# Climate Dynamics (PCC 587): Hydrologic Cycle and Global Warming

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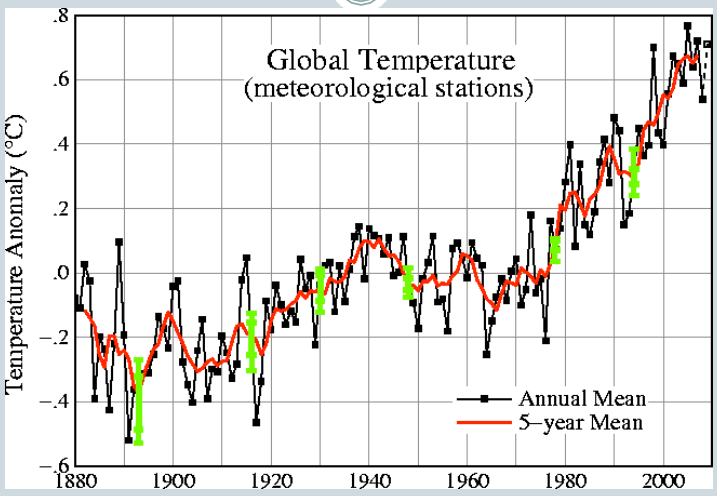
## Recent Global Temperatures

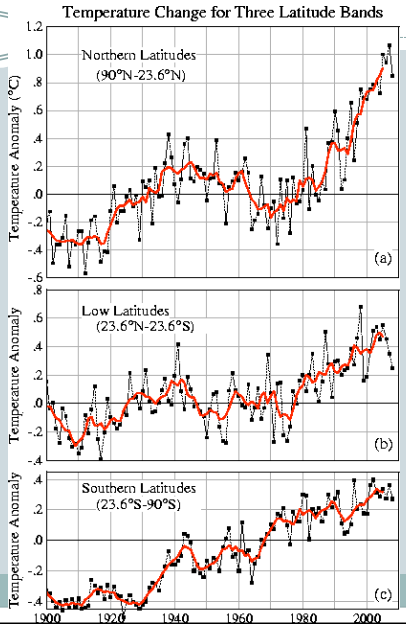



Source: GISS

## Different Latitude Bands

- Tropics vs NH/SH extratropics:

When temperatures go up in the tropics, global water vapor content goes up a lot




## Tropical Water Vapor Content

- Models can simulate changes in water vapor content well, if they're given the SSTs

Model (solid) vs obs (dashed):

Almost all plots today (including this) are from Held and Soden, J. Climate, 2006

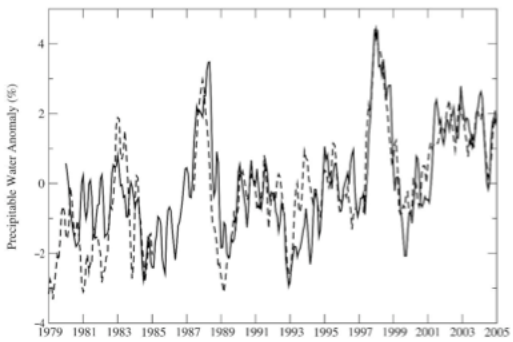


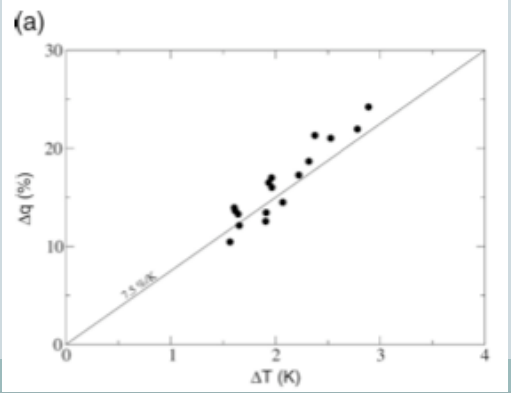

FIG. 1. A time series of the tropical-mean (30°N–30°S), ocean-only column-integrated water vapor from satellite observations (dashed) and GFDL GCM simulations with prescribed SST (solid). The satellite observations for 1979–84 are from the SMMR (Wentz and Francis 1992) and for 1987–2004 are from the SMM/I (Wentz 1997). The mean seasonal cycle is removed from both the observations and model simulations, and the SMMR anomalies are adjusted such that their mean equals that of the model for their overlapping time period (1980–84). All time series are smoothed using a 3-month running mean.

