



# Climate Change in the Great Lakes Region

## Starting a Public Discussion

# Global Warming Is Unequivocal

Kevin Trenberth

Senior Scientist, National Center for Atmospheric Research



# Global Warming is unequivocal

- ❖ The recent IPCC report has clearly stated that “Warming of the climate system is unequivocal” and it is “very likely” caused by human activities.
- ❖ Moreover, most of the observed changes are now simulated by models over the past 50 years adding confidence to future projections.

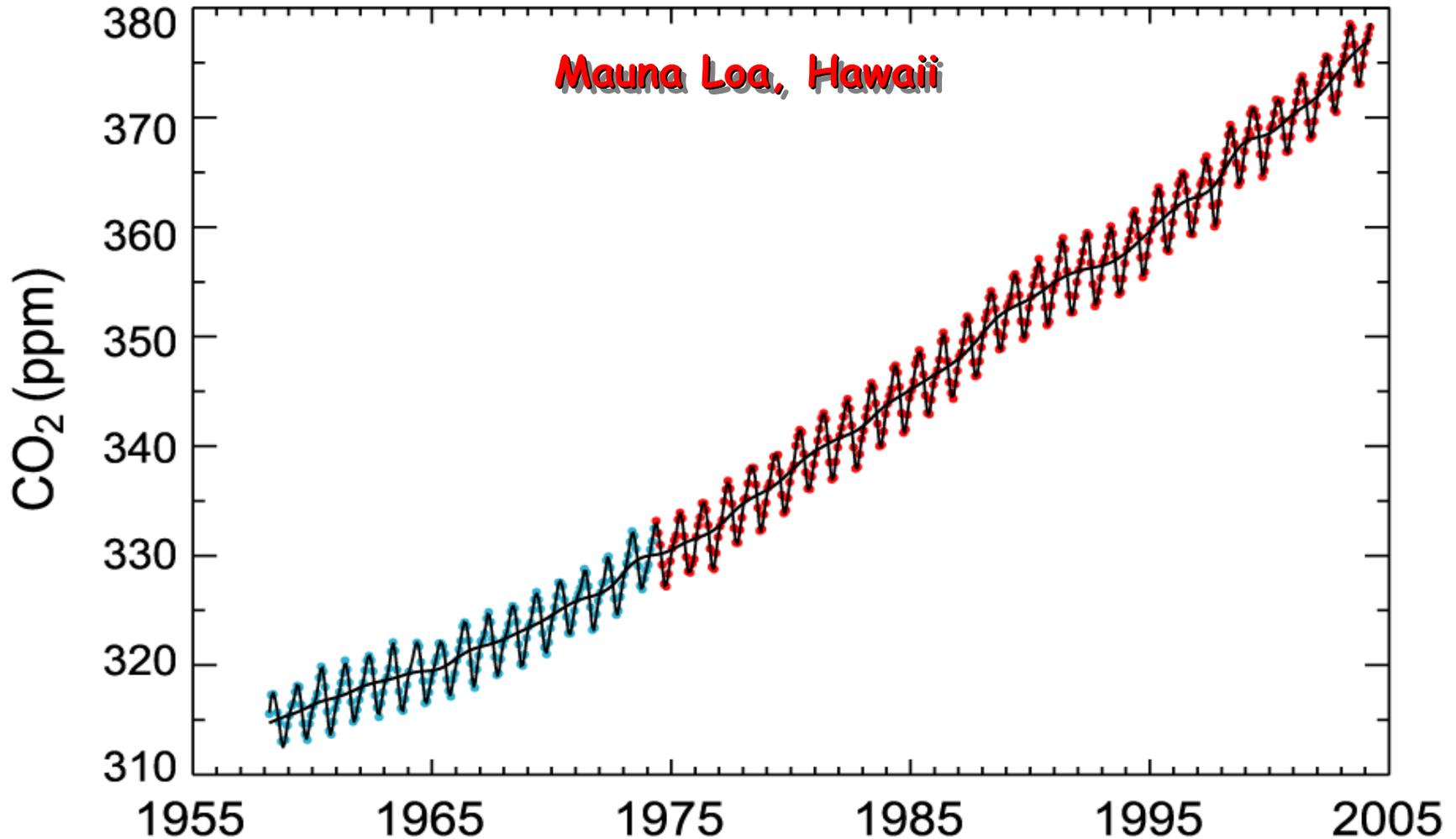
## Climate

The atmosphere is a "global commons."  
Air over one place is typically half way round the world a week later, as shown by manned balloon flights.



The atmosphere is a dumping ground for all nations for pollution of all sorts. Some lasts a long time and is shared with all. **One consequence is global warming!**

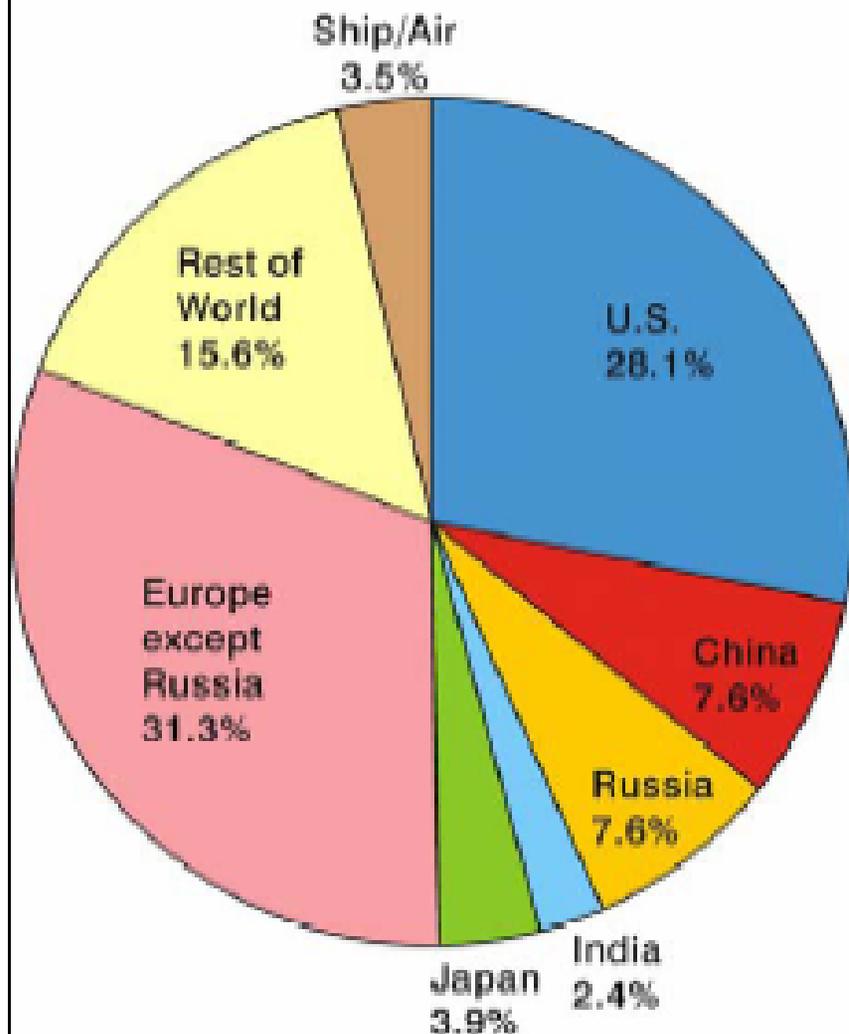
# Changing atmospheric composition: CO<sub>2</sub>



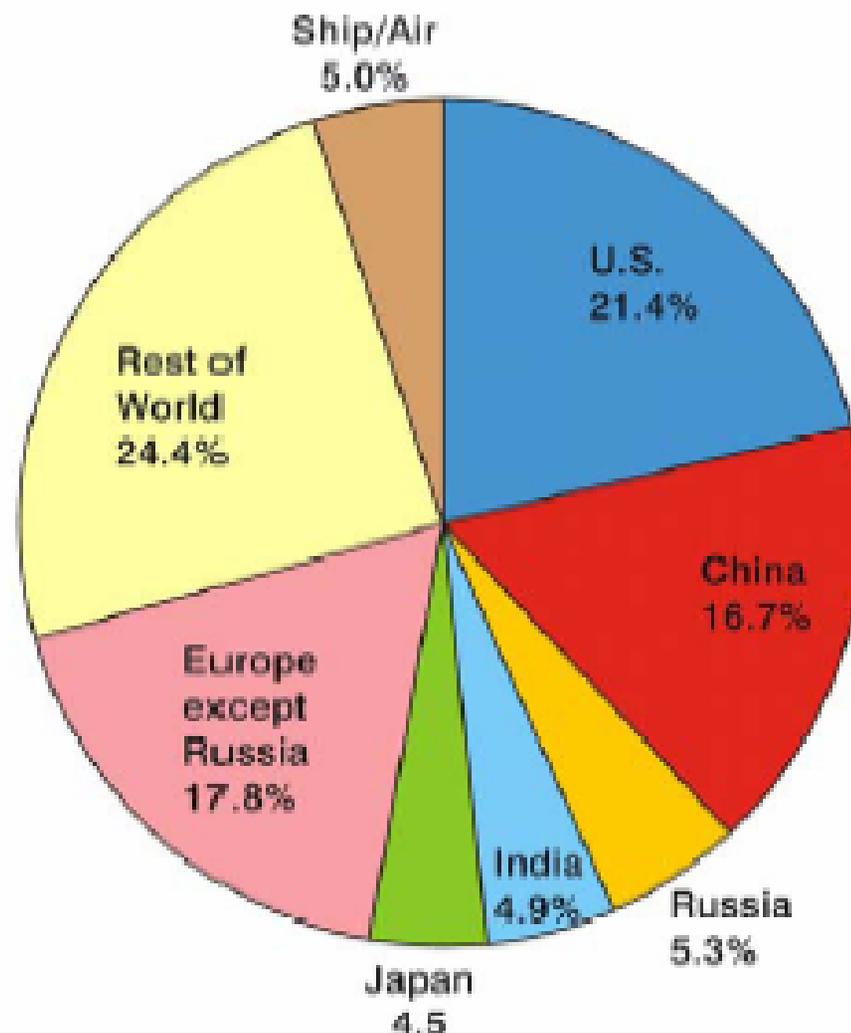
Data from Climate Monitoring and Diagnostics Lab., NOAA.  
Data prior to 1973 from C. Keeling, Scripps Inst. Oceanogr.

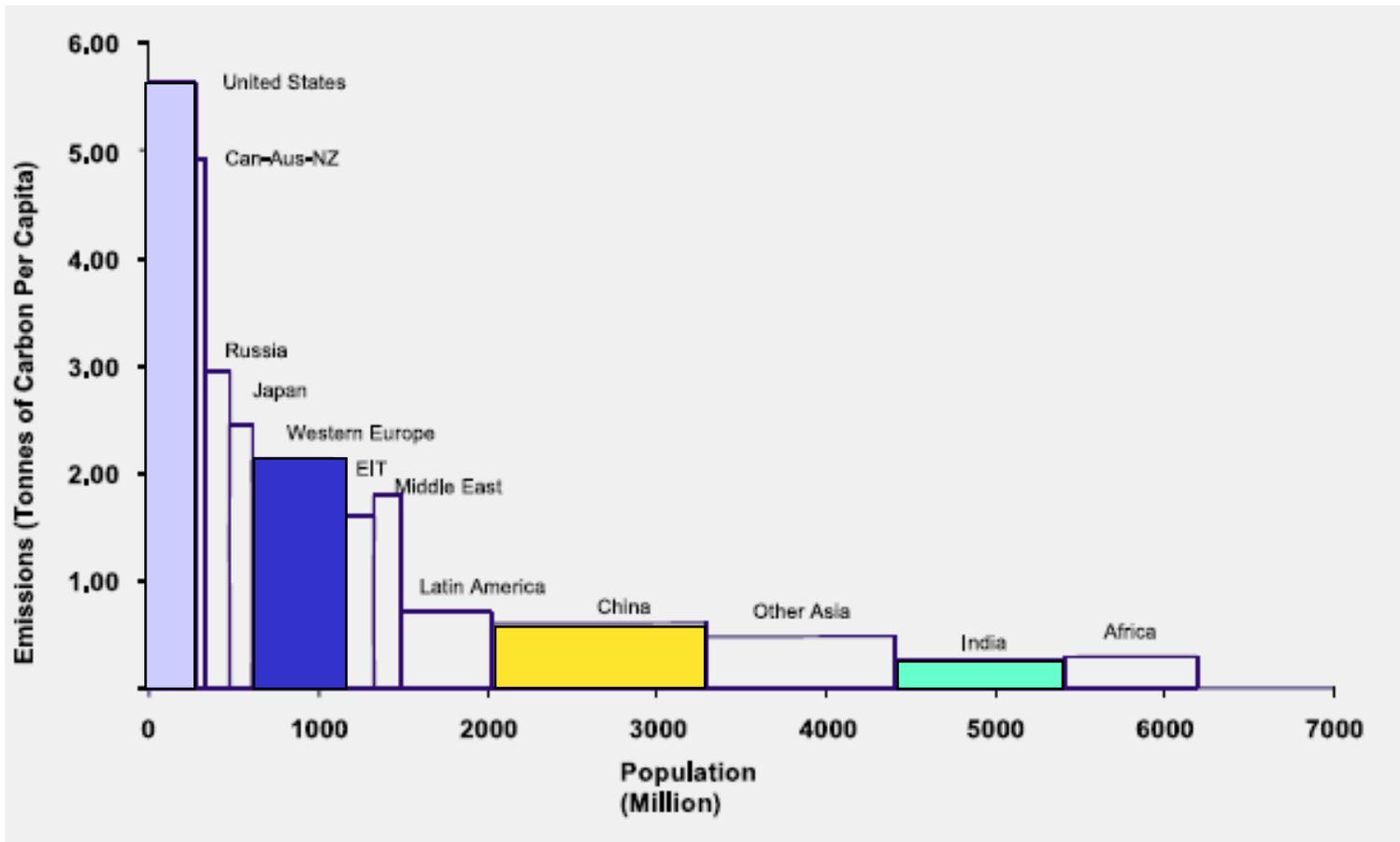
# Fossil Fuel CO<sub>2</sub> Emissions

Accumulated Fossil Fuel CO<sub>2</sub> (1850-2004)



2004 Portions of CO<sub>2</sub> Emissions

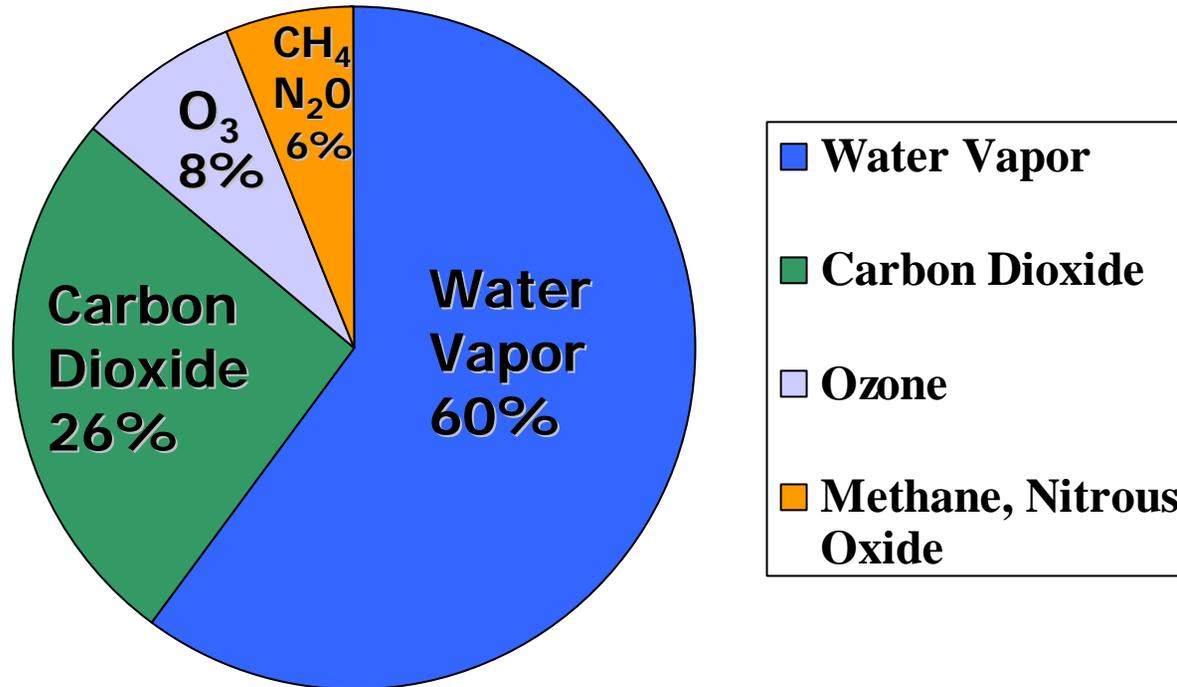




***CO2 emissions in different regions in 2000 in terms of emissions per capita (height of each block); population (width of each block); and total emissions (product of population and emissions per capita = area of block).***

