DEEP-C – update on literature, WP1 radiation budget and WP4 dissemination

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Partners: Walker Institute, NASA Langley, DECC, NCAS, NCEO.

Radiative forcing or energy redistribution?

Journal articles: http://www.met.reading.ac.uk/~sgs02rpa/research/DEEP-C.html#PAPERS

- Radiative forcing?
  - volcanic, solar, sulphate, stratospheric water vapour, Pinatubo overshoot
  - Fyfe et al. (2013) Nature Climate; Fyfe et al. (2013) GRL ; Murphy (2013) Nature Geosci ; Kaufmann et al. (2011) PNAS; Solomon et al. (2011) Science ; Hansen et al. (2011) ACP ; Solomon et al. (2010) Science ; Murphy et al. (2009) JGR

- Unforced variability?
  - Cloud forcing/adjustment/feedbacks, El Niño, PDO/IPO/climate shift, ocean circulation
  - Kosaka & Xie (2013) Nature; Watanabe et al. (2013) GRL ; Balmaseda et al. (2013) GRL; Guemas et al. (2013) Nature Climate ; Loeb et al. (2012) Nature Geosci.; Chikamoto et al.(2012) GRL ; Katsman & van Oldenborgh (2011) GRL; Foster and Rahmstorf (2011) ERL ; Meehl et al. (2011) Nature Climate Change (NCC); Palmer et al. (2010) GRL

Causes of Climate Change 1998-2012

Cause	Estimated Change in Radiative Forcing (W per sq.m)[1]
Greenhouse gases	+ 0.48
Solar	– 0.16
Volcanoes	– 0.06
Other (e.g. aerosols)	± ?
TOTAL	**+ 0.26 ± ?**

1. Since 1998 natural factors have **masked** some of the greenhouse gas warming influence

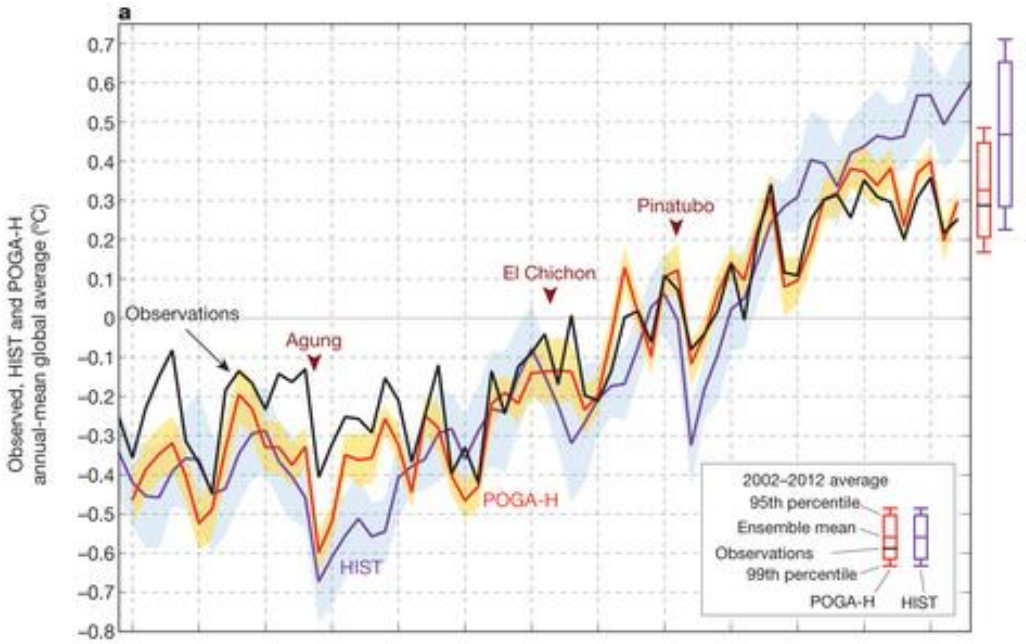
2. In the 1990s natural factors (especially recovery from Mt. Pinatubo) **added** to the greenhouse warming influence

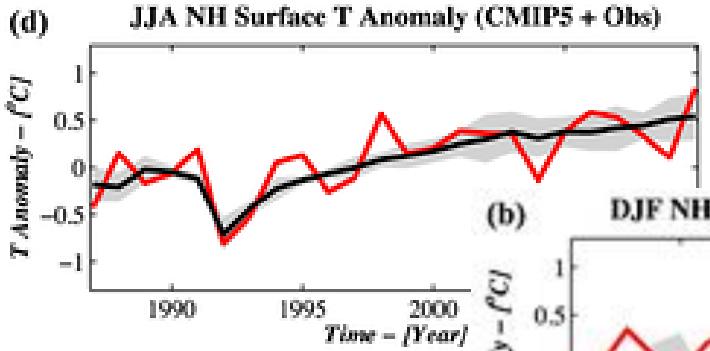
3. Little overall influence of natural factors since the 1950s

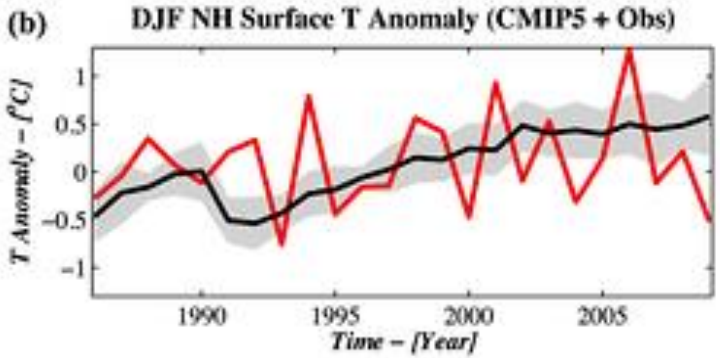
[1] Quantifying other forcings and uncertainties is ongoing research

