Estimating emissions from Oil and Natural Gas production using Aircraft Observations

NOAA/CIRES

Colm Sweeney , Gaby Pétron, Anna Karion, Lori Bruhwiler, Greg Frost, Michael Trainer, Ben Miller, Steve Montzka, Jon Kofler, Pat Lang, Ed Dlugokencky, Mike Hardesty, Alan Brewer, Arlyn Andrews, Carolina Siso, Molly Heller, Eric Moglia, Dan Wolfe, Pieter Tans and Russ Schnell

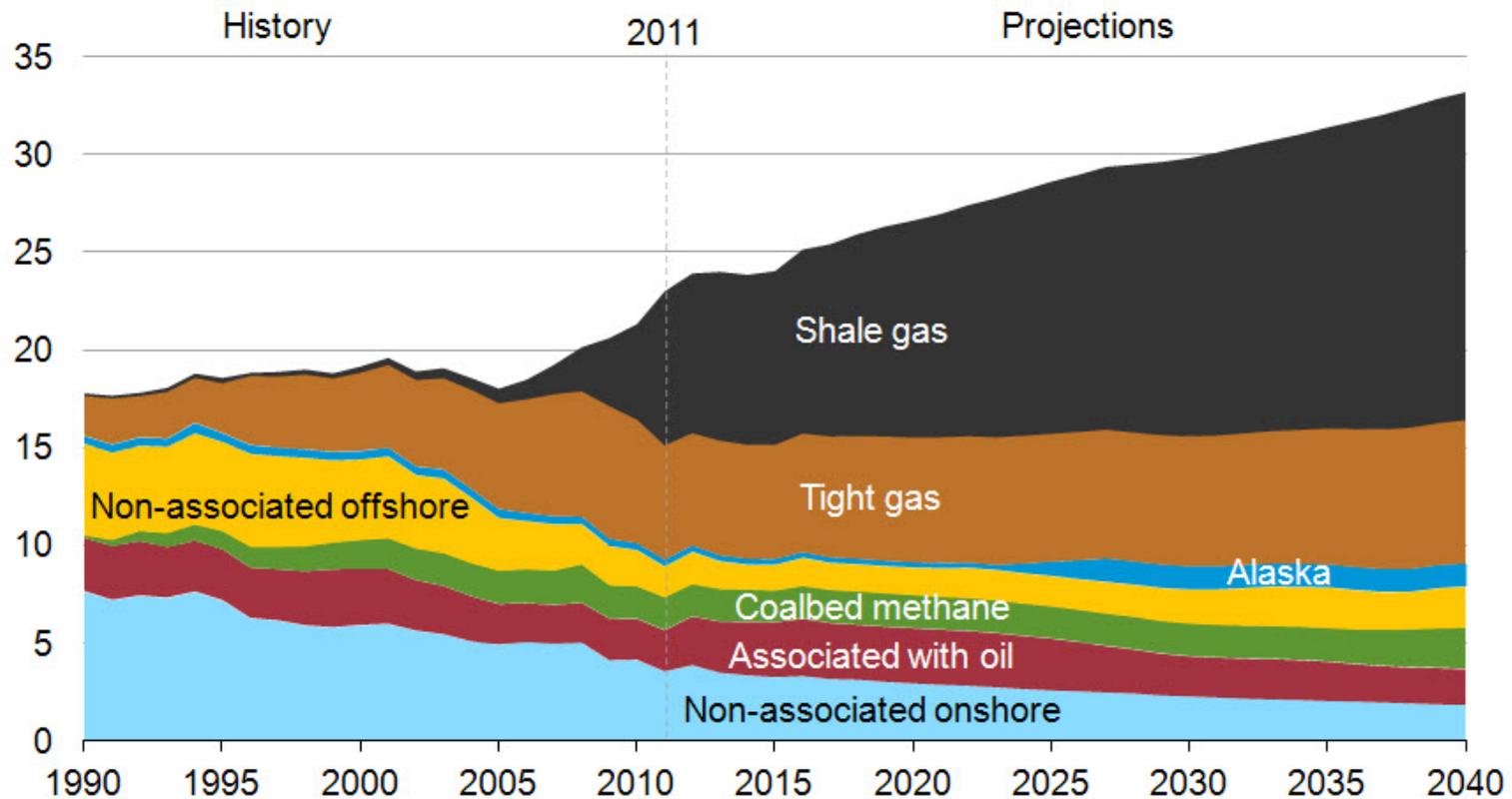**Scientific Aviation**

Steve Conley

Picarro

Eric Crosson, Chris Rella, Tracy Tsai

Aerodyne

Scott Herndon, Tara Yacovitch

US Natural Gas Production

U.S. dry natural gas production
trillion cubic feet

