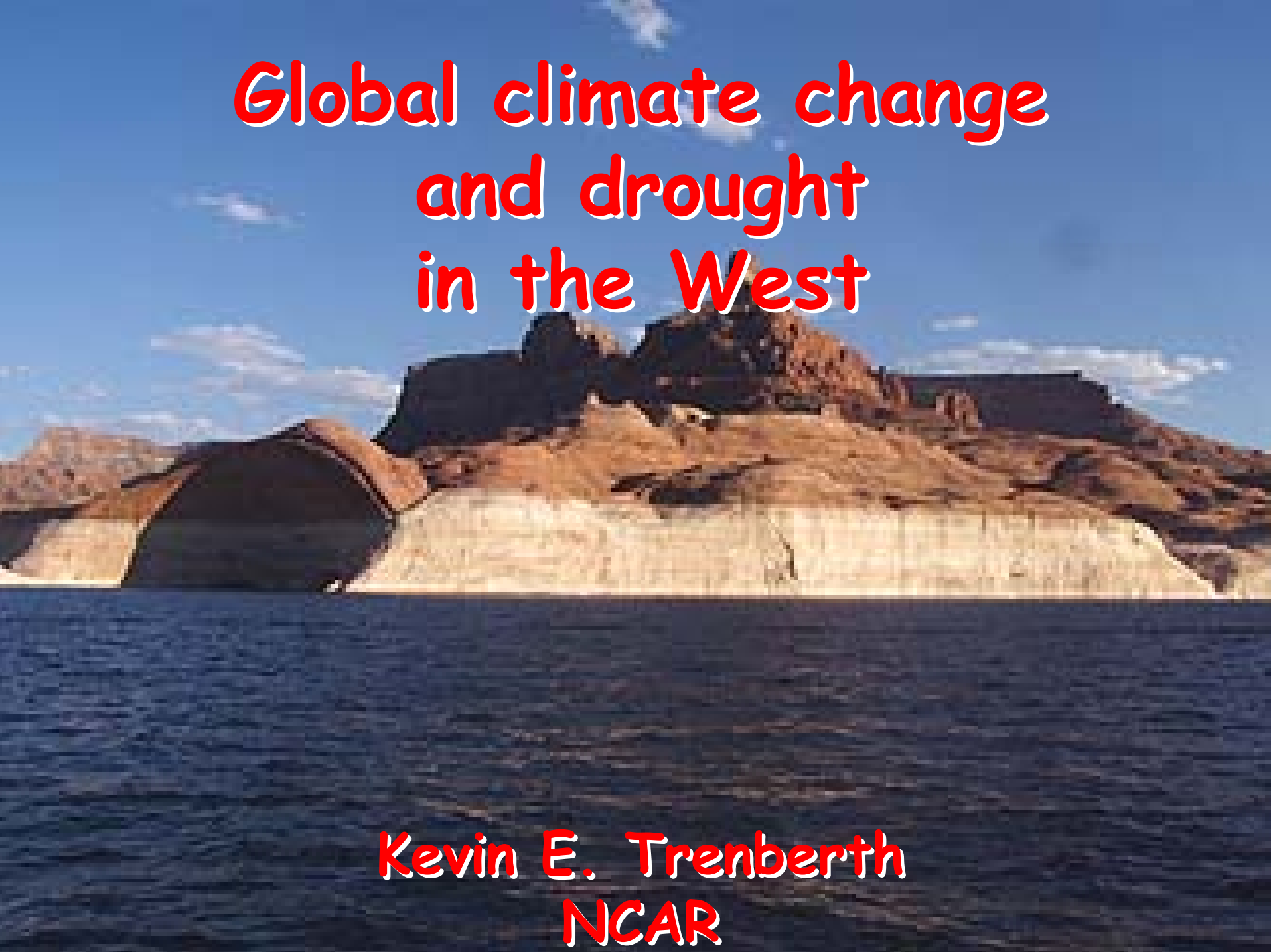


Global climate change and drought in the West

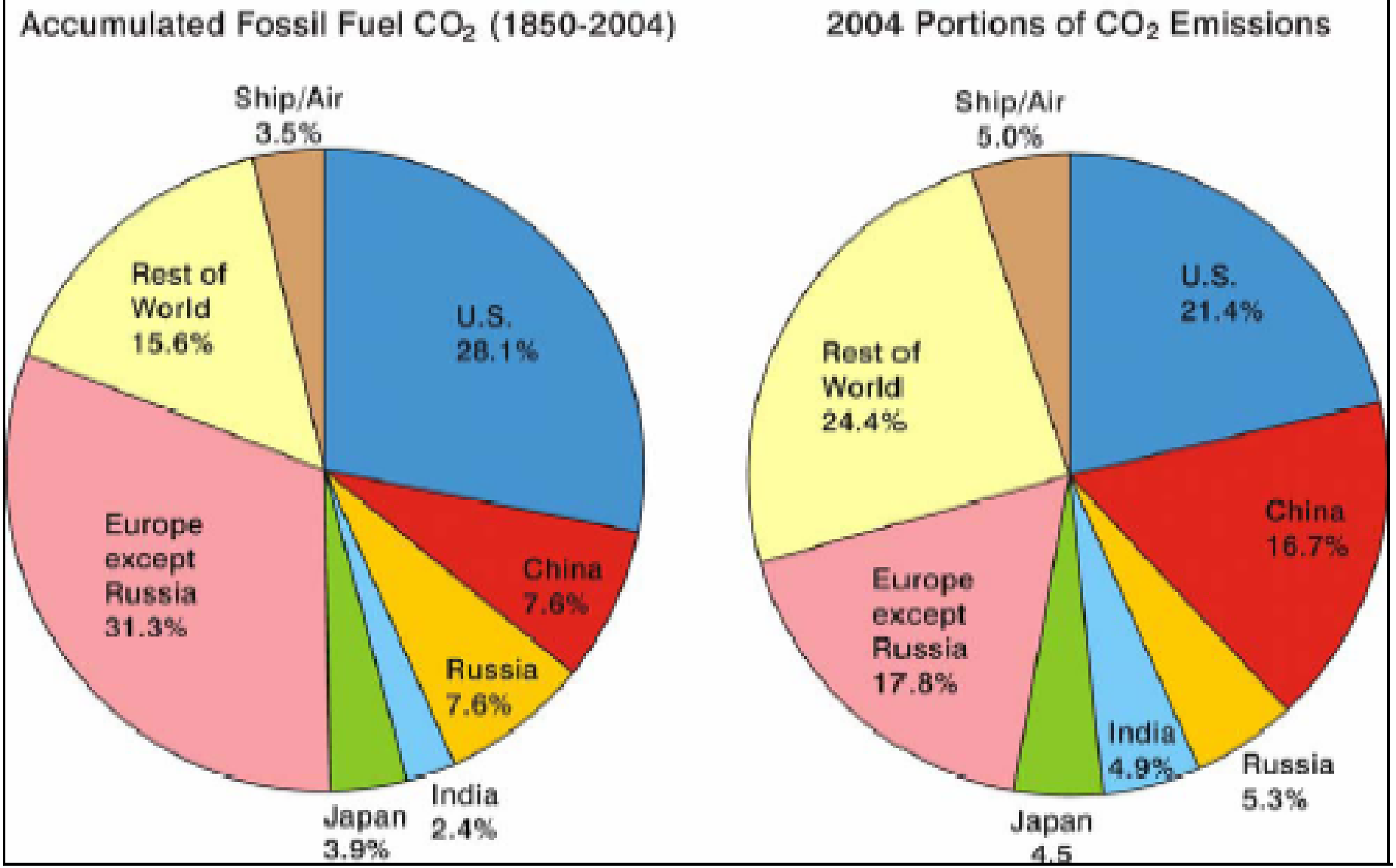
Kevin E. Trenberth
NCAR

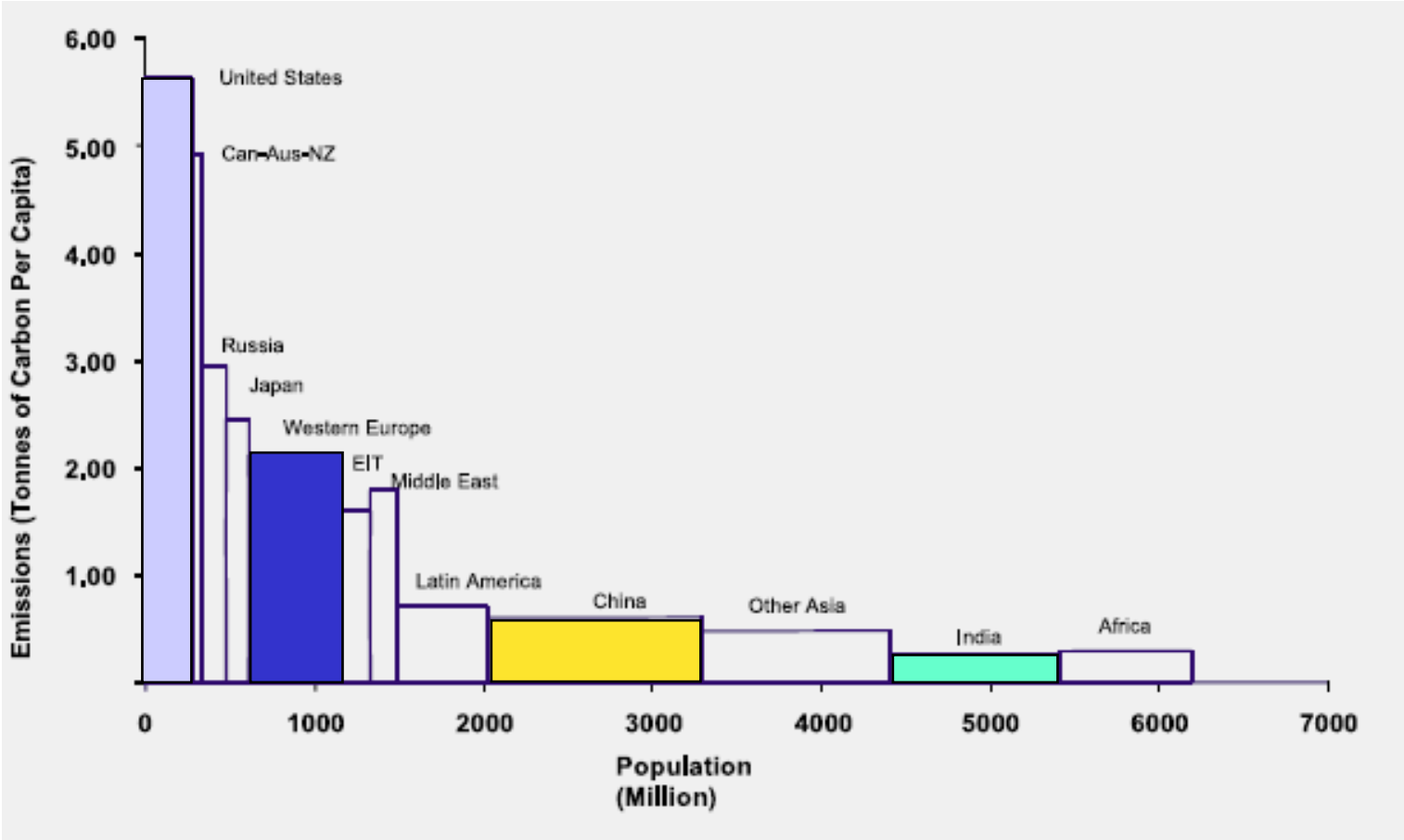
Climate

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!**

Fossil Fuel CO_2 Emissions

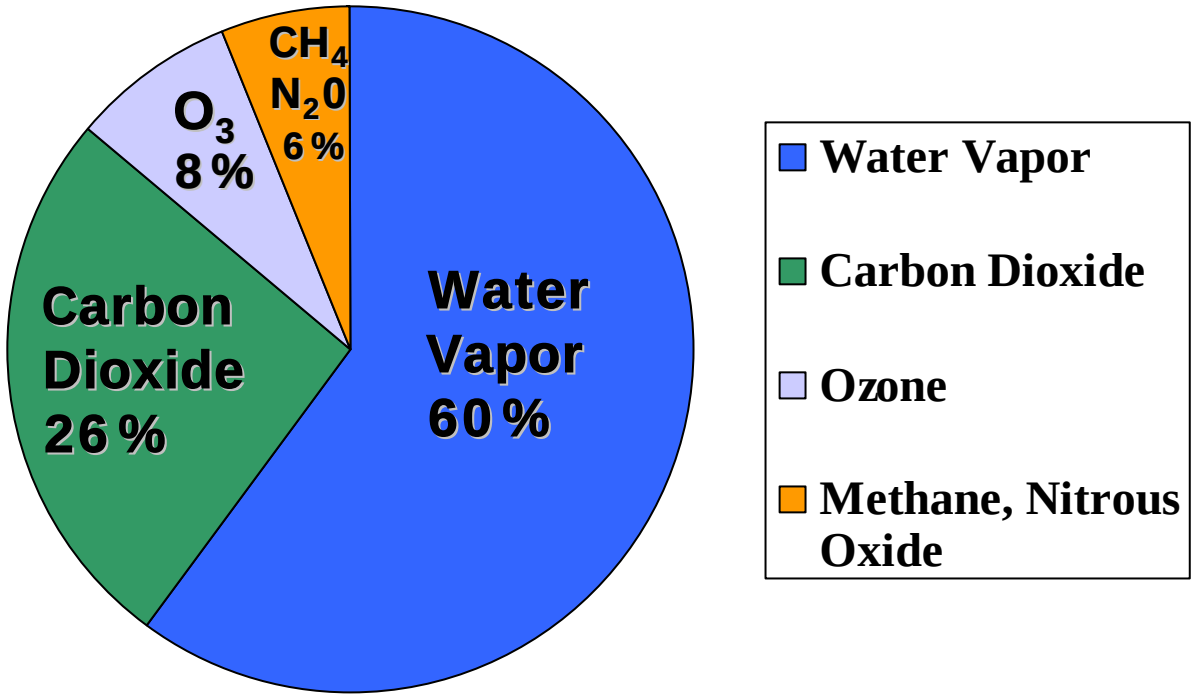




CO2 emissions in different regions in 2000 *in terms of emissions per capita (height of each block); population (width of each block); and total emissions (product of population and emissions per capita = area of block).*

