A comprehensive approach to understanding renewed increase in atmospheric CH_4

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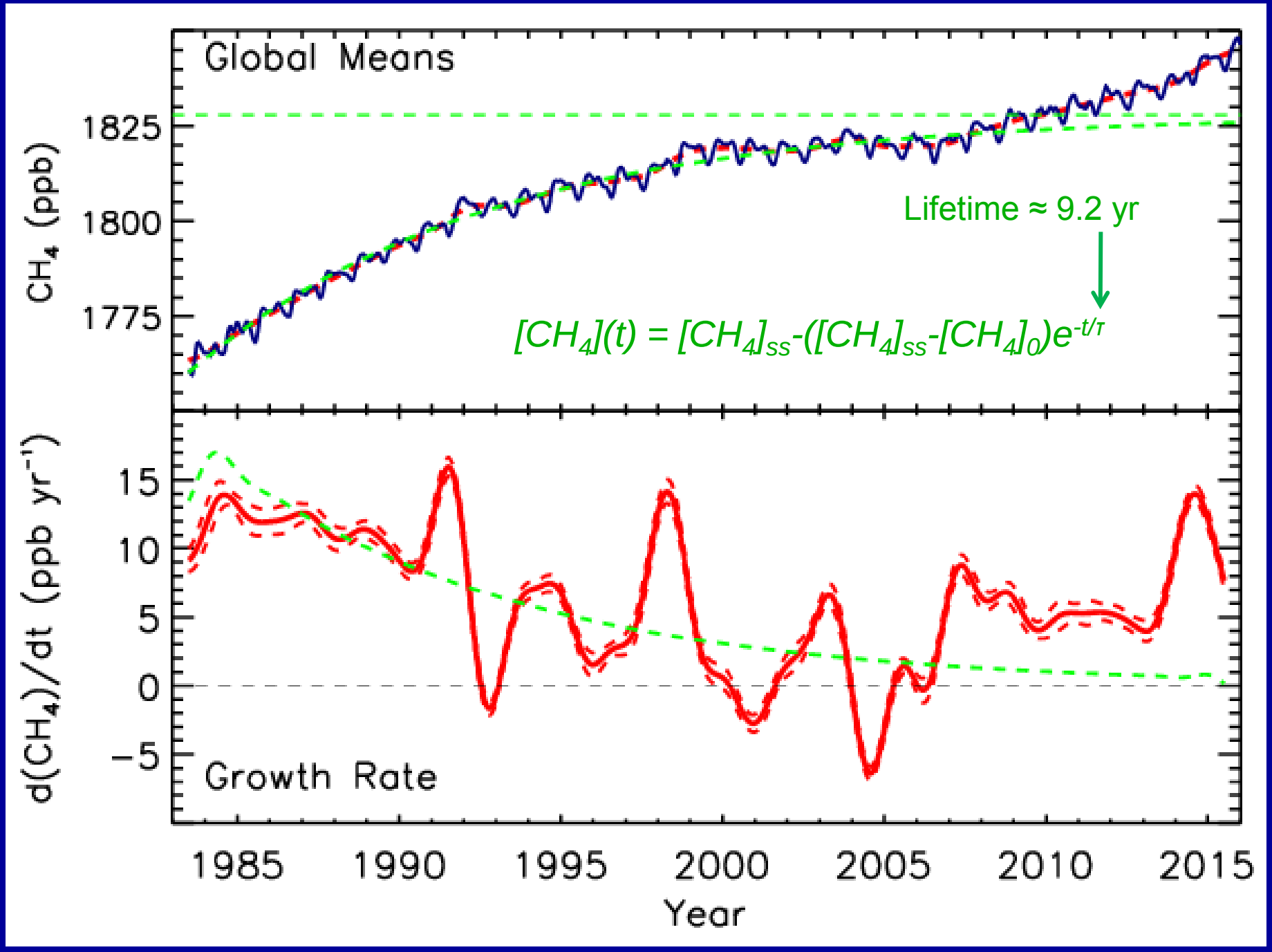
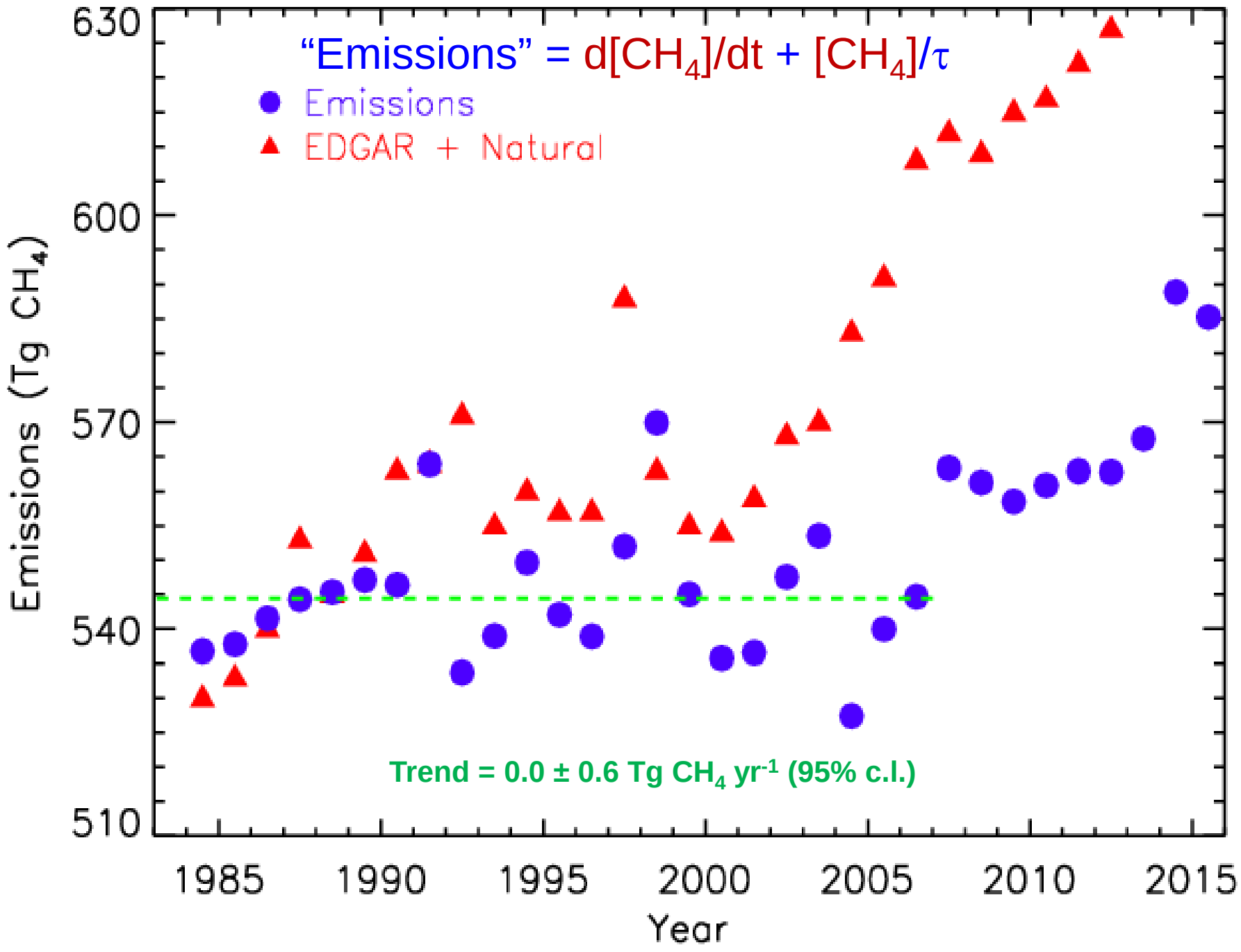
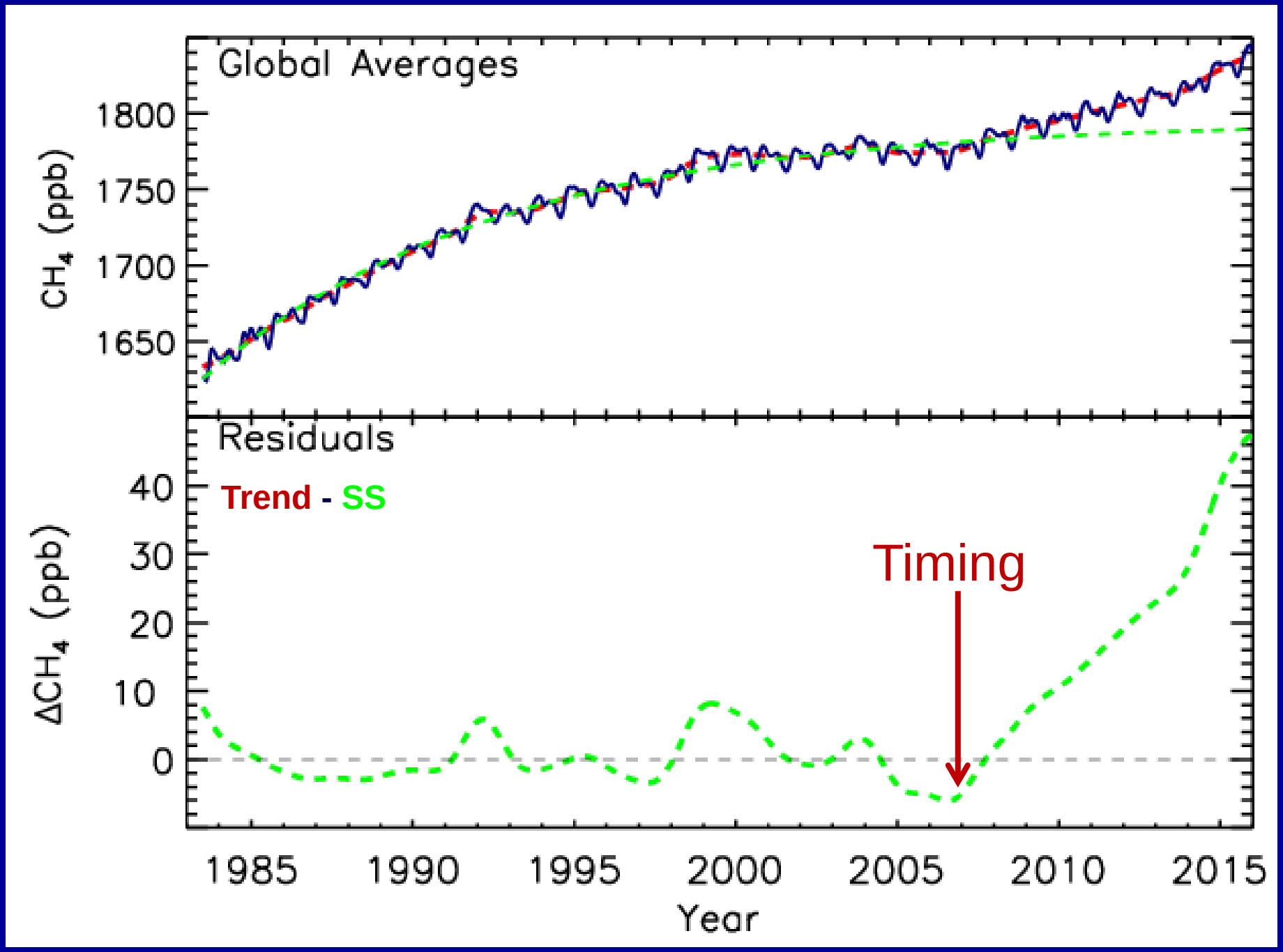

