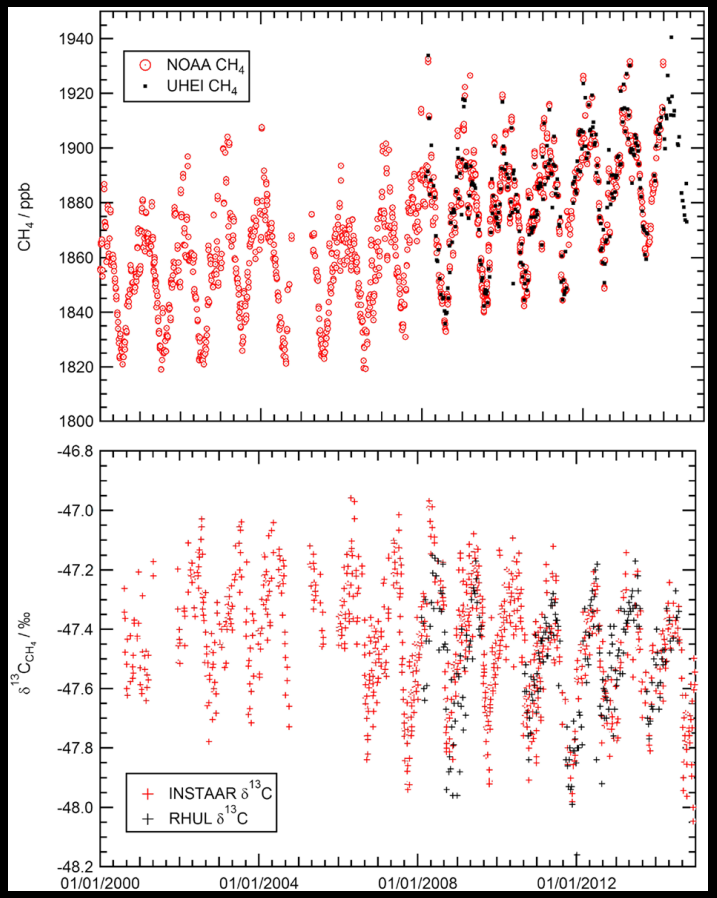
Fossil Fuel Discussion



Has energy production played a role?

What can we learn from energy production?

Nisbet et al. 2016

Main Points

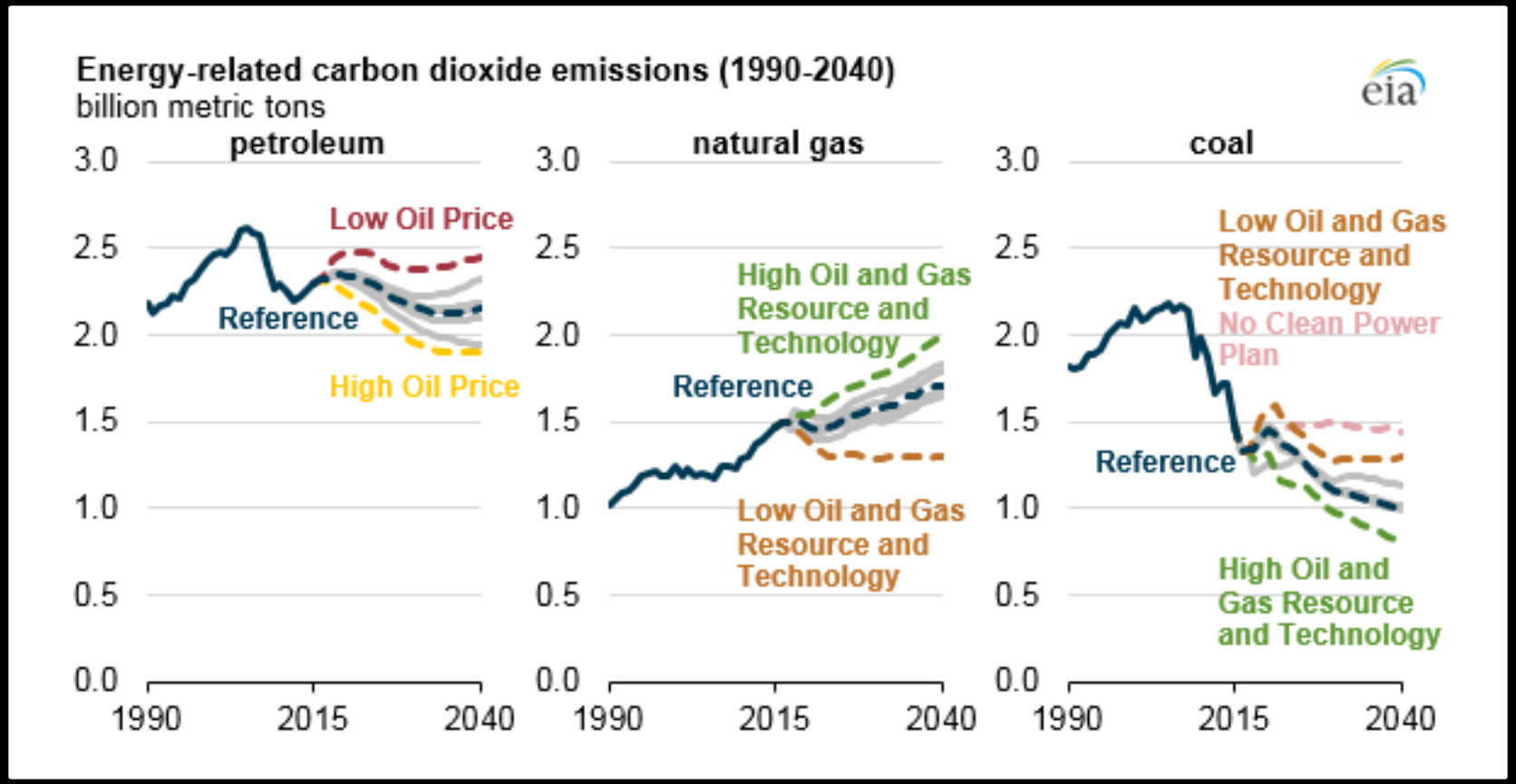
1. The exploration of fossil fuel emissions of CH4 have given us a set tools that can be used to look at methane emissions in other source categories.
2. Relying on tracer ratios may get us into trouble and we have to be careful how much we interpret these ratios.

Outline:

1. Regional studies in the US
    a. Methods
    b. Changing end-members
2. Global constraints
    a. Ethane
    b. $^{13}CH_4$

Energy production

US CO_2 emissions from oil/gas/coal



Source: EIA

NOAA aircraft mass balance study regions

Bakken, ND (Oil)
0.4%

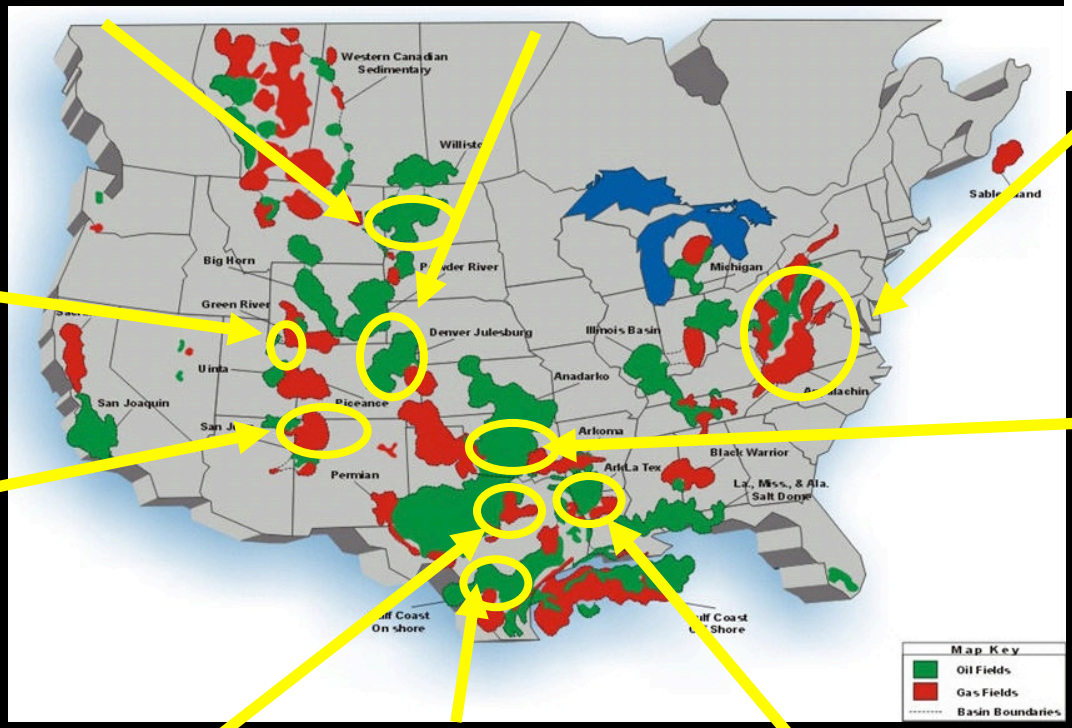
Peischl et al. 2016

Denver Julesburg, CO
0.9%

Petron et al. 2012; 2014

Marcellus, PA/NY
8%

Peischl et al., 2015
Barkley et al., 2016



Uinta, UT
1.0%

Karion et al., 2013

Fayetteville, LA/TX
3.3%

Peischl et al., 2015

San Juan, NM
(Coal bed) 2.6%

Smith et al., 2017

Barnett, TX
6.6%

Karion et al., 2015

Eagle Ford
9%

Peischl et al., 2016

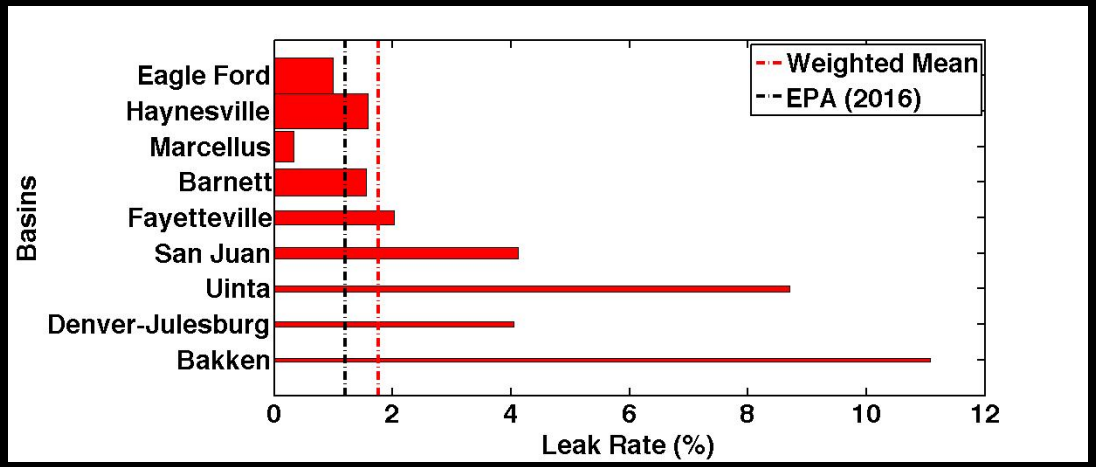
Haynesville, LA/TX
9%

Peischl et al., 2015

>40% US total natural gas production

>70% of shale gas production

Summary regional studies

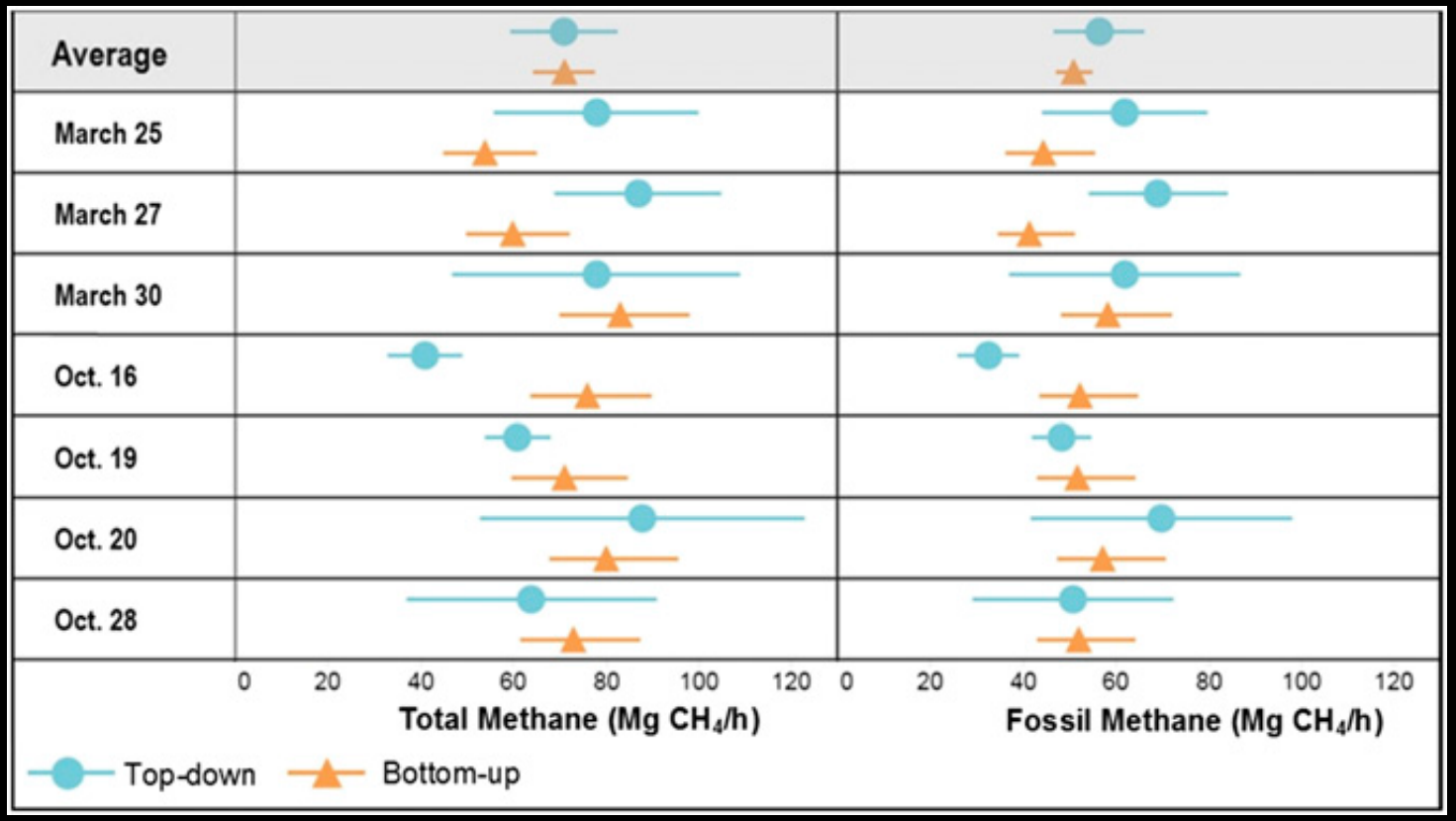


- The NOAA mass balance estimates from 9 different basins suggest a weighted mean of 1.6% .
- The smaller producing fields are driving the average leak rate up.

