# 3. Climate Change

## 3.1 Observations

## 3.2 Theory of Climate Change

## 3.3 Climate Change Prediction

## 3.4 The IPCC Process

## 3.1 Observations

Need to consider:

- Instrumental climate record of the last century or so
- Recent changes in greenhouse gases and other quantities



**Acknowledgement: Steve Arnold (University of Leeds, UK)**

## Important Questions Concerning the Climate Record

- How much is the world warming?
- Is the recent warming unusual?
- How rapidly is climate changing compared to earlier changes?
- Have precipitation and atmospheric moisture changed?
- Are atmospheric/oceanic circulations changing?
- Has climate variability (e.g., extremes) changed?

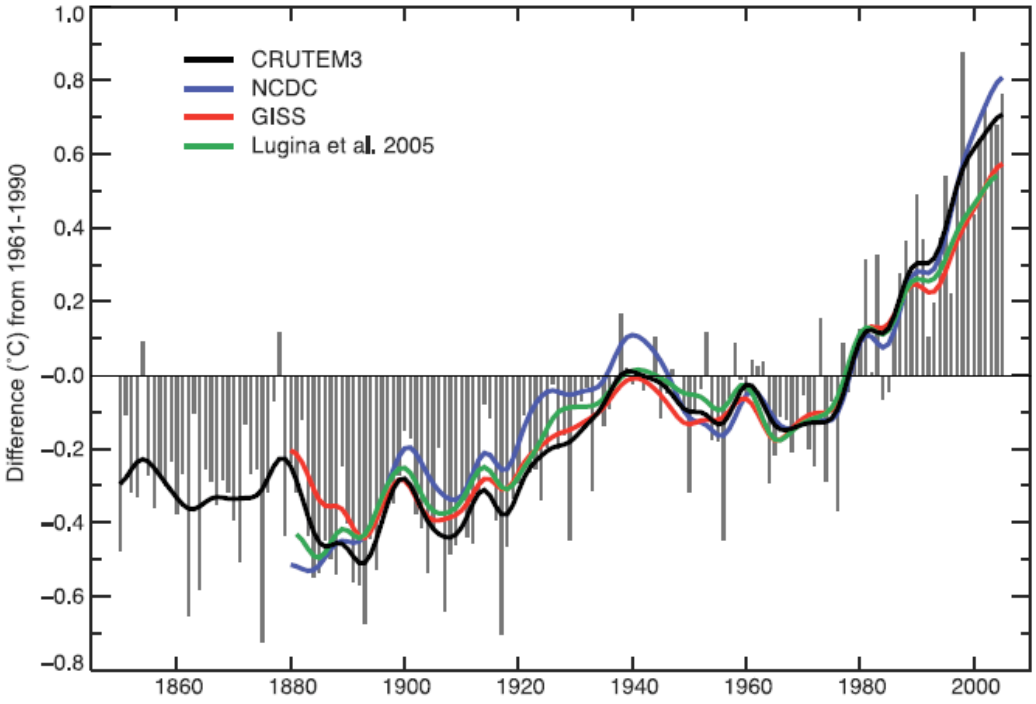
## Observed Climate Variables

- Temperature (global mean, regional, diurnal range, upper air...)
- Precipitation, humidity, cloud cover
- Snow cover
- Sea-ice thickness and extent
- Natural modes (El Nino, North Atlantic Oscillation, Atlantic Multidecadal Oscillation)
- Climate extremes

## Use of ‘Anomalies’

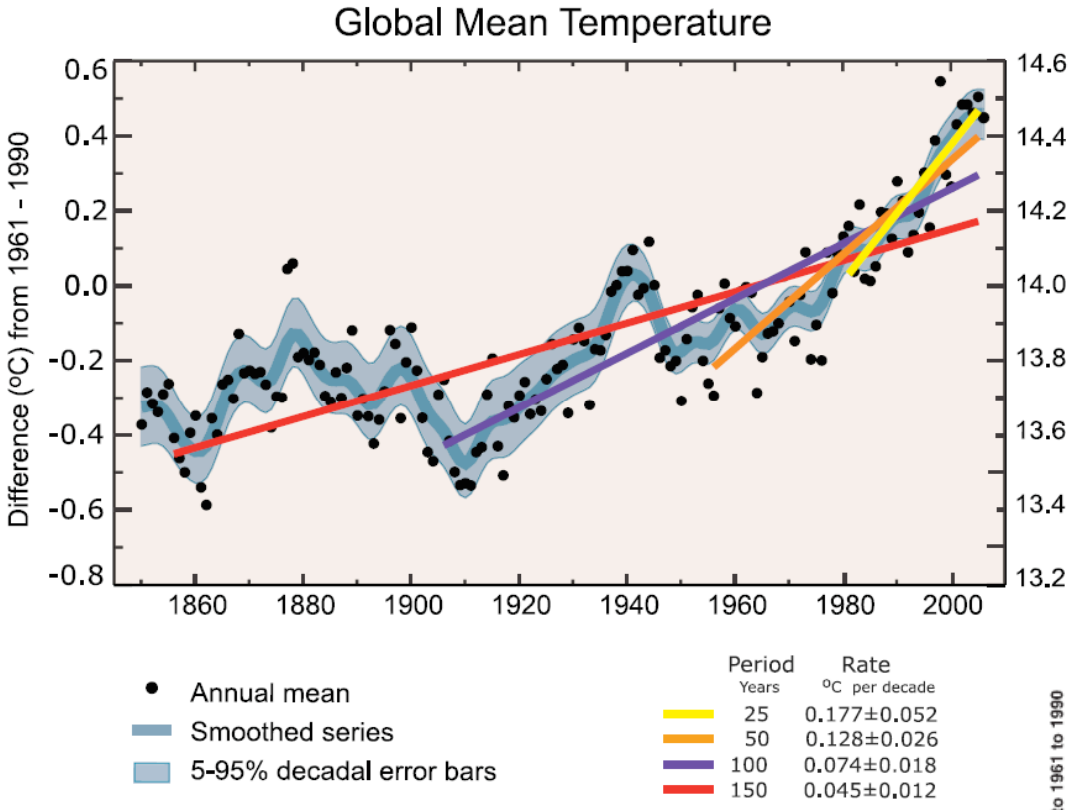
- Anomalies are changes relative to some particular reference period used to emphasise positive and negative excursions around a long-term mean

# Global Mean Land-Surface Temperatures

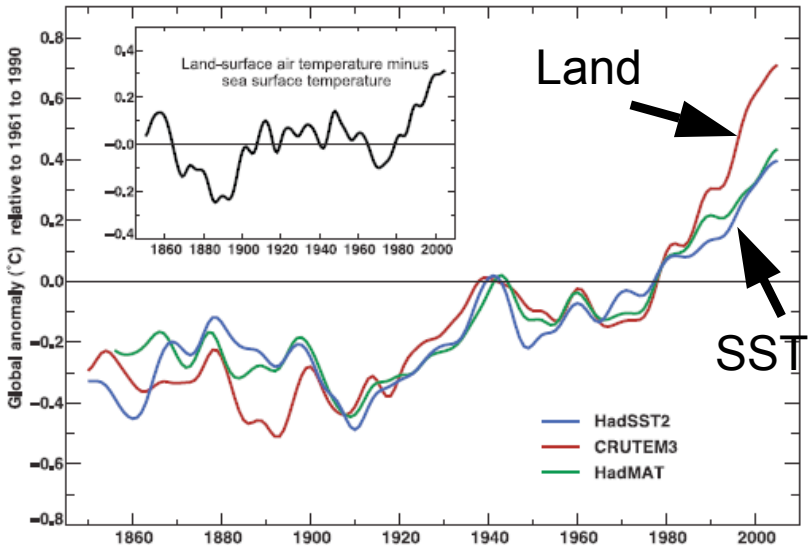



- Temperature anomalies (difference from 1961-1990 mean)
- Surface temperature trend ~0.05$^{O}$C / decade since 1850.
- Urban “heat island” effect is negligible (~0.006$^{O}$C / decade)
- Differences between compilations arise from weighting of observation density