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

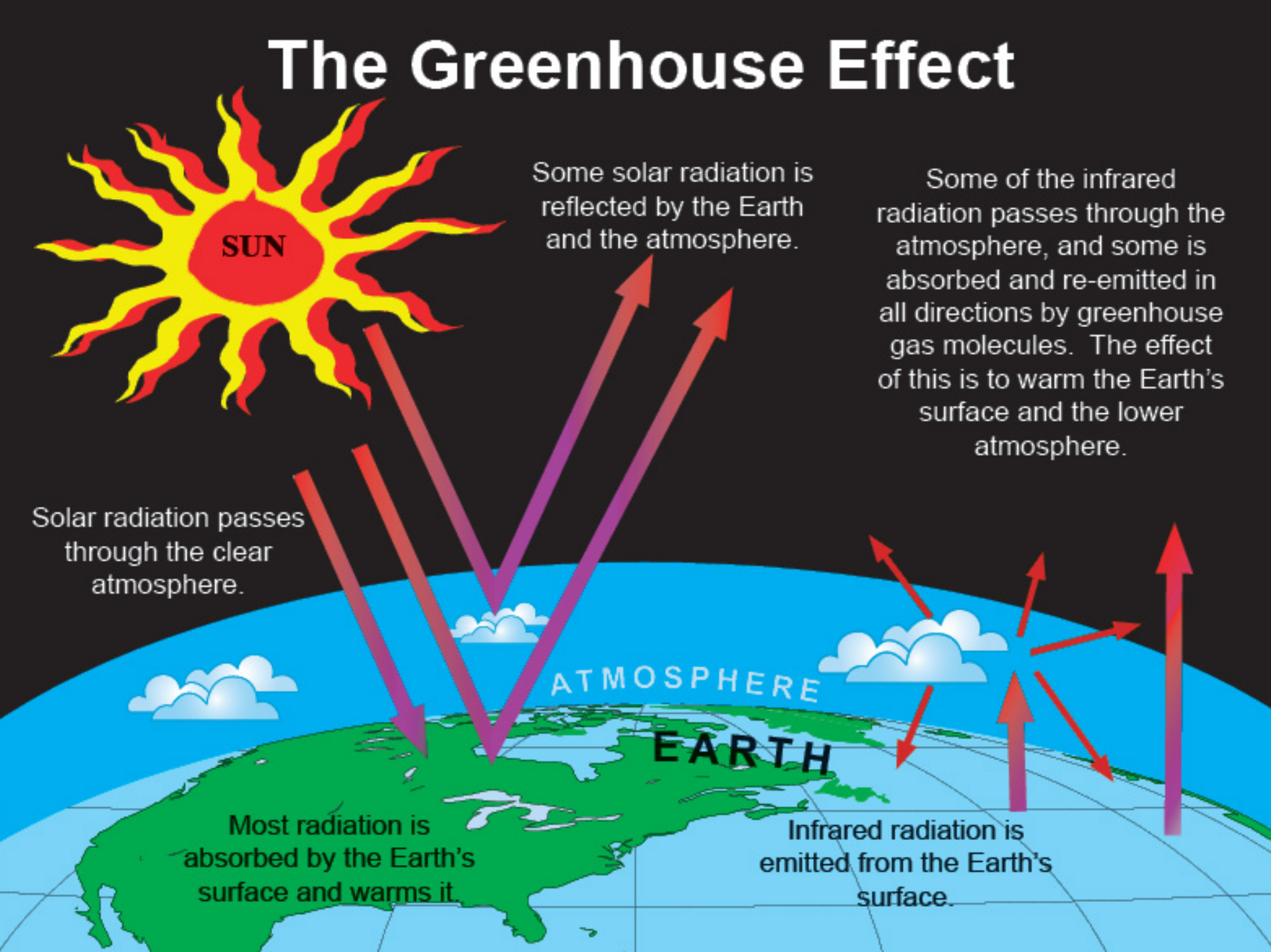
The Natural Greenhouse Effect: clear sky



Clouds also have a greenhouse effect

Kiehl and Trenberth 1997

The Greenhouse Effect



Global Warming is happening

Since 1970, rise in:

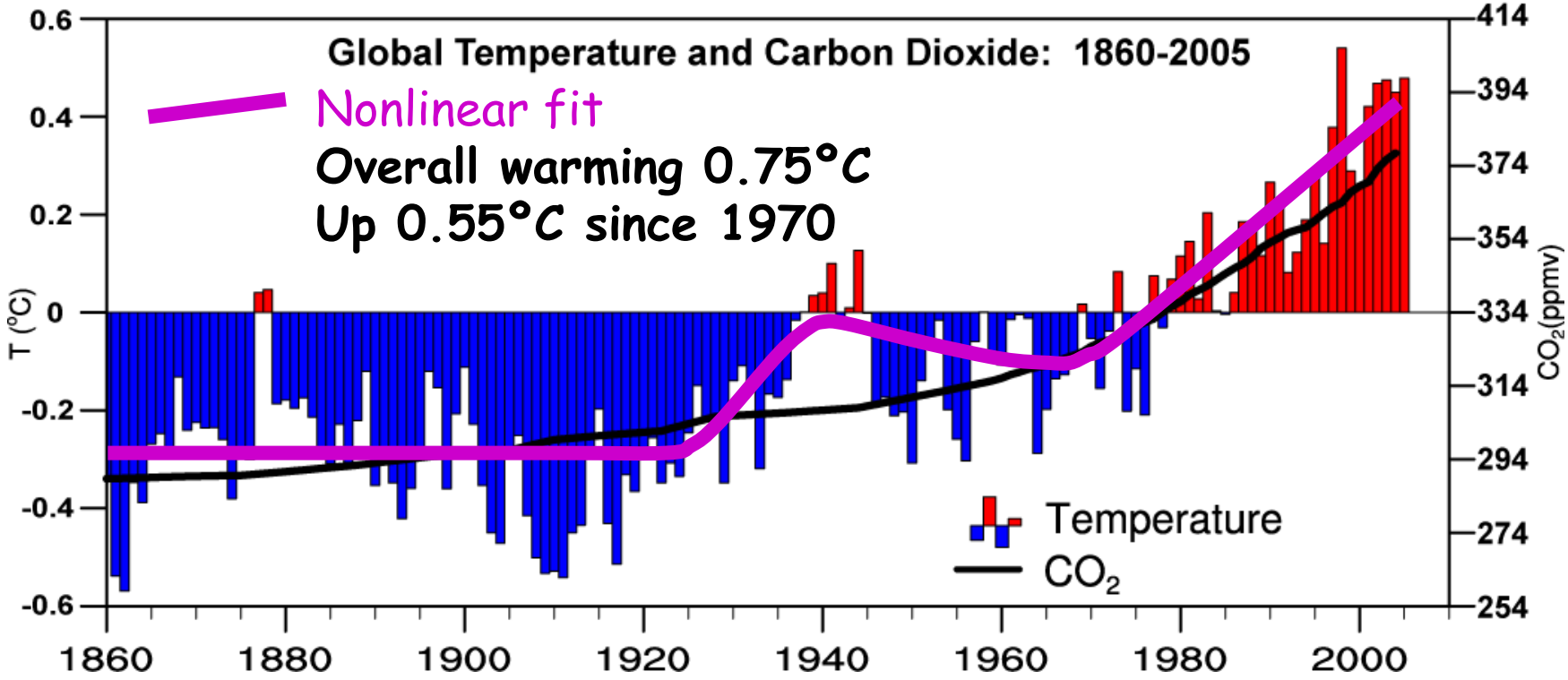
- Carbon Dioxide
- Global temperatures
- Global SSTs
- Global sea level
- Tropical SSTs
- Water vapor
- Rainfall intensity
- Precipitation extratropics
- Hurricane intensity
- Drought

Decrease in:

Snow extent

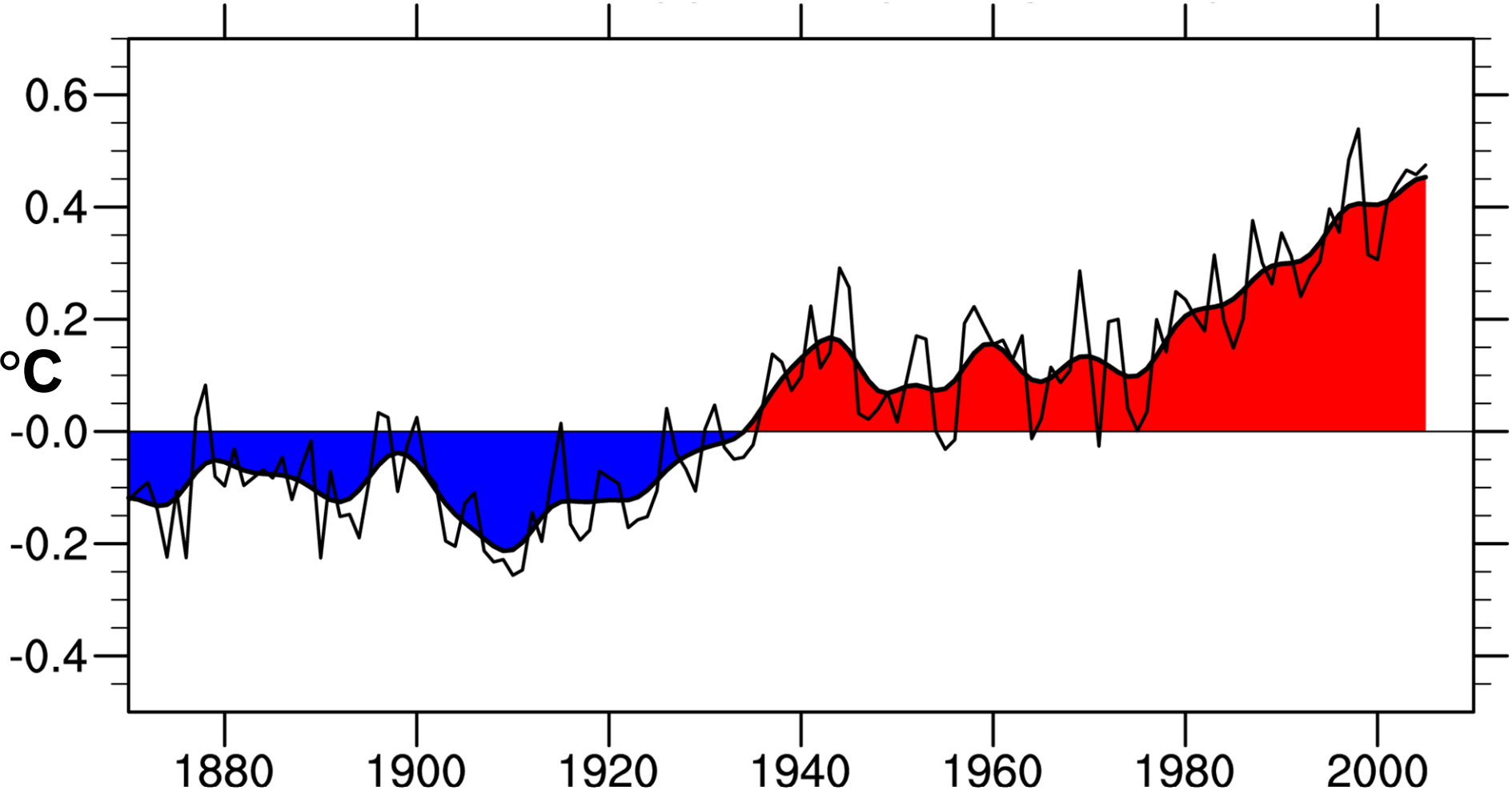
Arctic sea ice

Variations of the Earth's surface temperature

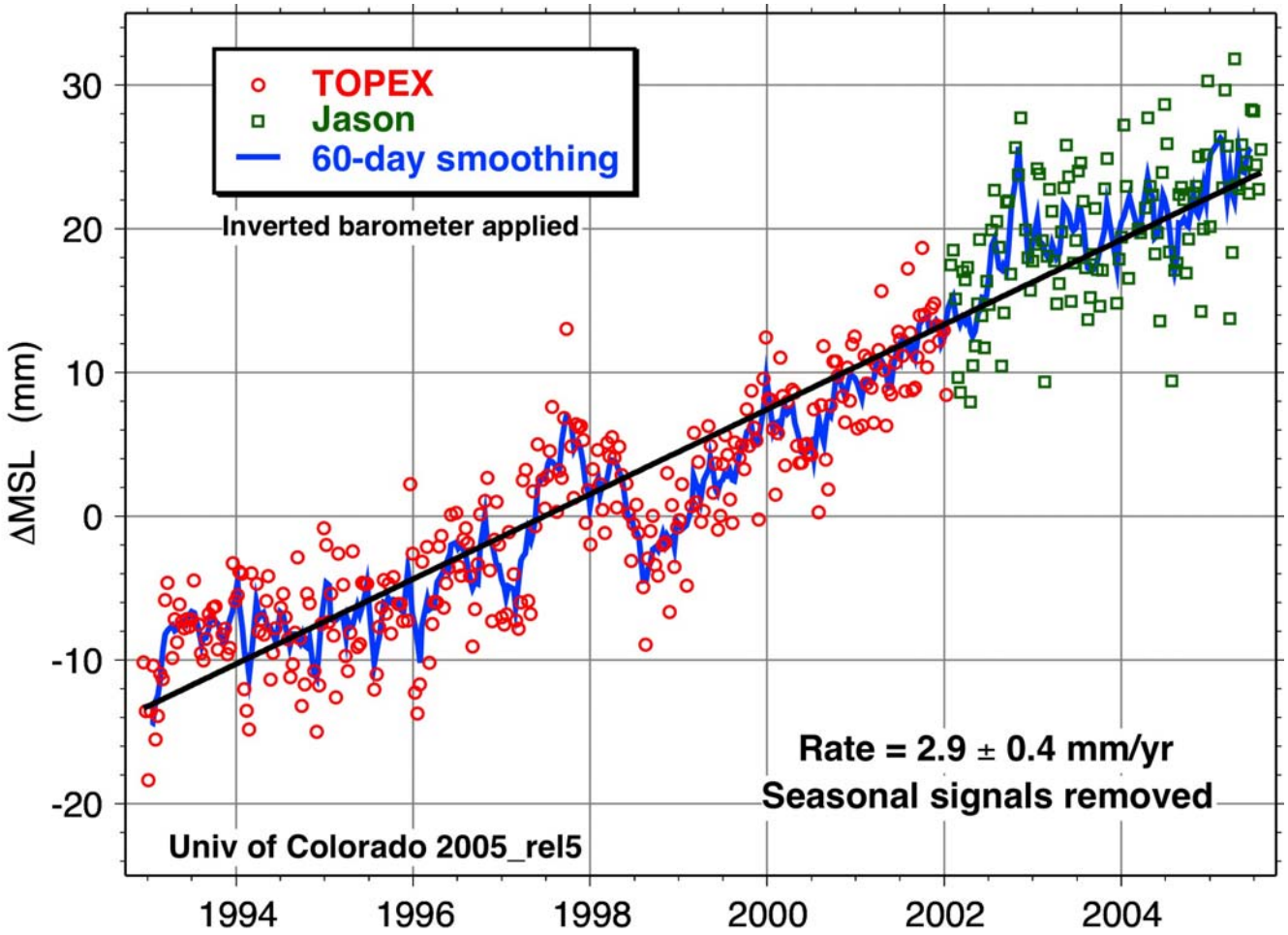


Annual mean departures from the 1961-90 average for global temperatures, mean 14.0°C, and carbon dioxide concentrations from ice cores and Mauna Loa (1958 on), mean 333.7 ppmv. Updated from Karl and Trenberth 2003.

