Top-down estimation of CH_4 emissions from oil and natural gas operations in the Denver and Uintah oil and gas Basins

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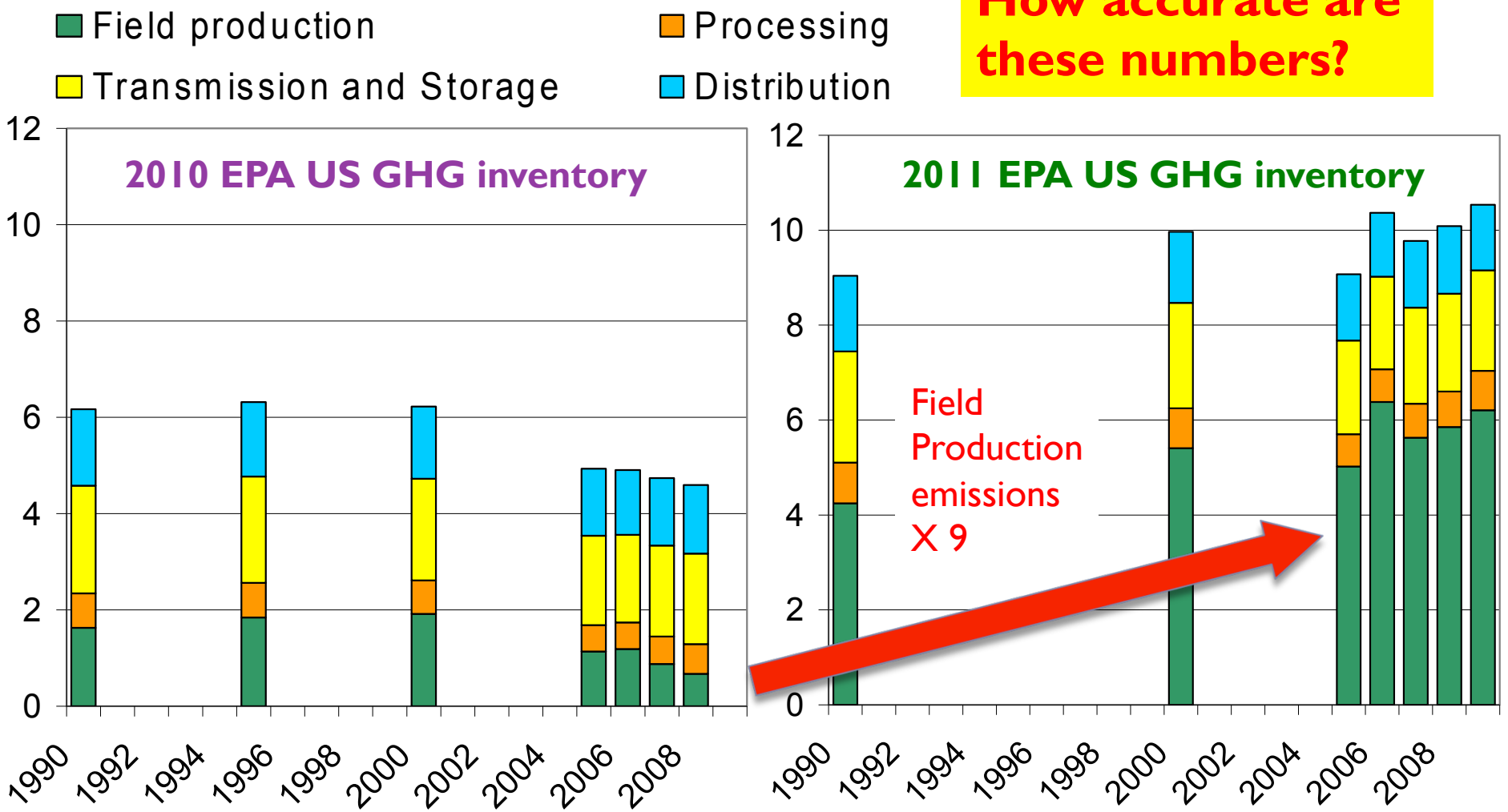
US CH_4 emissions (Tg/yr) from natural gas systems
Impact of change in EPA inventory methodology

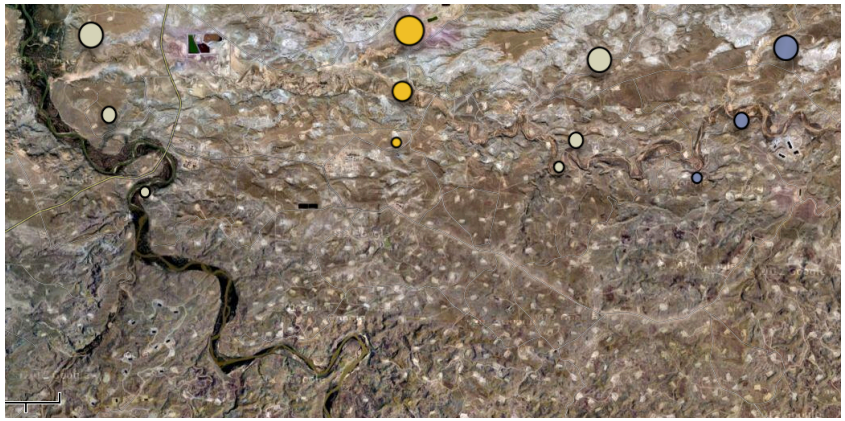
How accurate are these numbers?



