

# Changes in global net radiative imbalance 1985-2012

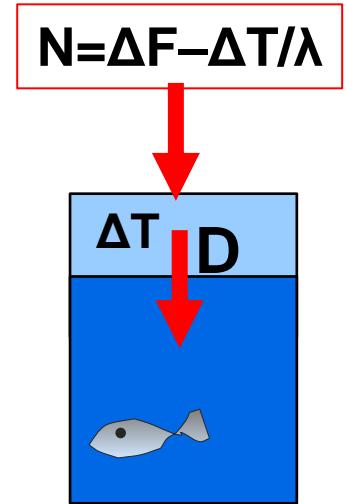
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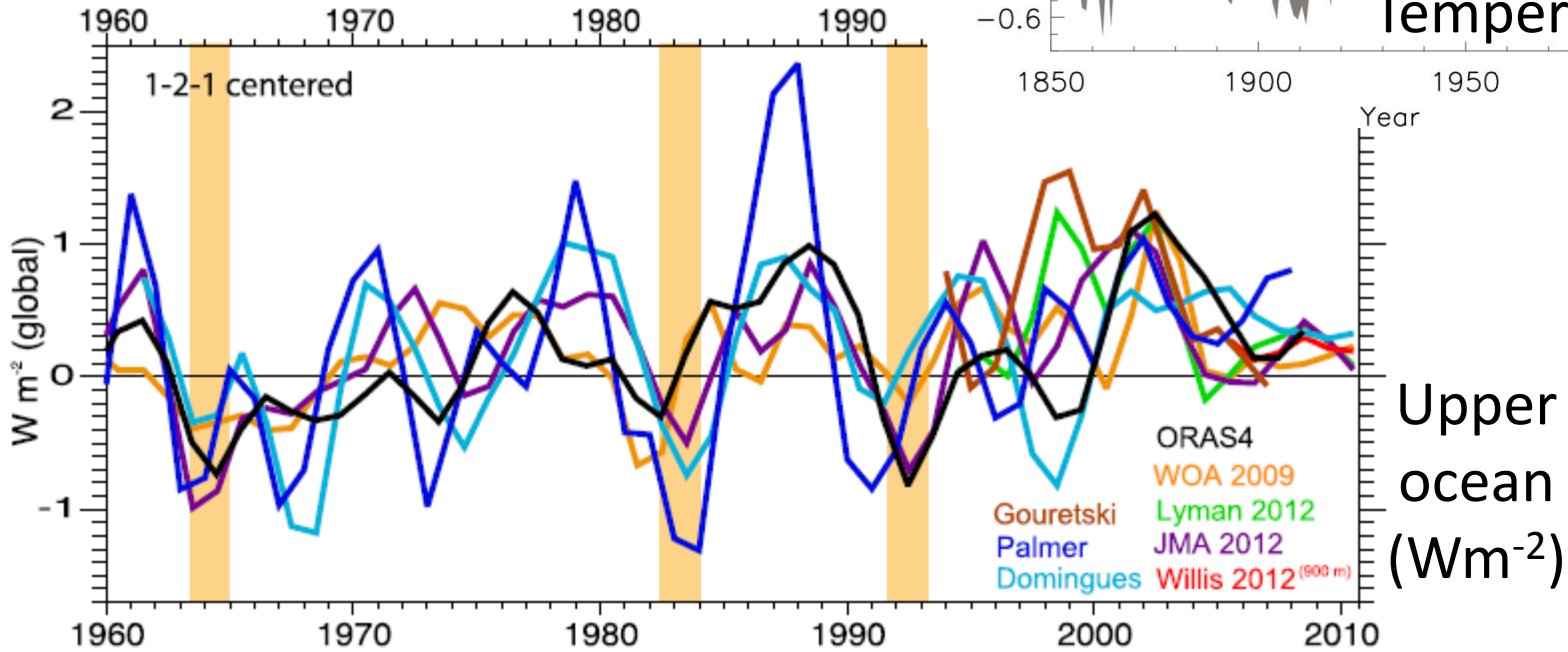
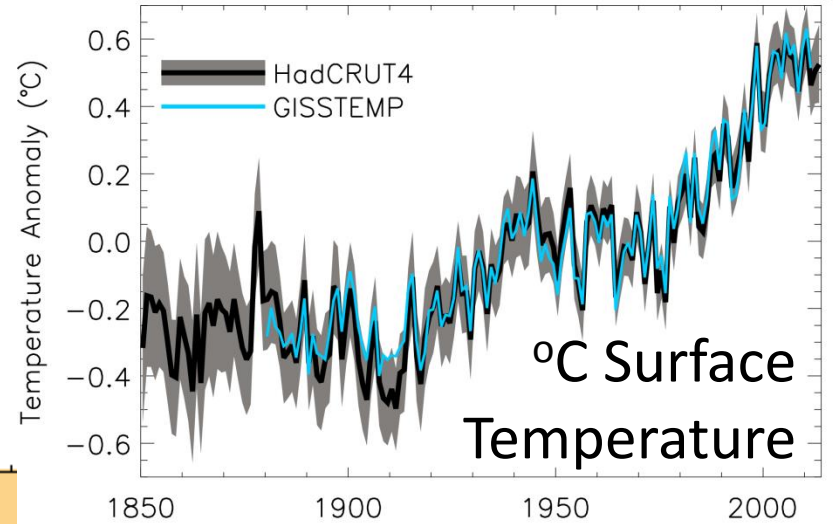
# Changes in Earth's Energy balance

- Key variable linking radiative forcing, responses (adjustments/feedbacks) and surface temperature/ocean heat uptake
- Diagnostic of changes in cloud, aerosol, etc
- Global energy and water cycle coupling
  - Fast and slow precipitation responses  
[O’Gorman et al. \(2012\)](#); [Allan et al. \(2014\)](#) Surv. Geophys
  - Vertical & spatial nature of forcing important
- UK NERC project: Diagnosing Earth’s Energy Pathways in the Climate system: [DEEP-C](#)



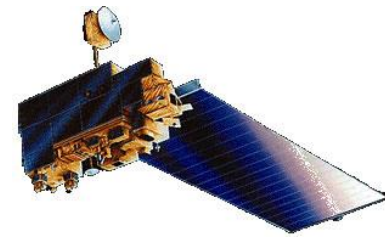
# At what rate is Earth heating?

