

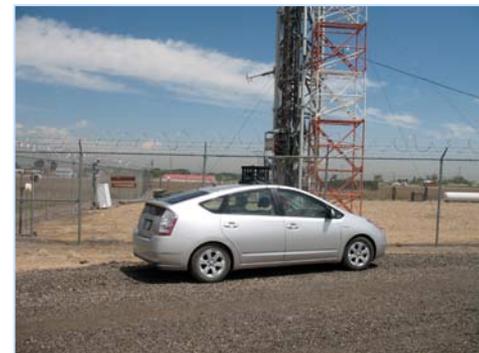
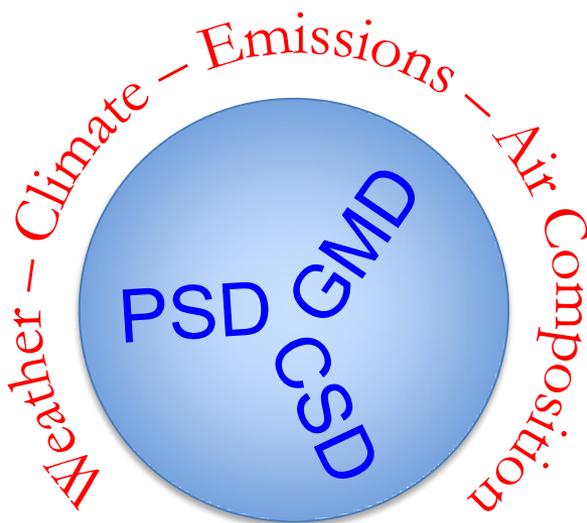
Evidence of Emissions from Oil and Gas Drilling Operations in Northeastern Colorado

NOAA GMD: Gaby Petron, Steve Montzka, Ben Miller, Adam Hirsch*, Anna Karion, Colm Sweeney, Jon Kofler, Arlyn Andrews, Ed Dlugokencky, Laura Patrick, Pieter Tans & NOAA Carbon Cycle Group
*now at the National Renewable Energy Laboratory, Golden, CO

NOAA CSD: Greg Frost, Michael Trainer
NOAA PSD: David Welsh, Dan Wolfe

Acknowledgments

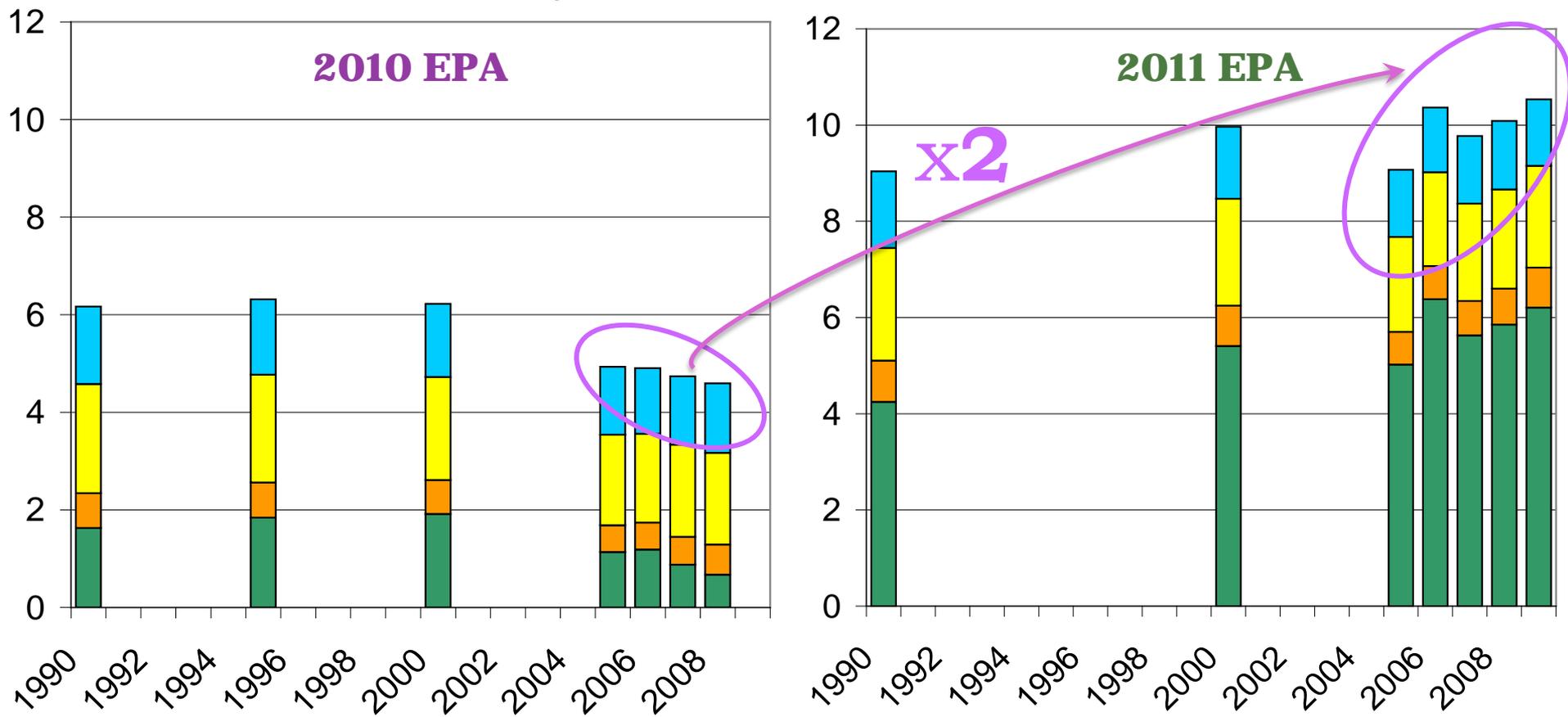
Western Regional Air Partnership: Tom Moore
Environ: Amnon Bar-Ilan and John Grant



Methane emissions (Tg) from natural gas systems

EPA US GHG inventory 2010 vs 2011

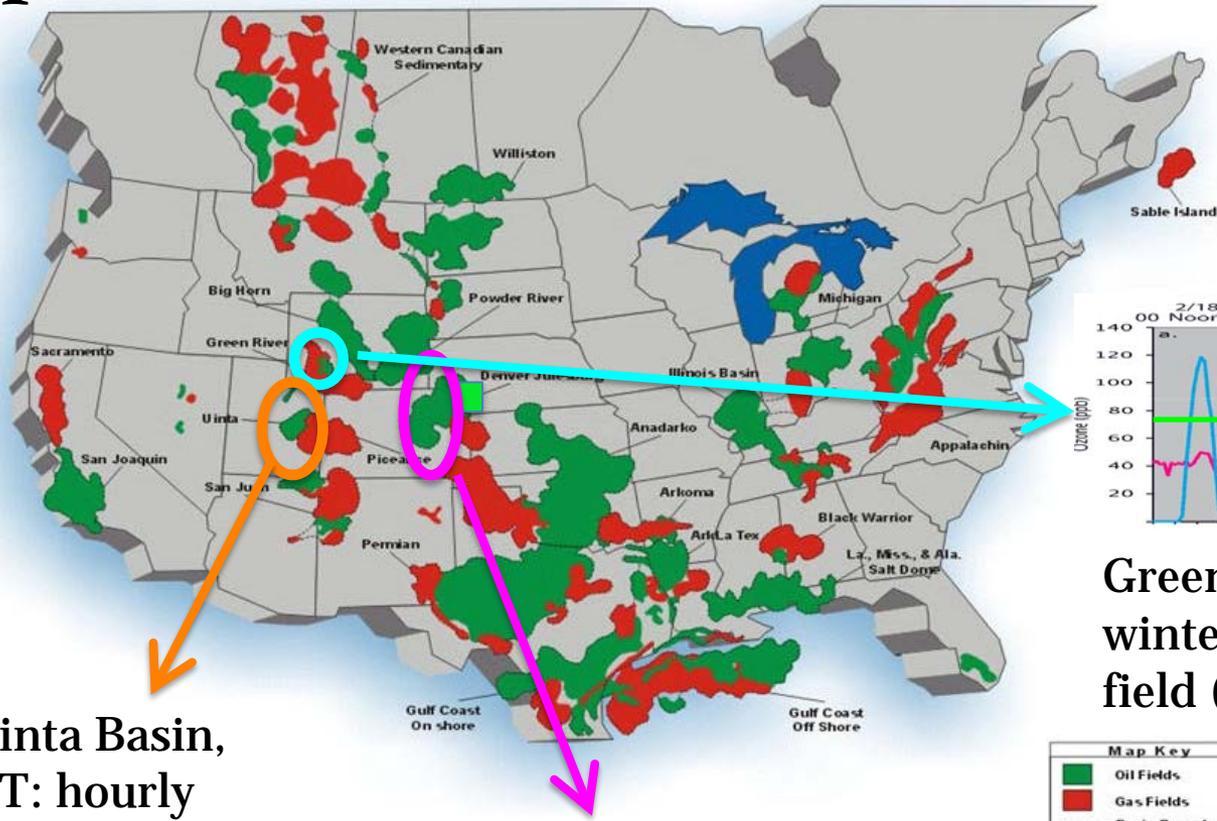
- Field production
- Processing
- Transmission and Storage
- Distribution



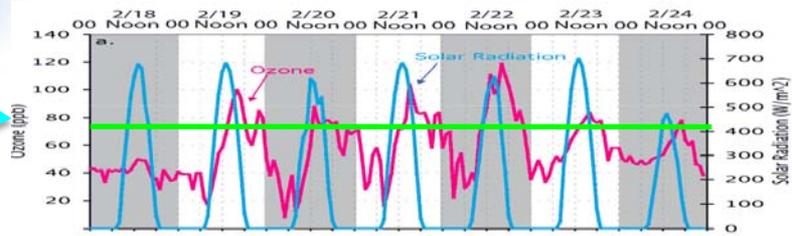
2009 Methane emission estimates:

