Observing methane from space

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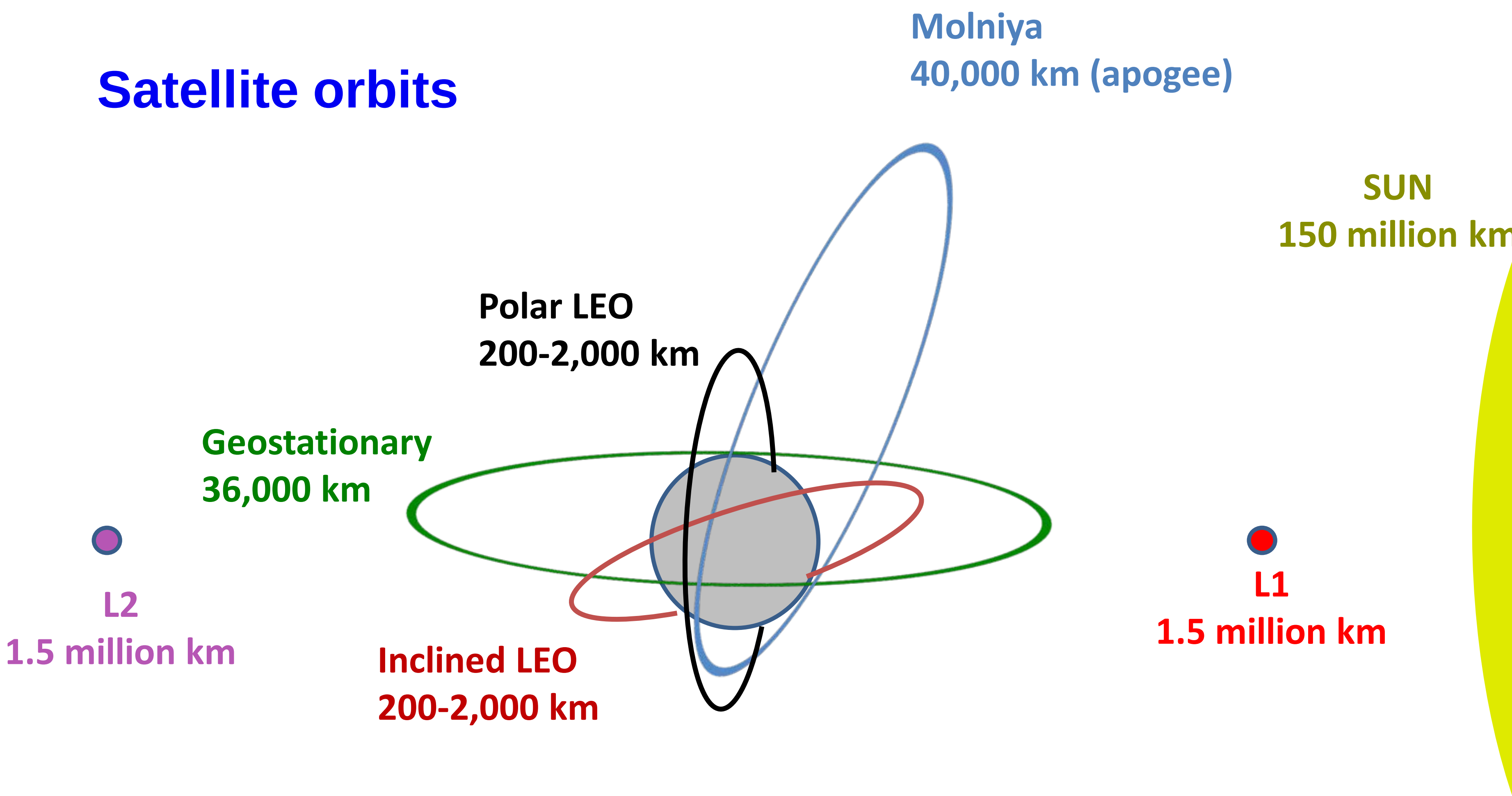
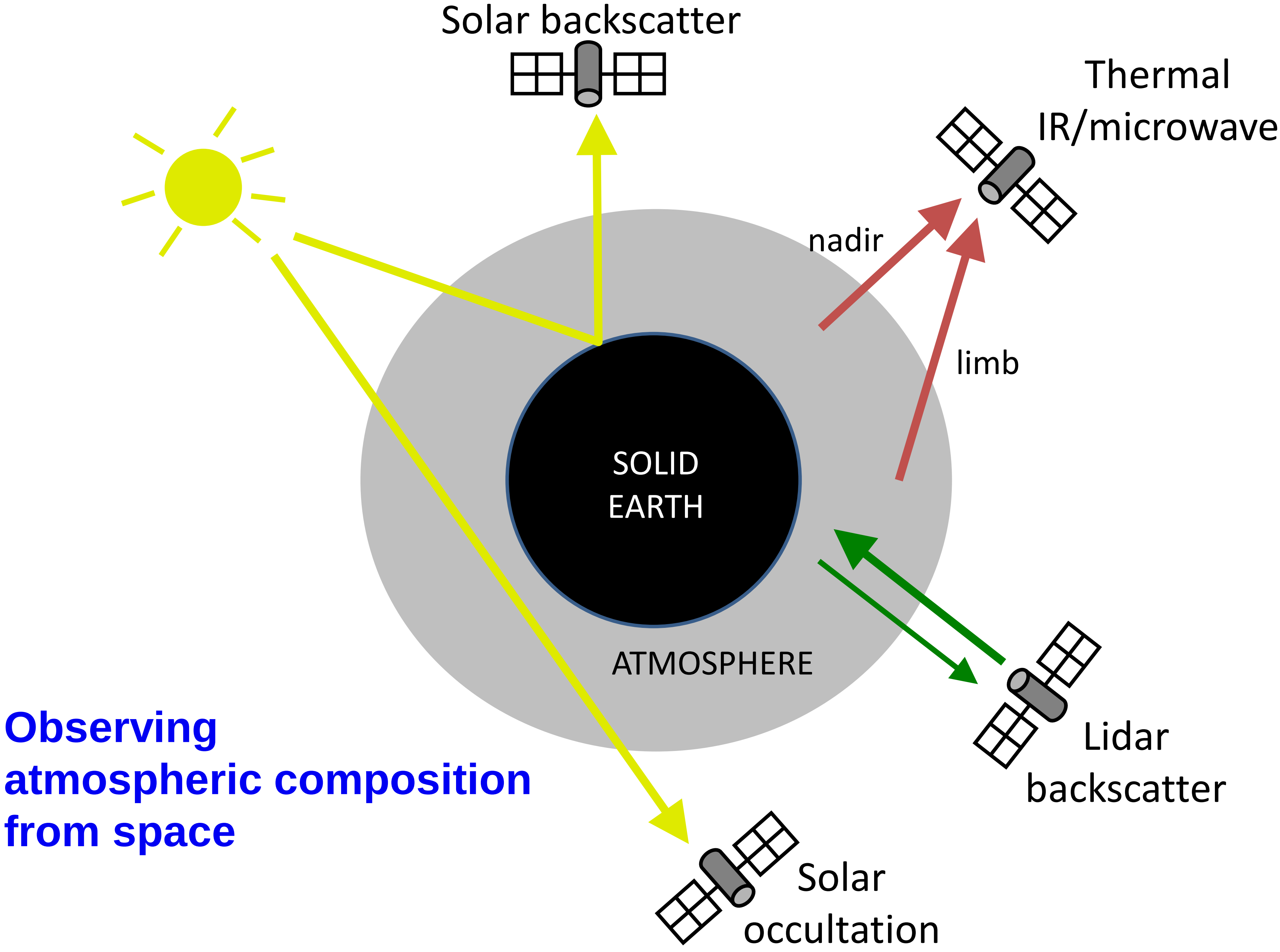
Atmospheric Chemistry Modeling Group

