[AV]Impact of Anthropogenic Carbon Dioxide and Other Greenhouse Gases on Climate since 1940, Including Water Vapor Feedback*

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Abstract

Increases in greenhouse gases cause global warming. This really means global heating of the planet. Carbon dioxide has increased about 38% since preindustrial times, and over half of this has occurred since 1970. It is responsible for about half of the total radiative heating increase, with the rest coming from increases in methane, nitrous oxide and changes in ozone. However, about half is also estimated to be compensated for by increases in visible aerosol pollution that blocks the sun and causes cooling. The net effect is similar to the increase in carbon dioxide alone. Some of this heating goes into raising temperatures, while some goes into evaporating water and changing the hydrological cycle. The increased drying exacerbates droughts, heat waves, and wild fires and increases atmospheric water vapor. As atmospheric temperatures increase, the water-holding capacity of the atmosphere also increases, at a rate of about 4% per degree F. This is observed to be happening over the oceans, where surface water is not limited, and also to a slightly lower degree over land. Water vapor itself is a powerful greenhouse gas and roughly doubles the heating. The result is that global warming is “unequivocal” to quote the IPCC and is manifested not only in temperature increases throughout the atmosphere and ocean, but also through melting glaciers and ice sheets, rising sea level, melting Arctic sea ice, and changes in storms and hurricanes.

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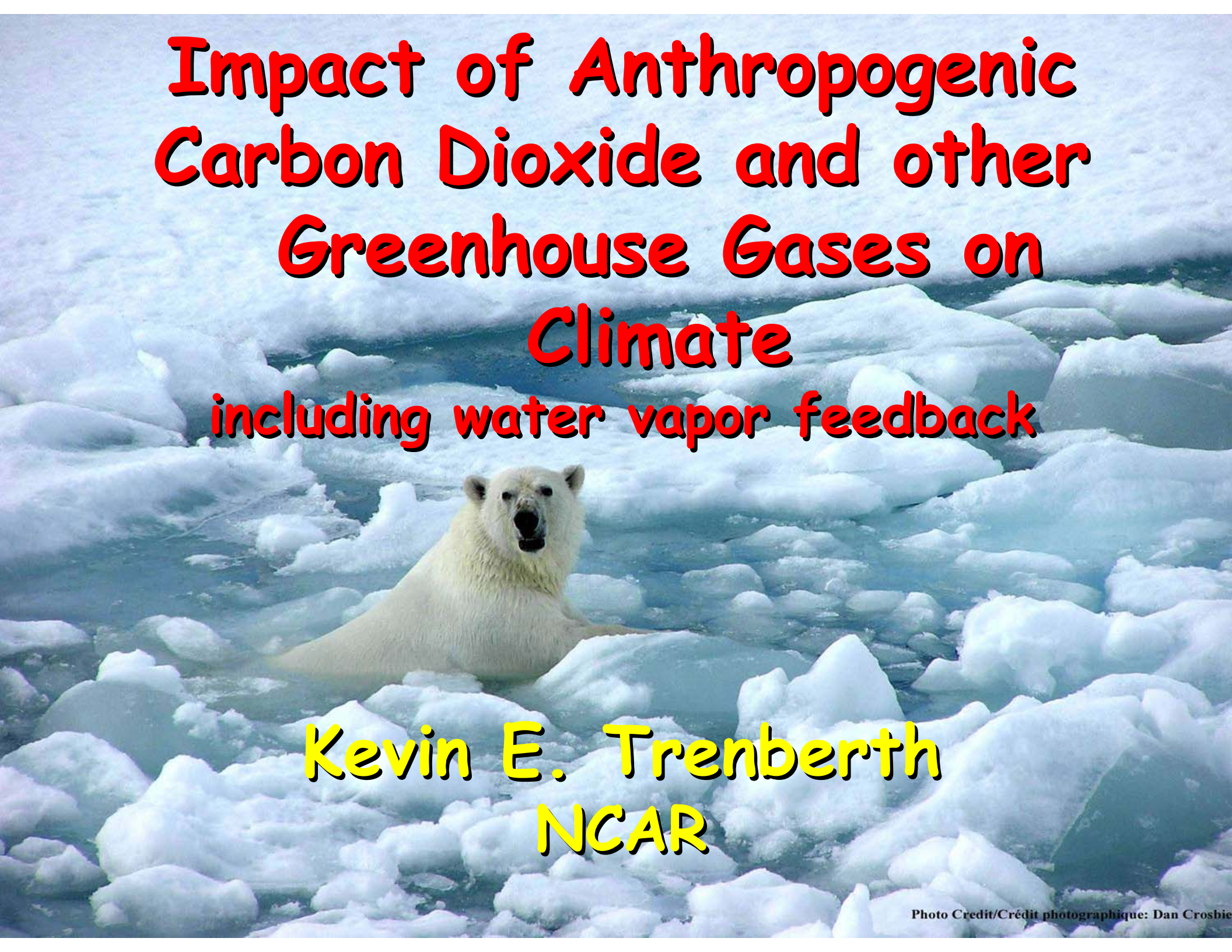
DOI: 10.1175/2008JCLI2691.1.

Impact of Anthropogenic Carbon Dioxide and other Greenhouse Gases on Climate

including water vapor feedback



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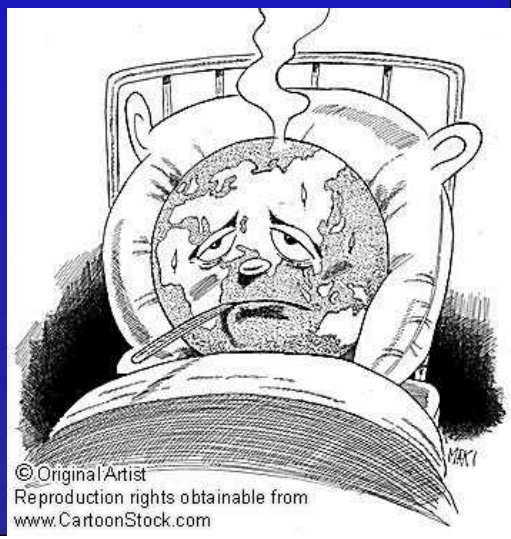
The planet is running a fever

- Symptoms: temperatures rising and carbon dioxide 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)



Changes in climate have a cause

External

- Sun-Earth orbital changes
- Sun output
- Atmospheric composition

Internal

- Changes in ocean, ice, land

The geological record is rife with examples

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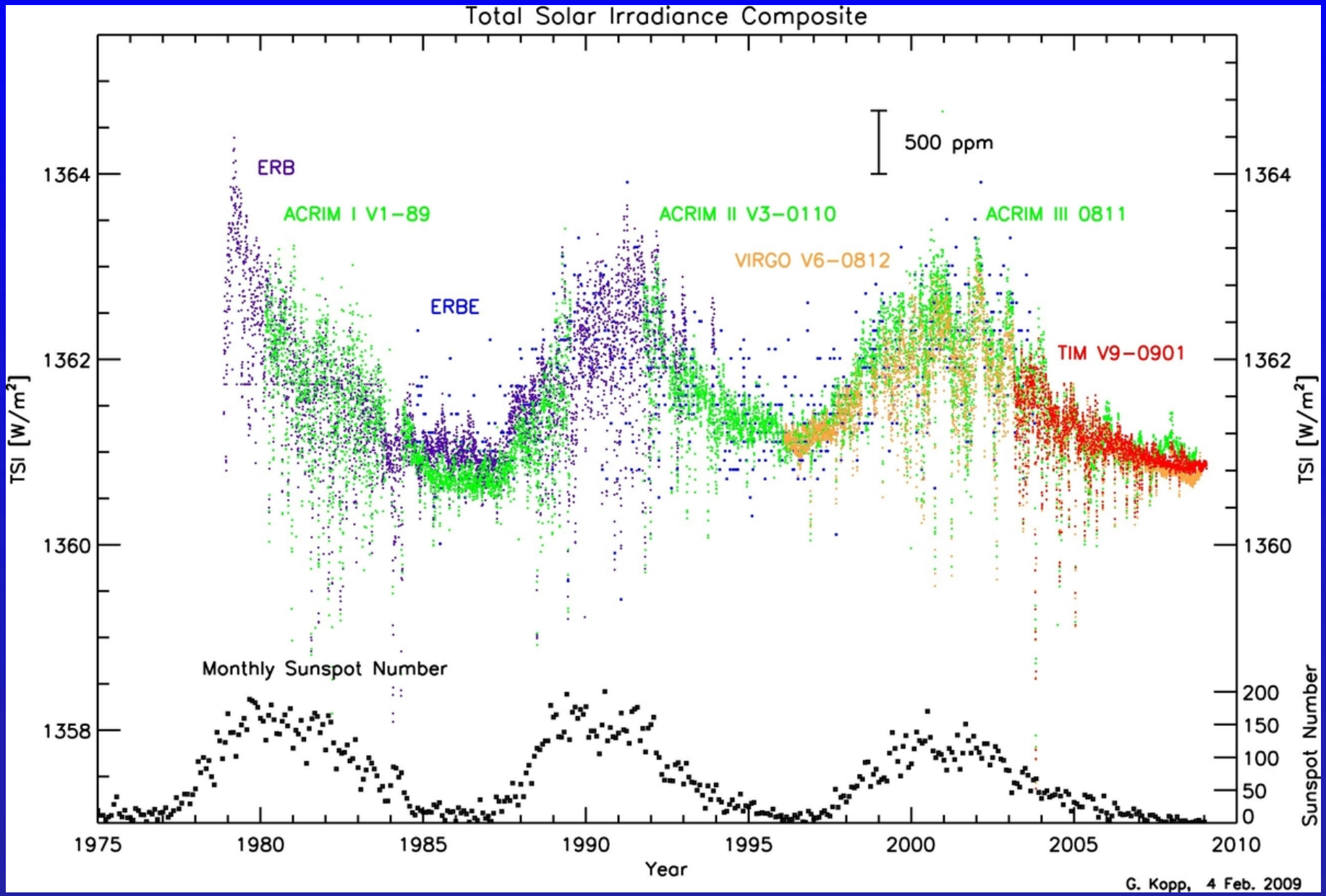
Changes in the sun are tiny and cyclic



