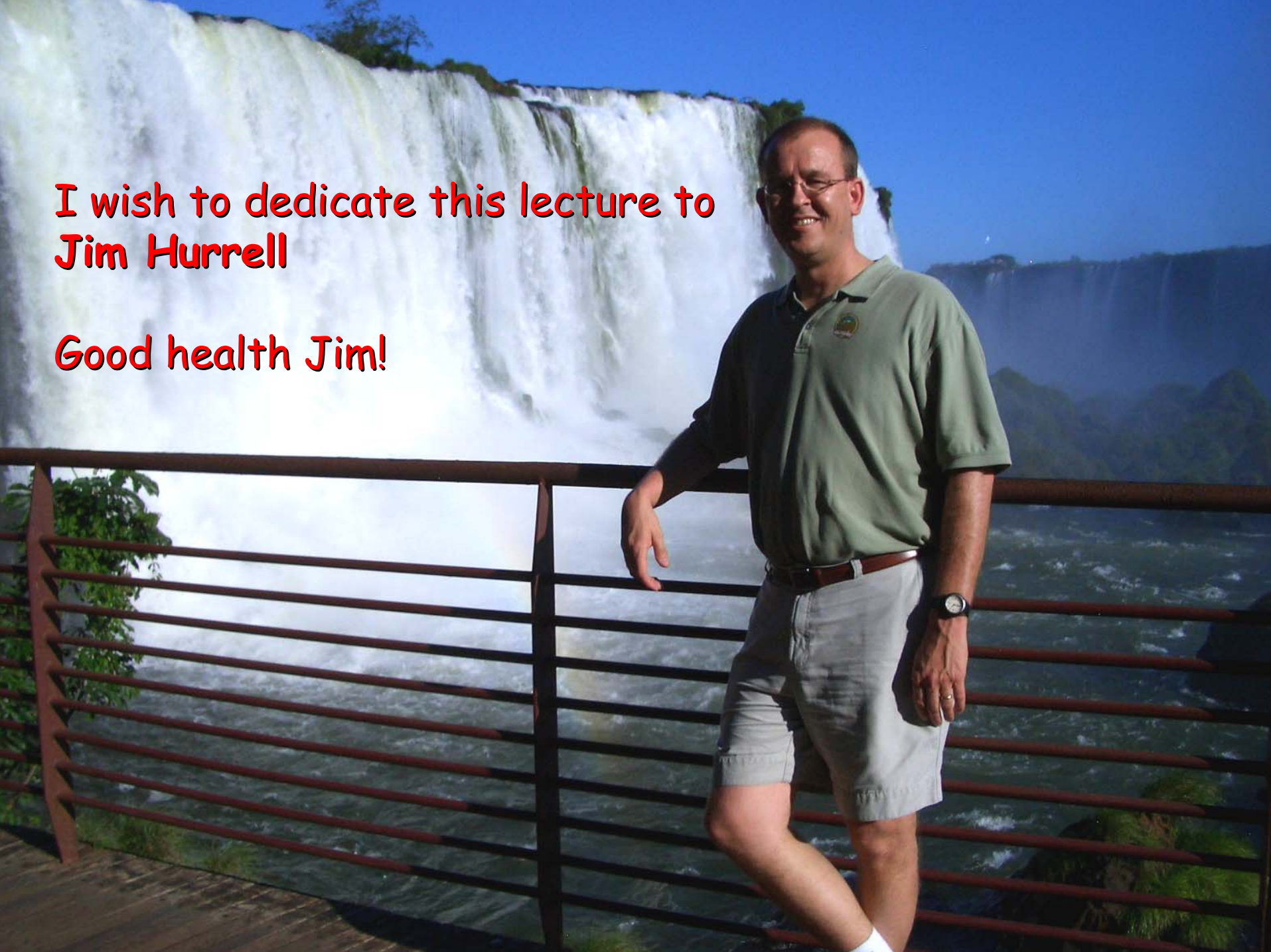
Global Warming: Coming ready or not!

Kevin E Trenberth
NCAR

Photo Credit/Crédit photographique: Dan Crosbie


I wish to dedicate this lecture to
Jim Hurrell
Good health Jim!

- 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 climate models over the past 50 years adding confidence to future projections.

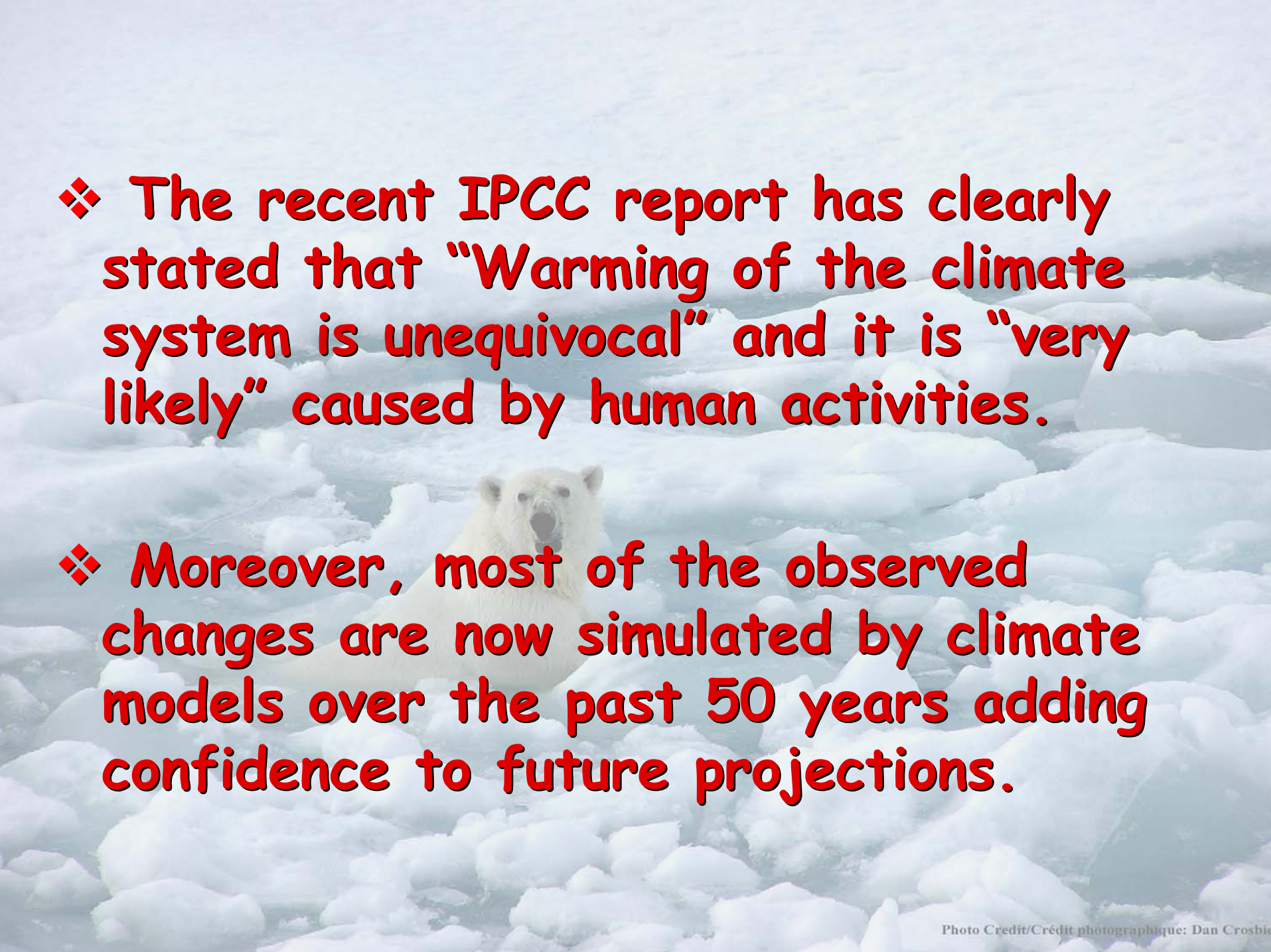


Photo Credit/Crédit photographique: Dan Crosbie

IPCC

2007:

The Nobel Peace Prize goes to the **Intergovernmental Panel on Climate Change (IPCC)** and **Albert Arnold (Al) Gore Jr.** "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change".

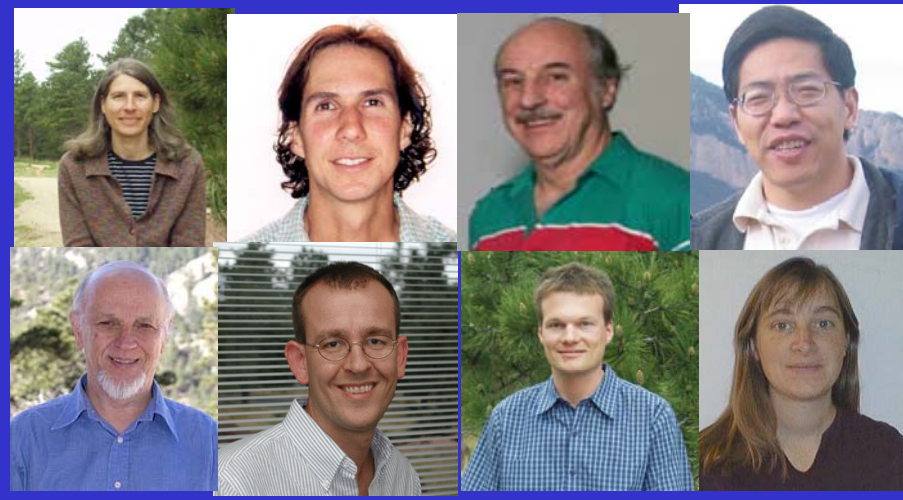
2007
Coordinating Lead Authors

IPCC

NCAR
Some Contributing "Authors"

CCSM

Lead Authors



1988 - The establishment of the IPCC

Role of the IPCC:

The role of the IPCC is to **assess** on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation.

Review by experts and governments is an essential part of the IPCC process.

1988 - The establishment of the IPCC
WMO, UNEP

1990 - First IPCC Assessment Report

1992 - IPCC Supplementary Reports

1992- Adoption of the UNFCCC
1994- Entry into force of the UNFCCC
Ratified by 189 countries

1994 - IPCC Special Report

1995 - Second IPCC Assessment Report

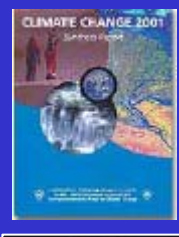
1996 - COP-2, 1997 - COP-3

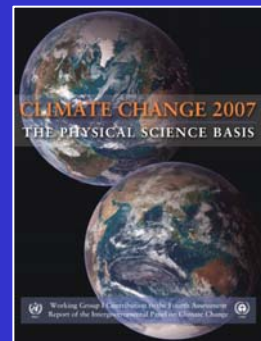
1997- Adoption of Kyoto Protocol at COP-3
2005 Feb 16- Kyoto Protocol ratified by 164 countries
(But not by USA or Australia)

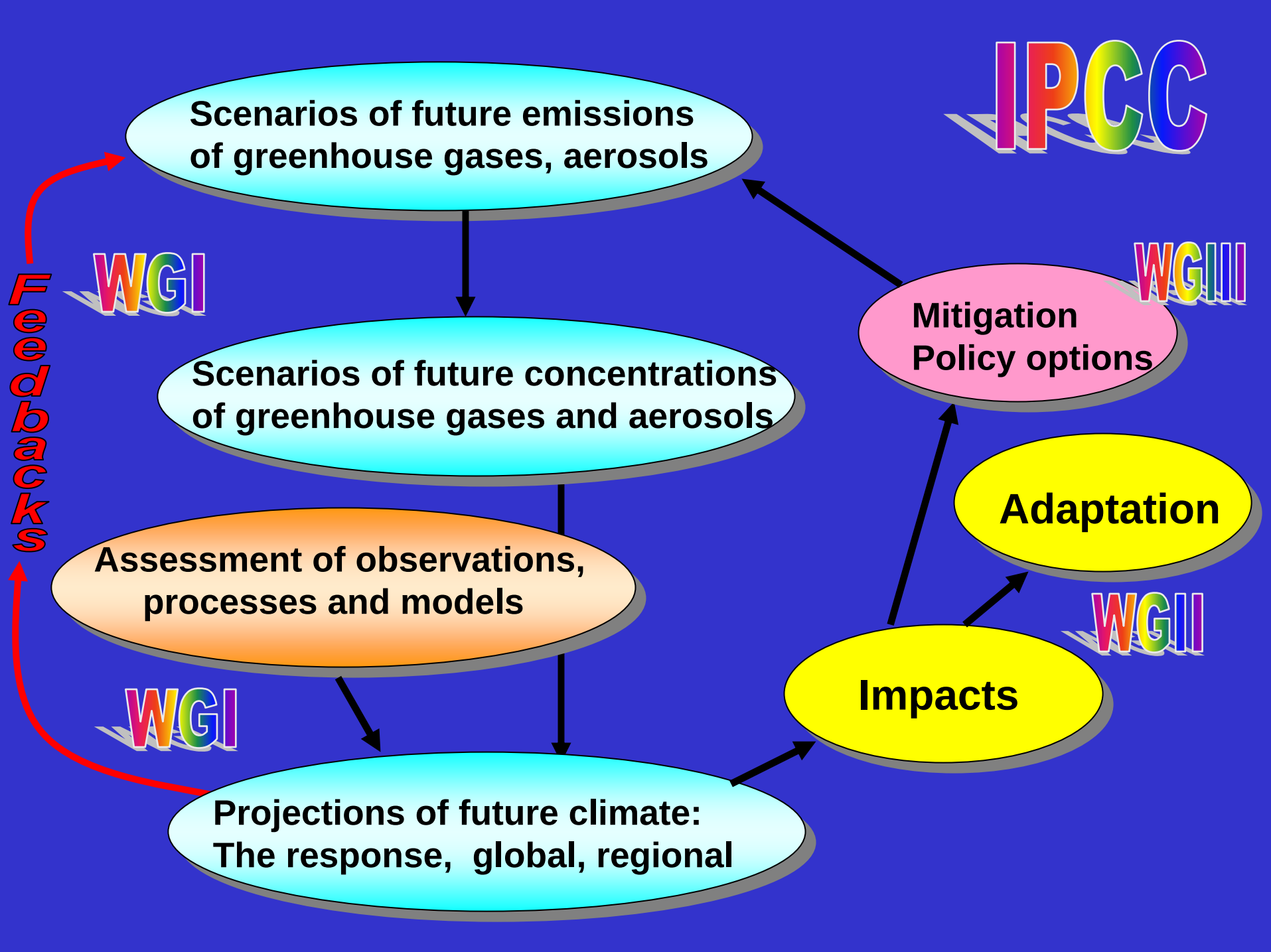
2001 - Third IPCC Assessment Report

2002 - COP-8, 2003 - COP-9

2007 - Fourth IPCC Assessment Report






IPCC
Scenarios of future emissions of greenhouse gases, aerosols
WGI
Feedbacks
Scenarios of future concentrations of greenhouse gases and aerosols
Assessment of observations, processes and models
WGI
Projections of future climate: The response, global, regional
WGIII
Mitigation Policy options
Adaptation
WGII
Impacts

A major strength of the IPCC process has been the **intergovernmental** process, through reviews and then approval of the **Summary for Policy Makers** on a word-by-word basis. This provides ownership.

But it has also been subject to criticism as it is much more political. In principle, this process is designed to provide a report in which the content is **determined by the science** while **how it is stated** is determined jointly with the governments. Hence it aids communication between scientists and politicians.

