The Arctic Carbon Cycle and its Response to Changing Climate

"Scene in the Arctic", William Bradford, 1880

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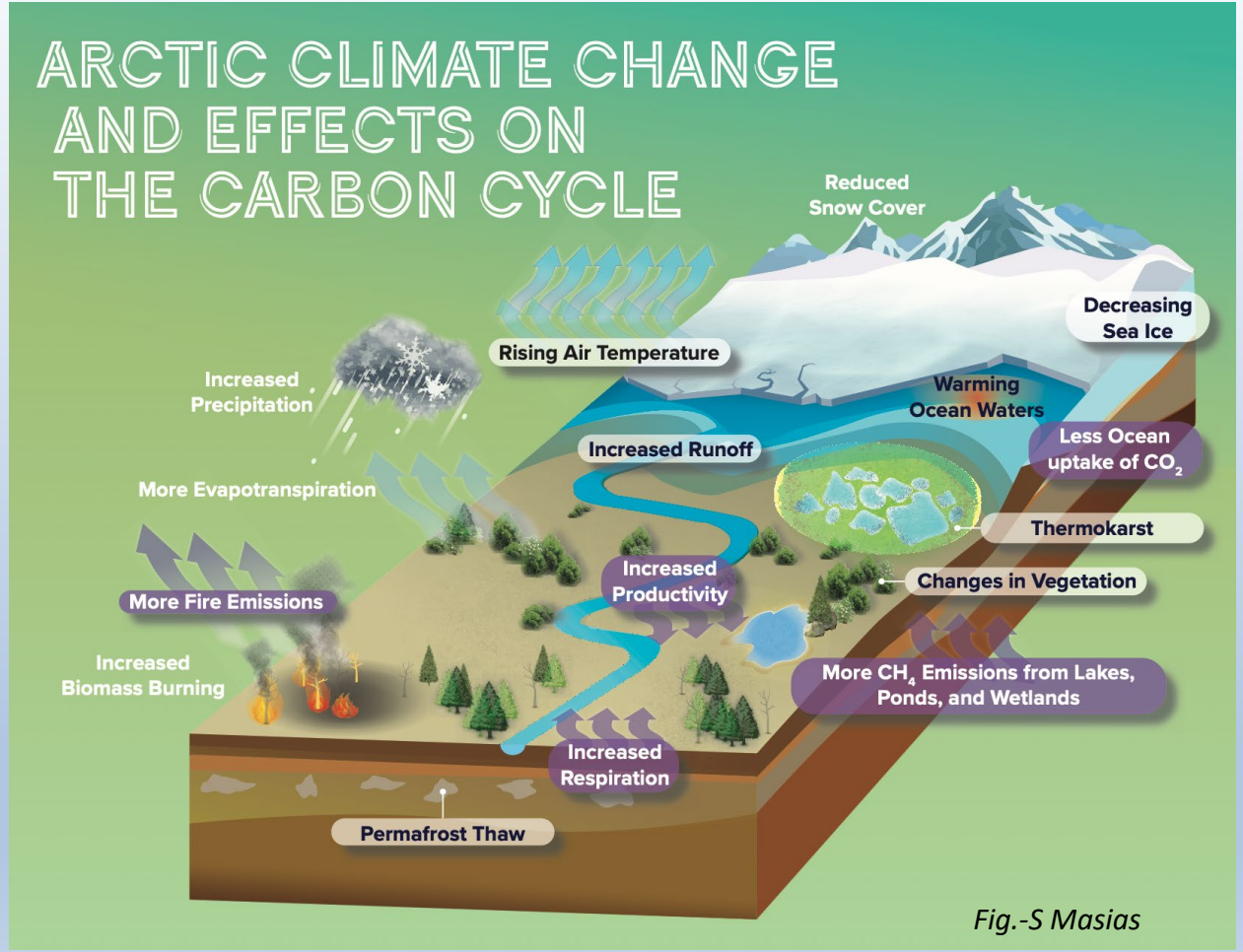


Fig.-S Masias

1137-1850 PgC
In Arctic soils

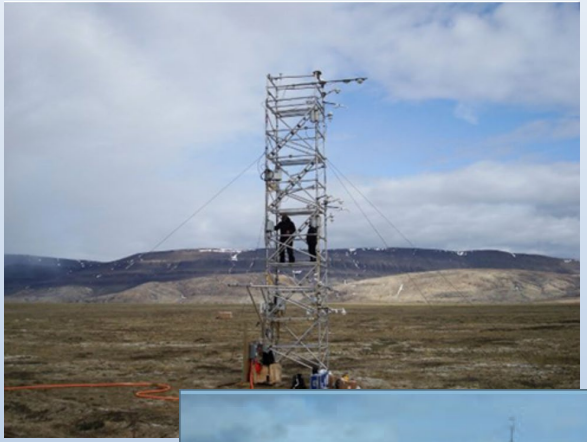
Possible 21st Century Emissions :

0.9 +/- 0.5 PgC/yr
~ 30 TgCH$_4$/yr

(assuming constant annual emissions)

(Schurr et al., 2015,2013)