Karion et al. (2013; 2015)
Petron et al. (2012; 2014)
Peischl et al. (2015; 2016)
Smith et al. (2016)

Mass Balance v. Inventory

Comparison between bottom up and top down in Barnet using 8 mass balance flights



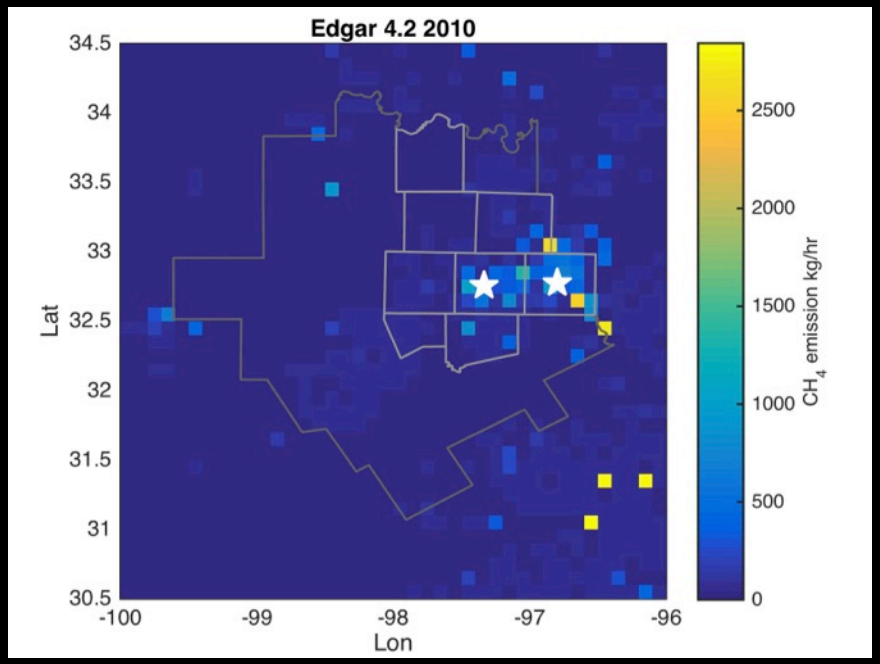
Reconciliation of top down and bottom up was 10% for total CH4 and 0.1% for fossil CH_4:

- **Better accounting of facilities (missing from EPA database)**
- **Accounting for "outlier emitters" – the fat tail**

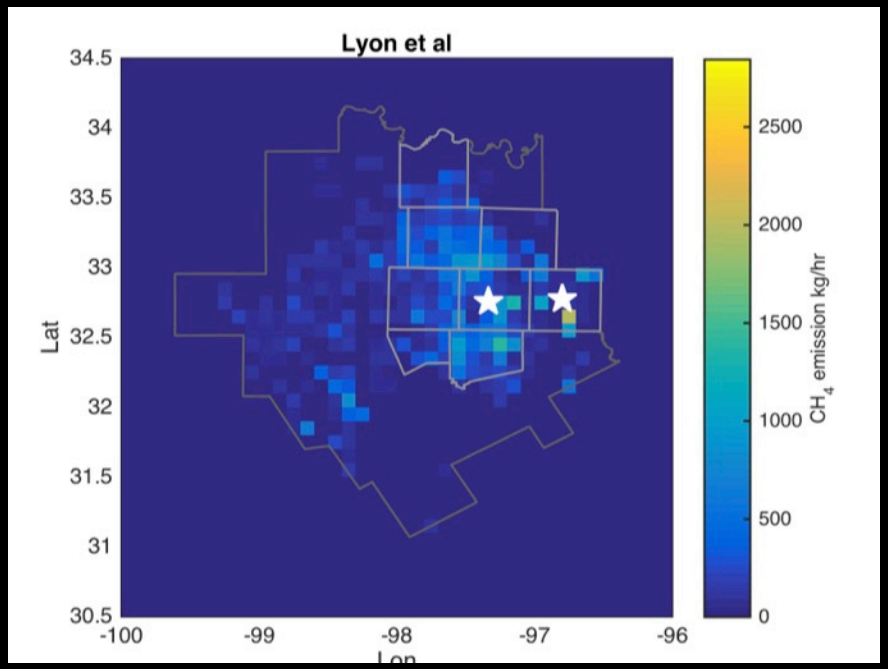
Source: Zavala-Araiza et al. 2015

Spatial comparison

Bottom up inventories for Barnet Shale Region



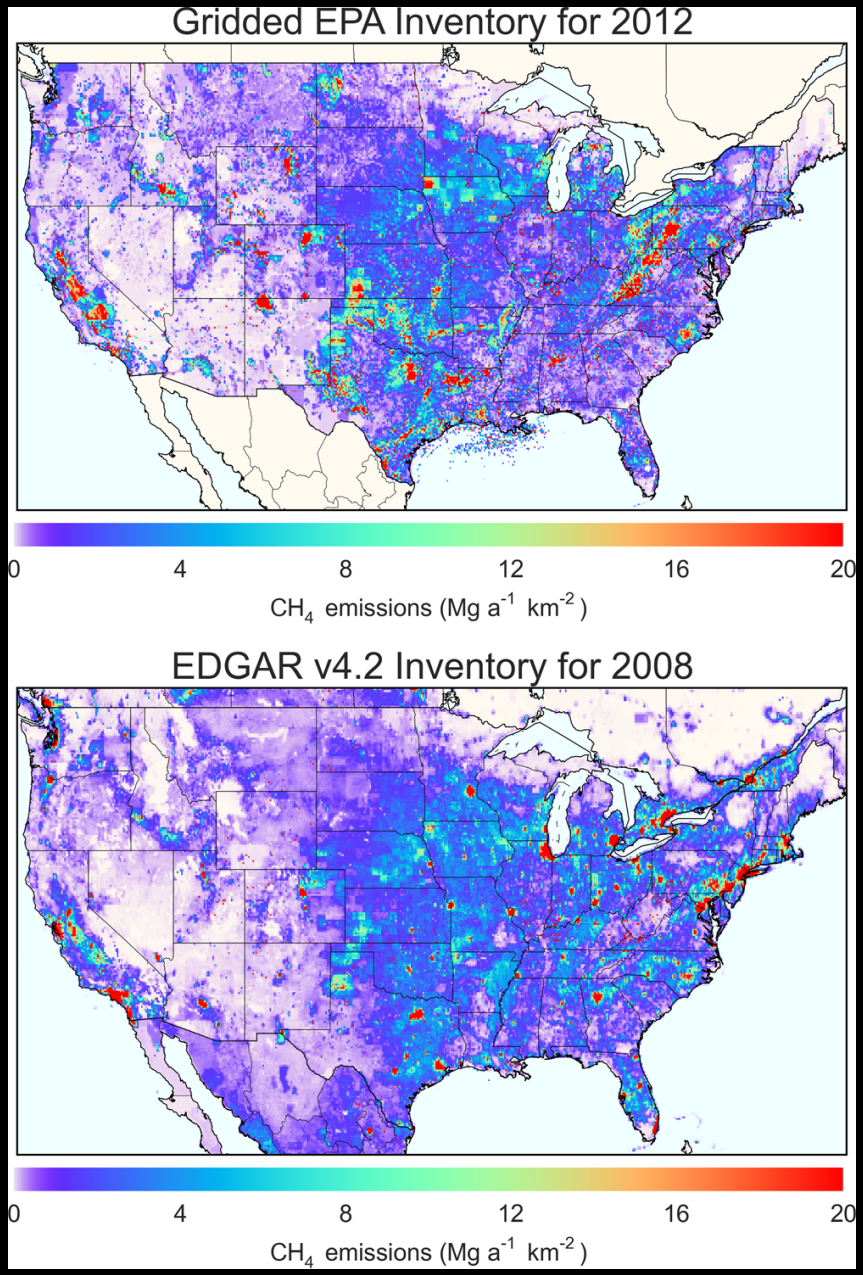
EDGARv4.2



EDF – Lyons et al. 2015

Vast difference in where the source was located between the two inventories.

Improvements in bottom up

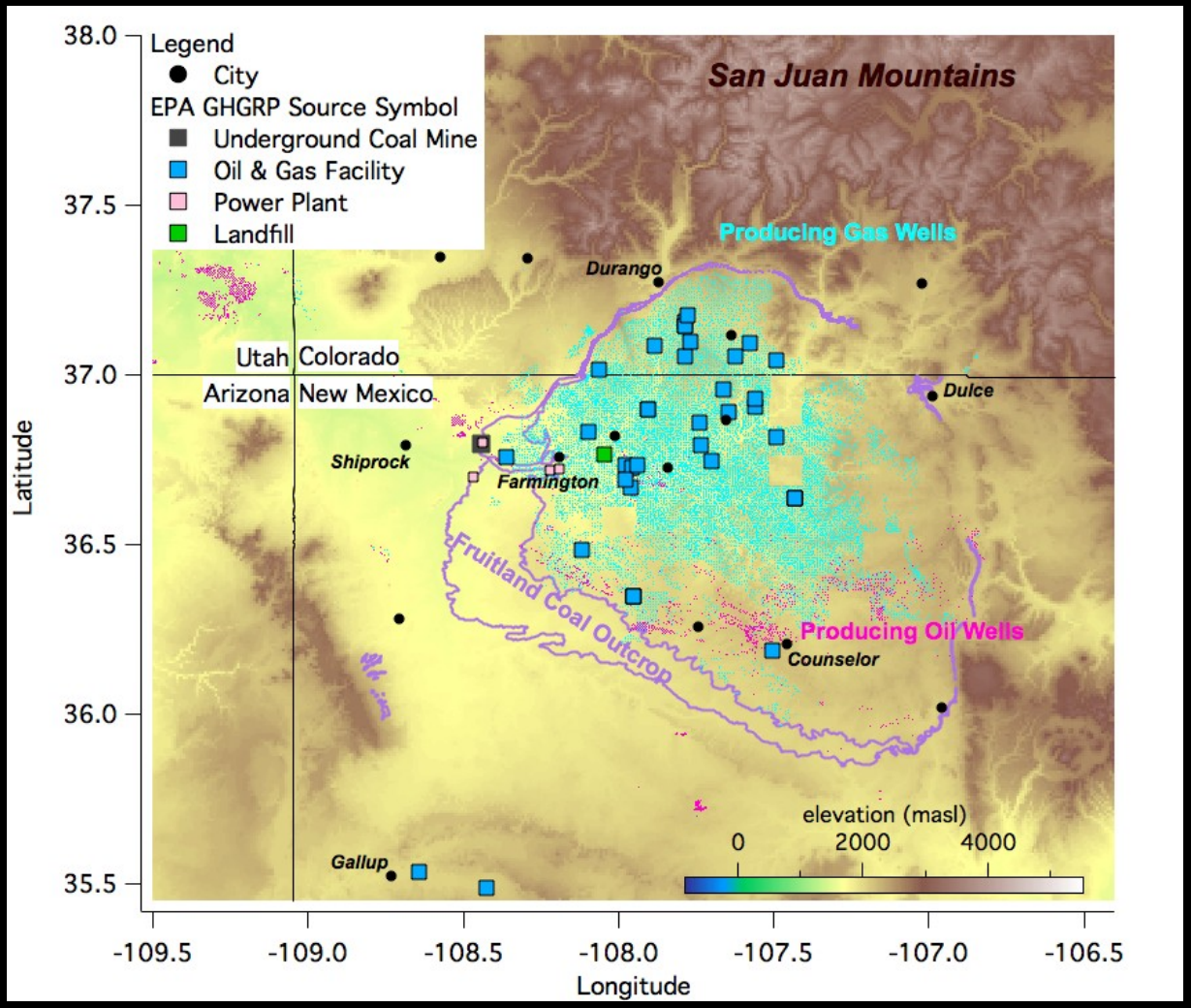


Maasakkers et al., 2016

TOPDOWN 2015

Twin Otter Projects Defining Oil Well and Natural gas emissions

Potential sources of CH_4 in San Juan Basin

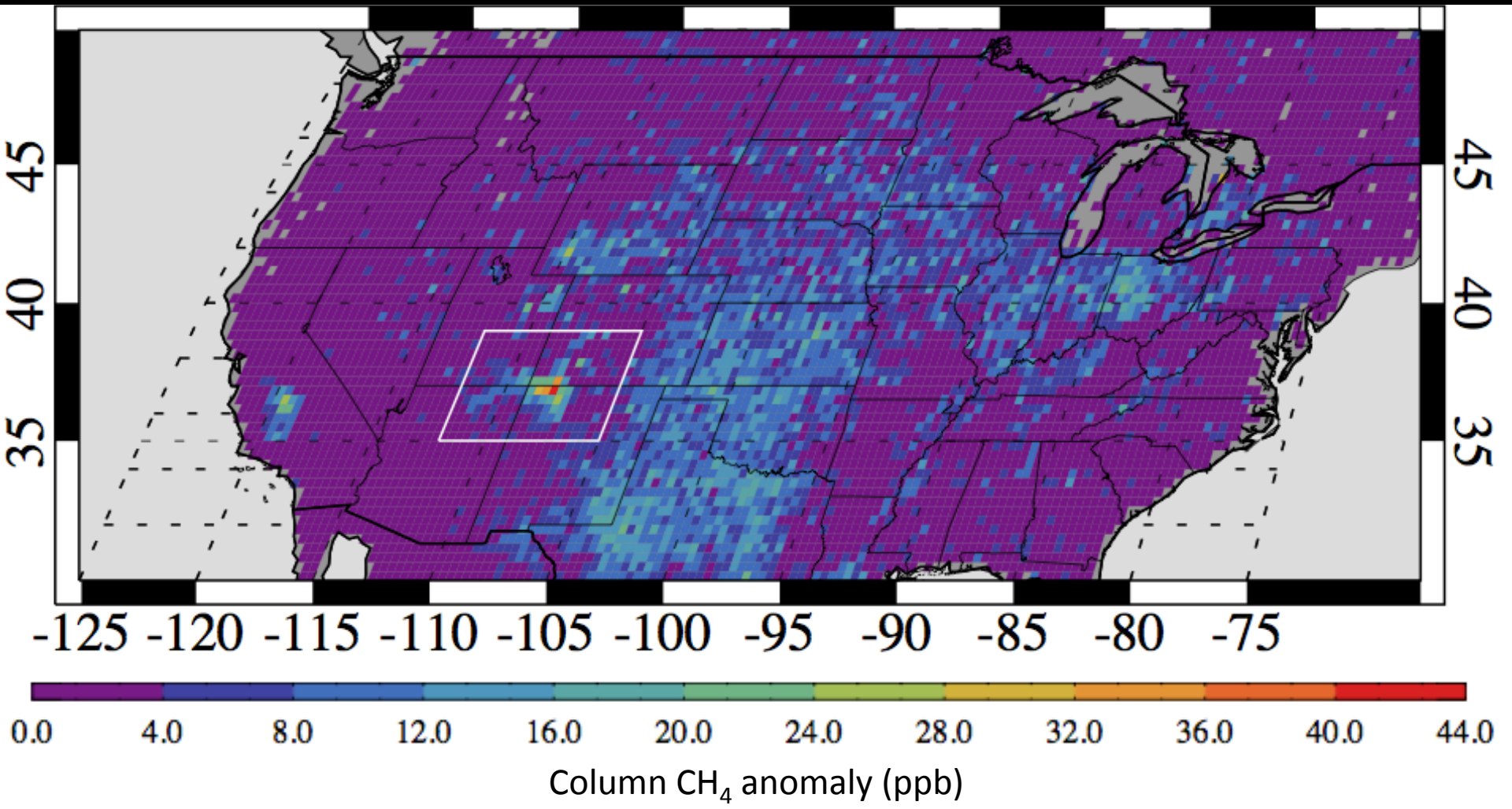


- Coal bed methane (CBM)
- Tight Sandstone natural gas production
- Active Coal mining
- Geological seeps
- Large Power plants
- Oil production
- Emissions from agricultural sources, waste management facilities and wetlands are small

