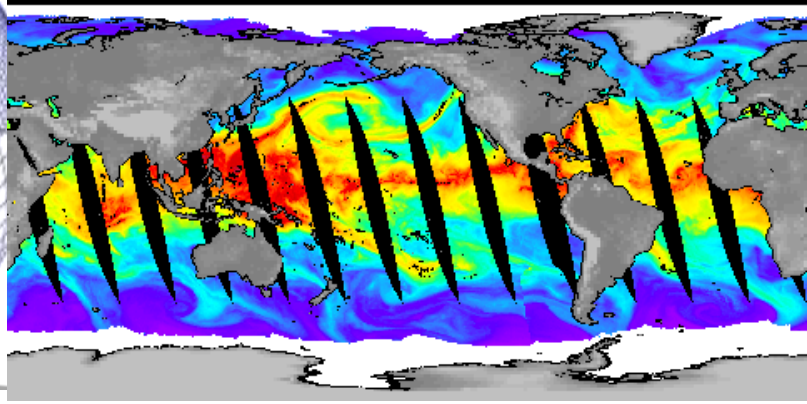

Current and future changes in atmospheric moisture and global precipitation extremes

Richard P. Allan, Chunlei Liu, Matthias Zahn, David Lavers
Department of Meteorology/NCAS Climate, University of Reading
www.met.reading.ac.uk/~sgs02rpa

Thanks to Brian Soden (Miami) and Viju John (UK Met Office)

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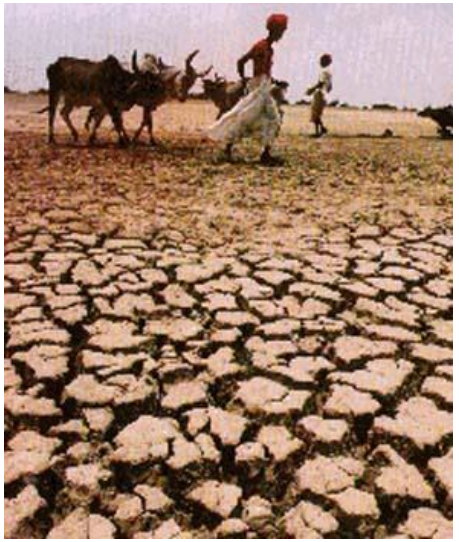
Introduction

"Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems."
IPCC (2008) Climate Change and Water



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How will global precipitation respond to climate change?

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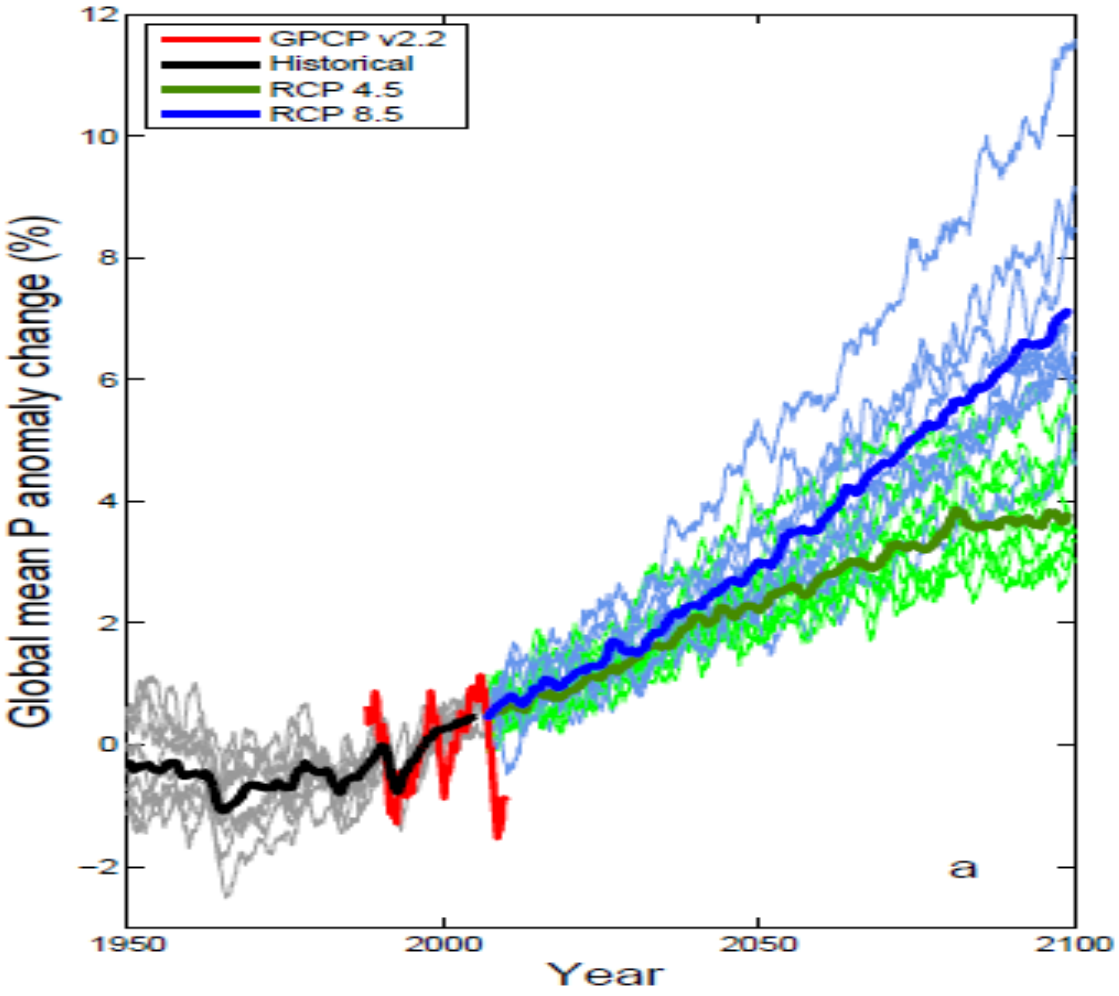

CMIP5 simulations

Allan et al. (2013) Surv. Geophys. in press.

See also: Hawkins & Sutton (2010) Clim. Dyn.

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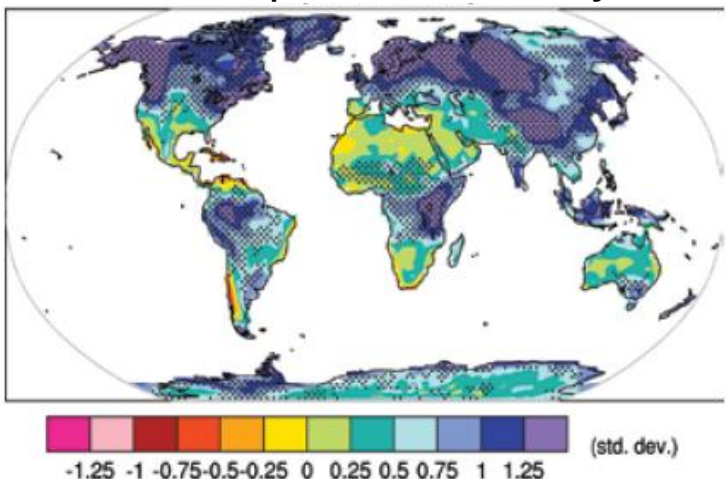
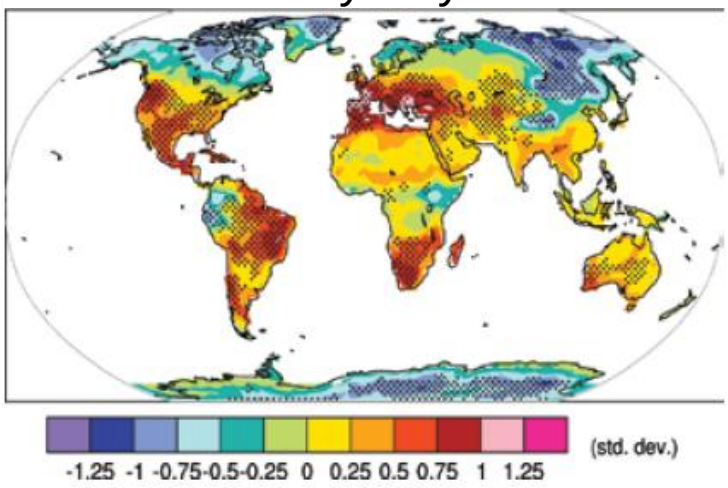
Climate model projections

Precipitation Intensity

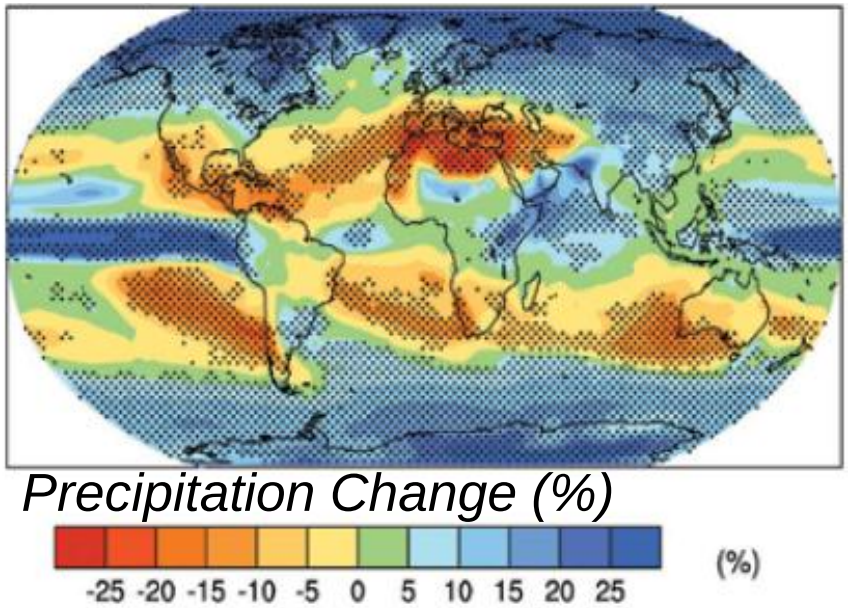


Dry Days



IPCC WGI (2007)

- Increased Precipitation
- More Intense Rainfall
- More droughts
- Wet regions get wetter, dry regions get drier?
- Regional projections??



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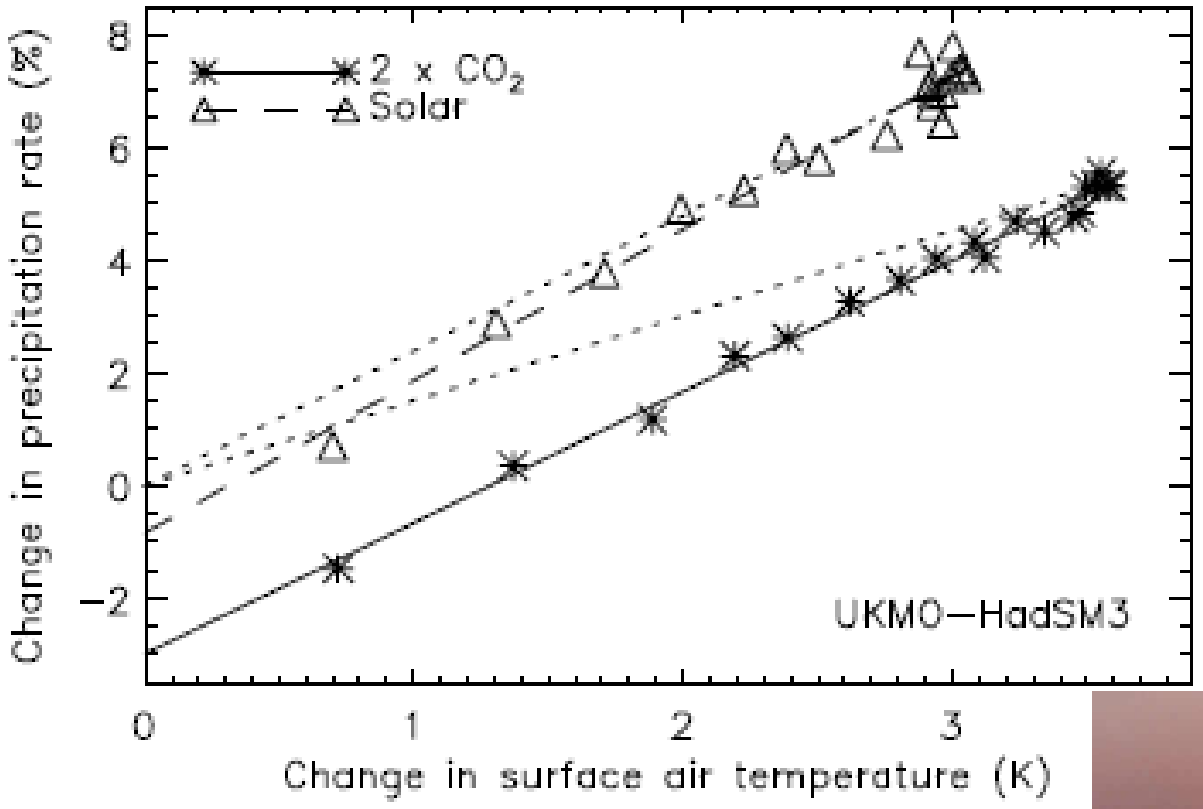
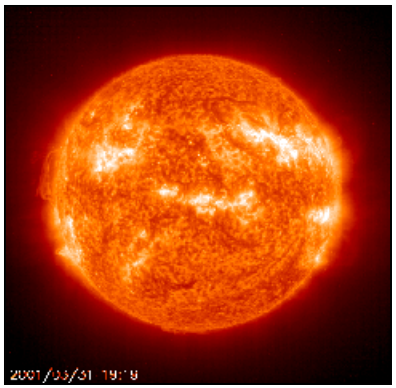
Physical basis: (1) Radiative cooling