TOTAL 32.7 Tg, **Natural gas systems 10.5 Tg**, Enteric fermentation 6.6 Tg, Landfills 5.6 Tg, Coal mining 3.4 Tg, Manure management 2.4, Petroleum Systems 1.5 Tg

Examples of air pollution from O&G operations in Western States



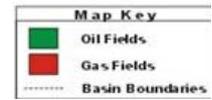
Pinedale smog
Jonah, Feb 2008



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

Uinta Basin, UT: hourly ozone in natural gas field up to 155 to 159 ppb last winter

Northern Colorado Front Range ozone non attainment area: Estimated 40% of total VOC in the region due to oil and gas operations in Denver Julesburg Basin (DJB)

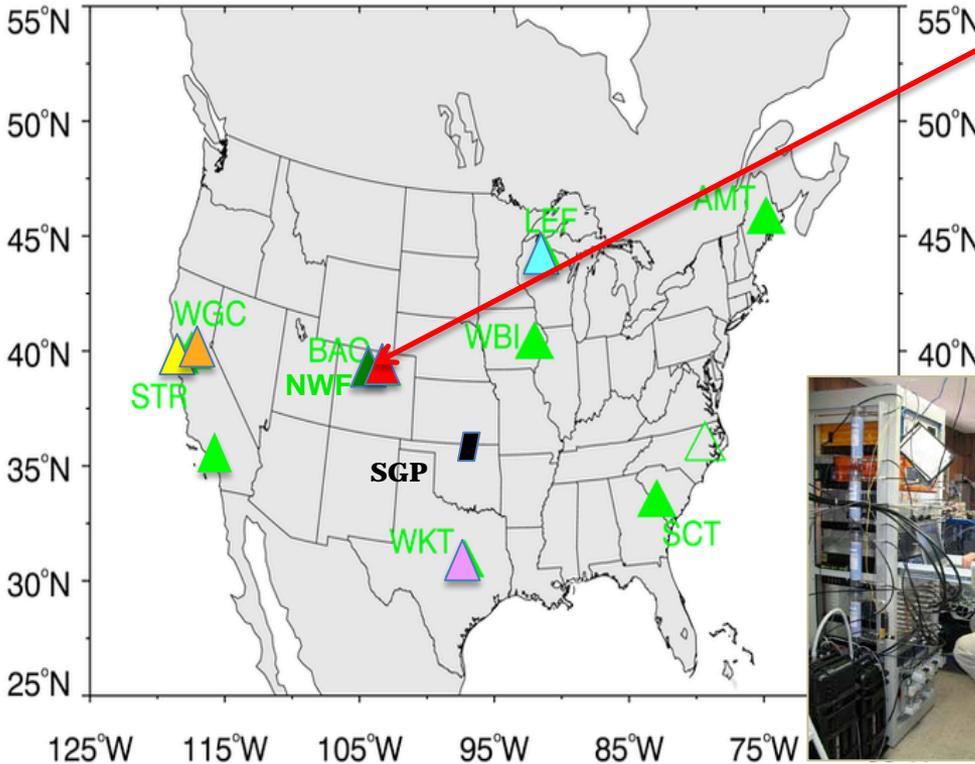


Outline

- Oil and gas operations emission signature in Colorado Northern Front Range
- Source estimates &
- Comparison with inventories
- Conclusions

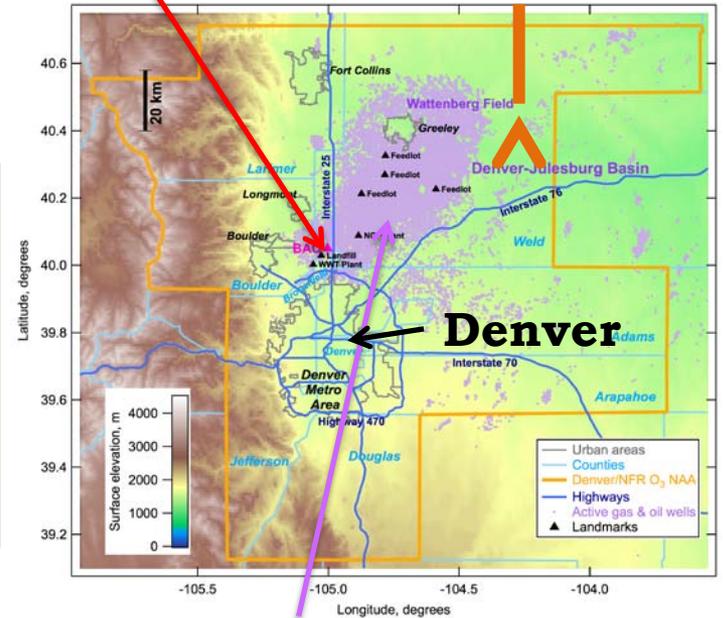


NOAA Cooperative Tower Long Term Measurement and Sampling Network



**Boulder Atmospheric Observatory,
Erie, Weld county (NOAA PSD)**

Non attainment area for
summer time ozone



- 300 meter tall tower
- 30 sec- Meteorological Data
- **Daily discrete air samples from 300 meter level since Aug 2007**

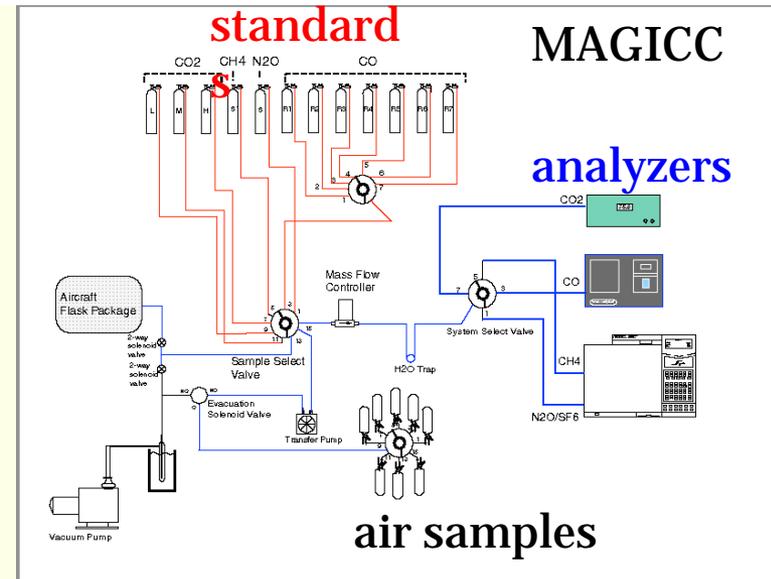
Denver Julesburg Basin
12,000 gas wells in Weld County
~ 900 new ones in 2006

Tower team: Arlyn Andrews, Jonathan Kofler, Jonathan Williams

Discrete Air Samples Analyses

NOAA Boulder Lab

- **MAGICC System (Carbon Cycle Group):**
 - ✓ CO_2 , CH_4 , N_2O , CO , H_2 , SF_6
 - ✓ CH_4 repeatability error: 1.2 ppb
- **GC/MS System (HATS group):**
 - ✓ C_3H_8 , $n\text{C}_4\text{H}_{10}$, $i\text{C}_5\text{H}_{12}$, $n\text{C}_5\text{H}_{12}$, C_2H_2 , C_6H_6 , CFCs, HFCs, PFCs...
 - ✓ Most species: total uncertainty < 5%
 - ✓ n-butane and C_2H_2 : 10-15%
- **High precision long term well calibrated measurements**



Logistics: Molly Heller, Chris Carparelli, Jack Higgs,...

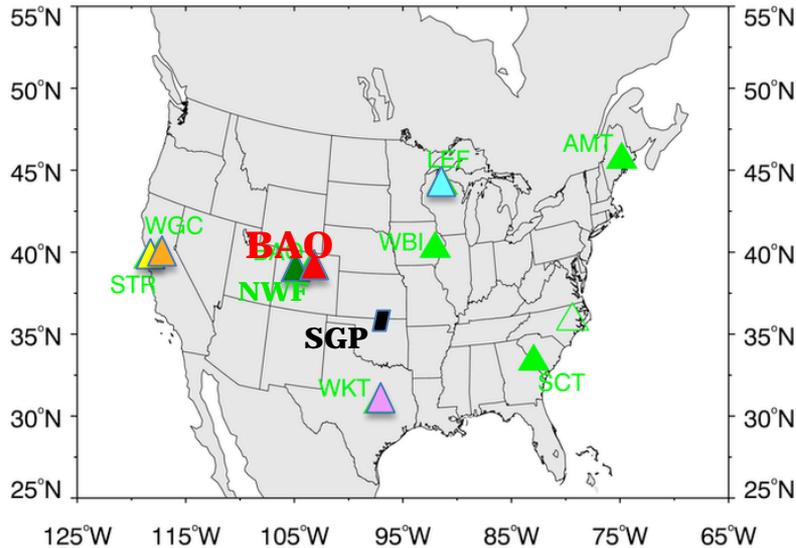
Analysis:

GMD: Tom Conway, Andy Crotwell, Ed Dlugokencky, Pat Lang, Paul Novelli, Kelly Stroker

