What have we learned from three decades of atmospheric CH_4 measurements?

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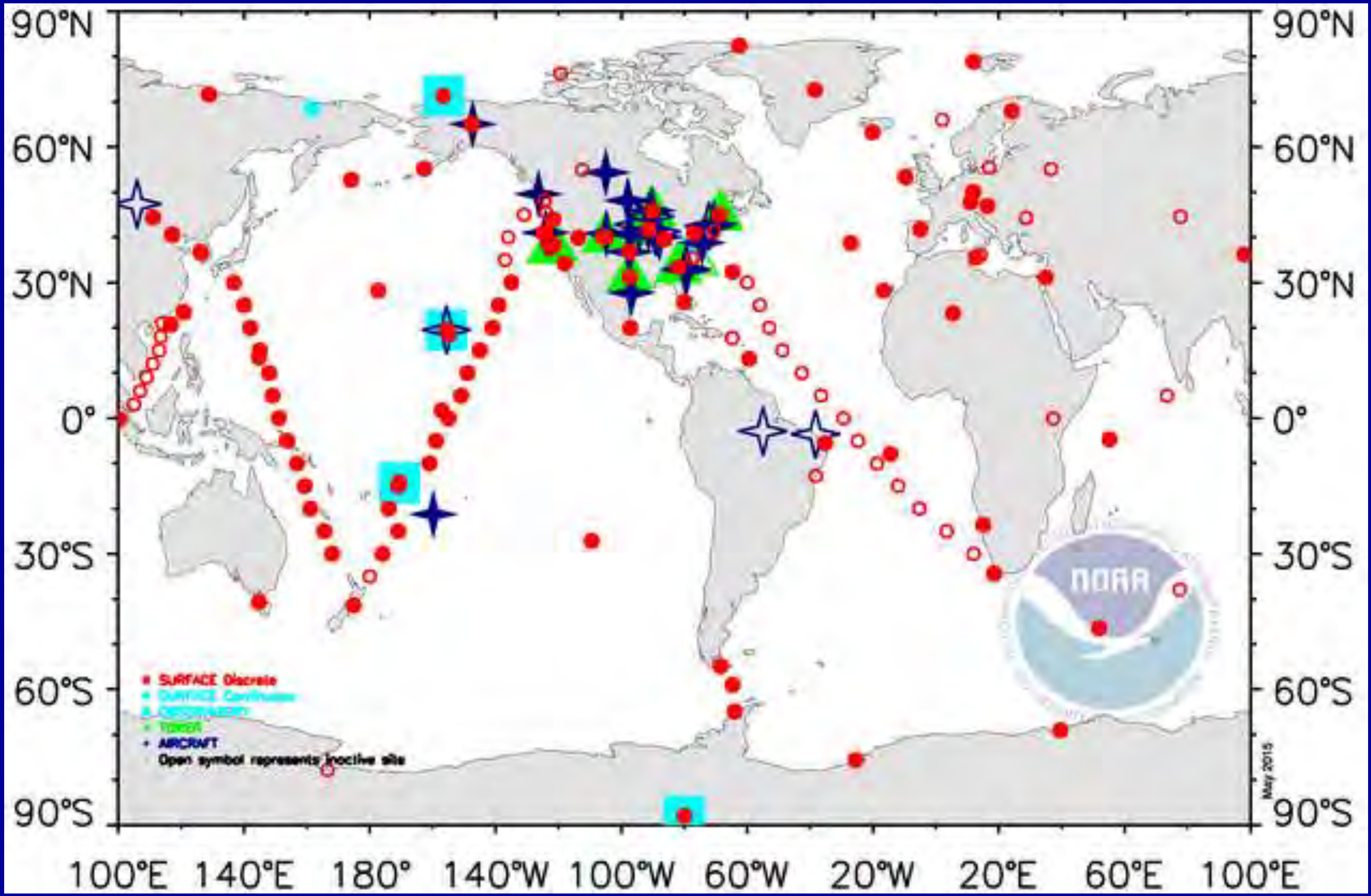
[1]NOAA ESRL GMD, [2]CIRES,

Outline

- NOAA CH_4 data
  - Quality control
- Long term trends
  - Approach to steady state
  - Estimates of emissions
- Interannual Variability
  - Eruption of Mt. Pinatubo
- Renewed increase since 2007
  - Possible causes
- Summary and Conclusions

