Anticipated and Observed Trends in the Global Hydrological Cycle

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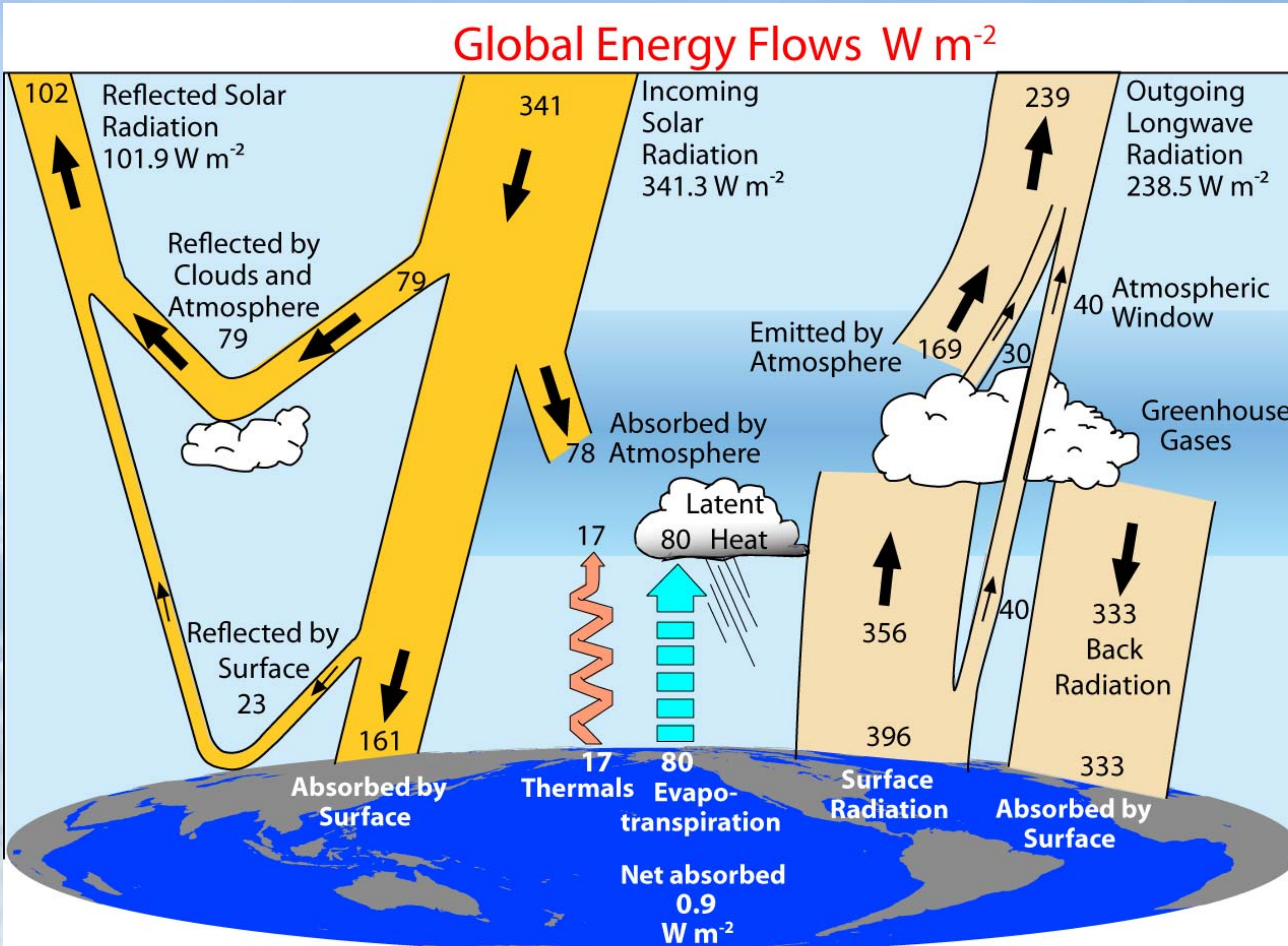


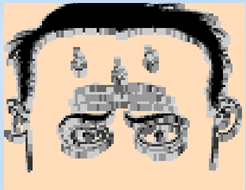
Trenberth et al 2008

Controlling Heat

The presence of moisture affects the disposition of incoming solar radiation:

Evaporation (drying) versus temperature increase.

Human body: sweats



Homes: Evaporative coolers (swamp coolers)

Planet Earth: Evaporation (if moisture available)

e.g., When sun comes out after showers,

the first thing that happens is that the puddles dry up: before temperature increases.

How should rainfall change as climate changes?

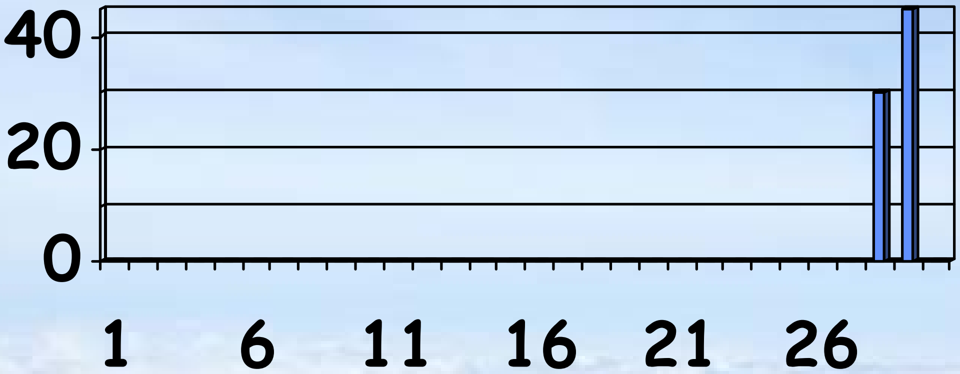
Usually only total **amount** is considered

- But most of the time it does not rain
- The **frequency and duration** (how often)
- The **intensity** (the rate when it does rain)
- The **sequence**
- The **phase**: snow or rain

The intensity and phase affect how much runs off versus how much soaks into the soils.

