Recent Increases in the Burden of Atmospheric CH_4: Implications for the Paris Agreement

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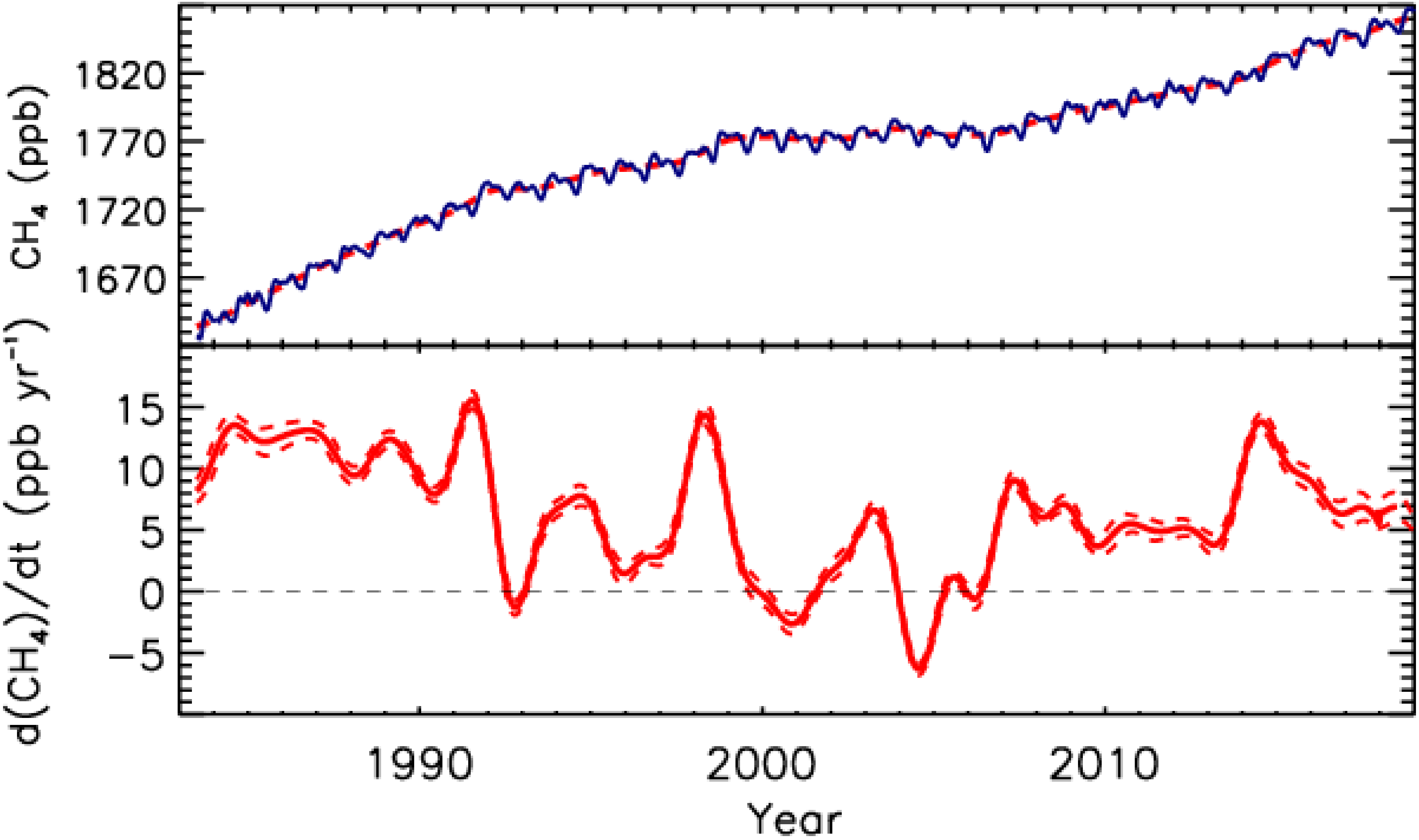
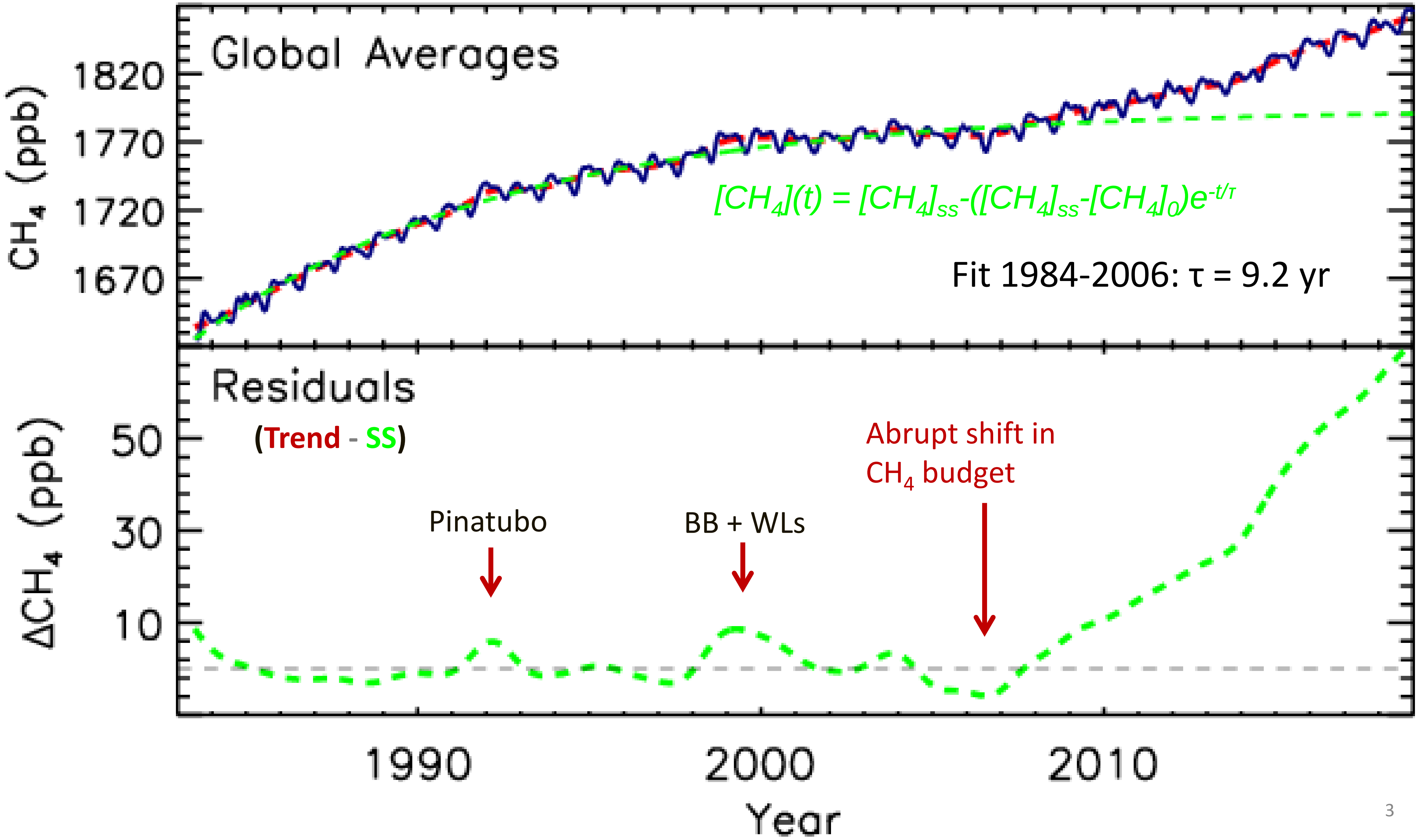
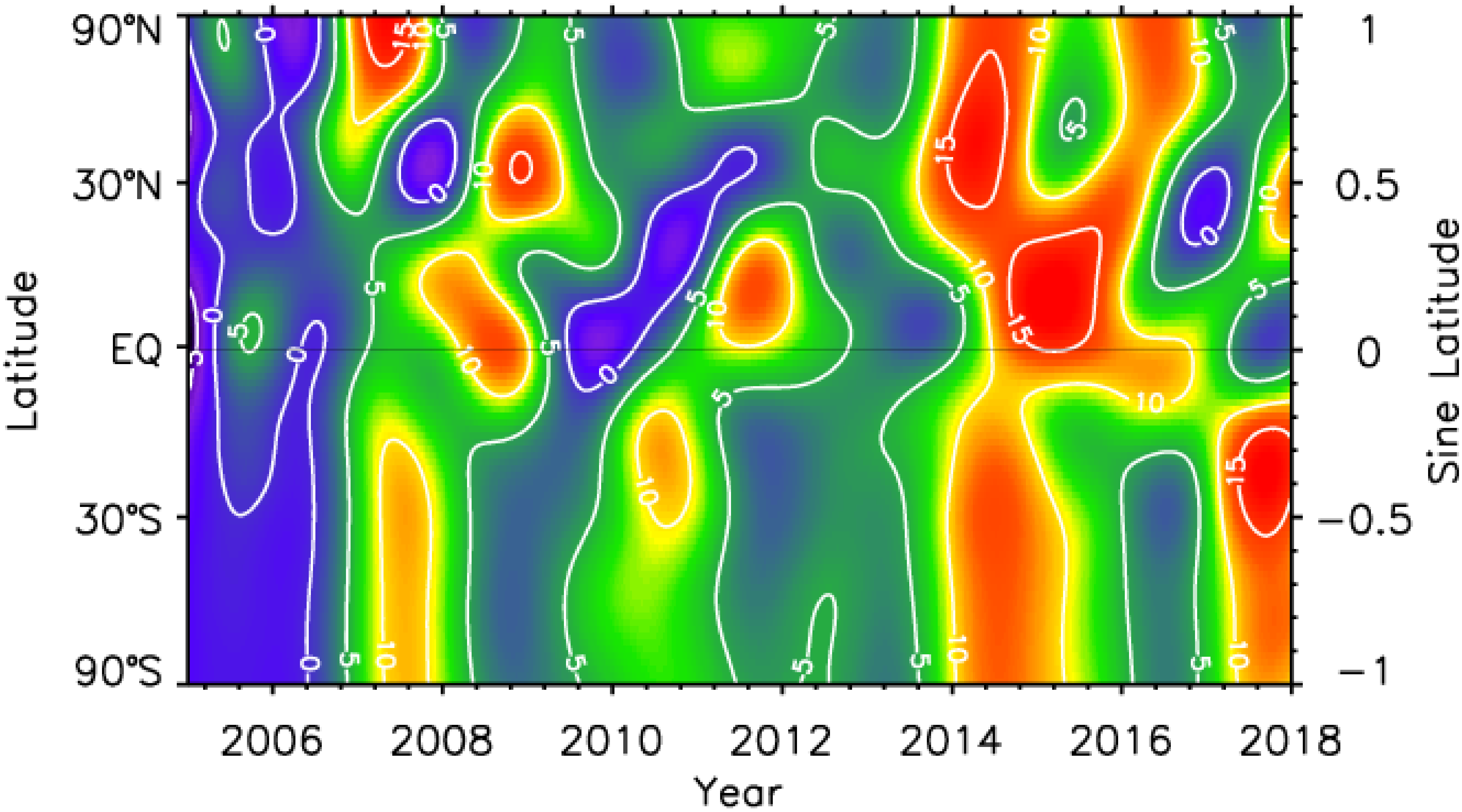


