Effect of climate change on the hydrological cycle

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In collaboration with Tapio Schneider

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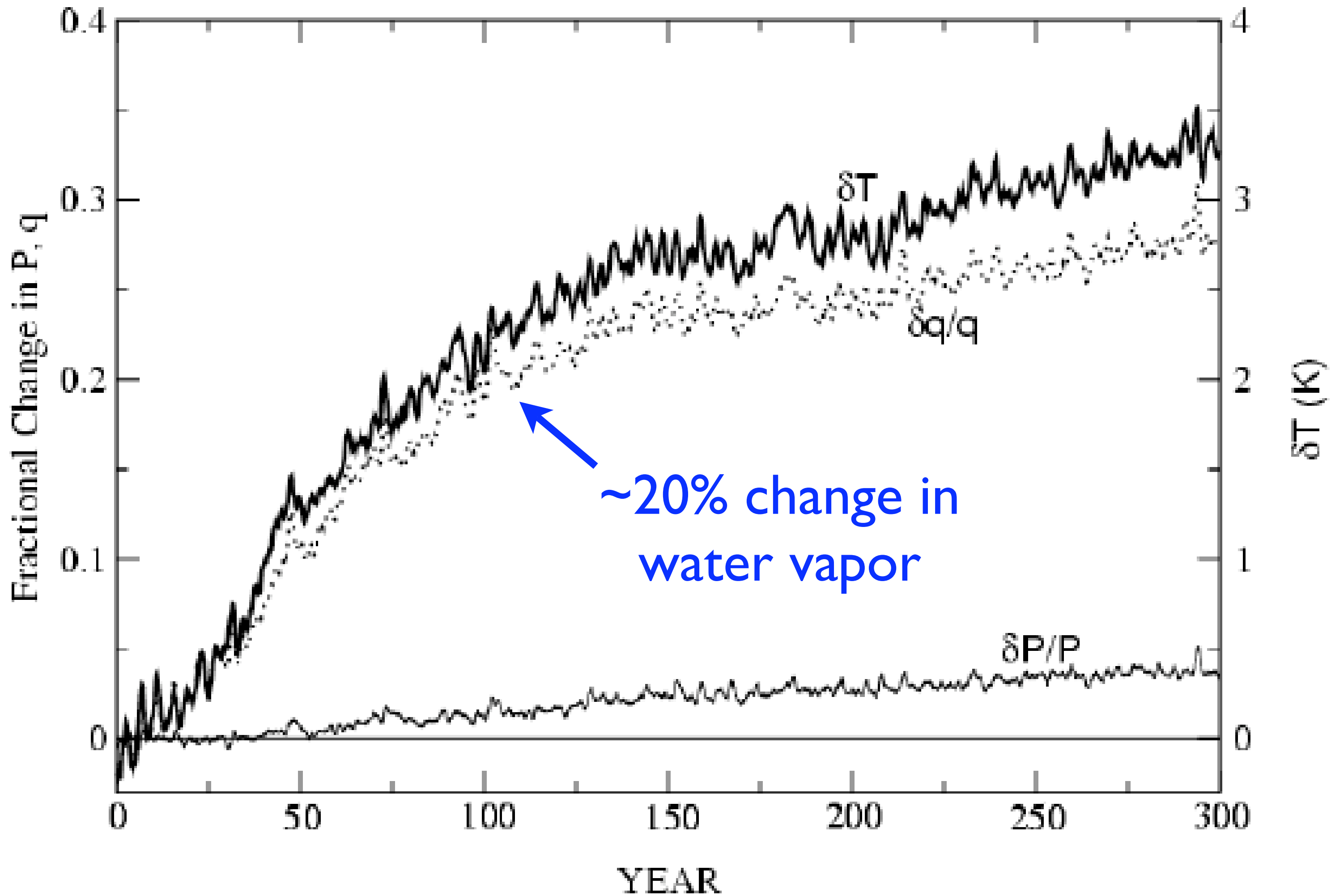
Big changes in water vapor with climate change

GFDL climate model under A1B global warming scenario



Held and Soden, 2006

Atmospheric water vapor and thermodynamics

Vapor pressure = Relative humidity x Saturation vapor pressure

Relative humidity: Stays relatively constant with climate change

Saturation vapor pressure: Grows exponentially in temperature (Clausius-Clapeyron relation)

Effects of big increase in water vapor?

Effect of climate change on:

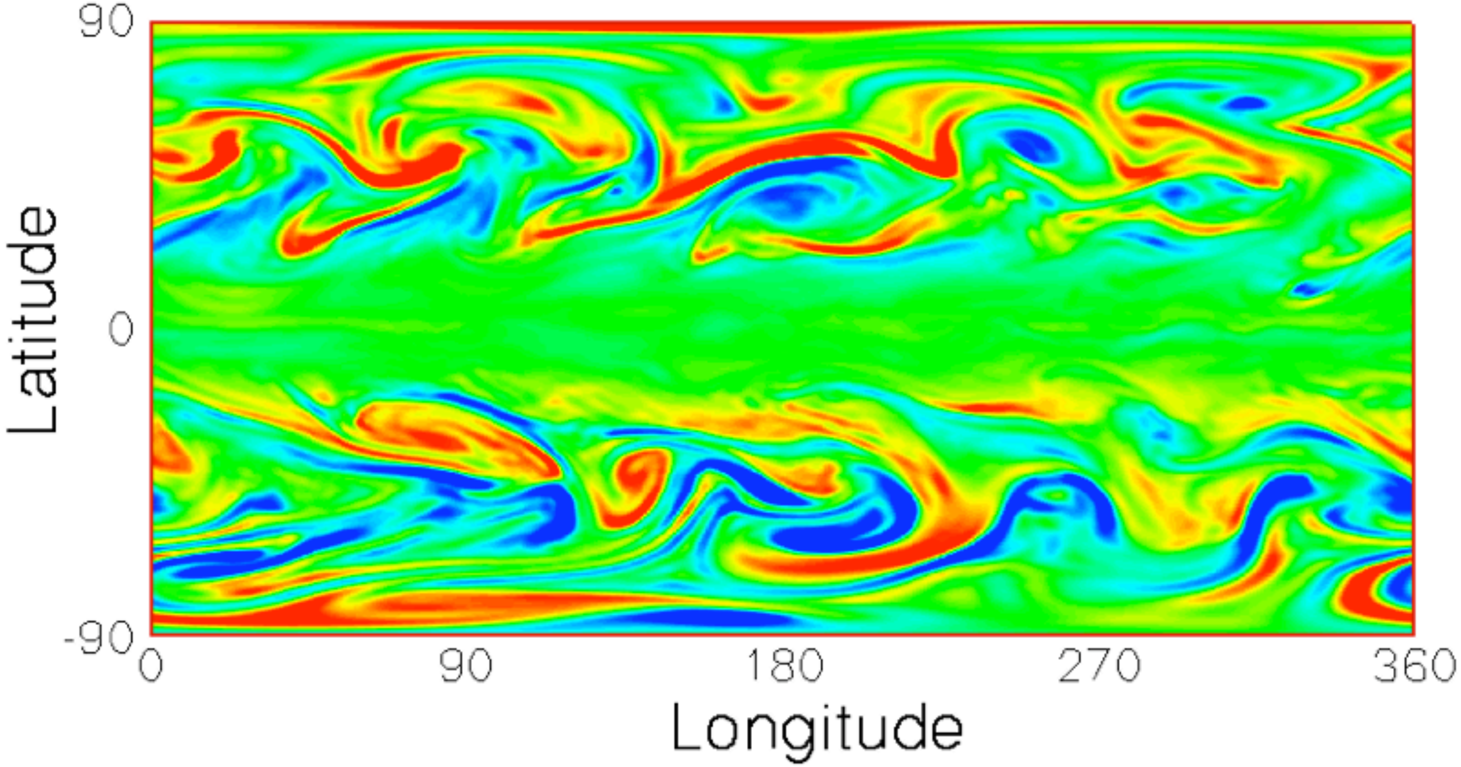
1) Mean precipitation: *(O'Gorman and Schneider, JOC 2008)*

- growth of global precipitation?

