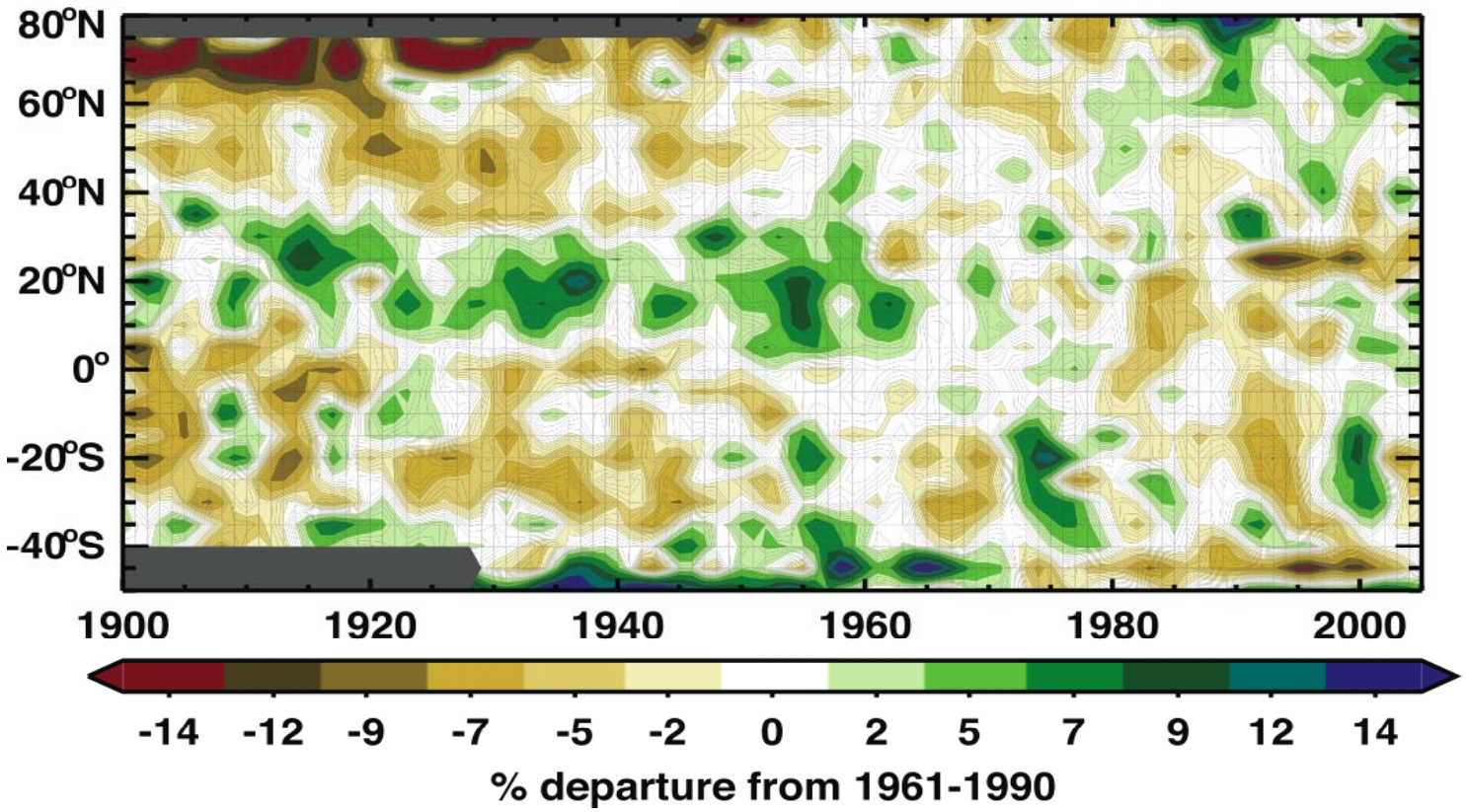
Technical Paper :
Climate Change and Water

Observed and projected changes in climate as they relate to water

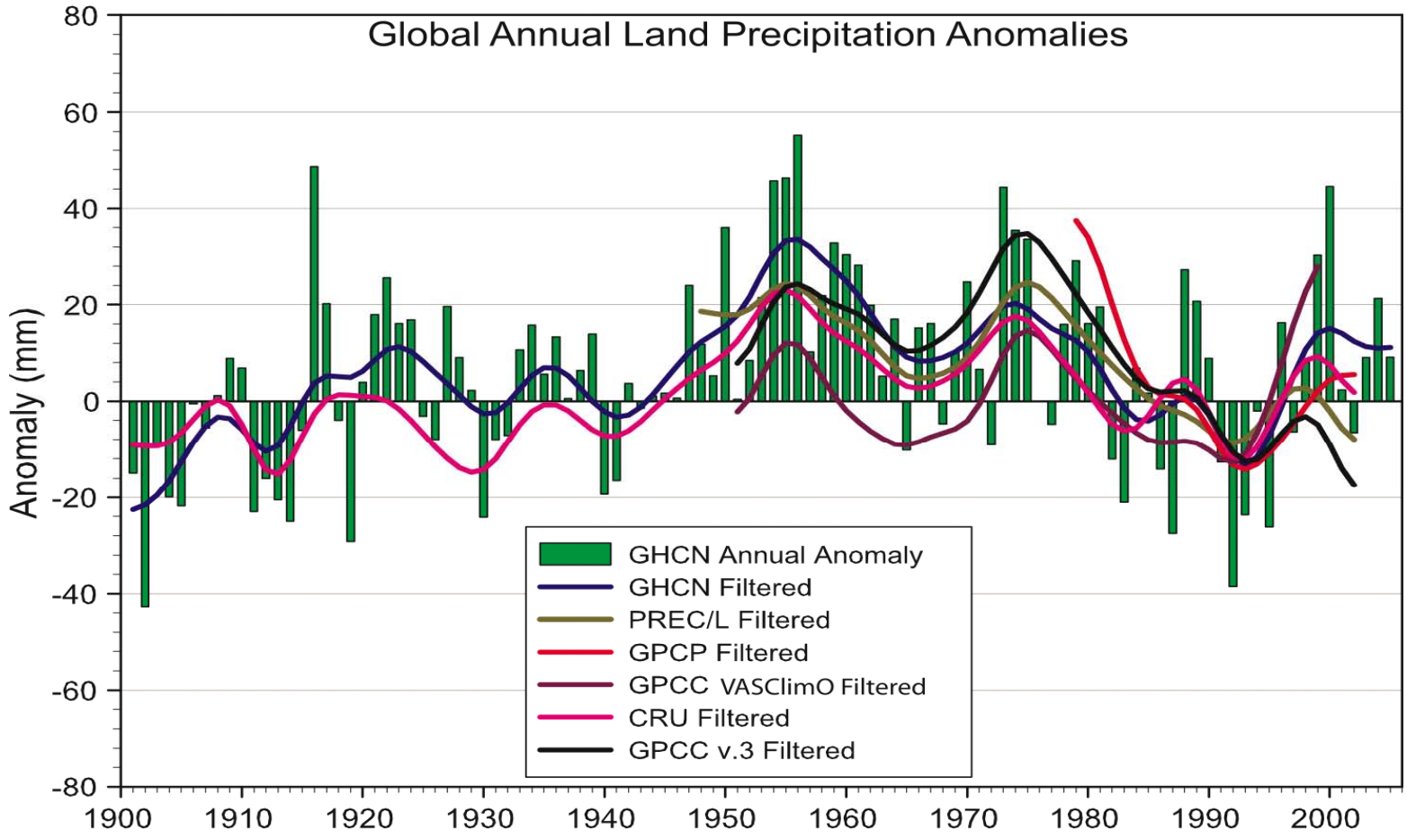
Additional section on latest scientific findings concerning attribution of precipitation change and atmospheric moisture changes (not assessed by IPCC)

Observed changes in precipitation (1)



