The Many Mysteries of Atmospheric Methane

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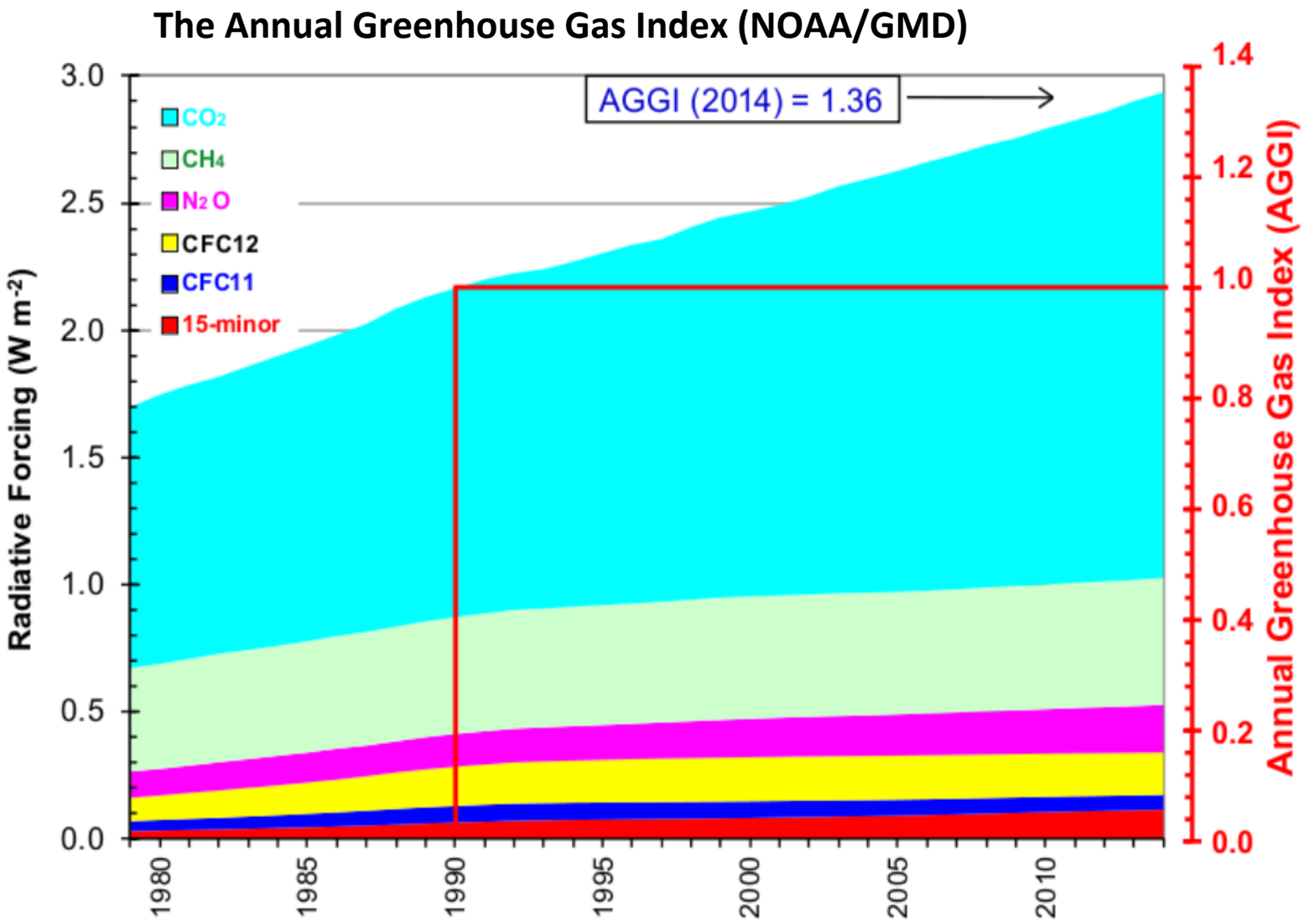
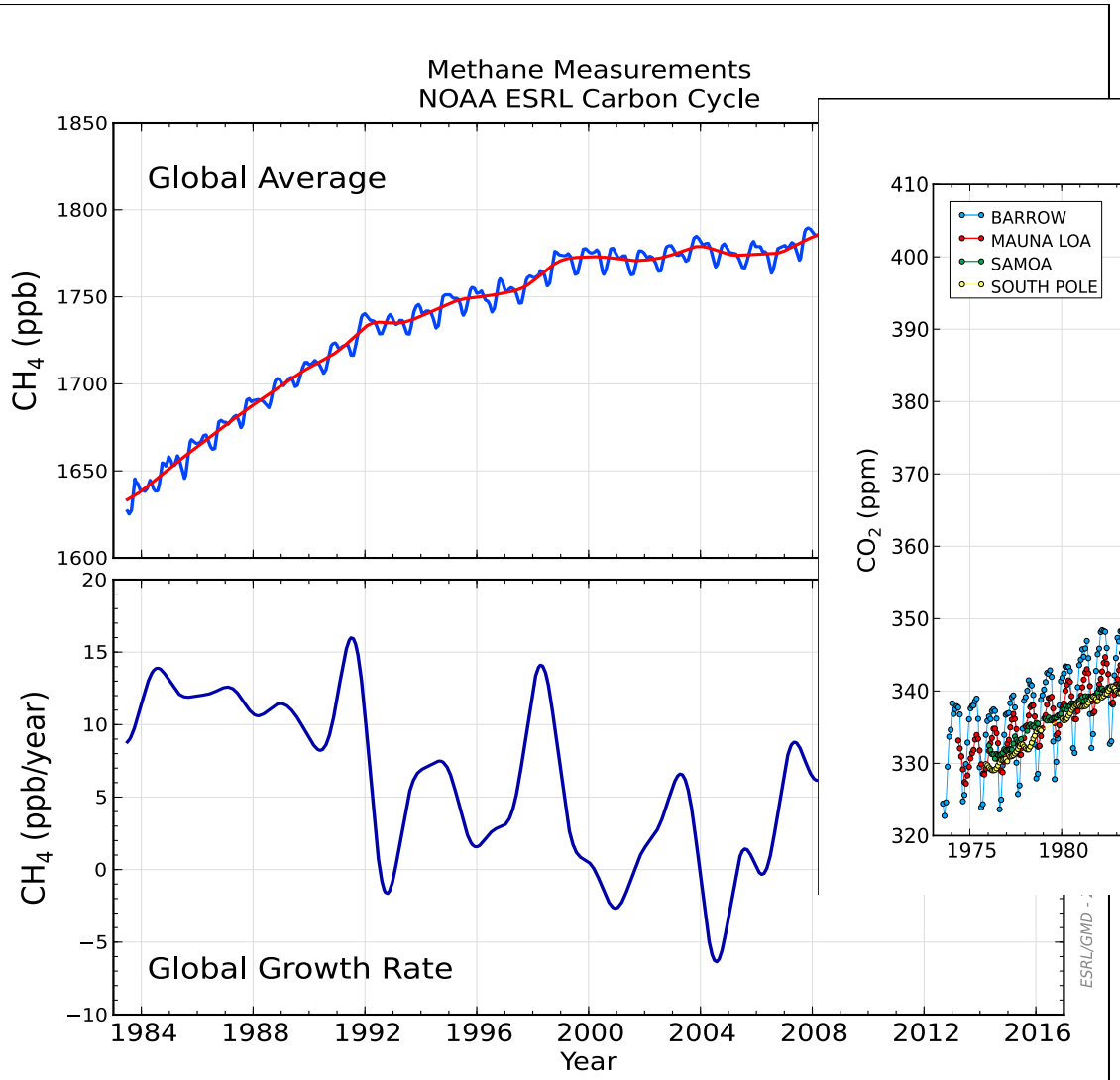
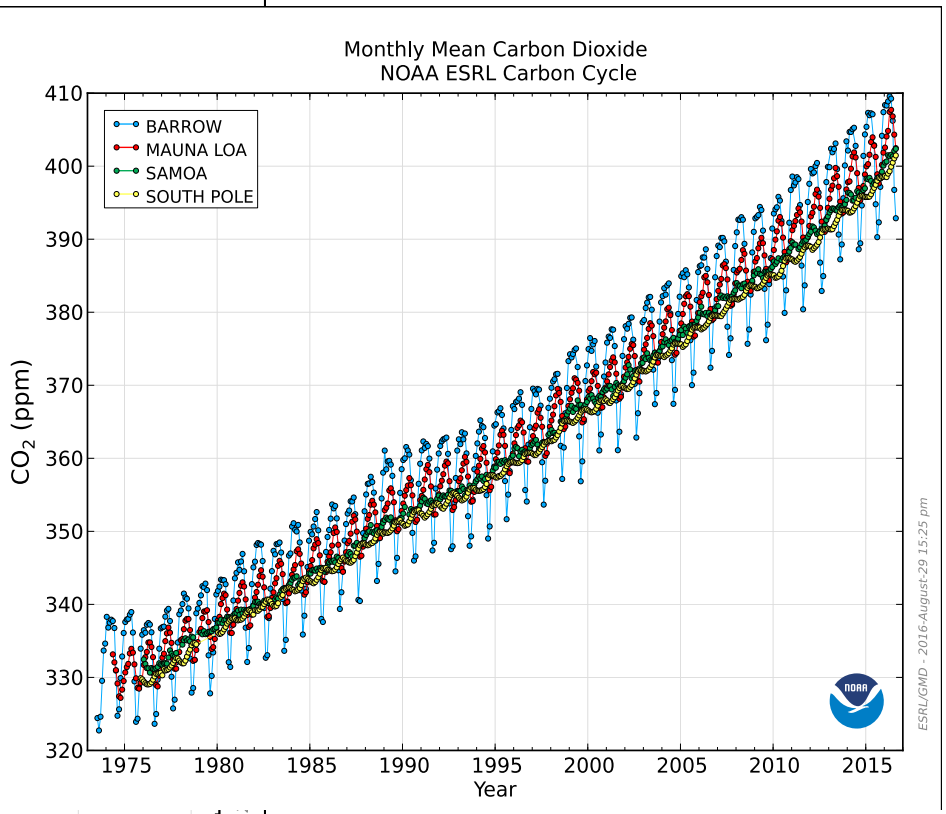
Why Do We Care About Methane?



A Fundamental Difference from CO_2: an Atmospheric Chemical Sink (But GWP of 28!)

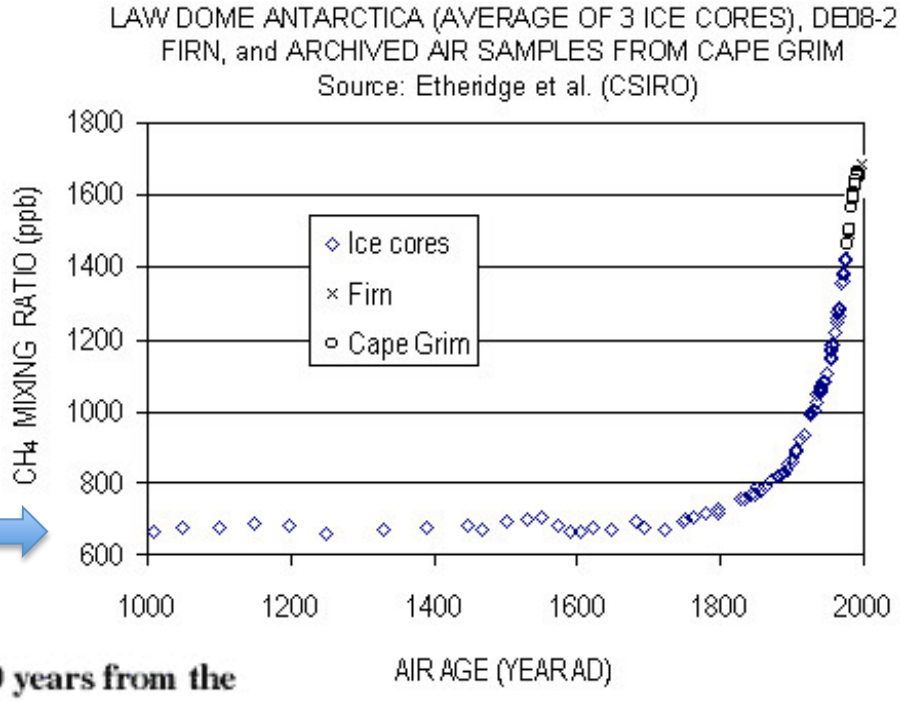


Top: Global average atmospheric methane mixing ratios (blue line) determined using measurements from the Carbon Cycle cooperative air sampling network. The red line represents the long-term trend. Bottom: Global average growth rate for methane. Contact: Dr. Ed Dlugokencky, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6228, ed.dlugokencky@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.

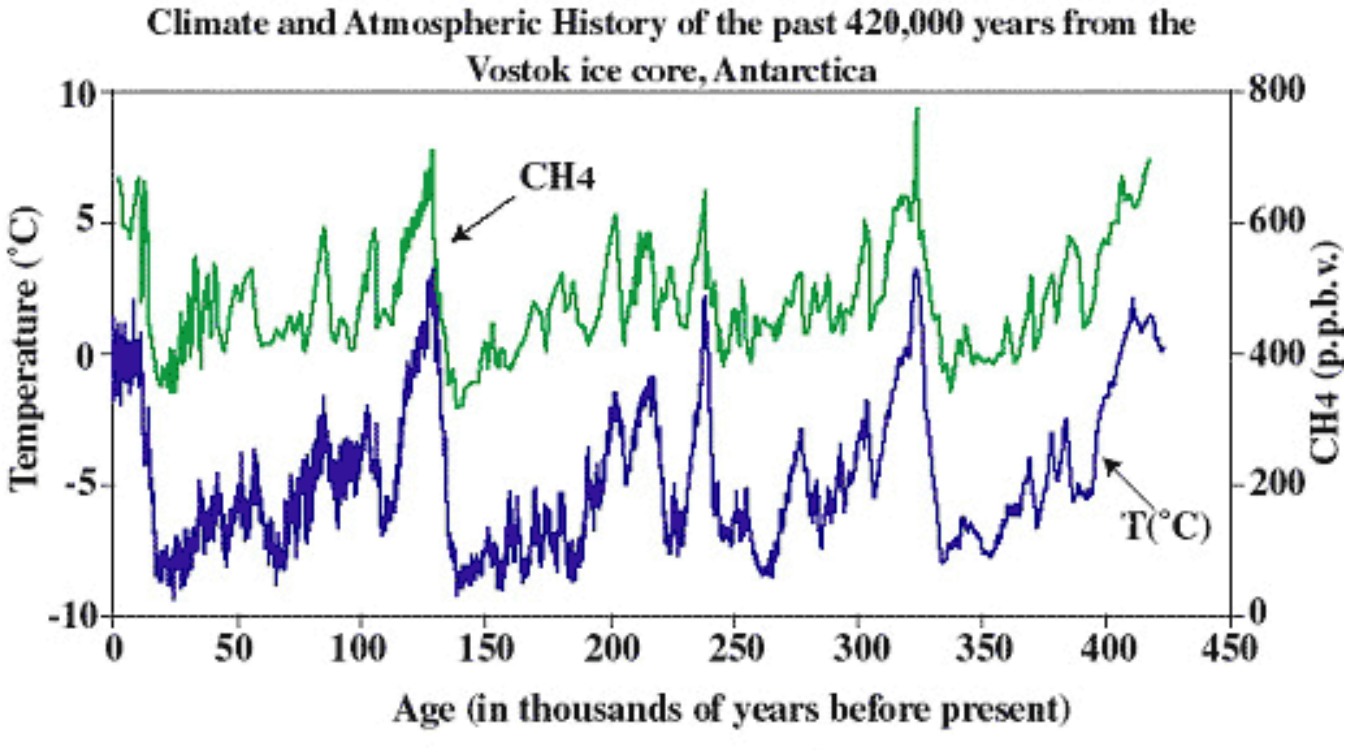


Anthropogenic Sources of CH_4

Atmospheric CH_4 Before People



Could there be an anthropogenic Component?



