Department of Meteorology

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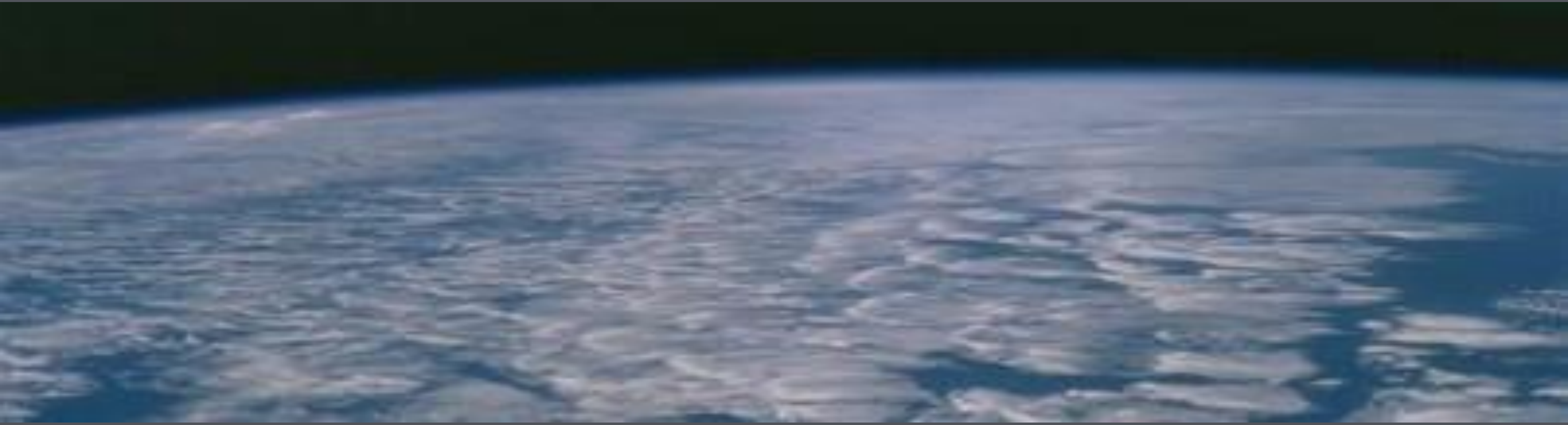
GLOBAL TO REGIONAL DRIVERS OF WATER CYCLE SENSITIVITY TO CLIMATE CHANGE



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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?

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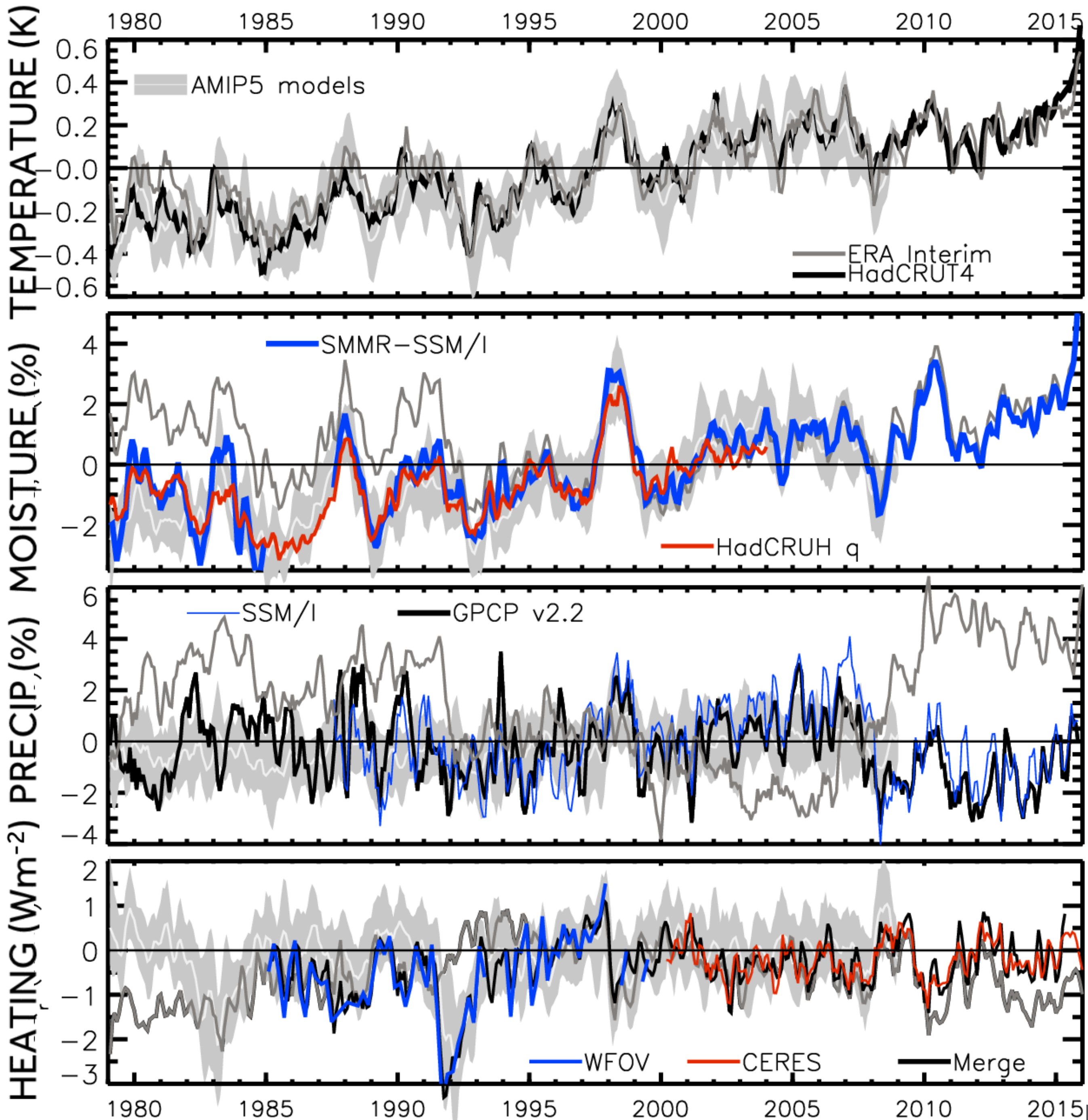
TRACKING GLOBAL CLIMATE CHANGE



