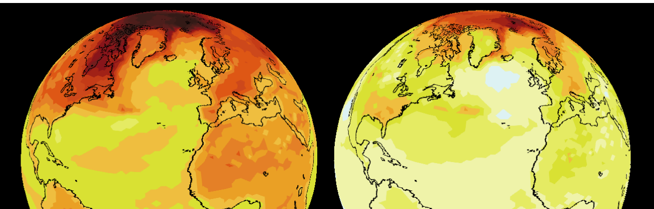
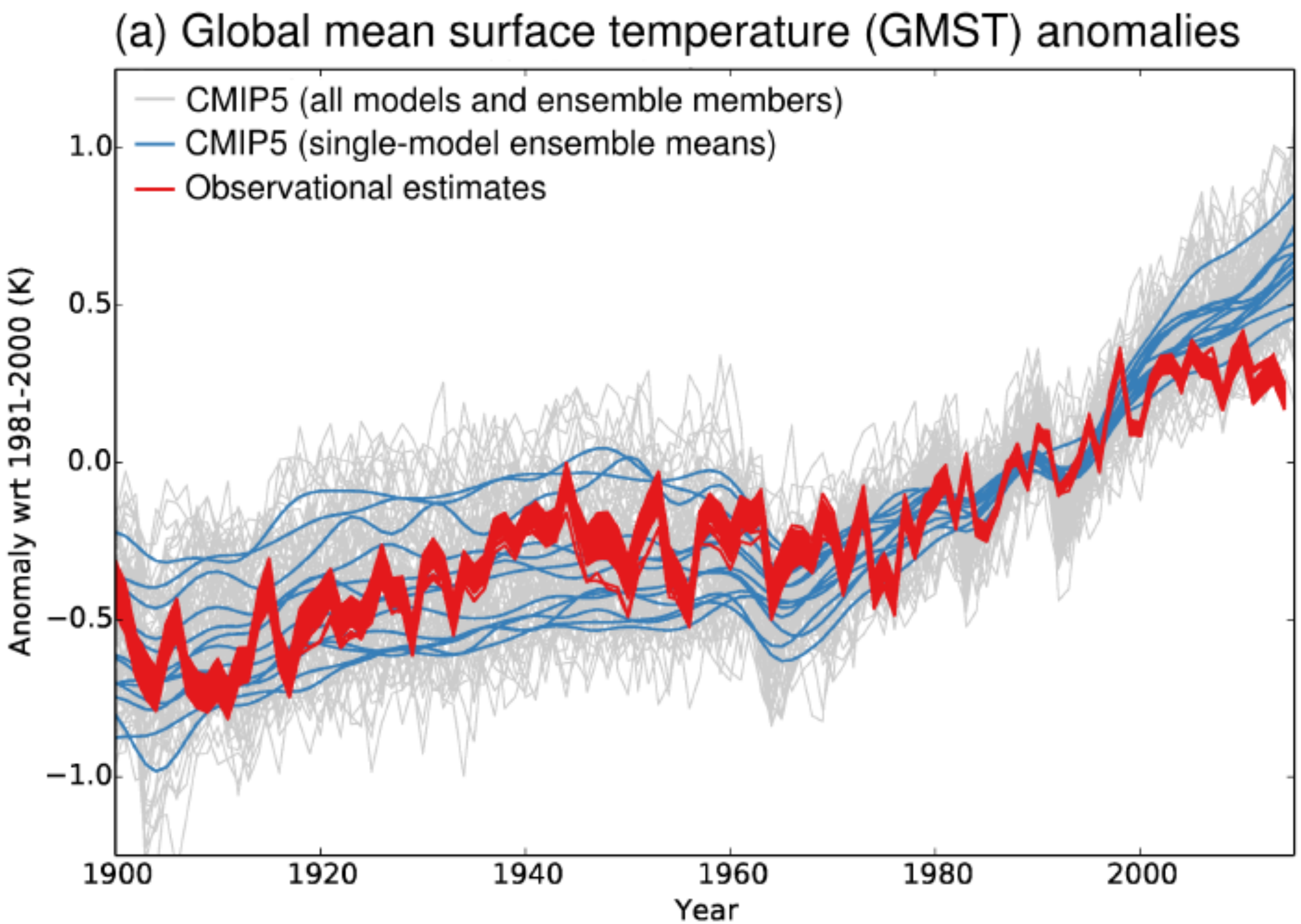
Energy Flow and the Global Warming Hiatus

Mat Collins *et al.*

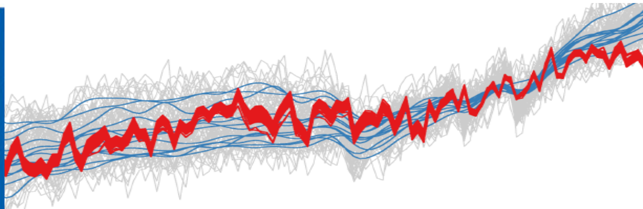
@mat_collins



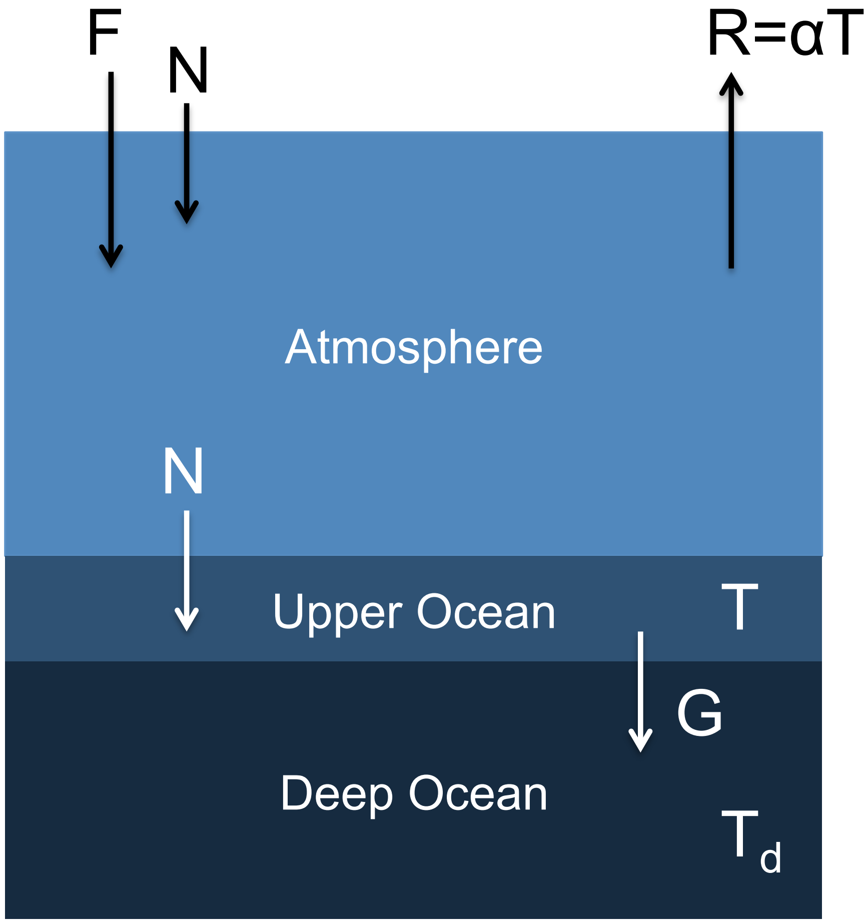
Warming 'Pause' or 'Hiatus'



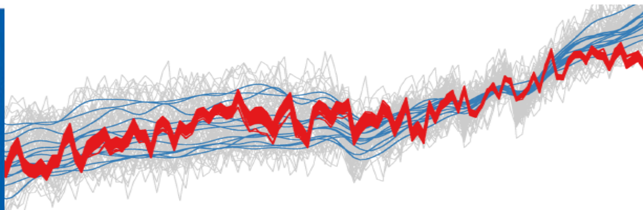
Roberts, Palmer, McNeall, MC, 2015



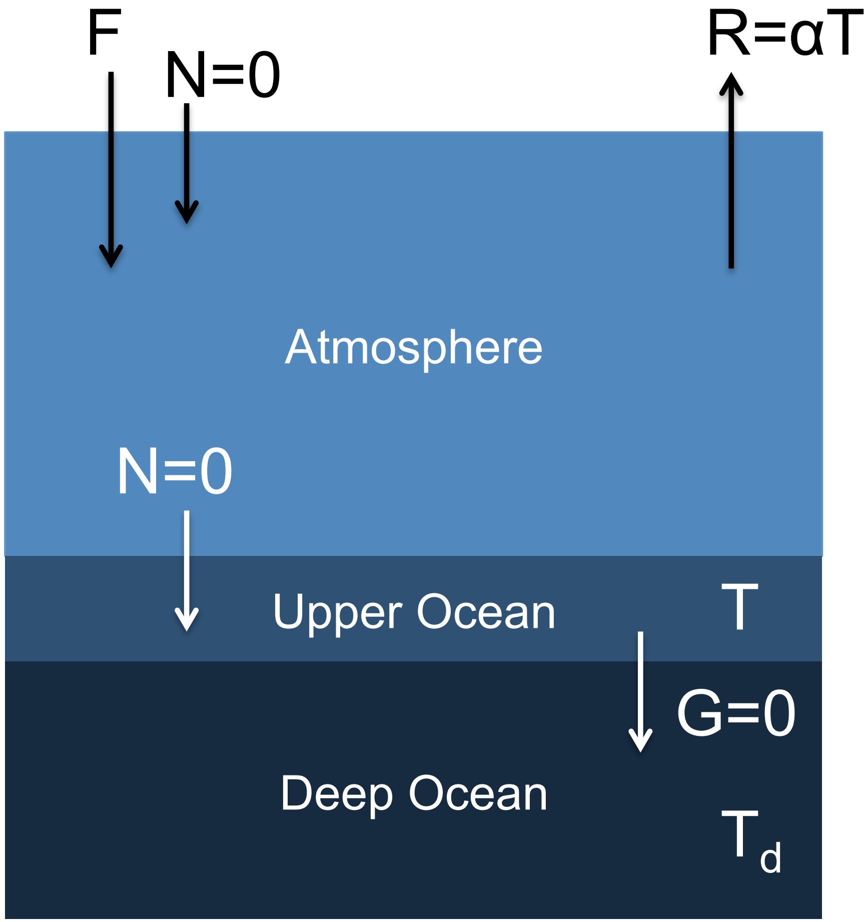
Global Mean Temperature



T = Global Mean Temperature
T_d = Deep Ocean Temperature
F = Radiative Forcing
R = Radiative Response
α = Feedback Parameter
N = Net Heat Flux at TOA and into Ocean (N = F – R)
G = Heat Flux from Upper Ocean to Deep Ocean