- change in region where condensation and precipitation occurs?

2) Precipitation extremes?

Idealized General Circulation Model (GCM) as testbed for effects of climate change



Snapshot of midtropospheric vorticity in idealized GCM

Idealized General Circulation Model (GCM) as testbed for effects of climate change

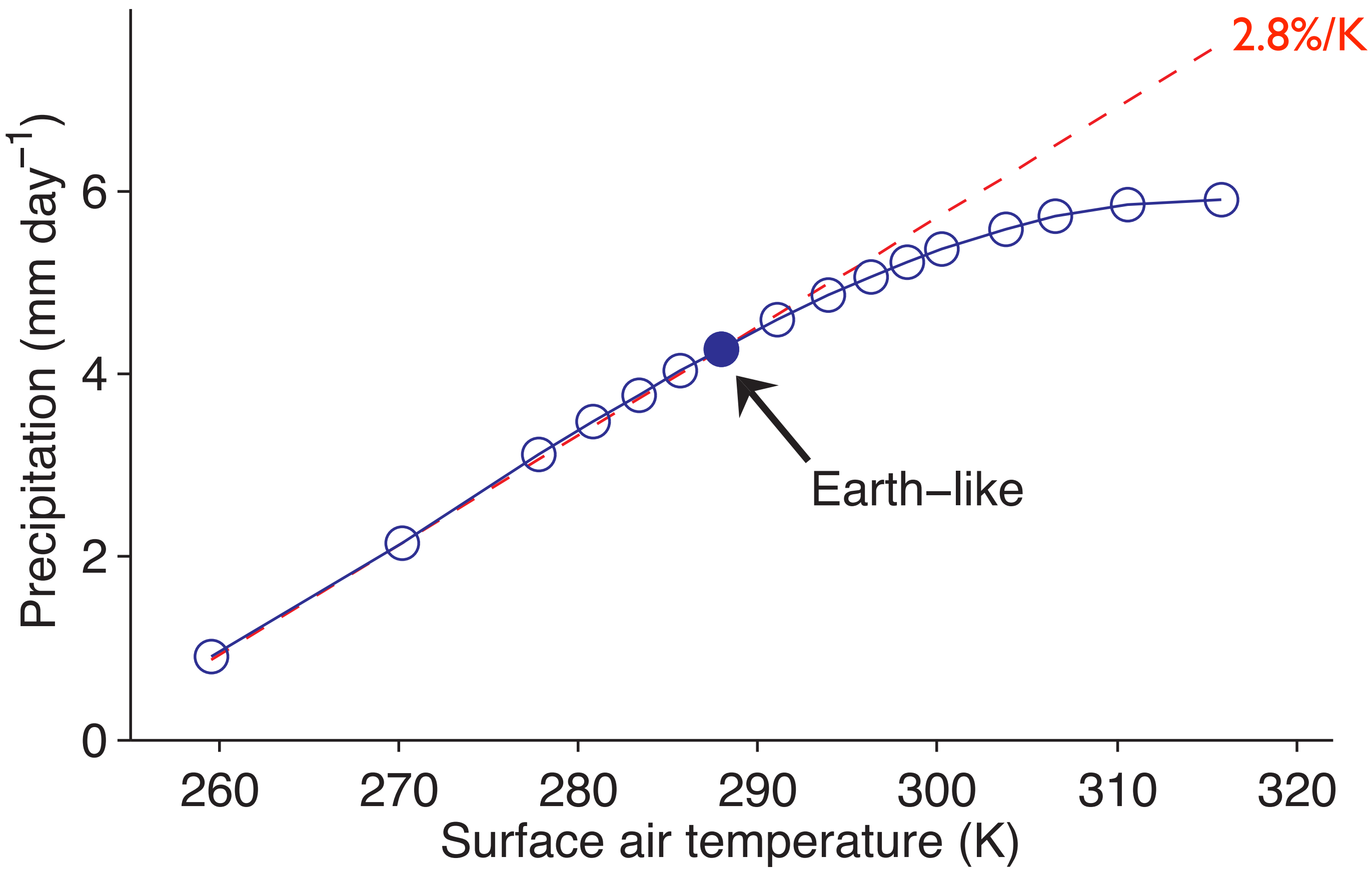
Idealized GCM has ‘full’ large-scale fluid dynamics with:

- mixed layer ocean as lower boundary condition
- semigray radiation and no clouds or ice

Optical thickness of longwave radiative absorber varied to mimic changes in greenhouse gases

