Airborne quantification of methane emissions over the Four Corners region

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NOAA aircraft mass balance study regions

Bakken, ND (Oil)
0.4%

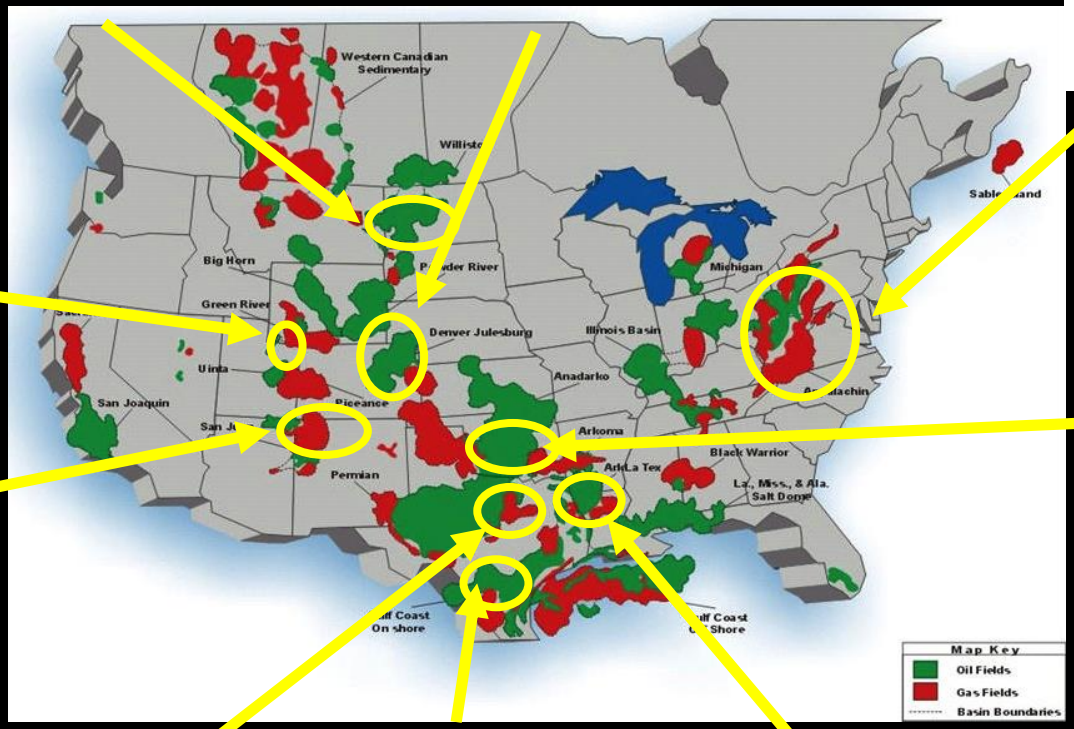
Peischl et al. 2016

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
Schwietzke et al.,2017

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%

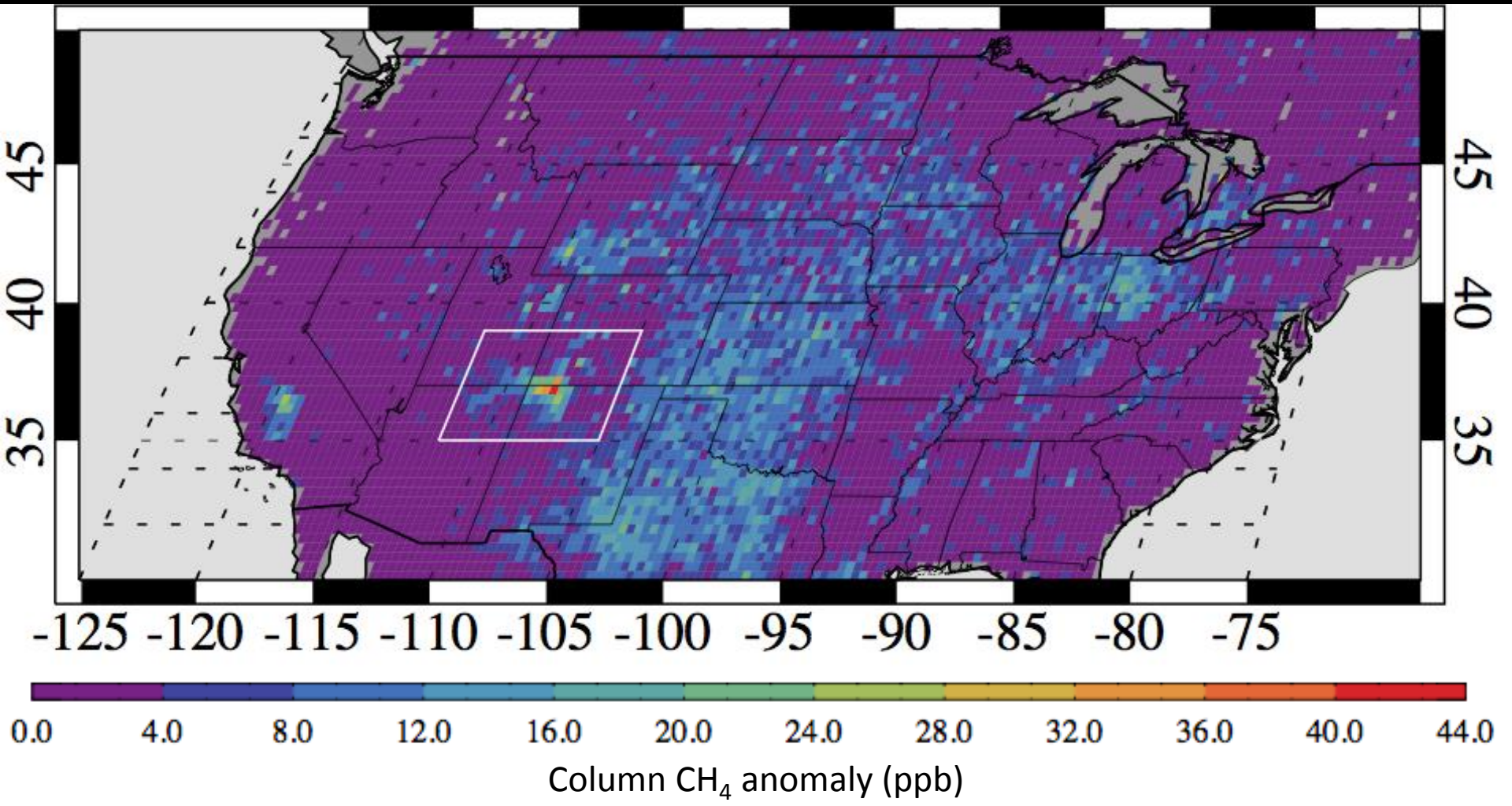
Peischl et al., 2015

>40% US total natural gas production

>70% of shale gas production

San Juan Basin

The largest Coal Bed Methane producer in the US



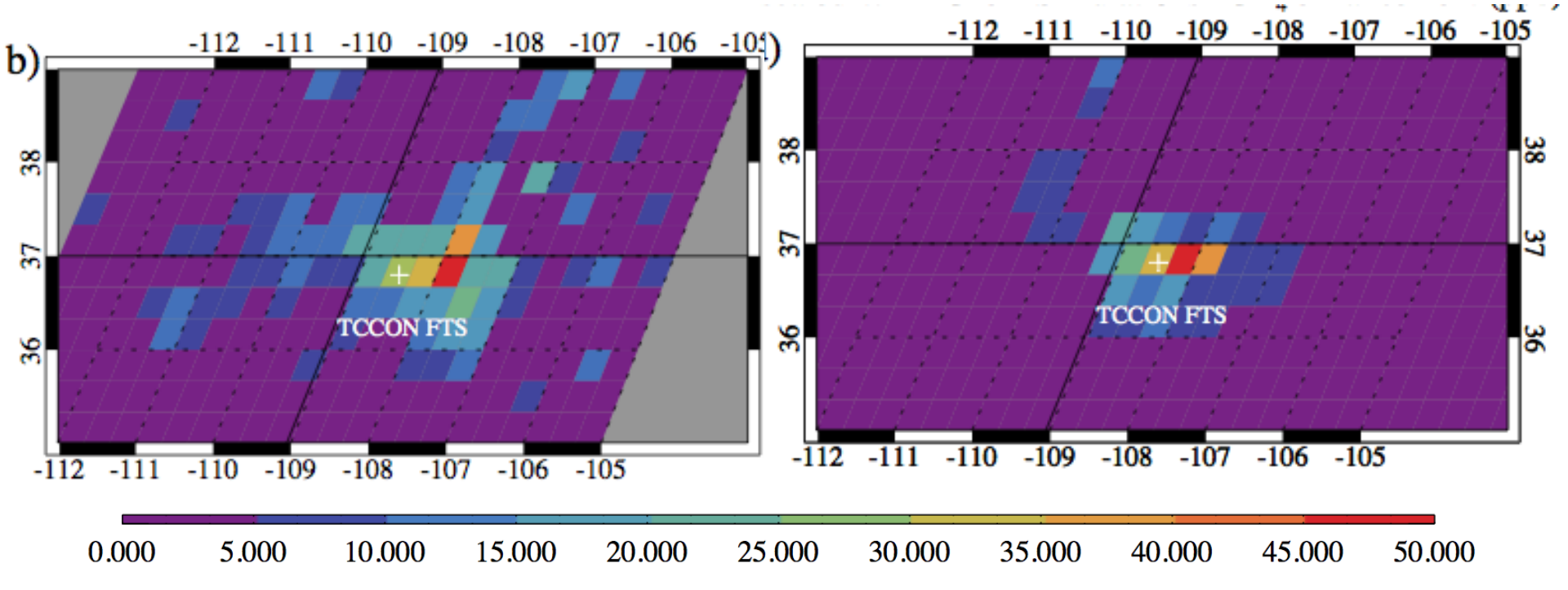
SCIAMACHY 2003-2009

Kort et al. 2013

Scaled simulations match observations
0.59 Tg/yr

SCIAMACHY xCH_4 enhancements

Scaled Model xCH_4 enhancements



Observations

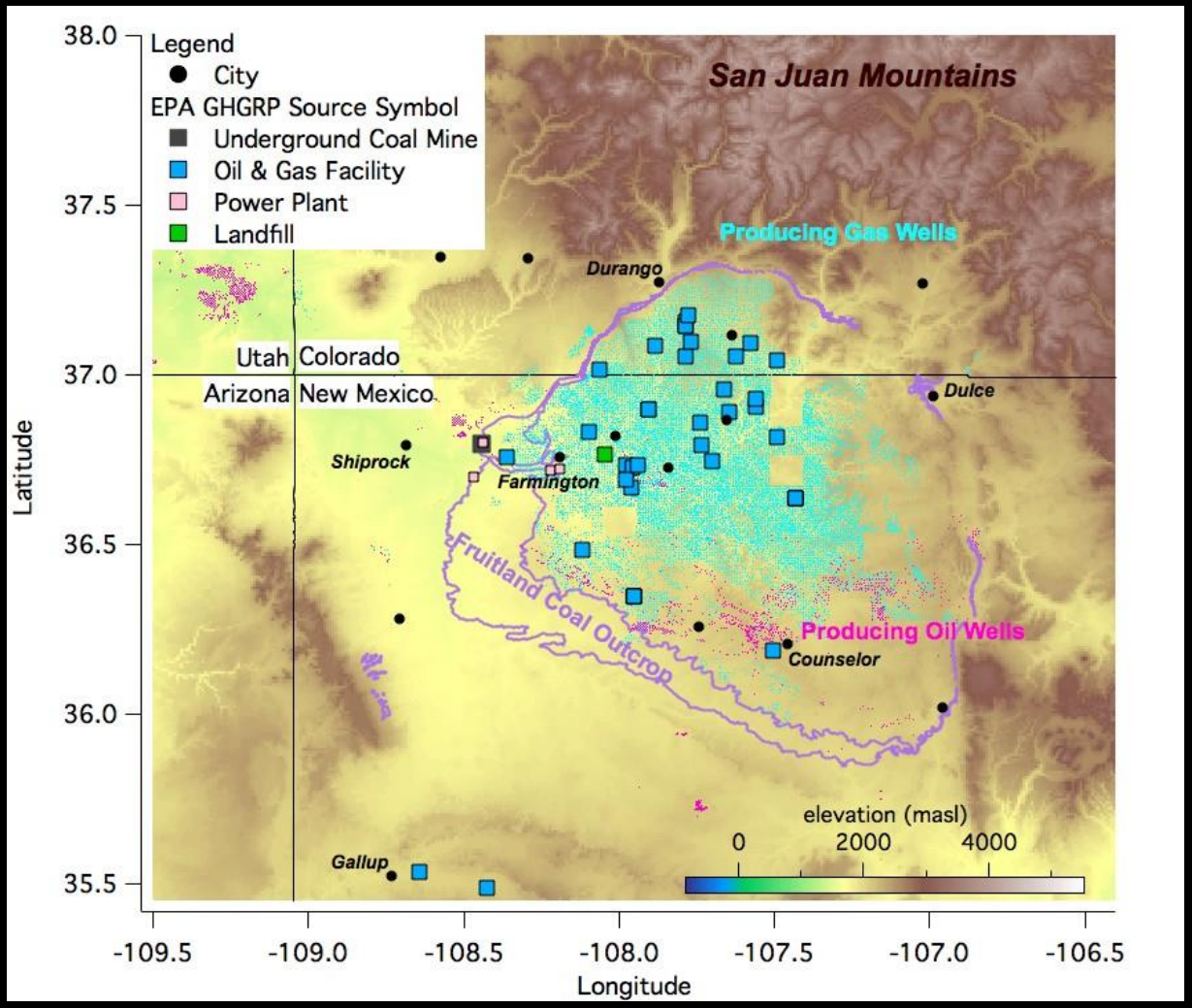
Simulations

Kort et al. 2013

TOPDOWN 2015

Twin Otter Projects Defining Oil Well and Natural gas emissions