## Changes in Water Vapor Content

- Changes in water vapor content go essentially as fixed relative humidity
  - Warmer oceans (e.g., due to El Nino) → more moisture
- Global warming simulations say the same thing
  - Moisture content goes up similar to fixed relative humidity
    - **7% per degree warming**
  - There are important deviations from this locally, but it doesn't change the global mean picture

## Changes in Water Vapor in AR4 Simulations

- Changes in water vapor content (% increase) versus temperature change (K) for change over 21st century (A1B scenario):




Water vapor increases by 10-25% with warming.

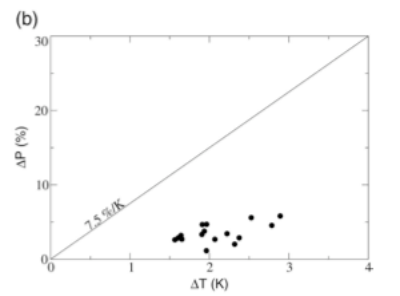
Spread among models is mostly due to spread in amount of warming.

## How about precipitation?

- Precipitation doesn't necessarily increase when water vapor increases
  - Can consider this from two perspectives: what determines evap or what determines precip
  - Surface budget perspective: evaporation = solar – net surface LW – sensible heat flux
    - Incoming solar radiation limits evaporation to some extent
  - Atmospheric energy budget perspective: precipitation = net radiative cooling of atmosphere – sensible heat flux
    - How easily the atmosphere can radiate away heat limits precipitation

## Precipitation Changes with Warming

- Models show approximately 2% increase in global precipitation per degree warming
  - Significantly less than water vapor content increase

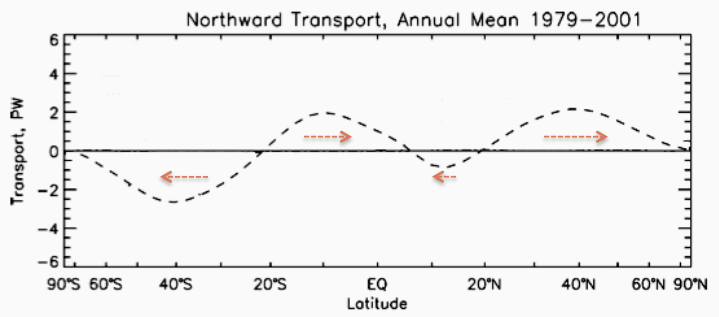


## So far…

- Global moisture content increases quickly with warming
  - Up to 25% by 2100
  - One of the largest responses with warming
- Global precipitation increases much less quickly
  - Only up to around 5% by 2100
  - So the Earth will get somewhat wetter… but what about the distribution of the precipitation changes?
- Next: why wet gets wetter and dry gets drier…
  - We'll start zonally averaged, and move on to more local changes

## Moisture Transports

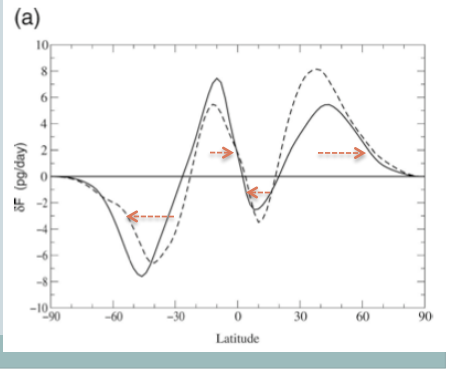
- Moisture content increases rapidly. How about moisture transports?
- Northward moisture flux in current climate:




