Hydrologic cycle: past, present and future

- Observed climatology & basic physics
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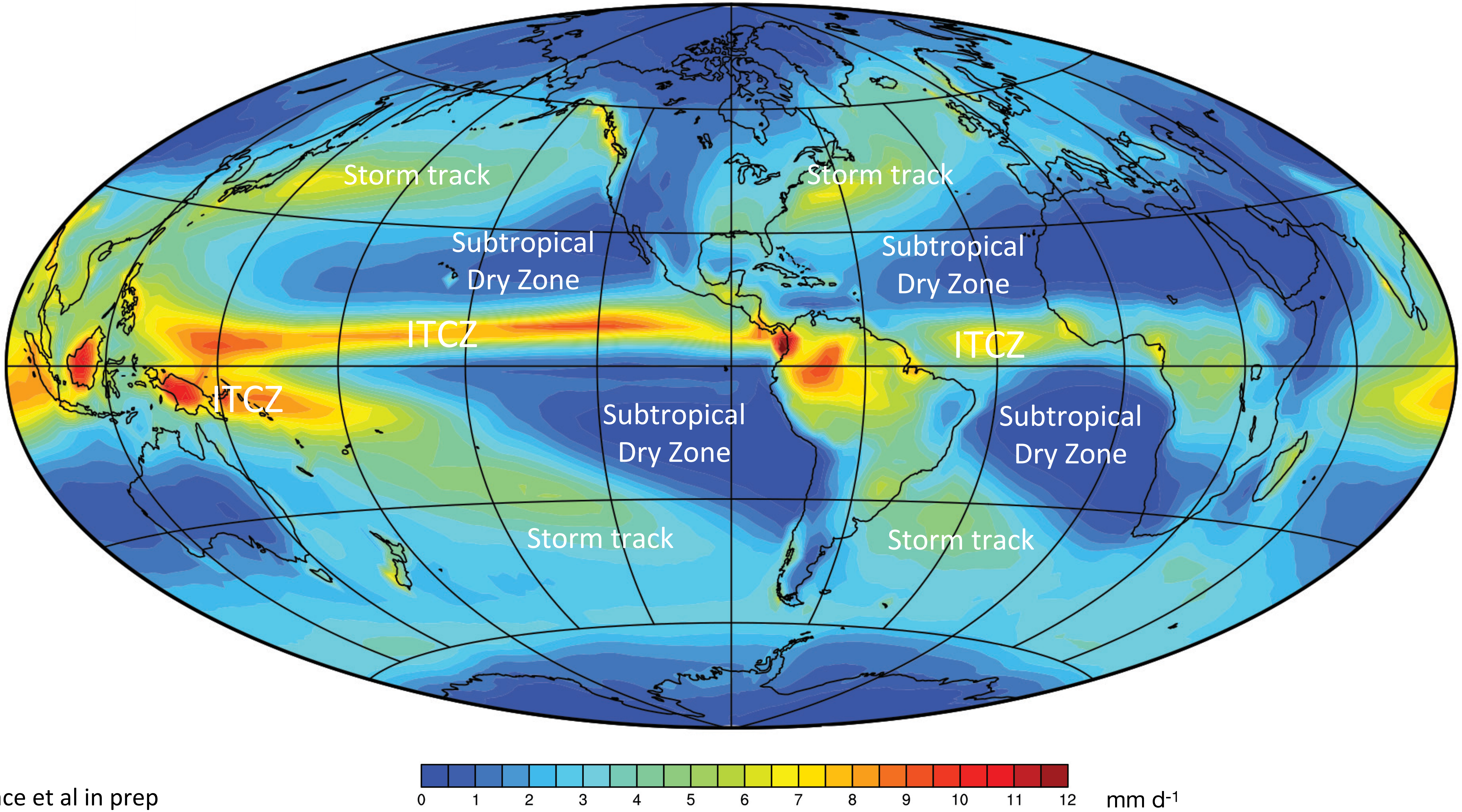
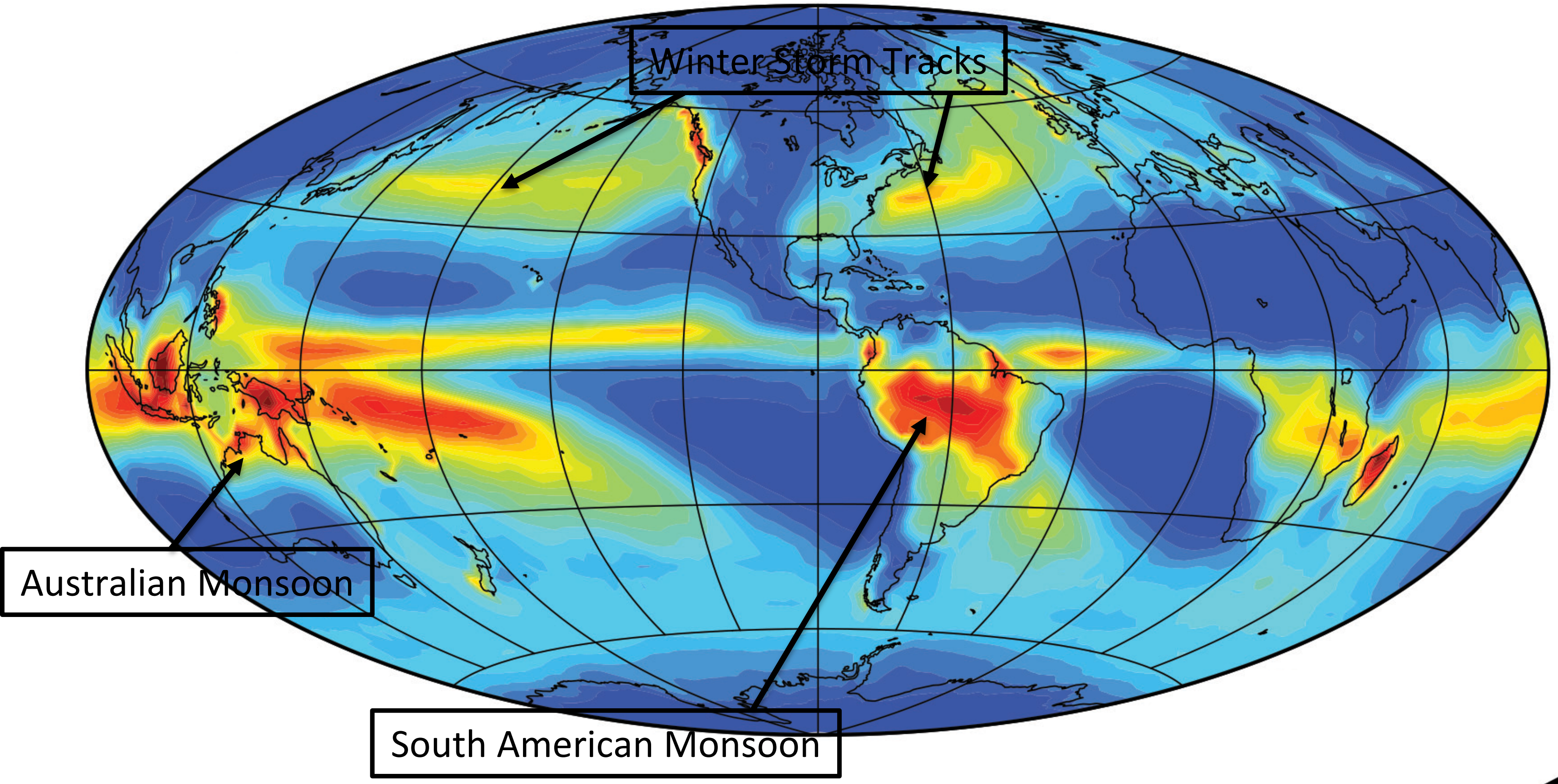
Annual mean precipitation