# Global Mean Land-surface and Sea Surface Temperatures

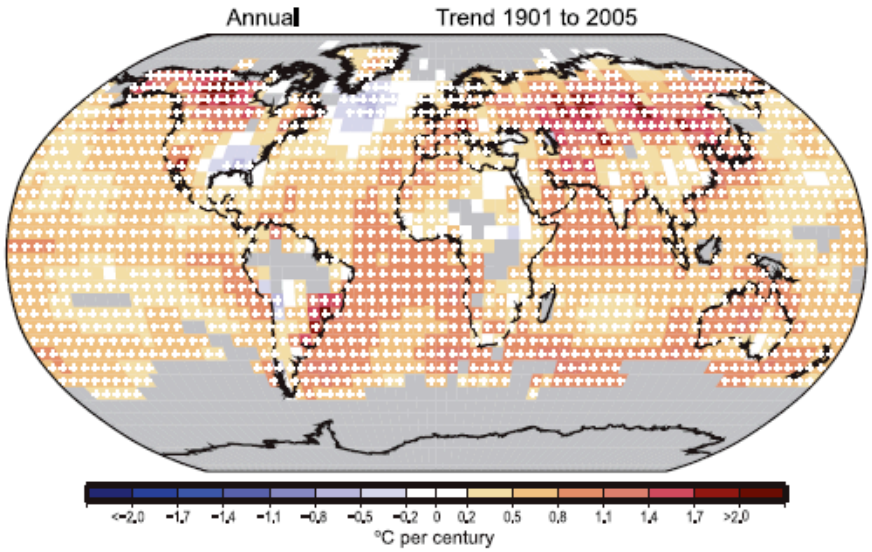



- Recent land warming dominated by NH continents
- Ocean warming slower
- 20th-century T Change ~0.7±0.2 °C
  - Compare 0.45 °C estimated by IPCC in 1995.

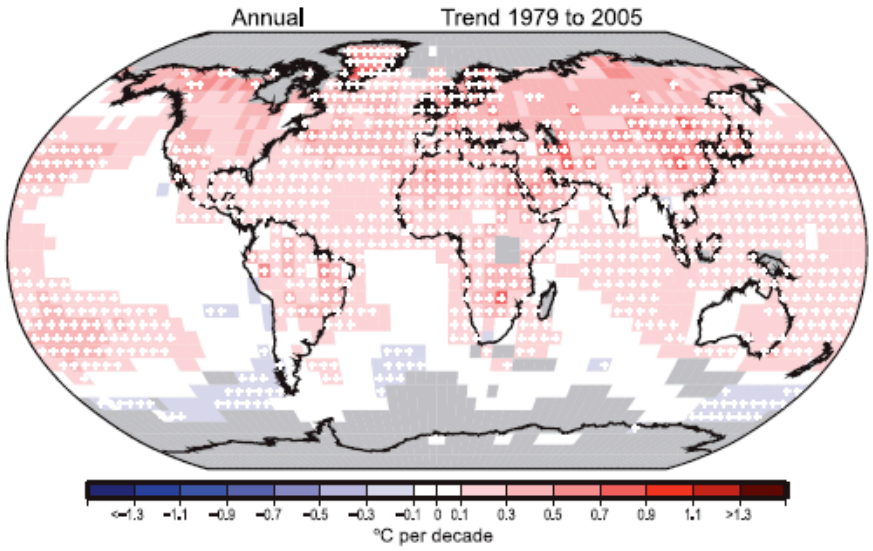


# Spatial Pattern of Surface Temperature Changes

## 1901-2005




## 1975-2005




Grey areas: not enough data

White crosses: significant trend

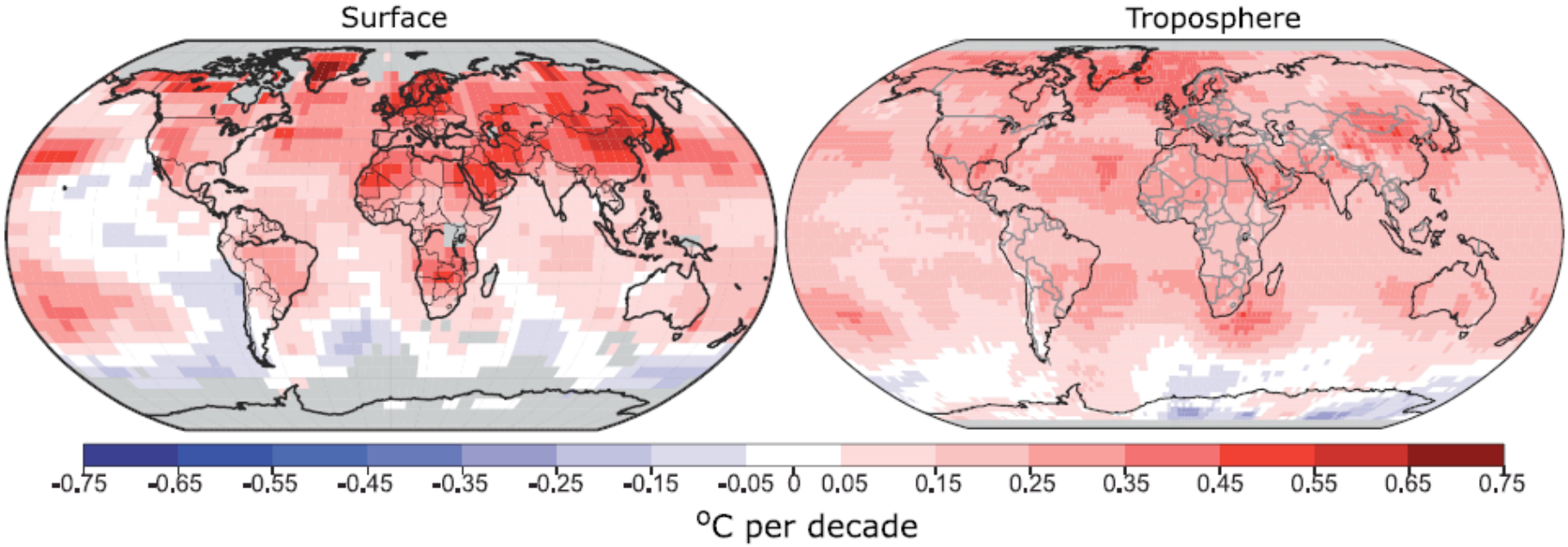
## Summary of Surface Temperature Changes

- In the 20th century there has been a consistent large-scale warming of the land and ocean surface.
- Rate of warming appears to be accelerating
- Some regional details can be explained by atmospheric circulation changes

## Upper Air Temperatures

- Weather balloons (radiosondes)
  - T at discrete levels
  - Difficulties with changes in instruments
- Satellite (Microwave Sounding Unit – MSU and stratospheric Sounding Unit - SSU) since 1979
  - T over broad regions
  - Problems with orbit drift, calibration, etc. -> spurious T trends

# Upper Air Temperatures




- Stratosphere cooling at > 0.5 °C/decade
- Volcanic eruptions cool troposphere and heat stratosphere
- Troposphere up to ~10km has warmed at slightly faster rate than surface since 1950s.
- Stratosphere cooled markedly since 1979.

