Department of Meteorology
National Centre for Earth Observation

University of Reading

THE ROLE OF EARTH'S ENERGY BUDGET IN RECENT CLIMATE VARIABILITY AND CHANGE

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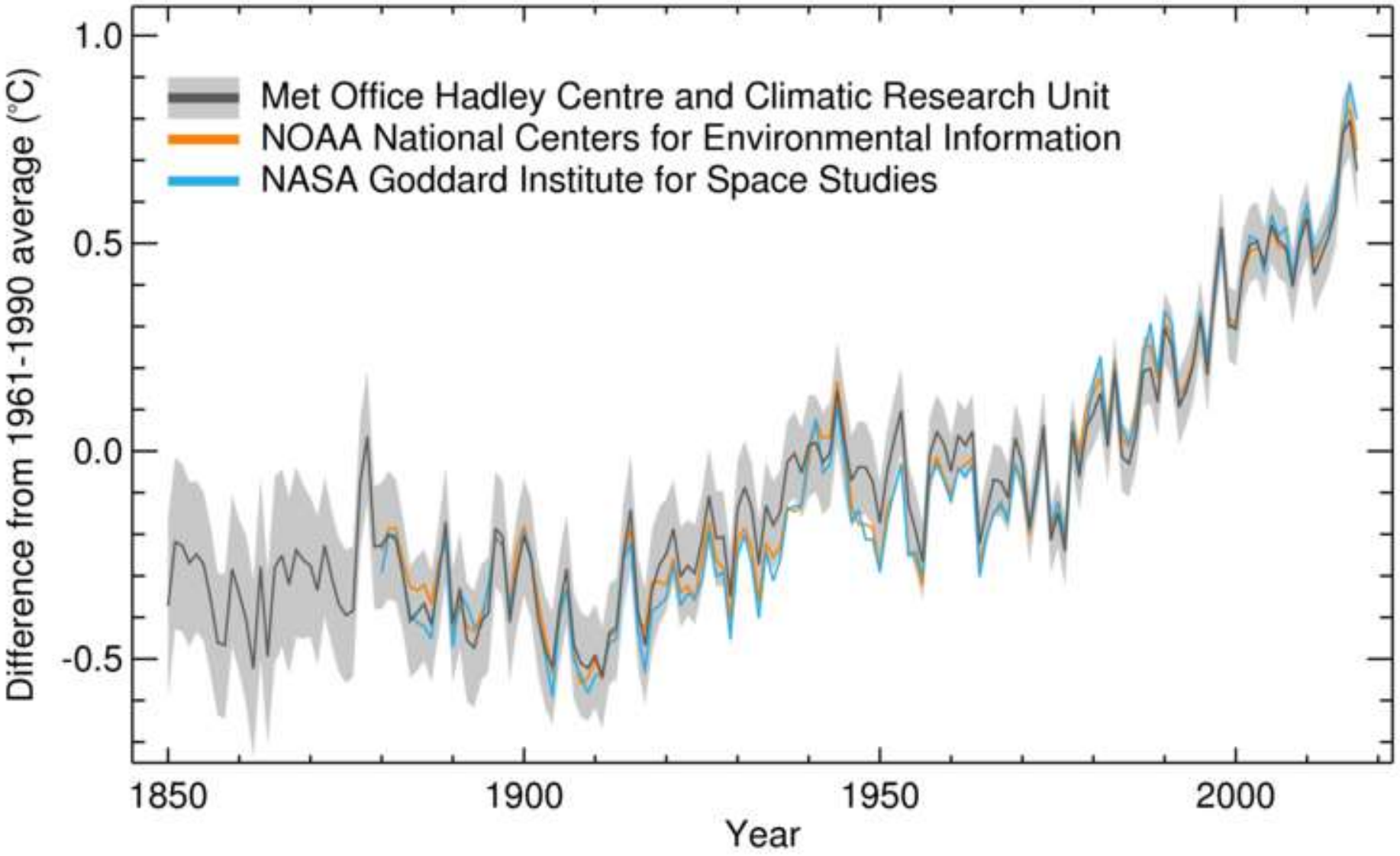
SMURPHS

NERC SCIENCE OF THE ENVIRONMENT

Global average temperature anomaly (1850-2017)



DID GLOBAL WARMING GO ON HOLIDAY?

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- Global surface warming rate slower in early 2000s than 1980s/90s
  - Energy imbalance remains positive/strengthens, sea level rise accelerates
  - Ocean heat uptake to deeper levels, distinct Pacific variability pattern
- Unusual climate phenomena
  - Unprecedented Pacific trades, suppressed El Niño, AMOC & ITF ocean changes, Arctic warming, cold northern winters, NAO/PDV/AMV phase
- Warming rate unusually low compared to climate simulations
  - Radiative Forcing & sampling explains some of discrepancy
  - Internal variability explains much of remaining discrepancy
  - Amplified by SST-pattern related cloud/circulation feedbacks
  - Unrepresented forced circulation responses can't be discounted

  http://www.met.reading.ac.uk/~sgs02rpa/research/DEEP-C.html#PAPERS
- Multiple factors explain hiatus/surge events: understanding decadal variability advances climate science Cassou et al. 2018 BAMS