Annual precipitation anomalies over land (%): 1900 to 2005

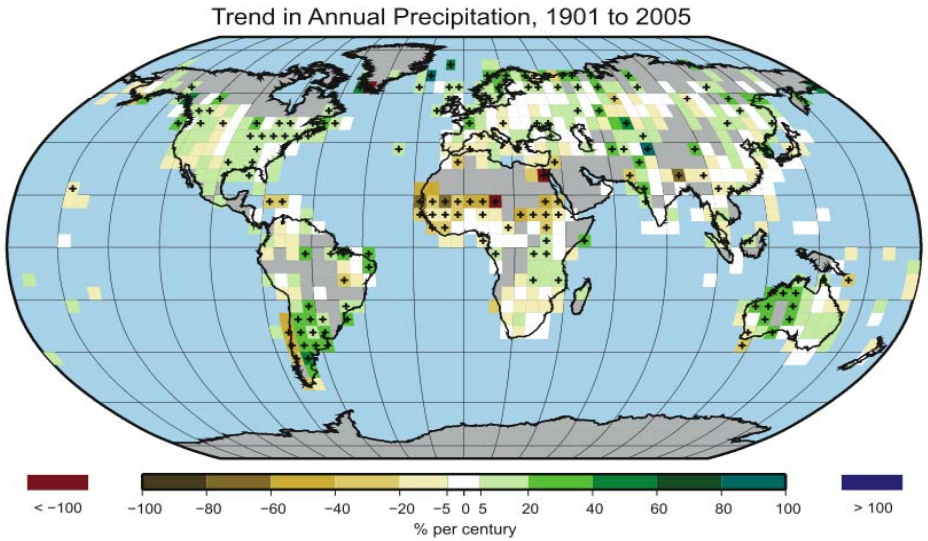
Observed changes in precipitation (2)



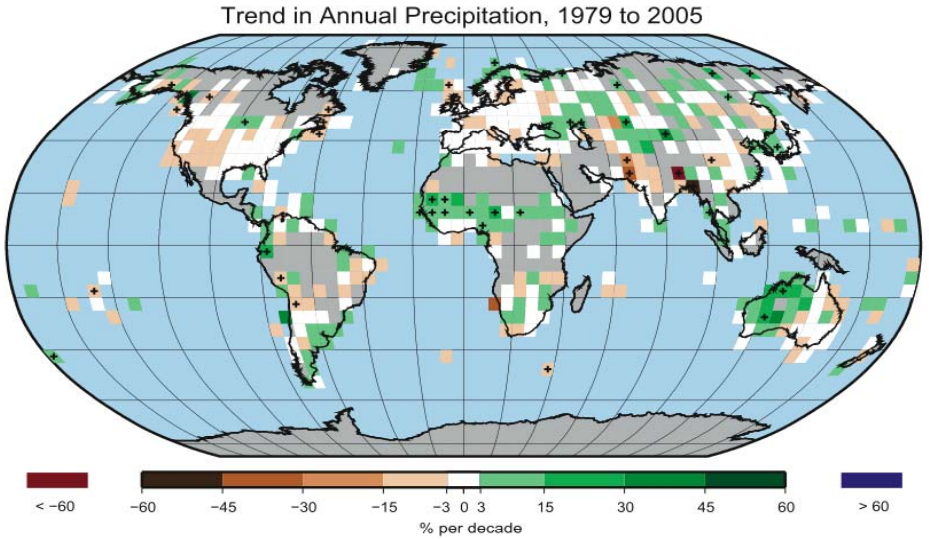
Global precipitation anomalies from different data sets

Precipitation trends

1901-2005 (% per century)

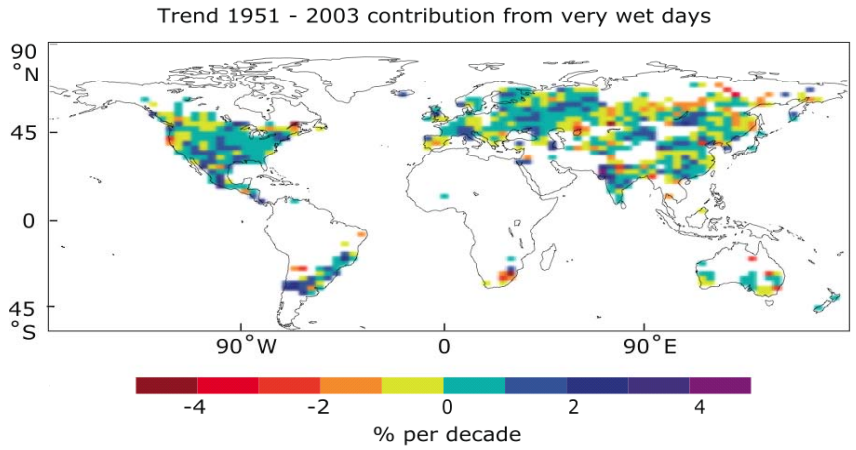


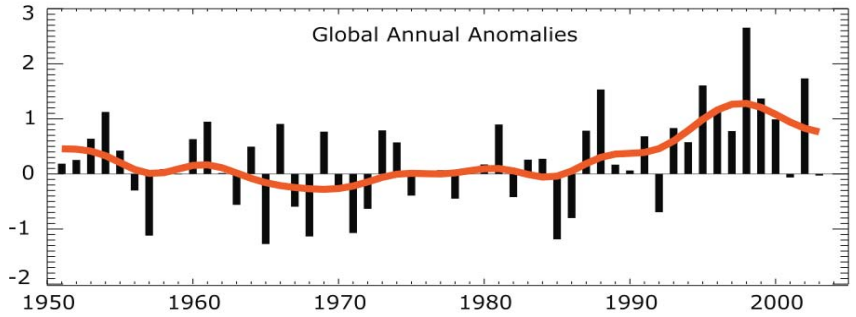
1979-2005 (% per decade)



Changes in heavy precipitation

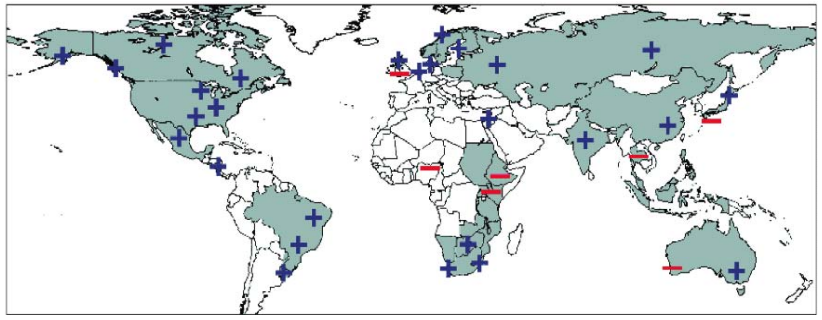
Trend in contribution from very wet days (1951-2003)





Global change in contribution from very wet days (cf. 1961-90 average 22.5%)

Regions showing strong change in proportion (+/-)



