

Climate Change and Water

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with thanks to numerous others



Overview

- The past 100-150 years
 - Global, continental, regional and local
- What does the future hold?
 - Model projections
- Water cycle – Western water

Climate: mean and variability of weather—
temperature & precipitation—over a period of
time in a particular geographic region

*The difference between weather and climate
is really statistical. Climate is weather with
a long enough record to characterize in
statistical terms, such as mean and
variance.*

Direct Observations of Recent Climate Change

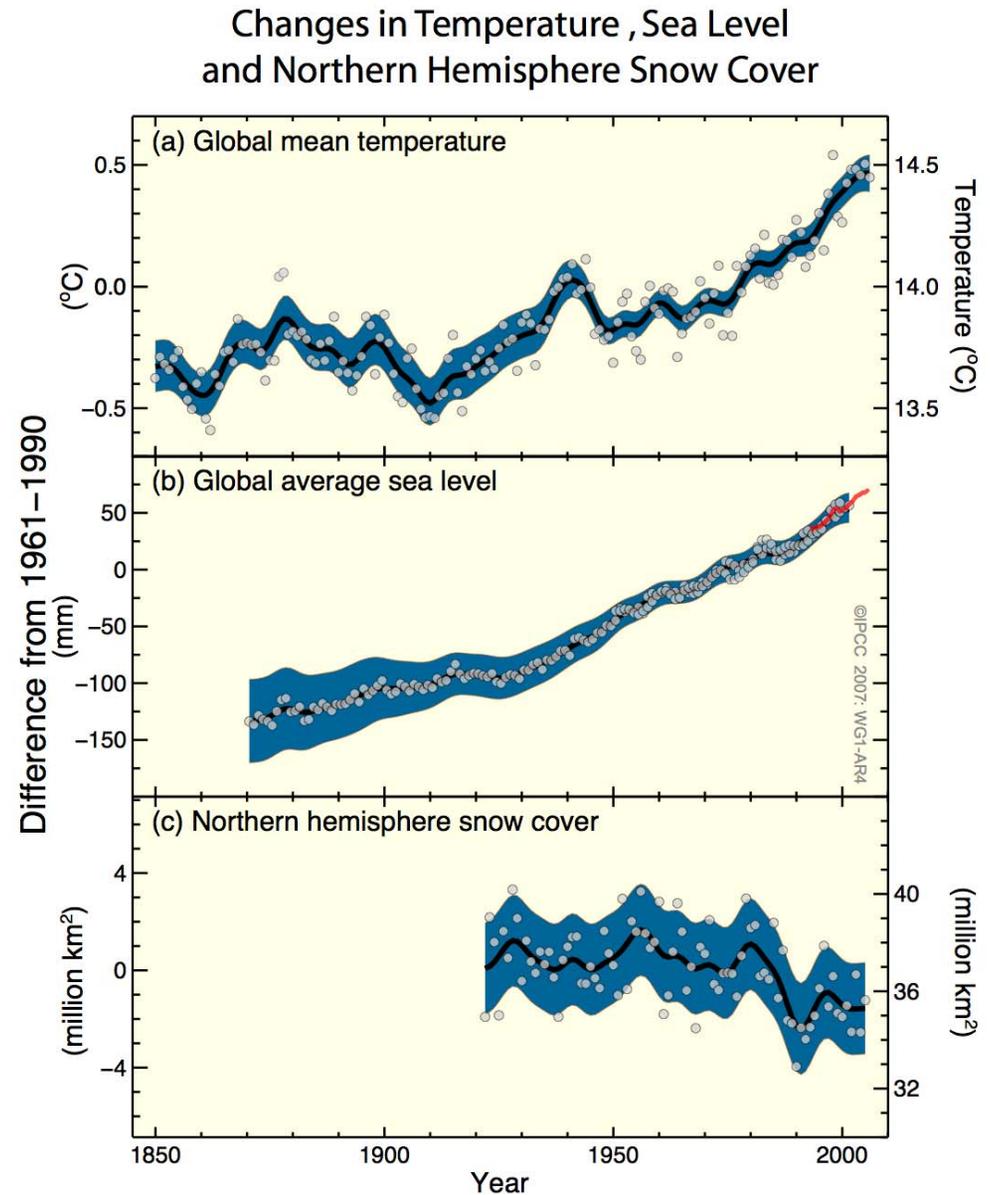
Warming of the climate system is unequivocal, and is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.

Direct Observations of Recent Climate Change

Global mean temperature

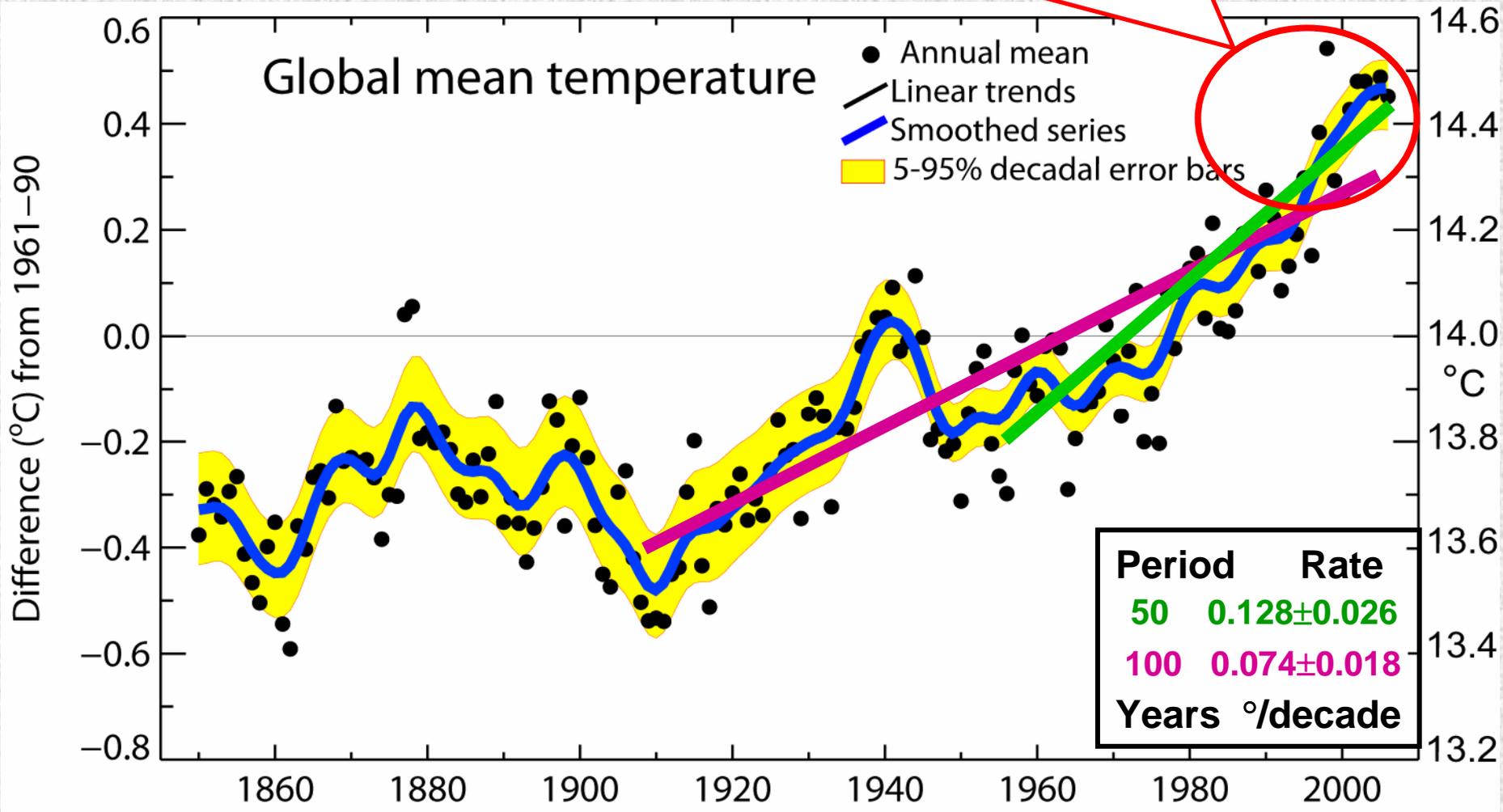
Global average sea level

Northern hemisphere snow cover

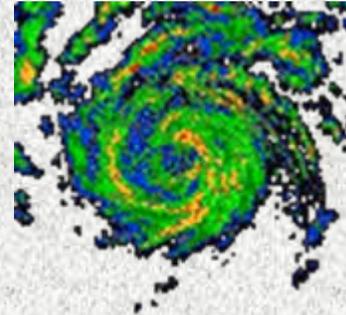


Global mean temperature difference from 1961-90

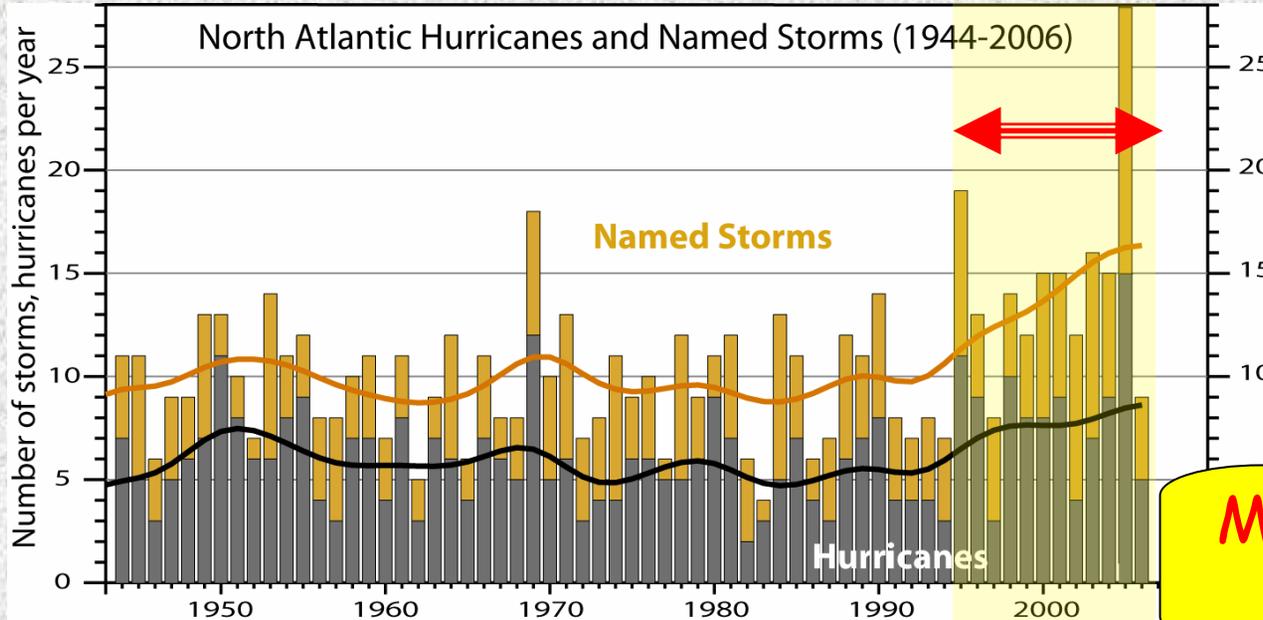
Warmest 12 years:
1998, 2005, 2003, 2002, 2004, 2006,
2001, 1997, 1995, 1999, 1990, 2000



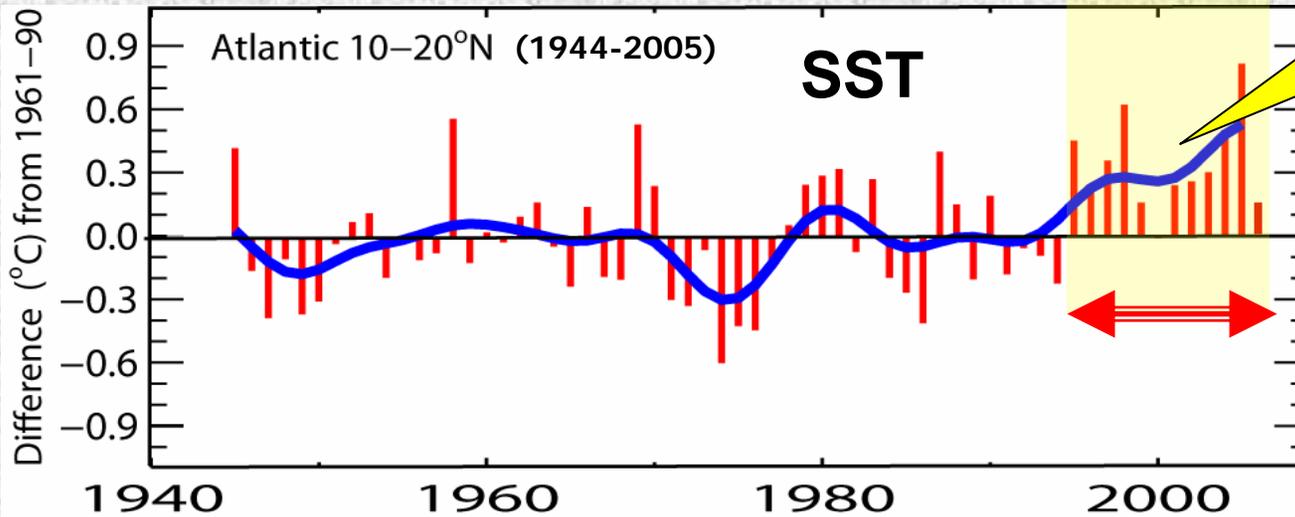
North Atlantic hurricanes have increased with SSTs



