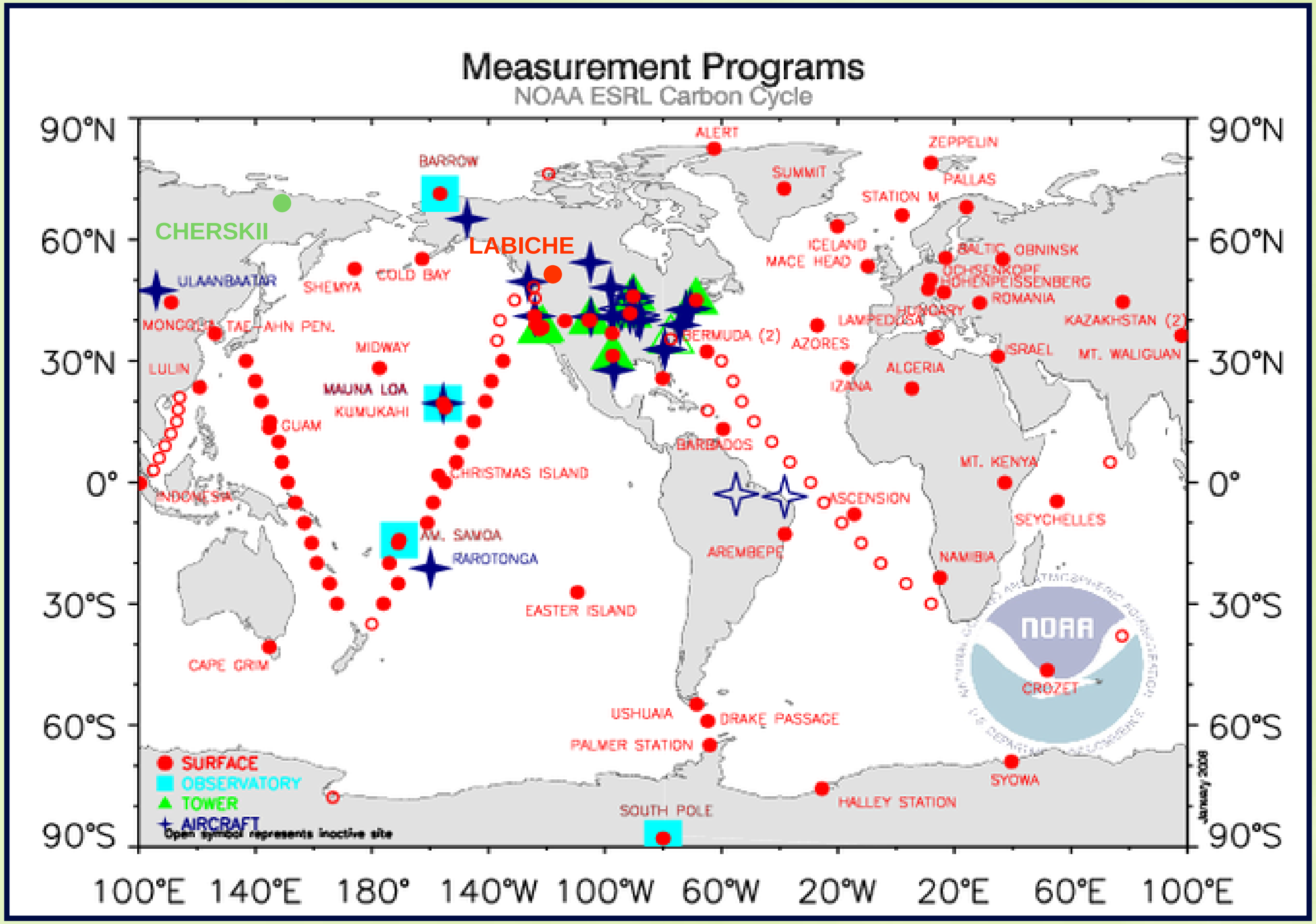
Recent Trends in the Global Atmospheric CH_4 Burden

Lori Bruhwiler, Ed Dlugokencky

Ken Masarie, Pat Lang, Pieter Tans

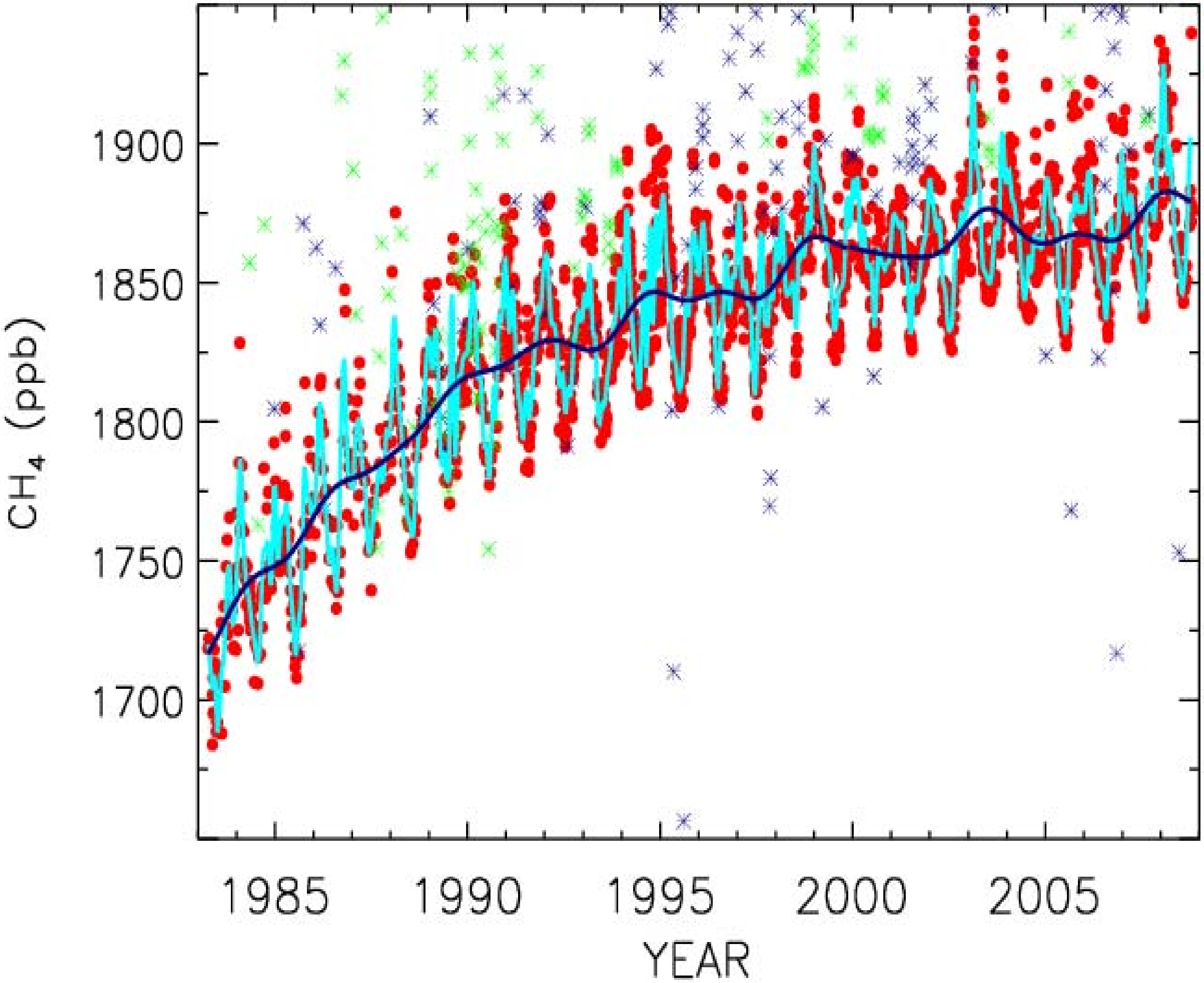


*Weekly samples *Portable sampler *Analyzed by GC/FID

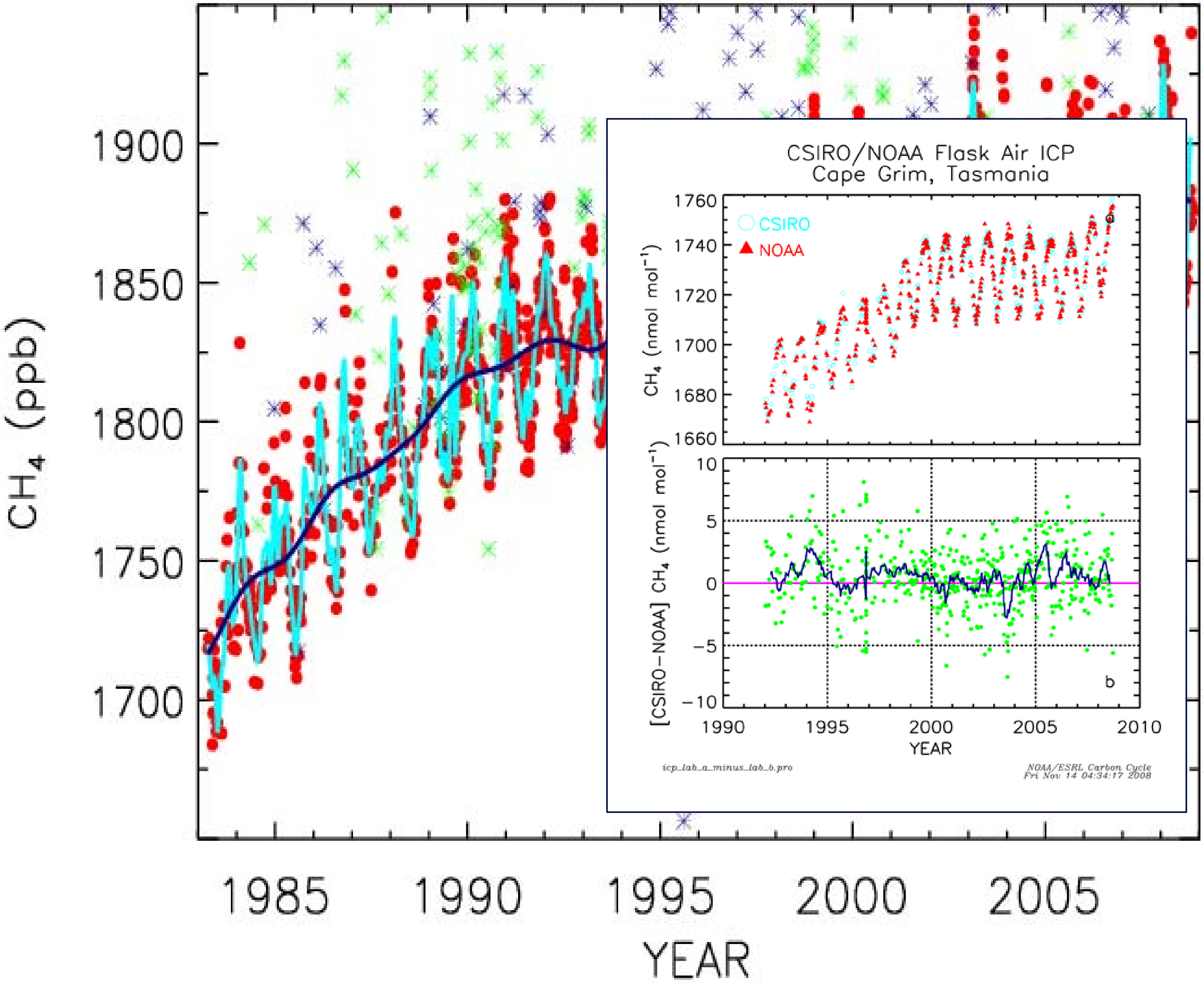
*Cooperative *Broad participation

* Data Available at www.esrl.noaa.gov/gmd/ccgg/iadv/

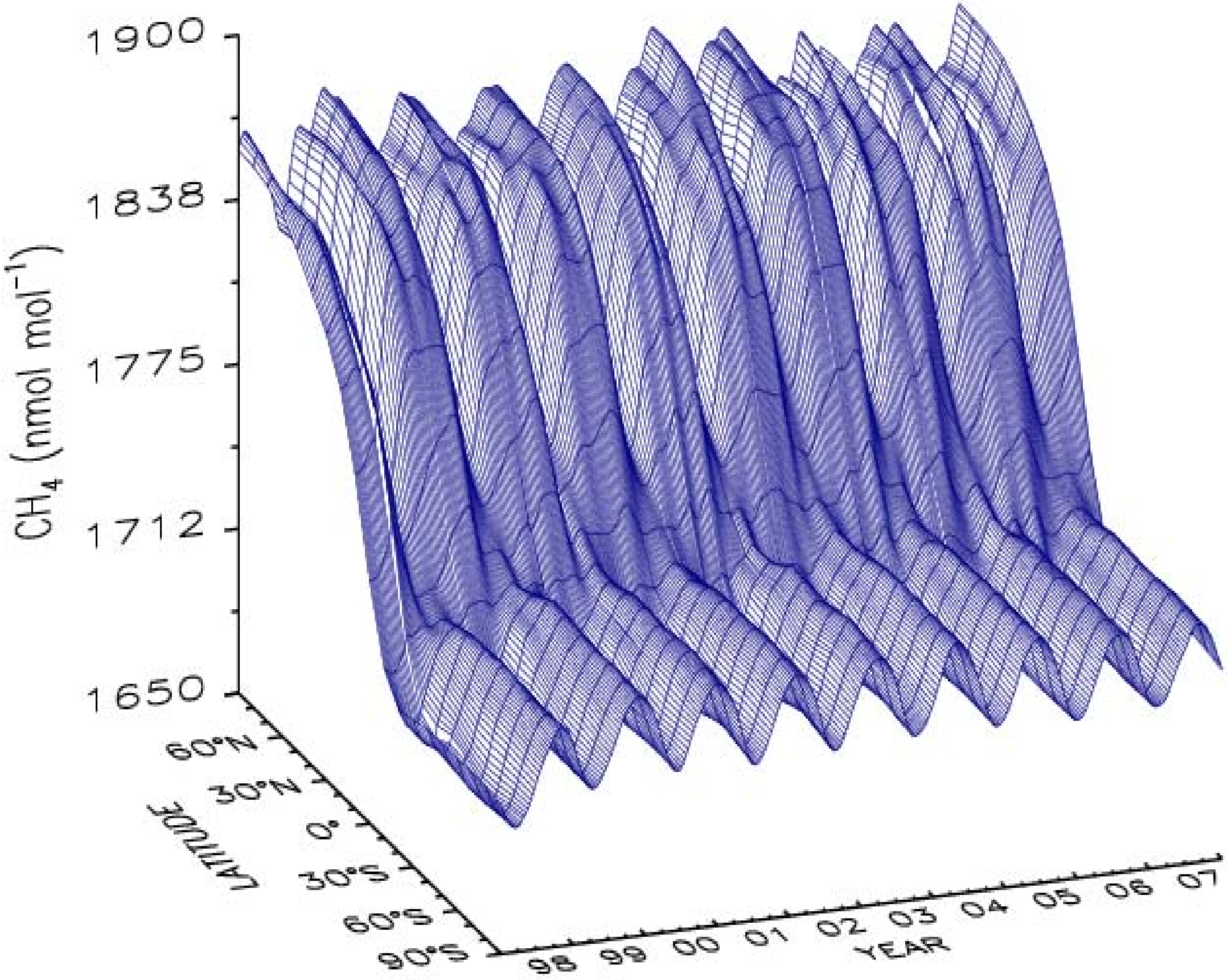
Barrow, Alaska



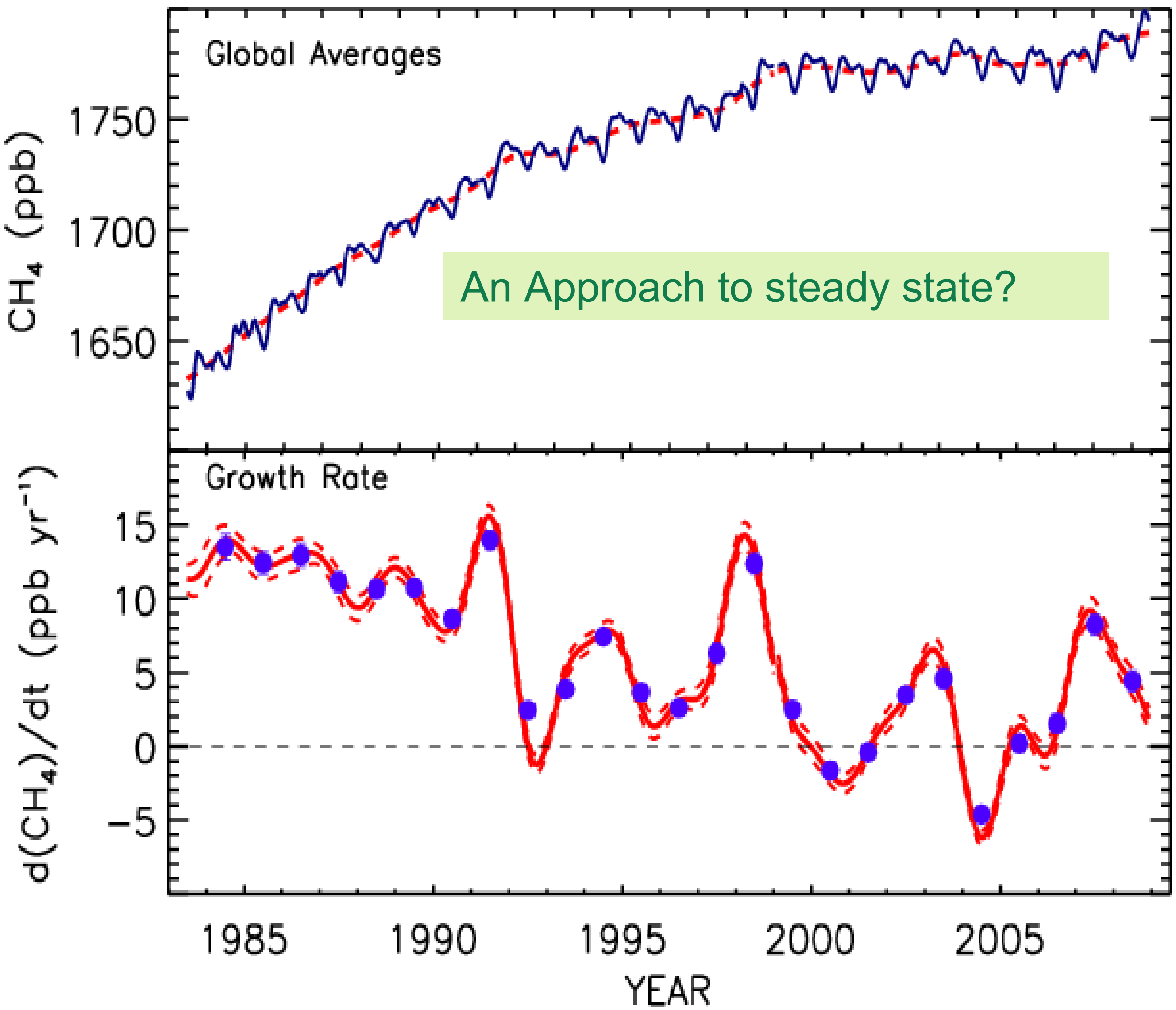
Barrow, Alaska



"The Rug"