Equilibrium Case



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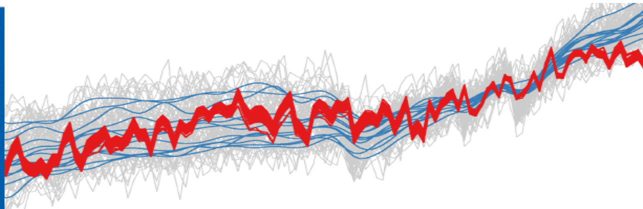
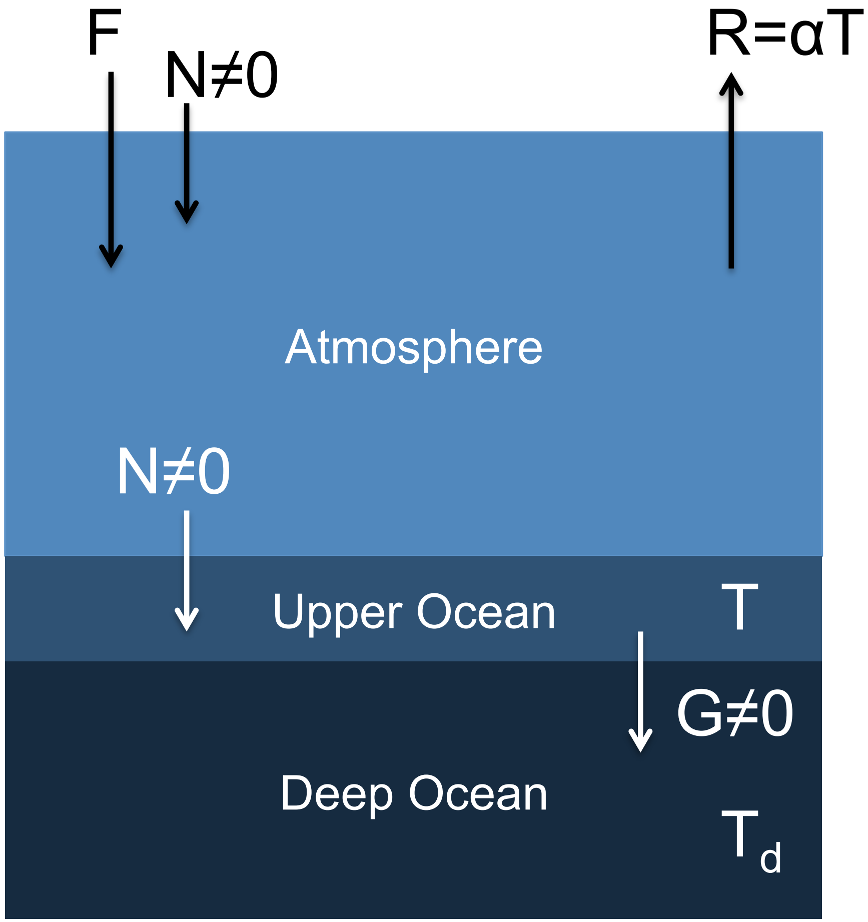
$$T=\alpha/F$$

Gregory, Forster



Transient Case



= Global Mean Temperature
T_d = Deep Ocean Temperature
F = Radiative Forcing
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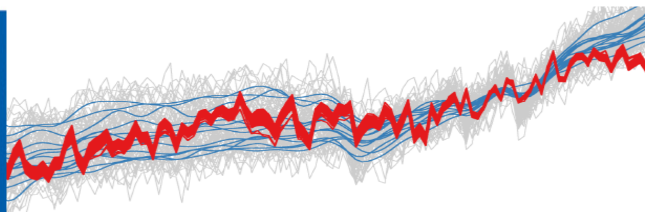
N = Net Heat Flux at TOA and into Ocean (N = F – R)
G = Heat Flux from Upper Ocean to Deep Ocean = $\gamma(T - T_d)$
C = Heat Capacity



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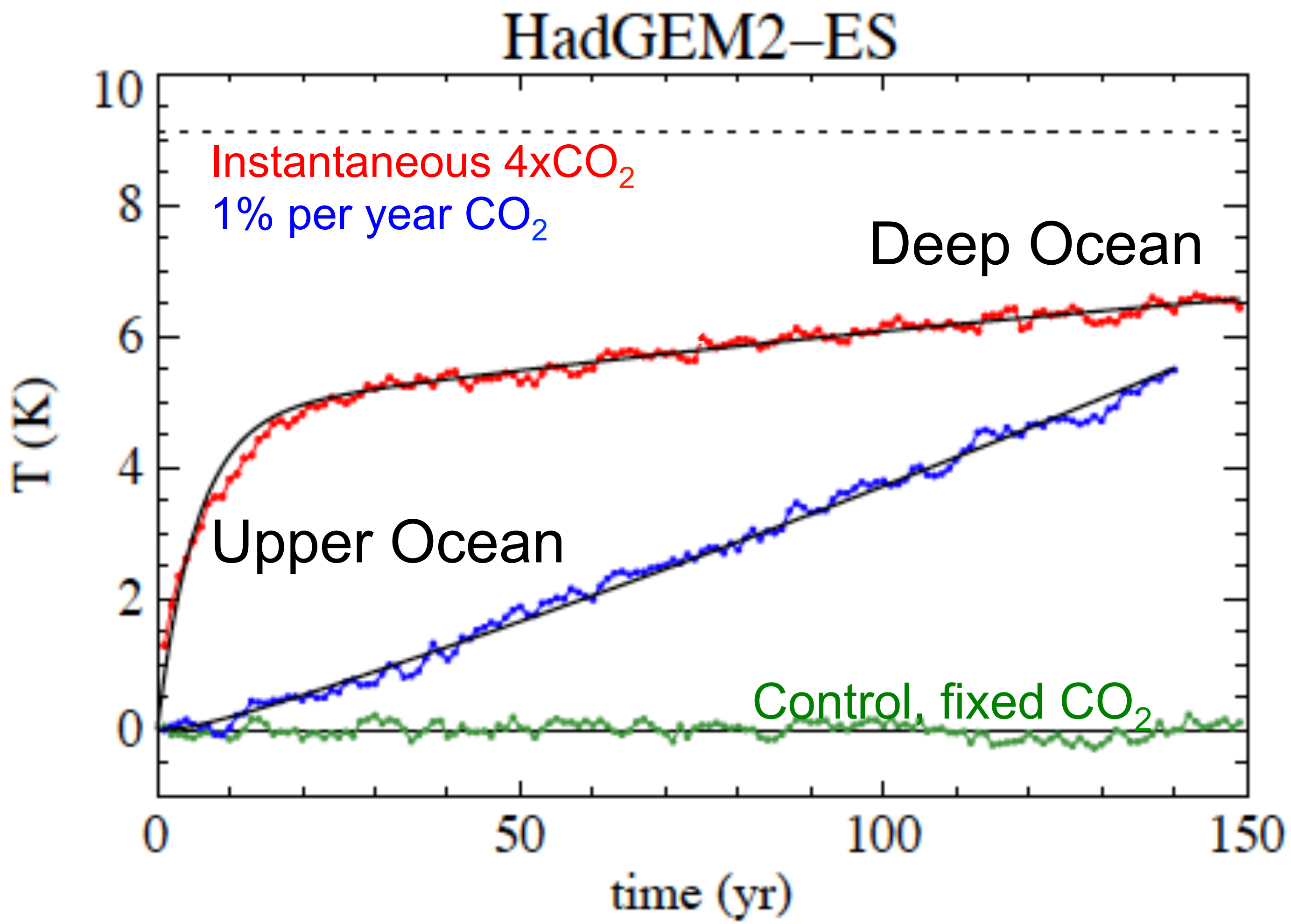
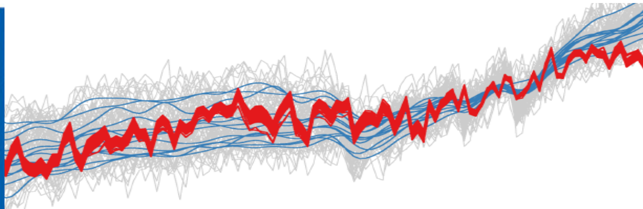
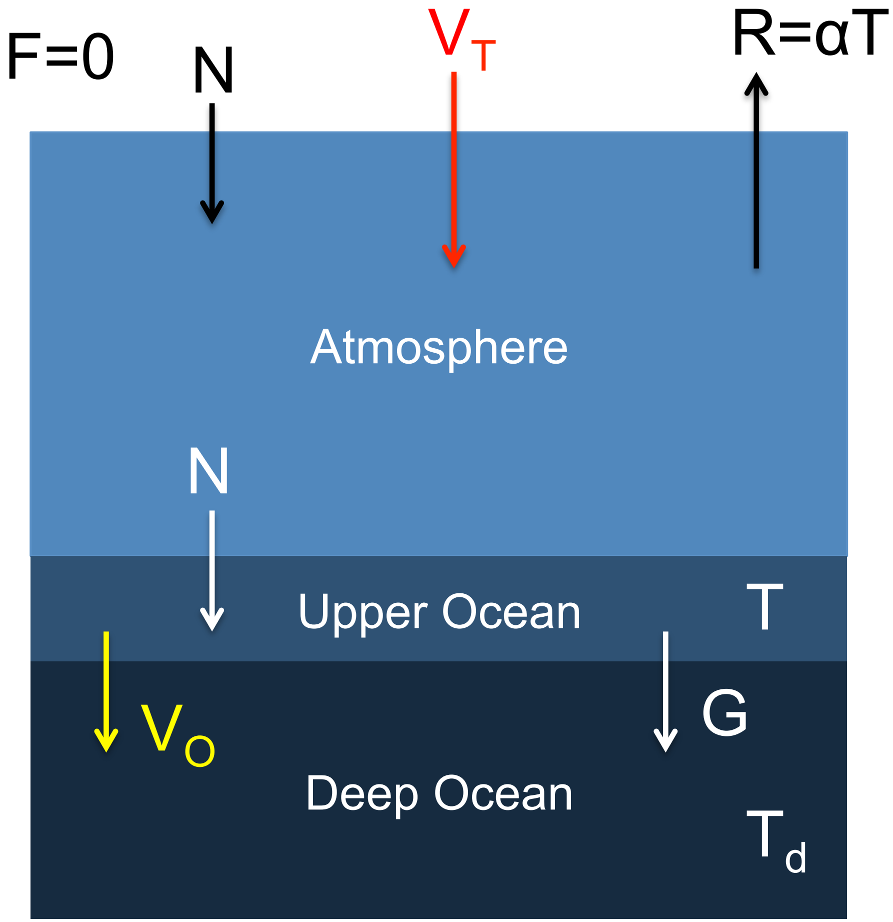