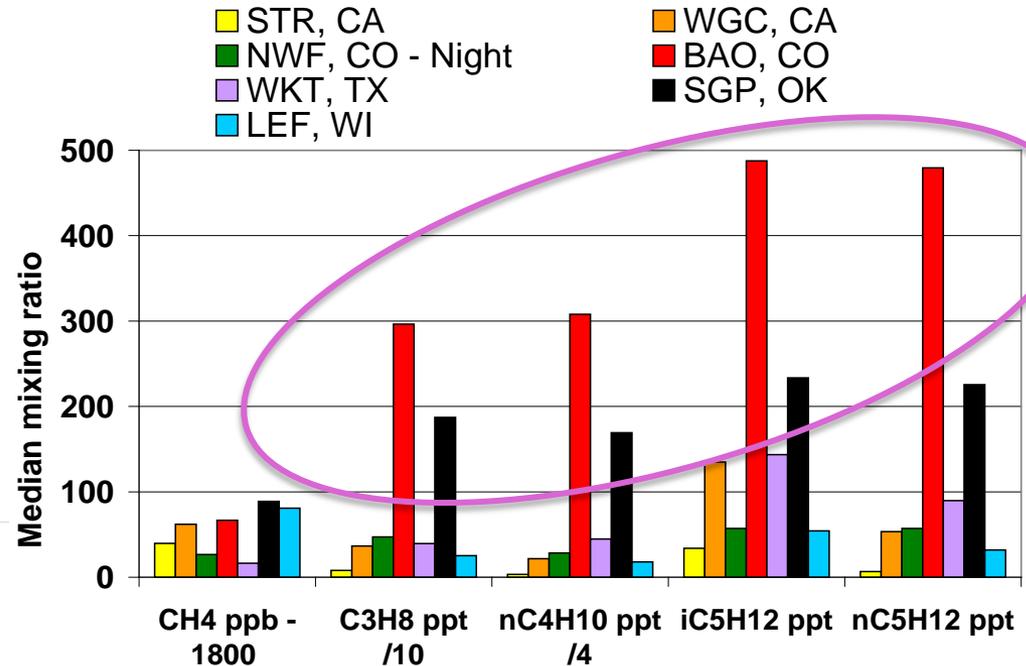
HATS: Ben Miller, Carolina Siso, Steve Montzka

BAO: Distinct Alkane Signature

Median summer mixing ratio at 7 NOAA Towers
Midday data only (June-Aug 2007-2009)



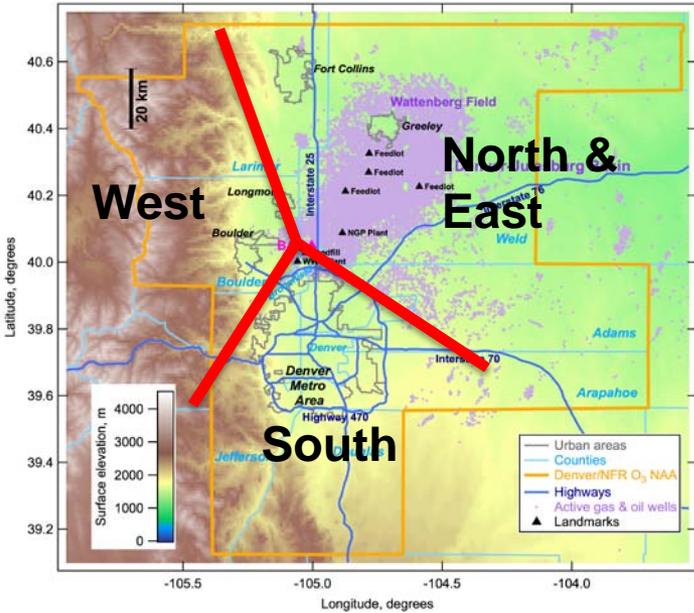
NOAA Cooperative Tall Tower
Measurement and Sampling Network



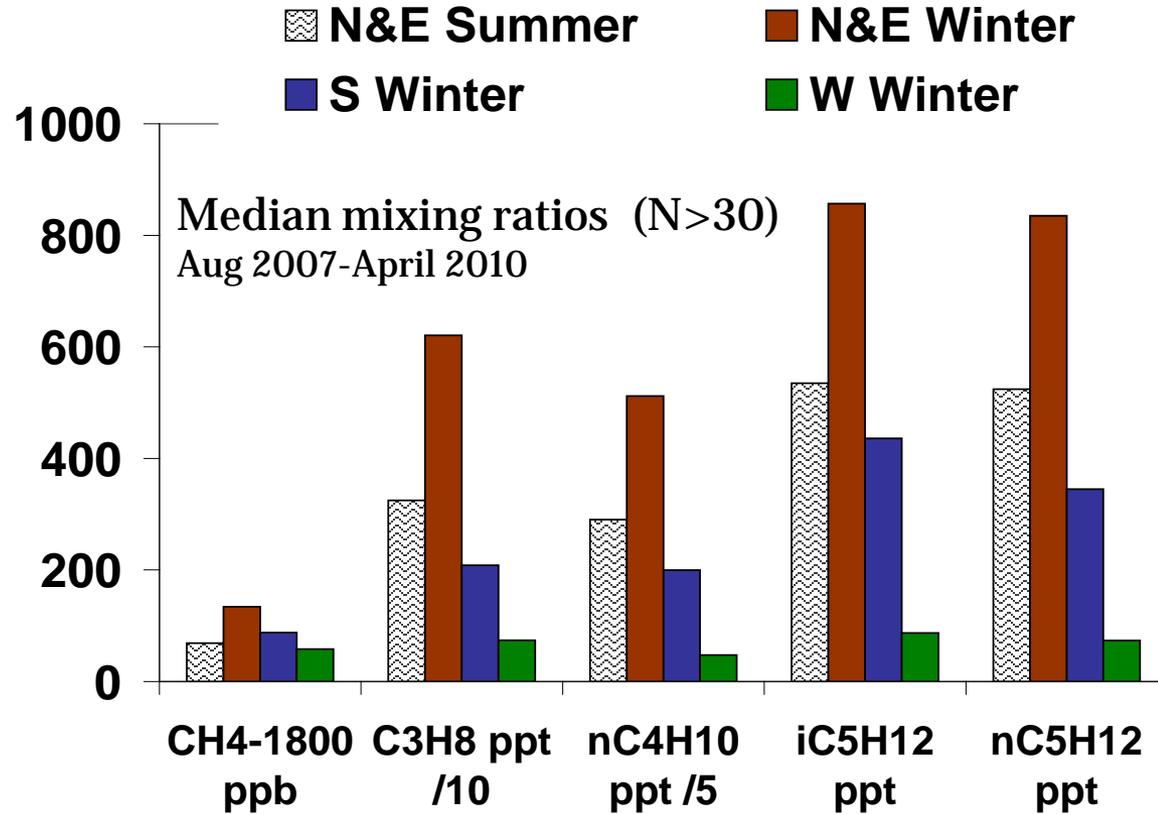
Air samples collected at the BAO and SGP* have a strong alkane signature. Both sites are in major oil and gas production regions.

* SGP is a NOAA aircraft site in Northern Oklahoma. Samples collected below 650 meters were used for this analysis. GMD aircraft program leader: Colm Sweeney.

Alkane source in N&E wind sector: Denver Julesburg Basin



Boulder Atmospheric Observatory
 - 30-sec met data at 3 vertical levels (NOAA PSD)
 - daily* midday air sample collection from 300 meter level and analysis in NOAA GMD labs



Air samples from the North and East wind sector have the strongest alkane signature (all year round), suggesting this is where the alkane source is likely located.

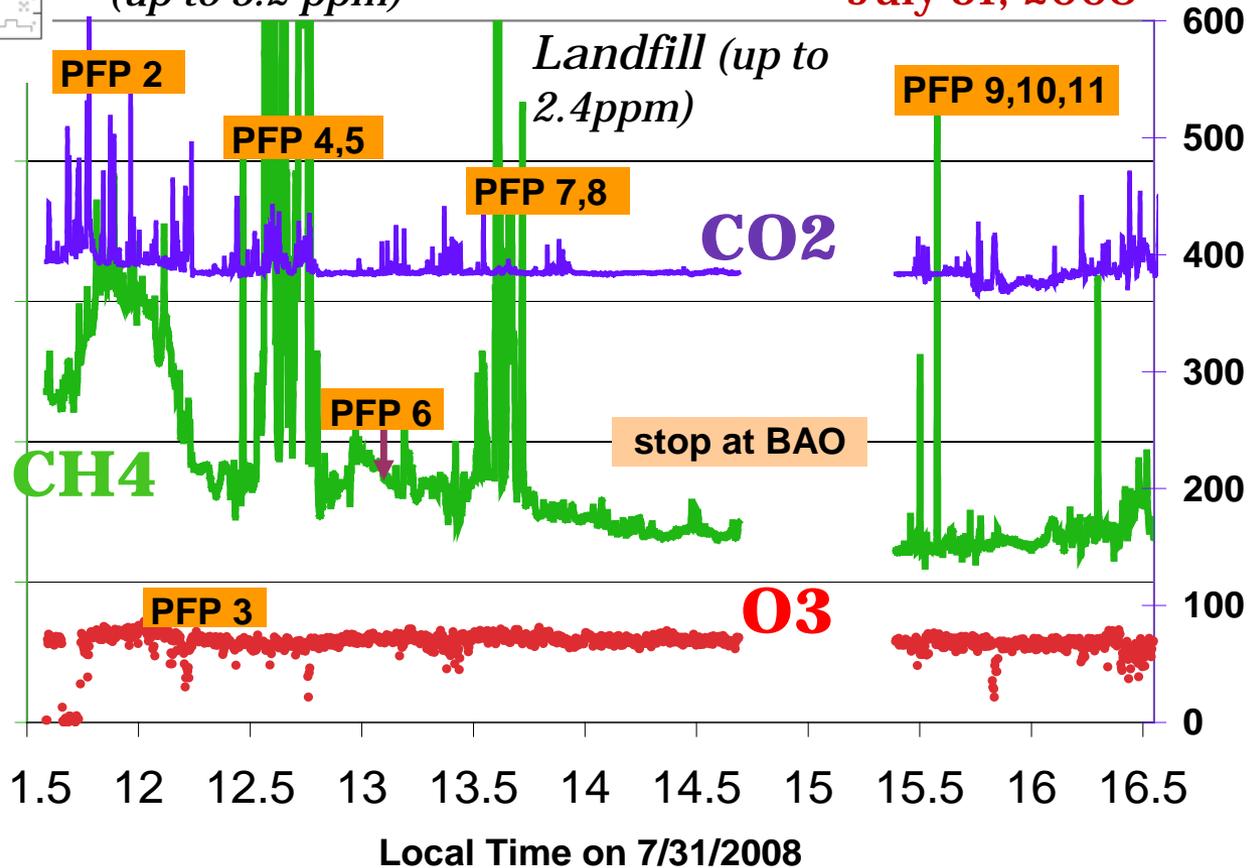
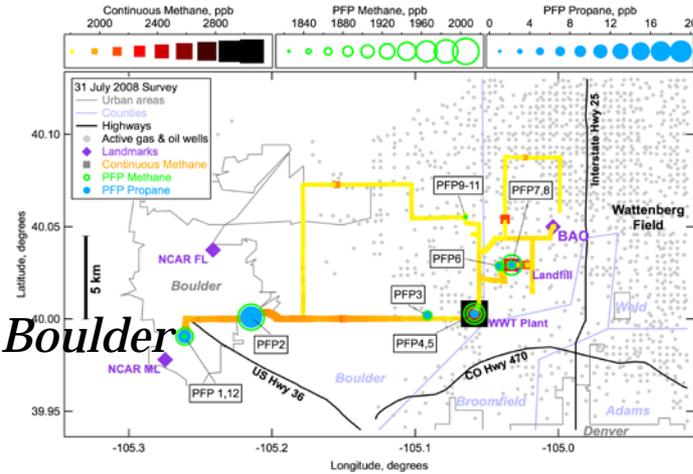
Mobile Lab intensive sampling in Front Range