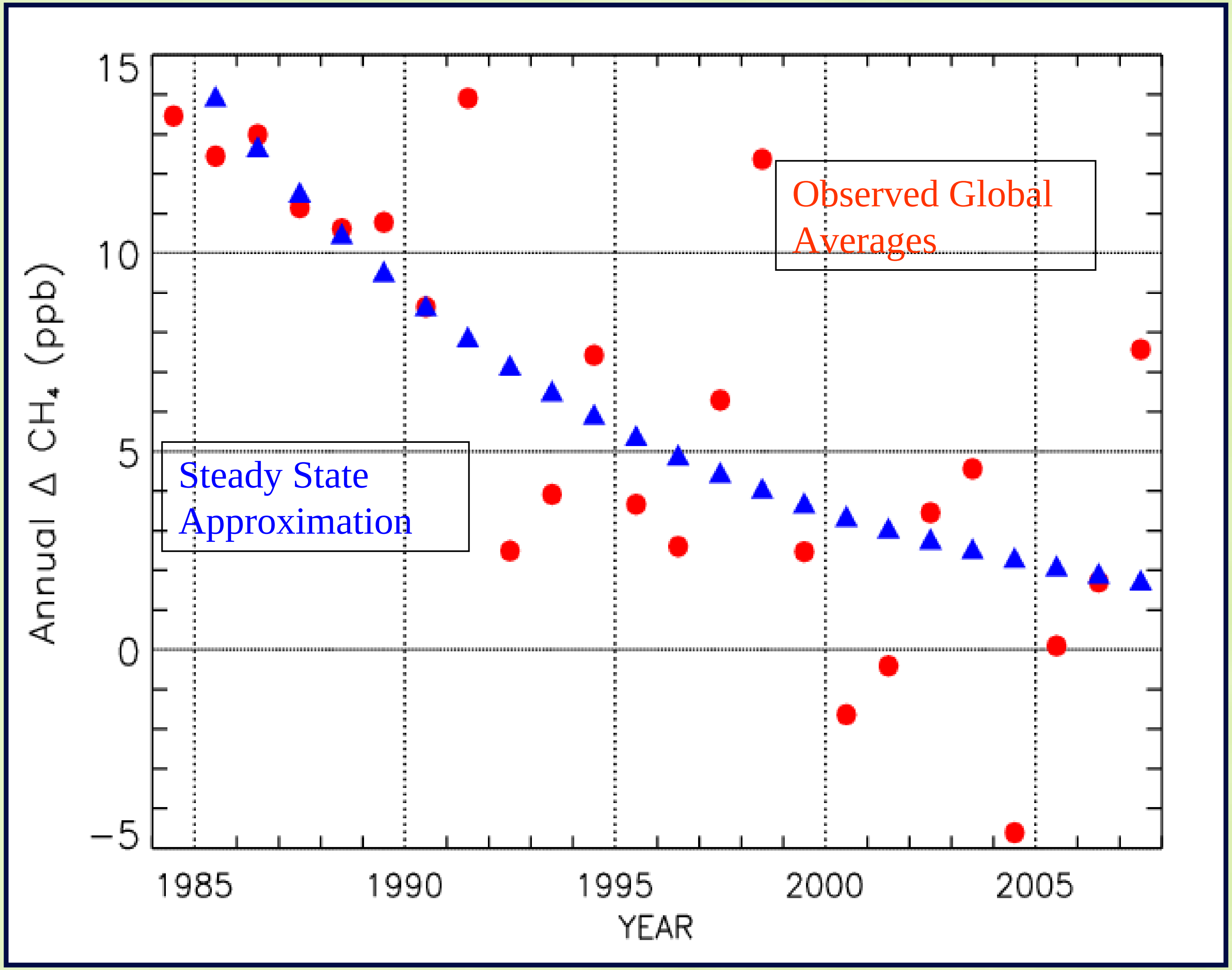


1900
1838
1775
1712
1650
CH$_4$ (nmol mol^{-1})
60°N
30°N
0°
30°S
60°S
90°S
LATITUDE
98
99
00
01
02
03
04
05
06
07
YEAR

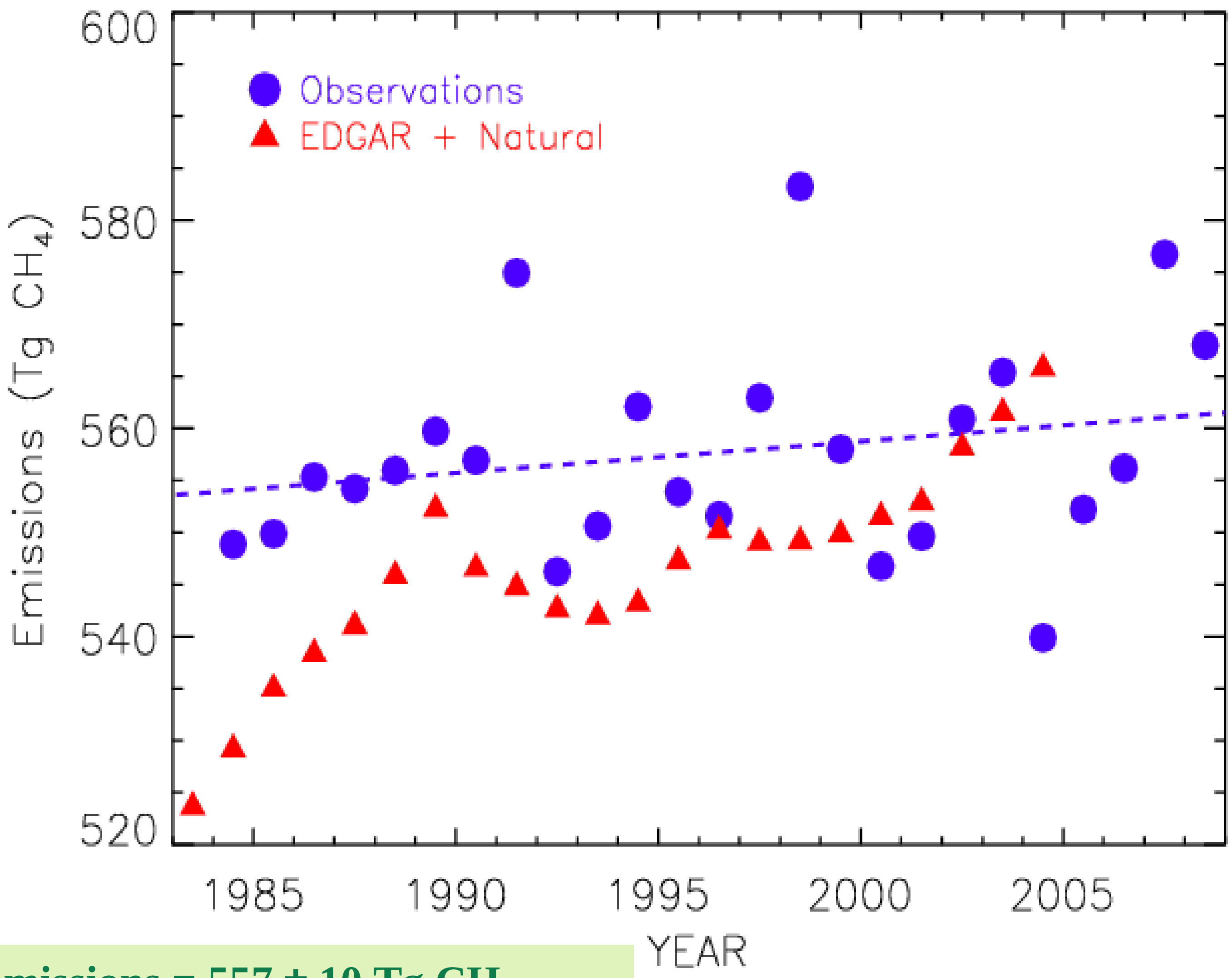


Global Averages
An Approach to steady state?
CH_4 (ppb)
1650
1700
1750
Growth Rate
$d(CH_4)/dt$ (ppb yr^{-1})
15
10
5
0
−5
1985
1990
1995
2000
2005
YEAR

Do the data fit the hypothesis of approach to steady state?



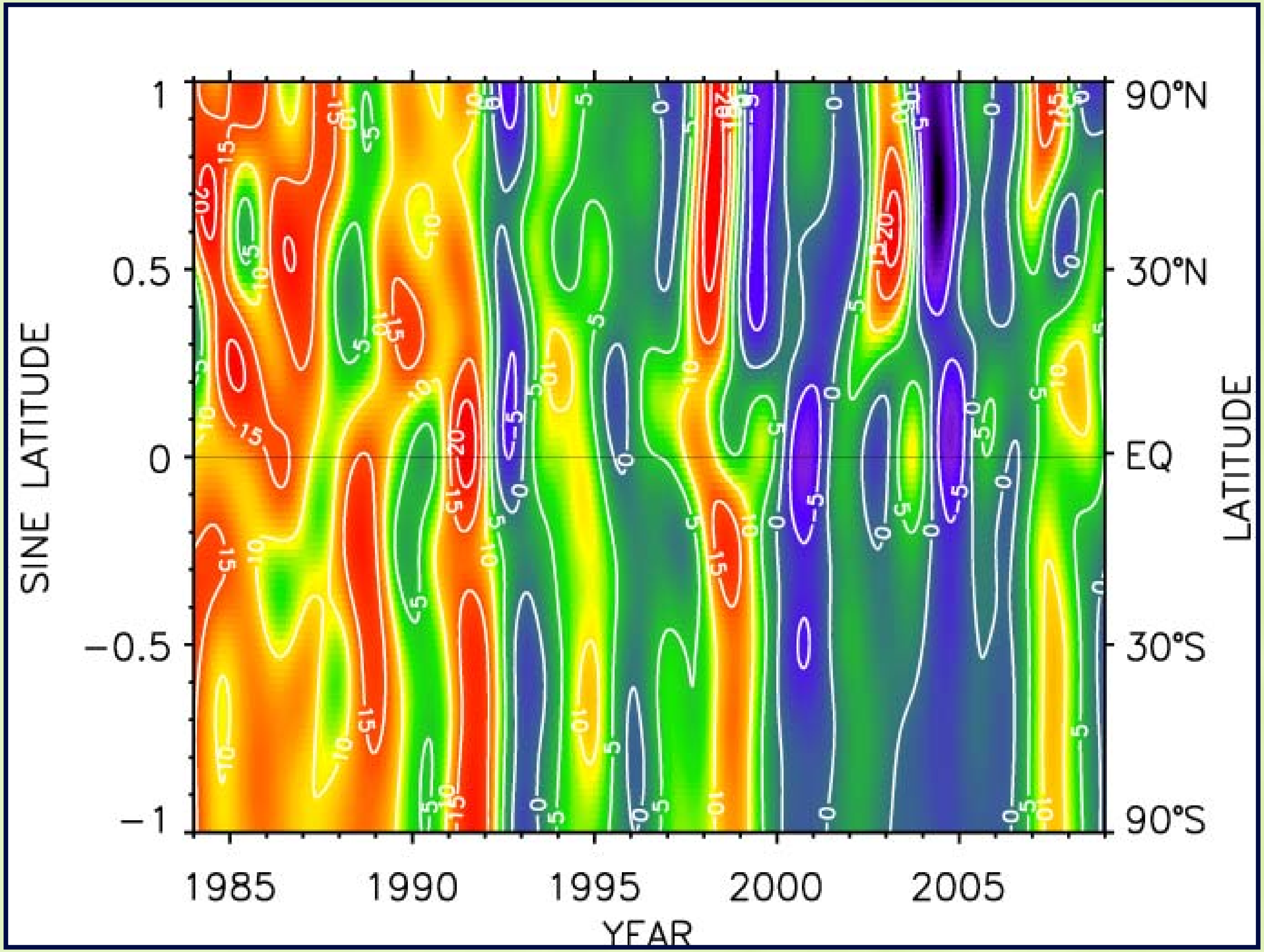
Emissions = $d[CH_4]/dt + [CH_4]/\tau$



Average Emissions = 557 ± 10 Tg CH_4

Trend = 0.3 ± 0.3 Tg CH_4 yr^{-1}

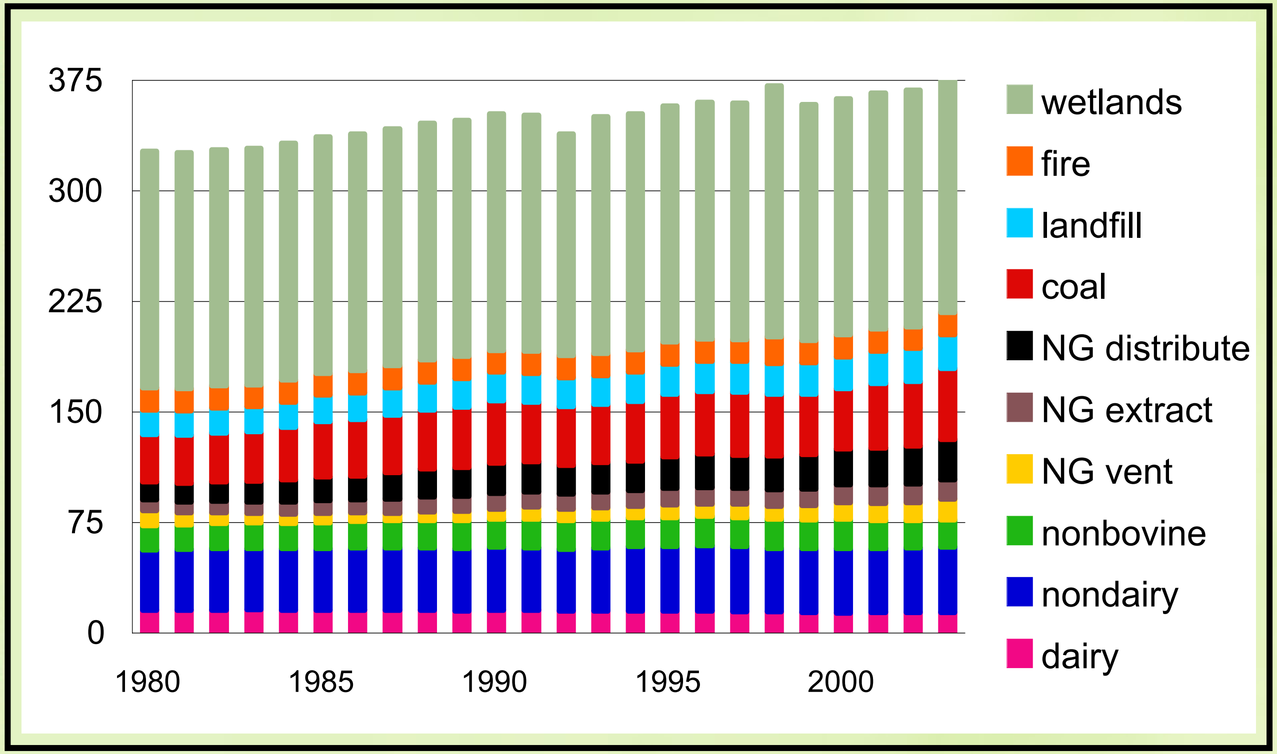
CH_4 Growth Rate (ppb/yr)

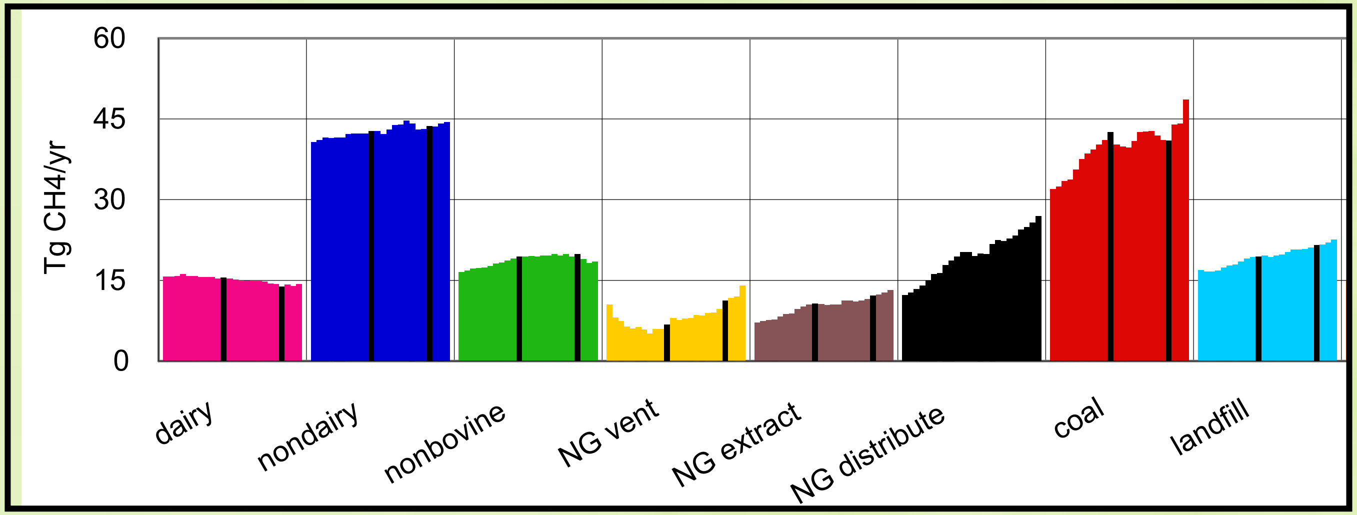


What Caused the 2007 and 2008 CH_4 Growth Rate Increases?

- Increases in Anthropogenic Sources
- Decreased Chemical Loss Rate
- Fires
- Increased Wetland Emissions
- CH_4 "Burp" from Permafrost Decomposition, Hydrates or Clathrates (the time bomb is starting to go off)

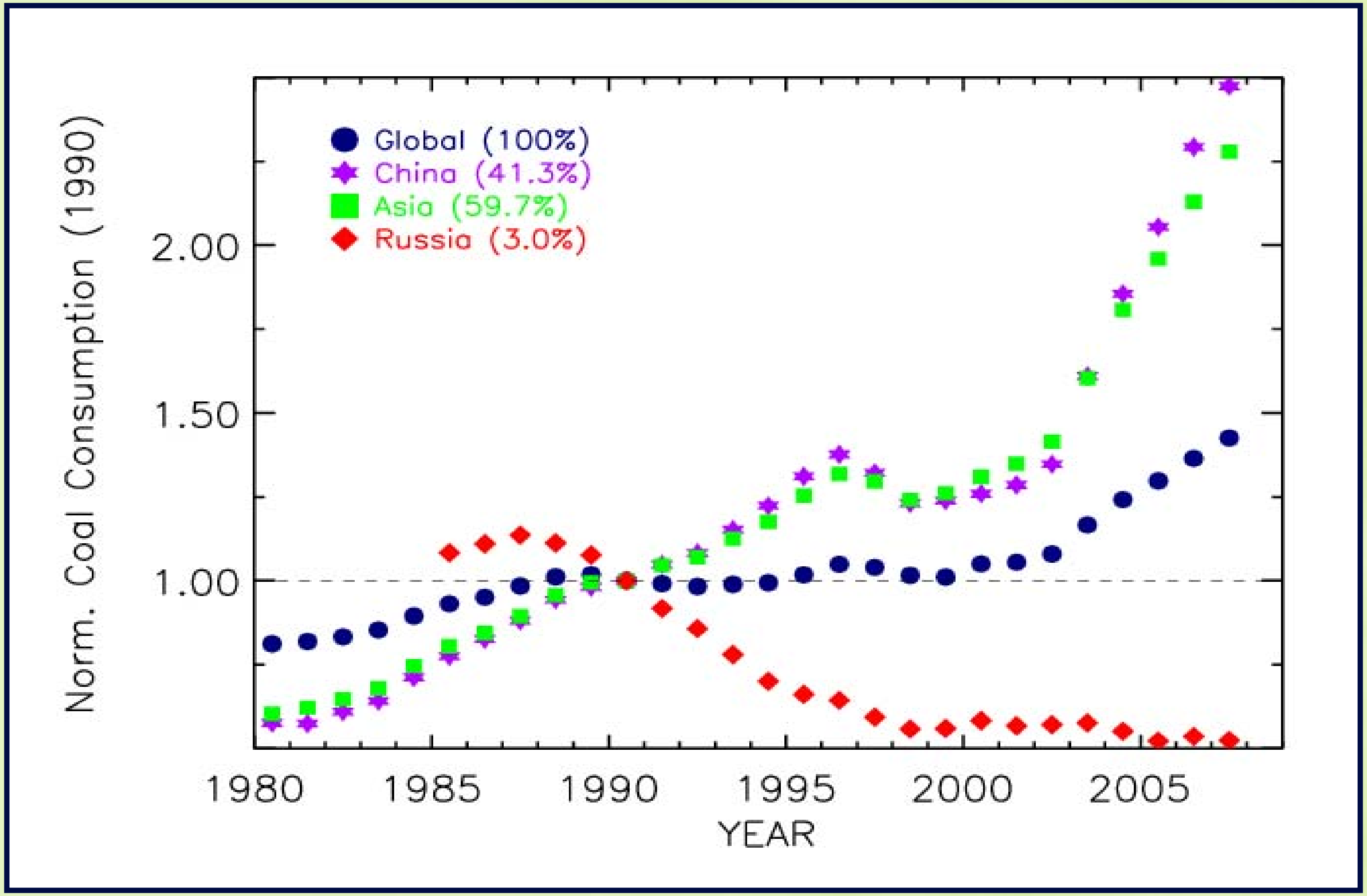
Where Did It All Go?





