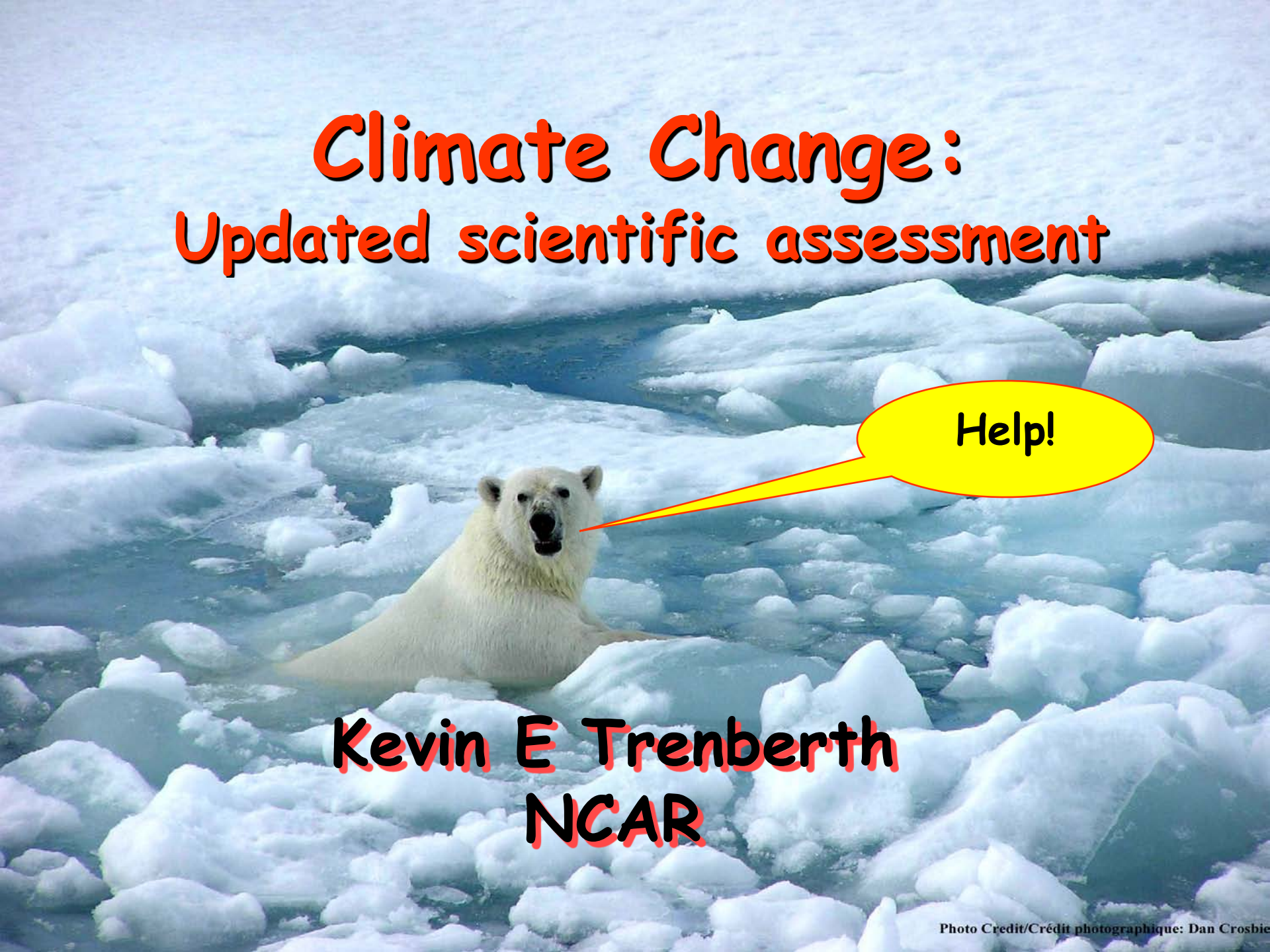
Climate Change:
Updated scientific assessment



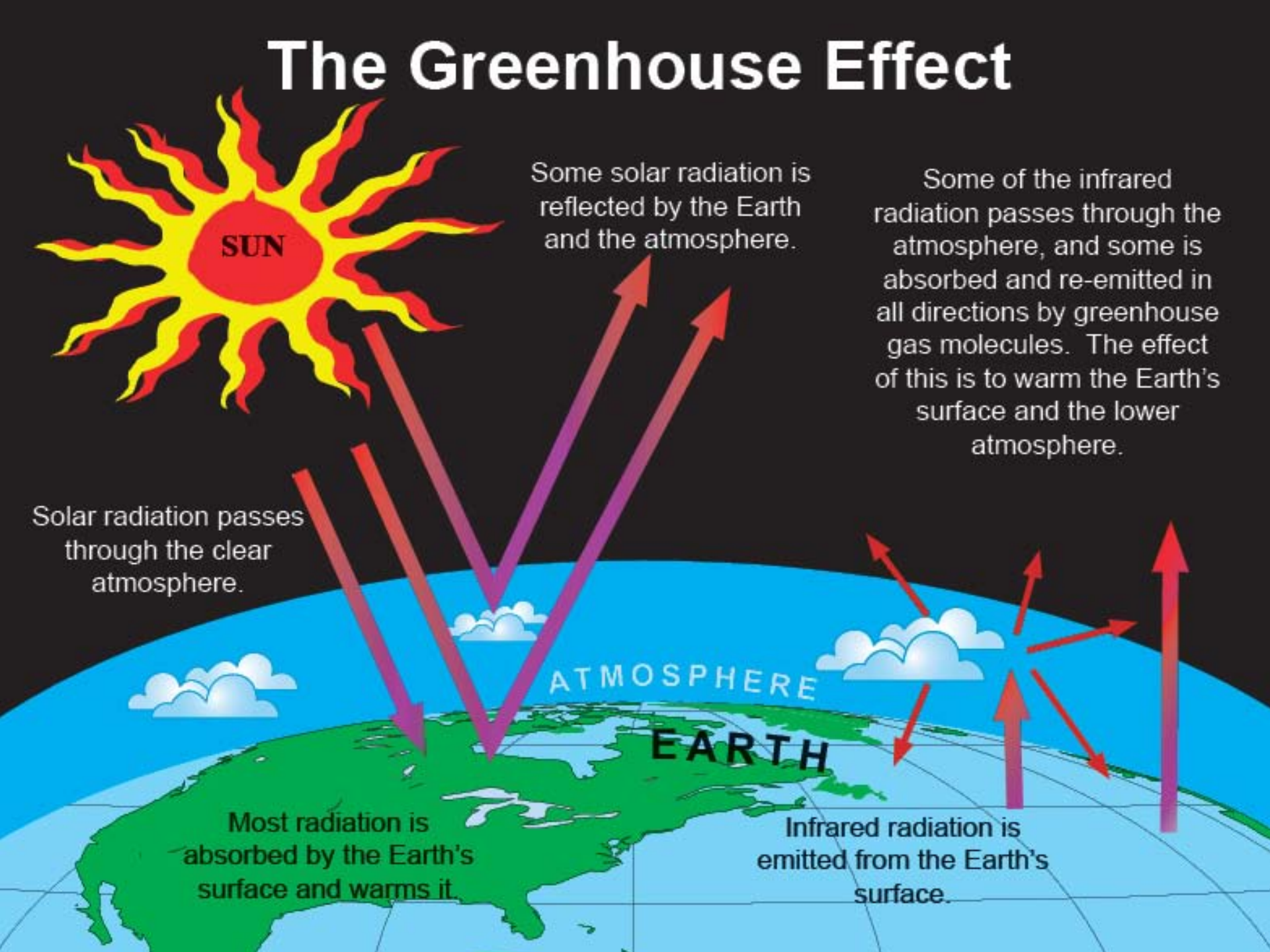
Kevin E Trenberth
NCAR

Photo Credit/Crédit photographique: Dan Crosbie

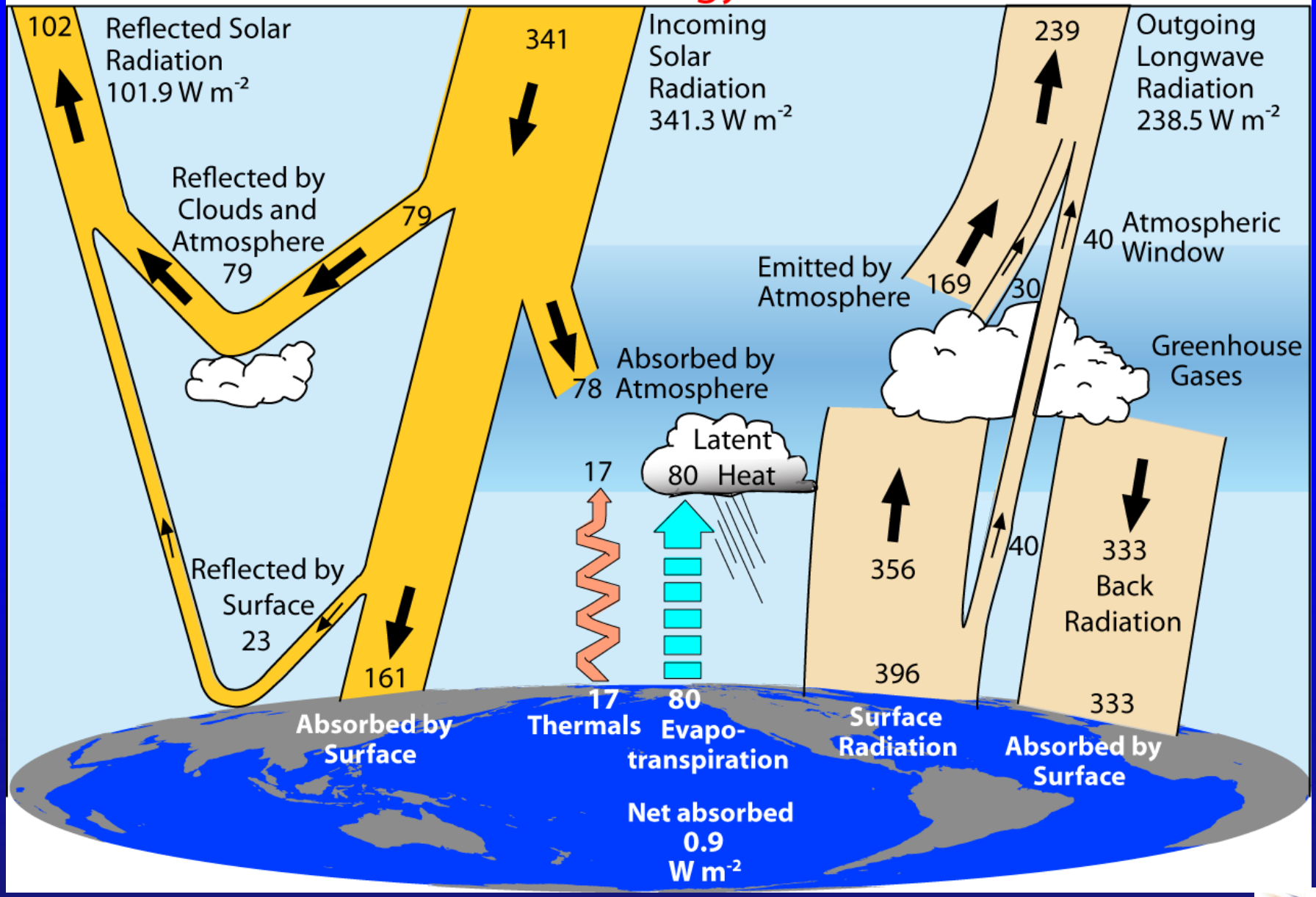
Running a fever: Seeing the doctor

- **Symptoms**: the planet's temperature and carbon dioxide are increasing
- **Diagnosis**: human activities are causal
- **Prognosis**: the outlook is for more warming at rates that can be disruptive and will cause strife
- **Treatment**: mitigation (reduce emissions) and adaptation (planning for consequences)