Mobile Platform to sample close to sources



Waste water treatment plant (up to 3.2 ppm)

July 31, 2008



Picarro Sensor:
CO₂, CH₄, H₂O
(Colm Sweeney,
Anna Karion)

**Ozone 2B
Analyzer (Laura
Patrick)**

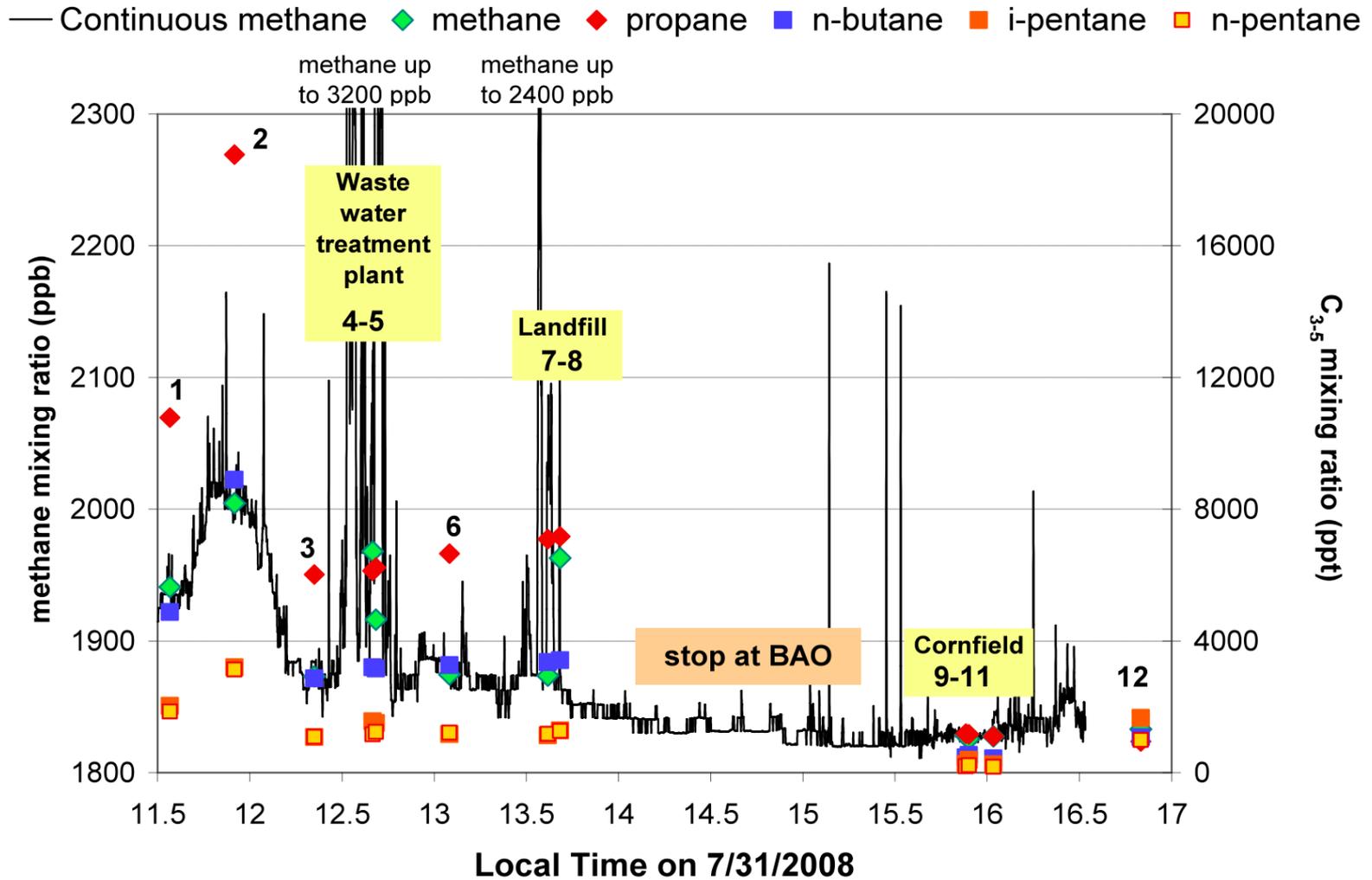
GPS

**Targeted flask
sampling on most
rives: total of 88
flasks collected over
June-July 2008**

ane

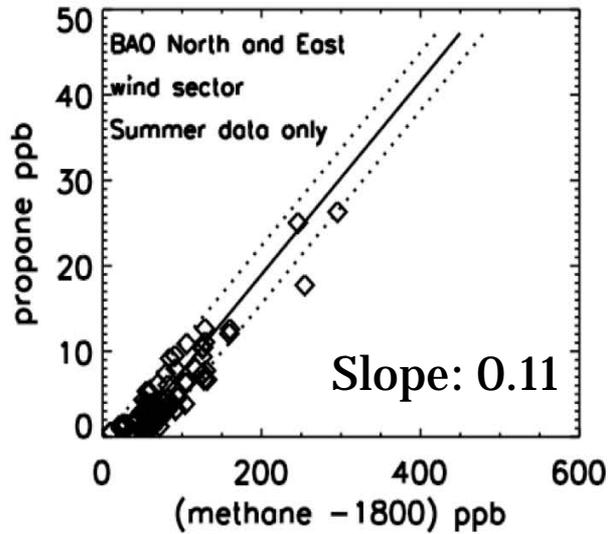
C₃₋₅ mixing ratio (ppt)

Regional alkanes enhancements vs point CH₄ sources

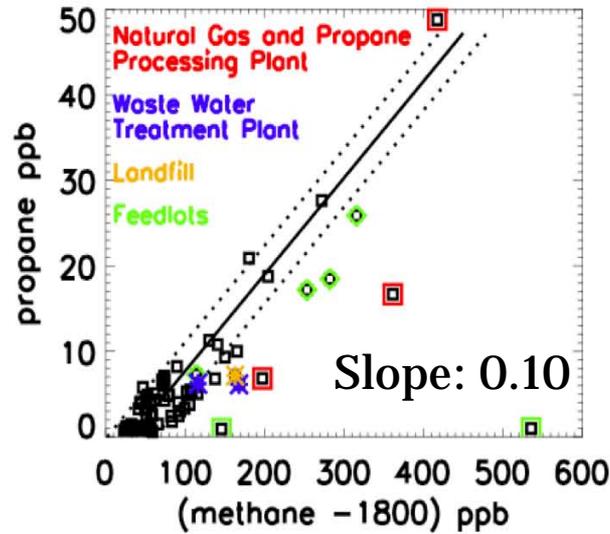


Same alkane signature at BAO and in Mobile Lab samples

BAO N&E summer

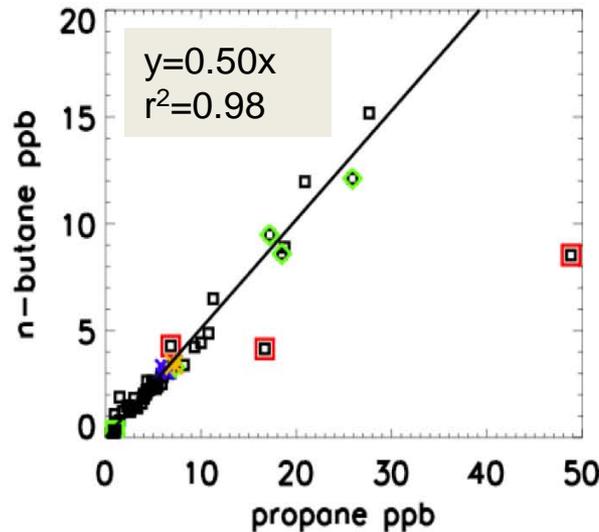
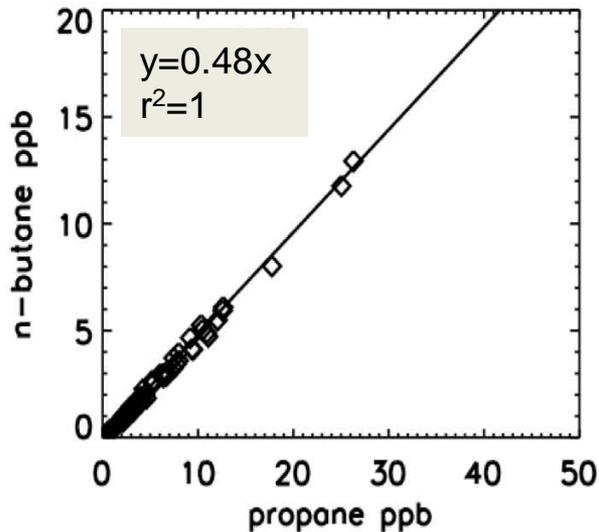


