

DEEP-C:

Introduction & WP1 update

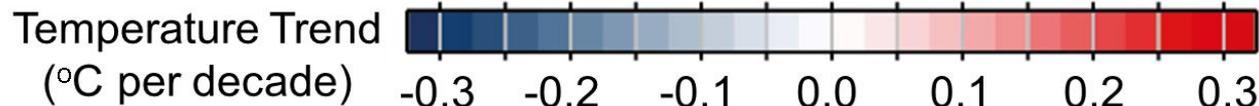
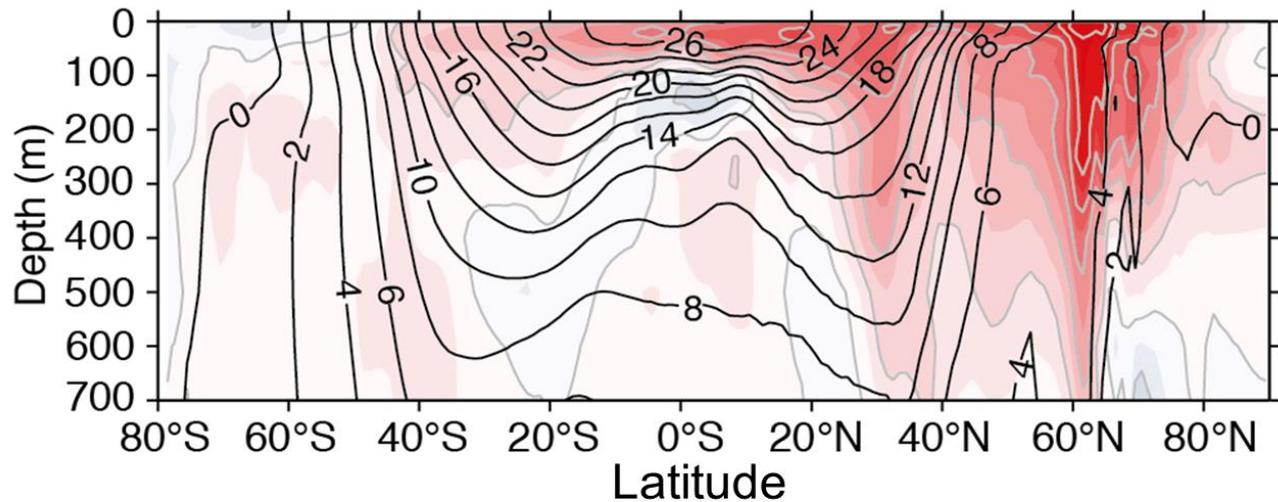
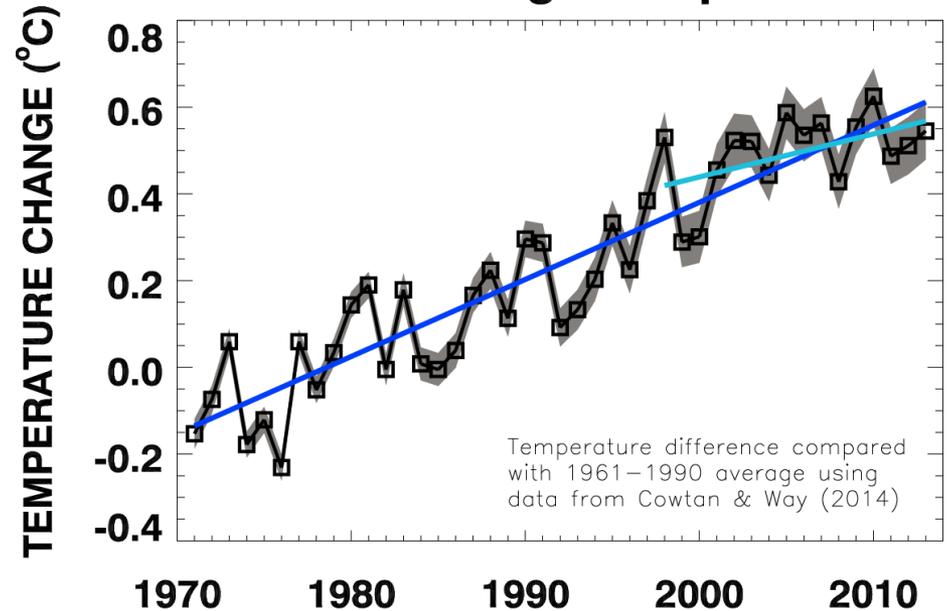
Richard Allan, Chunlei Liu - University of Reading

Thanks to: Norman Loeb, Matt Palmer, Doug Smith

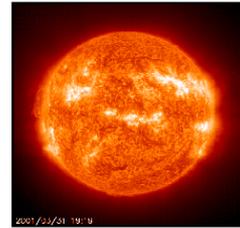
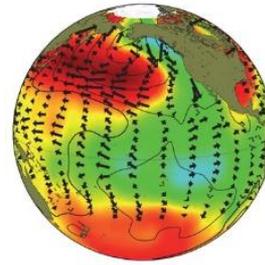
DEEP-C Meeting, Met Office, 20th September 2014

- 1) There has been a slowing (rather than a pause) in the rate of surface warming
- 2) Heating from greenhouse gases continue to warm upper oceans
- 3) Currently more heat is reaching deeper ocean levels rather than warming the mixed layer which influences surface temperature

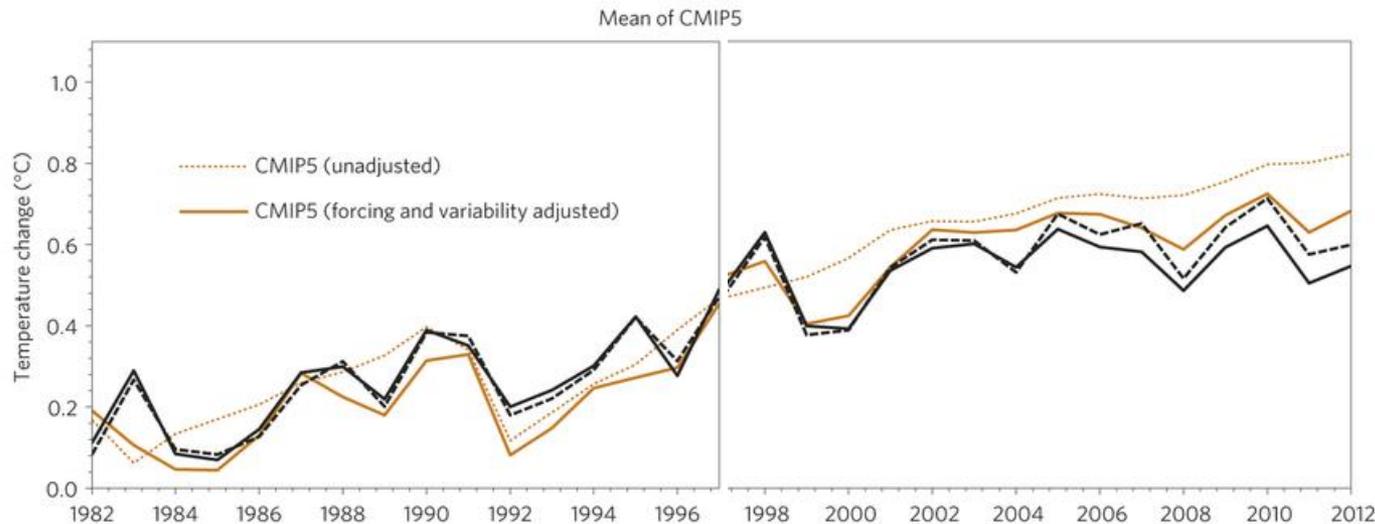
Global Average Temperature



Factors explaining the hiatus



- Declining solar forcing, more small volcanos & more La Niñas compared to late 1990s can explain:
 - Slowing in surface warming (e.g. [Foster & Rahmstorf 2012](#))
 - Slow surface warming compared with coupled simulations (e.g. [Risbey et al. 2014](#) ; [Huber & Knutti 2014](#))



Simulations
Adjusted Simulations
Observations

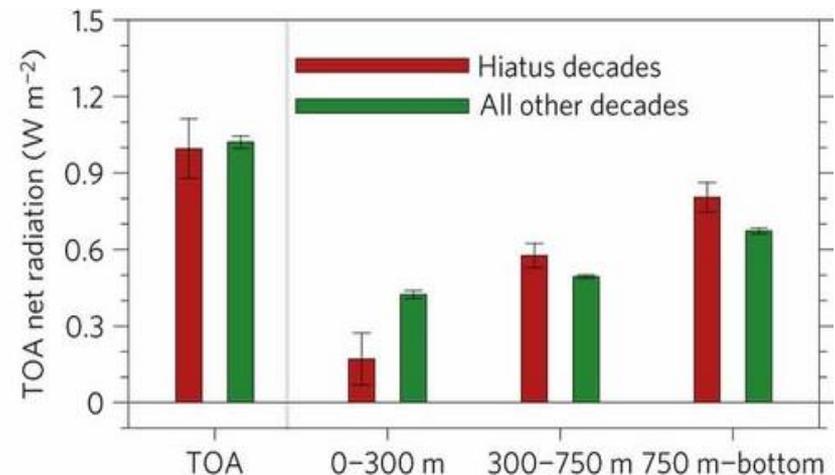
Huber & Knutti 2014

Heating of Earth continues

- The oceans have continued to heat up in the 2000s as expected from rising atmospheric concentrations of greenhouse gas (e.g. [Hansen et al. 2011](#) ; [Trenberth et al. 2014](#))
 - Ocean measurements and satellite observations show ocean heating rate has not declined (e.g. [Loeb et al. 2012](#))
 - Heat is mixing to deeper levels (e.g. [Balmaseda et al. 2013](#); [Watanabe et al. 2013](#))

