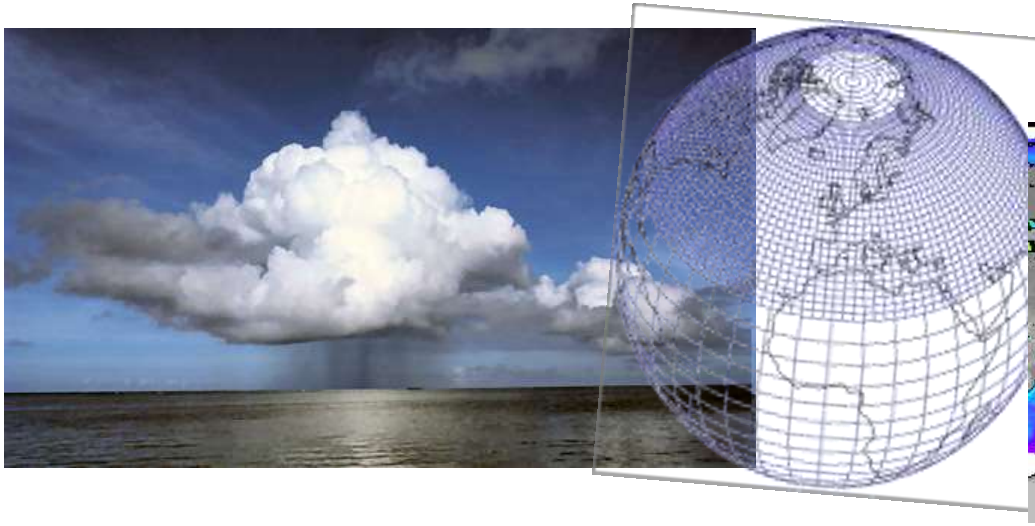

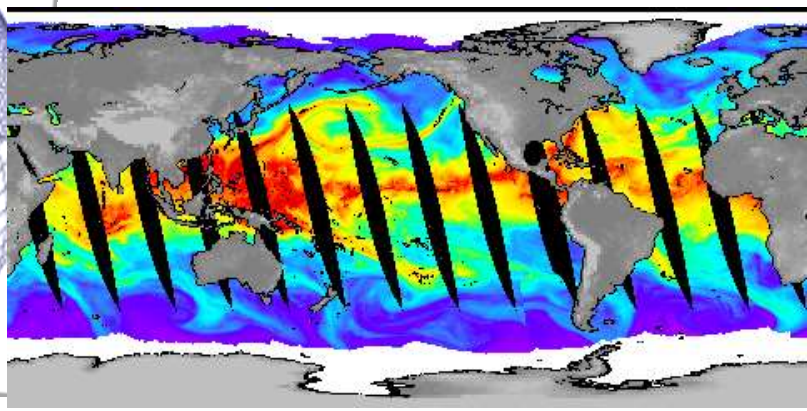

Evaluating changes in global precipitation and Earth's radiation budget

Richard P. Allan @rpallanuk www.met.reading.ac.uk/~sgs02rpa

Thanks to Chunlei Liu and Norman Loeb (NASA Langley)
Work from PAGODA, PREPARE and DEEP-C NERC projects

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Motivations

- Fundamental question:
  - *How much will the world warm this century, how will the global water cycle respond and what are the implications for society?*
- More specific questions:
  - *How and why are precipitation patterns changing?*
  - *Why has global surface warming slowed?*

Precipitation bias & response

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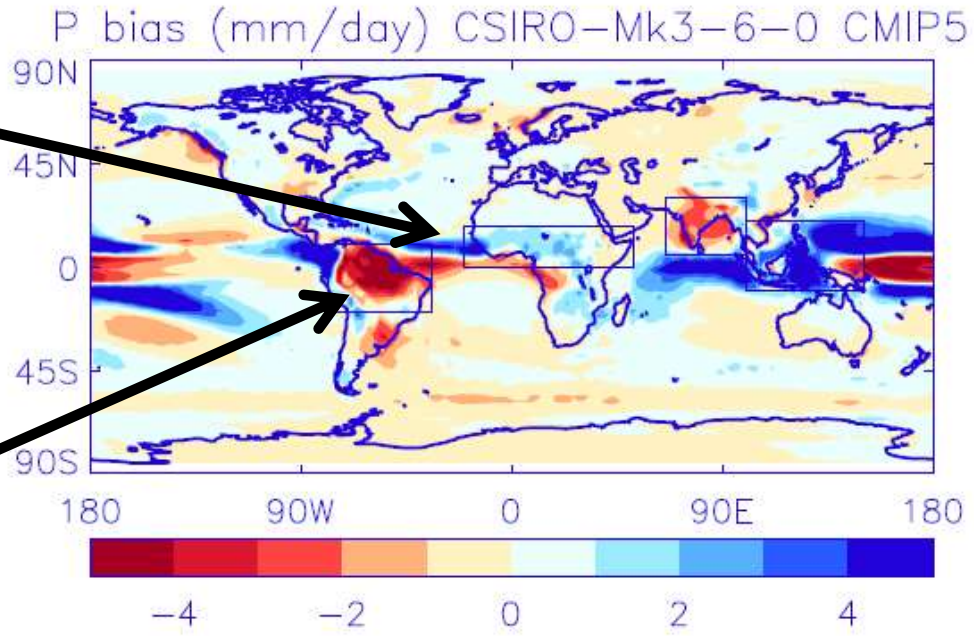
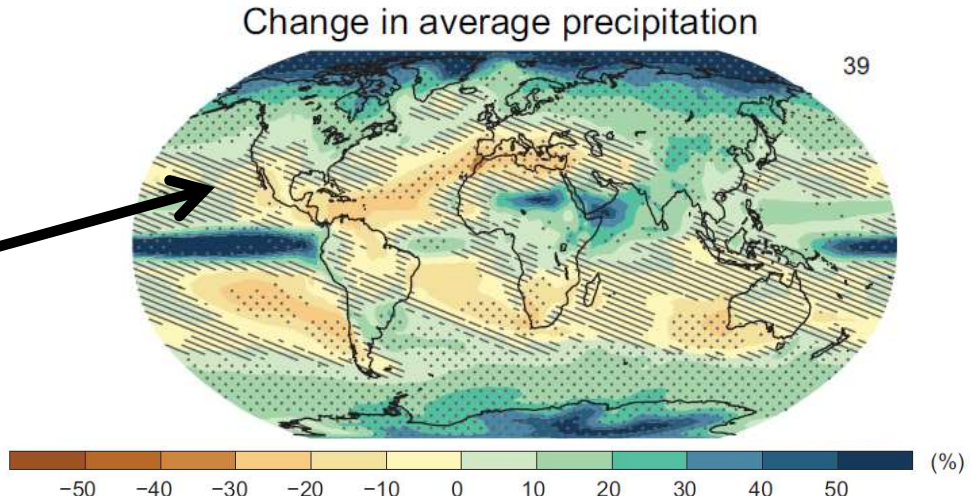
Positional errors?

Process errors?