  - Equatorward moisture flux by Hadley cell, poleward flux by midlatitude eddies

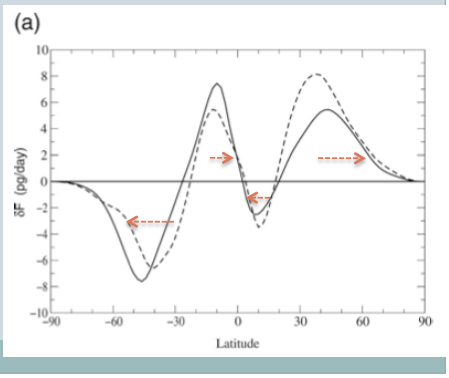
## Moisture Flux Changes

- Moisture content increases faster than most circulation changes
  - **Change in moisture flux** (solid line) looks like mean moisture flux
- Rough guess of moisture flux change (dashed line):
  - **Same circulation**, increased moisture content



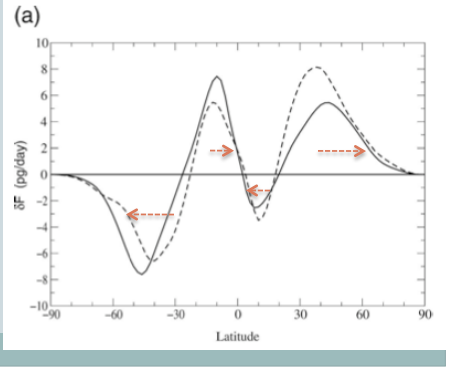

## Moisture Flux Changes

- Can see evidence for changes in circulations from difference from simple prediction
  - Poleward shift of baroclinic eddies
  - Weakening of NH midlatitude circulation



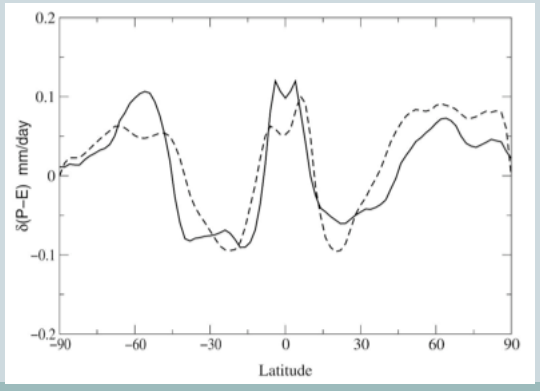
## Implications for Precipitation

- More moisture fluxed **into deep tropics** and **high latitudes**
  - Precipitation will strongly increase in those places
    - Evaporation and moisture flux increase there
- More moisture fluxed **out of subtropics**
  - This reduces the precipitation
  - Evaporation changes offset somewhat




## Prediction of P-E

- The moisture flux argument most directly relates to P-E (this is equal to moisture transport)