History   2011   Projections

Shale gas

Non-associated offshore

Tight gas

Alaska

Coalbed methane

Associated with oil

Non-associated onshore

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2013 Early Release*

2005 Started shale gas boom

US Energy Strategy

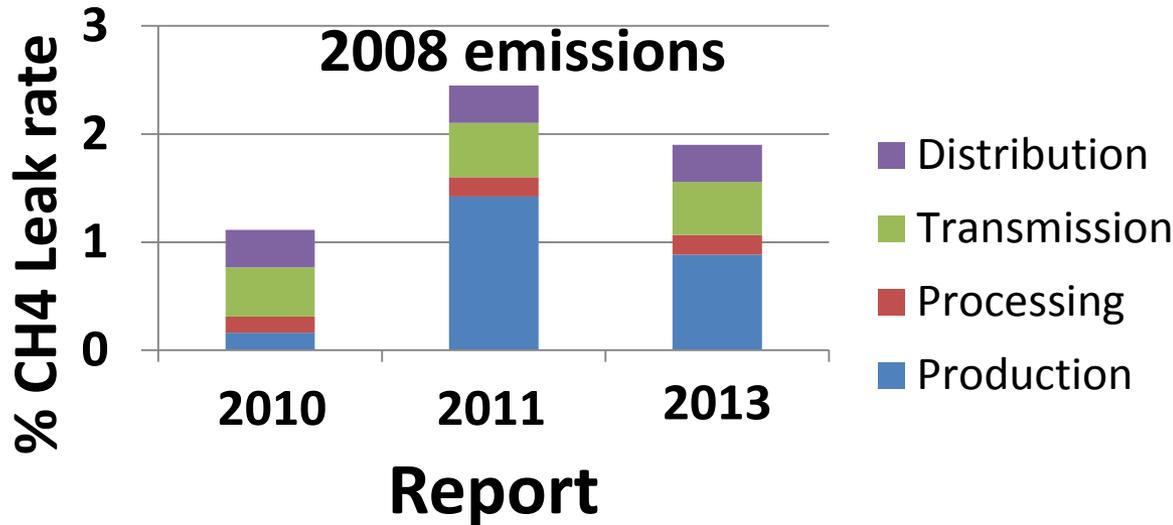|	Climate	Air Quality	Foreign Policy	Reserves/ Storage	Cost
Natural Gas	?	?	✓	✓	✓
Oil	✗	✗	✗	✗	✓
Coal	✗	✗	✓	✓	✓

Natural gas is portrayed in the US as a bridge fuel towards a more sustainable energy system
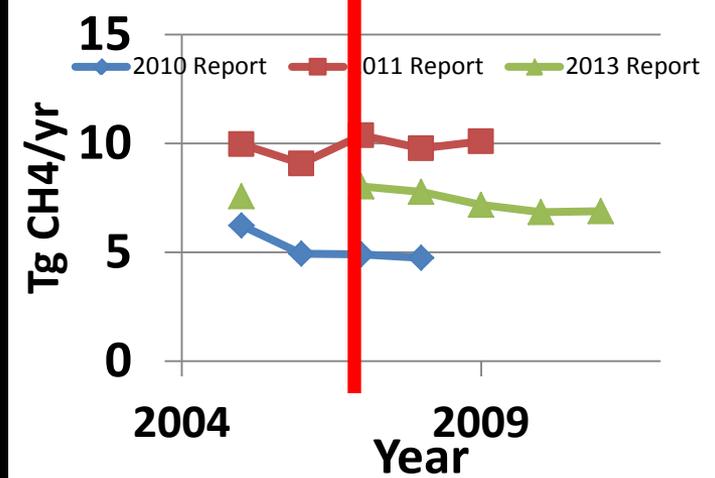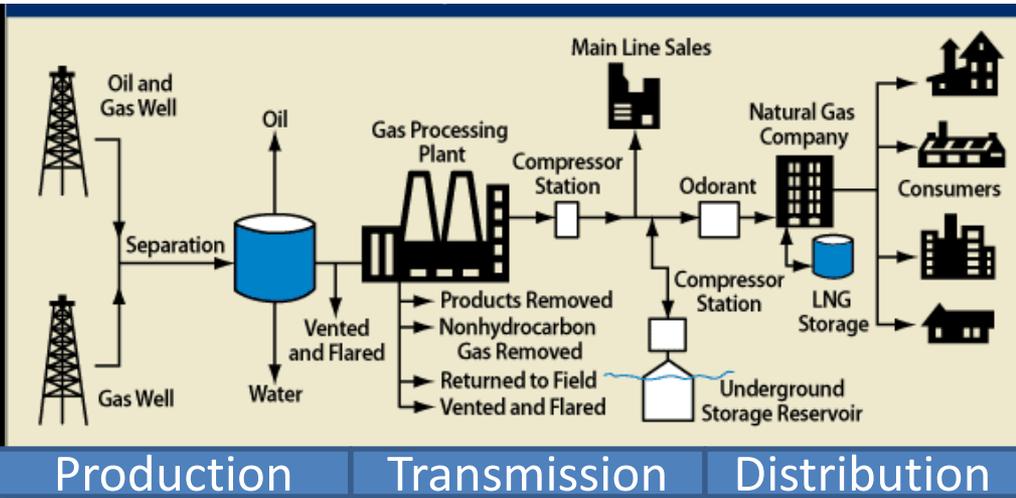
Is natural gas really a benefit to the climate?