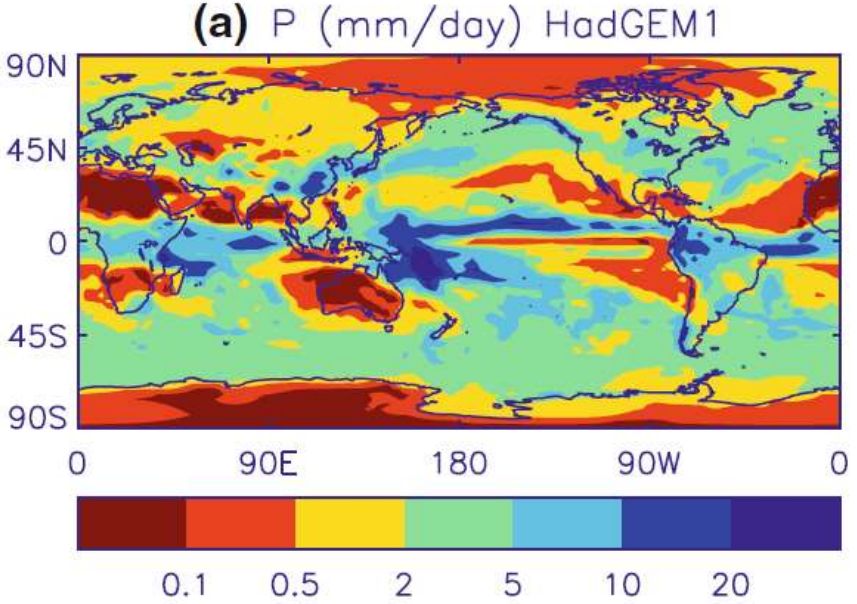


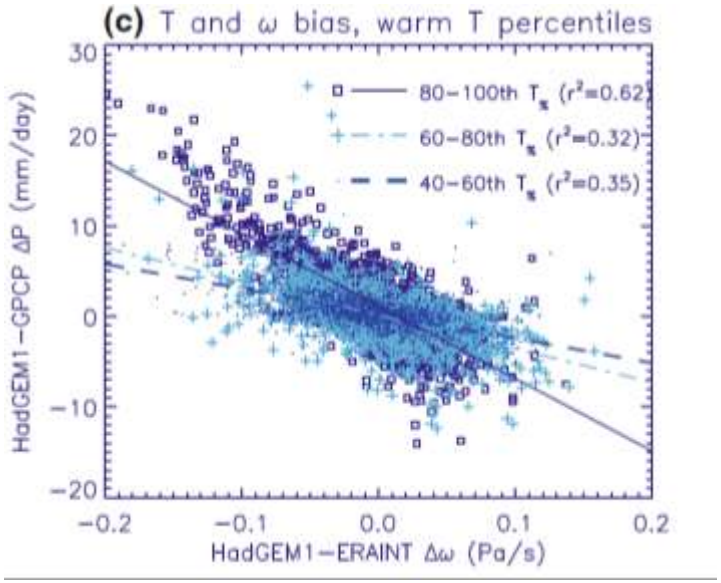
Disagreement in sign of precipitation change

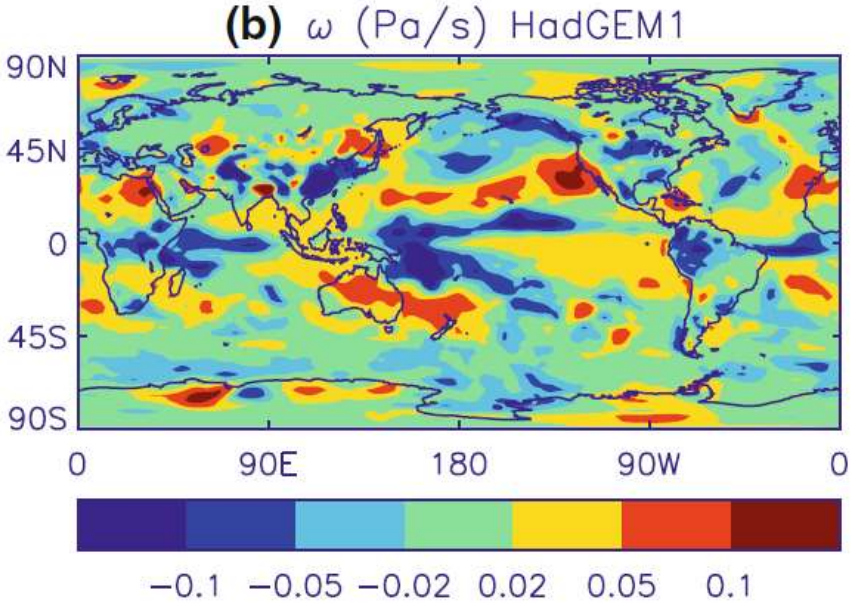


It's the dynamics, stupid!

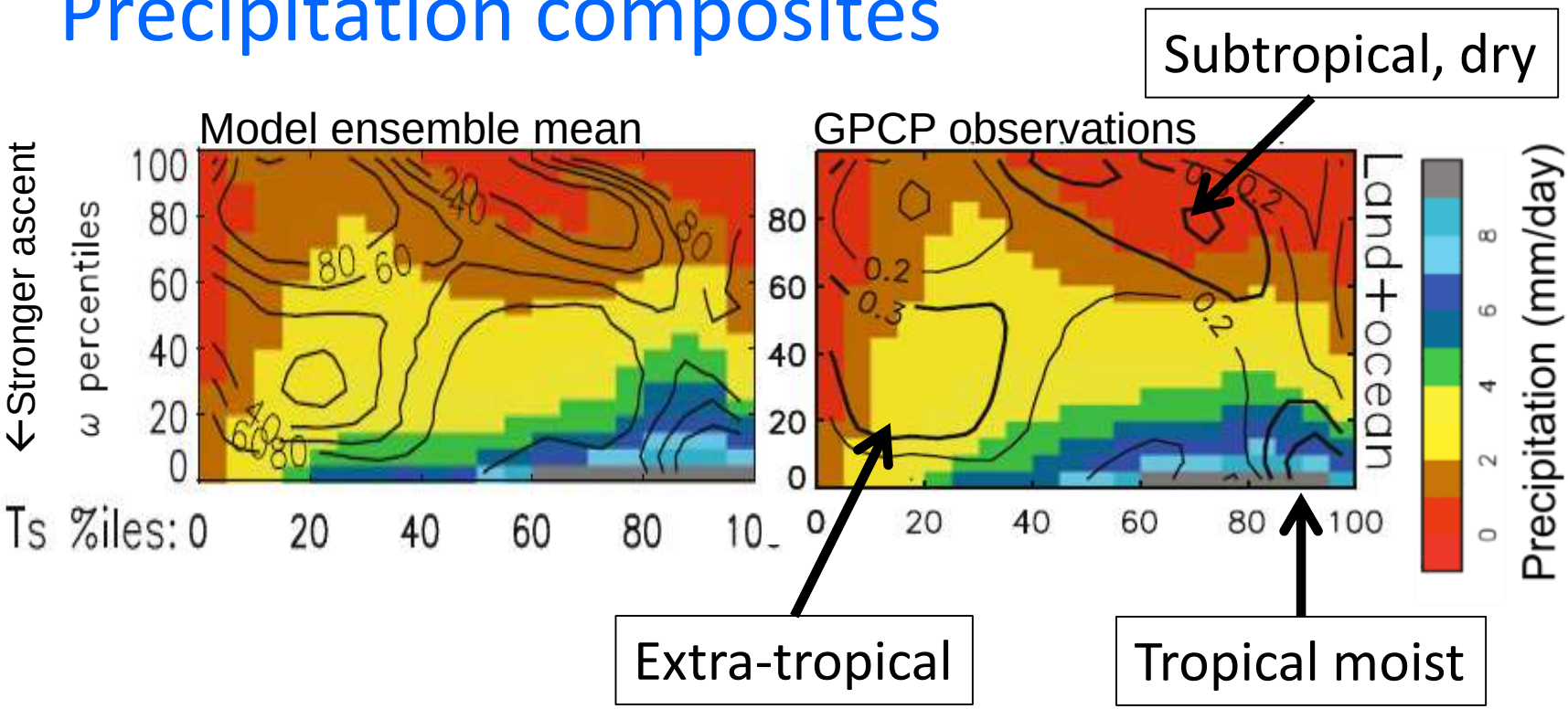
- Most tropical precipitation where air is rising…
  - 500 hPa vertical motion commonly used diagnostic
  - Strong association between model bias in precipitation and vertical motion (below)
  - Thermodynamics also crucial







Precipitation composites



- Composite precipitation by percentiles of vertical motion (strong decent to strong ascent) and temperature
- Contour values enclose % of total area (left) or show percentage contribution of each composite box to total area (right)