Bottom up Estimates = 0.42-0.52 Tg/yr

San Juan Basin

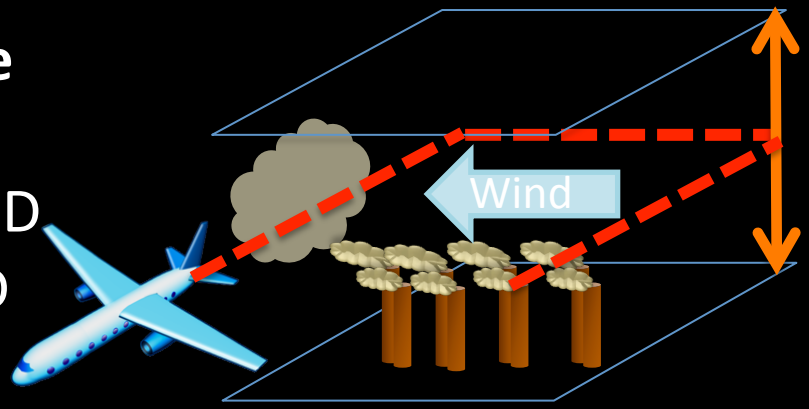
The largest Coal Bed Methane producer in the US



SCIAMACHY 2003-2009 → 0.59 Tg CH_4/yr Kort et al. 2013

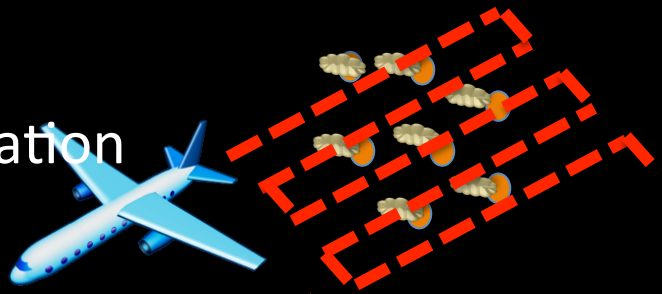
Multi-scale/level Approach

Mass Balance
- Umich
- NOAA/GMD
- NOAA/CSD

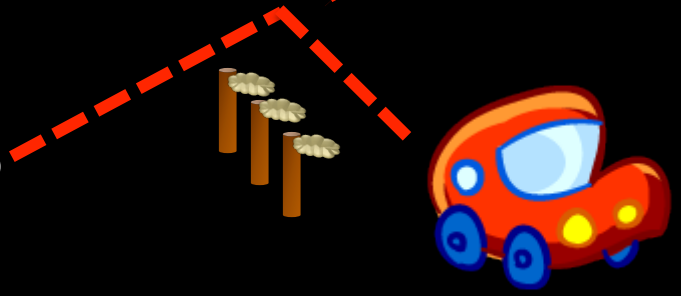


Total basin emissions and large-scale source allocation

Point Source identification
- Scientific aviation
- NASA/JPL



Large emitter site location and emissions quantification

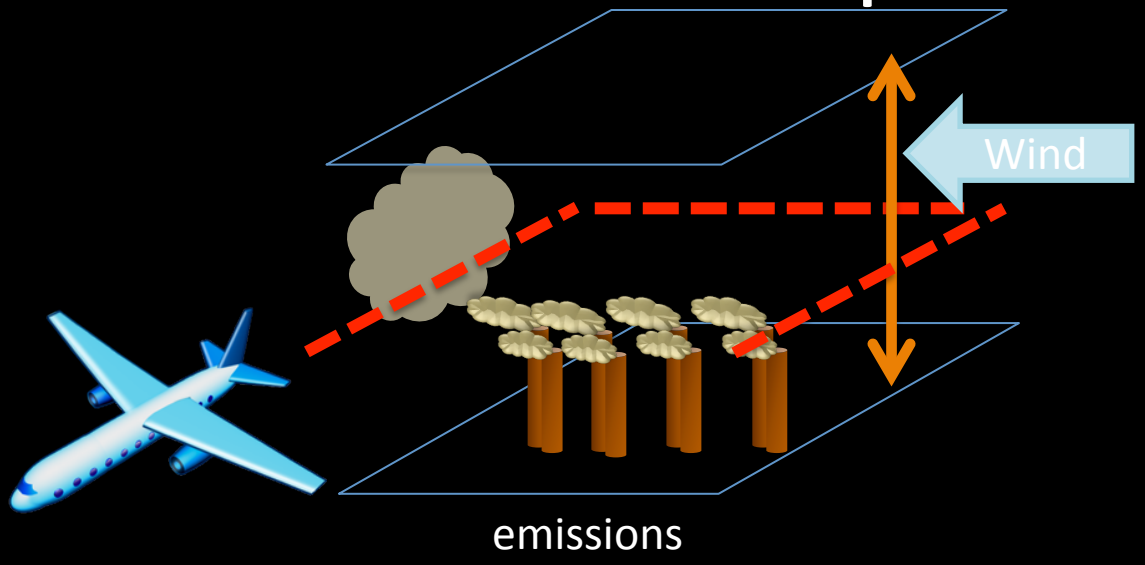


- U of Colorado
- NOAA/GMD
- LANL

Process level emissions verification and emissions profile (e.g. CH_4/C_2H_6)

Scales

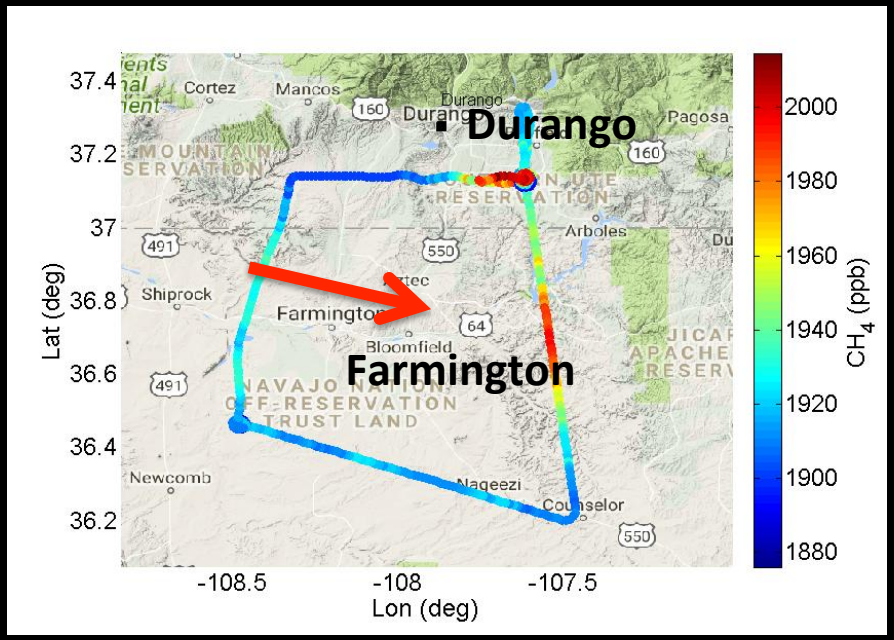
Mass Balance Concept

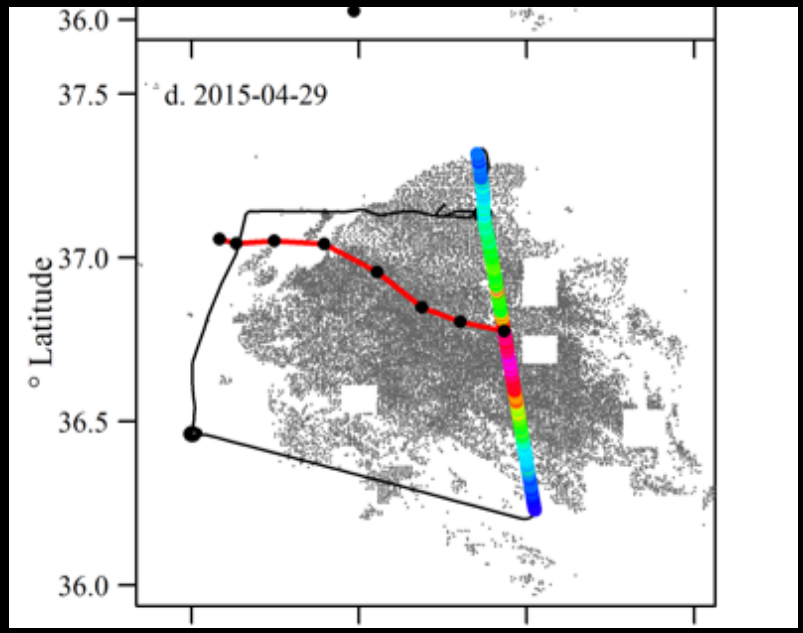


$$\dot{n}_{CH_4} = V\cos\theta \int_{-b}^{+b} \Delta X_{CH_4} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air}\, dz \right) dx$$

Mass Balance

Winds (Vcosθ)

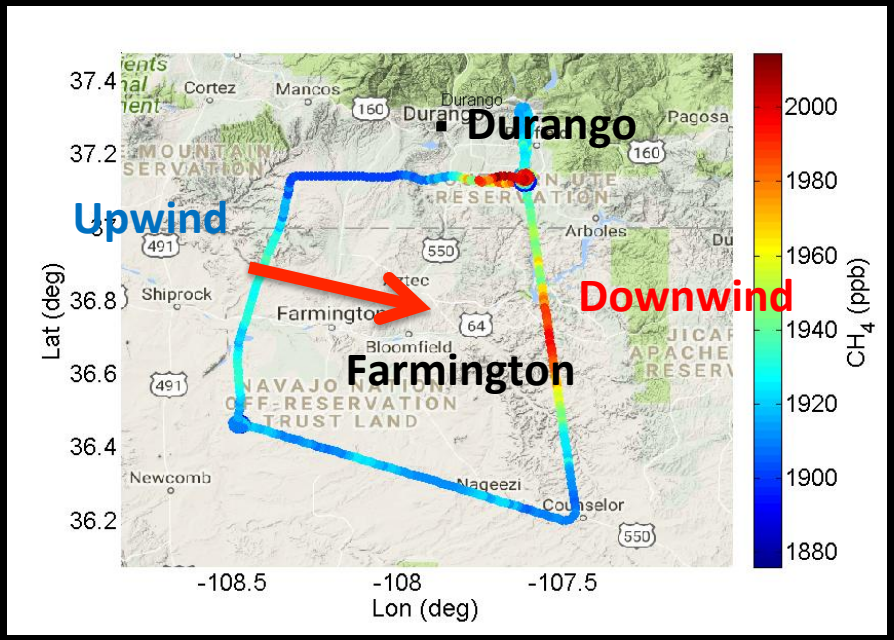


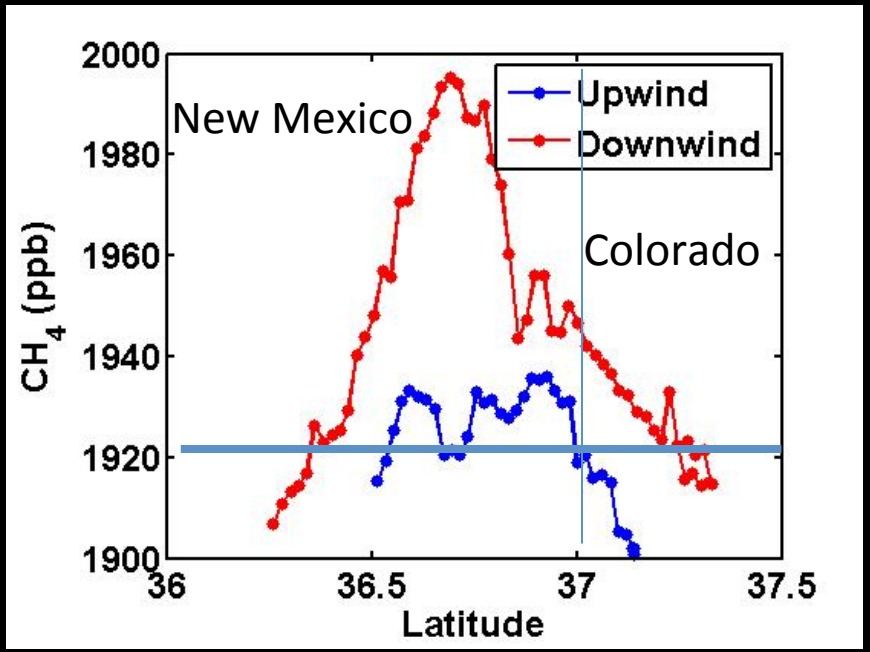


$$\dot{n}_{CH_4} = V\cos\theta \int_{-b}^{b} \Delta X_{CH_4} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air}\, dz \right) dx$$

Mass Balance

Methane Enhancement (ΔCH4)



