Land-Atmosphere Carbon Exchange in Alaska

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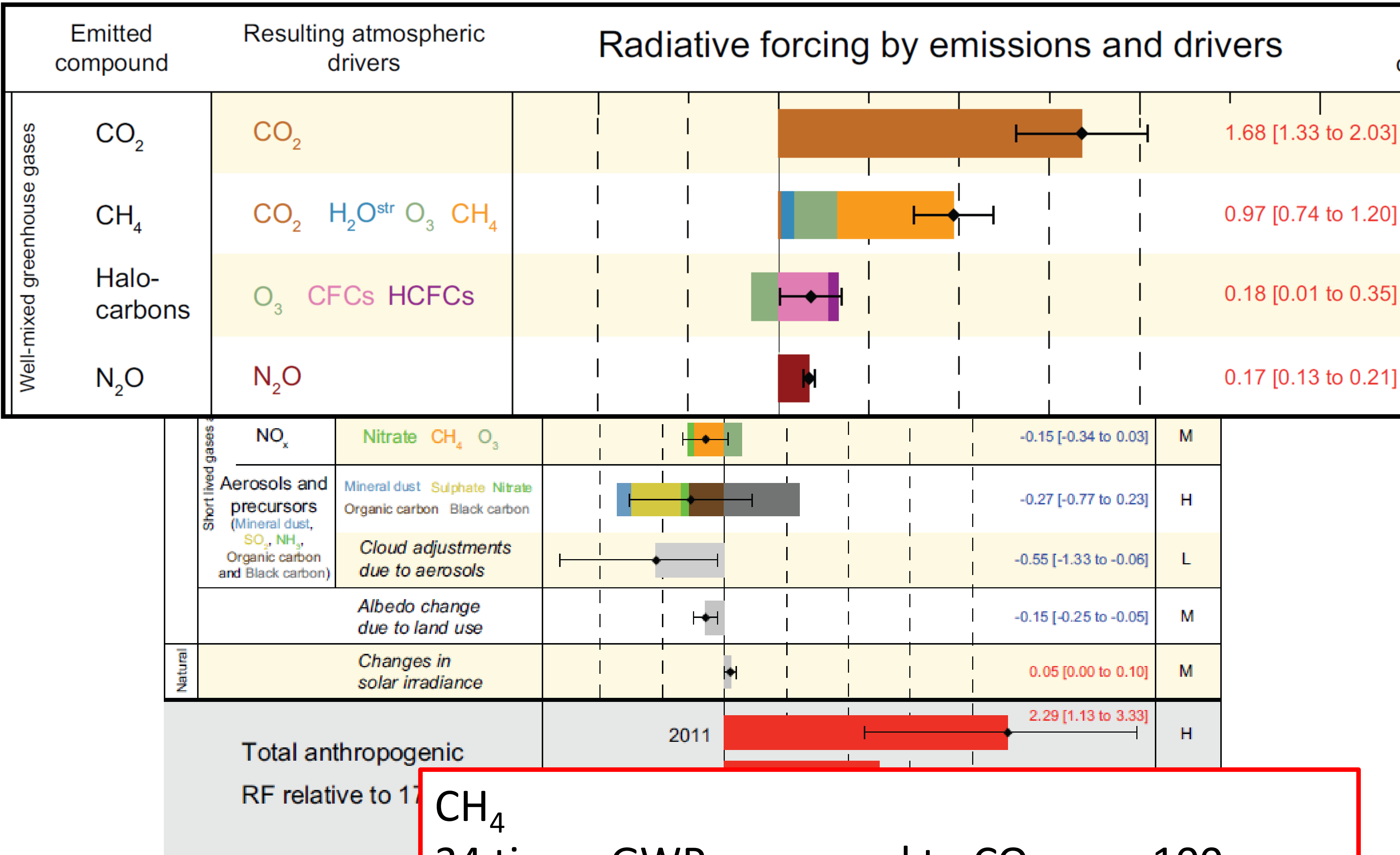
Contributors to Radiative Forcing



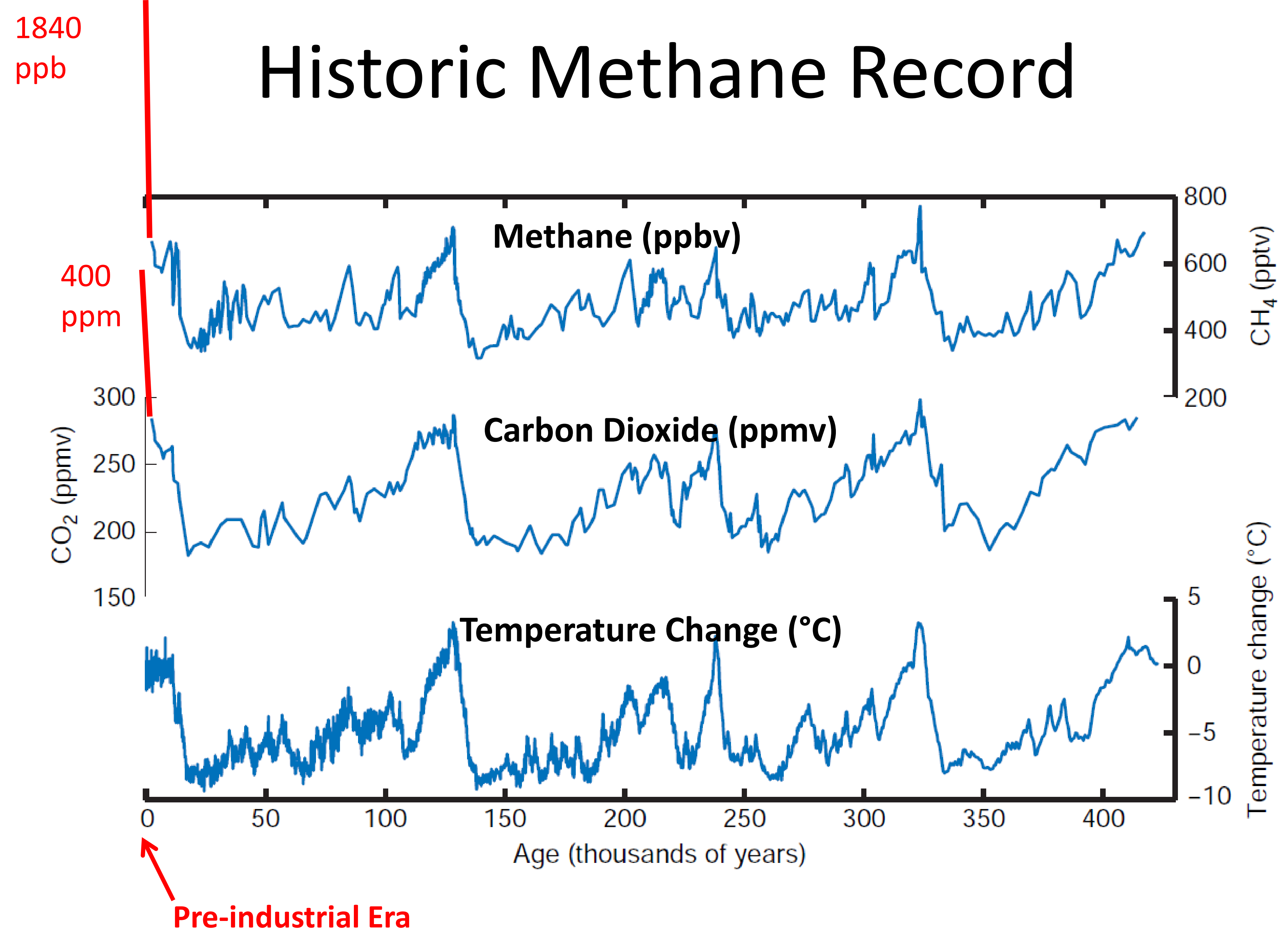
CH_4

34 times GWP compared to CO_2 over 100 years

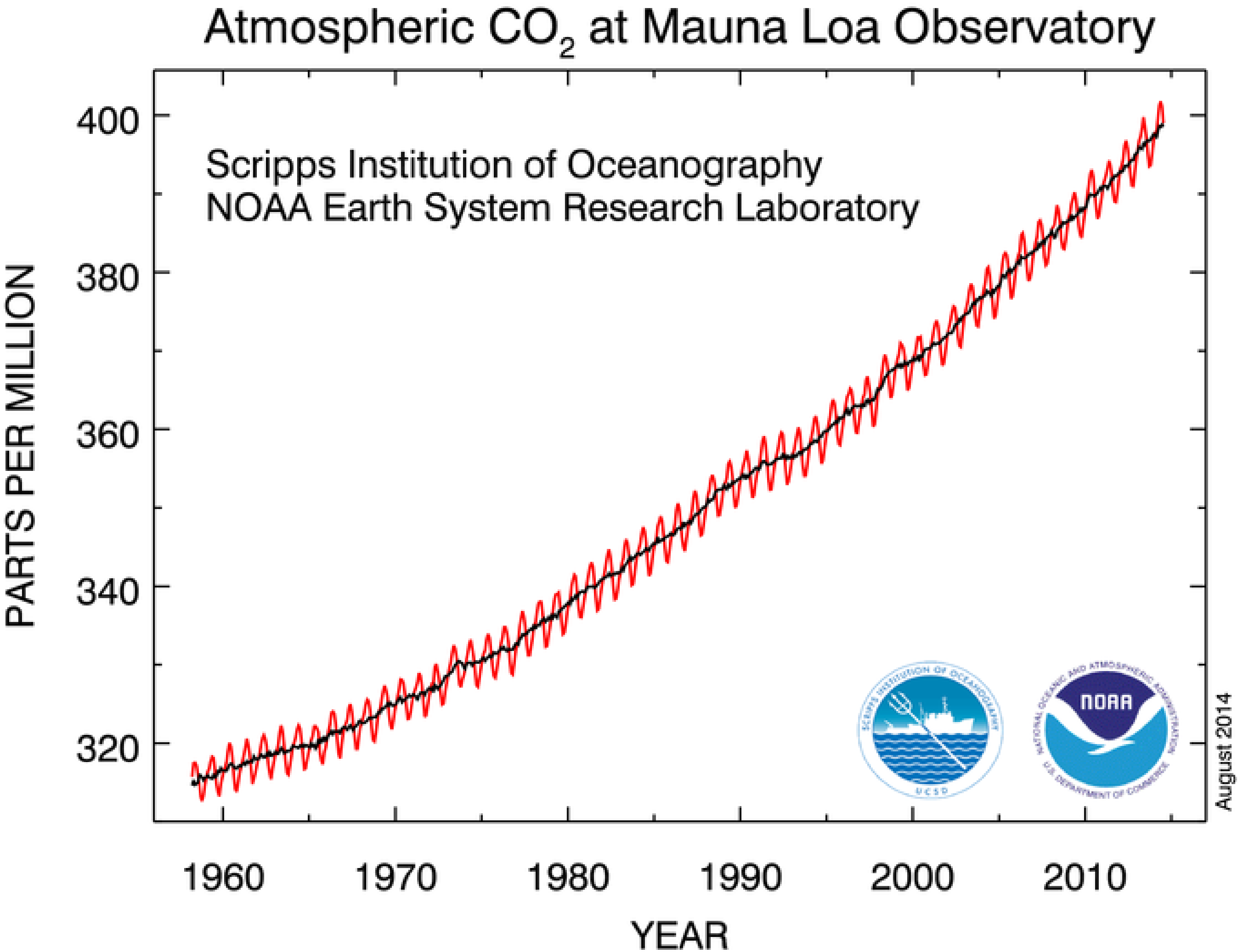
86 times over 20 years

IPCC AR5, 2013

Historic Methane Record

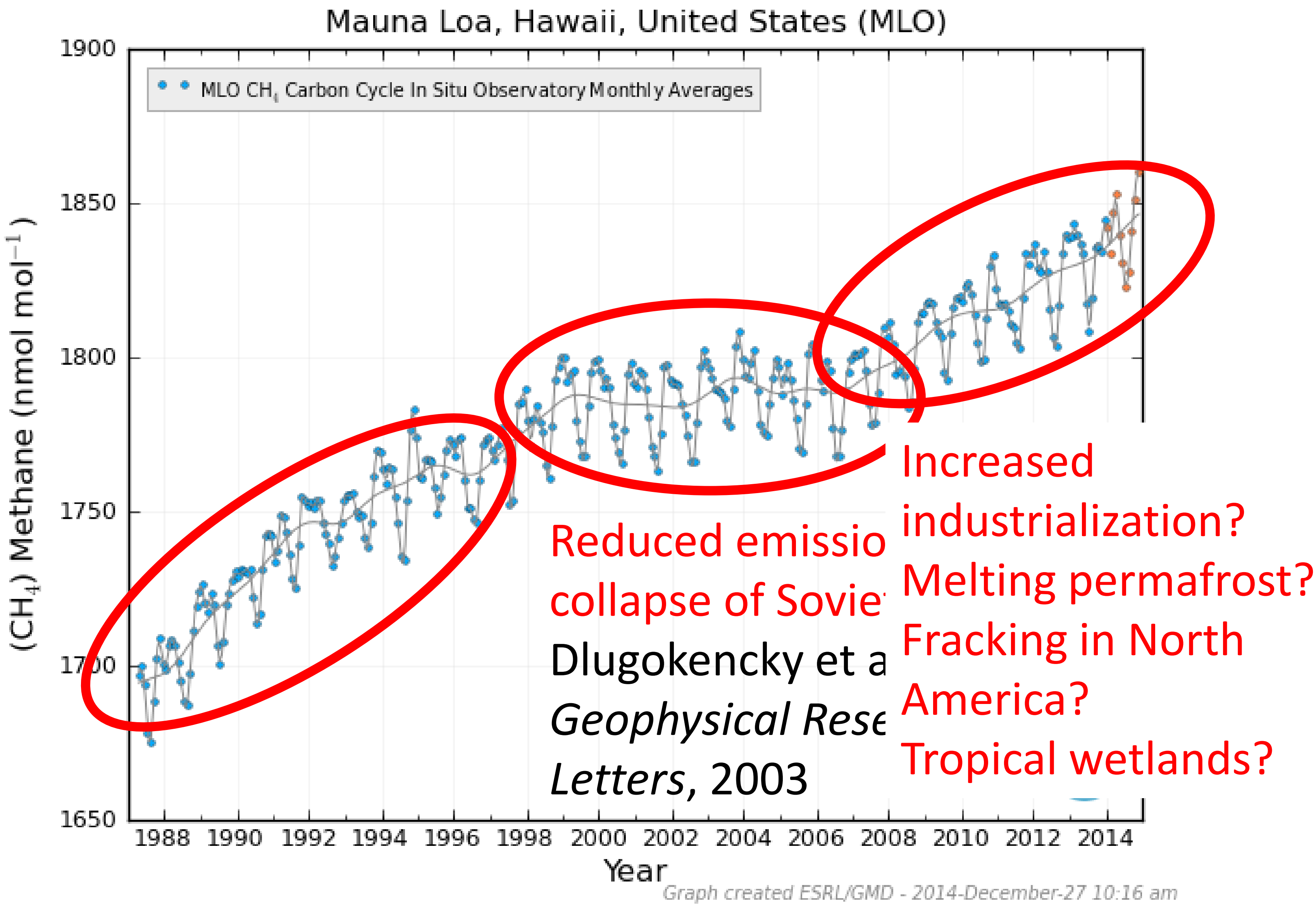


Atmospheric Science by Wallace and Hobbs, Fig 2.31



http://www.esrl.noaa.gov/gmd/ccgg/trends/

Global Methane Trends



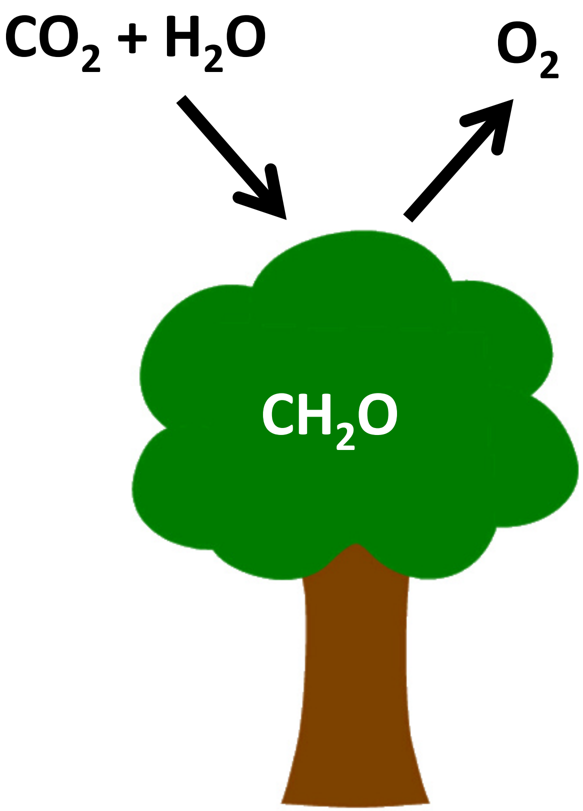
http://www.esrl.noaa.gov/gmd/dv/iadv/graph.php?code=MLO&program=ccgg&type=ts