Variations are <±0.1%

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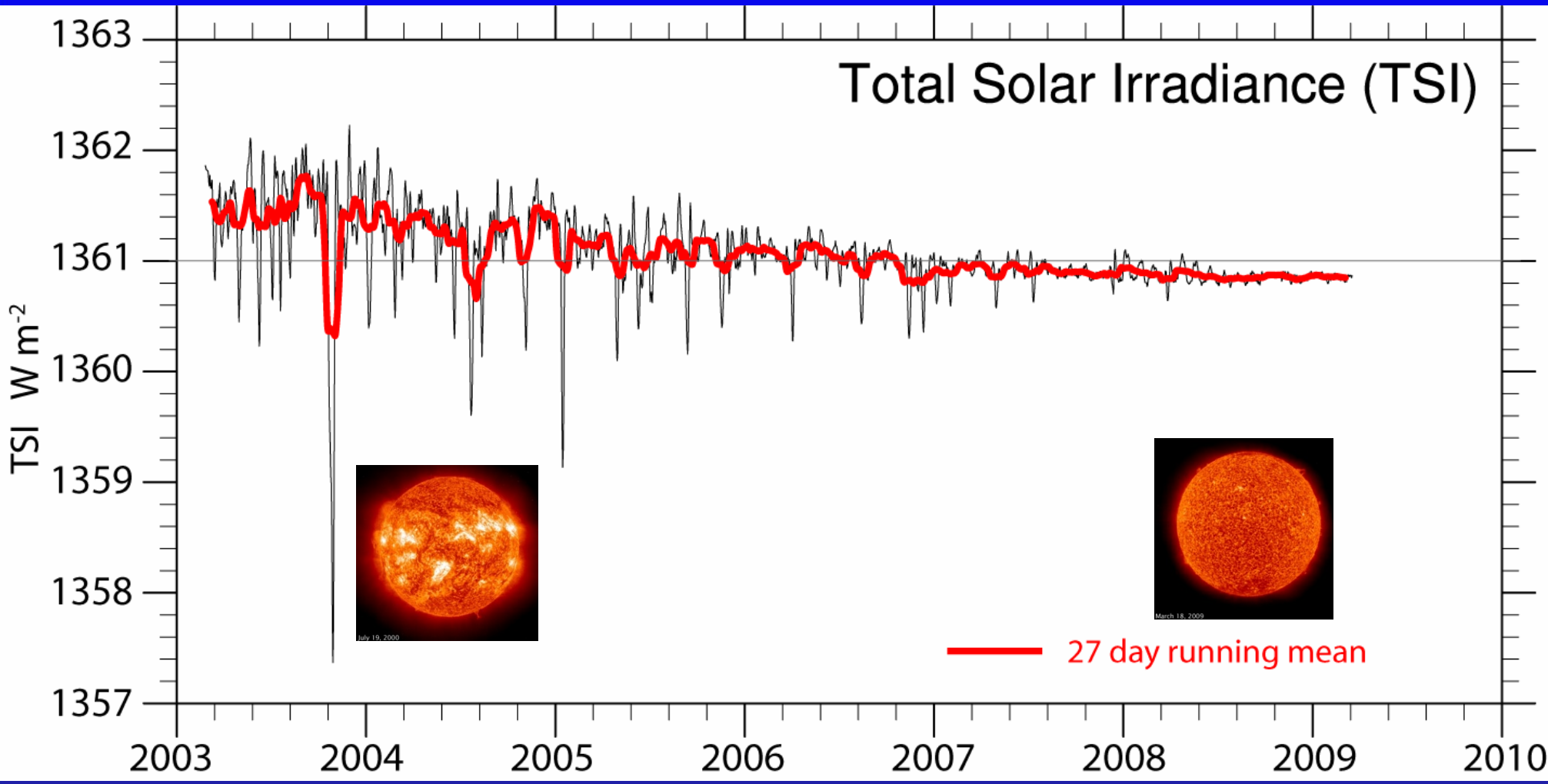
Solar irradiance



The drop of 0.5 W m^{-2} since 2003 is equivalent to -0.1 Wm^{-2} in radiative forcing

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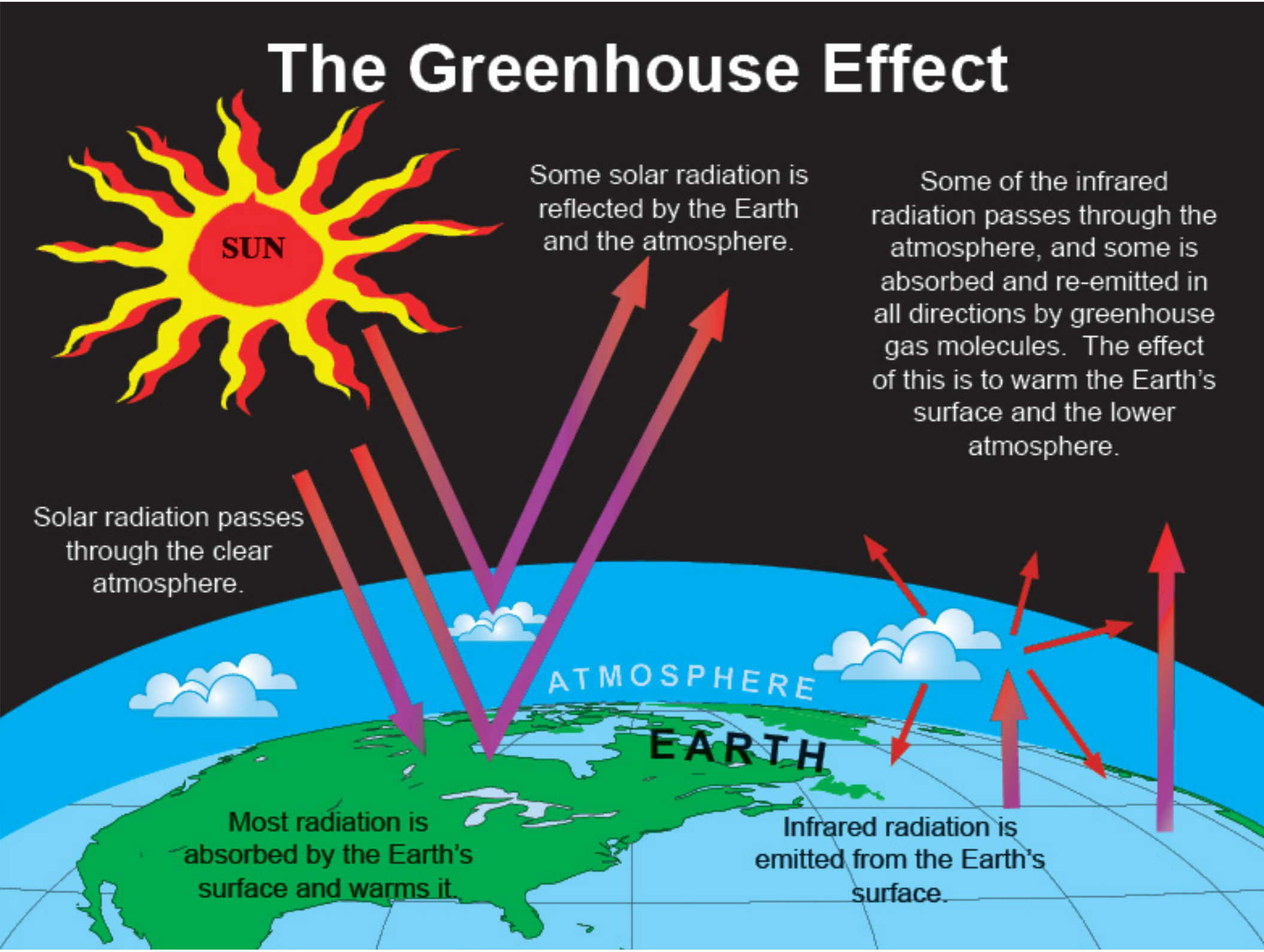
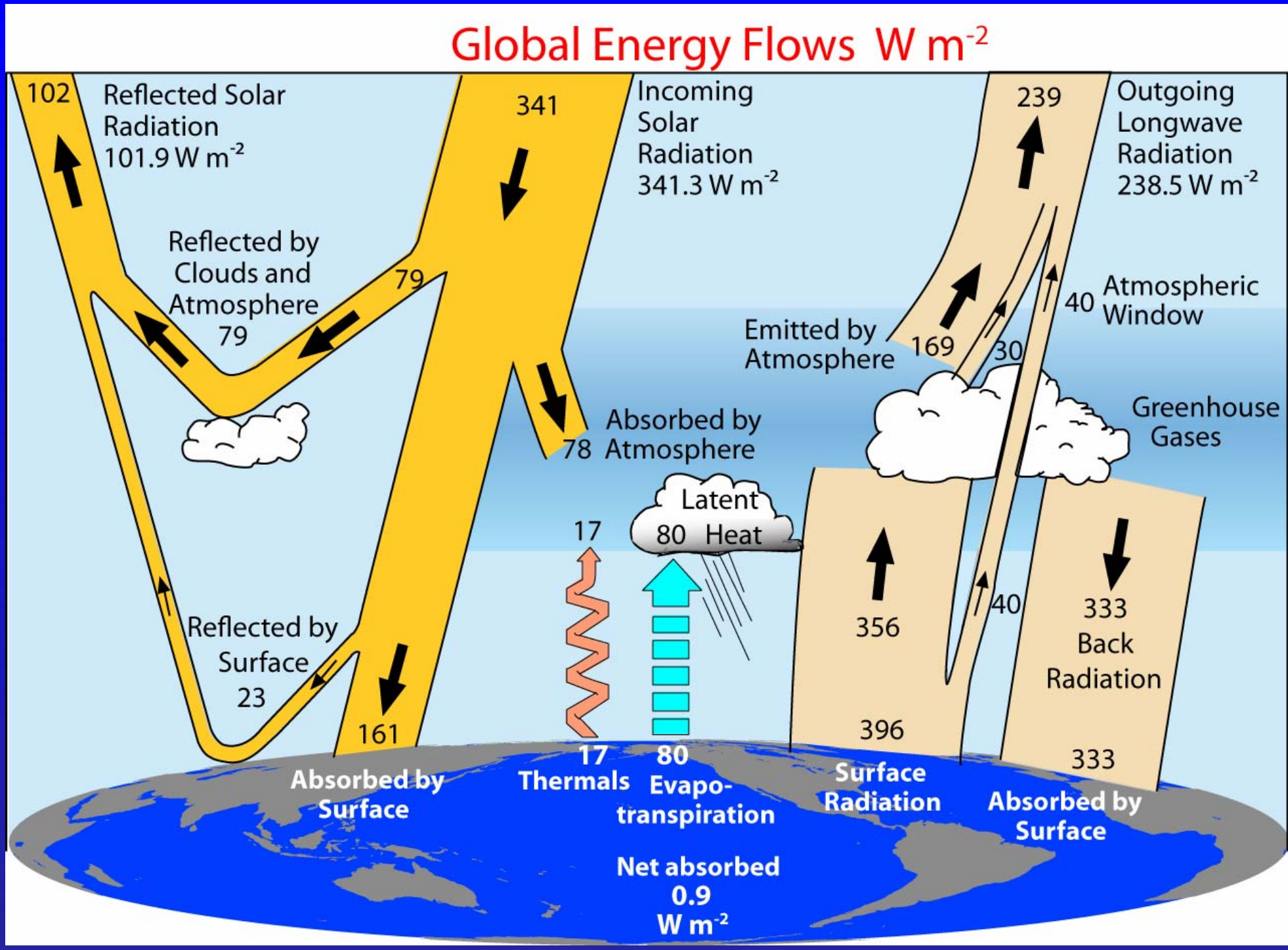
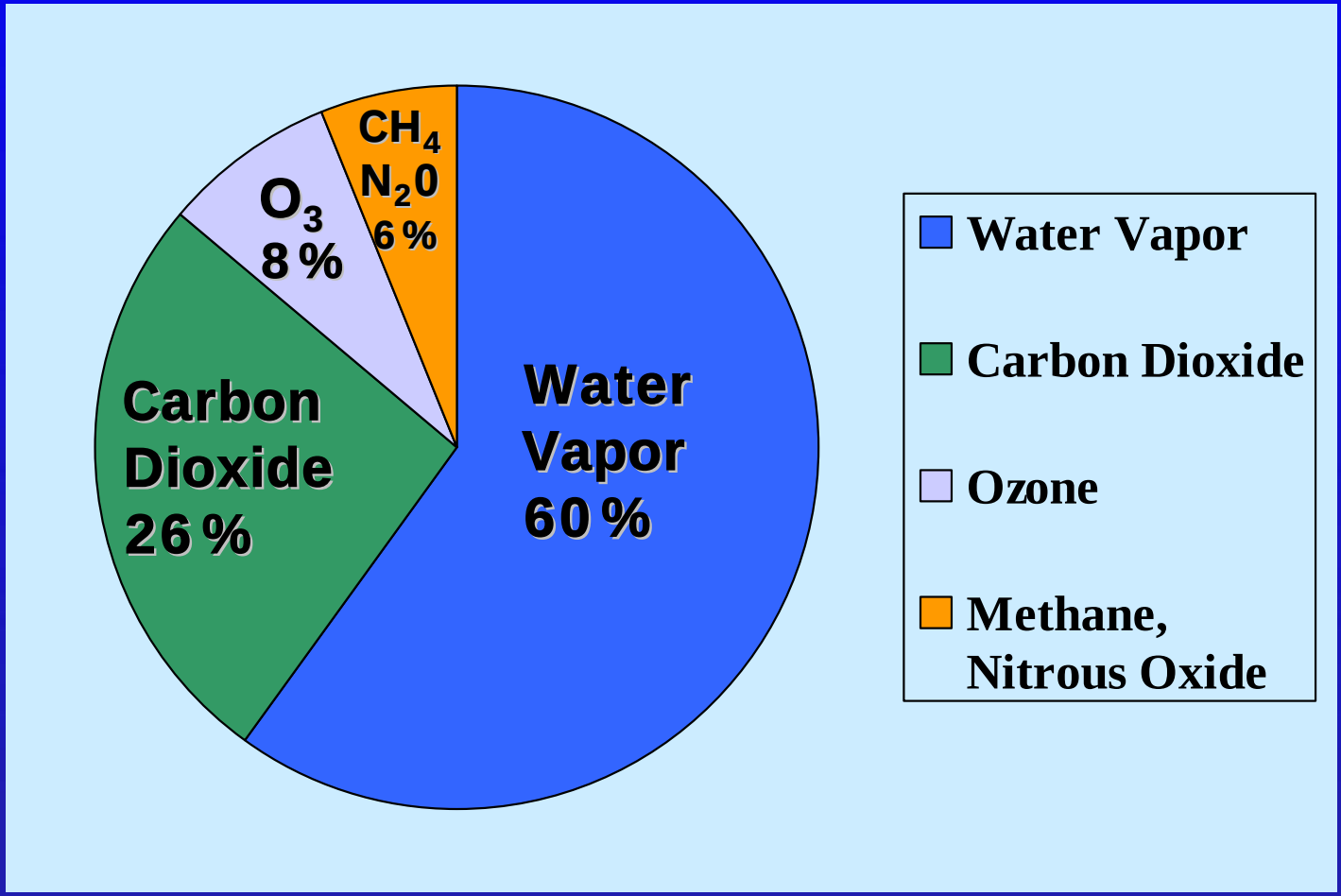