CH4 (ppb)
1820
1770
1720
1670
d(CH4)/dt (ppb yr-1)
15
10
5
0
−5
1990
2000
2010
Year


Global Averages
CH_4 (ppb)
1820
1770
1720
1670
$[CH_4](t) = [CH_4]_{ss}-([CH_4]_{ss}-[CH_4]_0)e^{-t/\tau}$
Fit 1984-2006: τ = 9.2 yr
Residuals
(Trend - SS)
ΔCH_4 (ppb)
50
30
10
Pinatubo
BB + WLs
Abrupt shift in
CH_4 budget
1990
2000
2010
Year



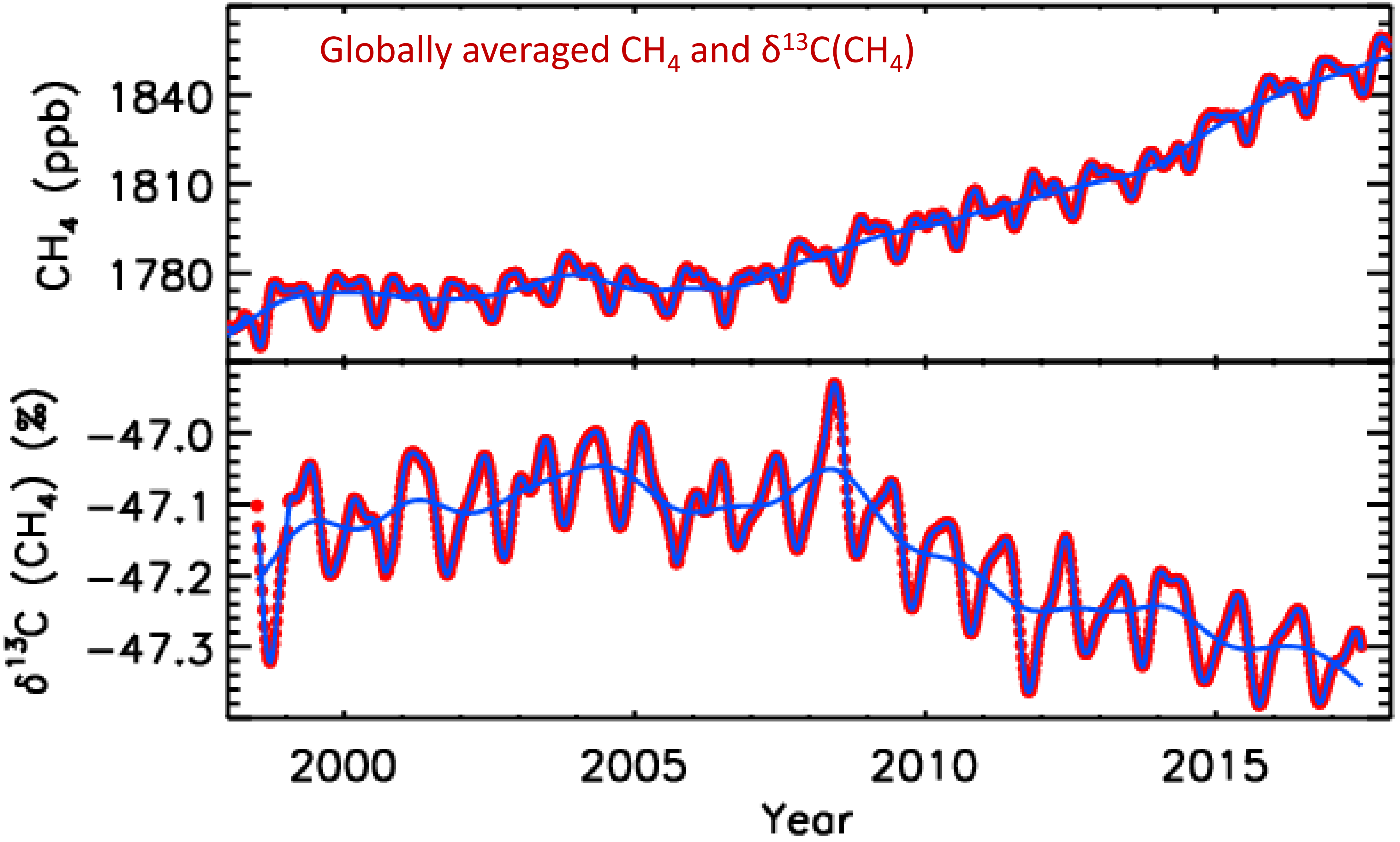
90°N
30°N
EQ
30°S
90°S
Latitude
1
0.5
0
−0.5
−1
Sine Latitude
2006
2008
2010
2012
2014
2016
2018
Year

Potential Causes of Increased CH_4: Changes in [OH]?

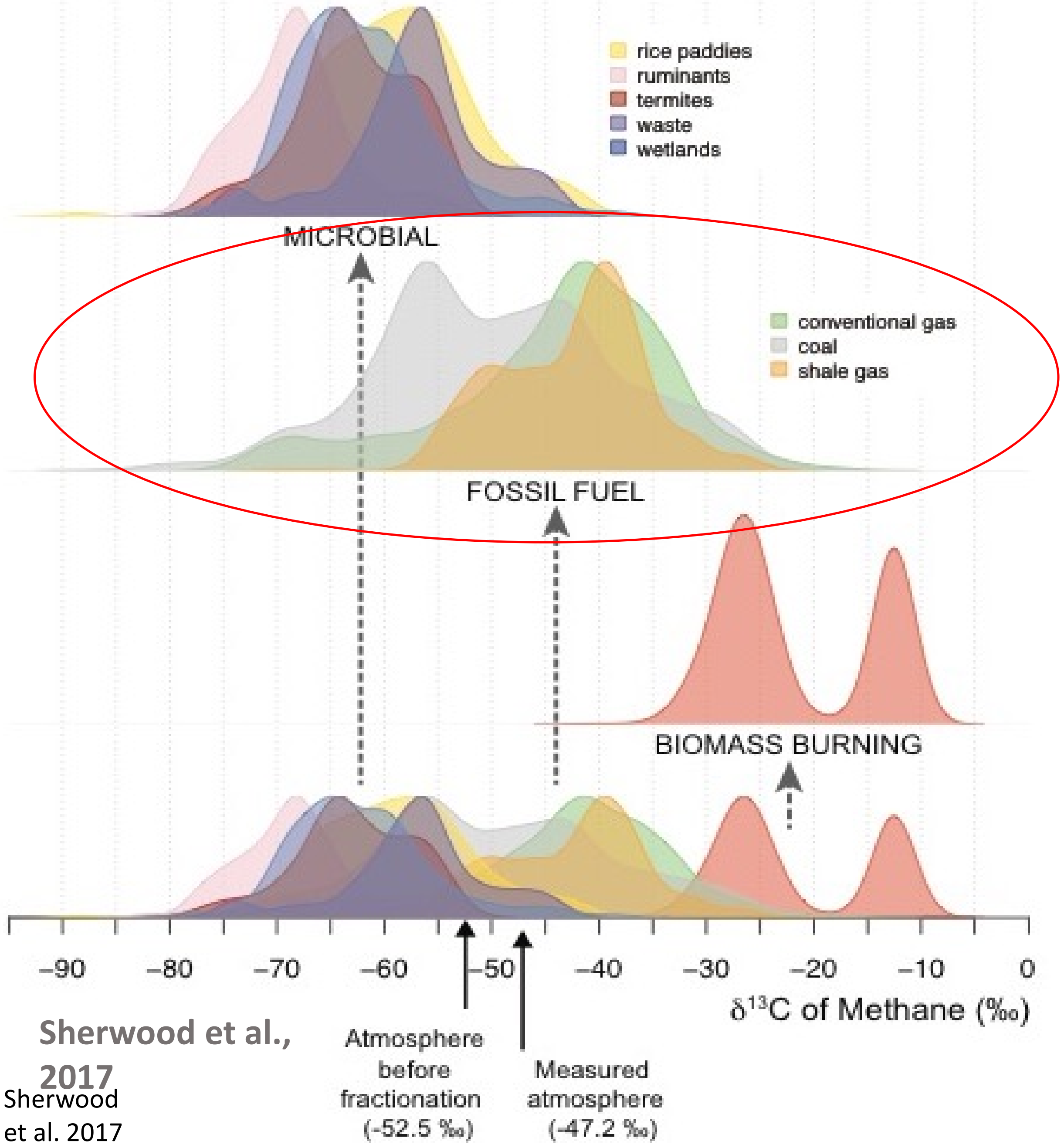
- Two 2-box-model studies:
  - Rigby et al. 2017; Turner et al., 2017
- Using MC as proxy, both suggest decreasing trend in [OH]
- Both agree data are consistent with no trend in [OH]
- Detailed spatial and temporal information not used
- Neither suggests a mechanism for Δ[OH]
- Not consistent with 3-D CTM calculations of [OH] (nor ^{14}CO constraint for SH extra-tropics)
- Δ[OH] can not explain $\delta^{13}C(CH_4)$
- Suggest $\delta^{13}CH_4$ provides only a weak constraint