The Greenhouse Effect



Global Energy Flows W m^{-2}



2000-2005 Trenberth et al 2009

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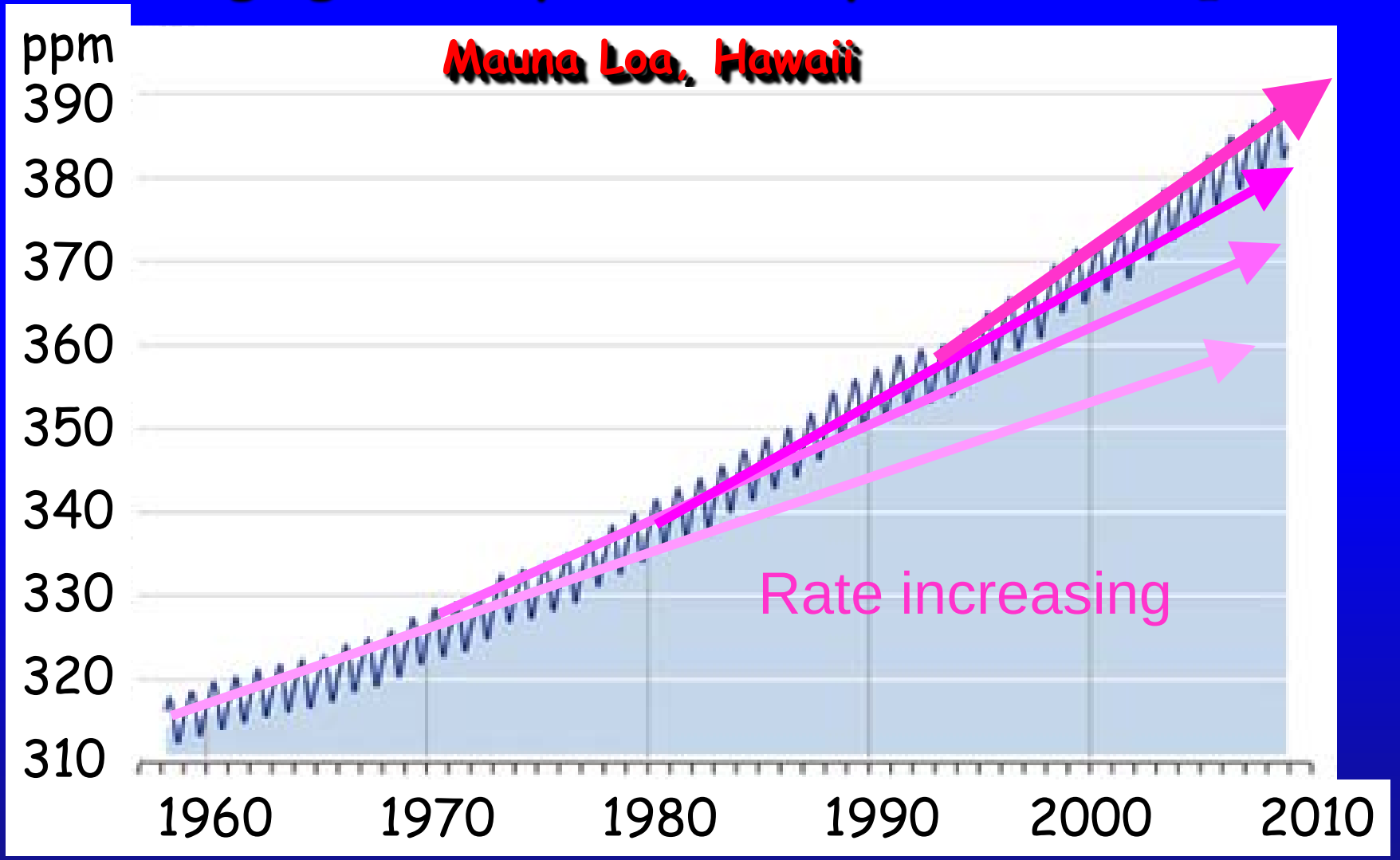
Changing atmospheric composition: CO_2



Data from Climate Monitoring and Diagnostics Lab., NOAA. Data prior to 1974 from C. Keeling, Scripps Inst. Oceanogr.

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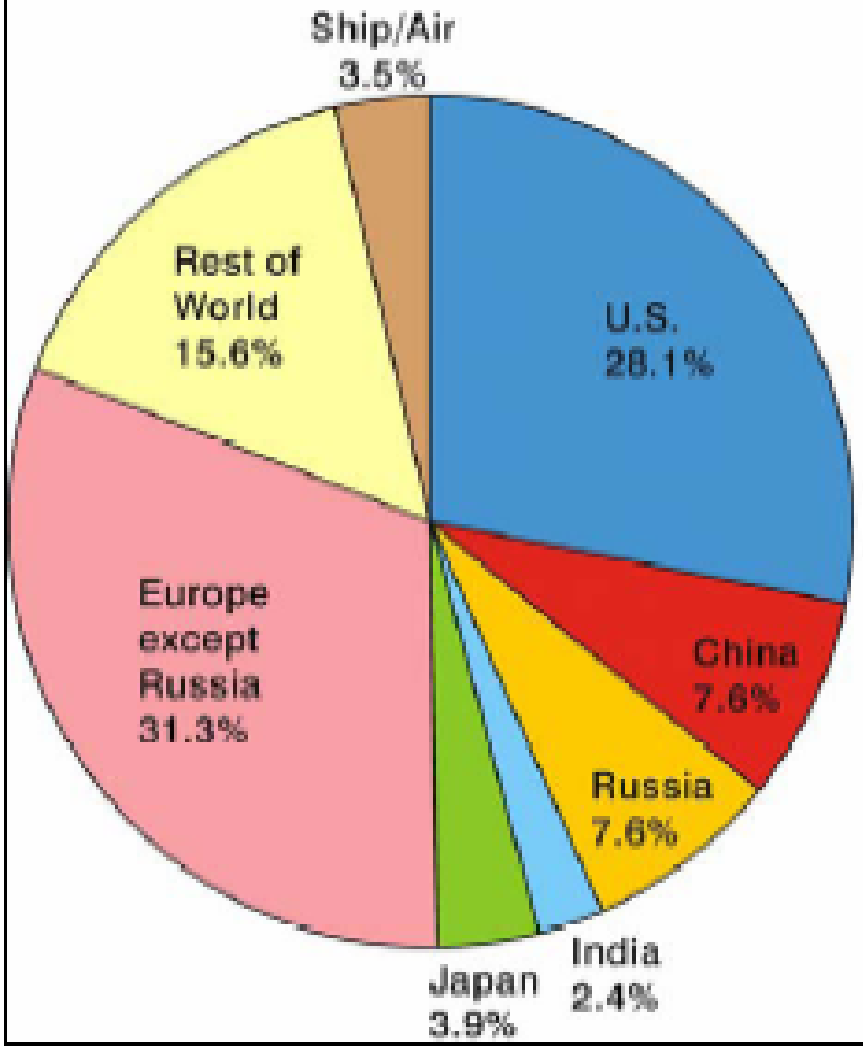
Fossil Fuel CO_2 Emissions

Accumulated Fossil Fuel CO_2 (1850-2004)

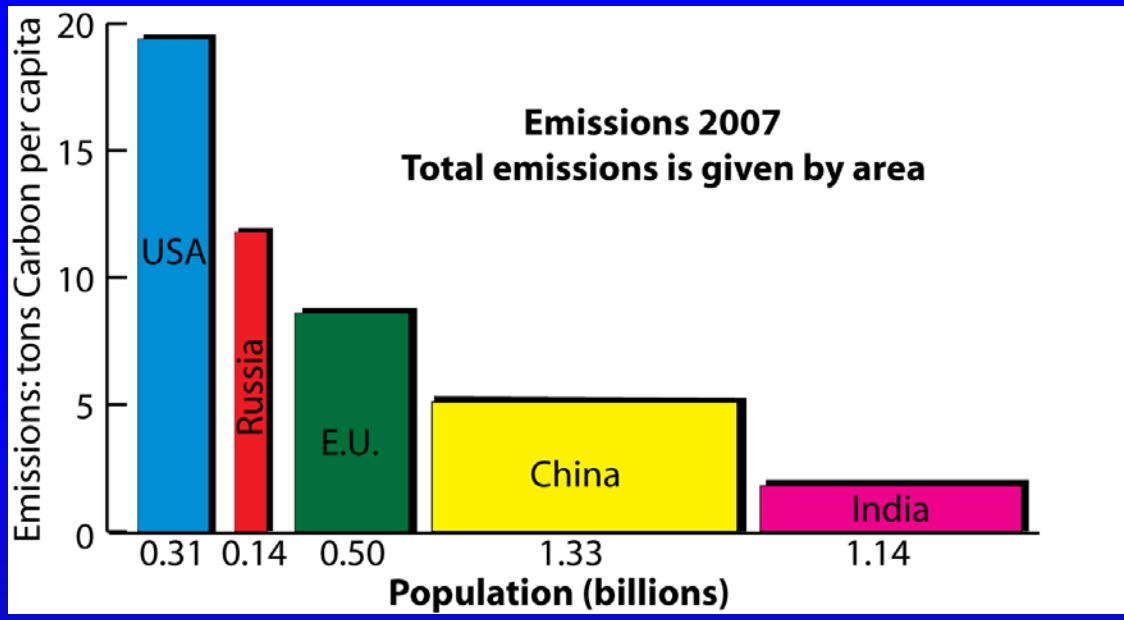


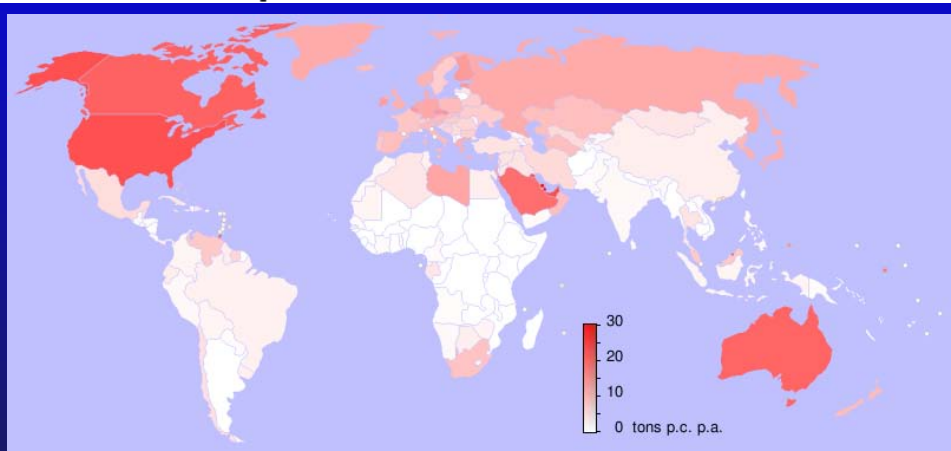
2007 emissions:

China biggest emitter (up 8% in 2007)

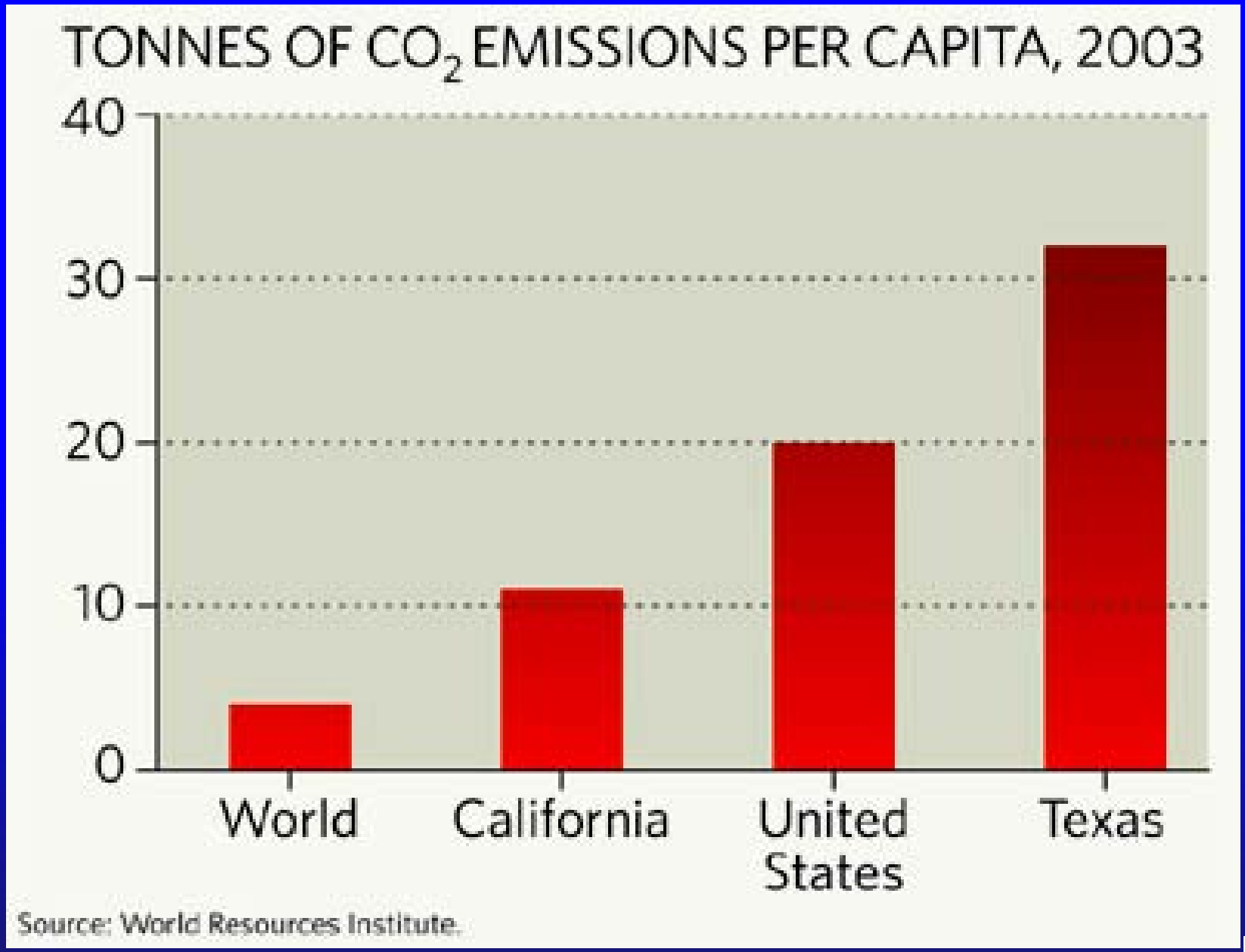
- 14% more than US
- Per capita Pop.