## Changes in the Cryosphere

- Snow cover
- Sea-ice extent
- Mountain glaciers

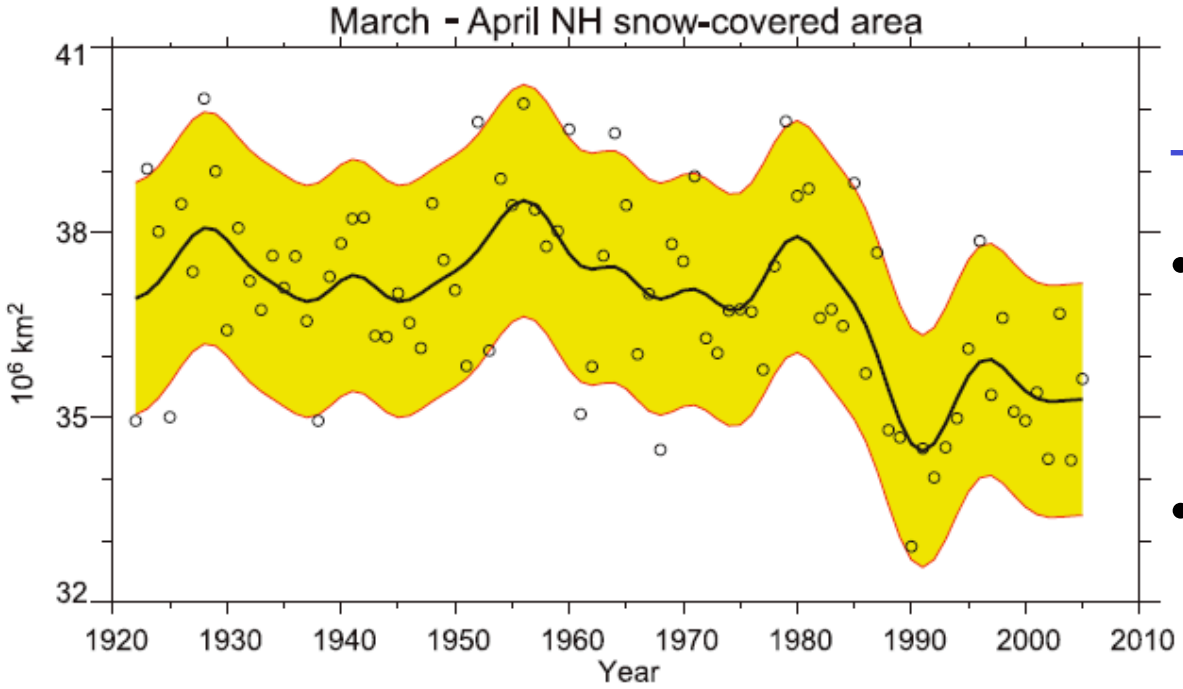
- Average Arctic temperatures have increased at almost twice the global average rate in past 100 years.

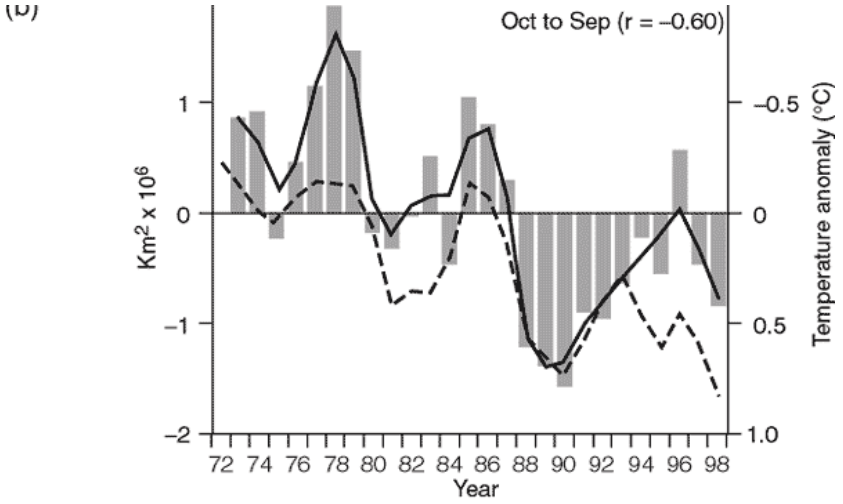
WMO International Polar Year 2007-2008

INTERNATIONAL 2007 2008 POLAR YEAR

www.ipy.org

# Observed Northern Hemisphere Snow Cover




TOP

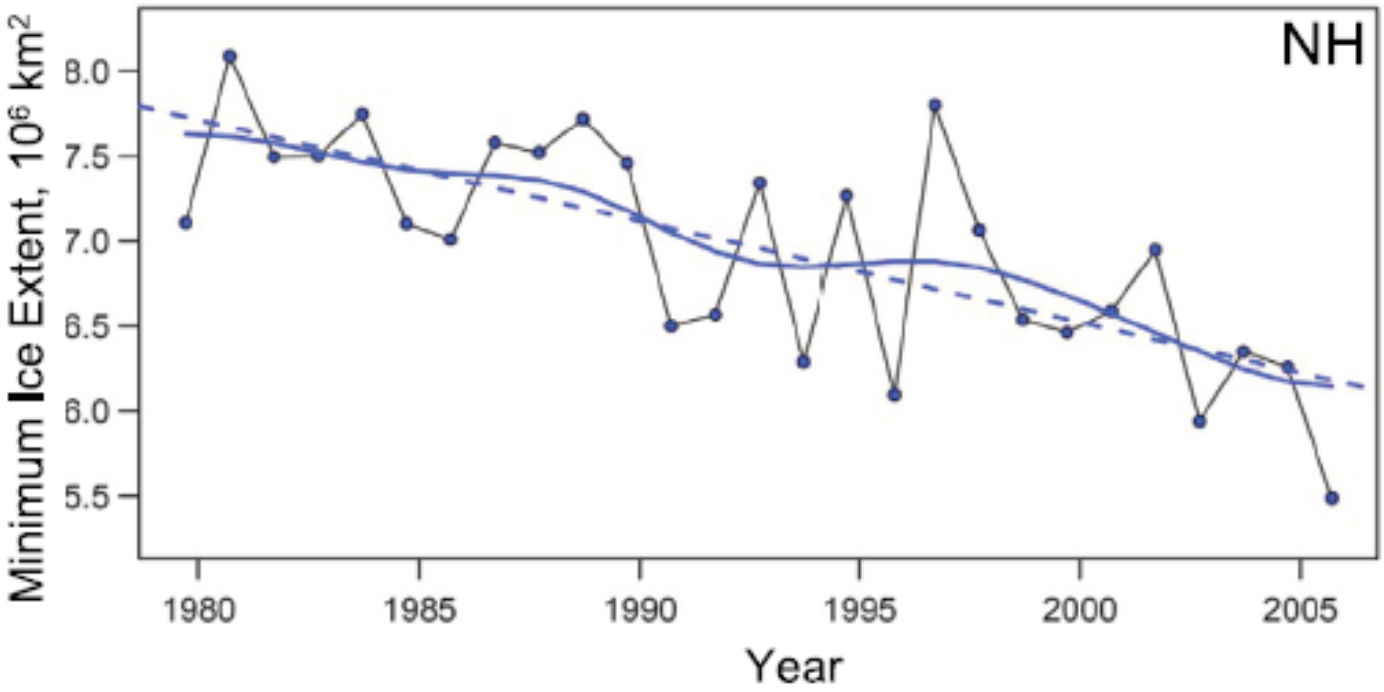
- Annual snow-cover extent decreased by 10% since 1966
- Mostly accounted for by spring/summer since 1980s