Updated from Allan et al. (2014) Surveys of Geophys & Allan et al. (2014) GRL

2.8
1.8
0.8
-0.2
-1.2
-2.2

Earth's energy imbalance (Wm^{-2})

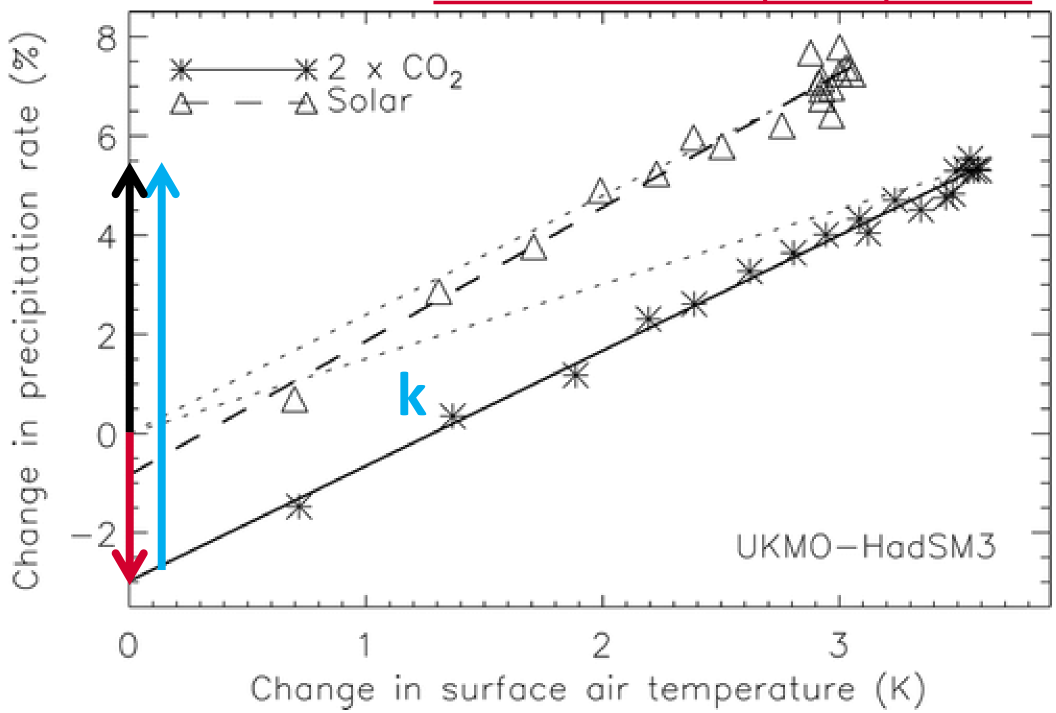
EARTH'S ENERGY BUDGET AND PRECIPITATION RESPONSE

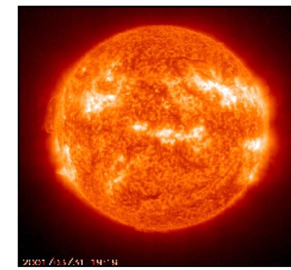
Andrews et al. (2009) J Clim

$L\Delta P \approx k\Delta T - f_F\Delta F$

ahem?

ΔSH





See also: Allen and Ingram (2002) Nature ; O'Gorman et al. (2012) Surv. Geophys ; Bony et al. 2014 Nature Geosci.

See also talk by Alex Hall.