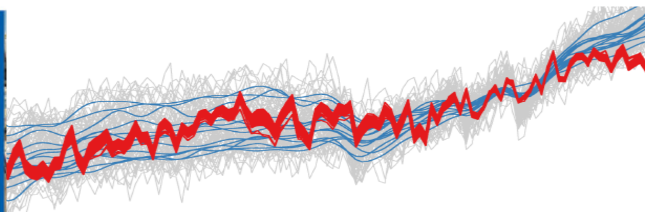
Goffroy et al., 2013



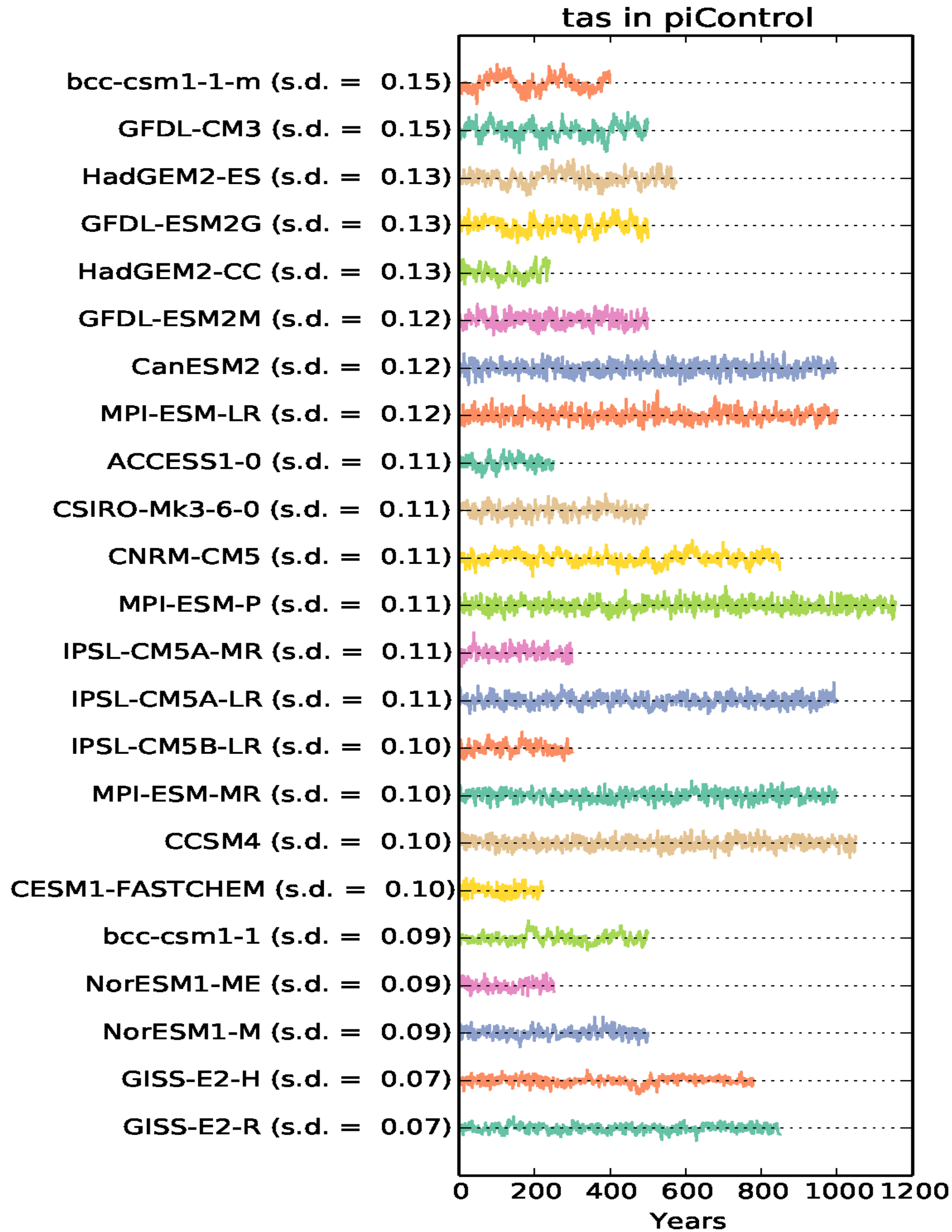
Natural Internal Variability



T = Global Mean Temperature
T_d = Deep Ocean Temperature
F = Radiative Forcing
R = Radiative Response
α = Feedback Parameter
N = Net Heat Flux at TOA and into Ocean ($N = V_T – R$)
G = Heat Flux from Upper Ocean to Deep Ocean = $\gamma(T – T_d)$
C = Heat Capacity
V_T = Unforced Variability in the Atmosphere
V_O = Unforced Variability in the Ocean