Global SST: base period 1901-70



Sea level is rising:
from ocean expansion and melting glaciers



Since 1993 Global sea level has risen 37 mm (1.46 inches)

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

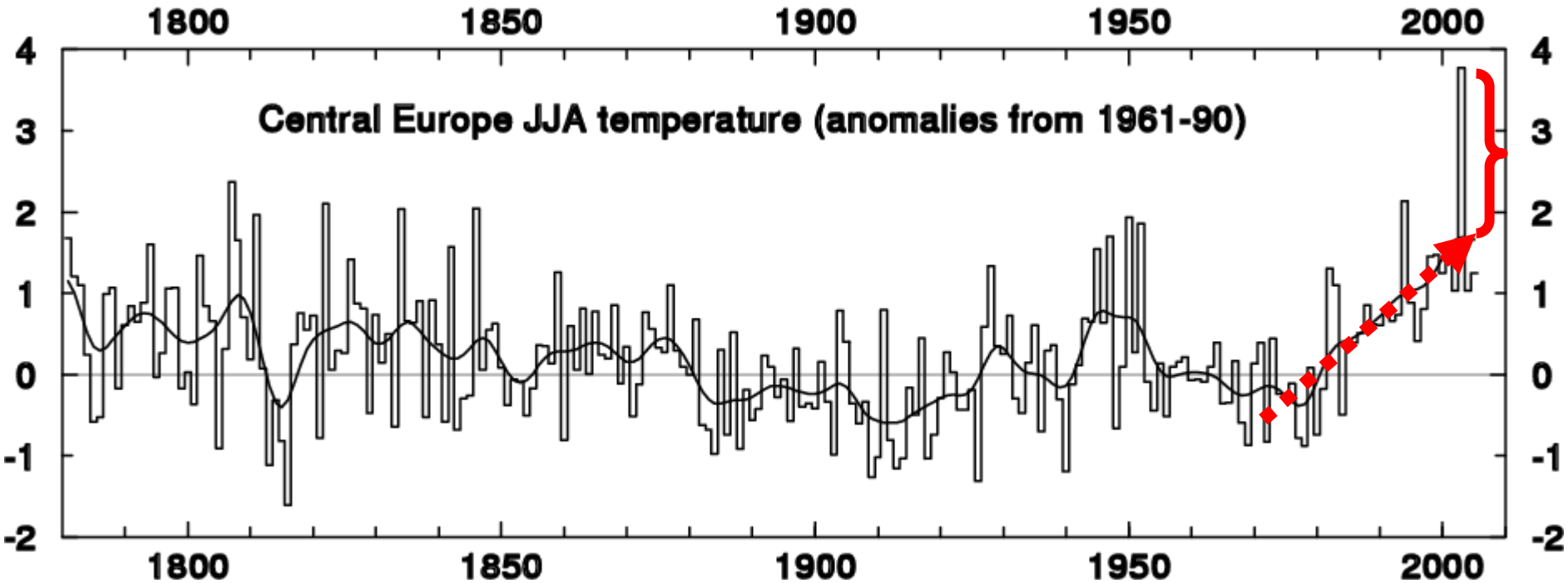
Steve Nerem

Heat waves and wild fires

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

Europe summer temperatures

Exceptional heat wave and drought of 2003 was a major extreme made more likely by global warming: 30K deaths



From P. Jones

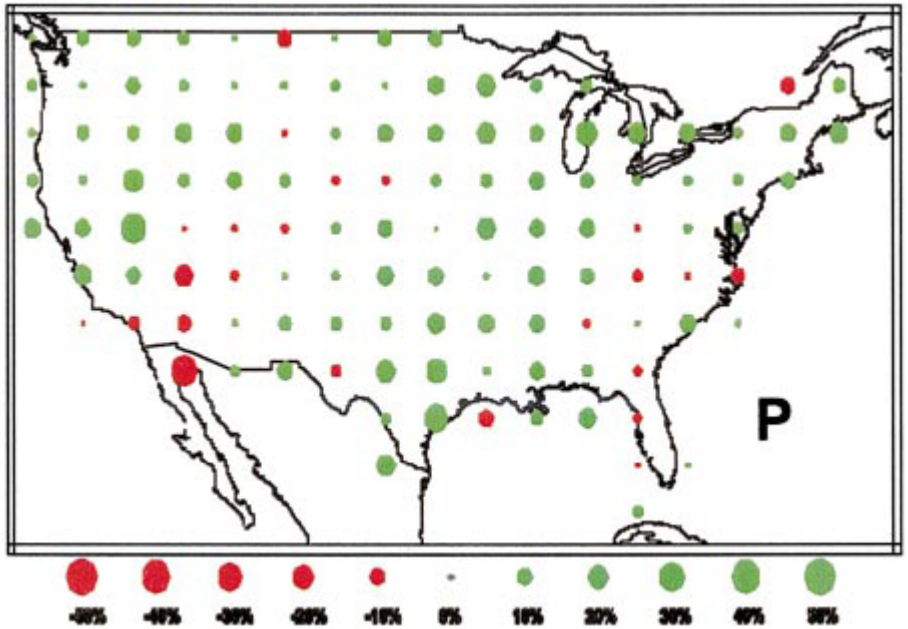
Water Holding Capacity

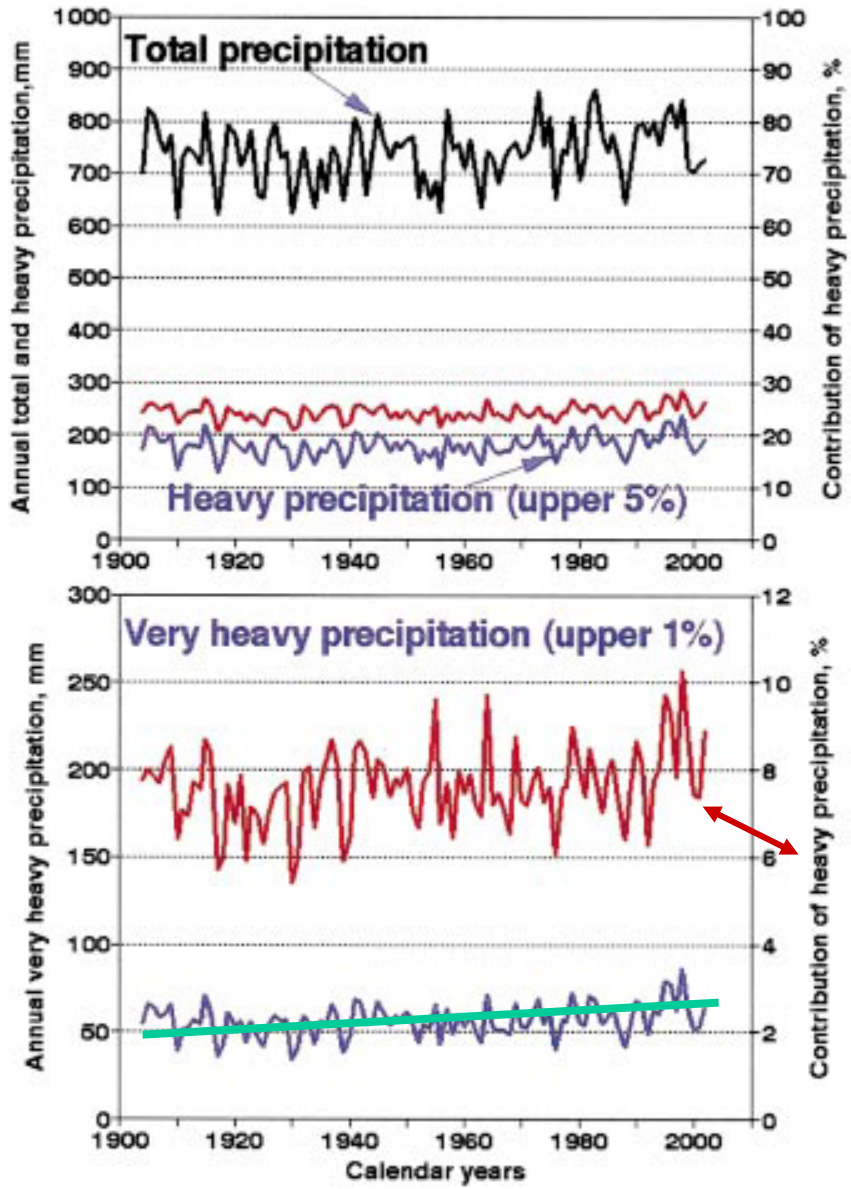
A basic physical law tells us that the water holding capacity of the atmosphere goes up at about 4% per degree Fahrenheit increase in temperature.

Observations show that this is happening at the surface and in lower atmosphere, by 4% since 1970 over global oceans.

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

Changes in U.S. precipitation 1900 to 2002



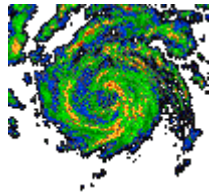


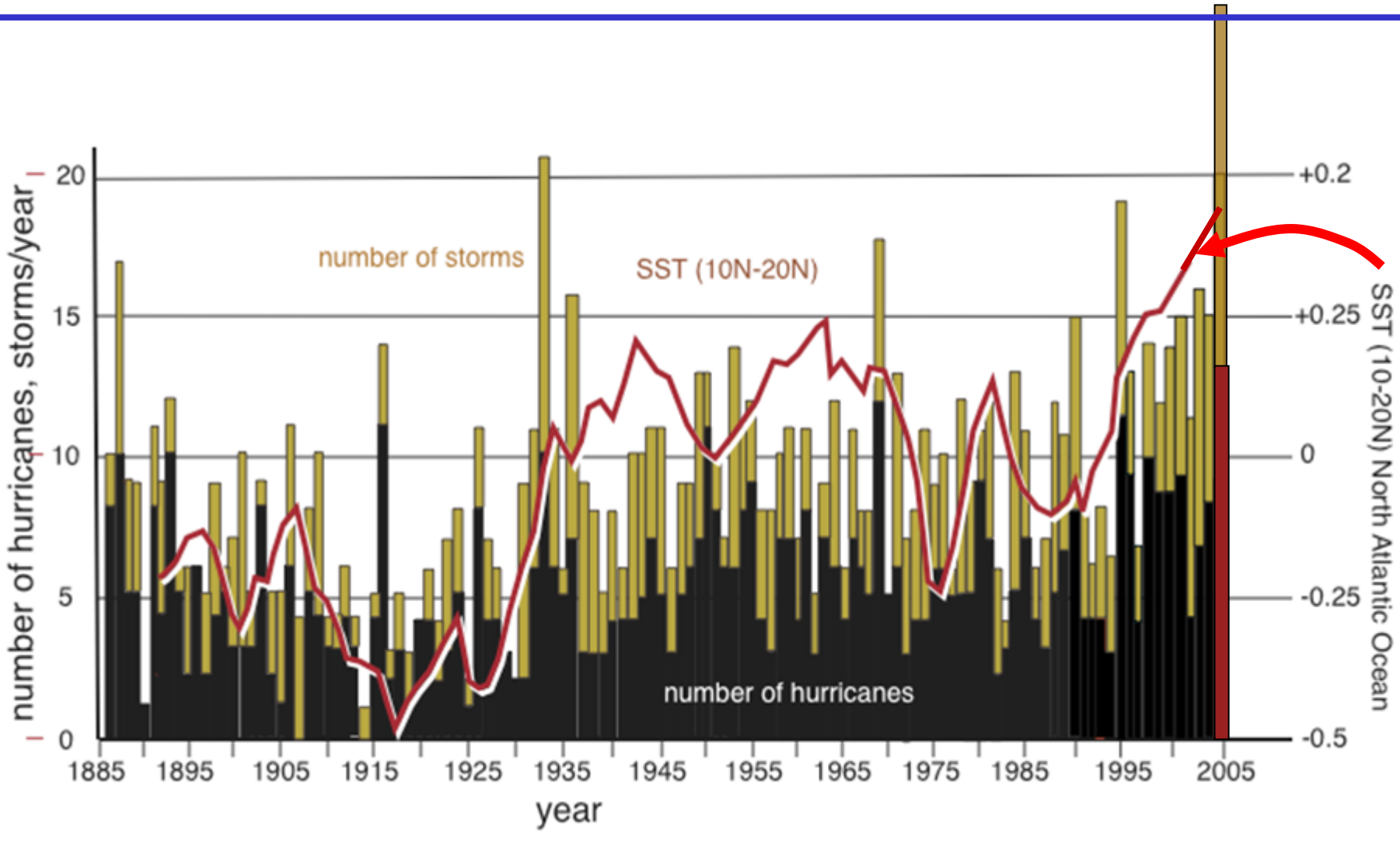
Changes in **total, heavy, and very heavy** precipitation over contiguous U.S.