The Greenhouse Effect
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.
Solar radiation passes through the clear atmosphere.
ATMOSPHERE
EARTH
Most radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.



2000-2005

Trenberth et al 2009

The Natural Greenhouse Effect: clear sky



Clouds also have a greenhouse effect

Kiehl and Trenberth 1997

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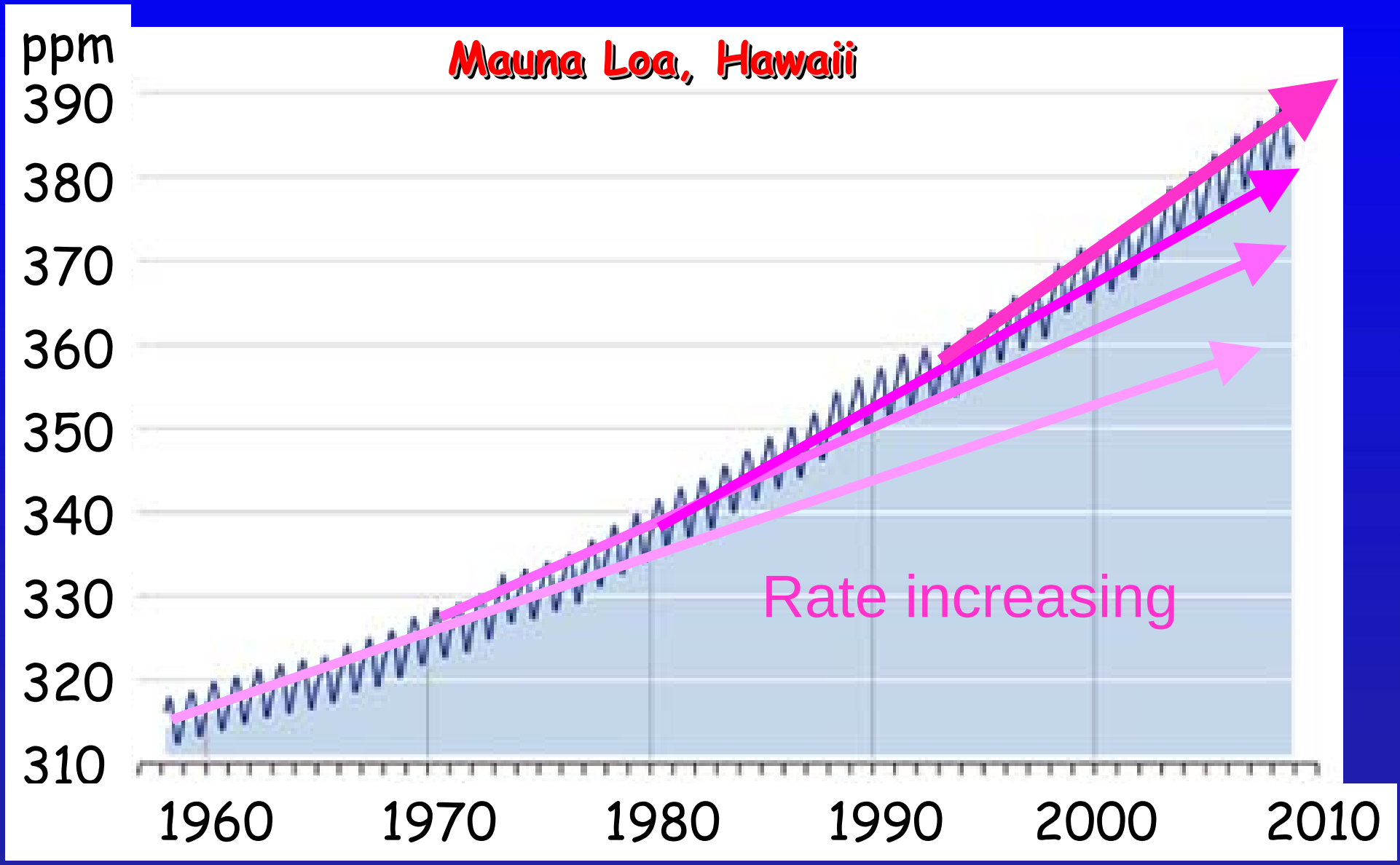
Changing atmospheric composition: CO_2



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

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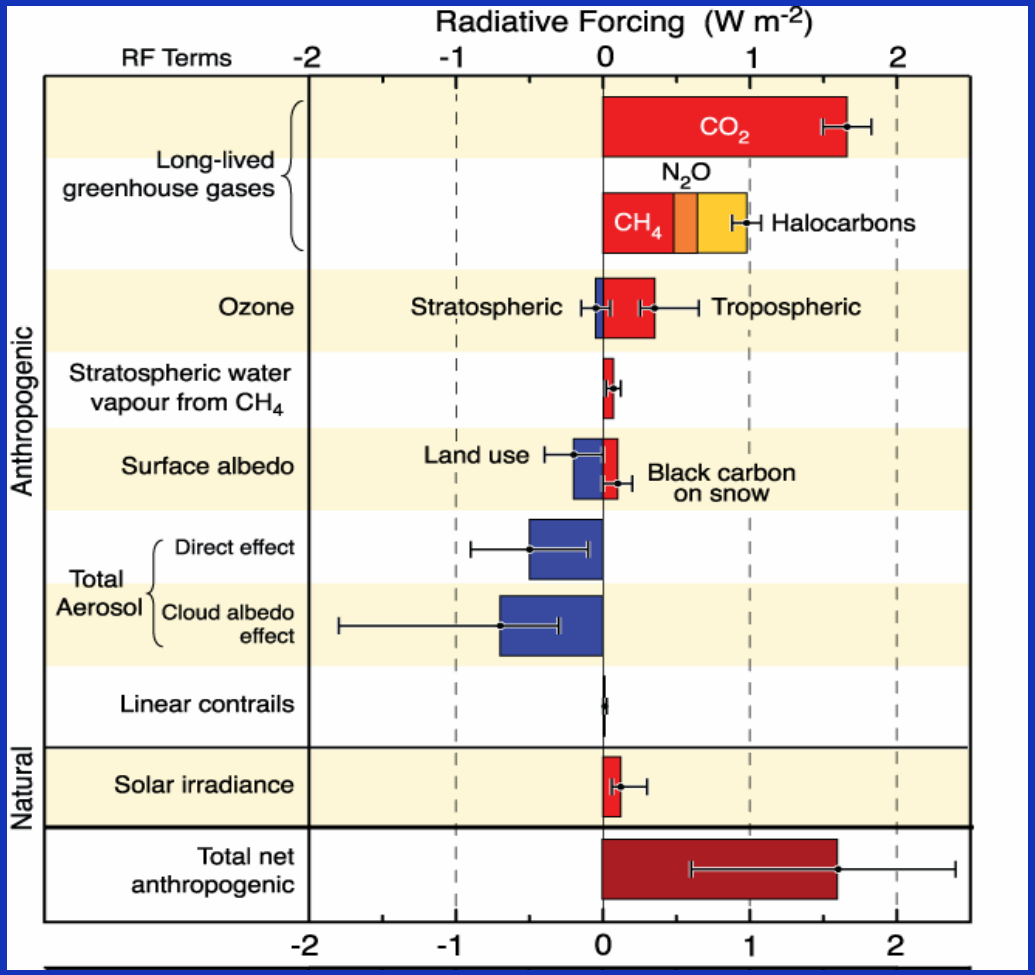
A warming climate has a cause:
Radiative Forcing and Response of Climate



Forcings	W m^{-2}
CO_2:	1.6
GHGs:	3.0
Aerosols:	-1.4
Net:	1.6

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Global Warming is Unequivocal

IPCC: unanimously approved 113 govts

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
- Ocean acidity

Decrease in:

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

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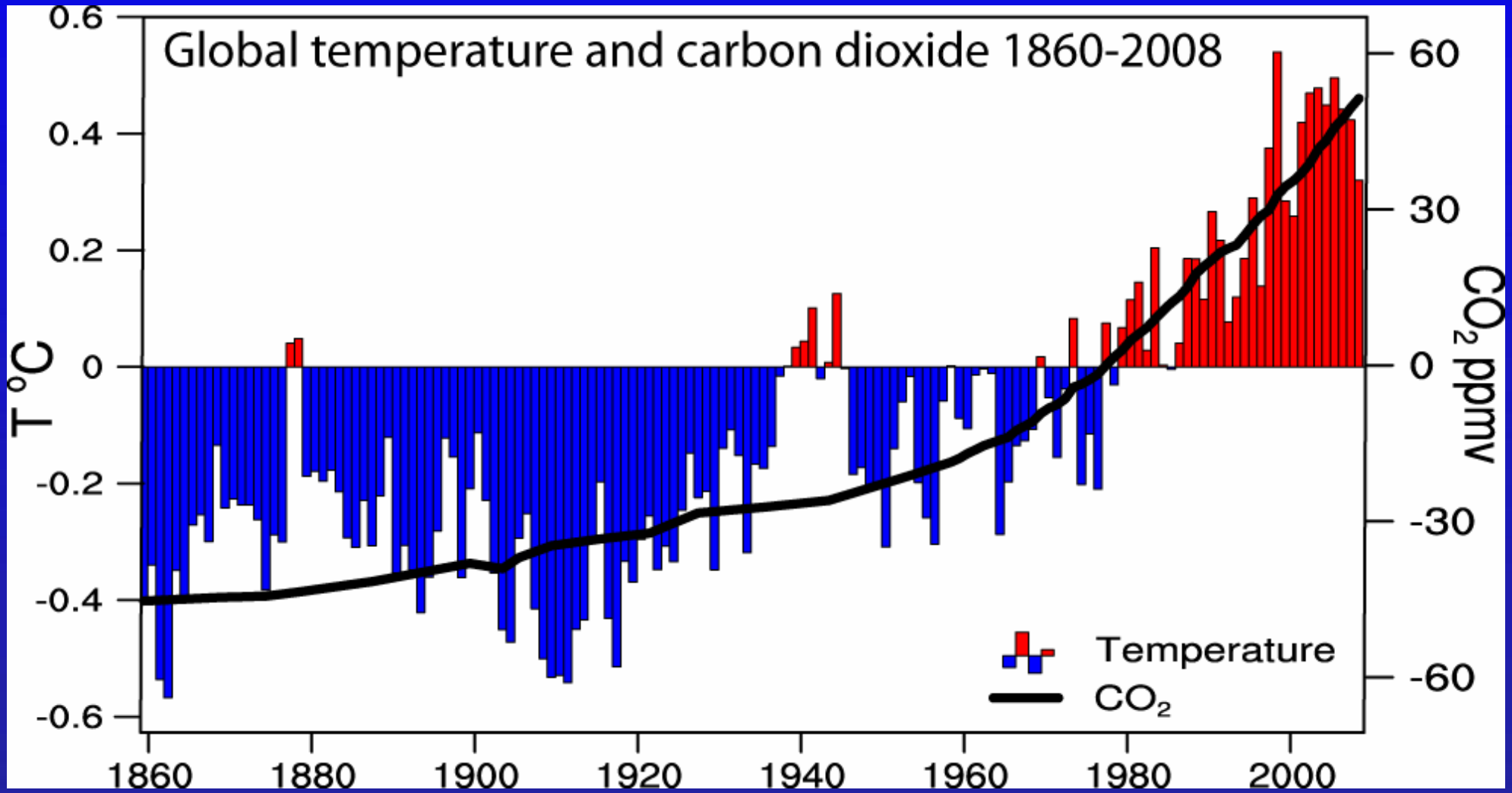
Global temperatures and carbon dioxide through 2008



Annual means; 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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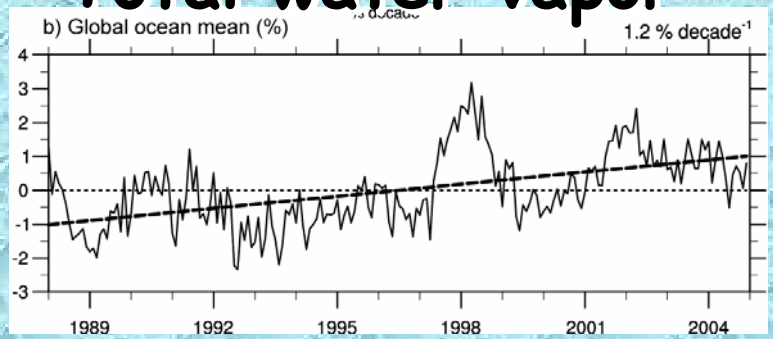
Air holds more water vapor at higher temperatures

A basic physical law tells us that the water holding capacity of the atmosphere goes up at about 7% per degree Celsius increase in temperature. (4% per °F)

Observations show that this is happening at the surface and in lower atmosphere: 1°F since 1970 over global oceans and 4% more water vapor.

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

Total water vapor

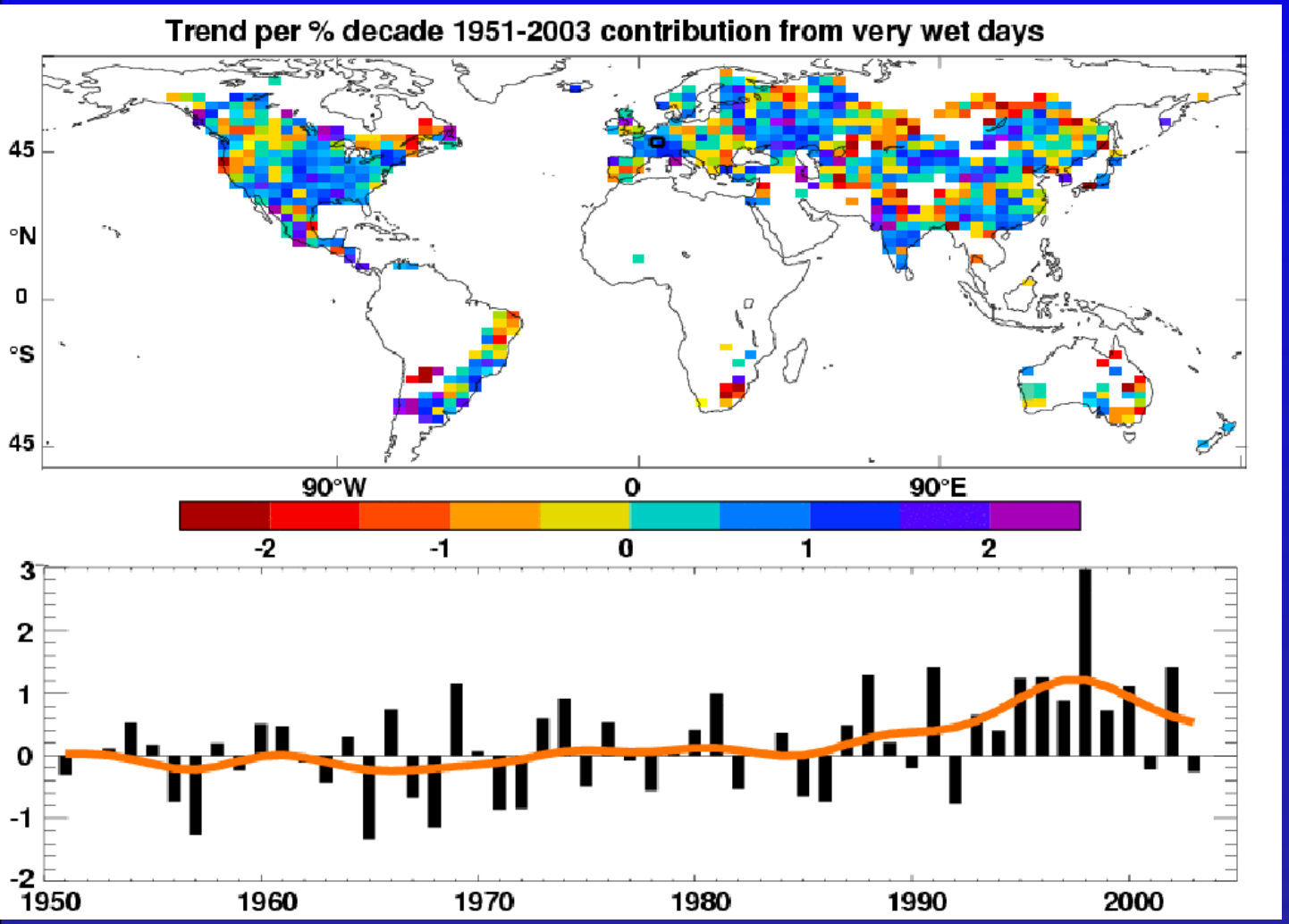


Declining Snow Pack in many mountain and continental areas contributes to drought

- 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

Heavy precipitation days are increasing even in places where precipitation is decreasing.



Precipitation

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

Alexander et al 2006
IPCC AR4

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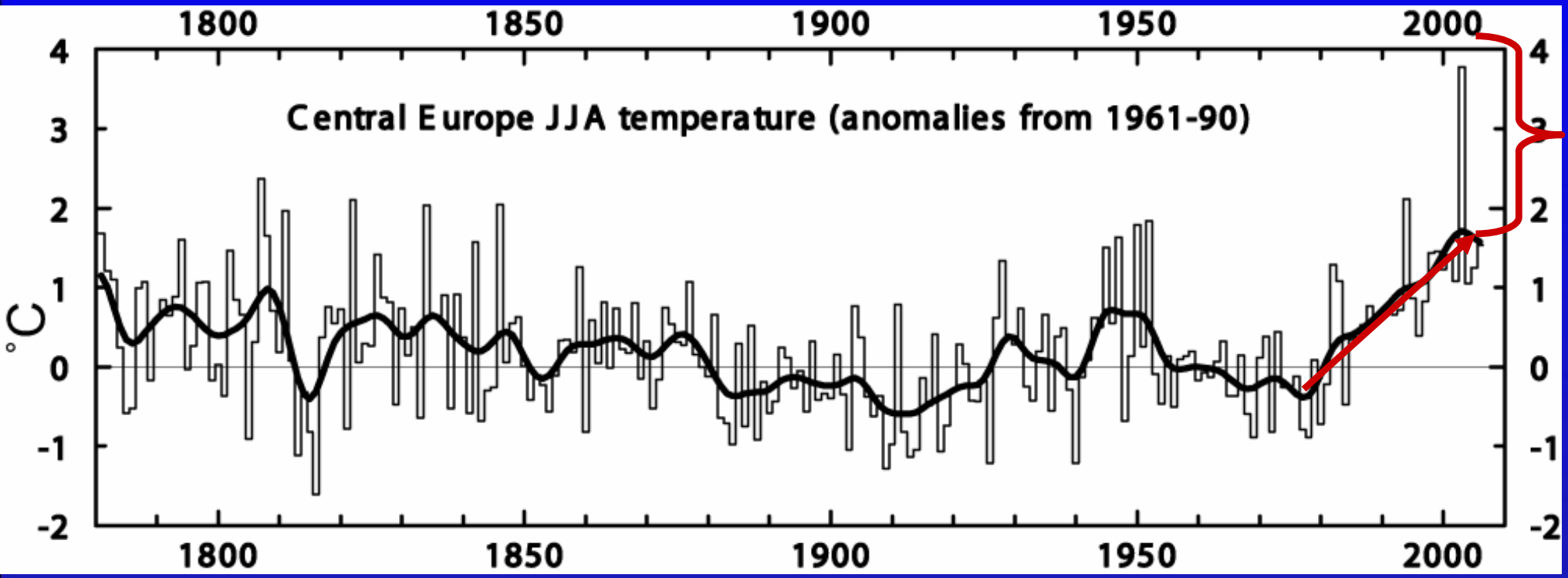
Heat waves are increasing: an example



Extreme Heat Wave
Summer 2003
Europe
>50,000 deaths

Trend plus variability?