Global Means
1825
1800
1775
CH4 (ppb)
Lifetime ≈ 9.2 yr
[CH4](t) = [CH4]ss-([CH4]ss-[CH4]0)e-t/τ
15
10
5
0
−5
d(CH4)/dt (ppb yr-1)
Growth Rate
1985
1990
1995
2000
2005
2010
2015
Year

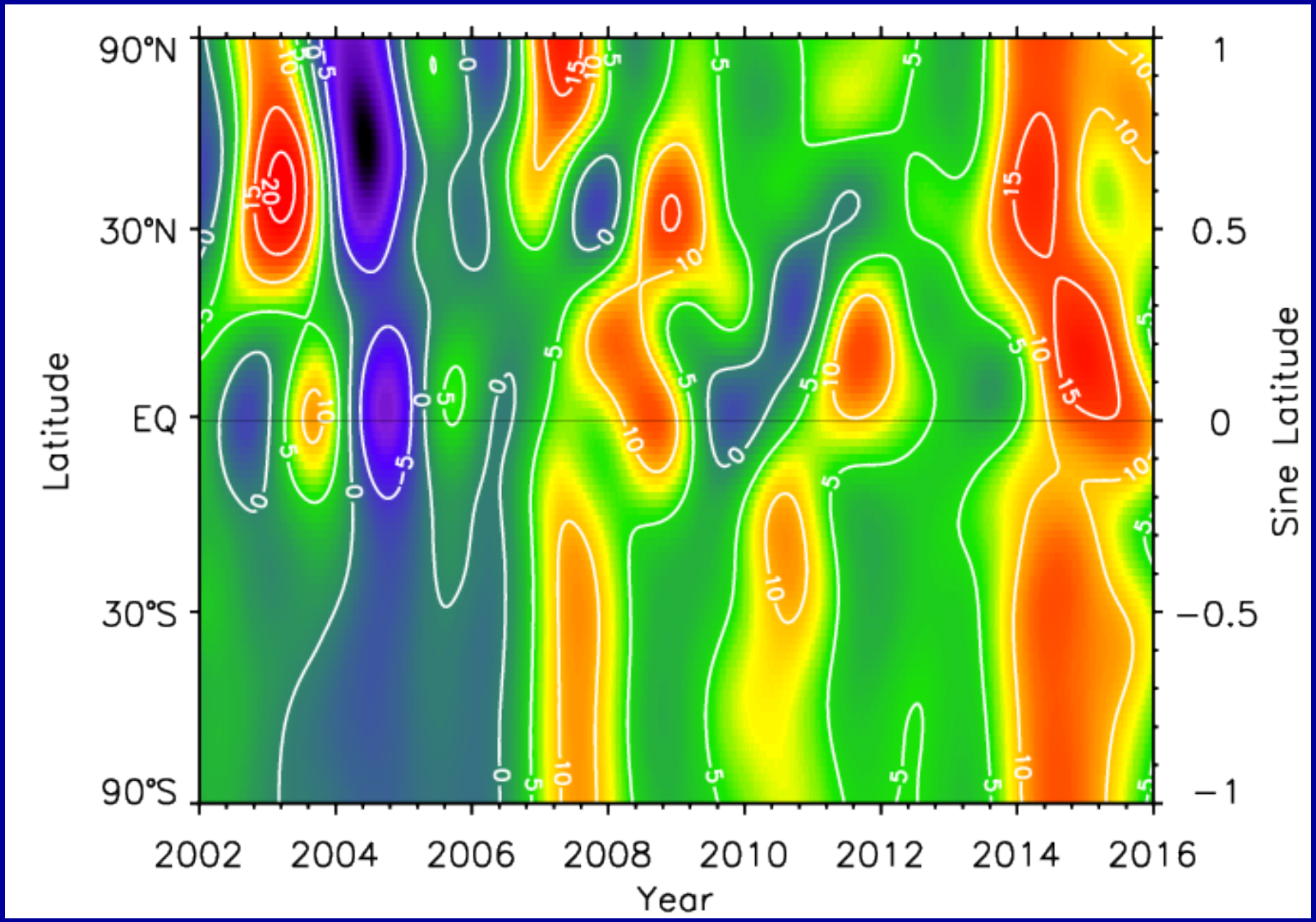
What caused the renewed CH_4 increase since 2007?