Courtesy of Elaine Matthews

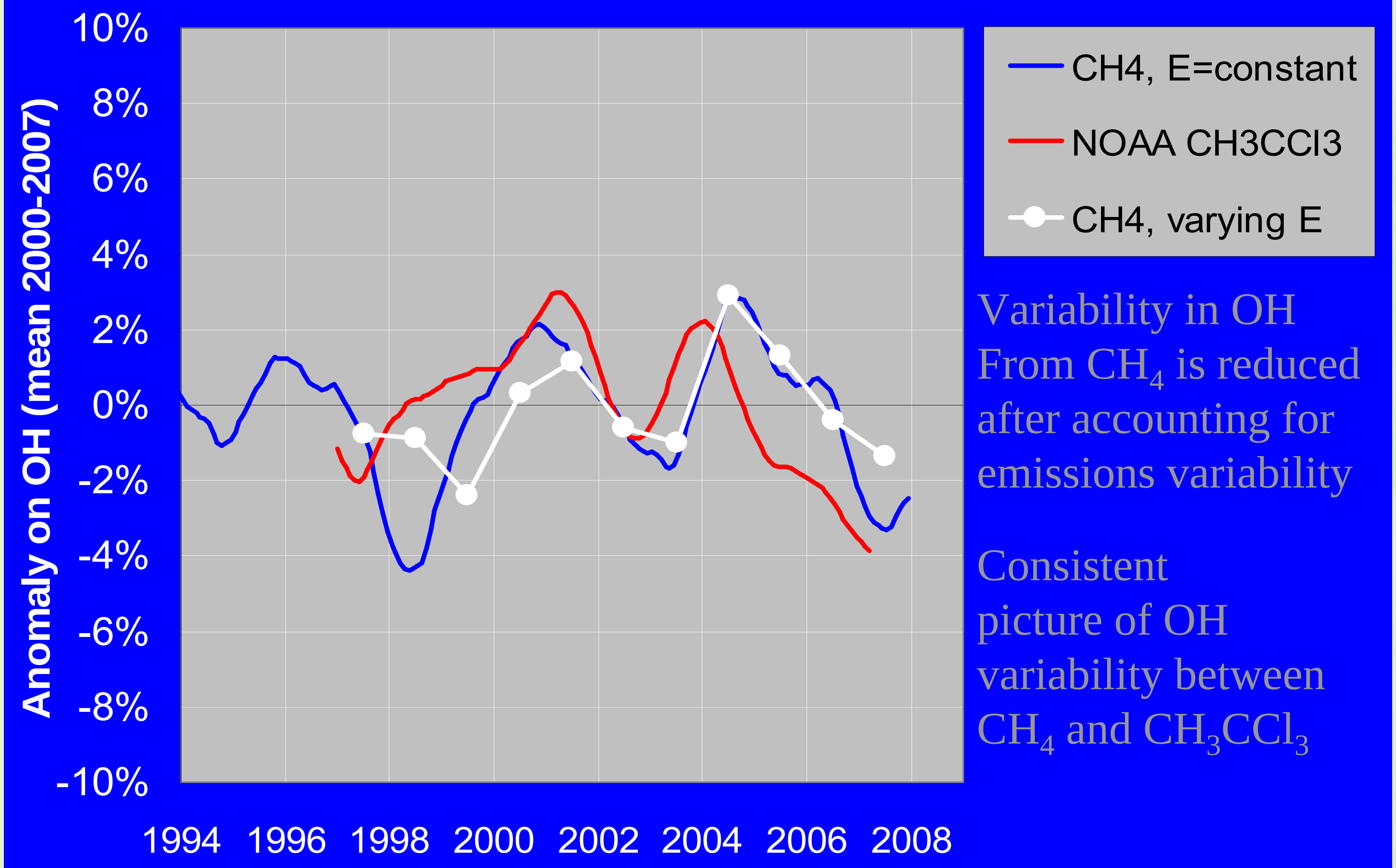
Recent Rapid Increases in Emissions from Asia
Source: BP Energy Statistics



OH Variability Implied by Variability in CH_3CCl_3 and CH_4:

Varying CH_4 Emissions: GFED for Fires

Wetlands from Walters Model (2001)



Variability in OH From CH_4 is reduced after accounting for emissions variability

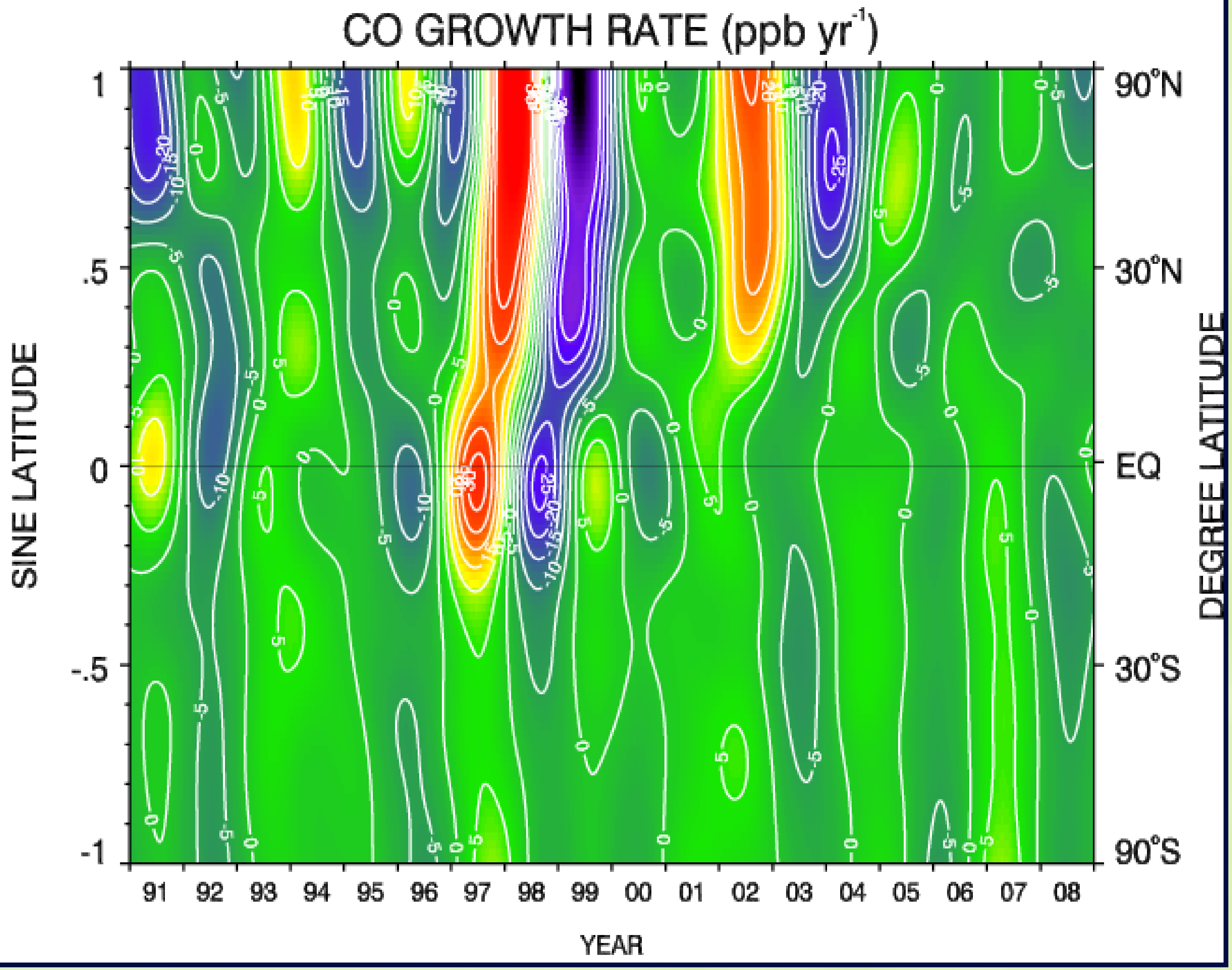
Consistent picture of OH variability between CH_4 and CH_3CCl_3

Courtesy of Steve Montzka

Biomass burning contribution to 2007/2008 CH_4 increases:

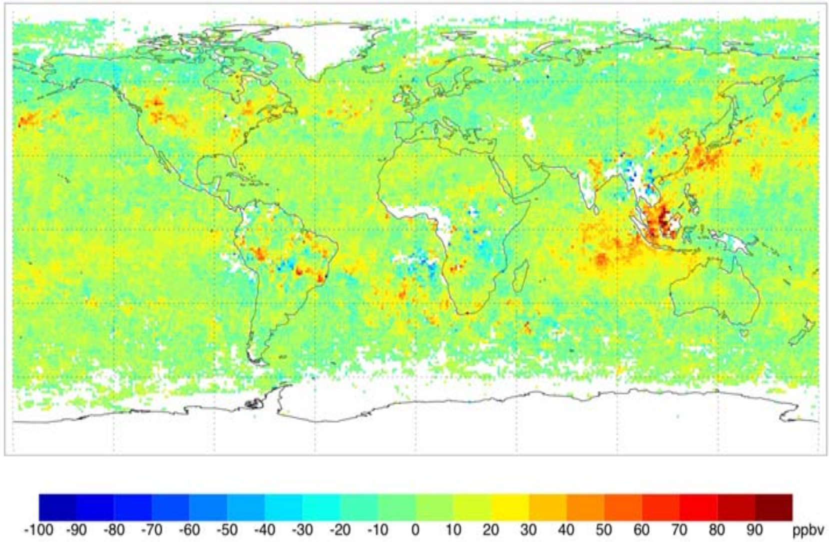
What Data Can We Use?

- NOAA surface CO observations
- Remotely sensed CO (MOPITT)
- Ethane (UCI)
- Chloromethane, CH_3Cl (NOAA)

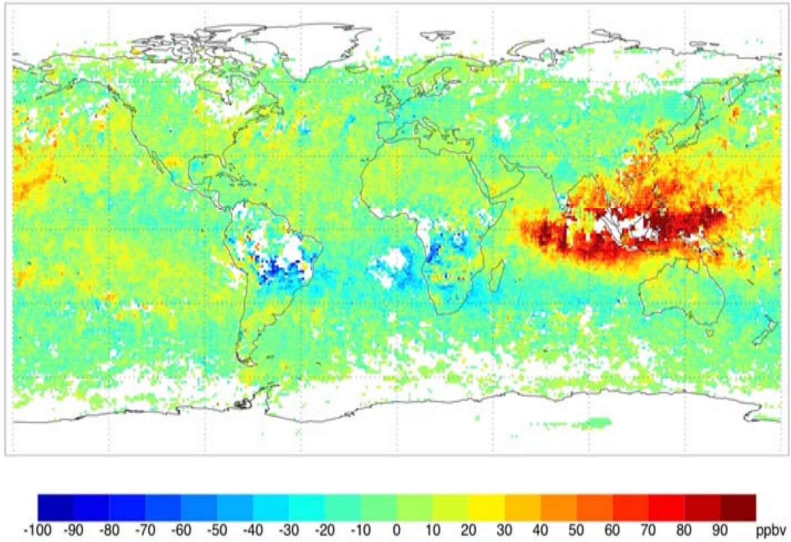


Paul Novelli, NOAA ESRL

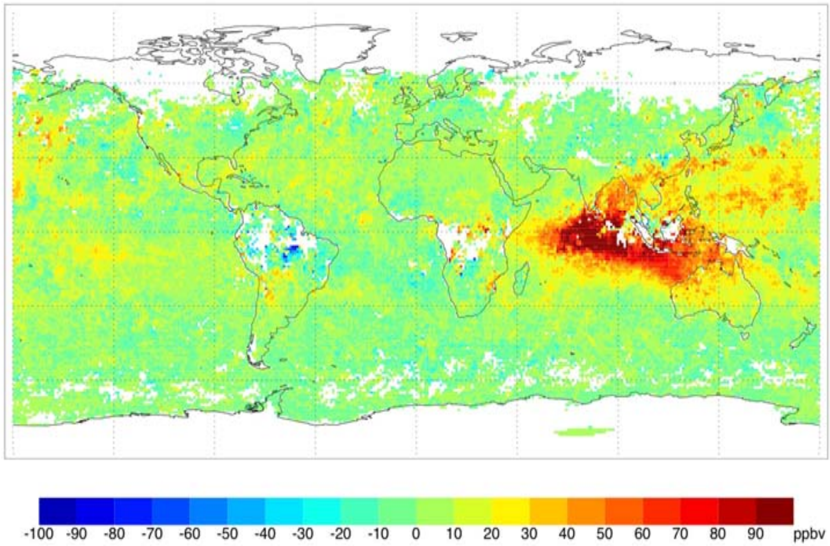
MOPITT CO 700 hPa Anomaly 200609



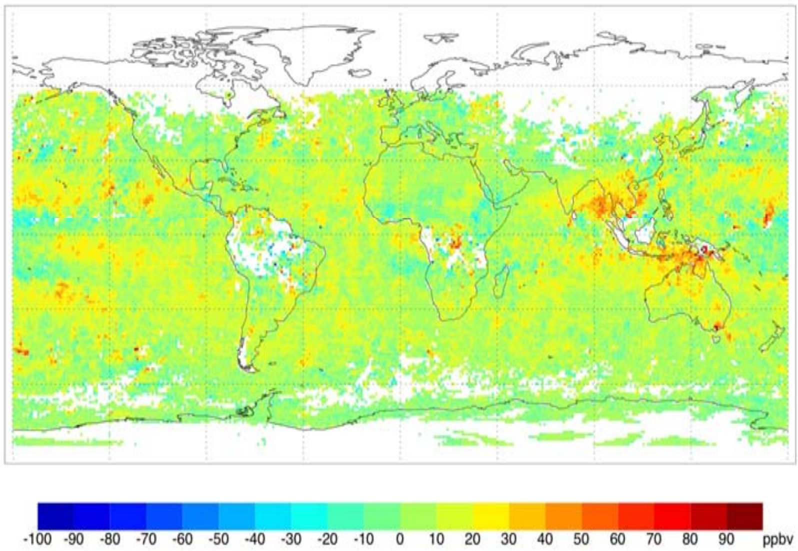
MOPITT CO 700 hPa Anomaly 200610



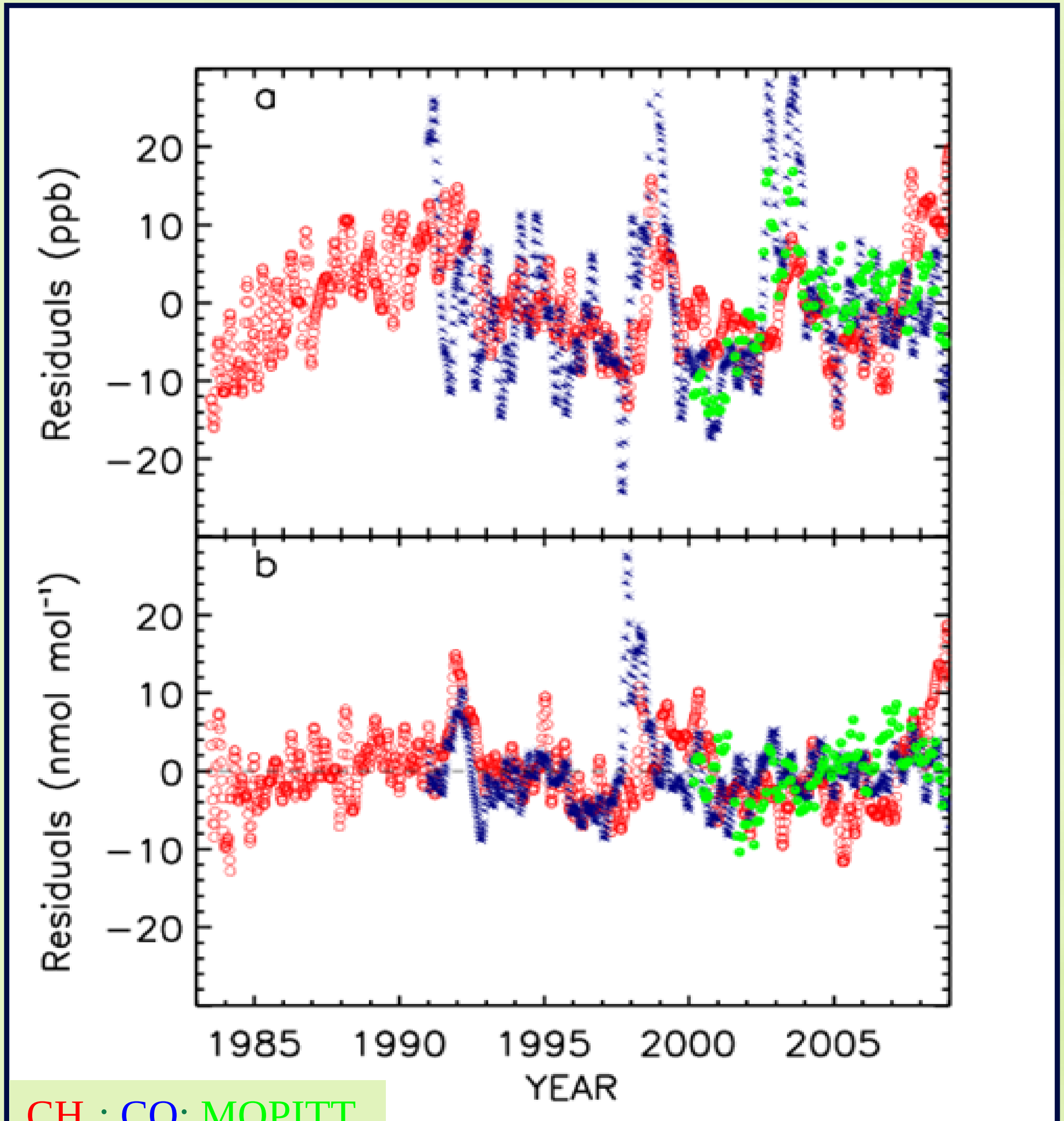
MOPITT CO 700 hPa Anomaly 200611



MOPITT CO 700 hPa Anomaly 200612



MOPITT CO courtesy of Louisa Emmons, NCAR



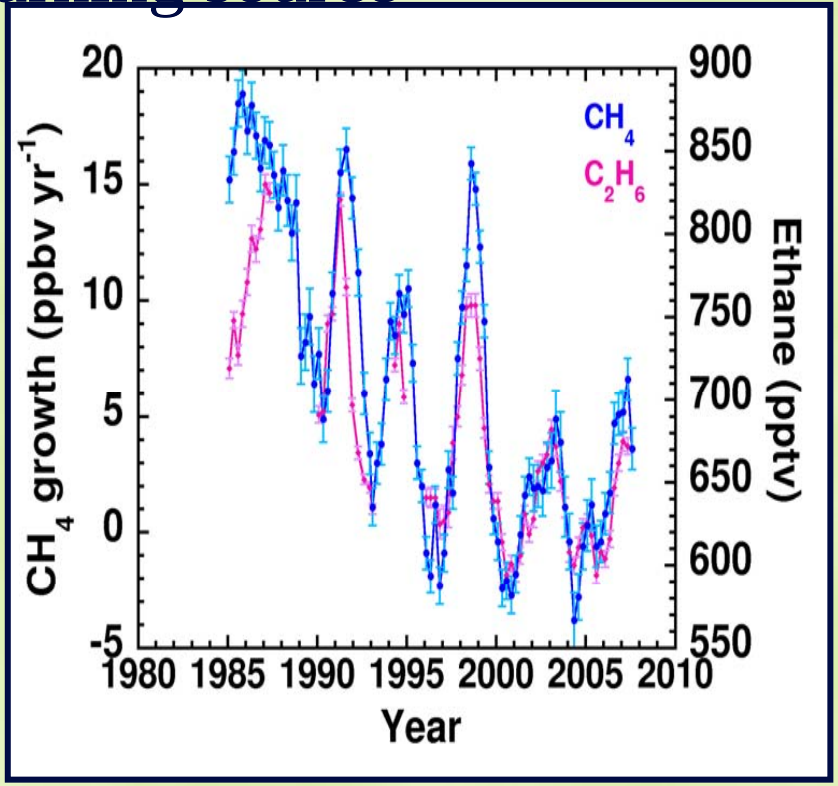
CH_4; CO; MOPITT

Polar northern latitudes

Tropics

Thirty years of global atmospheric CH_4 and ethane monitoring: What can ethane teach us about CH_4?