RECENT GLOBAL CLIMATE VARIABILITY

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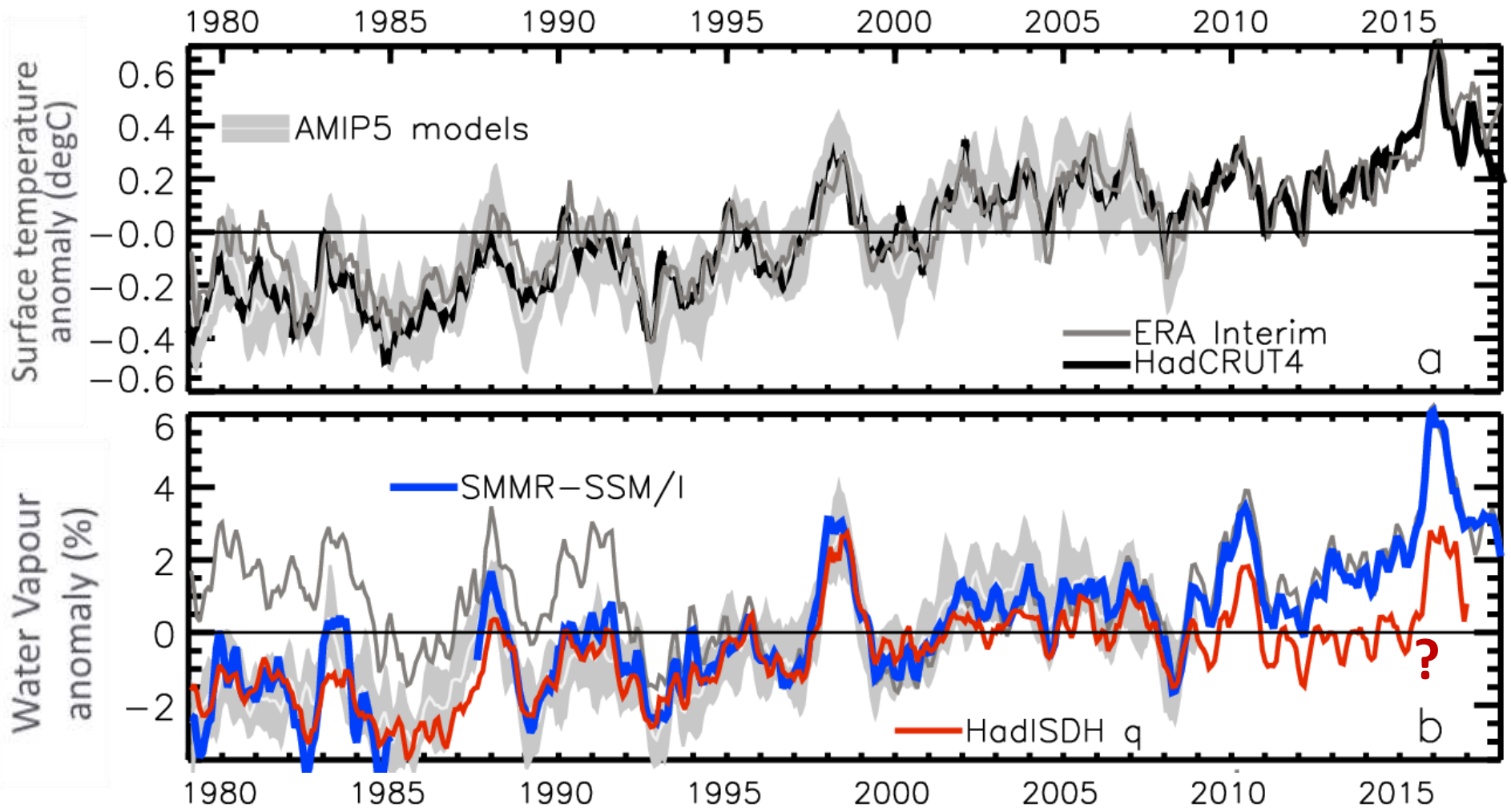

