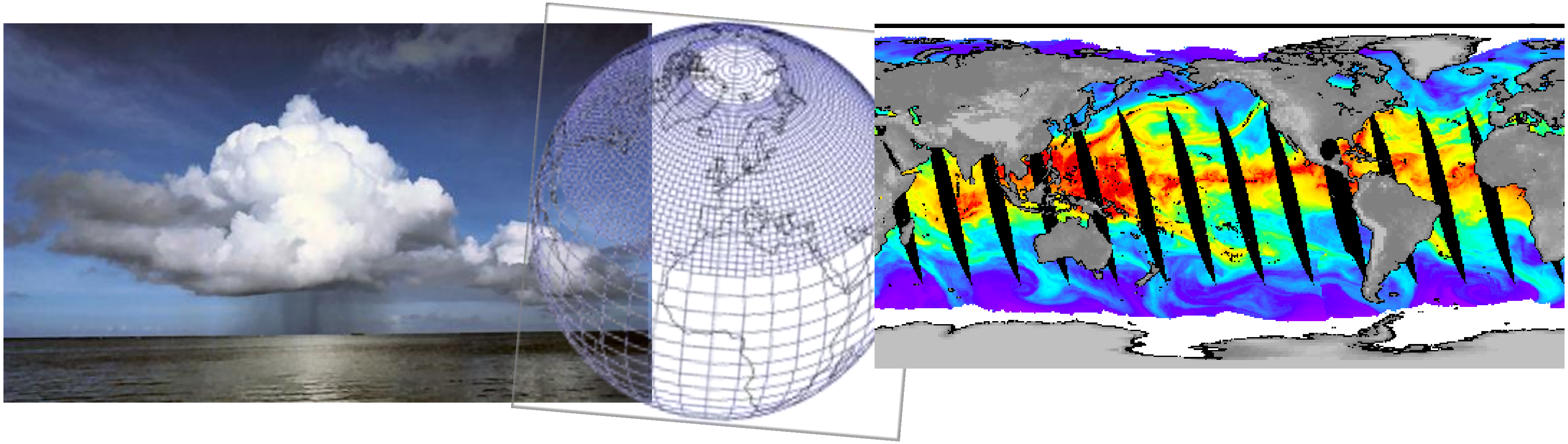

A Changing Character of Precipitation in a Warming World: Physical Drivers

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How will the water cycle change?

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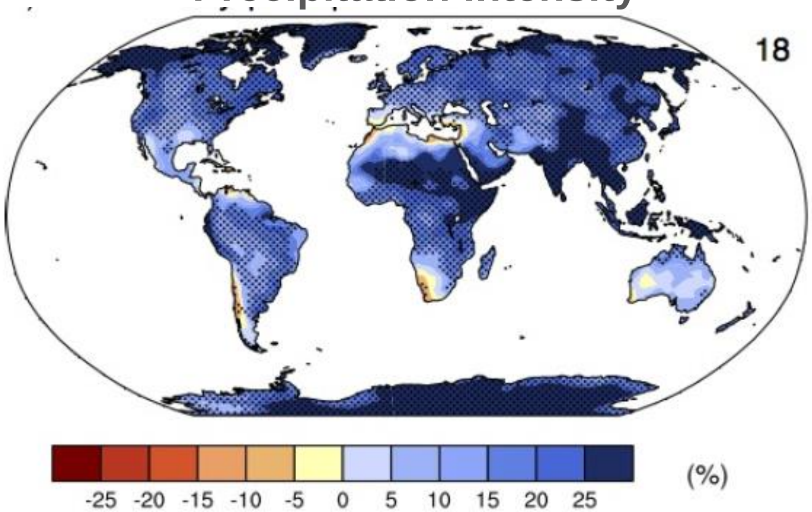
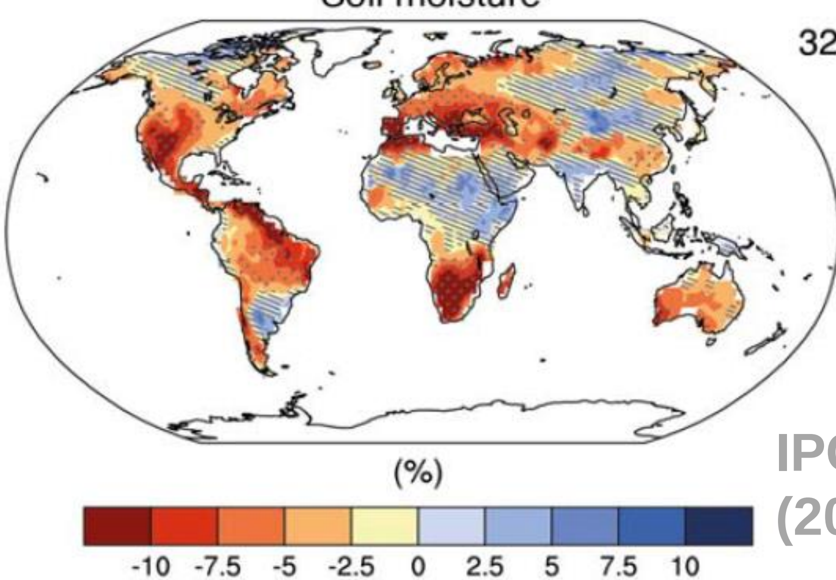
Precipitation intensity

