Methane Emissions Estimates from Oil and Natural Gas Production Using Atmospheric Measurements

Anna Karion, Colm Sweeney, Eric Kort, Paul Shepson, Mackenzie Smith, M. Obie Cambaliza, Tegan Lavoie, Sonja Wolter, Stephen Conley, Gabrielle Pétron, Tim Newberger, Scott Herndon, Tara Yacovitch, Chris Rella, Mike Hardesty, Alan Brewer, Jon Kofler

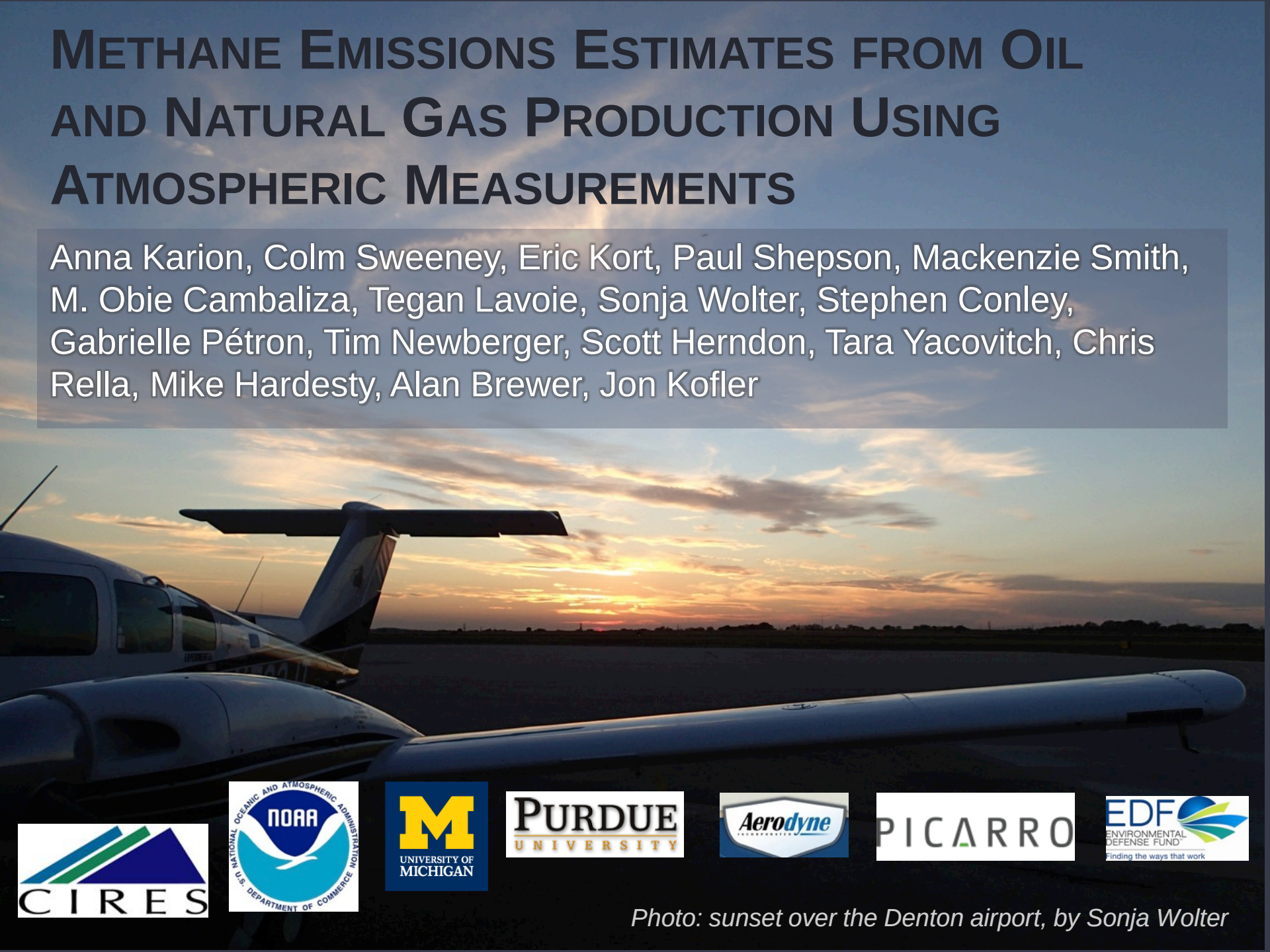


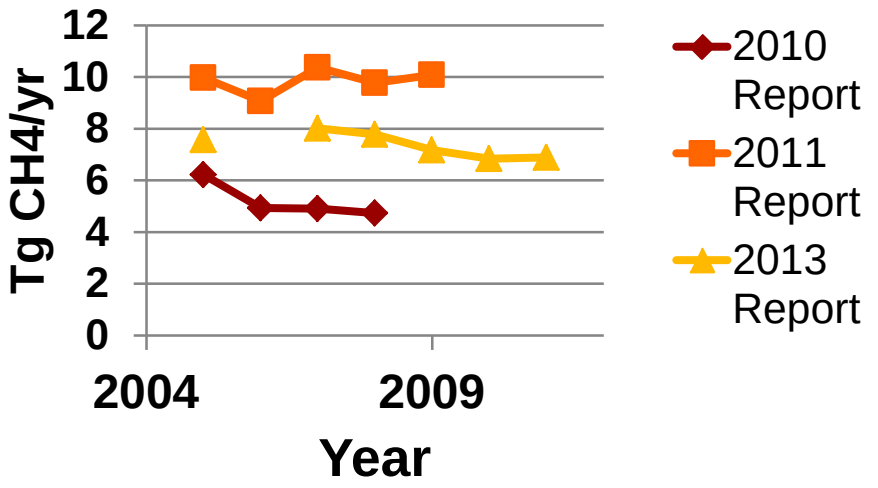
Photo: sunset over the Denton airport, by Sonja Wolter

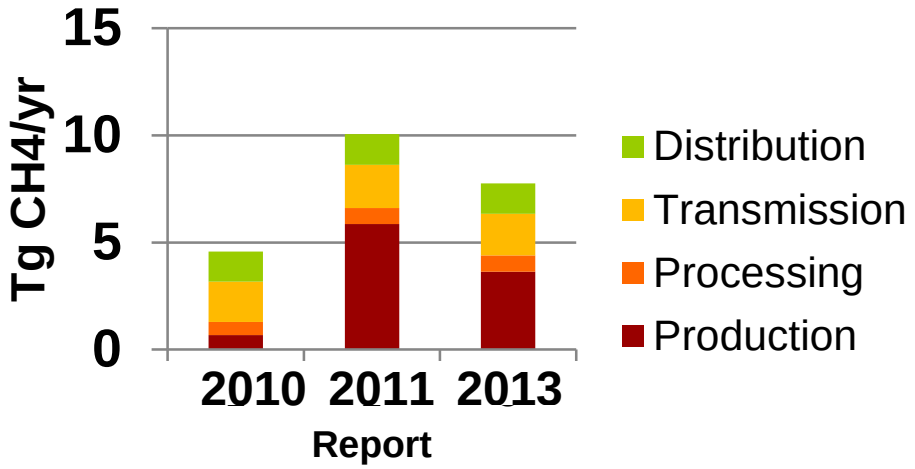
Why (continue to) study US oil and gas CH_4 emissions?

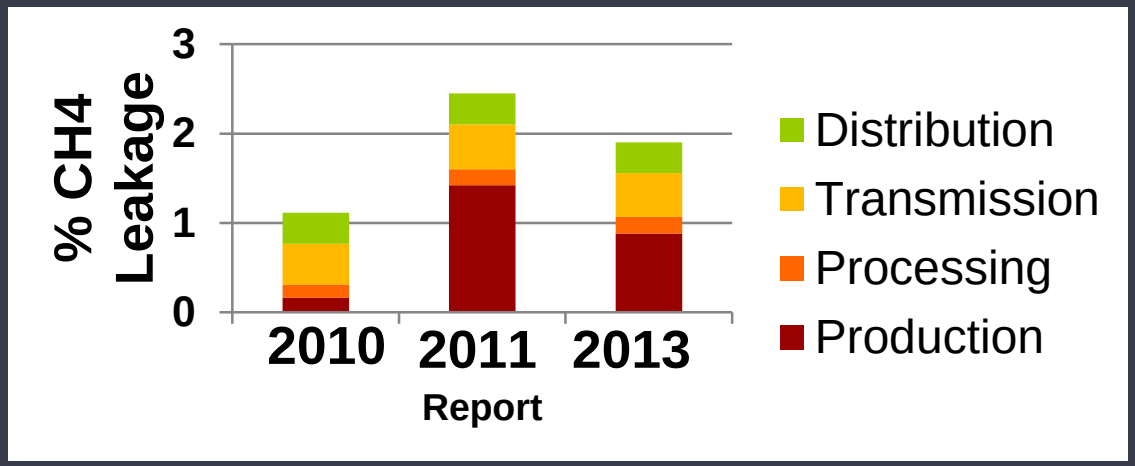
- Methane (CH_4) is the principal component of natural gas and a powerful greenhouse gas (GWP 100 yrs = 28)
- Methane is released in fugitive emissions from oil and natural gas production, processing, etc.
- Emissions of methane from natural and anthropogenic sources are not well quantified (globally or regionally).
- Recent studies and overviews (Brandt et al., *Science*, 2014) show high emissions but they generally cover only a small fraction of US production.

So what are the CH_4 emissions from natural gas?

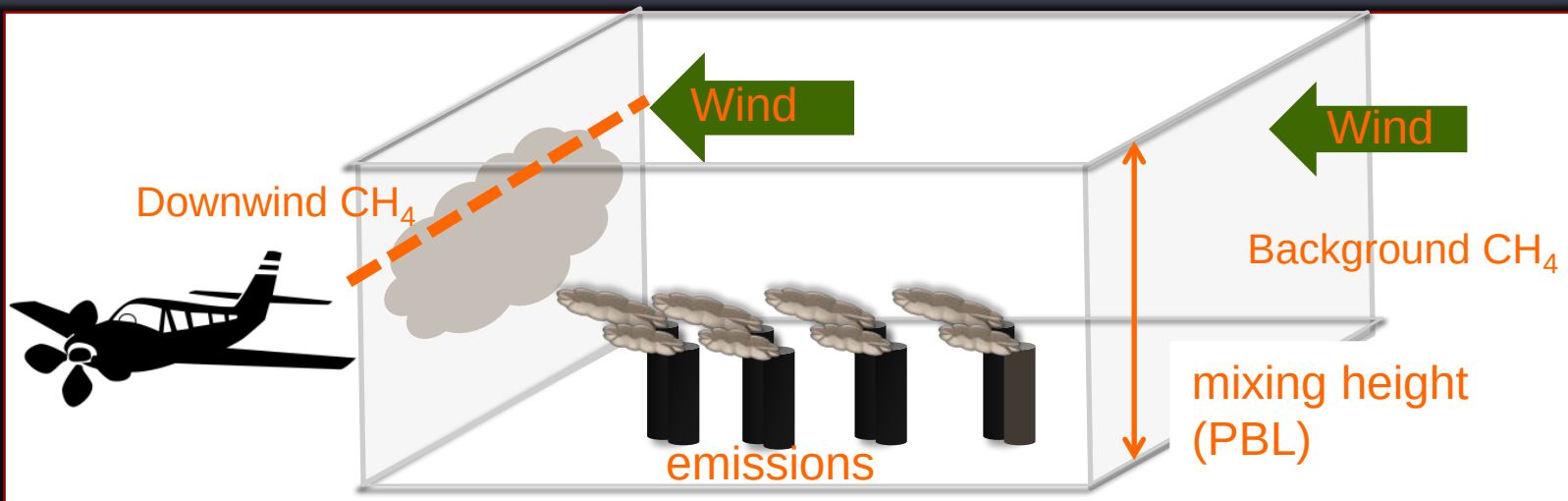
EPA Inventory of GHG Sources and Sinks







Mass Balance Approach for Emissions Estimation



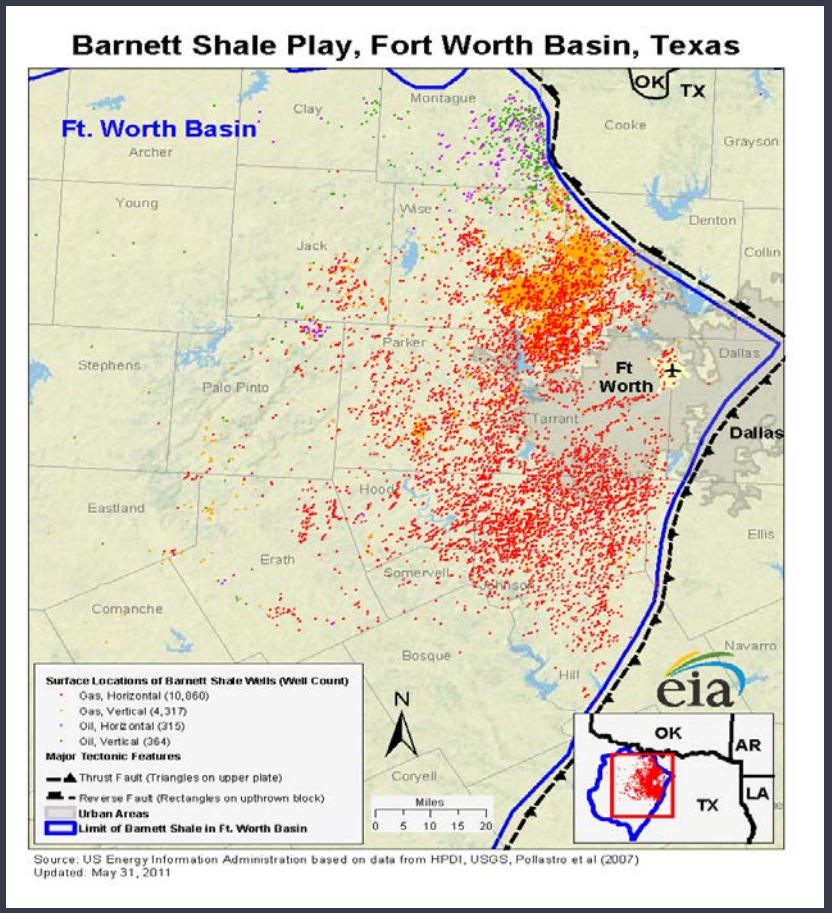
CH_4 flux

Molar CH_4 enhancement in PBL

$$\dot{n}_{CH_4} = \underbrace{V\cos\theta}_{\text{Perpendicular wind speed}} \int_{-b}^{+b} \Delta X_{CH_4} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air}\, dz \right) dx$$