N. Atlantic hurricane record best

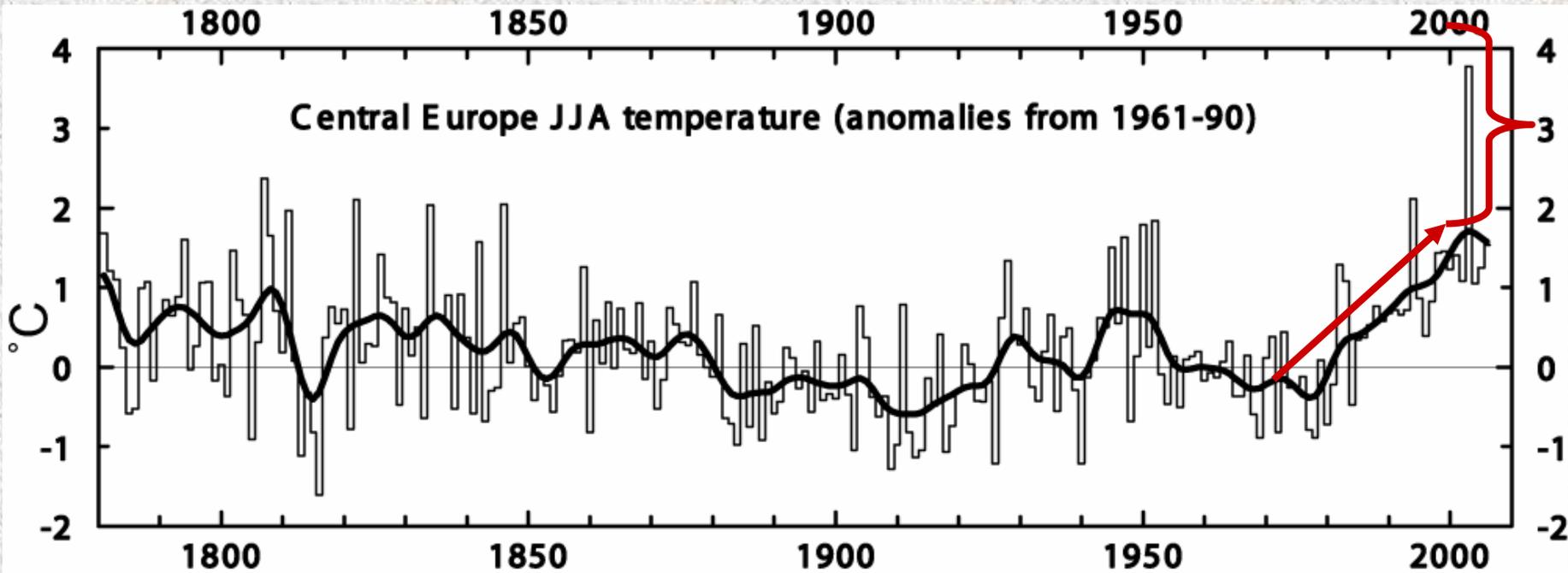


Marked increase after 1994



Global number and percentage of intense hurricanes is increasing

Heat waves are increasing: one example

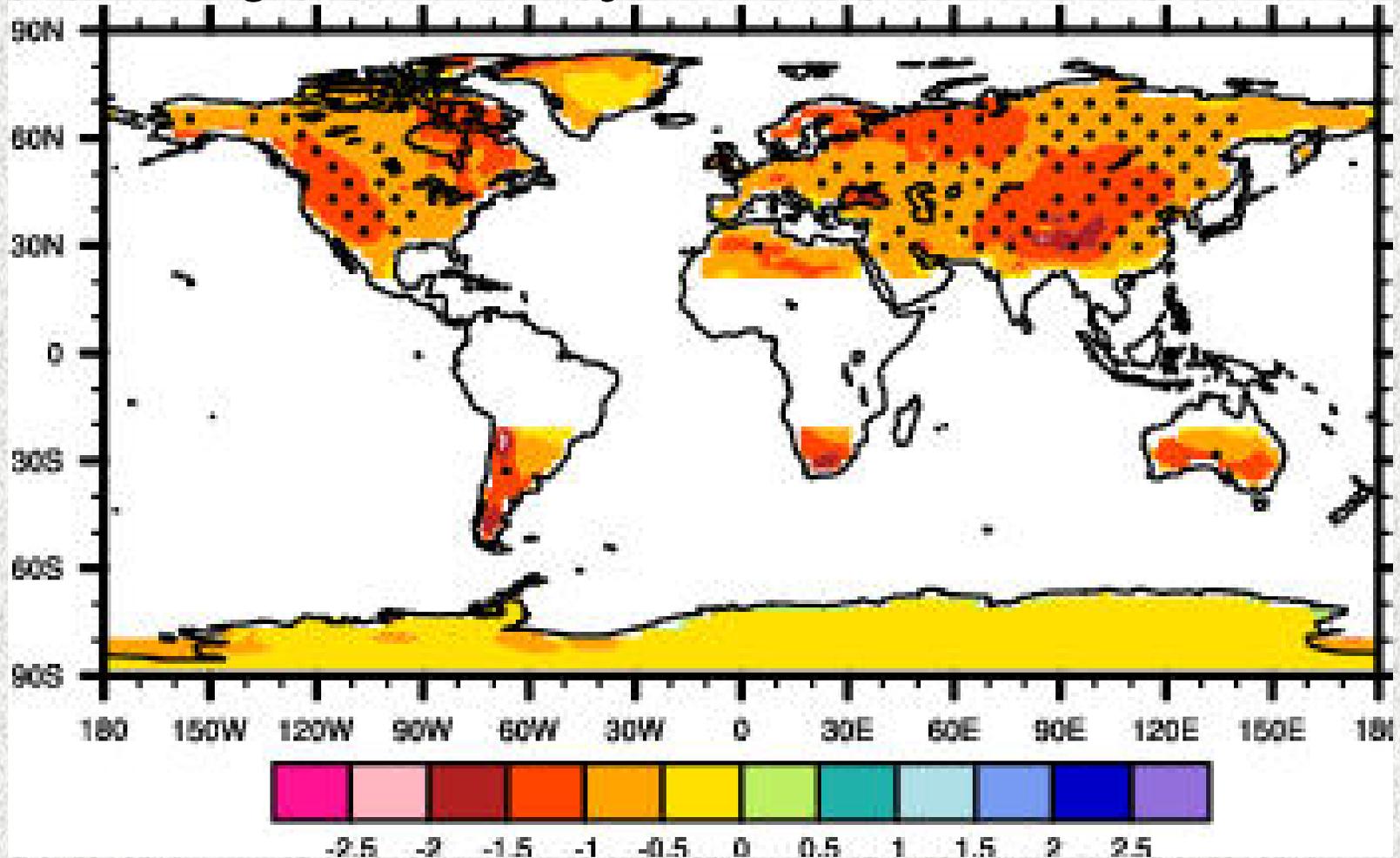


Extreme Heat Wave
Summer 2003
Europe

35,000 deaths
>100°F in UK, 1st time
in recorded history

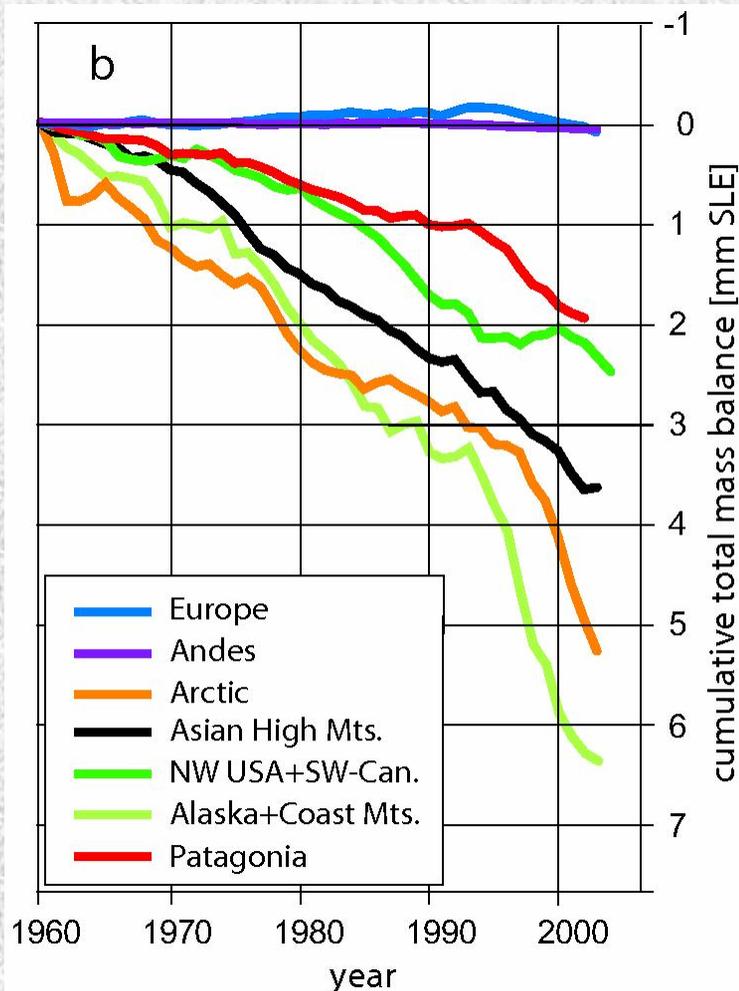
Frost-Free Days Are Increasing

Changes in frost days 1980-1999 vs. 1900-1919

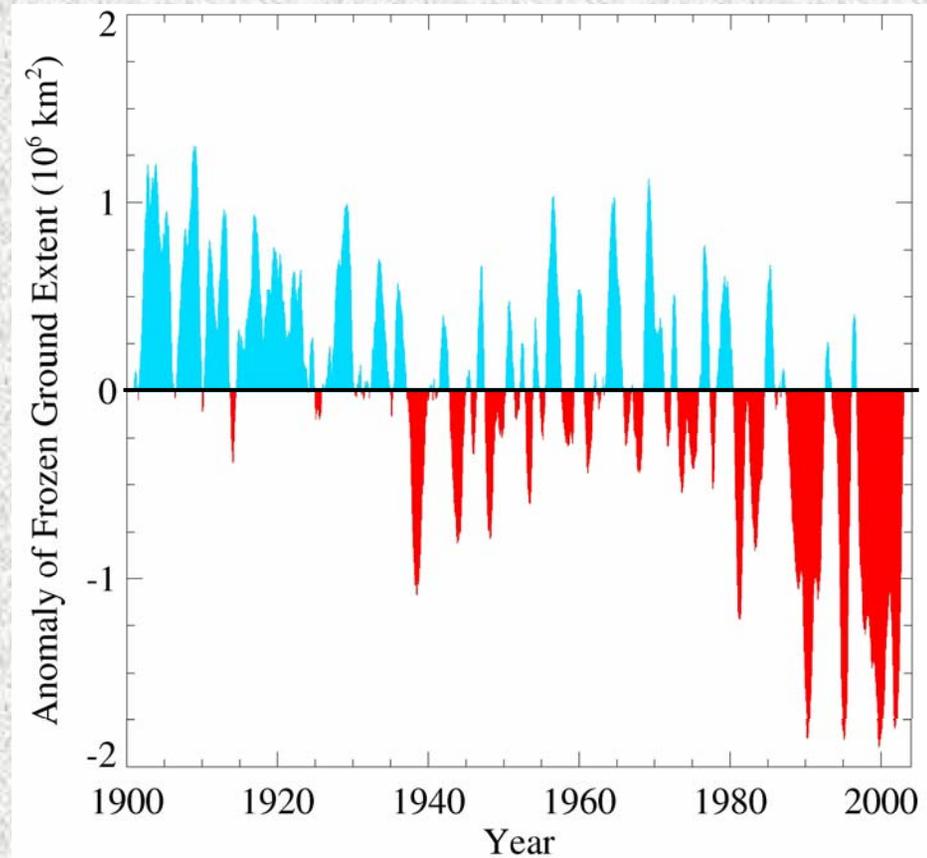


Tebaldi et al. 2006. Climatic Change

Glaciers and frozen ground are receding



Increased Glacier retreat since the early 1990s

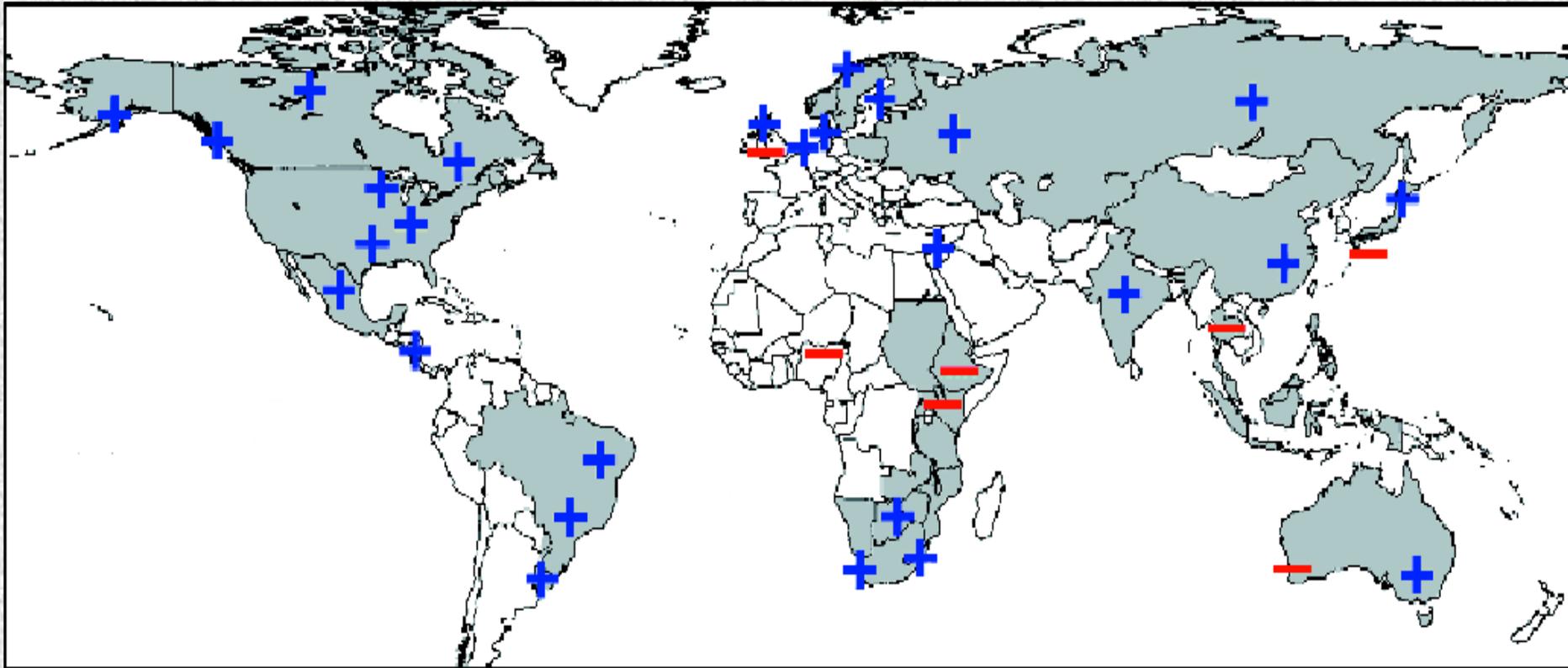


Area of seasonally frozen ground in NH has decreased by 7% from 1901 to 2002

Changes in Precipitation, Increased Drought

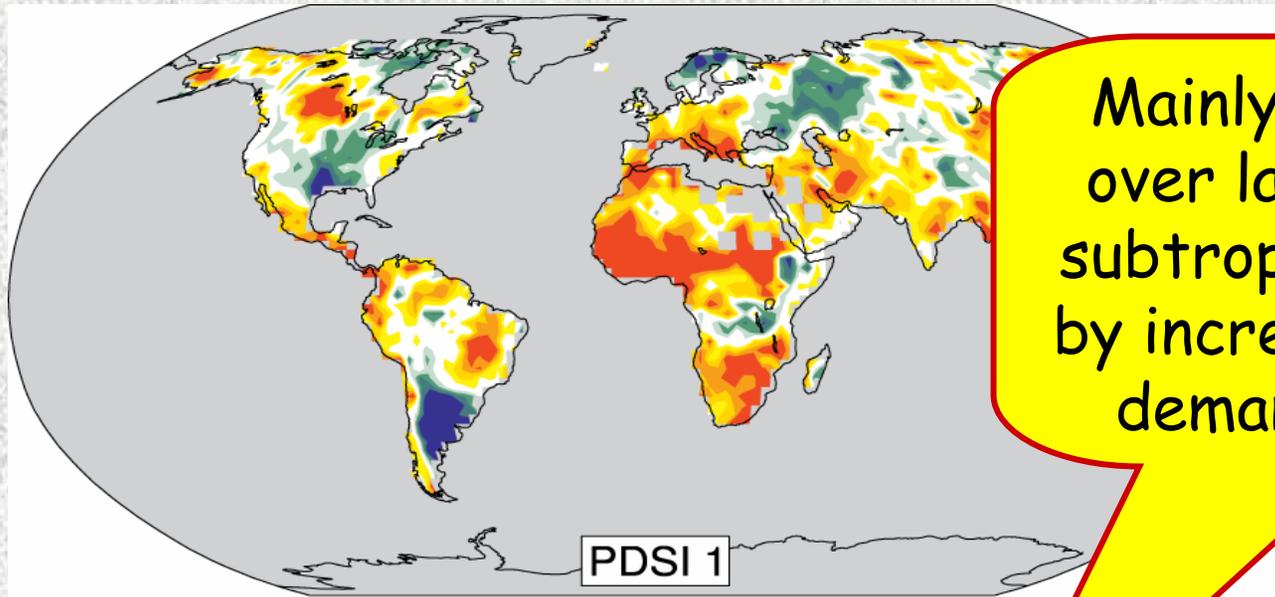