SIMPLE MODEL FOR GLOBAL PRECIPITATION

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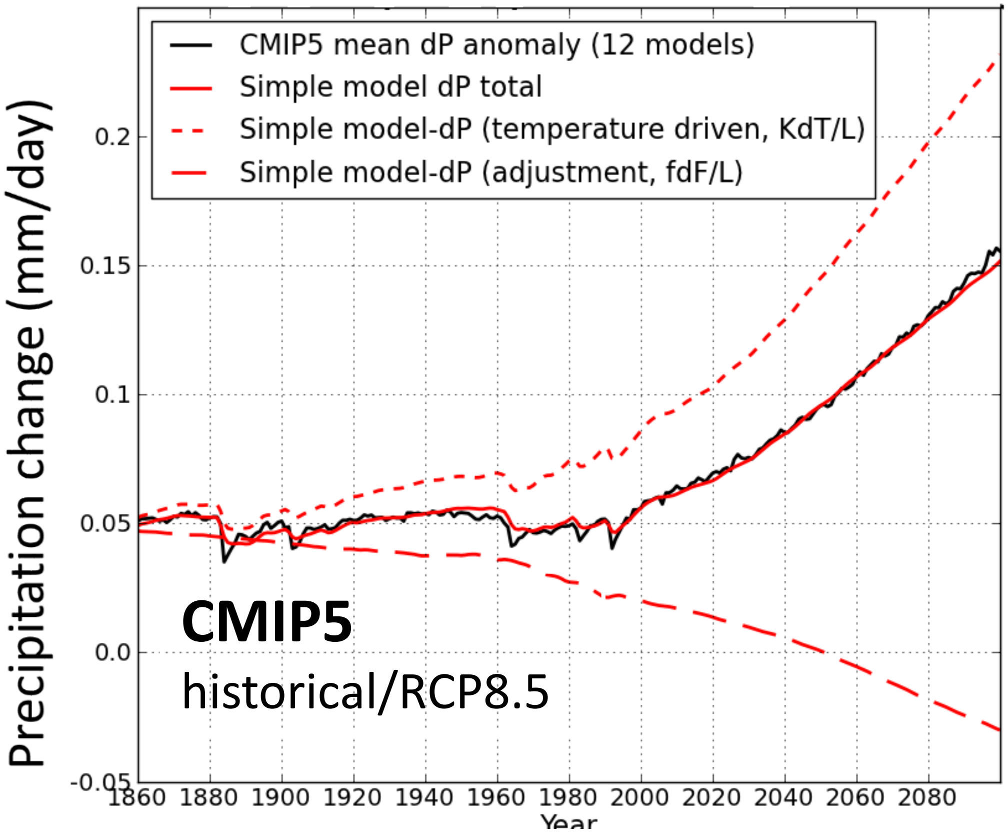


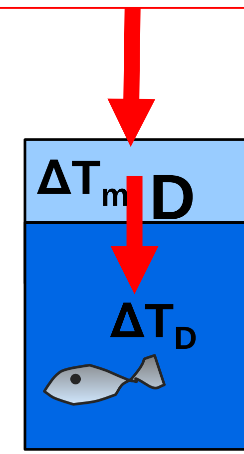
After Allan et al. (2014) Surv. Geophys and Thorpe and Andrews (2014) ERL

Using simple model:

$$\mathbf{L\Delta P = k\Delta T - f_F\Delta F}$$

$$\frac{d\Delta T_m}{dt} = \frac{1}{C_m}(\Delta F - Y\Delta T_m - D)$$

$$\mathbf{N = \Delta F - Y\Delta T_m}$$



$$D = c(\Delta T_m - \Delta T_D)/d$$

Zahra Mousavi
(PhD project)

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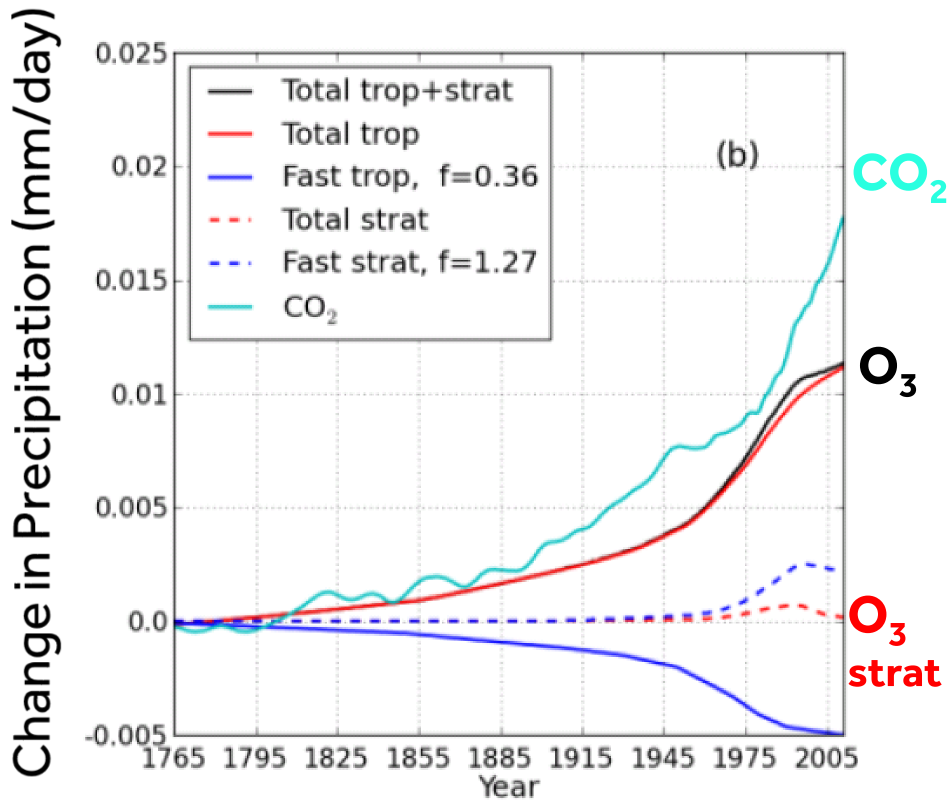
CURIOUS CASE OF GLOBAL PRECIPITATION RESPONSE TO OZONE RADIATIVE FORCING

- Detailed modelling of radiative response to ozone changes (ECLIPSE project inc. Bill Collins, Keith Shine, Nicolas Bellouin)
- Precipitation response to ozone changes >50% that due to CO_2, even though the RF is only ~20%
- **Increased ozone pollution at low levels effective at increasing P**
- Stratospheric ozone depletion also contributes to increased P