Percent natural gas leakage (y-axis)

Gasoline Car — **<1.8%**

Heavy-duty vehicle — **Leak rate: <1.0%**

Coal Power plant — **<3.1%**

Years until climate benefit is achieved

CH4 → CO2

GWP (y-axis), Time (x-axis)

Bar values: 112 (at 0), 72 (at 20), 25 (at 100), 7.1 (at 500)
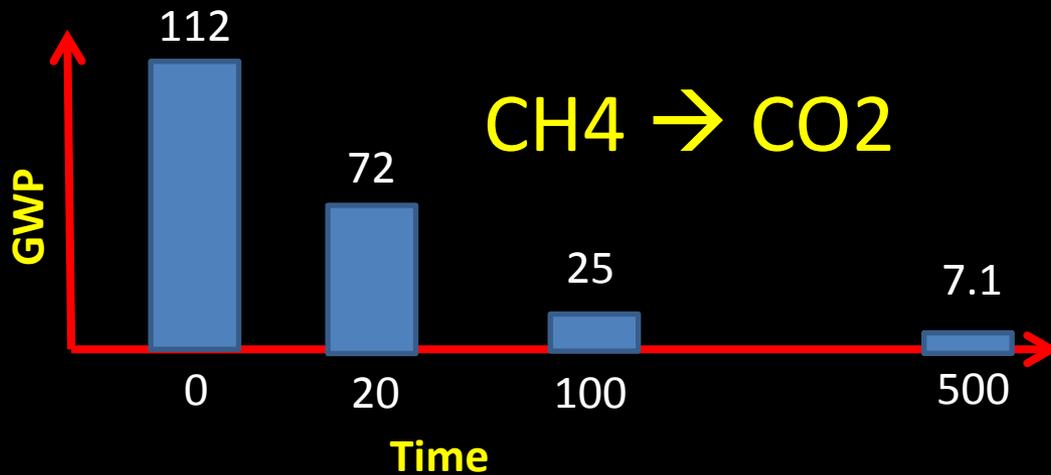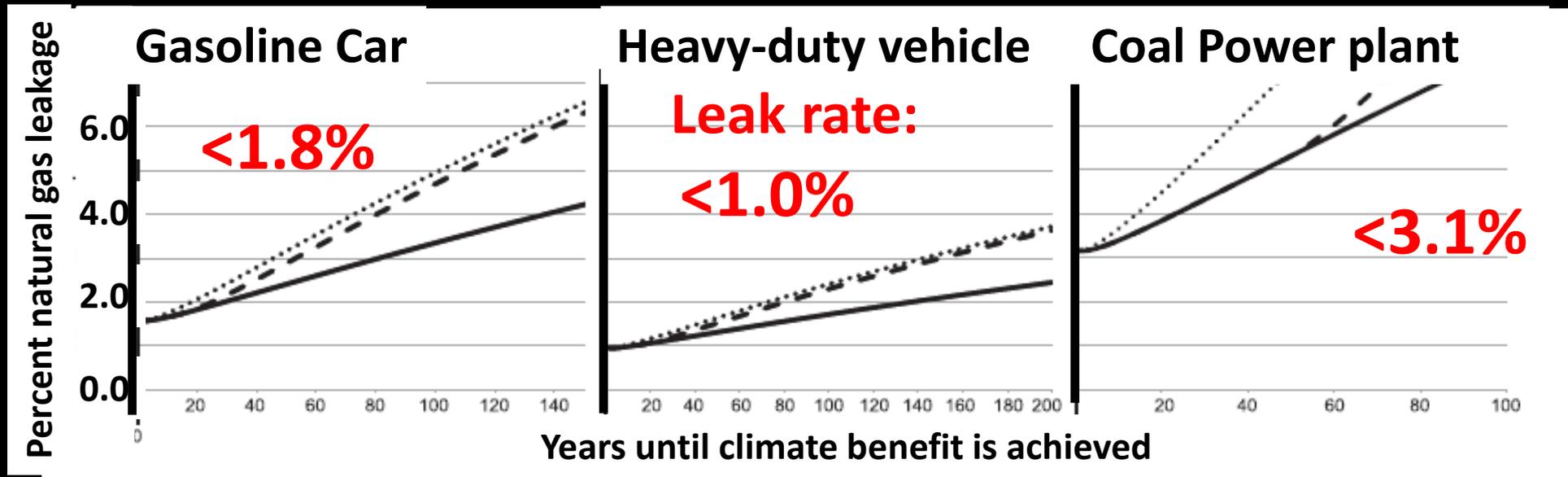
With only 3.1% leakage from well to power plant we will see immediate benefit of switching to electric power.