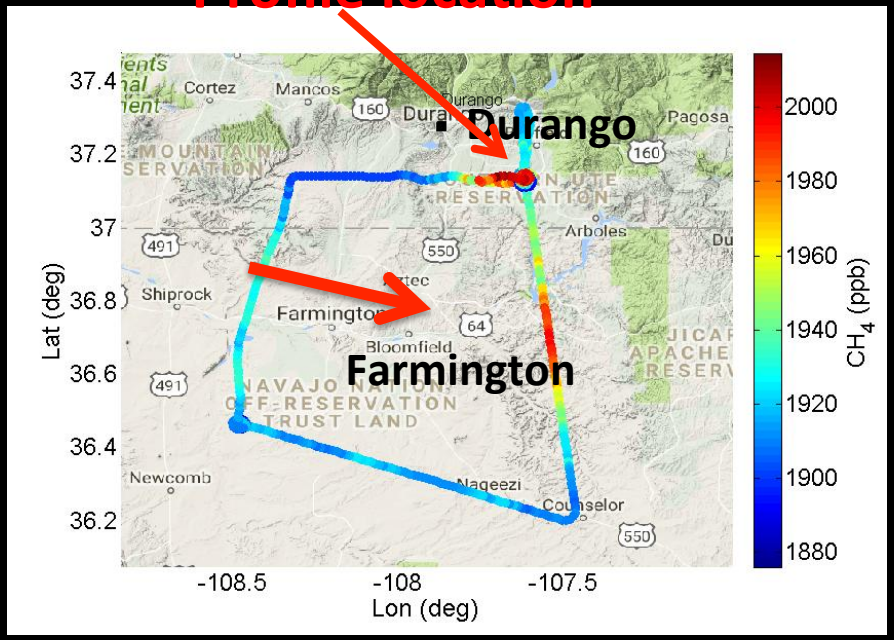


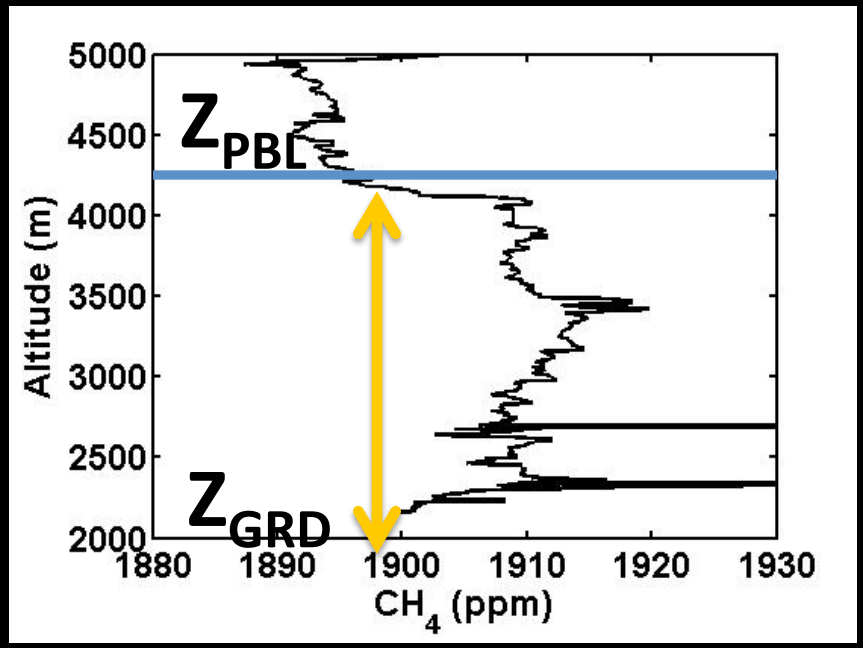
$$\dot{n}_{CH_4} = V\cos\theta \int_{-b}^{+b} \Delta X_{CH_4} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air}\, dz \right) dx$$

Mass Balance

Boundary Layer Height (PBL)

Profile location





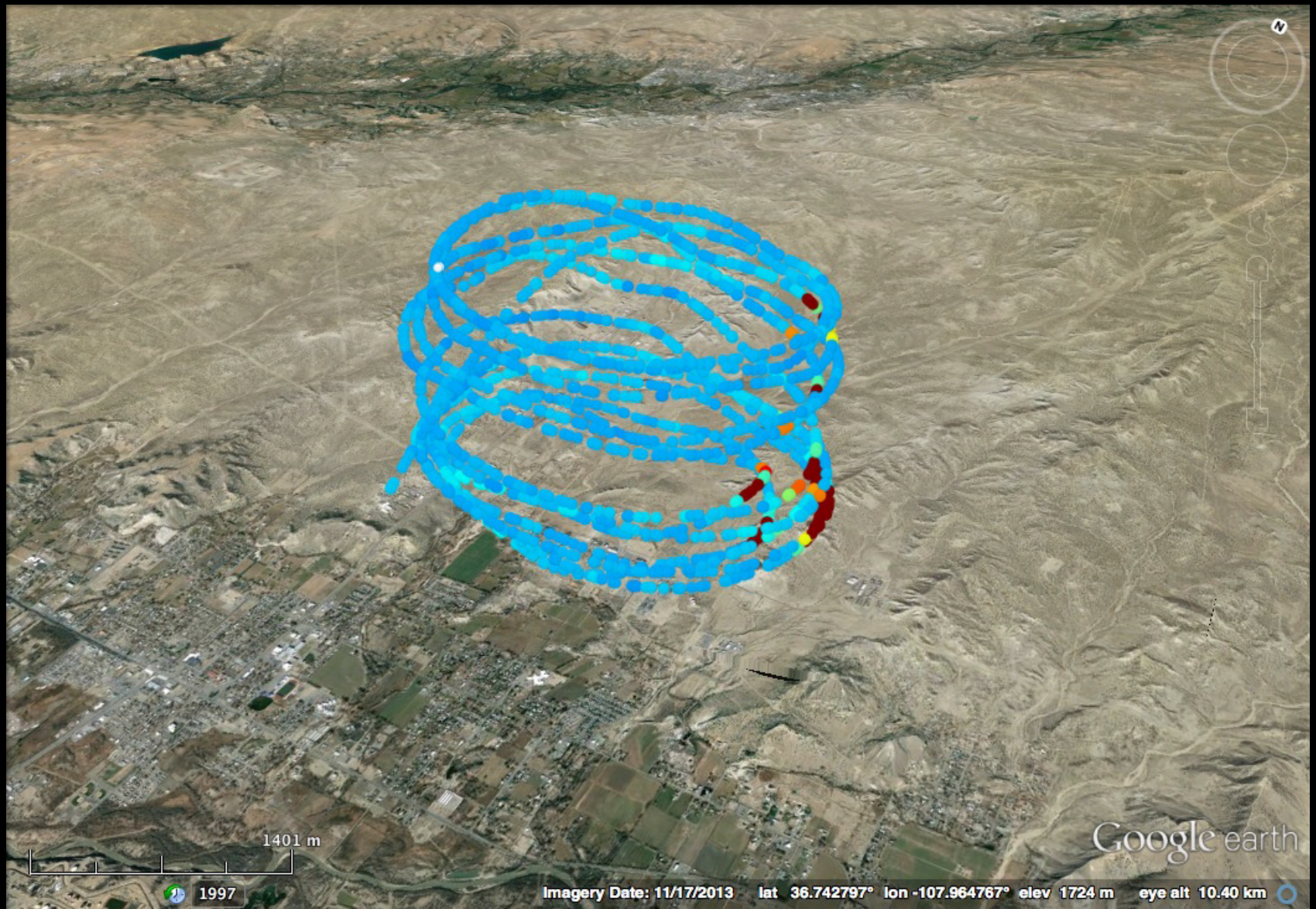
$$\dot{n}_{CH_4} = V \cos\theta \int_{-b}^{+b} \Delta X_{CH_4} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air} dz \right) dx$$

Mass Balance Summary

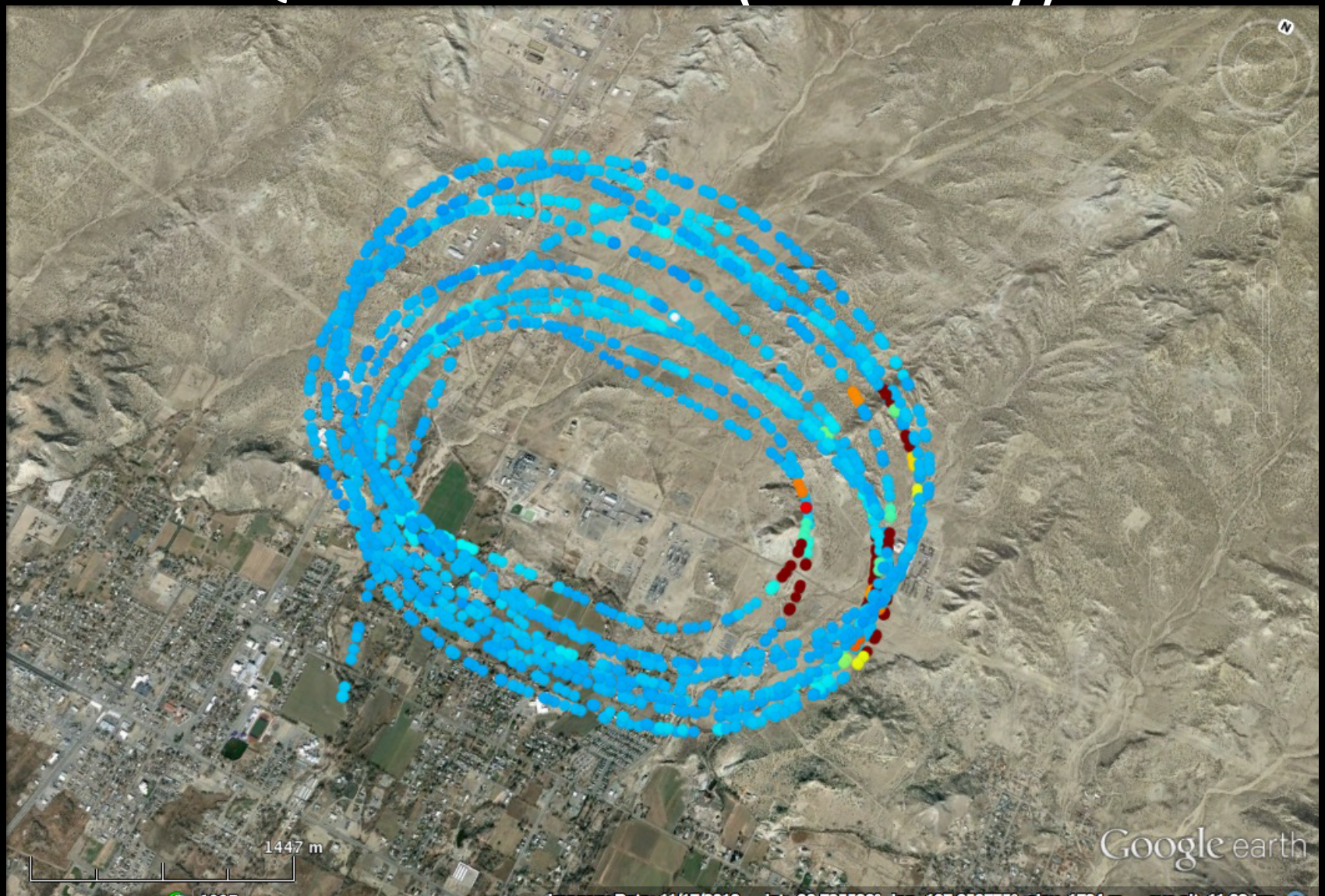
Date	Local hr (-6 UTC hr)	No. of Transects	Θ (deg)	υ (m s^{-1})	z_1 (magl)	$flux_{CH4}$ (Tg yr^{-1})
Mooney:						
4/07/2015	15.5	1	42 ±10	10 ±2	2138 ±71	0.45 ±0.15
Otter:						
4/19/2015	16.2	1	93 ±24	8.1 ±2.6	2250 ±124	0.57 ±0.25
4/21/2015	16.2-17.2	4	95 ±22	6.8 ±1.9	2263 ±106	0.31 ±0.13
4/23/2015	15.8	1	45 ±20	7.0 ±1.8	2450 ±257	0.55 ±0.19
4/29/2015	17.0	1	83 ±25	5.8 ±1.6	2150 ±347	0.84 ±0.30
				Campaign Mean:		**0.54 ±0.20**

Total Mass Balance was consistent with 0.59 Tg/yr found from satellite

Point Source ID and Quantification

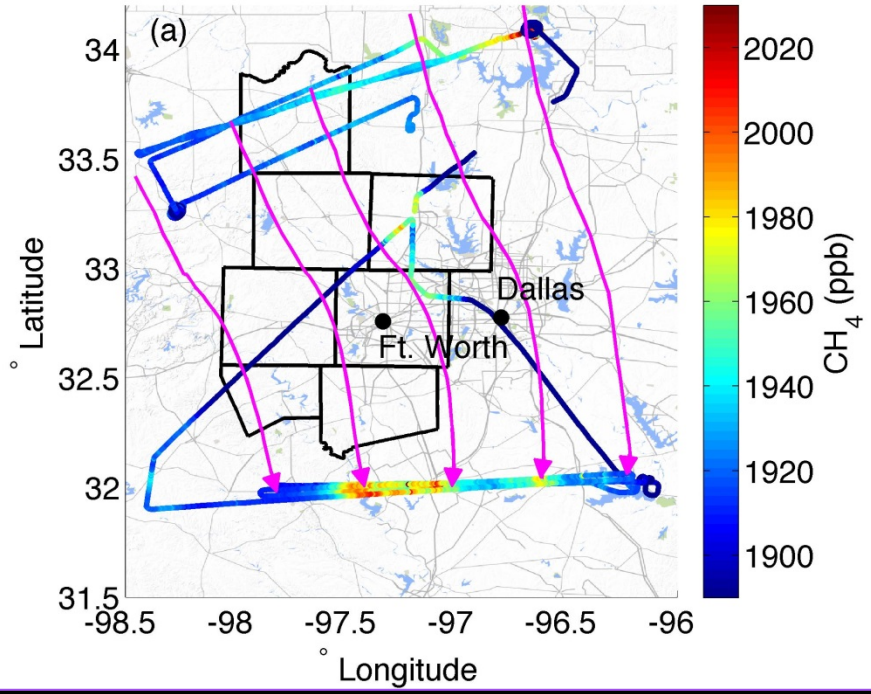


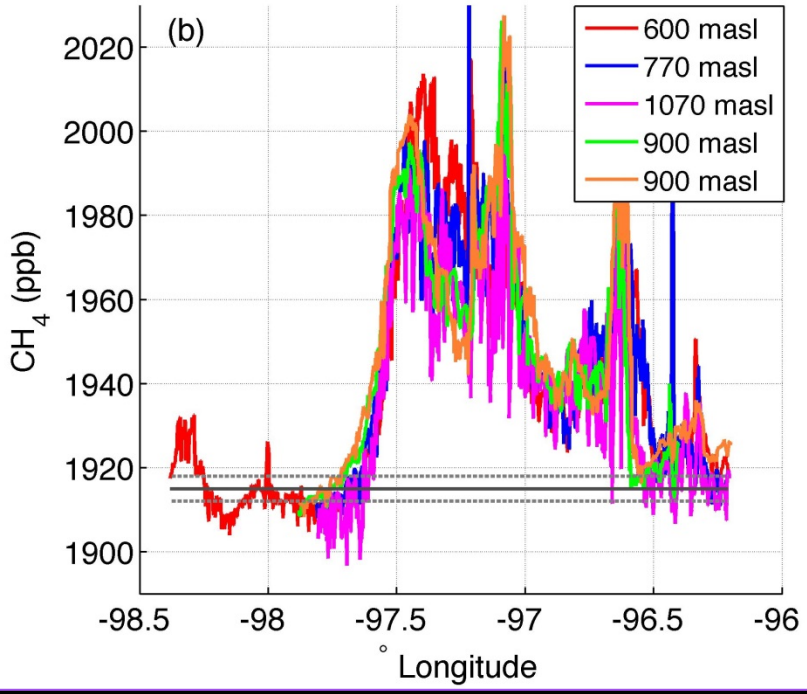
Example of Point Source ID and Quantification (Mooney)