Global Annual Mean Temperature Anomaly

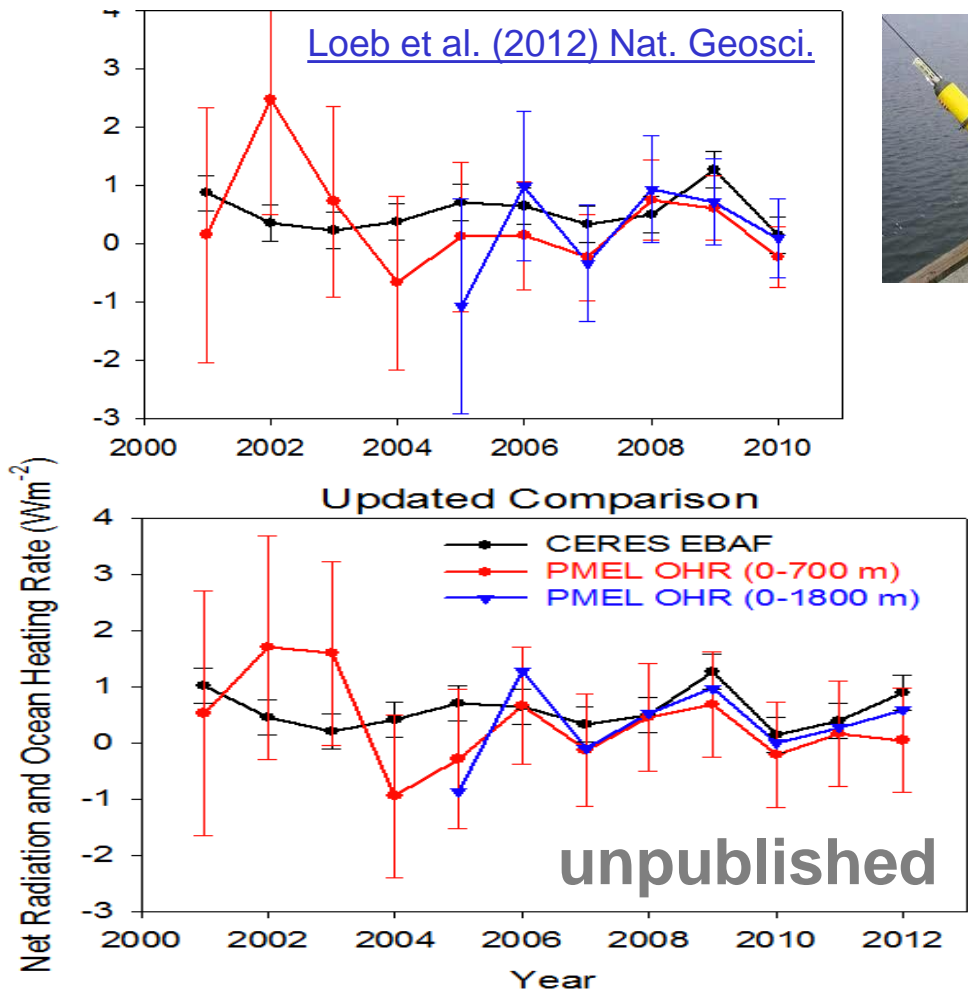


[Trenberth et al. \(2014\) J Clim](#)

# Combining Earth Radiation Budget data and Ocean Heat Content measurements



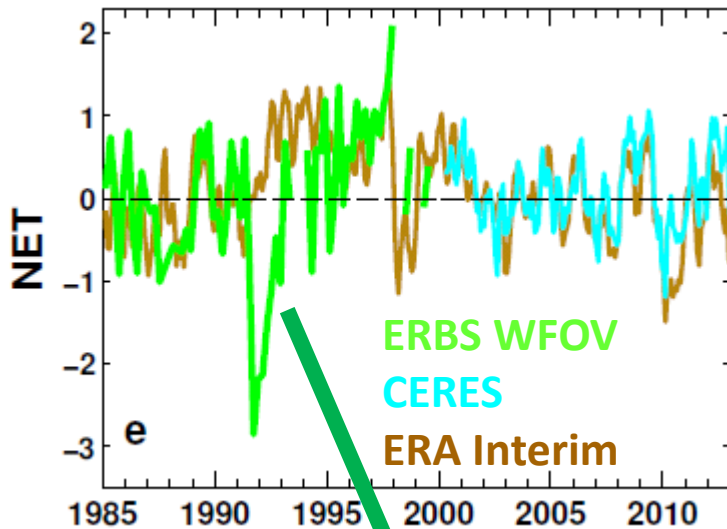
- Tie 10-year CERES record with SORCE TSI and ARGO-estimated heating rate 2005-2010 + minor additional storage terms
- Variability relating to ENSO reproduced by CERES and ERA Interim
- Ocean heating rate sensitive to dataset and sampling
- What about prior to 2000?



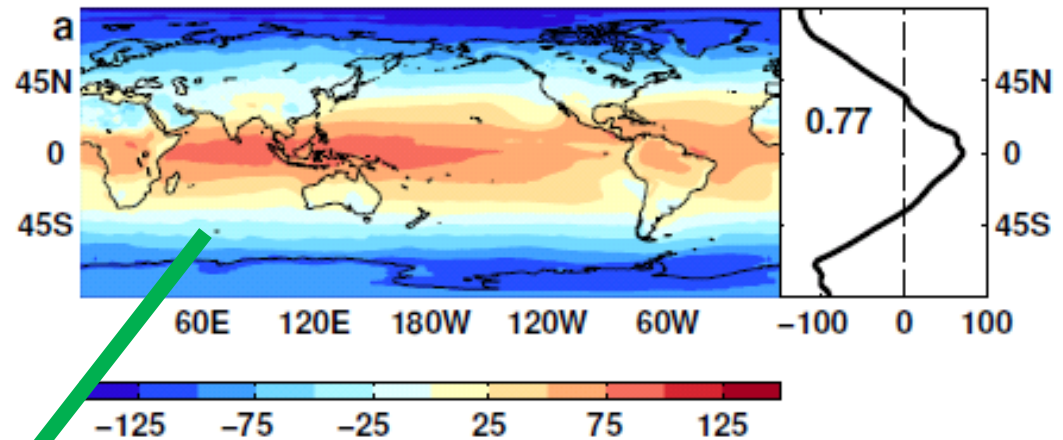
[Loeb et al. \(2012\) Nat. Geosci.](#) See also [Hansen et al. \(2011\) ACP](#)