- **Reported** uncertainty for CH_4 national emissions from NG systems: **20-30%.**

Can we detect CH_4 emissions in the atmosphere?

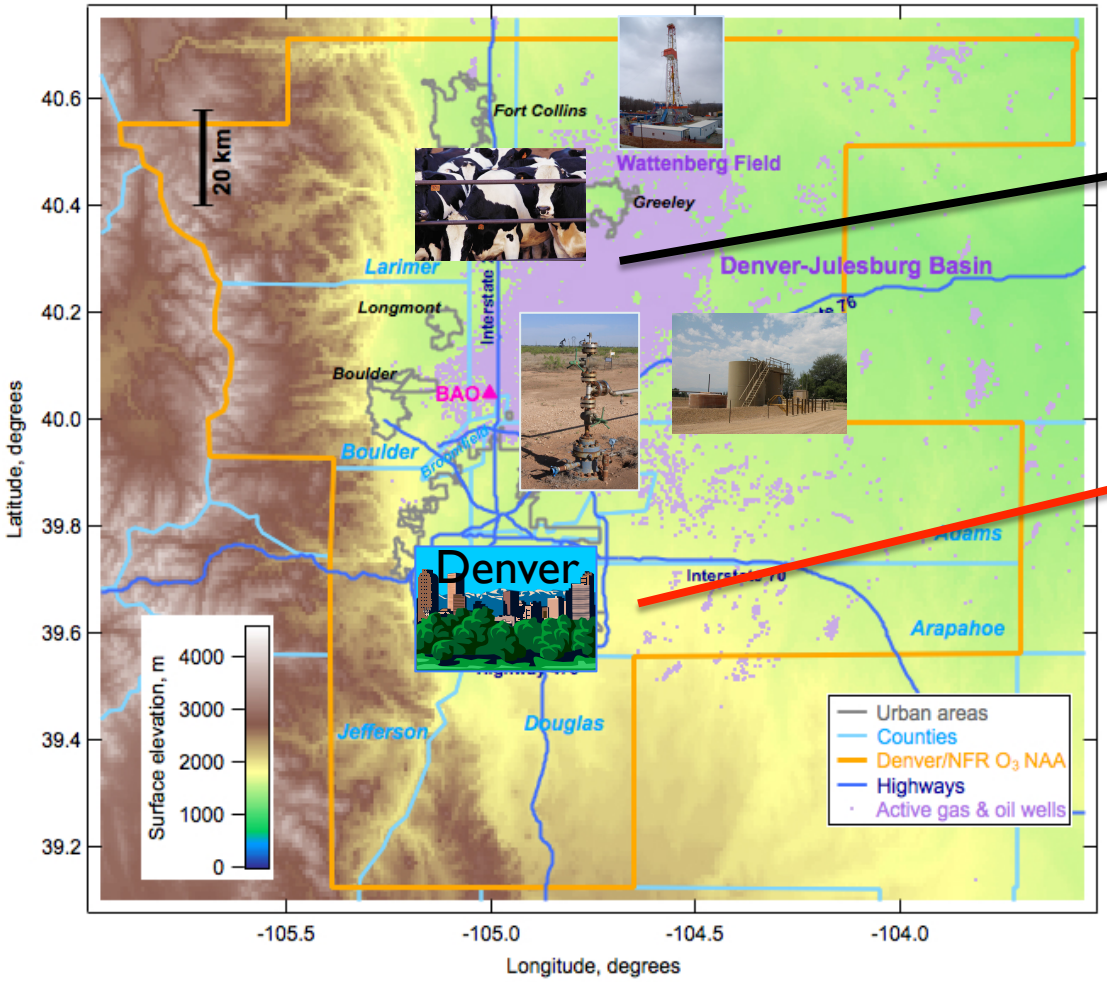
CH_4 "cloud" from surface emissions

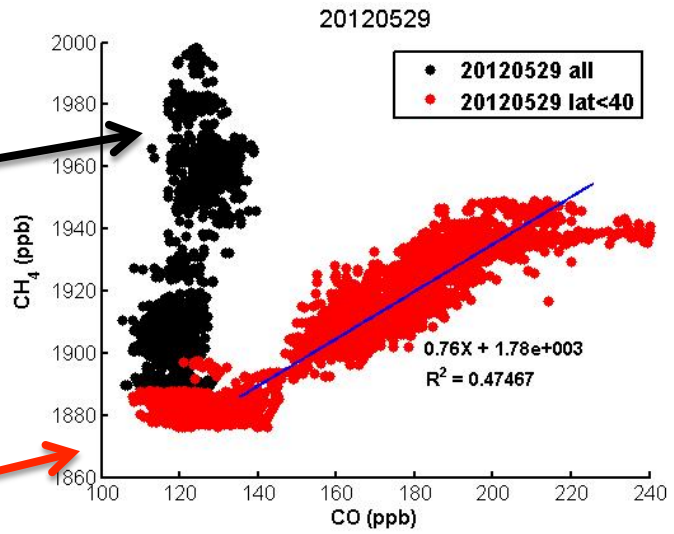


wind

Ambient levels of CH_4 measured by instrumented tower, van or aircraft downwind of the area source reflect emissions from oil and gas production operations

Can we use multiple species measurements for source attribution?