- **Significantly increased precipitation** in eastern parts of North and South America, northern Europe and northern and central Asia.
- **The frequency of heavy precipitation events** has increased over most land areas - consistent with warming and increases of atmospheric water vapour
- **Drying** in the Sahel, the Mediterranean, southern Africa and parts of southern Asia.
- **More intense and longer droughts** observed since the 1970s, particularly in the tropics and subtropics.

Proportion of heavy rainfalls: increasing in most land areas



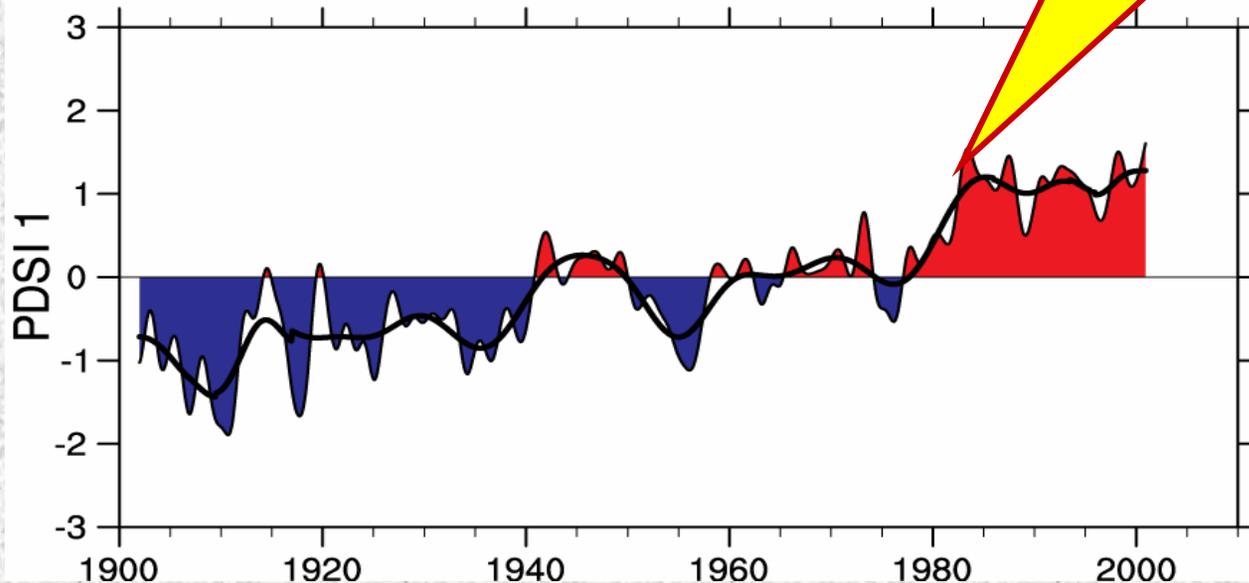
**Regions of disproportionate changes
in heavy (95th) and very heavy (99th)
precipitation**

Drought is increasing most places



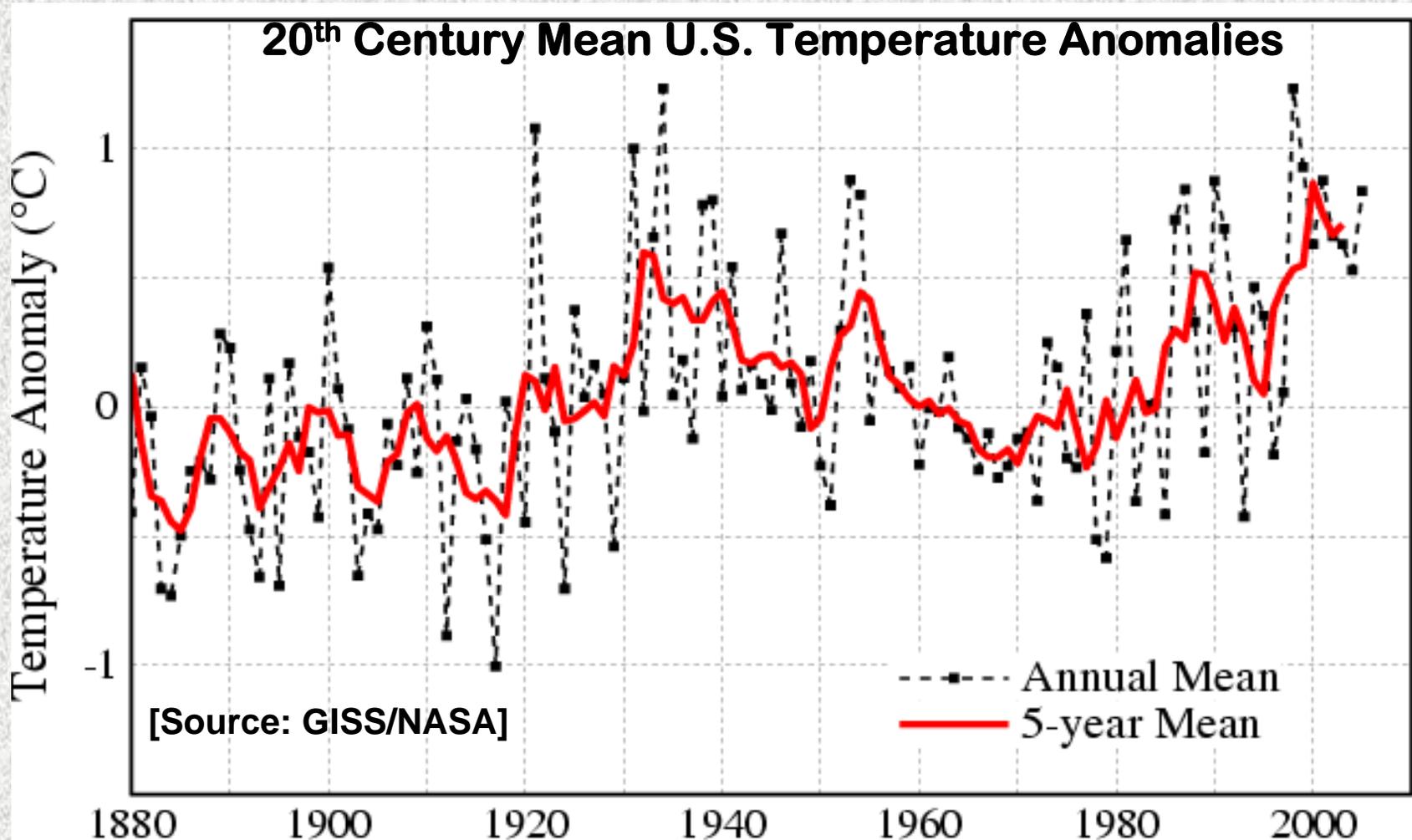
Mainly decrease in rain over land in tropics and subtropics, but enhanced by increased atmospheric demand with warming

2002.