# Reconstructing global radiative fluxes prior to 2000

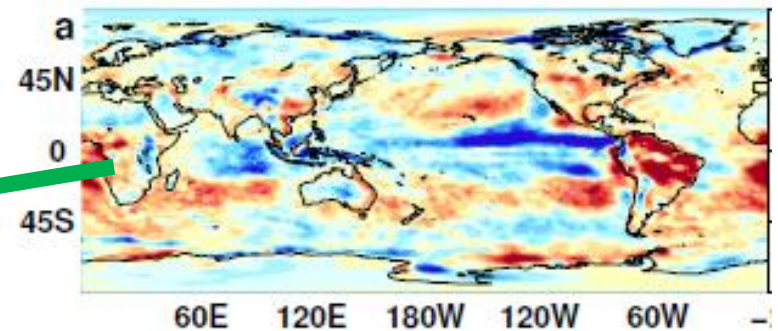
## ERBS/CERES variability



## CERES monthly climatology



## ERA Interim spatial anomalies

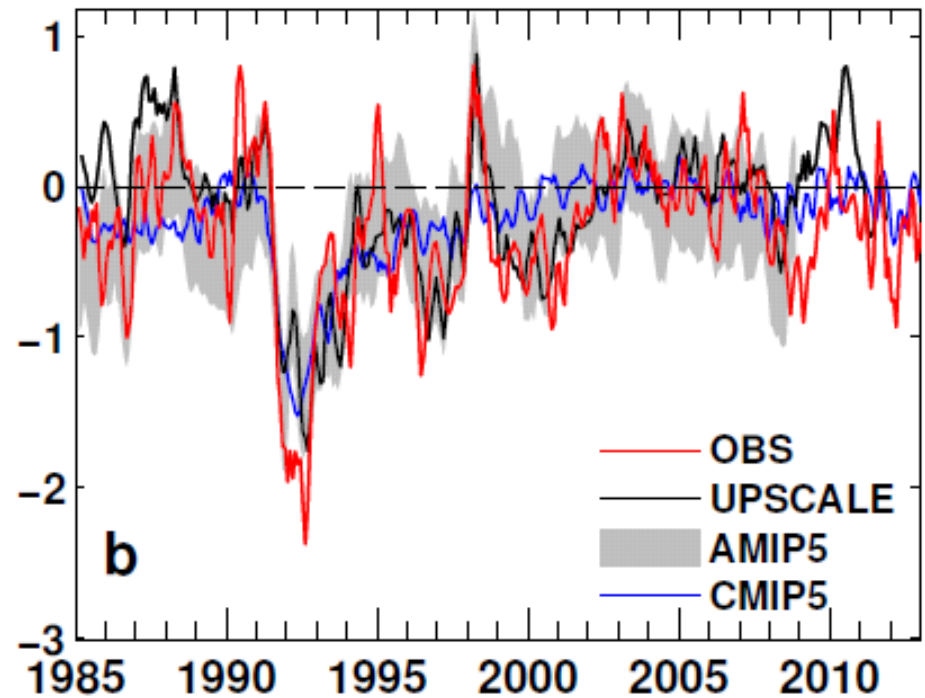


Combine CERES/ARGO accuracy,  
ERBS WFOV stability and  
reanalysis circulation patterns to  
reconstruct radiative fluxes

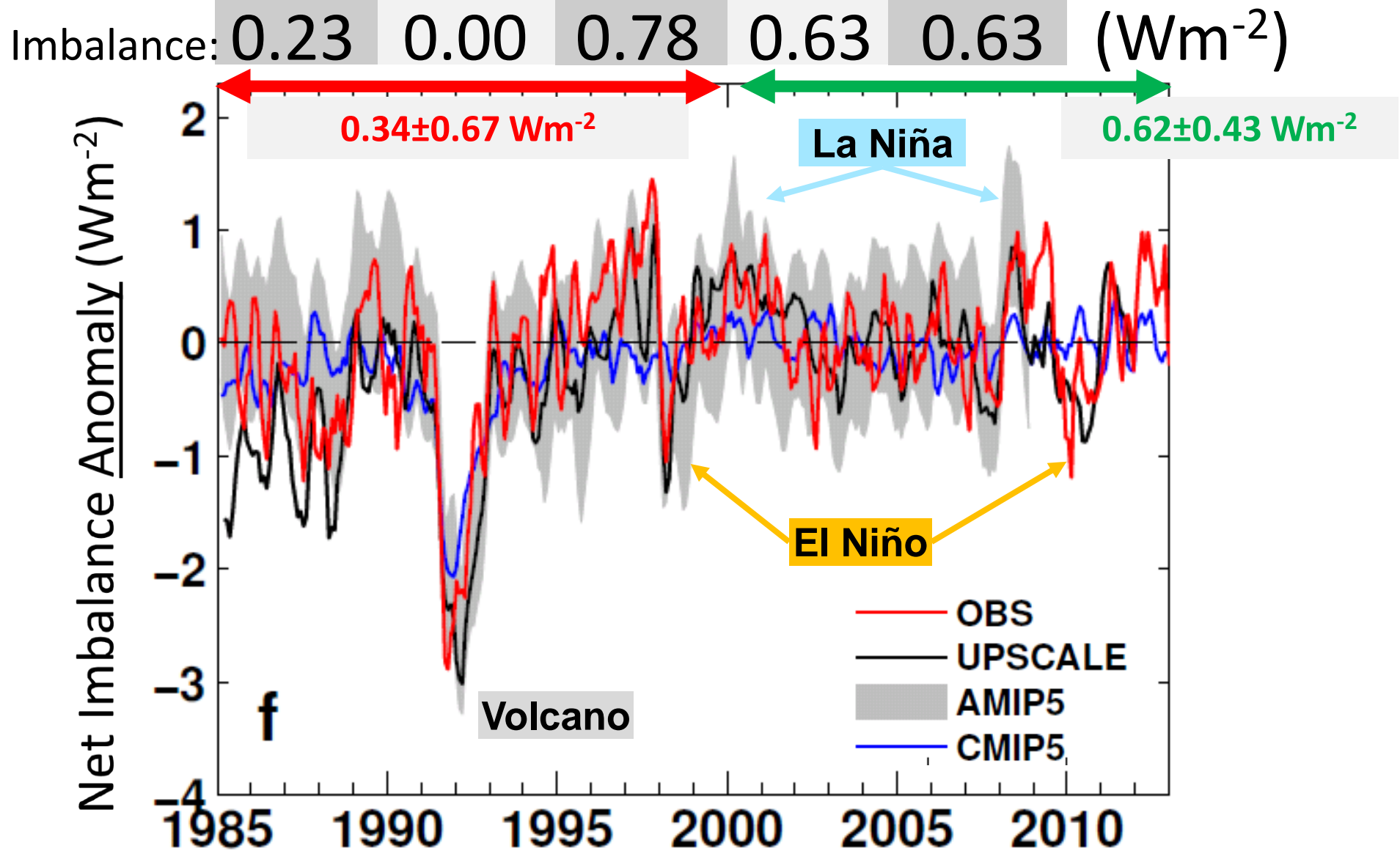
# Use reanalyses or models to bridge gaps in record (1993 and 1999/2000)