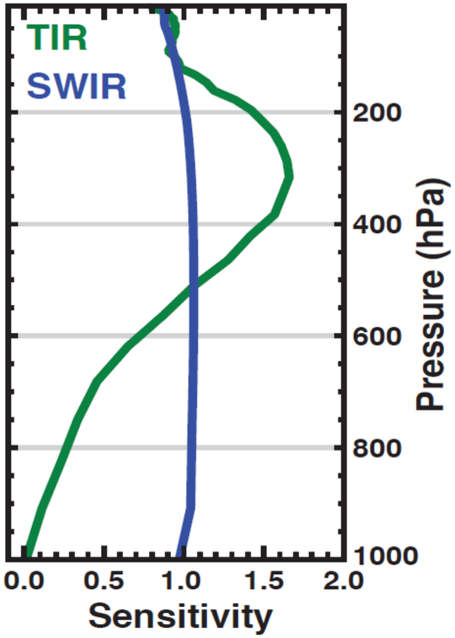
Satellite orbits

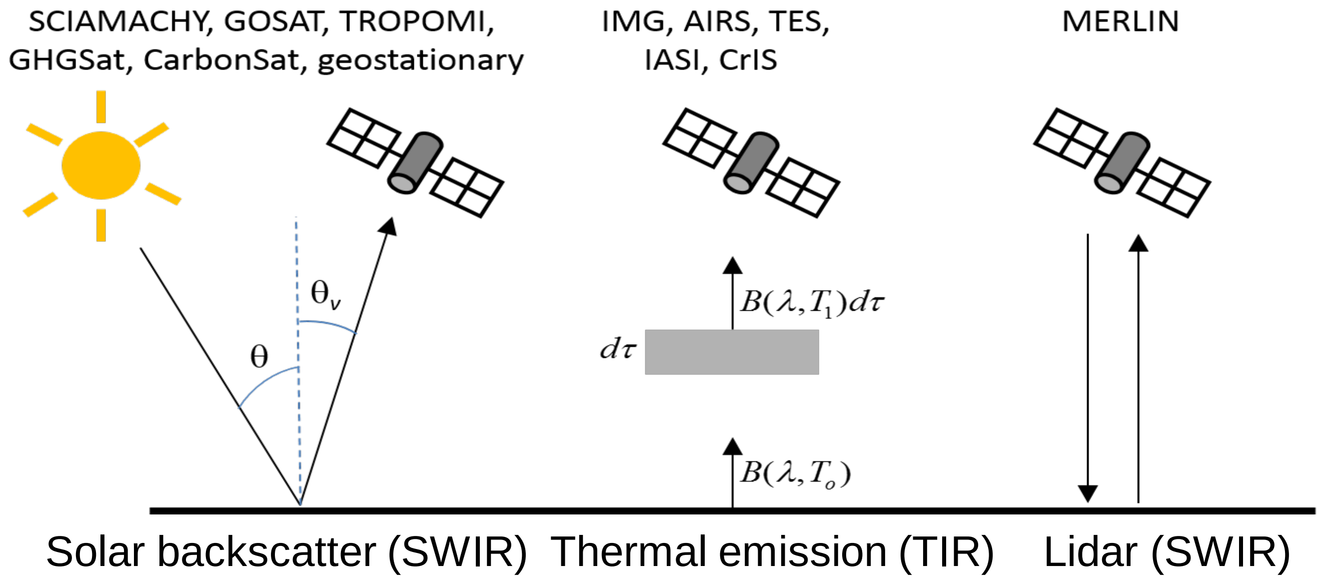




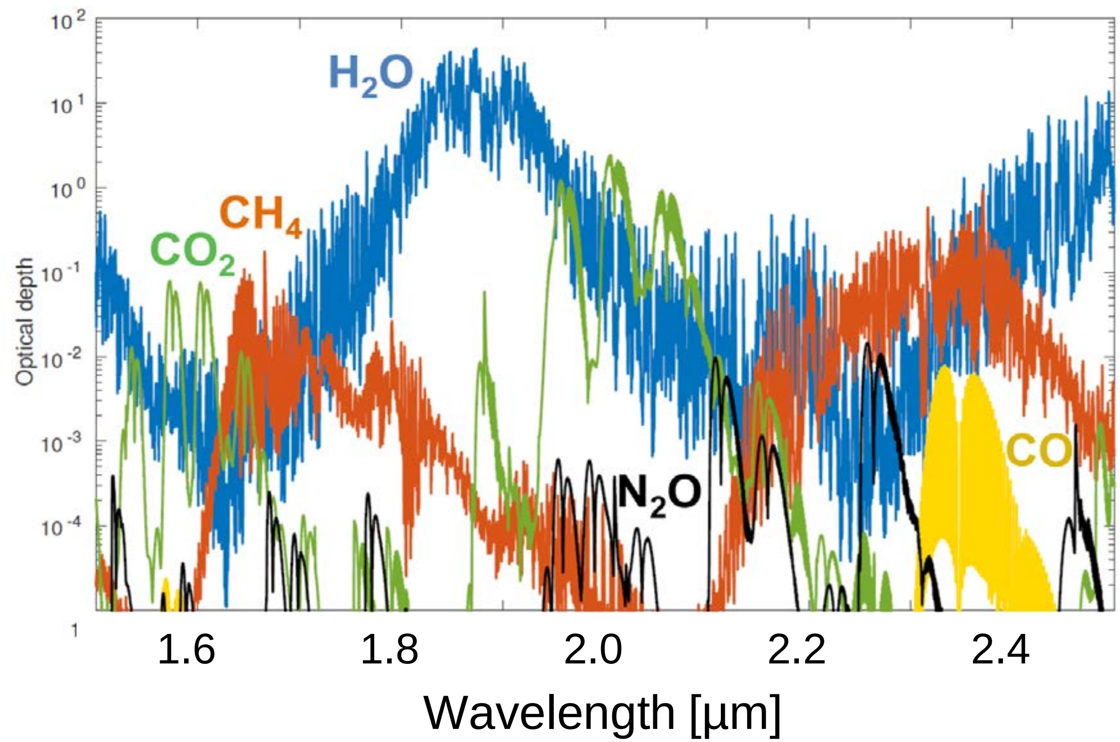
Solar backscatter
Thermal
IR/microwave
nadir
limb
SOLID
EARTH
ATMOSPHERE
Lidar
backscatter
Solar
occultation
Observing
atmospheric composition
from space

Space-based instruments for atmospheric methane

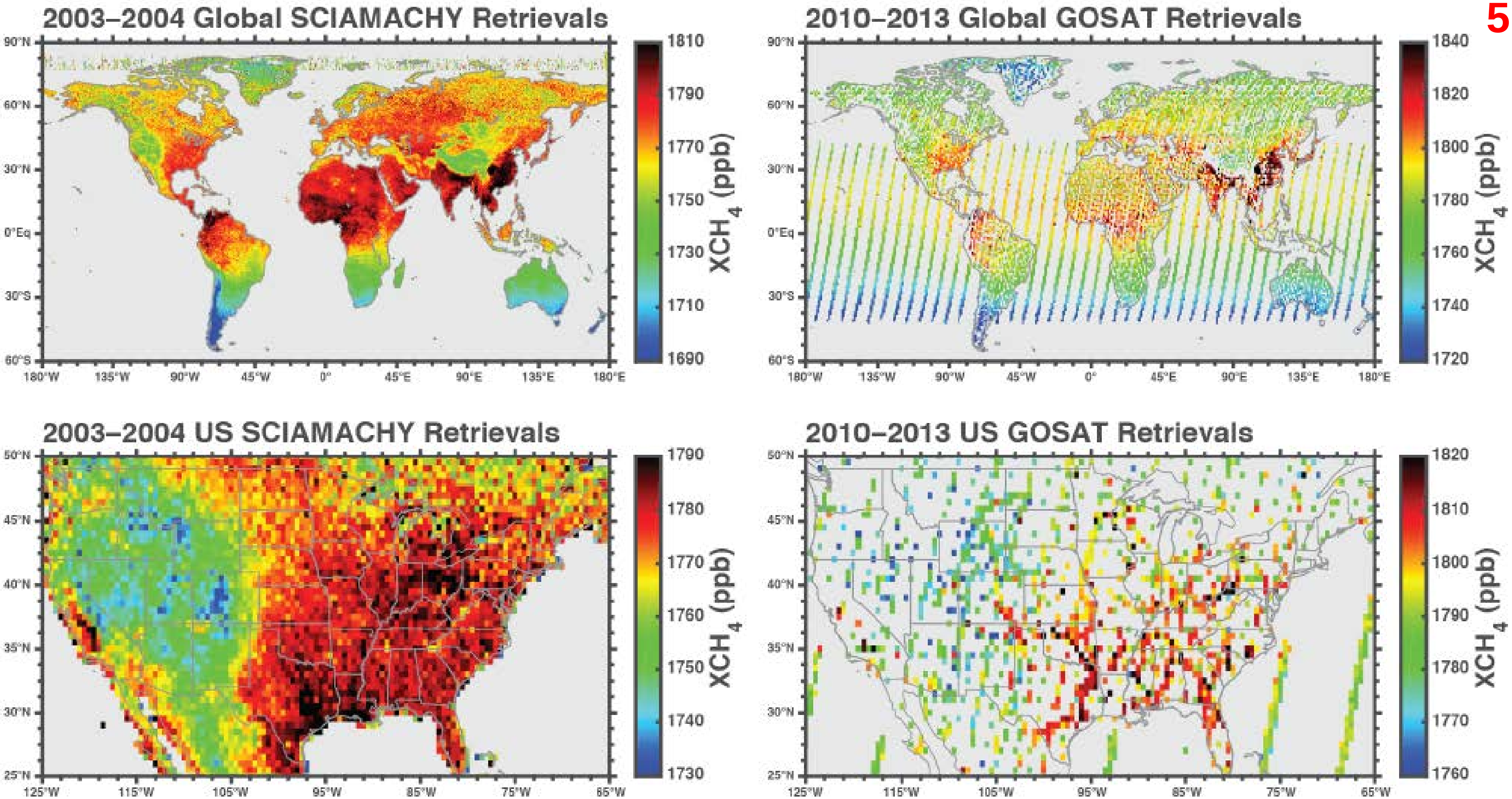




- 1.65 µm allows "proxy method" from combined CO_2 retrieval
- 2.3 µm allows CO retrieval
- SWIR+TIR allows vertical separation