- Increased Arctic emissions responding to climate change?
  - Melting permafrost releases carbon
  - CH_4 clathrates
- Increased CH_4 emissions from hydraulic fracturing in the US?
  - Natural gas as bridge fuel

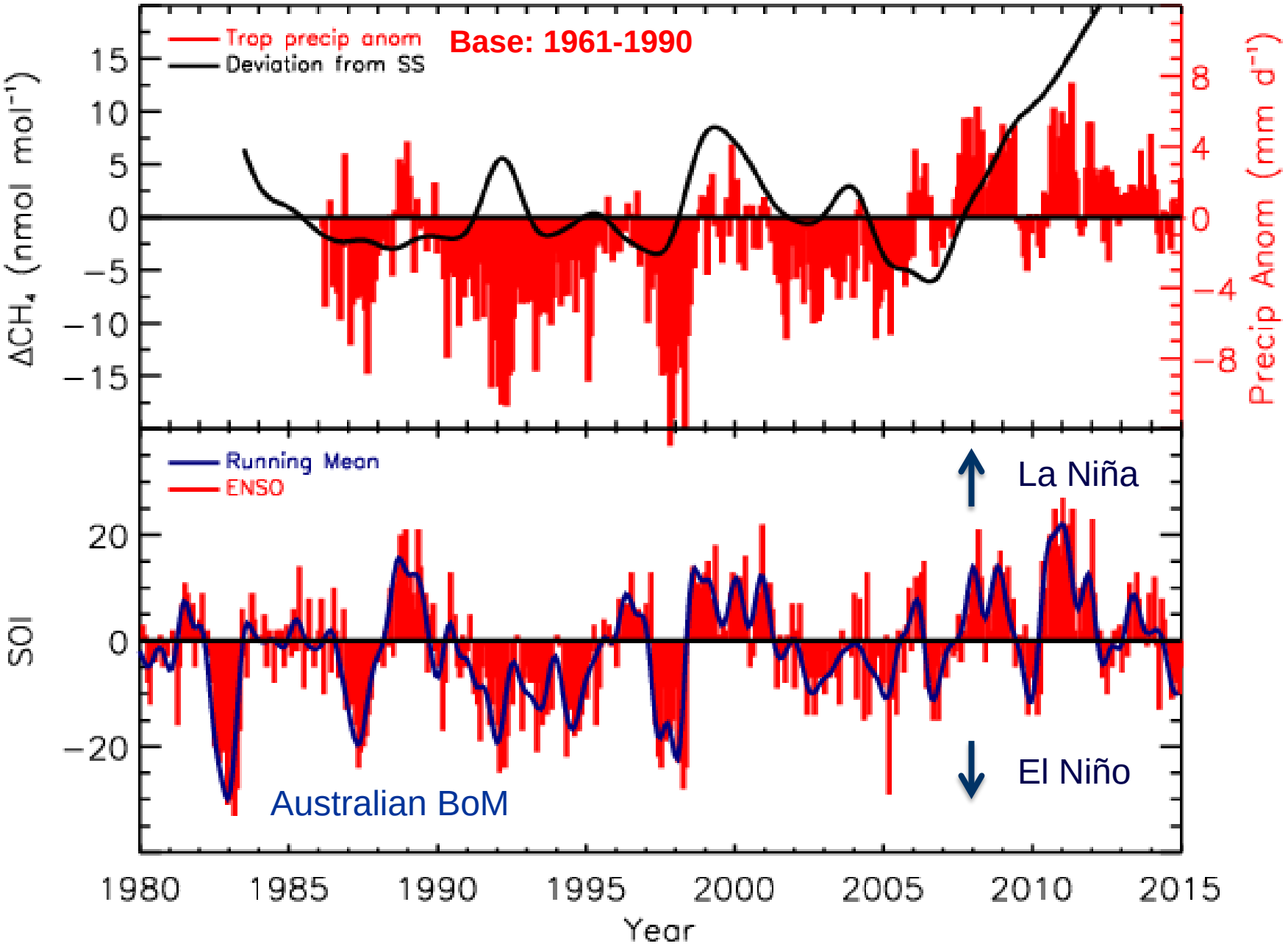

"Emissions" = d[CH4]/dt + [CH4]/τ
Emissions
EDGAR + Natural
Trend = 0.0 ± 0.6 Tg CH4 yr-1 (95% c.l.)
Emissions (Tg CH4)
Year
630
600
570
540
510
1985
1990
1995
2000
2005
2010
2015

