Earth's Radiation Budget & Current Changes in the Global Water Cycle

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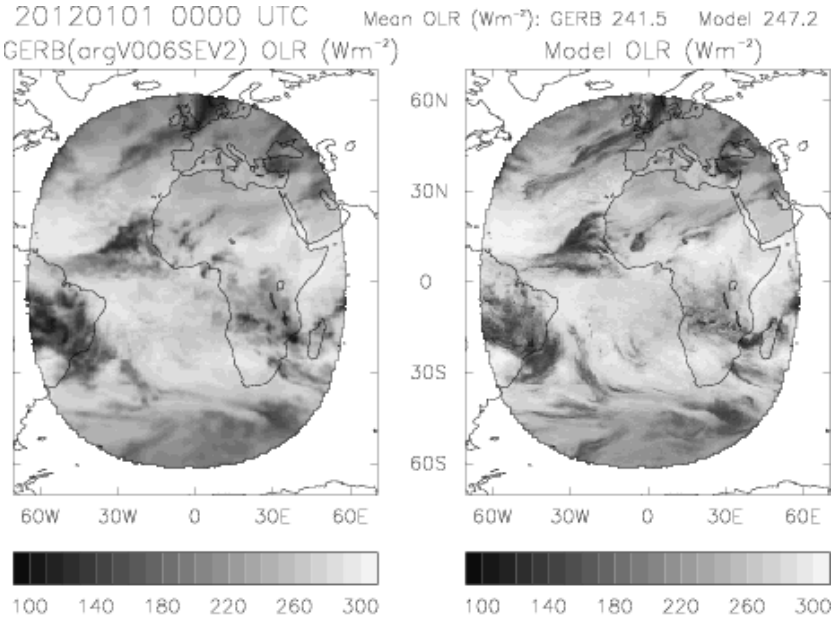
AMS 14th Conference on Atmospheric Radiation

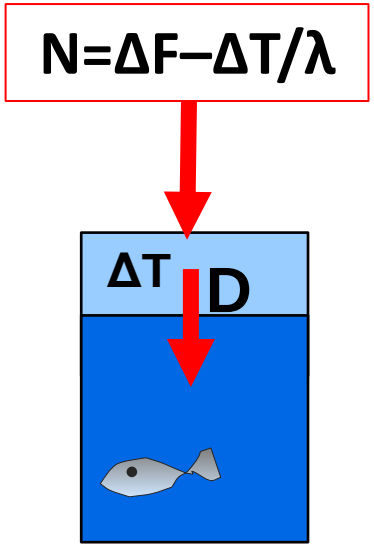
Tony Slingo Symposium 8th July 2014

Tony would have enjoyed & enriched the exciting, developing science linking Earth's radiative energy budget, the global water cycle and climate change

Earth's Energy budget: a key variable…

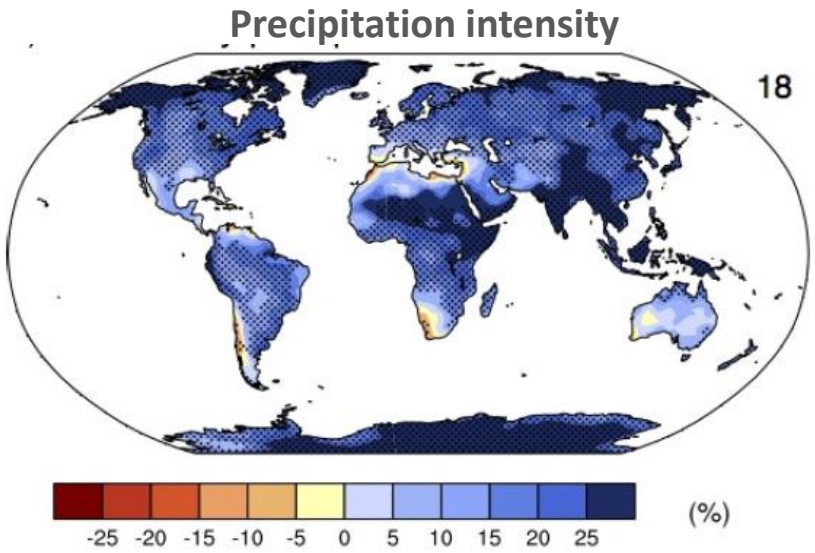
- Evaluation of weather and climate model processes
- Radiative forcing/feedbacks and ocean heat uptake
- Coupling of global energy and water cycle





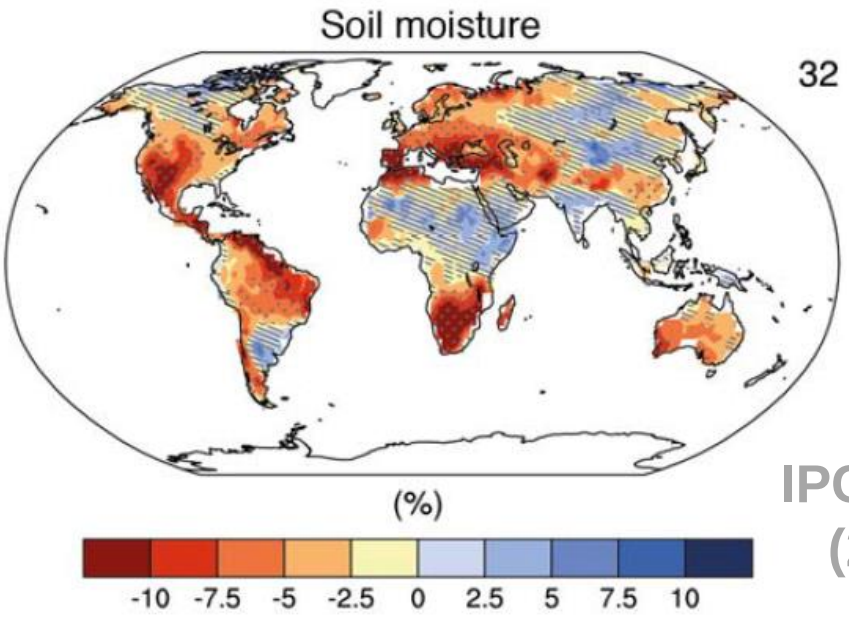
Allan et al. (2007) QJRMS

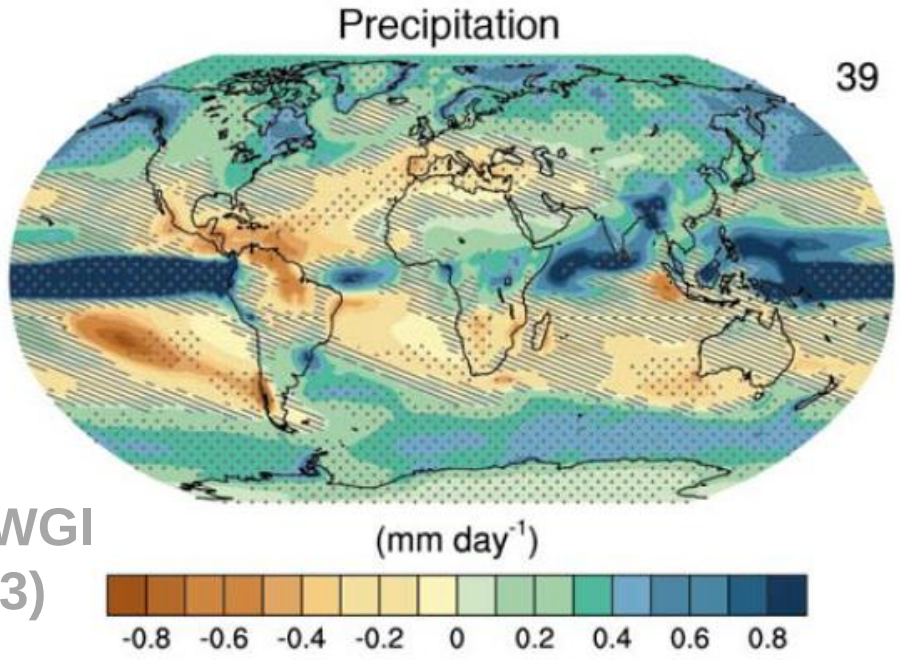
How will the water cycle change?



- Increased Precipitation
- More Intense Rainfall
- More droughts
- Wet regions get wetter, dry regions get drier?