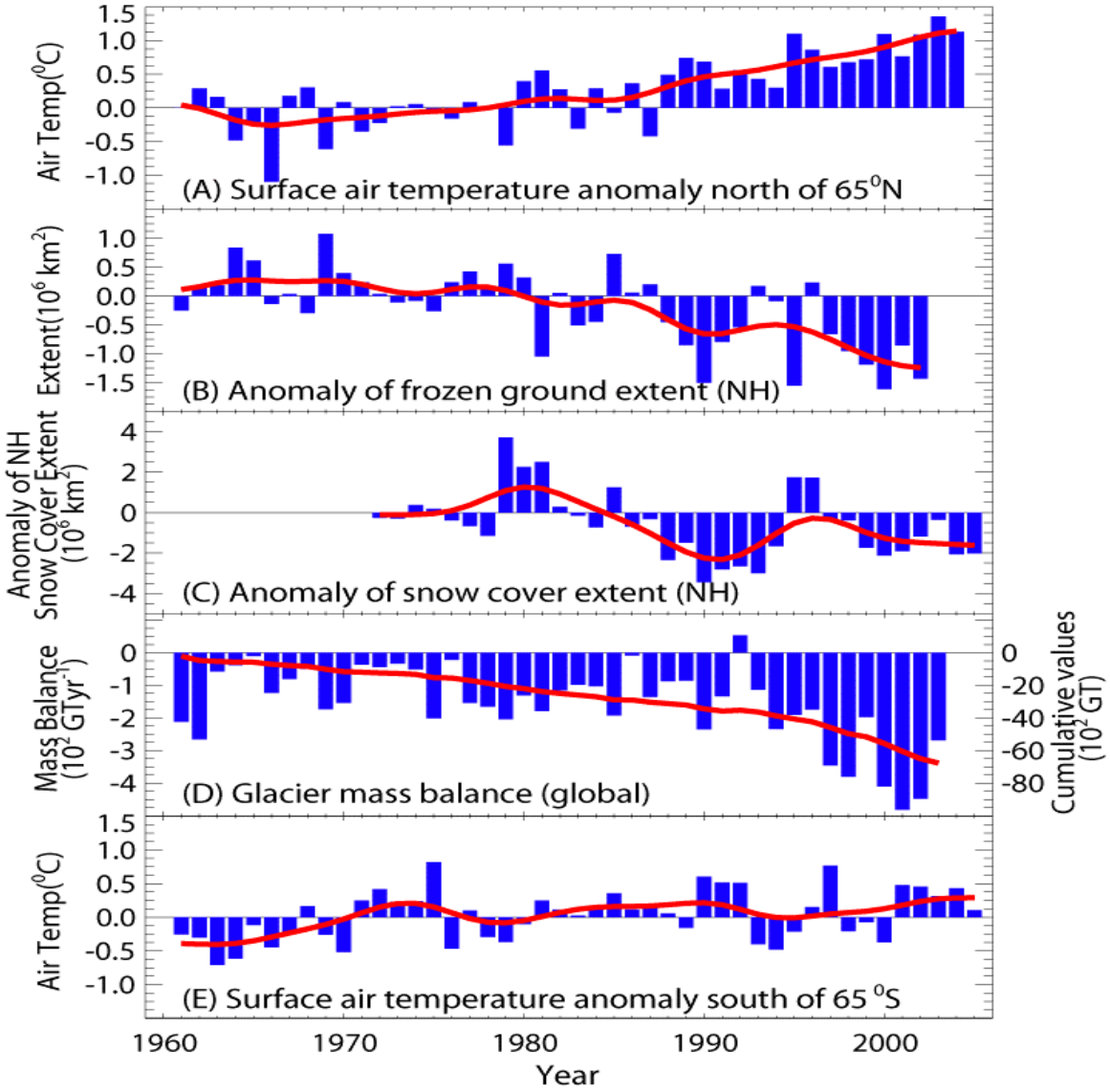
Attribution of observed changes

Several model studies suggest changes in radiative forcing have played a part in observed trends in mean precipitation. But no formal attribution results available at time of AR4.

Increase in heavy precipitation *likely* to have occurred over most land areas over late 20th Century. *More likely than not* includes an anthropogenic contribution.

Total column water vapour increased over oceans from 1988 to 2004. Suggestion of anthropogenic influence but no formal attribution results available at time of AR4.

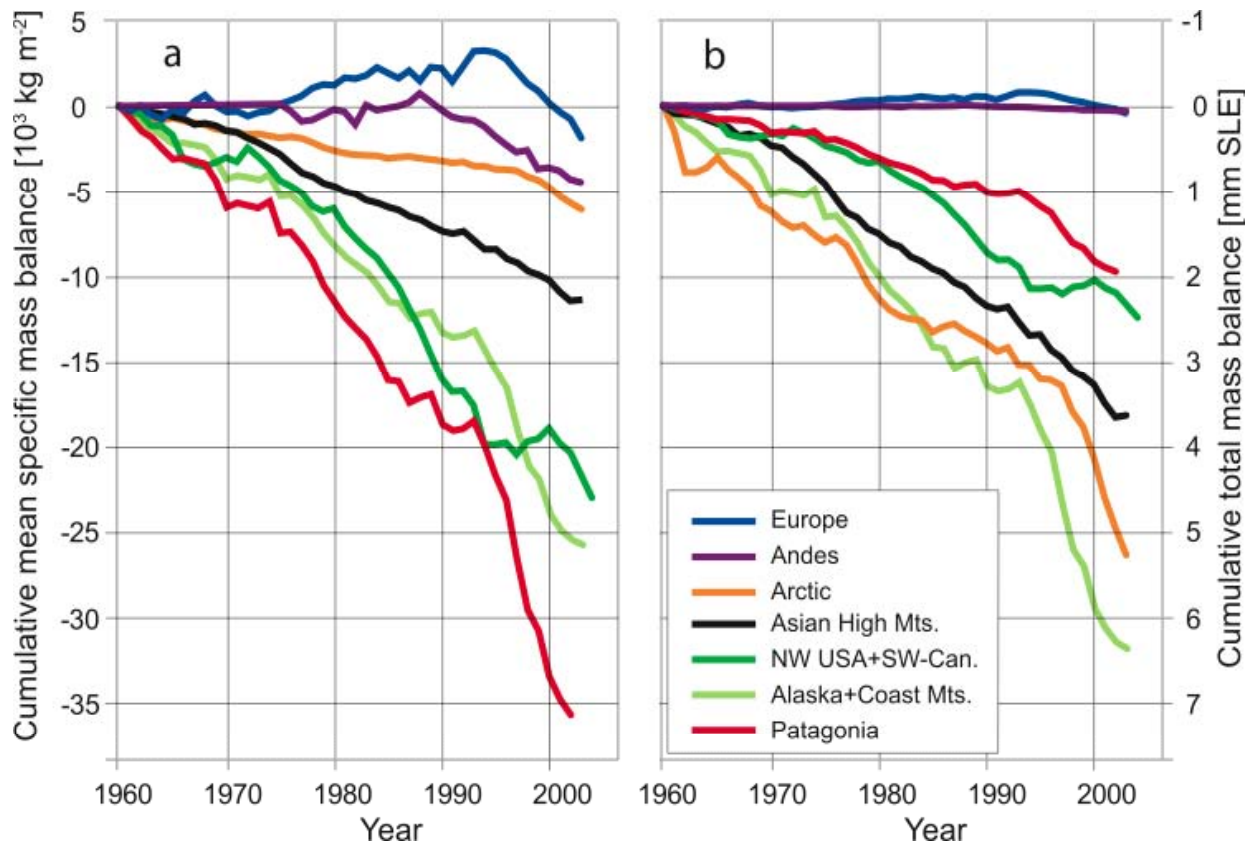
Changes in high-latitude water-related variables



Note also:

River/lake ice shows later freezeup and earlier breakup dates over past 150 years

Changes in glaciers and ice caps



Cumulative specific mass balance

Cumulative total mass balance

Note: thermal expansion and glaciers/ice caps have made larger contributions to recent sea level rise than have Greenland and Antarctic ice sheets

