Estimation of emissions from oil and natural gas operations in northeastern Colorado

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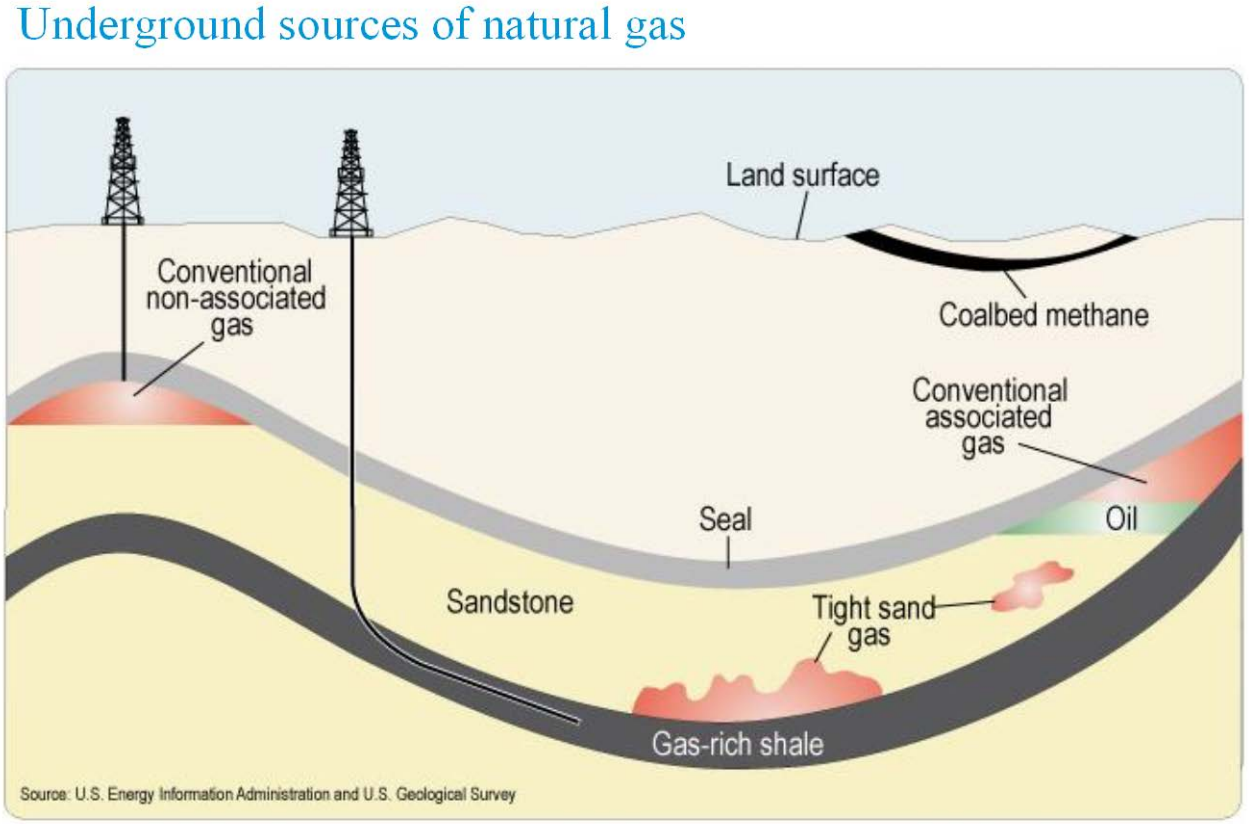
Outline

- Background information
  - natural gas and oil production
- Upstream Methane Emission Estimations
  - Bottom-up "engineered" inventories
  - Top-down evaluation
    - Denver-Julesburg Basin, Colorado northern Front Range
    - Uintah Basin, northeastern Utah
- Conclusion

Background information on natural gas

Part of the Jonah natural gas field, Wyoming

Conventional and unconventional gas



Source: modified from U.S. Geological Survey Fact Sheet 0113-01

Conventional natural gas deposits have been the most practical and easiest deposits to mine

Unconventional gas refers to gas that is more difficult or less economical to extract.

Extraction in the unconventional low permeability formations requires hydraulic fracturing.

Unconventional resources around the world

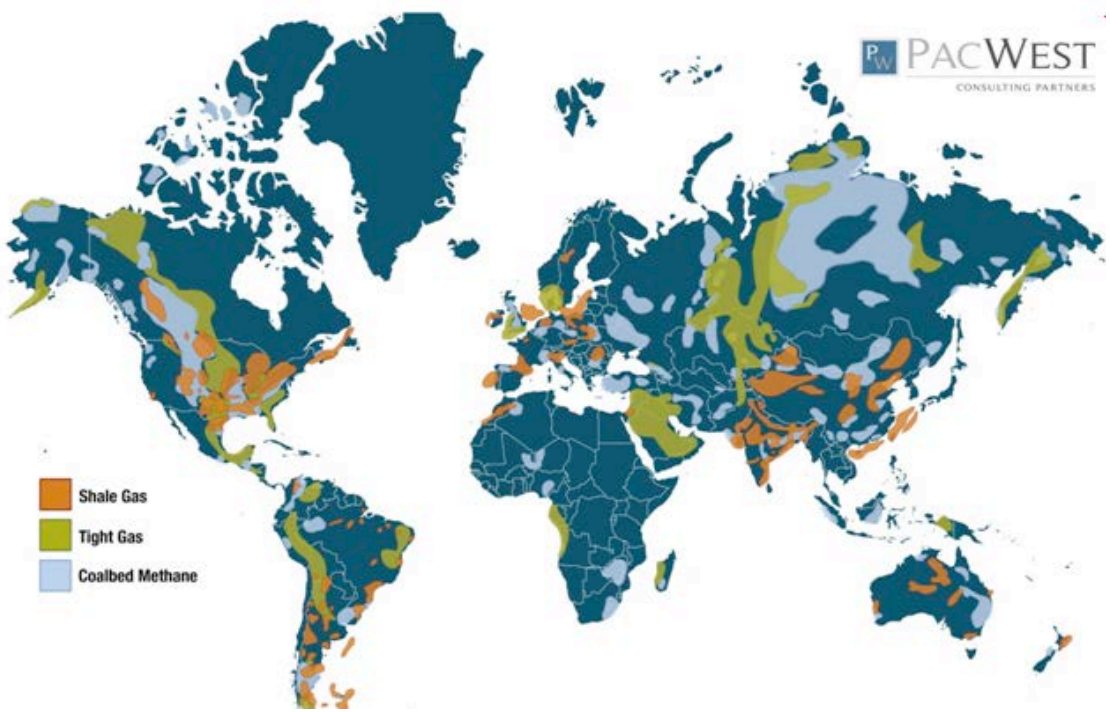
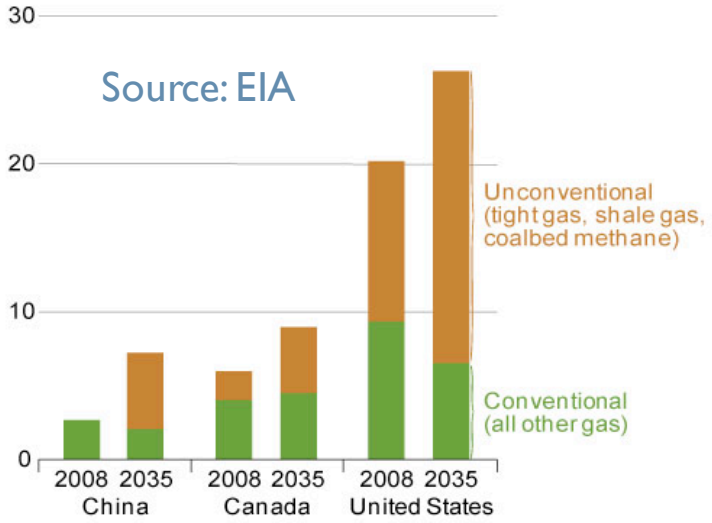
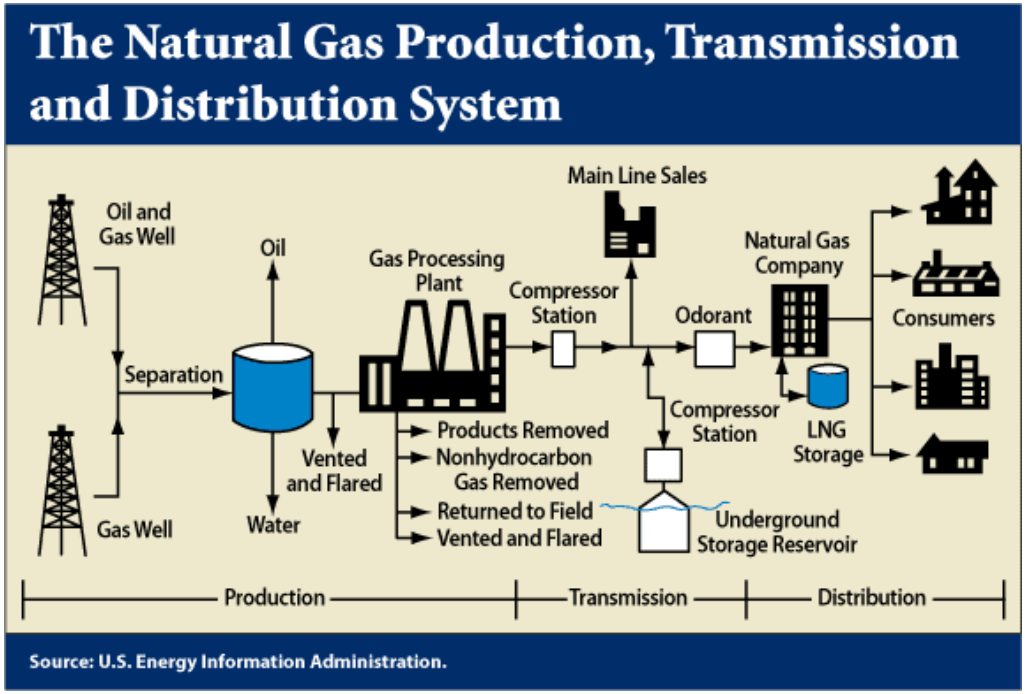


Figure 42. Natural gas production in China, Canada, and the United States, 2008 and 2035
(trillion cubic feet)

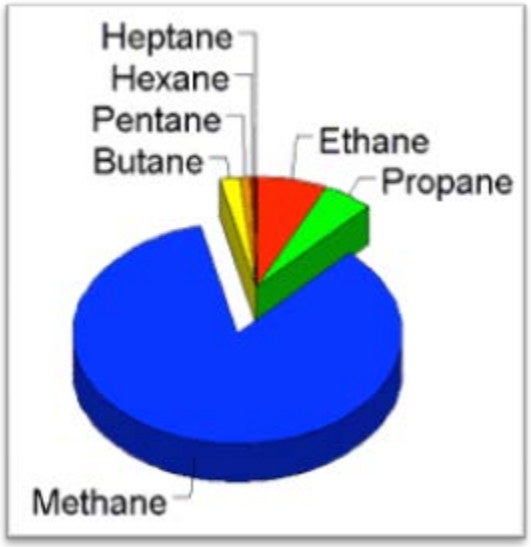


Unconventional resources will play a bigger role worldwide in the next decade and beyond.

From Well to Furnace

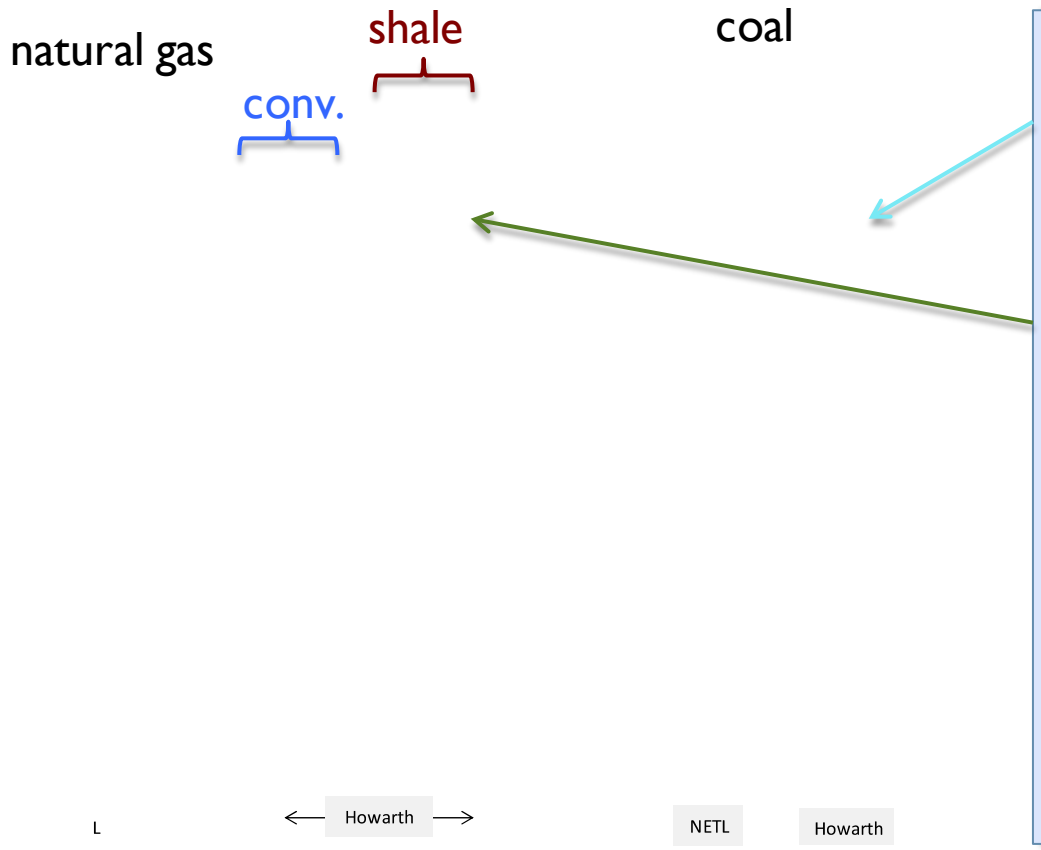


Raw gas composition



Raw natural gas is ~ 80% methane.
It will contain varying amounts of higher alkanes (saturated hydrocarbons C_nH_{2n+2}). Raw natural gas also contains water, acids (CO_2, H_2S), and BTEX (benzene, toluene, ethylbenzene, xylenes (hazardous air pollutants).

Life Cycle Assessment of Gas versus Coal



Gas burns cleaner than coal.