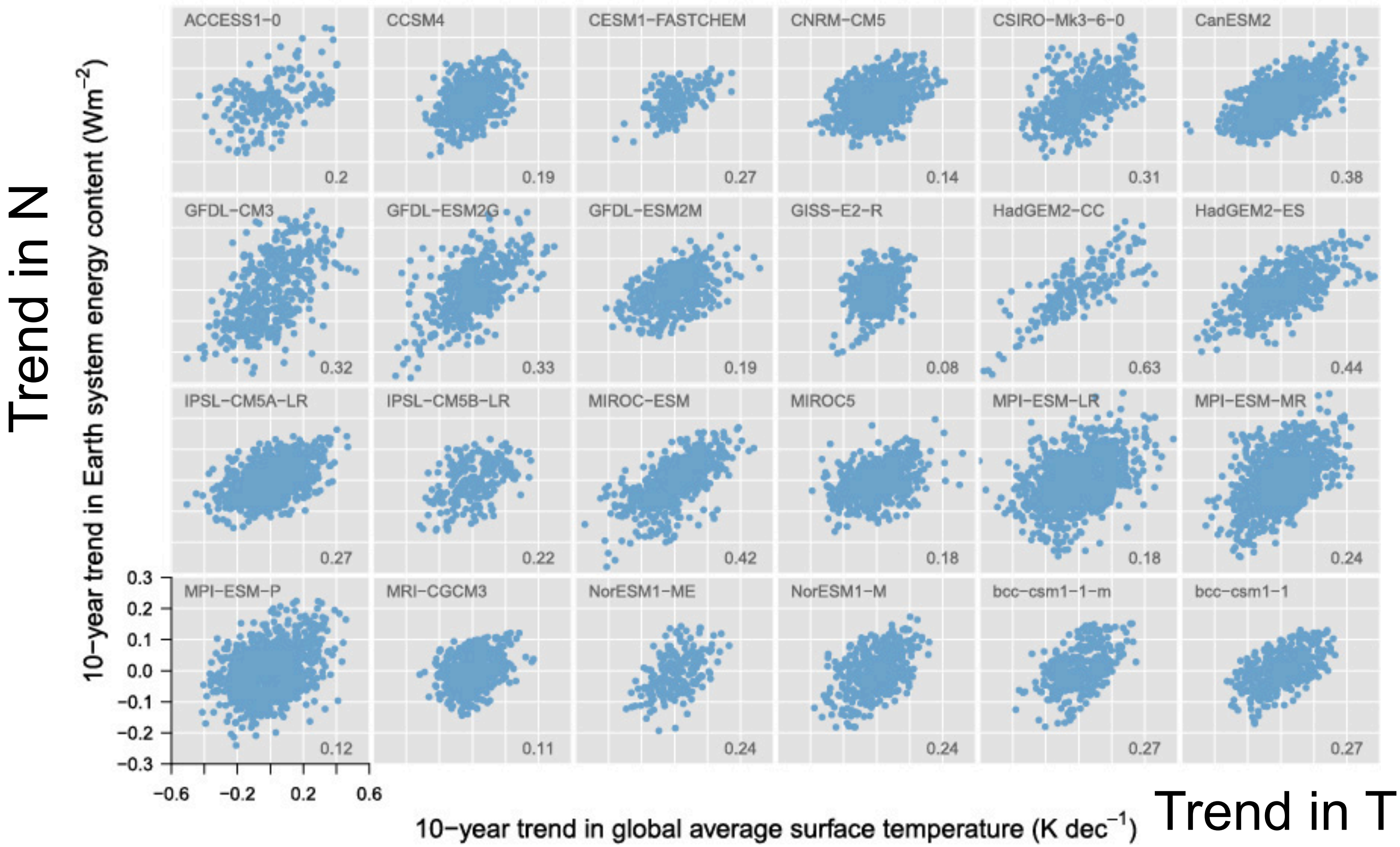


Control Run Variability

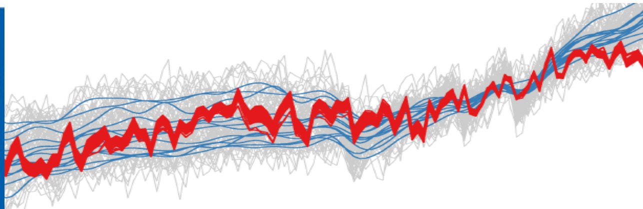


Chris Roberts, MO

Control Run Variability



Palmer, McNeall, 2013



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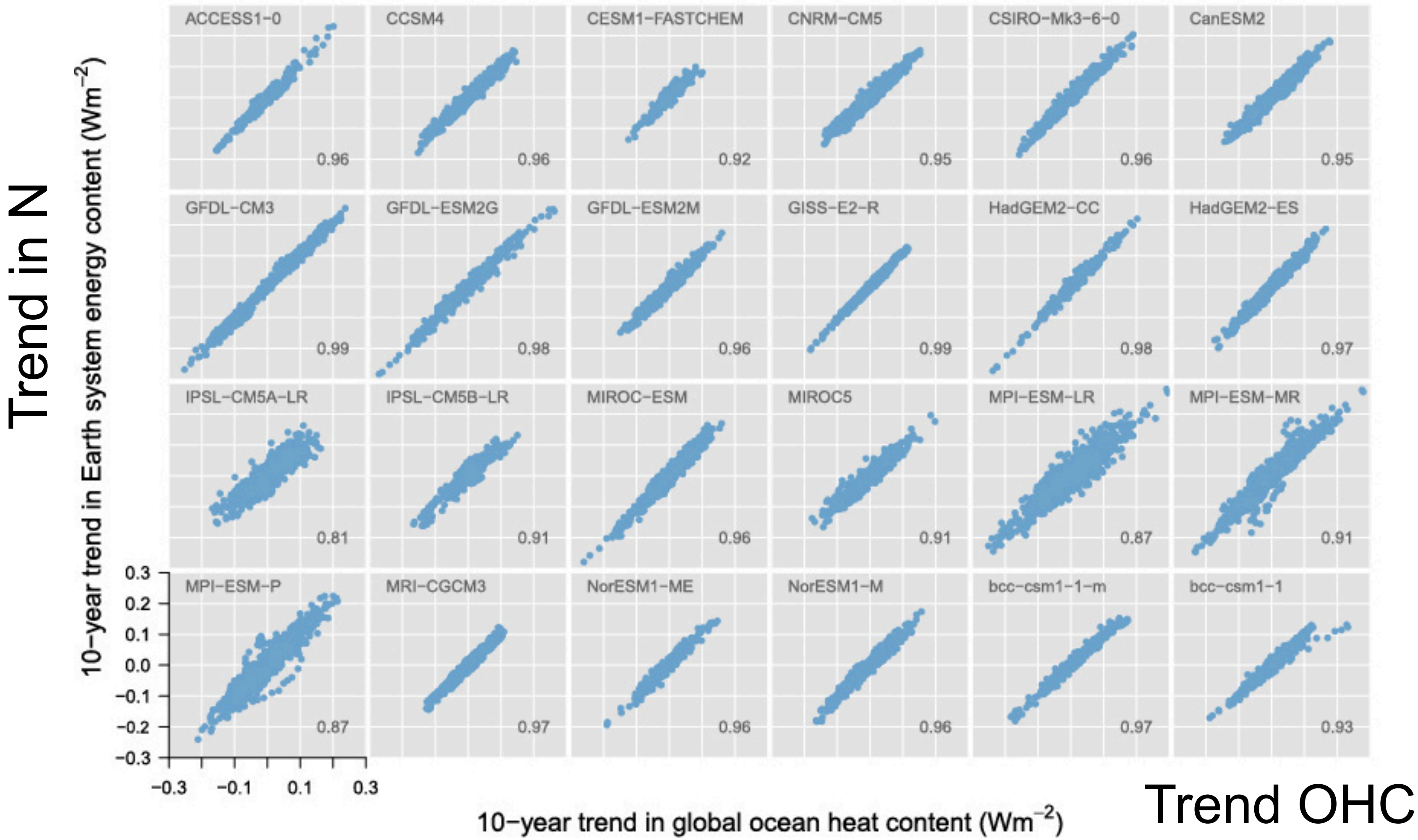
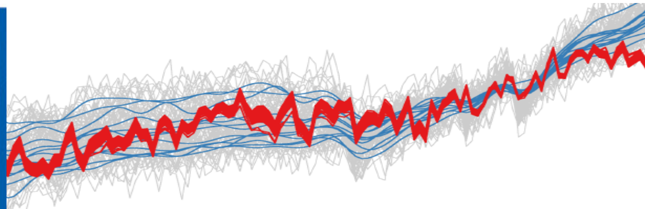
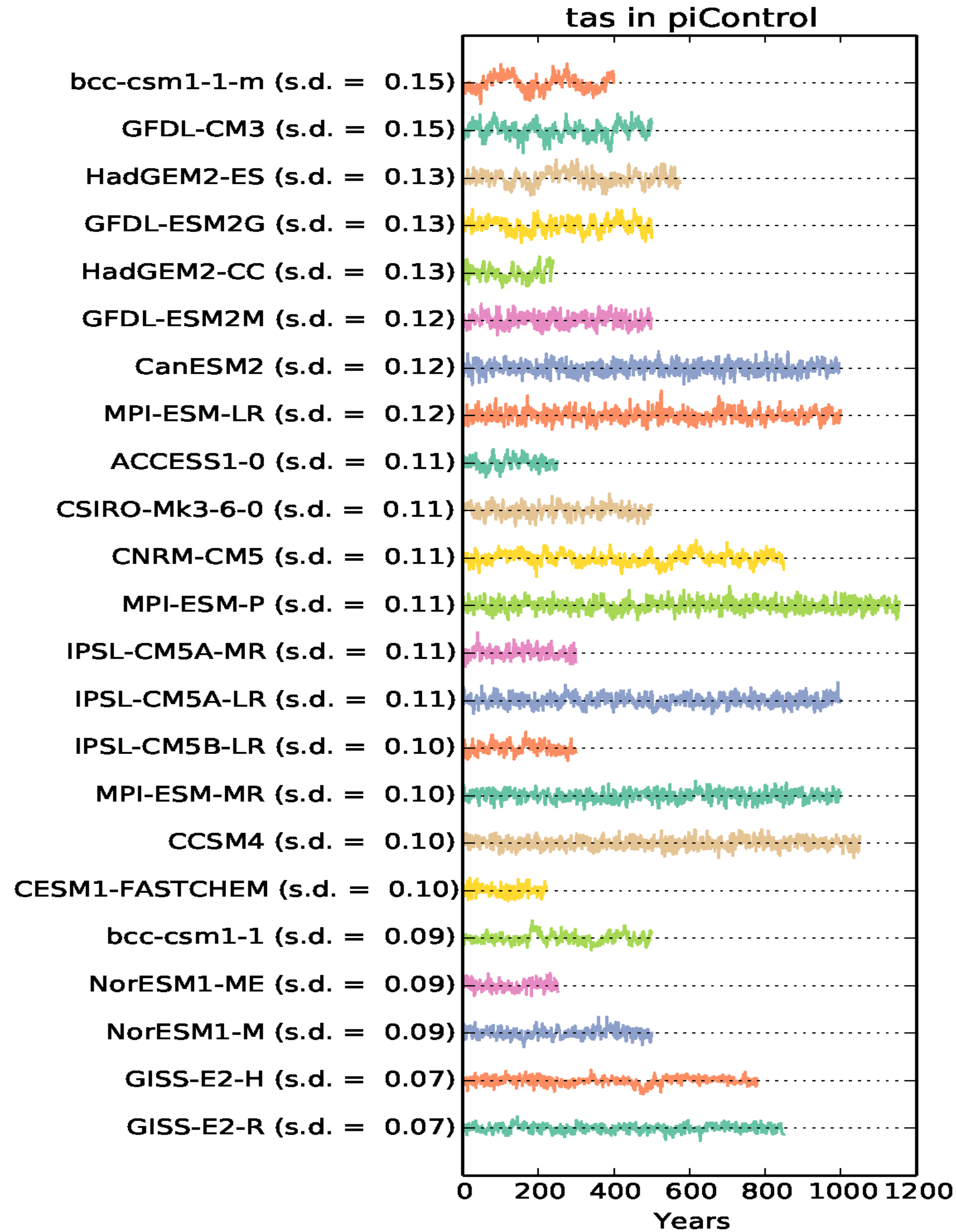