Mobile Lab

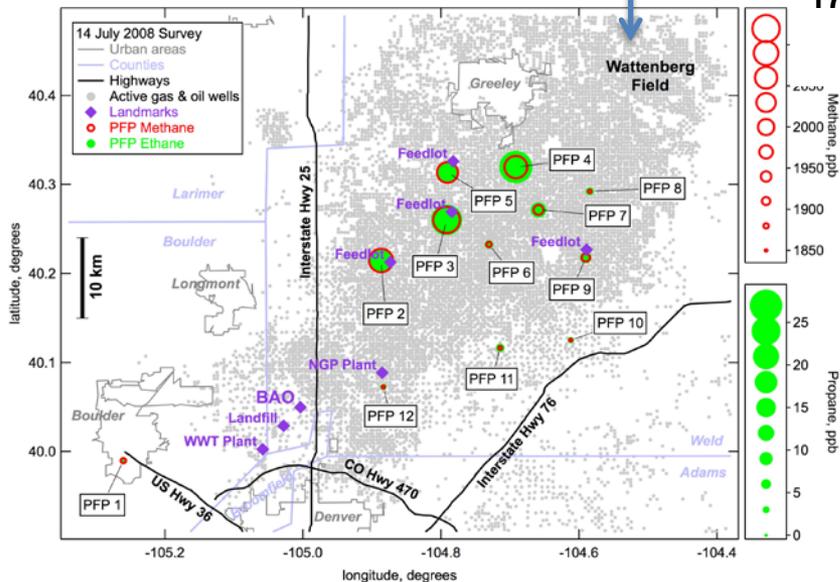
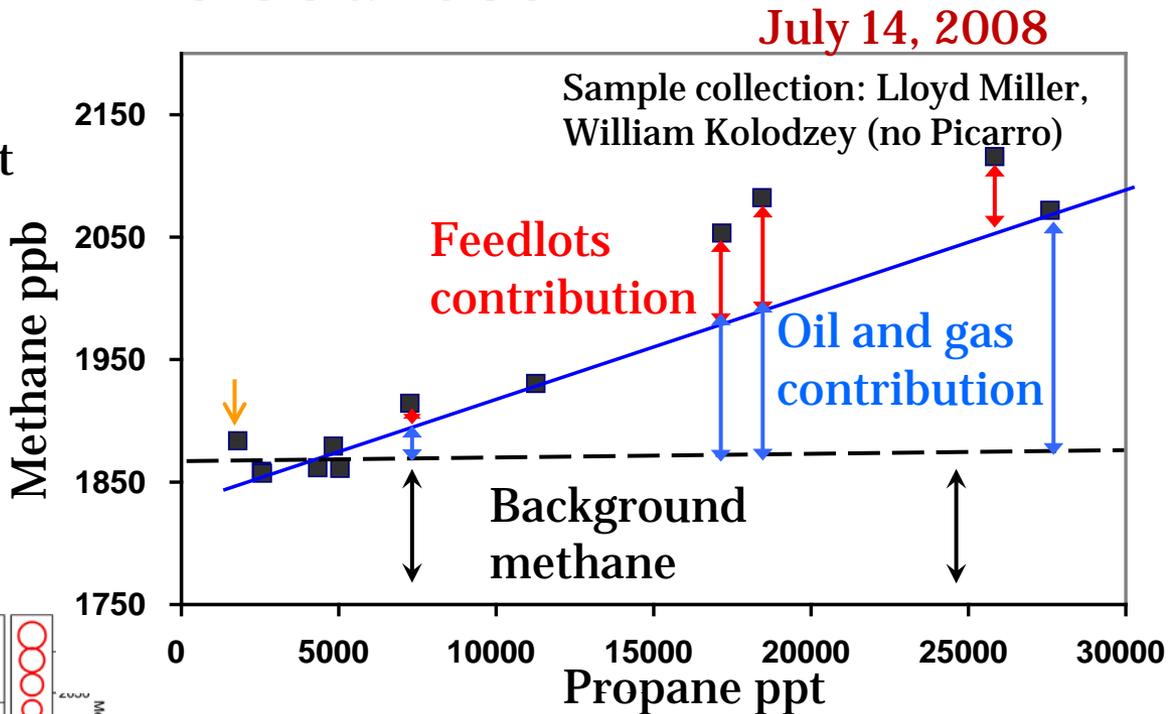
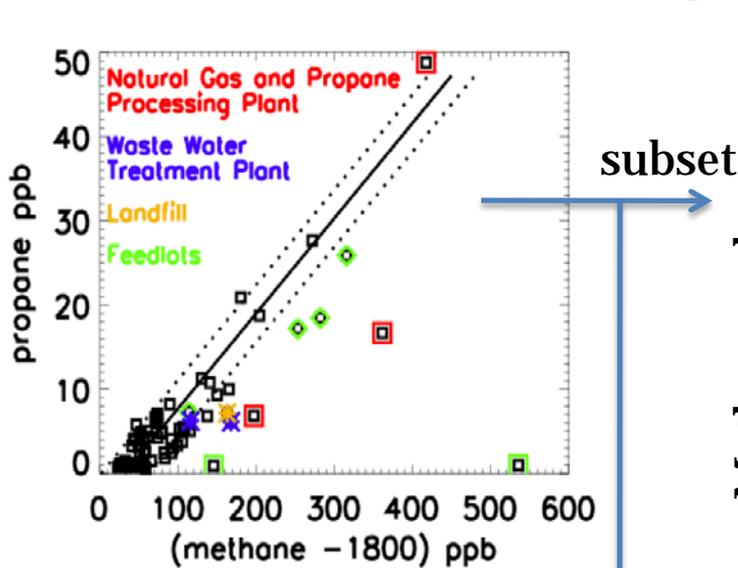


The alkanes are strongly correlated in BAO N&E wind sector samples and in Mobile Lab samples.

→ The alkanes come from the same source located in NE part of the Front Range.



Multi species analysis: Separation of various methane sources



Samples collected with the Mobile Lab close to feedlots, a landfill, and a waste water treatment plant are above the oil and gas methane-to-propane correlation line.