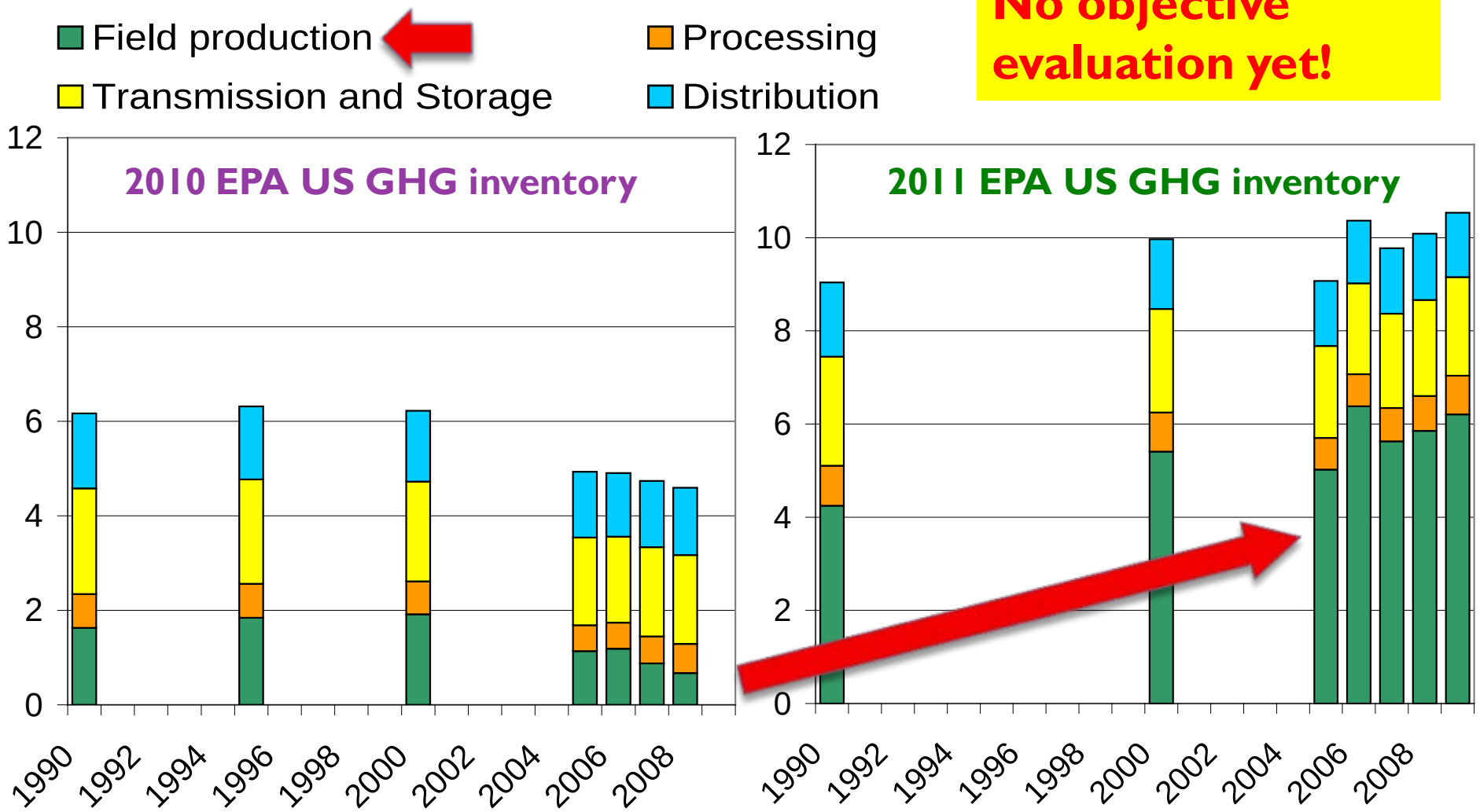
However natural gas extraction is accompanied by fugitive emissions of methane, which has a 100 yr GWP of 25.

How well do we know methane emissions from natural gas systems?

Source: Fulton et al. (2011)

US Methane emissions (Tg) from natural gas systems
Impact of change in methodology

No objective evaluation yet!

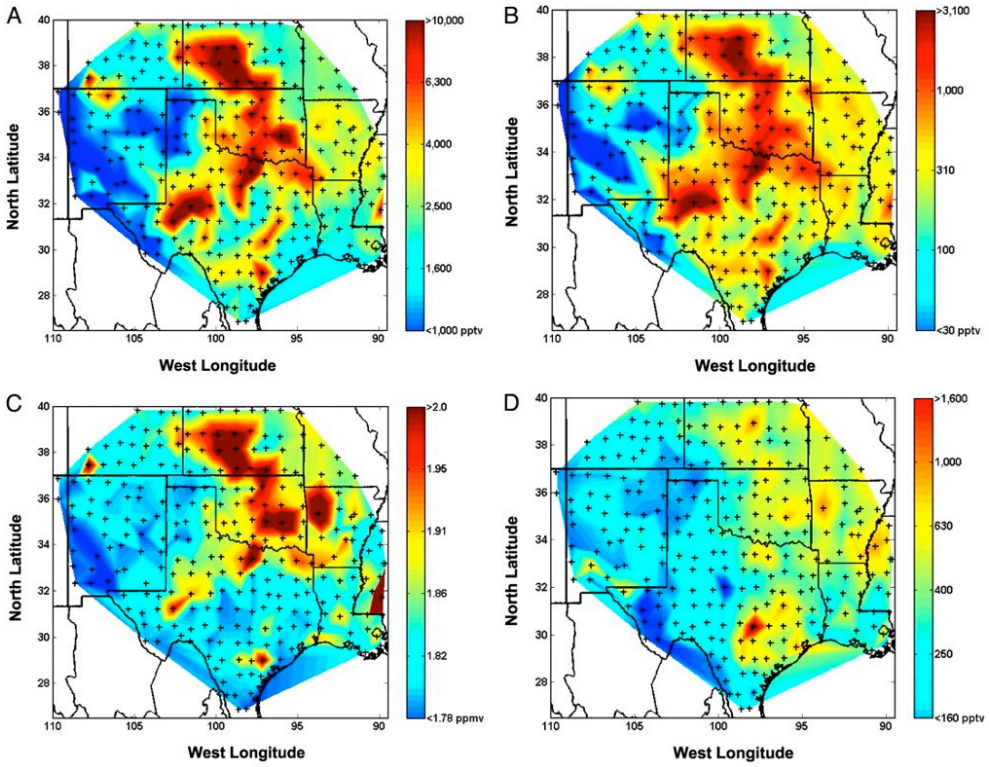


2009 Methane emission estimates:

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. Total reported uncertainty of 19%.

Atmospheric Impacts of Oil and Gas Extraction

Surface-level mixing ratios of ethane (A), n-butane (B), methane (C), ethyne (D) in the southwestern United States, April 28–May 3, 2002.



Katzenstein A. S. et al.,
Extensive regional atmospheric hydrocarbon pollution in the southwestern United States,
PNAS 2003;100:11975-11979

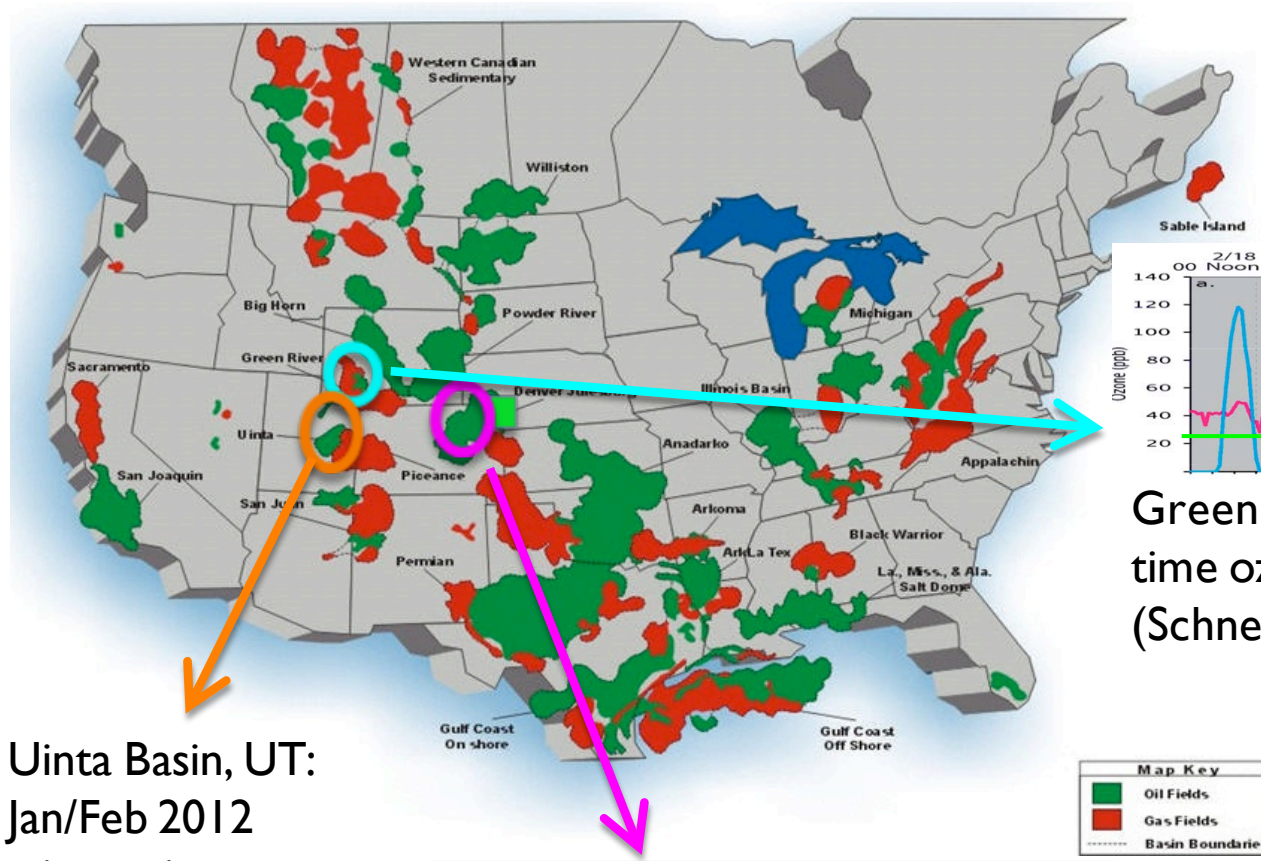
261 flasks were collected by 8 group members on a 80x80 km grid in 2002.

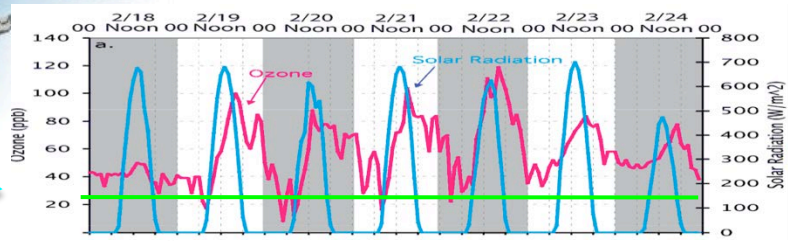
"Based on CH_4 mixing ratio enhancements integrated within the 2002 study area, a boundary layer height of 1 km, and a ventilation time of 2–3 days from the study area, a CH_4 emission estimate of 4 – 6 teragrams (Tg) per year is obtained. These calculations assume a constant emission of alkanes from the study area (720 x 820 km)."





Past and Ongoing Studies in Western US Oil and Gas Fields



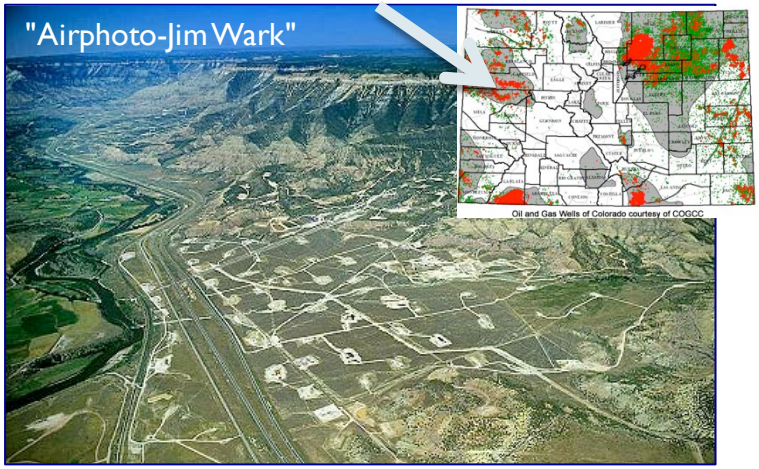


Green River Basin, WY: high winter time ozone in natural gas field (Schnell et al., Nature, 2009)

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

CO Northern Front Range ozone non attainment area: Hydrocarbon emissions from oil and gas operations in 2008 in Weld County (Pétron et al., 2012)

Potential Health Impacts of Natural Gas development



Oil and gas well pads in Garfield County

MCKenzie et al.,
Human health risk assessment of air emissions from development of unconventional natural gas resources, Sci Total Environ (2012)

Ambient air samples every 6 days 2008-2010.
64 samples near new wells being completed

- Residents living ≤1/2 mile from wells are at greater risk for health effects from NGD than are residents living >1/2 mile from wells. Subchronic exposures to air pollutants during well completion activities present the greatest potential for health effects.
- The subchronic non-cancer hazard index (HI) of 5 for residents ≤1/2 mile from wells was driven primarily by exposure to trimethylbenzenes, xylenes, and aliphatic hydrocarbons.
- Cumulative cancer risks were 10 in a million and 6 in a million for residents living ≤1/2 mile and >1/2 mile from wells, respectively, with benzene as the major contributor to the risk. "

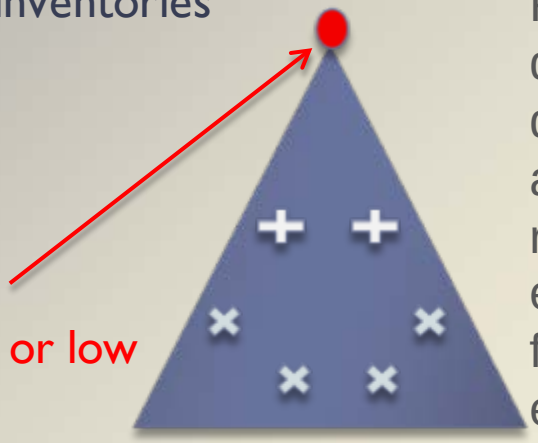




How inventories are built?

Regulatory or research bottom-up emissions inventories

- Sector specific/process specific
- Time specific
- Not always speciated (total VOCs)
- Regional or global scales
- Uncertainty estimates usually non-existent or low
- Rarely up-to-date



Relies on high quality activity data (routine and non routine), emissions factors, estimates of control effectiveness …

French: "La cerise sur le gateau"

English: "Icing on the cake"

Example of data used to build inventory

Number of wells drilled
Number of compressor stations
Miles of pipelines
Types/number of pneumatic devices
Production data
Emissions factors
Gas composition

Can we evaluate CH_4 emission inventories at the global, regional and local scales?

