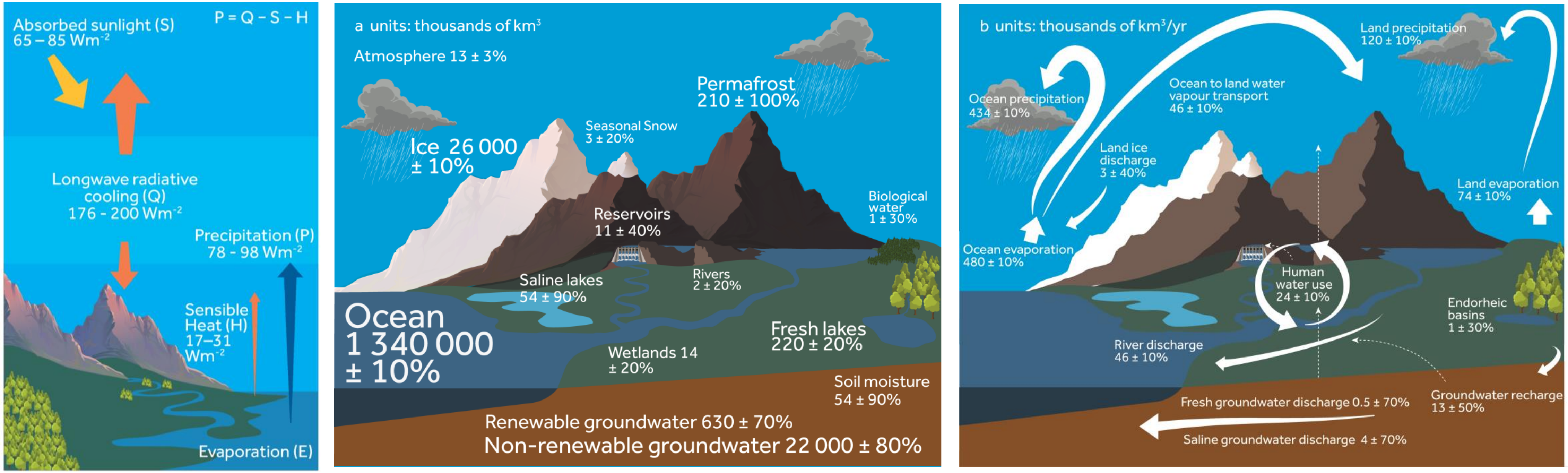
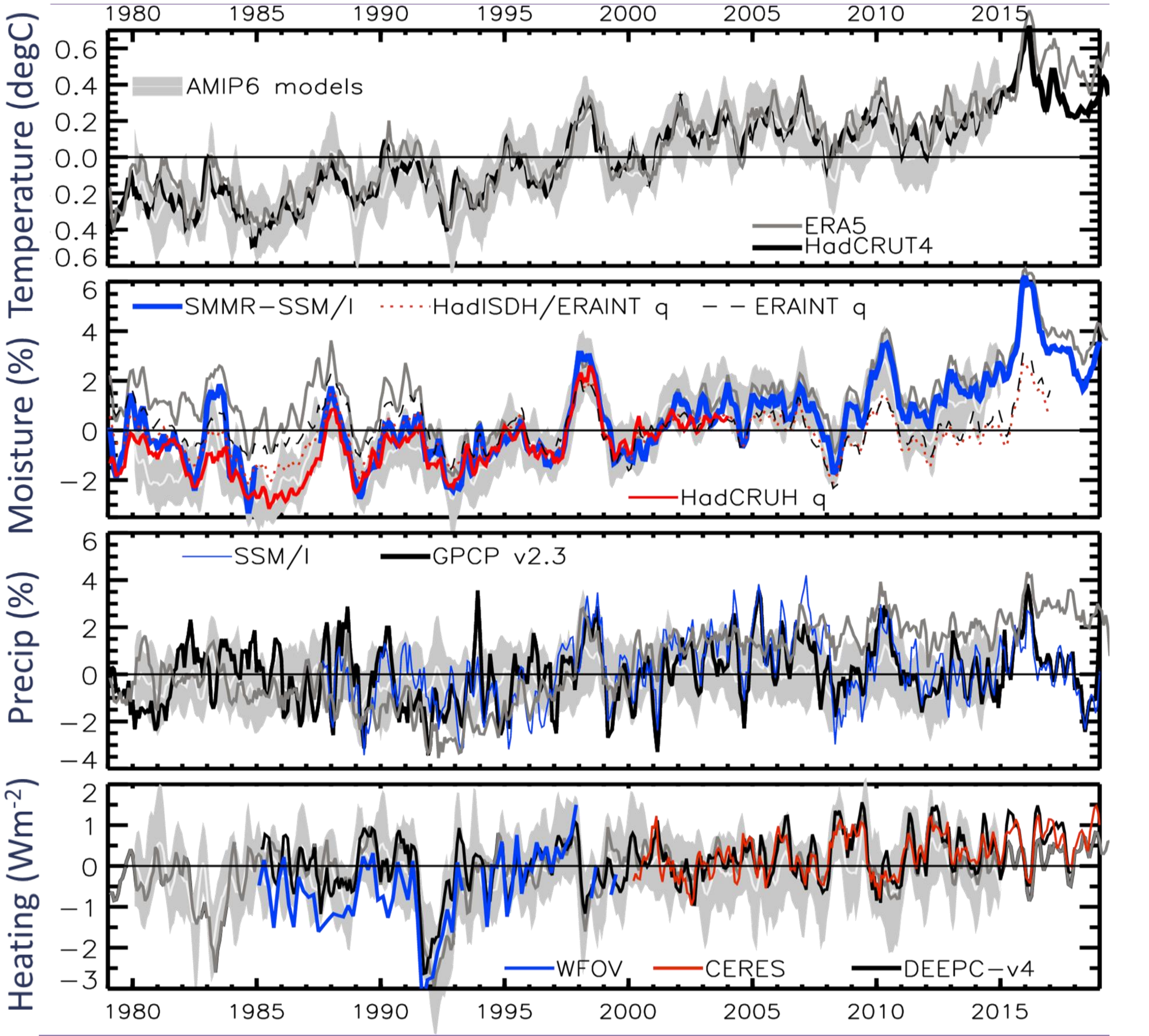
Evaluating simulated cloud, precipitation and water vapour responses to climate change