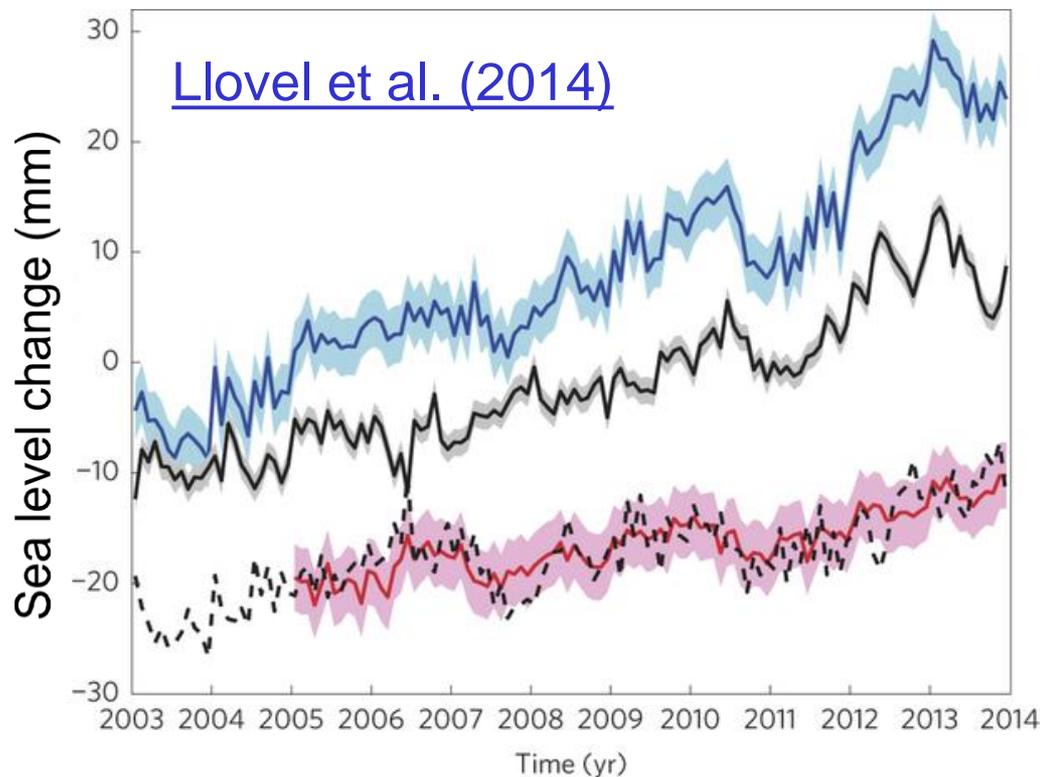
Hiatus decades are simulated by coupled models which mix more heat below 300m →

[Meehl et al. 2011](#)



Heating accounted for in “upper” ocean

- 0-700m ocean heating underestimated? ([Durack et al. 2014](#))
- Continued sea level rise; almost all of heating and sea level rise due to heating accounted for in upper 2000m



Altimeter (total)

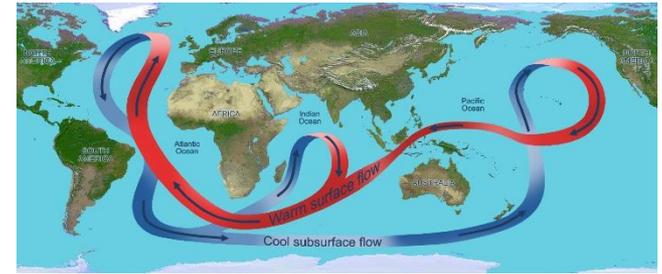
GRACE (mass contribution)

--- Thermal expansion (total
minus mass changes)

**0-2000m Argo-based thermal
expansion**

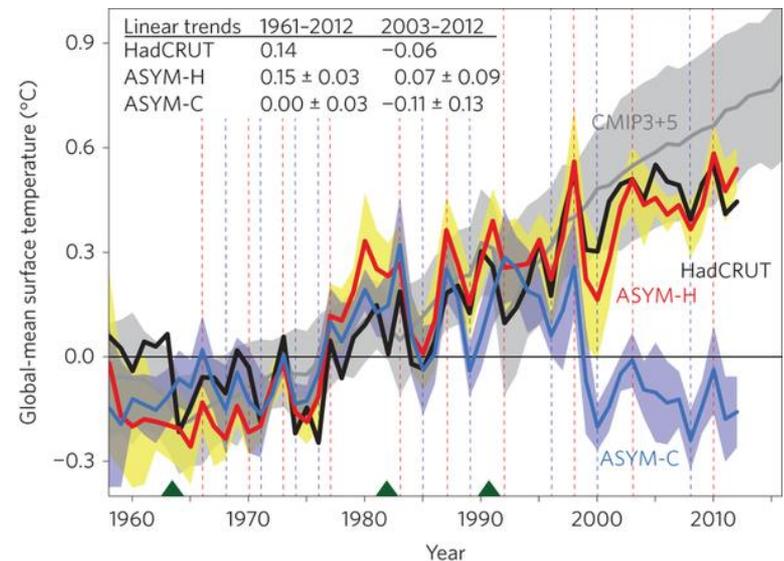
See also [Cazenave et al. \(2014\)](#)

Oceans mixing heat to deeper layers



- Observed strengthening of Pacific walker circulation e.g. [Merrifield \(2010\)](#) ; [Sohn et al. \(2013\)](#) ; [L'Heureux et al. \(2013\)](#)
- Simulations applying observed wind stress uptake more heat below mixed layer in Pacific e.g. [Kosaka & Xie \(2013\)](#) ; [England et al. \(2014\)](#)

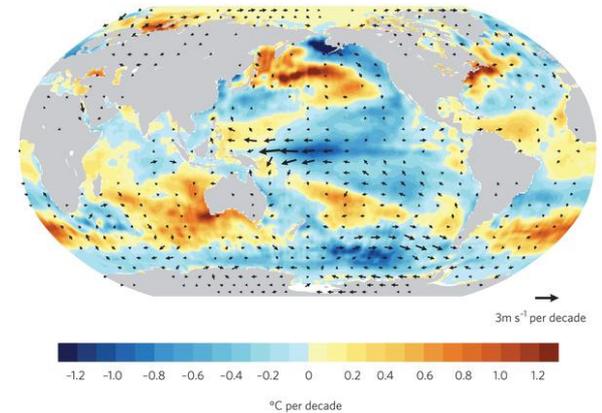
Simulations suggest internal variability contributes $+0.11$ - 0.13°C in 1980s/90s and -0.11°C in 2000s:
[Watanabe et al. 2014](#)



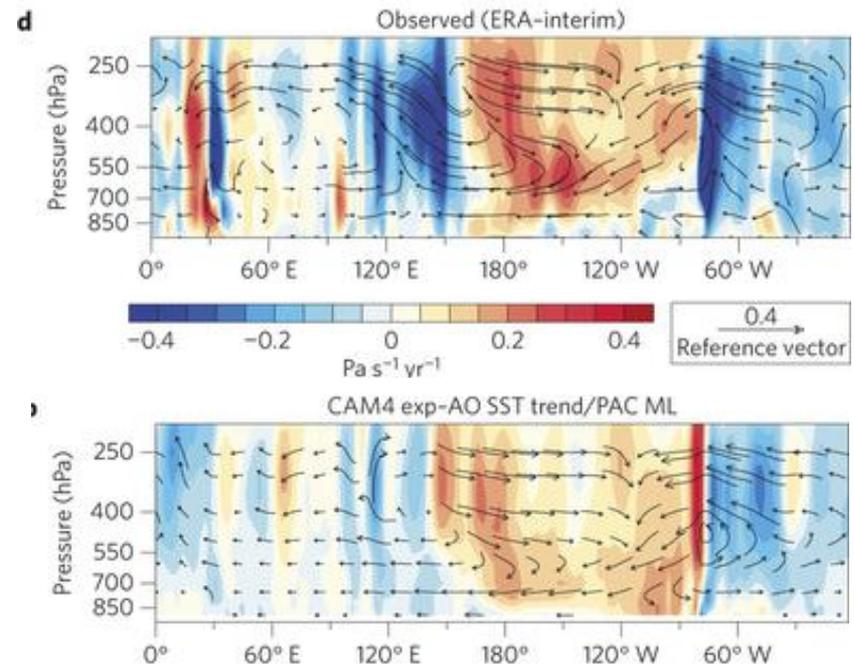
Mechanisms of ocean variability

- Pacific Decadal Variability Pattern
- Is Atlantic driving Pacific changes?
- Atlantic circulation salinity feedback?
([Chen & Tung 2014](#))