A Note About Units

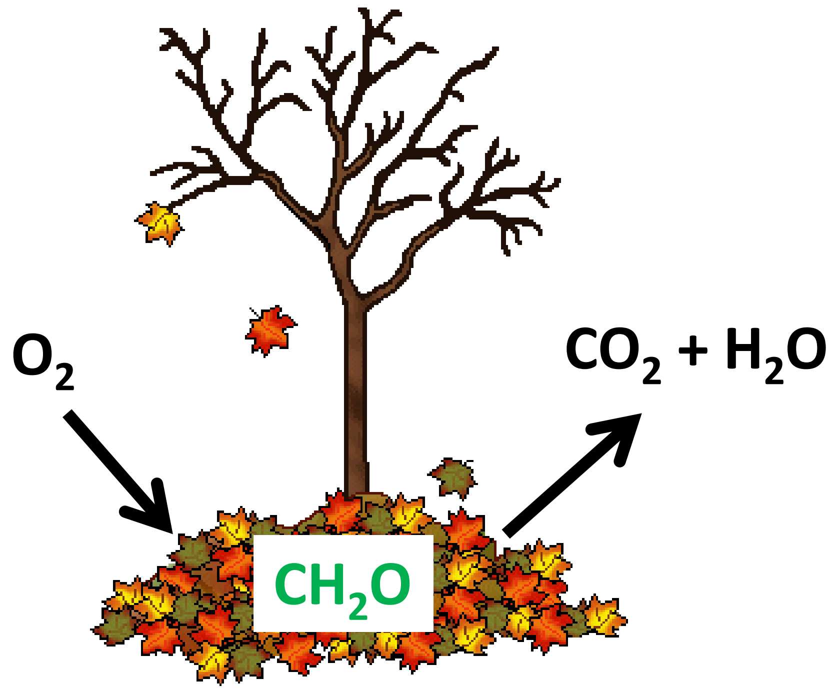
- concentration
  - molecules / volume [mol / L]
  - molecules of CO_2, CH_4 / 10^9 molecules of air [ppb]
- flux or emission rate
  - molecules / area / time [mol / m^2 / s]
  - mass / area / time [mg / m^2 / d]
- regional emission rate
  - mass / time [Tg / y]

Photosynthesis and Respiration

Photosynthesis

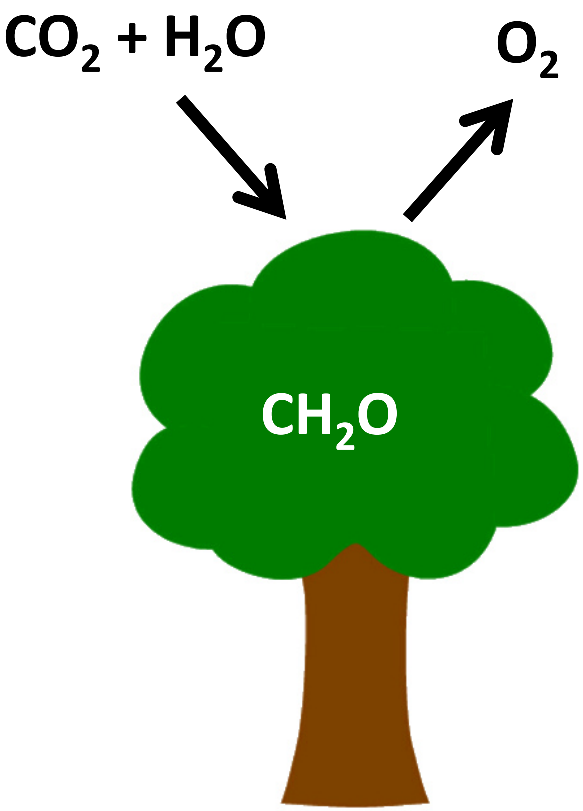


Aerobic Respiration

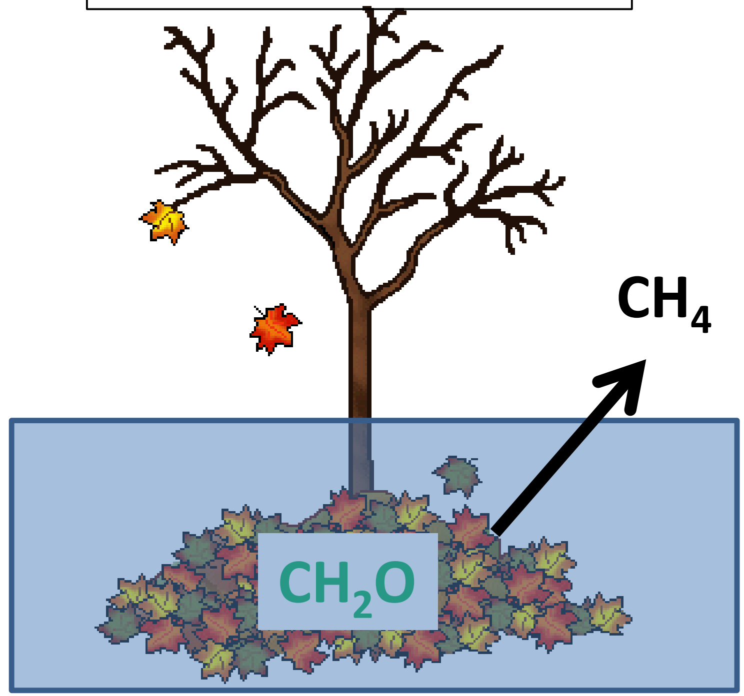


Photosynthesis and Respiration

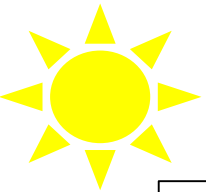
Photosynthesis



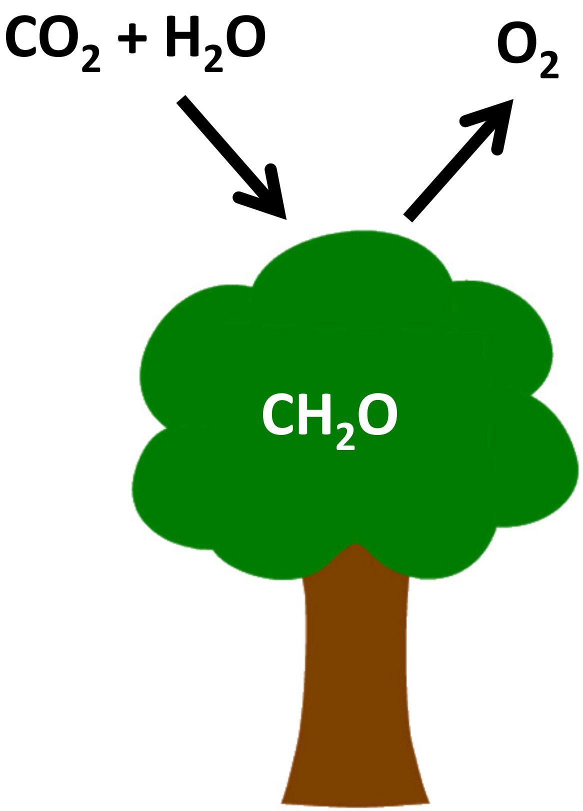
Methanogenesis
- wetlands
- rice fields
- landfills
- ruminants