Richard Allan, NCEO/Department of Meteorology, University of Reading

Global climate change

- Robust global water vapour response (~7%/K; 1%/decade)
- Do models underestimate declining relative humidity over land? [Dunn et al. 2017]
- Small precipitation response so far expected on energetic grounds (cooling from sulphate aerosol and fast adjustments to GHGs and absorbing aerosol) Allan et al. (2020) Annals of NYAS submitted →
- ERA5 captures water vapour changes since mid-1990s but not precipitation since water budget is not closed (e.g. Allan et al. 2014 SG)



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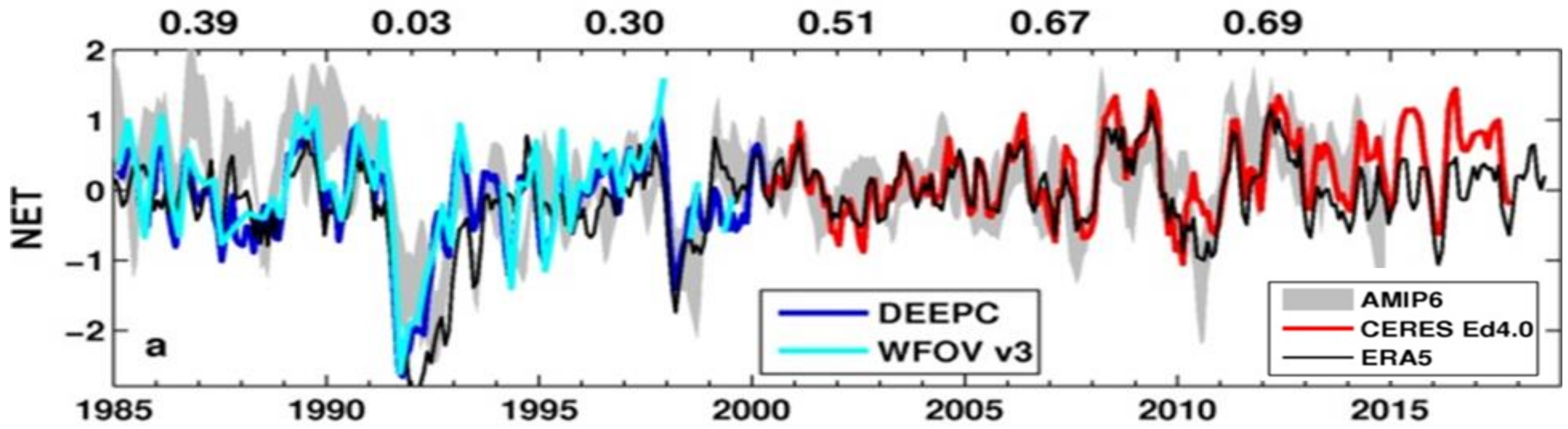
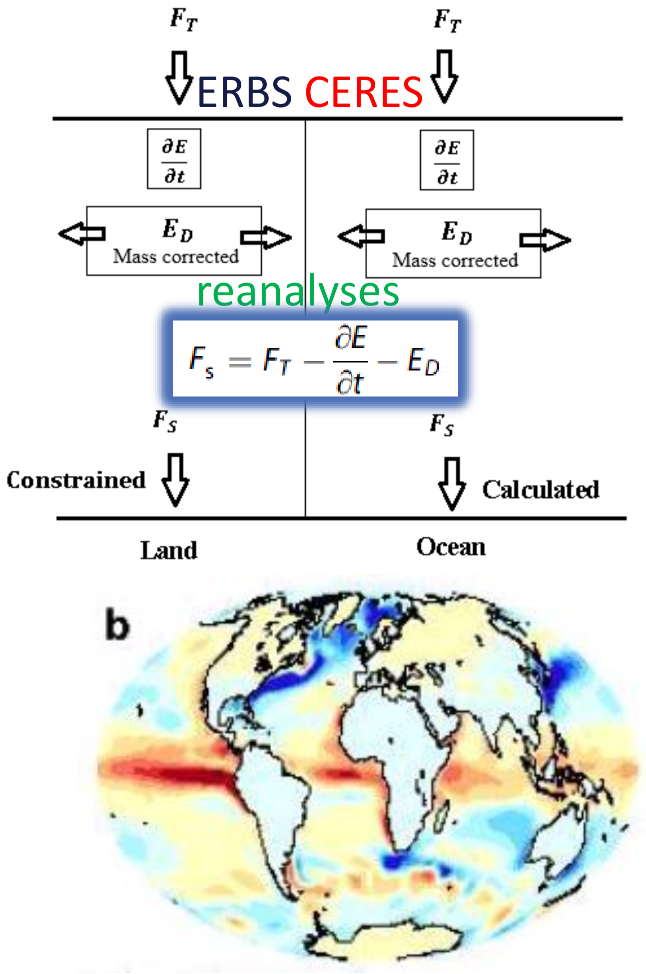
Richard Allan