Point Source ID and Quantification

Regional Mass Balance





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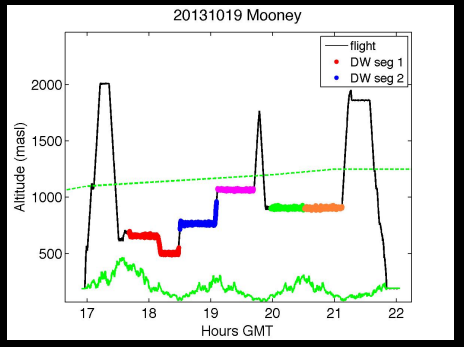
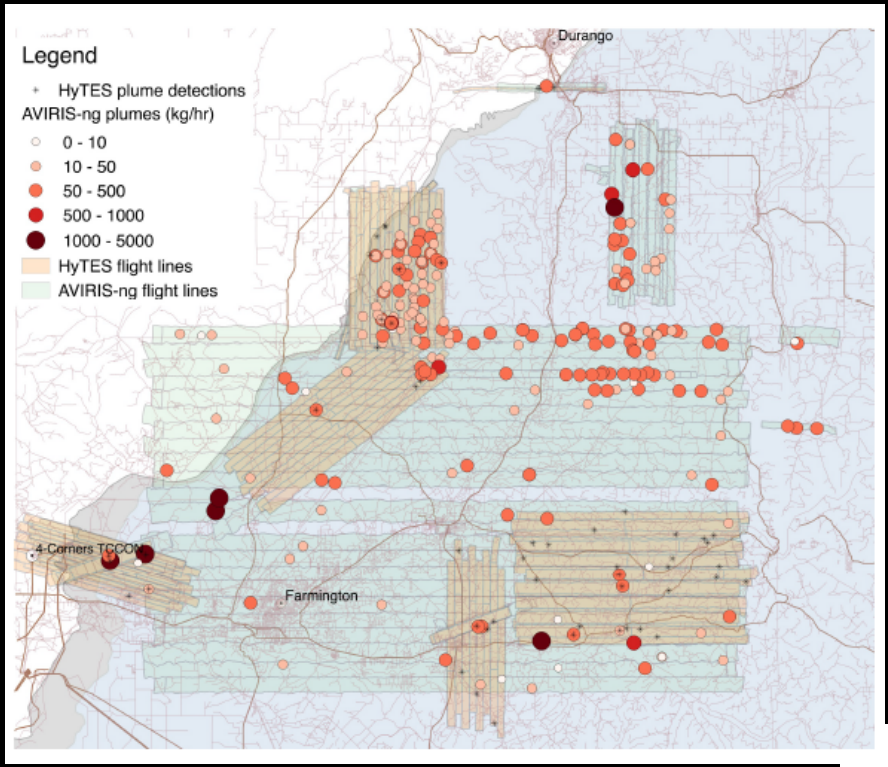


NASA HyTES and AVIRIS on Twin Otters CH_4 column measurements

AVIRIS

HyTES

Hyperspectral Images taken from the aircraft in the short-wave (AVIRIS-NG) and thermal range (HyTES)

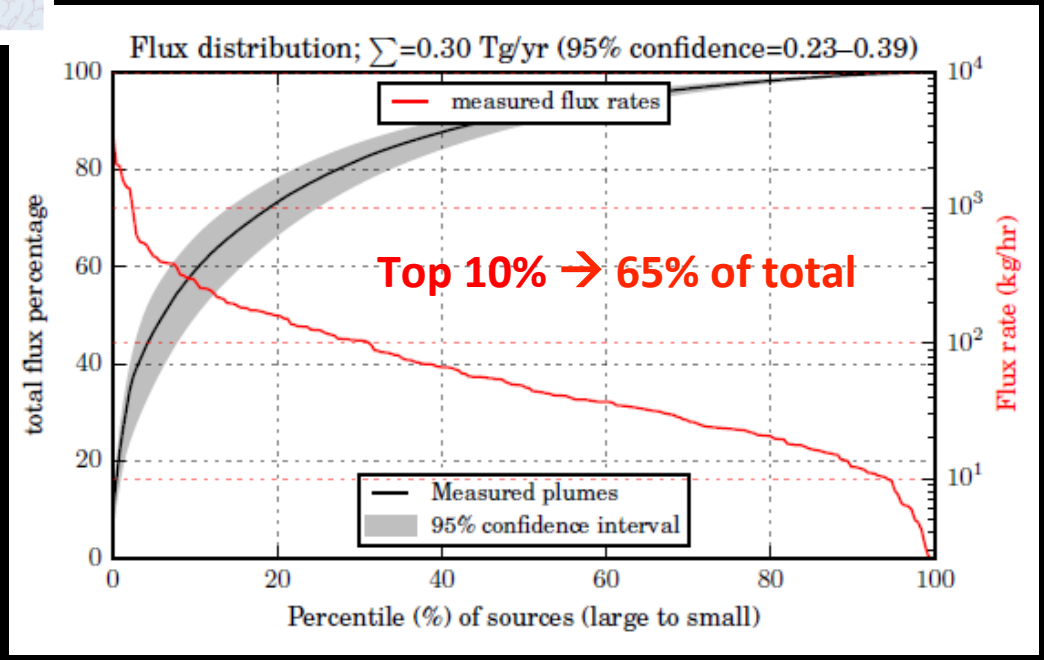


AVRIS finds the fat tail

0.23-0.38 Tg/yr

Like the Barnett the 4-corners region suggests a fat-tail distribution; however no single source dominates the regional emissions.

Frankenberg et al. 2016

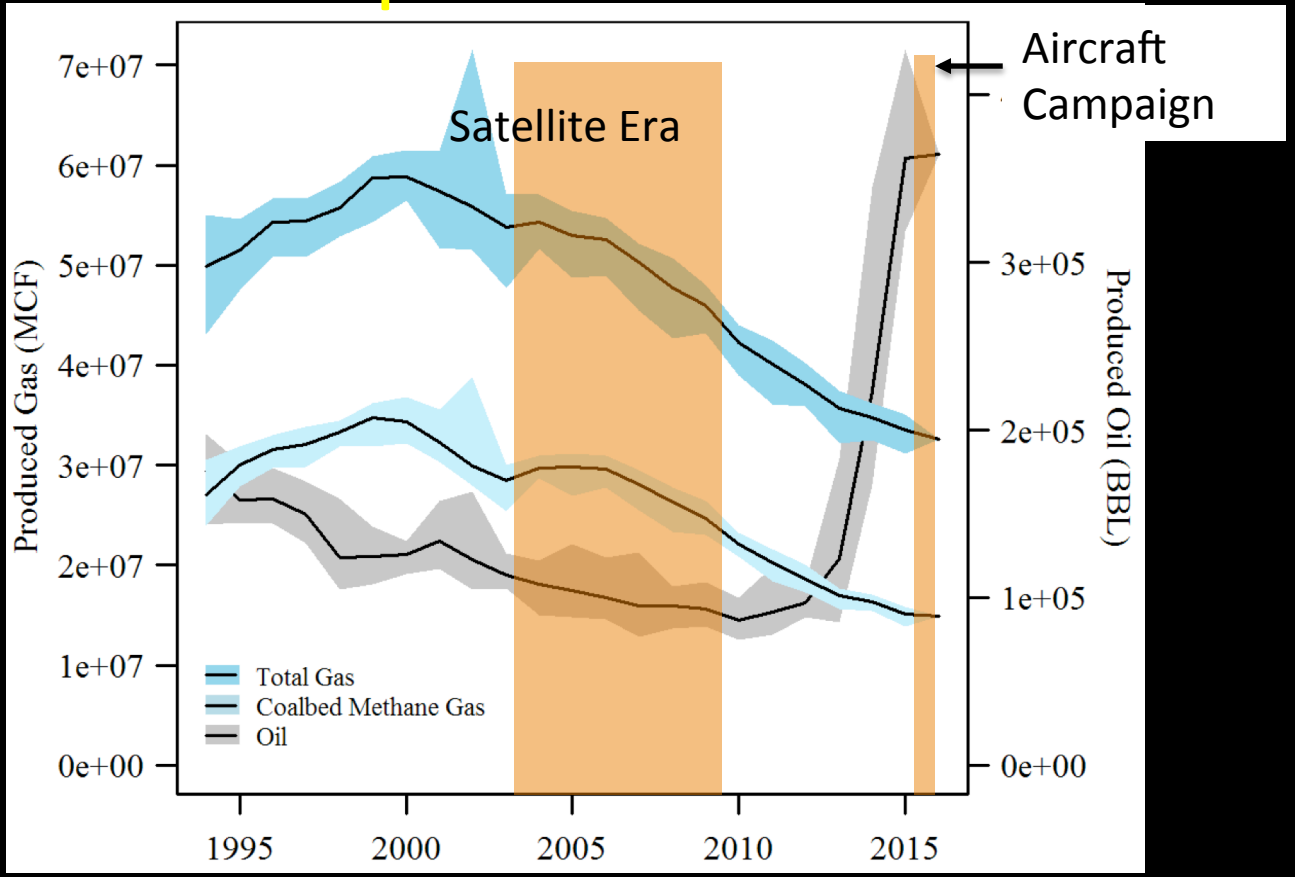


Point Source measurements

Point source	***flux*$_{CH4}$ (Tg yr^{-1})**	**% total basin *flux*$_{CH4}$**
This work (Mooney)		
Carbon Junction Seep	0.0062	1.2
Coal mine vent shaft	0.013	2.4
Σ Observed sources (n = 18)	**0.047**	**8.7**
Frankenberg et al. (2016)		
Coal mine vent shaft	0.014	2.6
Σ Observed sources (n = >200)	**0.23-0.38**	**43-72**

Despite fat tail distribution no one source accounts for more than 2.4% of the total basin wide production

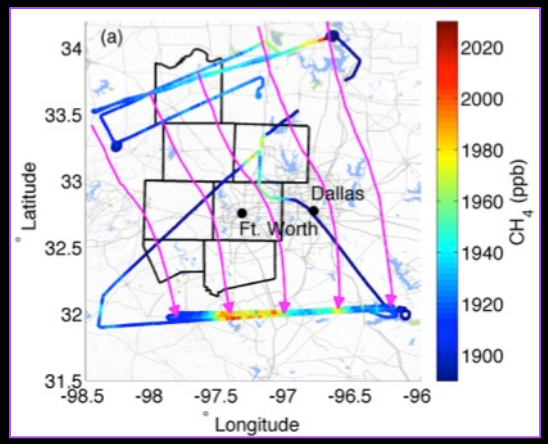
Time evolution of production in Four Corners

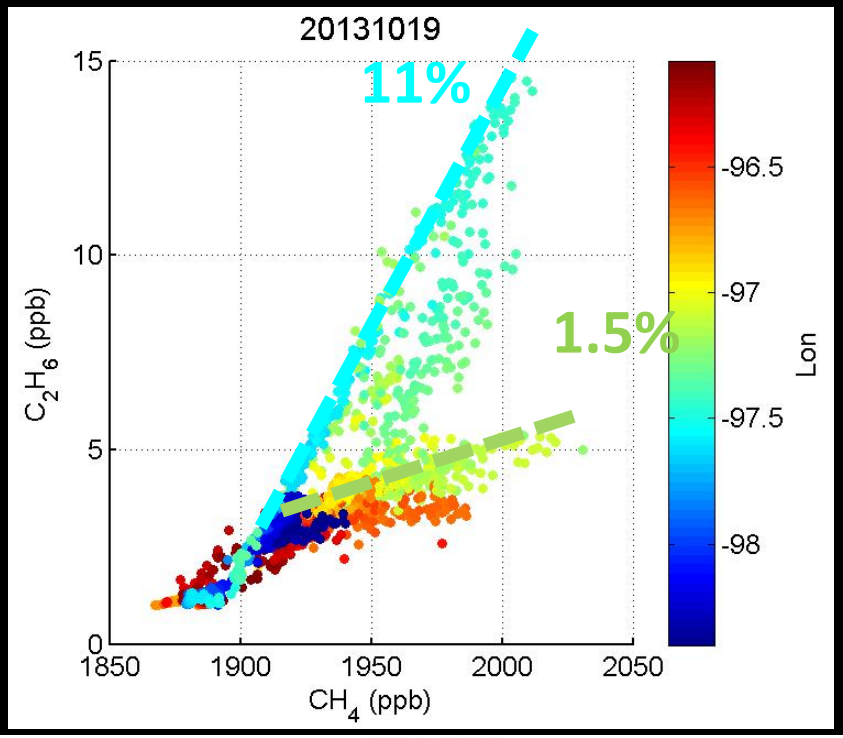


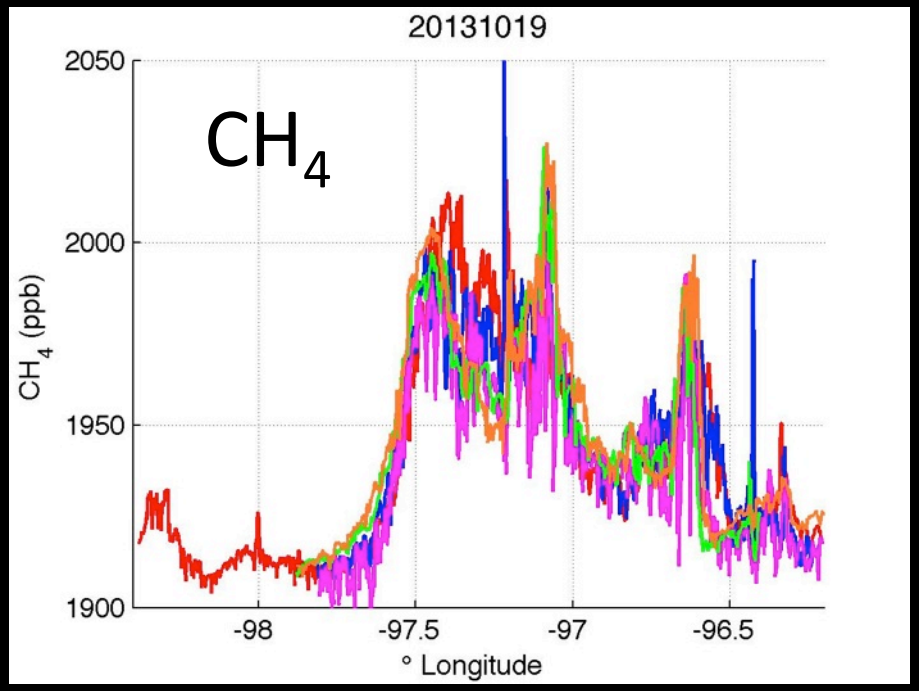
Gas production significantly decreased while oil production significantly increased:

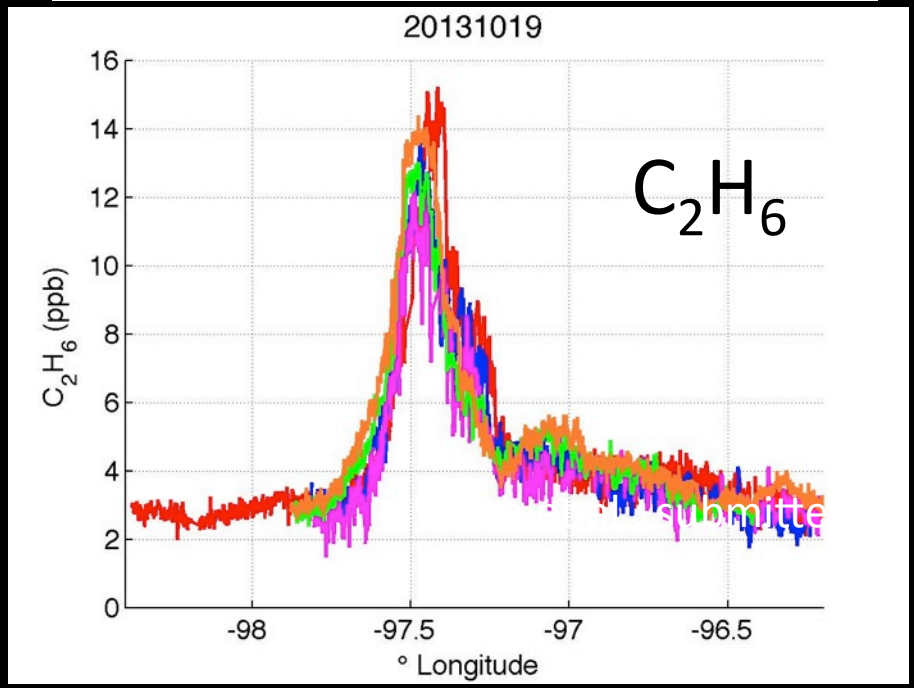
- Does this suggest that there is no correlation between gas production and leakage?
- Does this suggest that oil may be the cause of the leaks?
- Does this suggest there are other sources?