Linear trends are up and significant at 1%: 7, 14, 20% /century

Groisman et al 2004

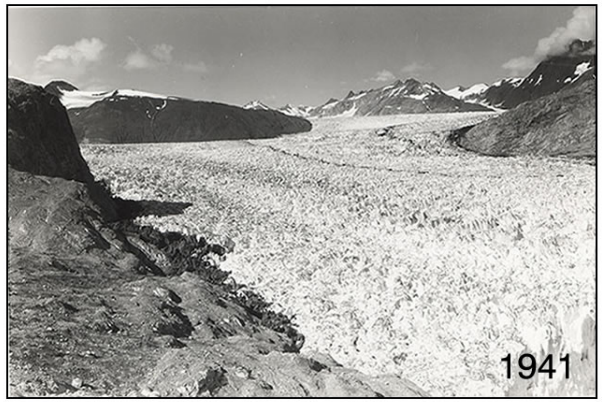
Changes in **hurricane** frequency in the North Atlantic Ocean





Evidence for reality of climate change

Glaciers melting



Muir Glacier, Alaska

1909

Toboggan Glacier Alaska

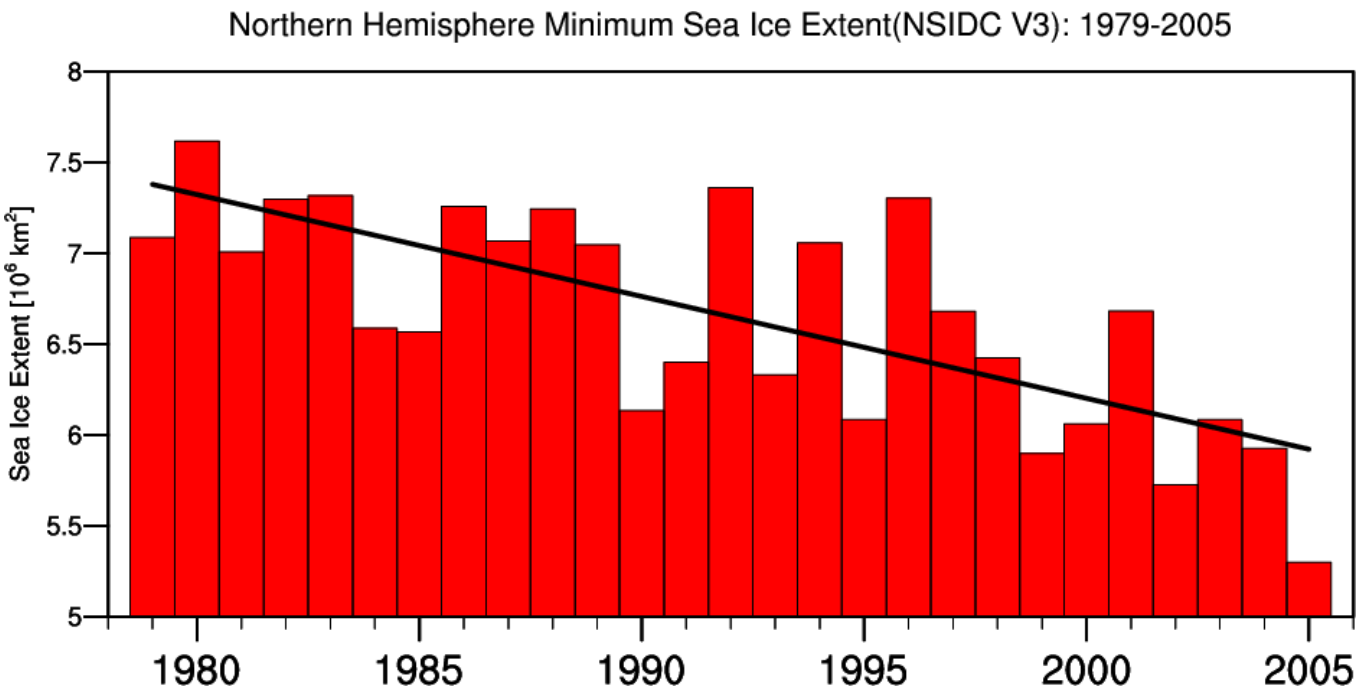
2000

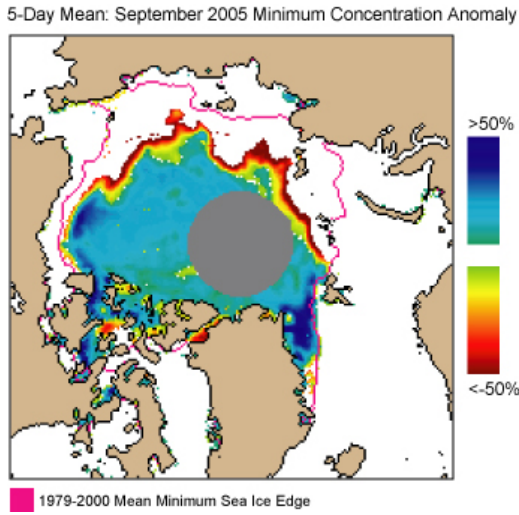
A. Circa 1900
Photo Source: Munich Society for Environmental Research