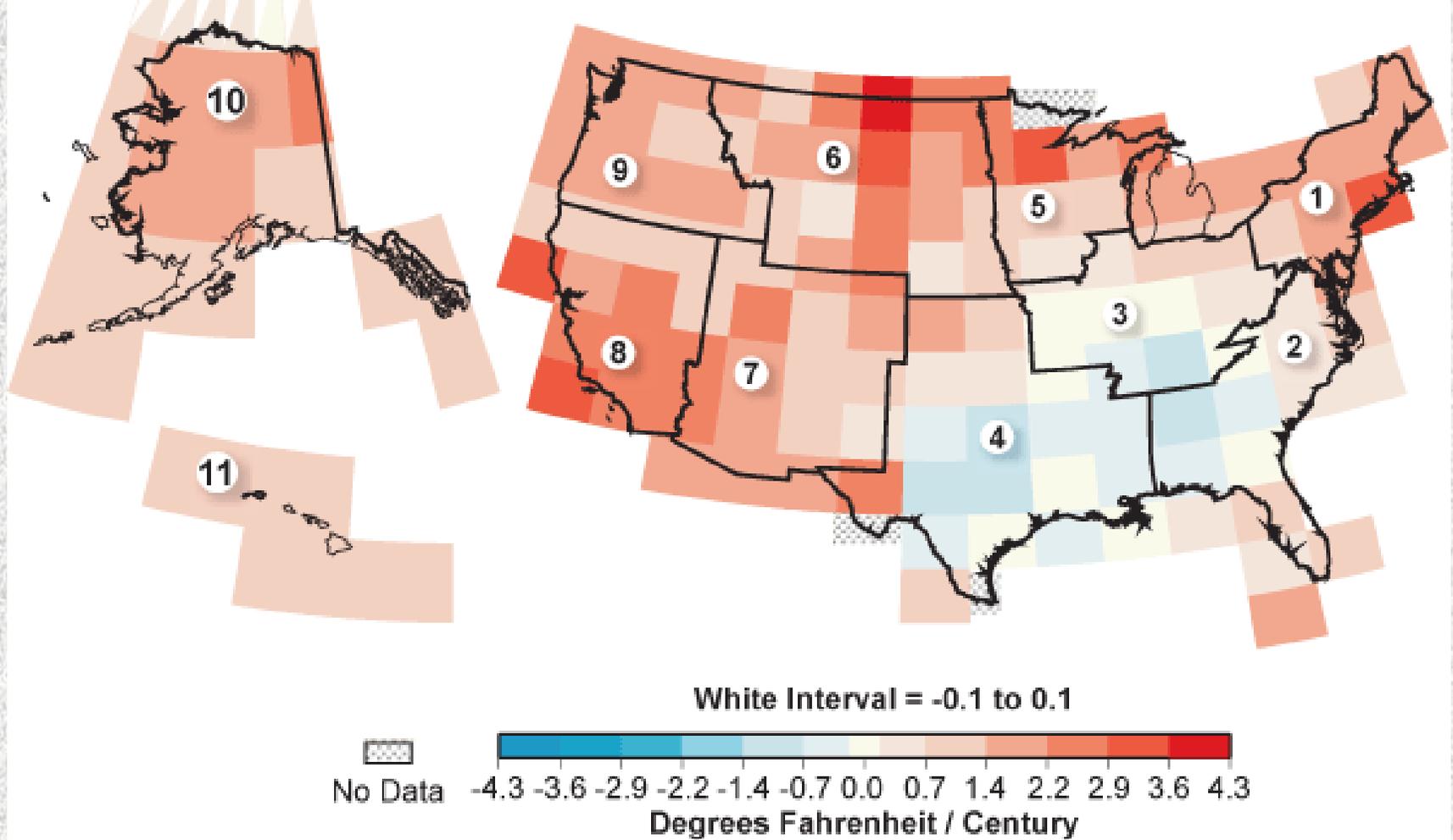
The time series (below) accounts for most of the trend in PDSI.

On Average, the US Warmed 0.5-1.0 °C in the Past 100 Years



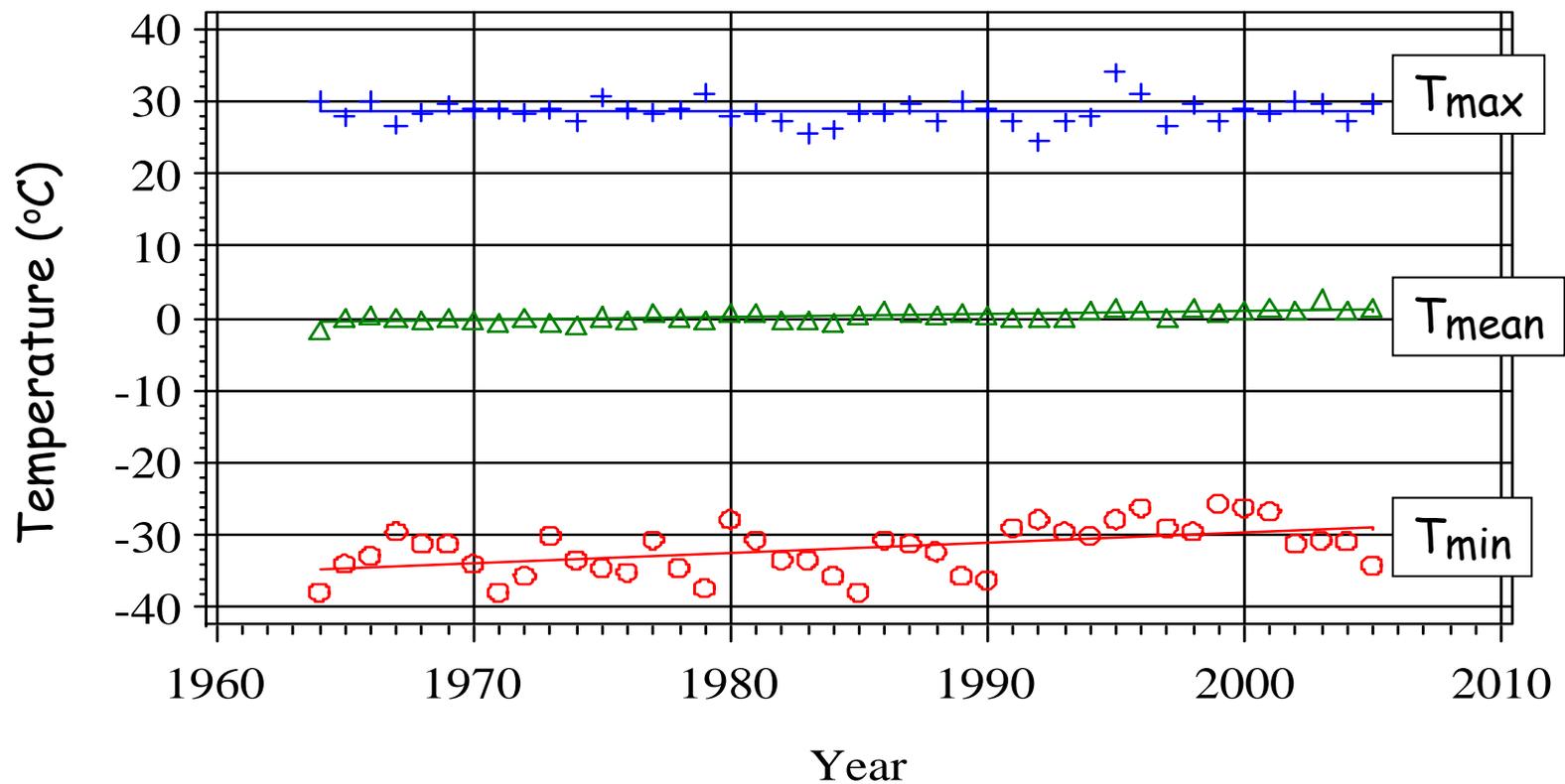
Warming Trend Observed in Most of US

Annual Mean US Temperature Trends 1901-2003



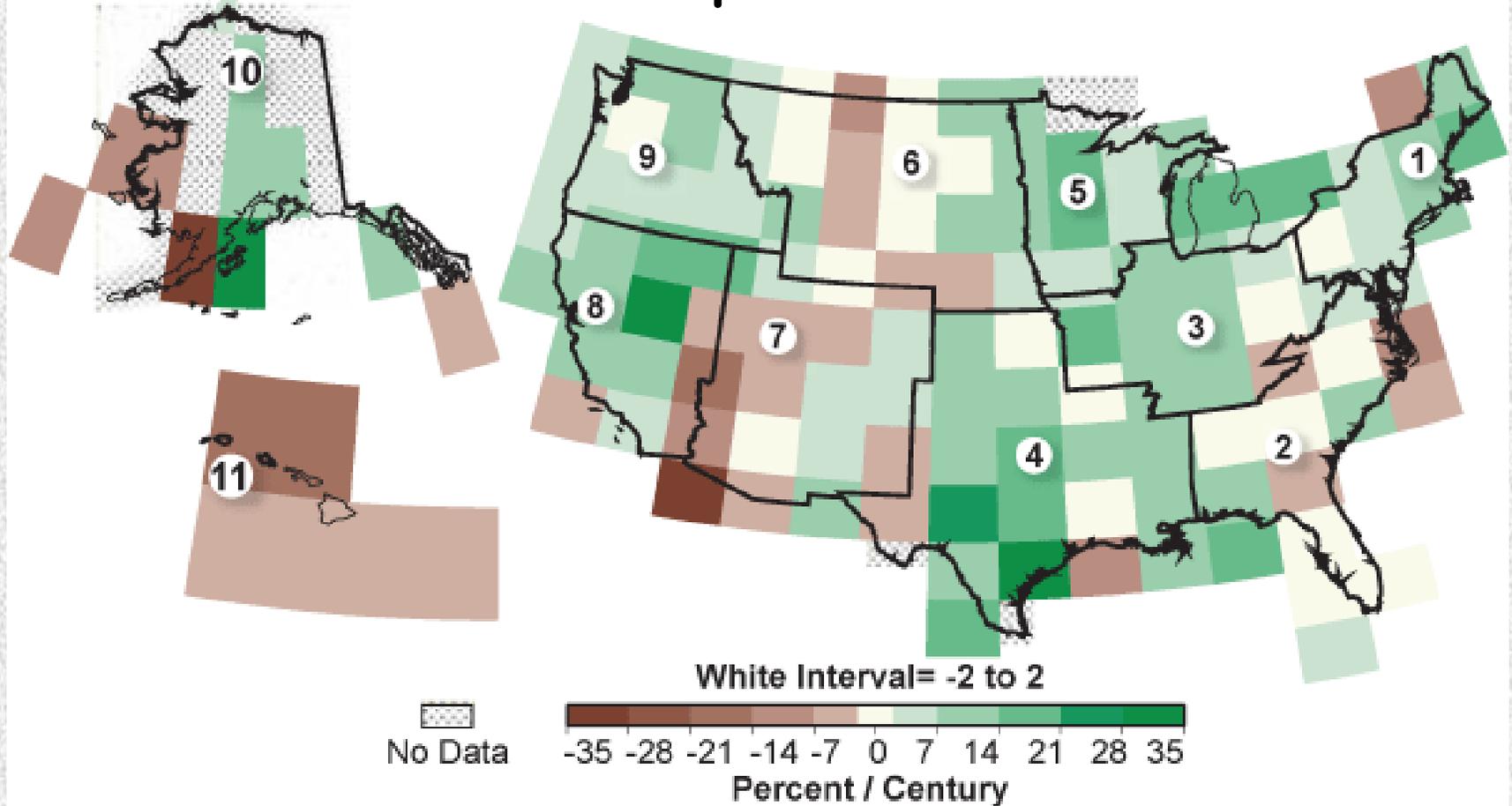
Data from NOAA/NCDC; See: <http://www.epa.gov/climatechange/science/recenttc.html>

Long-term Temperature Trends at Fraser Experimental Forest



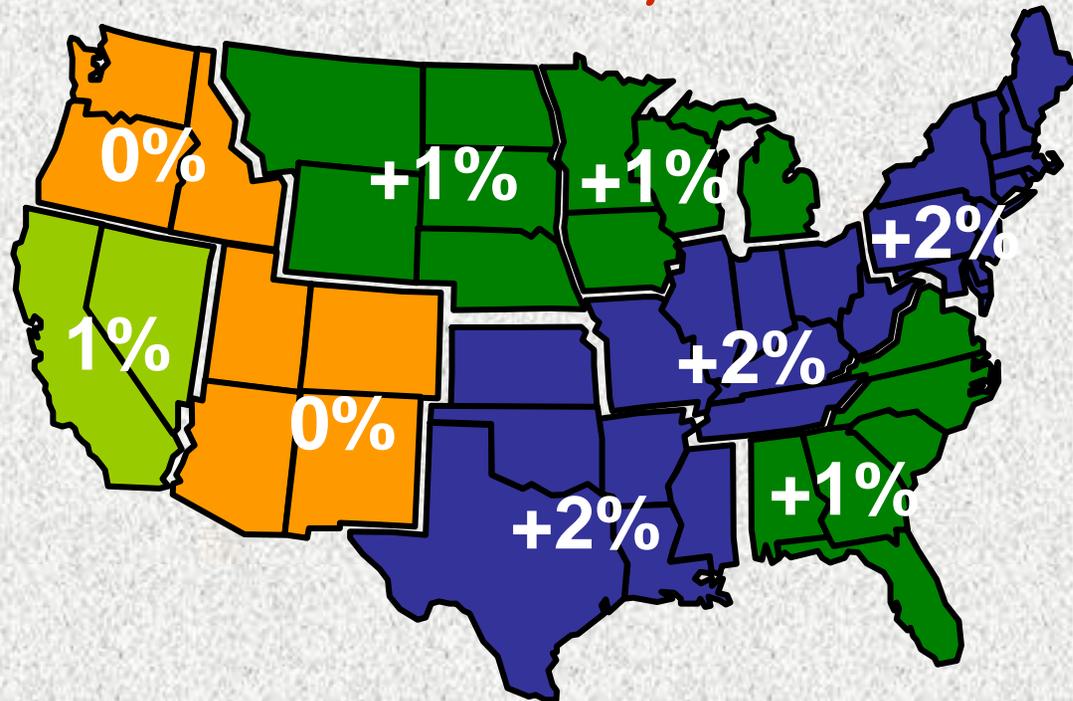
Precipitation increases or decreases depending on region