Estimating the Carbon Fluxes

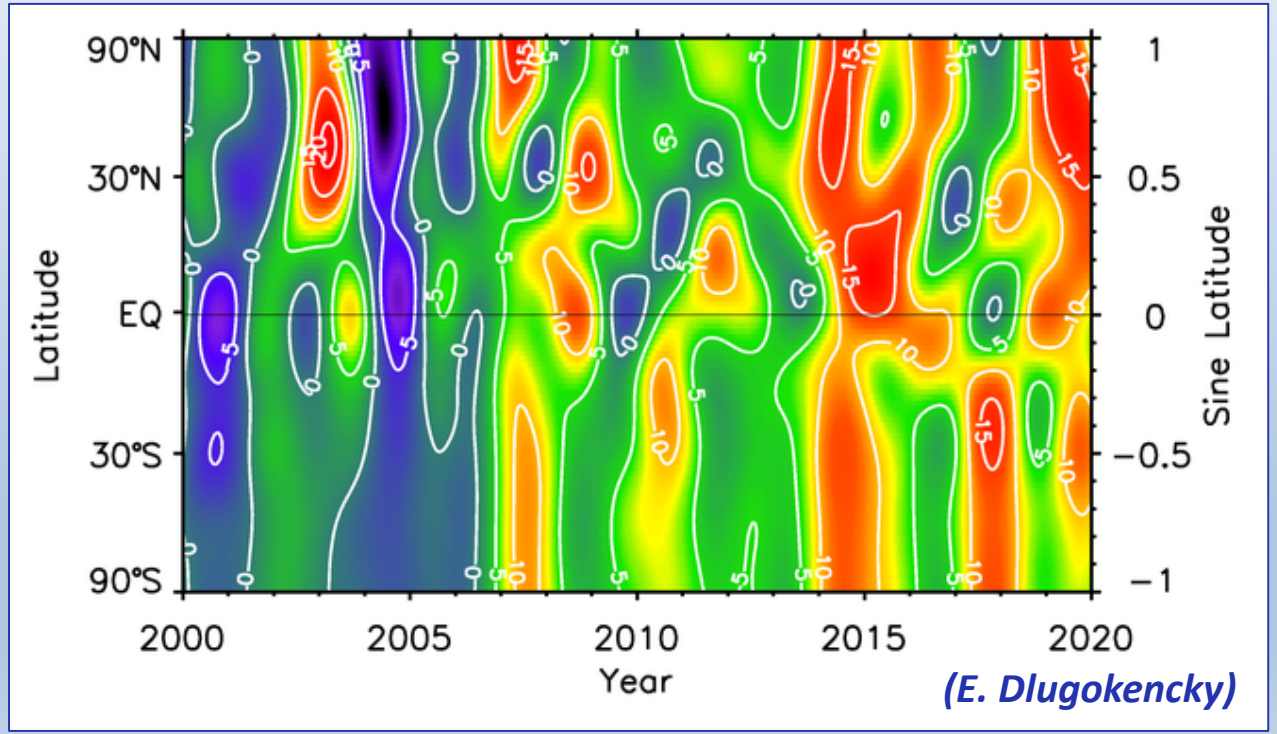


Bottom-Up (BU)

Top-Down (TD)

TD: Atmospheric Observations Give Spatial and Temporal Information About Emissions

(but you need to account for atmospheric transport)

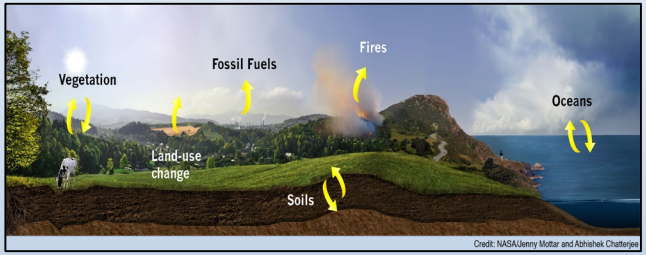


(E. Dlugokencky)

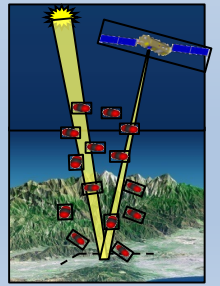
Growth Rate Anomalies (ppb/yr)