U.S.:	19.4	0.31
Russia:	11.8	0.14
E. U.:	8.6	0.50
China:	5.1	1.33
India:	1.8	1.14
	tons	Billions





Netherlands Environmental Assessment Agency 2008


TONNES OF CO_2 EMISSIONS PER CAPITA, 2003
40
30
20
10
0
World
California
United States
Texas
Source: World Resources Institute.

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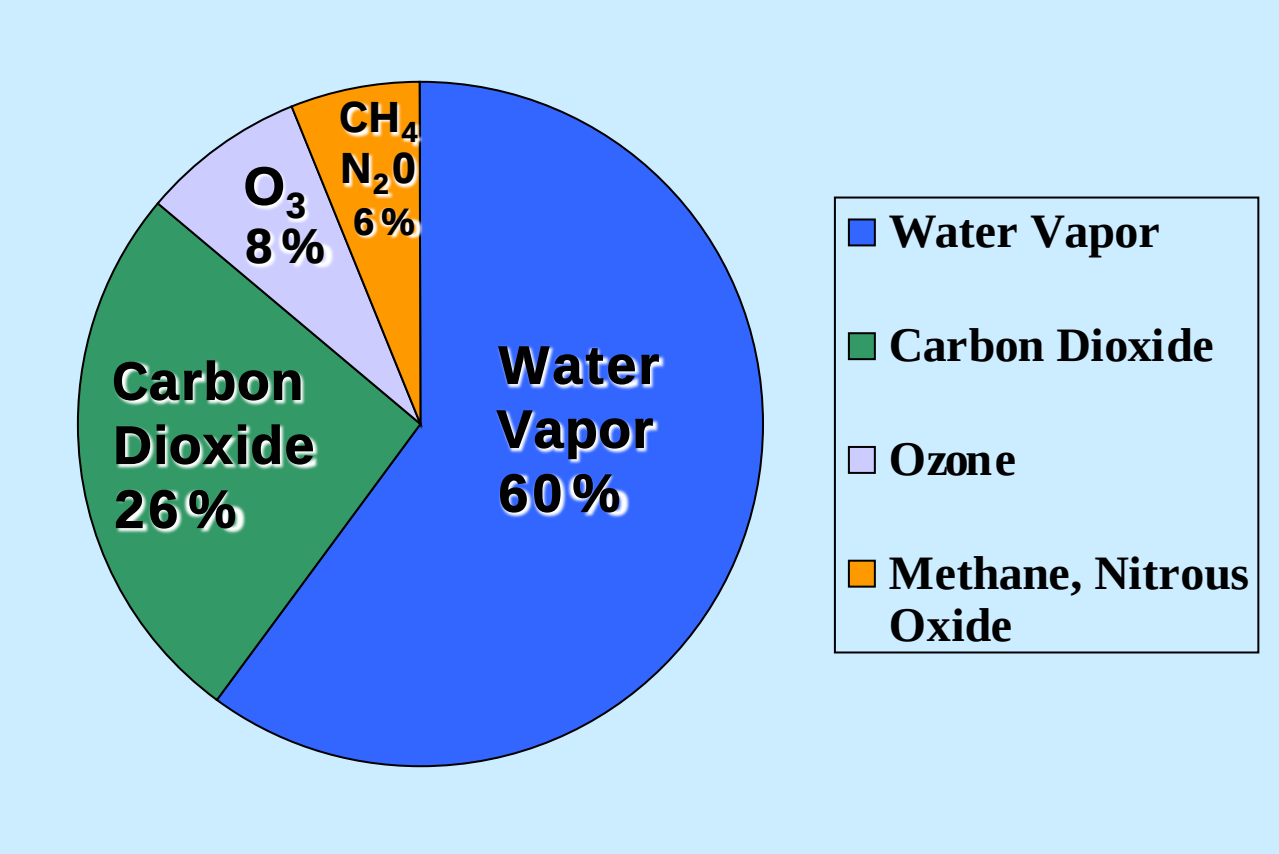
The Natural Greenhouse Effect: clear sky



Clouds also have a greenhouse effect

Kiehl and Trenberth 1997

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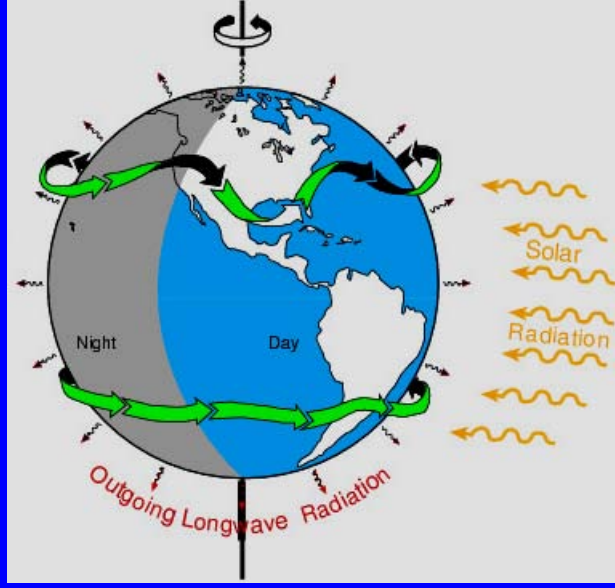
The incoming energy from the sun is 341 W m^{-2}: annual global mean:
It amounts to 175 PetaWatts
=175,000,000 billion Watts.
About 122 PW is absorbed.



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 122 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**

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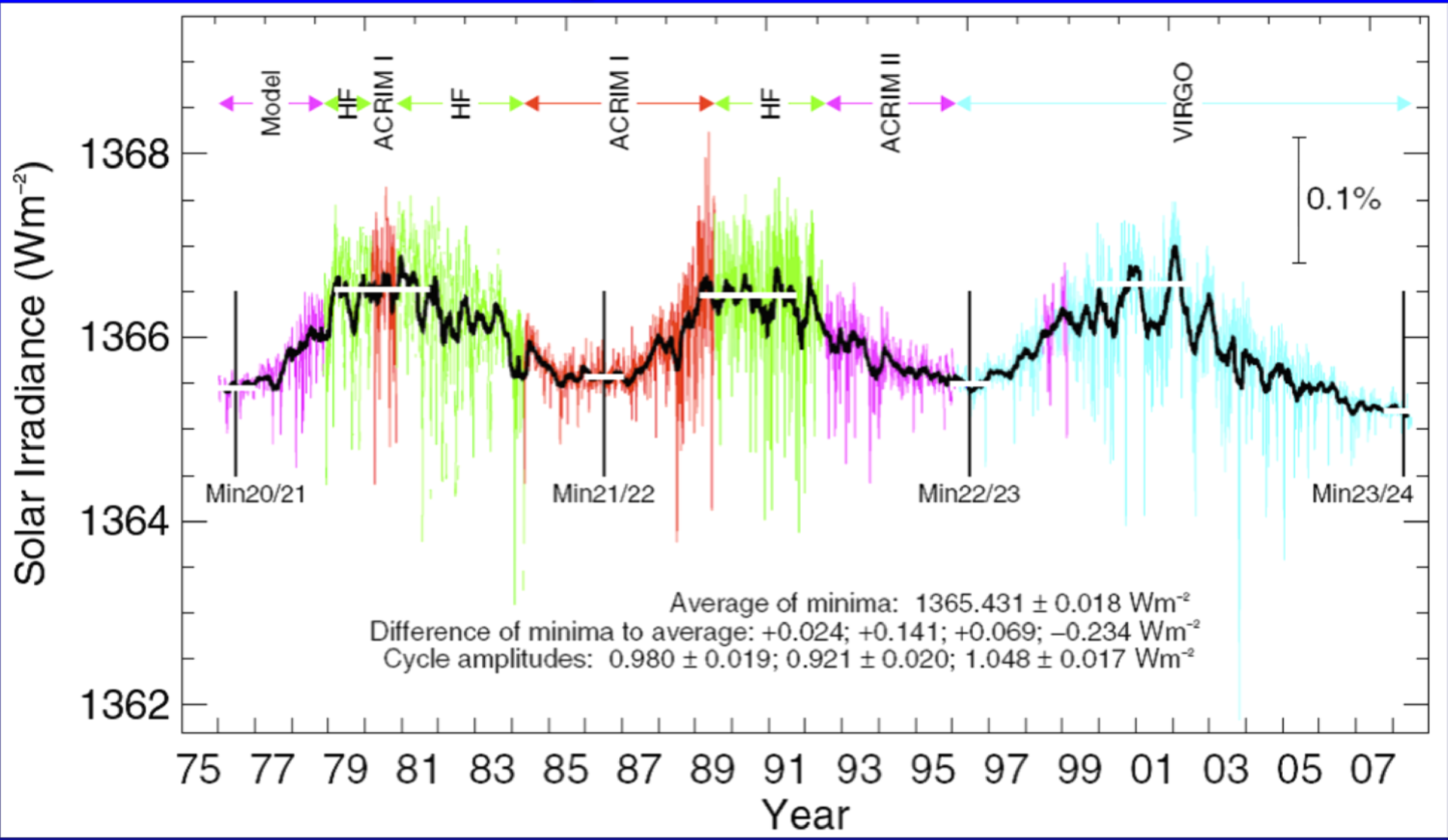
Changes in the sun



Solar irradiance from composite of several satellite-measured time series based on Frohlich & Lean (1998; http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant)

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The climate is changing

Global warming is "unequivocal"

to quote IPCC in 2007

Approved unanimously by 113 governments in Paris

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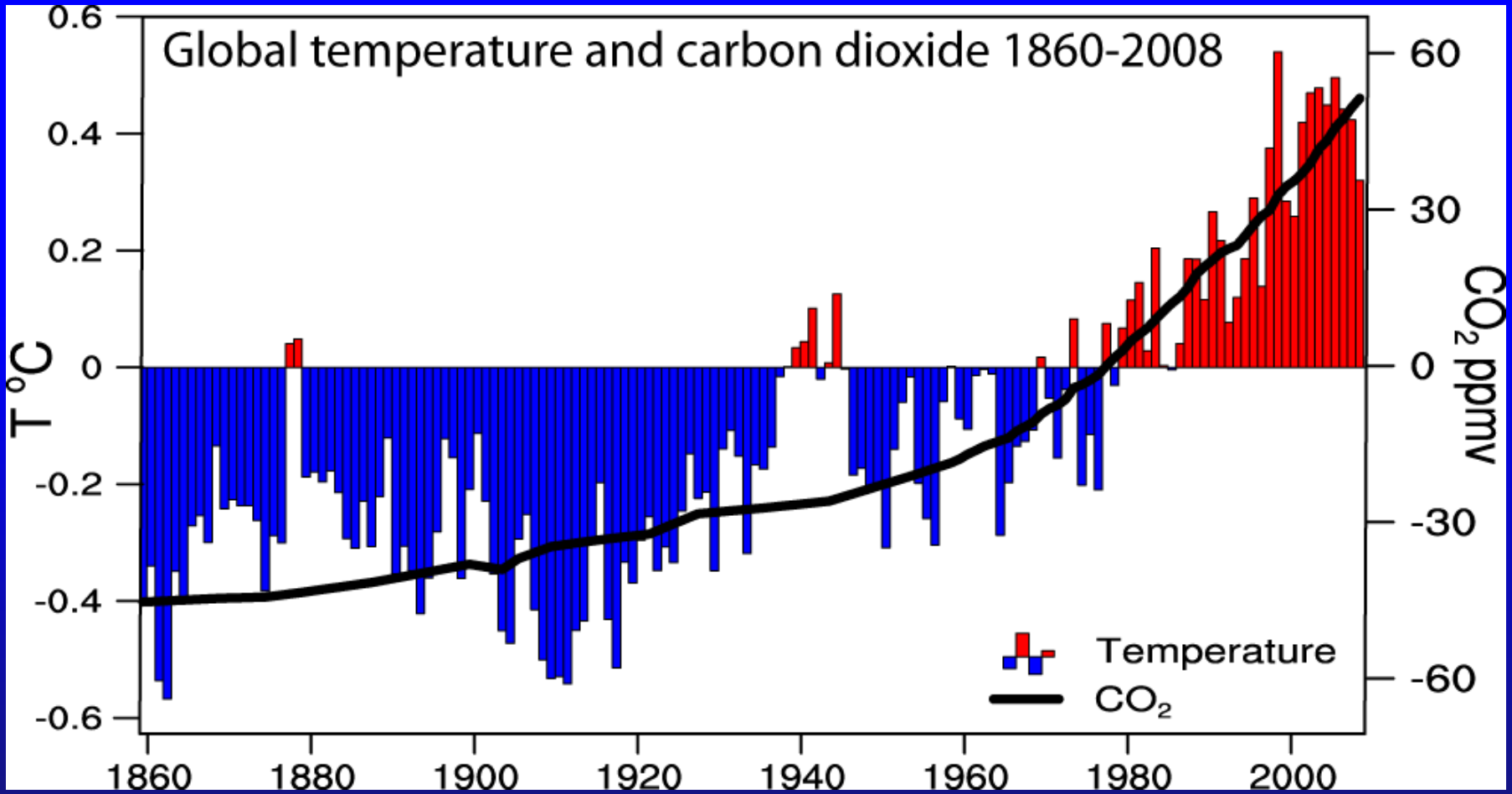
Global temperatures and carbon dioxide through 2008



Base period 1961-90

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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.