Research atmospheric measurements and modeling

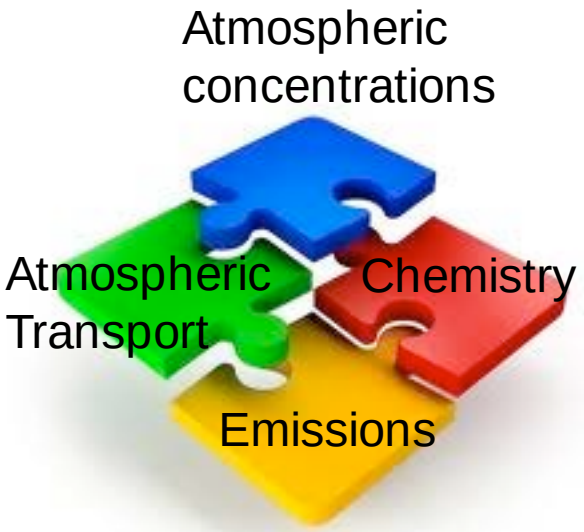
- Sector specific (multi-species)
- Time specific
- Speciated (VOCs)
- Regional or global scales
- Wide range of uncertainties

Relies on high quality atmospheric measurements of trace gas enhancements and measurements or modeling of the atmosphere mixing and wind characteristics

Balancing the atmosphere's budget

Emissions

Top-down: From mixing ratios to emissions



Top-down evaluation methods

1. Atmospheric enhancement ratios versus emissions ratios
   - *Tall Tower and Mobile Lab sampling and multiple species analysis*
2. Mass-balance "box" calculation
   - *Aircraft plume sampling with wind and mixing height measurements*
3. Inverse modeling (not covered in this talk)
   - *NOAA CarbonTracker-CH_4*

Top-down Emissions Evaluation # 1

2008-2009

Tall tower measurements

&

Surface measurement intensive in:

- Denver Julesburg Basin

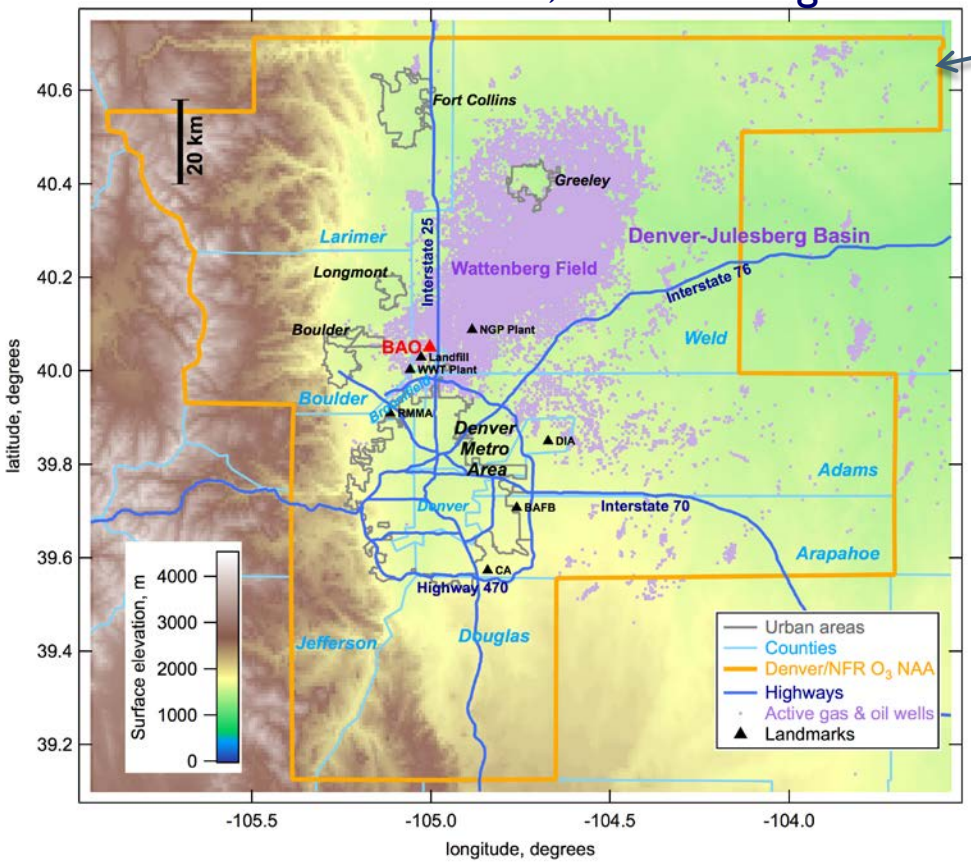
Winter/Spring 2012

Airborne and surface measurement intensive in:

- Uintah Basin
- Denver Julesburg Basin

Colorado Northern Front Range

~20,000 oil and gas wells



Most oil and gas E&P operations have been regulated so far at the state level.
New EPA rule into effect by 2015.

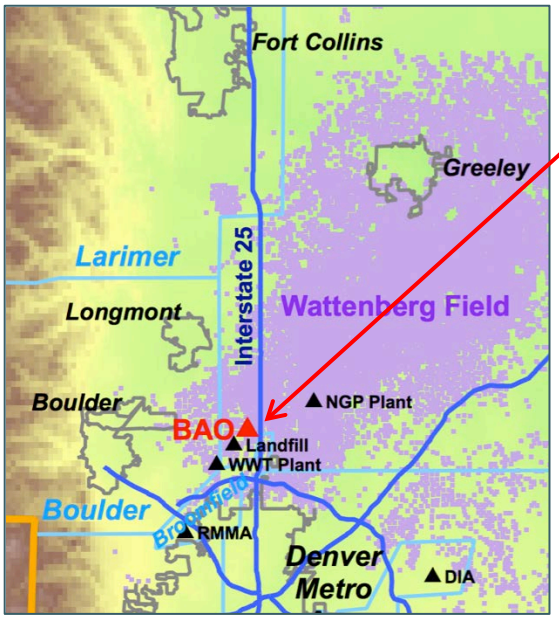
- http://www.epa.gov/airquality/oilandgas/

Denver Metropolitan Area/ Northern Front Range ozone non attainment area (designated 2007): Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas, Jefferson, Larimer, Weld Counties.

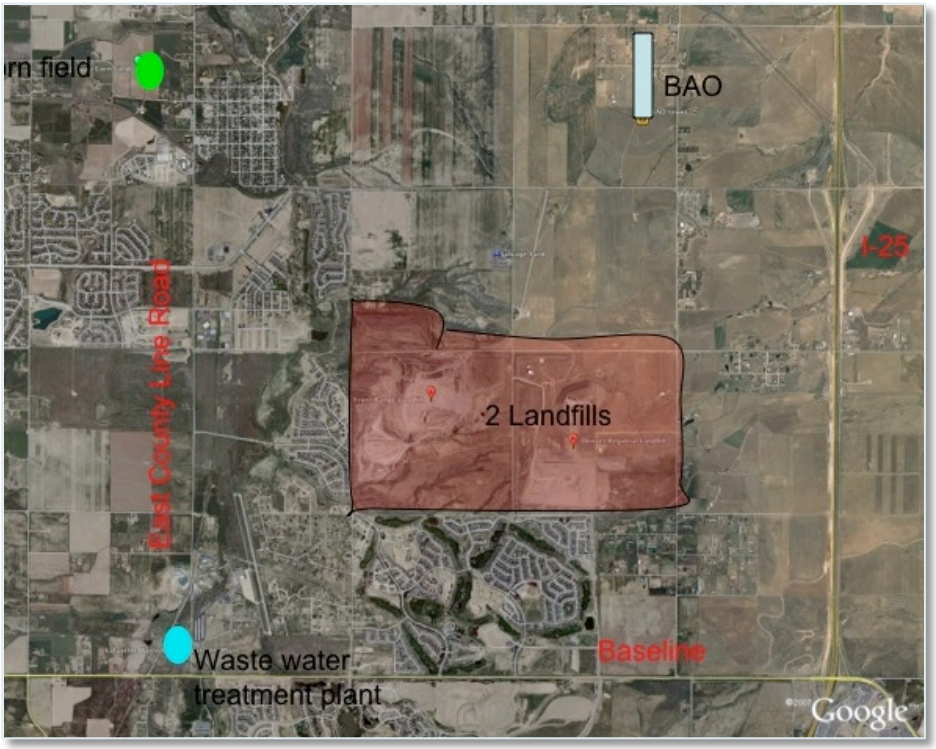
Colorado Front Range Ozone NAA Regulation 7:
Control of Ozone via Ozone Precursors
Oil and Gas VOC emissions

- Condensate Tanks controls:
  - 47.5% summer 2006
  - 75% summer 2007 and 2008
  - 81% summer 2009
  - 85% summer 2010
  - 90% summer 2011, 2012
  - 70% rest of the time
- Most high-bleed pneumatic

Boulder Atmospheric Observatory

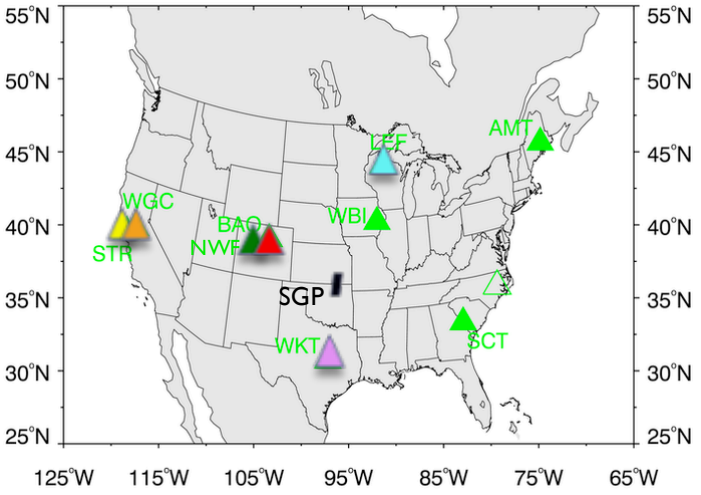


- 300 meter tall tower
- located in Erie, Weld County
- Instrumented with LICOR (CO_2) and TECO (CO) in April 2007: sampling from 3 intake heights (22m, 100m, 300m)
- 30 sec- Met Data at three levels
- Equipped to collect discrete air samples from 300 meter level in August 2007. Analyses performed in NOAA Boulder lab.

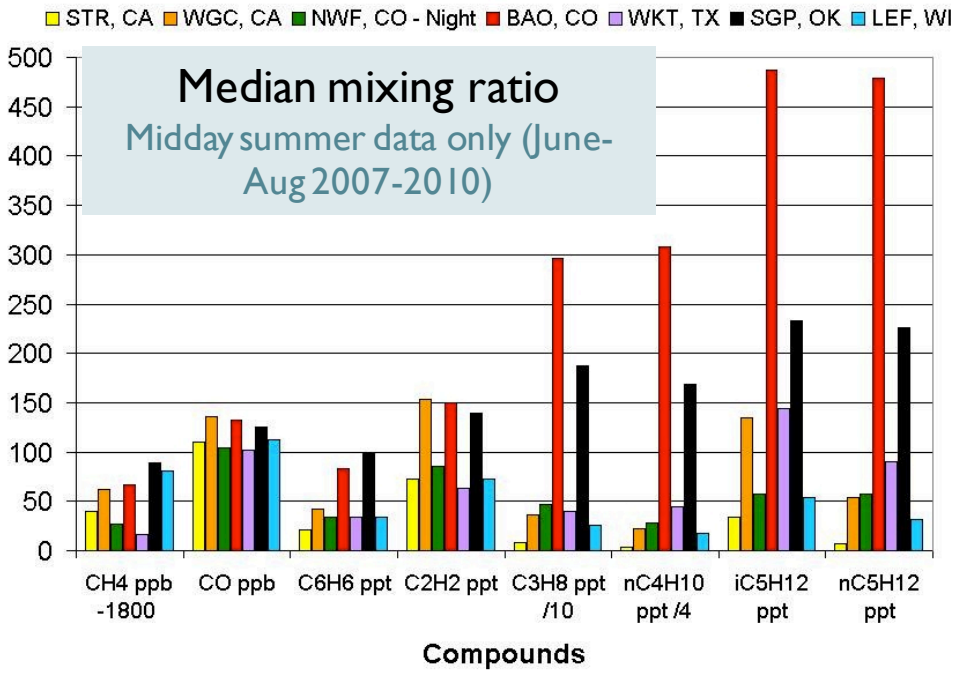


http://www.esrl.noaa.gov/gmd/ccgg/towers/index.html

BAO: Distinct Alkane Signature



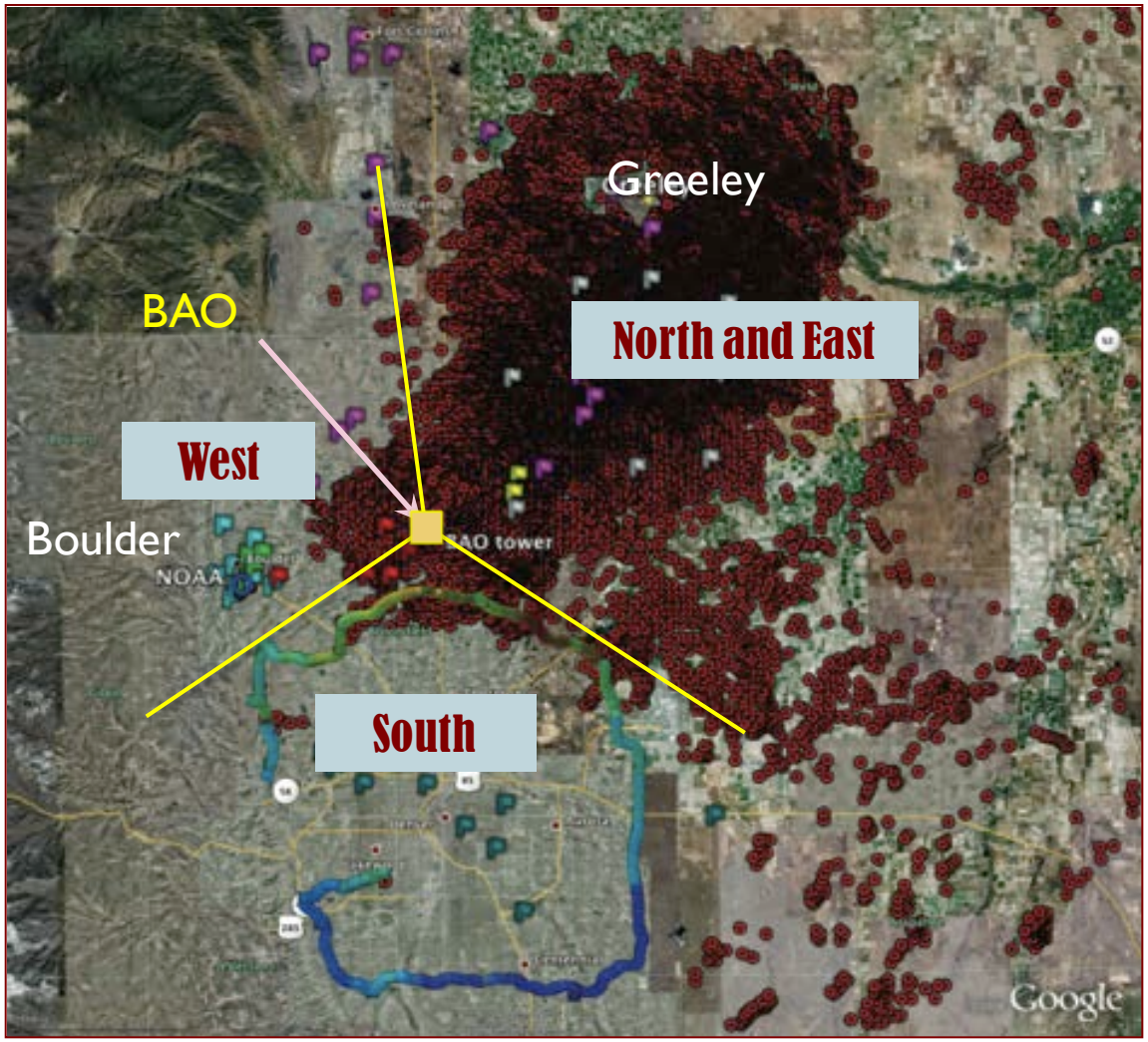
NOAA Tall Tower Measurement and Sampling Network (PI Arlyn Andrews)



Air samples collected at the BAO and SGP* have a strong alkane signature.