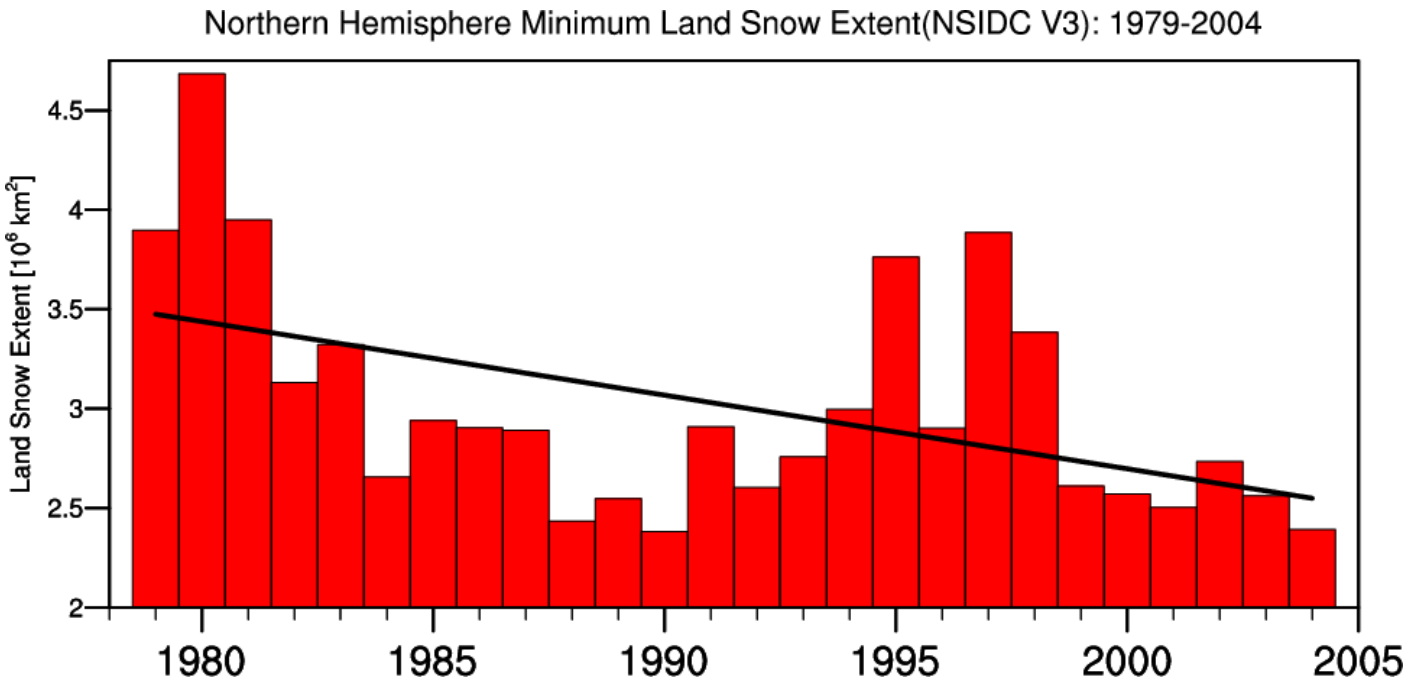
B. Recent

1900 2003

Alpine glacier, Austria

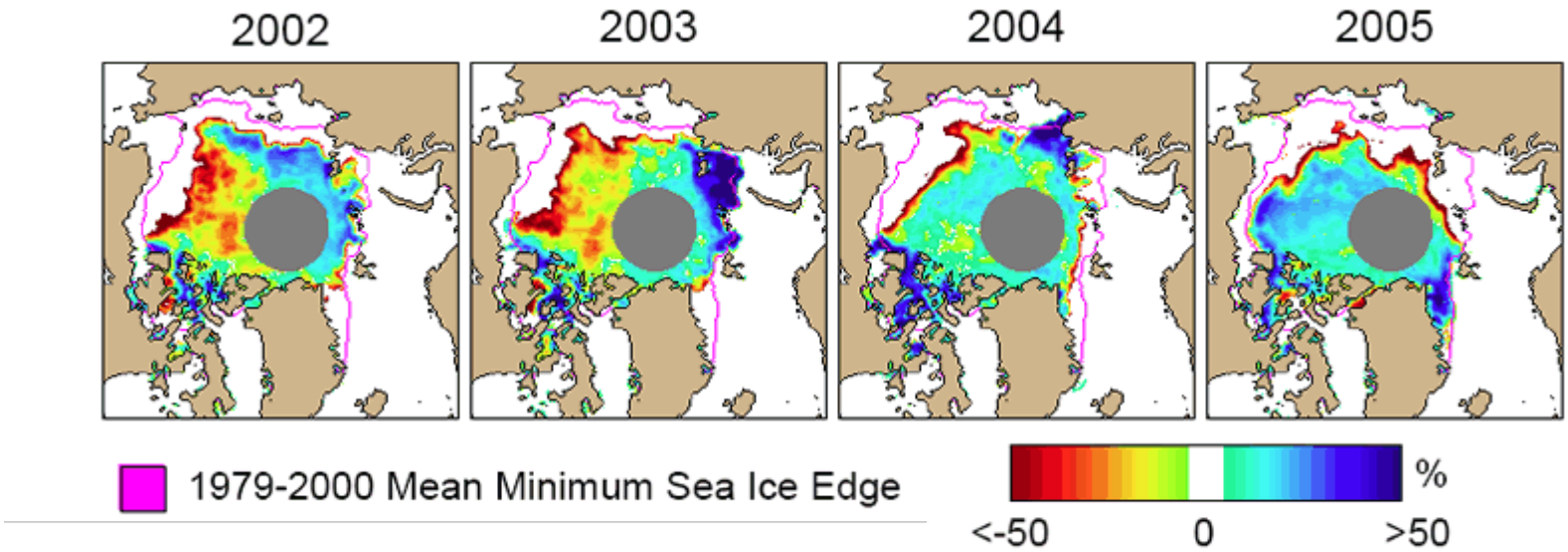


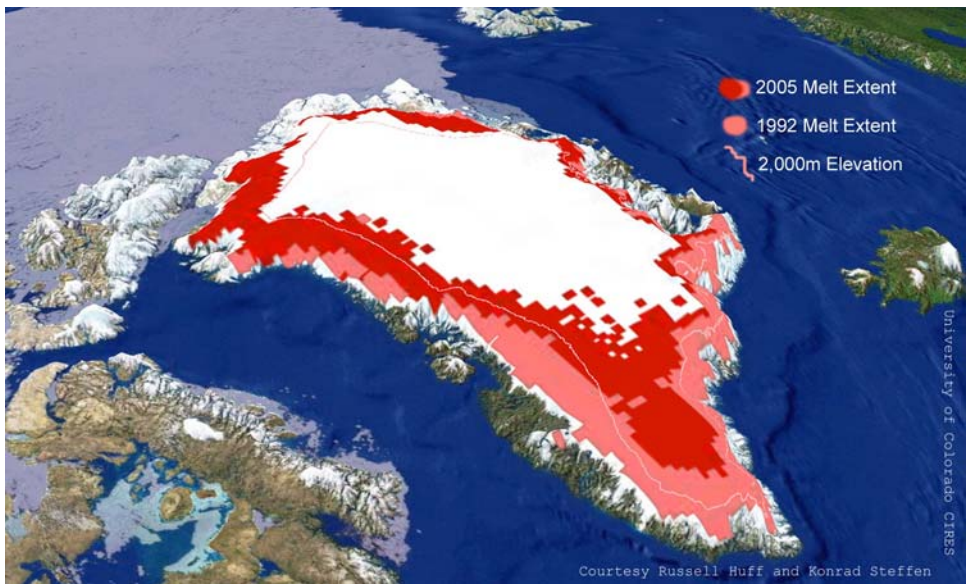




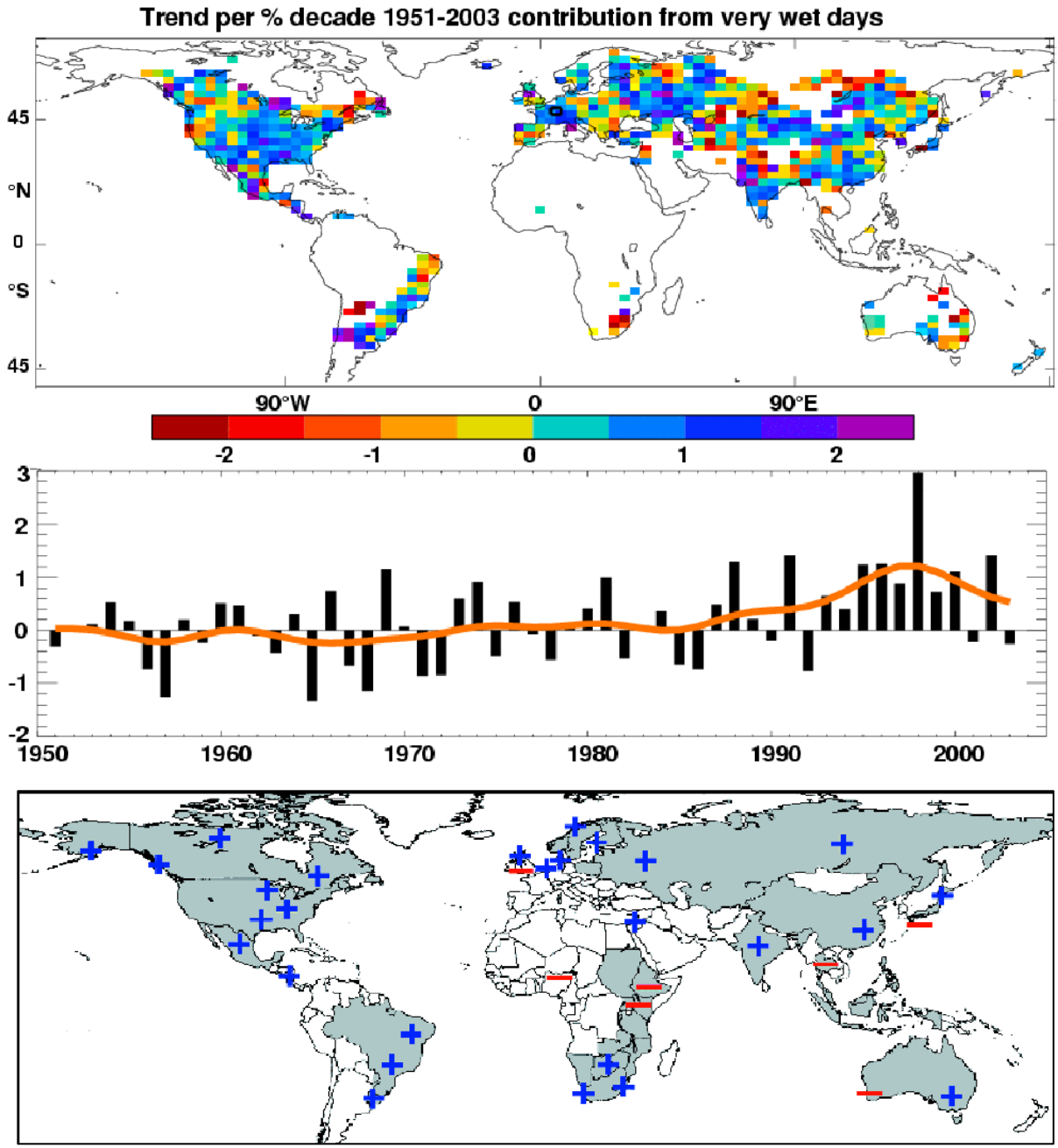
Declines in sea ice and snow cover

Recent warming greatest in the Arctic





NSIDC, 2005



Precipitation

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

Alexander et al 2006

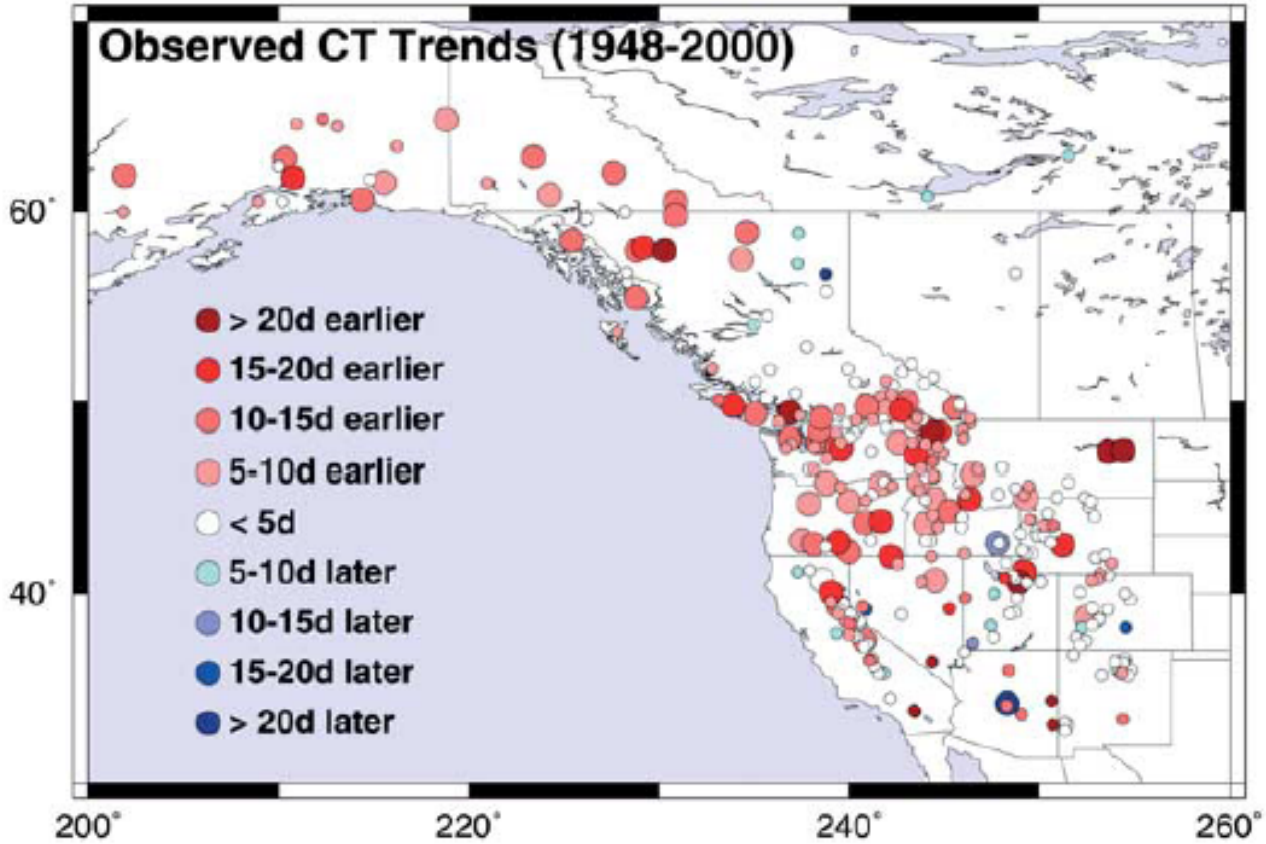
Regions where recent decades heavy precip >> mean precip

updated from Groisman et al. (2005a).

Surface melt on Greenland

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

Braithwaite
Univ. Manchester



Snow melt is occurring earlier along with runoff by 1 to 3 weeks. Larger circles indicate statistically significant trends at the 90% confidence level.

From Stewart et al 2004 Climatic Change

SNOW PACK: In 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**

Wildfire near Denver 2002

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.

Global warming

⇓

Heating ↑

⇓

Temperature ↑ & Evaporation ↑

⇓

water holding capacity ↑

⇓

atmospheric moisture ↑

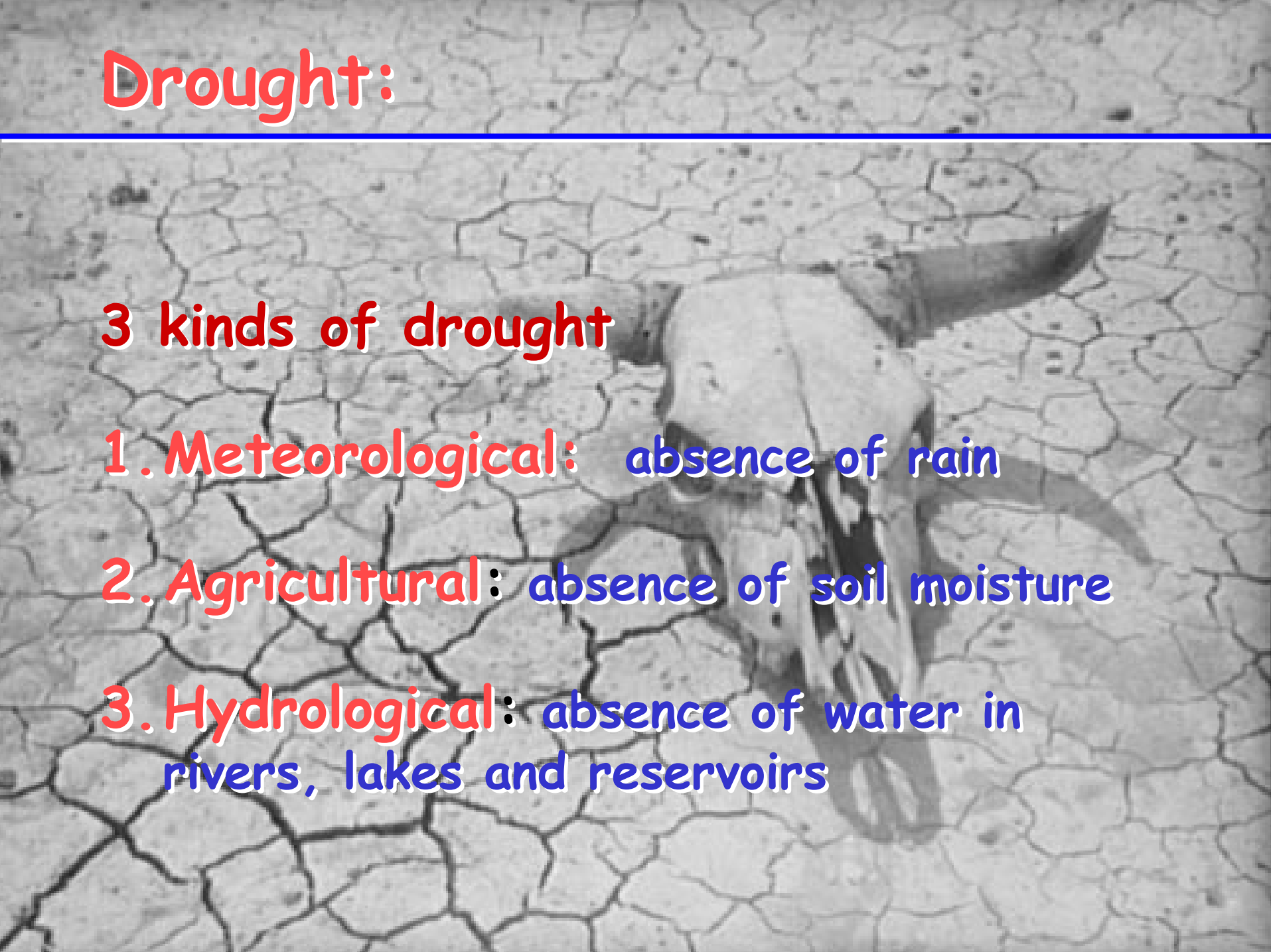
⇓ ⇓

greenhouse effect ↑ & rain intensity ↑

⇓

&

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

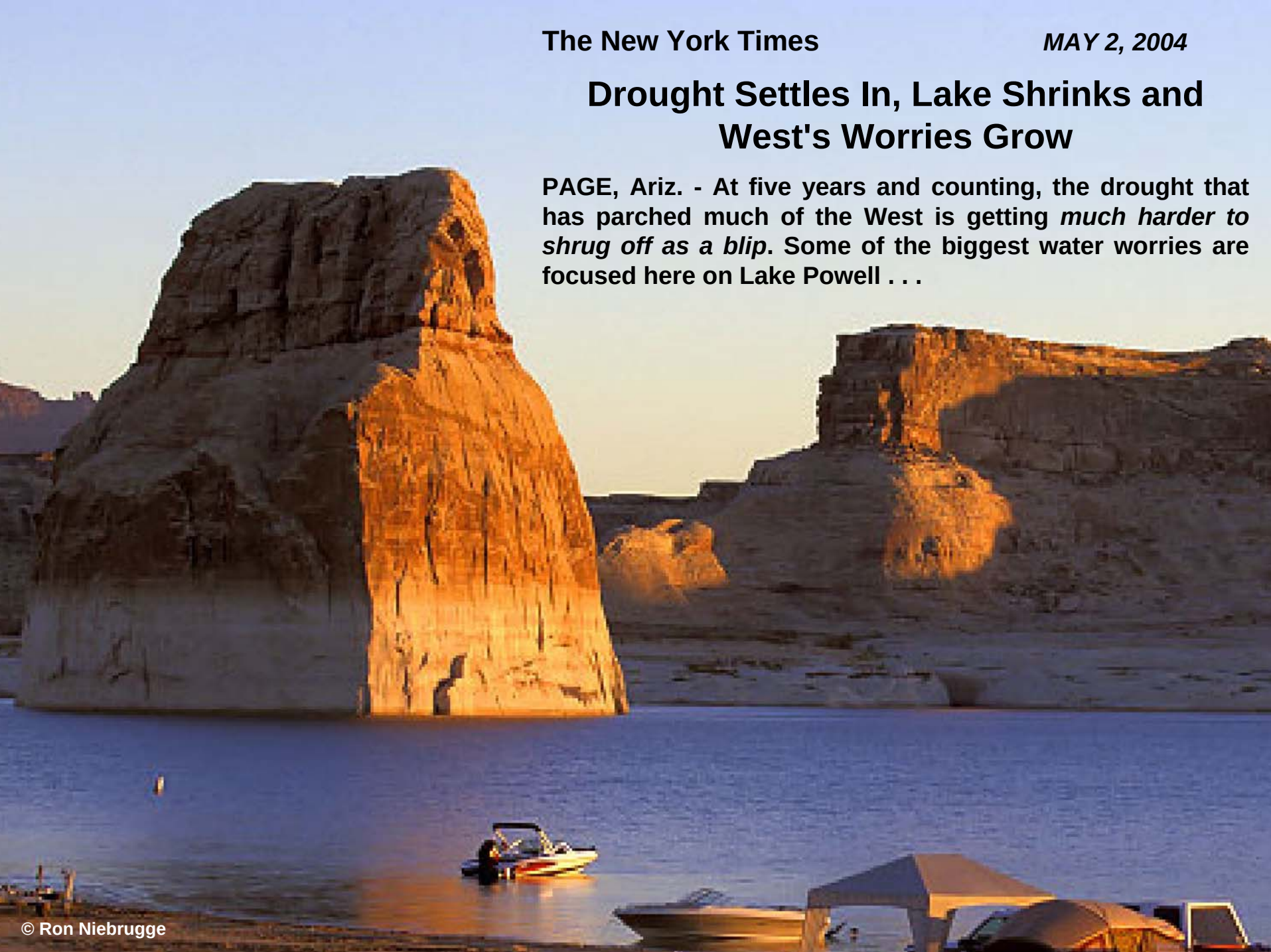
Lake Dillon, Colorado, August 8, 2002

Courtesy R. Anthes

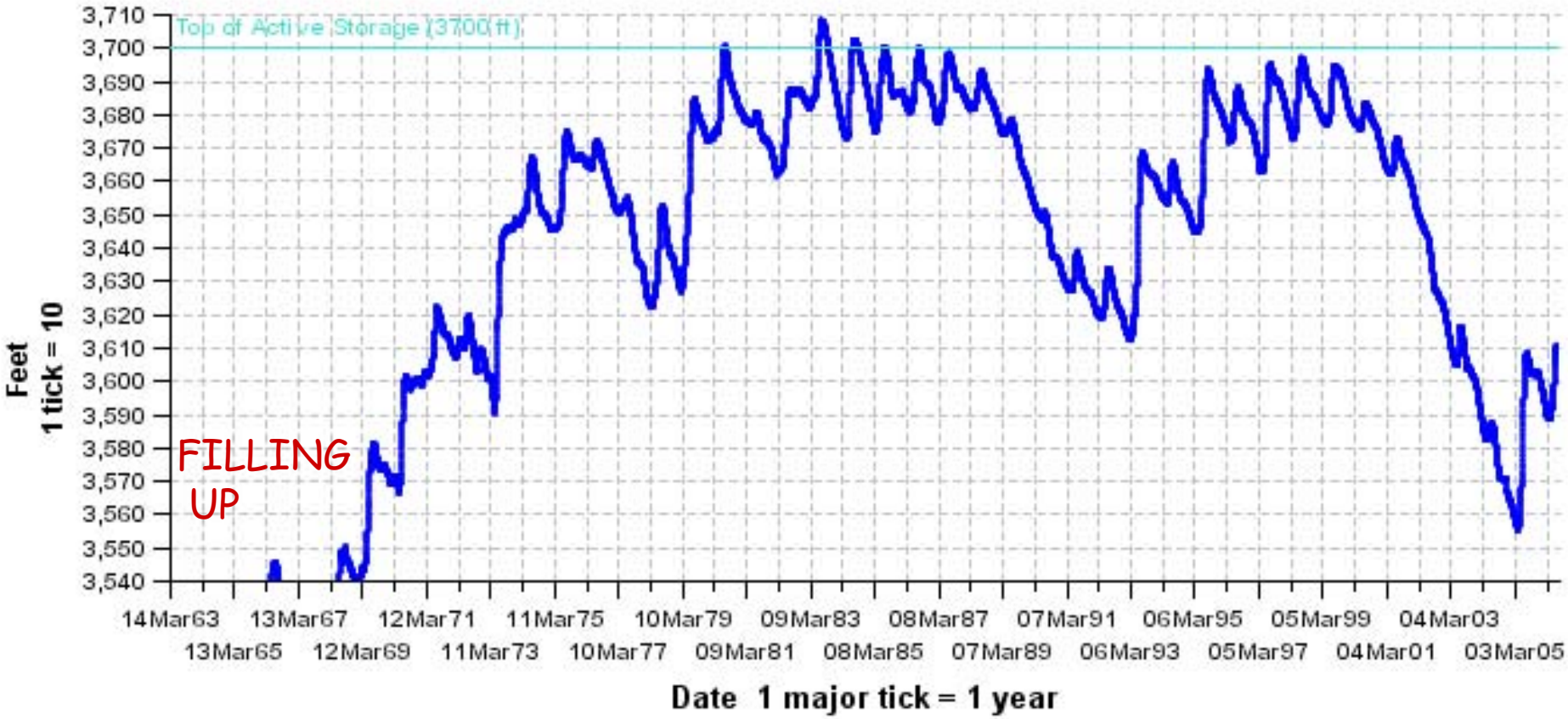
The New York Times *MAY 2, 2004*

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'