Daily Precipitation at 2 stations

A



drought
wilting plants

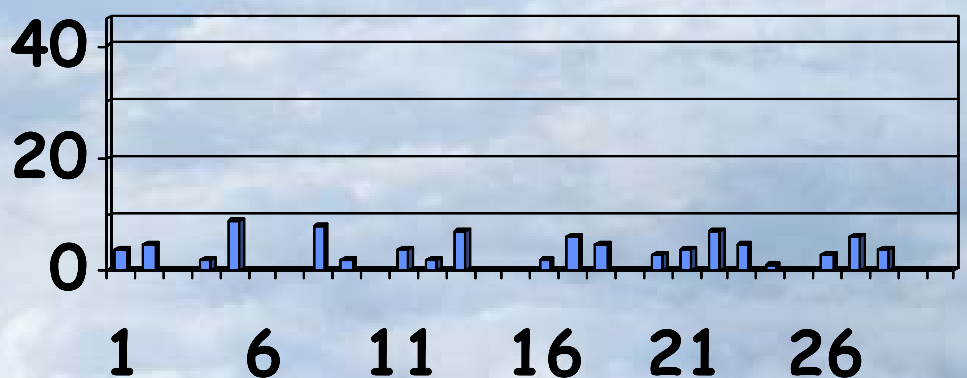
wild fires

local
floods

Monthly
Amount 75 mm

Frequency 6.7%
Intensity 37.5 mm

B



soil moisture replenished
virtually no runoff

Amount 75 mm

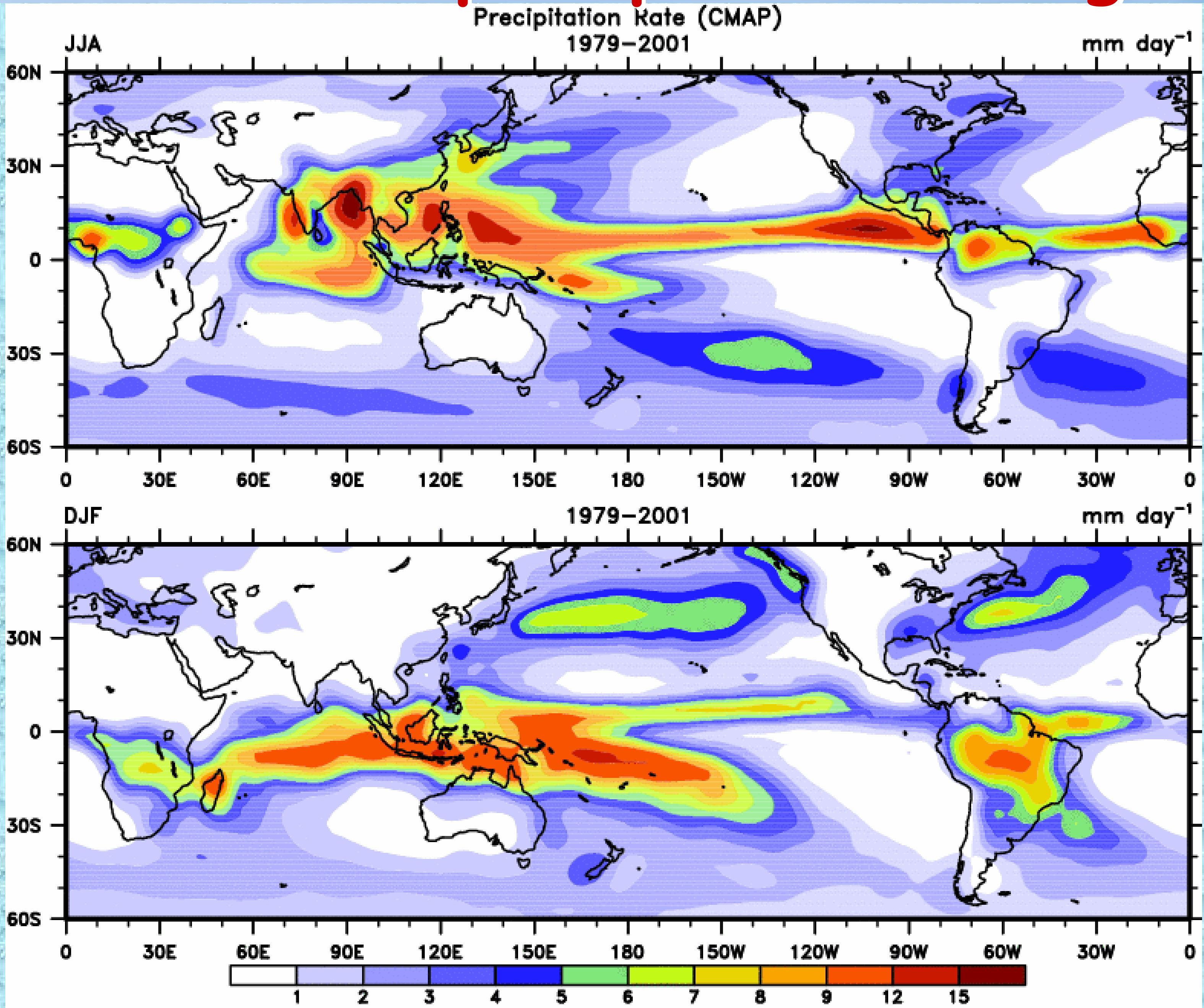
Frequency 67%
Intensity 3.75 mm

Moderate or heavy precipitation:

- Can not come from local column.
- Can not come from E, unless light precipitation.
- Has to come from transport by storm-scale circulation into storm.

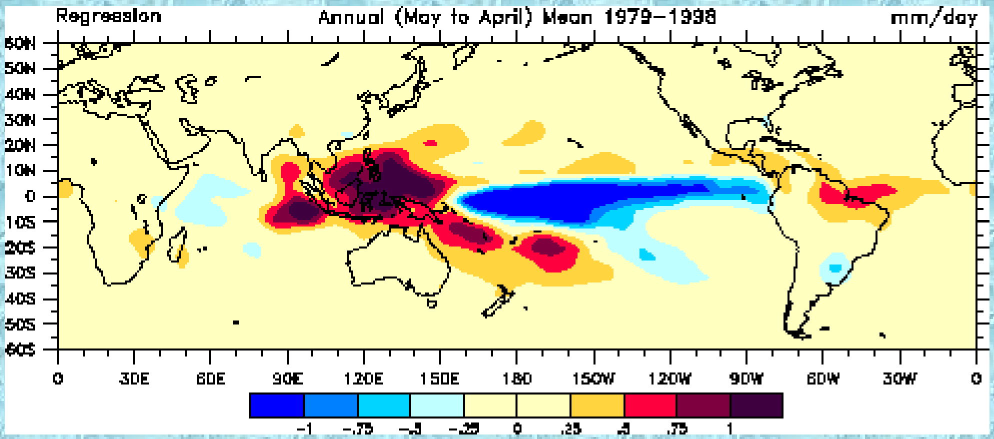
On average, rain producing systems (e.g., extratropical cyclones; thunderstorms) reach out and grab moisture from distance about 3 to 5 times radius of precipitating area.

How should precipitation change?



Changes in precipitation depend a lot on the mean

- Precipitation has strong structure with convergence zones
- A small shift creates a dipole: big increases some places, big decreases in others
- This is the first order effect in El Niño



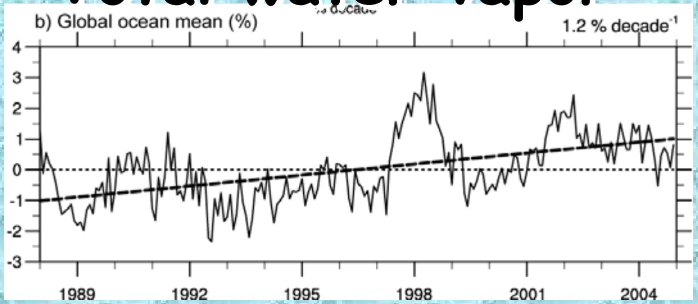
Air holds more water vapor at higher temperatures

A basic physical law tells us that the water holding capacity of the atmosphere goes up at about 7% per degree Celsius increase in temperature. (4% per °F)

Observations show that this is happening at the surface and in lower atmosphere: 0.55°C since 1970 over global oceans and 4% more water vapor.

This means more moisture available for storms and an enhanced greenhouse effect.