Alvarez et al. 2013

So what are the CH₄ emissions from natural gas in the US?

2008 emissions

% CH4 Leak rate vs Report (2010, 2011, 2013)
- Distribution
- Transmission
- Processing
- Production

EPA has changed their methodology for estimating production emissions twice in the last three years

Main Line Sales

Oil and Gas Well — Oil

Gas Processing Plant

Compressor Station

Natural Gas Company

Odorant

Consumers

Separation

Vented and Flared

Water

Gas Well

- Products Removed
- Nonhydrocarbon Gas Removed
- Returned to Field
- Vented and Flared

Compressor Station

LNG Storage

Underground Storage Reservoir

| Production | Transmission | Distribution |

Source: U.S. Energy Information Administration.

2010 Report · 011 Report · 2013 Report
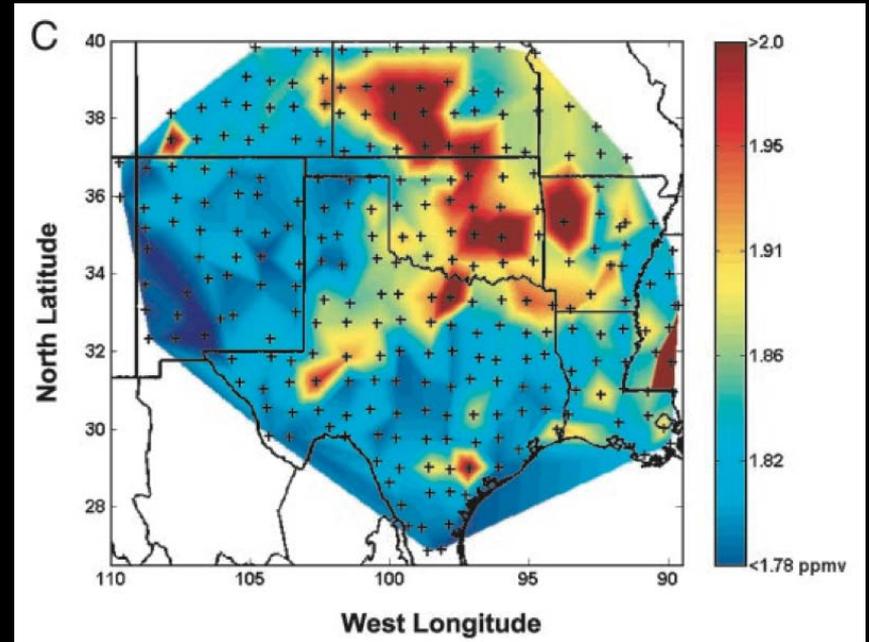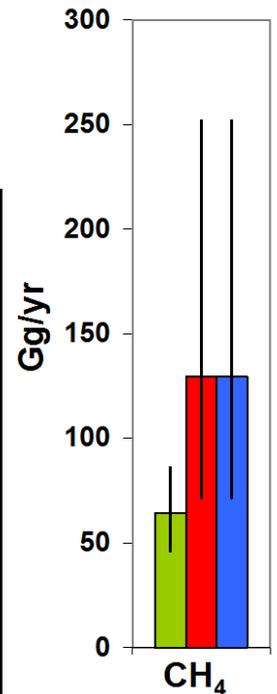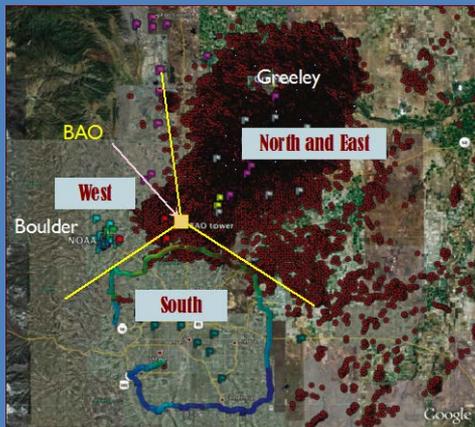
Tg CH4/yr vs Year (2004, 2009)

Lower Production emissions?
## Top down measurement

Petron et al. 2012: Used the measured atmospheric propane-to-methane enhancement ratios observed at the BAO tall tower and at the surface across the Front Range to evaluate the proportion of flashing and venting emissions.

Bottom-up Emissions
Top-Down BAO/
Mobile Lab Emissions

Katzenstein et al. 2003: Used surface concentrations of CH_4 Texas, Oklahoma, and Kansas to suggest that EPA estimates were too low.