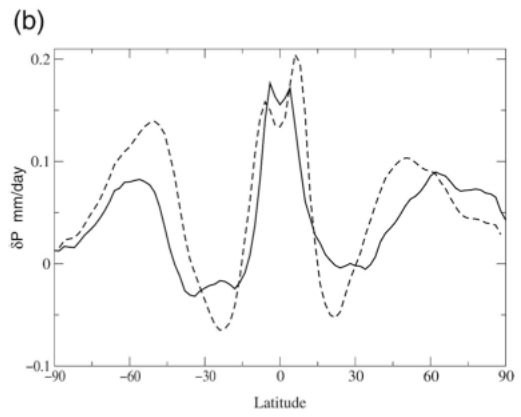

Clear increase in deep tropics & High latitudes

Clear decrease in subtropics

Also see clear poleward shifts

# Change in Precipitation

- Change in precipitation in global warming simulations



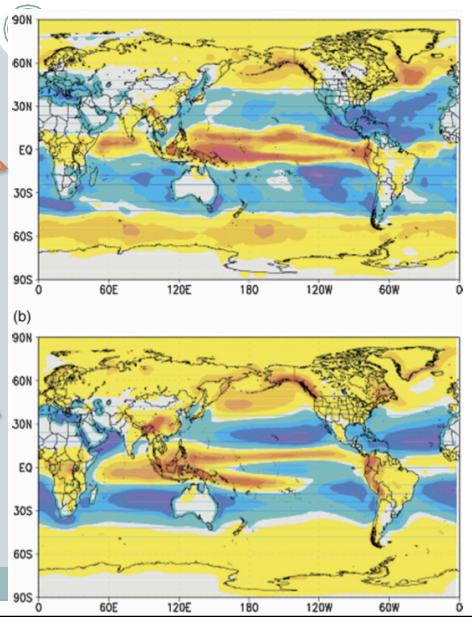

Wet gets much wetter, dry gets a bit drier (although this can be a large percentage change relative to the current value in arid regions)

Note also poleward shifts relative to simple prediction

# Predictions of P-E

- **Actual** P-E change (top) **vs simple prediction** as proportional to P-E (bottom)

(Here red = moistening, blue = drying: future plots will be opposite)




Can see more drying over many continents (SW US/Mexico, Southern Africa, Northern Europe)

Some of this is clearly associated with **poleward shifts of circulations**

But there are kind of fundamental problems over land – what is up?

## Complications of Land Surfaces

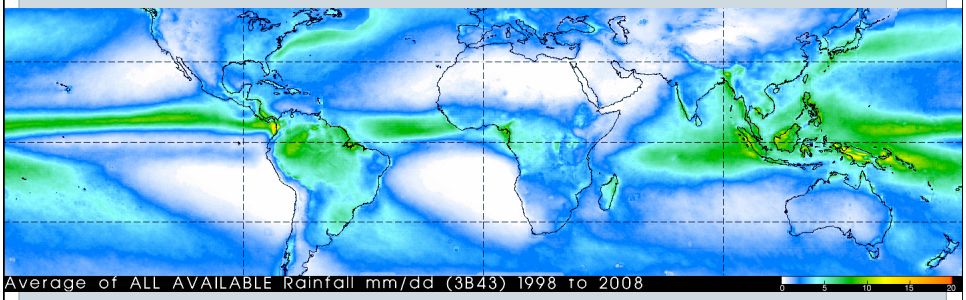
- Over a whole continent, precipitation minus evaporation must be greater than zero
  - This is equal to the runoff (and there can't be "run-on" into a given water basin)
  - Simple argument about moisture fluxes doesn't necessarily respect this
- Arid land regions have P ~ E
  - Everything that precipitates later evaporates
  - Near surface humidity can be small and is very variable
    - One wouldn't expect moisture content over arid regions to increase with warming

## Complications of Simple Argument: Arid Land

- Simple argument thus predicts an *increase* in moisture flux over even the driest land surface
  - Can see this in previous predictions
- Arid land: what happens?
  - In reality, P-E would remain close to zero over arid land
  - How P changes over these locations is then determined by changes in moisture fluxes (which may increase, but won't necessarily…)
- Let's next examine changes in modeled precip

## Annual Mean Precipitation

- For reference, the precip climatology from TRMM (1998-2008)