TD: Atmospheric Inversions – Synthesizing Models and Observations

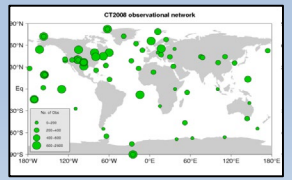
Carbon Flux Models



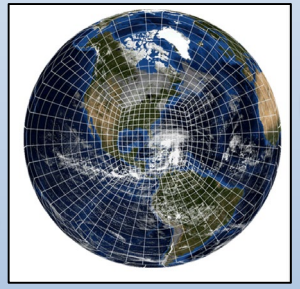
Remotely- Sensed Column Data



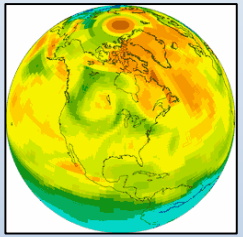
In Situ Surface Network Data

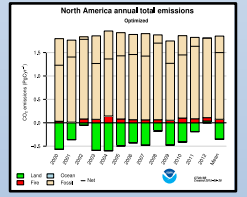


Earth System Model
With Data Assimilation
Now: TM5
Future: NGGPS



Carbon Analyses

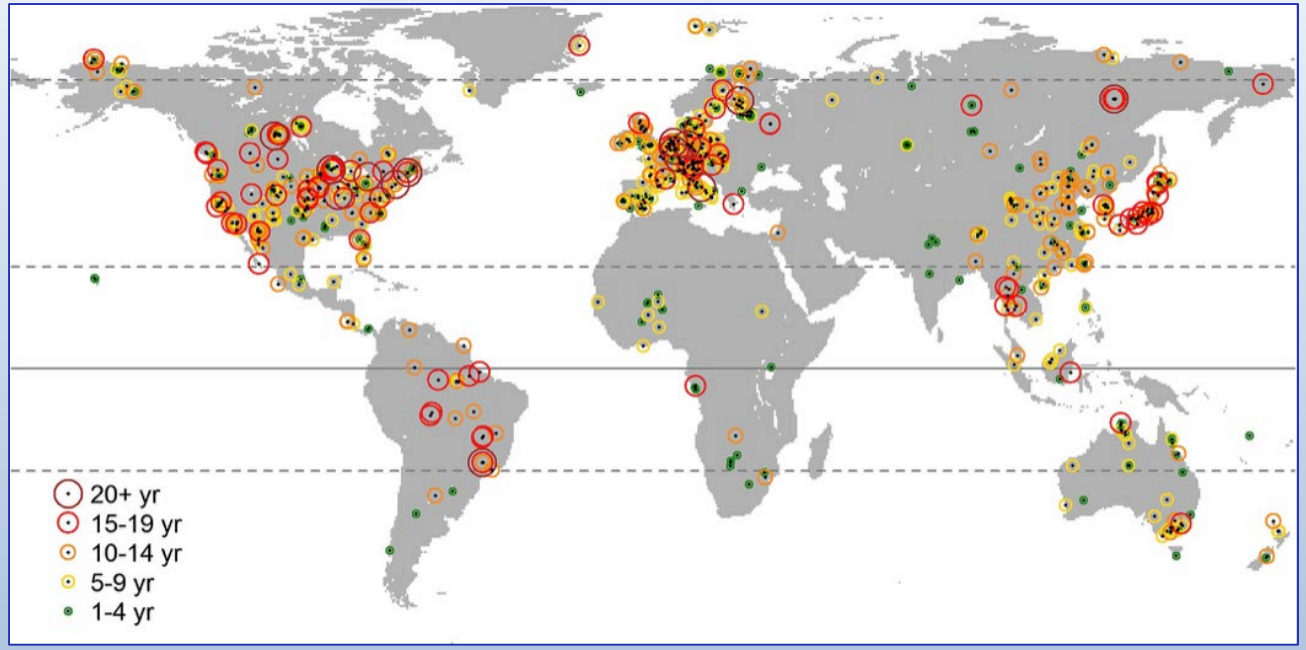




Estimated Fluxes

www.esrl.noaa.gov/gmd/ccgg/carbontracker/
www.esrl.noaa.gov/gmd/ccgg/carbontracker-ch4/

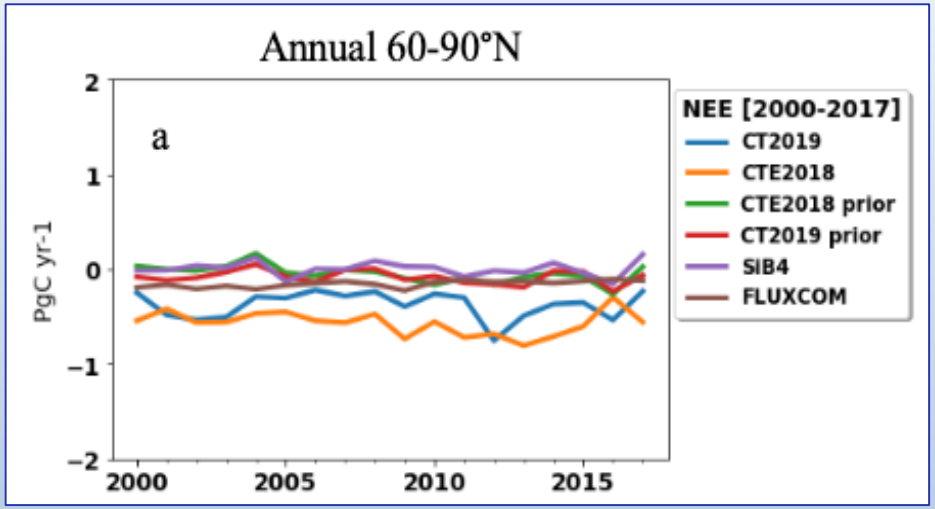
FLUXNET Sites (2015)