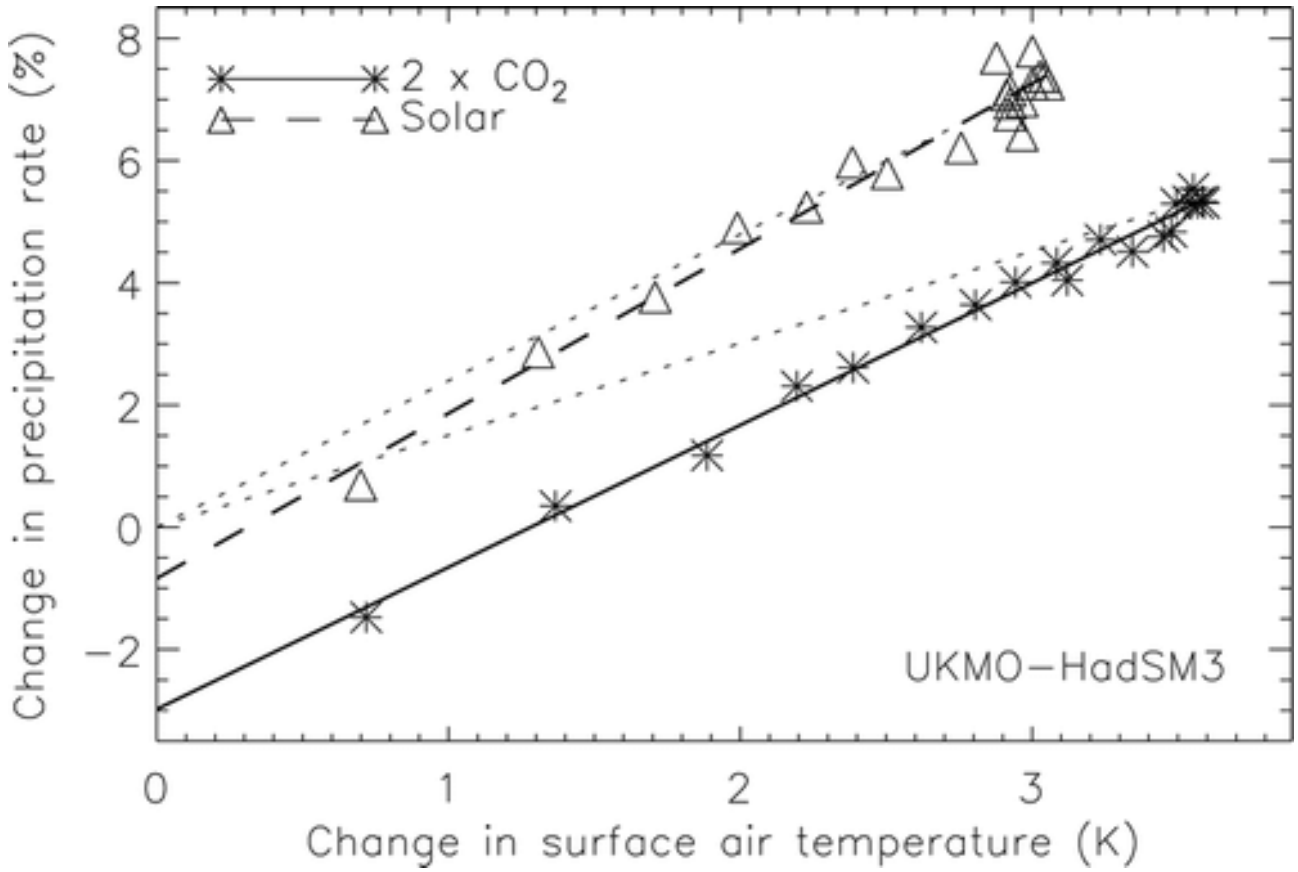
  e.g. Liu & Allan (2013) ERL

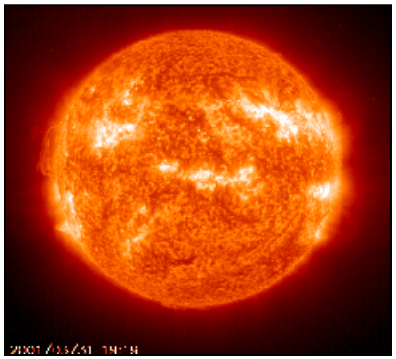




IPCC WGI (2013)

Improved understanding: radiative forcing & global precipitation response



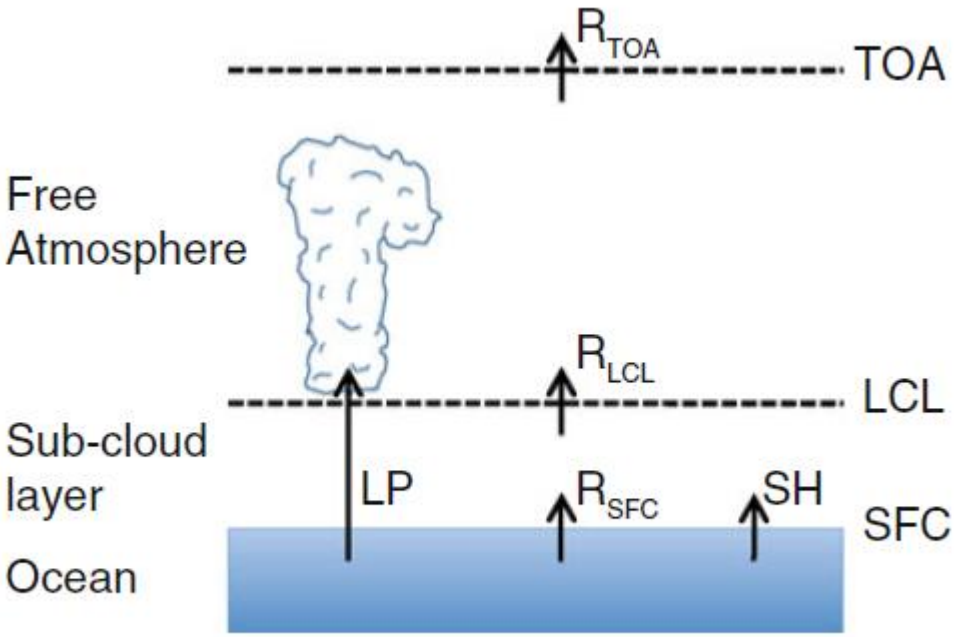


Andrews et al. (2009) J Climate

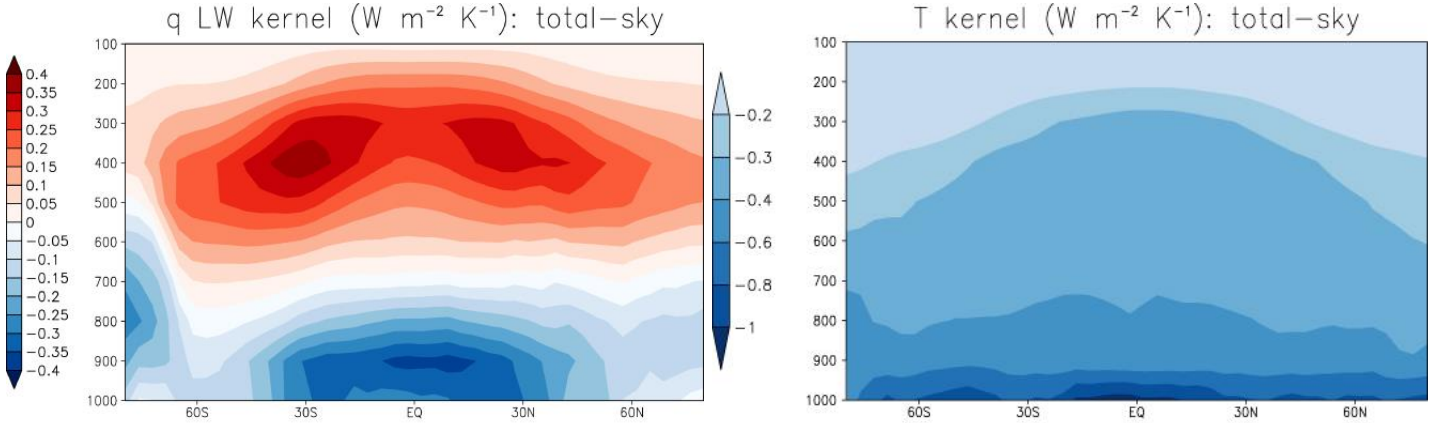
See also: Allen and Ingram (2002) *Nature* ; O'Gorman et al. (2012) Surv. Geophys ; Pendergrass & Hartmann (2012) GRL

Radiative energy budget of the atmosphere and hydrological response

- Adjustments in latent heating LP (precipitation) balance change in radiative energy budget ΔR above LCL (lifting condensation level)
- ΔR below LCL → adjustments in SH (sensible heat flux) important
  e.g. Ming et al. (2010) GRL

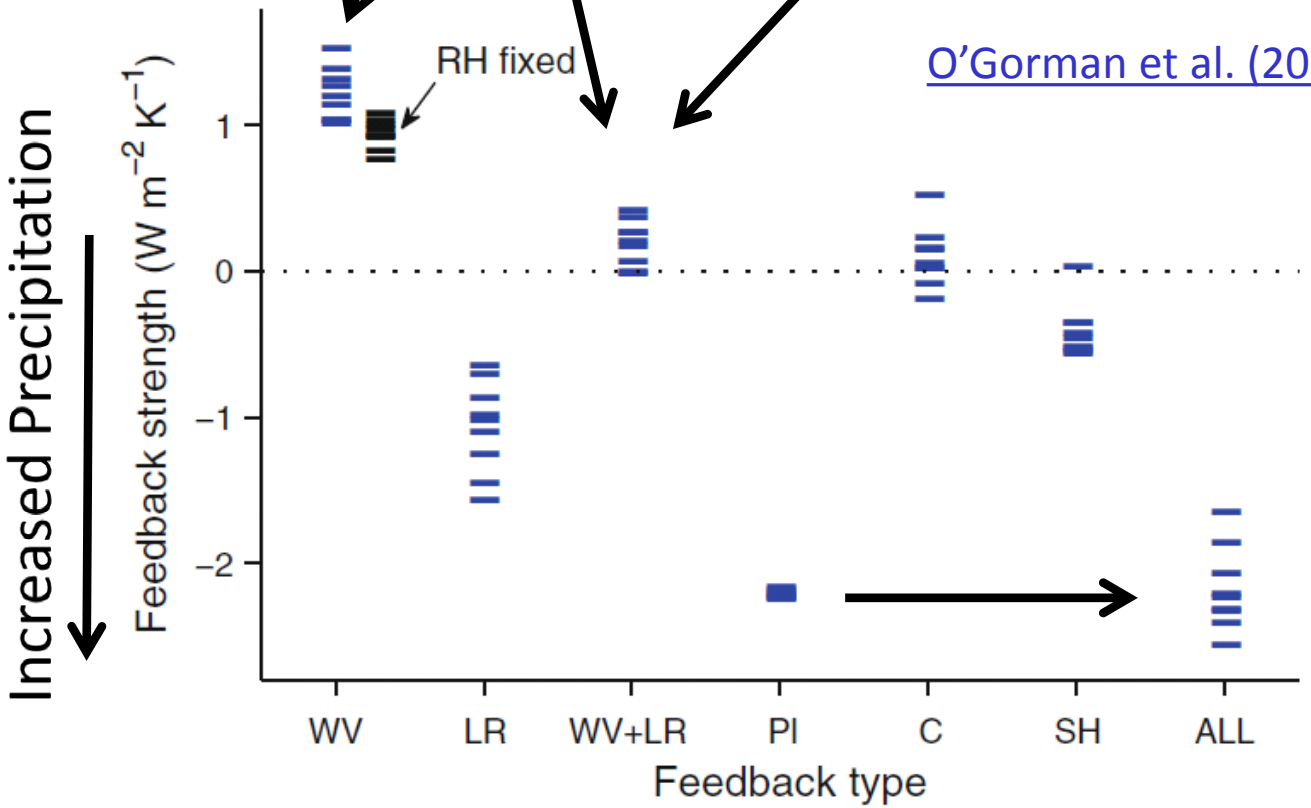


O'Gorman et al. (2012) Surv. Geophys
After Takahashi (2009) JAS.
See also Manabe & Wetherald (1975) JAS



Radiative kernals

Previdi (2010) ERL



O'Gorman et al. (2012) Surv. Geophys

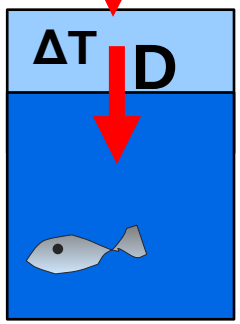
Radiative constraint on precipitation:

≈ 2 $Wm^{-2}K^{-1}$

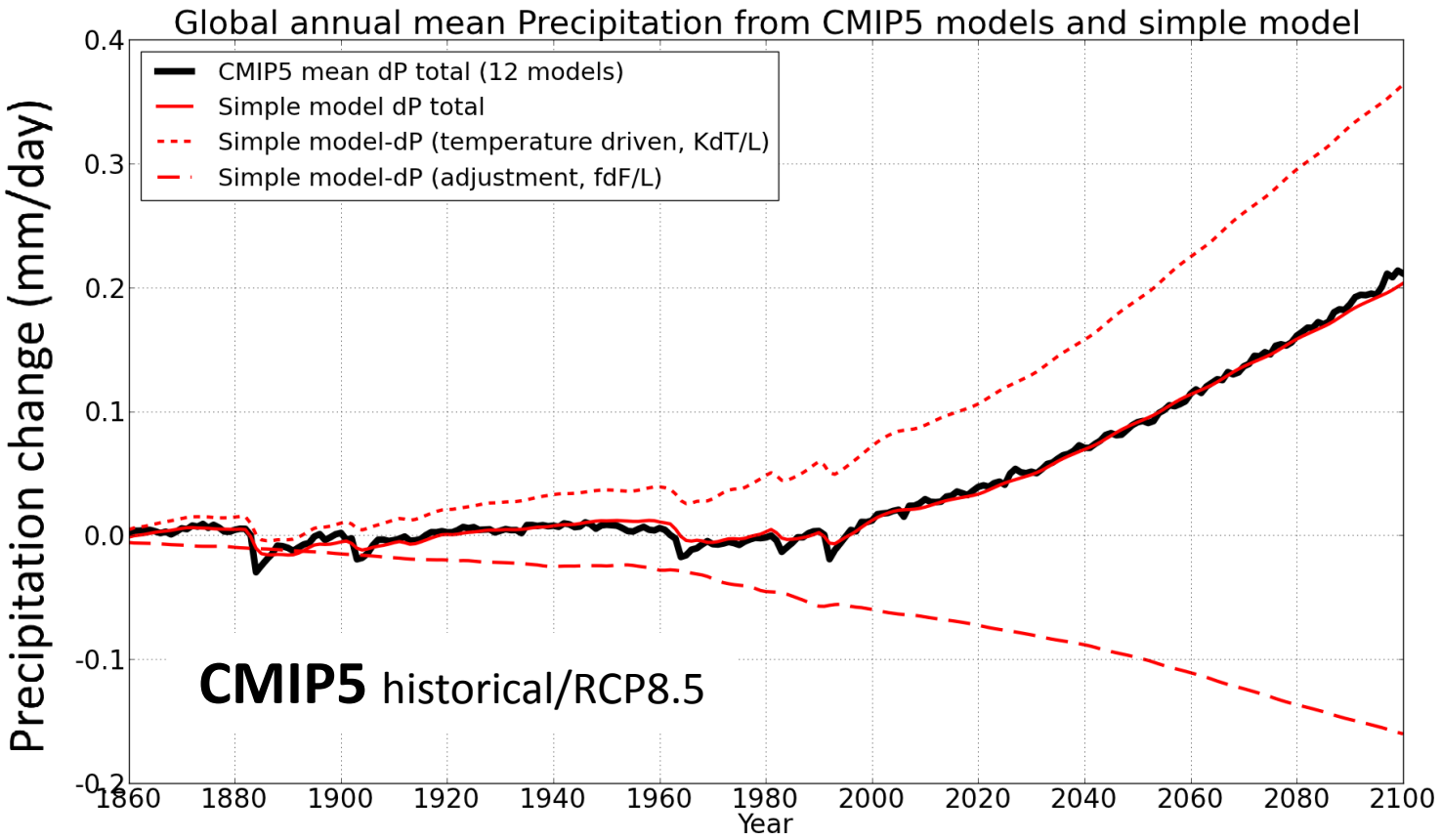
≈ 2-3%/K

Simple model for global precipitation

$N = \Delta F - \Delta T/\lambda$



Using simple model: $L\Delta P = k\Delta T - f_F \Delta F$



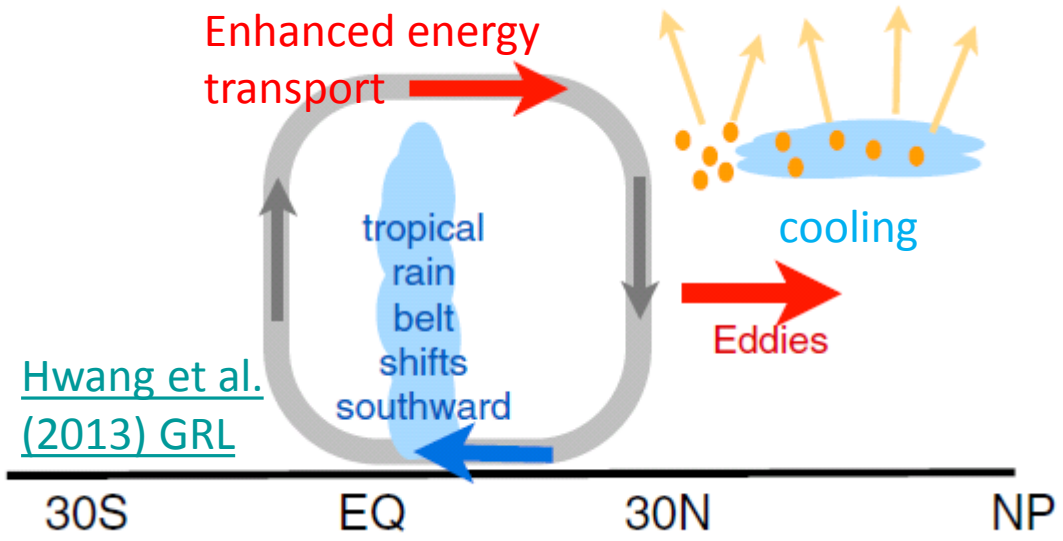
Zahra Mousavi
(PhD project)

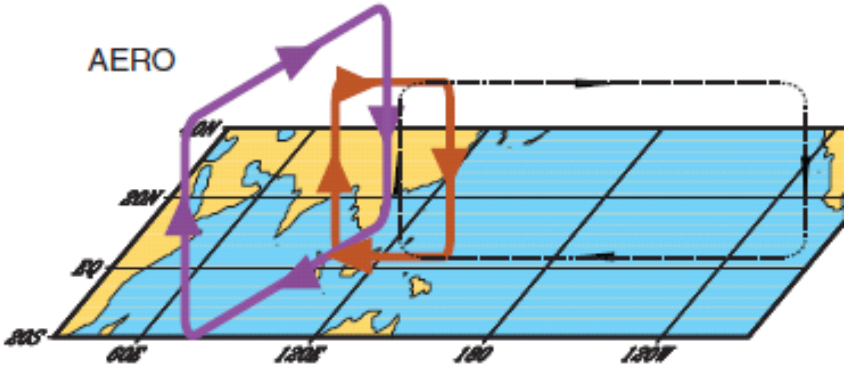
After Allan et al. (2013) Surv. Geophys and Thorpe and Andrews (2014) ERL

See also Andrews et al. (2010) ; Allen and Ingram (2002) ; Stephens and Ellis (2008)

Interhemispheric heating and the water cycle

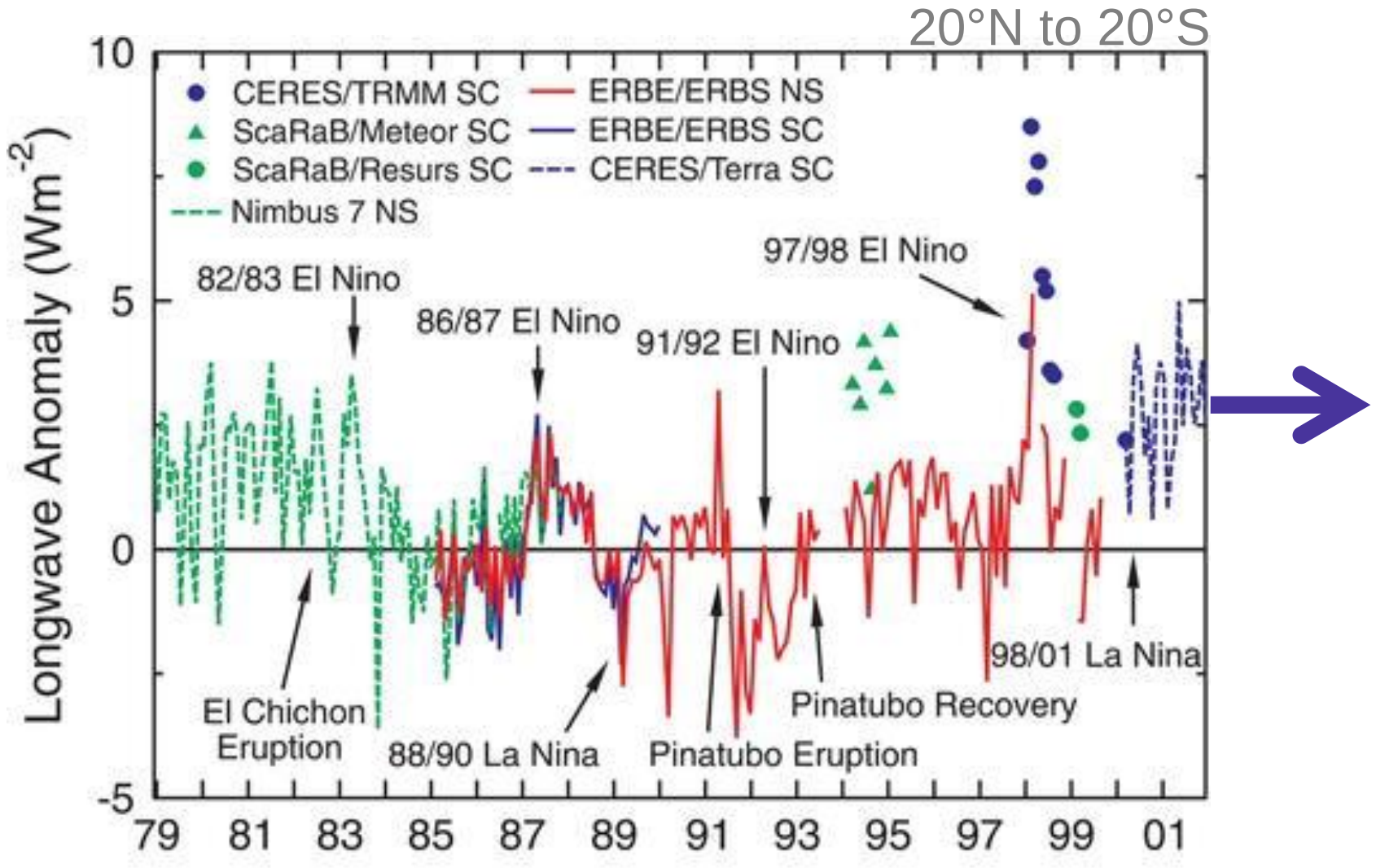
- N Hemisphere Aerosol cooling 1950-1980s
- Induces southward movement of ITCZ
- Reduced Sahel rainfall →
- Recovery after 1980s e.g. Wild 2012 BAMS
- +Asymmetric volcanic forcing e.g. Haywood et al. (2013) Nature Climate