Potential sources of CH_4 in San Juan Basin

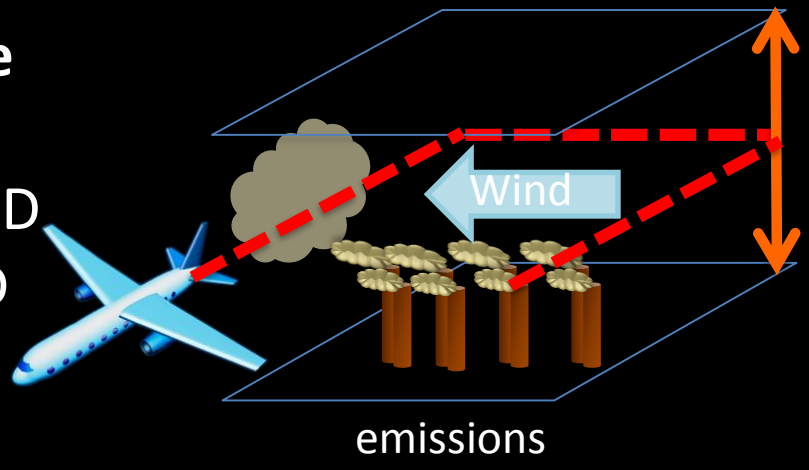


- Coal bed methane (CBM)
- Tight Sandstone natural gas production
- Active Coal mining
- Geological seeps
- Large Power plants
- Oil production
- Emissions from agricultural sources, waste management facilities and wetlands are small

Bottom up Estimates = 0.42-0.52 Tg/yr

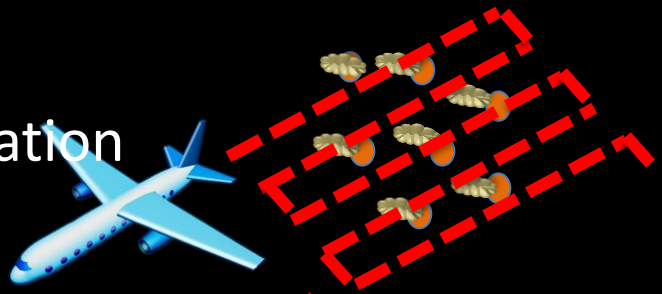
Multi-scale/level Approach

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



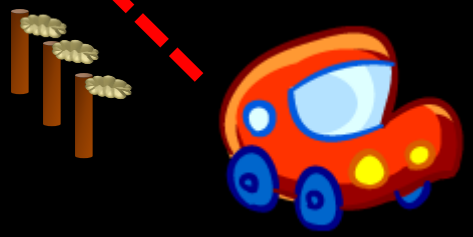
Total basin emissions and large-scale source allocation

Point Source identification
- Scientific aviation
- NASA/JPL



Large emitter site location and emissions quantification

- U of Colorado
- NOAA/GMD
- LANL

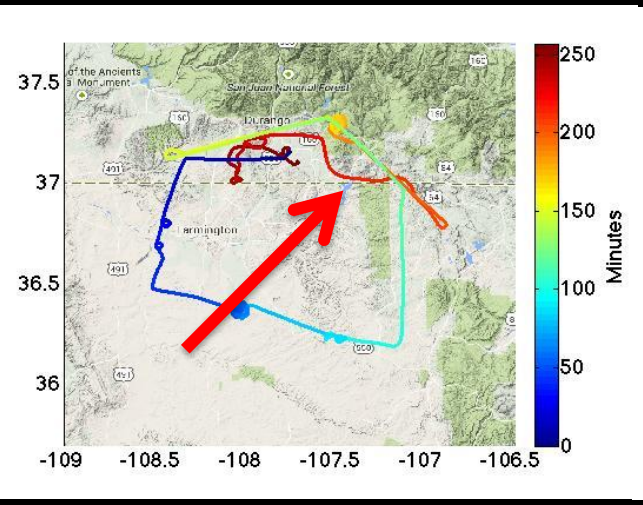


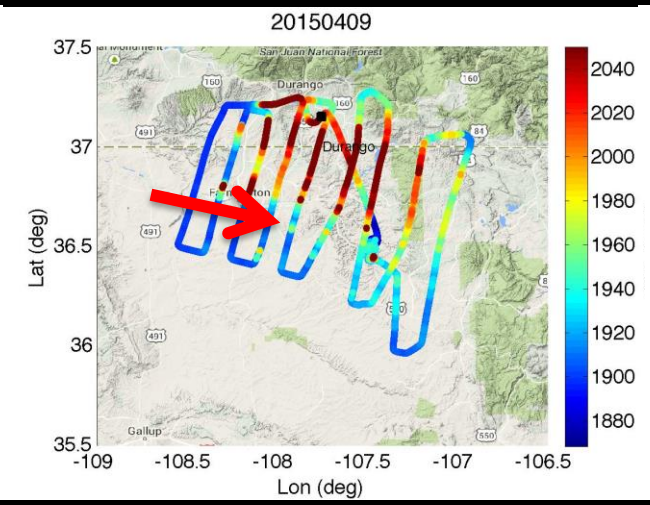
Process level emissions verification and emissions profile (e.g. CH_4/C_2H_6)