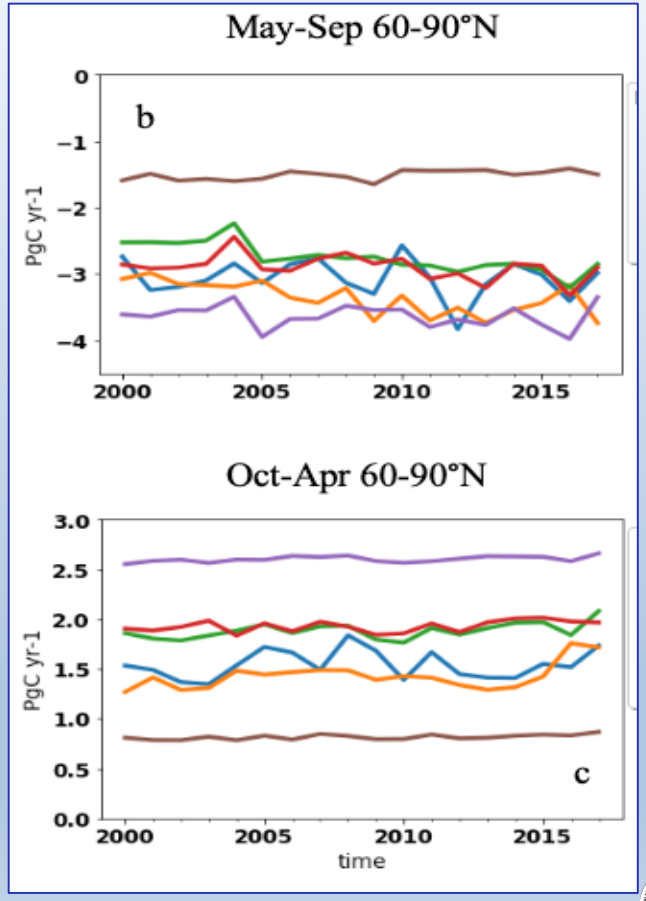


Need ~20 yrs to detect trends (Baldocchi et al, 2018)

Chu et al., 2017

Do TD and BU CO_2 Flux Estimates Agree ?





FLUXCOM, NDVI-Based Approaches, SiB4 – Arctic is Neutral or a Small Sink
(Natali et al., 2019 – Arctic is a Source)

Inversions – Arctic is a Sink

(M. Leonard)

Do TD and BU CH_4 Flux Estimates Agree ?

Table 1. Arctic CH_4 Budget; Bottom-Up Versus Top-Down[a]

	Tg y^{-1}	Study
Bottom-Up Estimates		
Lakes and ponds > 50°N	16.5 ± 9.2	*Wik et al.* [2016b]
Lakes and ponds > 60°N (bLake4Me model)	11.9	*Tan and Zhuang* [2015]
Rivers and streams > 54°N	0.3	*Bastviken et al.* [2011]
Rivers and streams > 54°N	7.5	*Stanley et al.* [2016]
Reservoirs > 54°N	1.2	*Bastviken et al.* [2011]
Arctic Ocean + Beaufort and Chukchi Seas (<82°N)	2	*Kort et al.* [2012]
ESAS	2.9	*Thornton et al.* [2016]
ESAS	17	*Shakhova et al.* [2014]
Wetlands > 60°N	23.2	*Zhang et al.* [2004]
Wetlands > 53.1°N (CarbonTracker prior model, based on *Bergamaschi et al.* [2005])	31	*Bruhwiler et al.* [2014]
Wetlands > 50°N (ORCHIDEE model)	31 ± 5	*Bousquet et al.* [2011]
Sources sum (minimum–maximum)	59.7 (36.9–89.4)	
Top-Down Inverse Model Estimates		
>60°N, all natural sources	23 ± 5	*Bruhwiler et al.* [2014] *Saunois et al.* [2016]
ESAS	0–4.5	*Berchet et al.* [2016]

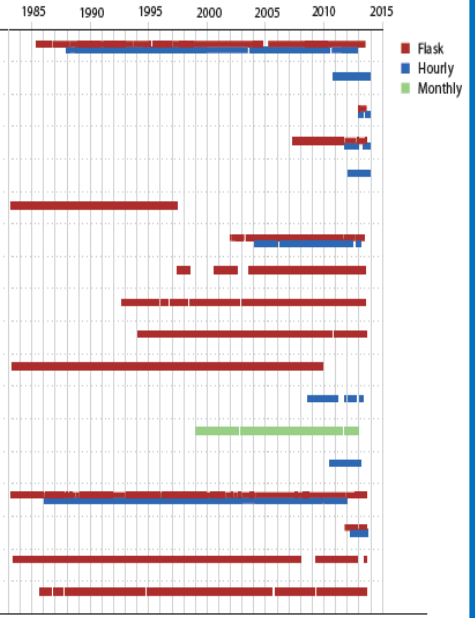
~ 2.5x !