IPCC

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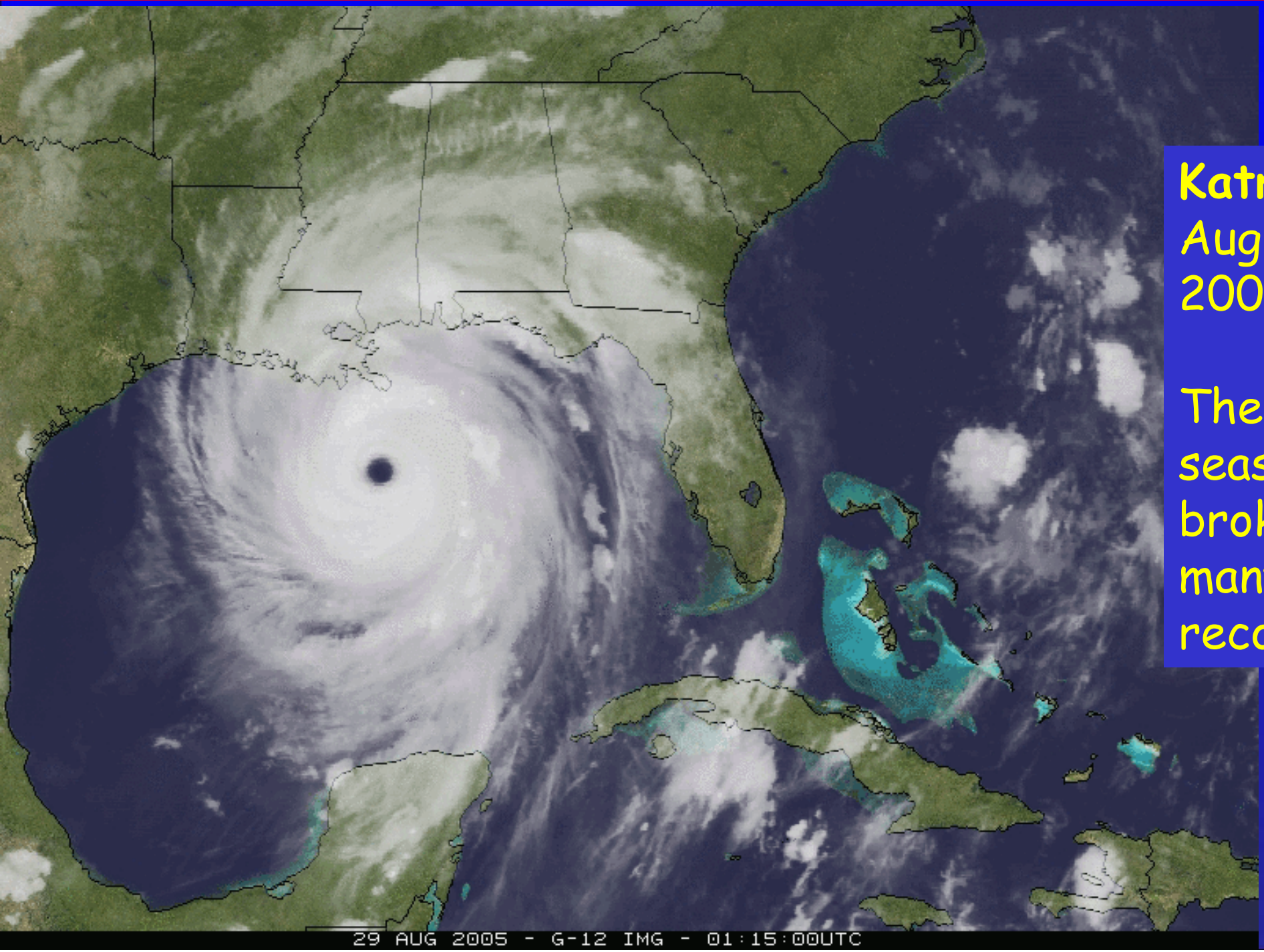
North Atlantic hurricanes have increased with SSTs



Katrina
August
2005

The 2005
season
broke
many
records

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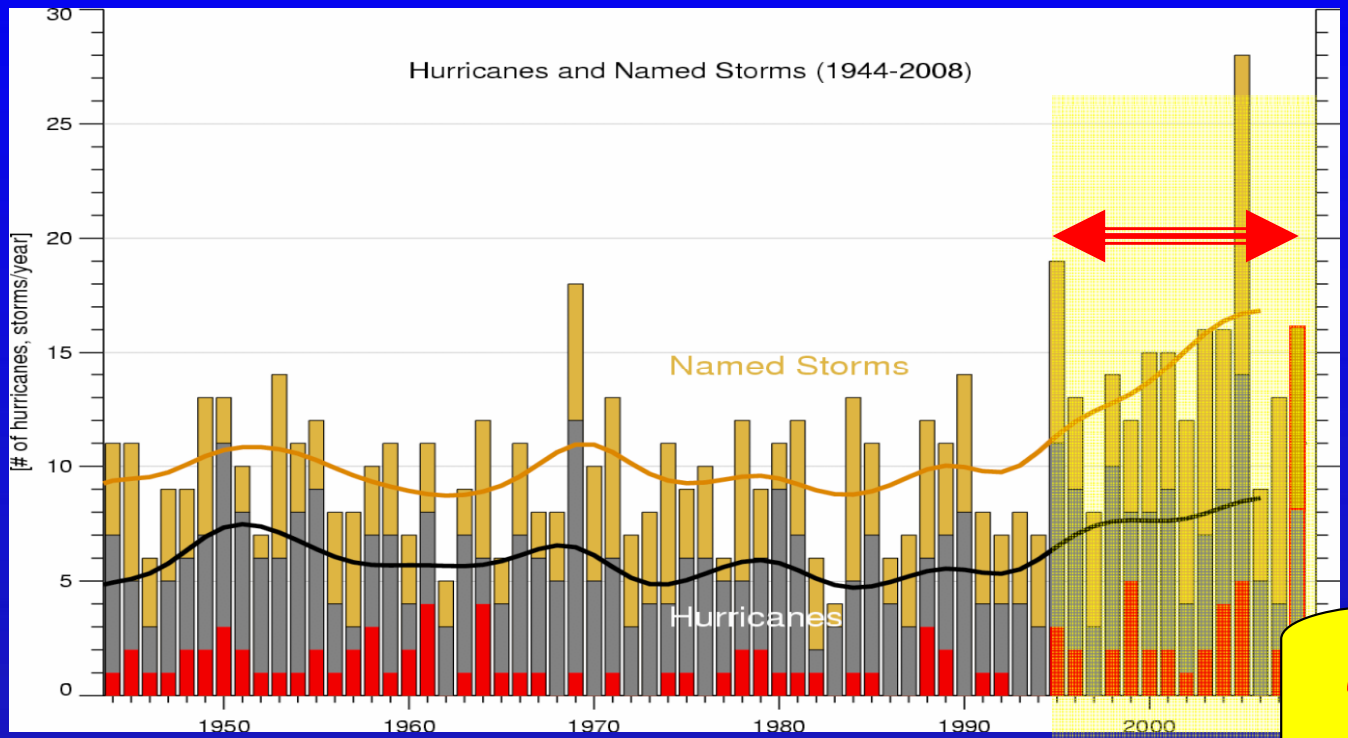
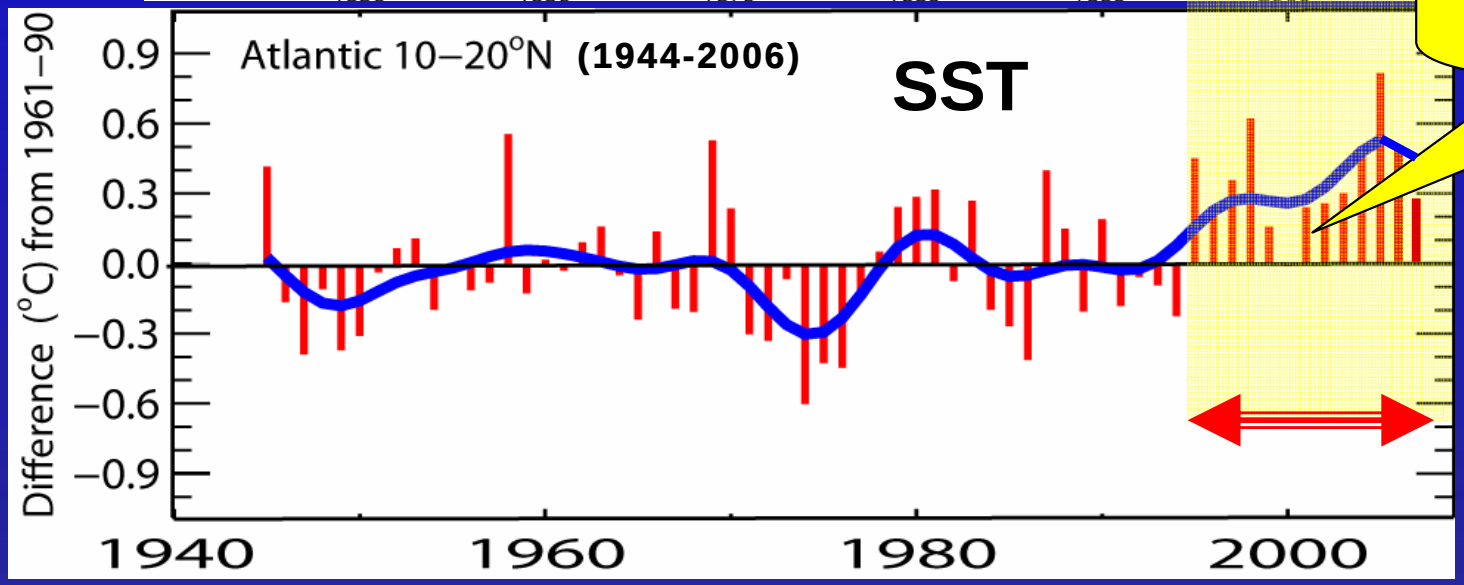
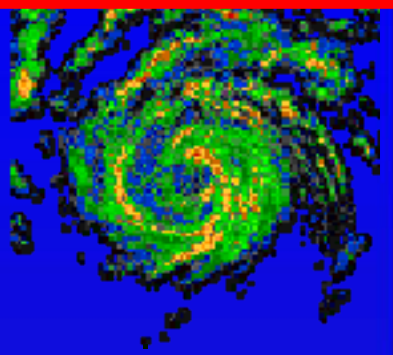
North Atlantic hurricanes have increased with SSTs