Update from Allan et al.(2014) Surv. Geophys

RECENT GLOBAL CLIMATE VARIABILITY

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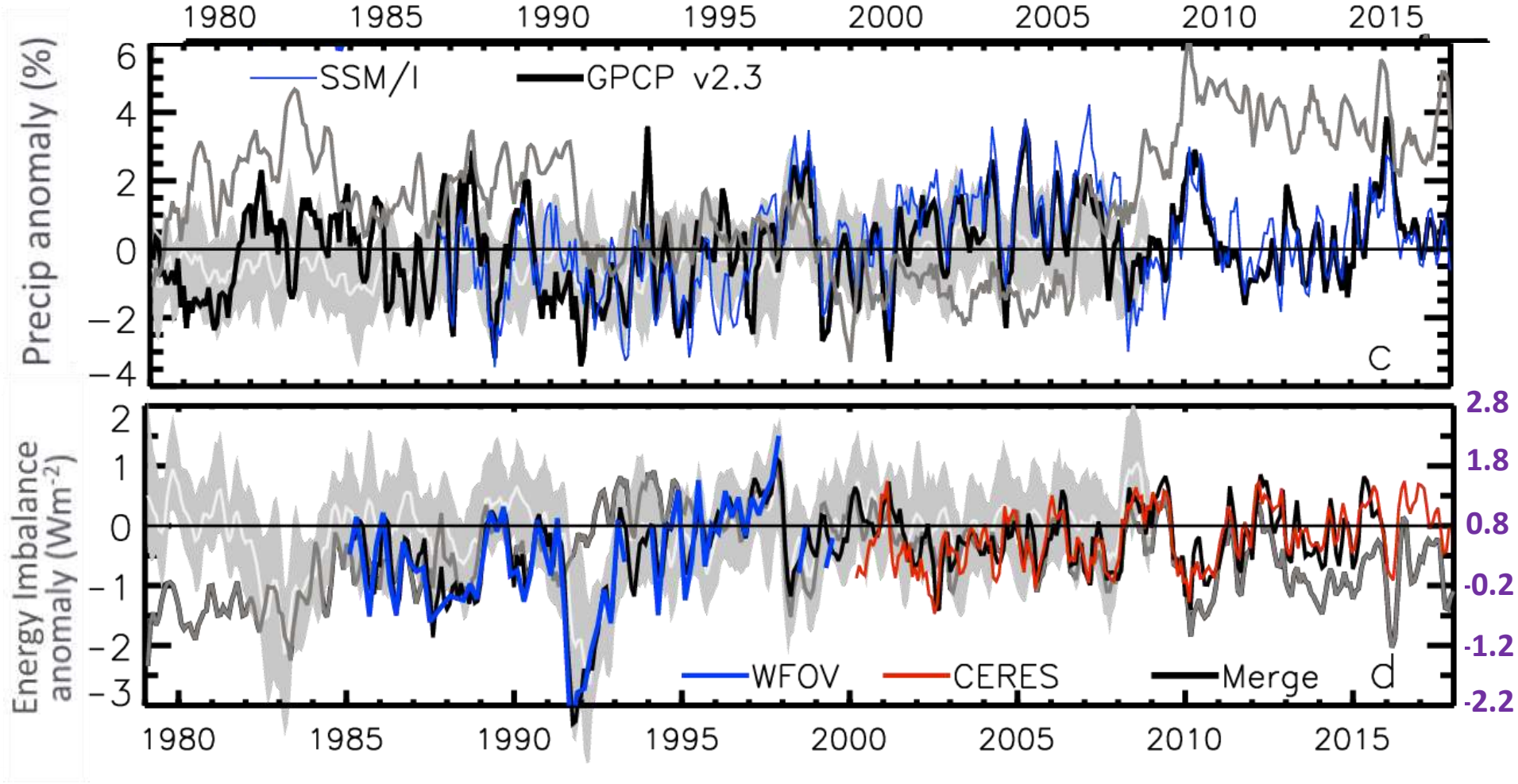
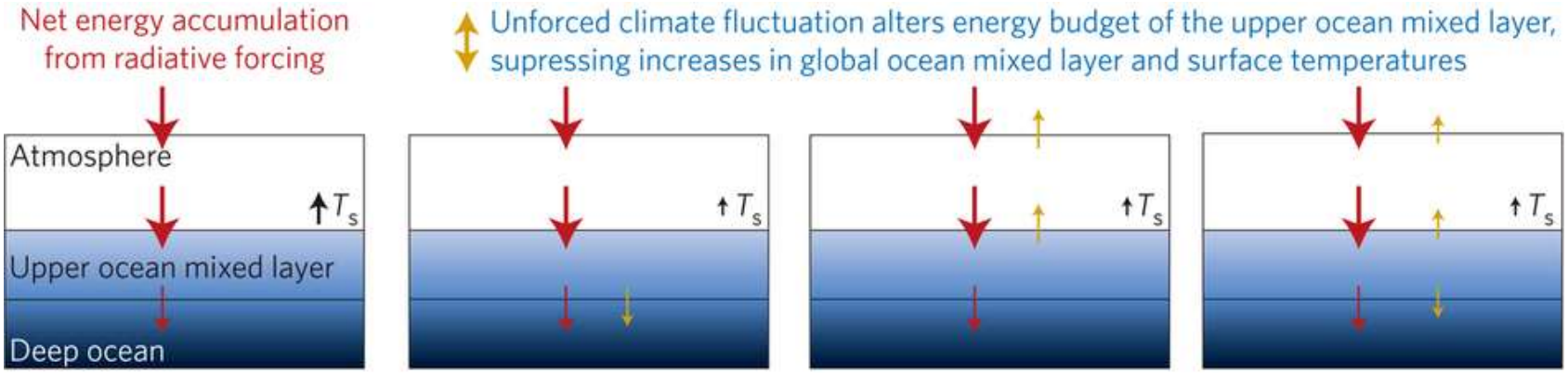