Source: M. Grubb, <http://www.eia.doe.gov/iea/>

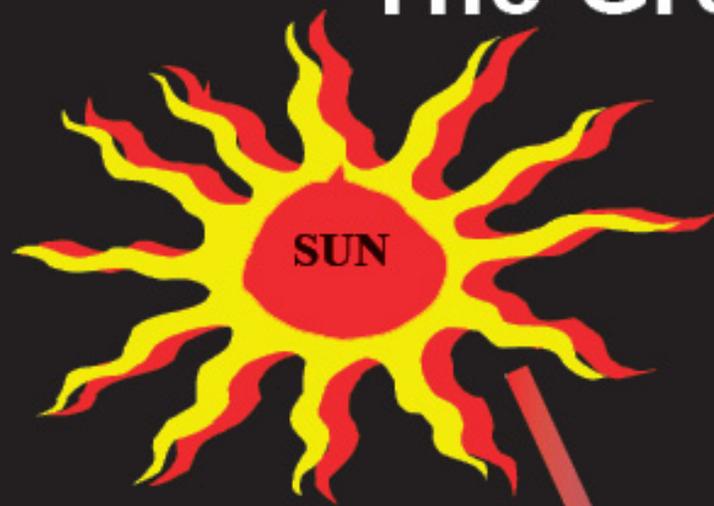
# The Natural Greenhouse Effect: clear sky



Clouds also have a greenhouse effect

Kiehl and Trenberth 1997

# The Greenhouse Effect



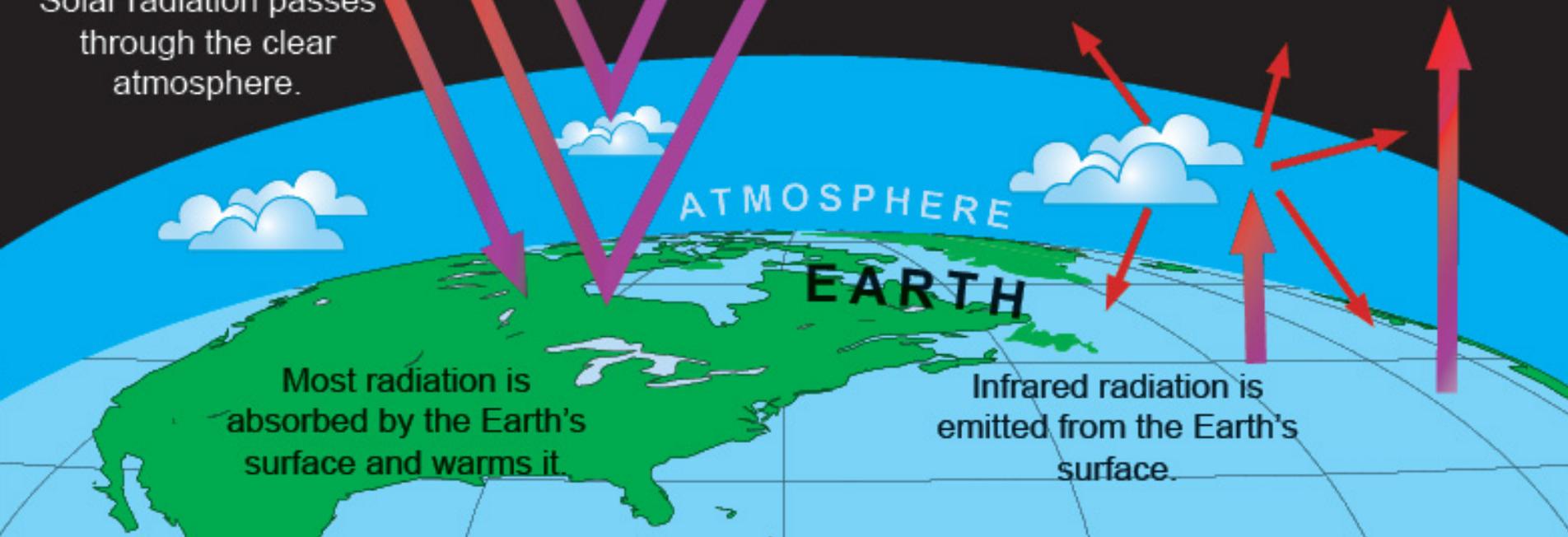
Some solar radiation is reflected by the Earth and the atmosphere.

Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.

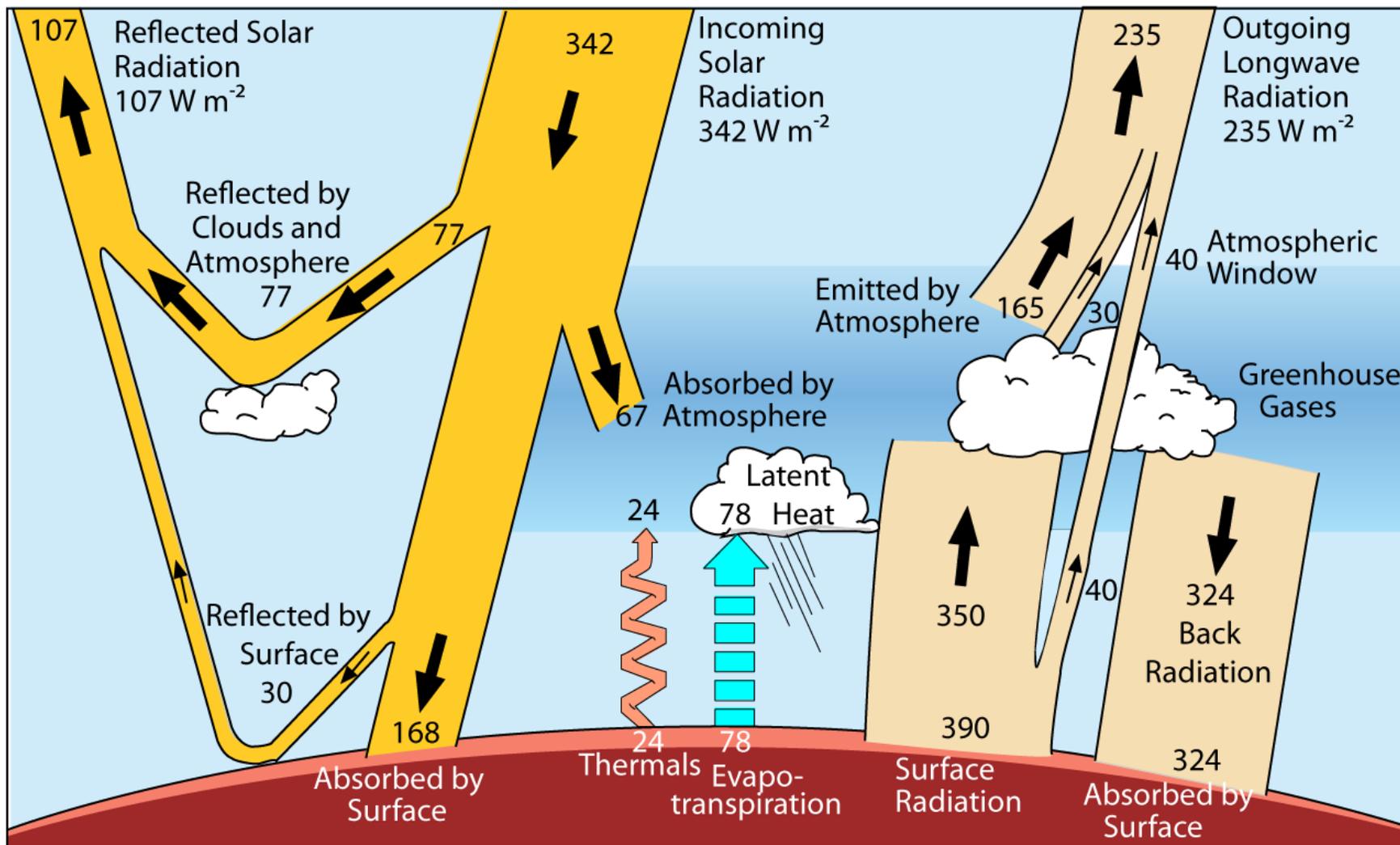
Solar radiation passes through the clear atmosphere.

Most radiation is absorbed by the Earth's surface and warms it.

Infrared radiation is emitted from the Earth's surface.

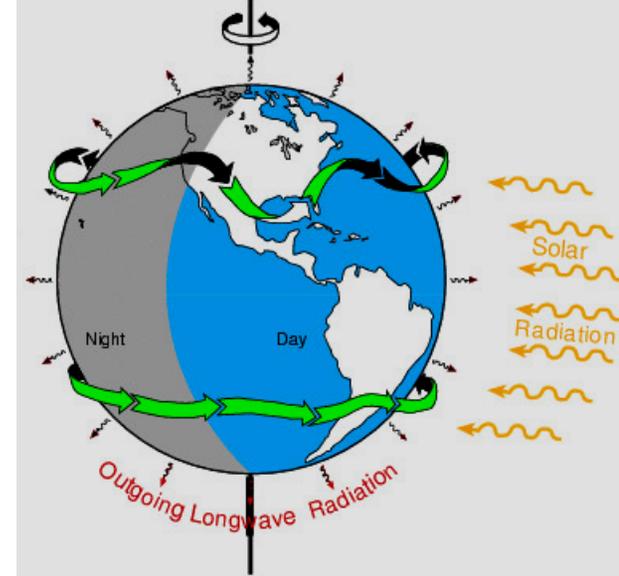


# Global Heat Flows



*Kiehl and Trenberth 1997*

The incoming energy from the sun is  $342 \text{ W m}^{-2}$ : annual global mean:  
It amounts to 175 PetaWatts  
=175,000,000 billion Watts.  
About 120 PW is absorbed.



The biggest power plants in existence are 1000 MegaWatts and we normally think of units of 1 KiloWatt (= 1 bar heater), or a 100 W light bulb.

So the energy from the sun is 120 million of these power stations. It shows:

- 1) Direct human influences are tiny vs nature.
- 2) The main way human activities can affect climate is through interference with the natural flows of energy such as by changing the composition of the atmosphere

# Global Warming is unequivocal

## Since 1970, rise in:

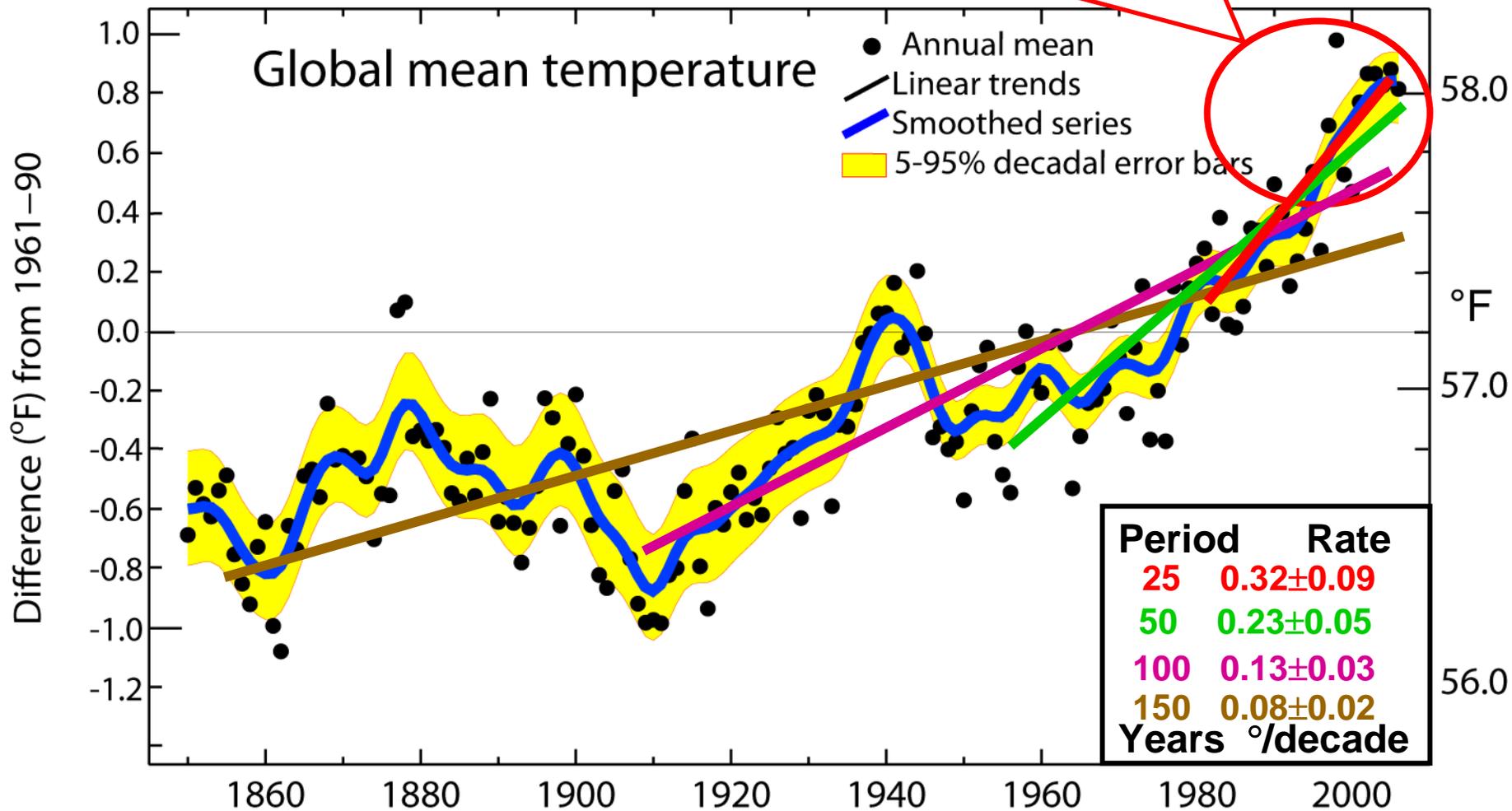
- ❖ Global surface temperatures
- ❖ Tropospheric temperatures
- ❖ Global SSTs, ocean Ts
- ❖ Global sea level
- ❖ Water vapor
- ❖ Rainfall intensity
- ❖ Precipitation extratropics
- ❖ Hurricane intensity
- ❖ Drought
- ❖ Extreme high temperatures
- ❖ Heat waves