## Modeled Precipitation Changes

- Seasonal *percentage change* in precip from IPCC AR4

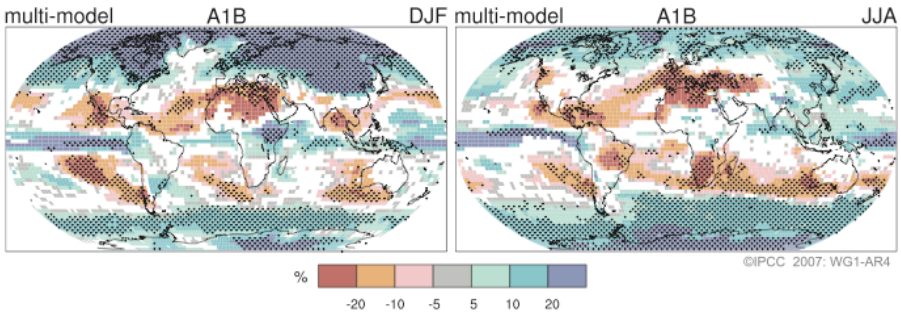
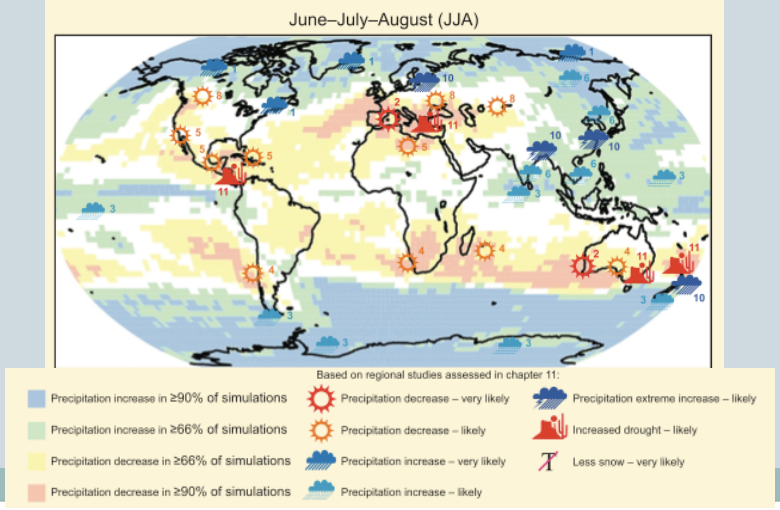