Palmer, McNeall, 2013

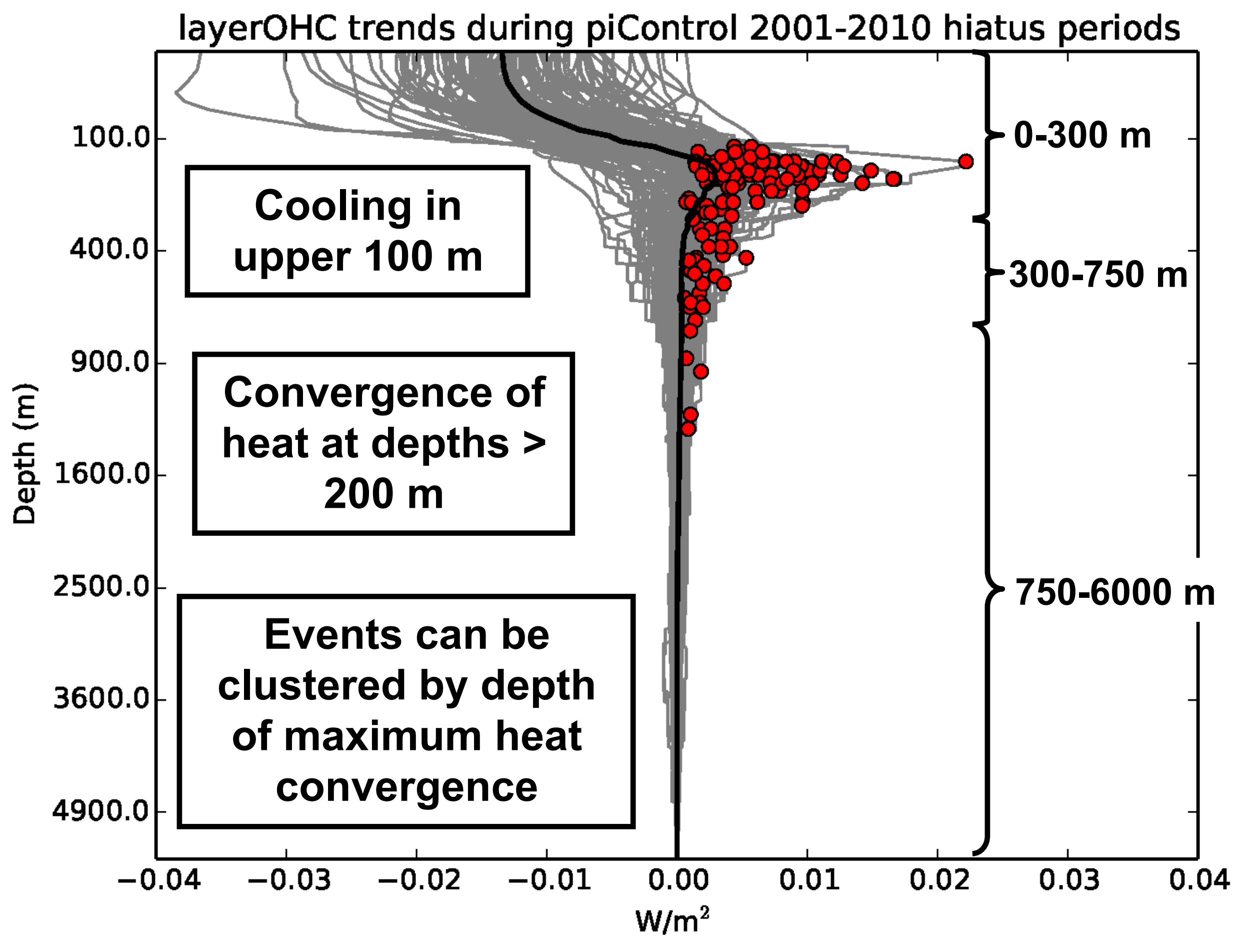


Control Run Variability

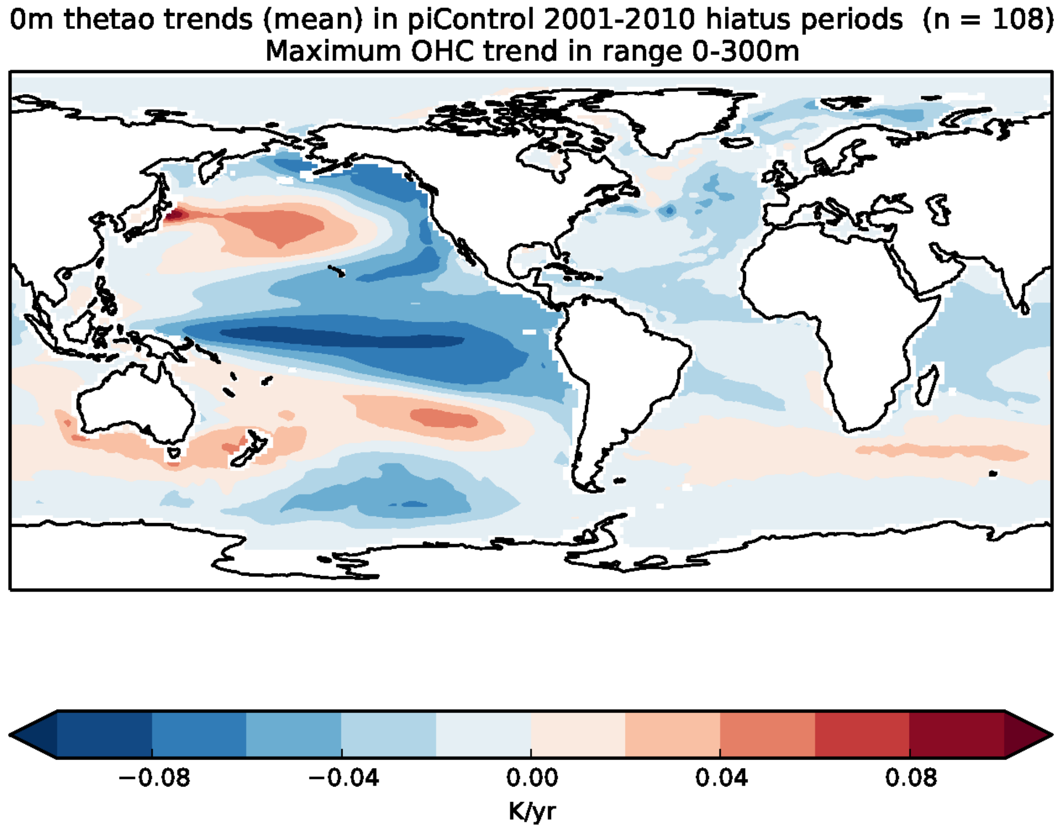


Chris Roberts, MO

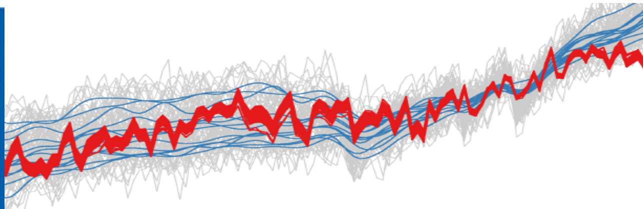
10-year Cooling Trends from Control Runs



Upper Ocean Cooling Events



Composite mean SST trends



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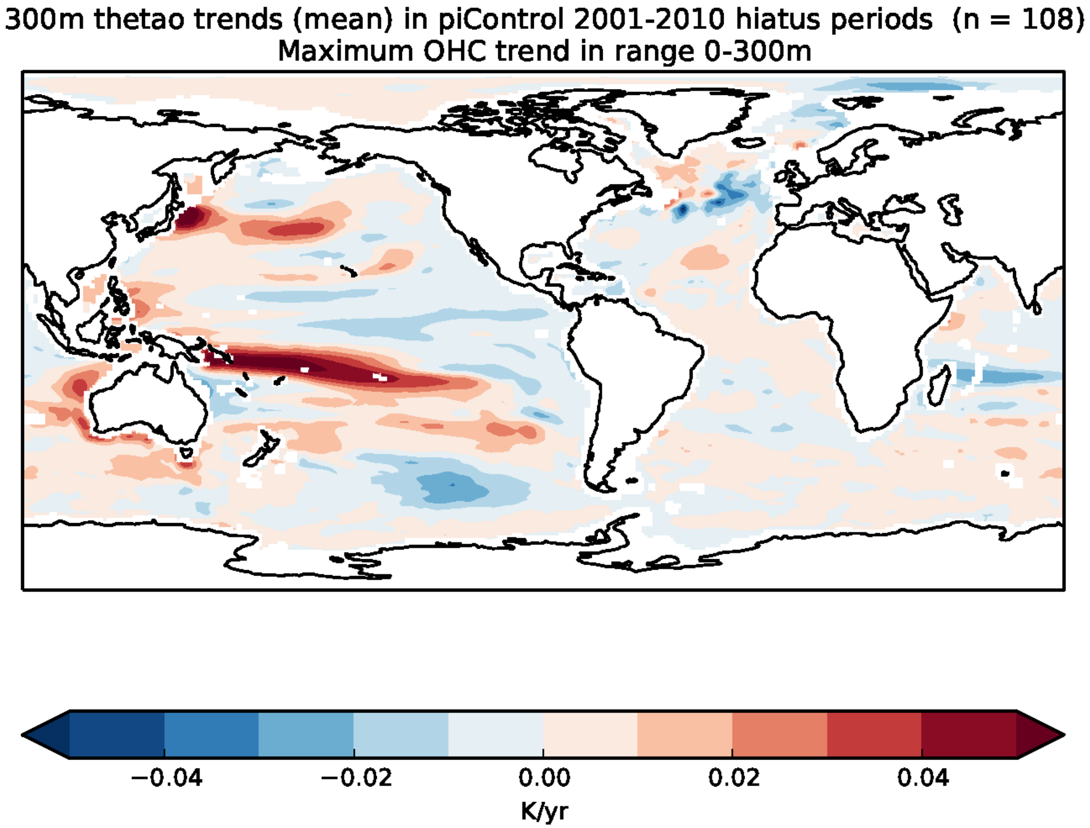
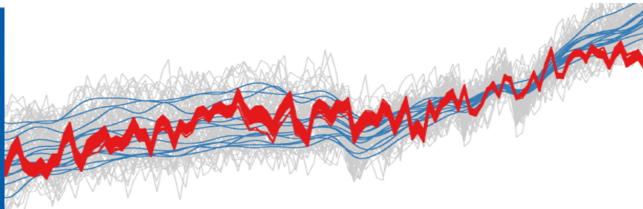
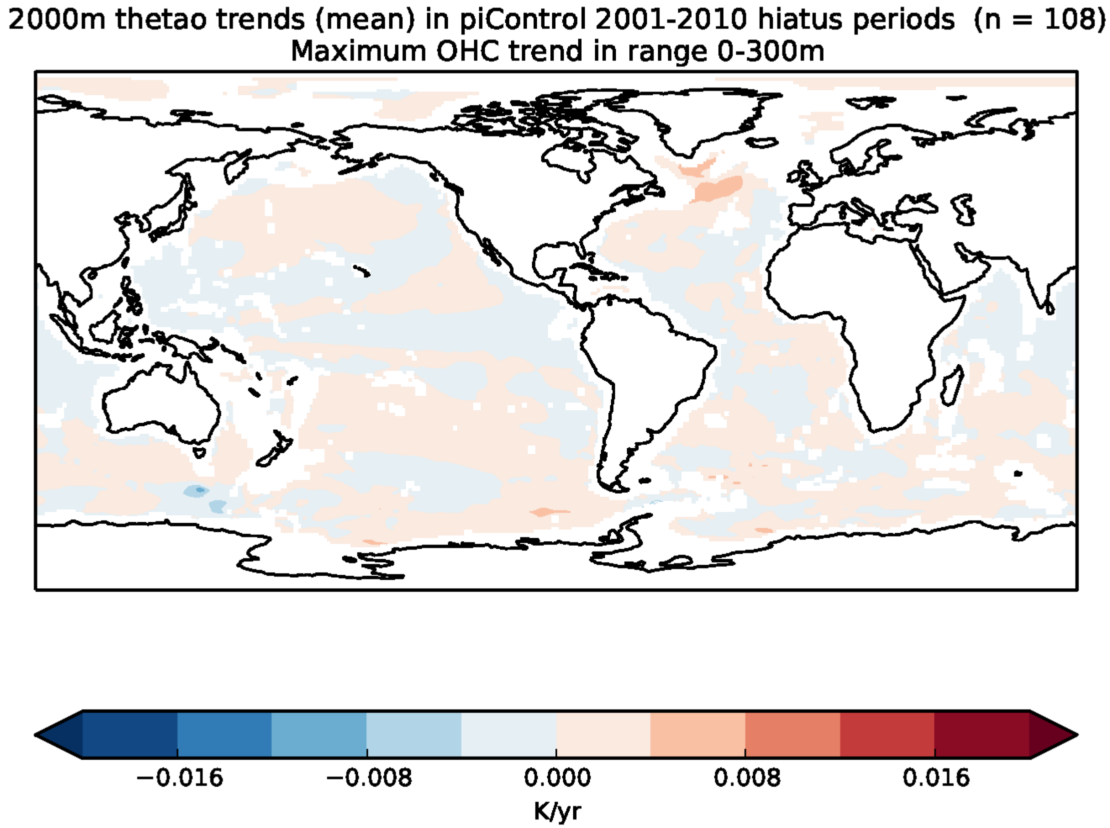


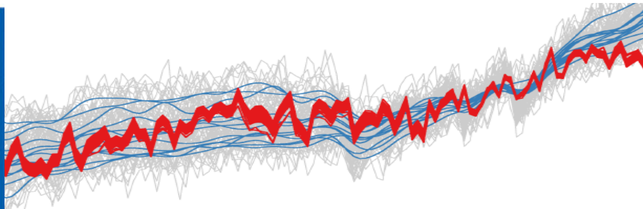
Composite mean 300m ocean temperature trends