GMD Cooperative Global Air Sampling Network



*Weekly samples

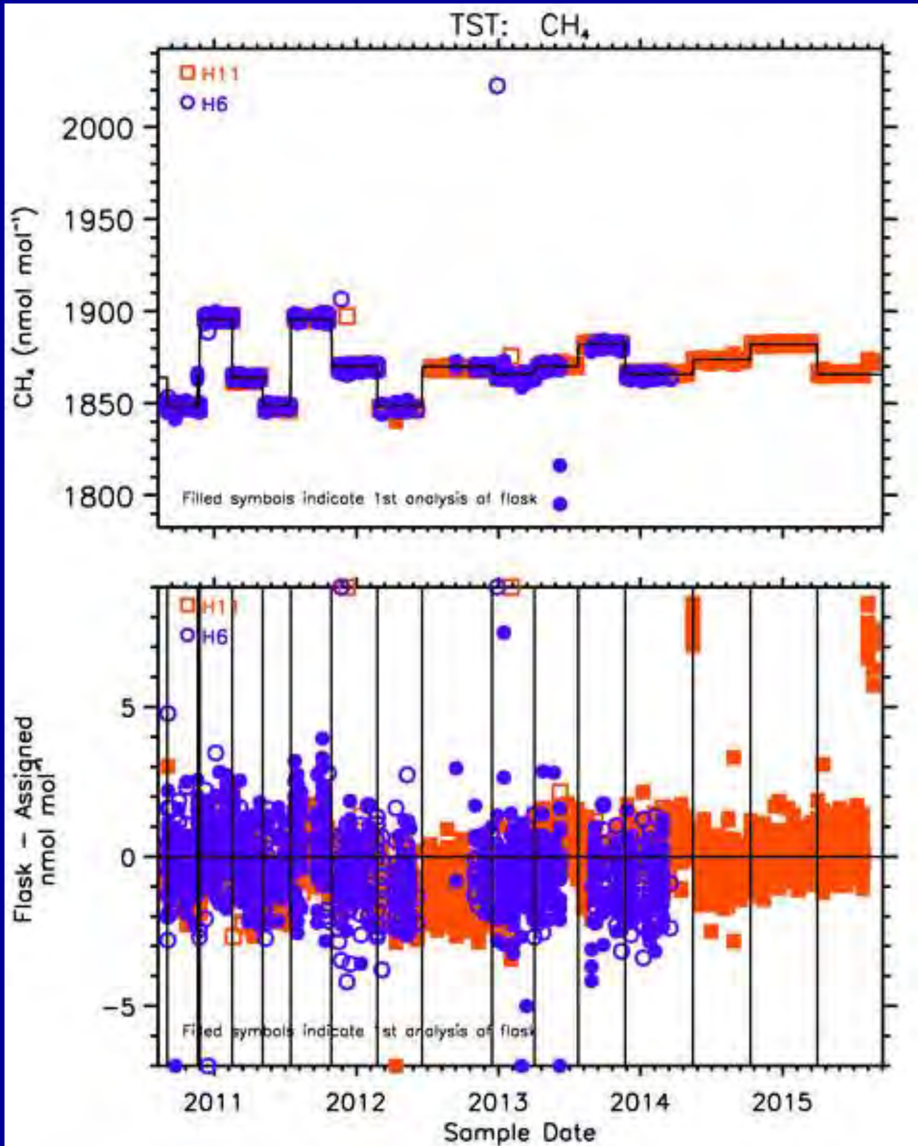
*Portable sampler

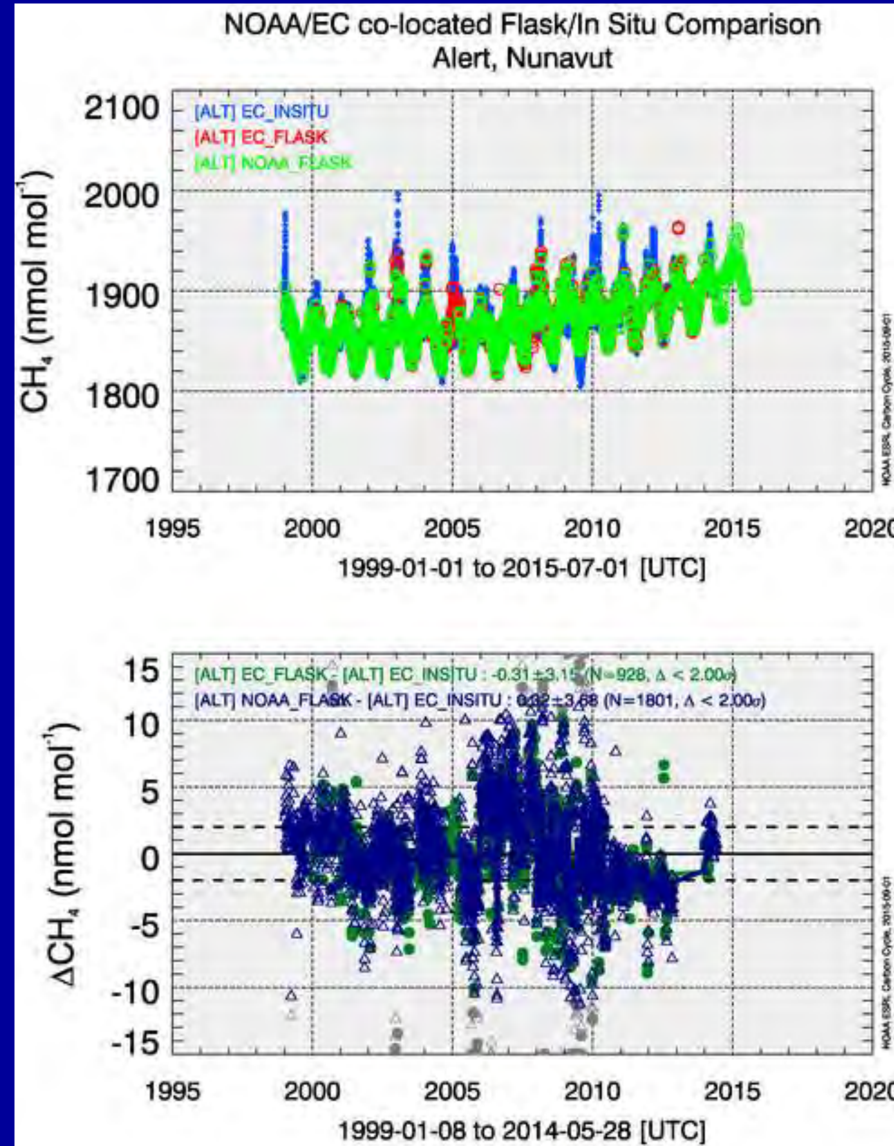
*Analyzed by GC/FID

* Cooperative

*Broad participation

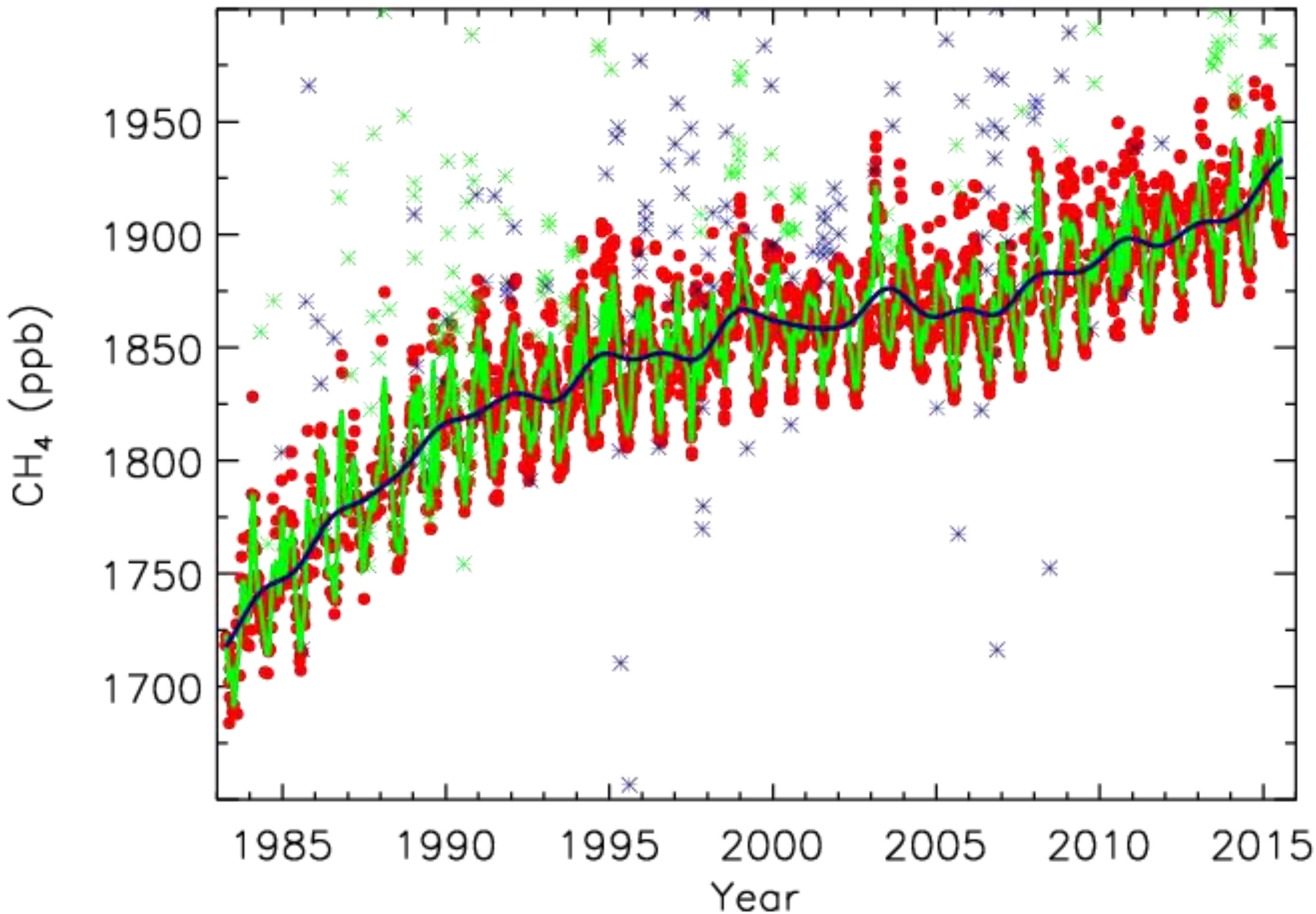
*www.esrl.noaa.gov/gmd/ccgg/iadv/

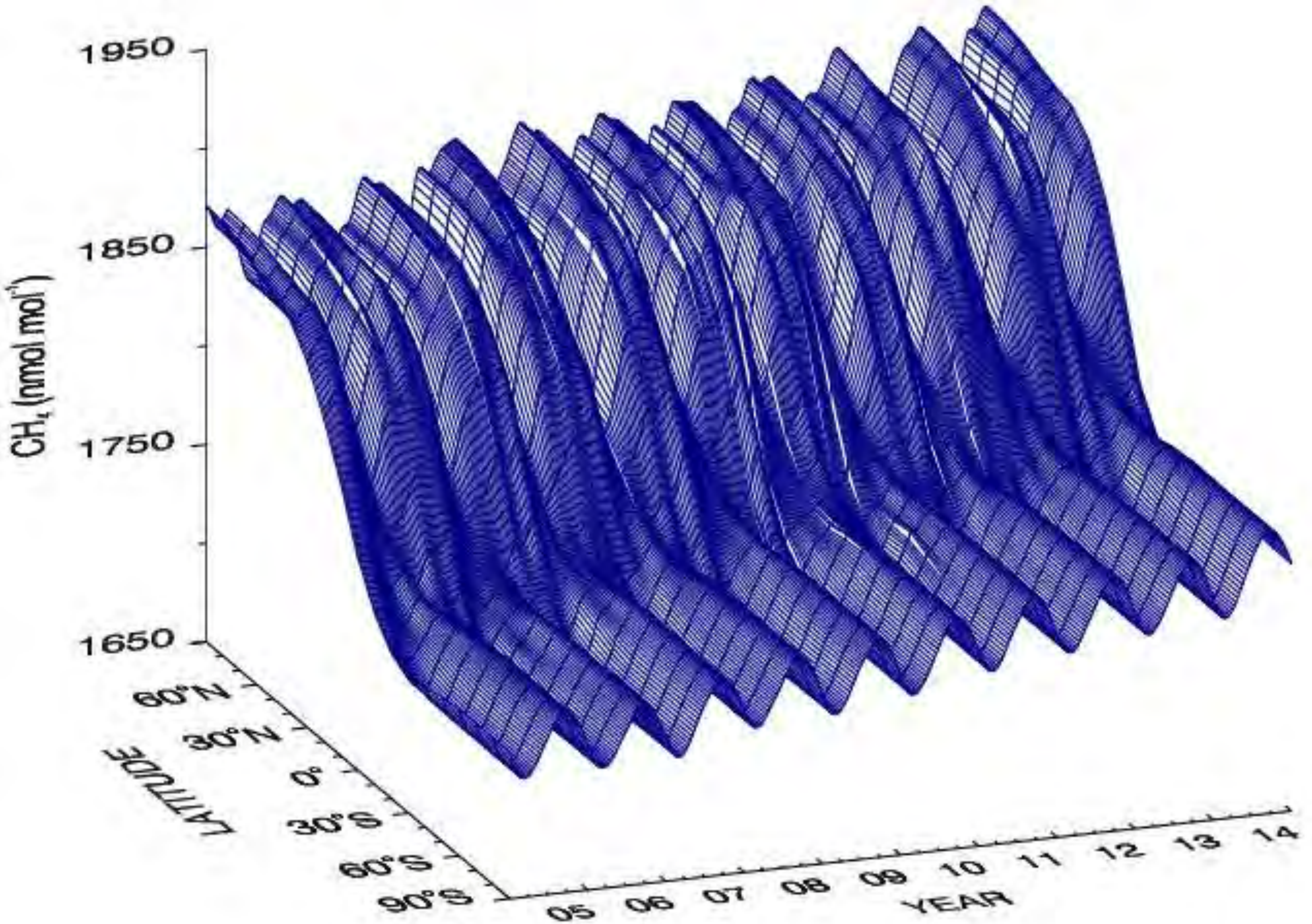


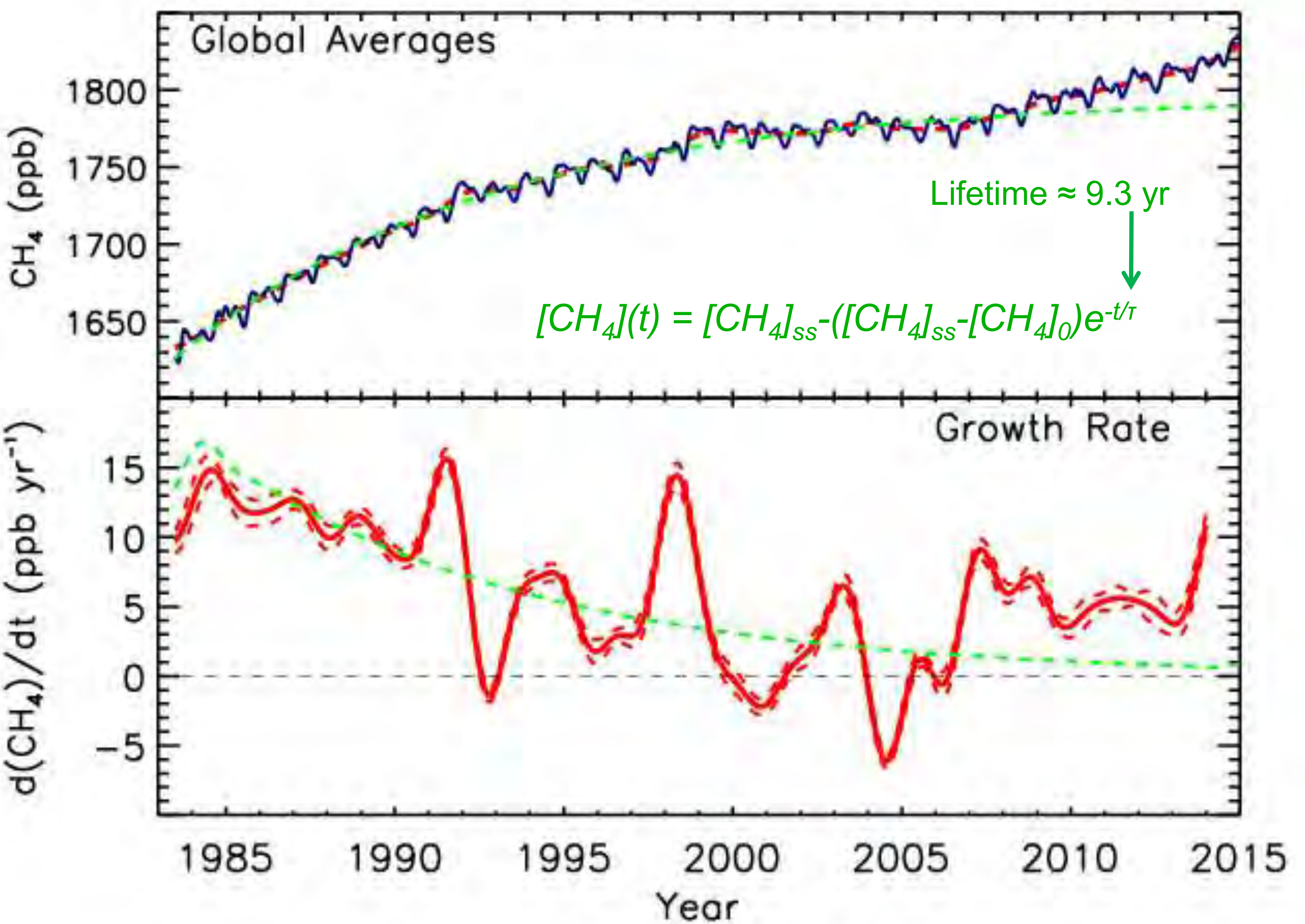


Quality Control

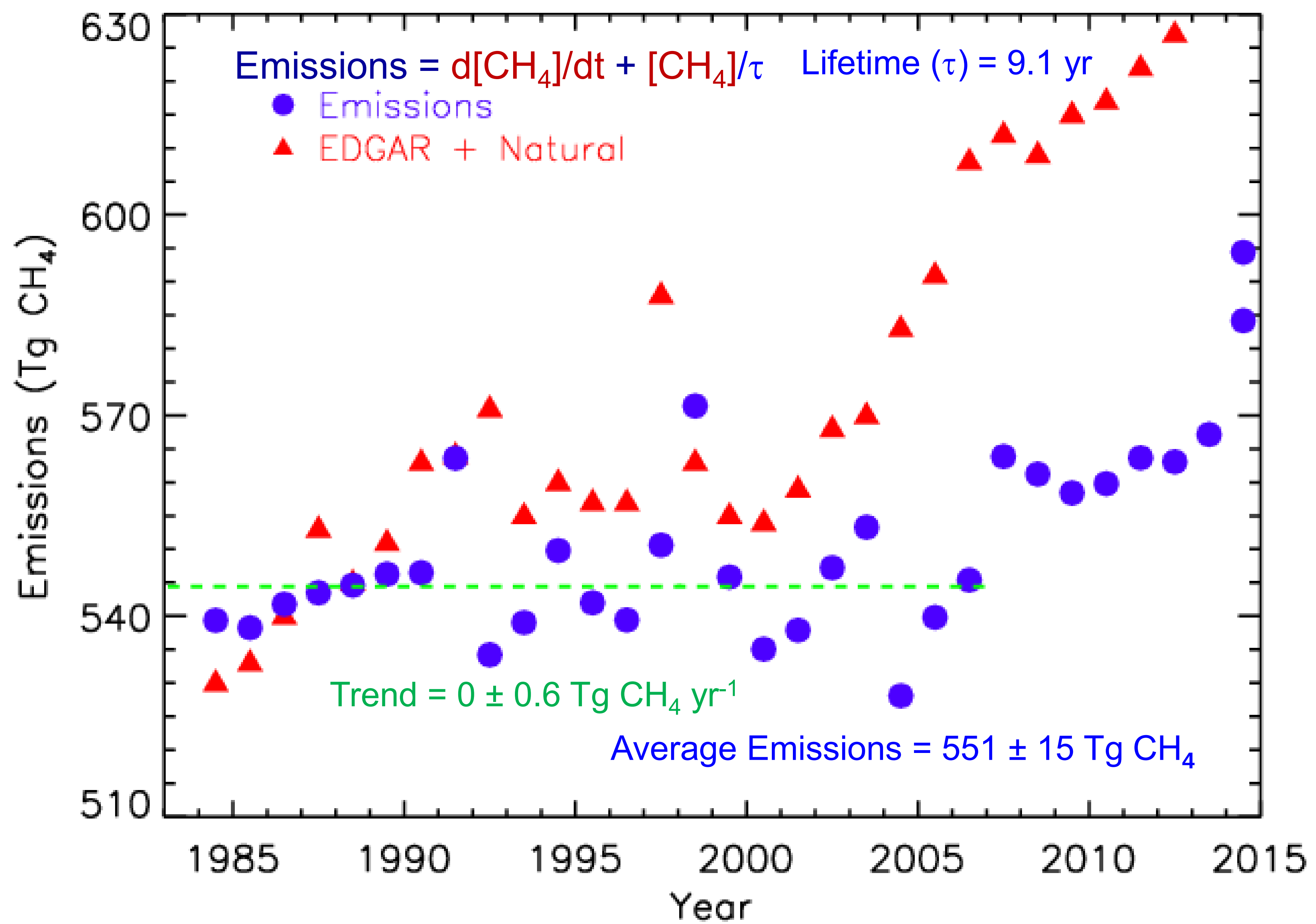
Barrow, Alaska



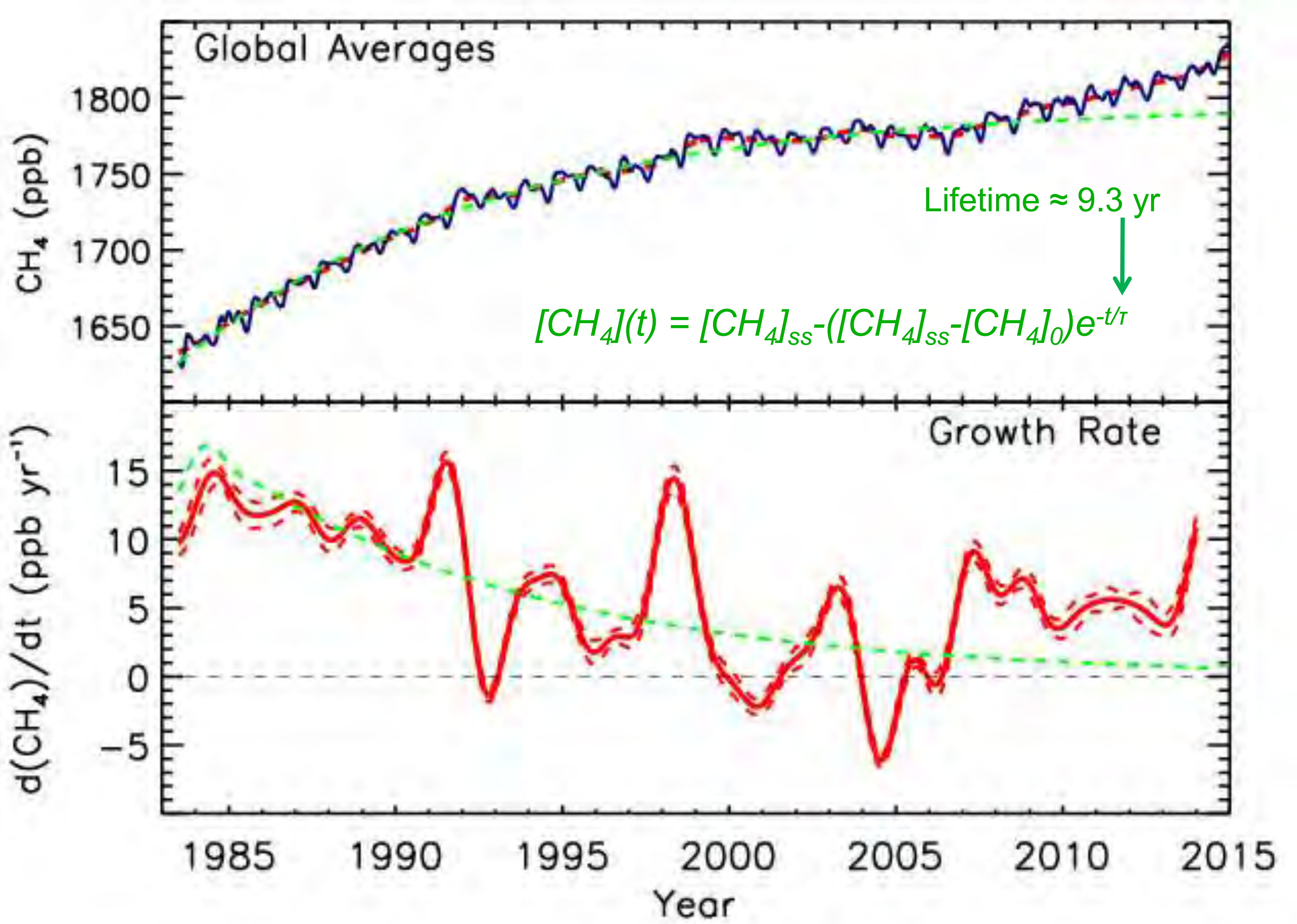

1950
1850
1750
1650
CH_4 (nmol mol^{-1})
60°N
30°N
0°
30°S
60°S
90°S
LATITUDE
05
06
07
08
09
10
11
12
13
14
YEAR



Global Averages
1800
1750
1700
1650
CH4 (ppb)
Lifetime ≈ 9.3 yr
[CH4](t) = [CH4]ss-([CH4]ss-[CH4]0)e-t/τ
Growth Rate
15
10
5
0
−5
d(CH4)/dt (ppb yr-1)
1985
1990
1995
2000
2005
2010
2015
Year



Emissions = d[CH4]/dt + [CH4]/τ
Lifetime (τ) = 9.1 yr
Emissions
EDGAR + Natural
Trend = 0 ± 0.6 Tg CH4 yr-1
Average Emissions = 551 ± 15 Tg CH4
Emissions (Tg CH4)
630
600
570
540
510
1985
1990
1995