Precipitation bias and response by dynamical regime

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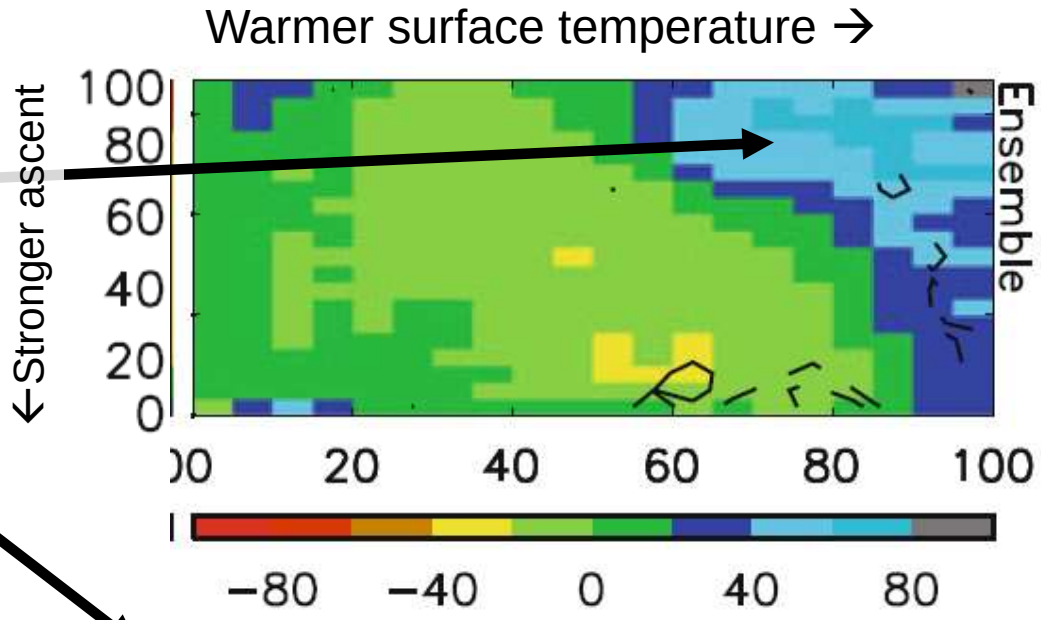
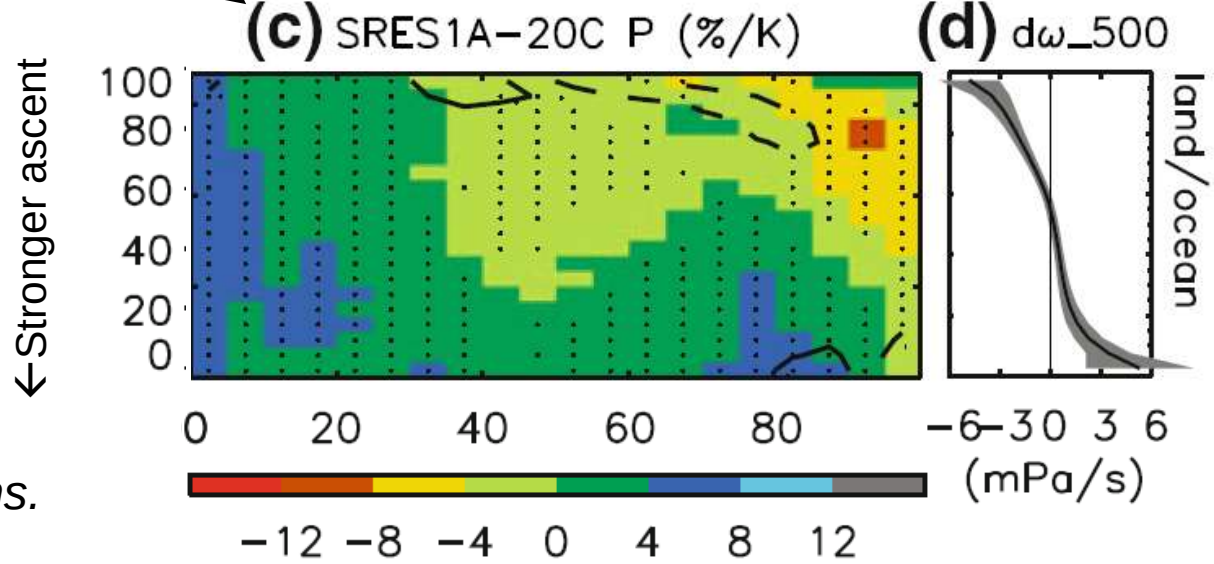
- Model biases in warm, dry regime
- Strong wet/dry fingerprint in model projections (below)





[Allan (2012) Clim. Dyn.]

Also: Liu & Allan (2013) ERL; Allan et al. (2014) Surv. Geophs.

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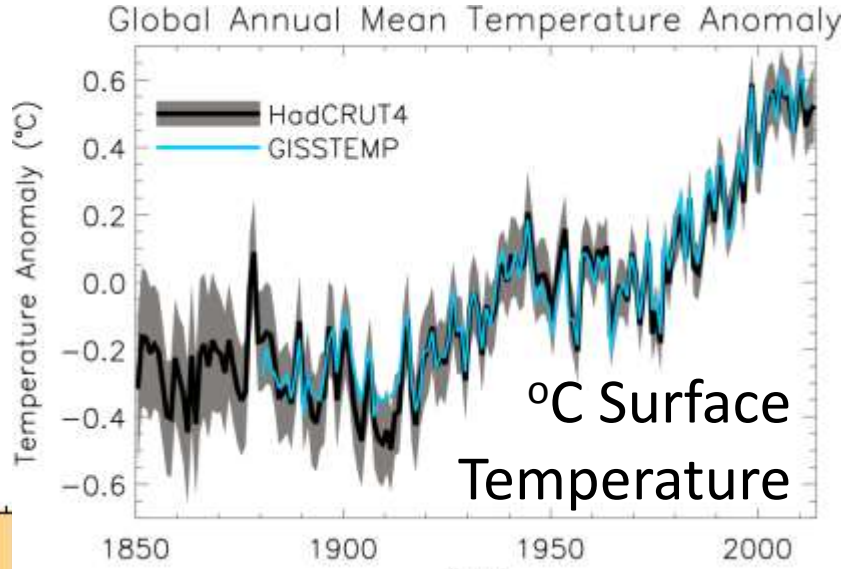
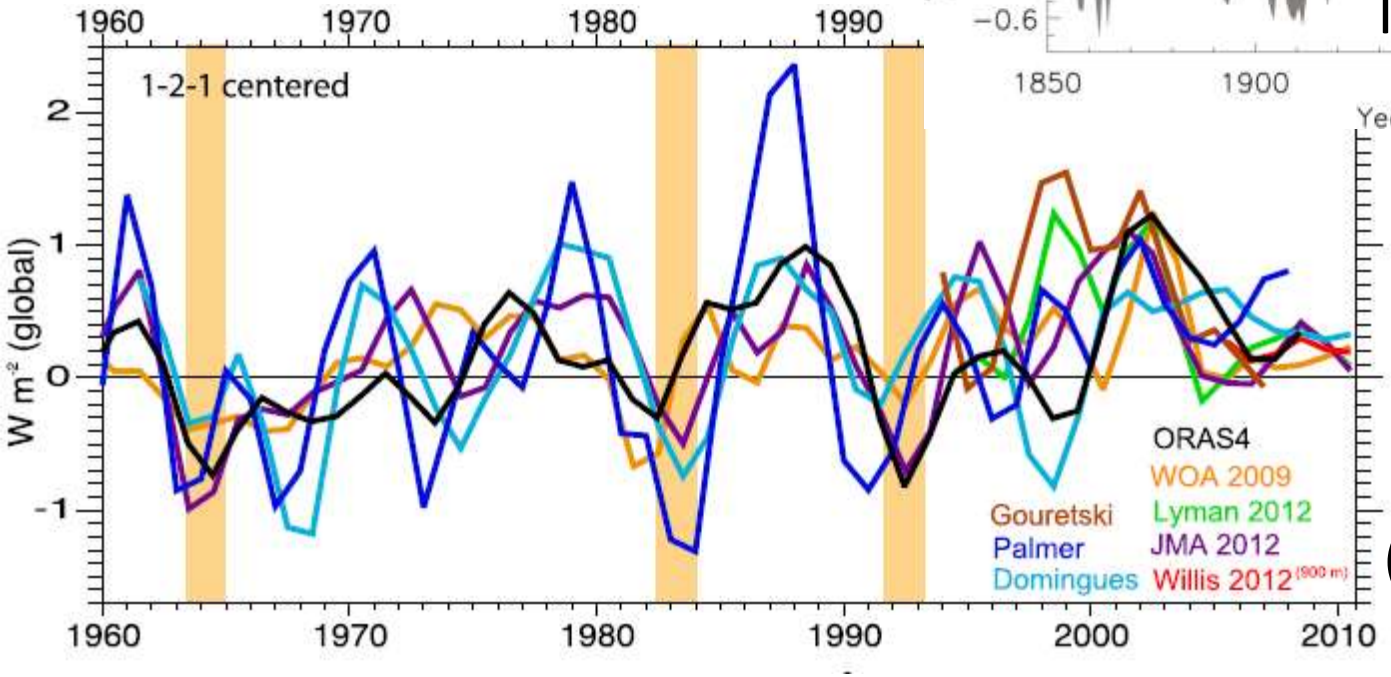
Conclusions (1)

