Monitoring and Detecting Arctic Greenhouse Gas Budgets: The Importance of Long-term Surface Observations and the Role of CarbonTracker-CH4

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(Pieter Tans & the NOAA ESRL CCGG Group)

~1700 PgC stored in permafrost soils

(About equal to known coal reserves, and several times the amount of carbon already emitted by fossil fuel combustion)

Photo: National Geographic

- ~200 GtC may be released by 2200 (Schaefer et al., 2011)
- CO_2 could increase by ~90 ppm
- Arctic will become a net source of carbon by the 2020s

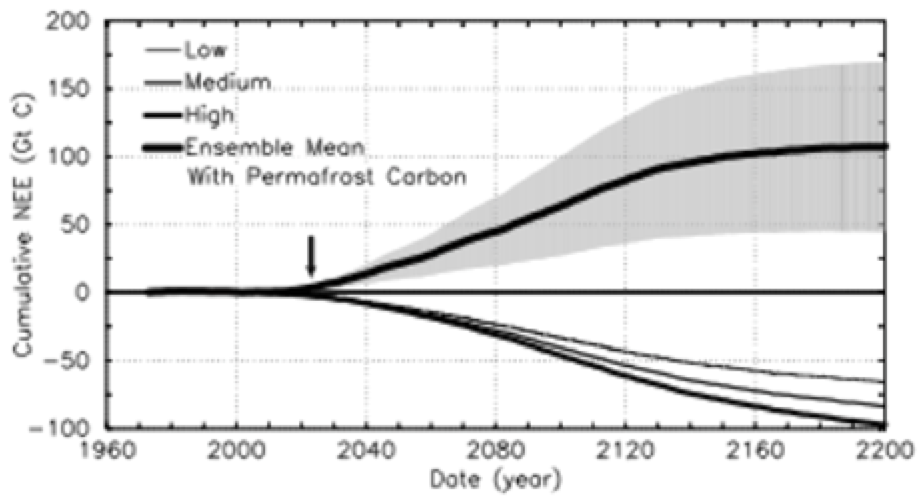
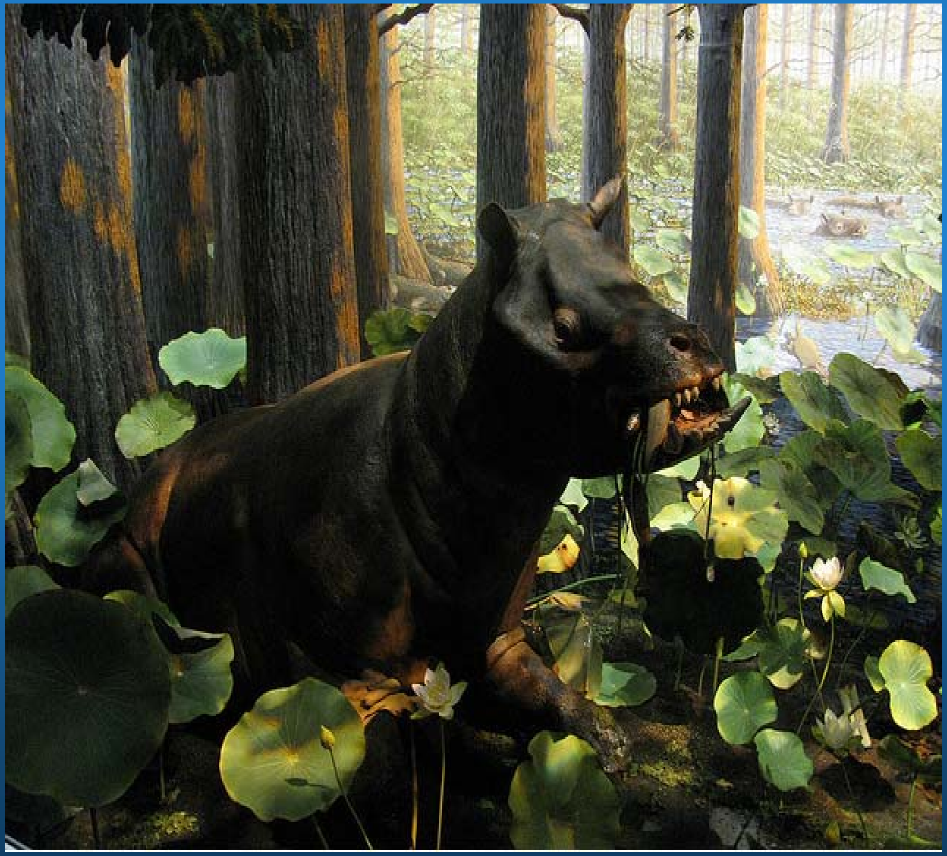


Fig. 6. Pan-Arctic total cumulative Net Ecosystem Exchange (NEE) for low, medium and high warming rates without permafrost carbon and the ensemble mean cumulative NEE with permafrost carbon flux. The grey bar represents uncertainty and the arrow marks the pan-Arctic starting point of 2023 ± 4.

Paleo permafrost carbon feedbacks?

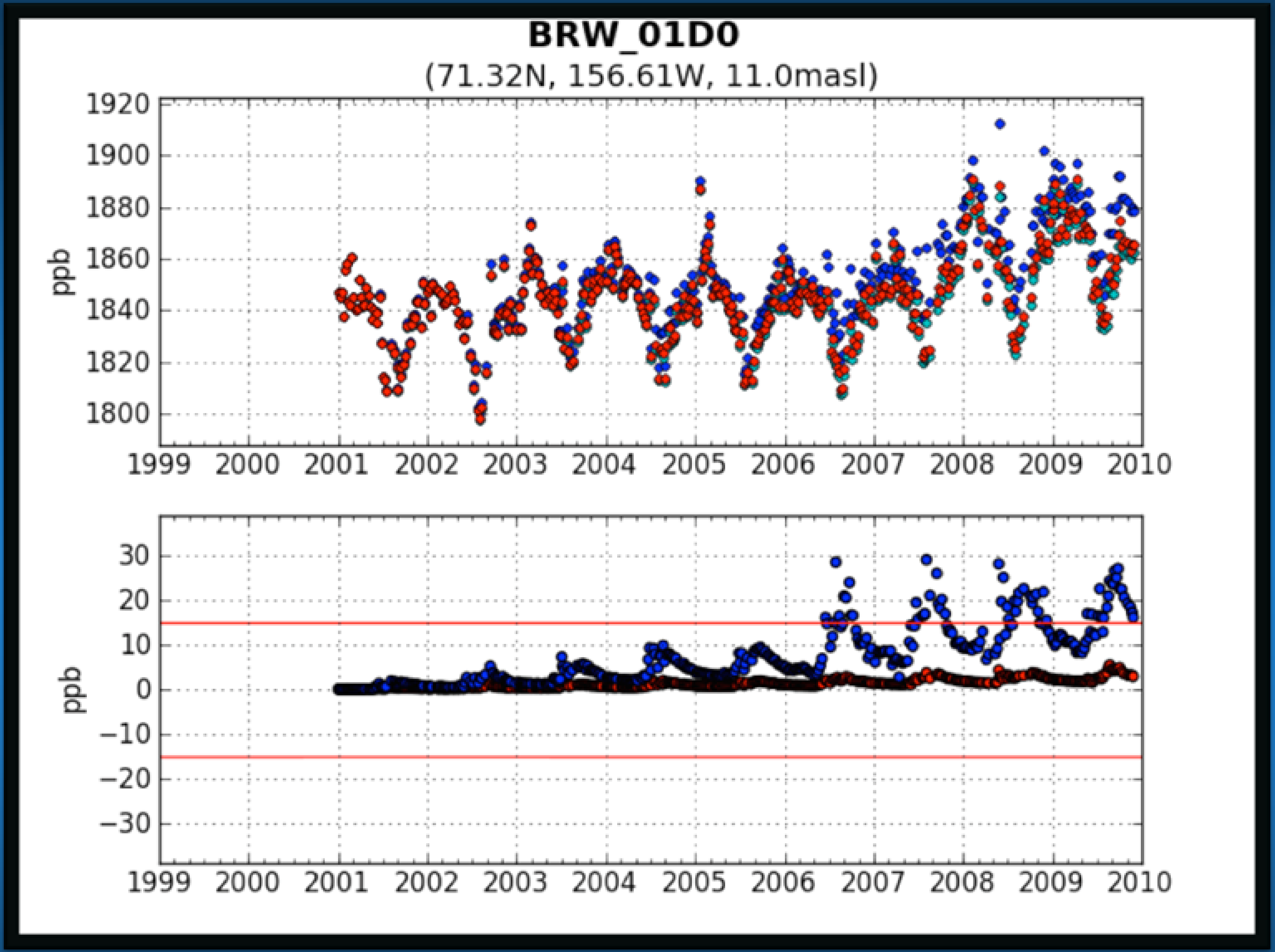
- Orbital Forcing and Permafrost Carbon Feedbacks may explain hyperthermal events ~55Mya
- Global T increase of 5 C within a few 1000 years
- ~3700 PgC in Eocene permafrost (~1700 PgC today) (DeConto et al. Nature 2012)



(A coryphodon basking in the Warm eocene)

1) We Need Long Observational Records to Detect Change in the Arctic

Signals are probably small and observations can be noisy!