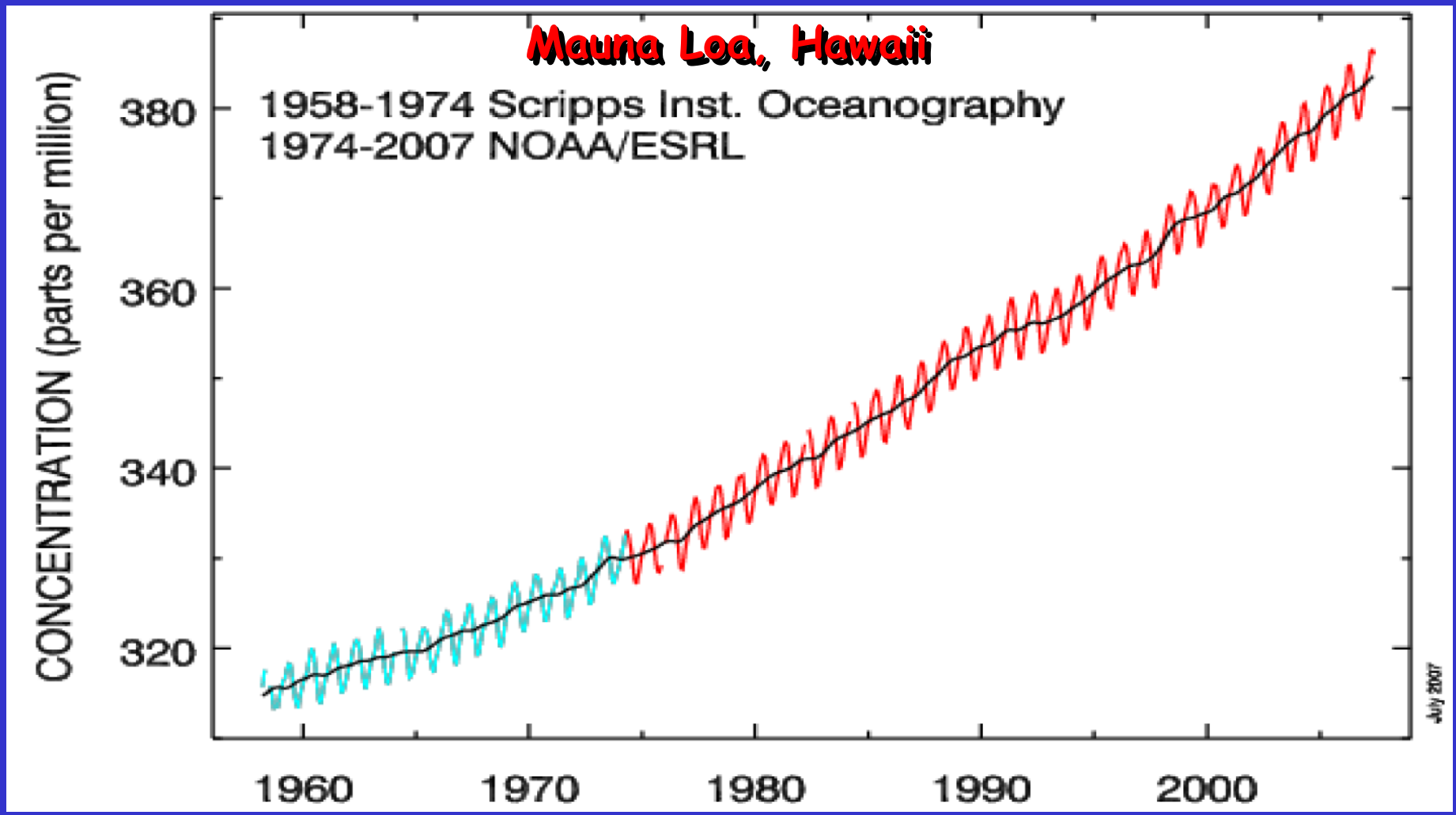
NOTE: **In terms of impact of the report, the process is as important as the report itself.**

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!**

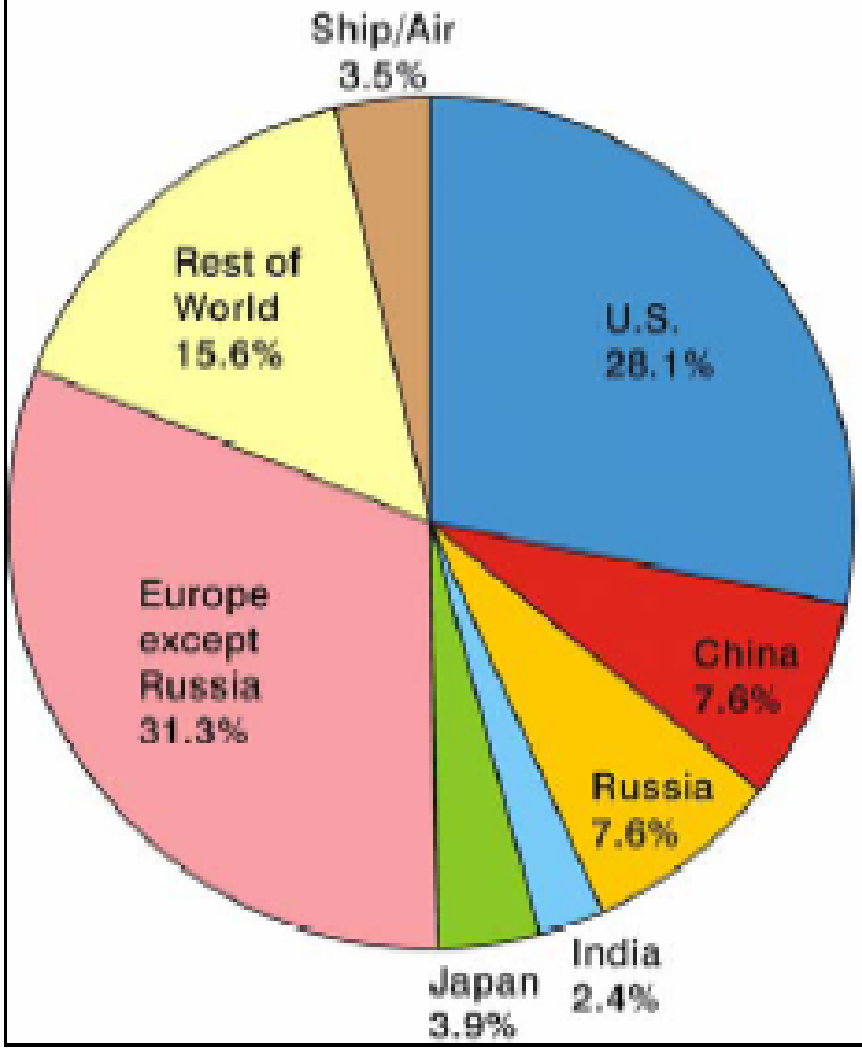
Changing atmospheric composition: CO_2

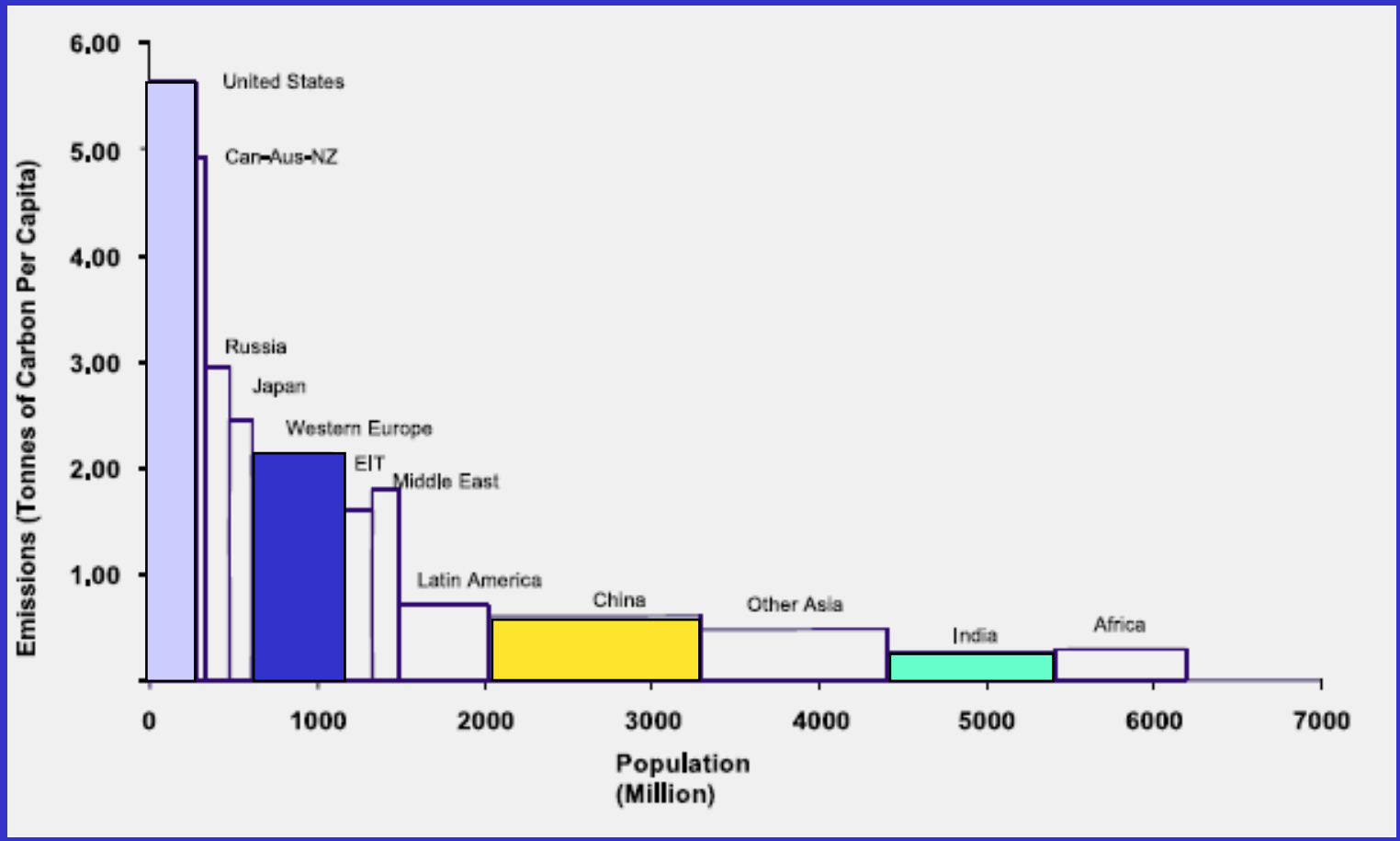


Data from Climate Monitoring and Diagnostics Lab., NOAA. Data prior to 1974 from C. Keeling, Scripps Inst. Oceanogr.

Fossil Fuel CO_2 Emissions

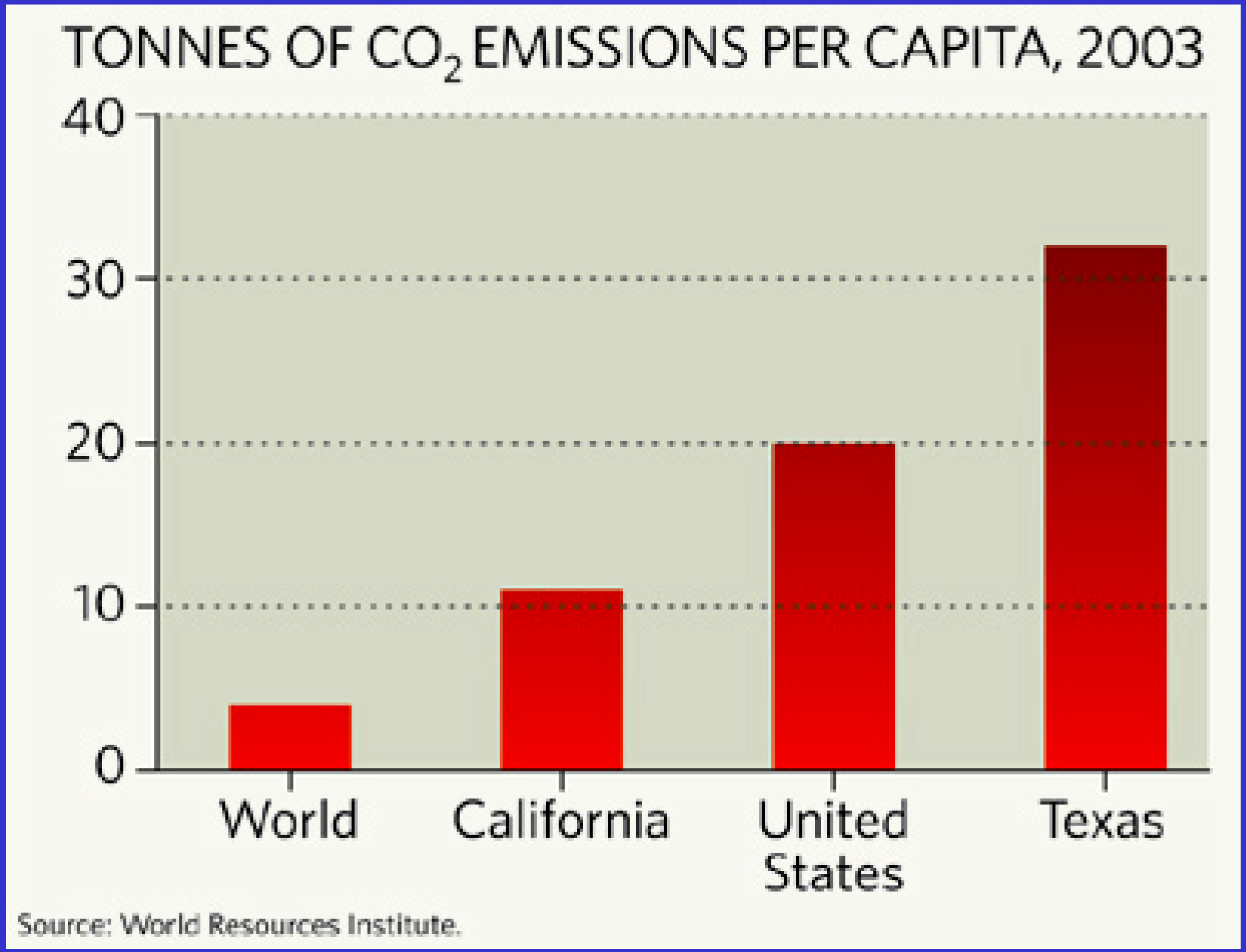
Accumulated Fossil Fuel CO_2 (1850-2004)