Natural Sources of CH_4

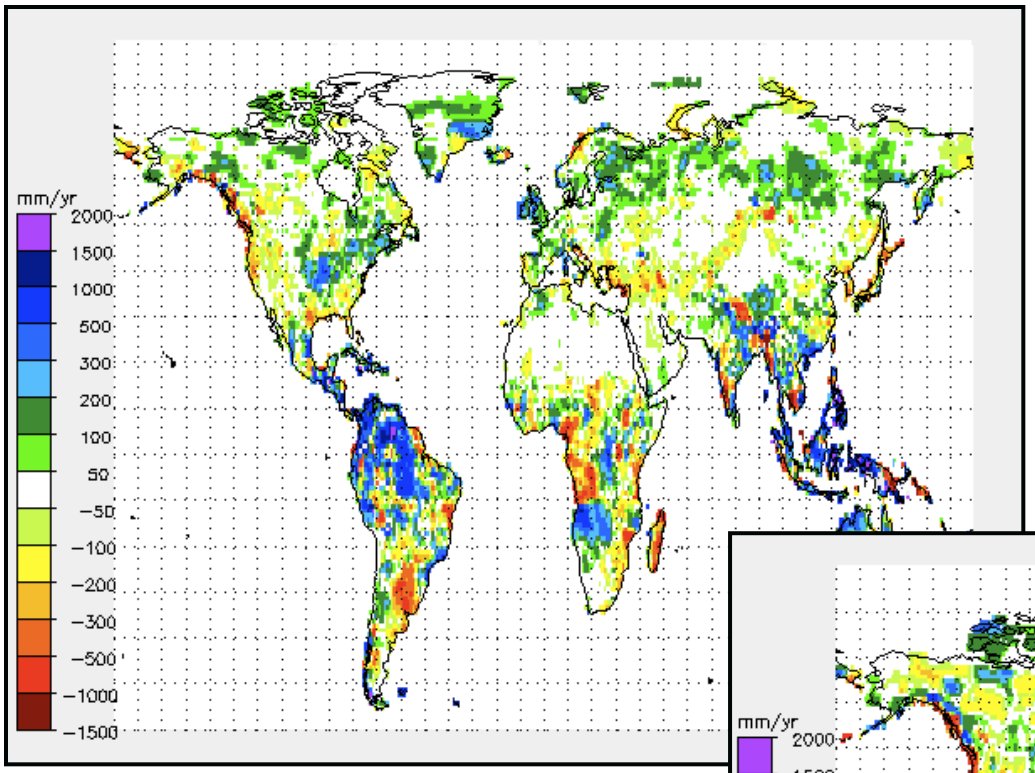
A possible climate-carbon feedback: permafrost carbon

- Orbital Forcing and Permafrost Carbon Feedbacks may explain hyperthermal events ~55Mya
- Global T increase of 5 C within a few 1000 years
- ~3700 PgC in Eocene permafrost (~1700 PgC today) (DeConto et al. Nature 2012)

How much could have been CH_4? ~3%?

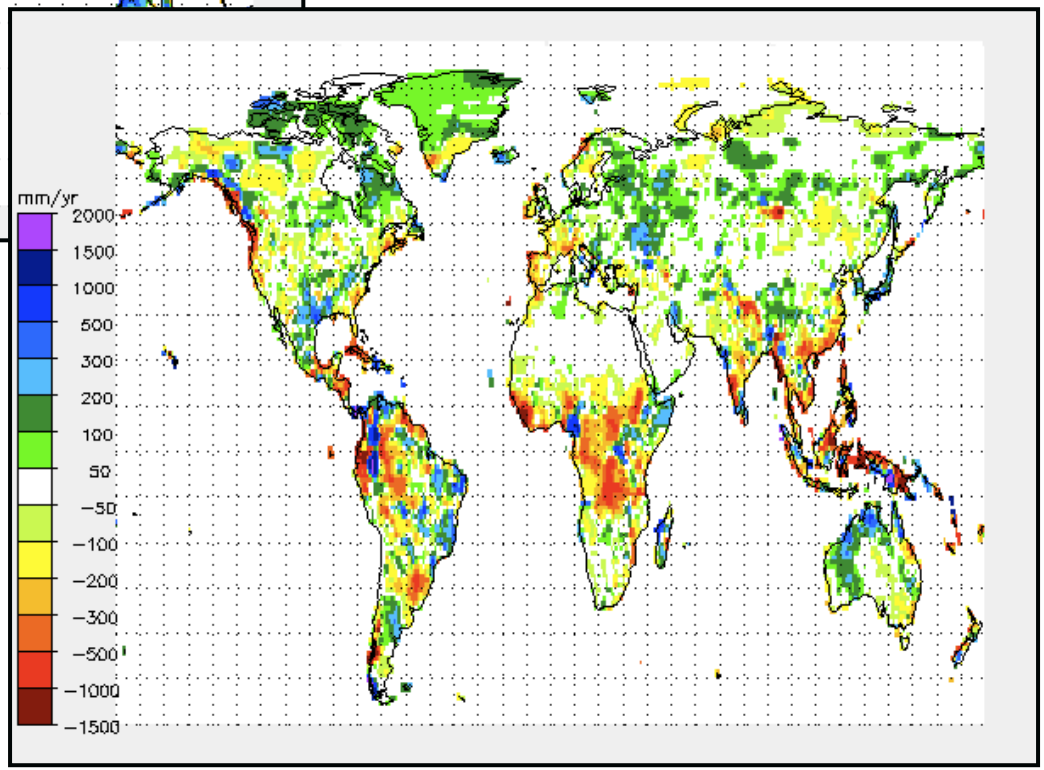
(A coryphodon basking in the warm eocene)

Composite Precipitation - La Ninã



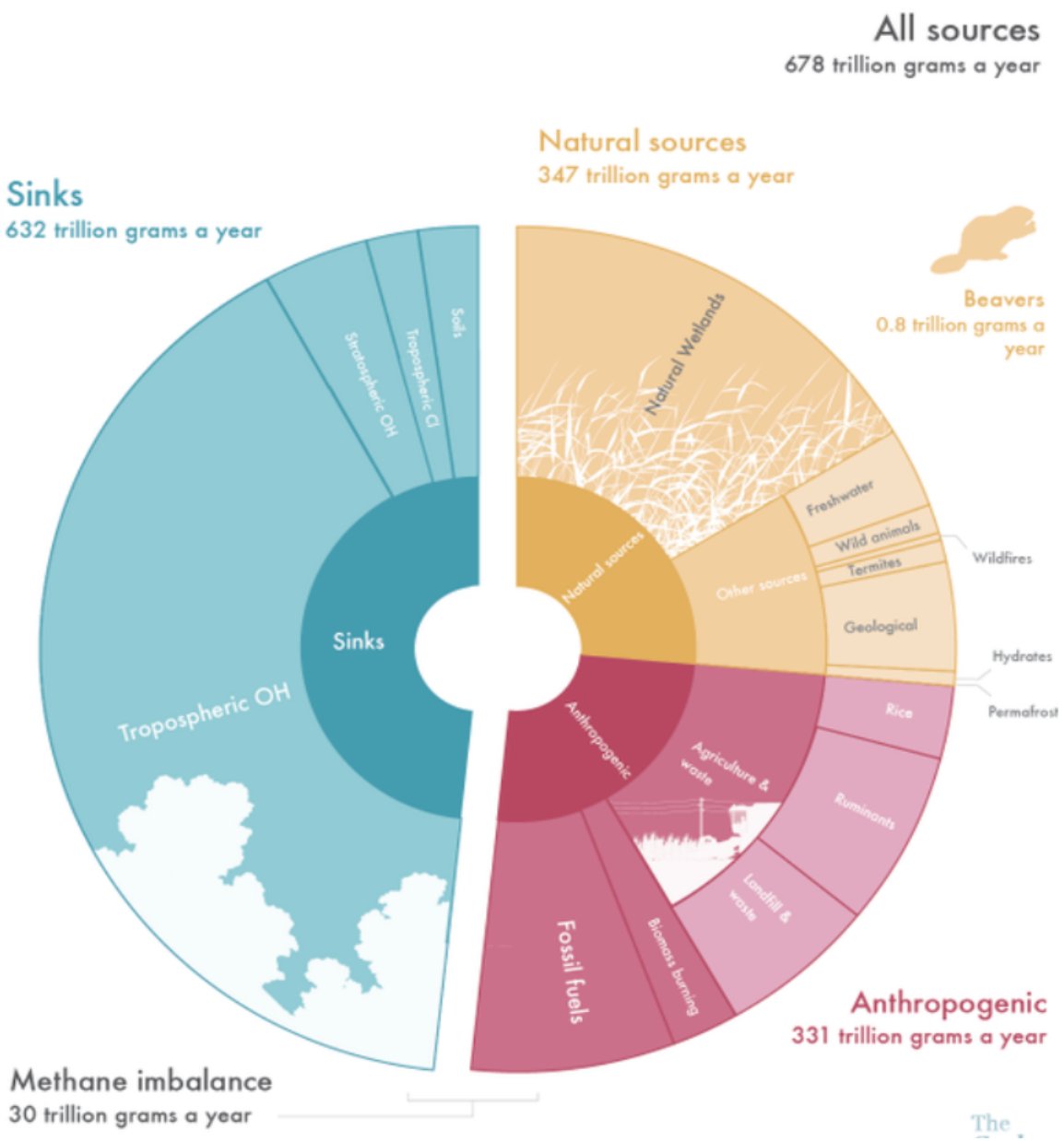
Inter-annual Variability

El Ninõ



Source: GPCP

Global methane budget for 2000-2009



The Carbon Brief

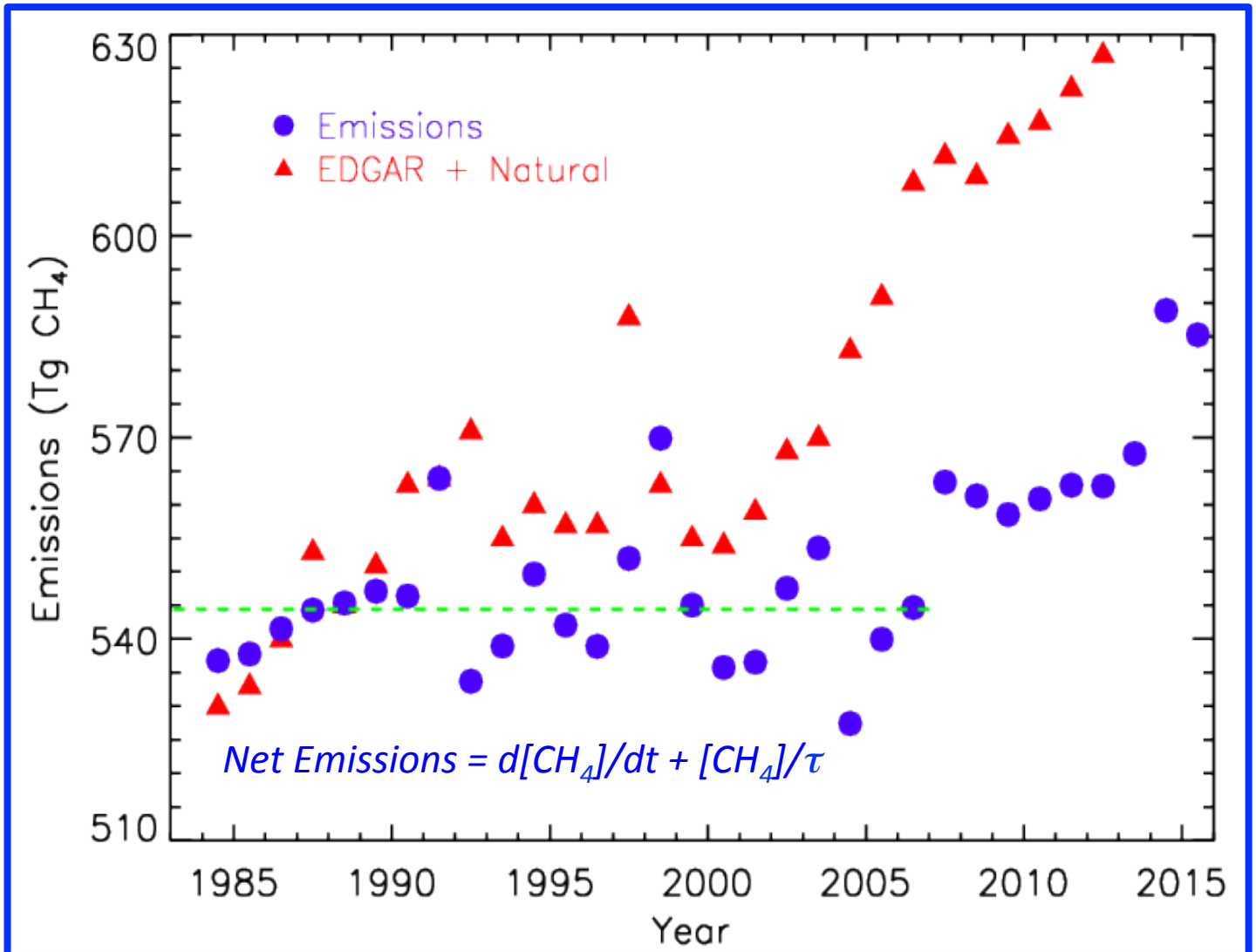
"Bottom-Up" Estimates of CH4 Emissions May Not be Consistent with Atmospheric Observtions (But Flux Inversions may Help).