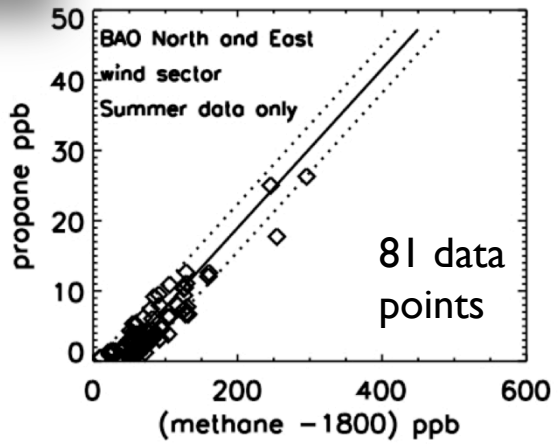
Different sources of CH_4 have different chemical signatures. Here flight measurements in the Denver Basin in May 2012 show two distinct plumes downwind of Denver (red) and downwind of the oil and gas field (black).

Denver Basin, home to > 20,000 oil and gas wells.

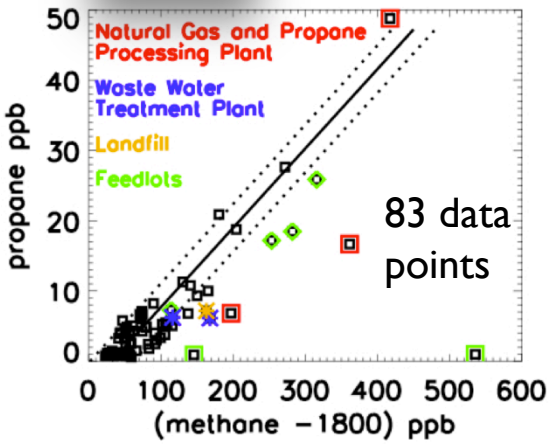
*A **multi-species** approach is needed to determine the significance of different CH_4 sources as well as to separate different emission processes within the NG industry.*

Strong Natural Gas Signature in Colorado Northern Front Range Airshed

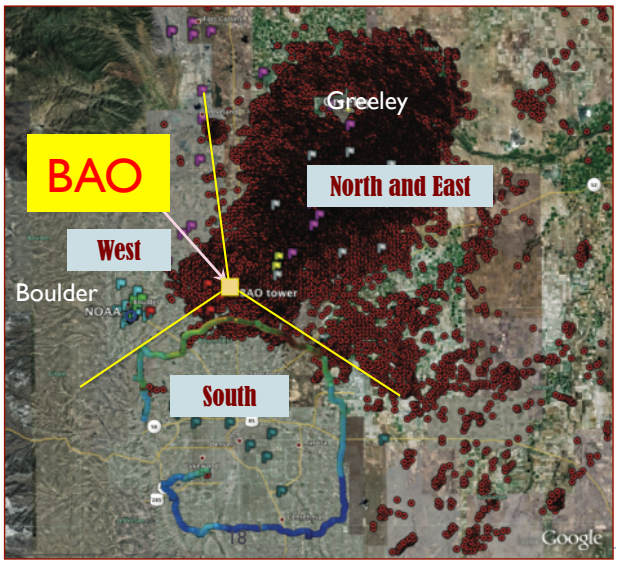
BAO N&E wind sector



Mobile Lab



- Methane is strongly correlated with propane.
- Samples collected downwind of feedlots, a landfill, and a waste water treatment plant have enhanced methane compared to the other samples.

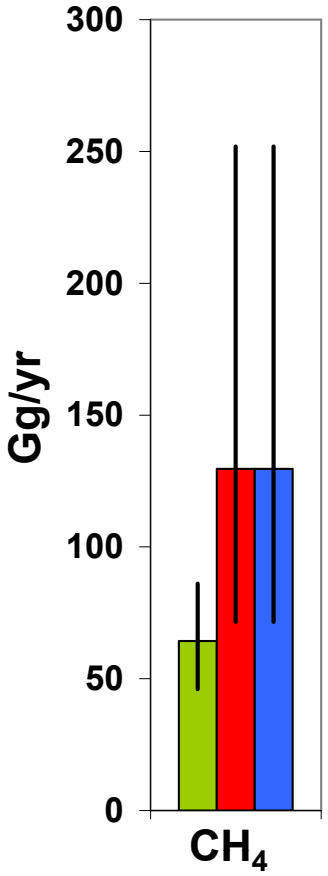


We use the measured atmospheric propane-to-methane enhancement ratios observed at the BAO tall tower and at the surface across the Front Range to evaluate the proportion of flashing (condensate/oil tanks) and venting (fugitive) emissions.