MacIntosh et al. (2016) GRL

MOISTURE BALANCE CONSTRAINT

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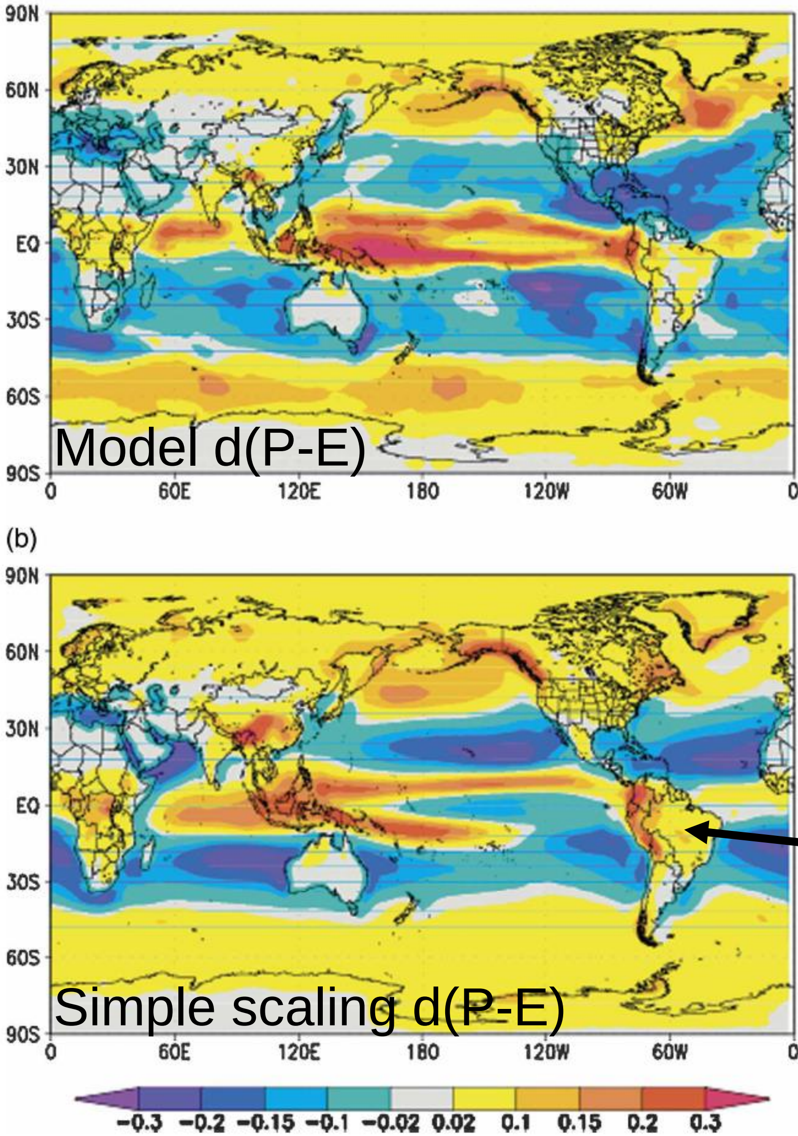

FIG. 7. The annual-mean distribution of $\delta(P - E)$ from the ensemble mean of (a) PCMDI AR4 models and (b) the thermodynamic component predicted from (6) from the SRES A1B scenario.

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

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

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)

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

See also talks by Paul Durack, Peter Greve

MOISTURE TRANSPORT AND INTENSIFICATION OF WET/DRY SEASONS

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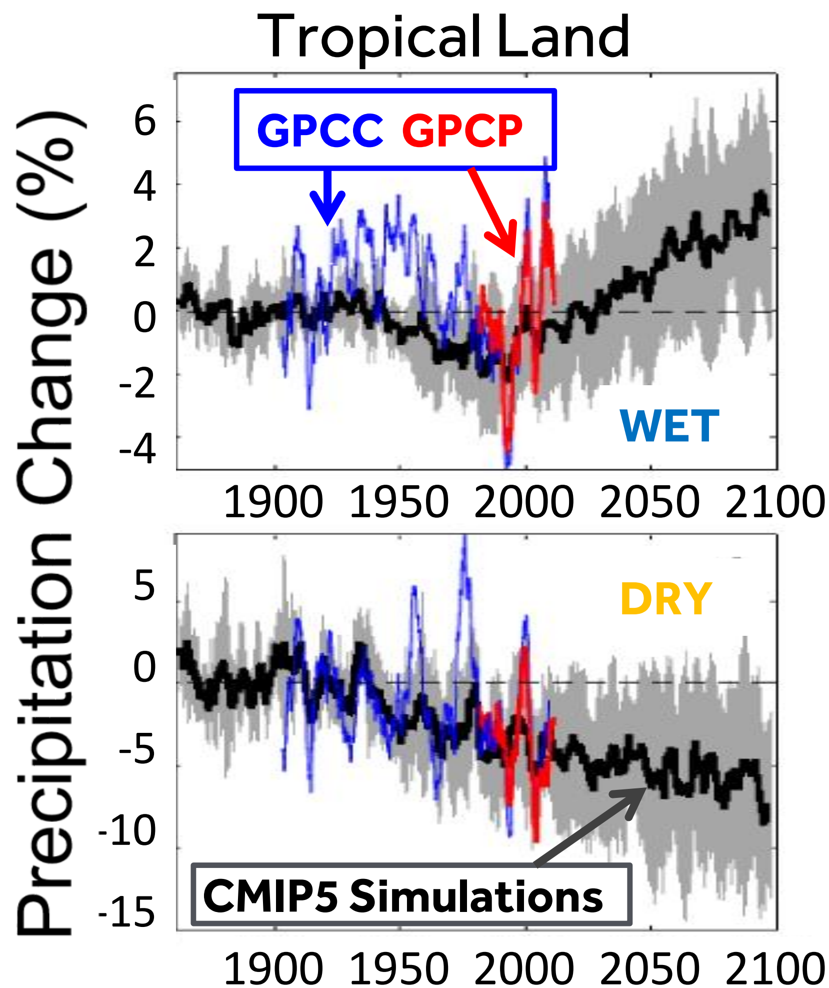
- Increased moisture with warming implies amplified P-E (e.g. Held & Soden 2006)
- Multi-annual P-E > 0 over land implies increased P-E (e.g. Greve et al. 2014)
- Changes in T/RH gradients also important (Byrne & O'Gorman 2015)
- P-E < 0 in dry season over land: more intense dry *and* wet seasons? (Chou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