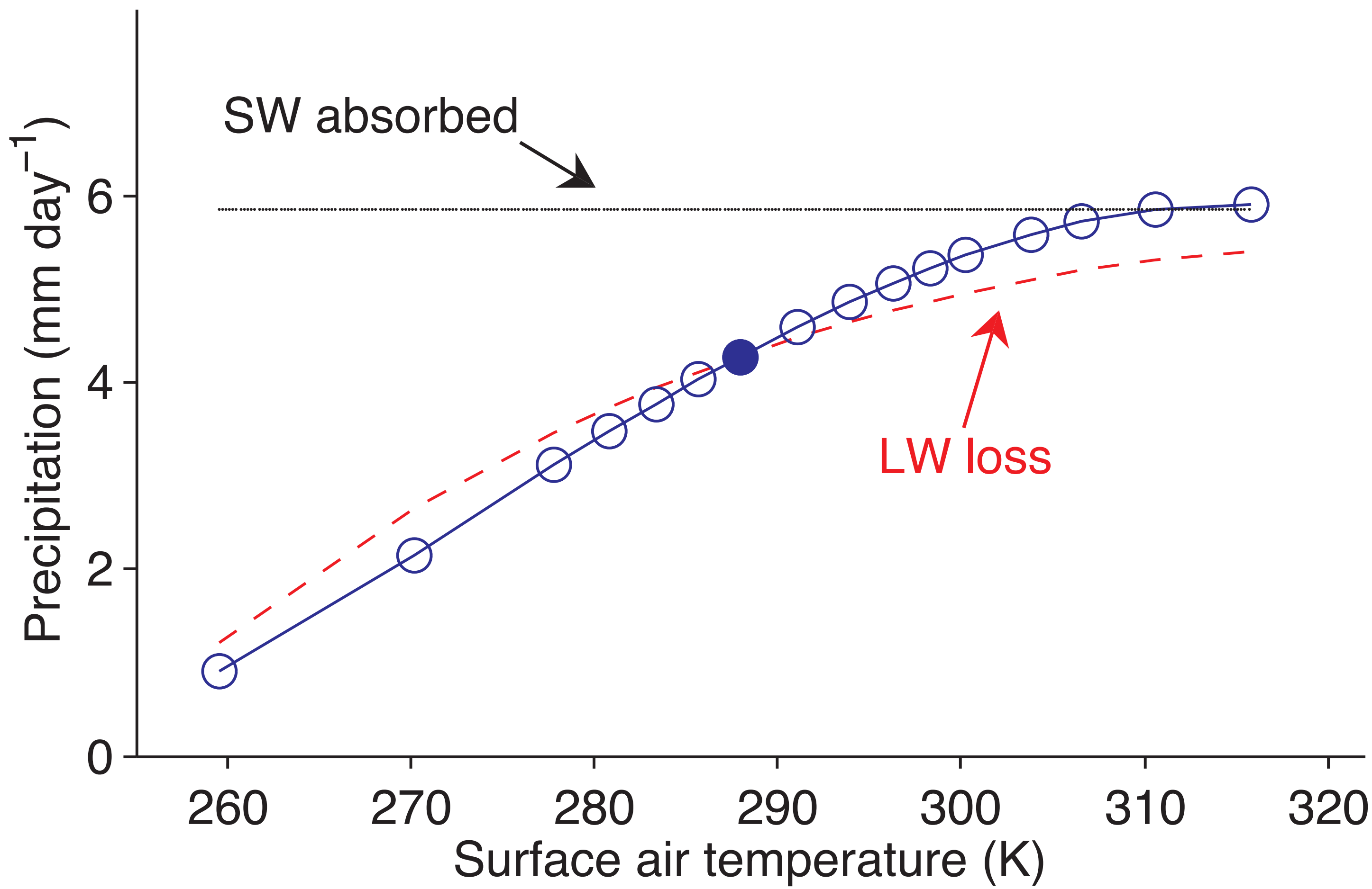
Mean precipitation

Global mean precipitation in idealized GCM



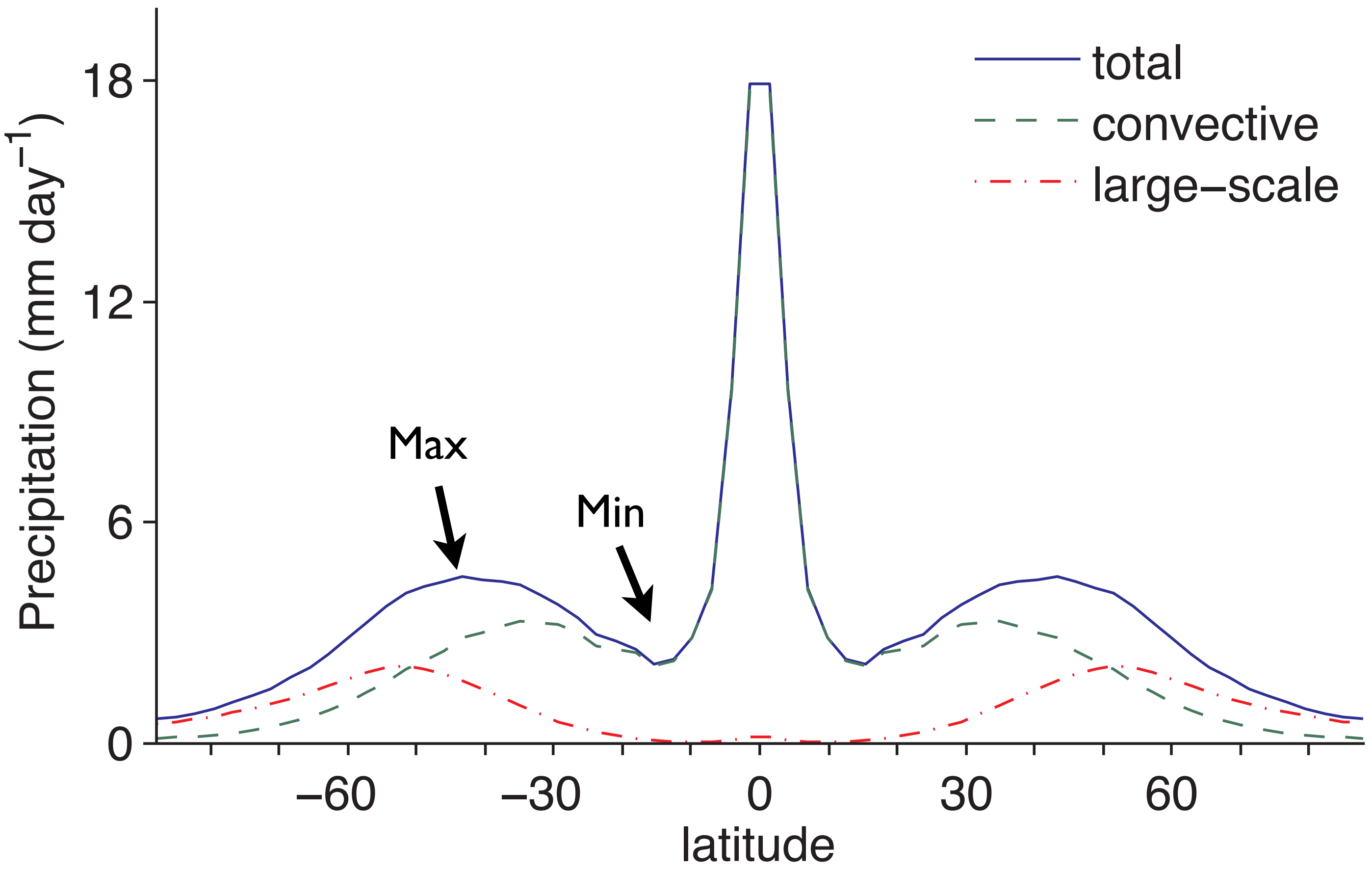
16 equilibrium simulations with different LW optical depths