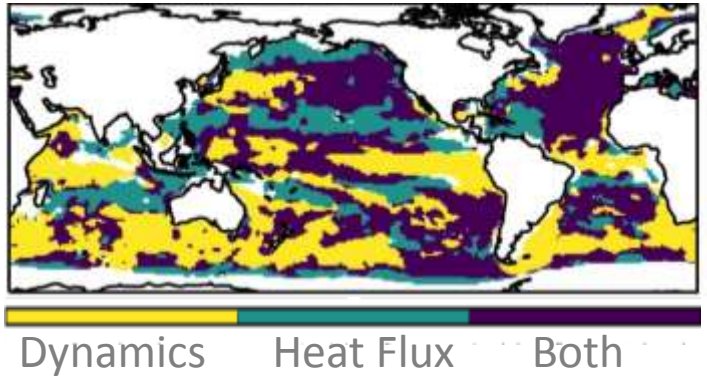
Update from Allan et al.(2014) Surv. Geophys.; Allan et al. (2014) GRL

OCEAN MIXED LAYER ENERGY BUDGET



Allan (2017) Nature Clim.

- Energy imbalance increase since 1990s, steady in 2000s 0.6-0.8 Wm^{-2}
  Cheng et al. 2017 Sci. Adv.; Allan et al. 2014 GRL
- Slowdown events simulated by climate models
  - ↑ocean heat uptake below 300m
    Meehl et al. 2011 Nature Hiatus
- Upper ocean mixed layer heat budget interface of energy imbalance/global surface temperature
  Hedemann et al. 2017 Nature Clim.
  - Small perturbations obfuscate attribution
  - Useful interpretive framework



Origins of ocean mixed layer heat content variability Roberts et al. 2017 JGR

NEW GLOBAL SURFACE FLUX ESTIMATES

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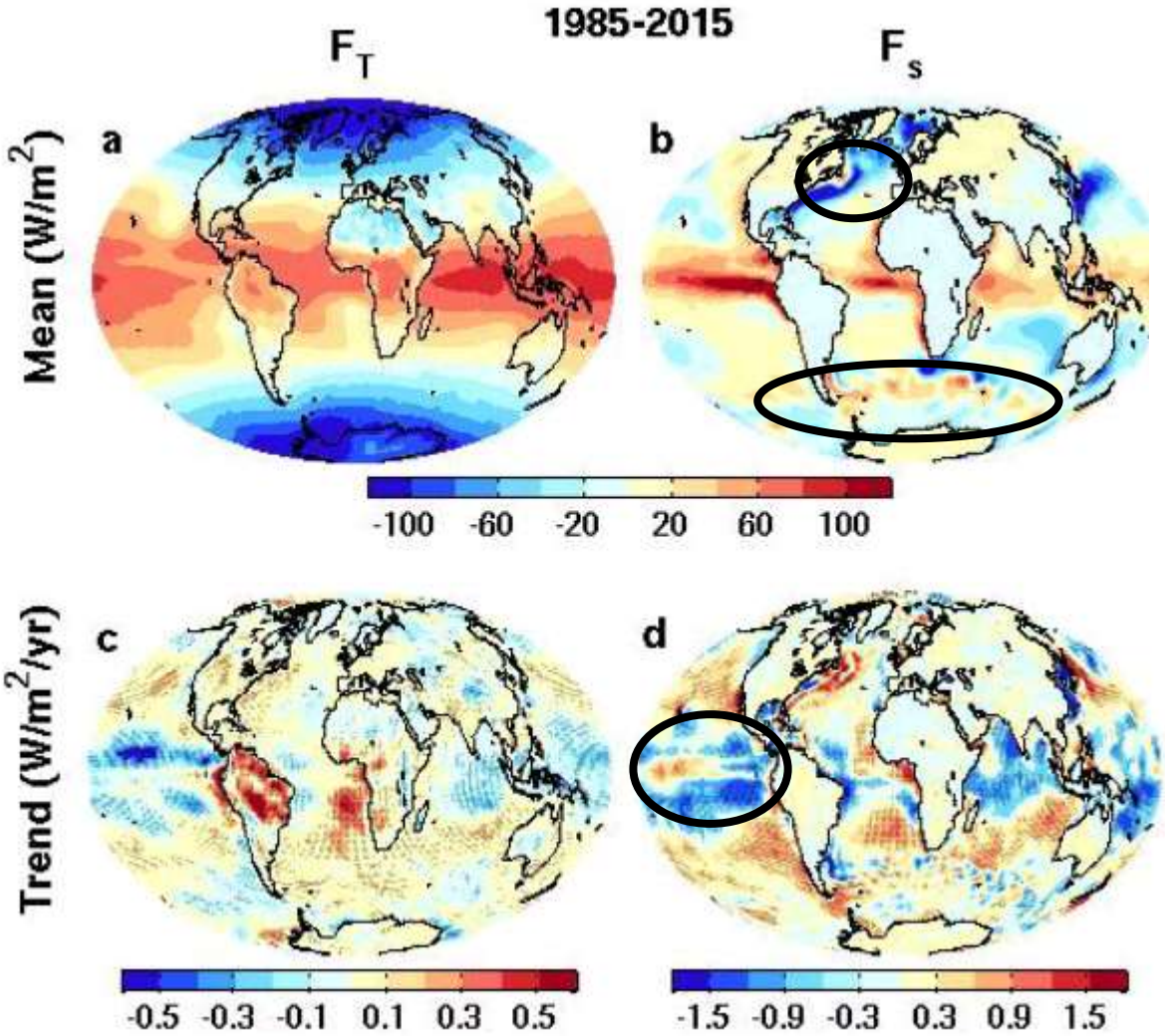
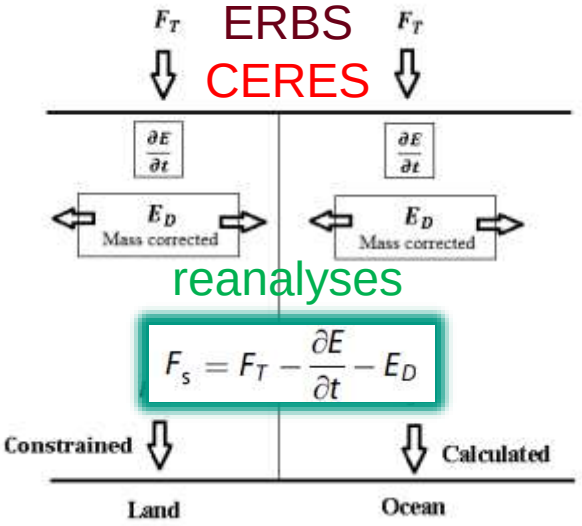
top of atmosphere surface