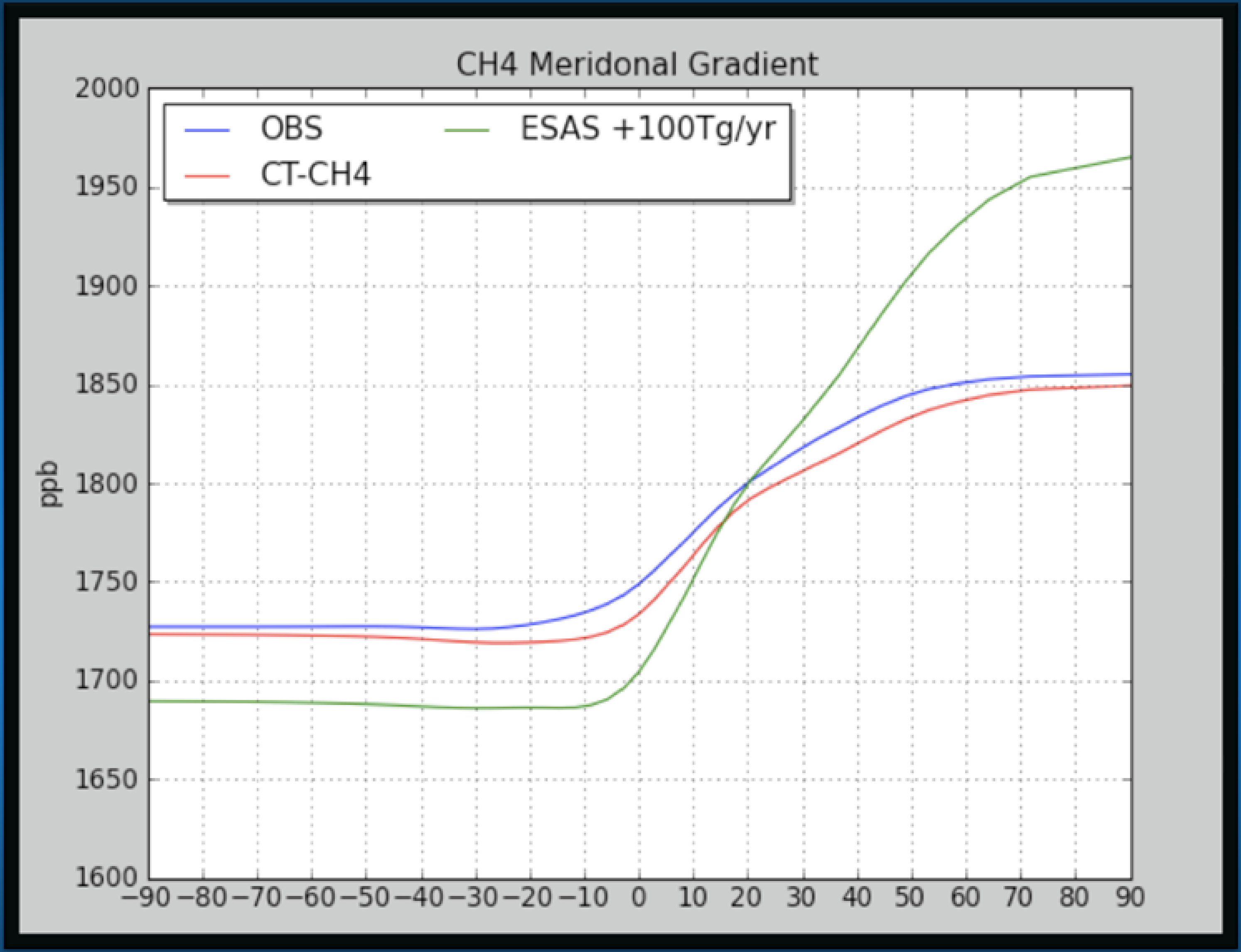


Red – 1 Tg/yr increase

Blue – 5 Tg/yr increase

2) The Meridional Gradient Rules!

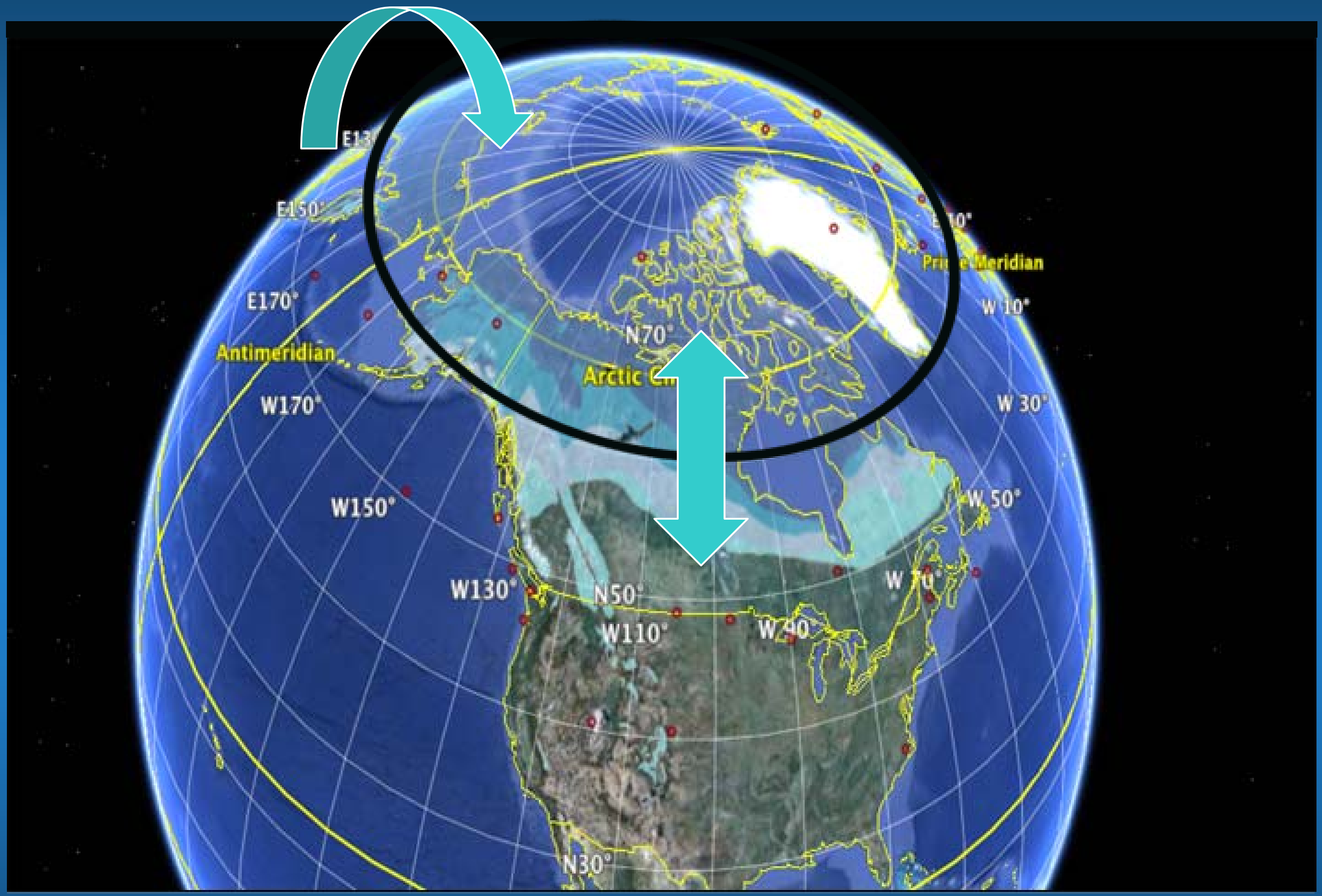
We don’t just need Arctic observations, we need global information.



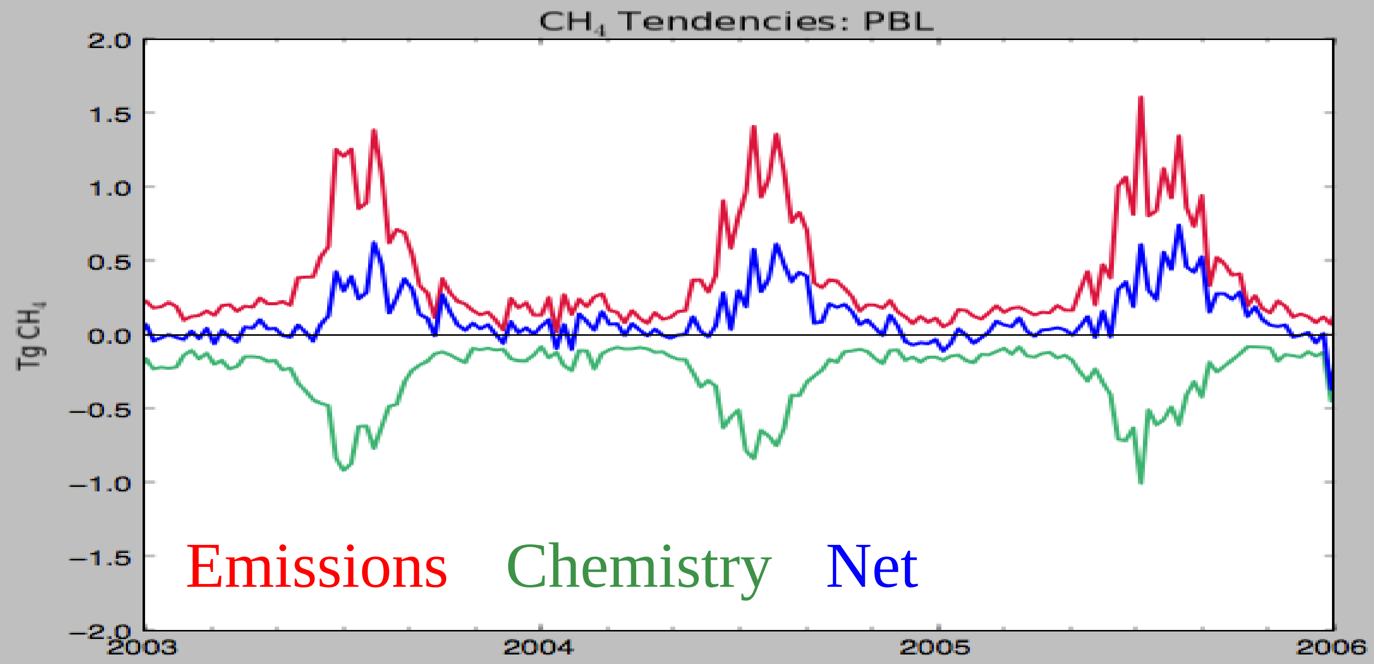
(We probably can't have 100 $TgCH_4$/yr bubbling out of the Arctic)

3) Measure where the sources are (at the surface) and make sure the spatial coverage is adequate!