BOTTOM

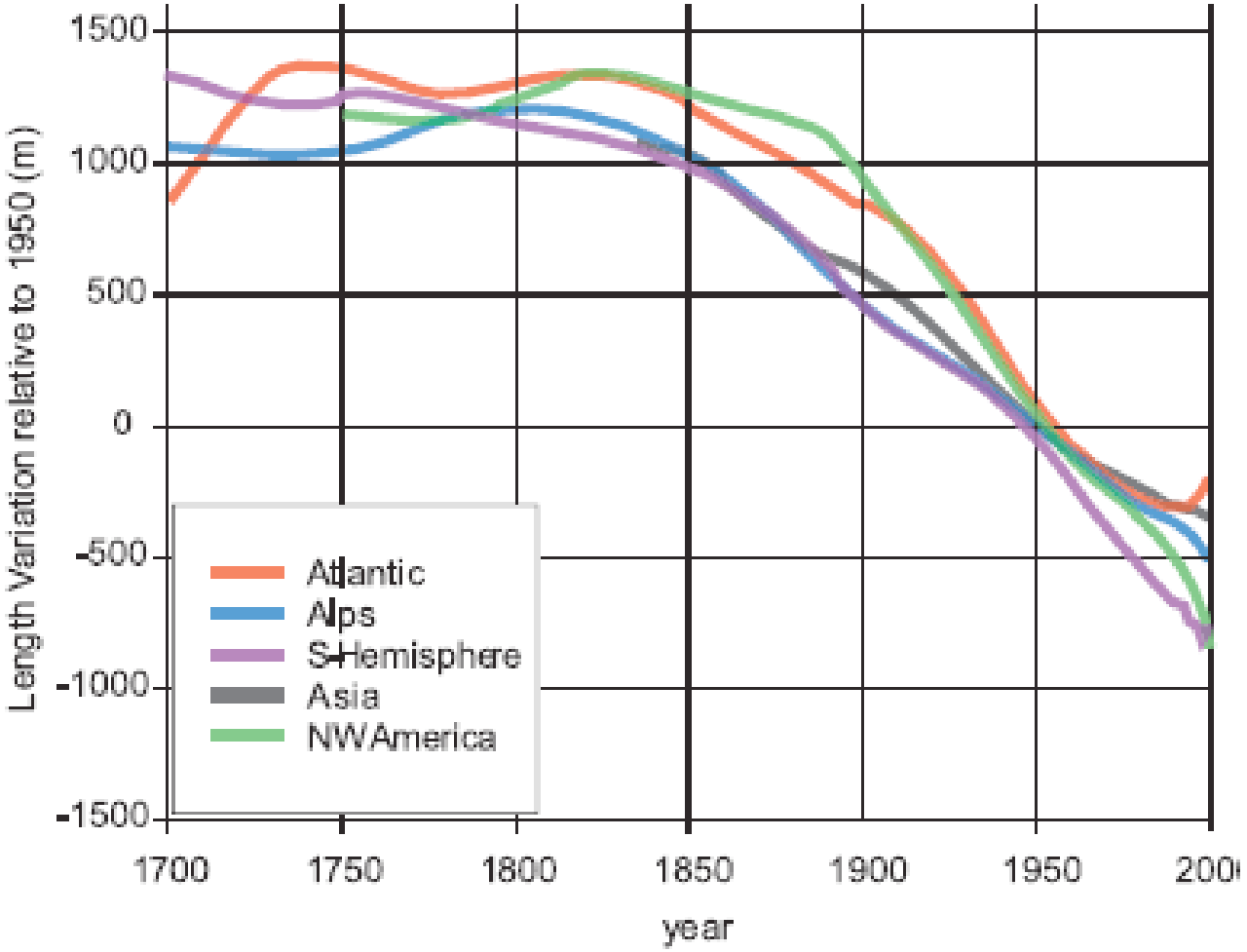
- Annual snow cover anomalies correlate with T (dashed line)