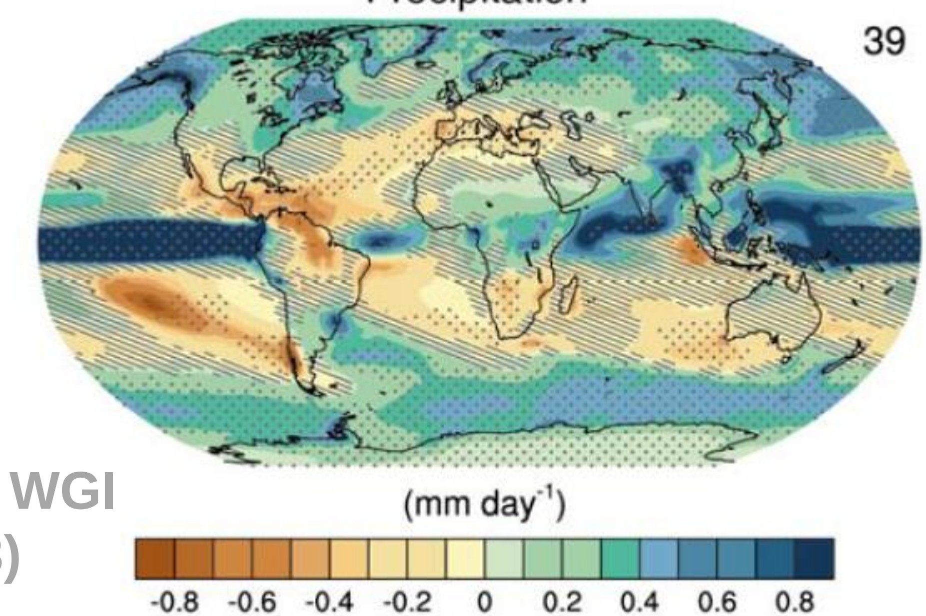


Soil moisture



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

Precipitation



IPCC WGI (2013)

Physical Driver: Earth's Energy Balance

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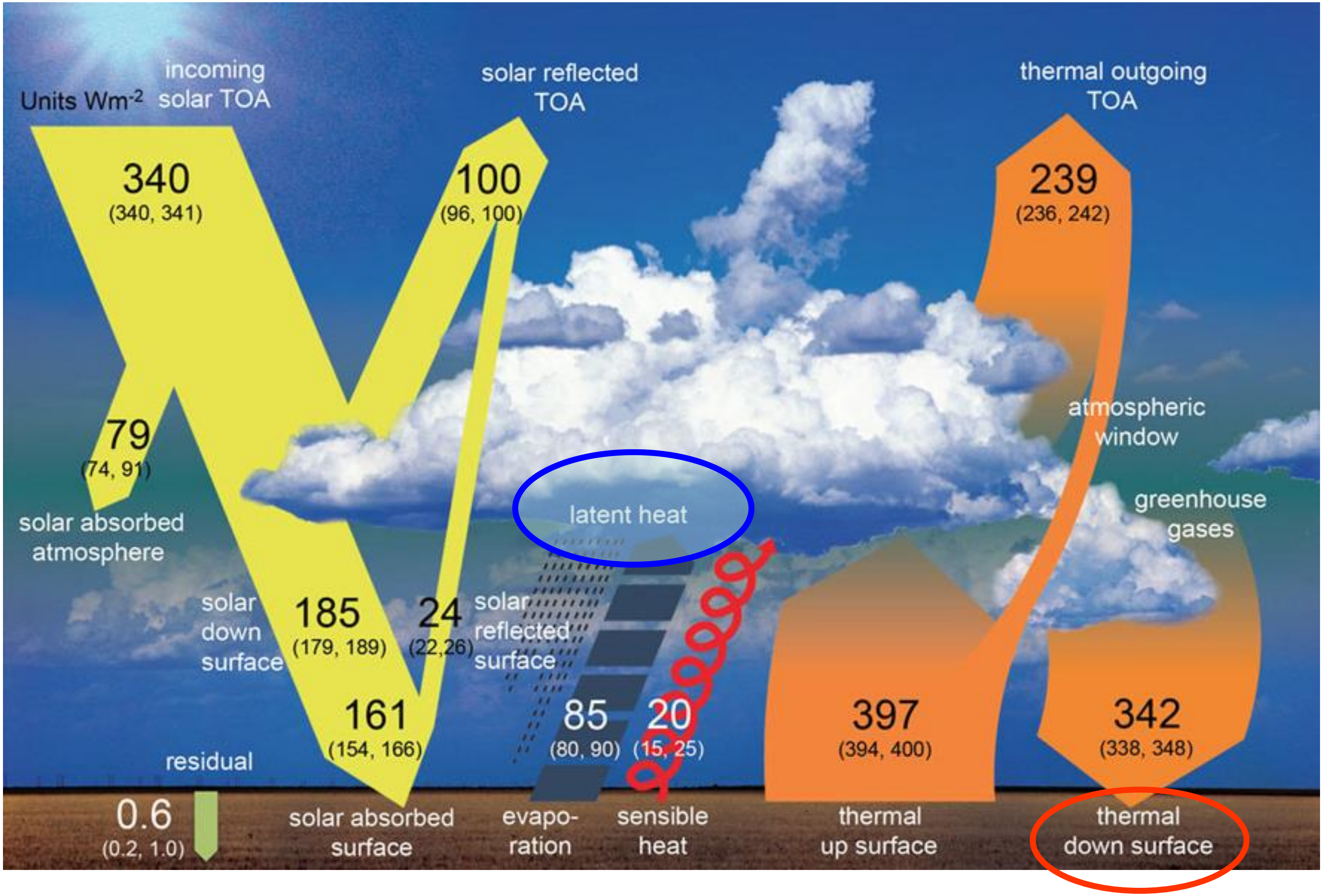