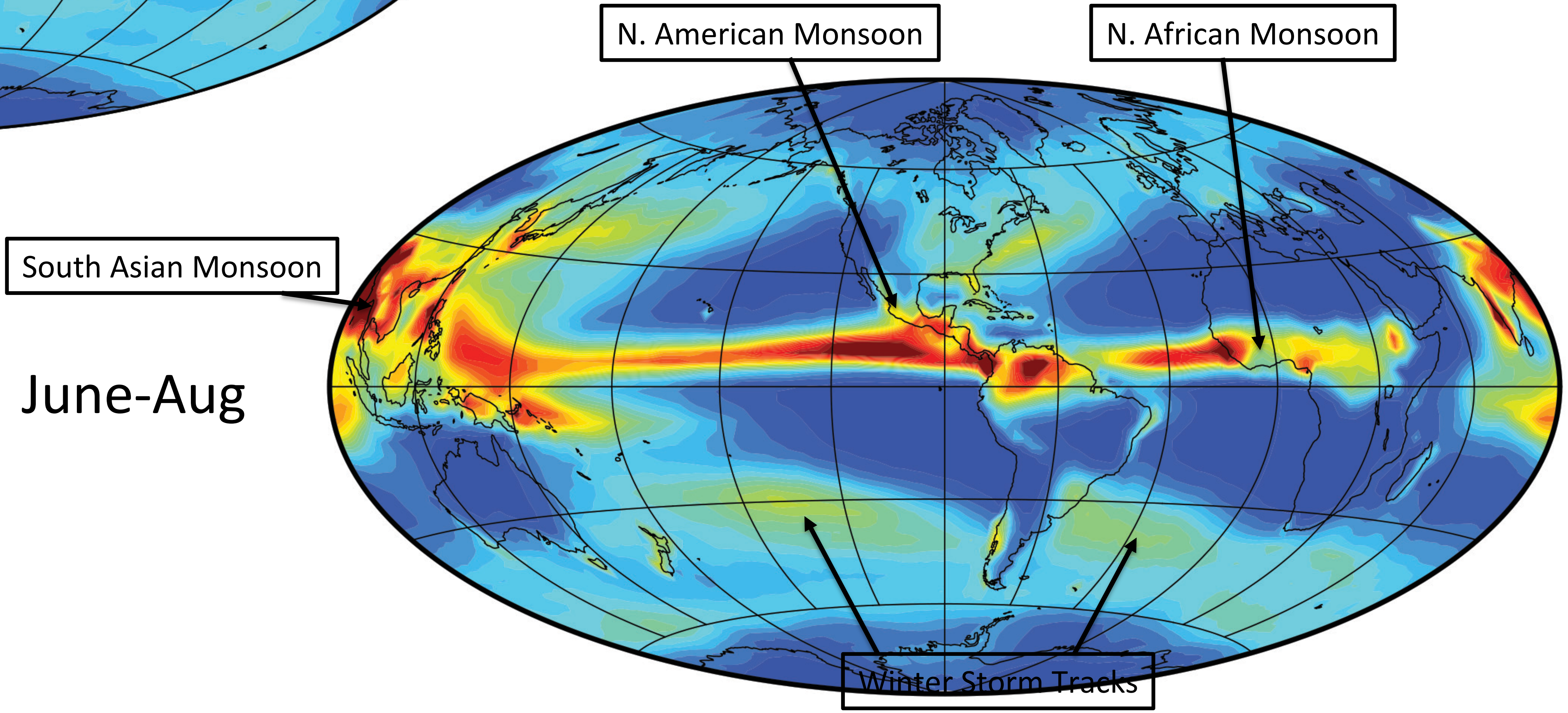


Wallace et al in prep

Seasonal climatologies



Dec-Feb



June-Aug

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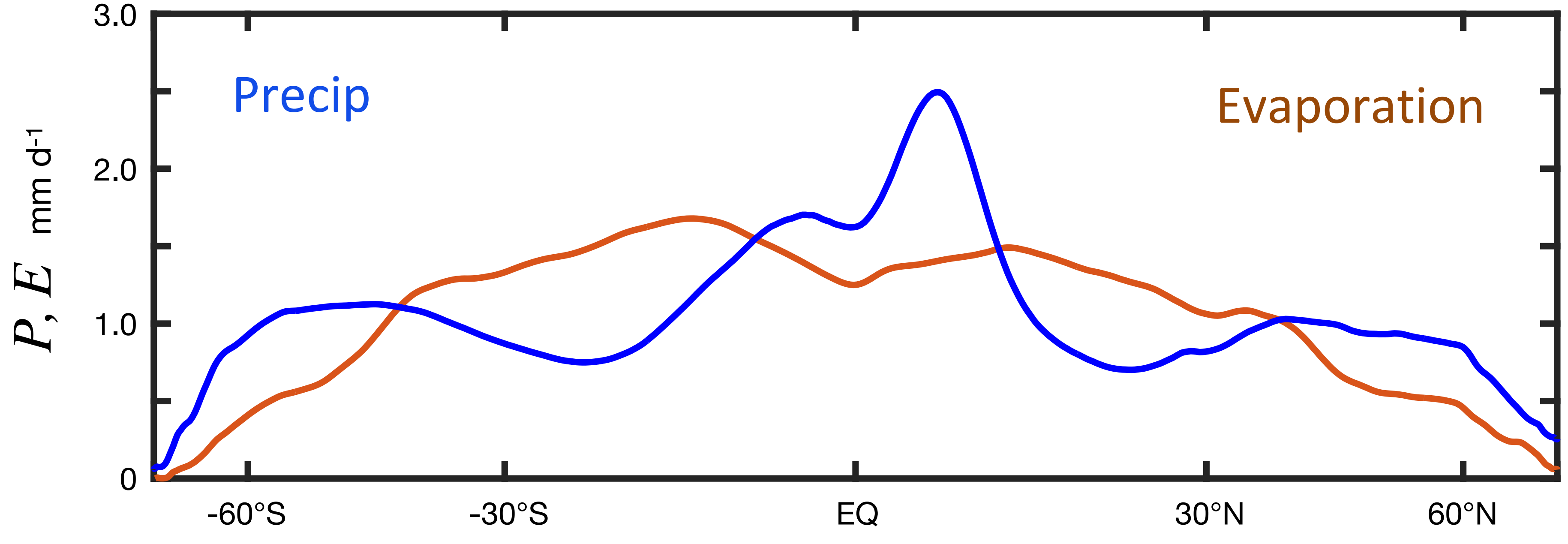