Changes in Earth's energy budget



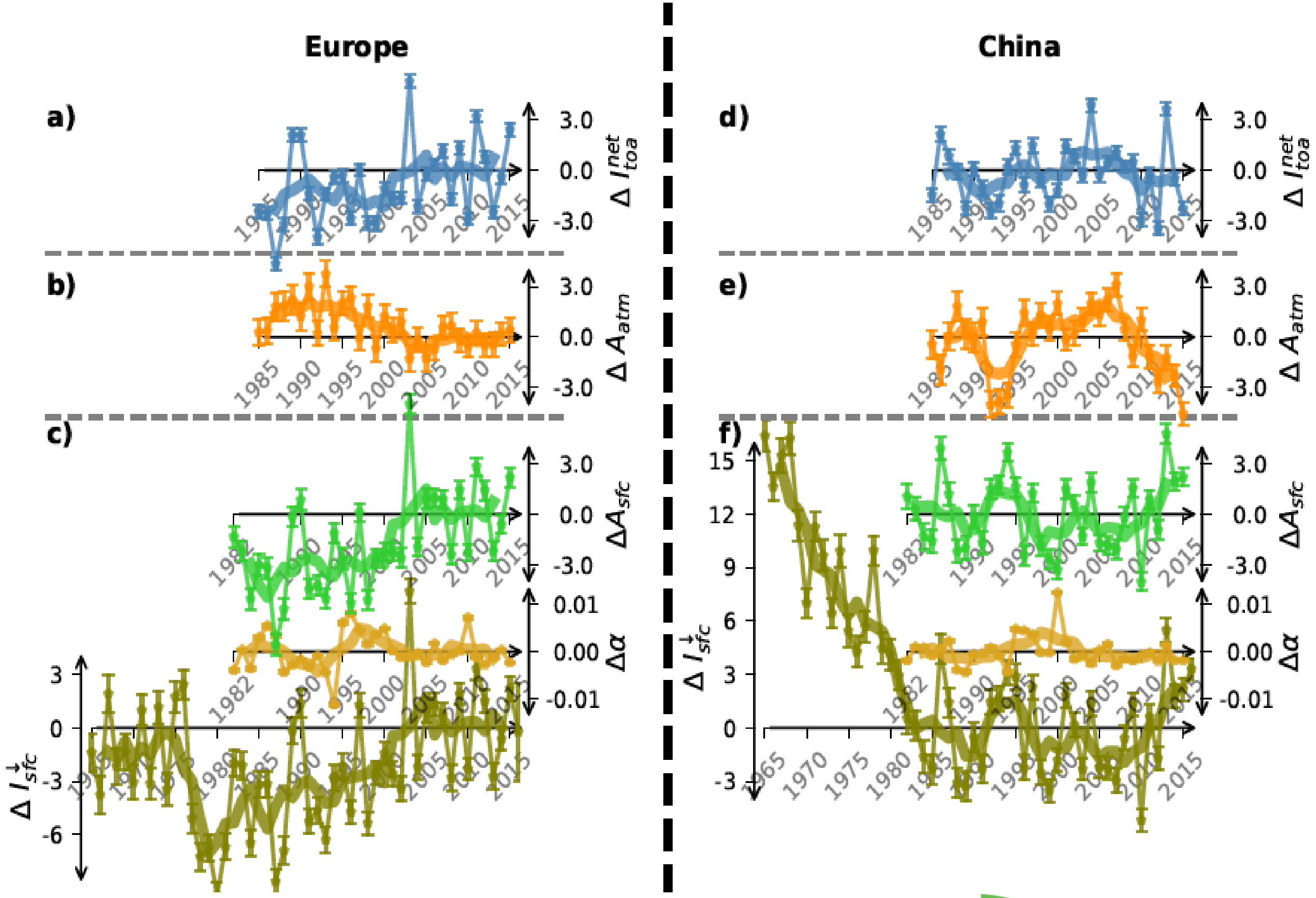
Update from Liu et al. (2017) JGR Data: http://dx.doi.org/10.17864/1947.111



- What is net imbalance and how is it changing (e.g. Allan et al. (2014) GRL) – implications for transient climate change
- Evaluation of volcanic forcing and response (Schmidt et al. 2018 JGR) in collaboration with Cambridge.