Annual Mean US Precipitation Trends 1901-2003



Precipitation Patterns Are Changing

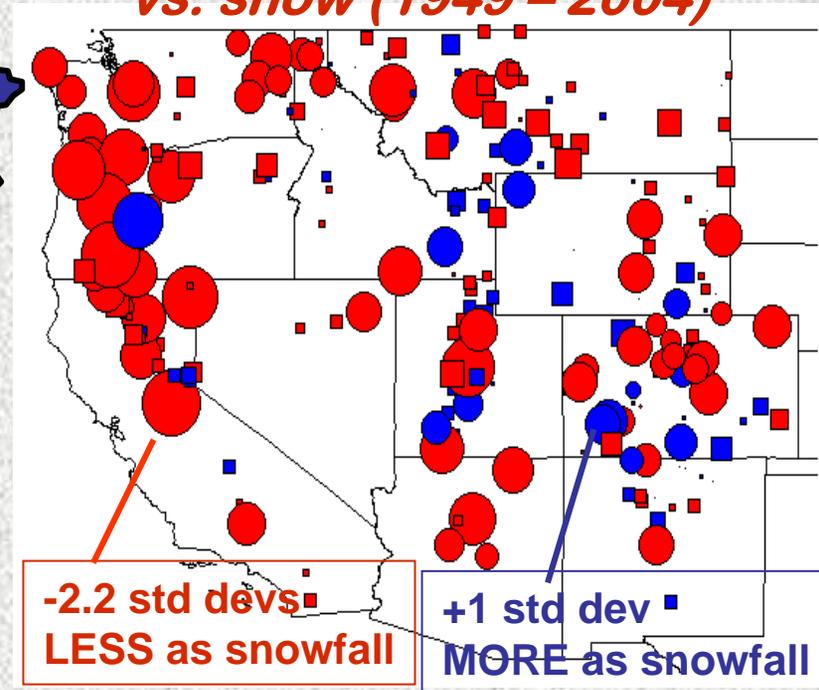
More precipitation from intense downpours



Trends in proportion of annual precipitation of extreme intensity (> 2" per day): 1910 – 1995

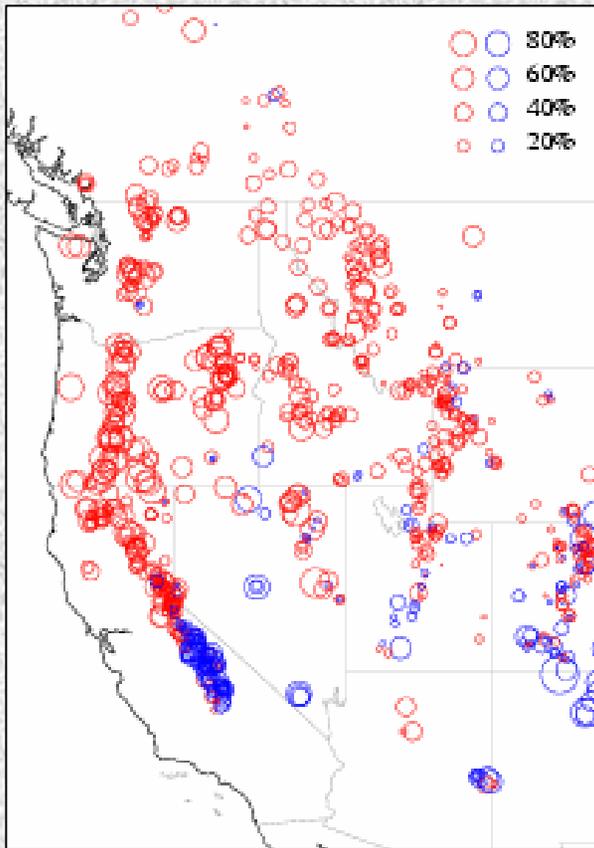
Karl & Knight 1998

More precipitation as rain vs. snow (1949 – 2004)



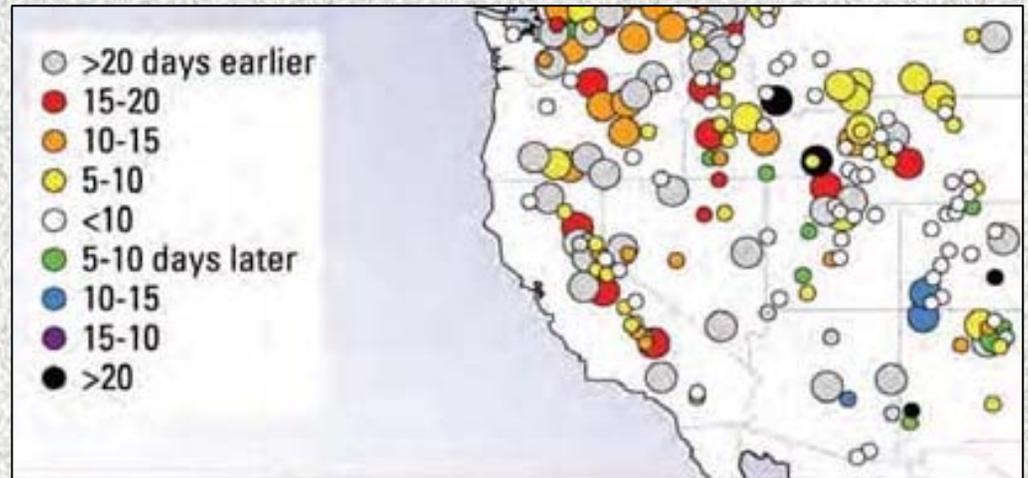
Knowles et al. 2006

Earlier Onset of Spring Snowmelt and Less Snowpack



Less spring snowpack

Mote, 2003



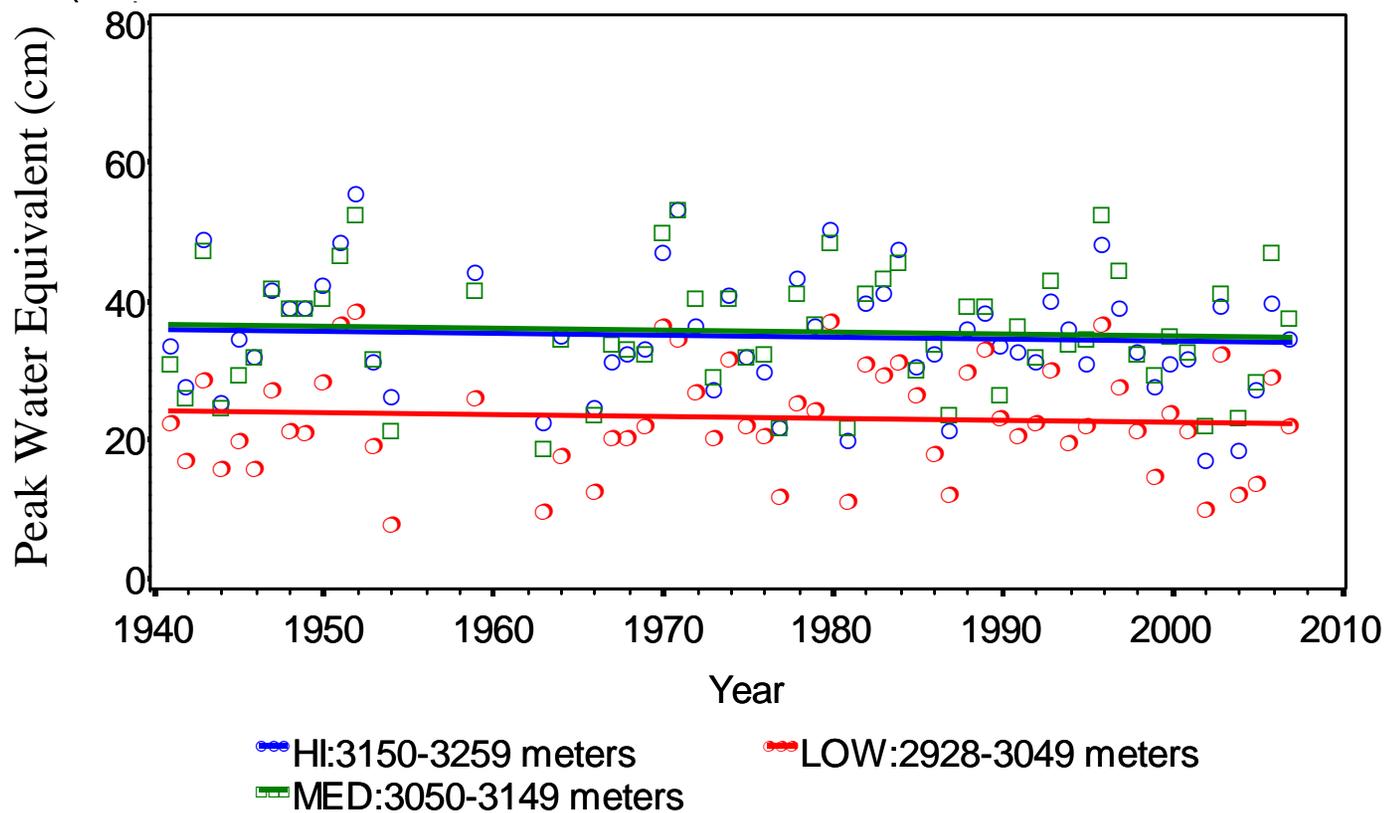
Earlier snowmelt runoff

Stewart et al., 2005

Snow season 16 days shorter in CA & NV (1951-1996)

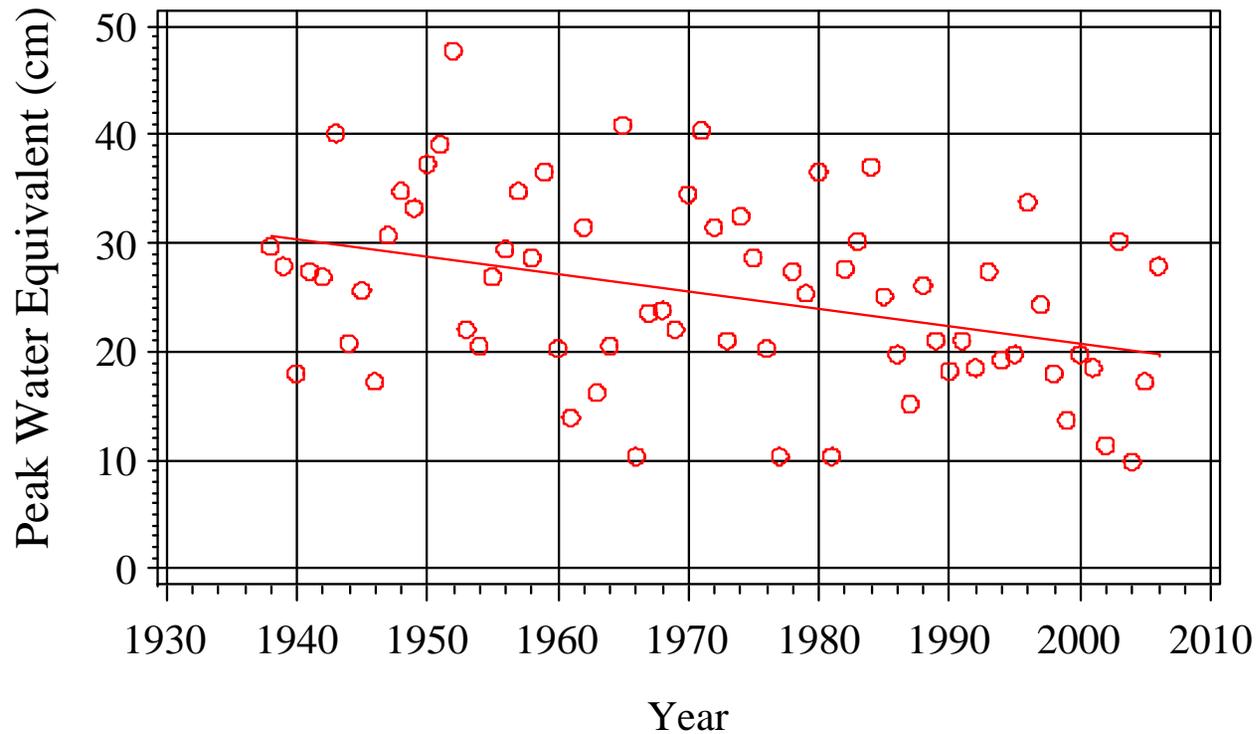
Long-term Snowpack Trends at Fraser Experimental Forest

Fool Creek Snow Course – FEF, Fraser, Colorado



Long-term Snowpack Trends at Fraser Experimental Forest

Lapland Snow Course – FEF, Fraser, Colorado



Regional Climate Trends in Last 100 Years

Pacific Northwest

- Temp. rose 1–3°F
- Precip. rose ~11%; most in NE WA & SW MT

Midwest

- Temp. rose ~4°F (north); decreased ~1°F (south)
- Precip. rose ~20% mostly due to heavy rainstorms

Northeast

- Temp. increased up to 4°F
- Precip. rose ~20 mostly due to heavy rainstorms
- 7 day shorter snow season

West

- Temp. increased 2–5°F
- Precip. rose >50% in some areas; other areas drier, more droughts
- 16 day shorter snow season

Great Plains

- Temp. rose 2–5.5°F in north & central regions
- Precip. decreased by 10%
- Texas – more high intensity rainfall