- ERA Interim trends suspect. Use model...
- **UPSCALE** simulations (obs. SST, sea ice & realistic radiative forcings) “**OBS**”
- Net less sensitive to method than OLR/ASR

Outgoing Longwave Radiation Anomalies ( $\text{Wm}^{-2}$ )

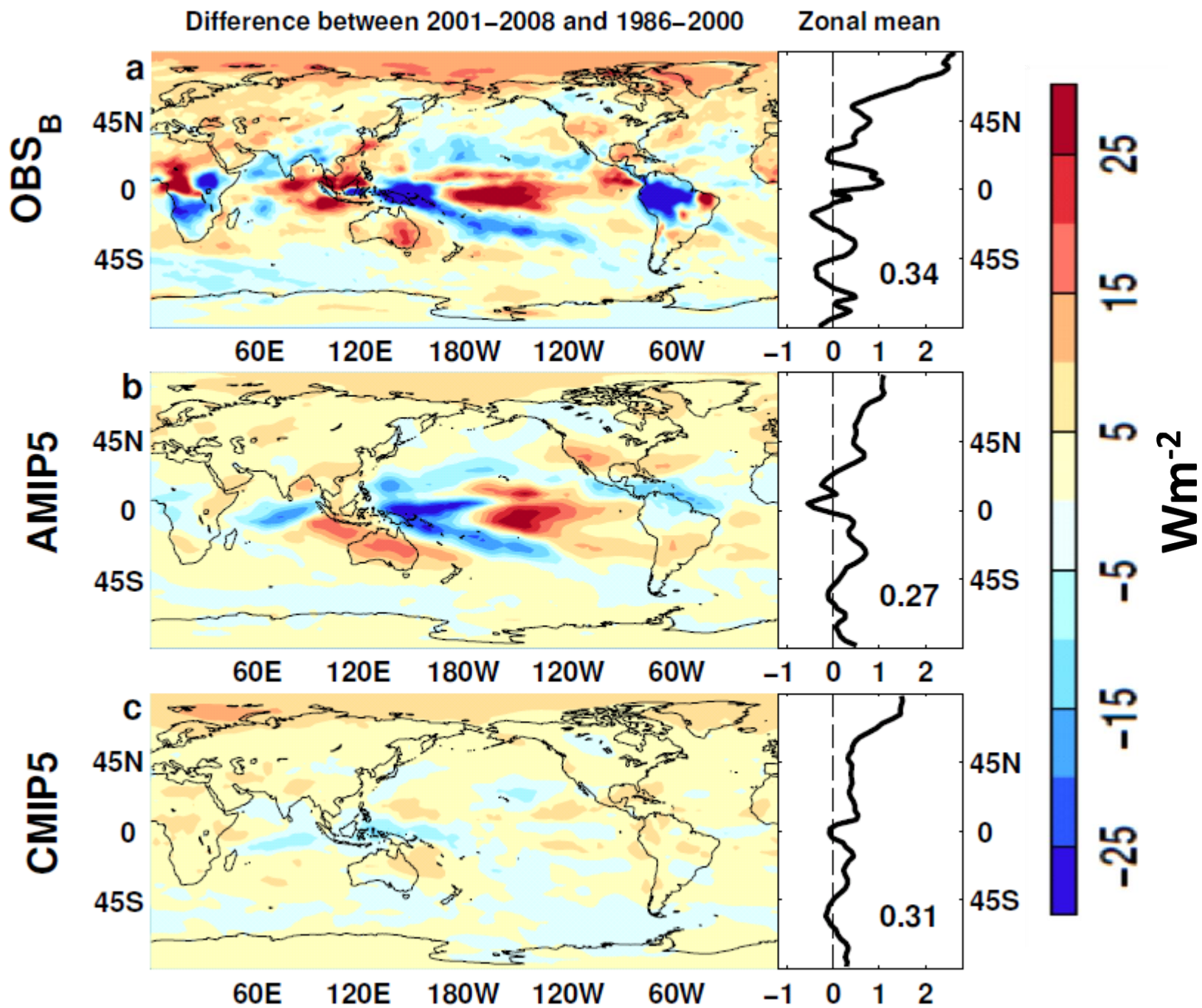


# Changes in imbalance in models & observations



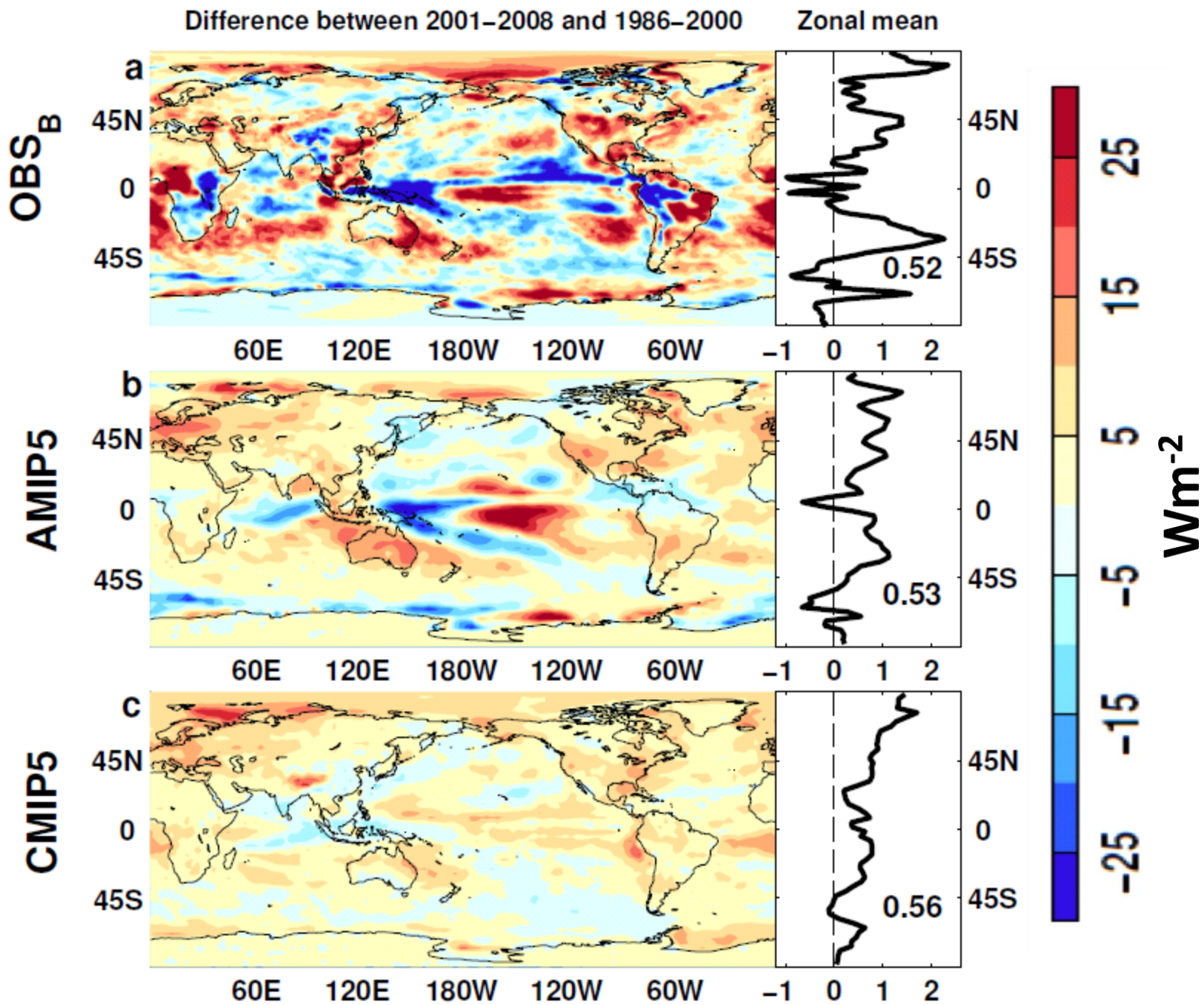
Allan et al. (2014) [to appear](#)

