Department of Meteorology

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ACCOUNTING FOR CIRCULATION CHANGES TO INTERPRET WATER CYCLE RESPONSES

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Thanks to Chunlei Liu

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

National Centre for Atmospheric Science
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NERC SCIENCE OF THE ENVIRONMENT

Met Office

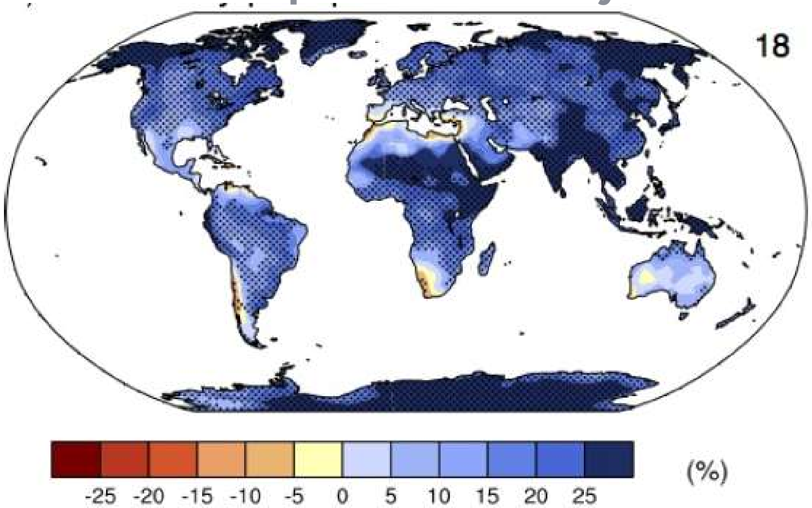
INTRODUCTION

- Changes in the global water cycle are dictated by radiatve transfer and thermodynamics but dominated locally by circulation changes
- There is a distinction between detection, physical understanding and prediction of regional changes in the water cycle but all are linked
- How can the influences of circulation and thermodynamics be separated to better understand & predict regional water cycle?

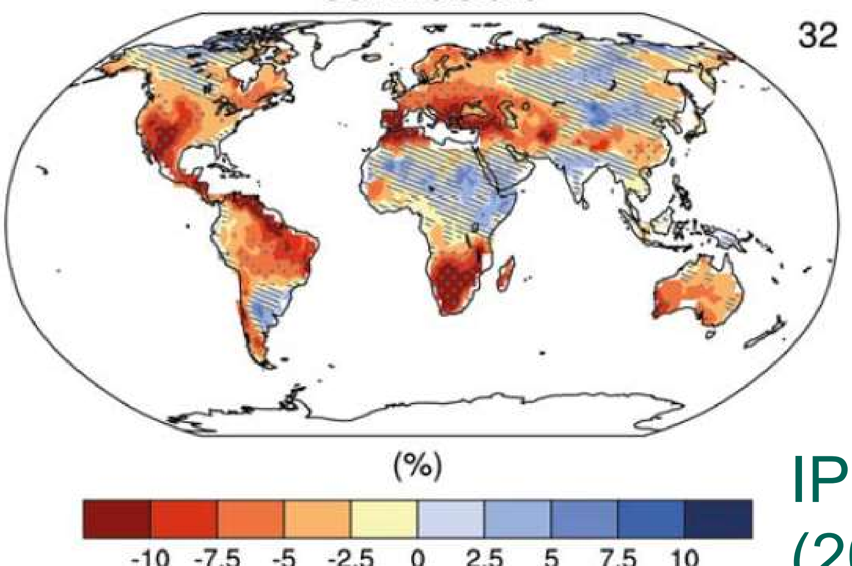
HOW WILL WATER CYCLE CHANGE?

- More global mean precip.
- More intense rainfall
- More intense droughts?
- Intensification of wet and dry seasons?
- Regional projections??

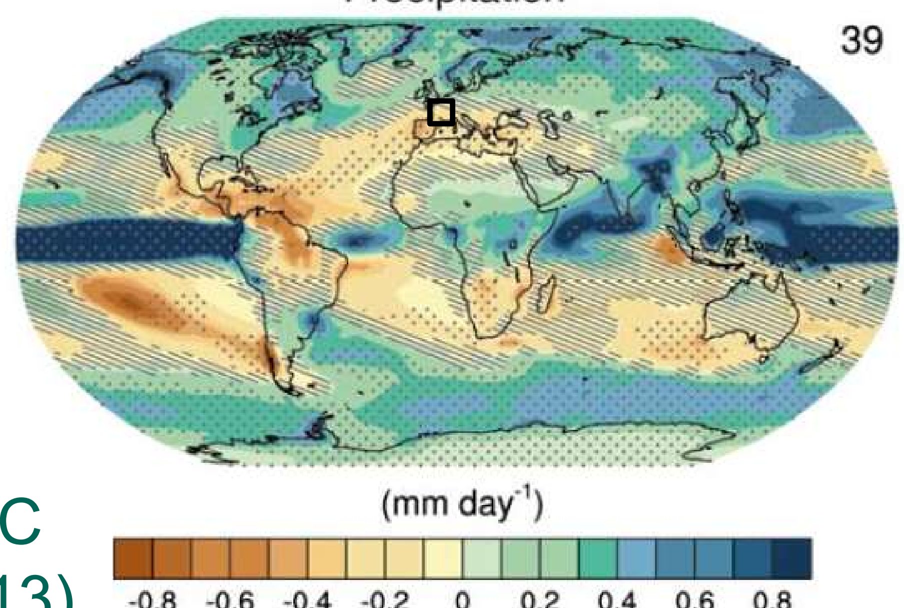
Precipitation intensity



Soil moisture



Precipitation



IPCC (2013)