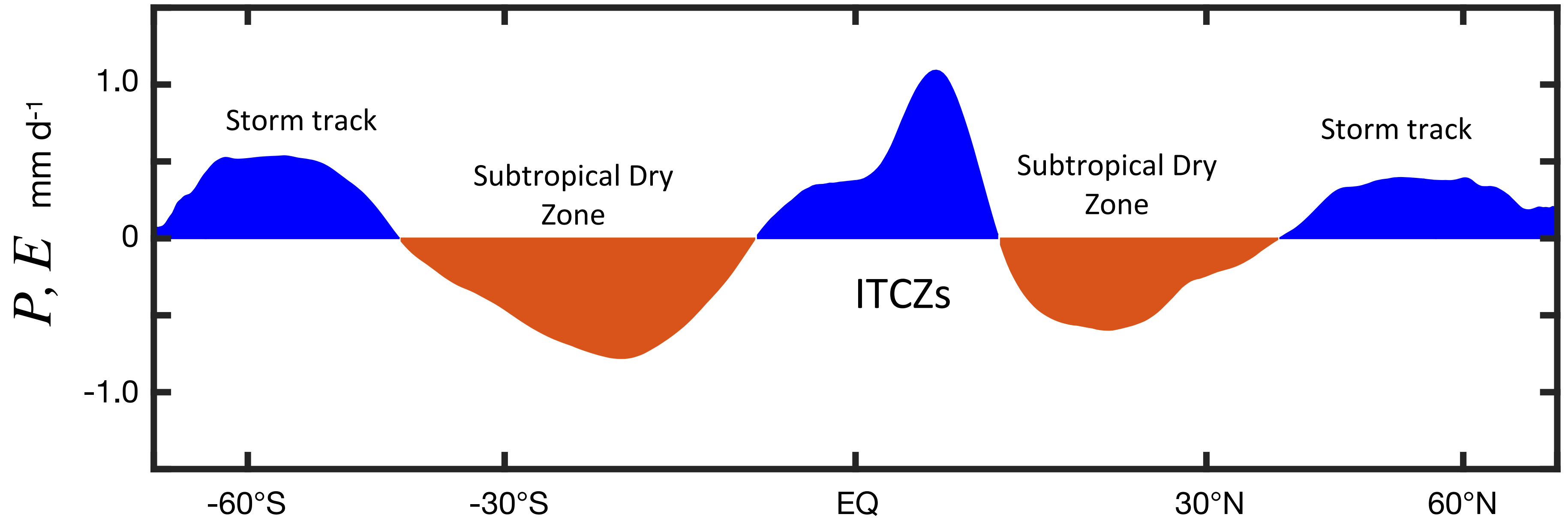
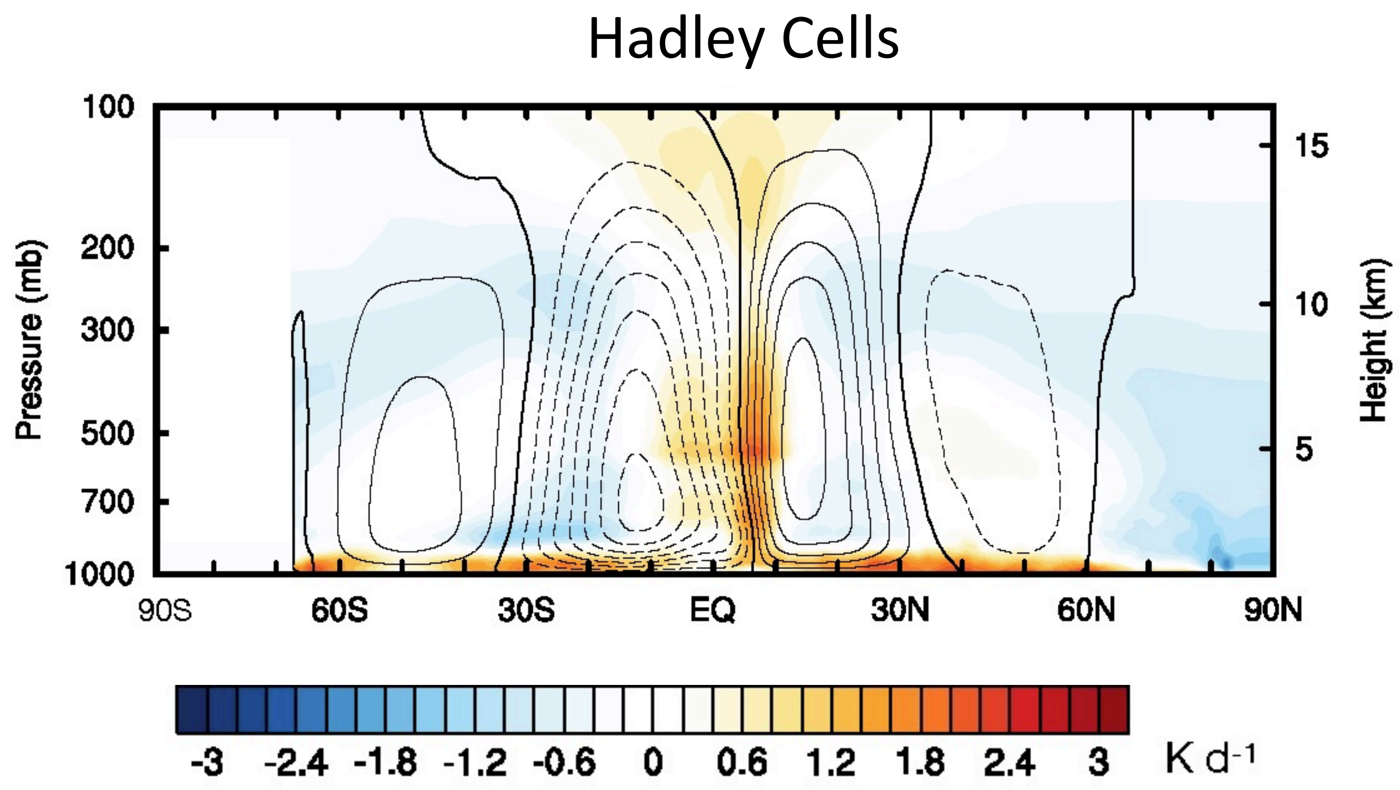
Annual mean precipitation







Hadley circulation supplies the water vapor that falls as precipitation in the deep tropics (ie, in the ITCZs)