**Figure SPM.7.** *Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}*

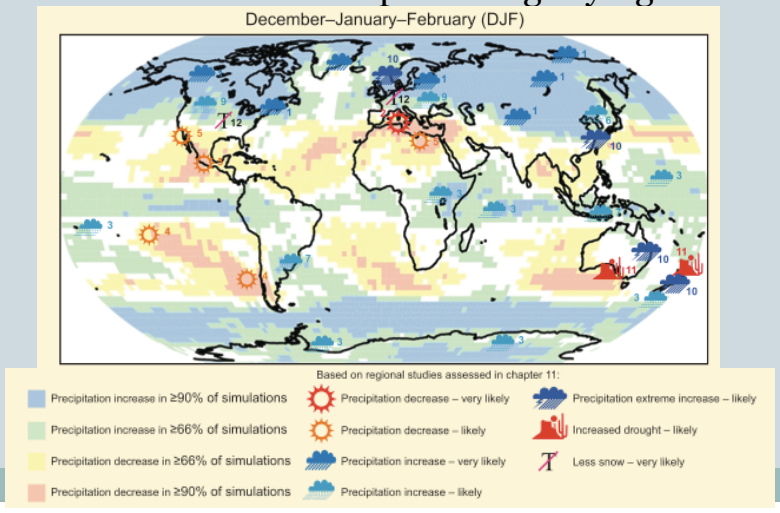
## Modeled Precipitation Changes

- Alternative: # of models predicting drying vs wetting




## Modeled Precipitation Changes

- Alternative: # of models predicting drying vs wetting

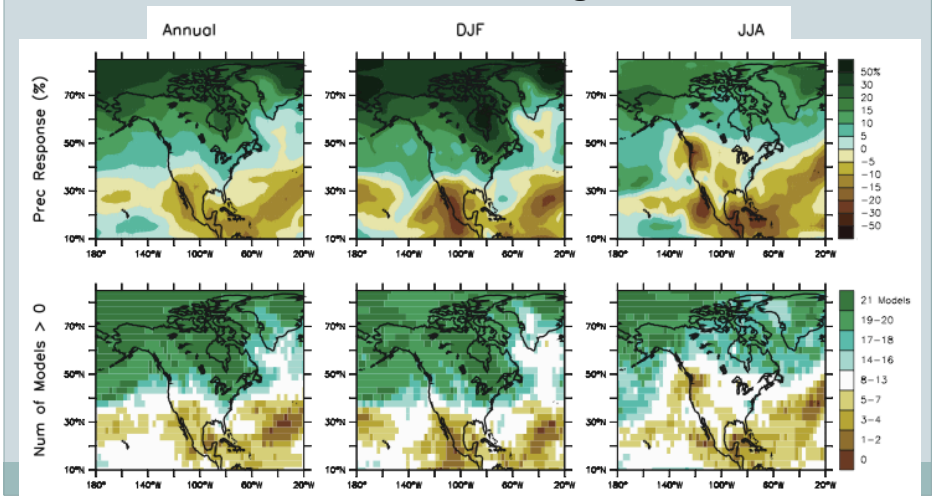


## Changes in Land Precipitation

- Note that many arid continental regions show decreases in precipitation
  - Even though increased moisture flux argument **doesn't constrain those locations**
  - Decrease in soil moisture important?
- Let's take a closer look at land precipitation changes all around the globe

## North America

- Predicted N. Amer. rainfall change (annual & seasonal)

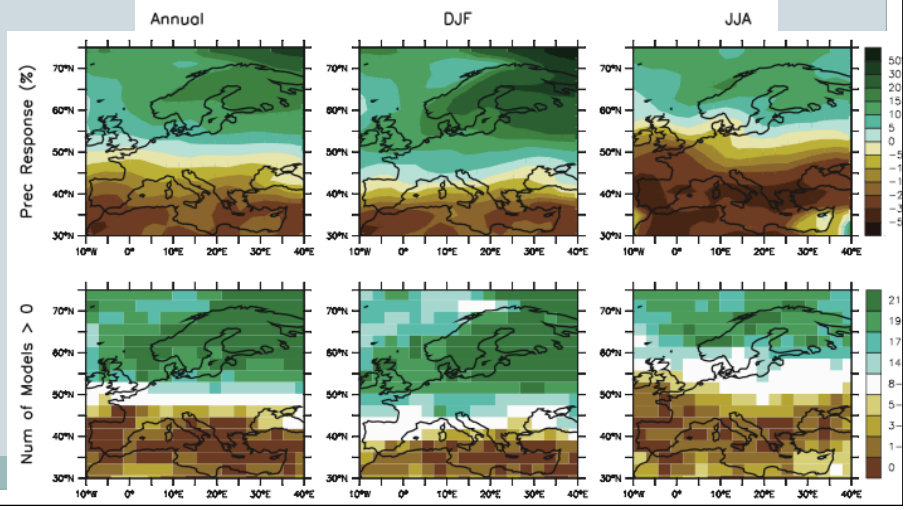


## SW North American Drying

- Seager et al 2007: Model Projections of an Imminent Transition to a More Arid Climate in SW North America
  - Poleward shift of eddies is key to their explanation of this decrease