Potential Causes of Increased CH_4: Changes in OH?

- **Not consistent with 3-D CTMs (e.g., Nicely et al., JGR, 2018)**
- Δ[OH] = -0.08±0.19%/decade (1985-2015)
  - Decreased [OH] from increased [CH_4] compensated by:
  - Changes in ↑H_2O, ↑[NO_x], ↓column O_3, tropical expansion, ↑T
- **Biases in box model (e.g., Naus et al., ACP, 2019)**
- Investigated systematic biases in transport and OH distribution in box models using 3-D CTM:
  - **Accounting for biases reverses trend in [OH], making it positive:**
    - Interhemispheric exchange rate
    - N/S asymmetry in [OH] (and "species-dependent" globally-averaged OH)
    - Stratospheric loss
    - Network bias in IHD (as in Pandey et al., 2019)



Globally averaged CH_4 and $\delta^{13}C(CH_4)$
CH_4 (ppb)
1840
1810
1780
$\delta^{13}C$ (CH_4) (‰)
−47.0
−47.1
−47.2
−47.3
2000
2005
2010
2015
Year



Sherwood et al., 2017

Sherwood et al. 2017

Is $\delta^{13}CH_4$ a weak constraint?

*Although wide range of values observed, emission-weighted mean well-defined.

Larger uncertainty may be with Cl

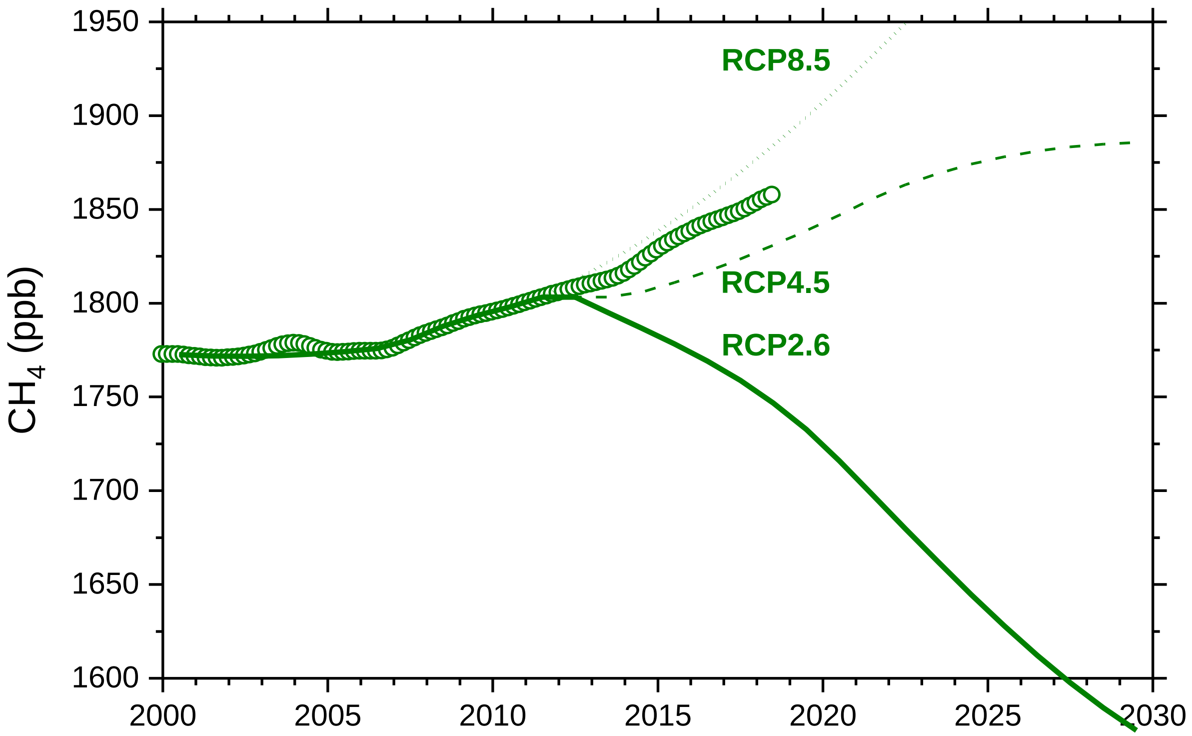
*Small impact on atmospheric XCH_4

*$k^{12}C/k^{13}C$ ~ 1.066

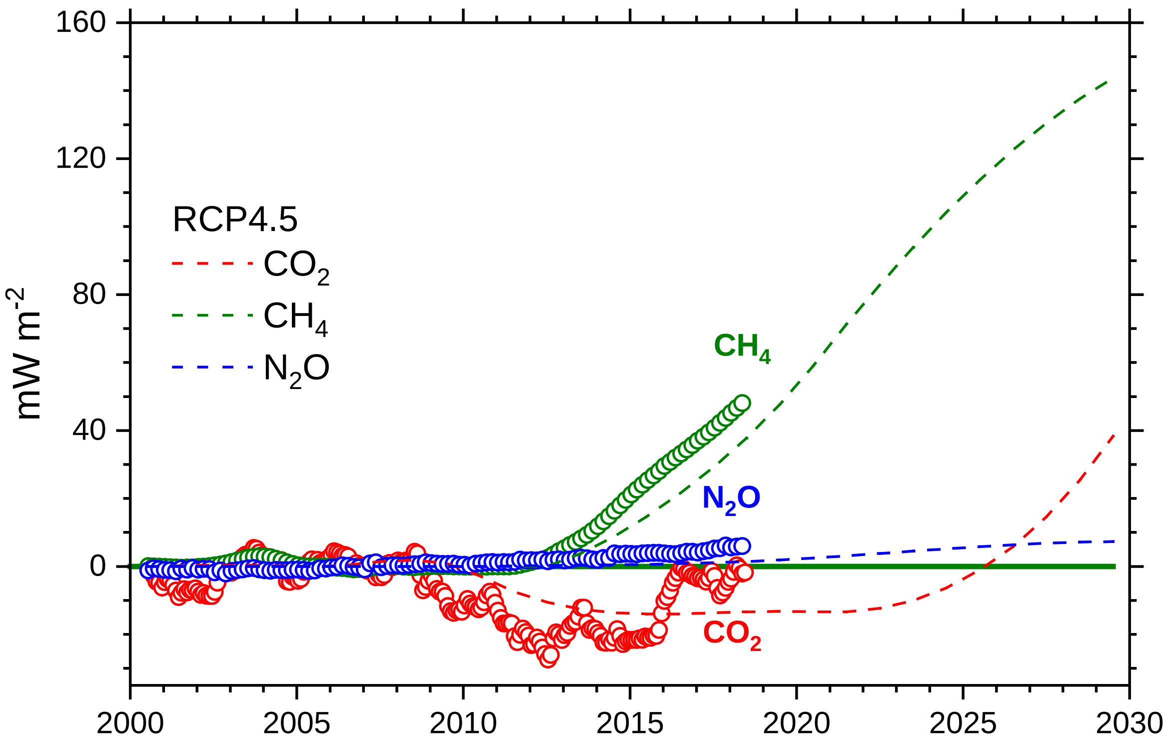
What does $\delta^{13}C$ tell us?