N. Atlantic hurricane record best after 1944

Marked increase after 1994

Global number and percentage of intense hurricanes is increasing

Thru 2008

IPCC

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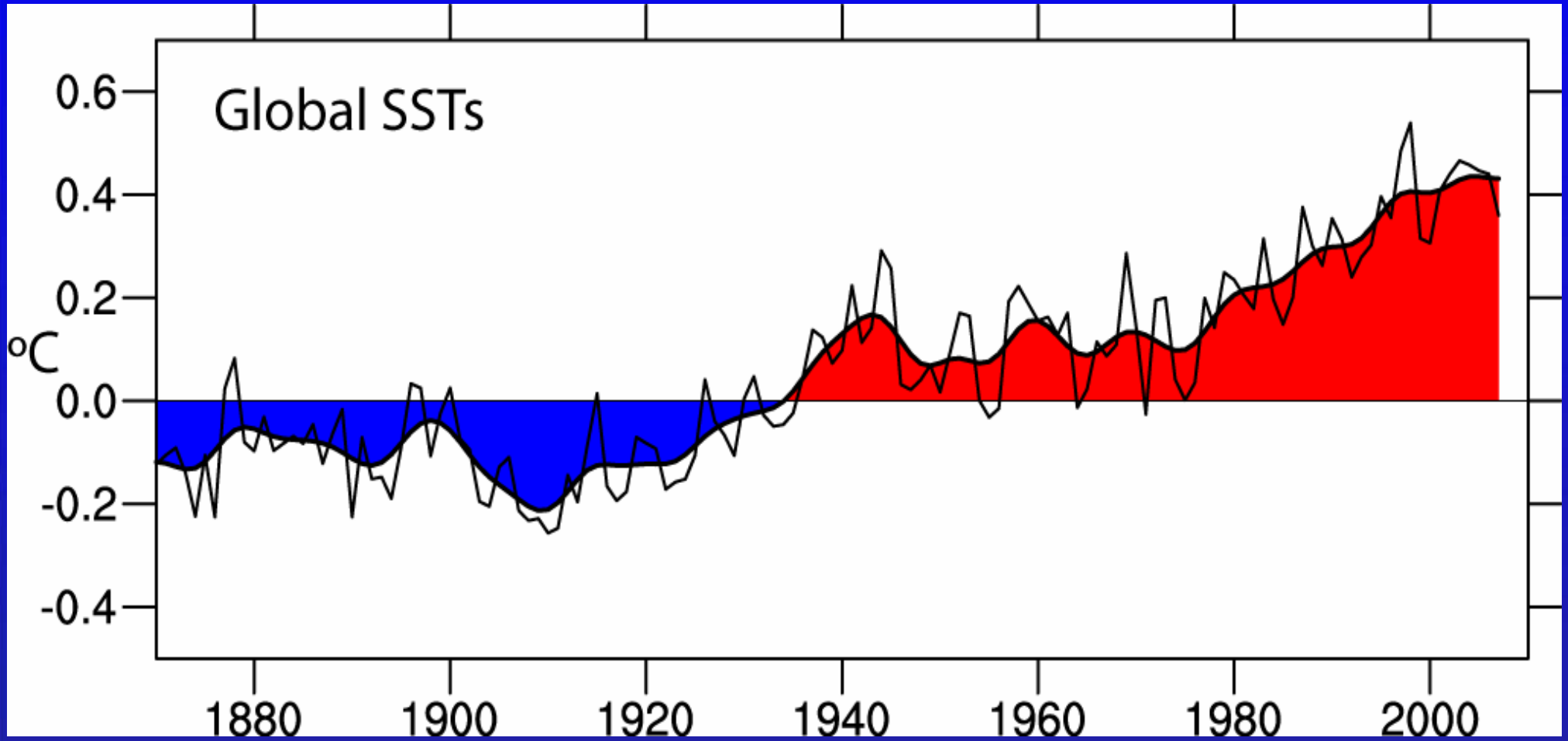
Global SSTs are increasing: base period 1901-70



Through 2007
Data: Hadley Centre, UK

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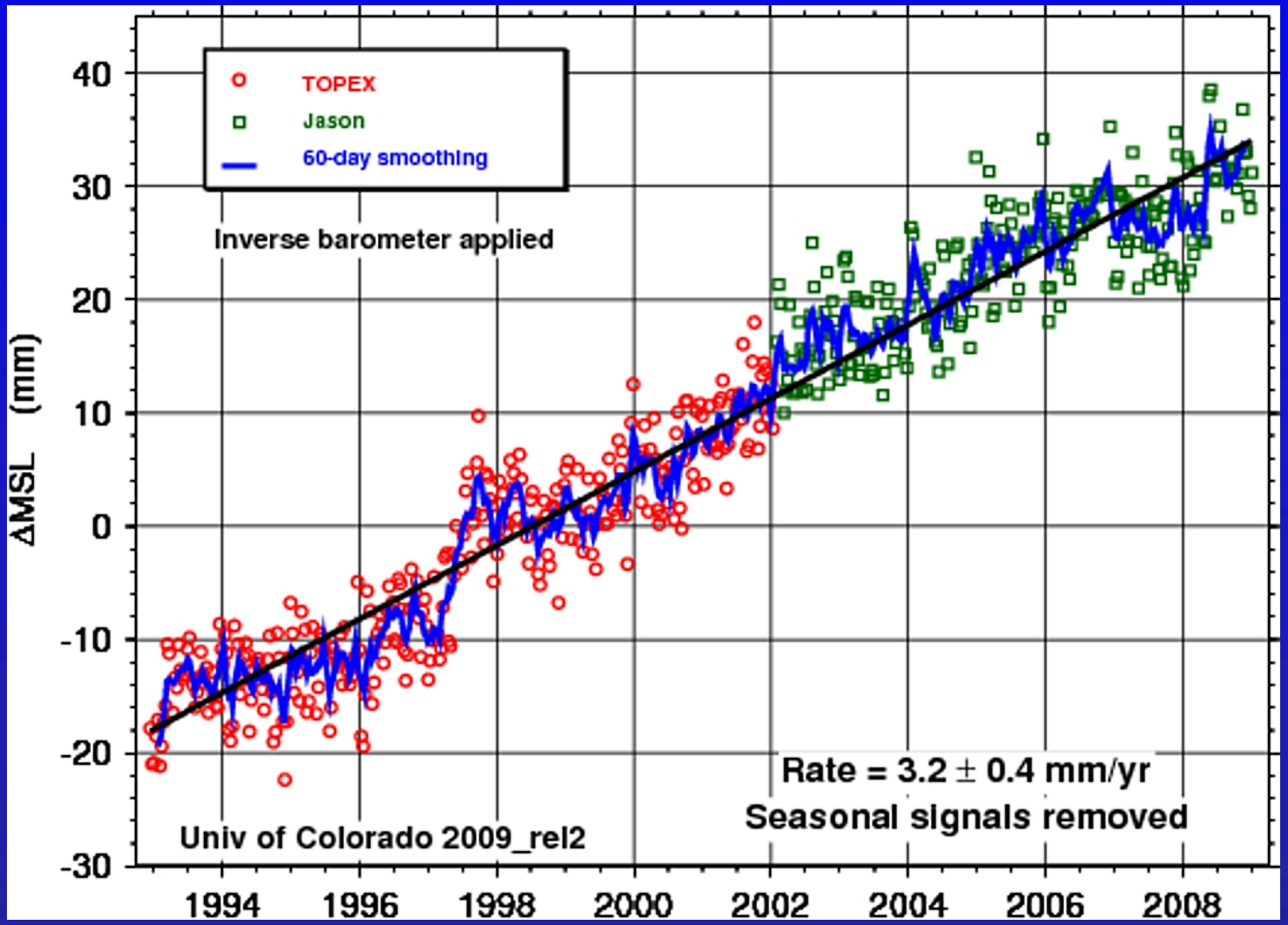
Sea level is rising:
from ocean expansion and melting glaciers



Since 1992 Global sea level has risen 50 mm (2 inches)

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

Courtesy Steve Nerem U Colo

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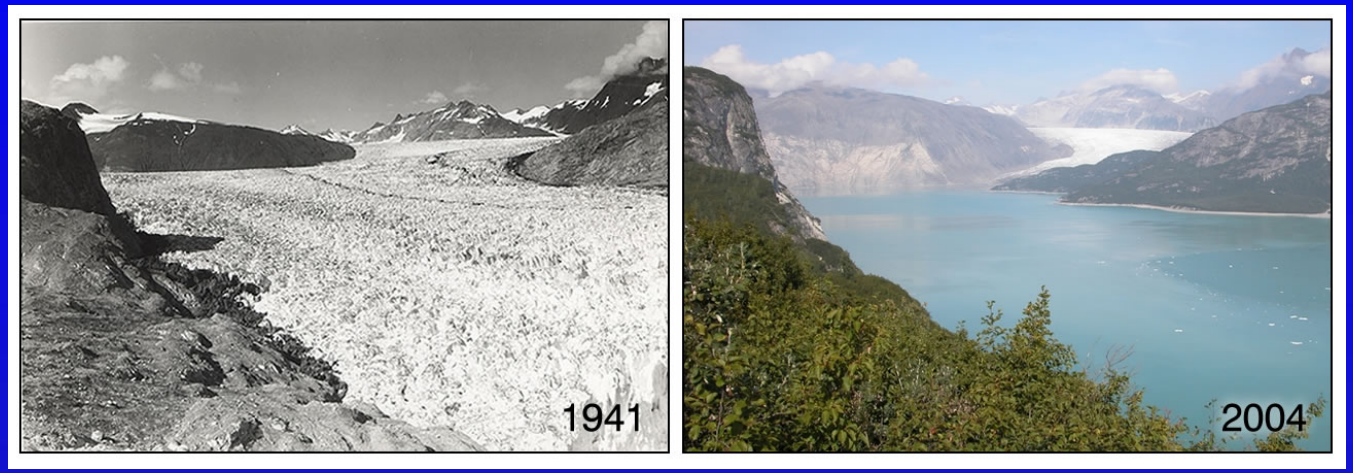
Evidence for reality of climate change

