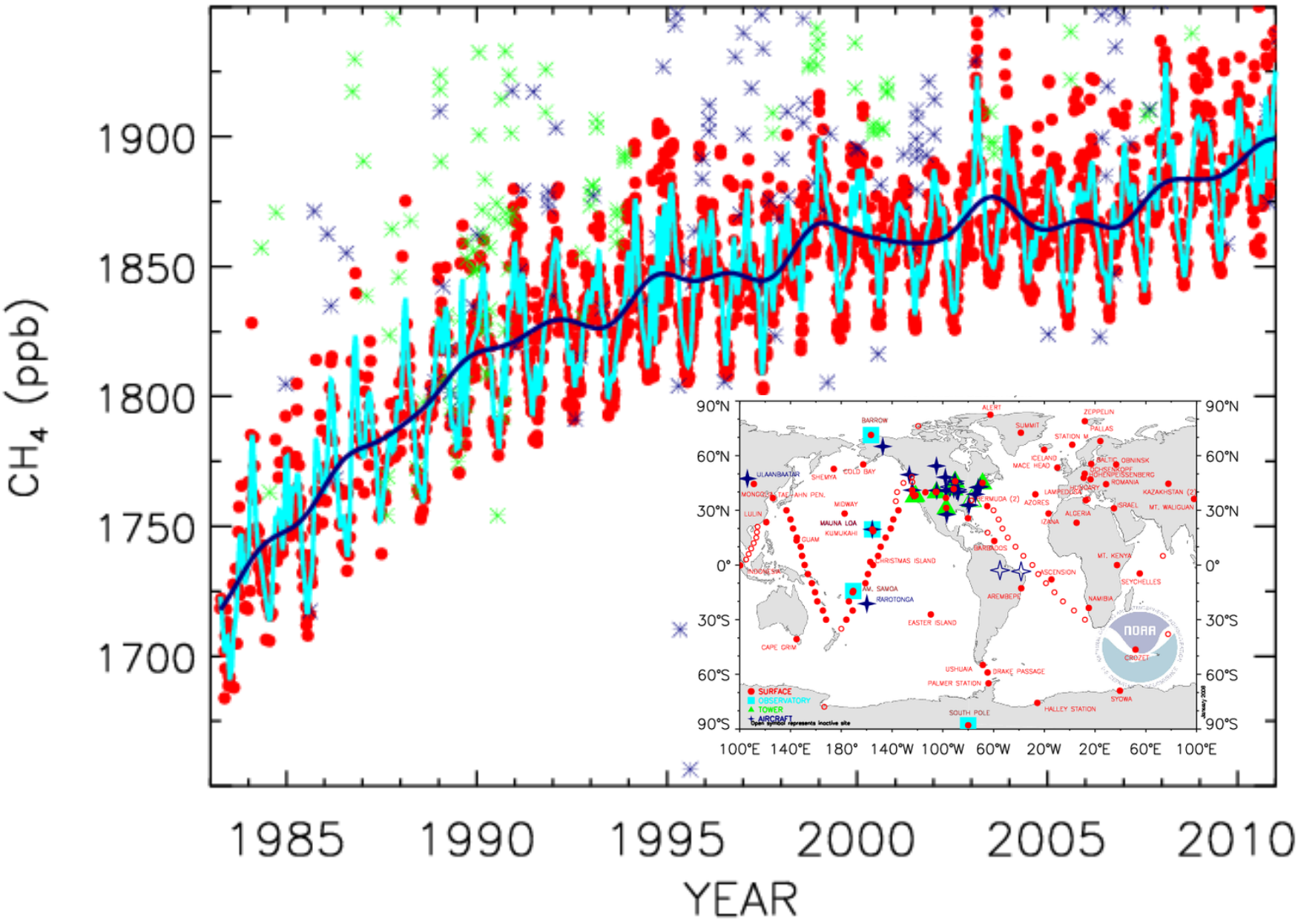
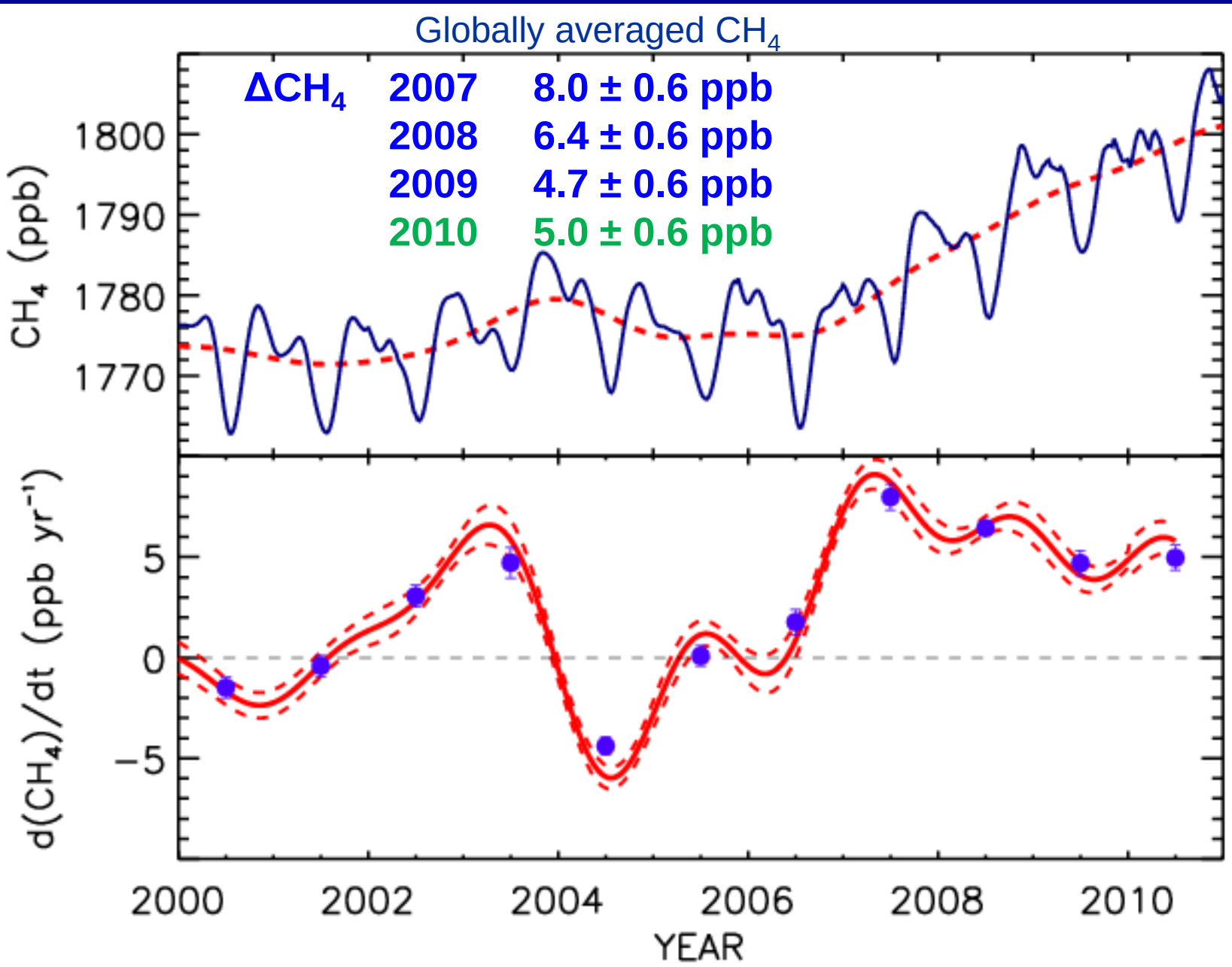
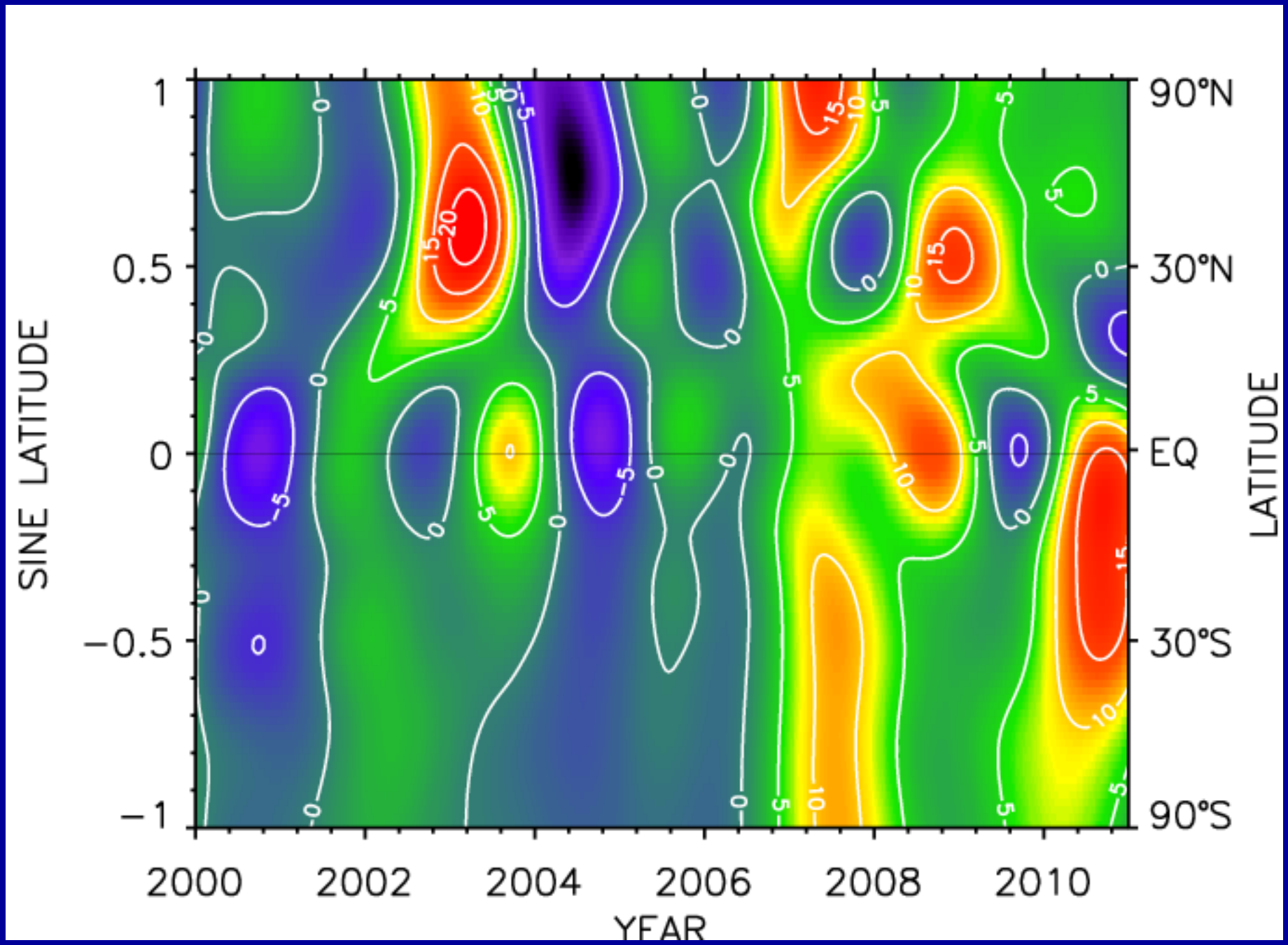
# Can We Explain Recent Increases in Atmospheric $CH_4$?