* SGP is a NOAA aircraft site in Northern Oklahoma. Samples collected below 650 meters were used for this analysis.

BAO: Filtering Data By Wind Sector



North and East

Weld County
Oil and Gas operations
Farming + Cattle Feedlots
I-25
Small towns

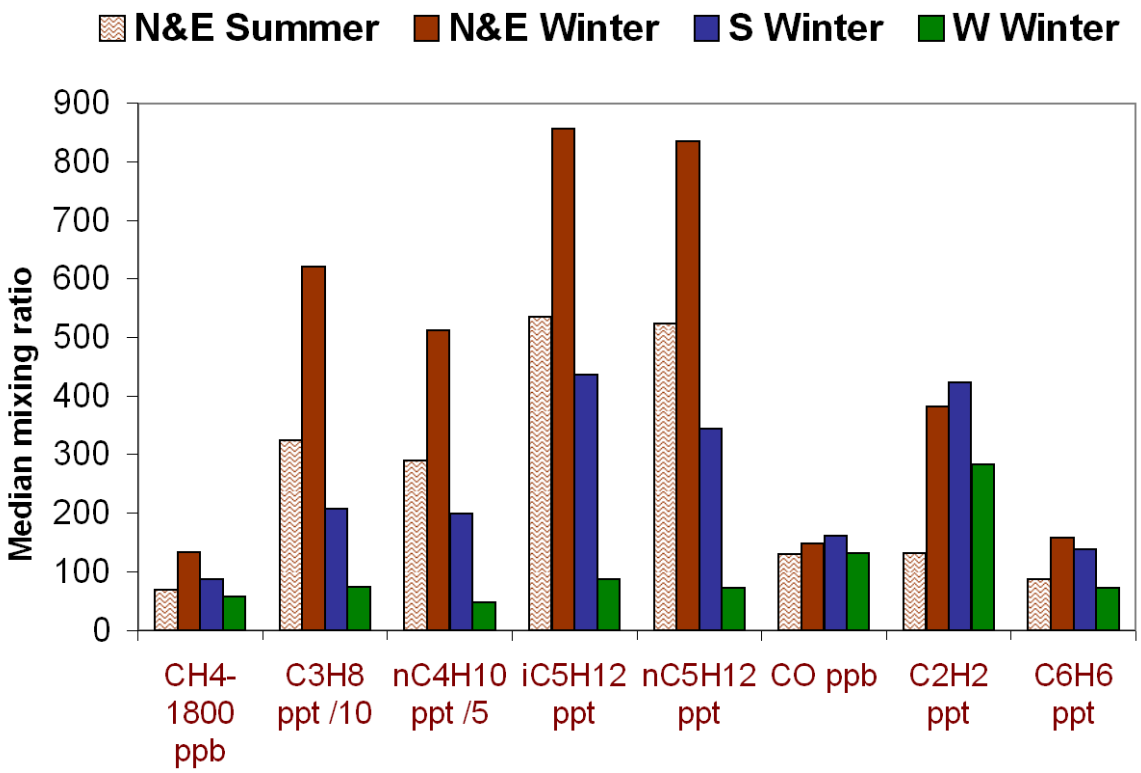
South

Denver Metropolitan Area

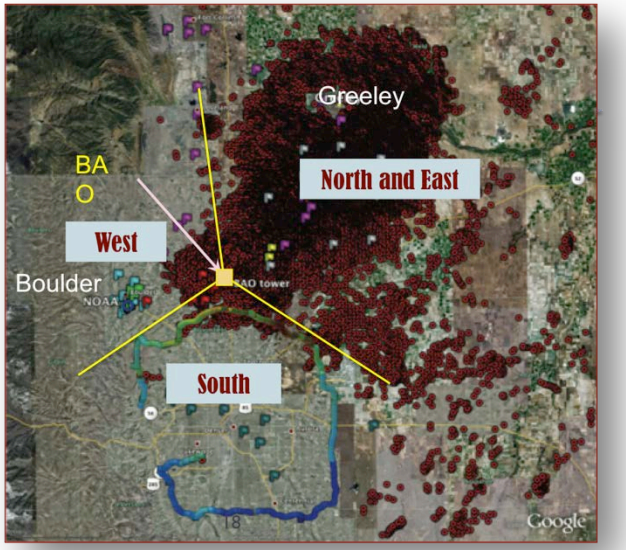
West

"Cleaner" Air Sector
Boulder

BAO: Data Filtered By Wind Sector



Strongest alkane signature in North & East wind sector

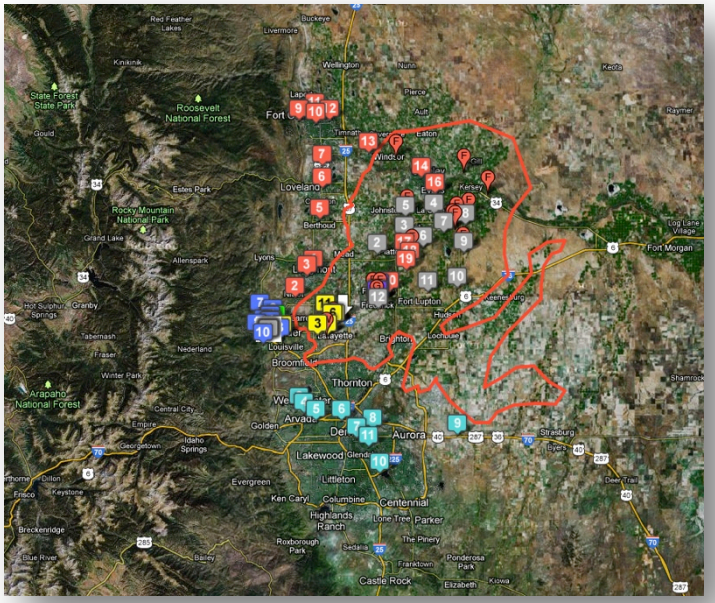


Midday Data from the BAO (August 2007-April 2010).
Wind sector designation based on 30-min average (prior to sample collection) wind direction and wind speed (data retained if |w.speed|> 2.5 m/s).

Field study to investigate methane sources chemical signatures in the Front Range

- Mobile Platform to sample close to sources
- High-frequency stable analyzers to detect plumes and target flask sampling
- Discrete air sampling for multi-species chemical analyses in the NOAA lab

Toyota Prius equipped with:
- Fast response CO_2 and CH_4 analyzer (Picarro)
- Real Time Display of Measurements
- GPS
- Programmable Flask Package (PFP with 12 sampling glass flasks) and Programmable Compressor Package (PCP) with GPS

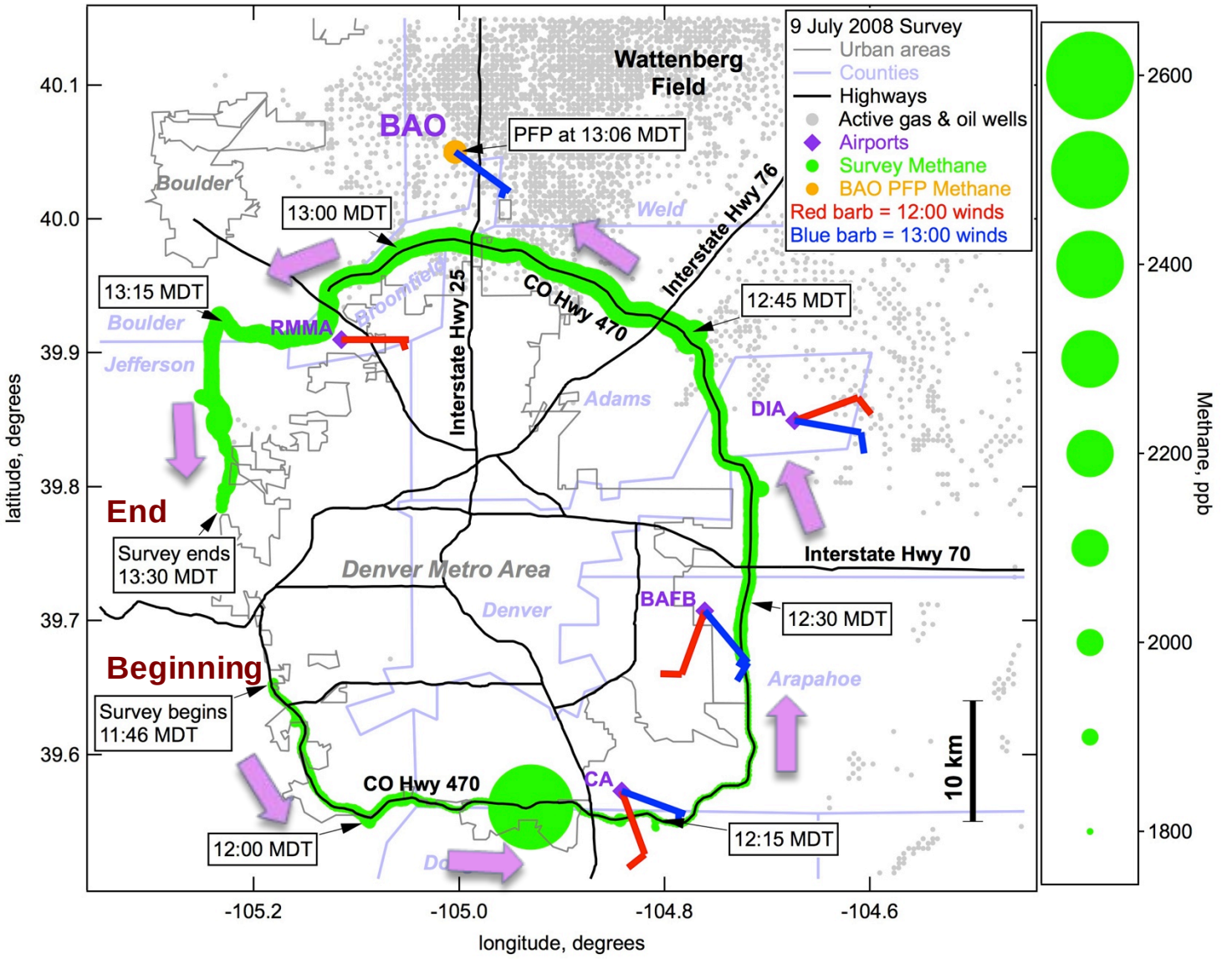


Regional Scale enhancement of CH_4

Example of Hybrid Lab Survey (July 9, 2008)

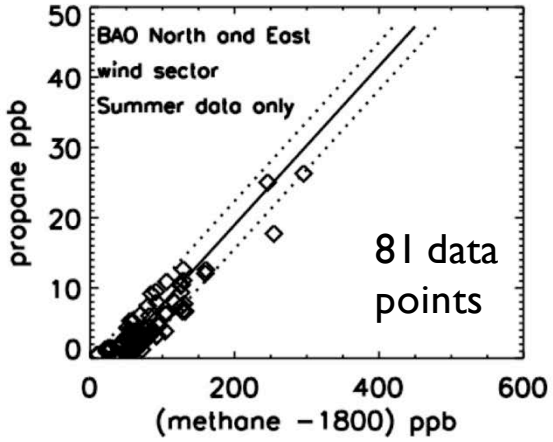
The size of the symbols along the survey track are proportional to the measured CH_4 mixing ratio.

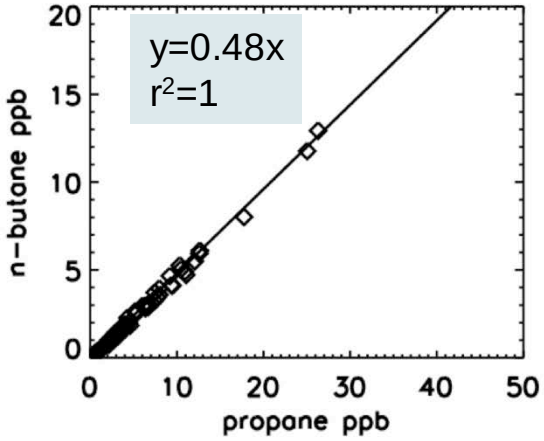
The CH_4 mixing ratio increased suddenly when the wind direction shifted and we started sampling air coming from the NE.



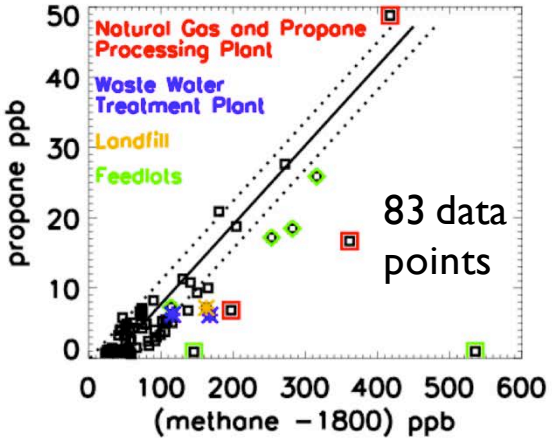
Strong Correlations between Alkanes

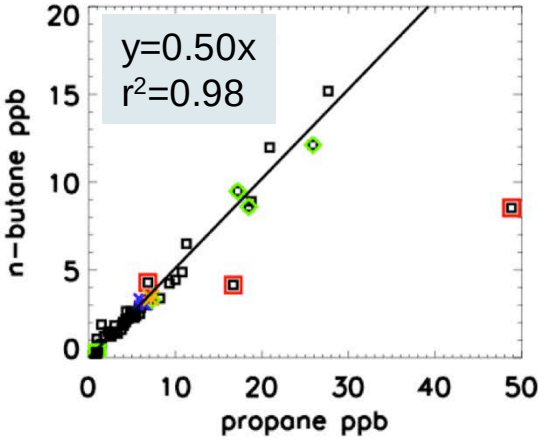
BAO N&E wind sector





Mobile Lab





- Methane is strongly correlated with propane.
- Samples collected close to feedlots, a landfill, a waste water treatment plant have enhanced methane compared to the other samples.
- Propane, n-butane, i-pentane and n-pentane are strongly correlated ($r^2 > 0.9$) in samples collected at BAO and with the Mobile Lab.

Denver Julesburg Basin Study of VOC and NOx emissions from oil and gas upstream and mid stream operations

Western Regional Air Partnership Phase III inventory

- *"The result from Phase III will include all criteria pollutant emissions for all point and area sources associated with the exploration, production, and gathering operations of oil and gas in the major basins throughout the six-state (CO, MT, NM, ND, UT, and WY) study region for year 2006 as well as future projection years."*

- Emission inventories for VOC and NOx from oil and gas exploration, production and midstream gathering and processing operations.