Thornton et al., 2016, also AMAP, 2015

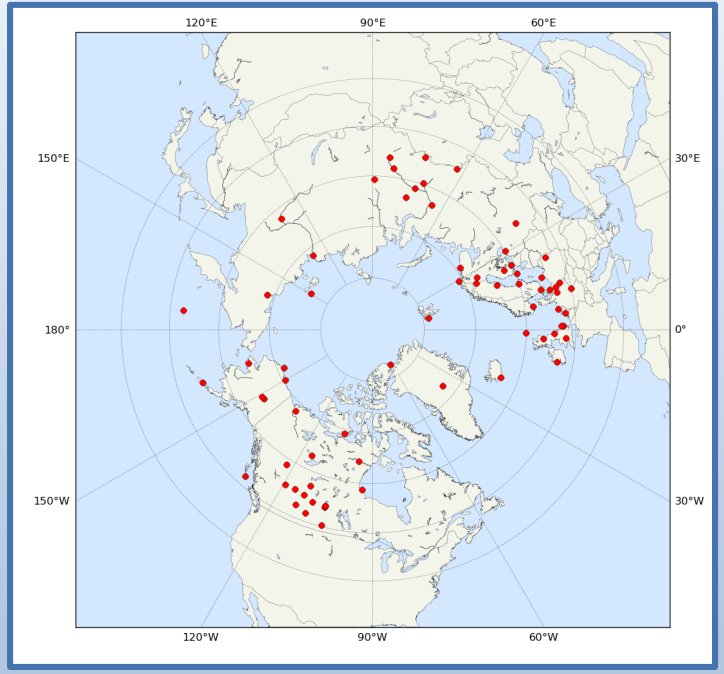
The Arctic Network: We Need Long Data Records to Detect Trends

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

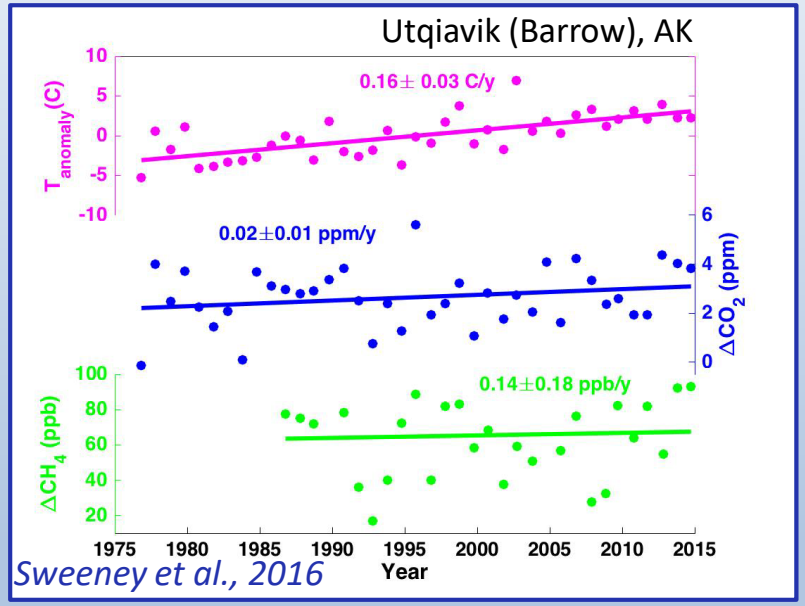


AMAP,2015



Arctic Monitoring Sites

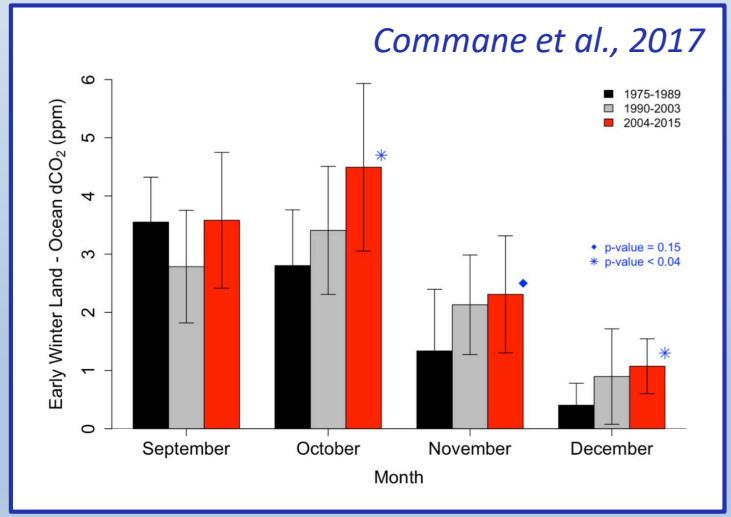
Regional Gradient Analyses Reveal Changing CO_2 Fluxes