Energy constraints on global mean precipitation

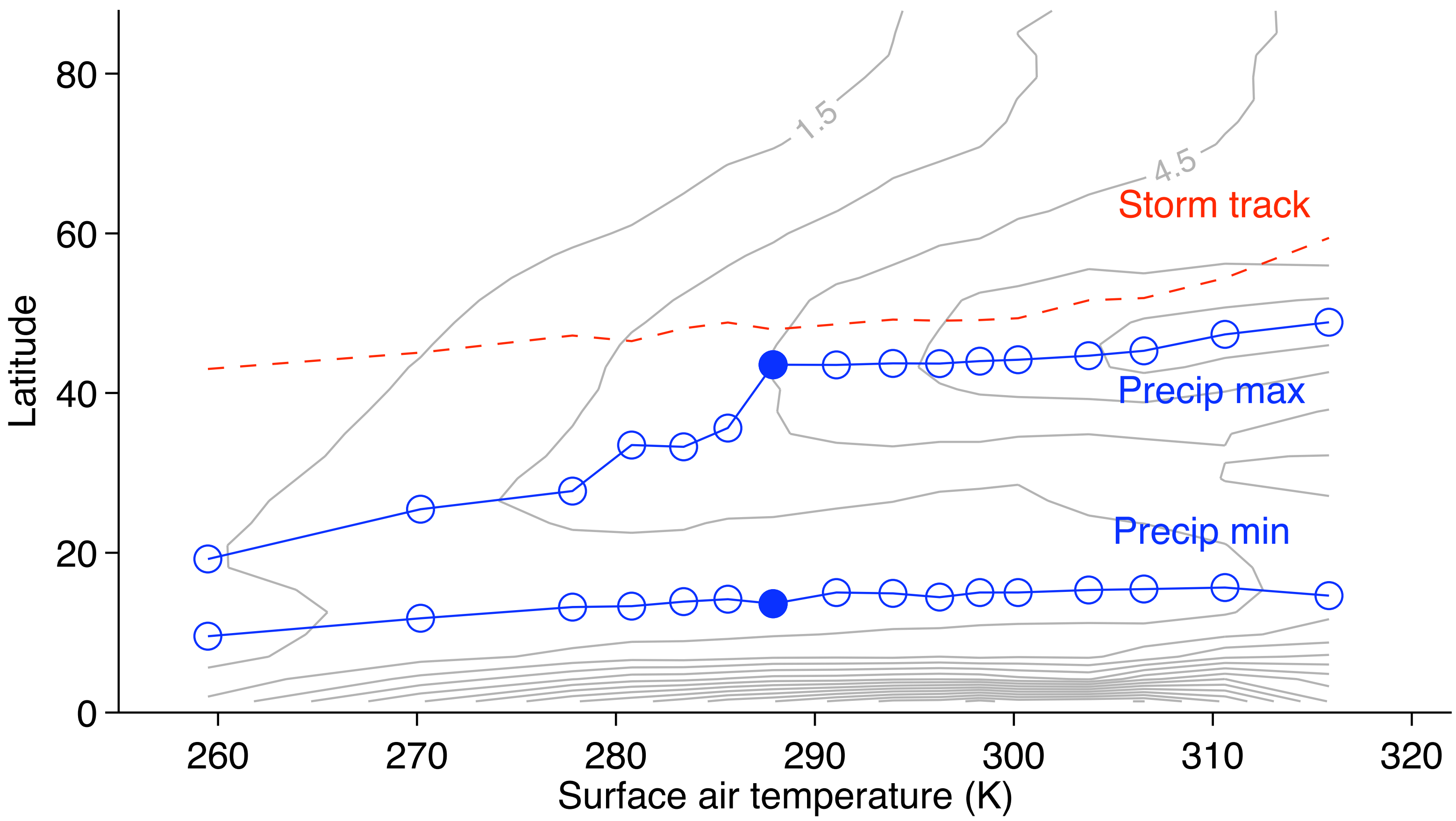


Evaporation limited by energy balance at surface

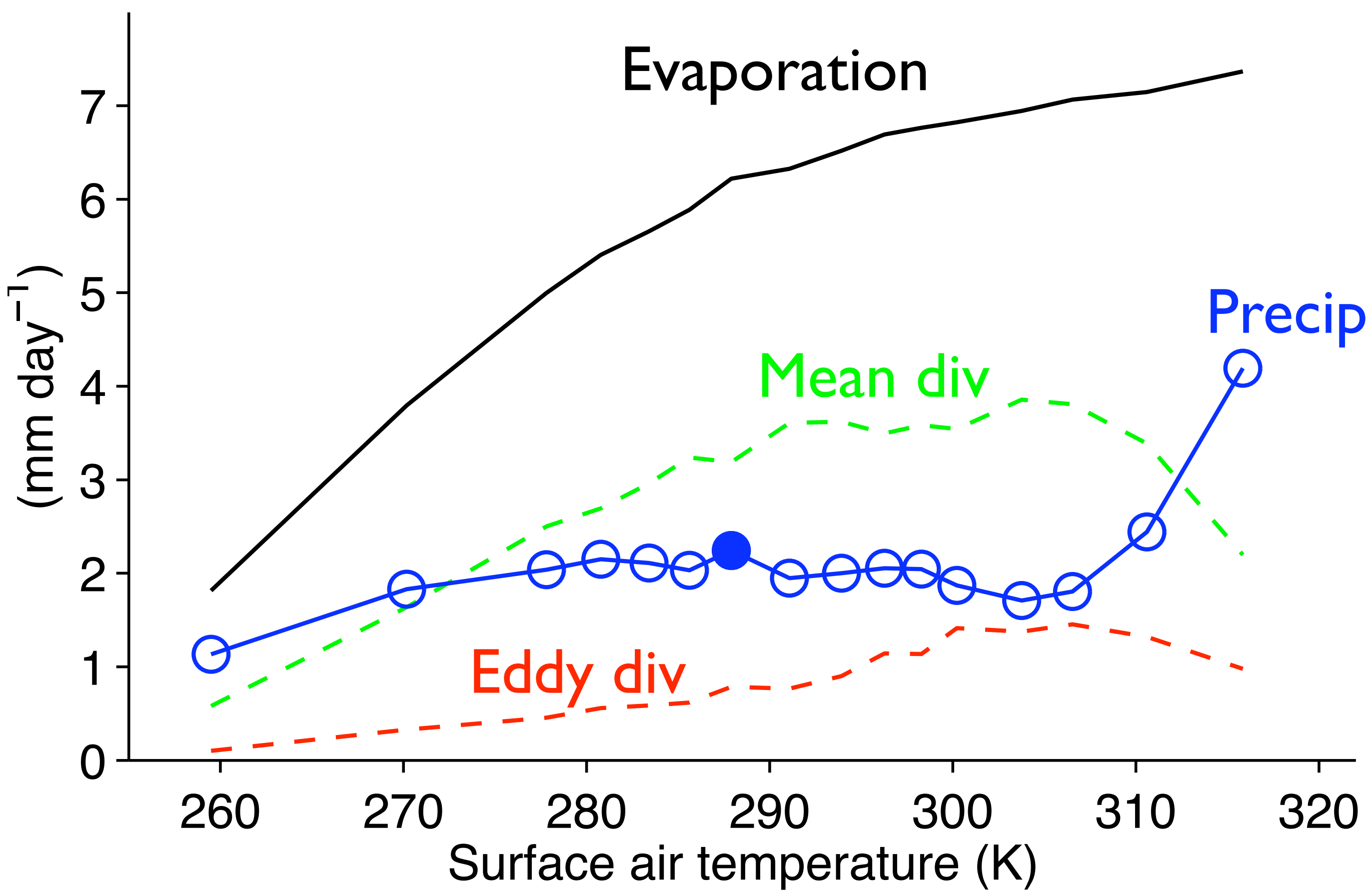
Distribution of mean precipitation in idealized GCM