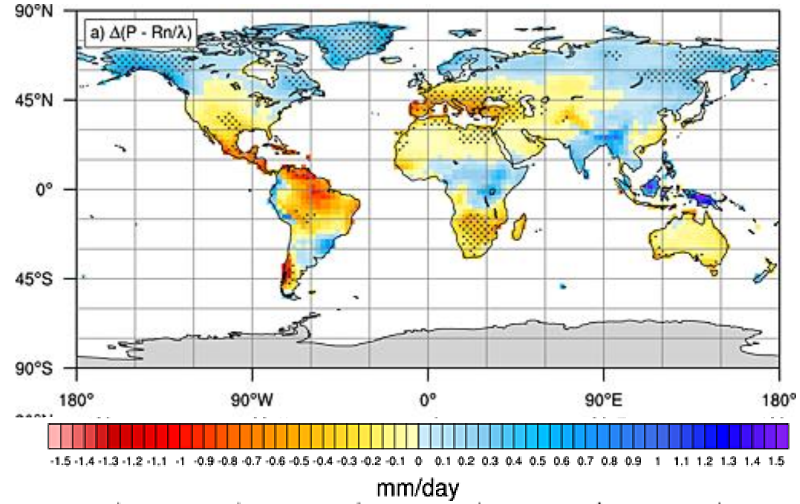
- Aridity index: $P - Eo \sim P - Rn/\lambda$

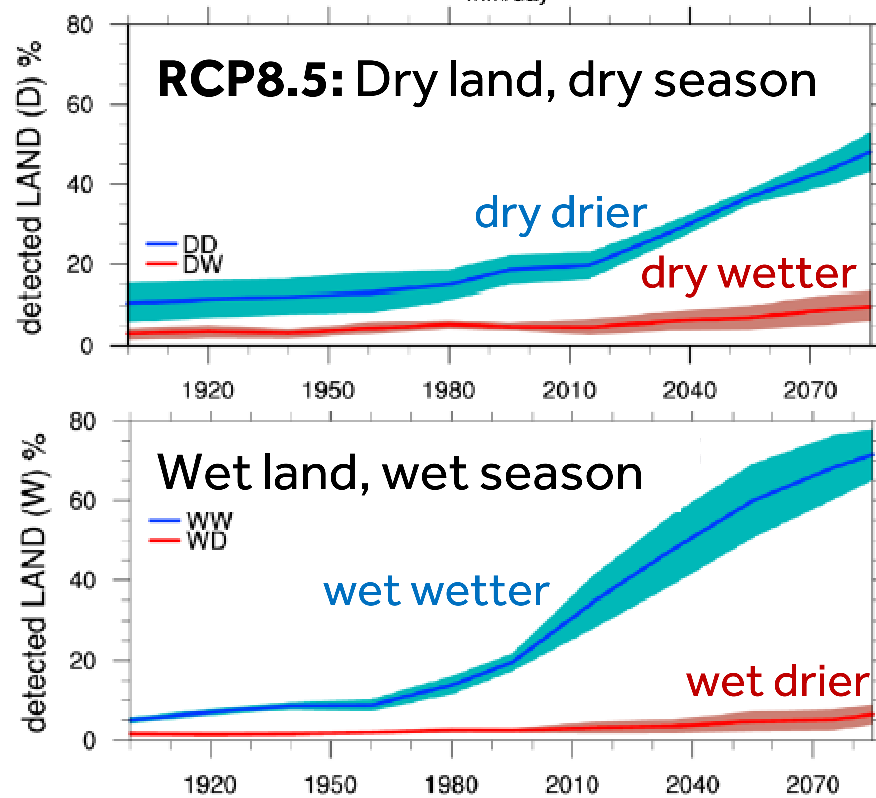
(E_o is potential evaporation, R_n is net radiation and λ is latent heat of vapourization). Top right: $\Delta(P - Rn/\lambda)$