MOISTURE BALANCE CONSTRAINT

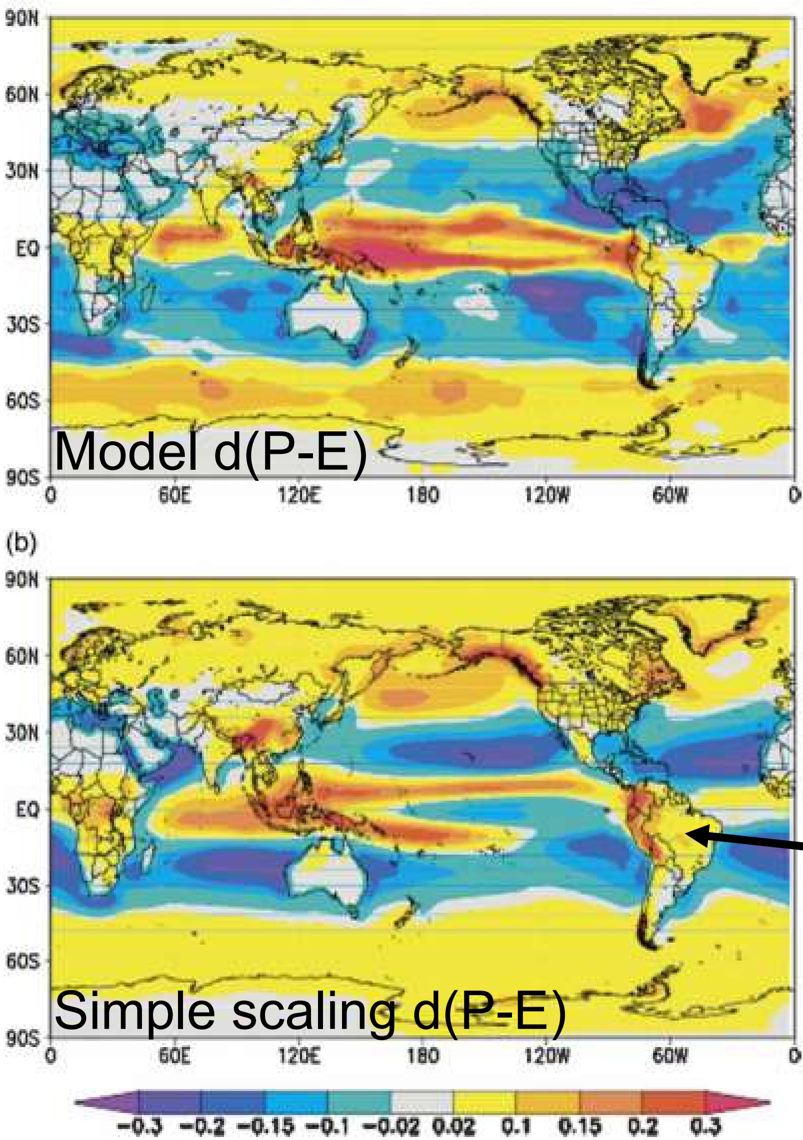


FIG. 7. The annual-mean distribution of $\delta(P-E)$ from the ensemble mean of (a) PCMDI AR4 models and (b) the thermodynamic component predicted from (6) from the SRES A1B scenario.

$$\frac{\delta F}{F} \approx \frac{\delta e_s}{e_s} \approx \alpha \delta T. \quad \alpha \approx 0.07\ \mathrm{K}^{-1}$$

$$\delta(P-E) = -\nabla \cdot (\alpha \delta T F). \approx \alpha \delta T (P-E).$$

Enhanced moisture transport *F* leads to amplification of:

(1) P–E patterns (left)

Held & Soden (2006) ; Mitchell et al. (1987)

(2) ocean salinity patterns

Durack et al. (2012) *Science*

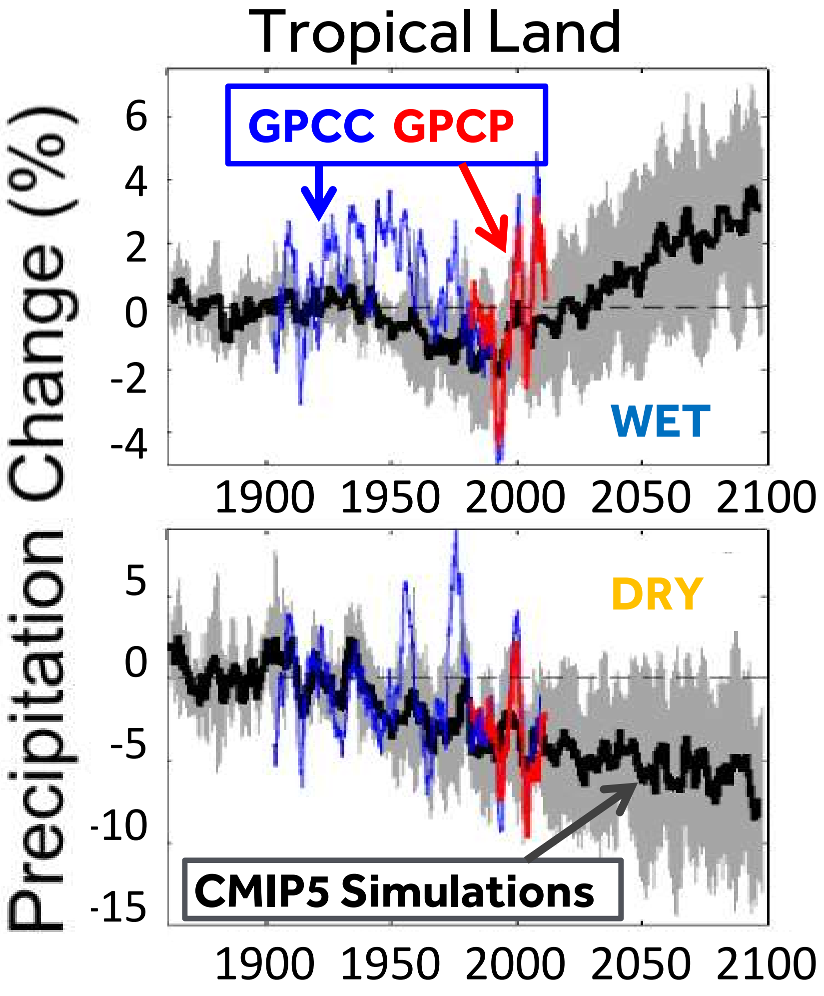
Changes over land are less clear as multi-annual P-E > 0 & RH changes