Movement of extratropical max and subtropical min of precipitation

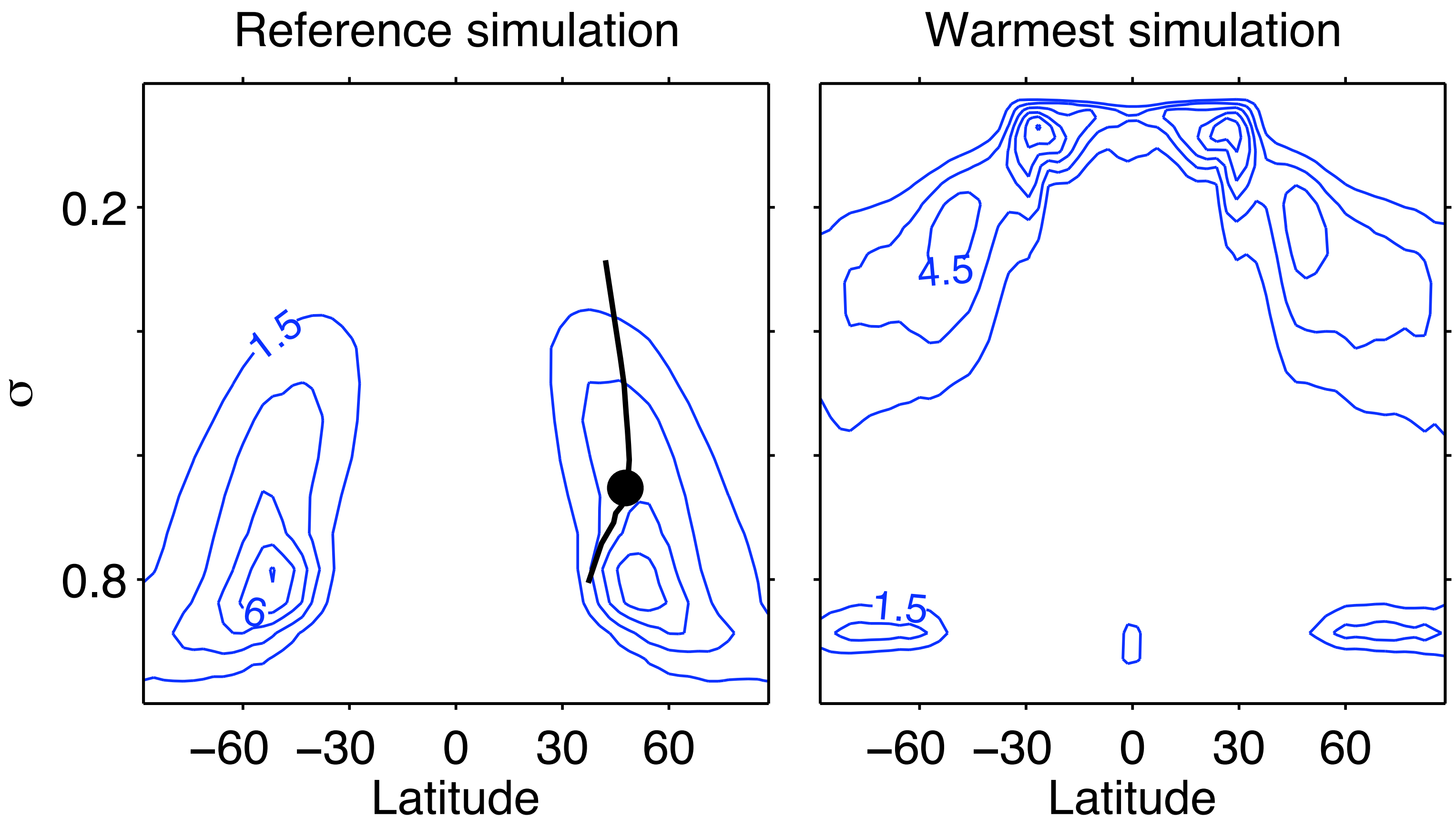


Subtropical precipitation and water vapor budget



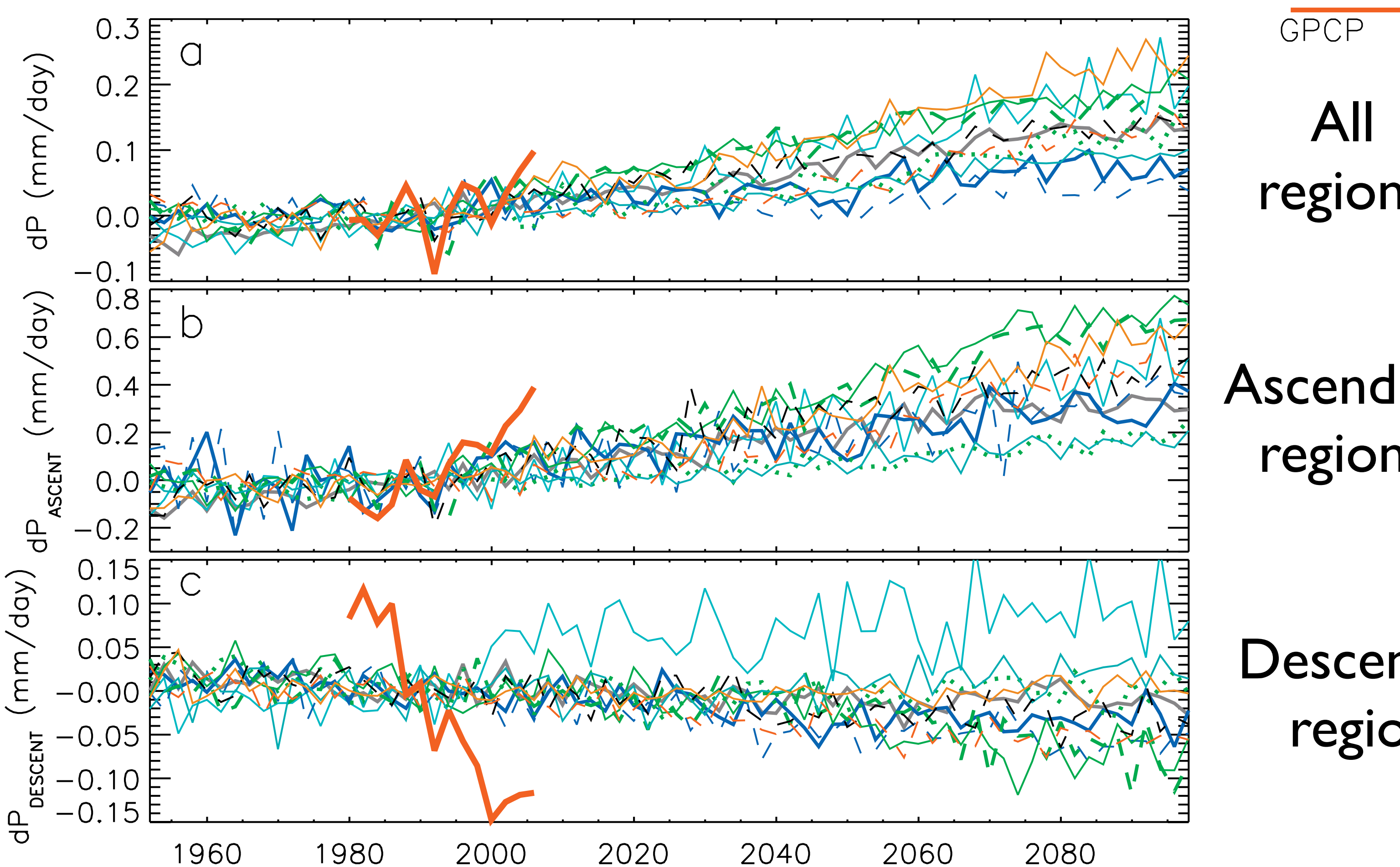
Opposing changes in divergence and evaporation

Large scale condensation rate as climate changes



Implications for precipitation, clouds, ...

Discrepancy between climate models and observations (red) in tropics ?



All regions

Ascending regions

Descending regions

Tropical precipitation relative to 1979-2000 (Allan and Soden, 2007)

Precipitation extremes

Effect of climate change on intense precipitation events

- High quantiles of daily precipitation, e.g. 0.999 corresponds to:
  - daily precipitation exceeded with probability 1/1000
  - a return period of ~3 years
- Longer accumulations (e.g. 5 days) may be relevant for flooding

High quantiles of precipitation scale like water vapor?