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 →





See also talks by Peter Greve, Martin Best, etc

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

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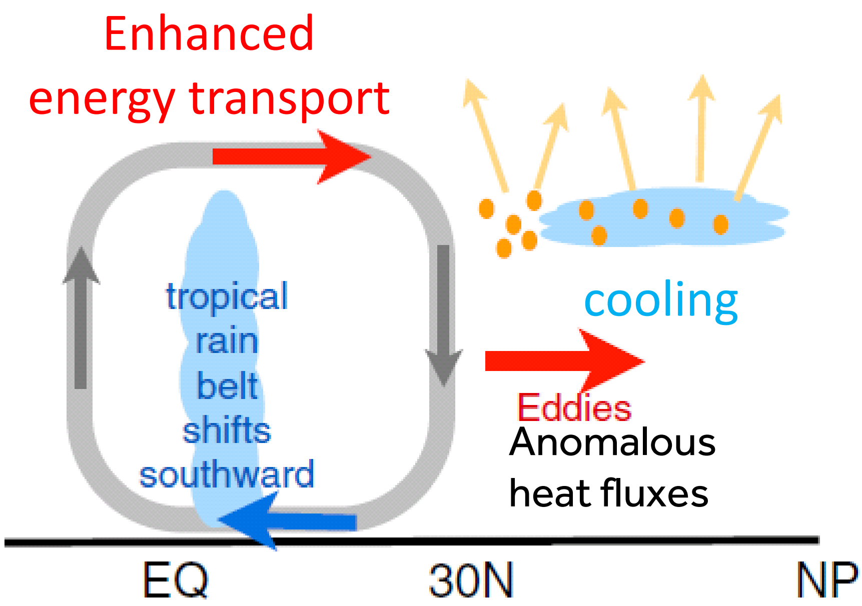
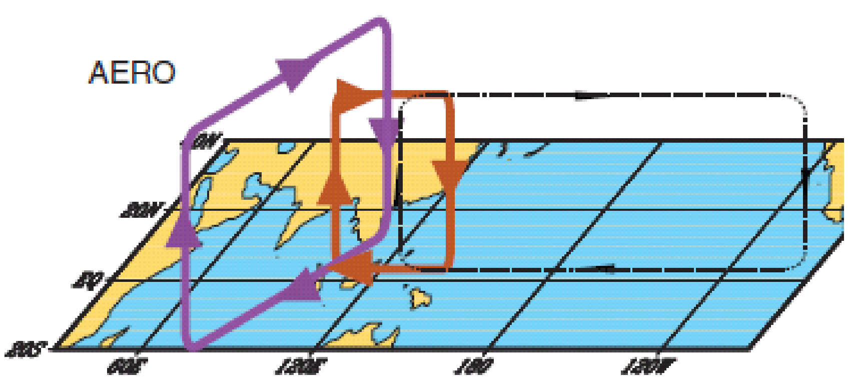
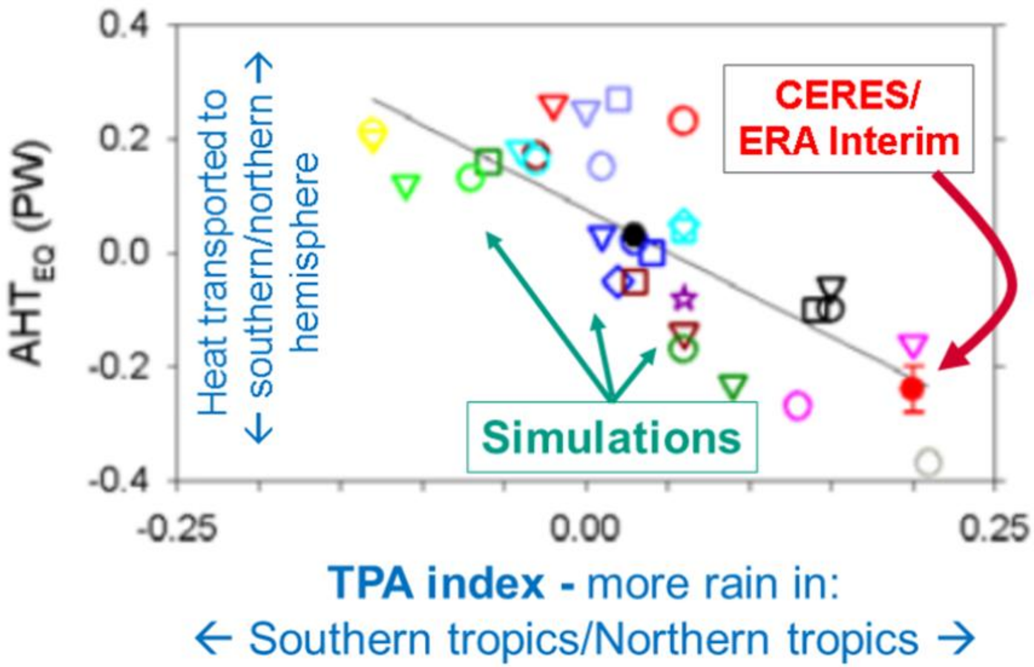
- Regional precipitation biases/changes sensitive to asymmetries in Earth's energy budget e.g. Loeb et al. (2015) Clim. Dyn; Haywood et al. (2016) GRL
- N. Hemisphere cooling: less heat transport out of hemisphere
- Reduced Sahel rainfall from:
- Anthropogenic aerosol cooling 1950s-1980s: Hwang et al. (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
- **See also talks by Paul O'Gorman, Mike Byrne, Robin Chadwick, Hugo Lambert**

CROSS-EQUATORIAL HEAT TRANSPORT LINKED TO MODEL PRECIPITATION BIAS



Estimated cross equatorial atmospheric heat transport in peta Watts (AHT_{EQ}) against an index of tropical precipitation asymmetry (TPA) between hemispheres in simulations and observations