Andrews et al. (2009) *J Climate*

See also:

Manabe & Wetherald (1975) *JAS*; Allen & Ingram (2002) *Nature*

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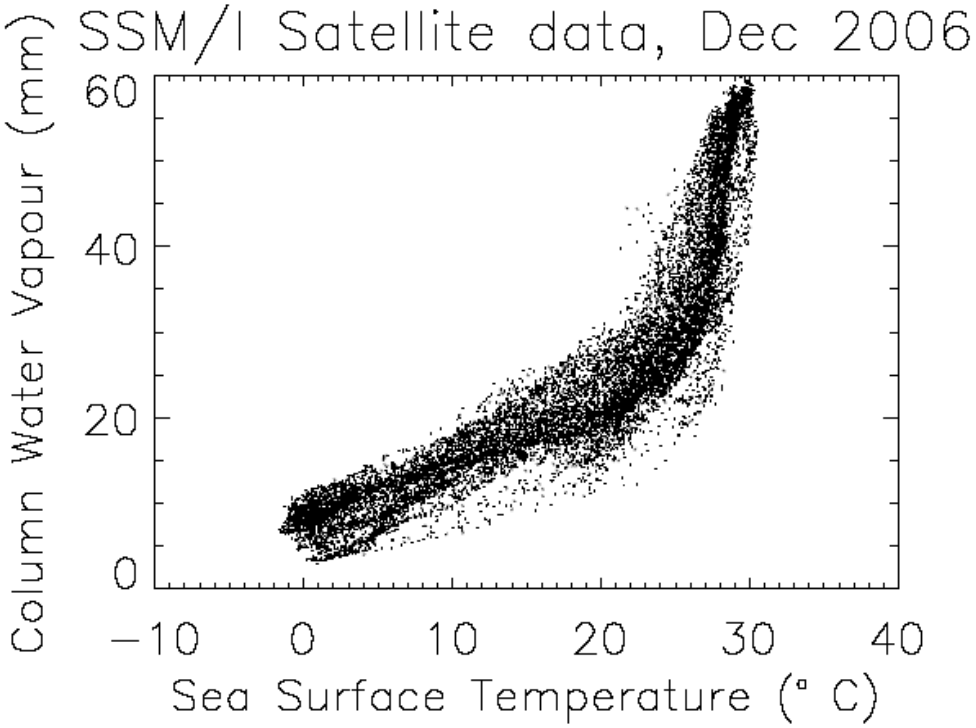
Physical basis: (2) Clausius Clapeyron

$$\frac{1}{q_s}\frac{dq_s}{dT} \approx \frac{1}{e_s}\frac{de_s}{dT} = \frac{L}{R_v T^2} = \begin{cases} 0.14K^{-1} & T = 200K \\ 0.07K^{-1} & T = 273K \\ 0.06K^{-1} & T = 300K \end{cases}$$



- Strong constraint upon low-altitude water vapour over the oceans
- Water vapour is a very forgiving climate variable!
- Land regions?
- Upper troposphere?

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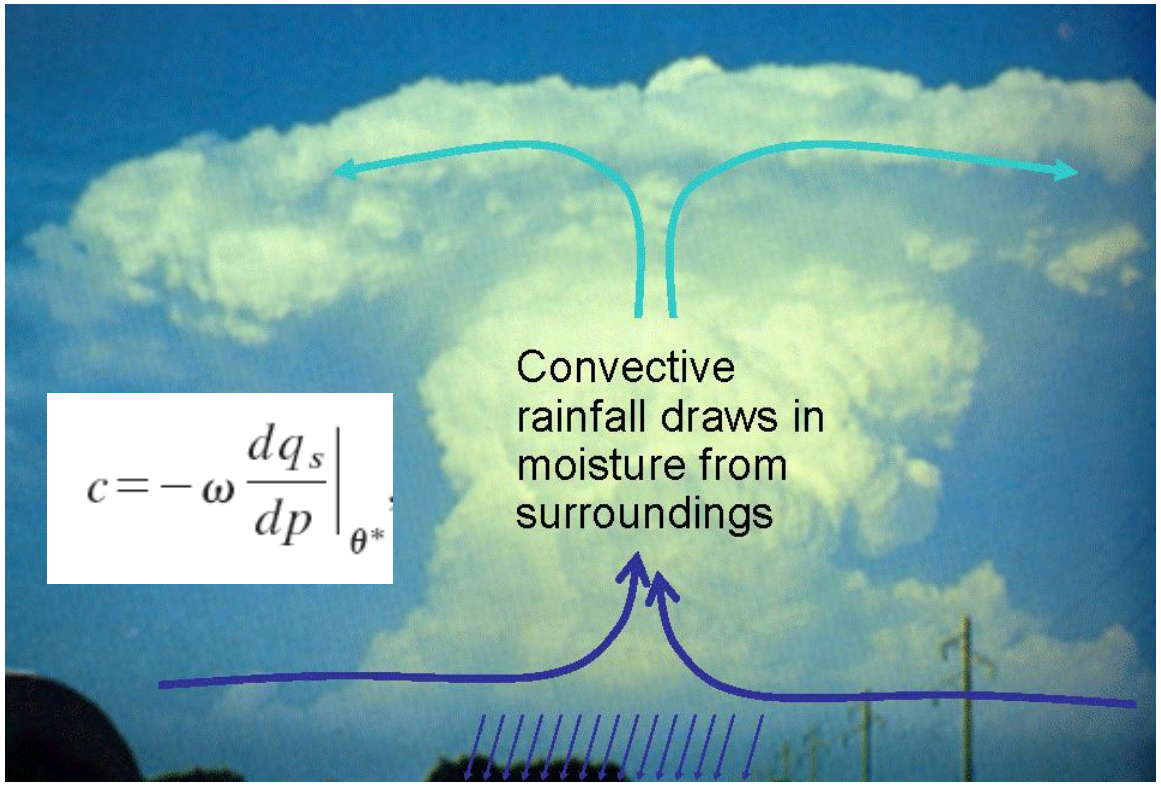
Extreme Precipitation



- Large-scale rainfall events fuelled by moisture convergence
  - e.g. Trenberth et al. (2003) *BAMS*. *But see also Wilson and Toumi (2005) GRL*

→ Intensification of rainfall (~7%/K?)

O'Gorman & Schneider (2009) *PNAS*; Gastineau and Soden (2009) *GRL*

- Is there a positive latent heating feedback on hourly intensities?

Lenderink & van Meijgaard (2010) *ERL*; Haerter et (2010) *GRL*

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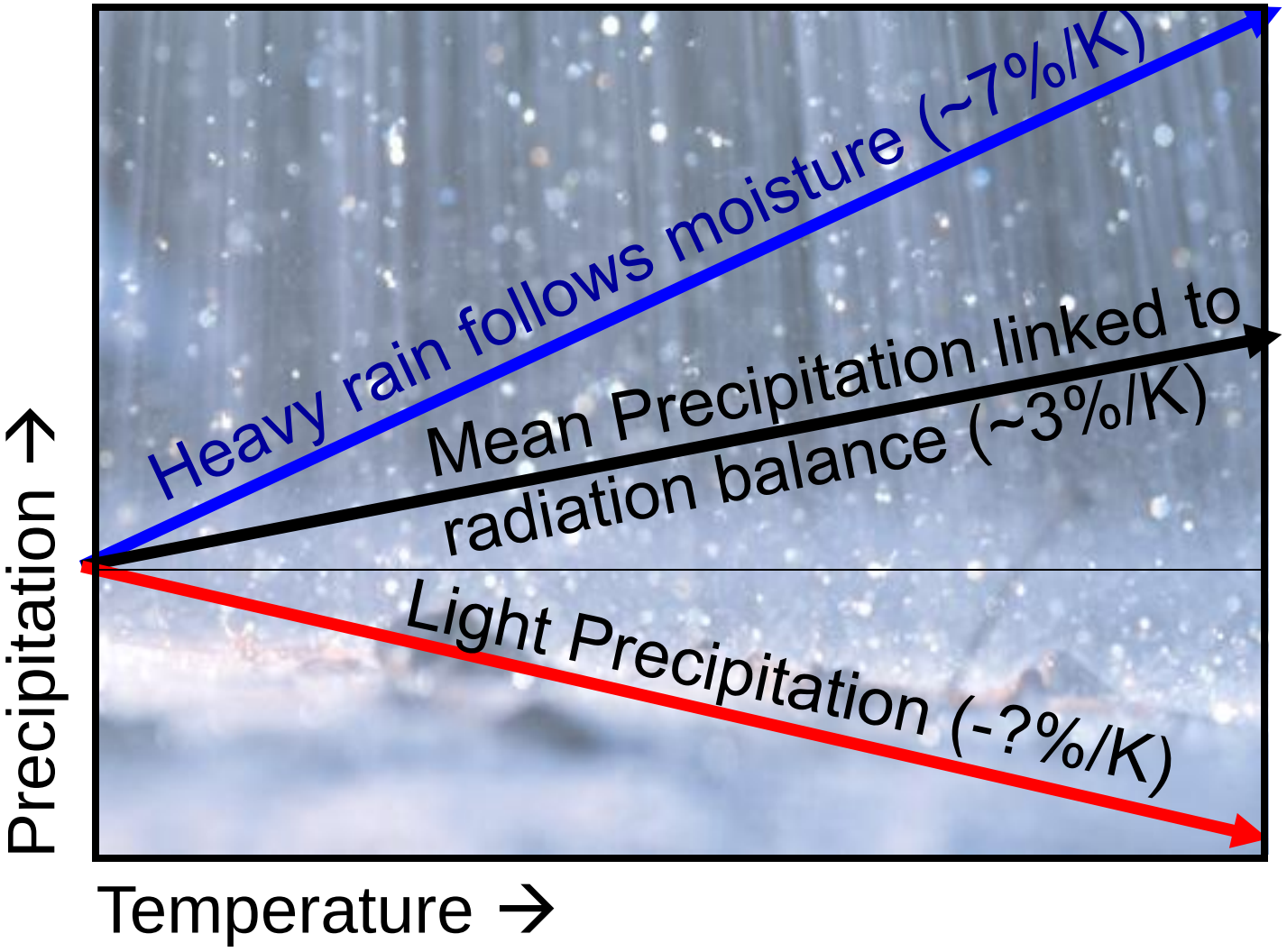
Contrasting precipitation response expected