Budyko framework useful (e.g. Roderick et al. 2014 ; Greve et al. 2014)

$$E = \frac{P E_0}{(P^n + E_0^n)^{1/n}}$$

MOISTURE TRANSPORT AND INTENSIFICATION OF WET/DRY SEASONS

- Increased moisture with warming implies amplified P-E (e.g. Held & Soden 2006)
- Multi-annual P-E > 0 over land implies increased P-E (e.g. Greve et al. 2014)
- Changes in T/RH gradients also important (Byrne & O'Gorman 2015)
- P-E < 0 in dry season over land: more intense dry *and* wet seasons? (Chou et al. 2013; Liu & Allan 2013; Kumar et al. 2014)
- Aridity metrics more relevant (Scheff & Frierson 2015; Greve & Seneviratne 2015; Roderick et al. 2014 ; Kumar et al. 2016)
- Changes in circulation dominate locally (e.g. Scheff & Frierson 2012; Chadwick et al. 2013; Muller & O'Gorman 2011; Allan 2014)



Liu & Allan 2013 ERL

AMPLIFICATION OF WET/DRY SEASONS?

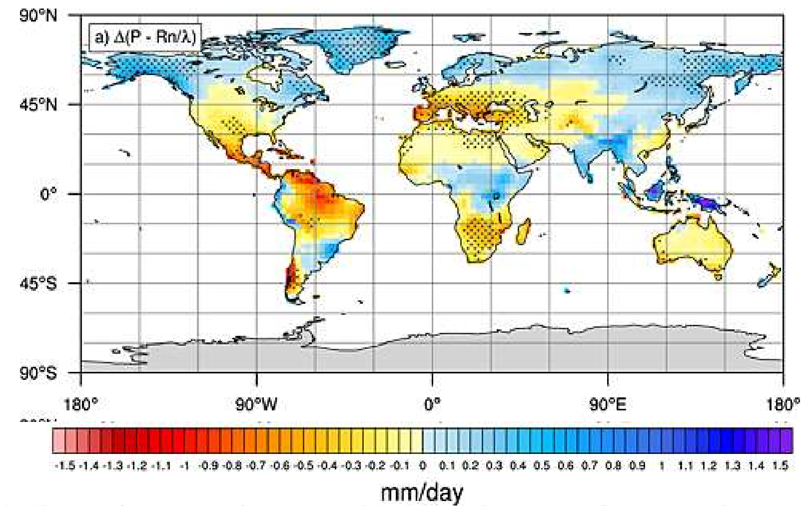
- Aridity index: P-Eo ~ P-Rn/λ

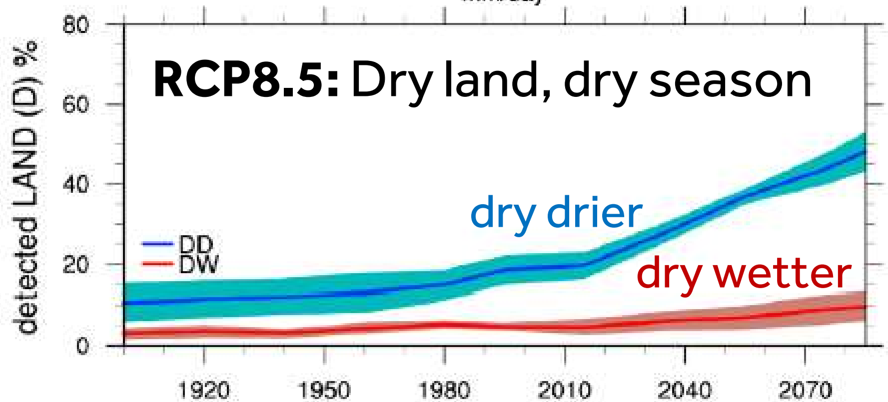
 (E_o is potential evaporation, R_n is net radiation and λ is latent heat of vapourization). Top right: Δ(P-Rn/λ)