Wild et al. (2012) Clim. Dynamics. See also: Trenberth et al. (2009) BAMS

Physical Driver: water vapour

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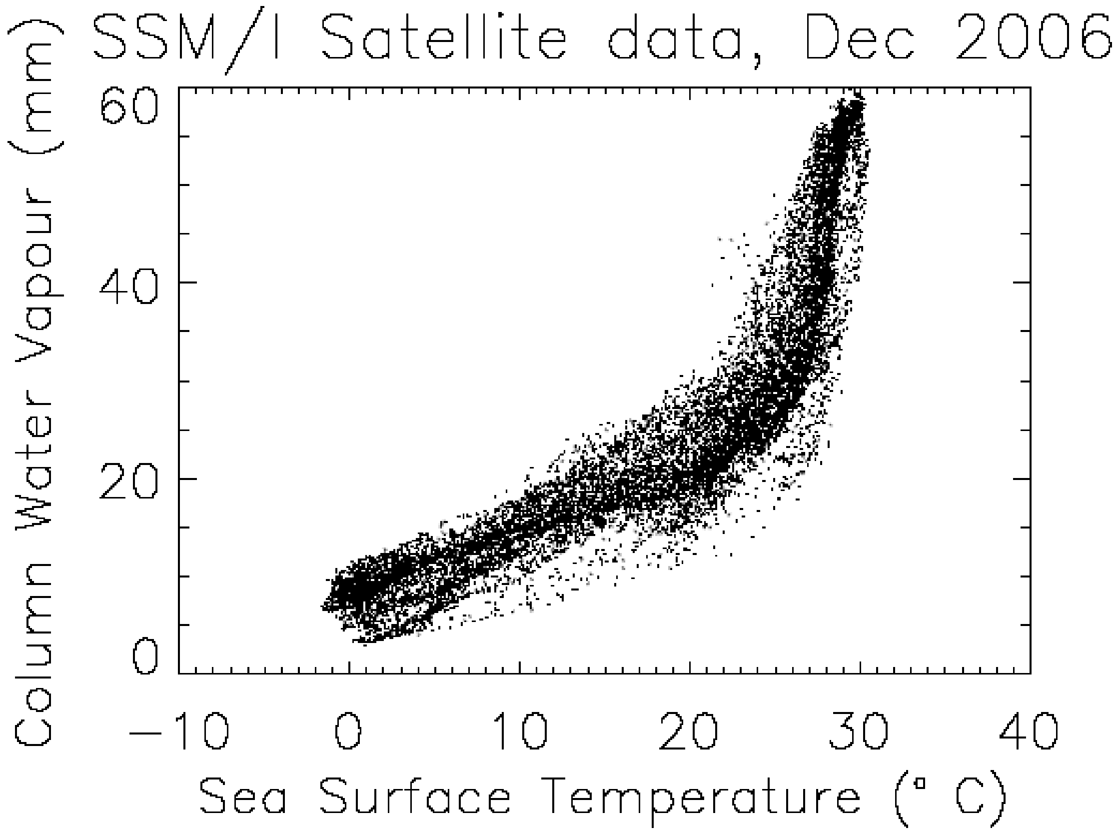
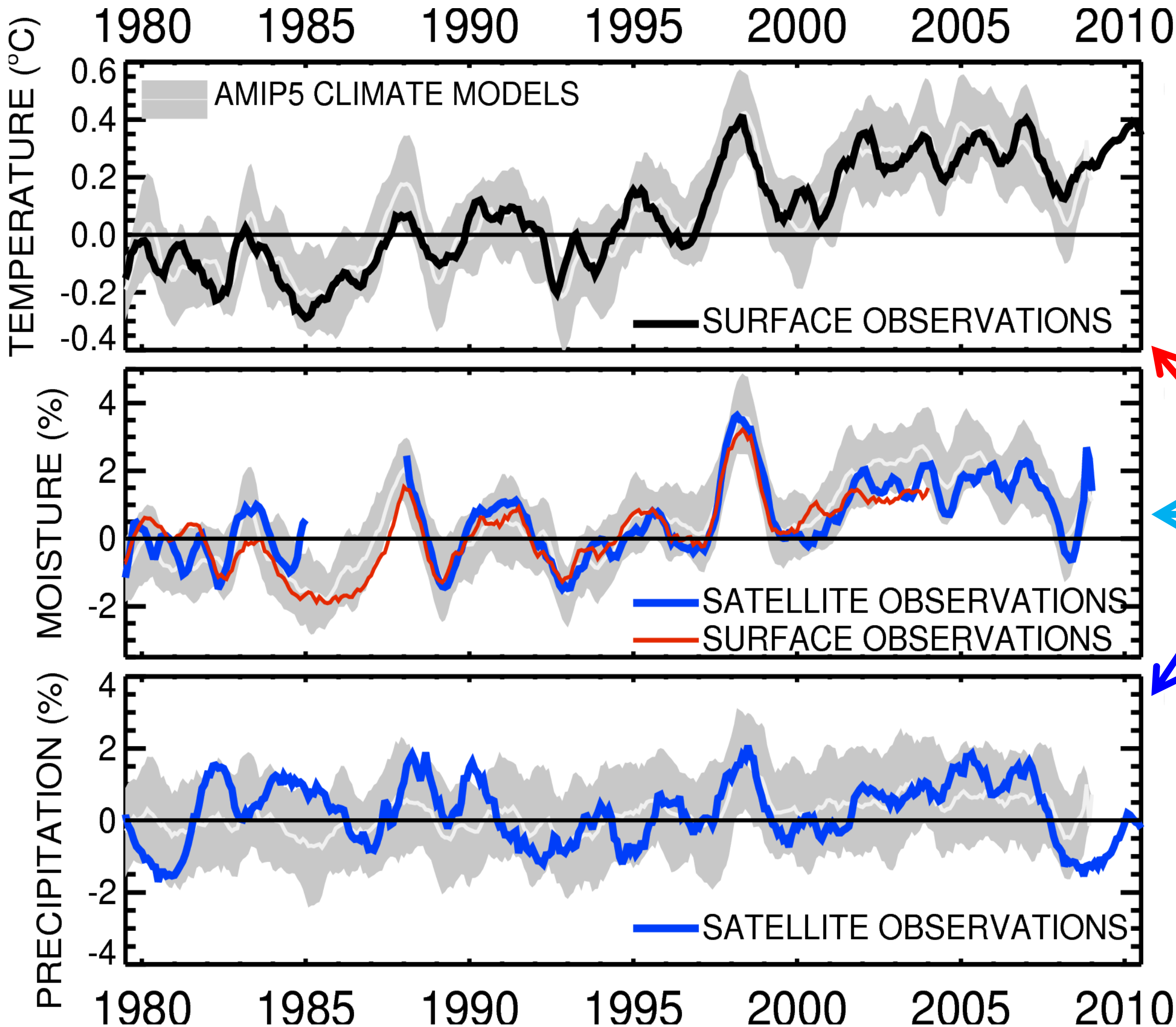


$$\frac{1}{e_s}\frac{de_s}{dT} = \frac{L}{R_v T^2}$$

$$= \begin{cases} 0.14K^{-1} & T = 200K \\ 0.07K^{-1} & T = 273K \\ 0.06K^{-1} & T = 300K \end{cases}$$

- Physics: Clausius-Clapeyron
- Low-level water vapour concentrations increase with atmospheric warming at about 6-7%/K
  - Wentz and Shabel (2000) *Nature*; Raval and Ramanathan (1989) *Nature*



Globally, in the present-day climate, temperature, moisture and precipitation are strongly coupled