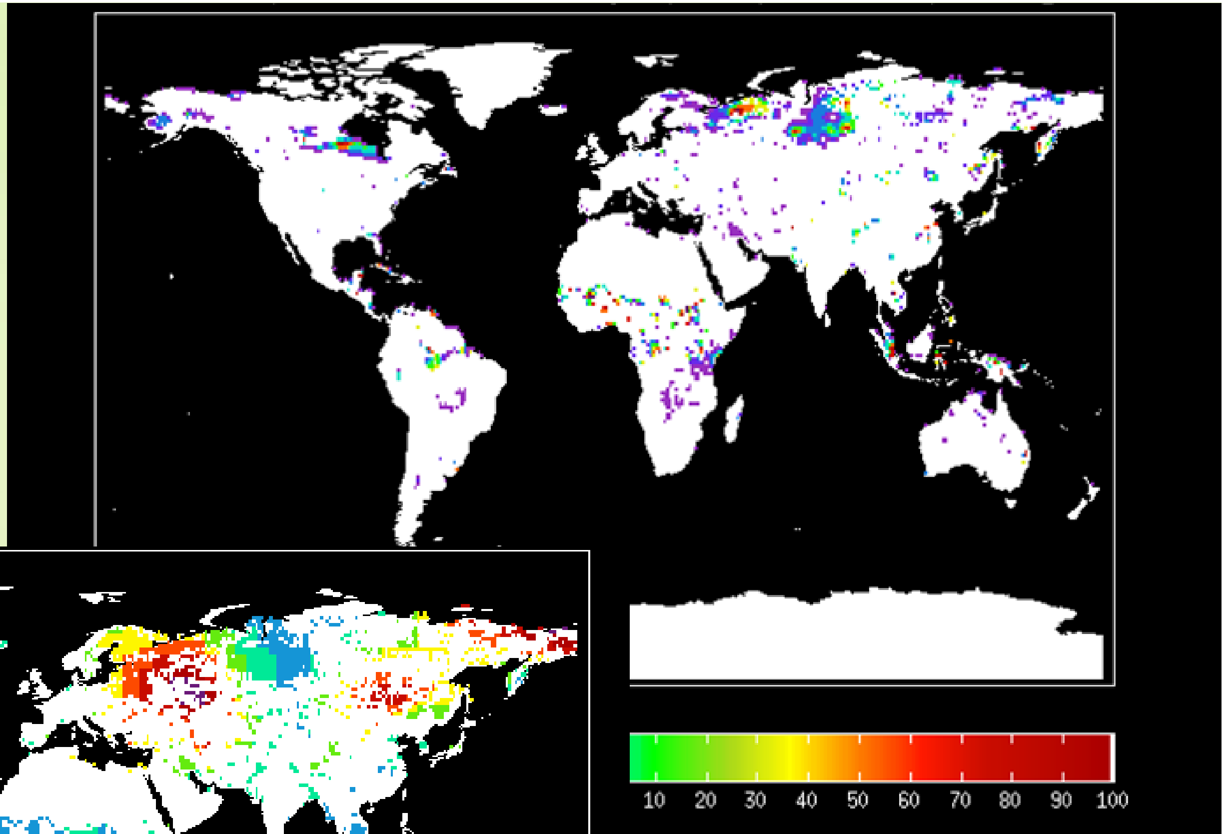
- Simpson et al., UCI; 2008 ESRL review
  - $d[CH_4]/dt$ and C_2H_6 correlate
  - Suggests a biomass burning source

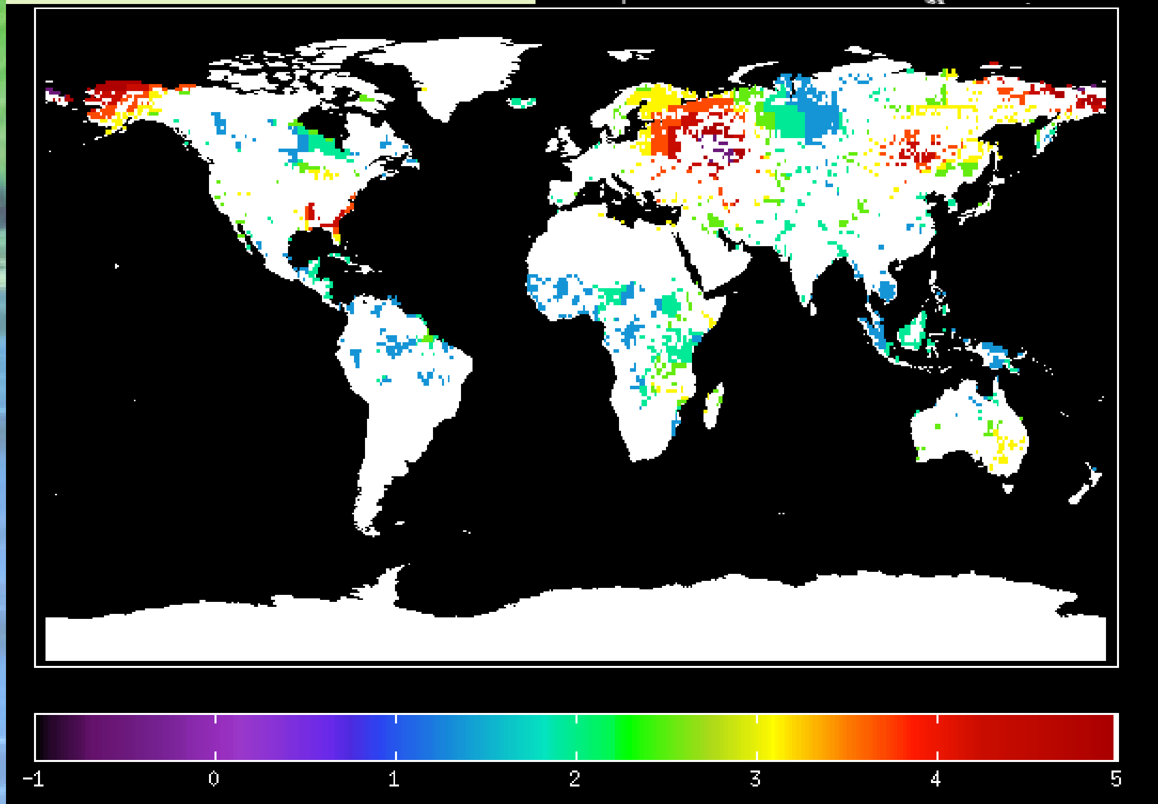


Wetlands

- Wetlands affected by soil T and moisture
  - 2007 warm and wet in Arctic
  - 2007, 2008 wet in the Tropics

(Source:GPCC)
Schneider et al, 2008
http://gpcc.dwd.de





mm/mont
h

(Source: GISS)
Hansen et al, JGR,104,1999

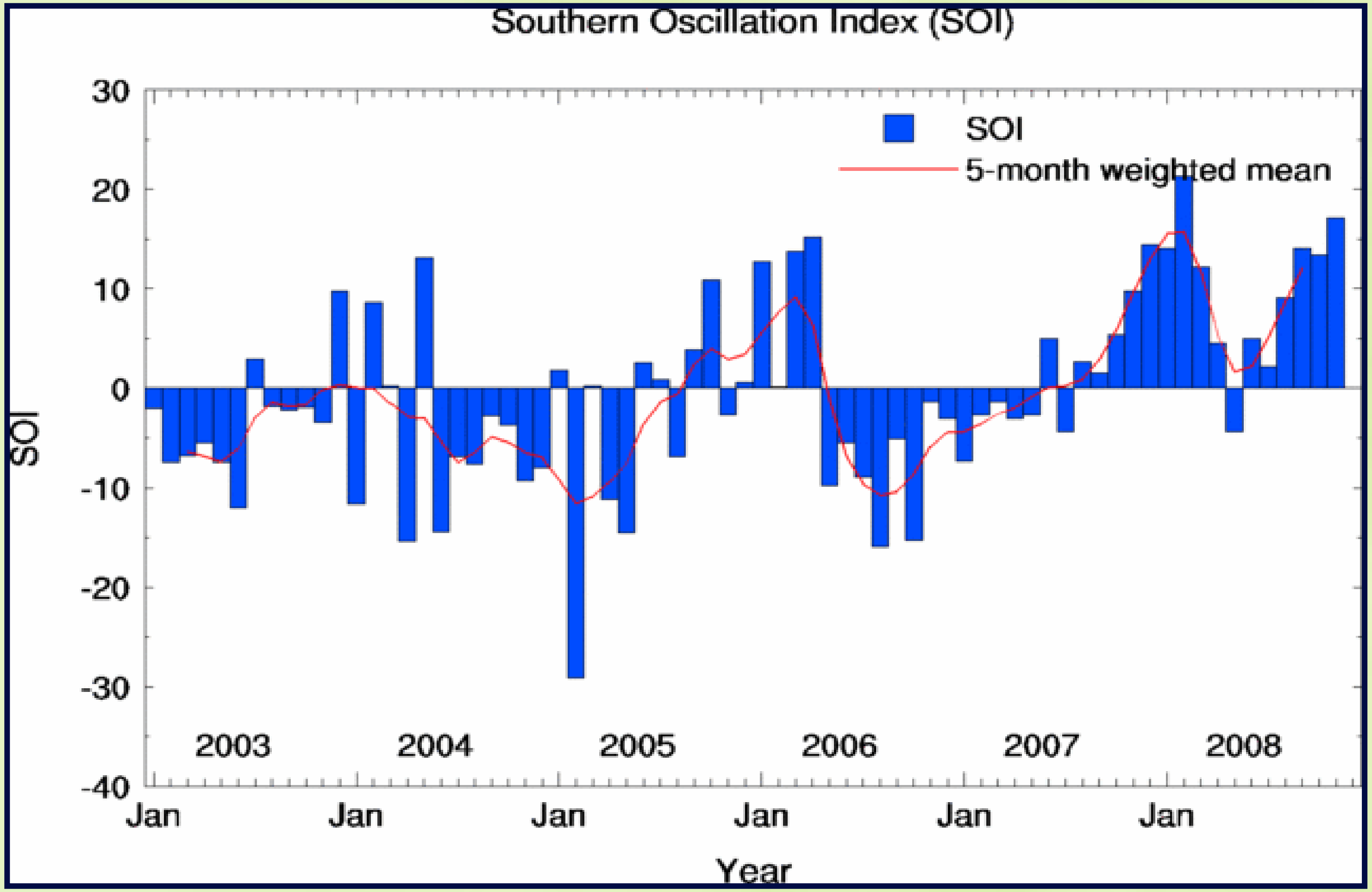
Wetland distribution:
Matthews and Fung

°C

August 2007

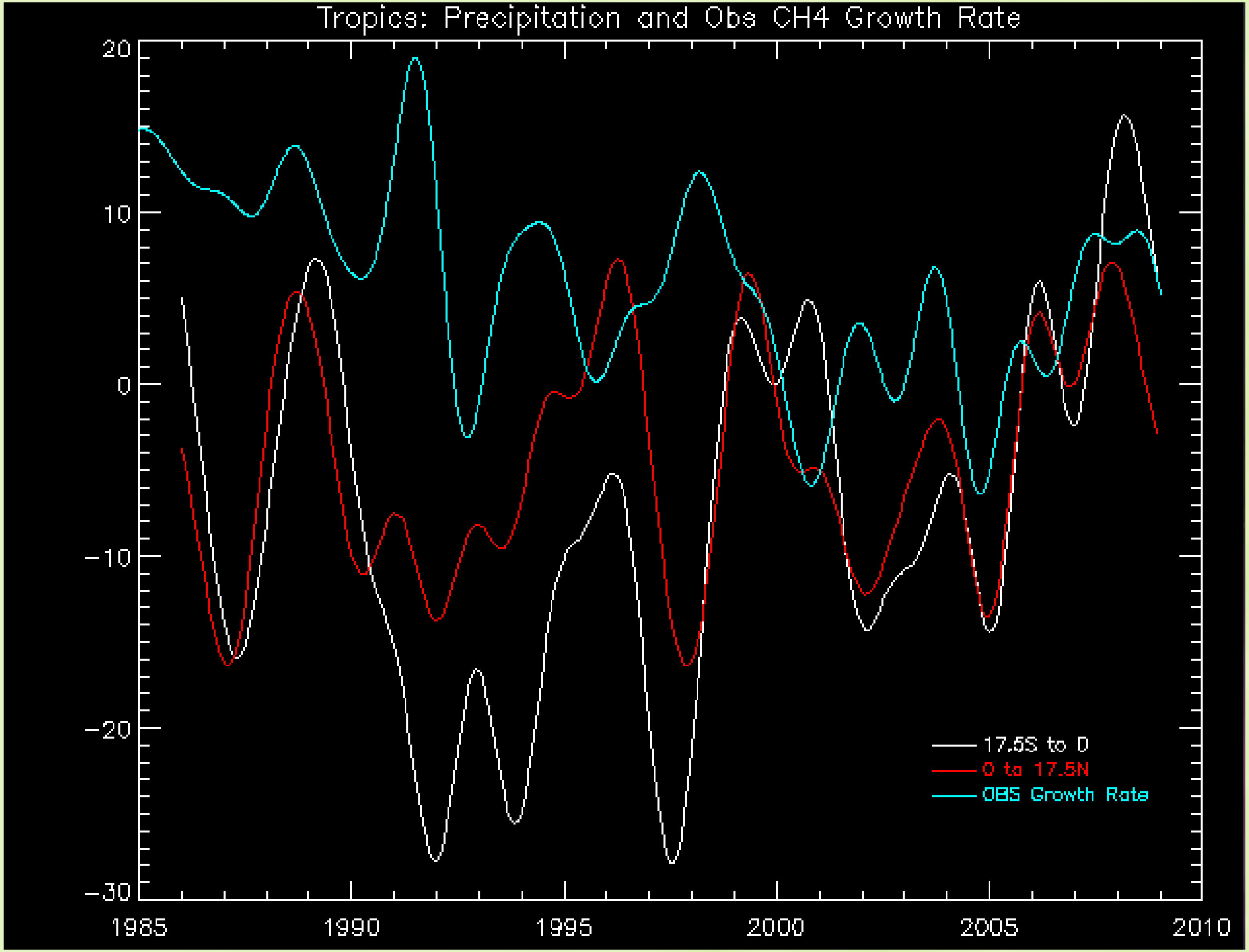
•Cold phase of ENSO tends to be wetter in the tropics: 2008,2007 were the wettest years in the tropics since 1986.

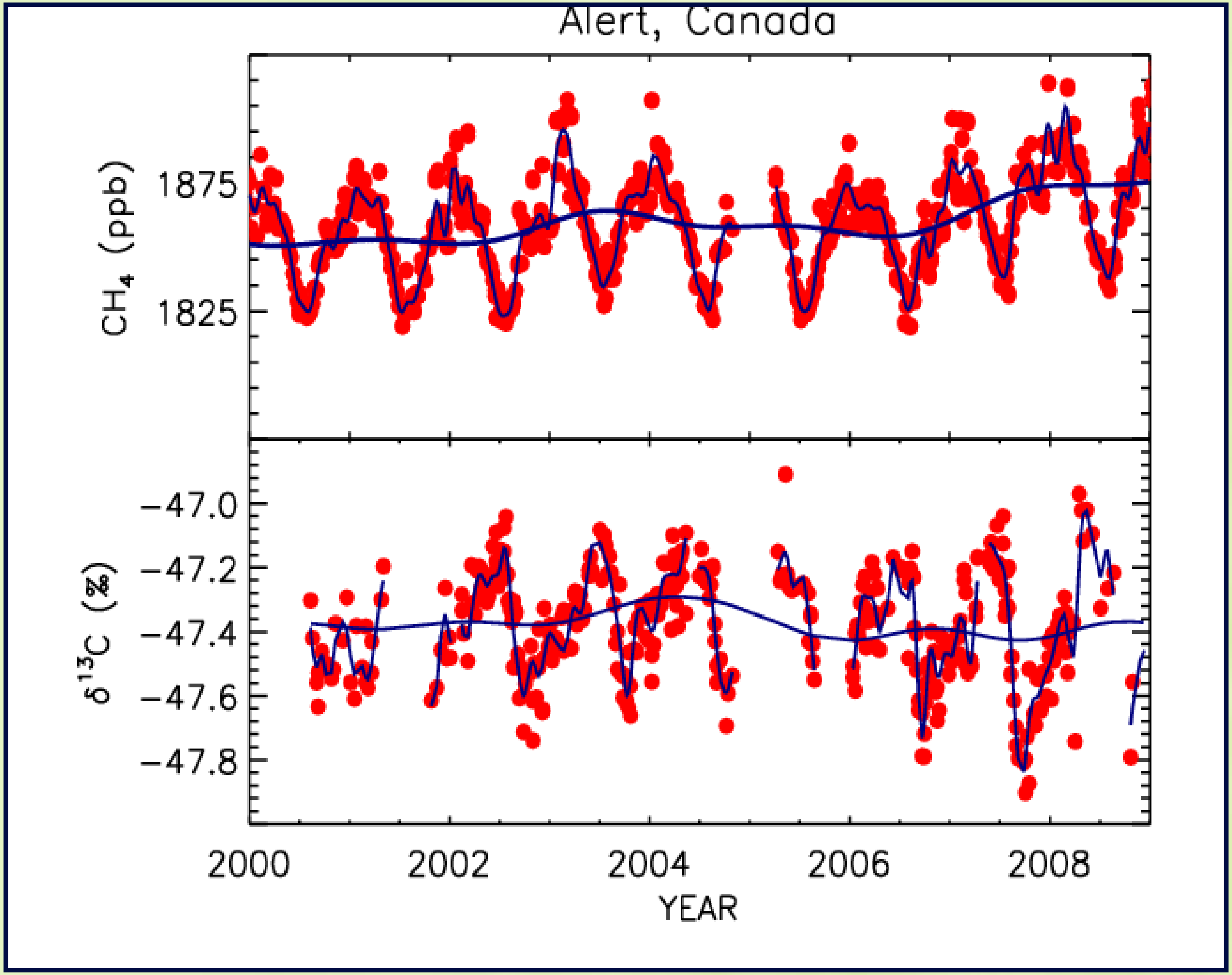
* Transport from Northern to Southern Hemisphere also changes between phases of ENSO



* (stay tuned….)

Is Tropical Precipitation Correlated with CH_4 Growth?





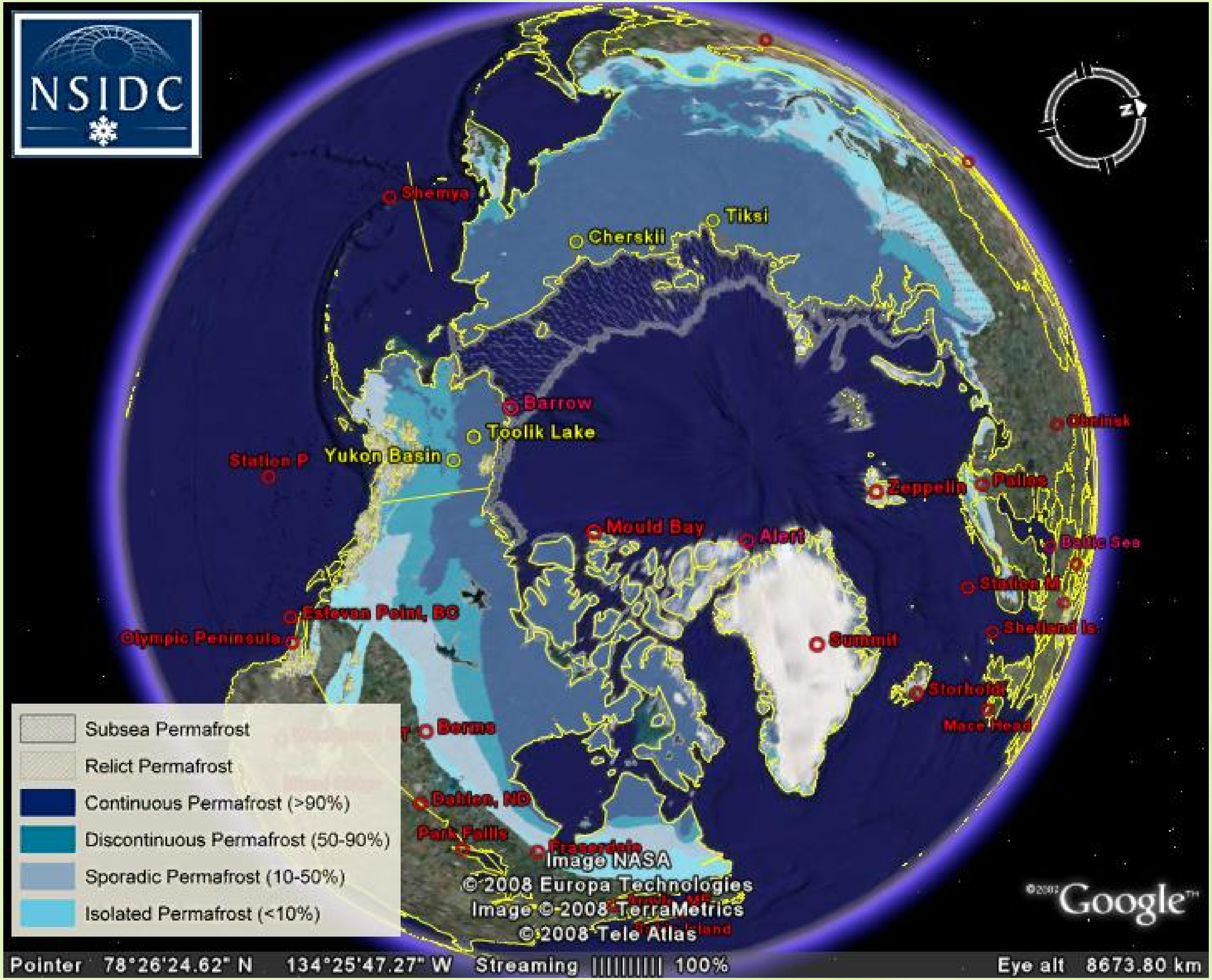
Alert, Canada
CH4 (ppb)
1875
1825
δ13C (‰)
−47.0
−47.2
−47.4
−47.6
−47.8
2000
2002
2004
2006
2008
YEAR

Permafrost Degradation?