e.g. Allen and Ingram (2002) *Nature;* Allan and Soden (2008) *Science*

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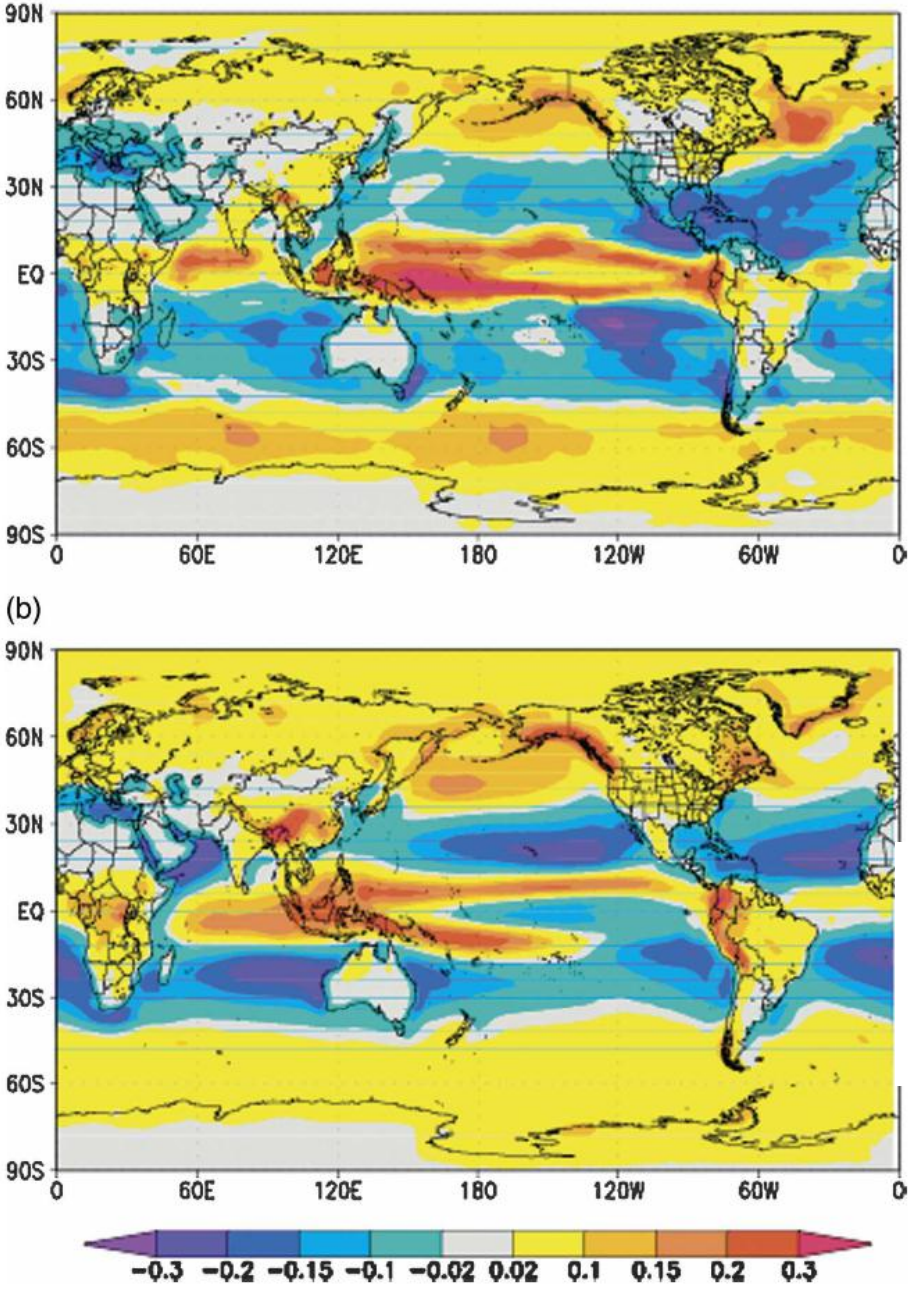

FIG. 7. The annual-mean distribution of $\delta(P - E)$ from the ensemble mean of (a) PCMDI AR4 models and (b) the thermodynamic component predicted from (6) from the SRES A1B scenario.

Physical basis (2a): Moisture Balance

Projected (top) and estimated (bottom) changes in P-E

Held and Soden (2006) J Climate

P-E ~ ($\nabla . (\mathbf{u}\, q)$) (units of s^{-1}; scale by ($p/g\rho_w$) for units of mm/day)

$$\frac{\delta F}{F} \approx \frac{\delta e_s}{e_s} \approx \alpha \delta T.$$

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

$$\alpha \approx 0.07\ \mathrm{K}^{-1}$$

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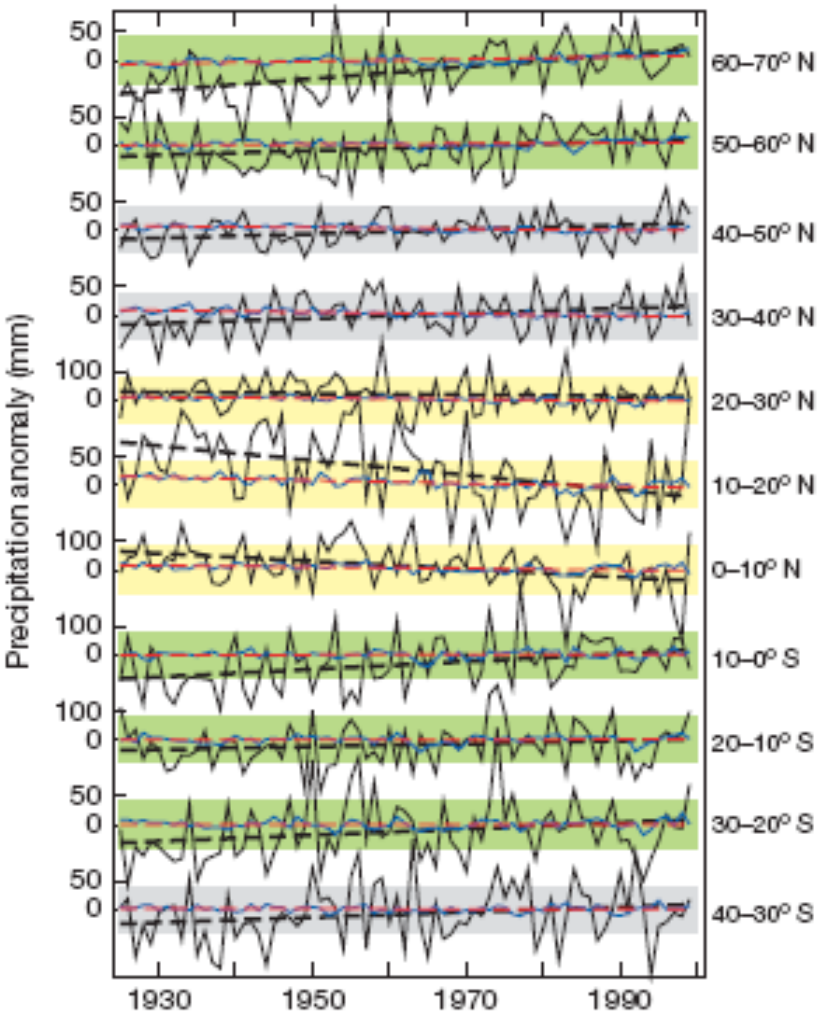
Detection of zonal precipitation trends



Zhang et al. 2007 Nature

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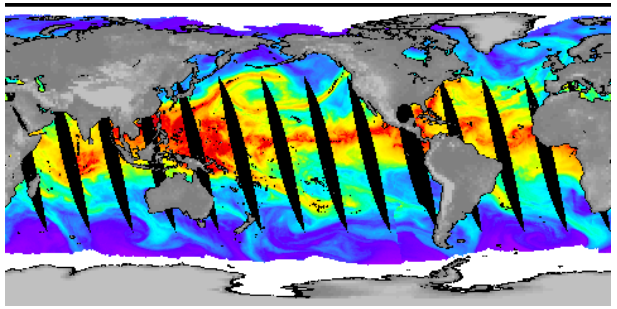
Observational perspective



- Can satellite era datasets be exploited to:
  - Understand systematic biases in simulations?
  - Detect trends in hydrological variables?
  - Quantify relationships describing physical processes operating with the global water cycle and evaluate climate simulations?
- Primarily focus on precipitation estimates and its “fuel”, water vapour

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Global changes in water vapour

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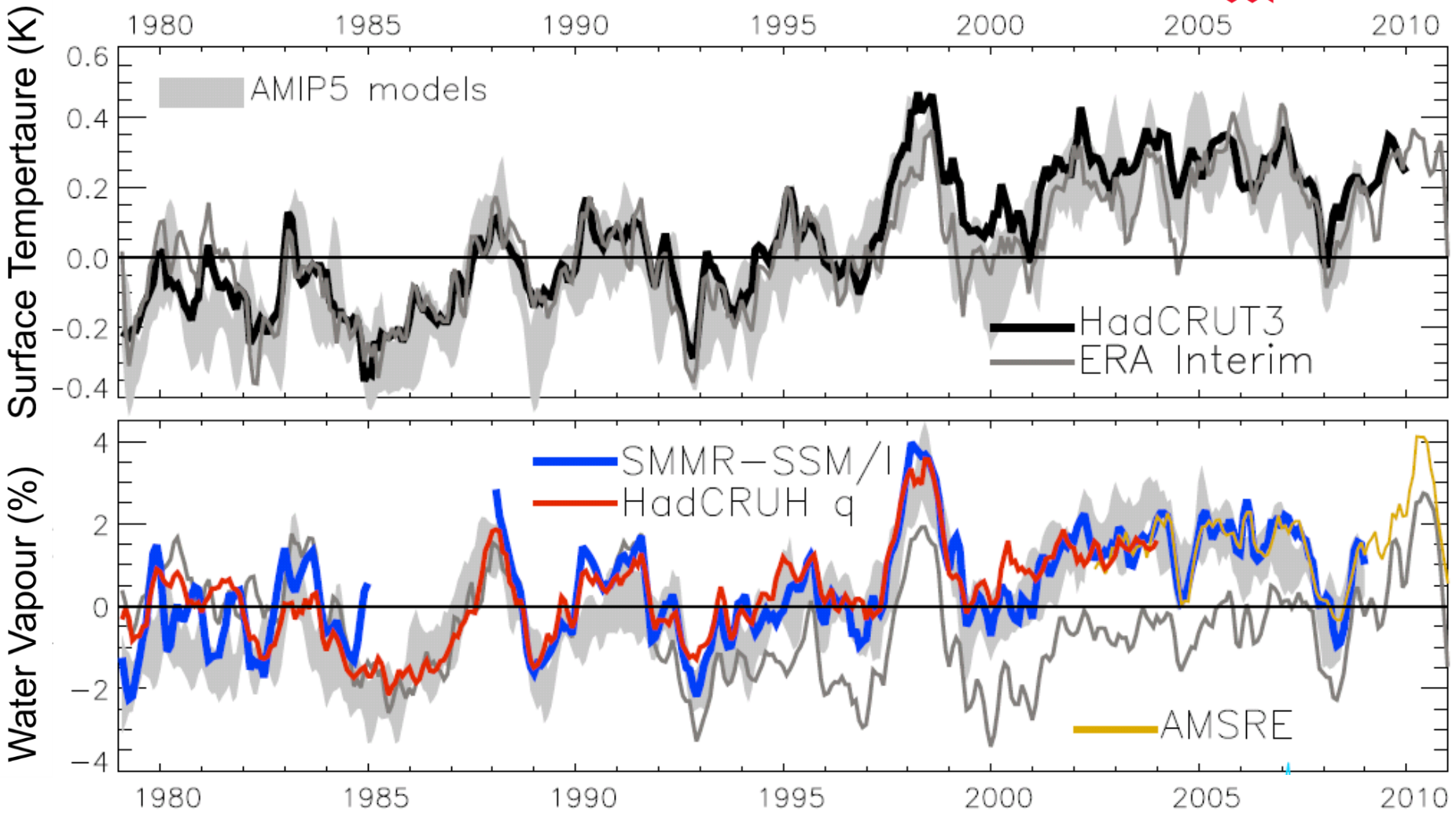

Allan et al. (2013) Surv. Geophys; see also O'Gorman et al. (2012); John et al. (2009)