- Schaefer et al., Nature, 2016
  - Increased microbial emissions outside Arctic
  - More likely agricultural sources than wetlands
- Nisbet et al., GBC, 2016; 2019
  - Increased microbial emissions in tropics
  - Wetlands and agricultural sources could contribute
    - Role for meteorology
  - Unlikely that changing lifetime contributed
- Thompson et al., GRL, 2018:
  - ↑microbial (36 ± 12) and FF (15 ± 8 CH_4 Tg yr^{-1})
  - Offset by BB (-3 ± 2) and soil sink (+5 ± 6 Tg CH_4 yr^{-1})
  - No change in atmospheric sink

Does CH_4 threaten target of warming below 1.5°C?



Recent global average CH_4 mixing ratio relative to three scenarios used in the last IPCC assessment report.

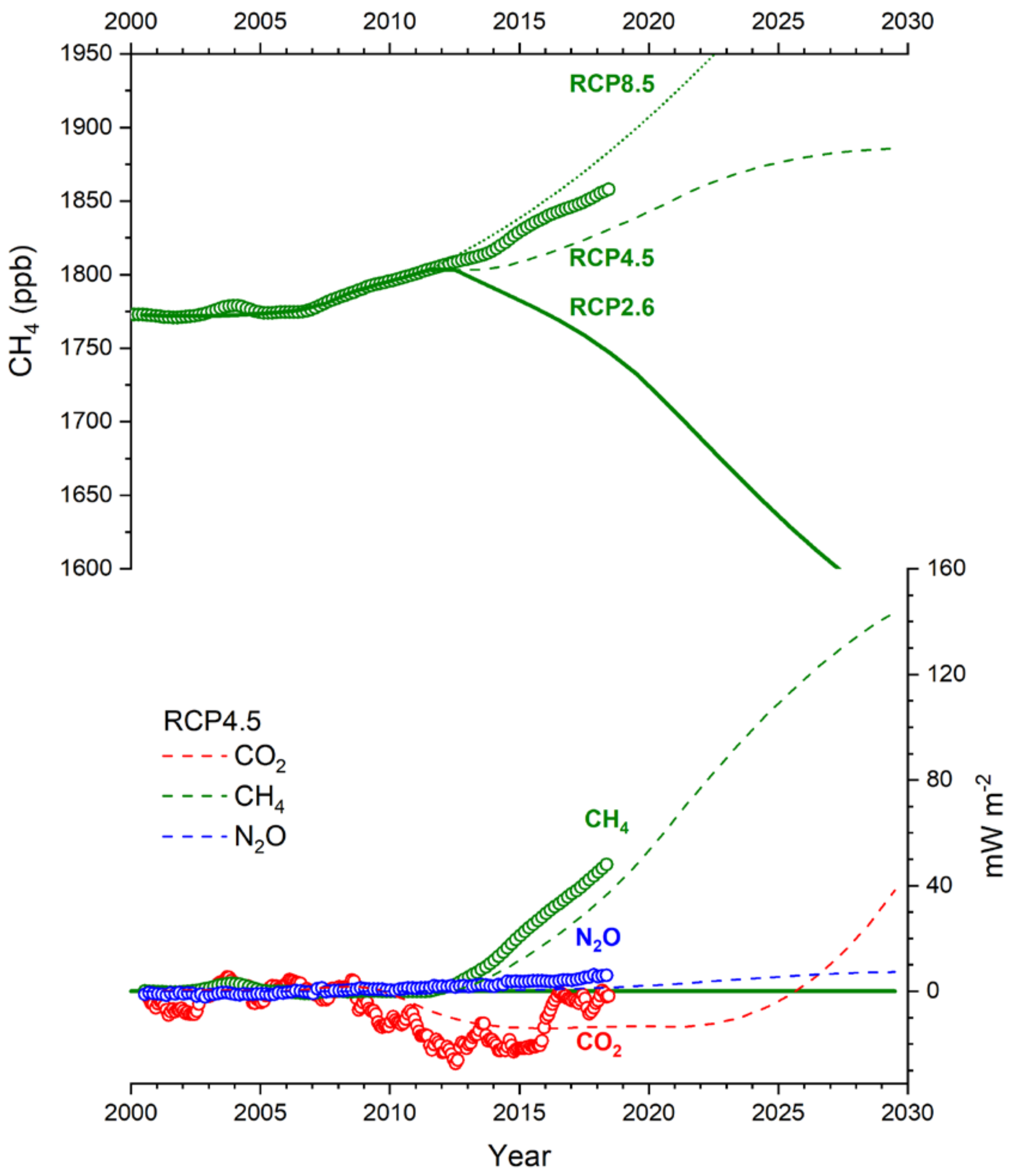


Observed changes in radiative forcing for CO_2, CH_4 and N_2O relative to the RCP2.6 scenario.

Summary: Can we Explain the Observations?

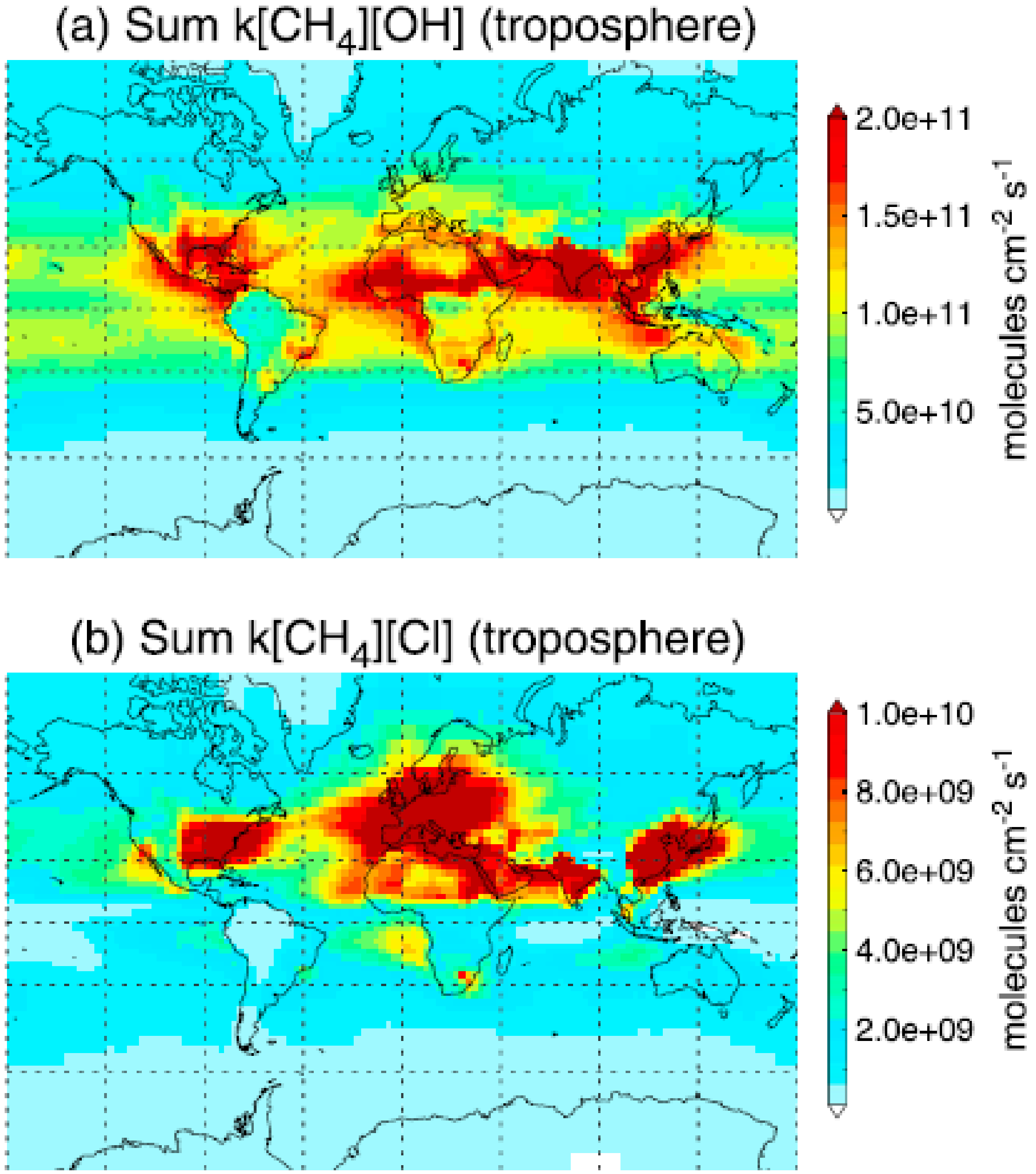
- Understanding small changes to global budget is challenging
  - CH_4 budget is complex: many sources and sinks, all uncertain
  - Problem poorly constrained by observations
  - Increase over past decade likely caused by combination of multiple processes
- Should not ignore temporal and spatial information
  - Observed changes are abrupt and significant; points to role for wetlands
- Suspect that wetlands are involved and process models are not realistic
  - Fail to account properly for IAV in WL area and “memory effects”
- $\delta^{13}C(CH_4)$ observations are certainly useful and perhaps misunderstood
  - Need better understanding of big levers: Cl and biomass burning
  - $\delta D(CH_4)$ currently too few to be useful
- Recent increase in CH_4 burden hinders attainment of $\Delta T \leq 1.5°C$
  - Increases need for costly and difficult carbon capture

Extra Slides



Climate impacts of increasing CH_4:

* RCP 2.6 could achieve 1.5°C target
* Already deviating from this trajectory for CH_4
* Without CH_4 reductions, need CO_2 removal
* Ignores SW component of RF (+25%)
* Policy: natural or anthropogenic processes?