Piers Forster, University of Leeds

Role of Pacific Ocean Natural Variability





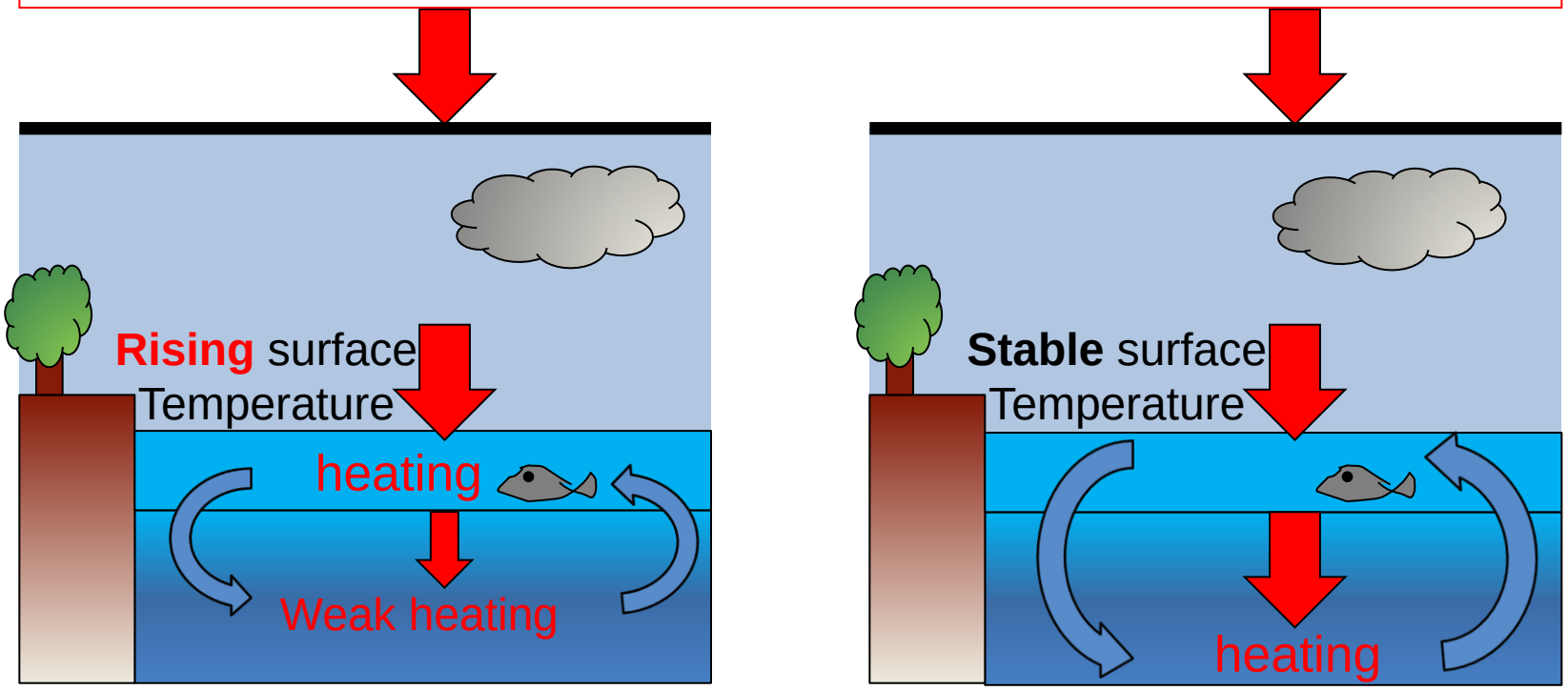


← Kosaka & Xie (2013) Nature

- Adjust heating in E Pacific to agree with obs SST
- Simulations reproduces hiatus and some regional climate anomalies
- Also explains why hiatus dominates NH winter (e.g. Cohen et al. 2012, below)
- Note, some models do not simulate matural variability well e.g. CNRM, CanCM4; Watanabe et al. 2013)

Heating due to rising greenhouse gas concentrations

also influenced by aerosol pollution and natural factors e.g. volcanoes, the sun



1980s-1990s: heating of upper layers of the ocean – rising surface temperature

2000s: heating of deeper layers of the ocean – slow rises in surface temperature

Cartoon above, *but what are the mechanisms*? WP2…

Natural fluctuation or some externally forced effect?