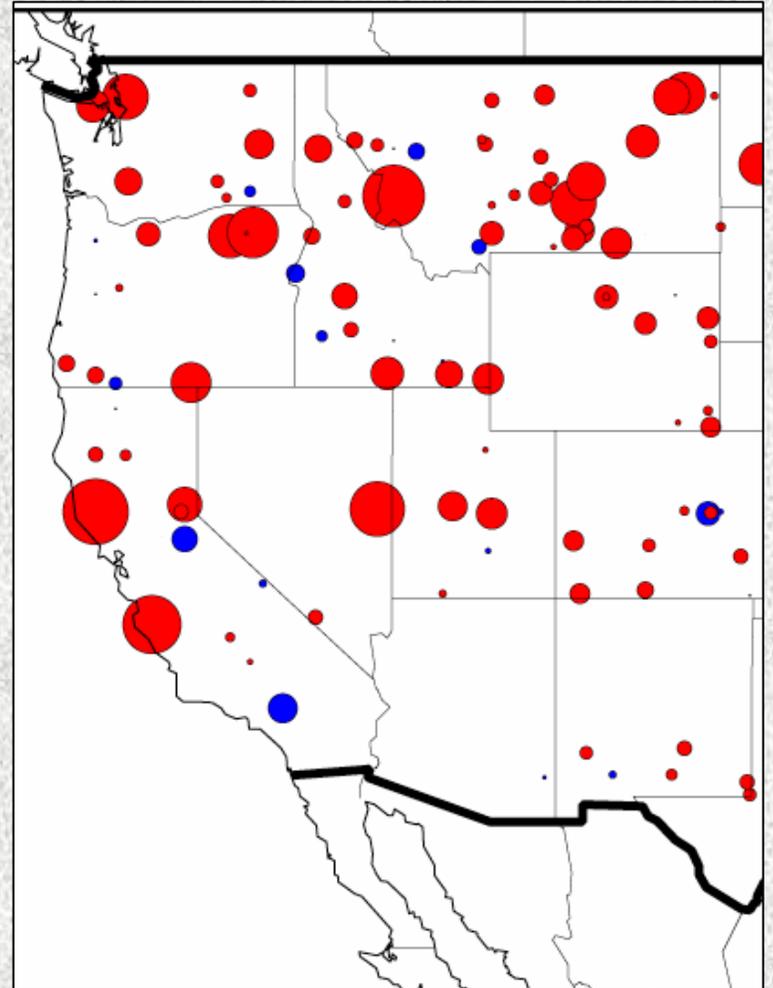
Southeast

- Cooled during 1960s; more recent warming
- Precip. rose 20–30%, mostly due to more intense rainstorms

Source: US National Assessment

Earlier Greenup of Vegetation

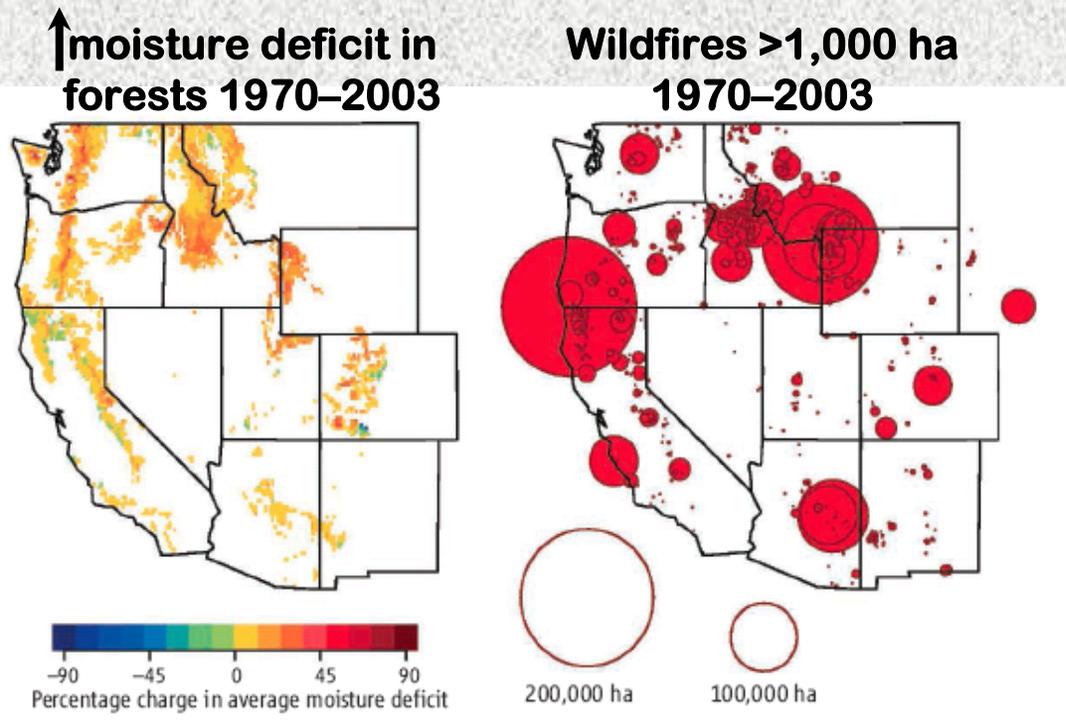
- Trends over 1954-1994 of lilac first-bloom dates
- Larger circles indicate significantly earlier dates



Cayan et al., 2001

Altered Disturbance Regimes

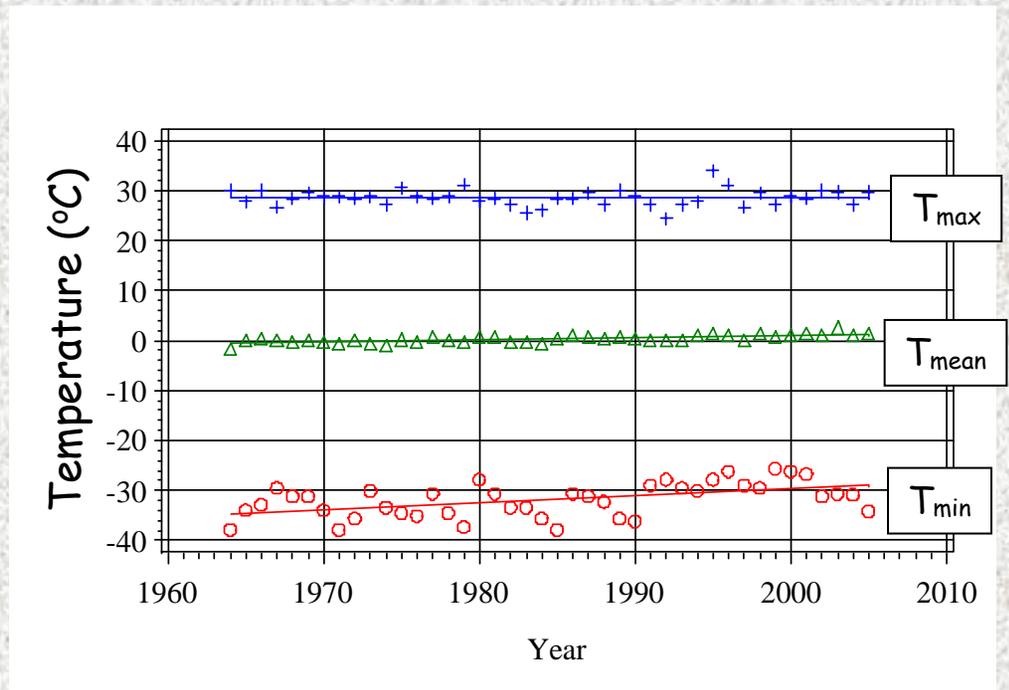
Larger, more frequent wildfires since 1980s in West



- Large wildfires are strongly associated with increased spring and summer temperatures and earlier spring snowmelt
- Longer wildfire durations and seasons

Running 2006, Westerling et al. 2006

MPB Found at Unprecedented Elevations



Community Shifts

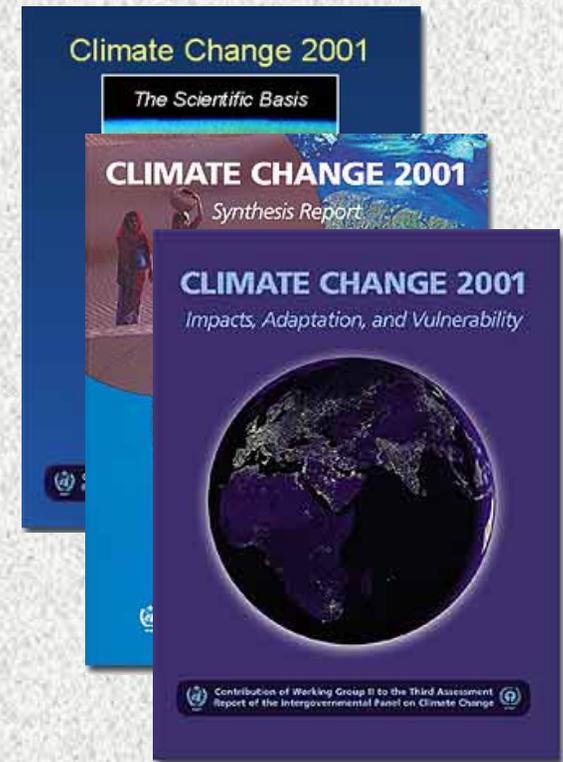
- 66% of the 36 most common bottom feeding fish in the North Sea moved to cooler waters, north or deeper from 1977 to 2001



IN HOT WATER: The eelpout has revealed how temperature change linked to global warming makes it harder for some fish species to thrive in their native seas.

Conclusions from the IPCC (Intergovernmental Panel on Climate Change)

- ***An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.***
- ***Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate throughout the 21st century.***



Projections of Future Changes in Climate

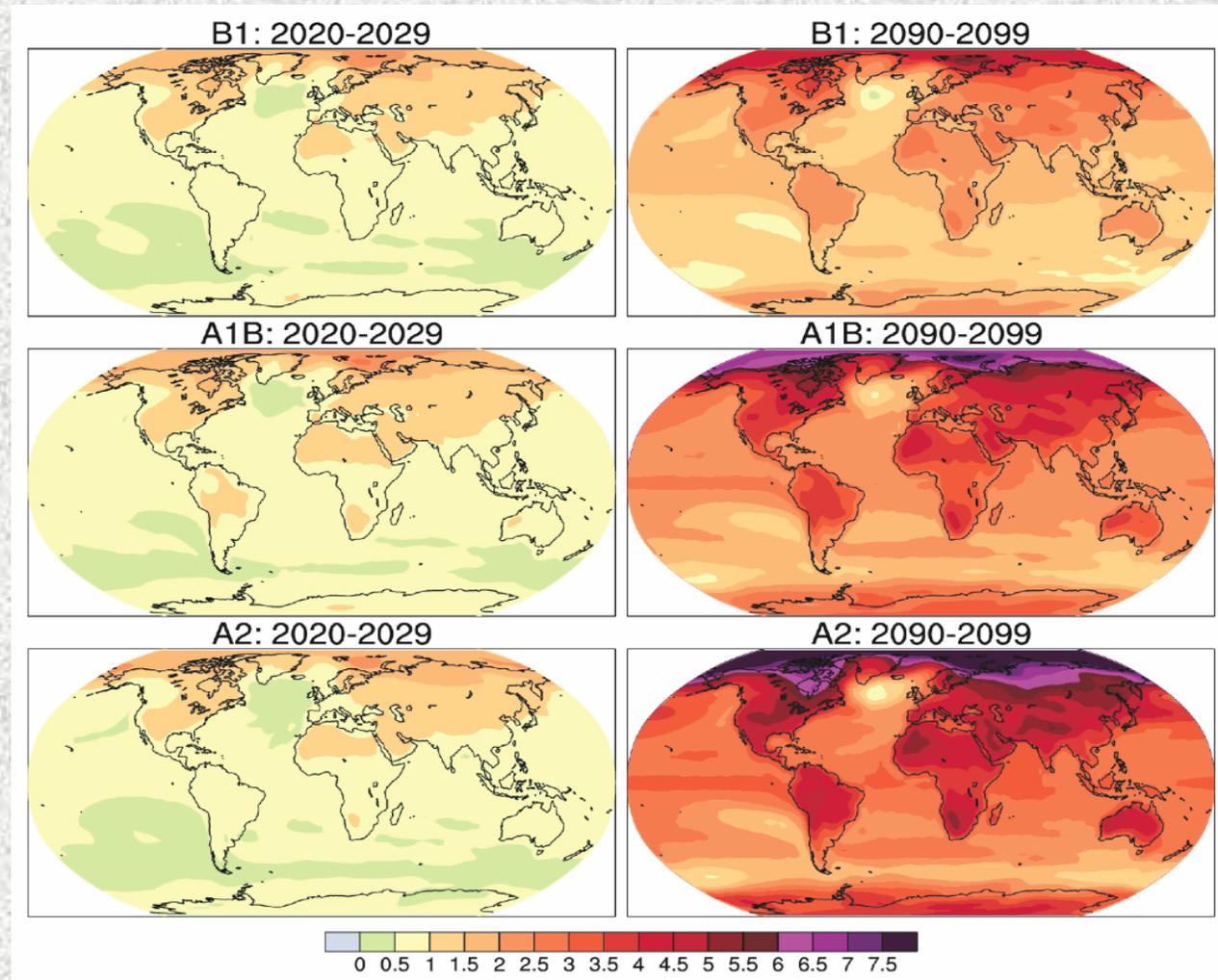
- **For the next two decades a warming of about 0.2°C per decade is projected for a range of emission scenarios.**
- **Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected.**
- **Earlier IPCC projections of 0.15 to 0.3 °C per decade can now be compared with observed values of 0.2 °C**