Measured:

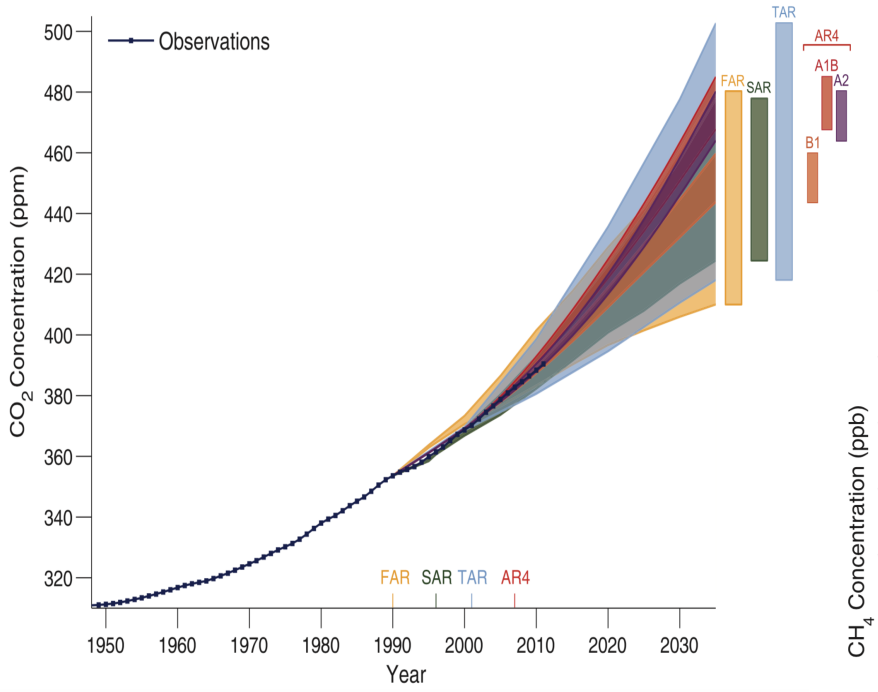
$[CH_4]$, $d[CH_4]/dt$

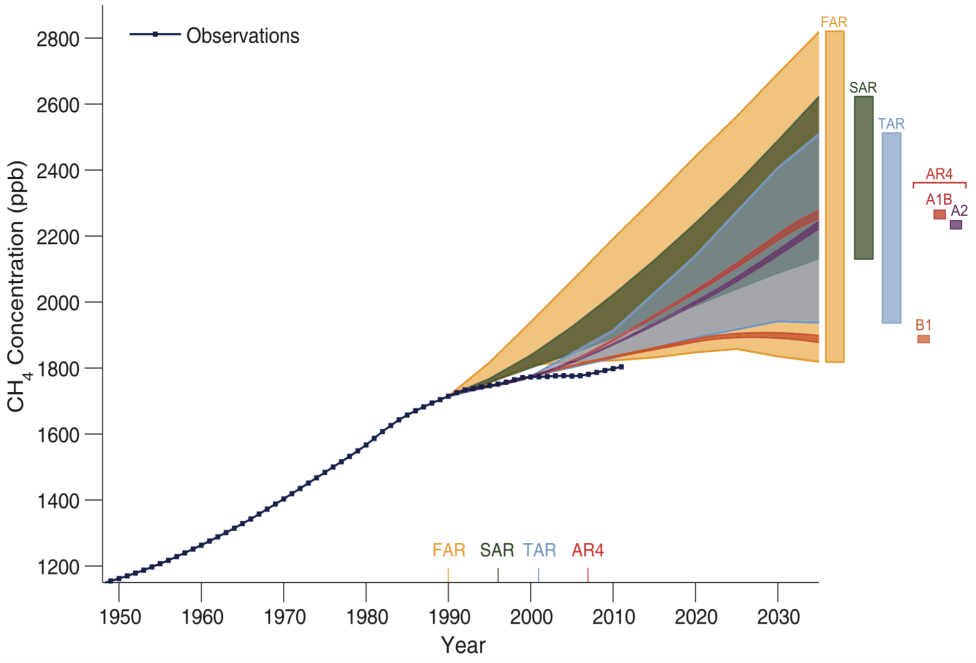
Inferred from Measurements of CH_3CCl_3:

τ *(chemical lifetime of CH_4)*



We Have More Success Predicting CO_2 than CH_4 - But the Good News is that We Underestimated It!





Cubasch, U., D. Wuebbles, D. Chen, M.C. Facchini, D. Frame, N. Mahowald, and J.-G. Winther, 2013: Introduction. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Atmospheric Monitoring of CH_4

1978- present:

Rowland-Blake Group, UC-Irvine
45 remote Pacific sites distributed from Alaska to New Zealand
~4 times per year
~100 halocarbons and hydrocarbons

1983- present:

NOAA Cooperative Air Sampling Network
60 sites (not all exactly remote)
~ Weekly
55 other radiatively active gases (CO, SF_6, N_2O, halocarbons)

Mid-1980s – present:

Advanced Global Atmospheric Gases Experiment (AGAGE)
~ dozen globally distributed sites
Also includes XX gases

CSIRO (Cape Grim, 1984), LSCE, ECCC (Alert, 1988), JMA, FMI, Others

Calibration:

Requires the air sample analysis system to accurately measure a known concentration.

Standards must not drift over time.

Span the range of possible concentrations – from ice age values to modern polluted values.

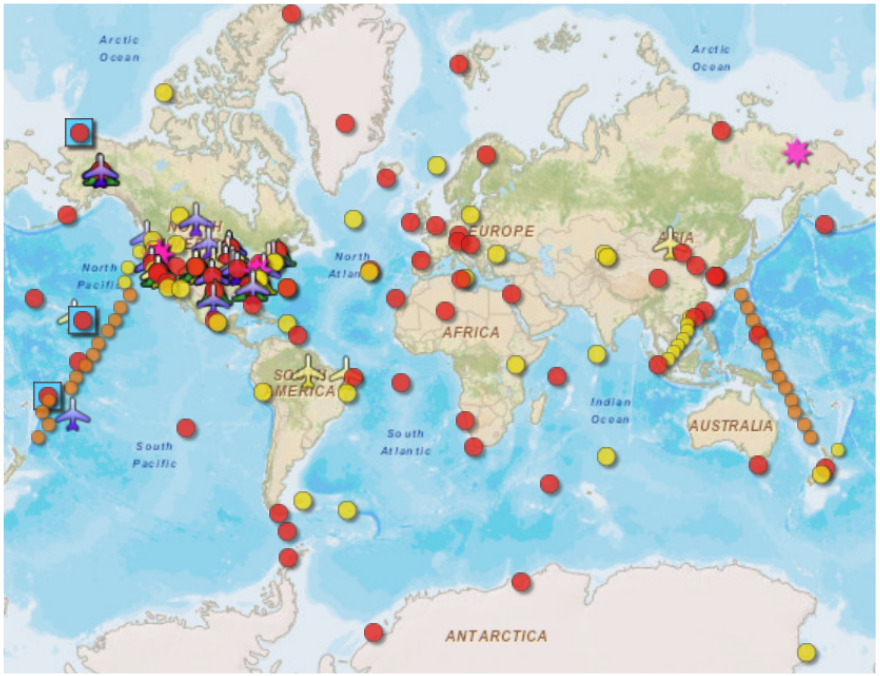
Uncertainty of NOAA Network: 2.4 – 1.1 ppb (95%). (0.06% of global concentration or 0.5% of global emissions (~3Tg)

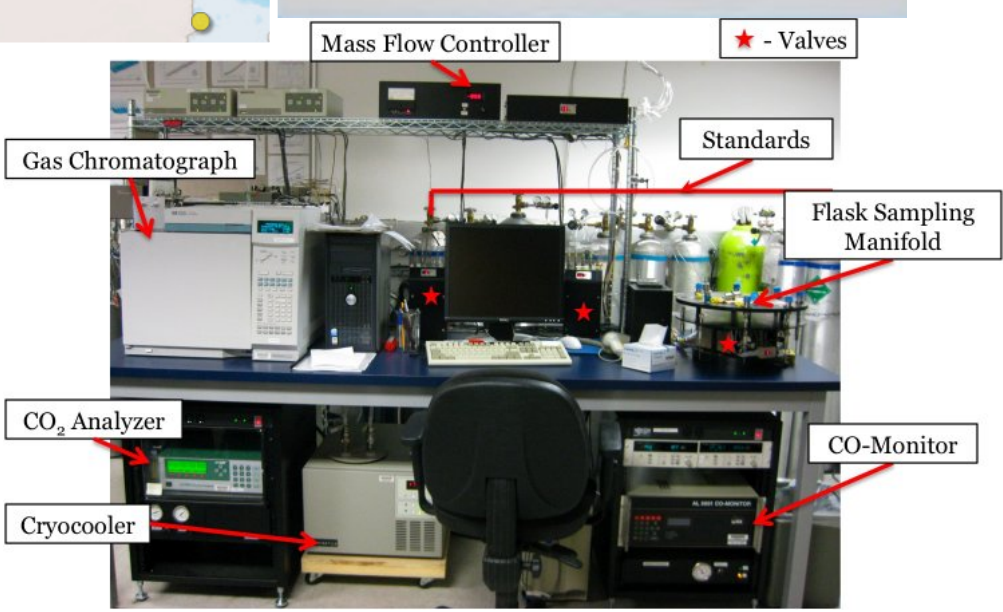
NOAA Maintains WMO Calibrations standards for CO_2, CH_4, N_2O, CO and SF_6

Why?

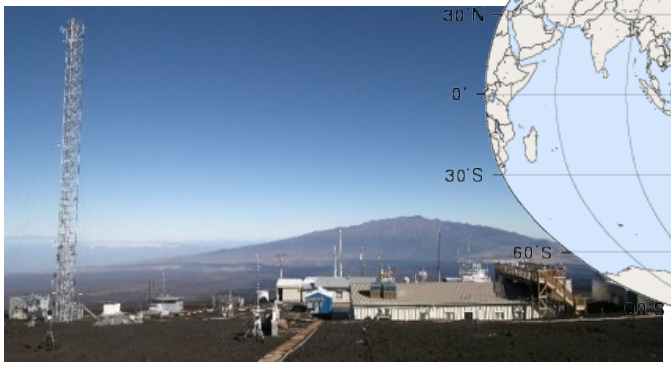
Global Average	~1850 ppb
N-S Gradient	~150 ppb
Pacific-Atlantic Gradient	~10ppb
Seasonal Cycle	~10s pbb
Trends	<1 -~10ppb/yr

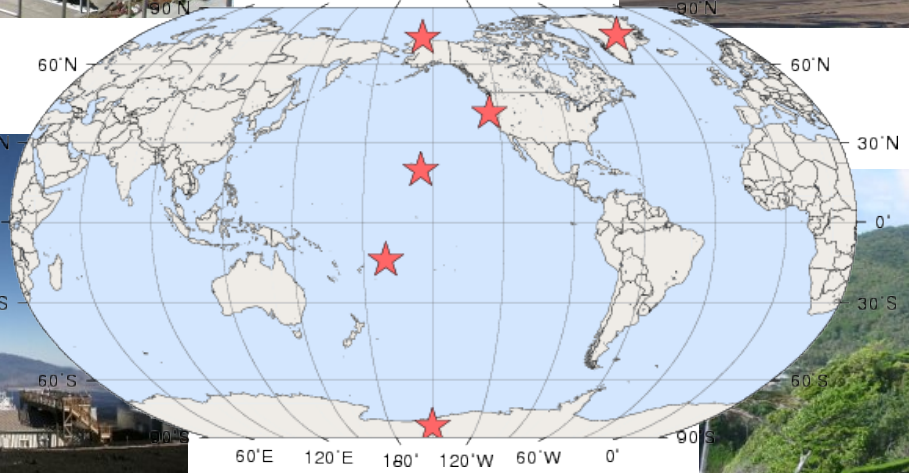
The NOAA Cooperative Air Sampling Network

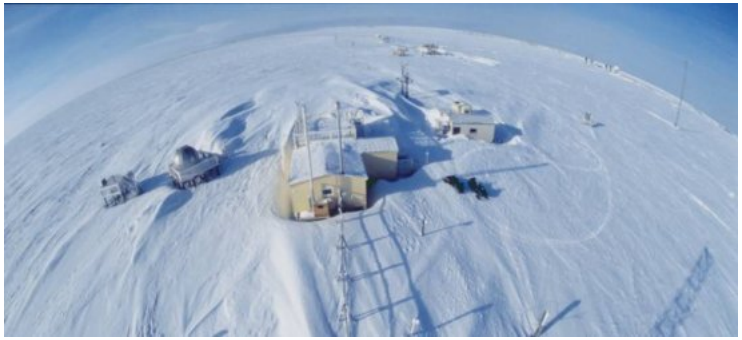




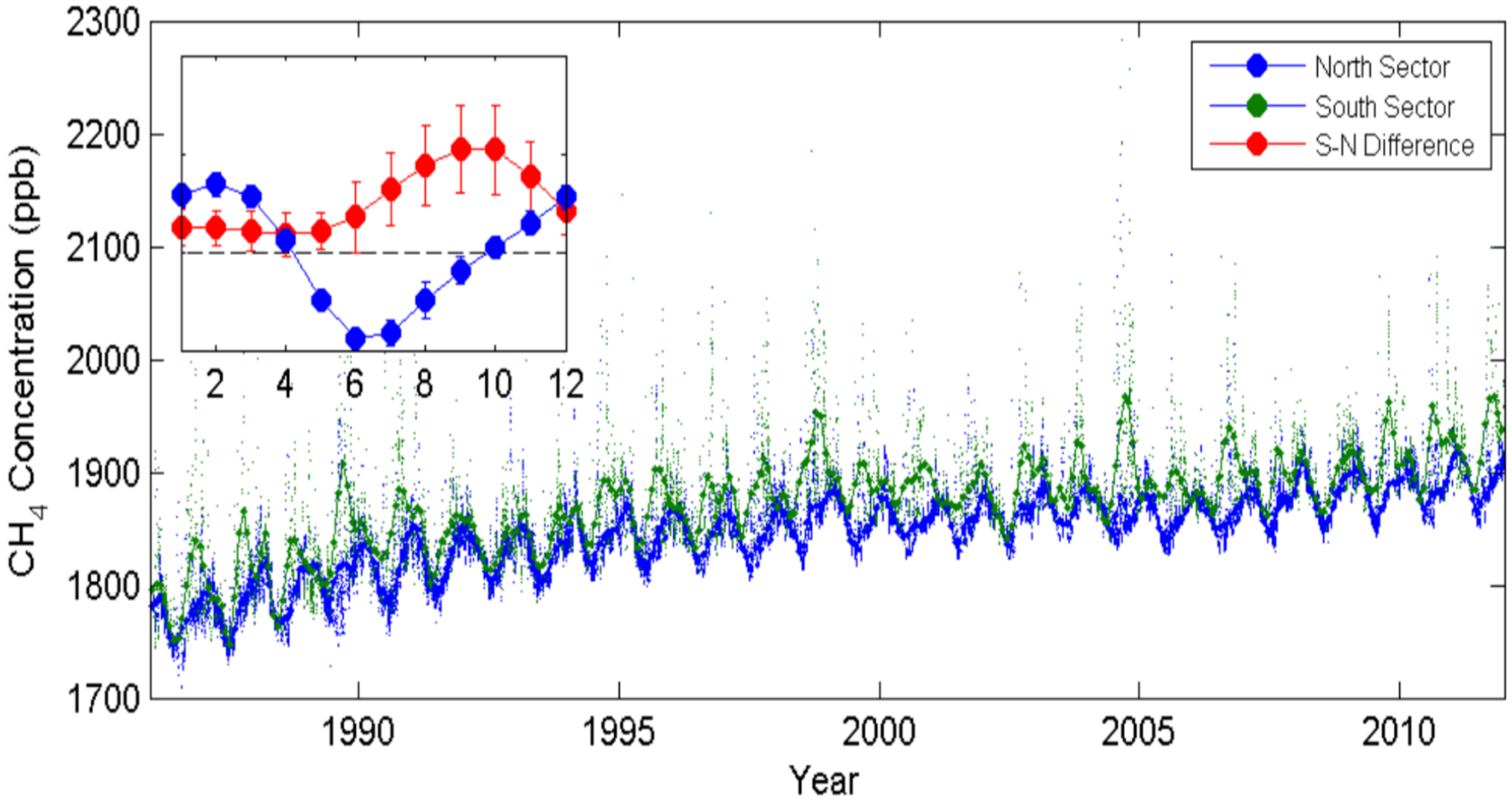
NOAA Baseline Observatories: Continuous In Situ Measurements