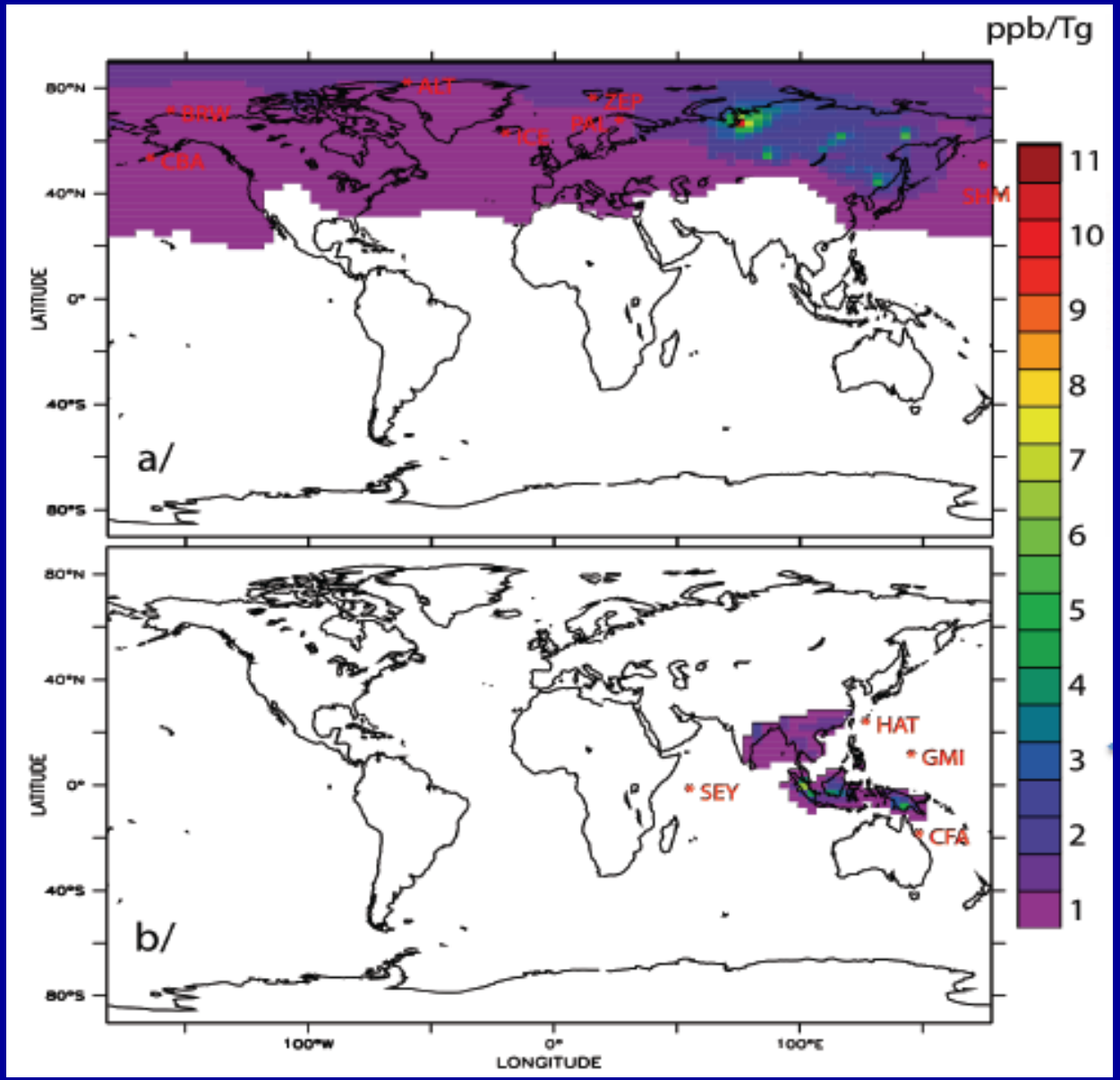
E. Dlugokencky[1], P.M. Lang[1], K.A. Masarie[1],
A. Crotwell[1,2], L. Bruhwiler[1]
[1]NOAA ESRL GMD, [2]CIRES

# Barrow, Alaska




Globally averaged $CH_4$
$\Delta CH_4$ 2007 8.0 ± 0.6 ppb
2008 6.4 ± 0.6 ppb
2009 4.7 ± 0.6 ppb
2010 5.0 ± 0.6 ppb
$CH_4$ (ppb)
1800
1790
1780
1770
$d(CH_4)/dt$ (ppb $yr^{-1}$)
5
0
−5
2000
2002
2004
2006
2008
2010
YEAR


SINE LATITUDE
1
0.5
0
−0.5
−1
LATITUDE
90°N
30°N
EQ
30°S
90°S
2000
2002
2004
2006
2008
2010
YEAR




1 Tg pulse over 1 month

- Boreal Asia
- Tropical Asia

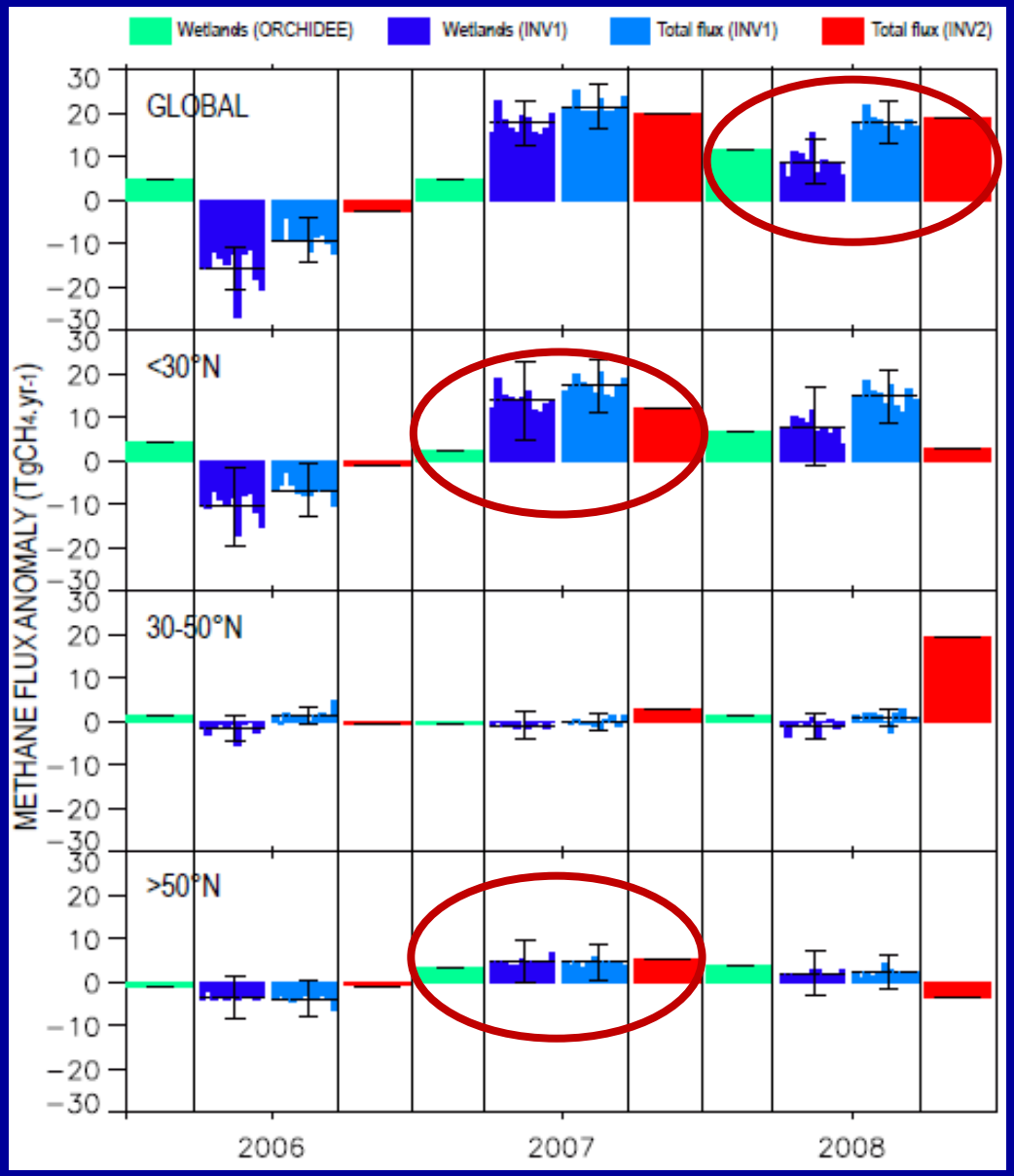
Transported for 11 months

- No sink

Bousquet et al., 2011, *ACP*.

# Causes of Recent Increases

- Rigby et al., GRL, 2008 [2007]
  - Potential contribution from Δ[OH].
- Dlugokencky et al., GRL, 2009 [2007, 2008]
  - T, precipitation drive increased $CH_4$ emissions.
  - Likely a contributor to 2010; 2009 unclear.
- NOAA CT-$CH_4$ [2007, 2008]
  - Largest anomalies in tropics in 2007 and 2008
- Bousquet et al., ACP, 2011 [2007, 2008]
- Satellite retrievals of $CH_4$ [2007 to 2009]




Bousquet et al., 2011, *ACP*.

2007:

Tropical WL – NOAA VPs

Arctic WLs - $\delta^{13}CH_4$ at ALT

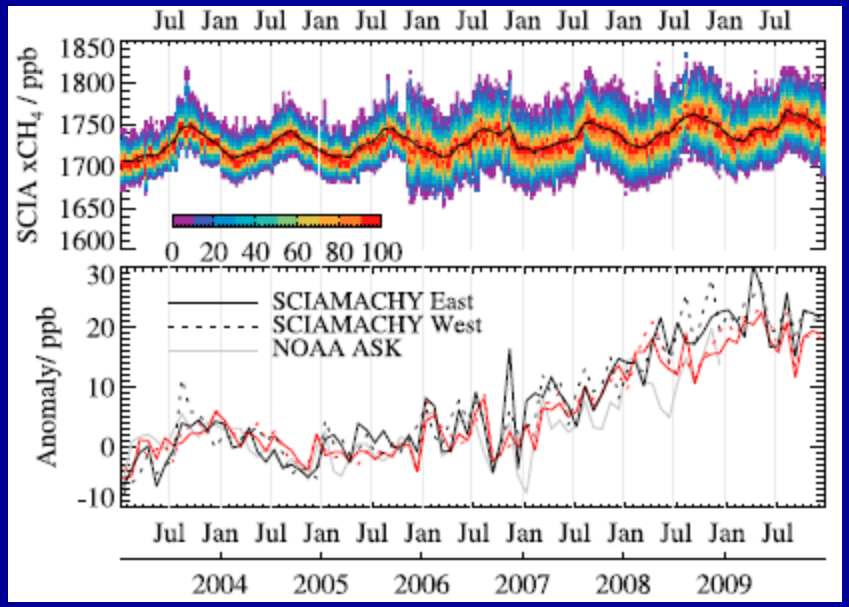
2008:

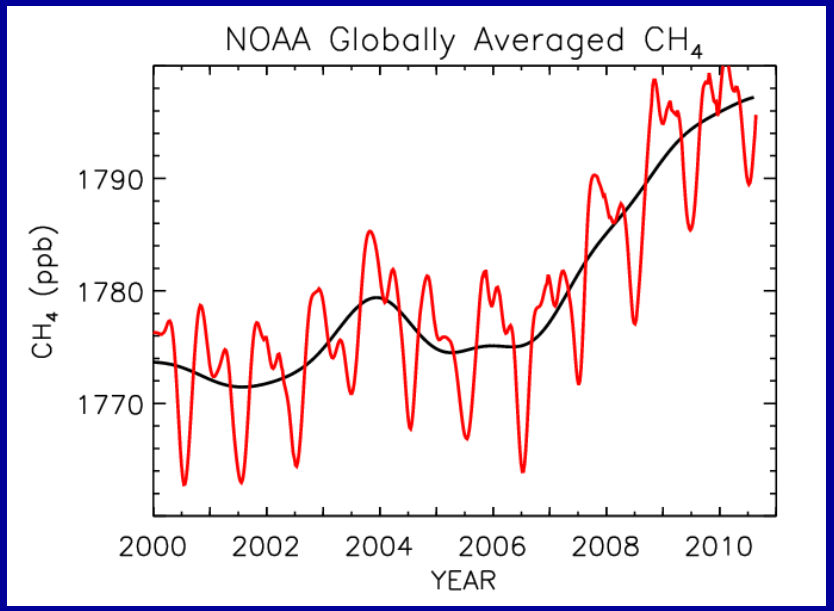
Inversions are inconsistent.