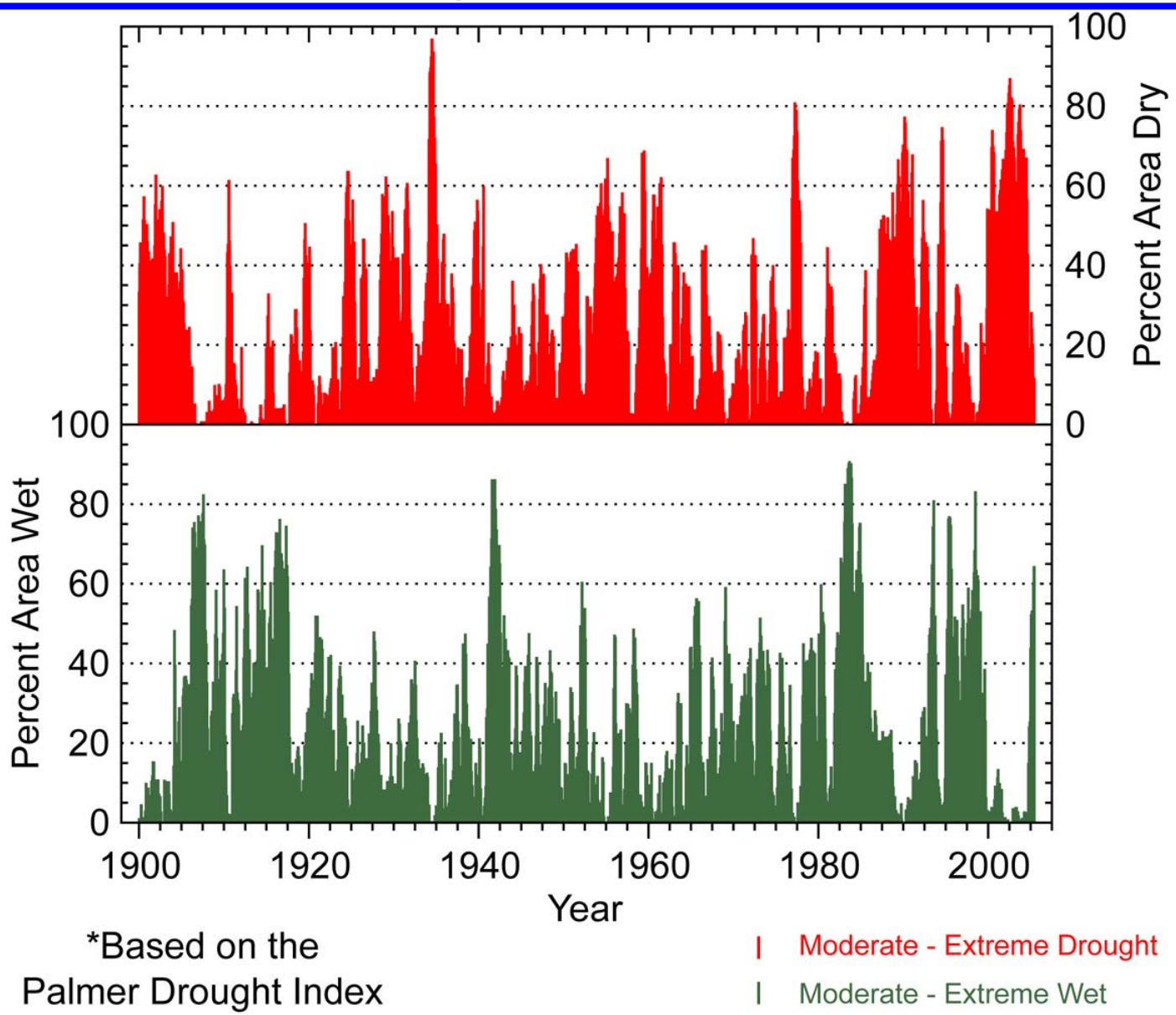
Min 2005 0408
3555.1' -144.9'

www.usbr.gov/uc/water/index.html

Now –2.0 inches per day

Western U.S. Percentage Area Wet or Dry

January 1900 - June 2005



% US west of the Rocky Mountains dry (top) or wet (bottom) based on PDSI for moderate to extreme drought or wet.

From NOAA NCDC.

North American Drought Monitor

June 30, 2006

Released: Monday, July 17, 2006

http://www.ncdc.noaa.gov/nadm.html

Analysts:

Canada - Trevor Hadwen
Dwayne Chobanik
Mexico - Miguel Cortez
U.S.A. - Doug LeComte
Tom Heddinghaus
Liz Love-Brotak*
Richard Heim*

(* Responsible for collecting analysts input & assembling the NA-DM map)

Intensity:

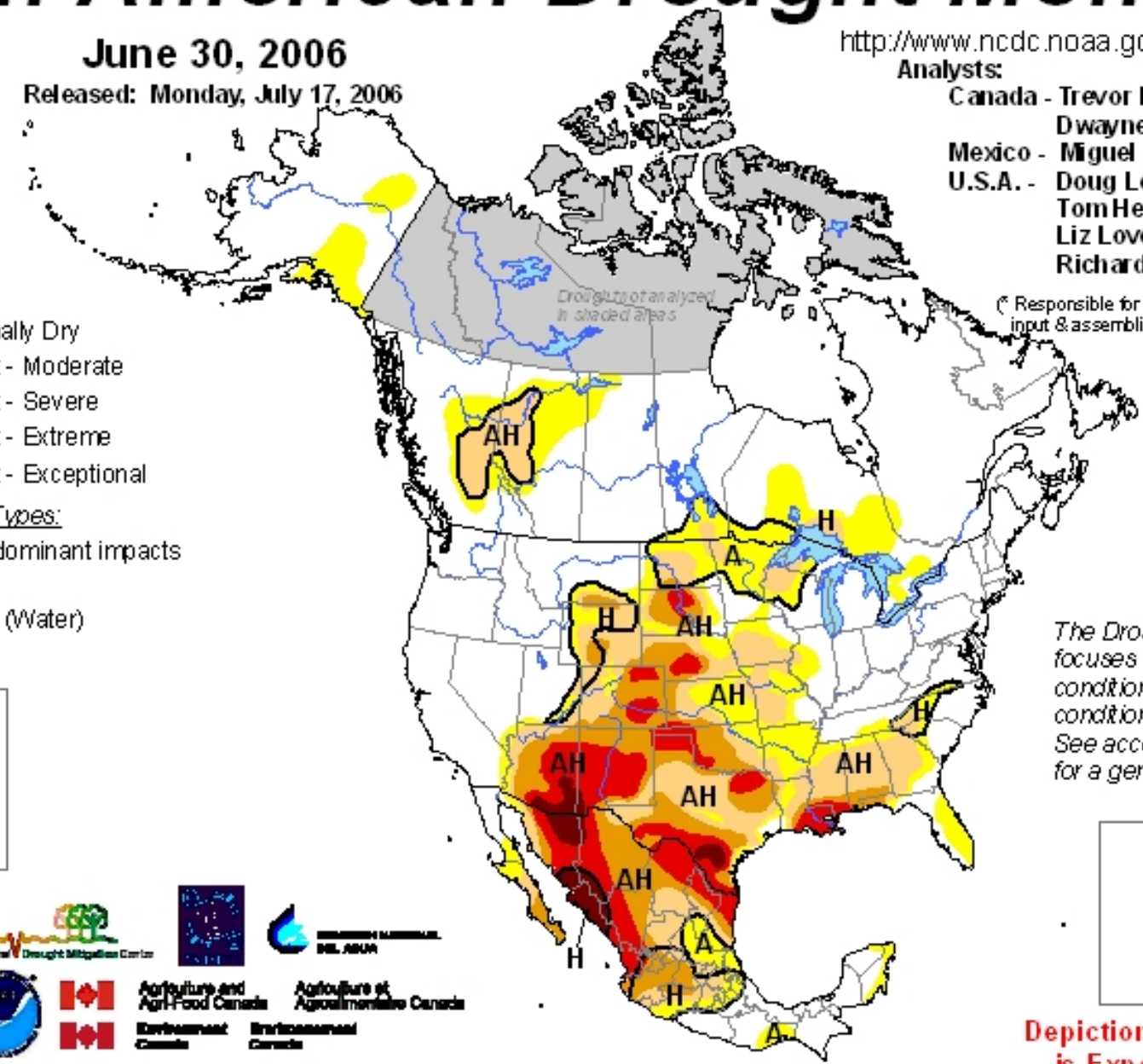
- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

Delineates dominant impacts

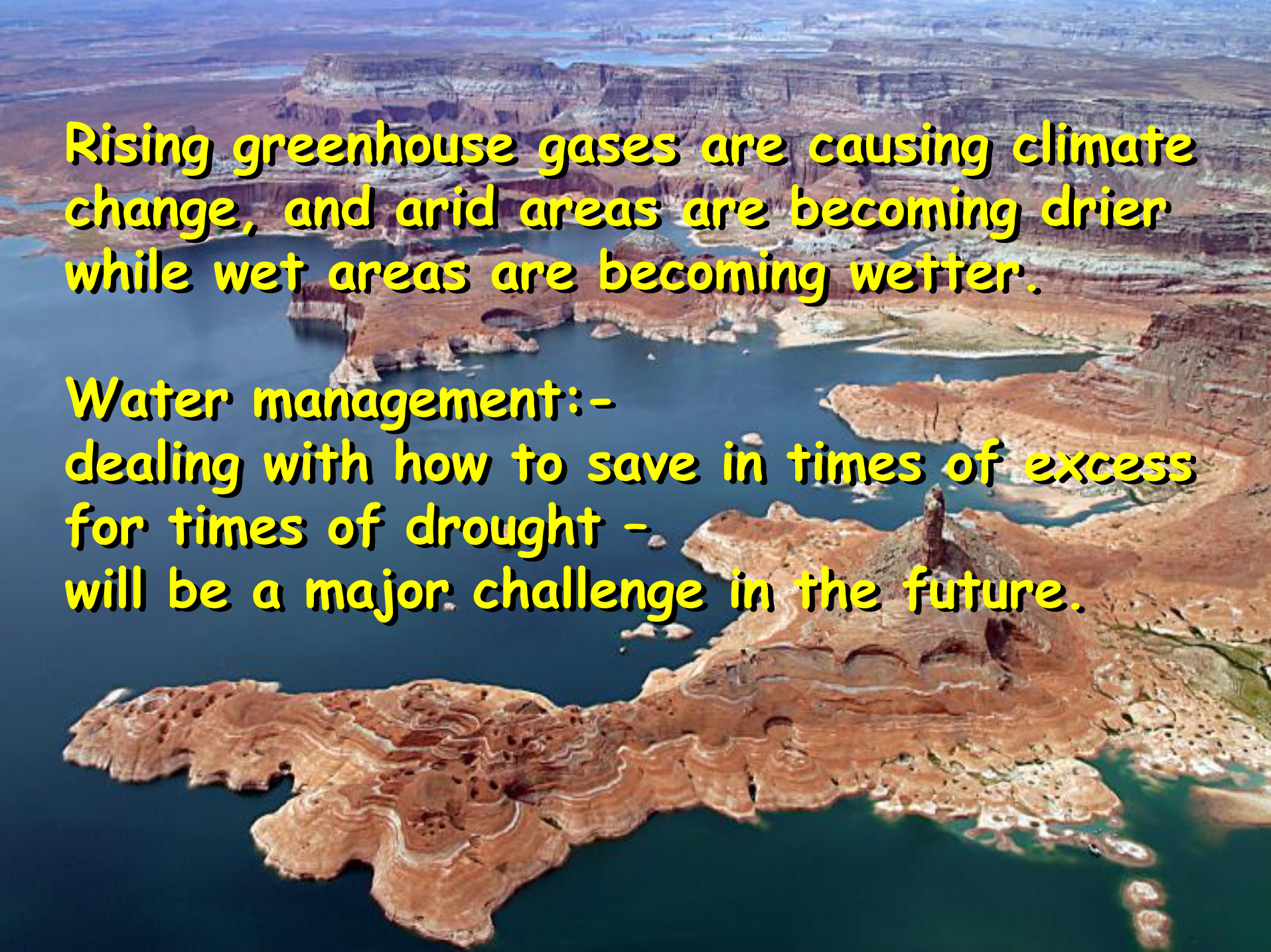
A = Agriculture

H = Hydrological (Water)



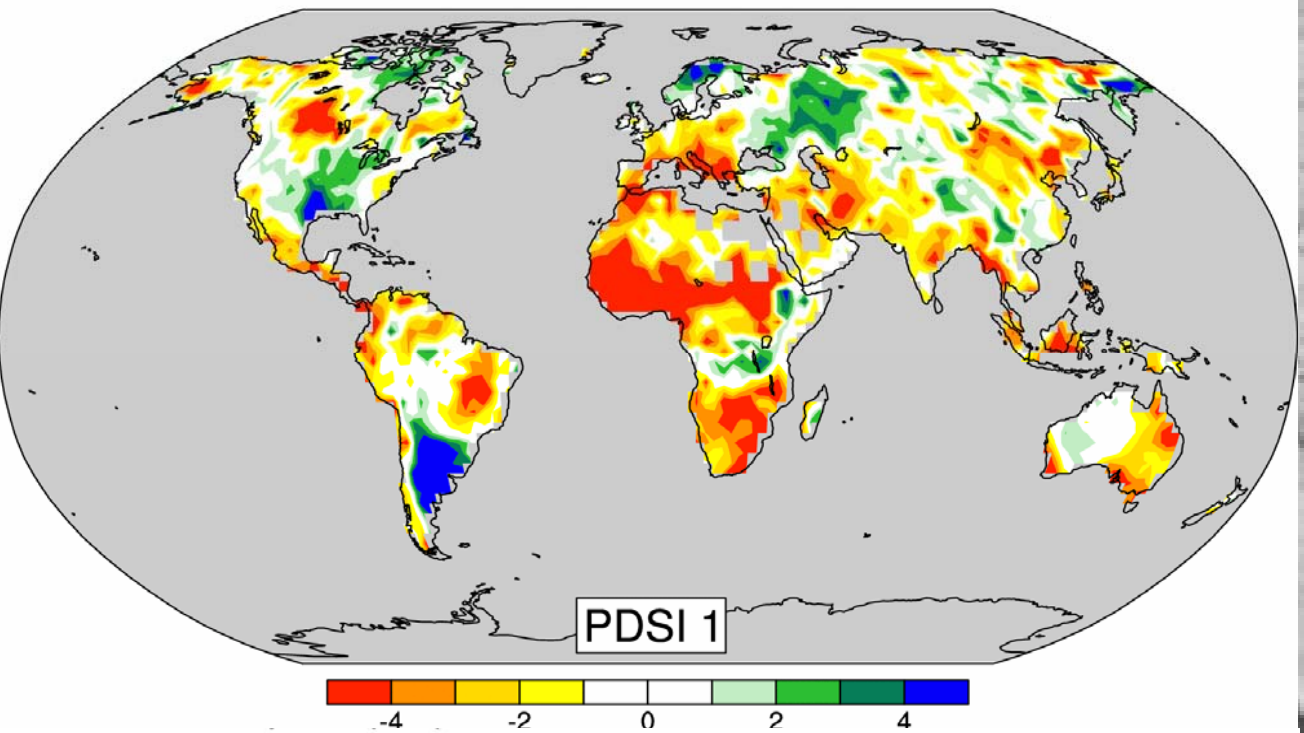
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text for a general summary.