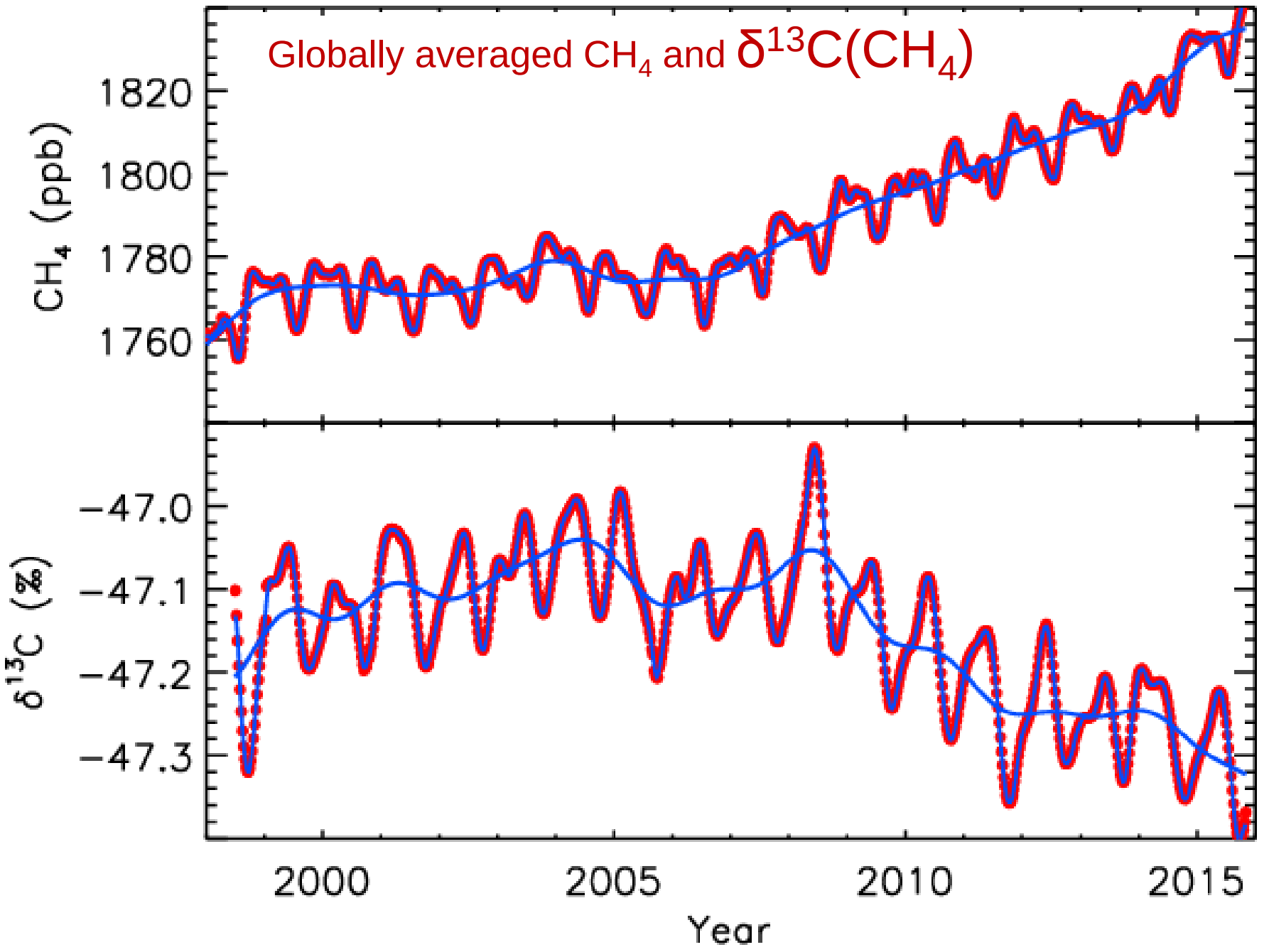

Global Averages
1800
1750
1700
1650
CH4 (ppb)
Residuals
Trend - SS
40
30
20
10
0
ΔCH4 (ppb)
Timing
1985
1990
1995
2000
2005
2010
2015
Year