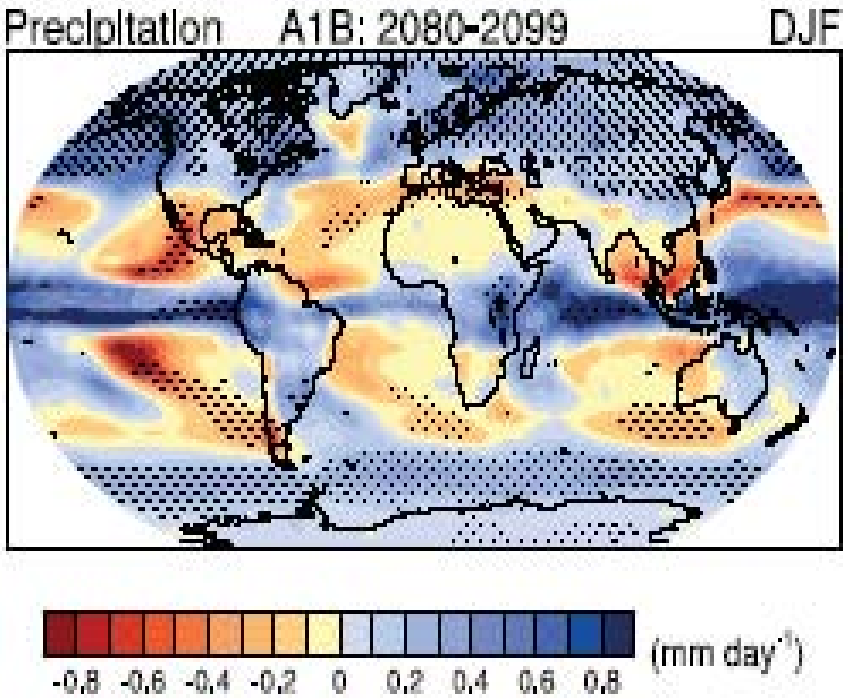
Observed changes in other variables

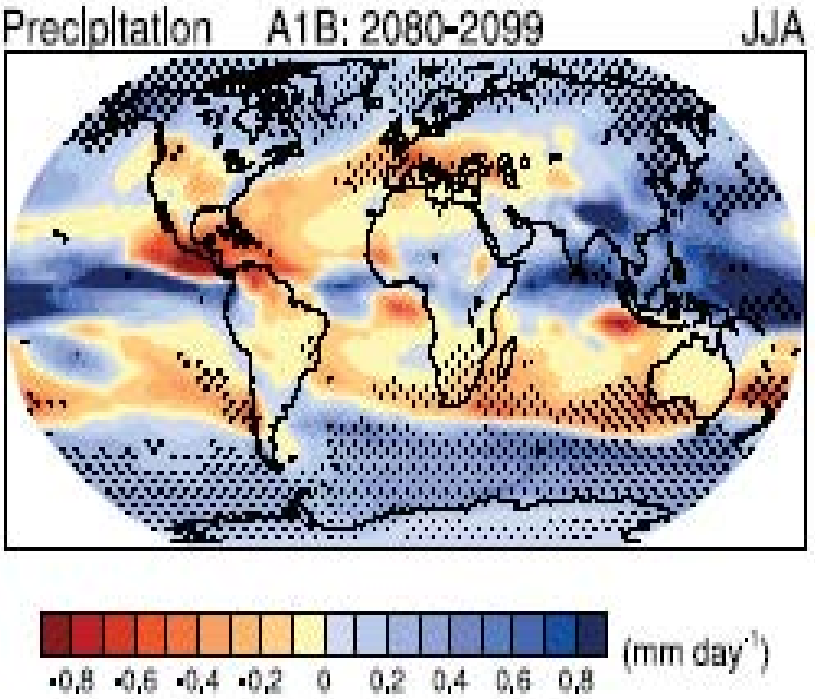
Evapotranspiration: little direct evidence of changes.

Runoff/river discharge: detection of trends difficult. Non-climate factors important. Possible effect of CO_2 enrichment on plant physiology. Changes seen in timing of runoff in snowmelt-fed rivers.

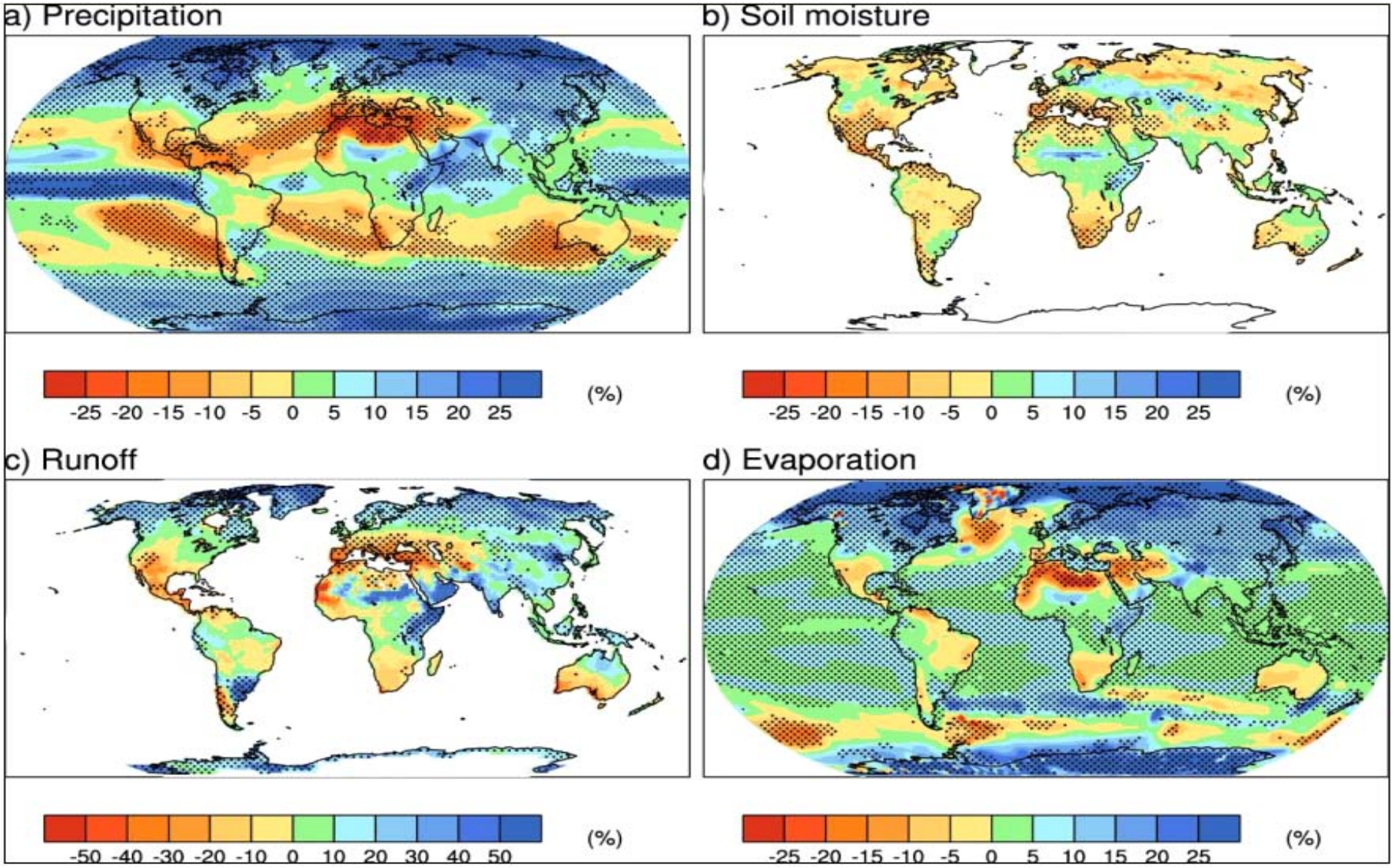
Modes of climate variability (ENSO, NAM, SAM, AMO) influence regional precipitation. Recent trends in NAM and SAM may in part be related to human activity.