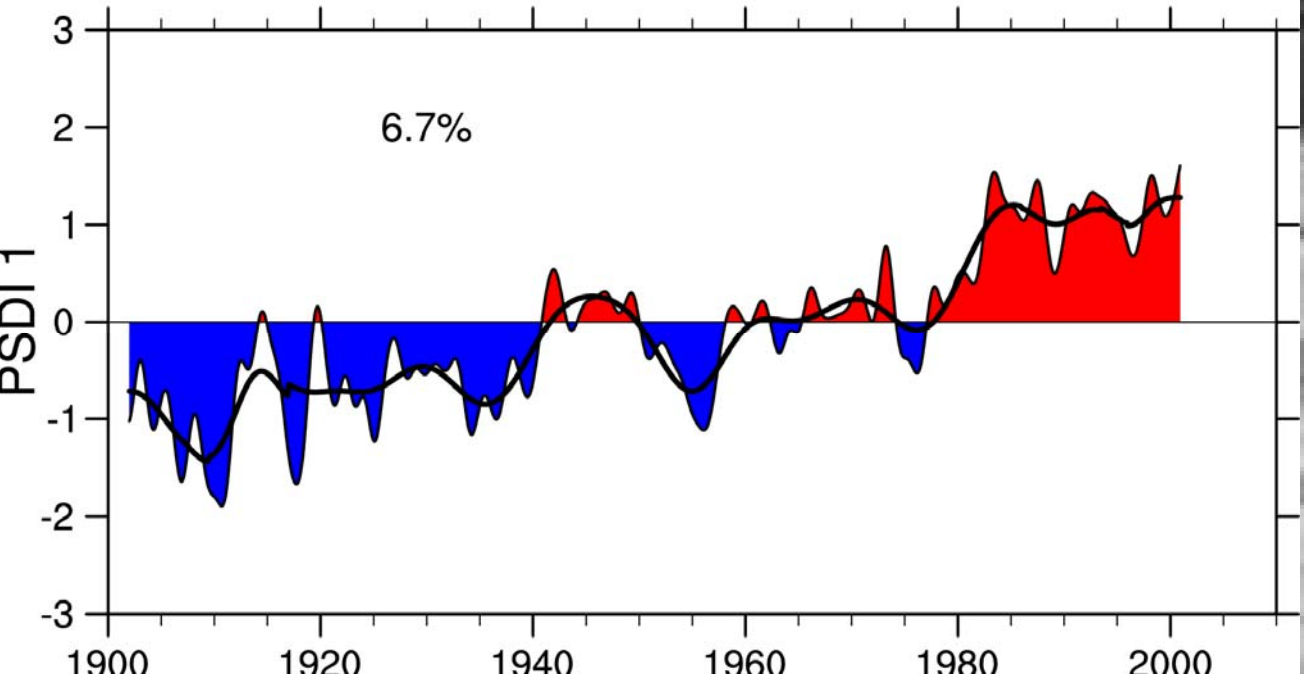
Depiction for Canada is Experimental



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.





Palmer Drought Severity Index

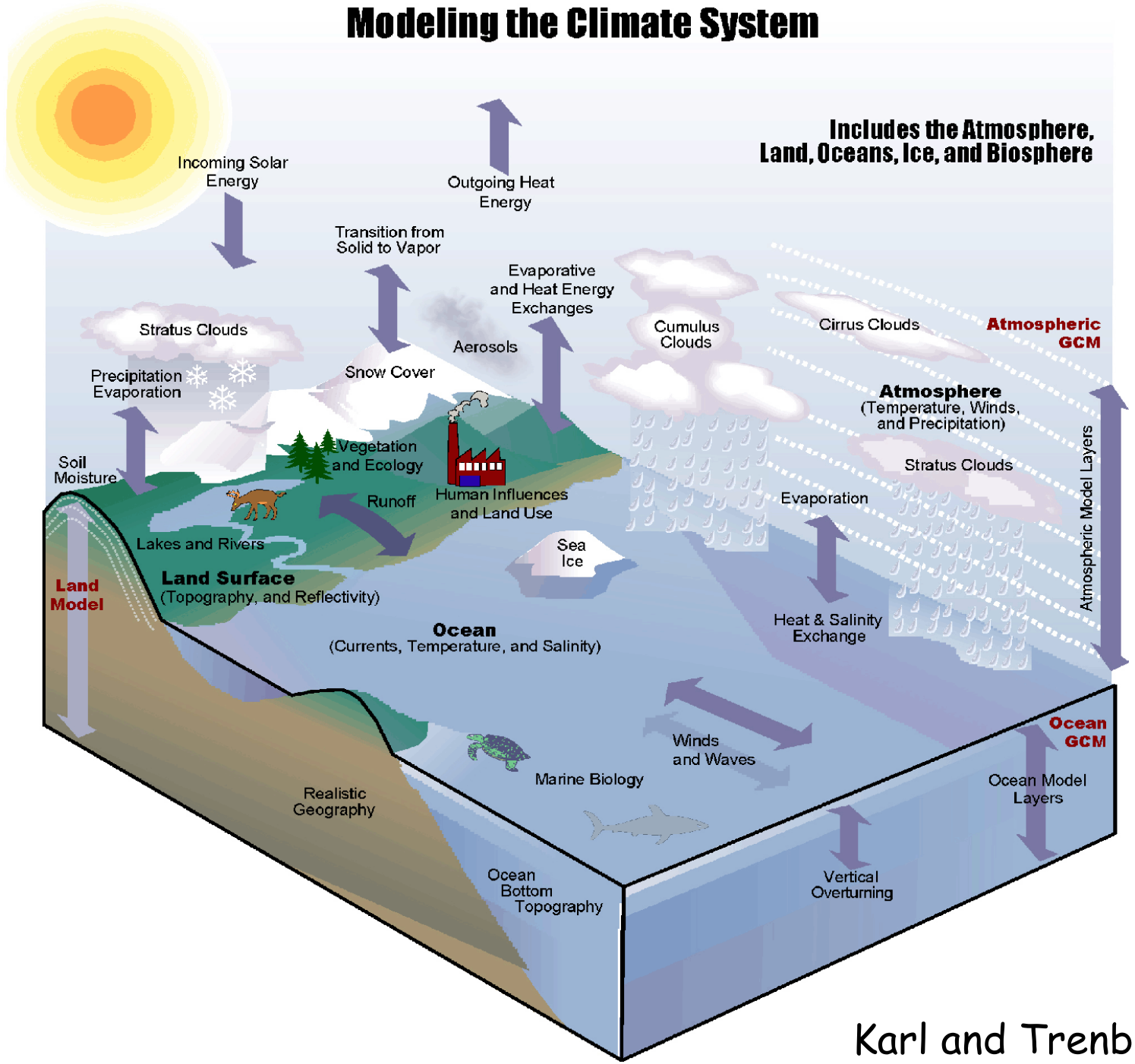
PDSI

first EOF: trend.