2000
2005
2010
2015
Year



Global Averages
Growth Rate
Lifetime ≈ 9.3 yr
$[CH_4](t) = [CH_4]_{ss} - ([CH_4]_{ss} - [CH_4]_0)e^{-t/\tau}$
CH_4 (ppb)
1650
1700
1750
1800
$d(CH_4)/dt$ (ppb yr^{-1})
15
10
5
0
−5
1985
1990
1995
2000
2005
2010
2015
Year

1991: Pinatubo and the CH_4 Lifetime

Eruption: 15 June 1991

- 20 MT SO_2 oxidized to SO_4^{-2}
- 3 to 5 km^3 ash

Affects [OH] by affecting photochemistry:

- Direct absorption of UV by SO_2
- Scattering of UV by ash and aerosols

Dlugokencky, E. J., E. G. Dutton, P. C. Novelli, P. P. Tans, K. A. Masarie, K. O. Lantz, and S. Madronich (1996), Geophys. Res. Lett., 23(20), 2761–2764, doi:10.1029/96GL02638.

Chemistry

(Largest term in CH_4 budget)

$$OH + CH_4 \rightarrow CH_3 + H_2O$$

$$O_3 + h\nu\ (330 \geq \lambda \geq 290\ \text{nm}) \rightarrow O(^1D) + O_2$$

$$O(^1D) + H_2O \rightarrow 2\ OH$$

Rate of formation $O(^1D) = j\,[O_3]$

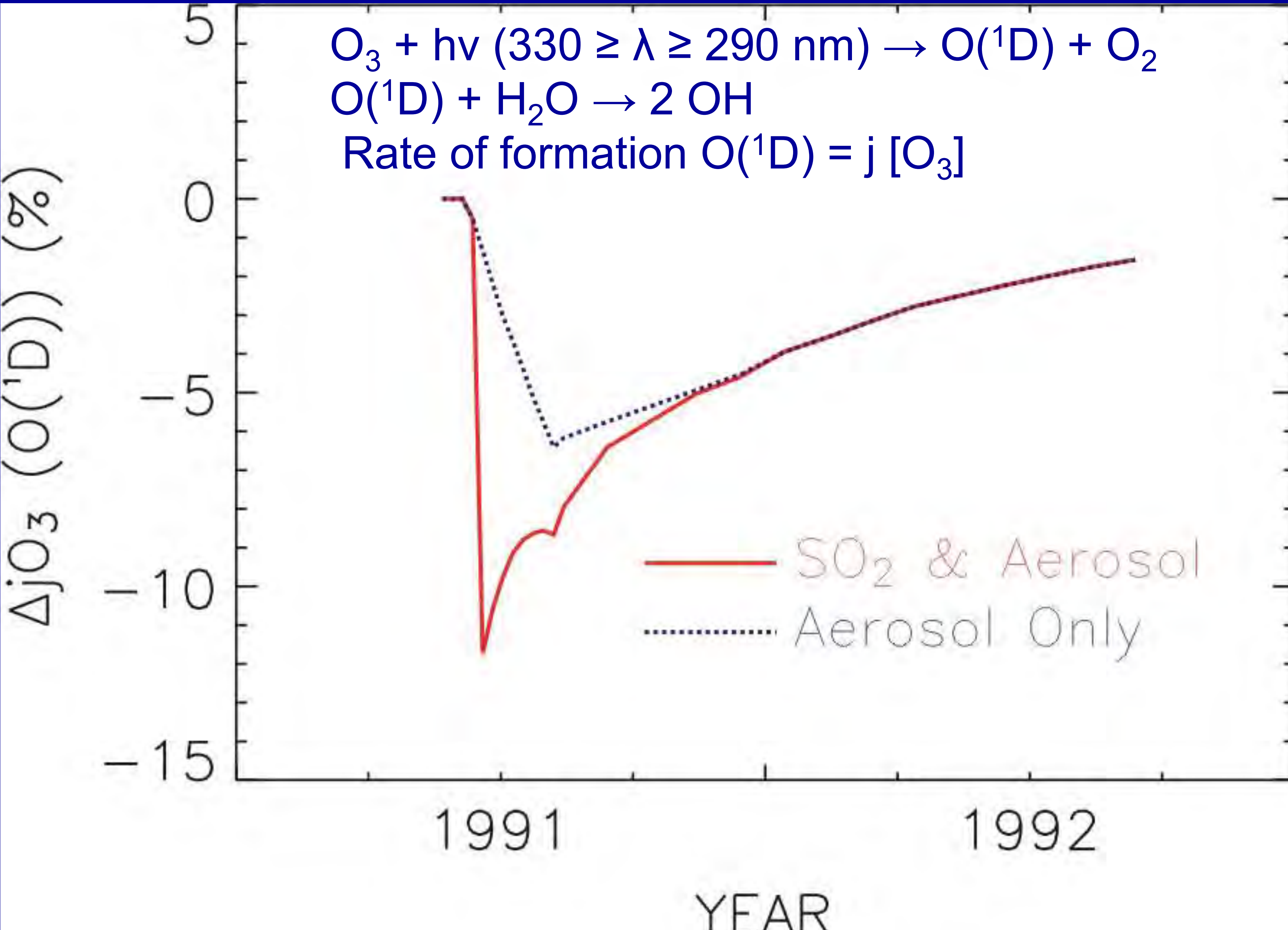
$$j = \int F(\lambda)\ \sigma(\lambda)\ \varphi(\lambda)\ d\lambda$$