DEVELOPMENT OF BASELINE 2006 EMISSIONS FROM OIL AND GAS ACTIVITY IN THE DENVER-JULESBURG BASIN
Prepared for Colorado Department of Public Health and Environment Air Pollution Control Division

Prepared by Amnon Bar-Ilan, John Grant, Ron Friesen, Alison K. Pollack ENVIRON International Corporation

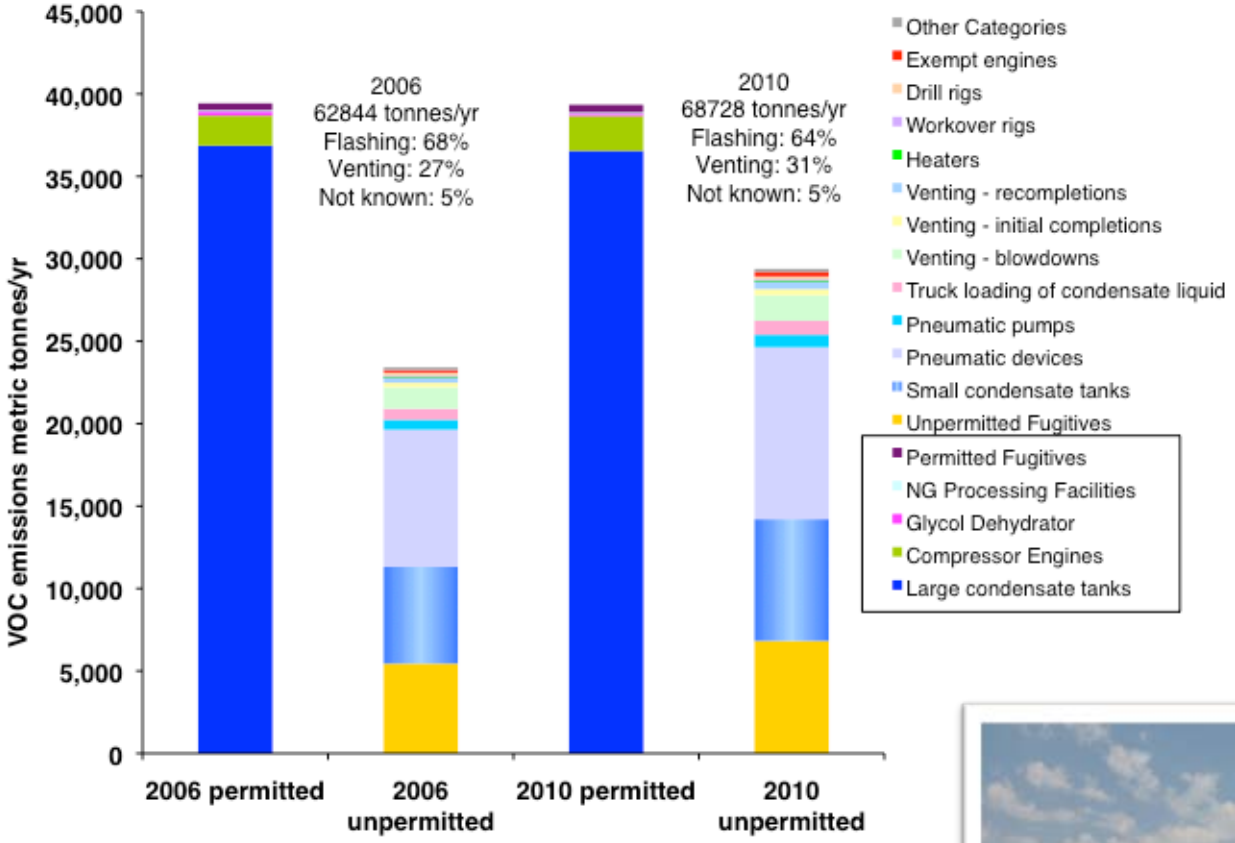
Doug Henderer, Daniel Pring
Buys & Associates

Kathleen Sgamma
Western Energy Alliance (formerly IPAMS)

April 30, 2008

- http://www.wrapair.org/forums/ogwg/PhaseIII_Inventory.html

WRAP VOC emissions inventory for NAA



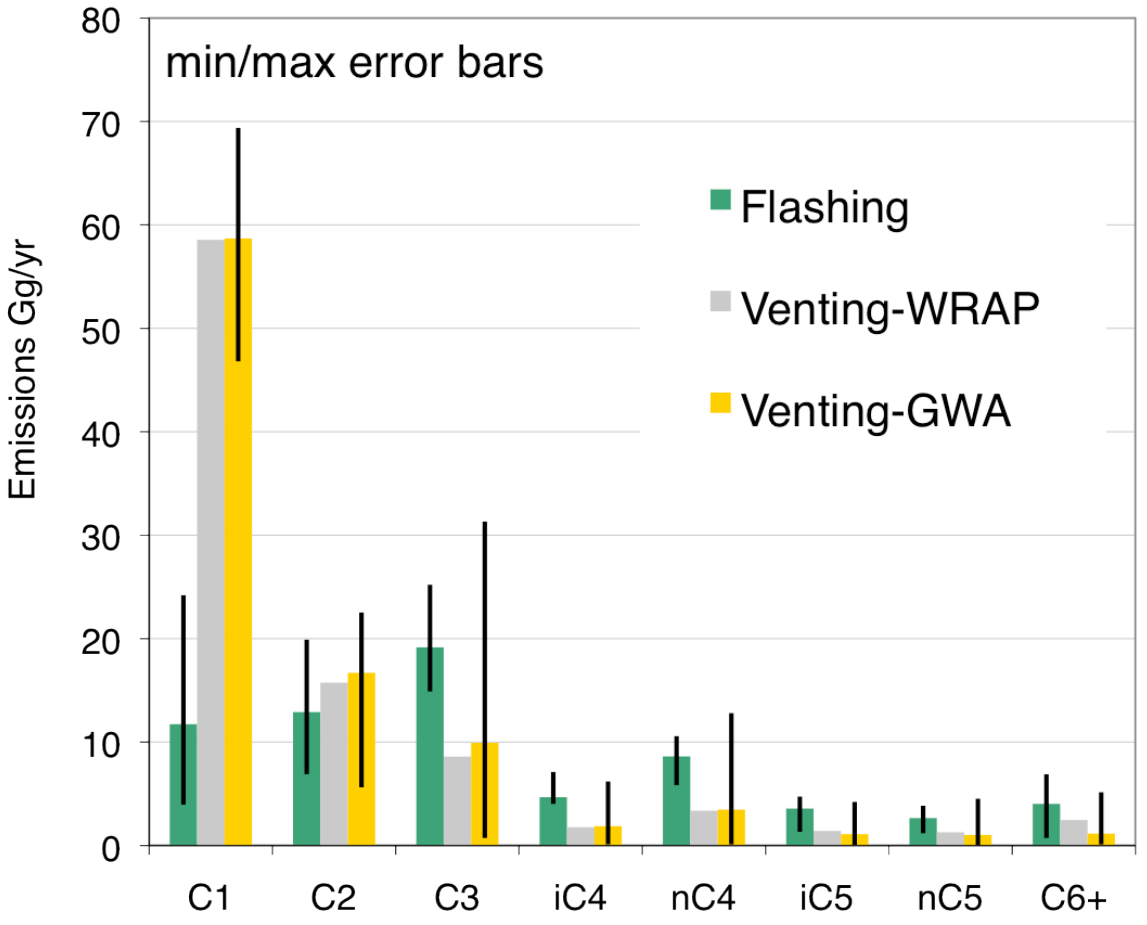
Venting (raw gas leak) and flashing (condensate tanks) emissions cover 95% of total VOC source in Front Range NAA [Bar-Ilan et al., 2008].

Bottom-up Emissions by Species

2008 taken as average of 2006 and 2010

Hypotheses:

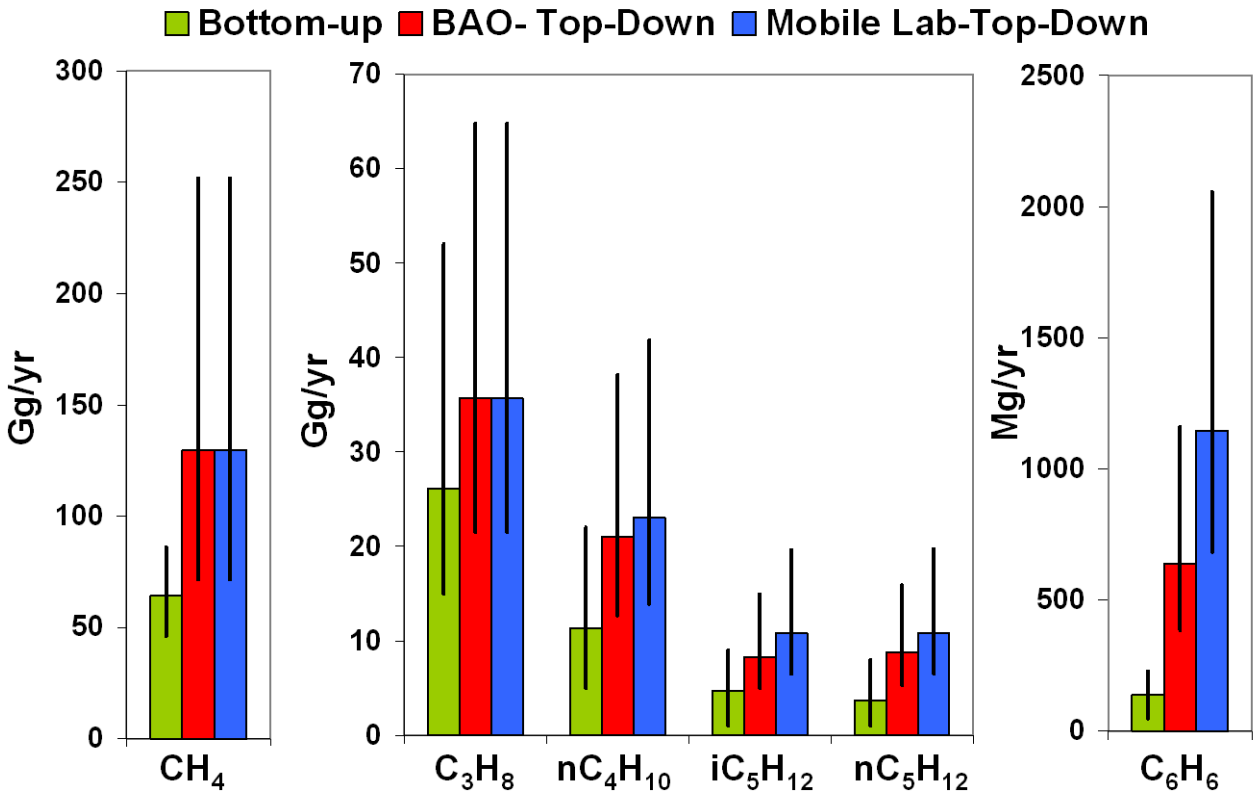
1. Flashing emissions by species were computed for the 16 flash tanks modeled, and the average (green color bar) and min and max (error bars) are shown.
2. Volume of gas vented calculated based on WRAP venting total VOC emissions and WRAP venting composition profile. WRAP mean raw gas composition and GWA raw gas data from 77 wells were used to derive emissions estimates.



WRAP estimate of gas vented:
2006: volume of gas vented=1.68% of total NG production

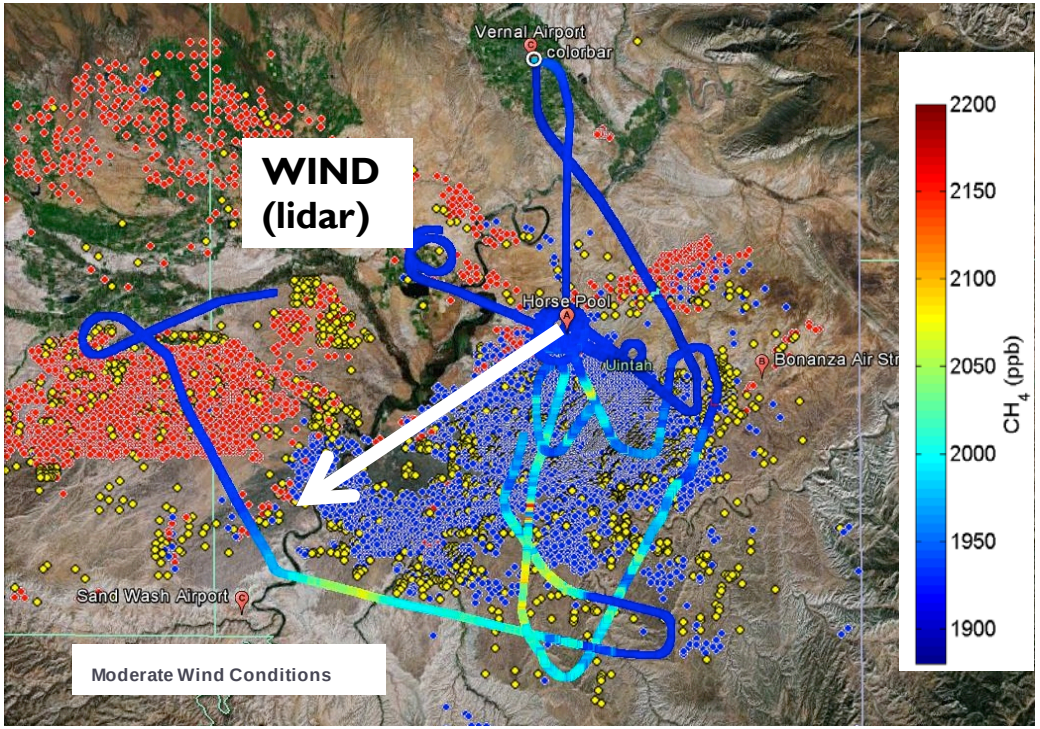
Top-down Estimates vs Inventory

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



The largest discrepancies between bottom-up and top-down estimates are for methane and benzene.
Fugitive emissions of raw natural gas are underestimated in the inventory.
Very little information is available on the benzene content of the raw natural gas

Top-down Emissions Evaluation #2



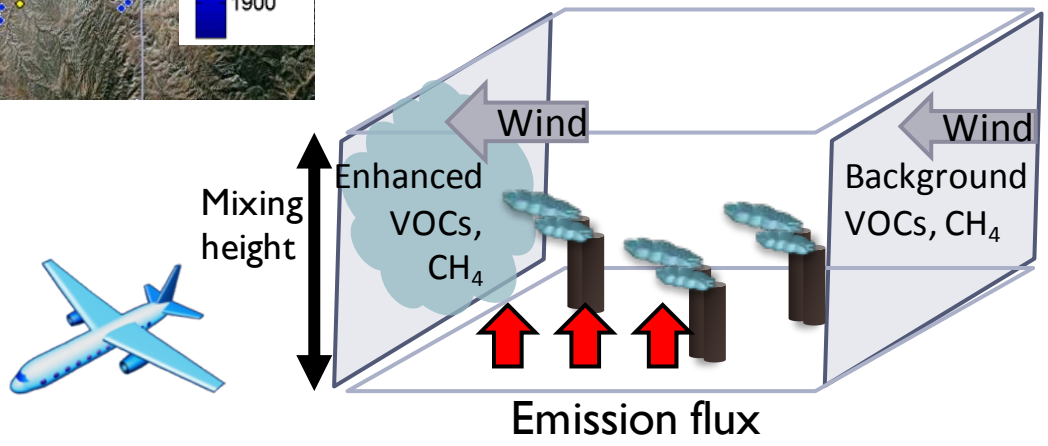
NOAA Global Monitoring Division

Anna Karion, Colm Sweeney, Steve Conley et al.