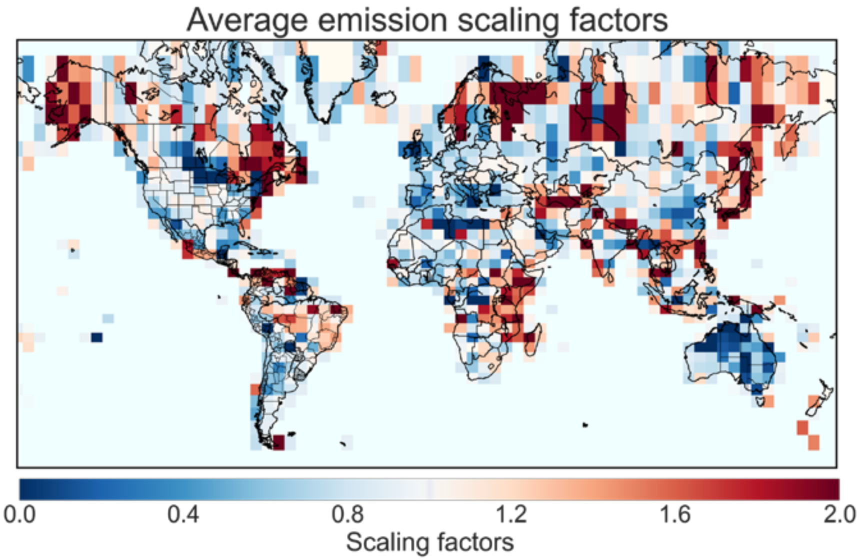


Jacob et al. [2016]


2003–2004 Global SCIAMACHY Retrievals
2010–2013 Global GOSAT Retrievals
2003–2004 US SCIAMACHY Retrievals
2010–2013 US GOSAT Retrievals
XCH4 (ppb)
1810
1790
1770
1750
1730
1710
1690
1840
1820
1800
1780
1760
1740
1720
1790
1780
1770
1760
1750
1740
1730
1820
1810
1800
1790
1780
1770
1760
90°N
60°N
30°N
0°Eq
30°S
60°S
180°W
135°W
90°W
45°W
0°
45°E
90°E
135°E
180°E
50°N
45°N
40°N
35°N
30°N
25°N
125°W
115°W
105°W
95°W
85°W
75°W
65°W

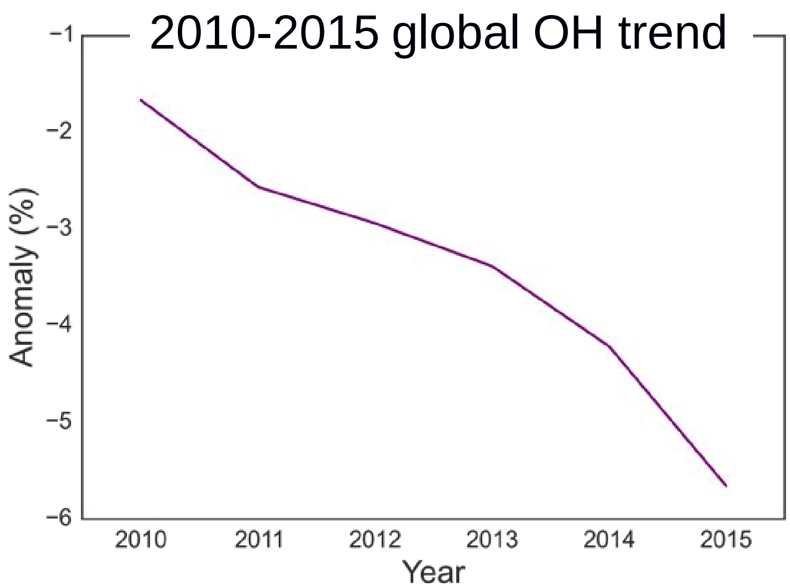
Optimization of methane sources and trends from 2010-2015 GOSAT data

Analytical inversion with improved bottom-up inventories

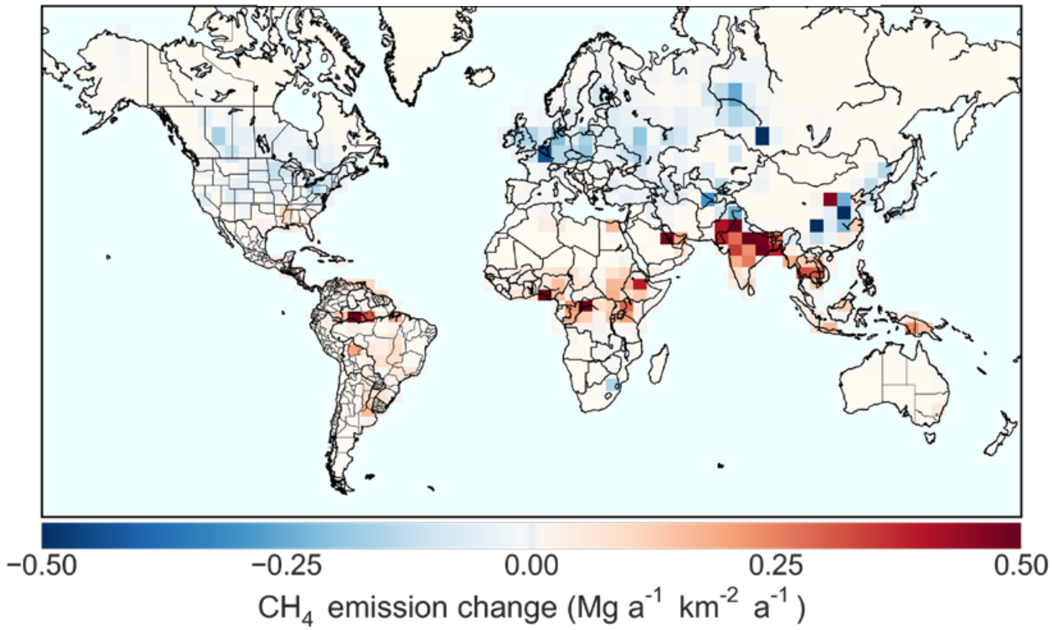


- Observed 2010-2015 trend could be explained by increasing emissions from India and 4% decrease in OH, with offset from decreasing emissions in China and Europe
  - explain isotopic shift?

Preliminary results
from J.D. Maasakkers, Harvard



2010-2015 emission trends



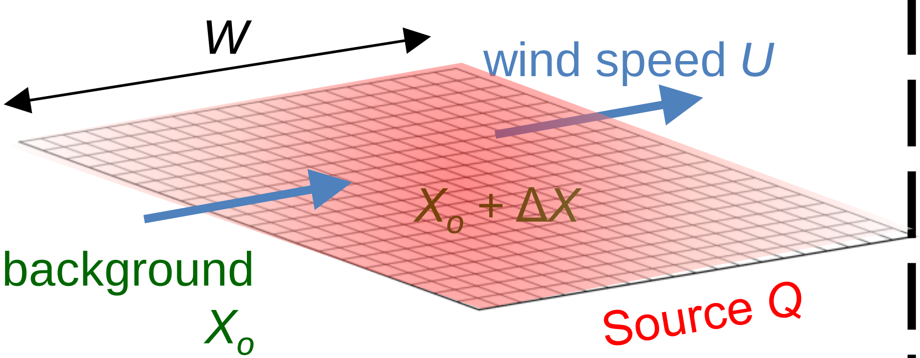
Shortwave IR (SWIR) instruments for observing methane from space

Instrument	Agency	Data period	Pixel size [km^2]	Return time	Band [μm]	Precision
Past/present						
SCIAMACHY	ESA	2003-2012	30×60	6 days	1.65	1.5 %
GOSAT	JAXA	2009-	10×10	3 days (sparse)	1.65	0.6 %
GHGSat	GHGSat, Inc.	2016-	0.05x0.05	targets	1.65	1-10%
Future						
TROPOMI	ESA	2017-	7×7	1 day	2.3	0.6%
GOSAT-2	JAXA	2018-	10x10	3 days (sparse)	both	0.3%
Bluebird	Bluefield, Inc.	2019-	0.02x0.02	targets	2.3	0.8%
MERLIN	DLR/CNES	2021-	pencil		1.65	1-2%
geoCARB	NASA	selected	3×3	2-3x/day	2.3	~0.6%
Proposed						
CarbonSat	ESA	proposed	2×2	5-10 days	1.65	0.4%
GeoFTS	NASA	proposed	3x3	2 hours	both	0.2%
G3E	ESA	proposed	2x3	2 hours	both	0.5%
CHRONOS	NASA	proposed	4x4	1 hour	2.3	1.0%

Simple mass balance approach to compare information on emissions from different satellite instruments