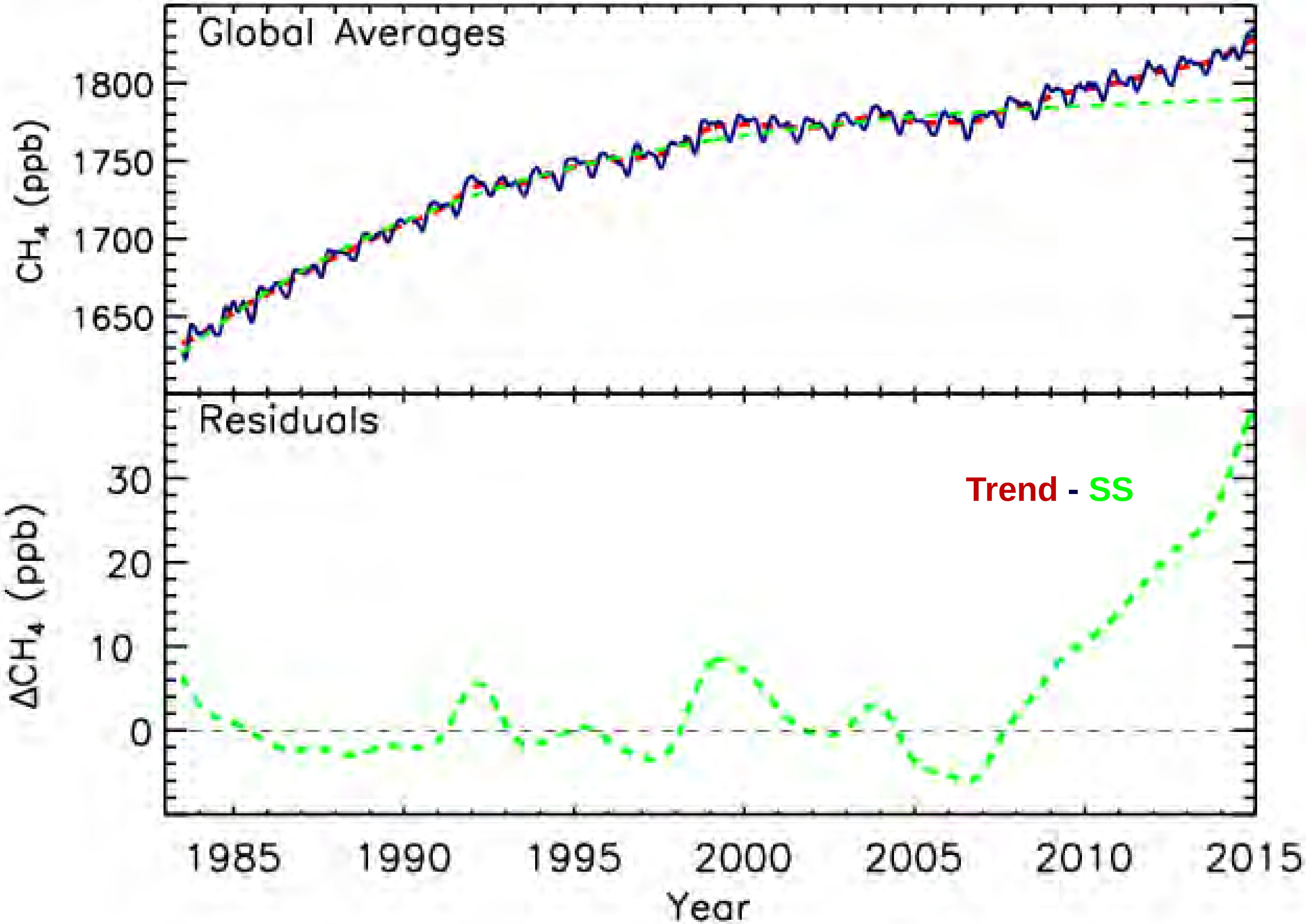
Also affected CO

$O_3 + h\nu\ (330 \geq \lambda \geq 290\ \text{nm}) \rightarrow O(^1D) + O_2$

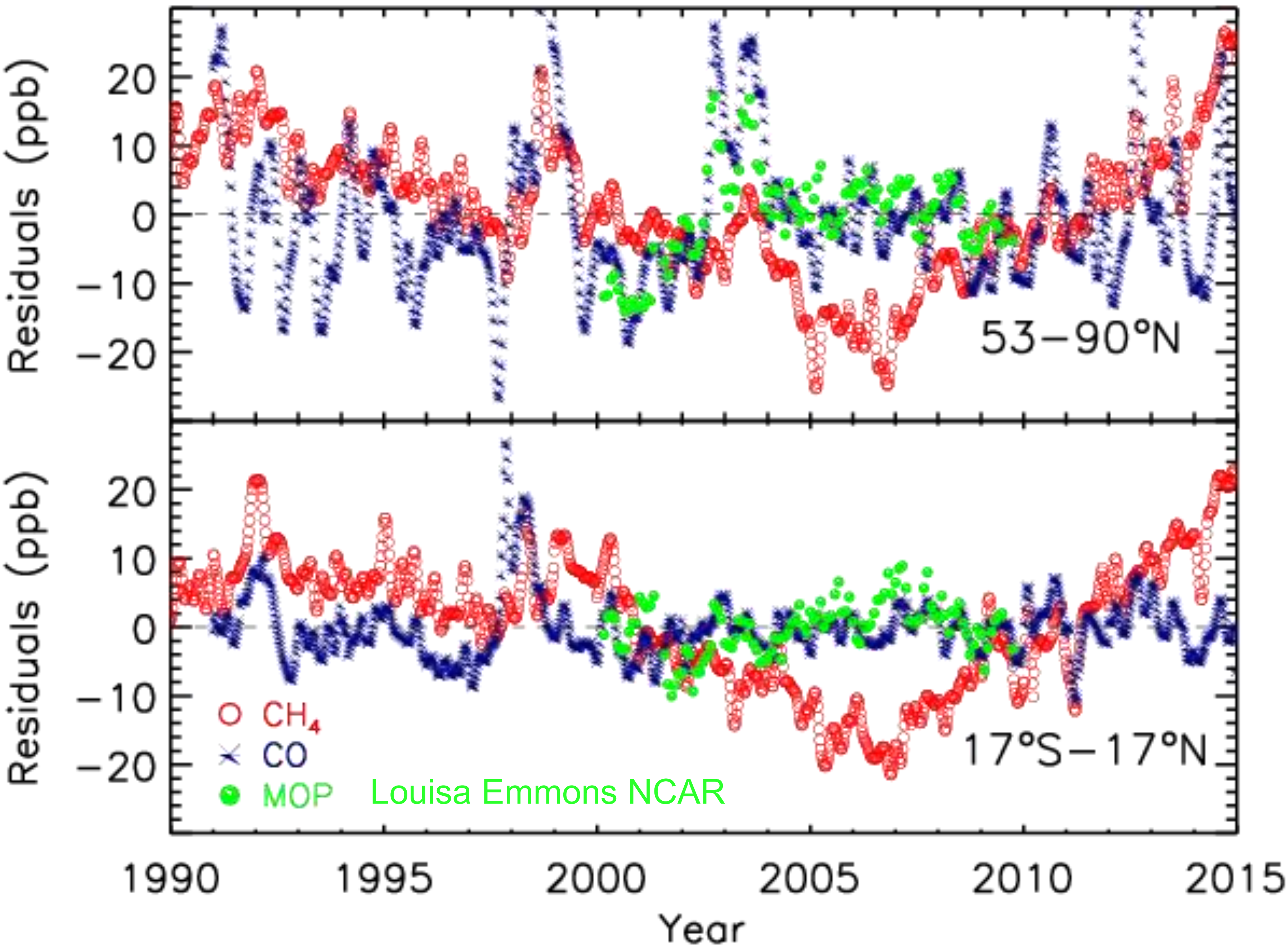
$O(^1D) + H_2O \rightarrow 2\ OH$

Rate of formation $O(^1D) = j\ [O_3]$

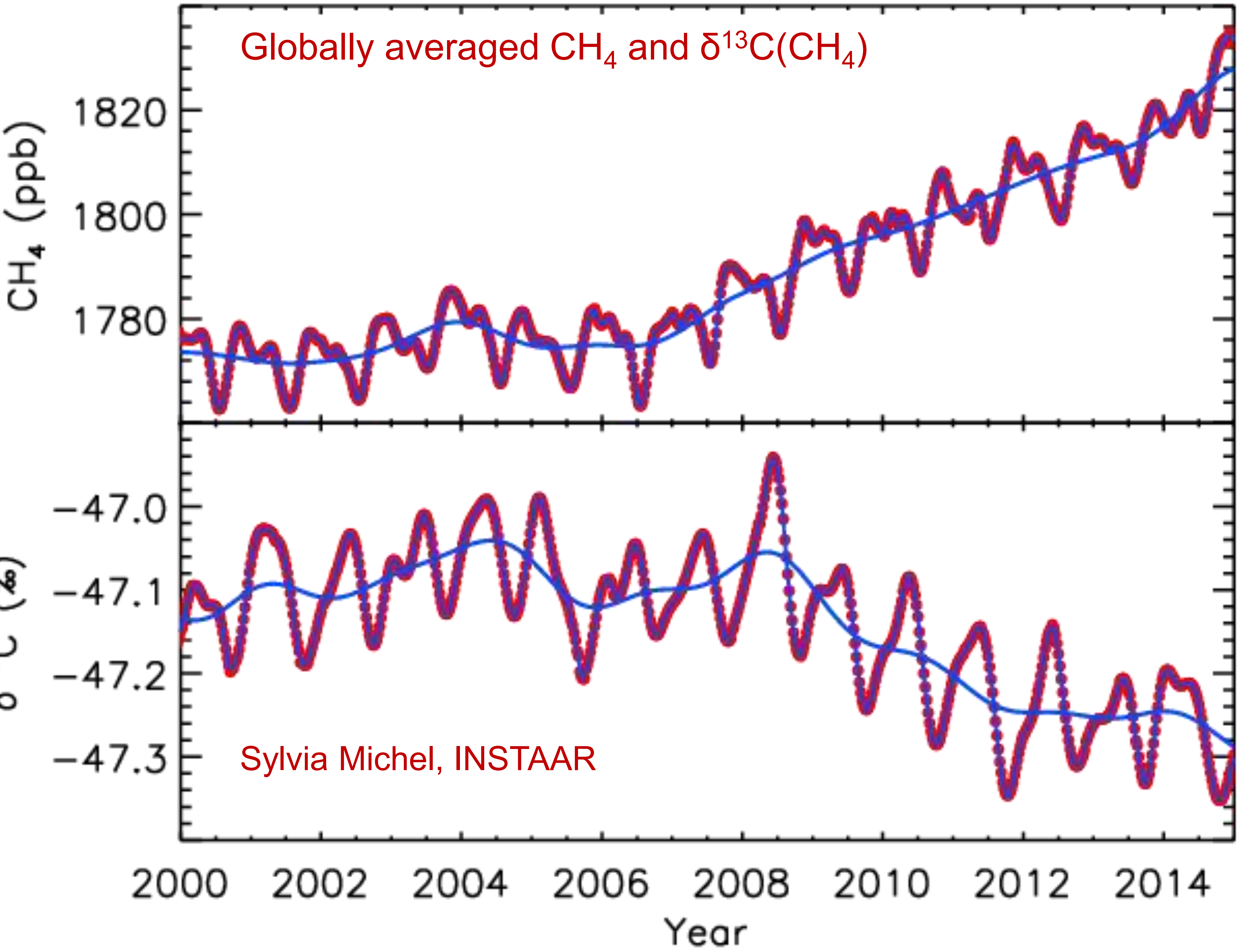




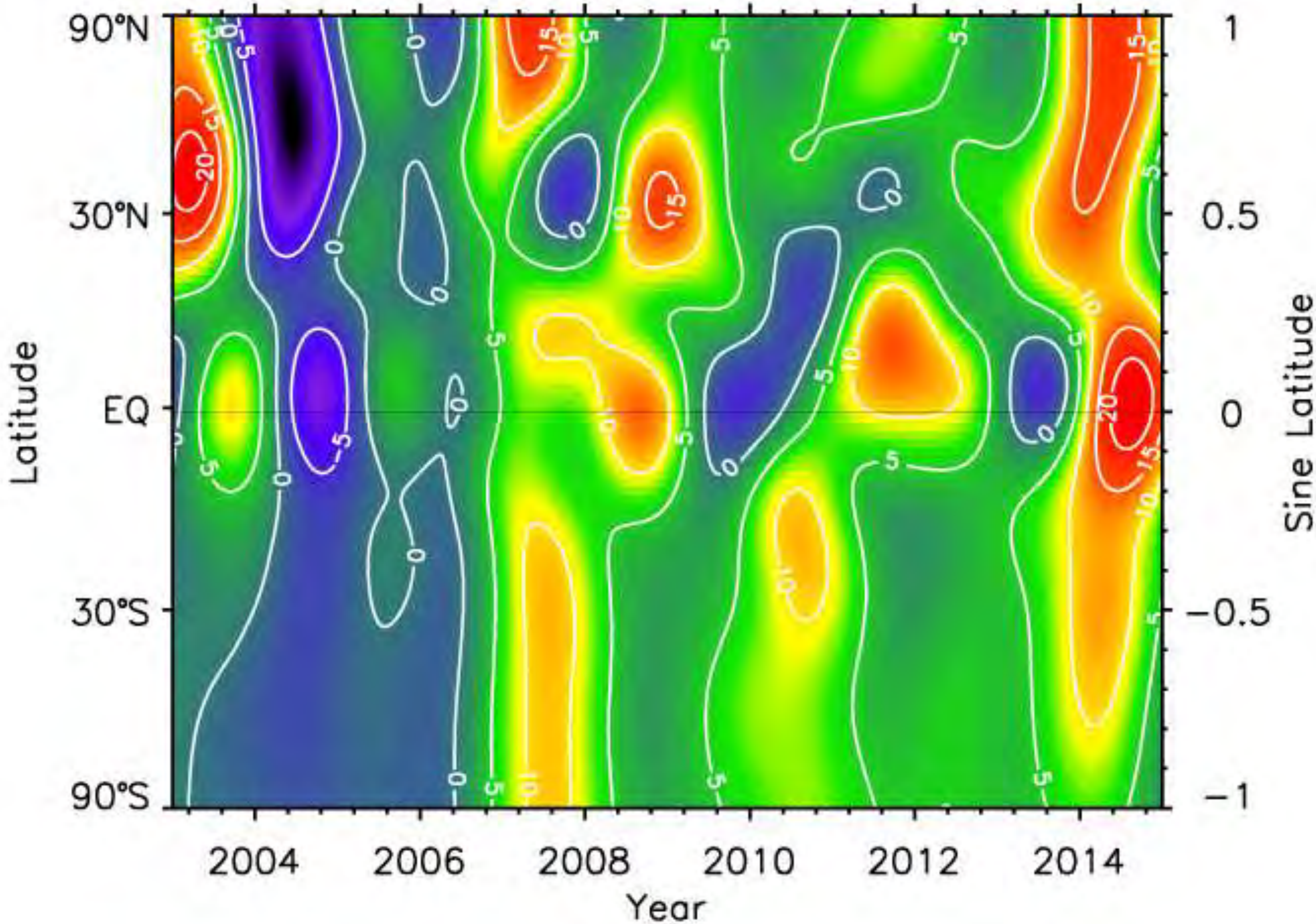
Global Averages
CH4 (ppb)
1800
1750
1700
1650
Residuals
ΔCH4 (ppb)
30
20
10
0
Trend - SS
1985
1990
1995
2000
2005
2010
2015
Year



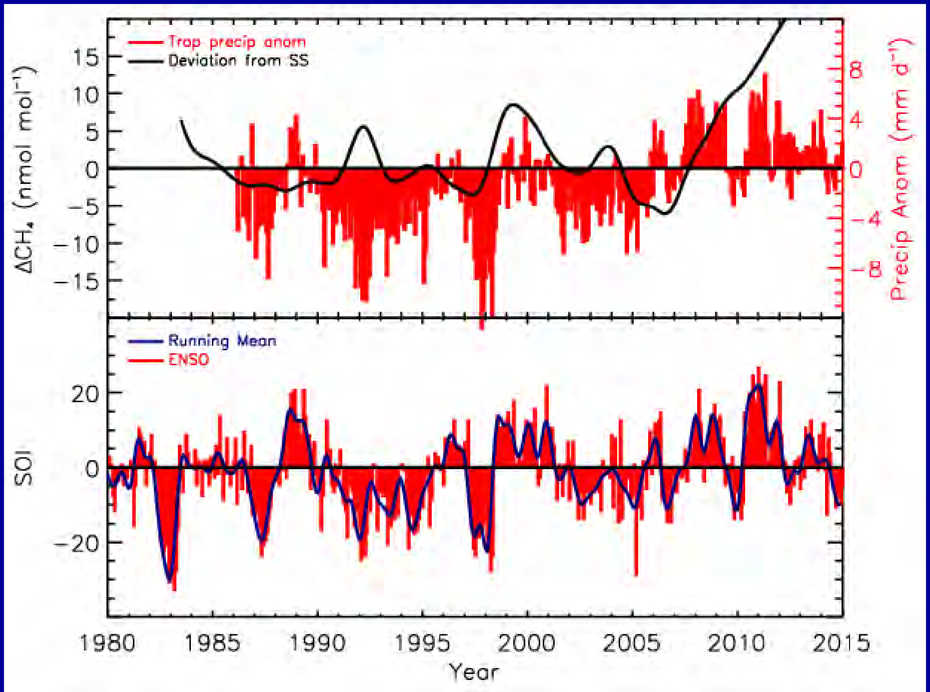
Residuals (ppb)
20
10
0
−10
−20
53−90°N
Residuals (ppb)
