

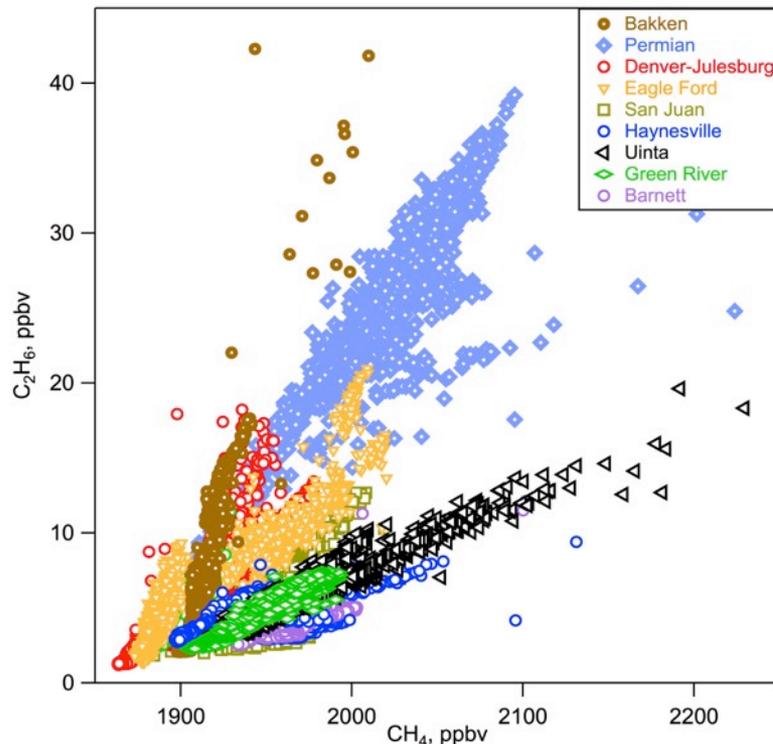
Quantification of methane emissions from oil and natural gas extraction regions in the Central/Western U.S. and comparison to previous studies

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- methane (CH_4) is the second most important greenhouse gas after CO_2
- many studies report inventories of CH_4 are lower than top-down emissions estimates
- fast ethane (C_2H_6) data are key to apportioning CH_4 emissions to specific sources

$\text{C}_2\text{H}_6/\text{CH}_4$ atmospheric enhancement ratio



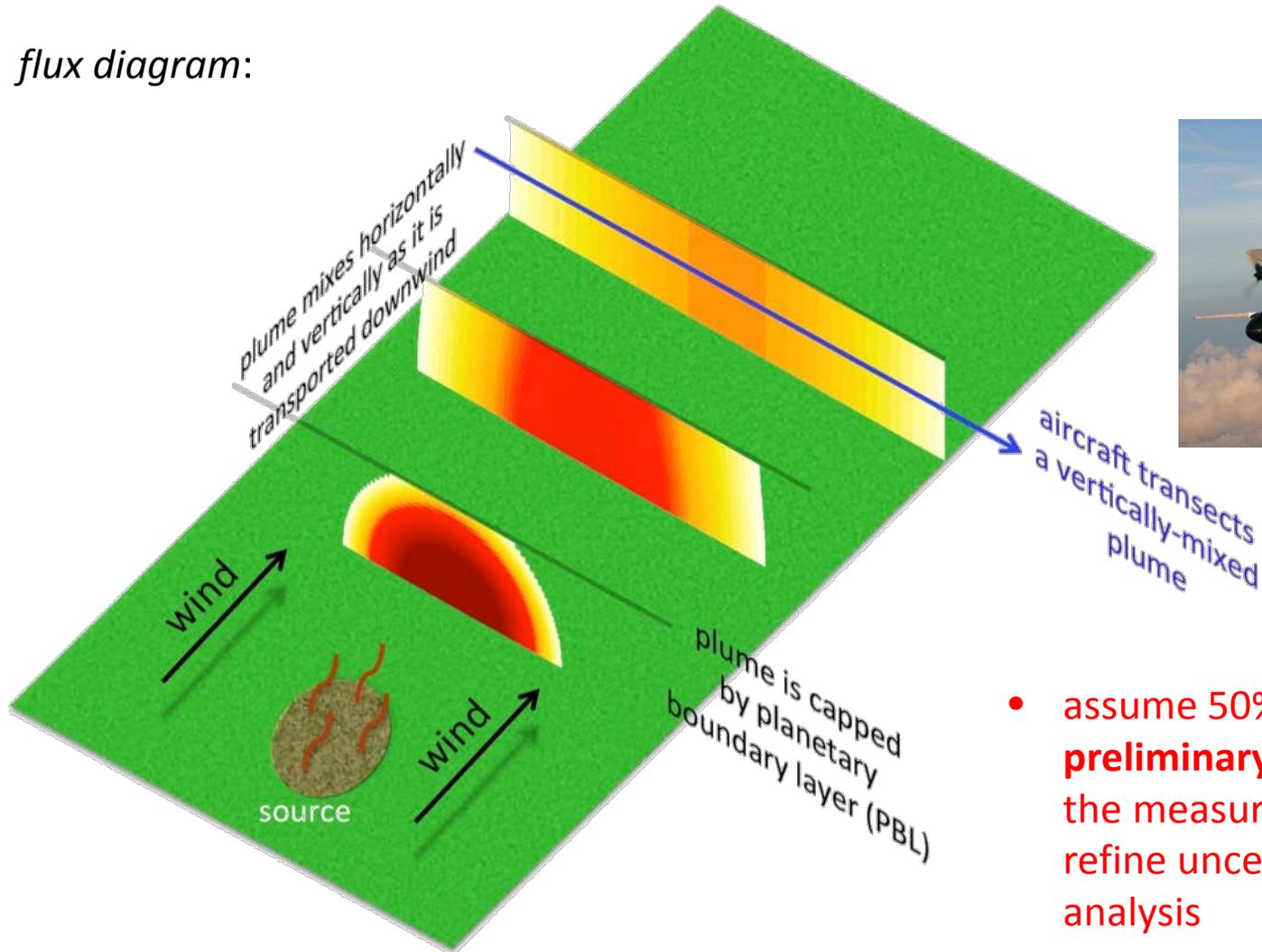
- 1-Hz CH_4 and C_2H_6 data from downwind transects only
- generally larger $\text{C}_2\text{H}_6/\text{CH}_4$ atmospheric enhancement ratios from fields with more oil production
- C_2H_6 and NH_3 measurements will be used to apportion CH_4 emissions to different source sectors (*e.g.*, natural gas and livestock)

CH₄ emissions are determined using the mass balance technique

$$\text{emitted mass}_i = v \cdot \int n_z dz \cdot \int X_i dy$$

= wind speed • PBL height • plume enhancement [White et al., Science, 1976]