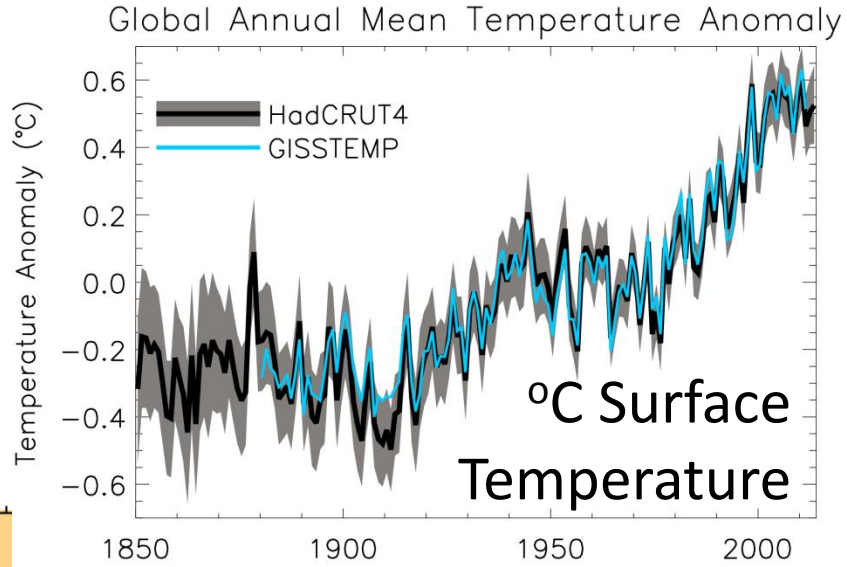
- Sulphate aerosol effects on Asian monsoon e.g. Bollasina et al. 2011 Science
- Links to drought in Horn of Africa? Park et al. (2011) Clim Dyn

Changes in Earth's radiative energy balance

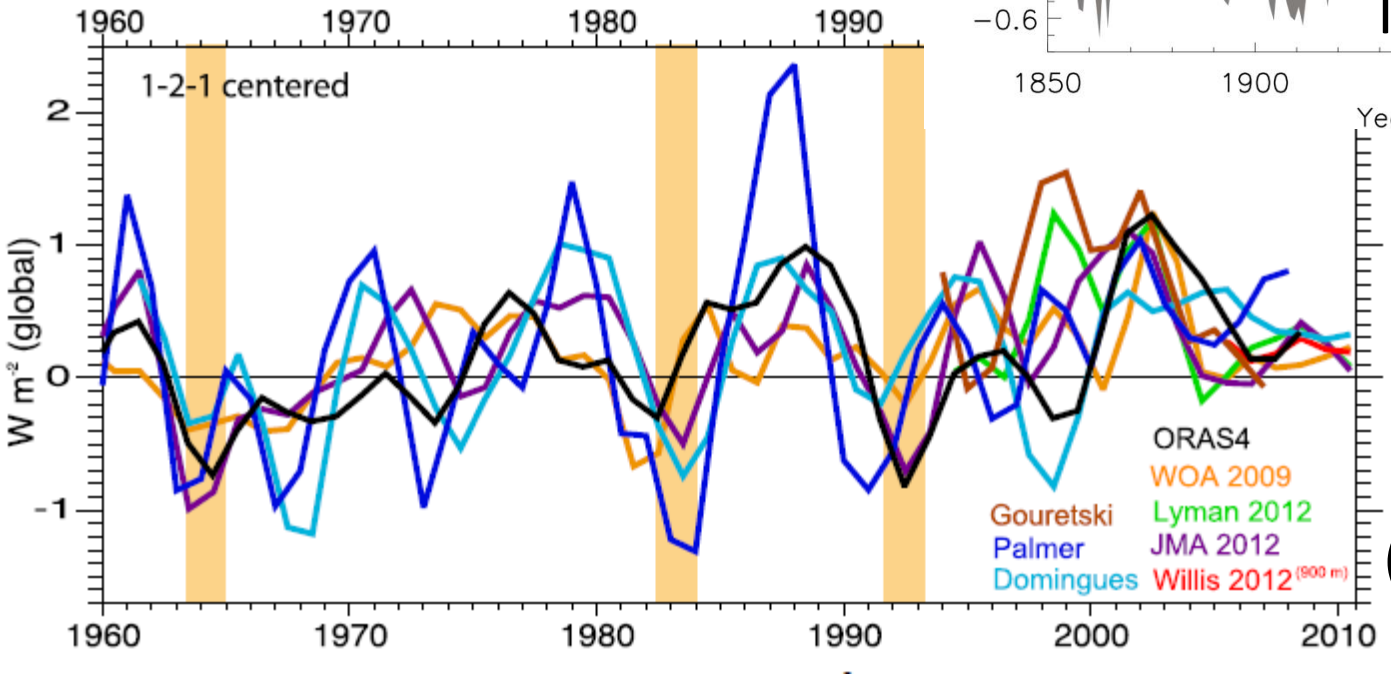


Wong et al. (2006) J Clim; Wielicki et al. (2002) Science

Estimating Earth's rate of heating



°C Surface Temperature



Upper ocean (Wm^{-2})

Trenberth et al. (2014) J Clim

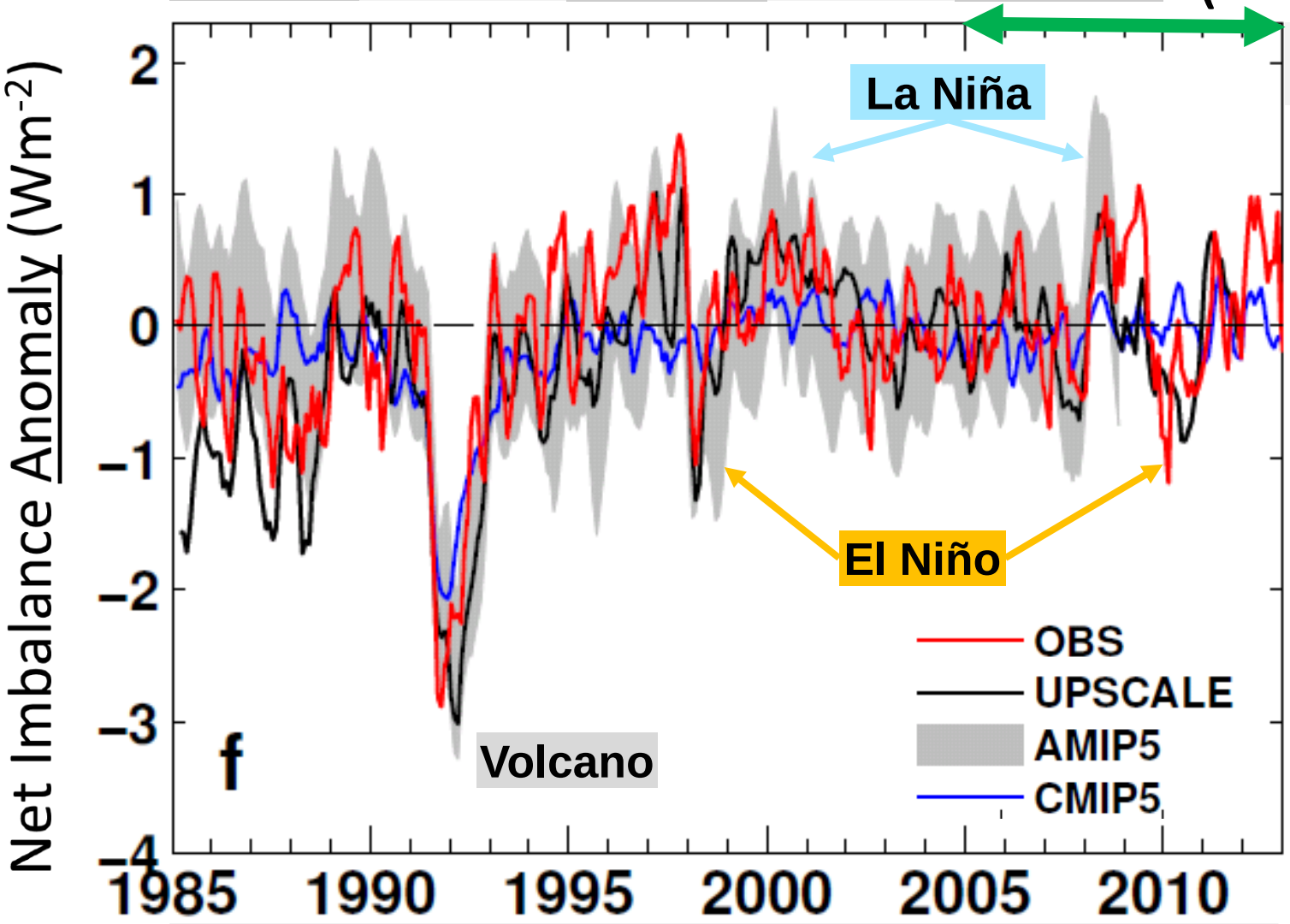
Combining Earth Radiation Budget data and Ocean Heat Content measurements

- Tie 14-year CERES record with SORCE TSI and Argo-estimated heating rate 2005-10 & minor additional storage terms
- Variability relating to ENSO reproduced by CERES and ERA Interim
- What about before 2000?

Loeb et al. (2012) Nat. Geosci. See also Hansen et al. (2011) ACP; Stephens et al. (2012) Nat Geosci.; Wild et al. (2013) Clim. Dyn.