Methane to Ethane ratio changes



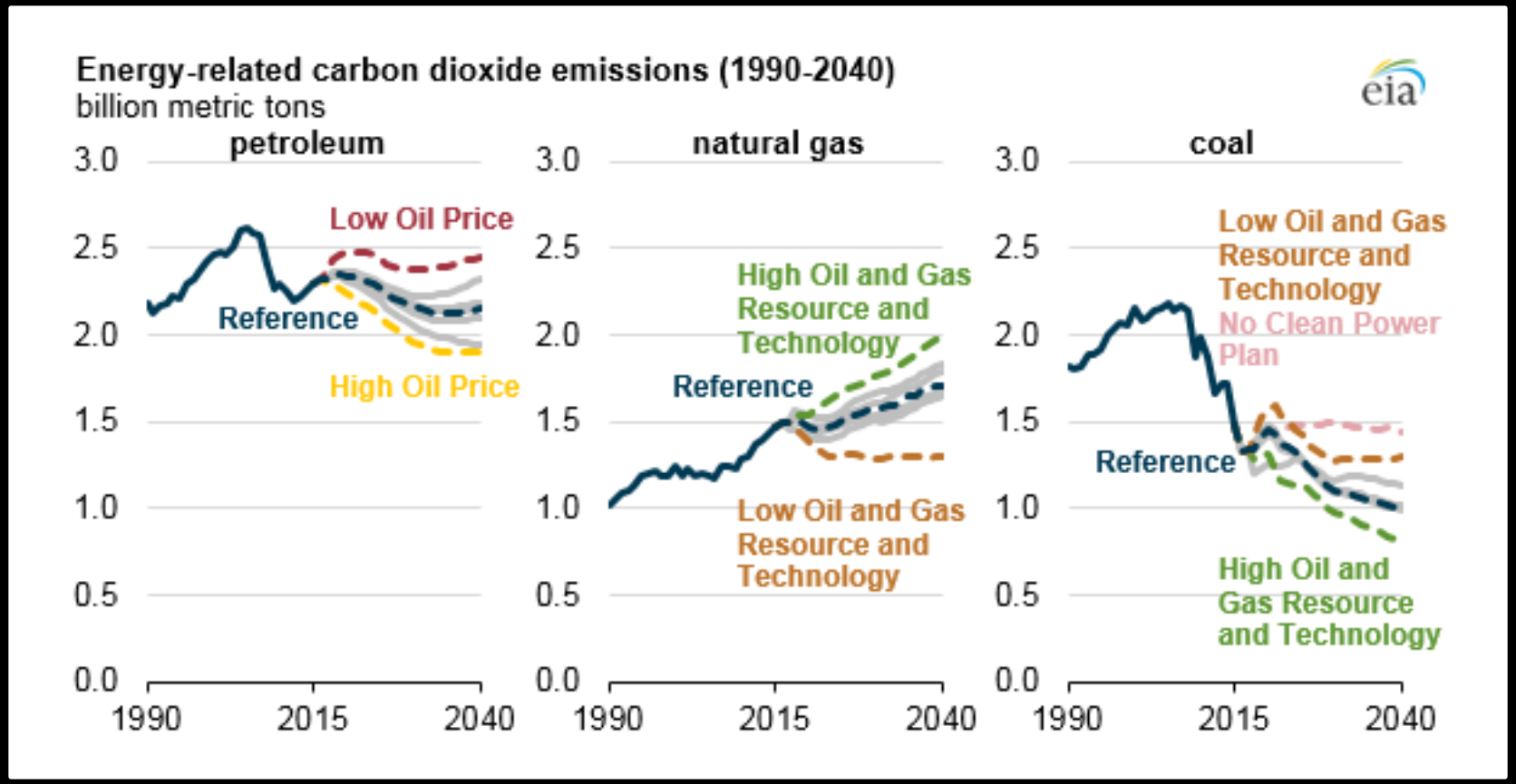






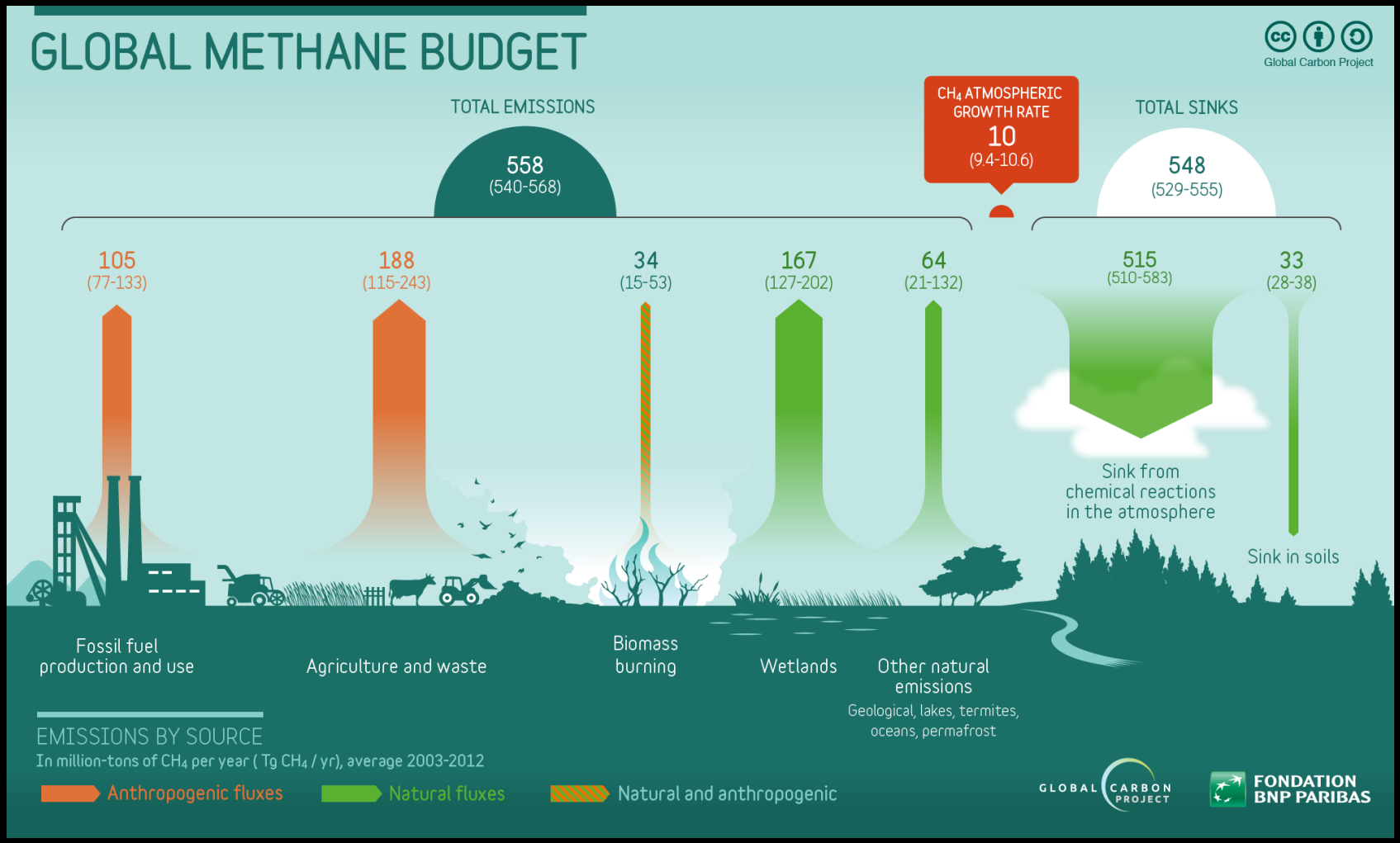
Energy production

US CO_2 emissions from oil/gas/coal

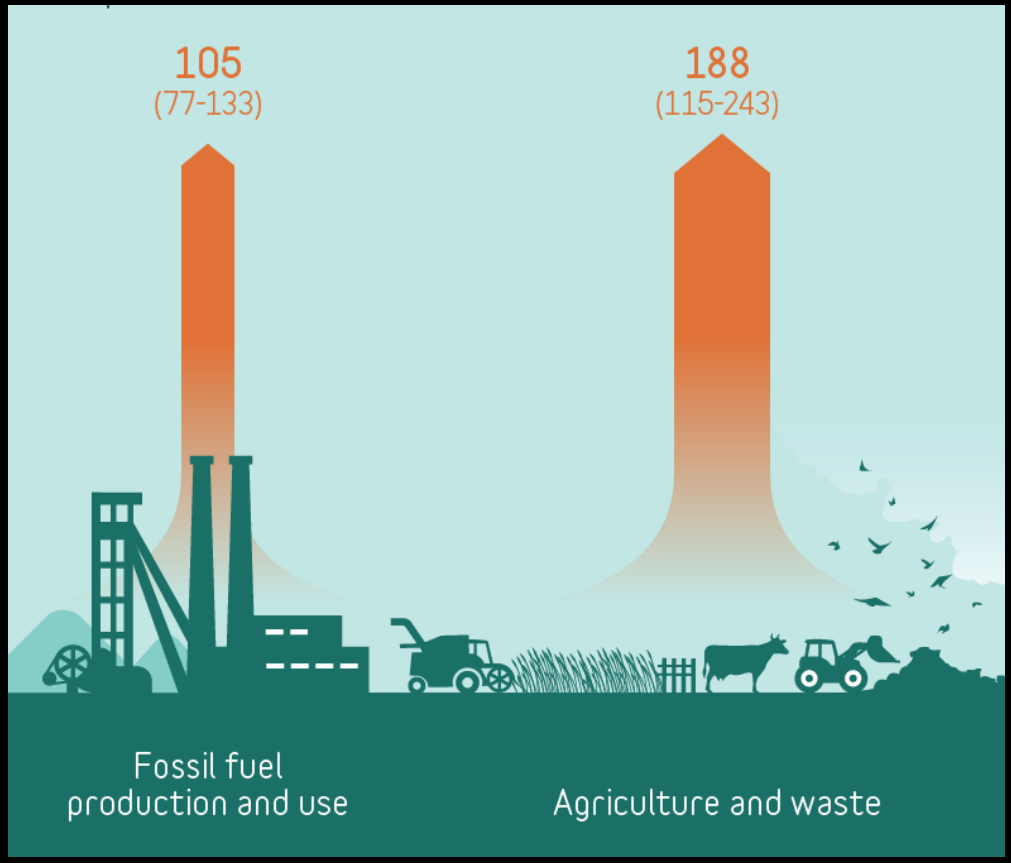


Source: EIA

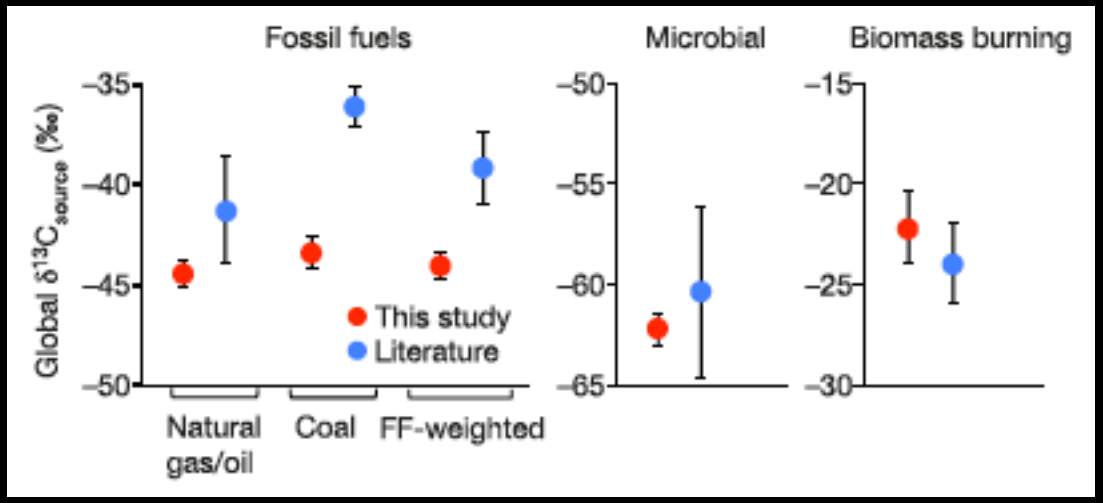
Global Carbon Budget

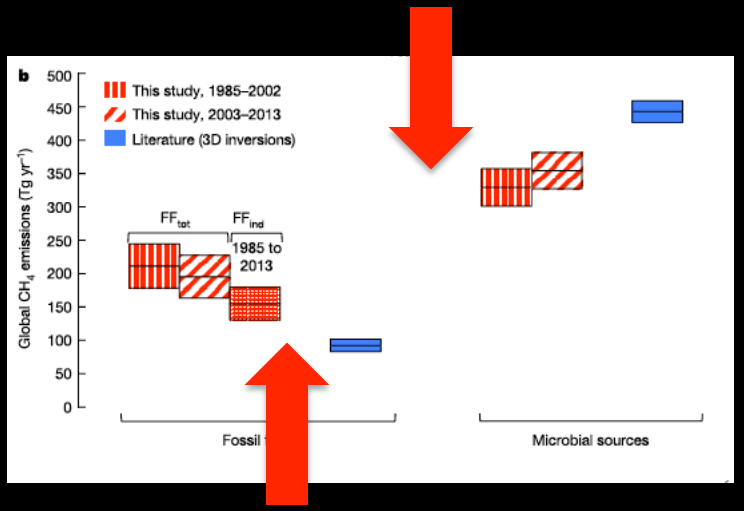


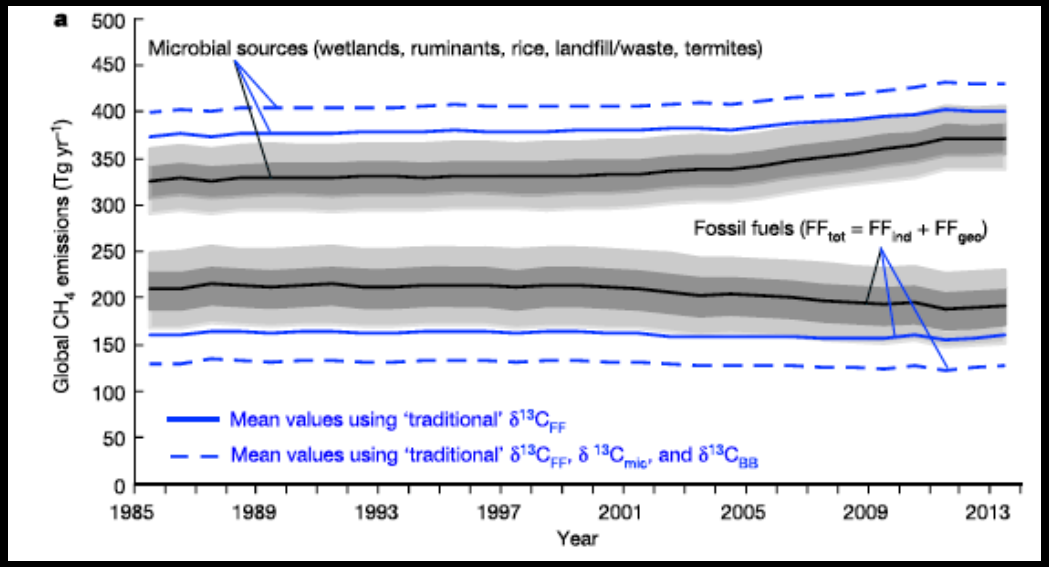
Global Carbon Budget



New Global Budget







Schwietzke et al., 2016

Fossil Fuel is now almost twice the global budget

Changes since the pre-industrial

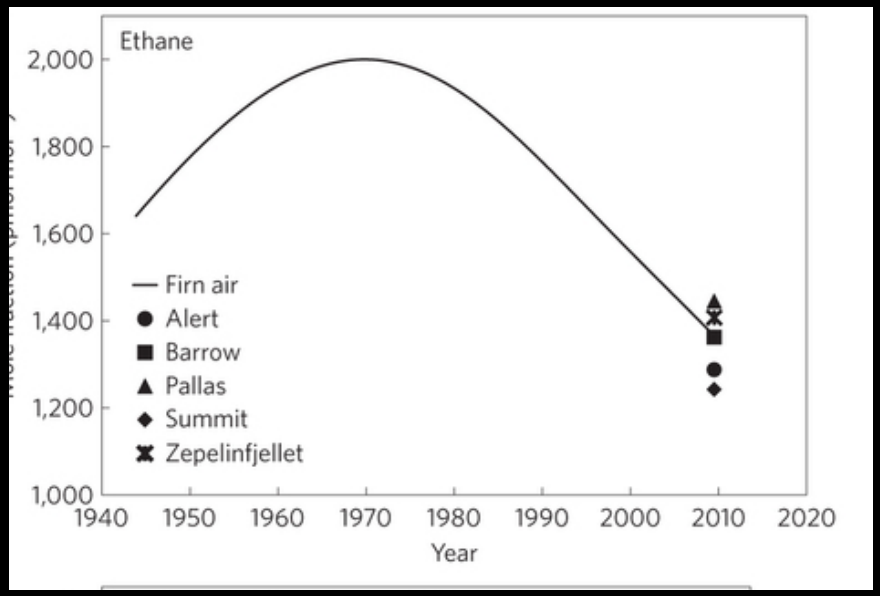
Table 1 | $\delta^{13}C$-based source attribution means for different periods.

	0–1700 AD*	1985–2002 AD	2003–2013 AD
Total fossil fuels†	51±20	211±33	195±32