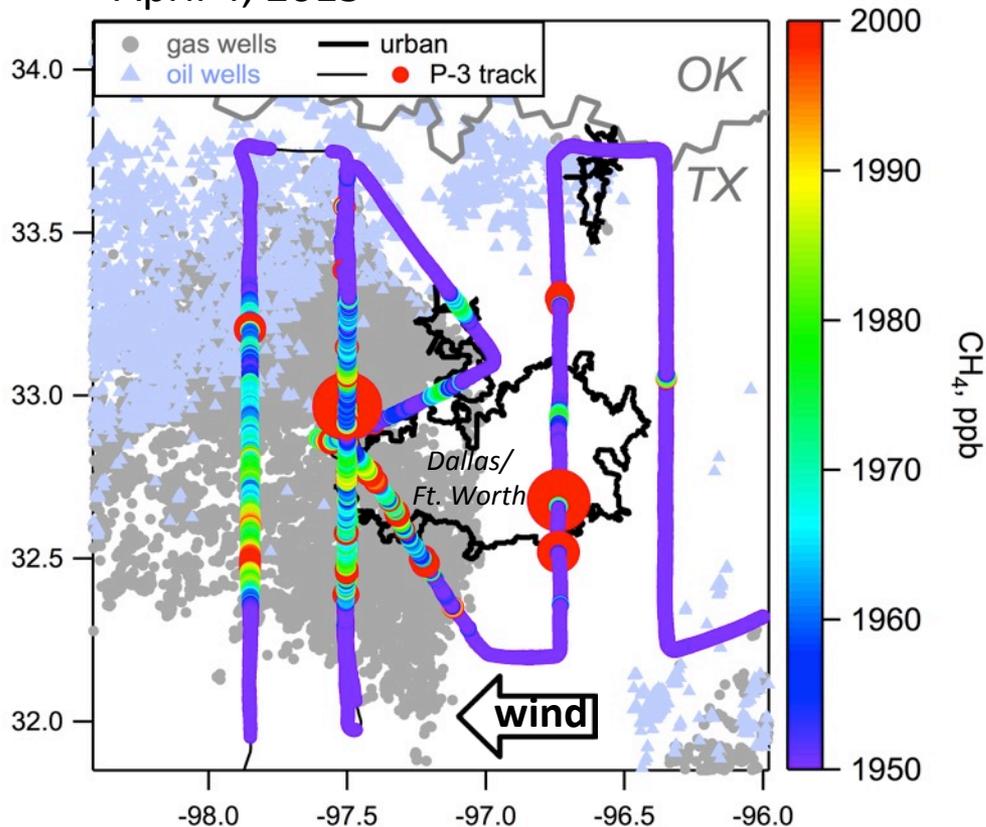
flux diagram:



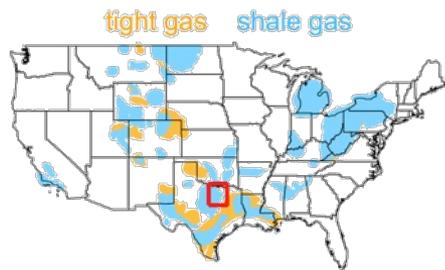
- assume 50% uncertainty for this **preliminary** analysis – we have the measurements needed to refine uncertainties in final analysis

CH₄ emissions from the **Barnett shale** region are *not significantly different* than found in a 2013 airborne study

April 4, 2015

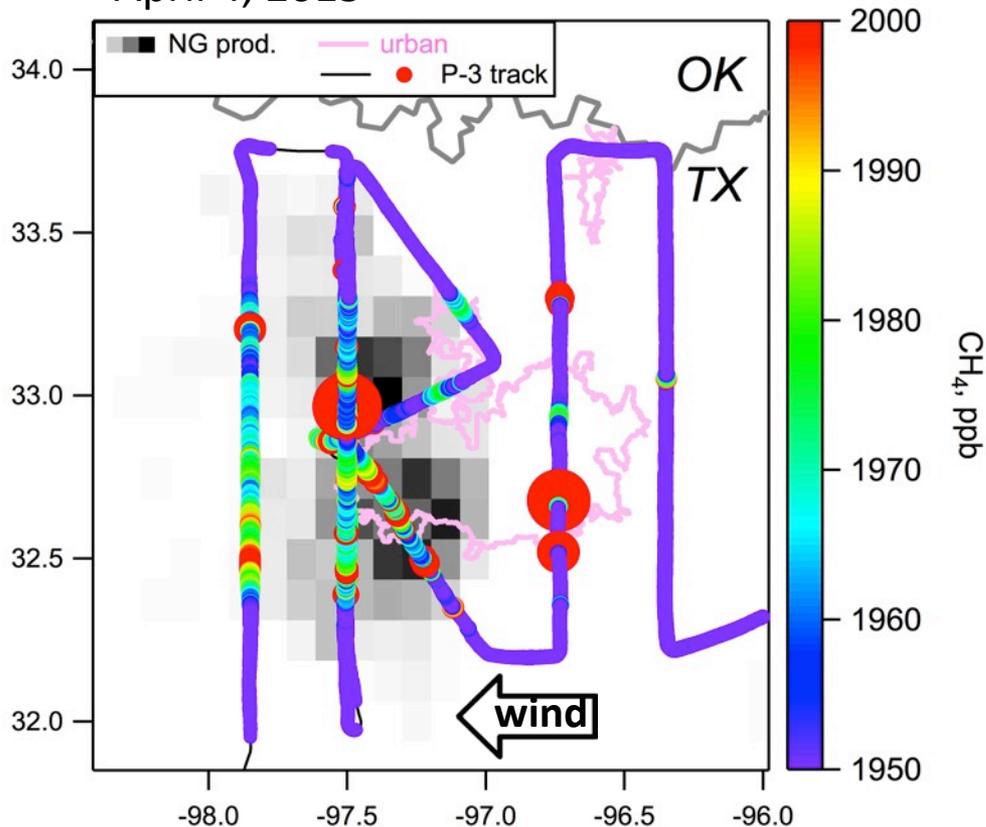


- landfill CH₄ emissions are apparent in Dallas-Ft. Worth plume
- most CH₄ enhancement above natural gas wells; but well locations alone do not always indicate likeliest CH₄ sources

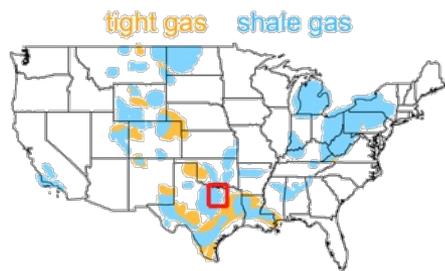


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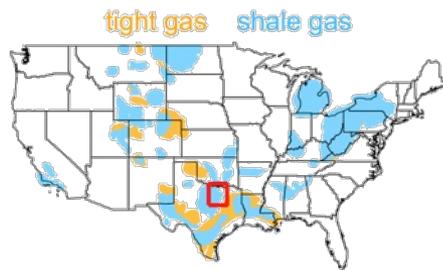
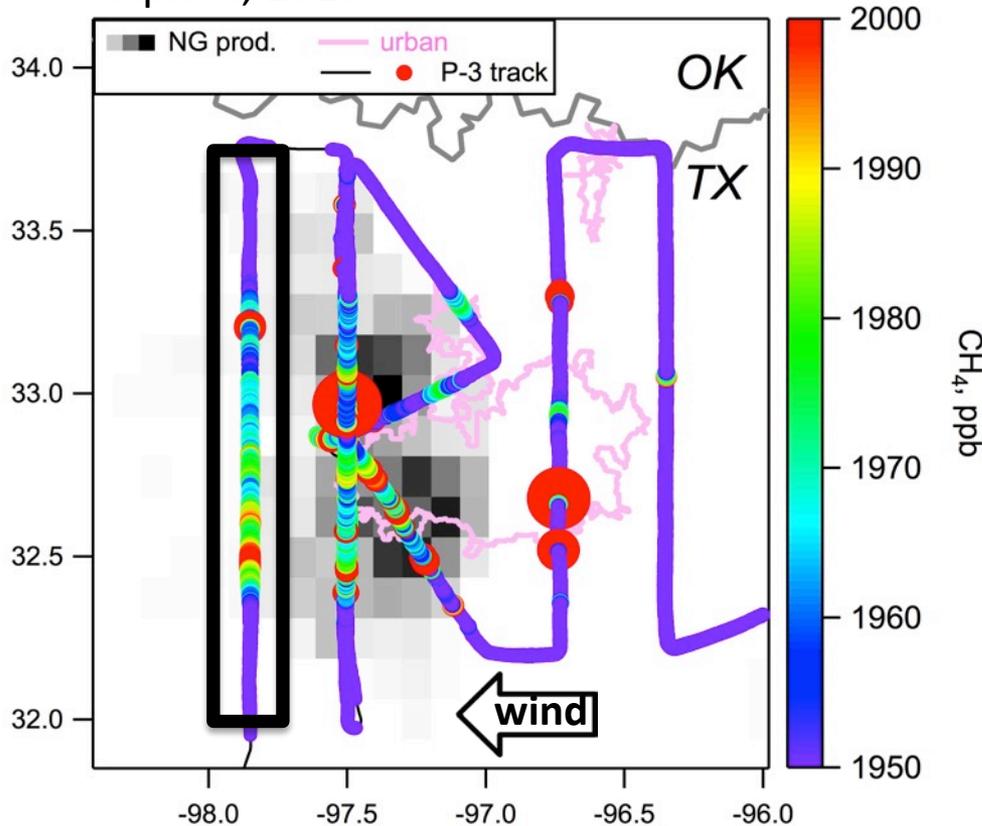