Total water vapor



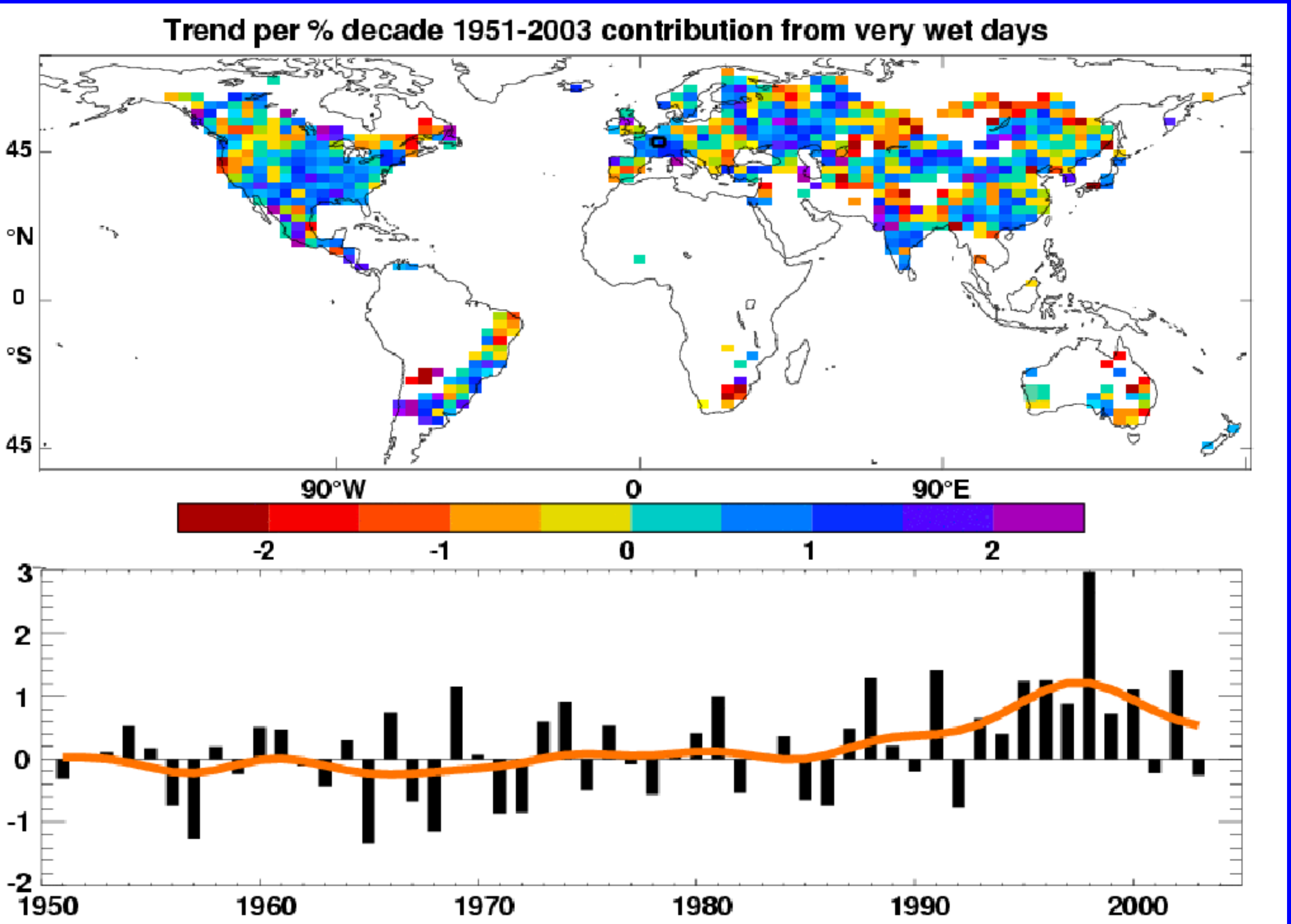
How should precipitation P change as the climate changes?

- With increased GHGs: increased **surface** heating evaporation E⇑ and P⇑
- With increased aerosols, E⇓ and P⇓
- **Net global effect is small and complex**

- Warming and T⇑ means water vapor ⇑ as observed
- Because precipitation comes from storms gathering up available moisture, **rain and snow intensity** ⇑ : **widely observed**
- But this must reduce lifetime and frequency of storms
- Longer dry spells

Trenberth et al 2003

Heavy precipitation days are increasing even in places where precipitation is decreasing.

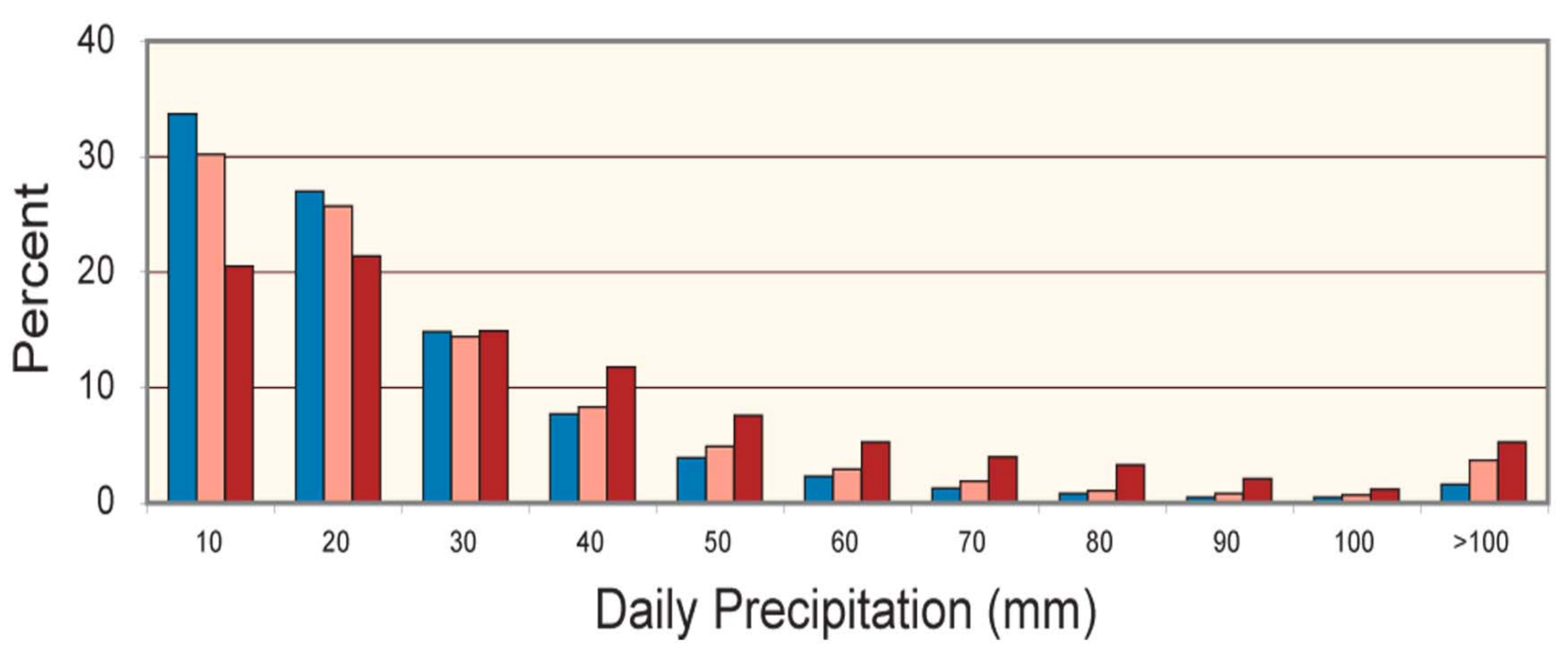


Precipitation

Observed trends (%) per decade for 1951-2003 contribution to total annual from **very wet days** > 95th %ile.

Alexander et al 2006
IPCC AR4

Higher temperatures: heavier precipitation



Percent of total seasonal precipitation for stations with 230mm±5mm falling into 10mm daily intervals based on seasonal mean temperature. Blue bar -3˚C to 19˚C, pink bar 19˚C to 29˚C, dark red bar 29˚C to 35˚C, based on 51, 37 and 12 stations.