Fossil fuel industries	0	161±24	145±23
Geological sources		51±20	
Microbial	154±19	330±28	355±27
Biomass burning	25±5	43±9	

Values are given as mean ± one standard deviation in units of teragrams of methane per year.

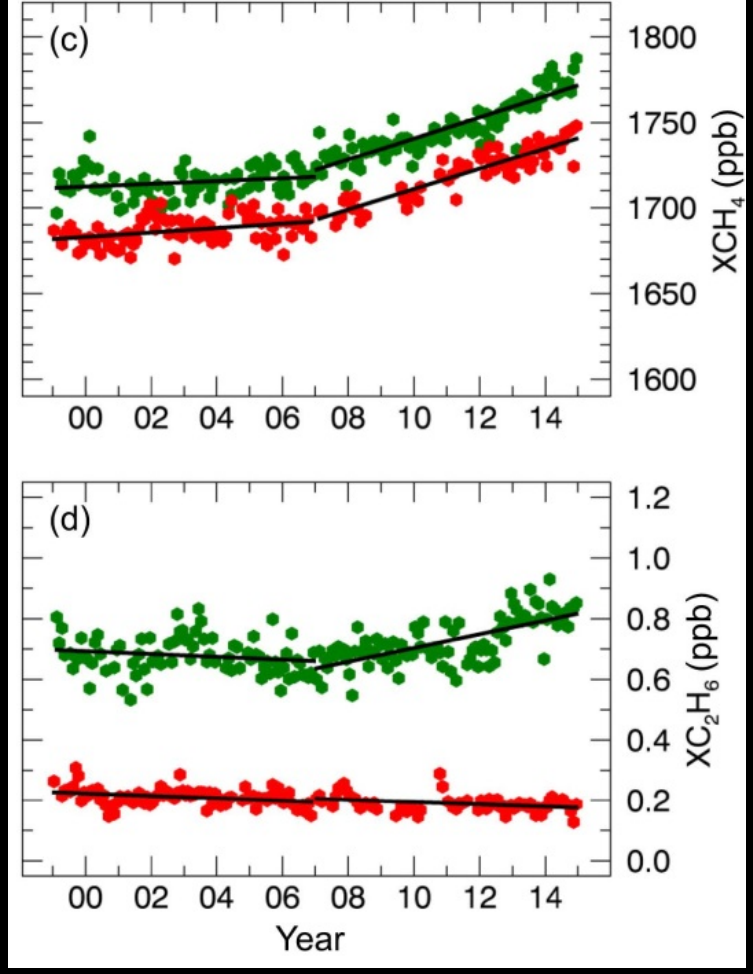
Only requires a doubling of the microbial component

Ethane



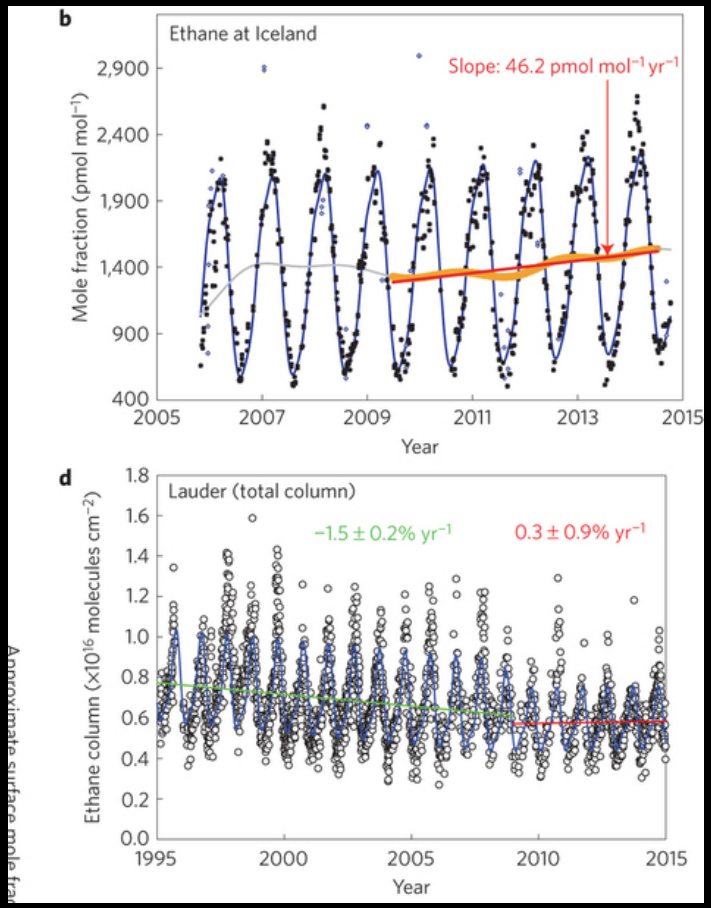
Simpson et al., 2012
Aydin et al., 2011

Ethane

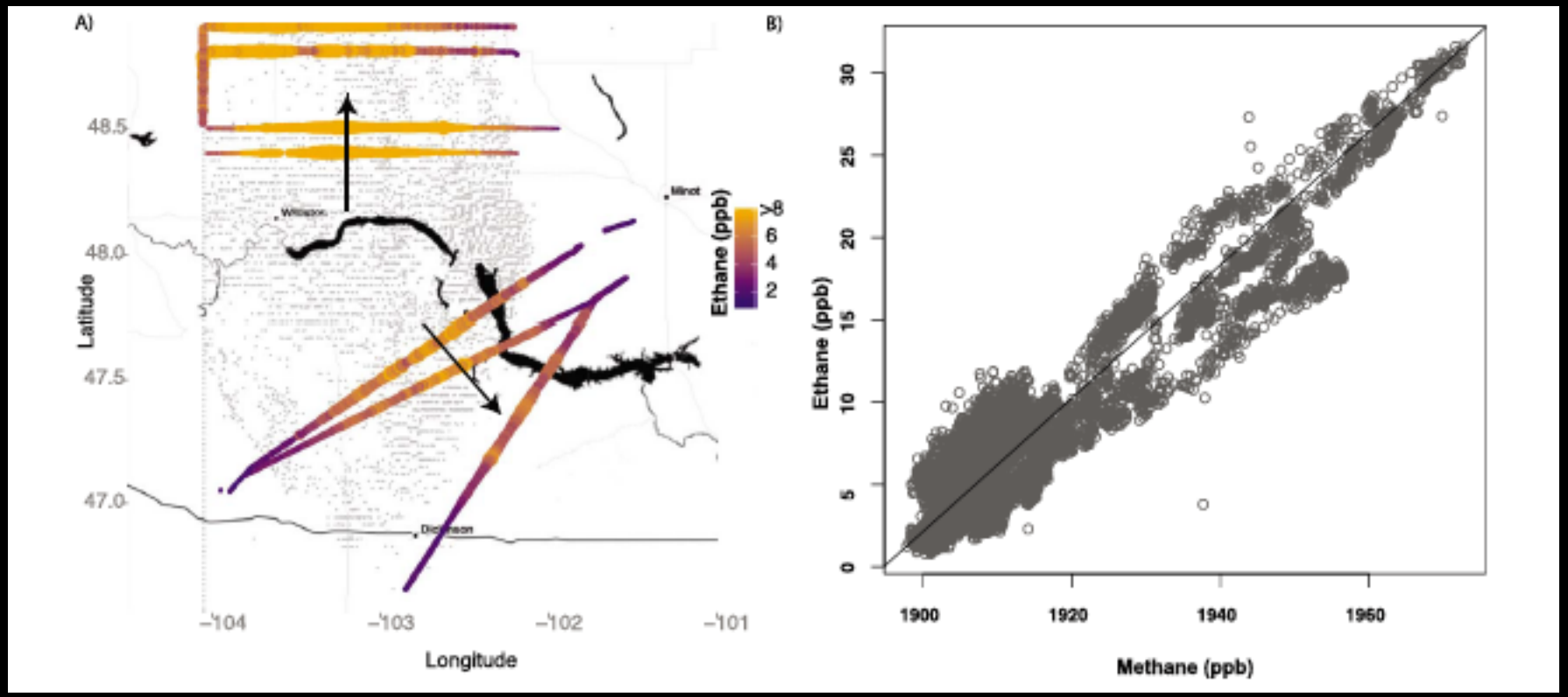


Hausmann et al. 2016

Helmig et al. 2016



Point source

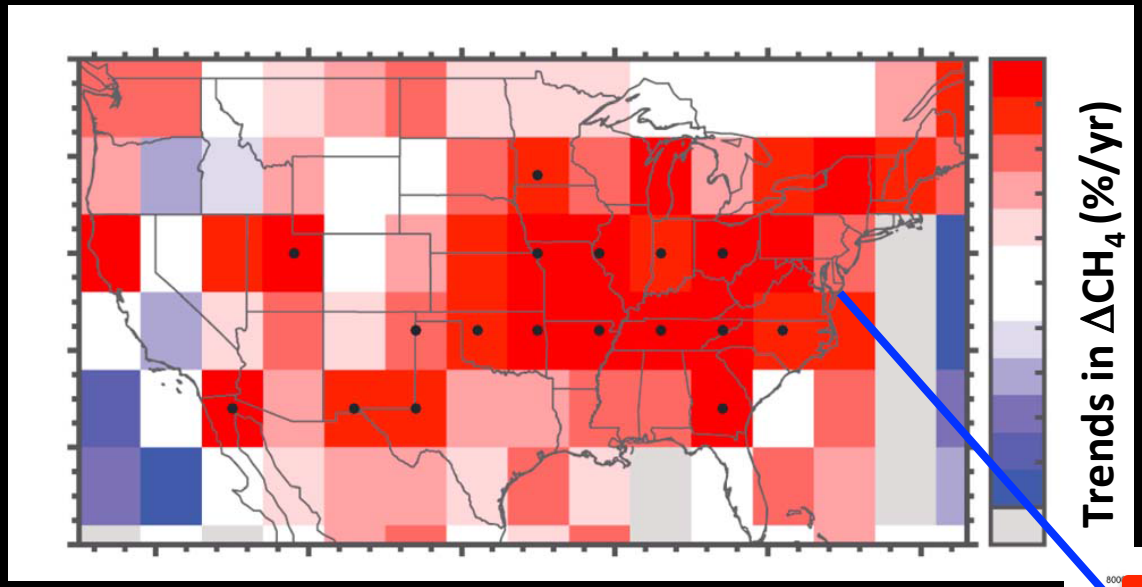


Kort et al. 2016

Ethane is going up but Methane is not

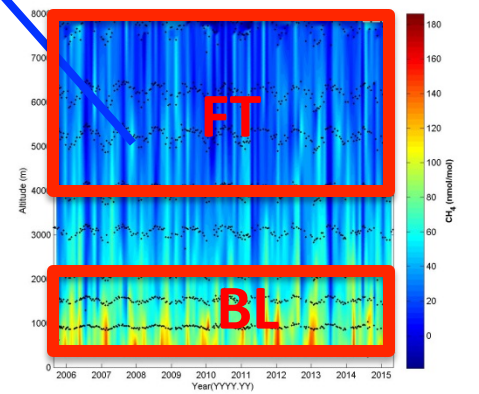
Comparison of methods

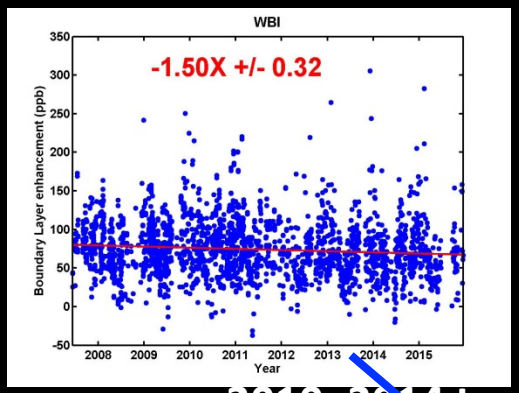
2010–2014 trend in U.S. methane enhancements