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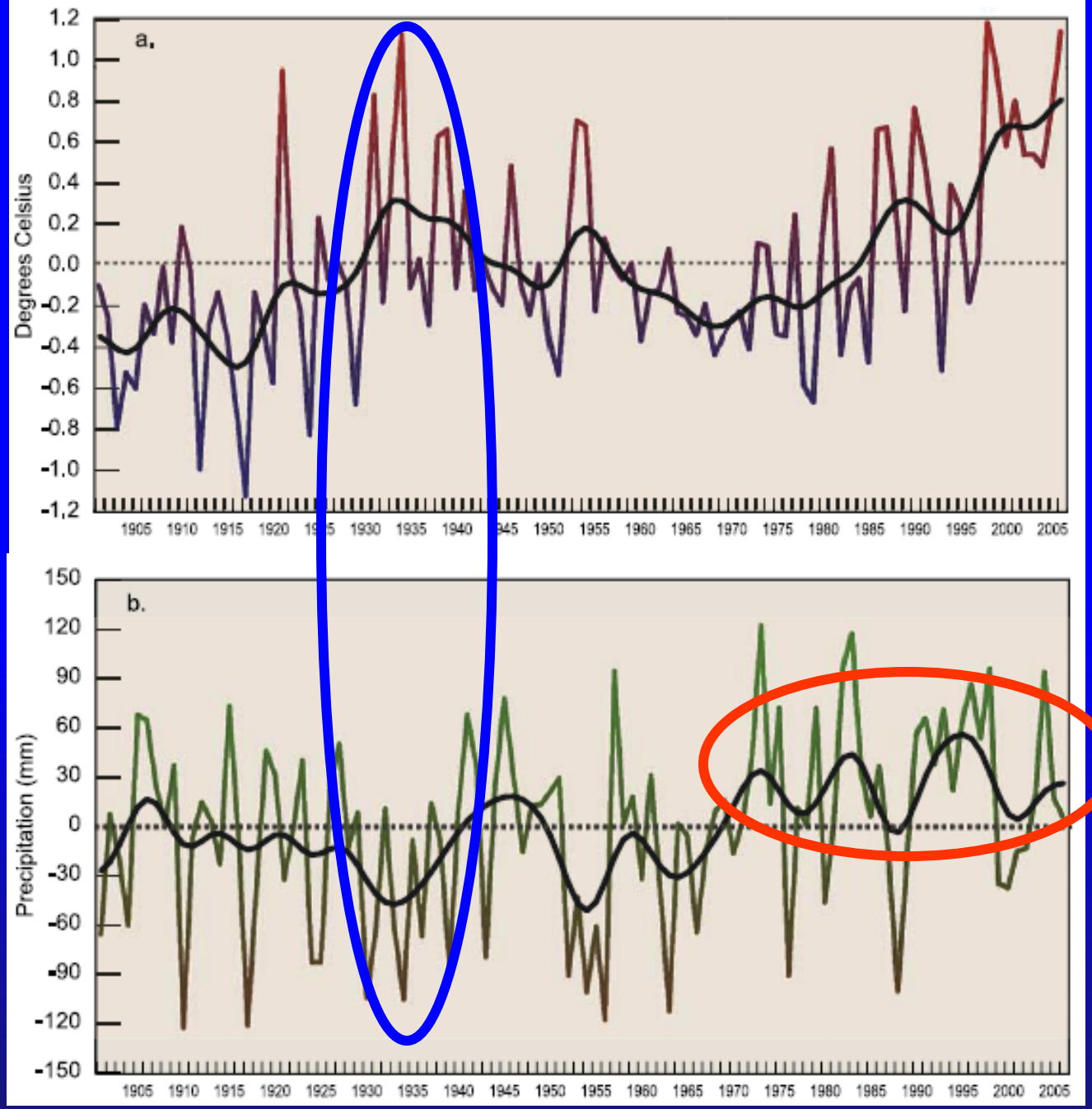
Declining Snow Pack in many mountain and continental areas contributes to drought

- 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

US changes in Temperature



1900 1950 2000

Precipitation

Much wetter

1930s:
Hot and dry

Easterling et al 2007
GRL

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Climate change and extreme weather events

Changes in extremes matter most for society and human health

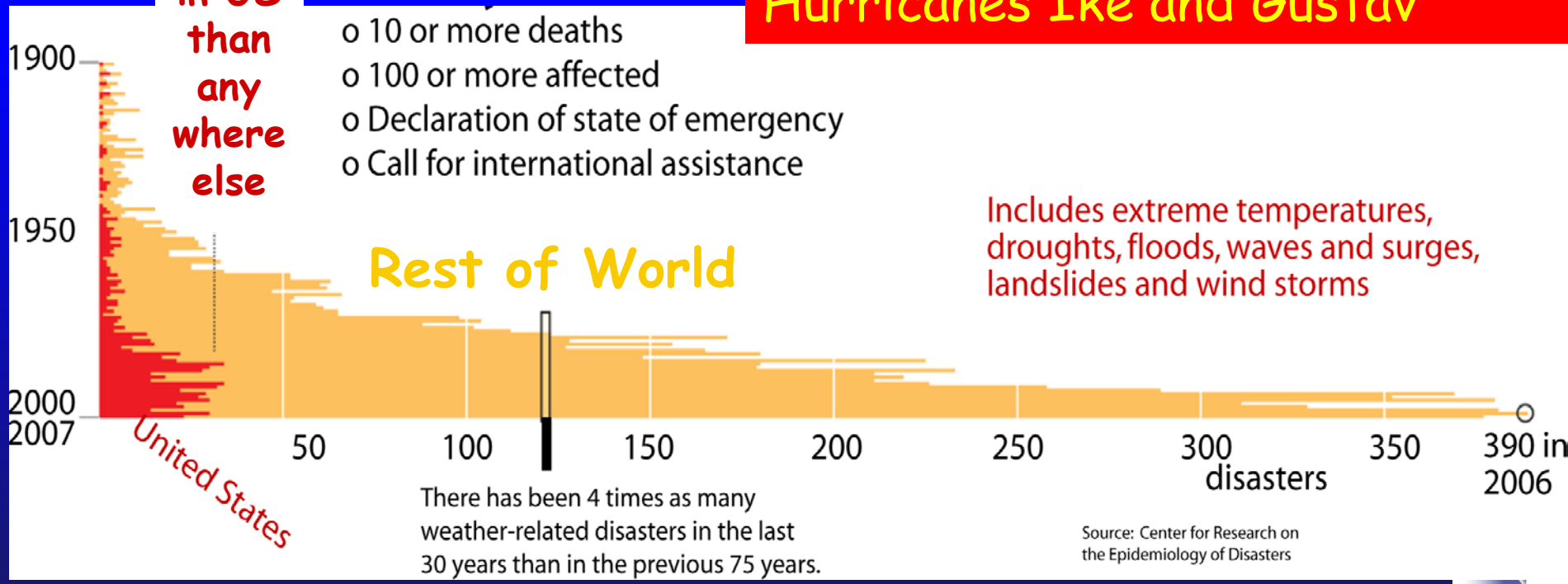
With a warming climate:

- More high temperatures, heat waves
- Wild fires and other consequences
- Fewer cold extremes.

- More extremes in hydrological cycle:
  - Drought
  - Heavy rains, floods
  - Intense storms, hurricanes, tornadoes

A century of weather-related disasters: Disasters are increasing, especially in U.S.

2008:
Wildfires, heatwaves, California
Tornadoes, deaths
Mississippi flooding
Hurricanes Ike and Gustav



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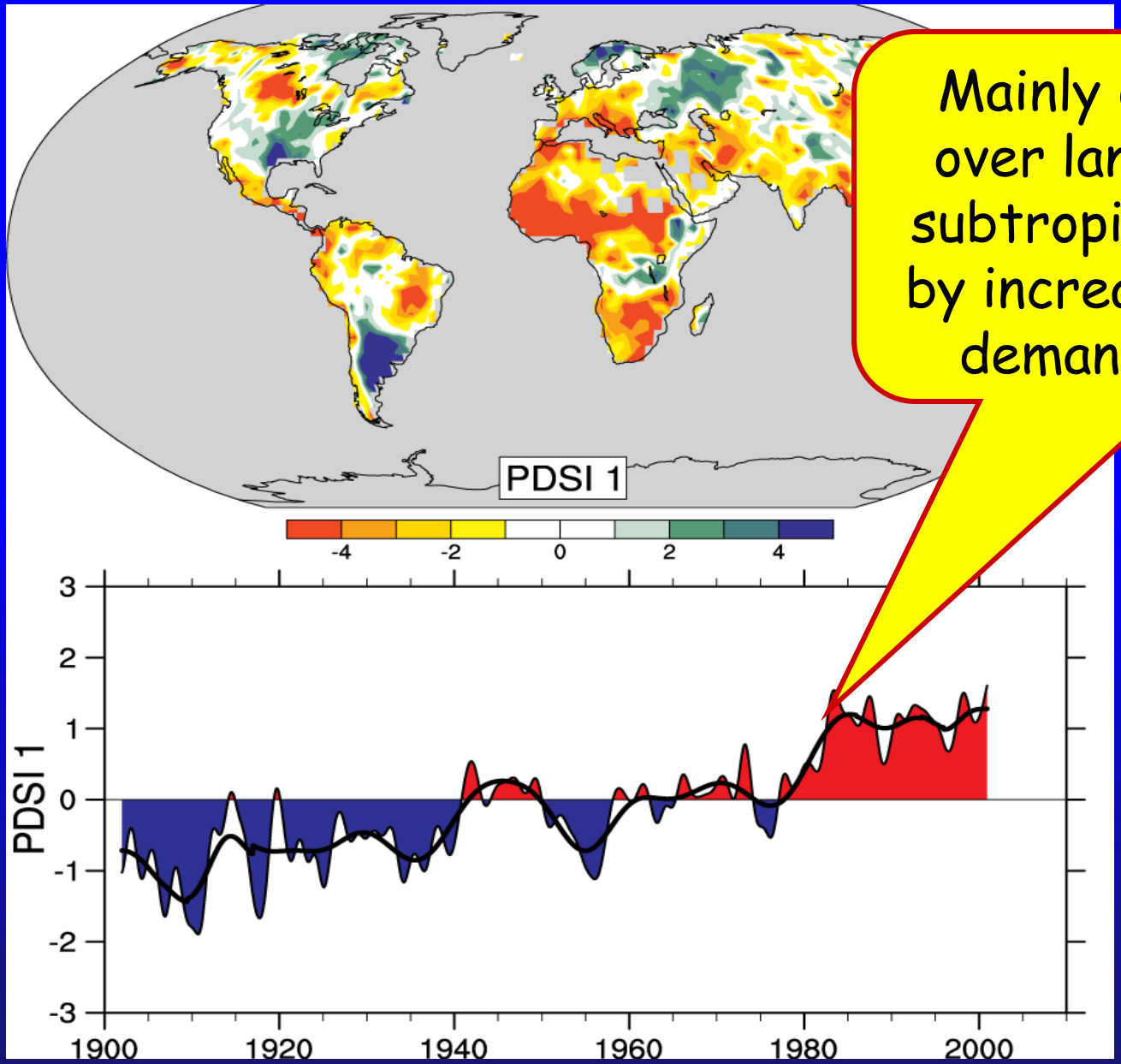
Drought is increasing most places



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.

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Impacts of hazardous weather

a: Brush fire in Macedonia, Greece during the SE European summer 2007 drought.
b: Upton-upon-Severn in Worcestershire, England during the flooding of July 2007.
c: Father and son in flood ravaged Bangladesh, 2007.
d: An Ethiopian shepherd leads livestock through the dust in the desert where severe drought in East Africa has forced overgrazing.