Projected changes in precipitation (SRES A1B 2080-99)

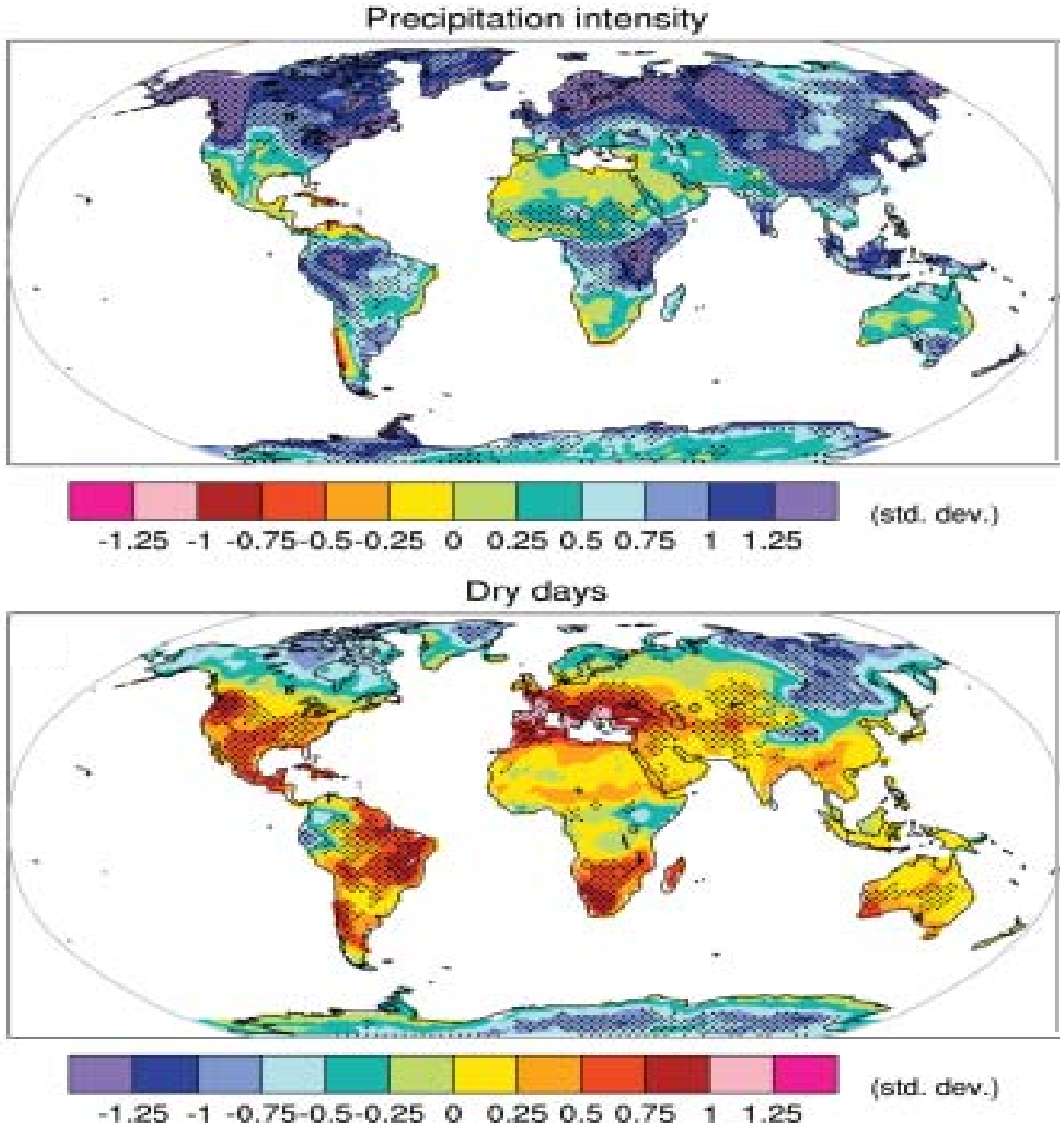




Projected changes in water-related variables (SRES A1B 2080-99)



Projected changes in precipitation extremes



Projected changes in other variables

Contraction of snow cover

Loss of mass in glaciers/ice caps

- **May be irreversible in some regions**

Increase in permafrost thaw depth

- **Seasonal thaw depth *likely* to decrease by 30-50% by 2080**
- **Permafrost area *likely* to decrease by 20-35% by mid-21st century**

Evapotranspiration

- **Competing effects of CO_2 increase on vegetation**

Changed seasonality of runoff in snow-fed regions

- **Especially at lower elevations**

Changed patterns of variability

- **Mid-latitude storm tracks move poleward**
- **More intense tropical cyclones (*likely*)**
- **No definitive projection for changes in ENSO variability**

Uncertainty in hydrological projections

Arises from several sources:

- Internal climate variability
- Emissions uncertainty
- Climate model uncertainty
- Simplification of processes, e.g. vegetation feedbacks, aerosols
- Downscaling and hydrological model uncertainty (few studies)

Some robust results, especially at larger spatial scales

- Climate model projections less consistent at smaller scales
- By late 21st Century, differences between climate models are a larger source of uncertainty than internal variability (A1B scenario)

Formal 'end-to-end' probabilistic assessments rare

Some developments since AR4 (NOT assessed by IPCC)

Attribution of zonal mean precipitation changes

Zhang et al, Nature, 2007

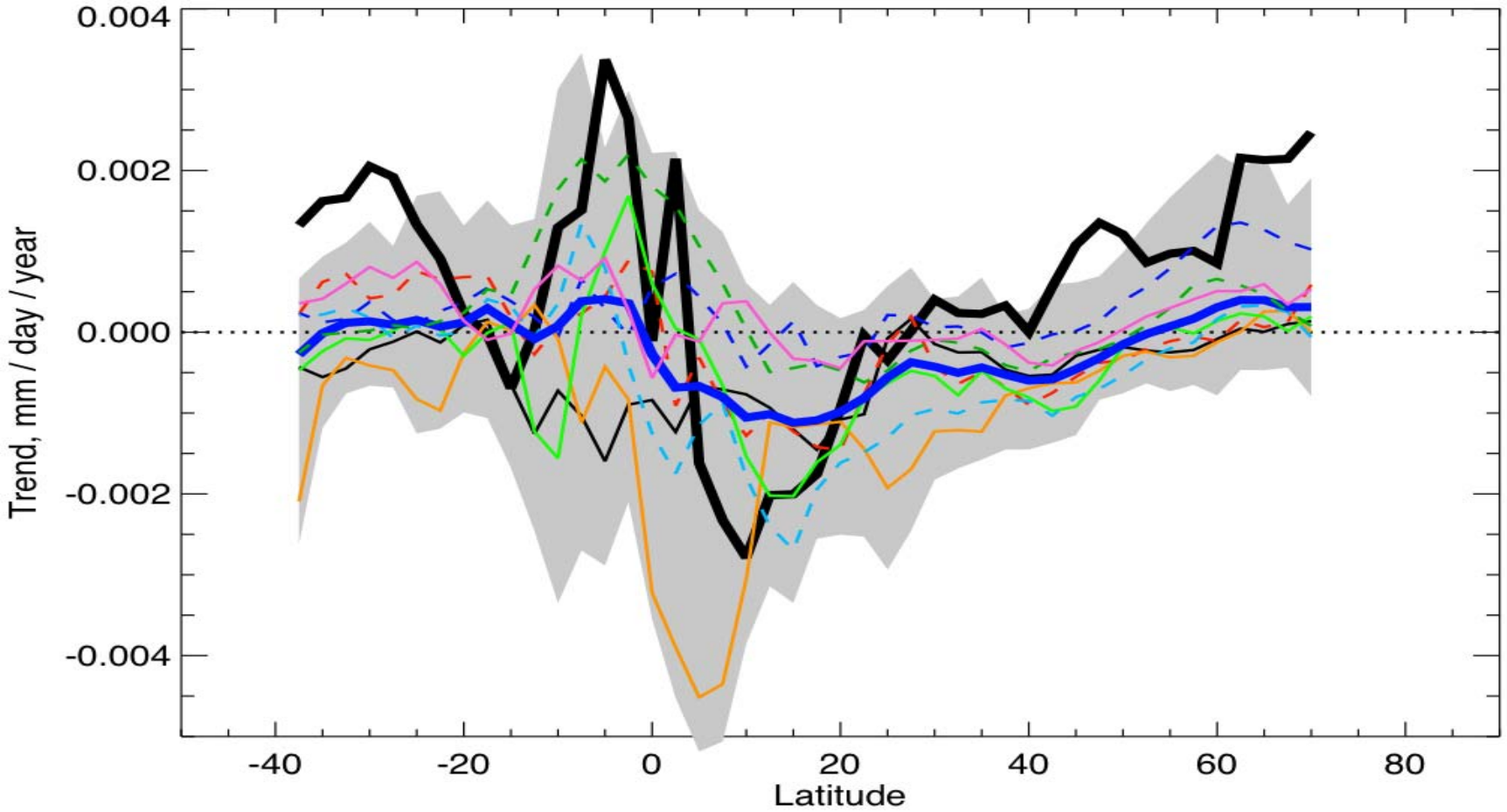
Attribution of atmospheric moisture changes