Photosynthesis and Respiration

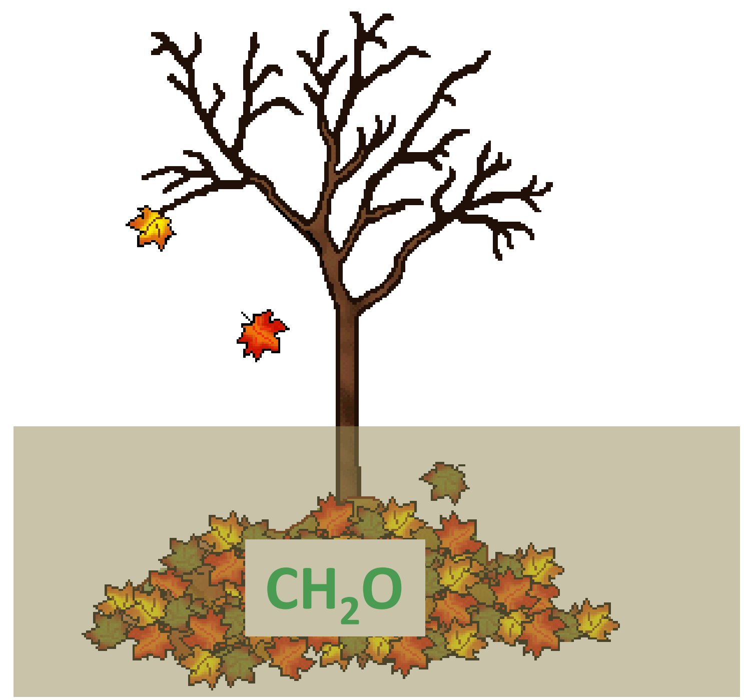


Photosynthesis

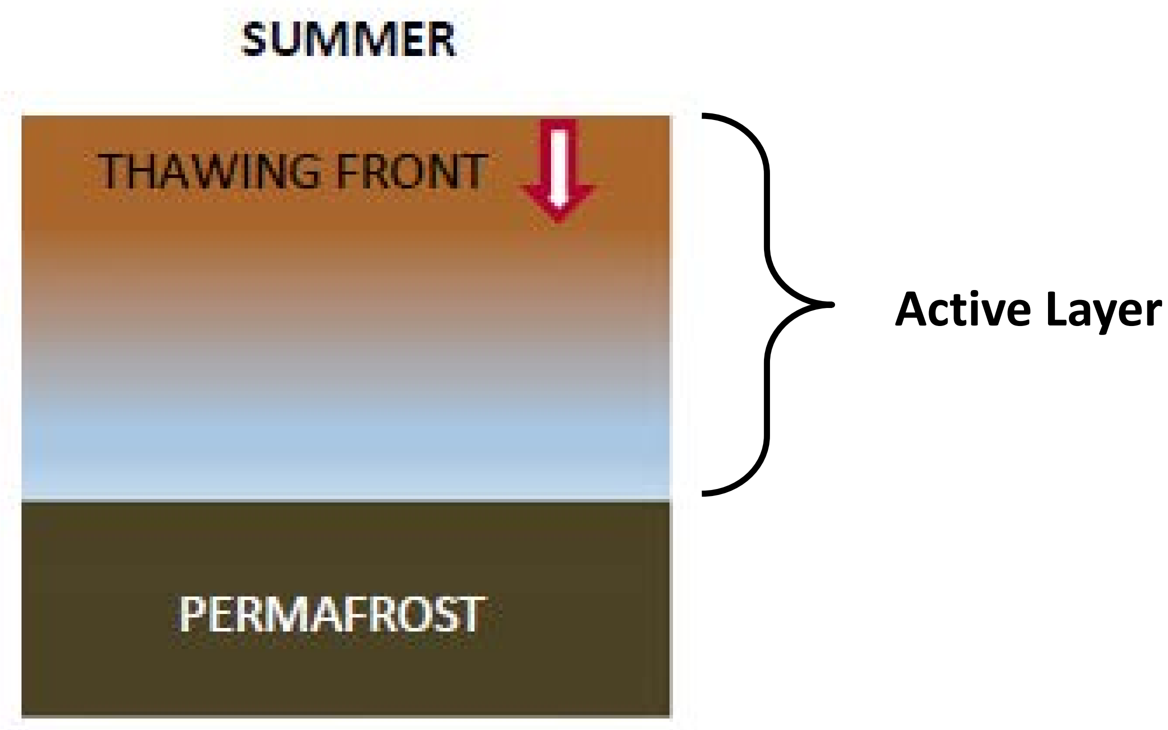


Sequestration of organic matter

- permafrost
- peat
- fossil fuel



Permafrost



Zona et al. **2016**, PNAS, 113, 40

Global Permafrost Distribution

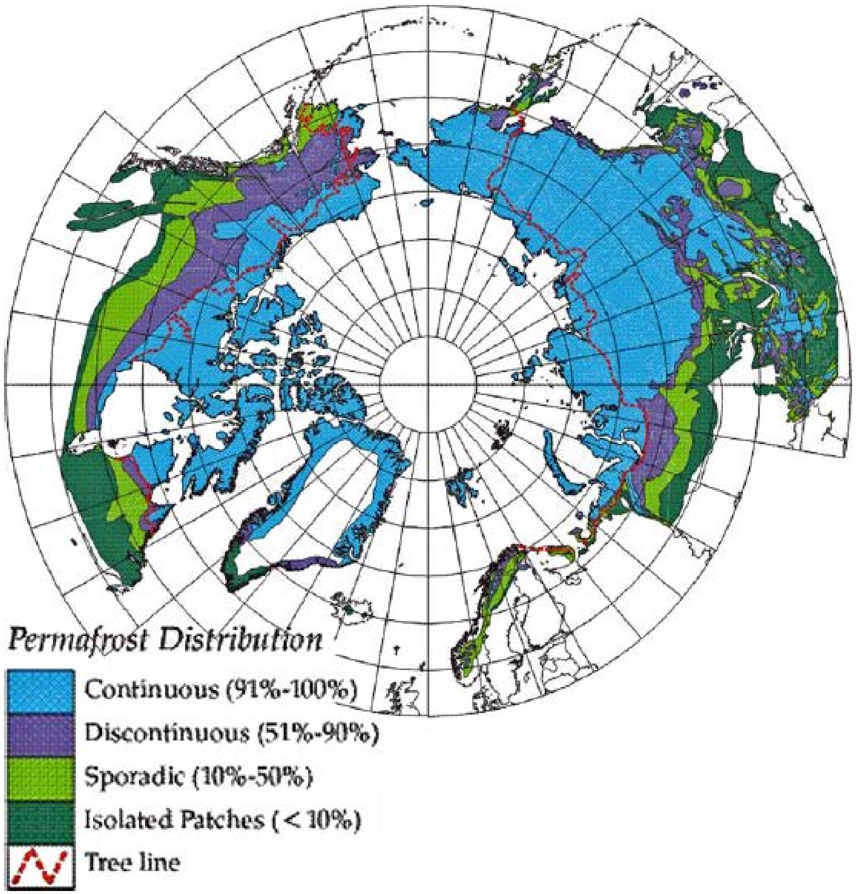
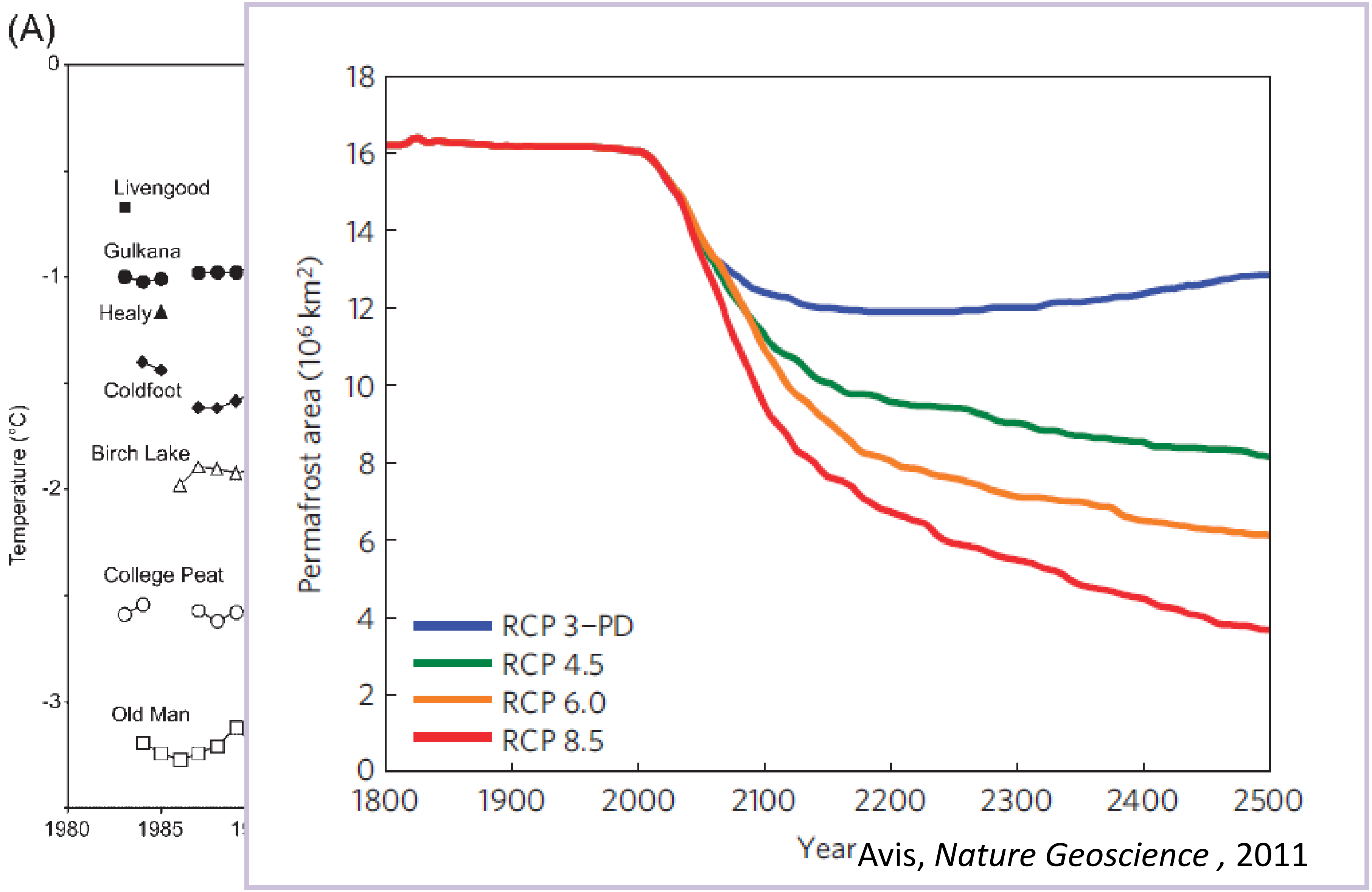


Figure 1. Northern circumpolar permafrost map (derived from information by *Brown et al.* [1997]).

- 1672 Pg C in permafrost
- 18.8×10^6 km^2
- 16% of global soil area
- 88% in perennially frozen soils
- 50% of global below ground carbon

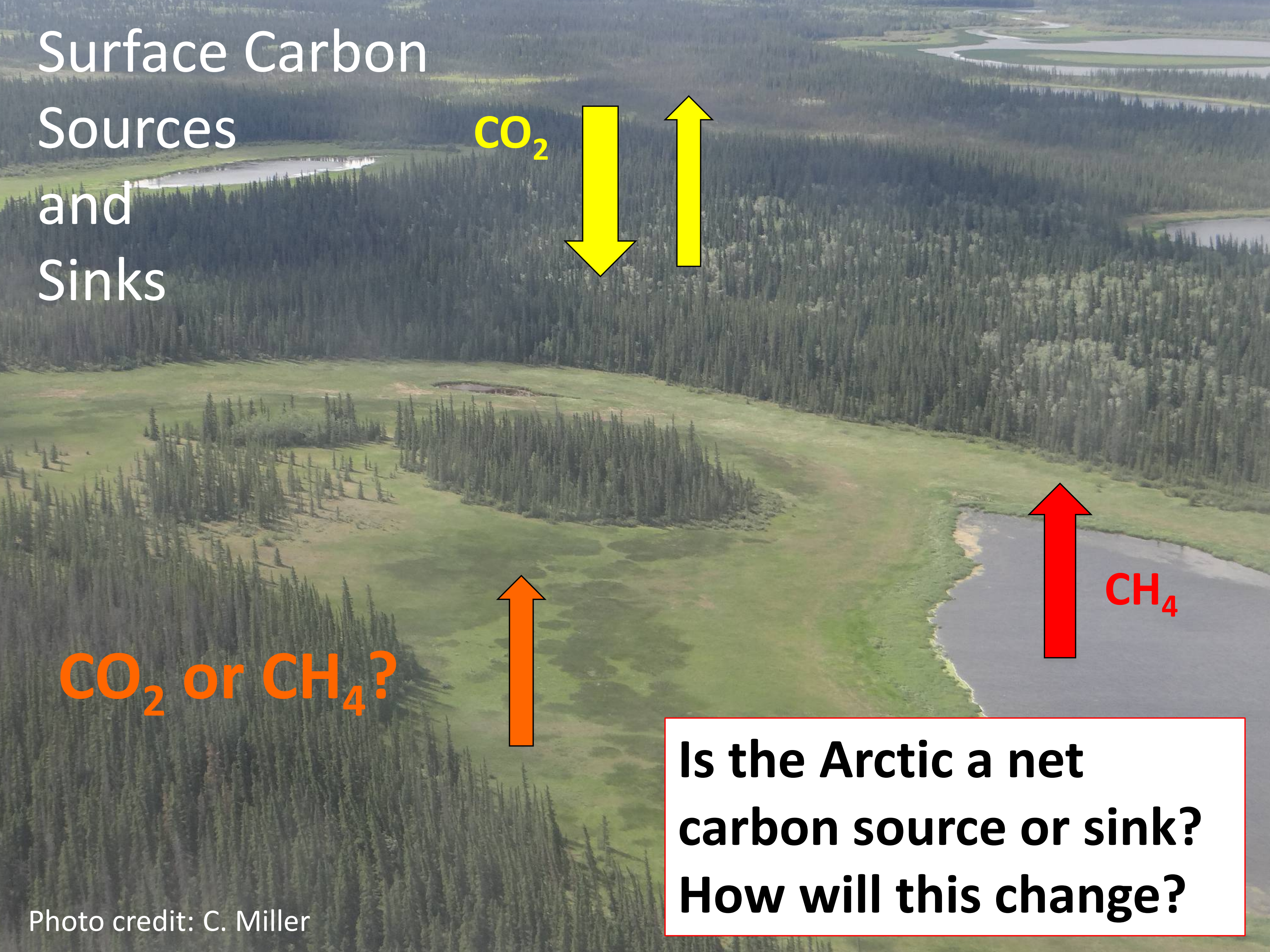
Tarnocai, *Global Biogeochemical Cycles,* 2009

Permafrost – A Vulnerable Carbon Pool

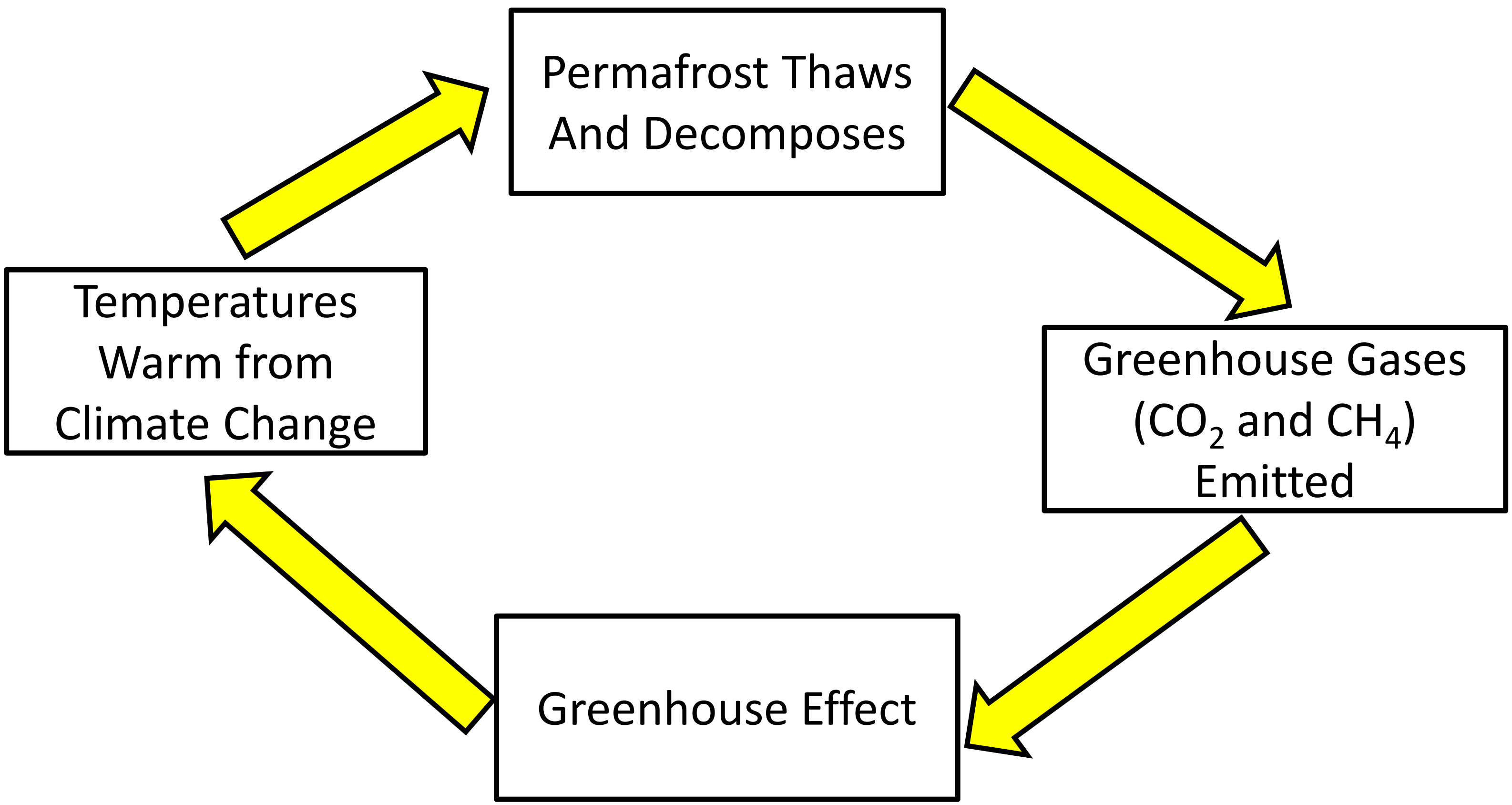


Avis, *Nature Geoscience* , 2011

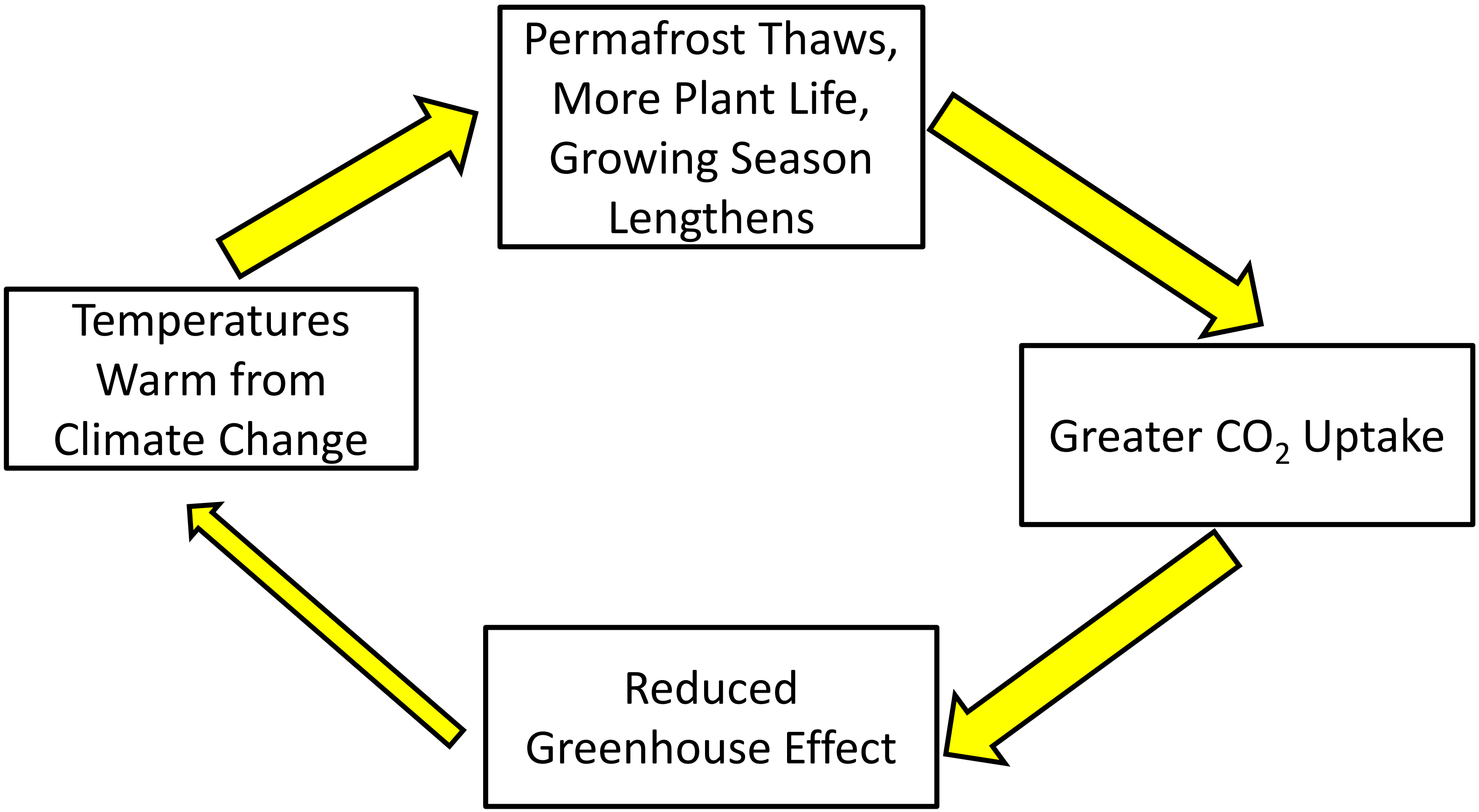
Smith et al., *Permafrost and Periglacial Processes*, 2010