Basic structures are found in aquaplanet models w/ slab oceans

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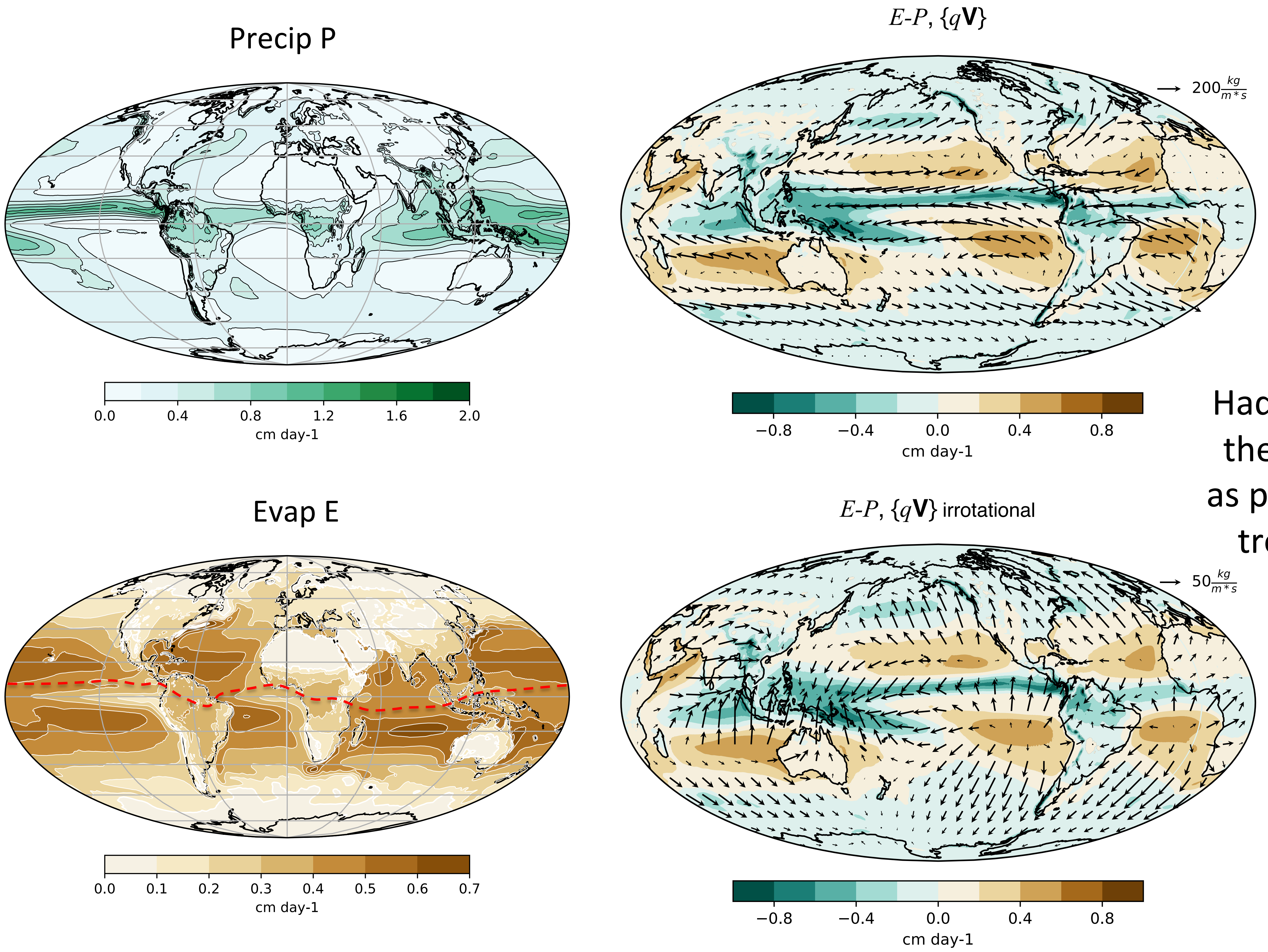

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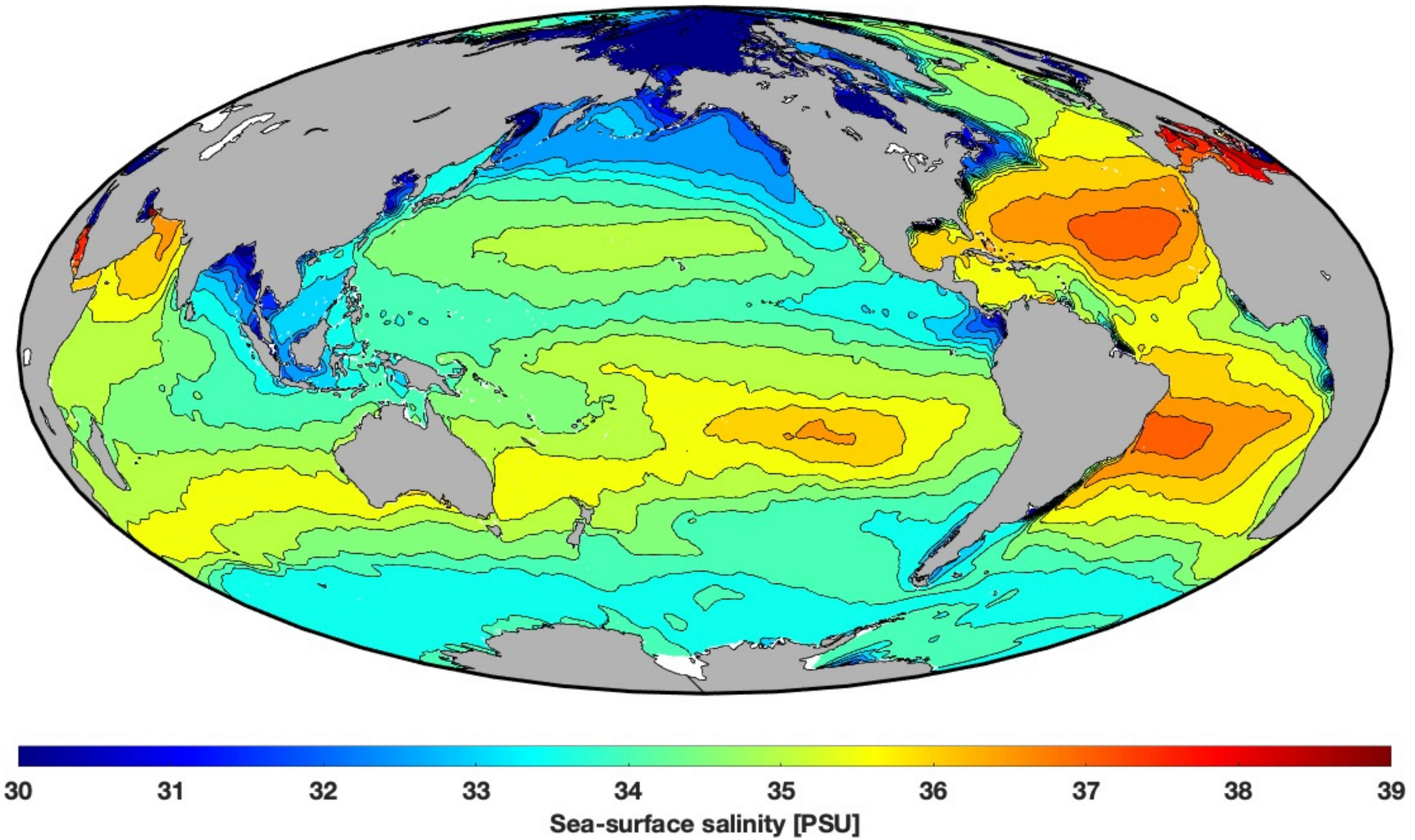
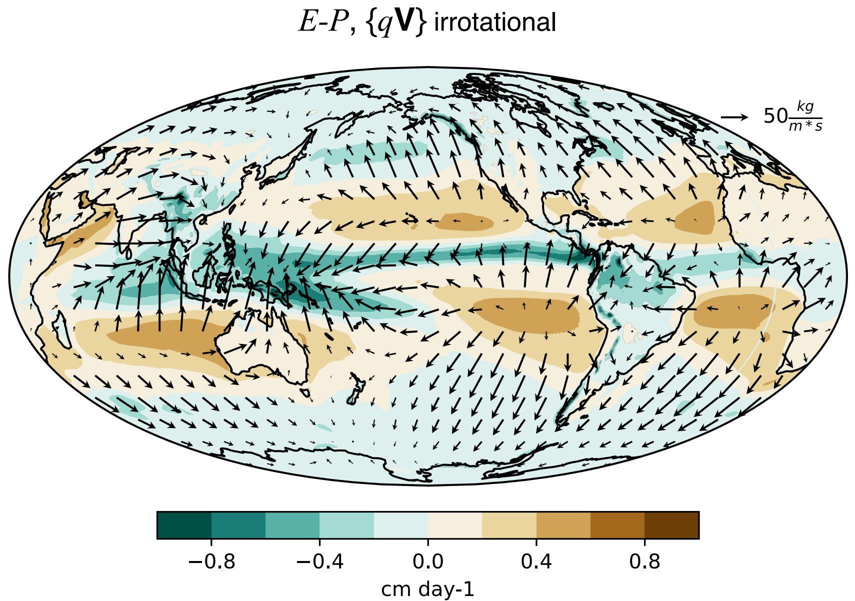
Wallace et al in prep