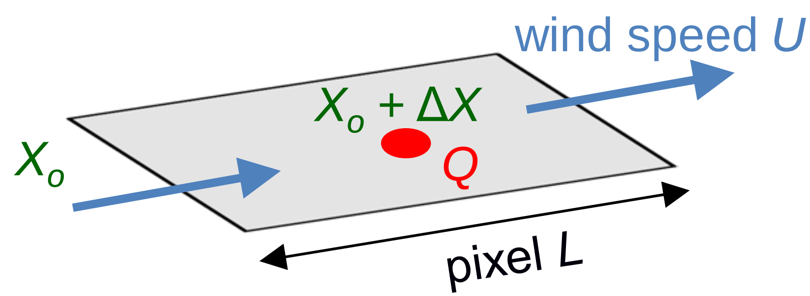
Instrument defined by pixel size L, precision σ, return time t_R

Integration time t required to quantify a regional source of domain W



$$t = t_R \max\left[1, \frac{1}{FN}\max\left[1, \left(\frac{M_{CH_4}}{M_a}\frac{5\sigma UWp}{Qg}\right)^2\right]\right]$$

Minimum point source Q_{min} detectable in a single pass

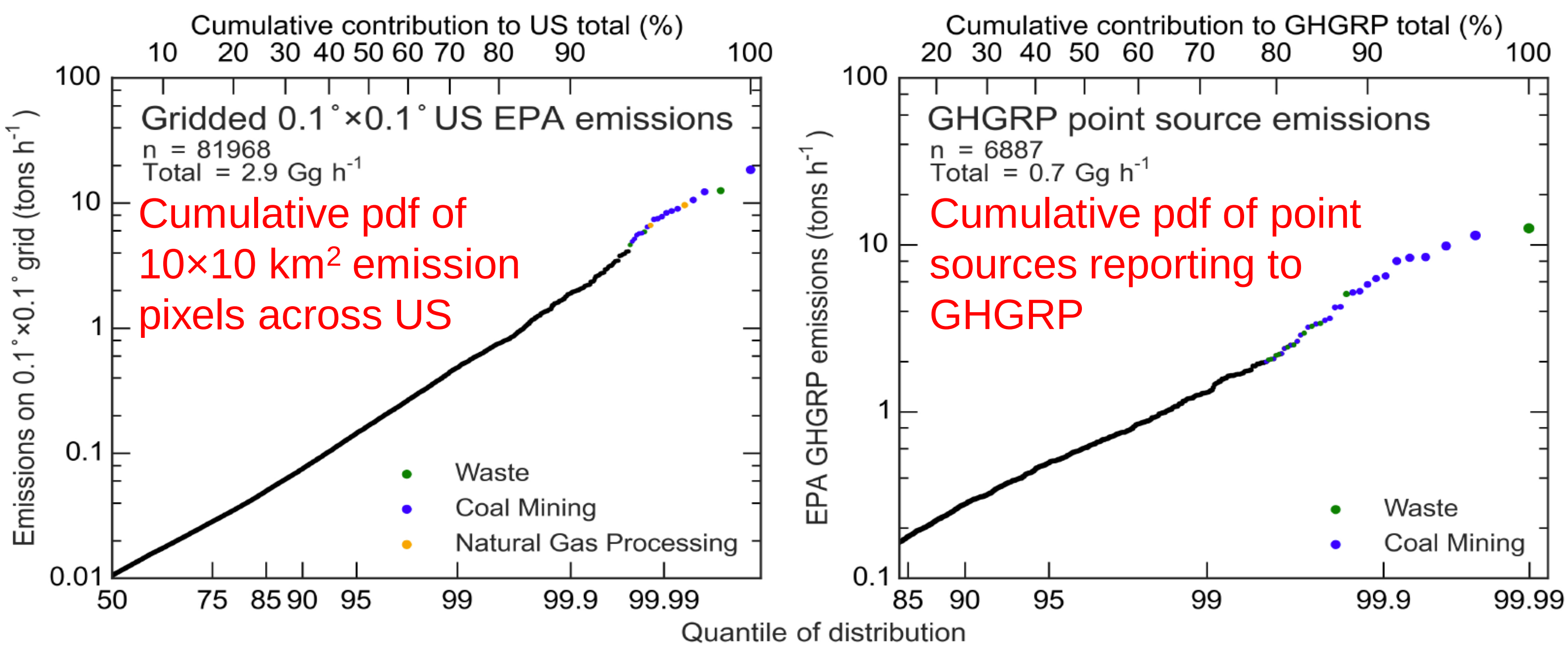


$$Q_{\min} = \frac{M_{CH4}}{M_a}\frac{2ULp\sigma}{g} \sim UL\sigma$$

Jacob et al. [2016]

Detectability of regional and point sources of methane

Instrument	Averaging time required to quantify regional source (Q =72 tons h^{-1} over 300×300 km^2)	Single-pass point source detection threshold [tons h^{-1}]
SCIAMACHY	1 year	68
GOSAT	1 year	7.1
TROPOMI	Single pass (1 day)	4.2
GOSAT-2	4 months	4.0
MERLIN	7 months	NA
geoCARB	Single pass (2-3x/day)	3.0
GHGSat	NA	0.25
Bluebird	NA	0.013



Jacob et al. [2016]

Lom Pangar Dam, Cameroon
April 20th, 2017
GHGSat-D excess CH_4 column measurement

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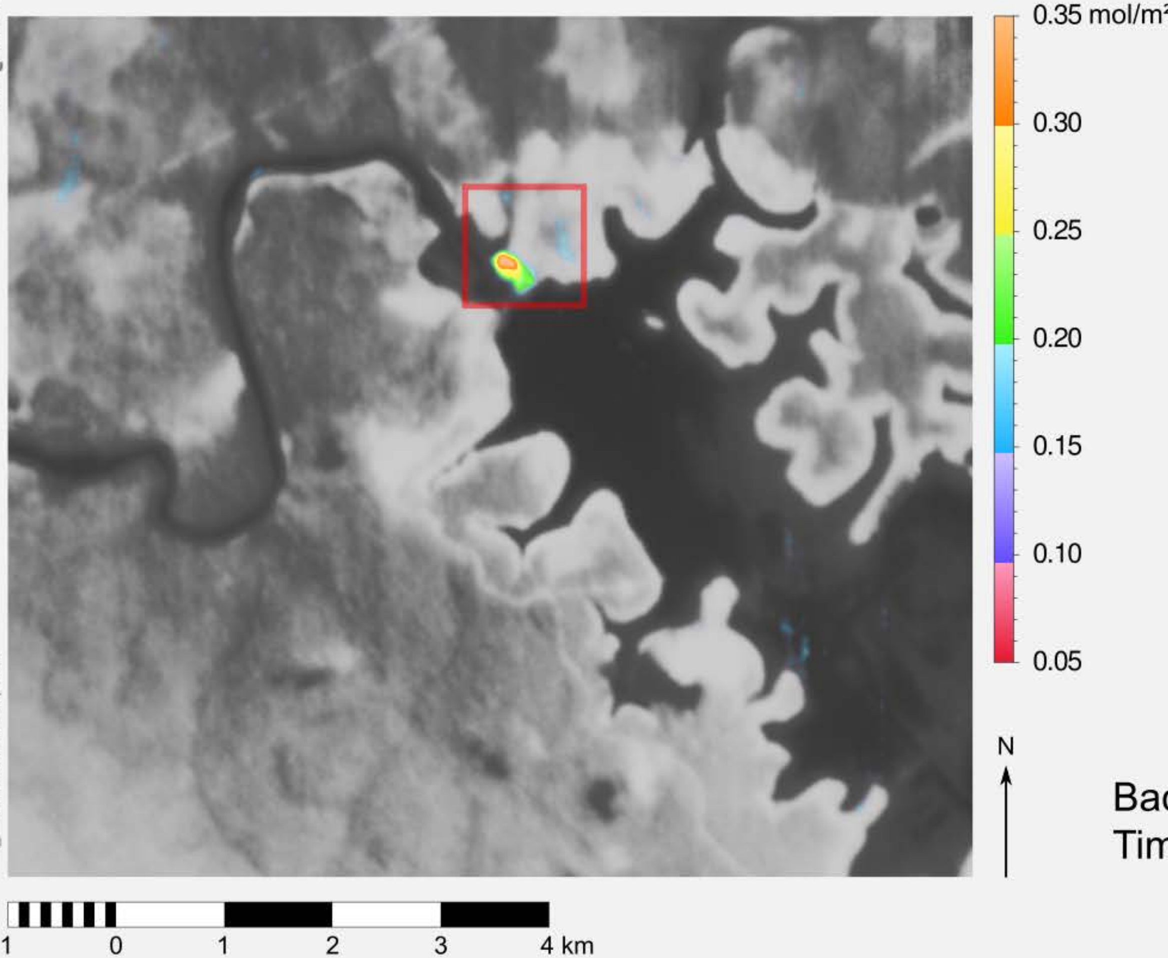
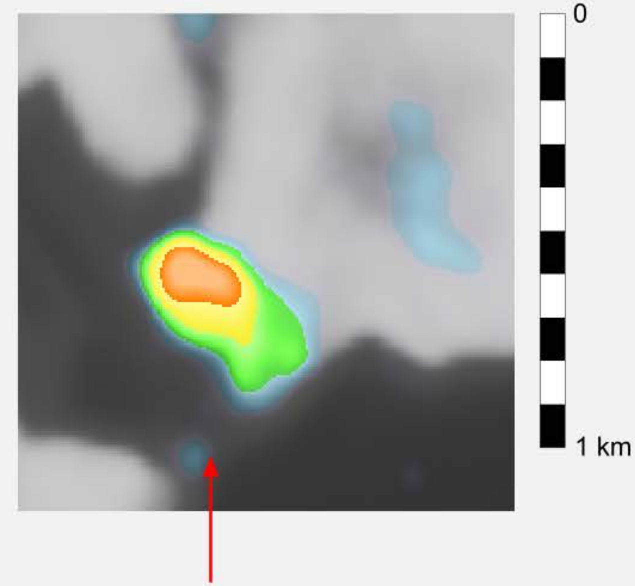
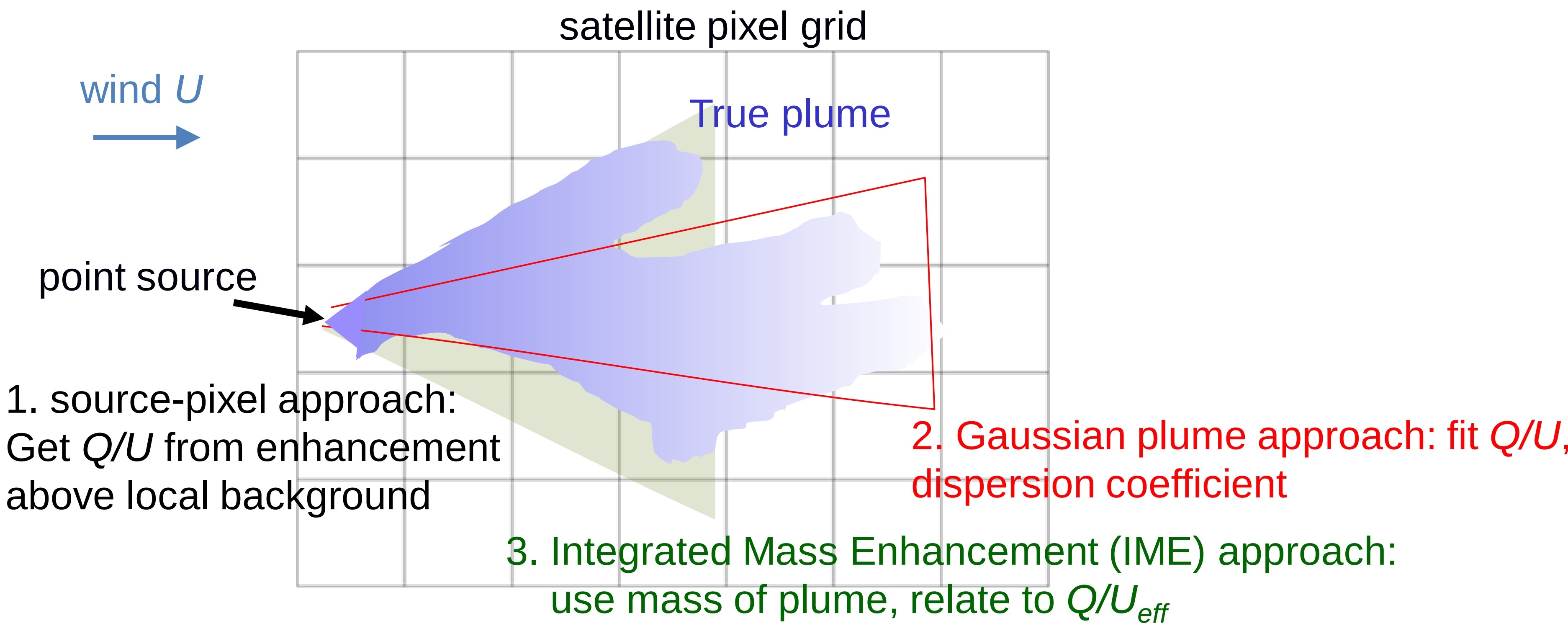