Aircraft Measurements of CH_4, Uintah Basin, Utah

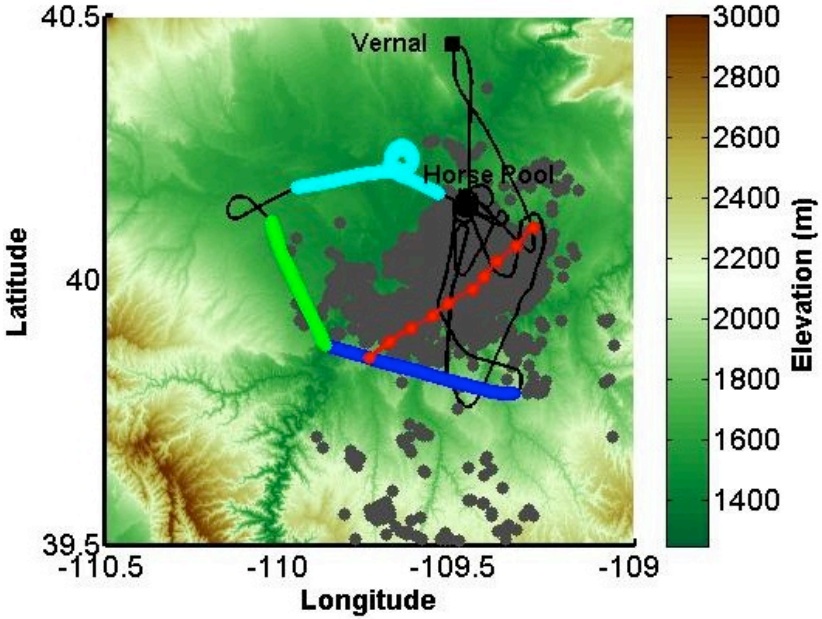
February 3 , 2012

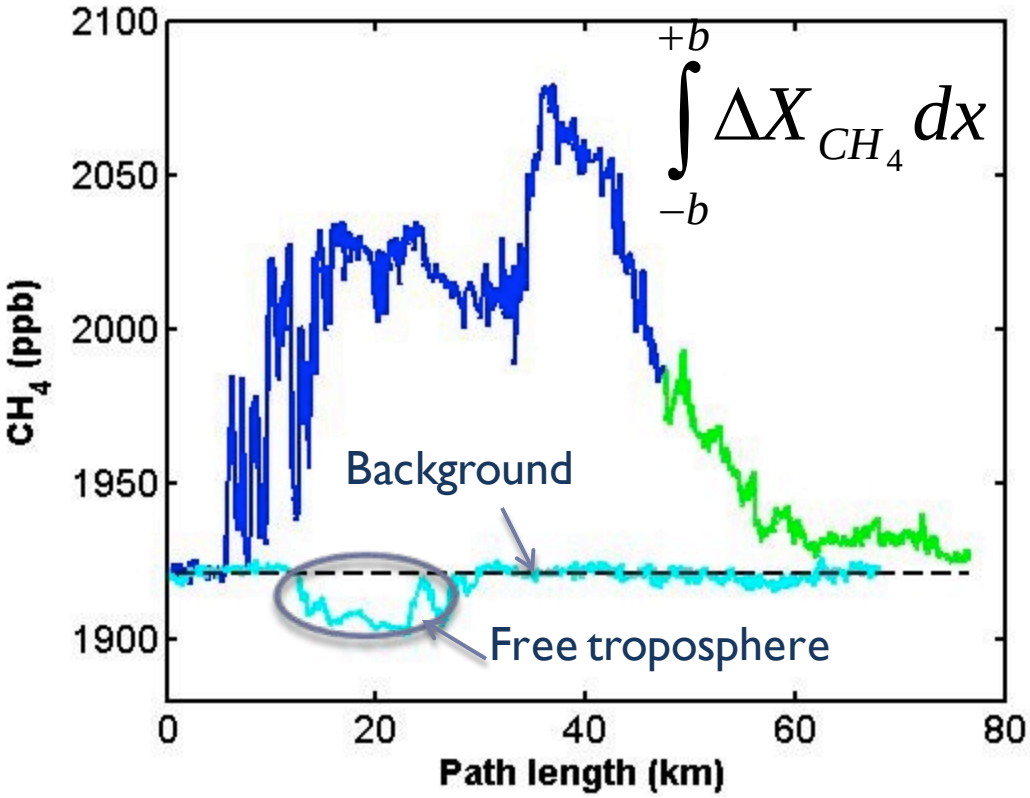
Mass-Balance "Box" Calculation



- The airplane samples upwind and downwind of the area source
- The airplane also documents the boundary layer height and how well mixed the plume is.

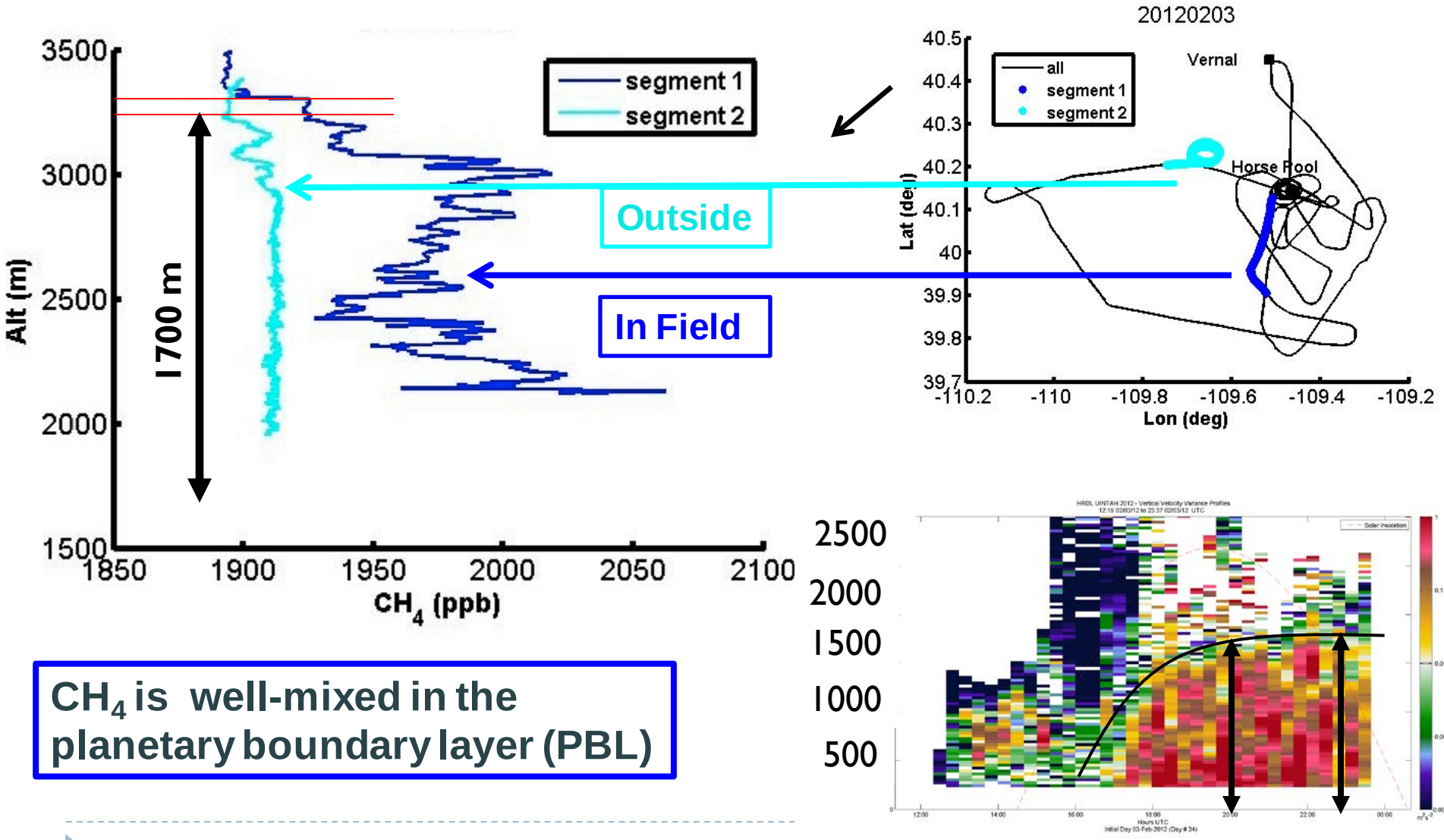
Downwind Plume Integration





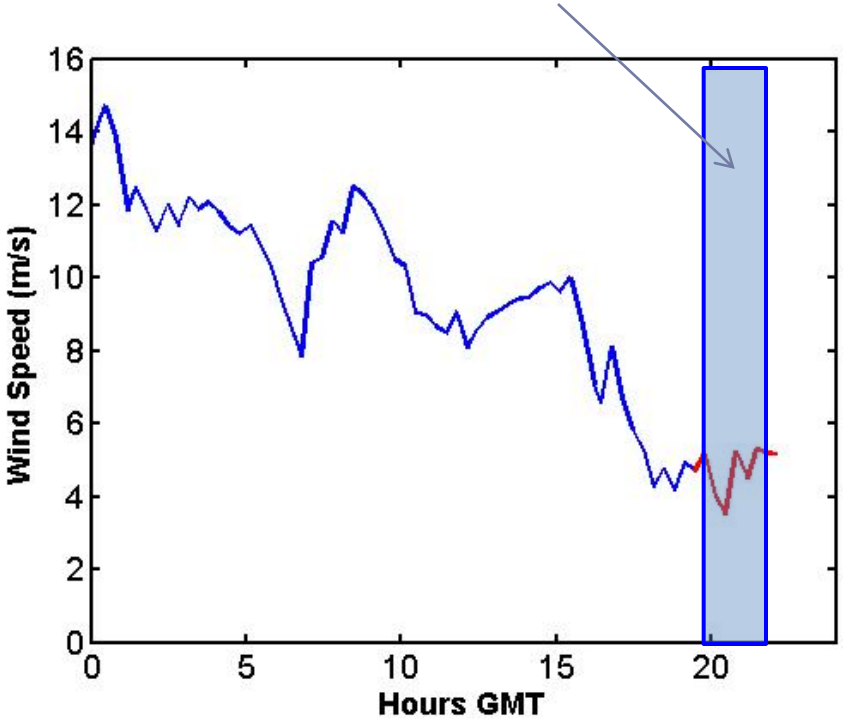
$$\dot{m}_{CH_4} = \iint_{CS} \rho_{CH_4} V_n dA_{out} - \iint_{CS} \rho_{CH_4} V_n dA_{in}$$

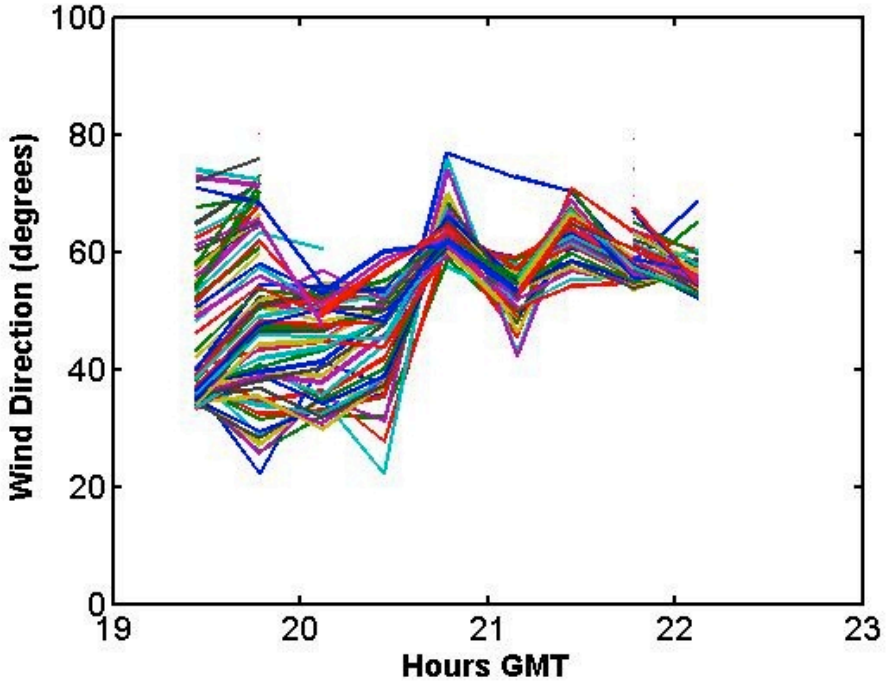
Boundary Layer Height



CH_4 is well-mixed in the planetary boundary layer (PBL)