Surface Ocean Salinity reflects E-P

Transport by atmosphere and ocean circulation also contribute





Wallace et al in prep

Land budget

- Storms deposit water over continents and rivers return it to the oceans
  - Some stored in groundwater, glaciers and ice sheets

- Precipitation is greater than one would expect from vapor import due to recycling (ET). Recycling accounts for
  - Recycling accounts from ~10% (~50%) of annual precip on a regional (continental) scale

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Basic Dynamics

- Basic zonal average features are found in models without orography, land or ocean heat transport:
  - ITCZs, subtropical dry zones, midlatitude storm tracks, and even monsoons
  - Strengths and specific latitudes found depend on Earth diameter & rotation rate, greenhouse gas concentration (within a factor of 10 or so), and distance from the Sun

- Precipitation amount in ITCZs largely proportional to strength of Hadley Cell, which regulates the rate water vapor is delivered from the subtropics to the ~equator
  - Hadley cell strength is primarily controlled by the intensity of the midlatitude storm tracks (dynamic) and secondarily on the mean temperature (thermodynamic) of the planet

- Location of ITCZ determined by
  - Pacific ITCZ: Andes, continental geometry (not coastal upwelling!)
  - Atlantic ITCZ: presumably continental geometry
  - A minor process: hemispheric asymmetry in heat transport

- Location/strength of midlatitude storm tracks largely set by strength and location of the maximum latitudinal gradient

- Role of continents
  - Resist evaporation (why forced changes in temp are greater over land than ocean)
  - Land: Breaks up the storm track
  - Orography: limits how much water vapor is delivered from one ocean to the next
    - Matters greatly for the ocean overturning circulation

Hydrologic cycle: past, present and future

Caution: model results! Sensitive (sensible) viewers may want to check email

- Observed clim... ogy & basic physics
  - ITCZs ... y zones, midlatitude storm ... ally) monsoons
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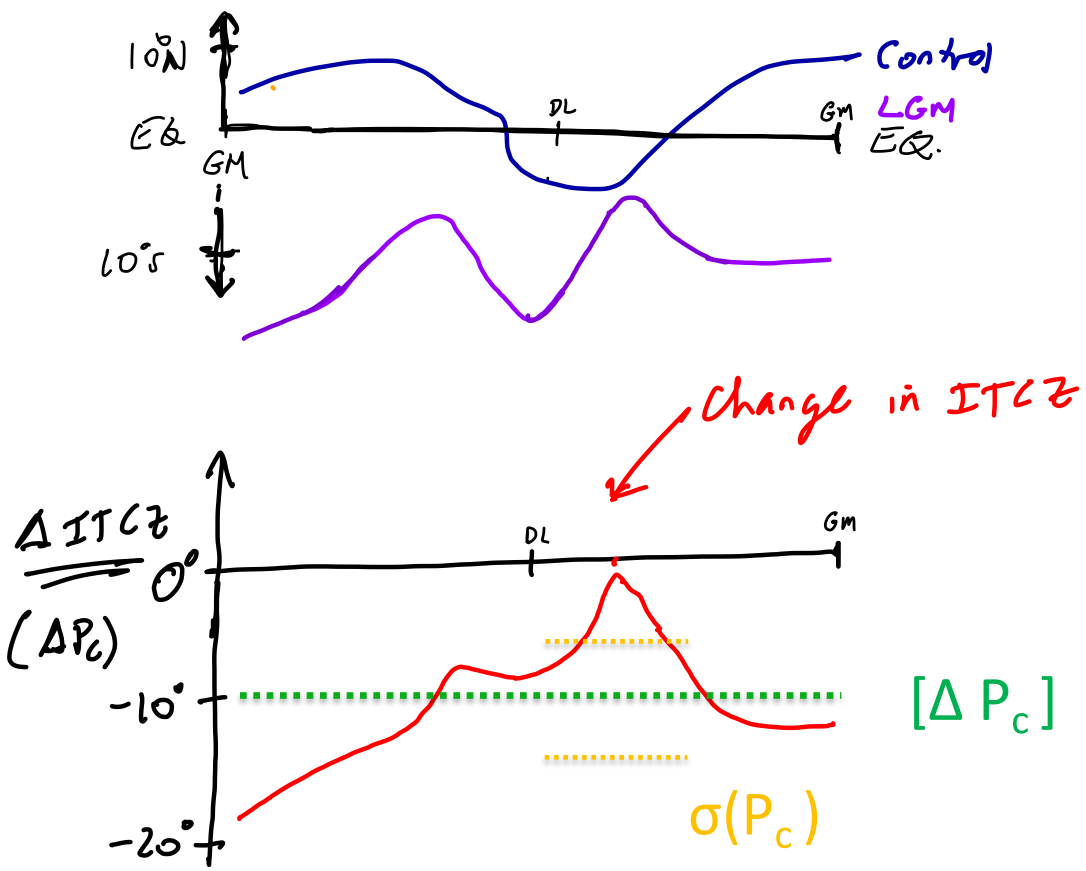
When is the response to forcing described by hemispheric energetics?