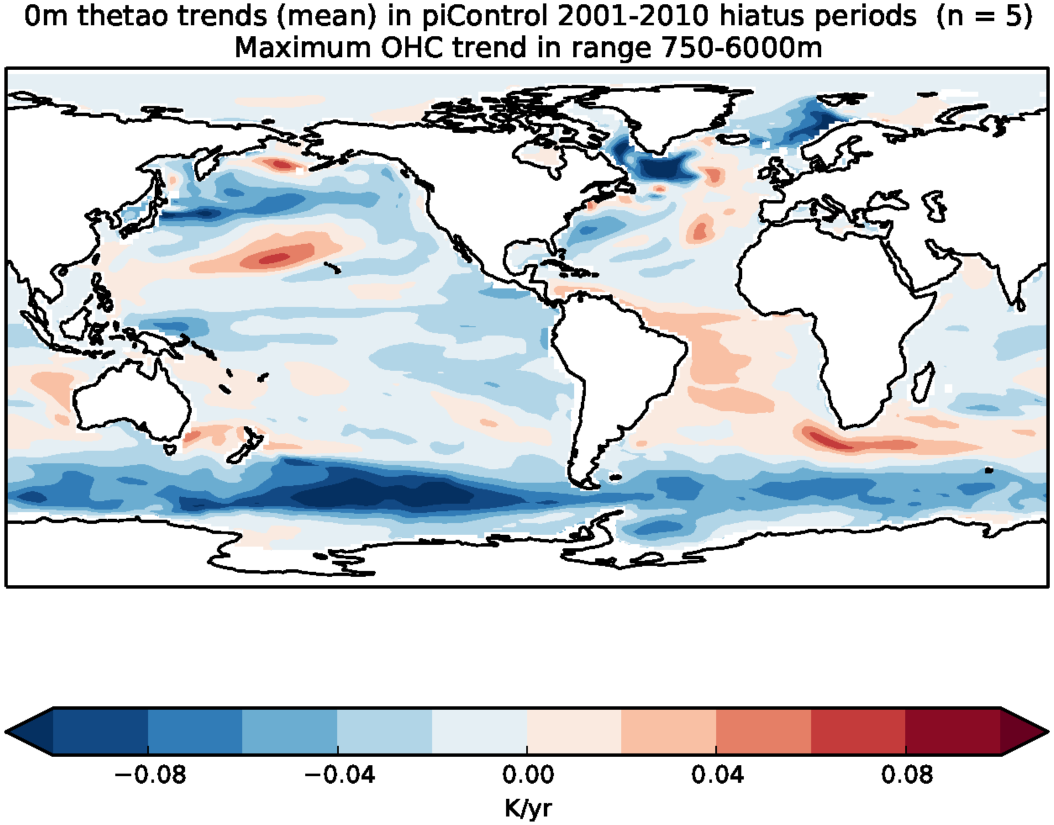
Upper Ocean Cooling Events



Composite mean 2000m ocean temperature trends

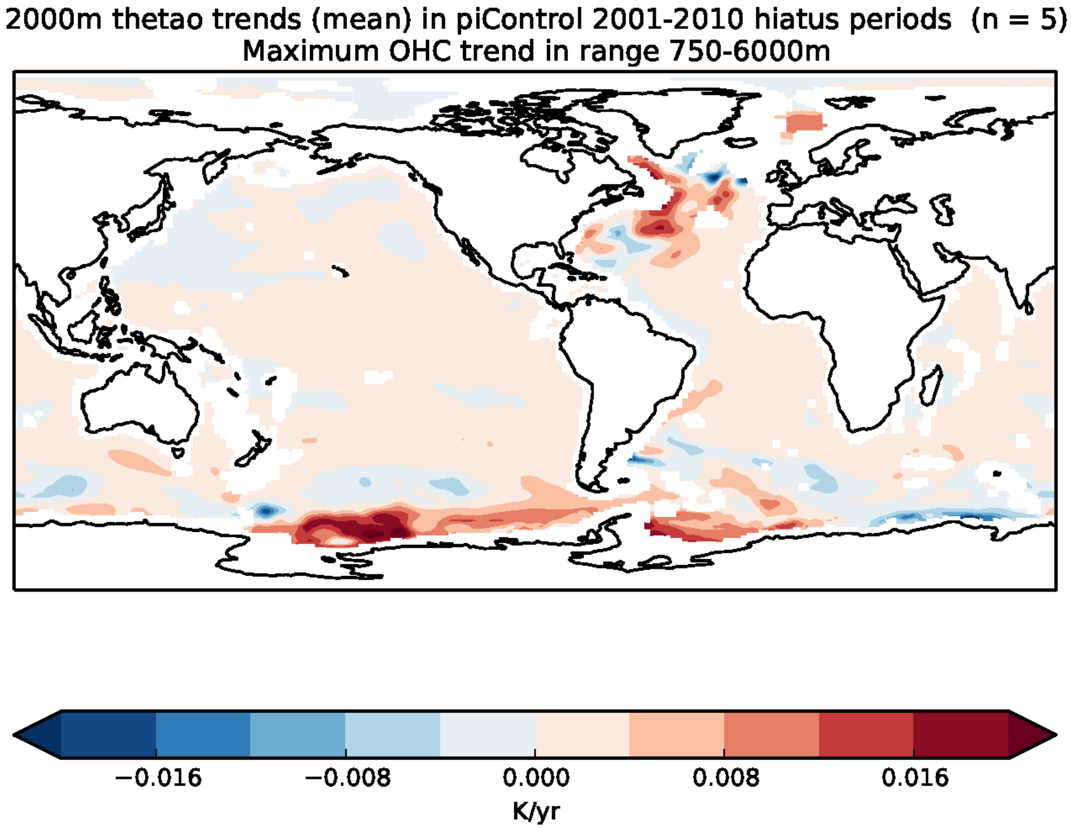


Deep Ocean Cooling Events



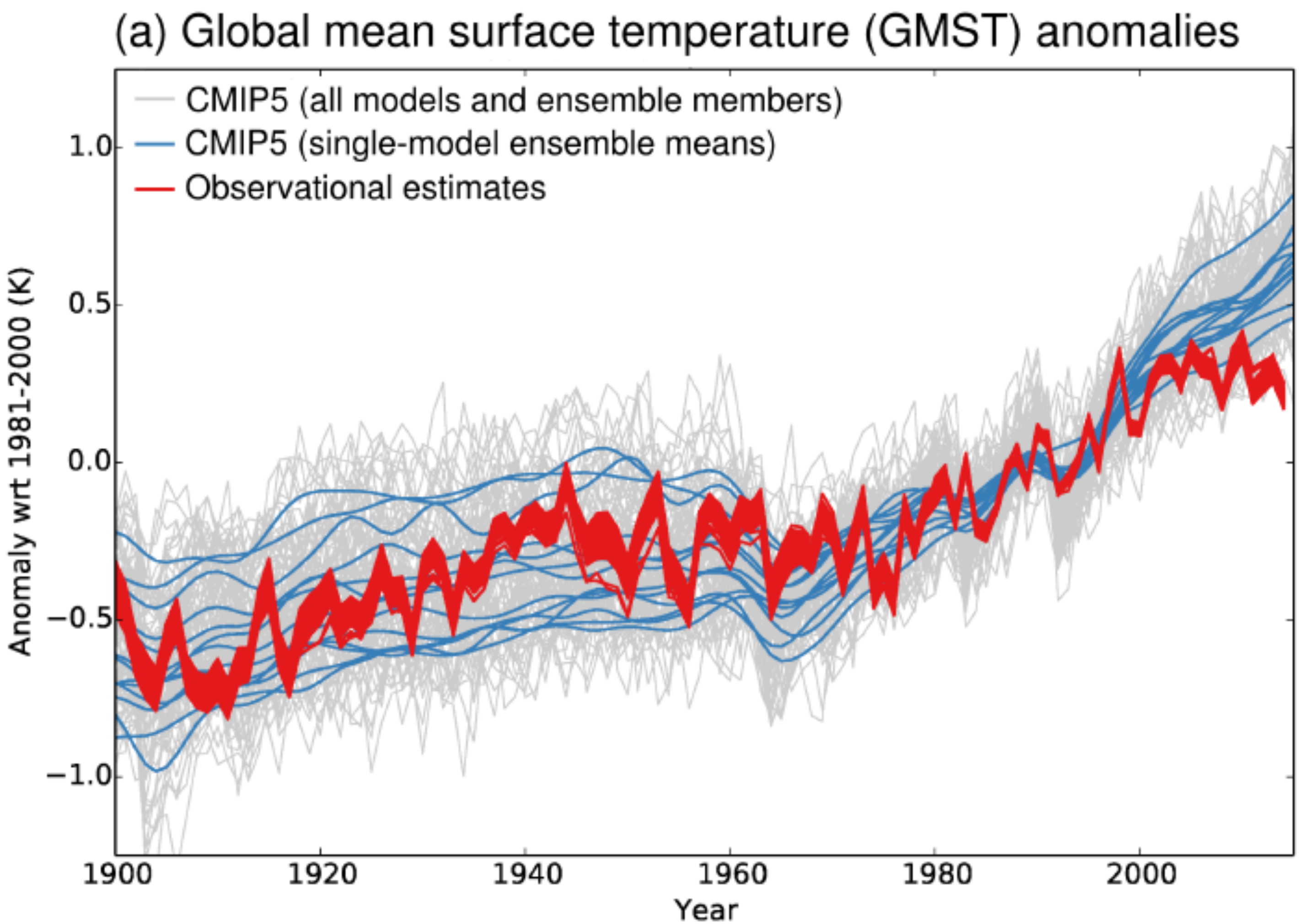
Composite mean SST trends

Deep Ocean Cooling Events



Composite mean 2000m ocean temperature trends

Warming ‘Pause’ or ‘Hiatus’

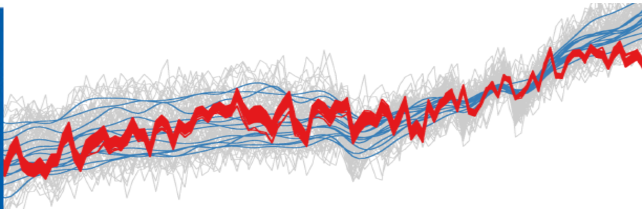


Roberts, Palmer, McNeall,MC, 2015

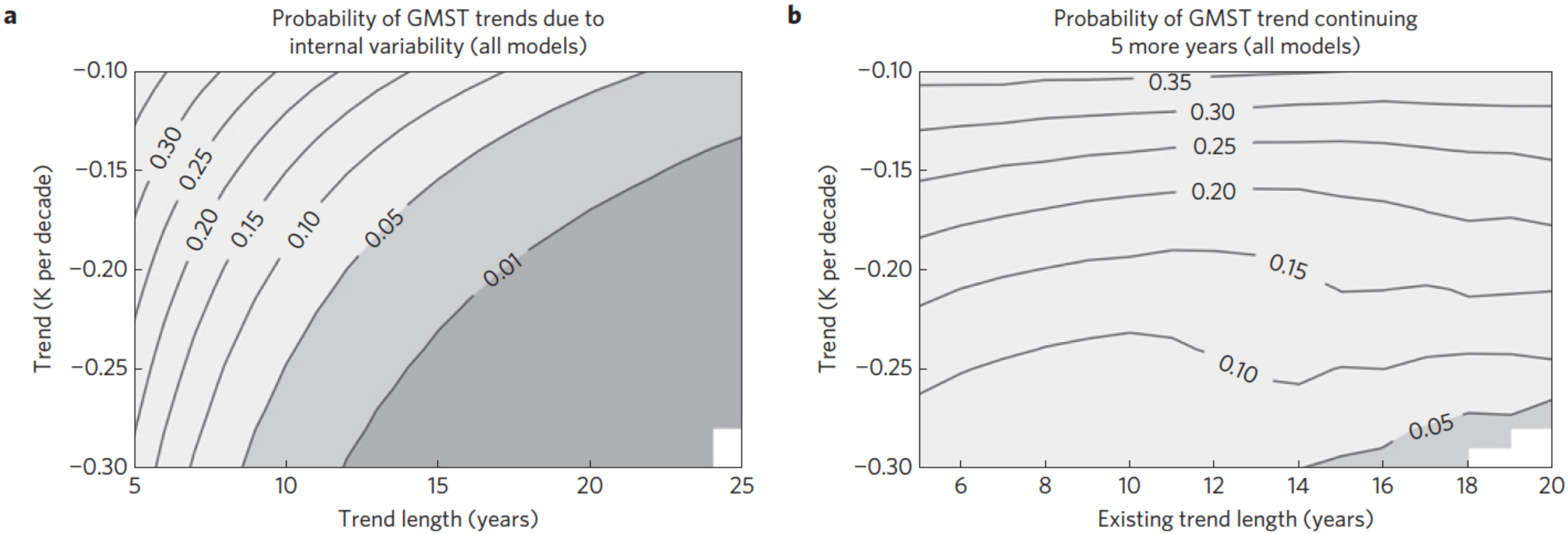
Hiatus

- Estimate forced response by averaging CMIP5 historical simulations (+ test sensitivity to this assumption)
- Generate large synthetic ensemble by adding control run variability to the forced response
- [Sub-select models based on some metrics of ability to simulate interannual variability – makes little difference]
- Estimate probability of occurrence of hiatus events and ‘surge’ or accelerated warming events
- Look at TOA and ocean heat budget during events