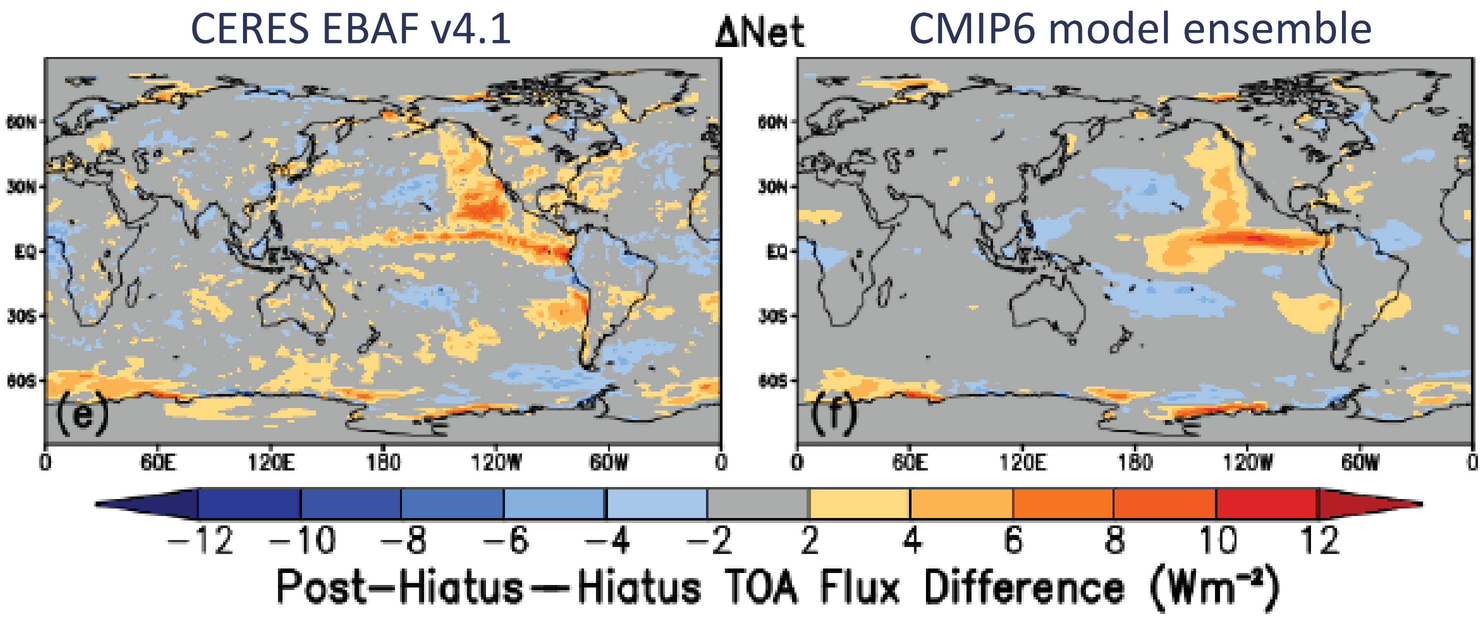
Changes in Earth's energy budget

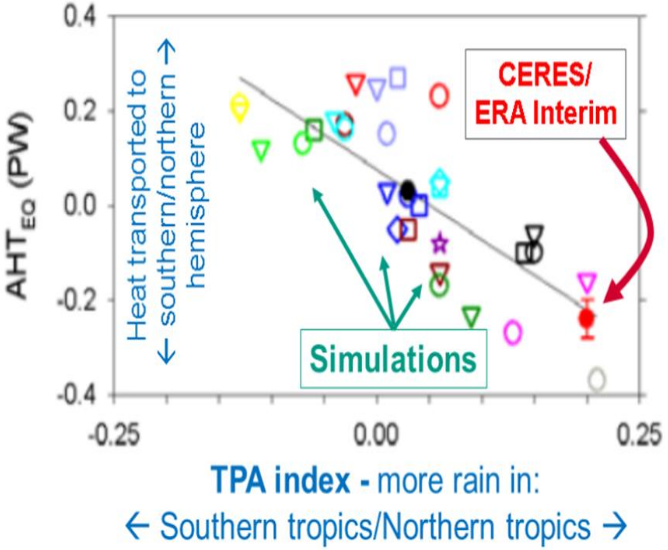
- Combining satellite and surface irradiance observations
- Solar absorption by aerosol major driver of European and Chinese surface brightening (Schwartz et al. 2020 *Nature Geosci*. in press)
- Collaboration with ETH Zurich

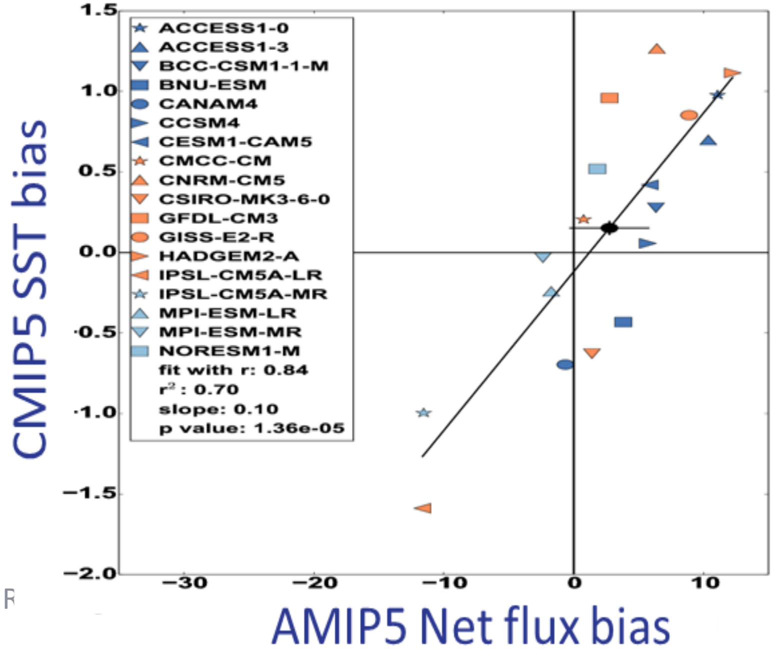


Cloud feedbacks

- Use 2015/16 El Nino as laboratory to test cloud feedbacks (Loeb et al. 2020 submitted) →
- Identification of systematic biases in hemispheric asymmetry in energy and water (Loeb et al. 2016 Clim. Dyn)
- Cloud errors and wind-feedbacks determine systematic model biases in Southern Ocean (Hyder et al. 2018 Nature Comms)
- Collaborations with Met Office and NASA Langely

