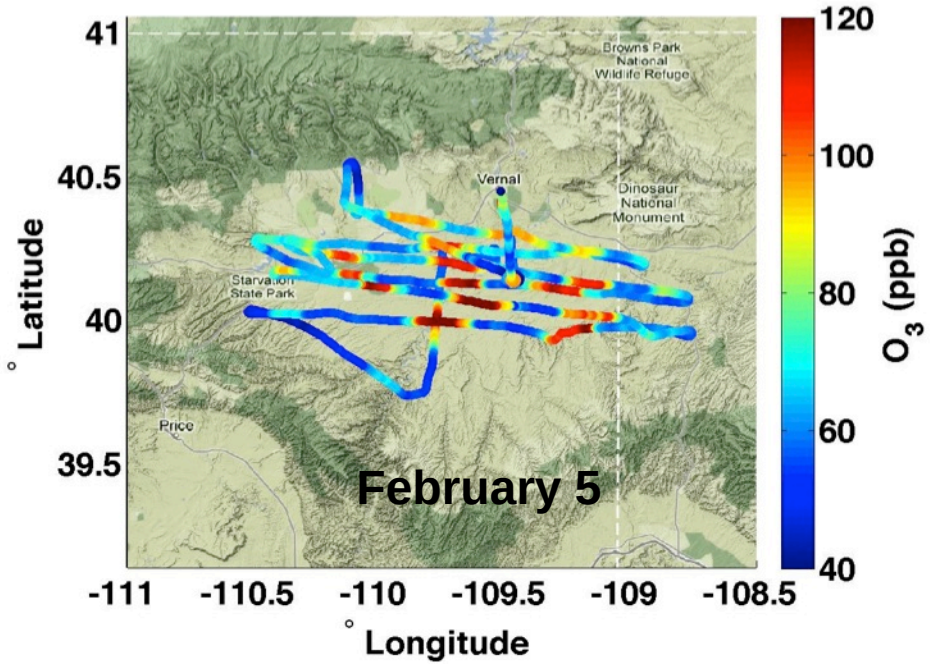


Ozone across the basin on Jan. 31, Feb. 1, 2, and 5

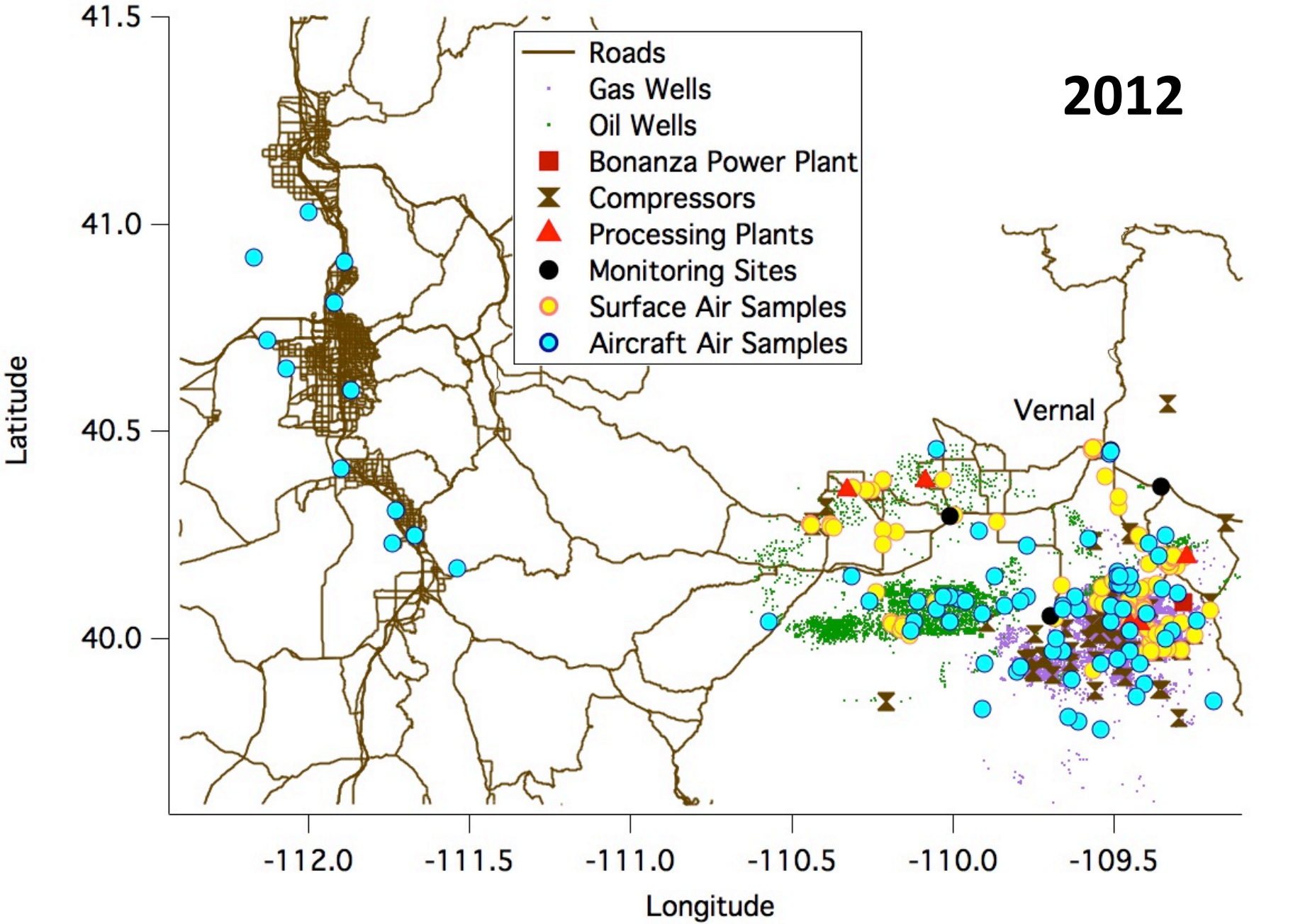




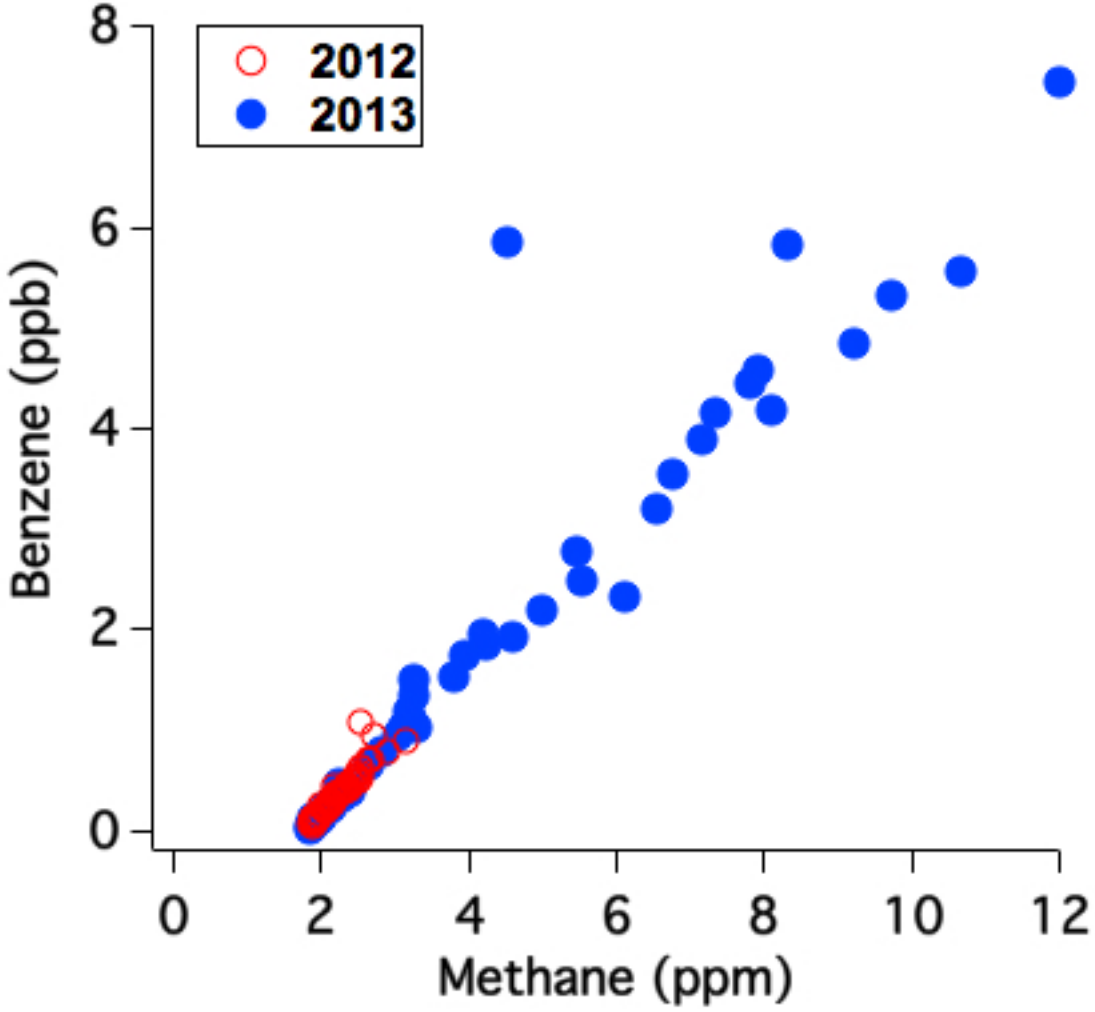




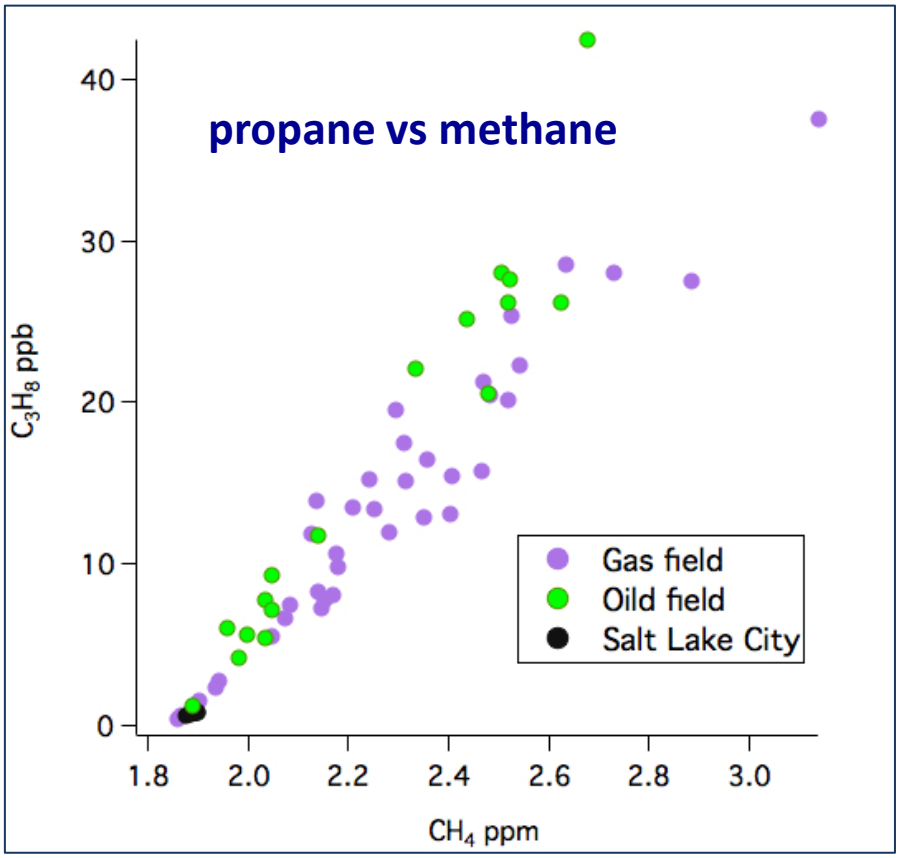
Map of flask samples location in NE Utah

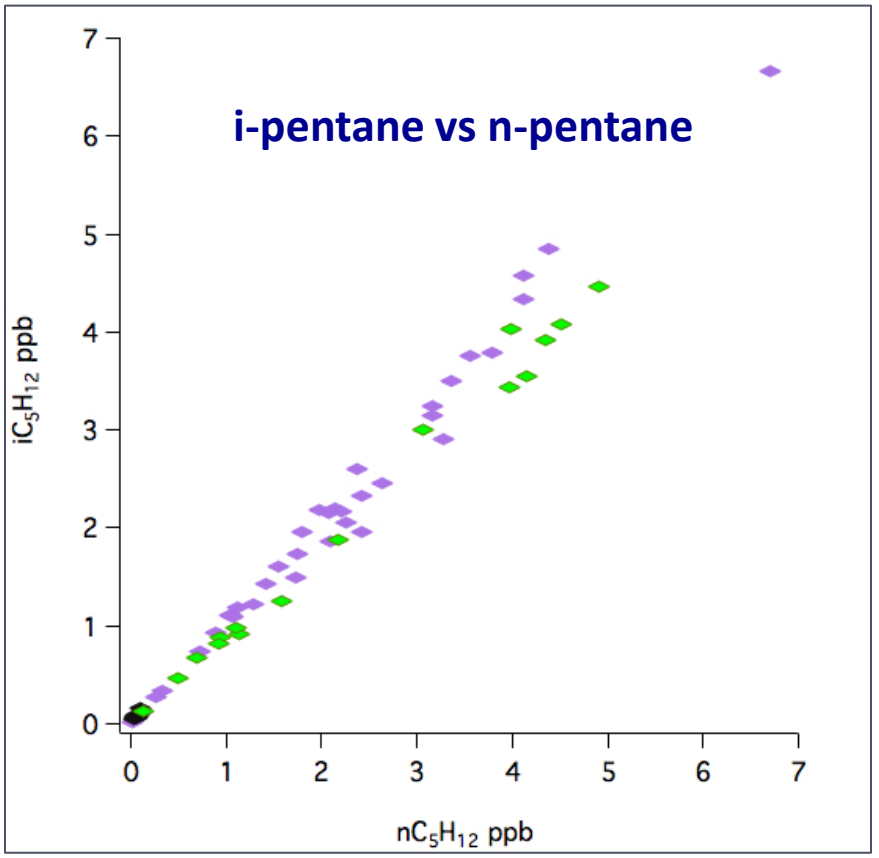


Airborne flask samples, Uintah Basin, Above and below Inversion 2012 and 2013



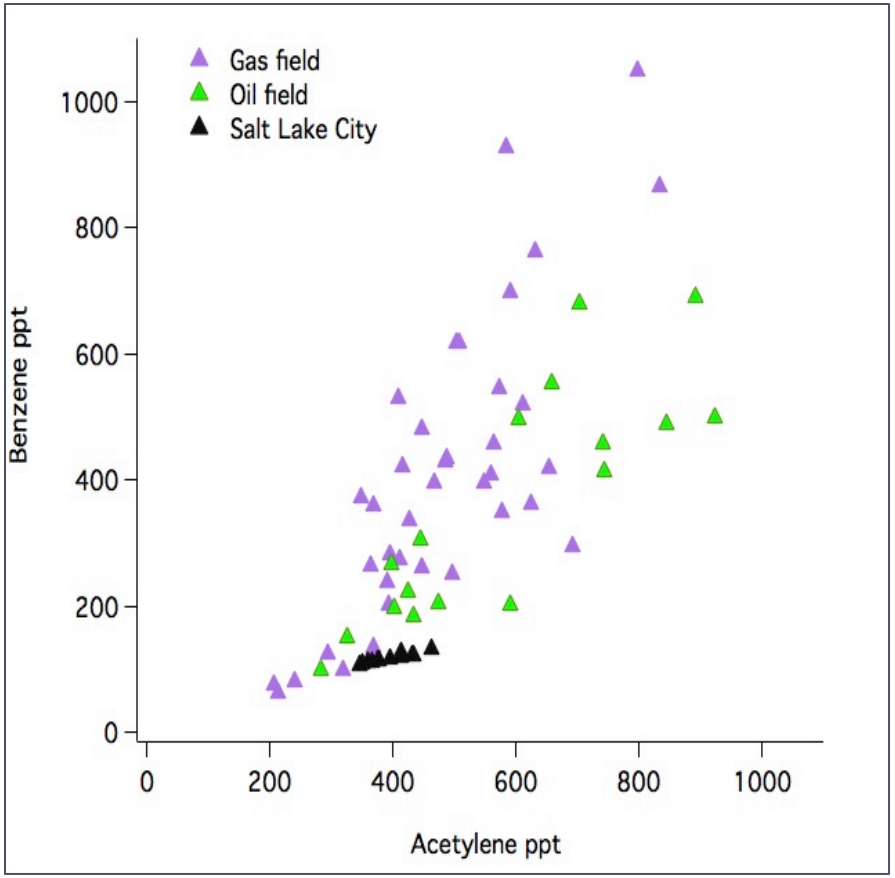
Very low alkane levels in SLC

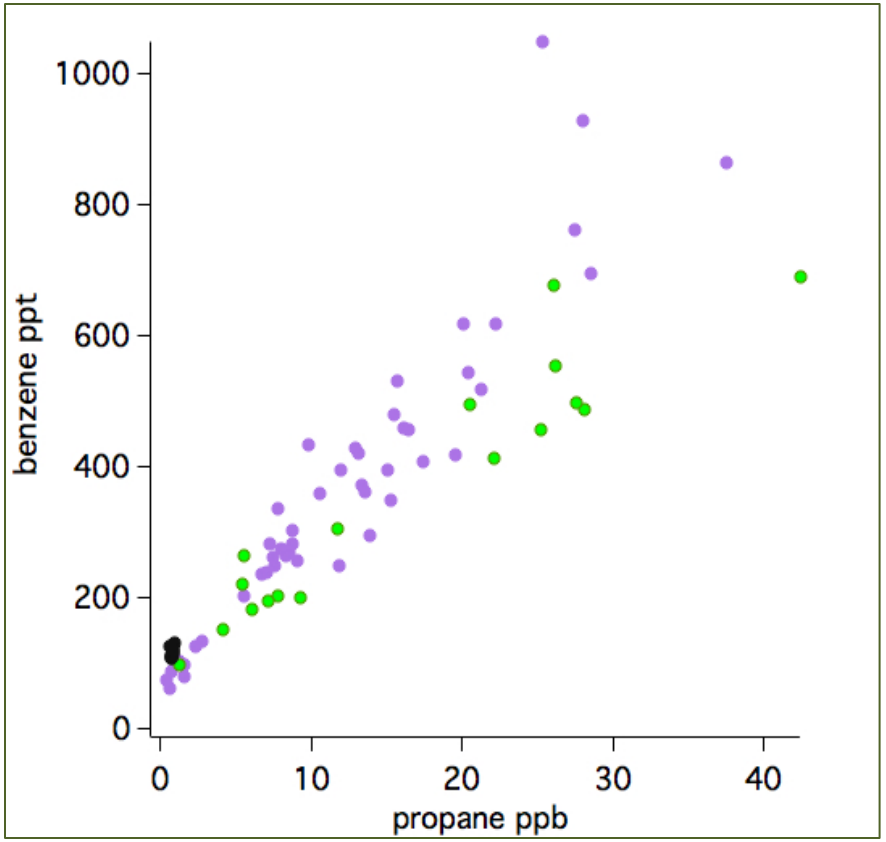




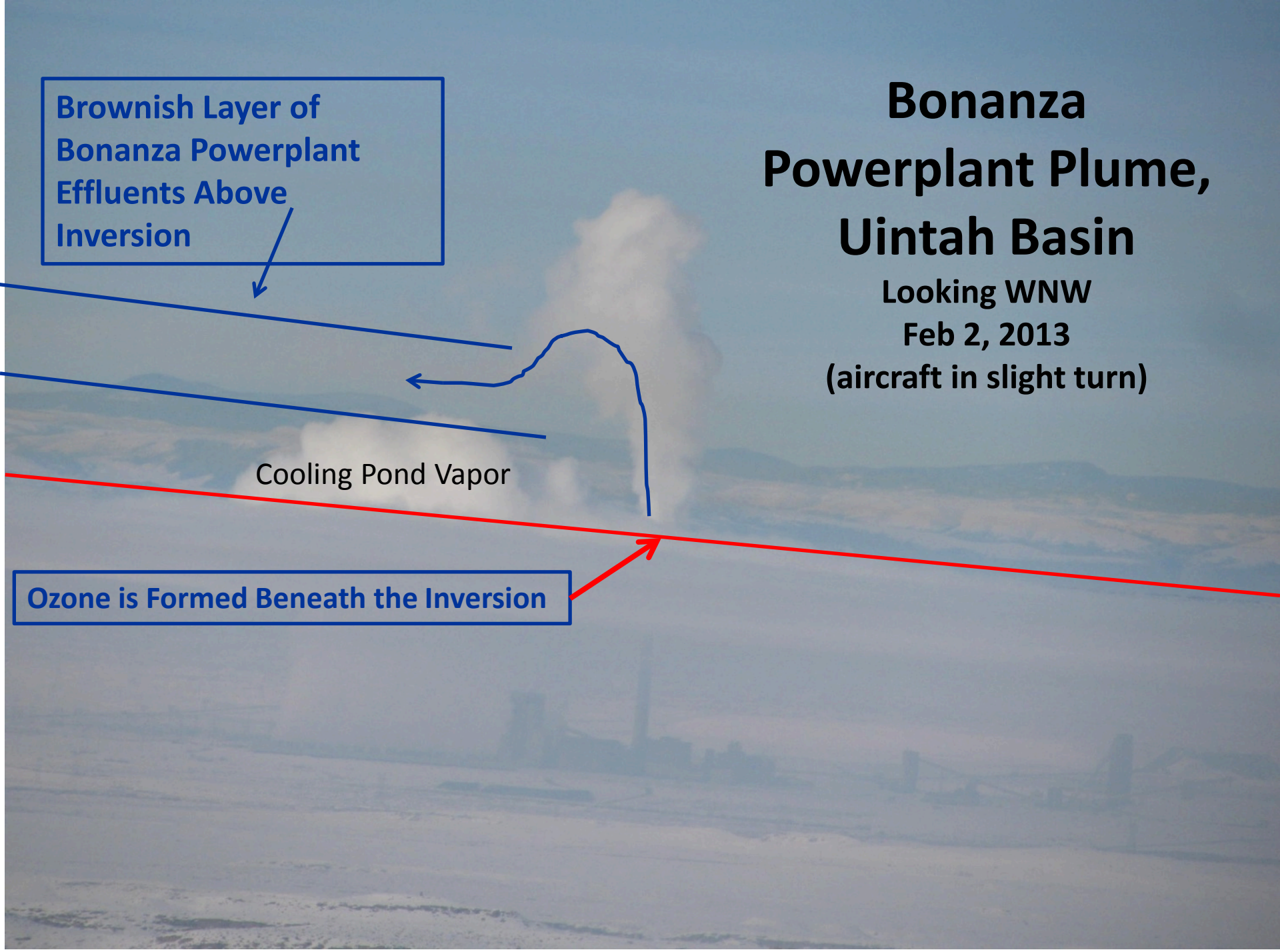
- **Alkanes such as methane and propane are very good markers of natural gas.**
- **High levels of alkanes were measured in the Uintah Basin, over both the oil (green) and gas (purple) fields**
- **i-pentane/n-pentane ratio is equal to 1 (typically close to 2 in urban areas).**

Vehicle Exhaust Signature in SLC are Not Seen in Uintah Basin



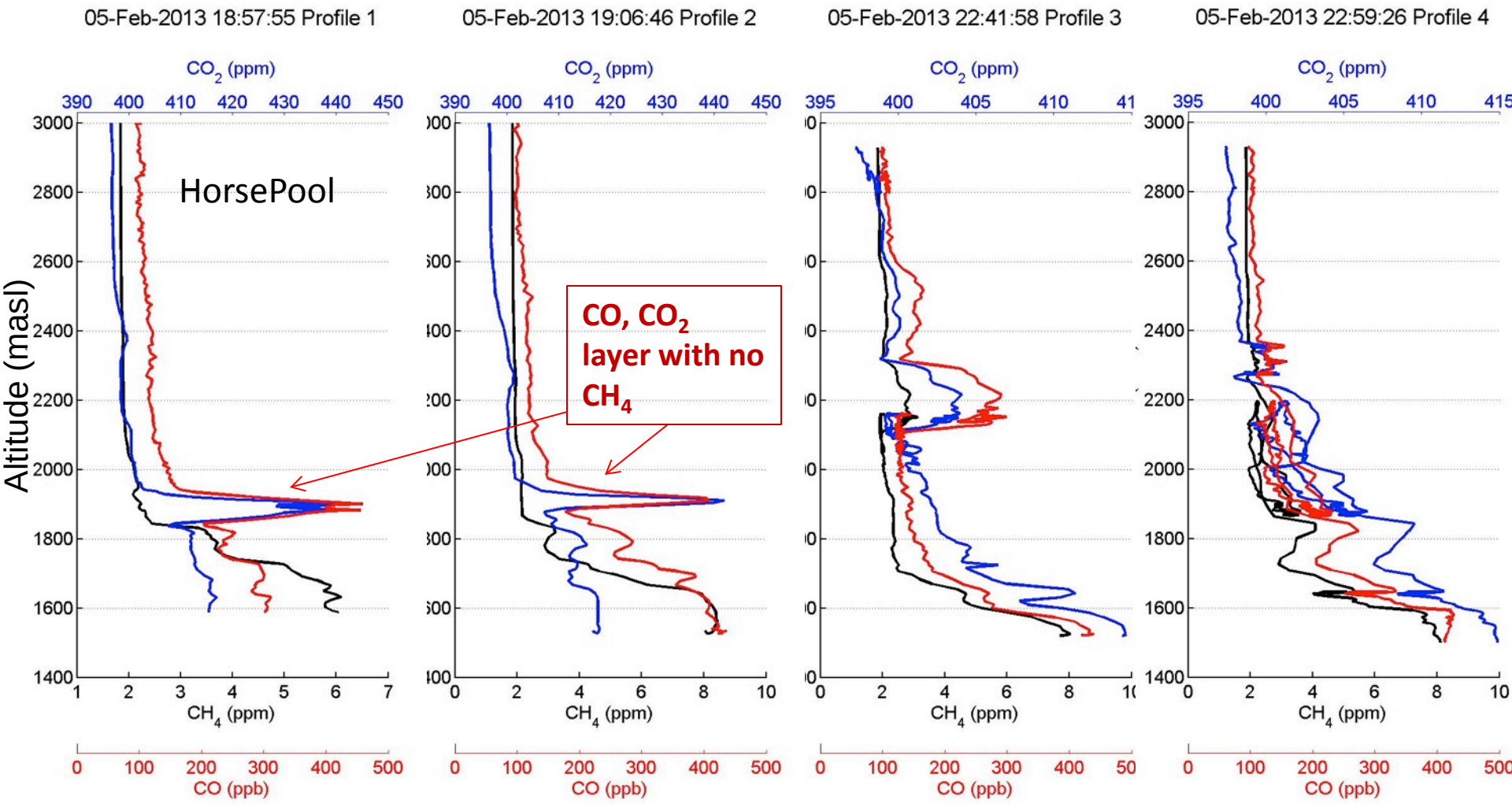


- **Benzene and acetylene are used as markers of vehicle emissions.**
- **The benzene-to-acetylene ratio in Salt Lake City is typical of urban regions.**
- **Air samples collected in the Uintah Basin show much higher levels of benzene than the Salt Lake City.**



Bonanza Powerplant Plume, Uintah Basin

Looking WNW
Feb 2, 2013
(aircraft in slight turn)

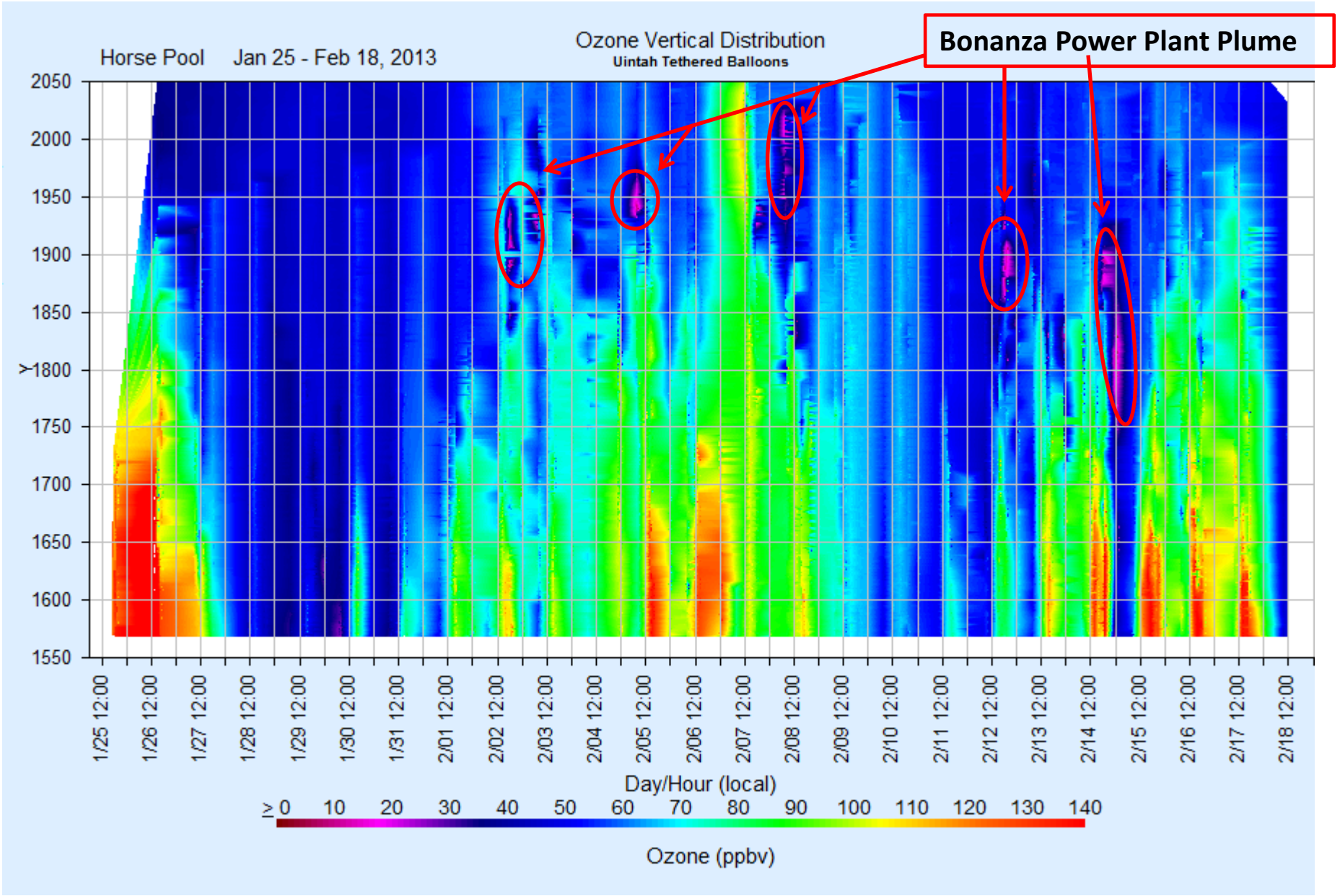


Power plant layer above inversion apparent in Profiles 1 & 2 in CO, CO_2

Plume between 1800 and 2000 masl has ratio of CO:CO2 ~6-8 ppb

Layer at higher altitudes (>2000 masl) has more CO, esp. in western side of basin.