Allan et al. (2014) Surv. Geophys

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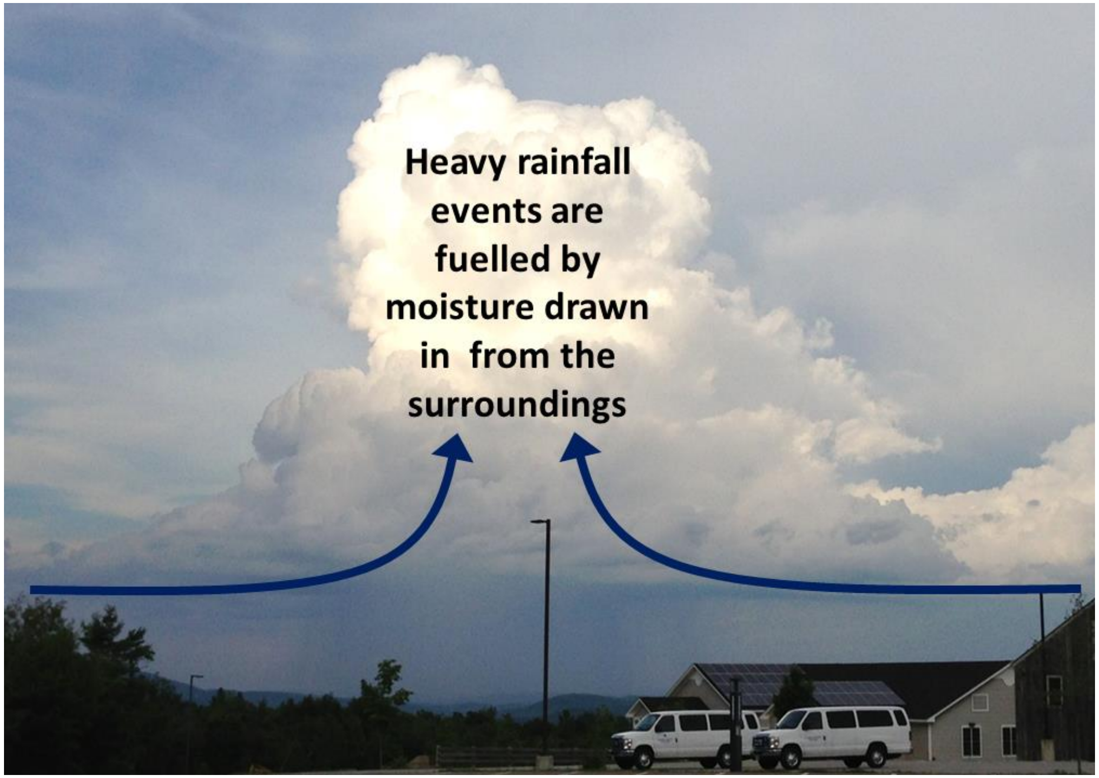
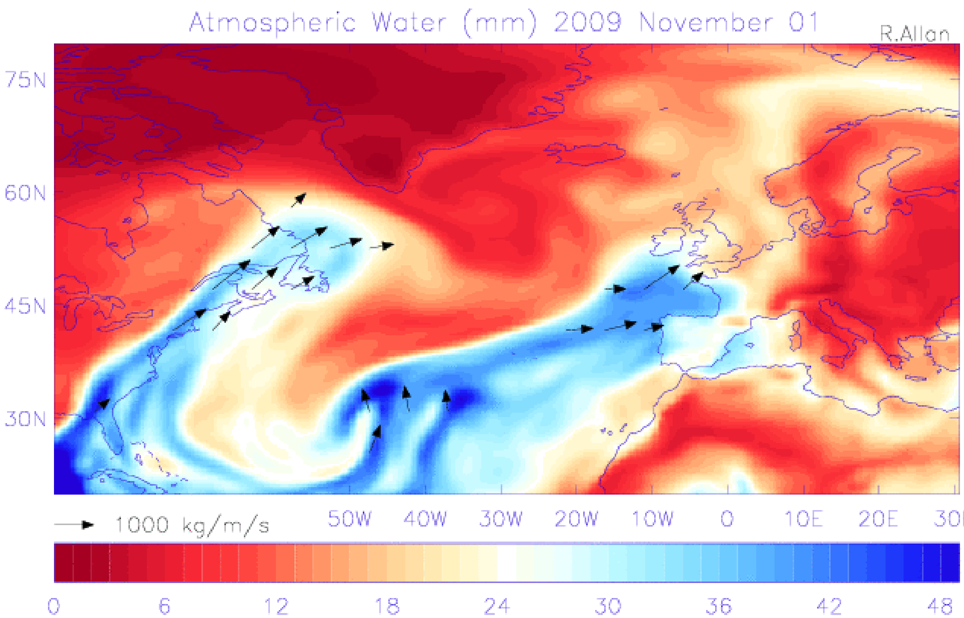
HydrOlogical cYcle Understanding via Process-bAsed GlObal Detection, Attribution and prediction