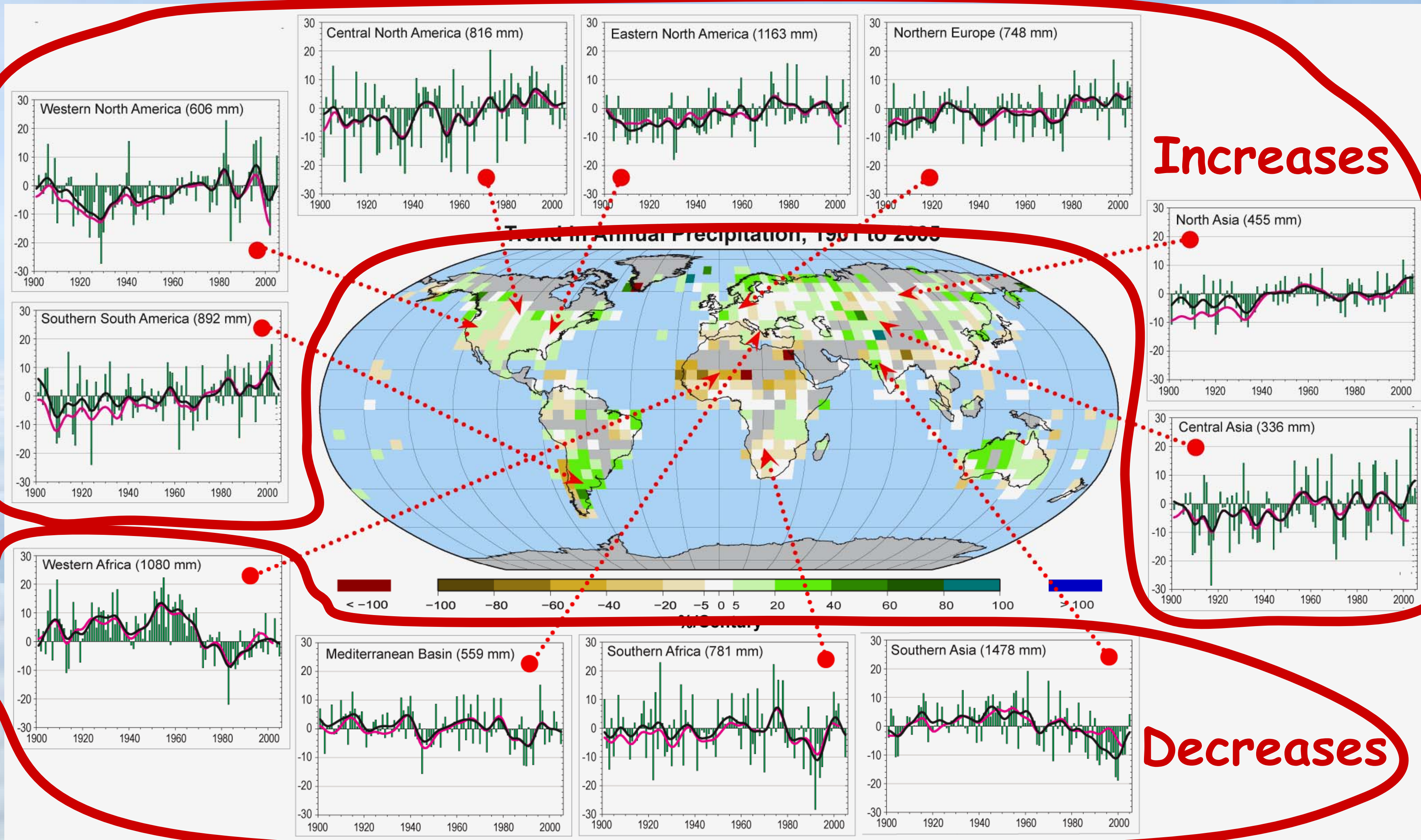
As temperatures and e_s increase, more precipitation falls in heavy (over 40mm/day) to extreme (over 100mm/day) daily amounts.

Karl and Trenberth 2003

How should precipitation P change as the climate changes?

- "The rich get richer and the poor get poorer". More water vapor plus moisture transports from divergence regions (subtropics) to convergence zones. Result: **wet areas get wetter, dry areas drier** (Neelin, Chou)
- "Upped ante" precip decreases on edges of convergence zones as it takes more instability to trigger convection: more intense rains and upward motion but broader downward motion. (Neelin, Chou)
- "More bang for the buck": The moisture and energy transport is a physical constraint, and with increased moisture, the winds can be less to achieve the same transport. Hence the divergent circulation weakens. (Soden, Held, et al)

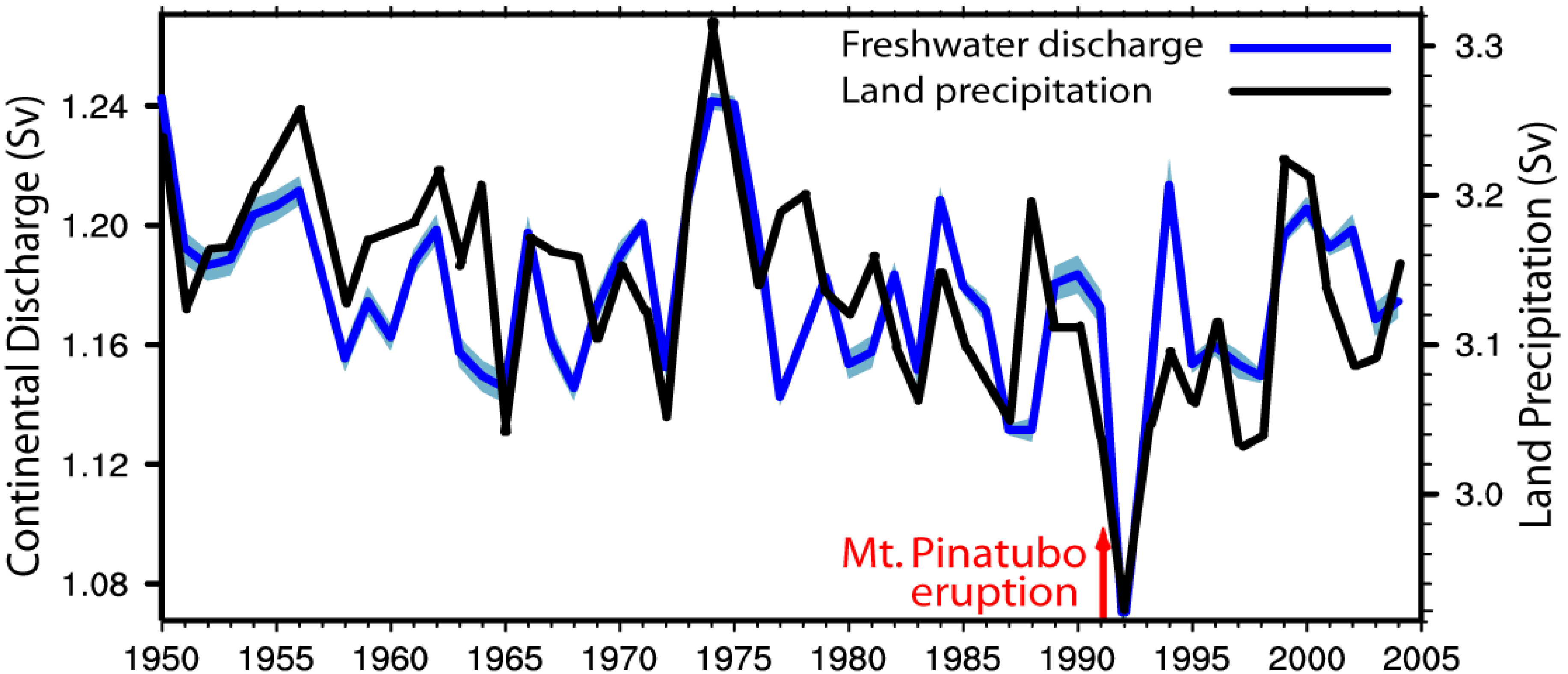
Land precipitation is changing significantly over broad areas



Smoothed annual anomalies for precipitation (%) over land from 1900 to 2005; other regions are dominated by variability.

IPCC

Pinatubo Effect on Hydrological Cycle



Estimated water year (1 Oct-30 Sep) **land precipitation** and river **discharge** into global oceans based on hindcast from output from CLM3 driven by observed forcings calibrated by observed discharge at 925 rivers.