# Observed Northern Hemisphere Sea-Ice Extent

## Summer minimum Arctic sea ice extent



# Observed Mountain Glacier Length

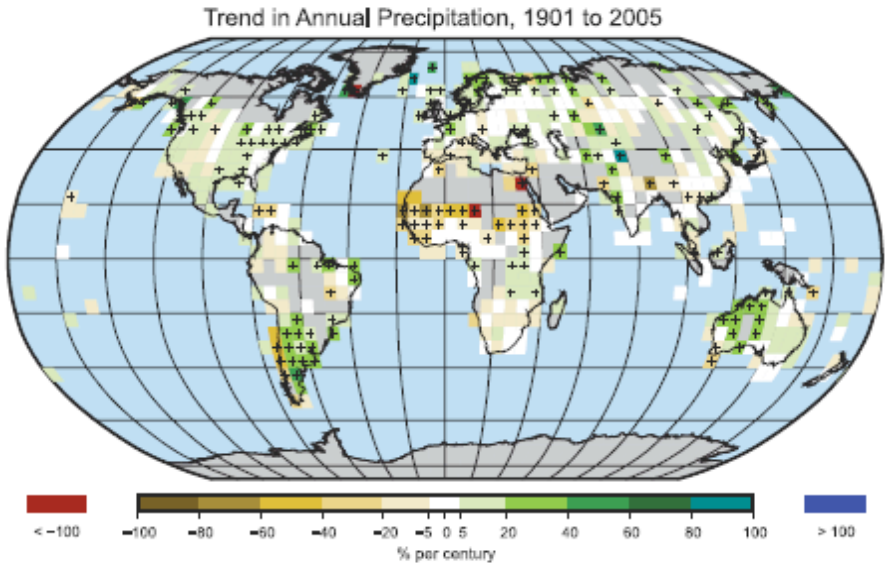


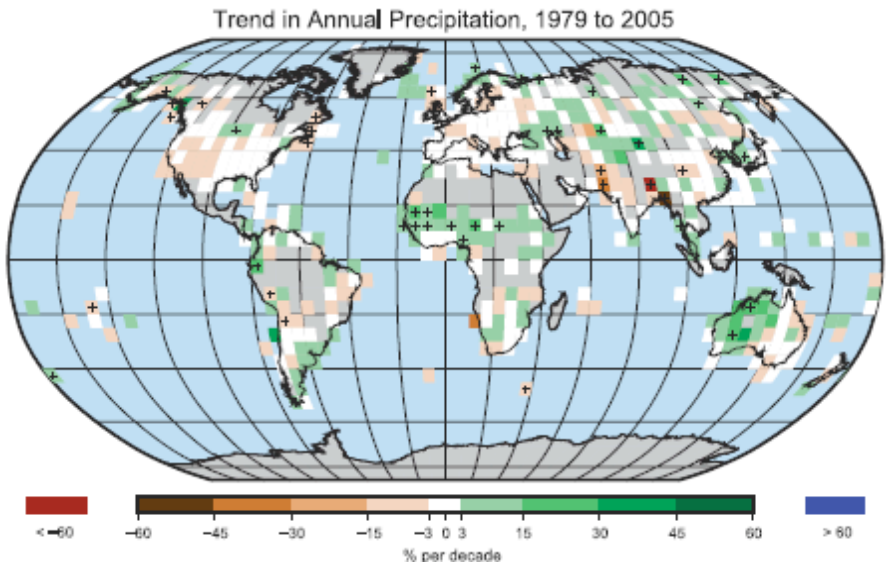

- 169 glacier length records
- Glacier retreat is worldwide

## Summary of Observed Cryospheric Changes

- Consistency of cryospheric changes and temperature changes
- NH snow cover correlates well with spring temperature changes
- Reduced sea-ice extent consistent with increases in spring temperatures
- Small changes in Arctic winter ice, despite large changes in winter T
- Major retreat of glaciers consistent with 20$^{th}$-century T changes

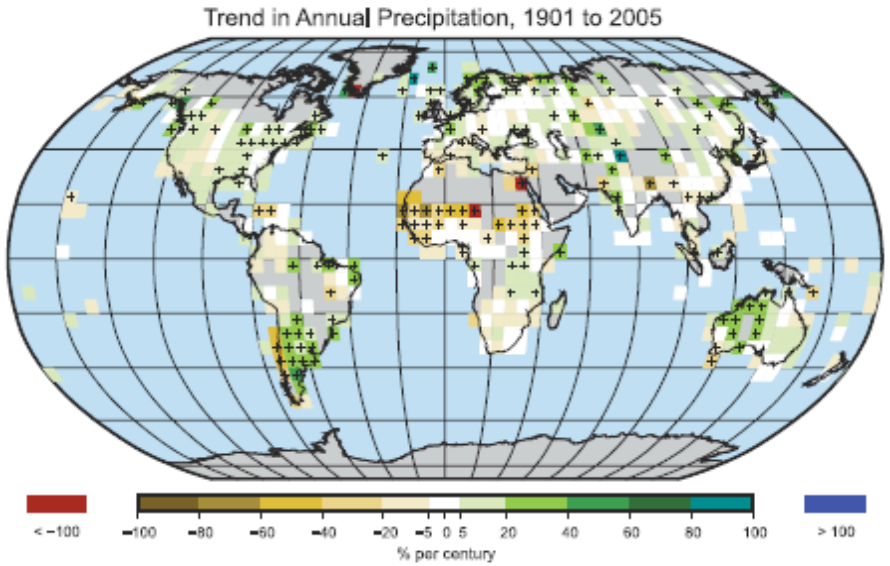
# Precipitation

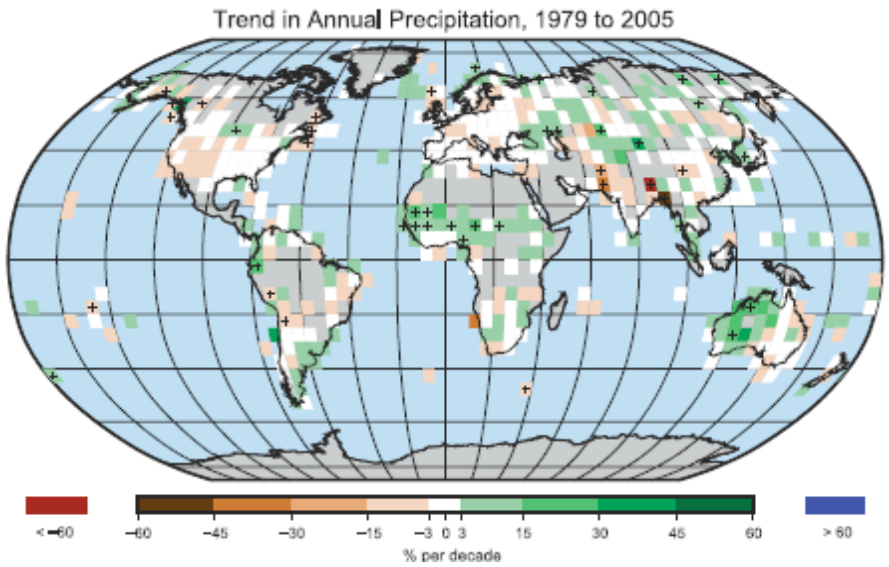



- Wetter: East North and South America, Eurasia
- Drier: Sahel, S Africa, Mediterranean, S Asia
- More rain, less snow in northern regions
- Increased frequency of heavy precipitation