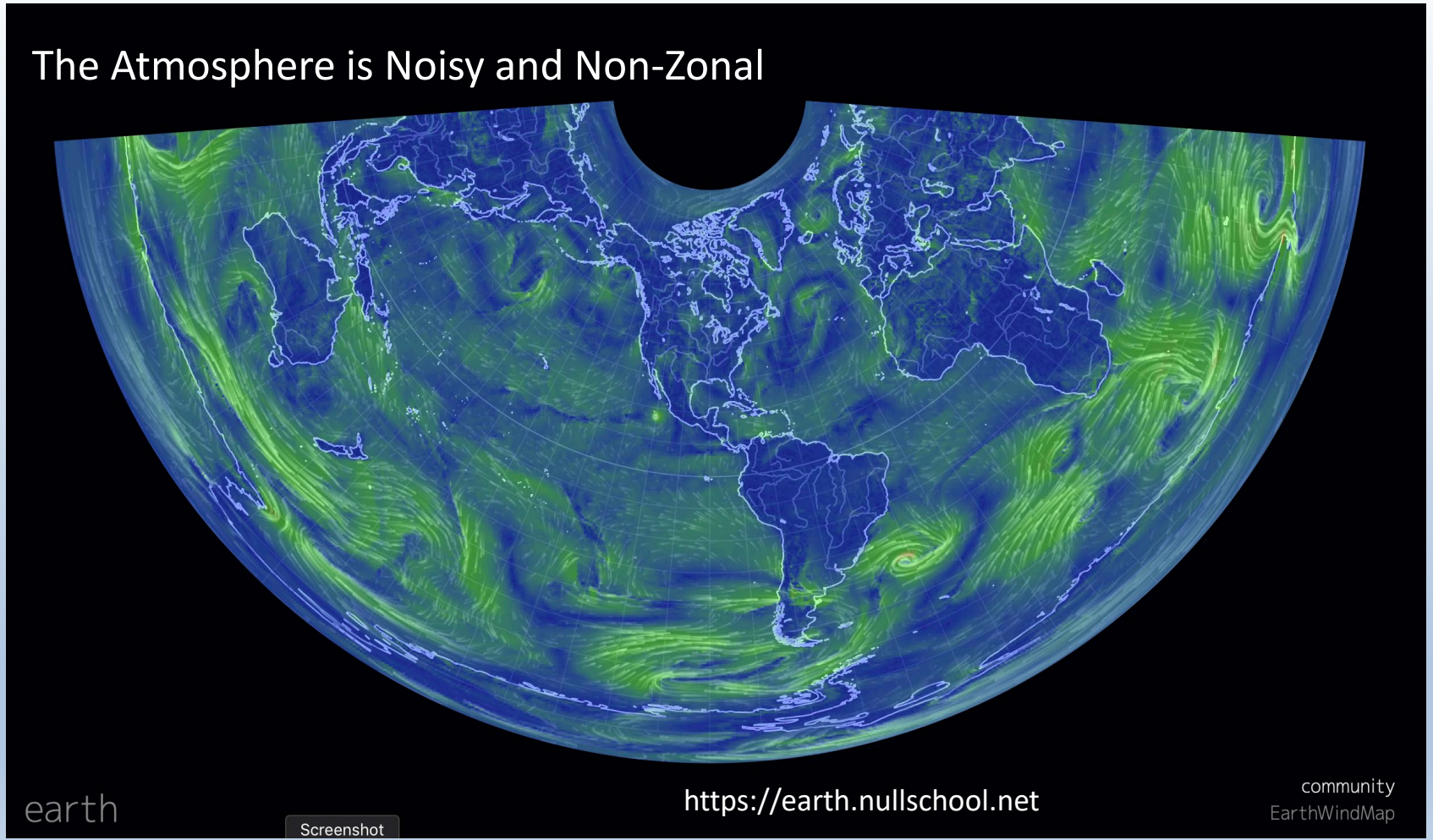
Sweeney et al., 2016

Scant Evidence for Increasing CH_4 Emissions

Evidence for Increasing Respiration

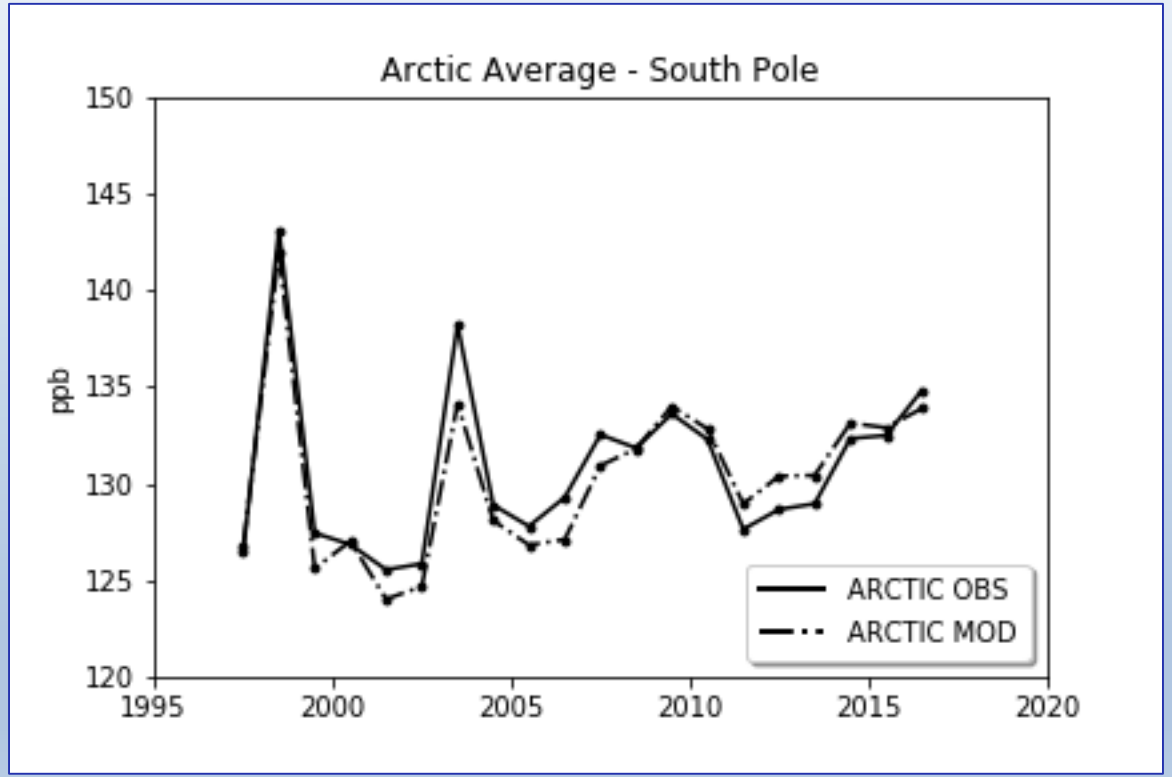


The Atmosphere is Noisy and Non-Zonal



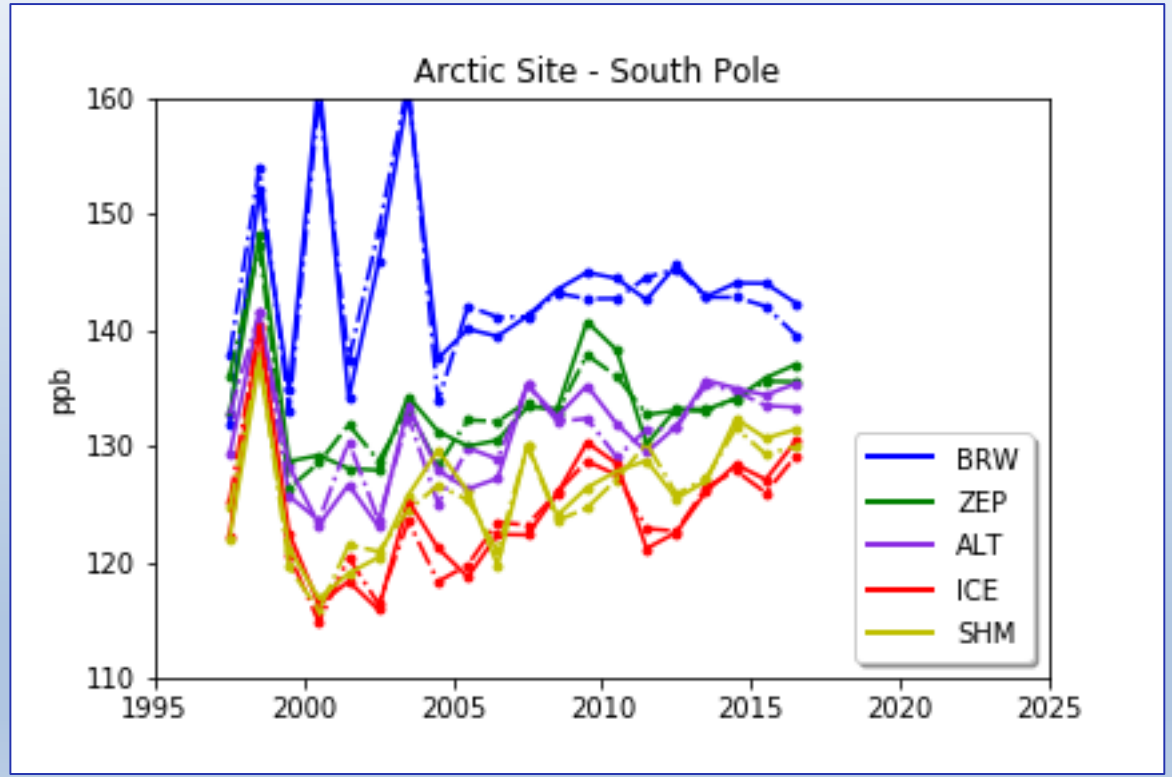