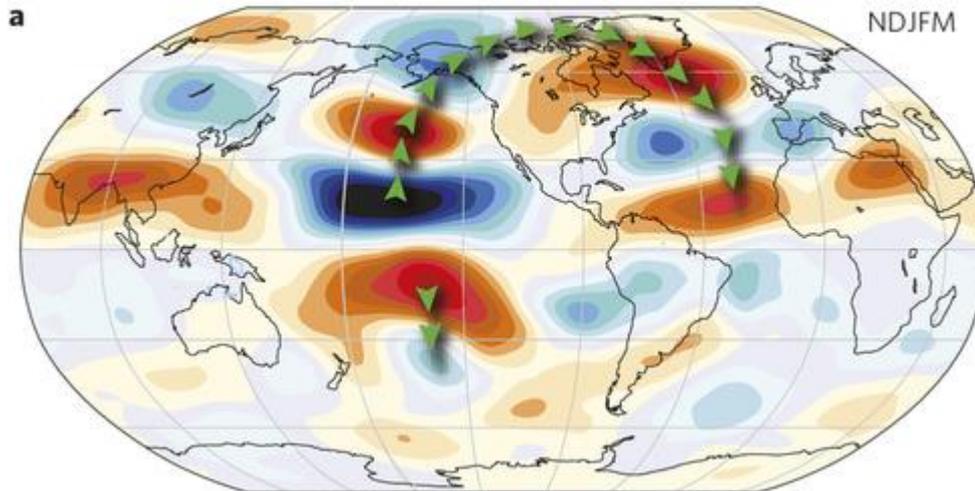
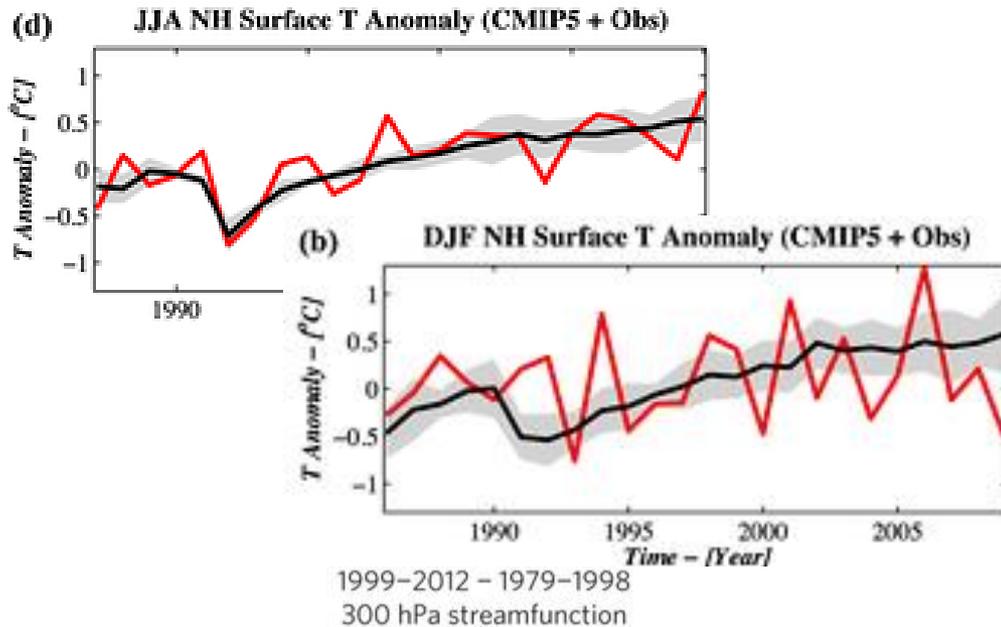
Model simulates stronger Pacific trades when apply Atlantic SSTs + Pacific SST allowed to respond →
[McGregor et al. \(2014\)](#)



([Kosaka 2014](#))



Remote influences on weather patterns



- Hiatus dominated by northern winter (e.g. [Cohen et al. 2012](#))
- Cooling in east Pacific explains reduced heat export during northern winter ([Kosaka & Xie 2013](#))
- Rapid Arctic warming linked to tropical changes ([Ding et al. 2014](#))
- Atmospheric bridges link tropical anomalies & mid latitude weather patterns (e.g. [Trenberth et al. 2014b](#))

DEEP-C Work Plan

Start date: March 2013; Project Ends February 2017

Workpackage	Year 1	Year 2	Year 3	Year 4
WP1 (Reading)	O1	D1 PDRA1		
		Allan		
WP2 (Southampton)	O2	D2 PDRA2		
		McDonagh, King		
WP3 (Met Office)	O3	D3		
		Palmer		
WP4 (All)	Recruitment, Integration, KO meeting	O4-O5-O6		D4,D5
Partners				Synthesis
		Kuhlbrodt, Gregory		

Table 2 - Management timeline for DEEP-C.

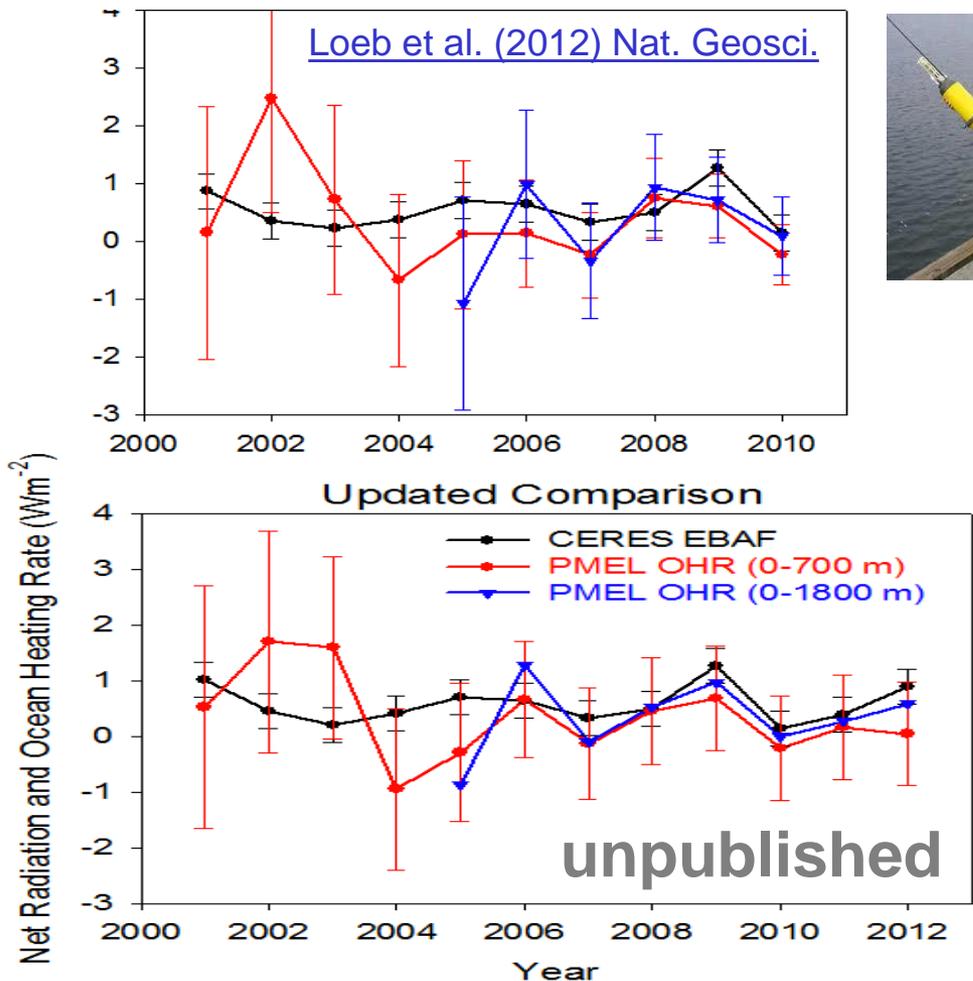
WP1 - Planned work

1. Analyse and update observed variability in TOA radiation balance (Allan et al. 2014: delivered)
2. Combine reanalyses/satellite data to provide independent estimates of surface flux (in preparation: C. Liu et al.)
 - Wider use of flux products by Pat Hyder et al. (Met Office)
3. *Other topics:*
 - *Investigate lags in climate system (preliminary work)*
 - *Evaluation of ERA CLIM radiation budget?*
4. *Monitoring of changes in energy balance (ongoing)*
5. *Reconcile TOA radiation balance and ocean heating (WP4)*

Combining Earth Radiation Budget data and Ocean Heat Content measurements



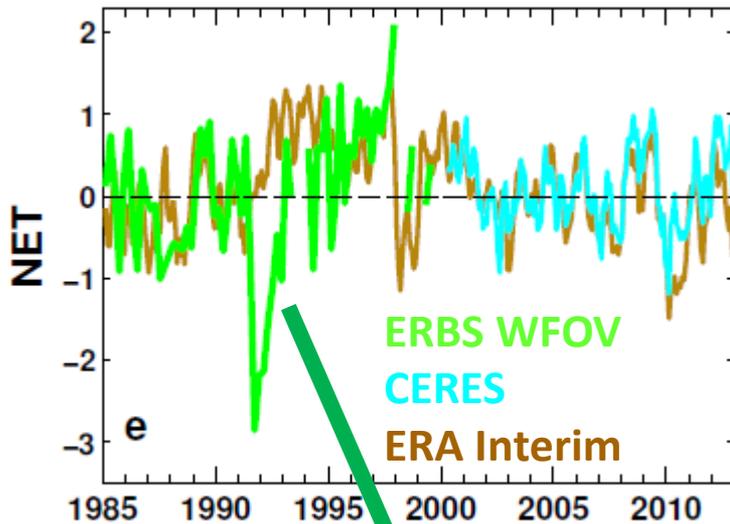
- Tie 10-year CERES record with SORCE TSI and ARGO-estimated heating rate 2005-2010 + minor additional storage terms
- Variability relating to ENSO reproduced by CERES and ERA Interim
- Ocean heating rate sensitive to dataset and sampling
- What about prior to 2000?