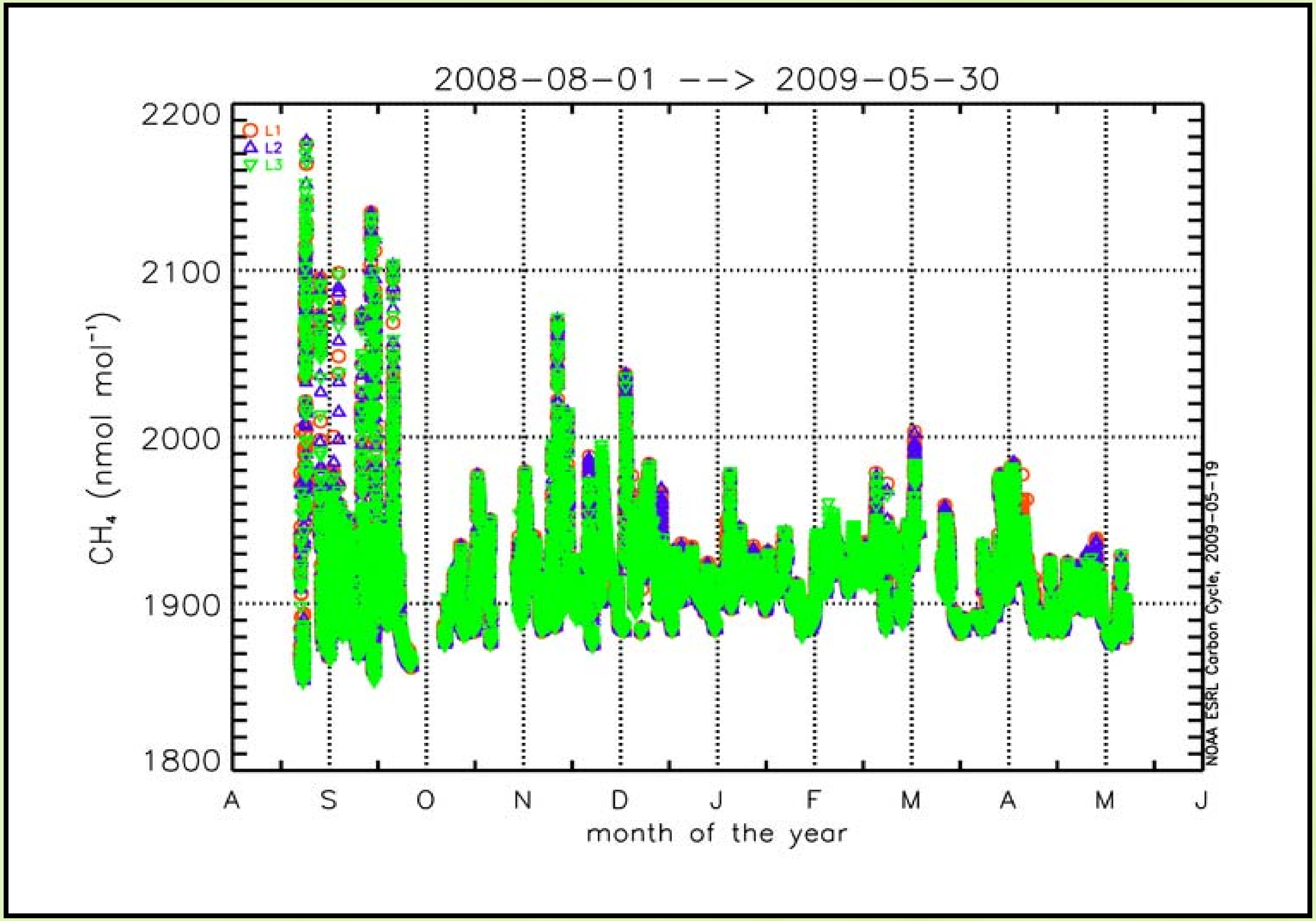
Photograph by Bernhard Edmaier

Photograph by Bernhard Edma

Photograph by Bernhard Edmaier


NSIDC
Shemya
Cherskii
Tiksi
Barrow
Toolik Lake
Yukon Basin
Station P
Mould Bay
Alert
Zeppelin
Pallas
Obninsk
Baltic Sea
Station M
Shetland Is.
Summit
Storhofdi
Mace Head
Estevan Point, BC
Olympic Peninsula
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

First Data from Cherskii!



Photos: Andy Crotwell

The Equipment Housed in
A Fish Drying Shed

Dragging the
Fish Box to the
Tower Site

The Wreck

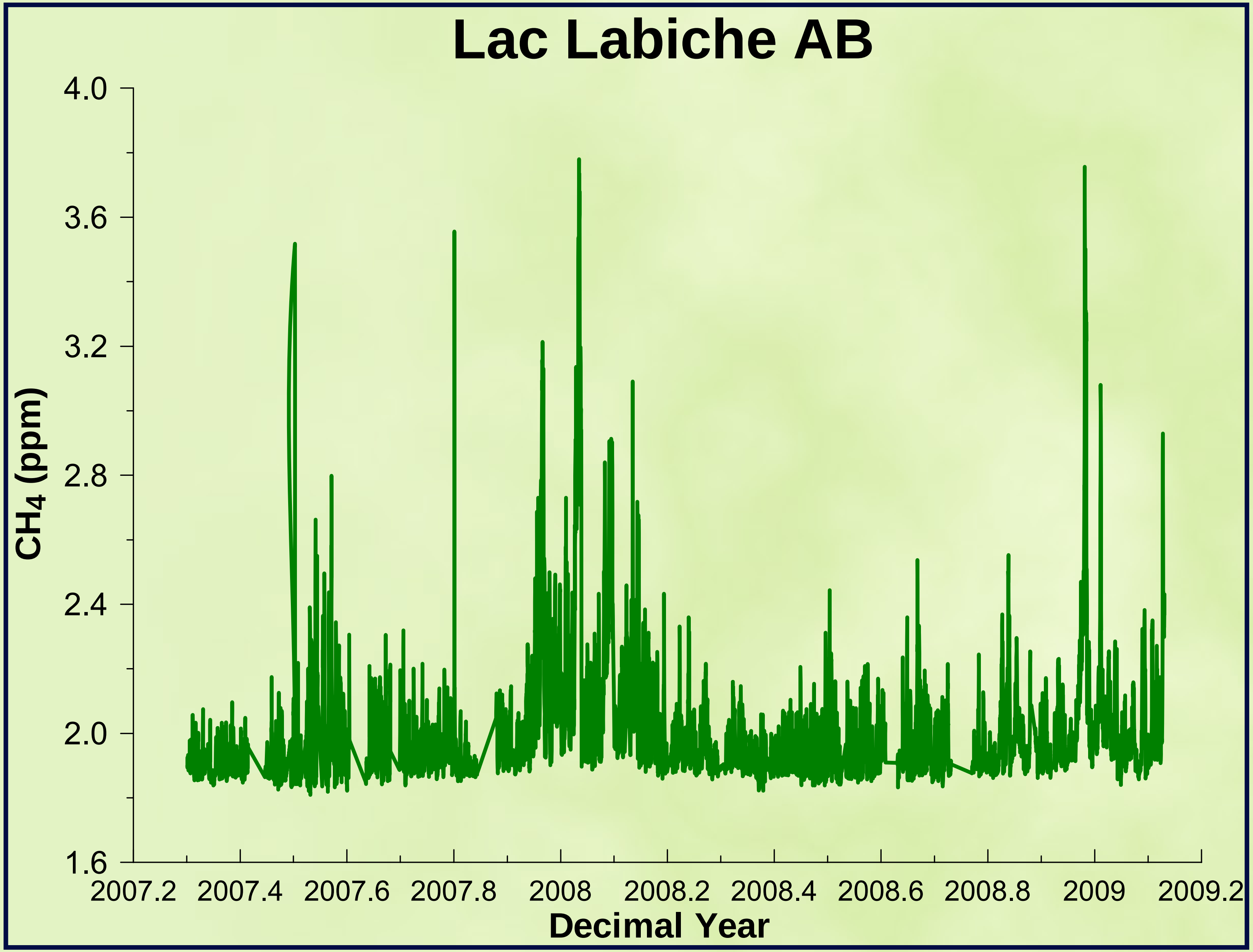
The Fish Box and Equipment Arrive

Lac LaBiche, Alberta, CA – Characterizing CH_4 sources

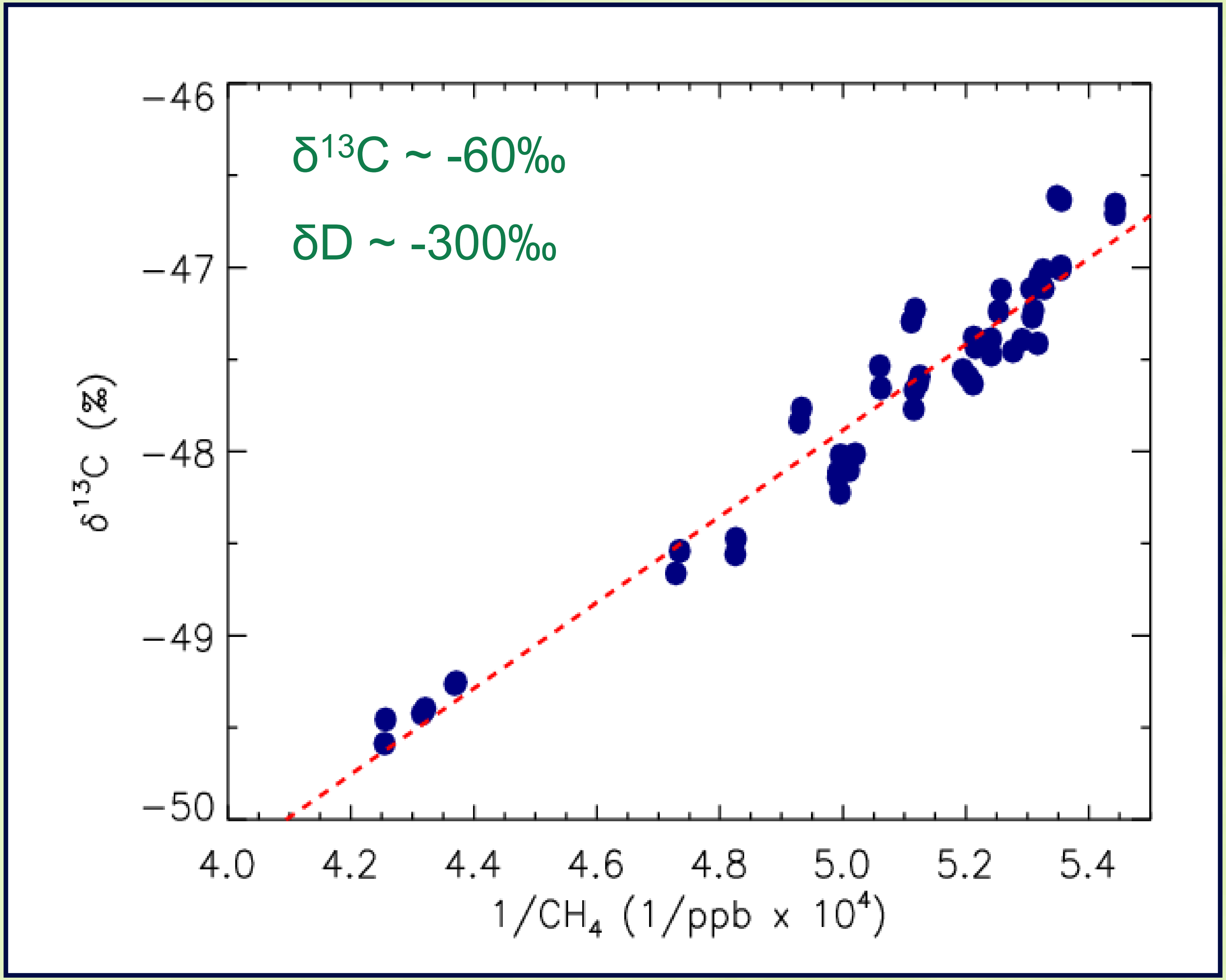
- NOAA/ESRL measurements complement the existing EC continuous measurements.
- Additional observations of CH_4-isotopes and NMHC's from flasks will be collected.
- We hope to be able to characterize local sources such as …

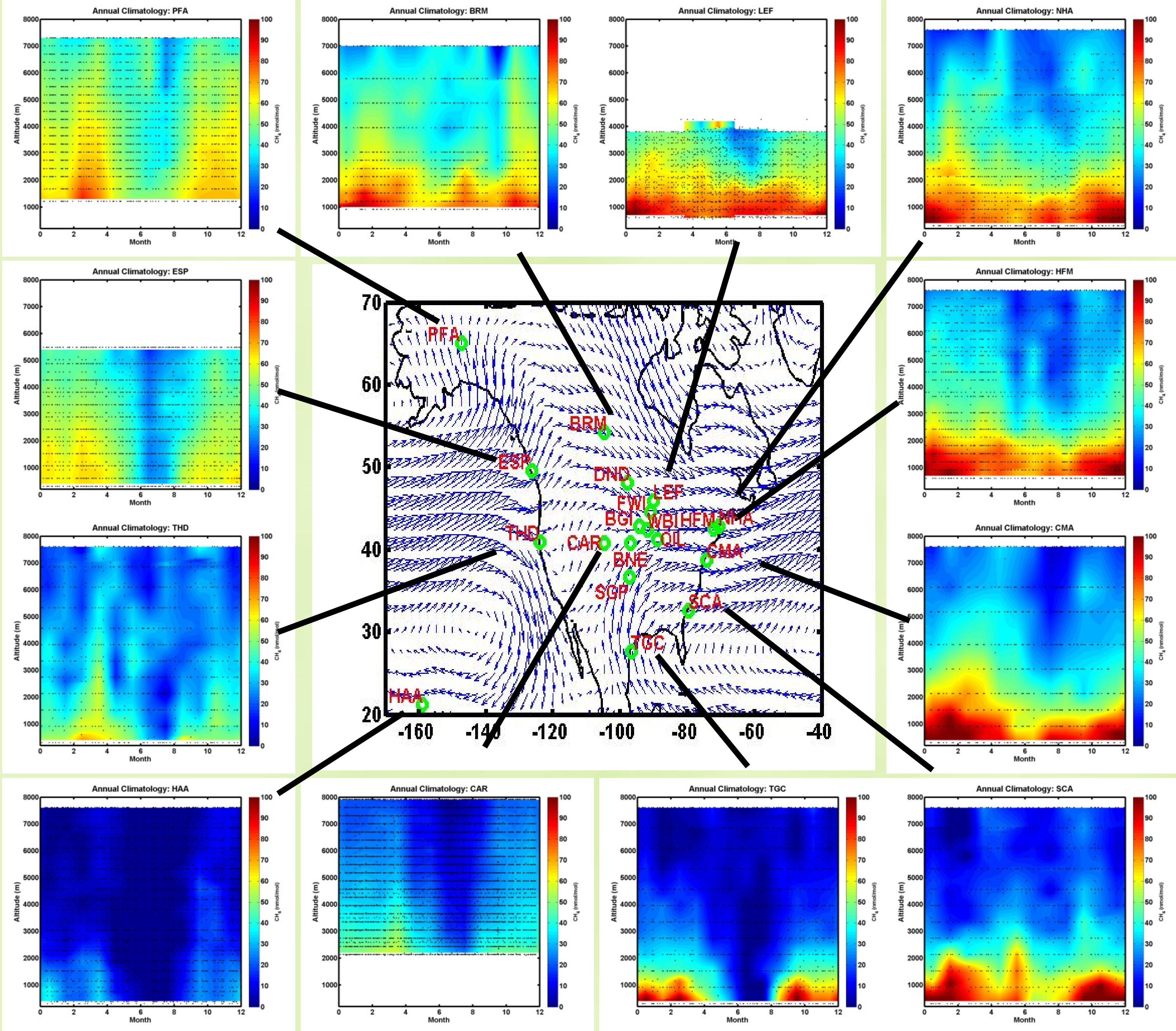
…..The nearby oil sand operations

(Photo: National Geographic Magazine)


Lac Labiche AB
4.0
3.6
3.2
2.8
2.4
2.0
1.6
CH4 (ppm)
2007.2
2007.4
2007.6
2007.8
2008
2008.2
2008.4
2008.6
2008.8
2009
2009.2
Decimal Year

Winter (mostly)