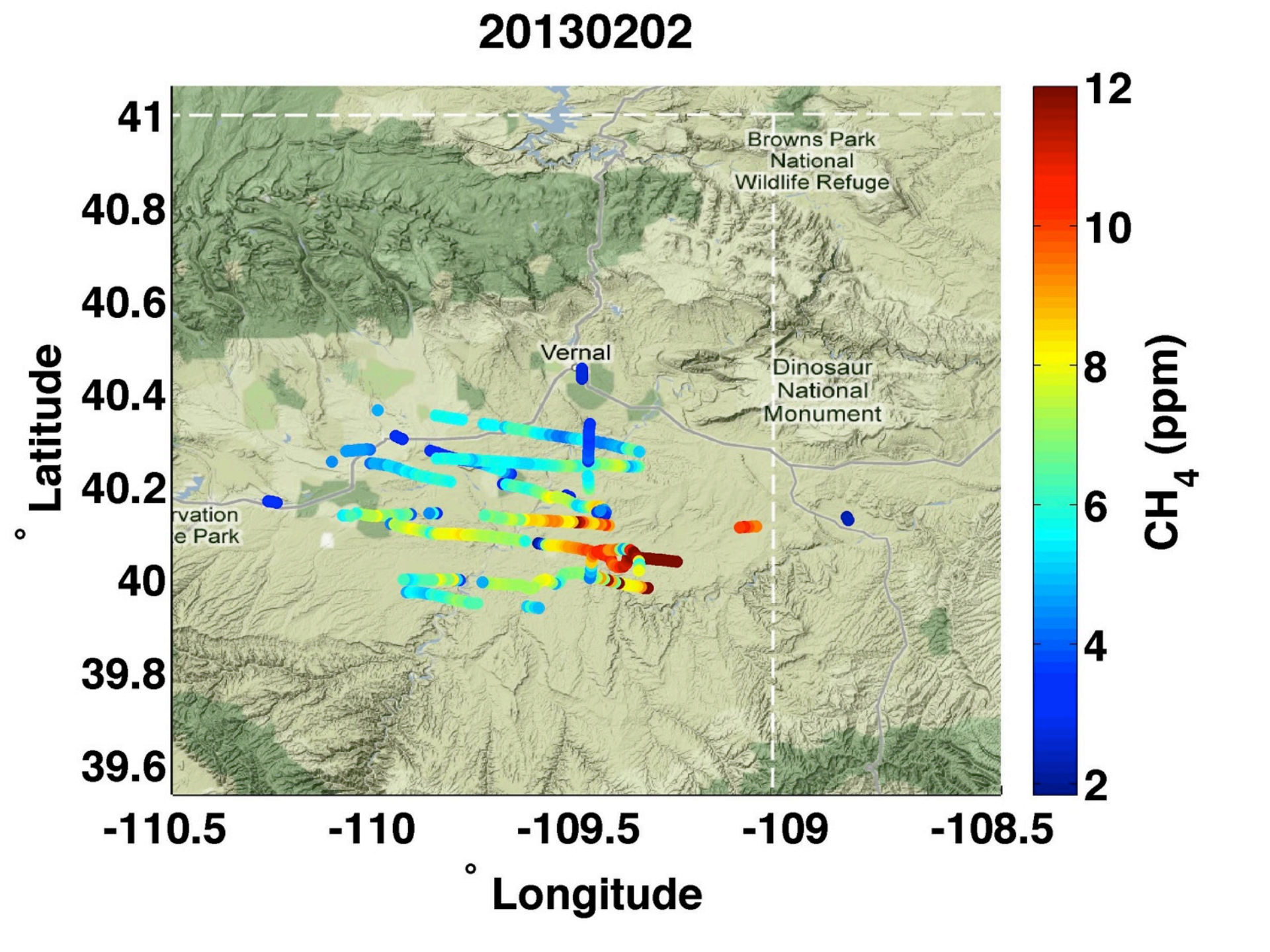
Horse Pool, Jan 25 - Feb 18, 2013



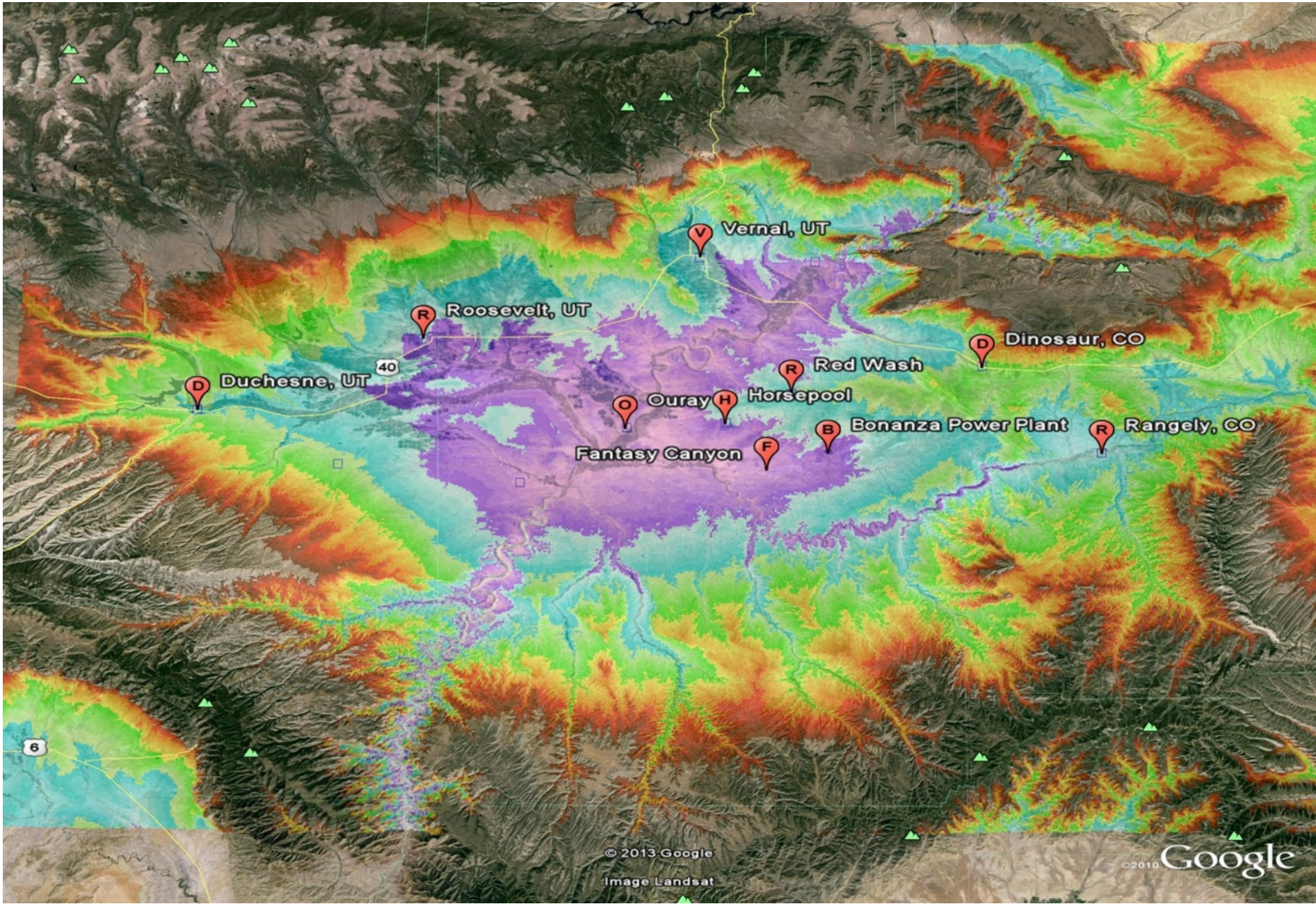
Conclusions

- **Snow is key to the meteorology and chemistry of winter ozone formation. No snow, no ozone.**
- **Bonanza power plant is not a contributor to NOx or ozone in winter Uintah ozone formation.**
- **The ozone precursors are coming from oil and gas extraction and transport processes.**
- **Transport of ozone and ozone precursors from outside the Basin is inconsequential.**
- **The depth of the enhanced ozone layer is shallow, varying from the equivalent of one to three 150 feet drill rig heights.**

Thank you for your time and attention.

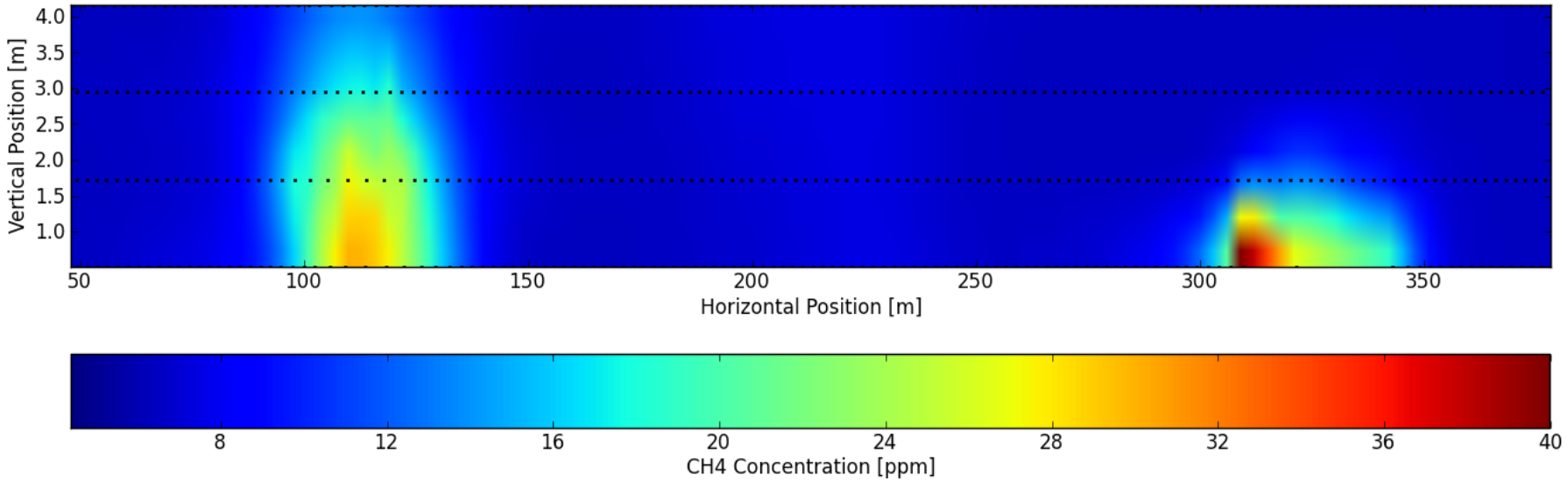

20130202
Browns Park
National
Wildlife Refuge
Vernal
Dinosaur
National
Monument
41
40.8
40.6
40.4
40.2
40
39.8
39.6
° Latitude
-110.5
-110
-109.5
-109
-108.5
° Longitude
12
10
8
6
4
2
CH4 (ppm)

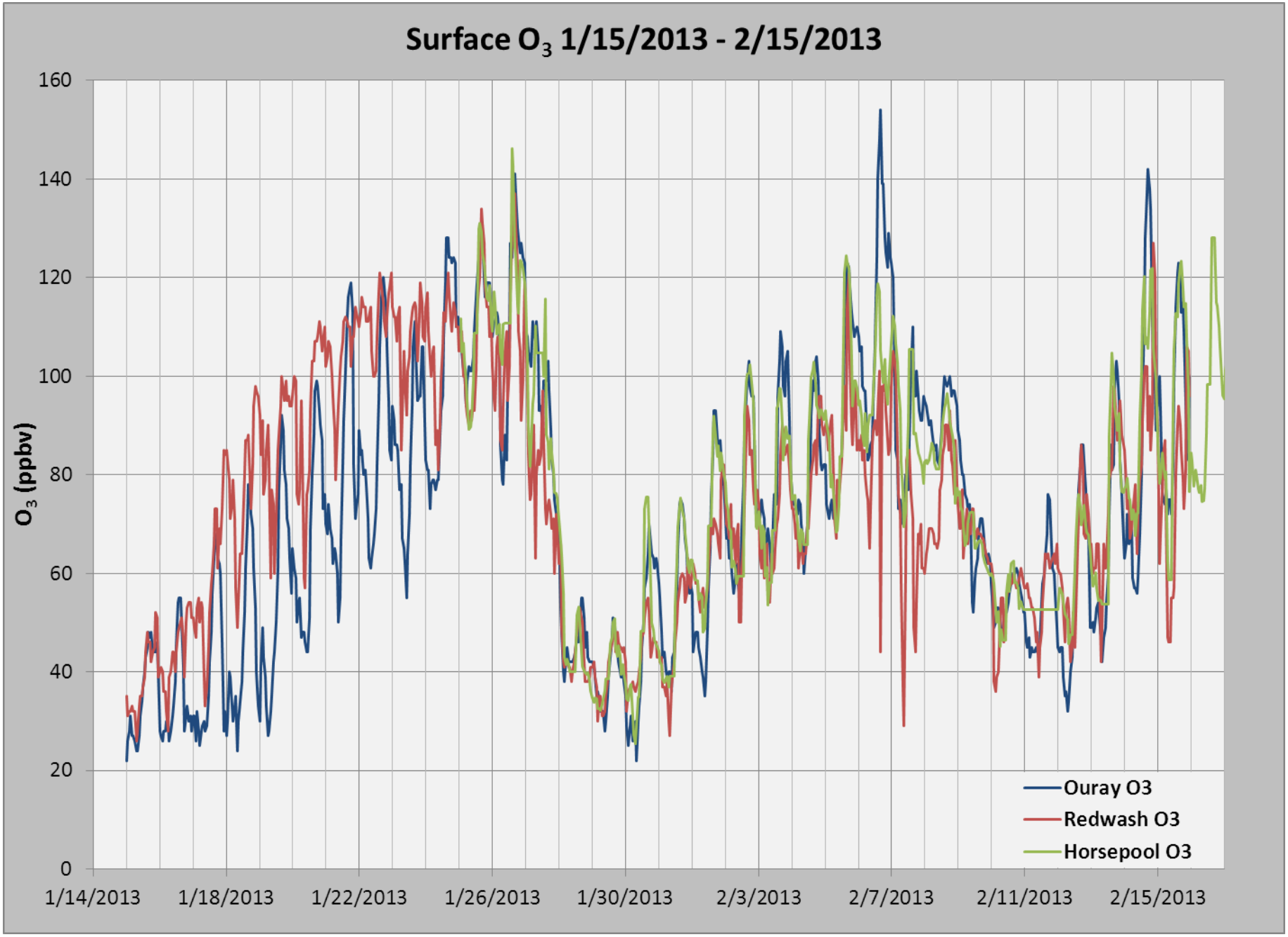
Physiography: Uinta Basin, Utah

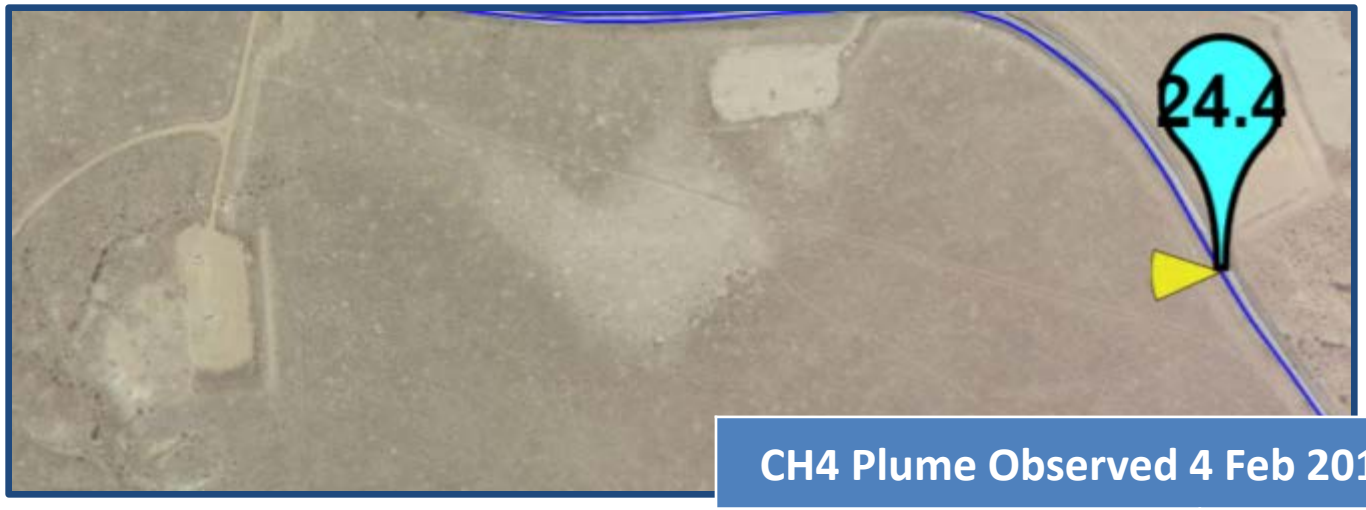


Uintah Basin, Feb 2013

CH4 Plume Observed 31 Jan 2013 13:00	
Car Speed	13.0 m/s
Lateral Wind Speed	1.5 m/s
Flux Estimate (Left)	**>3.2 L/s**
Flux Estimate (Right)	**>1.3 L/s**

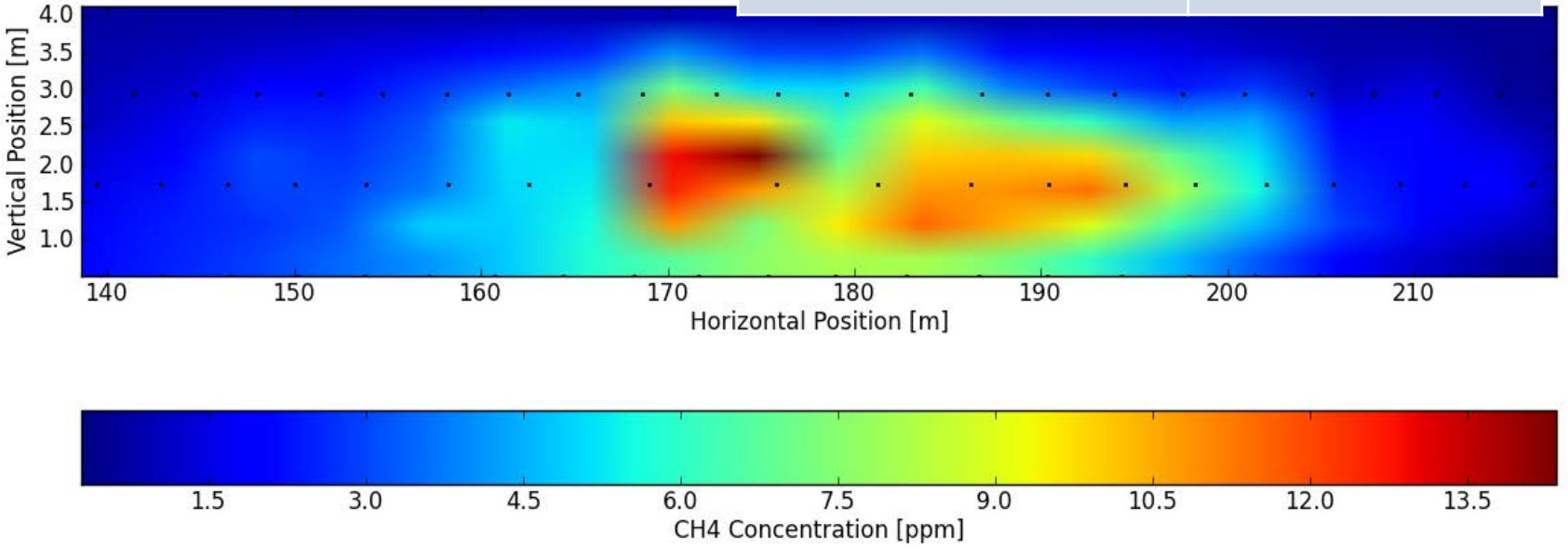



Surface O3 1/15/2013 - 2/15/2013
O3 (ppbv)
160
140
120
100
80
60
40
20
0
1/14/2013
1/18/2013
1/22/2013
1/26/2013
1/30/2013
2/3/2013
2/7/2013
2/11/2013
2/15/2013
Ouray O3
Redwash O3
Horsepool O3



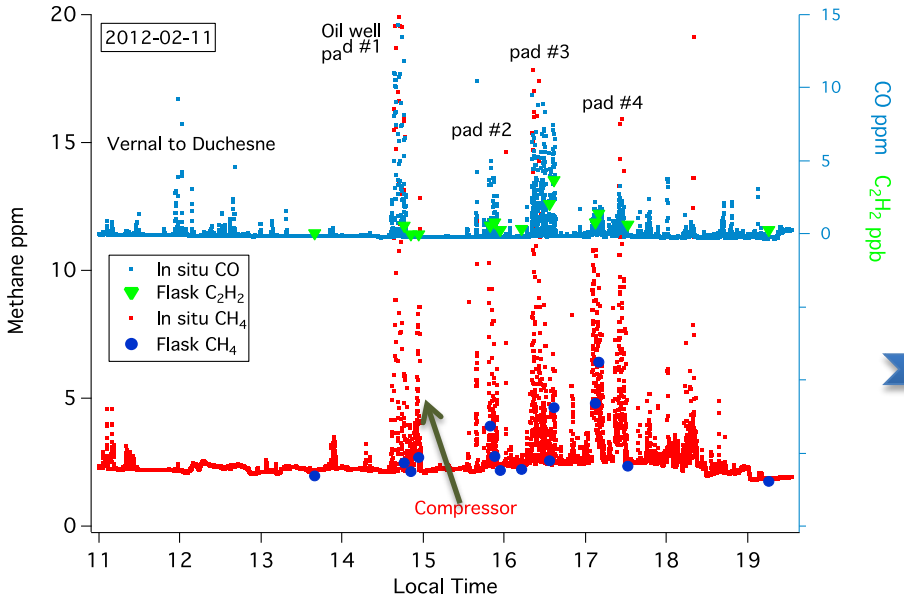
GPS: Uintah Basin

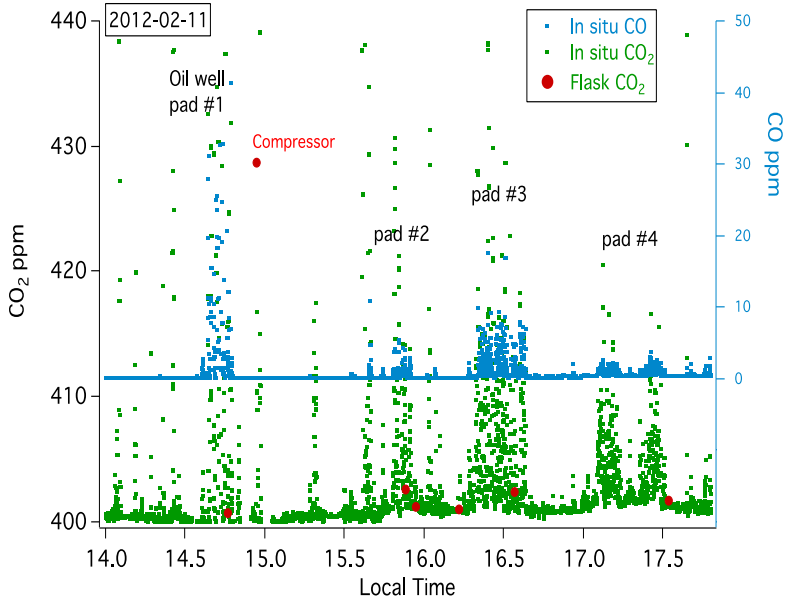
CH4 Plume Observed 4 Feb 2013 16:57	
Car Speed	18.8 m/s
Lateral Wind Speed	1.4 m/s
Flux Estimate	**>2.9 L/s**



Example of Emission Factor Derivation

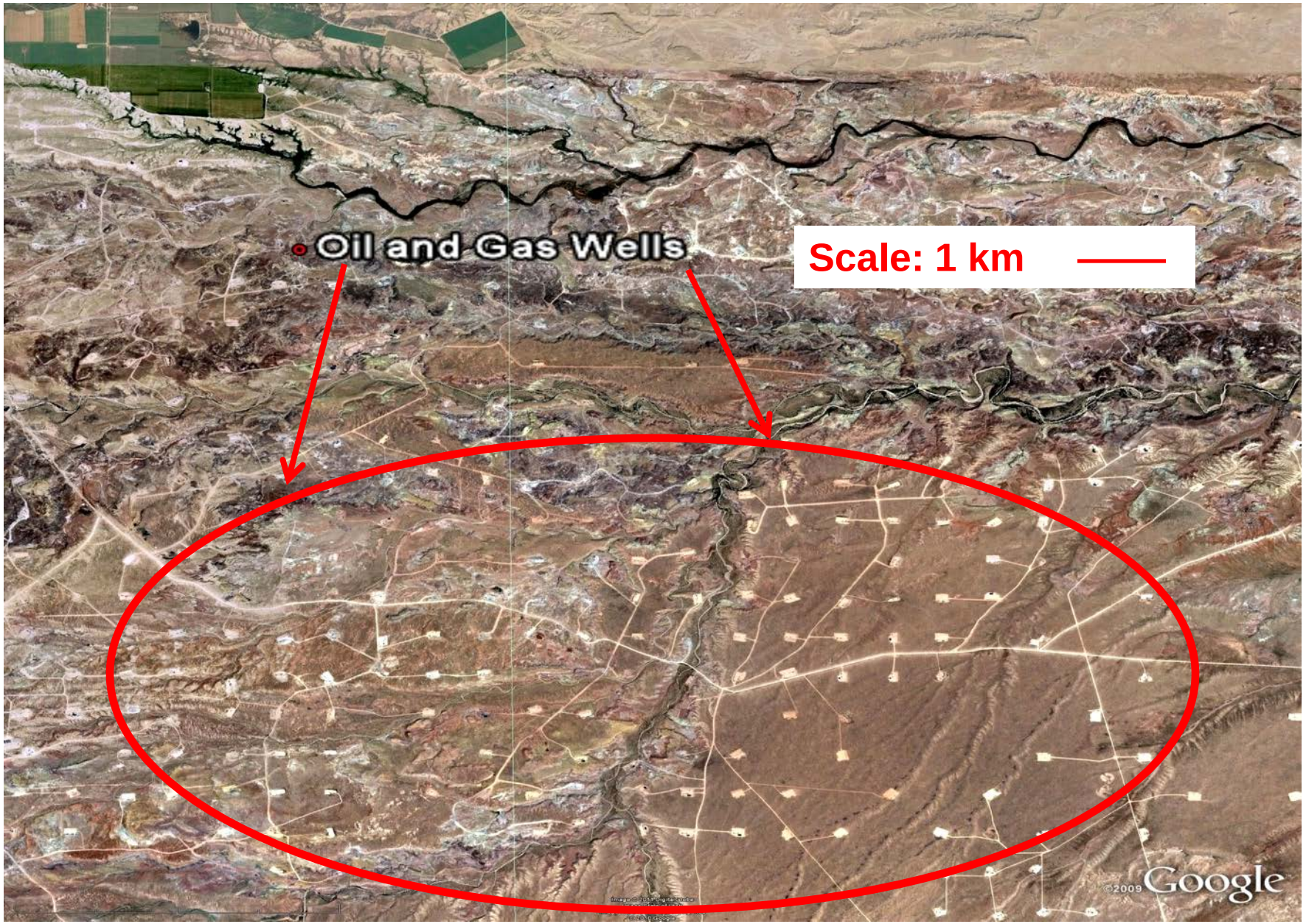
Natural gas leaks in oil field & combustion products



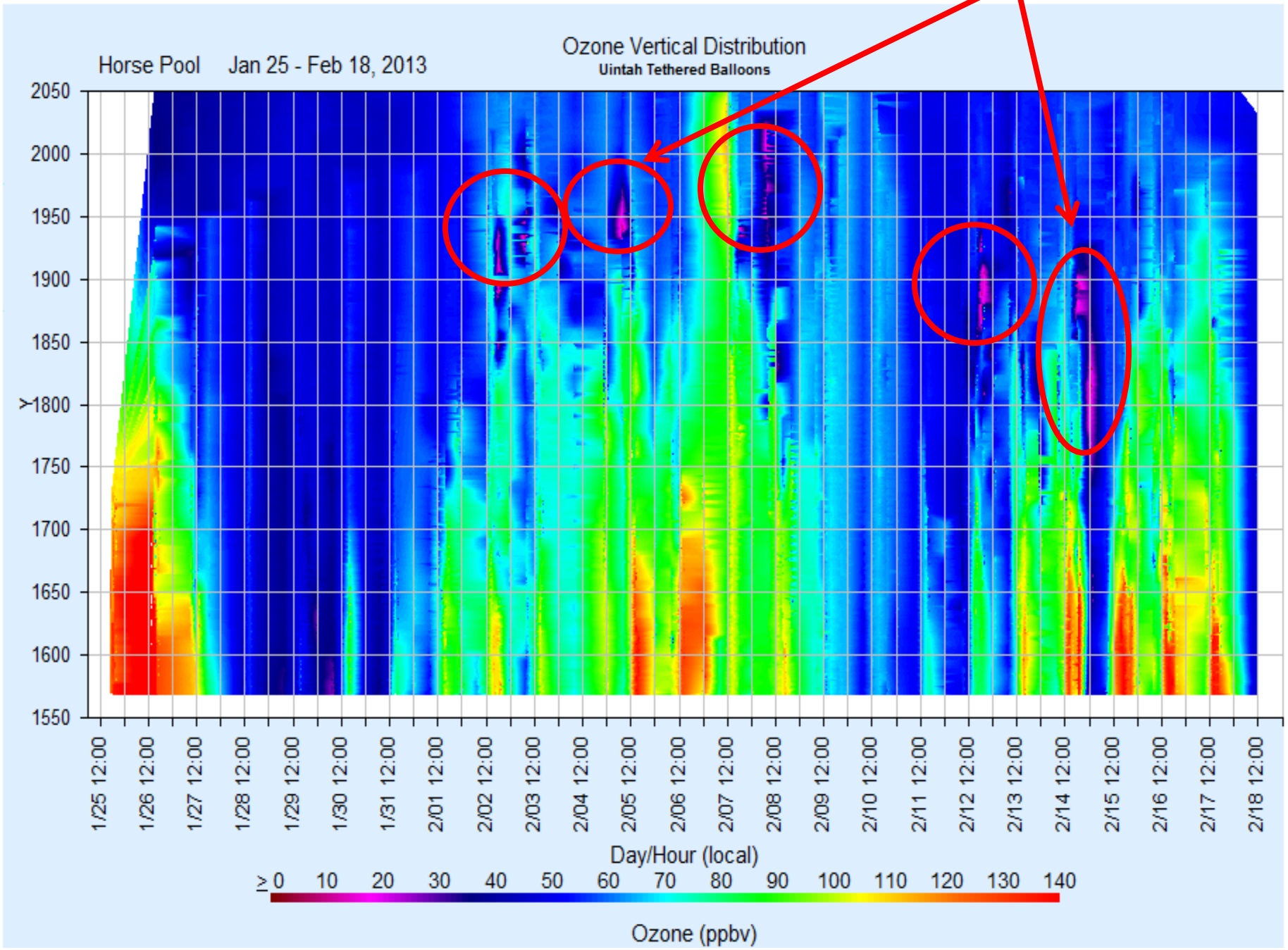


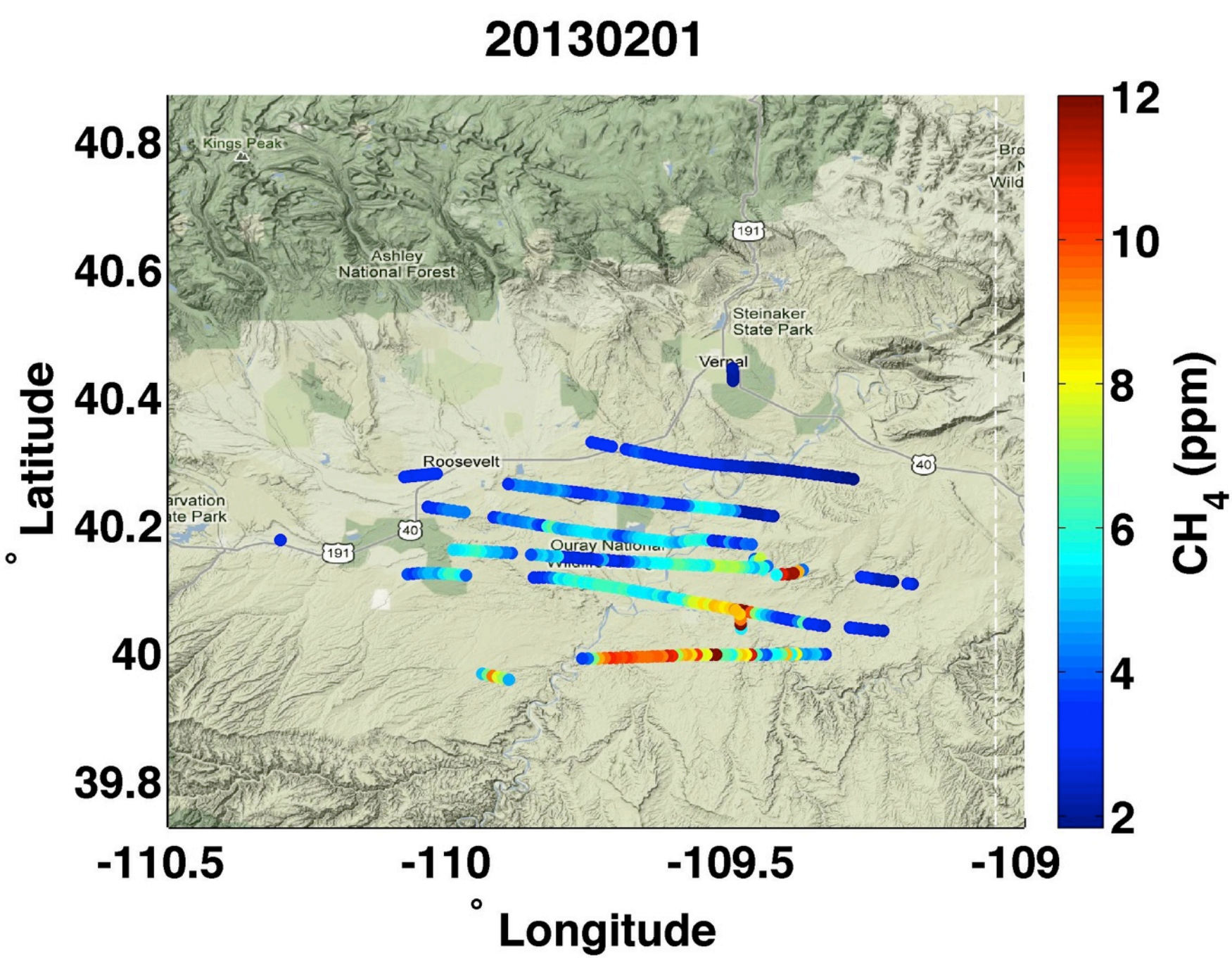
Molar ratio Pad #	CO/CO_2	$CH_4/(CO_2+CO)$
1	85%	22%
2	23%	25%
3	52%	17%
4	19%	61%