TEXas Methane EXperiment

Barnett Shale: 7% of US gas production; one of top 3 shale plays in US



Texas Methane Experiment

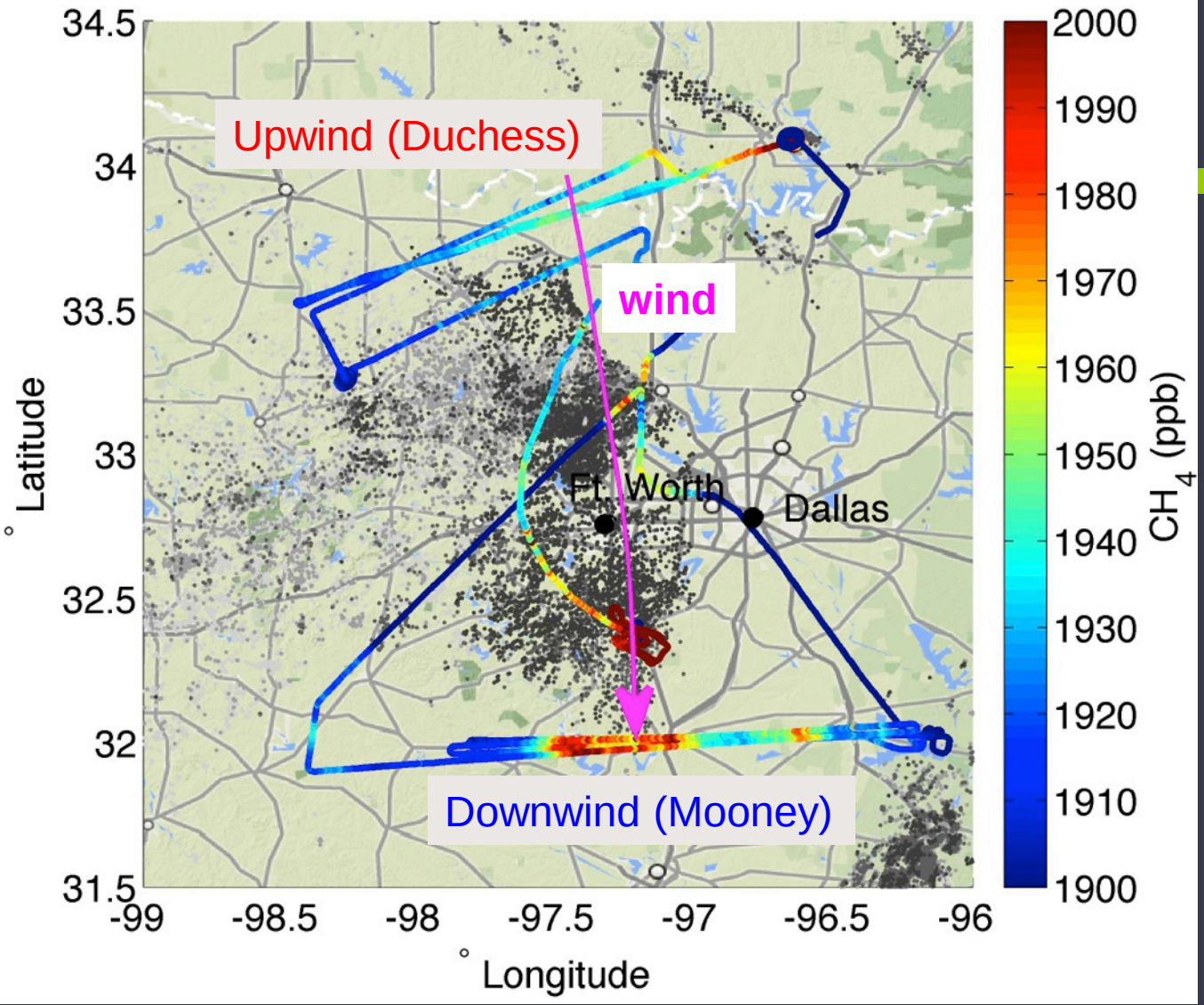
- Phase I: March 2013
  - University of Colorado
  - NOAA/ESRL (GMD, CSD)
  - Picarro
  - Shell / Sanders Geophysics
  - Aerodyne
  - Penn State (Davis group)
- Phase II: October 2013
  - Purdue (Shepson group)
  - University of Michigan (Kort)
  - University of Cincinnati (Townsend-Small)
  - UC Irvine (Blake group)
  - University of Houston
  - West Virginia University
  - Duke
  - Princeton & UT Dallas
  - LI-COR

Texas Methane Experiment: Aircraft

Scientific Aviation Mooney

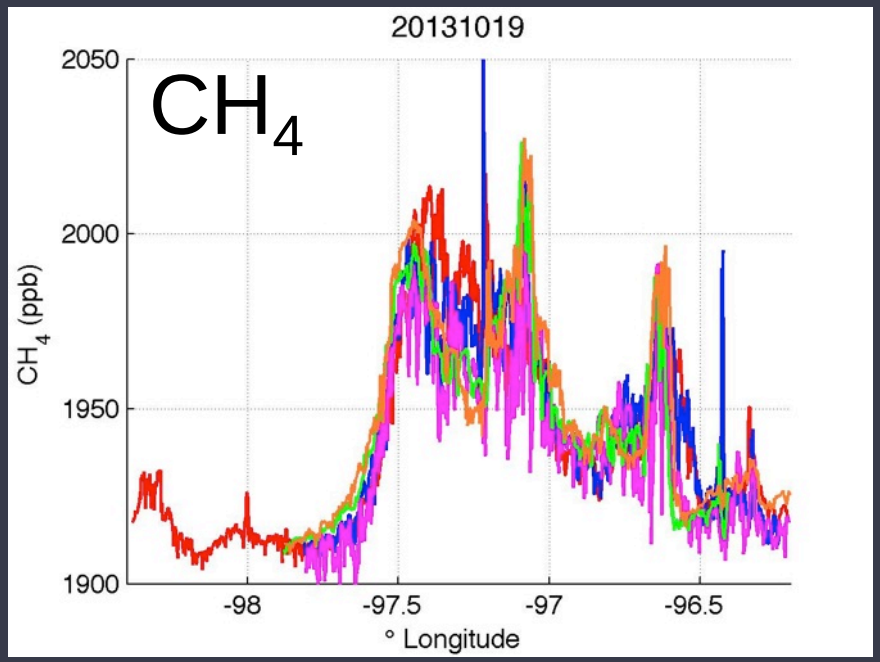
Purdue Duchess

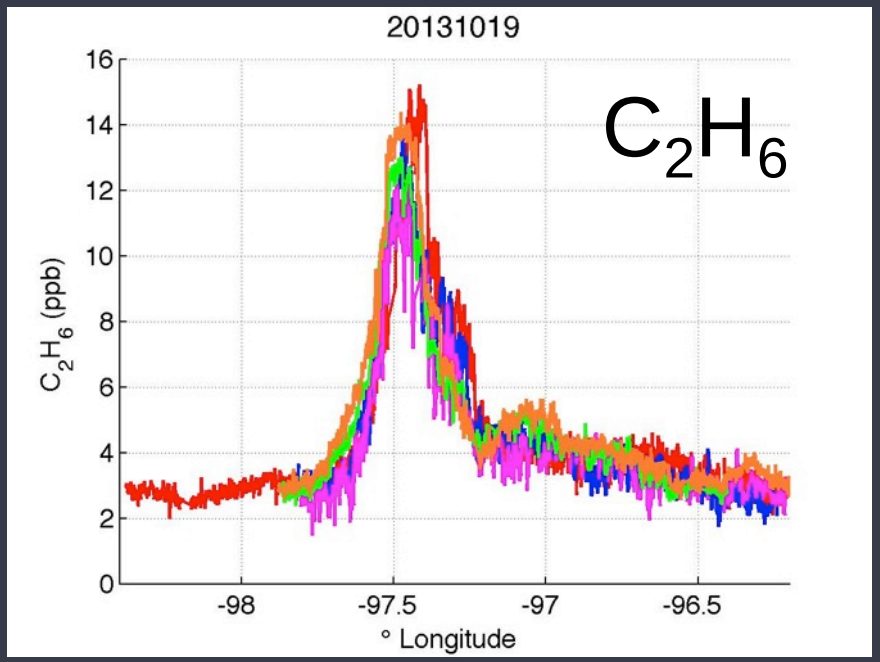
19 Oct 2013


Upwind (Duchess)
wind
Downwind (Mooney)
Ft. Worth
Dallas
34.5
34
33.5
33
32.5
32
31.5
° Latitude
-99
-98.5
-98
-97.5
-97
-96.5
-96
° Longitude
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
1900
CH4 (ppb)