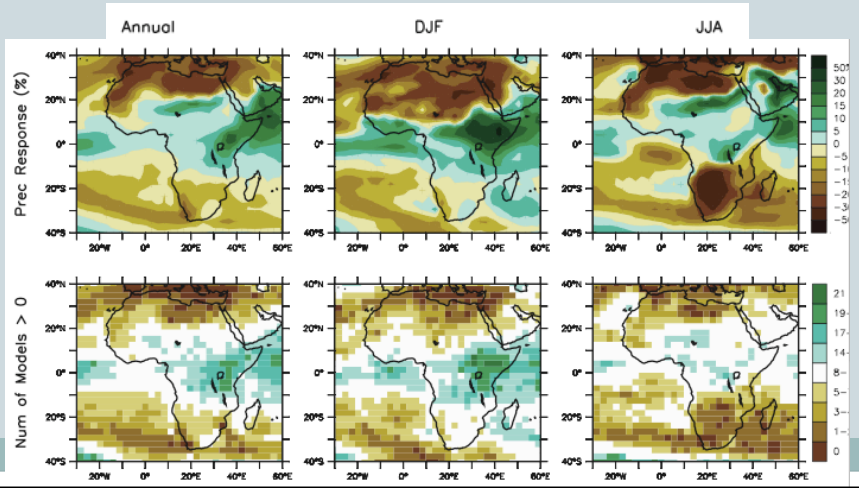
## Europe

- Modeled European precip changes



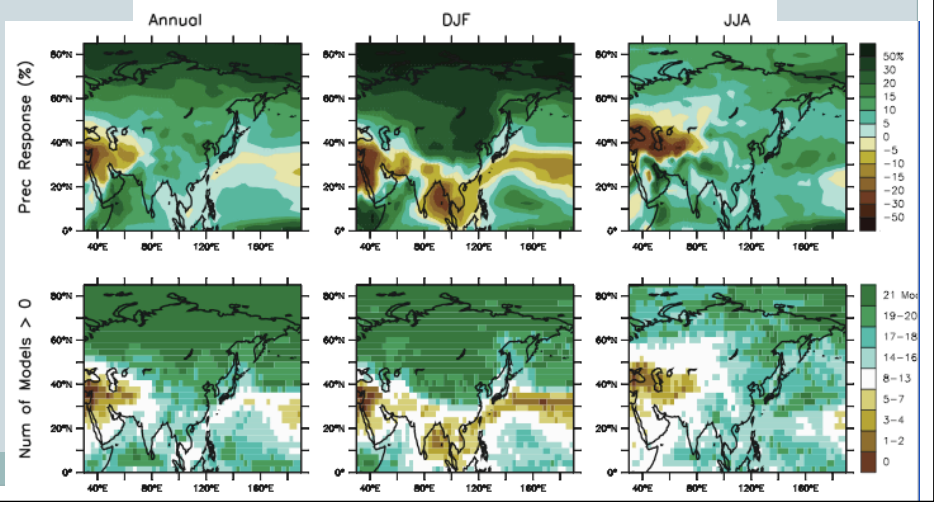
# Africa

- Modeled African precip changes



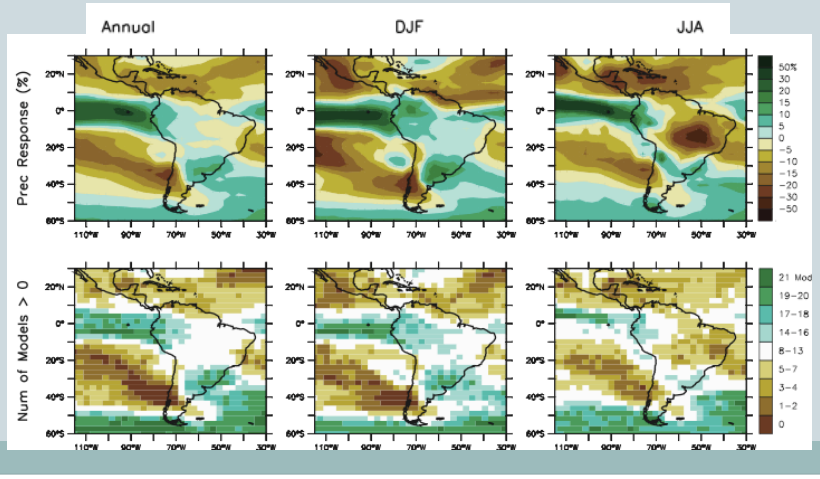

# Asia

- Modeled Asian precipitation changes



## South America

- Modeled South American precip changes




## Australia

- Modeled Australian precipitation changes