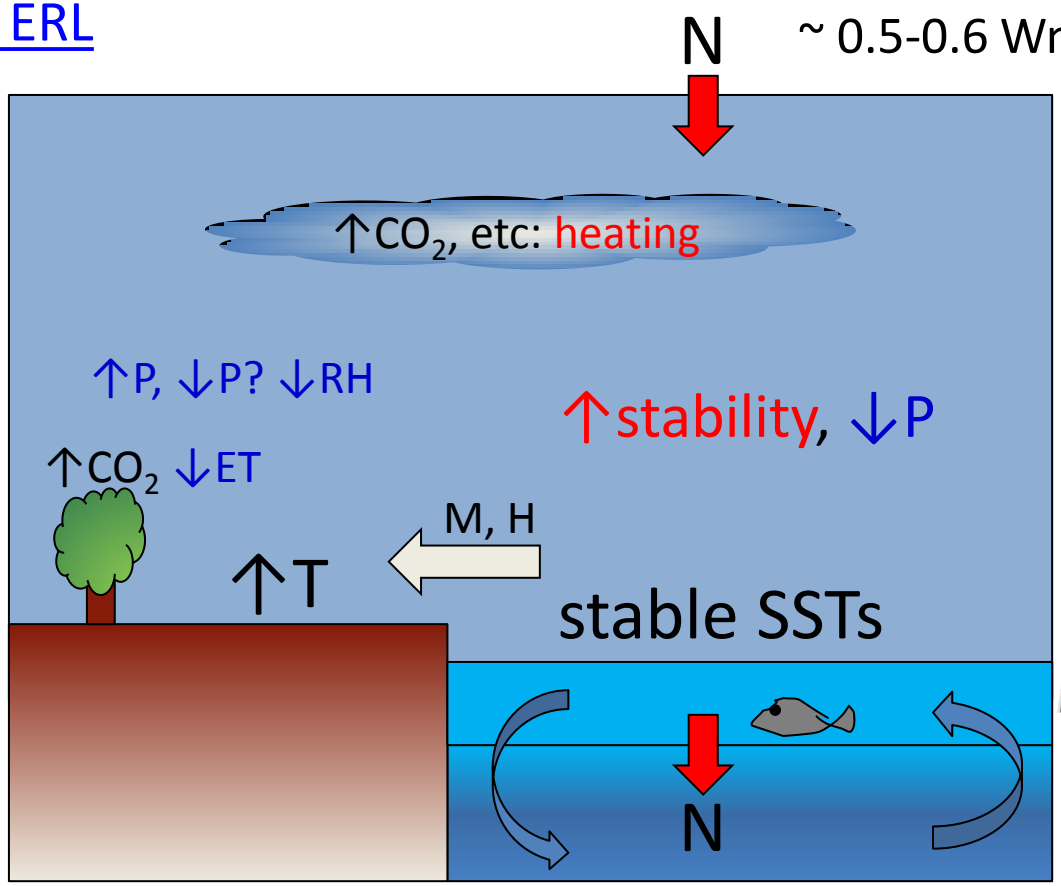
Mechanisms during SST warming hiatus?

After calculations from 4XCO_2 from [Cao et al. 2012 ERL]

↑ Monsoonal circulations: [Levermann et al. (2009) PNAS]

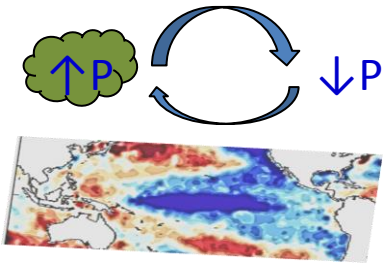
Energy flows: [Muller & O'Gorman (2011) Nature Clim.]

CO_2 bio. Effects – small over 15yrs? [Andrews et al. 2010 Clim. Dyn] ; [Dong et al. (2009) J. Clim]



~ 0.5-0.6 Wm^{-2} e.g. [Loeb et al. (2012) Nature Geo]

↑ Walker circ? [Sohn et al. (2012) Clim Dyn]