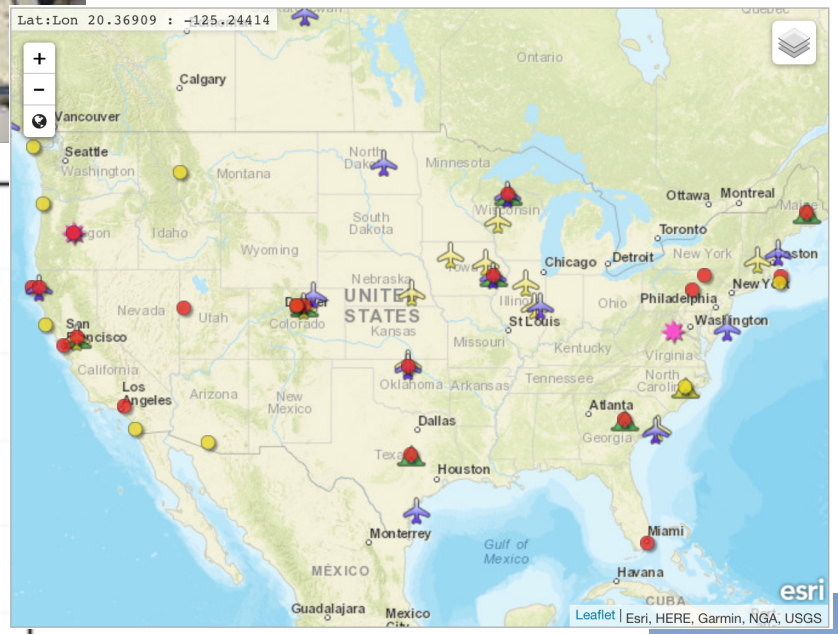


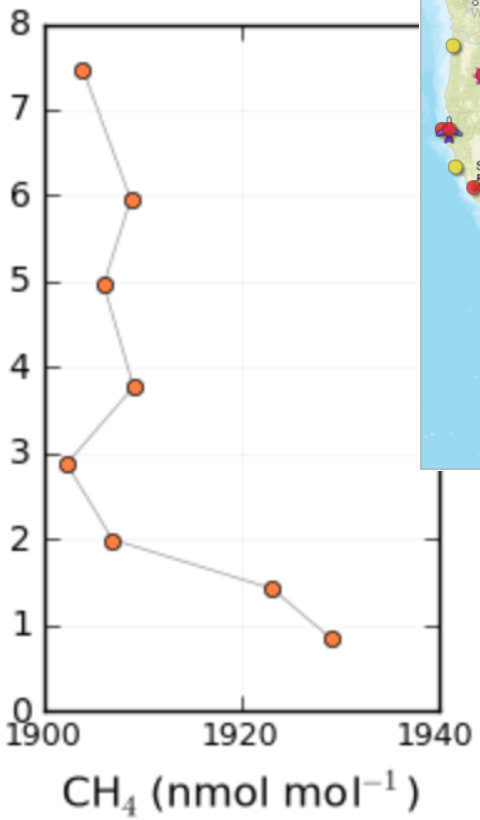


What Can Be Learned From High-Frequency Data?



The North American Network: Aircraft and Towers





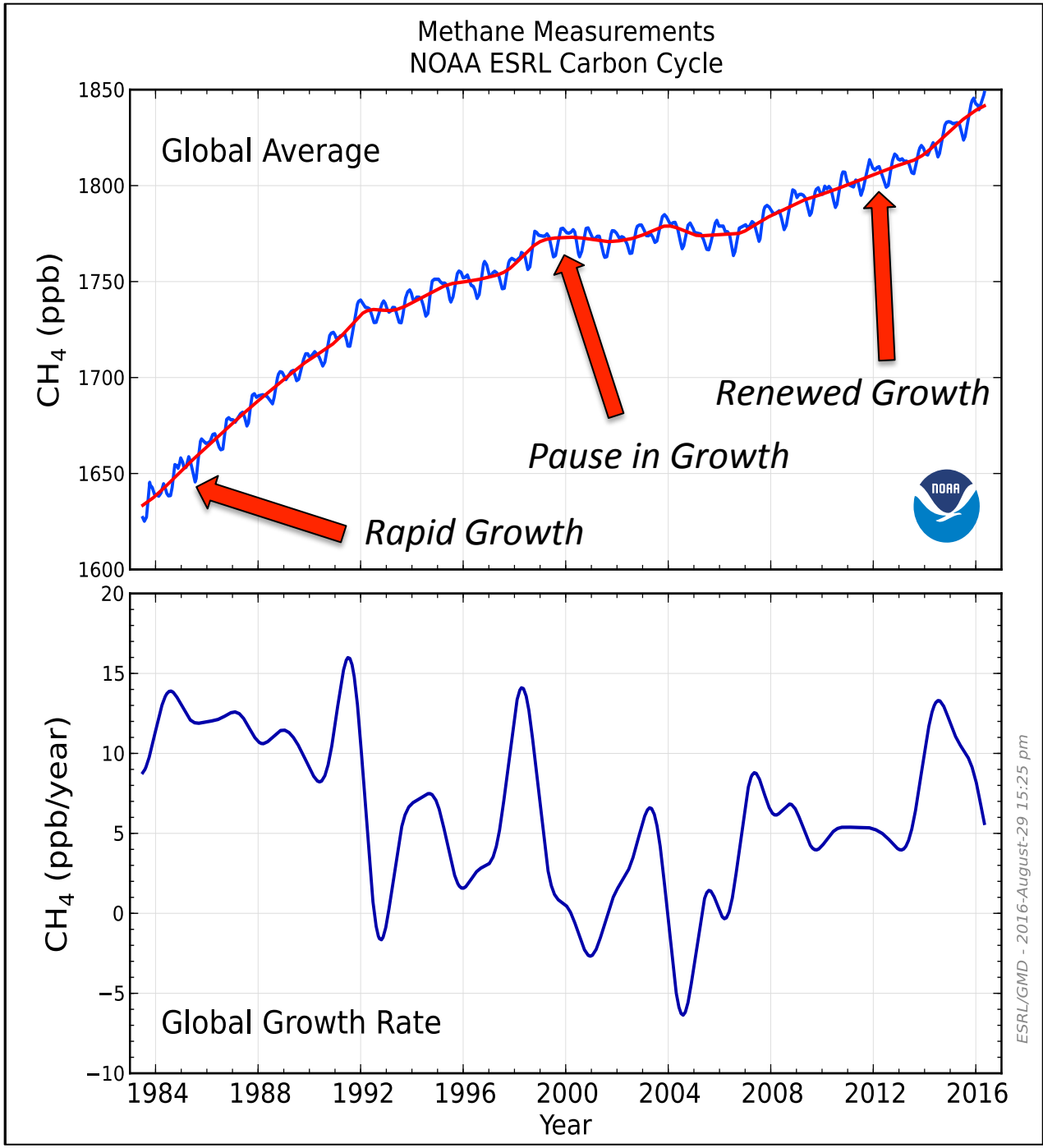
Pause in Growth

1) Approach to Steady-State (1780 ppb by 2010s) Dlugokencky et al., 1998,2003

2) Decreases in O&G Emissions Since the 1980s (Aydin et al., 2011; Simpson et al., 2012)

3) Reductions in Rice Emissions (Kai et al., 2011)

4) OH Increased (Rigby et al., 2017)



Renewed Growth

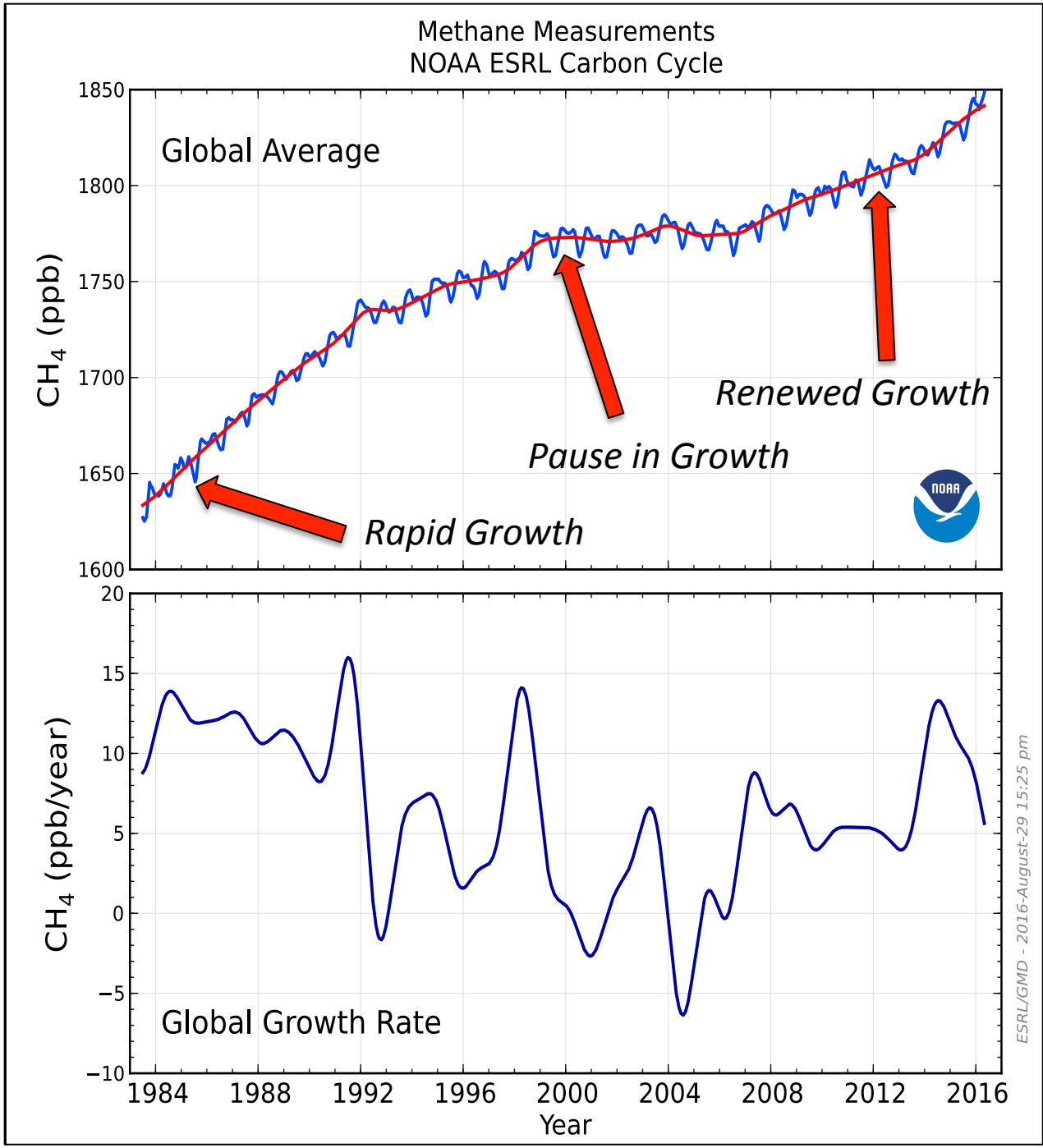
1) Microbial Emissions Going Up (Nisbet et al., 2016, Schaefer et al., 2016, Schwietzke et al. 2016)

2) Could be Anthropogenic Microbial (Schaefer et al., 2016, Saunois et al., 2016).