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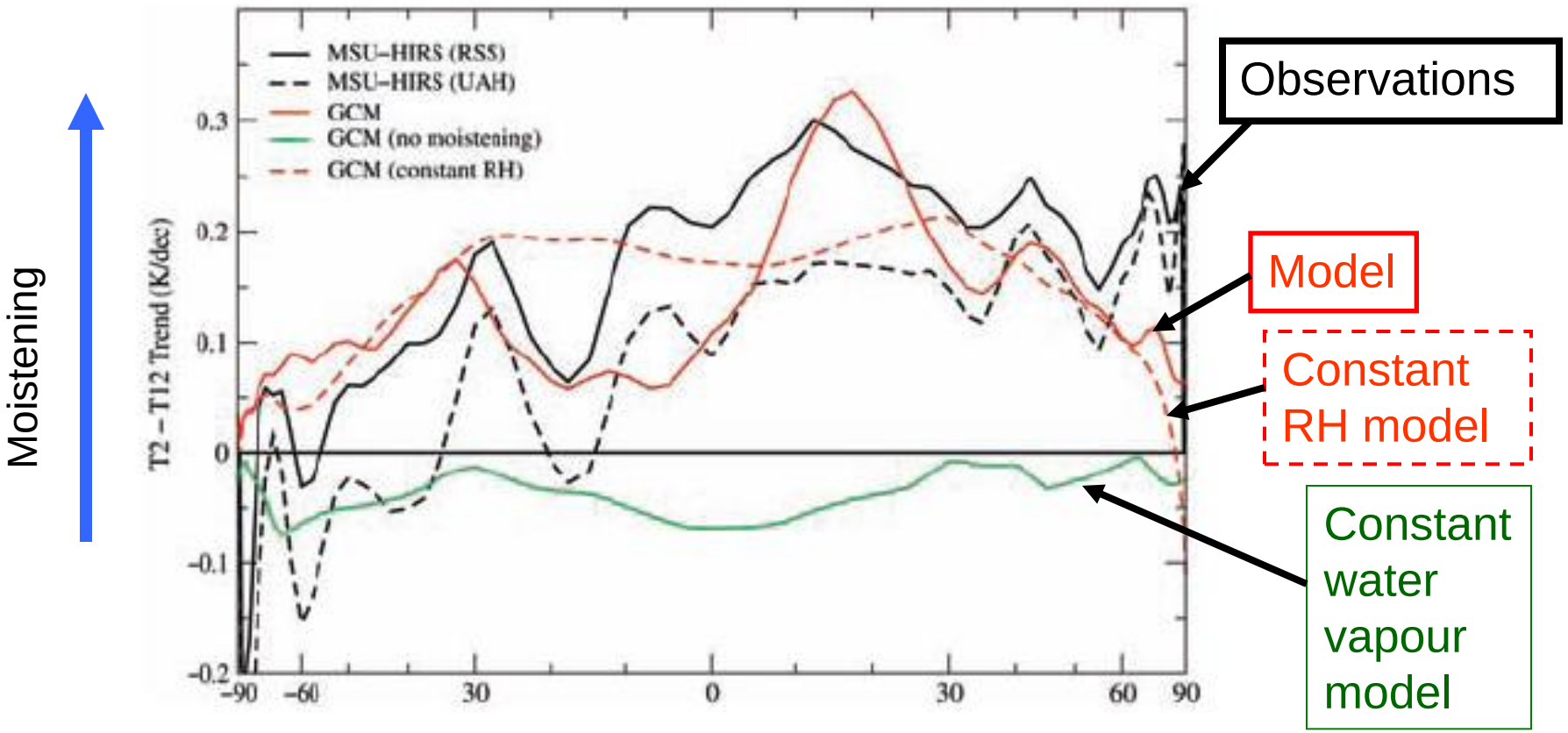
Upper Tropospheric water vapour?

Trend in brightness temperature difference: 1983-2004



Soden et al. (2005) *Science*

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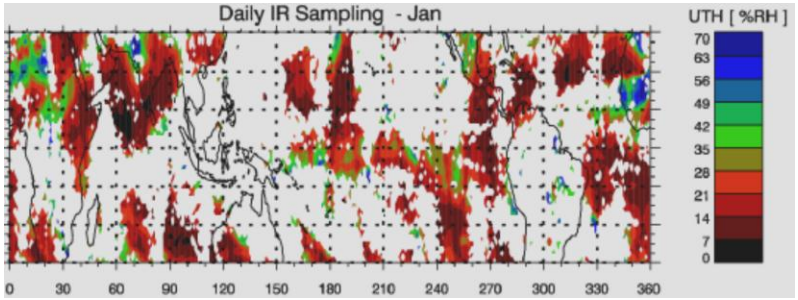
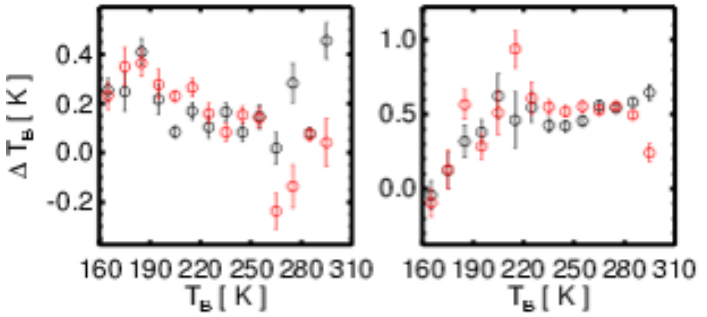
Intercalibration of Satellite Upper Tropospheric Humidity: HadIR/MW

University of Reading

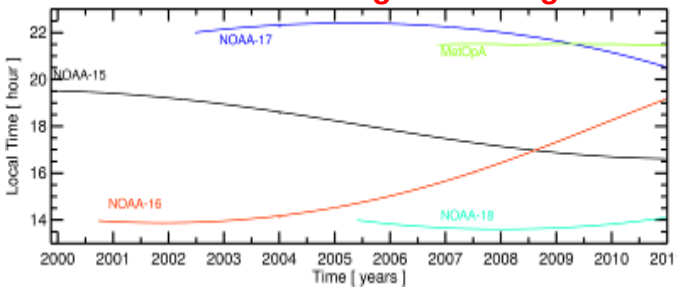
Met Office

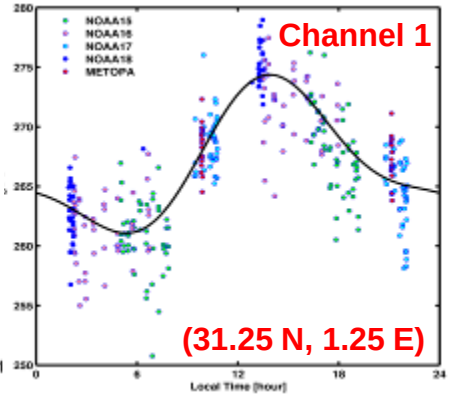
- Sampling issues
  - Infra-red vs microwave
- Inter-Calibration using satellite nadir overpasses
  - Polar overpasses
  - Satellite drift overpasses
- Correction for orbit drift
  - Diurnal correction
- Climate models?





Equator crossing times using ascending nodes



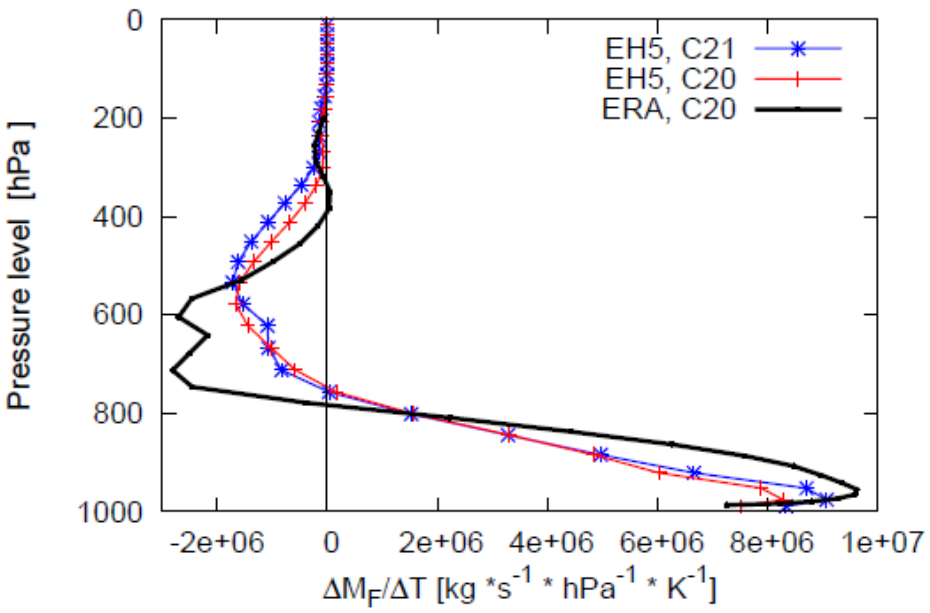


John et al. (2011) JGR;
John et al. in prep.

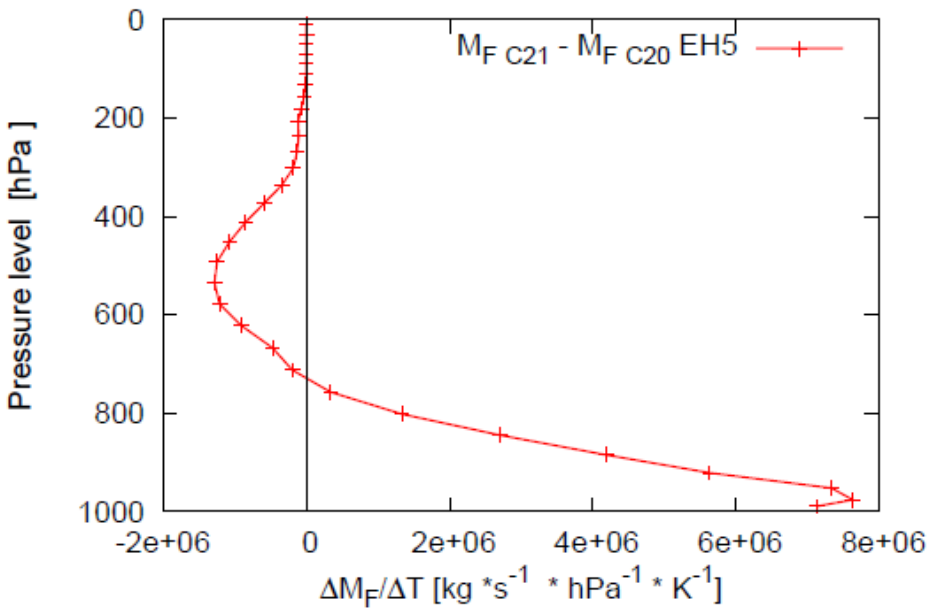
Changes in moisture transports into tropical wet region per K warming

University of Reading

interannual variability



climate change



Enhanced moisture convergence at low levels with warming

Significant outflow at mid-levels

Zahn and Allan (2013) J Clim, in press; Allan et al. (2013) Surv Geophys, in press

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

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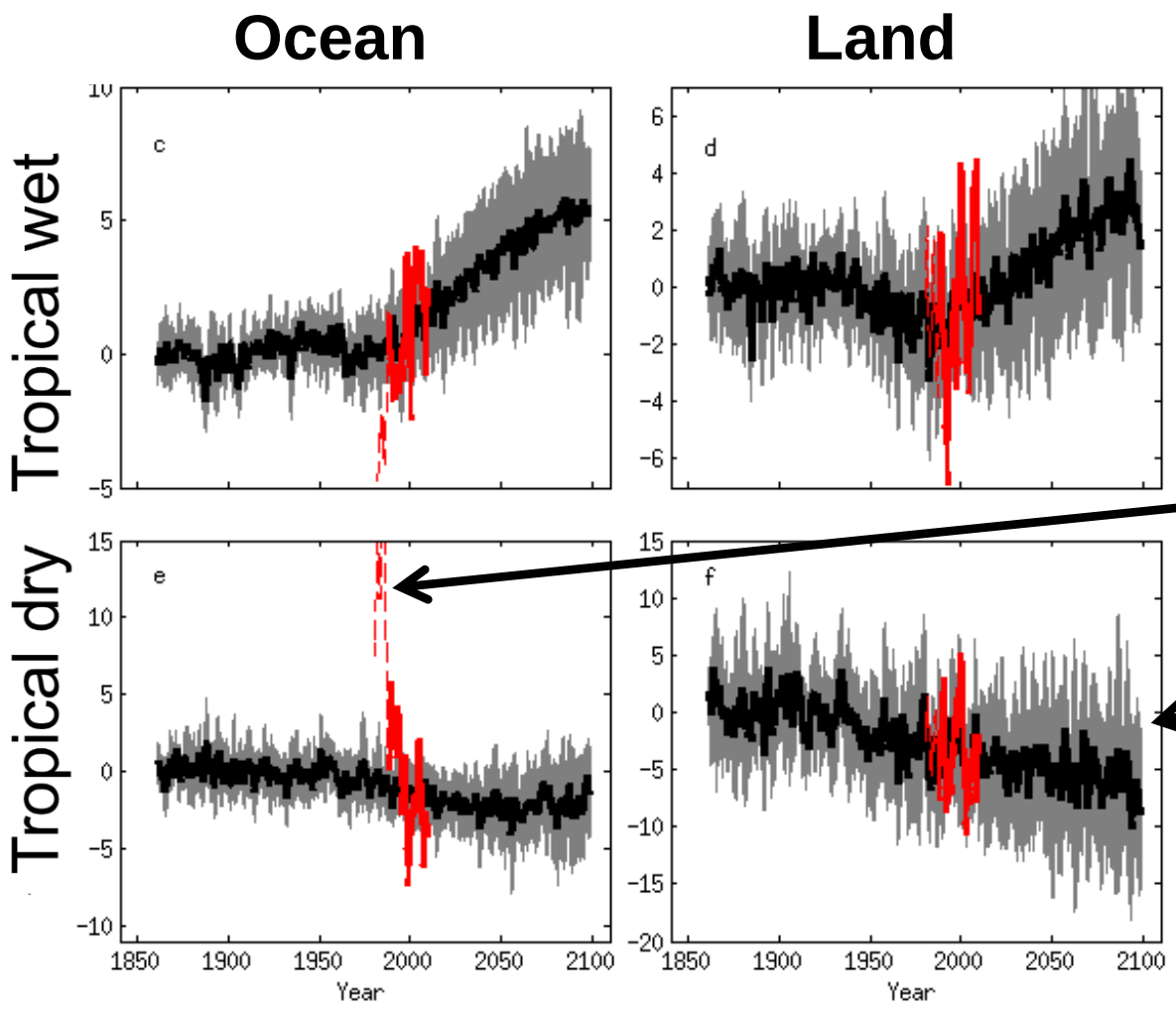
Changing water cycle



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.