# Outgoing Longwave Radiation

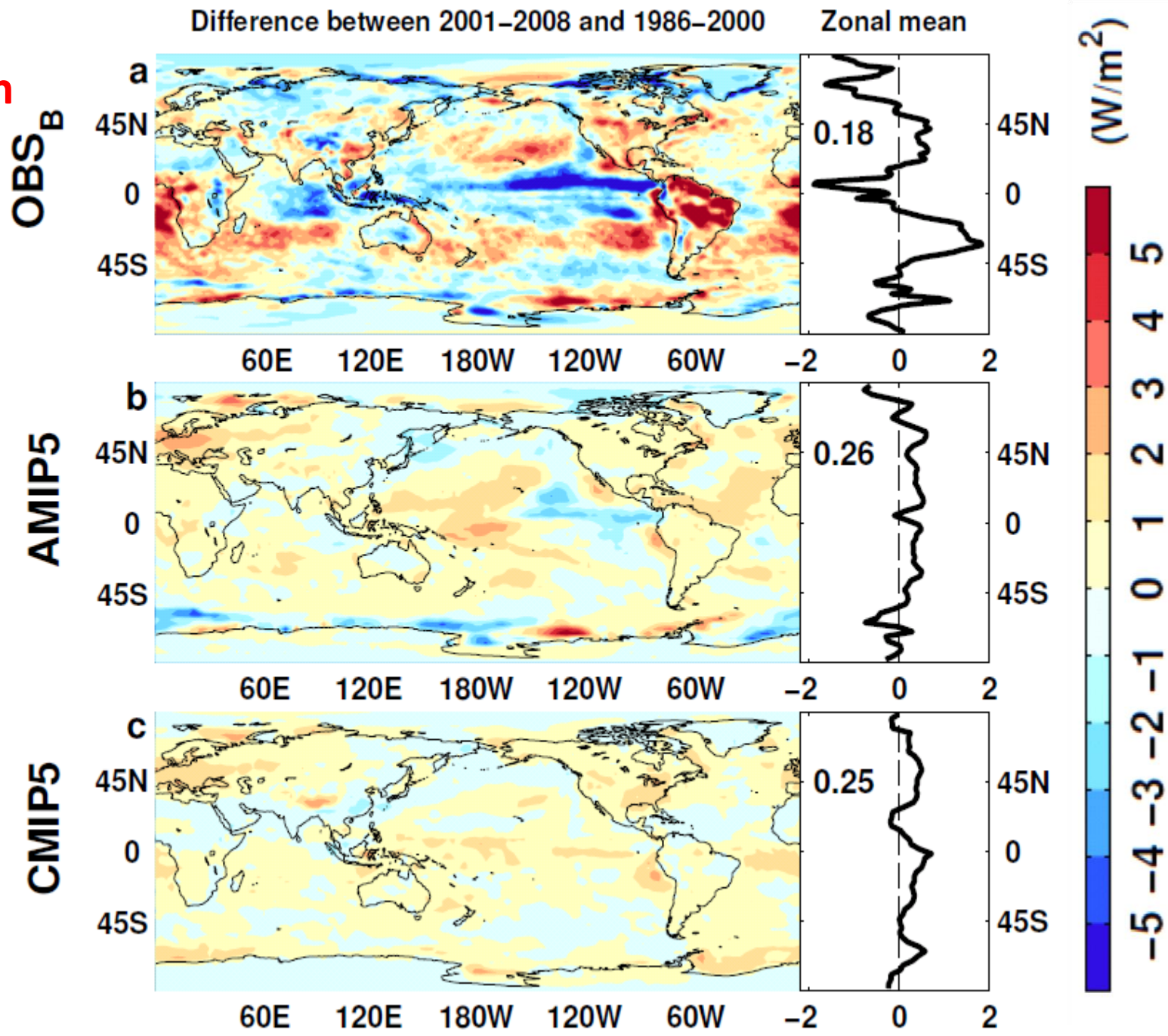




**Absorbed  
Shortwave  
Radiation**



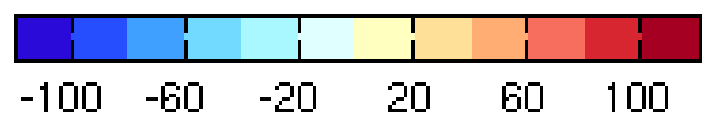
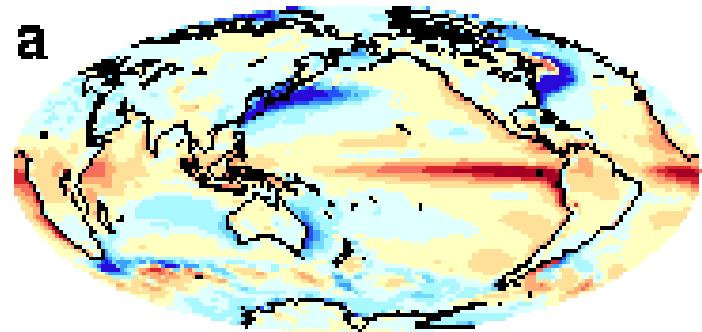
**NET  
Radiation**



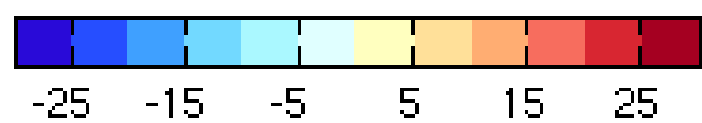
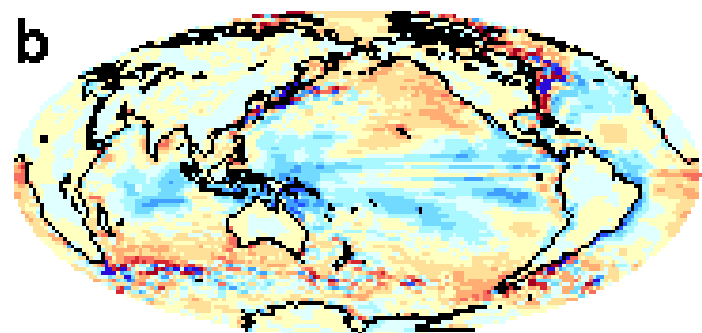
# Preliminary results

- Heating of Earth continues at rate of  $\sim 0.6 \text{ Wm}^{-2}$
- Current variability in TOA radiation (1985-2013)
- Net radiative flux imbalance fairly stable