Spatial Patterns

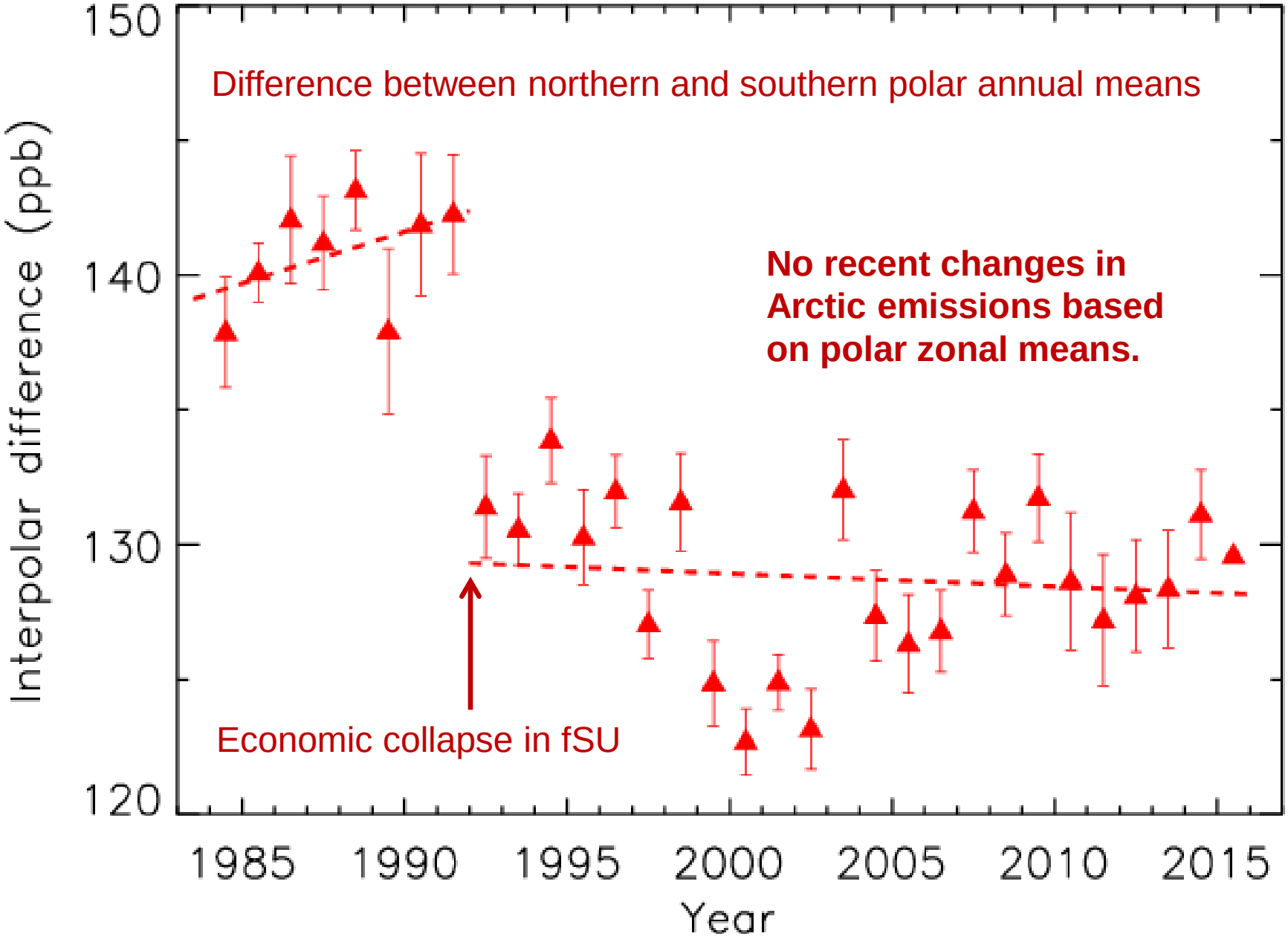


ENSO Phase: Precipitation



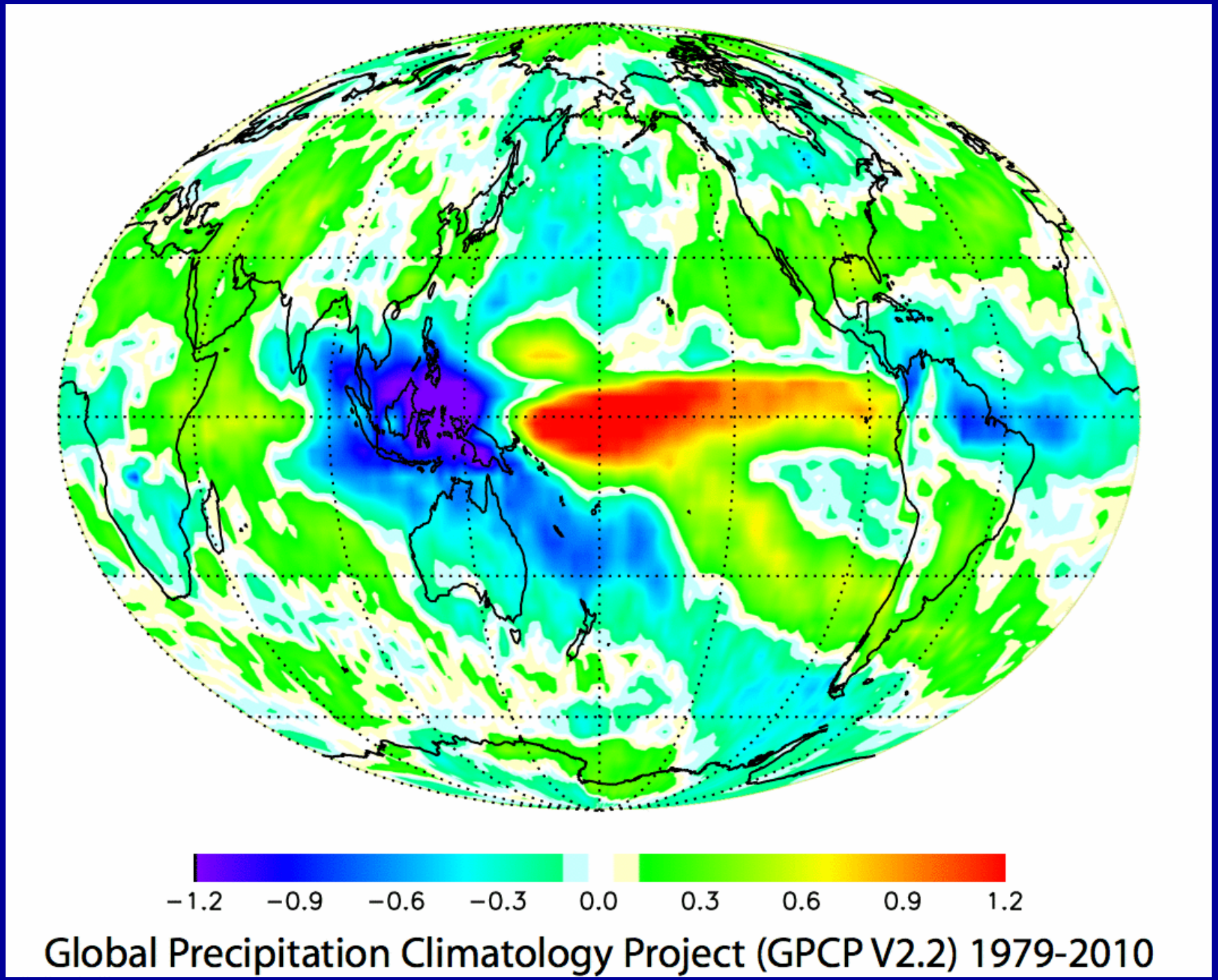

Globally averaged CH_4 and $\delta^{13}C(CH_4)$