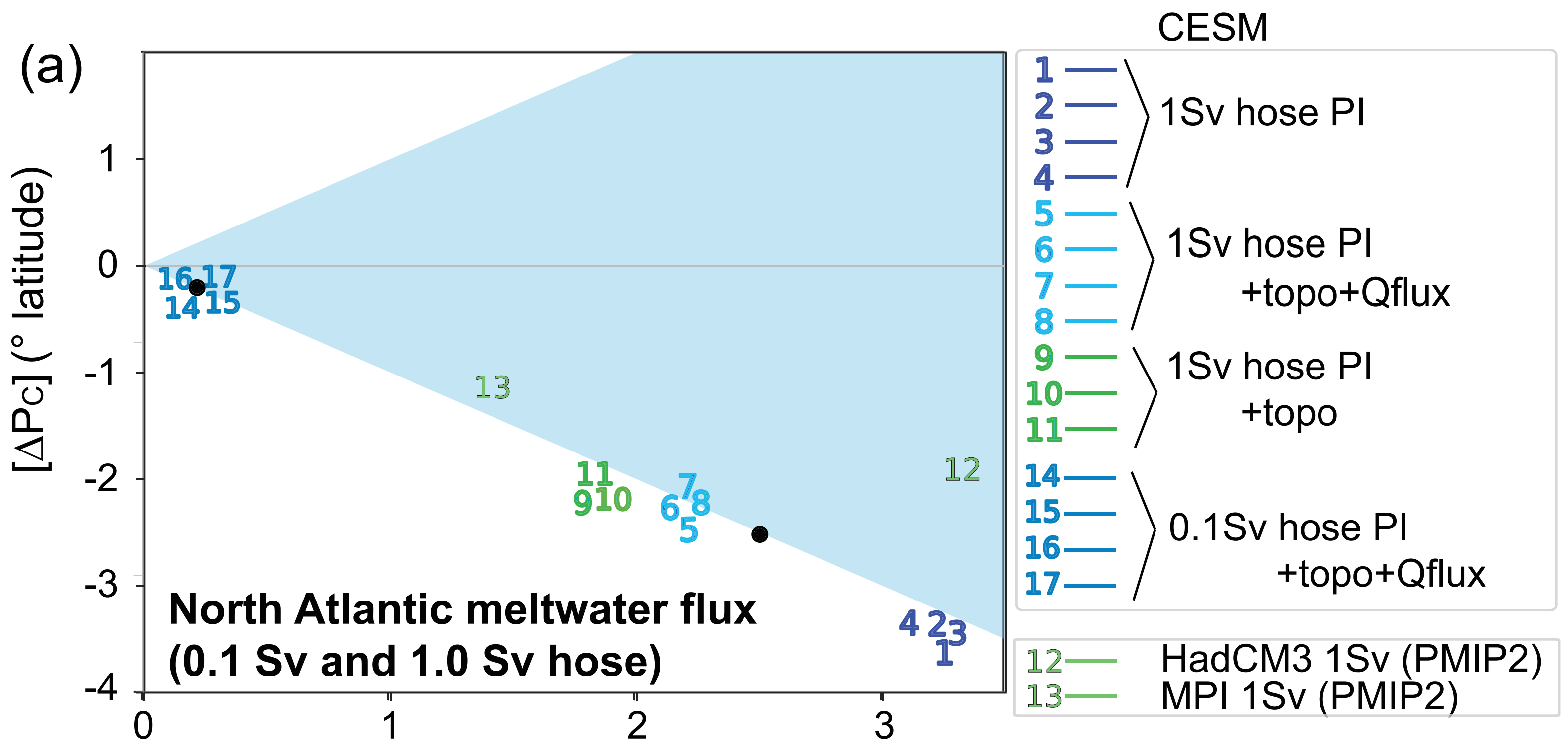


Change in zonal mean ITCZ [Δ P_c]

[Δ P_c]

σ(P_c)

Change in character of ITCZ



latitudinal variation in change σ(P_c)

[Δ P_c] = zonal mean change

σ(P_c) = typical longitudinal variation about [Δ P_c]

Atwood, A.R., A. Donohoe, D.S. Battisti, X. Liu, and F.S.R. Pausata, 2020: "Robust longitudinally-variable responses of the ITCZ to a myriad of climate forcings" Geophys. Res. Letts. DOI 10.1029/2020GL088833.

When is the response to forcing described by hemispheric energetics?

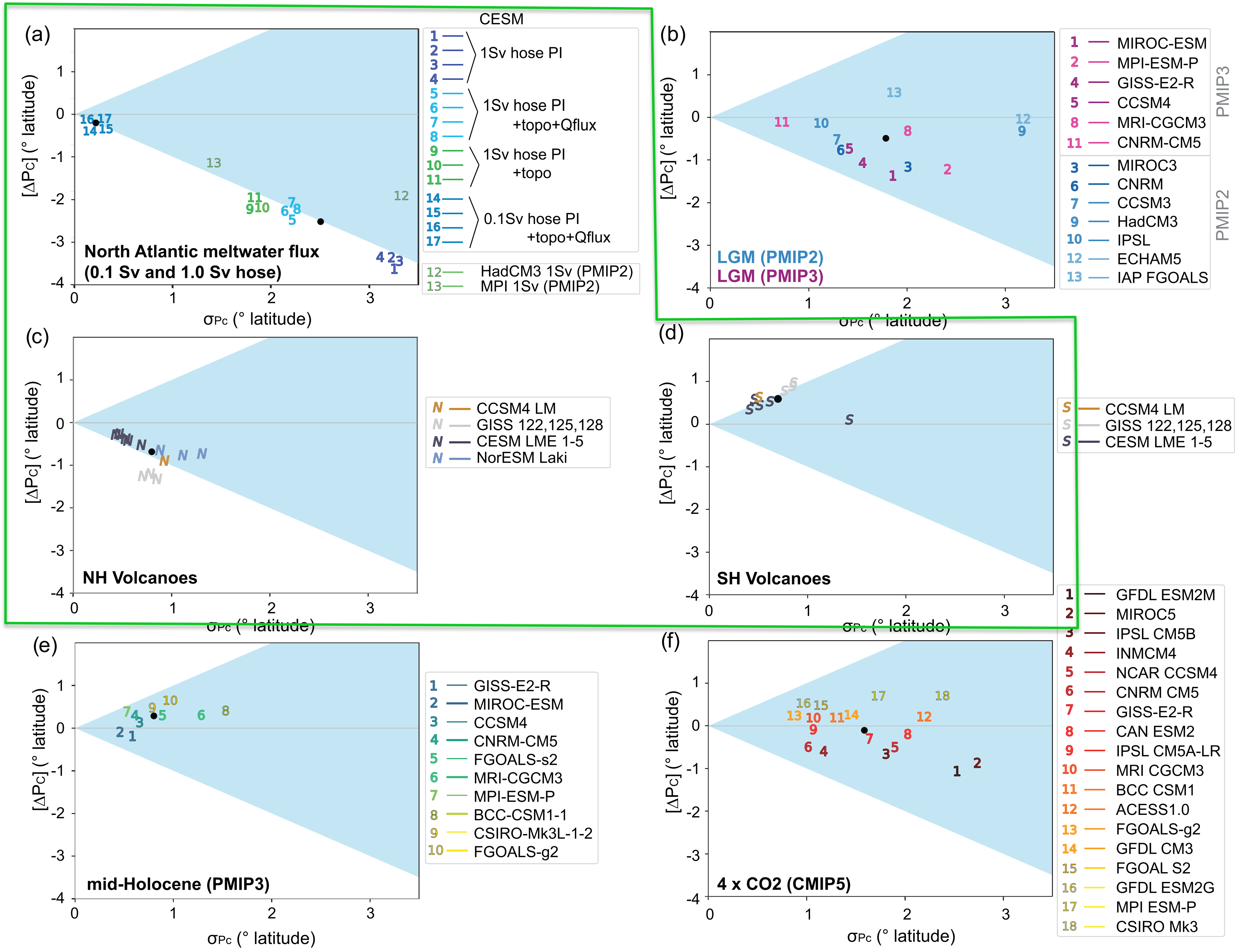
Change in character of ITCZ

- Forcings with large hemispheric asymmetry (e.g., volcanic forcing, meltwater forcing, and the LGM) give rise to robust zonal mean shifts of the ITCZ

- However, the direction and magnitude of the shift vary even *more* strongly in longitude than in the zonal mean

- Forcings with weak hemispheric asymmetry (CO2 and mid-Holocene) give rise to zonal mean shifts that are small or absent

- But the ITCZ **does** shift **regionally** in coherent ways ....