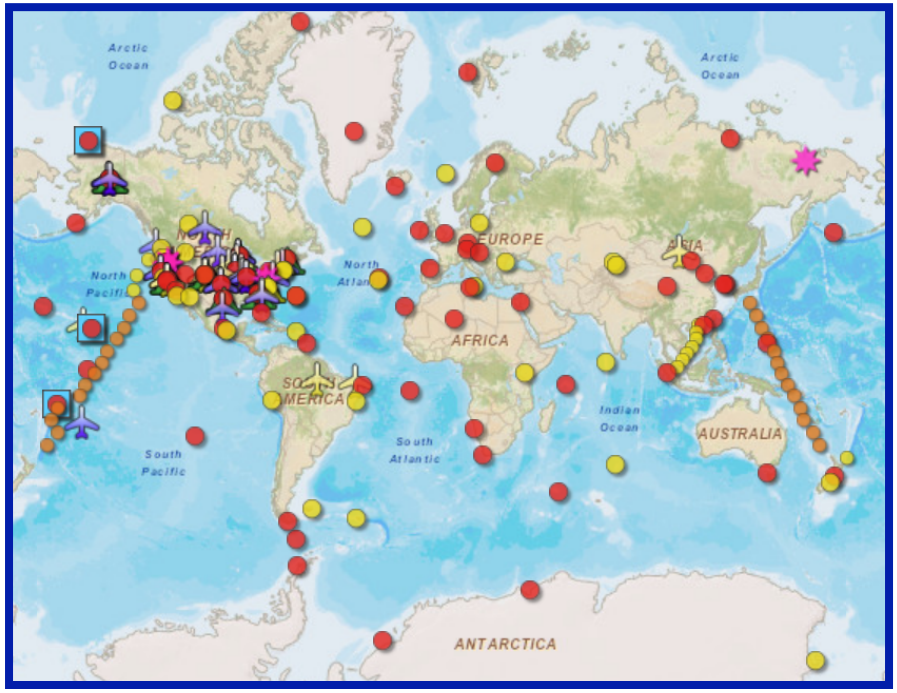
3) Significant Contribution from US Emissions (Turner et al., 2016) or global fossil fuel emissions (Rice et al., 2016)

4) OH Decreased (Rigby et al., 2017)

5) It could be OH, hard to tell anything from isotopes (Turner et al., 2017)



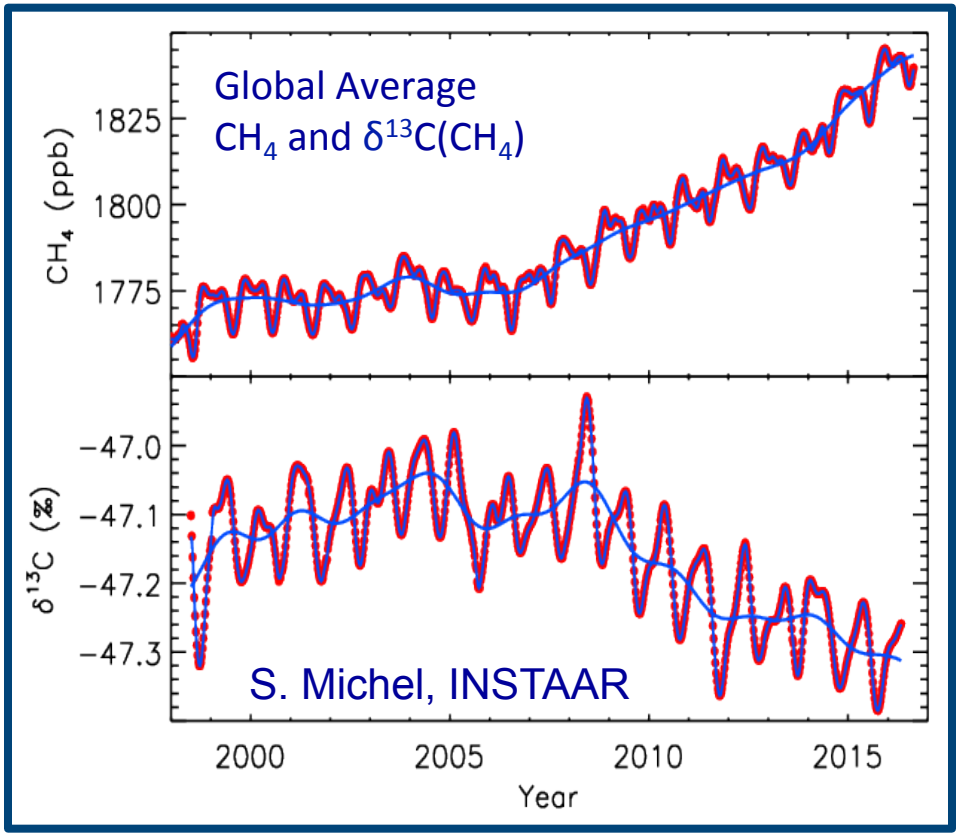
What Can We Learn About CH_4 From Global Network Observations Using Multiple Species?



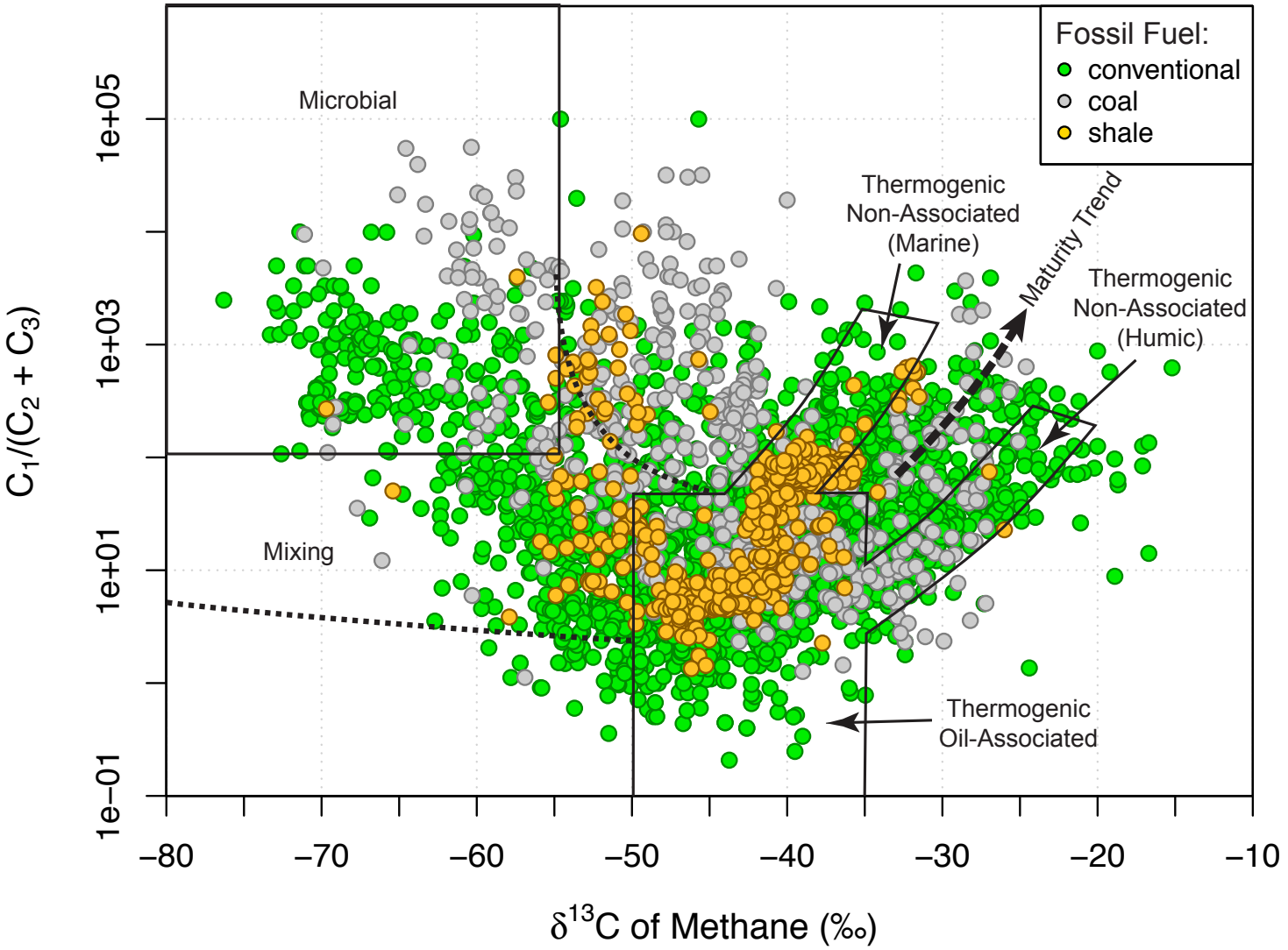
The Global Greenhouse Gas Reference Network: 190 sites in 46 countries

Other Observational Constraints:

$\delta^{13}C(CH_4)$
CH_3CCl_3 (to get OH)
C_2H_6

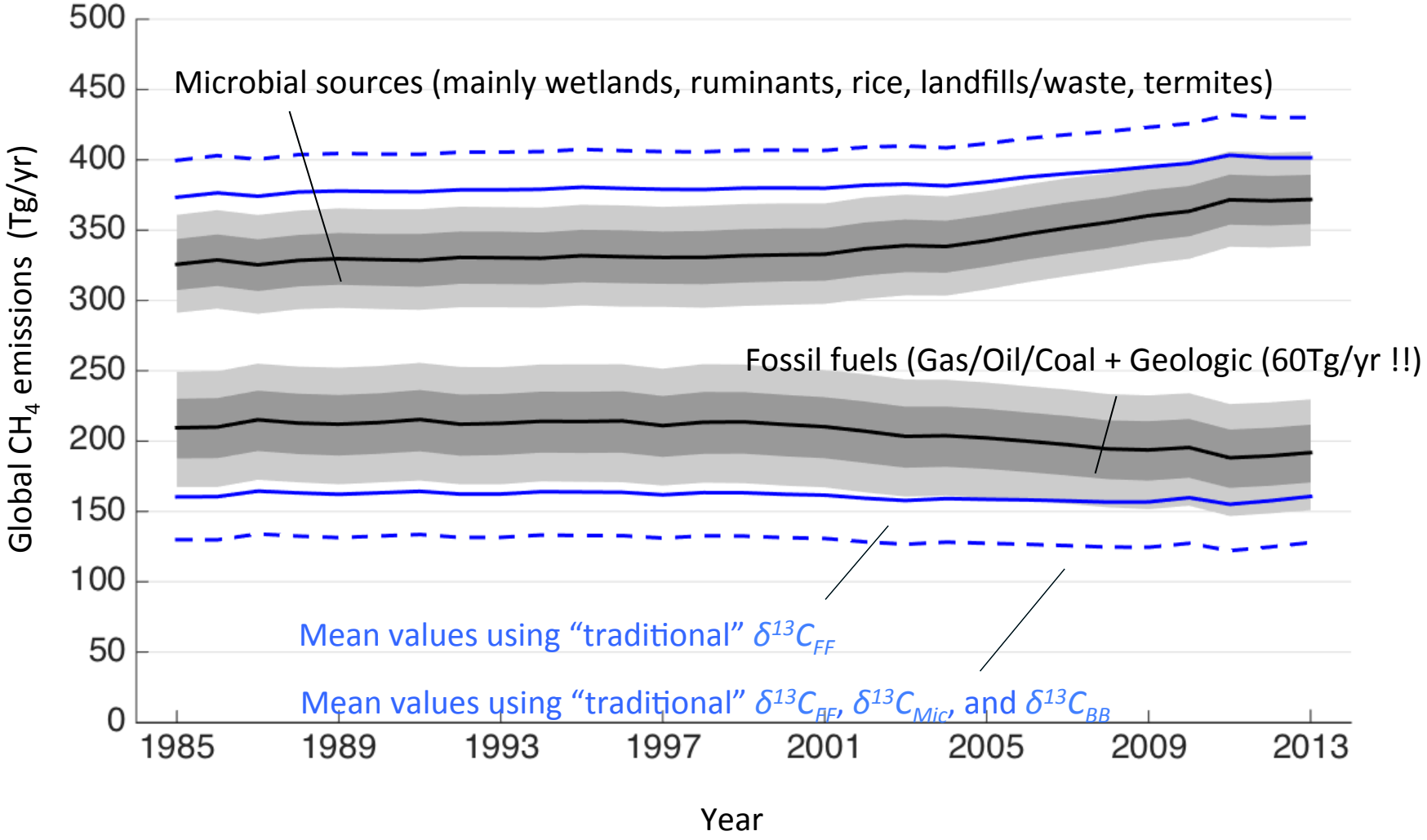


An Extensive Database of Isotopic Source Signatures Leads to a Revised Global CH_4 Budget



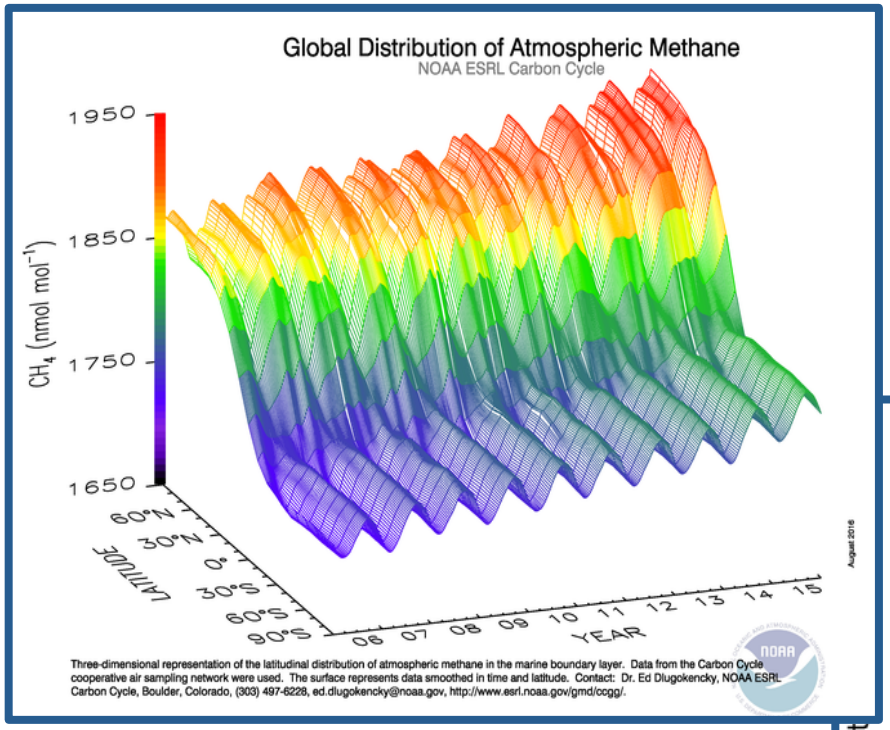
Sherwood OA, Schwietzke S, Arling VA, Etiope G (2017) Global Inventory of Gas Geochemistry Data from Fossil Fuel, Microbial and Biomass Burning Sources, Version 2017. Earth Syst Sci Data Discuss:1–35.

Global fossil fuel CH_4 emissions are ***not*** increasing

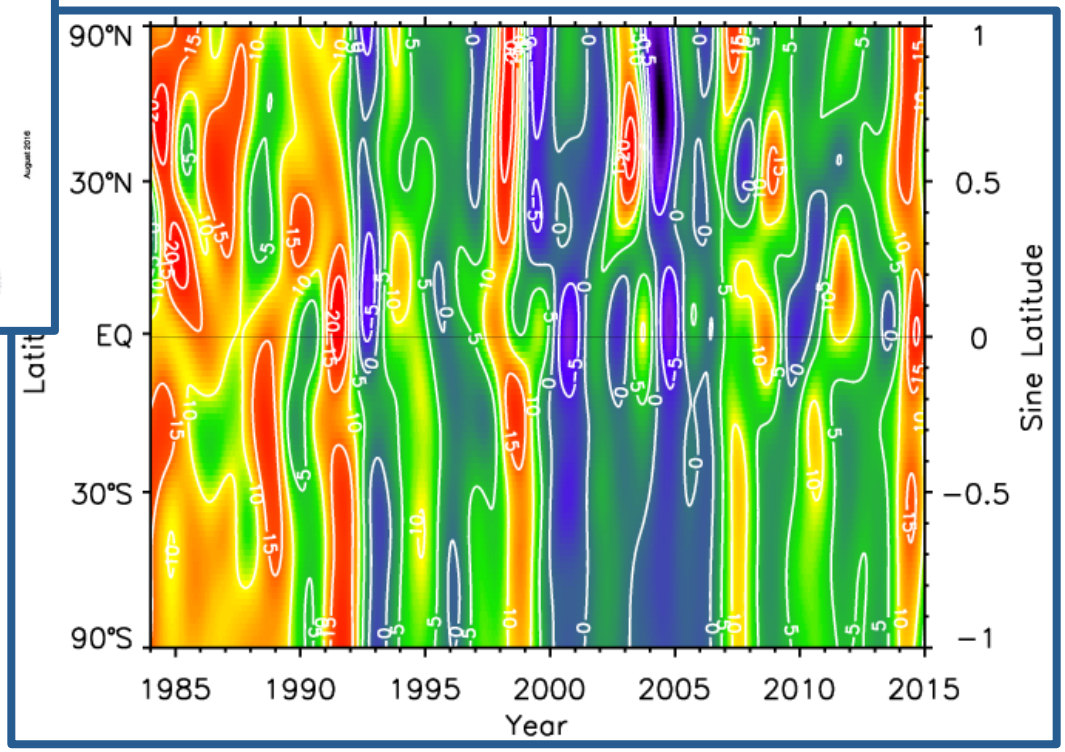


Schwietzke S, et al., (2017) Nature.