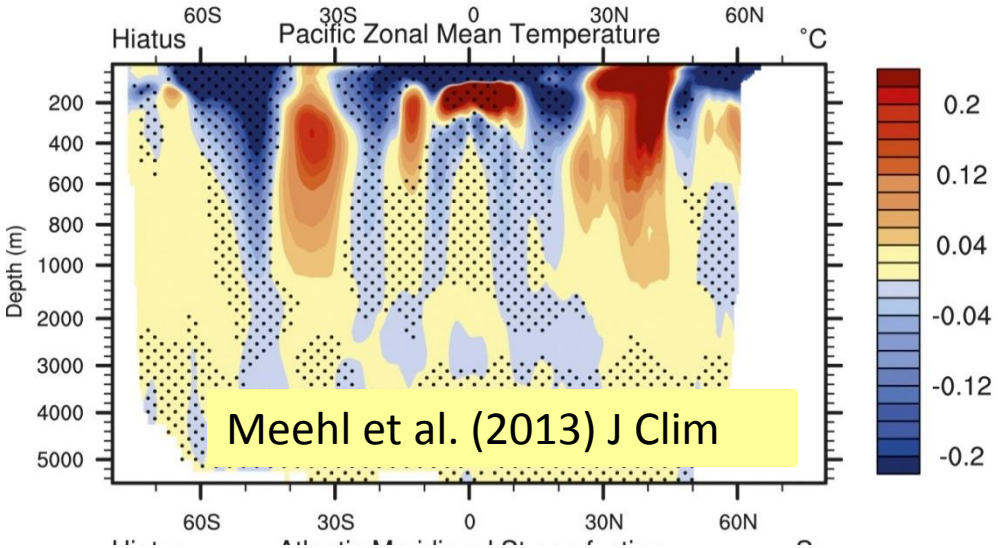


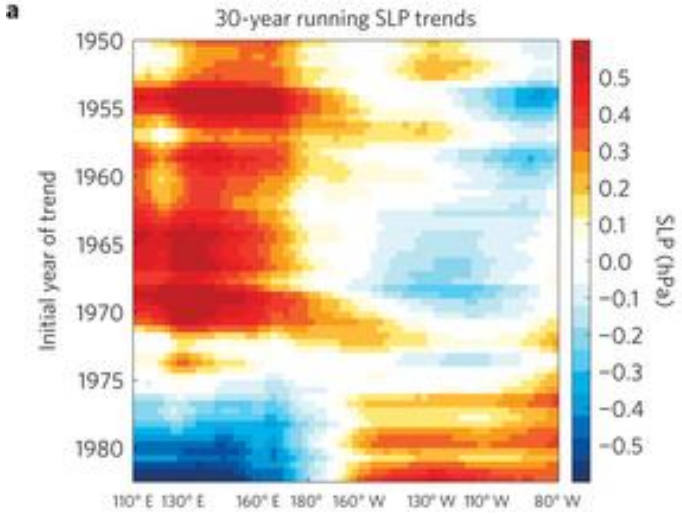
IPO pattern

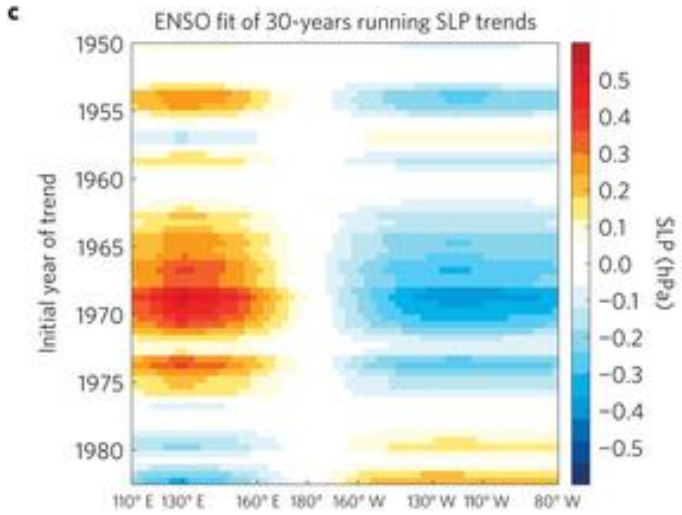
e.g. [Meehl et al. (2012) Nat. Clim].

Change from EP to CP El Nino? [Xiang et al. (2013) Clim Dyn]

Vertical profiles of heating in Pacific during hiatus decades →





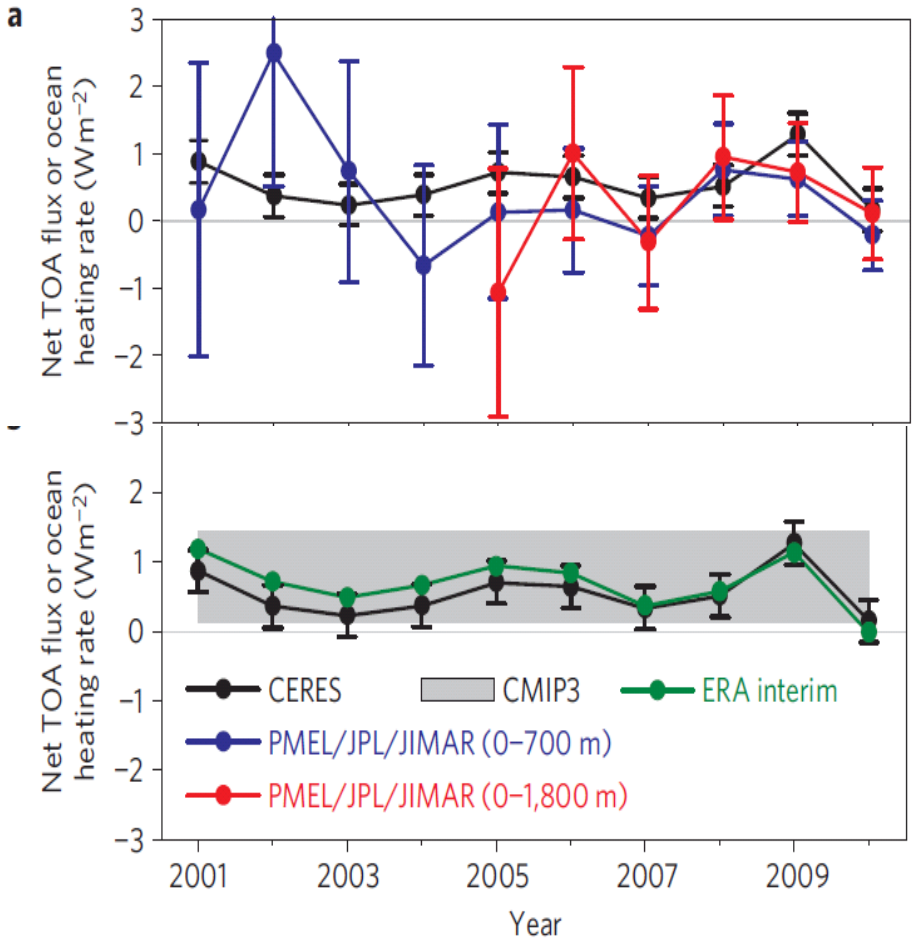


← Trends in SLP and decadal ENSO signal (L'Heureux et al. 2013; also Sohn et al. 2012; Merrifield 2011)

- Strengthening of Walker circulation in response to IPO pattern? Or has change in wind stress increased heat uptake below 700m (Balmaseda et al. 2013)?
- Slowdown predicted with initialisation (Guemas et al. 2013; Smith 2013)
- Other notable changes: freshening of Antarctic bottom waters since 1980s (Purkey & Johnson 2013)

Combining Earth Radiation Budget and Ocean Heat Content data

- Tie 10-year CERES record with SORCE TSI and ARGO-estimated heating rate 2005-2010
- Best estimates for additional storage terms
- Variability relating to ENSO reproduced by CERES and ERA Interim
- Estimate of decade long net energy imbalance of **0.50±0.43 Wm^{-2}**



Loeb et al. (2012) Nat. Geosci.