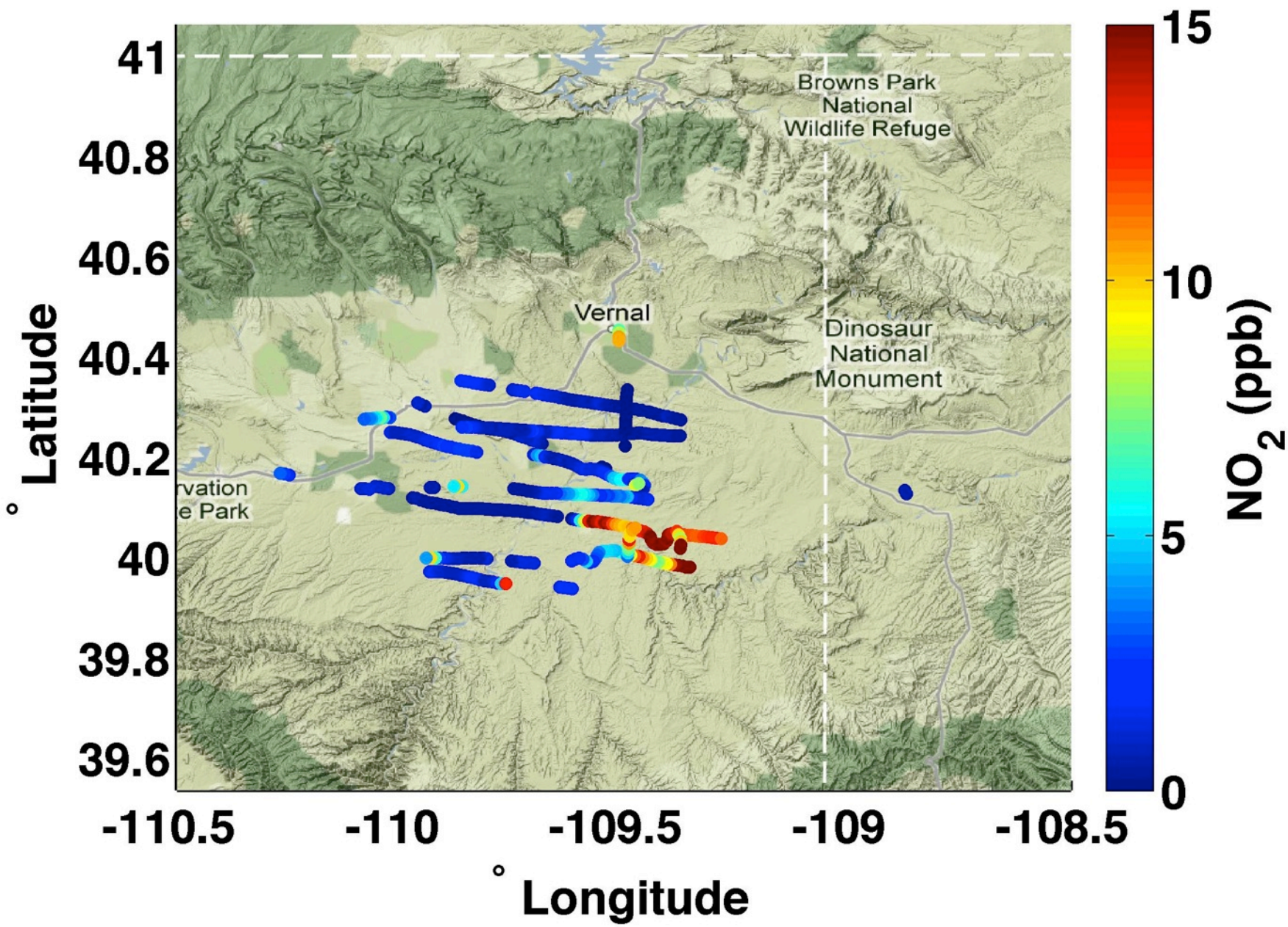
Uintah Basin Field

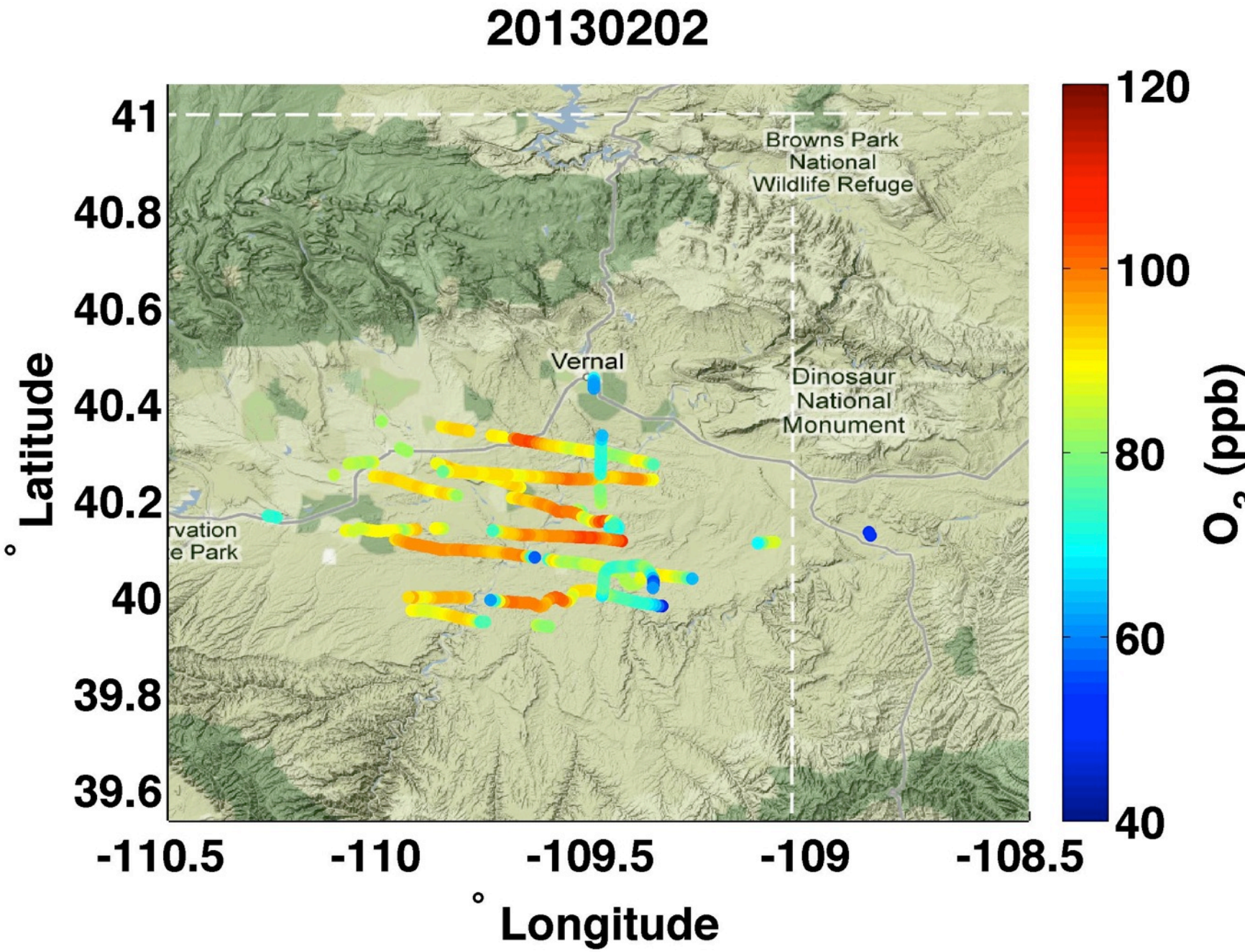


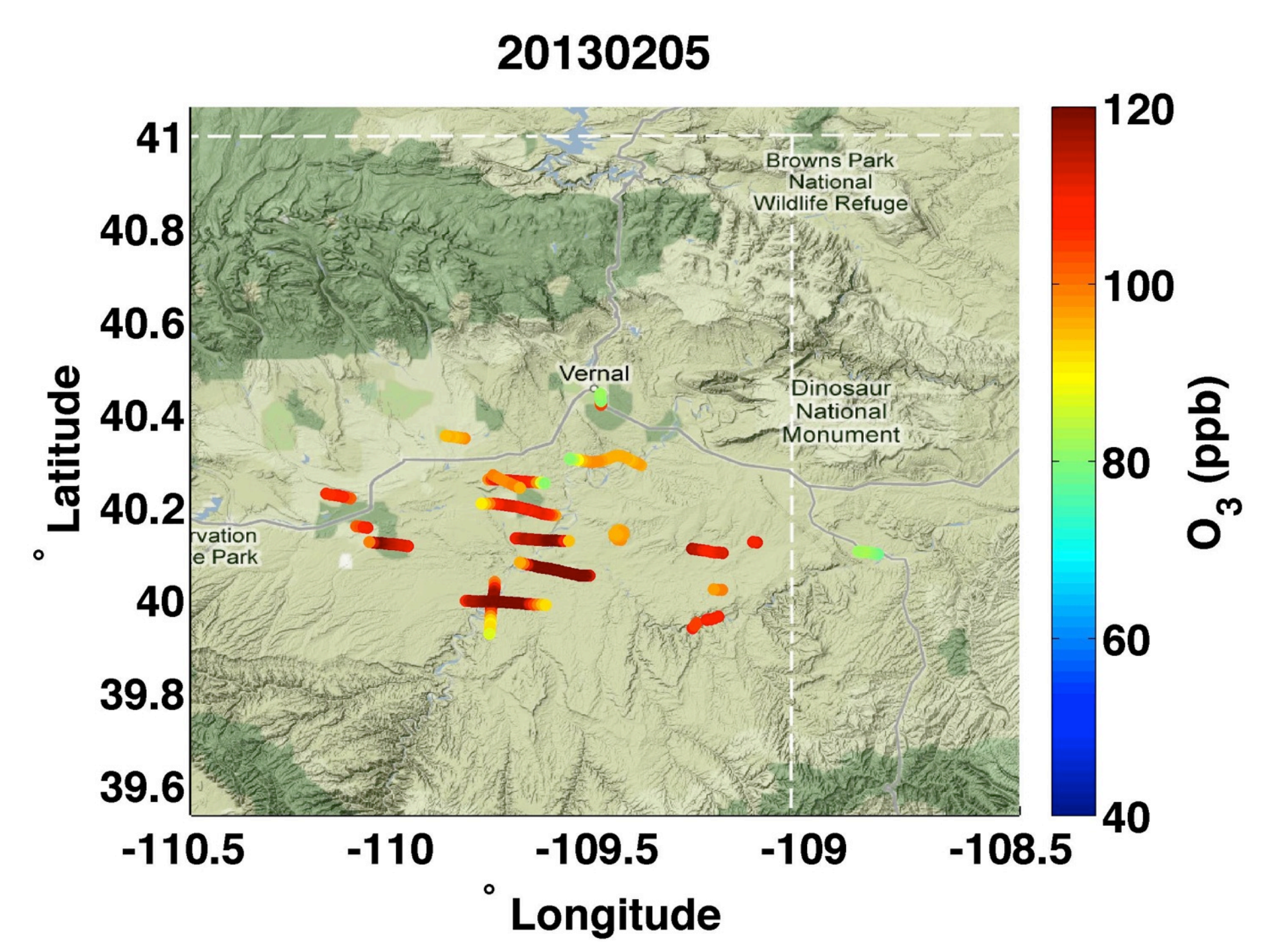
Ozone Events and the Bonanza Powerplant Plumes Aloft

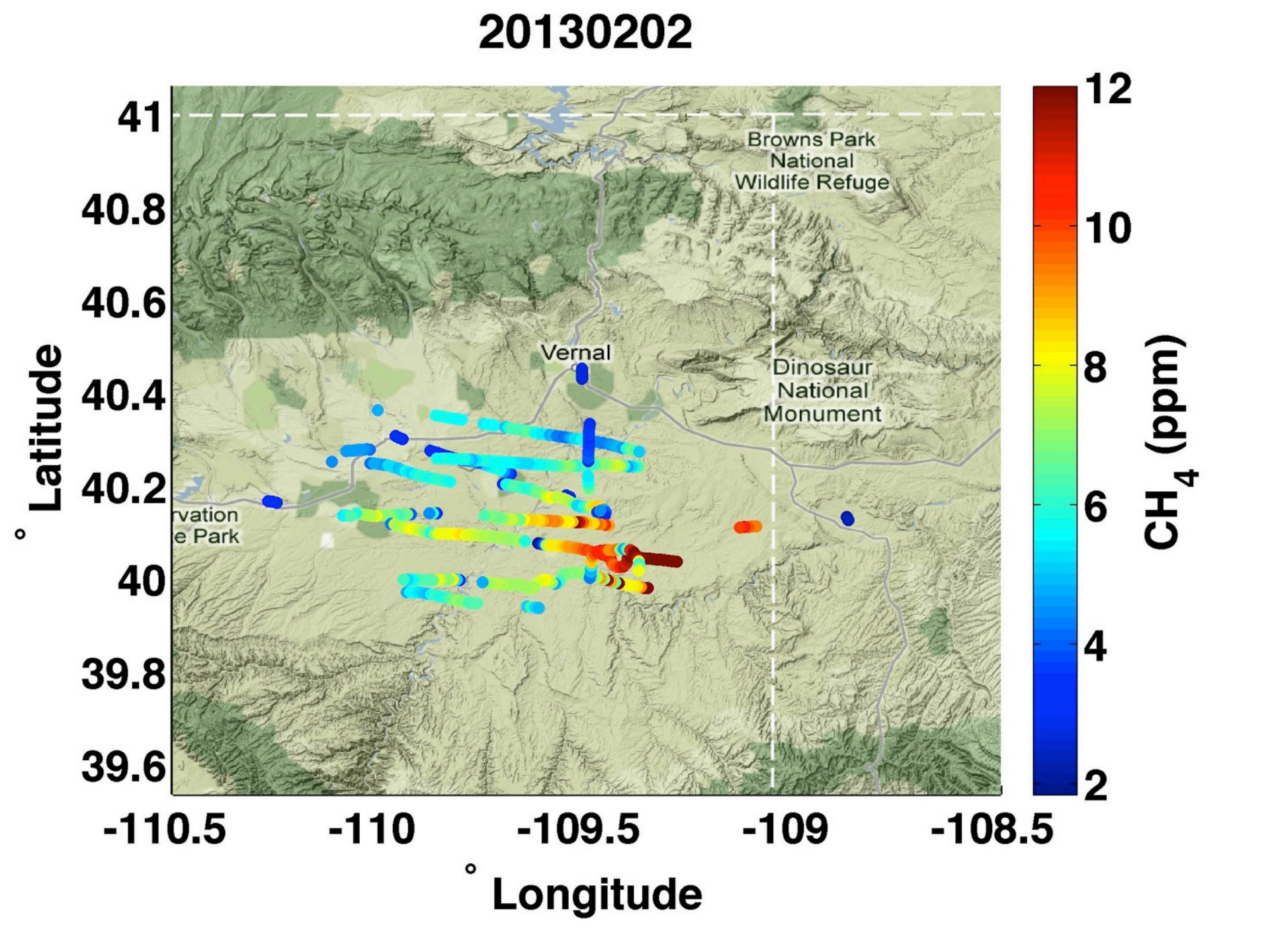



20130201
40.8
40.6
40.4
40.2
40
39.8
° Latitude
-110.5
-110
-109.5
-109
° Longitude
Kings Peak
Ashley
National Forest
Steinaker
State Park
Vernal
Roosevelt
191
40
12
10
8
6
4
2
CH4 (ppm)


20130202
Browns Park
National
Wildlife Refuge
Vernal
Dinosaur
National
Monument
41
40.8
40.6
40.4
40.2
40
39.8
39.6
° Latitude
-110.5
-110
-109.5
-109
-108.5
° Longitude
15
10
5
0
NO2 (ppb)

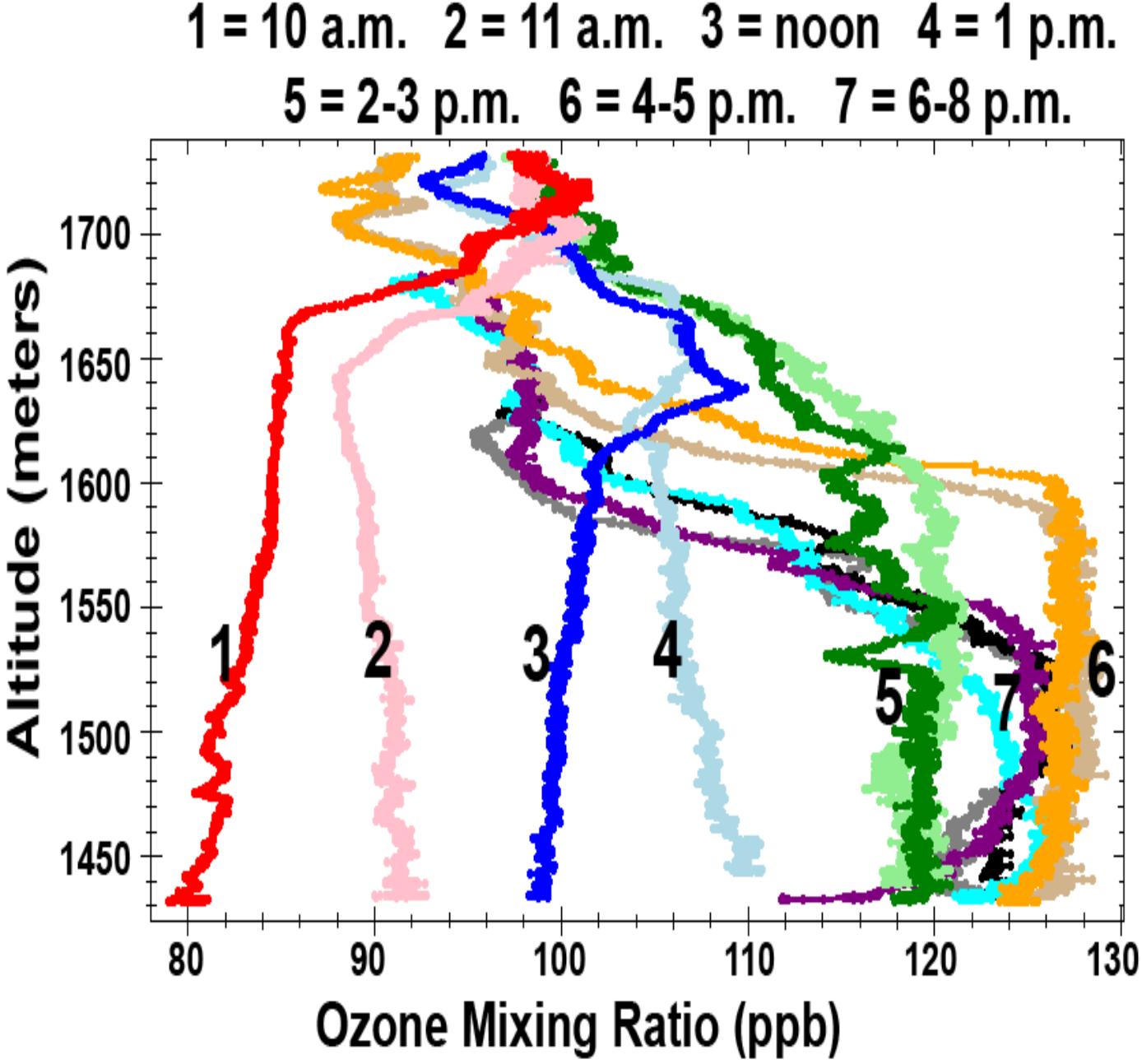

20130202
Browns Park
National
Wildlife Refuge
Vernal
Dinosaur
National
Monument
41
40.8
40.6
40.4
40.2
40
39.8
39.6
Latitude
°
-110.5
-110
-109.5
-109
-108.5
Longitude
°
120
100
80
60
40
O3 (ppb)


20130205
Browns Park
National
Wildlife Refuge
Vernal
Dinosaur
National
Monument
41
40.8
40.6
40.4
40.2
40
39.8
39.6
° Latitude
-110.5
-110
-109.5
-109
-108.5
° Longitude
120
100
80
60
40
O3 (ppb)

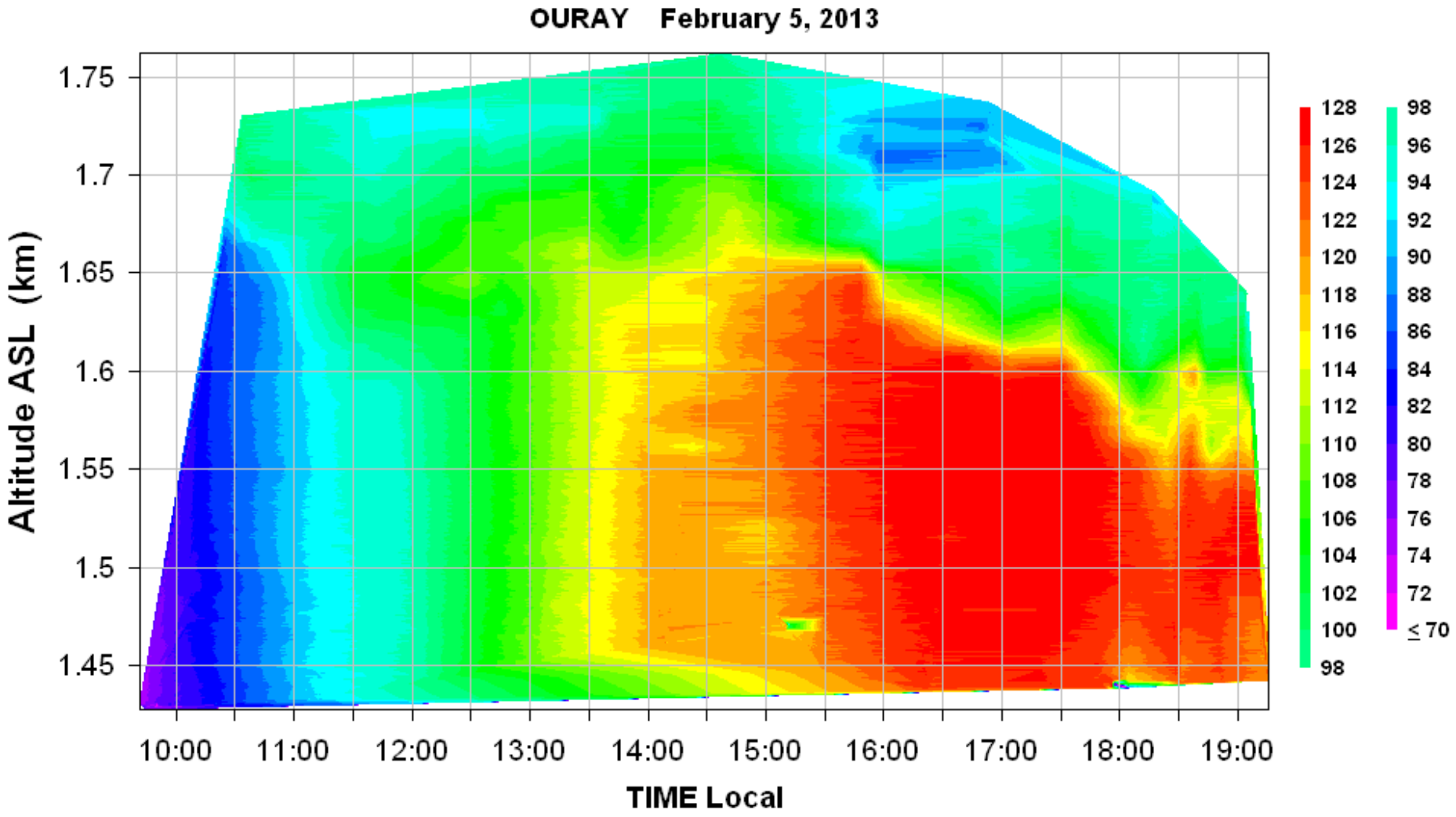

20130202
Browns Park
National
Wildlife Refuge
Vernal
Dinosaur
National
Monument
41
40.8
40.6
40.4
40.2
40
39.8
39.6
° Latitude
-110.5
-110
-109.5
-109
-108.5
° Longitude
12
10
8
6
4
2
CH4 (ppm)

Ingredients For Fast, High Concentration Wintertime Ozone Production

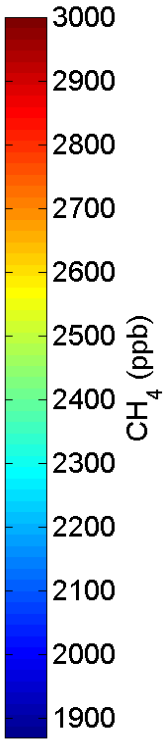
- **Precursor atmospheric effluents from natural gas and oil field operations.**
- **Effluents constrained within a geographical basin that hampers mixing.**
- **Snow deep enough to cover shorter vegetation.**
- **Temperatures cold enough to maintain the snow cover.**
- **Low winds.**
- **Clear skies.**
- **Maintenance of a strong temperature inversion.**

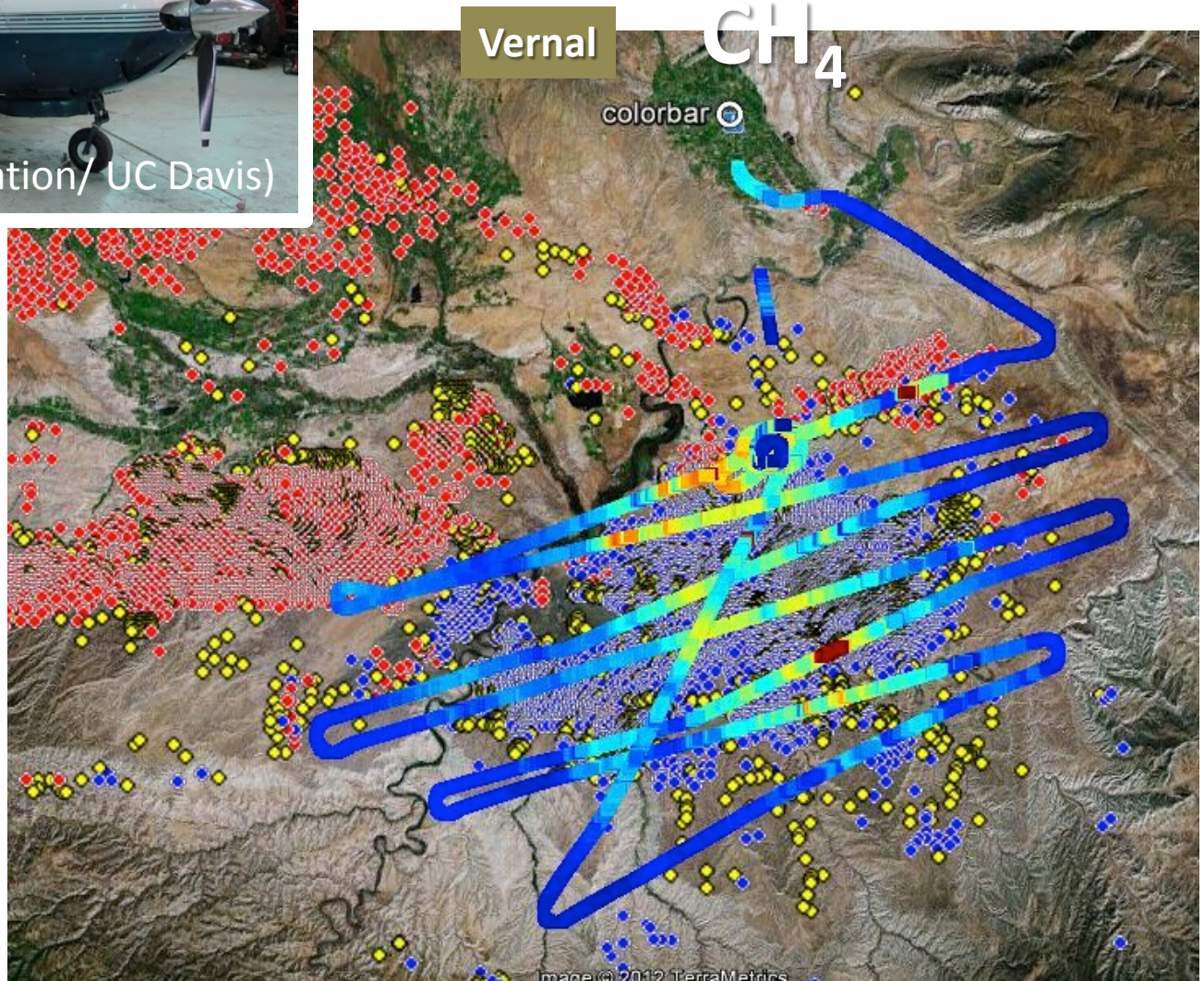

1 = 10 a.m. 2 = 11 a.m. 3 = noon 4 = 1 p.m.
5 = 2-3 p.m. 6 = 4-5 p.m. 7 = 6-8 p.m.
Altitude (meters)
1700
1650
1600
1550
1500
1450
80
90
100
110
120
130
Ozone Mixing Ratio (ppb)
1
2
3
4
5
7
6