Aircraft Mass Balance Method

Downwind CH$_4$

Wind

Wind

mixing height (PBL)

Background CH$_4$
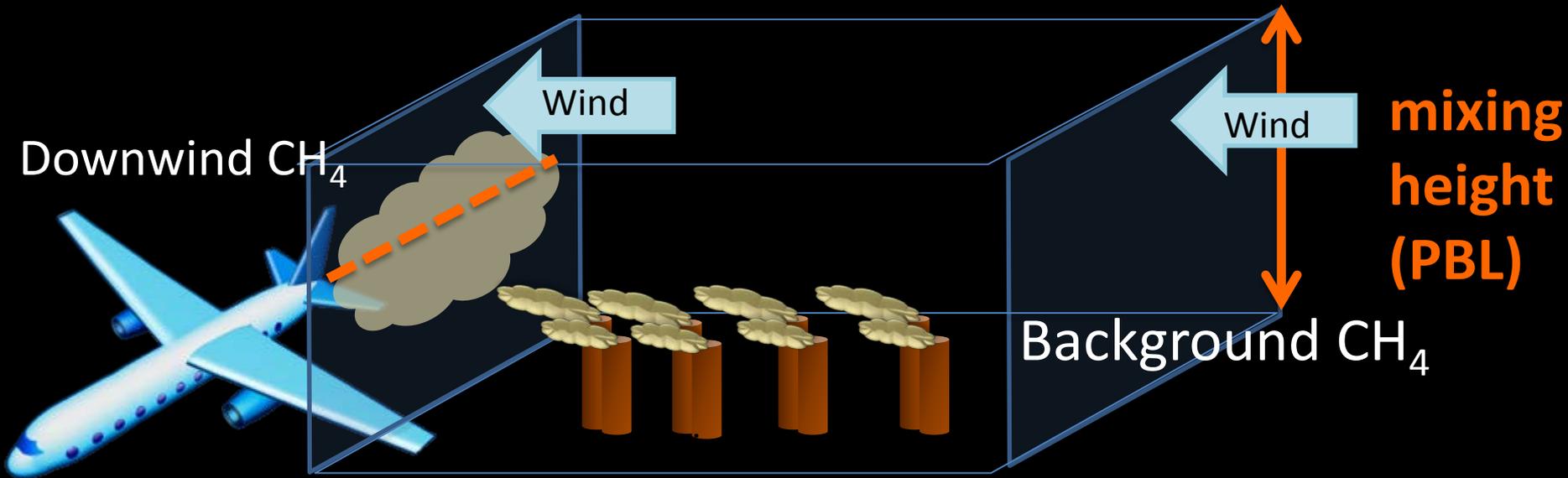
CH$_4$ flux

Molar CH$_4$ enhancement in PB[L]

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

Perpendicular wind speed

Not just CH_4 in Aircraft

Mass balance

Aircraft:
Continuous
- CH_4
- H2O
- Temp
- Winds

HRDL:
- PBL
- Wind profiles

Attribution/History

Aircraft:
Continuous
- CH_4
- CO_2
- CO
- H2O
- Temp
- Winds
- Ethane

Flask
- 55 species

Mobile ground:
Continuous
- CH_4
- CO_2
- CO
- H2O
- Temp
- Winds
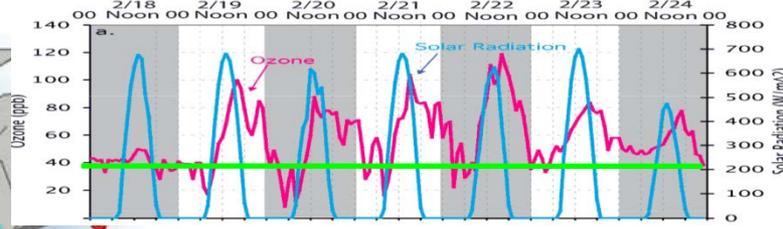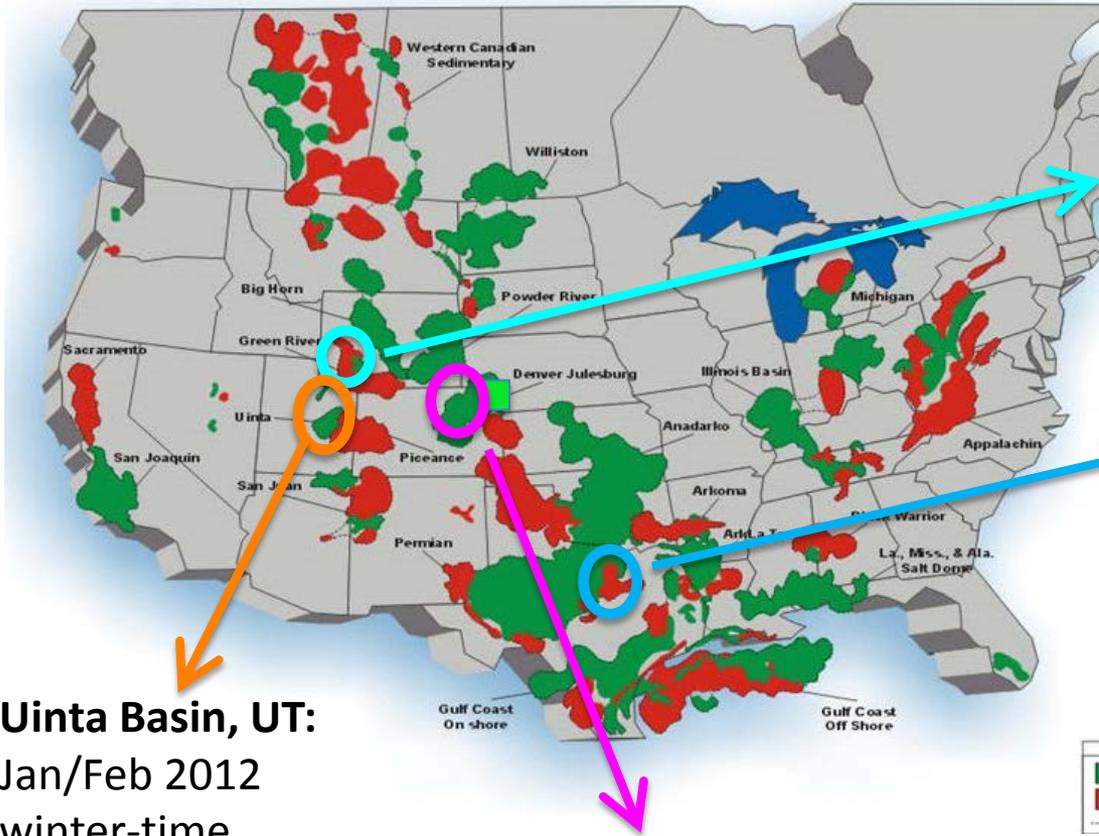- C-13
- Ethane