- Method for consistently comparing model and observations using dynamical regimes
- Large precipitation biases in subtropical dry regimes
- Clear wet/dry tropical signal of climate change
- Reduced Walker circulation offsets but does not cancel this thermodynamical signal
- Sampling daily or sub-daily data required for better representing regimes and extremes

At what rate is Earth heating?



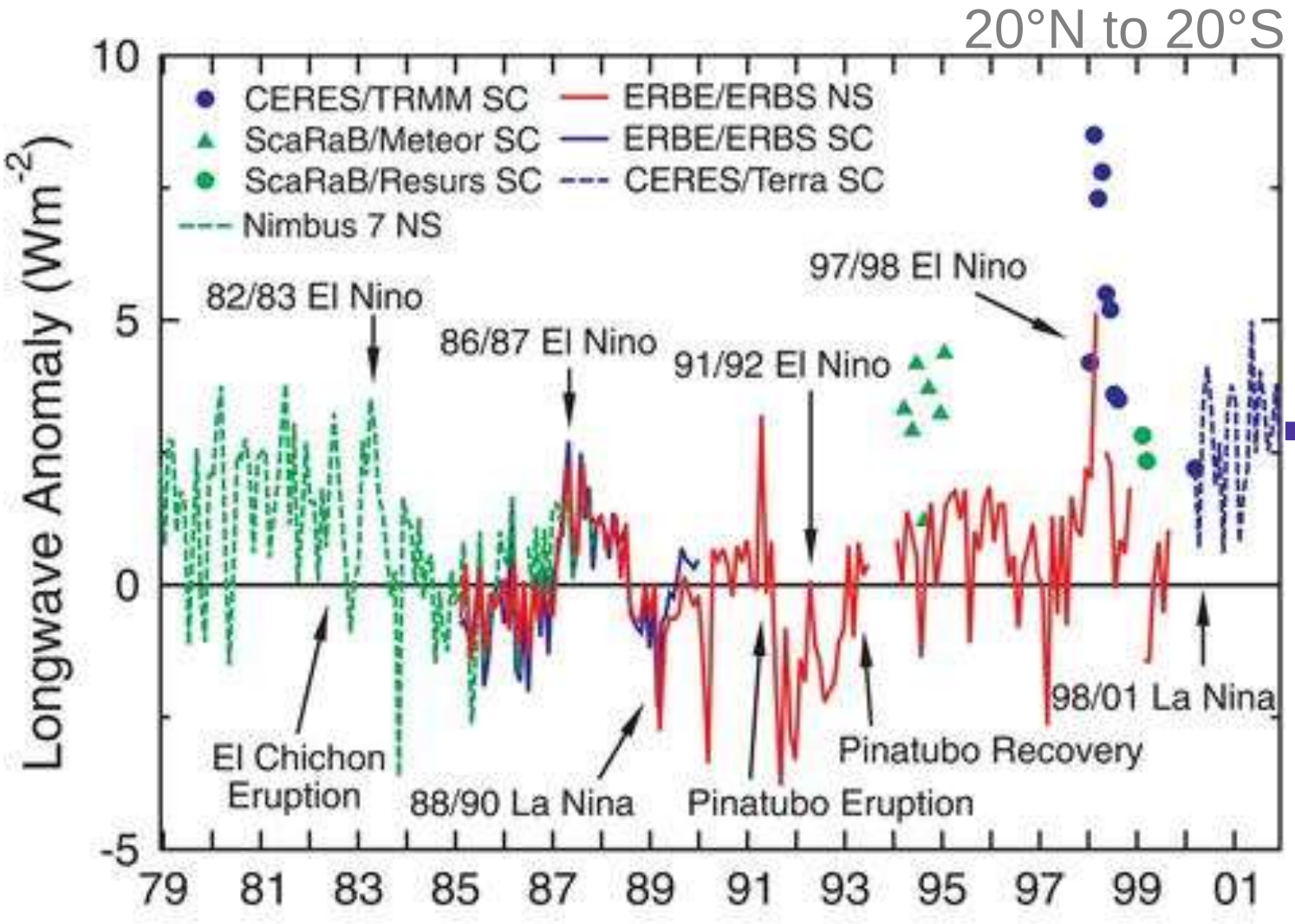
°C Surface Temperature



Upper ocean (Wm^{-2})

Trenberth et al. (2014) J Clim

Earth Radiation Budget Satellite Data



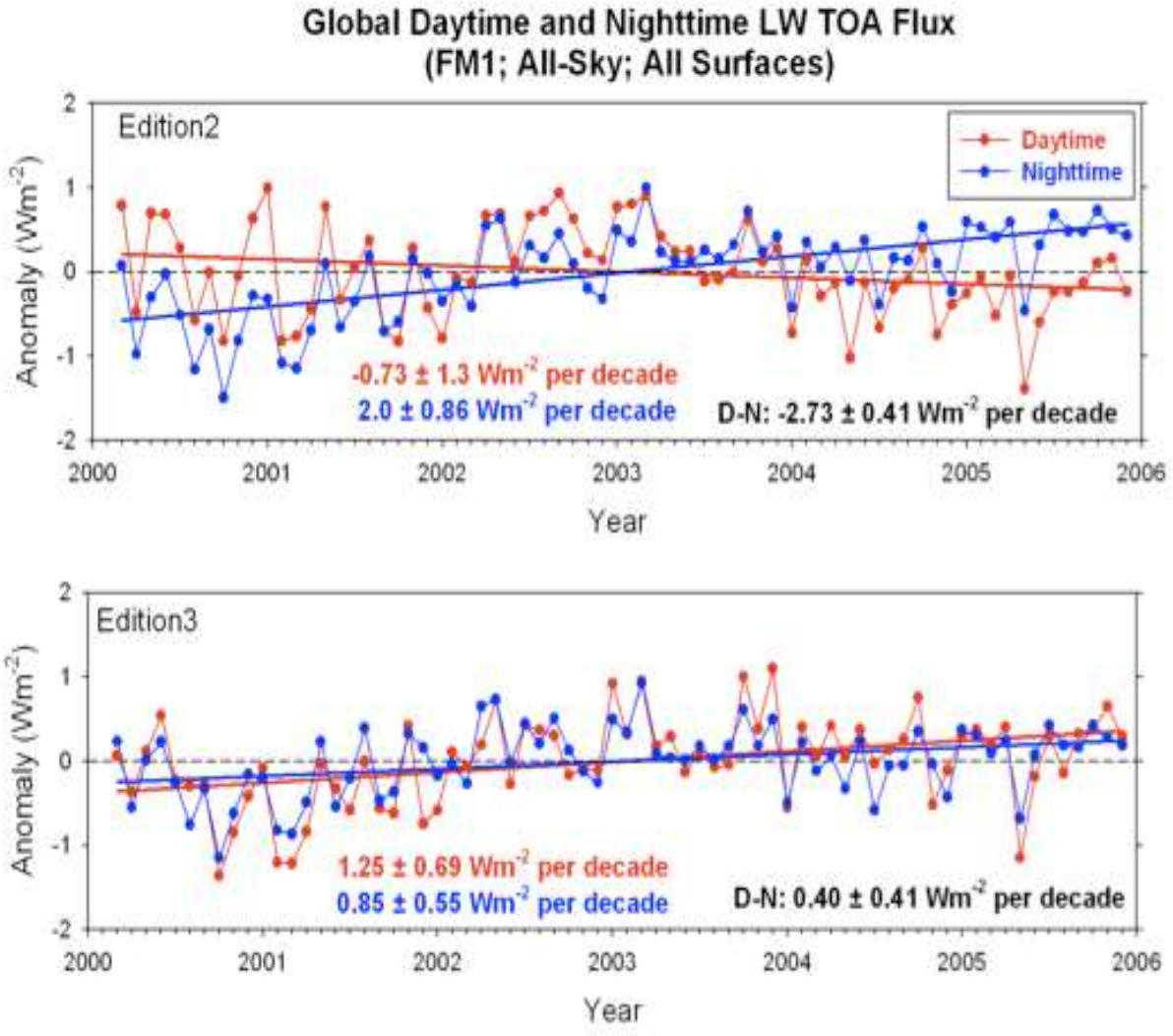
Wong et al. (2006) J Clim; Wielicki et al. (2002) Science