See also Hansen et al. (2011) ACP

WP1 - Planned work

1. Analyse and update observed variability in TOA radiation balance
2. *Investigate lags in climate system*
3. Combine ERA Interim and CERES to provide new estimate of surface heating
4. *Monitoring of changes in energy balance*
5. *Reconcile TOA radiation balance and ocean heating*

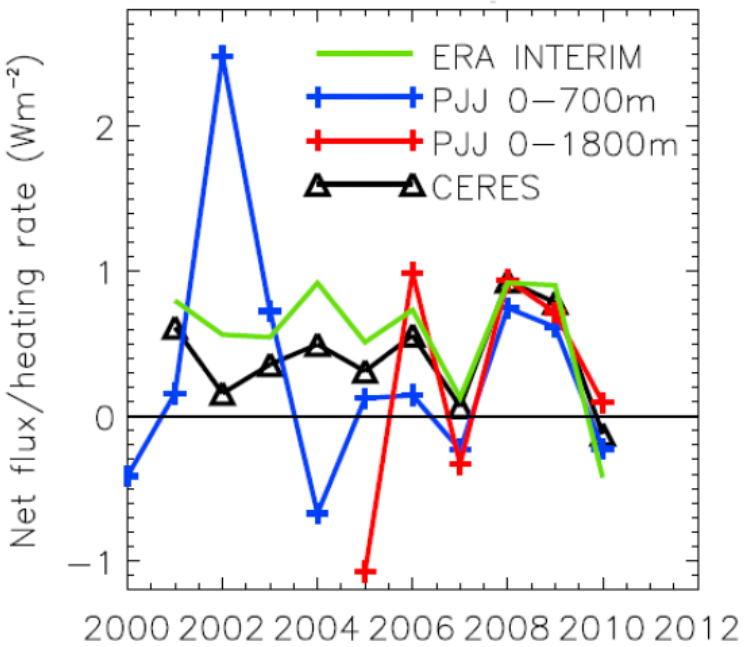
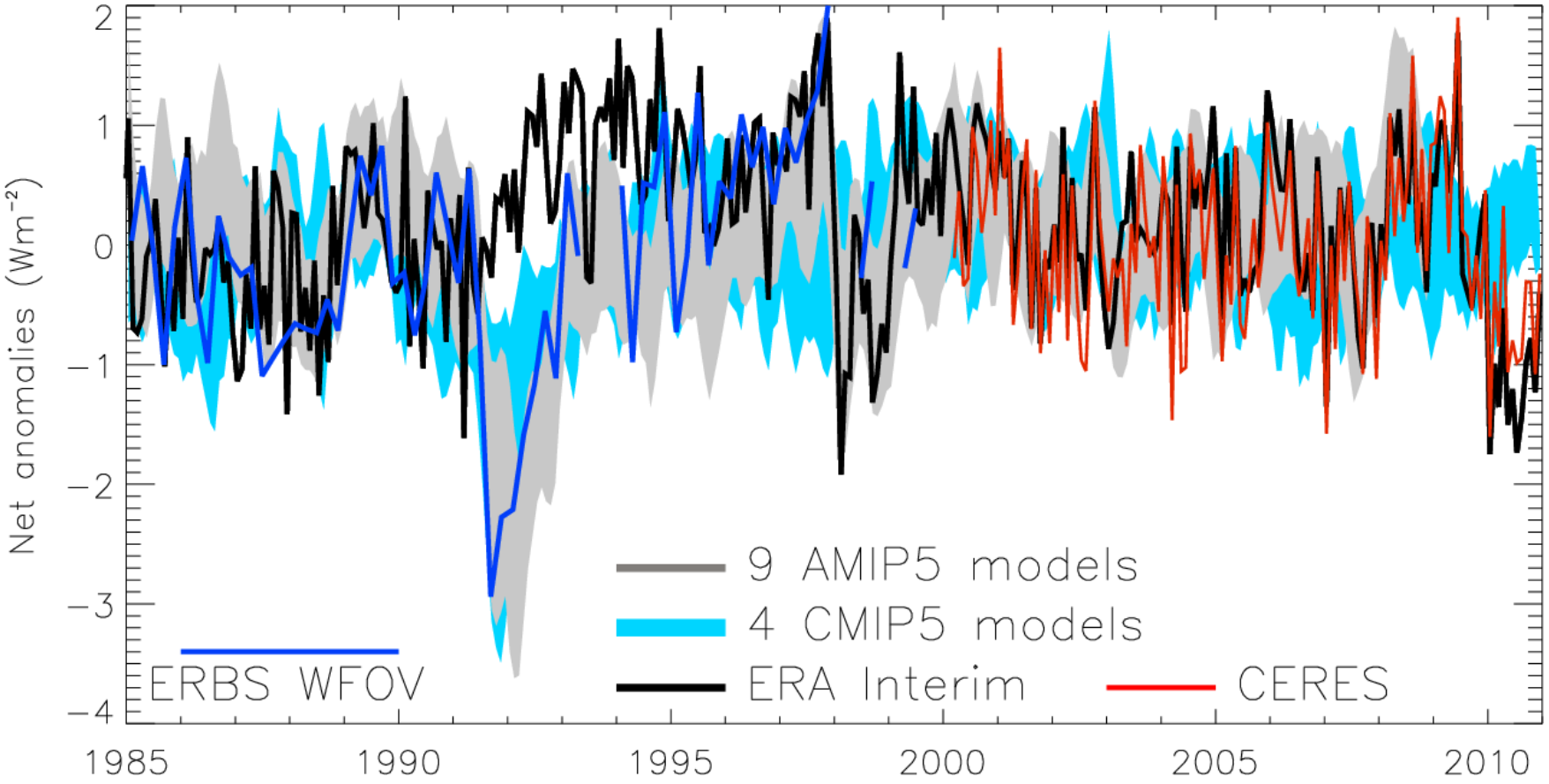


Figure 3 – Changes in energy entering top of Earth's atmosphere observed by CERES (black) and simulated by ERA-Interim (green) and observed heating of the upper ocean (blue, red). CERES and ERA-Interim estimates are "anchored" to the 2006-2010 mean ocean heating rate over this period but lagged by 6-months.