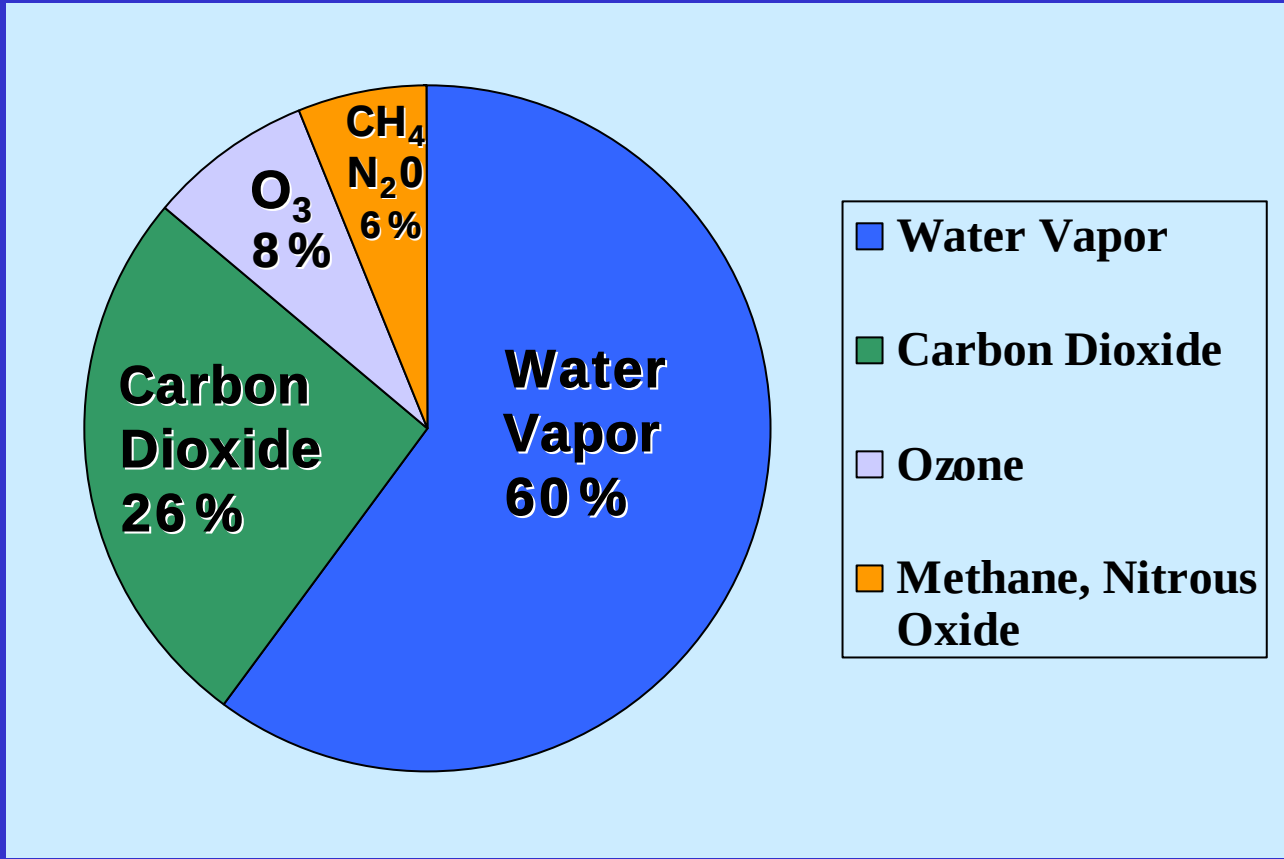
CO2 emissions in different regions in 2000 in terms of emissions per capita (height of each block); population (width of each block); and total emissions (product of population and emissions per capita = area of block).

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


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

Key issue:
What is your carbon footprint?

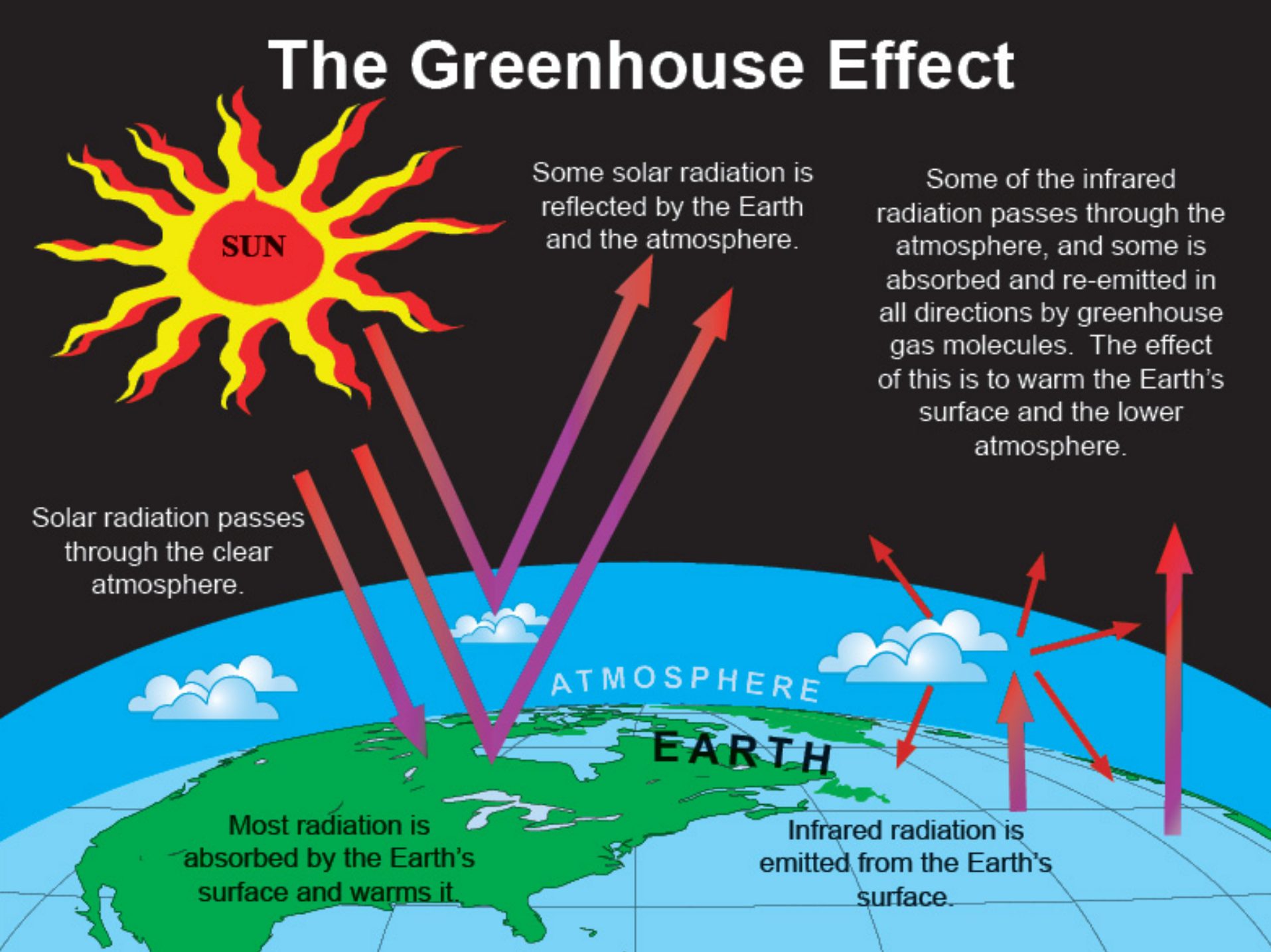
The Natural Greenhouse Effect: clear sky



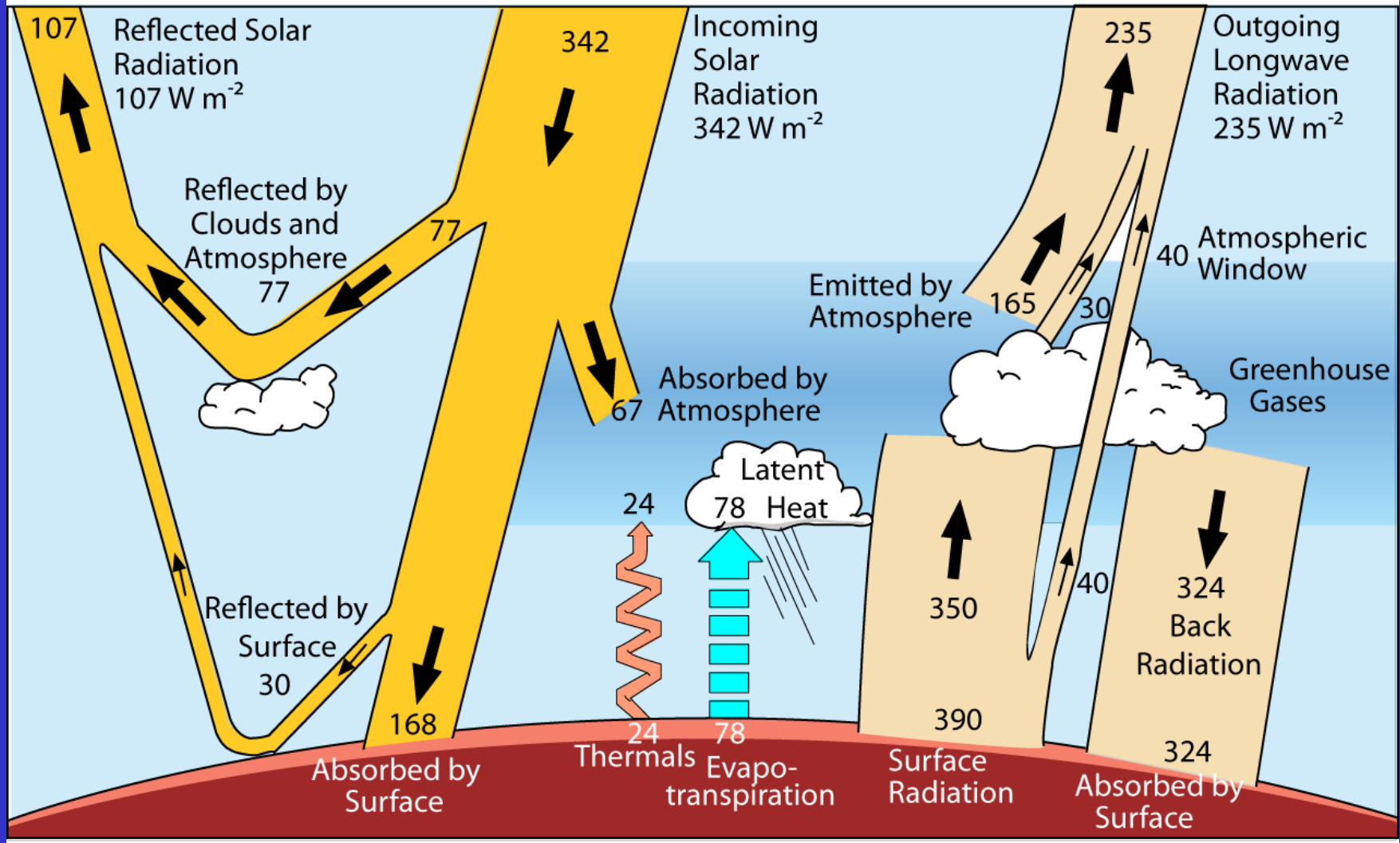
Clouds also have a greenhouse effect

Kiehl and Trenberth 1997

The Greenhouse Effect

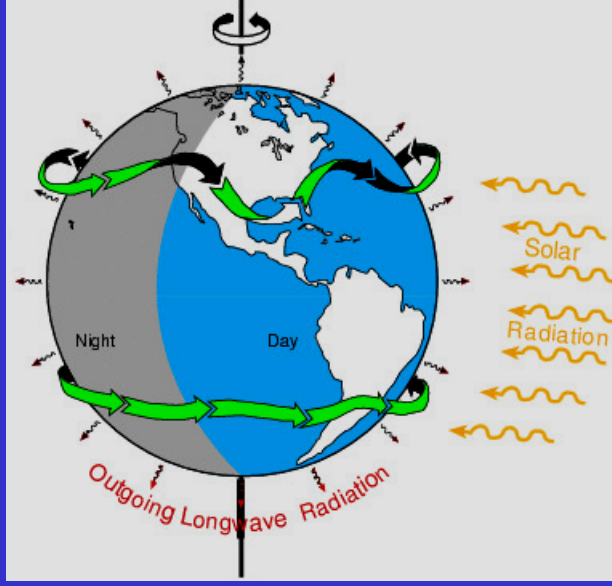


Global Heat Flows



Kiehl and Trenberth 1997

The incoming energy from the sun is 342 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:

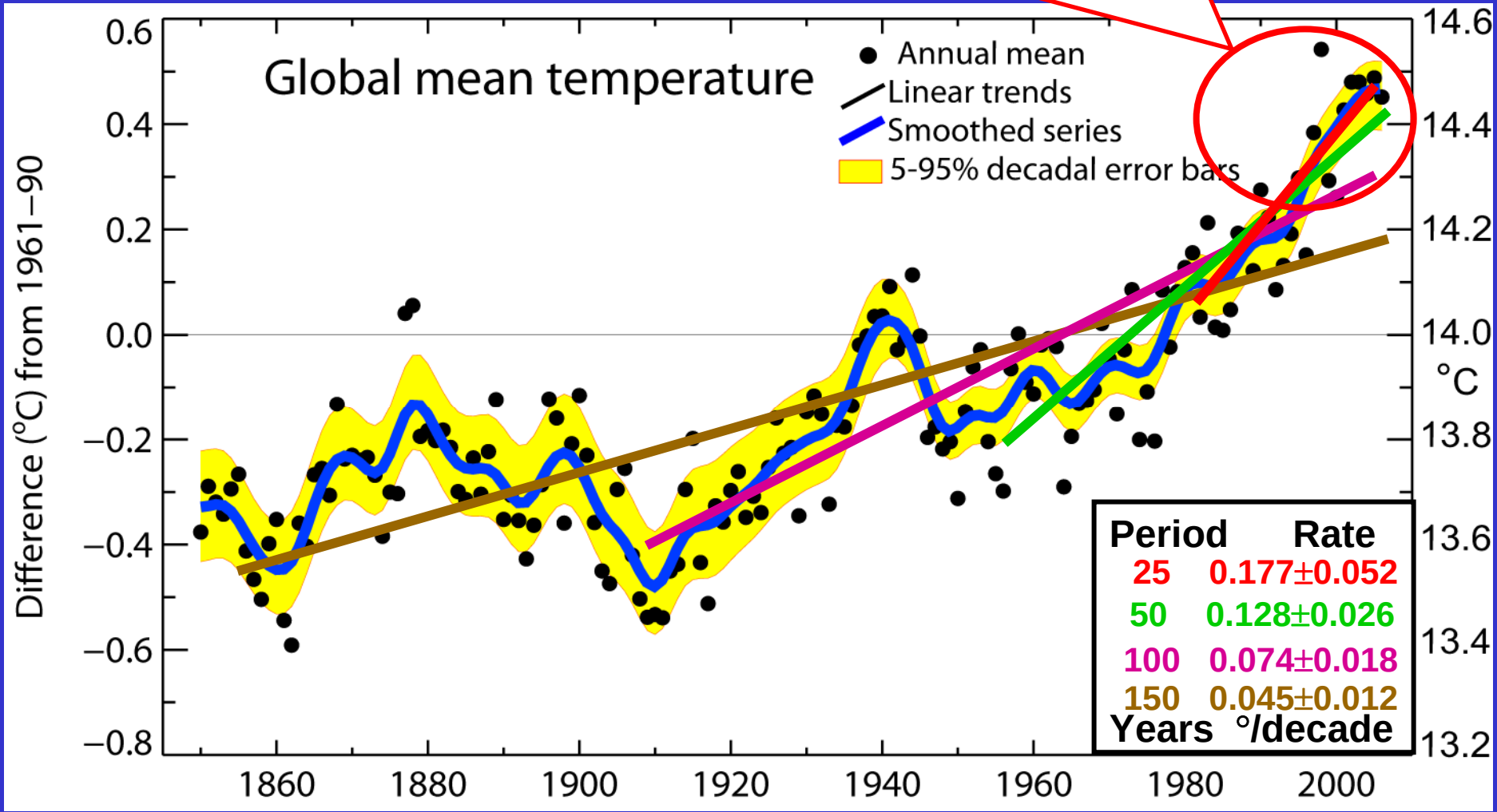
- Global surface temperatures
- Tropospheric temperatures
- Global SSTs, ocean Ts
- Global sea level
- Water vapor
- Rainfall intensity
- Precipitation extratropics
- Hurricane intensity
- Drought
- Extreme high temperatures
- Heat waves