Hossaini et al., 2016

Cl + CH_4 (Small contribution to total sink):

- Large influence on $\delta^{13}C(CH_4)$ with ($k(^{12}C/^{13}C) \approx 1.06$ or 60‰ fractionation)
- Distribution: Hossaini et al., 2016

Sources of tropospheric Cl:

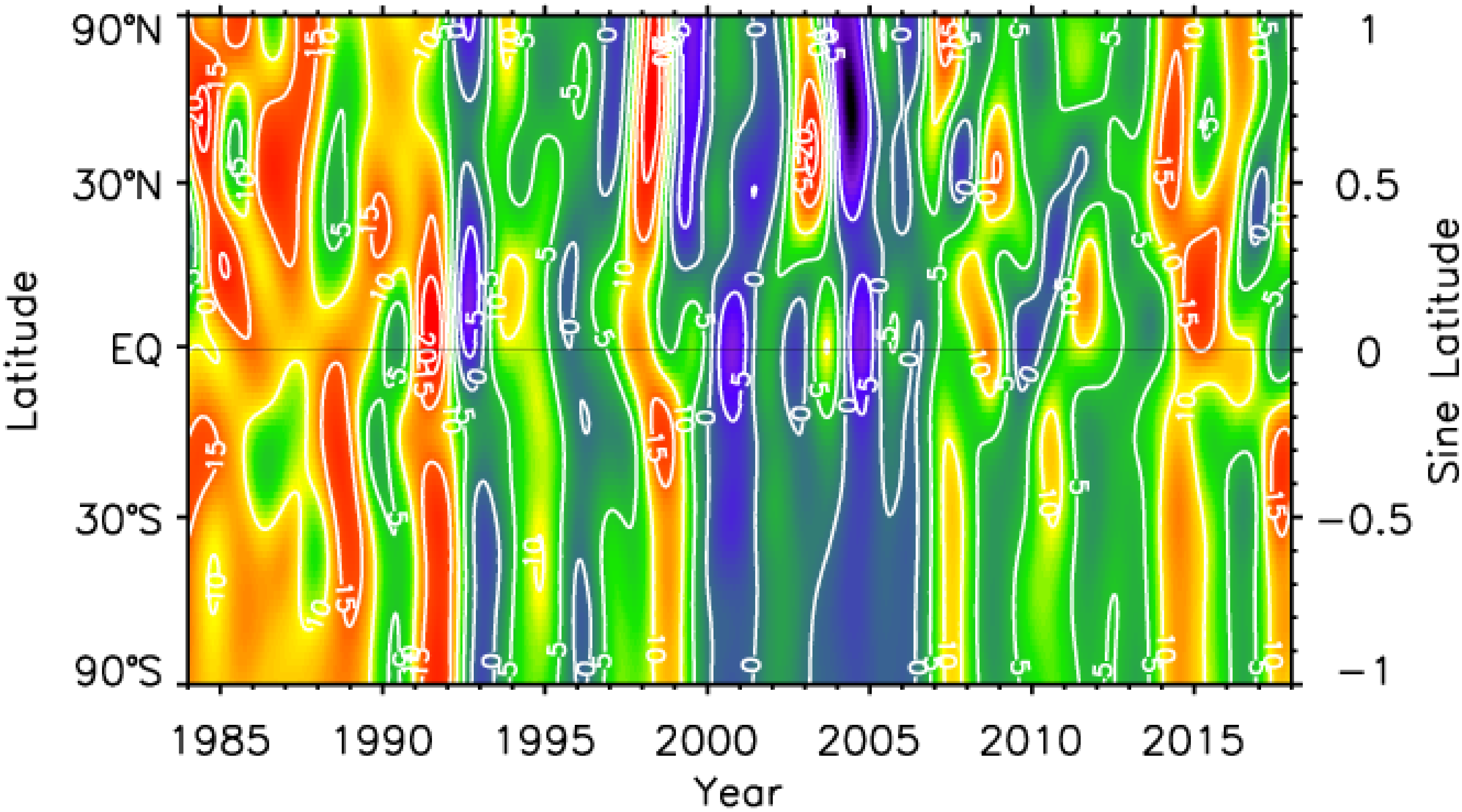
- Oxidation of natural and anthropogenic halocarbons (CH_3Cl, $CHCl_3$….)
- Heterogeneous reactions involving sea salt

Annual mean column-integrated loss for CH_4 oxidation by OH and Cl:

- Cl + CH_4: 12-13 Tg CH_4 yr^{-1} (2.5%)
- Contribution of Cl loss greatest at northern mid-latitudes
- Allan et al. (2007): 13-37 Tg CH_4 yr^{-1}
- Platt et al. (2004): up to 19 Tg CH_4 yr^{-1}

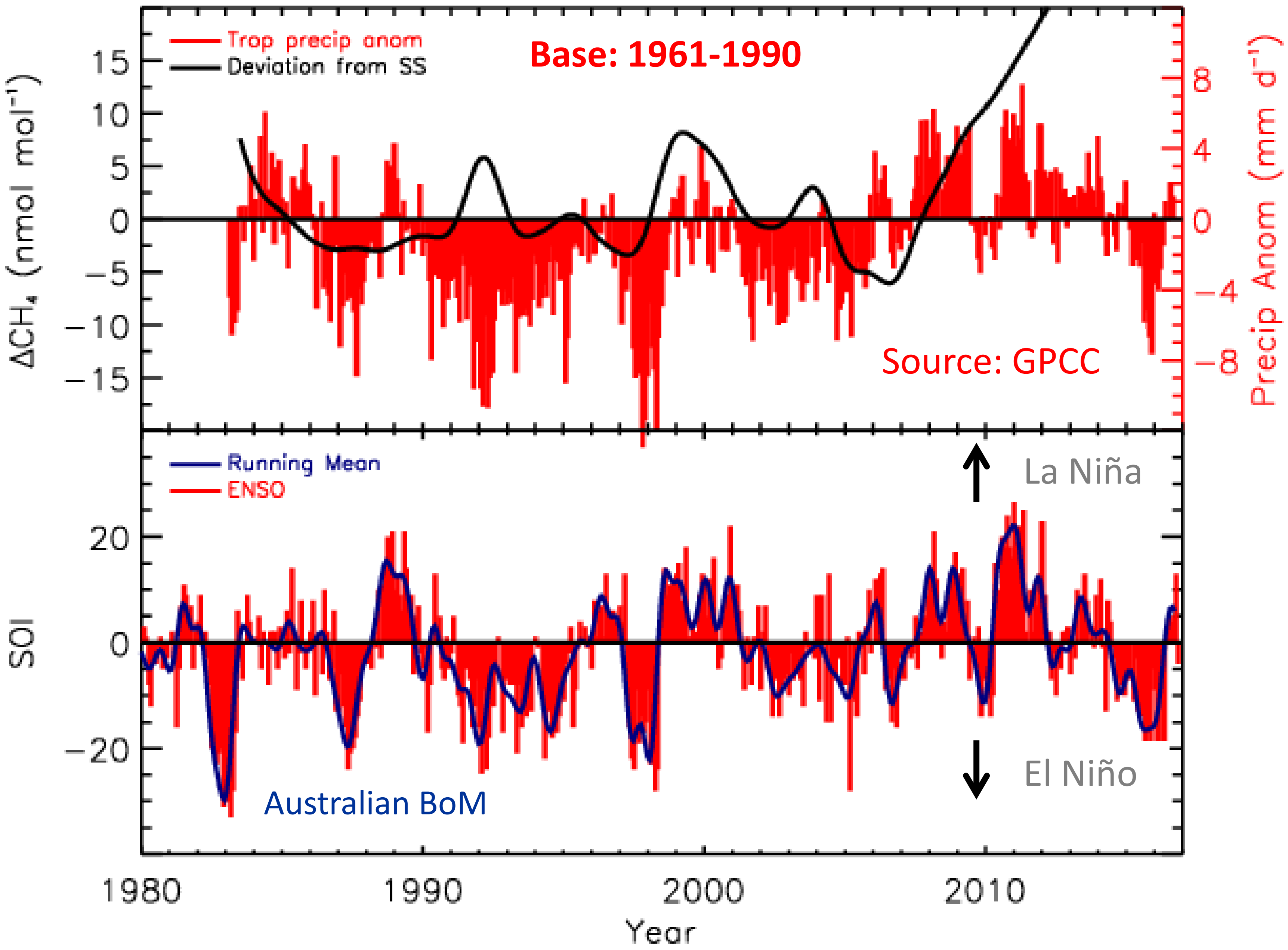
IPCC SR15: Simple Summary

- Climate change is happening
  - 1°C warming so far
  - Increased extreme weather
  - Rising sea level
- It is happening faster than we expected
  - Disappearing Arctic sea ice
- We are running out of time to limit its larger impacts
  - Zero CO_2 emissions by 2050!
  - Technological change must be guided by policy