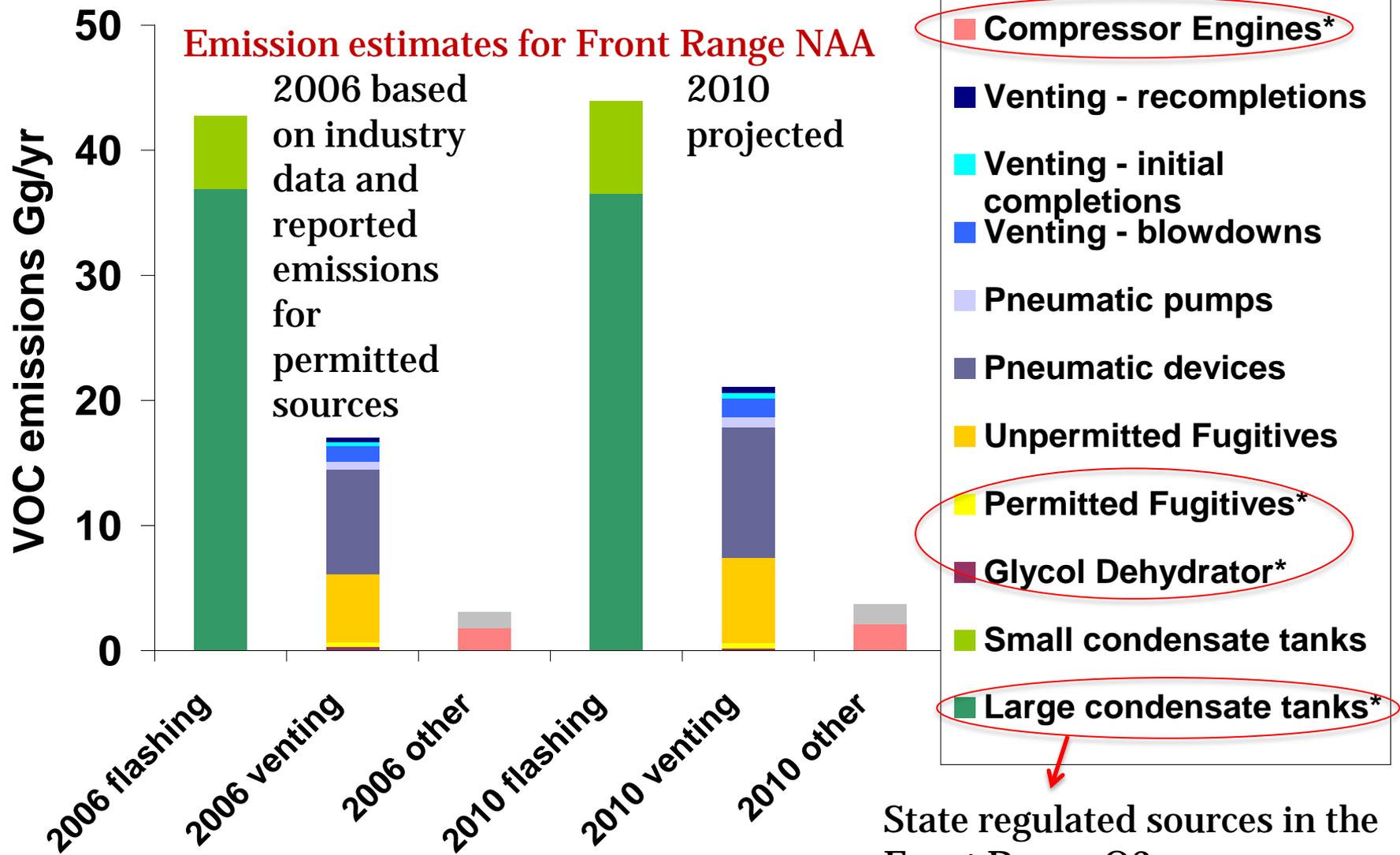
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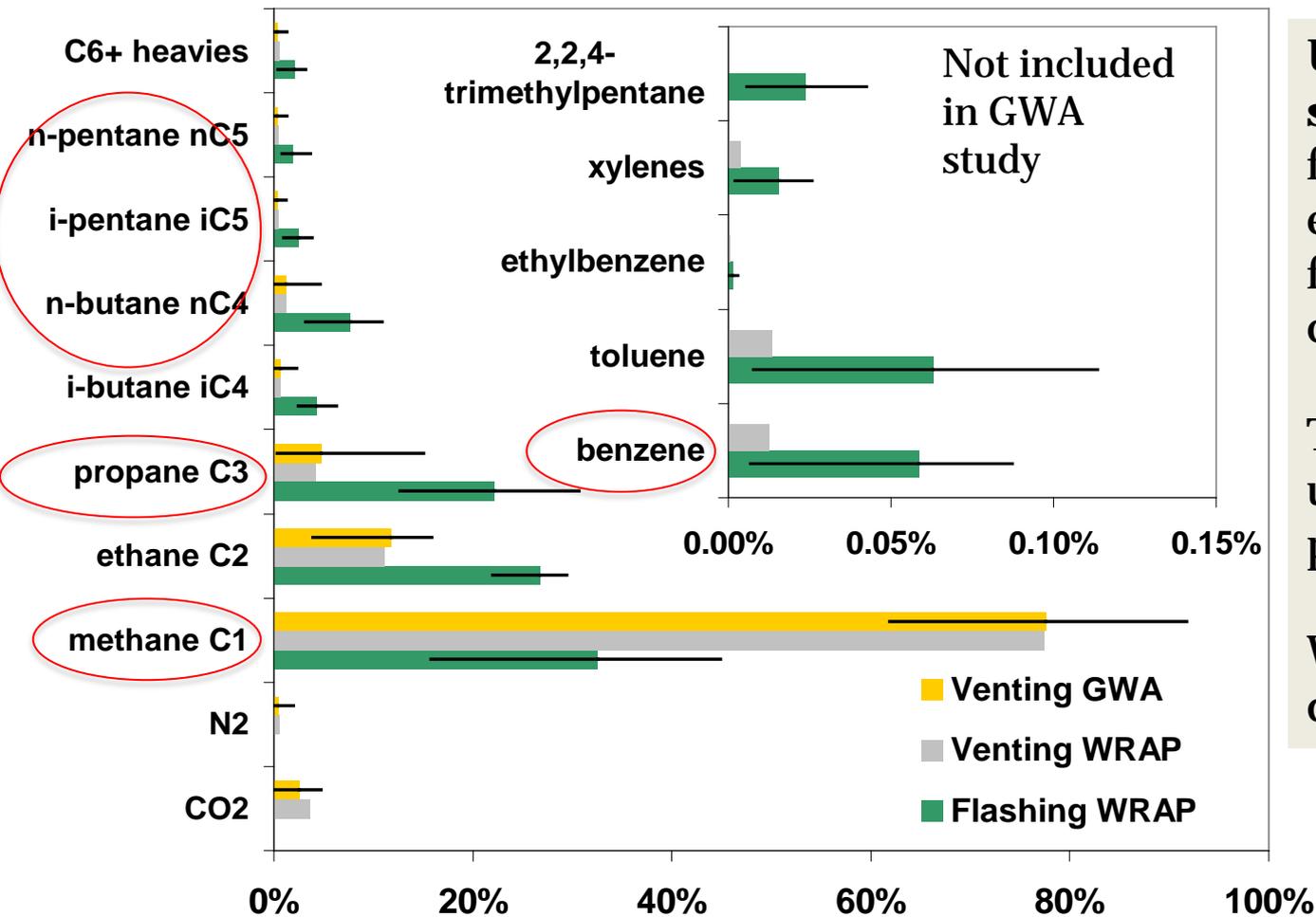
Western Region Air Partnership Oil and Gas Total VOC Inventory

Upstream and
midstream operations
only



State regulated sources in the Front Range O3 non attainment area (NAA)

Speciation profiles of raw natural gas and condensate tanks flash emissions



Used to derive **speciated** emissions for fugitive/vented emissions (raw gas) and flashing emissions from condensate tanks.

The WRAP inventory used average emission profile.

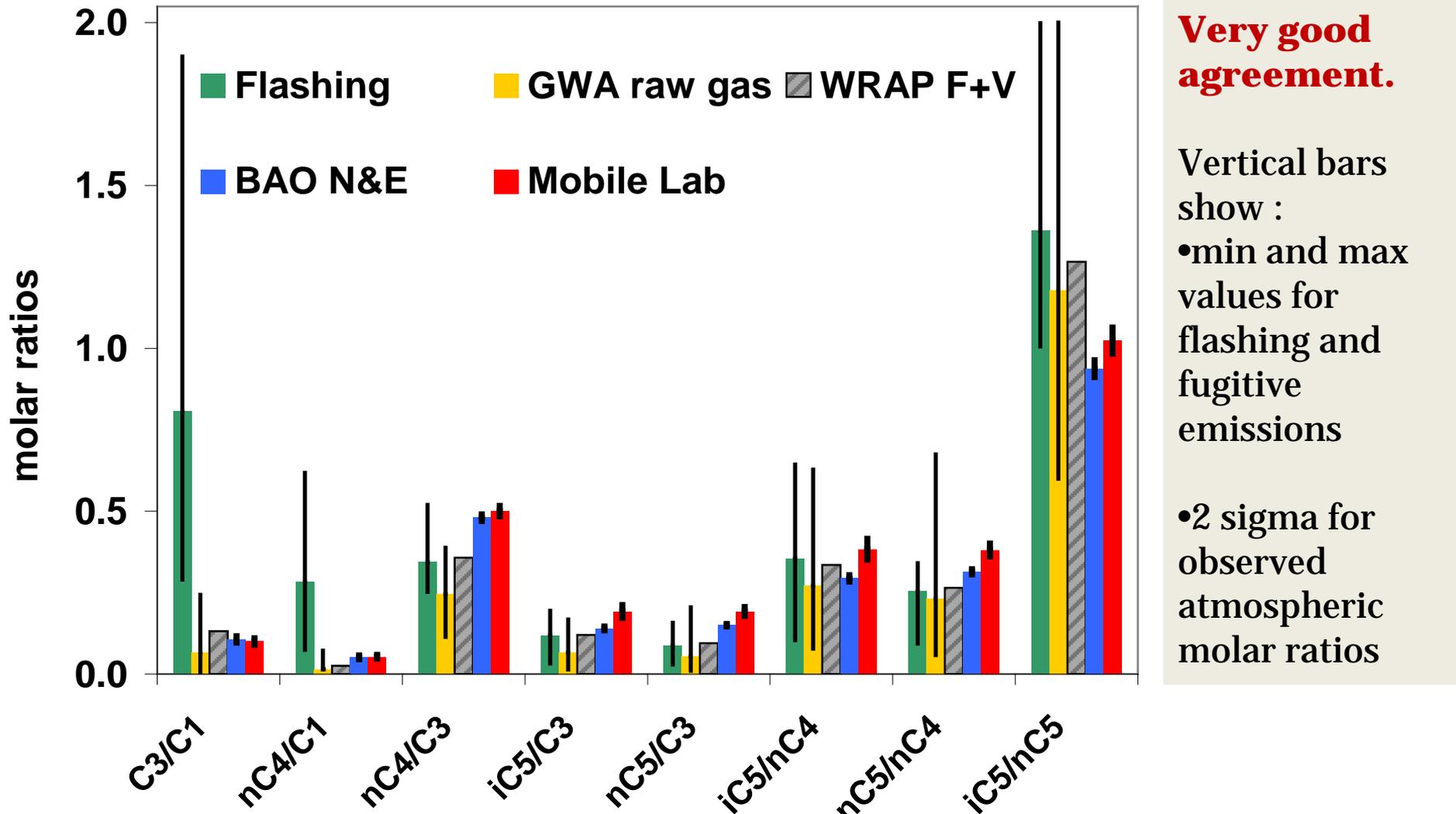
We used the entire documented range.