Pétron et al., JGR-Atmospheres, doi:10.1029/2011JD016360, *2012*

Top-down Estimates versus Inventory

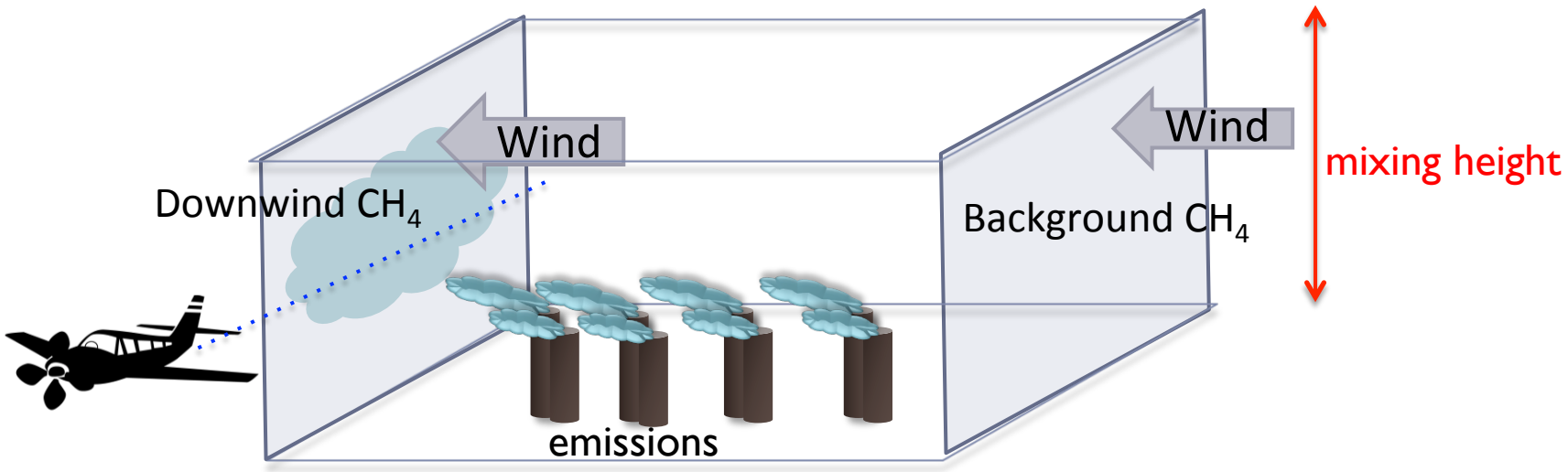
Bottom-up Emissions
Top-Down BAO/
Mobile Lab Emissions



Constraints	Bottom-up inventory	Enhancement Ratio Method
Flash emissions for tanks (total VOC mass) in Weld County	X	X
Fugitive emissions estimates (volume of raw gas)	X	
Raw gas composition profiles (average or subset)	X	X
Flash emissions composition profiles	X	X
Atmospheric enhancement ratios		X

- Fugitive emissions of CH_4 in Weld County are likely underestimated in bottom-up inventory for 2008.
- Still very large uncertainties on top-down estimates.
- **We need a truly independent method to evaluate inventories!**