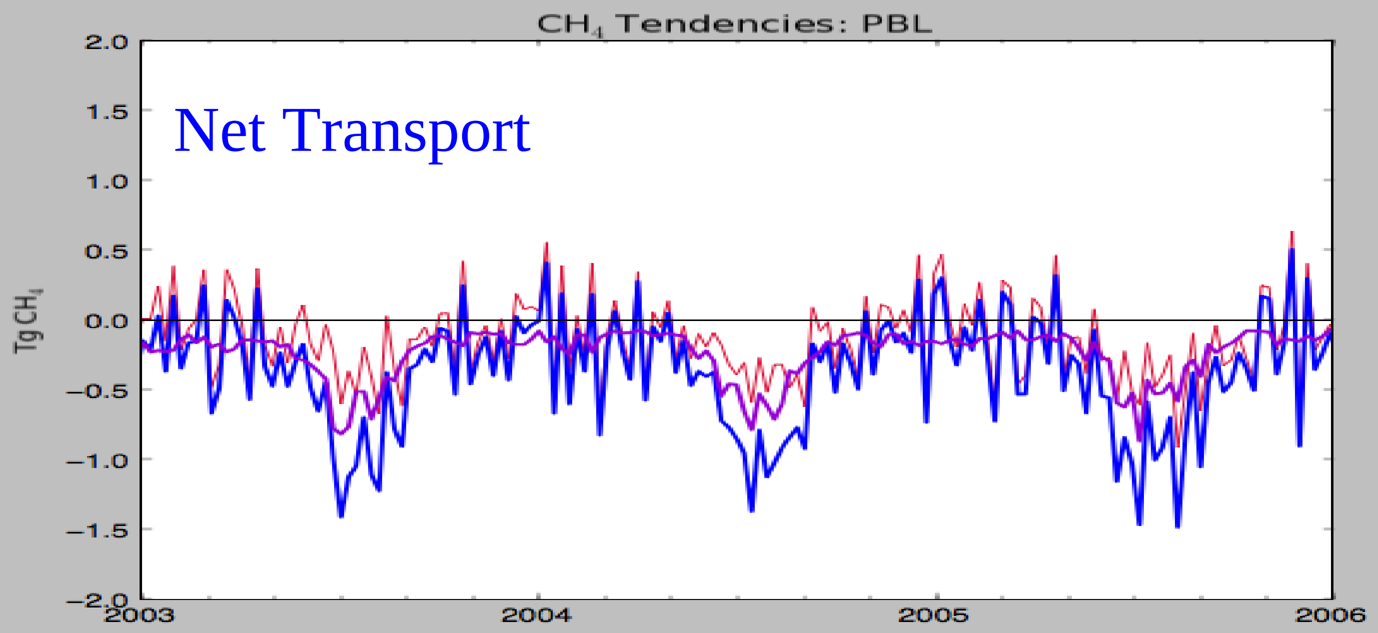
The Arctic CH_4 Budget



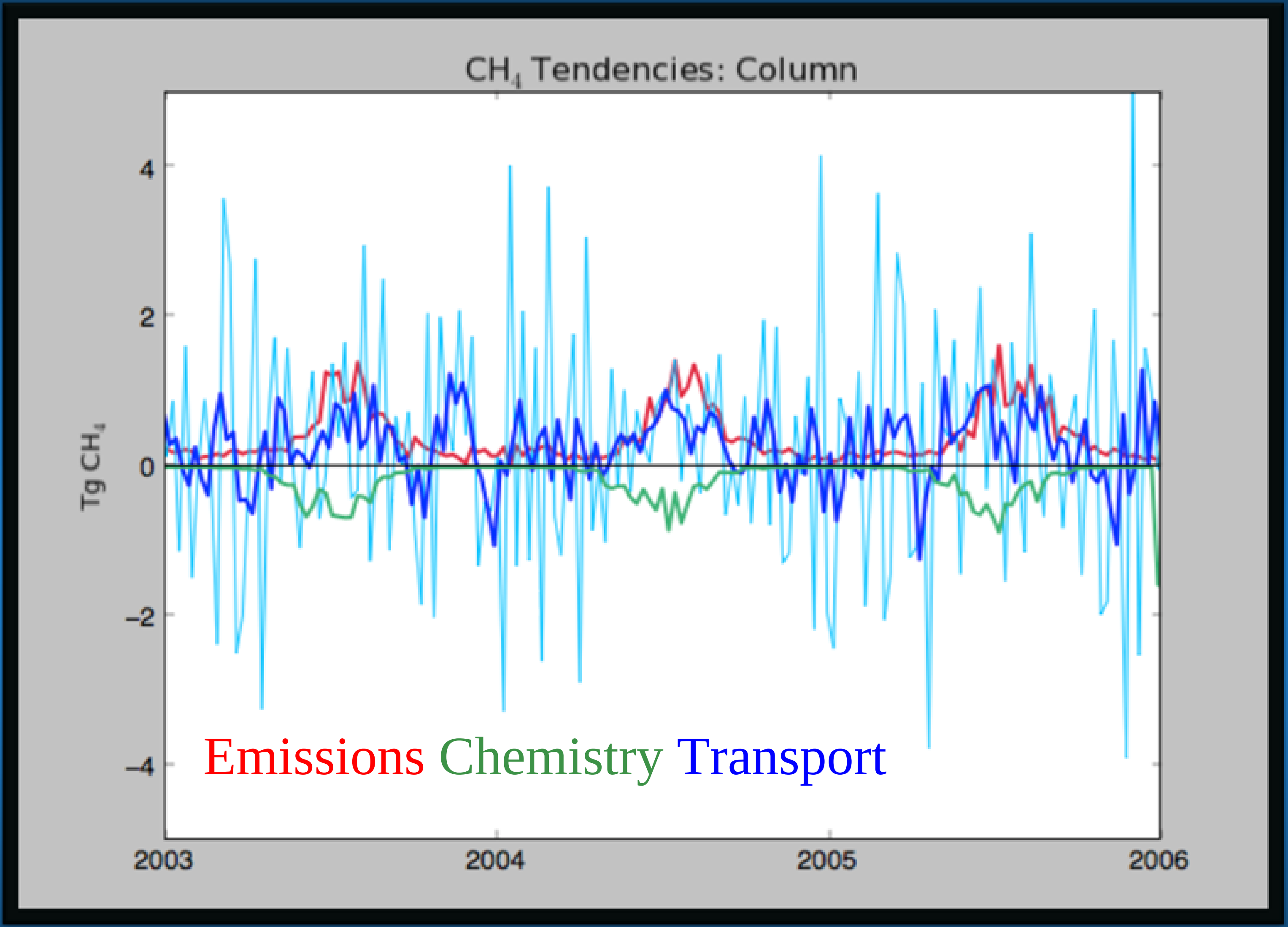
$$\Delta CH_4 = \text{Sources} - \text{Chemical Loss} - \text{Transport}$$



CH$_4$ Tendencies: PBL
Tg CH$_4$
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
2003
2004
2005
2006
Emissions
Chemistry
Net



CH$_4$ Tendencies: PBL
Tg CH$_4$
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
2003
2004
2005
2006
Net Transport

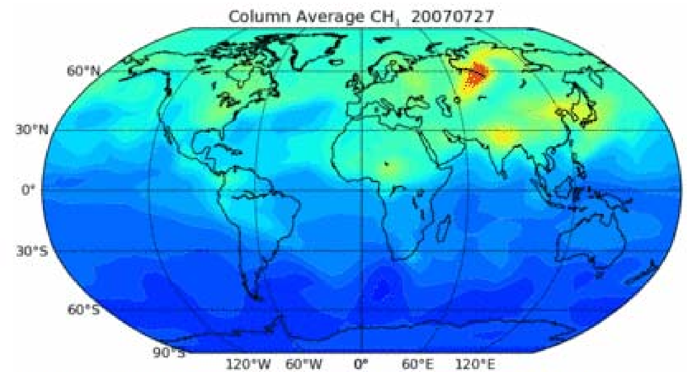

CH4 Tendencies: Column
Tg CH4
4
2
0
–2
–4
2003
2004
2005
2006
Emissions Chemistry Transport

4) Model/Data Syntheses can help us to understand variability and trends in CH_4 emissions and improve our ability to predict future emissions.

Given our best knowledge of emissions (prior flux models) and observations with adequate spatial and temporal coverage, what is our best estimate of CH_4 emissions?

CarbonTracker-CH_4

Welcome to the first release of the NOAA CarbonTracker-CH_4 Data Assimilation Product. It has been developed as a companion product to NOAA's CarbonTracker (CO_2), with the goal of producing quantitative estimates of emissions of methane to the atmosphere from natural and anthropogenic sources for North America and the rest of the world. CarbonTracker-CH_4 emission estimates are consistent with observed patterns of CH_4 in the atmosphere.