Surface energy flux dataset combines top of atmosphere satellite reconstruction with reanalysis energy transports: Liu et al. (2015) JGR

Liu et al. (2017) JGR Data: http://dx.doi.org/10.17864/1947.111

FEEDBACKS ON INTERNAL & FORCED CLIMATE CHANGE INVOLVING REGIONAL ENERGY BUDGET

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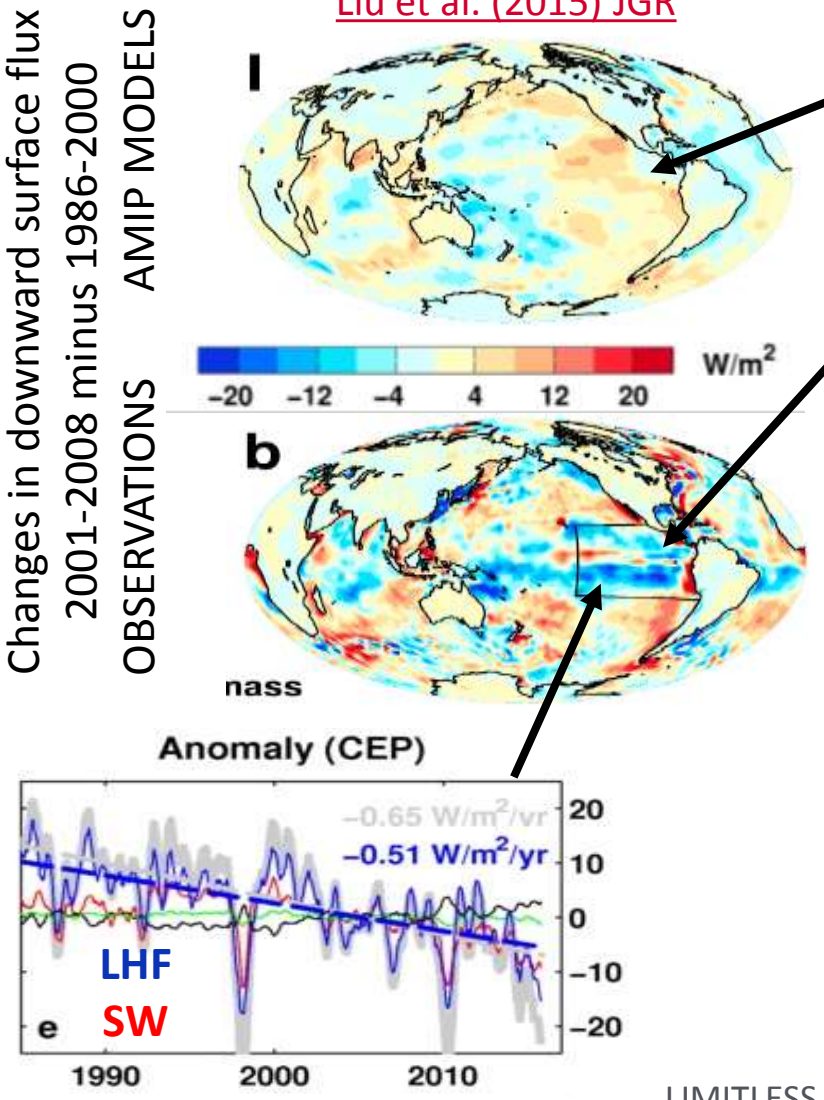
Liu et al. (2015) JGR