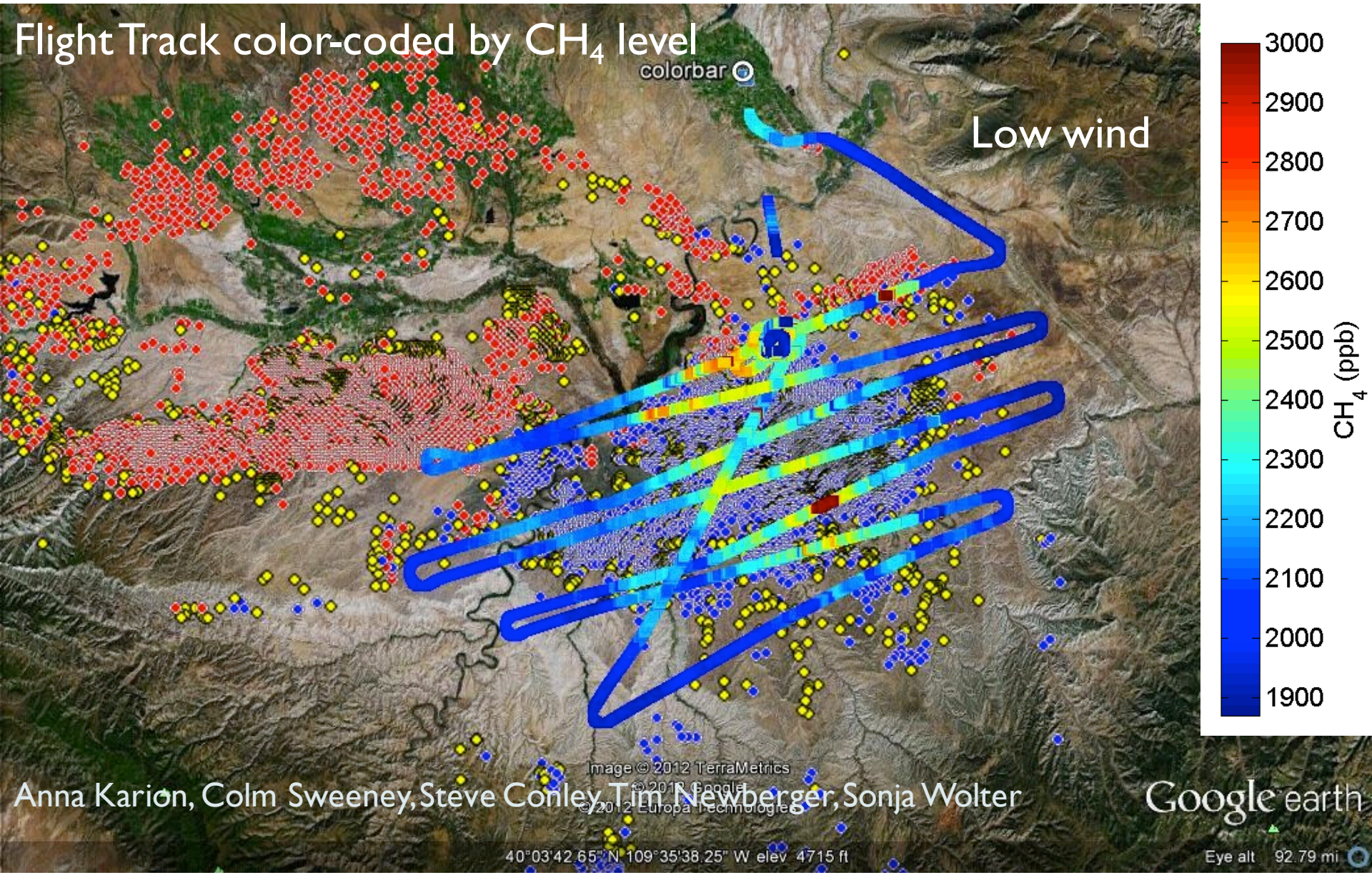
Wind direction and Speed





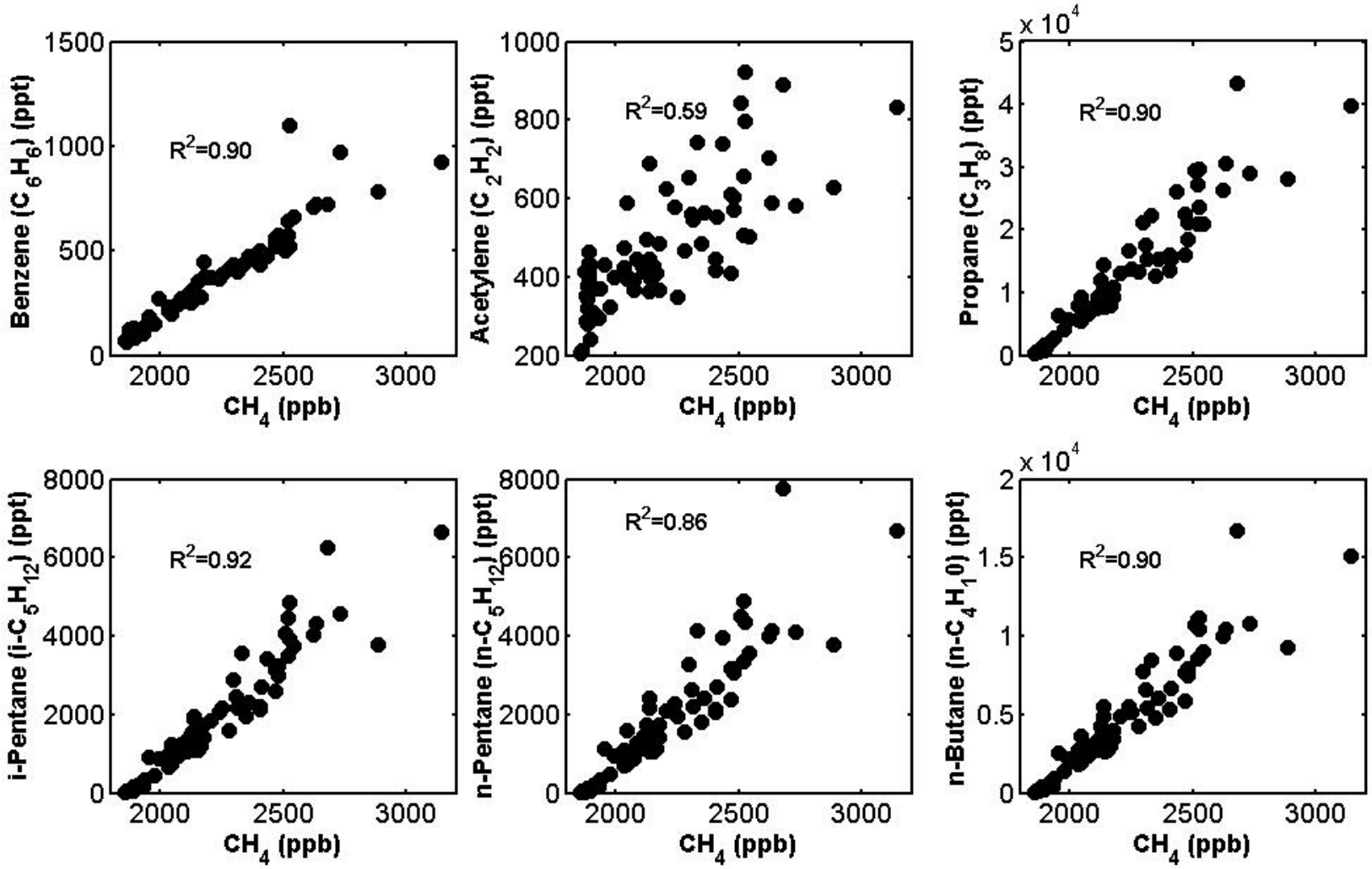
- CH_4 in basin has been flushed out by high winds previous to the flight.

Feb 7 2012: Uinta Basin
Flight over gas field - Low Wind Conditions



Anna Karion, Colm Sweeney, Steve Conley, Tim Newberger, Sonja Wolter

Airplane flask samples show that several hydrocarbons correlate well with CH_4



Uinta Basin, February 2012

Anna Karion, Colm Sweeney, Steve Conley, Ben Miller, Steve Montzka

Concluding remarks

- Atmospheric measurements can be used to quantitatively assess methane emissions from oil and gas upstream activities
  - Our top-down emission estimates are
    - for a specific location and time
    - integrated fluxes from various O&G operations
- This type of study provides an objective evaluation of bottom-up inventories
  - Specifically it can be used to assess at the regional scale
    - new inventory methodologies
    - impact of new regulation/practices
- VOC emission reduction strategies most likely also reduce CH_4 emissions
  - Example of co-benefit: Air quality/Climate
- Results from on-going experiments should be available later this year.




Pictures from Uinta Basin February 2012

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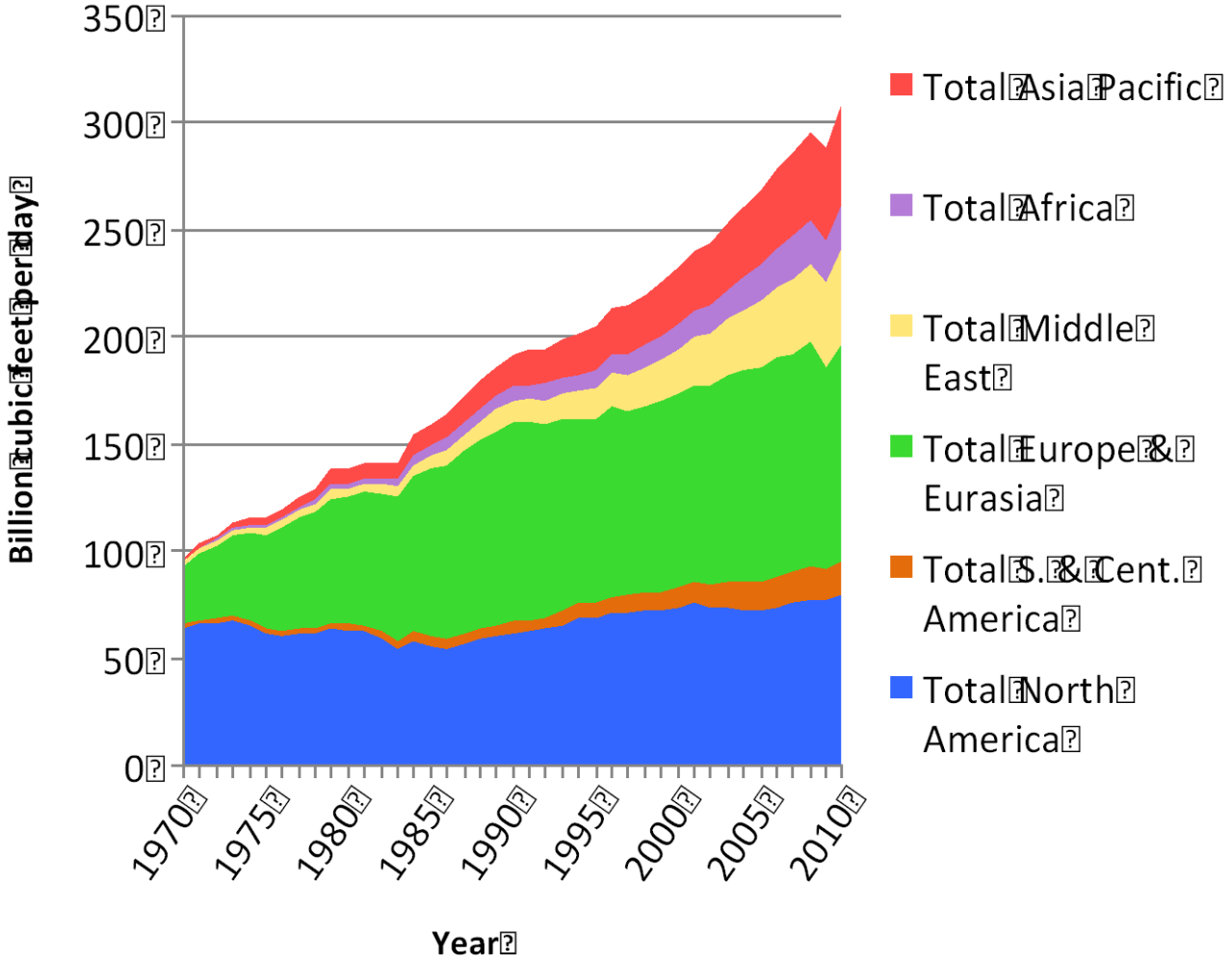
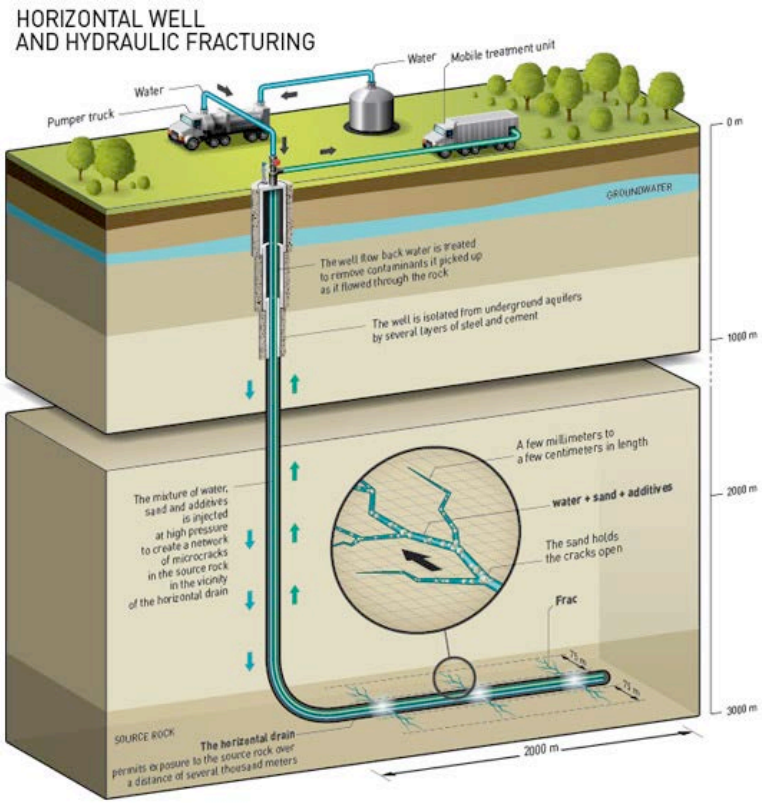
Extra Slides

World Natural Gas Production



USA and Russia combined represent 35% of world natural gas production.

Principle of Hydraulic Fracturing

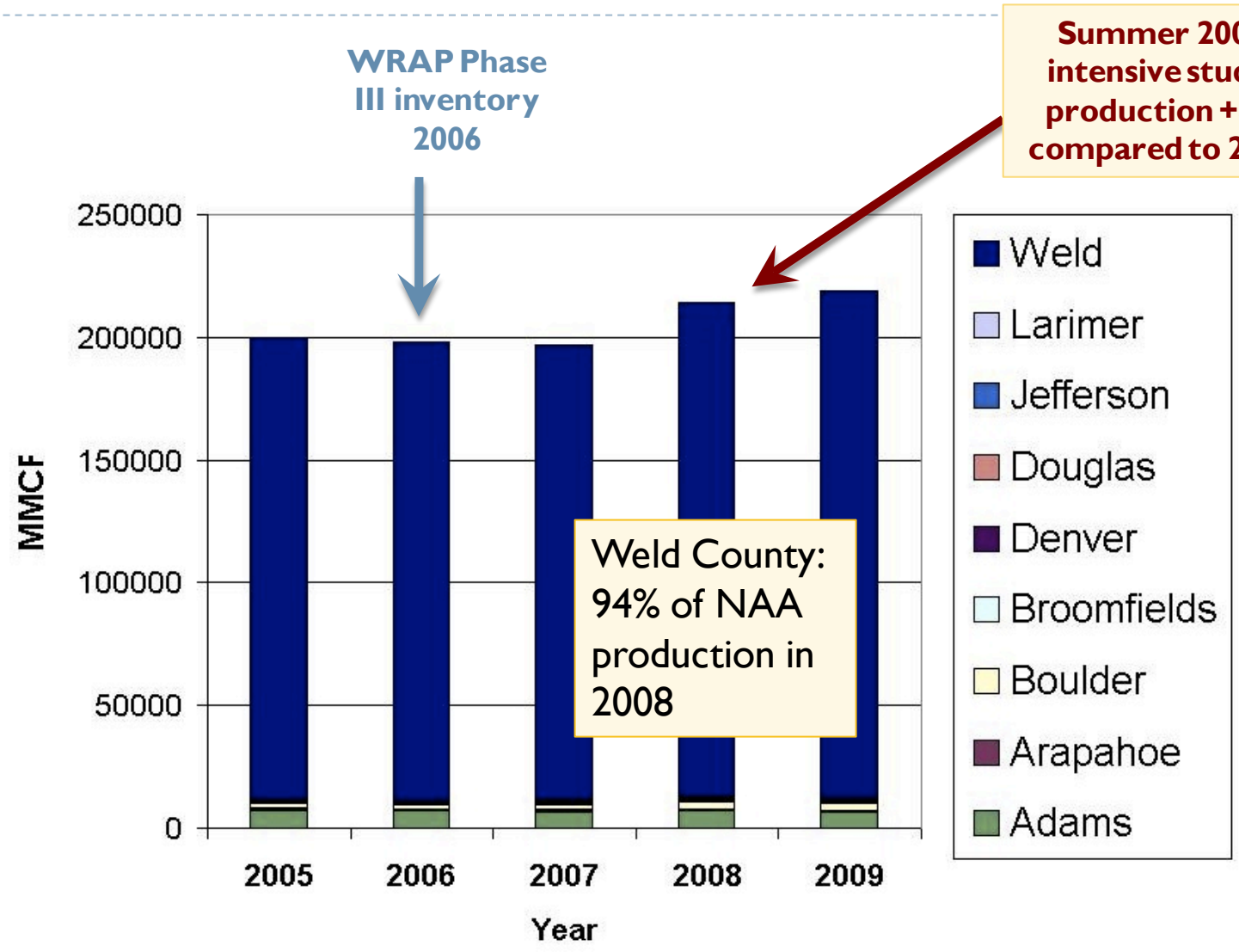


Source: Total

Hydraulic fracturing or "fracking" is a stimulation technique used to increase the amount of natural gas or oil that can be extracted from compact formations.