Mass Balance Approach for Area Flux Estimation



CH_4 flux = mass of CH_4 out of box − mass of CH_4 into box

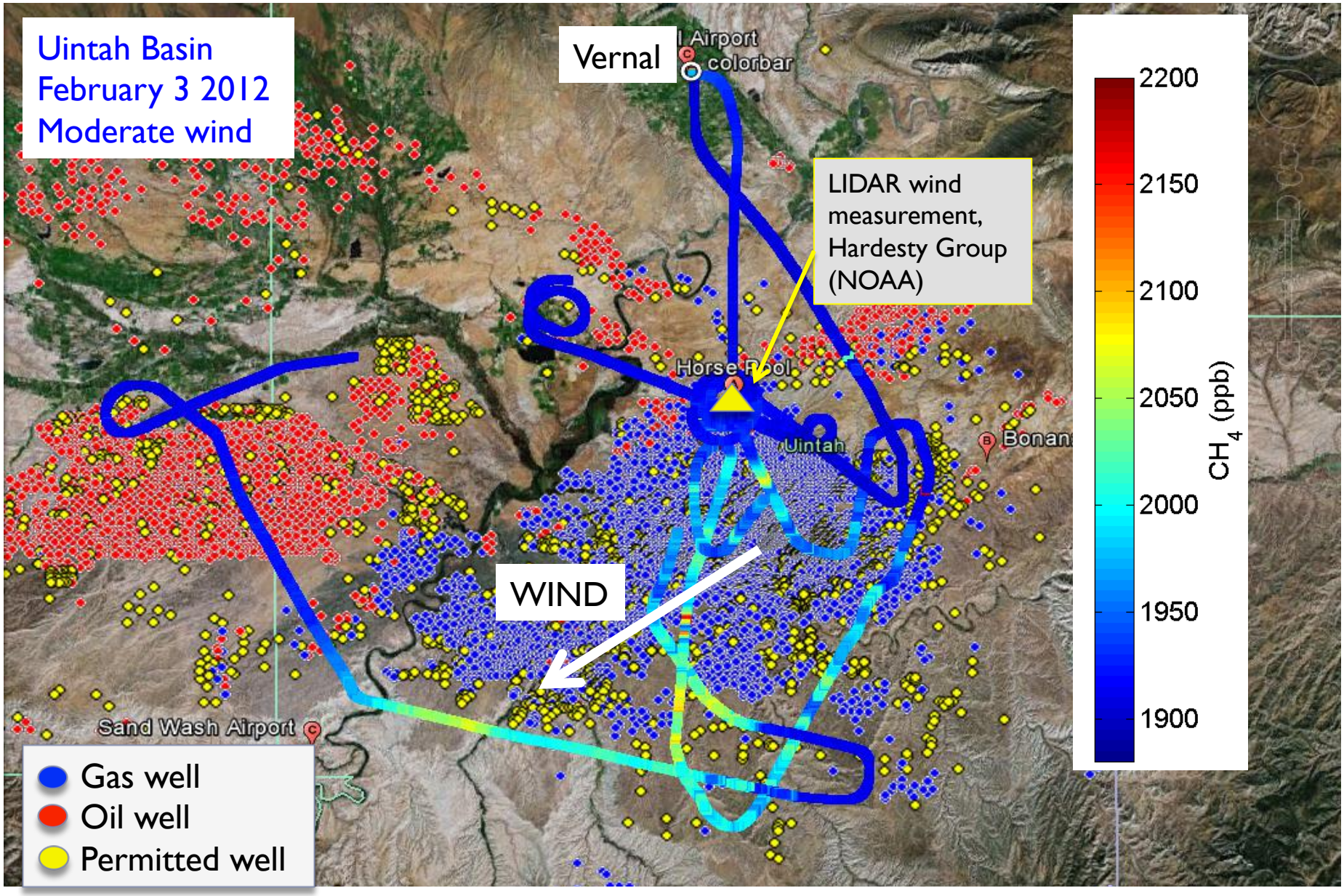
$$\dot{m}_{CH_4} = \iint_{CS} \rho_{CH_4} V_n \, dA_{out} - \iint_{CS} \rho_{CH_4} V_n \, dA_{in}$$

Density of methane (CH_4)