## Decrease in:

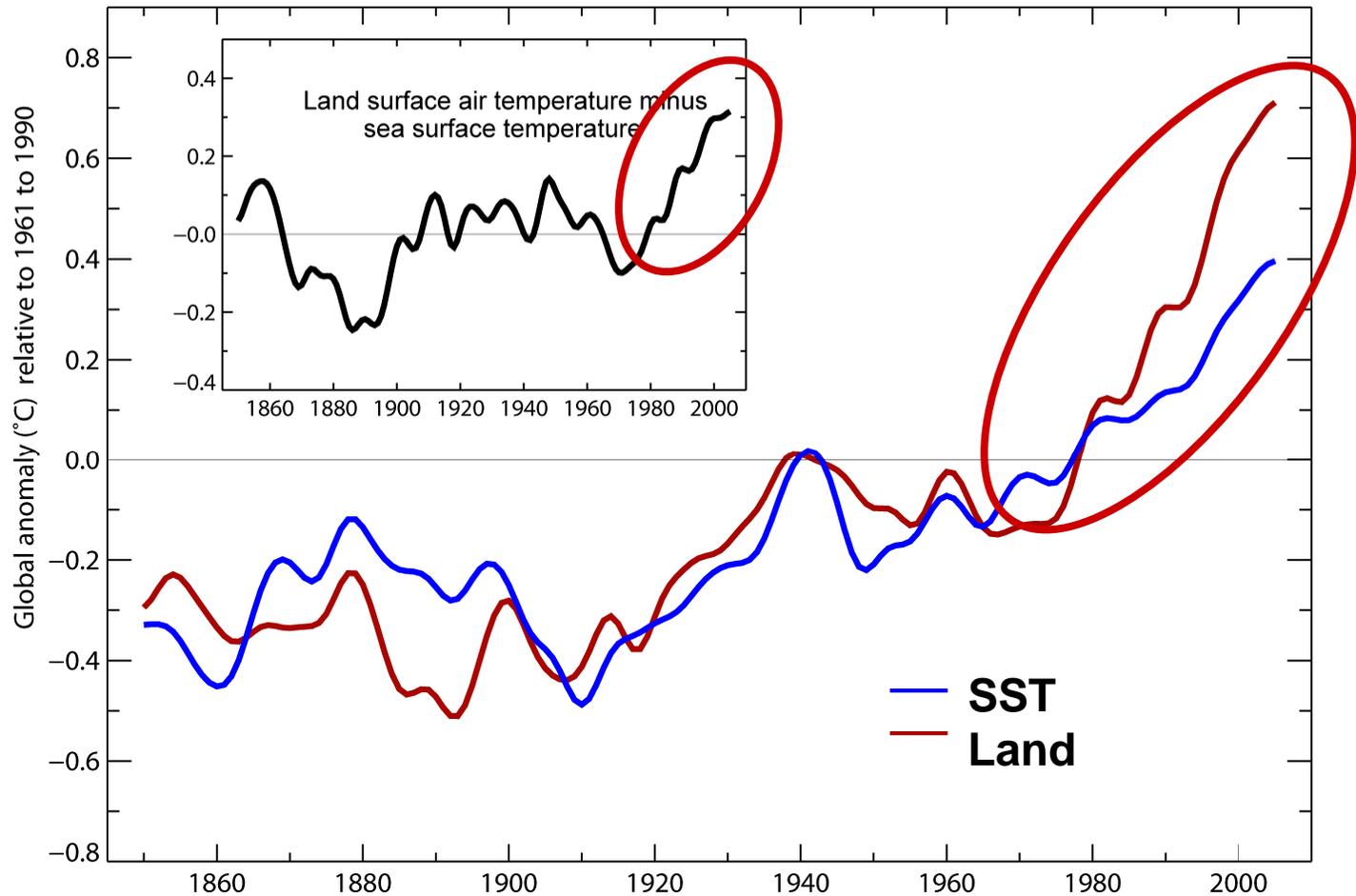
- NH Snow extent
- Arctic sea ice
- Glaciers
- Cold temperatures

# Global mean temperature difference from 1961-90 time

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



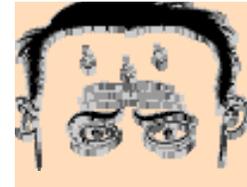
# Land surface temperatures are rising faster than SSTs



Annual anomalies of global average SST and land surface air temperature

# Controlling Heat

Human body: sweats



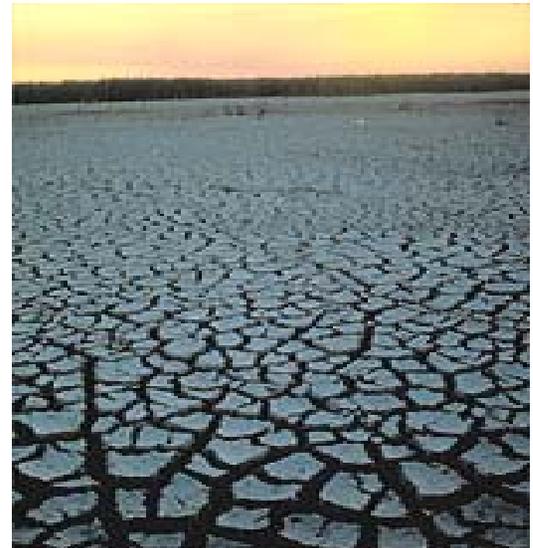
Homes: Evaporative coolers (swamp coolers)

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.

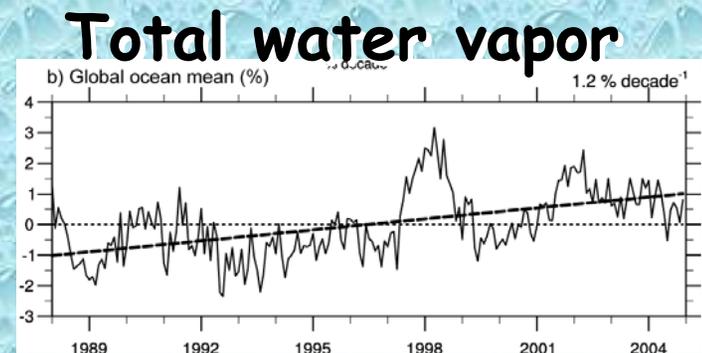


# Air holds more water vapor at higher temperatures

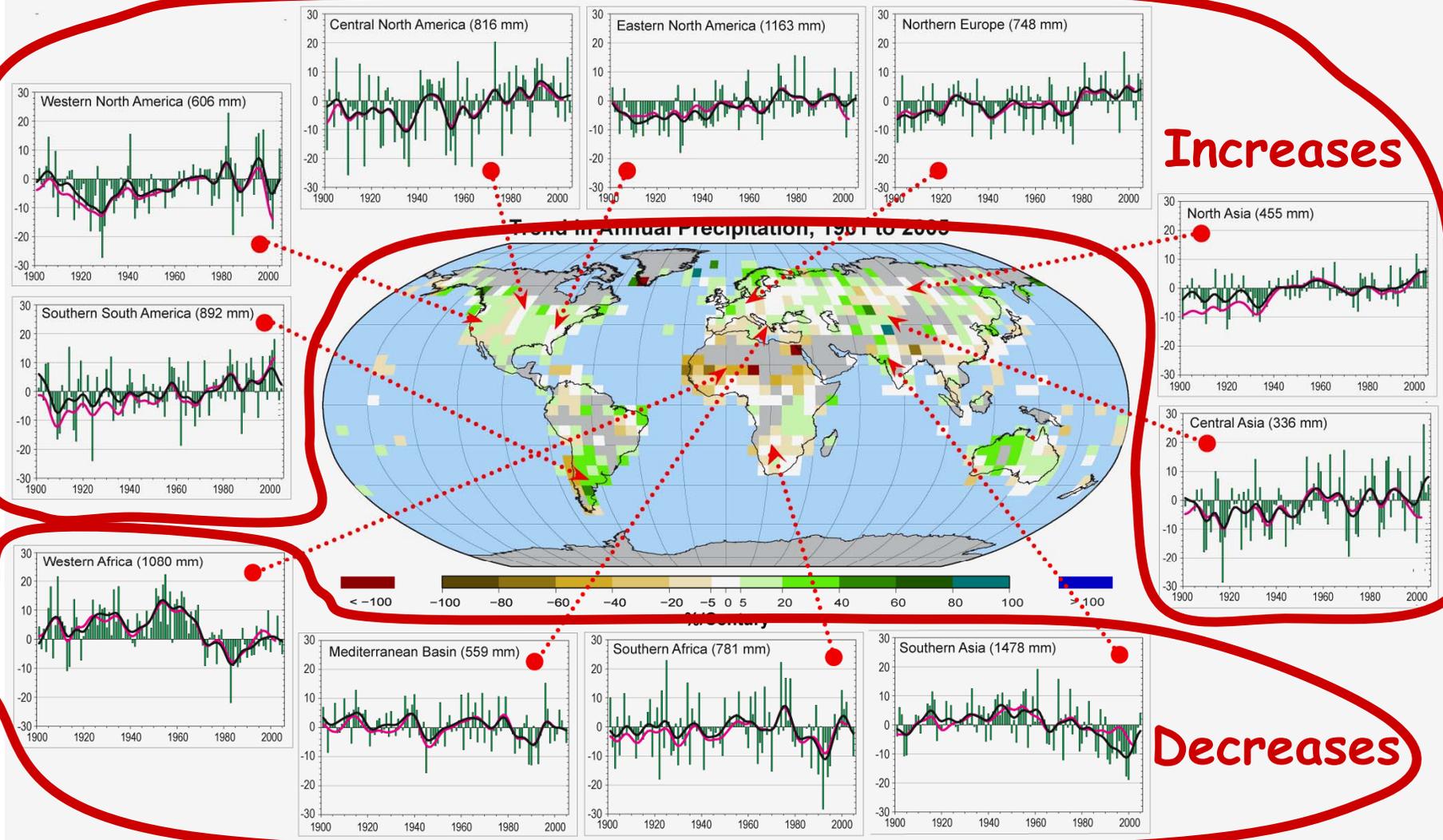
A basic physical law tells us that the water holding capacity of the atmosphere goes up at about **4% per degree Fahrenheit increase in temperature.**

Observations show that this is happening at the surface and in lower atmosphere: **1.0°F since 1970 over global oceans and 4% more water vapor.**

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

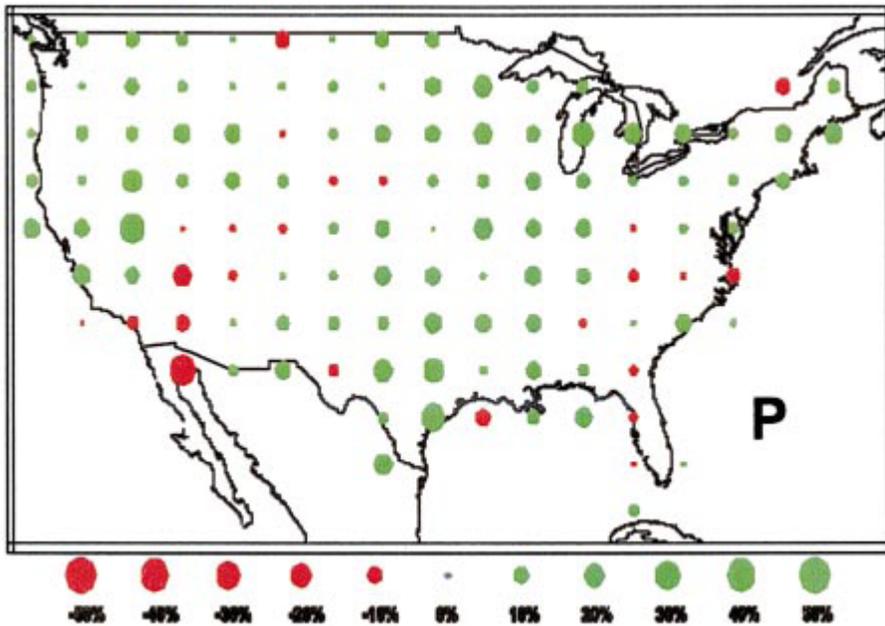


# Land precipitation is changing significantly over broad areas



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

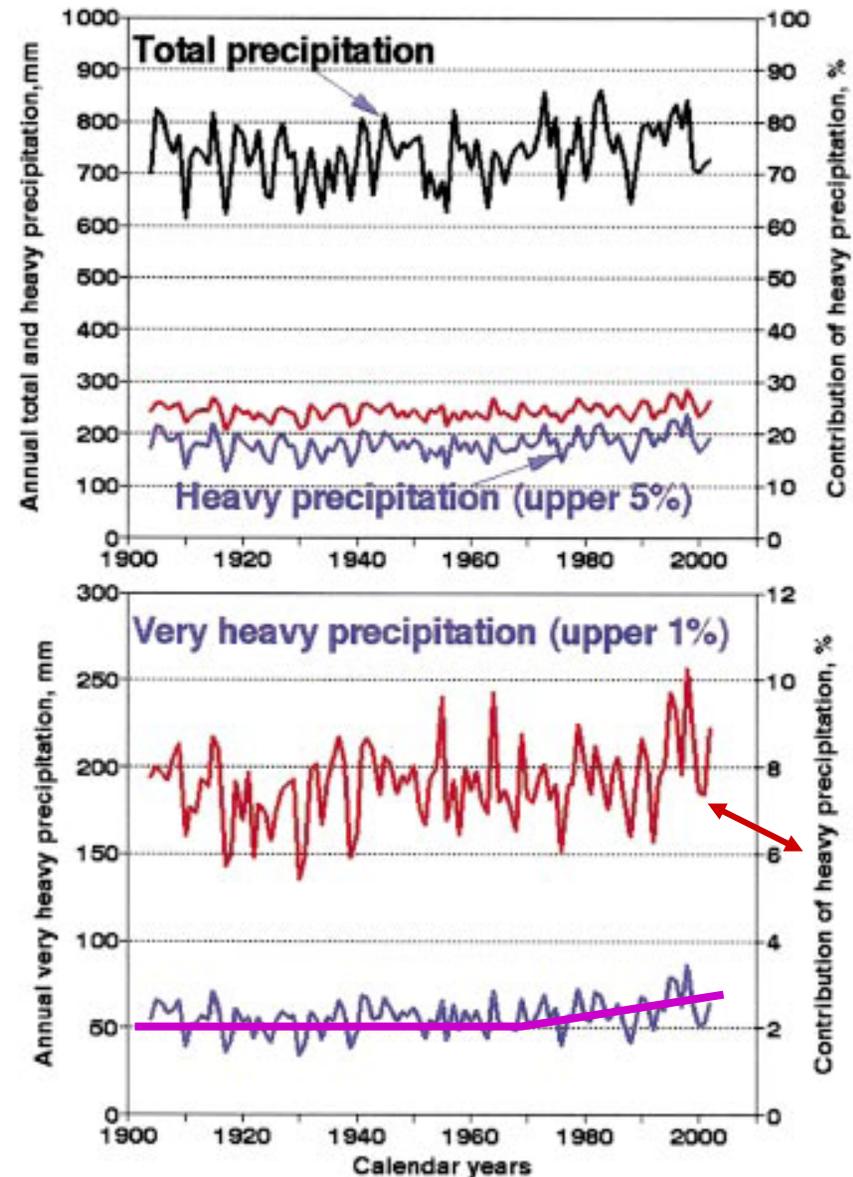
# Changes in U.S. precipitation 1900 to 2002



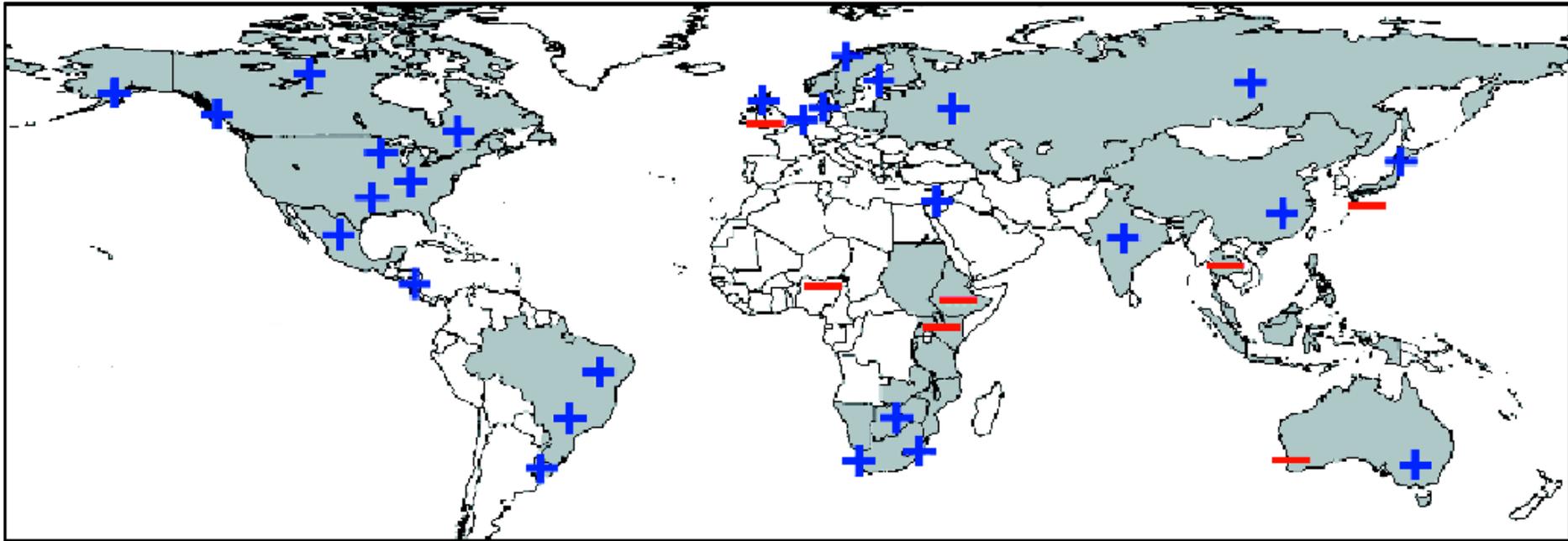
Changes in total, heavy, and very heavy precipitation over contiguous U.S.