Data suggest anomalous emissions in tropics and mid-latitudes.

High N latitudes recovered.

# SCIAMACHY

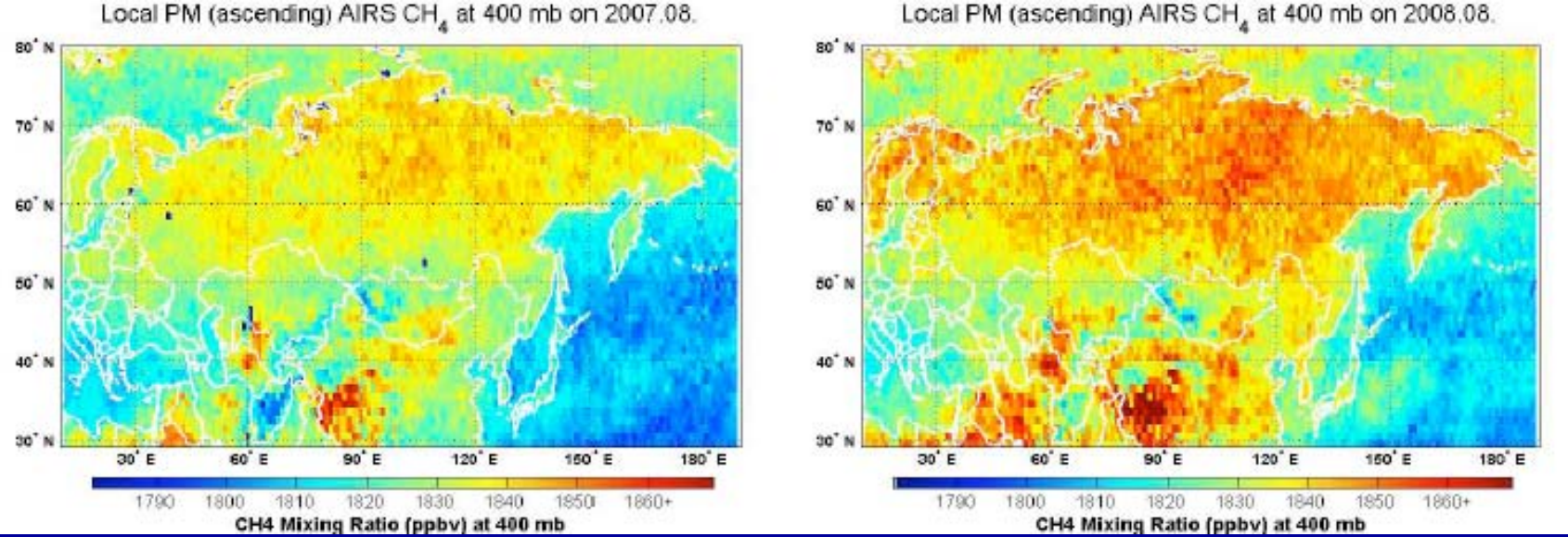


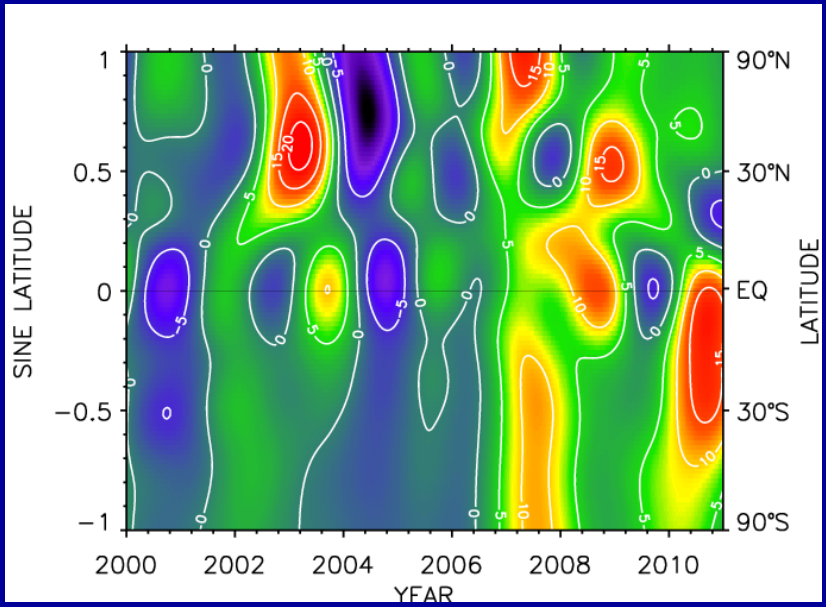



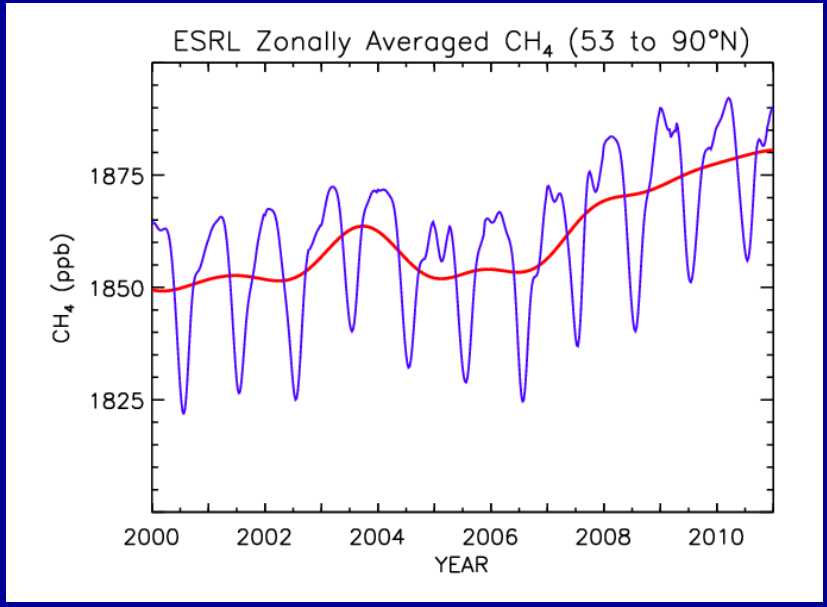

Increases in SCIA in 2007 and 2008 consistent with in situ observations.
Insufficient S/N to identify cause of recent $CH_4$ increase.
Frankenberg et al., JGR, 2011.

GOSAT may be better.

# AIRS


Local PM (ascending) AIRS CH4 at 400 mb on 2007.08.
Local PM (ascending) AIRS CH4 at 400 mb on 2008.08.
80° N
70° N
60° N
50° N
40° N
30° N
30° E
60° E
90° E
120° E
150° E
180° E
1790
1800
1810
1820
1830
1840
1850
1860+
CH4 Mixing Ratio (ppbv) at 400 mb

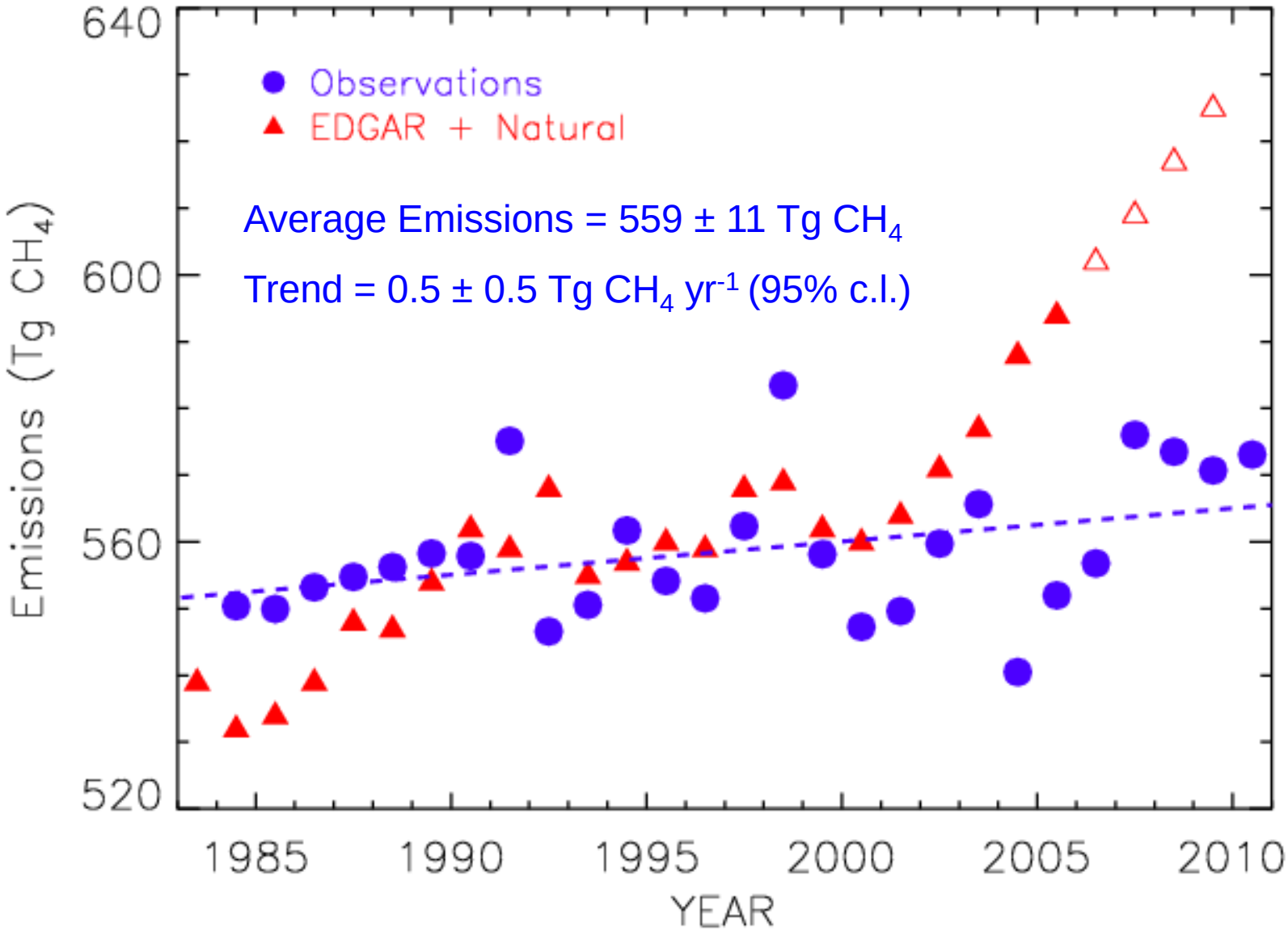

SINE LATITUDE
1
0.5
0
−0.5
−1
90°N
30°N
EQ
30°S
90°S
LATITUDE
2000
2002
2004
2006
2008
2010
YEAR


ESRL Zonally Averaged CH4 (53 to 90°N)
CH4 (ppb)
1875
1850
1825
2000
2002
2004
2006
2008
2010
YEAR