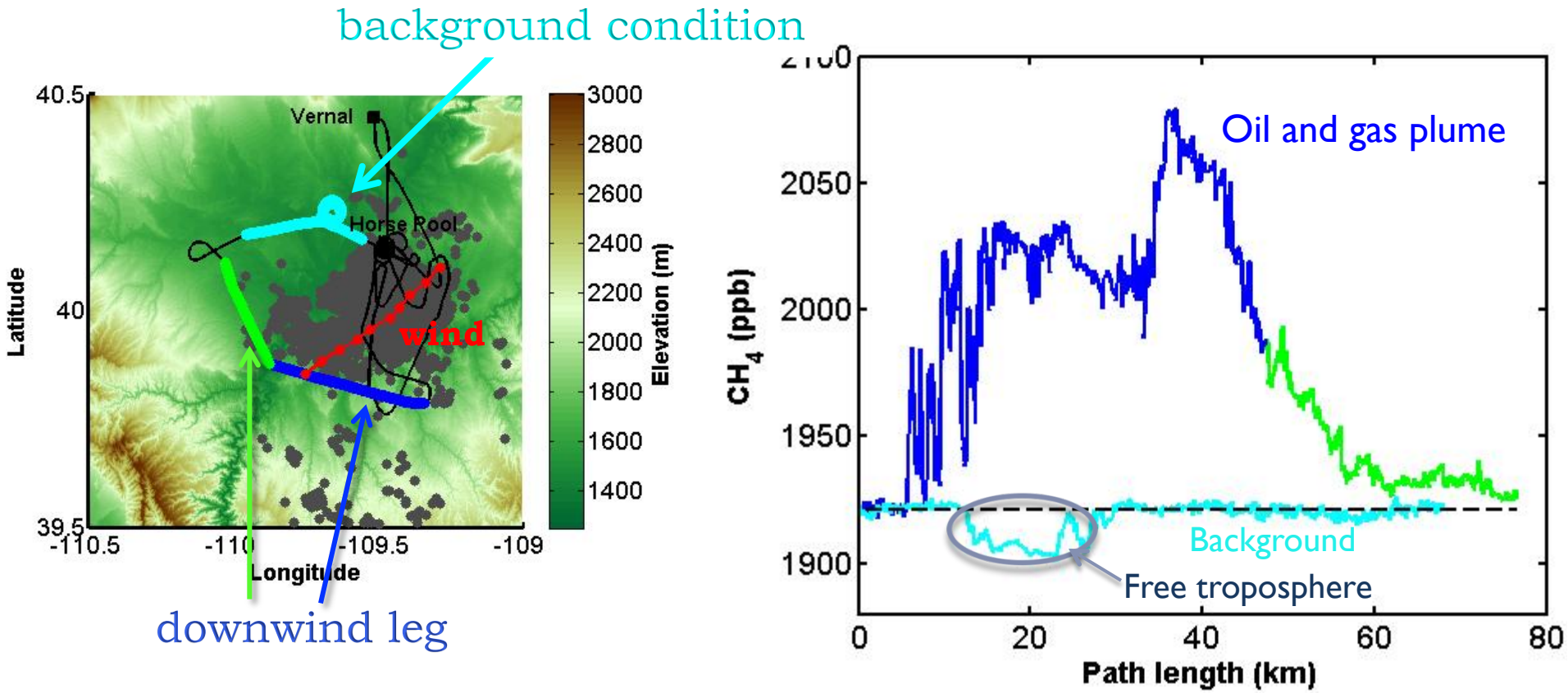
Wind speed normal to plane

- Under ideal meteorological conditions, we can calculate the area CH_4 flux with a low uncertainty.

Aircraft Measurements of CH_4



Downwind CH_4 Plume Integration



Methane enhancement in plume downwind of field is integrated over the horizontal extent to calculate the CH_4 surface flux.

Flux uncertainty calculation for February 3 2012

Parameter	% Uncertainty
Wind Speed	13%
Cosine of angle between wind direction and normal to heading	19%
Methane enhancement	6.4%
Mixing layer height	6%
Total Flux (CH_4)	**25%**

- This is the uncertainty of a single day observation.
  - Consistent winds lead to a relatively low uncertainty on this observation.

Karion et al., in prep.

Concluding remarks

- Atmospheric measurements can be used to quantitatively assess emissions from oil and gas upstream and midstream 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 Uintah Basin February 2012

Supplementary Slides

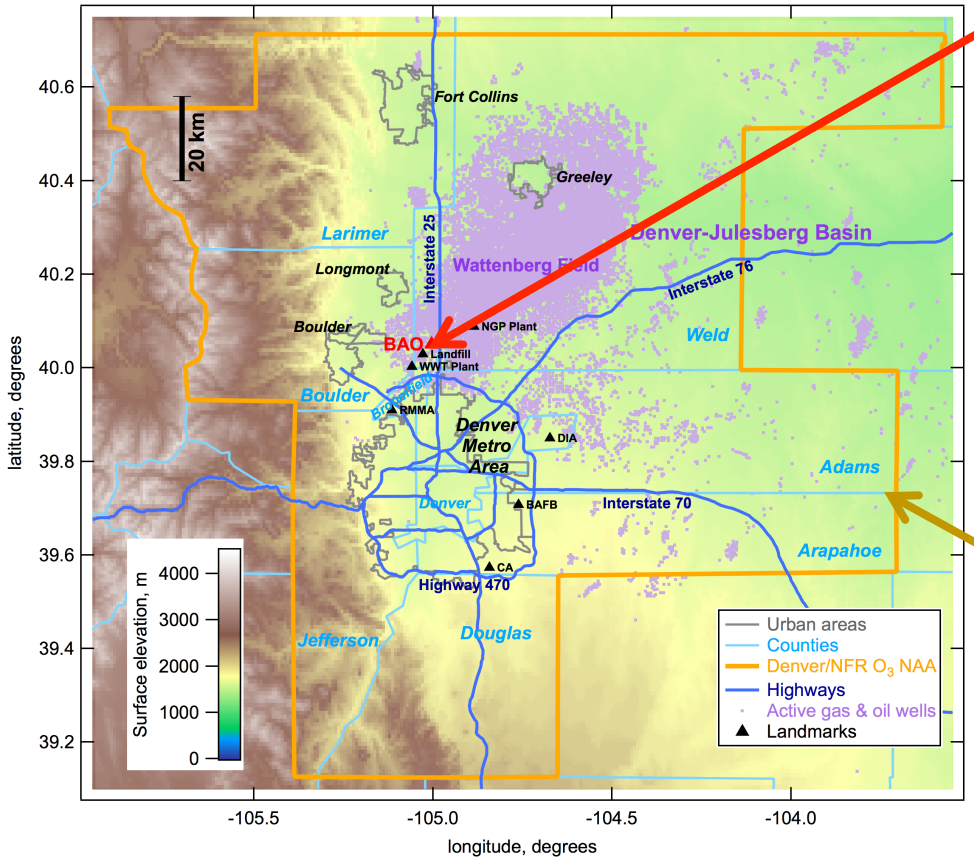
Flux calculation for February 3 2012

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

Parameter	Symbol	% Uncertainty
Wind Speed	V	13%
Cosine of angle between wind direction and normal to heading	cos α	19%
Methane enhancement	ΔX_{CH4}	6.4%
Mixing layer depth	PBL-h(x)	6%
Total Flux (CH_4)	$\dot{n}_{CH4}$	**25%**

This is the uncertainty of a single day observation. Relatively low uncertainty on this observation because of consistent winds.