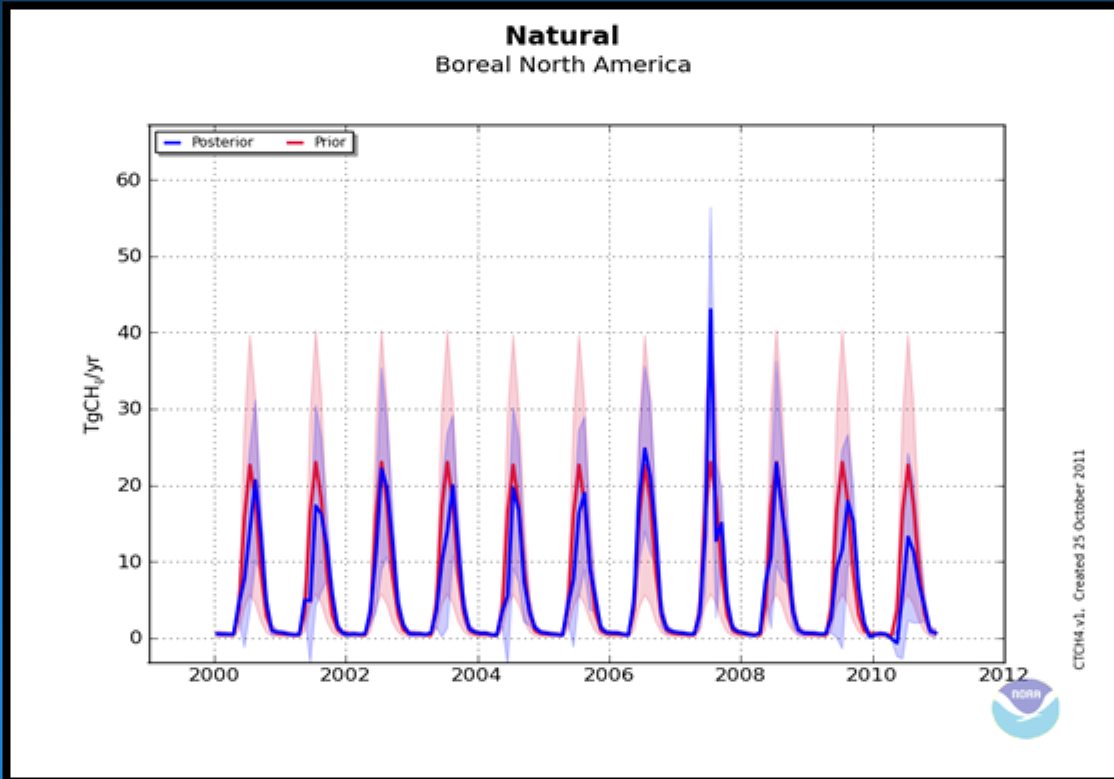


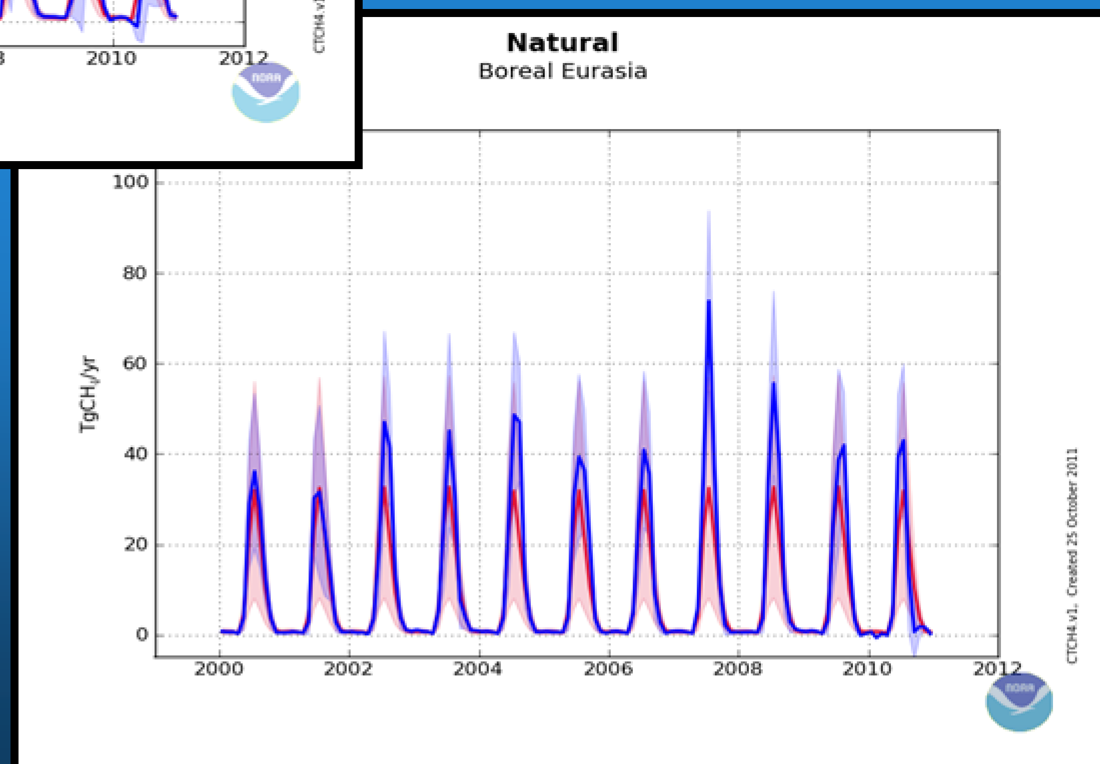
CarbonTracker CH_4 column average CH_4 for July-August, 2007. Warm colors show high atmospheric CH_4 concentrations, and cool colors show low concentrations. This sequence shows relatively large emissions from wetlands in Western Siberia and emissions from anthropogenic and natural sources in India and Asia. The resulting high CH_4 air masses are then moved around by weather systems to form the patterns shown in this animation. [More on CH_4 movies]

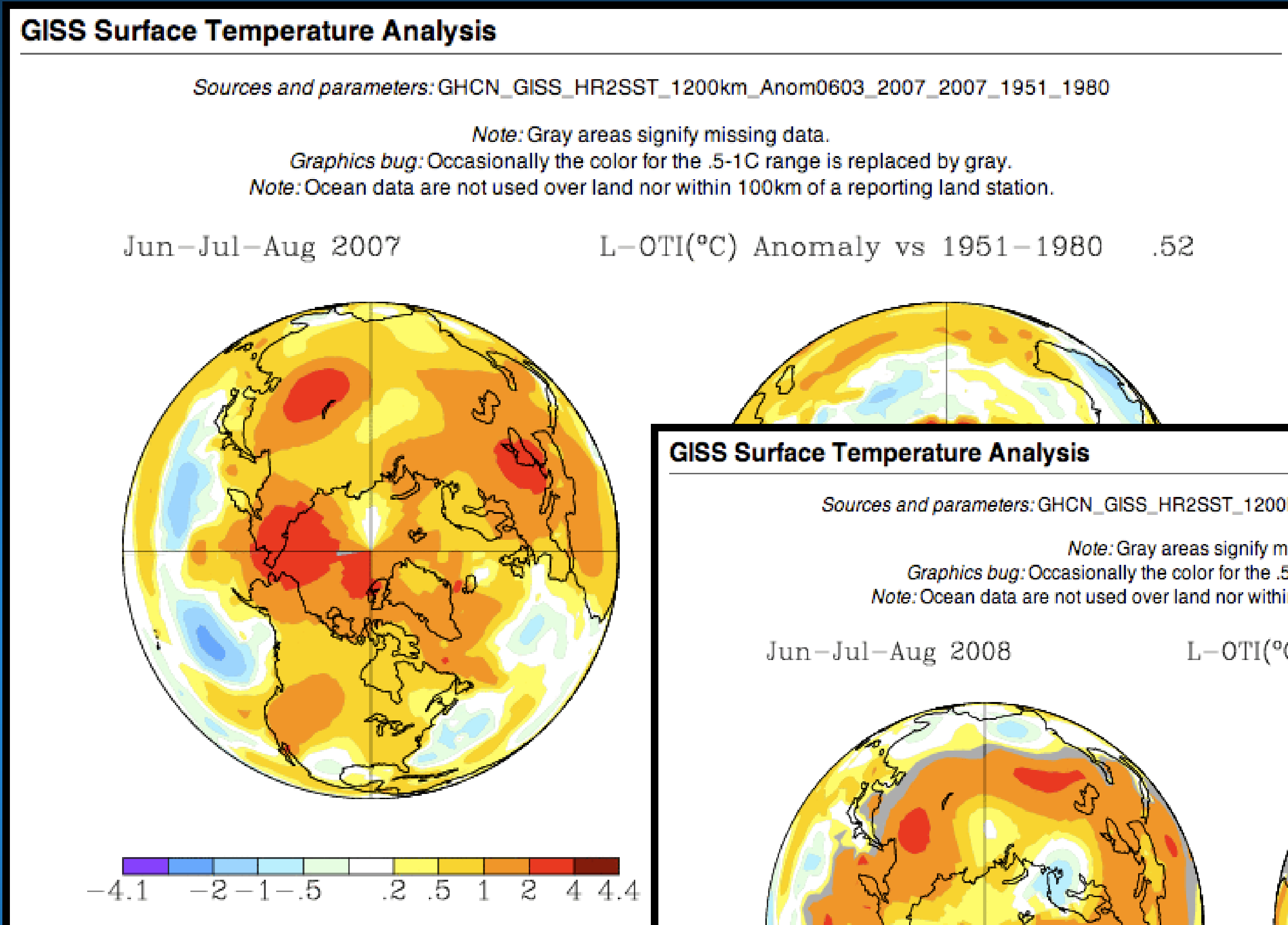
Methane plays an important role in the chemistry and radiative properties of the atmosphere. With a global warming potential of about 25 over a 100-year horizon, methane is a potent greenhouse gas (IPCC, AR4). Atmospheric methane has an atmospheric lifetime of about a decade, and it is ultimately oxidized to CO_2. It is one of the greenhouse gases targeted by the Kyoto Protocol, and may well be regulated by the United States in the future. Controlling methane emissions also has implications for air quality, since oxidation of CH_4 leads to tropospheric ozone formation in polluted environments.