Extreme Precipitation

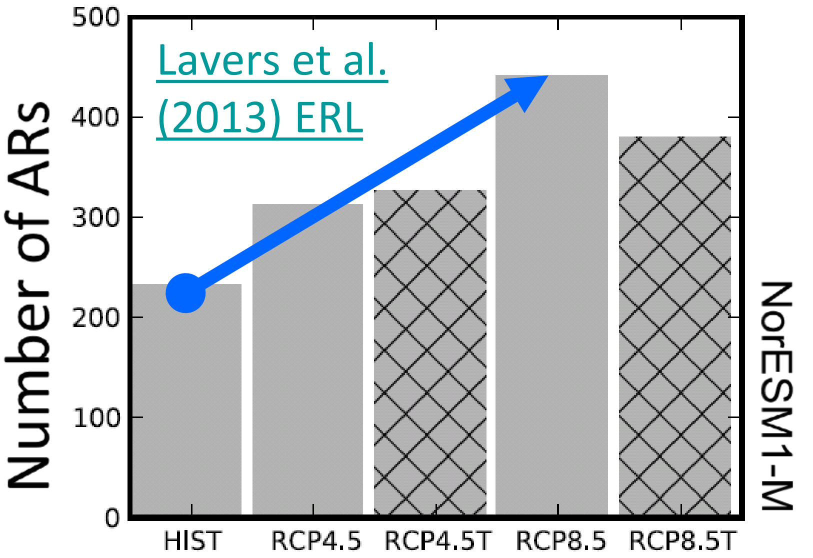


- Large-scale rainfall events fuelled by moisture convergence
  - e.g. Trenberth et al. (2003) *BAMS*
- Intensification of rainfall with global warming 7%/K or more?
  - *e.g. Allan and Soden (2008) Science ; Kendon et al. (2014) Nature Climate*

Water vapour and mid-latitude flooding

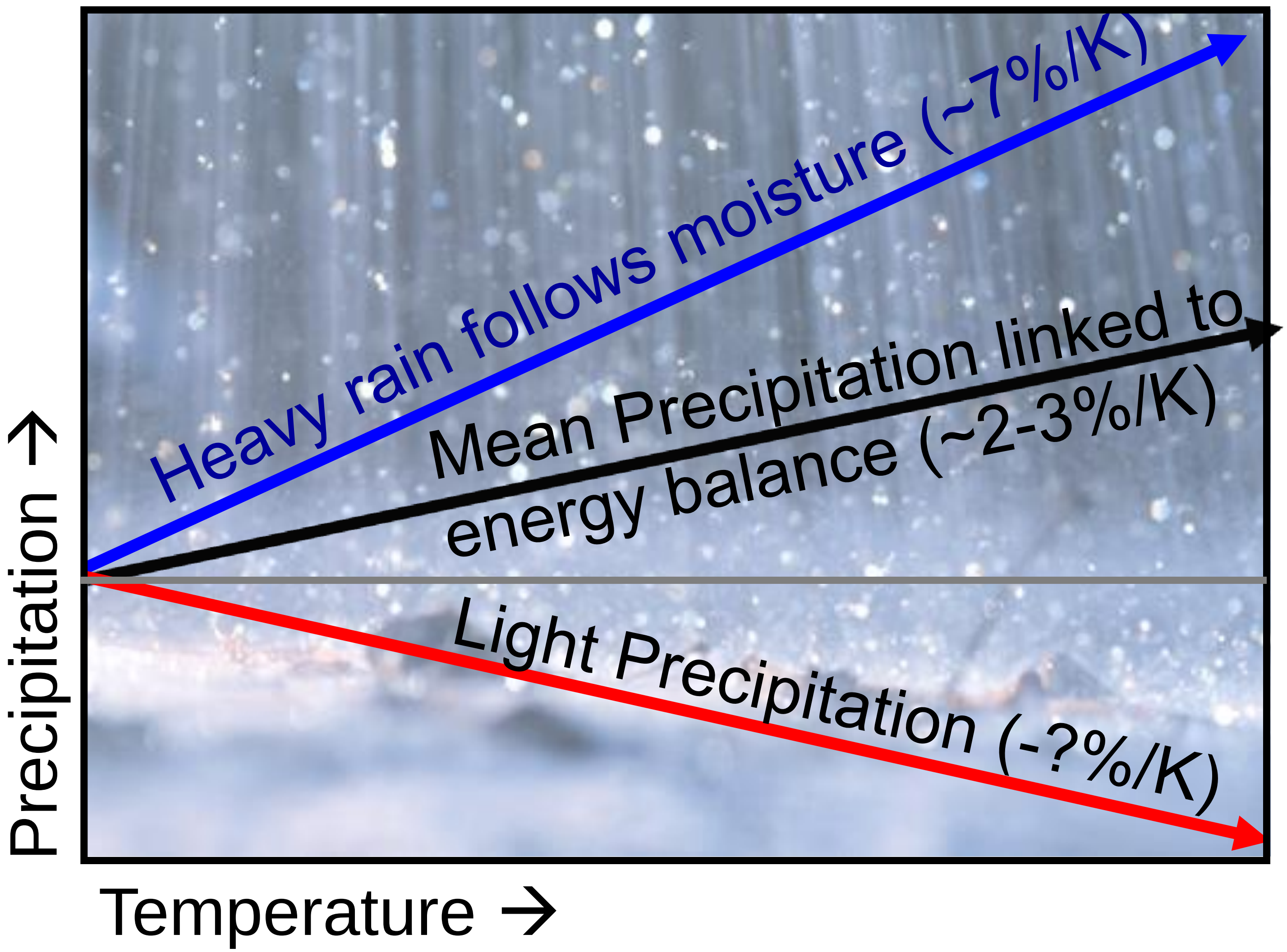


- UK winter flooding linked to strong moisture transport events
  - Cumbria November 2009 (Lavers et al. 2011 GRL)
  - "Atmospheric Rivers" (ARs) in warm conveyor