Ozone Time/Height/Concentration Plot, February 5, 2013, Ouray Site

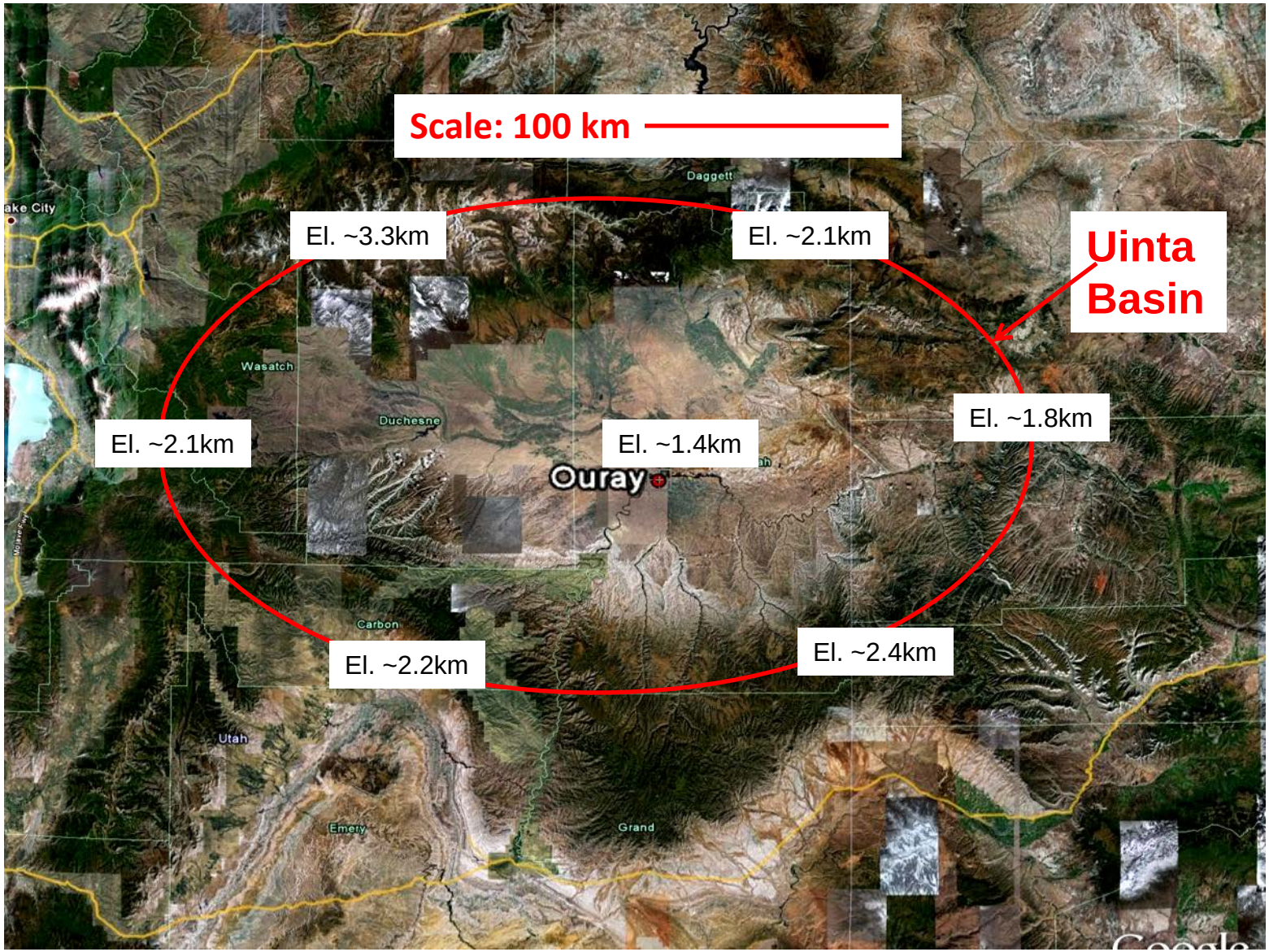


Feb 7, 2012: Low Wind Conditions

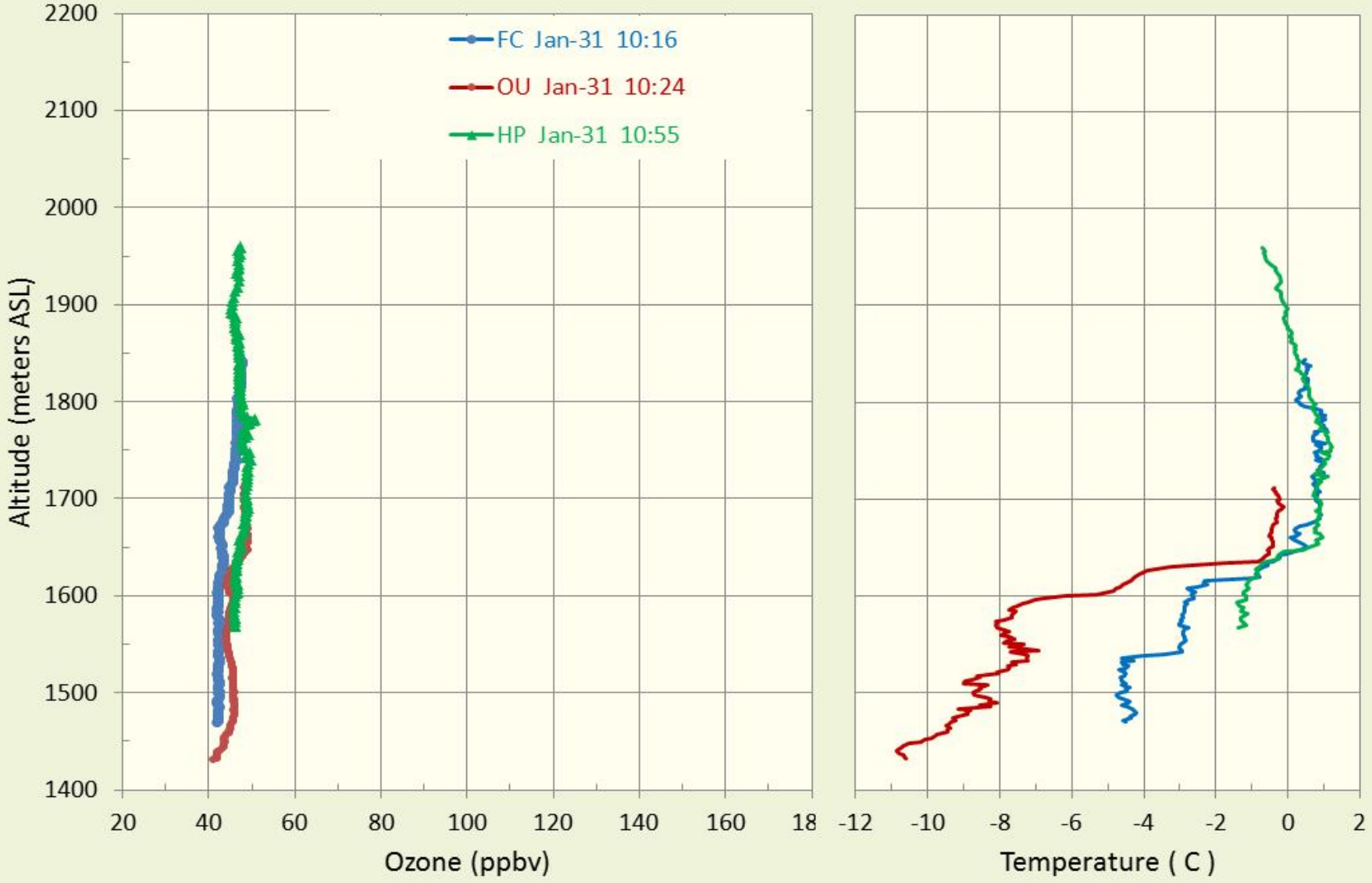




Physiography: Uinta Basin, Utah



Uintah Basin, Jan 31, 2013

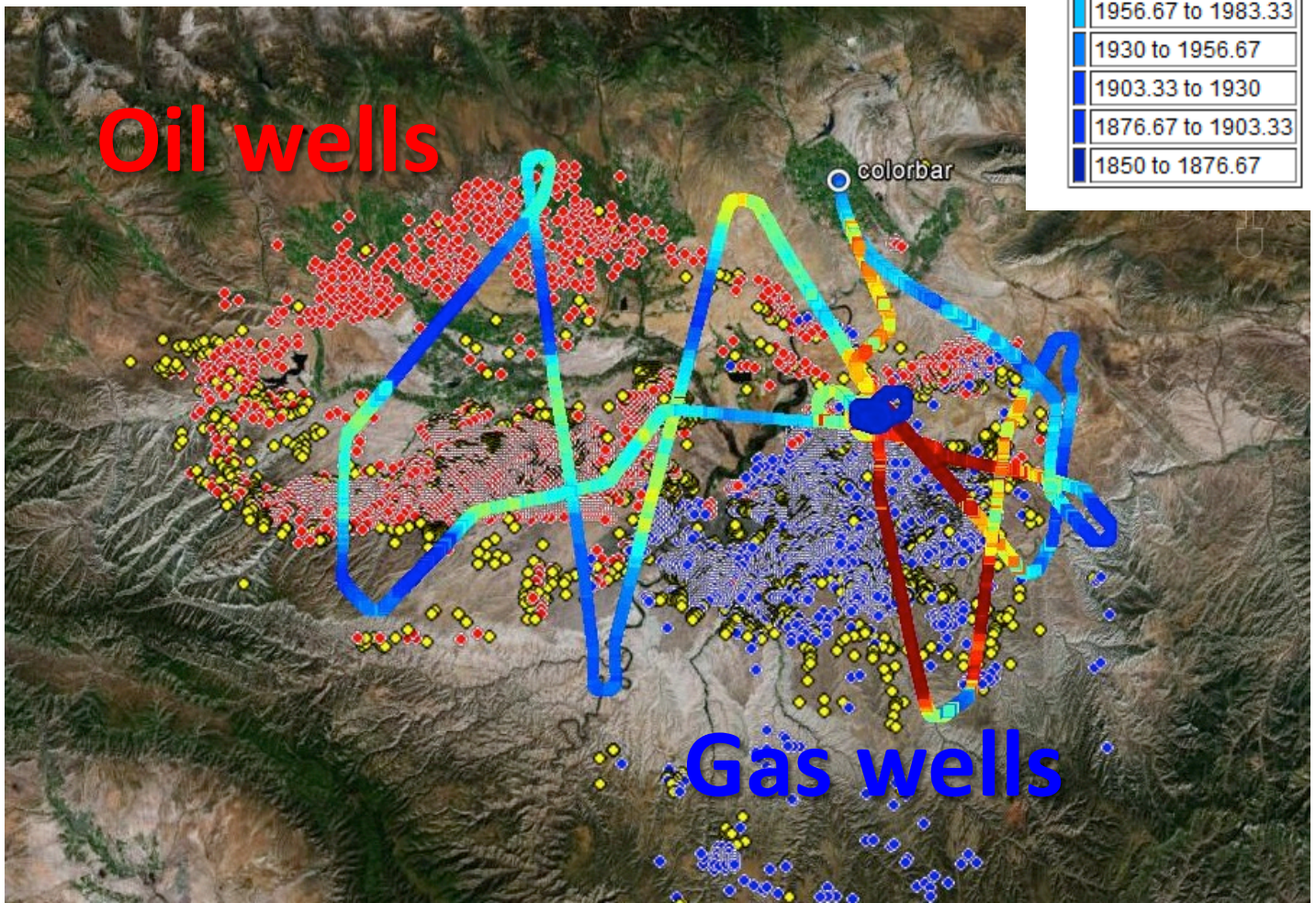


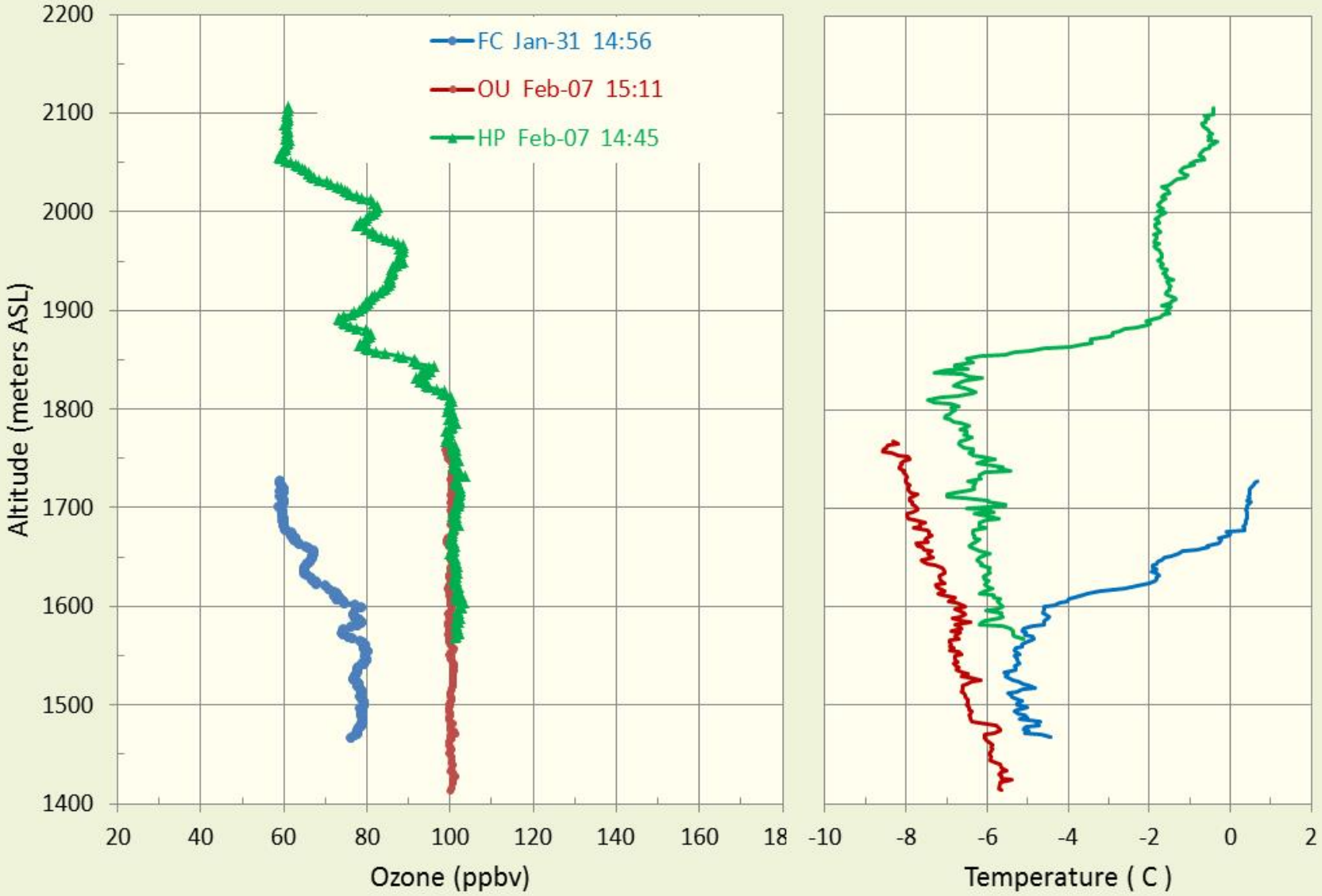
Feb 4, 2012

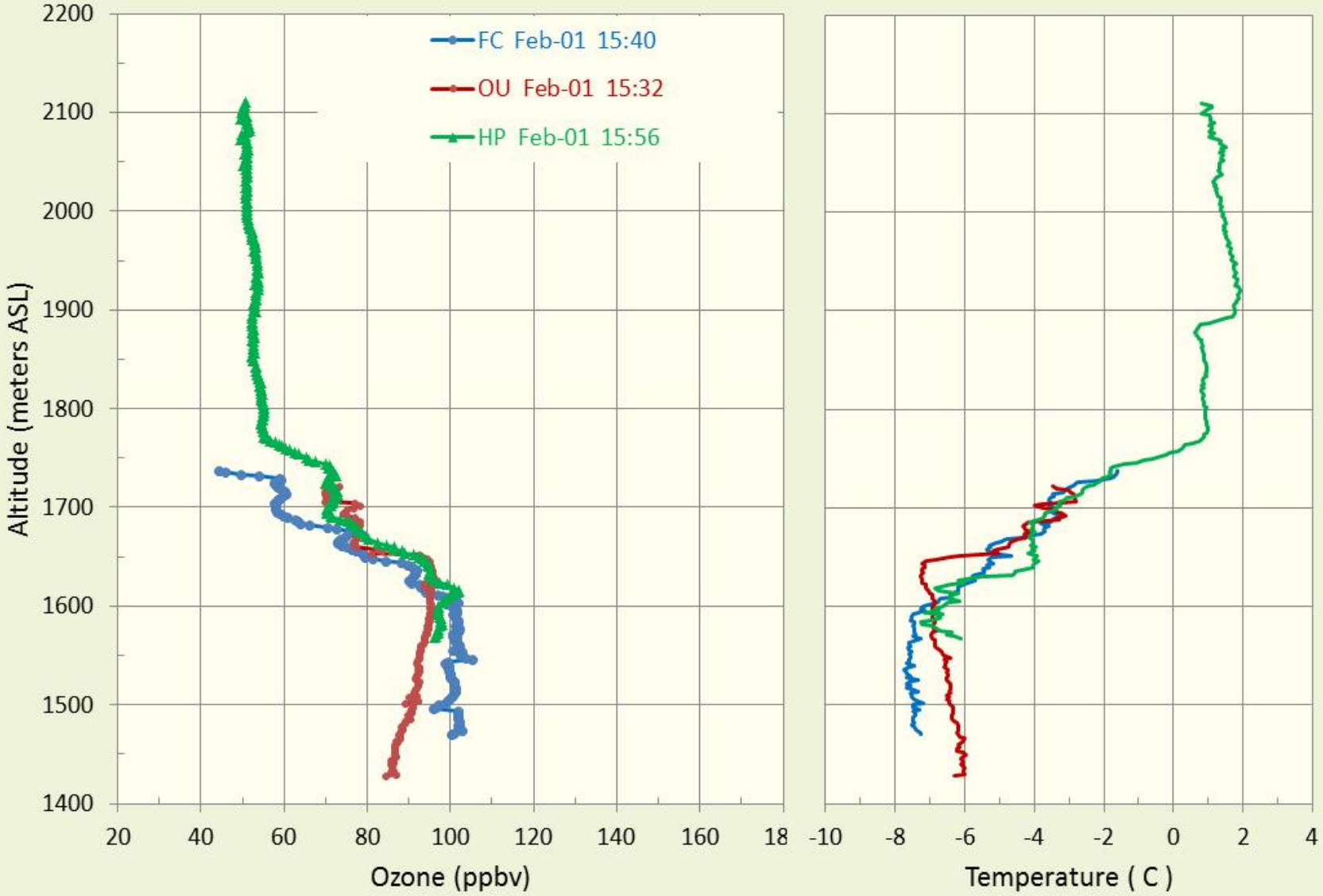
CH_4 (ppb)

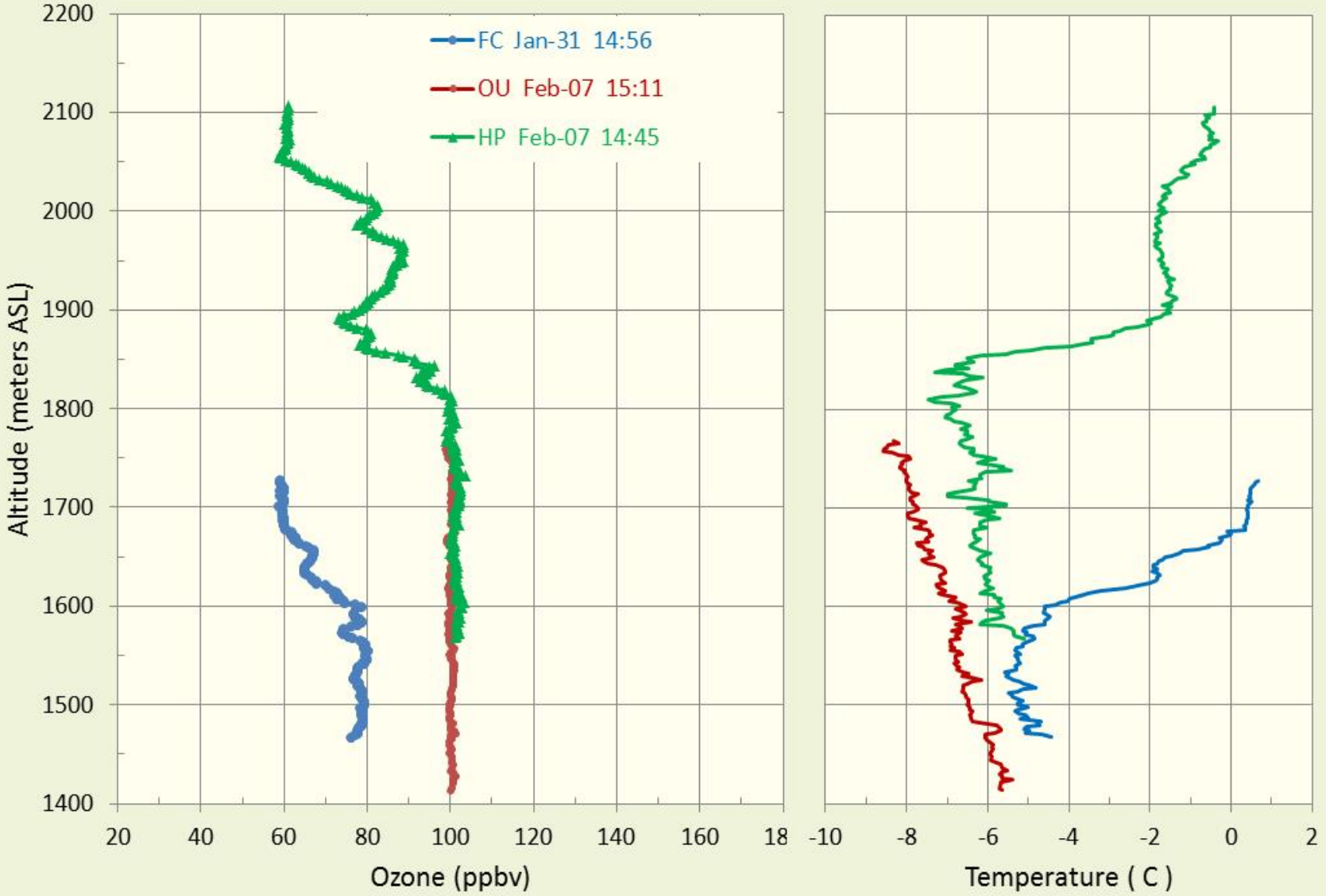
2223.33 to 2250
2196.67 to 2223.33
2170 to 2196.67
2143.33 to 2170
2116.67 to 2143.33
2090 to 2116.67
2063.33 to 2090
2036.67 to 2063.33
2010 to 2036.67
1983.33 to 2010
1956.67 to 1983.33
1930 to 1956.67
1903.33 to 1930
1876.67 to 1903.33
1850 to 1876.67

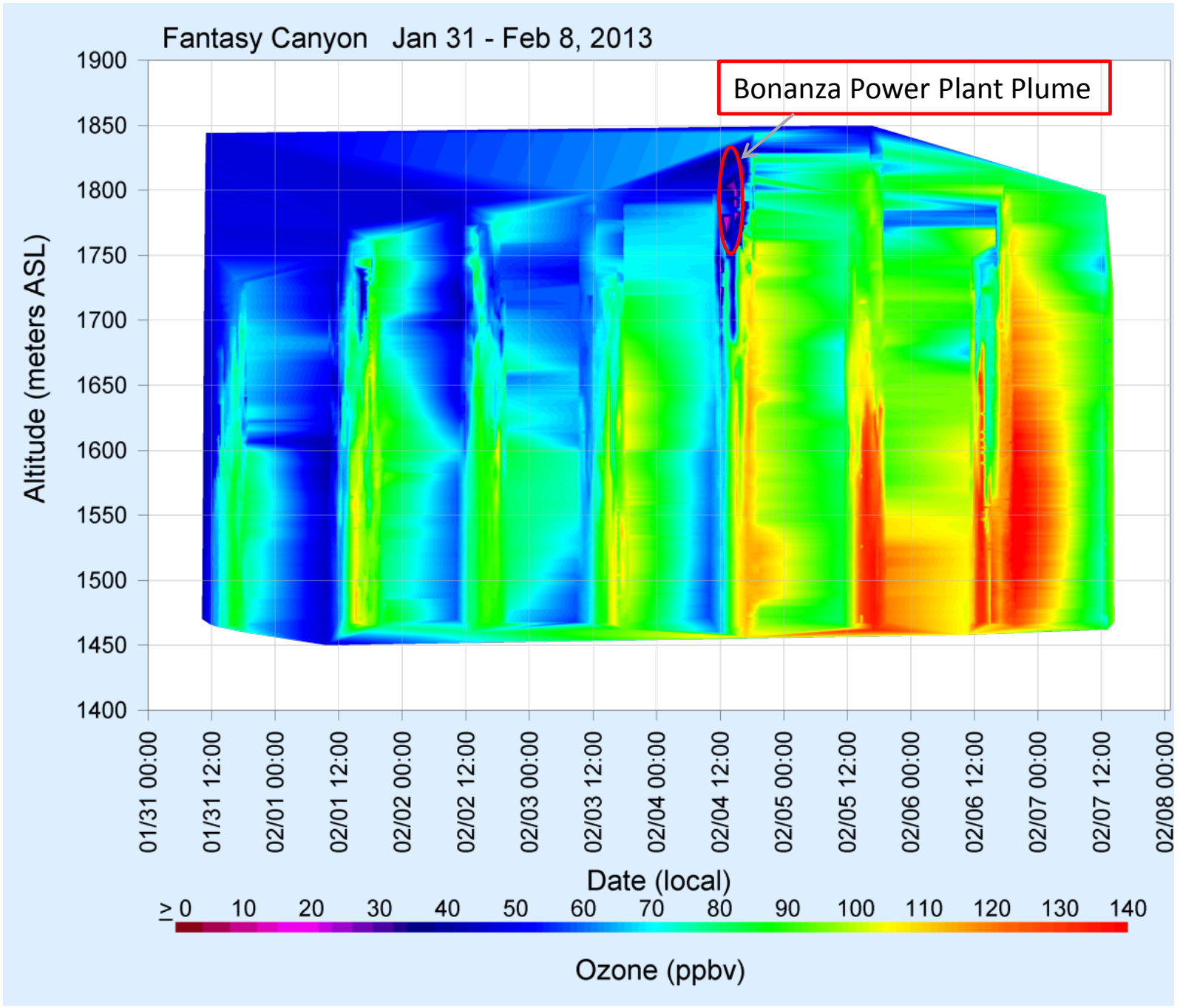
Methane (CH_4)

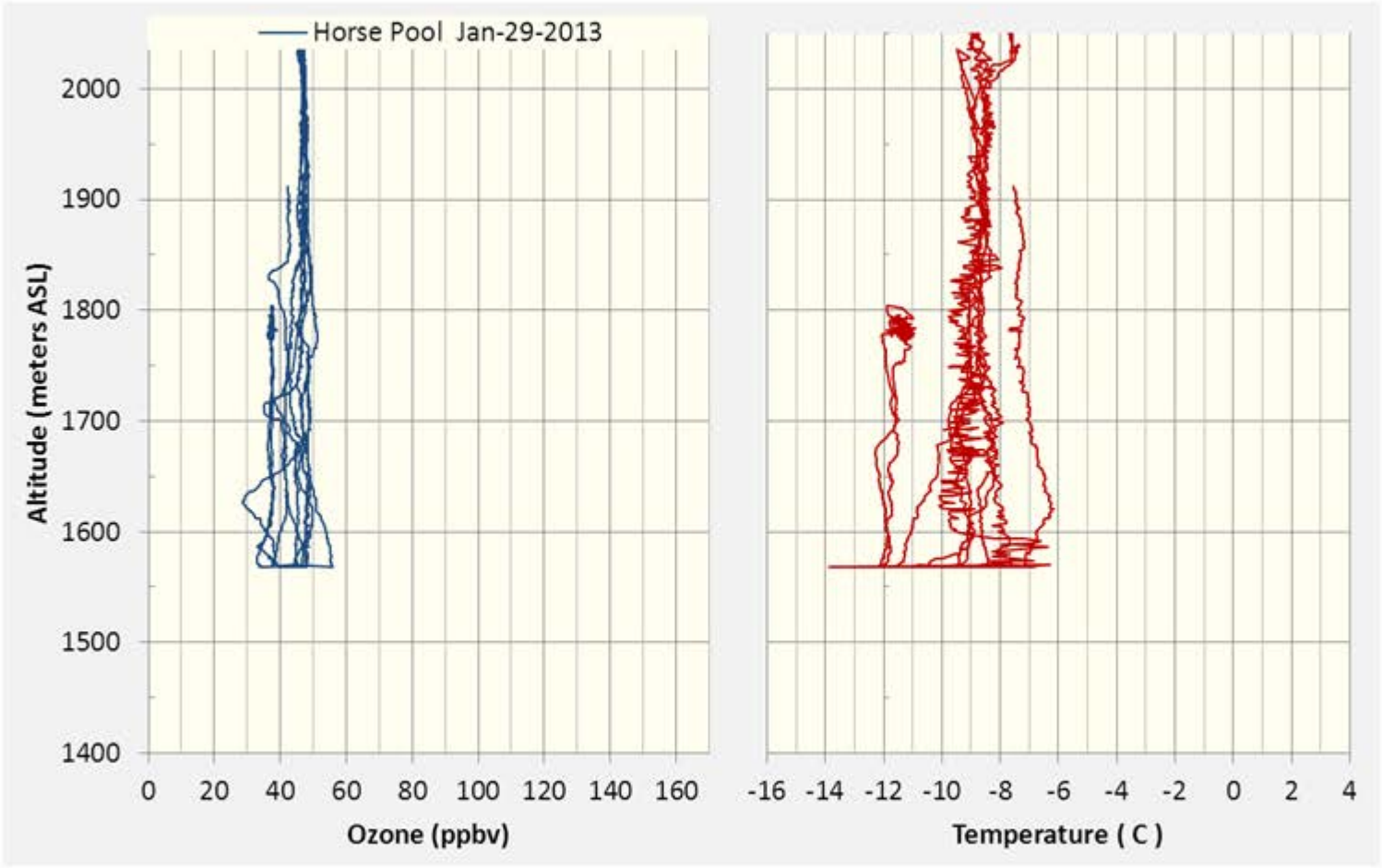


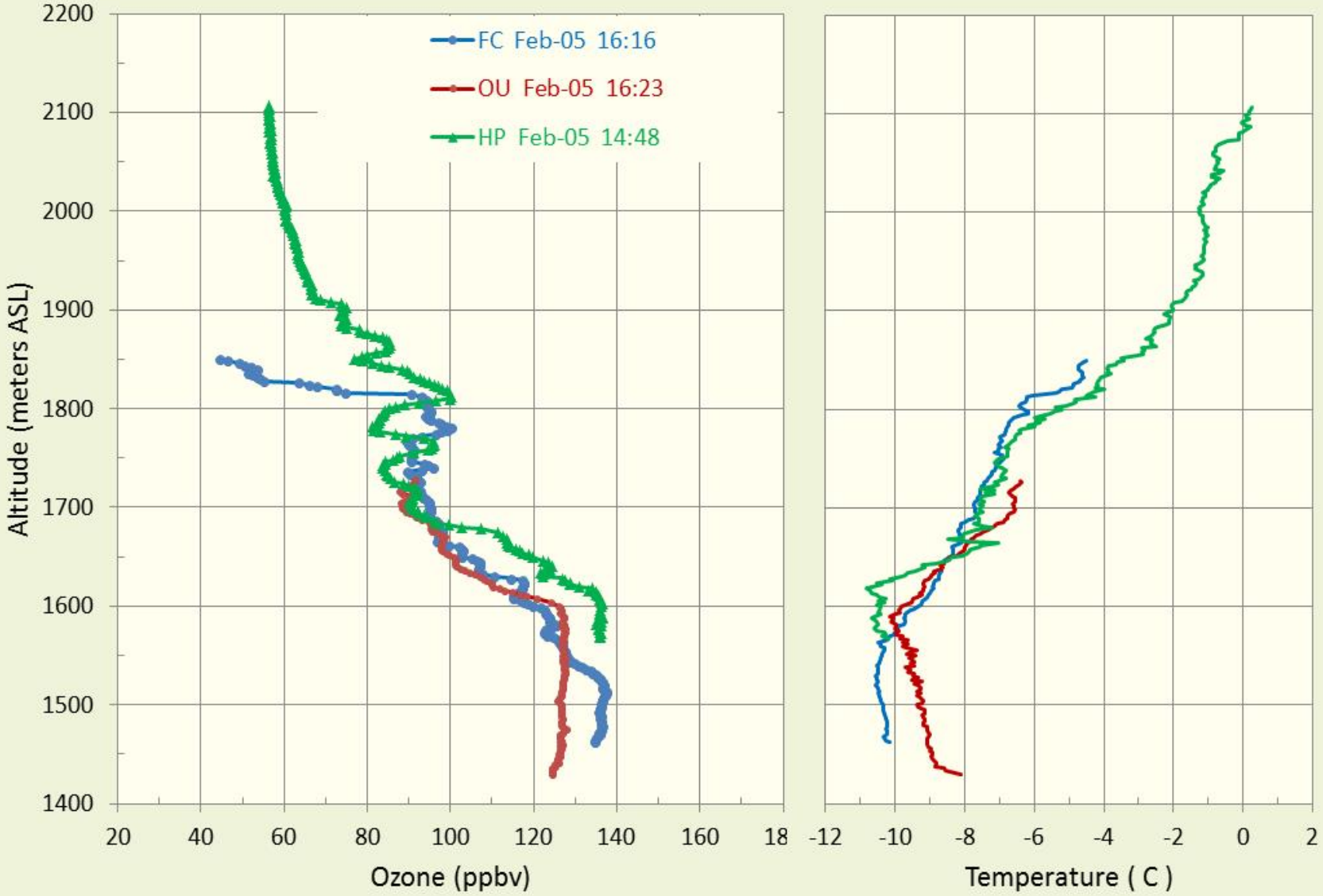

FC Jan-31 14:56
OU Feb-07 15:11
HP Feb-07 14:45
Altitude (meters ASL)
2200
2100
2000
1900
1800
1700
1600
1500
1400
20
40
60
80
100
120
140
160
18
Ozone (ppbv)
-10
-8
-6
-4
-2
0
2
Temperature (C)

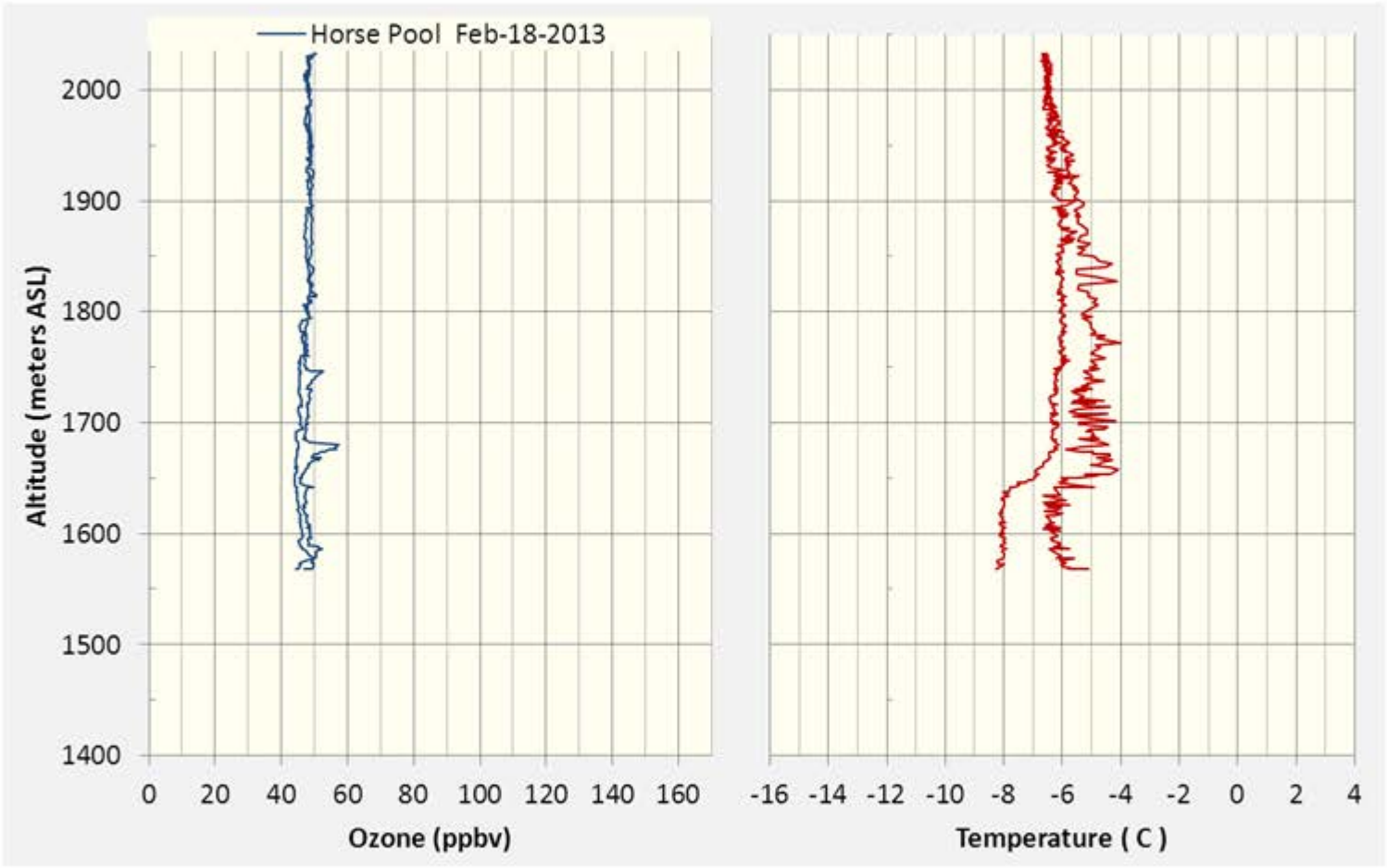

FC Feb-01 15:40
OU Feb-01 15:32
HP Feb-01 15:56
Altitude (meters ASL)
2200
2100
2000
1900
1800
1700
1600
1500
1400
20
40
60
80
100
120
140
160
18
Ozone (ppbv)
-10
-8
-6
-4
-2
0
2
4
Temperature (C)

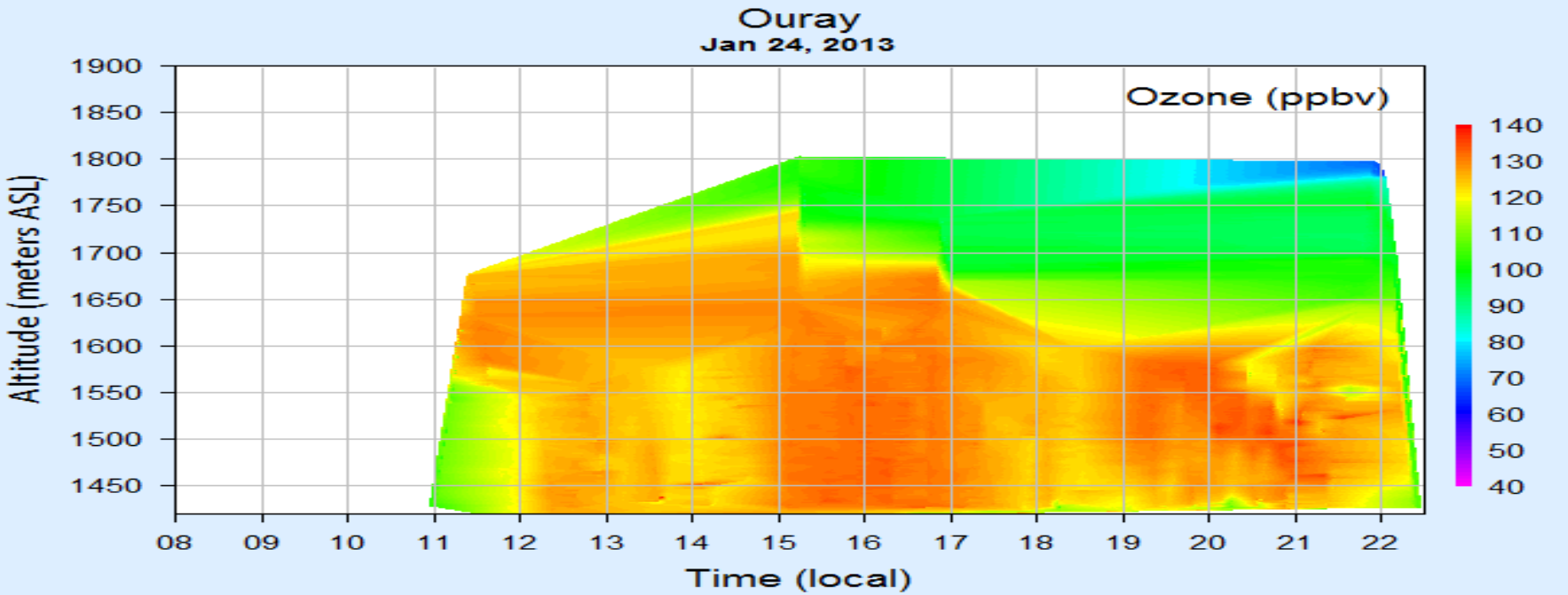

FC Jan-31 14:56
OU Feb-07 15:11
HP Feb-07 14:45
Altitude (meters ASL)
2200
2100
2000
1900
1800
1700
1600
1500
1400
20
40
60
80
100
120
140
160
18
Ozone (ppbv)
-10
-8
-6
-4
-2
0
2
Temperature (C)

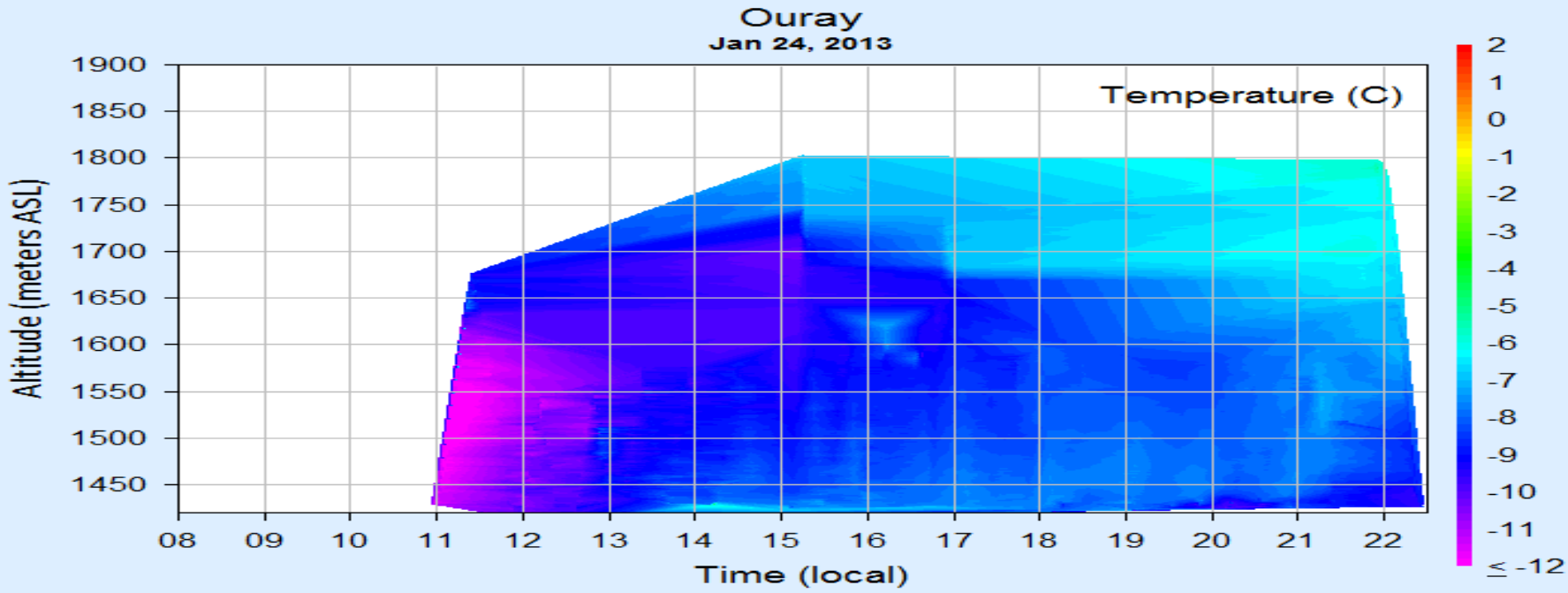

Fantasy Canyon Jan 31 - Feb 8, 2013
Bonanza Power Plant Plume
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
01/31 00:00
01/31 12:00
02/01 00:00
02/01 12:00
02/02 00:00
02/02 12:00
02/03 00:00
02/03 12:00
02/04 00:00
02/04 12:00
02/05 00:00
02/05 12:00
02/06 00:00
02/06 12:00
02/07 00:00
02/07 12:00
02/08 00:00
Date (local)
>= 0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Ozone (ppbv)