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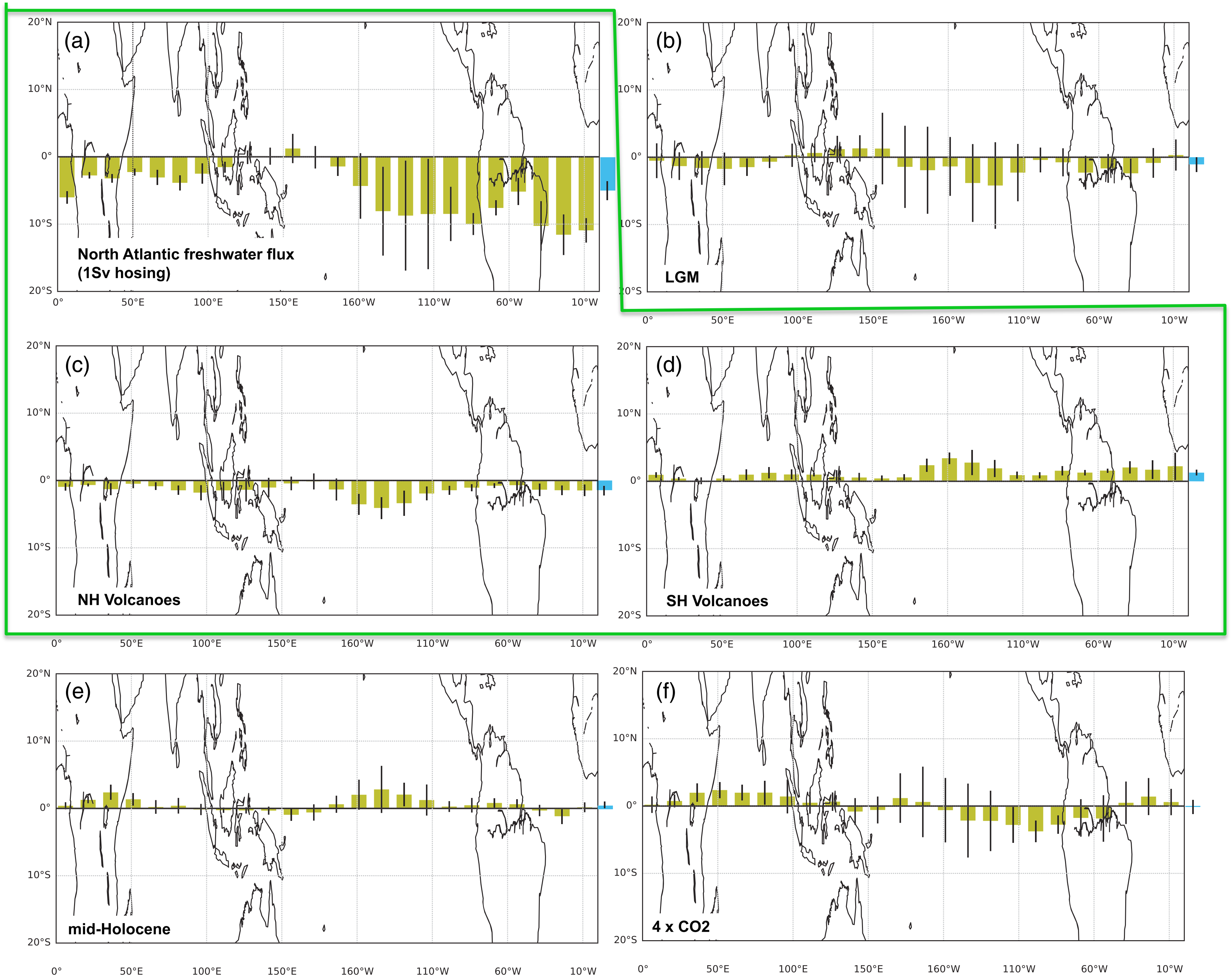
Change in latitude of ITCZ

(multimodel mean; multimodel zonal mean; whiskers = ±1σ)



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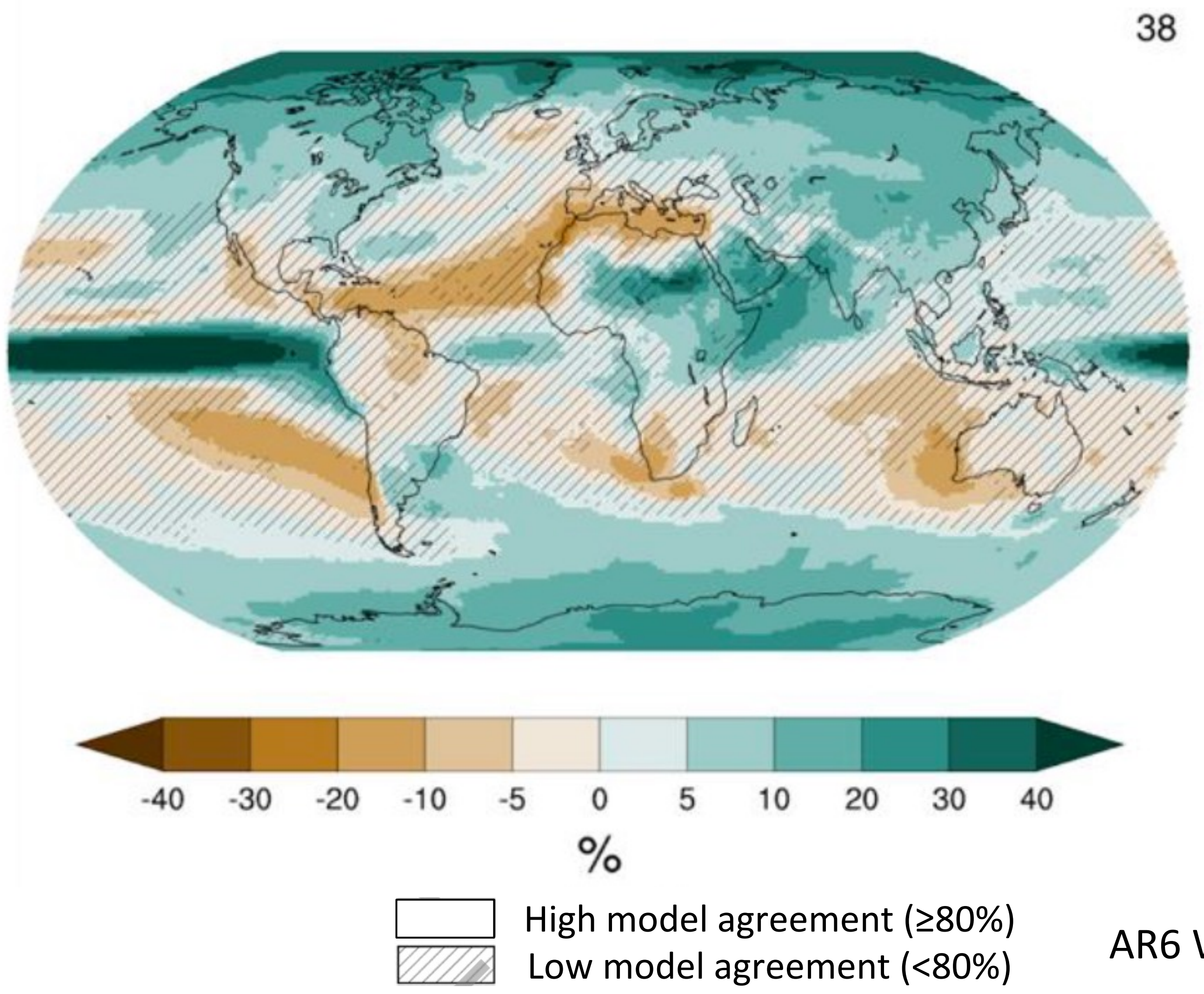
Changes in hydrologic cycle circa ~2100 (SSP4.5)