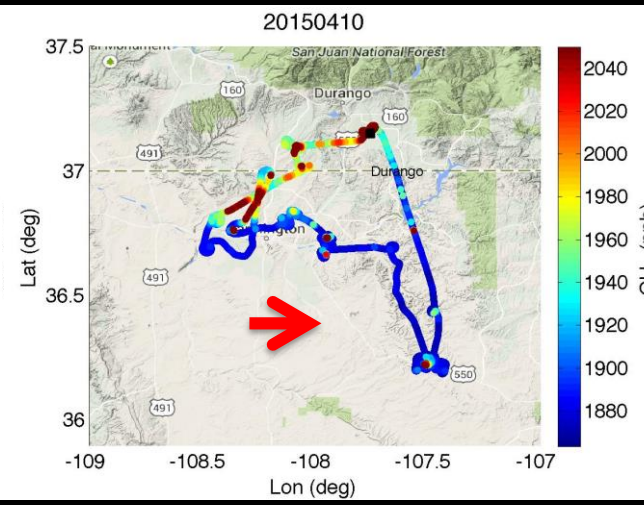
Scales

Examples of CH_4 levels along the flight track Mooney and Twin Otter Flights

Methane







Mass Balance

Total Basin Emissions

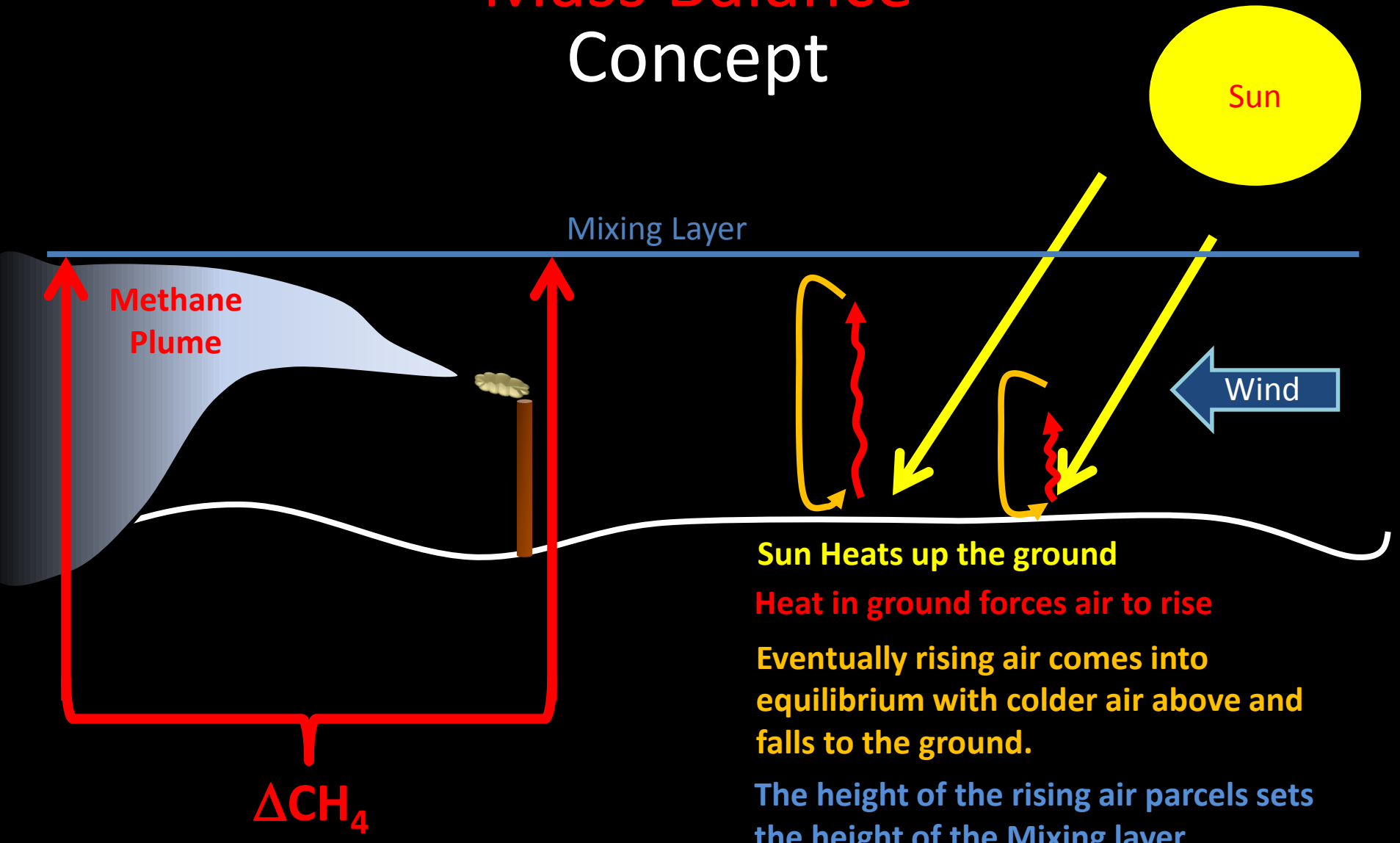
Attribution/Point Source ID

Looking for point source

Point Source Quantification

Quantifying point Sources

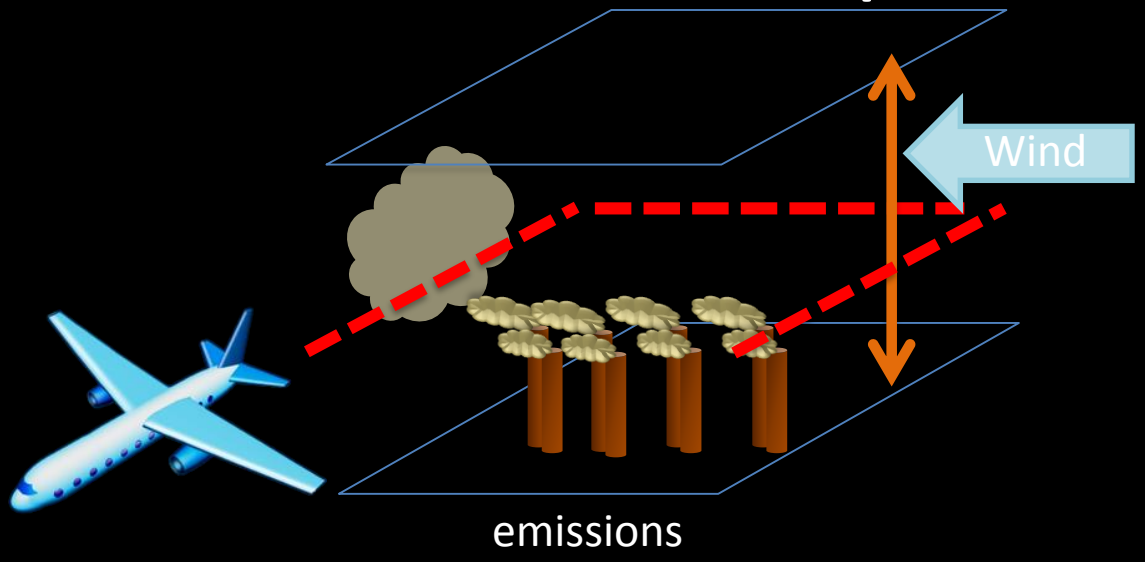
Mass Balance
Concept



Wind × **ΔCH_4** × **Mixing Height** × **Plume Width** = **CH_4 Emissions**

Mass Balance

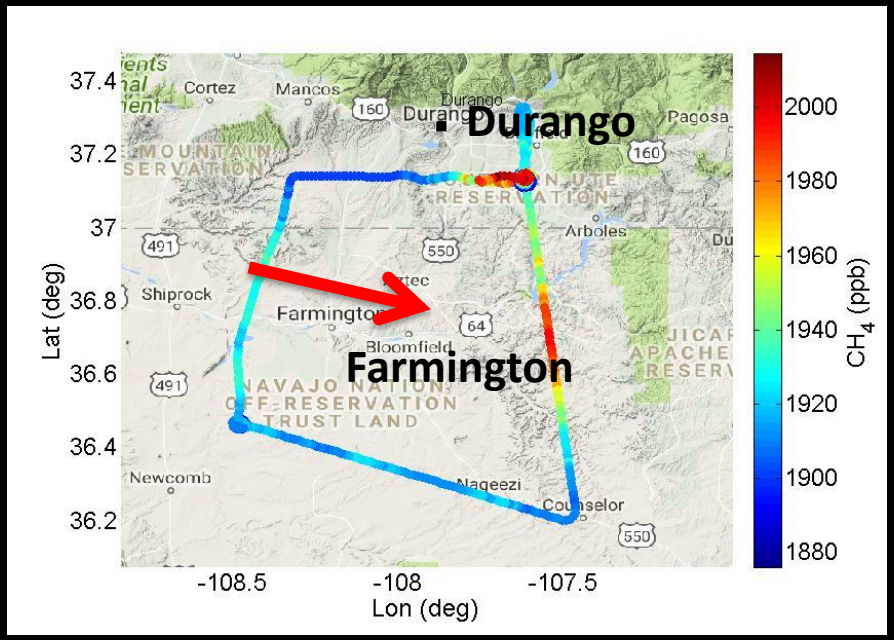
Concept

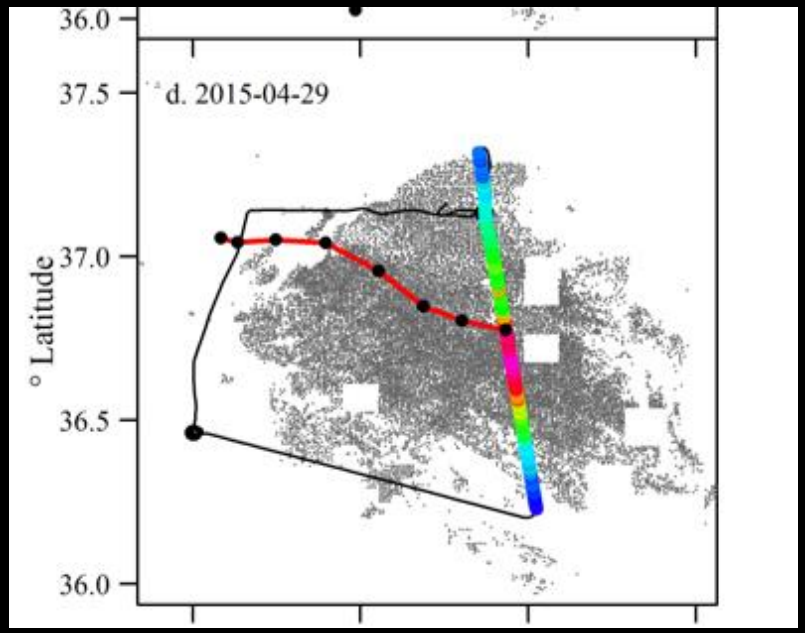


$$\dot{n}_{CH_4} = V \cos\theta \int_{-b}^{+b} \Delta X_{CH_4} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air} dz \right) dx$$