Horyuji PAGODA
HydrOlogical cYcle Understanding via Process-bAsed GlObal Detection, Attribution and prediction

How consistent are satellite precipitation datasets?

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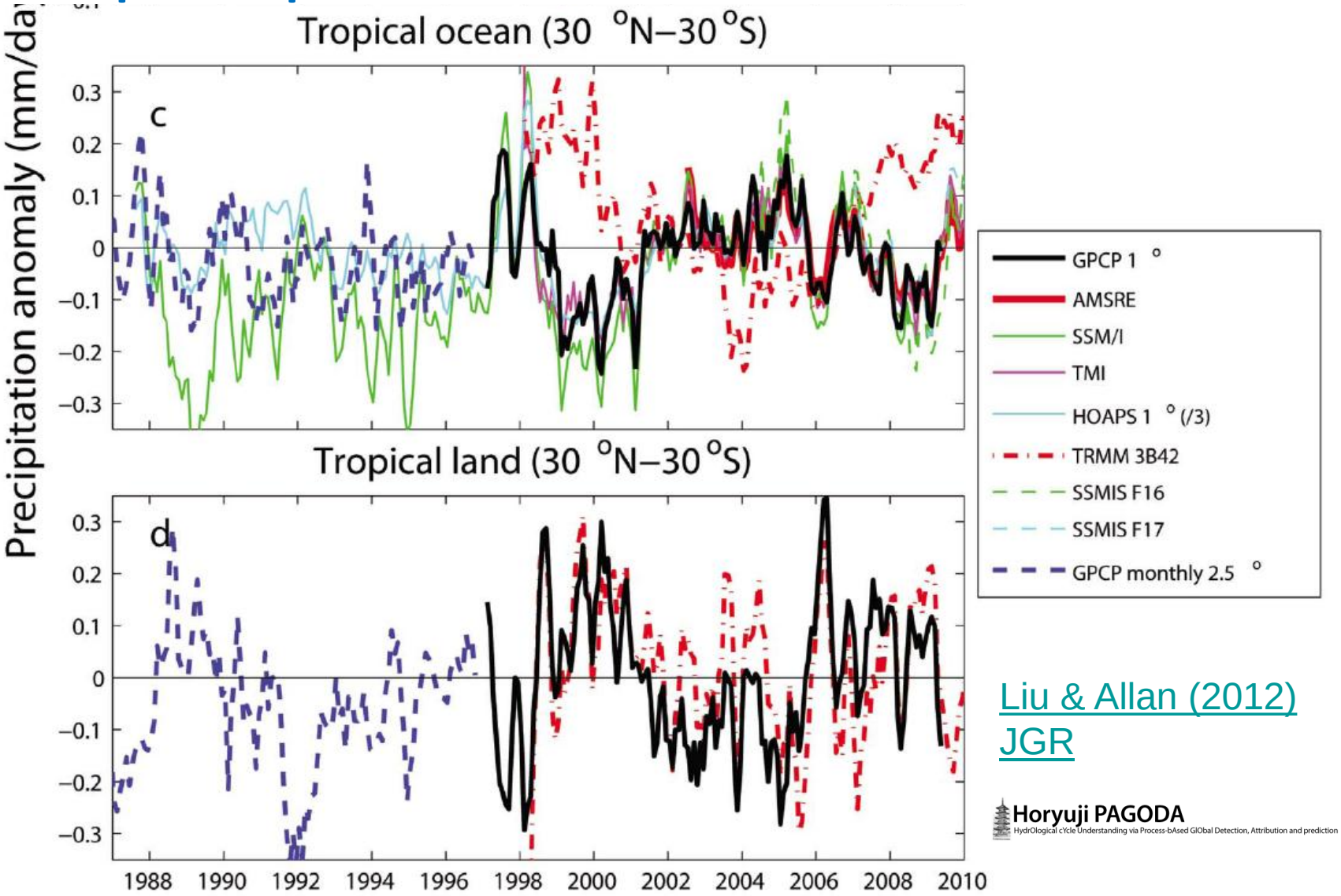

Liu & Allan (2012) JGR

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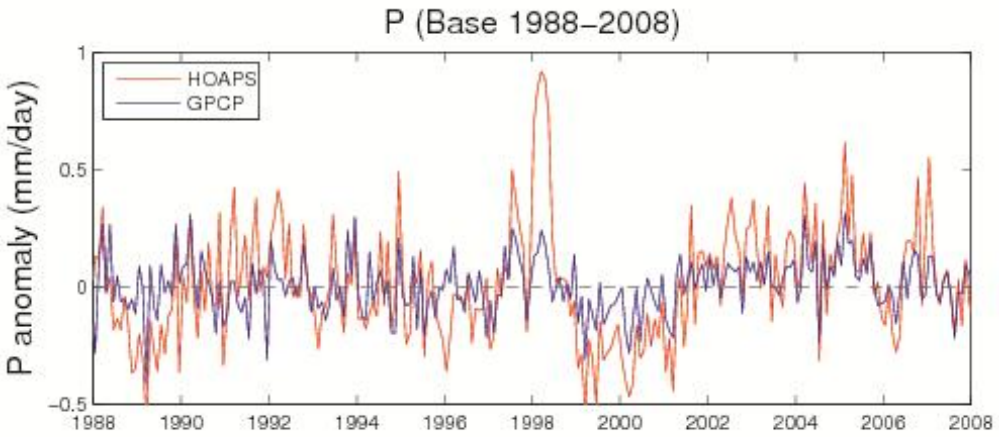
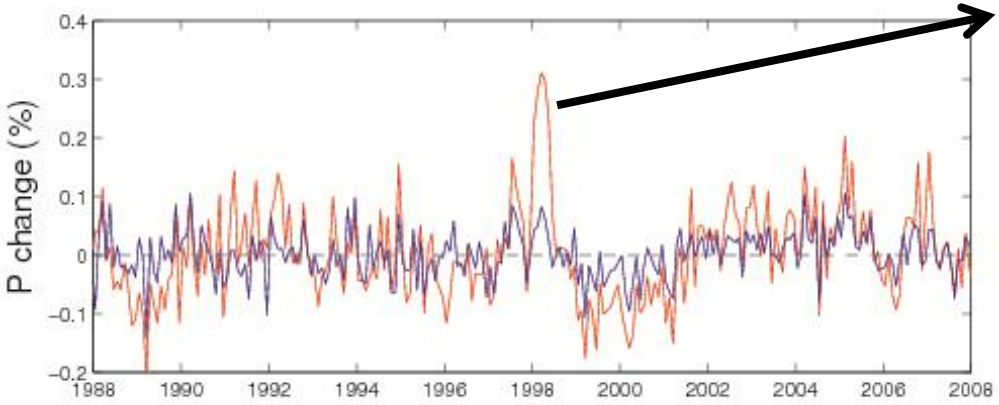
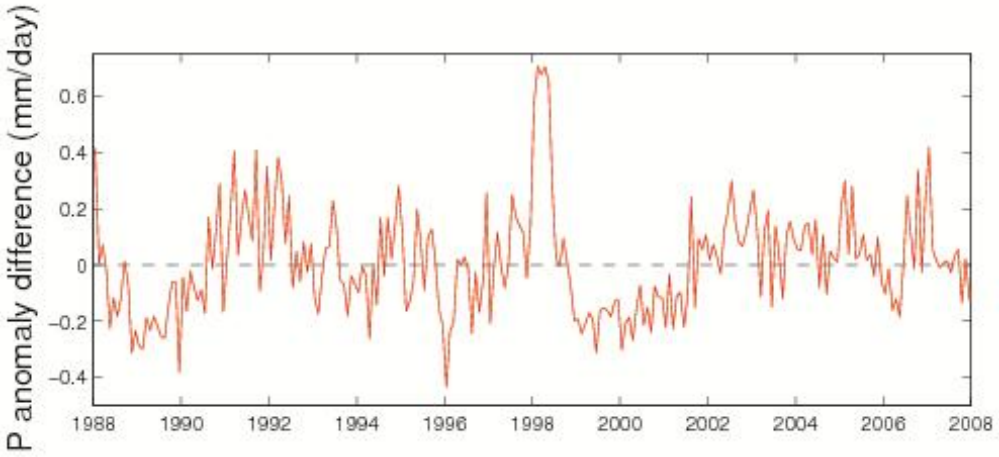
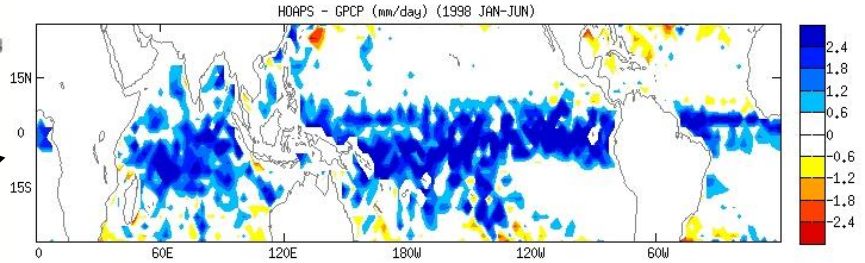
Comparison of HOAPS and GPCP









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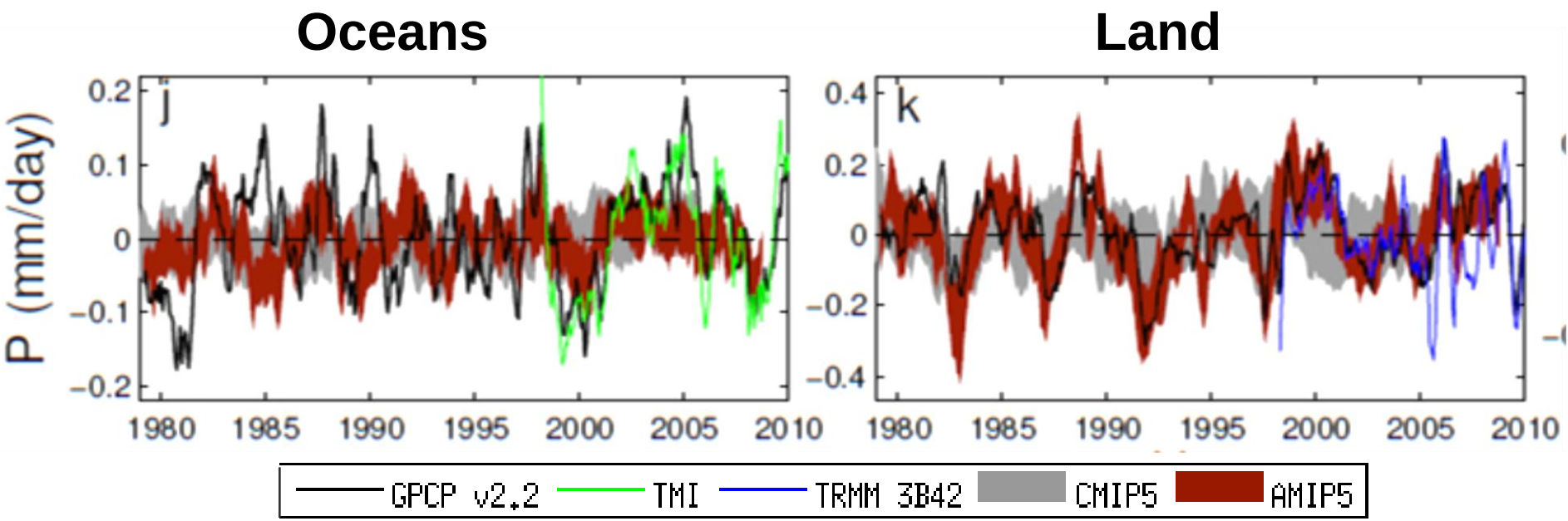
Are satellite and CMIP5 simulations of precipitation changes consistent?

Note consistency between atmosphere-only AMIP model simulations over land and GPCP observations. This is not the case for the ocean, in particular before about 1996.



Liu, Allan, Huffman (2012) GRL

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Can NWP models be used to investigate systematic biases?