We also have a Different Type of Constraint: the Spatial Distribution



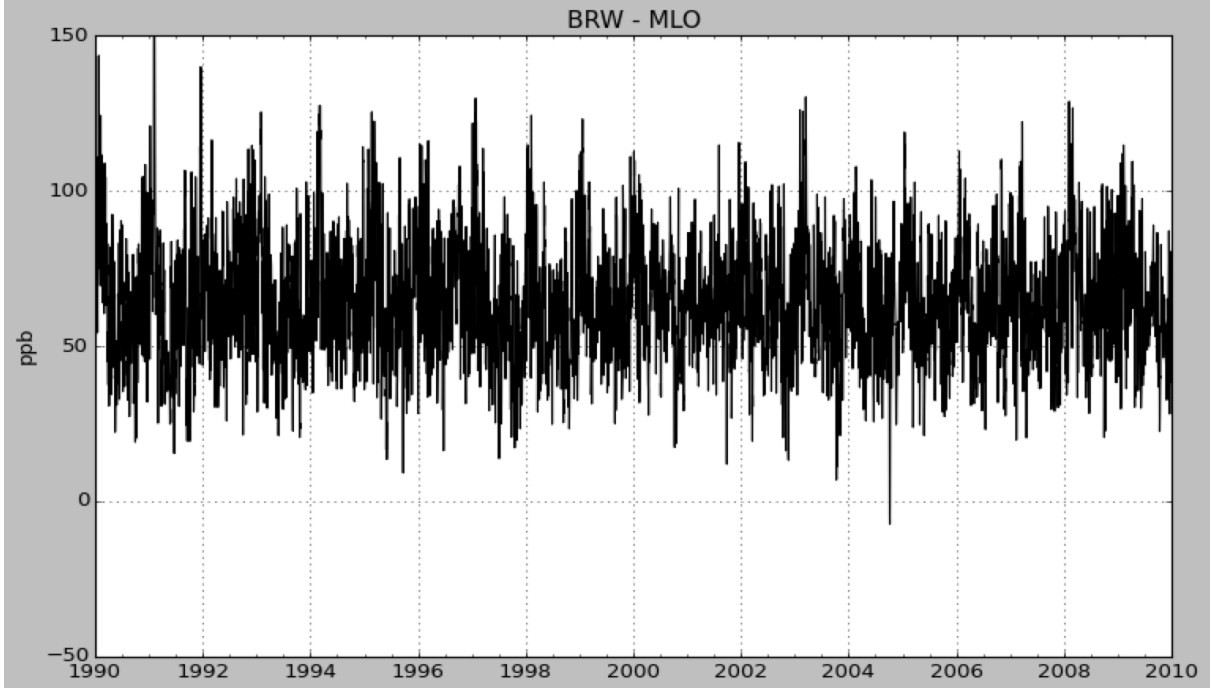
N-S Gradient



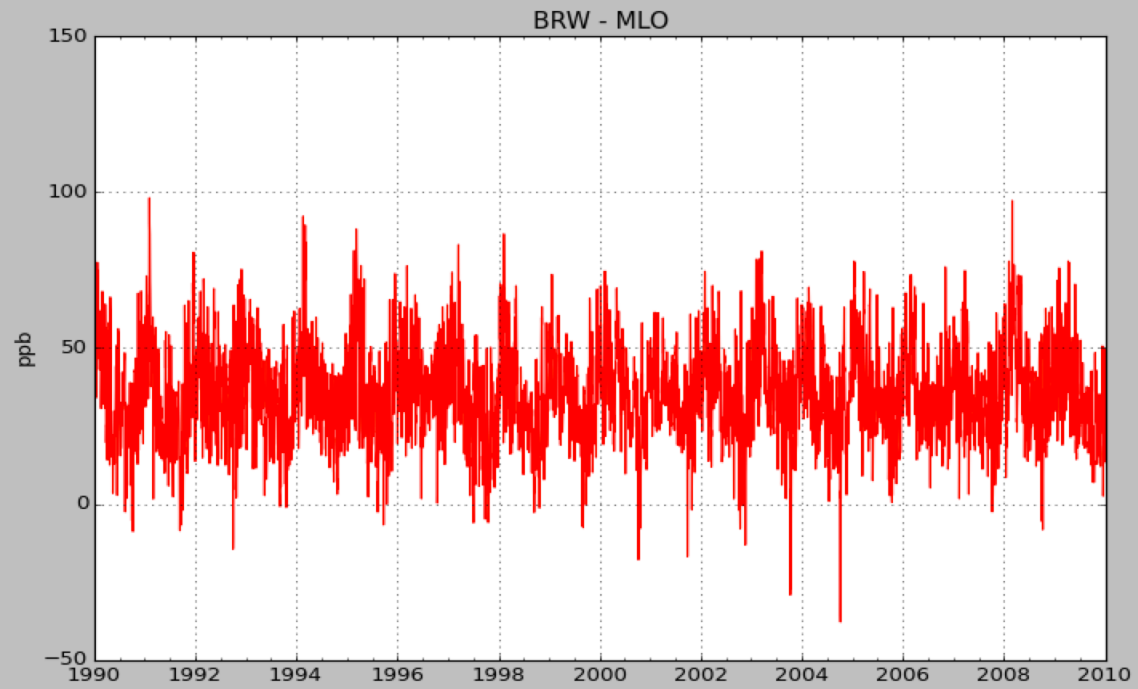
CH_4 Growth Rate (ppb/yr)

A Model Experiment

Control – Repeating Emissions

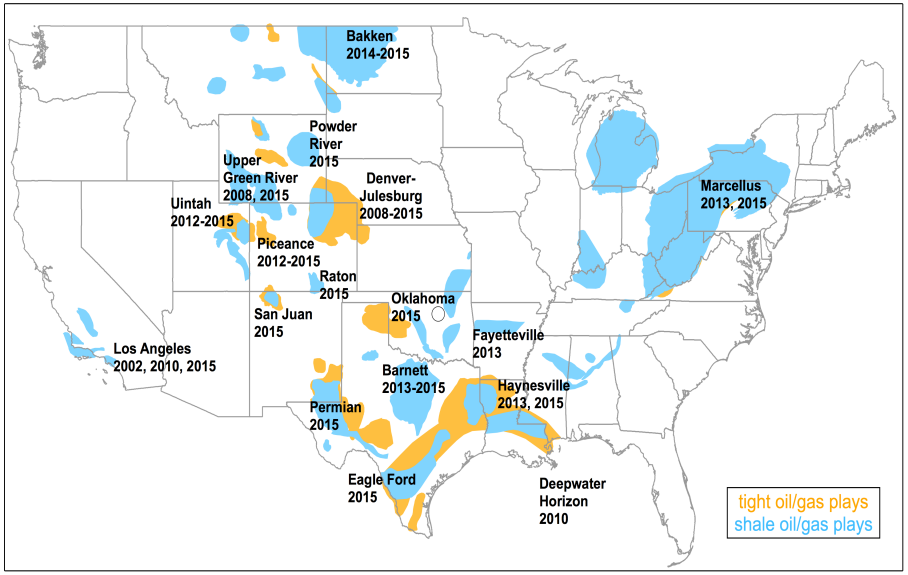


No Emissions north of 60N



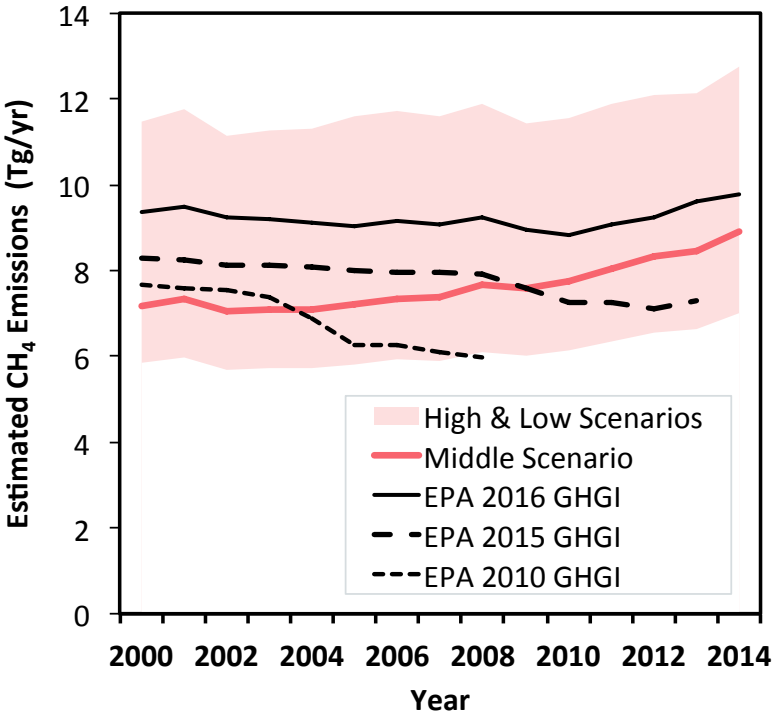
Top-down studies are critical for evaluating bottom-up/ inventory emission estimates

- Early top-down work found larger O&G CH_4 emissions than accounted for by the EPA GHG inventory.
- Findings from recent studies:
  - ➢ Skewed distribution of emission/facility or process
  - ➢ Underestimation of large emissions (gathering)



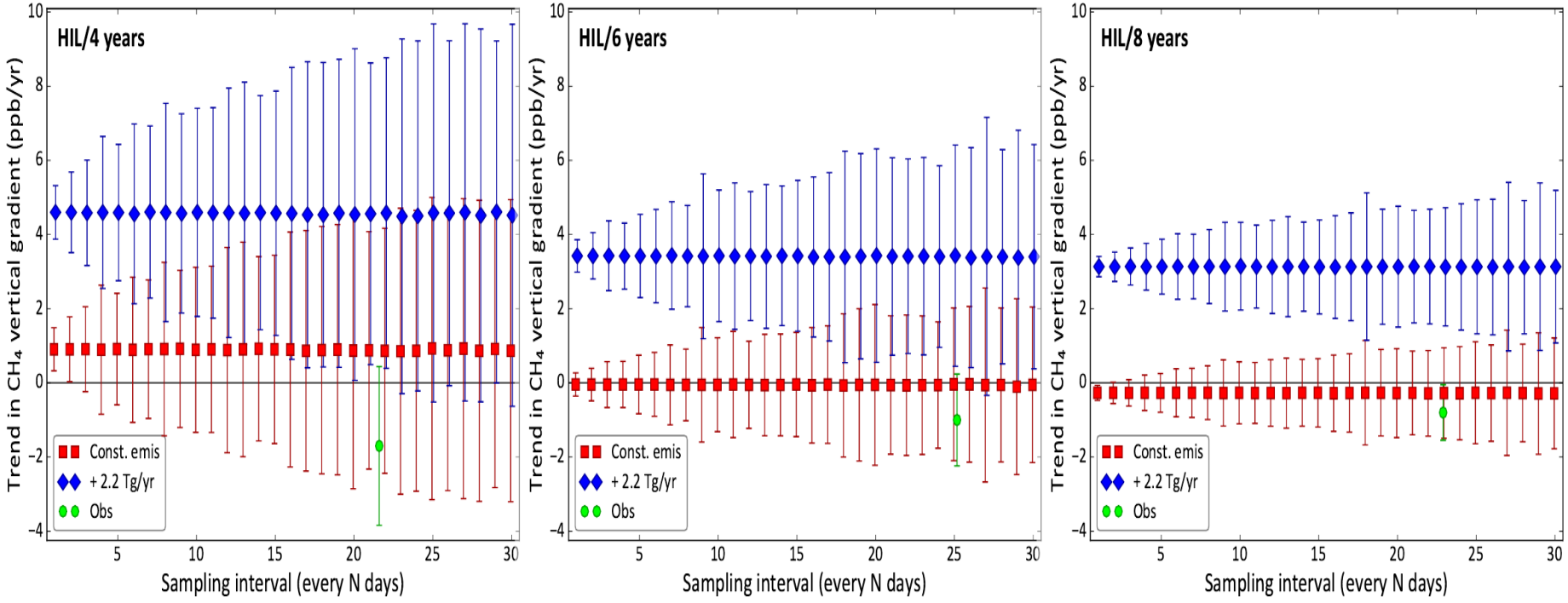
NOAA airborne measurement campaigns in unconventional O&G basins in 2012-2015

(G. Petron)



- Incremental revisions of EPA emissions inventory model for O&G CH_4 emission since 2010 (black lines).
- Low-Medium-High emissions scenarios for O&G CH4 (red) based on most recent studies show that uncertainties are still large but do not indicate a major sudden increase in emissions

Can We Detect A Short-Term Trend using Vertical Gradients Derived from Aircraft Partial Columns?

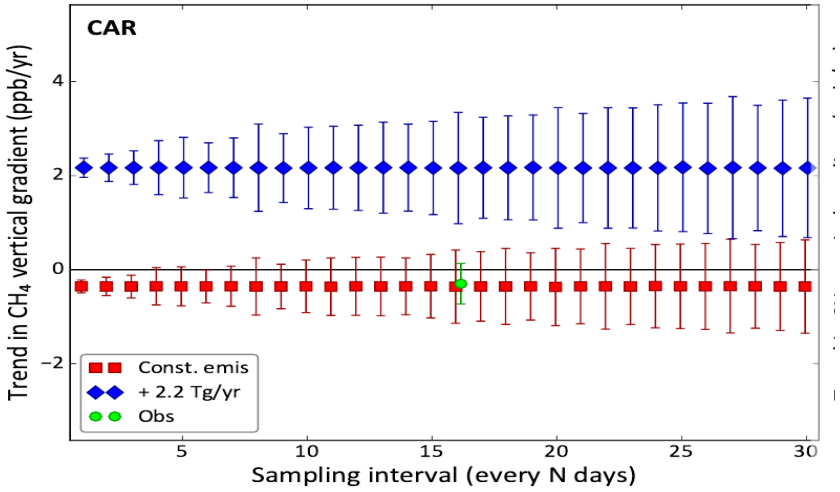


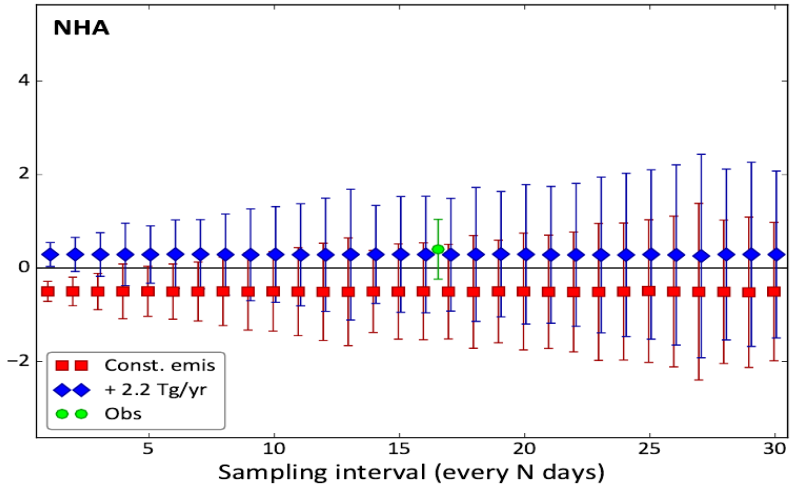
Vertical Gradient: PBL- Free Trop.