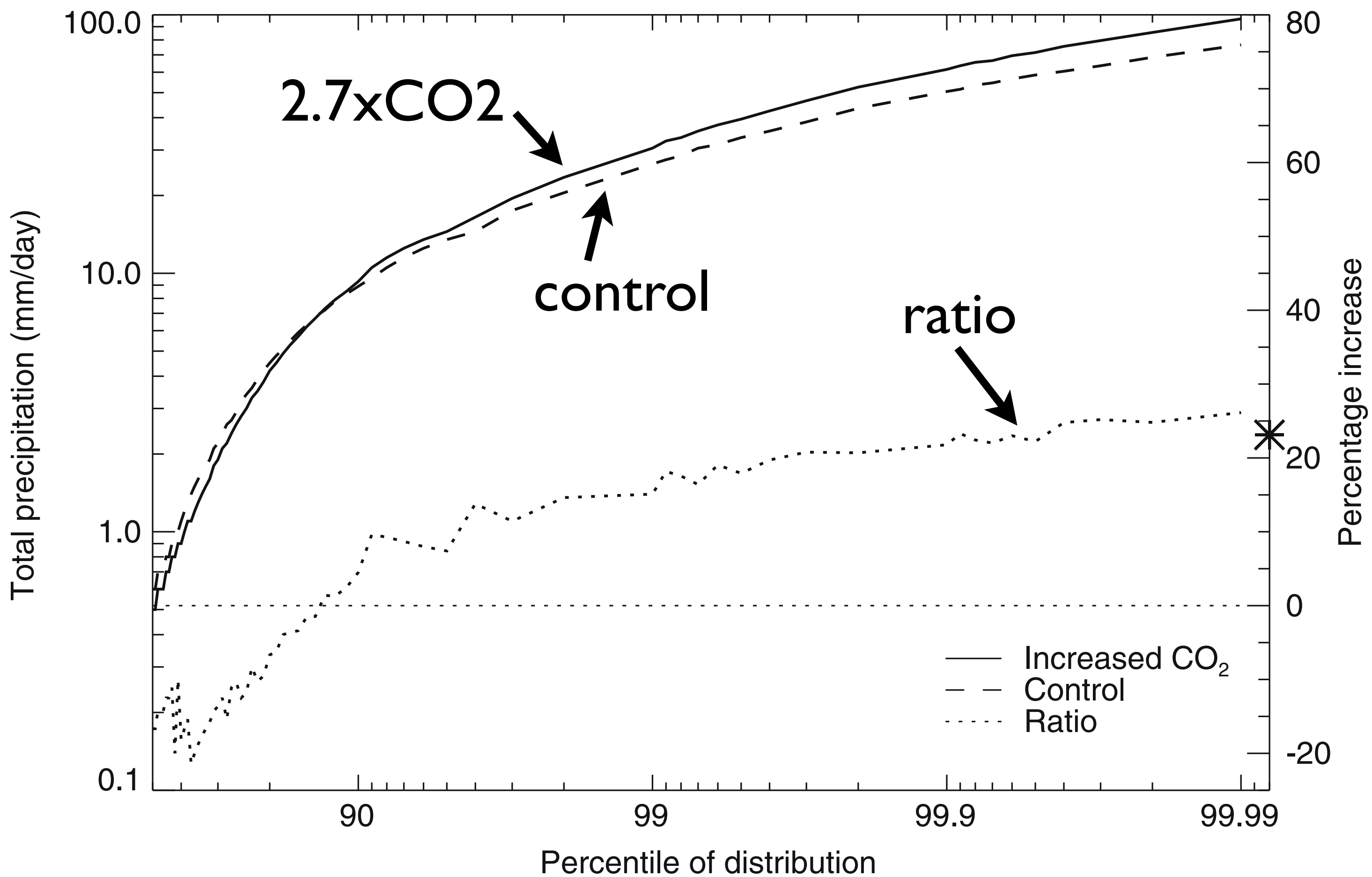
- Trenberth (1999) and Allen and Ingram (2002) argue for extremes scaling like water vapor:

  - extreme precipitation balanced by moisture convergence

  - assume updraft intensity unchanged

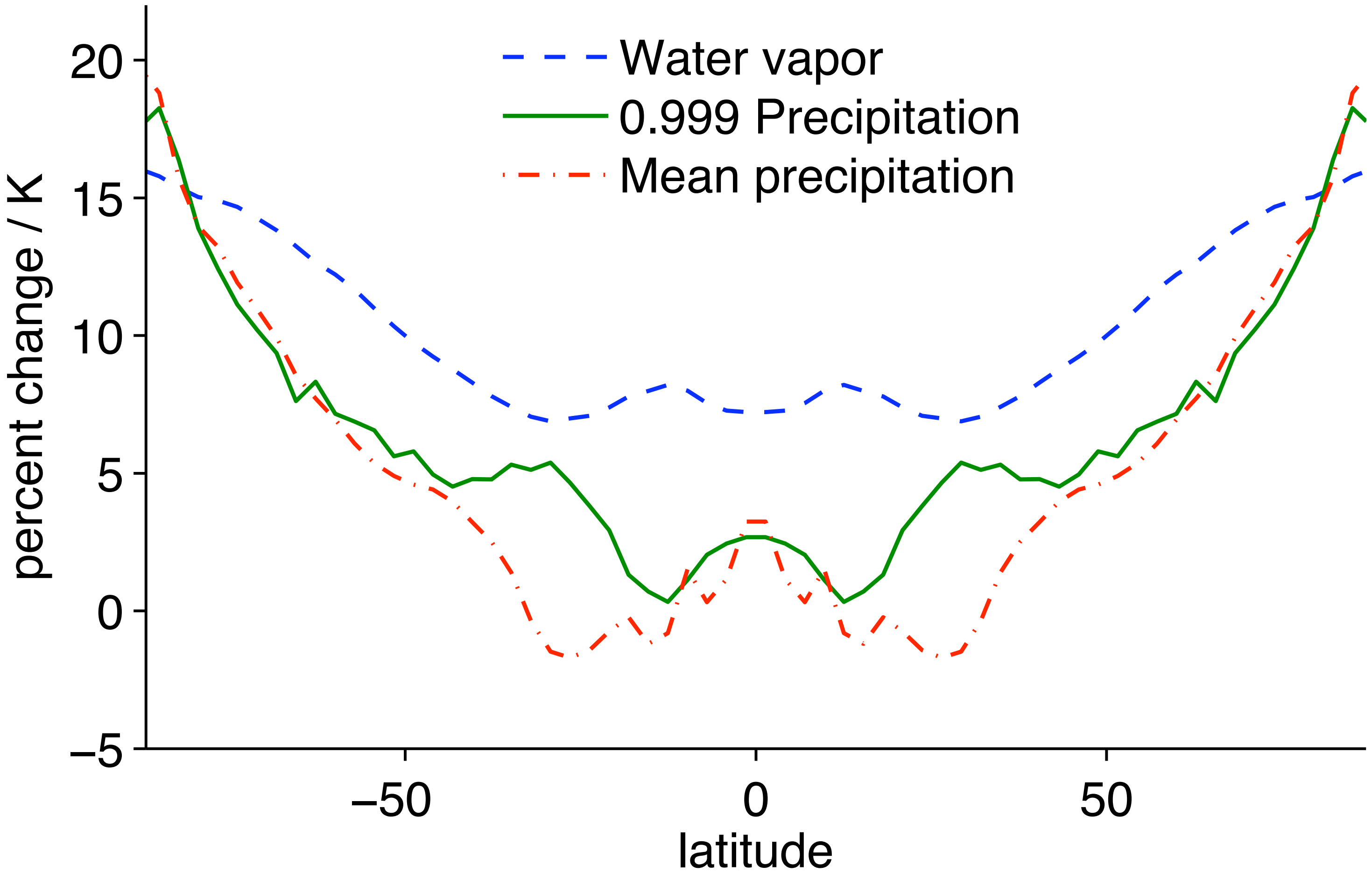
- Pall et al (2007) speculate on 'super Clausius-Clapeyron' growth of extremes

High quantiles of precipitation scale like water vapor?



Pall et al. 2007 (HadCM3 transient run)