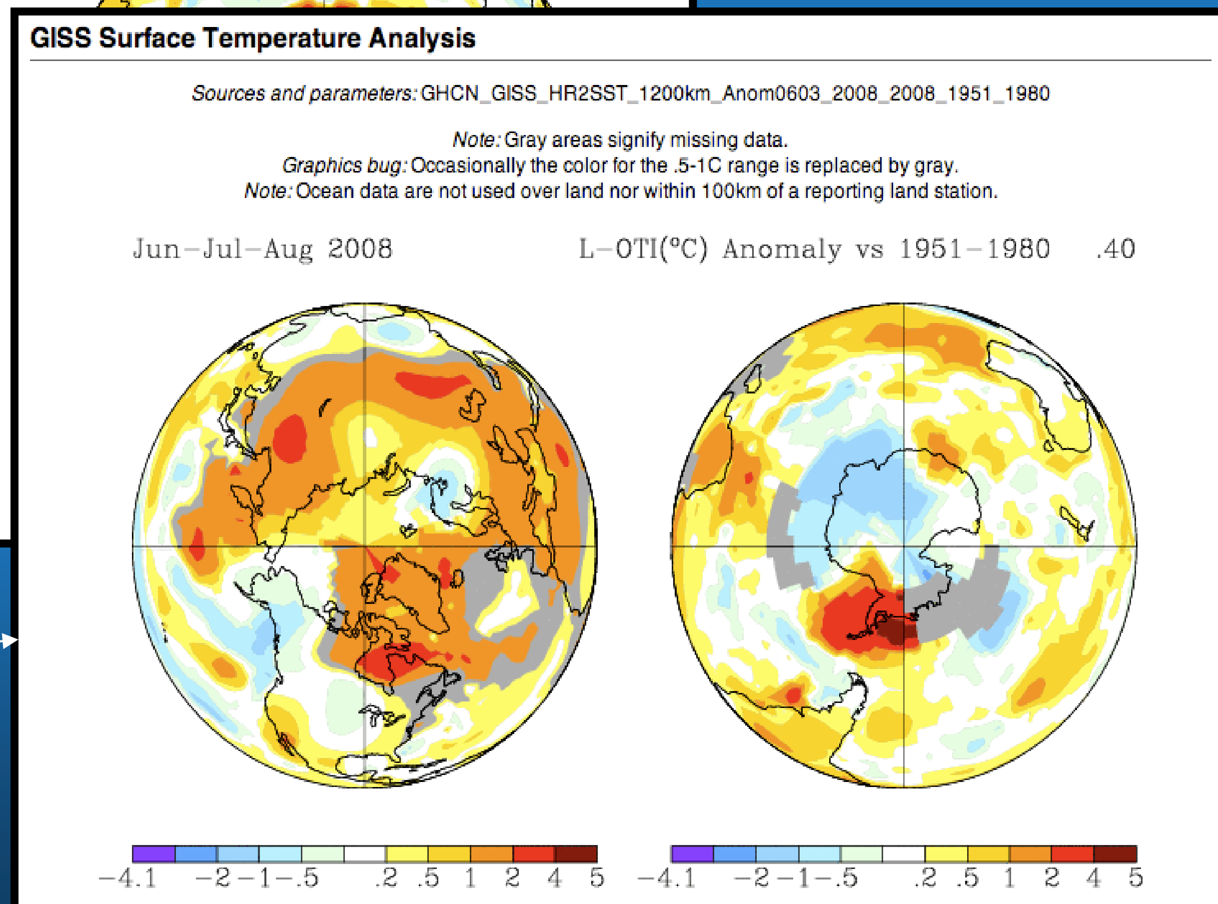
The largest natural source of methane is microbial production in wet, anaerobic environments such as bogs, swamps, peatlands and other wetland ecosystems. Smaller amounts of methane are emitted from fires, oceans and enteric fermentation in termites and wild animals. In addition, methane is emitted in relatively small amounts from geologic sources, such as seeps, clathrates, mud volcanoes and geothermal systems. Anthropogenic sources of methane are due to a wide range of human activities, from food production (rice and livestock) to energy extraction (coal mining, leakage associated with oil and gas

Regional Source Information from CarbonTracker-CH_4 Data Assimilation System





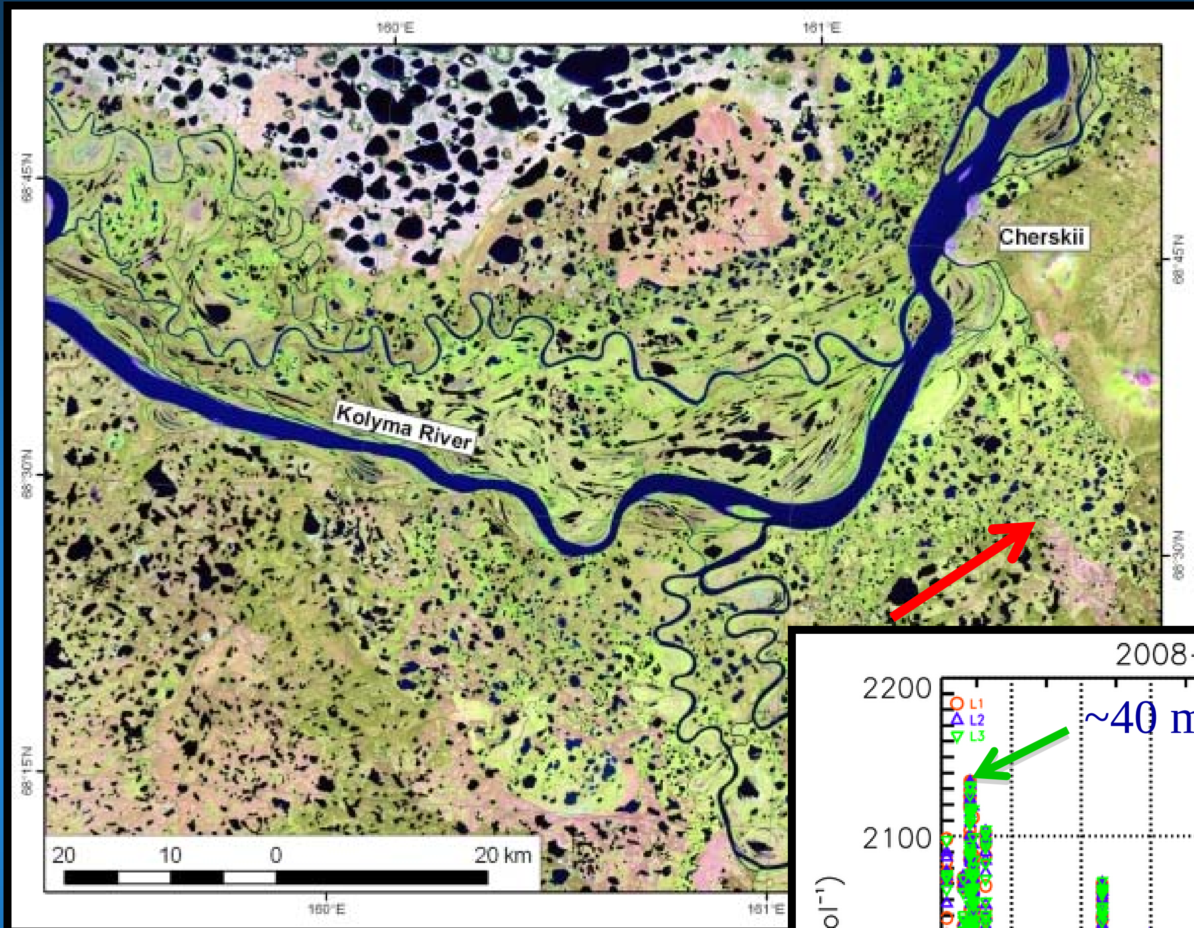


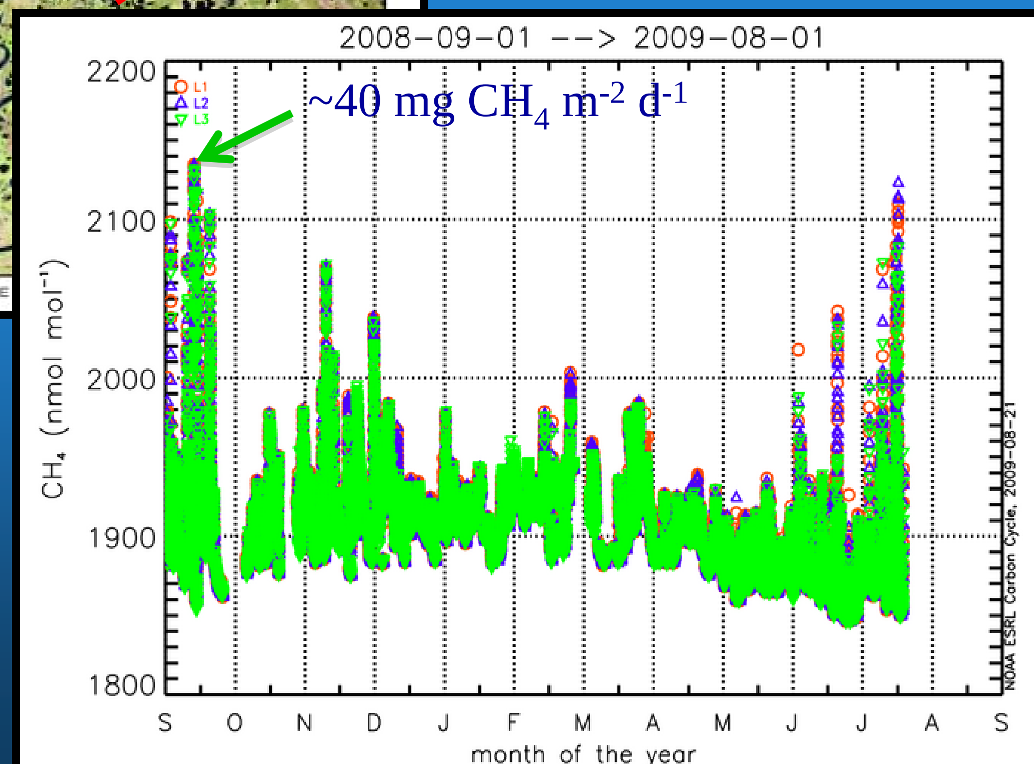


2008 was also warm in Boreal Eurasia

Conclusions

- To monitor trends in Arctic emissions we need long-term observations.
- We need global coverage.
- We need to measure at the surface where the emissions are.
- We need adequate spatial coverage
- Diagnostic models like CarbonTracker-CH_4 provide an opportunity to test and improve process models for improved prediction, as well as monitoring regional emissions.