  - Requires anchoring to ARGO ocean heating rate + minor terms
  - Influence of Pinatubo and ENSO
  - $\sim 0.3 \text{ Wm}^{-2}$  higher in 1995-1999 than 2000-2013 period
- Distinct East Pacific signal in  $\Delta T$  and  $\Delta N$
- Radiative forcing alone can't explain surface warming slowdown: internal variability important
- Next steps: combining with reanalyses energy transports to estimate surface fluxes

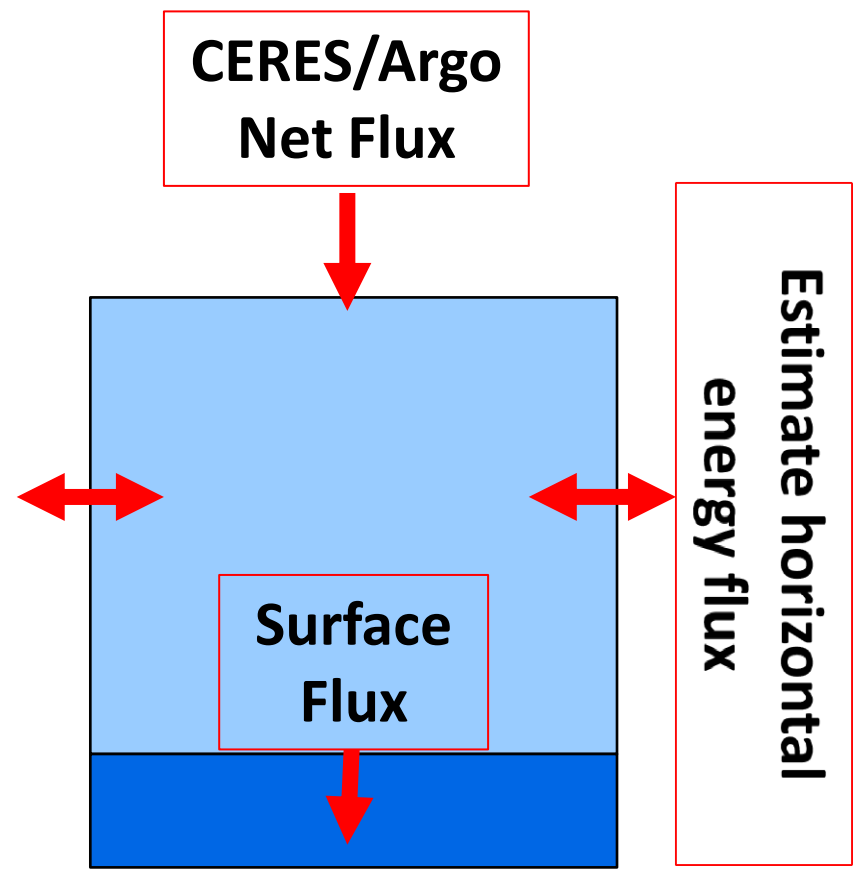
# Net downward surface flux (W/m<sup>2</sup>) 2001-2005