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- highest CH₄ enhancement over and downwind of highest natural gas production (normalized to black = 1)

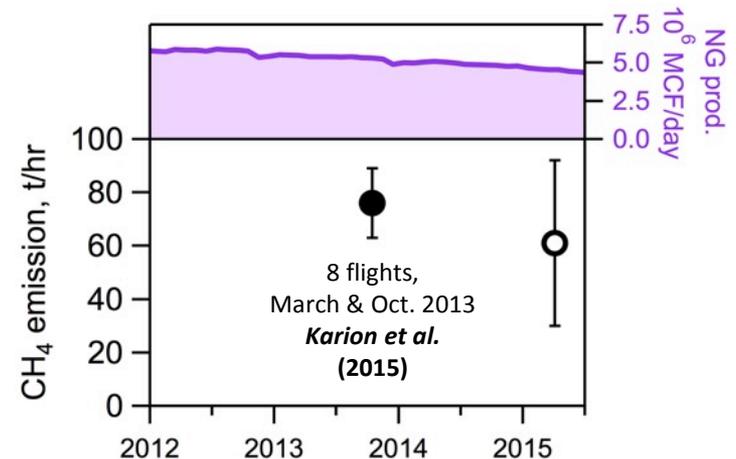


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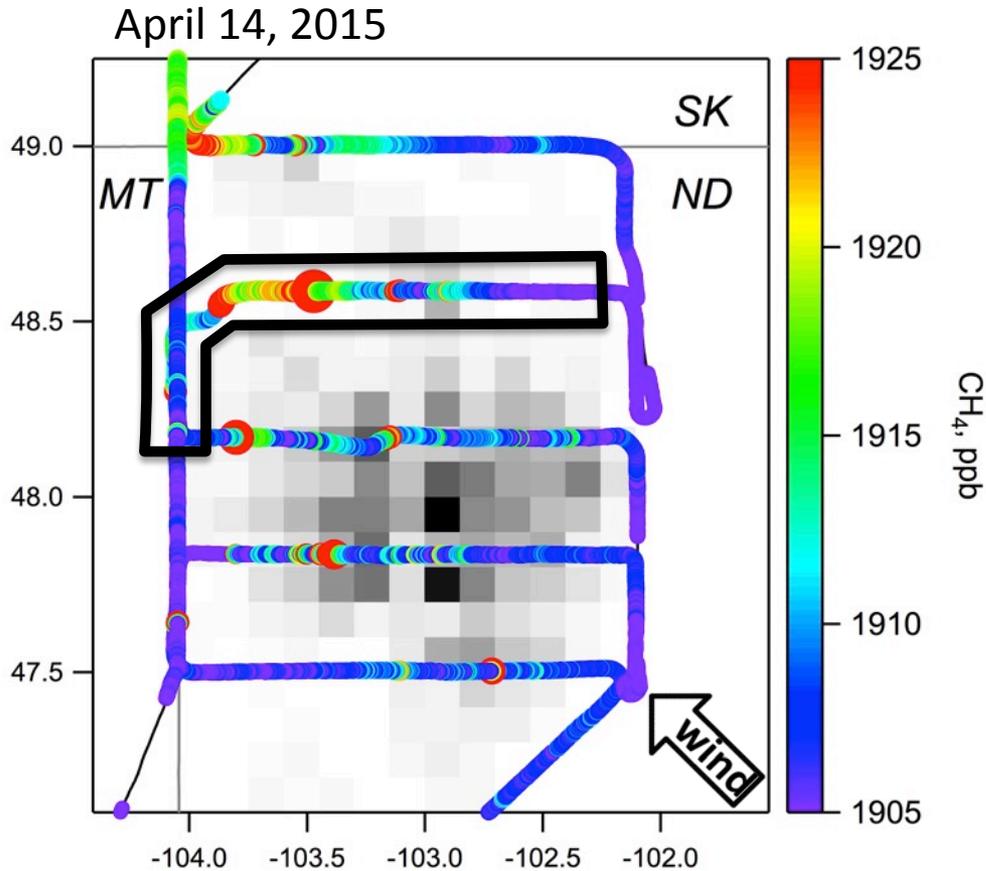
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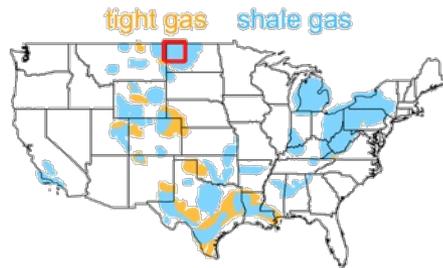
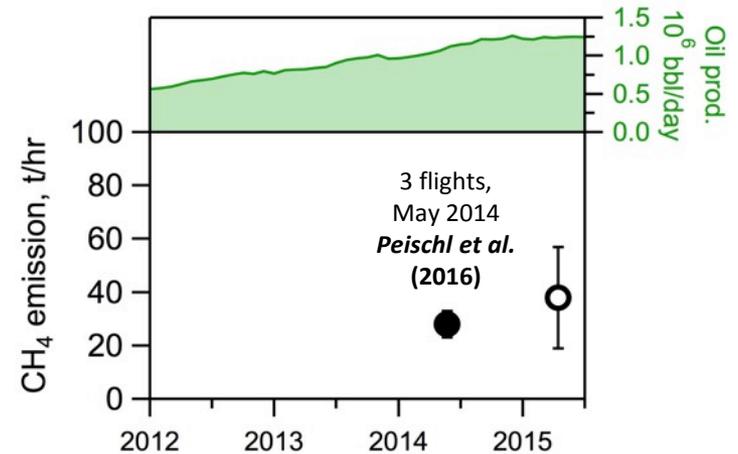
CH₄ attribution among different sources:

Karion et al. (2015) & Smith et al. (2015) attributed 71–85% of CH₄ from oil & gas sources

CH₄ emissions from the Bakken shale region are *not significantly different* than found in a 2014 airborne study



- remote location results in few sources of CH₄ immediately upwind
- highest CH₄ enhancement over and downwind of highest natural gas production (normalized to black = 1)