Updated CERES satellite data

- Sampling, radiance to flux conversion, calibration contribute uncertainty

- 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

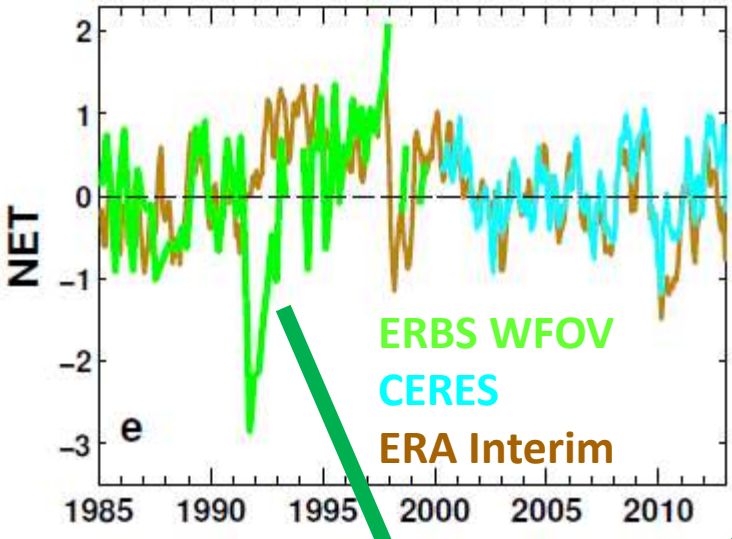
Combined CERES/Argo data

- 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)
  - Changes in heating rate within uncertainty of ocean observations
  - Loeb et al. (2012) *Nature Geosci*.

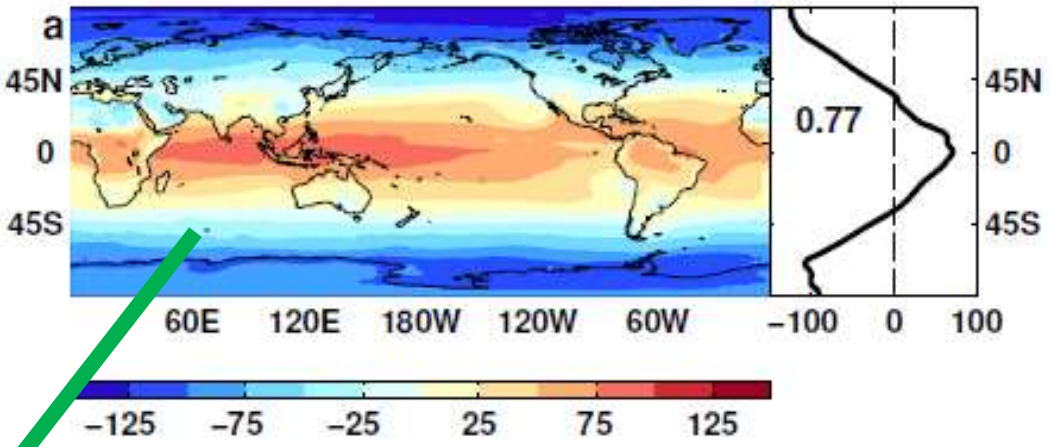
What about before 2000 (e.g. Wielicki et al. 2002 *Science*)?

Reconstructing global radiative fluxes prior to 2000

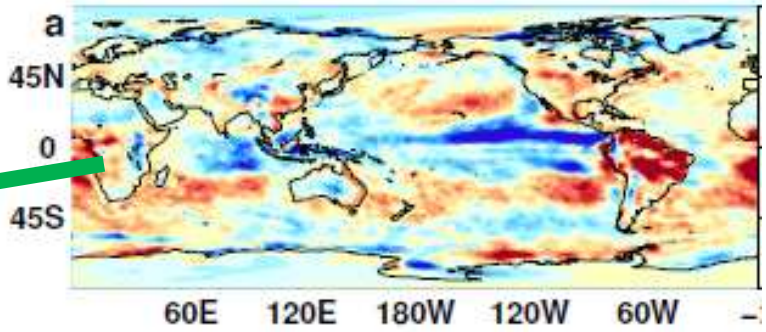
ERBS/CERES variability



CERES monthly climatology



ERA Interim spatial anomalies

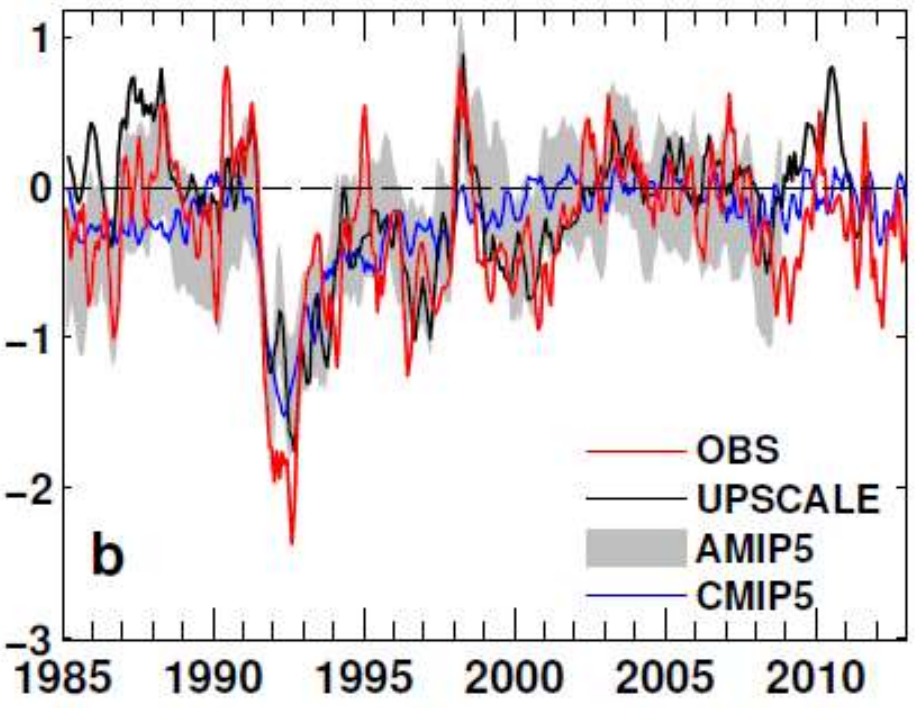


Combine CERES/ARGO accuracy, ERBS WFOV stability and reanalysis circulation patterns to reconstruct radiative fluxes