Linear trends are up and significant\*: 7, 14, 20% /century

\*at 1 %: Groisman et al 2004



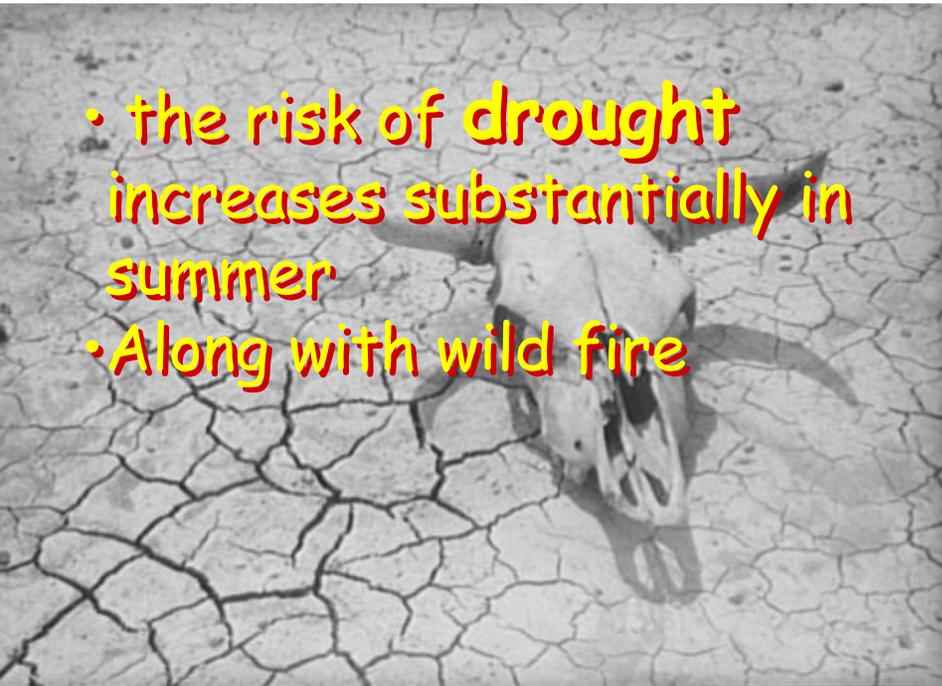
## Proportion of heavy rainfalls: increasing in most land areas



Regions of disproportionate changes in heavy (95<sup>th</sup>) and very heavy (99<sup>th</sup>) precipitation

# Declining Snow Pack in many mountain and continental areas contributes to drought

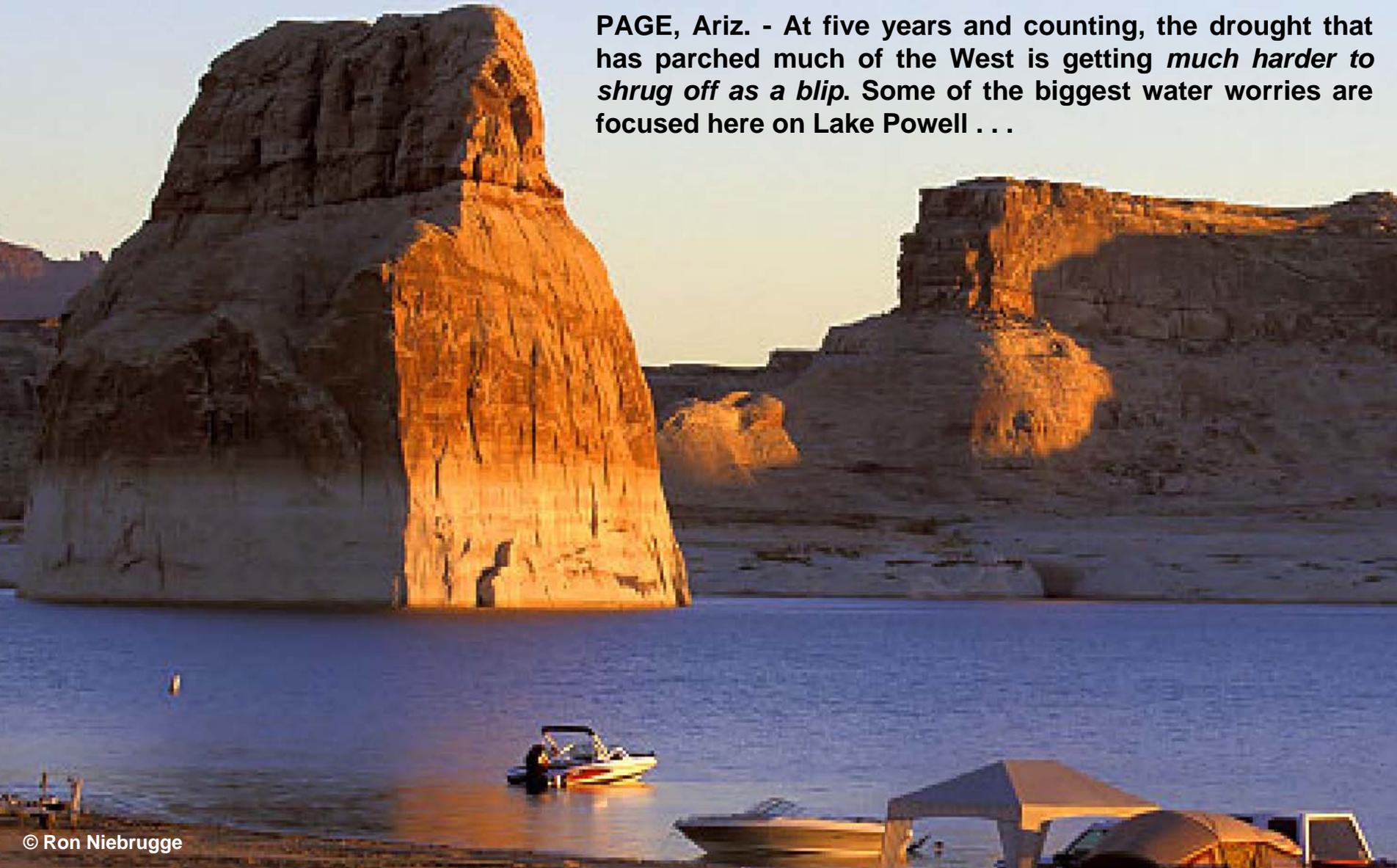
- more **precipitation** falls as **rain** rather than **snow**, especially in the fall and spring.
- **snow melt** occurs faster and sooner in the spring
- **snow pack** is therefore less
- **soil moisture** is less as summer arrives

- 
- the risk of **drought** increases substantially in **summer**
  - Along with **wild fire**

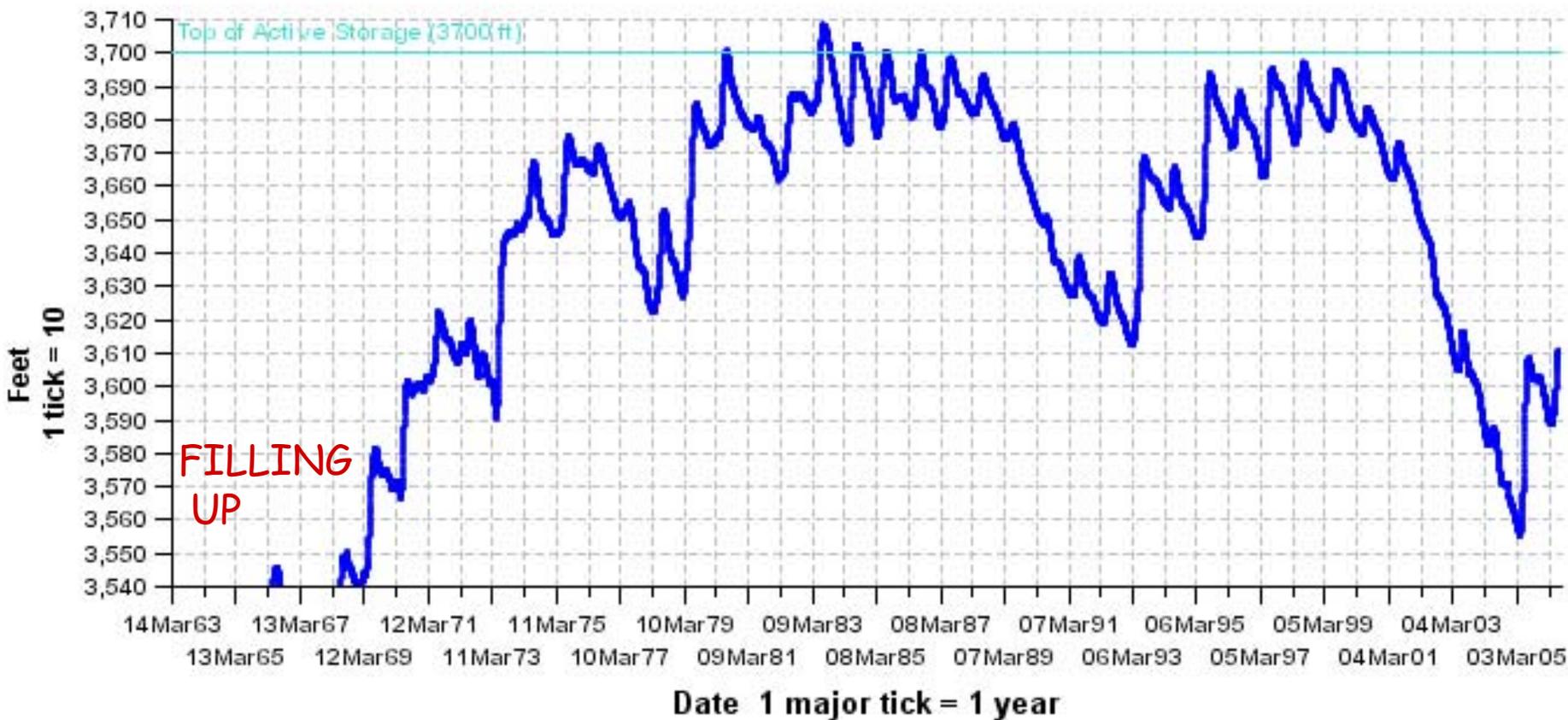


## Drought Settles In, Lake Shrinks and West's Worries Grow

**PAGE, Ariz. - At five years and counting, the drought that has parched much of the West is getting *much harder to shrug off as a blip*. Some of the biggest water worries are focused here on Lake Powell . . .**



## Lake Powell Elevation Through July 26, 2006



Inflows since 2000: est 73 %

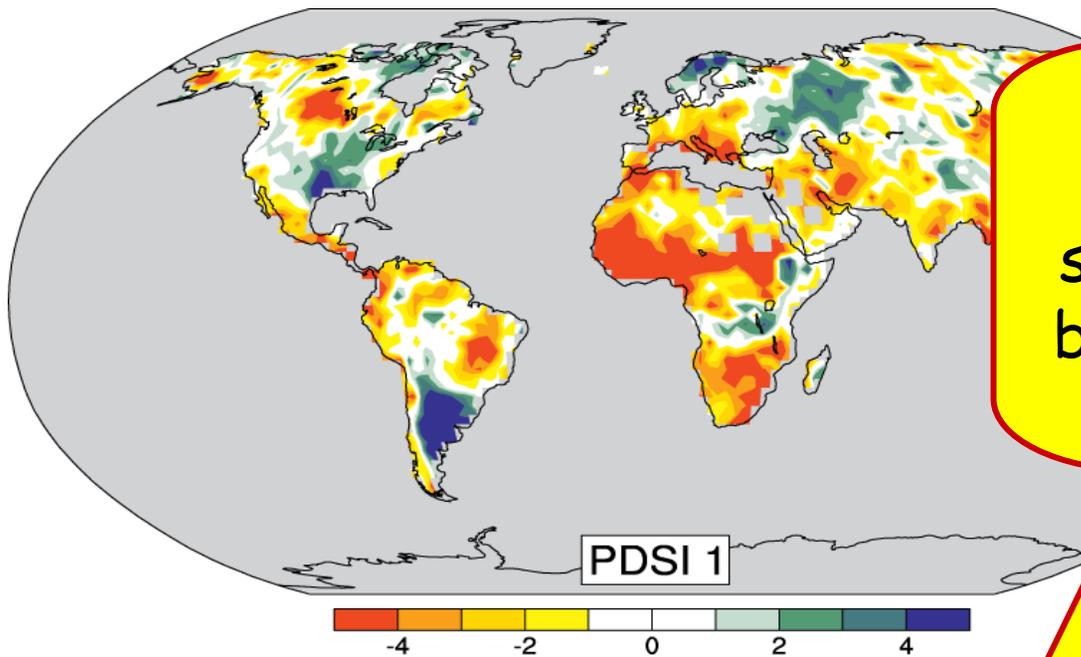
July 26, 2006: -92', 3607.7'

Min 2005 0408  
3555.1' -144.9'

[www.usbr.gov/uc/water/index.html](http://www.usbr.gov/uc/water/index.html)