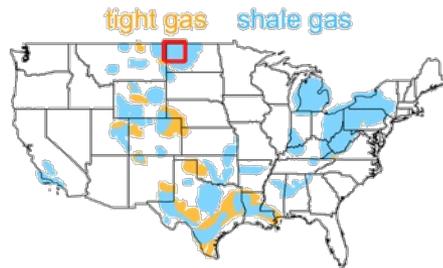
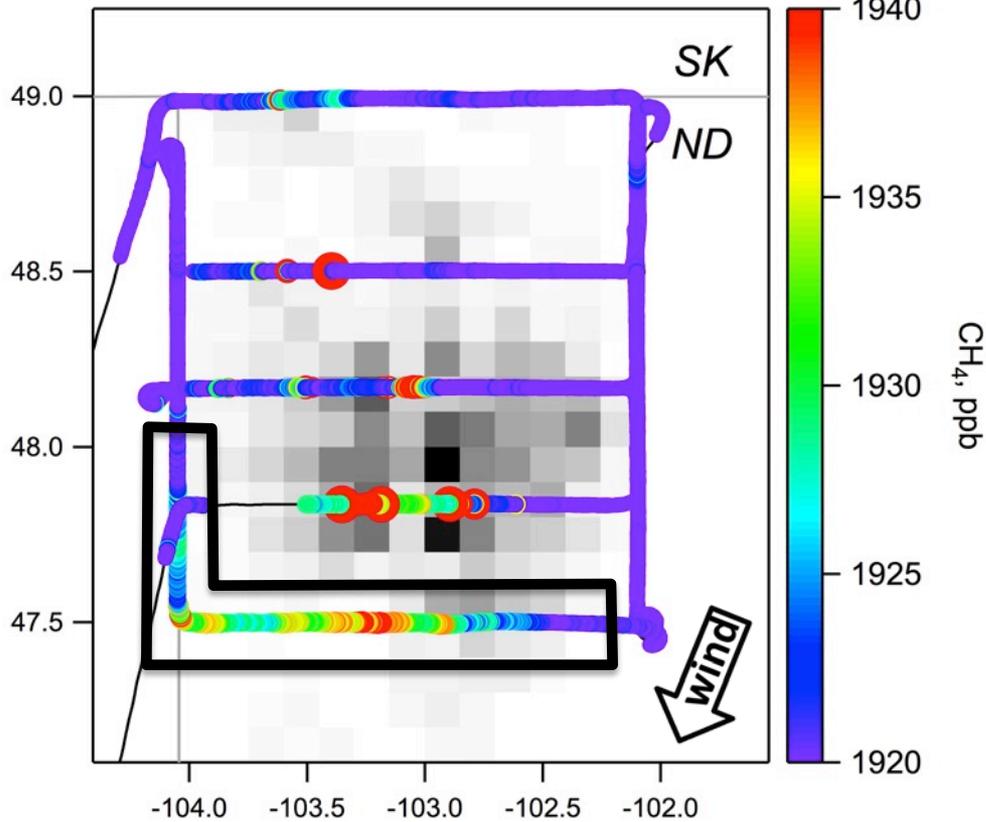


Attribution is simplified in this remote region

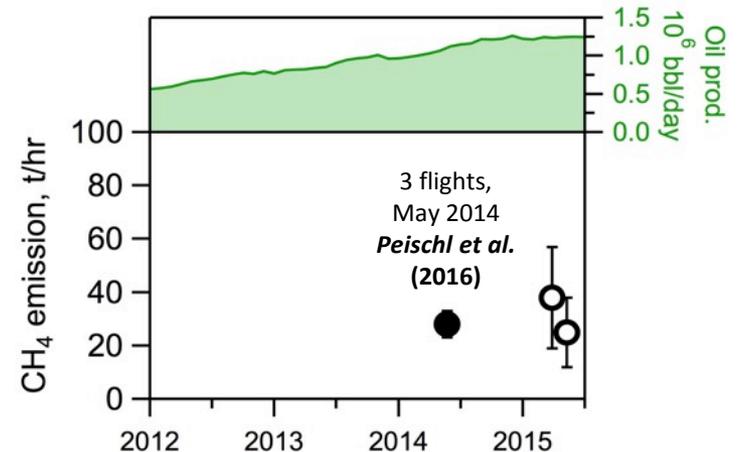
CH₄ sources dominated by oil & gas

CH₄ emissions from the Bakken shale region are *not significantly different* than found in a 2014 airborne study

April 21, 2015



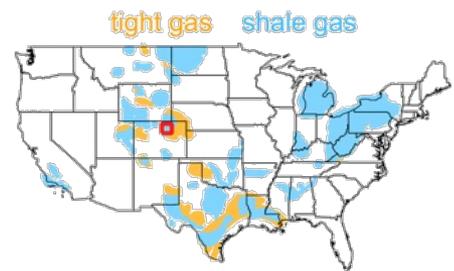
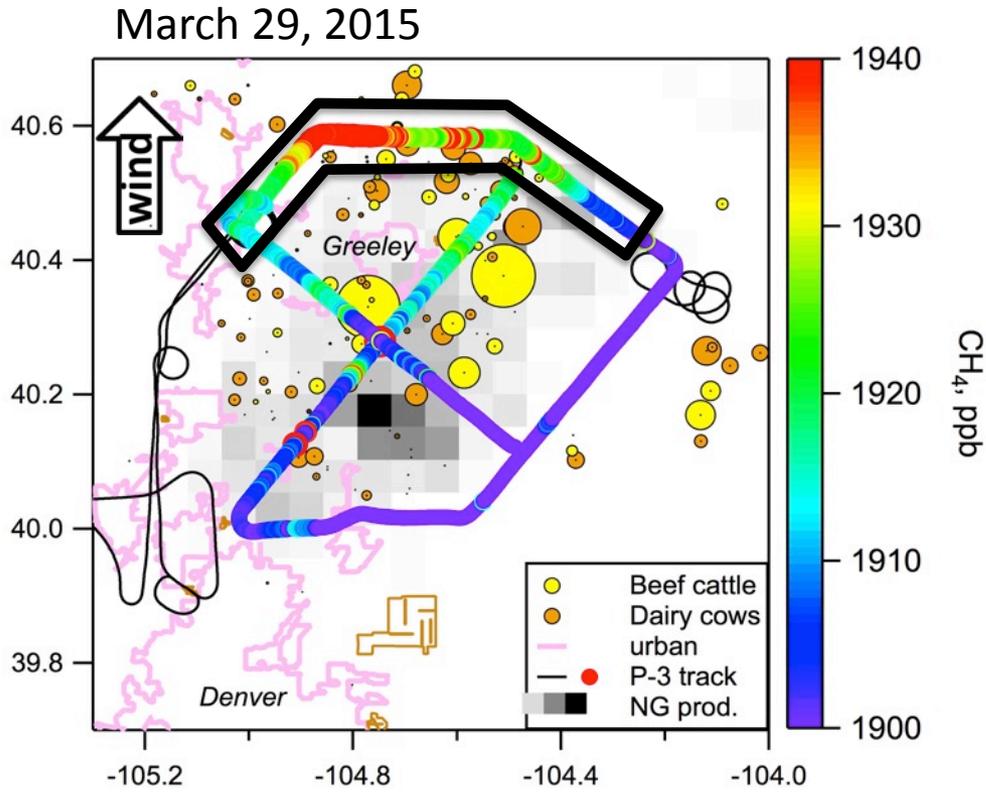
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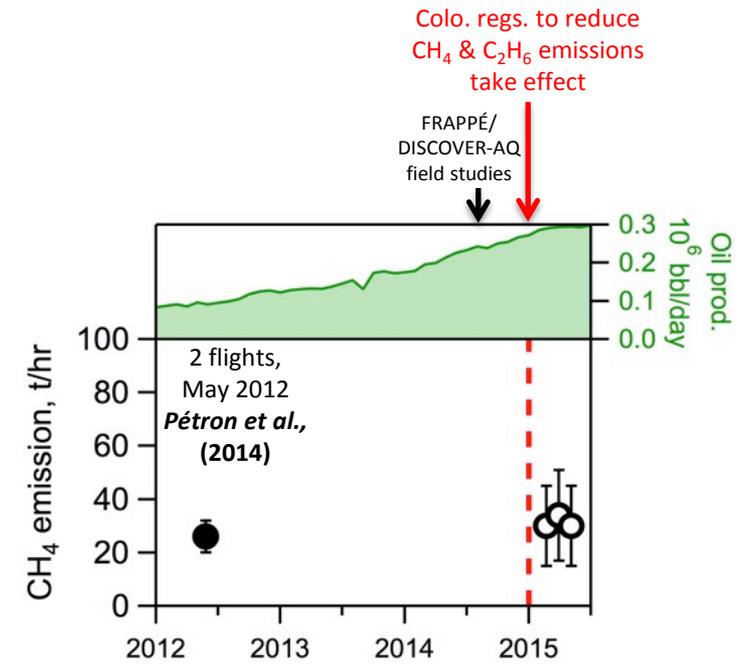
Attribution is simplified in this remote region

CH₄ sources dominated by oil & gas

CH₄ emissions from the Denver-Julesburg Basin region are *not significantly different* than found in a 2012 airborne study