Dam location
5°23'0.2"N 13°30'4.0"E

Background image: 1.6 µm reflectance
Timestamp: 2017-04-20 08:45:32 UTC

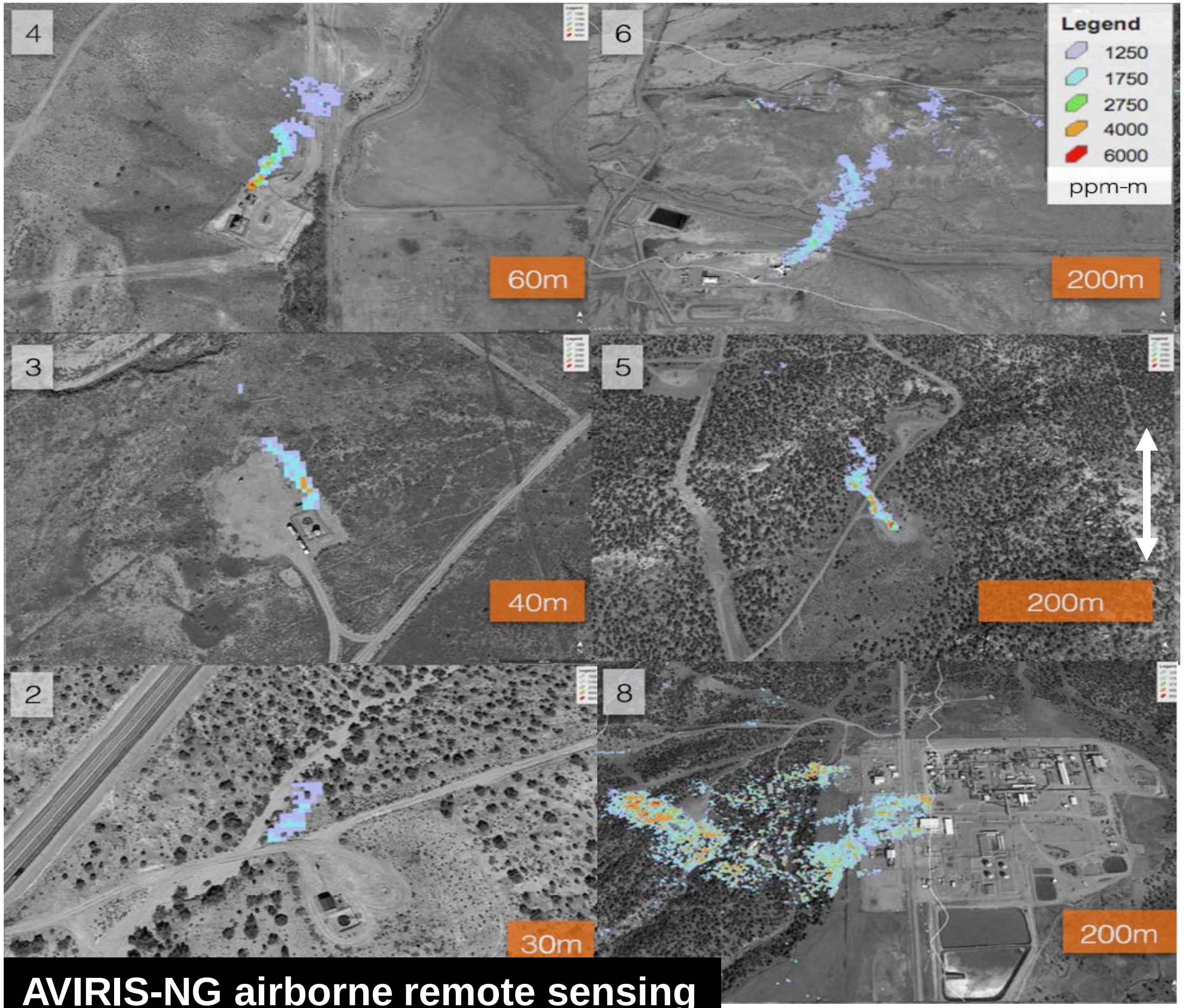
Using plume information to quantify point sources: 3 methods



In all cases we need independent info on *U:*

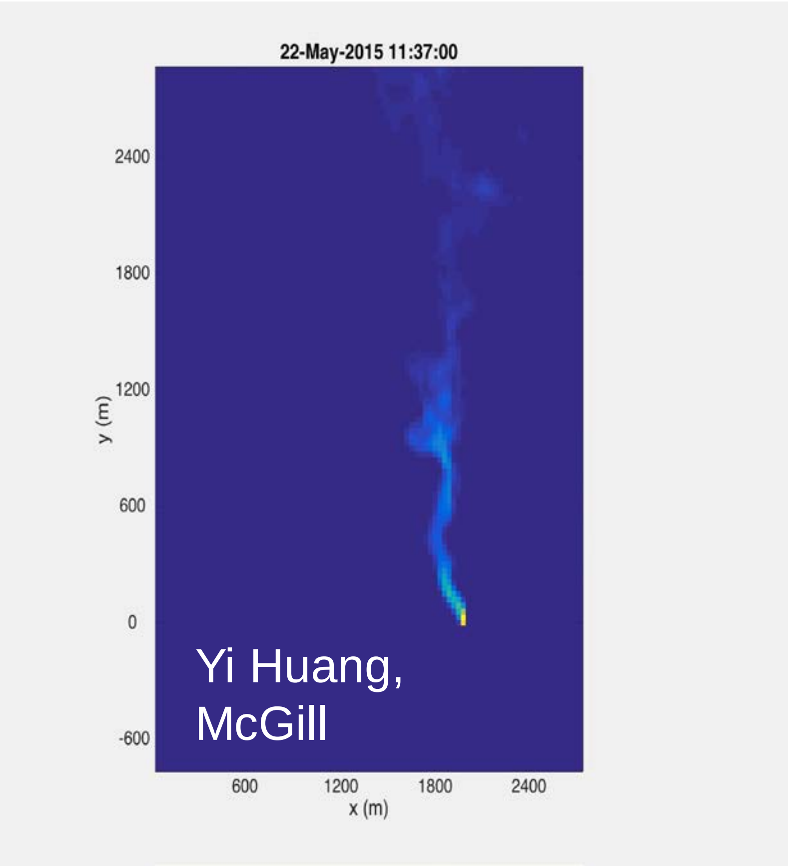
- Instantaneous wind at source location for method 1
- Instantaneous wind alomg plume for method 2
- Effective wind for transport of plume "blob" for method 3