Decrease in:

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

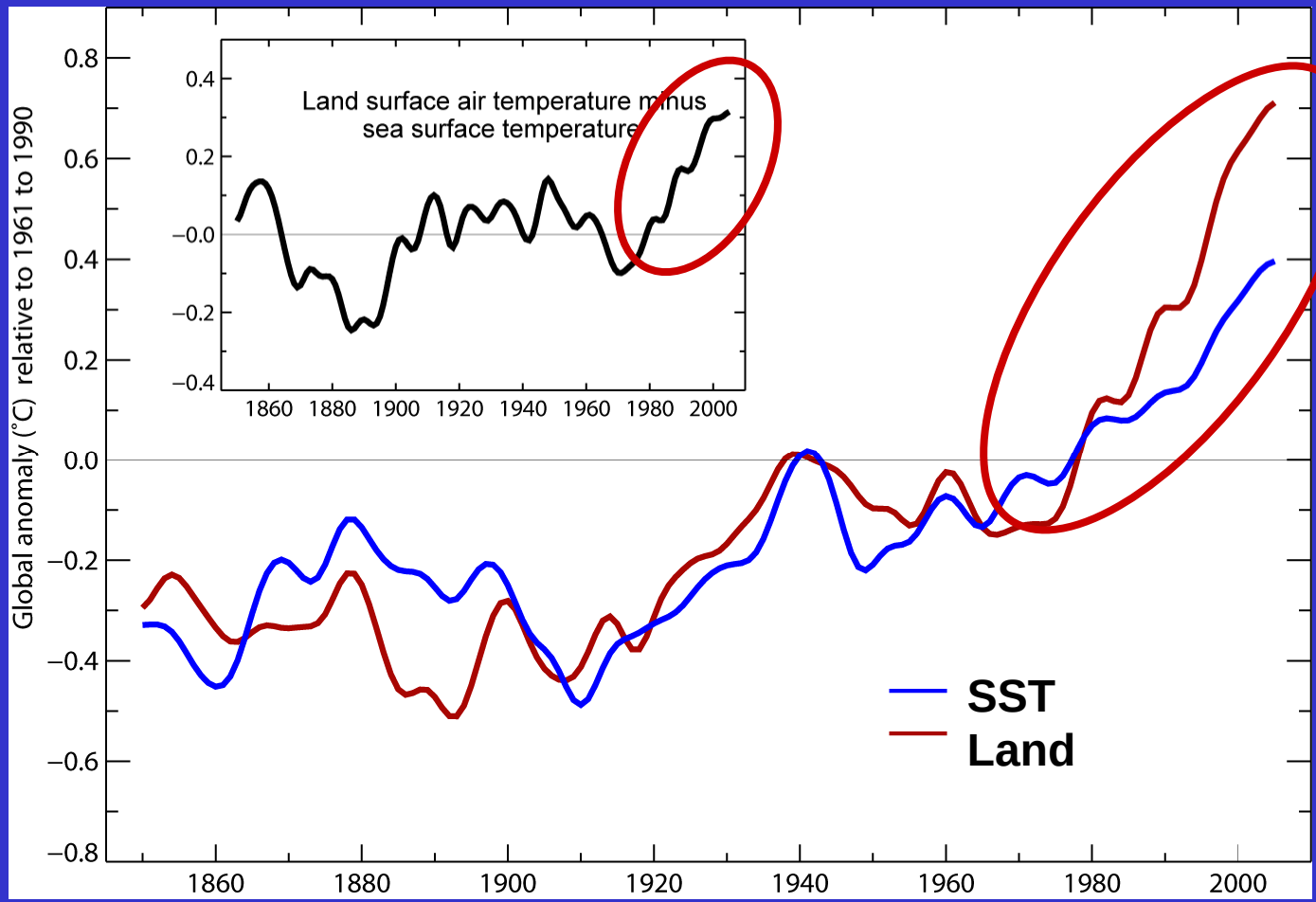
Global mean temperature

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



IPCC

Land surface temperatures are rising faster than SSTs



Annual anomalies of global average SST and land surface air temperature

IPCC

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.

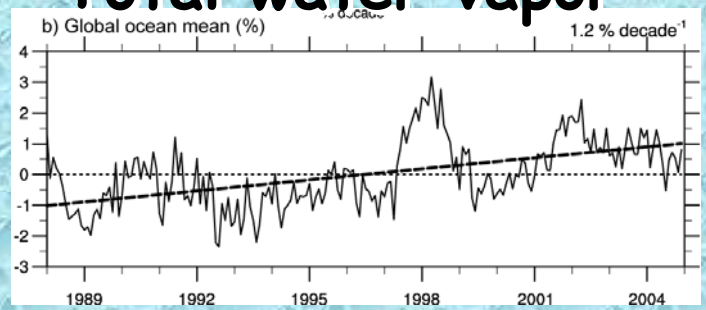
Air holds more water vapor at higher temperatures

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

Observations show that this is happening at the surface and in lower atmosphere: 0.6°C since 1970 over global oceans and 4% more water vapor.

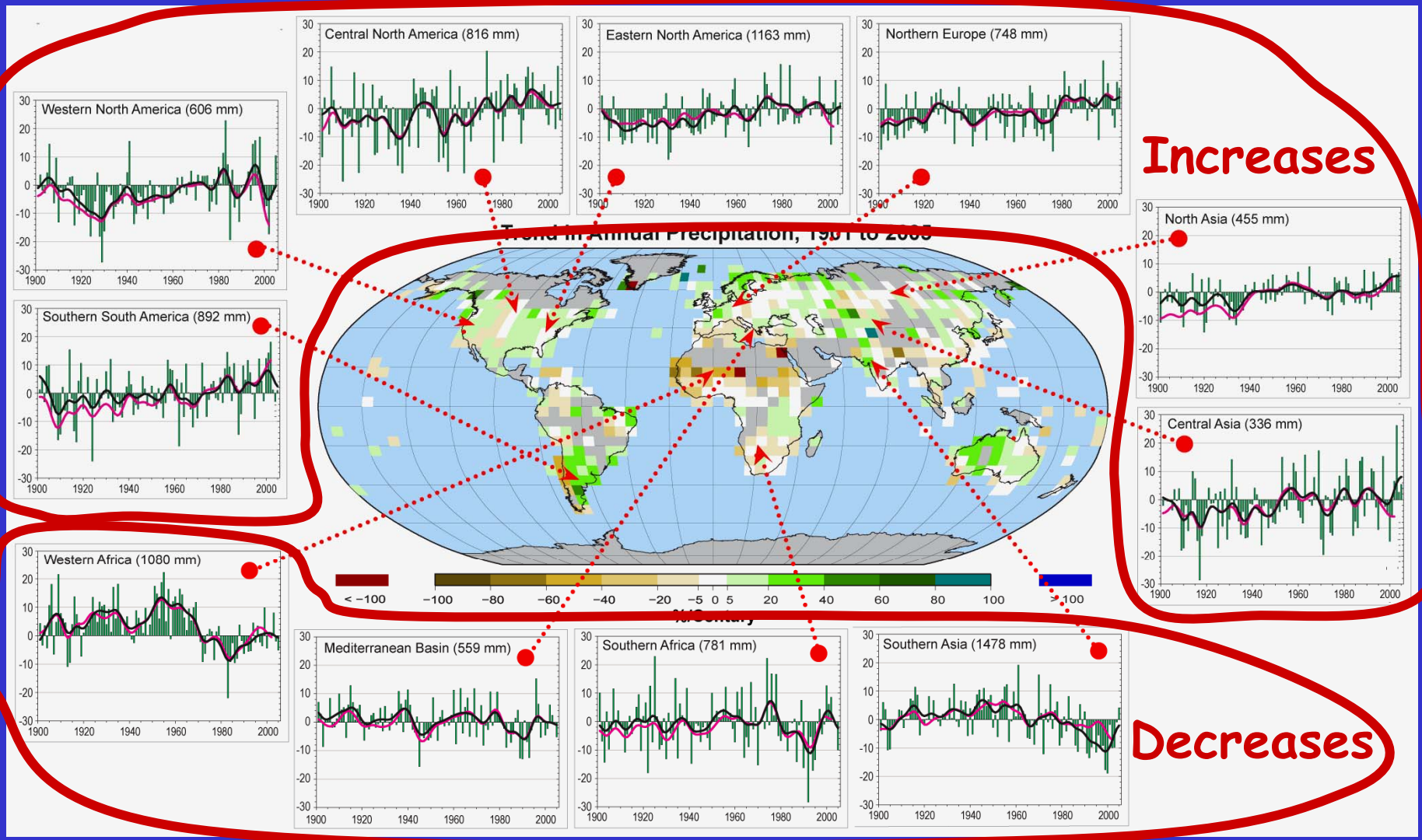
This means more moisture available for storms and an enhanced greenhouse effect.

Total water vapor



IPCC

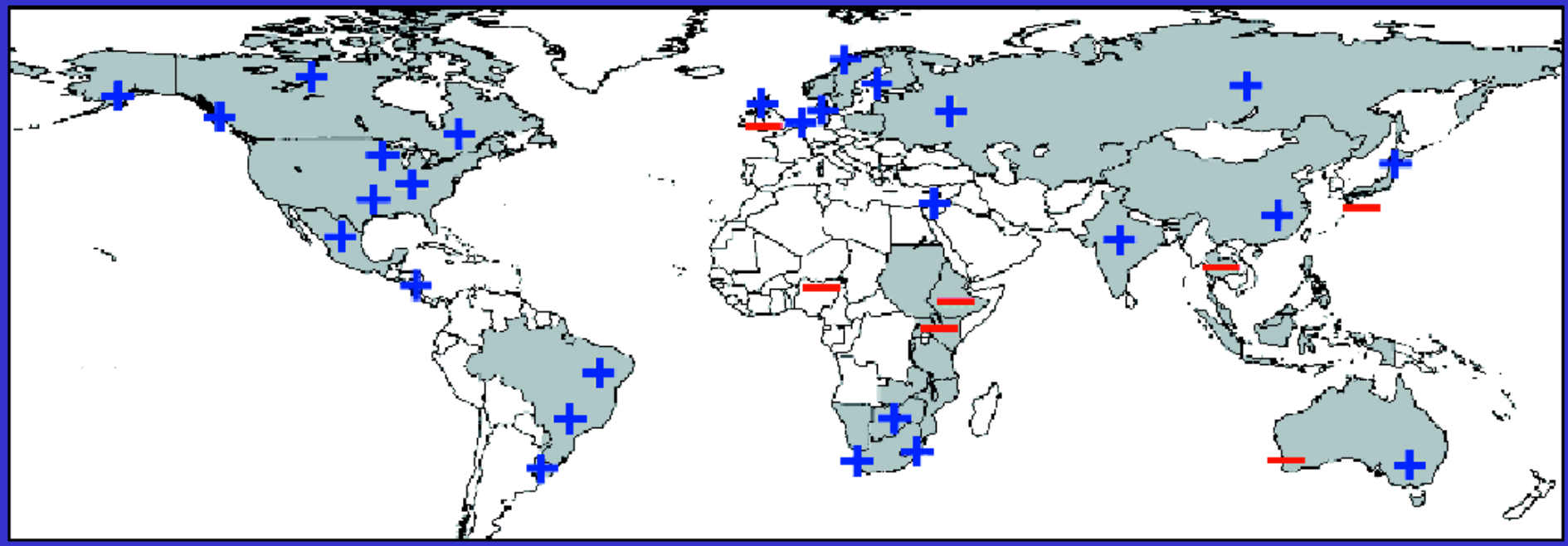
Land precipitation is changing significantly over broad areas