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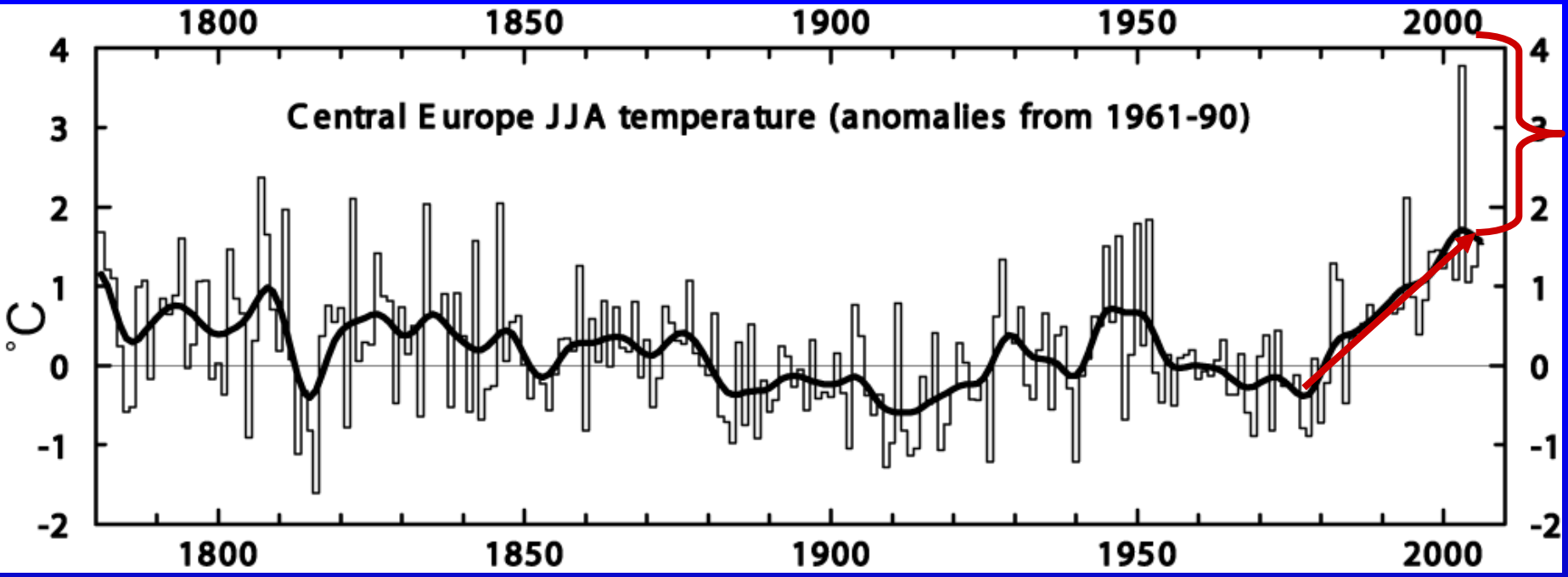
Heat waves are increasing: an example



Extreme Heat Wave
Summer 2003
Europe
>50,000 deaths

Trend plus variability?

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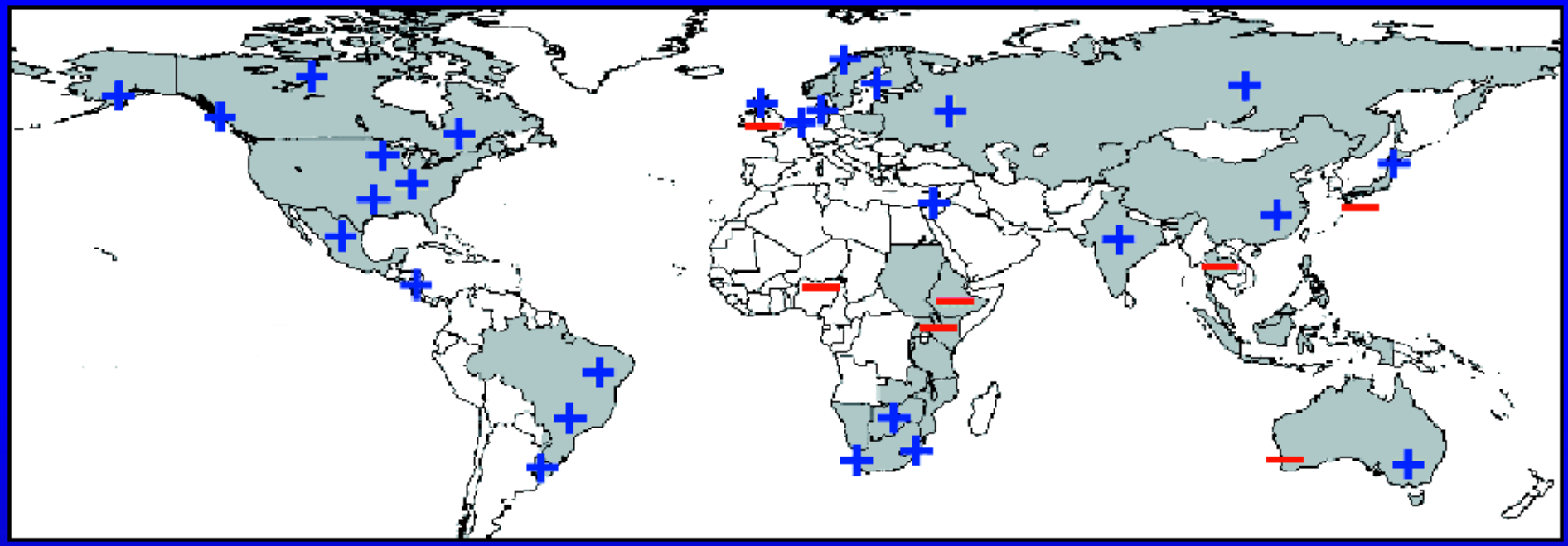
Proportion of heavy rainfalls: increasing in most land areas



Regions of disproportionate changes in heavy (95^{th}) and very heavy (99^{th}) precipitation

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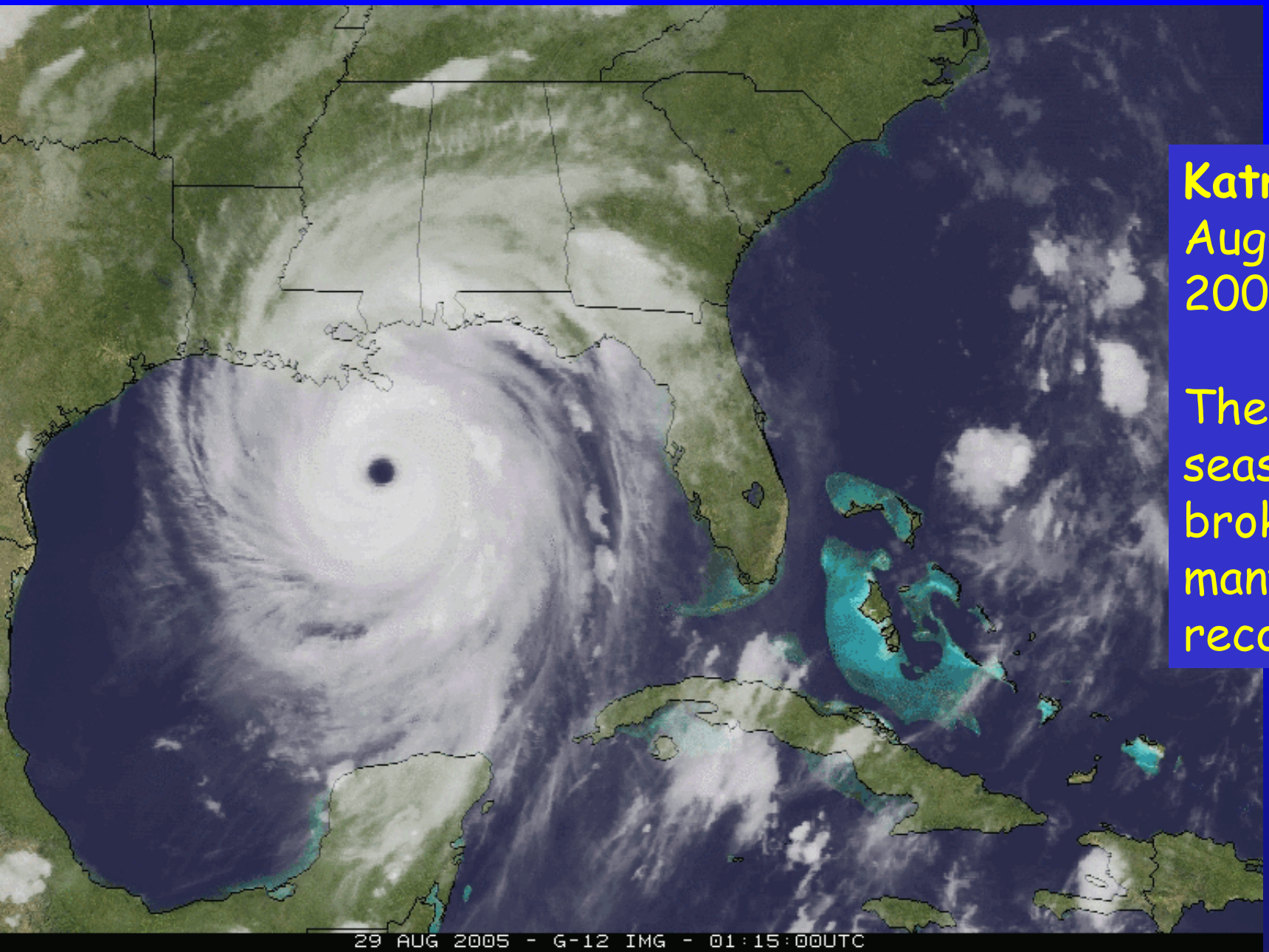
North Atlantic hurricanes have increased with SSTs



Katrina
August
2005

The 2005
season
broke
many
records

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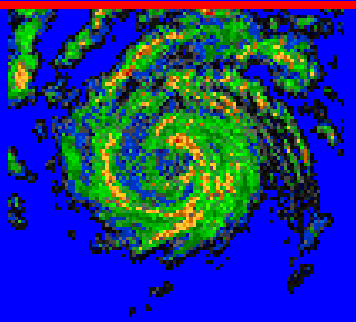
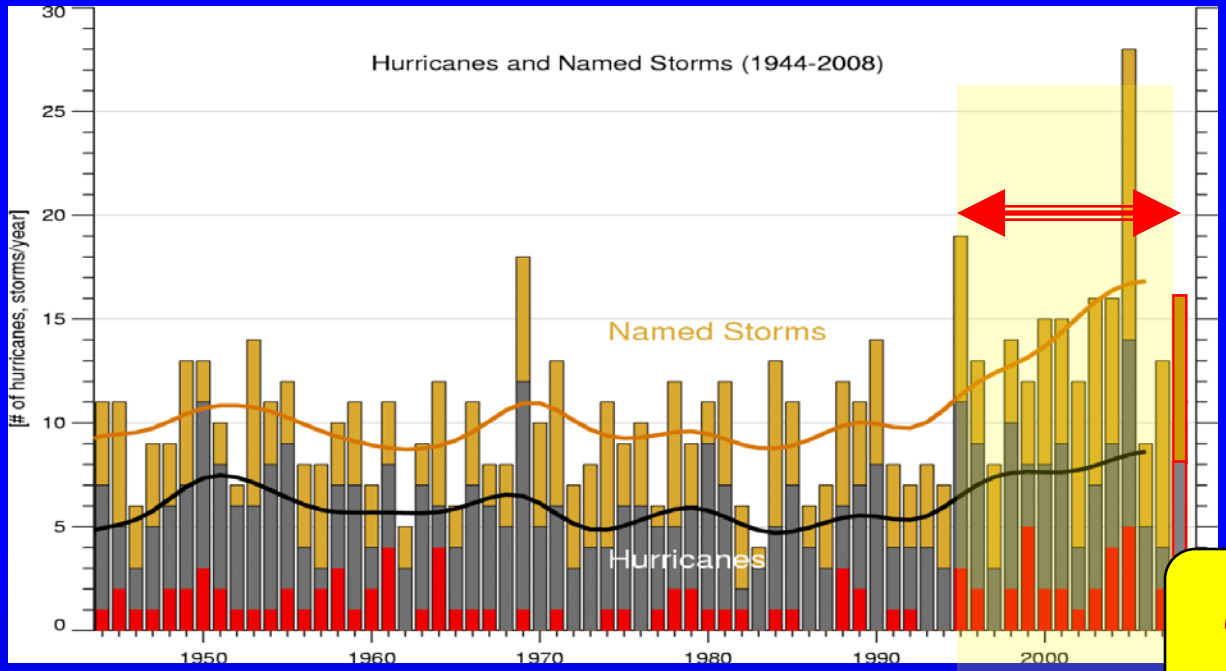
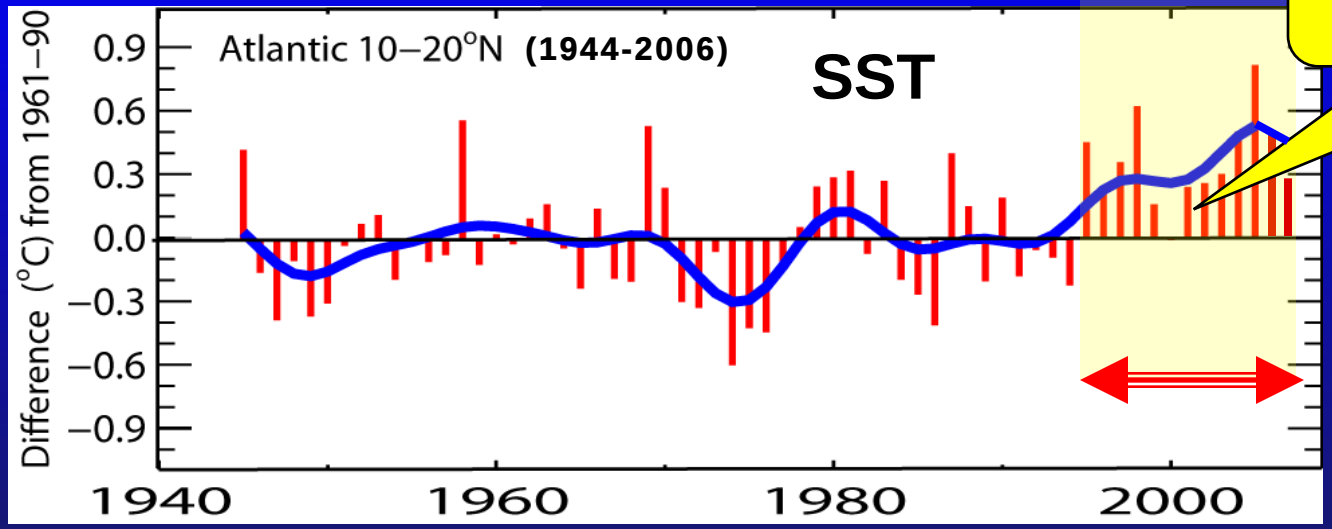
North Atlantic hurricanes have increased with SSTs