- in addition to oil & gas and urban CH₄ sources, the Denver-Julesburg Basin has significant agricultural sources of CH₄

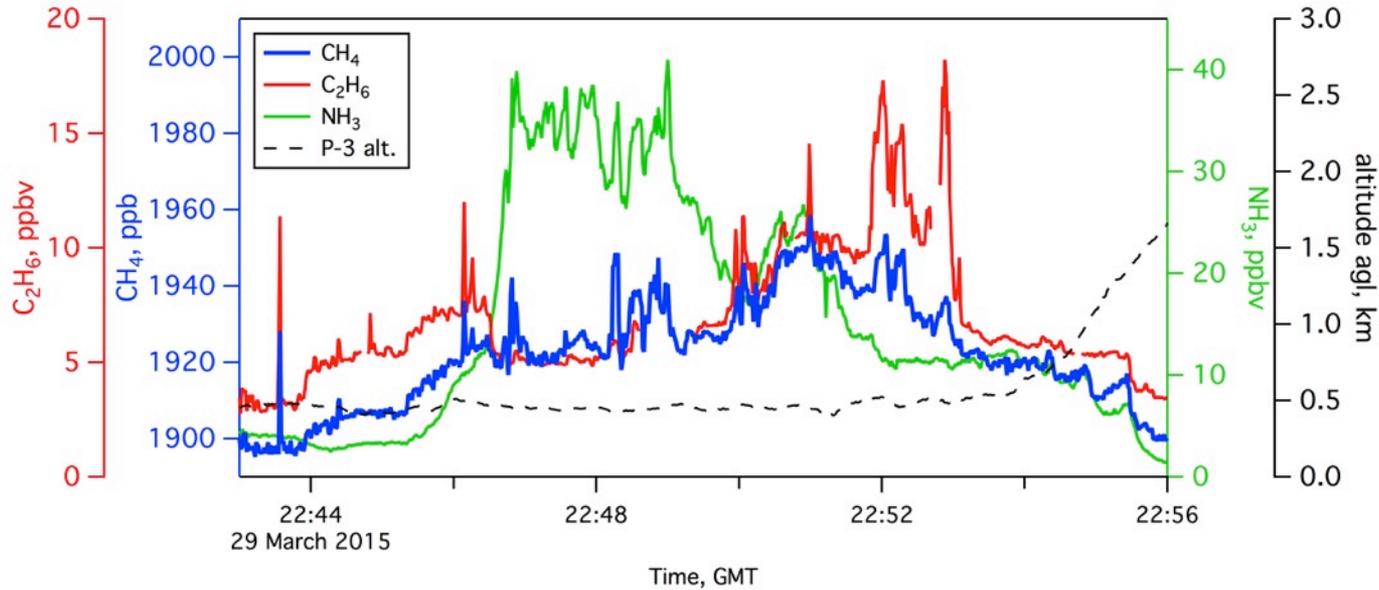


CH₄ attribution among different sources:

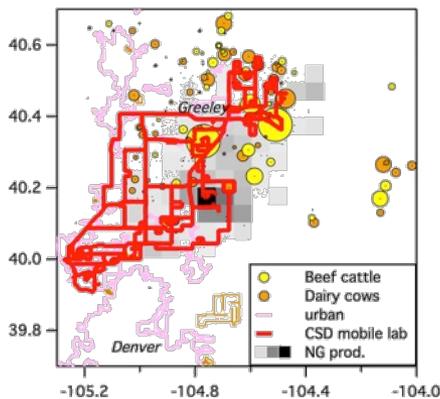
Pétron et al. (2014): 66% of CH₄ from oil & gas sources, 33% of CH₄ from agricultural sources

CH₄ emissions from **Denver-Julesburg Basin** are yet to be apportioned using C₂H₆ and NH₃ data

chemically-instrumented P-3 aircraft data



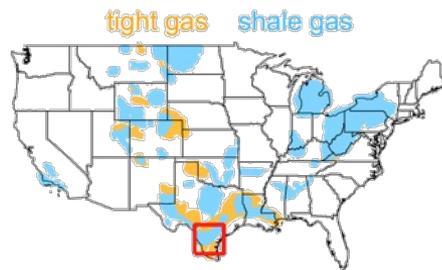
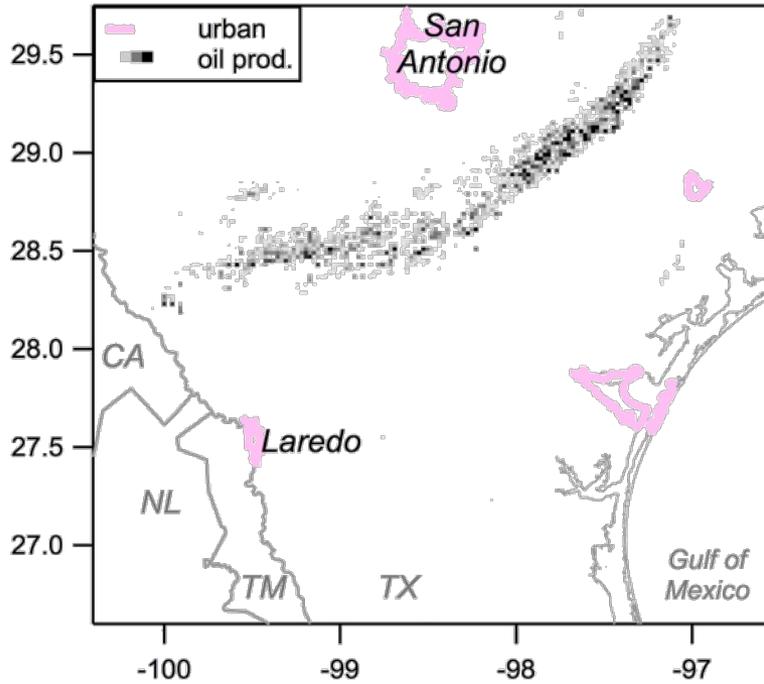
chemically-instrumented
CSD mobile lab data



Collaborative effort among NOAA, NASA, NSF, Aerodyne, Princeton University, University of Colorado, Colorado State, and others to quantify and apportion CH₄ in this region

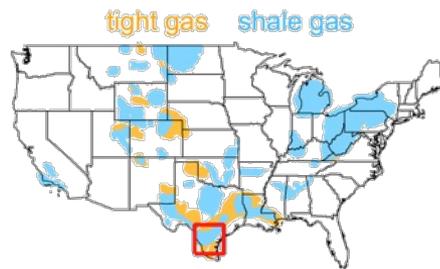
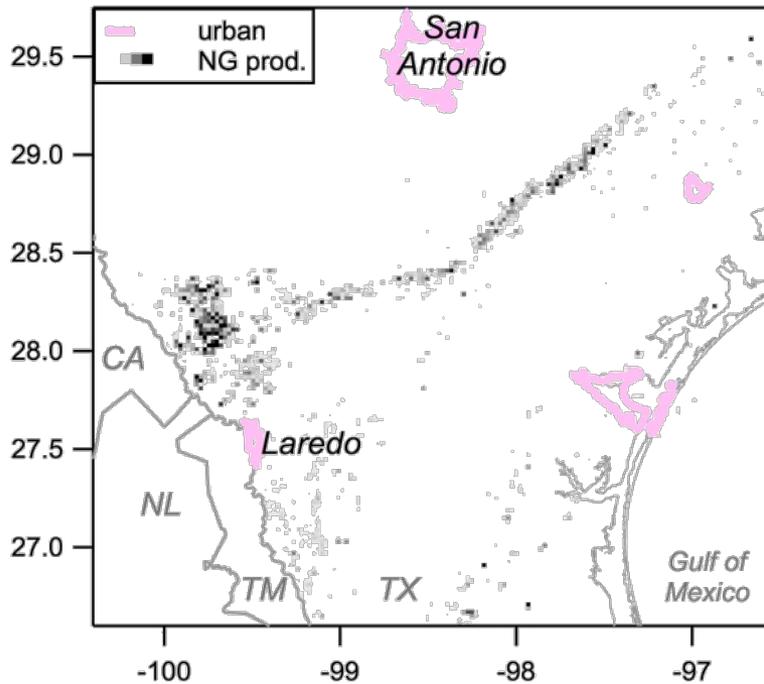
CH₄ emissions from the **Eagle Ford shale** region determined for first time using aircraft in situ data