Glaciers melting

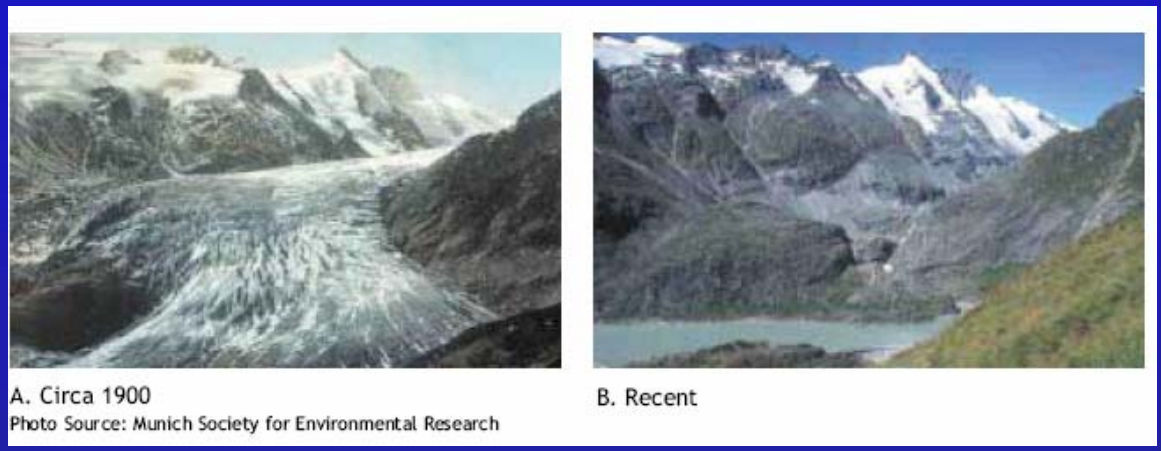


Muir Glacier, Alaska

1909

Toboggan Glacier Alaska

2000



1900 2003

Alpine glacier, Austria

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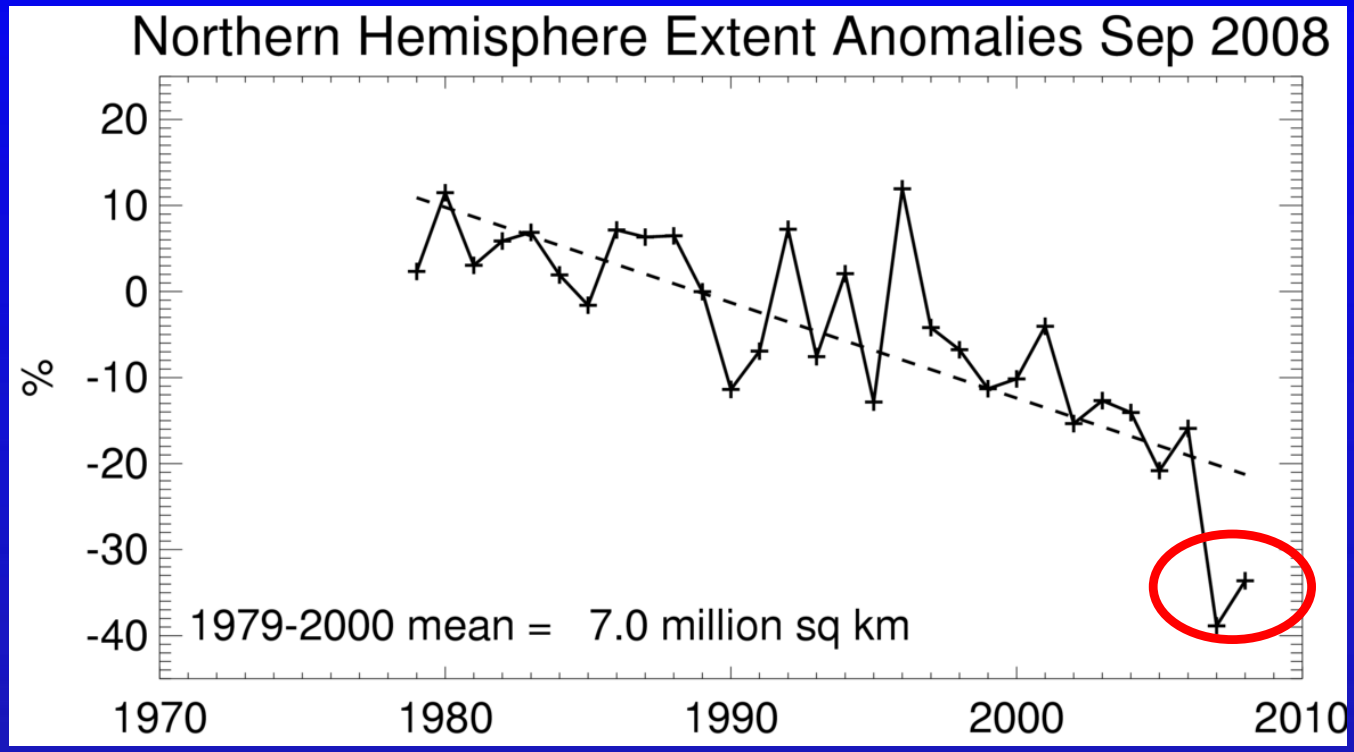
Snow cover and Arctic sea ice are decreasing



Arctic sea ice till 2006 (IPCC)

- area decreased by 2.7% per decade
  (Summer: -7.4%/decade)
- 2007: 22% (10^6 km^2) lower than 2005
- 2008 second lowest
- 40% decrease in summer

IPCC

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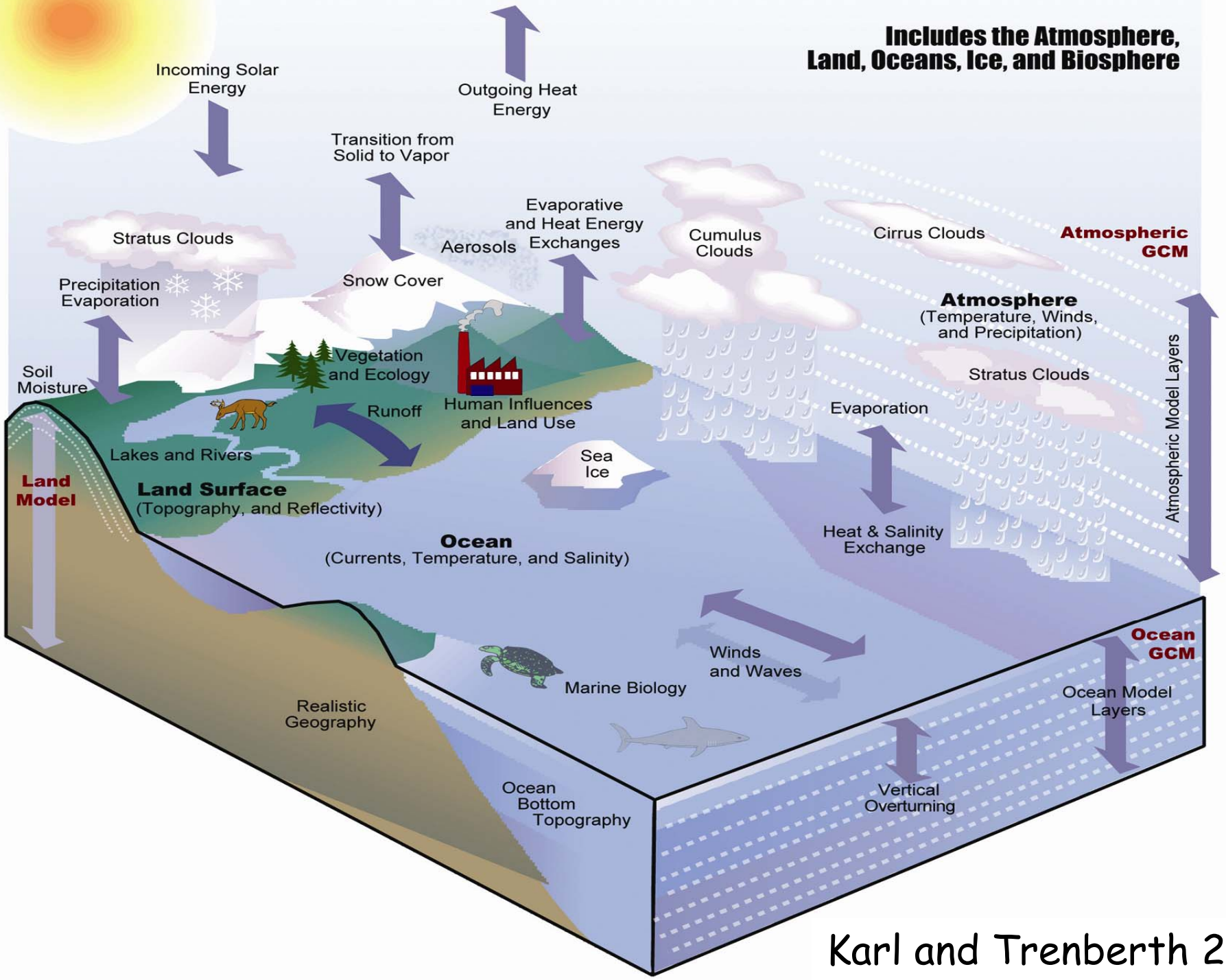
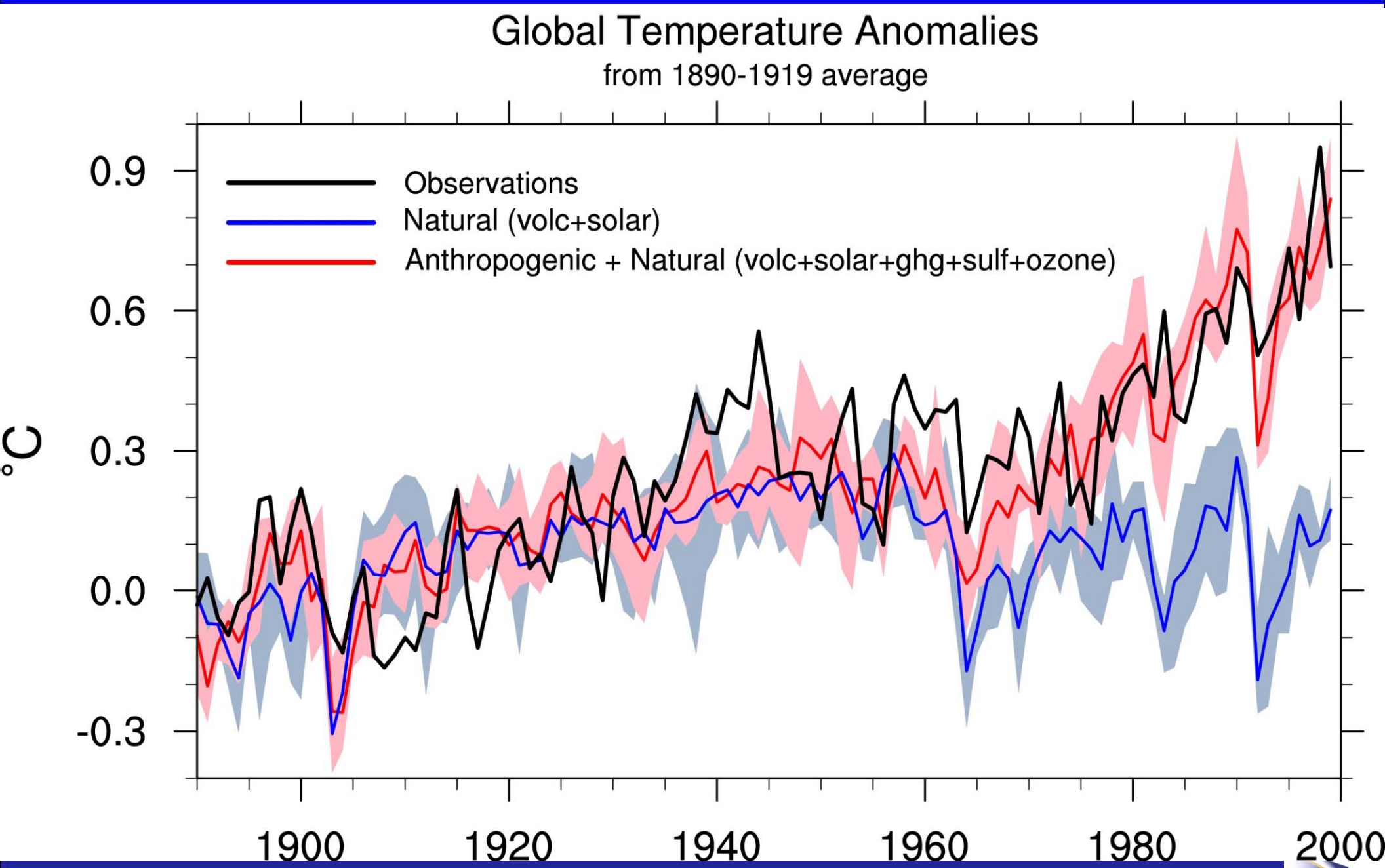
Modeling the Climate System



Karl and Trenberth 2003

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



Meehl et al, 2004: J. Climate.