20
10
0
−10
−20
CH4
CO
MOP
Louisa Emmons NCAR
17°S−17°N
1990
1995
2000
2005
2010
2015
Year



Globally averaged CH4 and δ13C(CH4)
CH4 (ppb)
1820
1800
1780
δ13C (‰)
−47.0
−47.1
−47.2
−47.3
Sylvia Michel, INSTAAR
2000
2002
2004
2006
2008
2010
2012
2014
Year



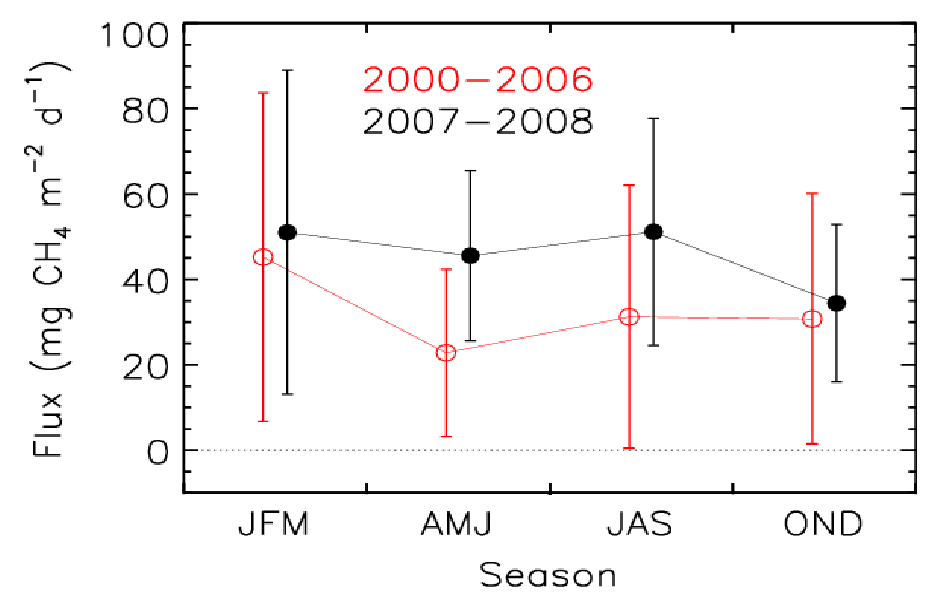
90°N
30°N
EQ
30°S
90°S
Latitude
1
0.5
0
−0.5
−1
Sine Latitude
2004
2006
2008
2010
2012
2014
Year



Precipitation anomalies in tropical wetlands. (Source: GPCP)

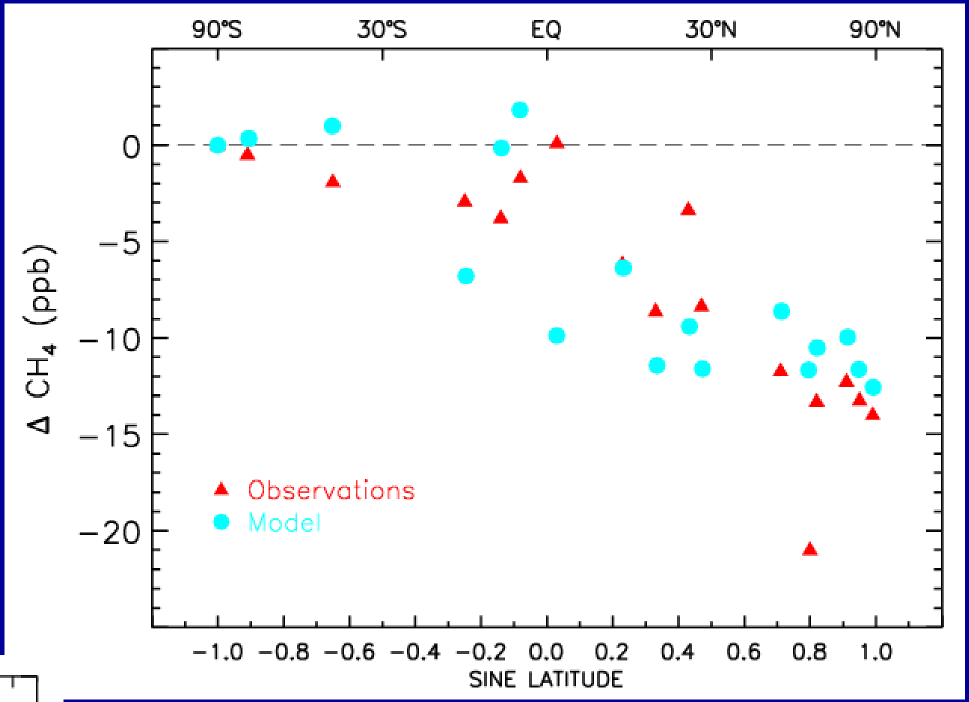
SOI: Australian BoM

Increased Amazon CH_4 fluxes in wet years.