- Eagle Ford shale is a source of both oil and natural gas



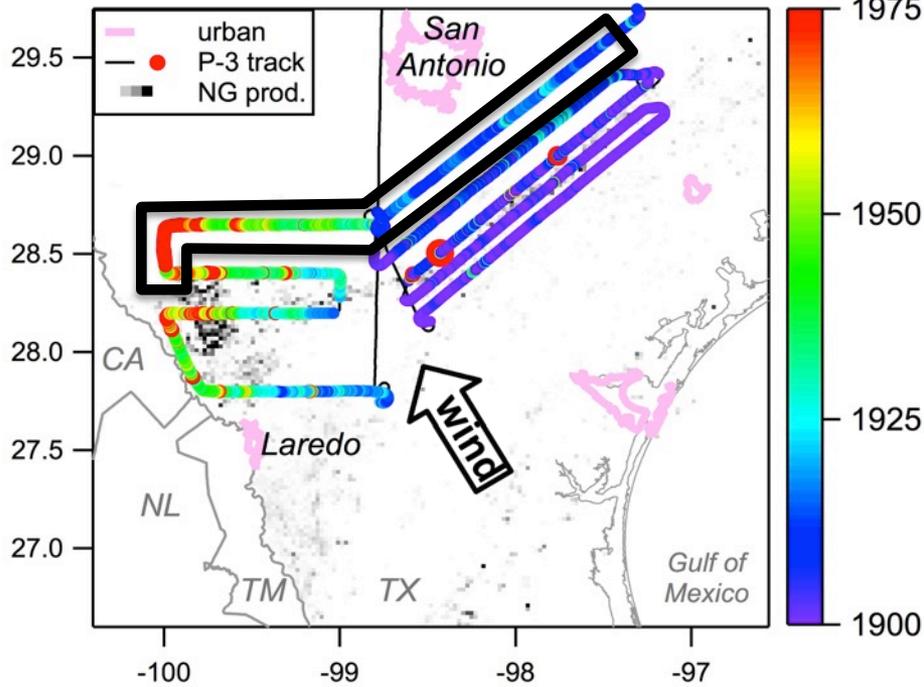
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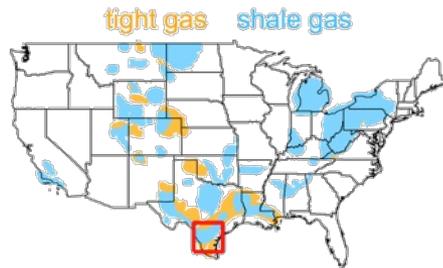
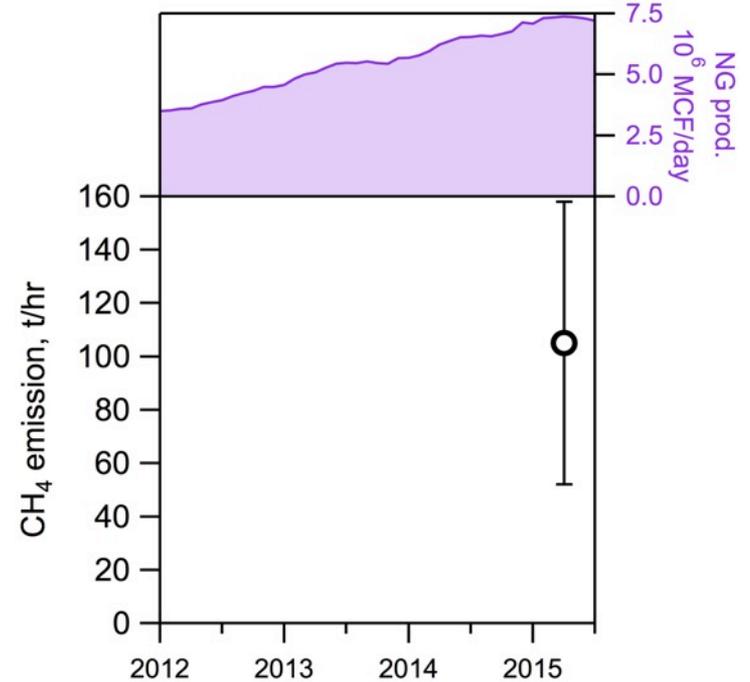


CH₄ emissions from the Eagle Ford shale region determined for first time using aircraft in situ data

April 2, 2015



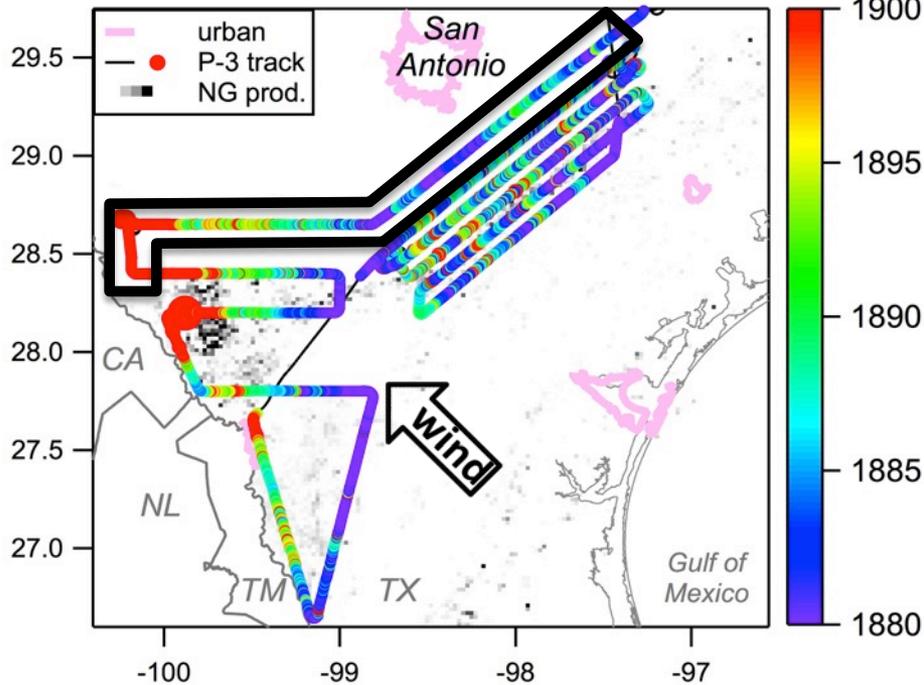
- Eagle Ford shale is a source of both oil and natural gas



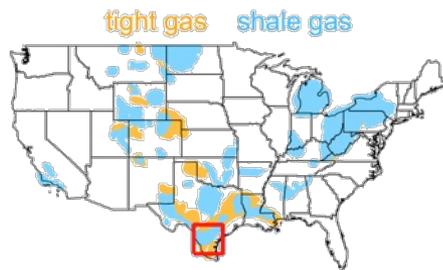
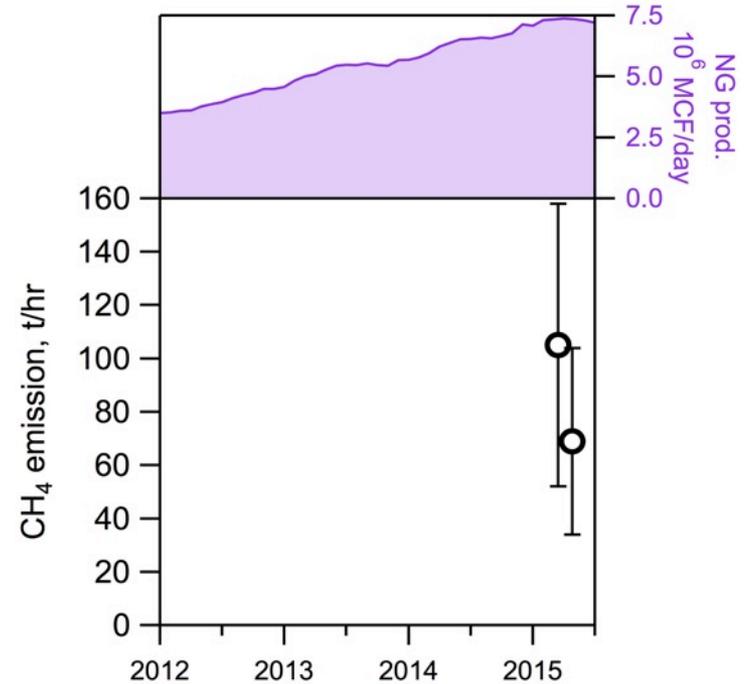
- total CH₄ mass emission rate from Eagle Ford is the largest of all basins studied to date