N. Atlantic hurricane record best after 1944

Marked increase after 1994

Global number and percentage of intense hurricanes is increasing

Thru 2008

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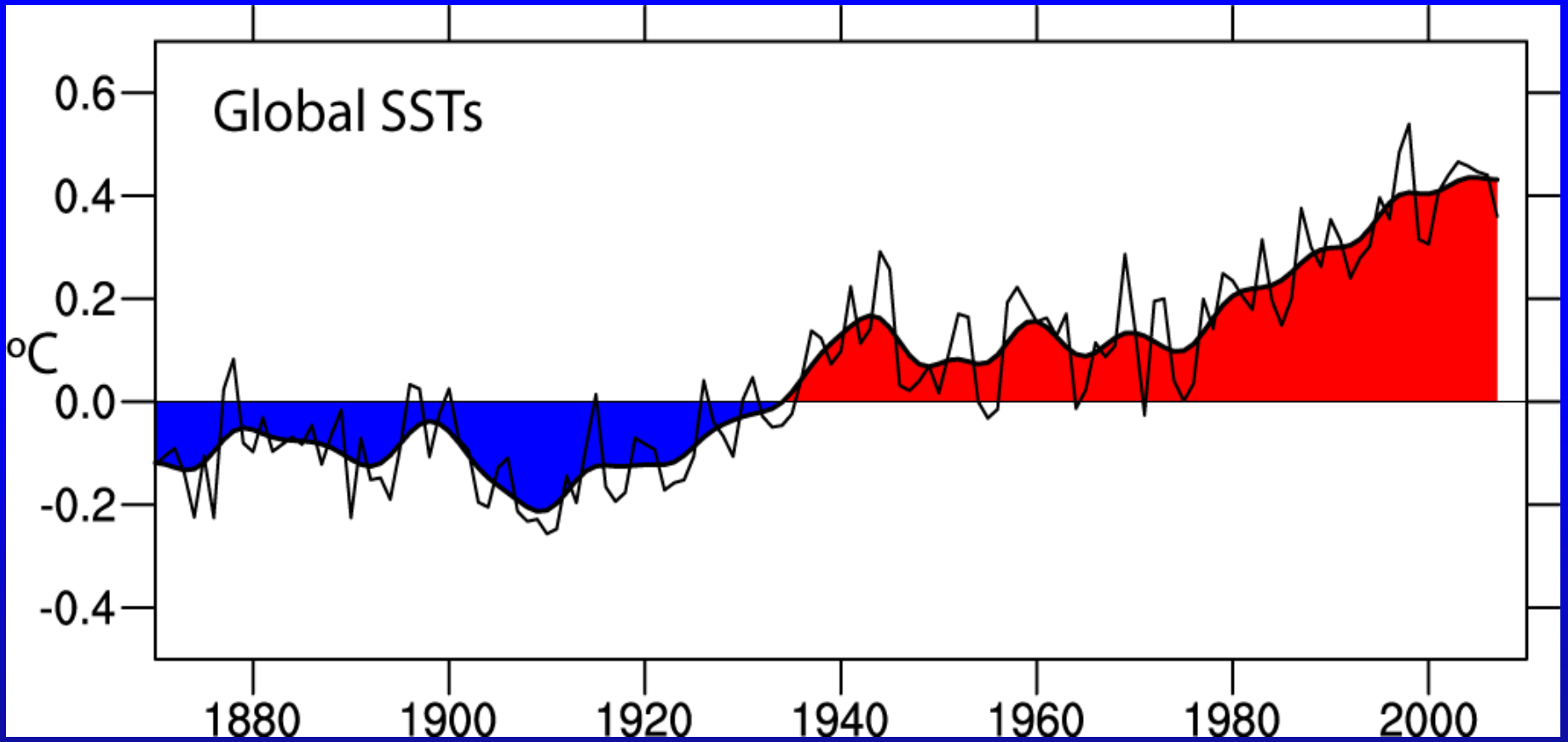
Global SSTs are increasing: base period 1901-70



Through 2007
Data: Hadley Centre, UK

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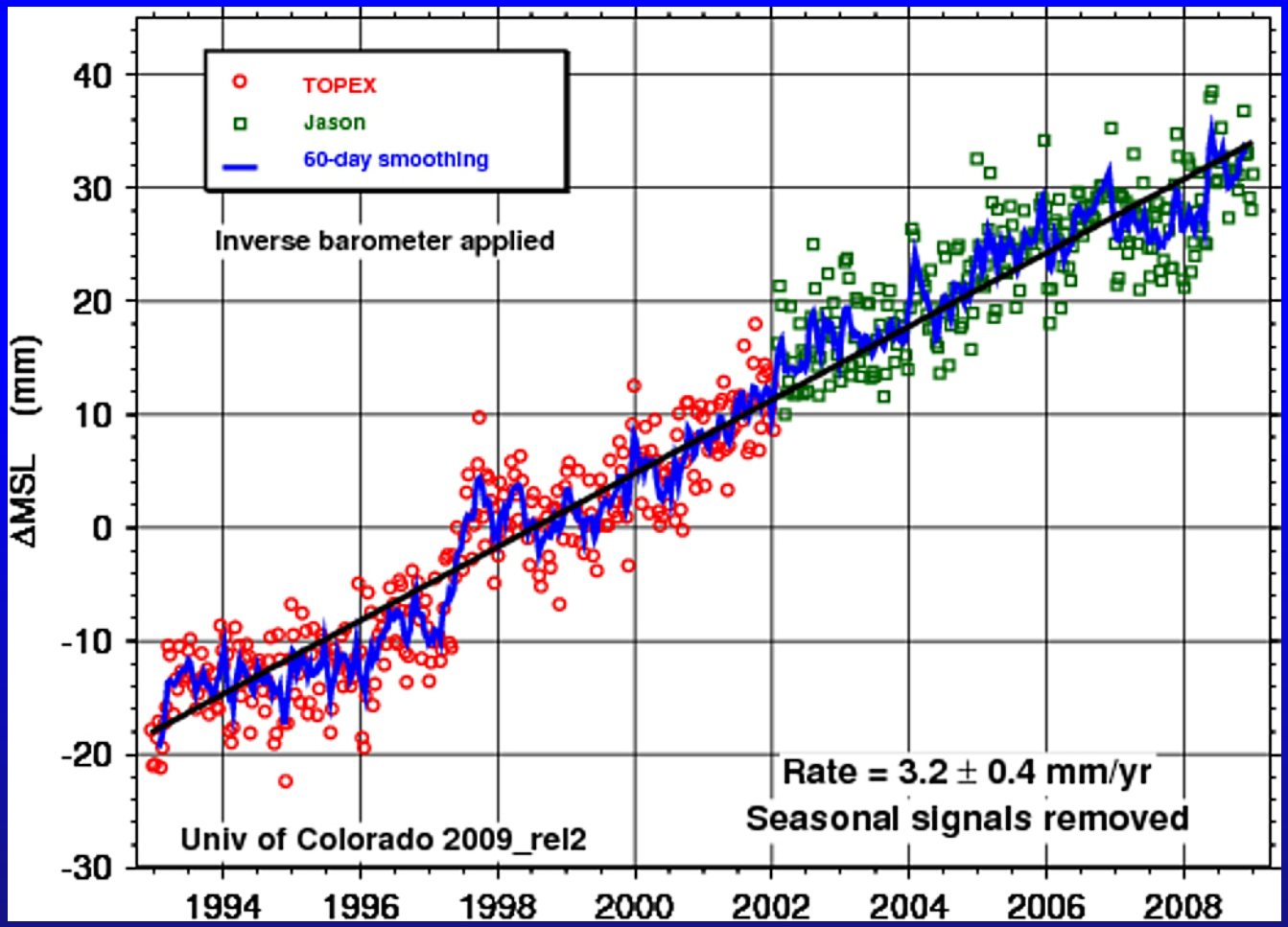
Sea level is rising:
from ocean expansion and melting glaciers



Since 1992 Global sea level has risen 48 mm (1.9 inches)

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

Courtesy Steve Nerem U Colo

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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

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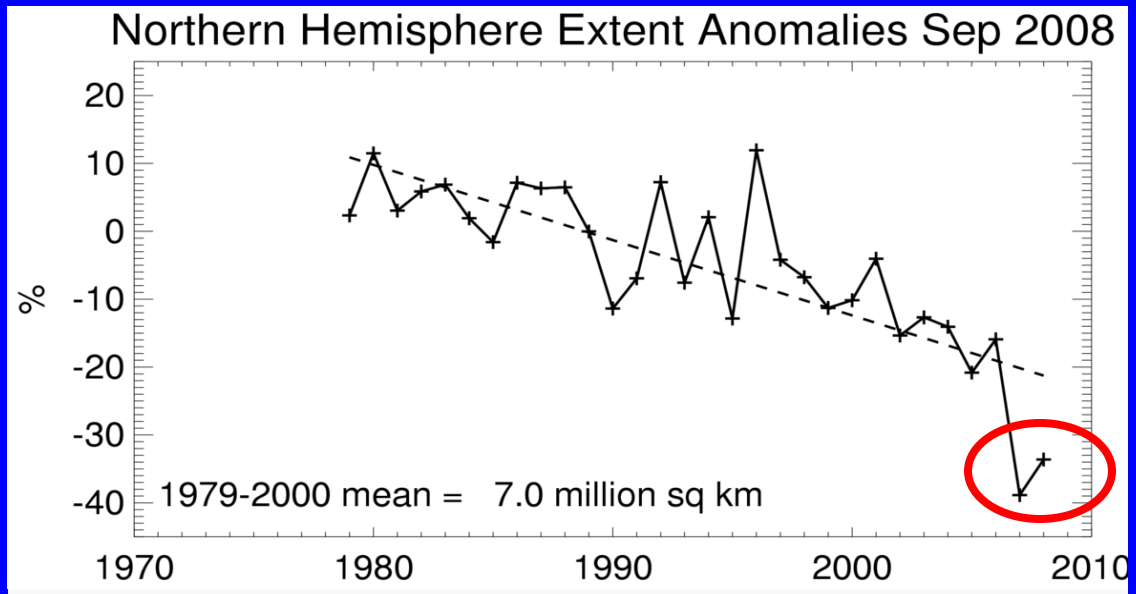
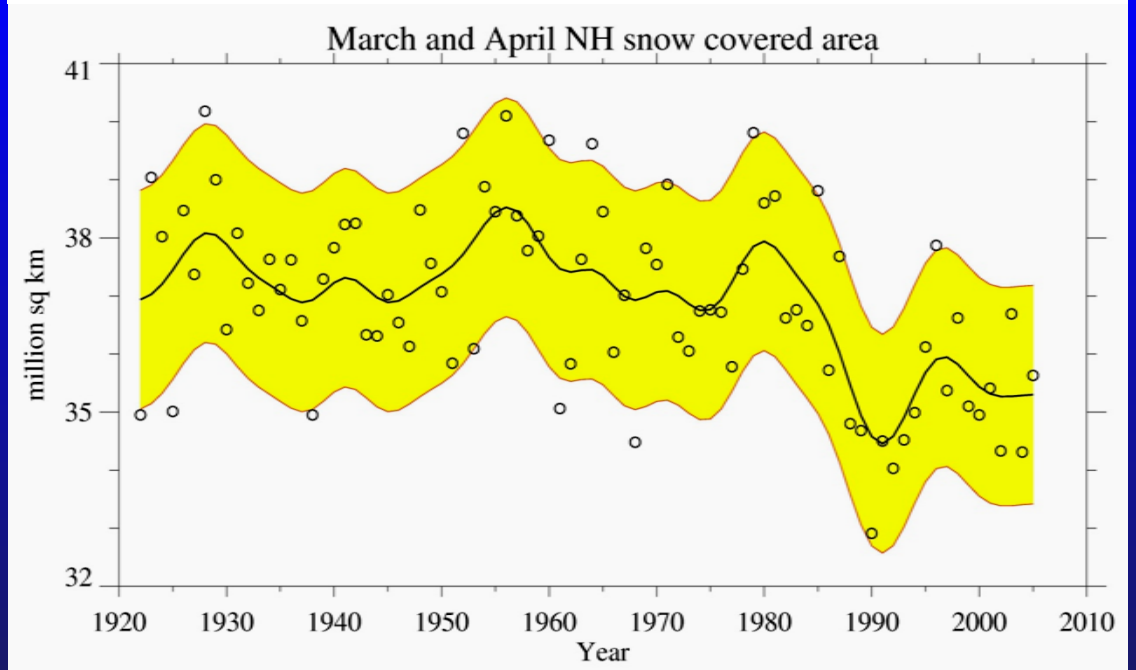
Snow cover and Arctic sea ice are decreasing