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

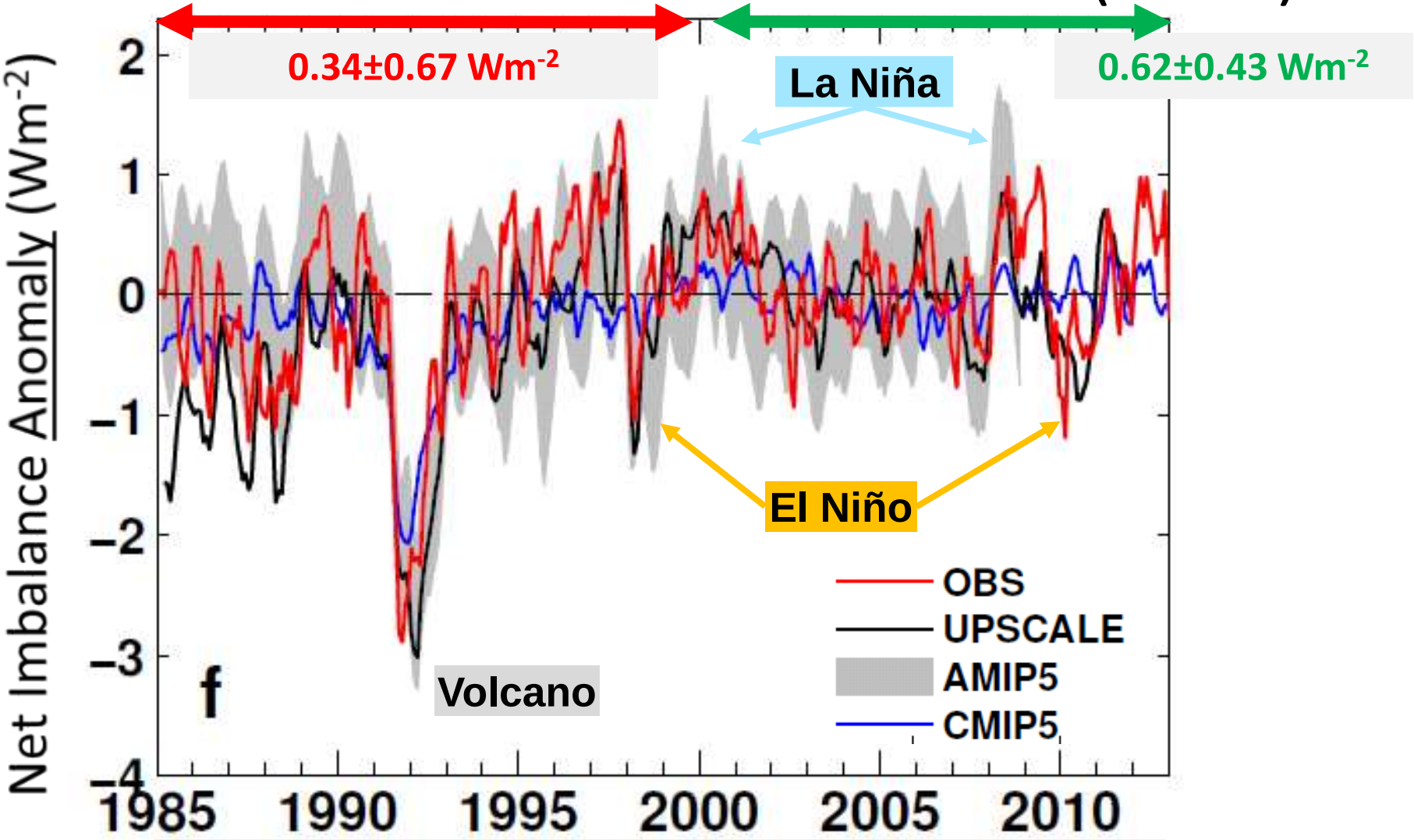
- ERA Interim trends suspect. Use model…
- **UPSCALE** simulations (obs. SST, sea ice & realistic radiative forcings) "**OBS**"
- Net less sensitive to method than OLR/ASR

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



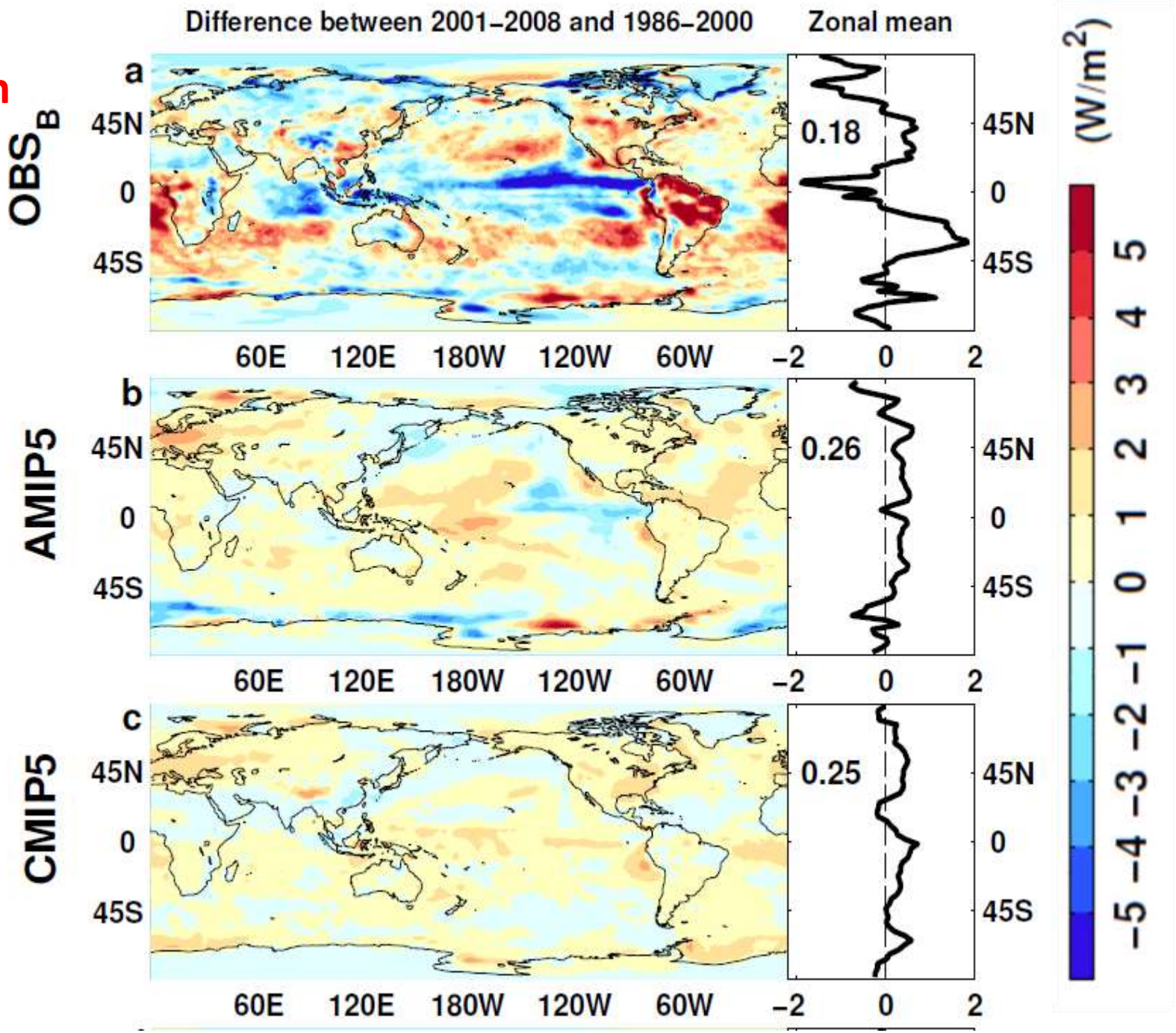
Changes in imbalance in models & observations