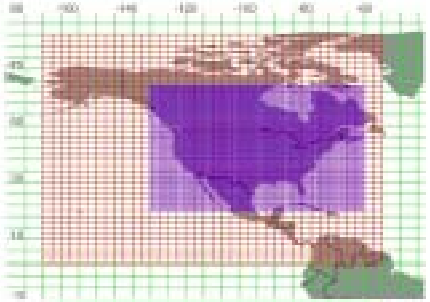


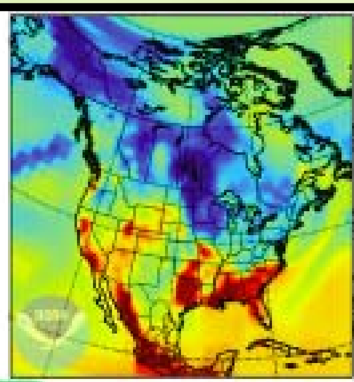


Courtesy of Colm Sweeney

CarbonTracker-CH_4

Best Estimates of Emissions and Chemical Loss Rates





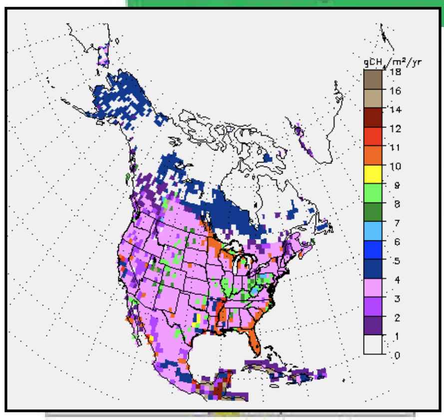
TM5 2-way nested transport

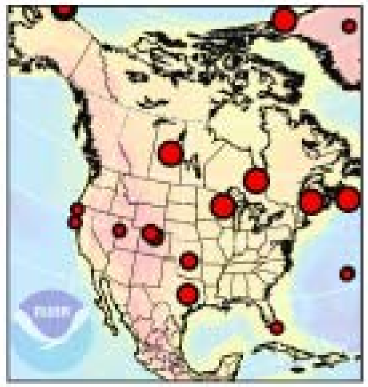
Simulated CH_4

Observed CH_4

Ensemble Kalman Filter

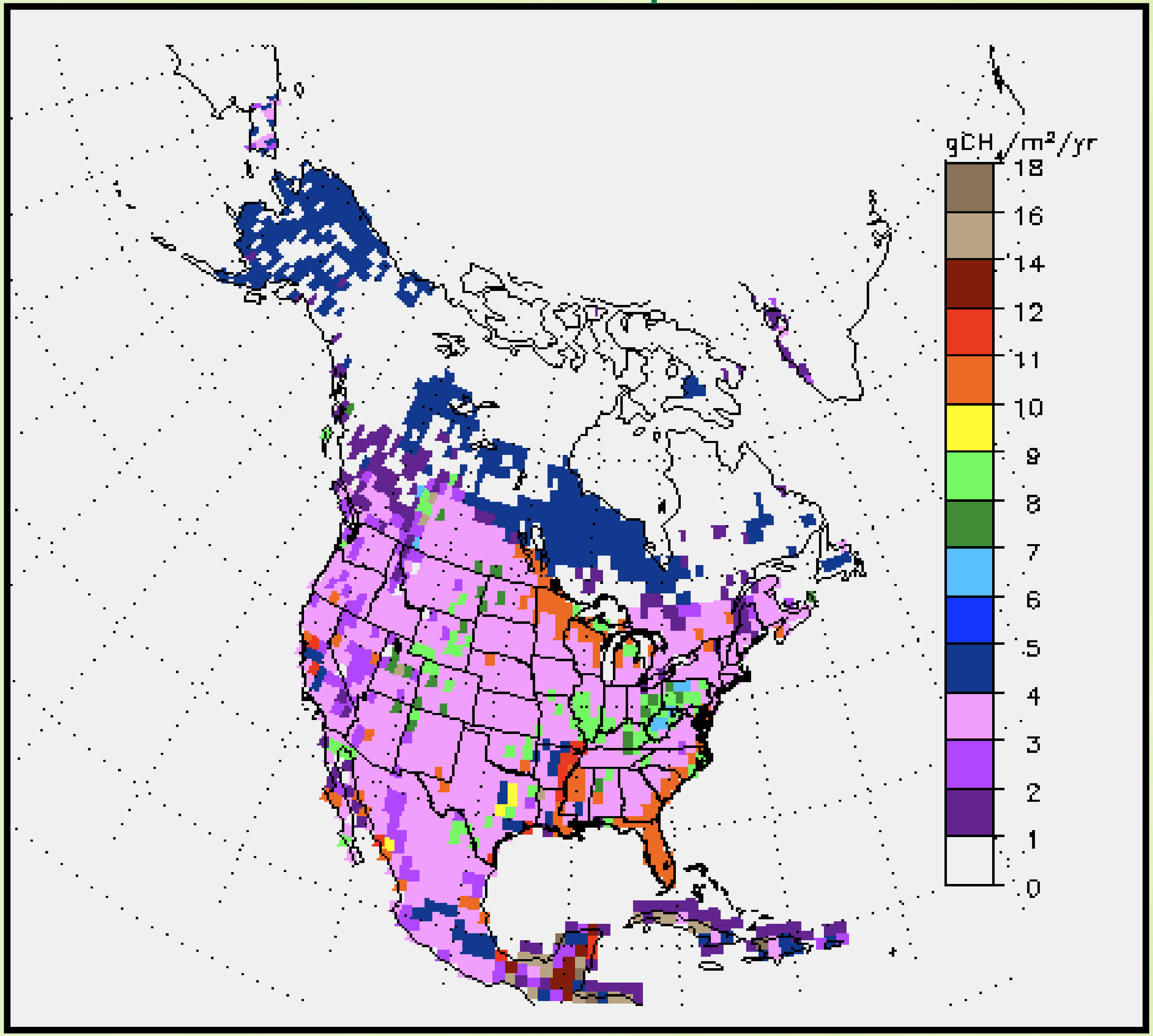
Flux adjustments



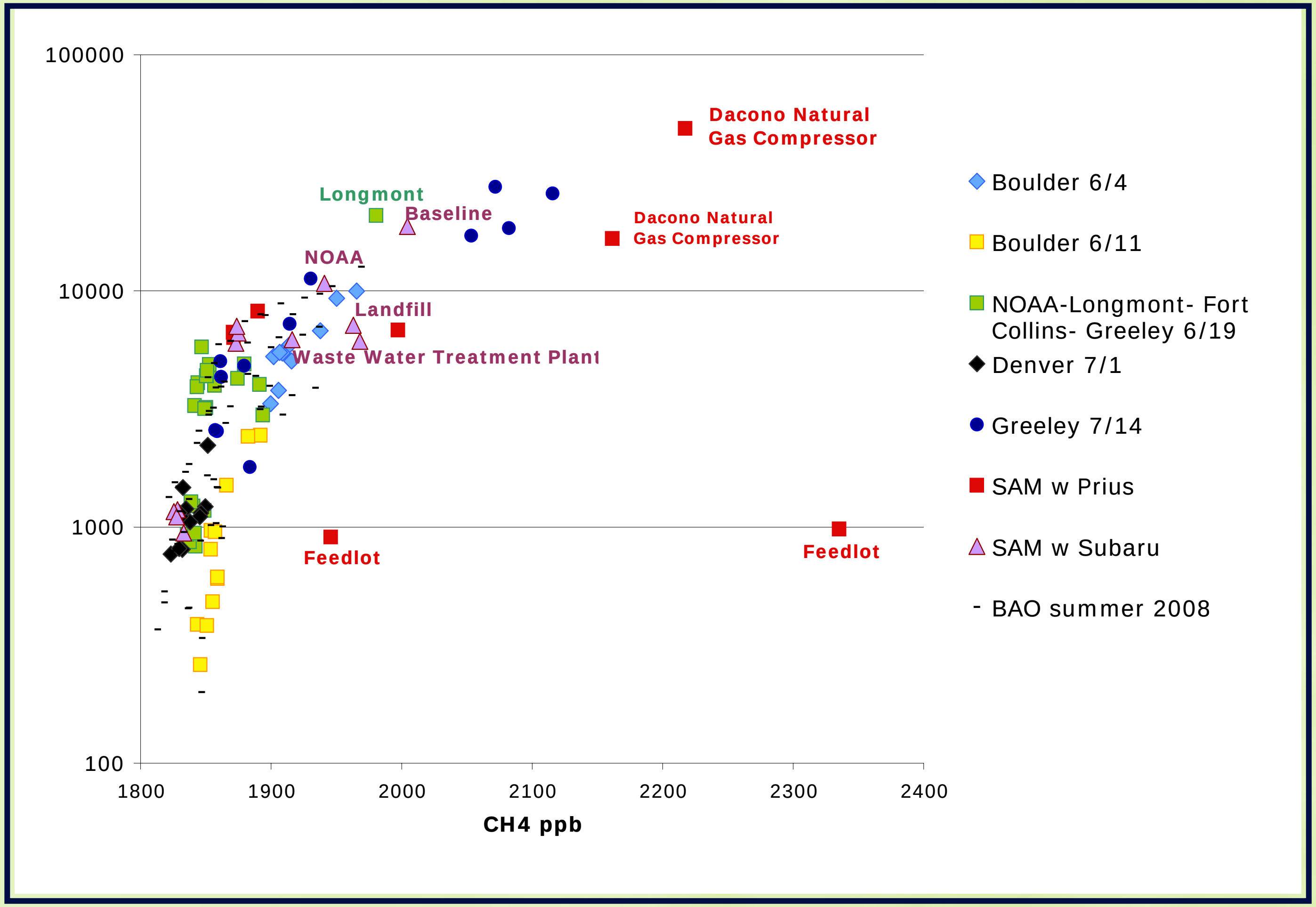


$$J(x) = \frac{(y - H(x))^2}{R} + \frac{(x - x^p)^2}{P}$$

CarbonTracker-CH_4



Propane vs. Methane for SAM & BAO



Courtesy of G. Petron

Conclusions

- Global Increases of CH_4:
  - 8.3±0.2 ppb in 2007; 4.4±0.2 ppb in 2008
- Causes of increase:
  - Tropical Biomass burning (likely minor)
  - Wetlands (Arctic, Tropics)
- The CH_4 bomb isn't going off yet…..
  - Recovery at Northern Polar Latitudes Suggests 2007 and 2008 Increases are Natural IAV

Extra Slides

Optimized 2001 Emissions: 526Tg/yr

(*Bergamaschi,2002*)

Coal	**30 (TgCH4/yr)**
Oil/Gas	**50**
Enteric Fermentation/Manure	**100**
Rice	**59**
Biomass Burning	**32**
Waste	**74**
Wetlands	**174**
Wild Animals	**5**
Termites	**19**
Soil	**-38**
Oceans	**17**

Isotope Effects in Chemistry and Biology, Kohen and Limbach

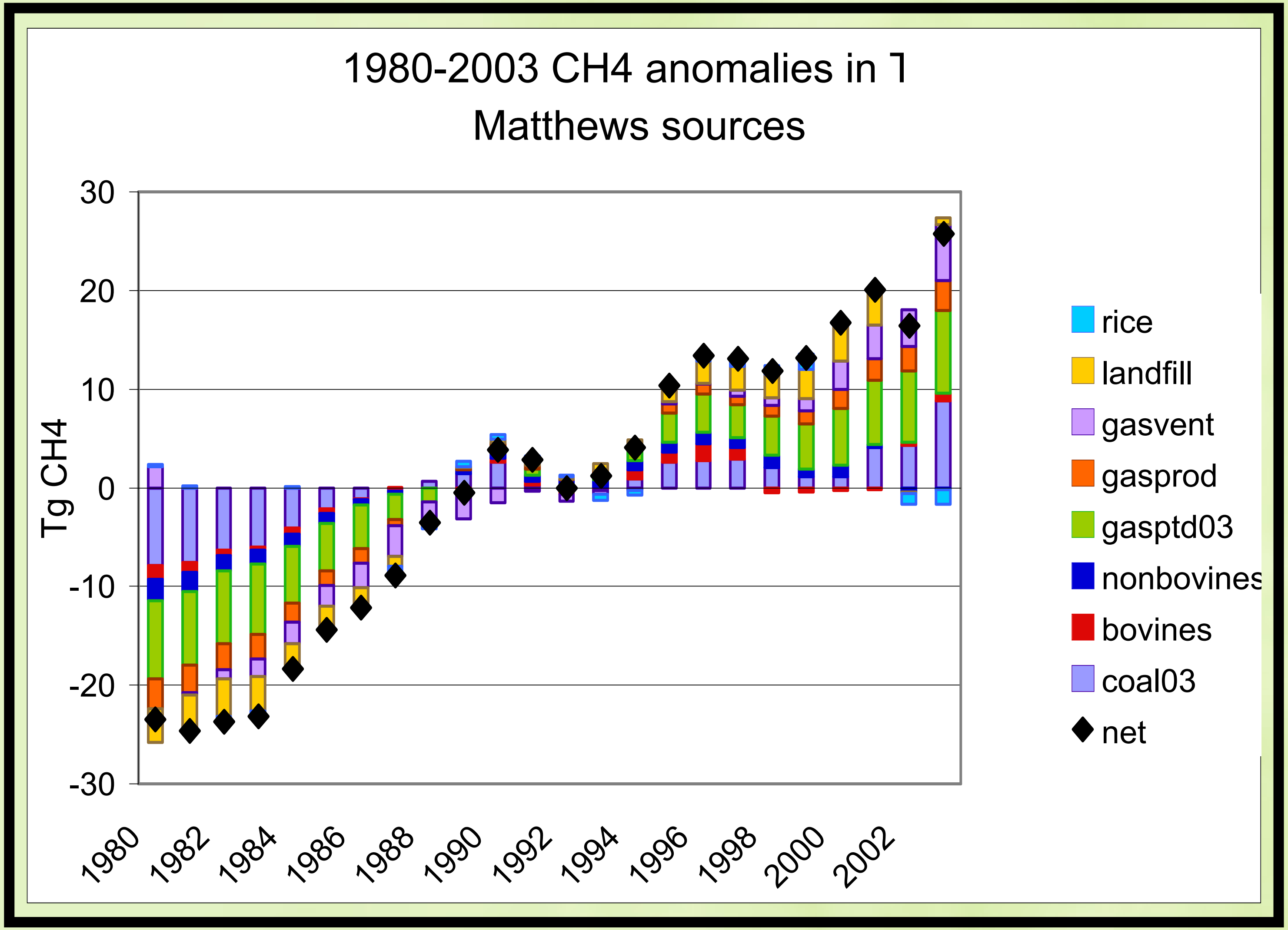
TABLE 13.1
Annual Emissions and Average Isotopic Values of Sources of Atmospheric Methane

Source	Annual Emissions[a]			
	$TgCH_4\ yr^{-1}$	$\delta^{13}C/^{12}C$ (‰)[b]	$^{14}CH_4$ (pM)[c]	δD (‰)[d]
Biogenic				
Wetlands	232 ± 14	−60 ± 5	116 ± 5	−320 ± 20
Ruminants	90 ± 10	−60 ± 5	120 ± 5	−300 ± 10
Rice paddies	69 ± 12	−63 ± 5	112 ± 5	−320 ± 30
Landfills	40 ± 8	−50 ± 2	120 ± 5	−310 ± 10
Fossil				
Natural gas	70 ± 14	−43 ± 7	0	−185 ± 20
Coal mining	33 ± 5	−36 ± 7	0	−140 ± 20
Biomass burning	41 ± 6	−24 ± 3	130 ± 5	−225 ± 5
Total flux (g)	580 ± 28	—	—	—

Reprinted from Ref. 44. Data from: [a] 45; [b] 47,51–58,61; [c] 54,56,59,60,62; [d] measured in the late 1980s and early 1990s in Refs. 47,56,57,62. PM means percent modern carbon.

Atmosphere: -47.33 +/- 0.04%
OH fractionation -5.4
-> 53.4+/- 2

Where Did It All Go?



Anthropogenic Sources

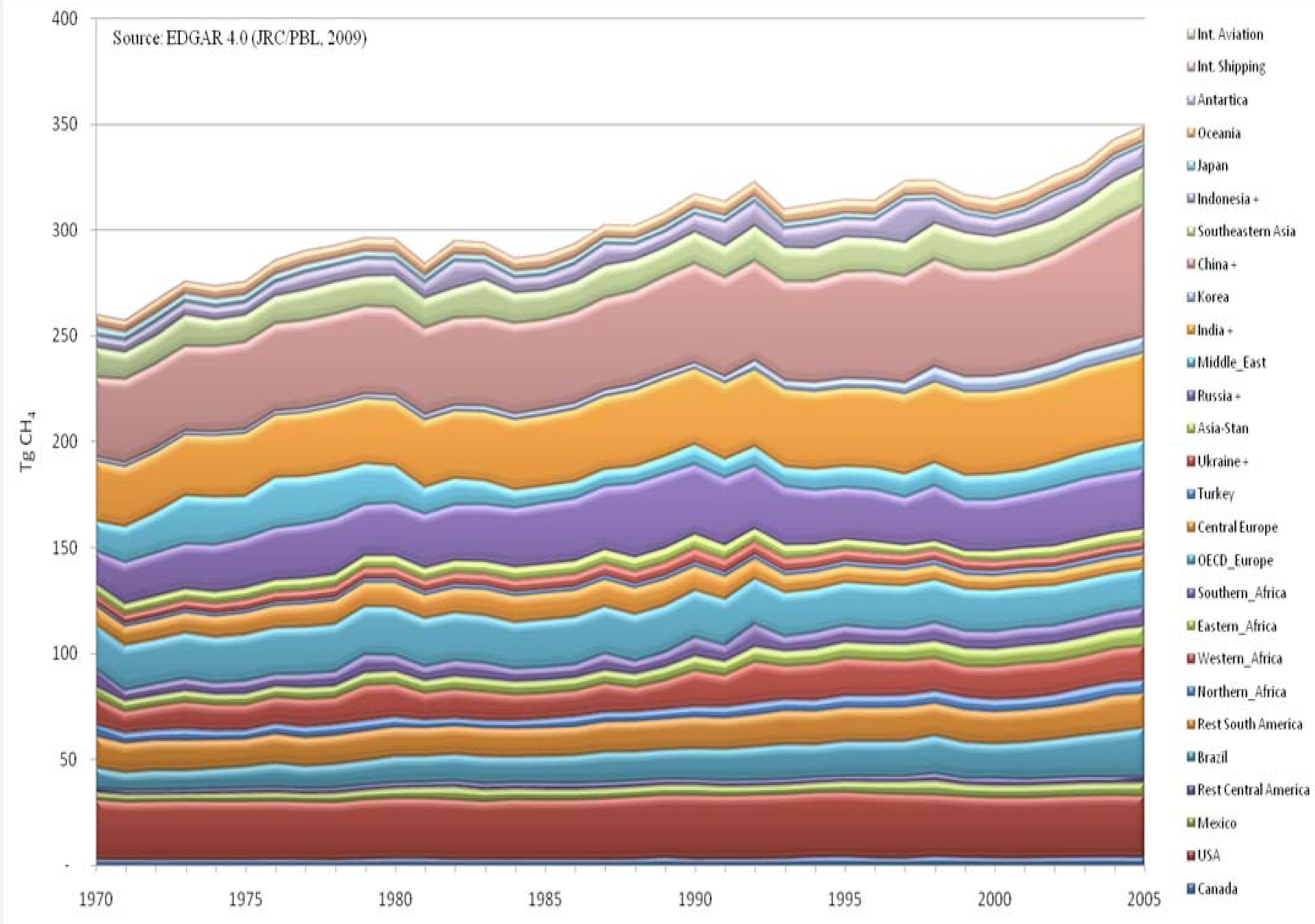


Figure 1: Global methane emissions by world region (1970-2005) in Tg CH4

press x to close

Impacts on Infrastructure

Yedoma Soils

IPY puts focus on the Arctic

- “Methane Bubbles in the Arctic Ocean Give Climate Scientists the Willies” (Discover, Sept., 2008)
- “Study says methane from ocean floor is 'time bomb‘” (CTV.ca, 27 Sept. 2008)
- “Arctic 'methane chimneys' raise fears of runaway climate change” (The Guardian 23 Sept. 2008)
- “Methane 'Fart' from the Earth Poses Enormous Global Warming Risk” (Independent, 24 Sept. 2008)
- “Una bomba de metano”

Arctic Climate Change

- Accelerating T increase since early-1990s (>0.3°C decade^{-1}) resulting in warming of wetland soils.
- Decreasing snow cover and sea ice.
- Increased plant growth; northward migration of tree line.
- Increased terrestrial precipitation.
- Destabilization of permafrost.

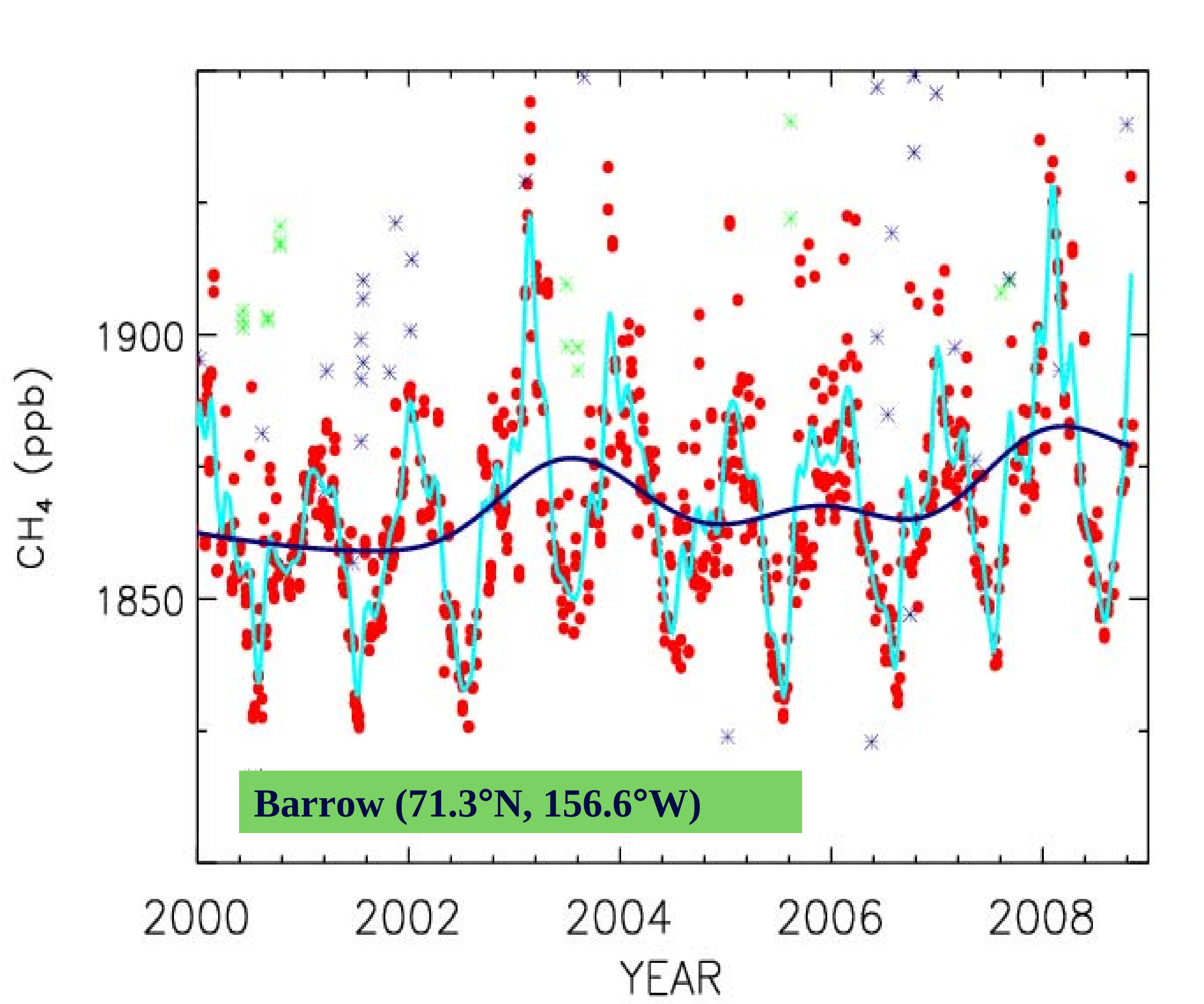
Walters et al., *Nature*, Sept. 2006

Methane Bubbling From Siberian Lakes

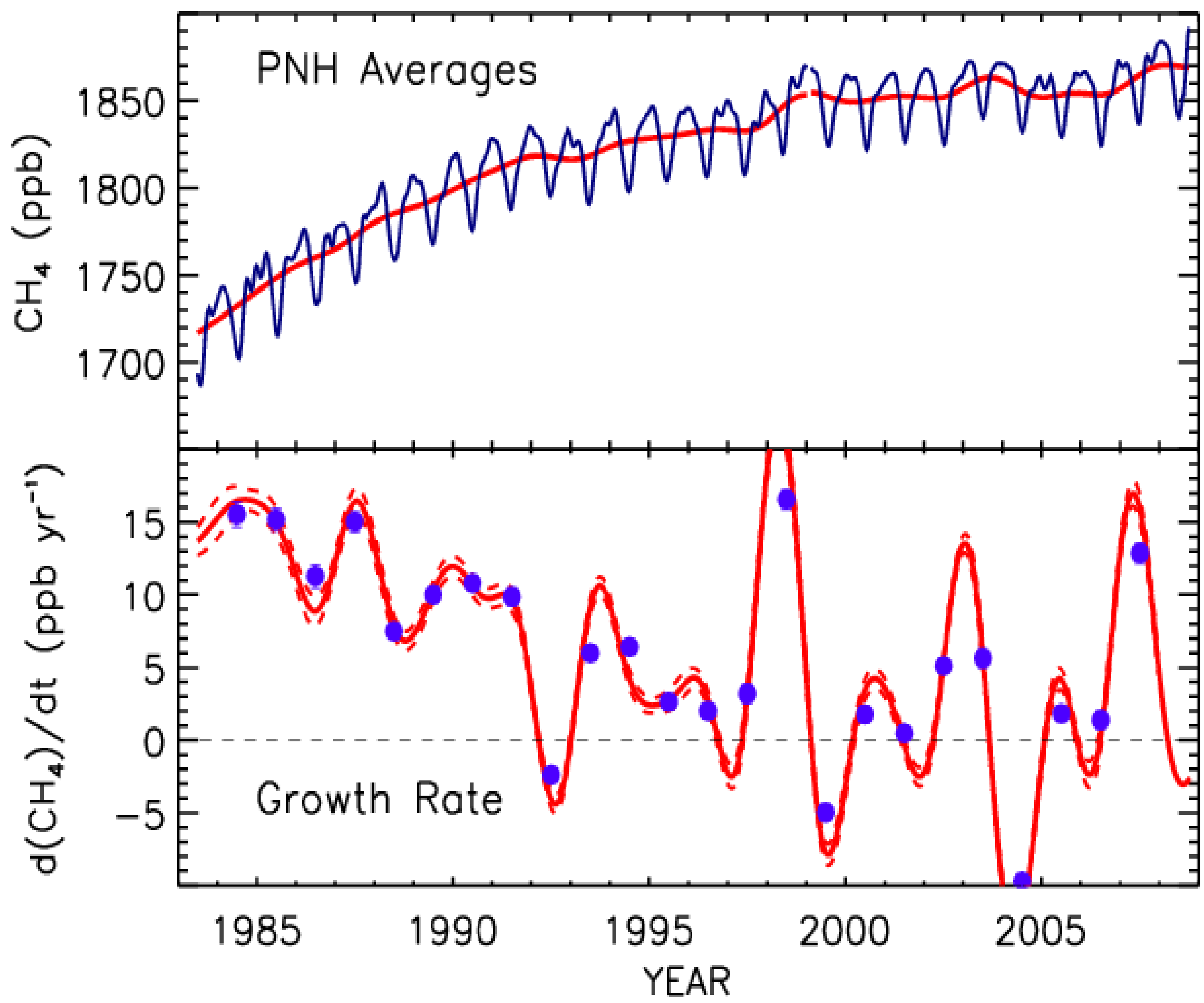
- **Year-round flux measurements.**
- **Remote sensing, aerial surveys quantify emissions.**
- **95% emissions from ebullition.**
- **3.8 TgCH4 yr^{-1} from Siberian thermokarst lakes**
- **Increased by 58%, from 1974 to 2000.**
- **Carbon source, 35-43k years old, d13C~-70‰.**