6.7% variance

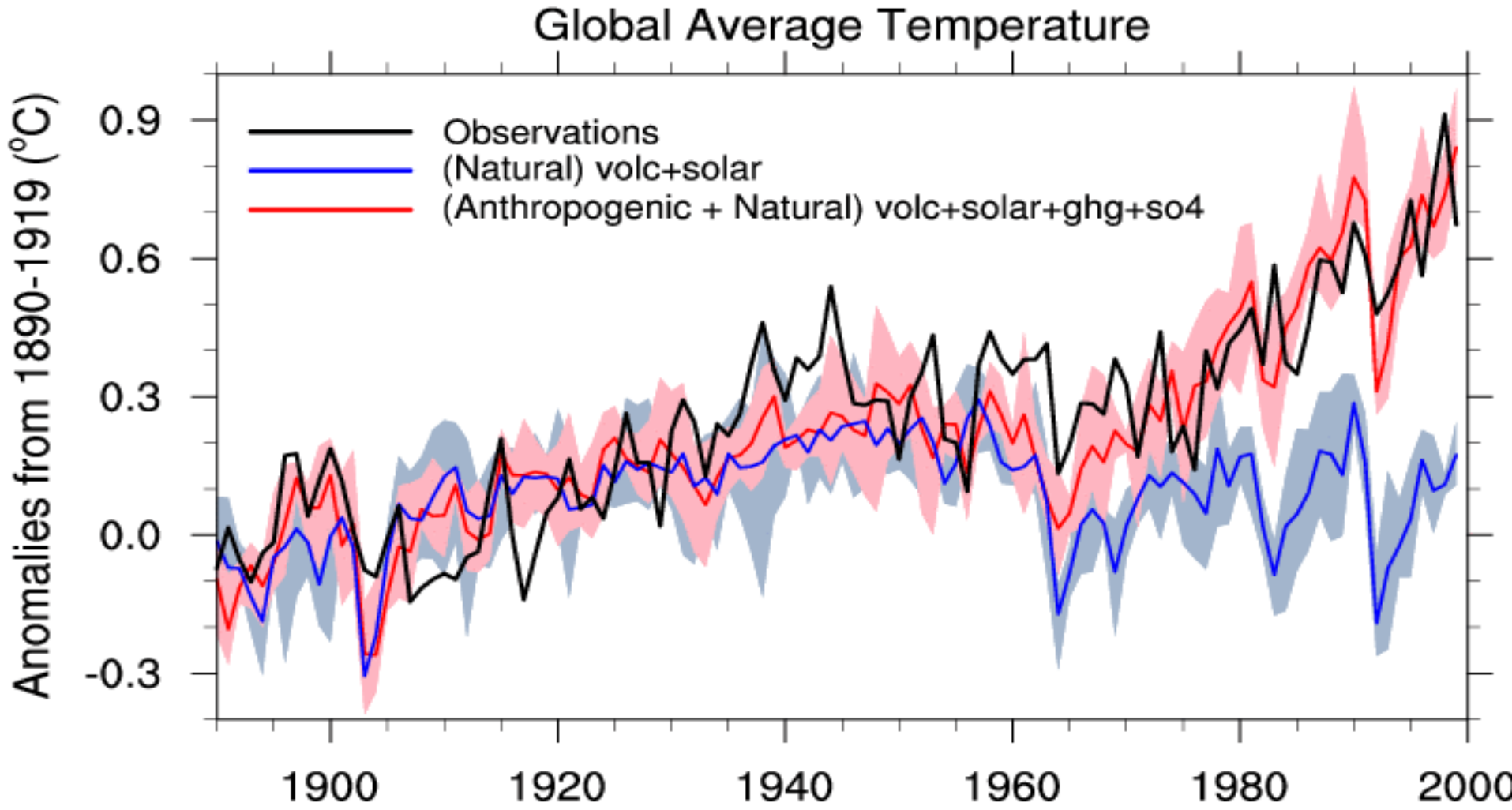
Dai et al 2004

Modeling the Climate System

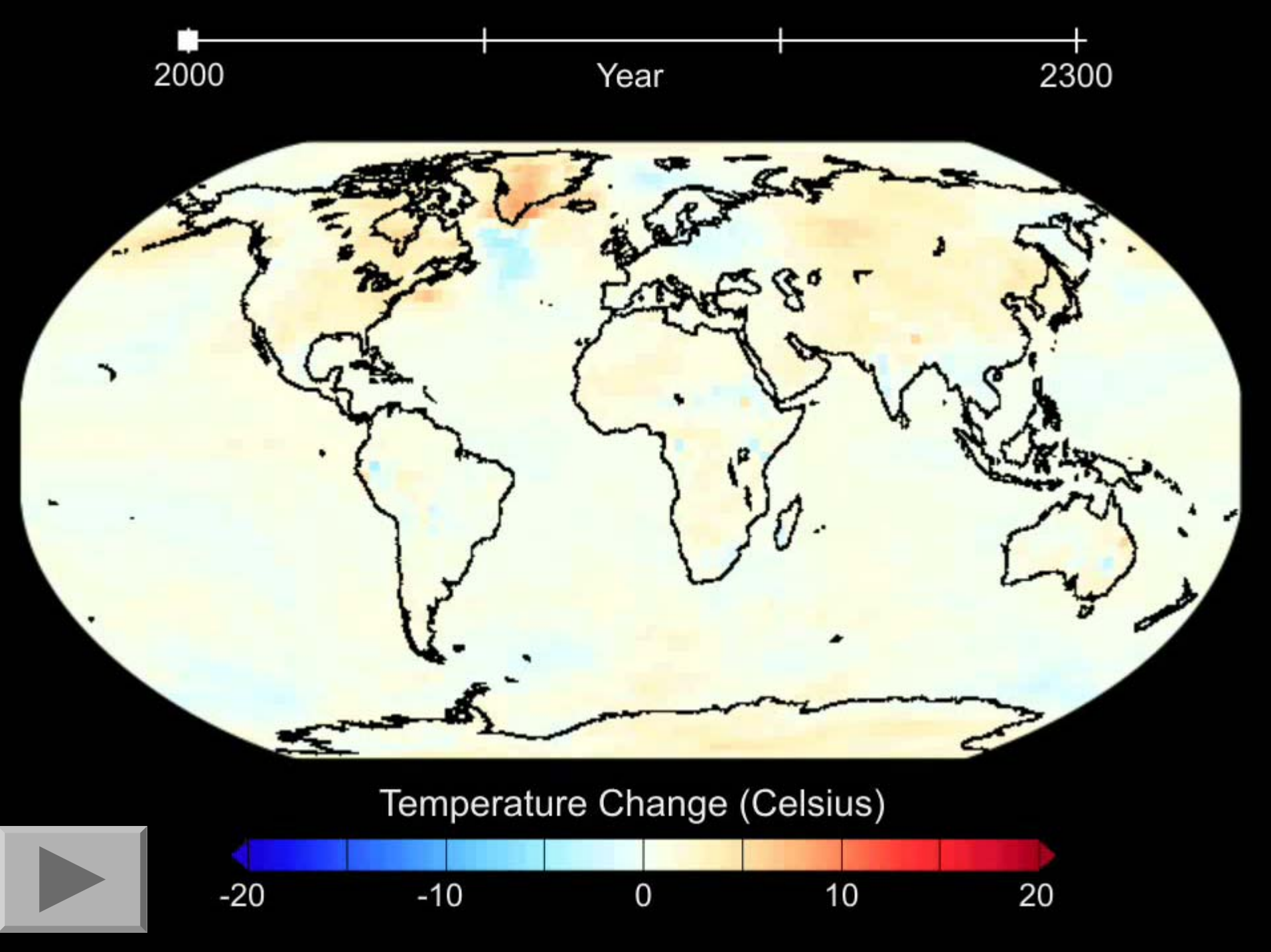


Karl and Trenberth 2003

Natural forcings do not account for observed 20th century warming after 1970

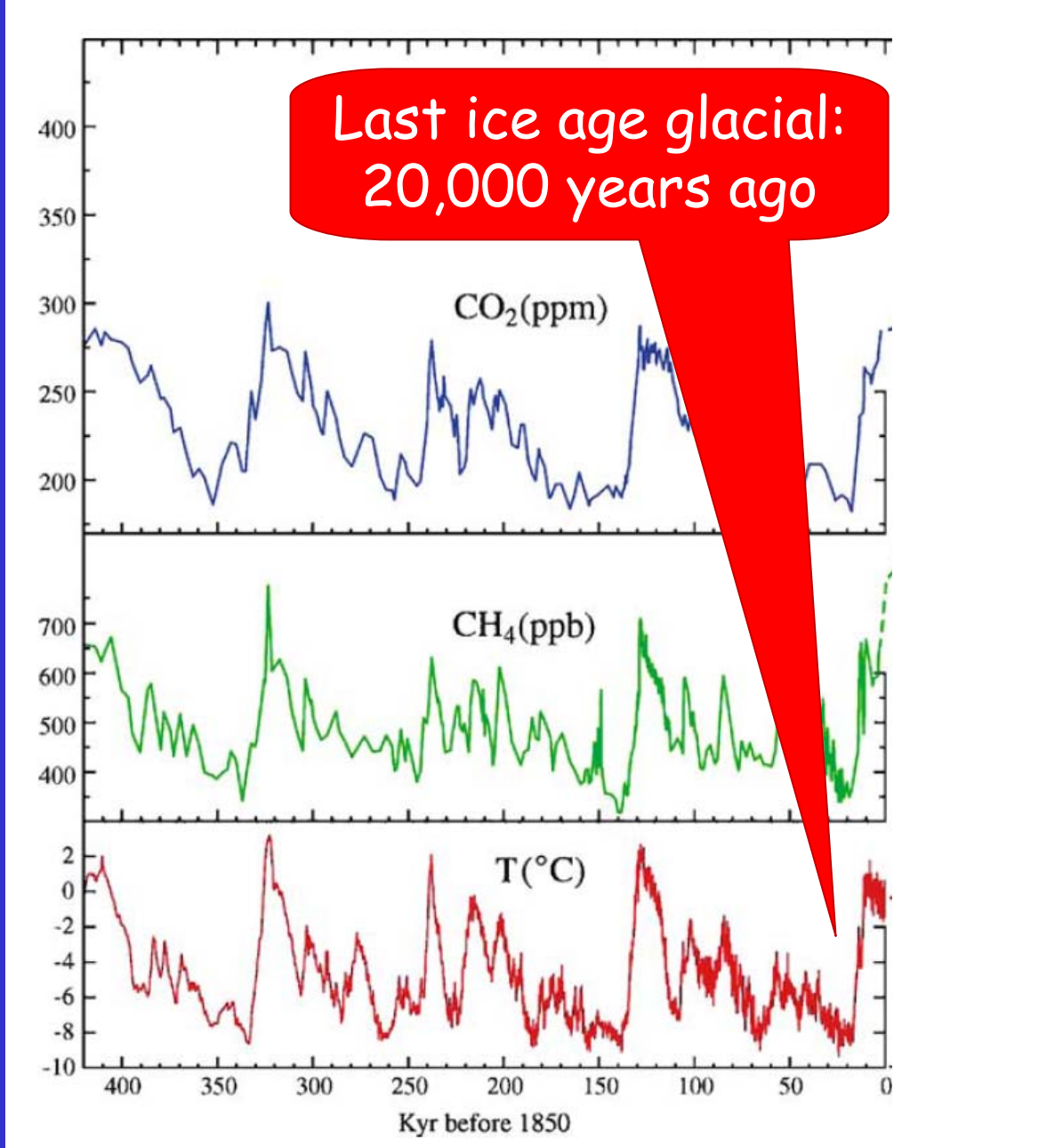


Meehl et al, 2004: J. Climate.

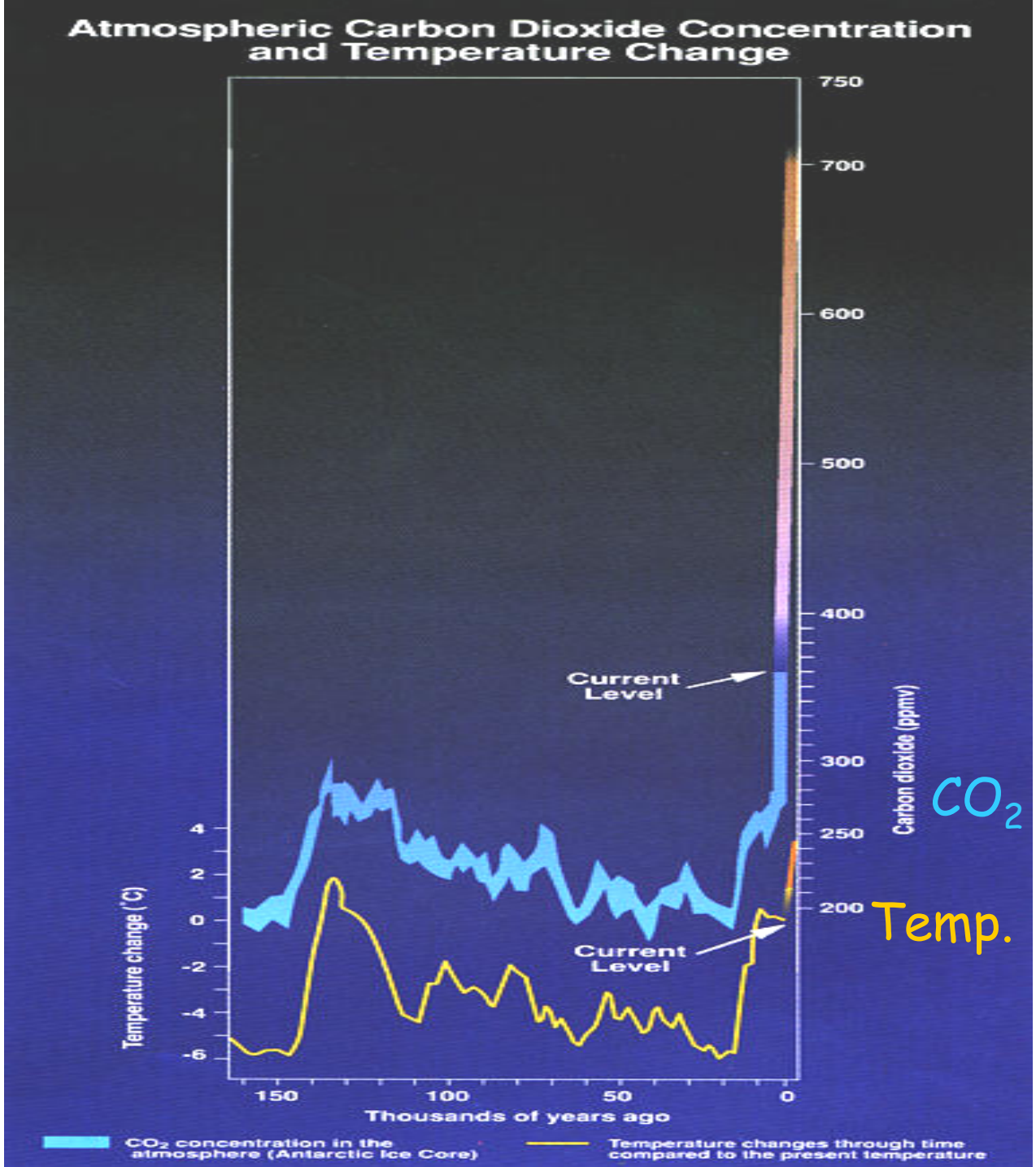

2000
Year
2300
Temperature Change (Celsius)
-20
-10
0
10
20

Context:

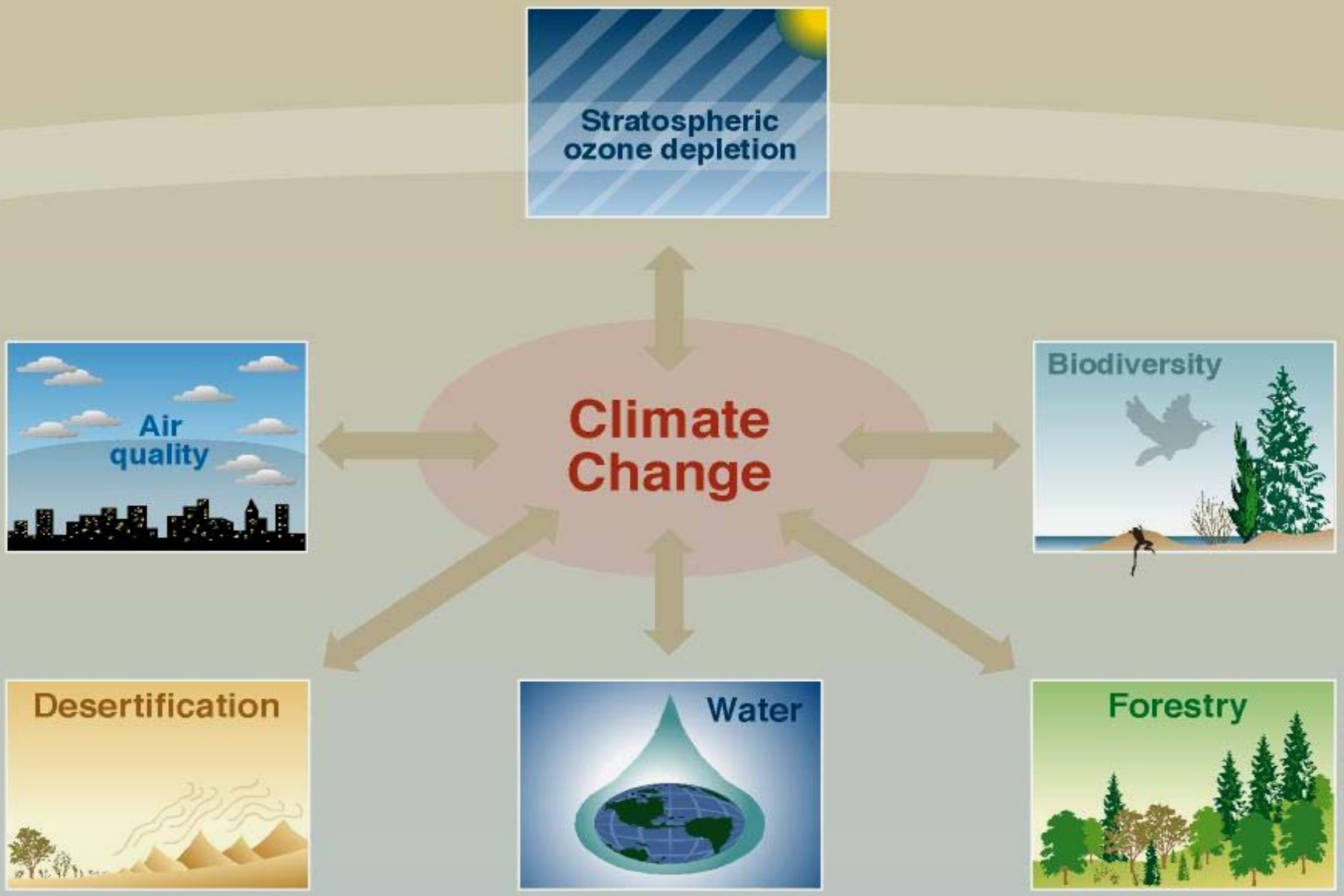
400,000 years of Antarctic ice core records of Temperatures, Carbon dioxide and Methane.



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


Atmospheric Carbon Dioxide Concentration and Temperature Change
750
700
600
500
400
300
250
200
Carbon dioxide (ppmv)
Current Level
Current Level
4
2
0
-2
-4
-6
Temperature change (°C)
150
100
50
0
Thousands of years ago
CO2 concentration in the atmosphere (Antarctic Ice Core)
Temperature changes through time compared to the present temperature
CO2
Temp.

Climate change & other environmental issues are inter-linked



Agricultural Lands | Coastal Zones | Forest Lands | Freshwater Systems | Arid Lands Grasslands

Food and Fiber Production

Provision of Clean and Sufficient Water

Maintenance of Biodiversity

Maintenance of Human Health

Storage and cycling of Carbon, Nitrogen, Phosphorus

Climate change will affect the ability of ecological systems to provide essential ecological goods and services

The parable of the frog

A frog placed in a pot of hot water, immediately jumps out to save himself.

But a frog placed in a pot of cold water that is slowly brought to the boil, remains in the pot and dies!

Is this a parable for global warming?