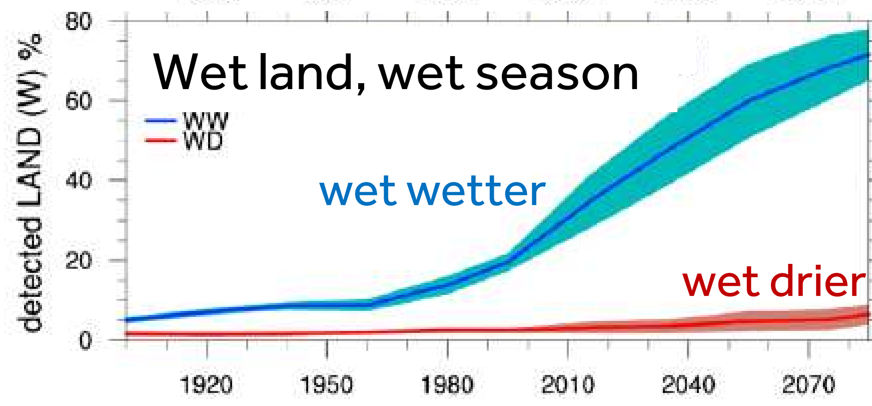
[Greve & Seneviratne (2015) GRL](#)

 See also: [Roderick et al. (2014) HESS](#)

- Trends in wetness and dryness:
  - Strongly influenced by shifts in atmospheric circulation
  - Constrained by P>E and water limitation over land
  - But: P-E < 0 after wet season
- Amplification of wet/dry seasons over land [Kumar et al. 2016 GRL](#) →

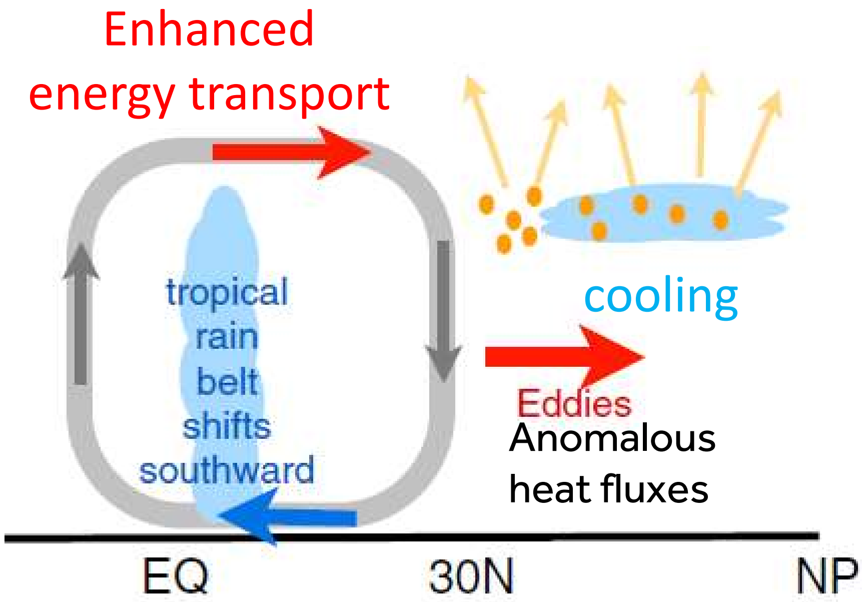


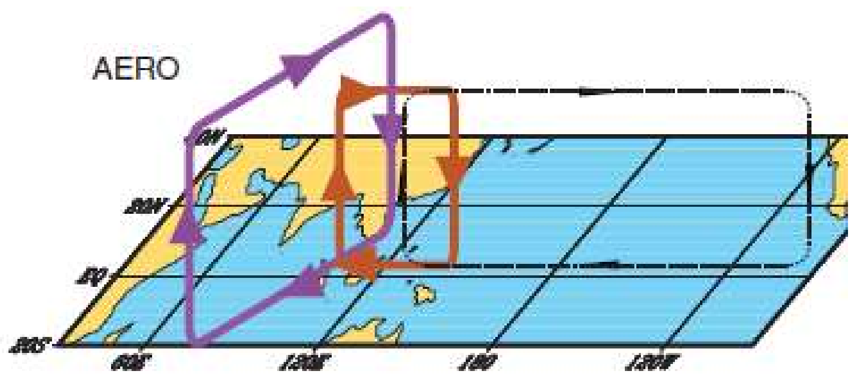




EARTH'S ENERGY BUDGET & REGIONAL CHANGES IN THE WATER CYCLE

- Regional precipitation biases/changes sensitive to asymmetries in Earth's energy budget e.g. Loeb et al. (2015) Clim. Dyn; Haywood et al. (2016) GRL
- N. Hemisphere cooling: less heat transport out of hemisphere
- Reduced Sahel rainfall from:
  - Anthropogenic aerosol cooling 1950s-1980s: Hwang et al. (2013) GRL →
  - Asymmetric volcanic forcing e.g. Haywood et al. (2013) Nature Climate