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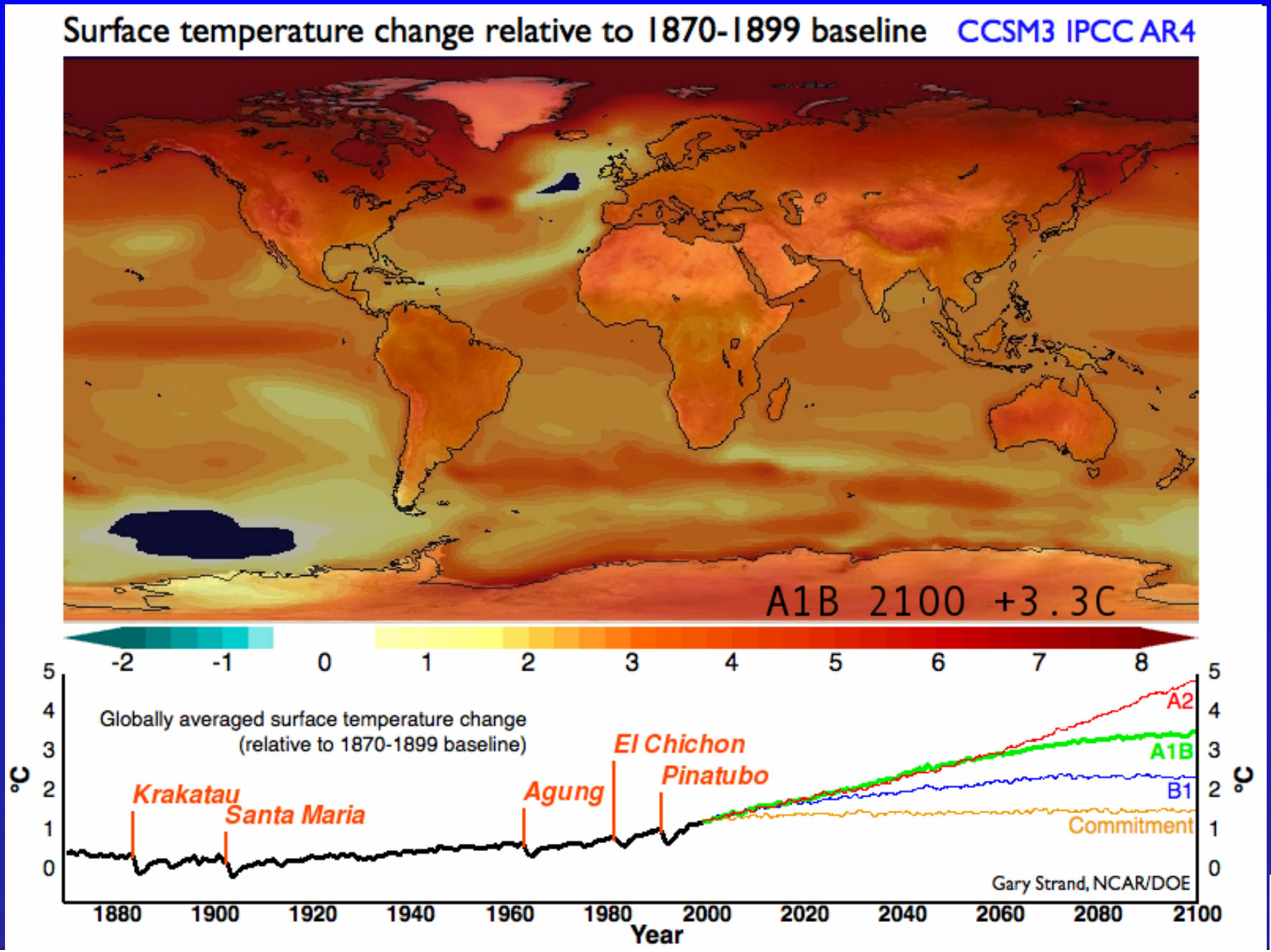
Projected temperature change



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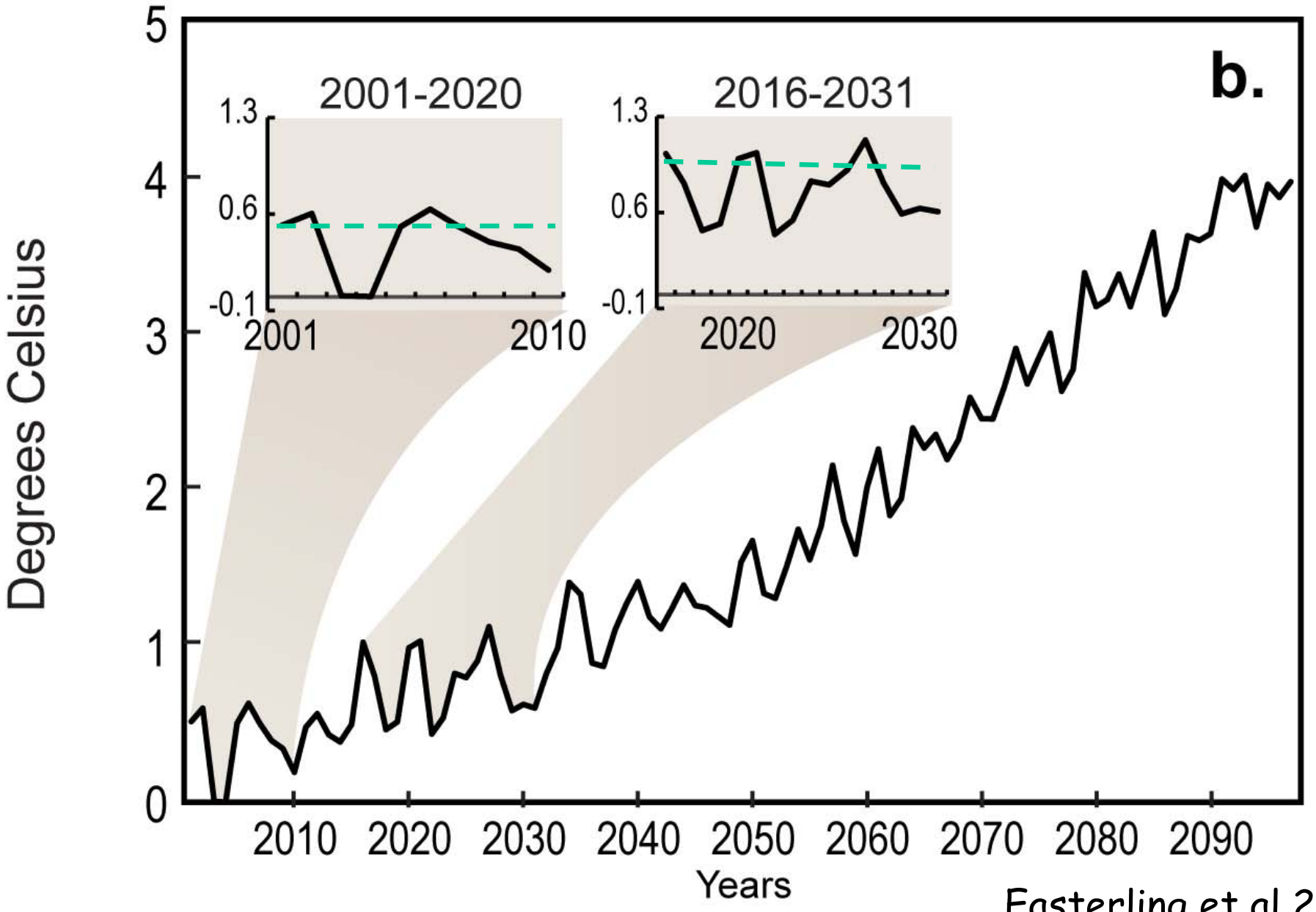
Cooling can easily happen for a decade or so

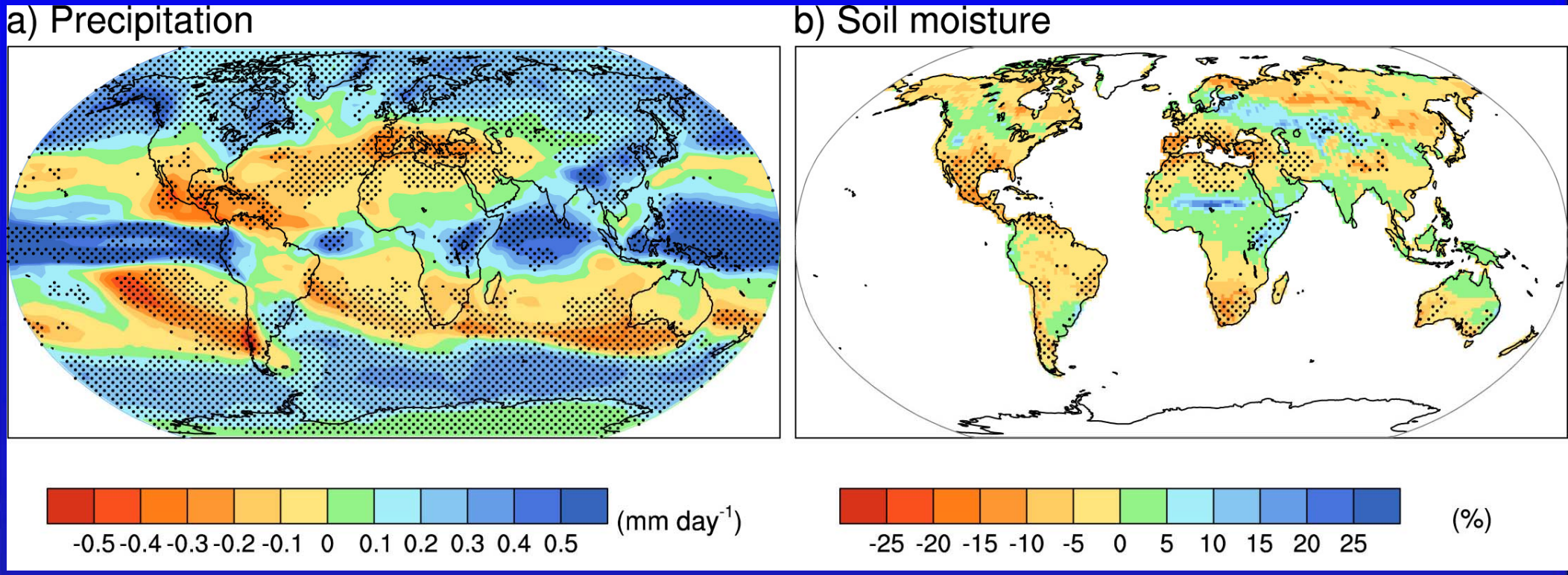
Global Annual Surface Air Temperature,

MPI-ECHAM CGCM: A2 Forcing



Easterling et al 2009 GRL

Projected Patterns of Precipitation Change
2090-2100



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

IPCC

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The Challenge:
Sustainable Management of an Ever-Changing Planet

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