Santer et al, PNAS, 2007; Willet et al, Nature, 2007

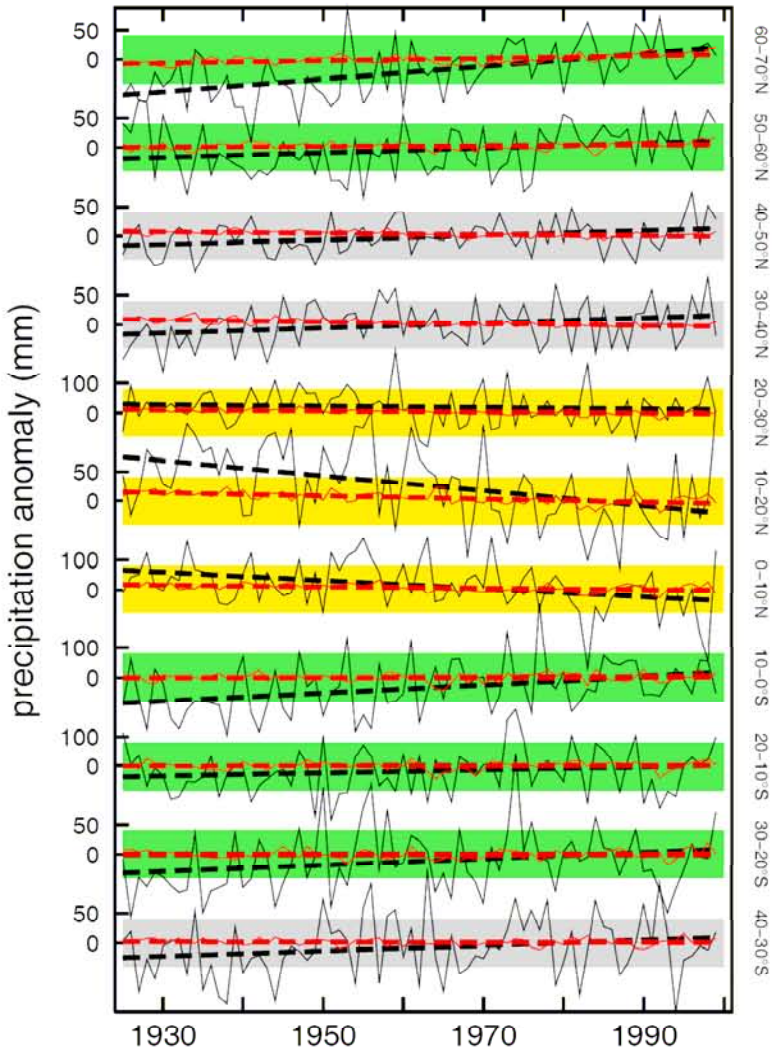
Attribution of ocean warming in hurricane formation regions

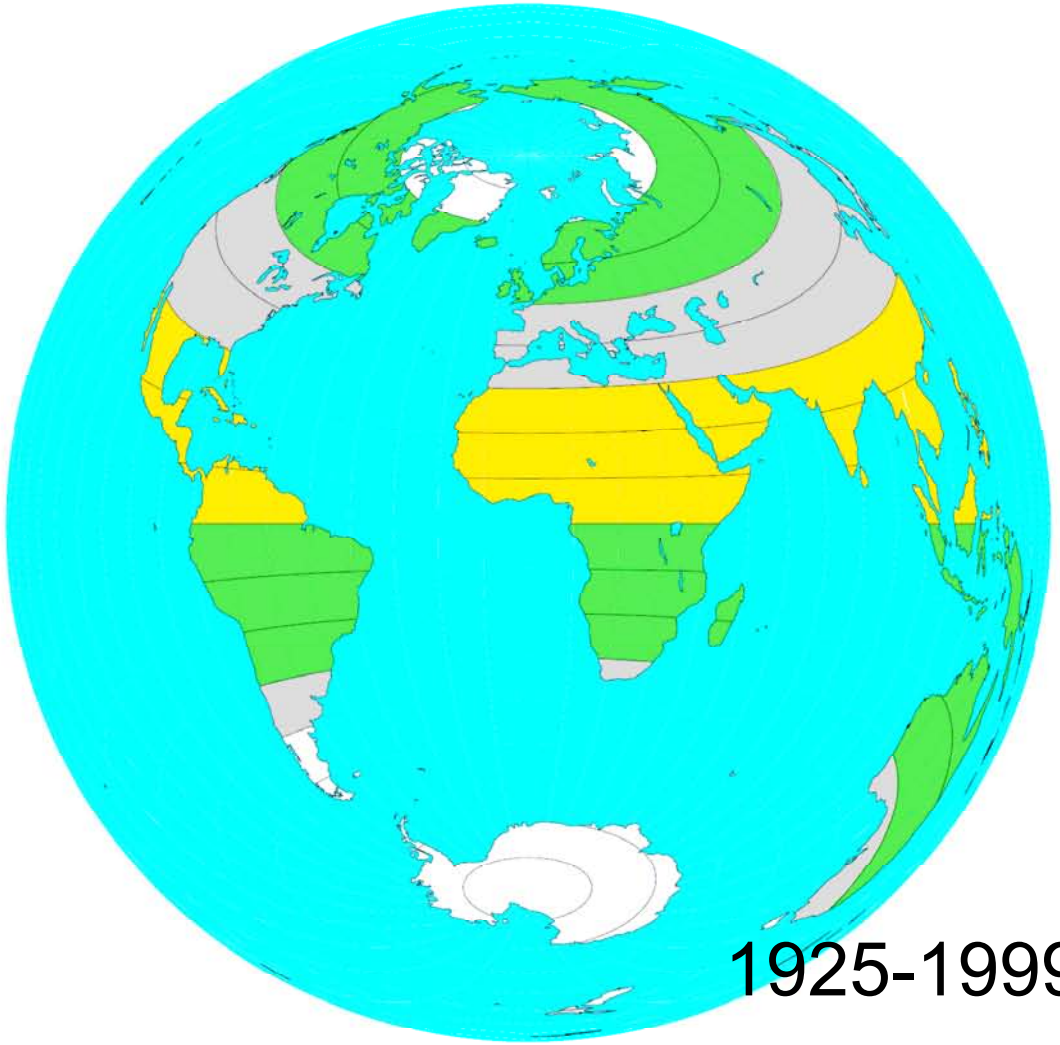
Santer et al, PNAS, 2006; Gillett et al, GRL, 2008

Zonal mean changes in precipitation



Detection of human influence on zonal mean precipitation changes.
Zhang et al, Nature, 2007