Surface Carbon Sources and Sinks
CO_2
CO_2 or CH_4?
CH_4
Is the Arctic a net carbon source or sink? How will this change?
Photo credit: C. Miller

Permafrost Thawing: Positive Feedback



Greening of Arctic: Negative Feedback



A Simple Model

- spring time thaw leads to green up, photosynthesis and net carbon uptake

- fall time respiration until soil freezes up

- winter time freeze up results in no carbon flux

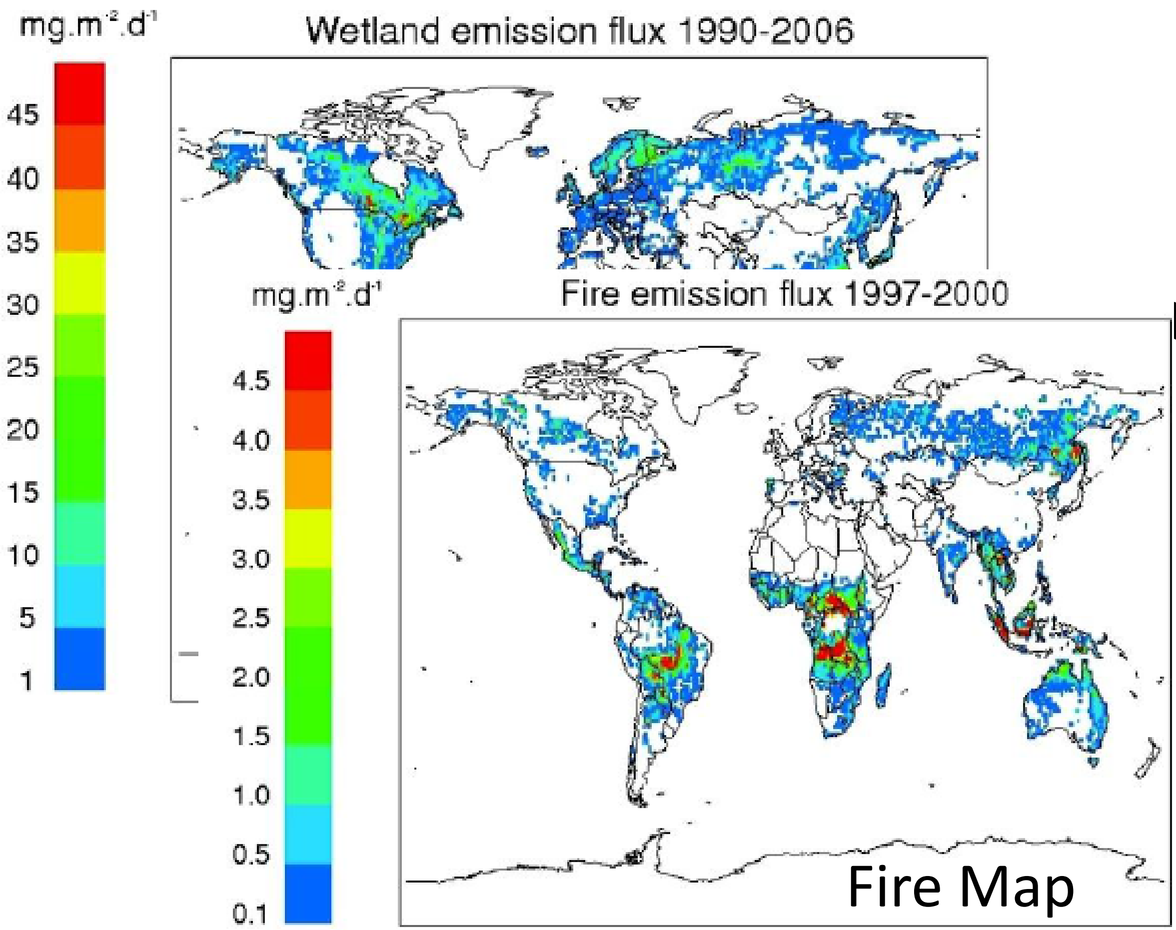
The Devil is in the Details

- spring time thaw leads to green up, photosynthesis and net carbon uptake
  - Depth of thaw? Which indicator for green up?
- fall time respiration until soil freezes up
  - Depth of freeze? How about sunlight?
- winter time freeze up results in no carbon flux
  - Other sources of CO_2 and CH_4?

How do we estimate emissions?

Determining the Global CH_4 Budget
Bottom-Up Approach

Wetland Map

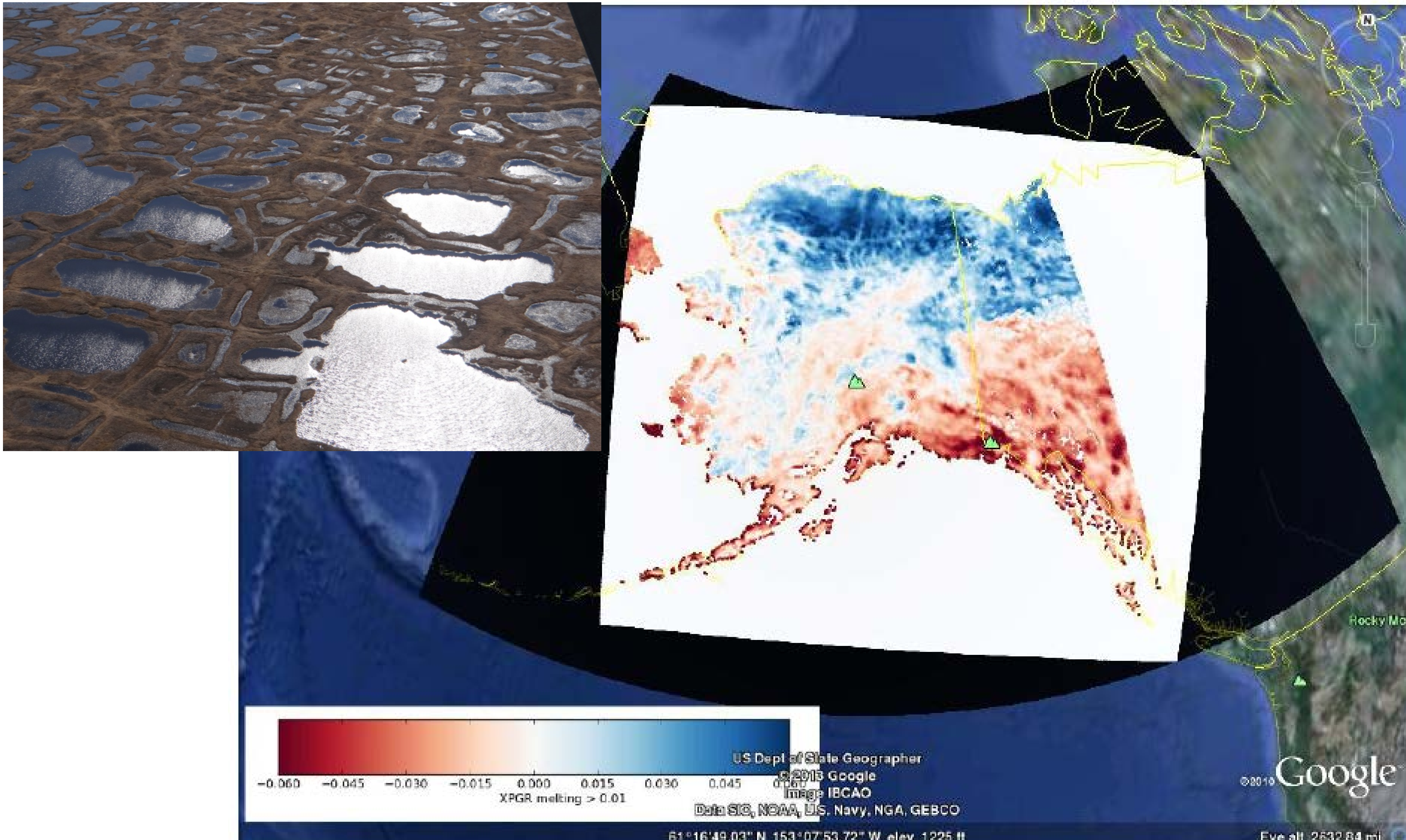


tland Emission Rate +

x Fire Emission Rate +
etc.