NOAA 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.

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

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

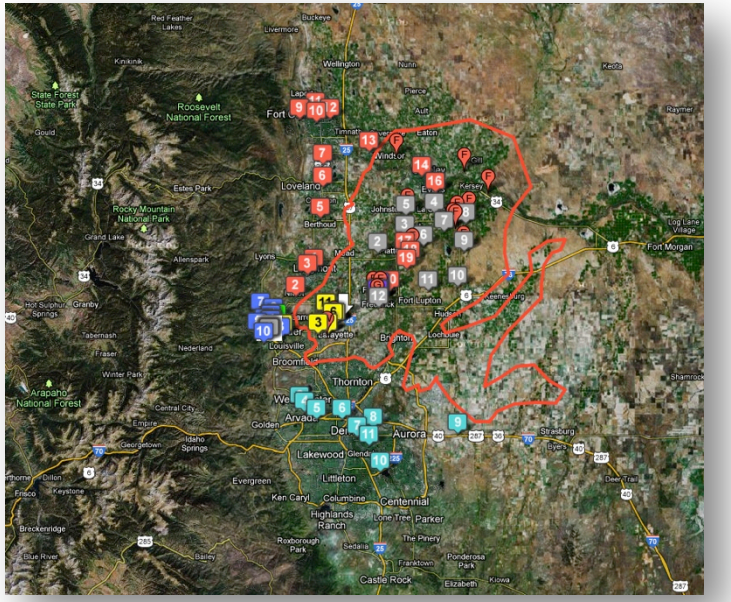
http://www.esrl.noaa.gov/gmd/ccgg/towers/index.html

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

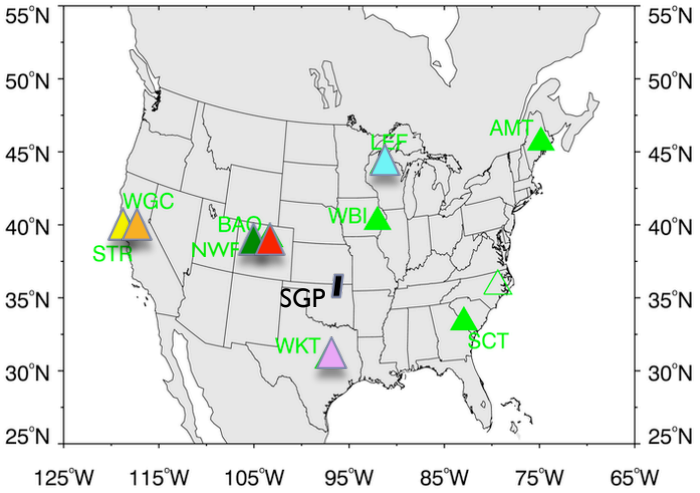
- Mobile Platform to sample close to sources
- High-frequency stable analyzers to detect plumes and target flask sampling
- Discrete air sampling for multi-species chemical analyses in the NOAA lab

Toyota Prius equipped with:

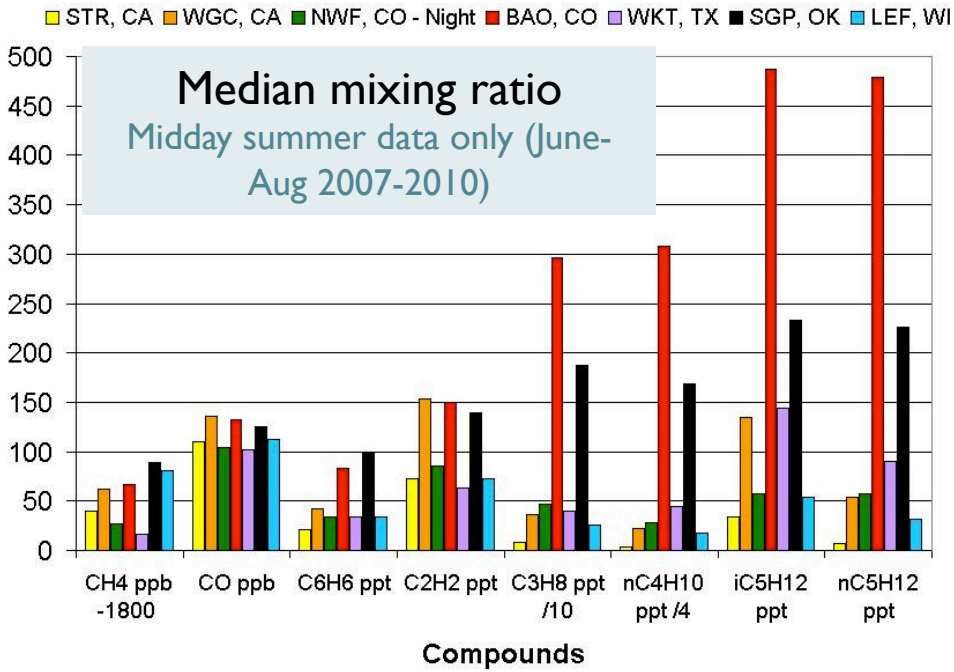
- Fast response CO_2 and CH_4 analyzer (Picarro)
- Real Time Display of Measurements
- GPS
- Programmable Flask Package (PFP with 12 sampling glass flasks) and Programmable Compressor Package (PCP) with GPS