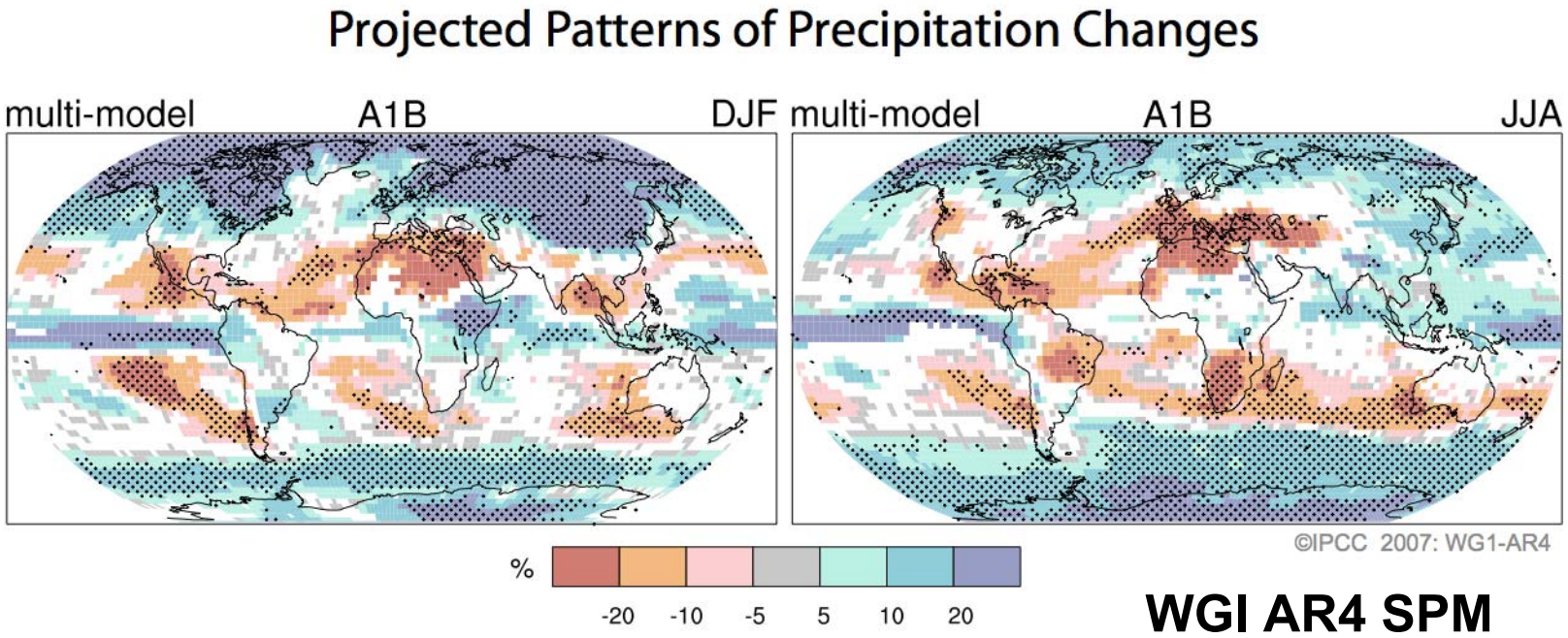




1925-1999

Global Historical Climatology Network

Global patterns of observed change in land precipitation attributable to anthropogenic forcing are broadly consistent with projected changes in precipitation in future

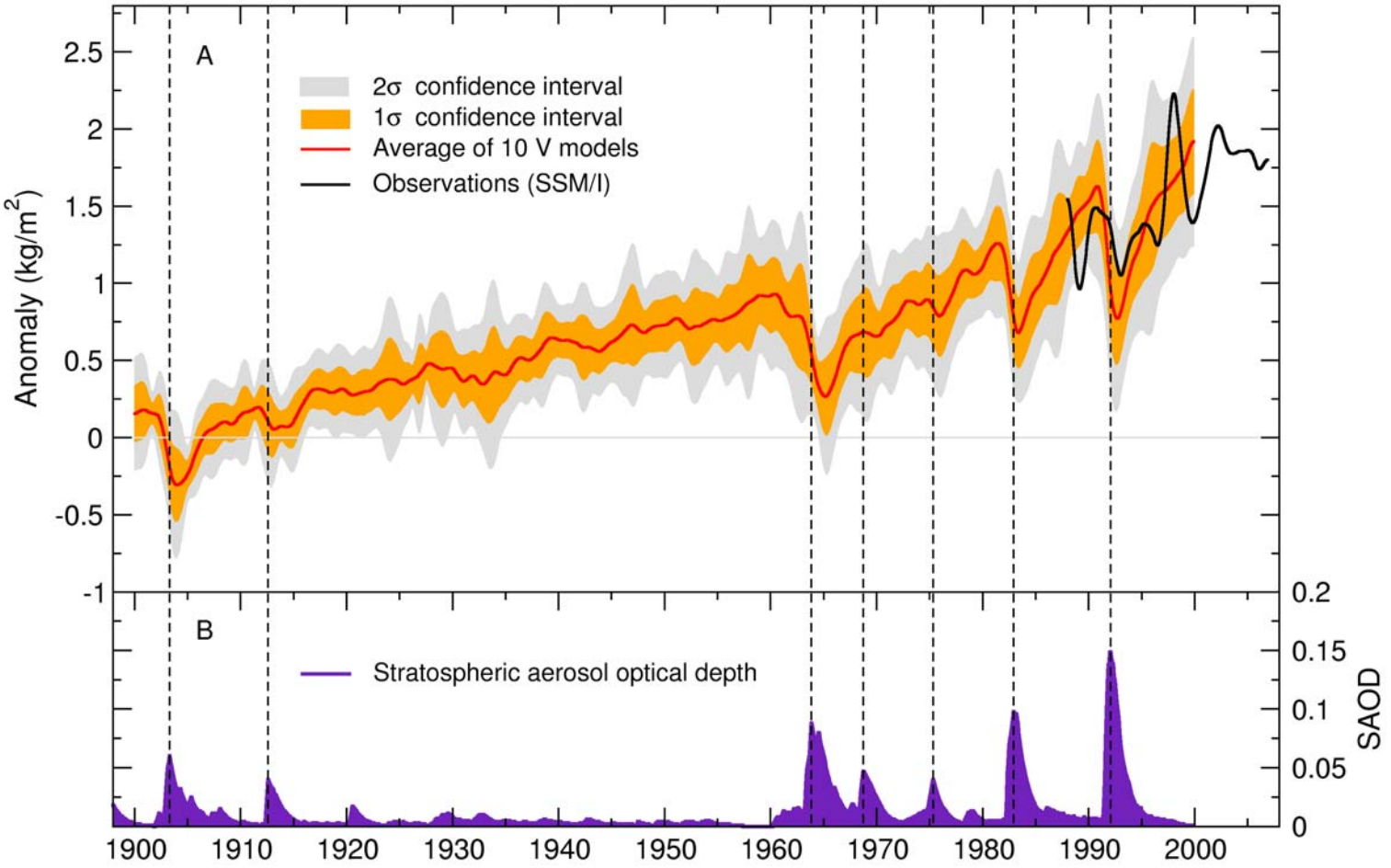


WGI AR4 SPM

Drying of the sub-tropics and increases at high latitudes and near the equator.