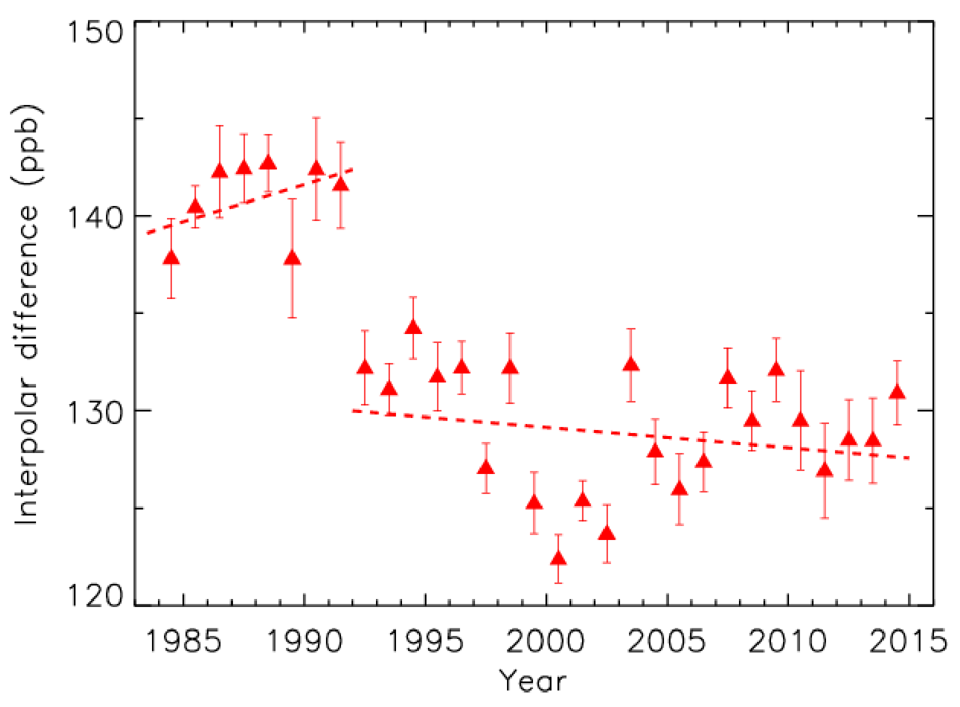


Consistent with decrease in $\delta^{13}C$ of CH_4

Late-1990s - mid-1980s



No measureable change in Arctic CH_4 emissions.

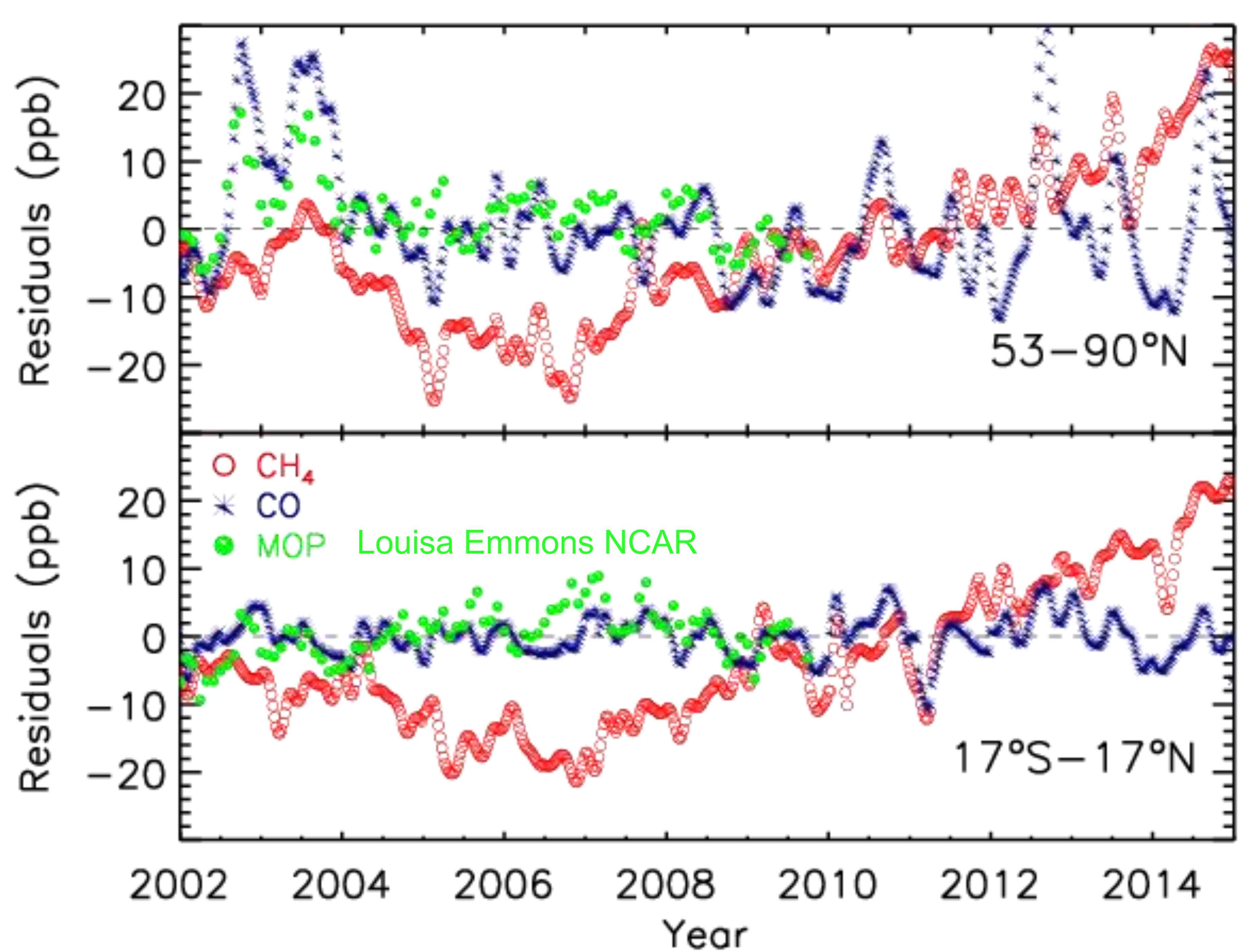


Dlugokencky, E. J., et al.,Geophys. Res. Lett., 30(19), 1992, doi:10.1029/ 2003GL018126, 2003.

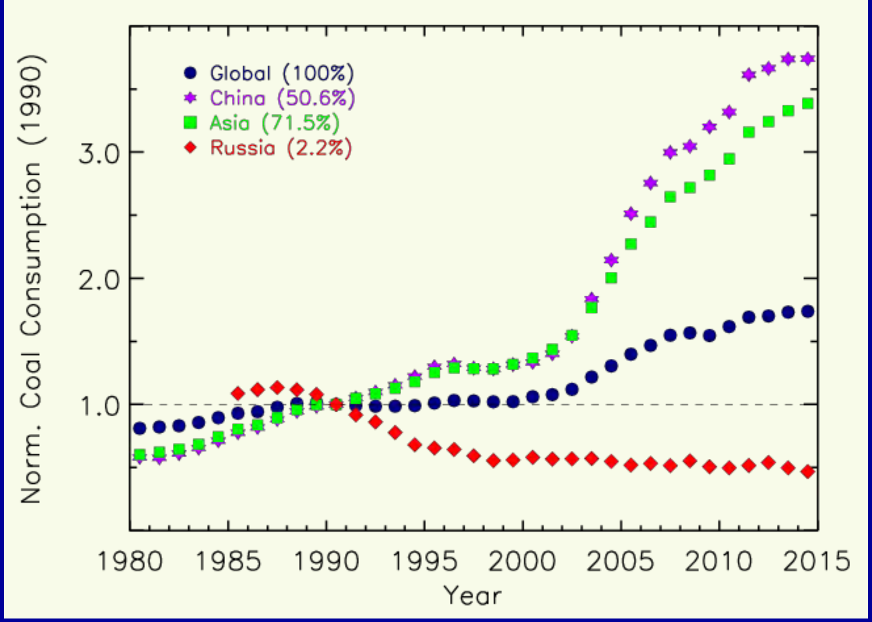
Interpolar difference (53-90°)

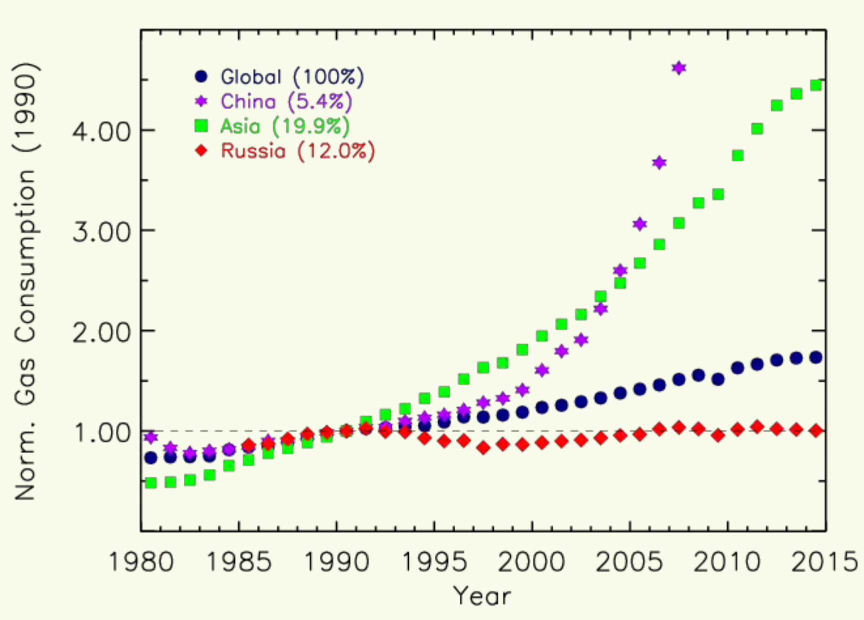
Summary and Conclusions

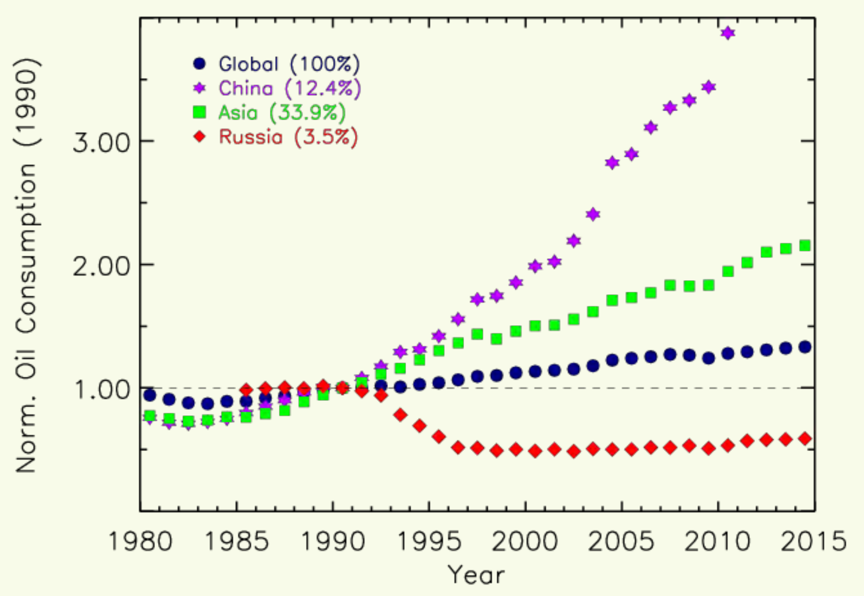
- No trend in global emissions: 1984-2006
  - Emissions from some sectors changing
  - Changes in WL emissions may have masked increased anthropogenic emissions
- Much to learn about processes from IAV
- Increased GR and emissions since 2007
  - Changes in tropical precipitation (ENSO)
  - $\delta^{13}C$ (CH_4) indicates microbial source
- 2014: CH_4 GR surged ($\geq$12 ppb)
  - Globally warm, Amazon wet, but reasons unclear