Mean and extreme precipitation grow slower than water vapor in idealized GCM

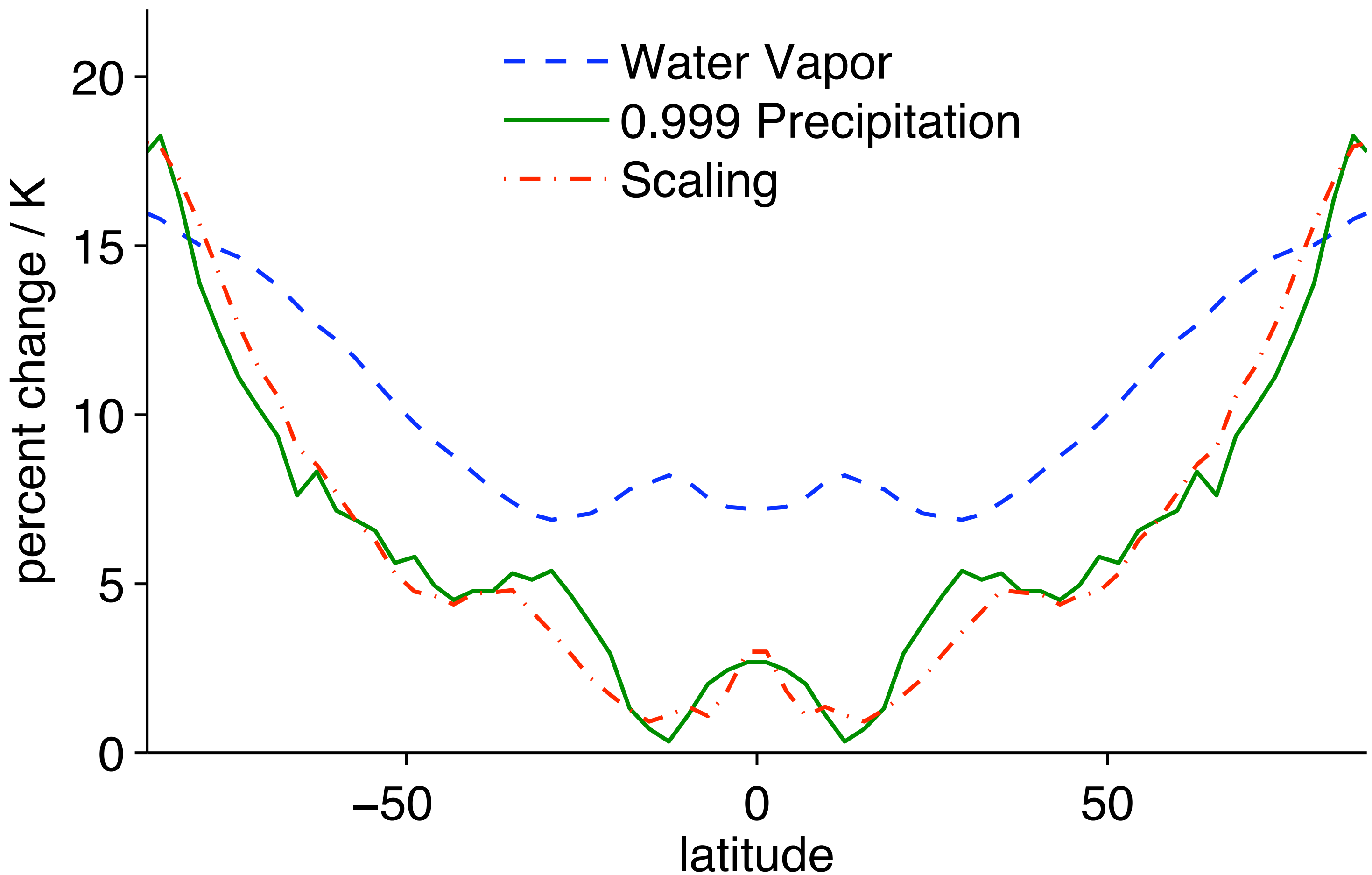


Change per degree global warming between two experiments

Scaling of precipitation extremes

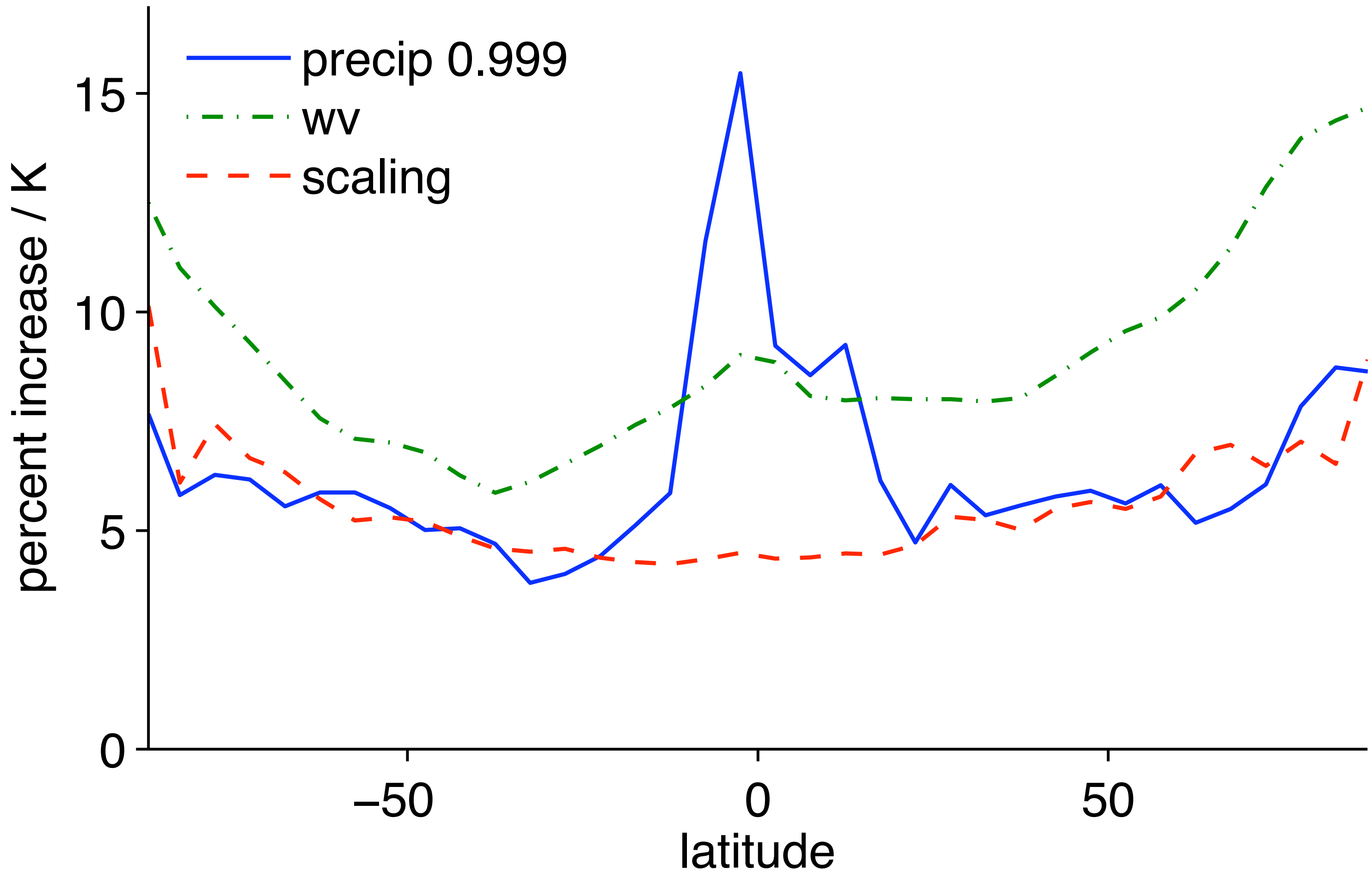
- Take account of:
  - circulation changes
  - water vapor
  - latent heat release
  - temperatures in extreme events

Can account for extremes if include latent heating, circulation changes, and temperature when precipitating