Roberts, Palmer, McNeall, MC 2015

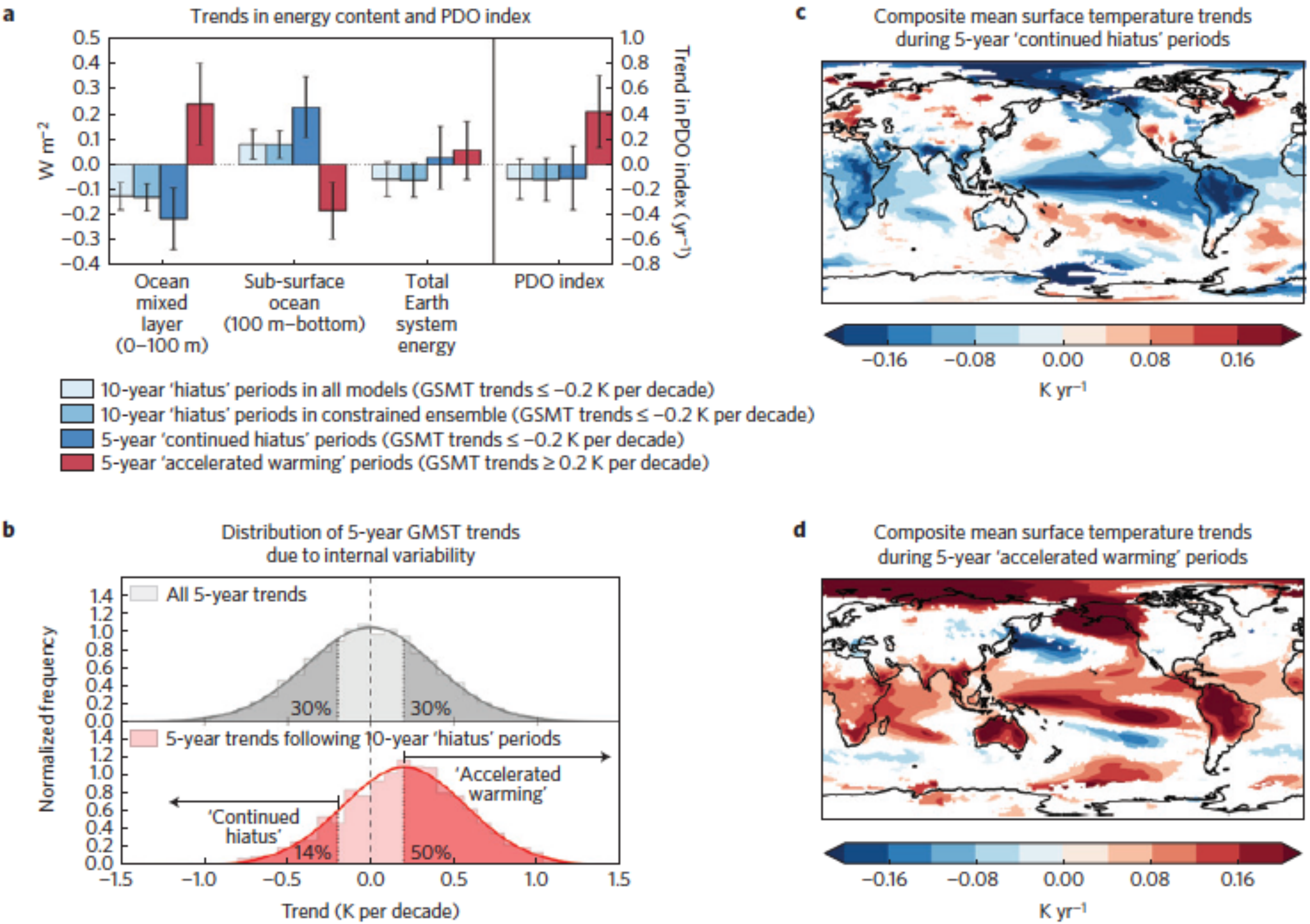


Probability of Hiatus Events



Roberts, Palmer, McNeall, MC 2015

Hiatus

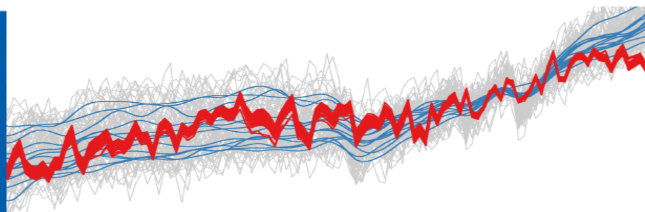


a
Trends in energy content and PDO index
W m⁻²
Trend in PDO index (yr⁻¹)
Ocean mixed layer (0–100 m)
Sub-surface ocean (100 m–bottom)
Total Earth system energy
PDO index
10-year 'hiatus' periods in all models (GSMT trends ≤ −0.2 K per decade)
10-year 'hiatus' periods in constrained ensemble (GSMT trends ≤ −0.2 K per decade)
5-year 'continued hiatus' periods (GSMT trends ≤ −0.2 K per decade)
5-year 'accelerated warming' periods (GSMT trends ≥ 0.2 K per decade)
b
Distribution of 5-year GMST trends due to internal variability
Normalized frequency
All 5-year trends
30%
30%
5-year trends following 10-year 'hiatus' periods
'Continued hiatus'
'Accelerated warming'
14%
50%
Trend (K per decade)
c
Composite mean surface temperature trends during 5-year 'continued hiatus' periods
−0.16
−0.08
0.00
0.08
0.16
K yr⁻¹
d
Composite mean surface temperature trends during 5-year 'accelerated warming' periods
−0.16
−0.08
0.00
0.08
0.16
K yr⁻¹

Headline Results

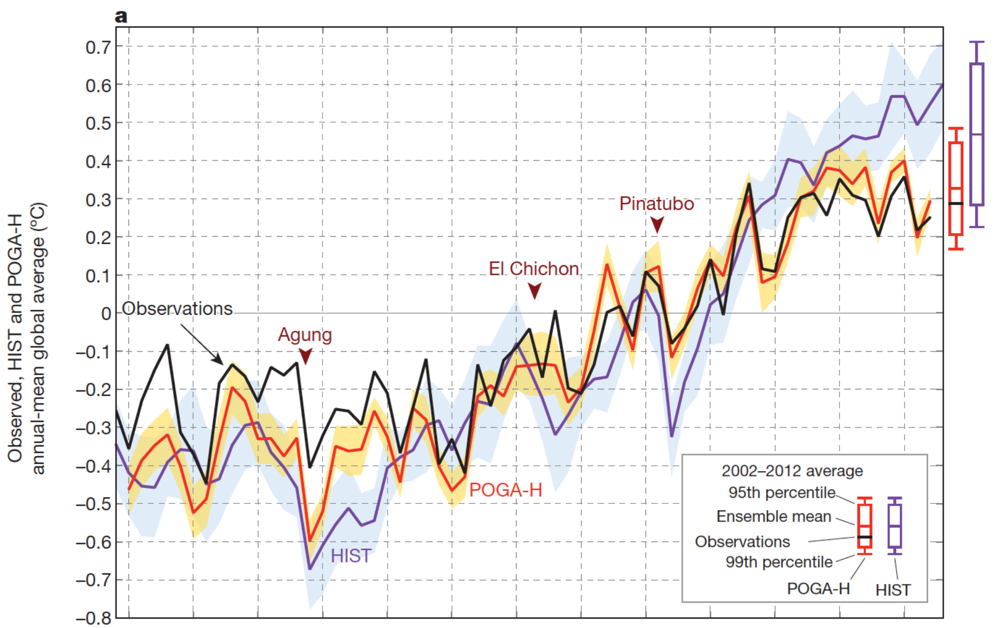
- Focusing on natural internal variability as the cause and assuming an expected forced response of 0.2°C/decade
- The probability of a variability-driven 10-year hiatus is ~10 %, but less than 1 % for a 20-year hiatus
- Although the absolute probability of a 20-year hiatus is small, the probability that an existing 15-year hiatus will continue another five years is much higher (up to 25 %)
- Therefore we should not be surprised if the current hiatus continues until the end of the decade
- An accelerated warming following termination is *more likely than not*