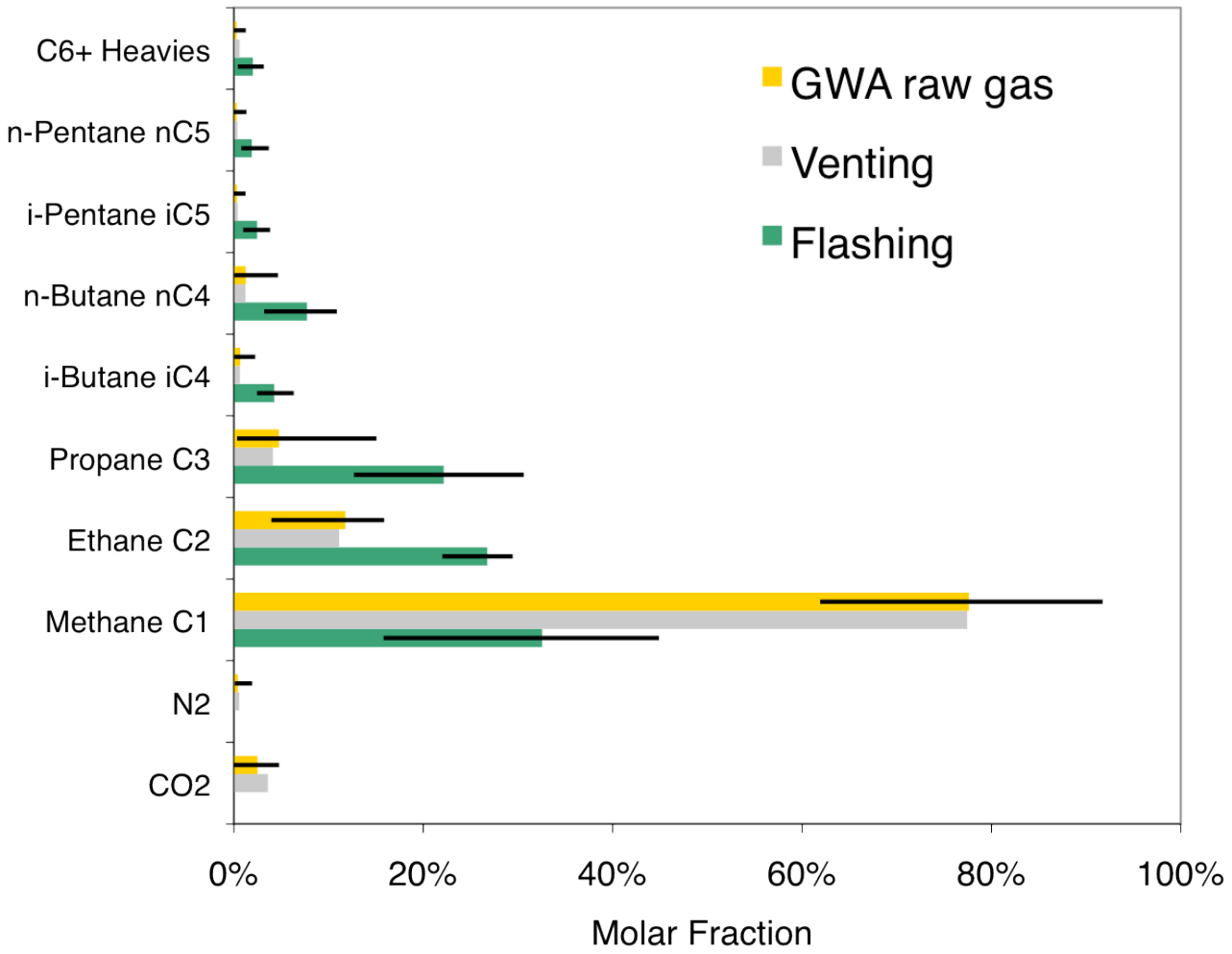
Fracking consists in injecting millions of gallons of water mixed with sand (9.5%) and chemical additives (0.5%) down the hole. The high pressure mixture causes the rock layer to crack. The natural gas present in very fine pores can flow to the well head via the fissures which are held open by the sand particles.

NAA Natural Gas production ~ 15% of the State's



- County level natural gas production data: http://cogcc.state.co.us/

Emission Profiles Used



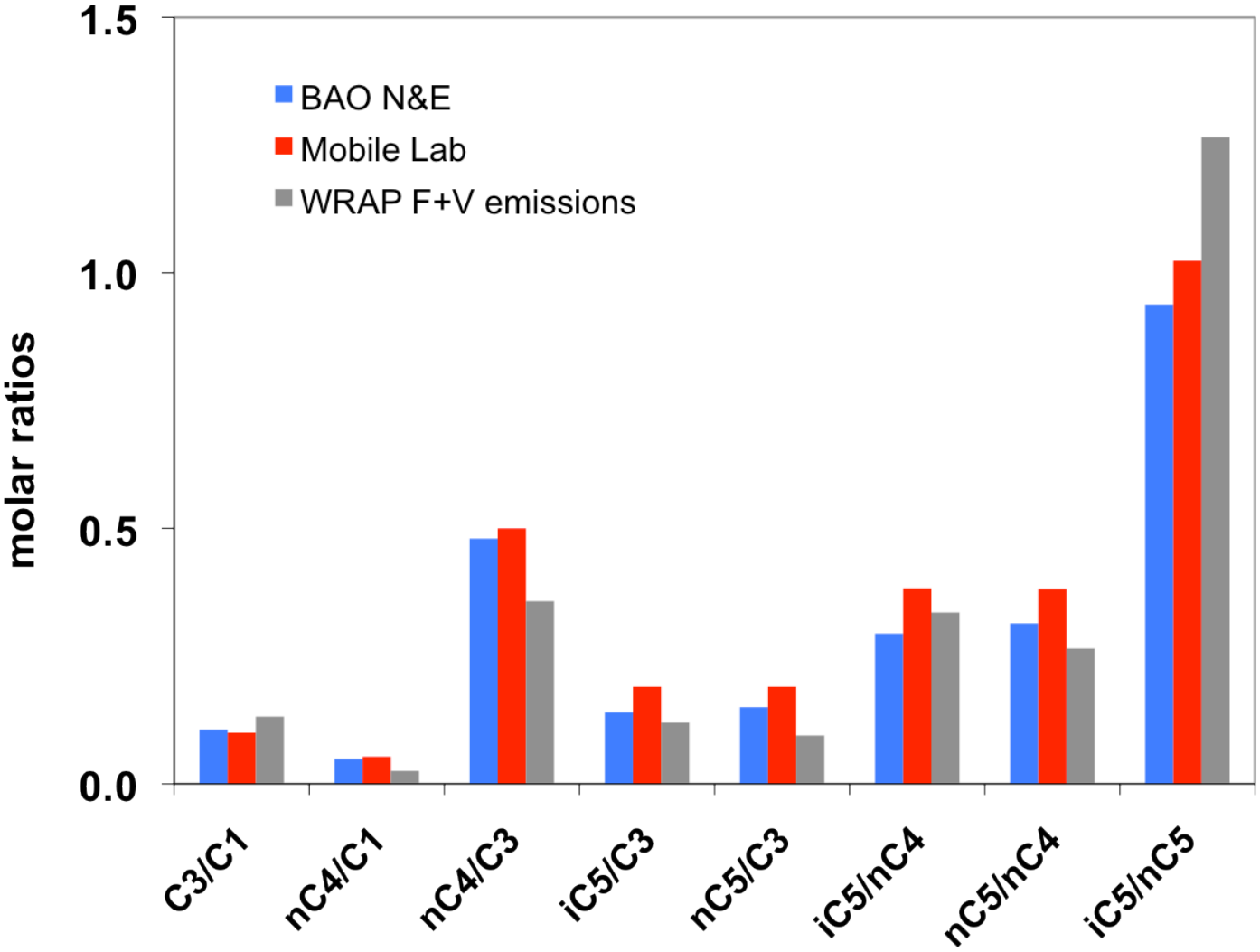
Columns show the average molar compositions of:

- raw natural gas (WRAP venting profile and Great Wattenberg Area study, COOGC, mean raw gas profile) &
- flashing emissions profiles modeled by CDPHE with EPA TANK2.0 and condensate composition data from 16 tanks in Weld County(2002).

The black error bars show the minimum and maximum for each profile – when available.

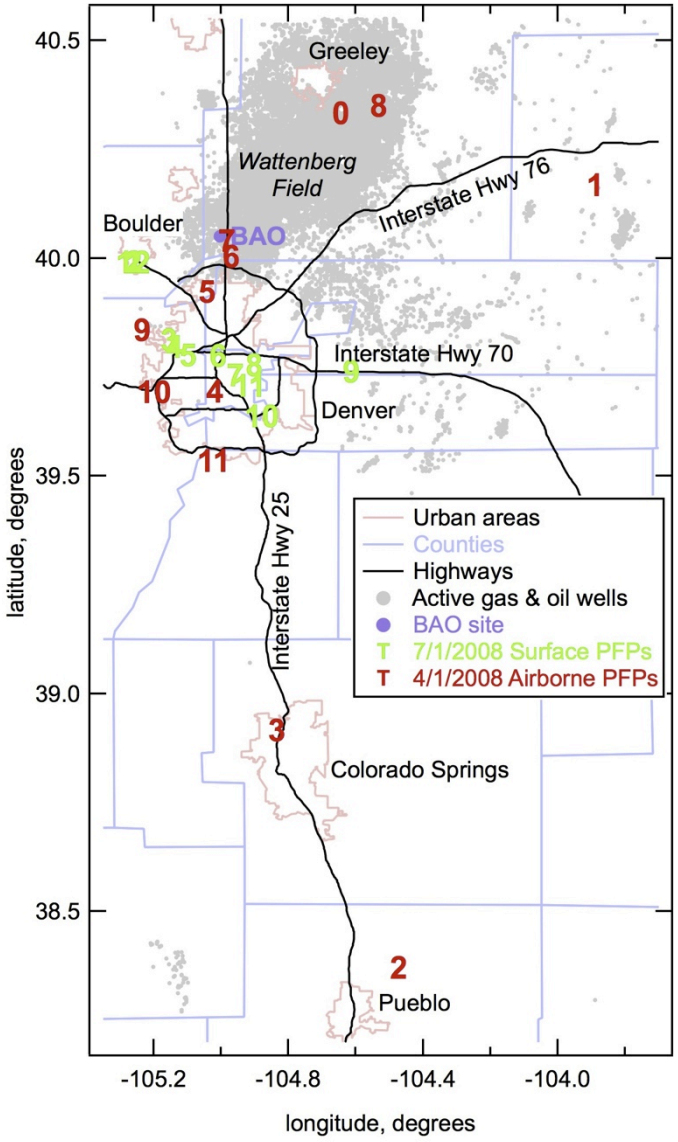
- Note notation convention in later plots for alkanes: methane=C1,… pentane=C5

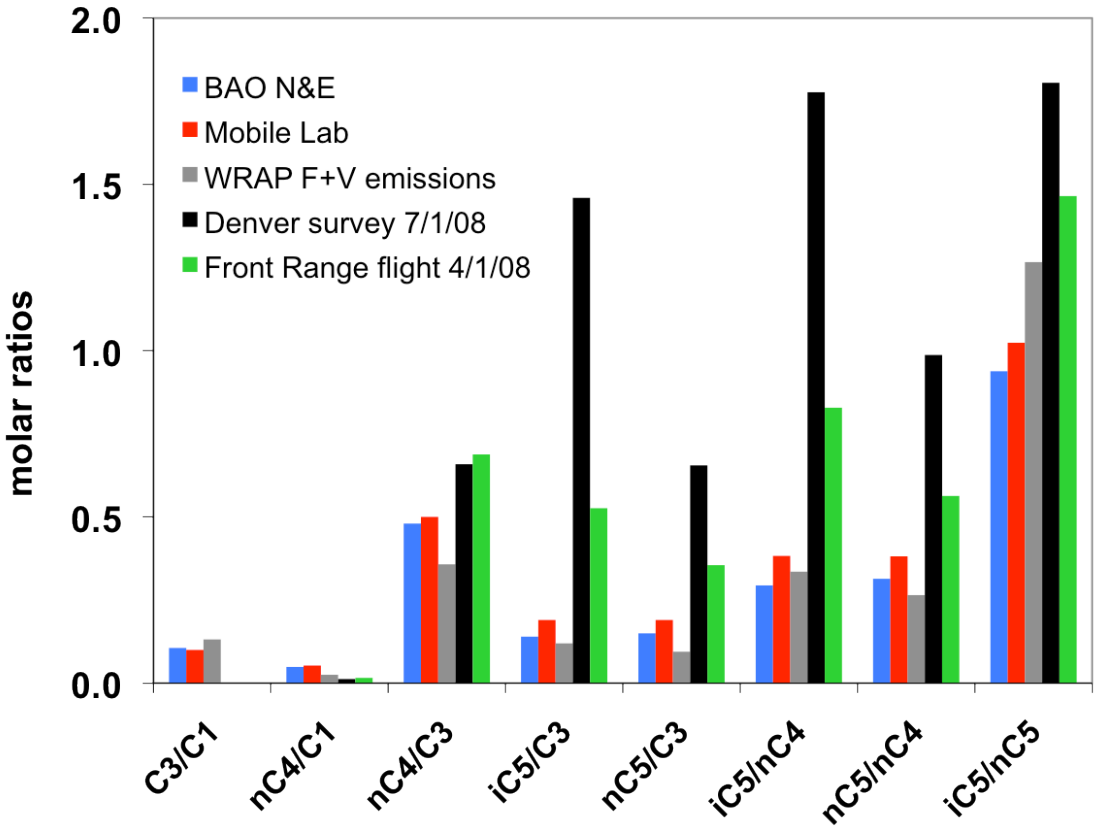
Observations vs Flashing+Venting emissions



The observed atmospheric ratios reflects a mix of sources with different emission profiles.

Comparison with signatures of urban air samples collected by Mobile Lab (July) and Aircraft (April)





The prevalent alkane signature observed in the Northern Front Range is different from the urban air signature.