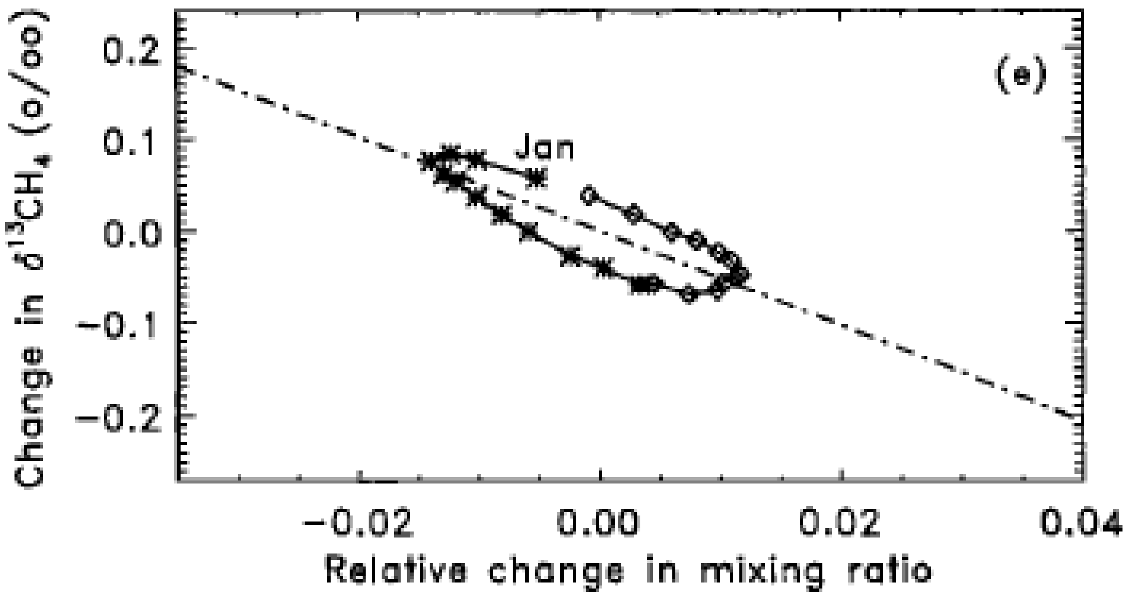
90°N
30°N
EQ
30°S
90°S
Latitude
1
0.5
0
−0.5
−1
Sine Latitude
1985
1990
1995
2000
2005
2010
2015
Year

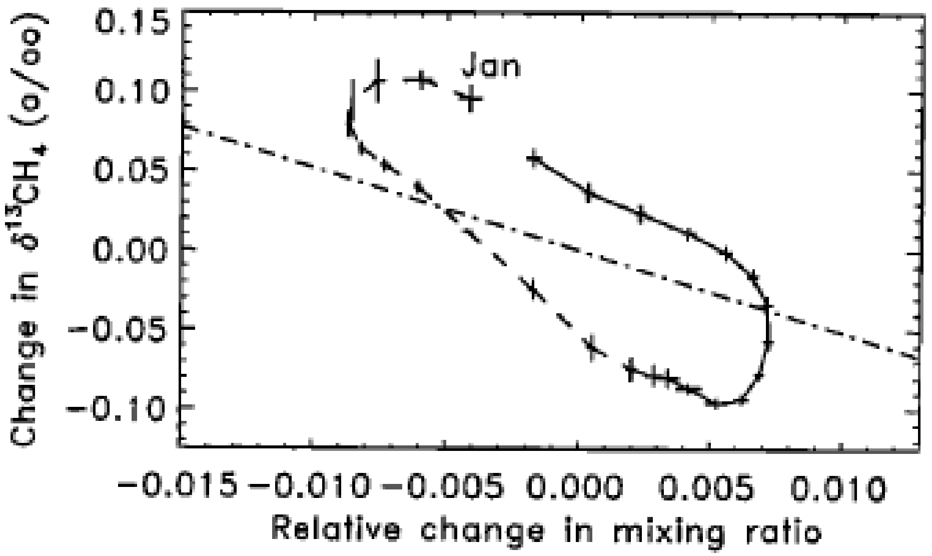
ENSO Phase: Precipitation



Role of Cl (Not just important in the stratosphere…)

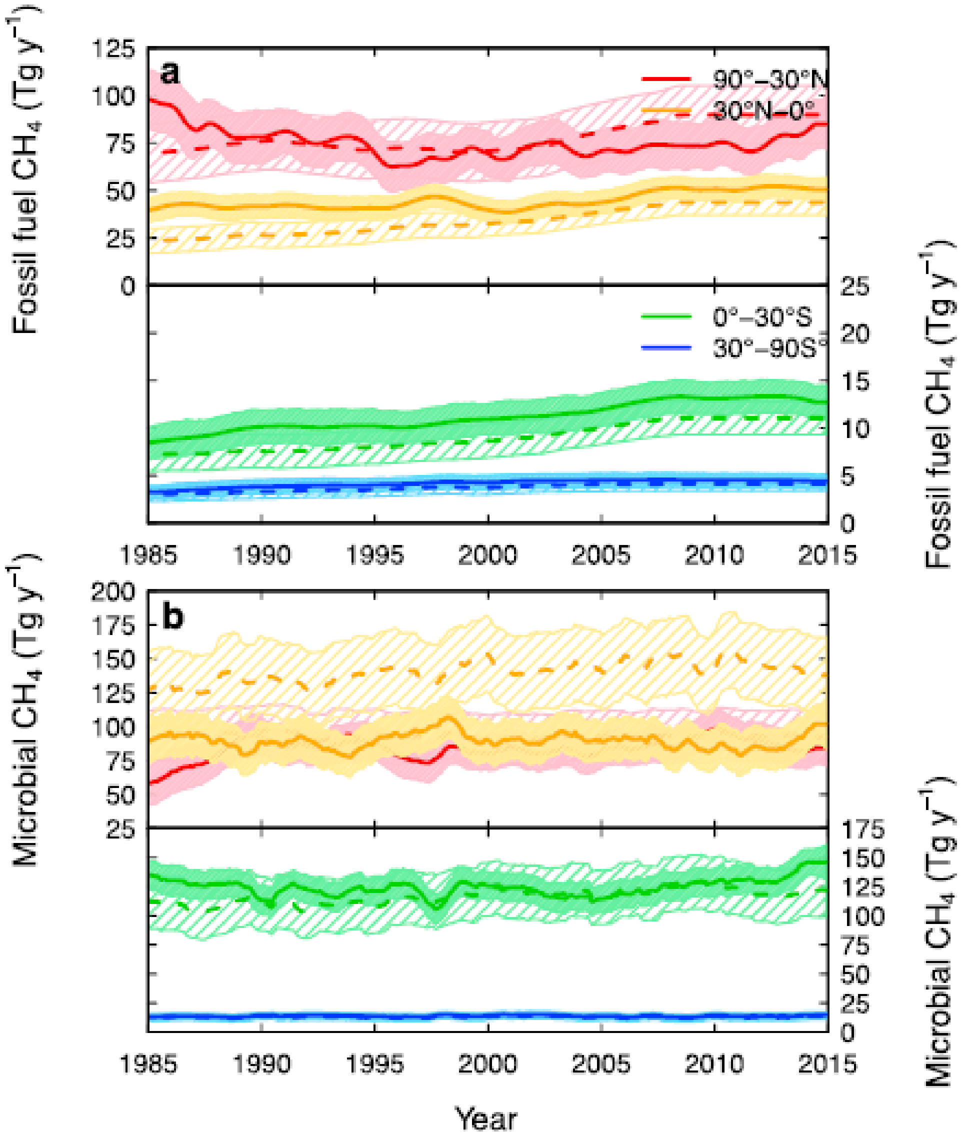
- Cl + CH_4: Small contribution to total sink despite larger *k* than for OH
  - Large influence on $\delta^{13}C(CH_4)$ ($k(^{12}C/^{13}C) \approx 1.06$)
- Allan et al., 2001
  - Evidence of role of Cl in observed $\delta^{13}C(CH_4)$ at ~40°S





- Cl magnitude and distribution not well constrained
  - Allan et al., 2007: assumed photochemical from sea salt; guessed distribution
  - Hossaini et al., 2016: calculated magnitude and distribution with CTM

Variability in Atmospheric Methane From Fossil Fuel and Microbial Sources Over the Last Three Decades, **R. L. Thompson et al., GRL, 2018**