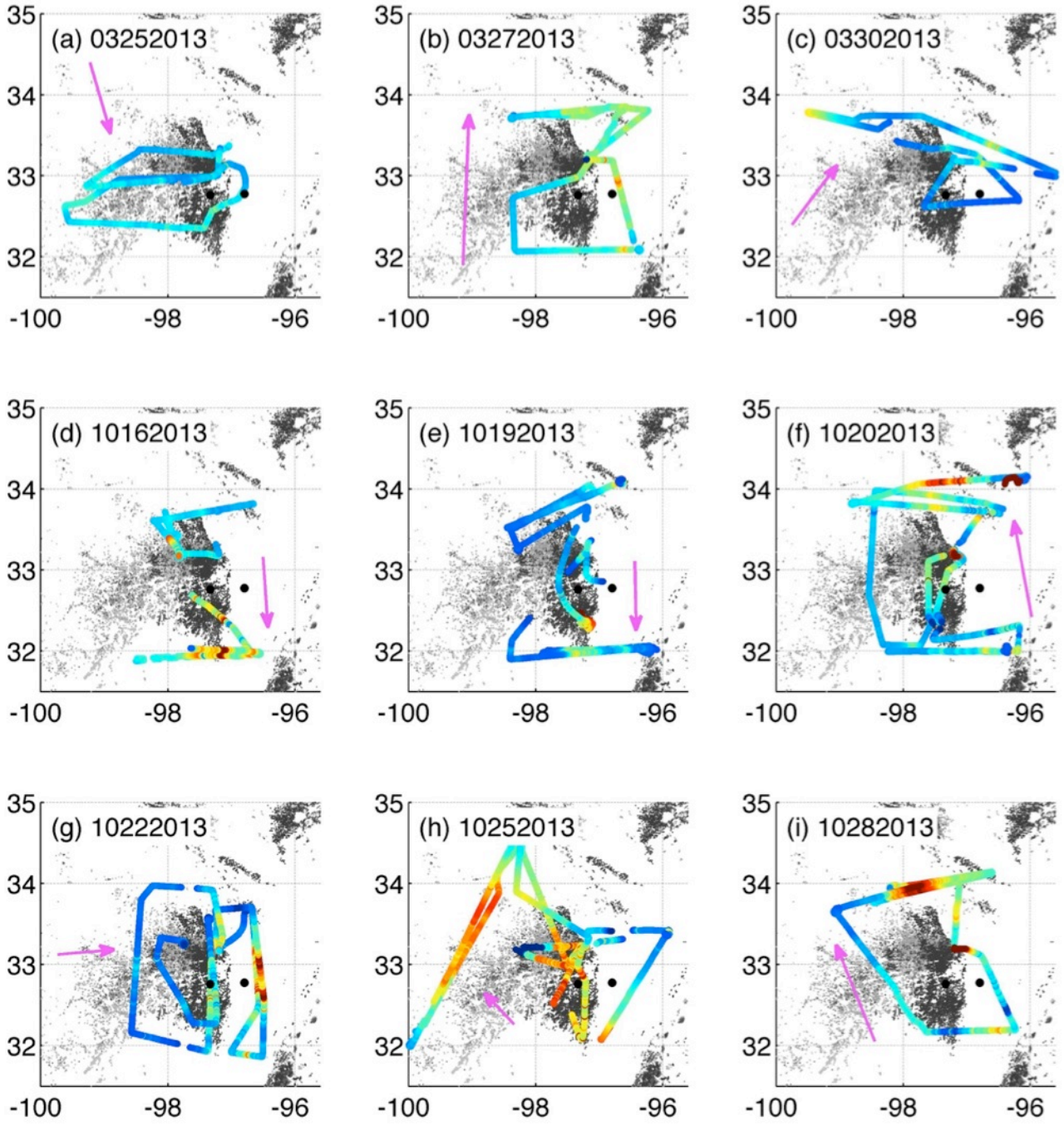
5 downwind transects

19 Oct 2013

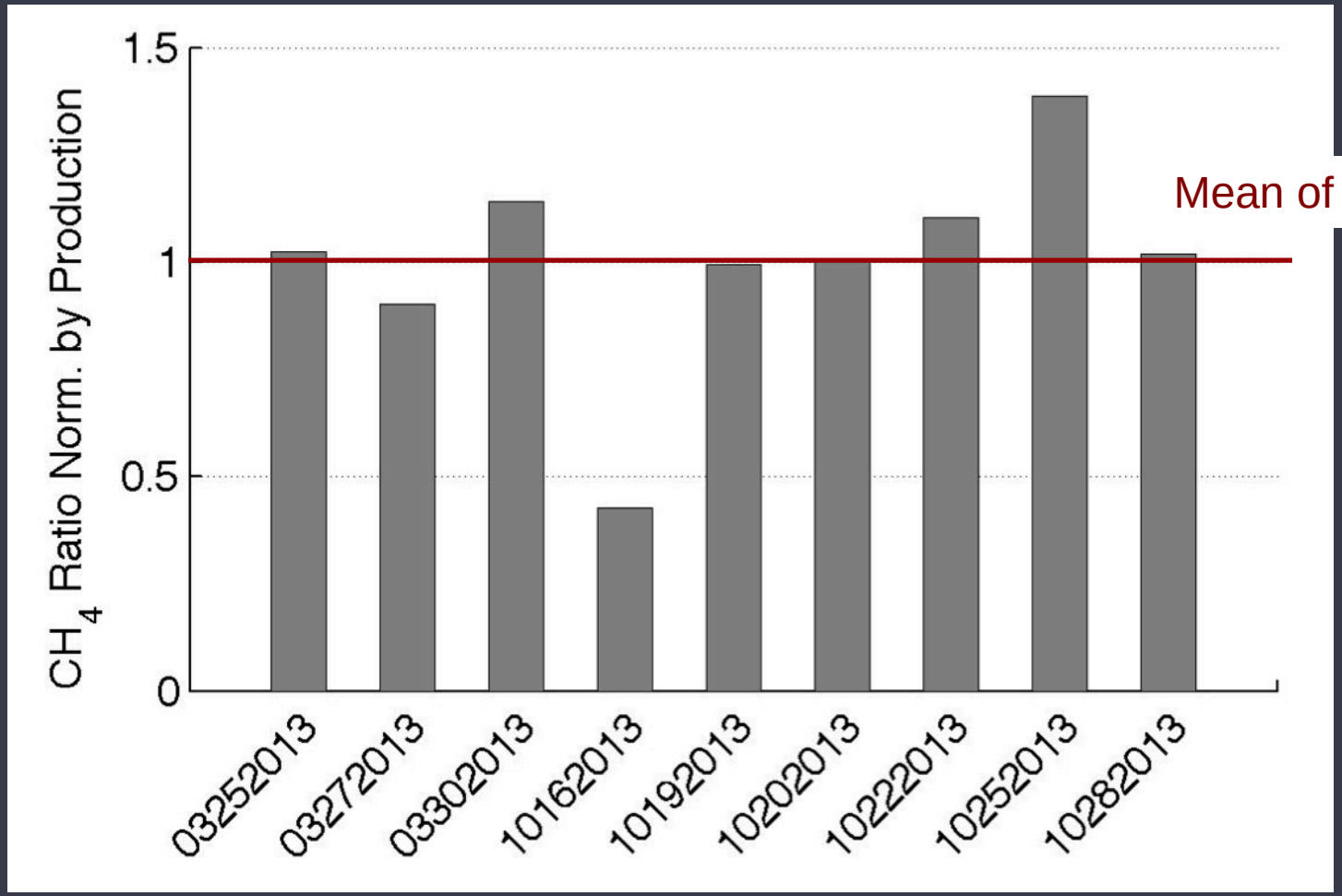


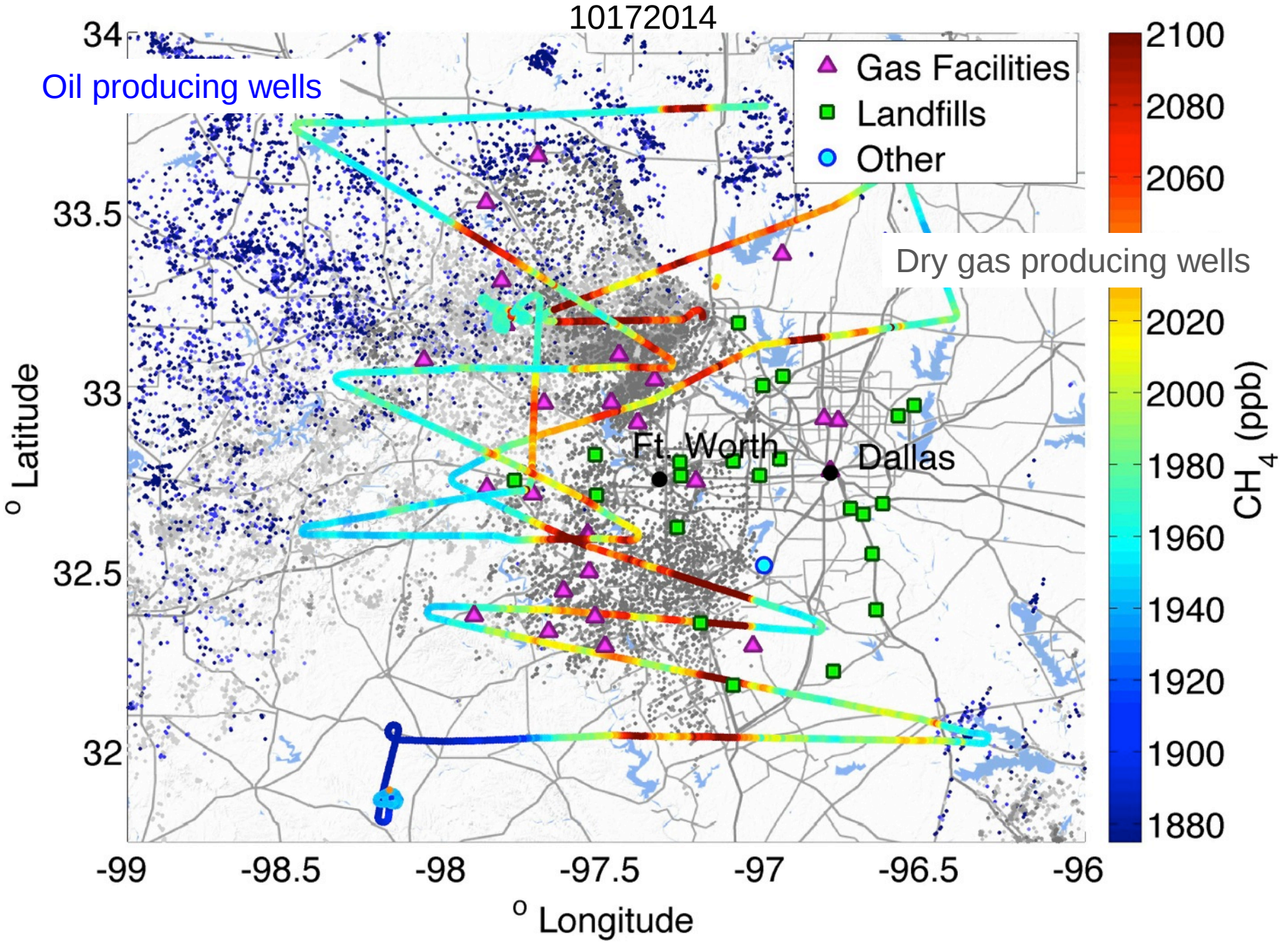


Methane (left) and ethane (right) in five separate downwind transects show consistency of plume. They also indicate that a portion of the methane enhancement does not correspond with an ethane enhancement.

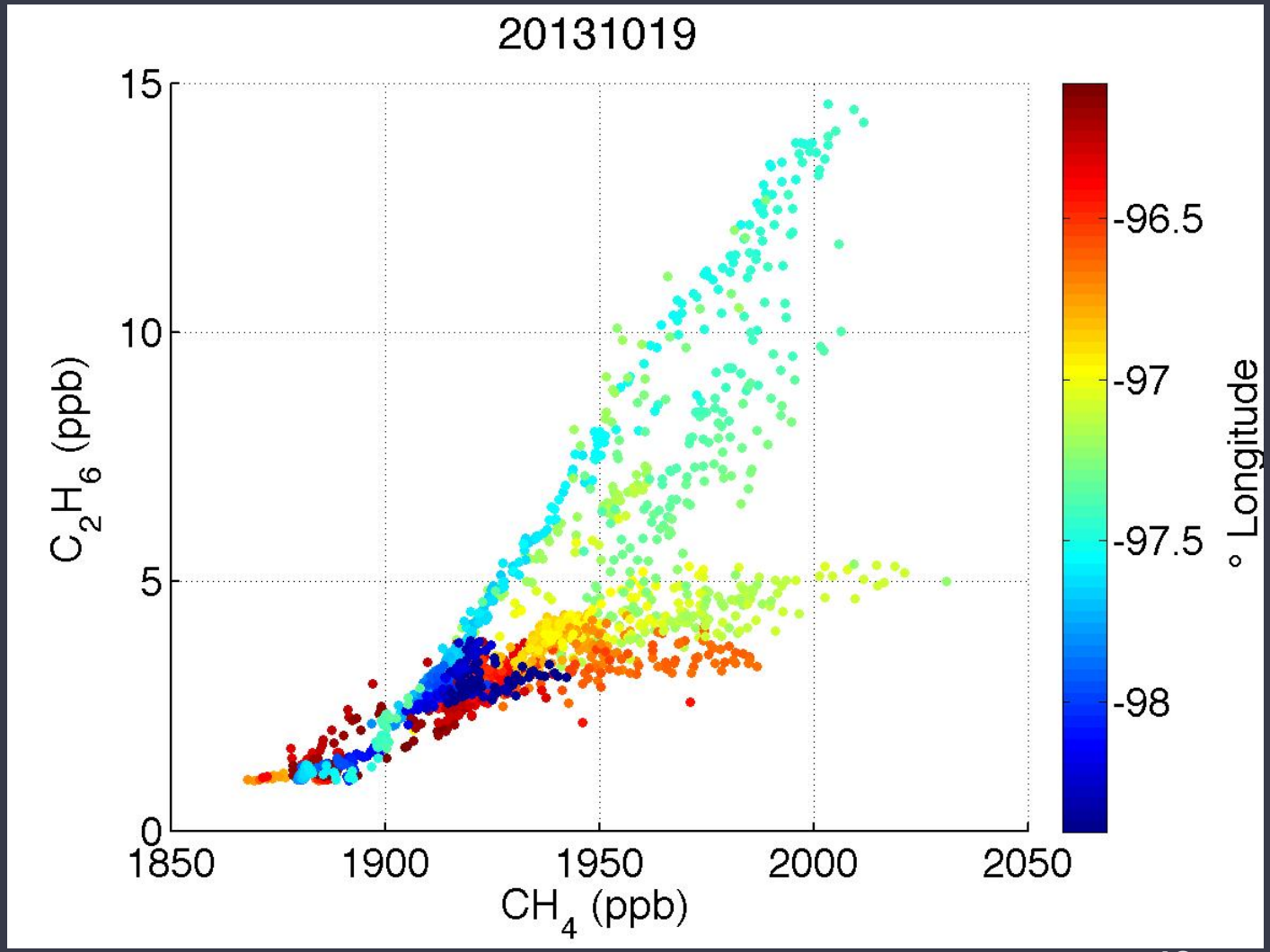

(a) 03252013
(b) 03272013
(c) 03302013
(d) 10162013
(e) 10192013
(f) 10202013
(g) 10222013
(h) 10252013
(i) 10282013
35
34
33
32
-100
-98
-96