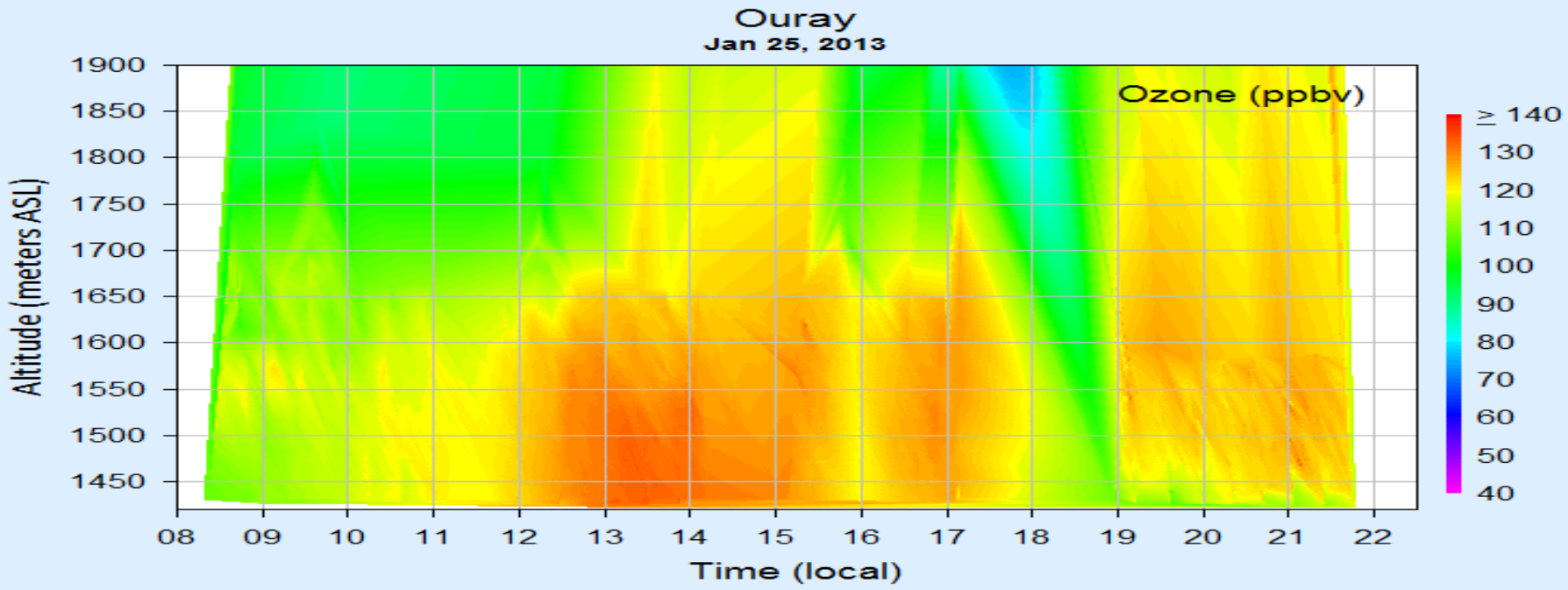

Horse Pool Jan-29-2013
Altitude (meters ASL)
2000
1900
1800
1700
1600
1500
1400
0 20 40 60 80 100 120 140 160
Ozone (ppbv)
-16 -14 -12 -10 -8 -6 -4 -2 0 2 4
Temperature (C)

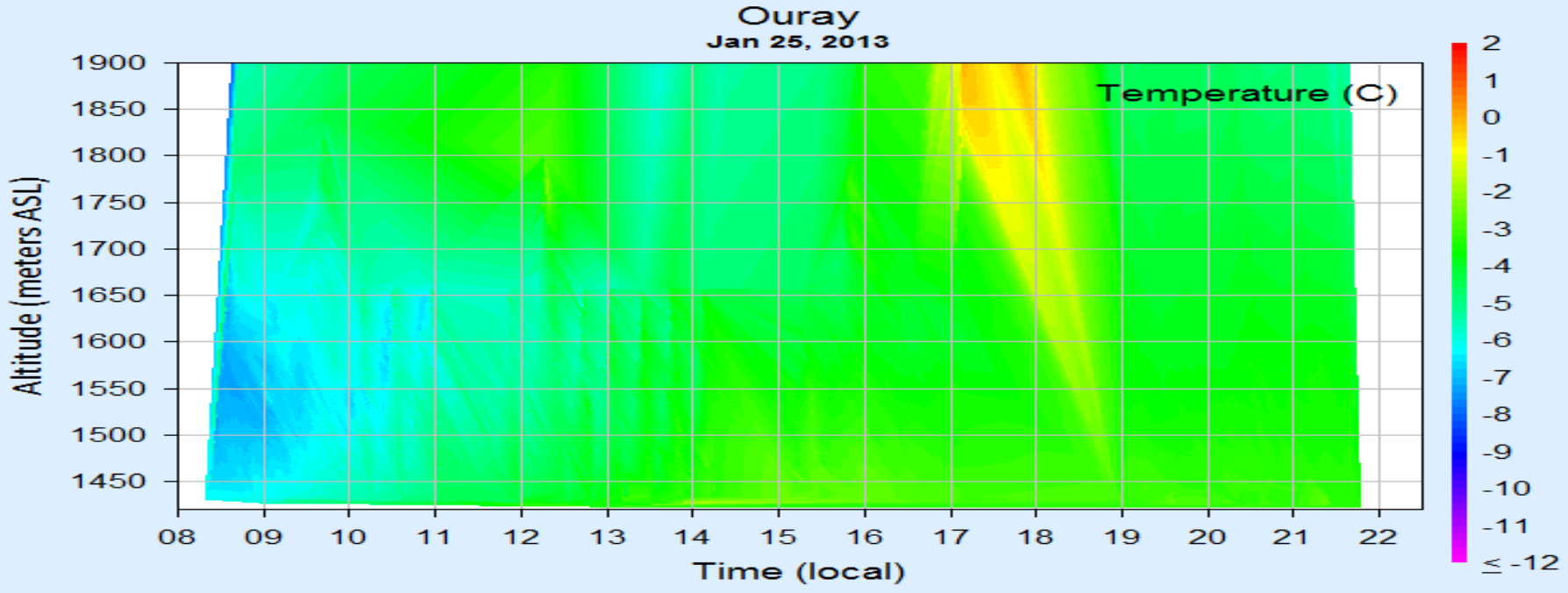

FC Feb-05 16:16
OU Feb-05 16:23
HP Feb-05 14:48
Altitude (meters ASL)
2200
2100
2000
1900
1800
1700
1600
1500
1400
20
40
60
80
100
120
140
160
18
Ozone (ppbv)
-12
-10
-8
-6
-4
-2
0
2
Temperature (C)

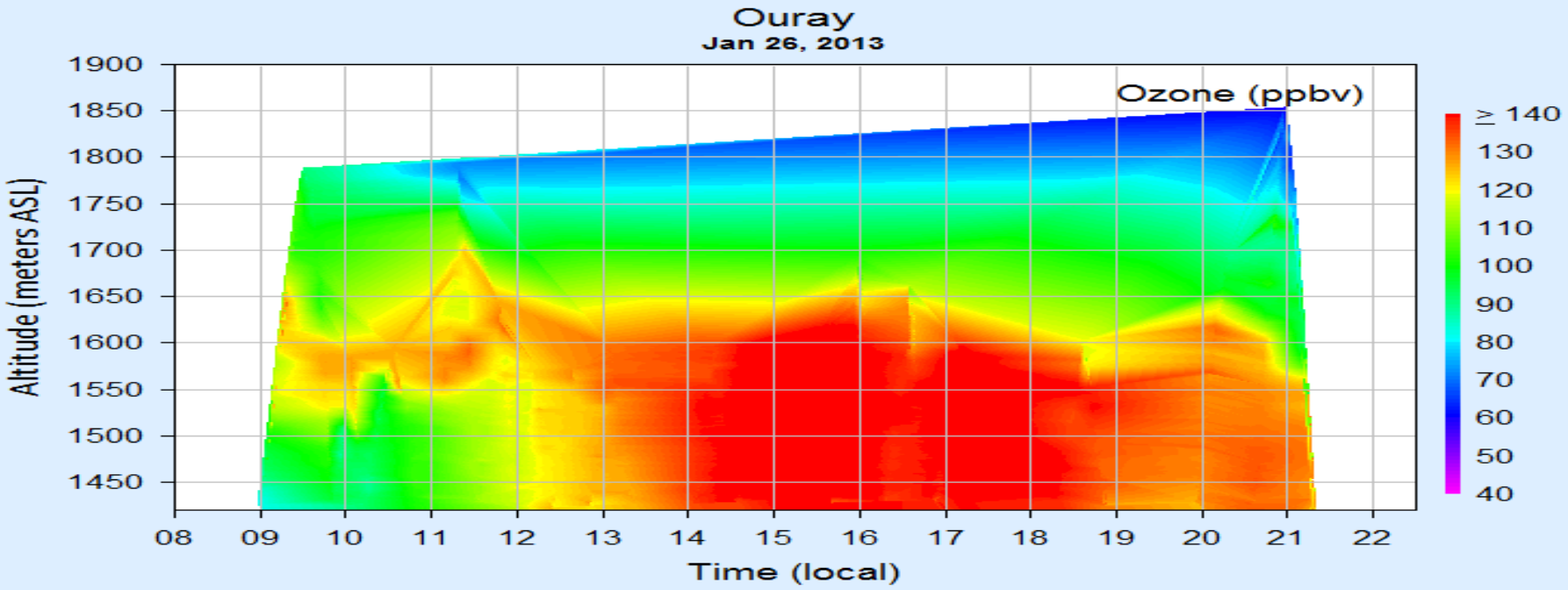

Horse Pool Feb-18-2013
Altitude (meters ASL)
2000
1900
1800
1700
1600
1500
1400
0 20 40 60 80 100 120 140 160
Ozone (ppbv)
-16 -14 -12 -10 -8 -6 -4 -2 0 2 4
Temperature (C)

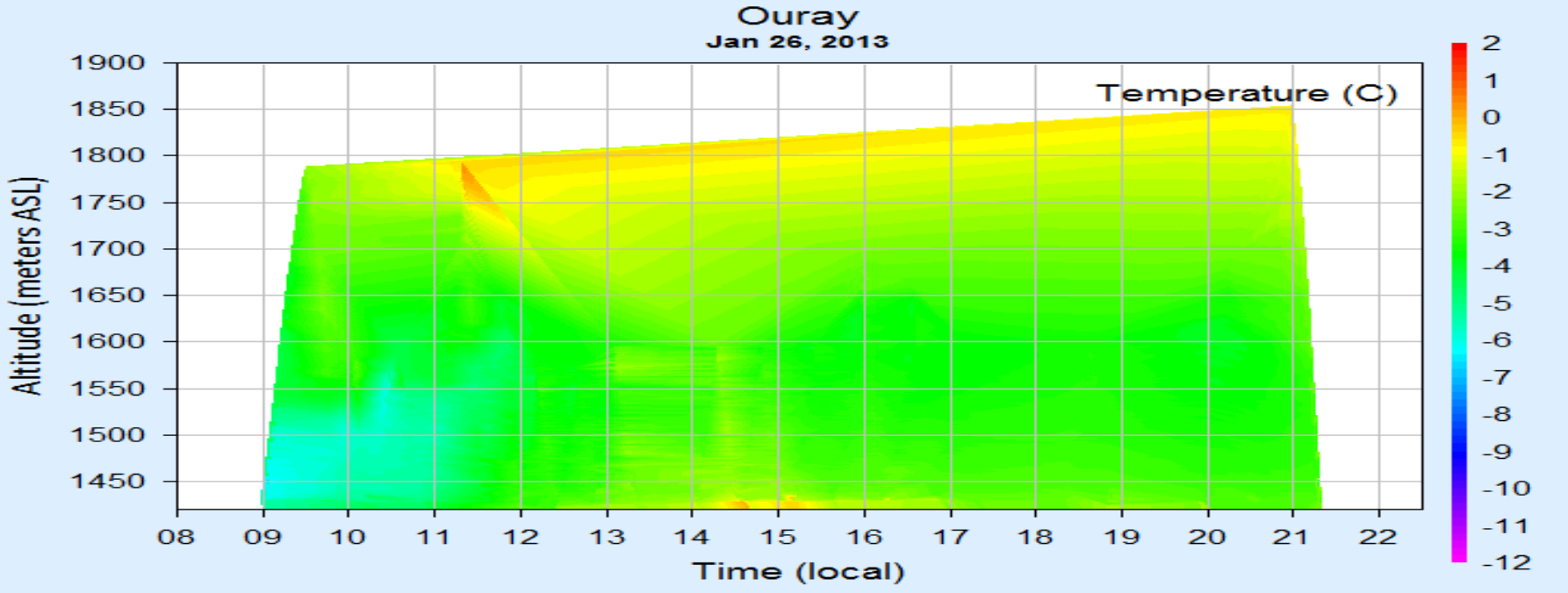

Ouray
Jan 24, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
140
130
120
110
100
90
80
70
60
50
40

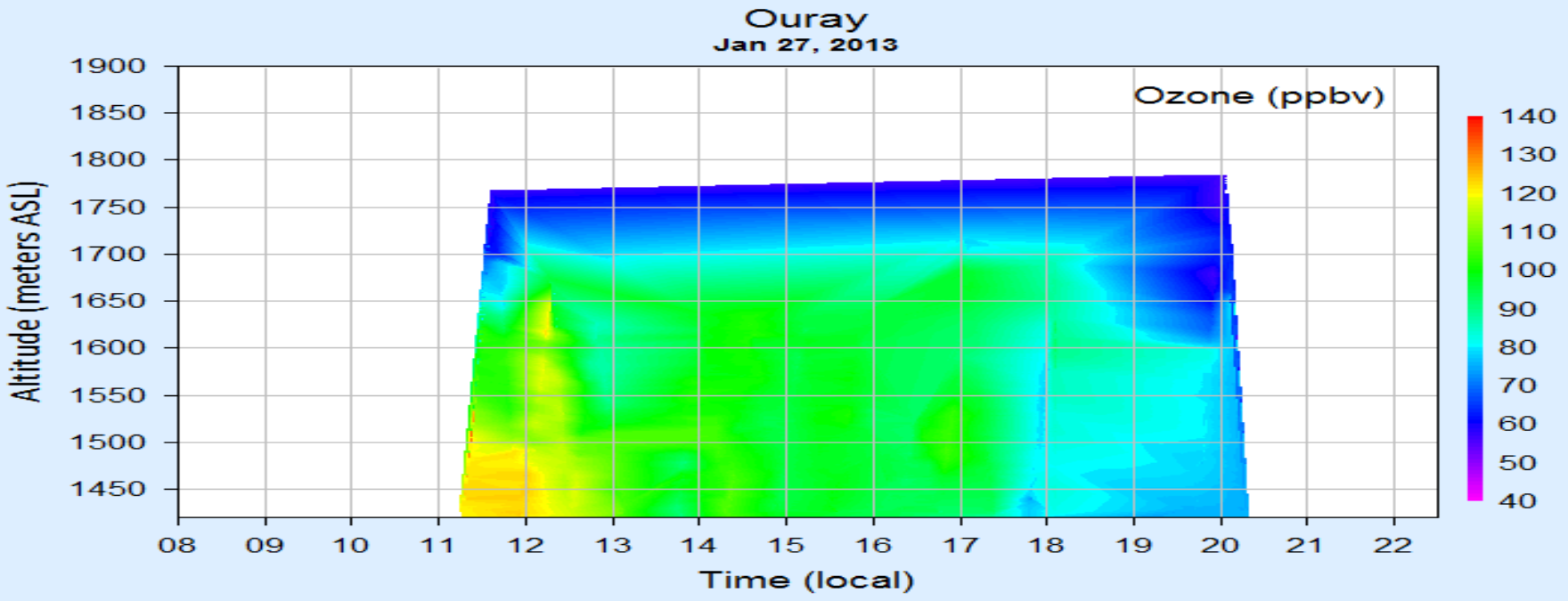

Ouray
Jan 24, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
≤ -12

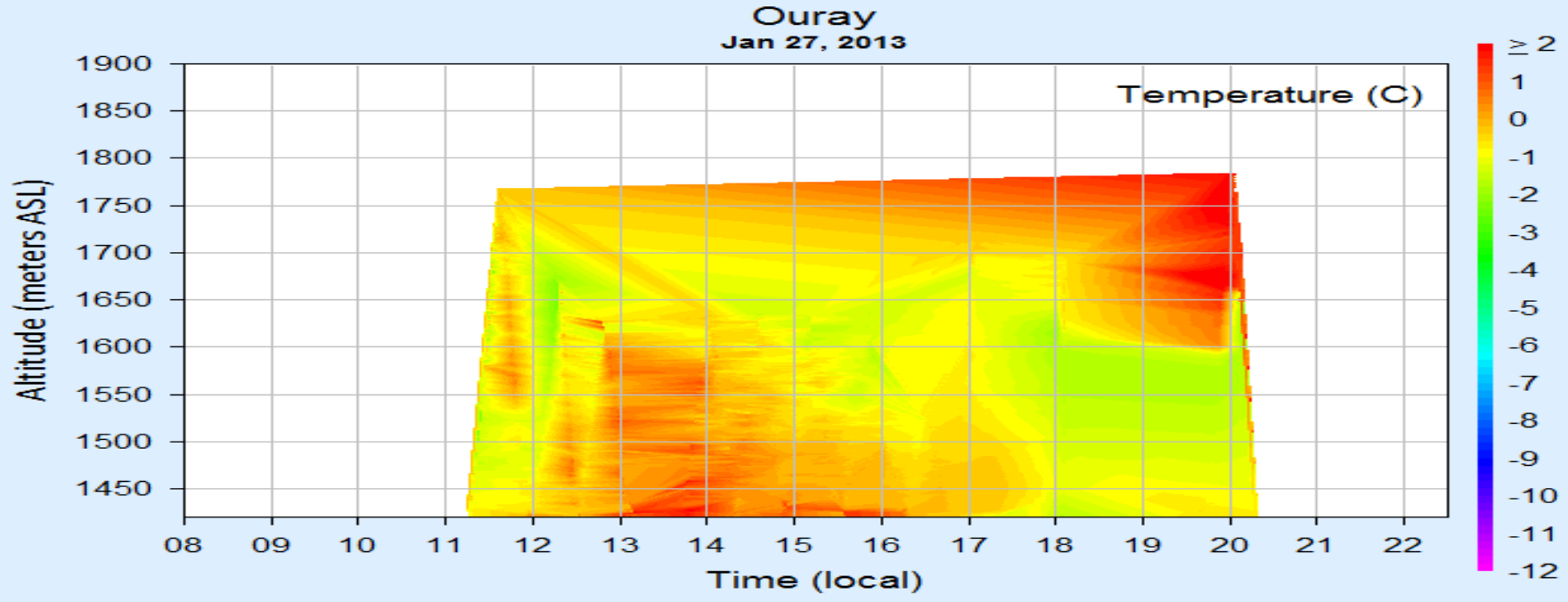

Ouray
Jan 25, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
≥ 140
130
120
110
100
90
80
70
60
50
40

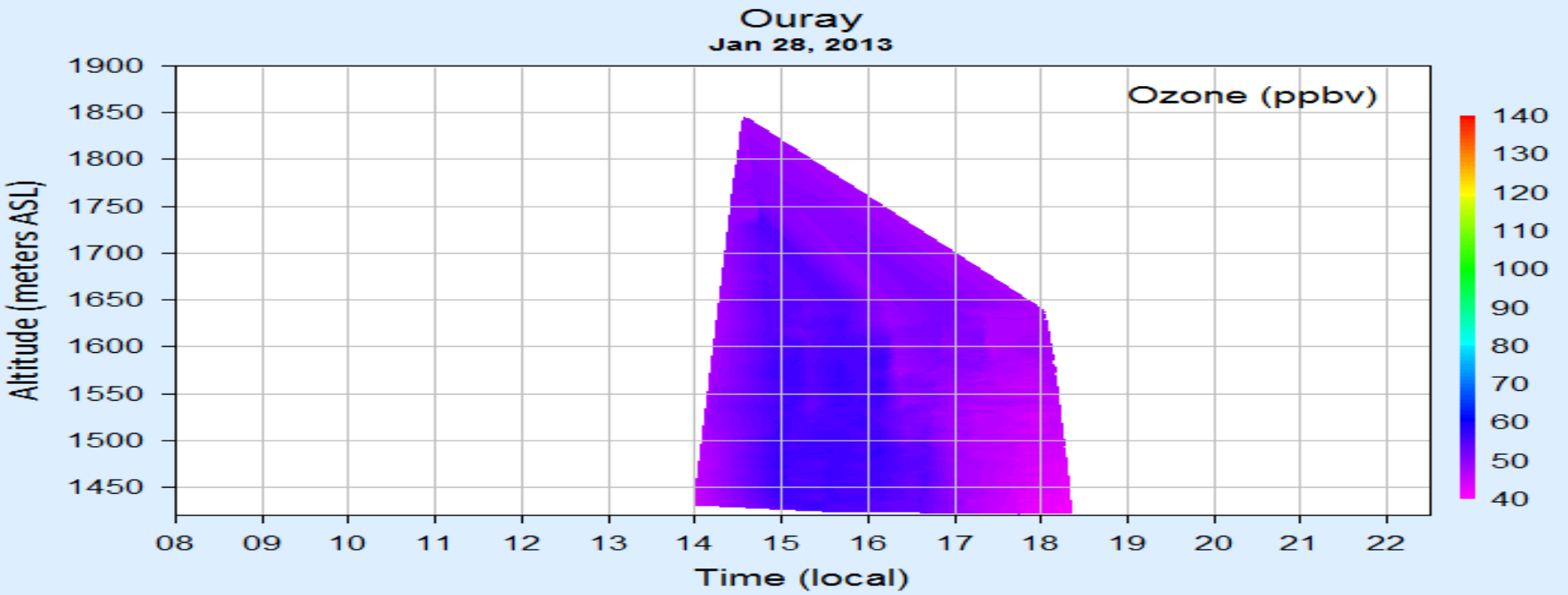

Ouray
Jan 25, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
≤ -12

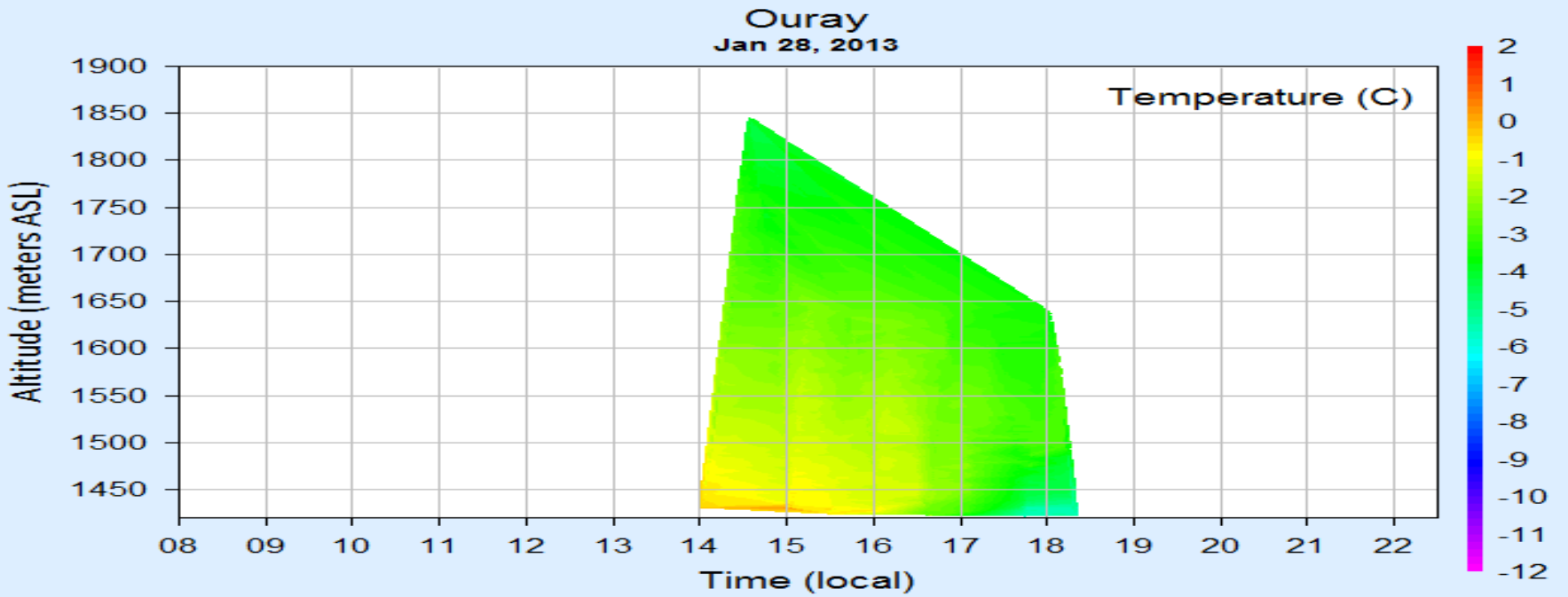

Ouray
Jan 26, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
≥ 140
130
120
110
100
90
80
70
60
50
40

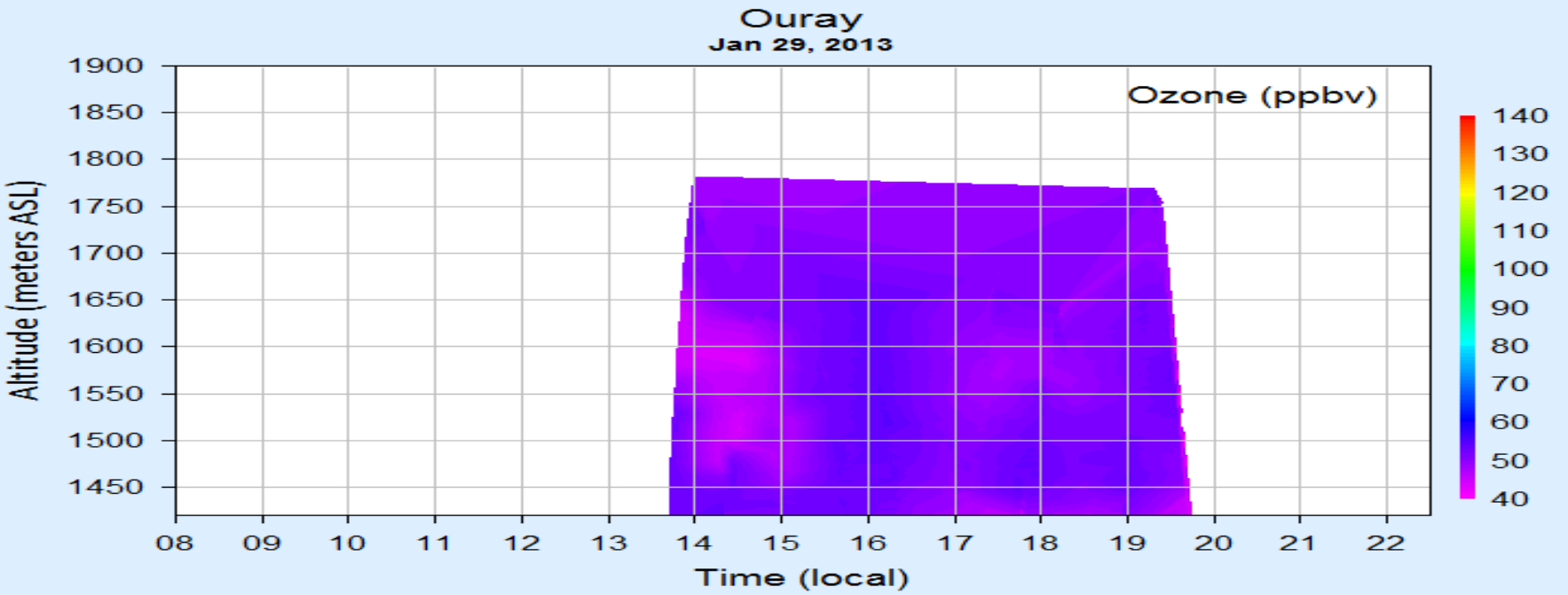

Ouray
Jan 26, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12

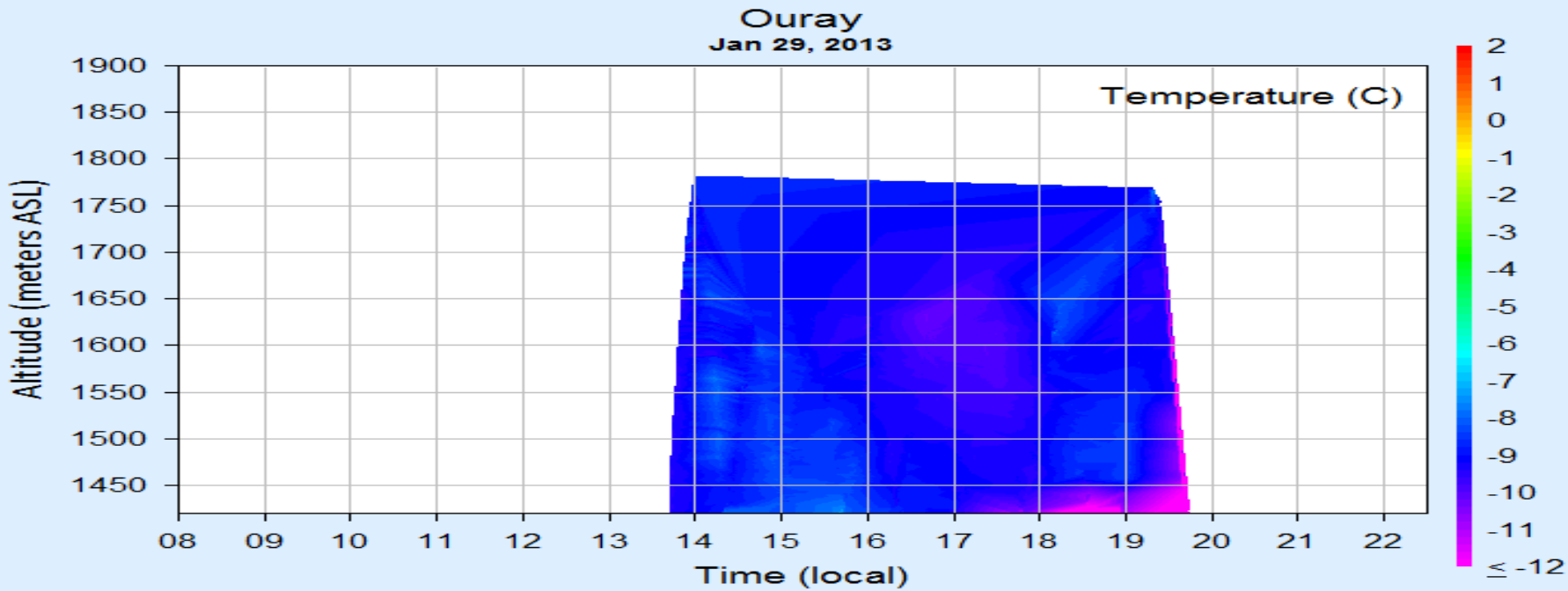

Ouray
Jan 27, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
140
130
120
110
100
90
80
70
60
50
40

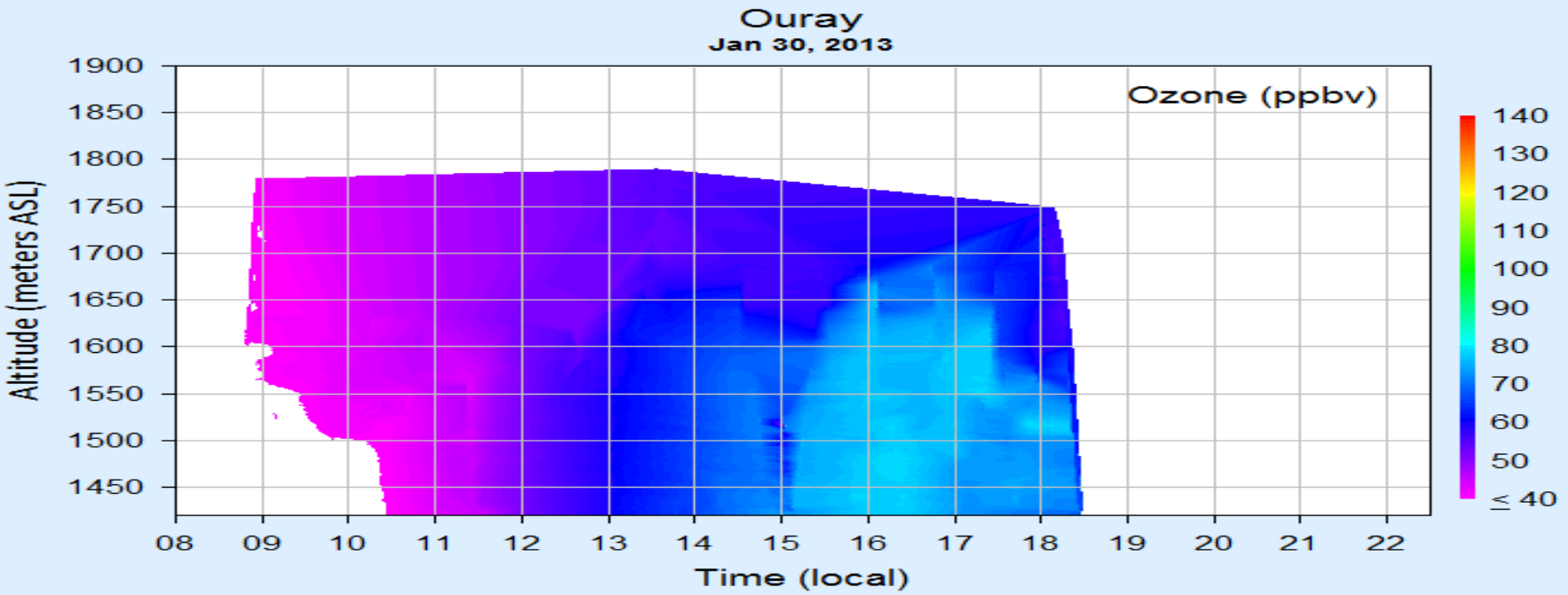

Ouray
Jan 27, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
≥ 2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12