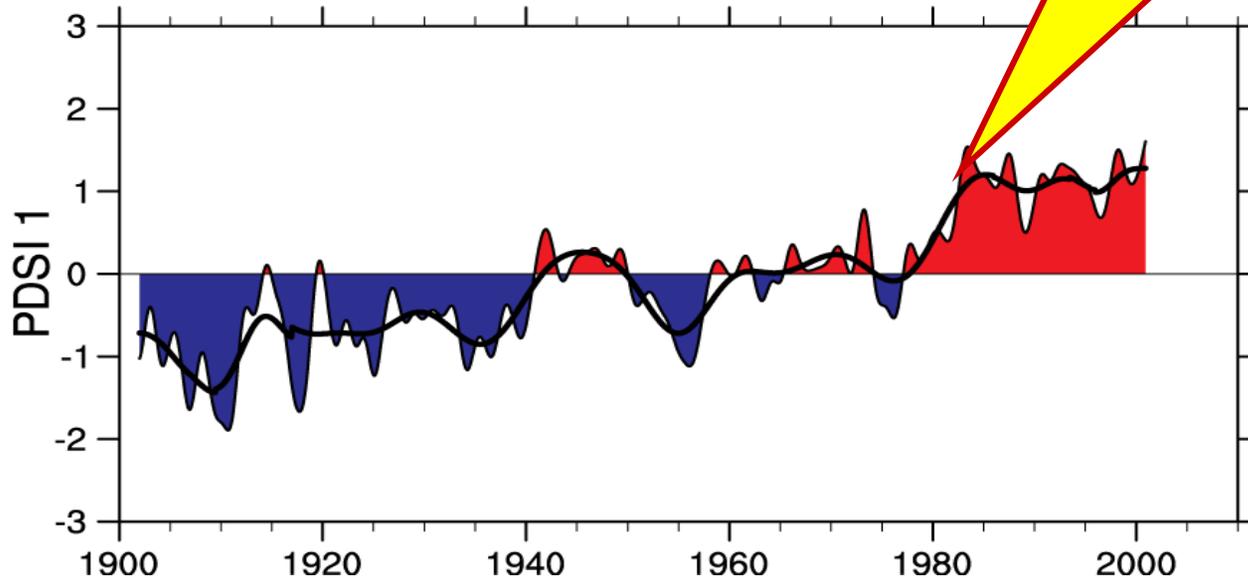
Now -2.0 inches per day

# Drought is increasing most places

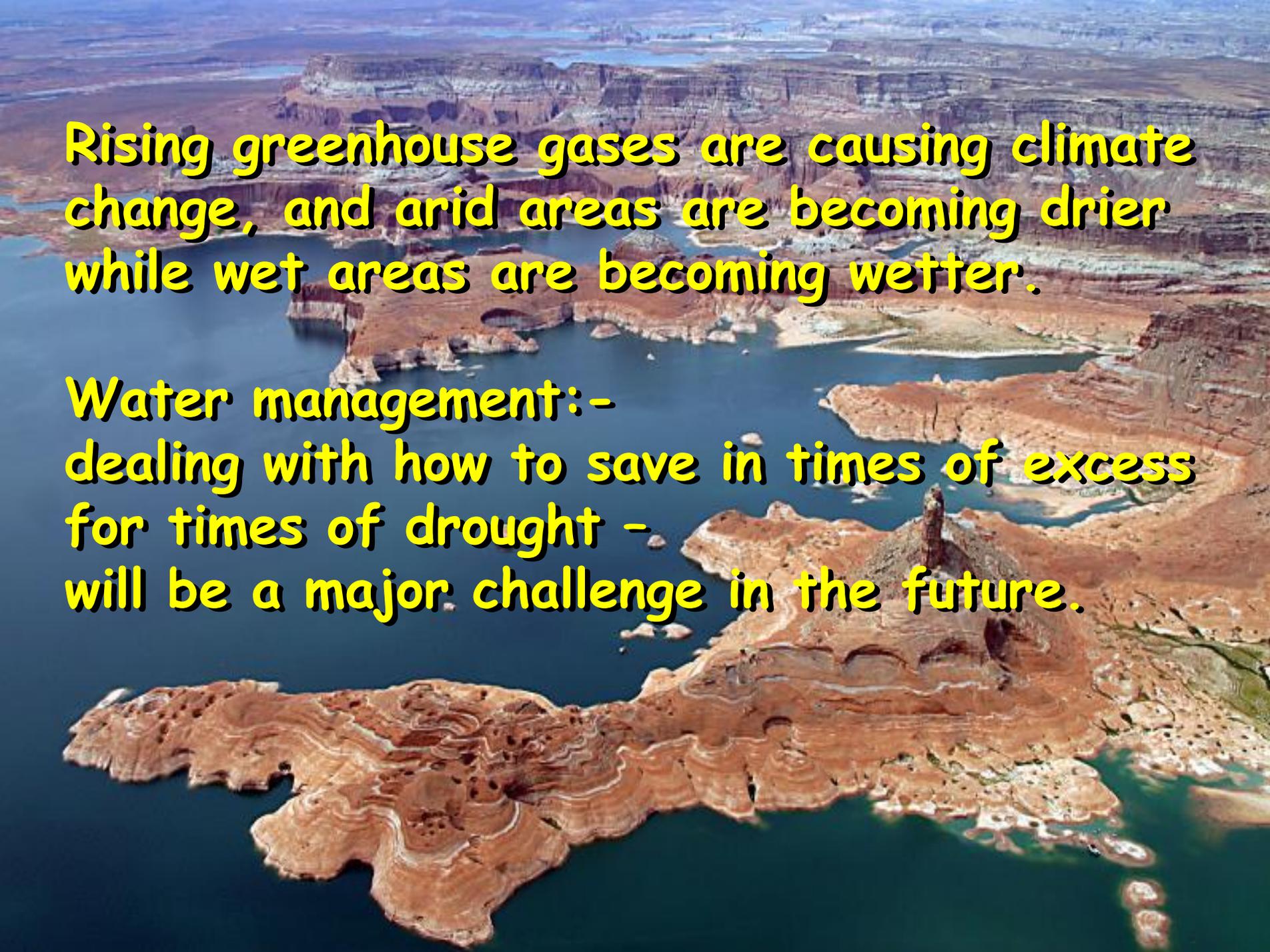


Mainly decrease in rain over land in tropics and subtropics, but enhanced by increased atmospheric demand with warming

Severity Index (PDSI) for 1900 to 2002.



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

An aerial photograph of a large reservoir, likely Lake Powell, showing the intricate, layered rock formations of the surrounding canyon. The water is a deep blue-green, and the rock is a mix of reddish-brown and tan. The text is overlaid on the upper left portion of the image.

**Rising greenhouse gases are causing climate change, and arid areas are becoming drier while wet areas are becoming wetter.**

**Water management:-  
dealing with how to save in times of excess  
for times of drought -  
will be a major challenge in the future.**

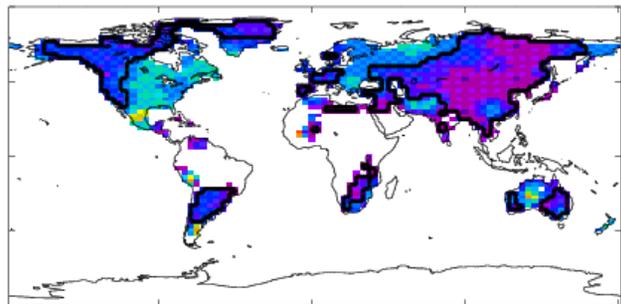
# Heat waves and wild fires

Impacts on human health and mortality, economic impacts, ecosystem and wildlife impacts

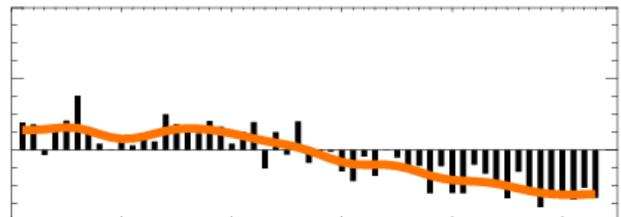


# Decadal trend (days) 1951-2003

## Cold nights

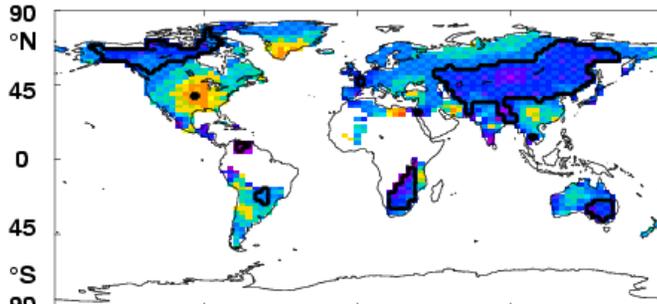


90°W 0 90°E

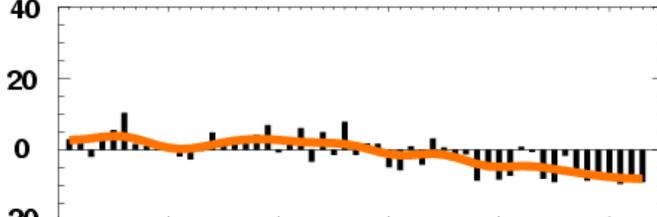


1950 1960 1970 1980 1990 2000

## Cold days

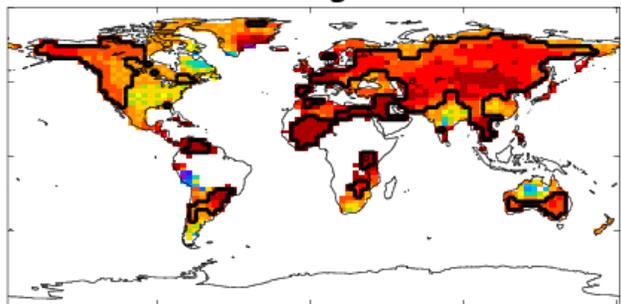


90°W 0 90°E

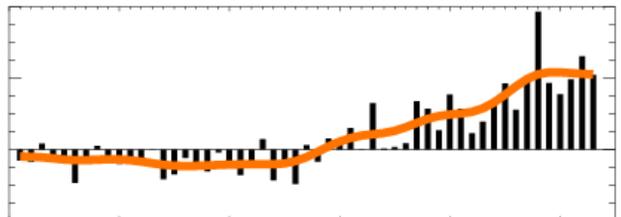


1950 1960 1970 1980 1990 2000

## Warm nights

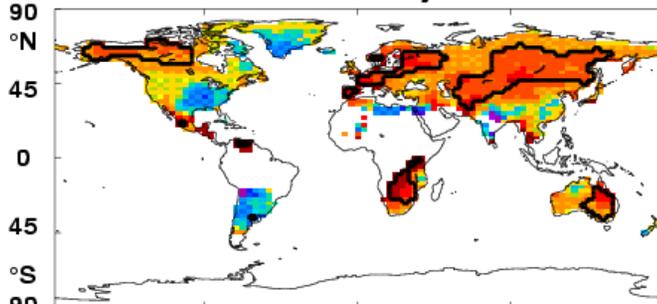


90°W 0 90°E

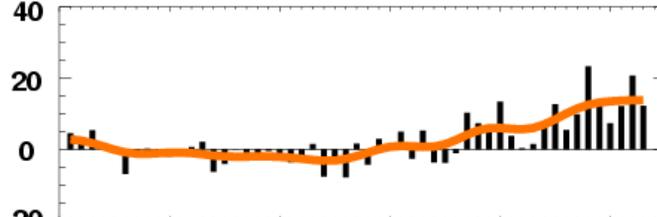


1950 1960 1970 1980 1990 2000

## Warm days



90°W 0 90°E



1950 1960 1970 1980 1990 2000



Days

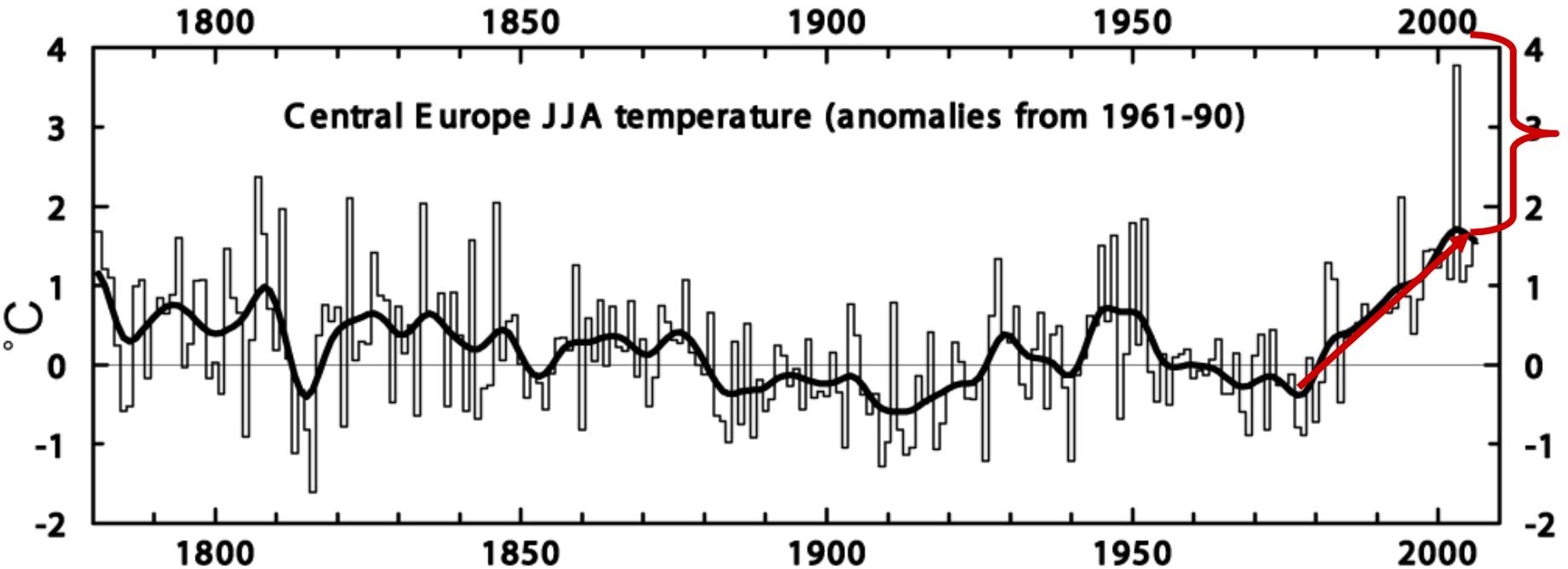
Extremes of temperature are changing!

Observed trends (days) per decade for 1951 to 2003:

5<sup>th</sup> or 95<sup>th</sup> percentiles

From Alexander et al. (2006)

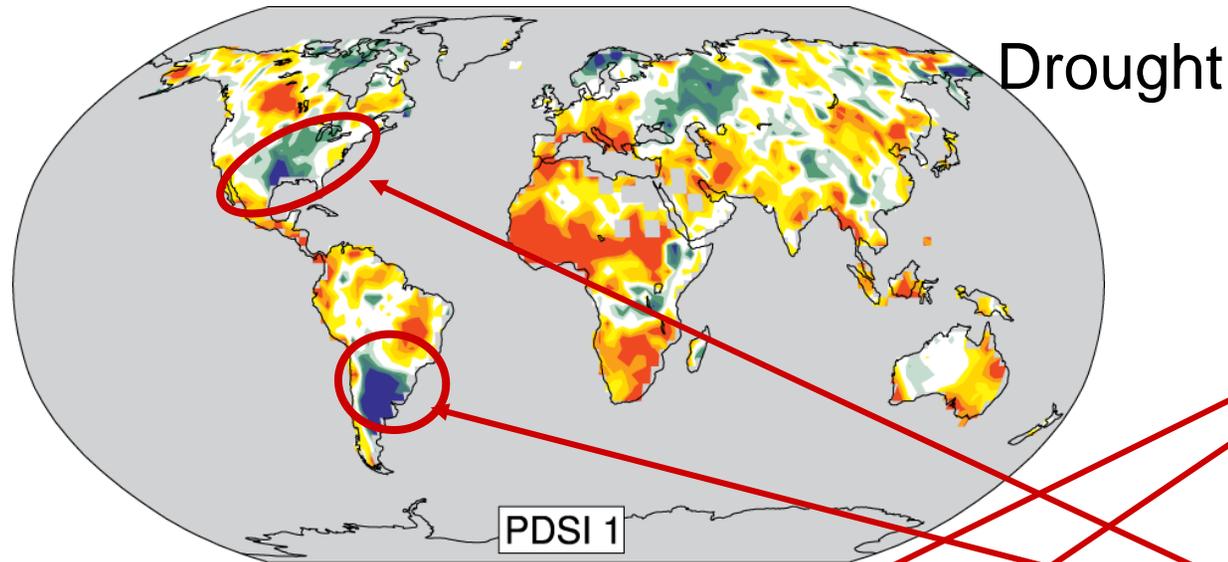
# Heat waves are increasing: an example



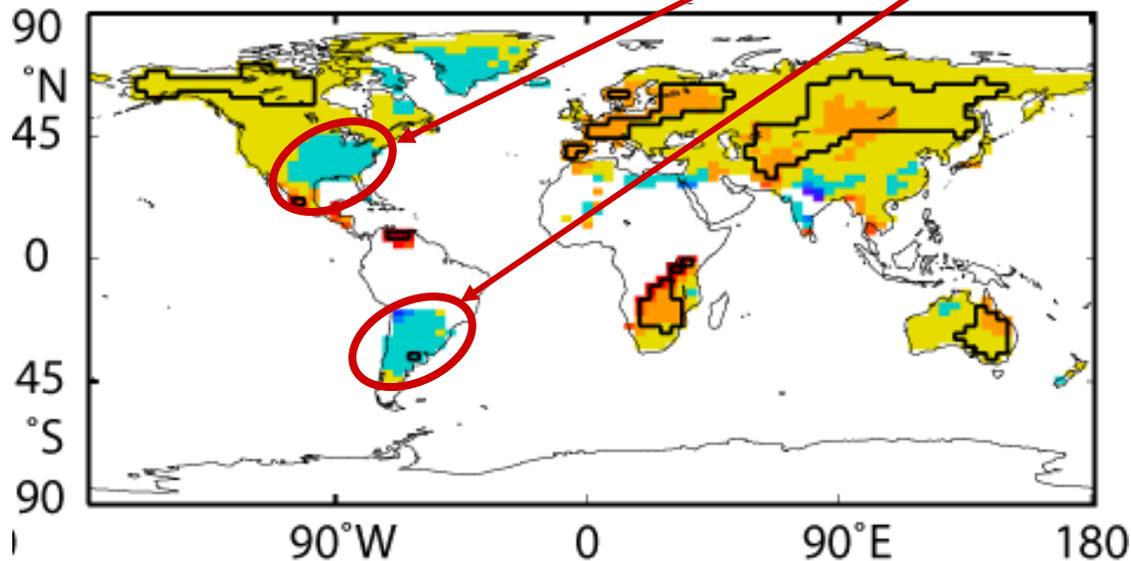
Extreme Heat Wave  
Summer 2003  
Europe  
30,000 deaths

Trend plus variability?