11/9/20

The Inter-Polar Difference (IPD)



Reasonable Agreement Between Analysis CH_4 and Observations

Variability and Trends are Dominated by Transport



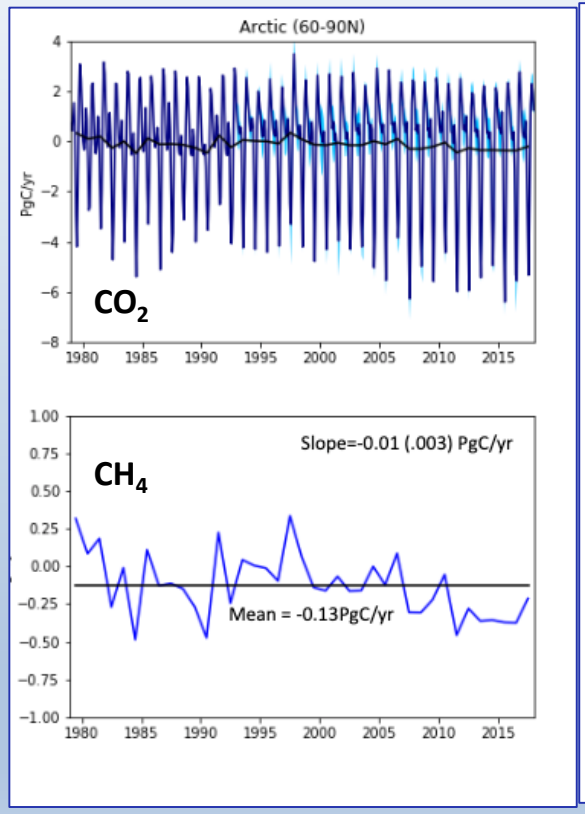
Lots of variability in the pole-to-pole gradient between sites.