# Conclusions

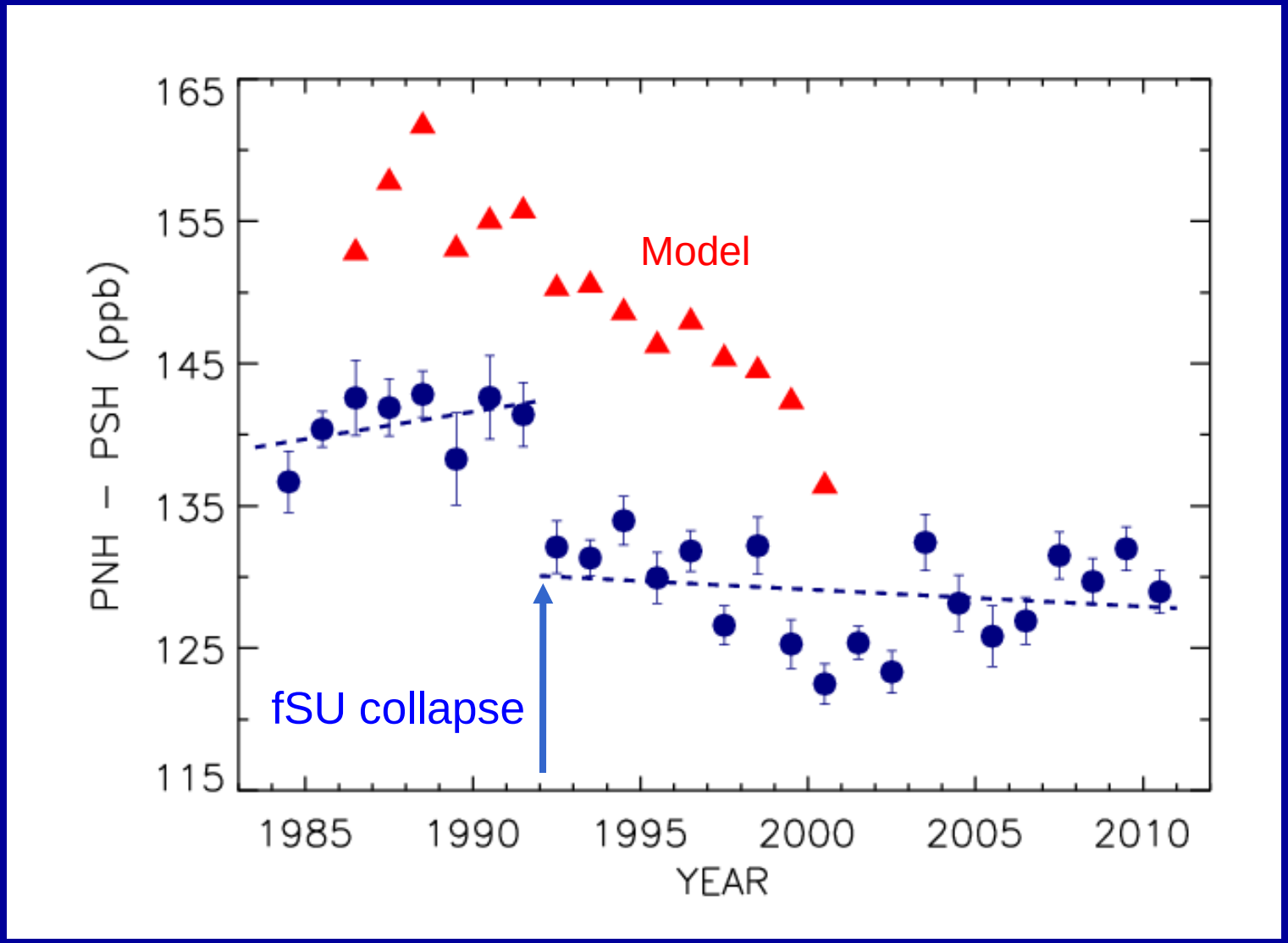
- Global $CH_4$ increase continues in 2010:
  - ~6.0 ppb $yr^{-1}$ from 2007 to 2010
  - Largest, most persistent anomaly in record
- Observation-based assessment of causes:
  - T and precipitation are key drivers
- Current observation network is insufficient:
  - Satellite sensors: low S/N and disinformation
  - *In situ* measurements: increase spatial coverage

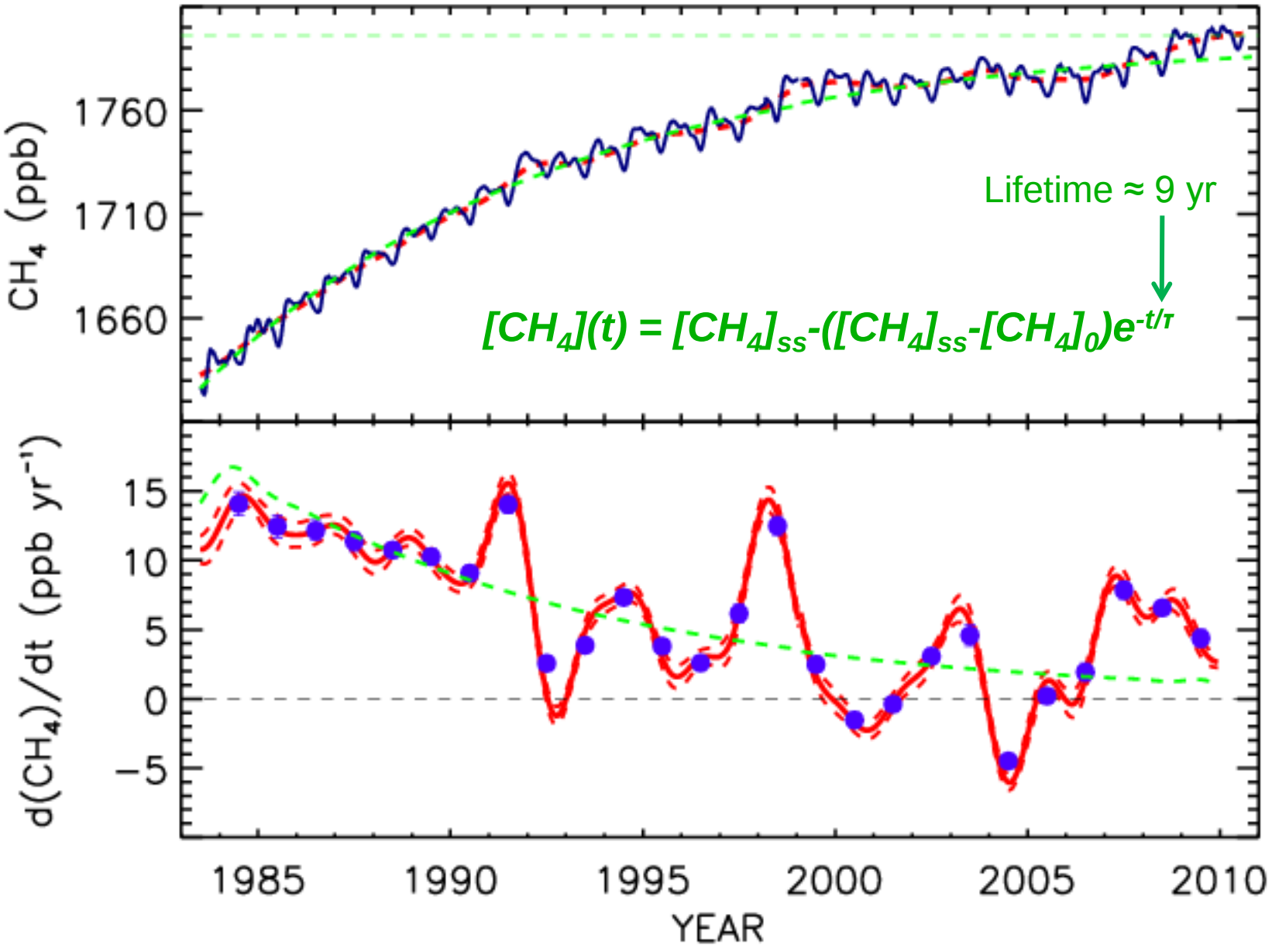
# Annual Emissions = $d[CH_4]/dt + [CH_4]/\tau$