Note: 1) effects of Pinatubo; 2) downward trend (contrast to Labat et al (2004) and Gedney et al (2006) owing to more data and improved missing data infilling)

Trenberth and Dai 2007; Dai et al. 2008

Flood damages:

1. Local and national authorities work to prevent floods (e.g., Corp of Engineers, Bureau of Reclamation, Councils)
   Build ditches, culverts, drains, levees
   Can backfire!

2. Deforestation in many countries:
   Leads to faster runoff, exacerbates flooding

3. Increased vulnerability to flooding through settling in flood plains and coastal regions
   Increases losses.

Flooding statistics NOT useful for determining weather part of flooding!

Drought:

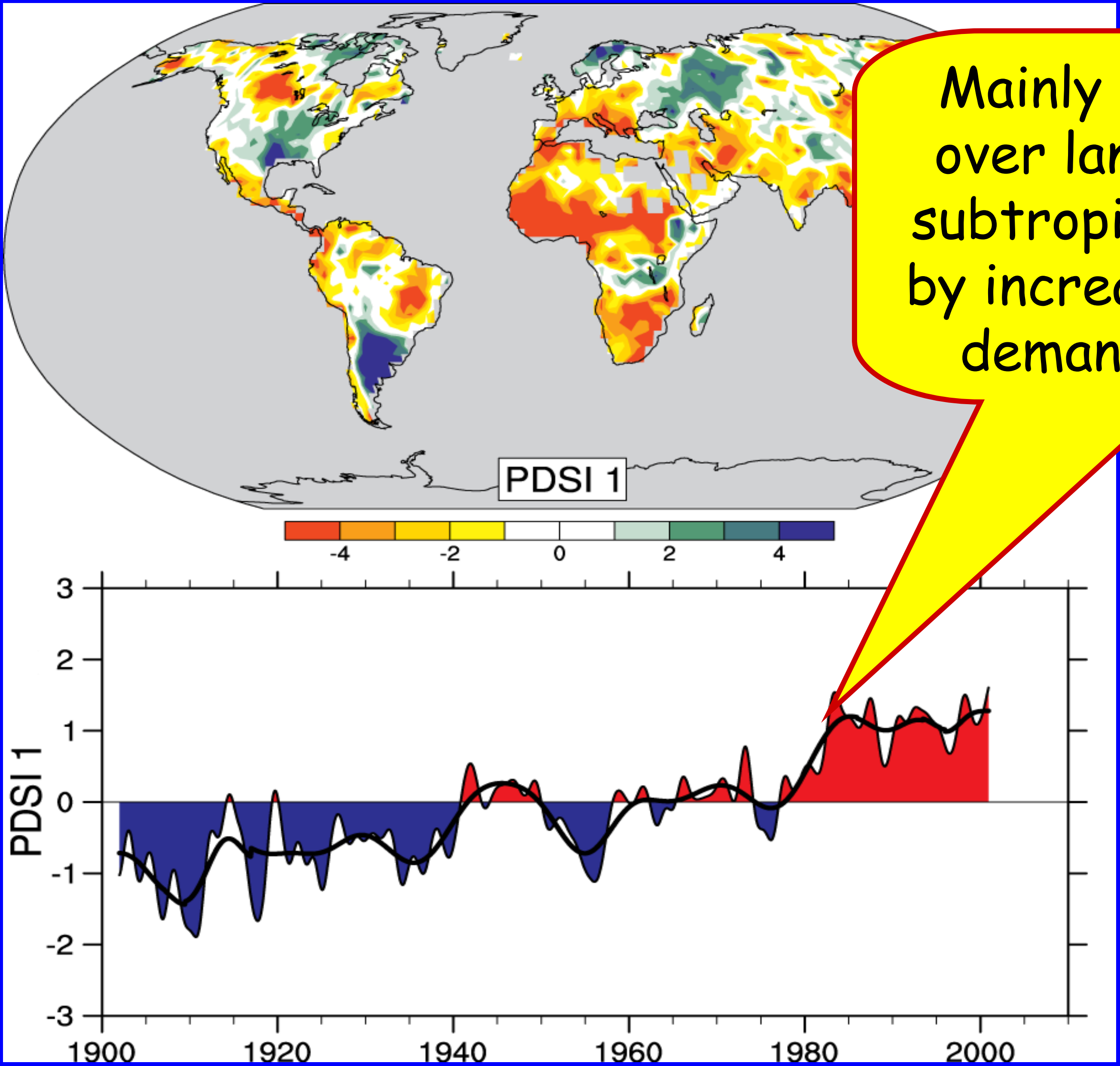
3 kinds of drought

1. Meteorological: absence of rain

2. Agricultural: absence of soil moisture

3. Hydrological: absence of water in rivers, lakes and reservoirs

Drought is increasing most places



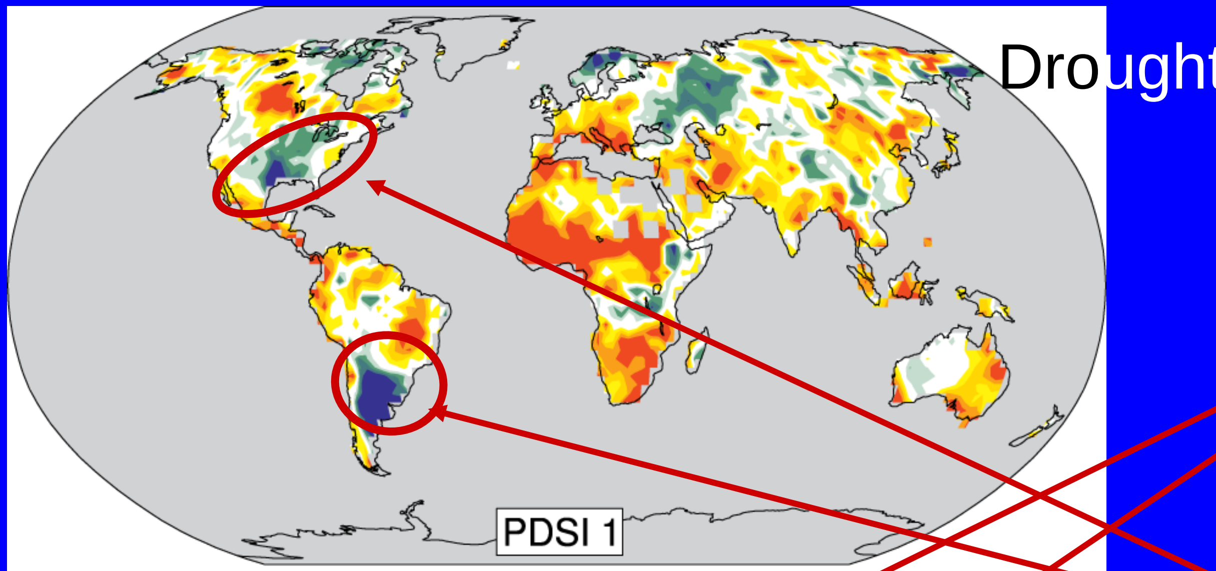
Mainly decrease in rain over land in tropics and subtropics, but enhanced by increased atmospheric demand with warming