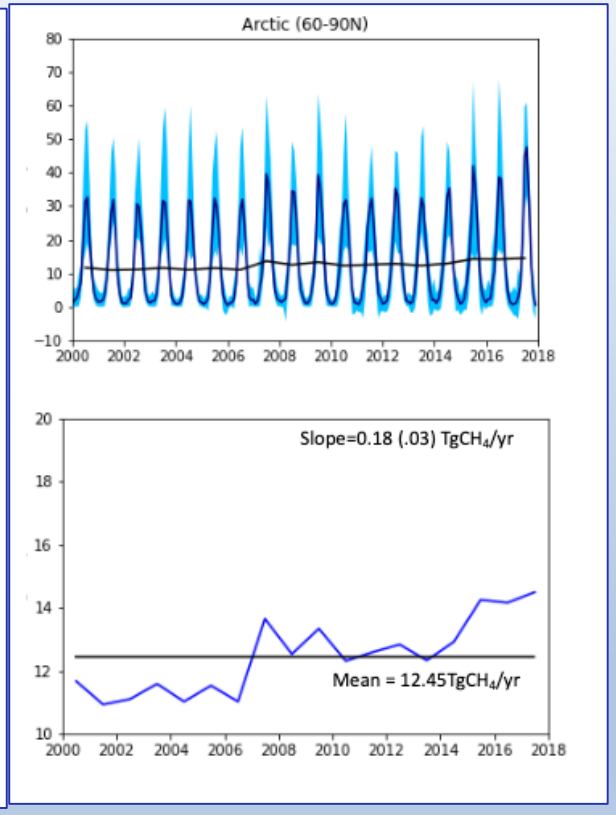
Not much difference between constant and varying emissions

How many sites are needed to get a representative average?

Trend is present in both simulations implying lower latitudes changes are driving it.

What Do Atmospheric Inversions Say?





Considerable disagreement between inversions.

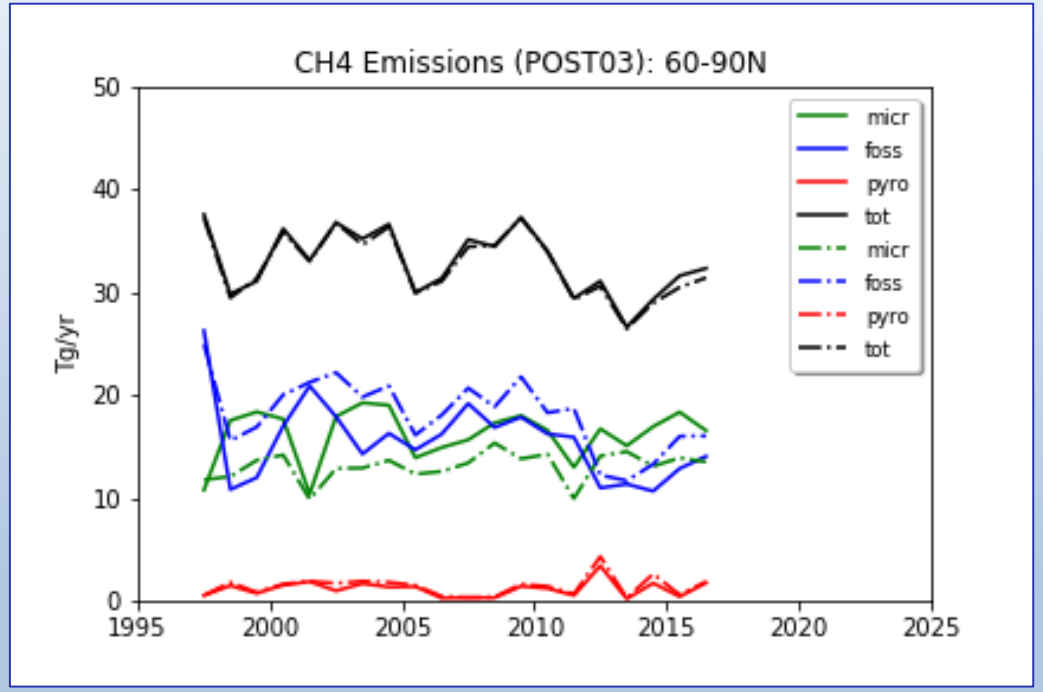
Black line is annual flux averaged over inversion ensemble.

Slight, statistically significant trend towards increased uptake of CO_2. (-0.01 PgC/yr)

Slight, statistically significant trend toward higher CH_4 emissions. (0.20 Tg/yr)

Are these trends likely to be robust? Probably not!

New Joint CH_4 - $^{13}CH_4$ Inversions



No Trend in Microbial Emissions

About Equal Contributions from Fossil and Microbial Sources

Using $^{13}CH_4$ Gives Higher Microbial Emissions

Wetland Map Has Relatively Low Areas Compared to Previous Maps

Conclusions

- *CO_2 emissions are likely changing in response to changes in Arctic Climate, but there is not yet strong evidence of changes in CH_4 emissions, although small changes cannot be ruled out.*
- *The Arctic observing network needs to be expanded.*
- *Globally distributed observations are essential.*
- *We need a strong international commitment to sustaining long-term data records, insuring their quality, and sharing data.*