# Increases in rainfall and cloud counter warming

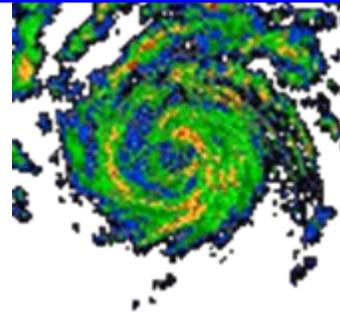
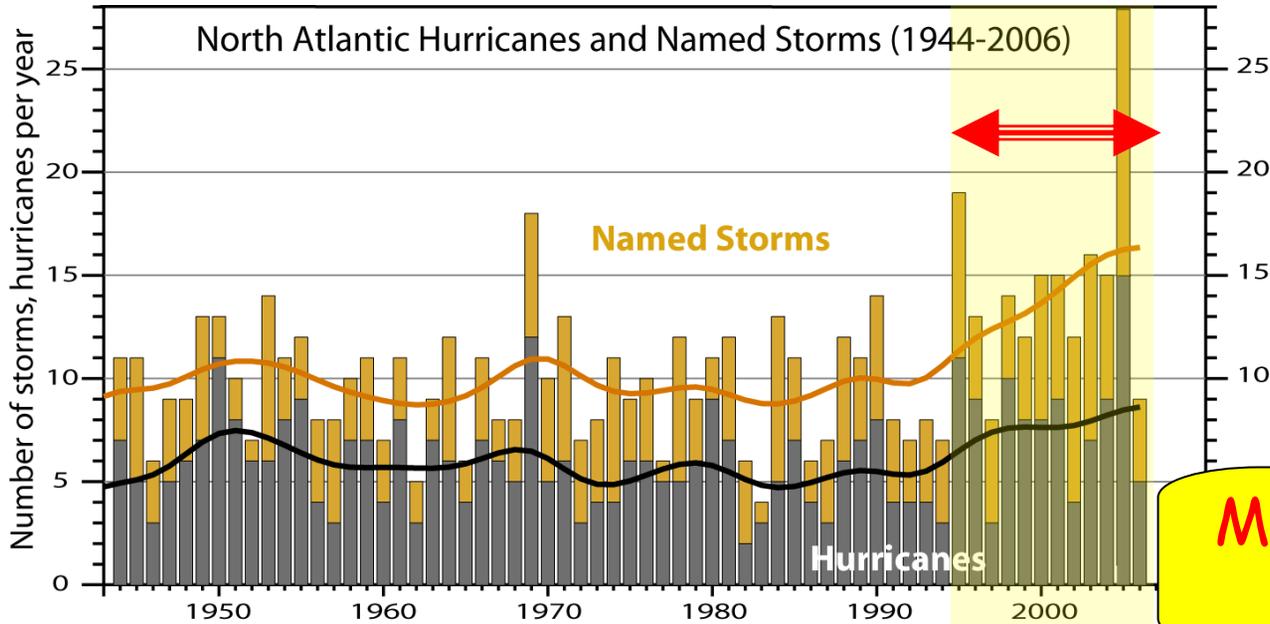


Trend in Warm Days 1951-2003



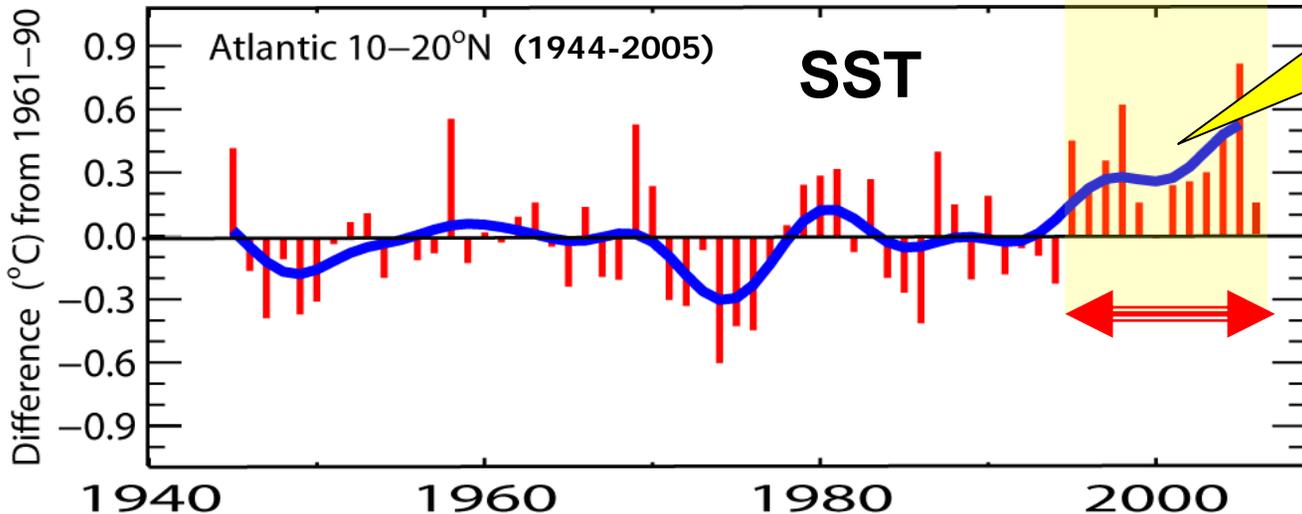
Absence of warming by day coincides with wetter and cloudier conditions

# North Atlantic hurricanes have increased with SSTs



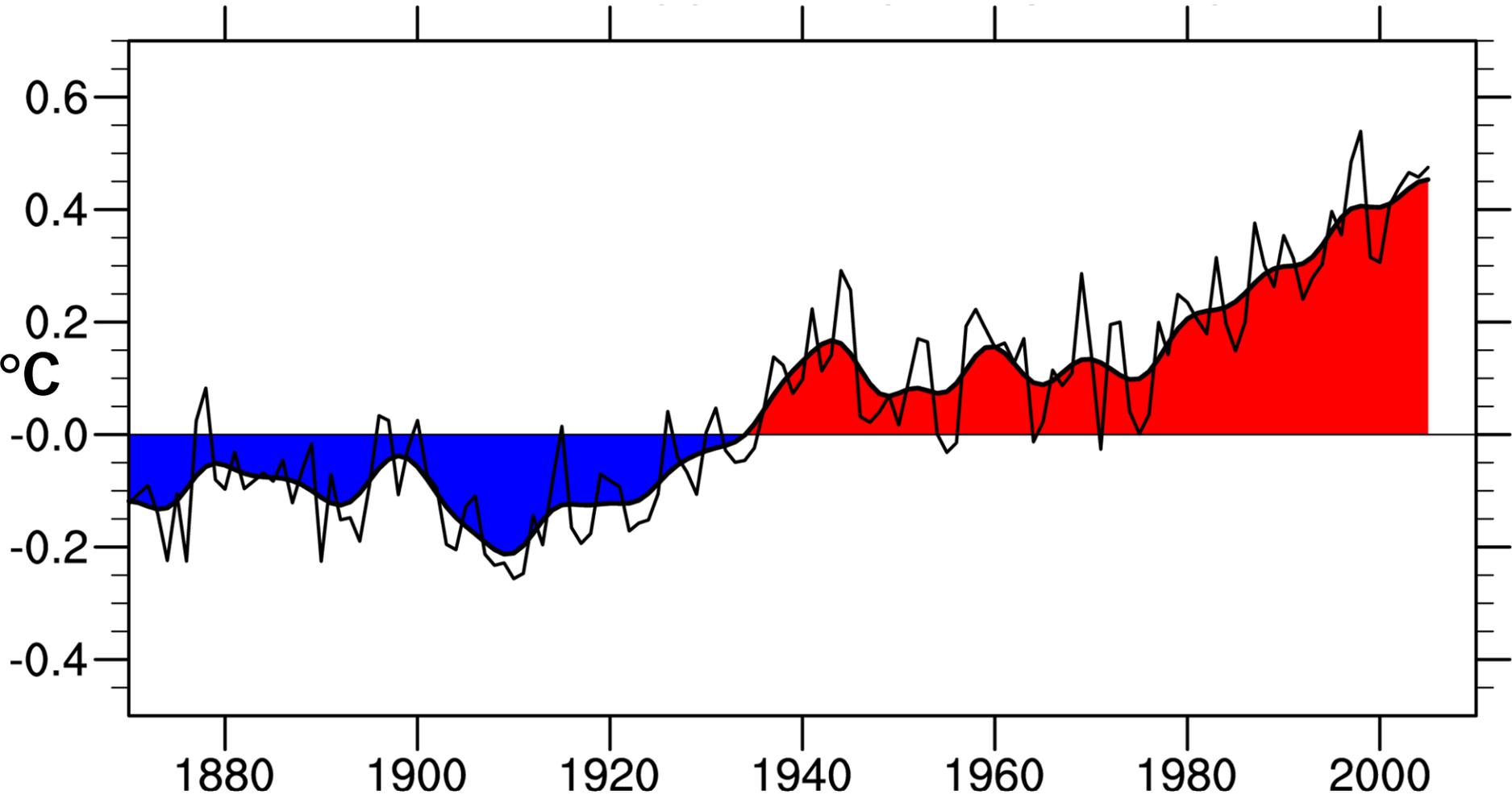
N. Atlantic hurricane record best

Marked increase after 1994

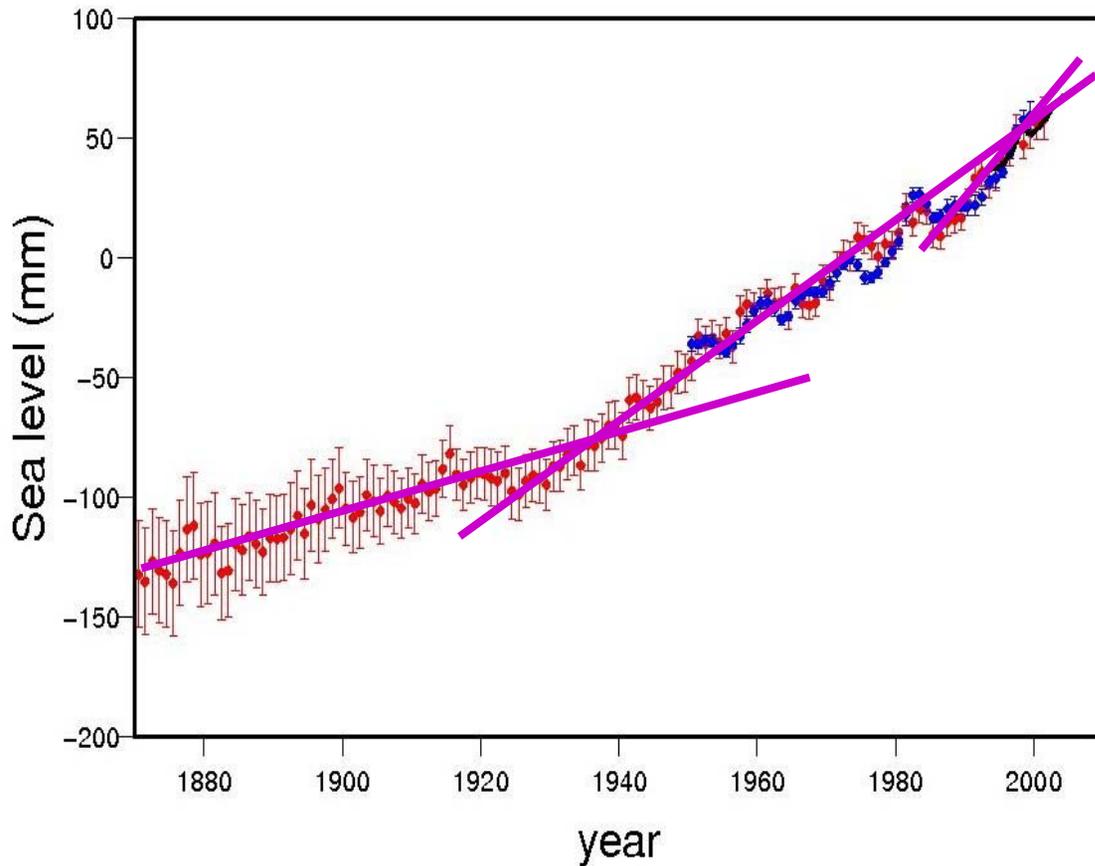


Global number and percentage of intense hurricanes is increasing

# Global SST: base period 1901-70



# Sea level is rising in 20<sup>th</sup> century



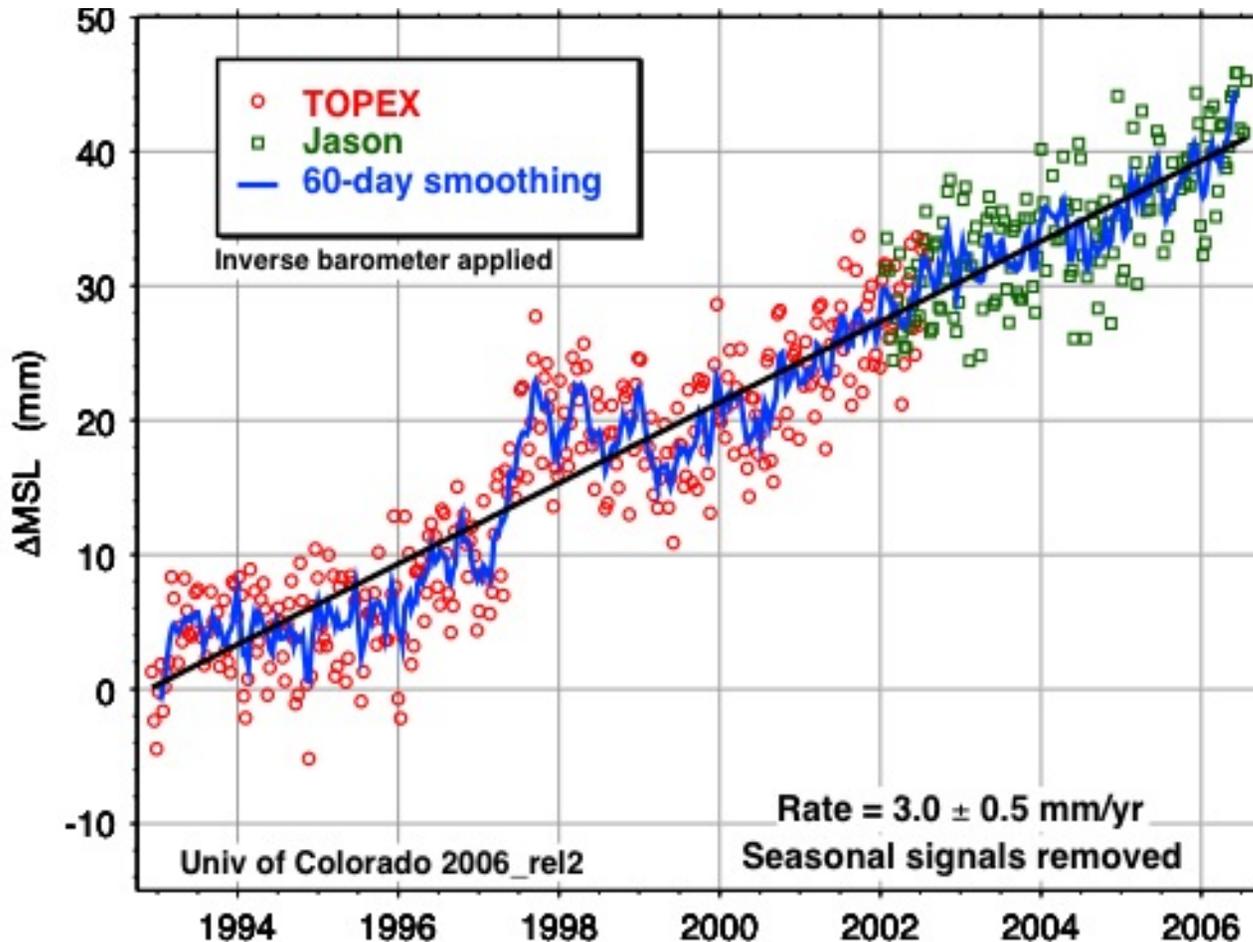
Rates of sea level rise:

- $1.8 \pm 0.5 \text{ mm yr}^{-1}$ , 1961-2003
- $1.7 \pm 0.5 \text{ mm yr}^{-1}$ , 20<sup>th</sup> Century
- $3.1 \pm 0.7 \text{ mm yr}^{-1}$ , 1993-2003

Sea level rise:

- $0.17\text{m} \pm 0.05 \text{ m}$  20<sup>th</sup> Century

# Sea level is rising: from ocean expansion and melting glaciers



Since 1993  
Global sea level  
has risen 41 mm  
(1.6 inches)

- 60% from expansion as ocean temperatures rise,
- 40% from melting glaciers

# Evidence for reality of climate change

## Glaciers melting



Muir Glacier, Alaska



1909

Toboggan  
Glacier  
Alaska



2000



A. Circa 1900  
Photo Source: Munich Society for Environmental Research



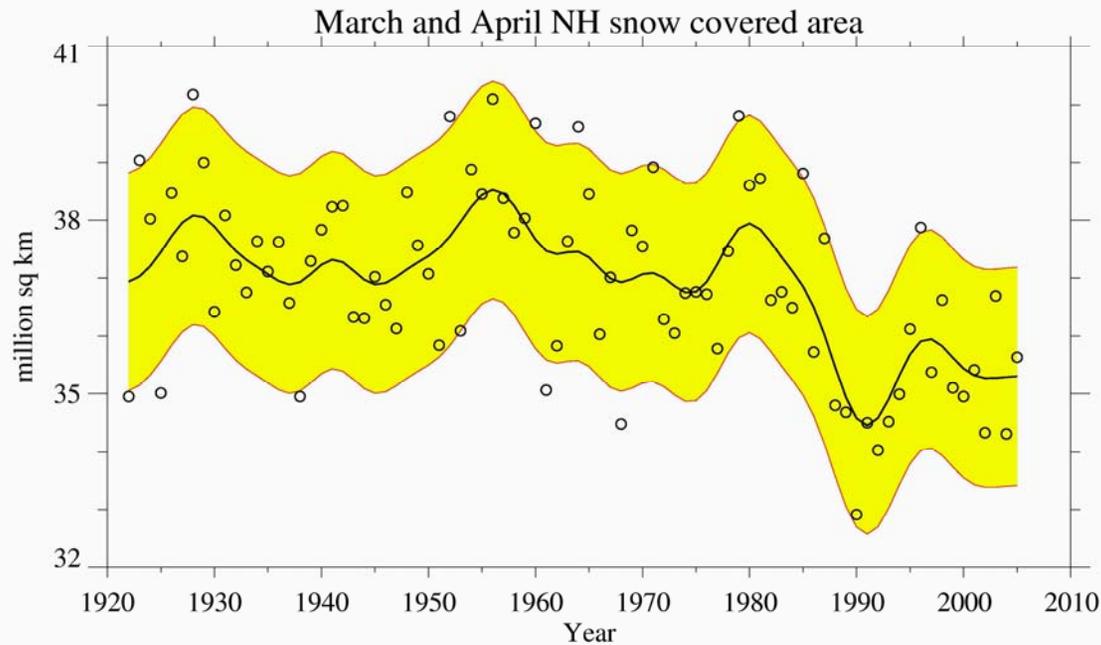
B. Recent

1900

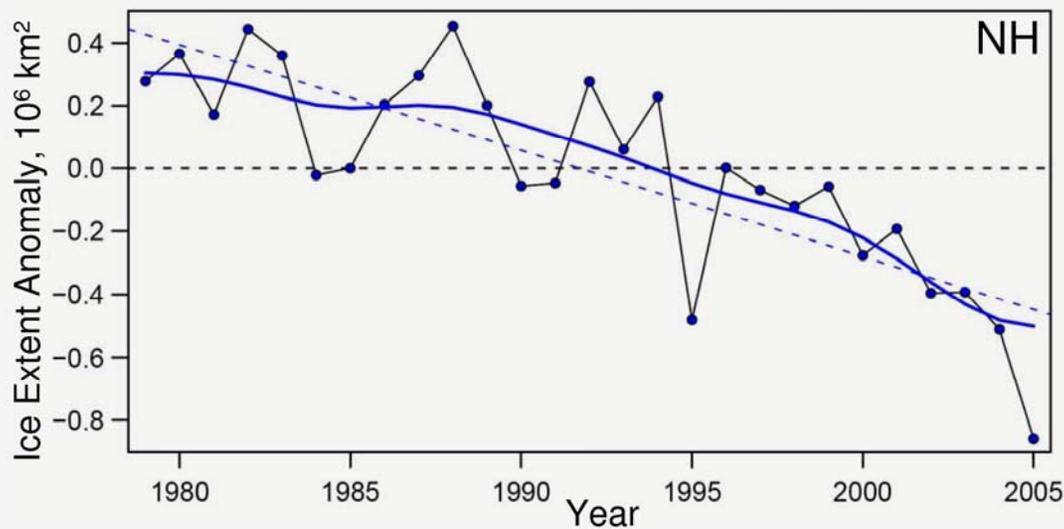
2003

Alpine glacier, Austria

# Snow cover and Arctic sea ice are decreasing

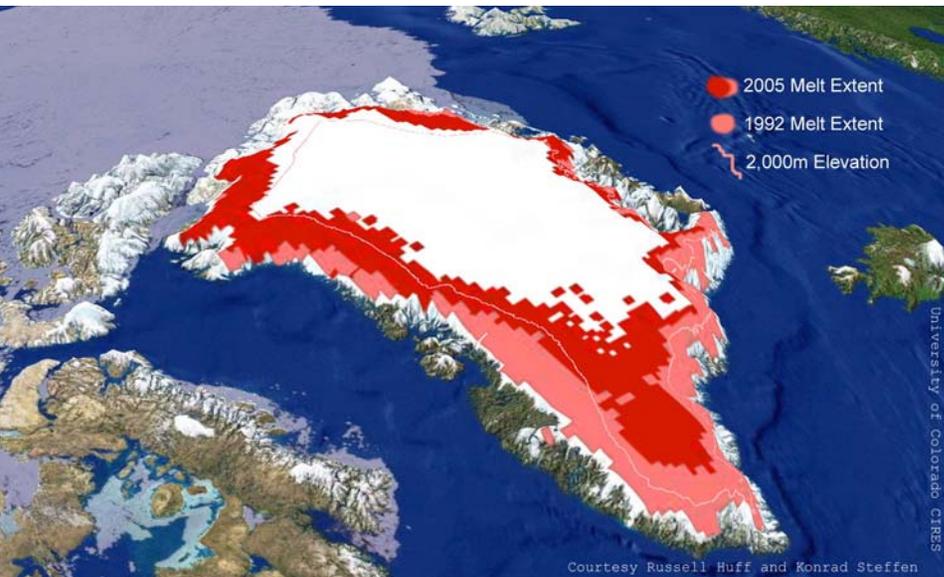


Spring snow cover shows 5% stepwise drop during 1980s



Arctic sea ice area decreased by 2.7% per decade (Summer: -7.4%/decade)

# Surface melt on Greenland



Increasing melt zones.

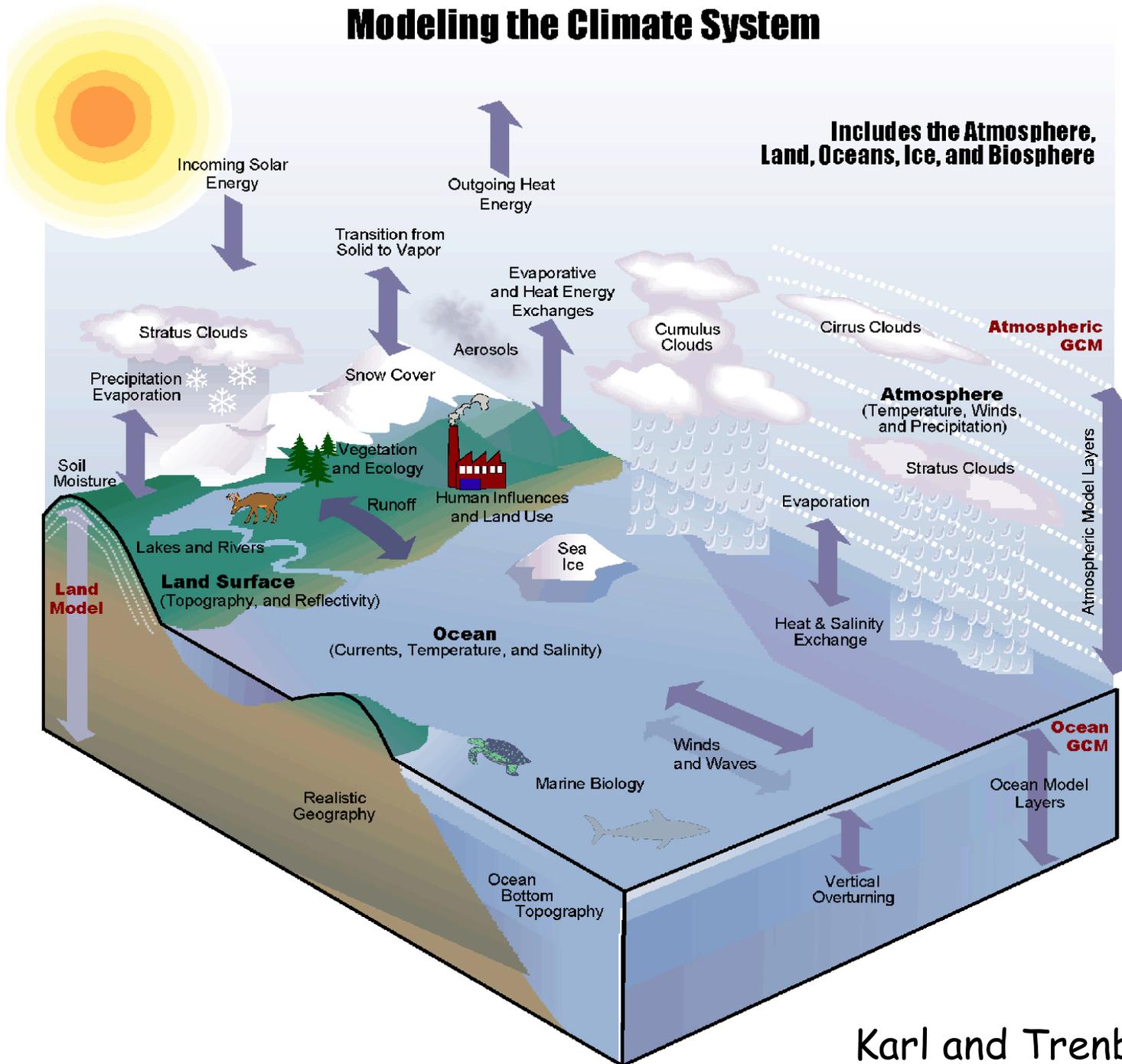
Melt descending into a moulin: a vertical shaft carrying water to the base of the ice sheet.

NSIDC (above)