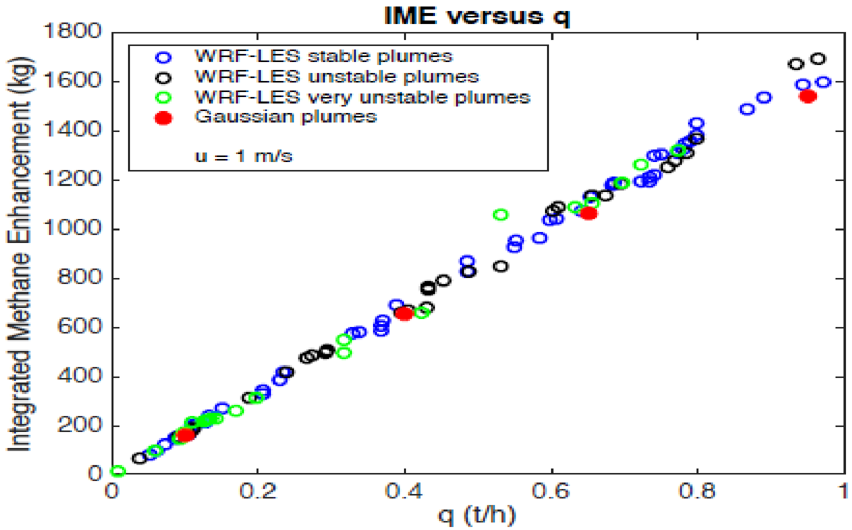
Instantaneous plumes don't look Gaussian

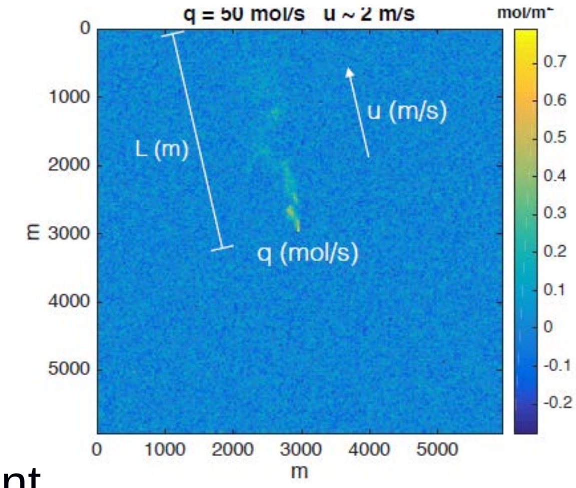


AVIRIS-NG airborne remote sensing of methane plumes in Four Corners Frankenberg et al. [2016]

Exporing IME method with LES of point source plumes







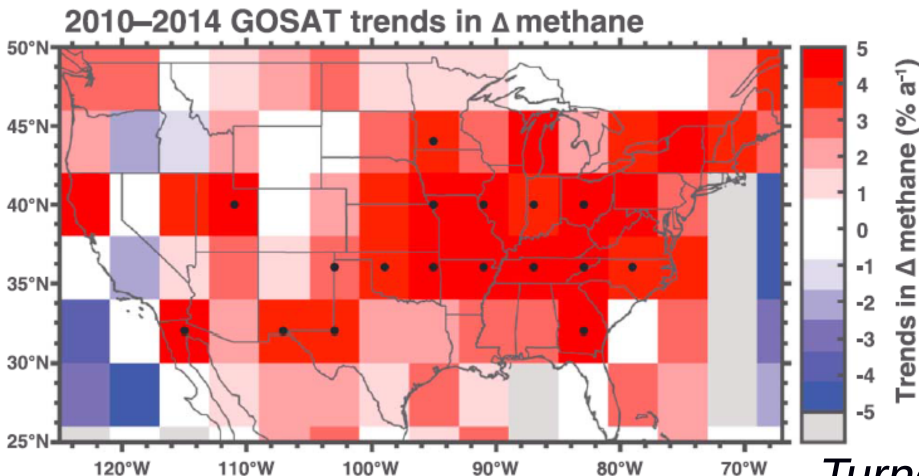
$$q = \frac{\mathrm{IME} \times U_{eff}}{L}$$

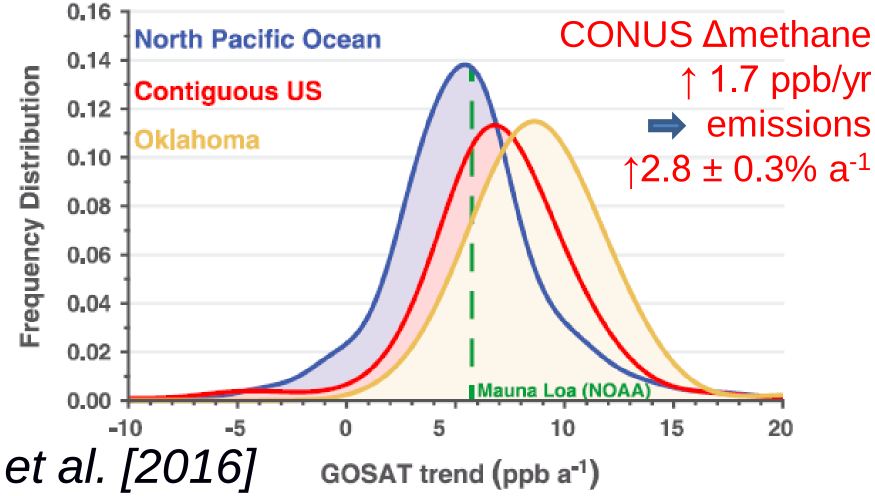
where

- q is source rate
- IME is integrated plume enhancement
- L is plume dissipation length
- U_{eff} is effective wind speed (relate to local 10-m wind speed)

Daniel Varon, Harvard

Debate over GOSAT-derived US methane emission trends





Turner et al. [2016]

Figure 2. The 2010–2014 trend in U.S. methane enhancements as seen from GOSAT. The methane enhancement (Δ methane) is defined as the difference in the tropospheric column mixing ratio relative to the oceanic background measured in the glint mode over the North Pacific (176–128°W, 25–43°N) and normalized with the 2010 Δ methane. Trends are computed on a 4° × 4° grid. Statistically significant trends ($p < 0.01$) are indicated by a dot.

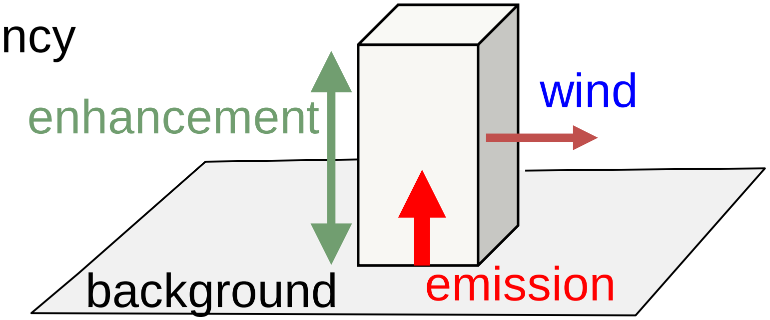
Figure 3. Spatial frequency distributions of 2010–2014 methane increases seen from GOSAT. Values are shown for the state of Oklahoma, the contiguous U.S. (CONUS), and the North Pacific (176–128°W, 25–43°N). The 2010–2014 trend at the NOAA Mauna Loa Observatory site (MLO) is also shown. GOSAT trends were computed on a 0.5° × 0.5° grid, weighted by the square root of the number of retrievals, and distributions were computed with kernel density estimation.