Kirschke et al., *Nature Geoscience*, 2013

Determining the Map



Images courtesy of C. Miller, JPL & N. Steiner, The City University of New York

Measuring Emission Rates

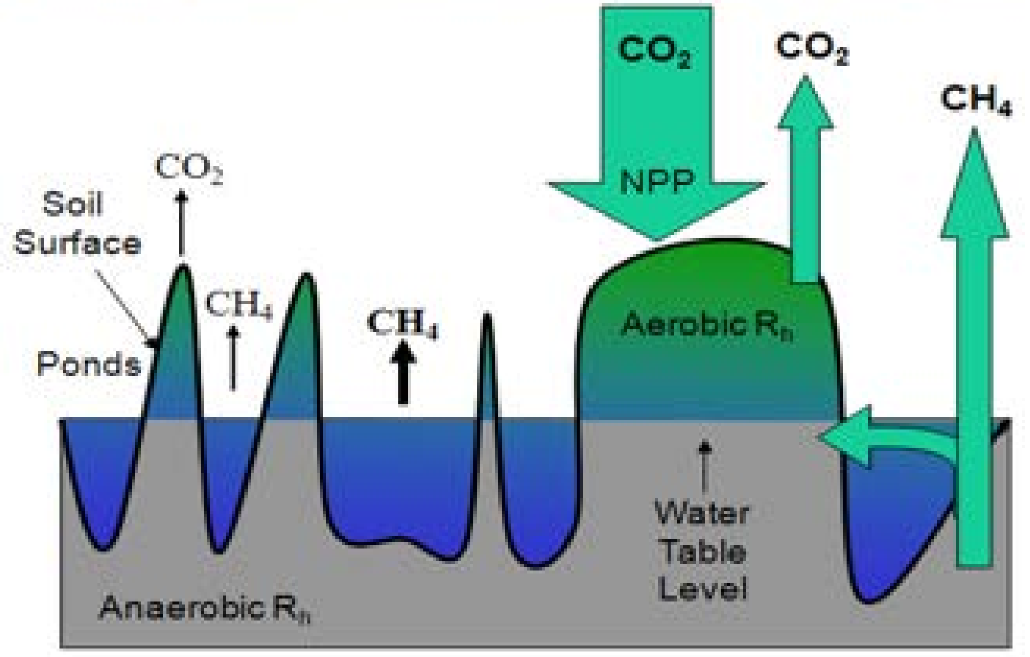
Image courtesy of W. Oechel, UCSD

SAN DIEGO STATE UNIVERSITY

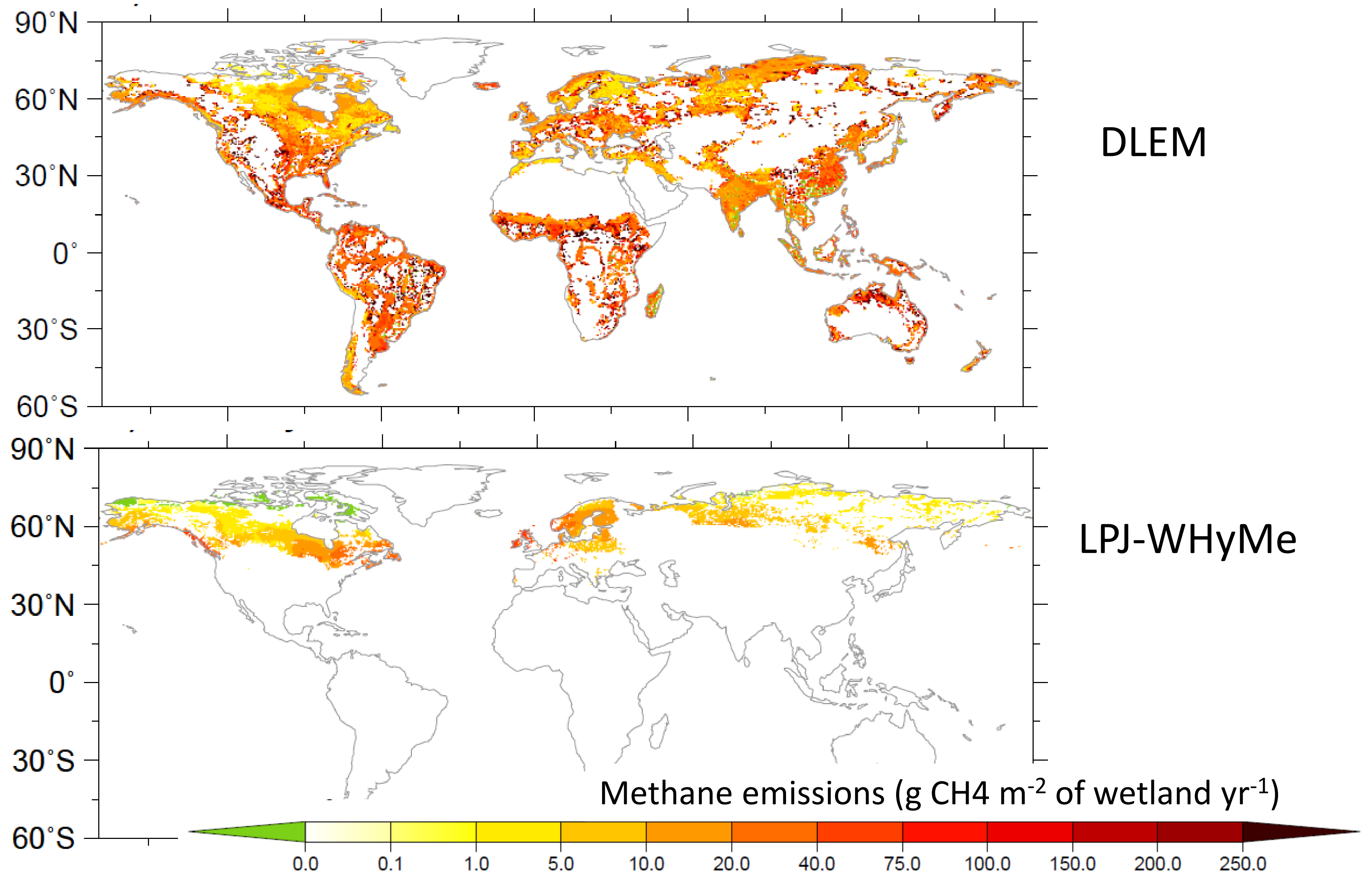
Image courtesy of W. Oechel

http://www.thepolarisproject.org/creative-contraptions/

Bottom-Up Models



Emissions from Bottom Up Models



Melton et al., *Biogeosciences*, 2013

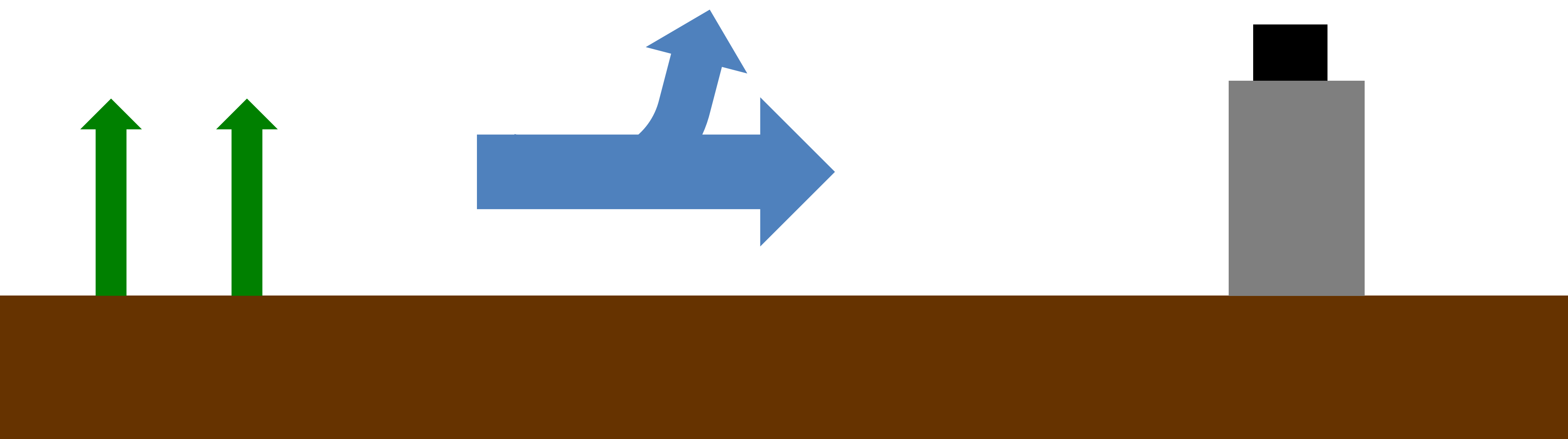
Determining the Global Budget
Top-Down Approach

Forward Analysis

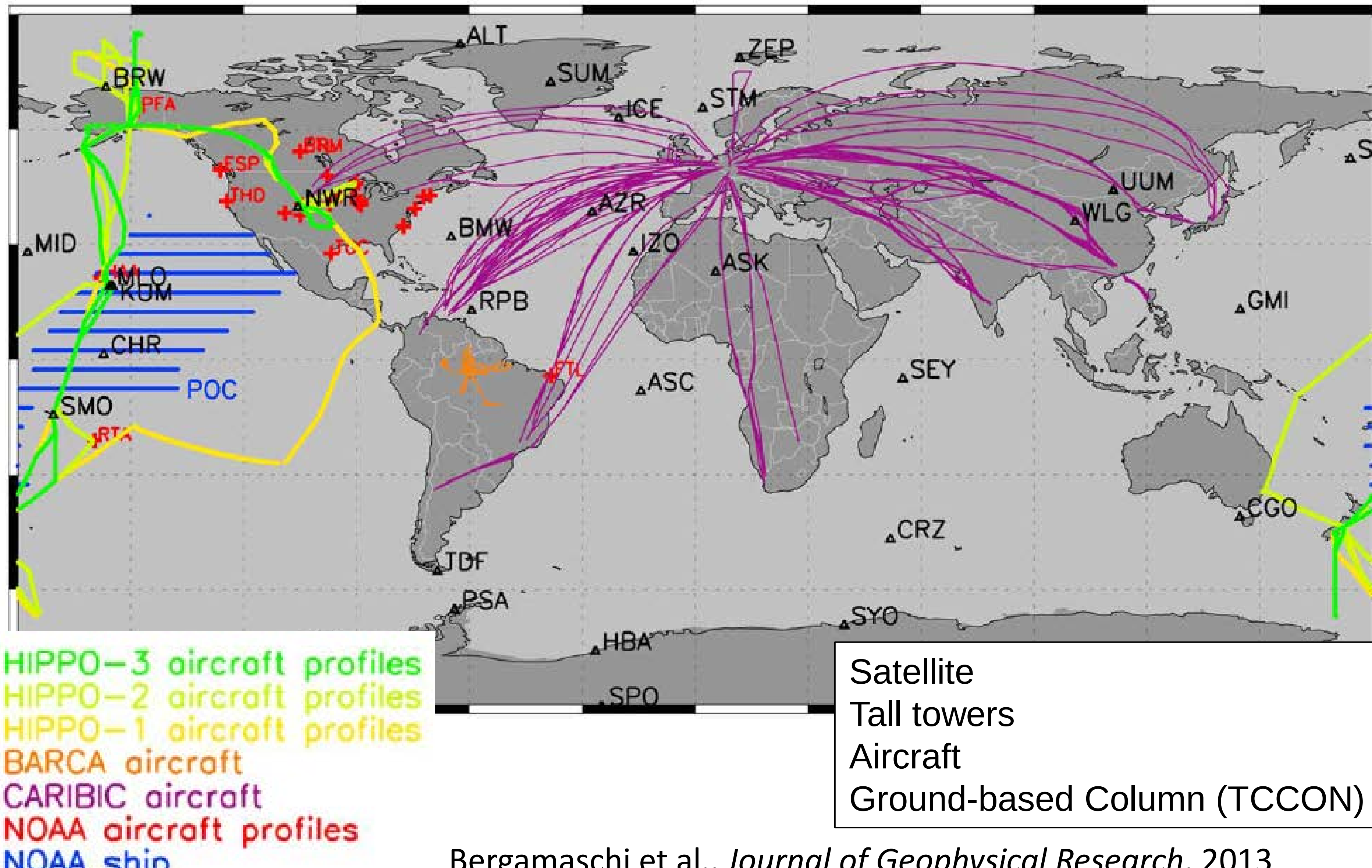
Emissions + Wind Transports = Concentration

= Methane Emissions + Measured at Station

Inverse Analysis



Measurements for Global Inversion



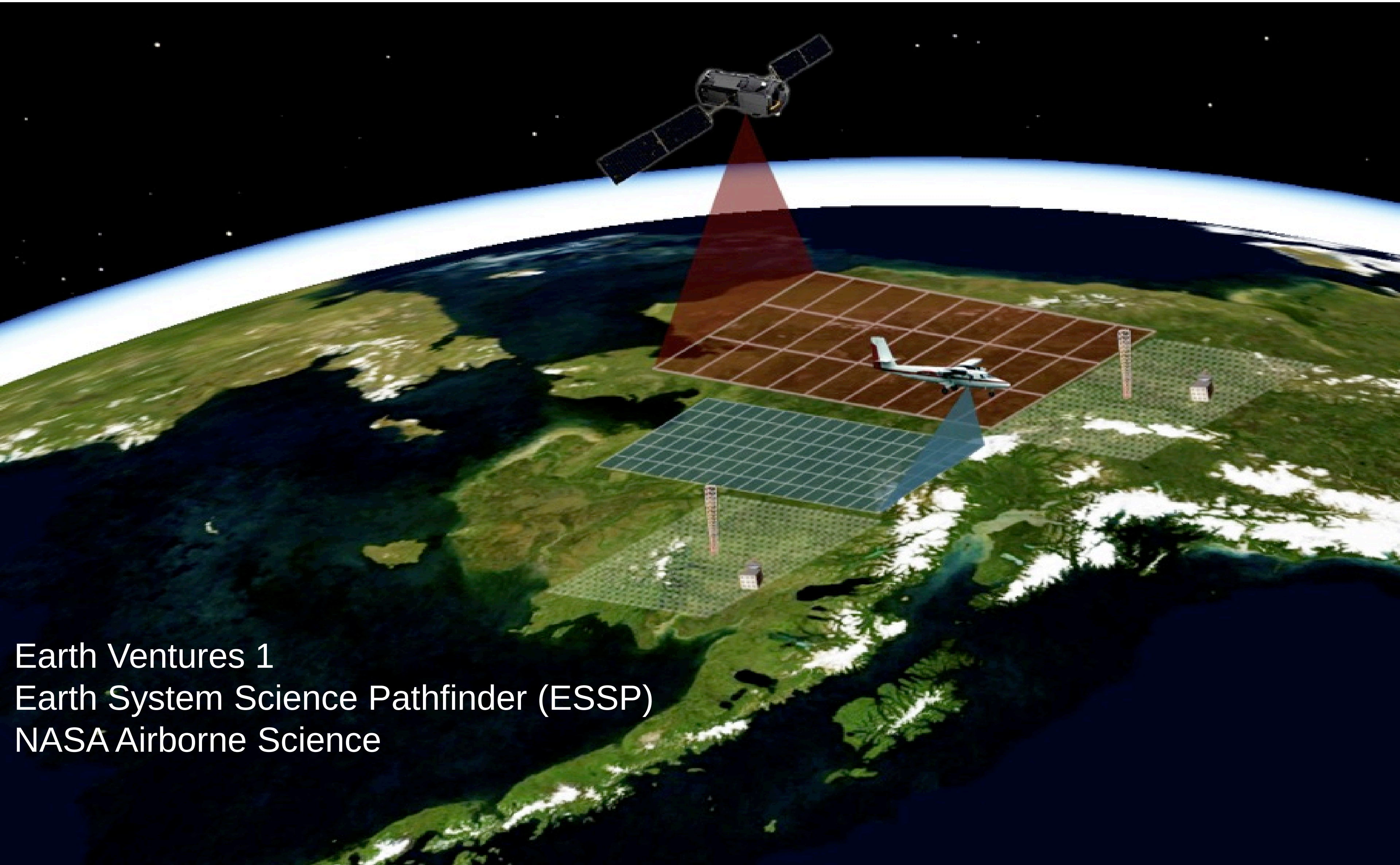
Satellite
Tall towers
Aircraft
Ground-based Column (TCCON)

Bergamaschi et al., *Journal of Geophysical Research*, 2013

The Devil is in the Details

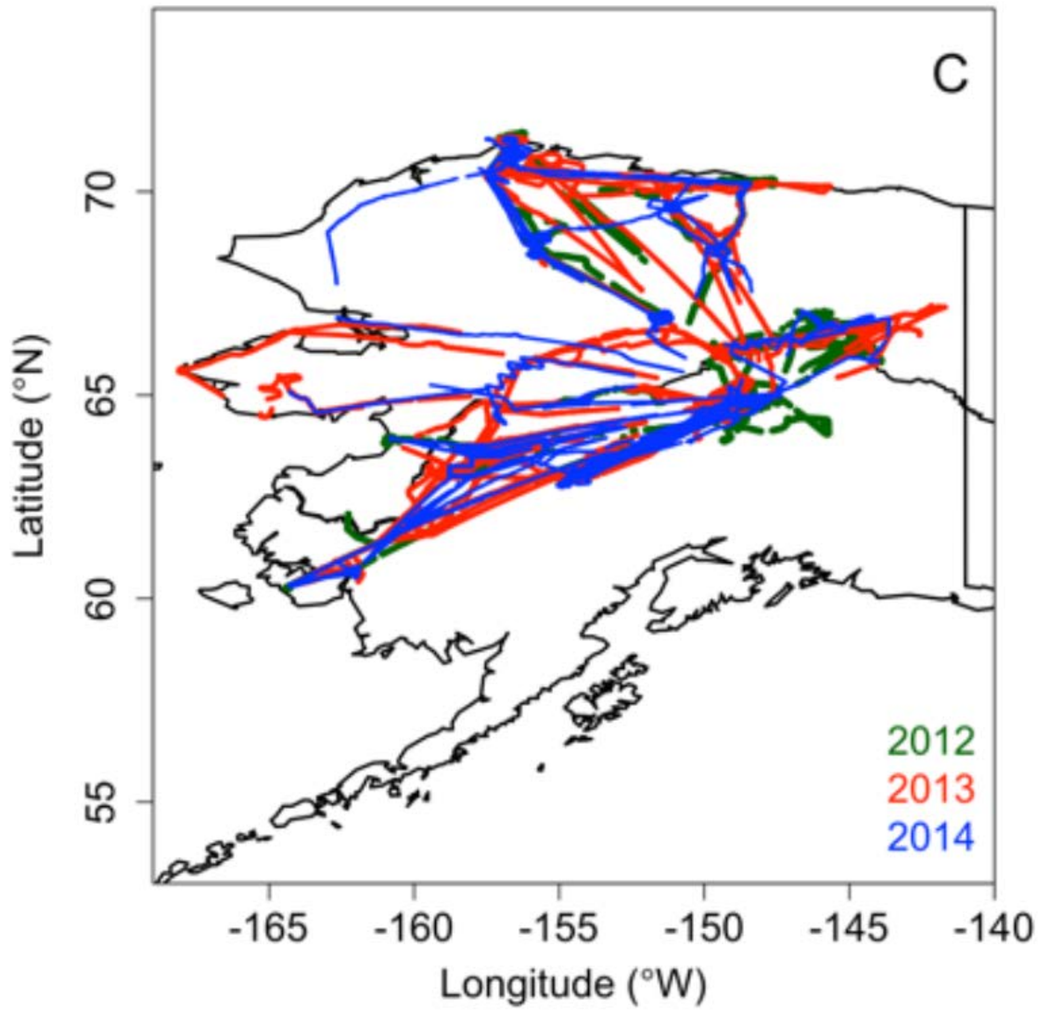
- spring time thaw leads to green up, photosynthesis and net carbon uptake
  - Depth of thaw? Which indicator for green up?
- fall time respiration until soil freezes up
  - Depth of freeze? How about sunlight?
- winter time freeze up results in no carbon flux
  - Other sources of CO_2 and CH_4?

Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE)

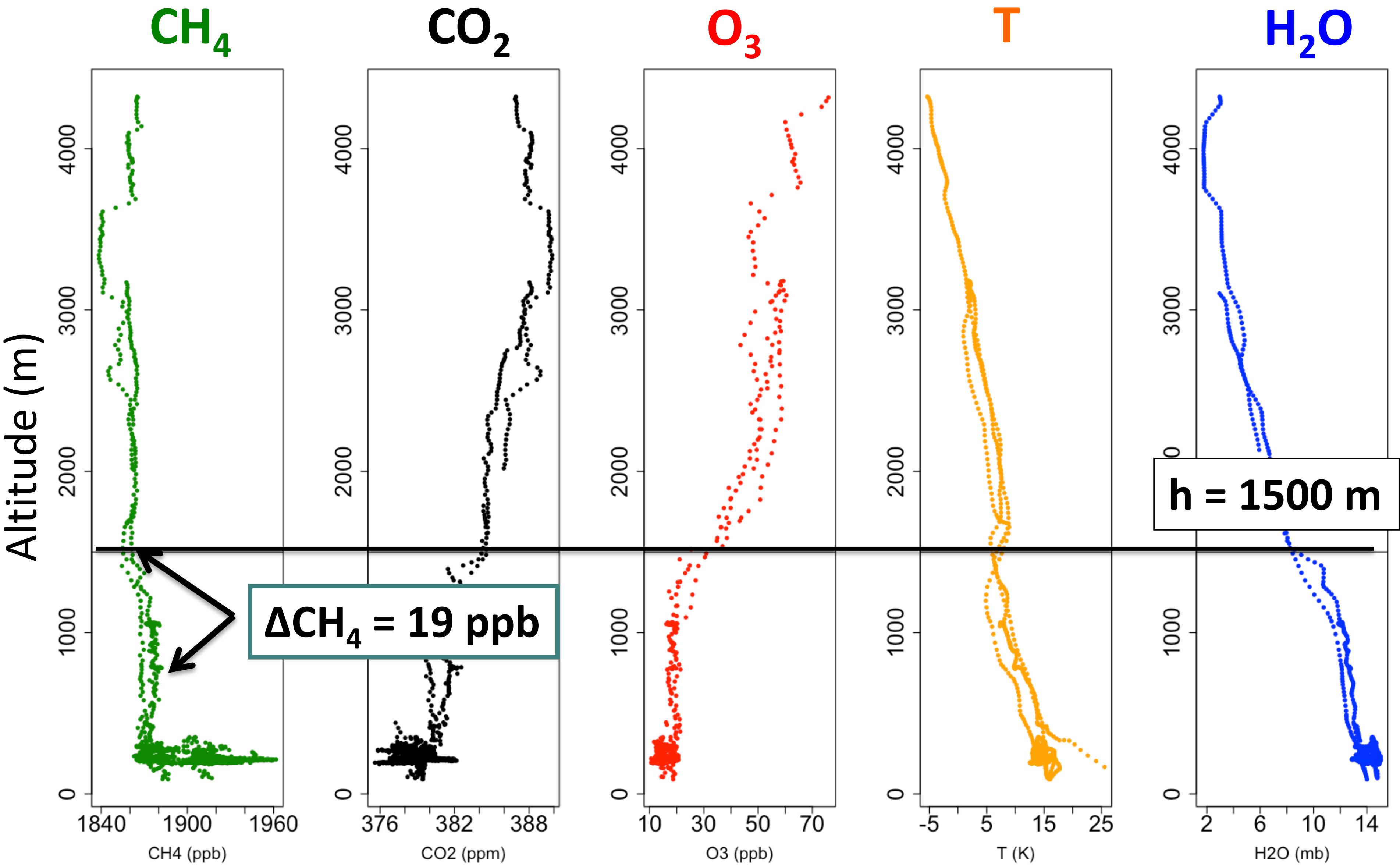


Flights in Alaska 2012-2014

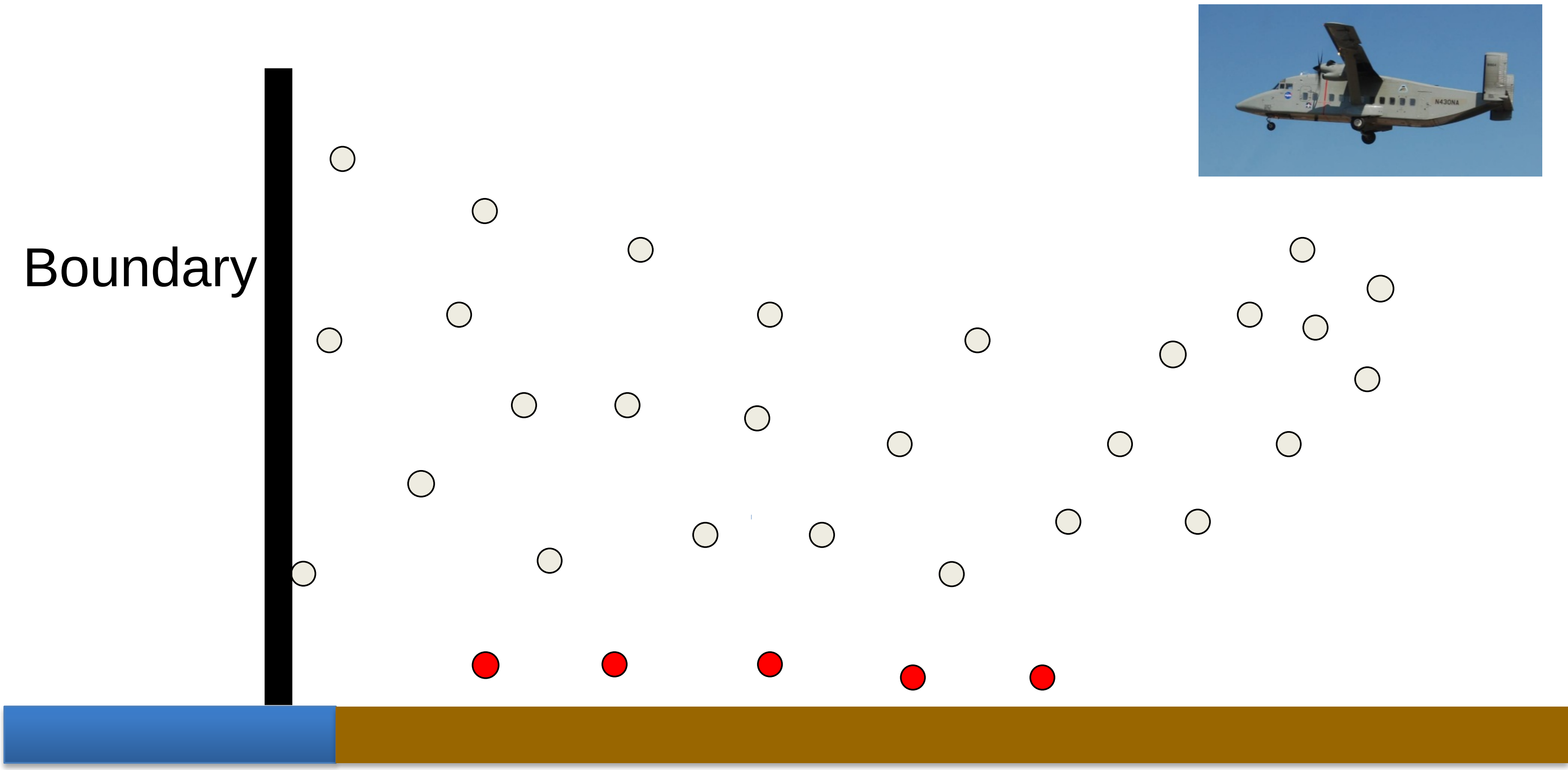
- Apr – Nov
- measured CO_2, CH_4, CO
- flew at heights of 150 m to 5 km



Innoko – July 25, 2012

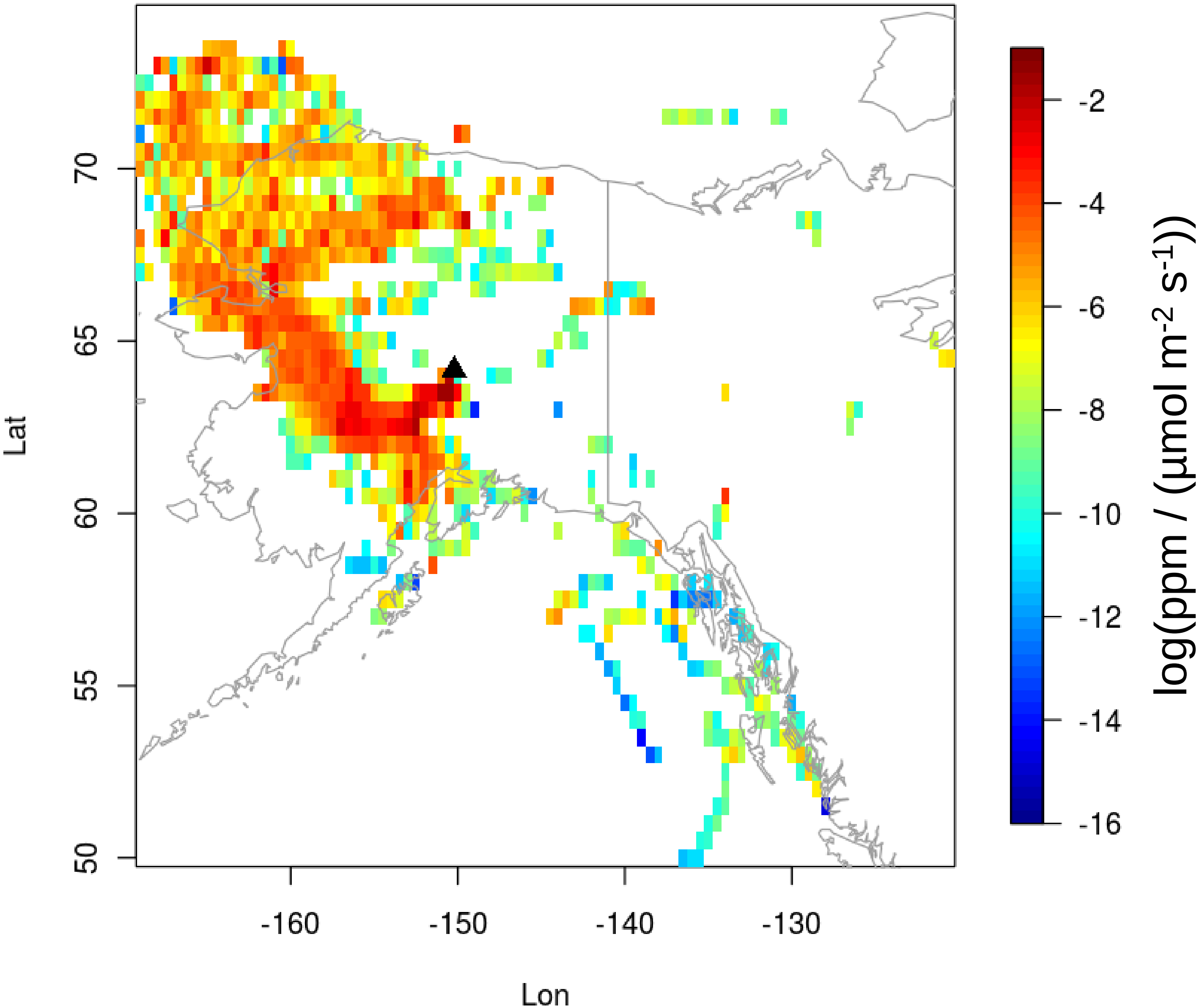


Stochastic Time-Inverted Lagrangian Transport Model



Lin et al. **2003** *J. Geophys. Res.*, 108, D16, 4493

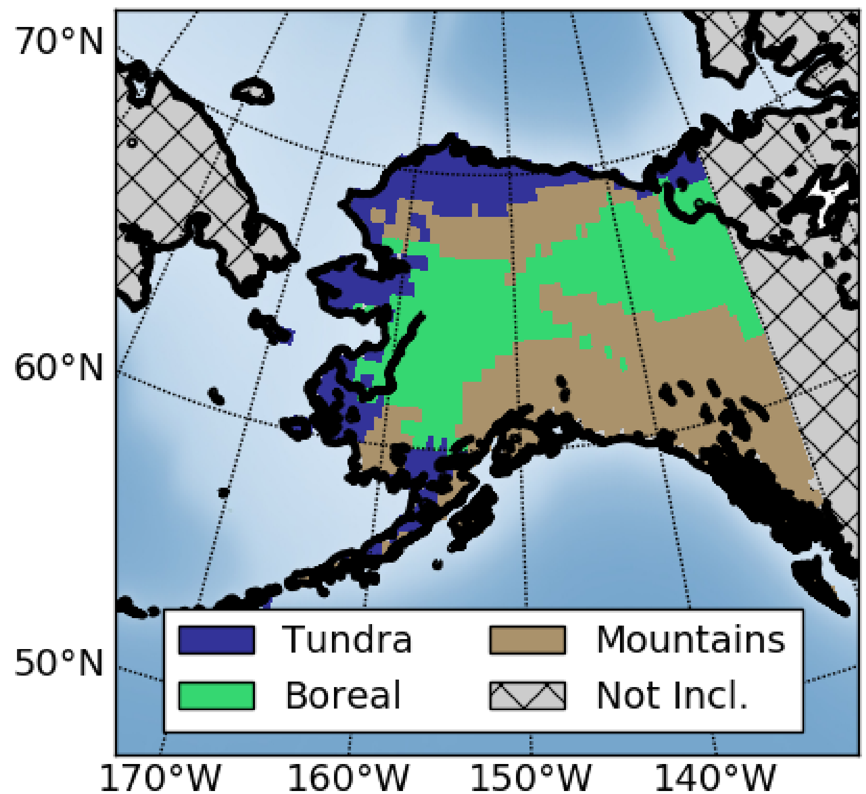
Surface Influence



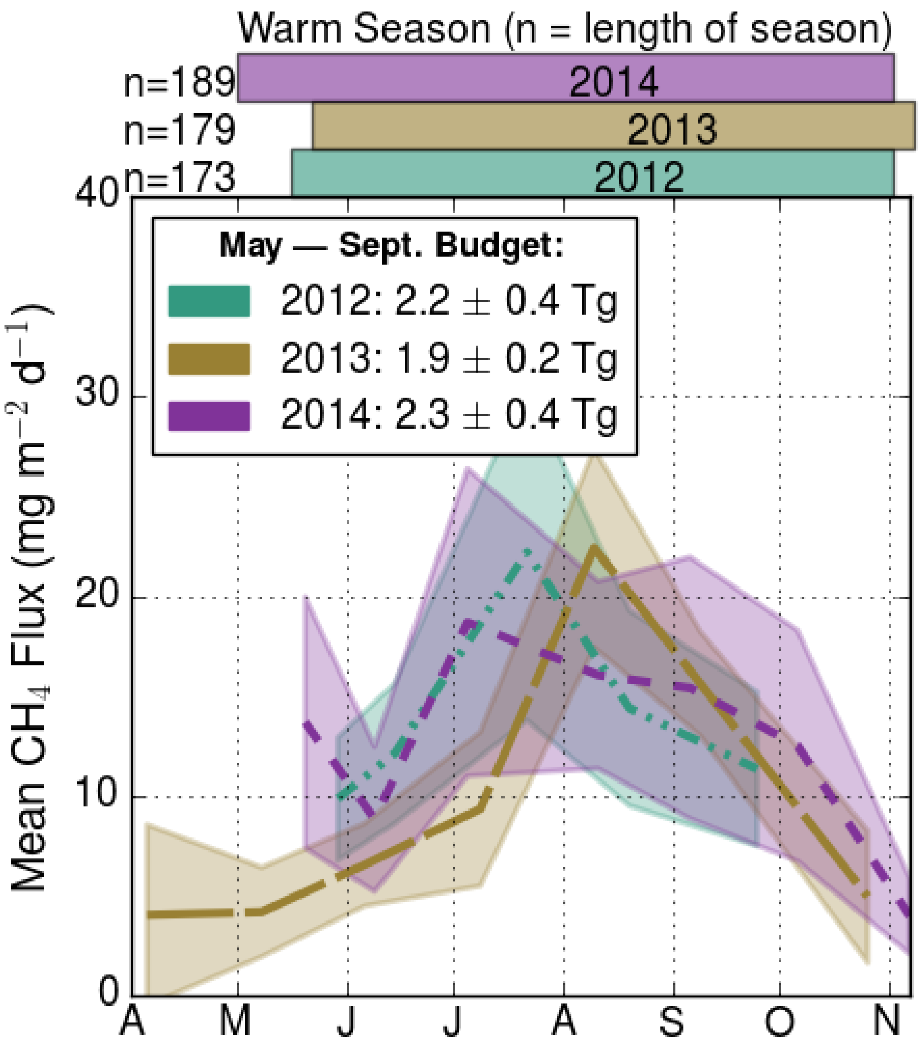
Footprint courtesy of J. Henderson, AER

Surface Assumptions

- assume all surfaces emit equally and uniformly
- exclude mountains
- separate ecoregions