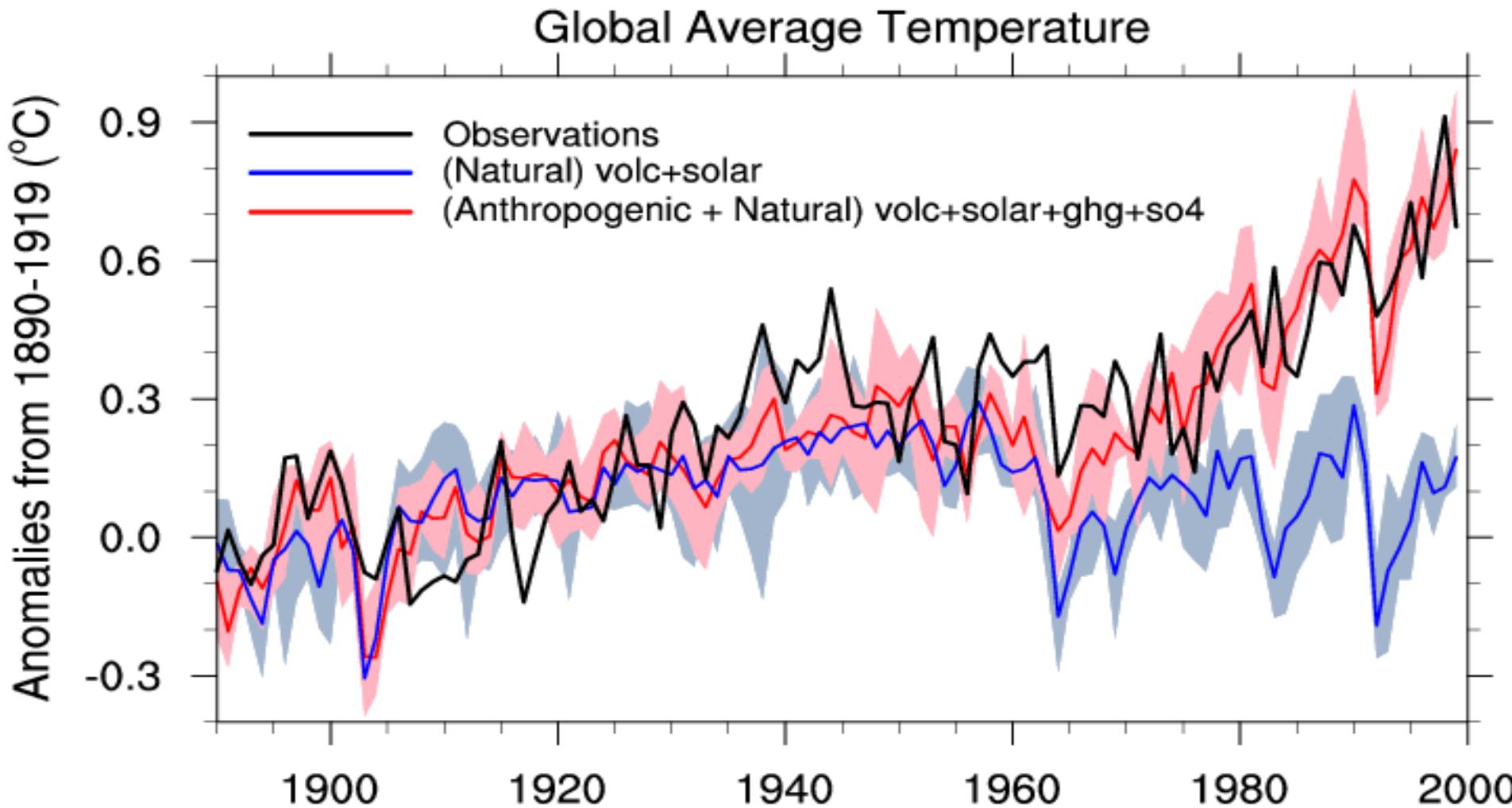
Braithwaite: Univ. Manchester



# Modeling the Climate System



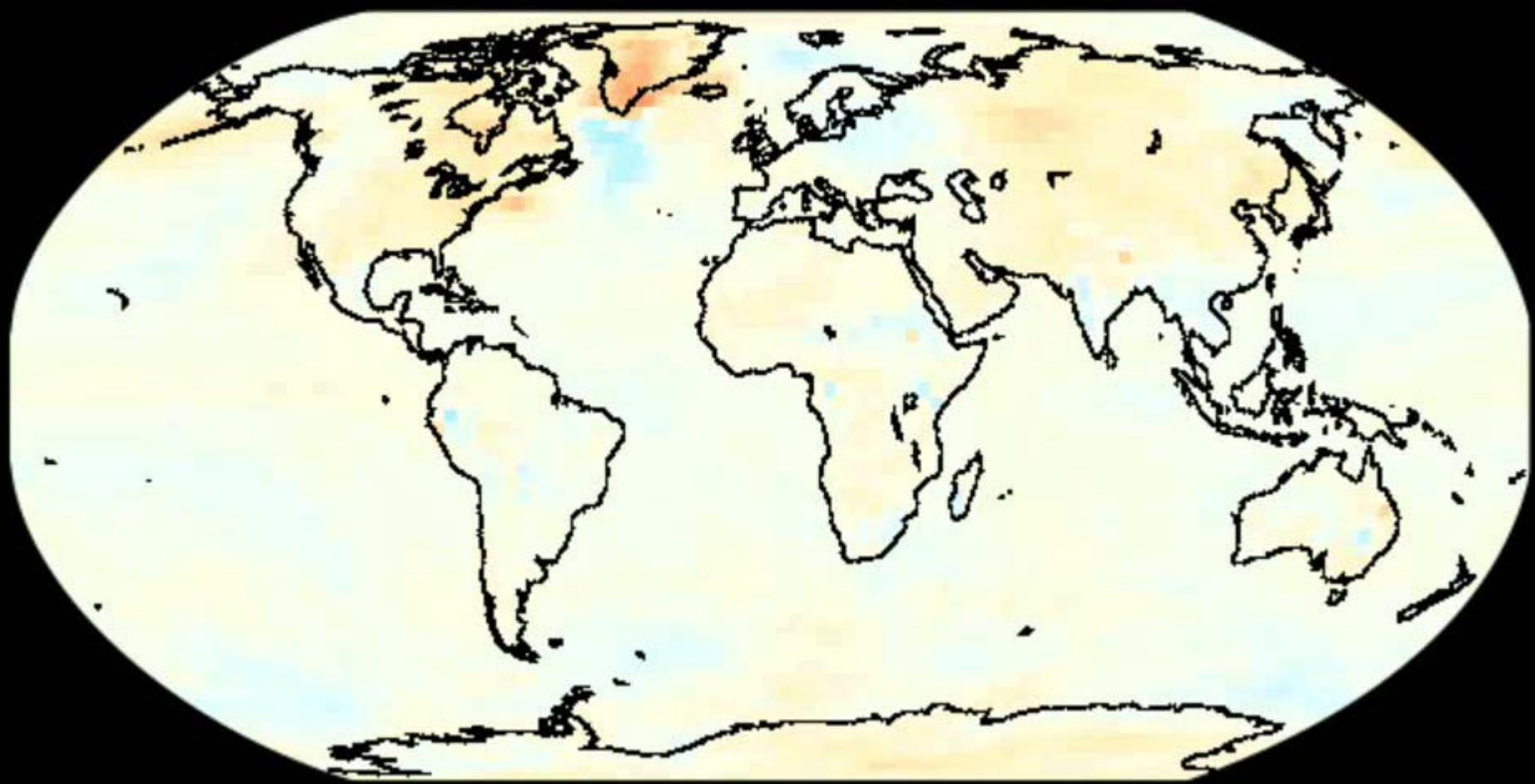
# Natural forcings do not account for observed 20<sup>th</sup> century warming after 1970



2000

Year

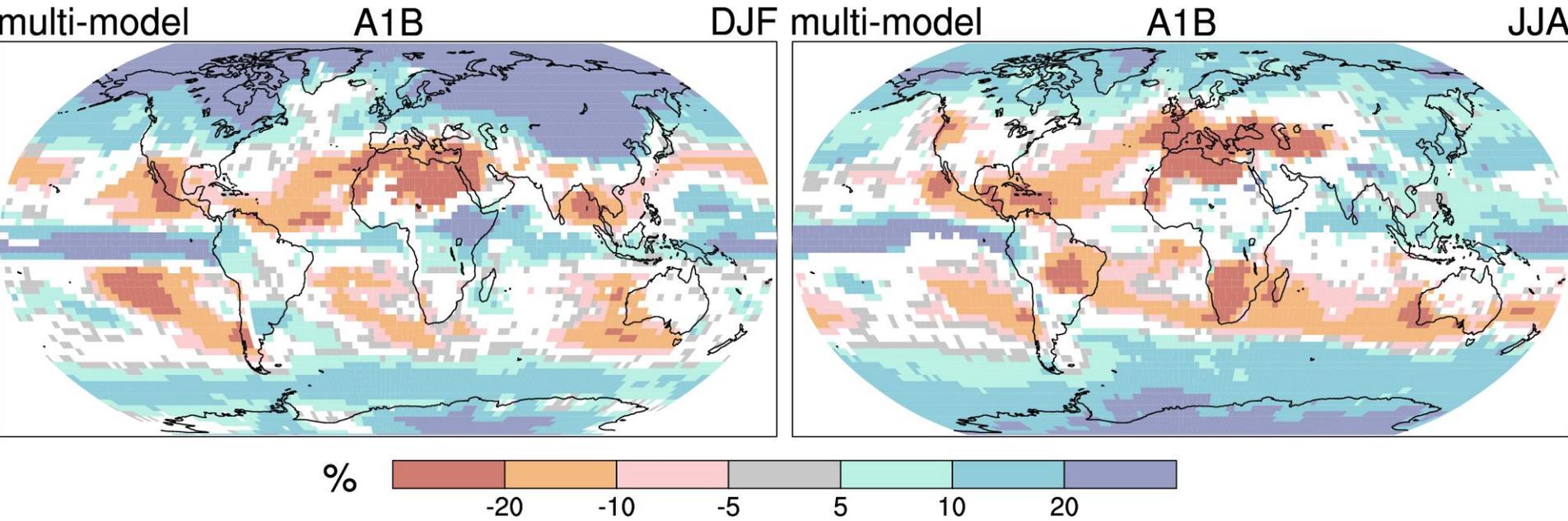
2300



Temperature Change (Celsius)



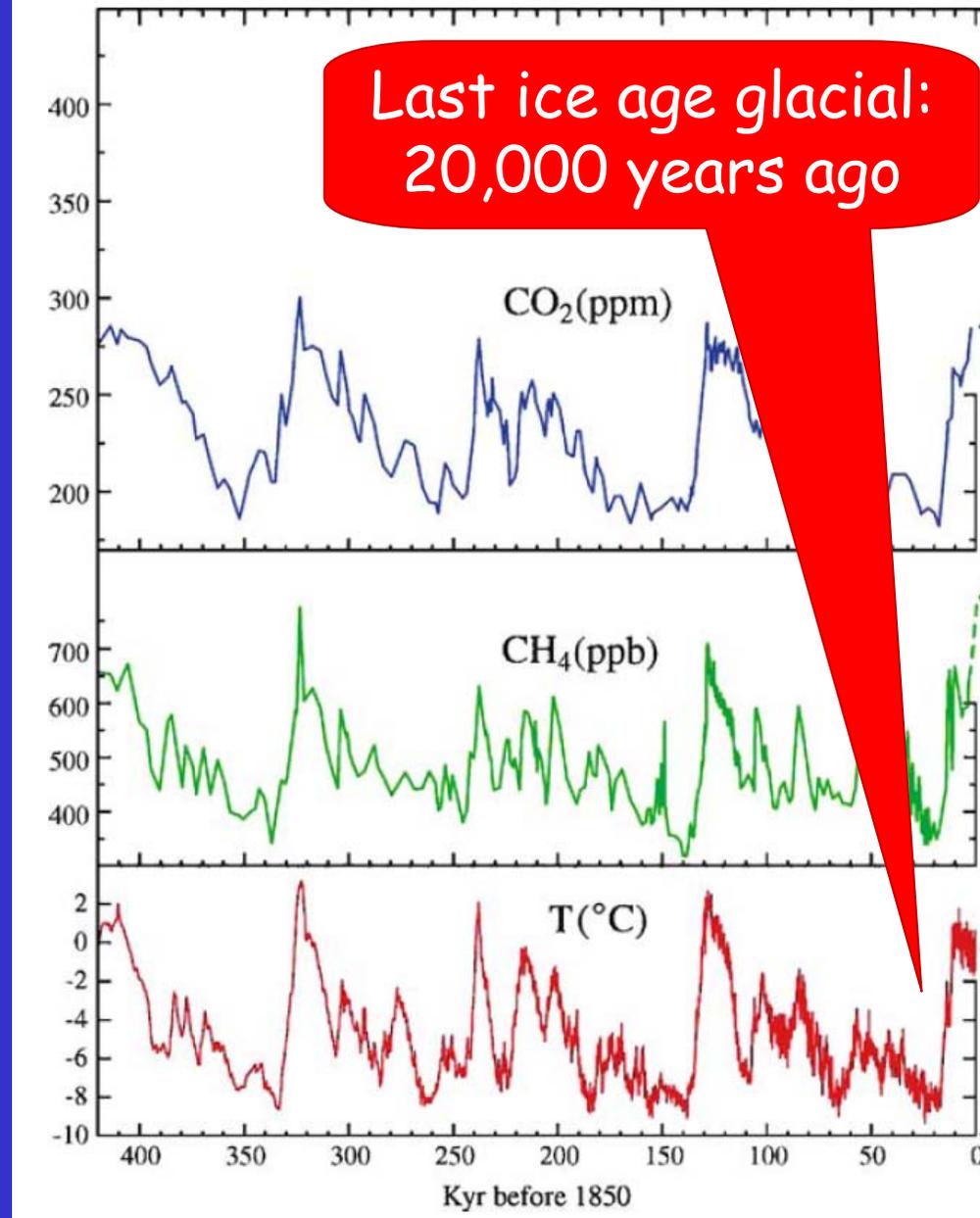
# *Projected Patterns of Precipitation Change 2090-2100*



**Precipitation increases very likely in high latitudes**  
**Decreases likely in most subtropical land regions**  
**This continues the observed patterns in recent trends**

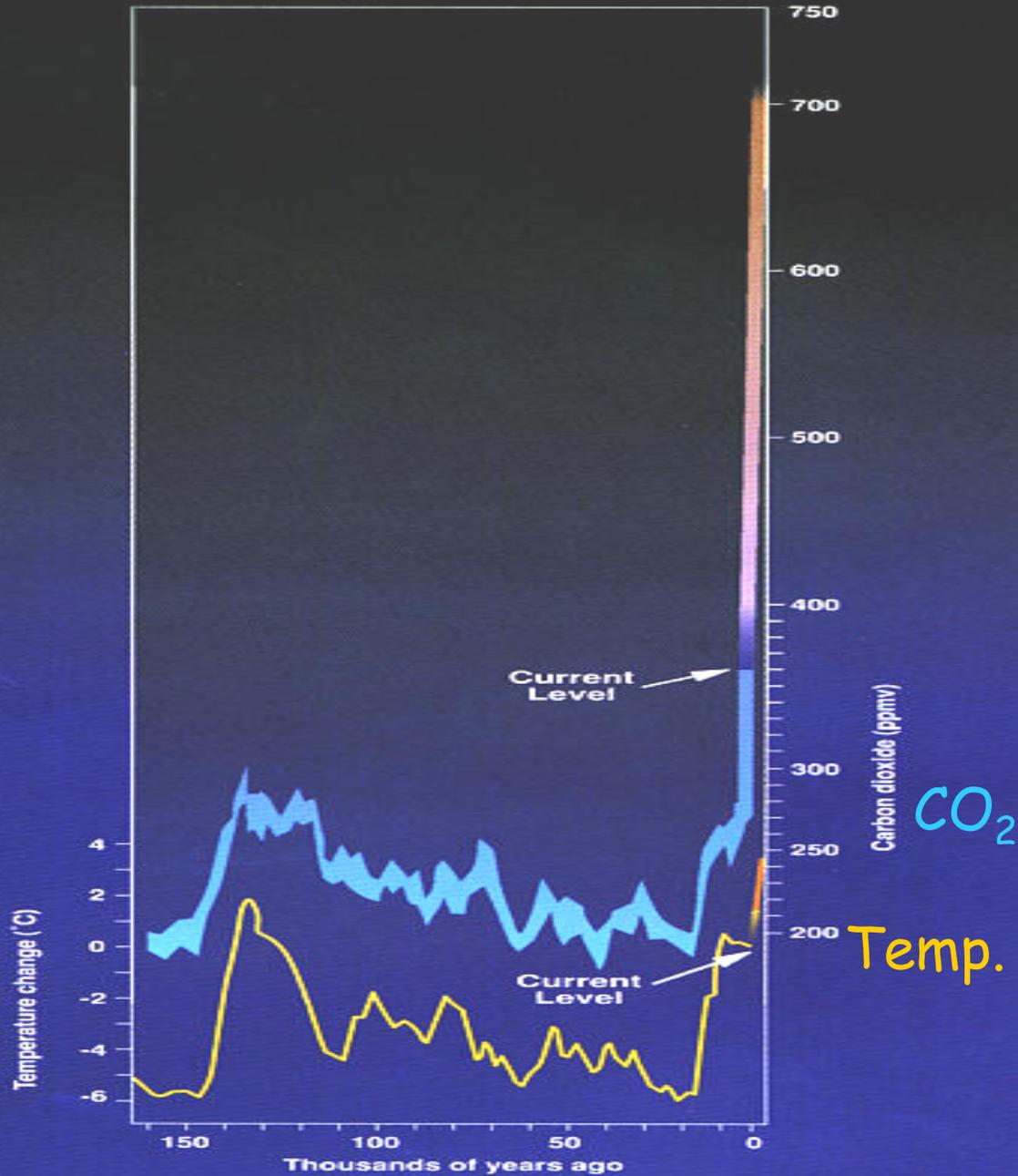
## Context:

400,000 years of Antarctic ice core records of Temperatures, Carbon dioxide and Methane.



Source: Hansen, Climatic Change 2005, based on Petit, Nature 1999

# Atmospheric Carbon Dioxide Concentration and Temperature Change



CO2 concentration in the atmosphere (Antarctic Ice Core)

Temperature changes through time compared to the present temperature

# The UN Framework Convention on Climate Change

- Ratified by 189 countries
- Ratified by the US
- Article 2 is statement of the objective
- Convention entered into force 21 March 1994



# Kyoto Protocol

- A legal instrument under UNFCCC
- Requires net reduction in developed country averaged annual GHG emissions of 5% (US 7%) over the period 2008-12 compared to 1990 levels
- "Basket" of GHGs ( $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ , HFCs, PFCs,  $\text{SF}_6$ )
- Provisions for "flexible" market mechanisms: international trading system, credits, etc.
- 164 countries have ratified
- Protocol has now been ratified; took effect Feb 16, 2005.
- US withdrew in 2001. In 2004 US emissions were 16% (20%) over 1990 levels for GHG ( $\text{CO}_2$ ).

# SUPREME COURT OF THE UNITED STATES

## Syllabus

MASSACHUSETTS ET AL. v. ENVIRONMENTAL  
PROTECTION AGENCY ET AL.  
CERTIORARI TO THE UNITED STATES COURT OF APPEALS FOR  
THE DISTRICT OF COLUMBIA CIRCUIT

No. 05–1120. Argued November 29, 2006—Decided  
April 2, 2007

Carbon Dioxide is a pollutant and  
the EPA has a right to limit auto-  
emissions.

Carbon dioxide must be regulated



## What about a carbon tax?

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A key problem is that anyone can burn stuff and put Carbon Dioxide into the atmosphere as a waste product. If there was a value to Carbon Dioxide then this would presumably be reduced.

A carbon tax, carbon emission limits, or pollution fines are designed to create a **cost** for burning carbon products, like coal and oil.

Given a **target** (such as in the Kyoto Protocol) only so much can be burned and **credits** to allow burning can be **traded** (carbon emissions trading).

Such a solution can be **equitable** if implemented across the board. But it can favor those who pollute if a country does not subscribe.

## Current trends: March 2007

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A recent analysis shows the likelihood of an extra 1.2 billion tons of carbon released per year:

Coal fired power stations have been brought on line at a rate of 2 per week over the past 5 years. China leads with one every 3 days or so last years (560 new plants from 2002 to 2006 and 113 GigaWatts of coal fired power).

(200 MW each)

In the next 4 years, China is expected to lead by bringing online over 55 GW of coal fired power, but the US is right behind with 38 GW, and India with 36 GW, and the rest of the world 47 GW.

(Total 176 GW)

Far from decreasing carbon dioxide emissions, the trend is much worse than what is assumed as "business as usual".

Christian Science Monitor March 22, 2007

# Global warming actions

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There are uncertainties about how climate will change.

But climate will change.

And it could be very disruptive.

There will be substantial costs incurred;

-often by innocent people and countries

The issue is directly linked to

- ❖ fossil fuel energy use.
- ❖ security (foreign oil imports).
- ❖ sustainability.

Oil supplies will be exceeded by demand sooner or later  
and long before we run out.