Total CH_4 Emission

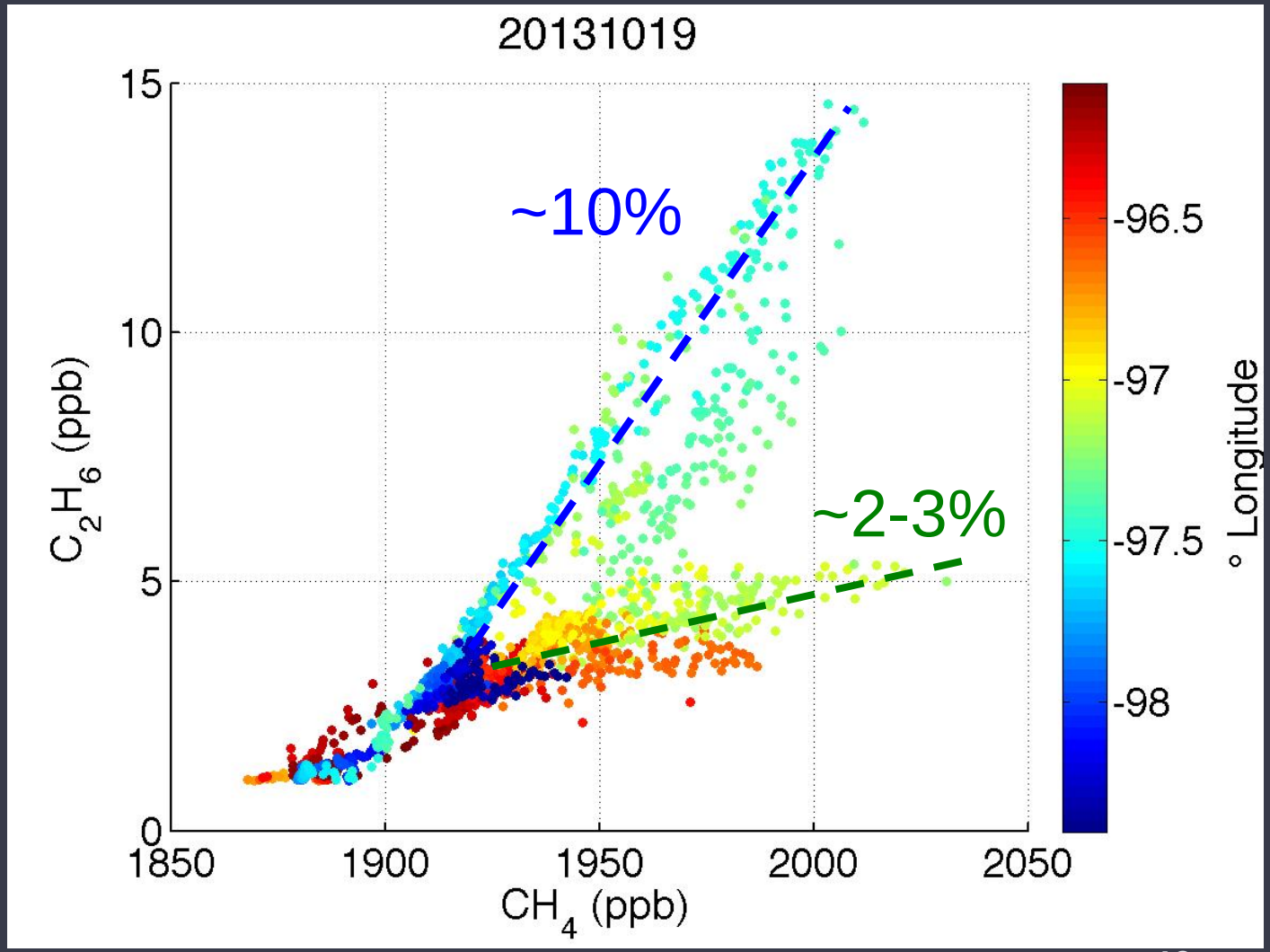


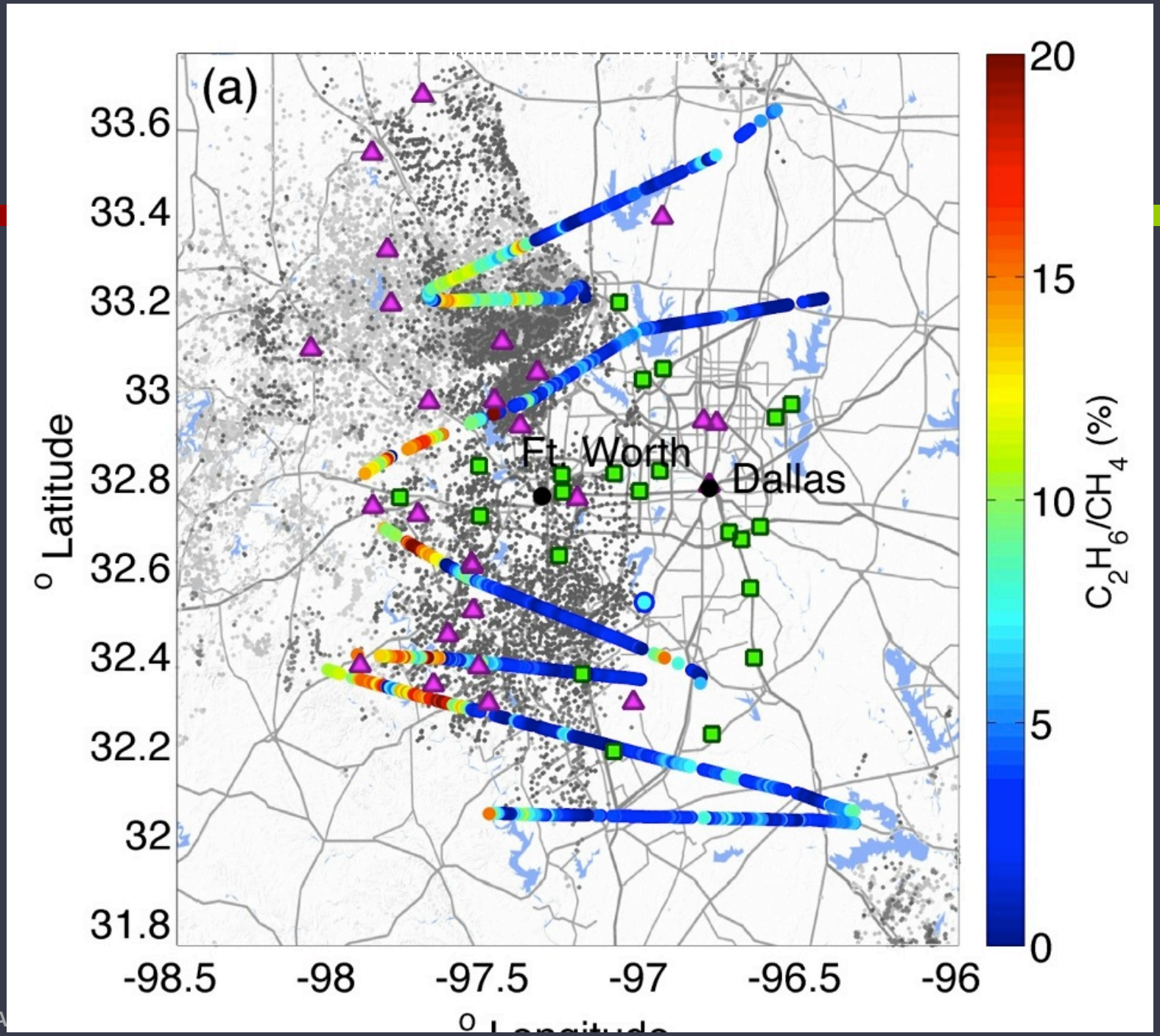

10172014
Oil producing wells
Gas Facilities
Landfills
Other
Dry gas producing wells
Ft. Worth
Dallas
34
33.5
33
32.5
32
-99
-98.5
-98
-97.5
-97
-96.5
-96
° Latitude
° Longitude
2100
2080
2060
2020
2000
1980
1960
1940
1920
1900
1880
CH4 (ppb)