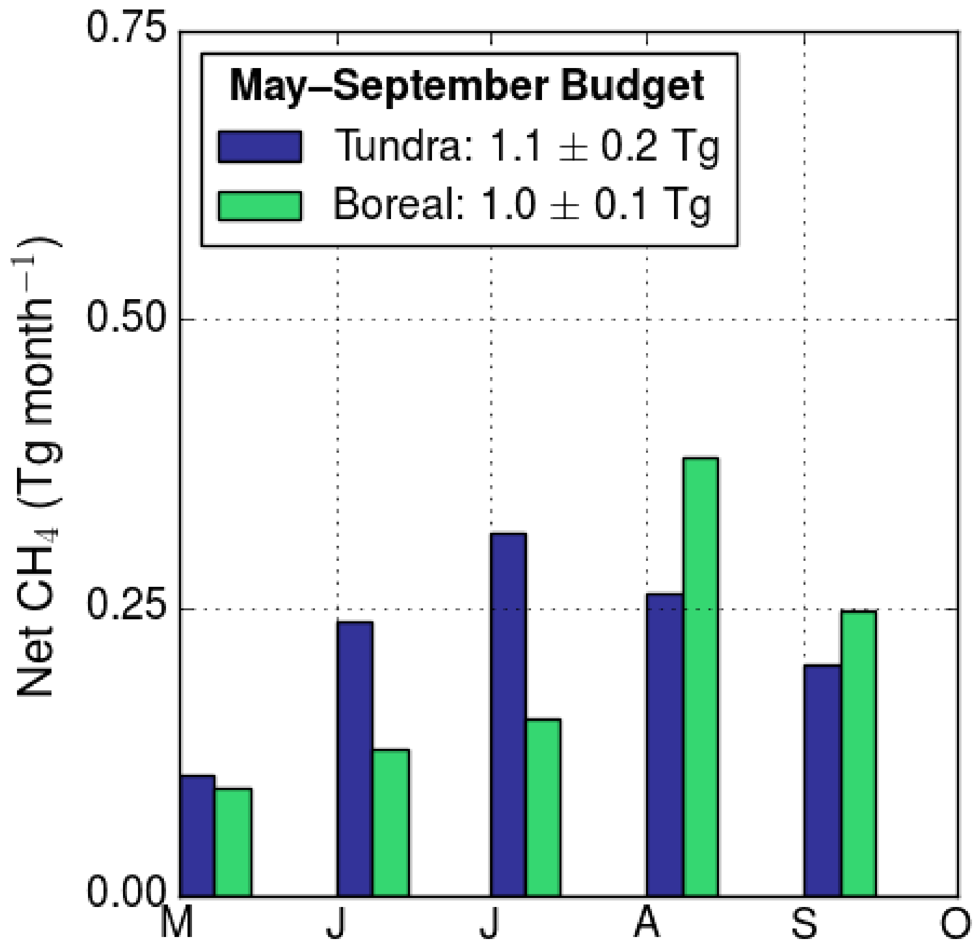


Estimated Methane Flux and Budget



Hartery et al. **2017**, *ACPD*, 17, in review

Methane Flux from Ecoregions



Tundra: 21±3 (6-34) mg/m2/d

Boreal: 10±2 (4-21) mg/m2/d

Hartery et al. **2017**, *ACPD*, 17, in review

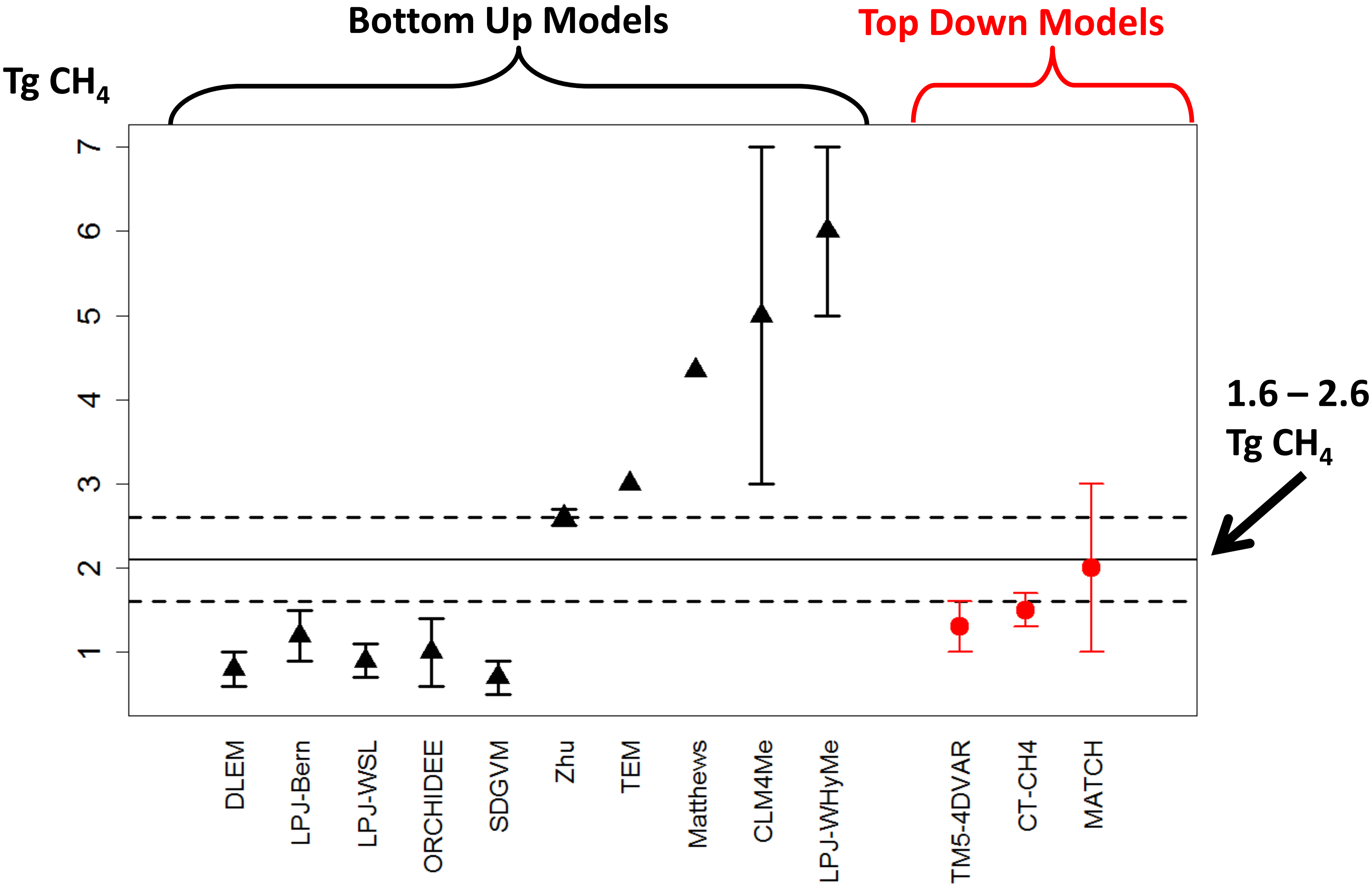
Depth Matters

N	Subset Condition	r^2	Predictors	Type
		All		
68	–	0.36	T_{40}, Z	Boltz.-Arrh., Inv.
		Sub-sets		
27	Wetlands Present	0.40	T_{10}, S_{10}	Boltz.-Arrh., Lin.
28	Wetlands Absent	0.48	T_{40}, S_{40}	Boltz.-Arrh., Lin.

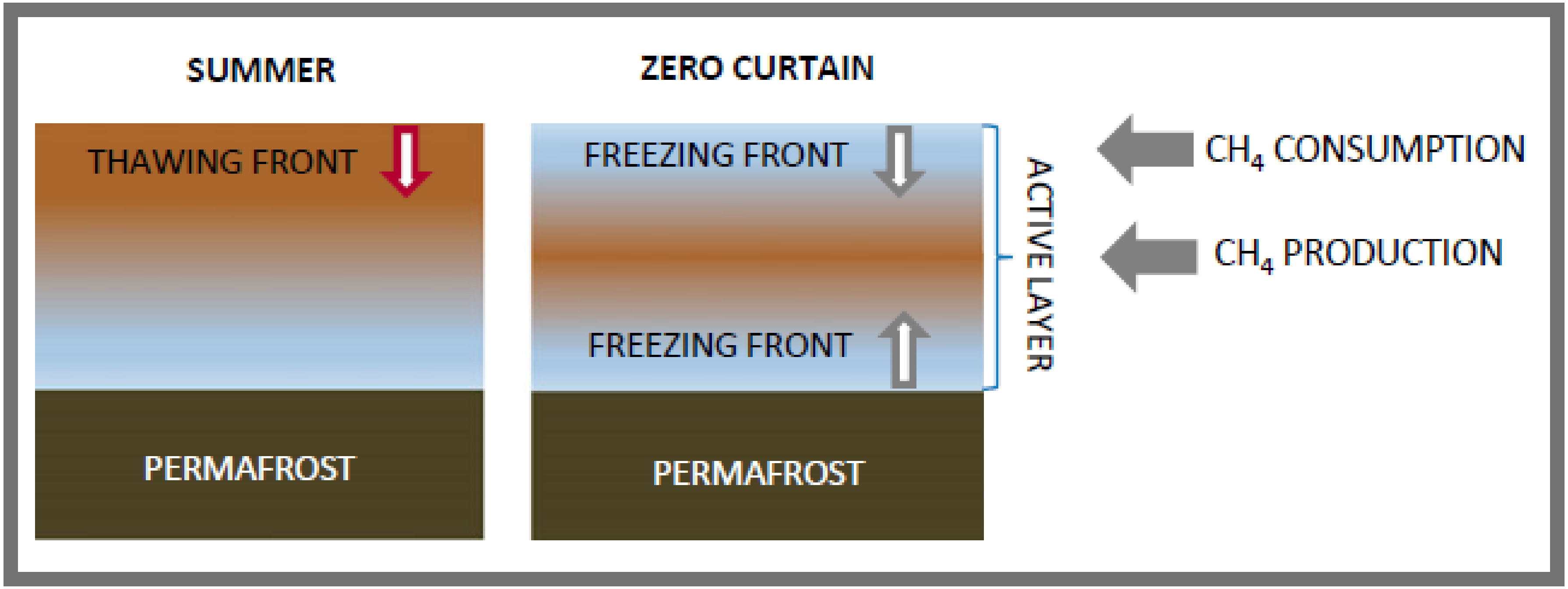
T_x: mean sampled x-cm subsoil temperature from NARR (K); S_x: mean sampled x-cm subsoil liquid moisture fraction from NARR (-); Z: soil surface elevation above sea-level (km).