- Cloud feedbacks in east Pacific important for internal decadal variability e.g. Zhou et al. (2016) Nature Geosci
- Latent heat flux changes dominate observed negative trend in east Pacific? Liu&Allan(2018)
- Distinct feedbacks on internal variability & forced change e.g. Brown et al. 2016; Xie et al. 2015 ; England et al. (2014)
- Spatial patterns of warming crucial for feedbacks & climate sensitivity e.g. He & Soden (2016); Richardson et al. (2016); Ceppi & Gregory (2017); Andrews & Webb (2017)
- Do climate models underestimate low cloud amplifying feedbacks, internal variability & climate sensitivity? Marvel et al. 2018; Silvers et al. 2017 ; Yuan et al. 2018

HEMISPHERIC ENERGY IMBALANCE & PRECIPITATION BIASES IN CLIMATE MODELS

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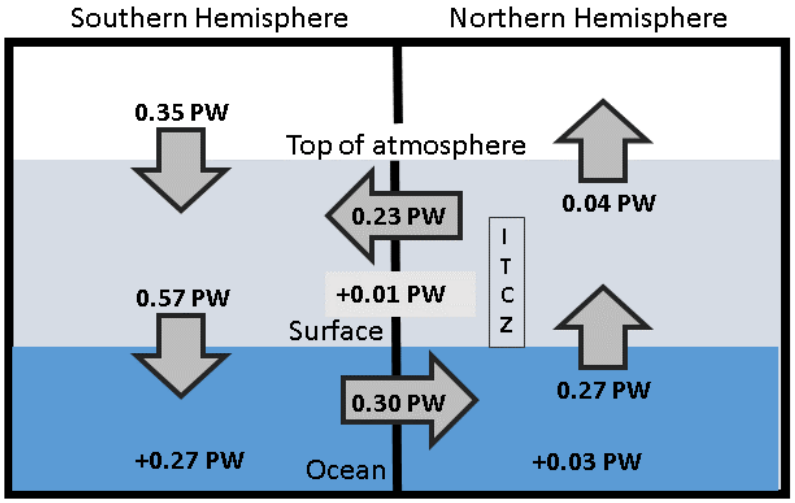
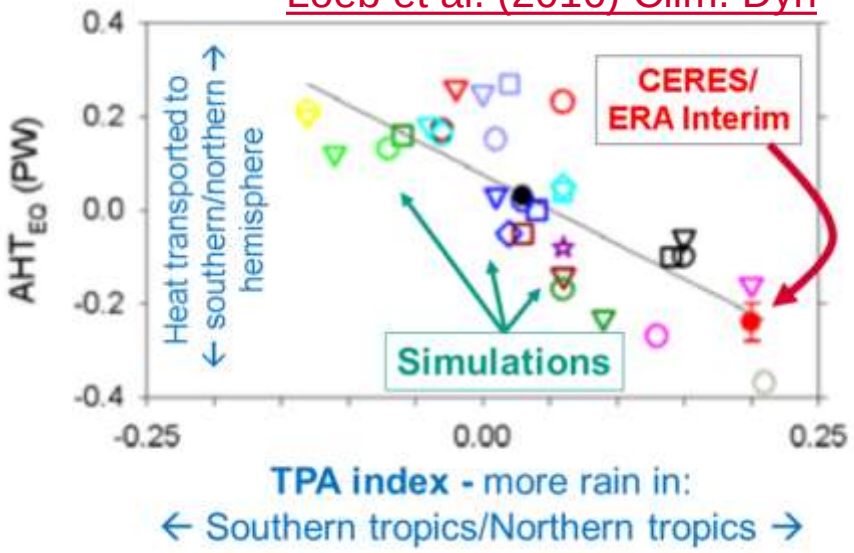


Loeb et al. (2016) Clim. Dyn



← Inferred 2000-15 cross equatorial energy flux (Liu et al. 2017) using ocean heating (Roemmich et al. (2015) Nature Clim.)

- Gross hemispheric precipitation biases linked to cross-equatorial heat transport e.g. Frierson et al. (2013) Nature Geoscience; Haywood et al. (2016) GRL; Hawcroft et al. (2016) Clim. Dyn.

← Many climate models simulate incorrect sign of cross equatorial energy flow and northern minus southern hemispheric precipitation difference

- Historical shifts in tropical rainy belts linked to high latitude volcanic eruptions (Haywood et al. (2013) Nature Clim) & anthropogenic aerosol-cloud interactions (He & Soden (2016) Nature Clim.; Wilcox et al. ERL 2013) but greenhouse gas forcing may now dominate (Dong & Sutton 2015 NatureCC)