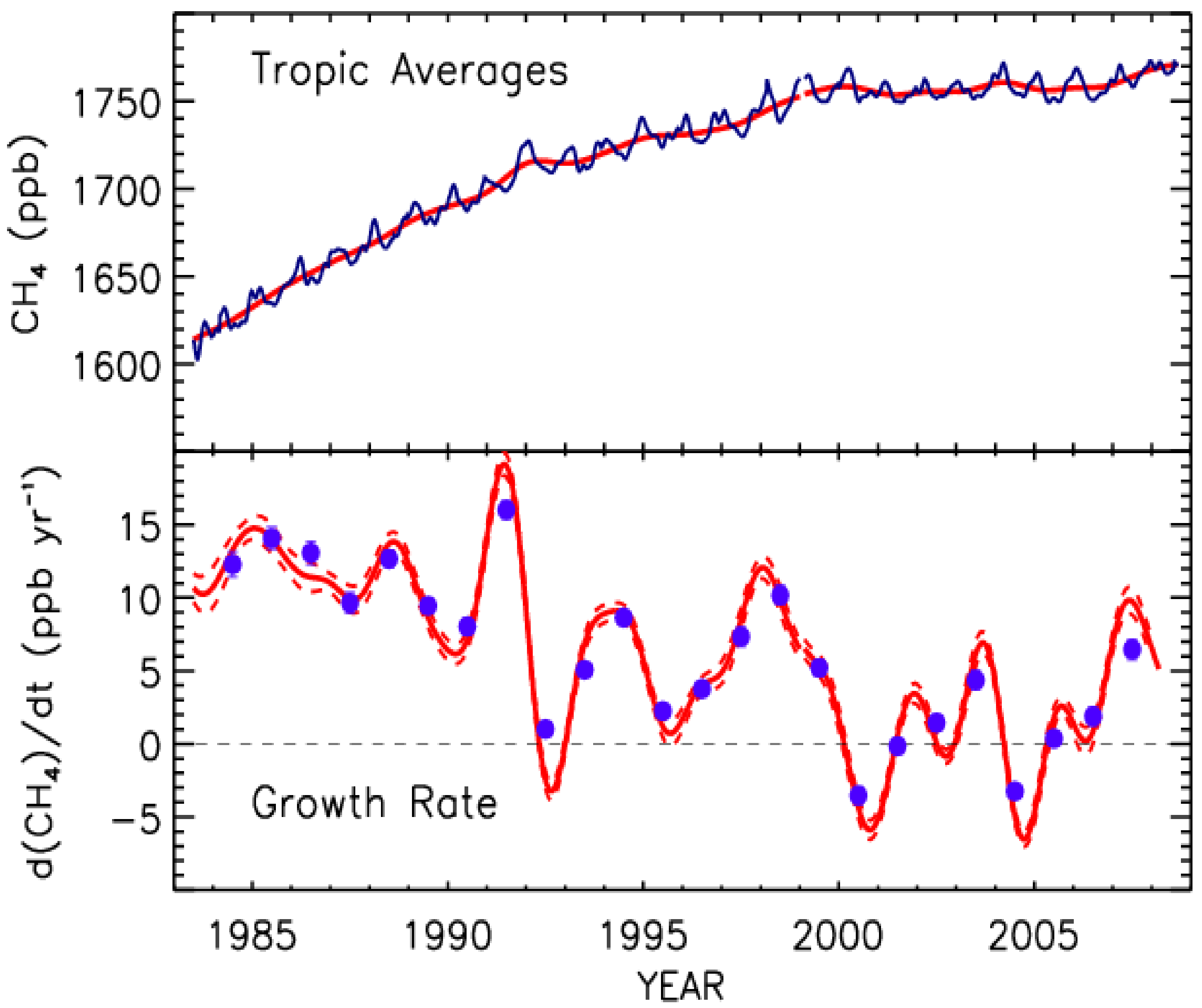
Potential contributions to 2007/2008 CH_4 increases:

- Δ Anthropogenic emissions
  - Expect gradual changes
- Δ Loss rate (Δ [OH])
  - CH_3CCl_3 analysis suggests not
  - PCE also suggests not (UCI)
- Enhanced inter-hemispheric exchange related to La Niña

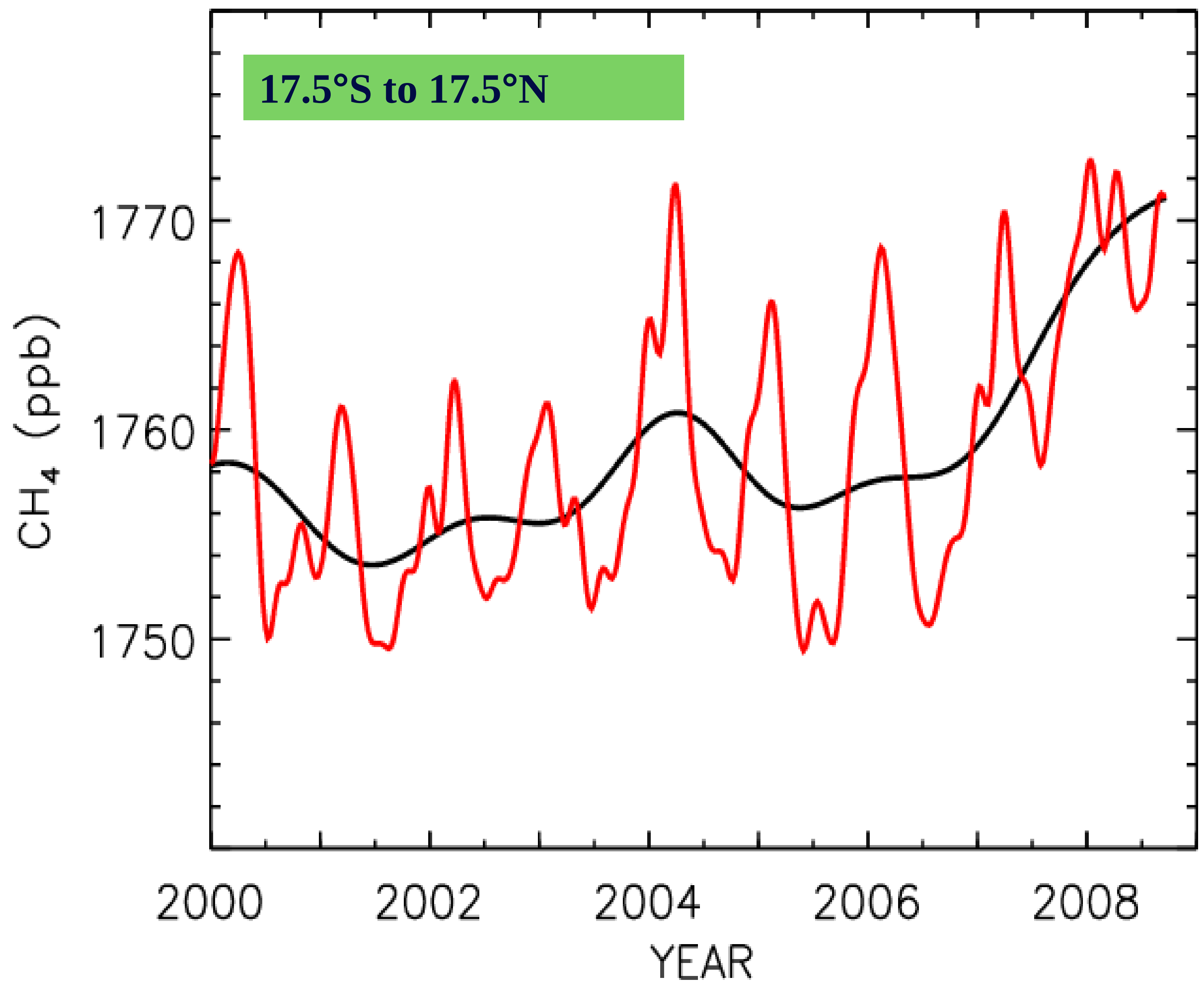


CH$_4$ (ppb)
1900
1850
2000
2002
2004
2006
2008
YEAR
Barrow (71.3°N, 156.6°W)

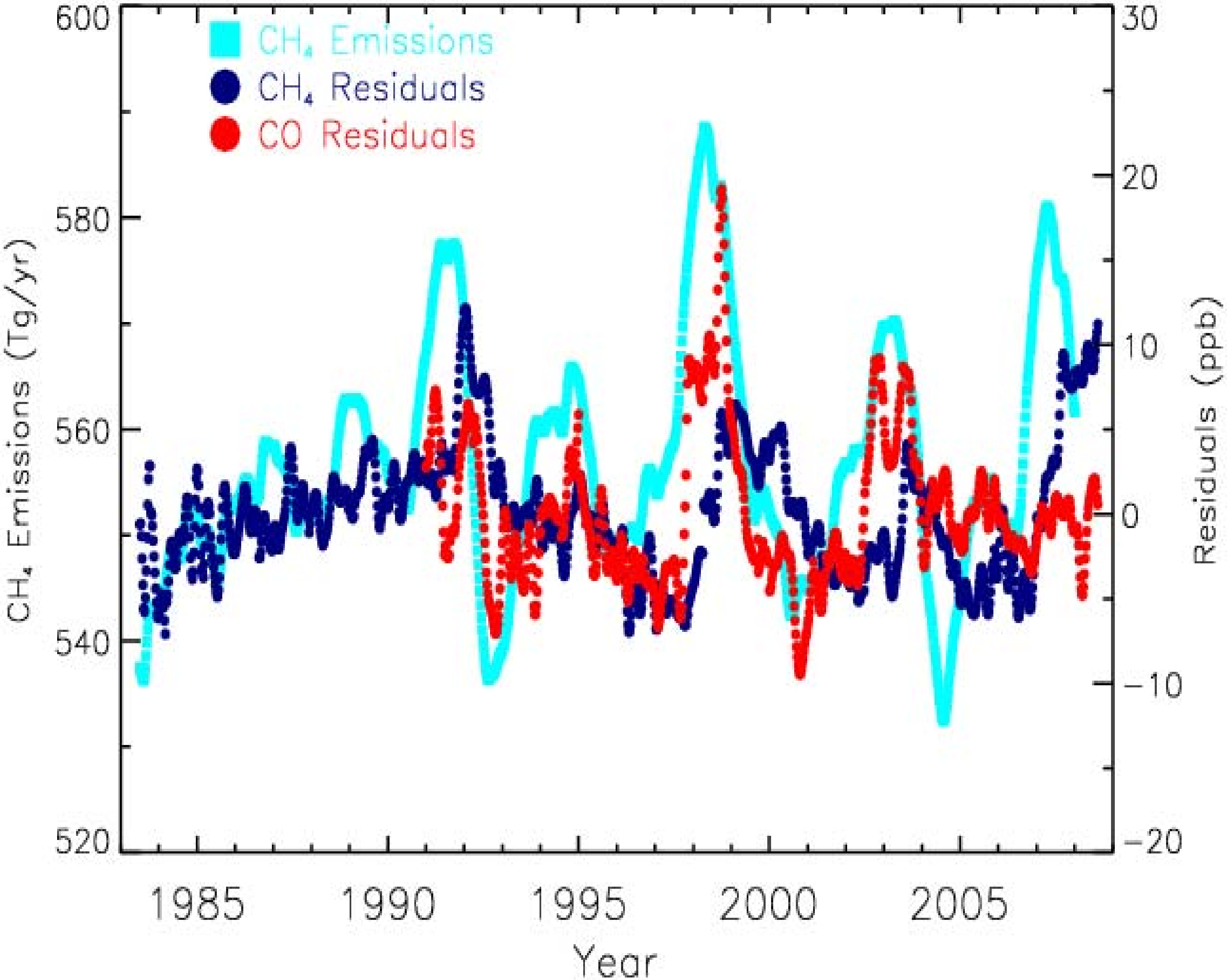

PNH Averages
Growth Rate
CH4 (ppb)
d(CH4)/dt (ppb yr-1)
1700
1750
1800
1850
-5
0
5
10
15
1985
1990
1995
2000
2005
YEAR



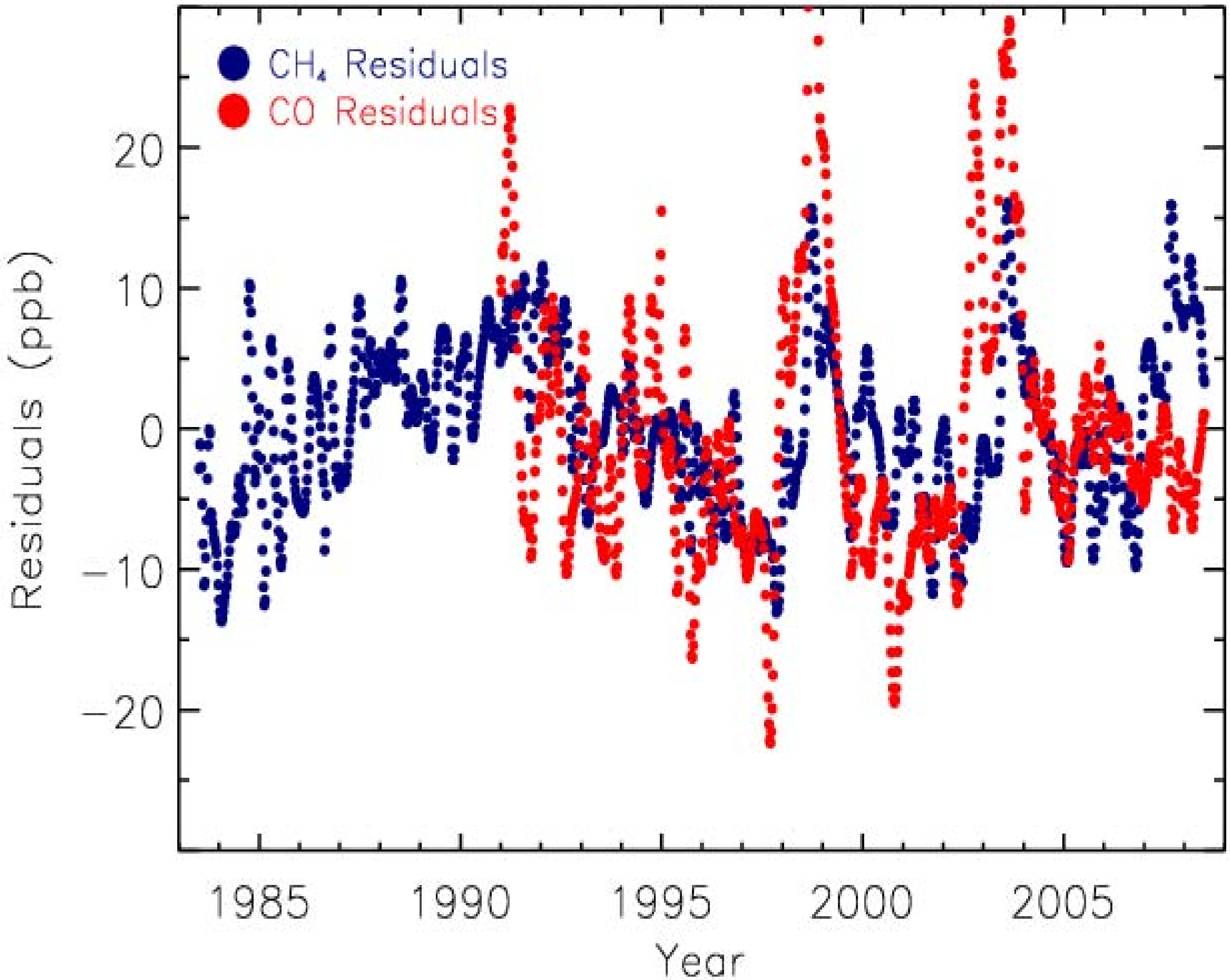
Tropic Averages
CH_4 (ppb)
1600
1650
1700
1750
$d(CH_4)/dt$ (ppb yr^{-1})
15
10
5
0
−5
Growth Rate
1985
1990
1995
2000
2005
YEAR