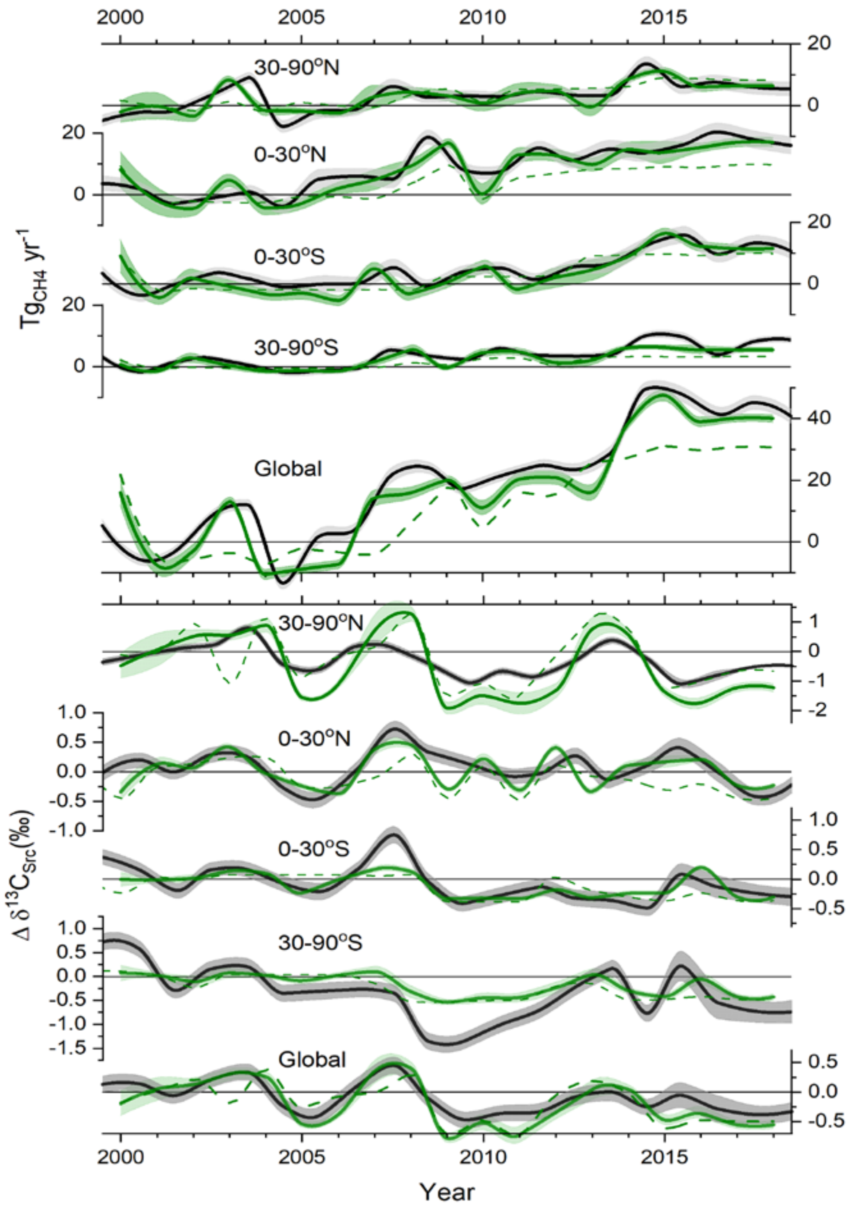


Optimized CH_4, C_2H_6, and $\delta^{13}C(CH_4)$; from 2006-14:

* ↑microbial (36 ± 12) and FF (15 ± 8 CH_4 Tg yr^{-1})
* Offset by BB (-3 ± 2) and soil sink (+5 ± 6 Tg CH_4 yr^{-1})
* No change in atmospheric sink

Important details:

* 2-D model (12-boxes, 4 x lat, 3 x vert)
* Used only Allan Cl distribution
* Used constant CH_4/C_2H_6 emission ratio



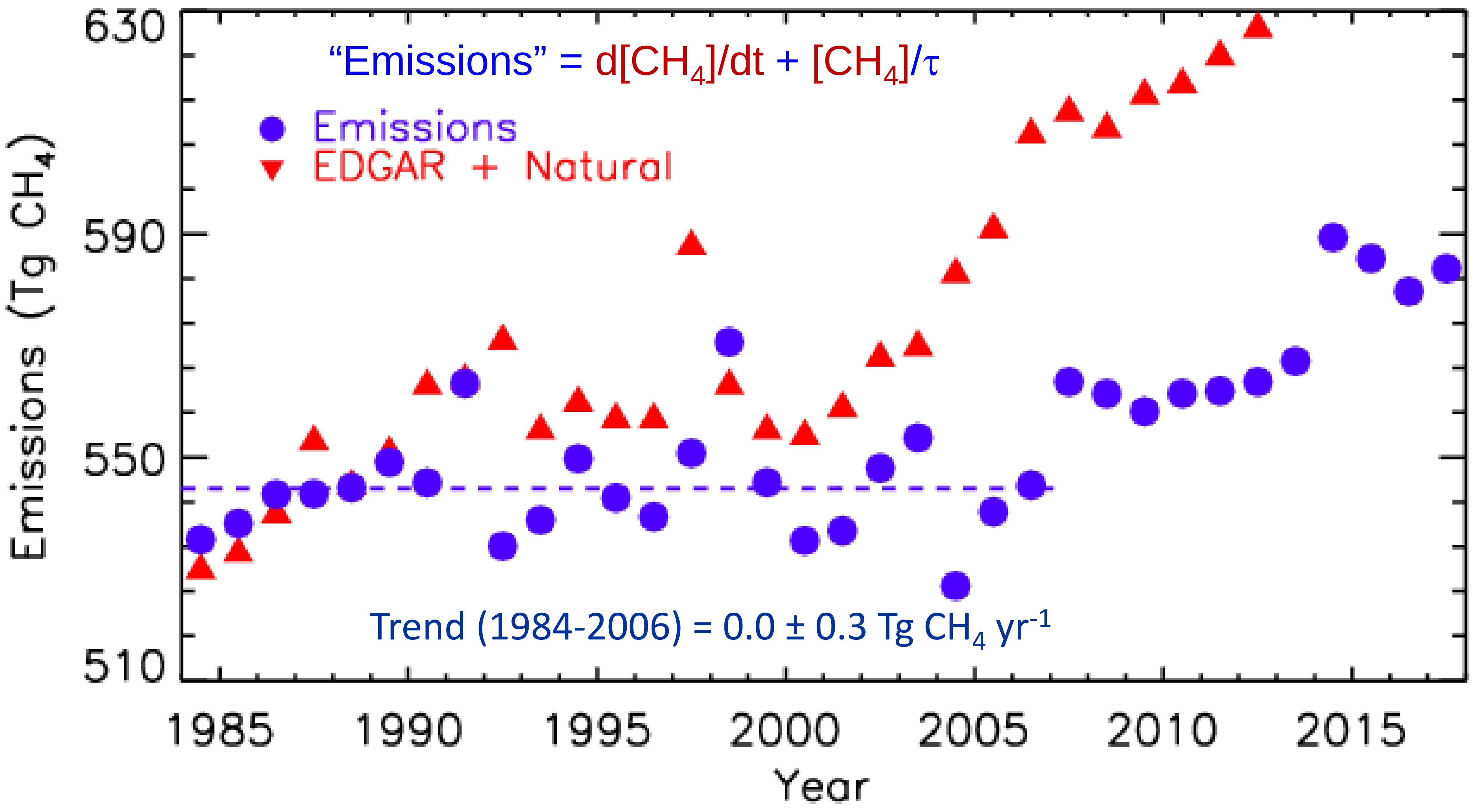
Nisbet et al., 2018, in review:

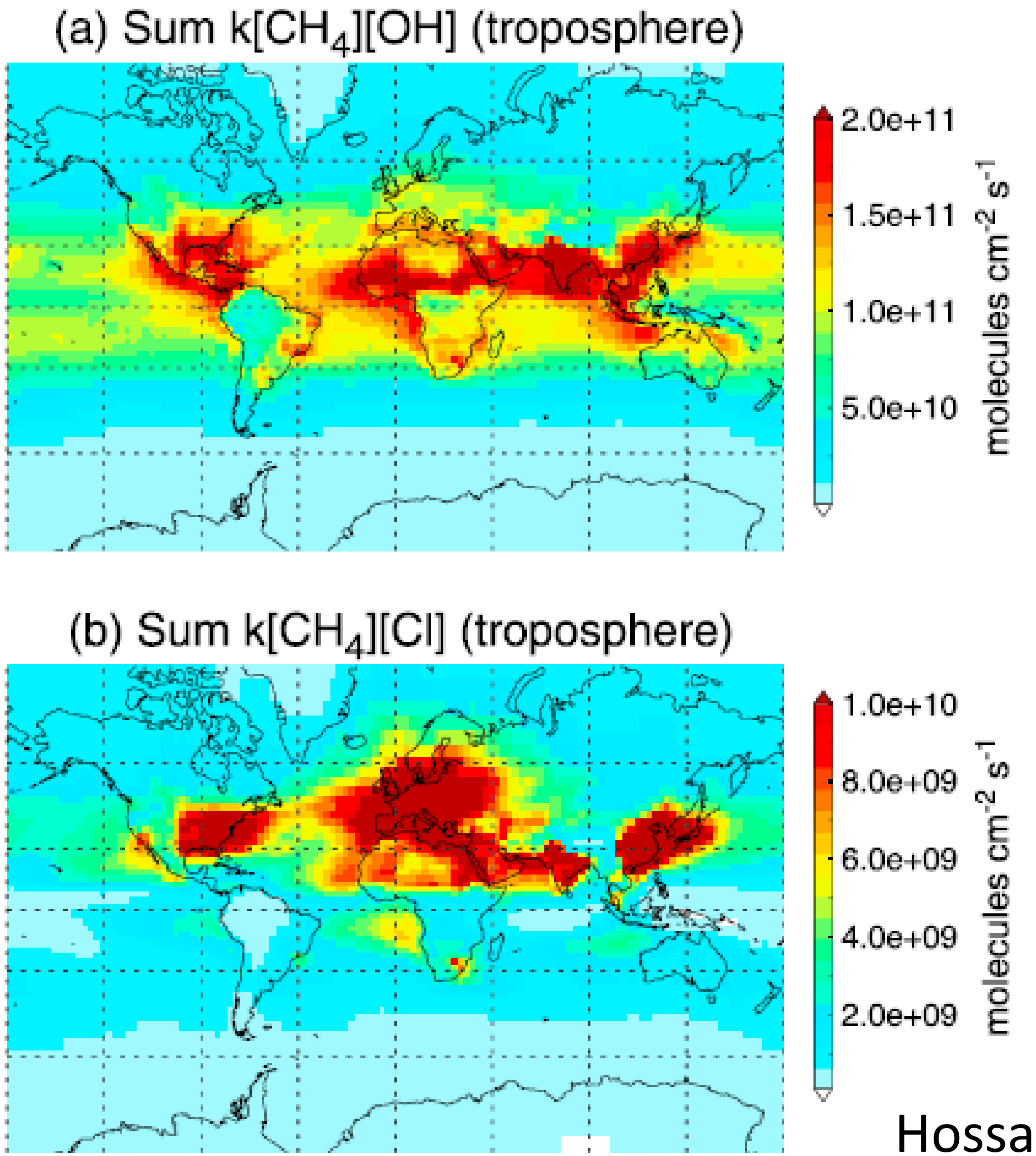
Emissions (black/gray):