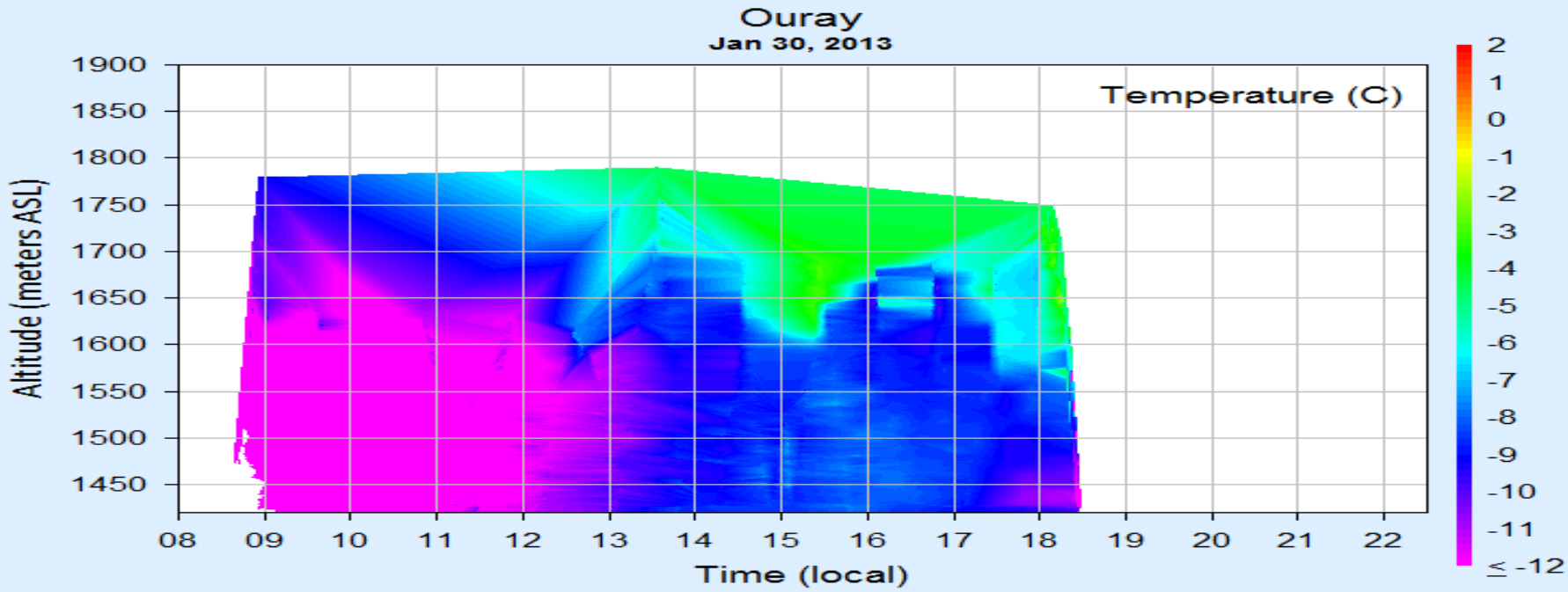

Ouray
Jan 28, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08 09 10 11 12 13 14 15 16 17 18 19 20 21 22
Time (local)
140
130
120
110
100
90
80
70
60
50
40

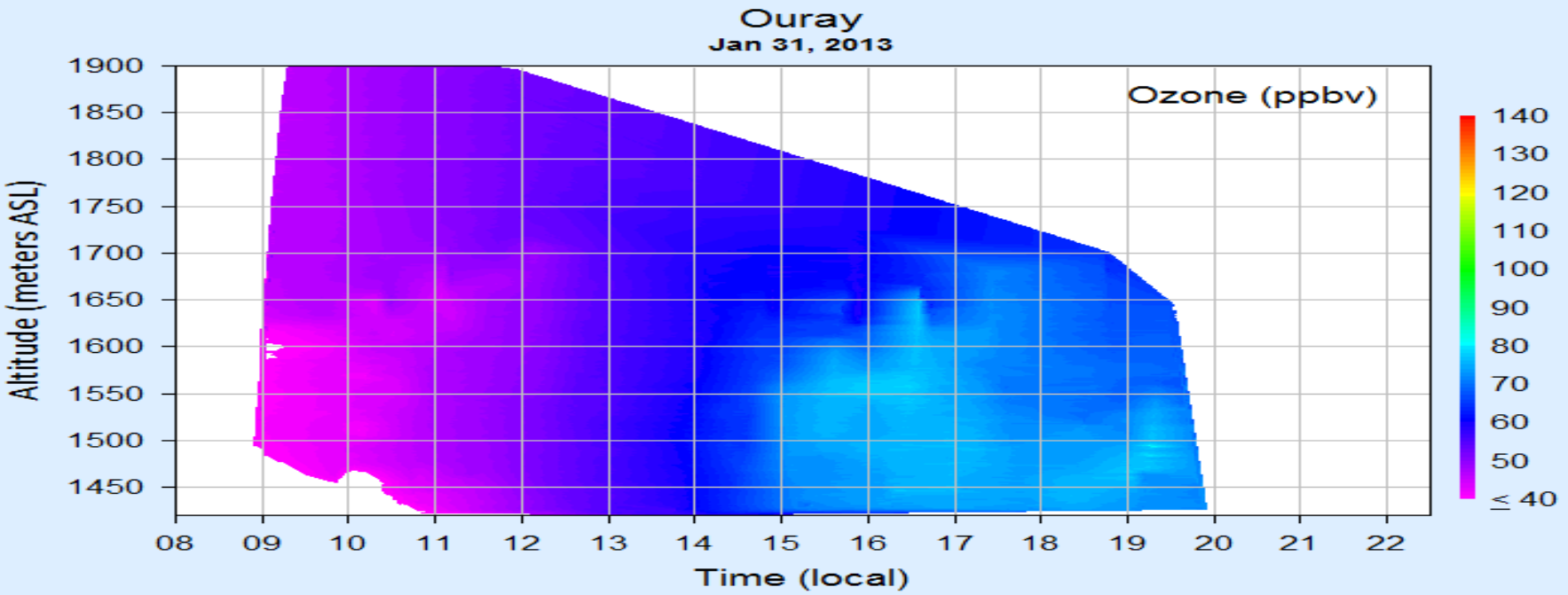

Ouray
Jan 28, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08 09 10 11 12 13 14 15 16 17 18 19 20 21 22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12

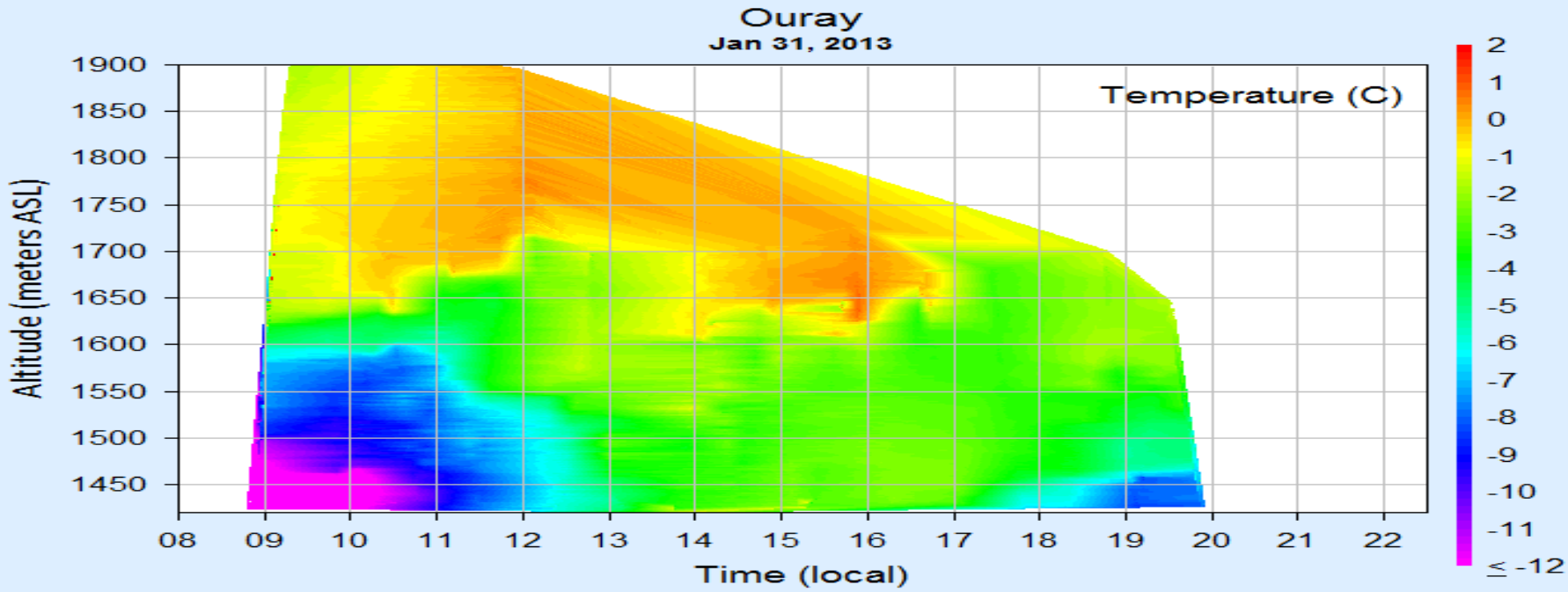

Ouray
Jan 29, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
140
130
120
110
100
90
80
70
60
50
40

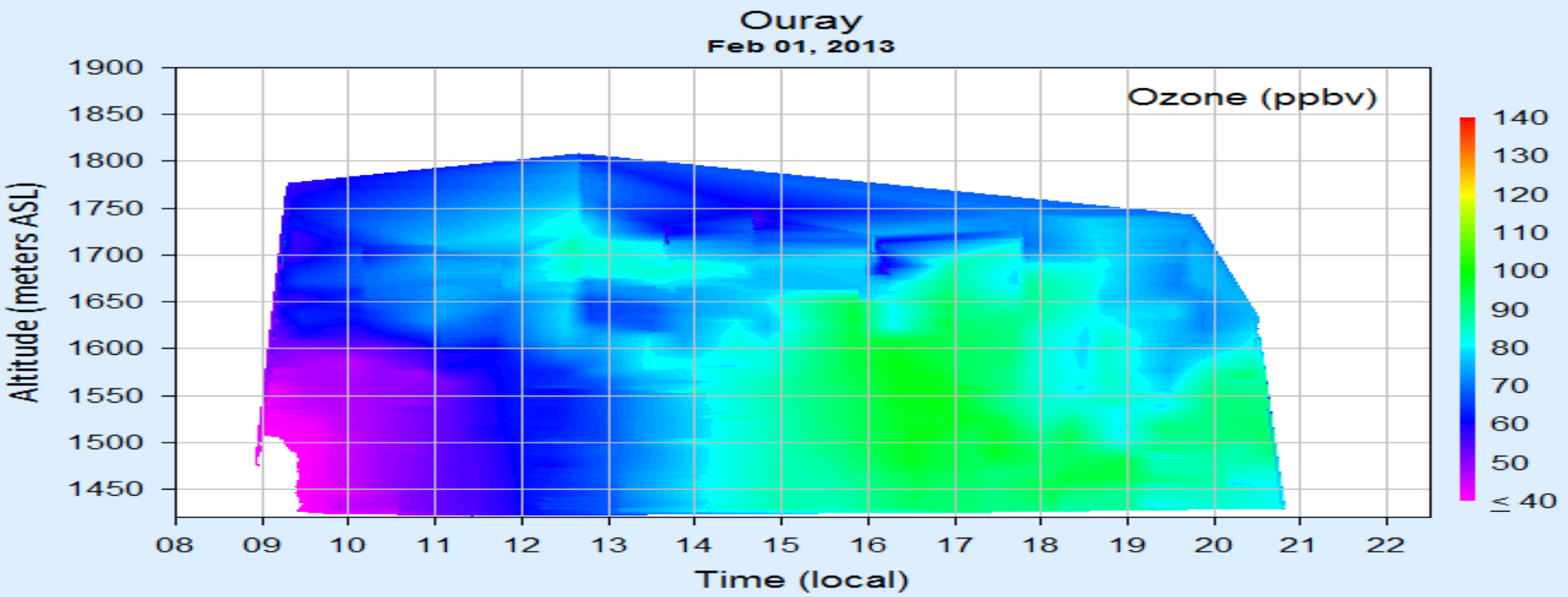

Ouray
Jan 29, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
≤ -12

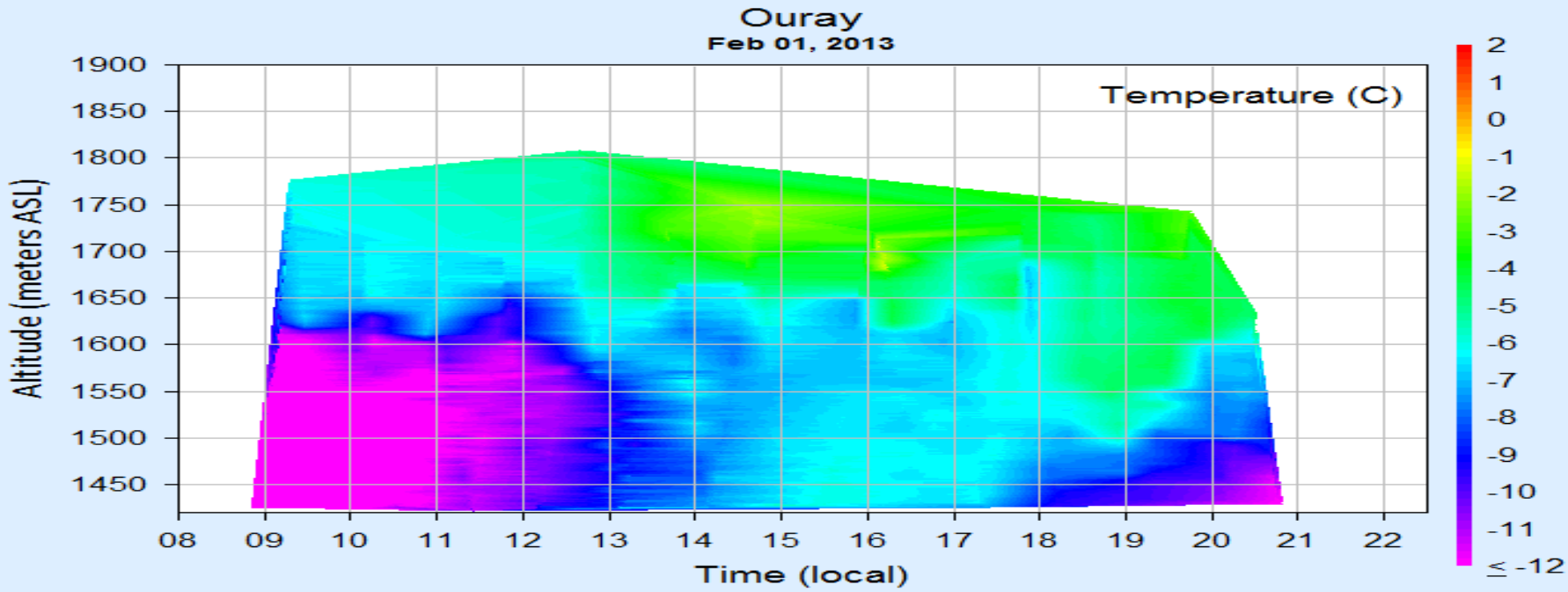

Ouray
Jan 30, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
140
130
120
110
100
90
80
70
60
50
≤ 40

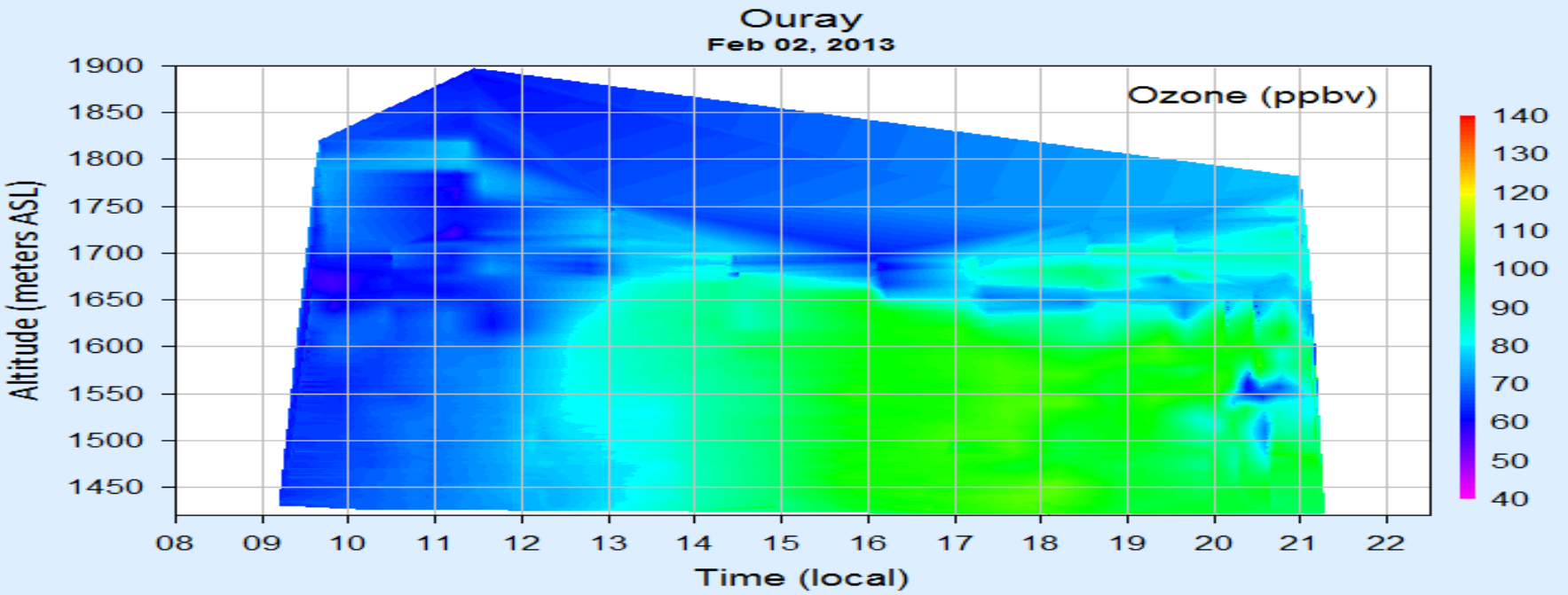

Ouray
Jan 30, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
≤ -12

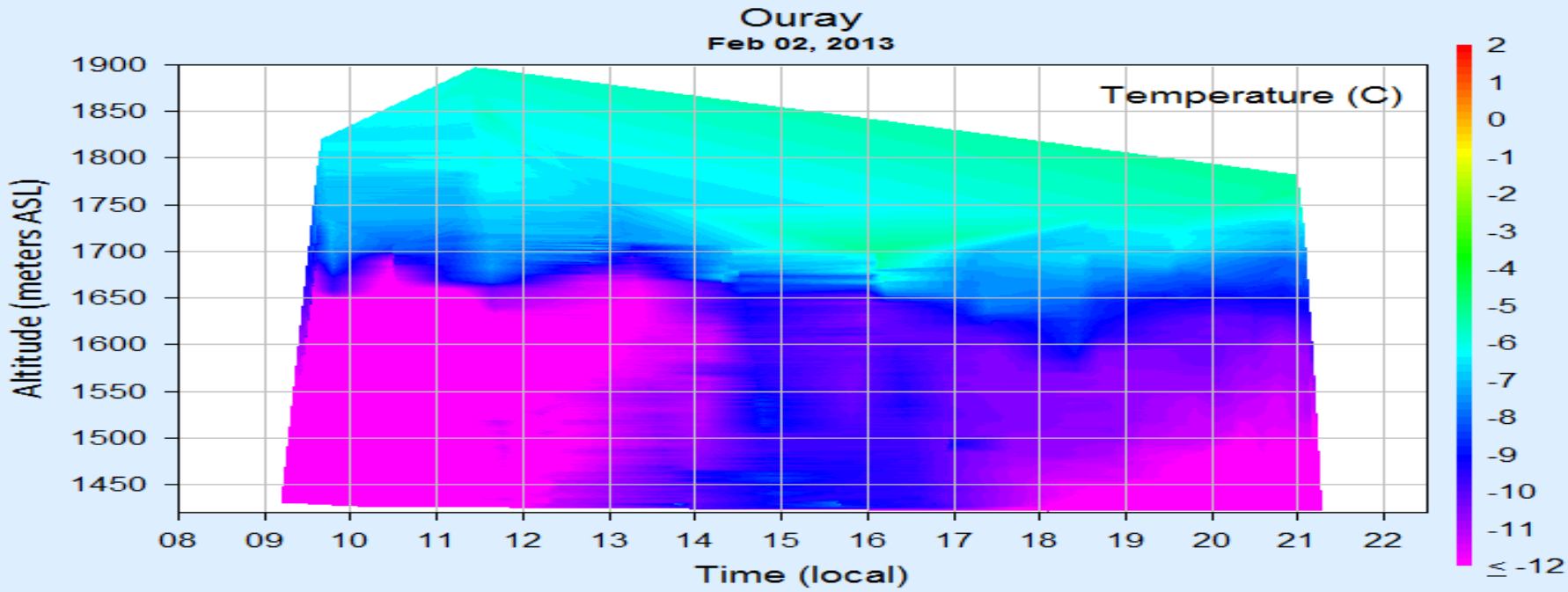

Ouray
Jan 31, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
140
130
120
110
100
90
80
70
60
50
≤ 40

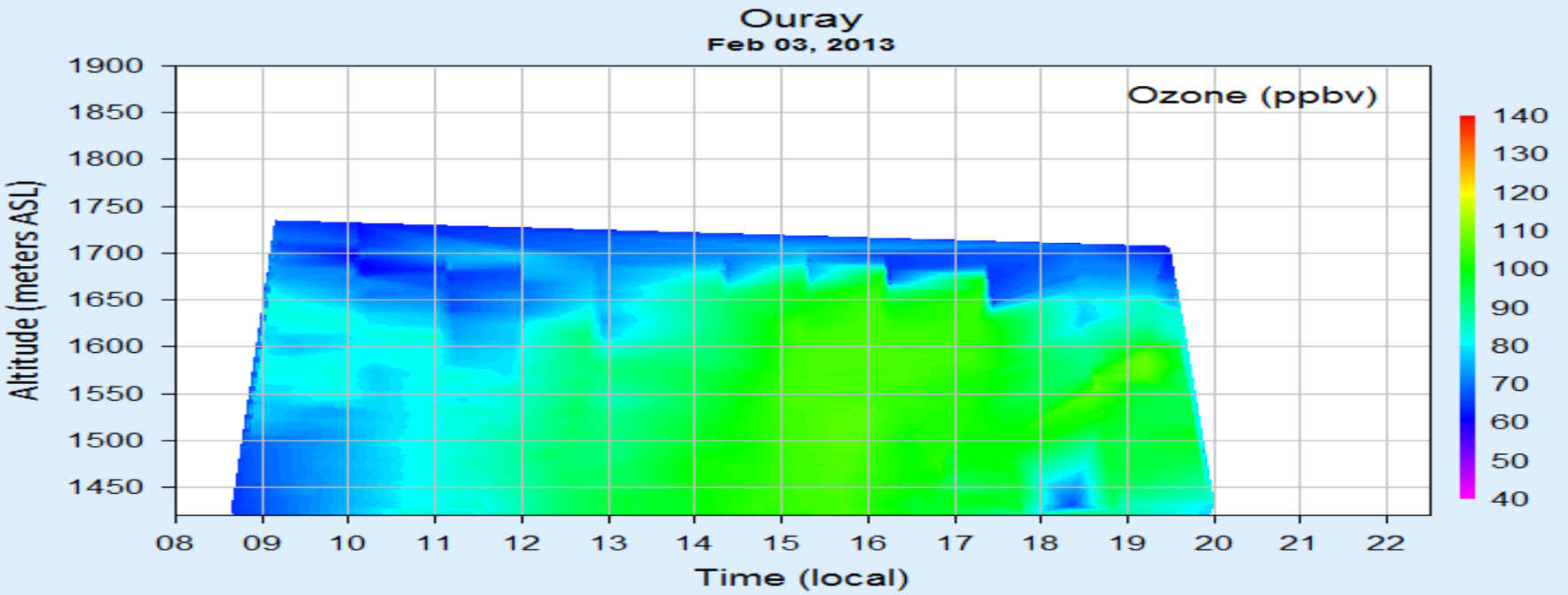

Ouray
Jan 31, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
≤ -12

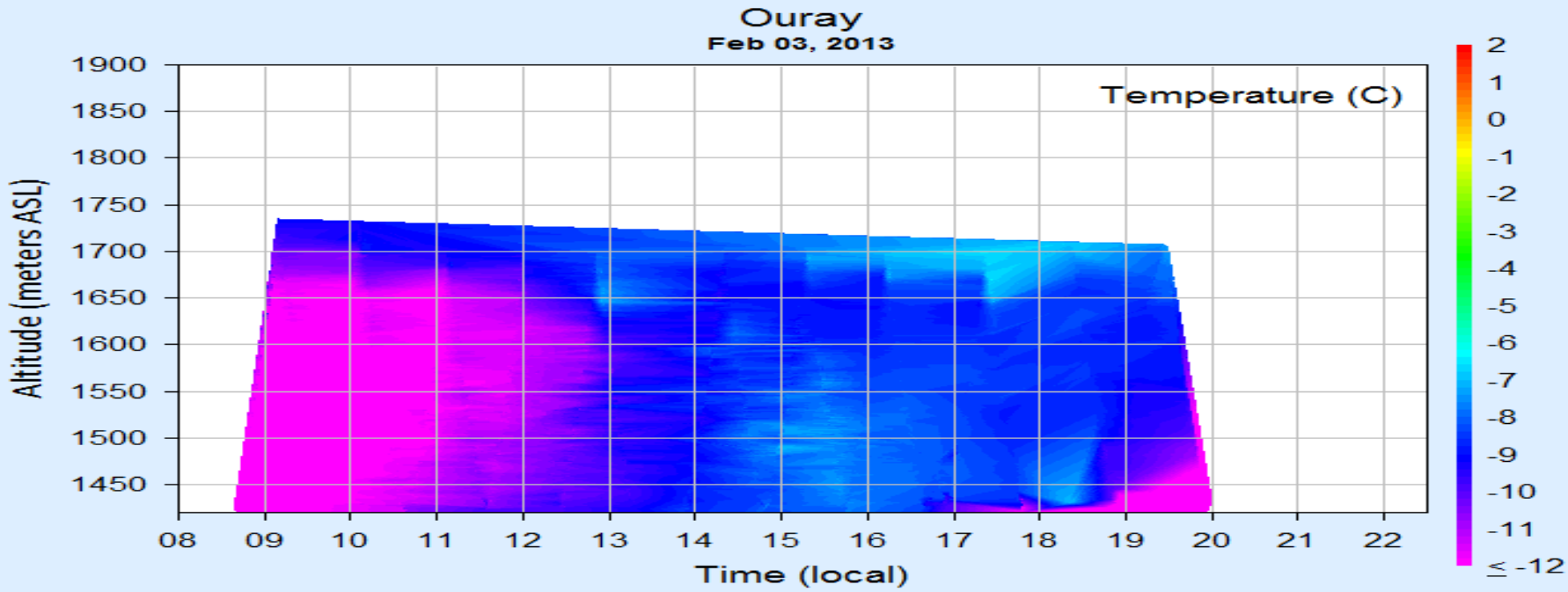

Ouray
Feb 01, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
140
130
120
110
100
90
80
70
60
50
≤ 40

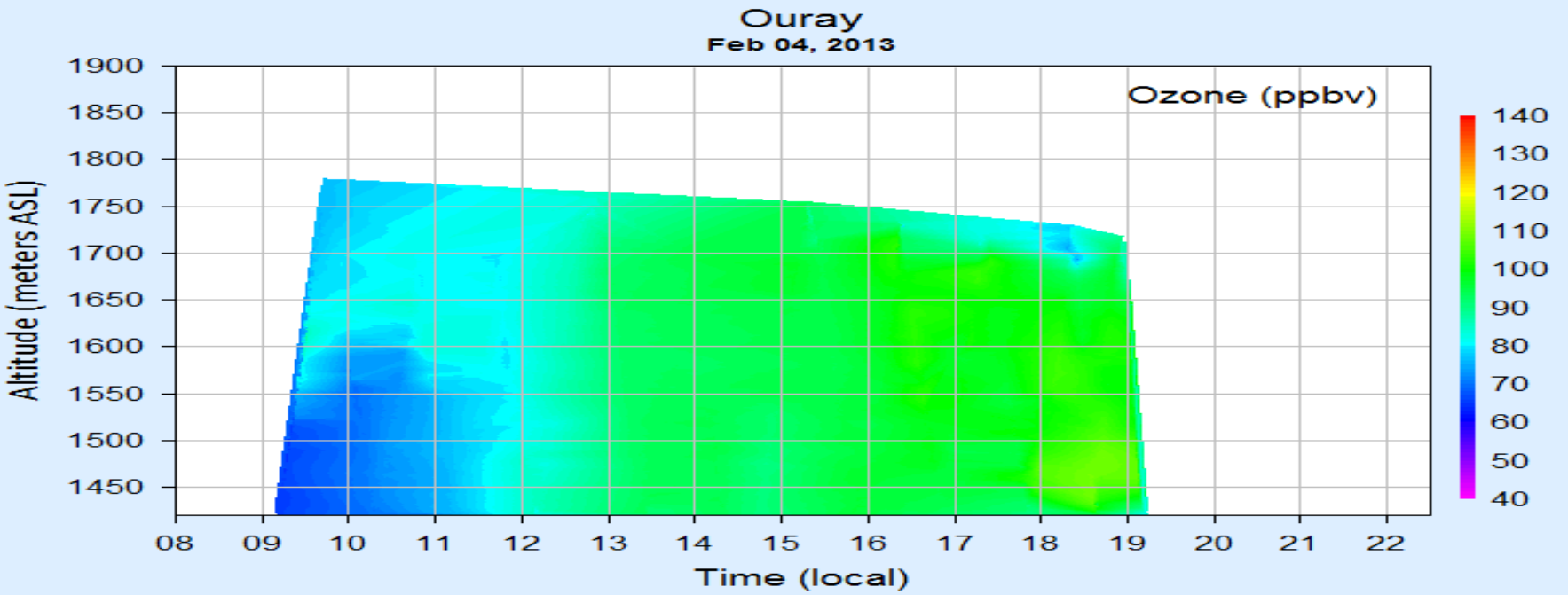

Ouray
Feb 01, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
≤ -12

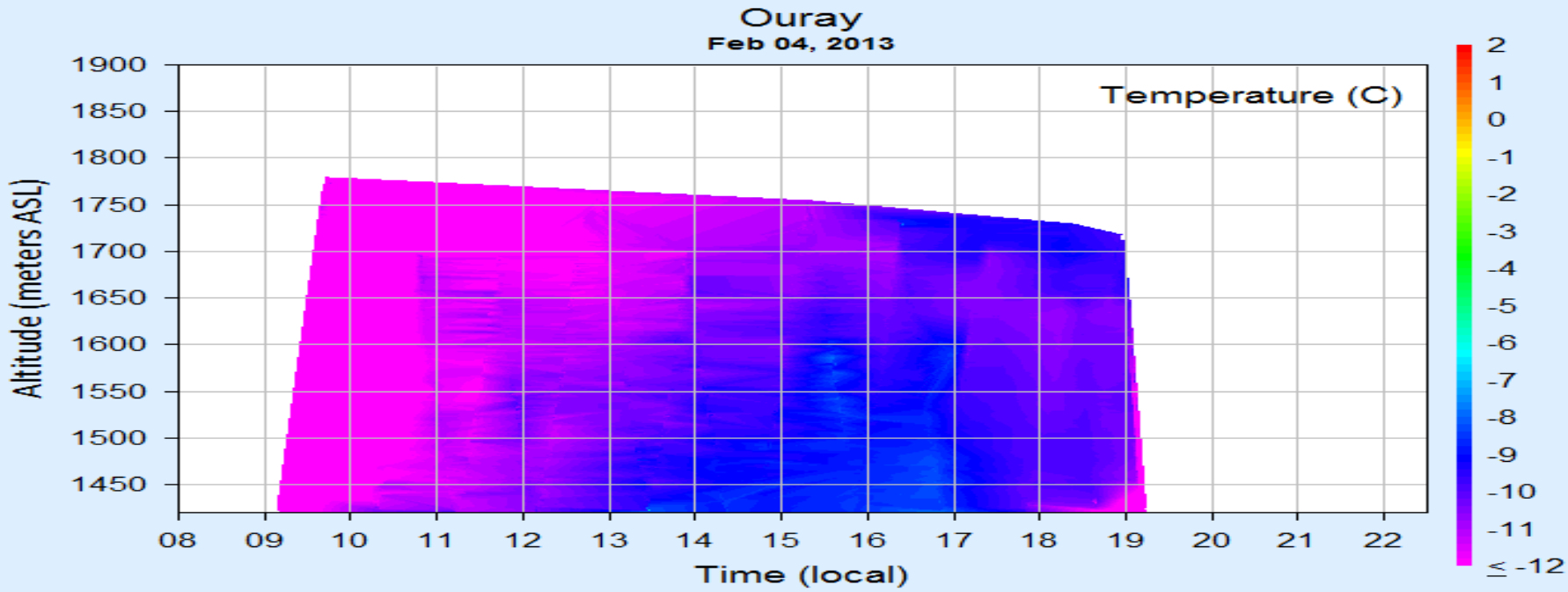

Ouray
Feb 02, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
140
130
120
110
100
90
80
70
60
50
40