Mass Balance

Winds (Vcosθ)



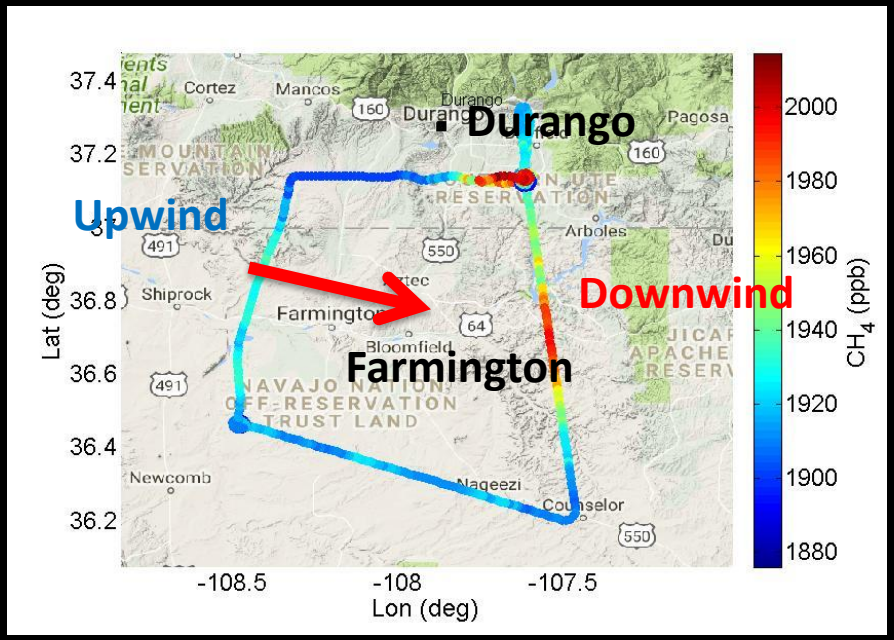


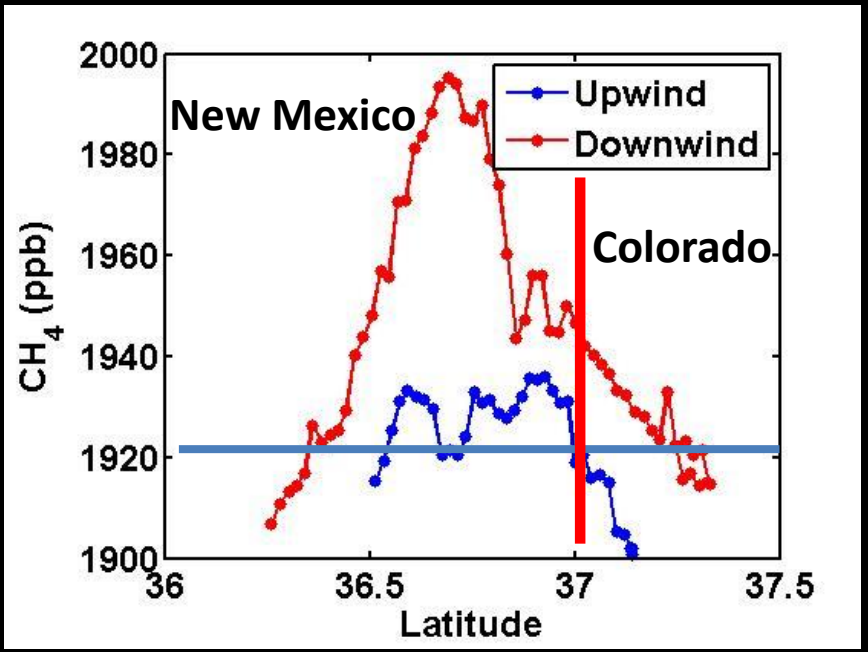
$$\dot{n}_{CH_4} = V\cos\theta \int_{-b}^{b} \Delta X_{CH_4} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air}\, dz \right) dx$$

Wind needs to be steady for 7-8 hour period before we do the experiment to guarantee that we are not double counting

Mass Balance

Methane Enhancement (ΔCH4)



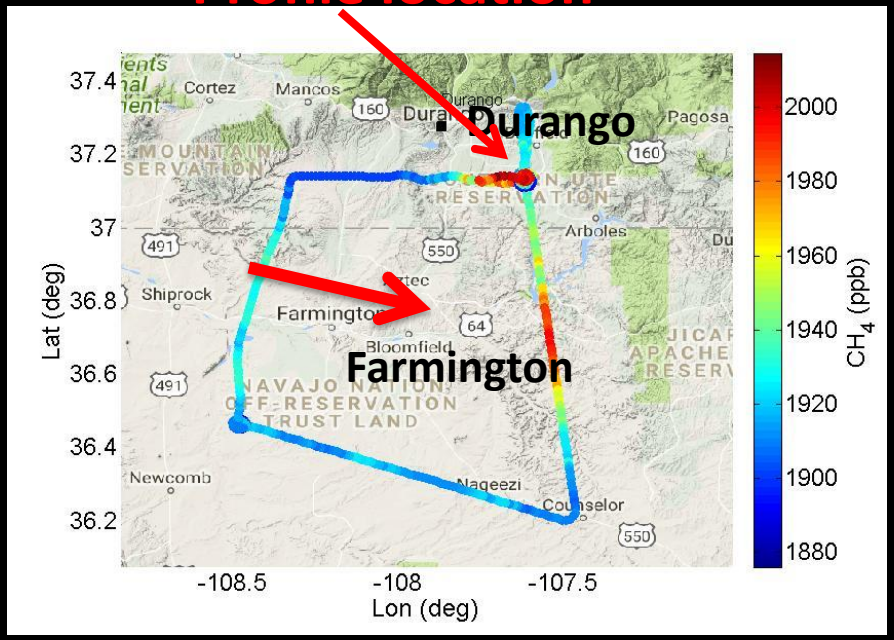


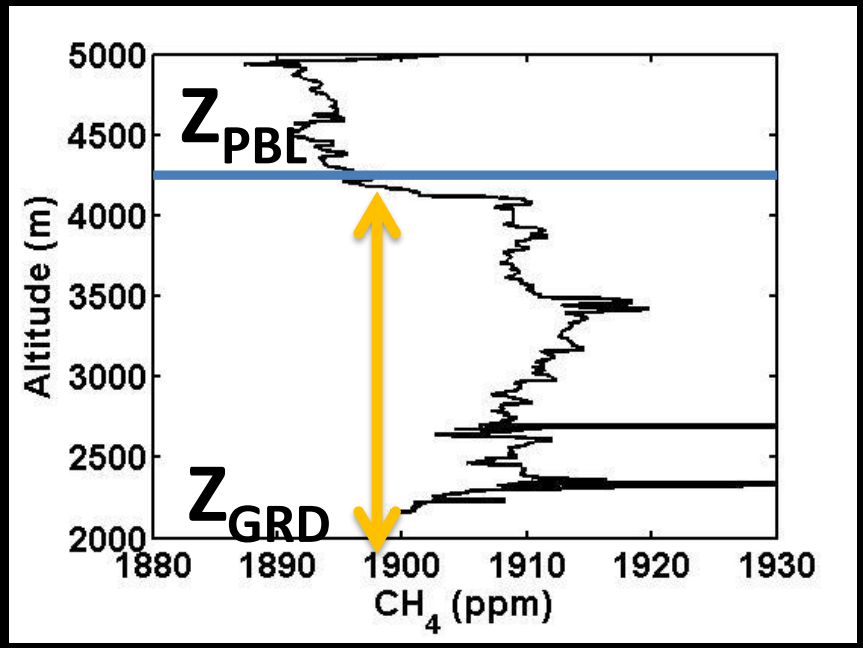
$$\dot{n}_{CH_4} = V \cos\theta \int_{-\infty}^{+\infty} \Delta X_{CH_4} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air} dz \right) dx$$