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

IPCC

Proportion of heavy rainfalls: increasing in most land areas



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

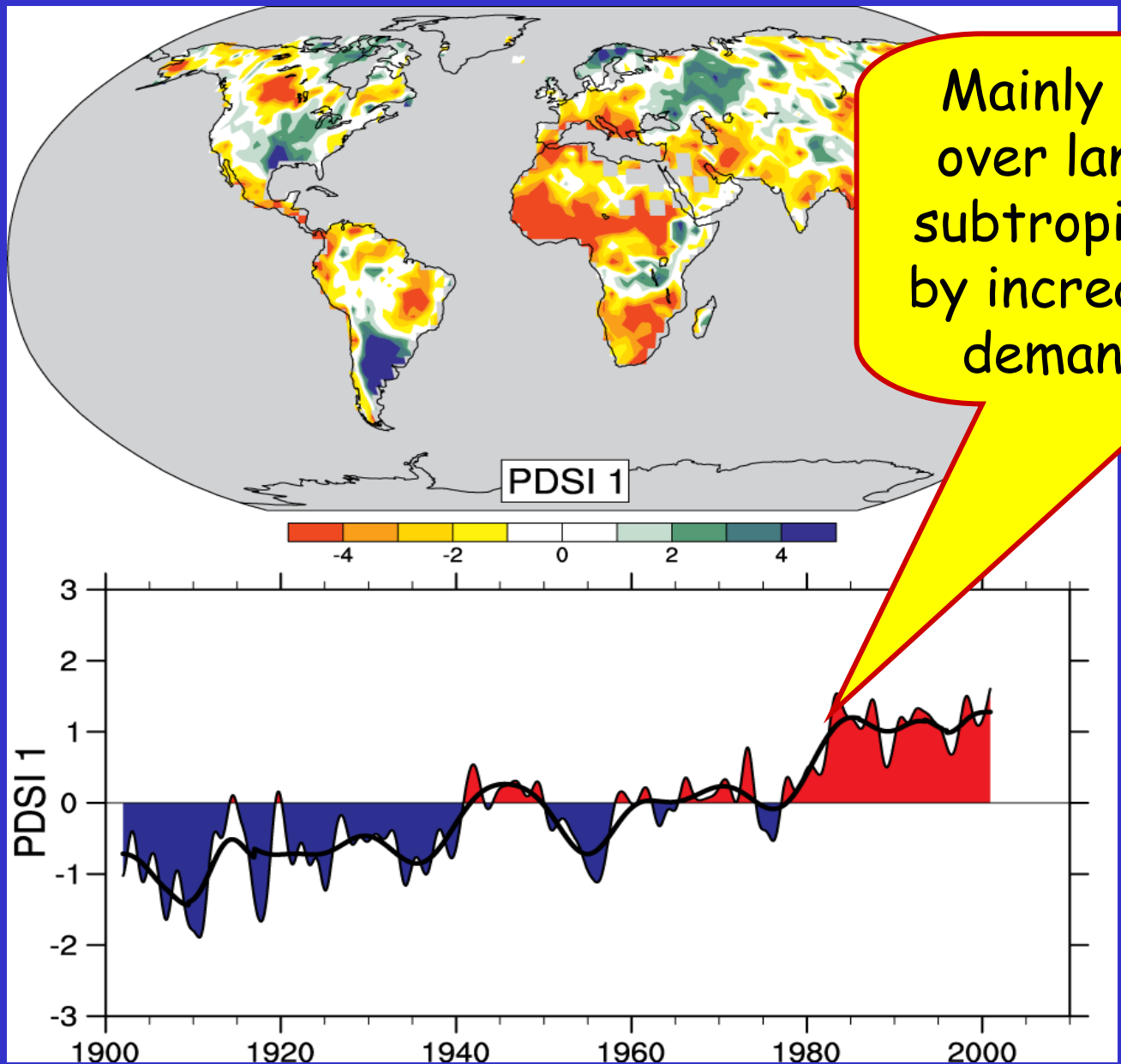
IPCC

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 is increasing most places

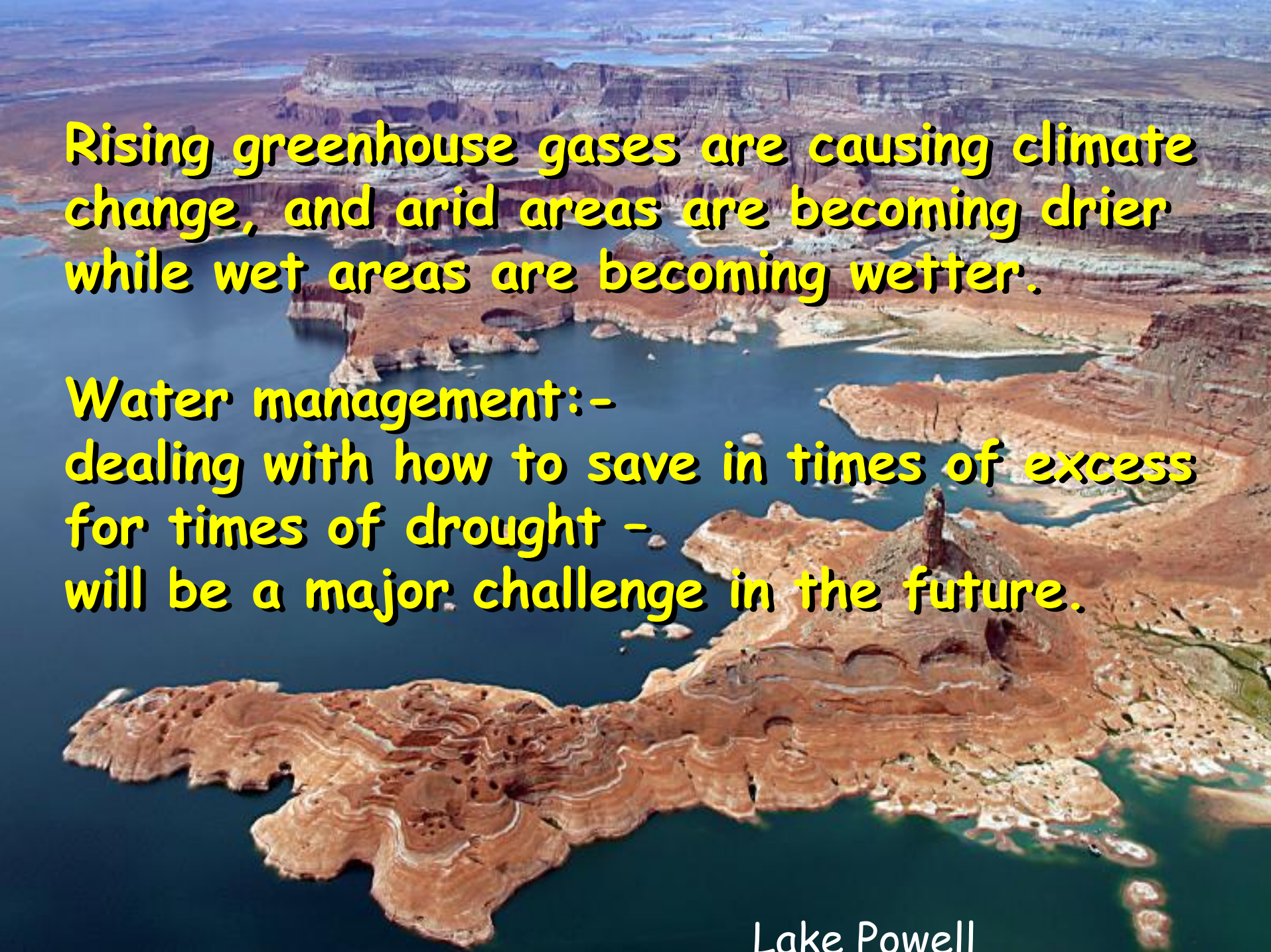


Mainly decrease in rain over land in tropics and subtropics, but enhanced by increased atmospheric demand with warming

Severity Index (PDSI) for 1900 to 2002.

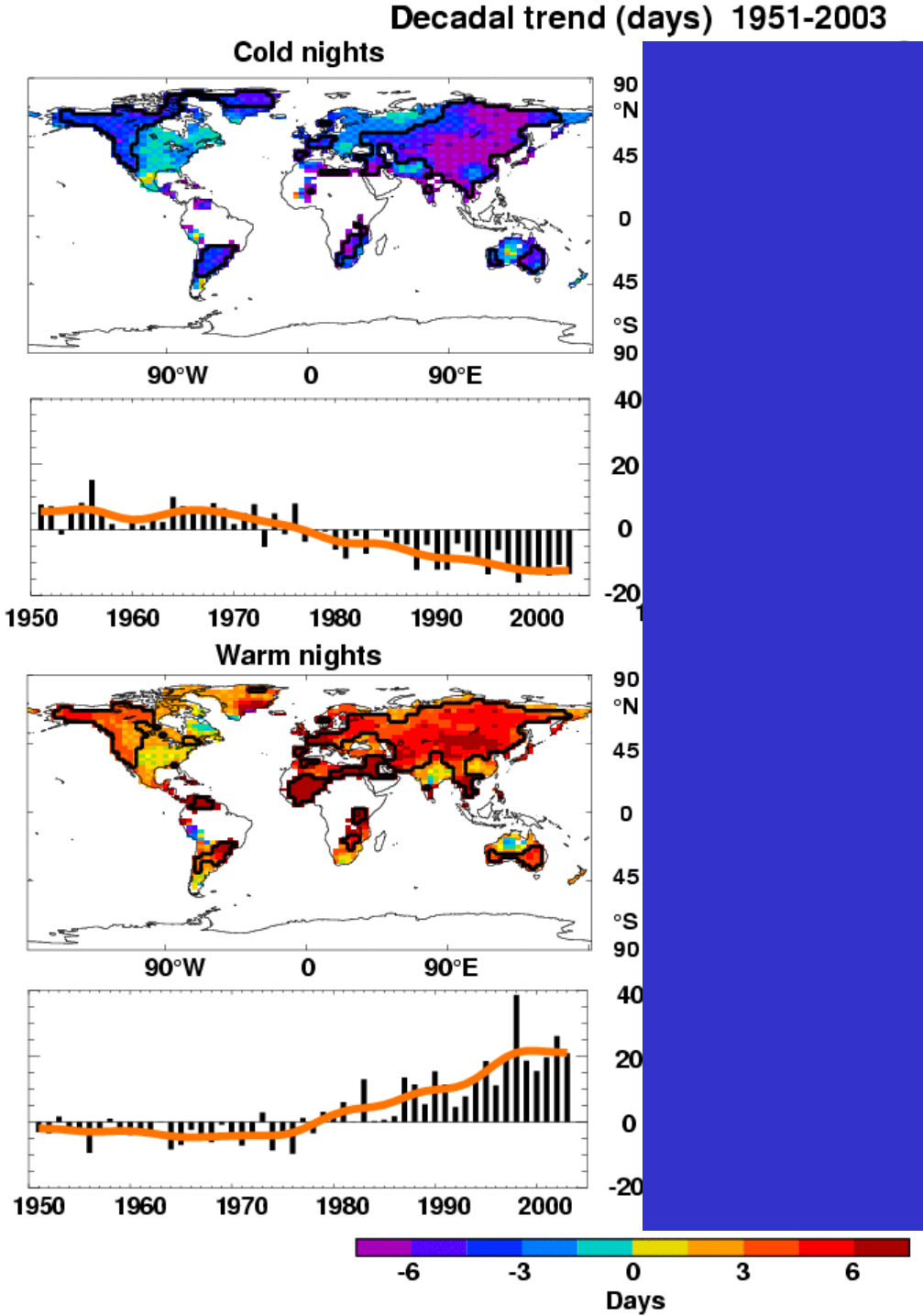
The time series (below) accounts for most of the trend in PDSI.

IPCC


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.
Lake Powell

Heat waves and wild fires

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



Extremes of temperature are changing!

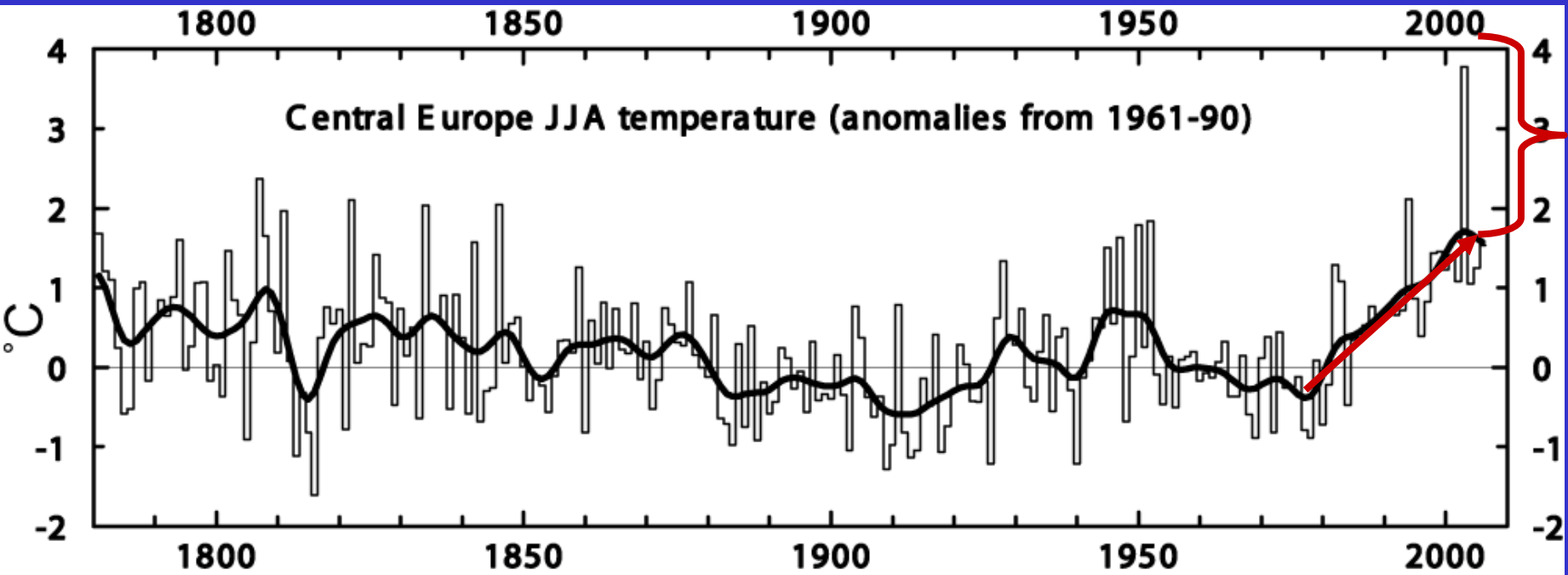
Observed trends (days) per decade for 1951 to 2003:

5th or 95th percentiles

From Alexander et al. (2006)

IPCC

Heat waves are increasing: an example



Extreme Heat Wave
Summer 2003
Europe
30,000 deaths

Trend plus variability?

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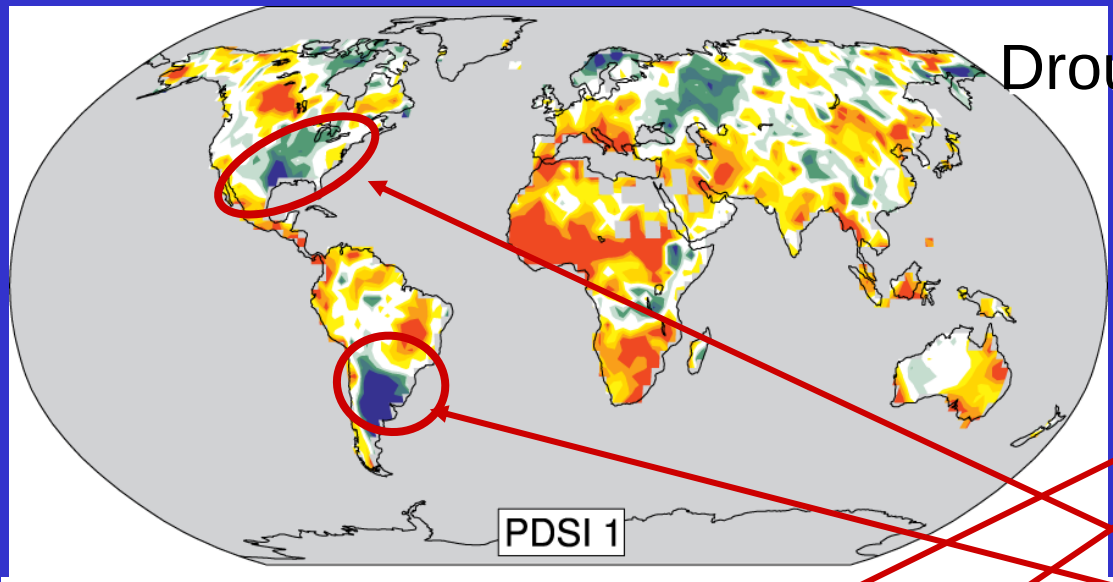
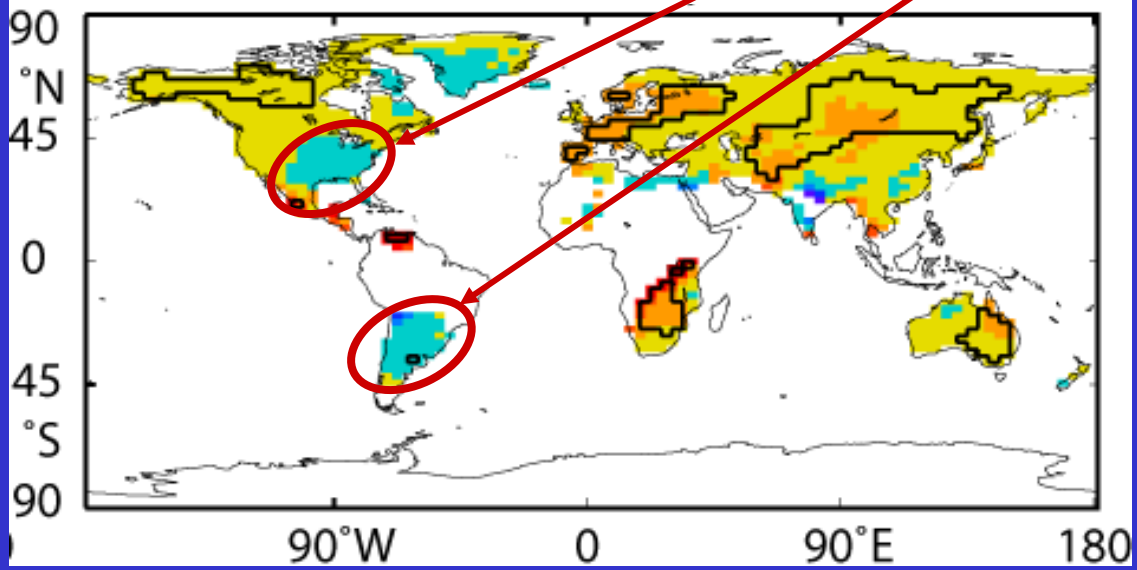
Increases in rainfall and cloud counter warming