CH₄ emissions from the Eagle Ford shale region determined for first time using aircraft in situ data

April 7, 2015



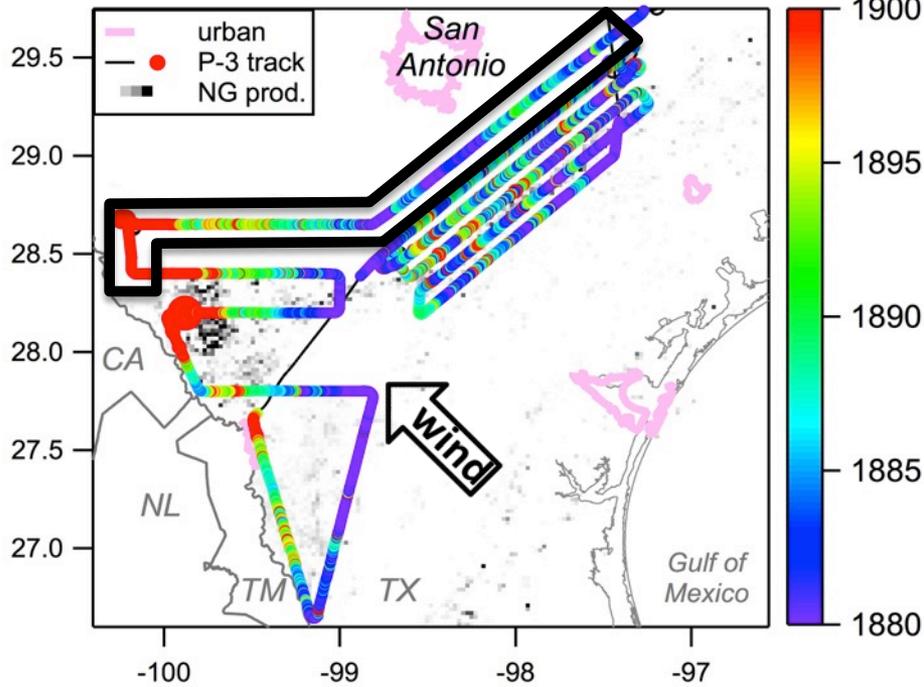
- Eagle Ford shale is a source of both oil and natural gas



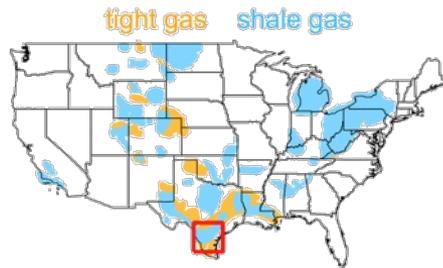
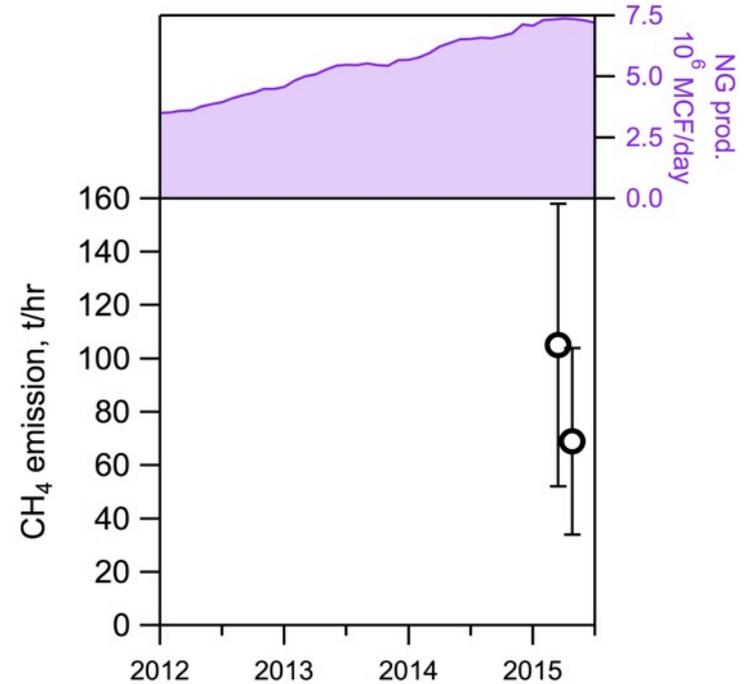
- total CH₄ mass emission rate from Eagle Ford is the largest of all basins studied to date
- Second flight suggests lower CH₄ emissions to the east

CH₄ emissions from the Eagle Ford shale region determined for first time using aircraft in situ data

April 7, 2015

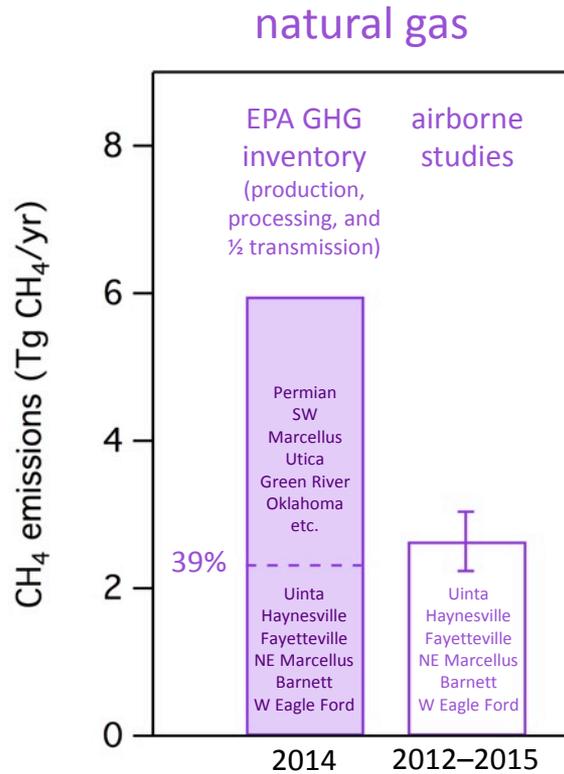


- Eagle Ford shale is a source of both oil and natural gas



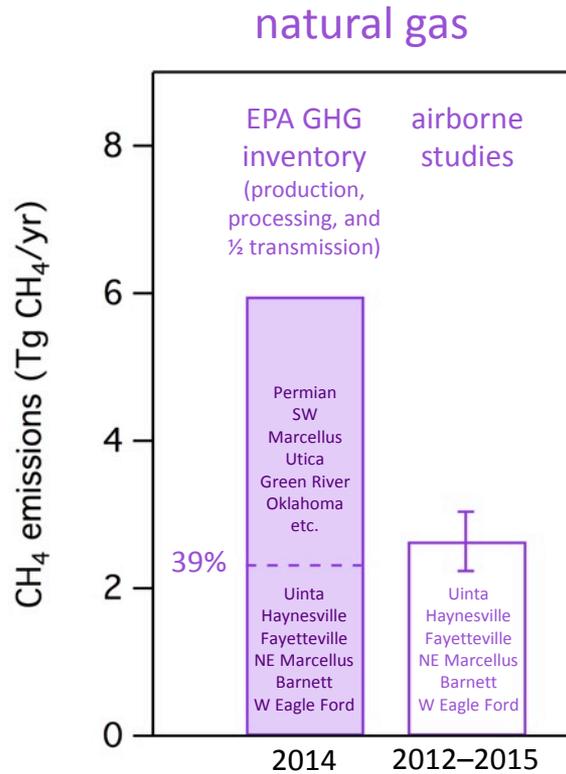
We have now quantified emissions from approximately **60%** of shale gas production in the U.S.