SSP4.5: 1.7C (1.2,2.6) global warming from 2010; 2.8C warming since PI

- Increased atmospheric water vapor: 7% per degree C
  - Clausius-Clapeyron Eqn.
- Increased global precipitation:
  - ~2% per degree C globally (4.5% over midlatitude land)
- In tropics: **wet regions get wetter** (ITCZs, most monsoons), **dry get drier** (subtropical dry zones)
- Mean precipitation increases in most monsoons by 2-8% (±5%)
  - Slight decrease in NAM and equatorial Americas
- Volatility in precipitation and drought more marked than mean changes
  - Increased heavy precipitation events
  - Increasing frequency and severity of droughts
  - Increase in frequency of Cat4&5 TCs

Δ Annual Precip



AR6 WG1 draft report

n.b. it is a low bar to achieve "high model agreement"

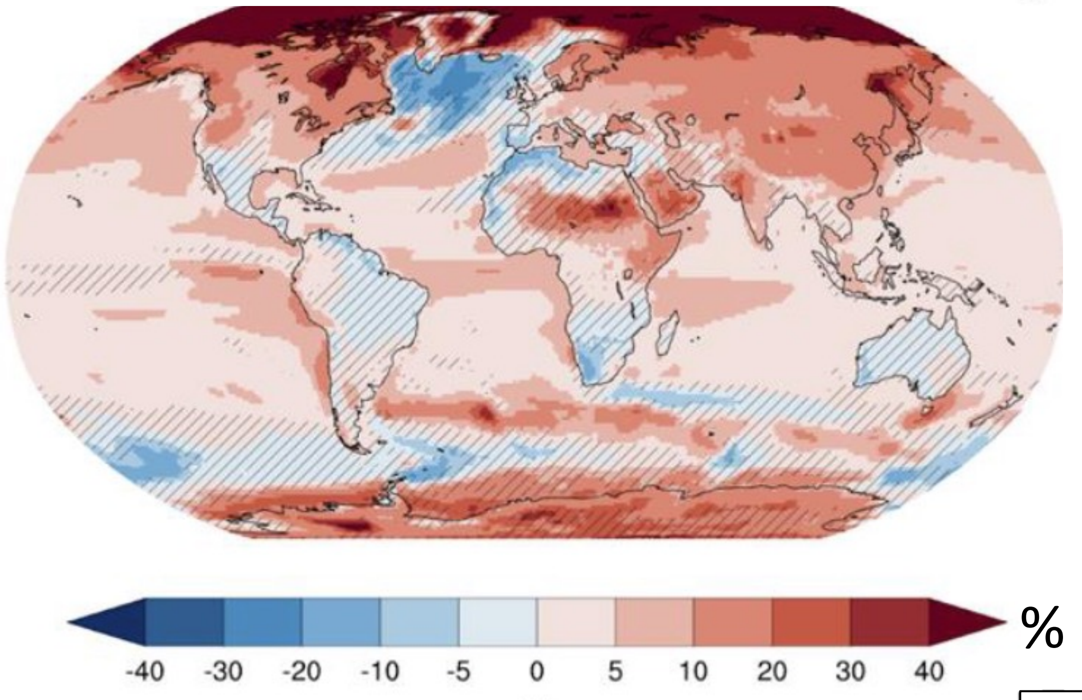
Changes in hydrologic cycle circa ~2100 (SSP4.5)

SSP4.5: 1.7C (1.2,2.6) global warming from 2010; 2.8C warming since PI

- In high latitudes, more precipitation (more water vapor organized by ~same strength storms)
  - Increased snow where cold enough
  - But decrease in snow area extent in NH
- Increased evaportranspiration in most places
- Net result: surface ocean gets saltier in tropics (where ΔE > ΔP) and fresher in high latitudes (where ΔP > ΔE)
  - Positive feedbacks associated with slowing ocean overturning circulation
- Over land, specific humidity increases but relative humidity decreases
  - Results in increased evapotranspiration that slightly outpaces increased precipitation
  - In Southern Europe and South Africa: less precipitation & more evaporation → acute reduction in soil moisture
- Decrease in arctic sea ice extent and thickness
  - 15% (0, 60%) of Sept ice cover in 1950
- Decrease in NH spring snow cover (~-25±10%)

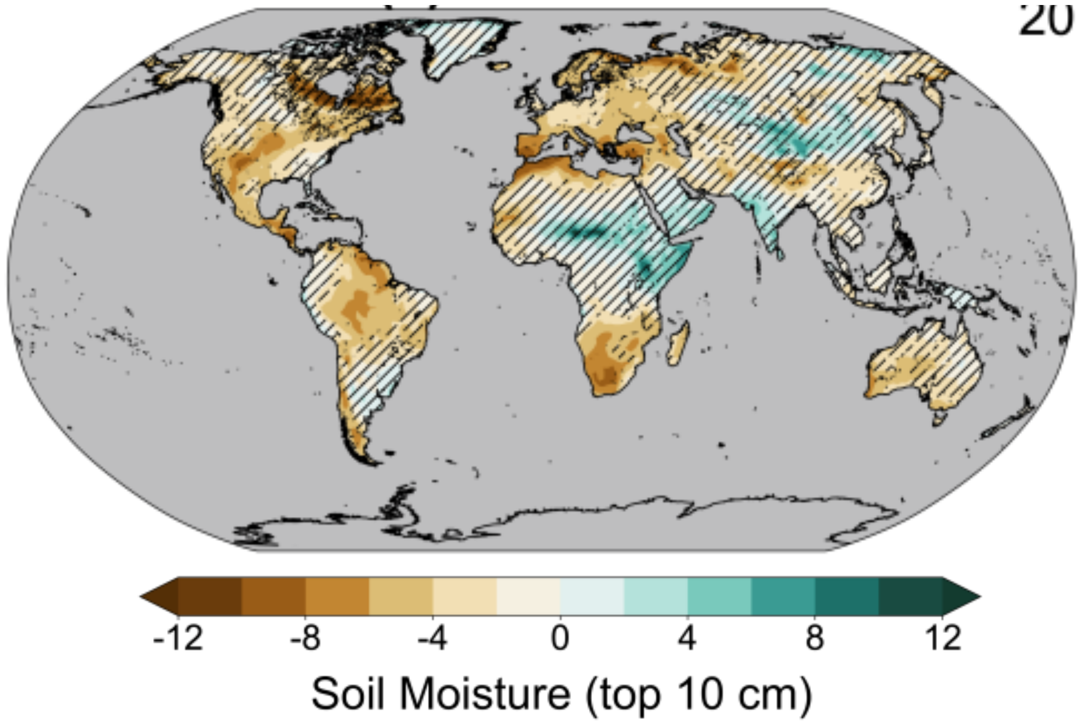
Δ Annual Evapotranspiration

37



High model agreement (≥80%)
Low model agreement (<80%)

Δ Soil Moisture



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AR6 WG1 draft report

Little change in projections in past 15 years