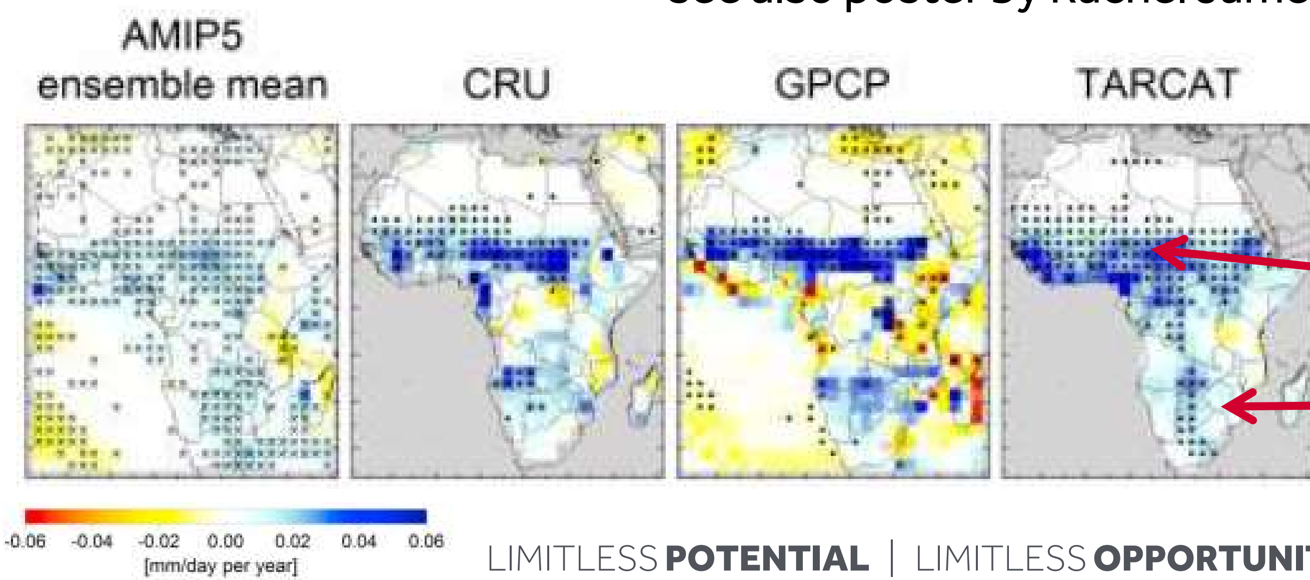
- Sulphate aerosol effects on Asian monsoon e.g. Bollasina et al. 2011 Science (left) & links to drought in Horn of Africa? Park et al. (2011) Clim Dyn
- GHGs & Sahel rainfall recovery? Dong & Sutton (2015) Nature Clim

Also: posters by Laura Wilcox, Angus Ferraro, Matt Hawcroft

AFRICA RAINFALL AND CIRCULATION CHANGES

- Regional rainfall sensitive to radiative forcings, inter-hemispheric heating & internal variability
- Africa susceptible to changes in water cycle: monitoring essential (e.g. TAMSAT group)
- West Africa - mix of pollution/cloud/dynamics: DACCIWA project, Knippertz et al. 2015

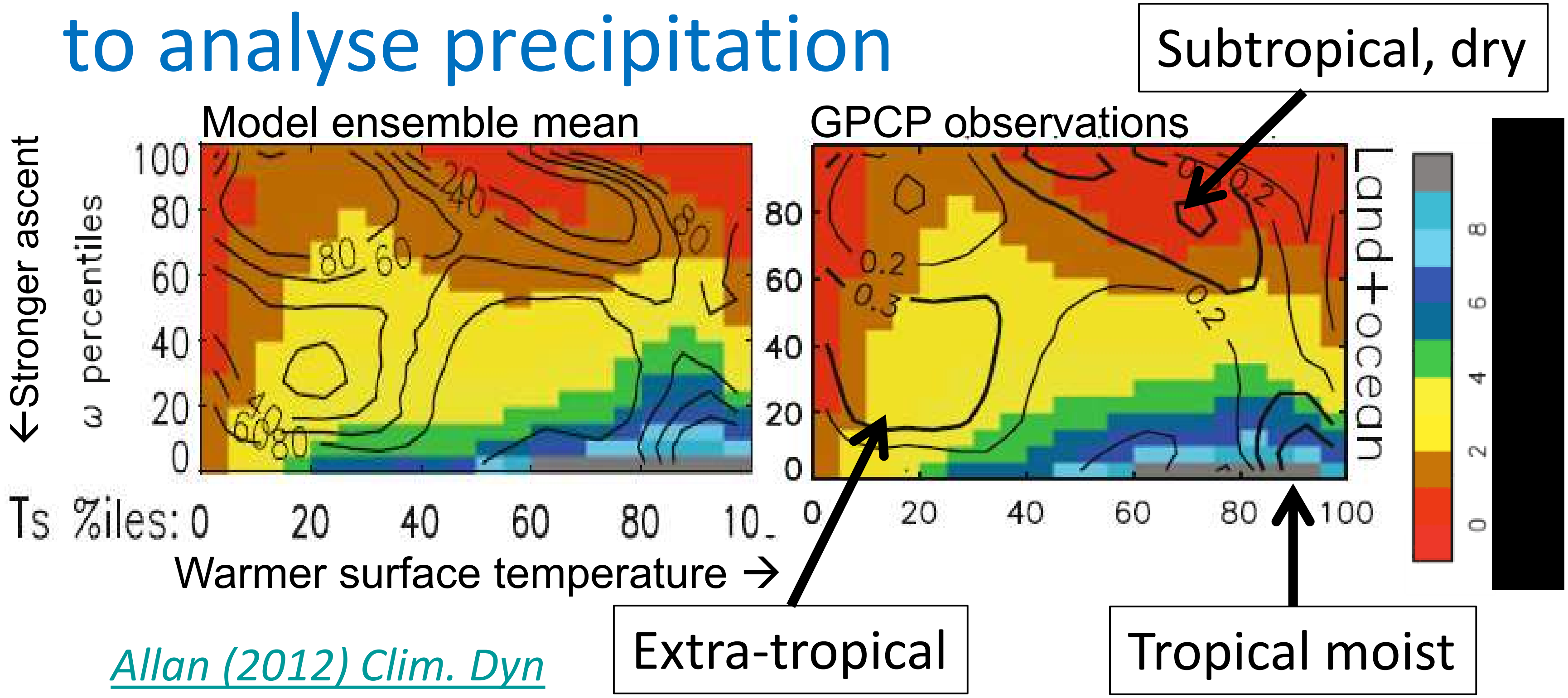
- Recent trends Africa rainfall: Maidment et al. (2015) GRL
  - see also poster by Rachel James



Radiative forcing?