Projections of Future Changes in Climate

**Projected warming
in 21st century
expected to be**

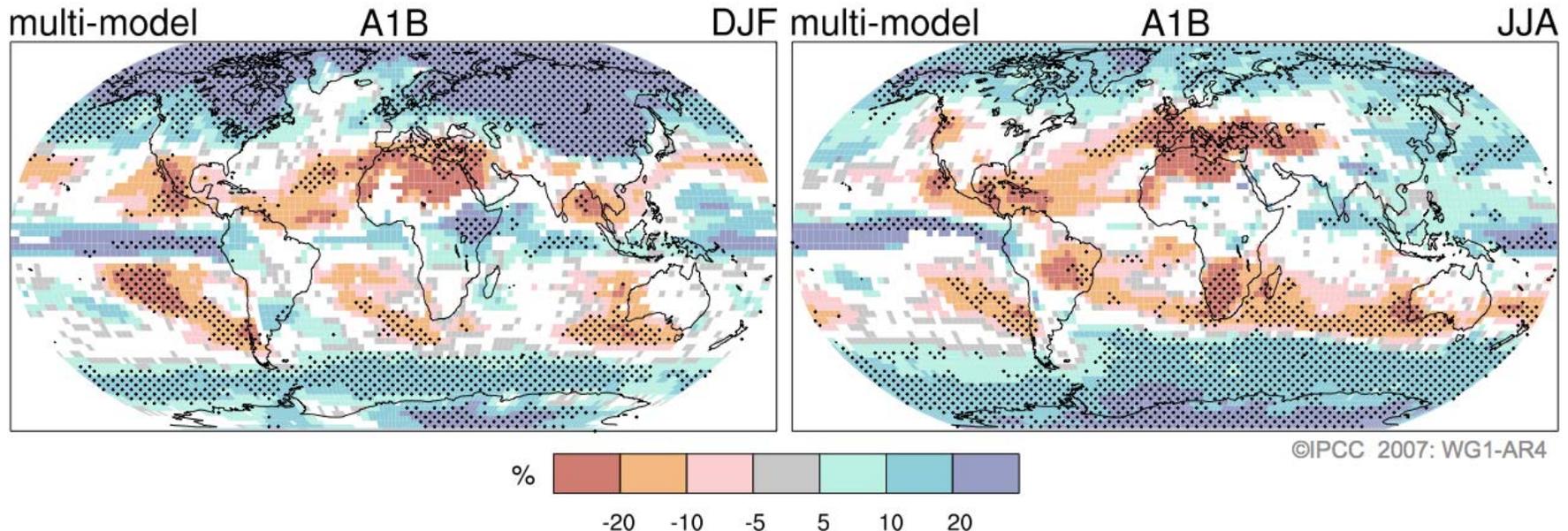
**greatest over land
and at most high
northern latitudes**

**and least over the
Southern Ocean
and parts of the
North Atlantic
Ocean**



Projections of Future Changes in Climate

Projected Patterns of Precipitation Changes

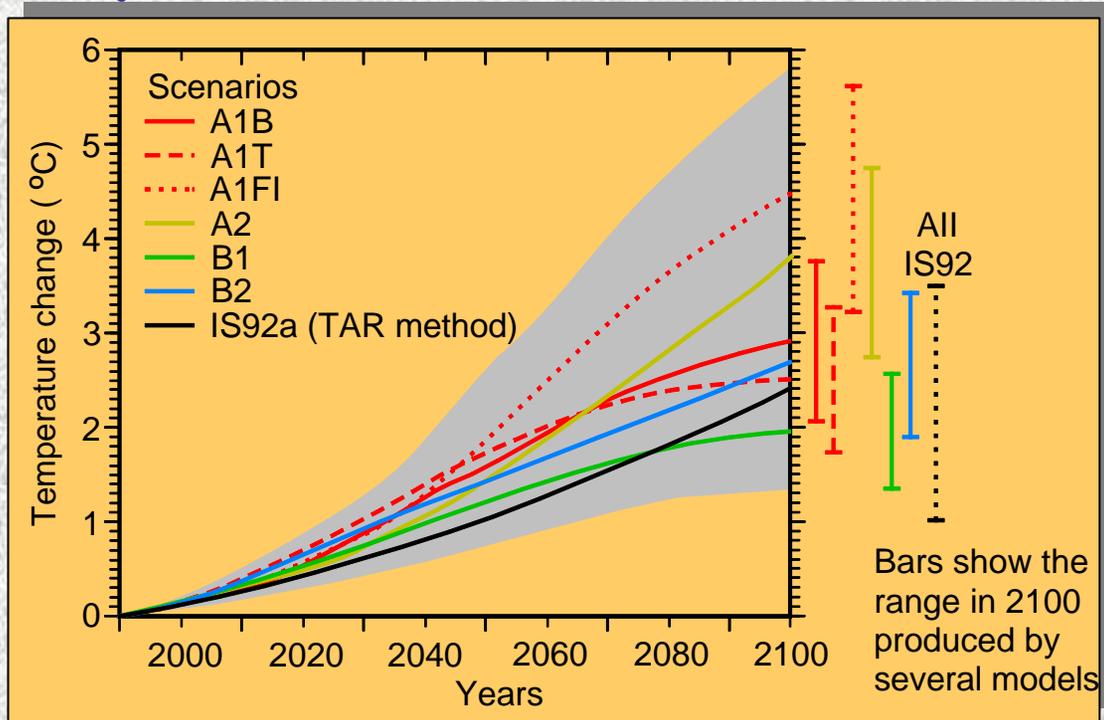


Precipitation increases very likely in high latitudes

Decreases likely in most subtropical land regions

Under All Scenarios, Next 100 Years Will Likely Be Warmer

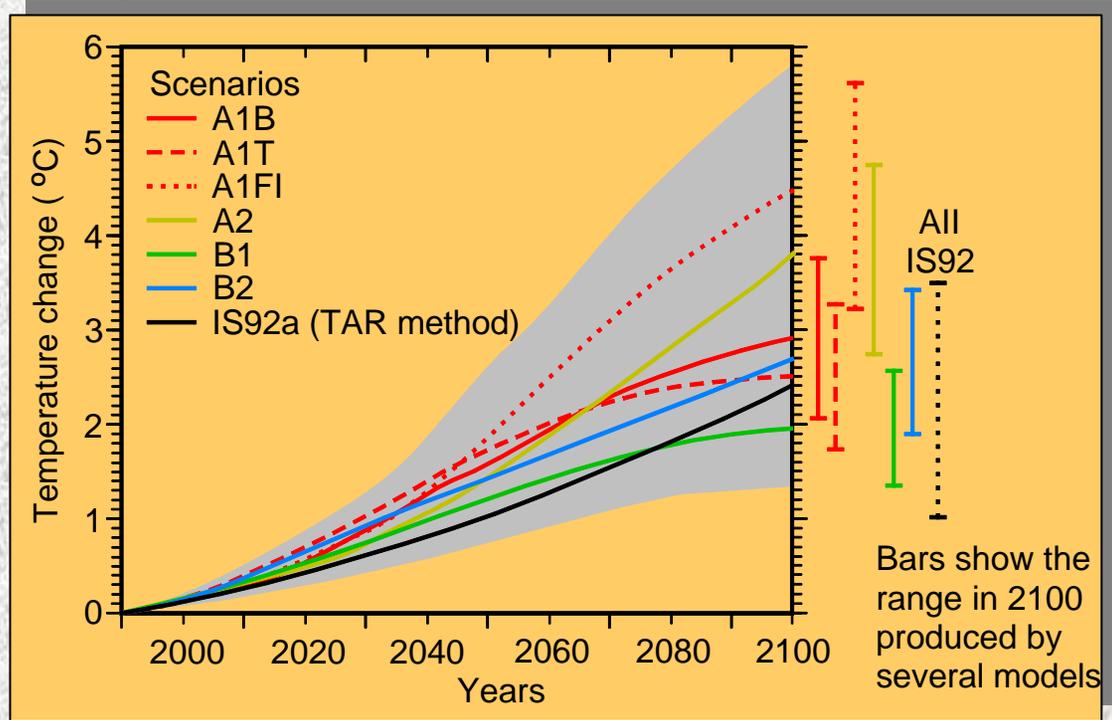
• Global mean temperature projected to rise 1.4 - 5.8 °C (3-10°F) depending on future emissions. (IPCC)



Source:
IPCC

Under All Scenarios, Next 100 Years Will Likely Be Warmer

- The mid-range of the estimates, a 5.4°F increase, is enough to make:
- Aspen as warm as Flagstaff
- Missoula as warm as Denver
- Reno as warm as Albuquerque



Source:
IPCC

North American temperature projections

- Annual mean warming *likely* to exceed global warming
- Warming *likely* to be largest in winter months in northern regions and in summer months in southwest
- Cold temperatures *likely* to be less extreme everywhere
- Maximum temperatures *likely* to be pronounced in southwest

North American precipitation projections

- Annual mean precipitation *very likely* to increase in Canada and northeast and *likely* to decrease in the southwest
- Snow season length and depth *very likely* to decrease in most of North America

Western Water

- 70-80% of our precipitation comes as snow
- Up to 90% of our runoff comes from snowmelt
- The snowpack is a convenient, as well as critical storage mechanism
- Altering the timing and volume of this reservoir has immediate and profound implications across the West

Changes in seasonal snow regimes

Western North America shows

- Earlier onset of spring
- Warmer winters and springs
- More fall precipitation as rainfall
- Reduced maximum snowpacks
- Earlier snowmelt and runoff
- Earlier "green-up" in spring

Managing Expectations

- Assumptions of stationarity are invalid
 - Changing means and variance
- We are playing a game of prediction where our best information comes from reducing uncertainty
- Physically-based models offer the best opportunities to forecast the future
- All models are wrong - some are useful

Conclusions

- Climate is changing
 - Temperature and atmospheric CO_2 will continue to increase
 - Precipitation patterns and amounts will change
- Climate change is uncertain and subject to many interacting factors, but it is real
- Feedbacks and interactions make planning challenging
- Our knowledge base is shifting
- Management must be tailored to local conditions
- A "learn as we go" strategy will be necessary
- Collaboration, cooperation, and communication between managers and scientists will result in the best response to climate change issues

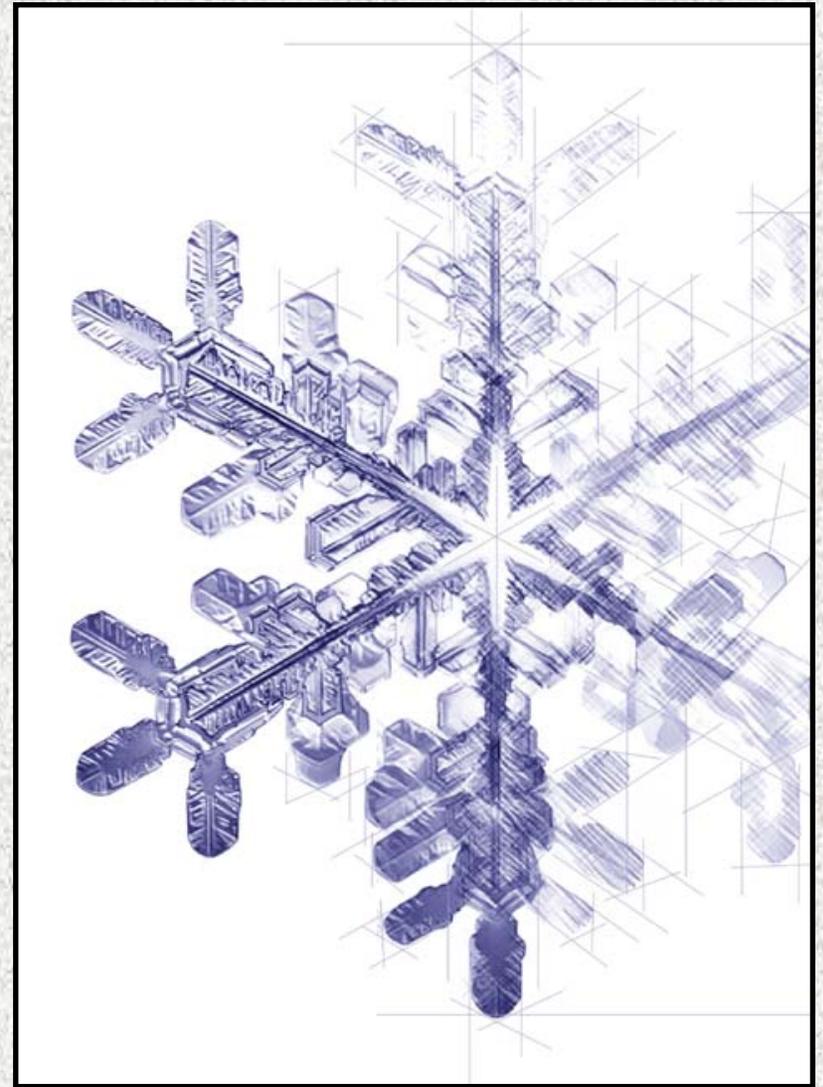
Questions?



Thank You!