Flask
- 55 species

Tower:
Continuous
- CH_4
- CO_2
- CO
- H2O
- Temp
- Winds

Flask
- 55 species

Past and Ongoing Studies in Western US Oil and Gas Fields

Green River Basin, WY: high winter time surface ozone in natural gas field (Schnell et al., Nature, 2009)

Barnett Shale, TX: Second largest shale gas field in the US.
   - March 2013

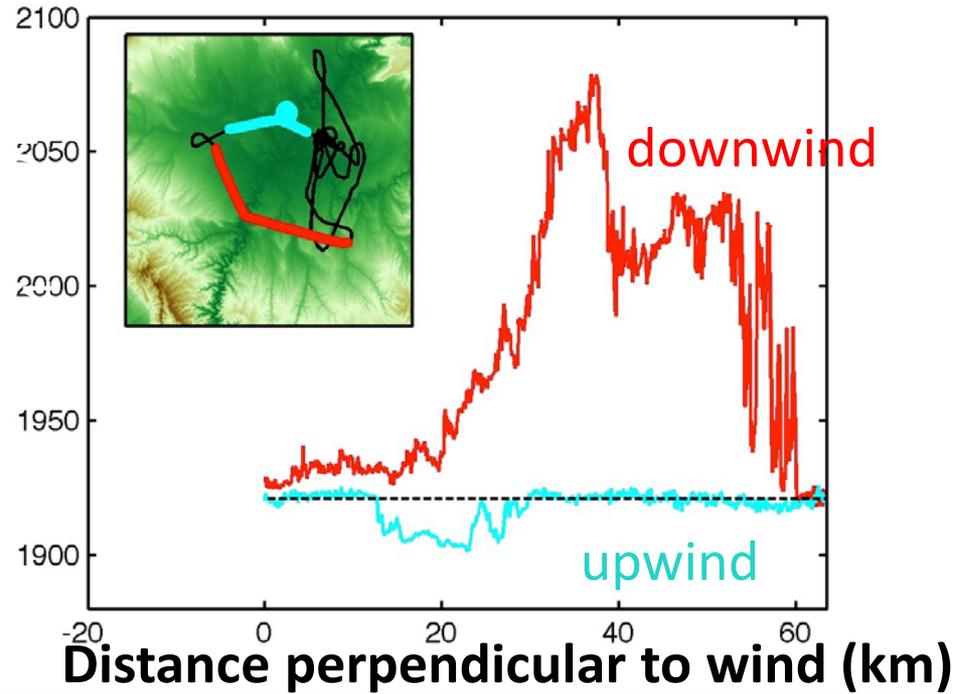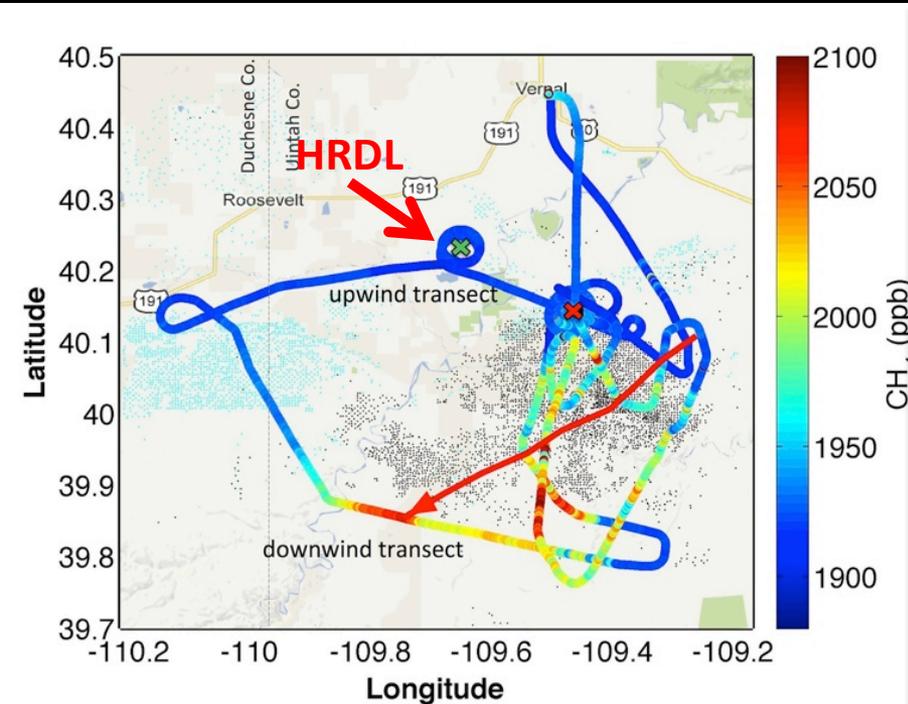**Map Key**
- Oil Fields
- Gas Fields
- Basin Boundaries