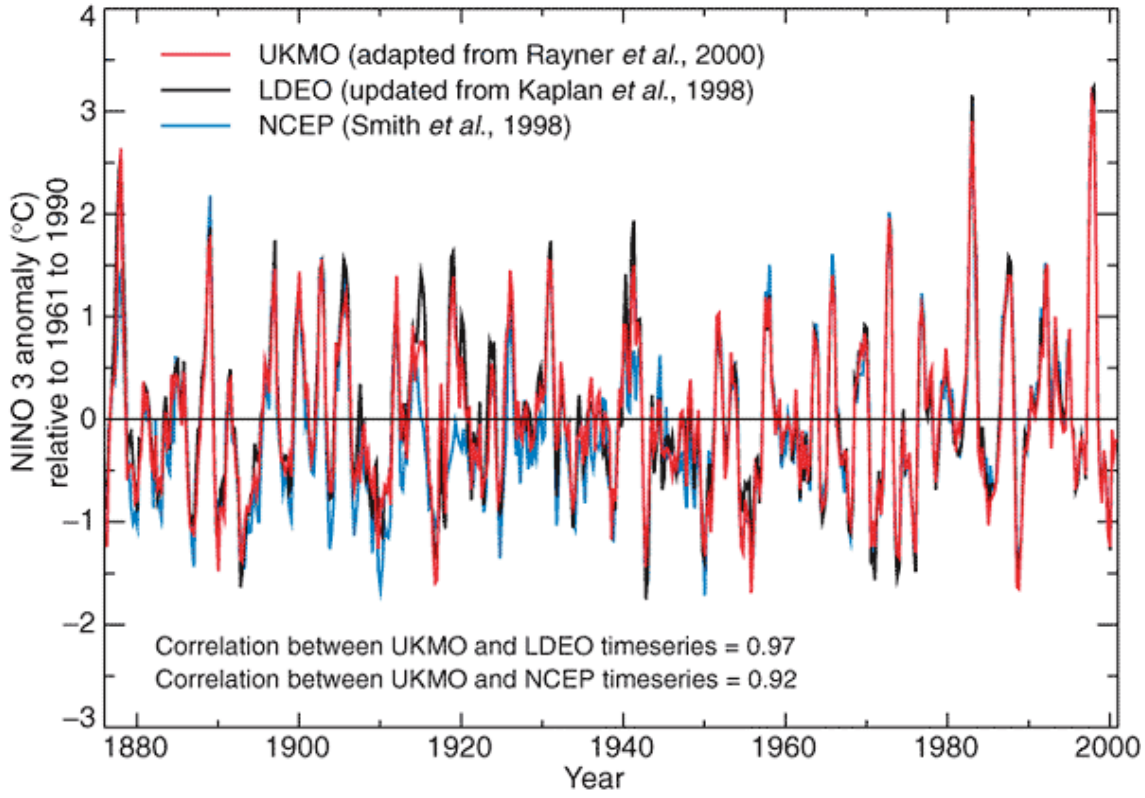
# Precipitation



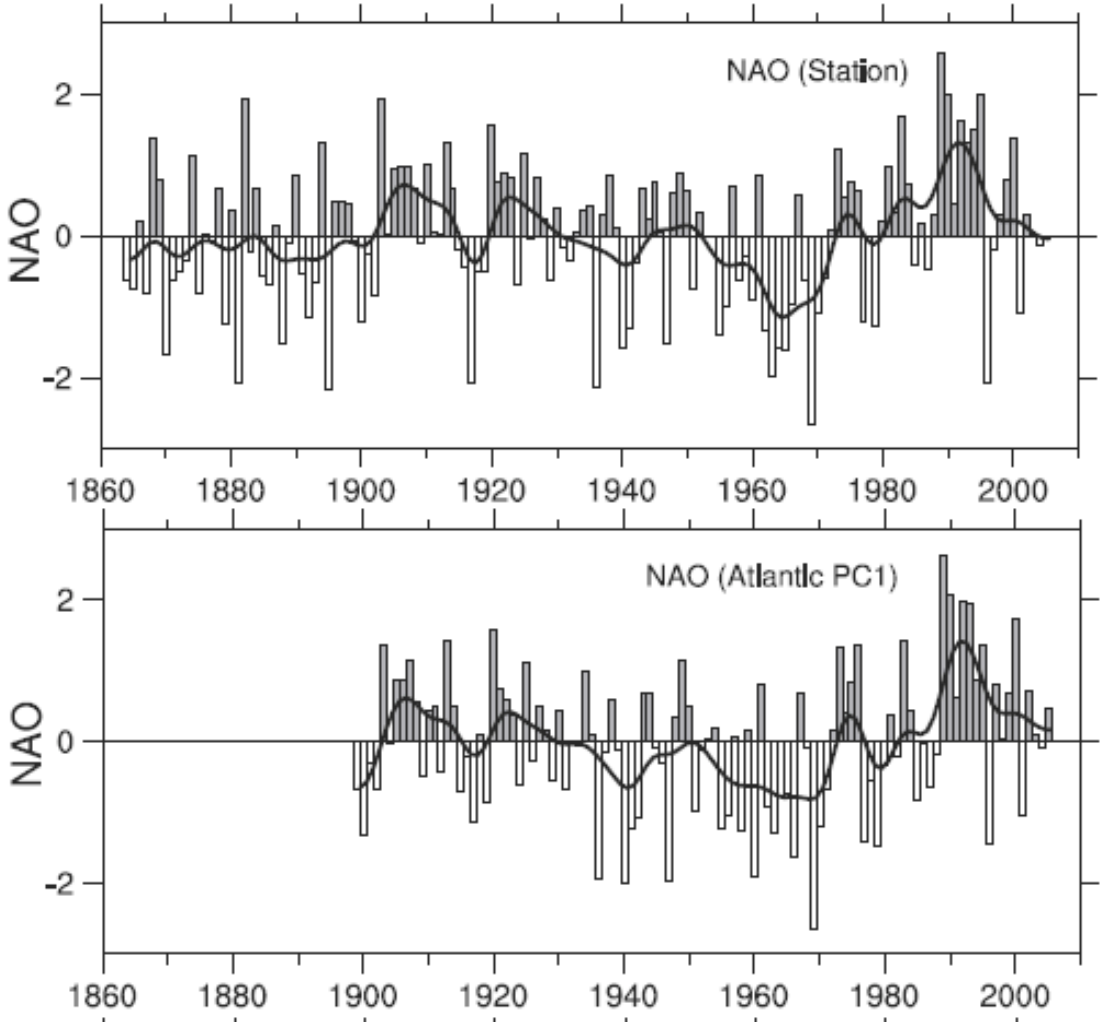

- Wetter: East North and South America, Eurasia
- Drier: Sahel, S Africa, Mediterranean, S Asia
- More rain, less snow in northern regions
- Increased frequency of heavy precipitation
- Beware of the AMO!

# Atmospheric/Oceanic Circulations (El Nino)




- Occurrence of strong El Ninos may be higher since 1980s
- But significance is low due to strong contribtion of natural variability

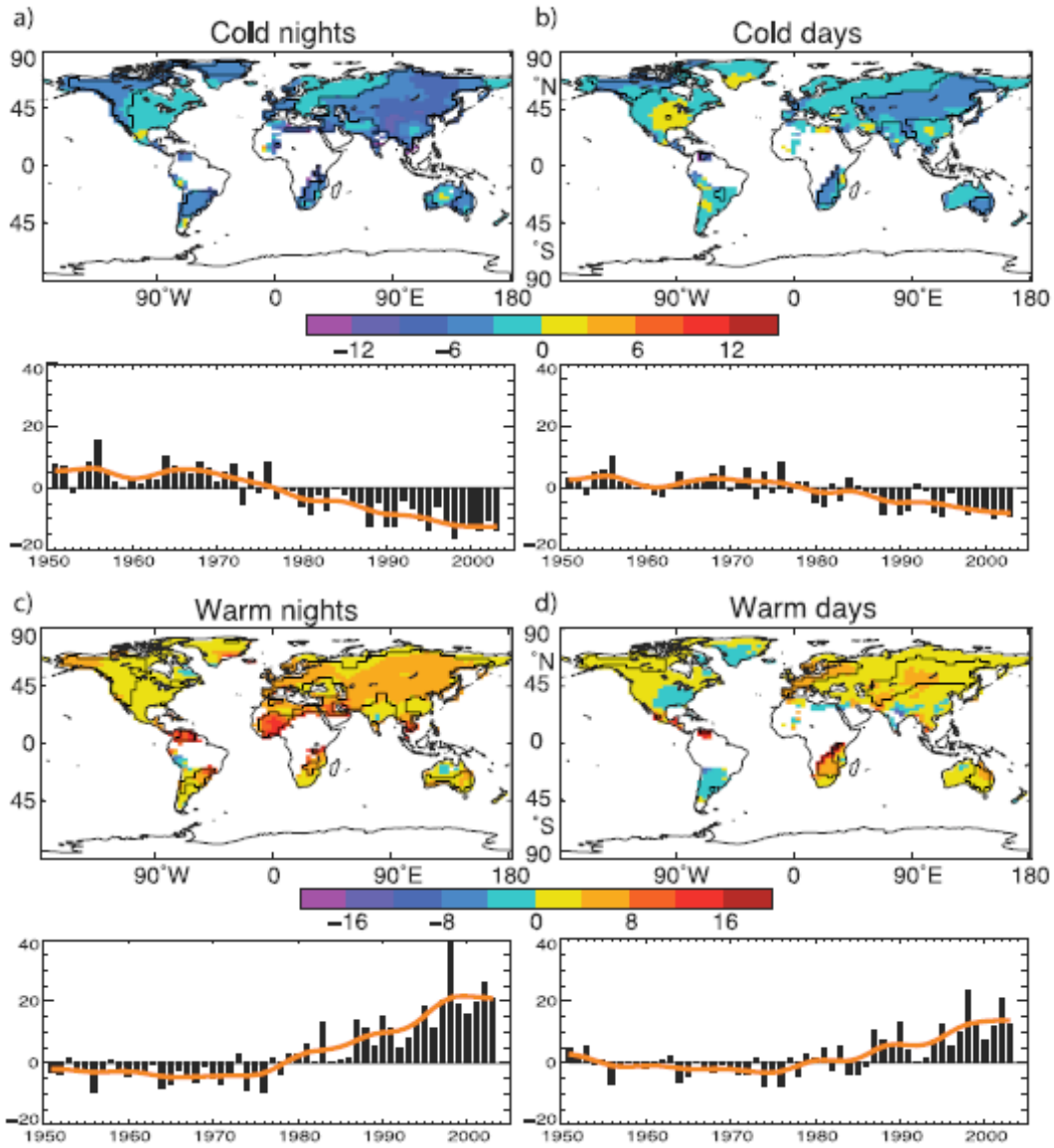
# Atmospheric/Oceanic Circulations (NAO)