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

Contrasting precipitation response expected

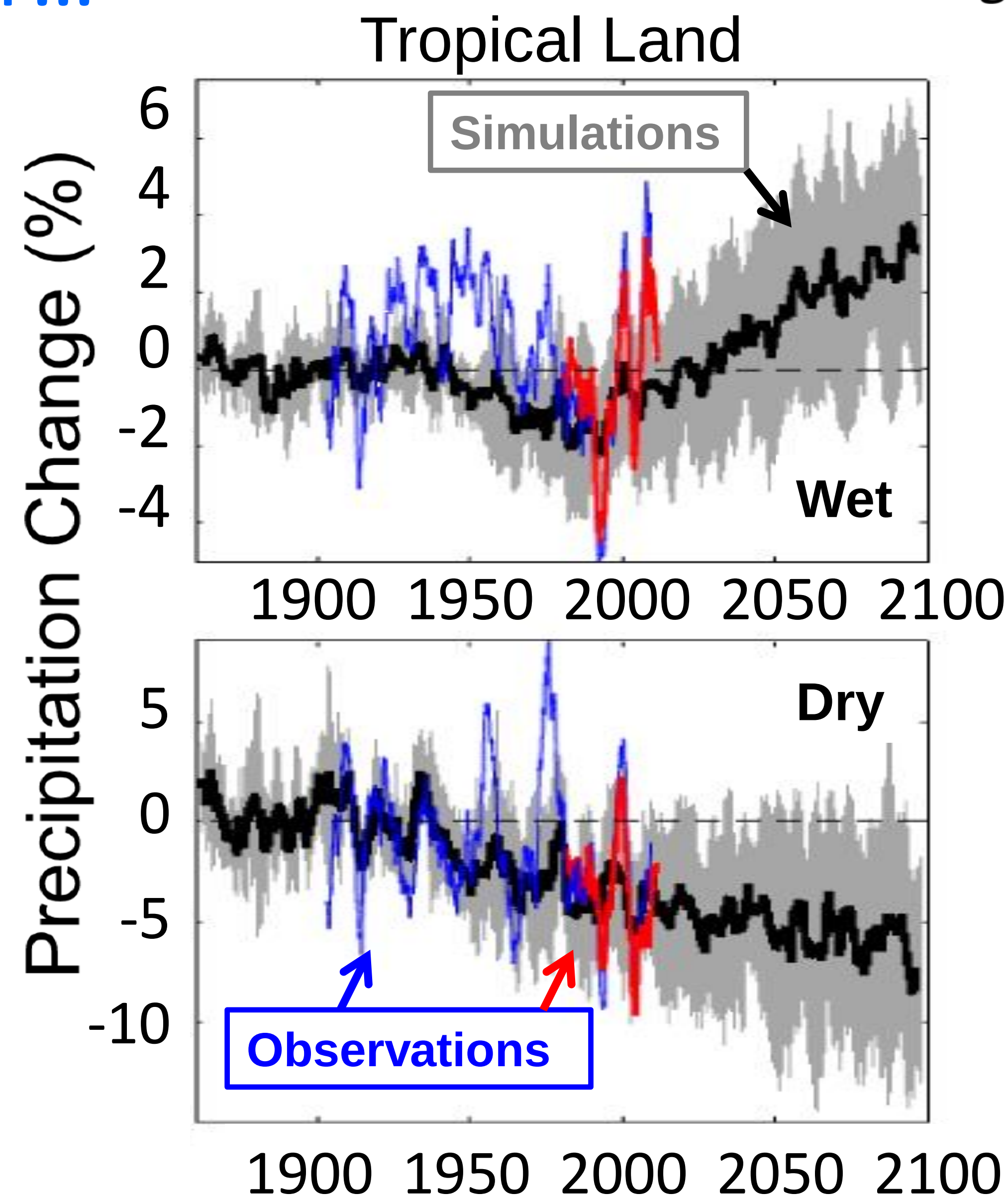


e.g. Allen and Ingram (2002) *Nature*; Allan (2011) *Nature*

The Rich Get Richer…

- Wet regions become wetter, already dry regions drier
- Observations and detailed computer simulations (CMIP5)
- But wet/dry regions move around

e.g. Allan (2014) Nature Geosci.