Trend in Warm Days 1951-2003



Absence of warming by day coincides with wetter and cloudier conditions

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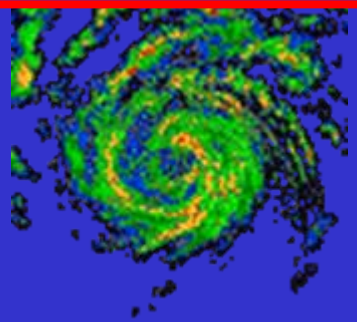
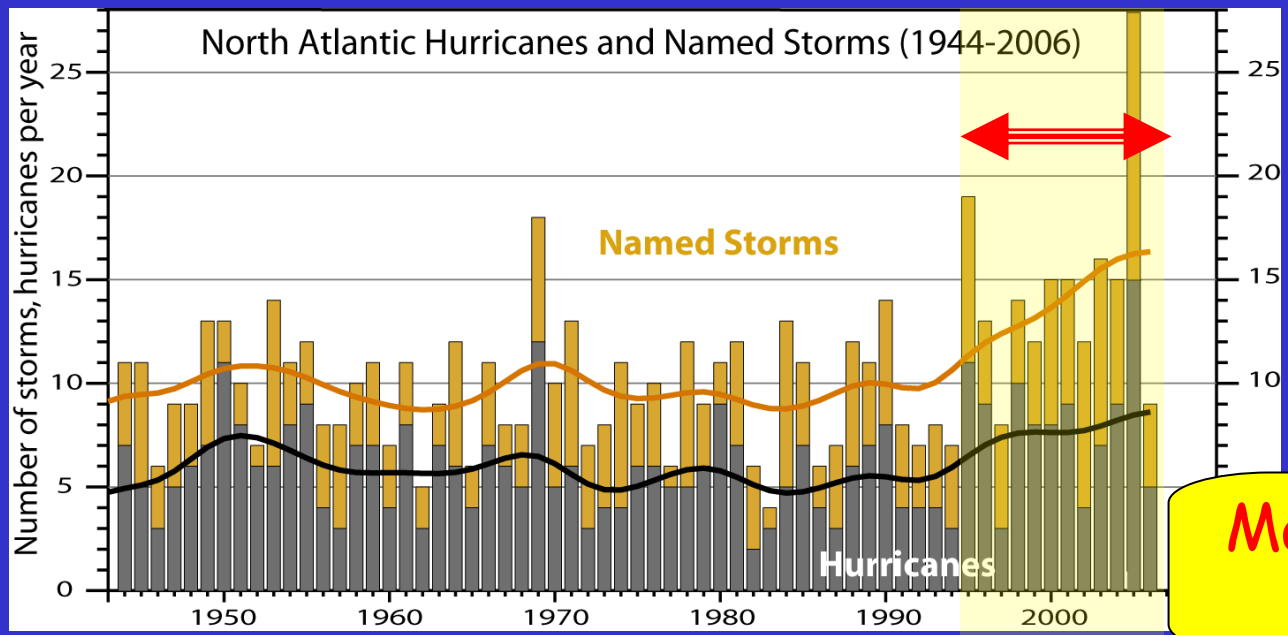
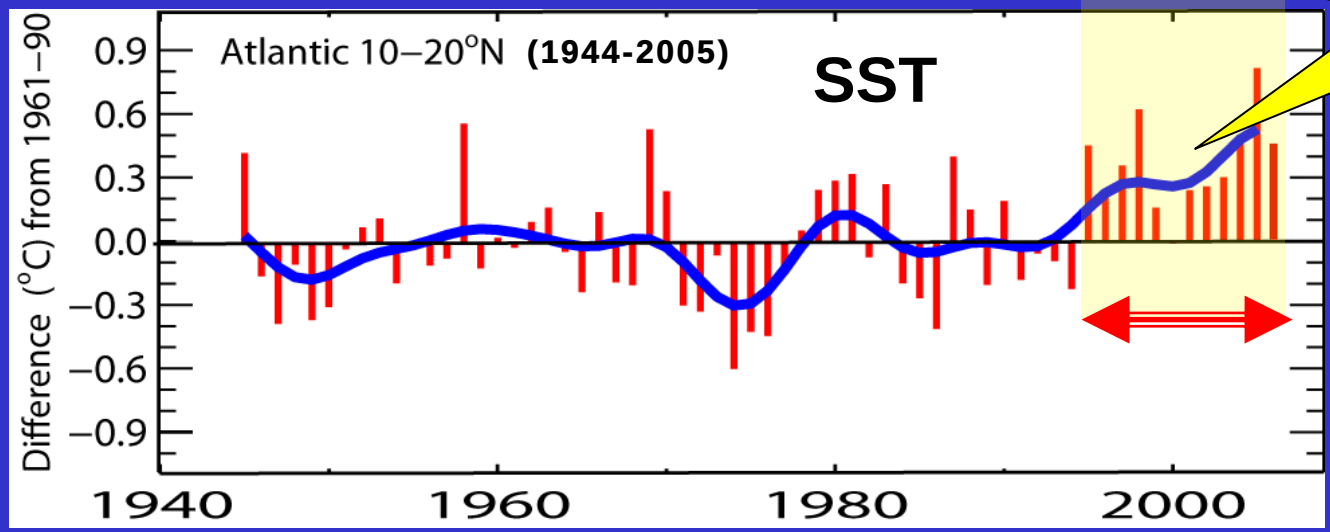
North Atlantic hurricanes have increased with SSTs







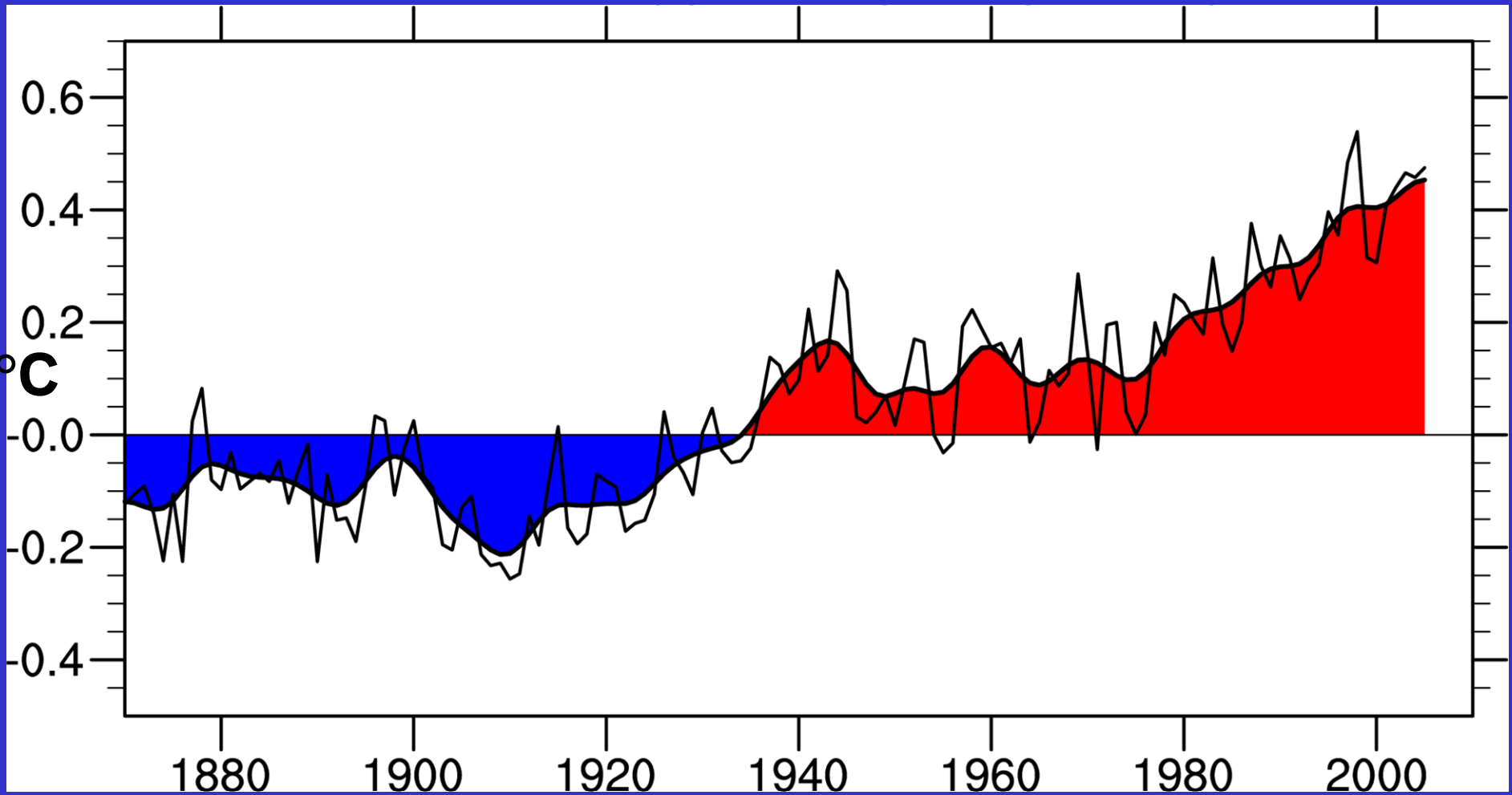
N. Atlantic hurricane record best

Marked increase after 1994

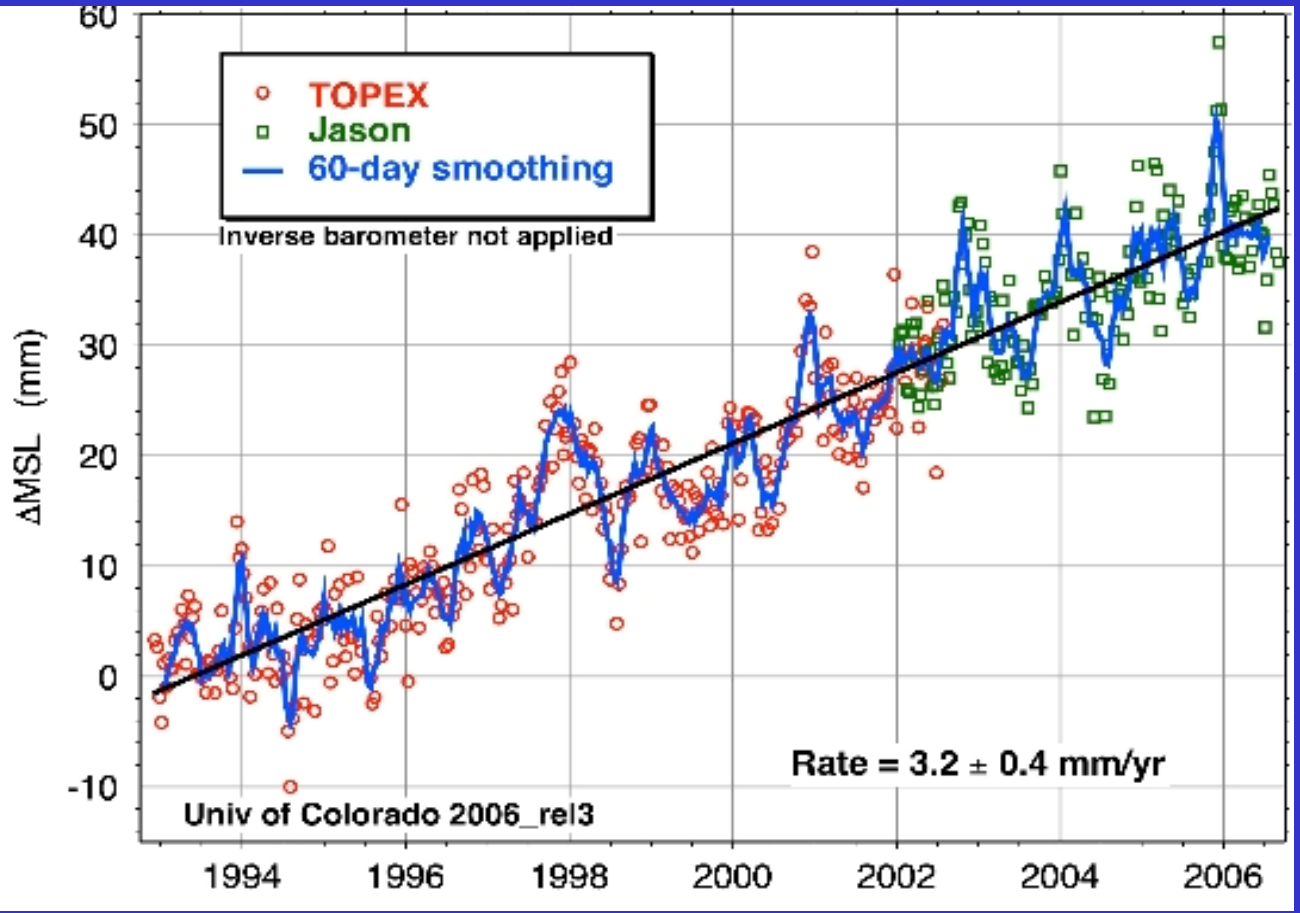
Global number and percentage of intense hurricanes is increasing

IPCC

Global SSTs are increasing: base period 1901-70



Sea level is rising:
from ocean expansion and melting glaciers



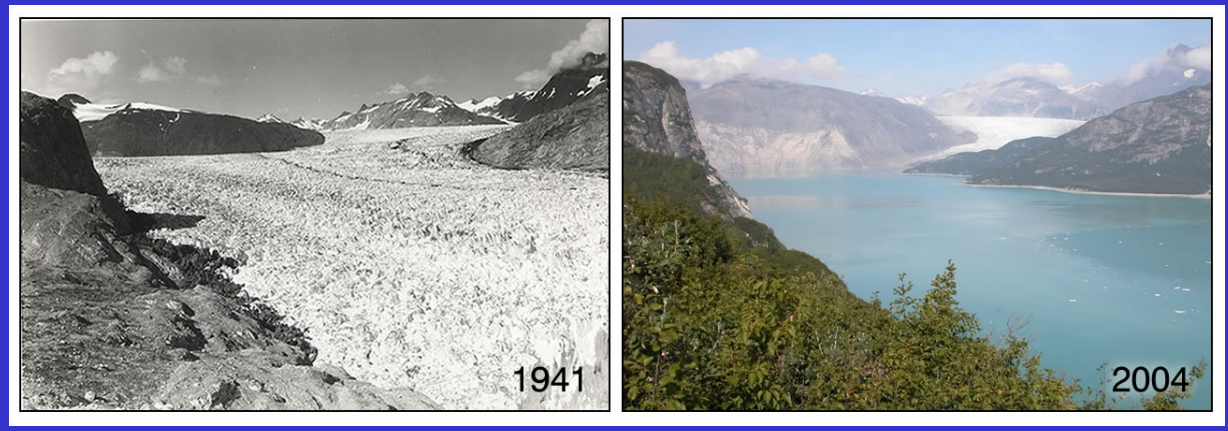
Since 1993 Global sea level has risen 43 mm (1.7 inches)