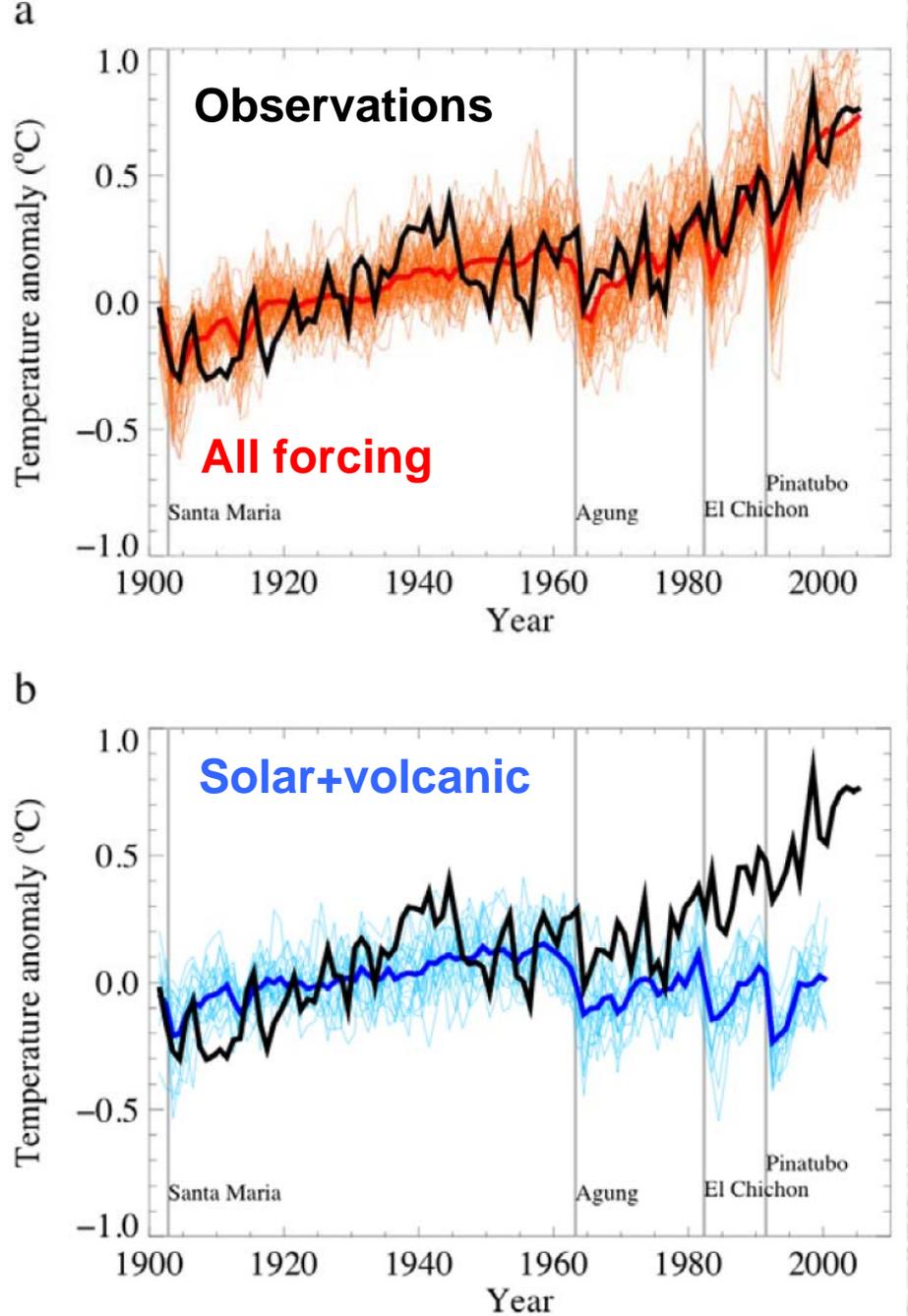


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Attribution

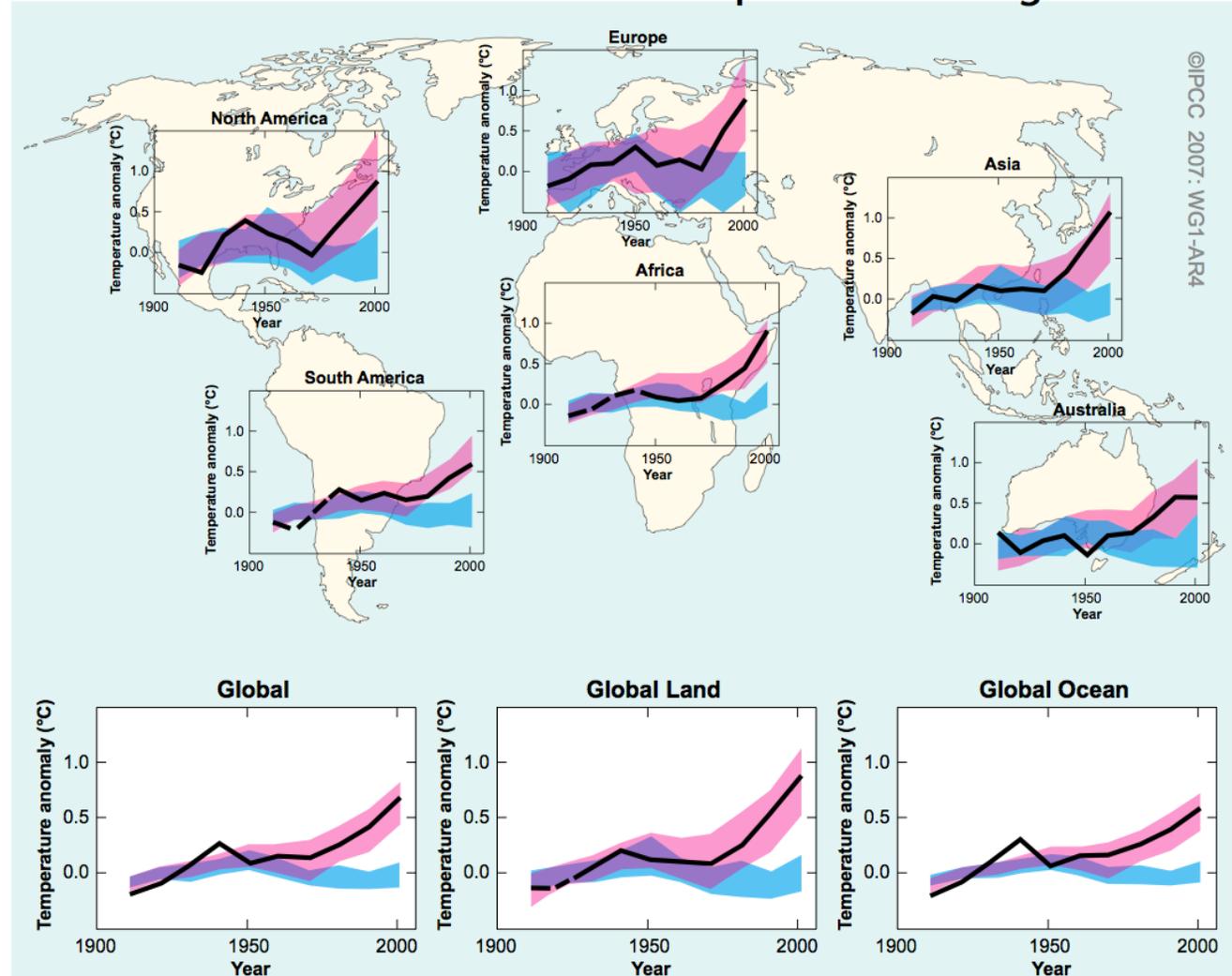
- observed changes consistent with
 - expected responses to forcings
 - inconsistent with alternative explanations



Understanding and Attributing Climate Change

Continental warming
likely shows a significant anthropogenic contribution over the past 50 years

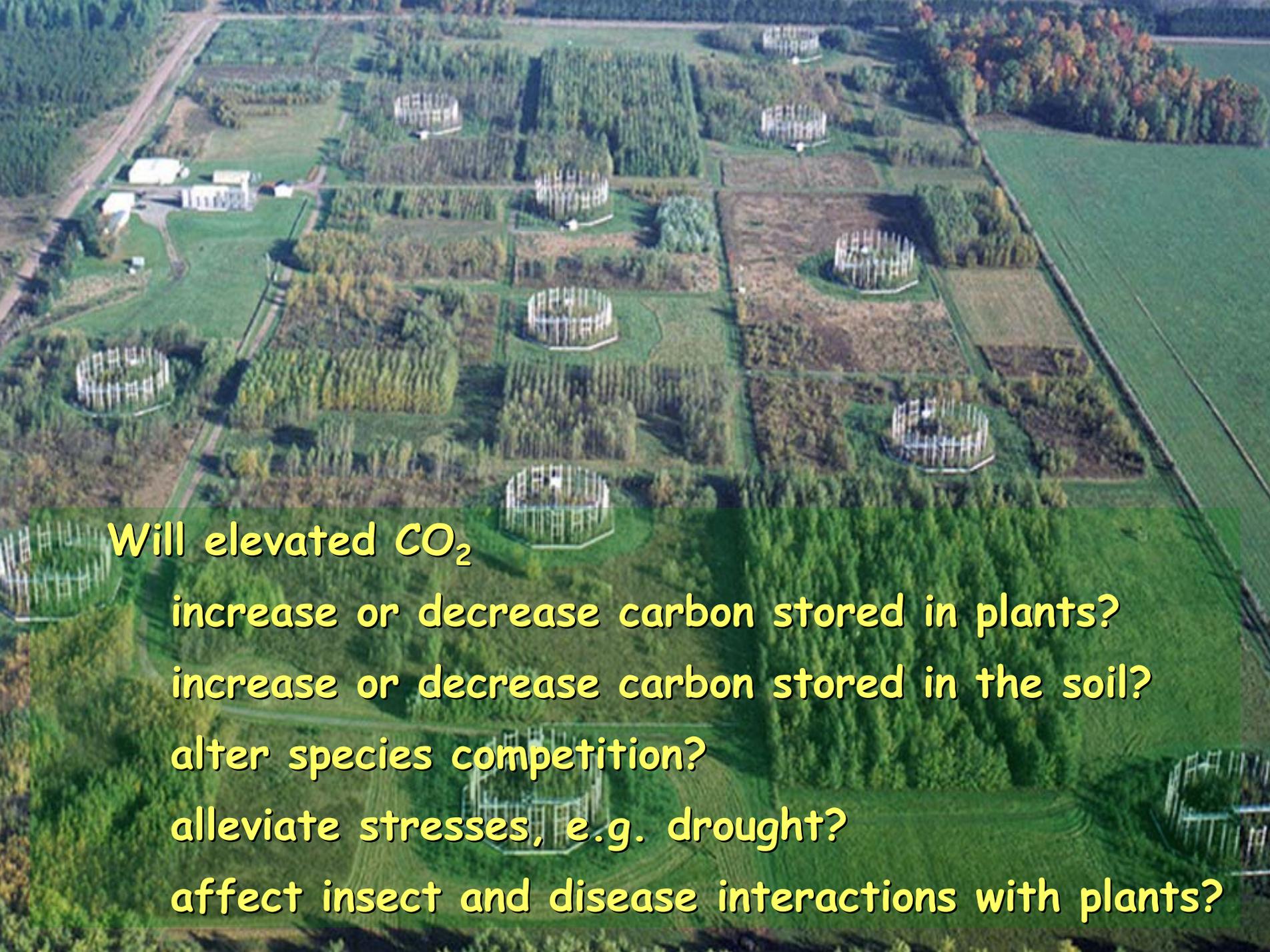
Global and Continental Temperature Change



Direct CO₂ Effects on Plants

Carbon dioxide is the substrate of photosynthesis, and as the substrate concentration increases, so does the reaction rate.

This analysis, however, is highly simplistic.



Will elevated CO_2

increase or decrease carbon stored in plants?

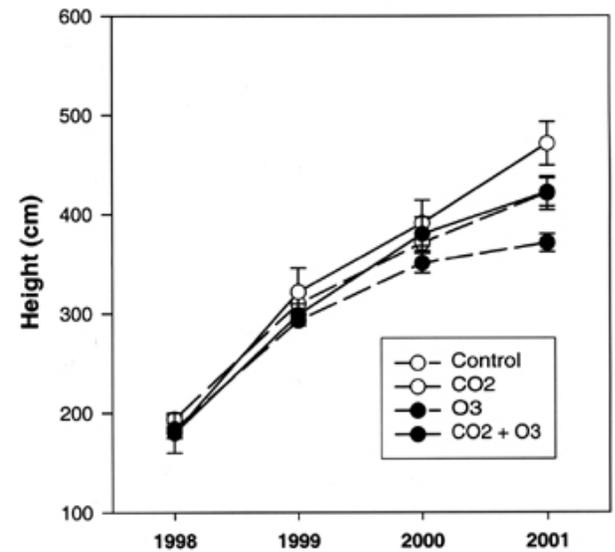
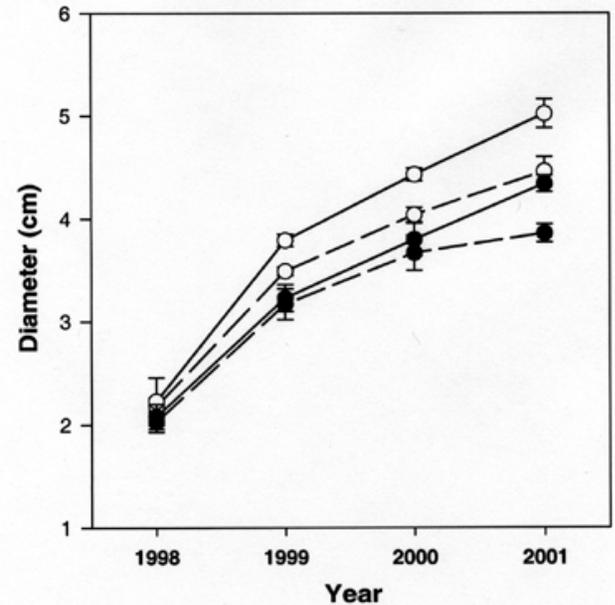
increase or decrease carbon stored in the soil?

alter species competition?

alleviate stresses, e.g. drought?

affect insect and disease interactions with plants?

- Doubling CO_2 concentration results in significantly increased aspen tree growth
- However pollutants (such as O_3) may reduce CO_2 fertilization effect



Response of Trees to Elevated CO₂

- Photosynthetic rates increase, up to 60%
 - But sensitive to nutrient availability
- Little evidence of rate decline over time
- Increased water use efficiency
 - But sensitive to water availability
- Possible increased fine root production