Changes in imbalance in models & observations

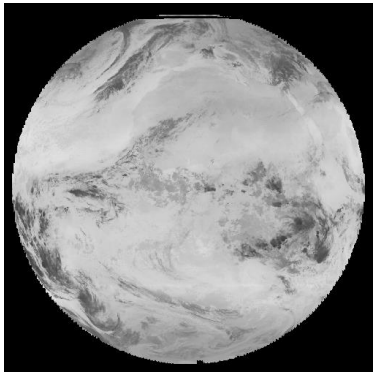
Imbalance: 0.23 0.00 0.78 0.63 0.63 (Wm^{-2})



Allan et al. (2014) in prep

Conclusions

- Heating of Earth continues at rate of ~0.6 Wm^{-2}
  - Variability from radiative forcings & ocean changes
- Radiative transfer & Thermodynamics explain increased global precipitation with warming ≈ 2%/K
  - Radiative forcings also affect water cycle responses
  - Greenhouse gas & absorbing aerosol forcing supress global precipitation response to warming
- Inter-hemispheric heating, moisture budget & unforced variability dictate regional responses
- How has the “hiatus” affected water cycle?
- How do changes in cloud/circulation fit in?
- Where is energy going? NERC DEEP-C project…

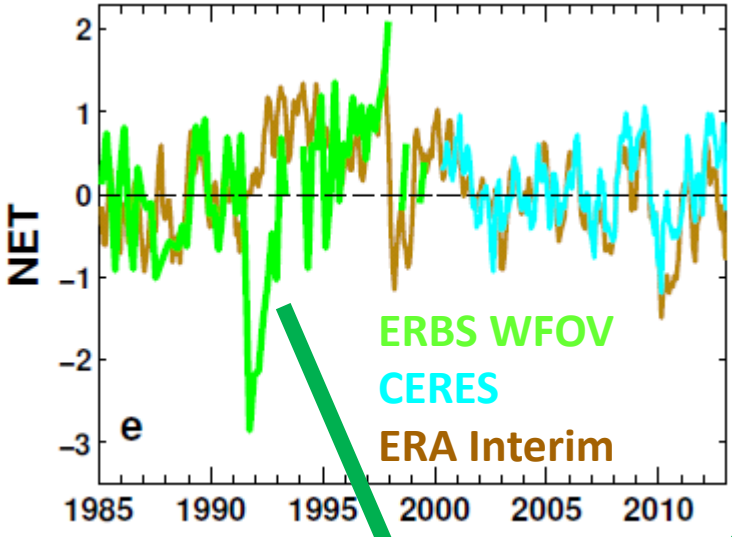


Combined CERES/Argo data

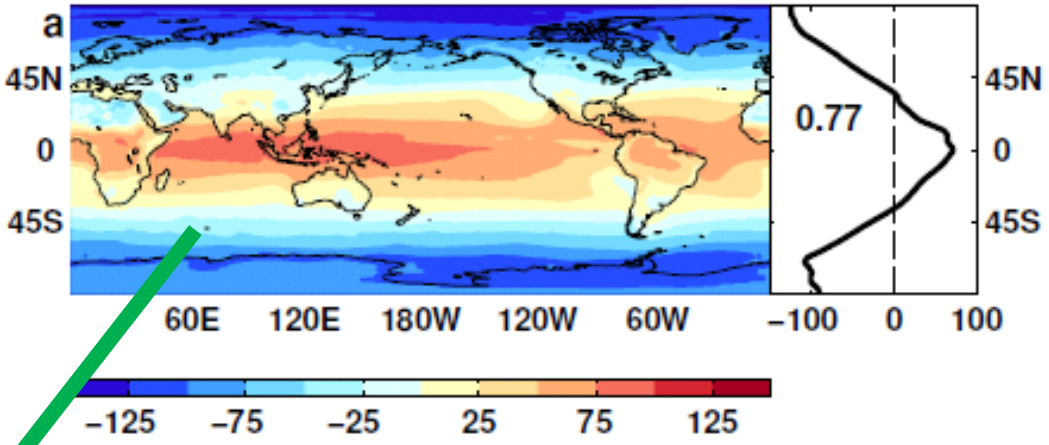
- Incoming Solar: SORCE Level 3 V10
- Reflected Shortwave/Outgoing Longwave from EBAF
  - (v2.6r → v2.8 → V3…)
- Added errors in quadrature to give ± 0.43 Wm^{-2}
  - Argo 0-2000m dOHCA/dt = 0.47 ± 0.38 Wm^{-2} (2005-2010)
  - >2000m ~ 0.07 ± 0.05 Wm^{-2}
  - Heating/melting ice, heating land/atmos ~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

Reconstructing global radiative fluxes prior to 2000

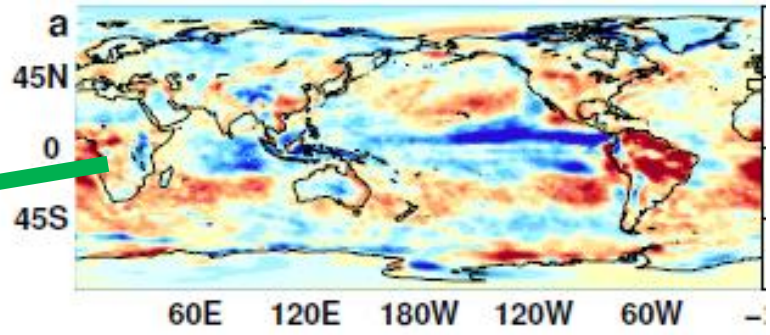
ERBS/CERES variability



CERES monthly climatology



ERA Interim spatial anomalies

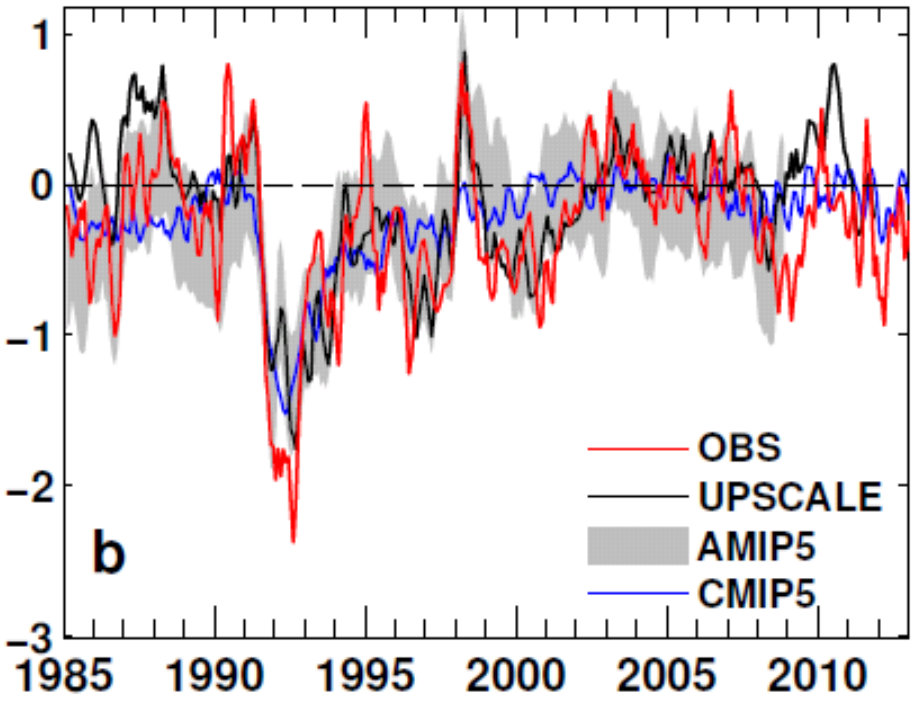


Combine CERES/ARGO accuracy, ERBS WFOV stability and reanalysis circulation patterns to reconstruct radiative fluxes

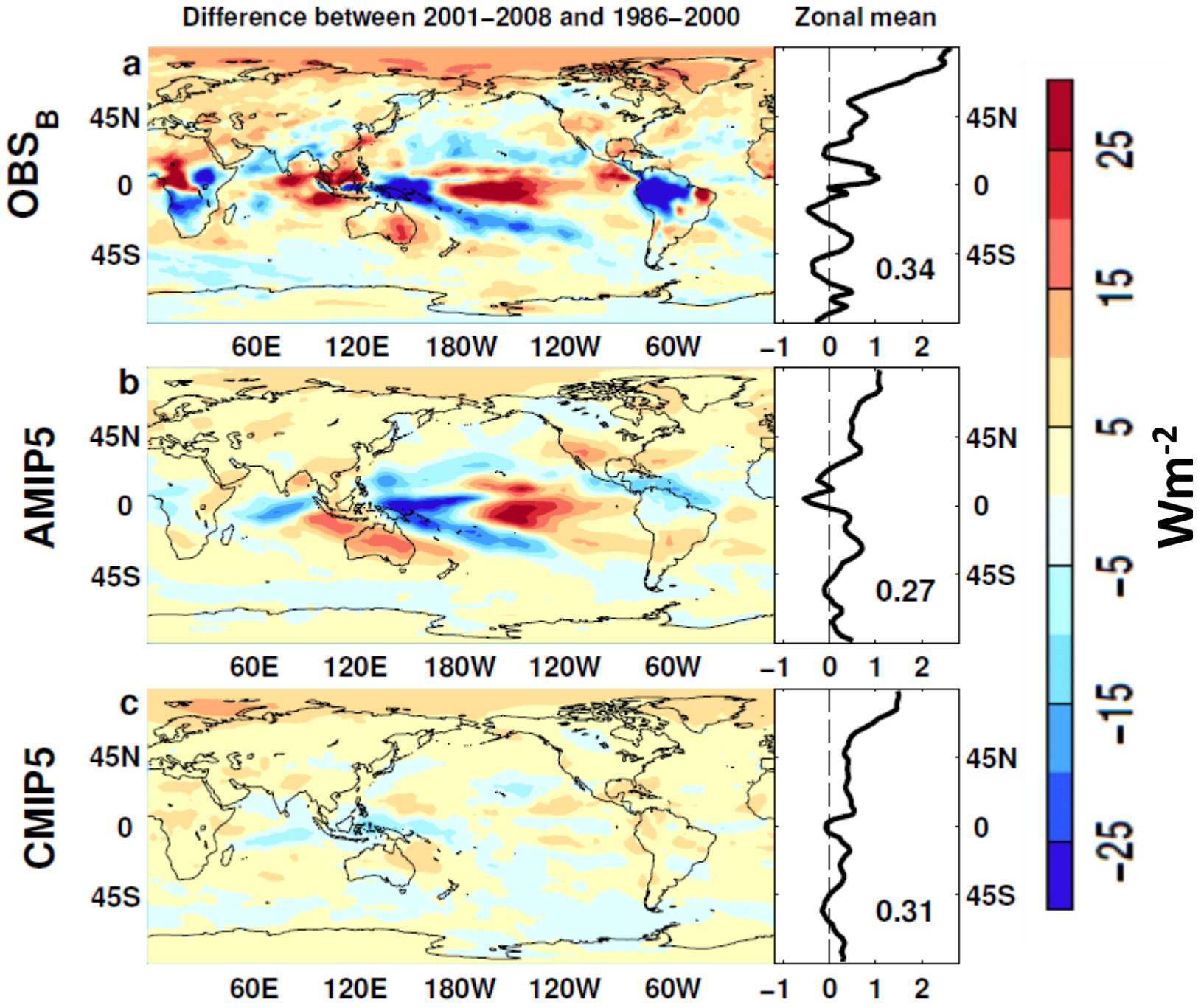
Use reanalyses or models to bridge gaps in record (1993 and 1999/2000)