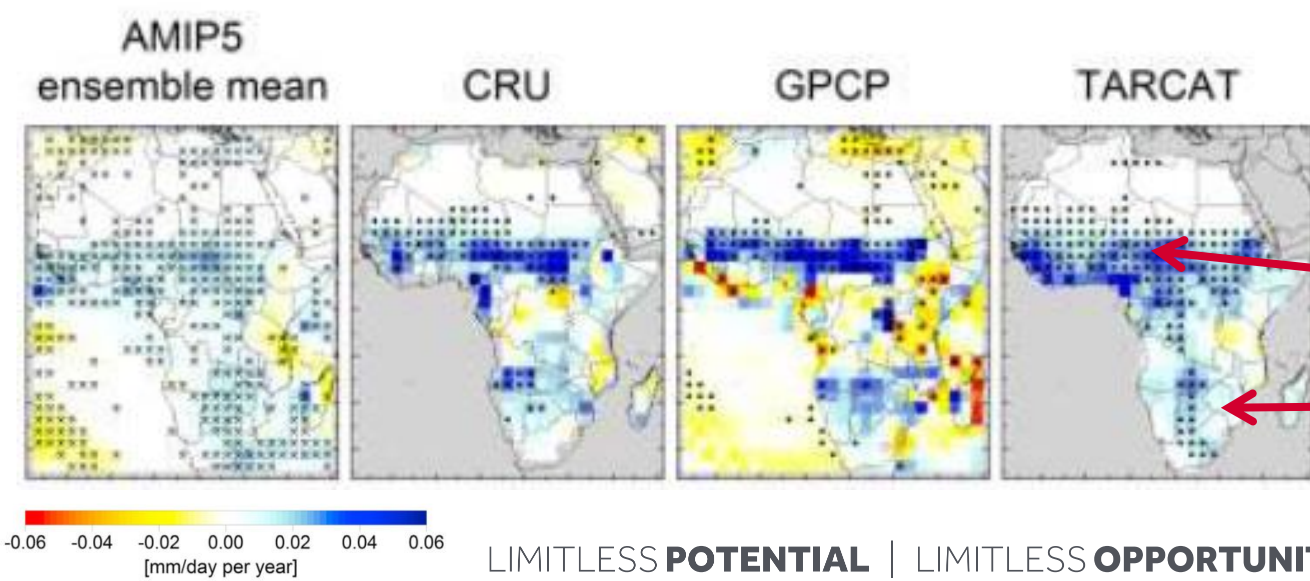
- Clear link between bias in cross-equatorial heat transport by atmosphere and inter-hemispheric precipitation asymmetry Loeb et al. (2015) Clim. Dyn

Also: Haywood et al. (2016) GRL Hawcroft et al. (2016) Clim. Dyn.

- **See also talks by Anita Rapp and Mike Byrne**

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



Radiative forcing?

Internal variability?

EVALUATING SENSITIVITY OF PRECIPITATION EXTREMES TO WARMING

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Observed/simulated 5-day mean response

① More positve dP/dT for heavier percentiles

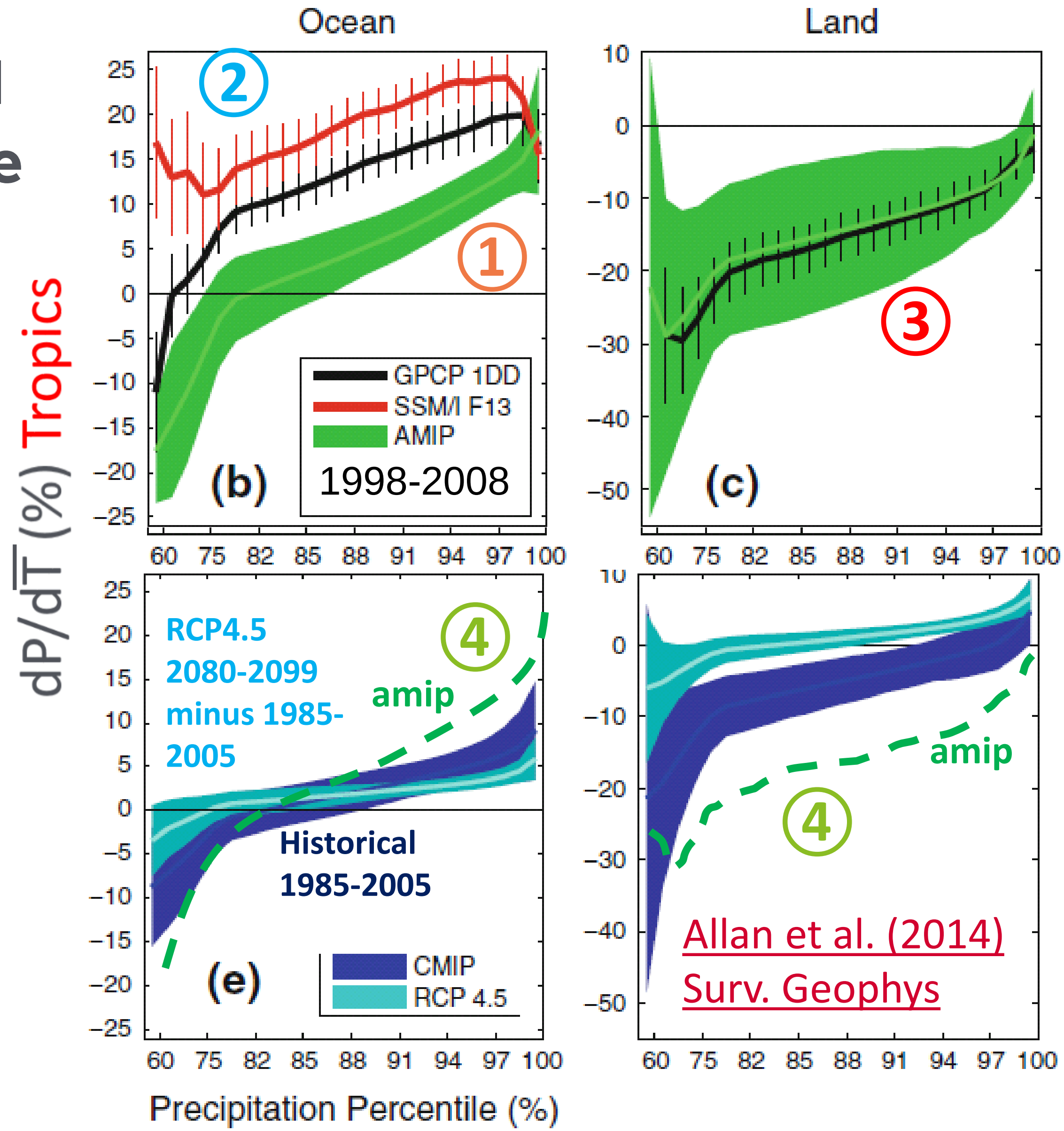
② More positive observed sensitivity over ocean