Variation in net radiation since 1985



60S-60N, after Allan (2011) Meteorol. Apps; see also Harries and Bettolli (2010) J. Clim

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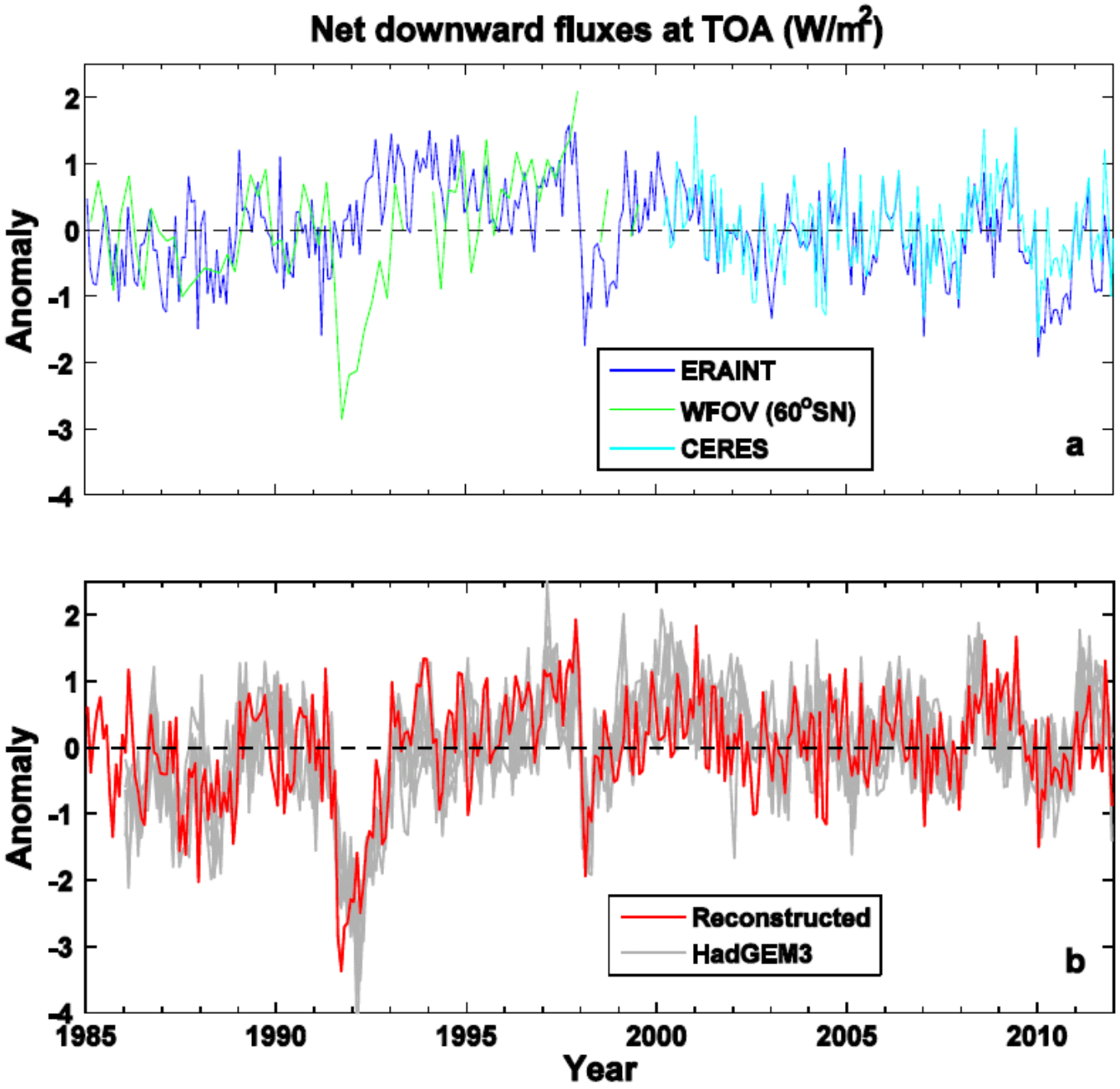

Reconstruction of global net radiation:

- ERA Interim
- CERES
- ERBS-WFOV

Compared with UK Met Office **HadGEM3** simulations with observed sea surface temperature