CH_4 (ppb)
1820
1800
1780
1760
$\delta^{13}C$ (‰)
−47.0
−47.1
−47.2
−47.3
2000
2005
2010
2015
Year

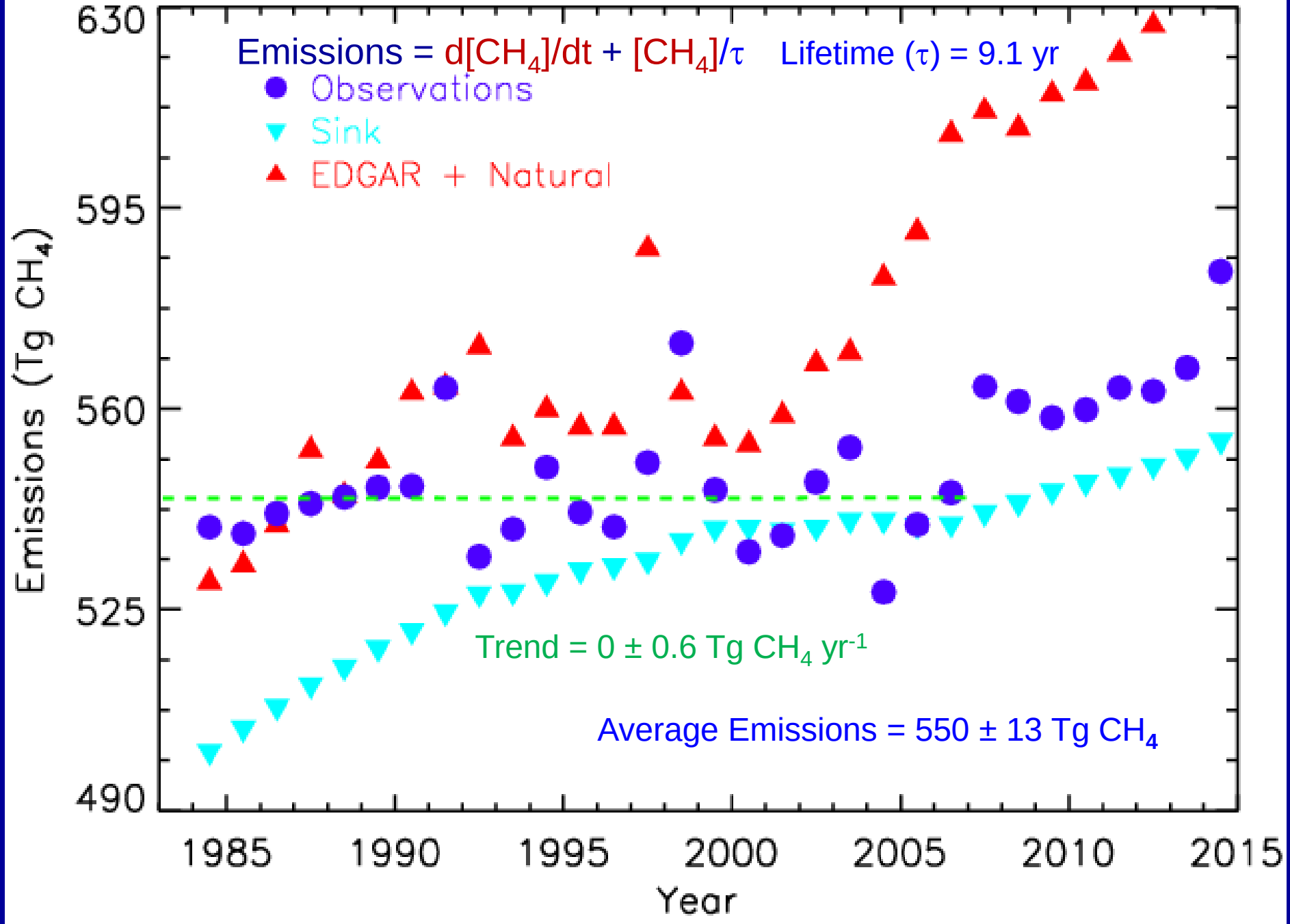
Arctic wetlands and clathrates?