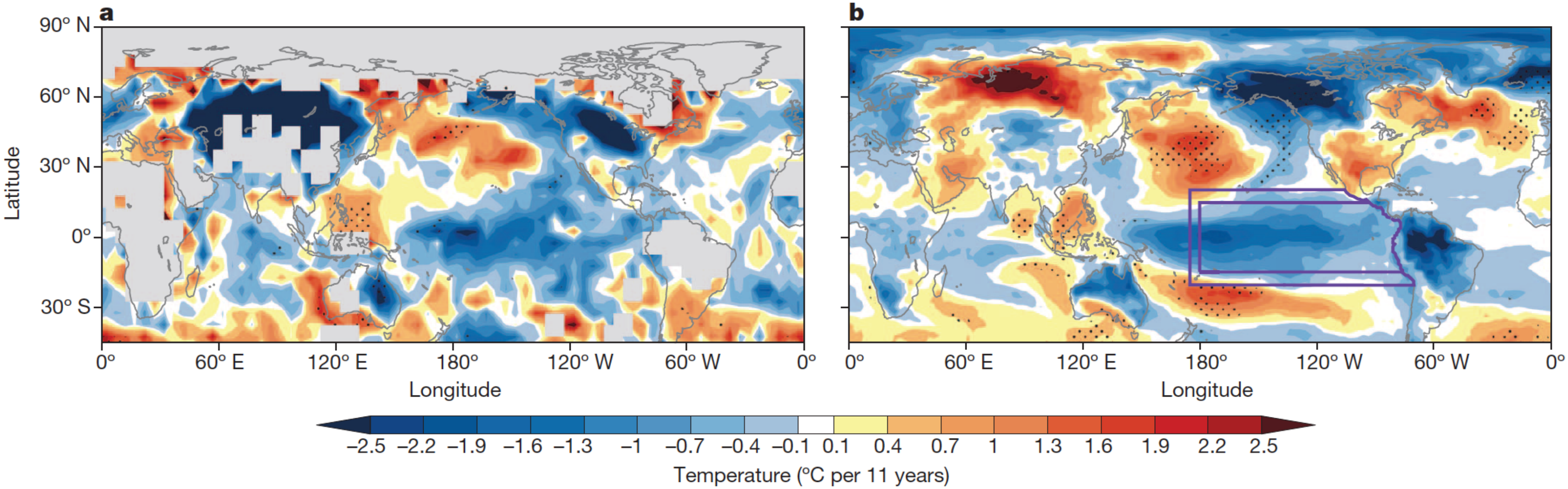
Roberts, Palmer, McNeall, MC 2015



Hiatus –
Kosaka & Xie 2013

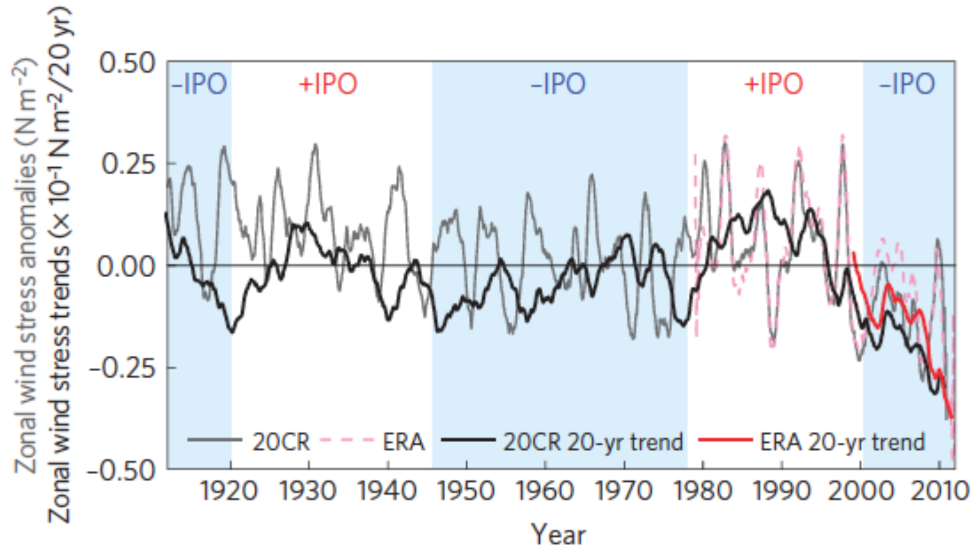
- Force SSTs in a coupled model
- Impacts temperature trend (2002-2012) over land

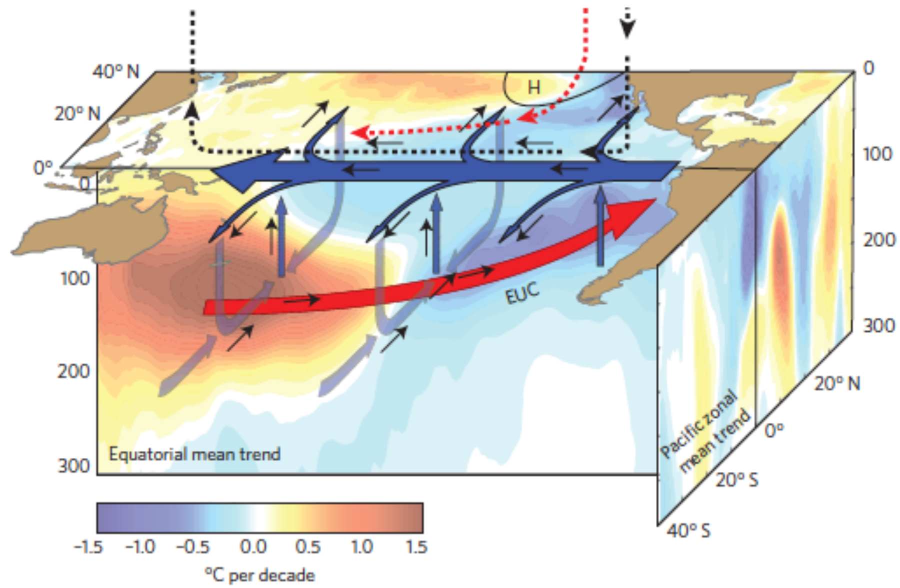


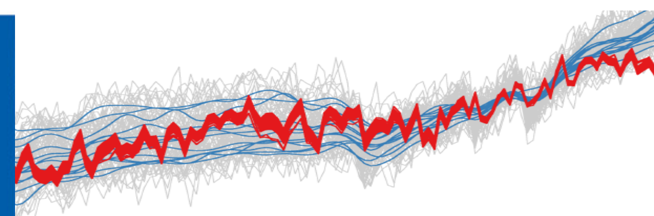


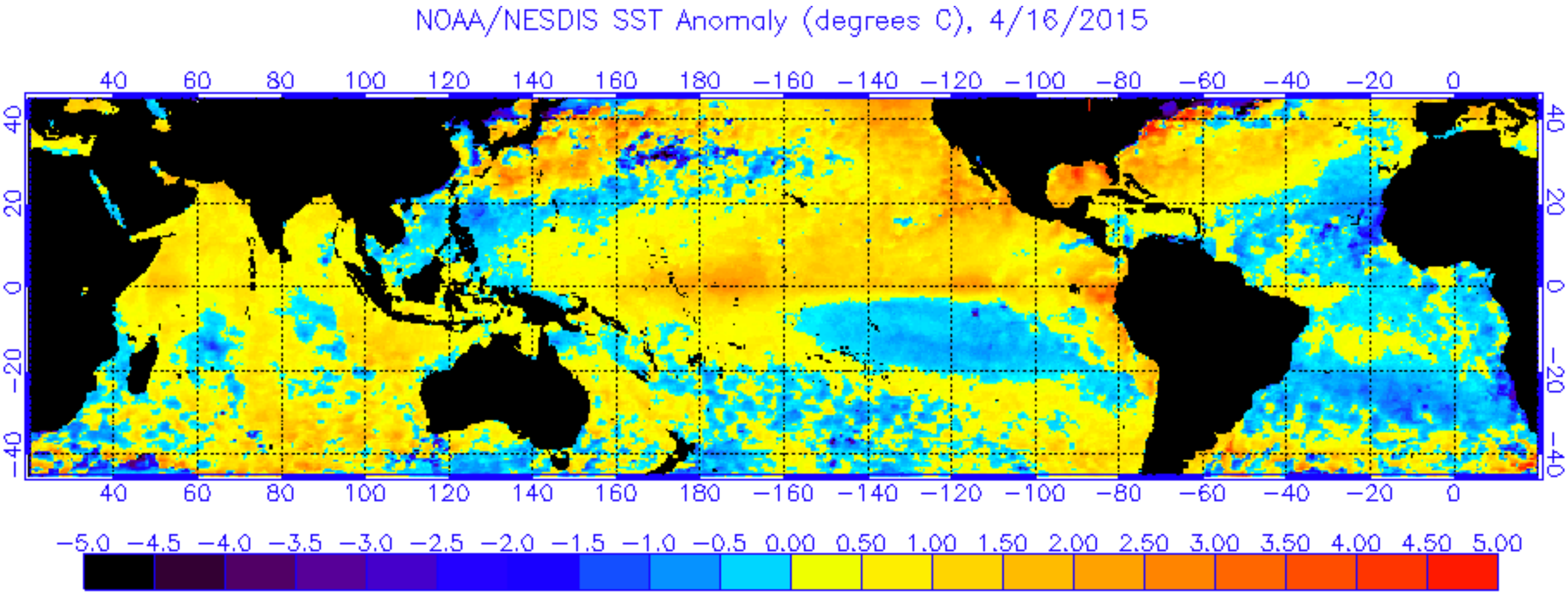
Hiatus –
England et al. 2014

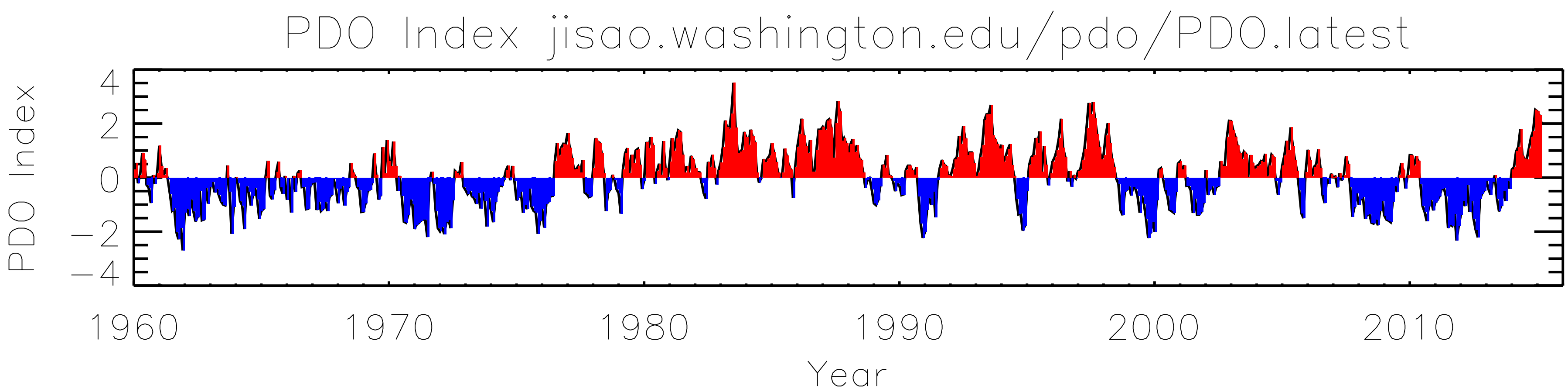
- Tropical Pacific trade winds intensifying (-ve IPO/PDO)
- Drives uptake of heat by the upper ocean (subtropical cells)








NOAA/NESDIS SST Anomaly (degrees C), 4/16/2015
40 60 80 100 120 140 160 180 −160 −140 −120 −100 −80 −60 −40 −20 0
40 20 0 −20 −40
−5.0 −4.5 −4.0 −3.5 −3.0 −2.5 −2.0 −1.5 −1.0 −0.5 0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00


PDO Index jisao.washington.edu/pdo/PDO.latest
PDO Index
4 2 0 −2 −4
1960 1970 1980 1990 2000 2010
Year

Summary

- Hiatus linked to tropical Pacific decadal variability, strengthen of the trade winds, cooling in the East relative to the West, negative PDO
- We have estimated likelihoods using ‘synthetic’ ensemble
- Pacific hiatuses are the most common type of events in models
- N. Atlantic and S. Ocean hiatuses exists but are much less common

- A Pacific hiatus must have a limited lifetime as it is hard to get heat to depth in the Pacific
- Accelerated warming follows termination – are we seeing this now?

Open Issues

- Saying the hiatus is caused by an extreme negative PDO doesn't really 'explain' it
- Conceptual framework for hiatus/surge/PDO events still required, taking into account multivariate information
- Quantify processes
  - Pathways of heat exchange
  - Role of minor radiative forcings/feedback (volcanoes, clouds, …)
  - Interactions between natural variability and forcings
- Predictability of hiatus and surge events
- Implications for predictions and projections