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

Steve Nerem

Evidence for reality of climate change

Glaciers melting

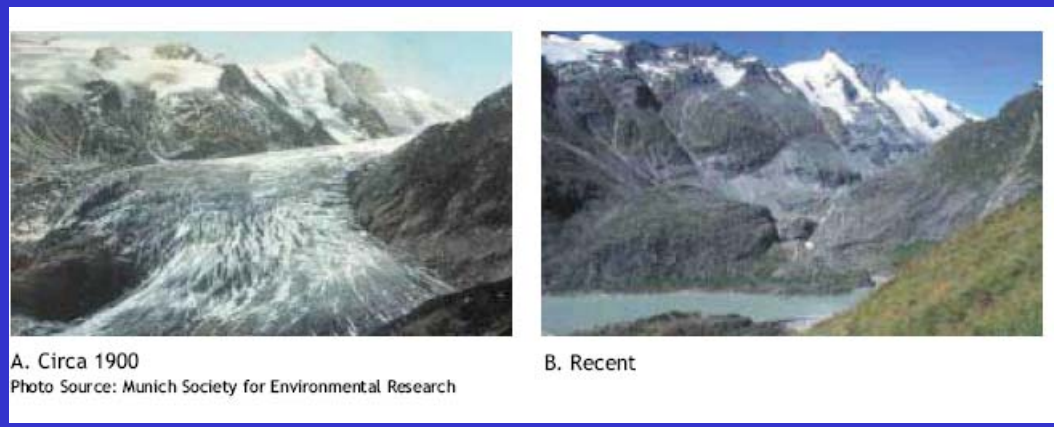


Muir Glacier, Alaska

1909

Toboggan Glacier Alaska

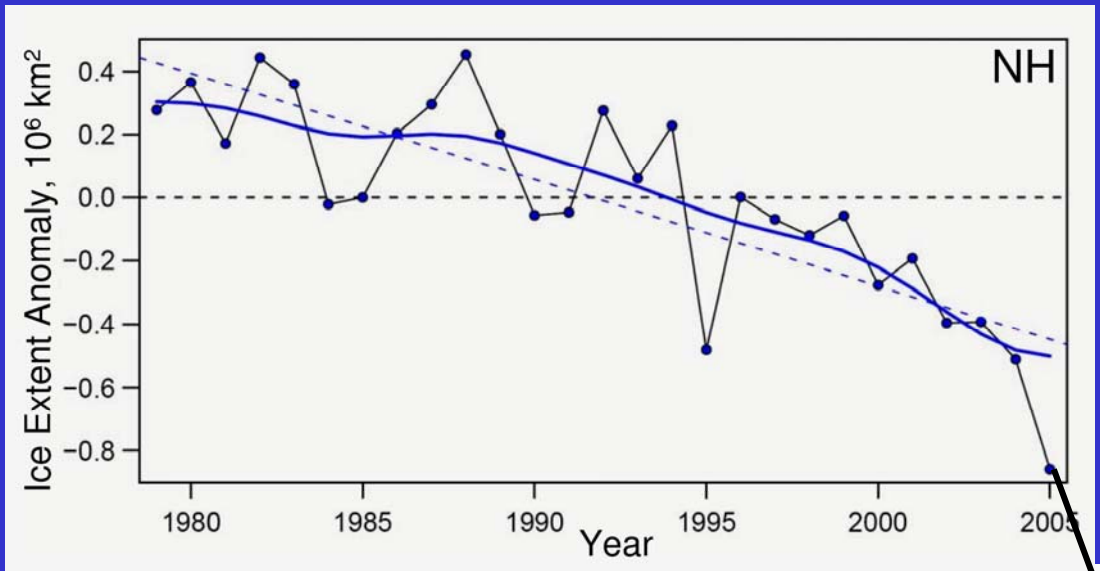
2000

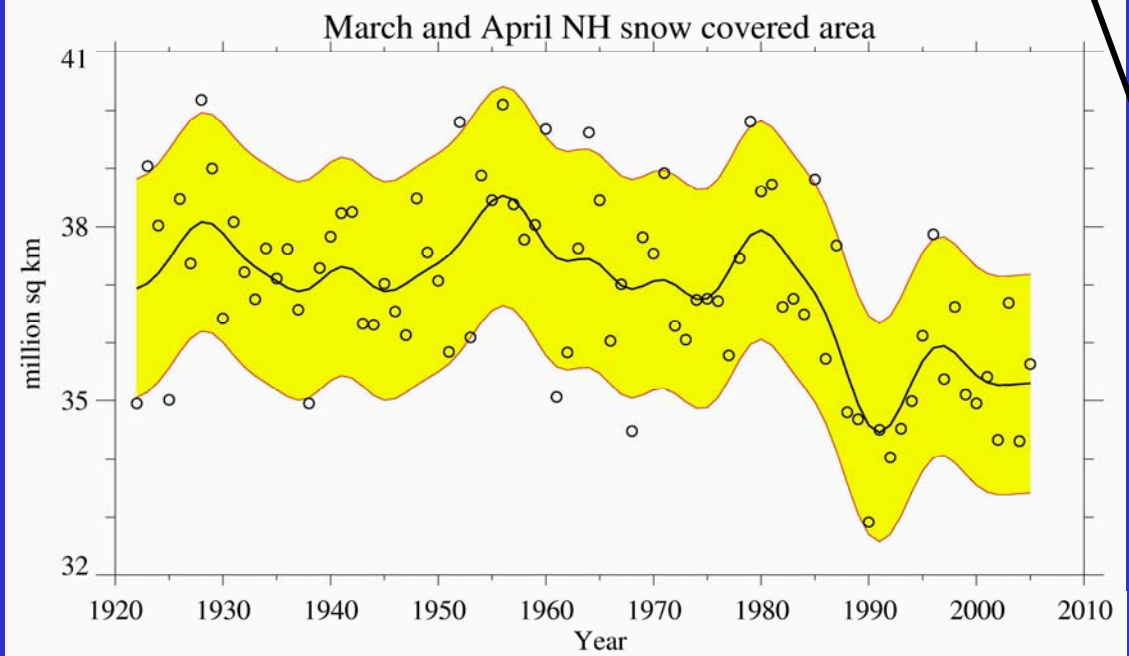


1900 2003

Alpine glacier, Austria

Snow cover and Arctic sea ice are decreasing





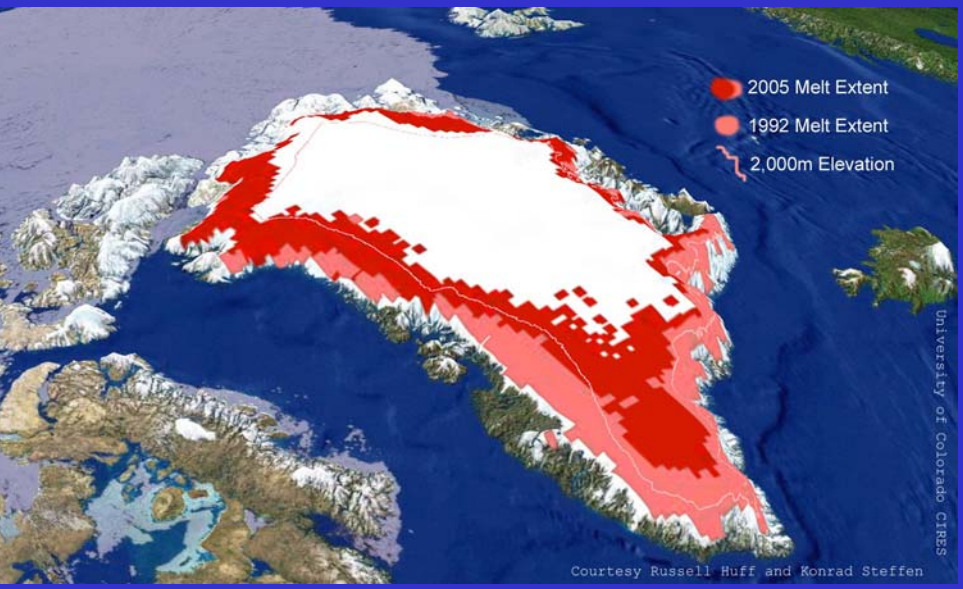
Arctic sea ice area decreased by 2.7% per decade (Summer: -7.4%/decade)

2007: 22% (10^6 km^2) lower than 2005

Spring snow cover shows 5% stepwise drop during 1980s

IPCC

Surface melt on Greenland

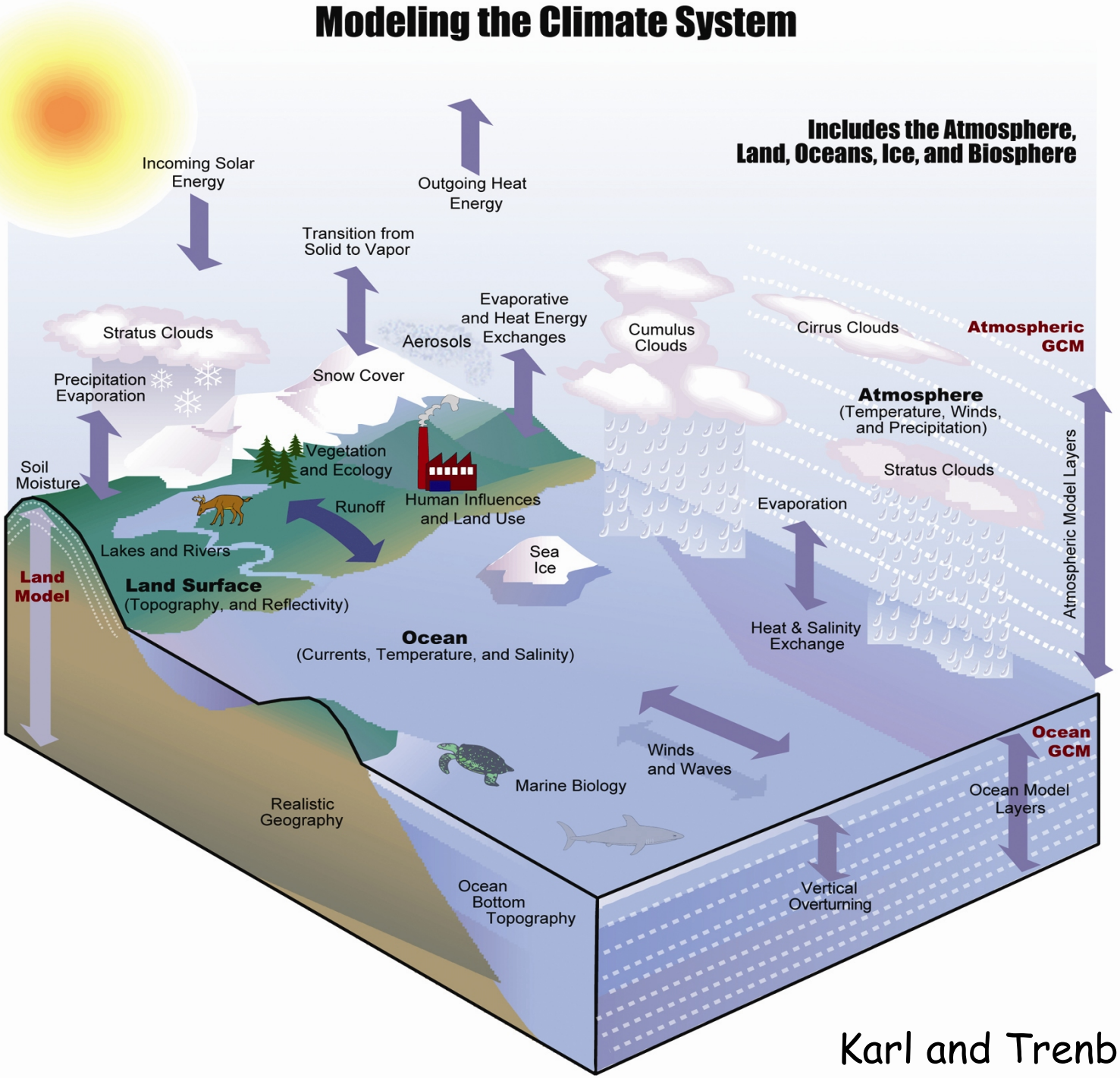


Increasing melt zones.

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

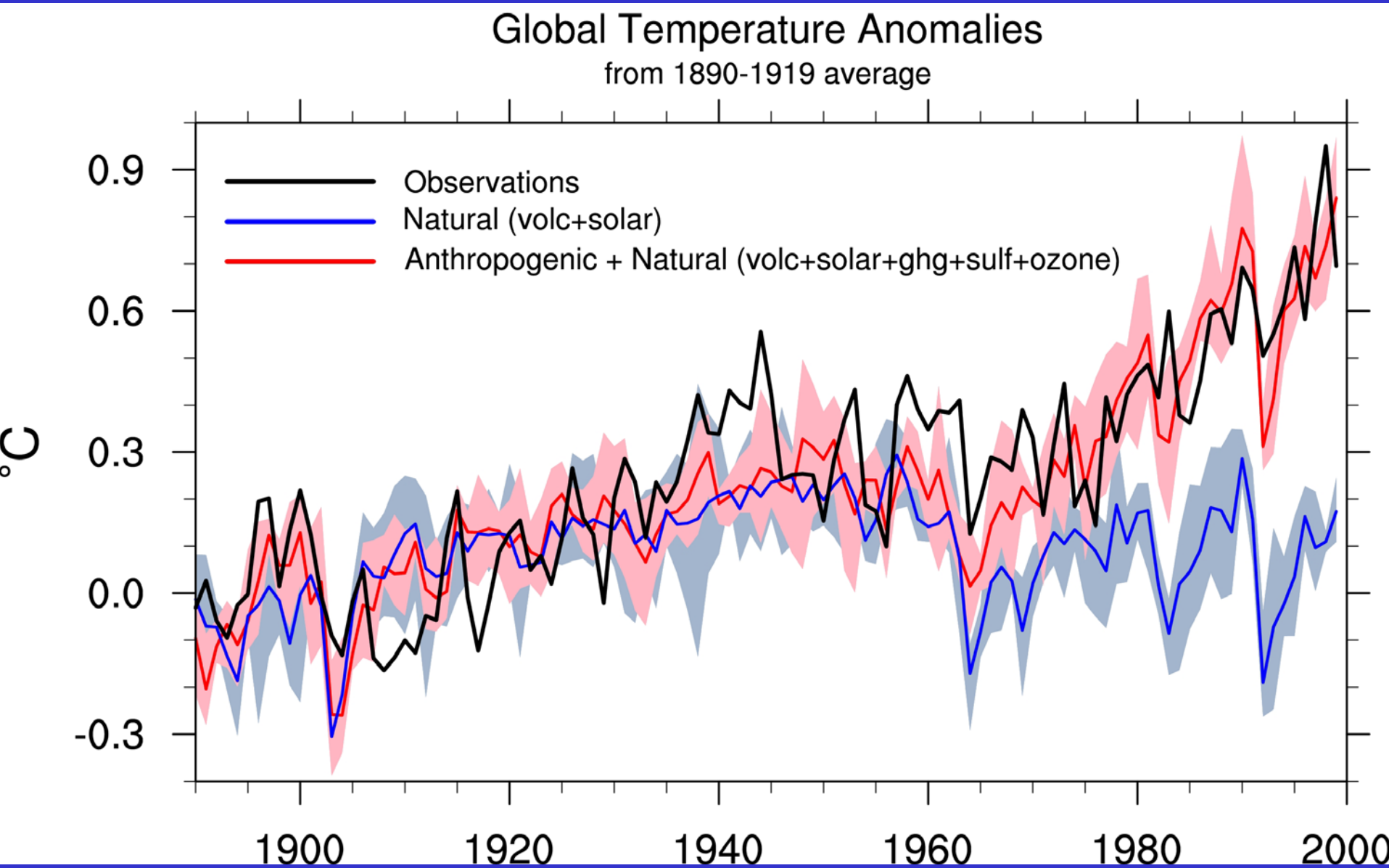
NSIDC (above)
Braithwaite: Univ. Manchester