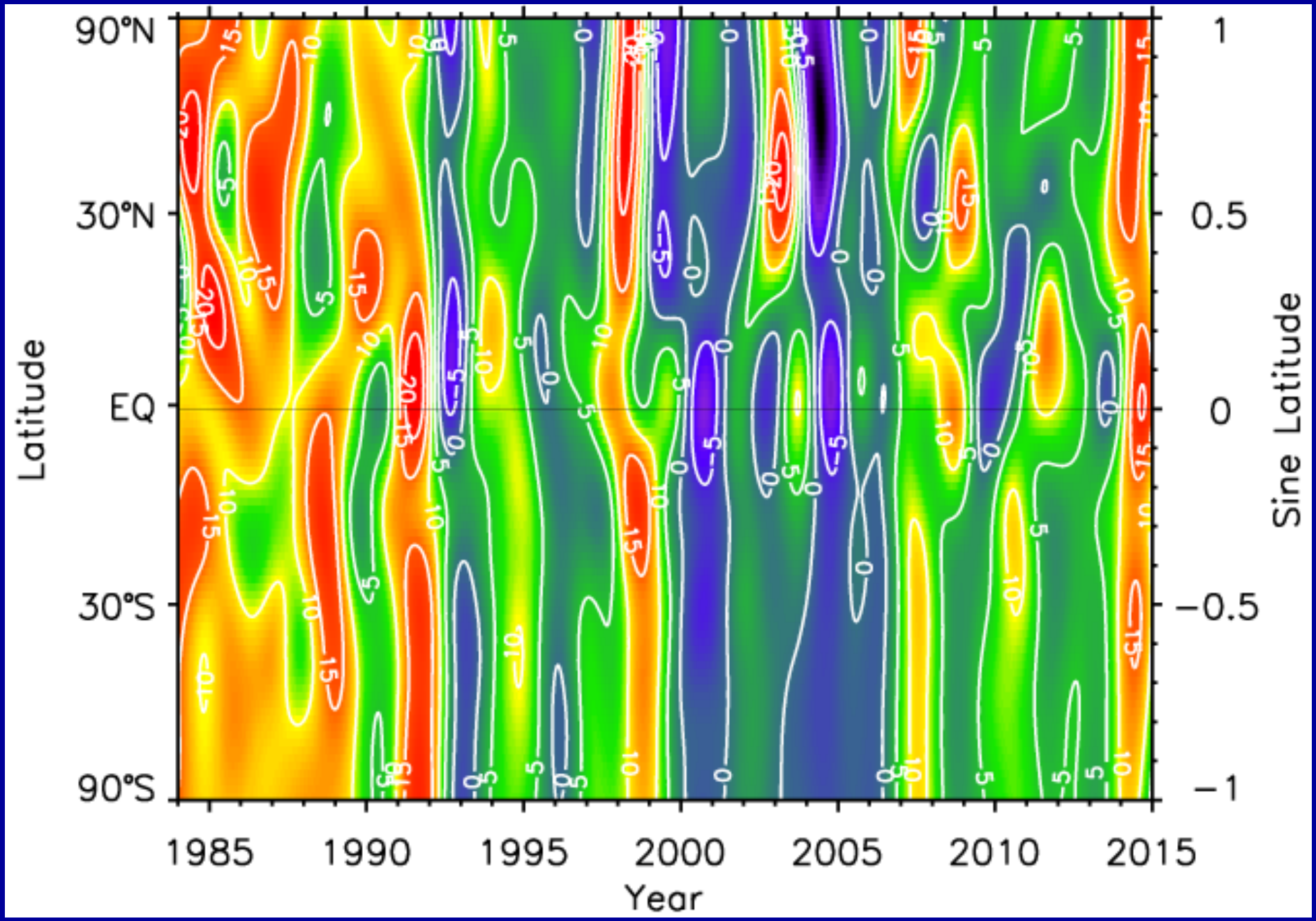


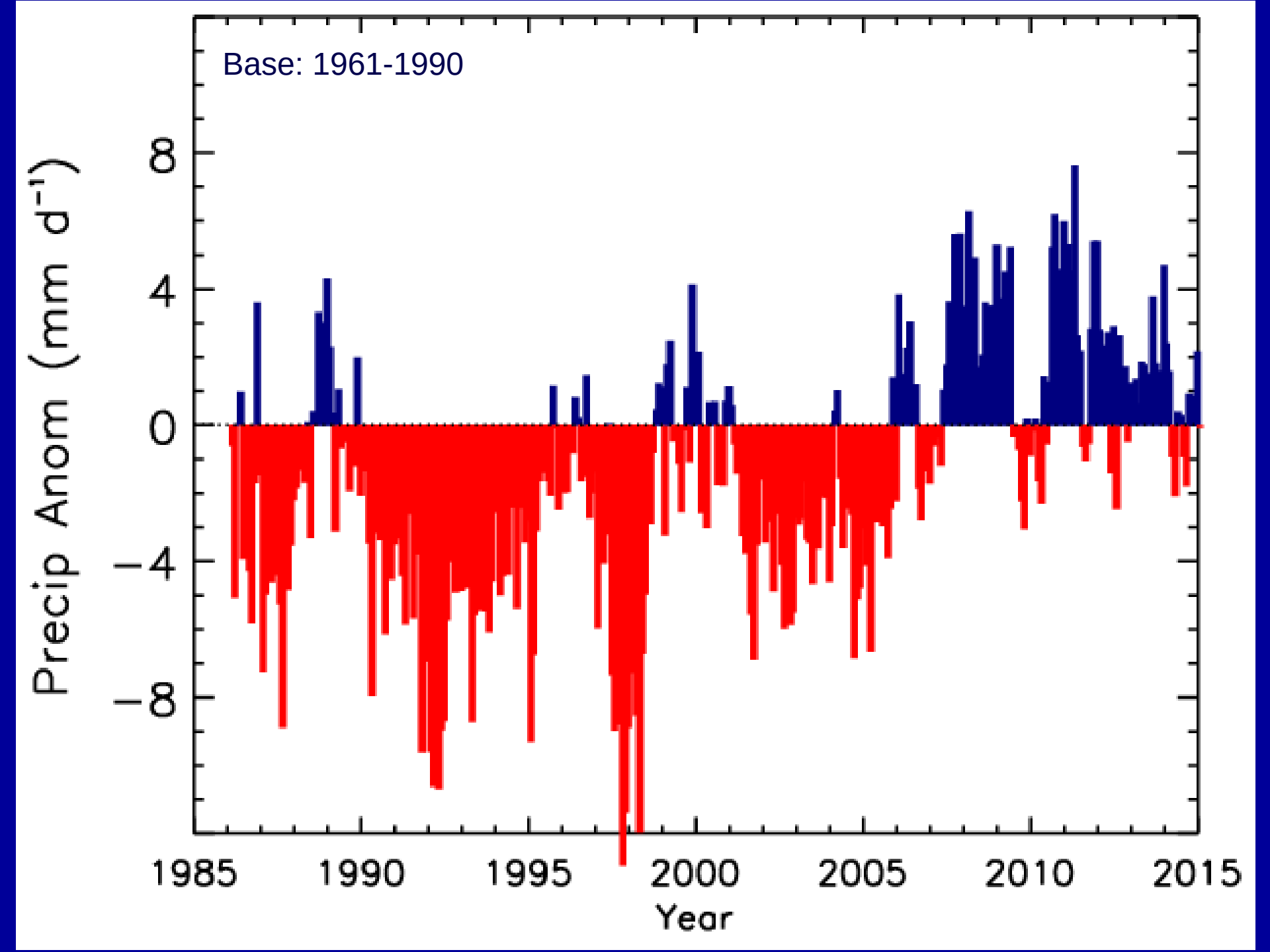
Conclusions

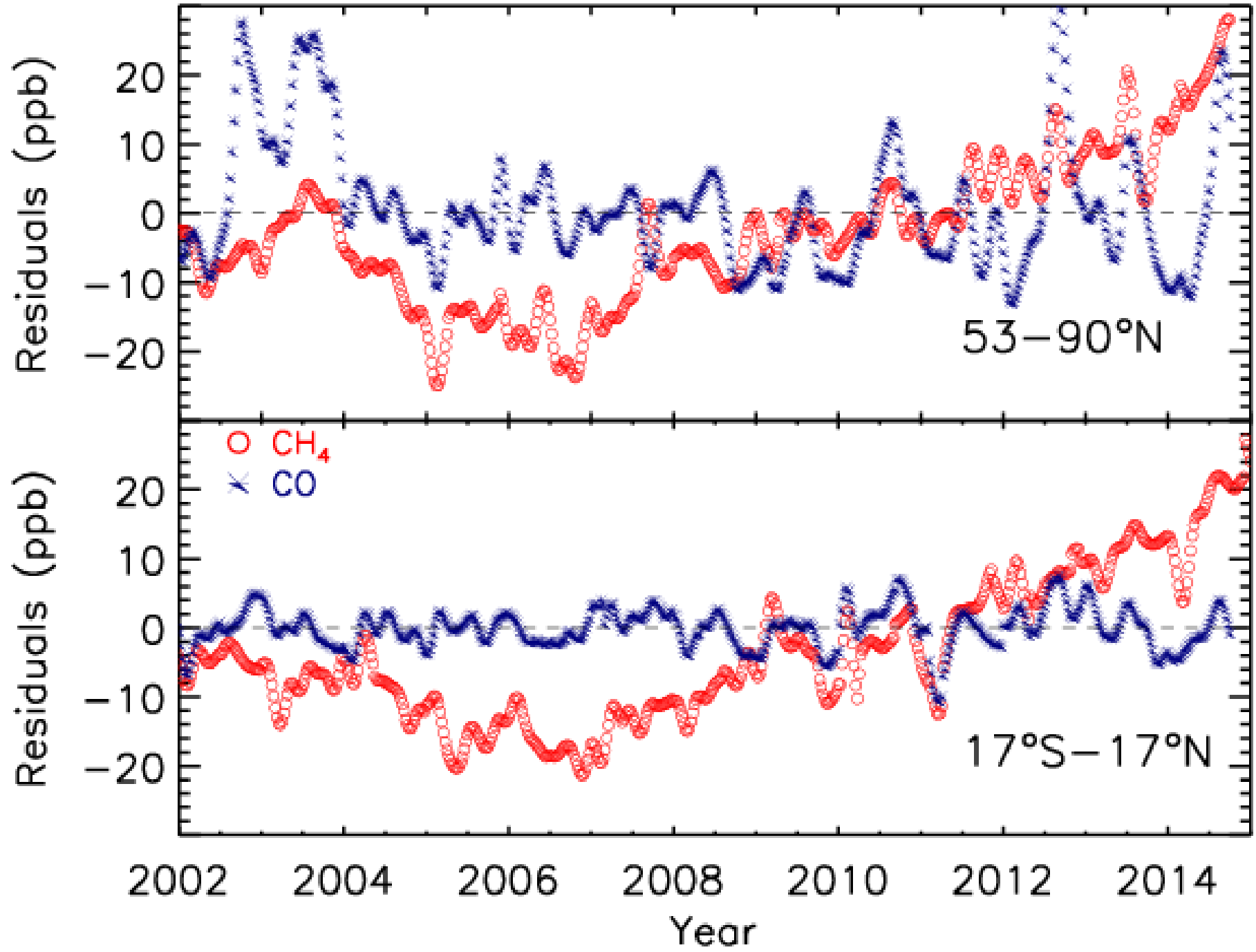
- Increased CH_4 GR starting in 2007
  - Strong contribution from tropical wetlands
    - Abrupt timing
    - Spatial patterns
    - Precipitation anomalies - ENSO
    - $\delta^{13}C$ (CH_4)
  - Other sources likely sustain increase
  - GR enhanced further in 2014 and 2015
- Need to carefully weigh all evidence