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

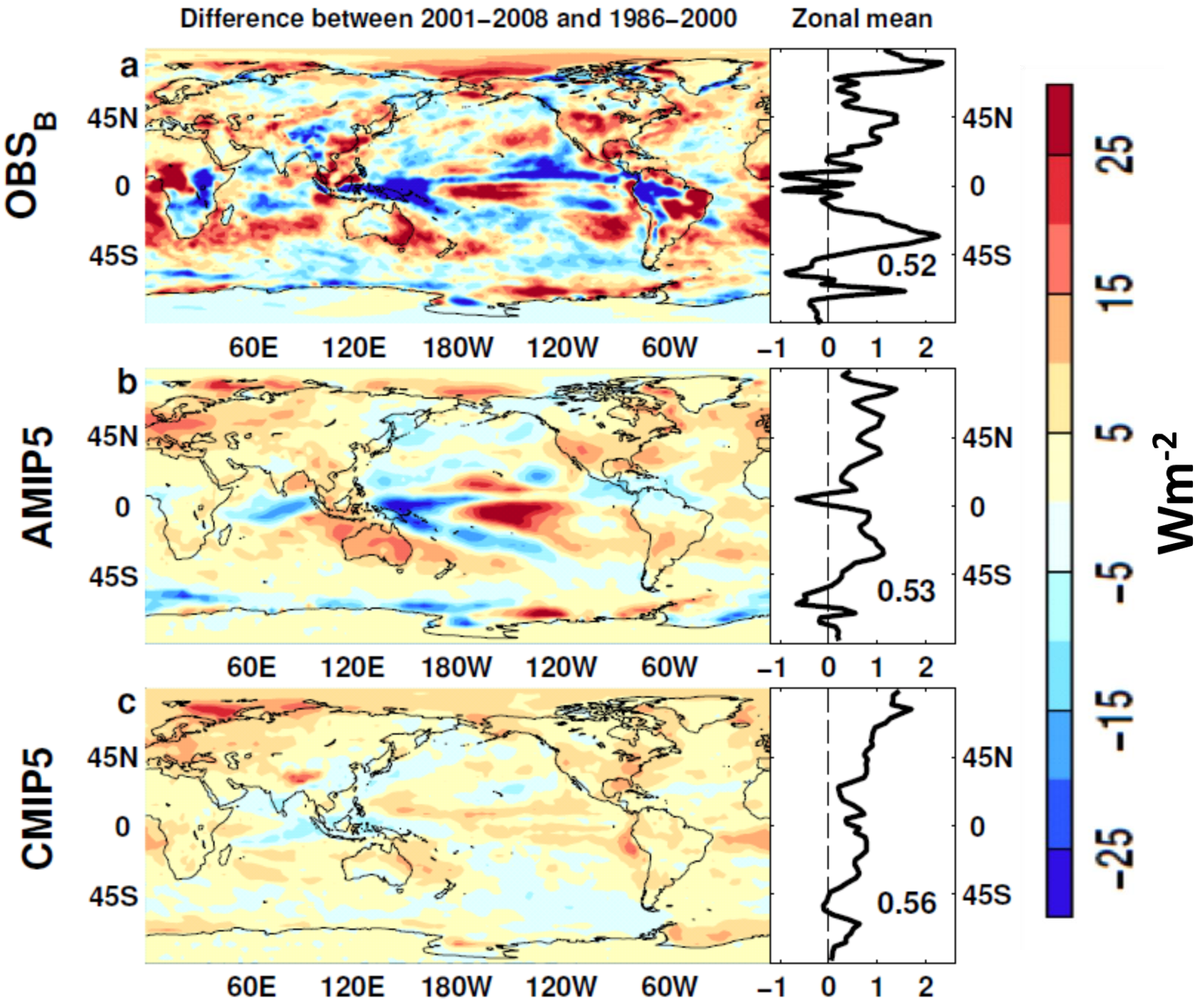
Outgoing Longwave Radiation Anomalies (Wm^{-2})