Ethane to Methane Ratio: 19 Oct 2013

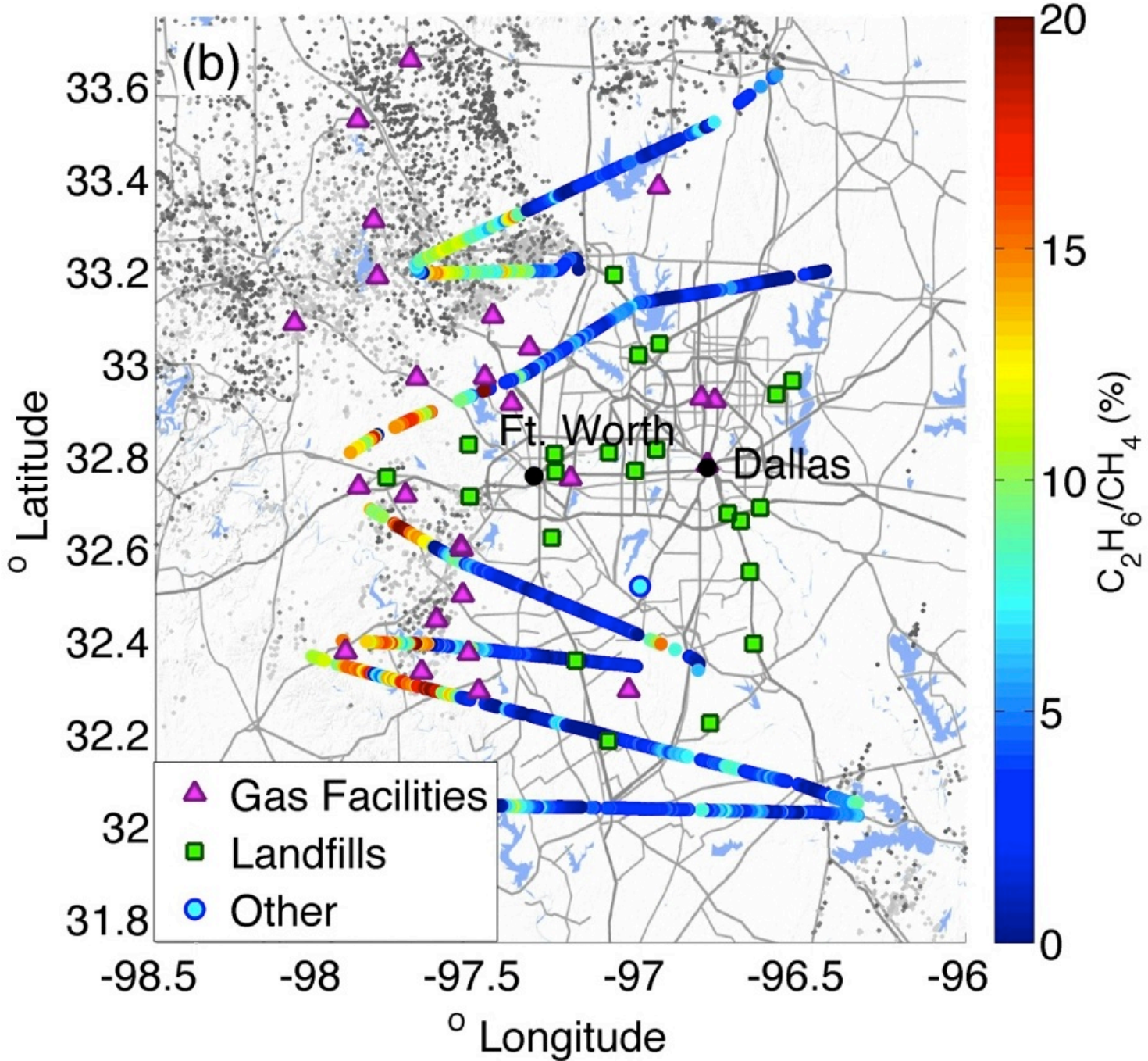


Ethane to Methane Ratio: 19 Oct 2013

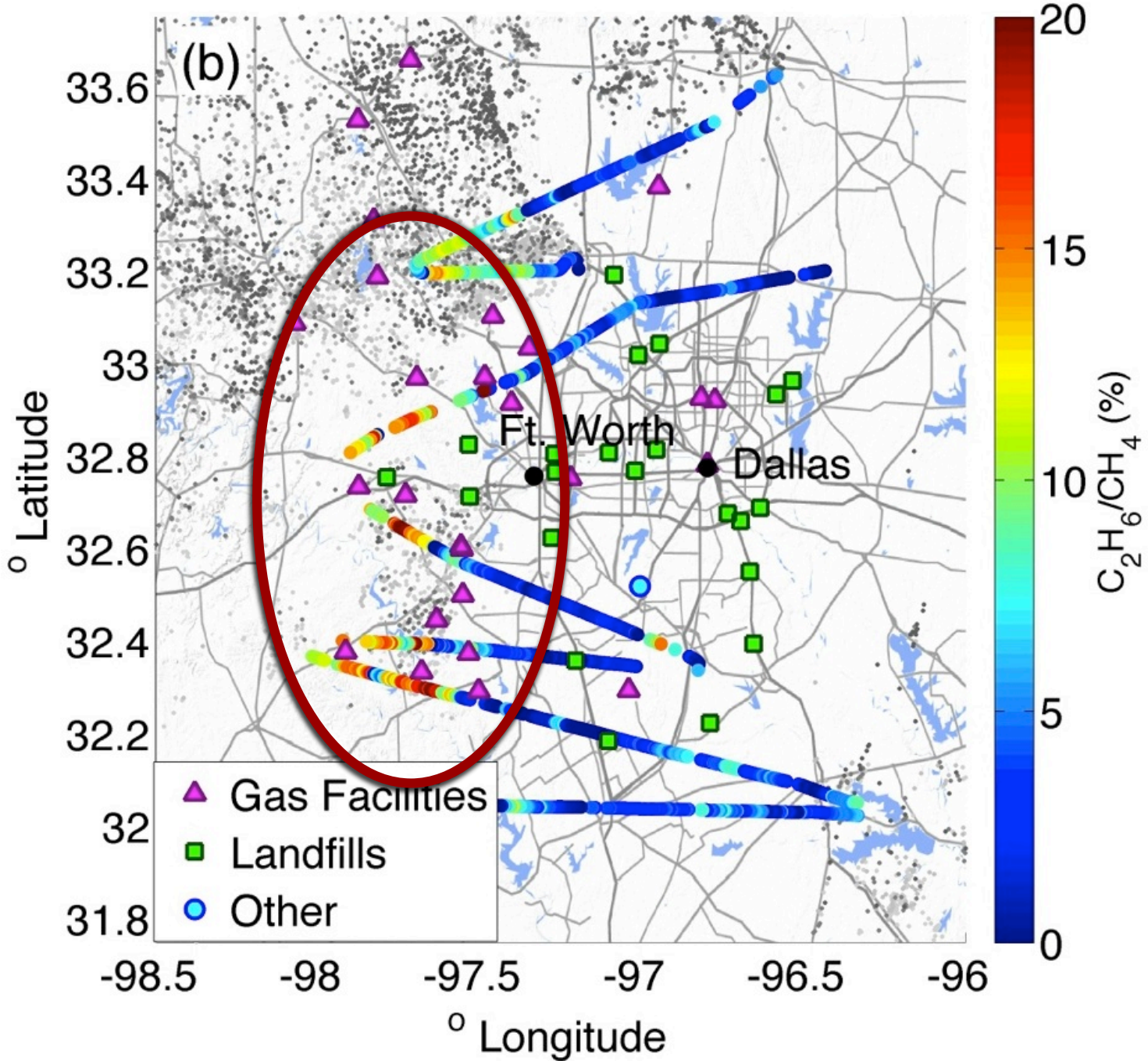




Gray dots = wells with gas production

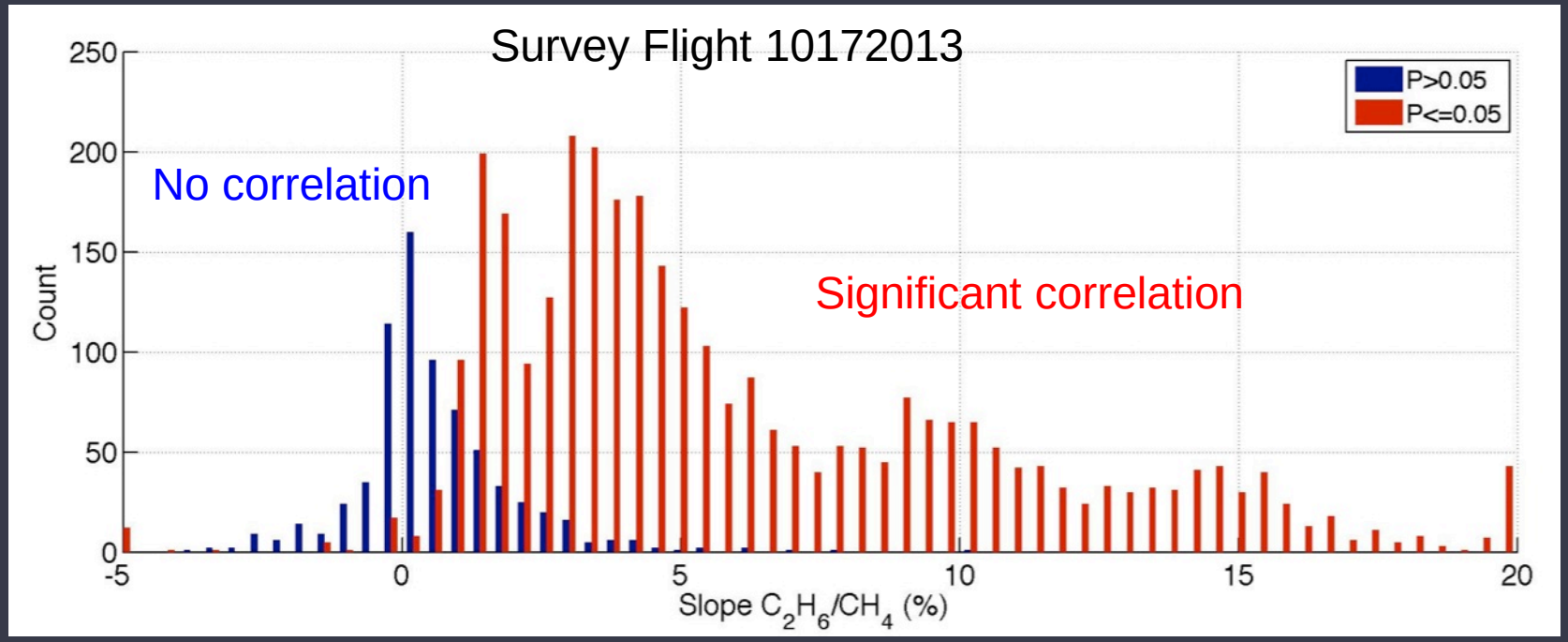


Gray dots = wells with oil (liquids) production



Gray dots = wells with oil (liquids) production

Correlations of C_2H_6 with CH_4



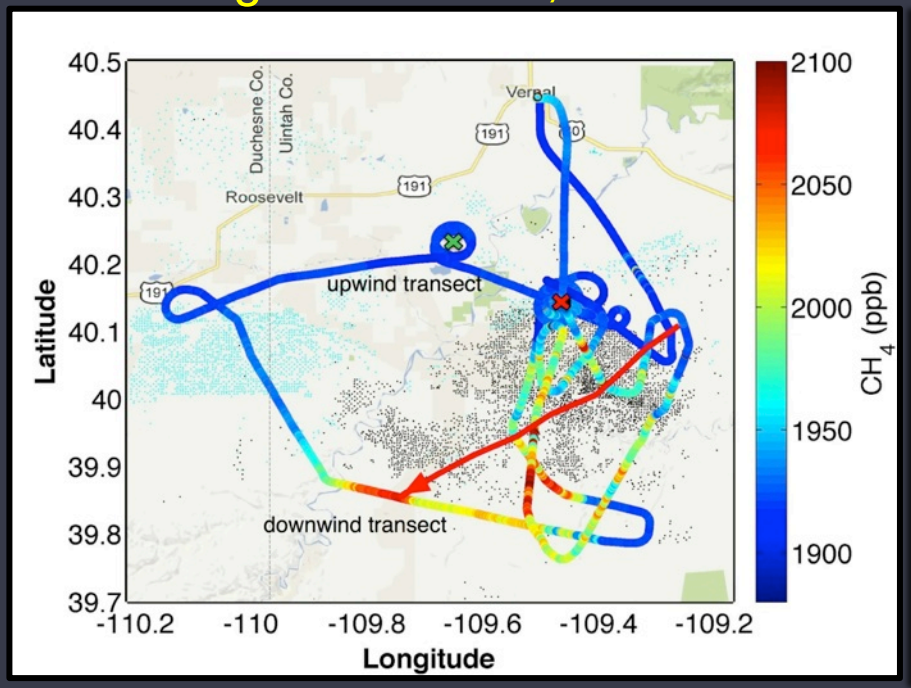
Use the sum of CH_4 that does NOT correlate with C_2H_6 (blue) to establish contribution from biogenic sources: ~25%.

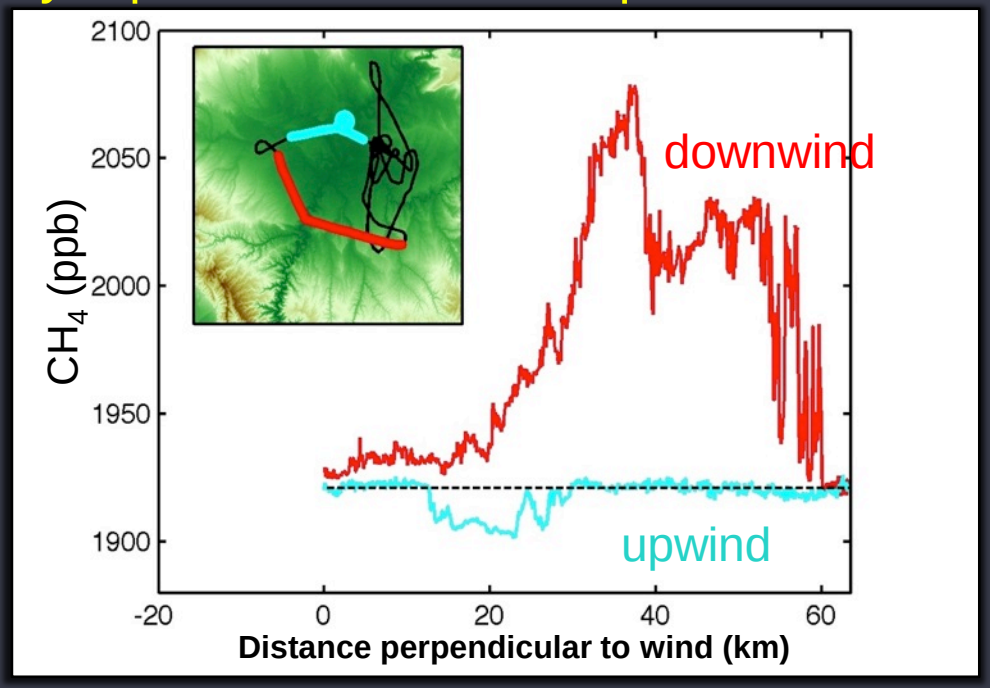
Conclusions & Future Work

- Methane emissions for several other basins are going to be published in the next year
  - Barnett
  - Fayetteville, Haynesville, Marcellus (Peischl, in prep.)
  - Bakken, San Juan, Marcellus – upcoming measurements planned
- Work is still needed to reconcile inventories with estimates based on atmospheric measurements.
- More work is going to focus on attribution using ethane (U Mich, Aerodyne) and $13CH_4$ (Picarro).

Utah, 2012

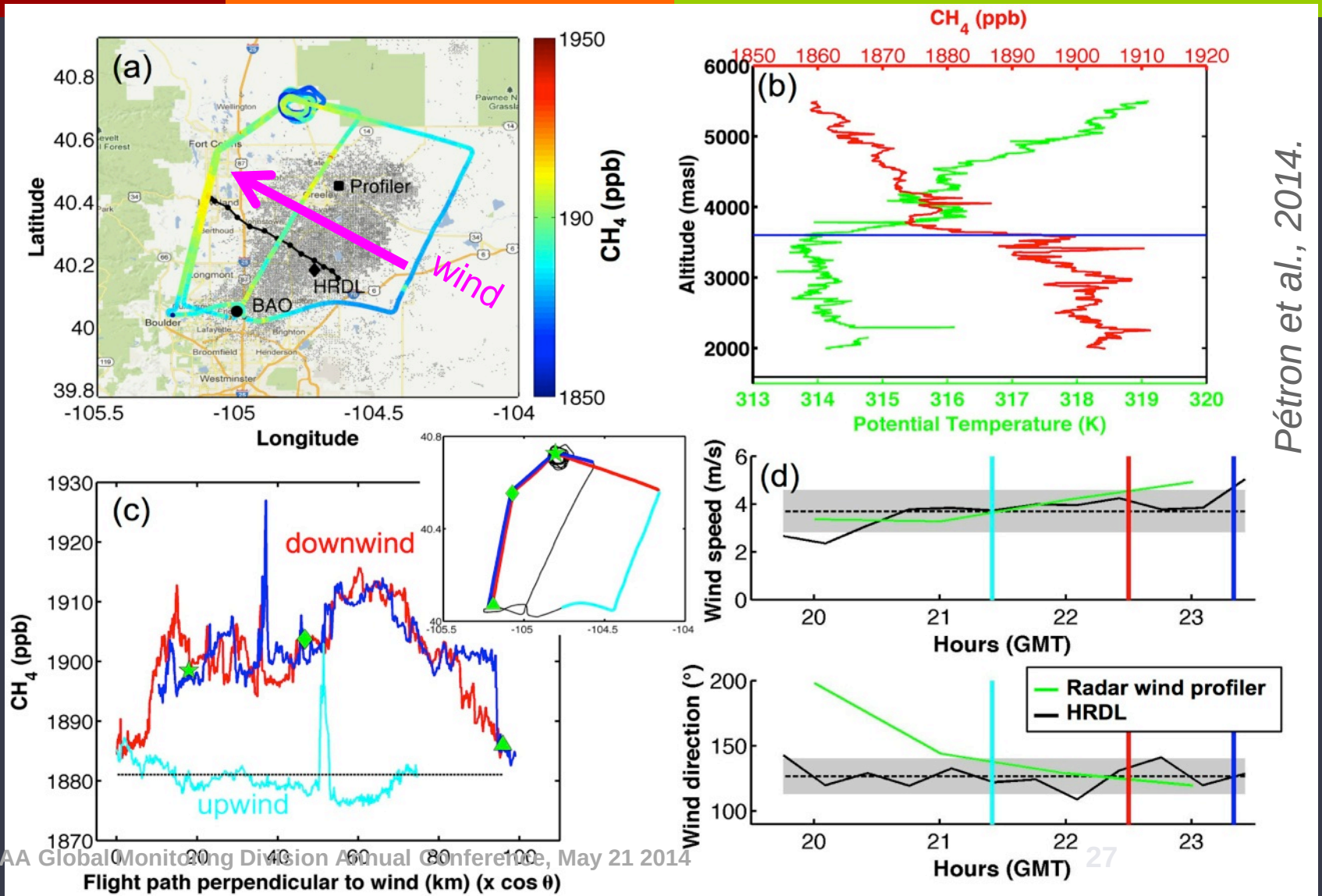
High emissions, but this field only represents ~1% of US production.