Internal variability?

Using dynamical regime composites to analyse precipitation



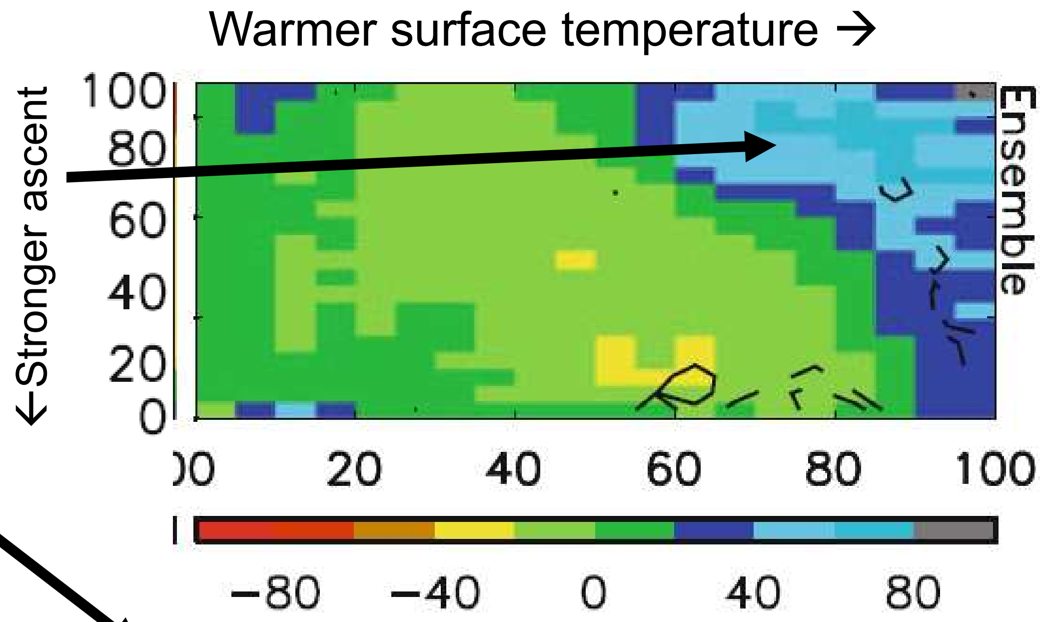
Allan (2012) Clim. Dyn

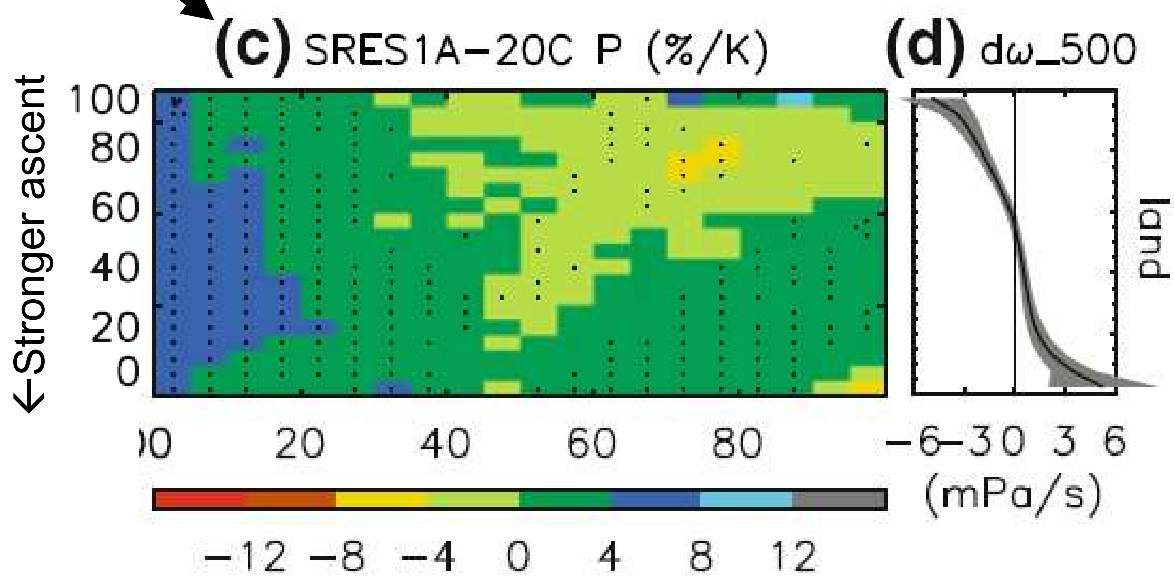
- Composite precipitation by percentiles of vertical motion (strong decent to strong ascent) and temperature
- Contour values enclose % of total area (left) or show percentage contribution of each composite box to total area (right)