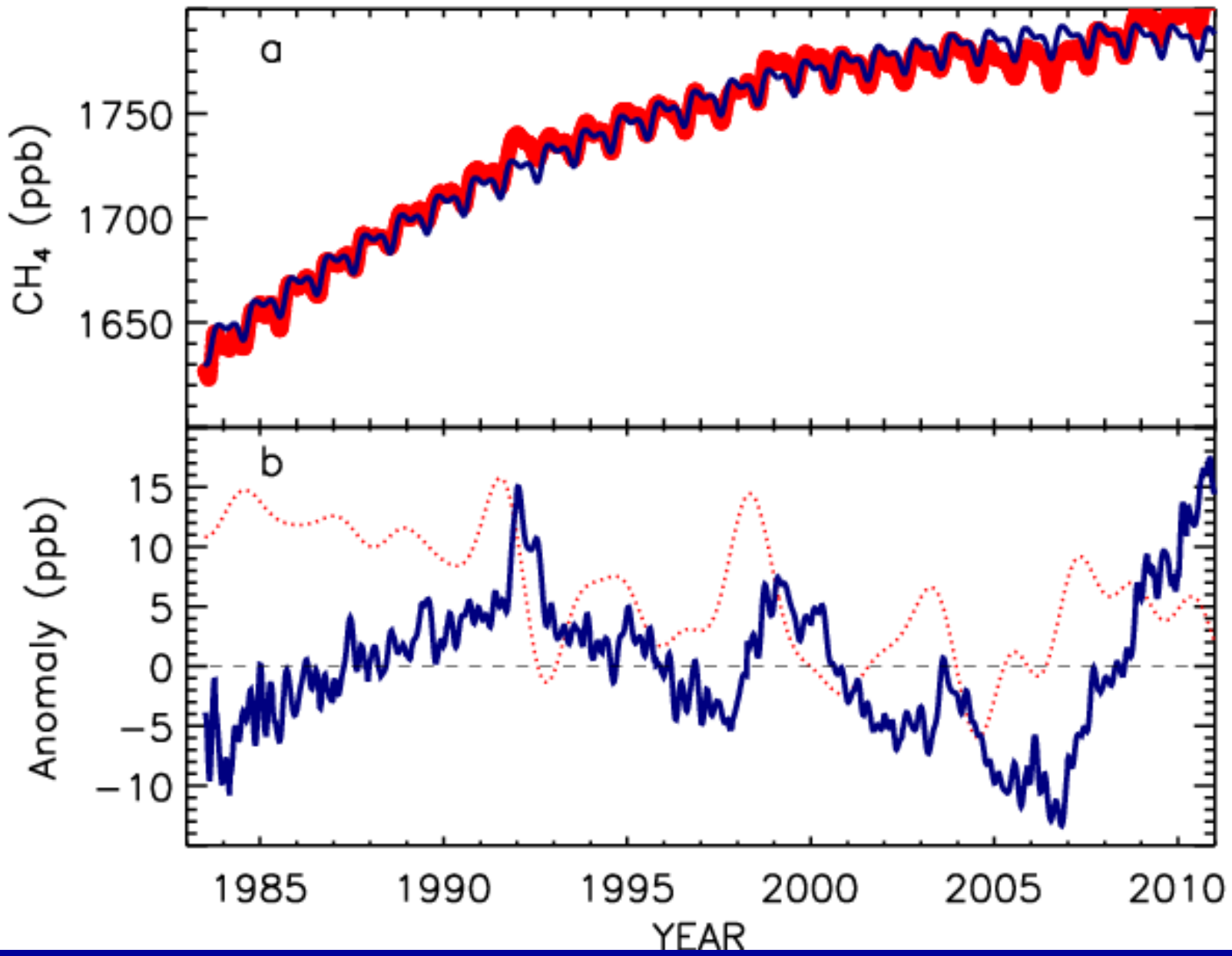


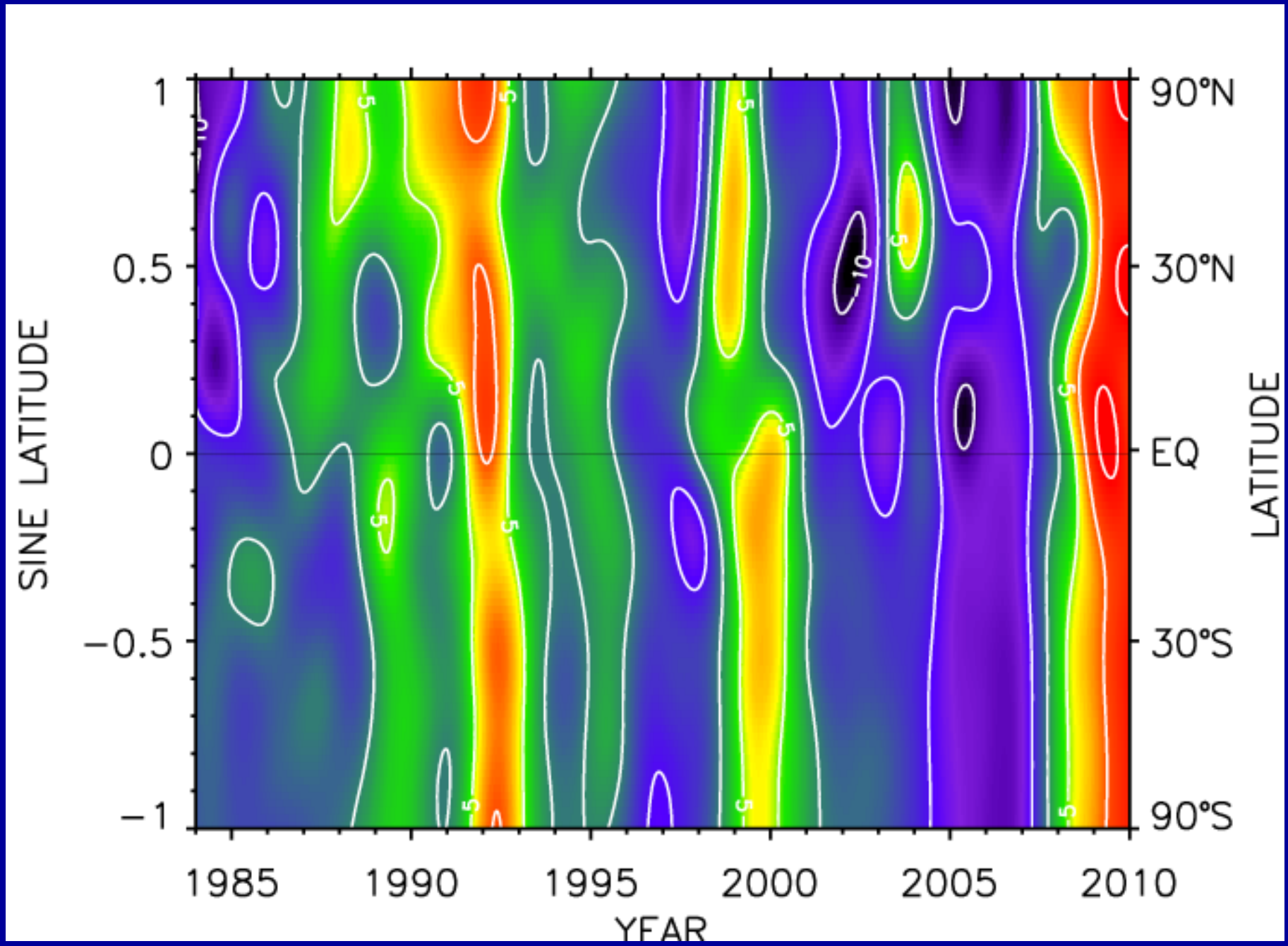
# Interpolar Difference

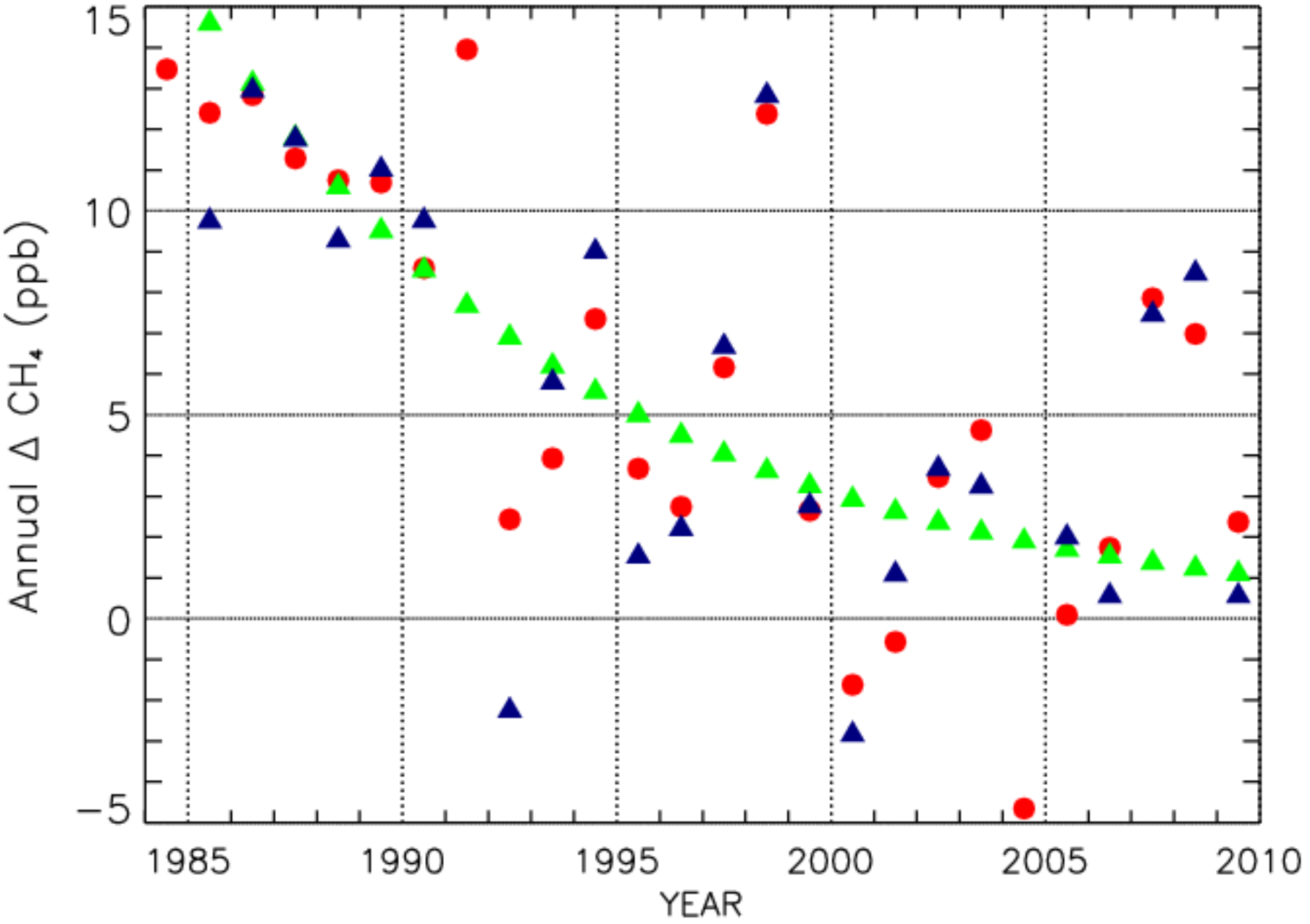
Update of: E. J. Dlugokencky, S. Houweling, L. Bruhwiler, K. A. Masarie, P. M. Lang, J. B. Miller, and P. P. Tans (2003), Atmospheric methane levels off: Temporary pause or a new steady-state?, *Geophys. Res. Lett.*, 30, 1992, doi:10.1029/2003GL018126.




CH4 (ppb)
1760
1710
1660
Lifetime ≈ 9 yr
[CH4](t) = [CH4]ss-([CH4]ss-[CH4]0)e-t/τ
d(CH4)/dt (ppb yr-1)
15
10
5
0
−5
1985
1990
1995
2000
2005
2010
YEAR


a
b
$CH_4$ (ppb)
1750
1700
1650
Anomaly (ppb)
15
10
5
0
−5
−10
1985
1990
1995
2000
2005
2010
YEAR


SINE LATITUDE
1
0.5
0
−0.5
−1
LATITUDE
90°N
30°N
EQ
30°S
90°S
1985
1990
1995
2000
2005
2010
YEAR
-10
-5


15
10
5
0
−5
Annual Δ CH₄ (ppb)
1985
1990
1995
2000
2005
2010
YEAR

# What Drove Recent Increases?

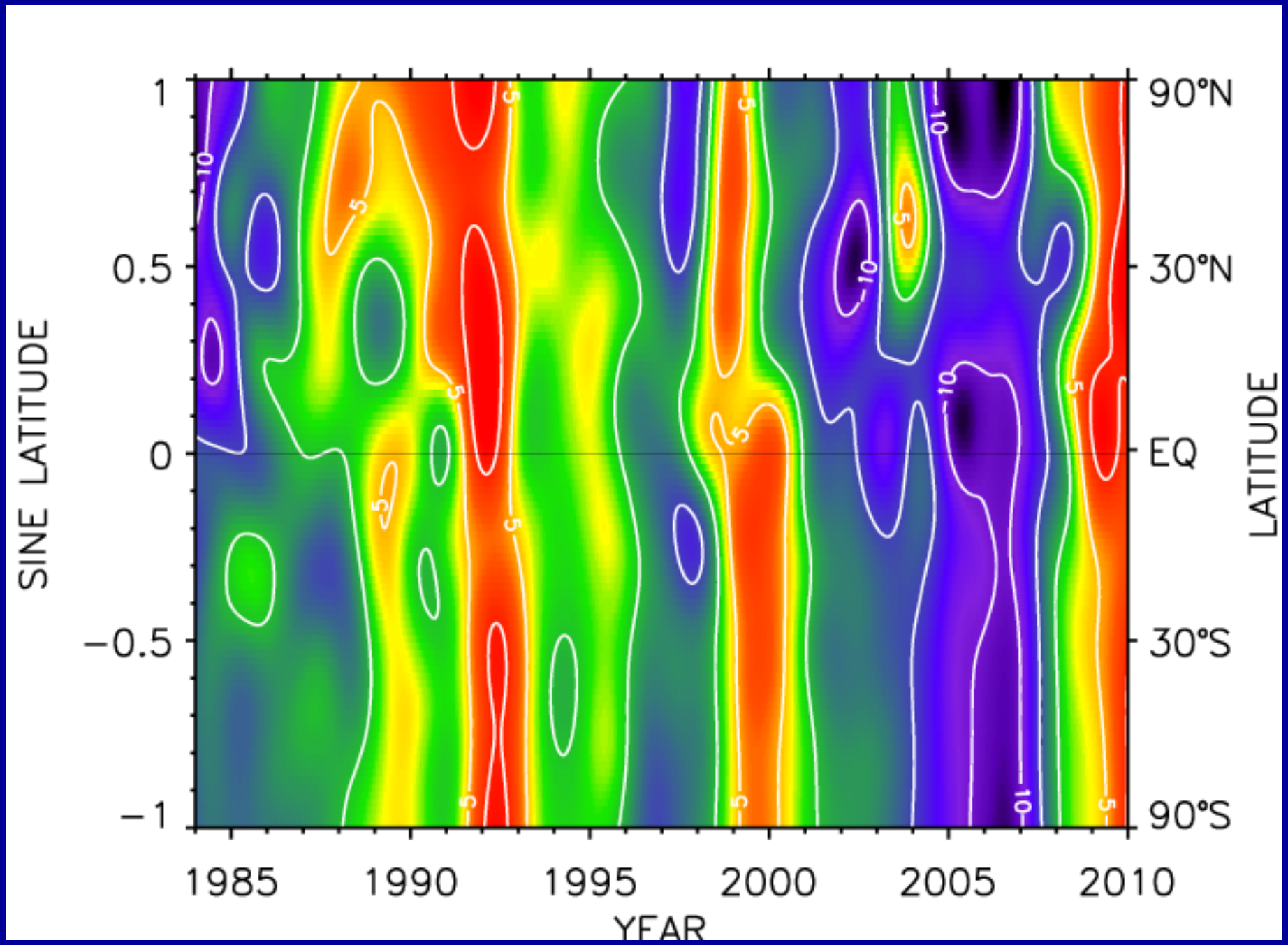
- Increased Arctic WL emissions
  - 2007: warmest year in N WL regions
  - $\delta^{13}C$ consistent with WL source
- Increased tropical WL emissions 2007/08
  - La Niña: increased tropical precipitation
  - $CH_4$ emissions in Amazon in 2007/8 ~50% greater than average for 2000-2006
- Biomass burning, Δ[OH] are minor