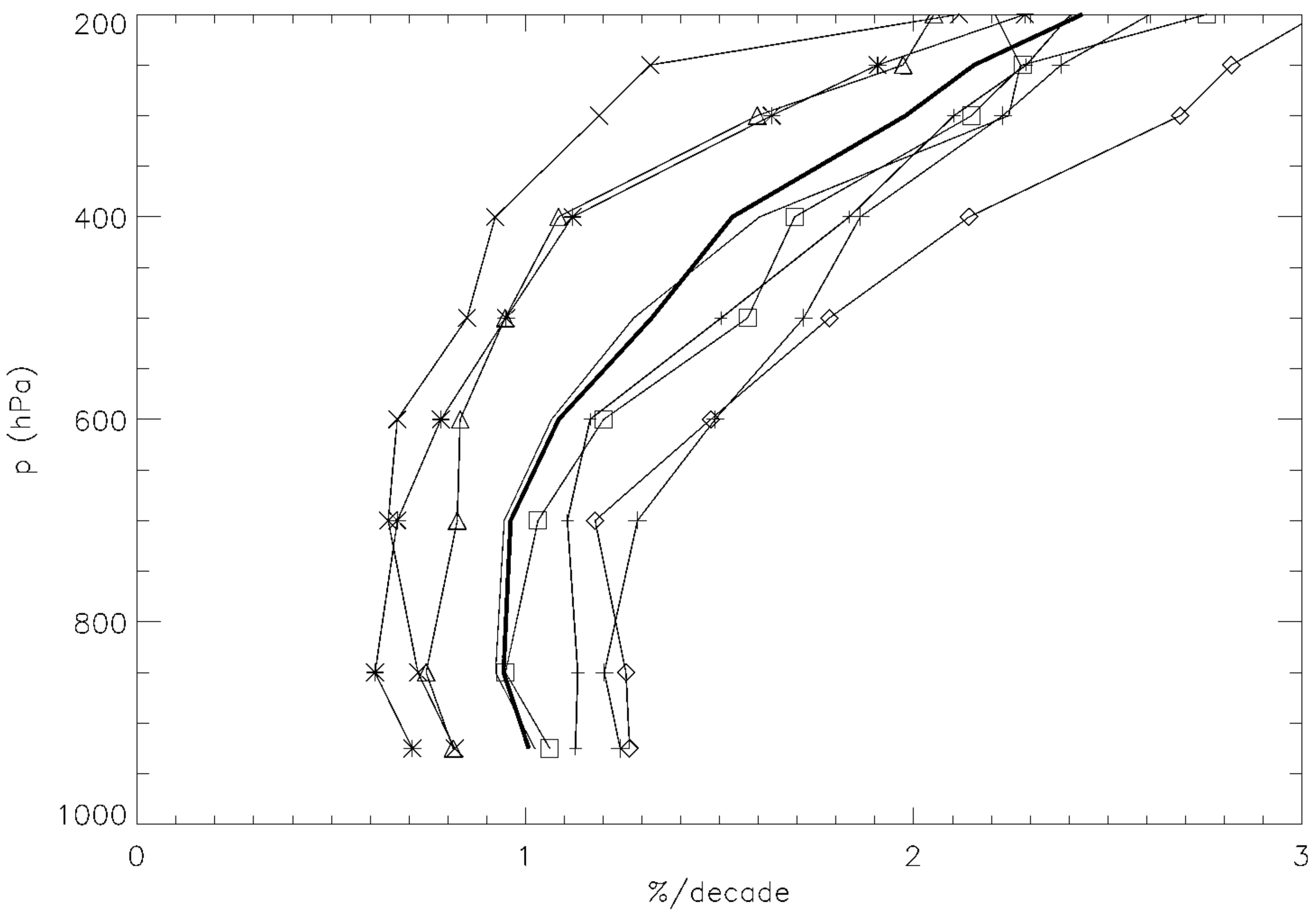






Water vapour

- Low-level water vapour increases around 1%/decade based on SSM/I-ERA5 record (see also Schroeder et al. 2016)
- Mid-upper tropospheric water vapour increases drive powerful amplifying feedback (e.g. John et al. 2019 in BAMS State of Climate)
- Right: water vapour trends in 8 CMIP6 models →
- New collaboration with Met Office, EUMETSAT, University of Exeter & Leicester