Precipitation bias and response by dynamical regime

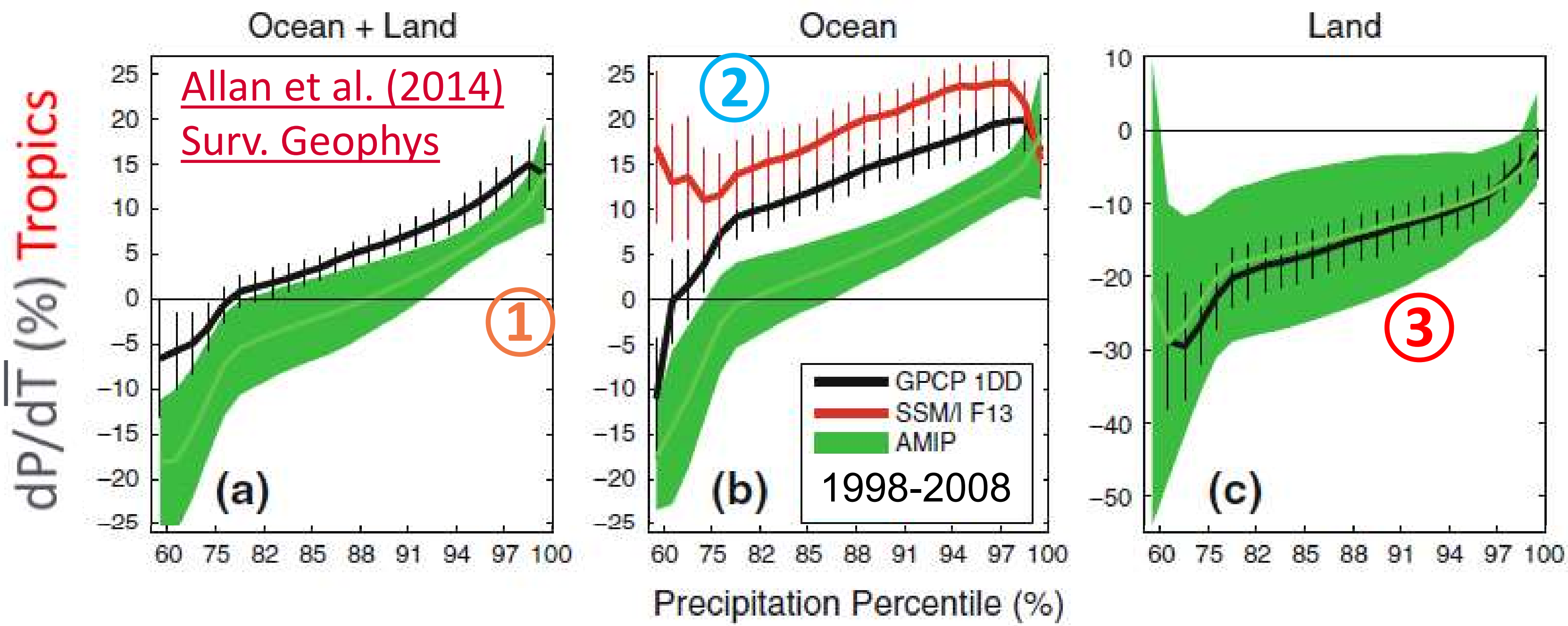
- Model biases in warm, dry regime
- Strong wet/dry fingerprint in model projections (even for land) *Allan (2012) Clim. Dyn*

Note: Since P constrained by energetics to increase more slowly than water vapour and static stability increases, reduced circulation/regional adjustments in circulation likely, e.g.: Bony et al. (2013) Nat Geosci ; Chadwick et al. (2012) J Clim ; Zelinka & Hartmann (2010) JGR





PROBABILITY DISTRIBUTION APPROACH TO PRECIPITATION EXTREMES



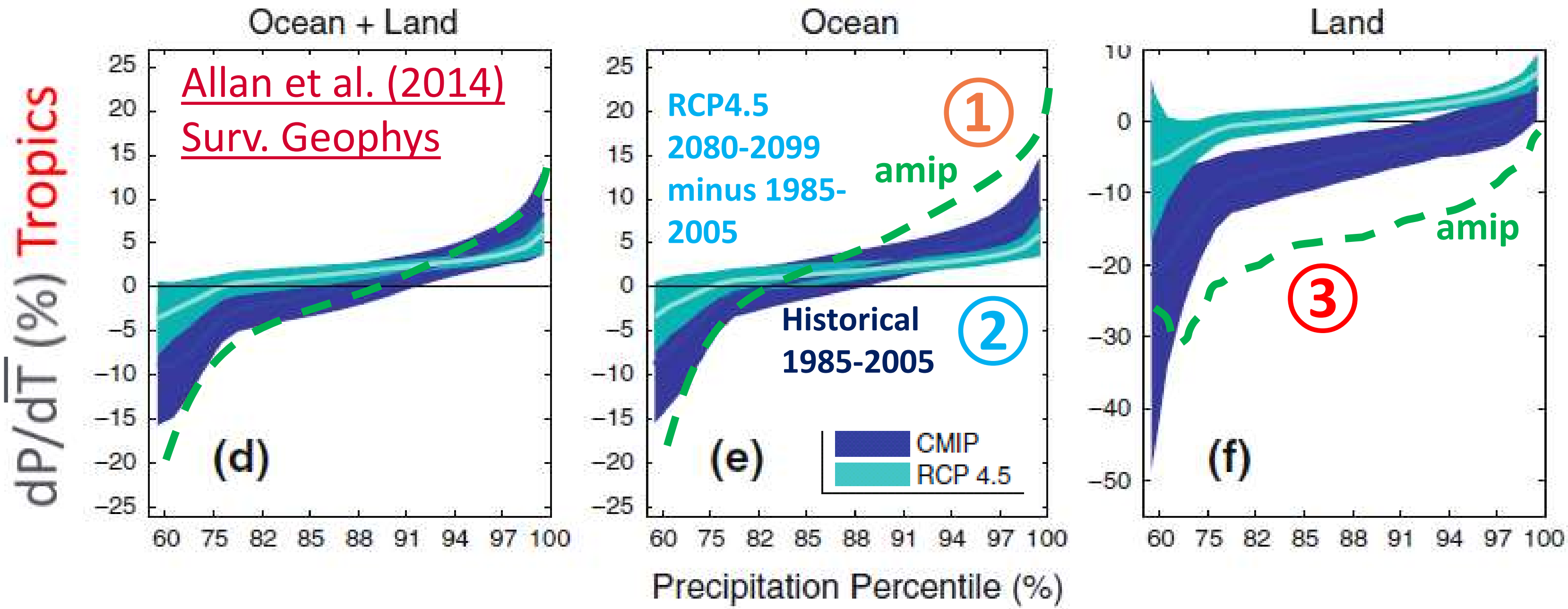
- 5-day means (observations and simulations)