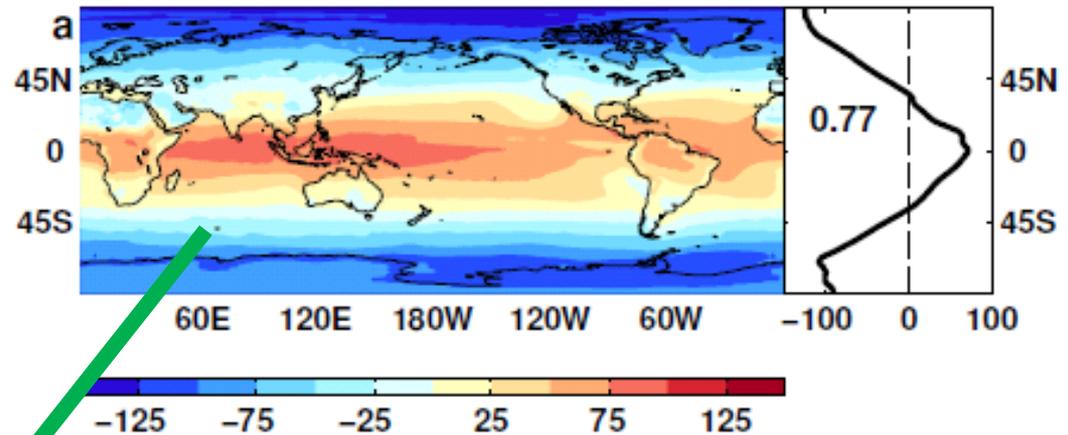
[Loeb et al. \(2012\) Nat. Geosci.](#) See also [Hansen et al. \(2011\) ACP](#)

Reconstructing global radiative fluxes prior to 2000

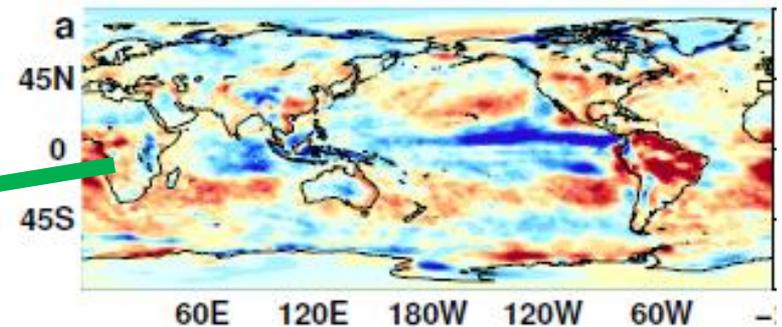
ERBS/CERES variability



CERES monthly climatology



ERA Interim spatial anomalies

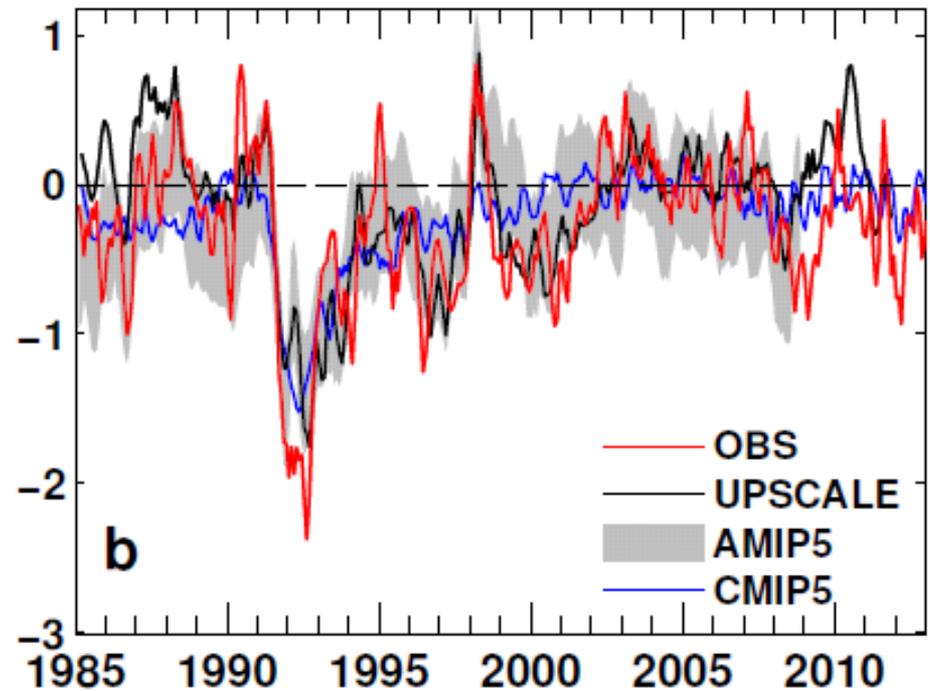


Combine CERES/ARGO accuracy,
ERBS WFOV stability and
reanalysis circulation patterns to
reconstruct radiative fluxes

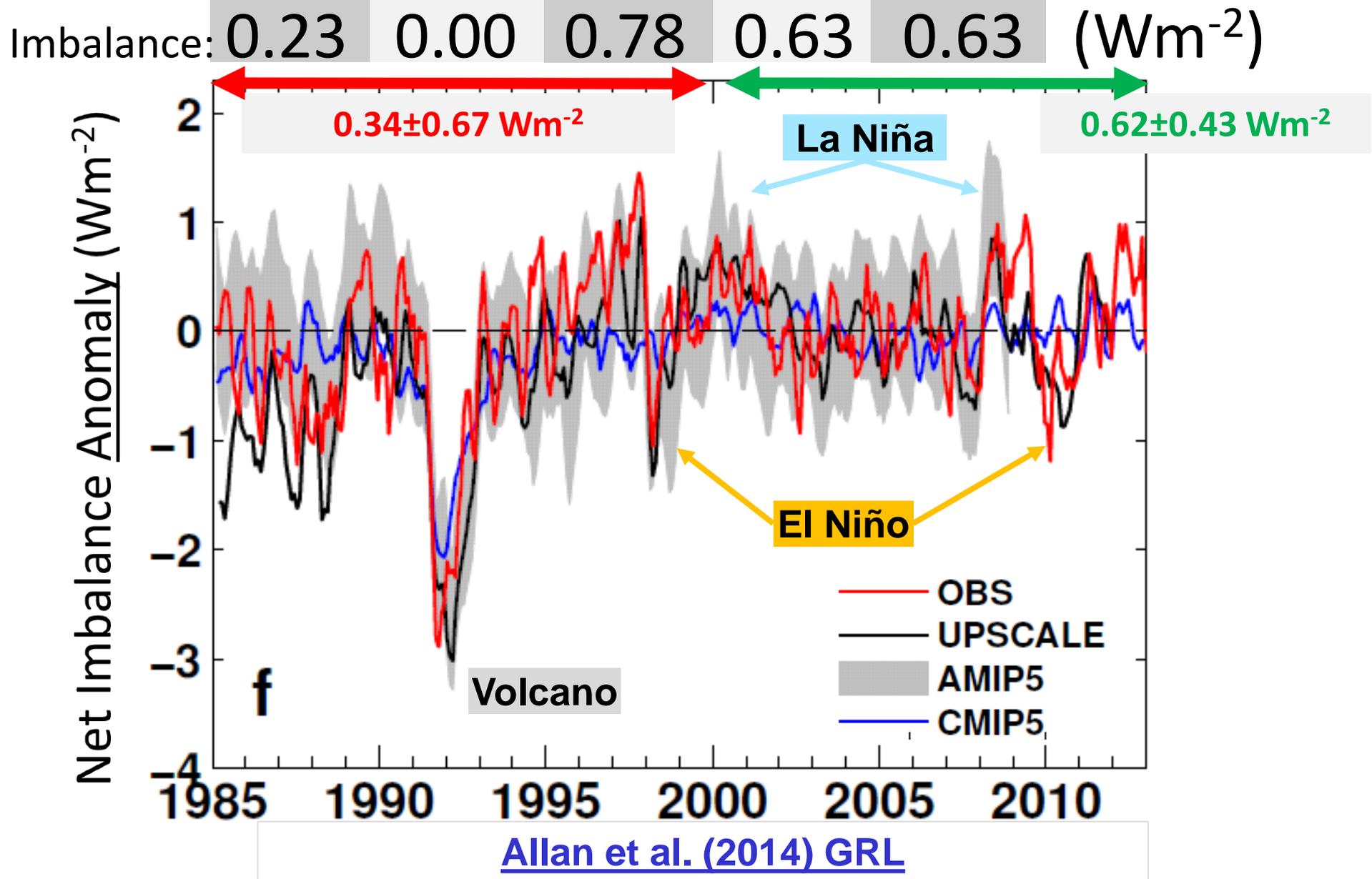
Use reanalyses or models to bridge gaps in record (1993 and 1999/2000)