Mass Balance

Boundary Layer Height (PBL)

Profile location





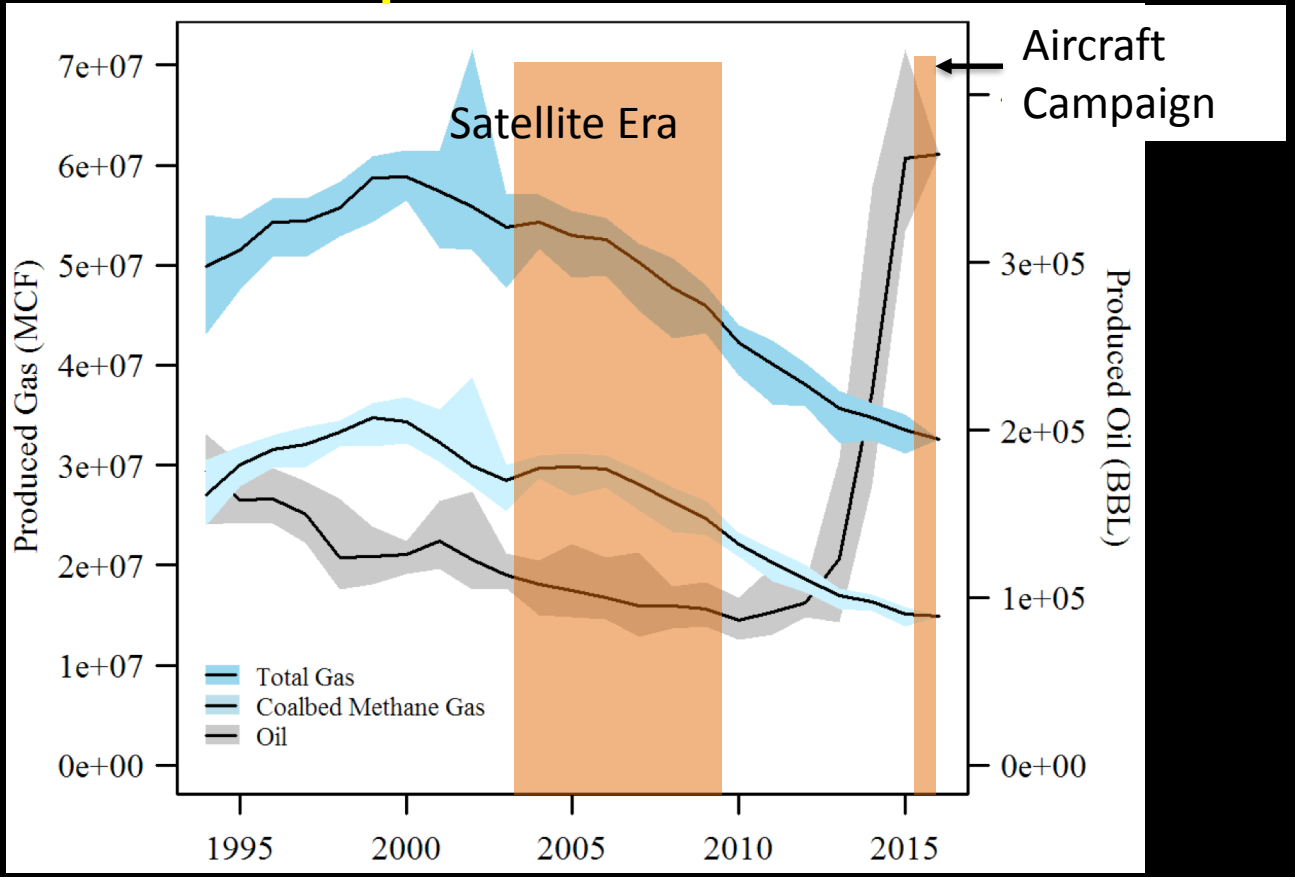
$$\dot{n}_{CH_4} = V \cos\theta \int_{-b}^{+b} \Delta X_{CH_4} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air} dz \right) dx$$

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

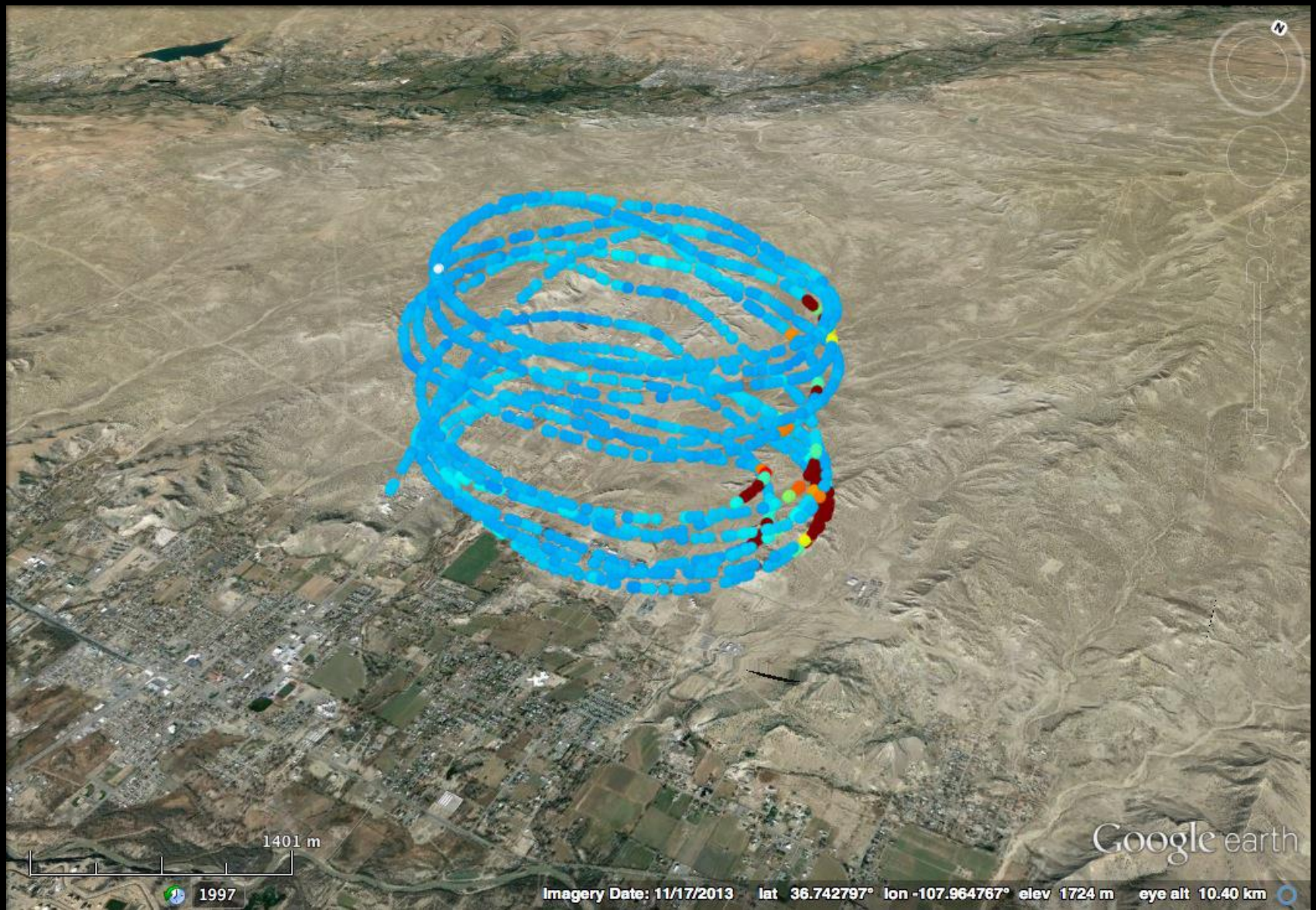
Time evolution of production in Four Corners