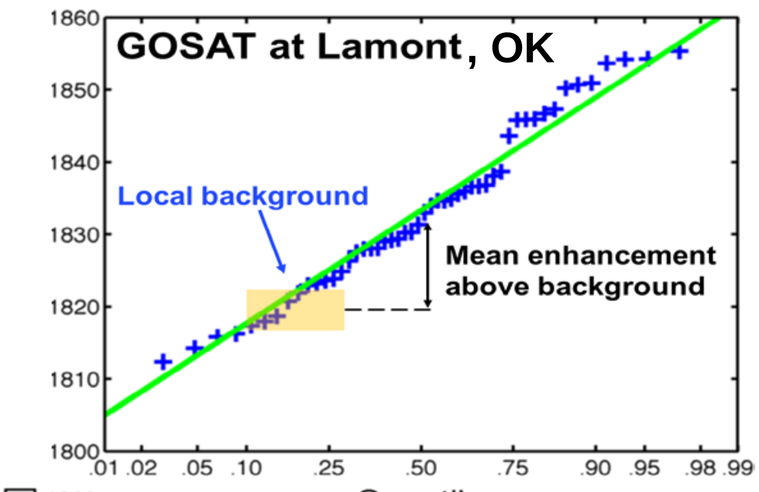
Bruhwiler et al. [2017] object that:

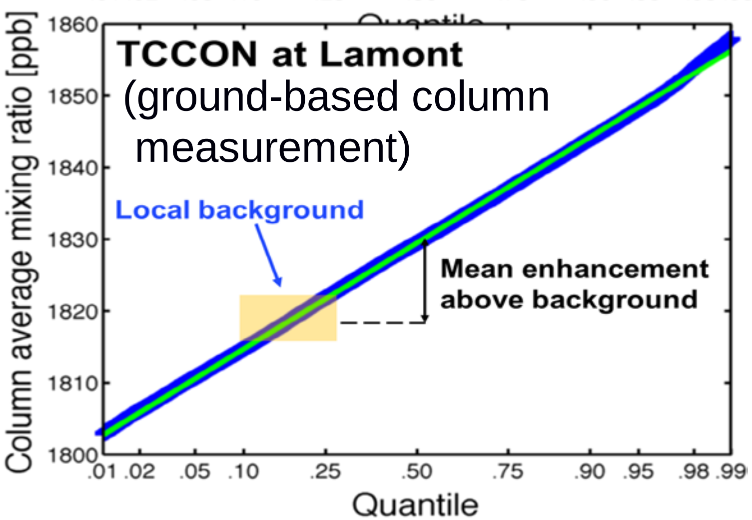
- Trends over 3 years are more likely driven by meteorological IAV than emissions
- Use of same-latitude N Pacific as background ignores meridional flow influences
- NOAA sites and related inversions show no trend

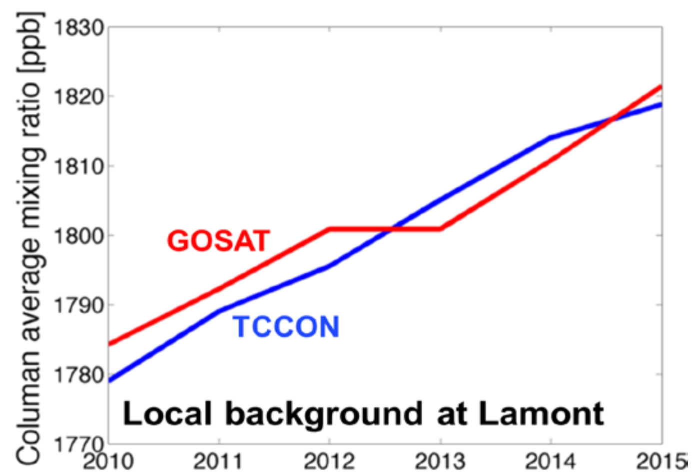
Trends in North American emissions inferred from GOSAT

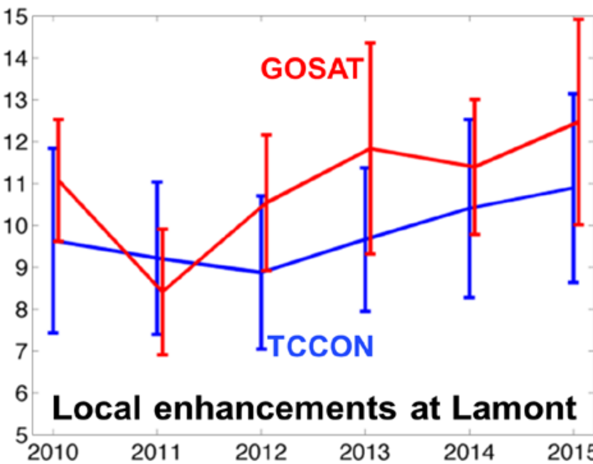
- Assume that methane enhancement above background is proportional to emissions
- Define background as 10th-25th quantile of frequency distribution in 0.5°x0.5° grid squares





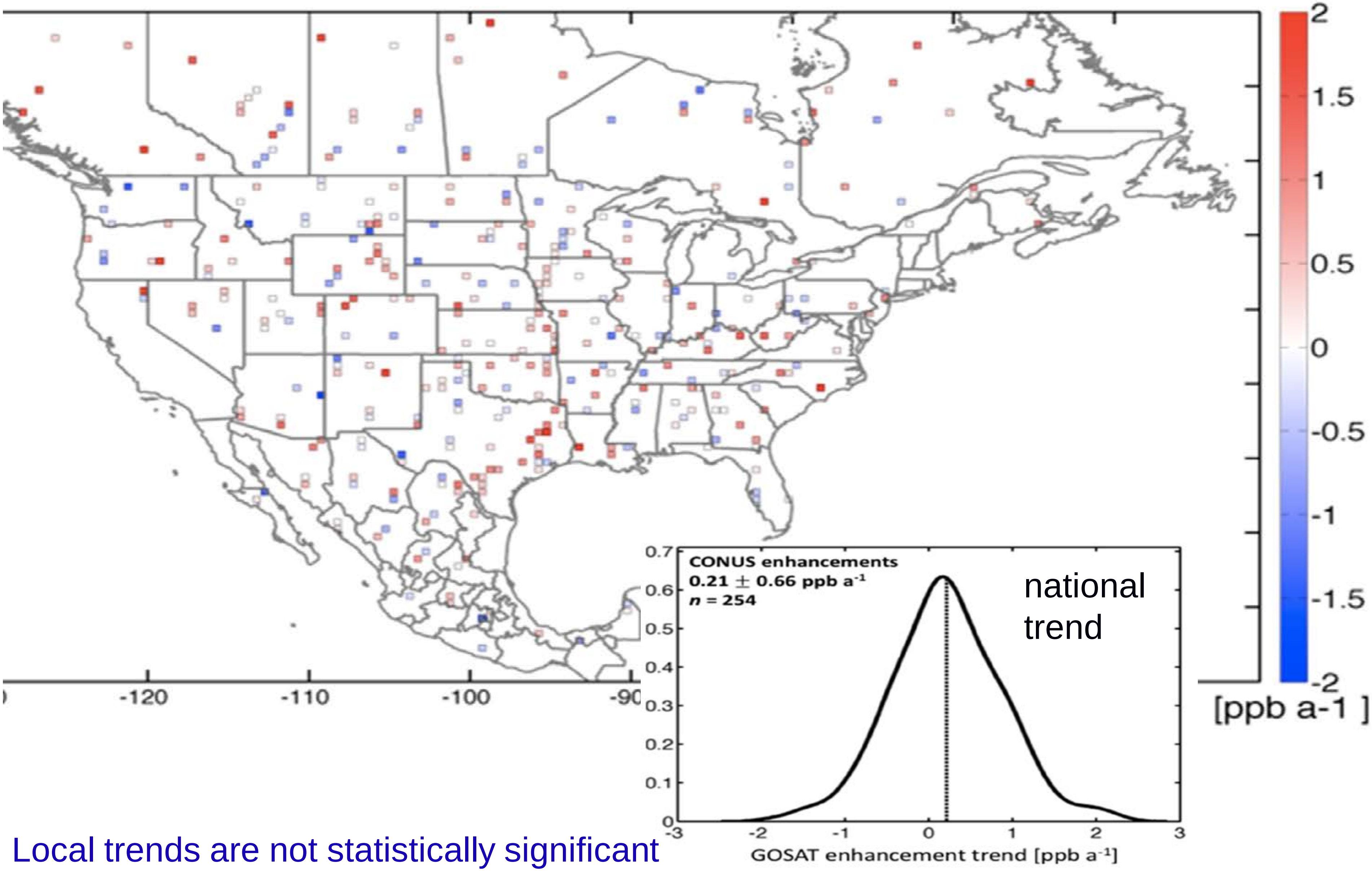






Sheng et al., in prep.