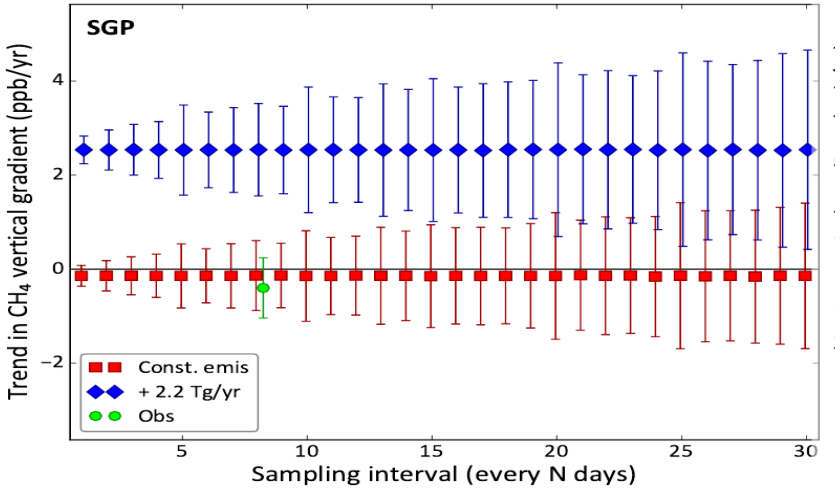
<5 Day Sampling Interval Needed to Detect a Trend in 4 Years.

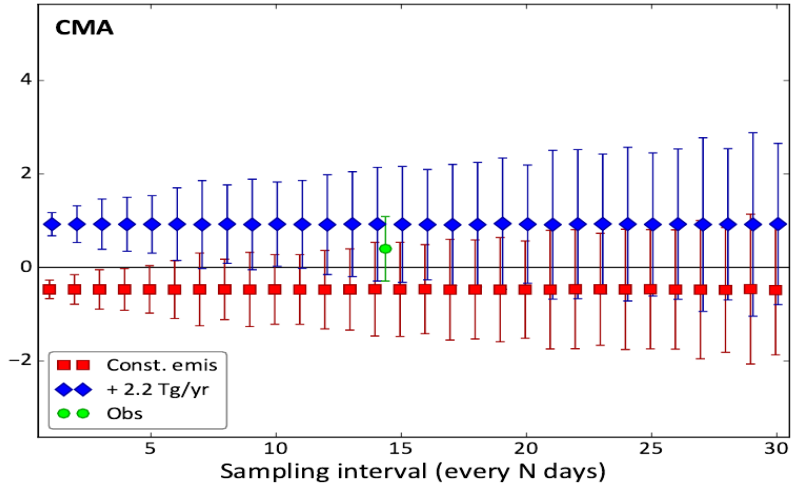
Sampling Interval Increases with Longer Time Detection Window.

Proximity to the Changing Source Matters





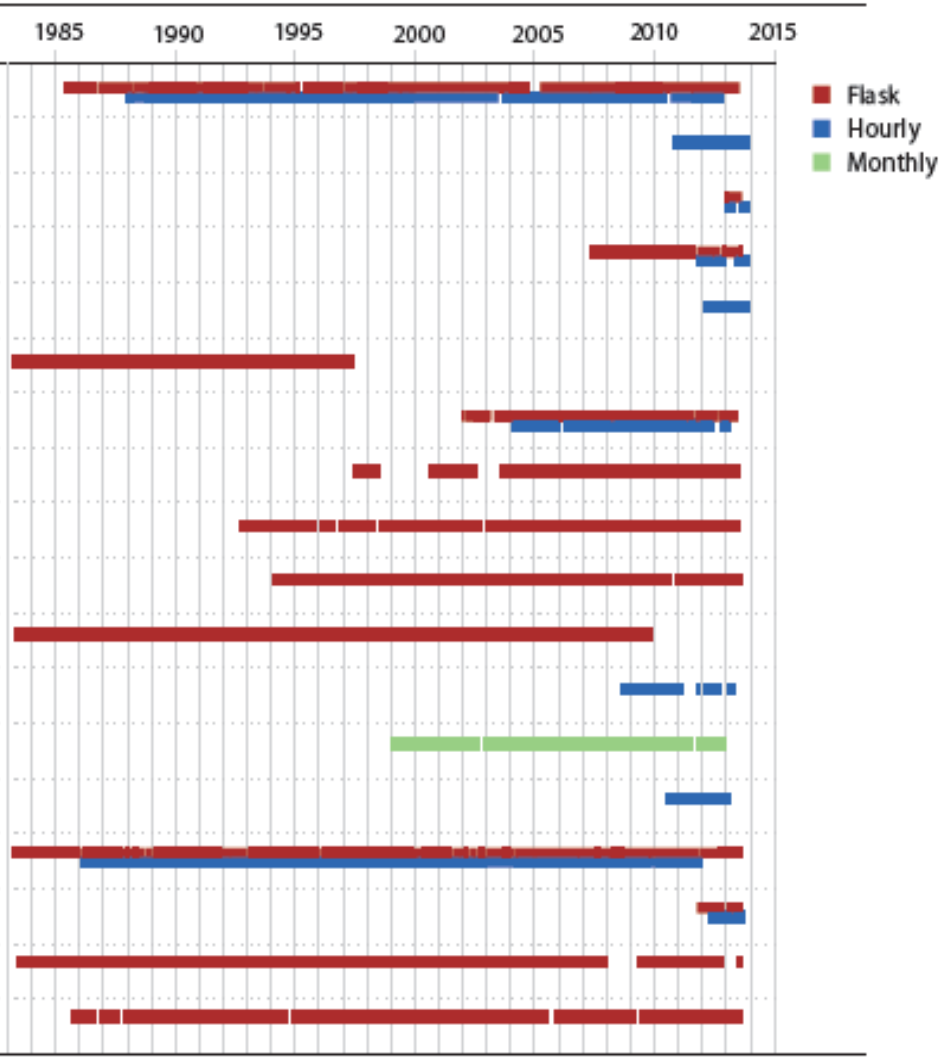




We Need Long Time Series to Detect Small Trends!

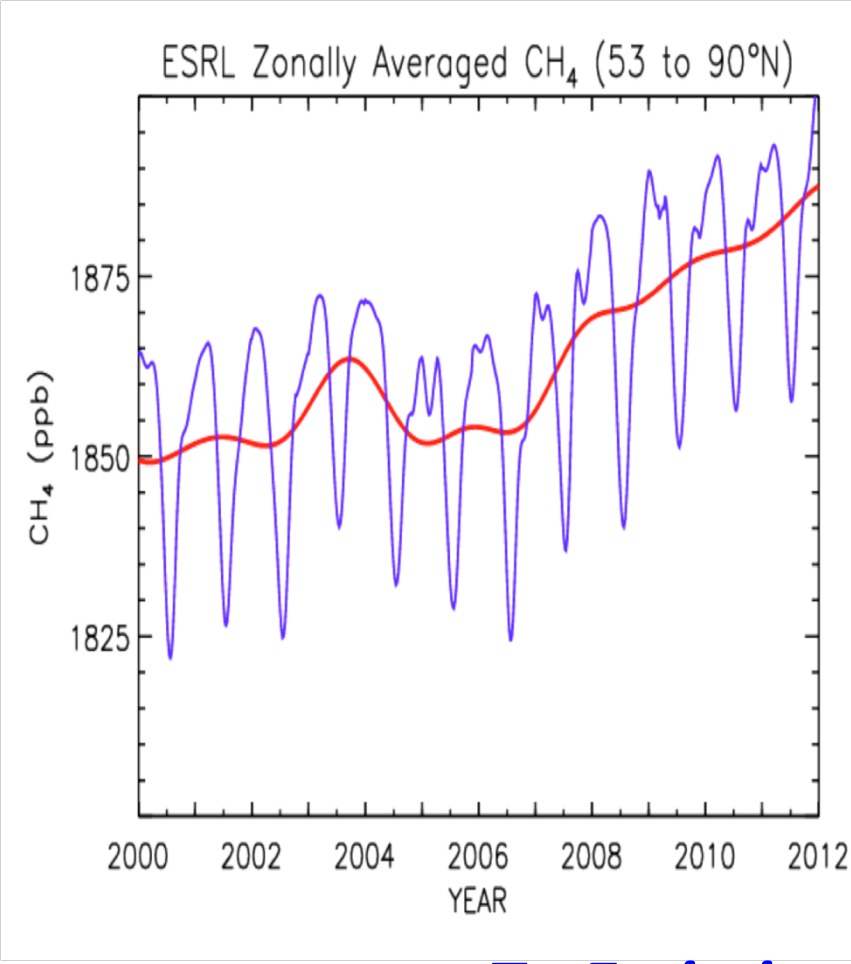
Table 6.1 Summary of available observations of methane in the Arctic.

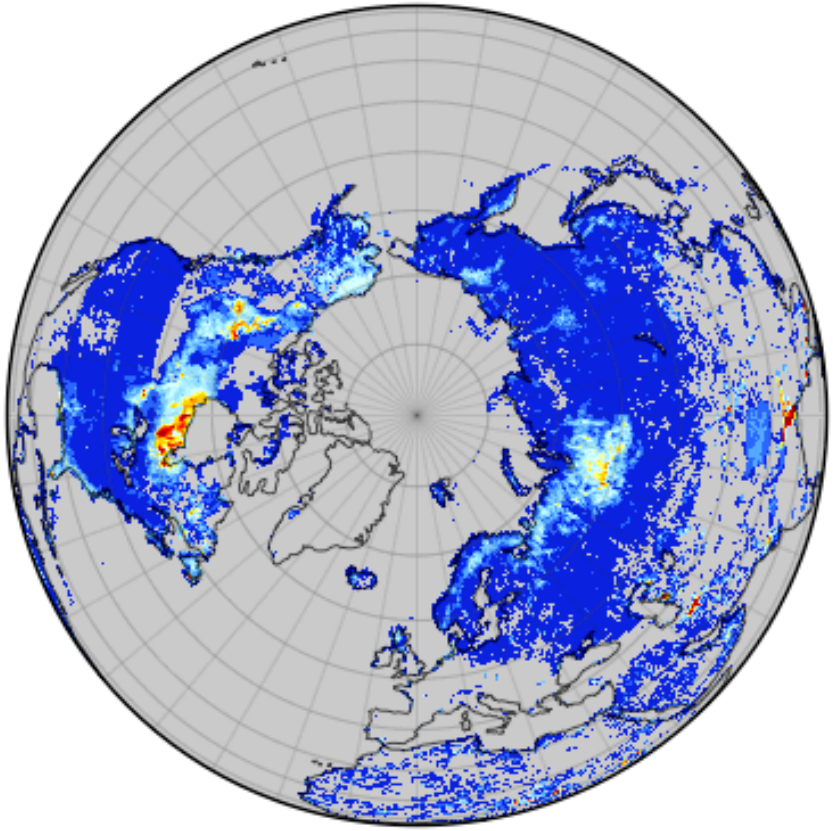
Station name (Country)	Latitude / Longitude	Height, m above sea level
Alert (Canada)	82.5°N / 62.5°W	210
Behchoko (Canada)	62.8°N / 116.1°W	179
Cambridge Bay (Canada)	69.1°N / 105.1°W	38
Churchill (Canada)	58.7°N / 93.8°W	29
Inuvik (Canada)	68.3°N / 133.5°W	100
Mould Bay (Canada)	76.3°N / 119.4°W	30
Pallas (Finland)	68°N / 24.1°E	560
Summit (Greenland)	72.6°N / 38.4°W	3238
Storhofdi (Iceland)	63.4°N / 20.3°W	118
Ny-Ålesund (Norway)	78.9°N / 11.9°E	474
Station M (Norway)	66°N / 2°E	0
Cherskii (Russia)	68.5°N / 161.5°E	30
Teriberka (Russia)	69.2°N / 35.1°E	40
Tiksi (Russia)	71.6°N / 128.9°E	8
Barrow (USA)	71.3°N / 156.6°W	11
CARVE Tower (USA)	65°N / 147.6°W	611
Cold Bay (USA)	55.2°N / 162.7°W	21
Shemya (USA)	52.7°N / 174.1°W	40



AMAP, 2015

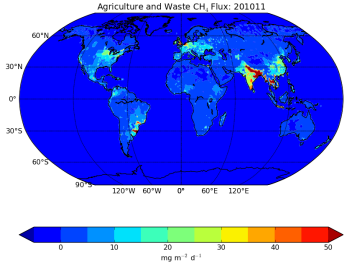
Atmospheric measurements can help us to understand the CH_4 Budget, but how do we get from here….





…..To Emissions? (Use Models!)