③ Negative land dP/dT as more rain during cold La Nina

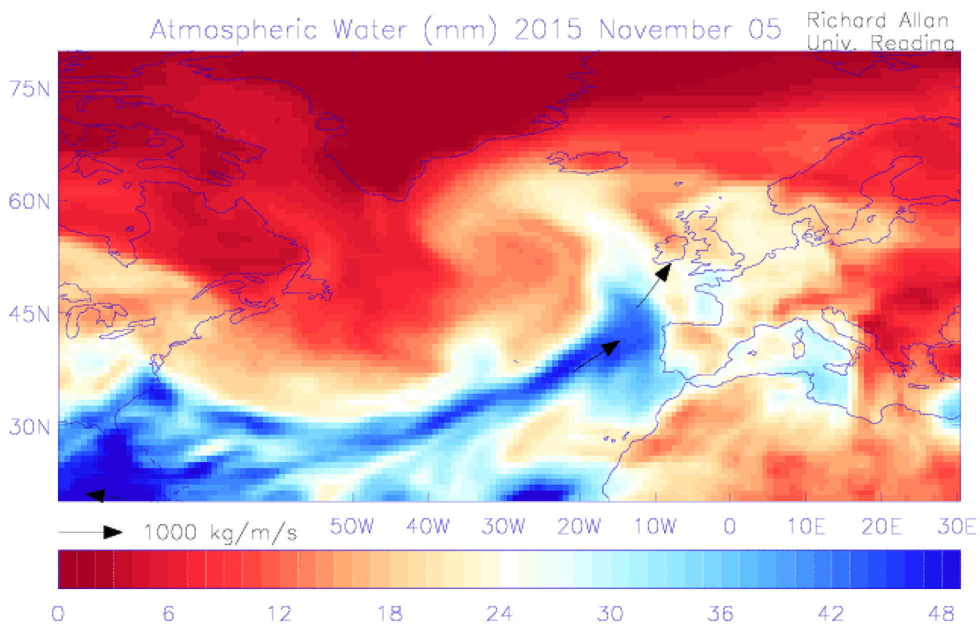
④ Interannual dP/dT not good direct proxy for climate change, especially over land

…but may be good global indicator of model diversity e.g. O'Gorman (2012)

See talks by Hayley Fowler, Angeline Pendergrass, etc

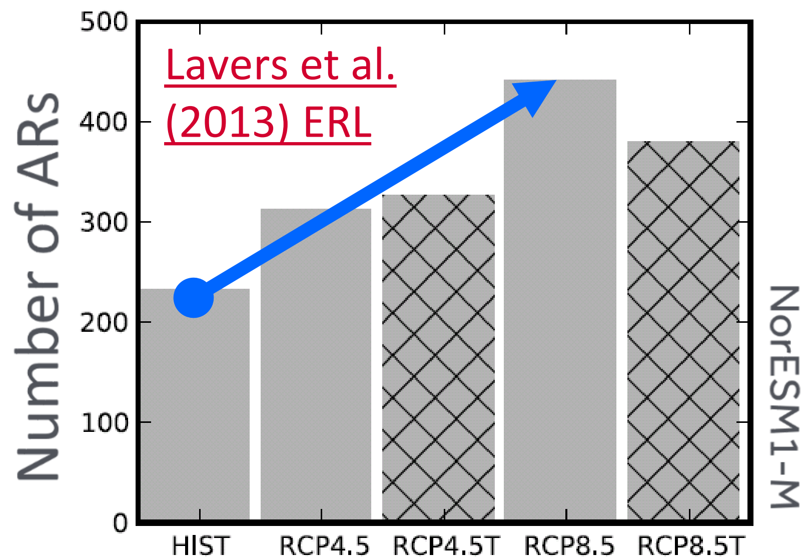


PROJECTING IMPACT-RELEVANT METRICS



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

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



CONCLUSIONS

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- Changes in the global water cycle are dictated by radiative transfer and thermodynamics but dominated locally by circulation changes
  - Radiative transfer & Thermodynamics explain increased global precipitation with warming ≈ 2%/K
  - Radiative forcings also directly affect water cycle responses
  - Greenhouse gas & absorbing aerosol forcing supress global precipitation response to warming (“hydrological sensitivity”)
- Hemispheric heating difference, moisture budget, unforced variability & feedbacks dictate regional responses and determine climate model biases
  - Decadal changes in ITCZ and global atmospheric/ocean circulation
  - Heterogeneous forcing (e.g. aerosol, ozone)
  - How does internal variability obscure/dominate signals?
- What set of impact-relevant metrics should be prioritised?
- No one-size-fits-all metric for detection, physical understanding and prediction of regional changes in the water cycle but all are linked
- Focus on high time/space resolution & robust circulation response to forcing/feedback?