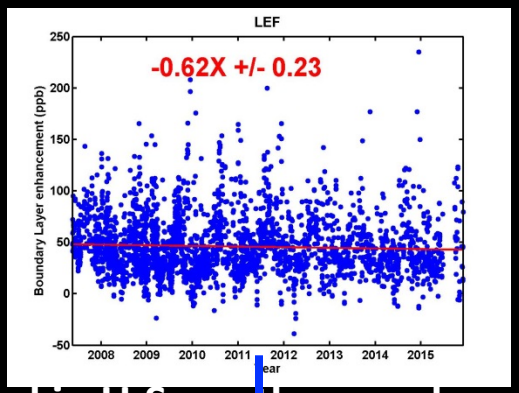


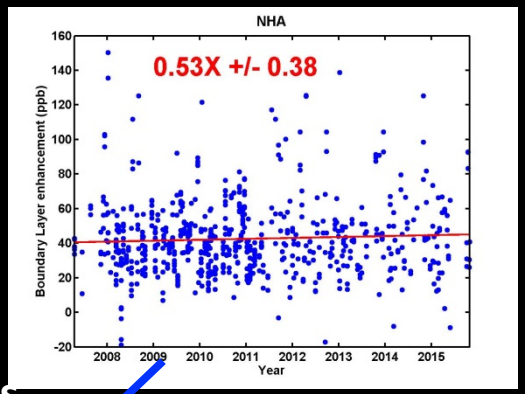
Turner et al. (2016)

ΔCH4= BL - FT



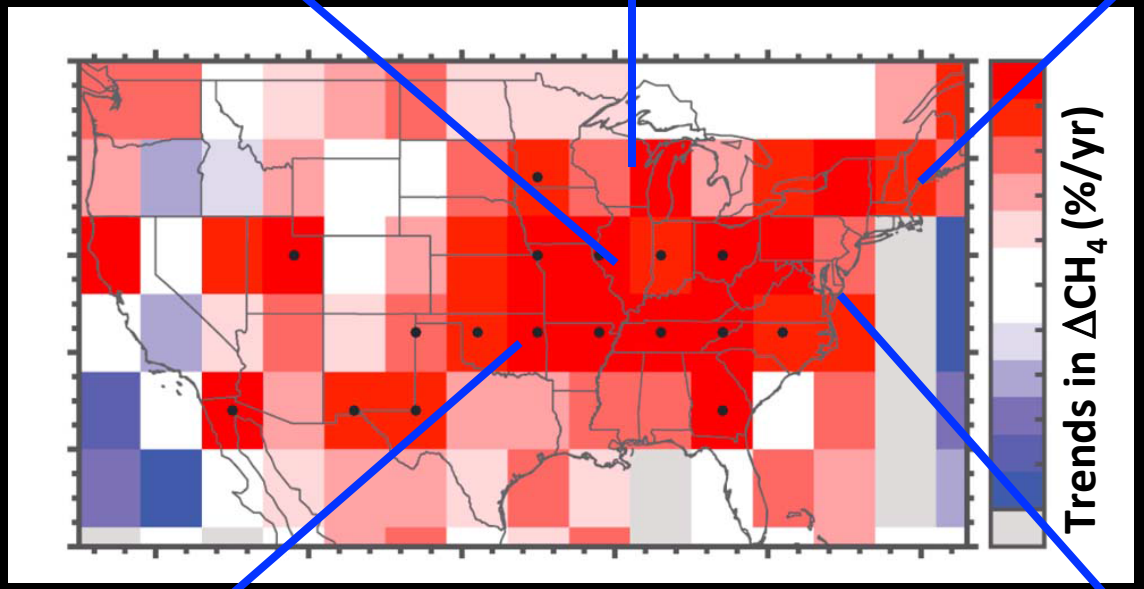






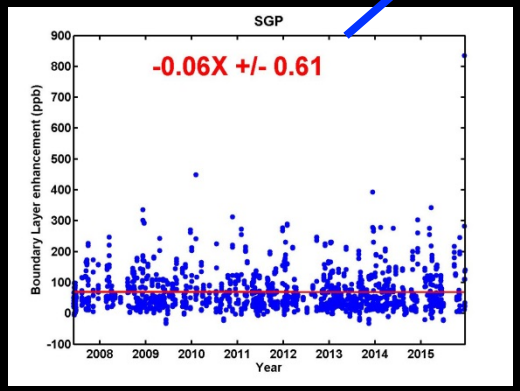
2010–2014 trend in U.S. methane enhancements

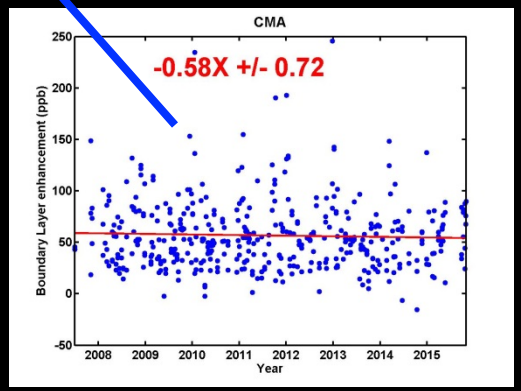
CH_4 trends in boundary layer

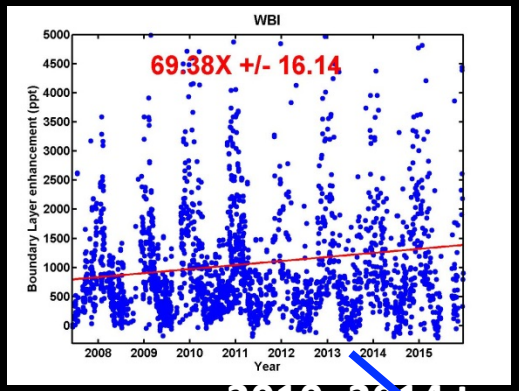


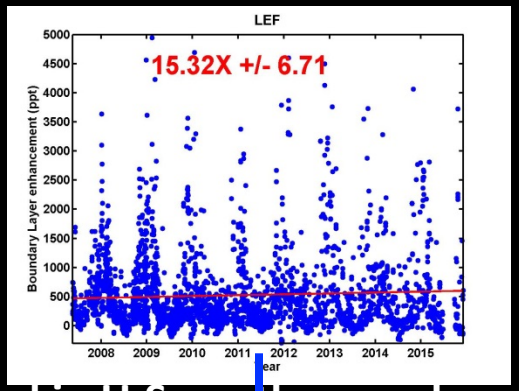
Aircraft observations show No Trends

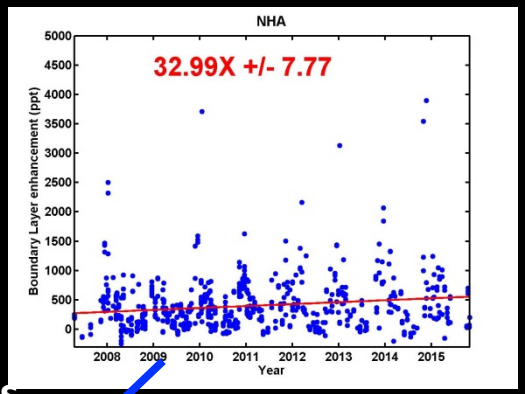
Turner et al. (2016)





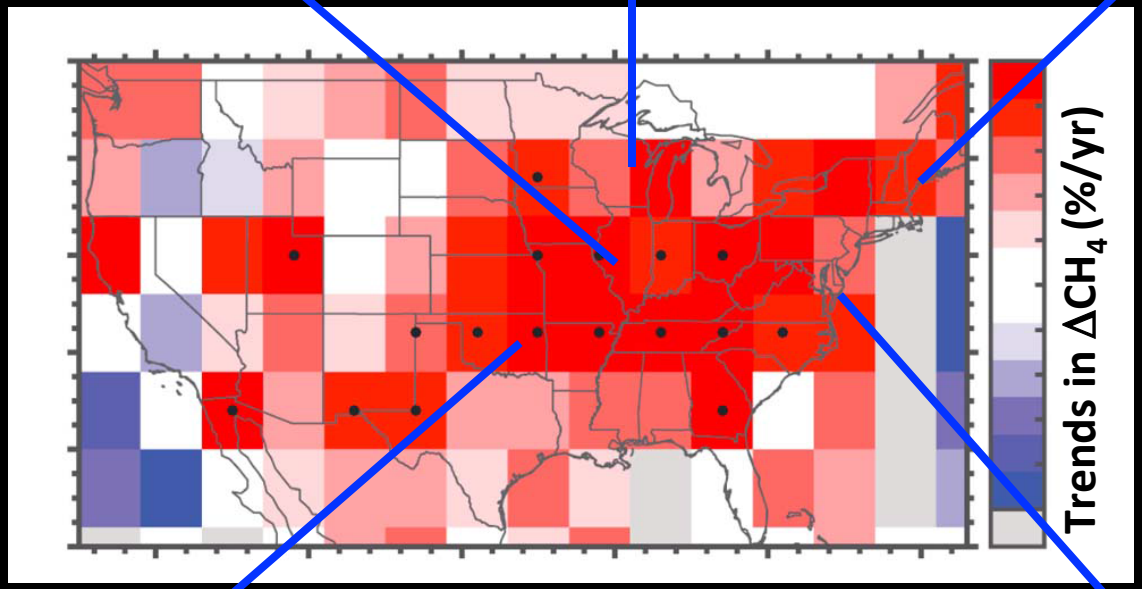




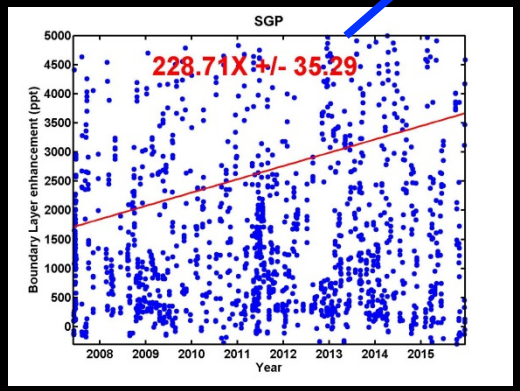


2010–2014 trend in U.S. methane enhancements

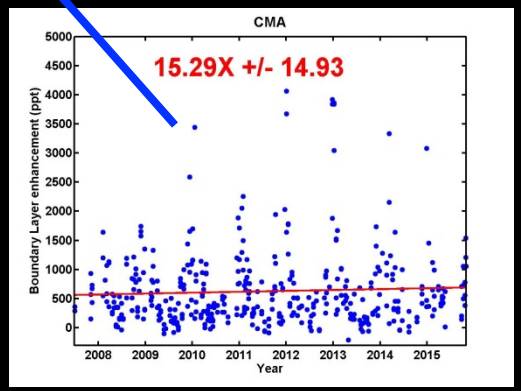
Propane trends in boundary layer



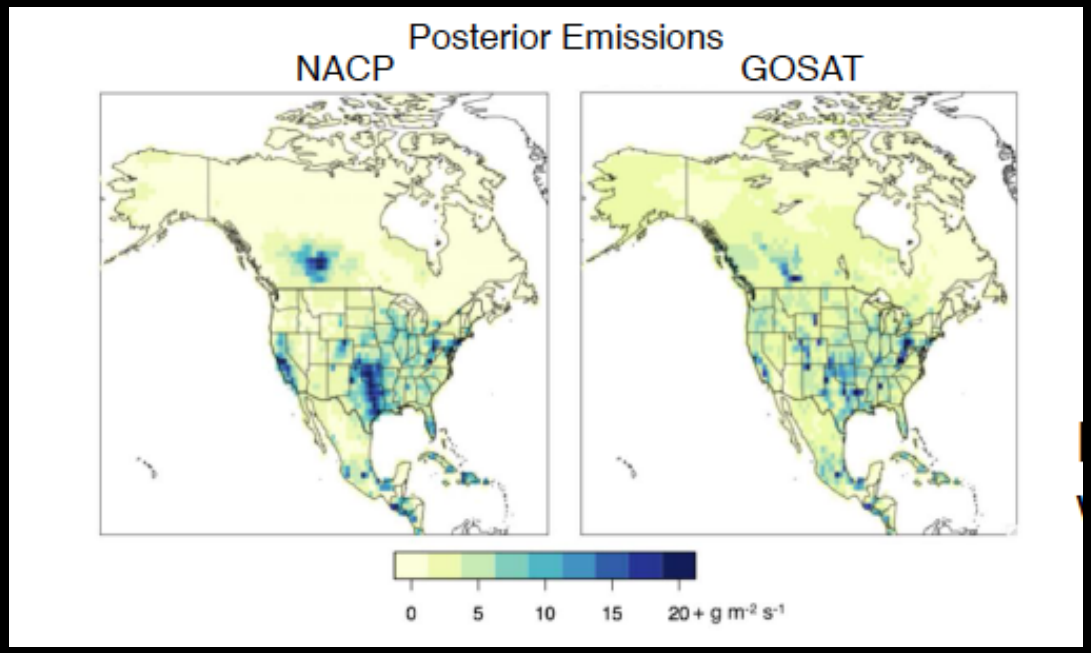
Aircraft observations show Significant Trends

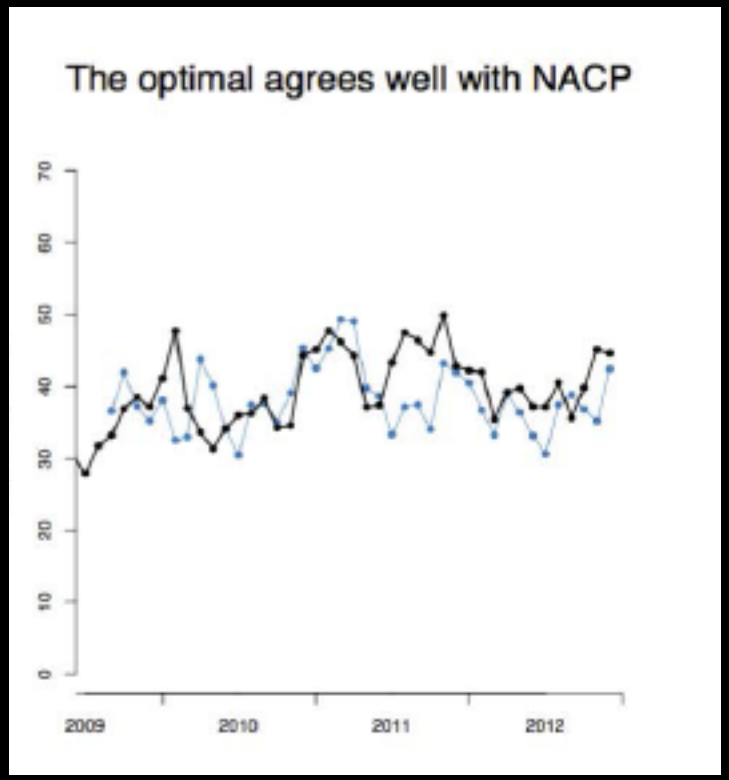


Turner et al. (2016)



US Methane Trends





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Main Points

1. The exploration of fossil fuel emissions of CH4 have given us a set tools that can be used to look at methane emissions in other source categories.
2. Relying on tracer ratios may get us into trouble and we have to be careful how much we interpret these ratios.