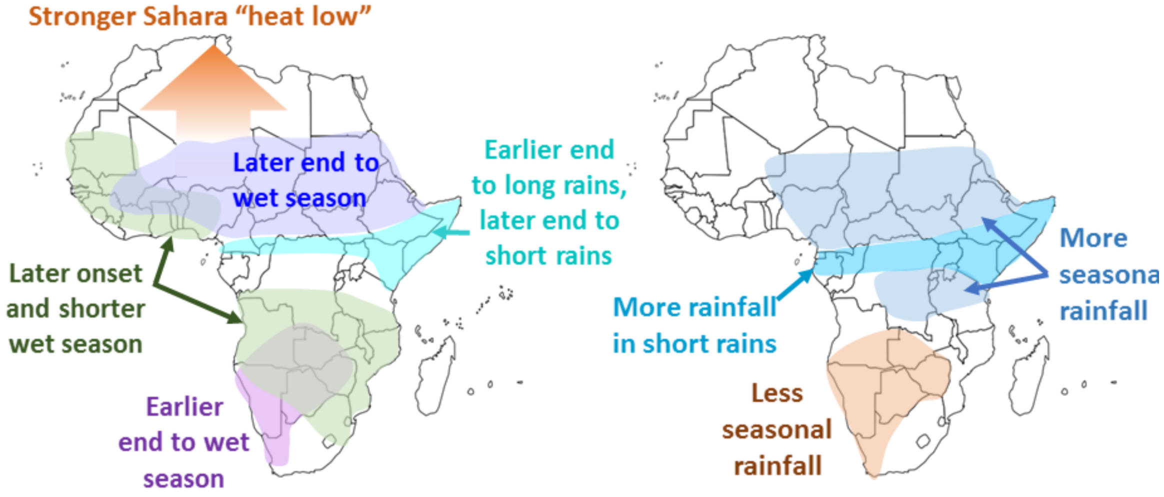
Changes in regional and seasonal precipitation

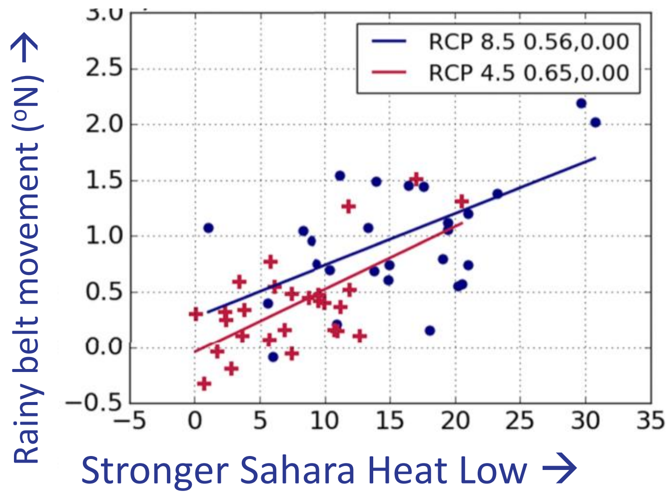
Daily satellite data used to:

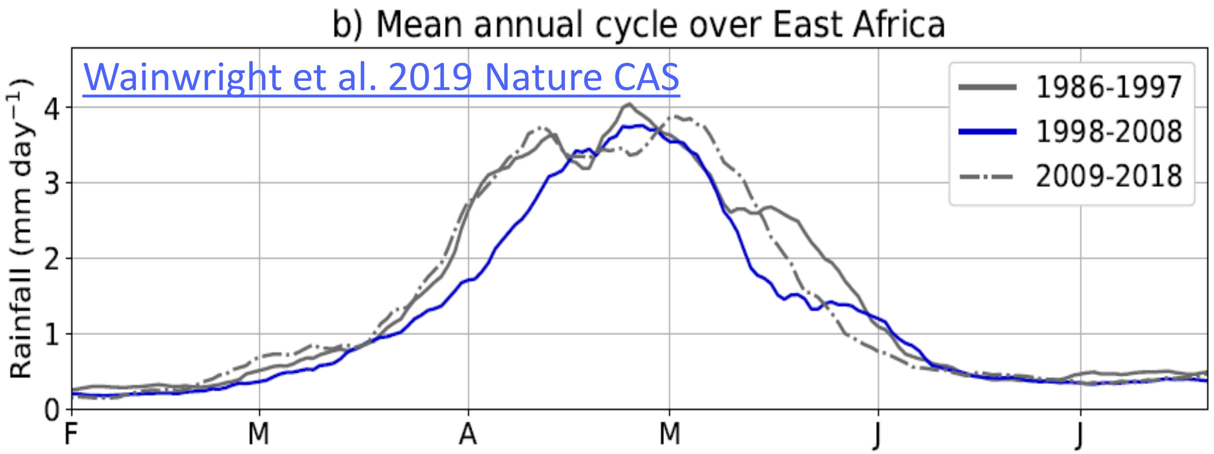
- Identify model deficiency in biannual wet seasons in southern west Africa (Dunning *et al.* 2017 ERL)
- Understand decline in East Africa long rains and attribute to climate variability (Wainwright et al. 2019 Nature CAS)
- Evaluate mechanisms driving more intense, later wet seasons over Sahel (Dunning et al. 2018 J. Clim)

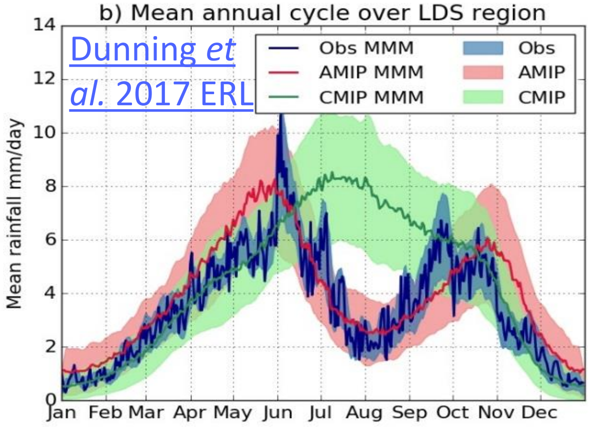
Collaboration with TAMSAT Reading & NCAS Leeds

Dunning et al. 2018 J. Clim









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Conclusions

- Multiple collaborations ongoing combining satellite data with in situ observations and CMIP6 simulations to evaluate energy and water cycles
- Improvements in models and process understanding of feedbacks of importance to IPCC
- Water vapour increases ~1%/decade near the surface but do models underestimate relative humidity decline?
- Modest global precipitation responses (~1%/^{o}C) are expected on physical grounds but challenging to detect
- Are systematic model errors in southern ocean and cross-equatorial flows reduced in CMIP6?
- How realistic are cloud feedbacks and responses to volcanic forcing and absorbing aerosols in simulations?
- How do regional precipitation changes relate to forced thermodynamic or circulation response and are these distinct from internal climate variability?

Some Questions

- Suppressed hydrological sensitivity over land and feedbacks
  - Are simulated rapid responses to radiative forcing realistic?
  - Do models underestimate declining relative humidity over land?
  - How realistic are vegetation/soil moisture feedbacks?
  - How do plants respond to elevated CO_2 (photosynthesis, stomata effects, water use efficiency and tolerance to drought)?
  - What is the possibility for abrupt, irreversible and worst case storylines?
- Water Cycle intensification
  - How is P-E and aridity responding over land?
  - How does are sub-daily to seasonal rainfall responding to warming? Does extra latent heat release invigorate storms?
  - How is mean and seasonal streamflow and soil moisture responding to warming and melting of ice?
  - How will flooding change? e.g. fluvial responses in large/small river catchments and pluvial responses in urban regions
- Circulation responses to warming
  - How do regional responses to aerosol/GHG forcing and SST patterns affect regional water cycle?
  - How will tropical rain belt & monsoon respond to evolving radiative forcing (aerosol, GHGs), cross equatorial heat transports & warming patterns?
  - What is the link between Arctic warming amplification and mid-latitude weather?
- How is land use change, irrigation and other water withdrawals directly affecting water cycle?
  - How do local effects from deforestation/afforestation, irrigation and urbanization affect local water cycle?
- How does aerosol affect water cycle?
  - Large-scale circulation changes, suppression of warm rain, invigoration of storms

Monitoring and attribution of water cycle changes

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