Hartery et al. **2017**, *ACPD*, 17, in review

Comparing with Other Models May – Sep from Alaska

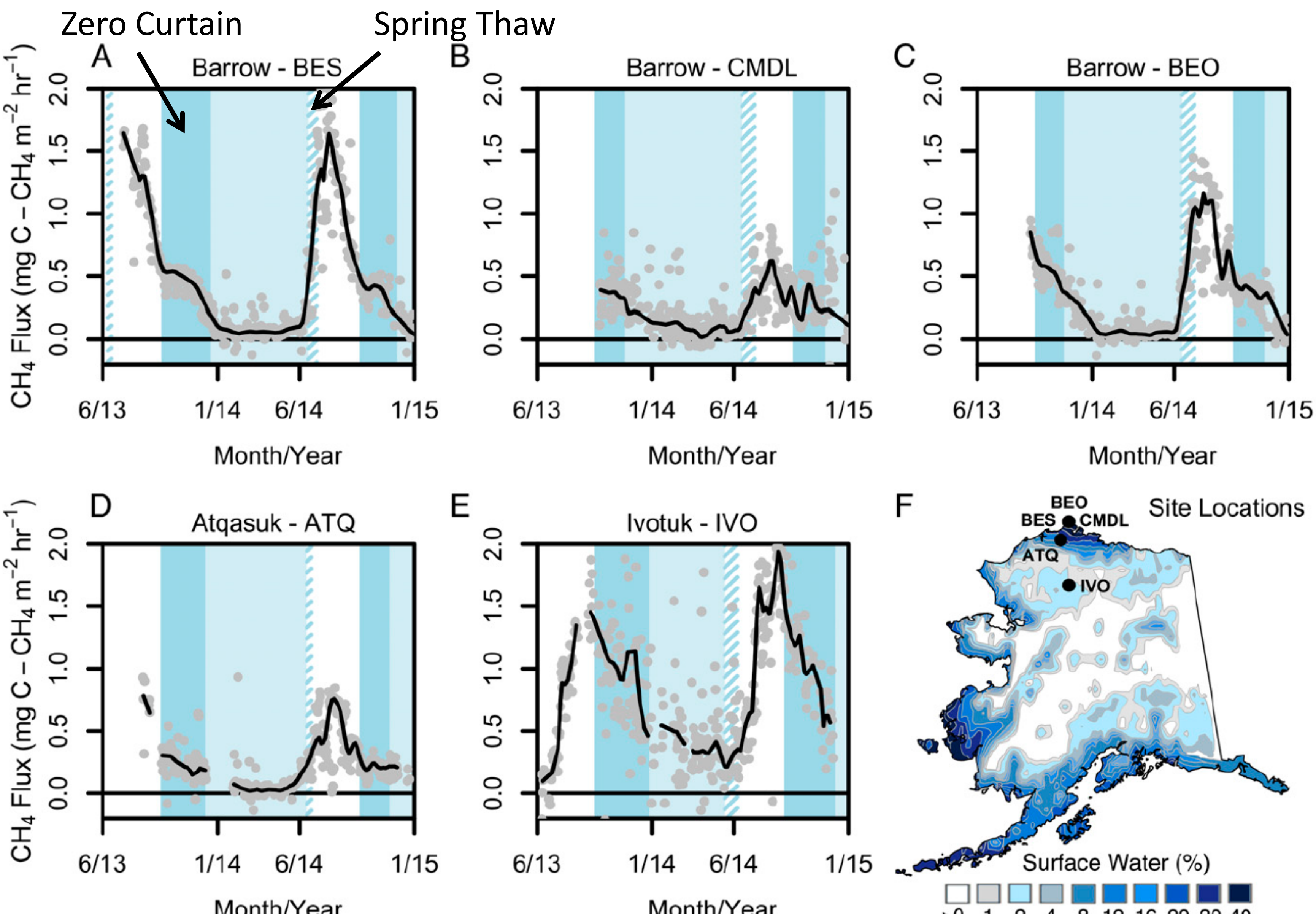


Methane Emissions from Active Layer



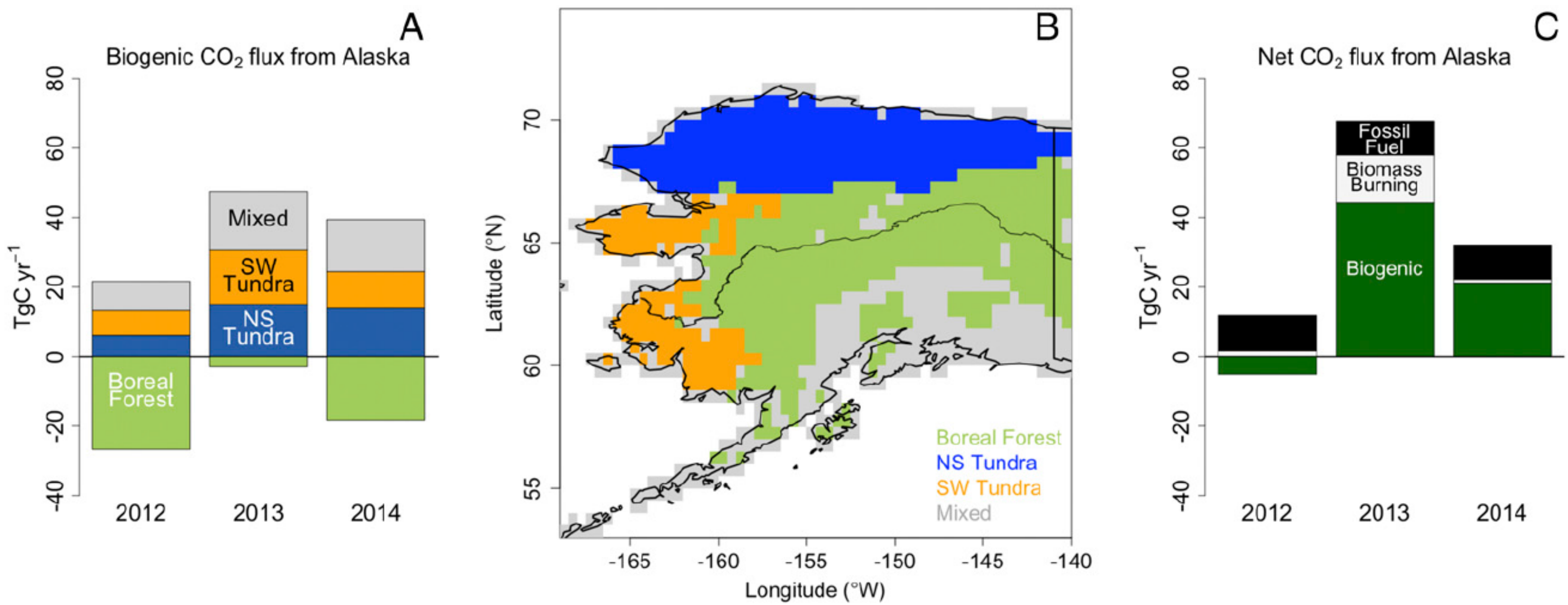
Zona et al. **2016**, PNAS, 113, 40

Fall CH_4 Emissions Dominate



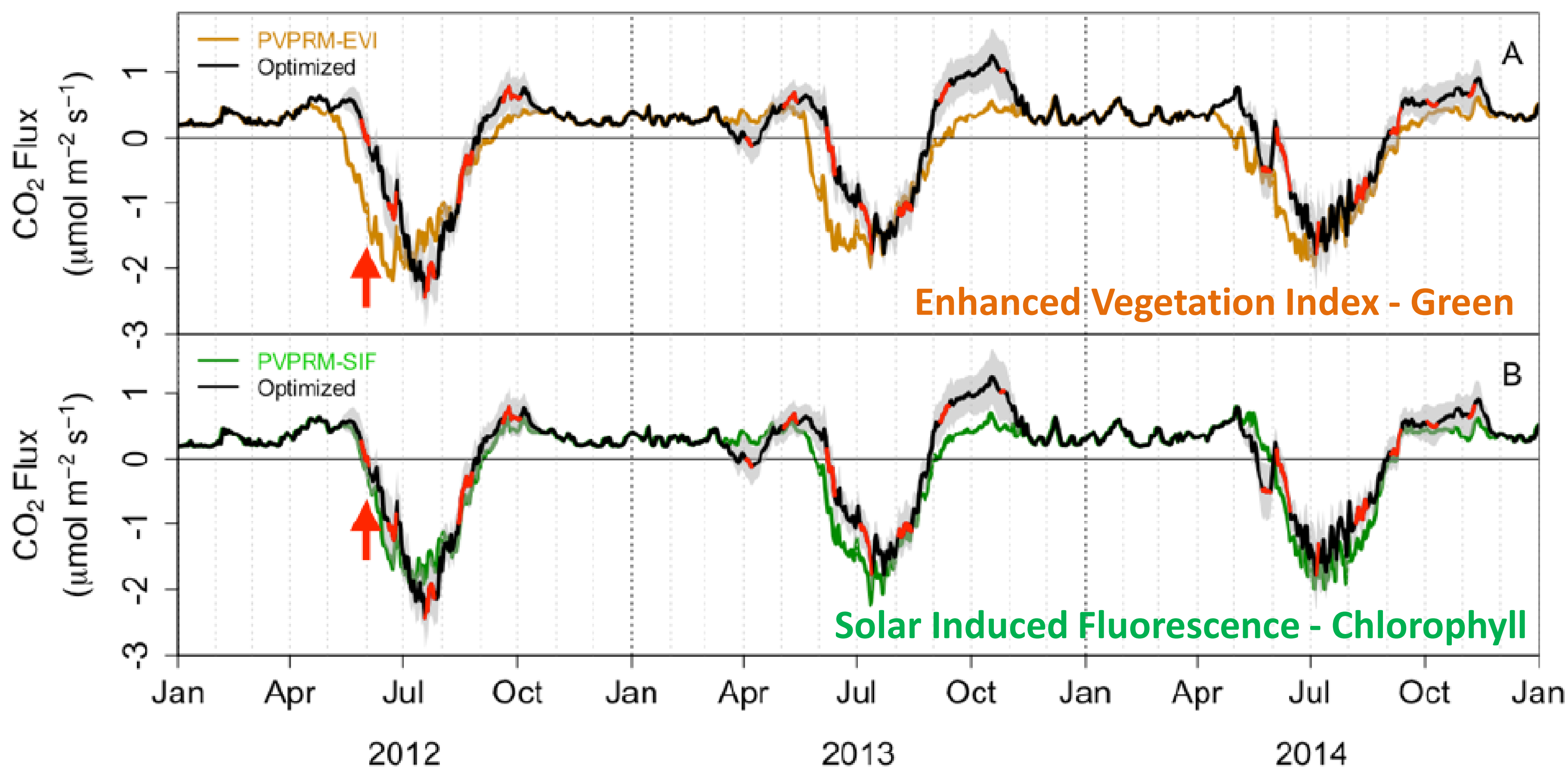
Zona et al. **2016**, PNAS, 113, 40

Alaska is a Net Source of CO_2



Commane et al. **2017**, PNAS, 114, 5361

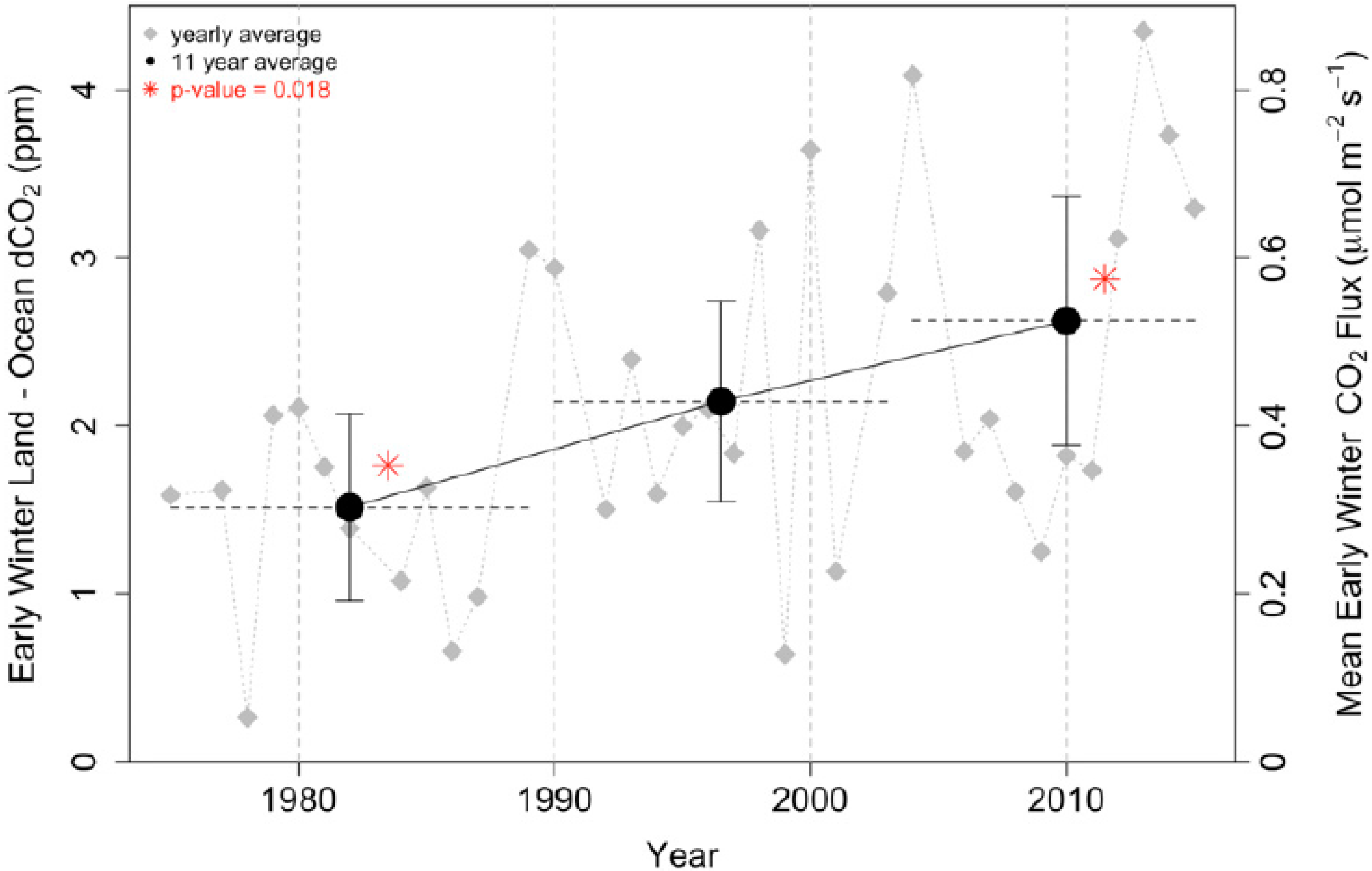
Proxy for Photosynthesis Matters



EVI predicts earlier uptake than observed

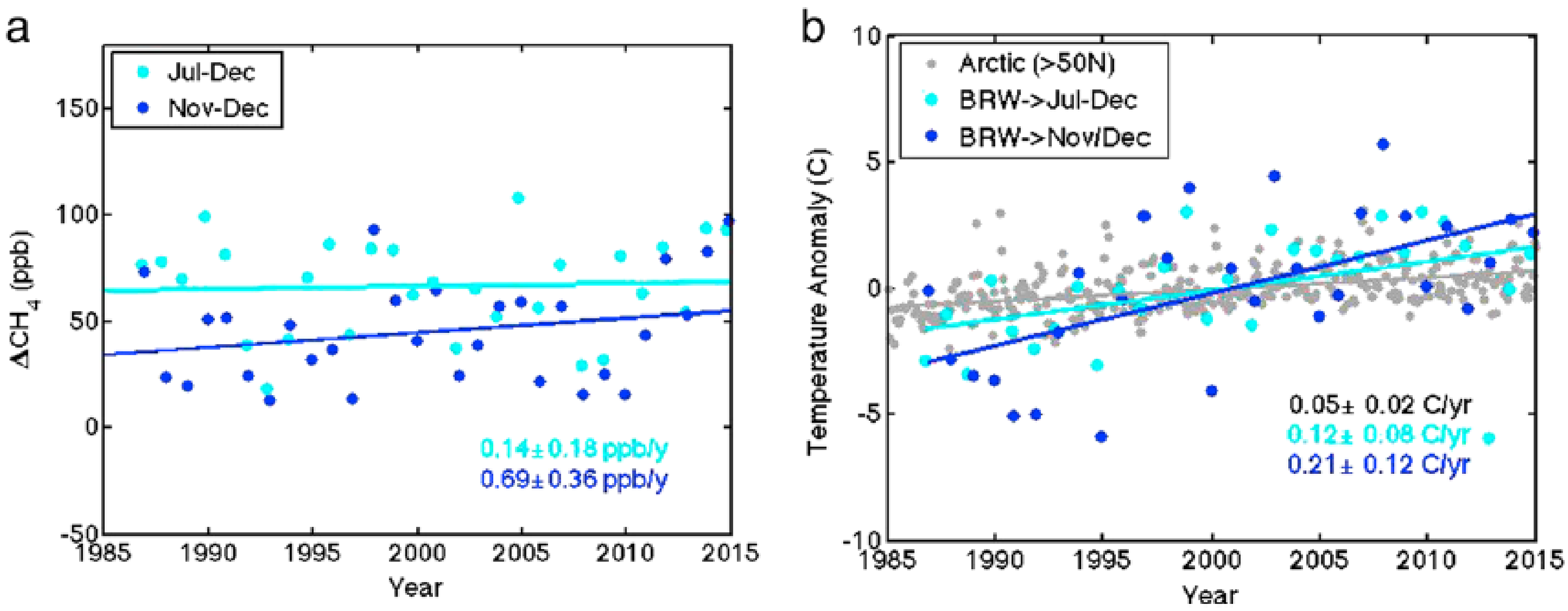
Commane et al. **2017**, PNAS, 114, 5361

Increased Oct-Dec CO_2 Respiration at Barrow Observatory



Commane et al. **2017**, PNAS, 114, 5361

But Not for Methane



Sweeney et al. **2016**, GRL

What will happen as the Arctic warms?

- increased uptake during spring and summer?
  - limited by solar radiation
- extended dark period in fall
- increased fall respiration?

Summary

- Models do a poor job of predicting CO_2 and CH_4
- Fall respiration is very important and increasing for CO_2
- Fall respiration is very important but not increasing for CH_4
- Cold season emissions are non-zero