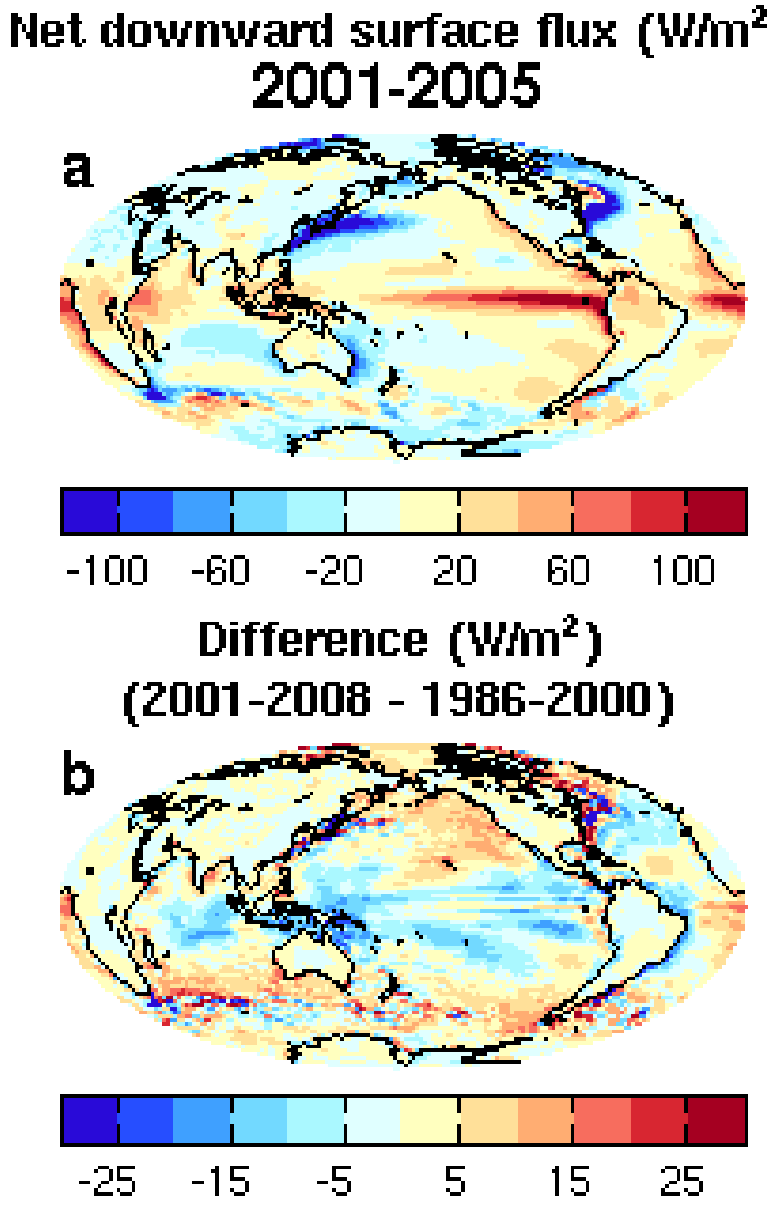
Imbalance: 0.23 | 0.00 | 0.78 | 0.63 | 0.63 (Wm^{-2})



Allan et al. (2014) *GRL*

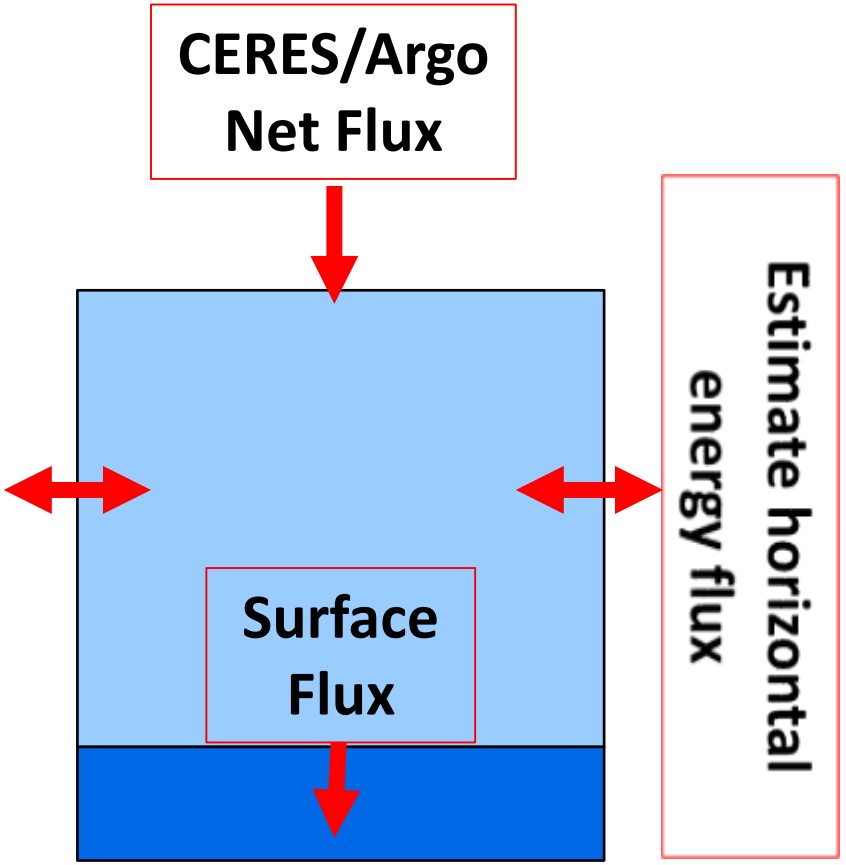
NET Radiation





Future work:

Estimates of Surface Flux



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

Conclusions

- Heating of Earth continues at rate of ~0.6 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
  - ~0.3 Wm^{-2} higher in 1995-1999 than 2000-2013 period
- Distinct East Pacific signal in ΔT and ΔN
- Radiative forcing alone can't explain surface warming slowdown: internal variability important
- Next steps: combining with reanalyses energy transports to estimate surface fluxes