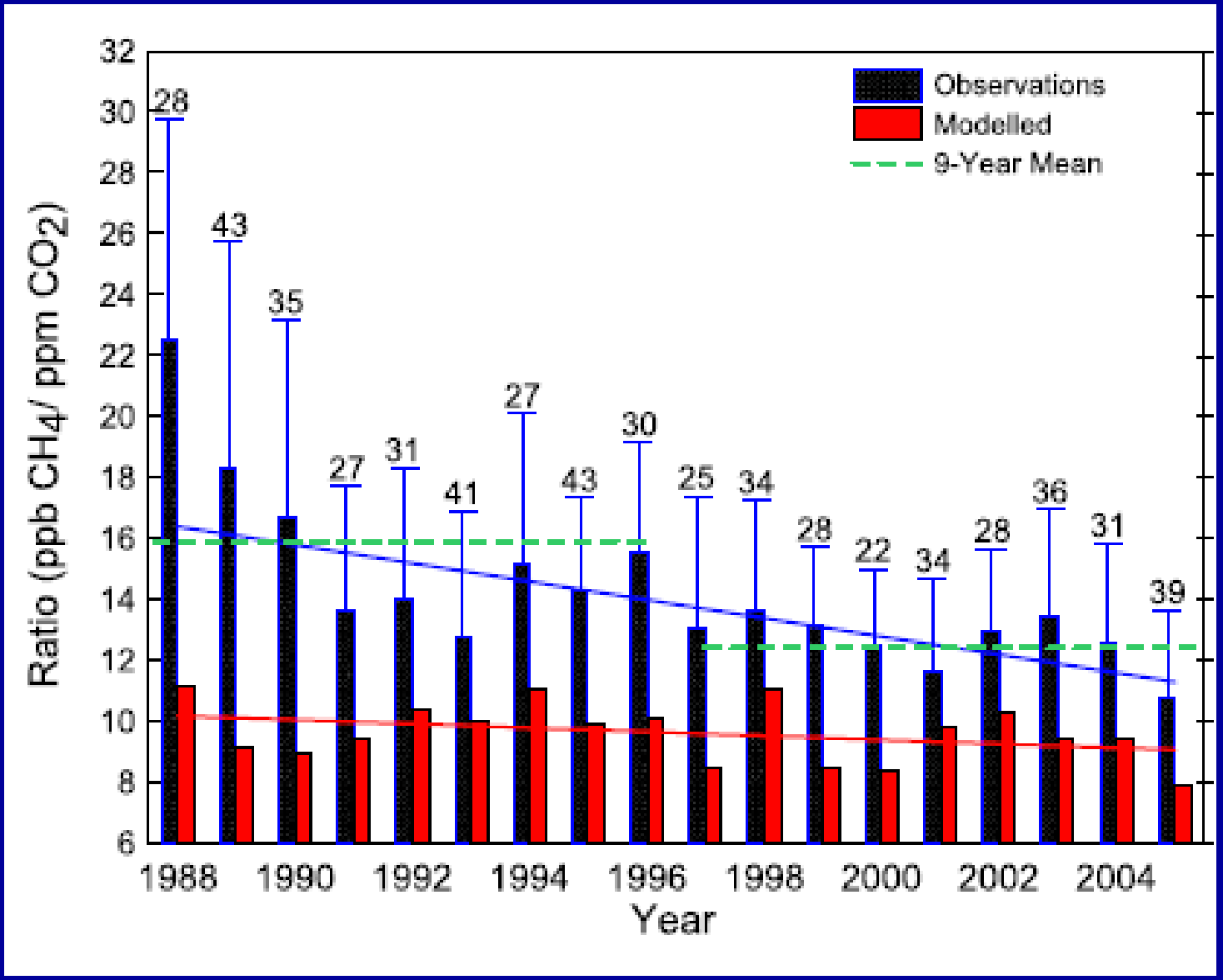
Dlugokencky et al., 2009, *GRL, 36*, doi:10.1029/2009GL039780
Bousquet et al., 2010, *ACPD*, under discussion.

# What Drove Recent Increases?

- 2007 – dominated by wetland emissions
  - Tropics (~50%) consistent Amazon obs.
  - Arctic (~20%) consistent with $\delta^{13}CH_4$ at ALT
- 2008 – dominated by tropics and mid-latitudes
  - La Niña: increased tropical precipitation
- Biomass burning, Δ[OH] are minor

Dlugokencky et al., 2009, *GRL, 36*, doi:10.1029/2009GL039780
Bousquet et al., 2010, *ACPD*, under discussion.


SINE LATITUDE
1
0.5
0
−0.5
−1
LATITUDE
90°N
30°N
EQ
30°S
90°S
1985
1990
1995
2000
2005
2010
YEAR




Worthy et al.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, D10301, doi:10.1029/2008JD011239, 2009

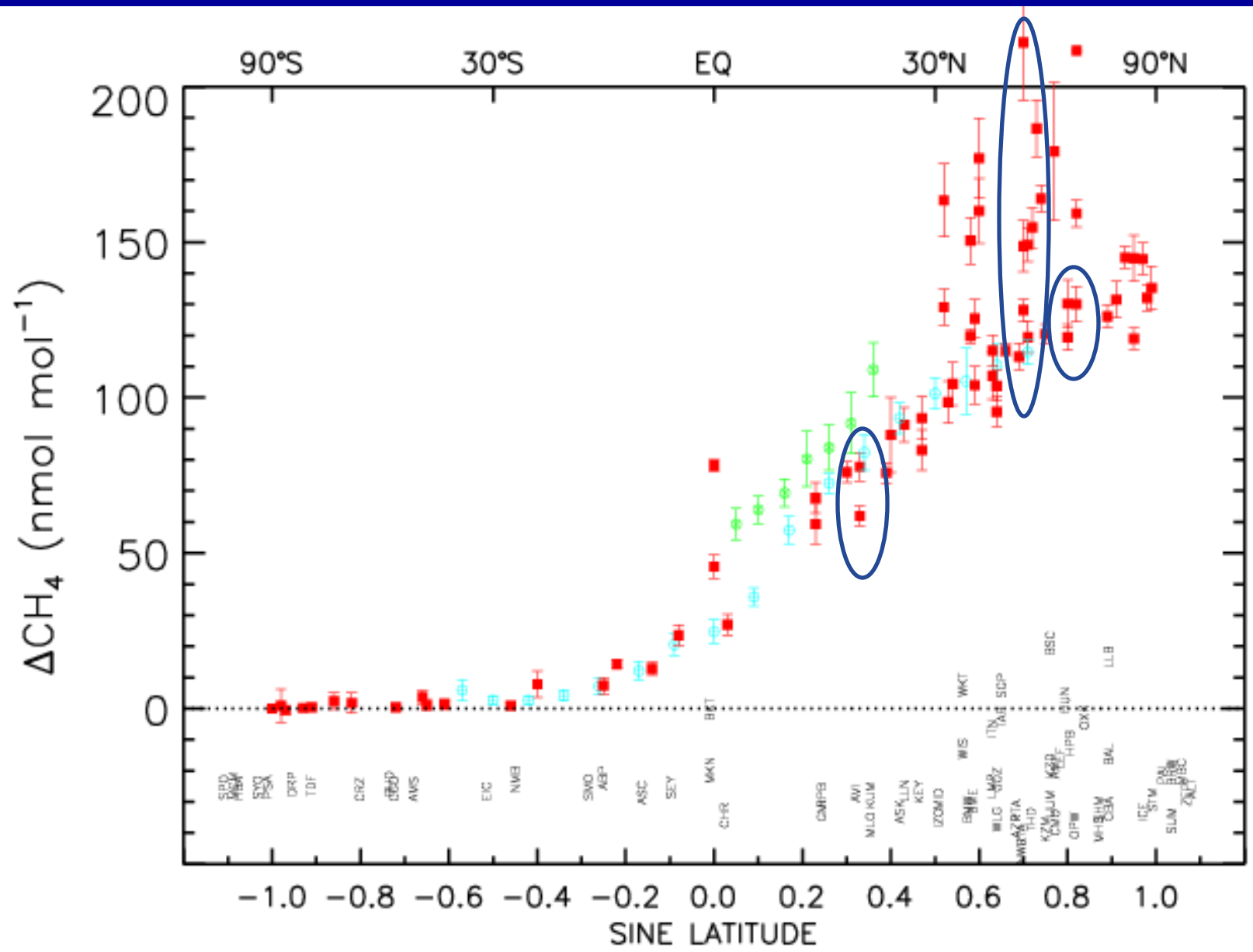
# Global Annual Emissions (Top Down)

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

Where E = emissions

$\tau$ = $CH_4$ lifetime = 8.9 years

(Oxidation by OH and soil microbes)

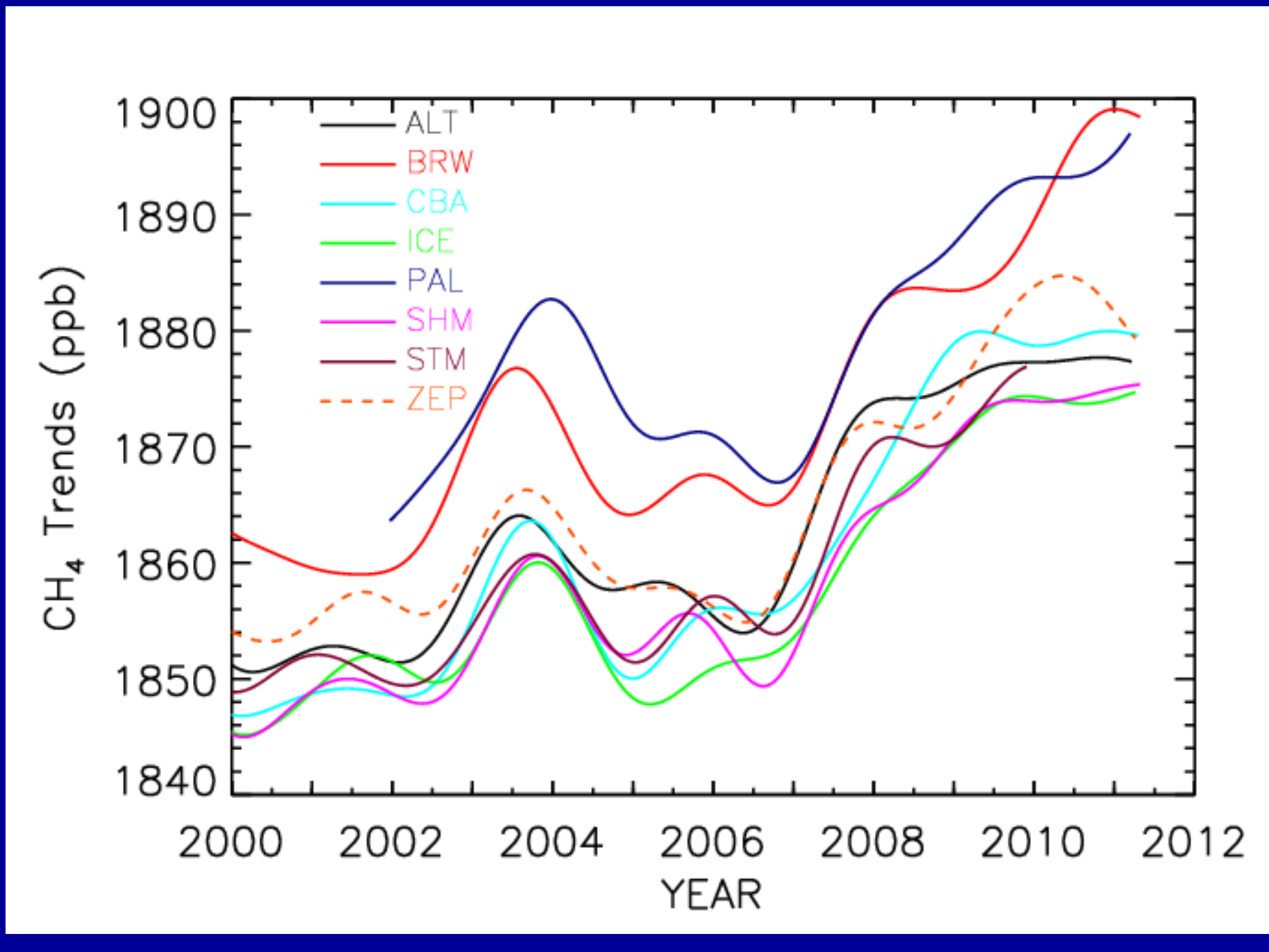

90°S
30°S
EQ
30°N
90°N
200
150
100
50
0
ΔCH4 (nmol mol−1)
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
SINE LATITUDE