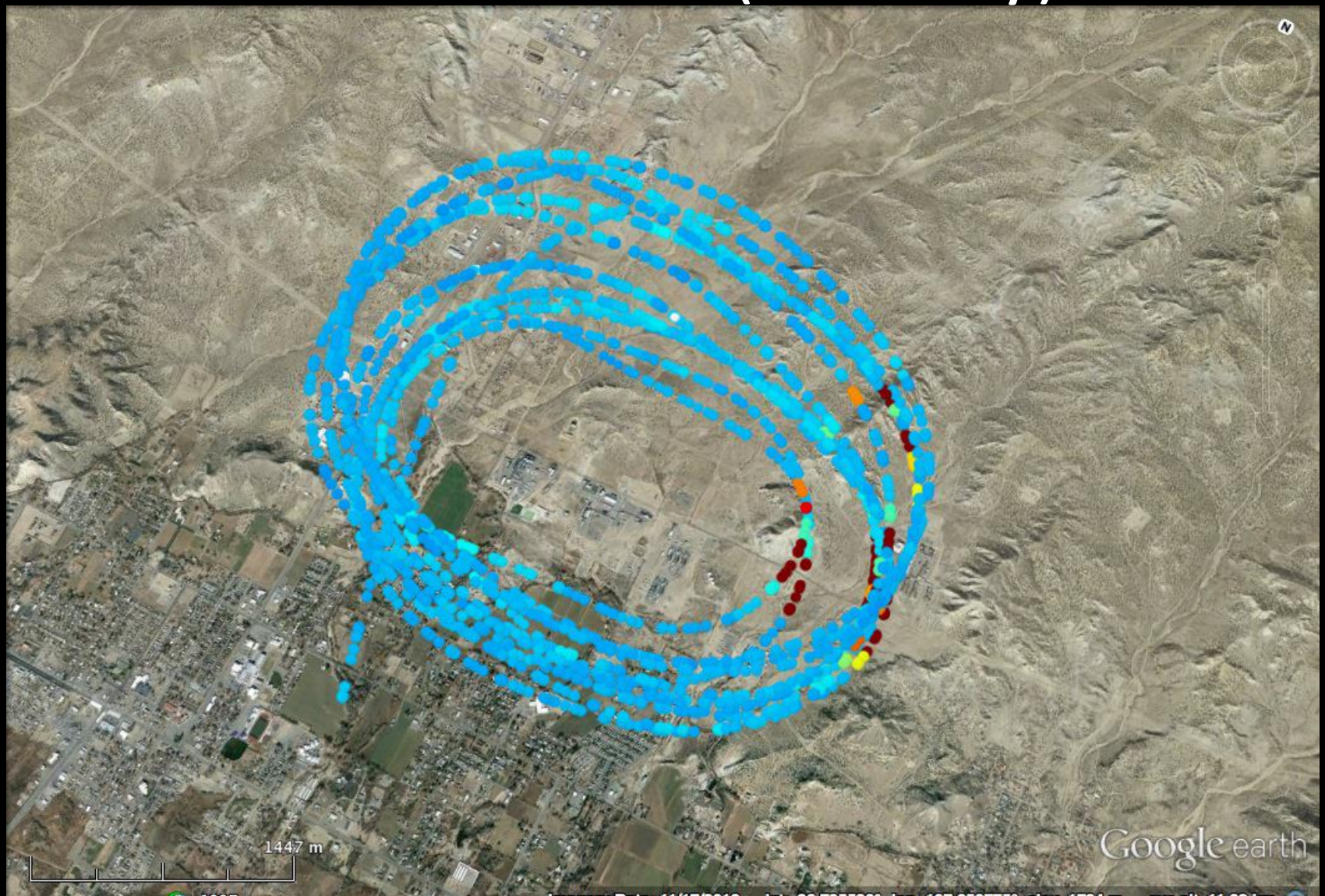
Gas production significantly decreased while oil production significantly increased:

- 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?

Point Source ID and Quantification



Example of Point Source ID and Quantification (Mooney)

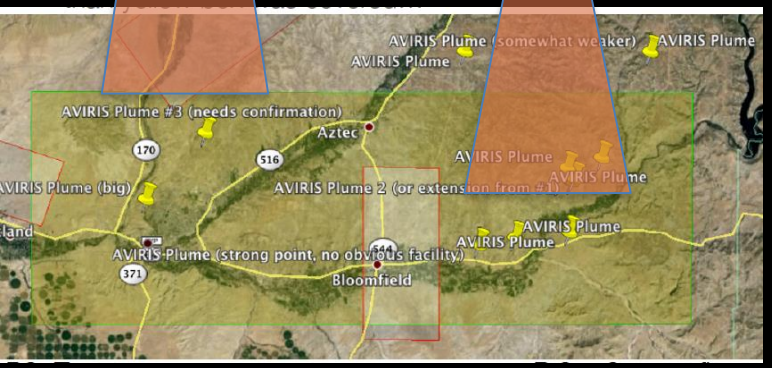


Point Source ID and Quantification

NASA HyTES and AVIRIS on Twin Otters CH_4 column measurements

AVIRIS

HyTES



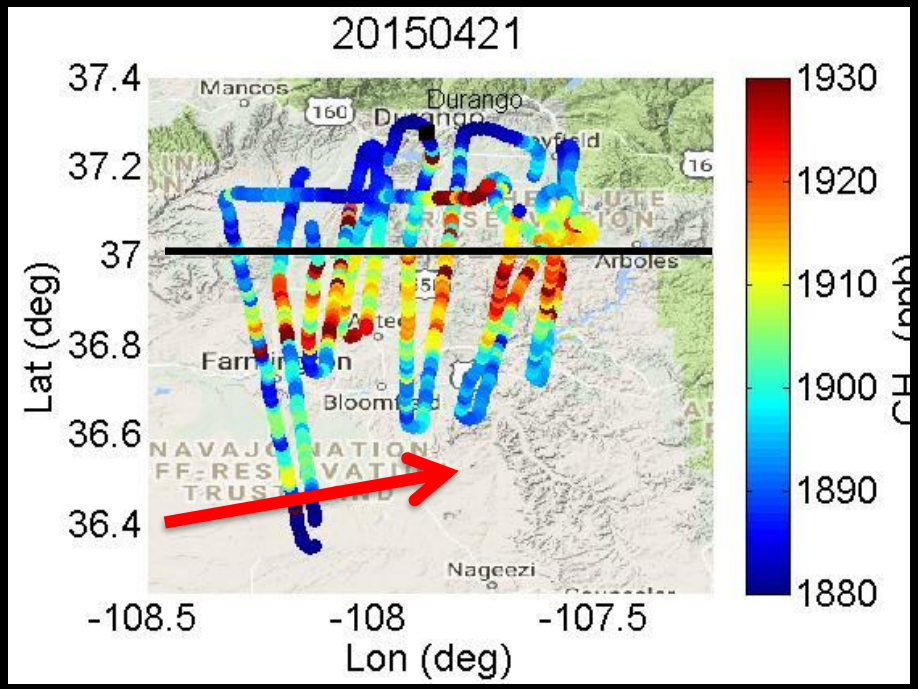
Hyperspectral Images taken from the aircraft in the short-wave (AVIRIS-NG) and thermal range (HyTES)

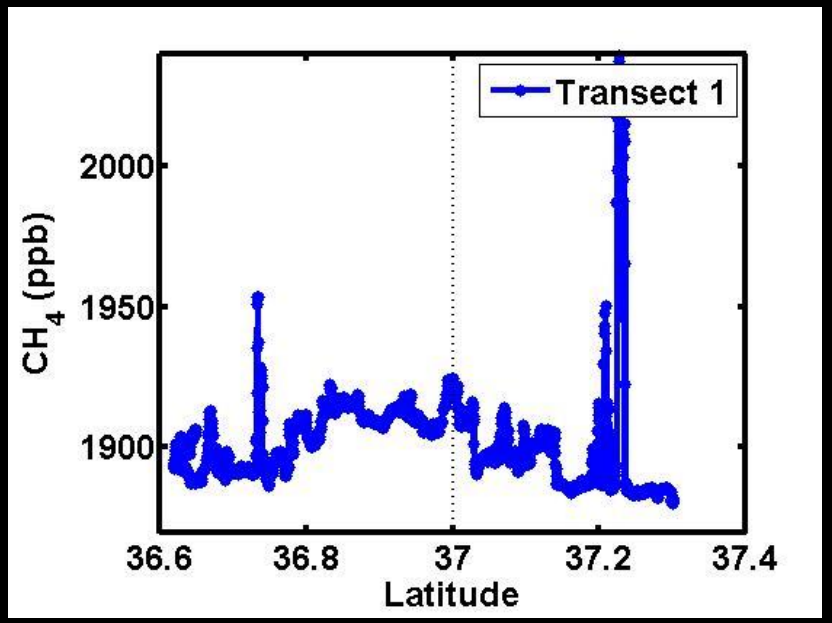
Point Source measurements

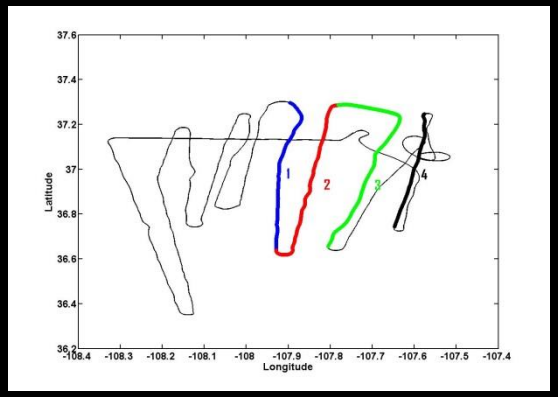
Point source	***flux*$_{CH4}$ (Tg yr^{-1})**	**% total basin *flux*$_{CH4}$**
This work (Mooney)		
Carbon Junction Seep	0.0062	1.2
Coal mine vent shaft	0.013	2.4
Σ Observed sources (n = 18)	**0.047**	**8.7**
Frankenberg et al. (2016)		
Coal mine vent shaft	0.014	2.6
Σ Observed sources (n = >200)	**0.23-0.38**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