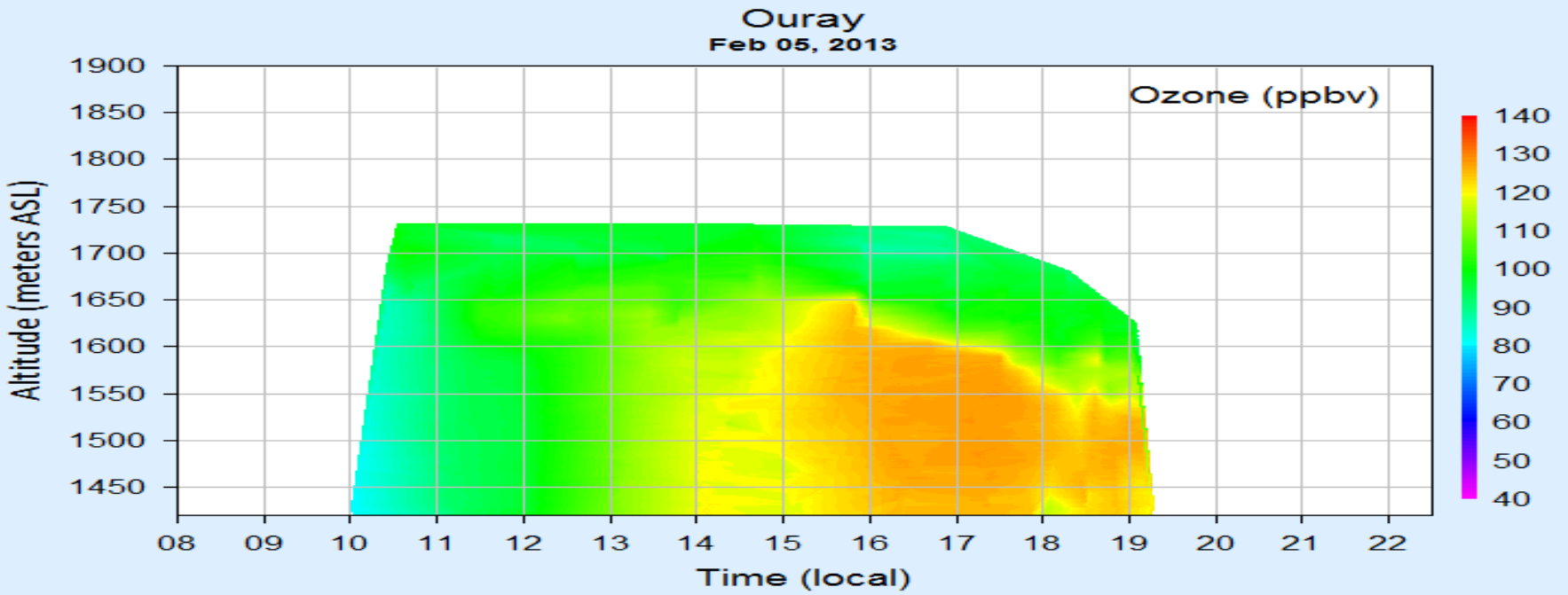

Ouray
Feb 02, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
≤ -12

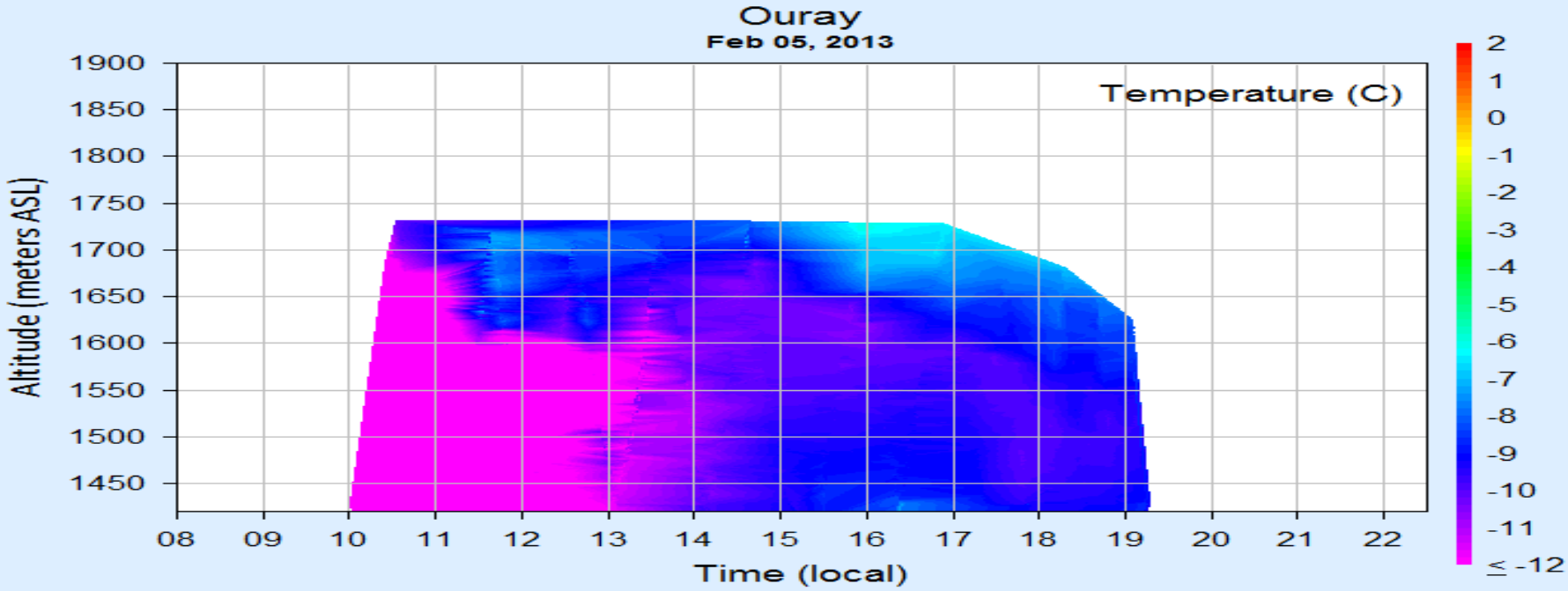

Ouray
Feb 03, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
140
130
120
110
100
90
80
70
60
50
40
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)

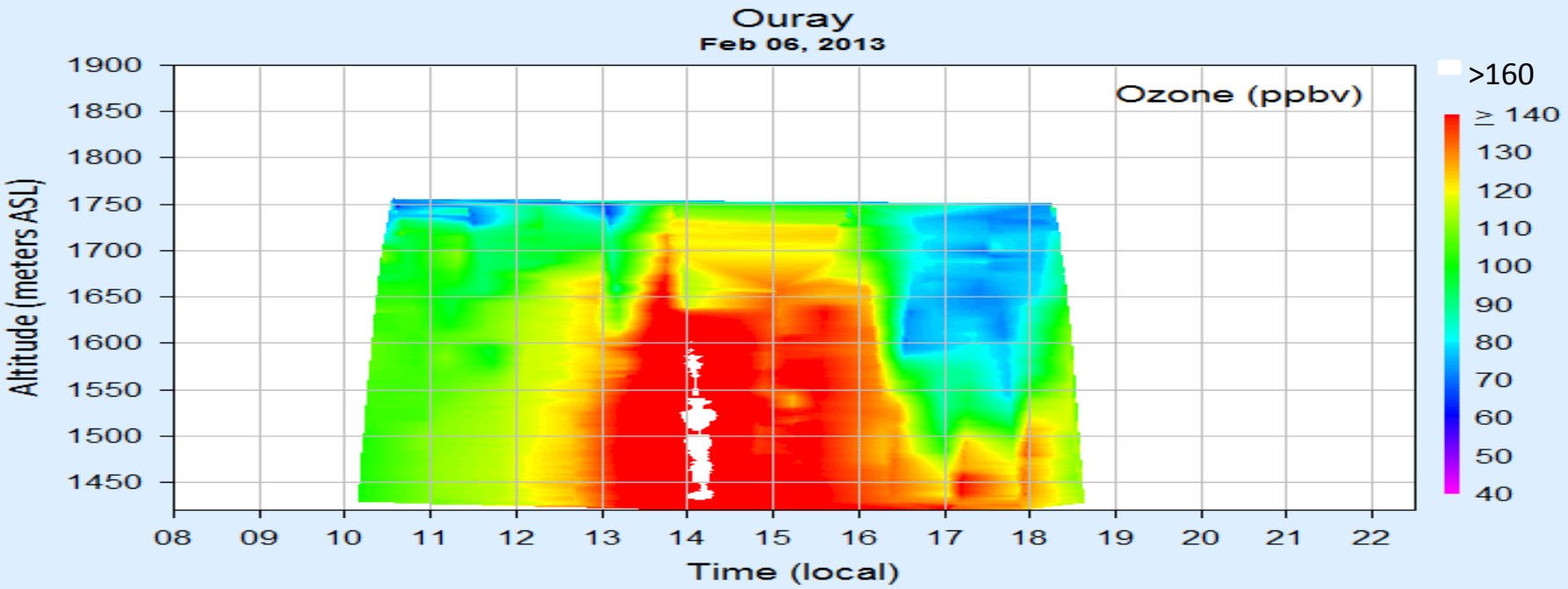

Ouray
Feb 03, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
≤ -12
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)

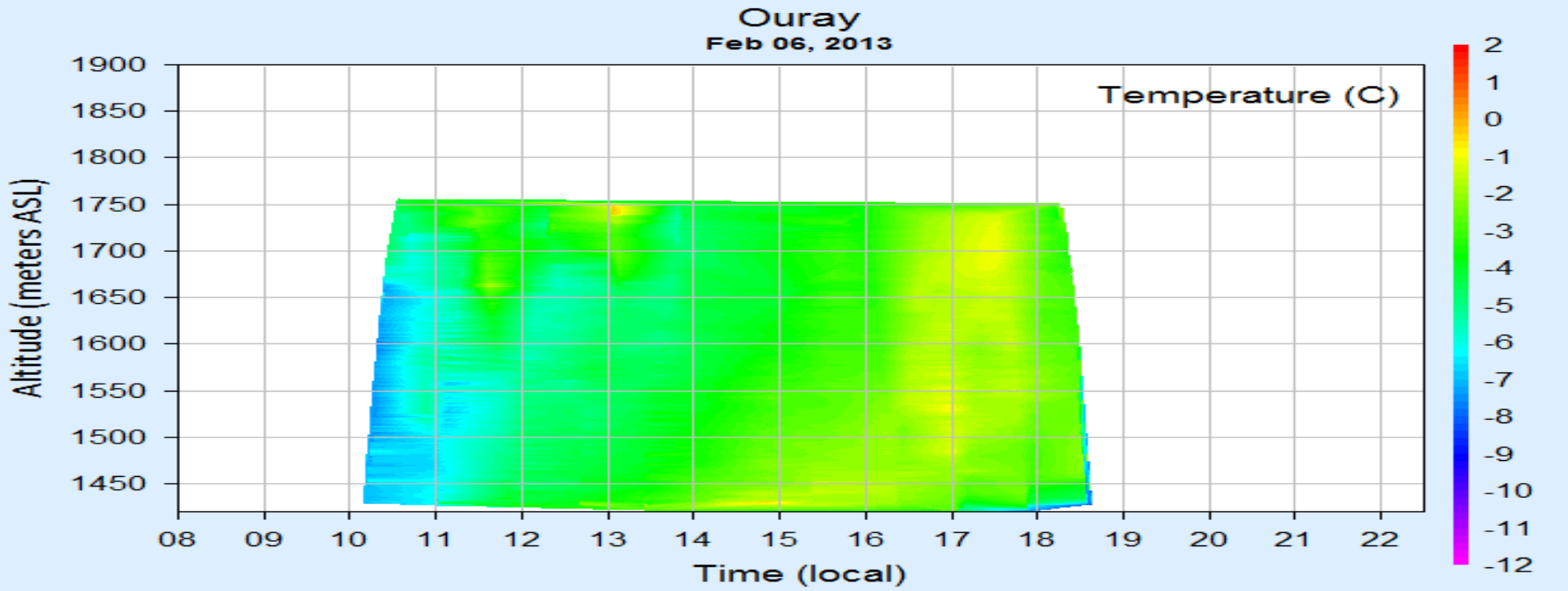

Ouray
Feb 04, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
140
130
120
110
100
90
80
70
60
50
40

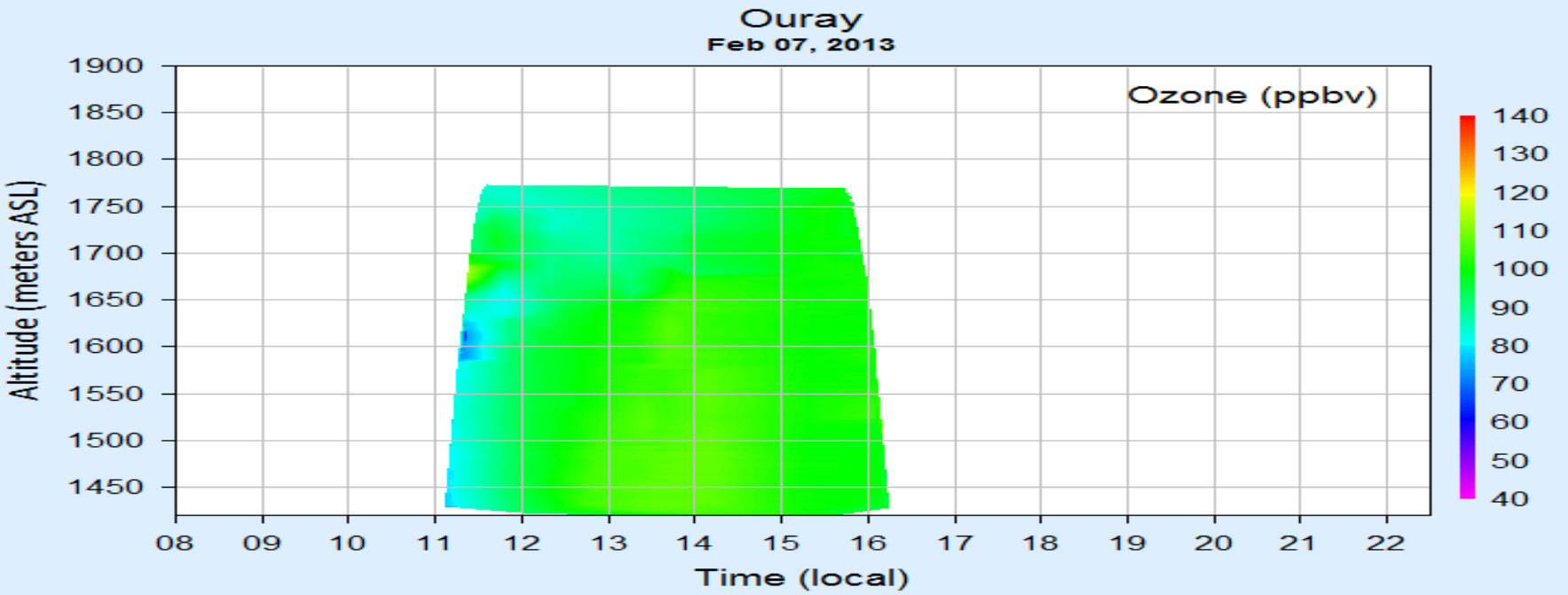

Ouray
Feb 04, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
≤ -12

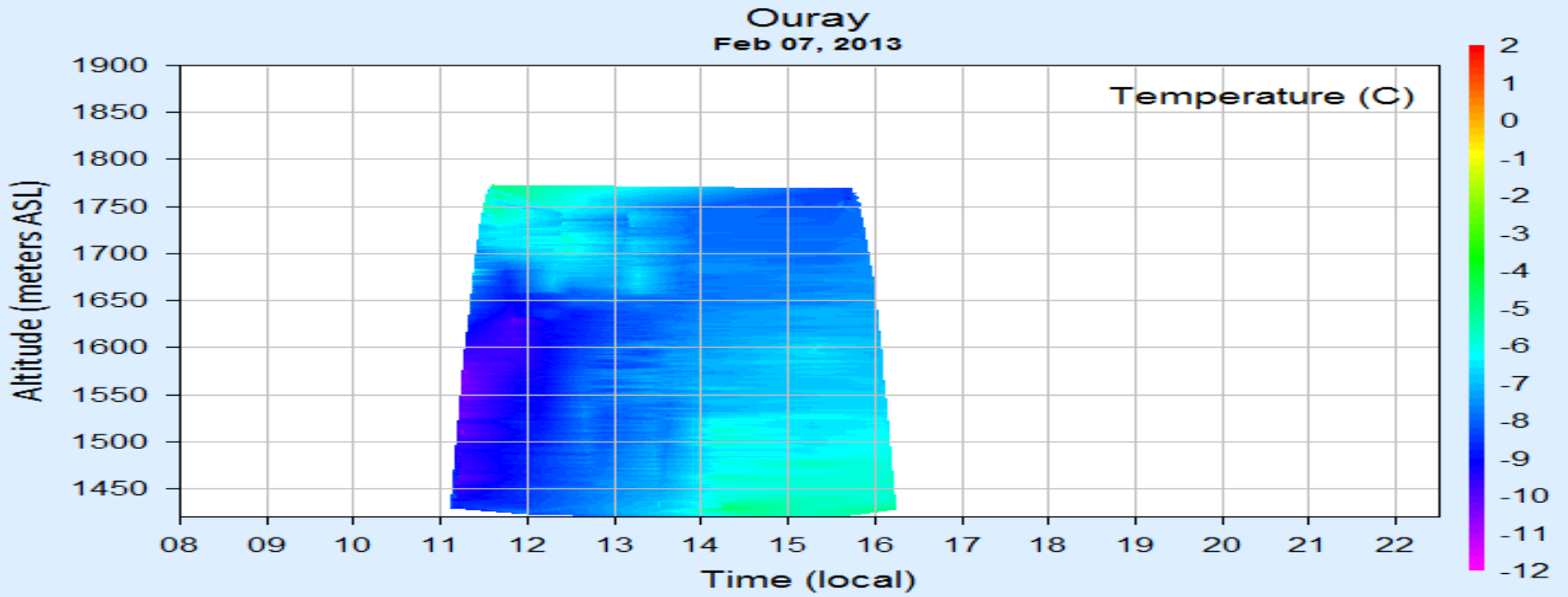

Ouray
Feb 05, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
140
130
120
110
100
90
80
70
60
50
40


Ouray
Feb 05, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
≤ -12


Ouray
Feb 06, 2013
Ozone (ppbv)
>160
≥ 140
130
120
110
100
90
80
70
60
50
40
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)

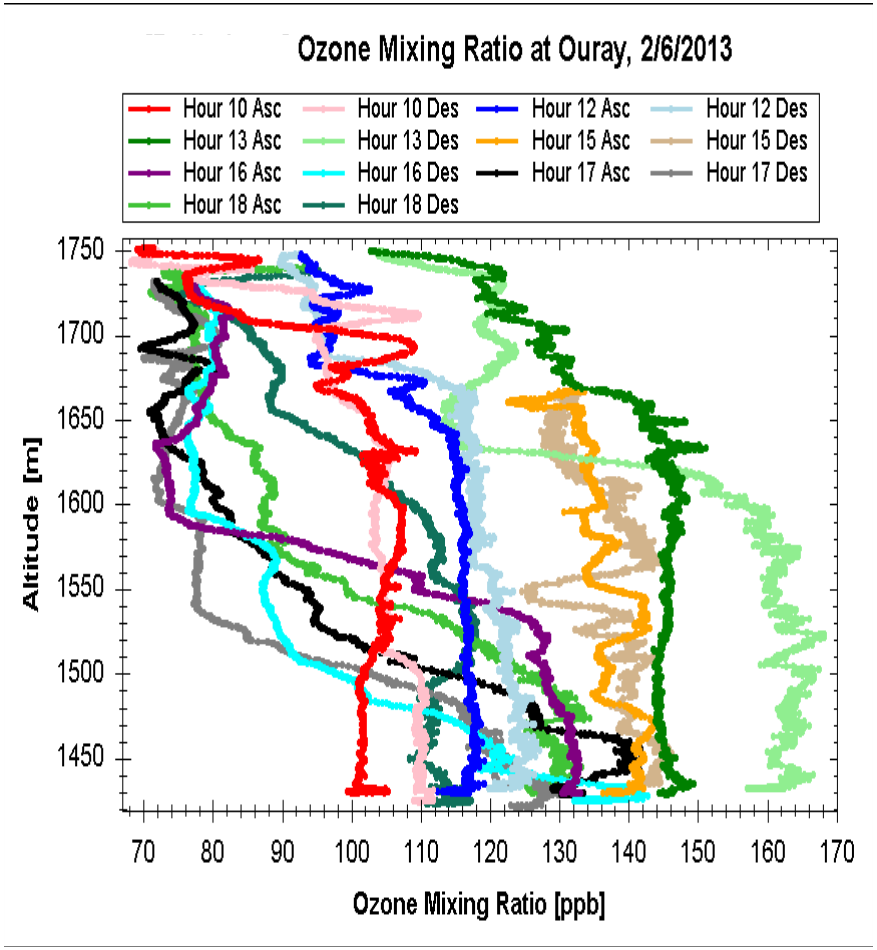

Ouray
Feb 06, 2013
Temperature (C)
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)


Ouray
Feb 07, 2013
Ozone (ppbv)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
140
130
120
110
100
90
80
70
60
50
40
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)

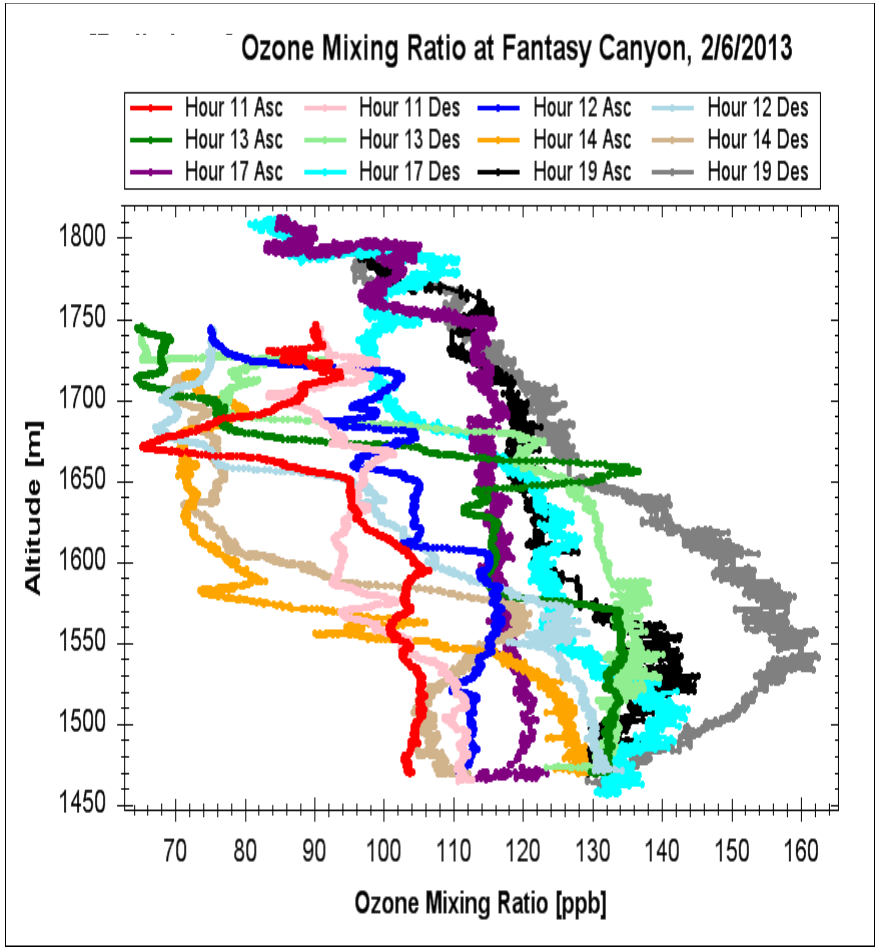

Ouray
Feb 07, 2013
Temperature (C)
Altitude (meters ASL)
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Time (local)

Uintah Basin, UT

Ouray

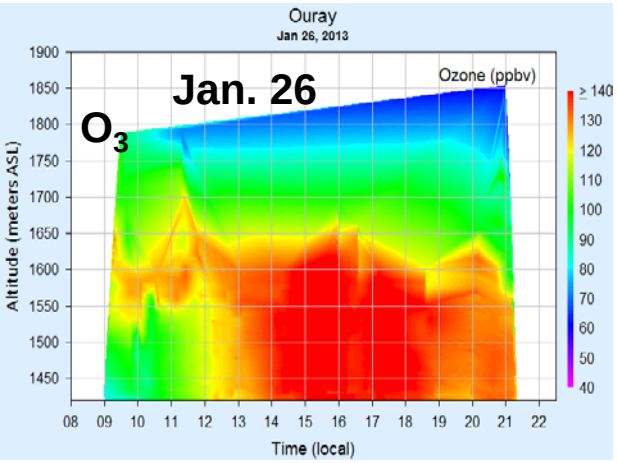


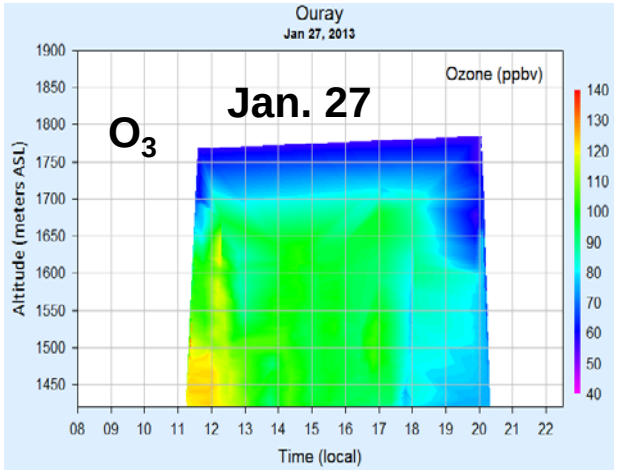
Fantasy Canyon

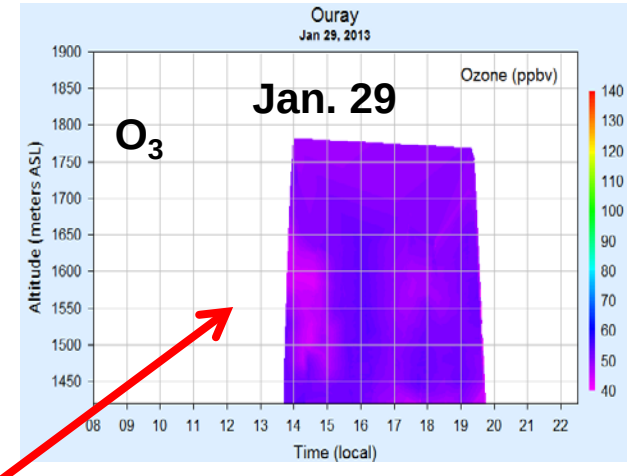


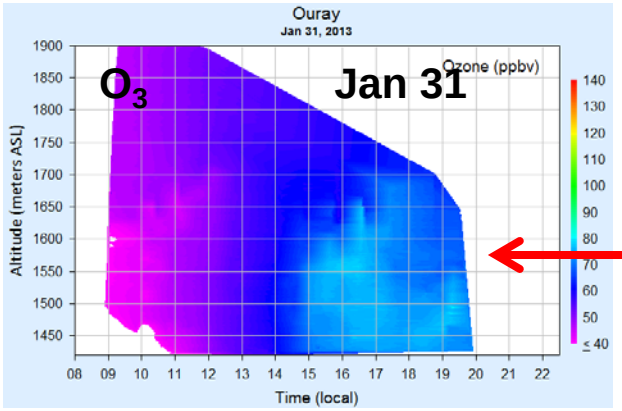
February 6, 2013

Tethered Balloon Profiles at Ouray

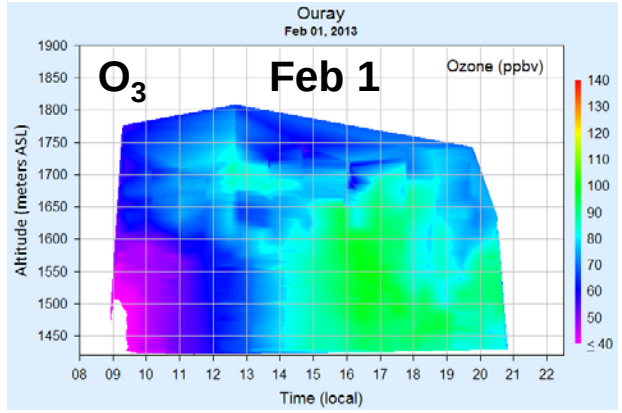


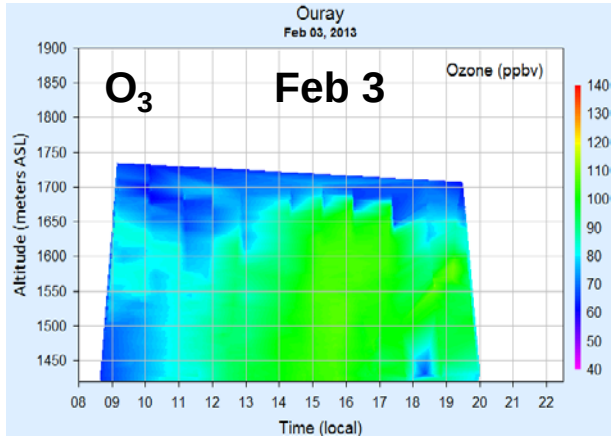


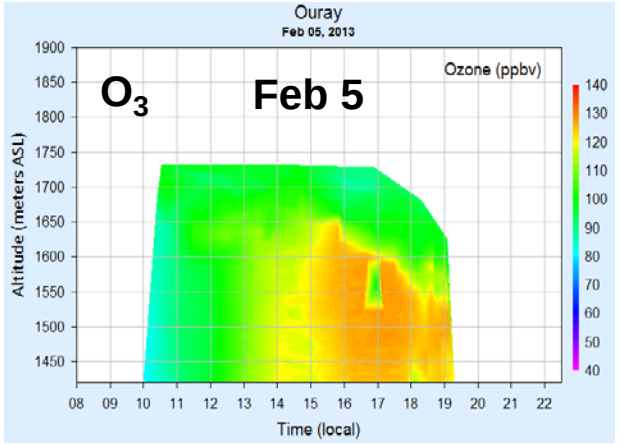


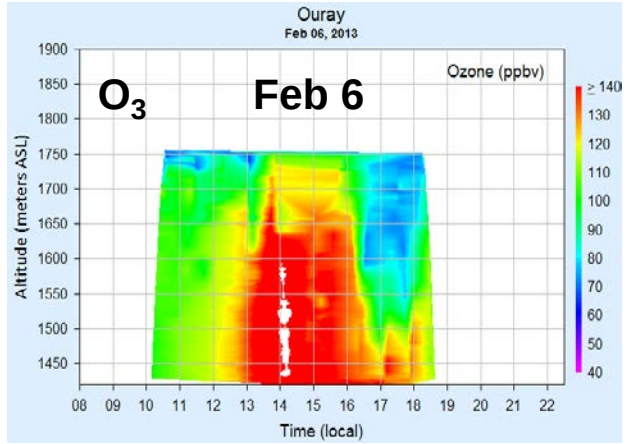


End of an event (Jan. 29). Beginning of the next event (Jan. 31))