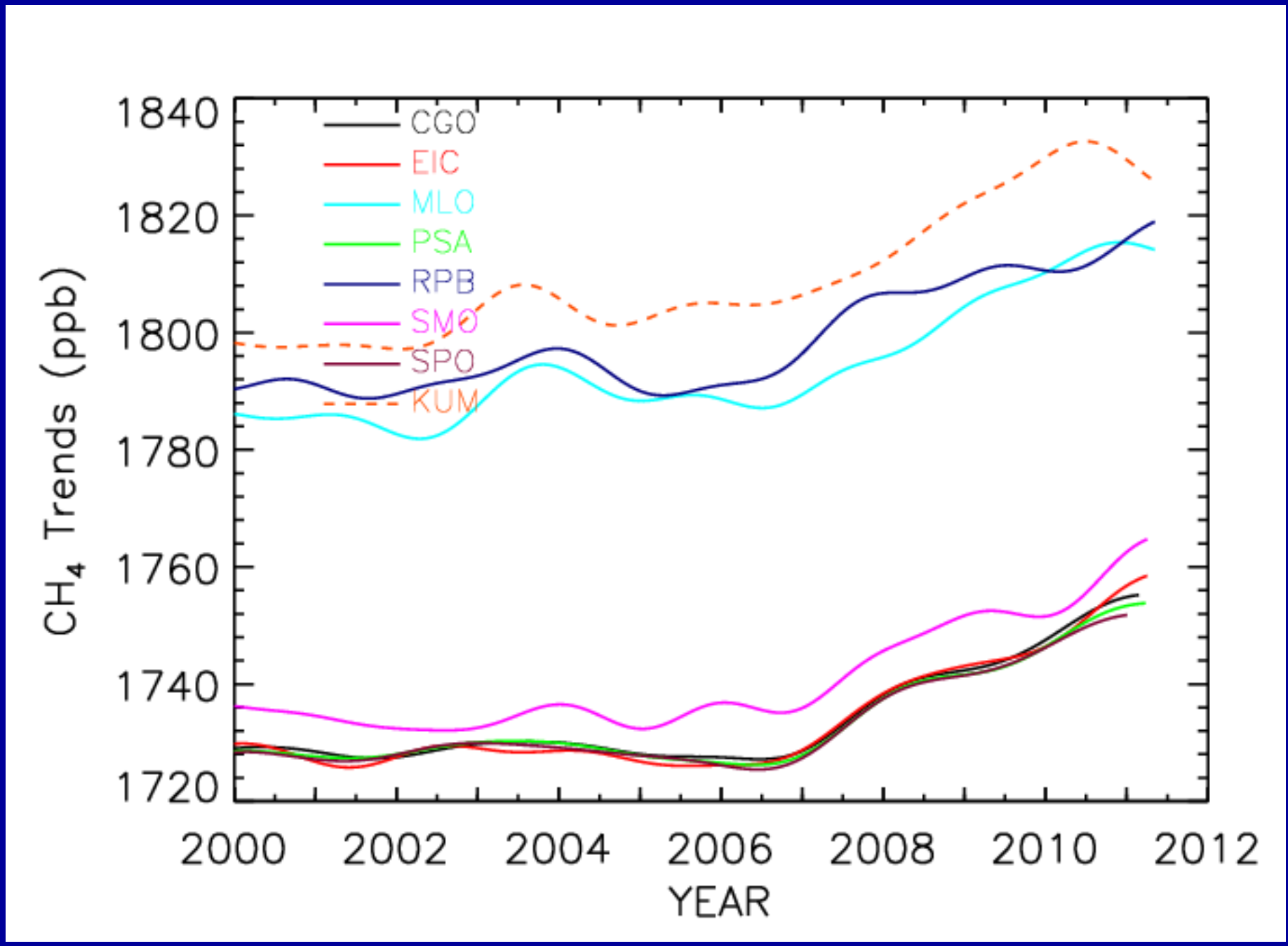
# Global $CH_4$ Budget by Source

| Source | Bousquet (Tg/yr) | IPCC Range (Tg/yr) |
|---|---|---|
| *Anthropogenic* | | |
| Energy | 110 13 | 74-106 |
| Enteric fermentation | 90 14 | 76-92 |
| Rice agriculture | 31 5 | 31-112 |
| Biomass burning | 50 8 | 14-88 |
| Waste | 55 11 | 35-69 |
| *Natural* | | |
| Wetlands | 147 15 | 100-231 |
| Termites | 23 4 | 20-29 |
| Oceans | 19 6 | 4-15 |
| **Total** | **525 8** | **503-610** |

| Sinks | Bousquet (Tg/yr) | IPCC (Tg/yr) |
|---|---|---|
| Troposphere | 448 1 | 428-511 |
| Stratosphere | 37 1 | 30-45 |
| Soil | 21 3 | 26-34 |
| **Total** | **506** | **492-581** |

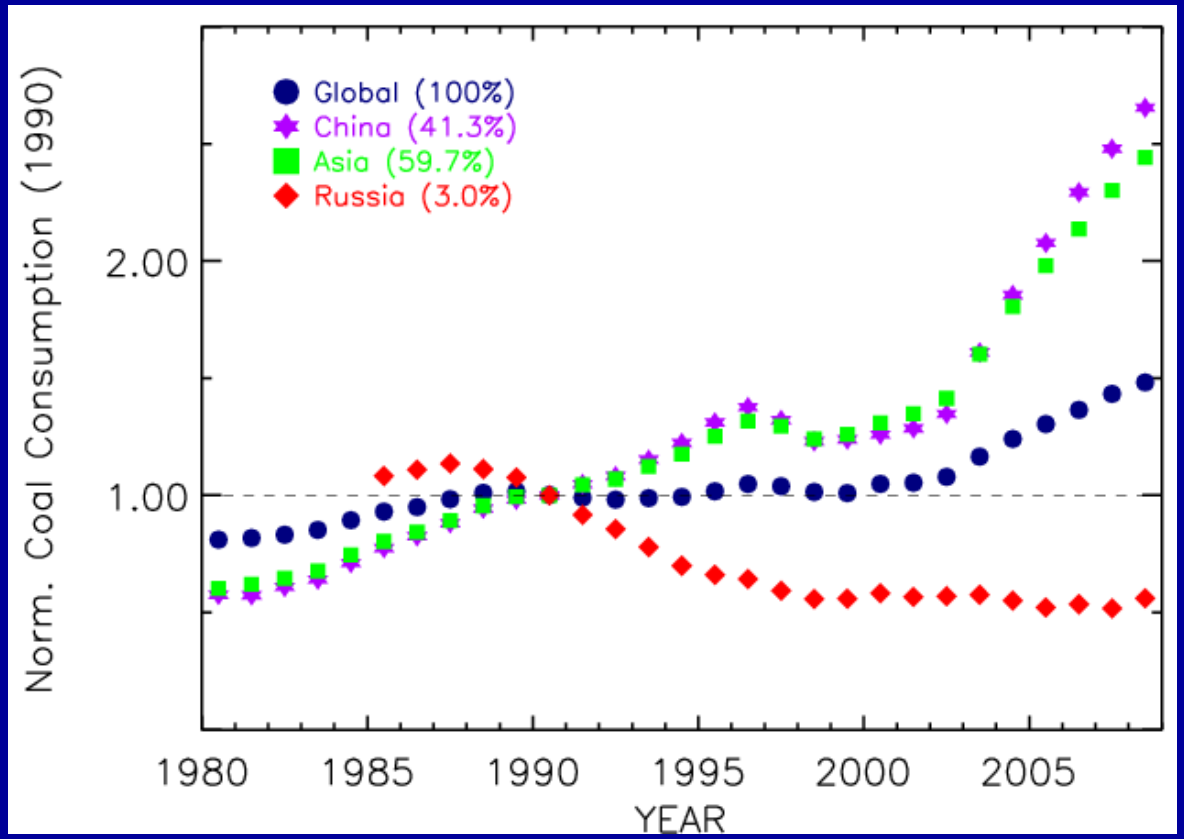
Bousquet et al., 2006, *Nature*, **443**, 439-443, doi:10.1038/nature05132.


ALT
BRW
CBA
ICE
PAL
SHM
STM
ZEP
1900
1890
1880
1870
1860
1850
1840
CH4 Trends (ppb)
2000
2002
2004
2006
2008
2010
2012
YEAR


CGO
EIC
MLO
PSA
RPB
SMO
SPO
KUM
1840
1820
1800
1780
1760
1740
1720
CH4 Trends (ppb)
2000
2002
2004
2006
2008
2010
2012
YEAR

# Anthropogenic contribution to 2007 - 2009 $CH_4$ increases

- Δ Anthropogenic emissions
  - Expect gradual changes



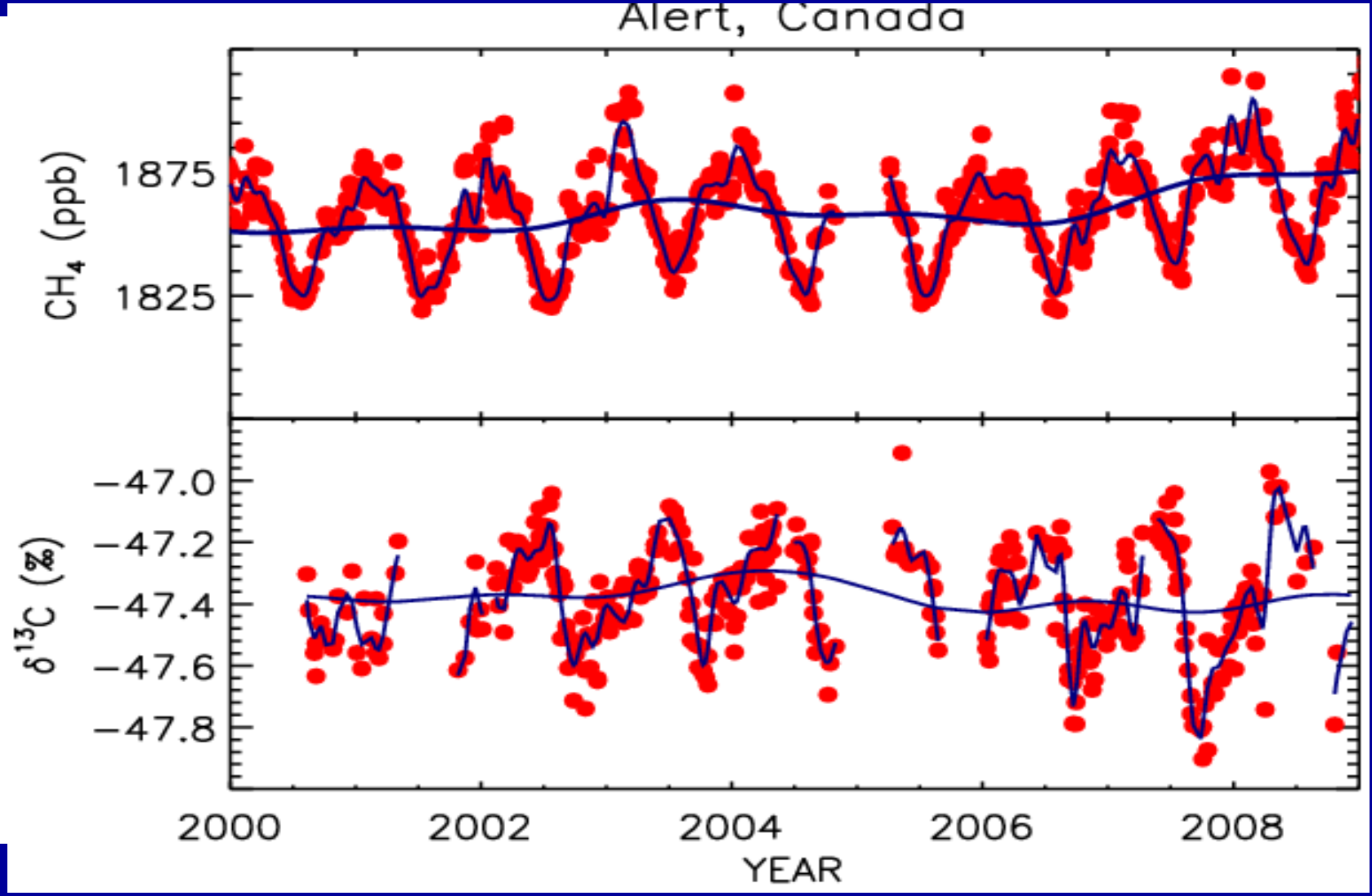
# Biomass burning contribution to 2007/2008 $CH_4$ increases:

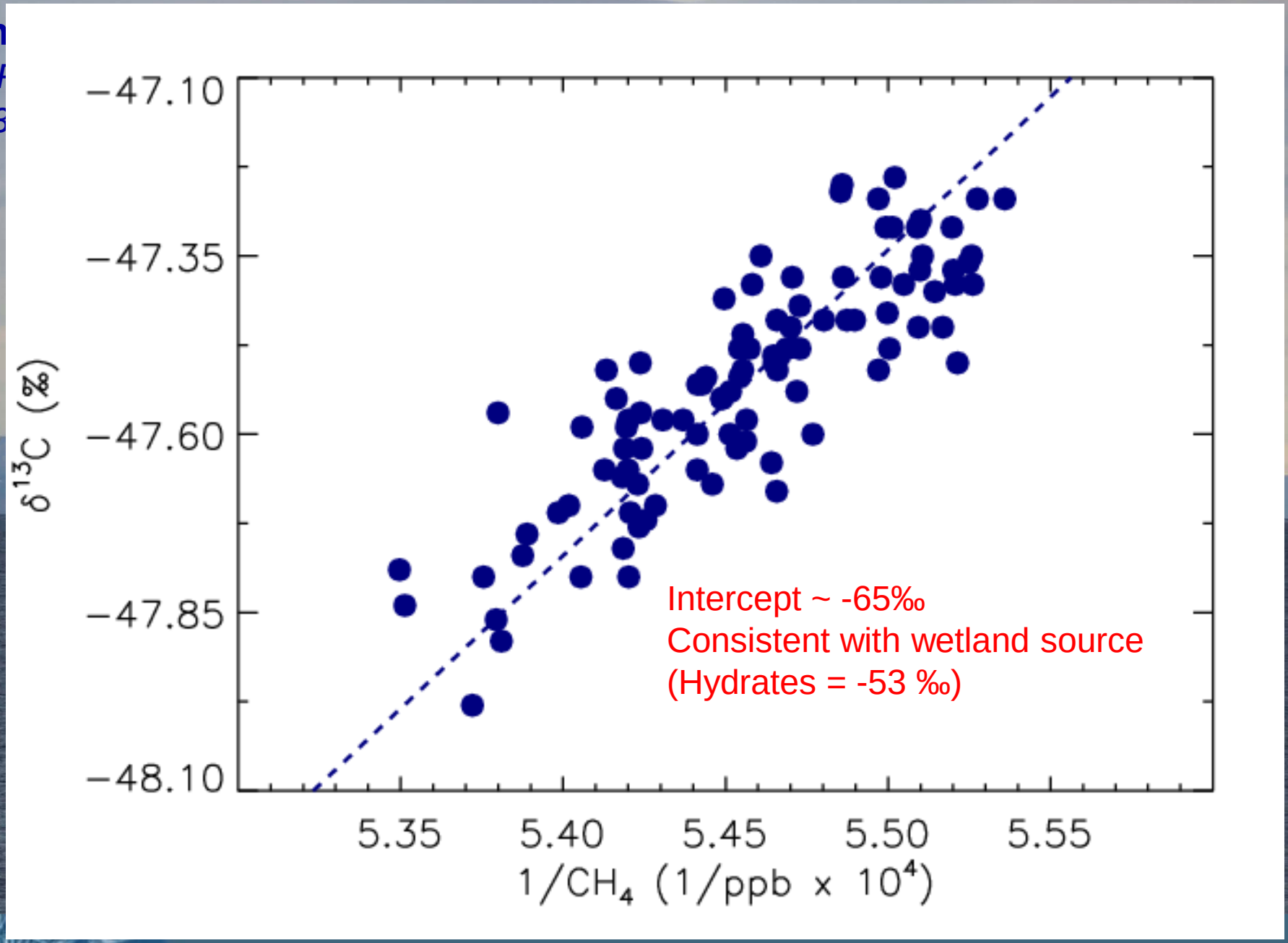
- Chloromethane, $CH_3Cl$ (NOAA)
- Remotely sensed CO (MOPITT)
- NOAA surface CO observations

# Sink contribution to 2007 - 2009 $CH_4$ increases

- Δ Loss rate (Δ [OH])
  - $CH_3CCl_3$ analysis suggests not (-2 to +1%)
  - PCE suggests not (I. Simpson, UCI)
  - CO suggests not

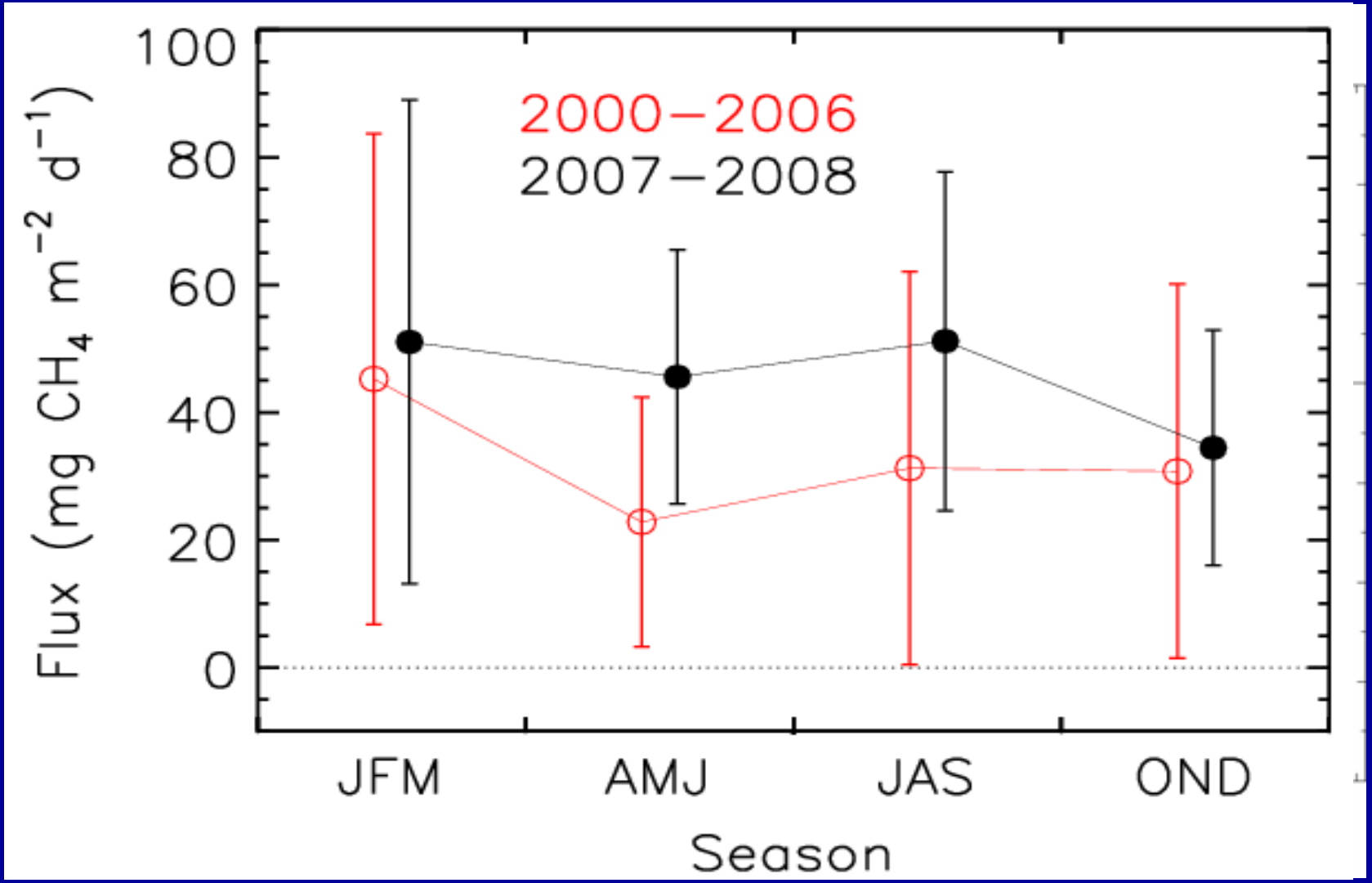
# Wetland contribution to 2007/2008 $CH_4$ increases:

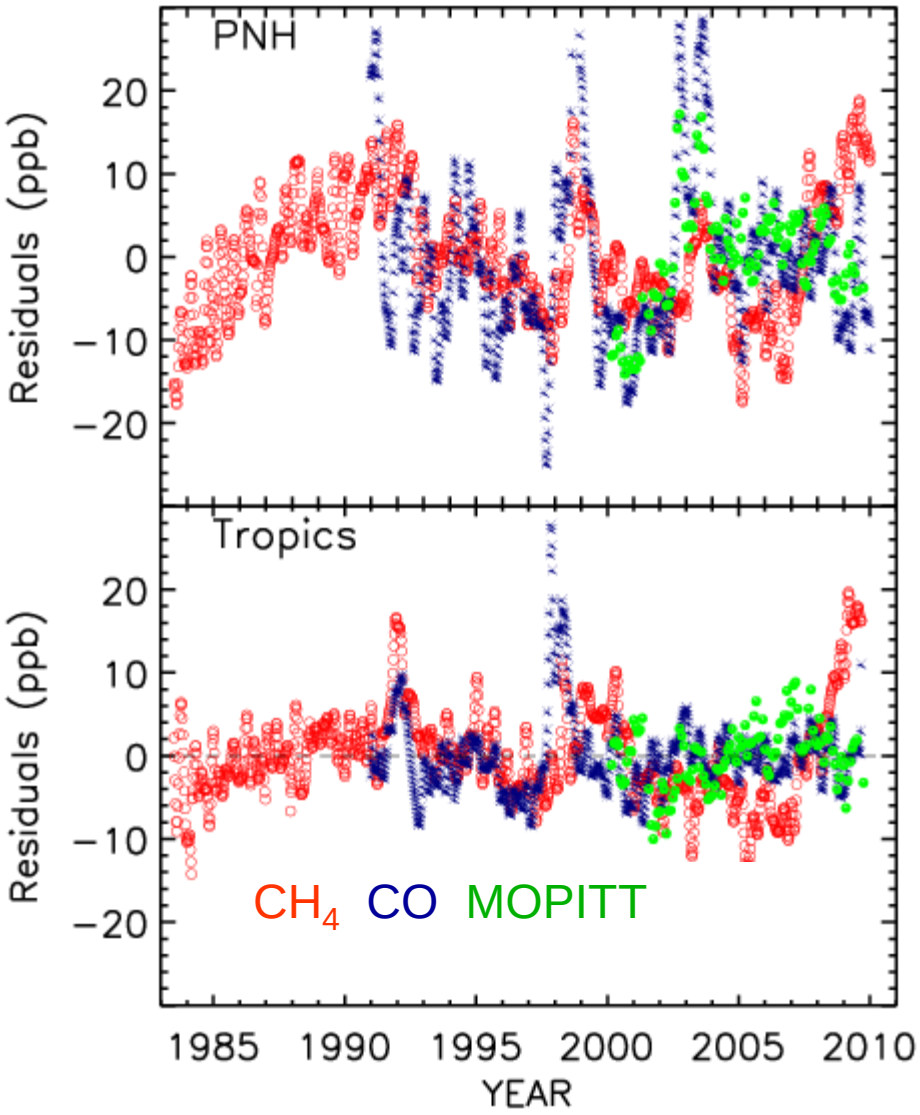





*Westbrook et al., Geophys. Res. Lett, 2009*

# Wetland contribution to 2007/2008 $CH_4$ increases:






Polar northern latitudes

Tropics

MOPITT CO courtesy of Louisa Emmons, NCAR