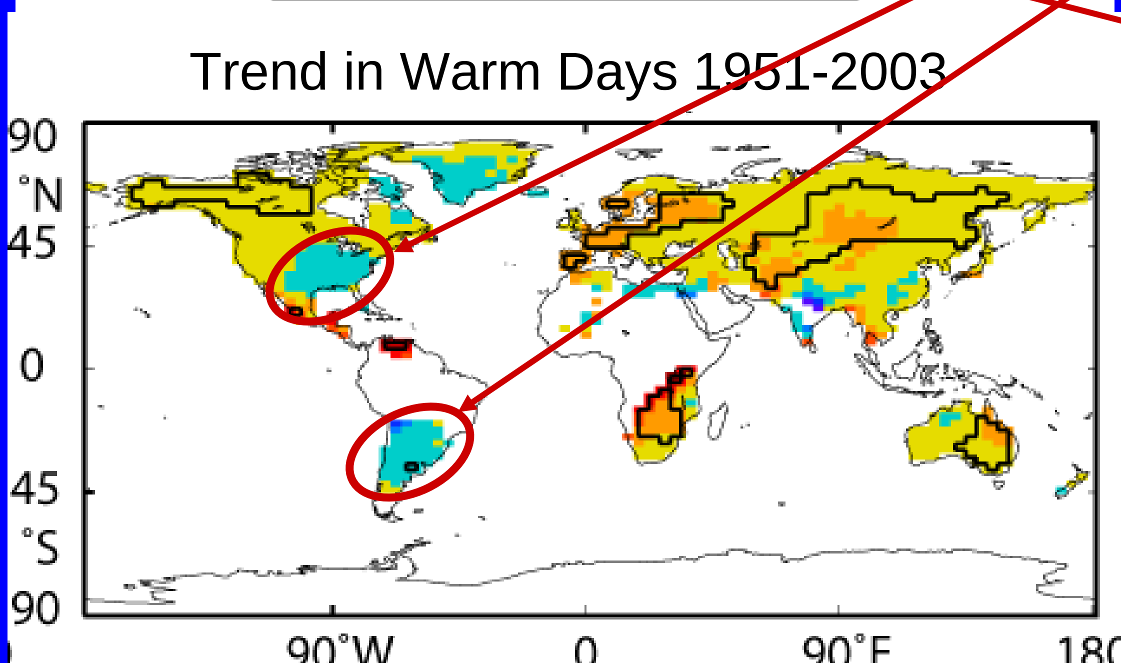
Severity Index (PDSI) for 1900 to 2002.

The time series (below) accounts for most of the trend in PDSI.