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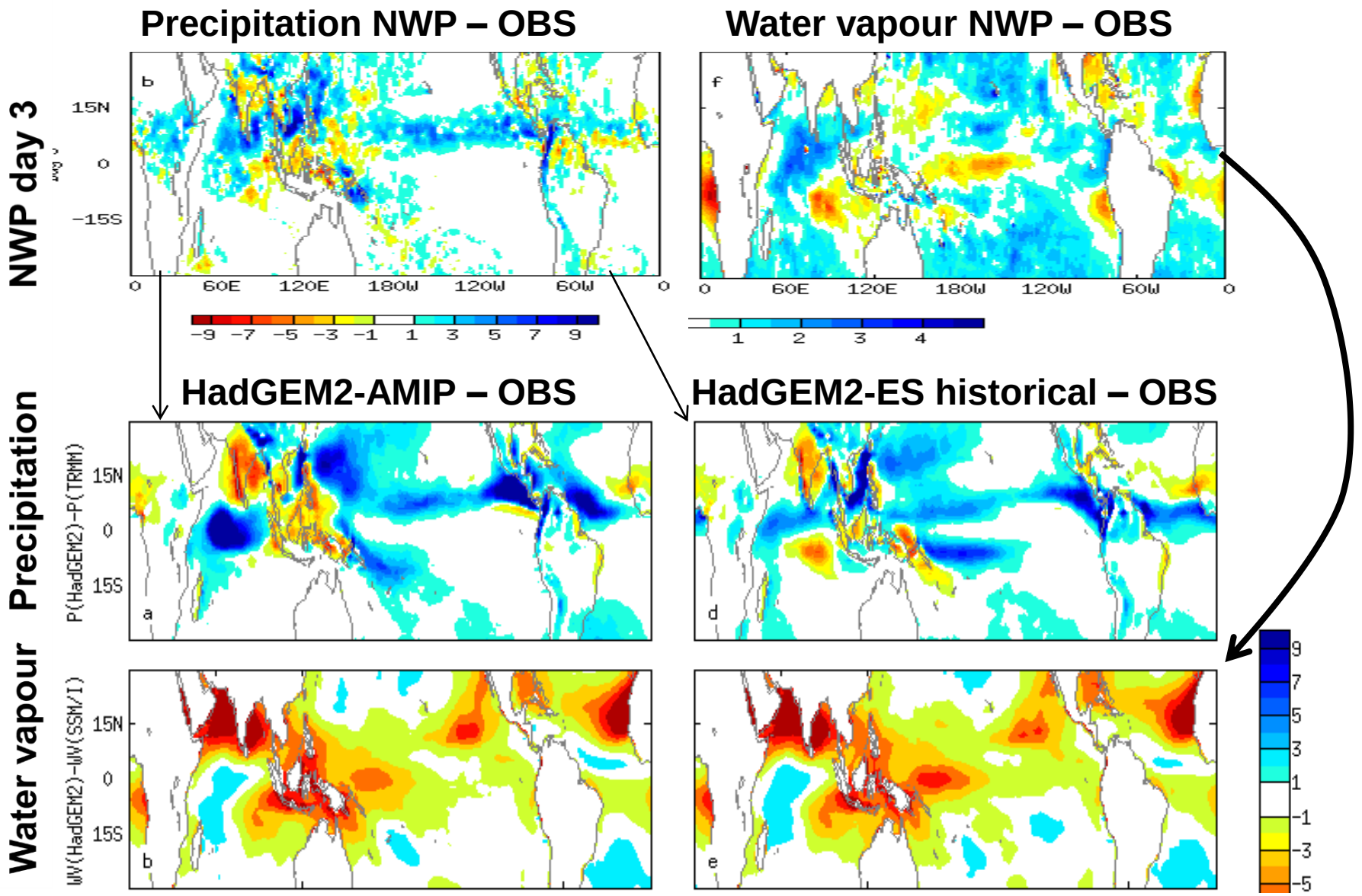

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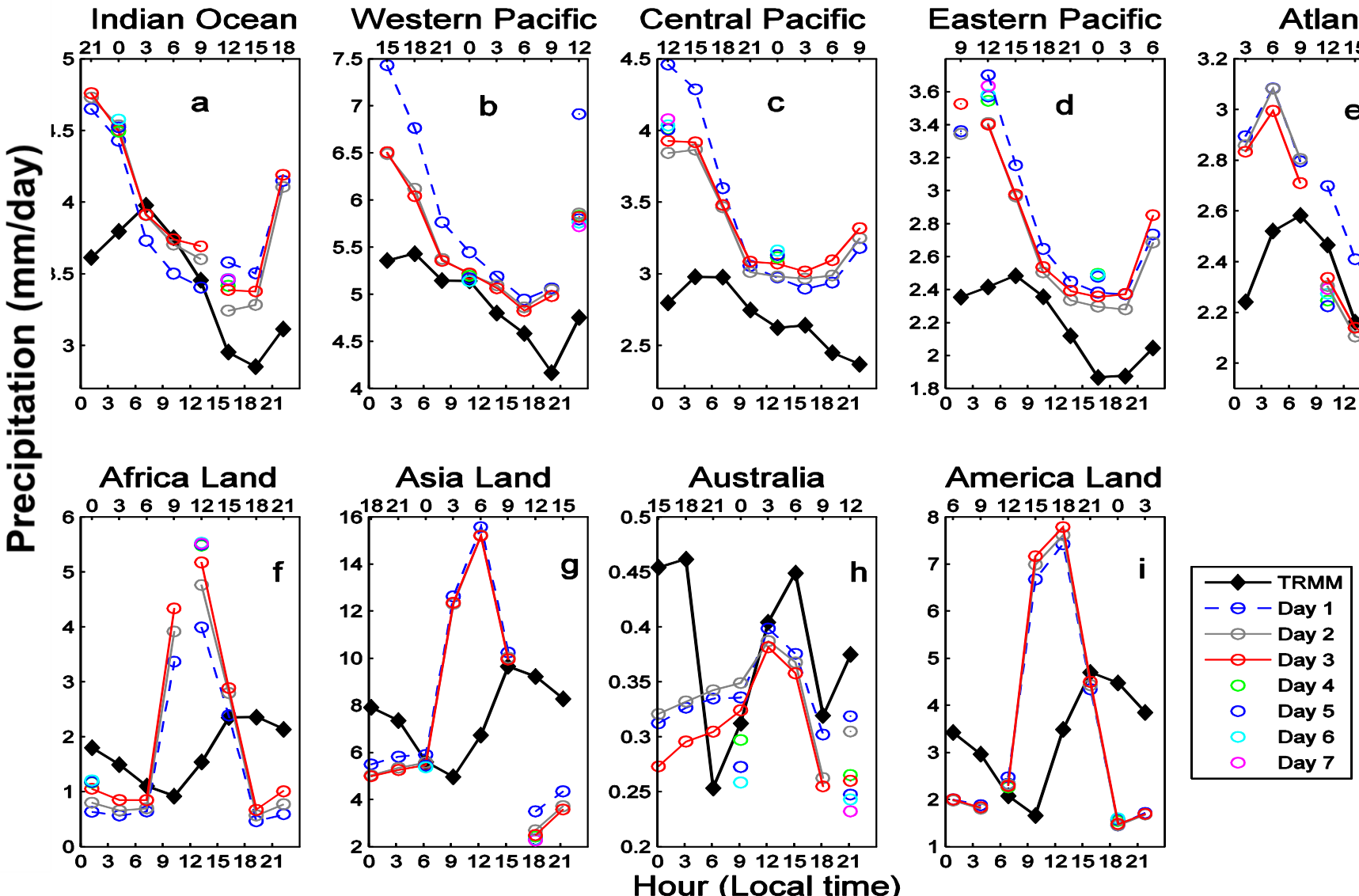
Diurnal Cycle in Precipitation:

UK Met Office NWP vs TRMM data



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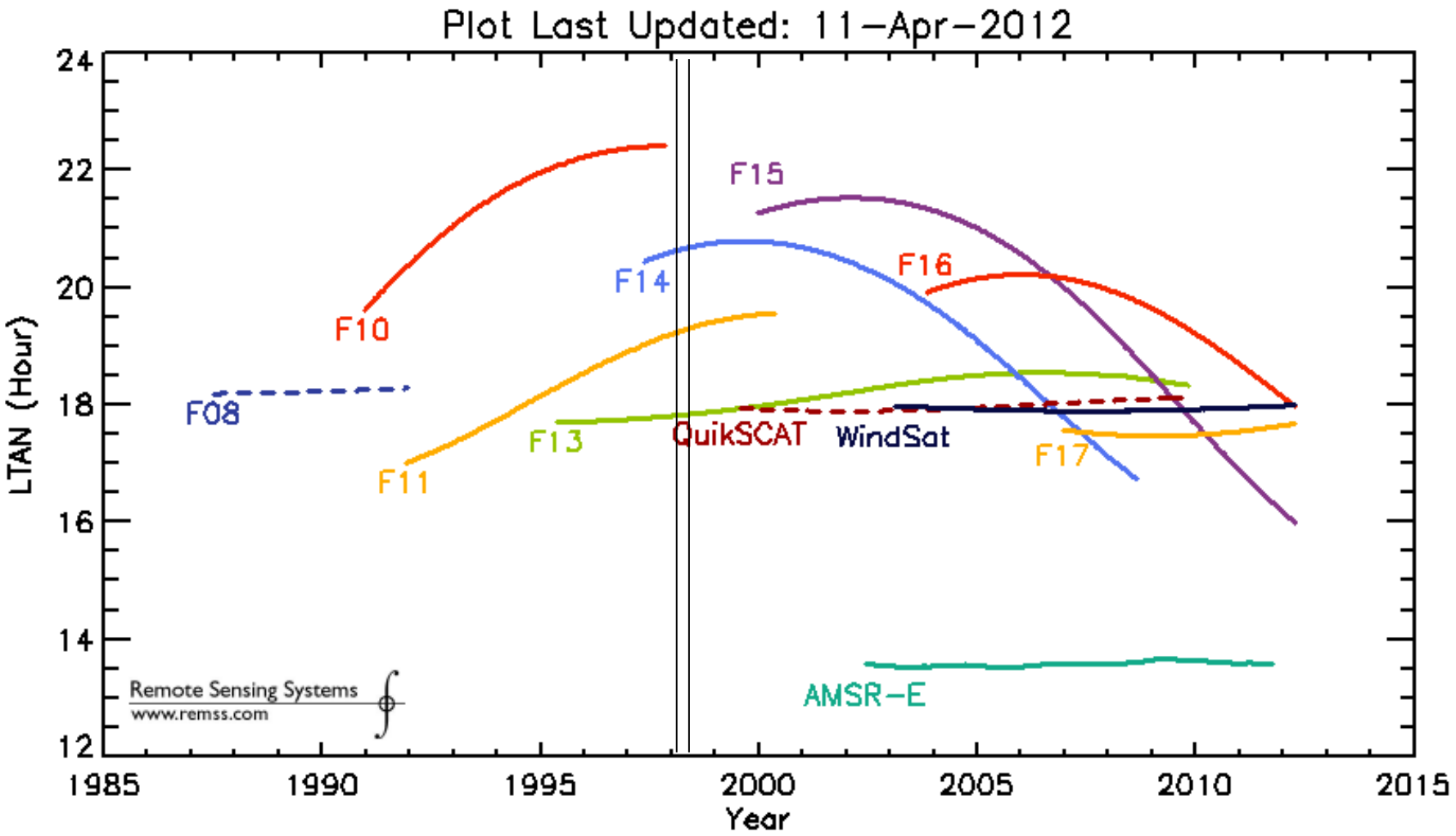
SSM/I(S) Equator Crossing Times