CH₄ emissions from NG producing regions are on pace with latest EPA GHG inventory scaled by NG production

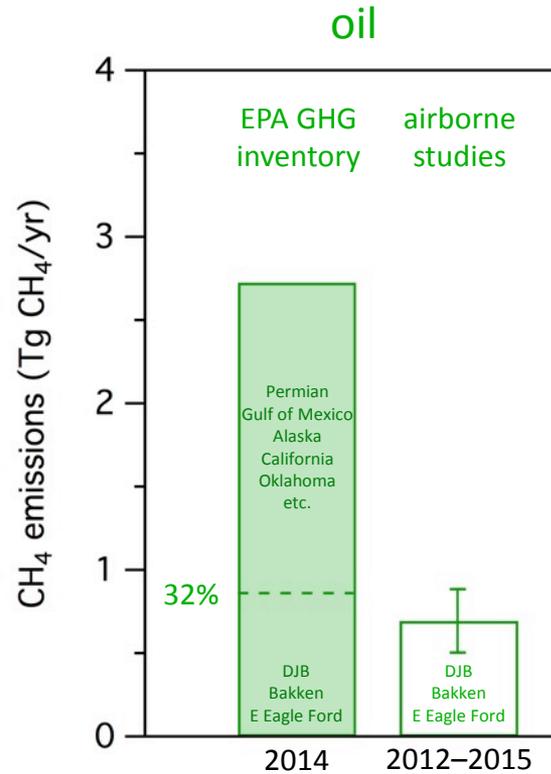


regions that account for ~**39%** of U.S. natural gas production account for **44 ± 7%** of 2014 EPA GHG inventory emissions

CH₄ emissions from oil producing regions are on pace with latest EPA GHG inventory scaled by oil production

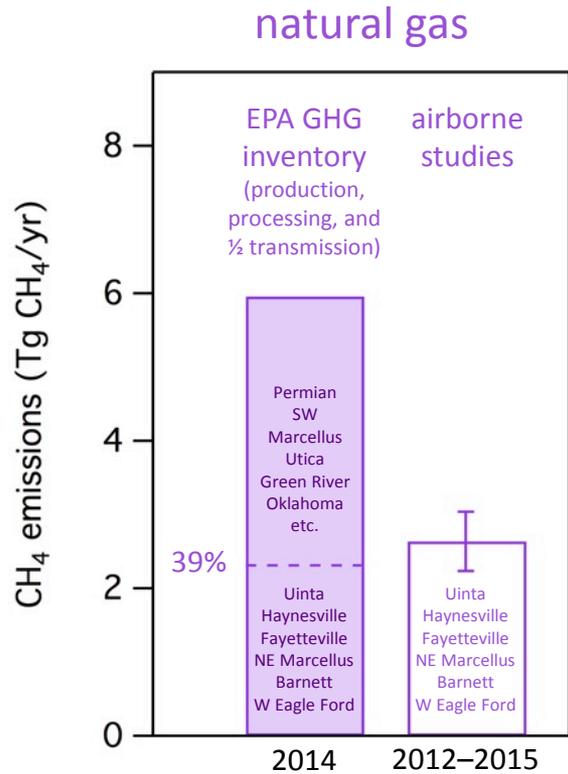


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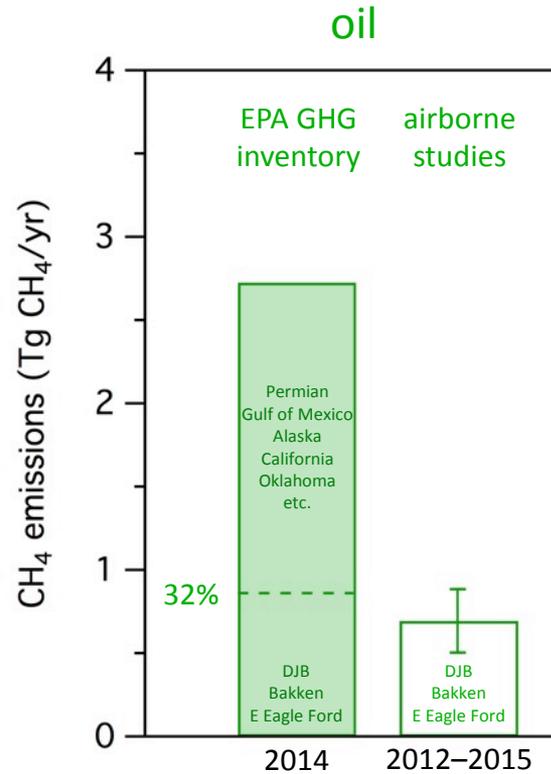


regions that account for ~**32%** of U.S. oil production account for **25 ± 7%** of 2014 EPA GHG inventory emissions

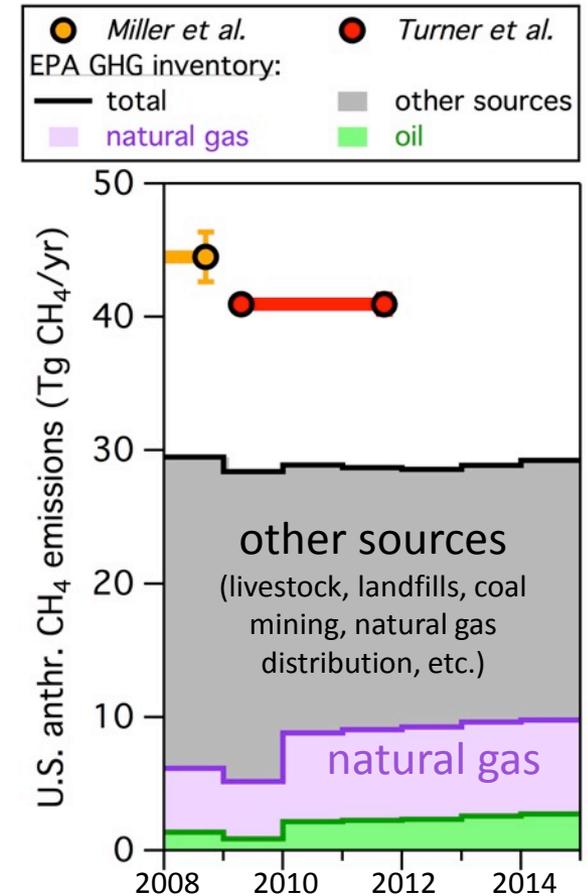
CH₄ emissions from oil & gas producing regions don't yet explain differences between specific top-down and EPA GHG inventory emissions estimates



regions that account for ~**39%** of U.S. natural gas production account for **44 ± 7%** of 2014 EPA GHG inventory emissions



regions that account for ~**32%** of U.S. oil production account for **25 ± 7%** of 2014 EPA GHG inventory emissions



emissions estimated from specific top-down studies still greater than latest 2014 EPA GHG inventory emissions

Conclusions

- analysis of SONGNEX data will provide refined estimates of CH_4 and C_2H_6 emissions from many different major oil and natural gas producing regions
- final CH_4 source apportionment will use simultaneous measurements of C_2H_6 and NH_3
- oil and natural gas producing regions studied to date do not account for the apparent difference between specific top-down and 2014 EPA GHG inventory CH_4 emissions estimates in the U.S.