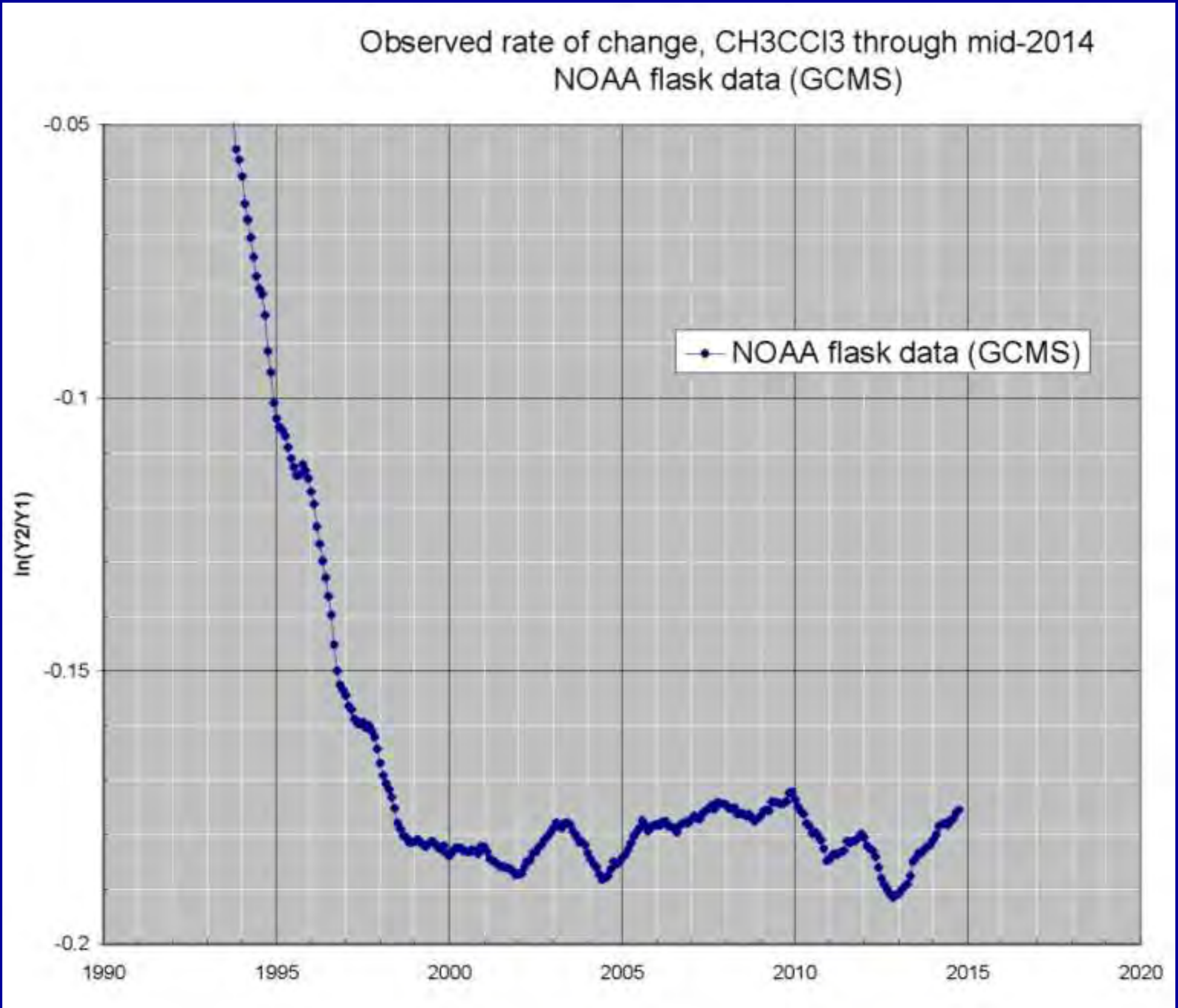
Residuals (ppb)
20
10
0
−10
−20
53−90°N
CH4
CO
MOP
Louisa Emmons NCAR
17°S−17°N
2002
2004
2006
2008
2010
2012
2014
Year