INFERRED NORTH ATLANTIC OCEAN HEAT TRANSPORT

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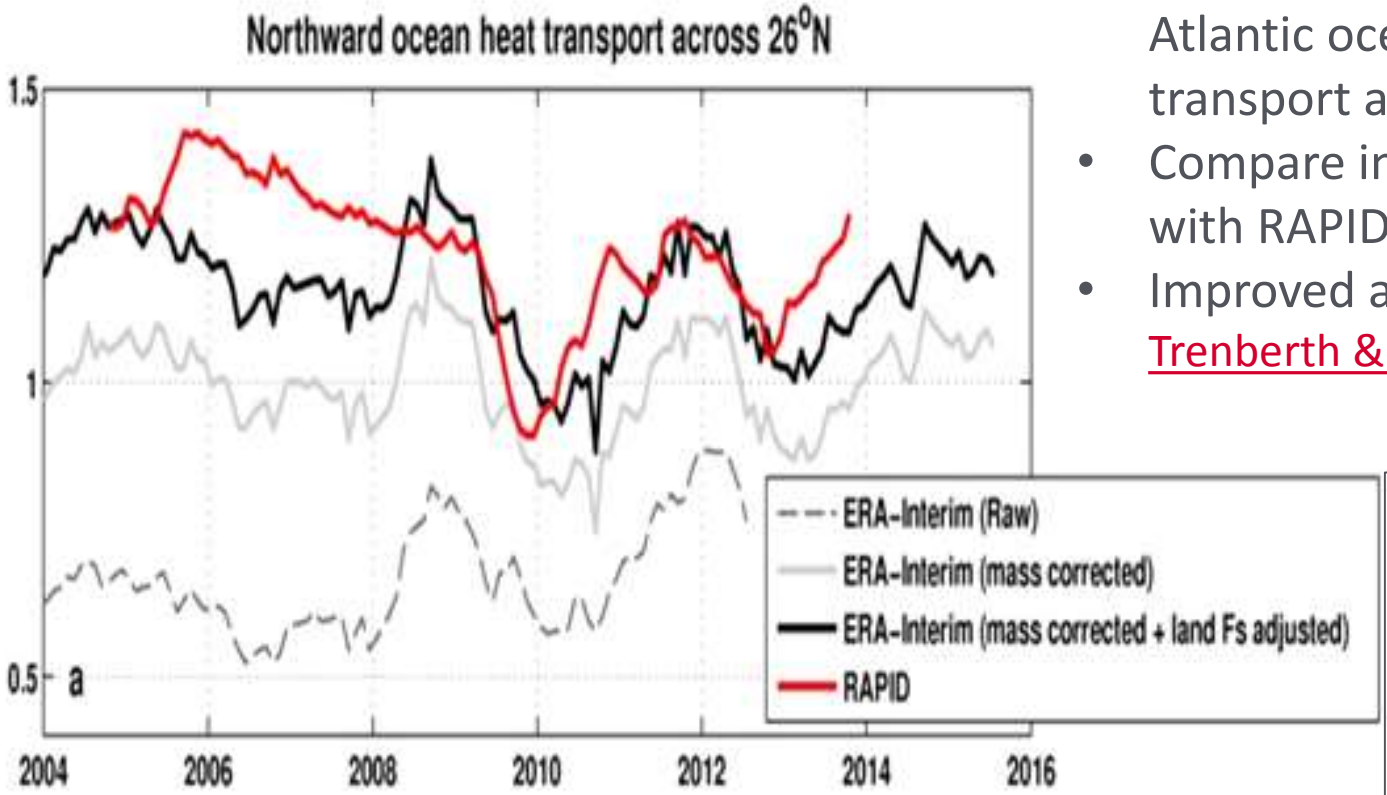
- Surface flux product combined with ORAS4 ocean heating to infer N Atlantic ocean heat transport at 26°N
- Compare indirect method with RAPID observations
- Improved agreement over Trenberth & Fasullo 2017 GRL



2004-2013
RAPID 1.23 PW
TF2017 1.00 PW
Liu et al: 1.16 PW
large uncertainty

SUMMARY

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- Earth's energy imbalance central to climate change:
  - nexus between forcing, feedback & responses
  - Ocean mixed layer interface between energy budget & surface temperature
  - Spatial warming pattern important for regional feedbacks that influence internal variability and climate sensitivity
- Energy budget & water cycle intimately linked
  - Hemispheric/regional energy budget asymmetries key to tropical precipitation
  - Ongoing monitoring of energy imbalance essential in linking forcing/response
- Outstanding Questions:

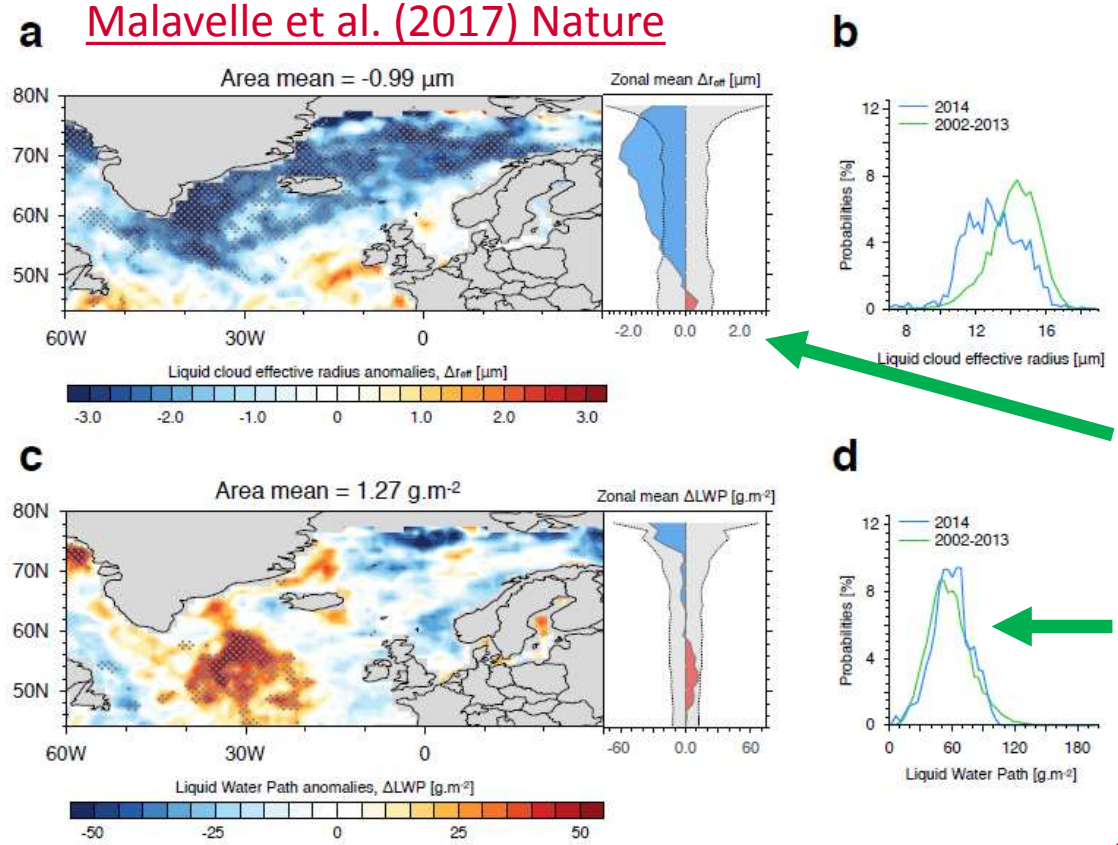
- How do feedbacks in east Pacific determine internal variability and climate sensitivity?
- Can net zero global radiative forcing with spatial pattern drive temperature change?
- Is there a missing ocean dynamical feedback on warming?
- Is internal variability adequately represented by models?
- What is the role of anthropogenic aerosol and volcanic eruptions?
- How does rebound from volcanic eruptions (e.g. Pinatubo) influence climate system?

MODIS-Aqua Observations

Droplet size

Cloud water

Malavelle et al. (2017) Nature

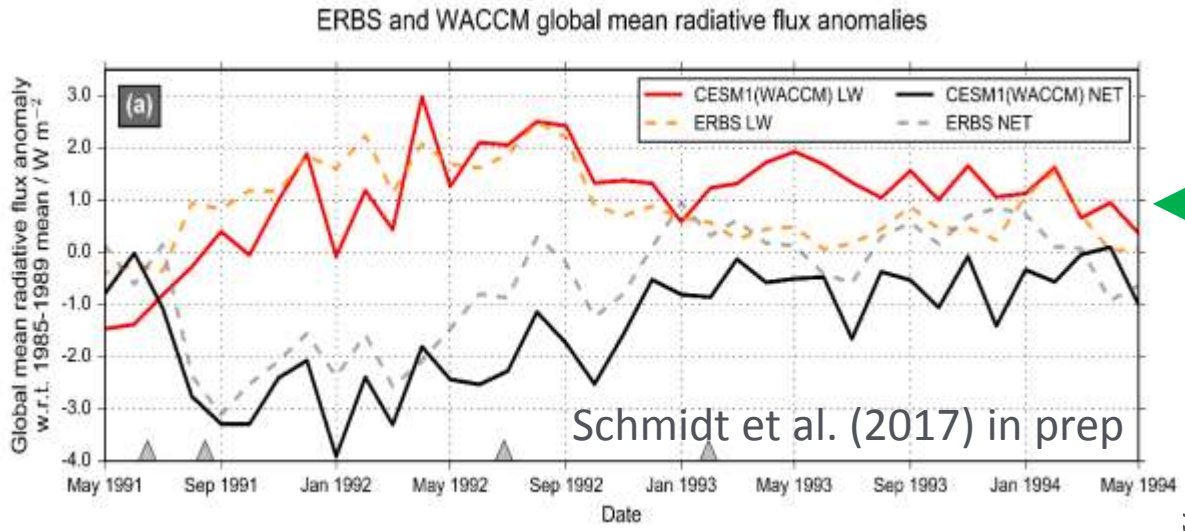


AEROSOL EFFECTS ON CLIMATE REMAIN UNCERTAIN

- Volcanic aerosol haze brightens low altitude clouds, cooling climate
- Further indirect effects in cloud water found to be negligible

Malavelle et al. (2017) Nature

- But not for cyclones? McCoy et al. (2018) ACPD



- New assessment of direct volcanic influence on climate combining nudged models & observations