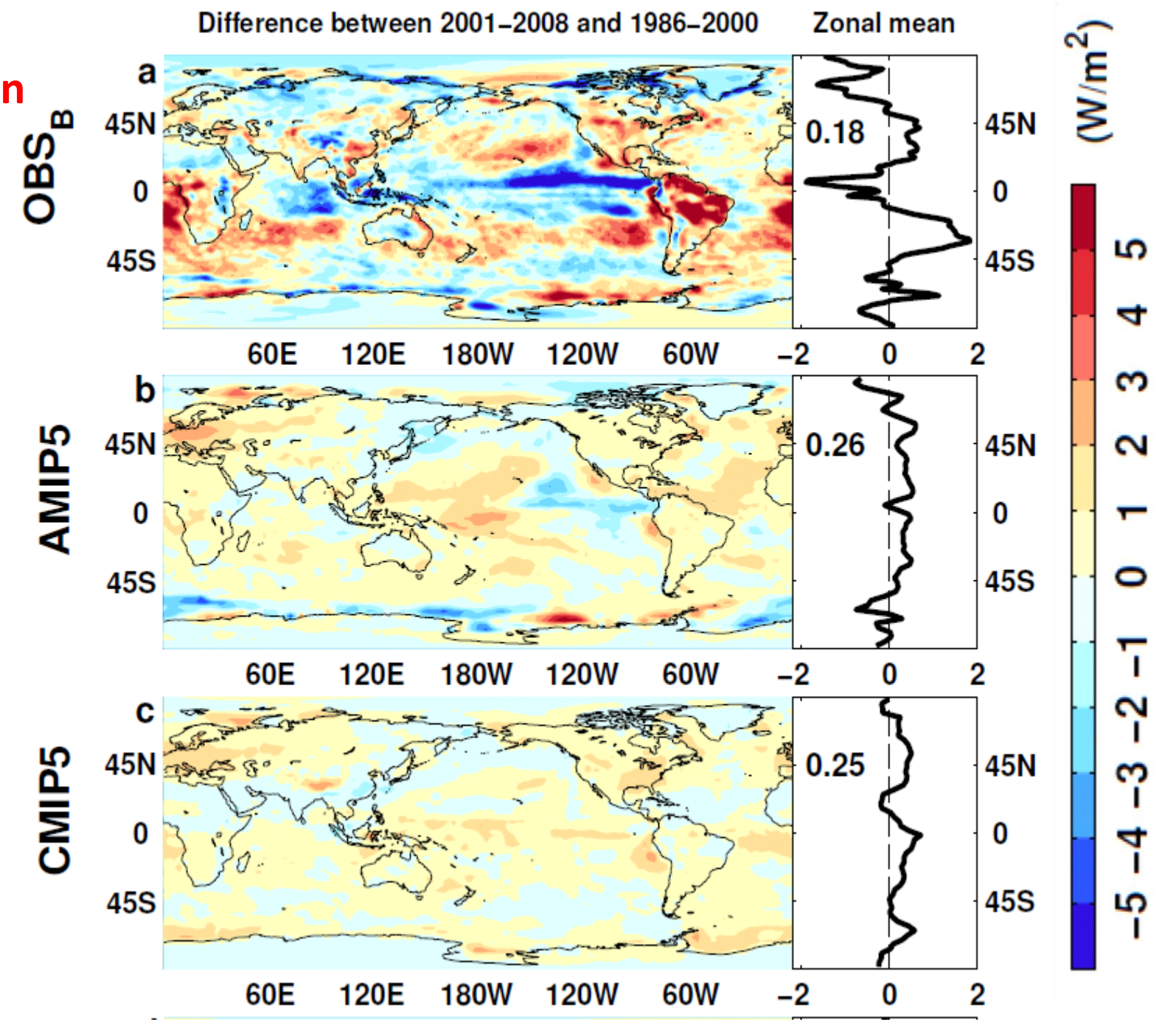
Outgoing Longwave Radiation



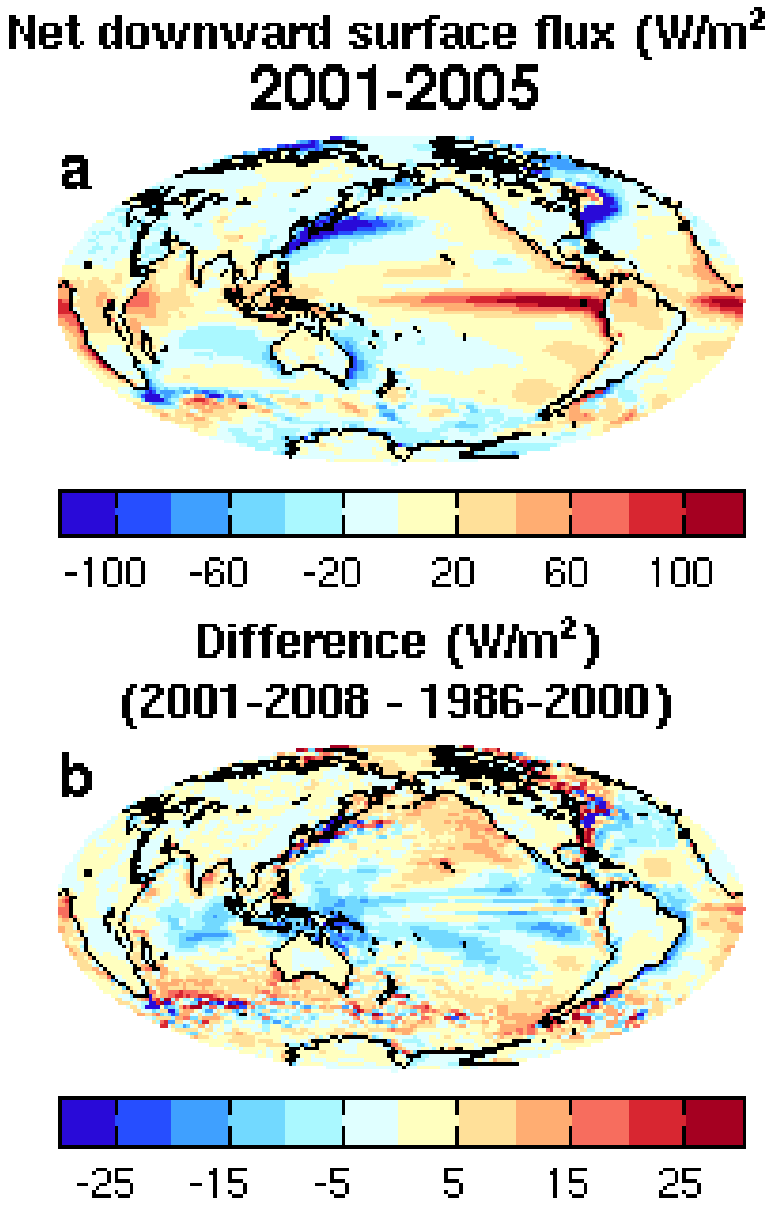
Absorbed Shortwave Radiation

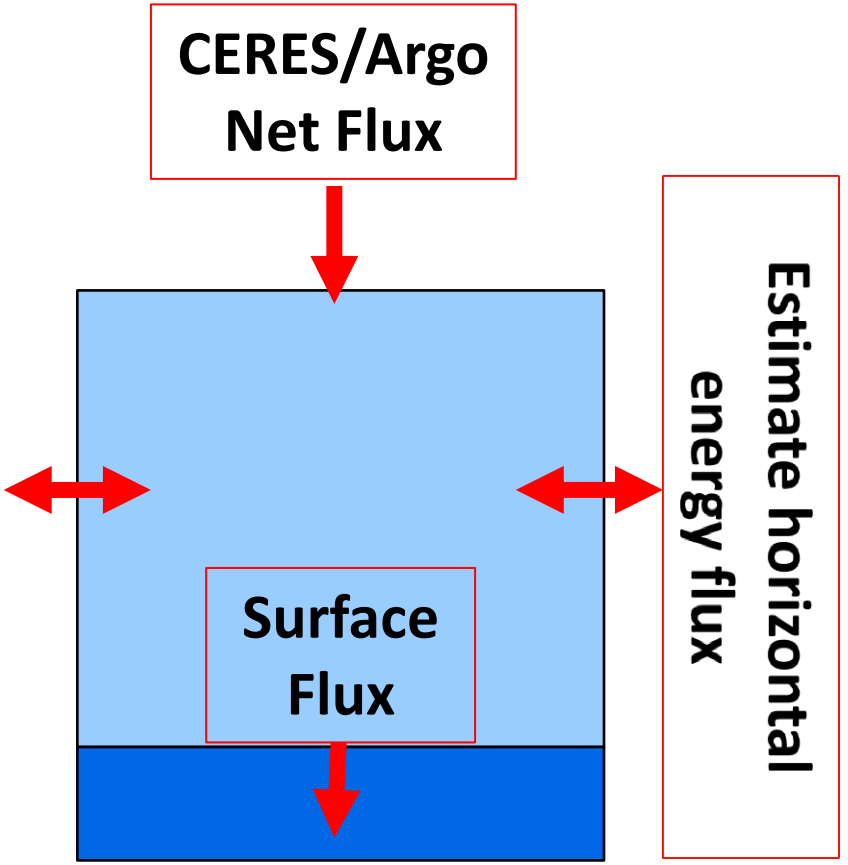


NET Radiation



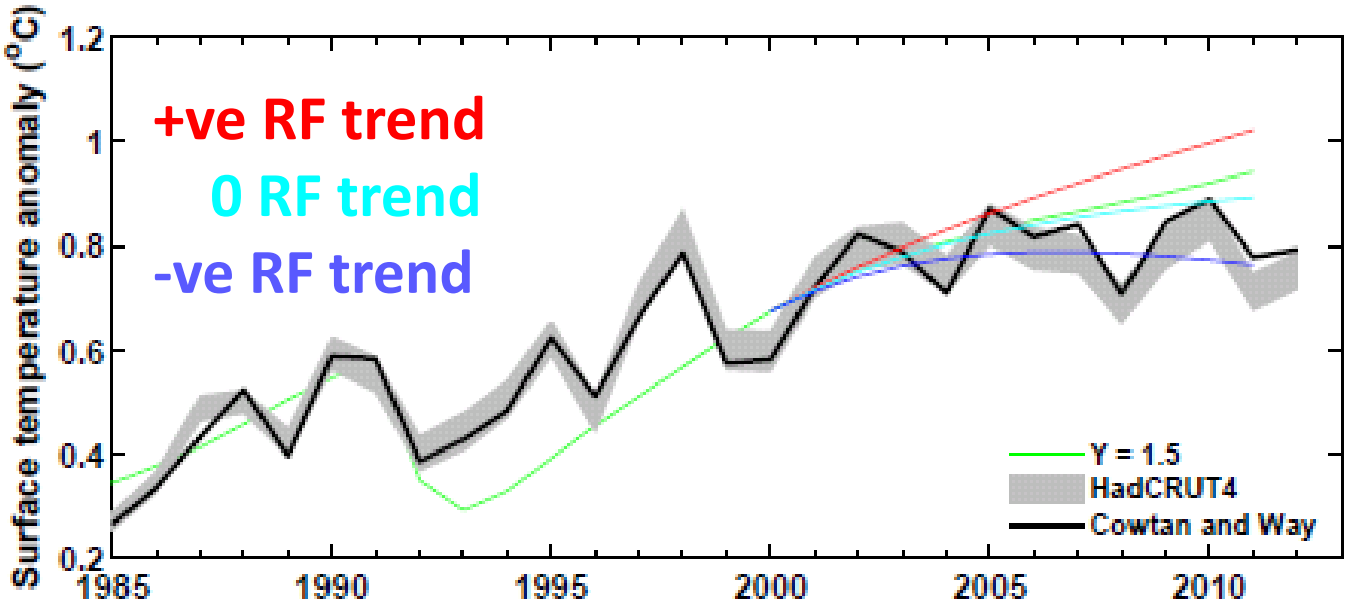
Estimates of Surface Flux



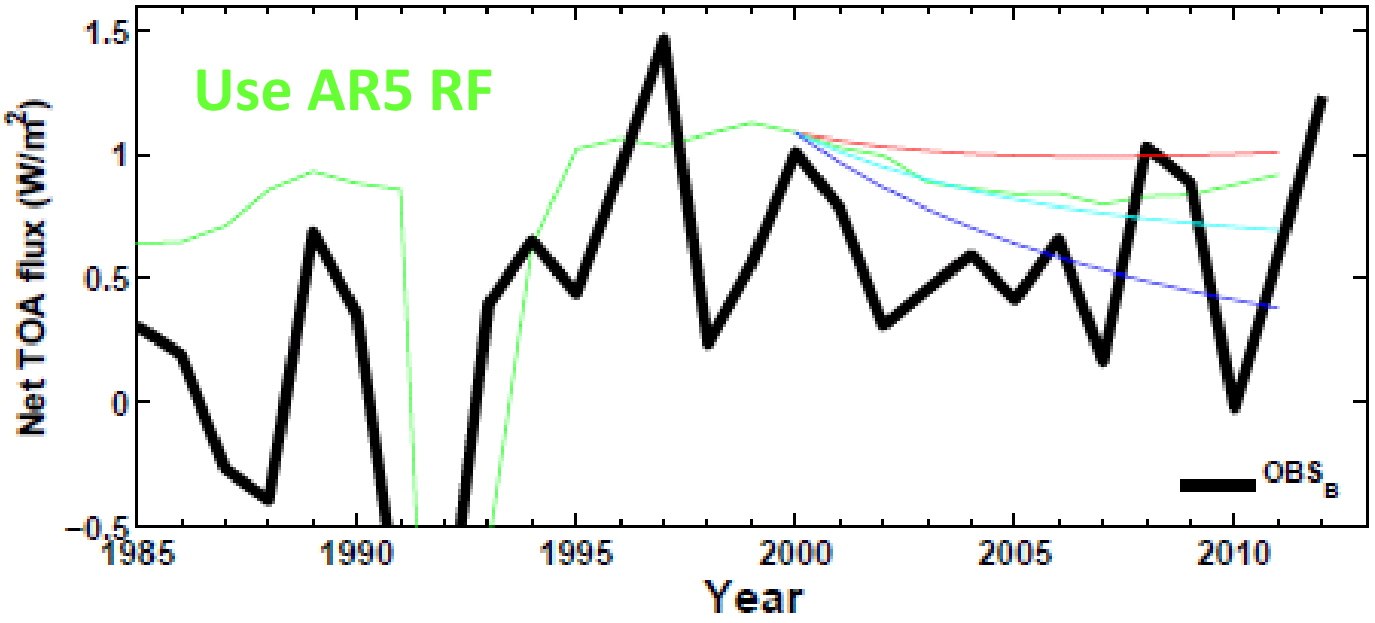


$$F_{SFC} = F_{TOA} - \frac{\partial TE}{\partial t} - \nabla \cdot \frac{1}{g} \int_0^1 V(Lq + C_p T + \varphi_s + k) \frac{\partial p}{\partial \eta} d\eta$$