- North Atlantic Oscillation (NAO) is a measure of circulation patterns in the NH
- Positive index implies warmer Europe
- Greater occurrence of positive indices since 1980s
- NAO trending towards negative values recently.
- Difficult to separate natural variability and long-term change

**http://www.cgd.ucar.edu/cas/jhurrell/indices.html**

# Climate Extremes (extreme temperatures)

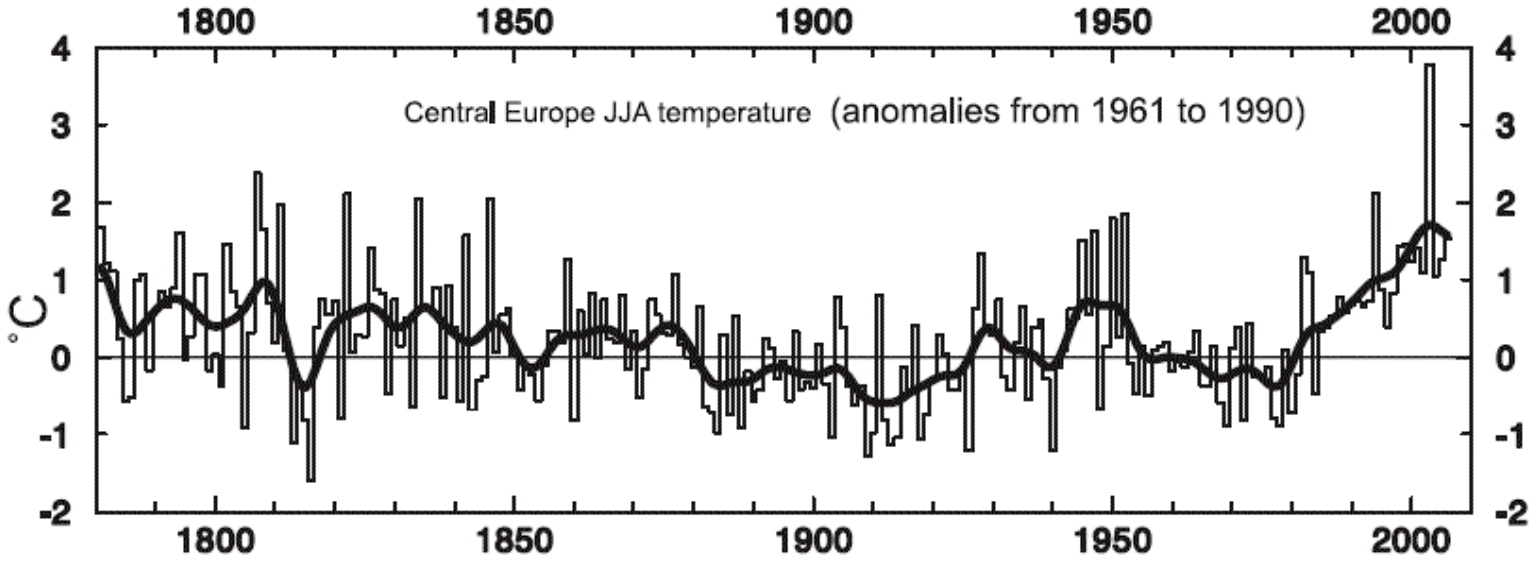


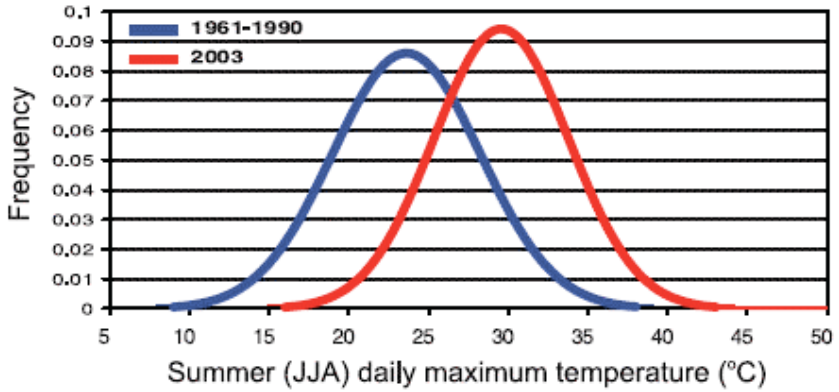

10th percentile

Trends in days/decade 1951-2003 (relative to 1961-1990).