Uinta Basin, UT: Jan/Feb 2012 winter-time study of surface ozone and its precursors
- **Feb. 2012**
- **Feb. 2013**

Denver Julesberg, CO: Hydrocarbon emissions from oil and gas operations in 2008 in Weld County (Pétron et al., 2012)
- **May 2012**

Utah, 2012

Karion et al. in prep

Uncertainty

Parameter	Mean Value	Variability (1σ)	Relative Uncertainty
wind speed (V)	5.2 m/s	1.2 m/s	24%
wind direction	55.2°	10.1°	
$V\cos\theta$	3.8 m/s	0.7 m/s	24%
ΔX_{CH4}	56.3 ppb	5.6 ppb	10%
BL depth	1700 m	125 m	7%
CH$_4$ Flux	**56000 kg/hr**	**15000 kg/hr**	**28%**

Inventory v. Top down

% Leak Rate (y-axis, values 0 to 10)

- Ground C_3H_8/CH_4
- Aircraft Mass Balance
- Aircraft Mass Balance

Legend:
- State Inventory (yellow)
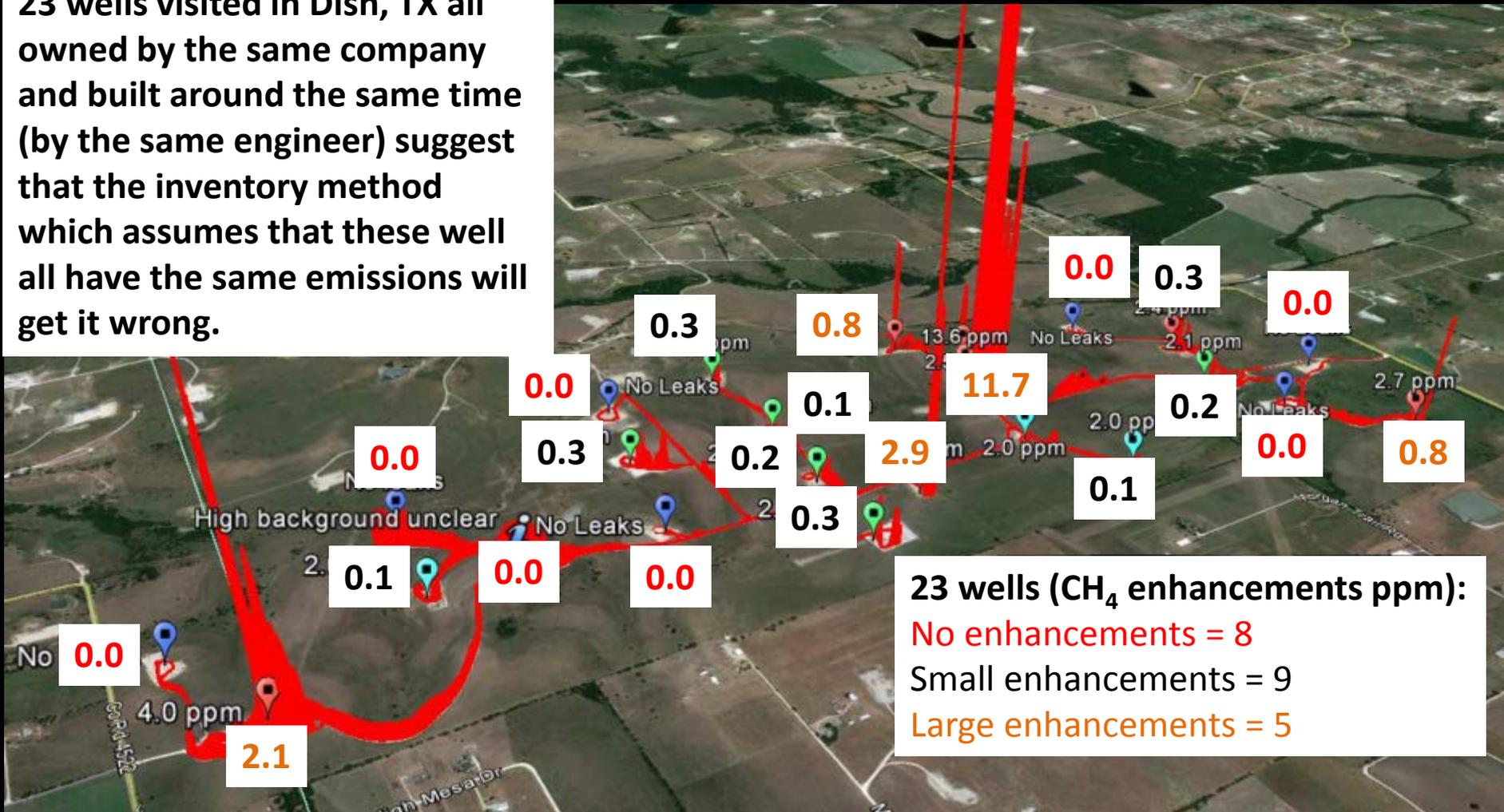- Top down (red)
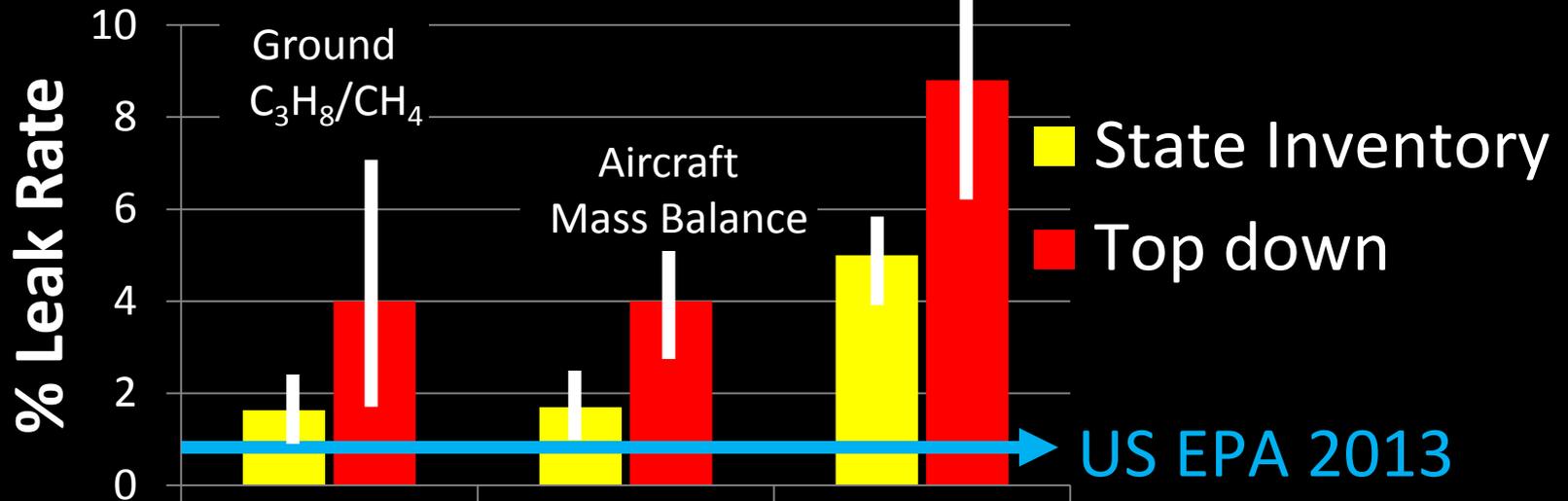
US EPA 2013

Petron et al. 2012 Denver
Petron et al. 2013 Denver
Karion et al. 2013 Uintah

Can inventories work?

23 wells visited in Dish, TX all owned by the same company and built around the same time (by the same engineer) suggest that the inventory method which assumes that these well all have the same emissions will get it wrong.

0.0   0.3   0.0

0.3   0.8   0.0

0.0   0.1   11.7   0.2

0.0   0.3   0.2   2.9   0.0   0.8

0.1

0.3

0.1   0.0   0.0

23 wells (CH$_4$ enhancements ppm):
No enhancements = 8
Small enhancements = 9
Large enhancements = 5

0.0

2.1

[Activity data] X [emissions factor] = flux

Conclusions

- Mass balance estimates in UT and CO suggest that inventories underestimate leakage rates.

- Ground measurement suggest that the inventories can not account for variability in emissions that exist in a typical oil and gas field.