IPCC 2007

Increases in rainfall and cloud counter warming





Absence of warming by day coincides with wetter and cloudier conditions

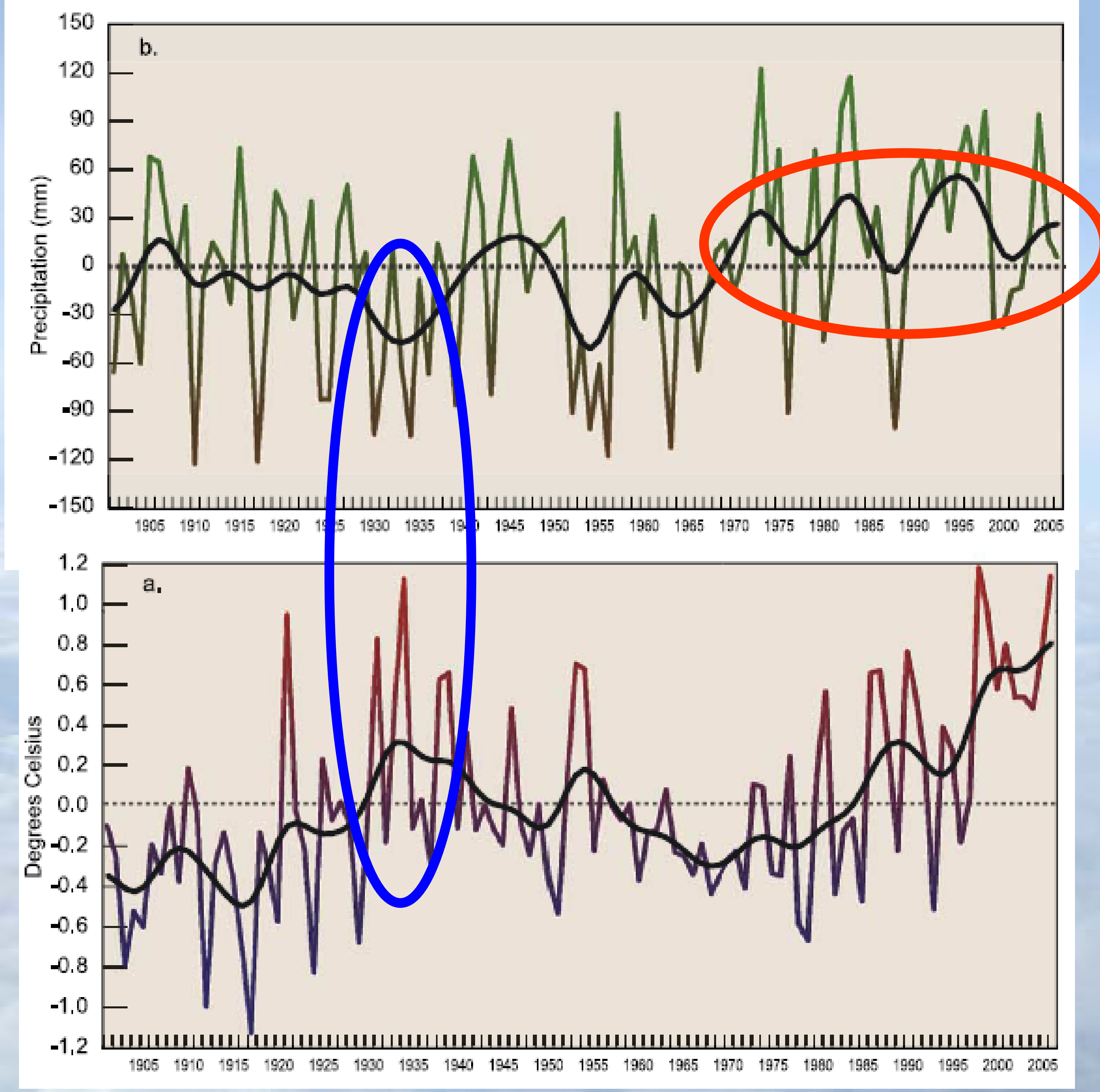
IPCC 2007

US changes in

Much wetter

Precipitation

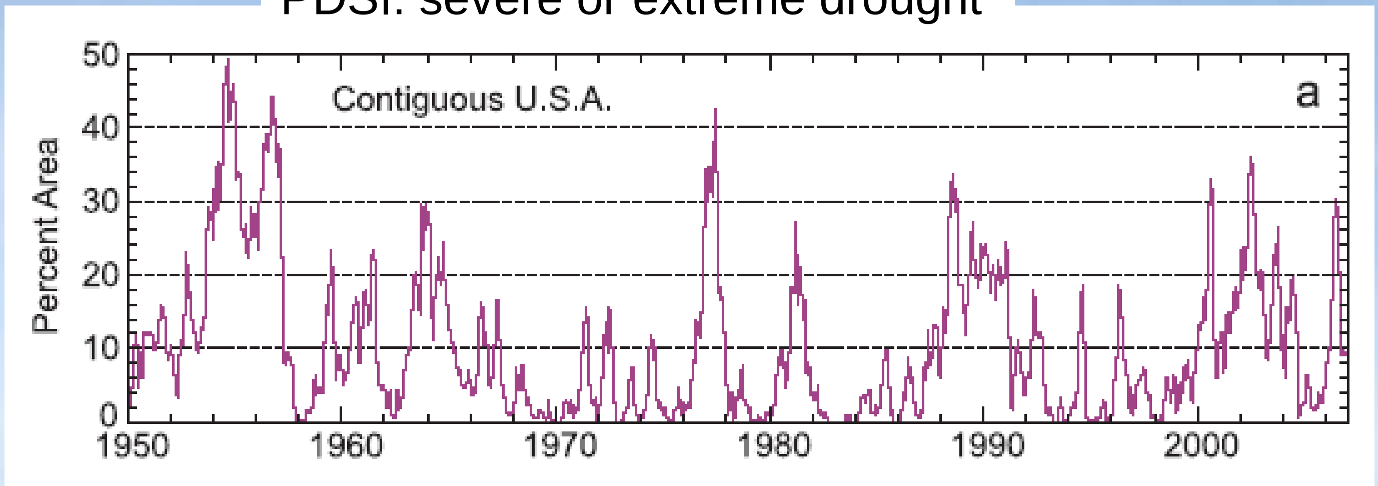
Temperature

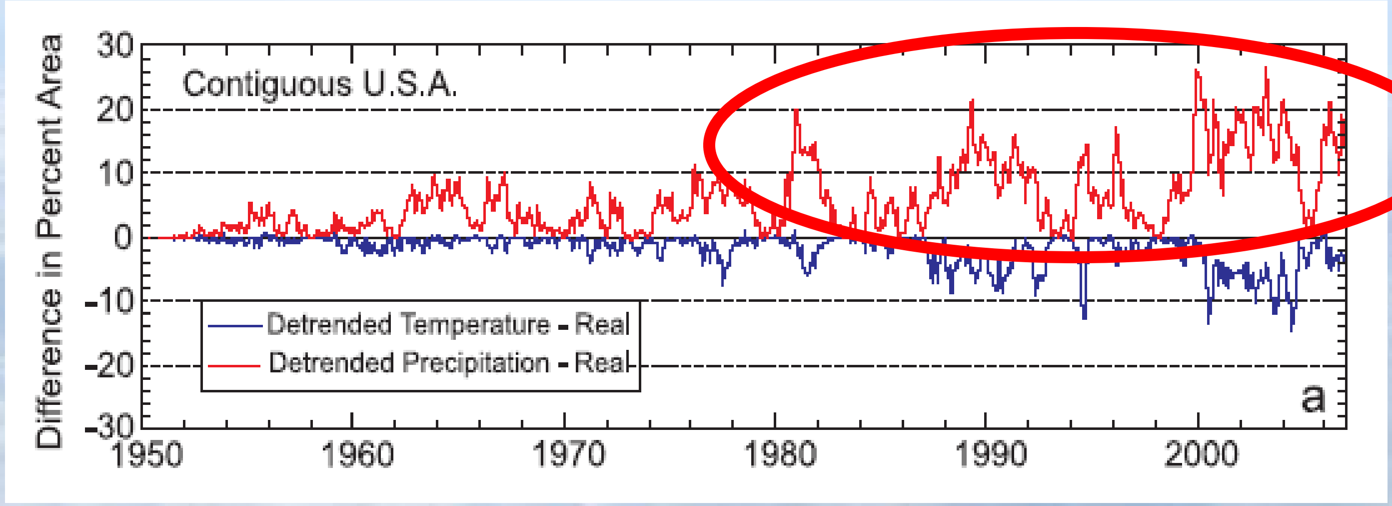


1930s:
Hot and dry

NCDC

PDSI: severe or extreme drought



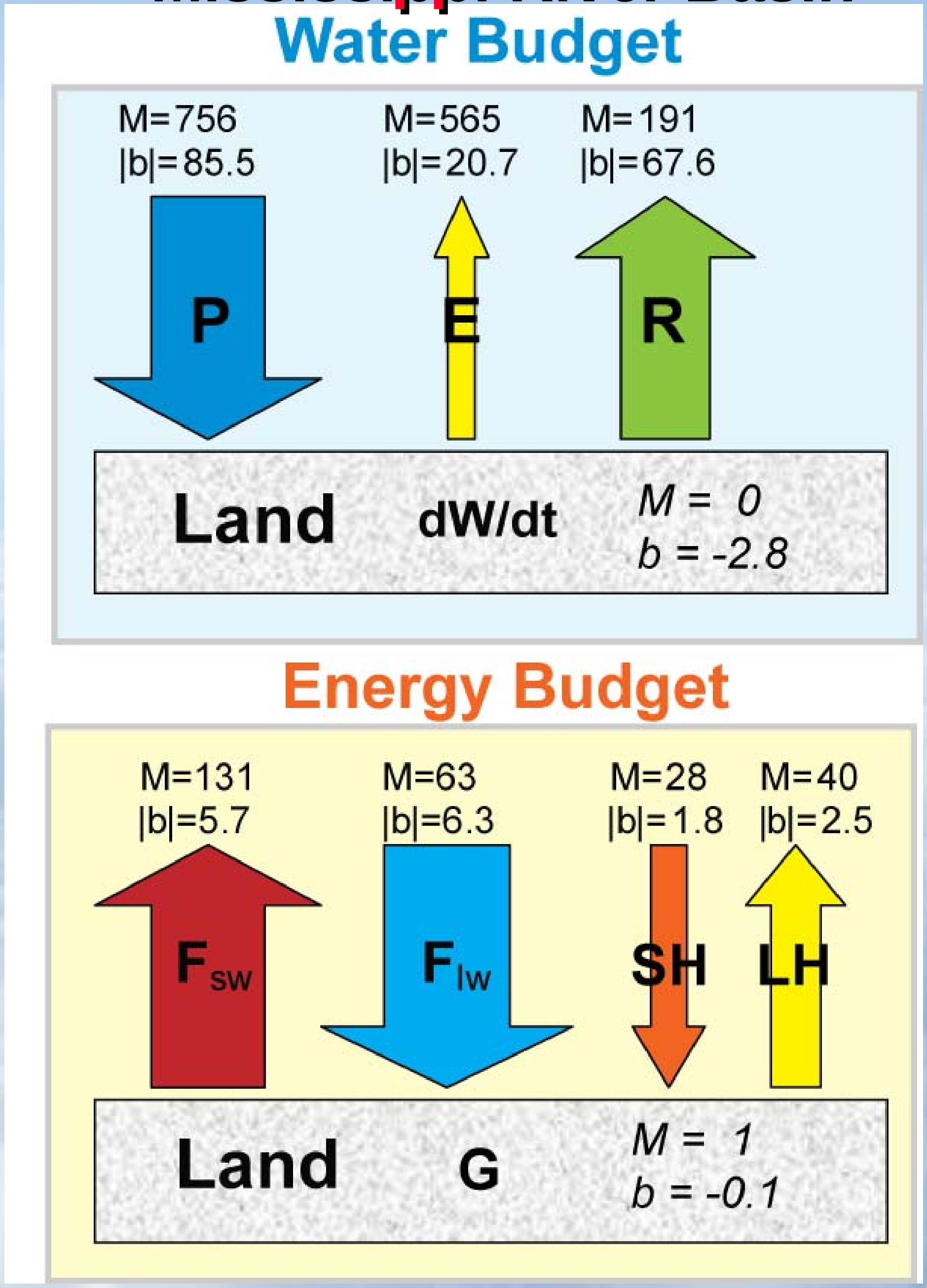


The warmer conditions suggest that drought would have been much worse if it were not for the much wetter conditions.

And it would have been much warmer too!

Change in area of PDSI in drought using detrended temperature and precipitation:
Red is no trend in precipitation:
Would be much more drought!
Blue is no trend in temperature. **Modest warming has contributed**   Easterling et al 2007

Mississippi River Basin



TRENDS: 1948 to 2004

M is the long-term annual (water-year) mean in mm for water components; W m^{-2} for energy components

b: annual linear trend 1948-2004 mm/century for water W m^{-2}/century for energy (proportional to arrow shaft width).

The downward arrow means that the flux increases the trend of *dW/dt* or *G*.

So it has become cloudier and wetter, with less solar radiation, but with increased ET and diminished SH (change in Bowen ratio).