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

Distribution of Emissions

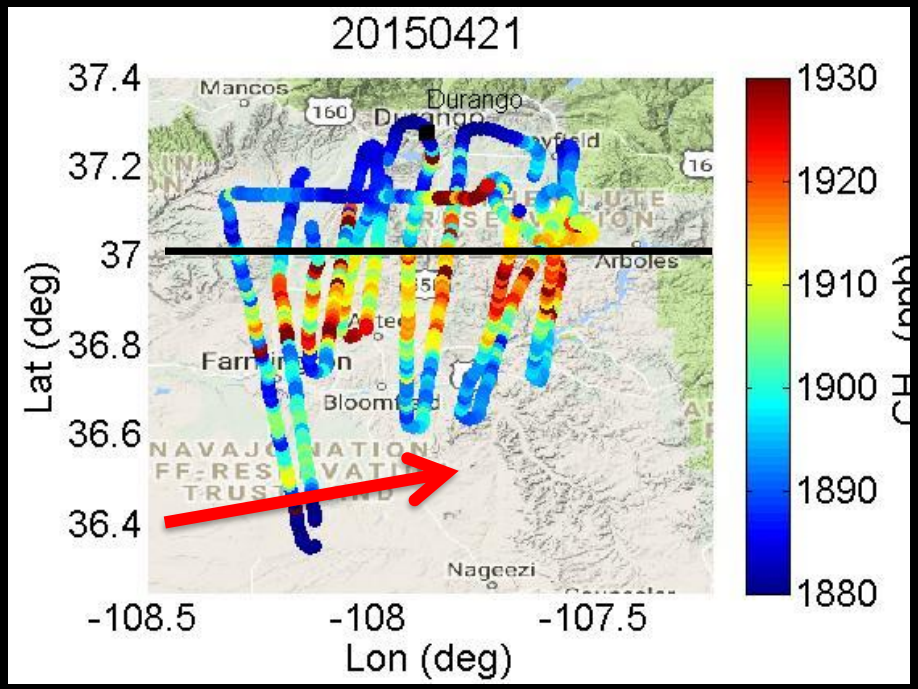


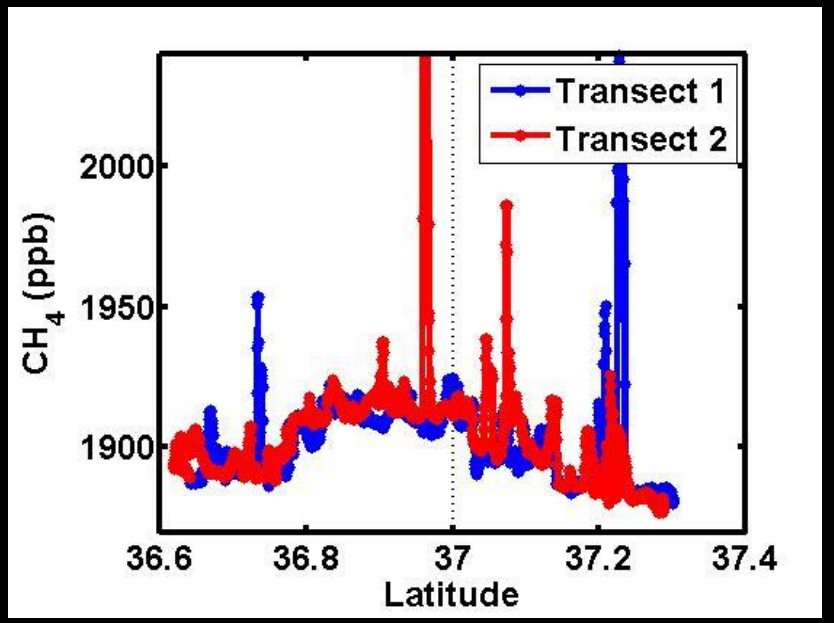


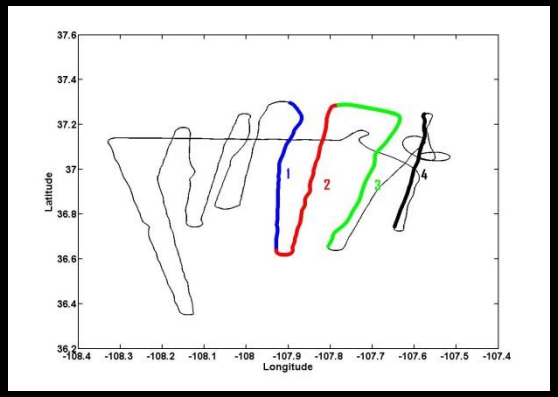


Transect 1

Distribution of Emissions

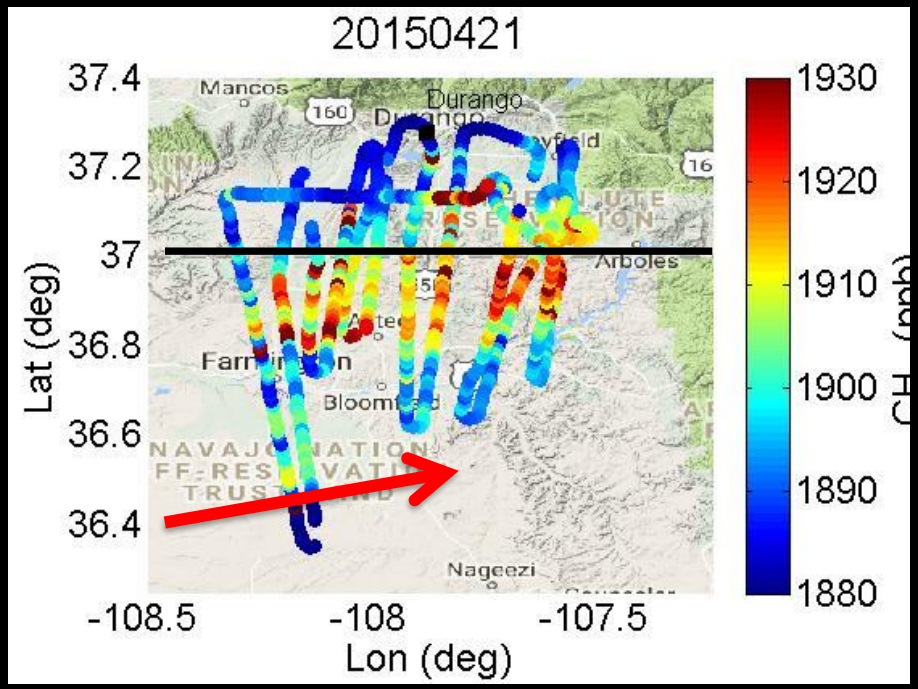


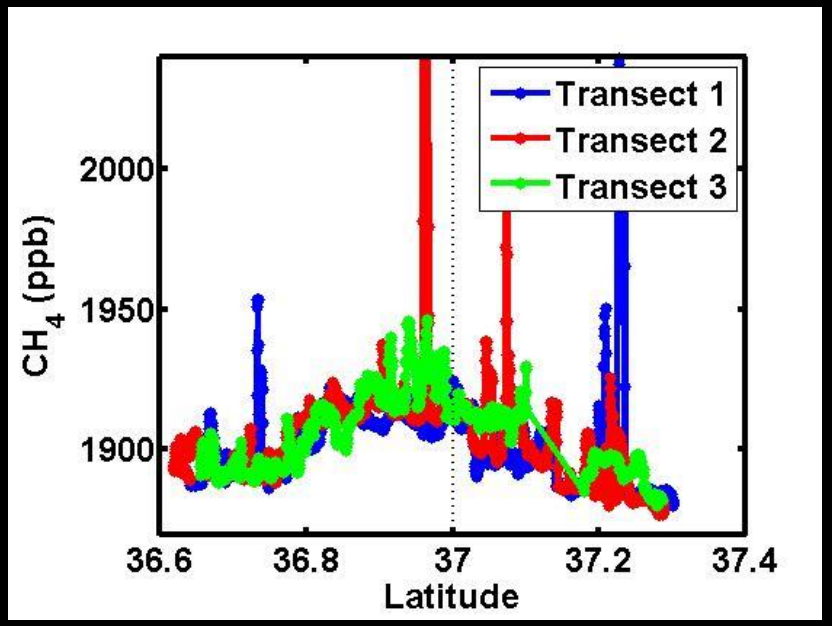


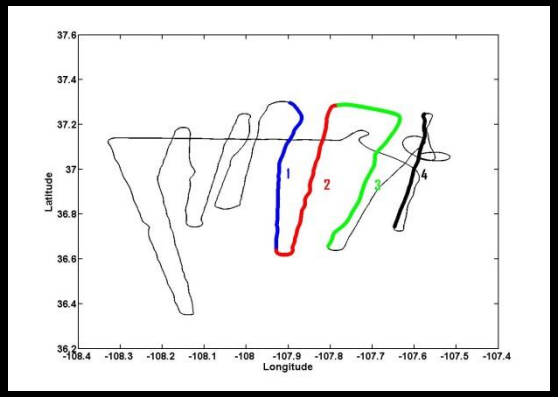


Transect 2

Distribution of Emissions

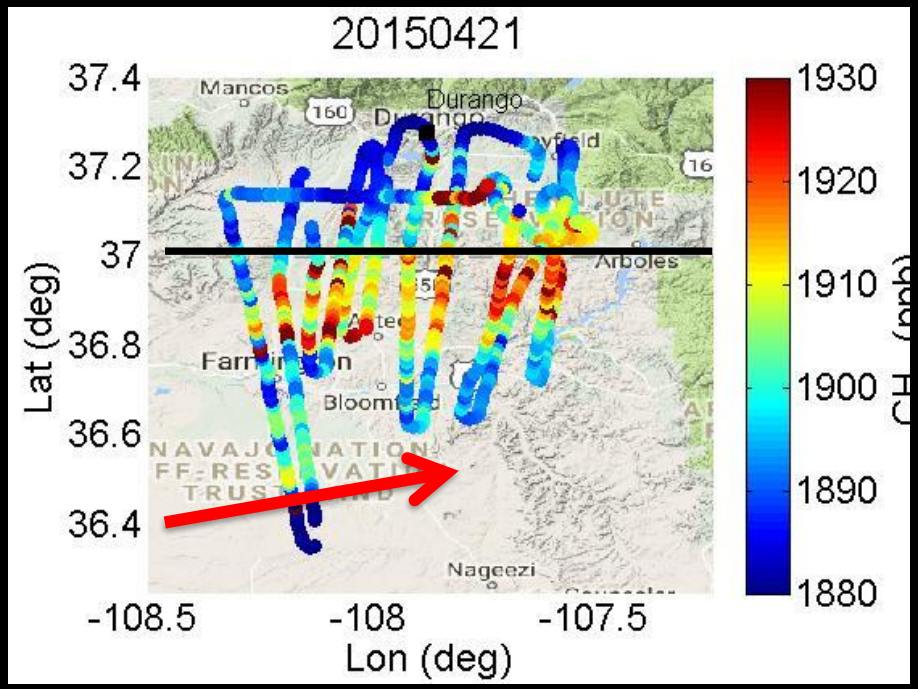


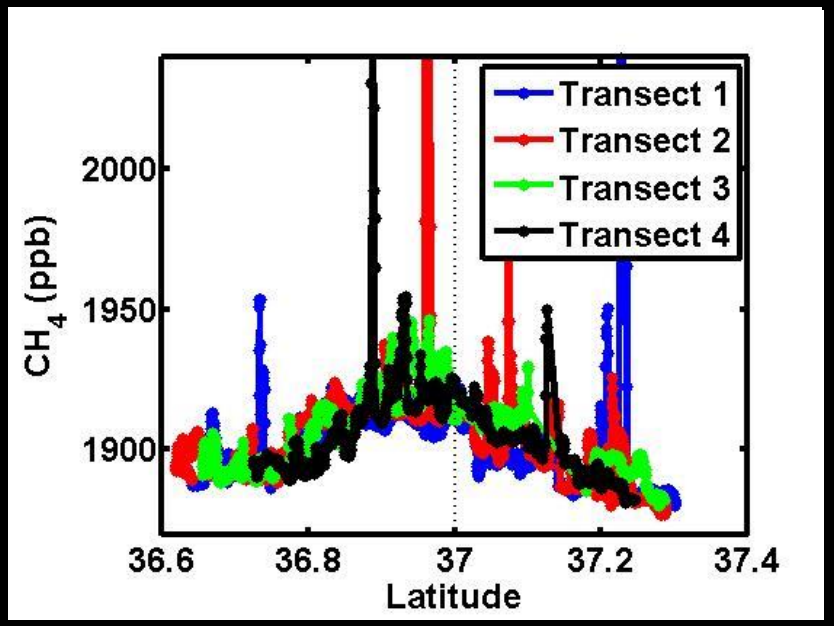


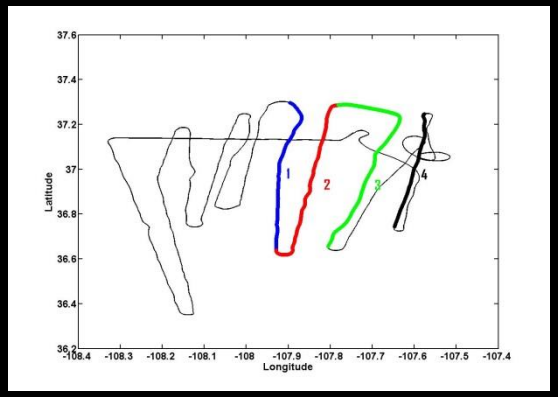


Transect 3

Distribution of Emissions

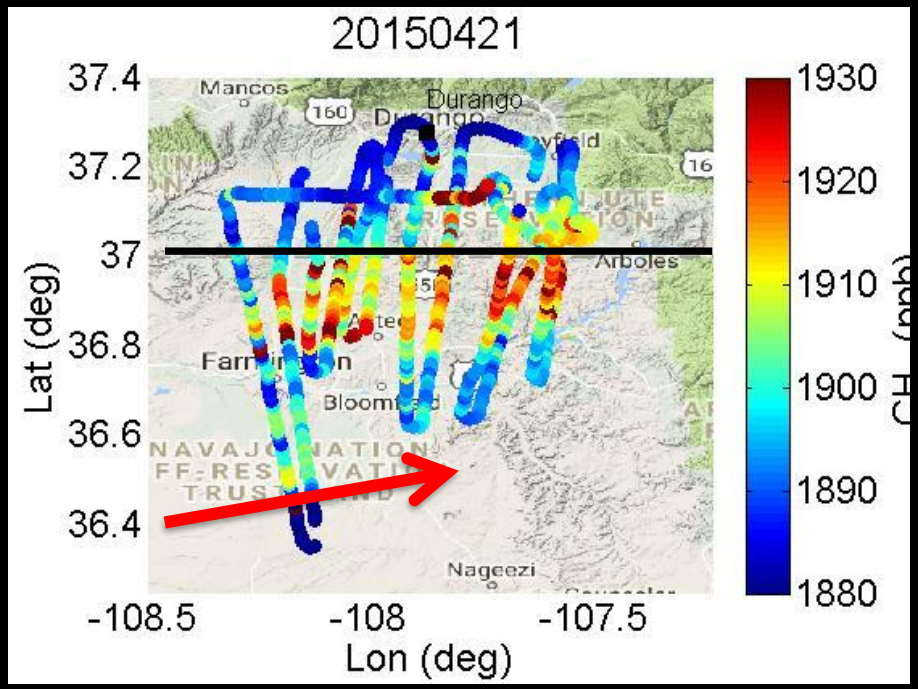