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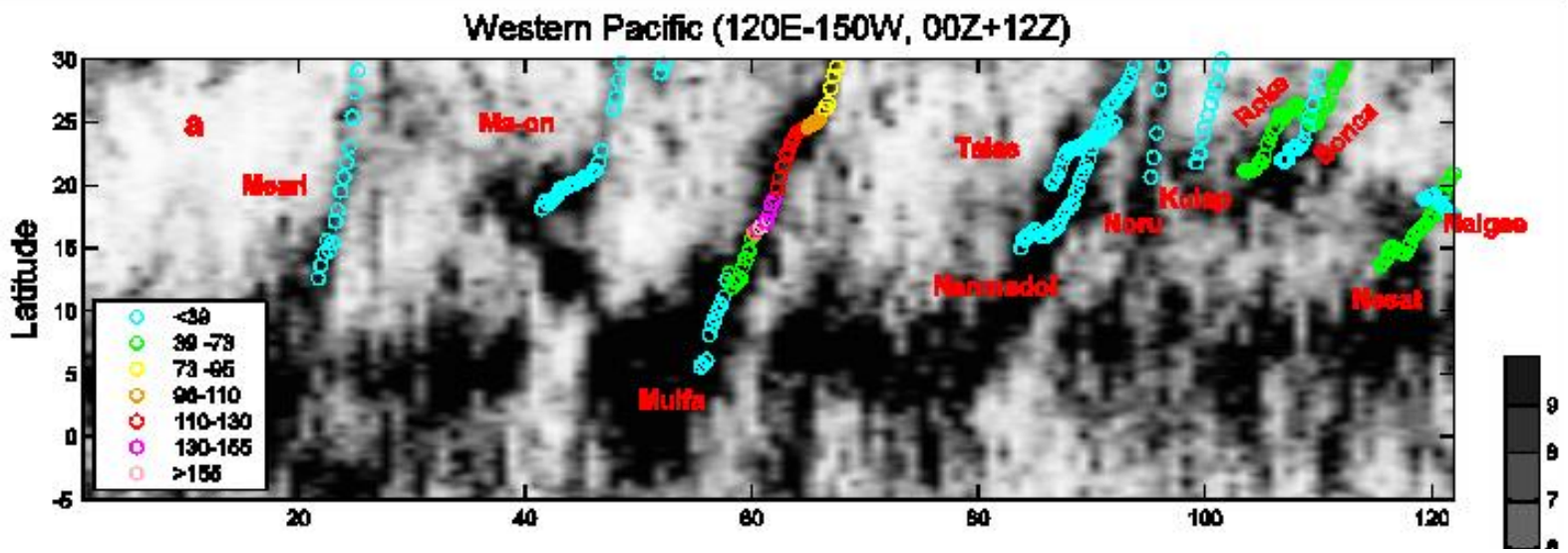
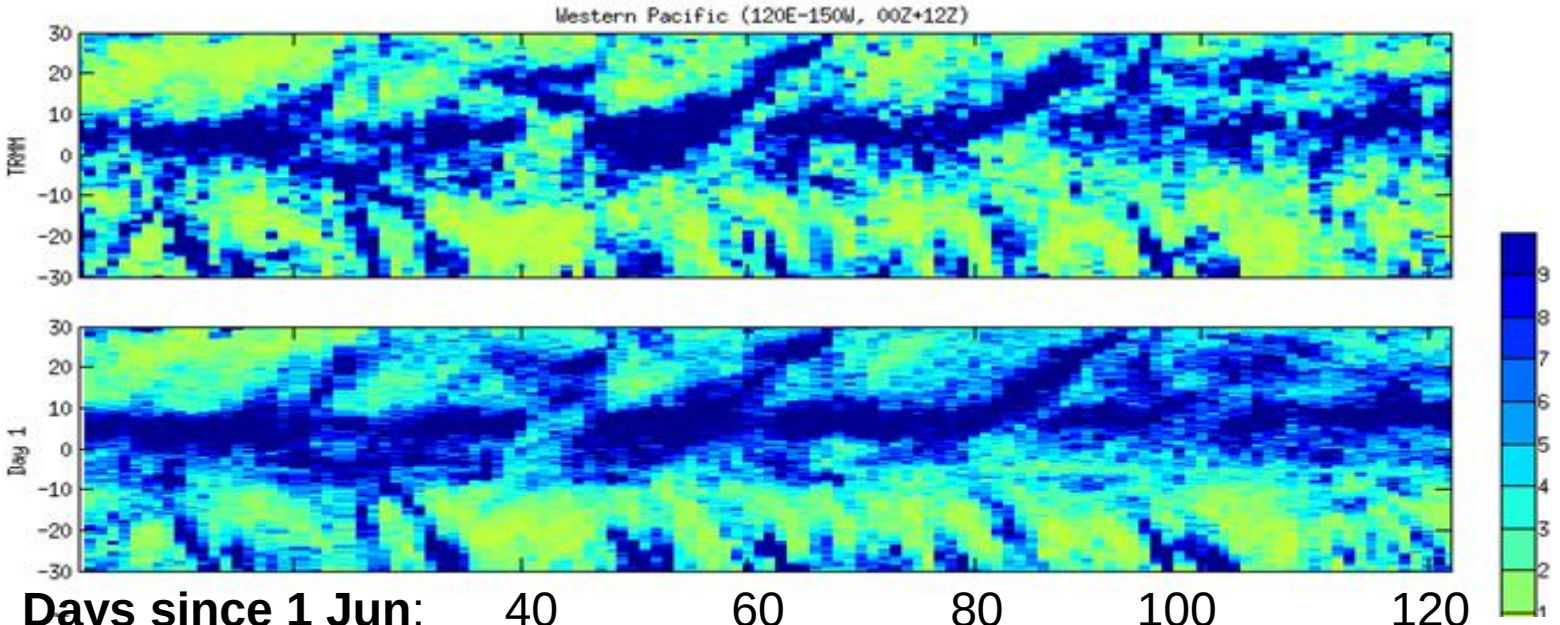
Propagation of precipitation anomaly



Western Pacific zonal mean Precipitation (mm/day): simulation



Evaluating climate model simulations of precipitation extremes

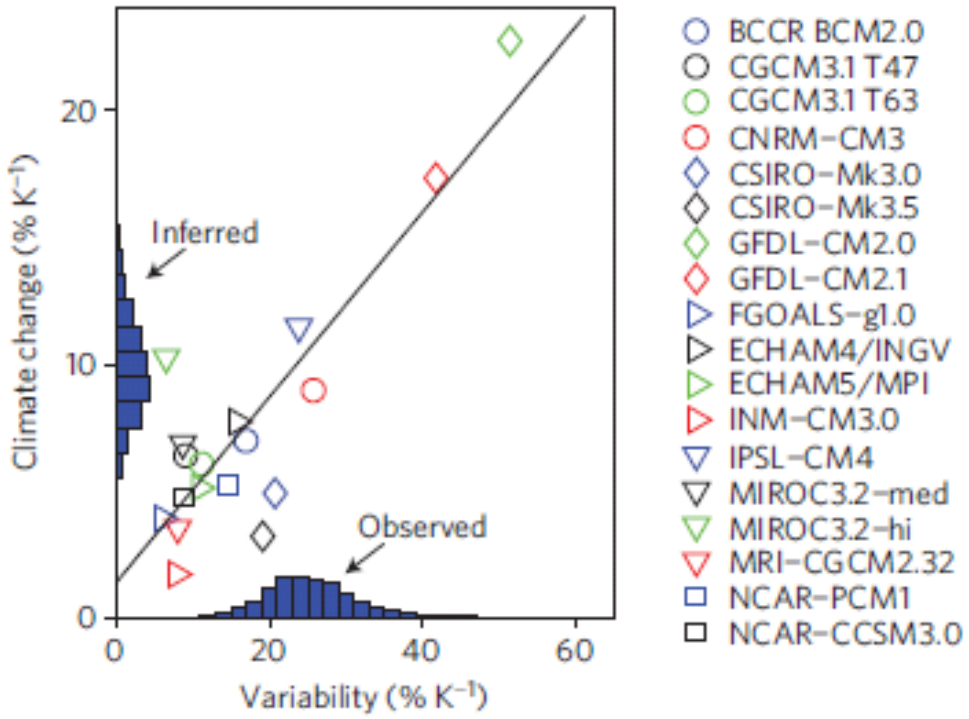


Figure 2 | Sensitivities (% K^{-1}) of the 99.9th percentile of precipitation for variability versus climate change in the CMIP3 simulations. The solid

Can observations be used to constrain the projected responses in extreme precipitation?

O'Gorman (2012) Nature Geosciences

See also Allan and Soden (2008) *Science*

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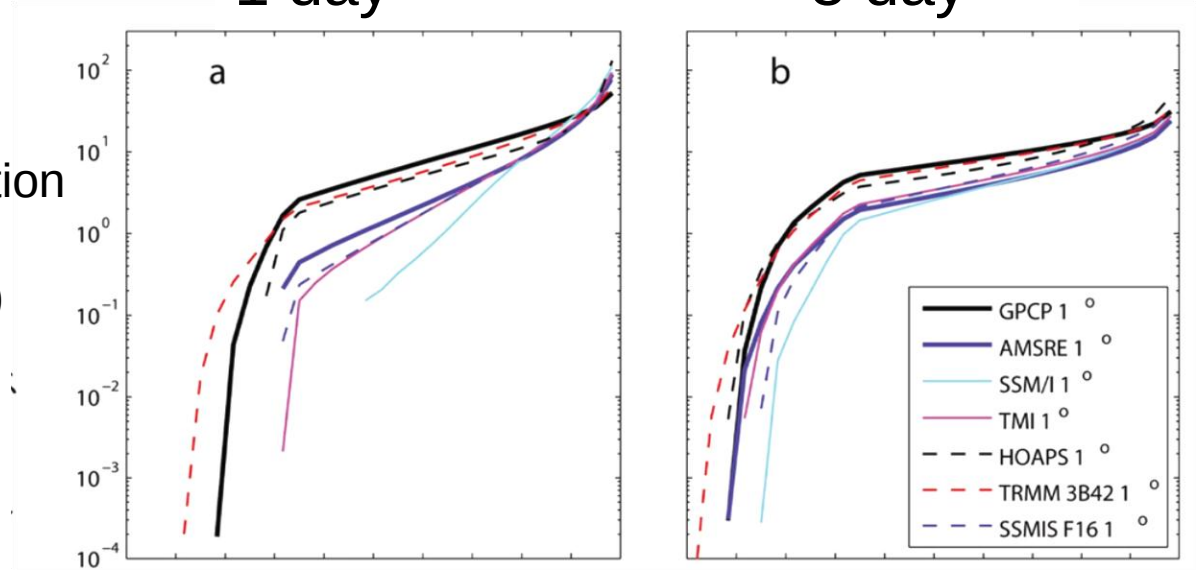
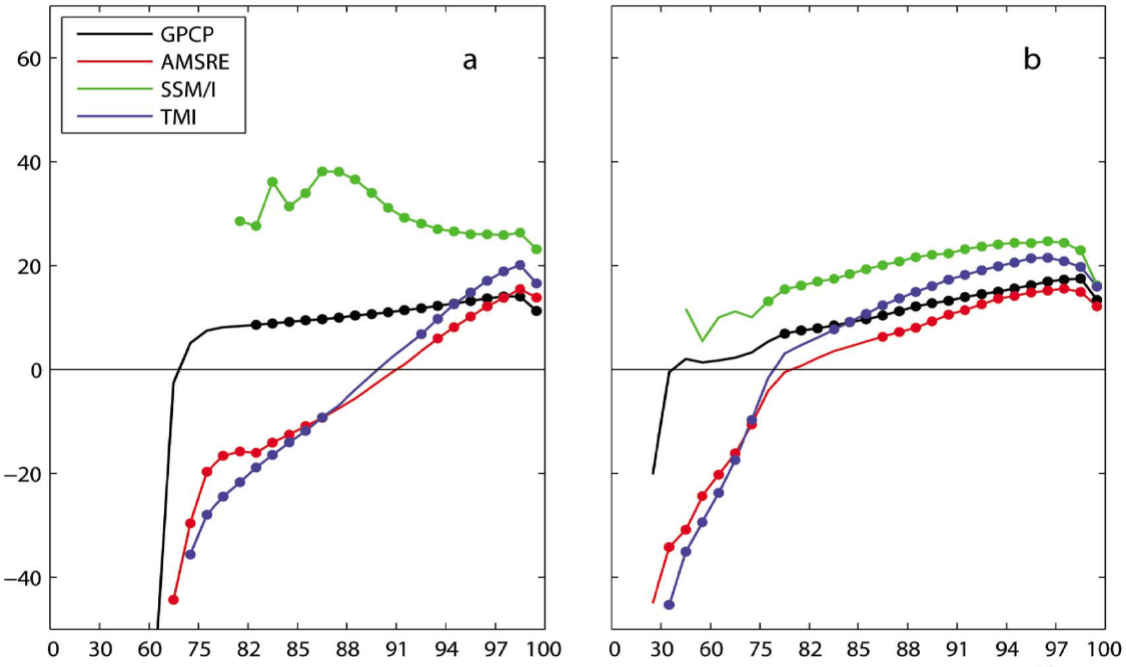
1 day

5 day

Precipitation intensity (mm/day)



Precipitation intensity change with mean surface temperature (%/day)



Precipitation intensity distributions & responses between datasets (tropical oceans)