Venting WRAP: average of industry data for DJB (company proprietary data)

Venting Greater Wattenberg Area Study: natural gas samples from 77 wells in DJB (2006, COGCC)

Flashing WRAP: EPA TANK model output for 16 condensate tanks in DJB (2002, CDPHE)

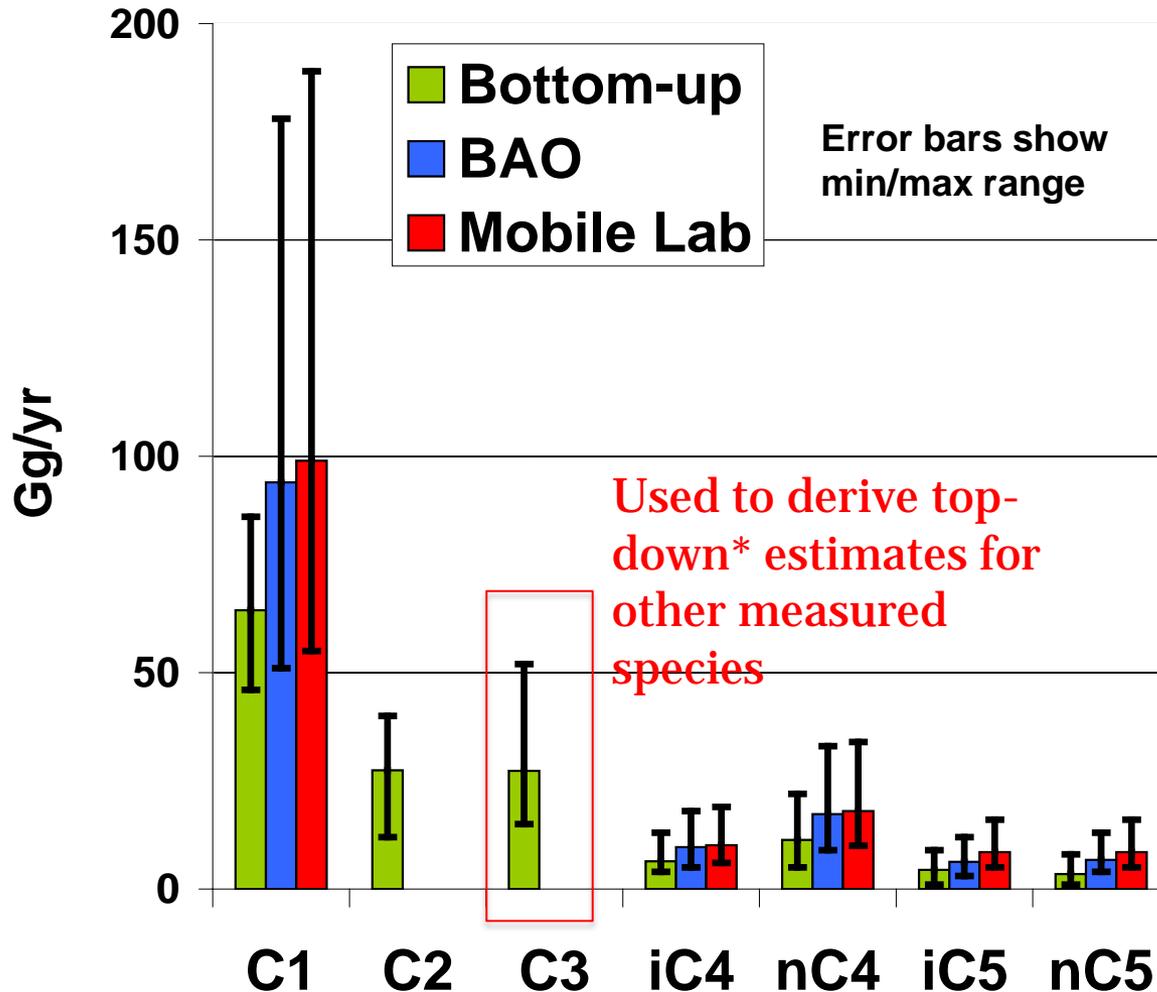
Atmospheric Molar Ratios versus Bottom-up Inventory Emission Ratios



C1: methane, C3: propane, nC4: n-butane, i or nC5: i or n-pentane, C2: ethane*

Emission estimates comparison

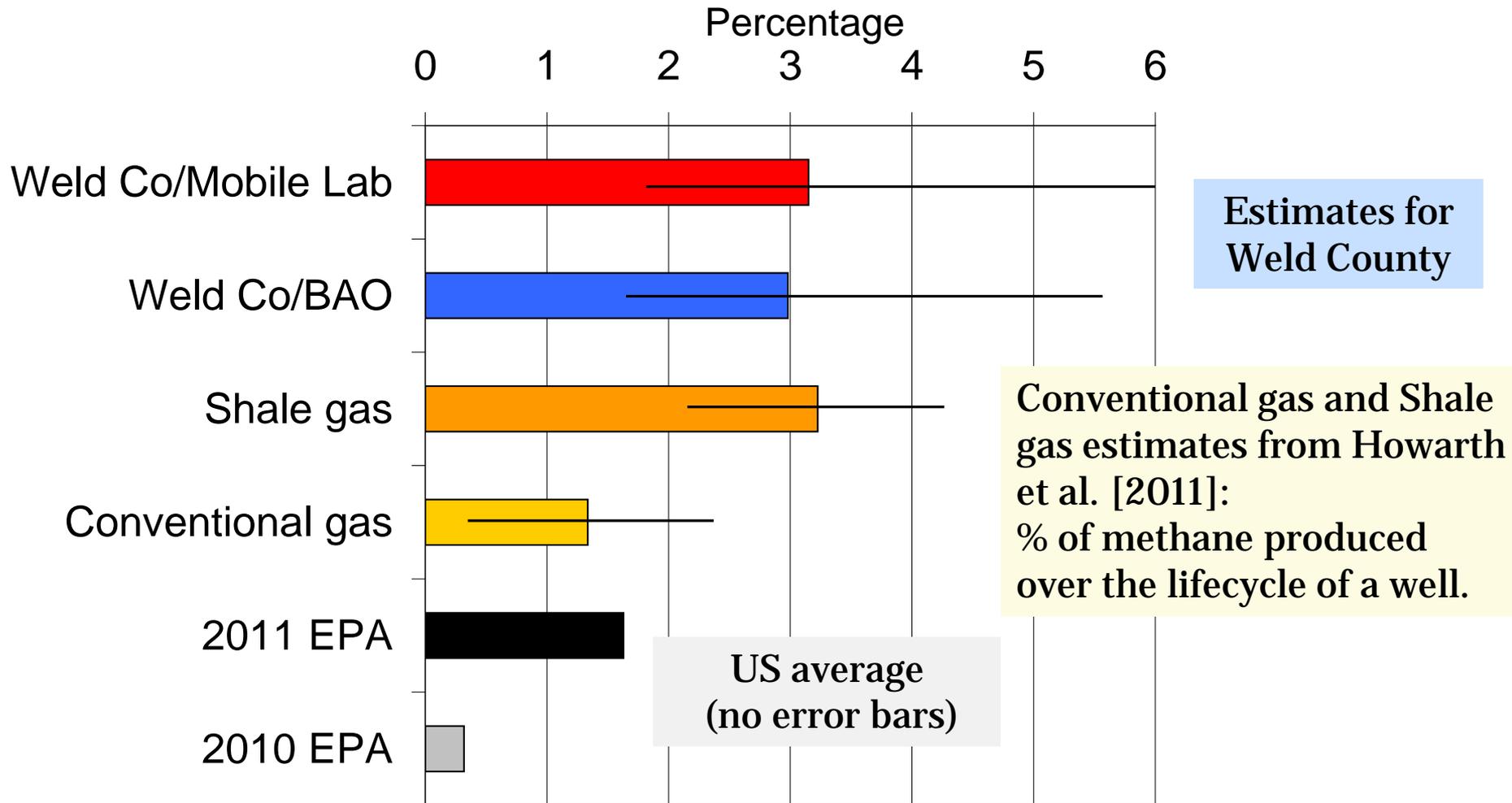
The bottom-up propane source estimate is used to derive top-down* emissions for all other species based on observed atmospheric ratios



Methane source = 1.6 to 6% of Weld County natural gas production in 2008

~ 50% discrepancy between bottom-up and top-down estimates for methane.

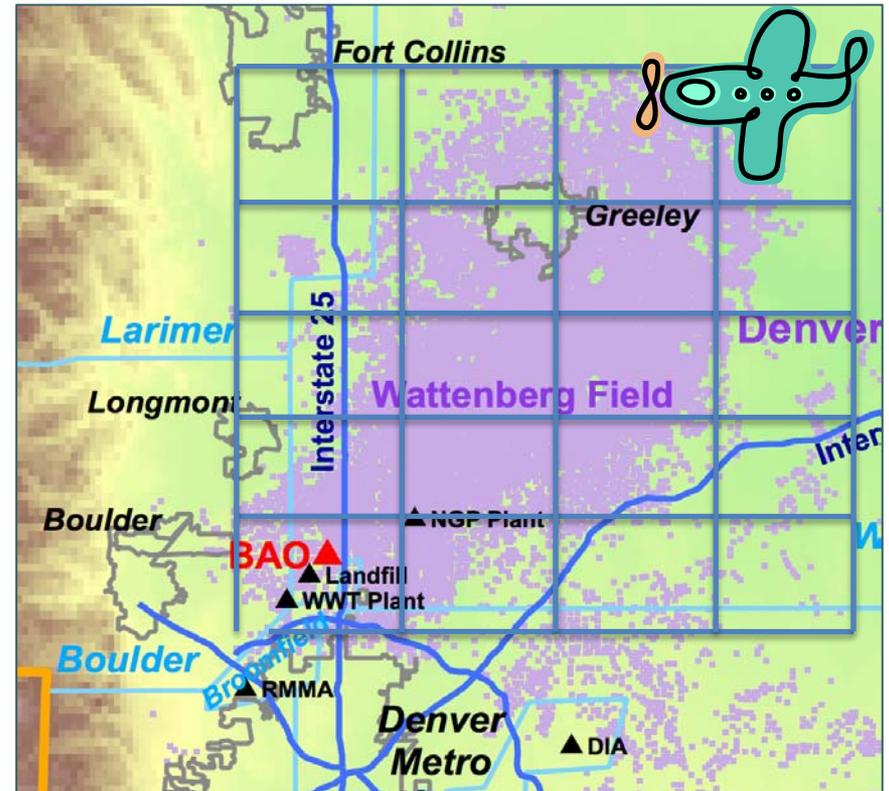
Fraction of total natural gas withdrawal vented to the atmosphere