Cherskii
Kolyma River
20 10 0 20 km
160°E
161°E
68°45'N
68°30'N
68°15'N


2008-09-01 --> 2009-08-01
~40 mg CH_4 m^{-2} d^{-1}
L1
L2
L3
CH_4 (nmol mol^{-1})
2200
2100
2000
1900
1800
S O N D J F M A M J J A S
month of the year
NOAA ESRL Carbon Cycle, 2009-08-21

Prototype CarbonTracker-CH_4: Priors

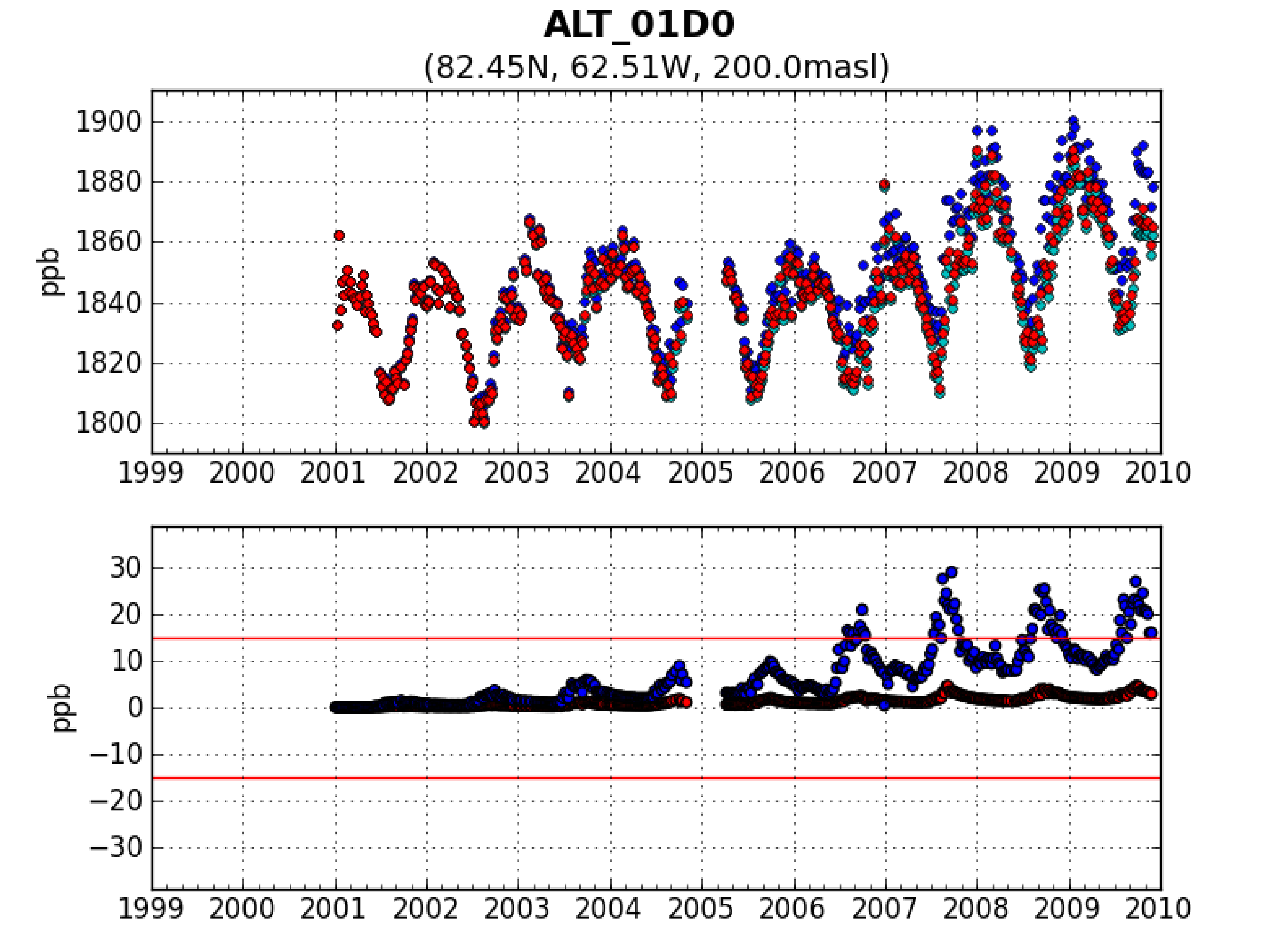
EDGAR 3; Bergamaschi et al. (2002)

- **Fossil**-Coal, Oil/Gas
- **Agwaste**-Enteric Fermentation, Rice, Waste
- **Biomass Burning** (GFEDv2/v3)
- **Natural**-Wetlands, Soil Uptake, Oceans, Termites

Photochemical Loss

- Repeating Seasonal Cycle, Optimized Using CH_3CCl_3

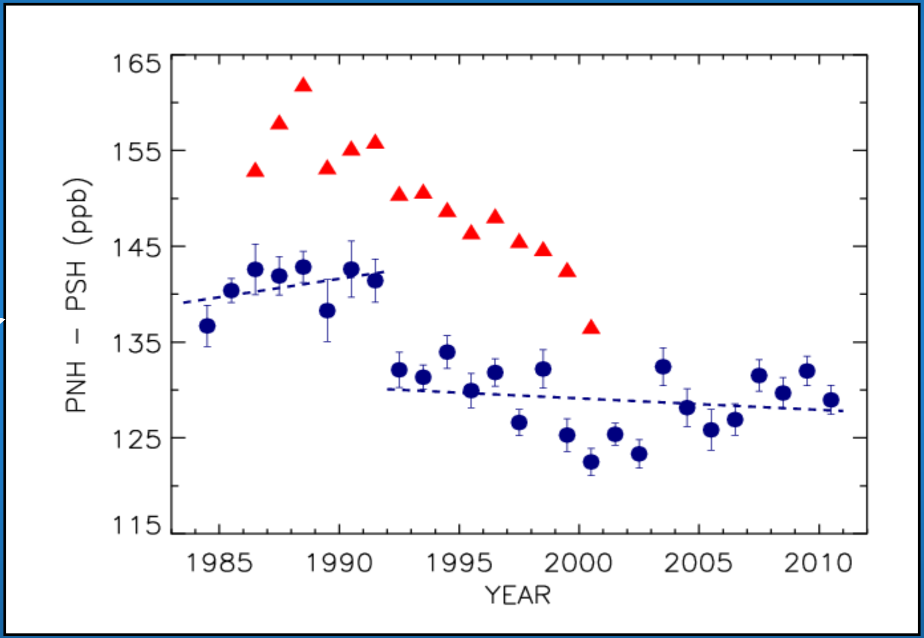
121 Estimated Parameters: 12 Land Regions x 10 Source Processes+1 Global Ocean Region

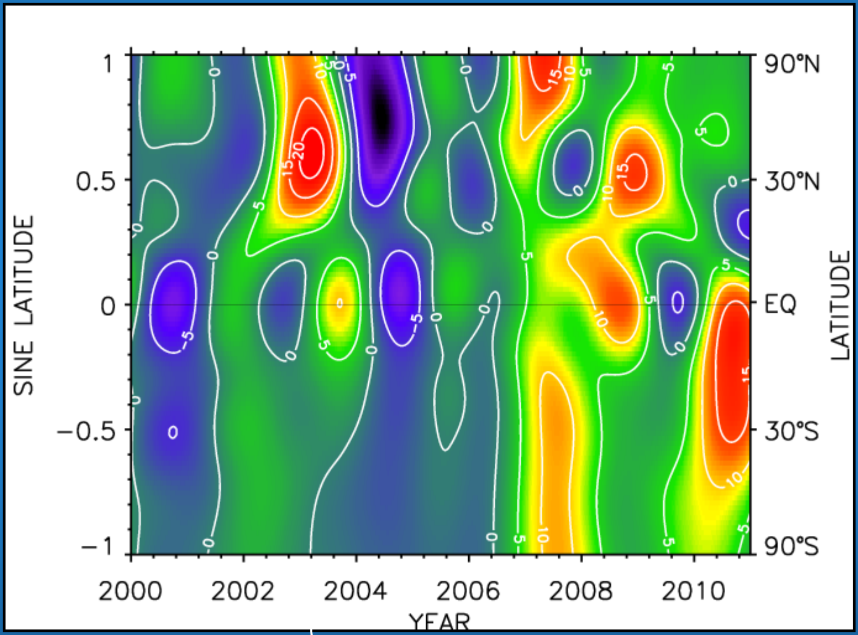


ALT_01D0
(82.45N, 62.51W, 200.0masl)
ppb
1800
1820
1840
1860
1880
1900
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
ppb
−30
−20
−10
0
10
20
30

What Might a Top-Down Model Be Used For?