# Difference (W/m<sup>2</sup>) (2001-2008 - 1986-2000)



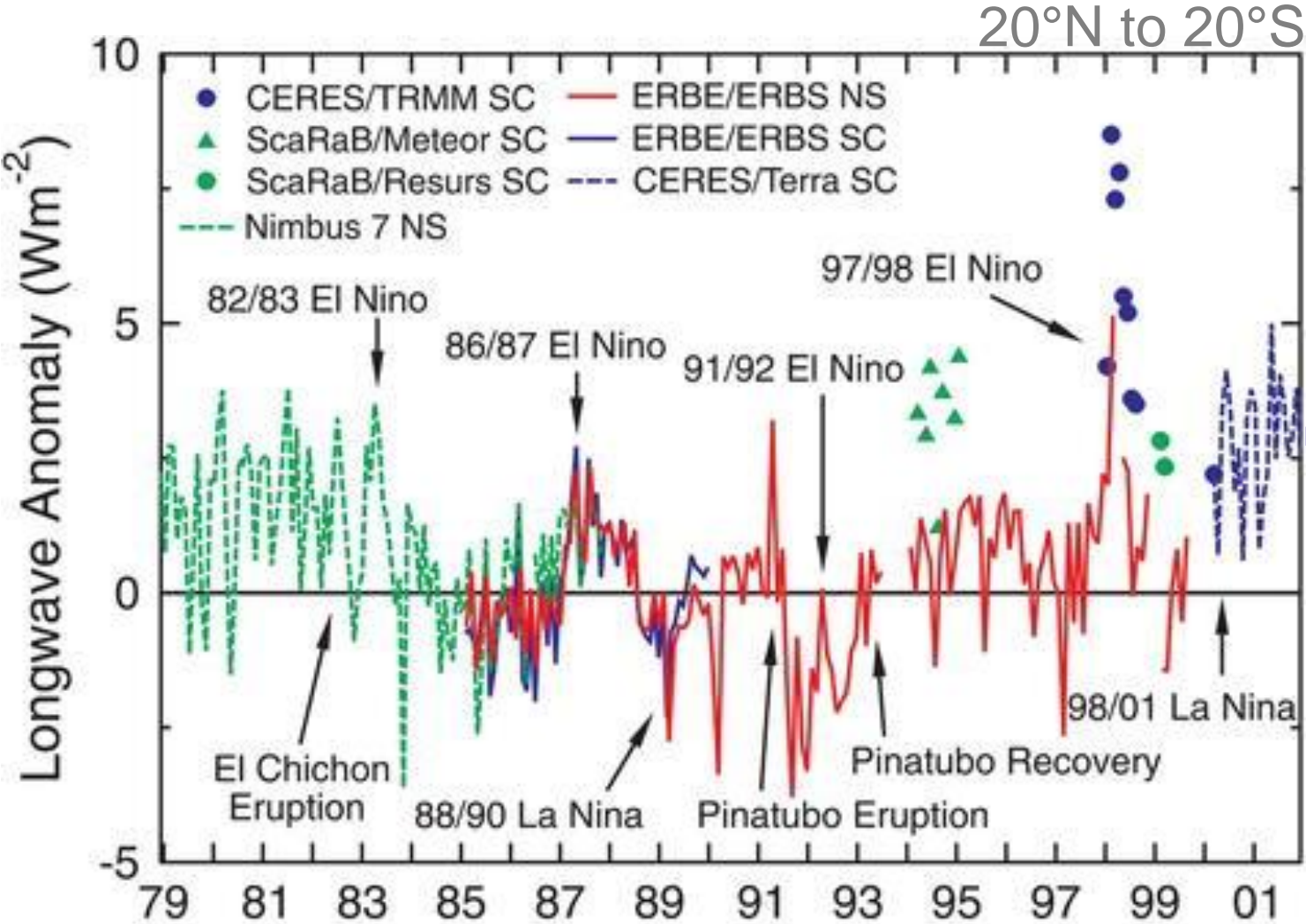
# Estimates of Surface Flux



$$F_{SFC} = F_{TOA} - \frac{\partial TE}{\partial t} - \nabla \cdot \frac{1}{g} \int_0^1 V(Lq + C_p T + \varphi_s + k) \frac{\partial p}{\partial \eta} d\eta$$