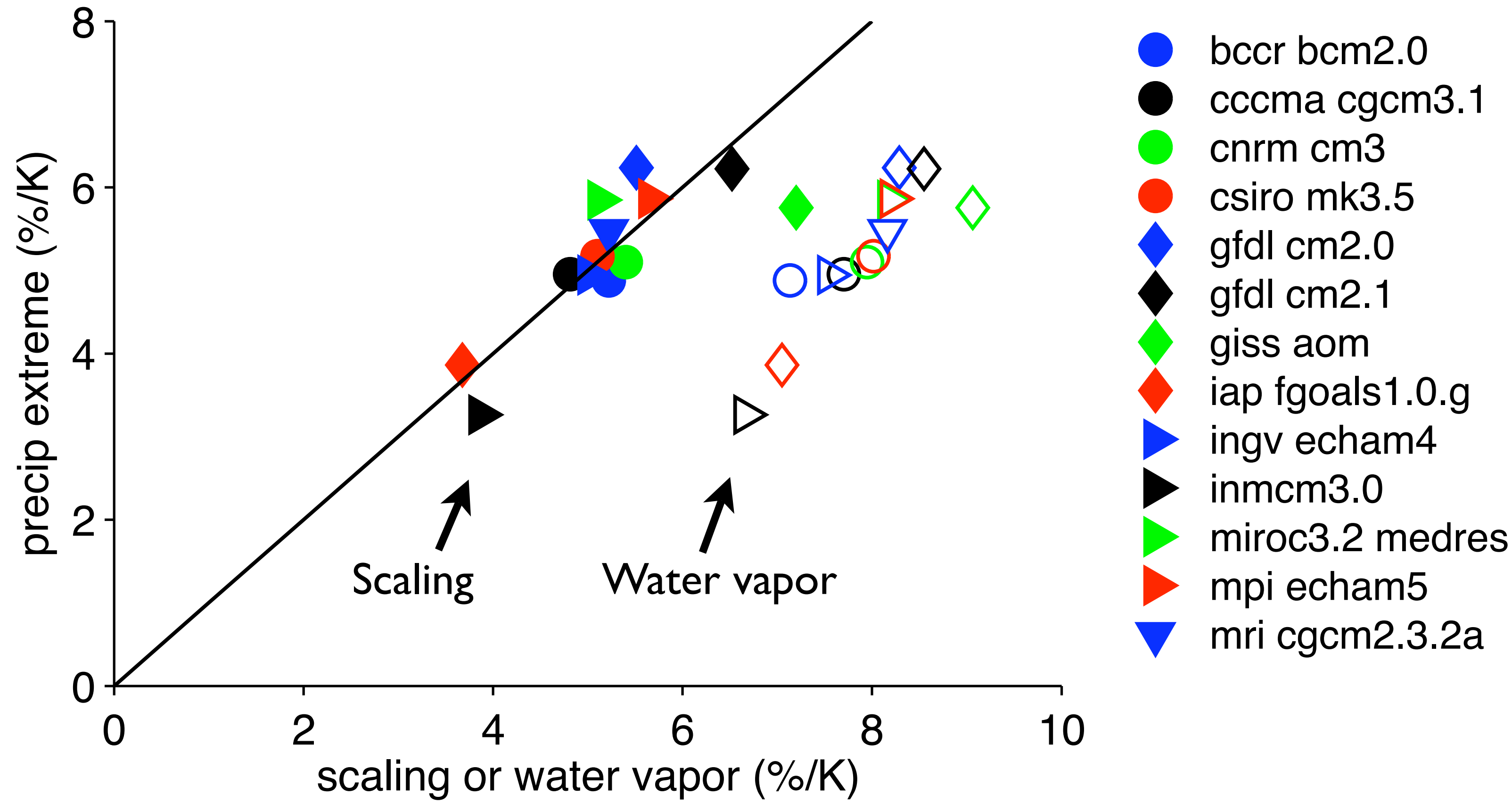
Change per degree global warming between two experiments

Growth of precipitation extremes in IPCC models



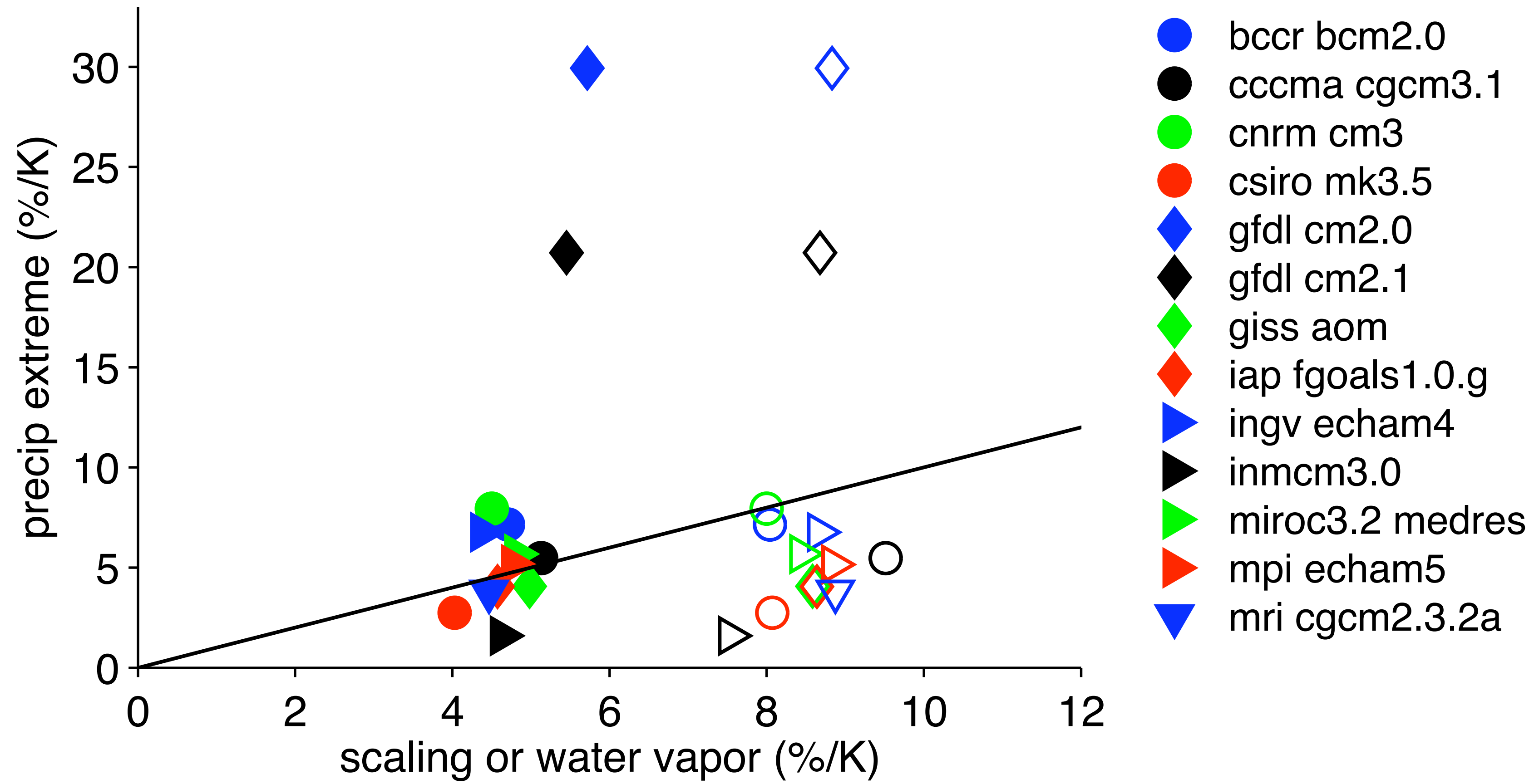
Multi-model mean change per degree global warming
(A1B 2000-2100) (scaling without ω_{rms})

Precipitation extremes (0.999) grow like scaling in extratropics



Change per degree extratropical warming (A1B 2000-2100)

No agreement for precipitation extremes (0.999) in tropics



Change per degree tropical warming (A1B 2000-2100)

Conclusions

- Neither mean nor extreme precipitation grow like water vapor
- Region of large-scale condensation moves poleward and upward as climate warms
- Extratropical maximum in precipitation doesn’t always follow storm track
- Can explain precipitation extremes in models in extratropics but little agreement in tropics