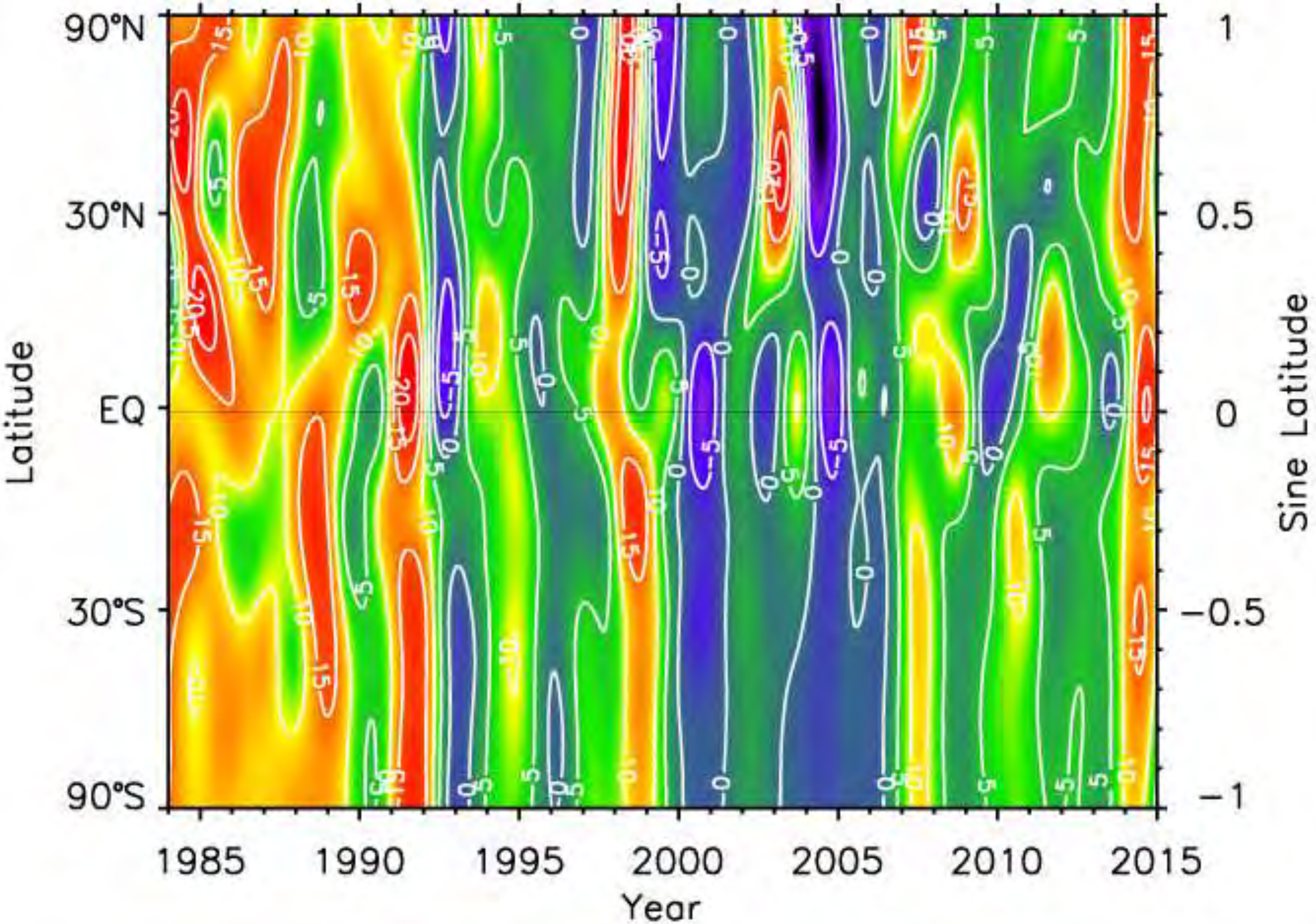


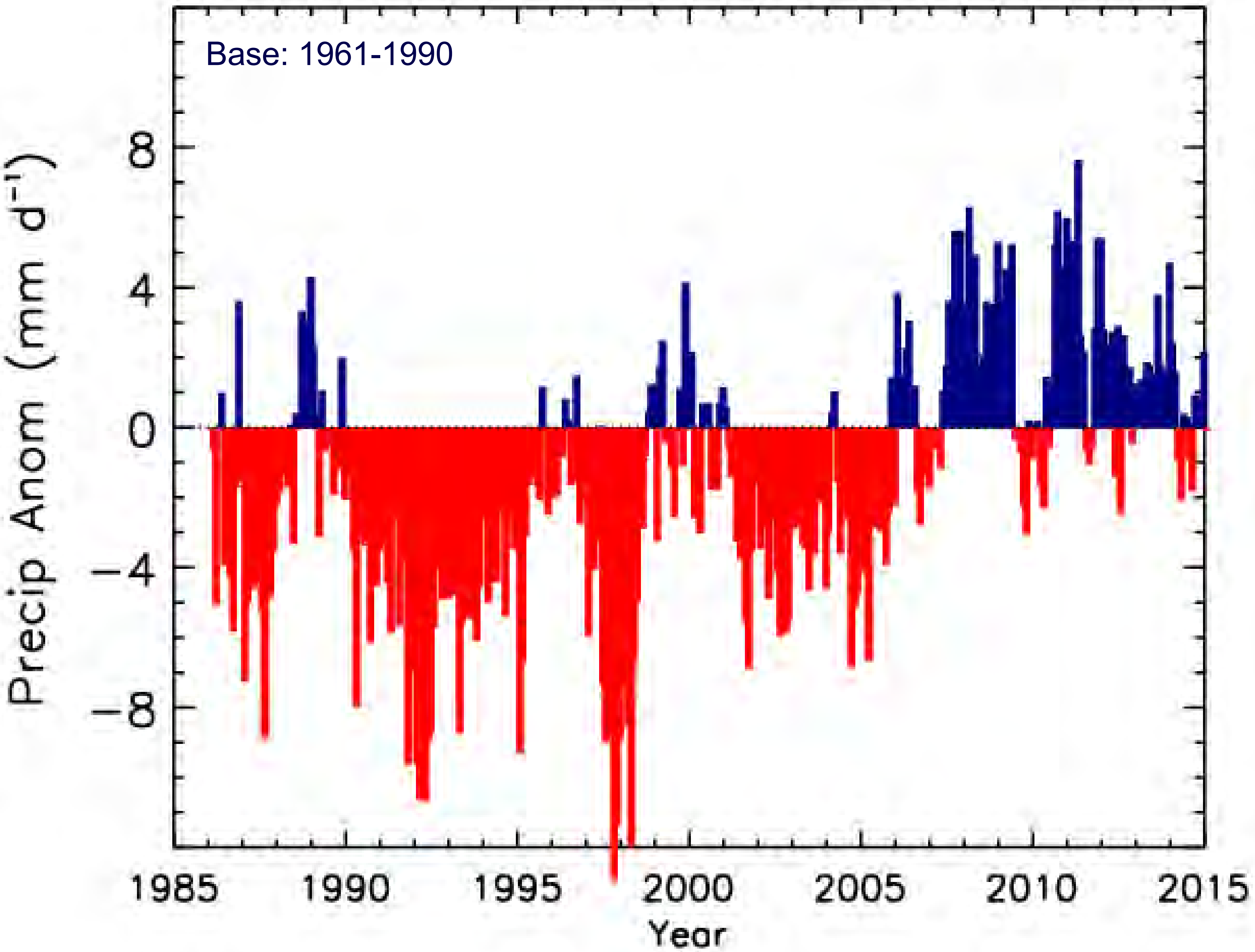


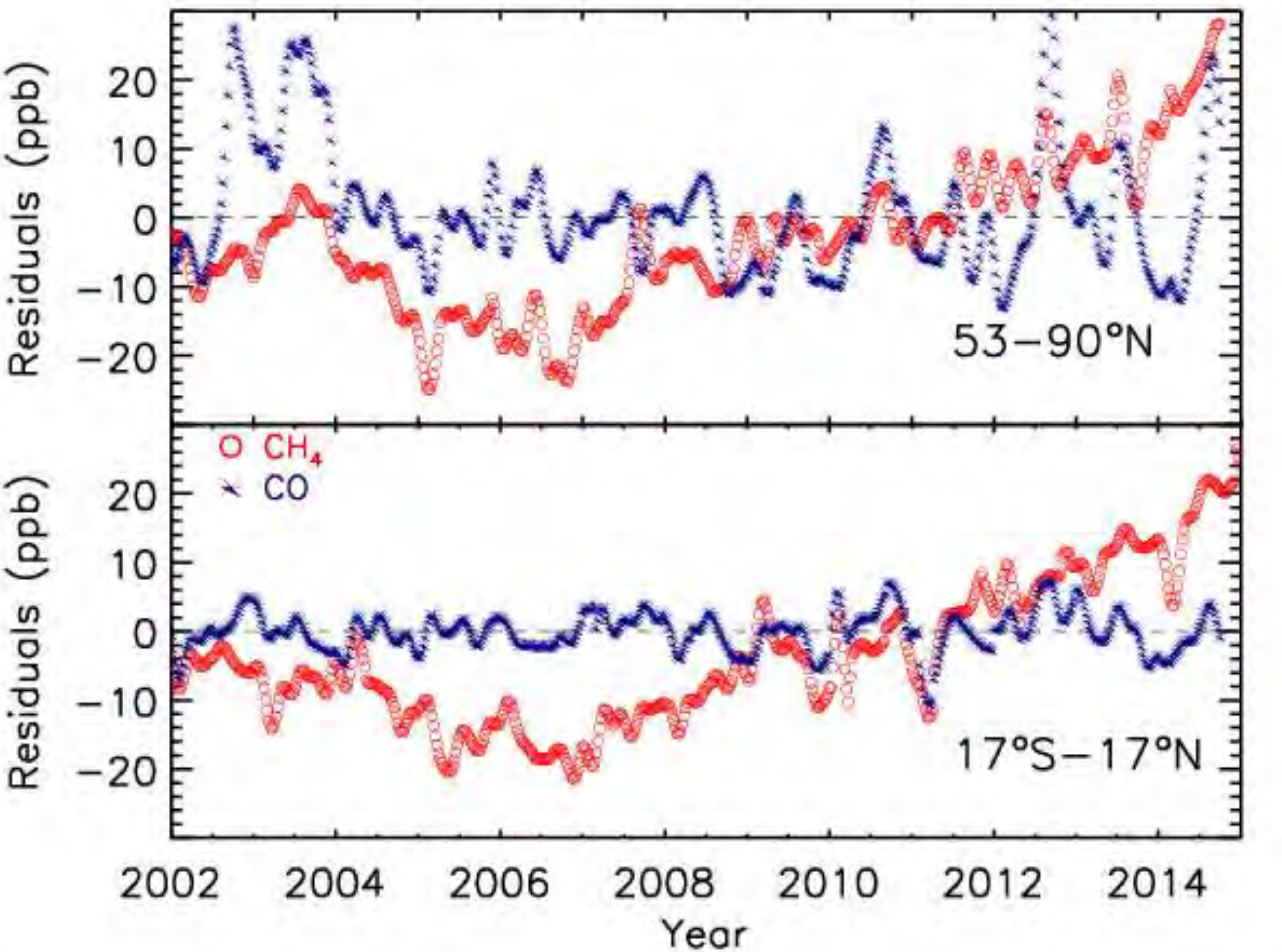
From BP Statistical Review of World Energy, 2015



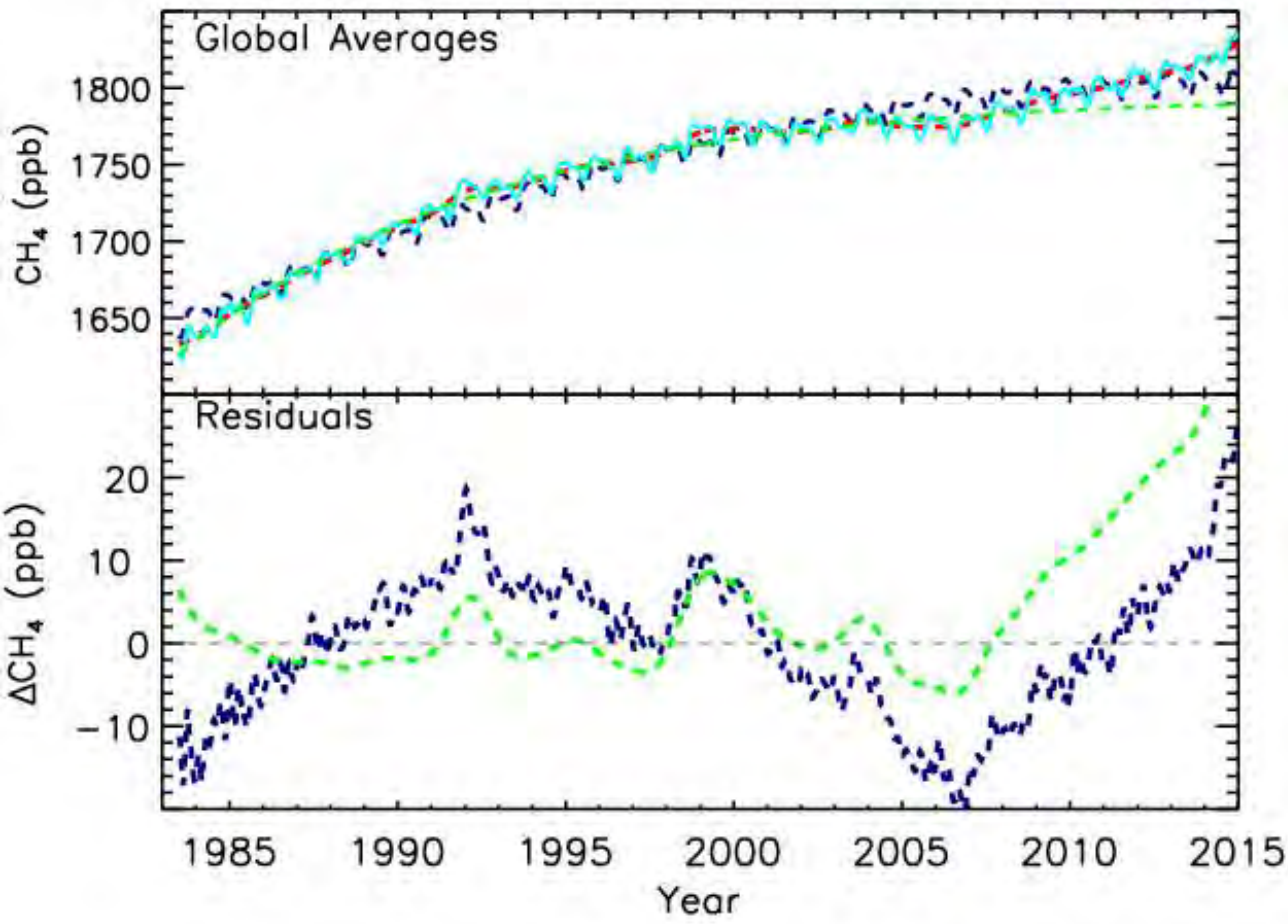
Observed rate of change, CH3CCl3 through mid-2014
NOAA flask data (GCMS)
NOAA flask data (GCMS)
ln(Y2/Y1)
-0.05
-0.1
-0.15
-0.2
1990
1995
2000
2005
2010
2015
2020


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

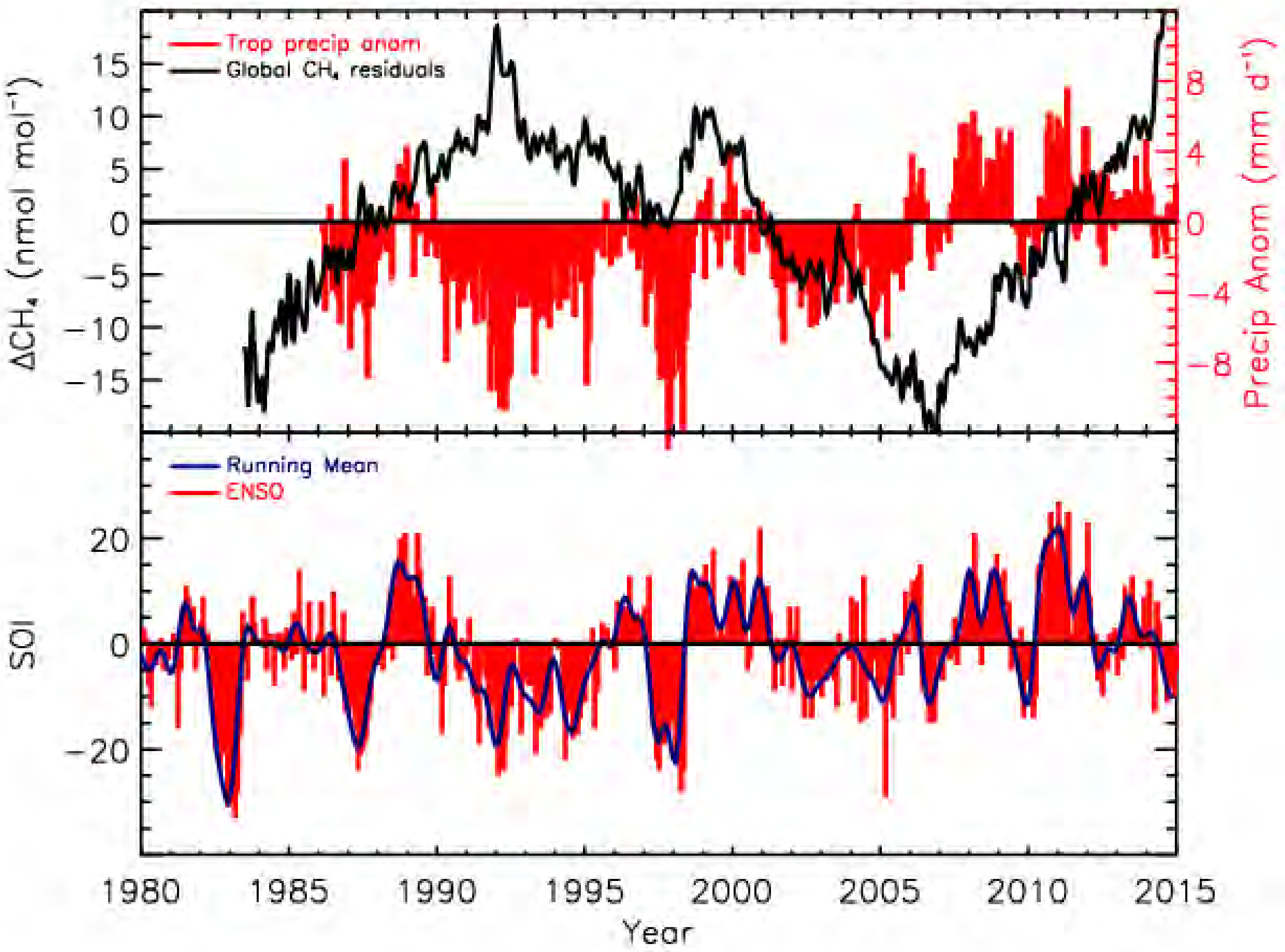

Base: 1961-1990
Precip Anom (mm d-1)
8
4
0
−4
−8
1985
1990
1995
2000
2005
2010
2015
Year



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
CH_4 (ppb)
1800
1750
1700
1650
Residuals
ΔCH_4 (ppb)
20
10
0
−10
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
15
10
5
0
−5
−10
−15
8
4
0
−4
−8
20
0
−20
1980
1985
1990
1995
2000
2005
2010
2015
Year

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.