Arctic sea ice area decreased by 2.7% per decade
(Summer: -7.4%/decade)
up to:
2007: 22% (10^6 km^2) lower than 2005
2008, second lowest

Spring snow cover shows 5% stepwise drop during 1980s

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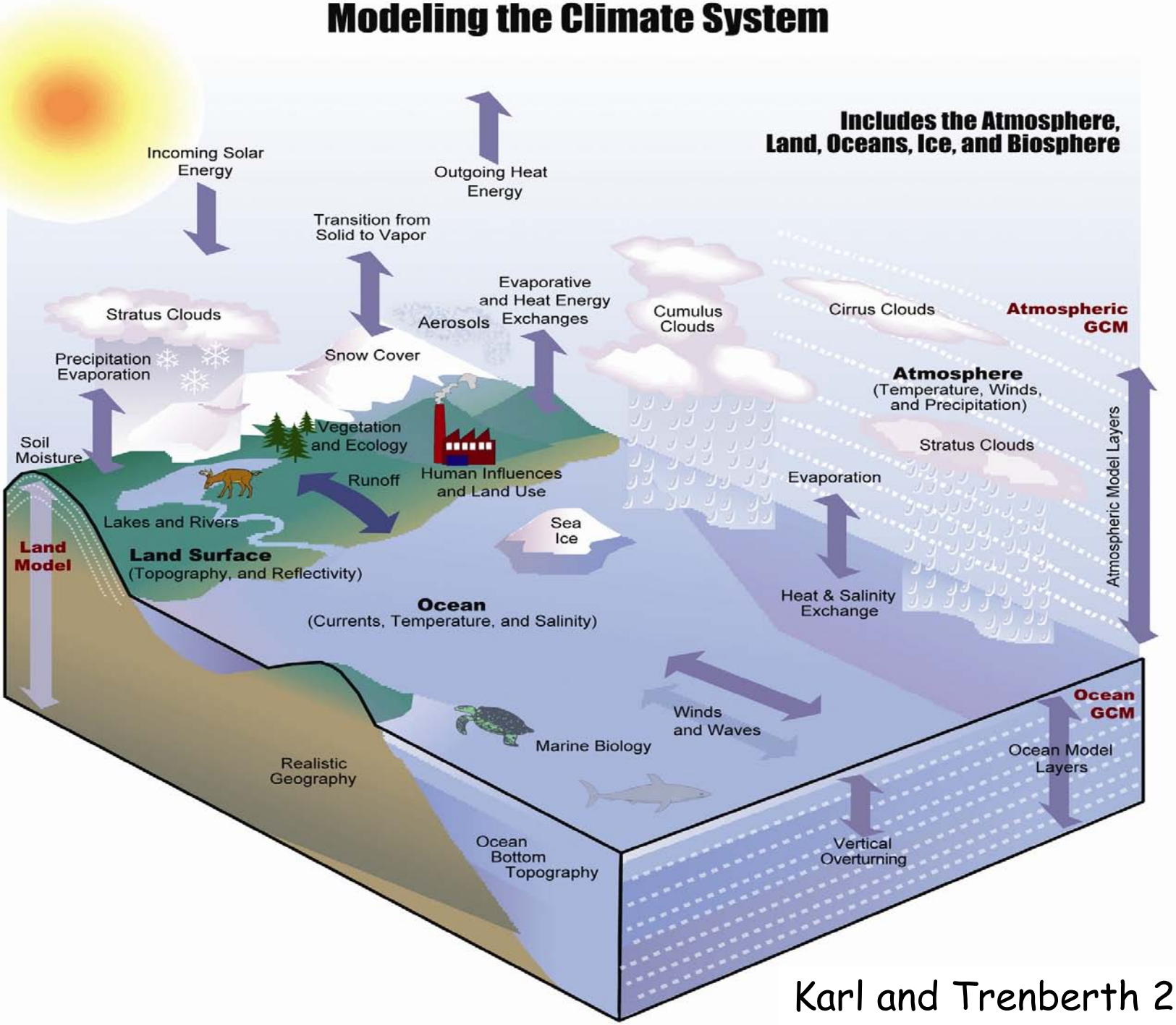
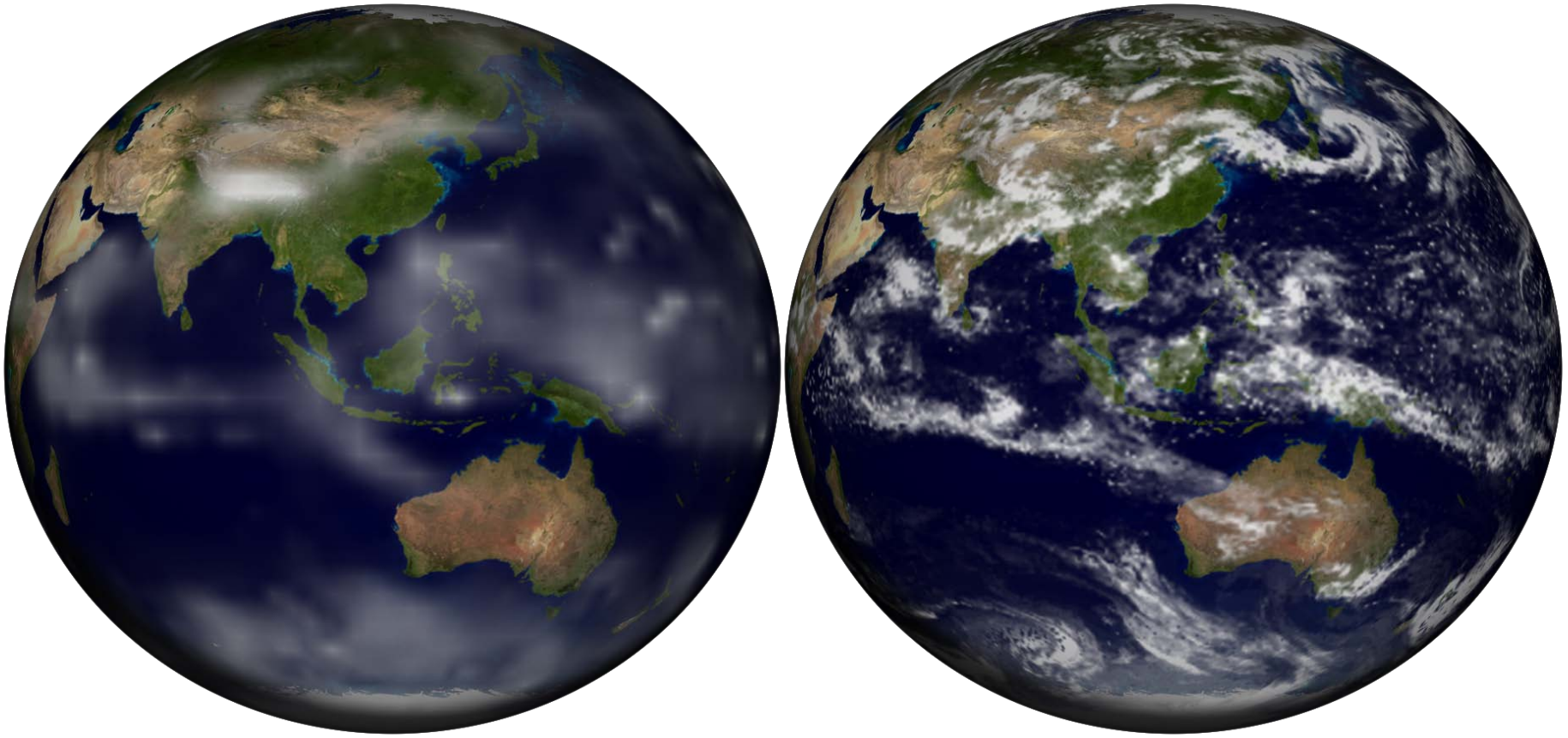
Modeling the Climate System



Karl and Trenberth 2003

Effects of resolution in models

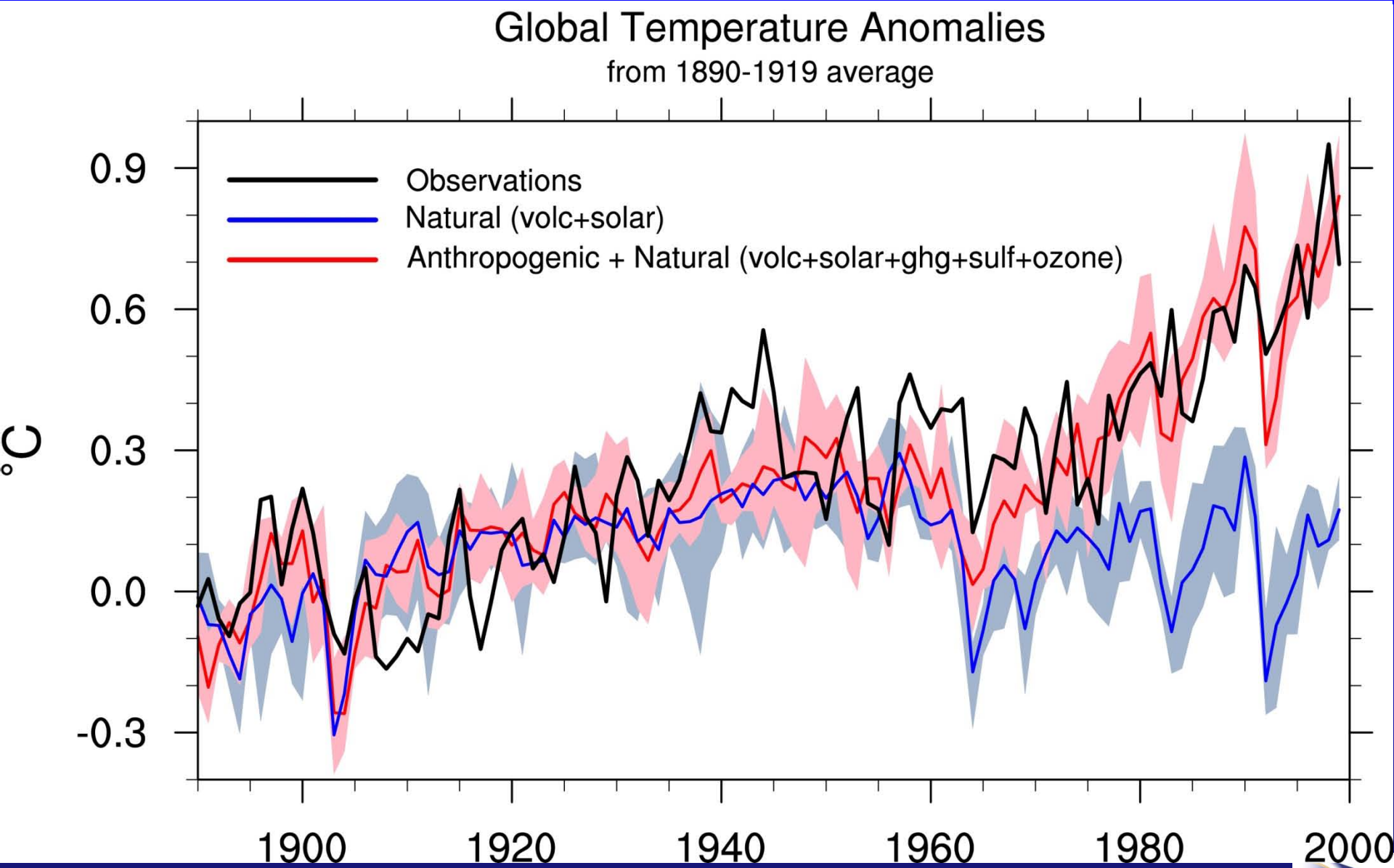


Global cloud distribution

320 km resolution

20 km resolution

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



Meehl et al, 2004: J. Climate.