Liu & Allan (2013) *Environmental Research Letters*

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Challenge: Regional projections

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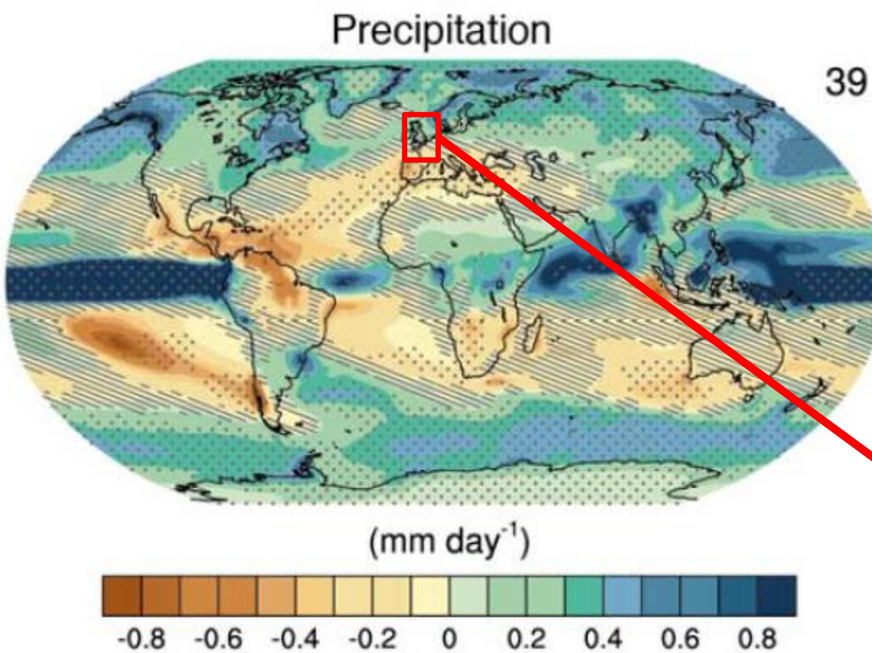
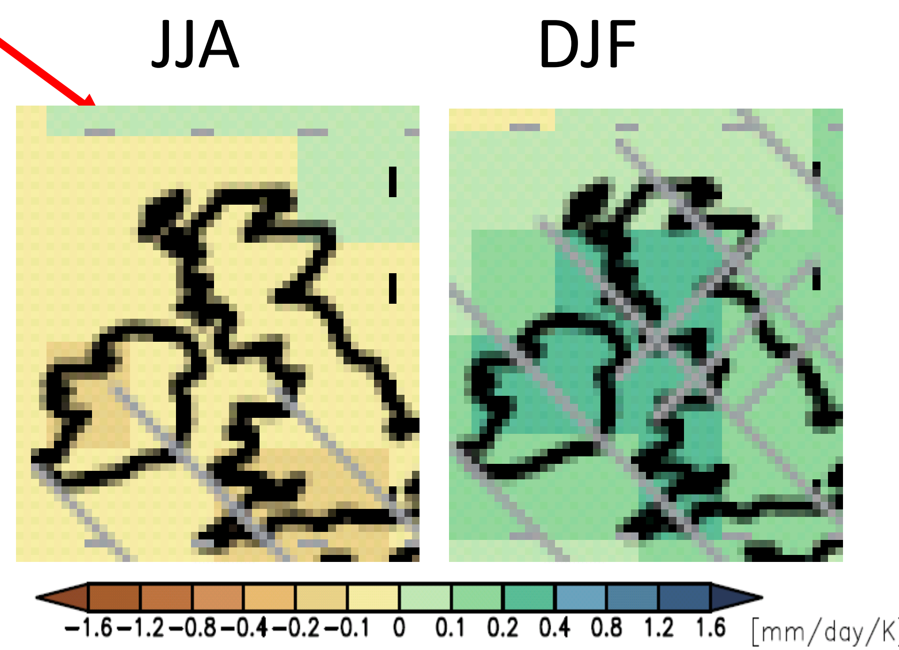


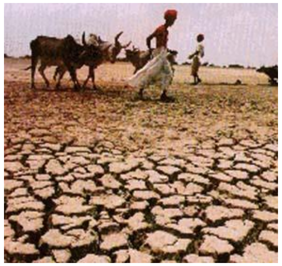
Shifts in atmospheric circulation are crucial to regional changes in water resources and risk yet this is the most challenging aspect of climate prediction



How will position of jet streams & monsoons respond to warming?

Aerosol radiative forcing, internal variability and feedbacks involving land surface & ocean-atmosphere coupling all influence regional circulation & precipitation patterns

Conclusions



- Global precipitation will rise with warming ~2%/K
  - Constrained by energy budget of atmosphere and surface
- Heavy rainfall becomes more intense
  - Fuelled by increased water vapour (~7%/K)
- Wet get wetter, dry get drier
  - More flooding, more drought ?
  - But wet and dry regions don’t stay still…
- Regional projections are a challenge
  - Sensitive to small changes in atmospheric circulation