Karion, A., C. Sweeney, et al. (2013). Methane emissions estimate from airborne measurements over a western United States natural gas field. Geophysical Research Letters.

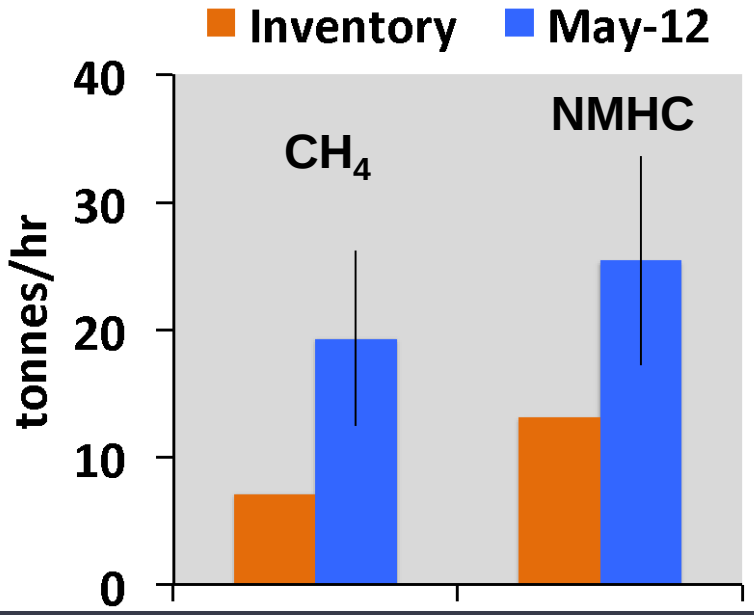
Denver-Julesburg, May 2012

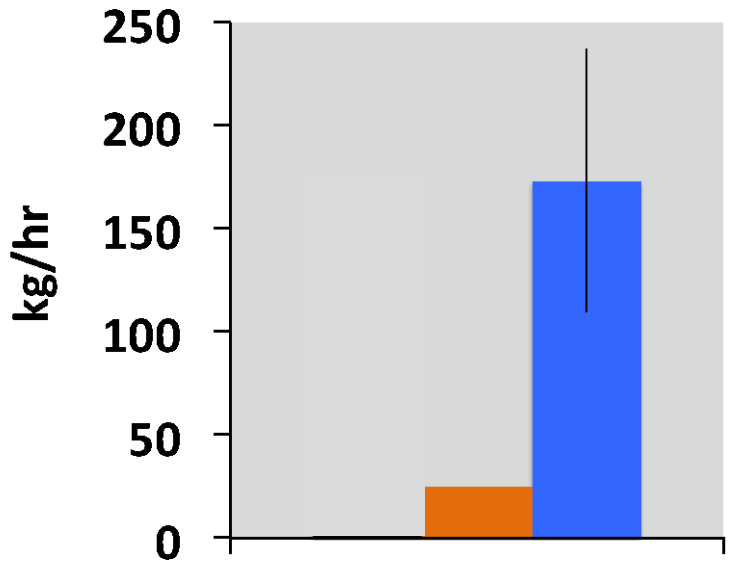


Pétron et al., 2014.

Summary of Results for O&G Emissions in the D-J Basin

Pétron et al., 2014



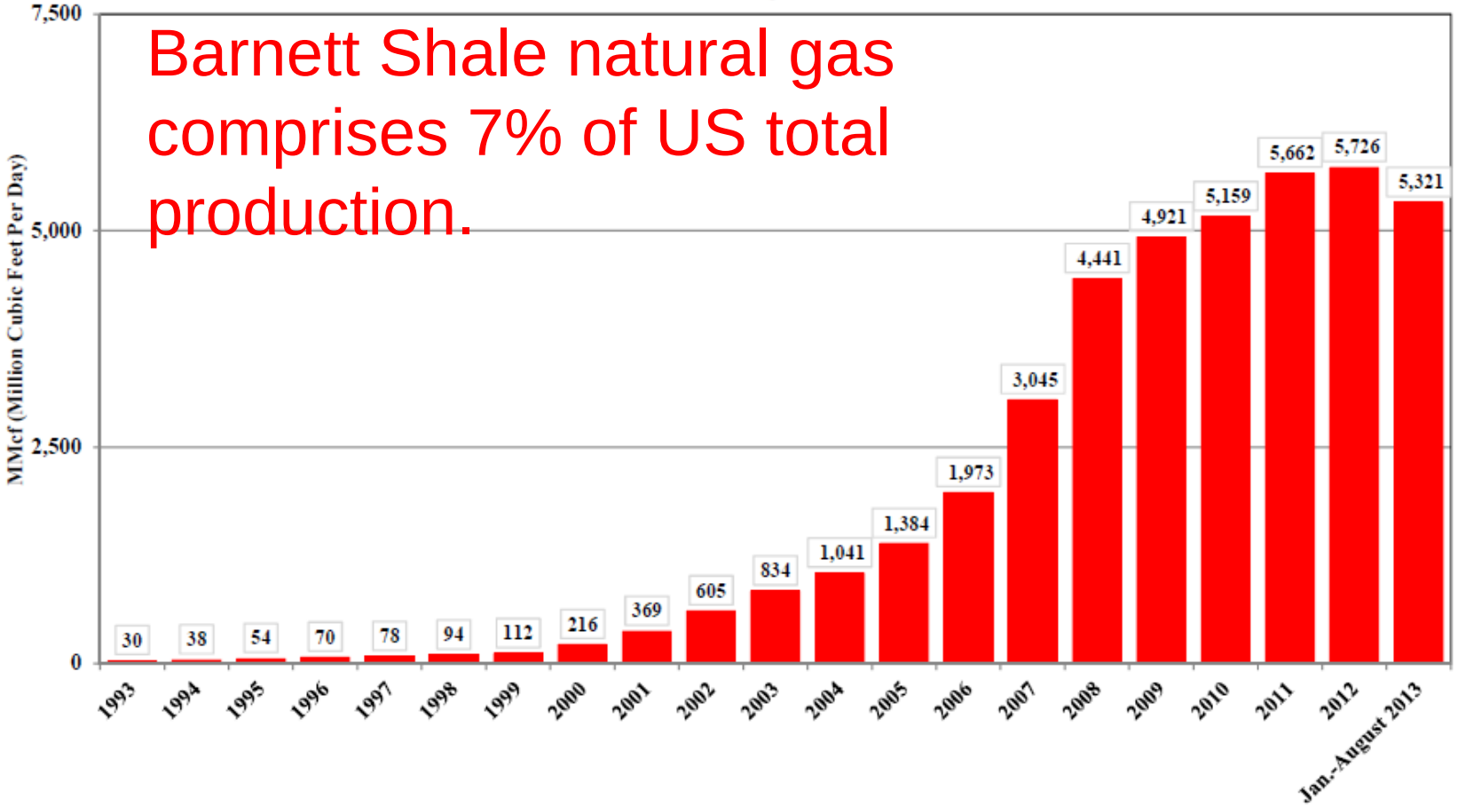


1. Top-down oil and gas emission estimates based on flight data in May 2012 are ~2 times larger than state inventory estimates for NMHCs and 7 times larger for the carcinogen benzene (C_6H_6).

2. CH_4 emissions are close to 3 times larger than an estimate based on EPA GHGRP data.

Average Daily NG Production

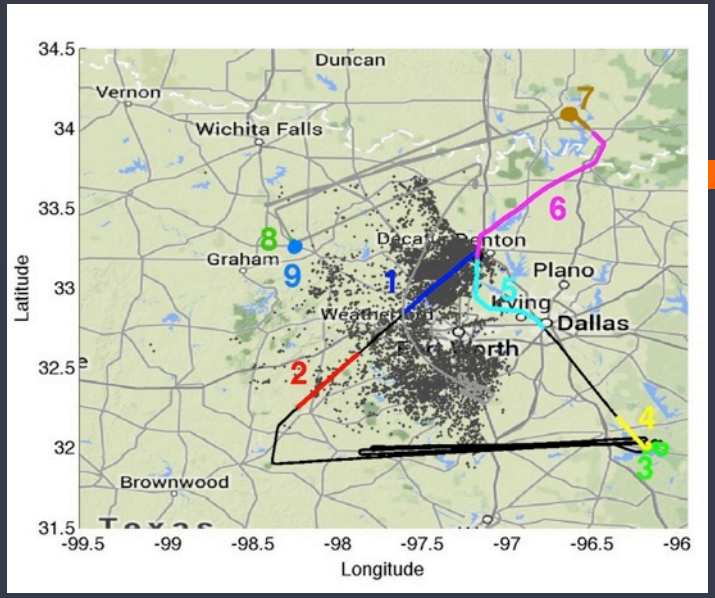
Barnett Shale natural gas comprises 7% of US total production.

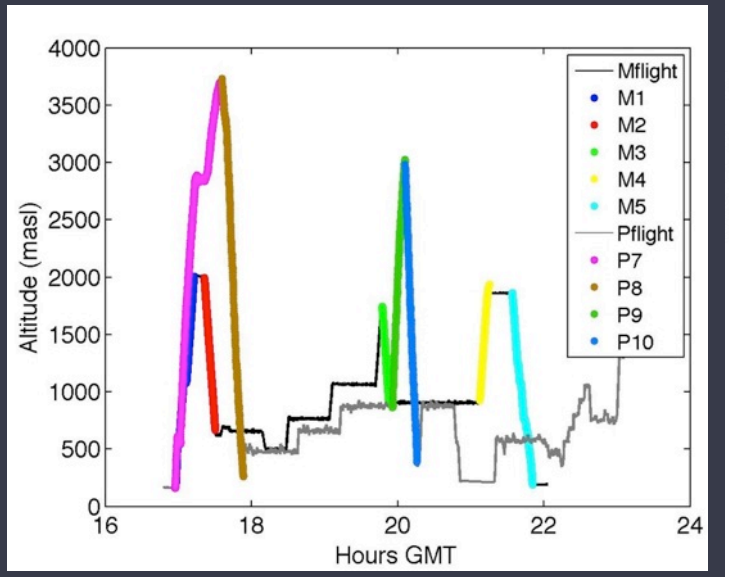


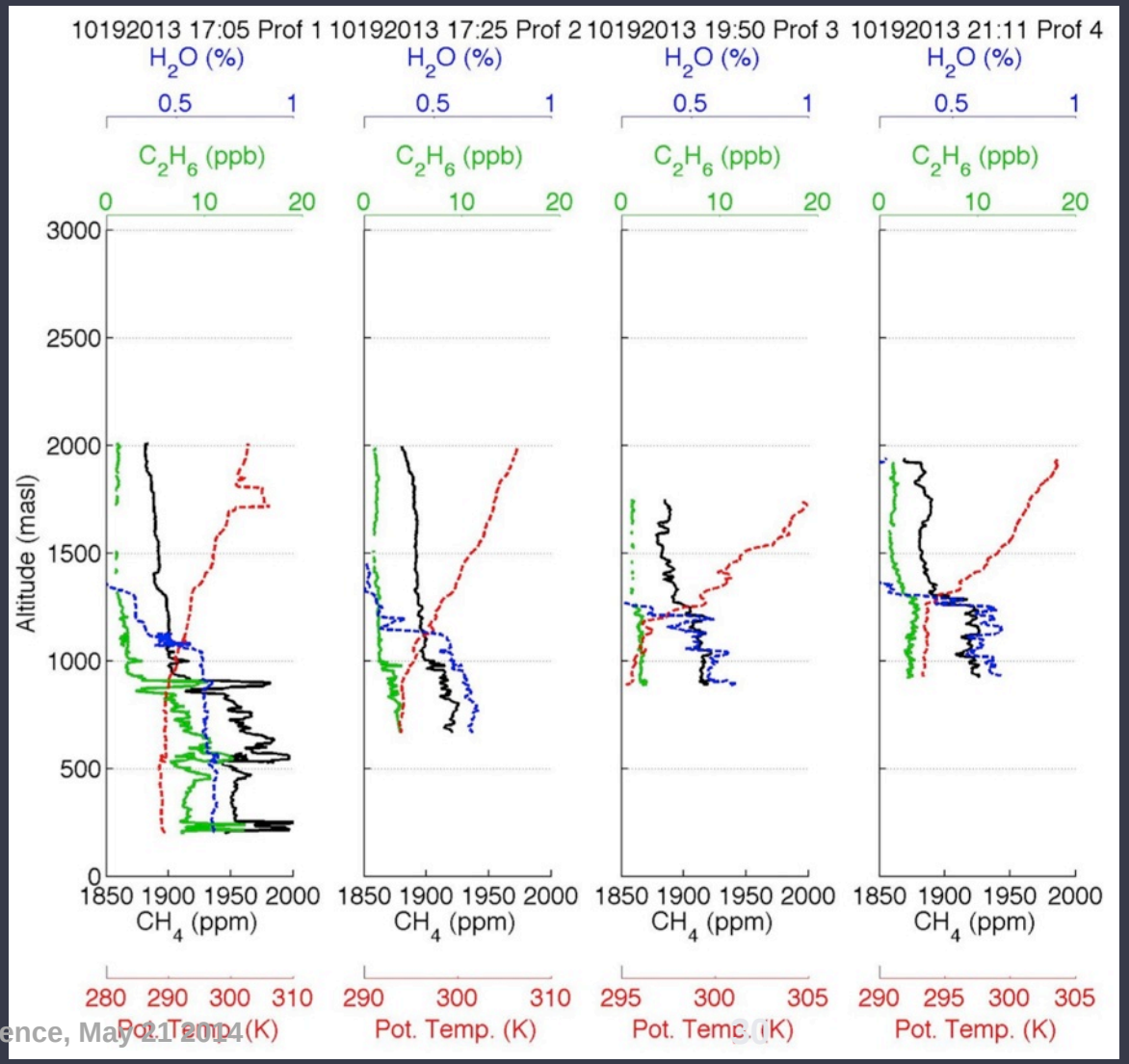
10/22/2013

Source: Texas Railroad Commission Production Data Query System (PDQ)