Trends in methane enhancements from GOSAT, 2010-2015

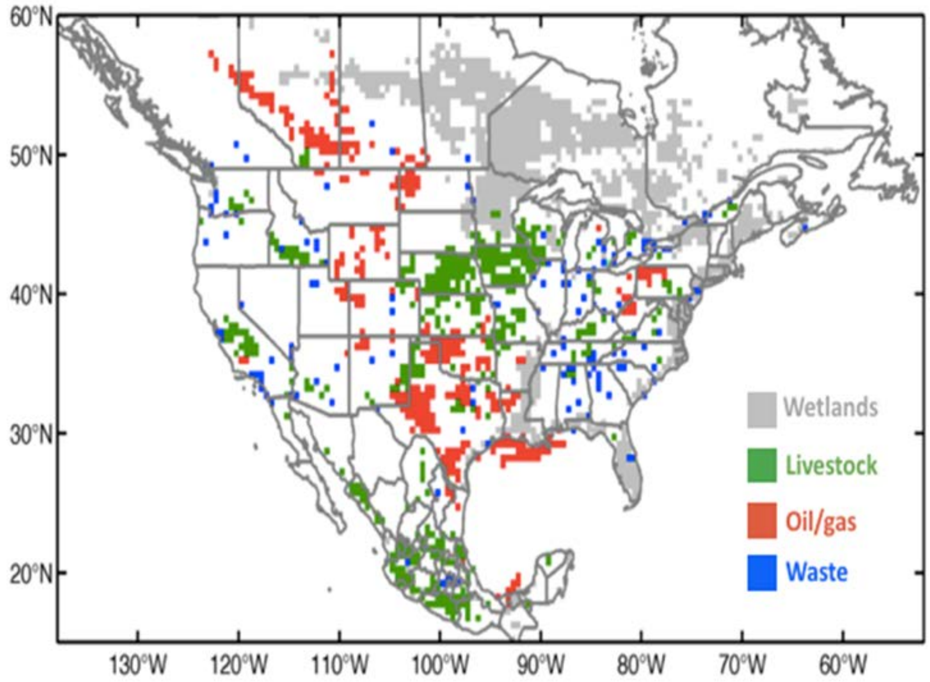


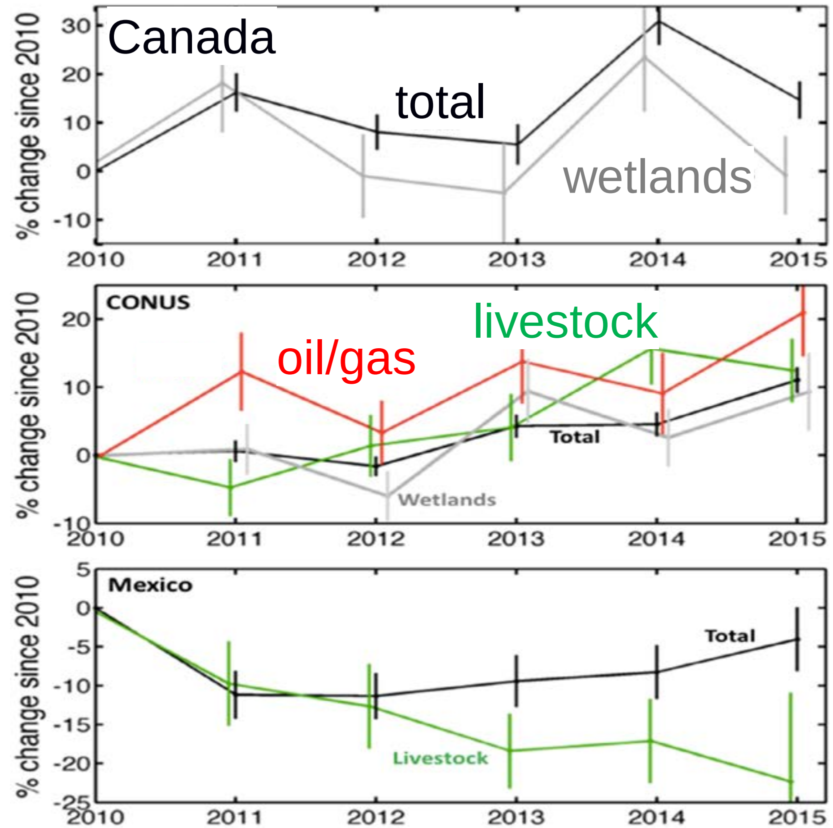
Local trends are not statistically significant but national trend is.

Sheng et al., in prep.

National and sectoral trends in methane enhancements

High-emitting grid cells (>0.7 tons h^{-1}) dominated by one source sector (>70%)



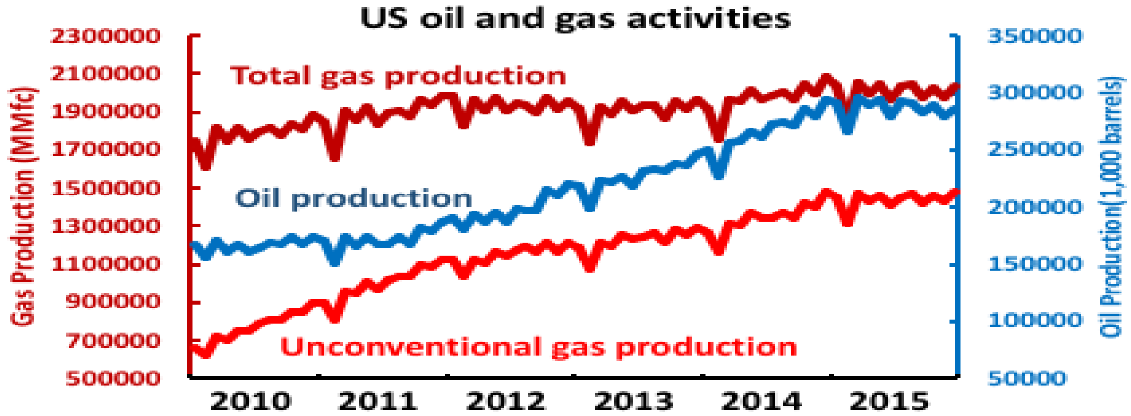


Inferred US emission trend is +2% per year, driven by both oil/gas and livestock

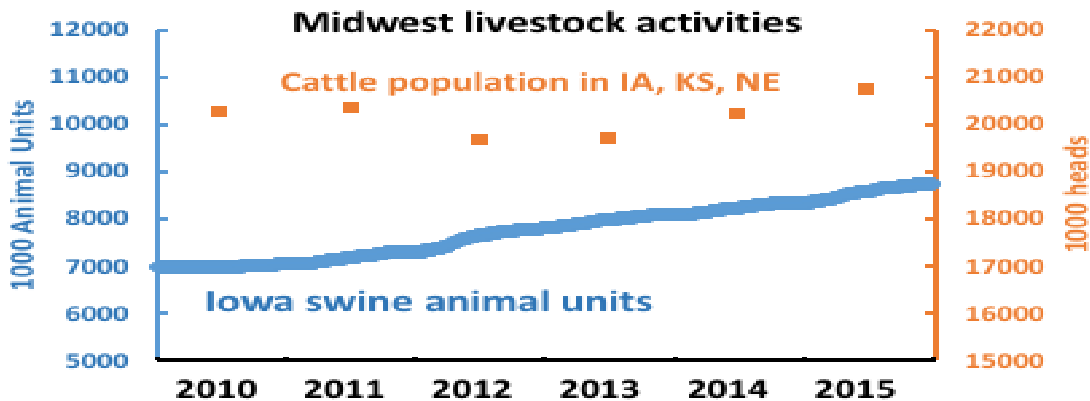
Sheng et al., in prep

What could be driving these trends?

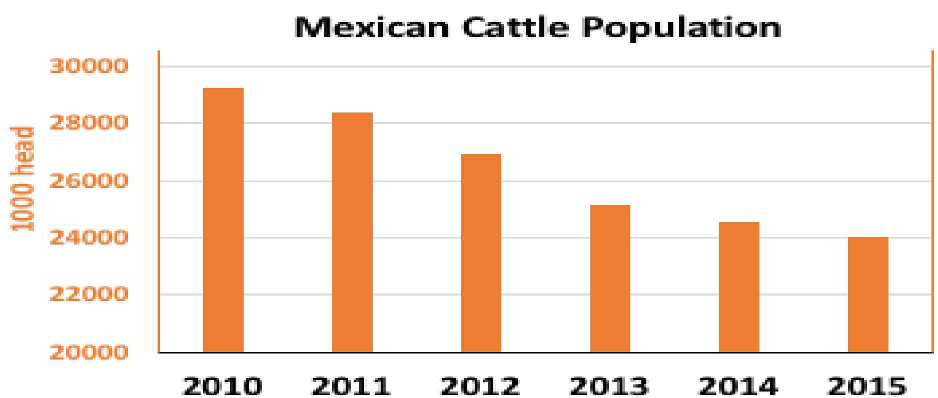
- Increasing fracking in US (Drillinginfo, 2016)



- Increasing swine manure in Midwest (Iowa DNR, 2015)



- Decreasing cattle in Mexico (USDA, 2015)



Sheng et al., in prep

Some recommendations for the future

- Combine SWIR and TIR retrievals to resolve vertical distribution of methane
  - Improve detectability and data interpretation for the Arctic
- Fly geostationary mission with staring sub-km capability over source regions
  - Detect point sources, “super-emitters”, cloudy wetlands
- Need improved algorithms to relate plume observations to point sources
  - We’re working on it…
- Improve global bottom-up inventories for inverse analyses
  - Improve quality and interpretation of inversions, top-down/bottom-up partnership
- Develop combined satellite + suborbital observing systems for source regions
  - Suborbital perspective essential for monitoring multitude of point sources