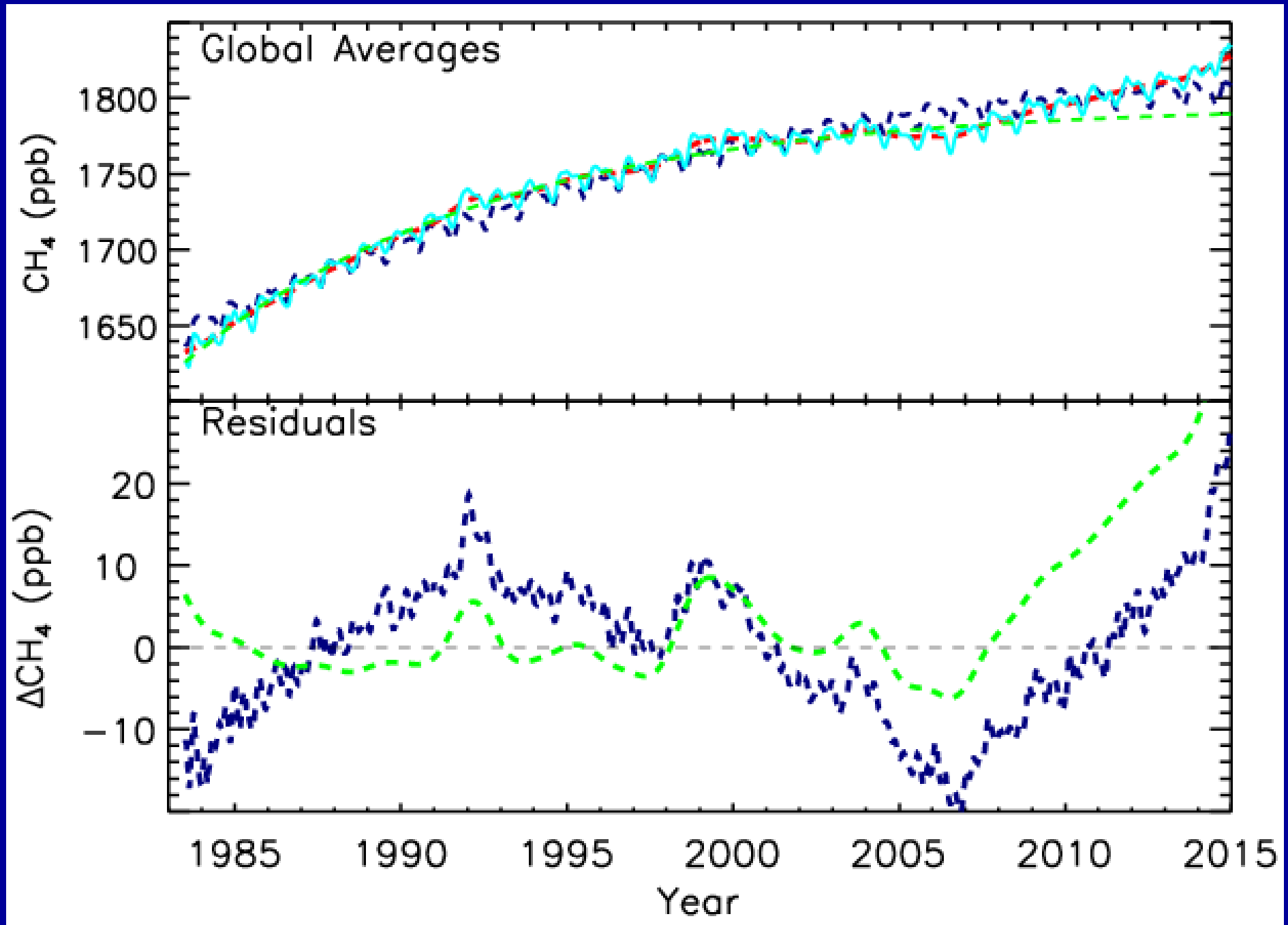

−1.2
−0.9
−0.6
−0.3
0.0
0.3
0.6
0.9
1.2
Global Precipitation Climatology Project (GPCP V2.2) 1979-2010

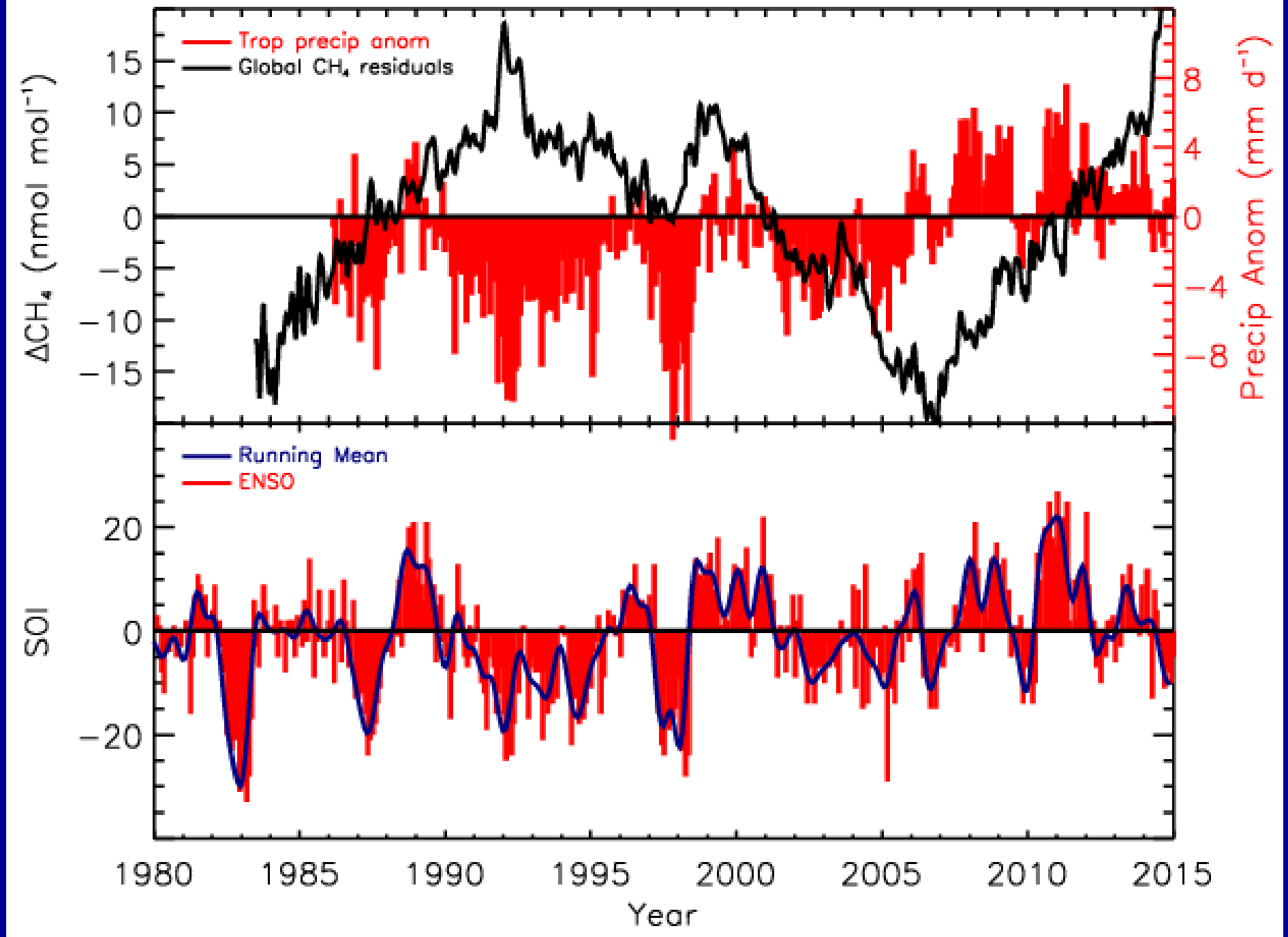

Emissions = d[CH4]/dt + [CH4]/τ
Lifetime (τ) = 9.1 yr
Observations
Sink
EDGAR + Natural
Trend = 0 ± 0.6 Tg CH4 yr-1
Average Emissions = 550 ± 13 Tg CH4
Emissions (Tg CH4)
Year
630
595
560
525
490
1985
1990
1995
2000
2005
2010
2015


90°N
30°N
EQ
30°S
90°S
Latitude
1
0.5
0
−0.5
−1
Sine Latitude
1985
1990
1995
2000
2005
2010
2015
Year


Base: 1961-1990
Precip Anom (mm d⁻¹)
8
4
0
−4
−8
1985
1990
1995
2000
2005
2010
2015
Year


Residuals (ppb)
20
10
0
−10
−20
53−90°N
CH4
CO
17°S−17°N
2002
2004
2006
2008
2010
2012
2014
Year


Global Averages
1800
1750
1700
1650
CH4 (ppb)
Residuals
20
10
0
−10
ΔCH4 (ppb)
1985
1990
1995
2000
2005
2010
2015
Year


Trop precip anom
Global CH4 residuals
ΔCH4 (nmol mol-1)
Precip Anom (mm d-1)
Running Mean
ENSO
SOI
Year
1980
1985
1990
1995
2000
2005
2010
2015

Possible changes to CH_4 emissions

- Rice: changing water management ↓
- FF sector: decreased venting and flaring ↓
- Emissions mitigation: M2M ↓
- FF emissions: hydraulic fracturing ↑
- Arctic permafrost and hydrates ↑

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.