See talk by Chunlei Liu

Minor energy flux terms

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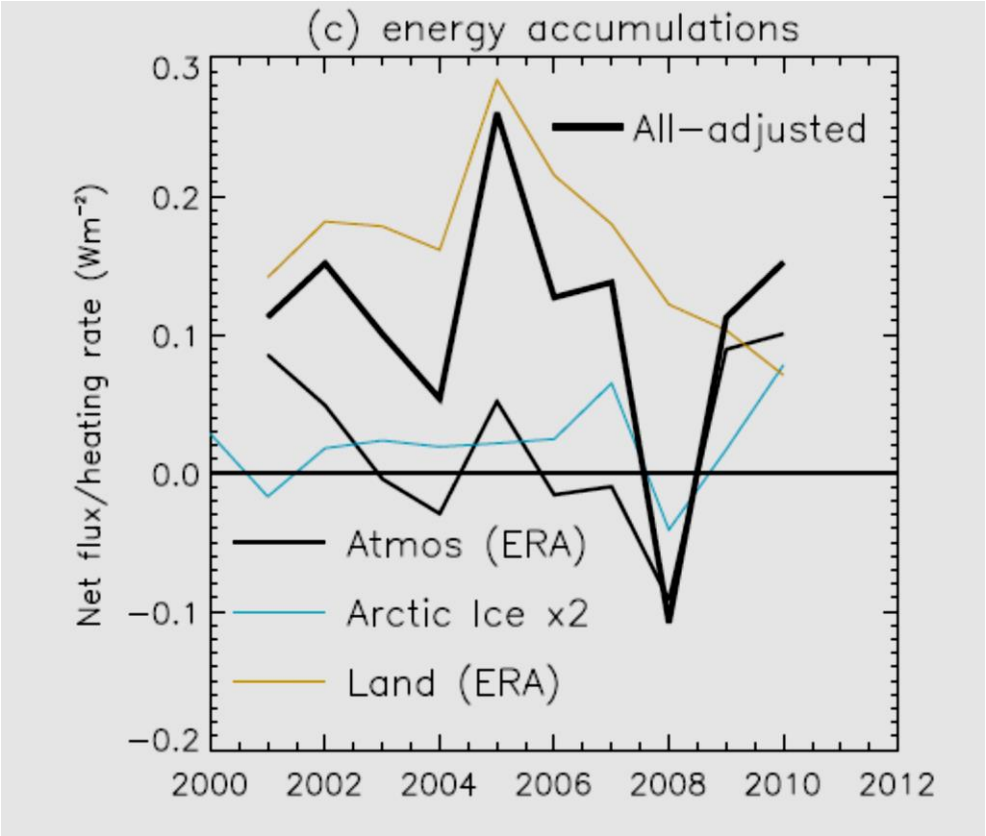
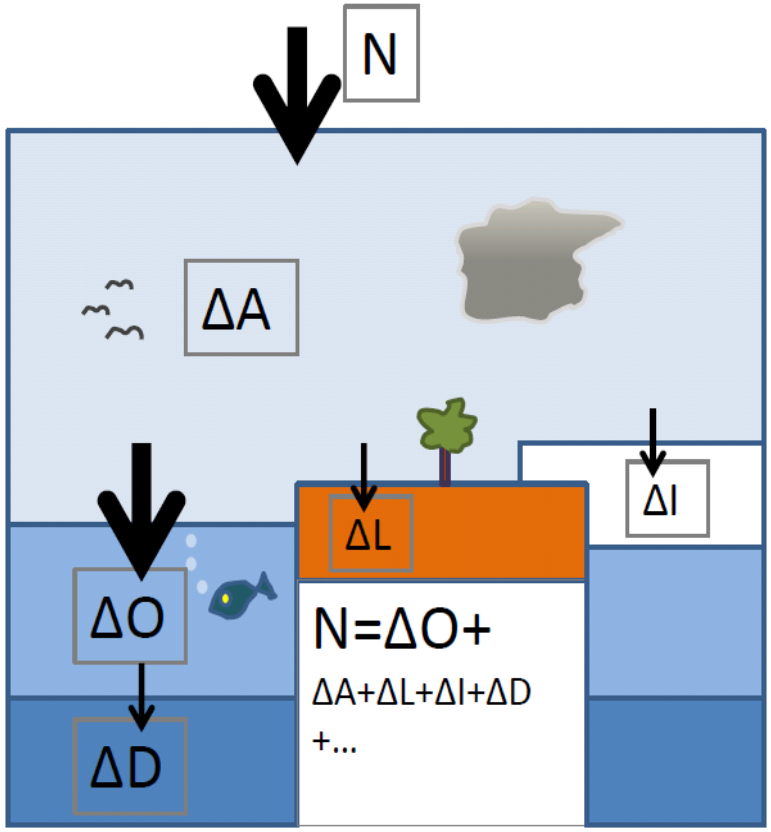
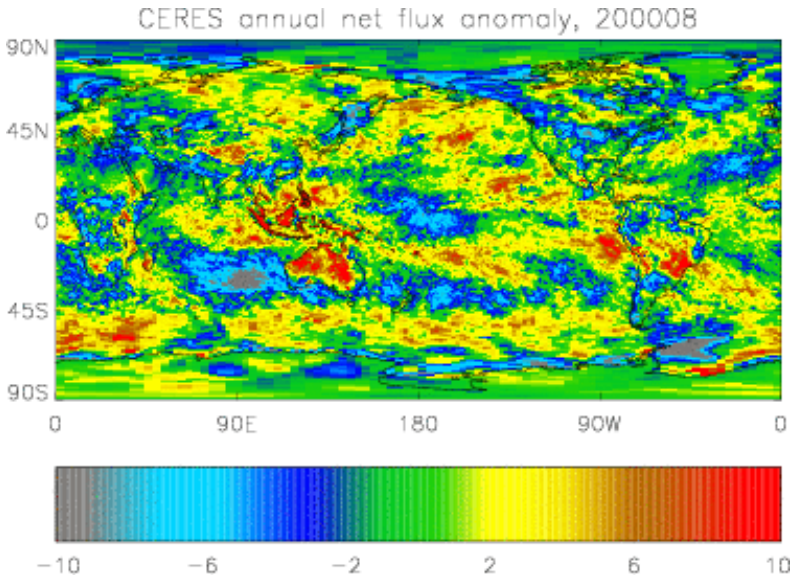




1) Changes in atmospheric energy (ΔA) from ERA Interim (thin black)
2) Changes in energy required to melt Arctic ice (ΔI). I assumed that additional land ice melt and heating increased these changes by factor of 2.
3) Heating of the land surface (ΔL) from ERA Interim (brown)
4) I adjusted the sum so that the average equalled the 0.07+0.04 Wm^{-2} minor heating terms assumed in Loeb et al. (thick black line) which included the deep ocean (ΔD) term.