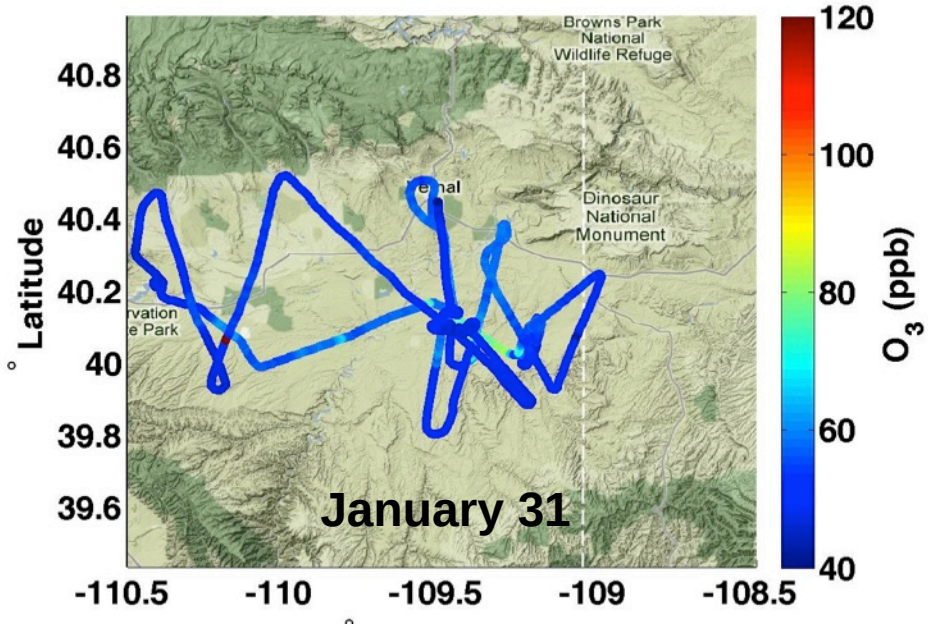


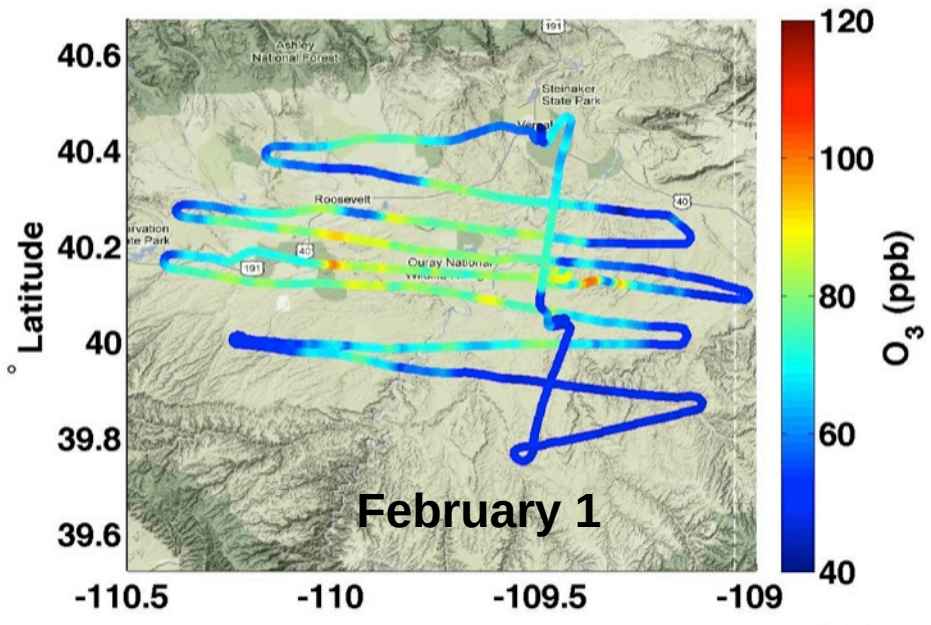


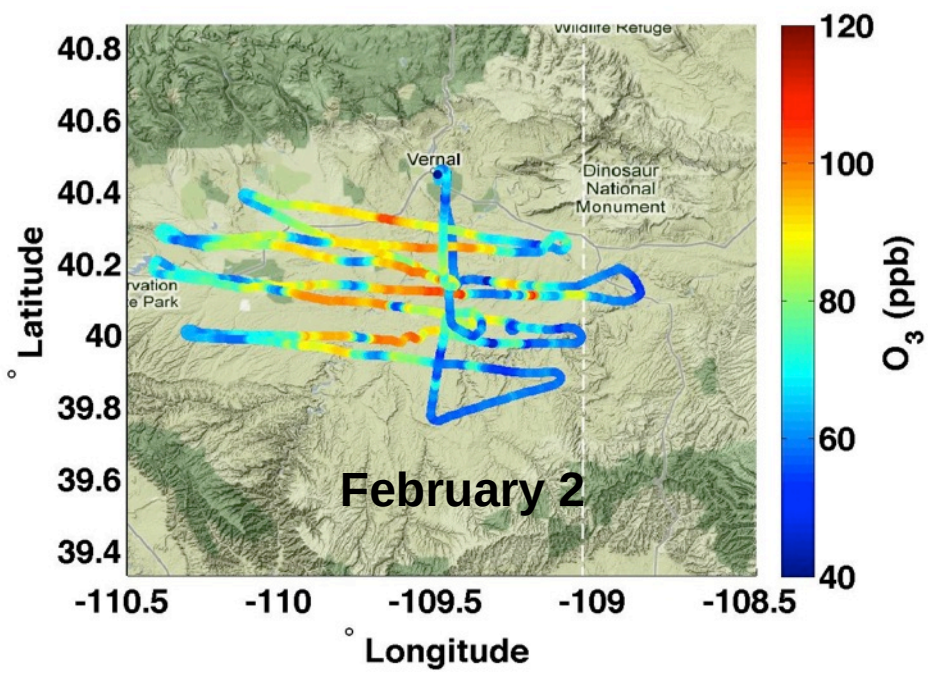


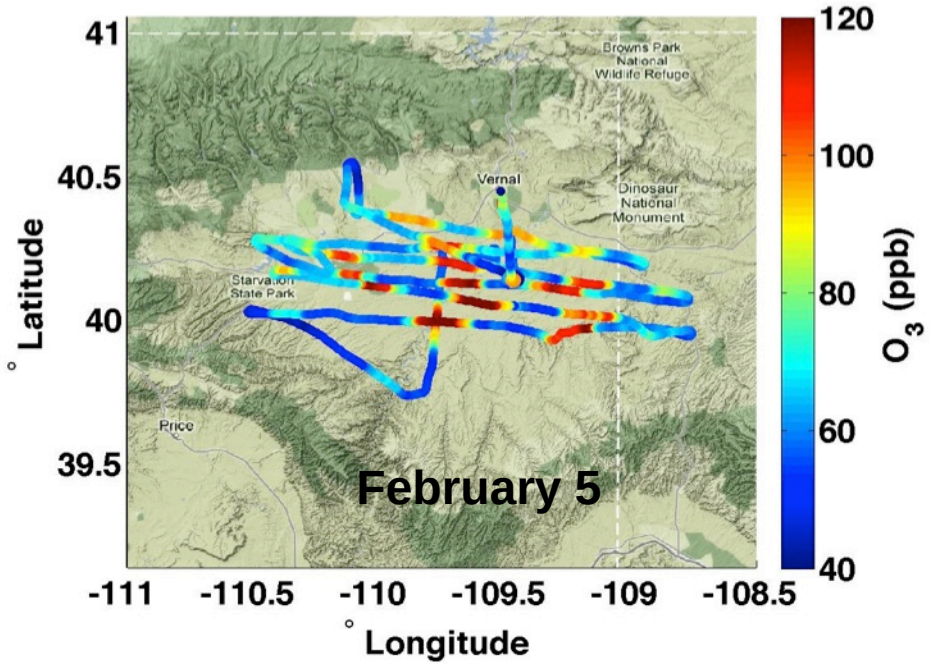


Ozone across the basin on Jan. 31, Feb. 1, 2, and 5

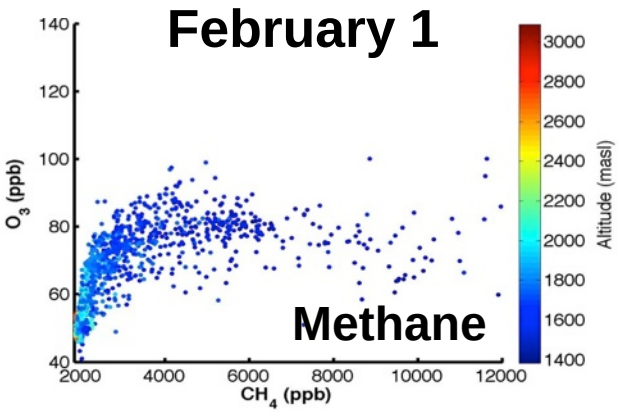


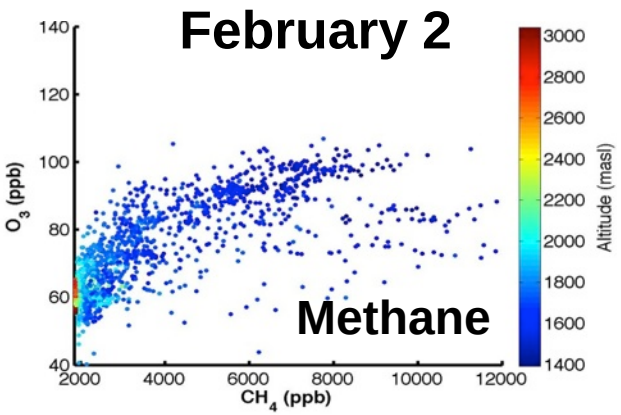


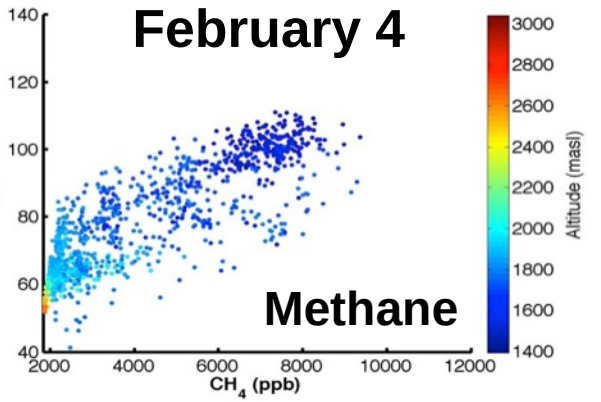




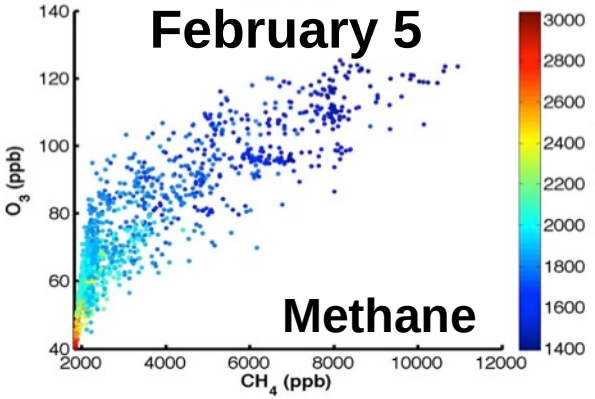
Correlation of O_3 with CH_4 and with CO, Feb. 1, 2, 4, 5, 6

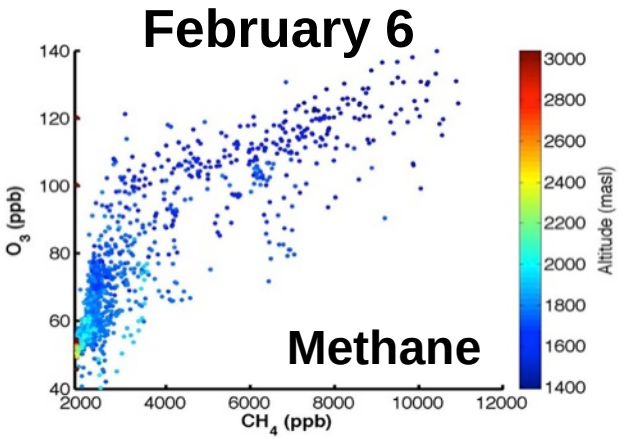


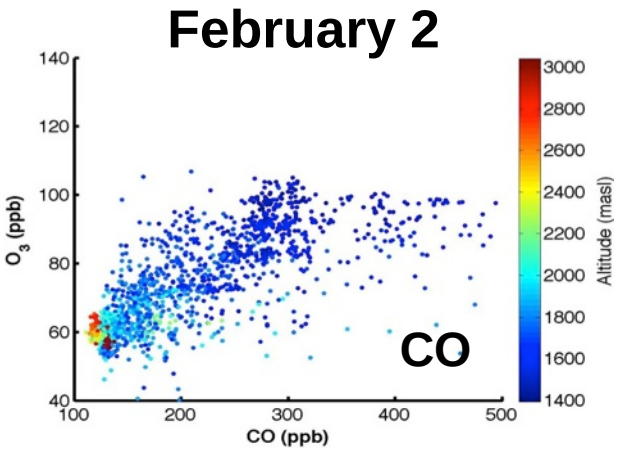


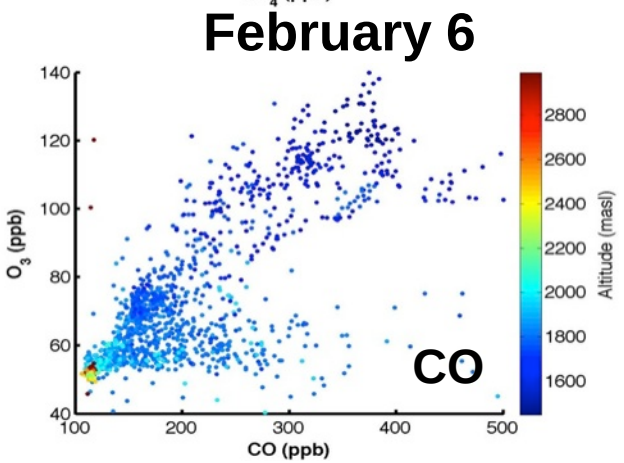


Aircraft continuous measurements both below and above the inversion.

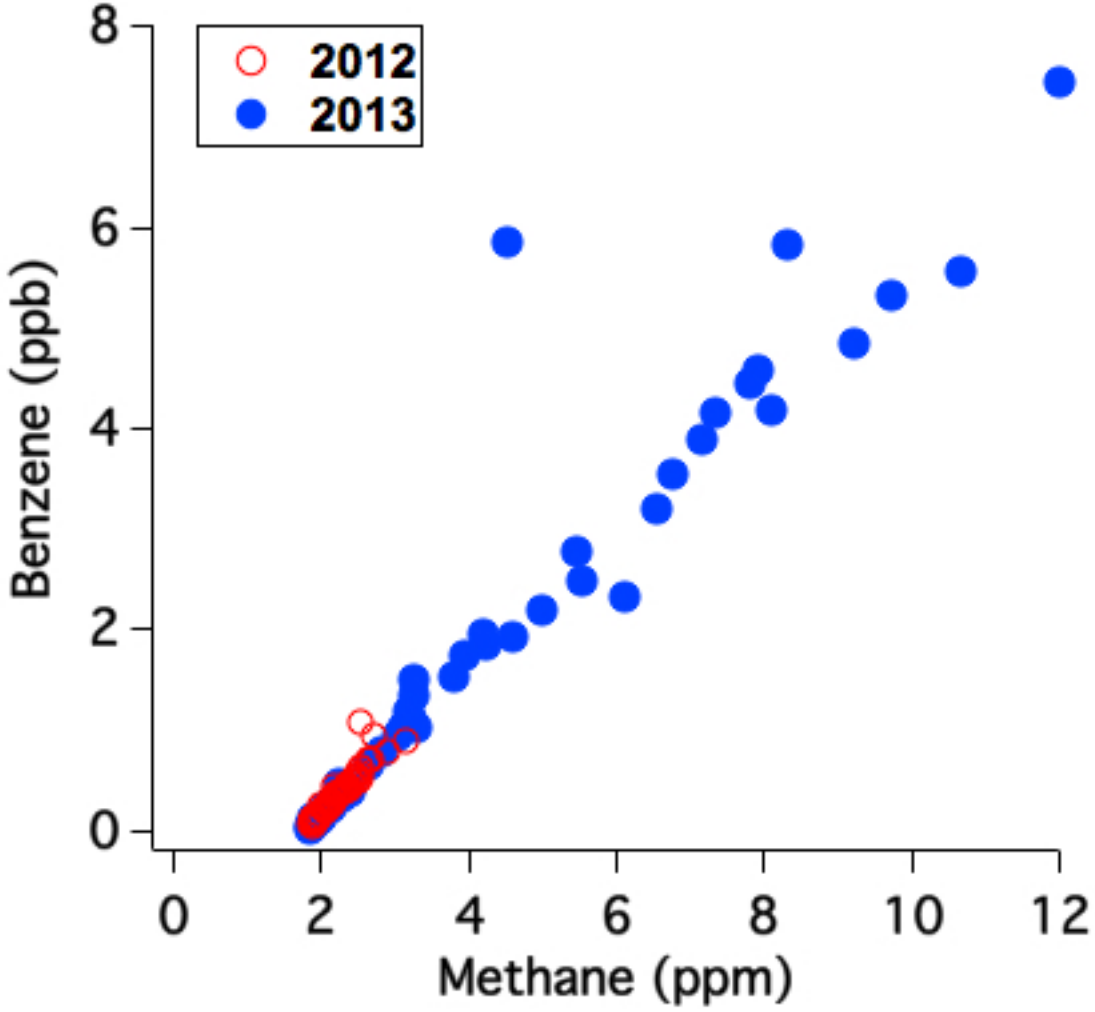




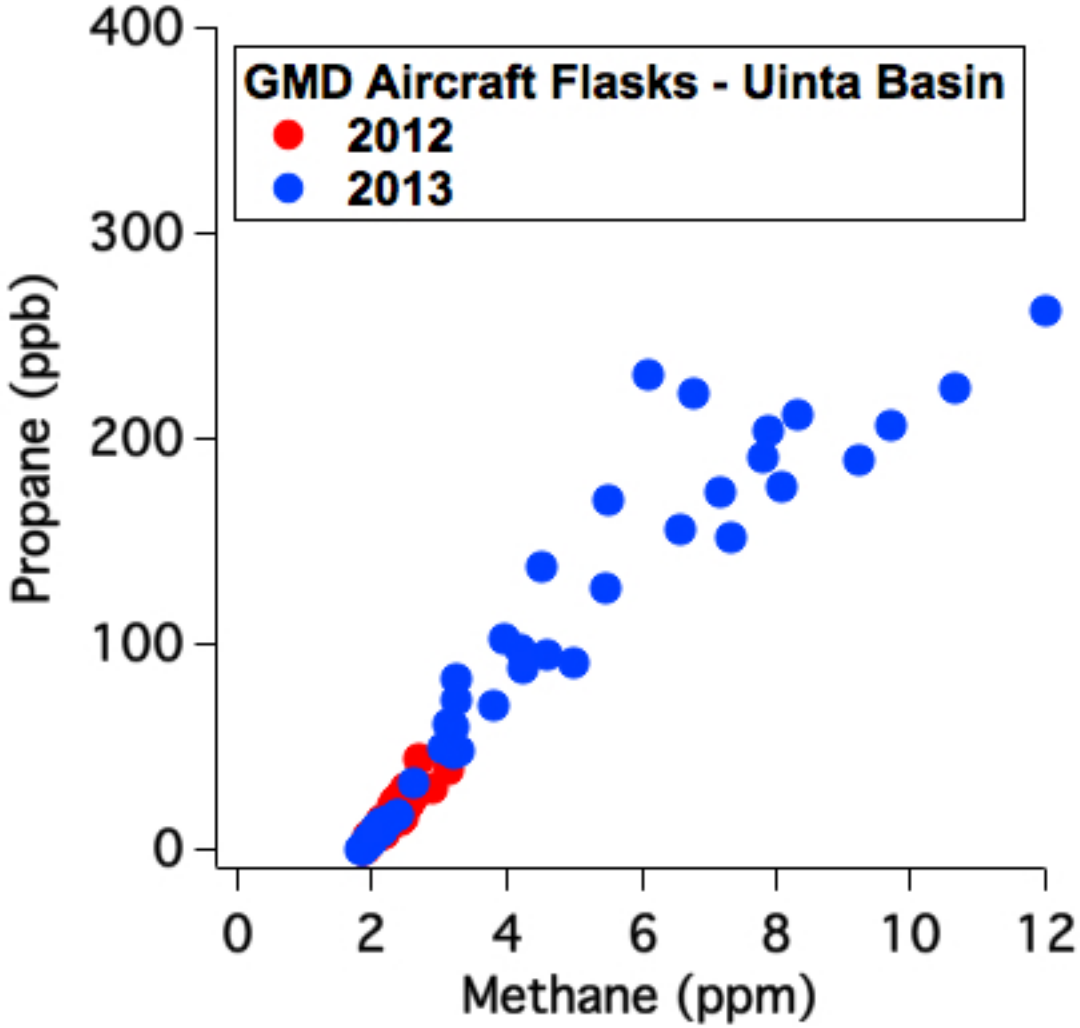




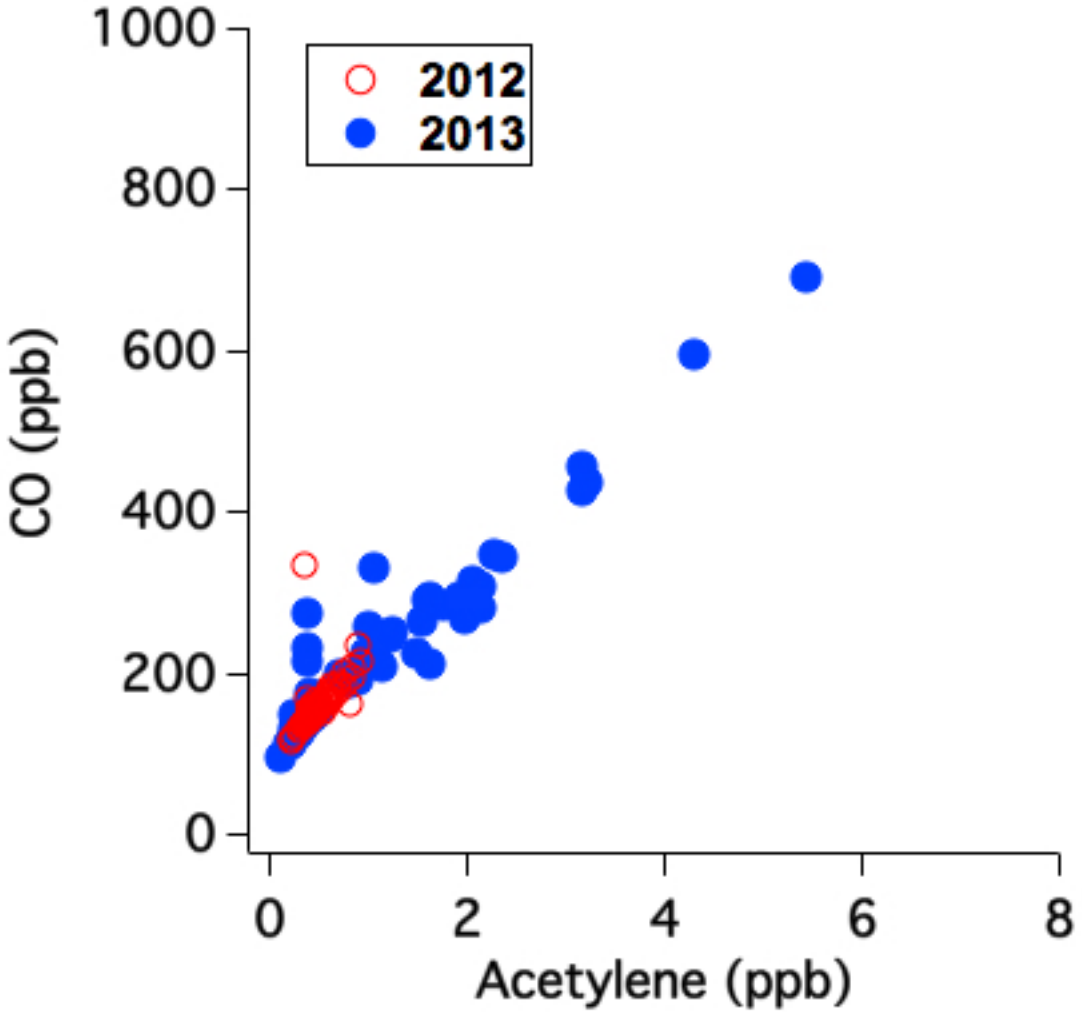
Airborne flask samples, Uintah Basin, Above and below Inversion 2012 and 2013

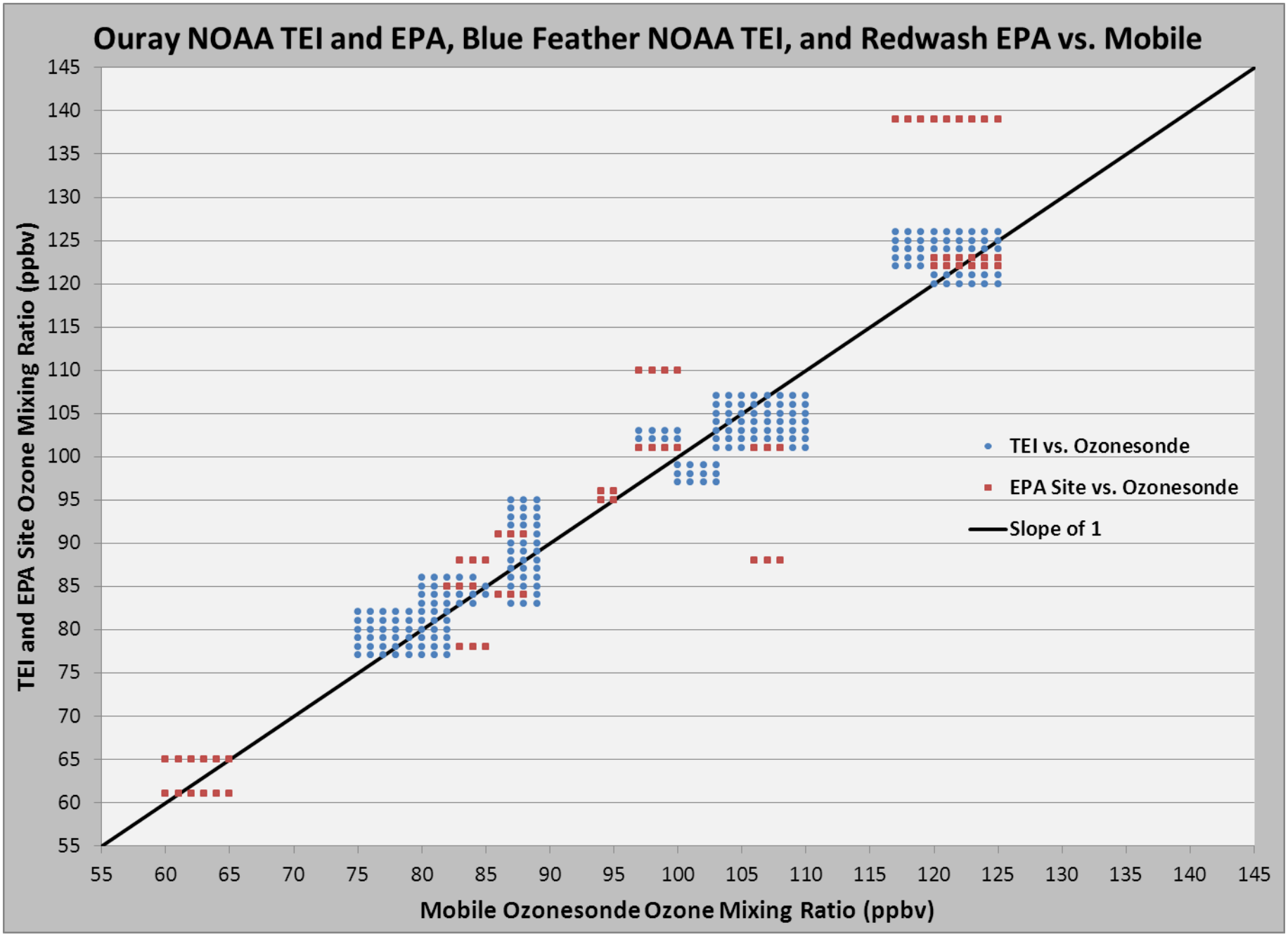


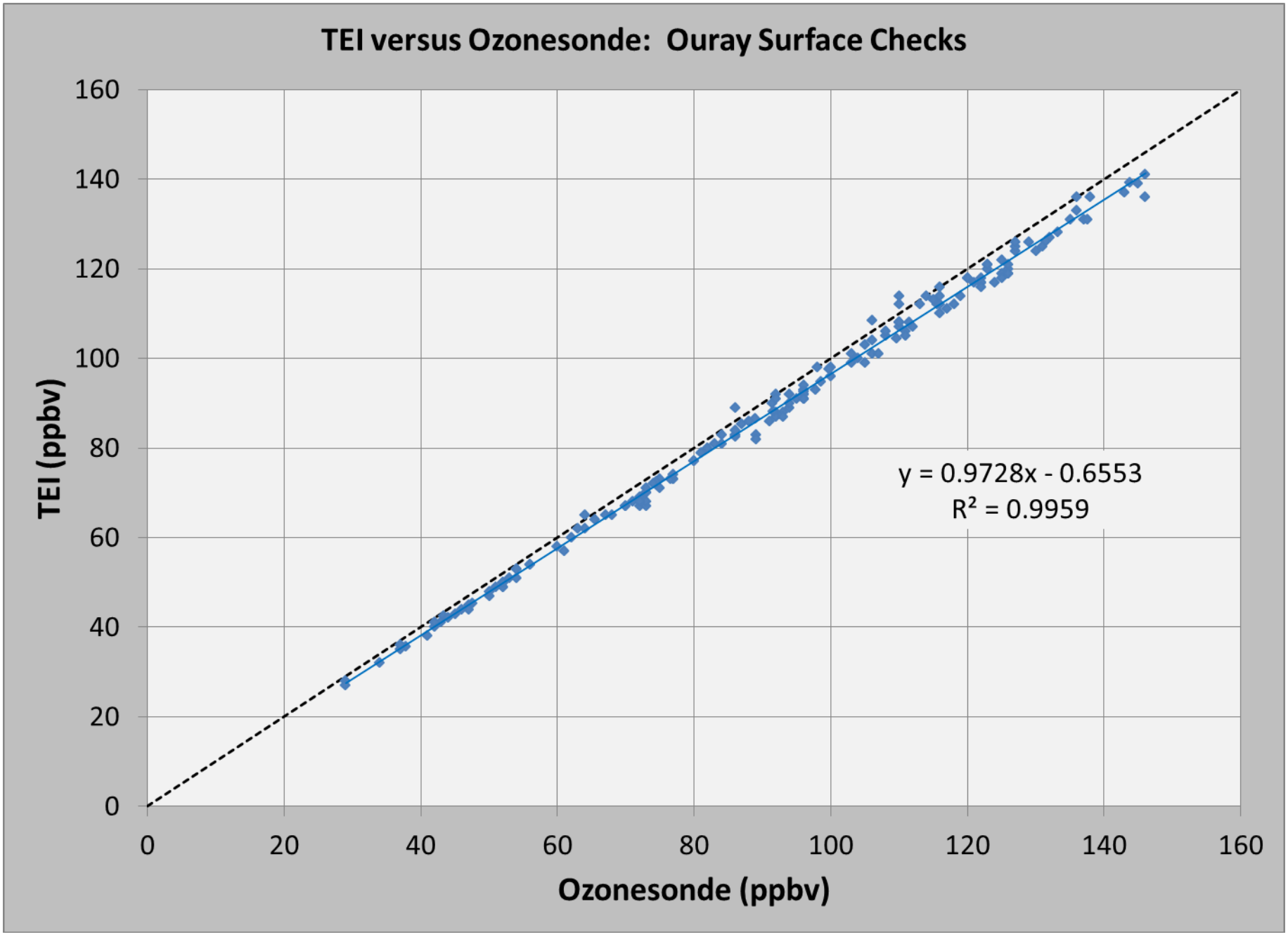
Airborne flask samples, Uintah Basin, Above and below Inversion 2012 and 2013



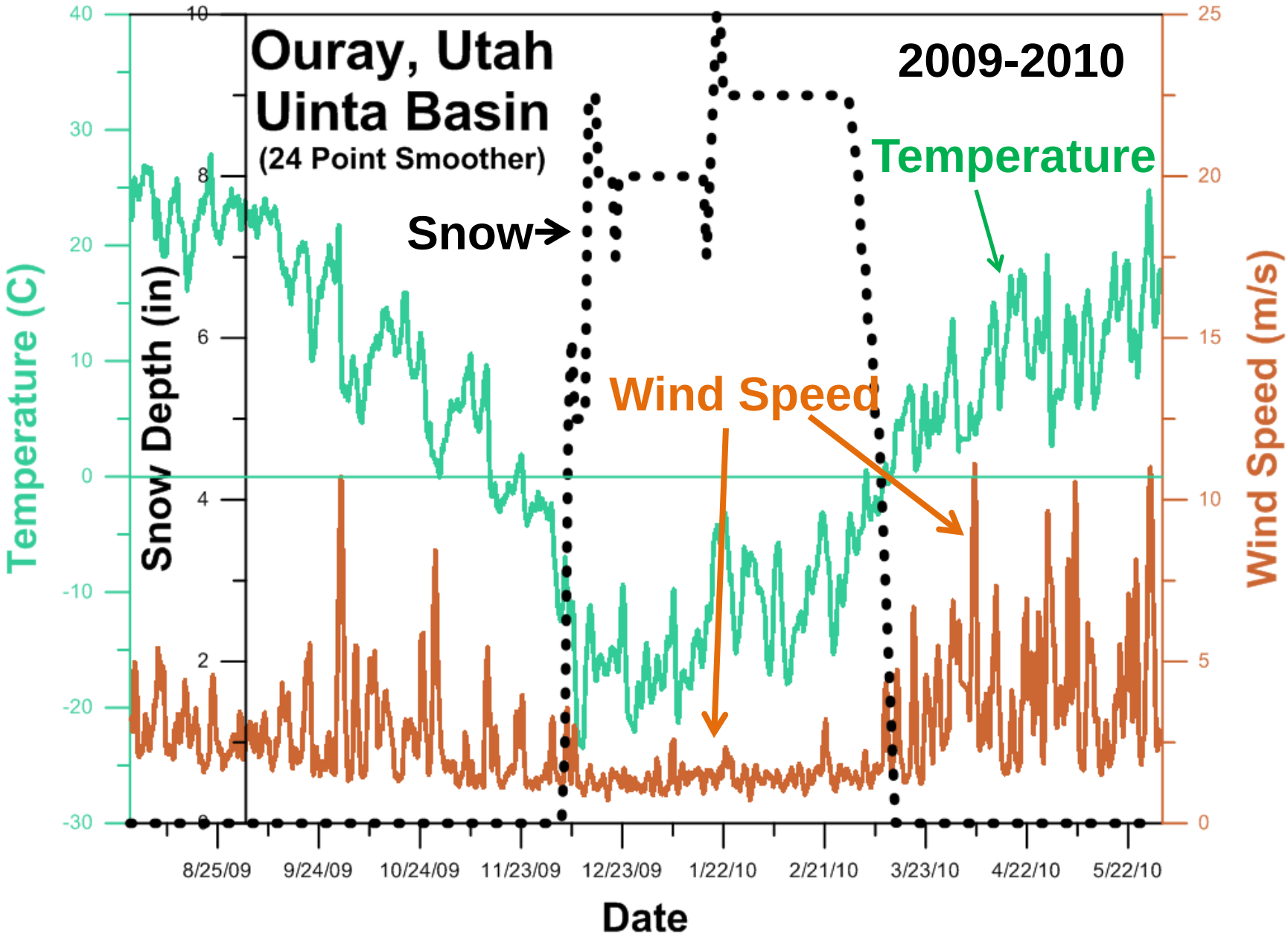
Airborne flask samples, Uintah Basin, Above and below Inversion 2012 and 2013

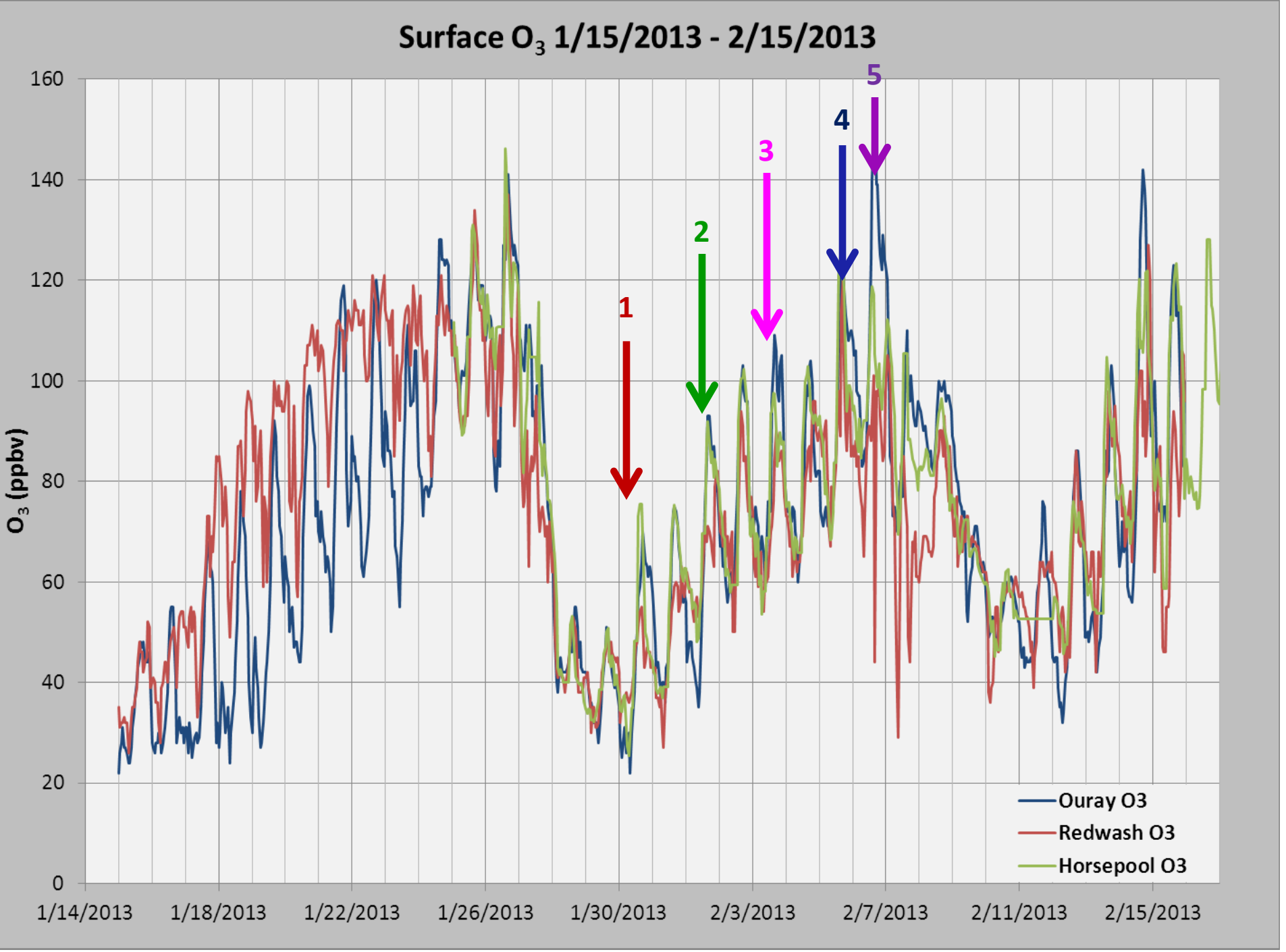



Ouray NOAA TEI and EPA, Blue Feather NOAA TEI, and Redwash EPA vs. Mobile
TEI and EPA Site Ozone Mixing Ratio (ppbv)
Mobile Ozonesonde Ozone Mixing Ratio (ppbv)
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
TEI vs. Ozonesonde
EPA Site vs. Ozonesonde
Slope of 1


TEI versus Ozonesonde: Ouray Surface Checks
TEI (ppbv)
Ozonesonde (ppbv)
0
20
40
60
80
100
120
140
160
y = 0.9728x - 0.6553
R² = 0.9959

Temperature, Snow Depth and Wind




Surface O3 1/15/2013 - 2/15/2013
O3 (ppbv)
160
140
120
100
80
60
40
20
0
1/14/2013
1/18/2013
1/22/2013
1/26/2013
1/30/2013
2/3/2013
2/7/2013
2/11/2013
2/15/2013
1
2
3
4
5
Ouray O3
Redwash O3
Horsepool O3