Liu & Allan (2012) JGR

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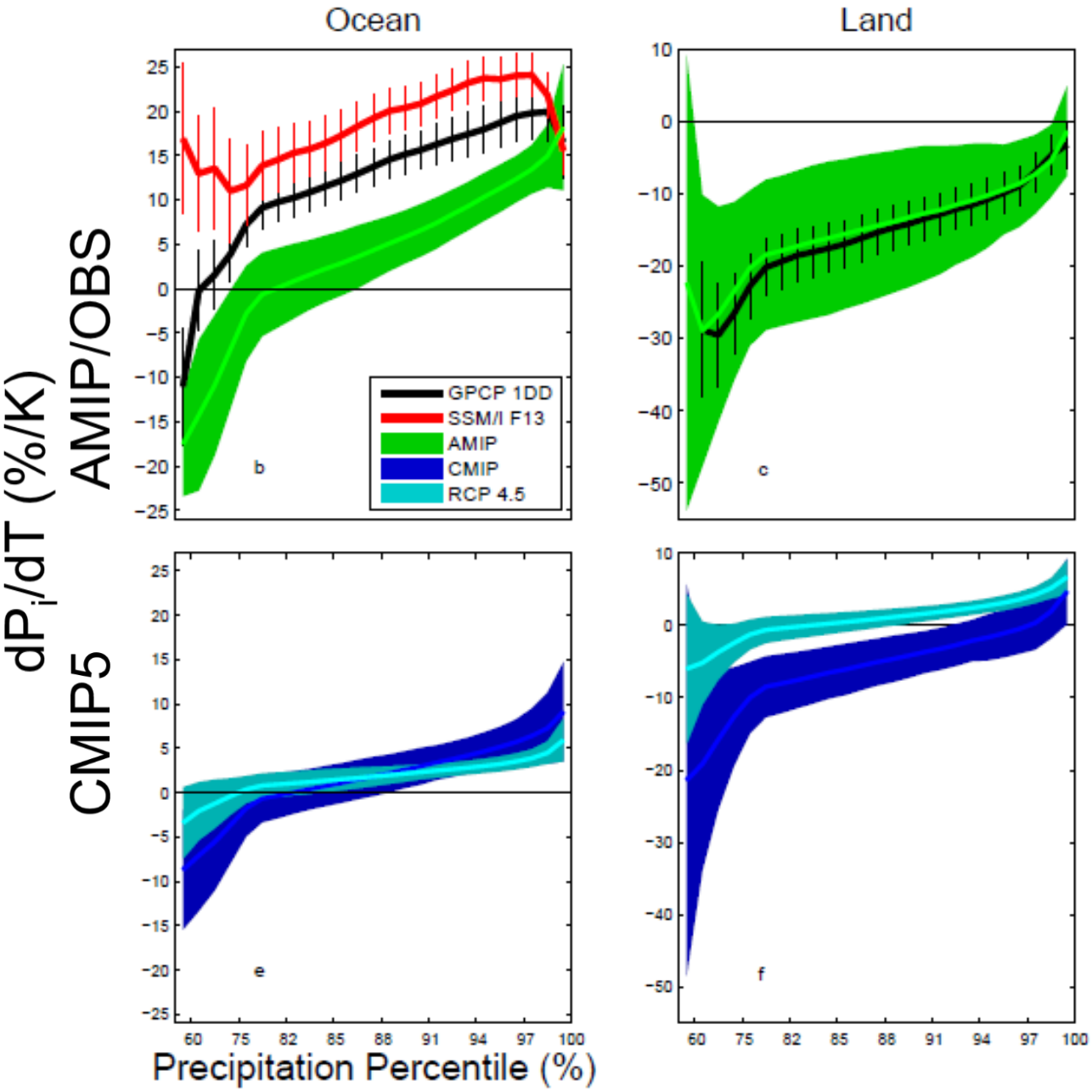
HydrOlogical cYcle Understanding via Process-bAsed GlObal Detection, Attribution and prediction

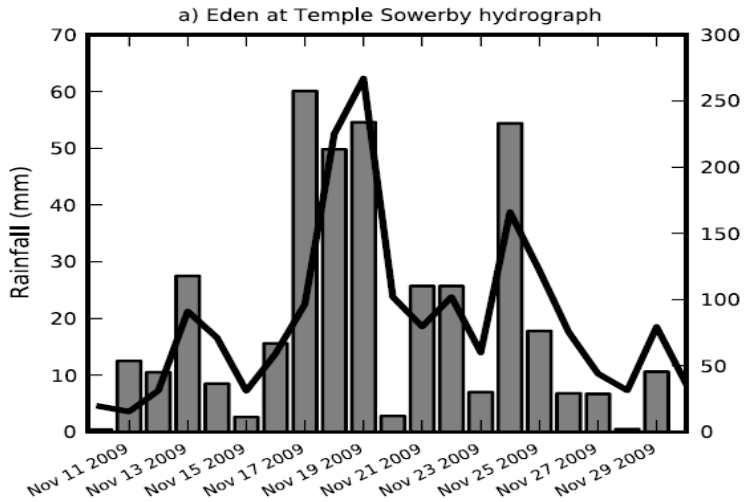
Response of 5-day Precip intensity distribution to warming: CMIP5 and observations

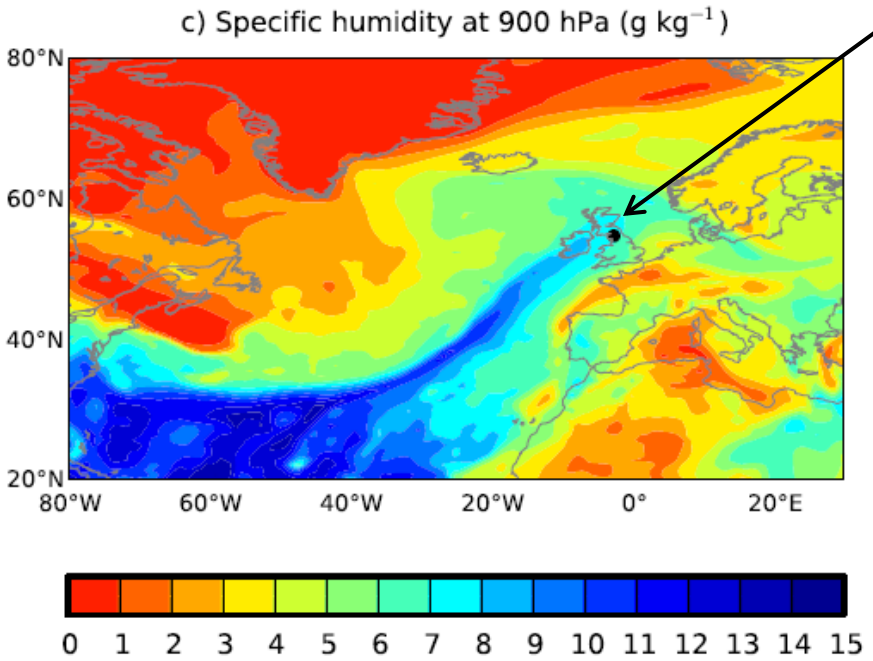


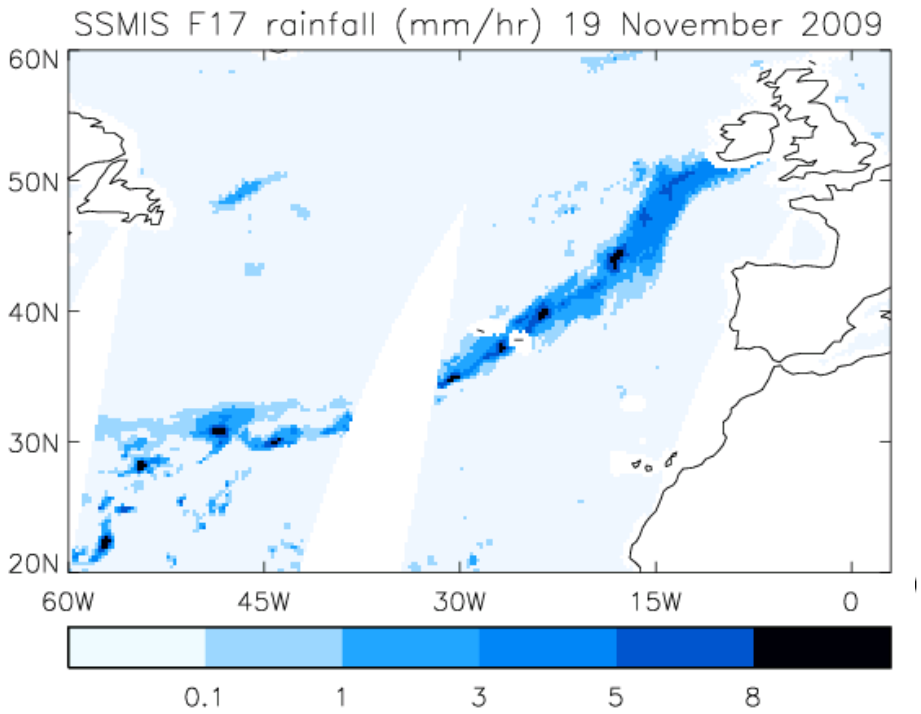
Allan et al. (2013) Surv. Geophys, in press

Linking flooding to moisture transports

Importance of large-scale atmospheric precursors for flooding
e.g. Nov 2009 Cumbria floods (UK)



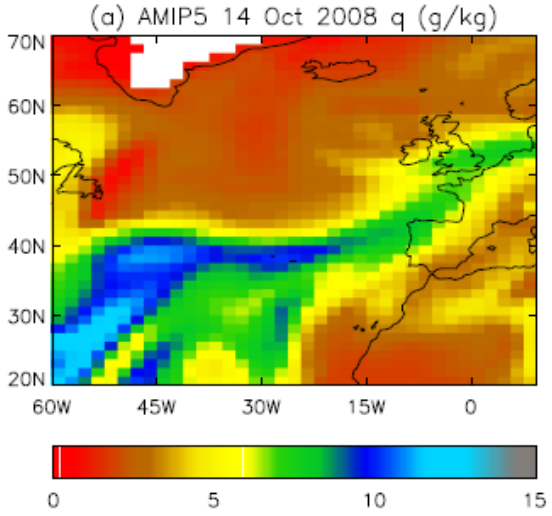




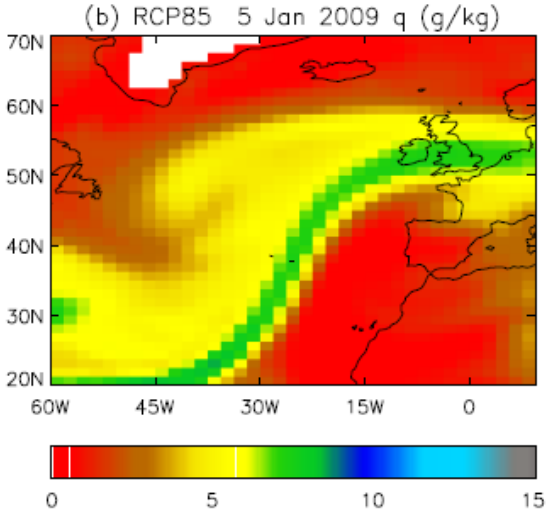
Lavers et al. (2011) Geophys. Res. Lett.

Are “Atmospheric Rivers” simulated by climate models?

AMIP



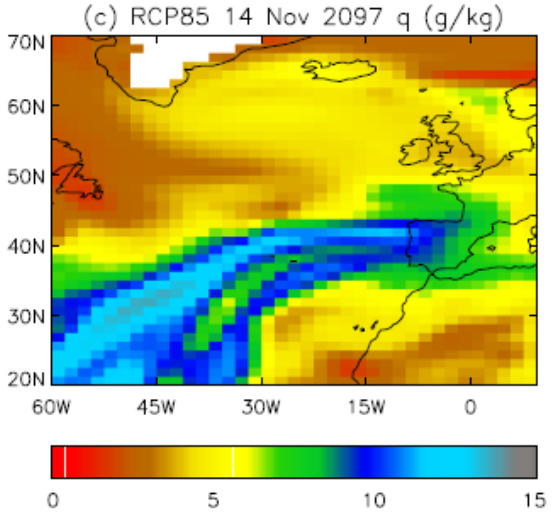
CMIP



← Coarse-scale climate models able to capture flood-generating mid-latitude systems

- Will thermodynamics dominate over changes in dynamics under climate change? →

…work in progress.



Conclusions

- Global rise in precipitation ~2%/K
  - Relate to energetics (O'Gorman et al. 2012)
  - **Regional projections a challenge**
- Robust increases in water vapour (~7%/K) →

Fuels comparable rise in precipitation intensity

  - Possible positive feedbacks on hourly time-scales

Enhanced moisture transport: wet get wetter, dry get drier

  - Moisture feedbacks over land?

- Observations
  - Water vapour over ocean well represented (land? upper troposphere?)
  - Satellite precipitation data: discrepancies over the ocean
  - Variability of land precipitation consistent between blended satellite/gauge datasets and simulations
  - can NWP models be exploited in understanding climate model biases?

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