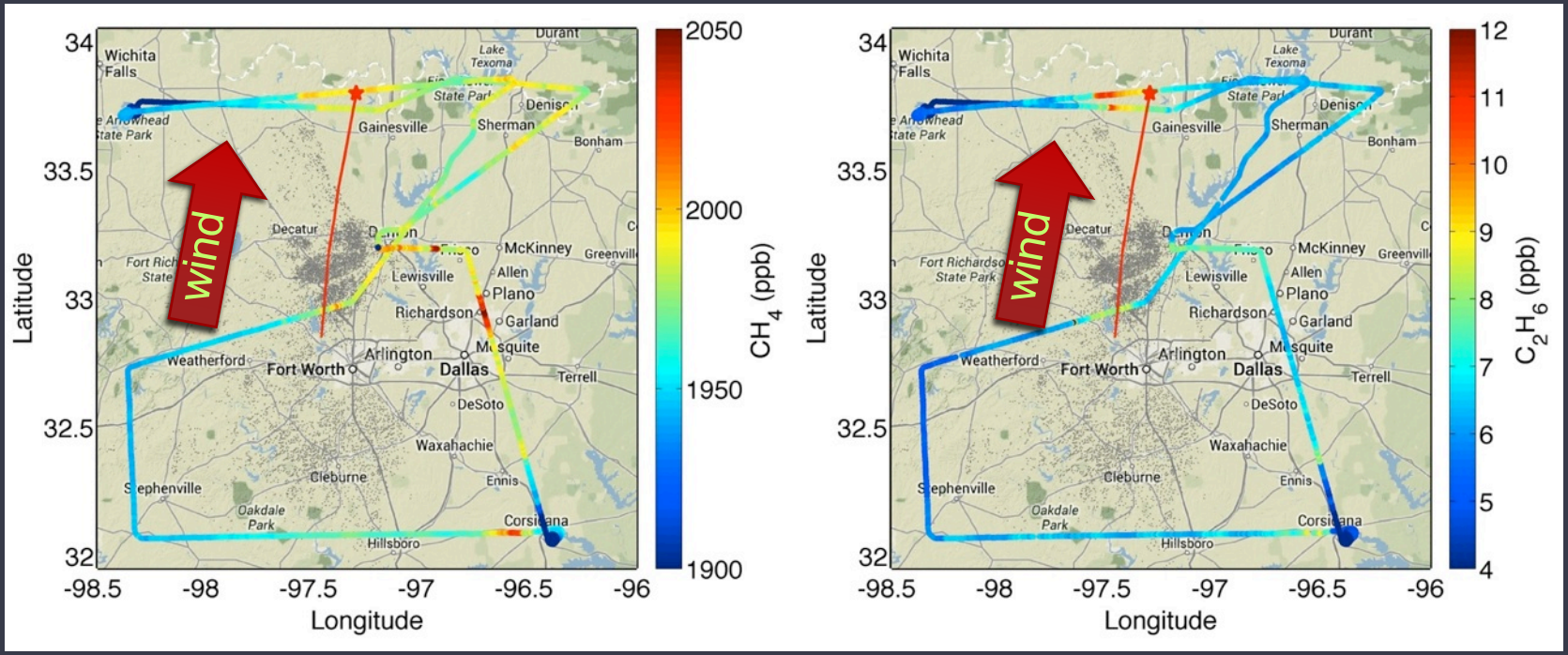
19 Oct 2013


Duncan
Vernon
Wichita Falls
Graham
Plano
Dallas
Brownwood
Latitude
Longitude
34.5
34
33.5
33
32.5
32
31.5
-99.5
-99
-98.5
-98
-97.5
-97
-96.5
-96
1
2
3
4
5
6
7
8
9


Mflight
M1
M2
M3
M4
M5
Pflight
P7
P8
P9
P10
Altitude (masl)
Hours GMT
4000
3500
3000
2500
2000
1500
1000
500
0
16
18
20
22
24


10192013 17:05 Prof 1
10192013 17:25 Prof 2
10192013 19:50 Prof 3
10192013 21:11 Prof 4
H2O (%)
C2H6 (ppb)
Altitude (masl)
CH4 (ppm)
Pot. Temp. (K)

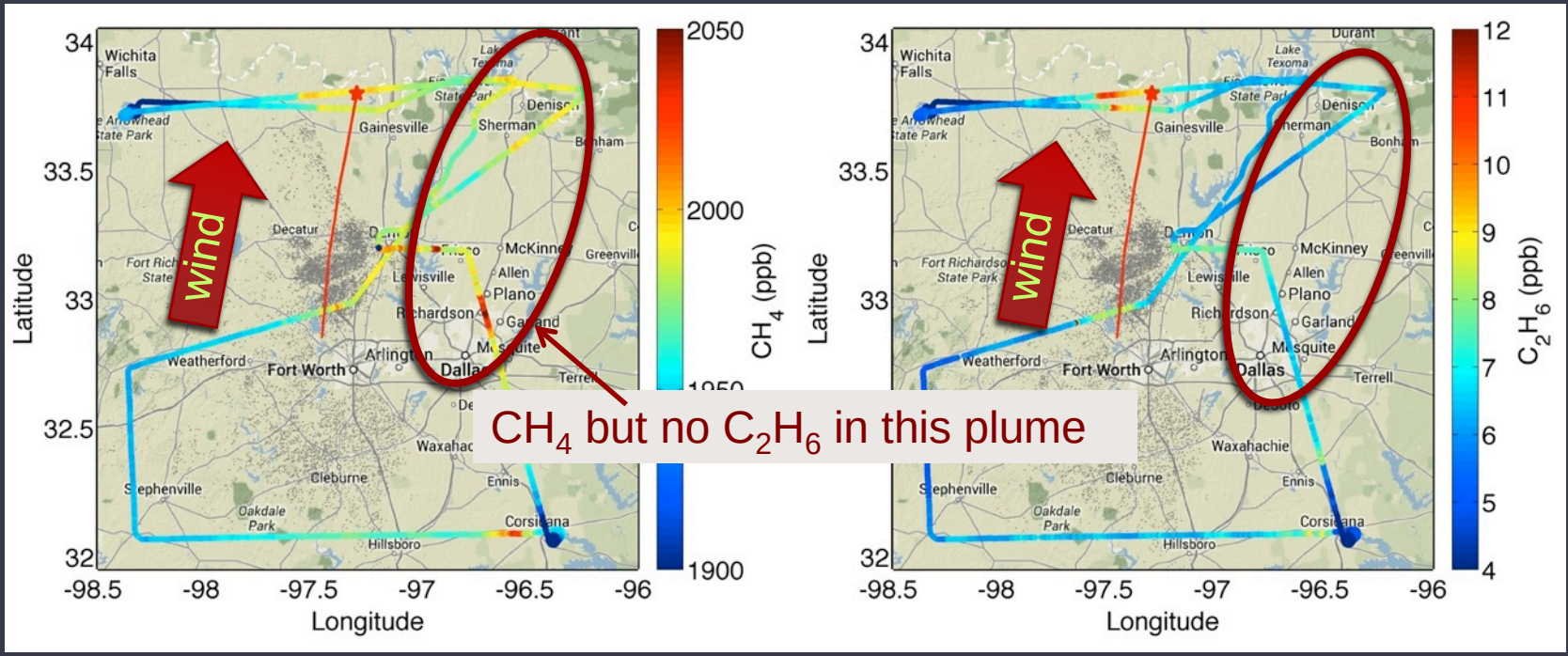
27 March 2013



Methane (CH_4)

Ethane (C_2H_6)

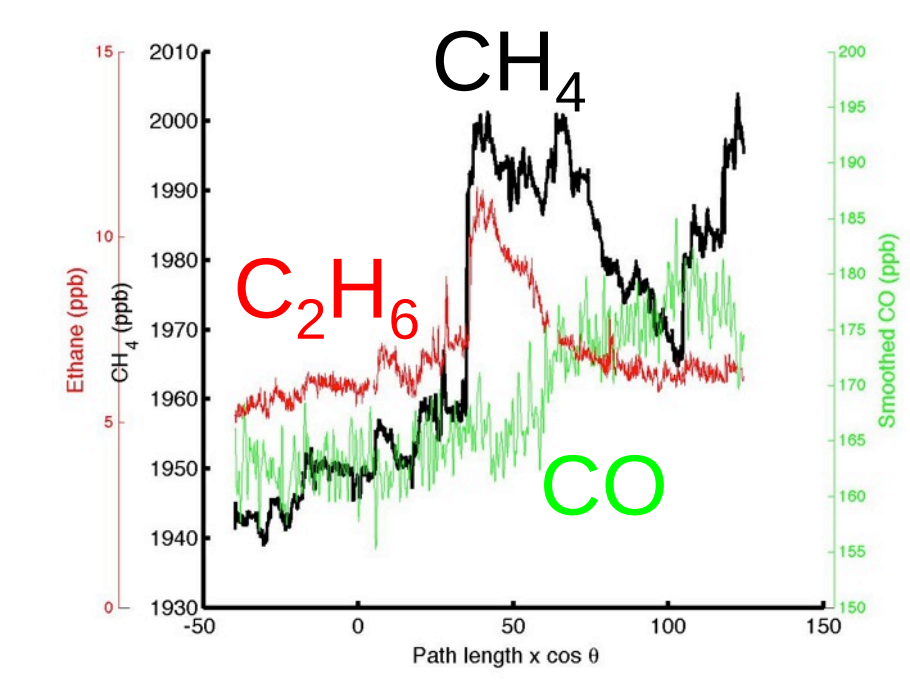
27 March 2013



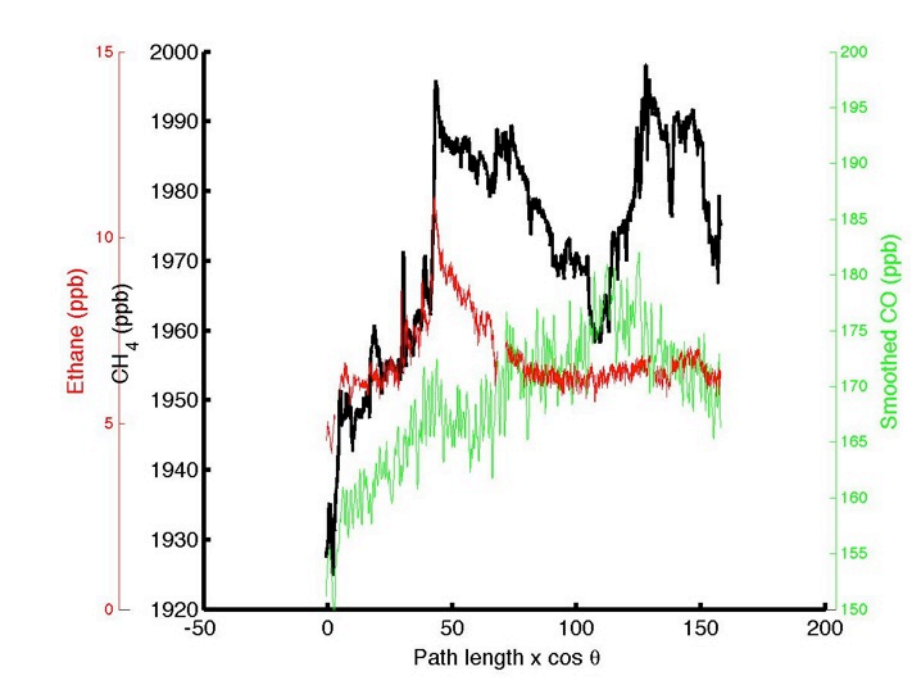
Methane (CH_4) Ethane (C_2H_6)

27 March 2013

CH_4 and C_2H_6 are both components of natural gas; CO is not.