ΔT

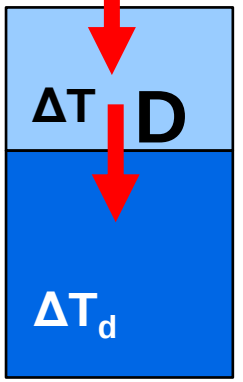


N



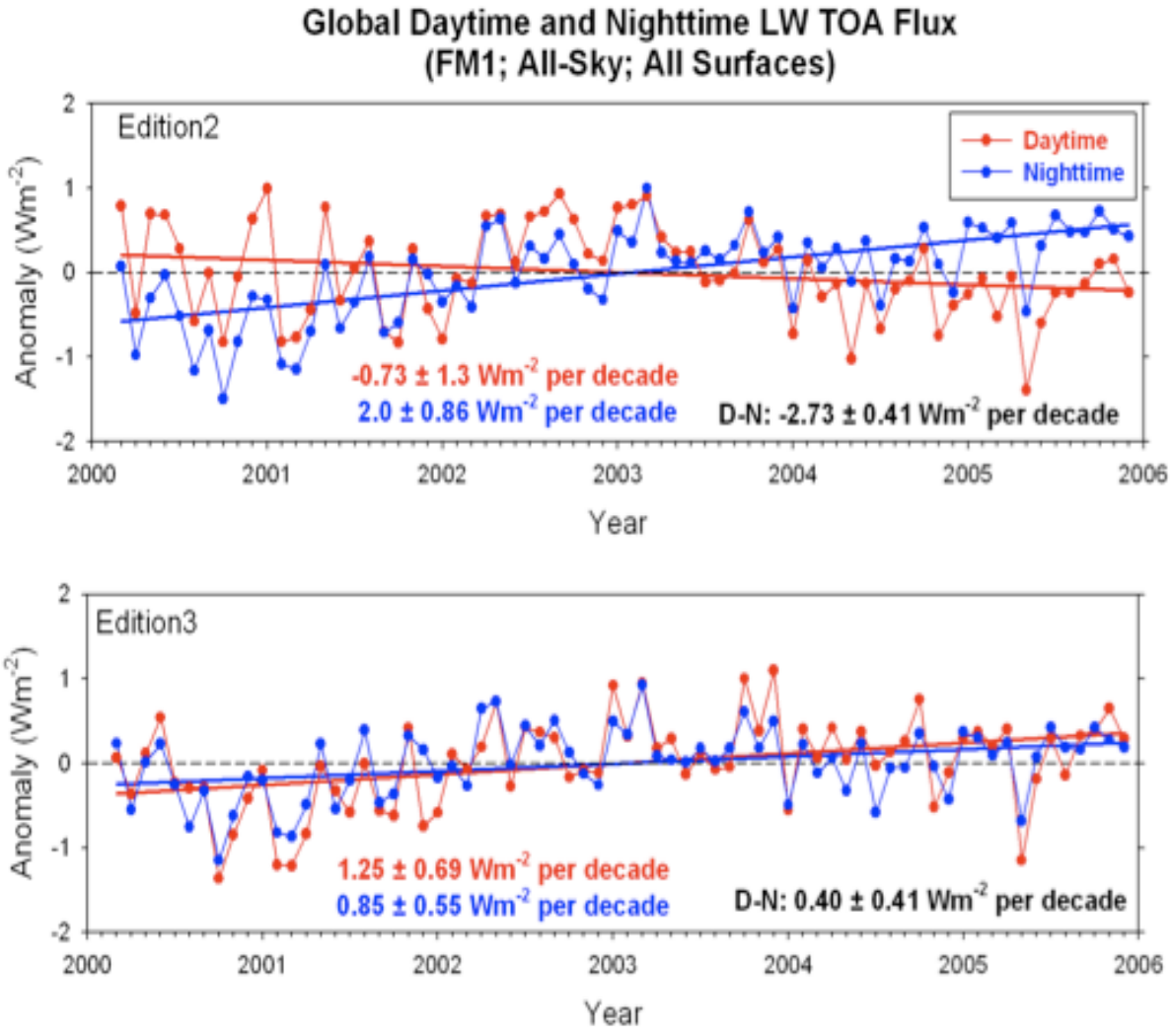
Analysis using simple energy balance model

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



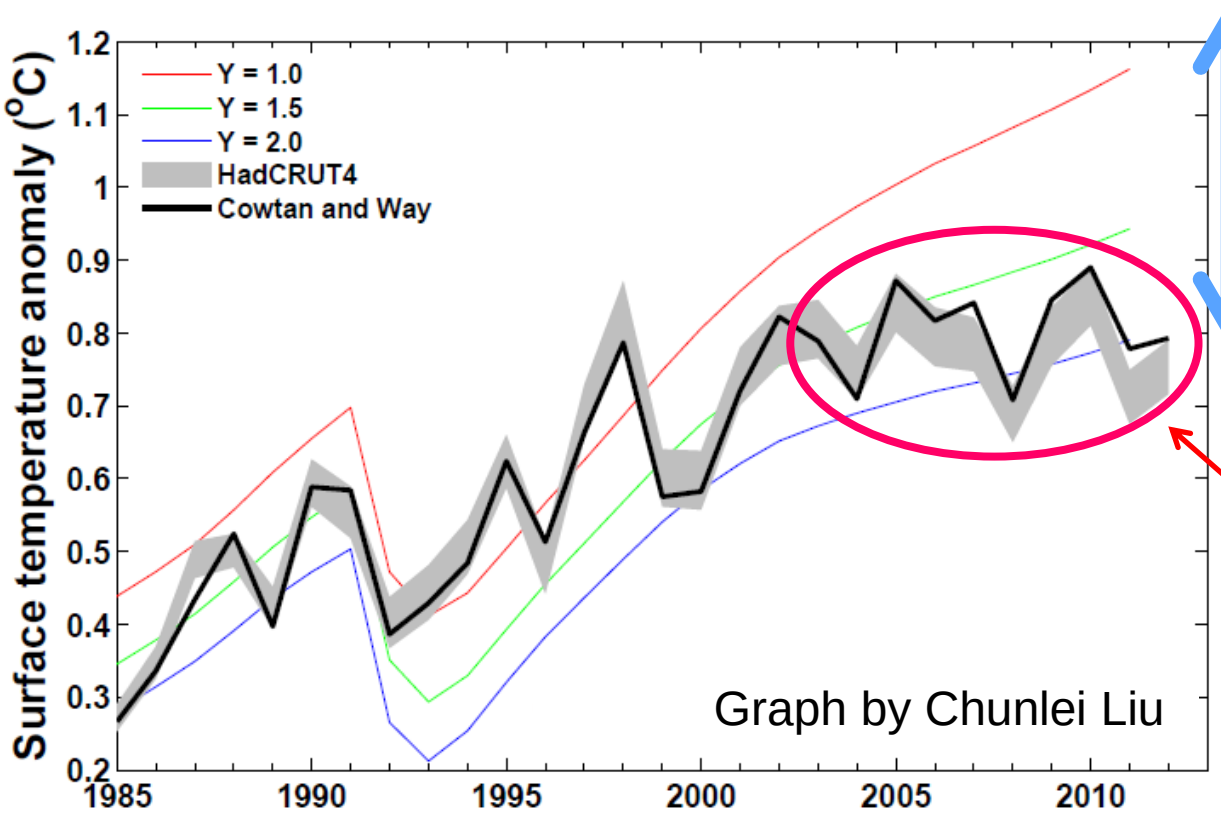
Updated CERES satellite data

- Issues with sampling, radiance to flux conversion, calibration, etc
- Correction for degradation of shortwave filter
- Correction also improves physical consistency of trends in daytime longwave



We used version CERES_EBAF-TOA_Ed2.6r; currently v2.8

Is the temperature record wrong or are computer models inaccurate?

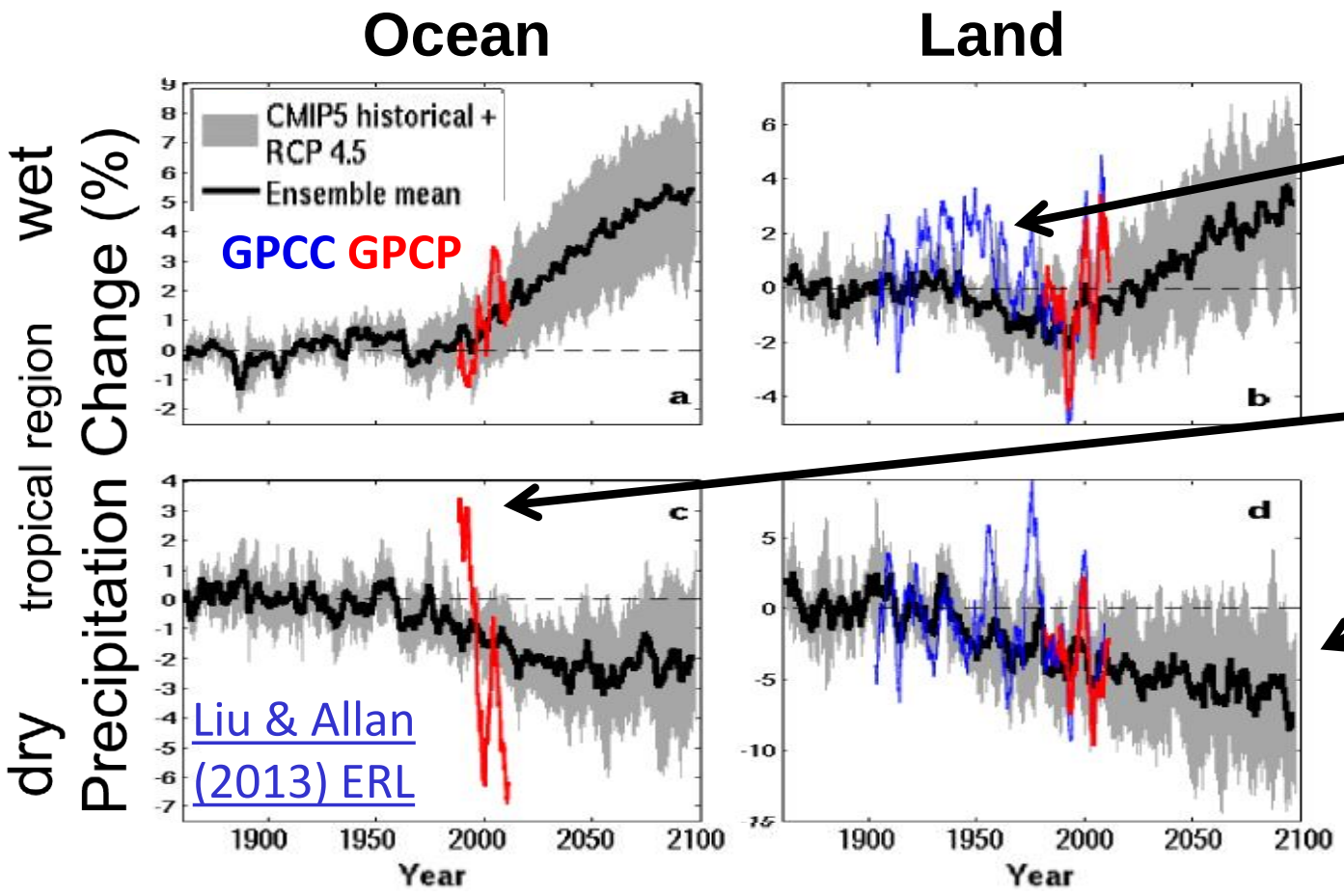


Can comparisons tell us about how sensitive climate is to radiative forcing? e.g. Otto et al. (2013) Nature Geosci

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

Energy and moisture budget:

wettest tropical grid-points becoming wetter, driest grid-points drier



Wet land: strong ENSO influence

Pre 1988 GPCP observations over ocean don't use microwave data

Robust drying of dry tropical land

30% wettest gridpoints vs 70% driest each month

See also: Chou et al. (2013) Nature Geosci; Chadwick et al. (2013) J Clim ; Allan (2012) Clim. Dyn.

Horyuji PAGODA
HydrOlogical cYcle Understanding via Process-bAsed GlObal Detection, Attribution and prediction