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

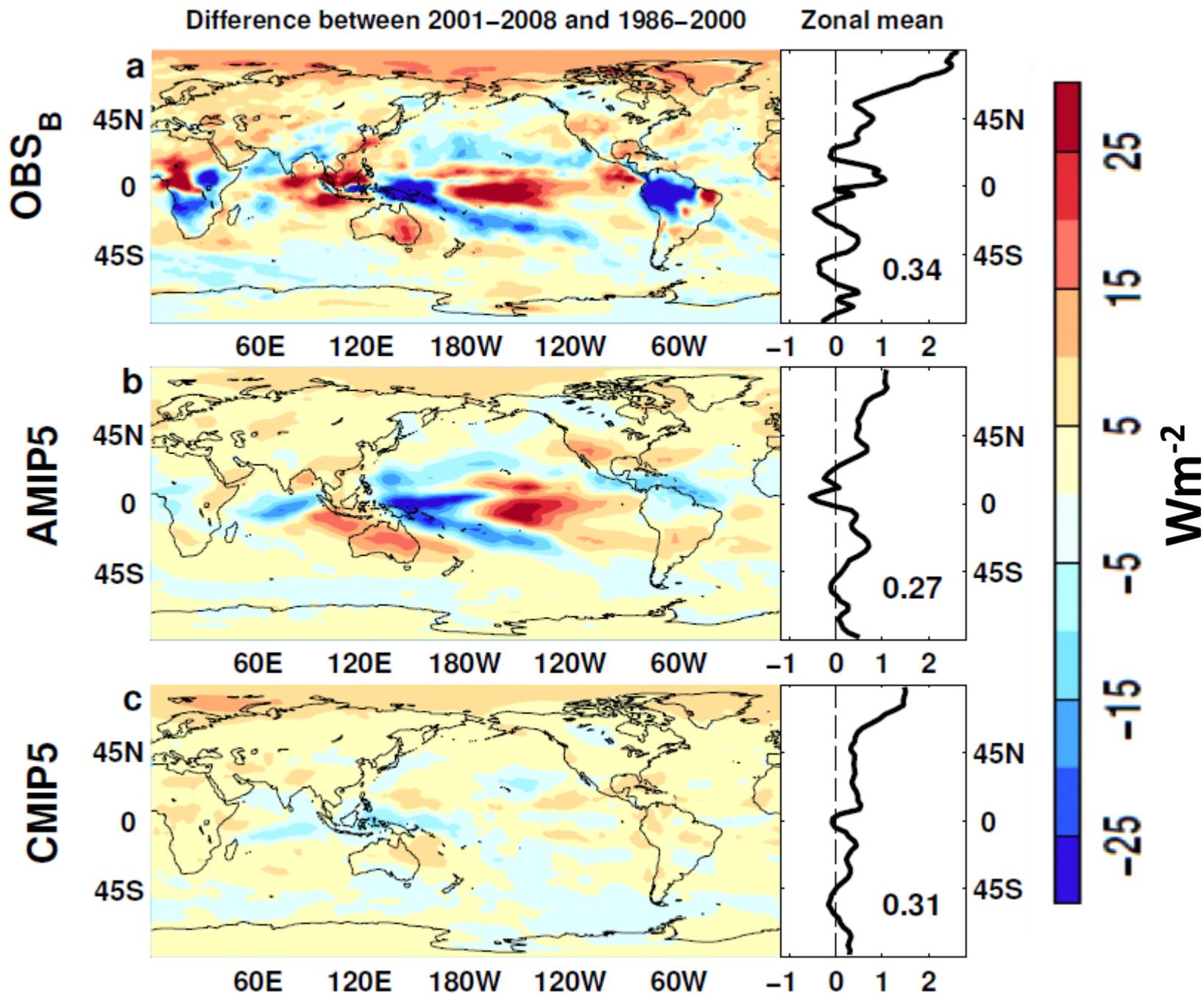
Outgoing Longwave Radiation Anomalies (Wm^{-2})



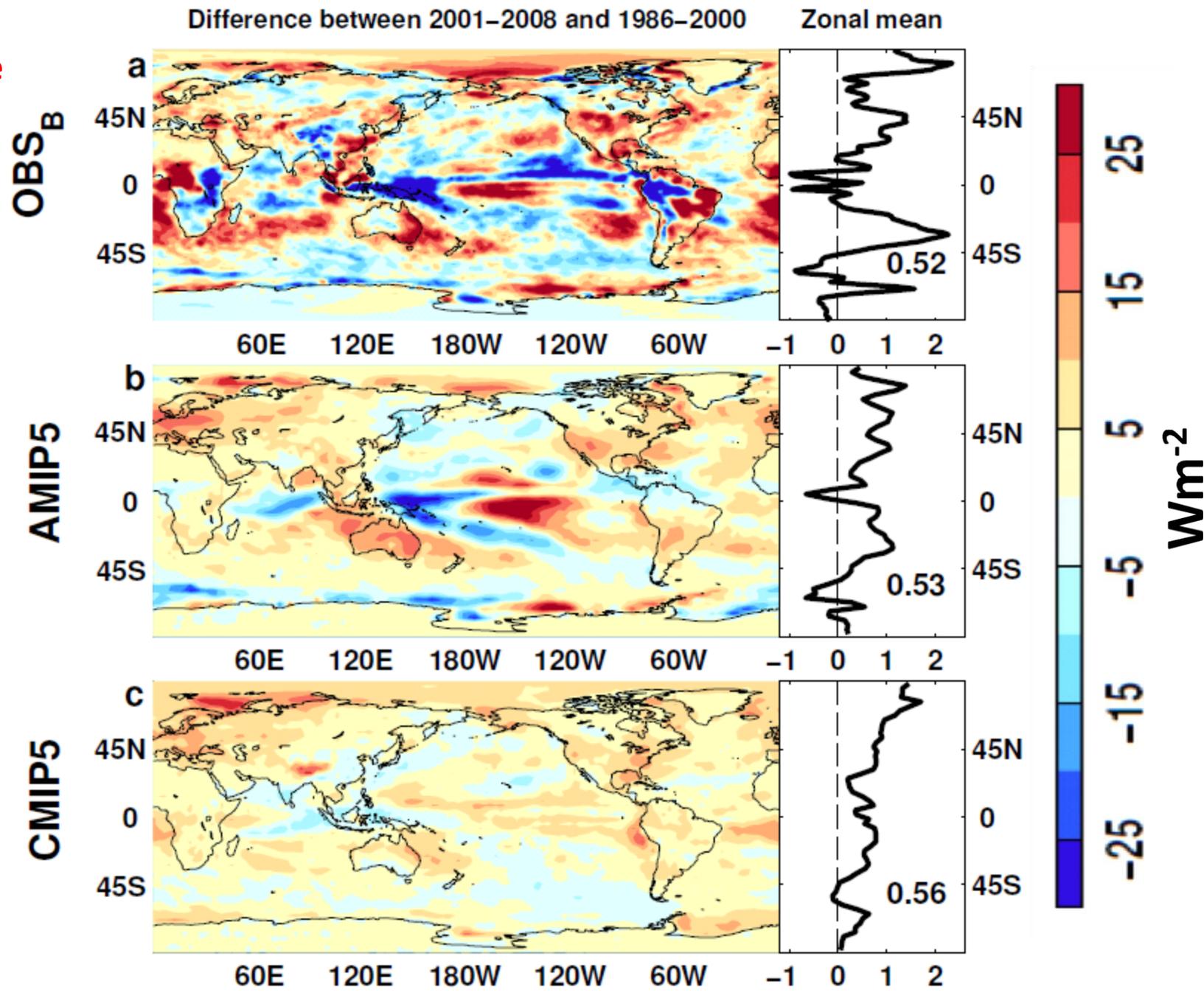
Changes in imbalance in models & observations