Extra slides

# Earth Radiation Budget Satellite Data

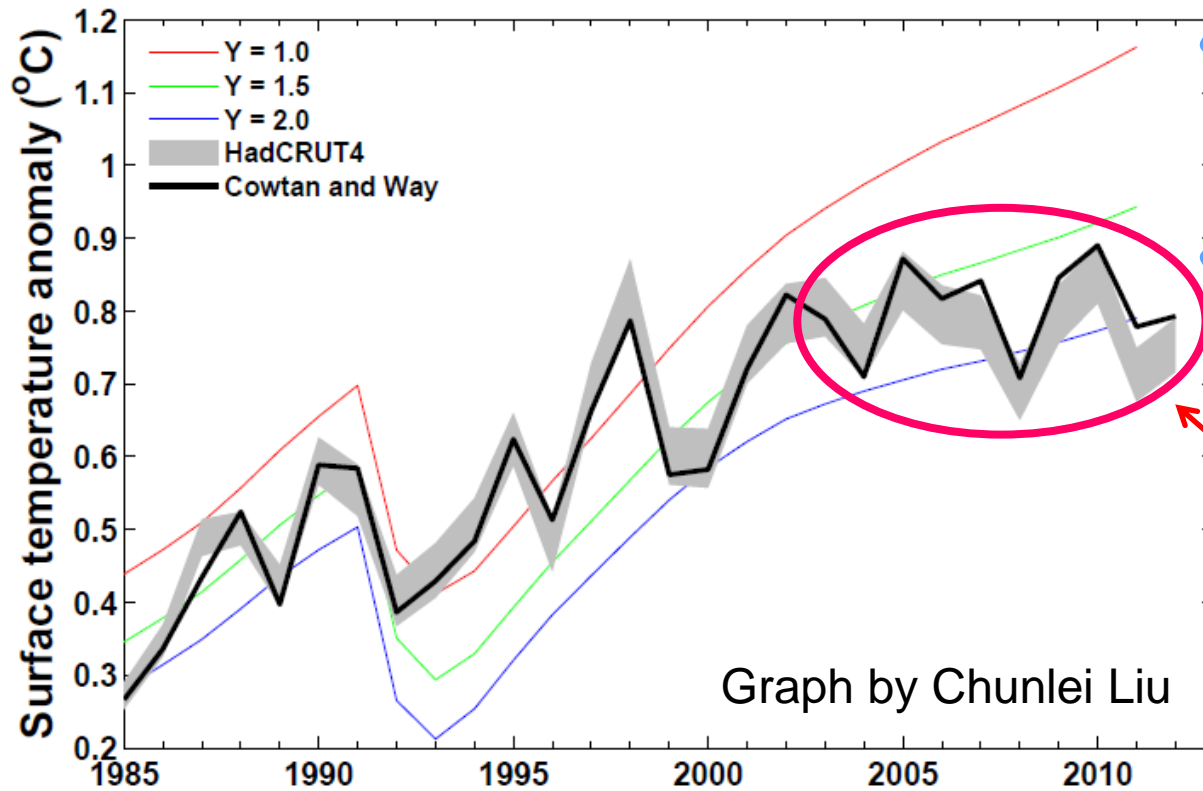


[Wong et al. \(2006\) J Clim](#); [Wielicki et al. \(2002\) Science](#)

# Combined CERES/Argo data

- Incoming Solar: SORCE Level 3 V10
- Reflected Shortwave/Outgoing Longwave from EBAF
  - (v2.6r → v2.8 → ? V3...)
- Added errors in quadrature to give  $\pm 0.43 \text{ Wm}^{-2}$ 
  - Argo 0-2000m dOHCA/dt =  $0.47 \pm 0.38 \text{ Wm}^{-2}$  (2005-2010)
  - >2000m  $\sim 0.07 \pm 0.05 \text{ Wm}^{-2}$
  - Heating/melting ice, heating land/atmos  $\sim 0.04 \pm 0.02 \text{ Wm}^{-2}$
  - CERES standard error  $\pm 0.2 \text{ Wm}^{-2}$
- Jan 2001-Dec 2010:  $0.50 \pm 0.43 \text{ Wm}^{-2}$  (EBAF V2.6r)
- March 2000 – February 2013:  $0.60 \pm 0.43 \text{ Wm}^{-2}$  (EBAF V2.8)
- CERES scanner data: cloud mask → clear-sky fluxes; not possible for ERBS wide-field of view

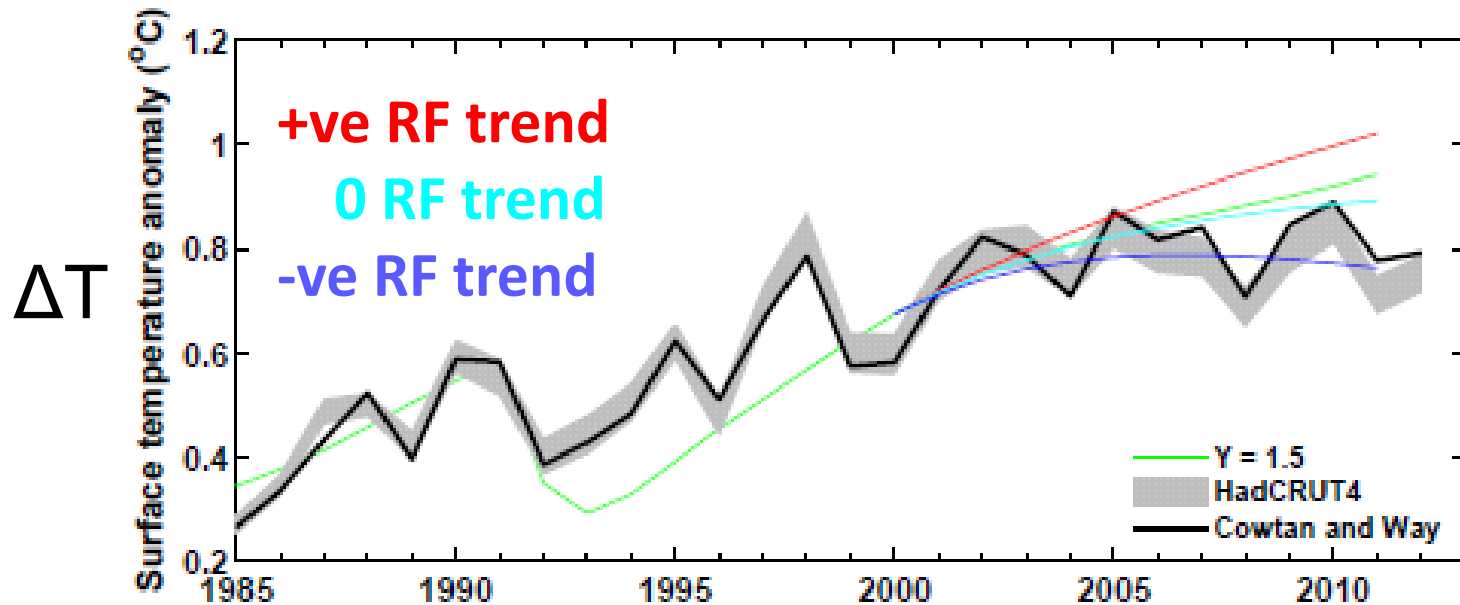
# Simple model: is the temperature record wrong or are computer models inaccurate?



Can comparisons tell us about how sensitive climate is to radiative forcing? e.g. [Otto et al. \(2013\) Nature Geosci](#)

Spatial infilling of data gaps influences trends in surface temperature ([Cowtan & Way, 2013 QJRMS](#)) and ocean heat content ([Lyman & Johnson 2014 J. Clim.](#))





Analysis  
 using  
 simple  
 energy  
 balance  
 model

$$N = \Delta F - Y \Delta T$$