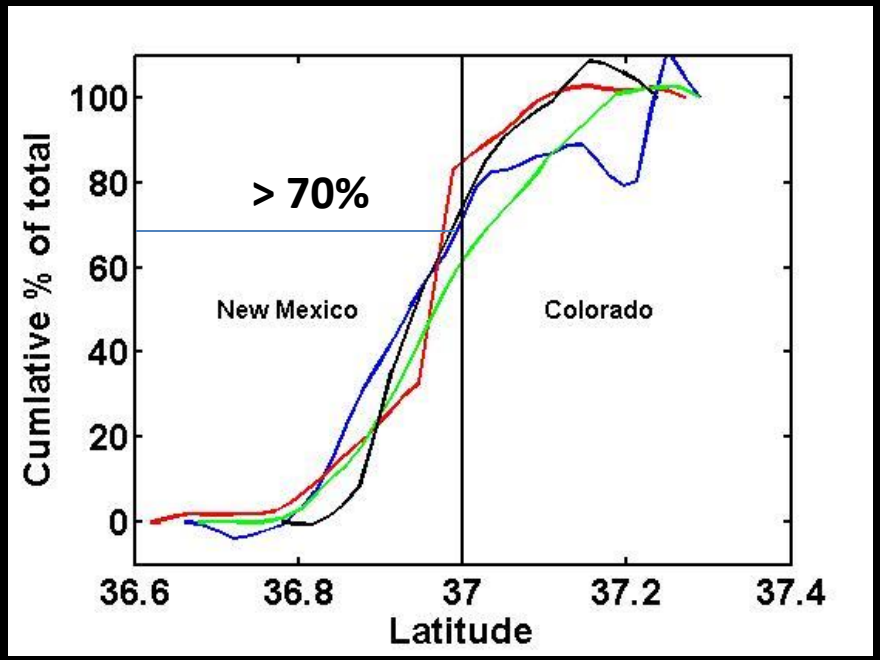


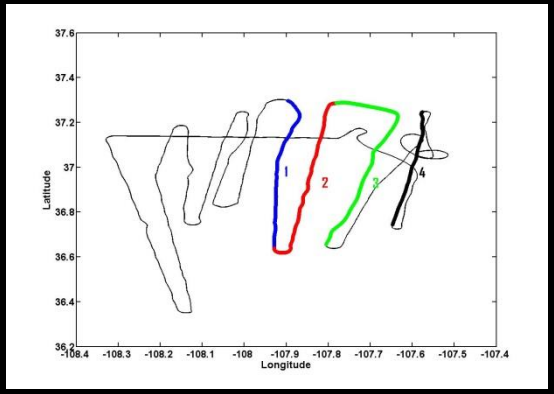


Transect 4

Distribution of Emissions







Greater than 70% of emissions are coming from the New Mexico

Conclusions

1. Total emissions are 0.54 Tg/yr – not significantly different from satellite study.
2. If the satellite-based estimates are representative of emissions during the 2003-2009 era, this study suggests that gas production is not correlated with leakage.
3. No one source provides more than 2.4% of the total emissions in the Four Corners Region.
4. The majority of the emissions are coming from the areas to the south of the Colorado boarder