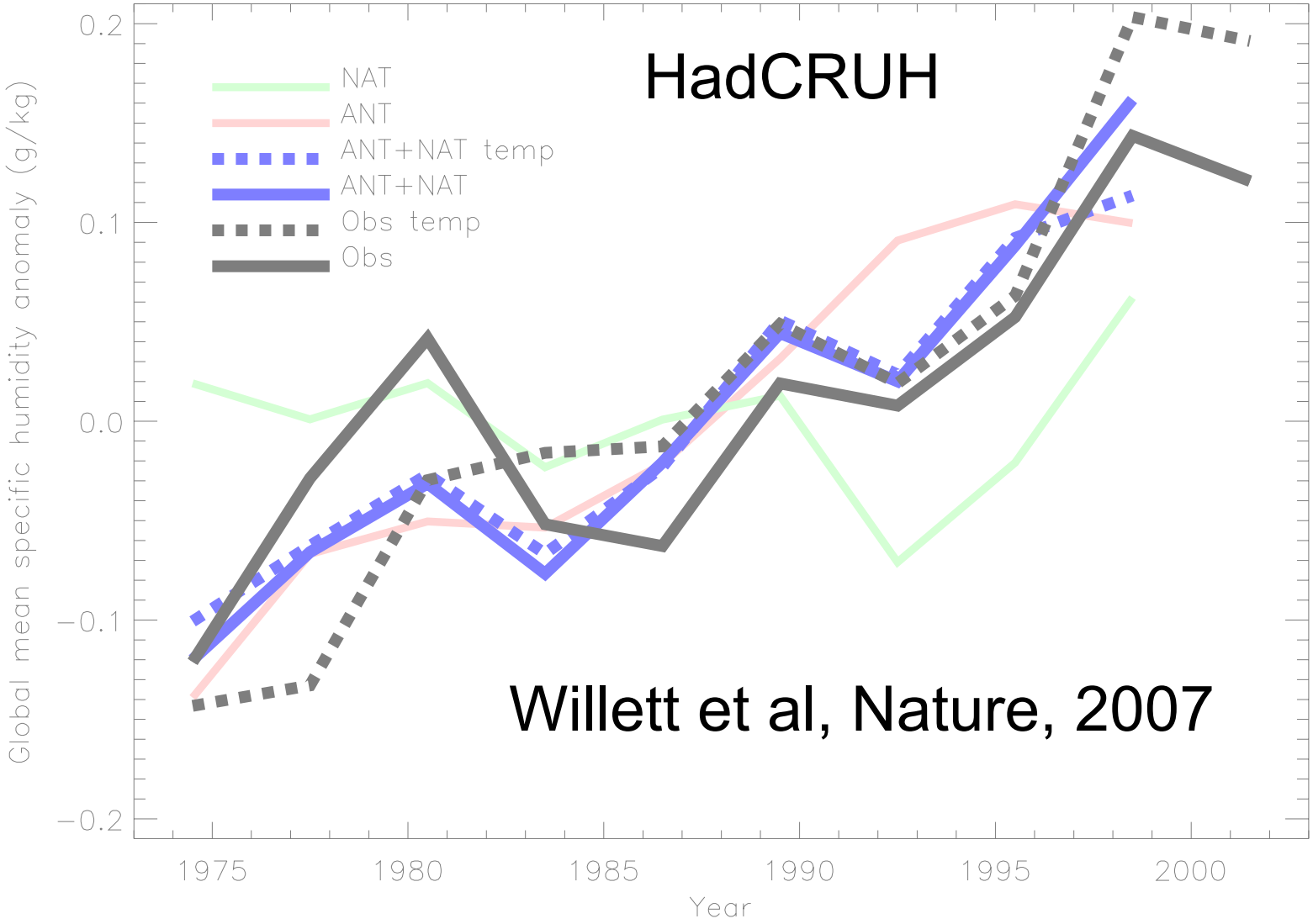
Identification of human-induced changes in atmospheric moisture content

SSM/I atmospheric moisture retrievals over oceans, 1988-2006



Santer et al, PNAS, 104, 15248-15253, 2007

Attribution of observed surface humidity changes to human influence



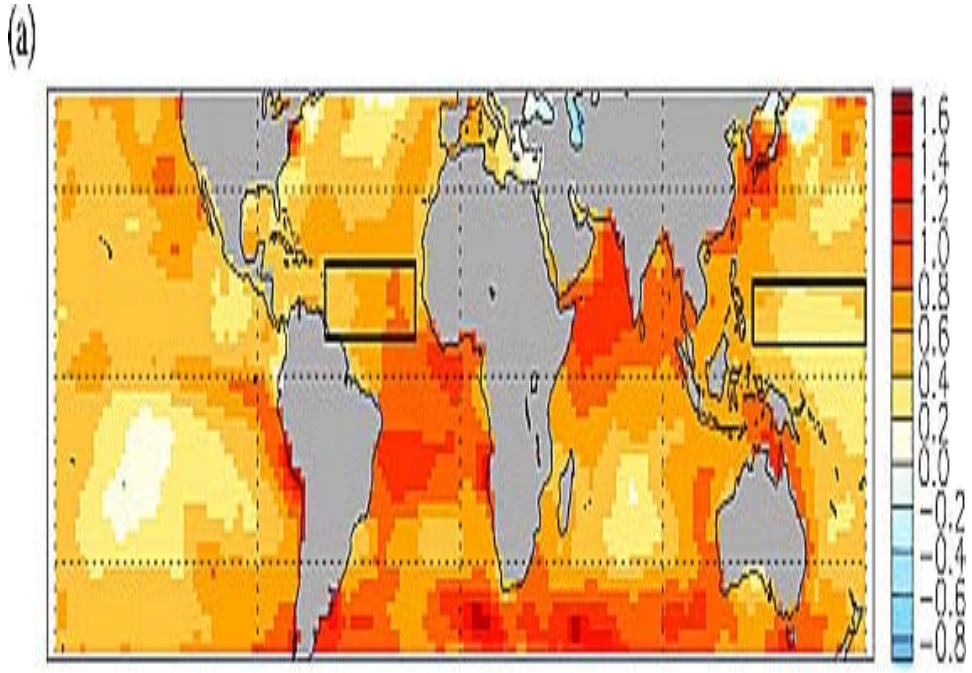
Detection of atmospheric moisture change

- Moistening trend apparent in simulated and observed global mean surface specific humidity, largest in tropics.
- Anthropogenic influence is also detectable in total column water vapour.
- Increases are consistent with warming under conditions of constant relative humidity.
- This is important because climate models have long predicted that relative humidity would remain approximately constant
  - leading to a water vapour feedback and higher climate sensitivity
  - leading to a greater increase in extreme precipitation than the mean
- Now observations have shown that this is indeed happening as climate warms.

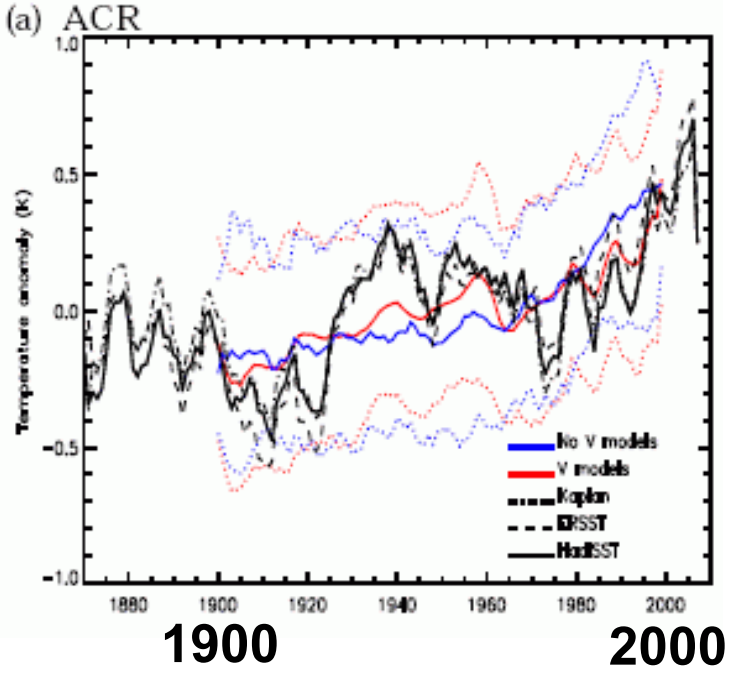
Intense tropical cyclone activity

- Observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures.
- Anthropogenic factors have *more likely than not* contributed to observed increases in intense tropical cyclone activity.

Greenhouse gases are probably the main cause of ocean temperature increases in hurricane formation regions



Atlantic hurricane formation region



1900 2000

Santer et al., PNAS (2006); Gillett et al, GRL (2008)

Intense tropical cyclone activity

- Observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures.
- Anthropogenic factors have *more likely than not* contributed to observed increases in intense tropical cyclone activity.
- Formal attribution studies since the AR4 show that greenhouse gases probably the main cause of ocean temperature increases in hurricane formation regions

Attribution of observed changes in mean precipitation and atmospheric moisture content

Several model studies suggest changes in radiative forcing have played a part in observed trends in mean precipitation. Since AR4, a formal attribution result has shown a detectable human influence on precipitation changes within latitude bands.

Total column water vapour increased over oceans from 1988 to 2004. Since AR4, formal attribution studies have shown a detectable human influence on the atmospheric moisture content of the atmosphere.

These attribution studies show that a physically consistent picture is emerging as the world warms and increases confidence in model projections of the global patterns of mean precipitation changes and of increases in frequency of heavy precipitation events.