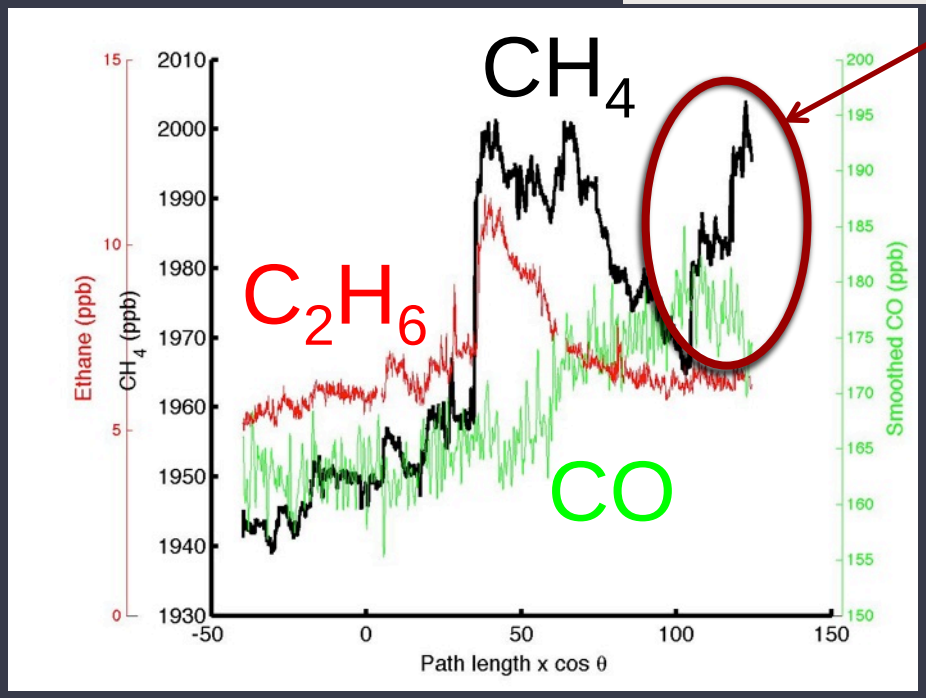
Downwind Transect 1



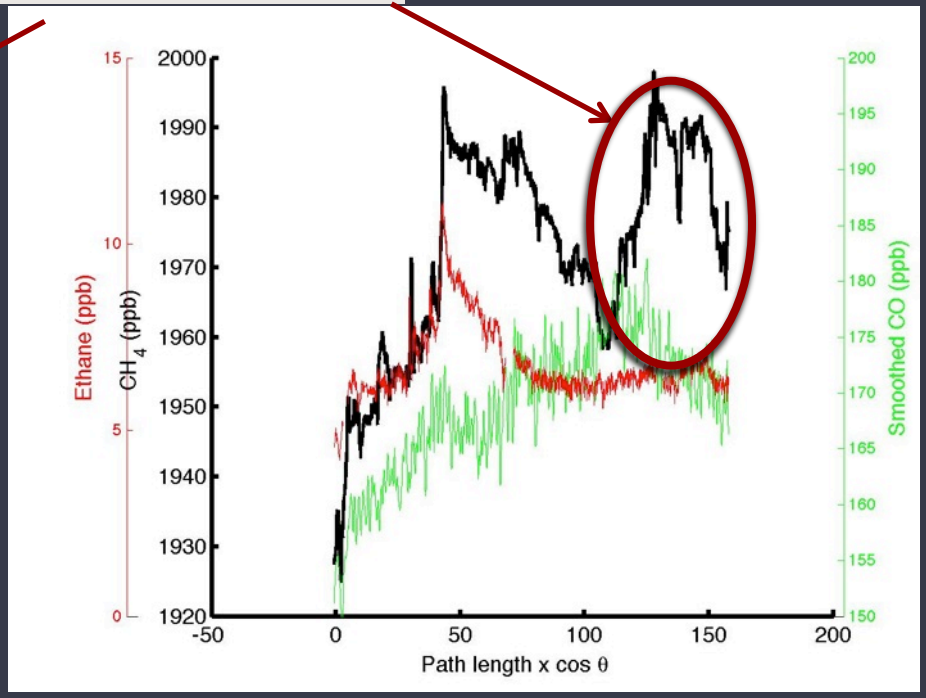
Downwind Transect 2

27 March 2013

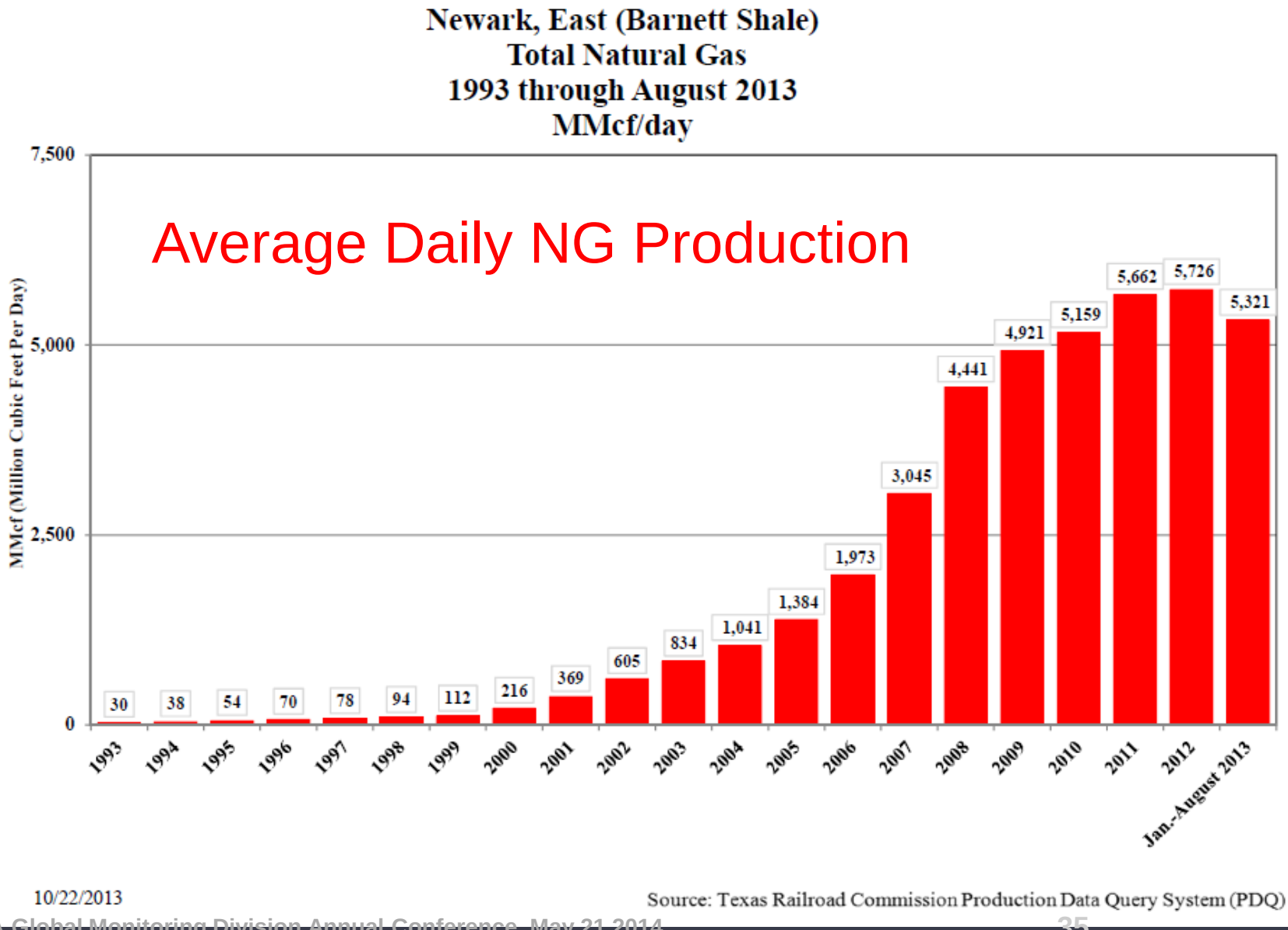
CH_4 but no C_2H_6 in this plume

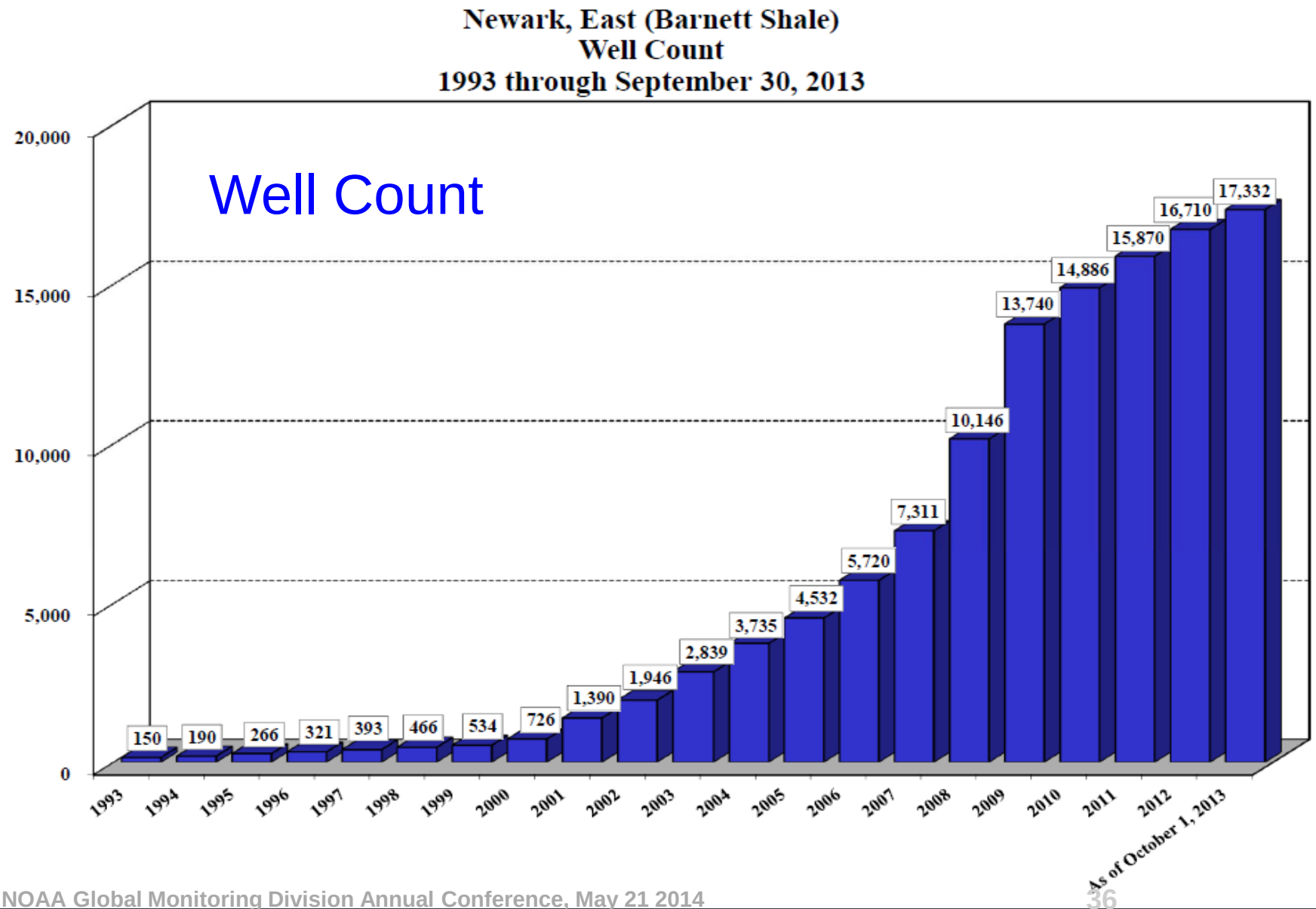


Downwind Transect 1



Downwind Transect 2


Newark, East (Barnett Shale)
Total Natural Gas
1993 through August 2013
MMcf/day
Average Daily NG Production
MMcf (Million Cubic Feet Per Day)
7,500
5,000
2,500
0
30
38
54
70
78
94
112
216
369
605
834
1,041
1,384
1,973
3,045
4,441
4,921
5,159
5,662
5,726
5,321
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Jan.-August 2013
10/22/2013
Source: Texas Railroad Commission Production Data Query System (PDQ)


Newark, East (Barnett Shale)
Well Count
1993 through September 30, 2013
Well Count
20,000
15,000
10,000
5,000
0
150
190
266
321
393
466
534
726
1,390
1,946
2,839
3,735
4,532
5,720
7,311
10,146
13,740
14,886
15,870
16,710
17,332
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
As of October 1, 2013