1. Getting More Specific Spatial or Process Information About Emissions



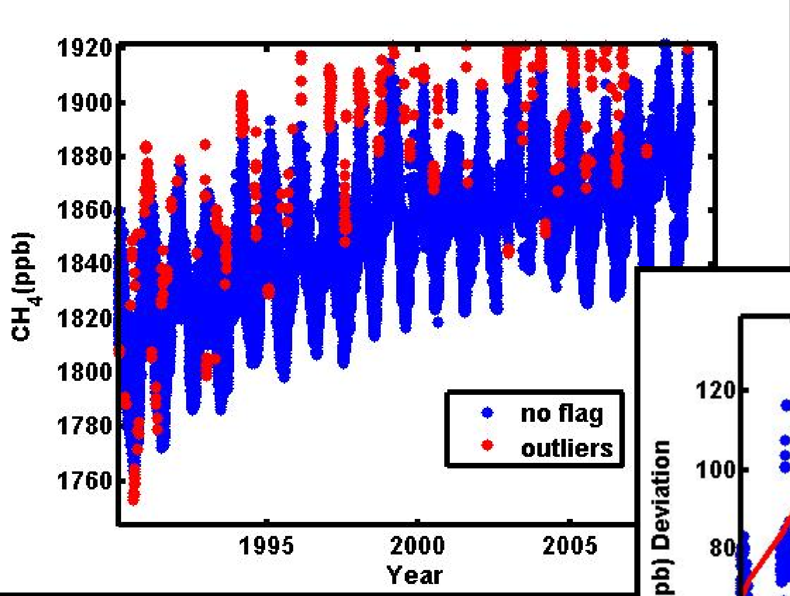


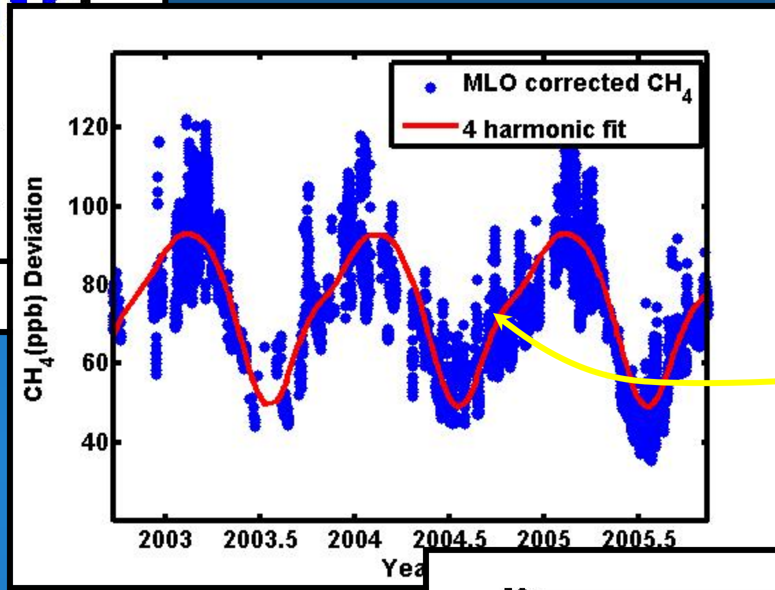
The Inter-Polar Difference - a sensitive indicator of high-latitude change! (e.g. Dlugokencky et al., 2003)

Contour plot of CH_4 Growth Rate (ppb/yr)

(Analysis by Colm Sweeney)