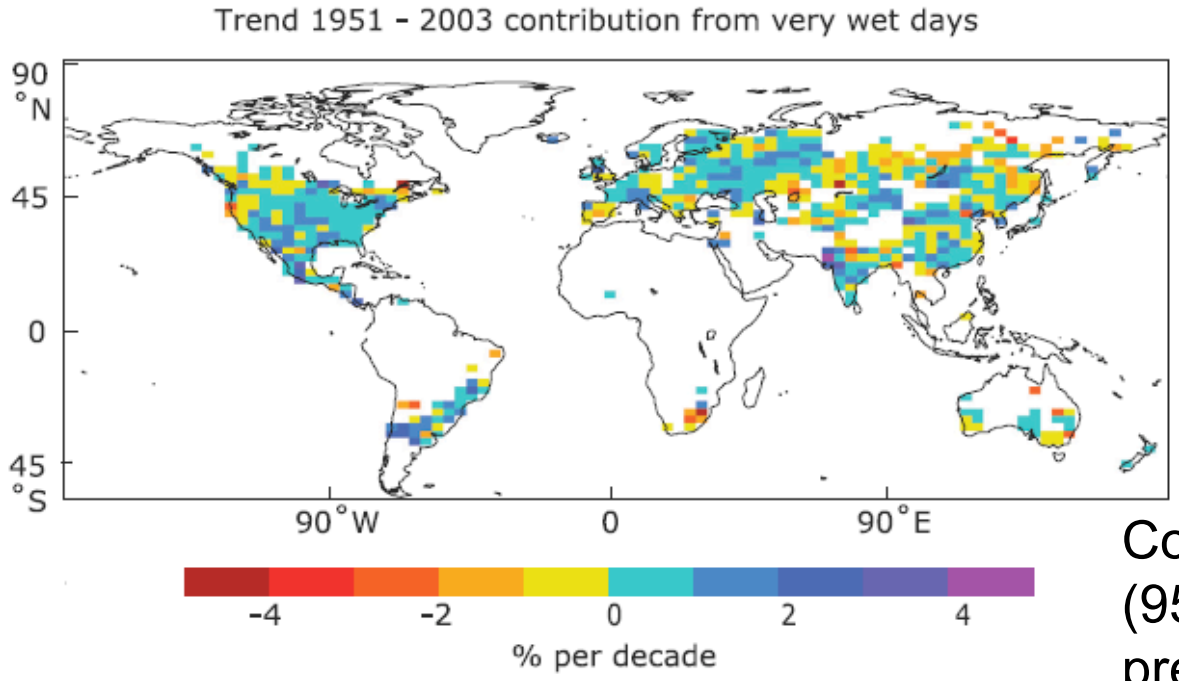
90th percentile

# Climate Extremes (heatwaves)

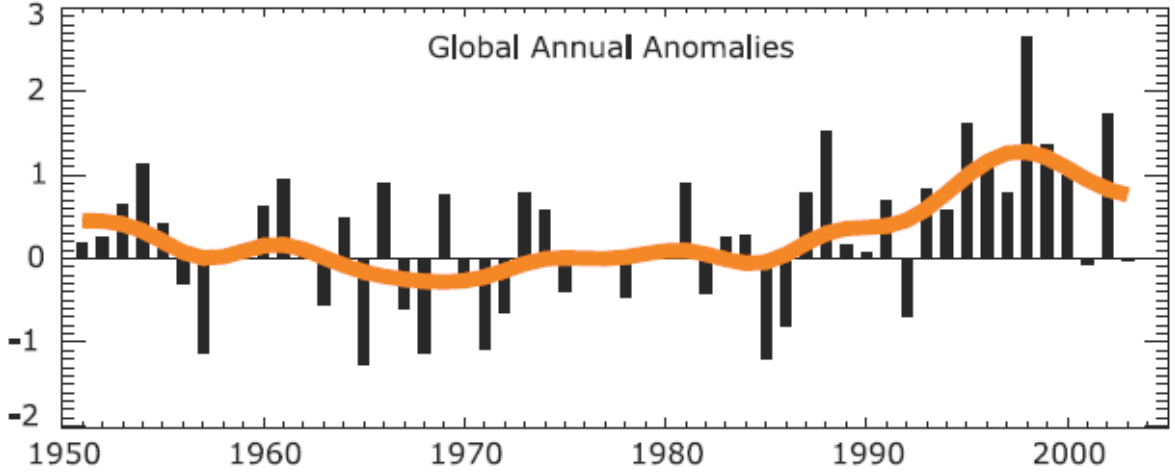


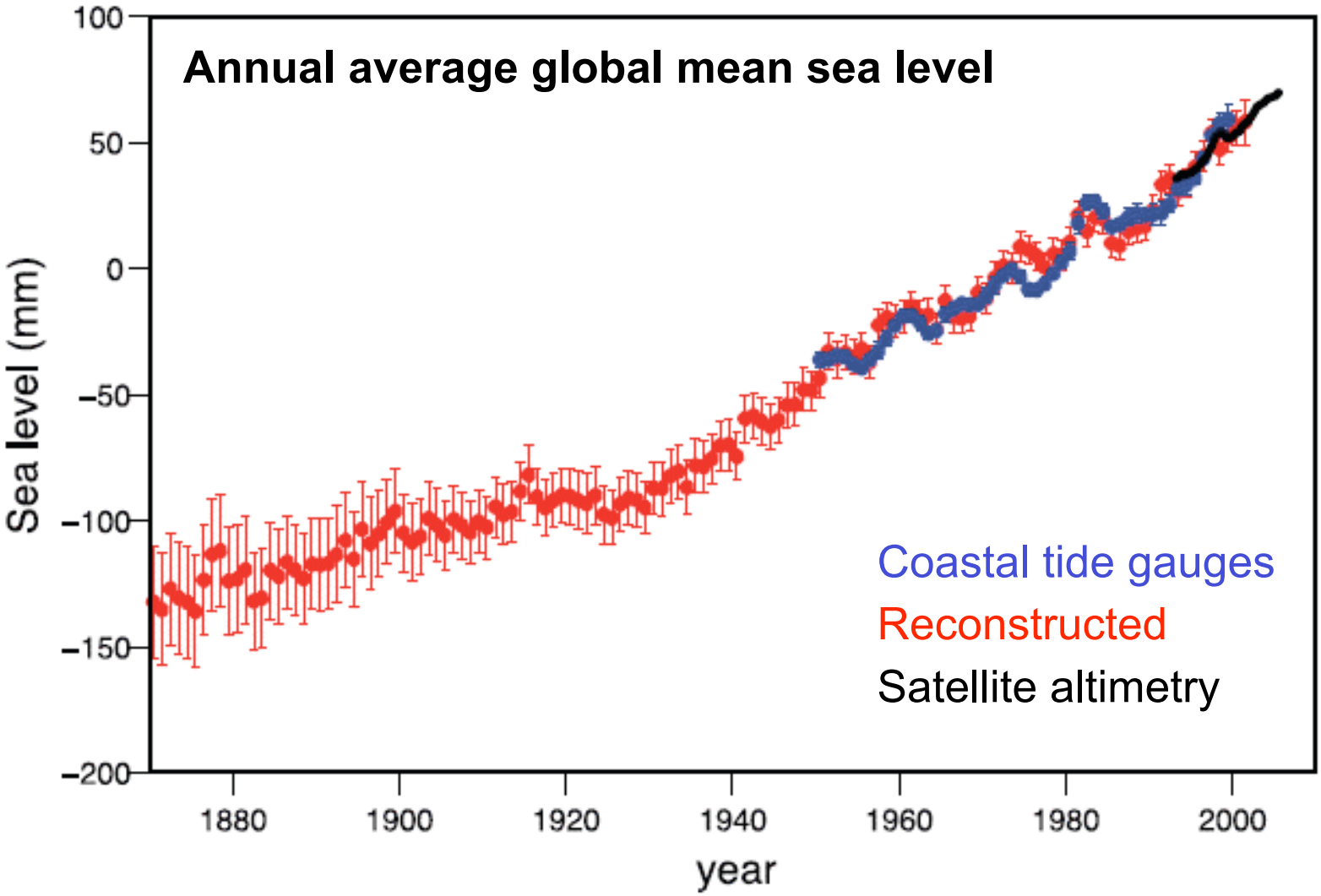
# Climate Extremes (precipitation)




Contribution from 'very wet' days (95th precentile) to total decadal precipitation.



# Sea-level Rise



# Changes in Greenhouse Gases