Qian et al 2007

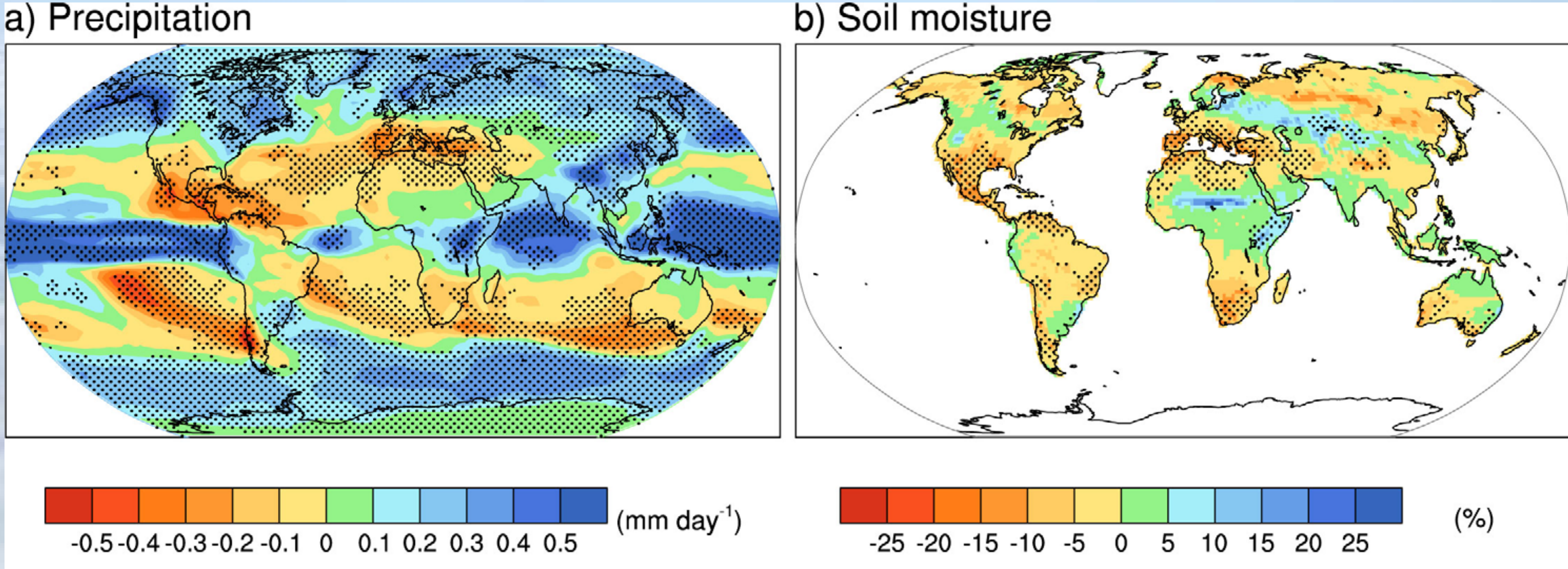
SNOW PACK: In continents and many mountain areas, global warming contributes to:

- more precipitation falls as rain rather than snow, especially in the fall and spring.
- snow melt occurs faster and sooner in the spring
- snow pack is therefore less as summer arrives
- soil moisture is less, and recycling is less
- global warming means more drying and heat stress
- the risk of drought increases substantially in summer
- along with heat waves and wildfires

Hayman wildfire near Denver 2002: 133 houses burned

"Rich get richer, poor get poorer"

Projections: Combined effects of increased precipitation intensity and more dry days contribute to lower soil moisture



2090-2100

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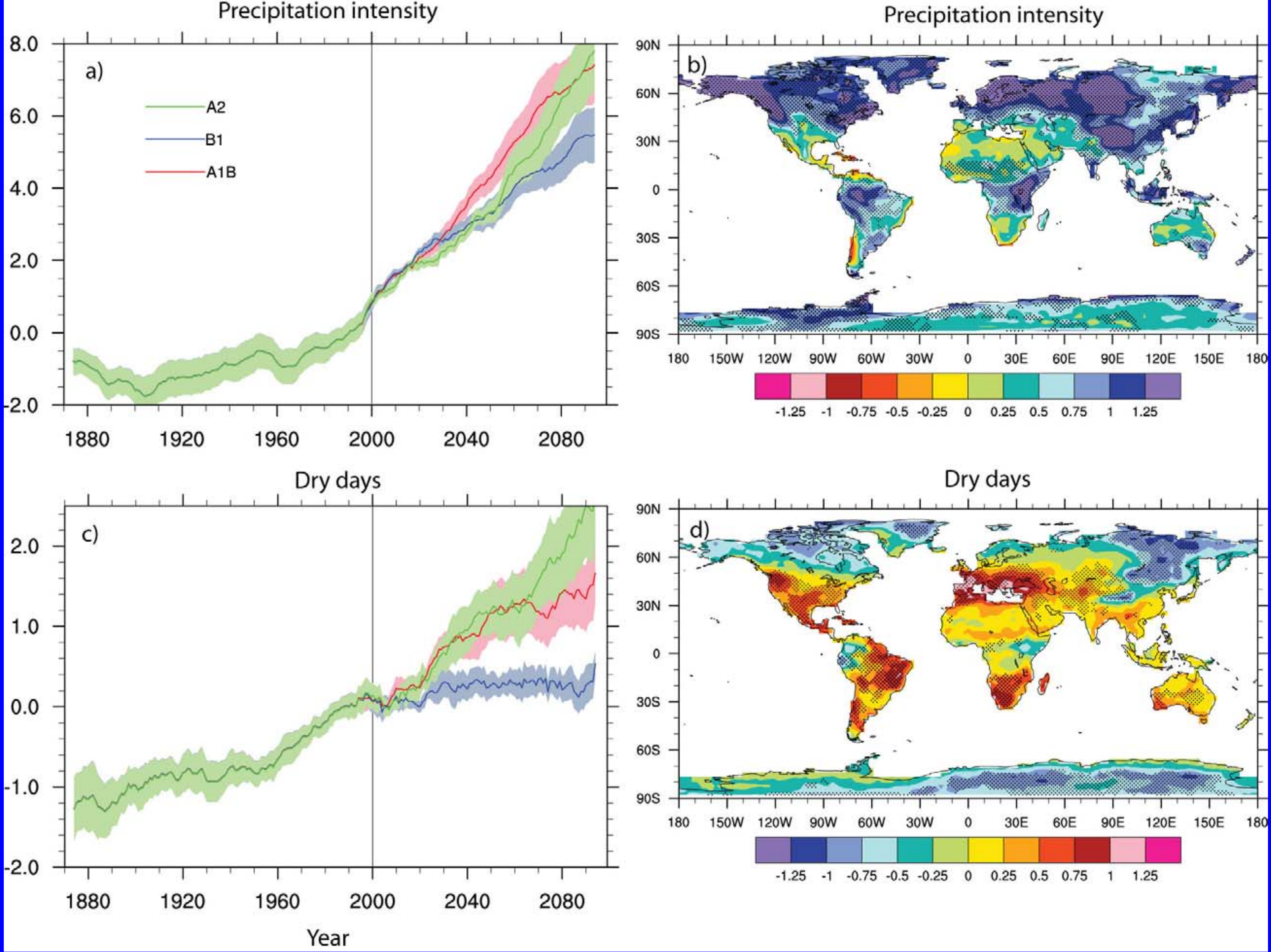

(Tebaldi , C., J.M. Arblaster, K. Hayhoe, and G.A. Meehl, 2006: Going to the extremes: An intercomparison of model-simulated historical and future changes in extreme events. *Clim. Change*.)

Climate changes in both rainfall and temperature should be considered together.

"It's not the heat it's the humidity!"

Comfort depends upon both.

Water serves as the "air conditioner" of the planet.

Water management will be a key issue:
How to save excesses in floods for longer dry spells and times of drought?

There are prospects for increases in extremes:
More floods and droughts: both have adverse impacts.

Prospects for increases in extreme weather events