Barrow Trend



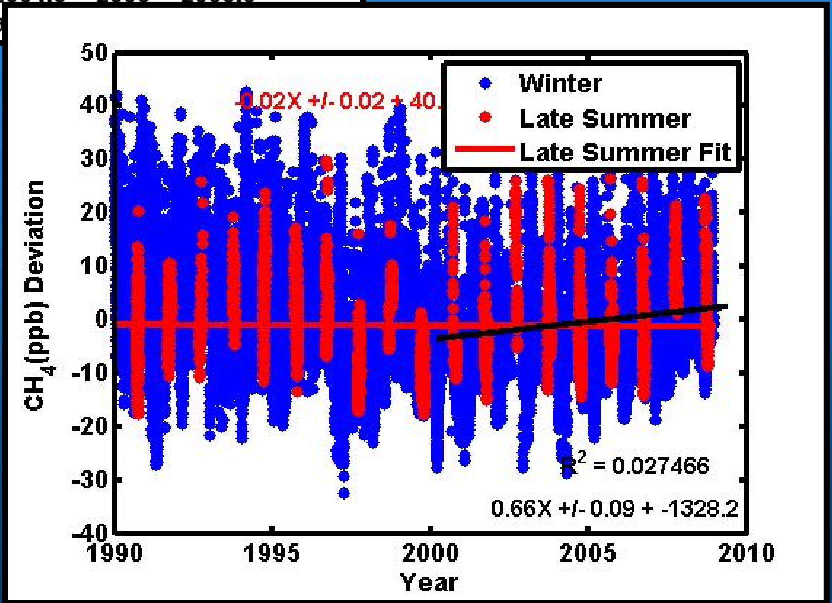


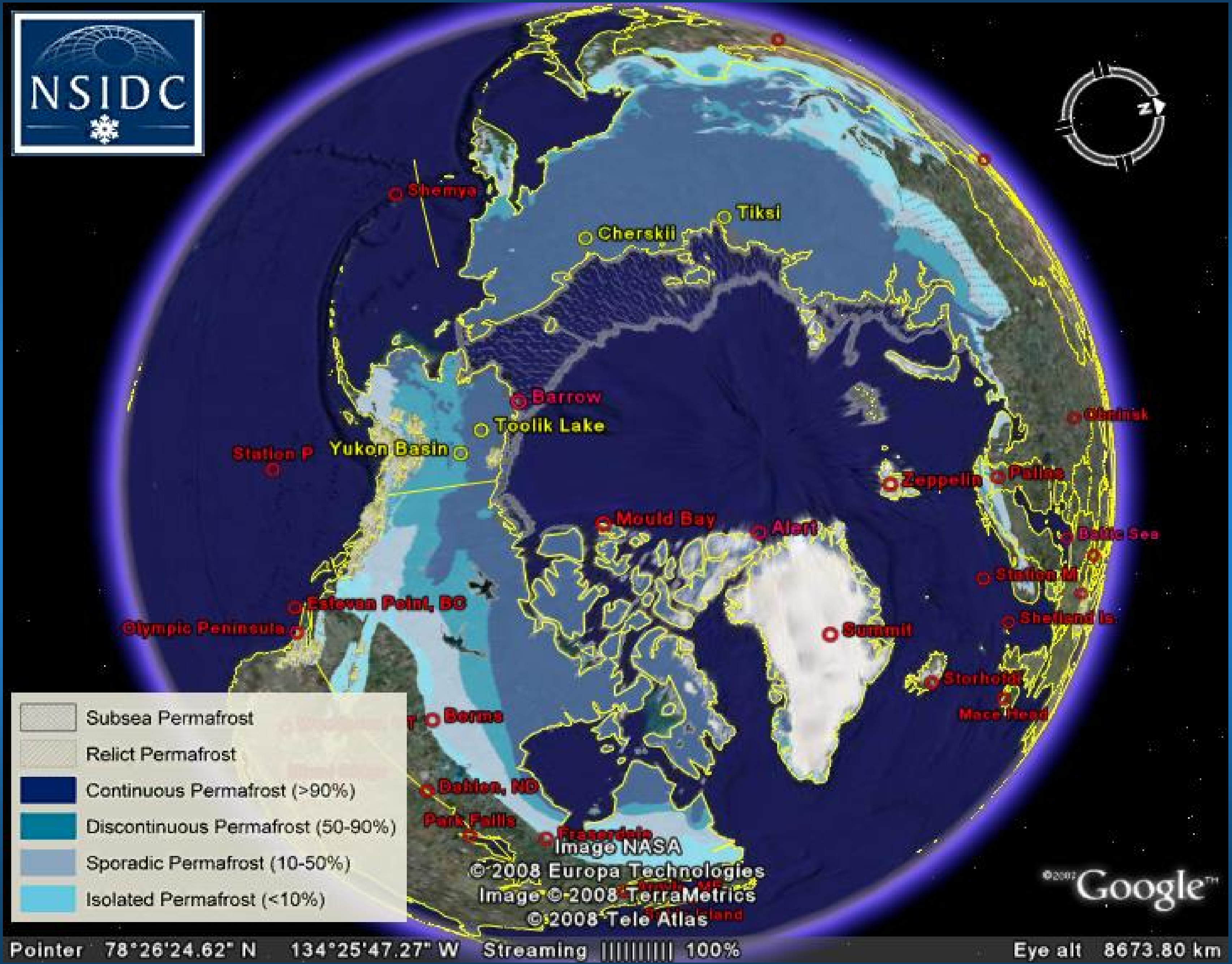
Deviation from MLO trend

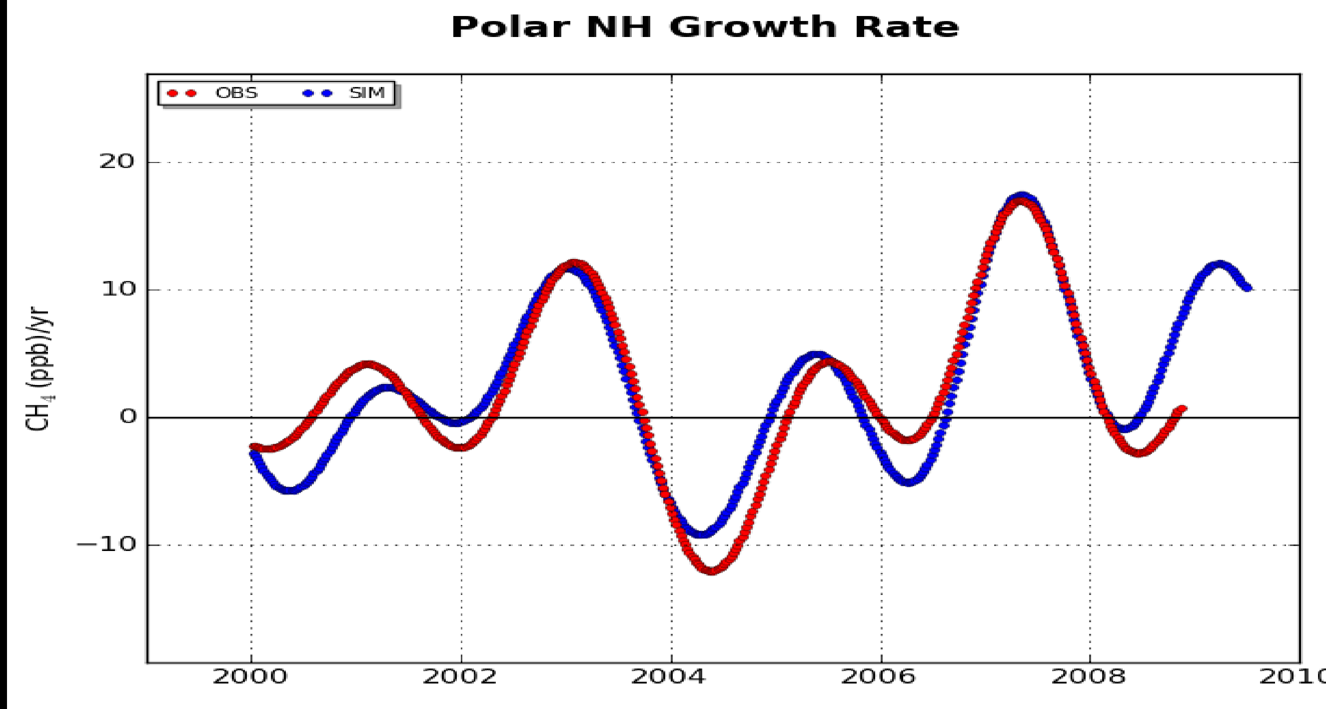
Note shoulder of increase in CH_4 – August/Sept

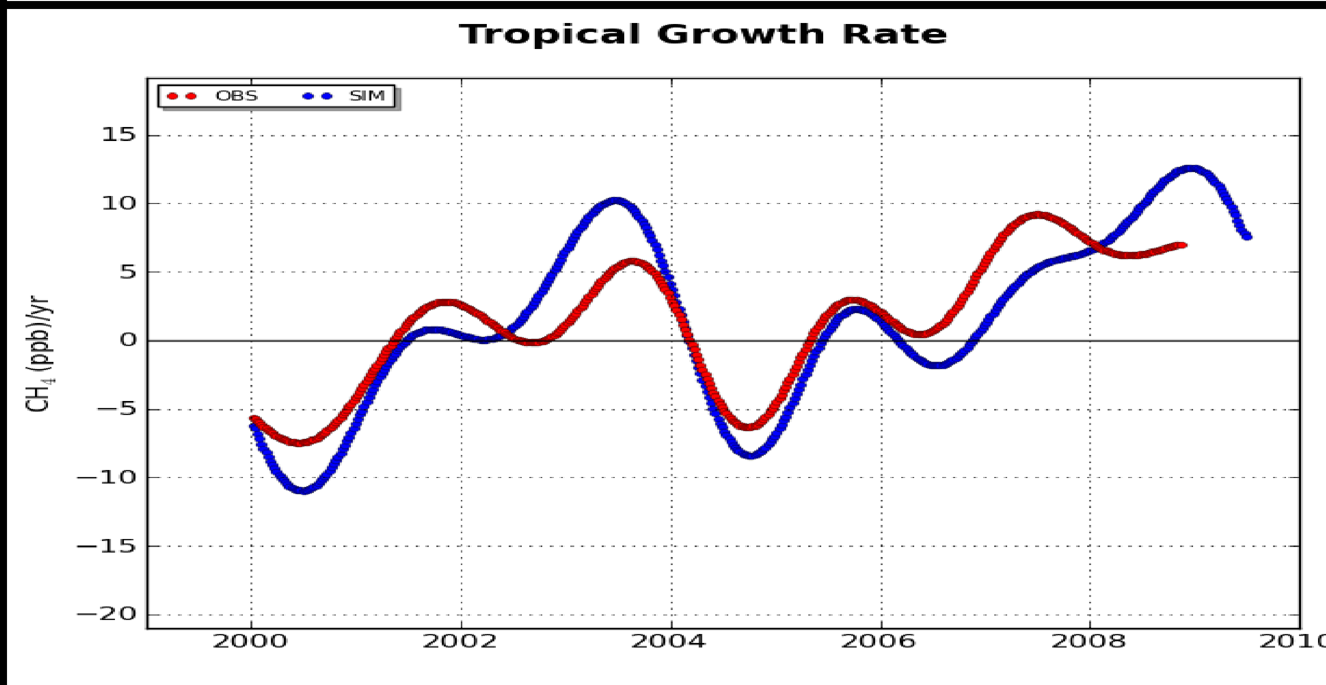
No apparent trend in August/September shoulder that might be associated with melting

Note significant increase 2007




NSIDC
Shemya
Tiksi
Cherskii
Barrow
Toolik Lake
Yukon Basin
Station P
Zeppelin
Pallas
Mould Bay
Alert
Baltic Sea
Station M
Shetland Is.
Summit
Estevan Point, BC
Olympic Peninsula
Storhofdi
Mace Head
Berms
Dahlen, ND
Park Falls
Fraserdale
Subsea Permafrost
Relict Permafrost
Continuous Permafrost (>90%)
Discontinuous Permafrost (50-90%)
Sporadic Permafrost (10-50%)
Isolated Permafrost (<10%)
Image NASA
© 2008 Europa Technologies
Image © 2008 TerraMetrics
© 2008 Tele Atlas
Google
Pointer 78°26'24.62" N 134°25'47.27" W Streaming |||||||||| 100%
Eye alt 8673.80 km

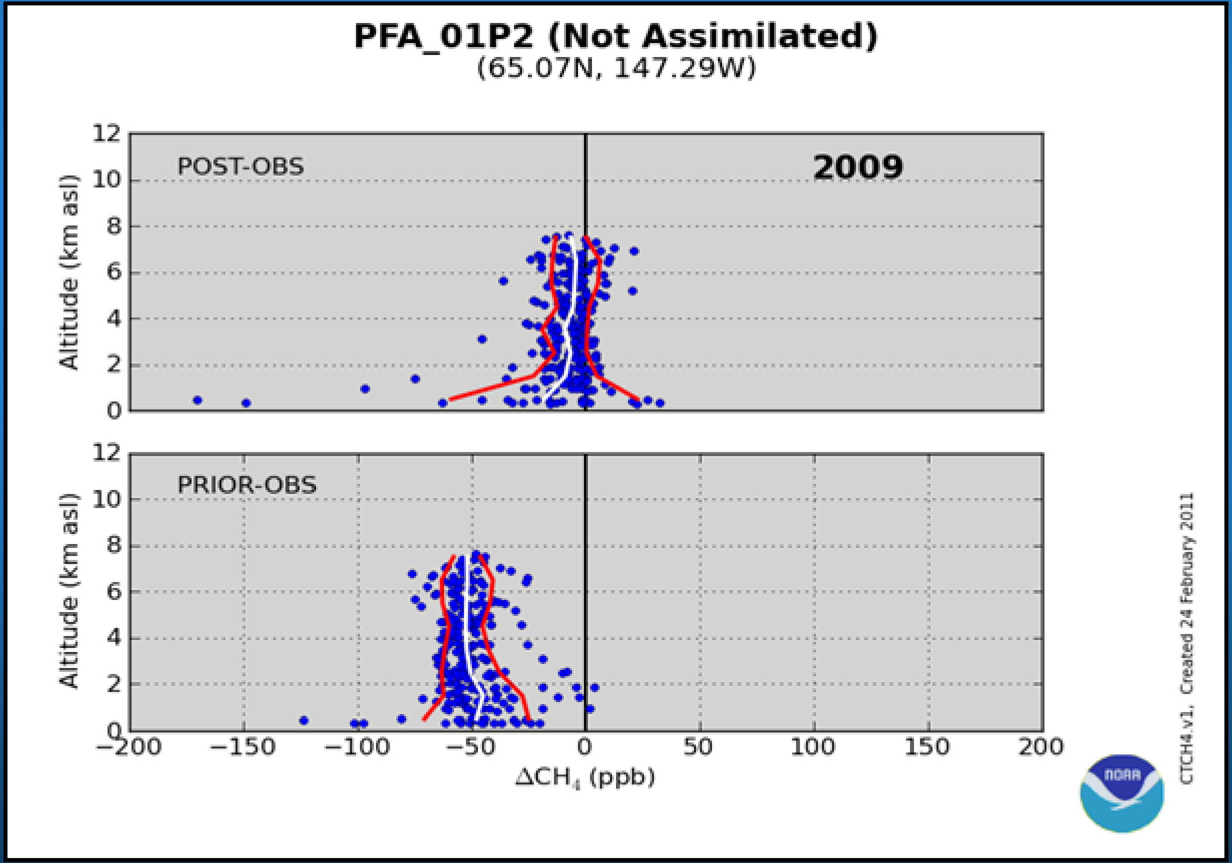




- Not much surface data available in the tropics.
- Wetland prior is probably too small.
- Transport model may not represent tropical transport accurately.

What Might a Top-Down Model Be Used For?

2. Revisions to Bottom-Up Models can lead to model improvements and better predictions



What role do local emissions play in differences? What about transport?