* Emissions increase by ~40 Tg CH_4 yr^{-1} globally
* Avg $\delta^{13}C$ of src gets lighter (30-90°N and 0-30°S)

Sinks (green):

* Large Δsink (±5% x [OH]) to explain observations
* Difficult to reconcile with short-term variability


"Emissions" = d[CH4]/dt + [CH4]/τ
Emissions
EDGAR + Natural
Trend (1984-2006) = 0.0 ± 0.3 Tg CH4 yr-1
Emissions (Tg CH4)
630
590
550
510
1985
1990
1995
2000
2005
2010
2015
Year



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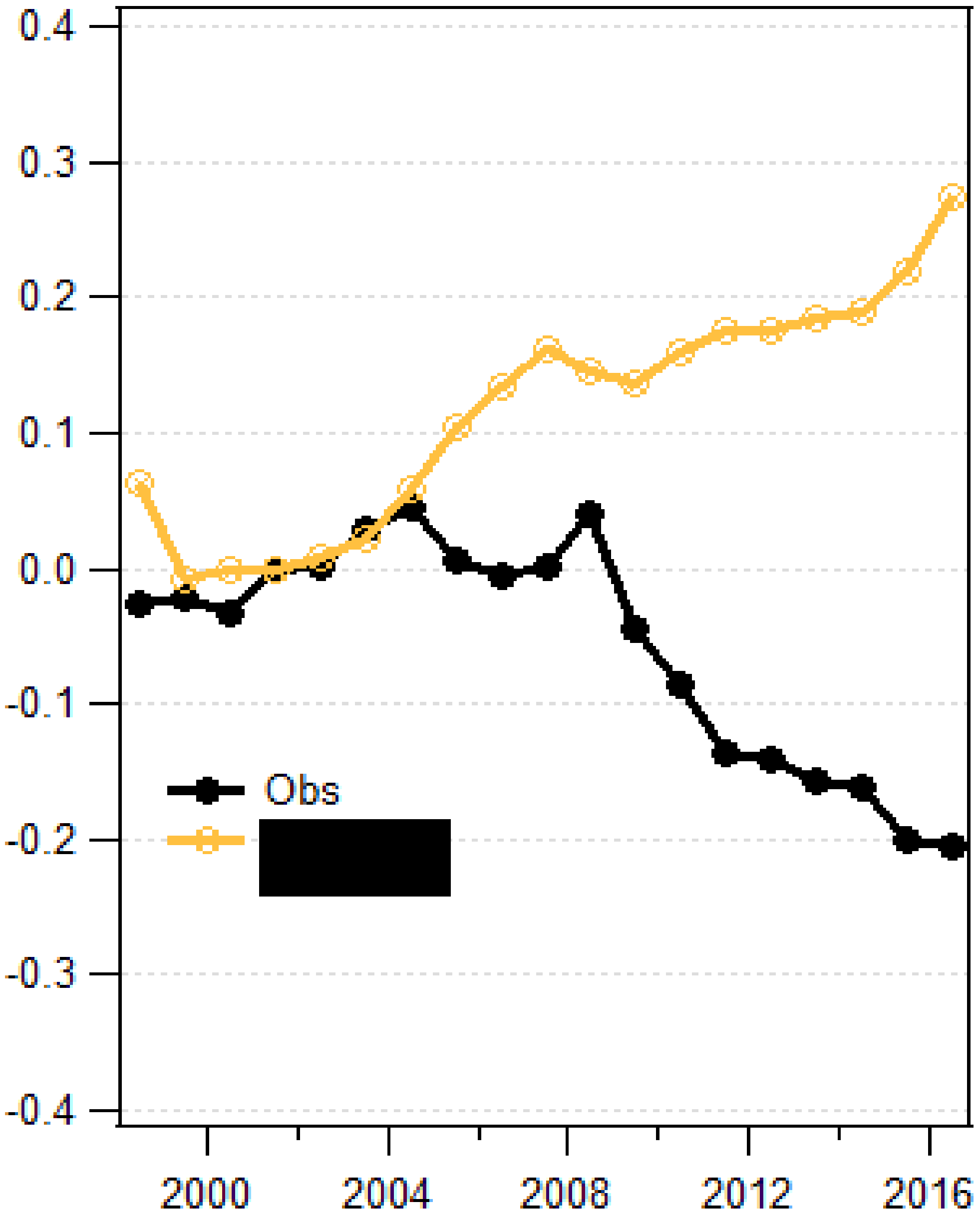
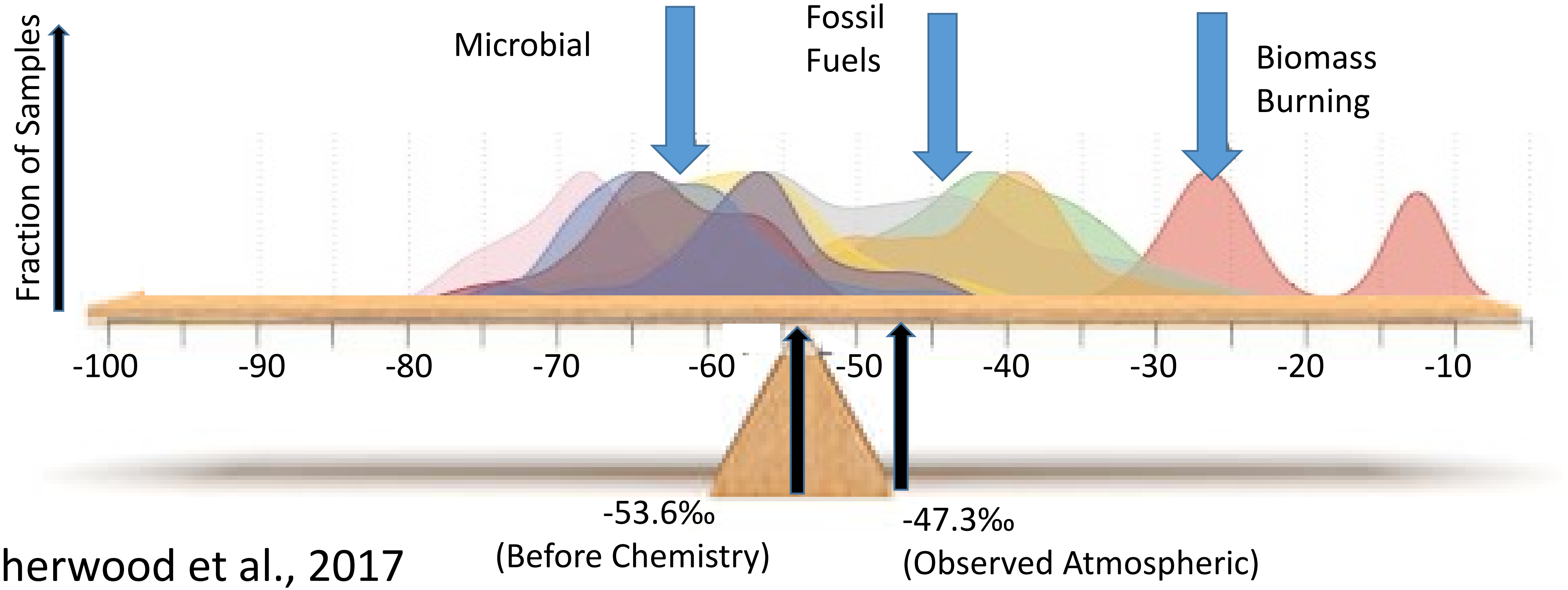


$\delta^{13}CH_4$ normalized to 2002:

*3-D CTM with [OH] reduced 8% and constant CH_4 emissions

*The influence of sink fractionation on atmospheric $\delta^{13}CH_4$ is determined not only by [OH], but the weighted averages of OH, Cl, $O(^1D)$, and soil sinks.

The $\delta^{13}C\text{-}CH_4$ Constraint:



Sherwood et al., 2017