BAO: Distinct alkane signature compared to other continental sites in the US



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

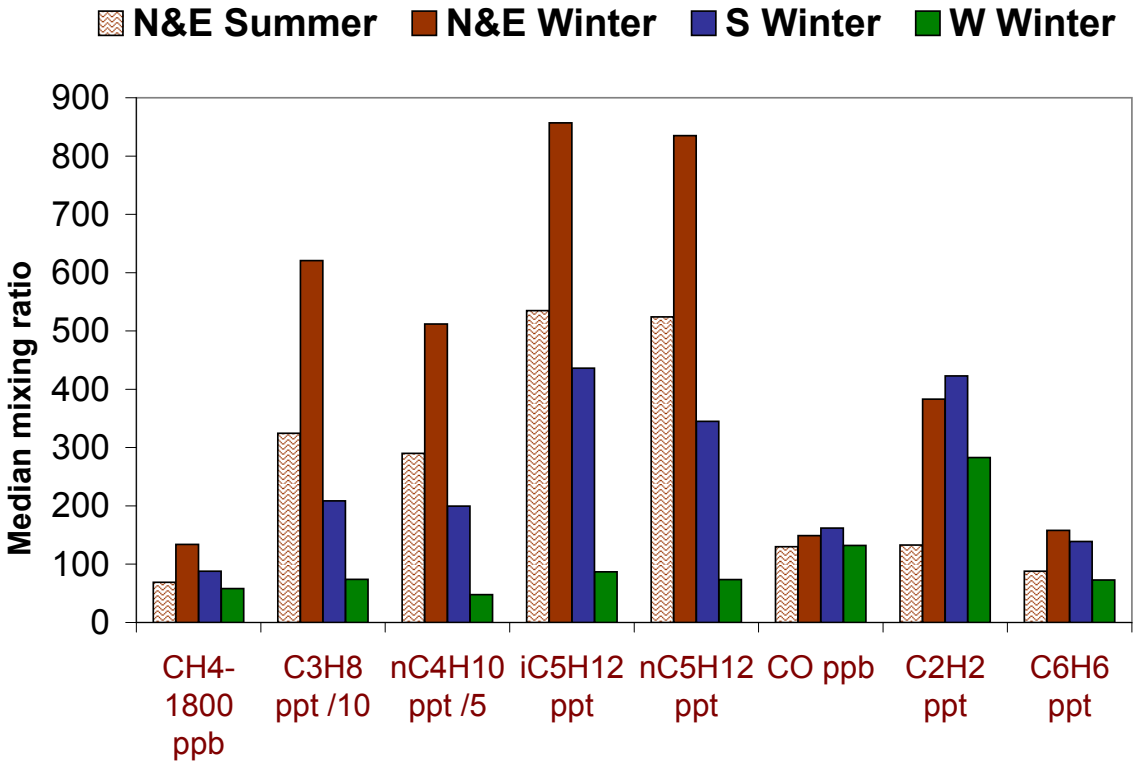


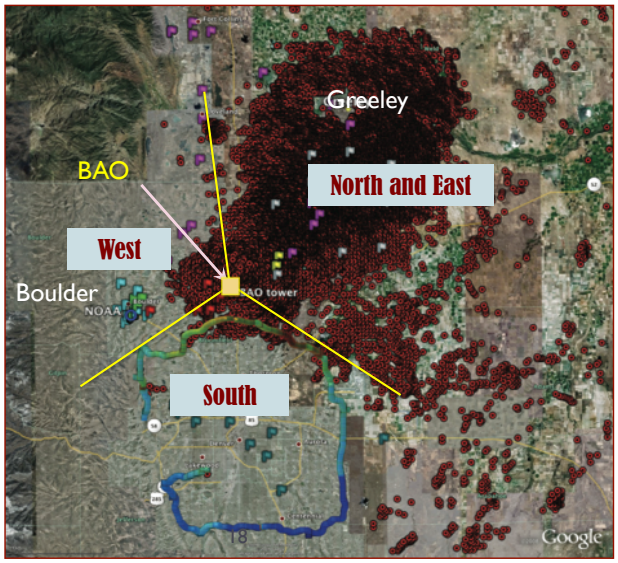
Air samples collected at the BAO and at Oklahoma site (SGP) have a strong alkane signature.

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

BAO: Data Filtered By Wind Sector

Strongest alkane signature in North & East wind sector





North and East — Oil and Gas
Farming + Feedlots
I-25
Small towns

South — Denver Metropolitan Area

West — "Cleaner" Air Sector
Boulder

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).

Regional Scale enhancement of CH_4

Example of Mobile 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.