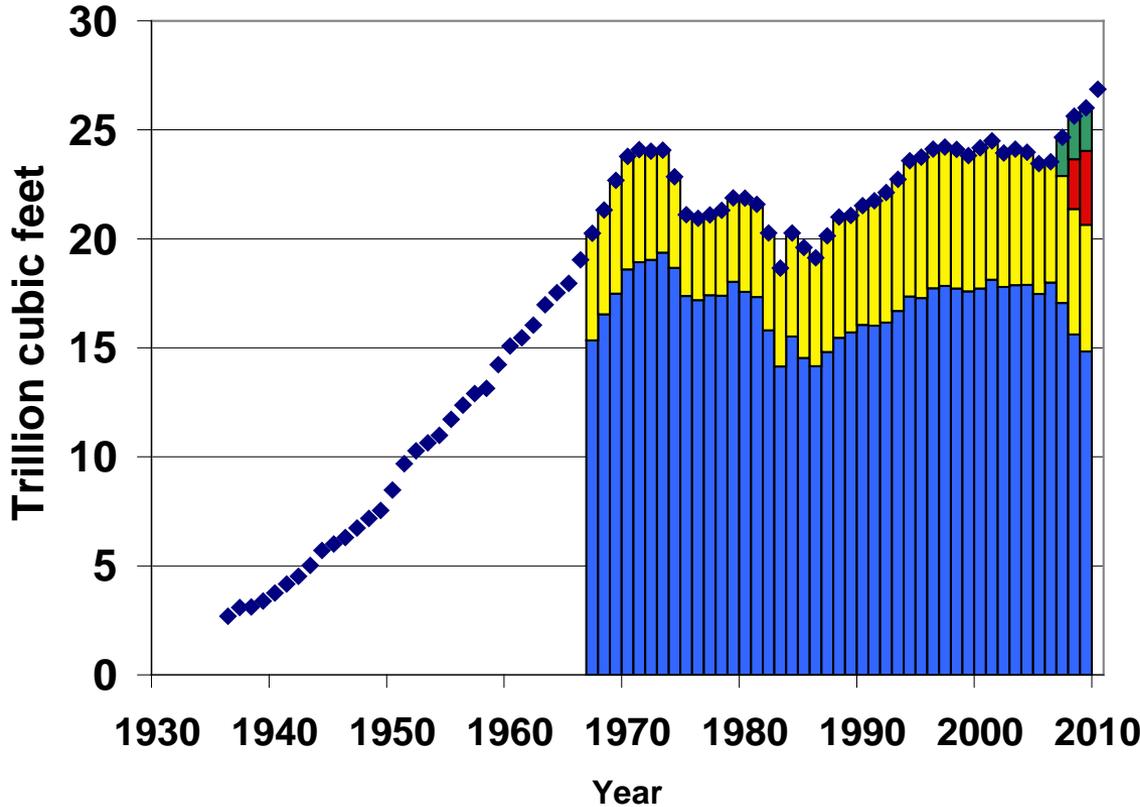
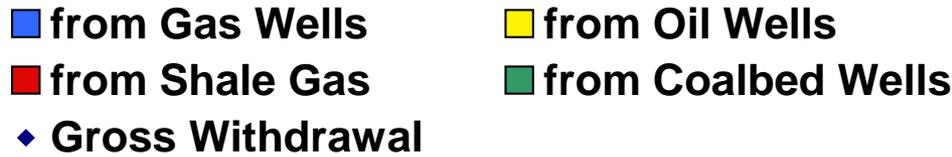
These estimates are still highly uncertain.

Conclusions

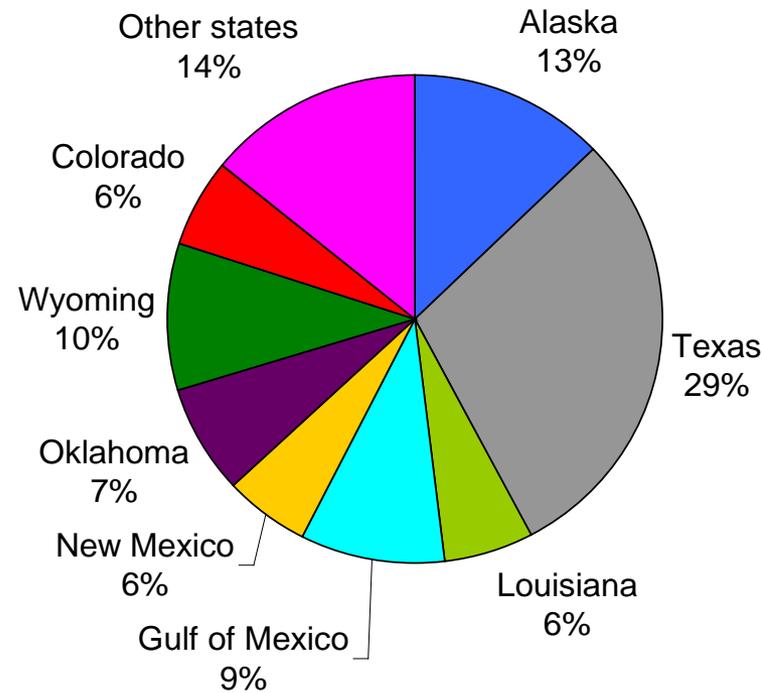
- High-quality multi-species measurements from the NOAA GMD Tower network provide unique information on regional sources of GHG and air pollutants.
- Oil and Gas operations in the Northern Front Range have a regional impact on air composition.
- Bottom-up emission inventories for oil and gas operations are quite uncertain.
- This was a study of opportunity to look at methane variability in the region.
- **Next possible steps:**
 - Aircraft and Mobile Lab mapping of the region to derive absolute fluxes
 - Active chemistry study



Natural Gas Production in the US since 1936

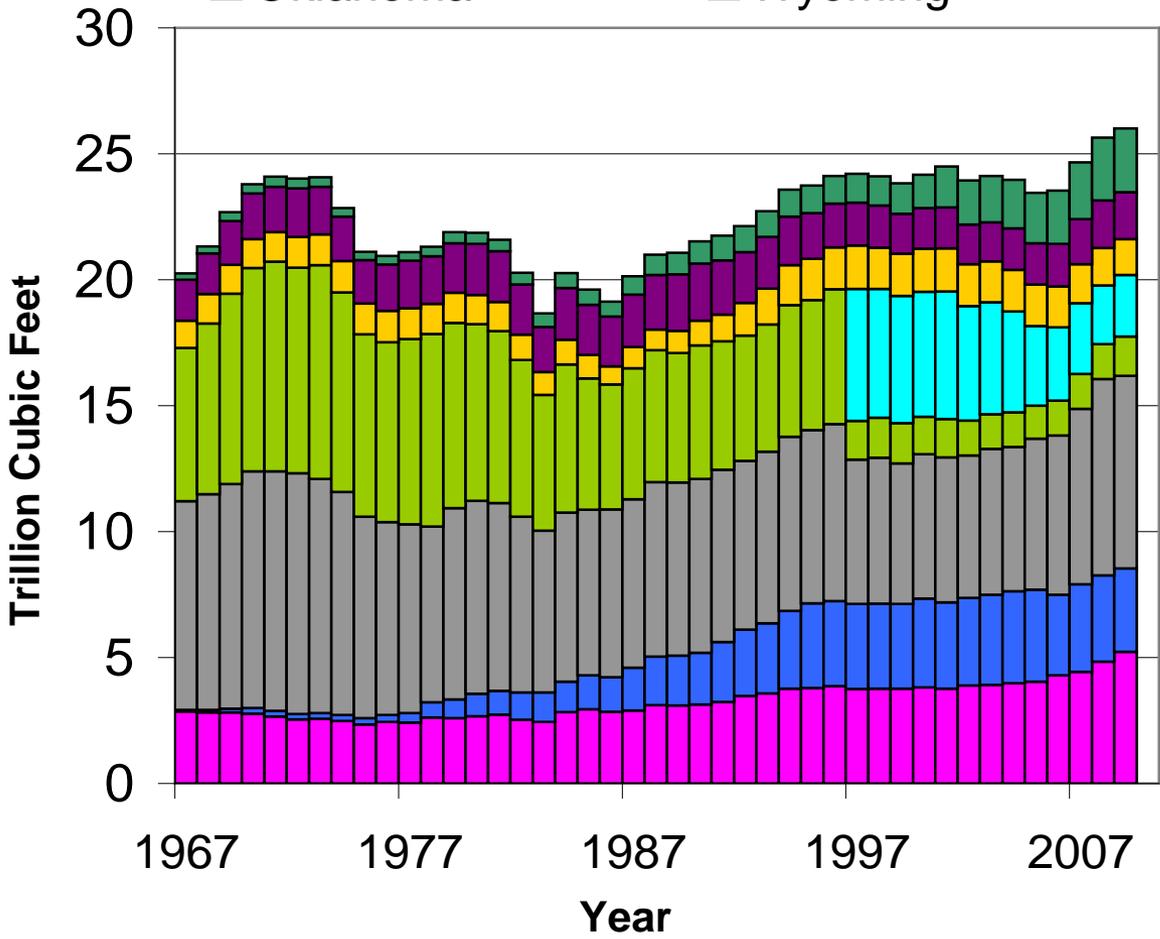
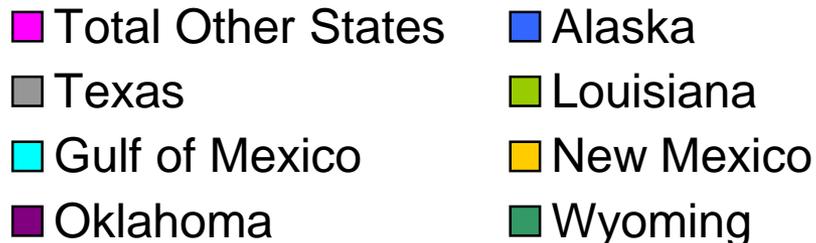


2009 breakdown of production by state



2009 natural gas production in the US = 19.5% of world production
 2010 US Total Production = 26.8 Trillion cubic feet (Tcf)
 From shale gas=3.4 From Coalbed= 2.0
 2010 US Consumption = 24.1 Tcf

Natural gas gross withdrawal by state



2009 Breakdown