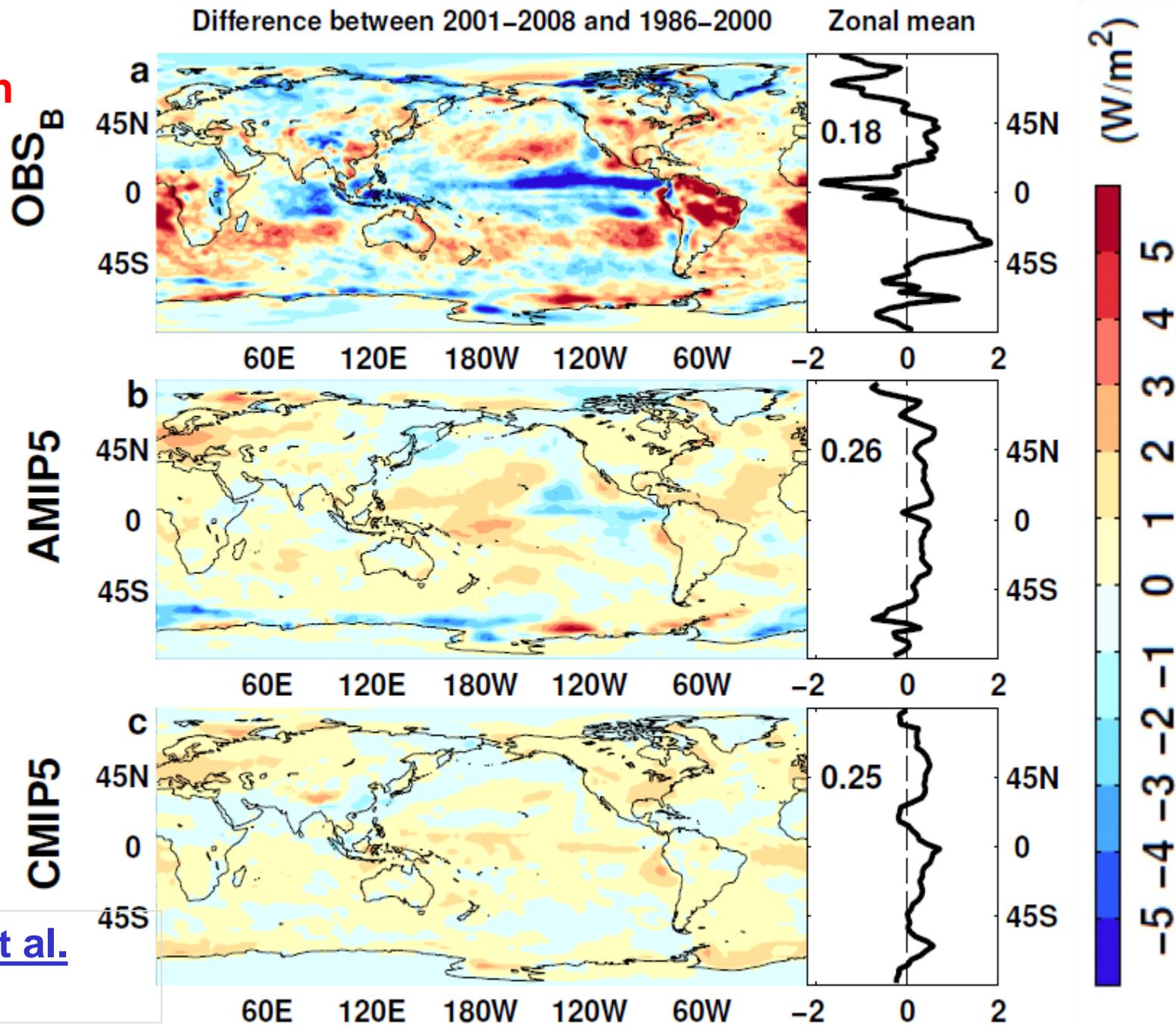
Outgoing Longwave Radiation



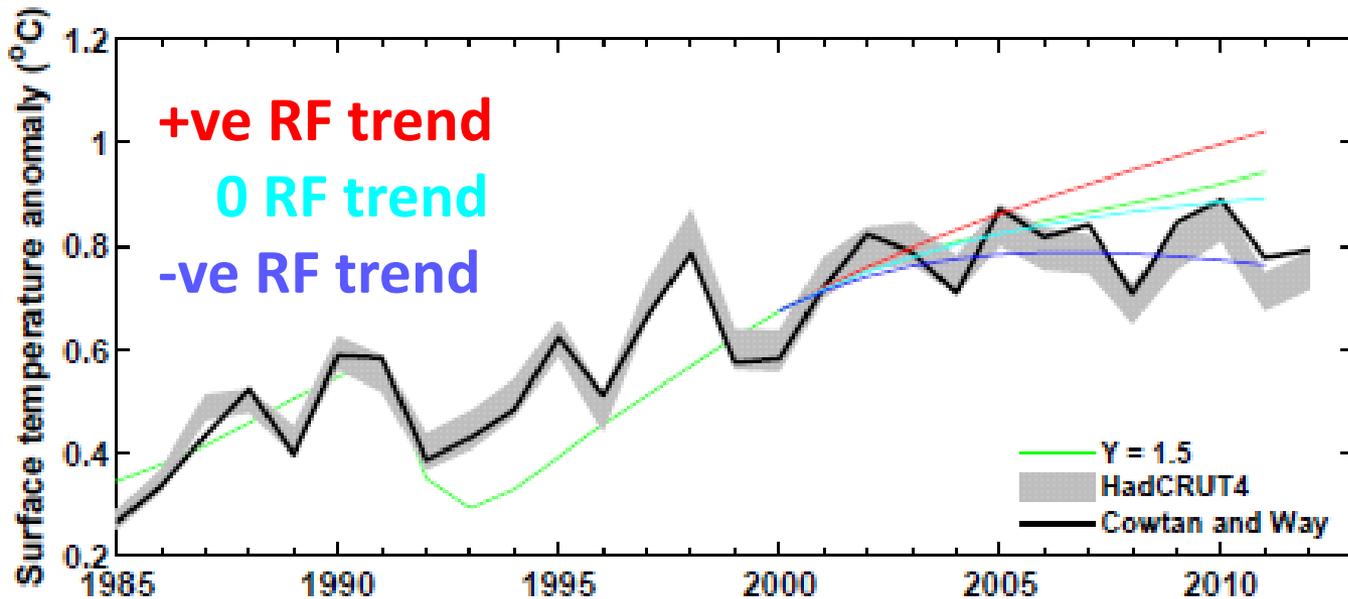
**Absorbed
Shortwave
Radiation**



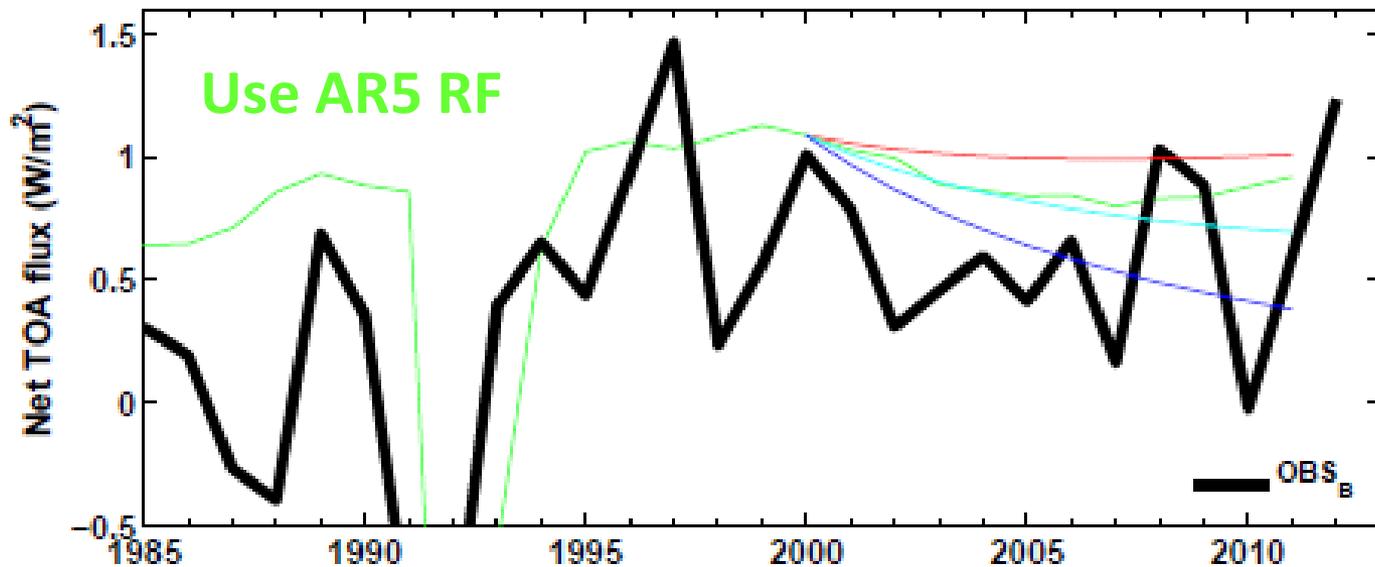
NET Radiation



[Allan et al. \(2014\)](#)

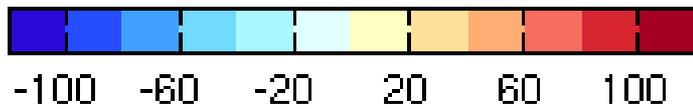
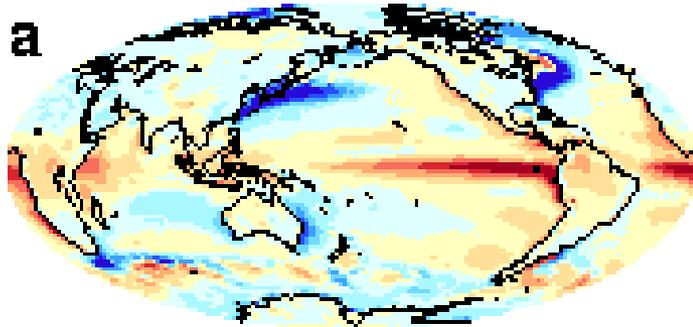