① More positve dP/dT for heavier percentiles (observations & models)

② Observations have more positive sensitivity over the ocean

③ Mostly negative dP/dT for all percentiles over land due to less rainfall over land during El Niño when warmer tropical mean Temperatures

PROBABILITY DISTRIBUTION APPROACH TO PRECIPITATION EXTREMES



① Smaller dP/dT sensitivity for coupled simulations (**historical** vs **amip**)

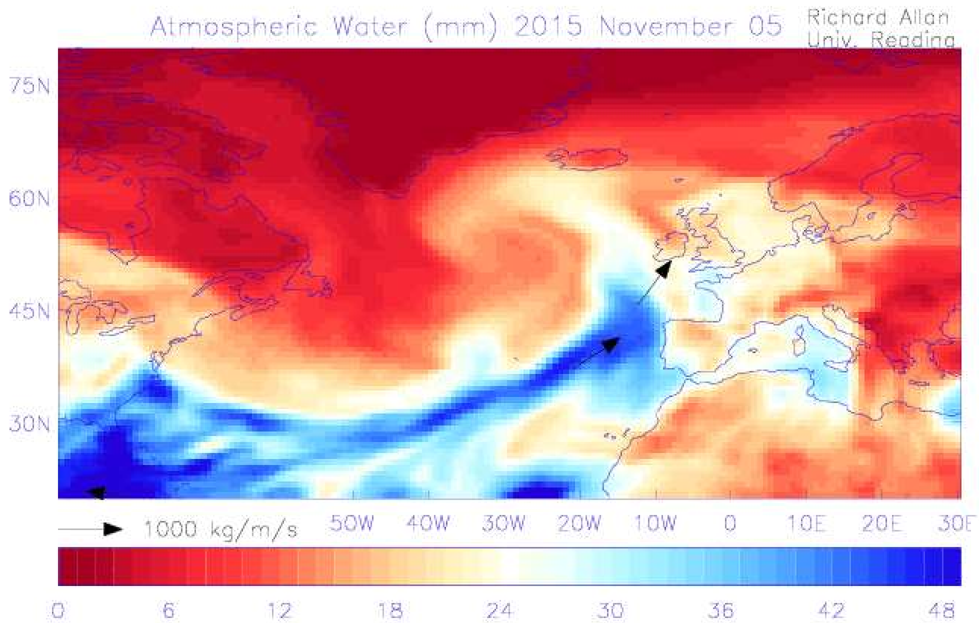
② Smaller dP/dT sensitivity under climate change (**historical** vs **rcp4.5**) as dP/dT supressed by direct atmospheric heating from rising greenhouse gases

③ More positive dP/dT over land under climate change (**rcp4.5** vs **historical**) as Temperature rises un-related to ENSO for climate change response

CONCLUSIONS: a. Amplification of precipitation extremes with climate warming

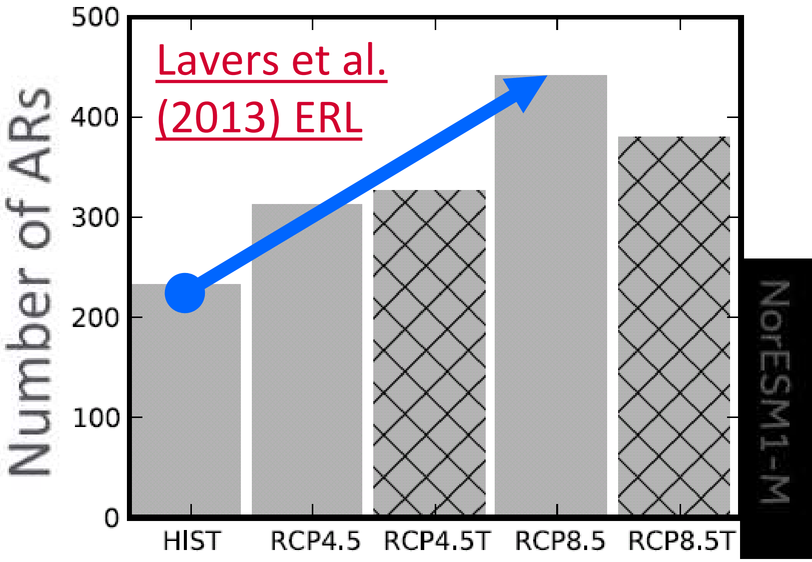
b. Interannual variability is not a good proxy for climate change over land

PROJECTING IMPACT-RELEVANT METRICS



- Future increase in moisture explains most (but not all) of intensification of AR events
  - Confident in the mechanisms and physics involved

- UK winter flooding linked to strong moisture transport events
  - Cumbria November 2009 (Lavers et al. 2011 GRL)
  - "Atmospheric Rivers" (ARs) in warm conveyor



CONCLUSIONS

- Changes in the global water cycle are dictated by radiatve transfer and thermodynamics but dominated locally by circulation changes
- Separating thermodynamic/dynamic factors necessary for detection, physical understanding and prediction of regional changes in the water cycle
- Some regional changes are unpredictable – deal with it!
  - e.g. when weather patterns deliver hydrological extremes they are liable to be more severe in a warmer world