New estimates of surface fluxes

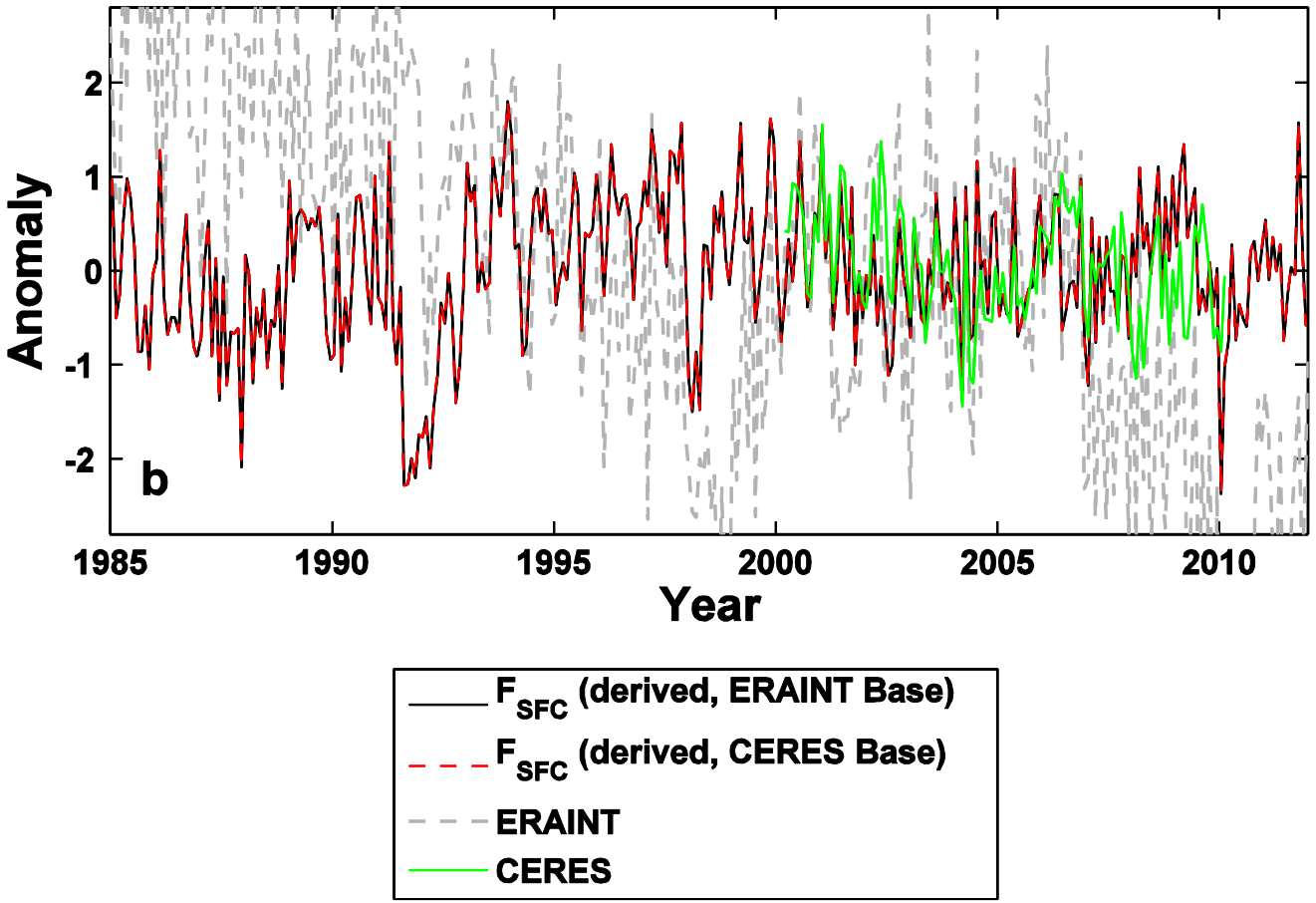
- WP1 – improved 2D estimate of surface fluxes combining ERA Interim transports and CERES TOA radiation budget



$$\frac{\partial E_{ATM}}{\partial t} = -\underline{\nabla}\bullet(1/g)\int_0^{p_s} \underline{v}(Lq + C_pT + \phi_S + k)dp + R_T - F_S,$$

e.g. Berrisford et al. (2011) QJRMS

Preliminary work on surface fluxes



Preliminary findings

- Previously highlighted "missing energy" explained by ocean heat content uncertainty combined with inappropriate net radiation satellite products
- Heating of Earth continues at rate of ~0.5 Wm^{-2}
  - Radiative forcing alone can't explain surface warming slowdown
  - Energy continues to accumulate below the ocean surface
  - Role of the Pacific Kosaka & Xie (2013) Nature;
  - Strengthening of Walker circulation, e.g. Merrifield (2011) J Clim; implications for hydrological cycle, e.g. Simmons et al. (2010) JGR?
- Ongoing WP1 work
  - Understanding current variability in TOA radiation (1985-2013)
  - Provide new estimates of surface radiation (preliminary analysis)
  - Lag/lead in climate system (preliminary analysis)

  Plans: collaborative work with WP2 (surface fluxes) and WP3 (simulations)

Dissemination Activities

- April 2013 - Science Media Centre briefing on warming slowdown
- April 2013 - Meeting with DECC partners in London to discuss project
- July 2013: Article on DEEP-C and how scientists measure Earth's temperature **Carbon Brief**
- **Also:** twitter, Walker Institute, media interaction