Analysis using simple energy balance model (Chunlei Liu)

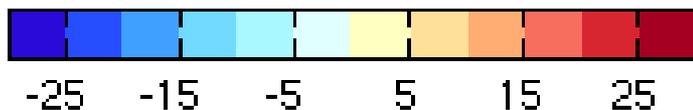
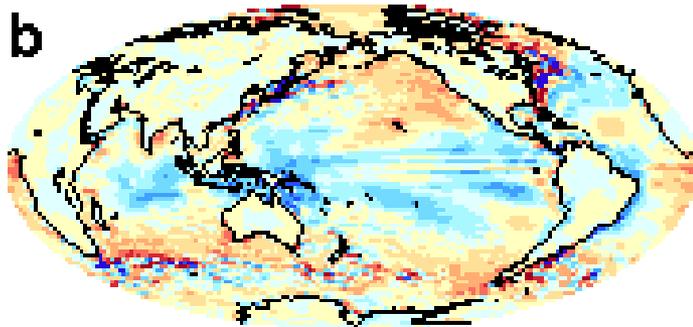


[Allan et al. \(2014\) GRL](#) supplementary

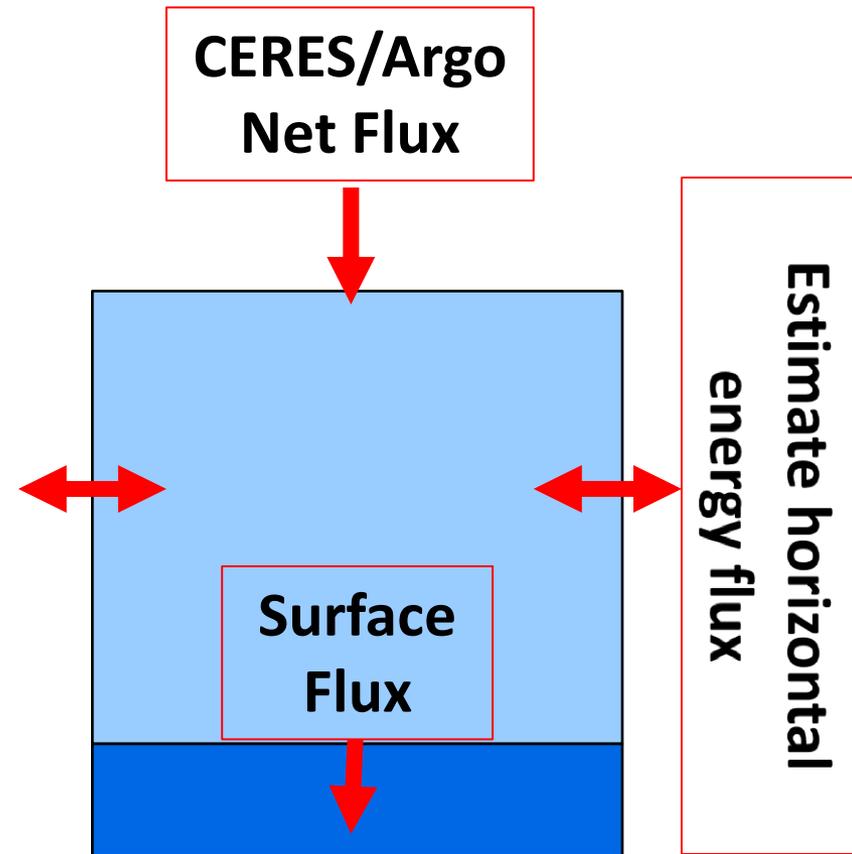
Net downward surface flux (W/m^2)
2001-2005



Difference (W/m^2)
(2001-2008 - 1986-2000)



Current work: estimates of Surface Flux (Chunlei Liu)



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

Conclusions

- Heating of Earth continues at rate of $\sim 0.6 \text{ Wm}^{-2}$
- Current variability in TOA radiation (1985-2013)
 - Net flux higher in 1995-1999 than 2000-2012 period
 - Pacific signal in ΔT and ΔN
 - Radiative forcing alone can't explain surface warming slowdown: internal variability important
- Plans:
 - Development of surface flux estimate (currently)
 - Evaluate with other datasets; basin-scale flux changes
 - Work with WP2 (surface fluxes) and WP3 (simulations) and comparison with surface fluxes products (Met Office)

WP1 Dissemination Activities

- **October 2014:** Conversation [article](#) on Durack/Llovel papers; BBC2 Jeremy Vine show; CERES/GERB/ScaRaB Science team meeting [talk](#)
- **August 2014:** Allan et al. (2014) [NCAS highlight](#), Nature Climate Change [highlight](#) ; [Climate Lab Book](#) , [Carbon Brief](#) , [Met Department](#) & [Conversation](#) blogs; [Telegraph](#) ; Eddington Astronomical Society [talk](#)
- **July 2014:** DEEP-C talks at [GEWEX](#) and [AMS](#) conferences
- **April 2014** – Royal Society “Hiatus” discussion meeting; [EGU](#) talk
- **Feb 2014** - ["Where has the warming gone?"](#) talk to RMetS local group ; [Comment on England et al.](#) (see also [Guardian](#) article).
- **Aug/Sep2013** - [Comment on recent Nature paper by Kosaka and Xie](#) (see also [BBC](#) and [Independent](#) articles); [Voice of Russia](#); IPCC [Sky](#)/BBC/etc
- **July 2013** - Science Media Centre [briefing](#) on “slowdown”
- **May 2013:** [Carbon Brief](#) article on DEEP-C temperature obs.
- **April 2013** - Meeting with DECC partners in London

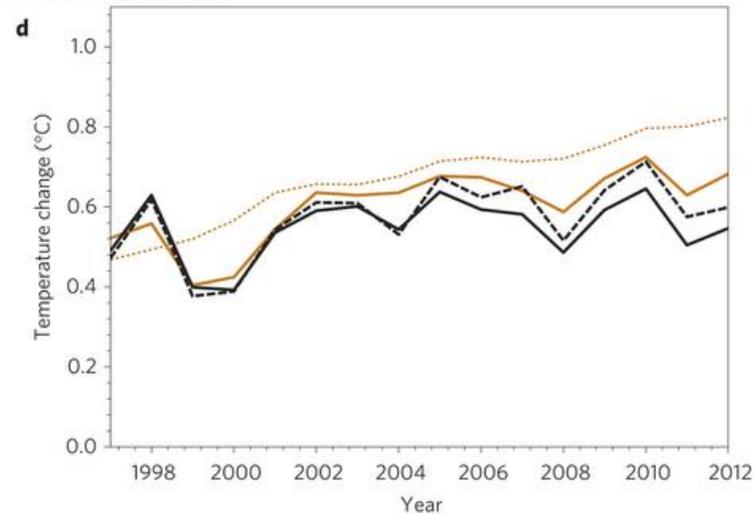
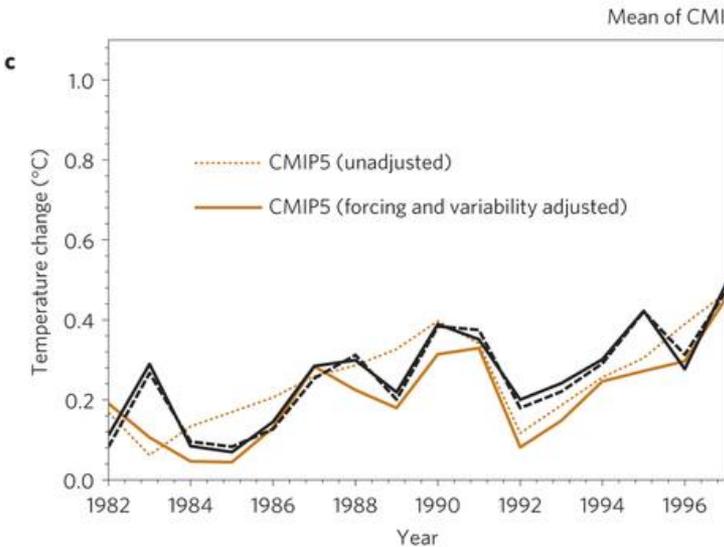
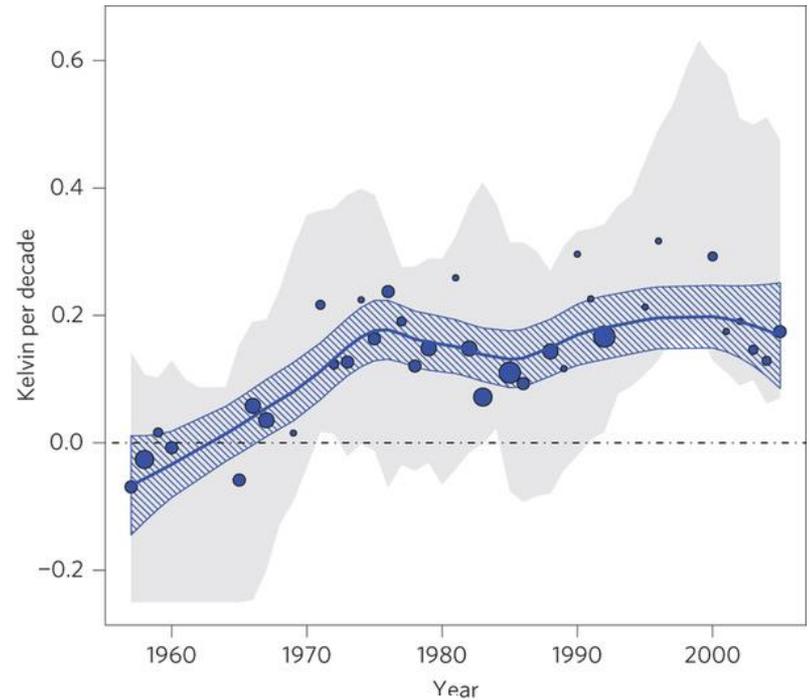
Also: twitter, Walker Institute, media interaction