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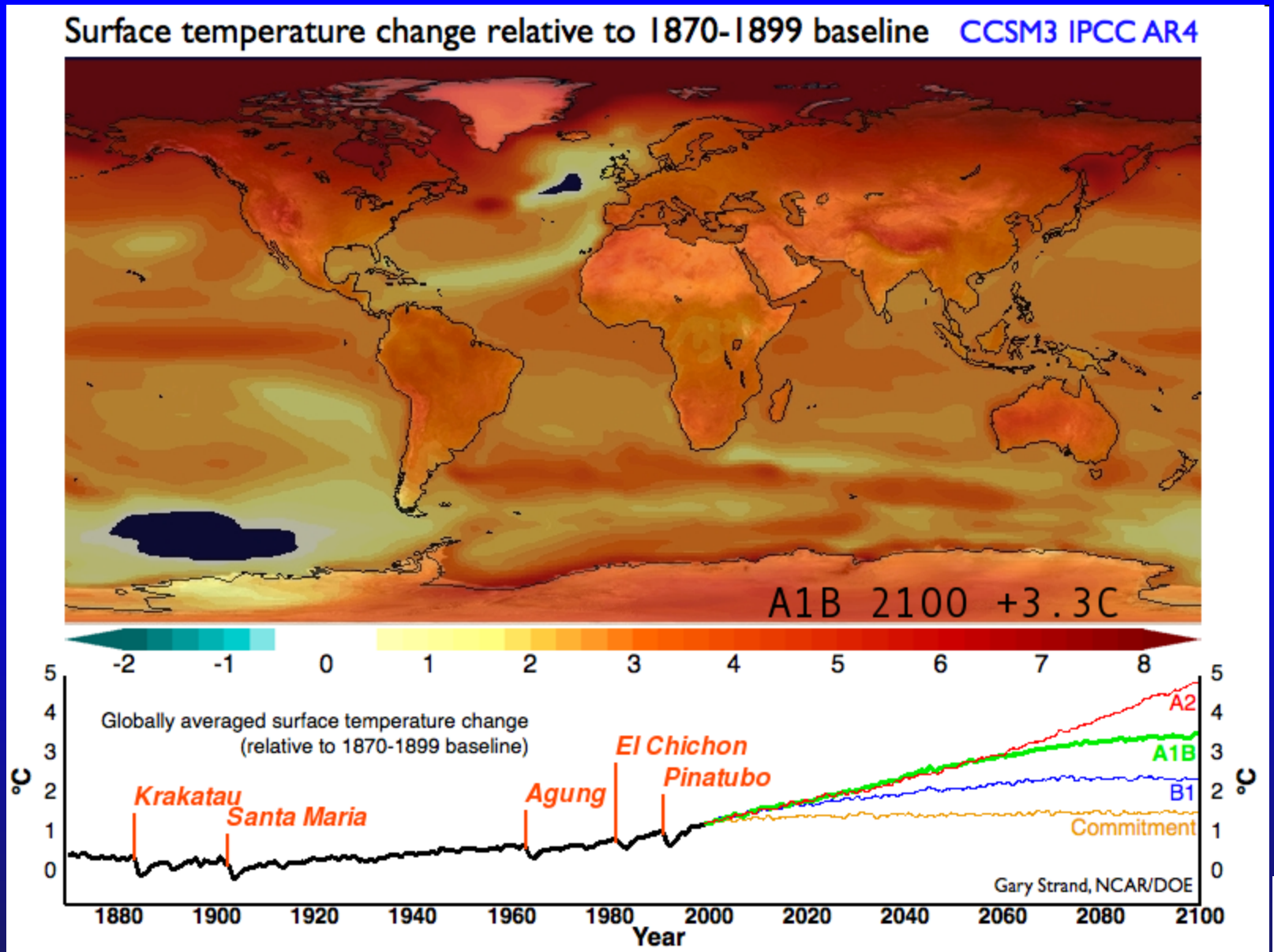
Projected temperature change



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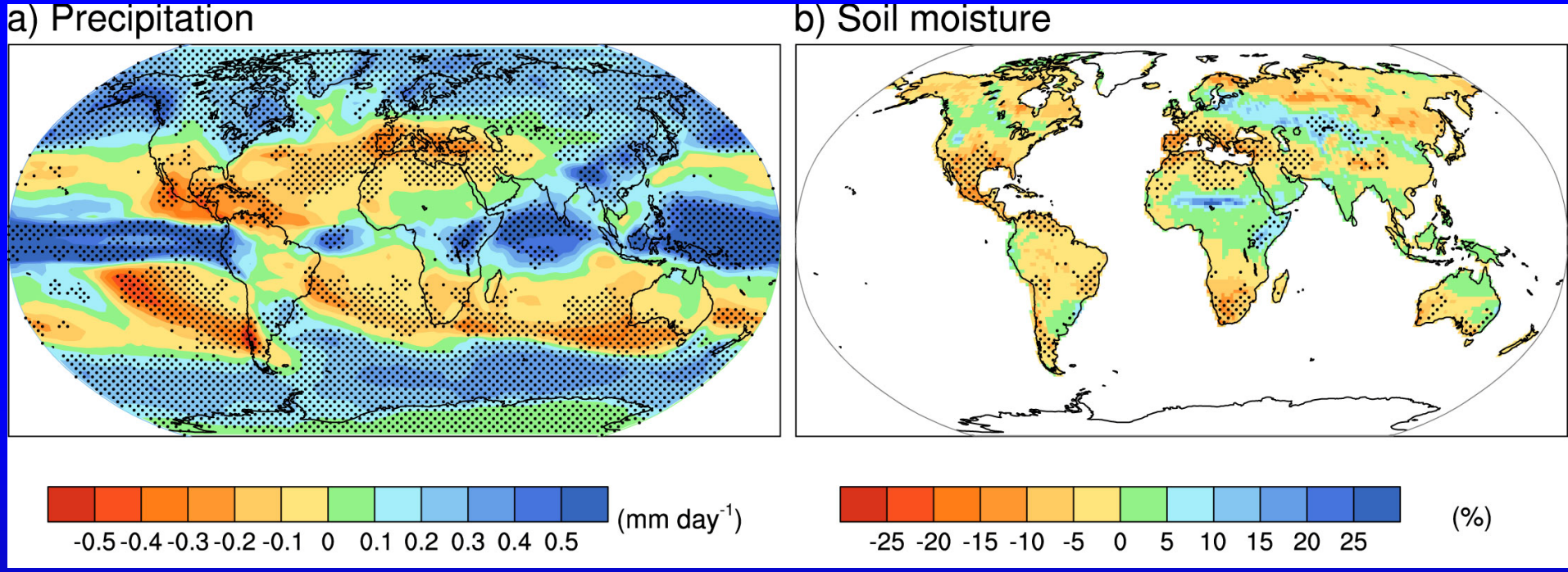
Projected Patterns of Precipitation Change 2090-2100



Combined effects of increased precipitation intensity and more dry days contribute to mean precipitation changes

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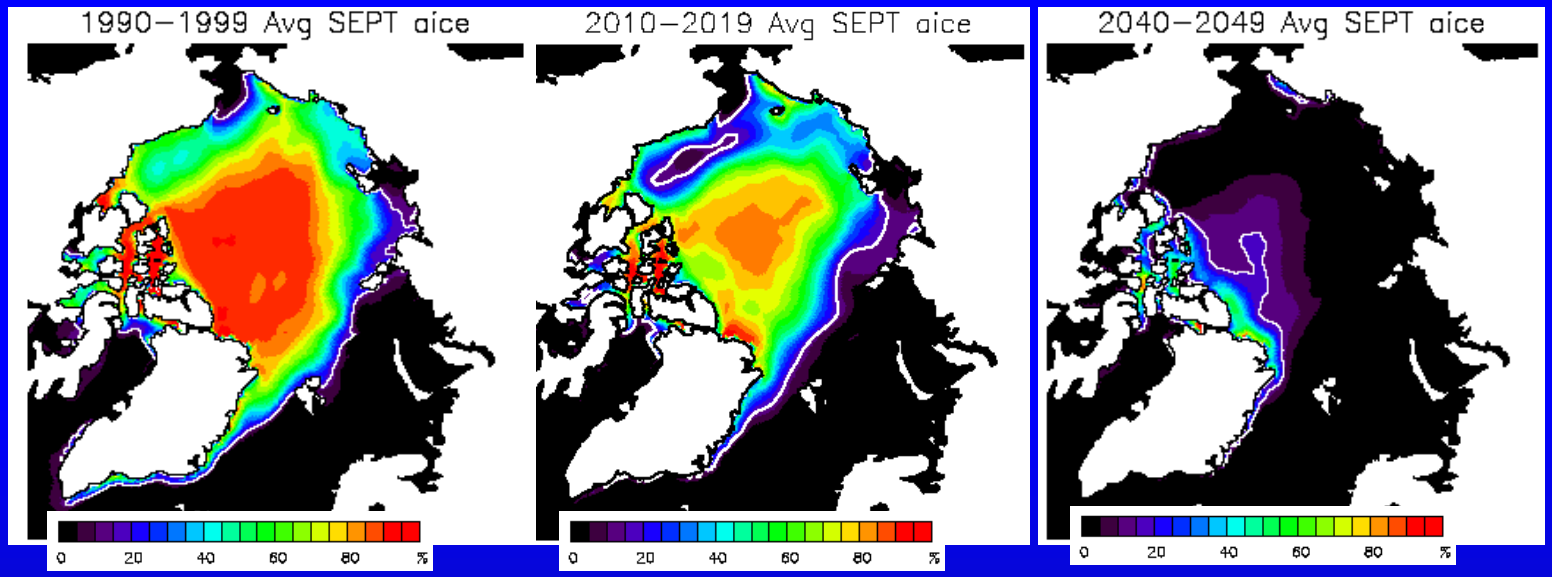
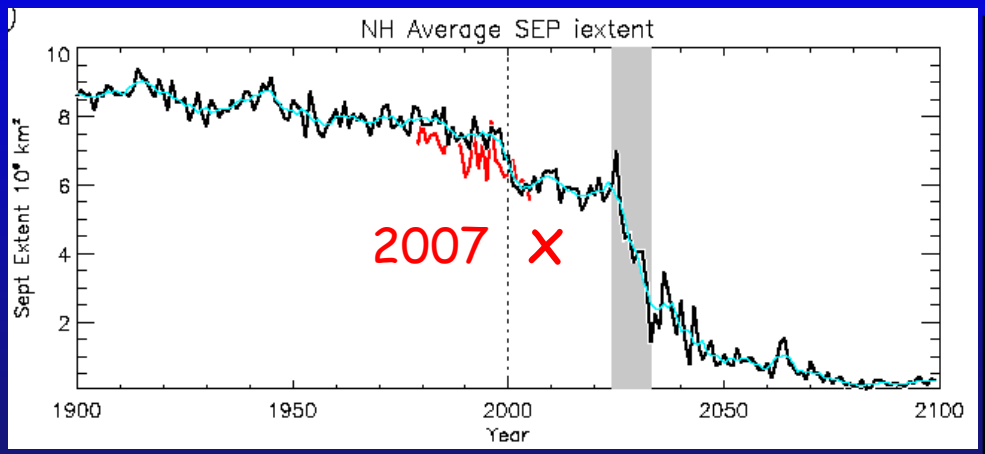
Arctic sea ice disappears in summer by 2050

Already 2007 lowest on record by 22%

Abrupt Transitions in Summer Sea Ice





- Gradual forcing results in abrupt Sept ice decrease
- Extent decreases from 80 to 20% coverage in 10 years.
- Relevant factors:
  - Ice thinning
  - Arctic heat transport
  - Albedo feedback

Holland et al., GRL, 2006

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Global warming effects from humans are already identifiable

- They are apt to become worse and more common
- They affect health and well-being
  - Direct loss of life
  - Loss of habitat, farming commodities, etc
  - Water shortages, or excesses
  - Increases in range and times of bugs
  - Heat waves, wildfires

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What is your carbon footprint?

- You will be affected by climate change (you are already)
- You will be affected by legislation designed to address climate change (whether good or bad)

Many things you can do:

Going Green!

The Challenge:
Sustainable Management of an Ever-Changing Planet

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