Estimating emissions from Oil and Natural Gas production using Aircraft Observations

NOAA/CIRES
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Scientific Aviation
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Picarro
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Aerodyne
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US Natural Gas Production

2005  Started shale gas boom
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?

Gasoline Car: Leakage rate <1.8%
Heavy-duty vehicle: Leakage rate <1.0%
Coal Power plant: Leakage rate <3.1%

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 CH$_4$ emissions from natural gas in the US?

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

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

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

Perpendicular wind speed

CH\(_4\) flux

Molar CH\(_4\) enhancement in PBL

Wind

Downwind CH\(_4\)

Background CH\(_4\)

mixing height (PBL)
Not just CH$_4$ in Aircraft

Mass balance

Aircraft:
- Continuous
- CH$_4$
- H2O
- Temp
- Winds

HRDL:
- PBL
- Wind profiles

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

**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
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean Value</th>
<th>Variability (1σ)</th>
<th>Relative Uncertainty</th>
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</thead>
<tbody>
<tr>
<td>wind speed (V)</td>
<td>5.2 m/s</td>
<td>1.2 m/s</td>
<td>24%</td>
</tr>
<tr>
<td>wind direction</td>
<td>55.2°</td>
<td>10.1°</td>
<td></td>
</tr>
<tr>
<td>Vcosθ</td>
<td>3.8 m/s</td>
<td>0.7 m/s</td>
<td>24%</td>
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<tr>
<td>ΔX_{CH4}</td>
<td>56.3 ppb</td>
<td>5.6 ppb</td>
<td>10%</td>
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<tr>
<td>BL depth</td>
<td>1700 m</td>
<td>125 m</td>
<td>7%</td>
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<tr>
<td>CH$_4$ Flux</td>
<td>56000 kg/hr</td>
<td>15000 kg/hr</td>
<td>28%</td>
</tr>
</tbody>
</table>
Inventory v. Top down

Ground $\text{C}_3\text{H}_8/\text{CH}_4$

Aircraft Mass Balance

Aircraft Mass Balance

State Inventory

Top down

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.

23 wells (CH₄ enhancements ppm):
No enhancements = 8
Small enhancements = 9
Large enhancements = 5

[Activity data] X [emissions factor ] = flux

Data provided by Eric Crosson, Picarro
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.