<http://www.met.reading.ac.uk/~sgs02rpa/research/DEEP-C.html>

Spare slides

Better agreement accounting for ENSO & natural forcings

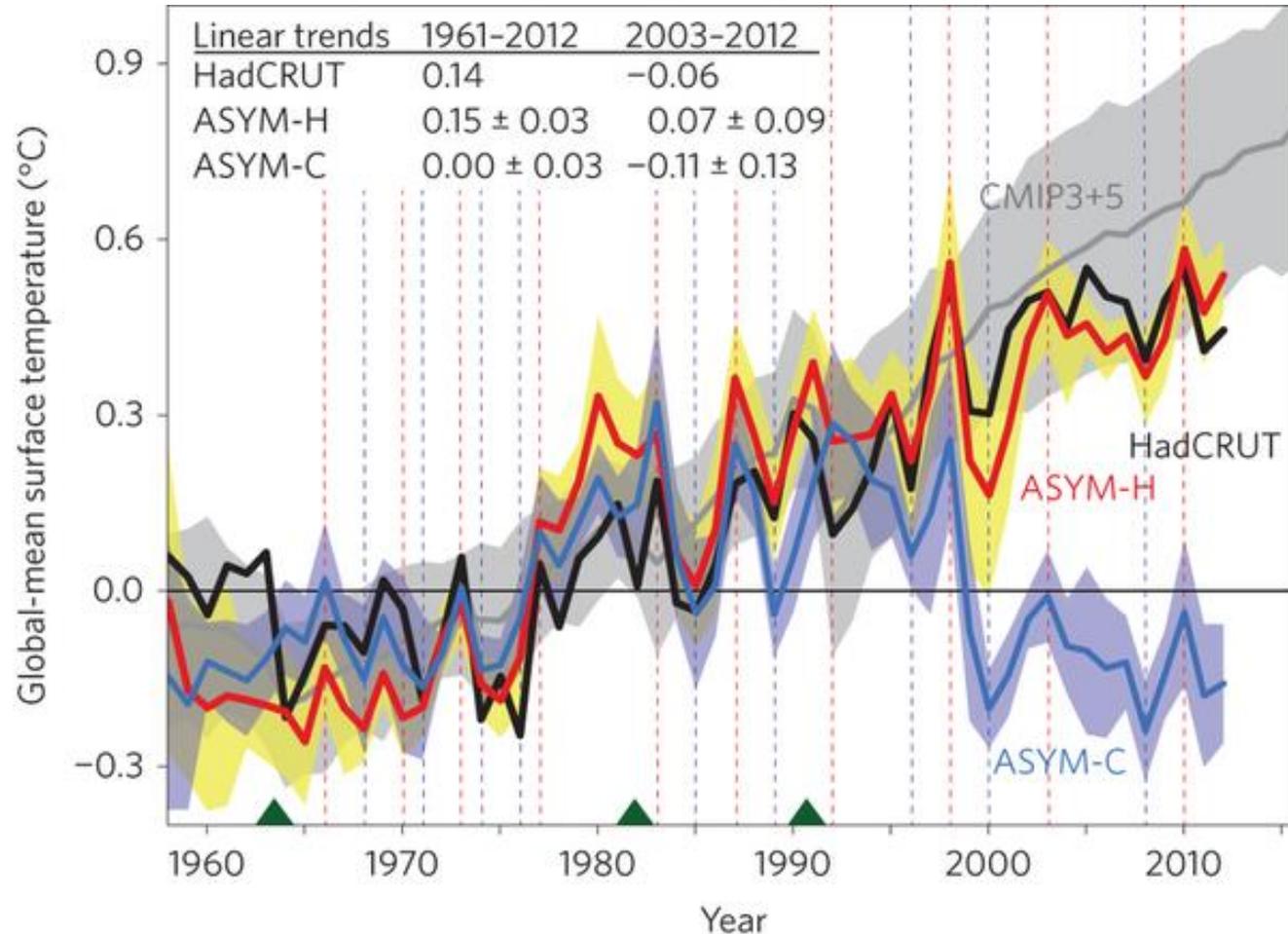
[Risbey et al. \(2014\)](#) Nature Climate Change →



Observations:
— HadCRUT4 (ref. 30)
- - - Cowtan and Way (ref. 10)

← [Huber & Knutti \(2014\)](#)
Nature Geosci

Role of Pacific Trade Winds



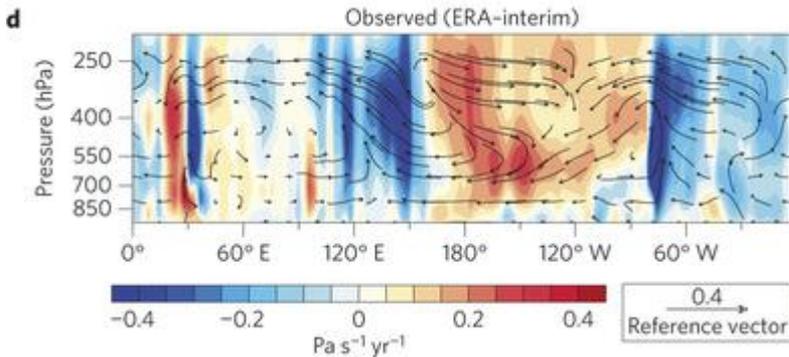
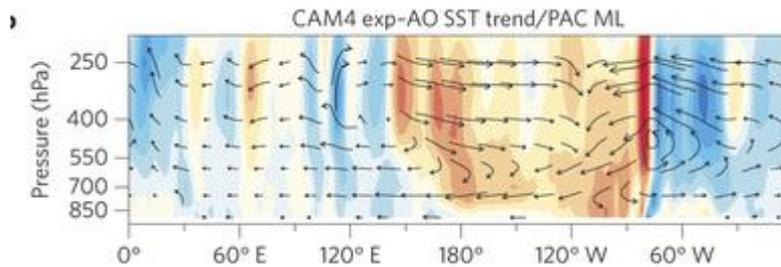
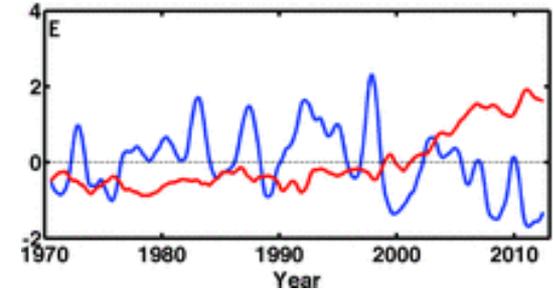
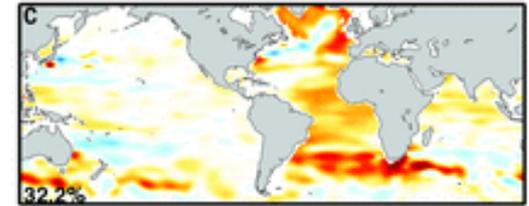
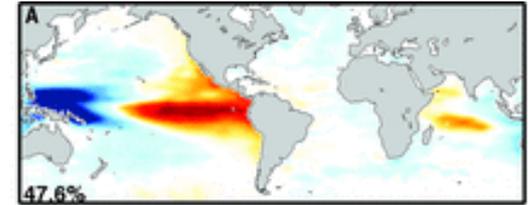
[Watanabe et al.](#)

(2014) Nature
Climate Change:

- Prescribe observed changes in Pacific trade winds
- Estimate Internal variability contributes $\sim +0.11-0.13^\circ\text{C}$ in 1980s/90s and -0.11°C in 2000s
- Is it all internal or is there a forced component?

Role of the Atlantic ?

[Chen & Tung \(2014\) Science](#) → propose mechanism involving deeper AMOC circulation and salinity feedbacks



[McGregor et al. \(2014\) Nature Clim.](#) Model simulated strengthened Pacific trades when forced by Atlantic SST and Pacific SST is allowed to respond

WP1 Objectives/Deliverables

- O1.** Combine satellite radiation budget measurements with atmospheric reanalyses, providing improved 2D estimates of surface heat fluxes across the ocean surface (WP1)
- O5.** Monitor co-variations in net radiative energy imbalance and ocean heating (from O1,O2,O4); quantify and understand lags between OHC and TOA radiation (WP1-4)
- O6.** Characterise spatial signatures/mechanisms of ocean and atmospheric heat re-distribution (from O4-5) during the hiatus period 2000-2015 using observations and simulations (WP1-4)
- D1.** Combined satellite-reanalysis atmosphere/surface energy flows: methodology, uncertainty and exploring lags in the climate system (paper 1,2; WP1, O1,4)