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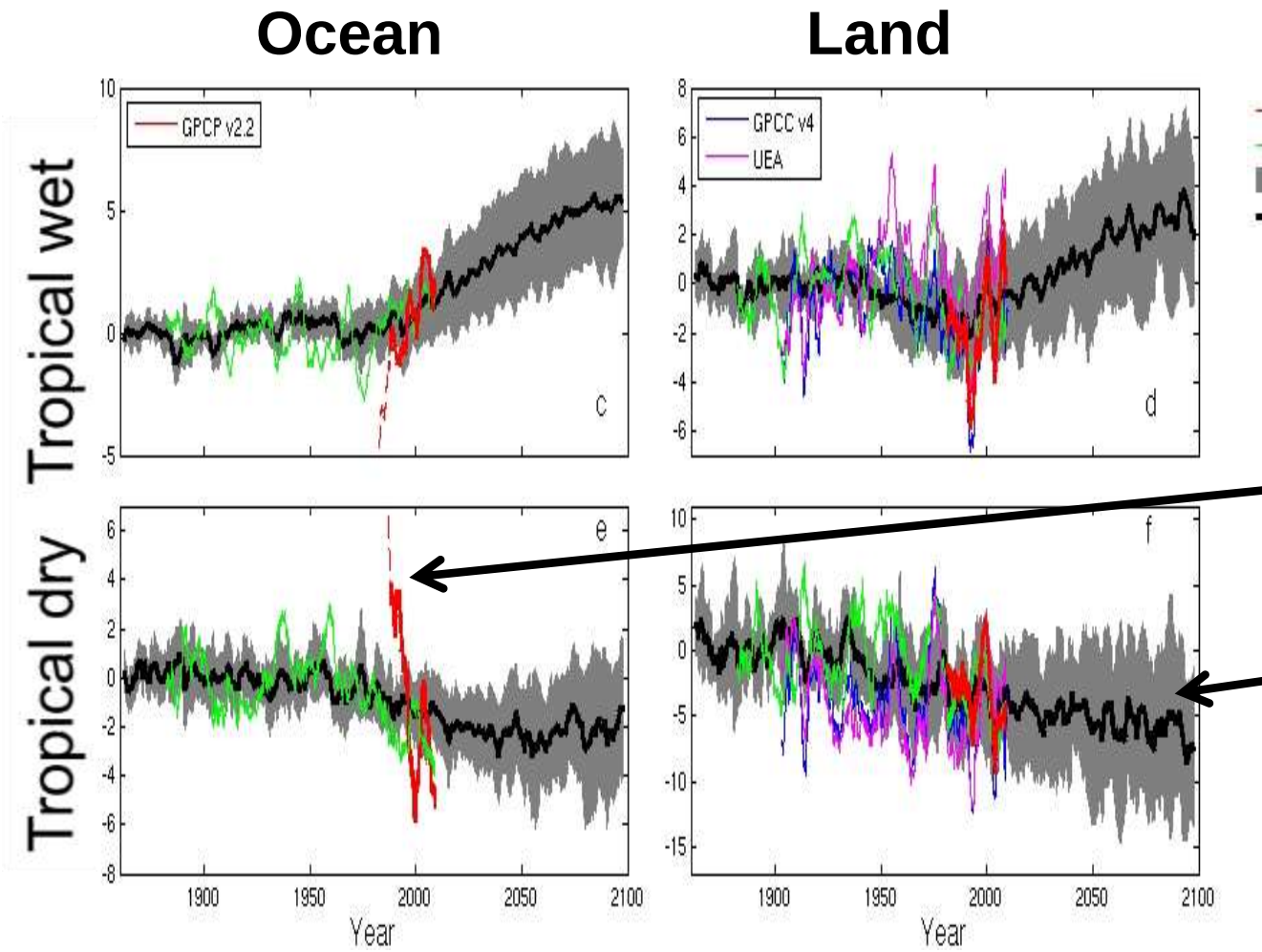
CMIP5 simulations: Wet regions get wetter, dry regions get drier



Pre 1988 GPCP ocean data does not contain microwave data

Robust drying of dry tropical land

30% wettest gridpoints vs 70% driest each month

Liu and Allan *in prep; see also* Allan et al. (2010) ERL.

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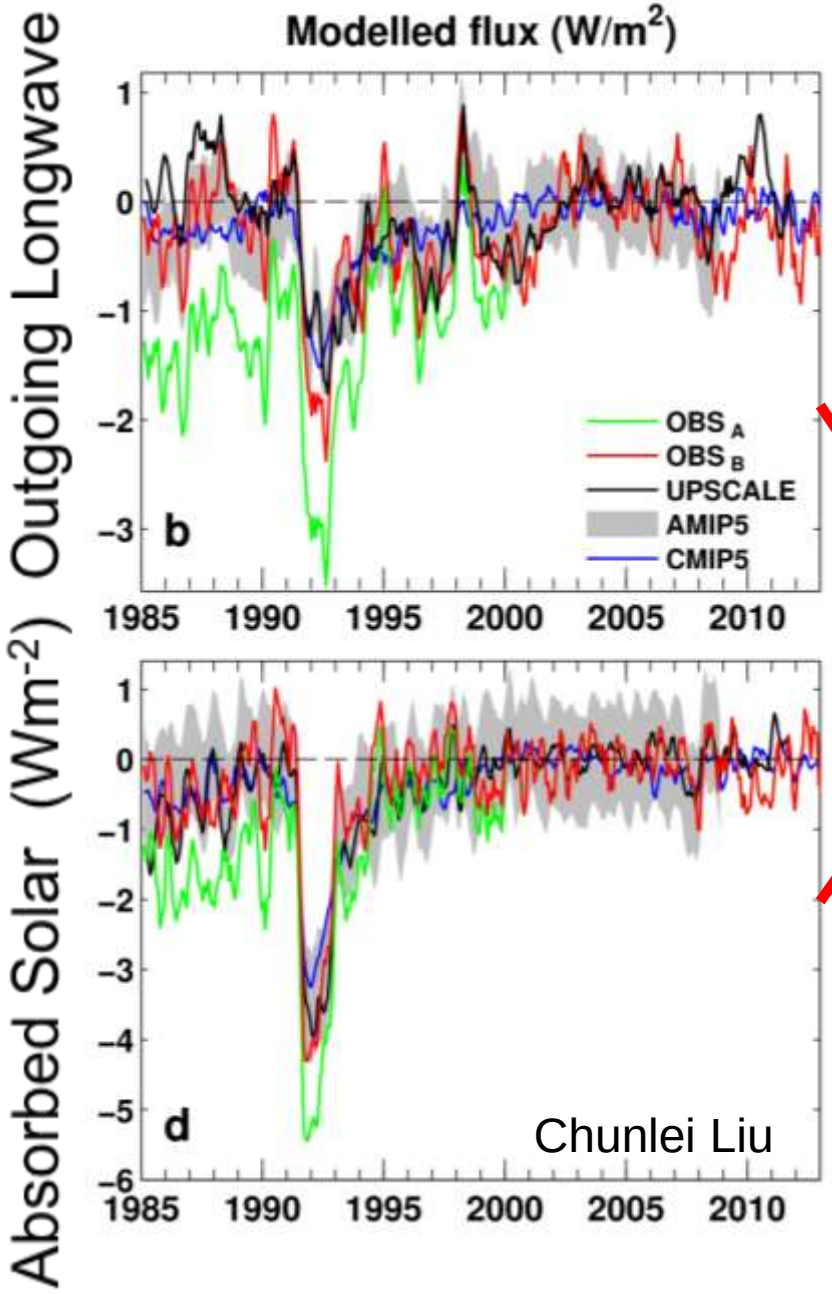
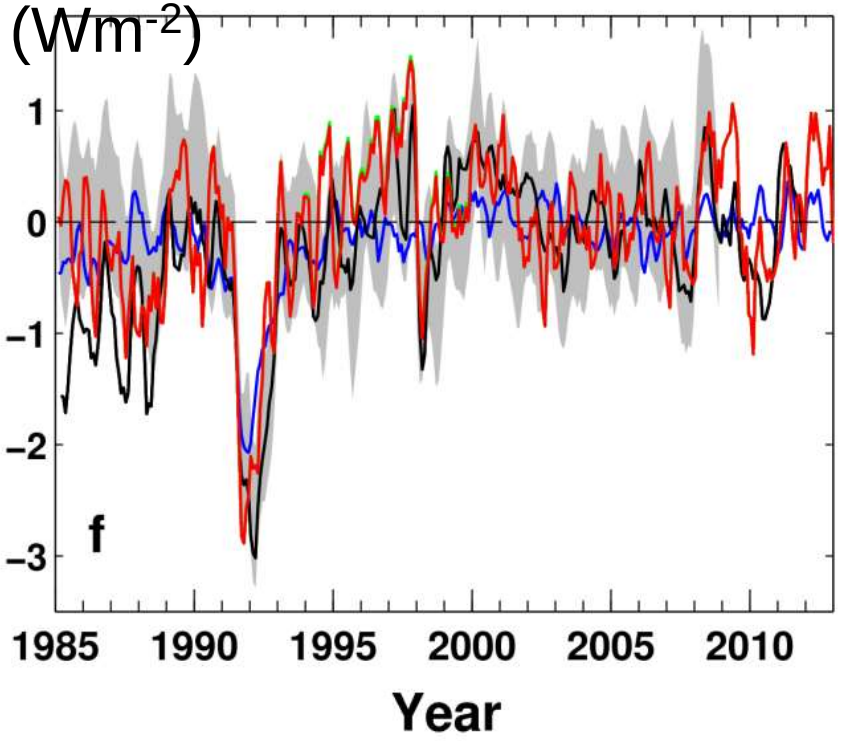
Changes in top of atmosphere radiative fluxes since 1985





Research in DEEP-C project at Reading…