But We Really Want Emissions at Continental Scales…



Prior Emission Estimates

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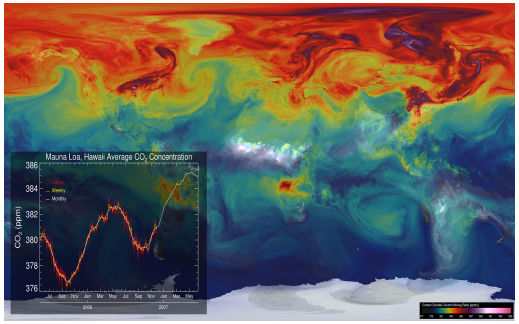
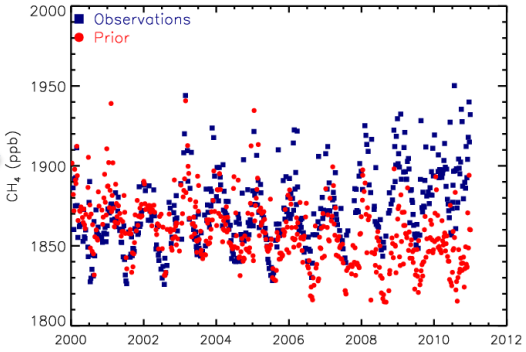
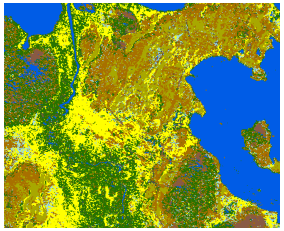


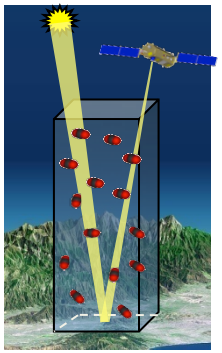
Atmospheric Transport Model



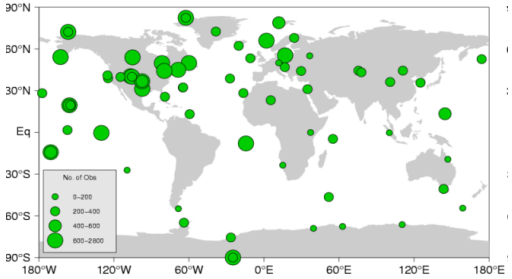


Satellites, TCCON (Column Data)

Remotely Sensed Ecological Data

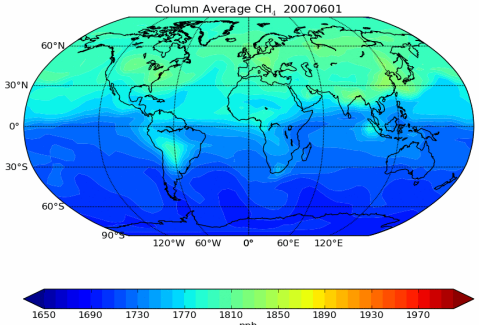


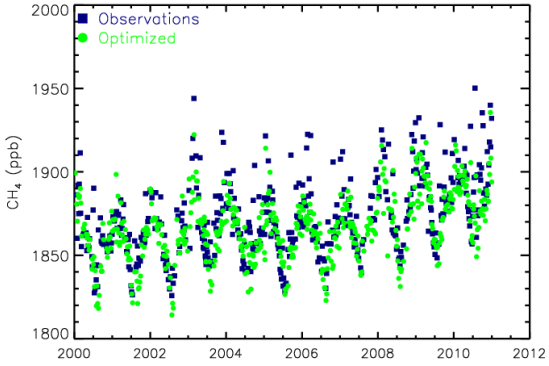
Current Surface Network



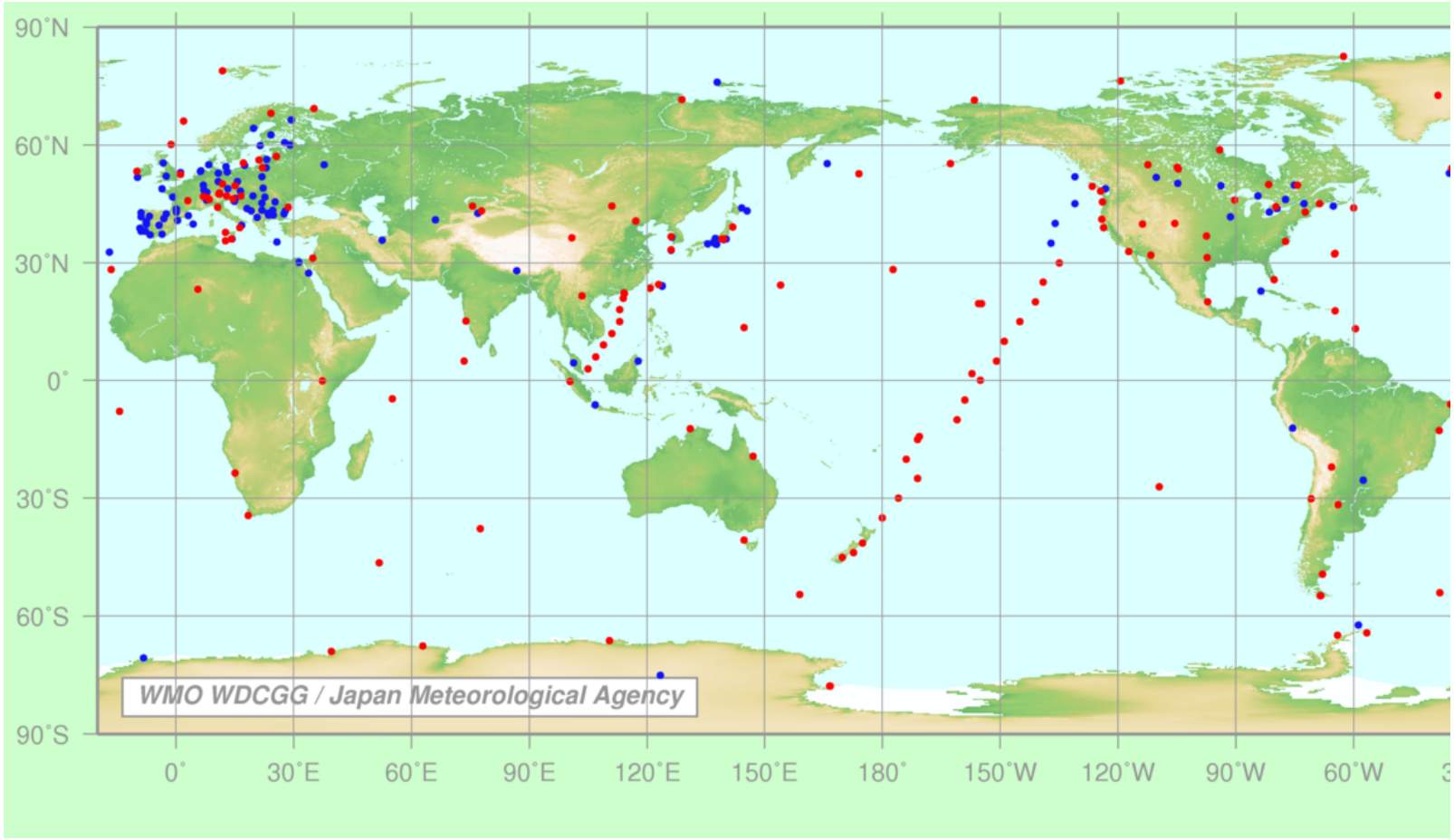
Optimization Used to Estimate the Atmospheric State (Concentration Emissions)

Earth System Analyzer-CH_4



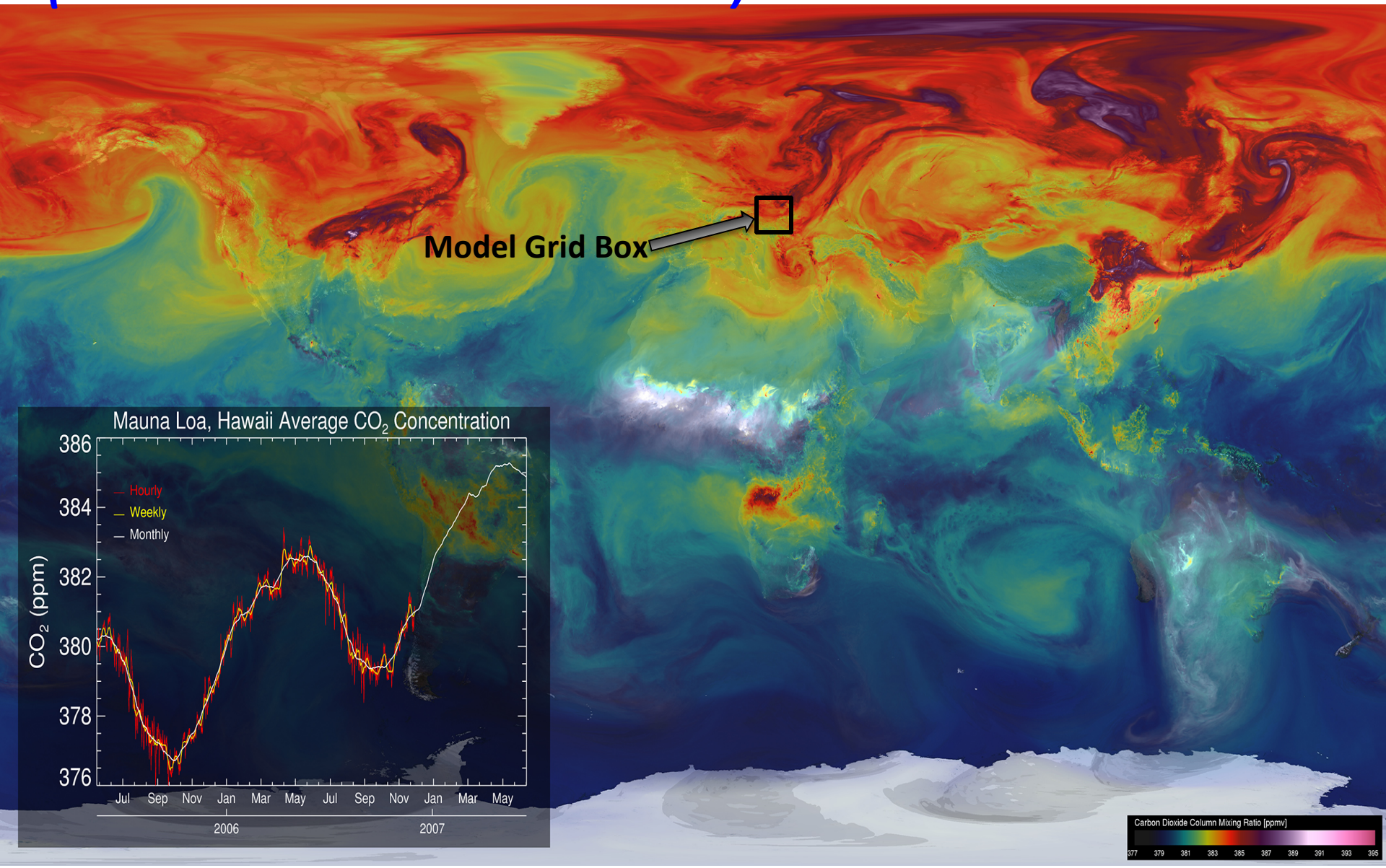


How Can We Increase Data Density?



World Data Centre for Greenhouse Gases, JMA

Representation Error (7 km NASA Nature Simulation)

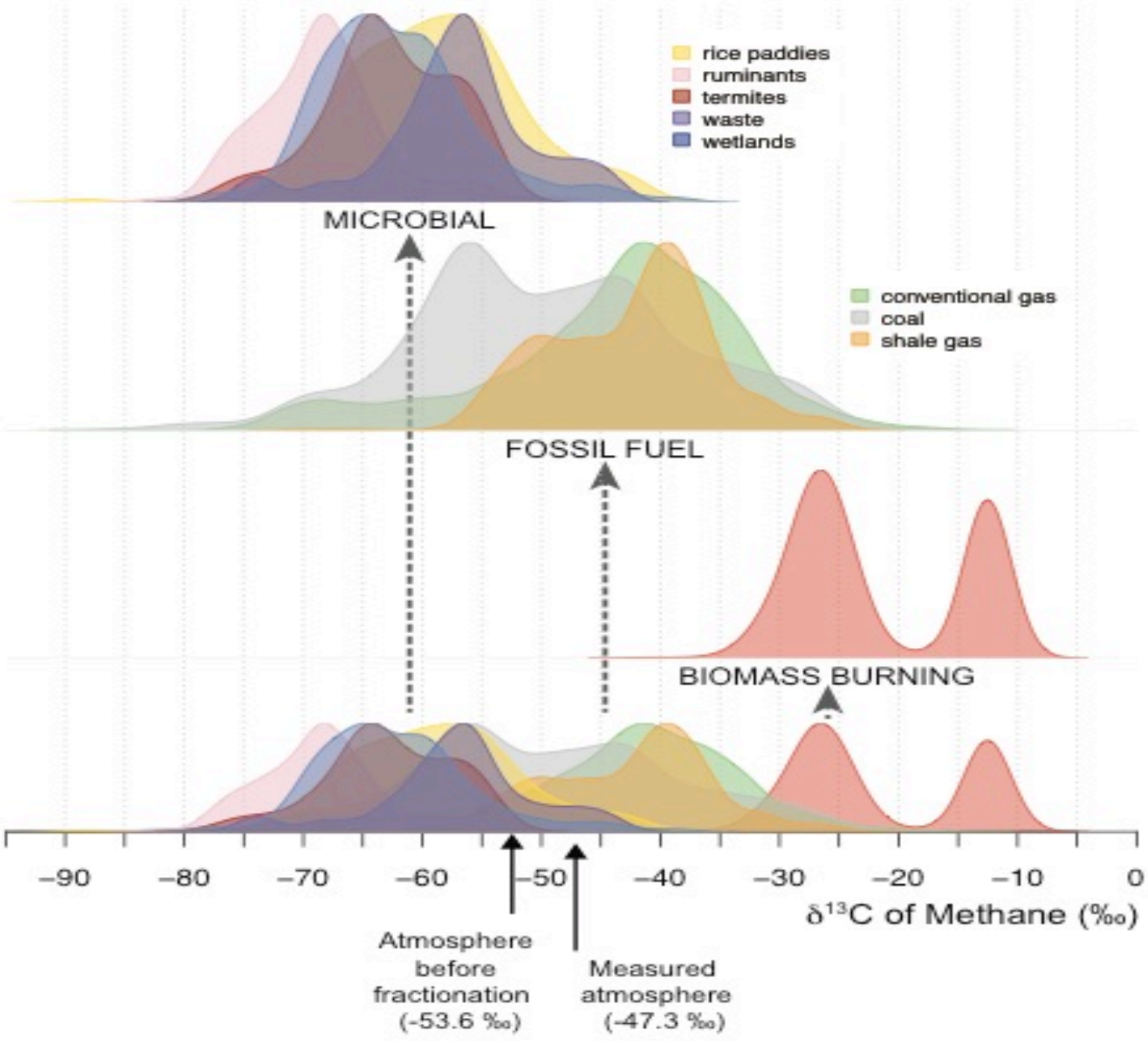


Conclusions

- There is still debate about what's driving the recent growth in CH_4, but probably microbial sources play a role.

- We need long-term, high quality data in order to monitor changes in the CH_4 budget.

- Improved ability to model continental observations will be needed if we are to learn about regional emissions


rice paddies
ruminants
termites
waste
wetlands
MICROBIAL
conventional gas
coal
shale gas
FOSSIL FUEL
BIOMASS BURNING
−90
−80
−70
−60
−50
−40
−30
−20
−10
0
δ13C of Methane (‰)
Atmosphere before fractionation (-53.6 ‰)
Measured atmosphere (-47.3 ‰)