17.5°S to 17.5°N
1770
1760
1750
CH4 (ppb)
2000
2002
2004
2006
2008
YEAR

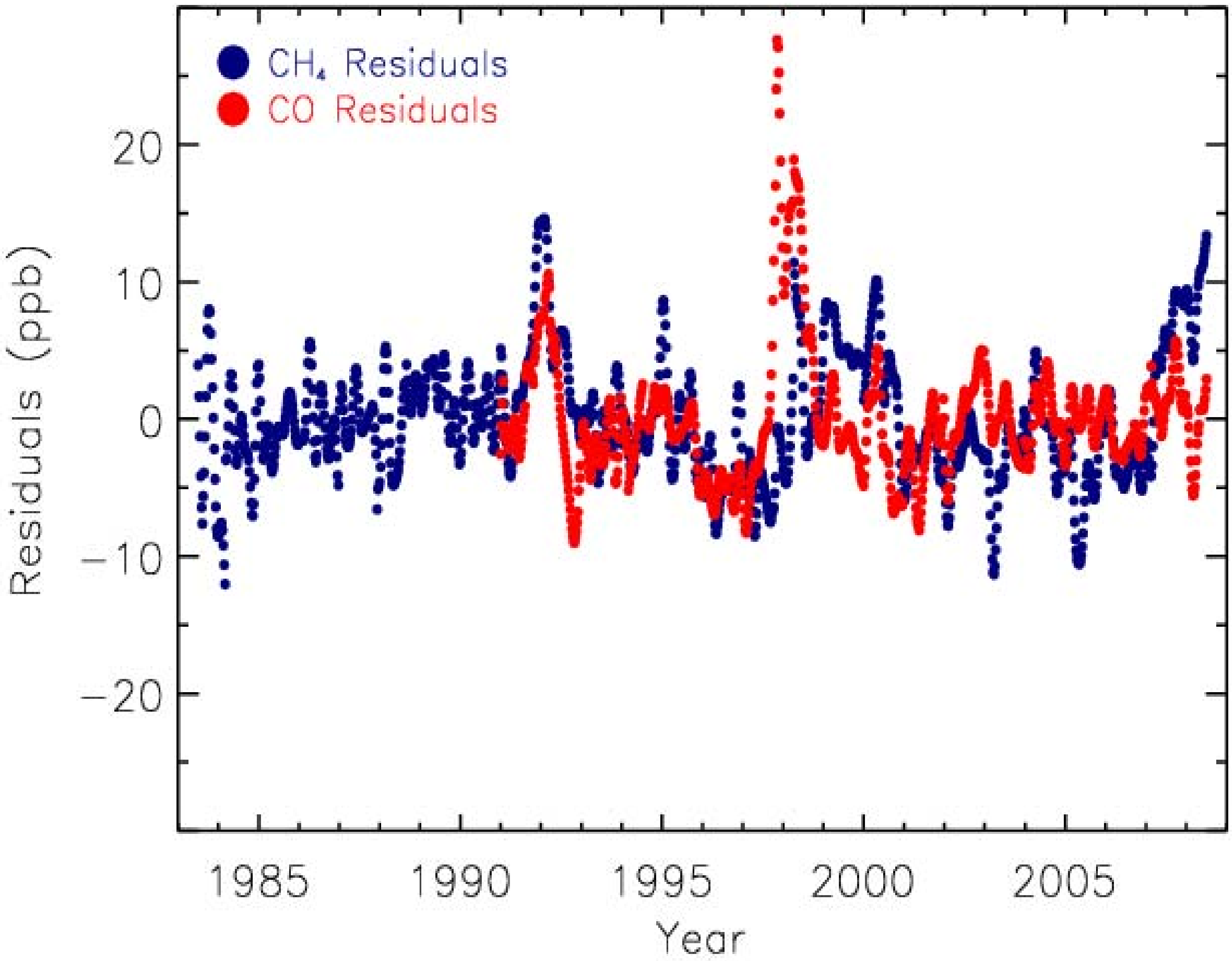
Globally Averaged Residuals

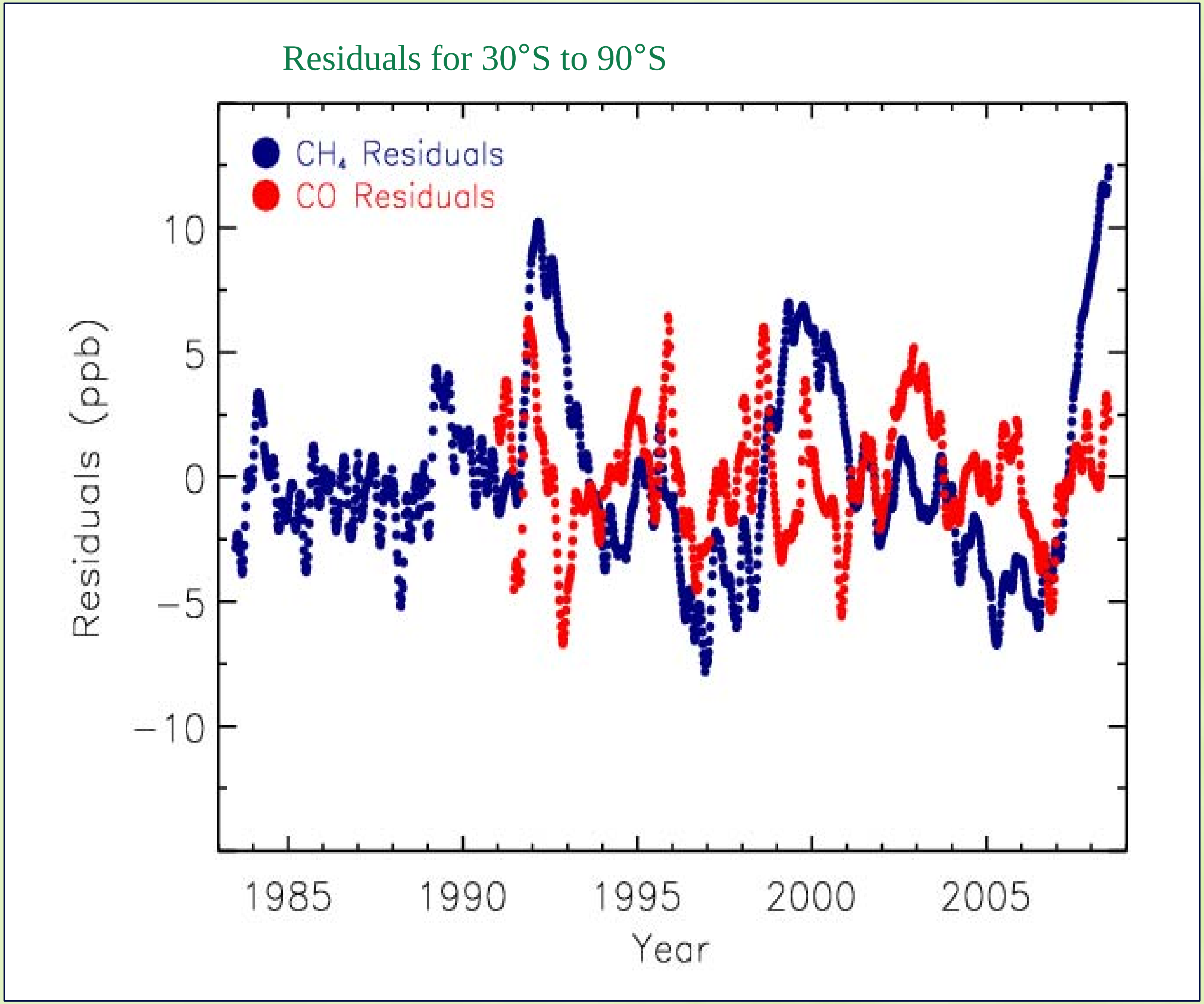


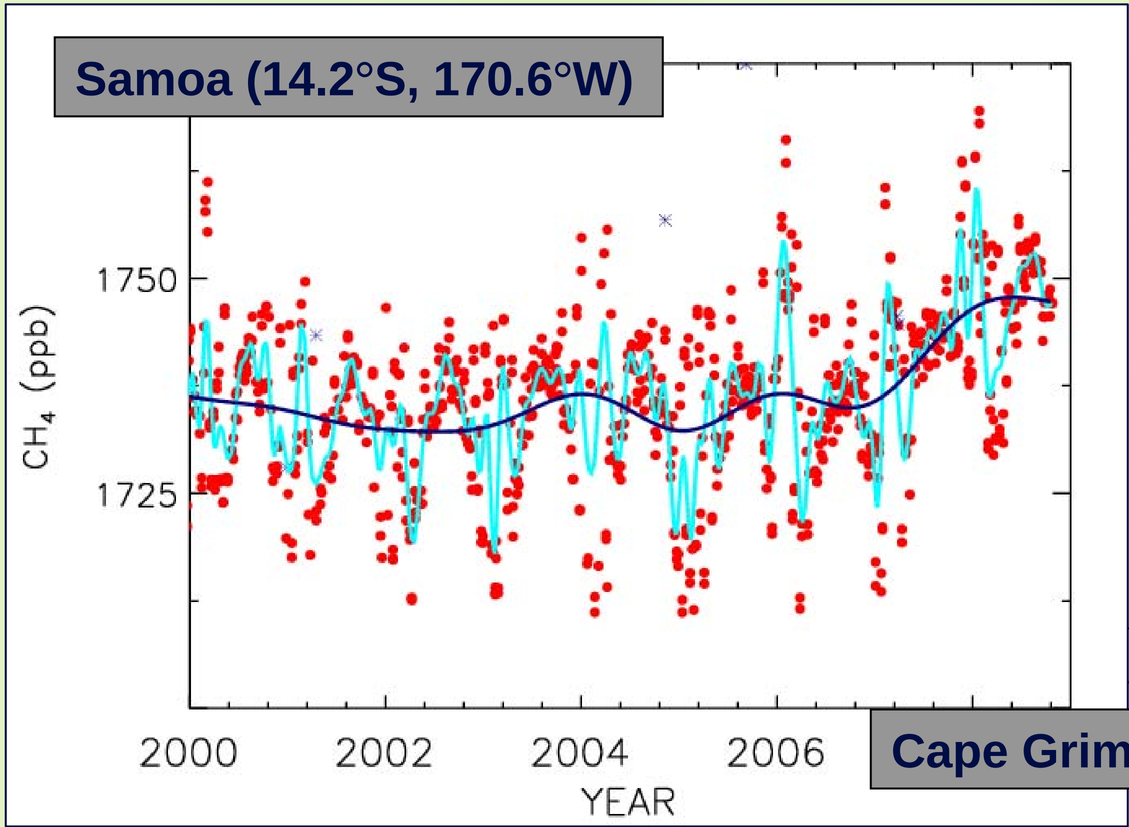
Residuals for 30°N to 90°N

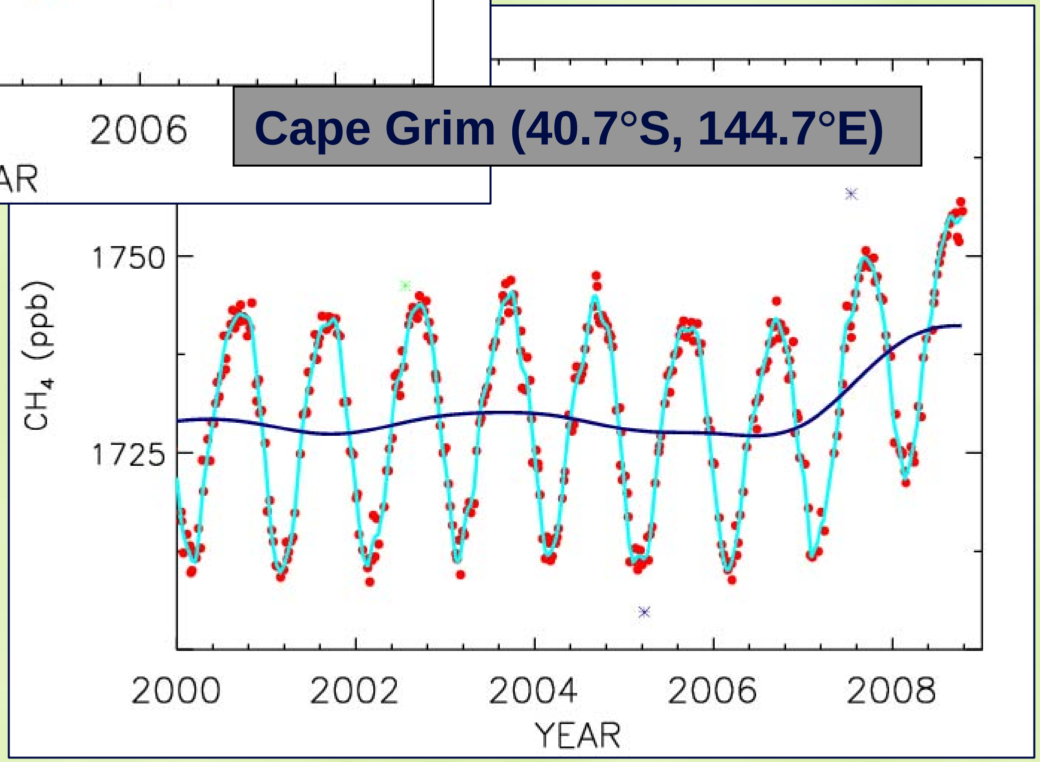


Residuals for 17.5°N to 17.5°S




Residuals for 30°S to 90°S
CH4 Residuals
CO Residuals
Residuals (ppb)
10
5
0
−5
−10
1985
1990
1995
2000
2005
Year


Samoa (14.2°S, 170.6°W)
1750
1725
CH4 (ppb)
2000
2002
2004
2006
YEAR


Cape Grim (40.7°S, 144.7°E)
1750
1725
CH4 (ppb)
2000
2002
2004
2006
2008
YEAR

Permafrost

- Accelerating melting → thermokarst formation → Expanding wetland area.
- Longer active season.
- Increased transport DOC to Arctic Ocean.
- Soils contain 500 to 900 Pg C, implying a potential for huge CH_4 and CO_2 emissions.

Wetland Warming

CH_4 emissions are very T sensitive.

- $E_T = E_{T_0} Q_{10}^{(T-T_0/10)}$ where $Q_{10} = E_{T+10}/E_T$
- Q_{10} = 2-15 for CH_4 wetland emissions. Mid-value used for this study.

Co-Located Distributed and Point Sources

(Natl. Geographic, June 08)

Photograph by Gerd Ludwig

A drill pad built on top of fragile wetlands probes for new oil reserves. Technology imported from the West is helping Russia's oil industry modernize, but Soviet-era spills and pipeline breaks have contaminated much of the region.

CO_2	CH_4
Fluxes We Estimate: Terrestrial Biosphere, Oceans	**Coal Production, Oil/Gas Leaks, Animals, Waste, Rice, Wetlands, Termites, Oceans, Soils, Others**
Fluxes We "Know": Fossil Fuels	**None**
Photochemistry: None	**Reaction with OH (and Cl)**
Measurement Sites ~100	**<100**

Arctic Climate Change

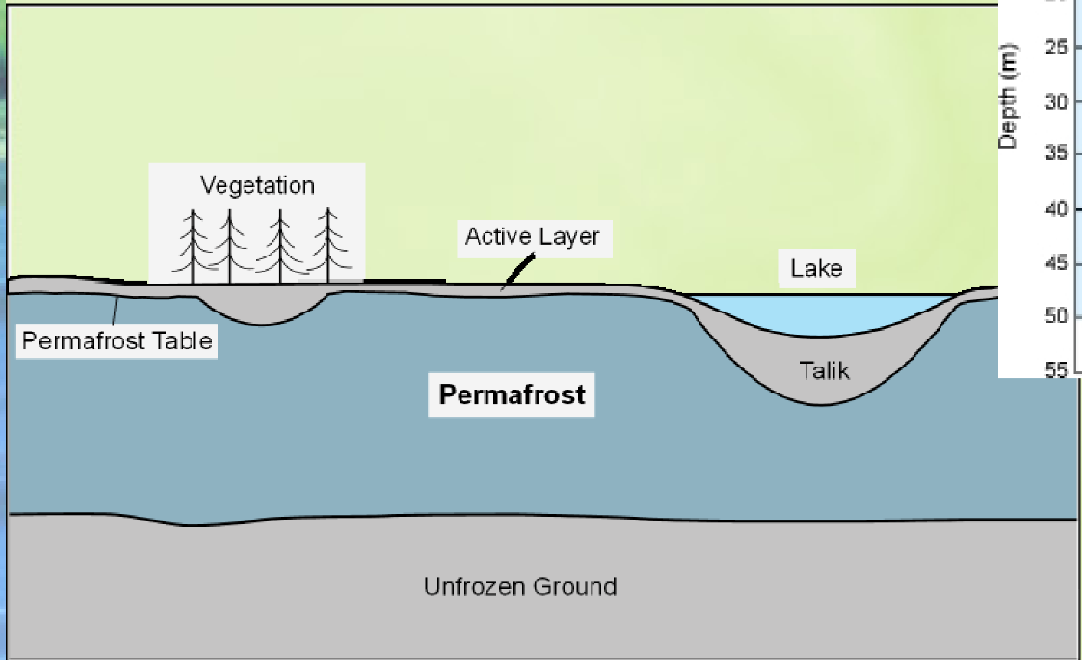
- Accelerating T increase since early-1990s (>0.3°C decade^{-1}) resulting in warming of wetland soils.
- Decreasing snow cover and sea ice.
- Increased plant growth; northward migration of tree line.
- Increased terrestrial precipitation.
- Destabilization of permafrost.

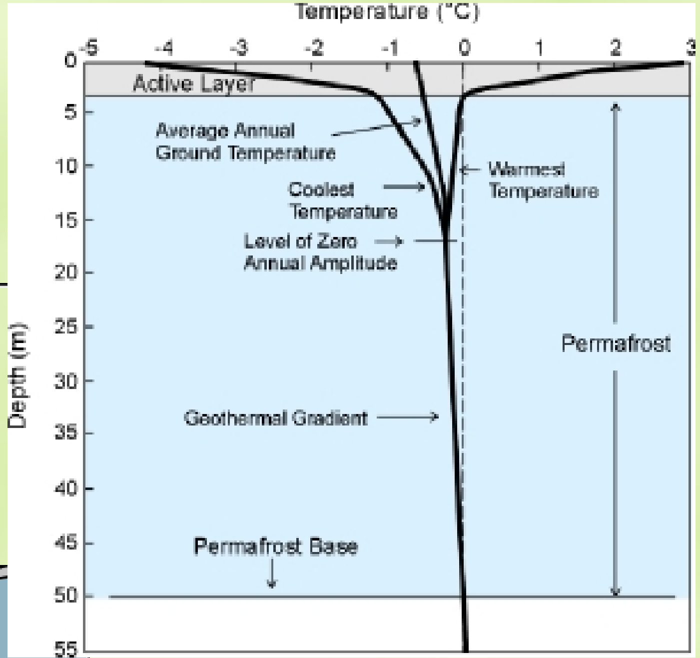
Permafrost

*Regions (dry or wet) below 0°C for two consecutive years.

*On land

*Undersea



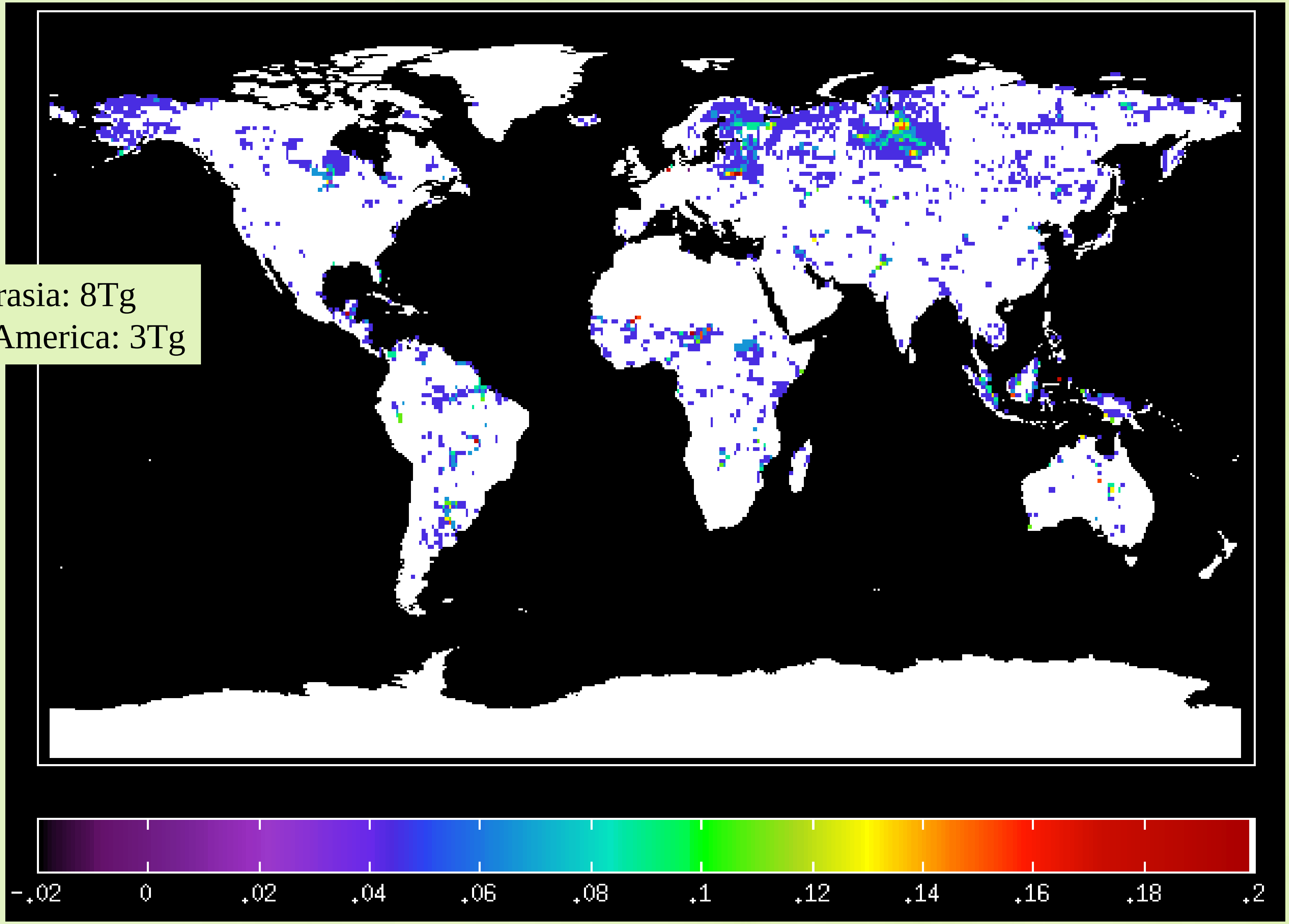


Why Focus on CH_4 ?

- Global Warming Potential ~23 (100 yr horizon), Ozone Precursor
- One of the greenhouse gases targeted by the Kyoto Protocol, and it could be targeted for future regulation in the USA.
- May play a role in rapid climate change :
  - Clathrates/Hydrates
  - Carbon stored in high latitude permafrost
- We Don't Understand its Budget! Or its Variability.

2007 Wetland Emissions(Annual Total)

Eurasia: 8Tg
N America: 3Tg



Tg CH_4