Modeling the Climate System

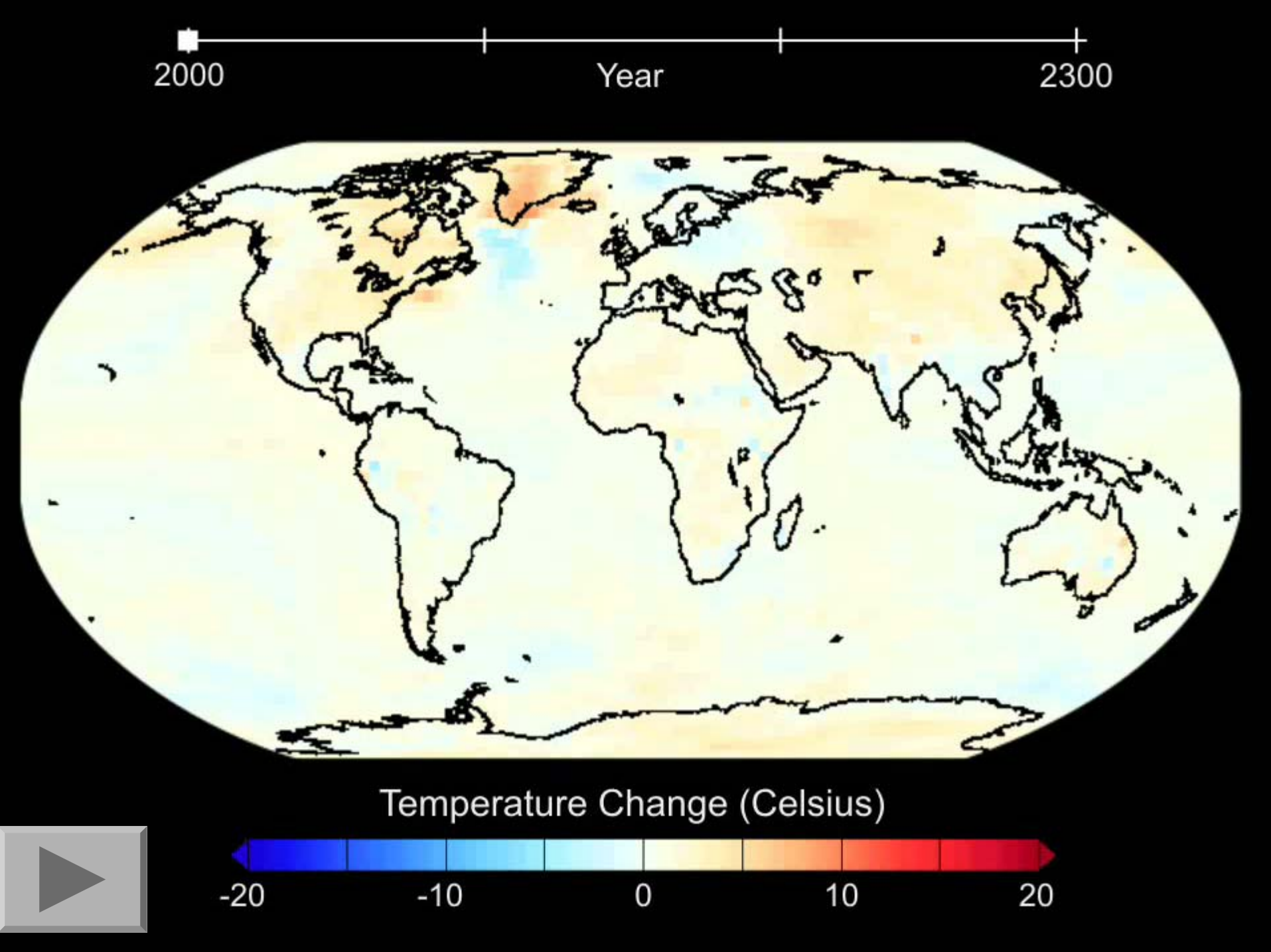


Karl and Trenberth 2003

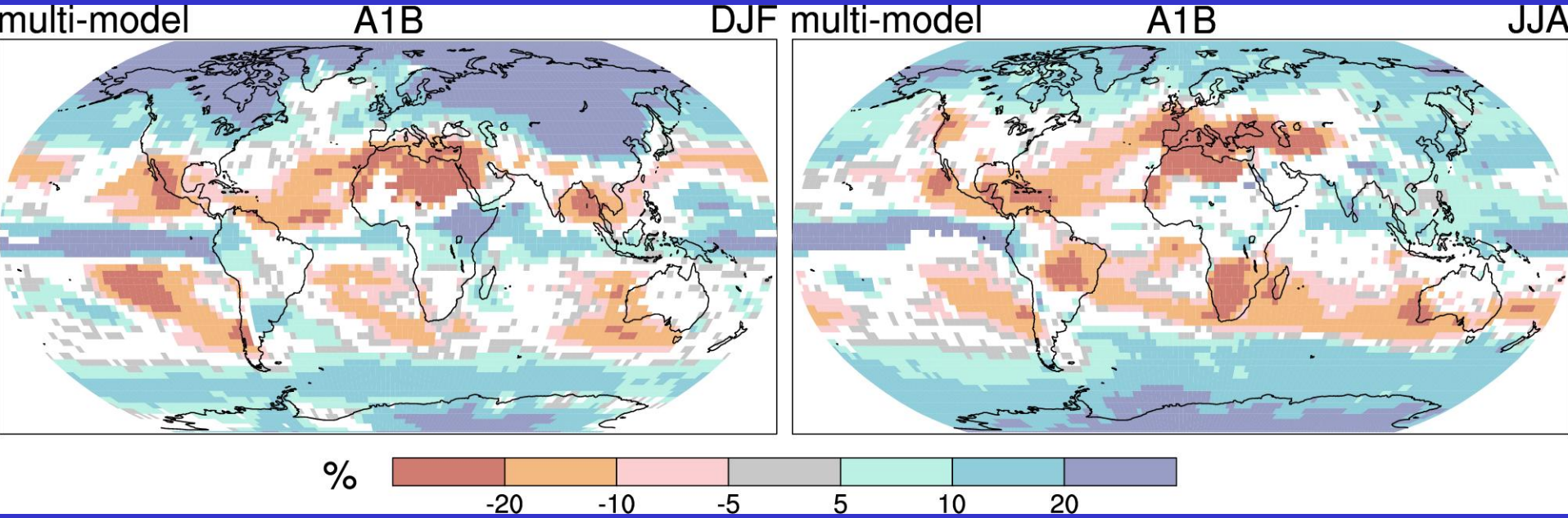
Natural forcings do not account for observed 20th century warming after 1970



Meehl et al, 2004: J. Climate.


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

Projected Patterns of Precipitation Change 2090-2100



Precipitation increases very likely in high latitudes

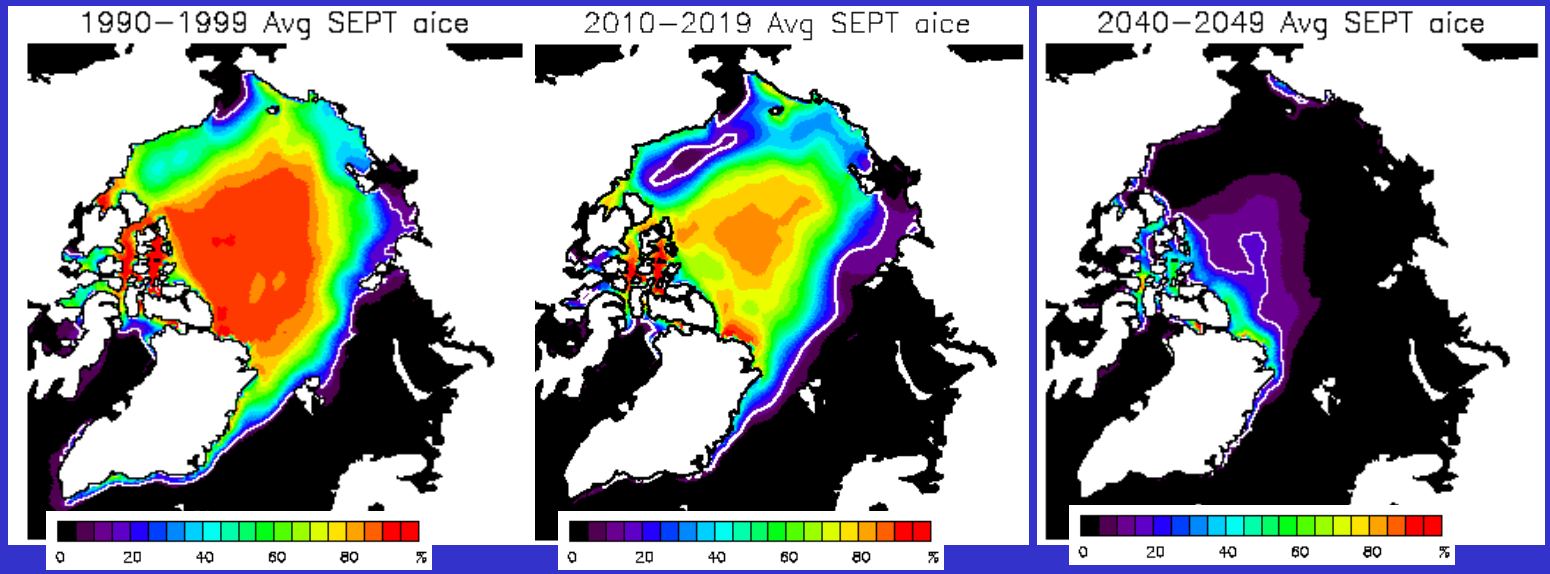
Decreases likely in most subtropical land regions

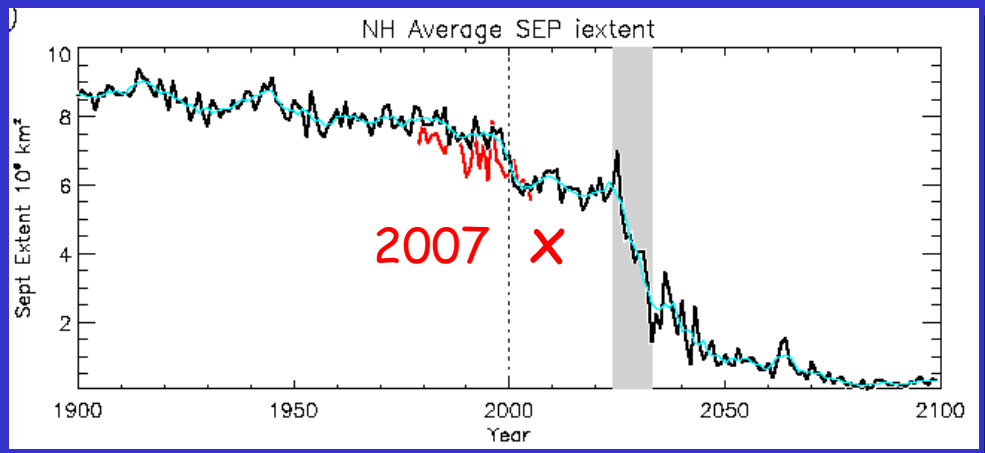
This continues the observed patterns in recent trends

Arctic sea ice disappears in summer by 2050

Already 2007 lowest on record by 22%

Abrupt Transitions in Summer Sea Ice



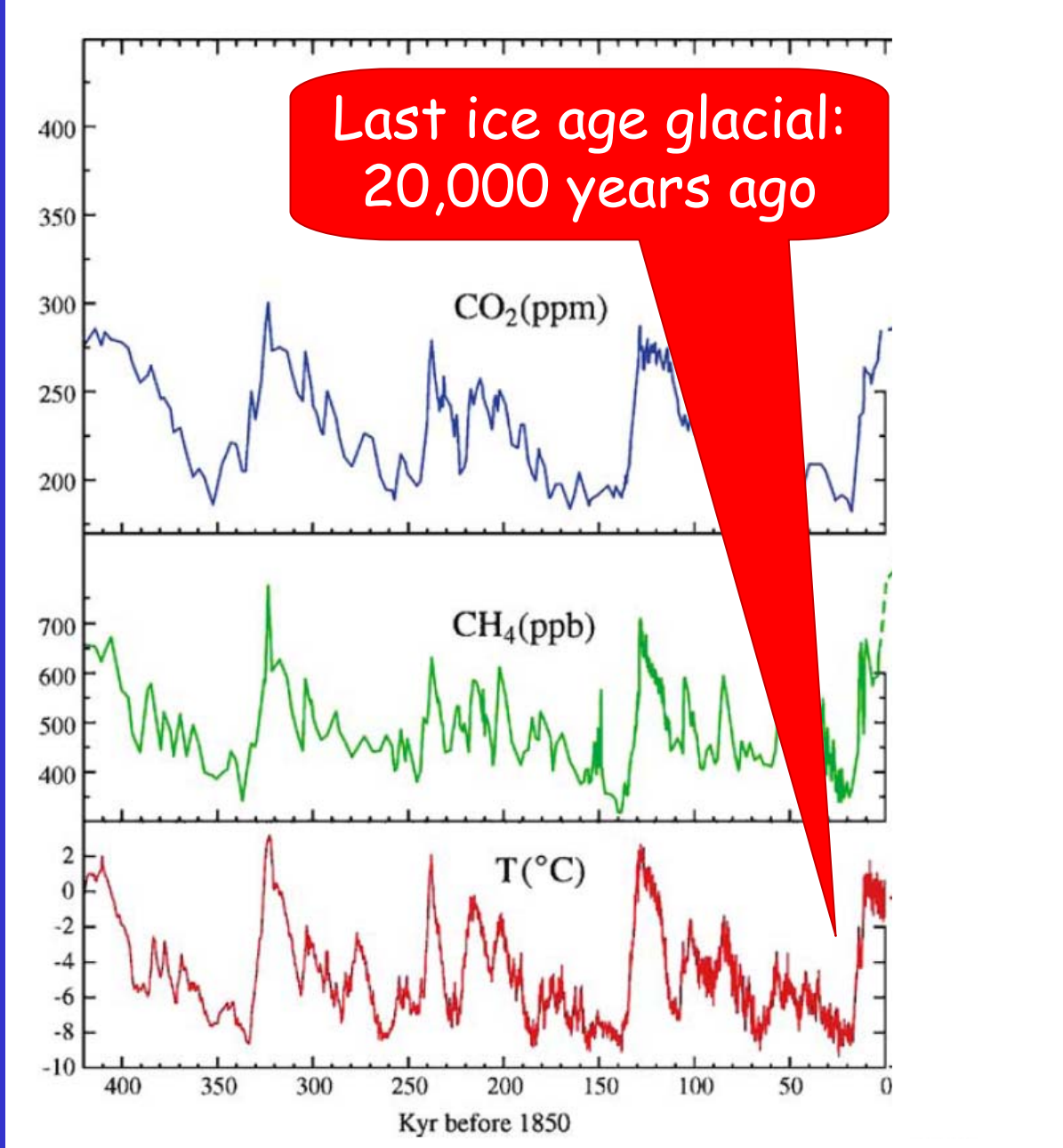


- Gradual forcing results in abrupt Sept ice decrease
- Extent decreases from 80 to 20% coverage in 10 years.
- Relevant factors:
  - Ice thinning
  - Arctic heat transport
  - Albedo feedback

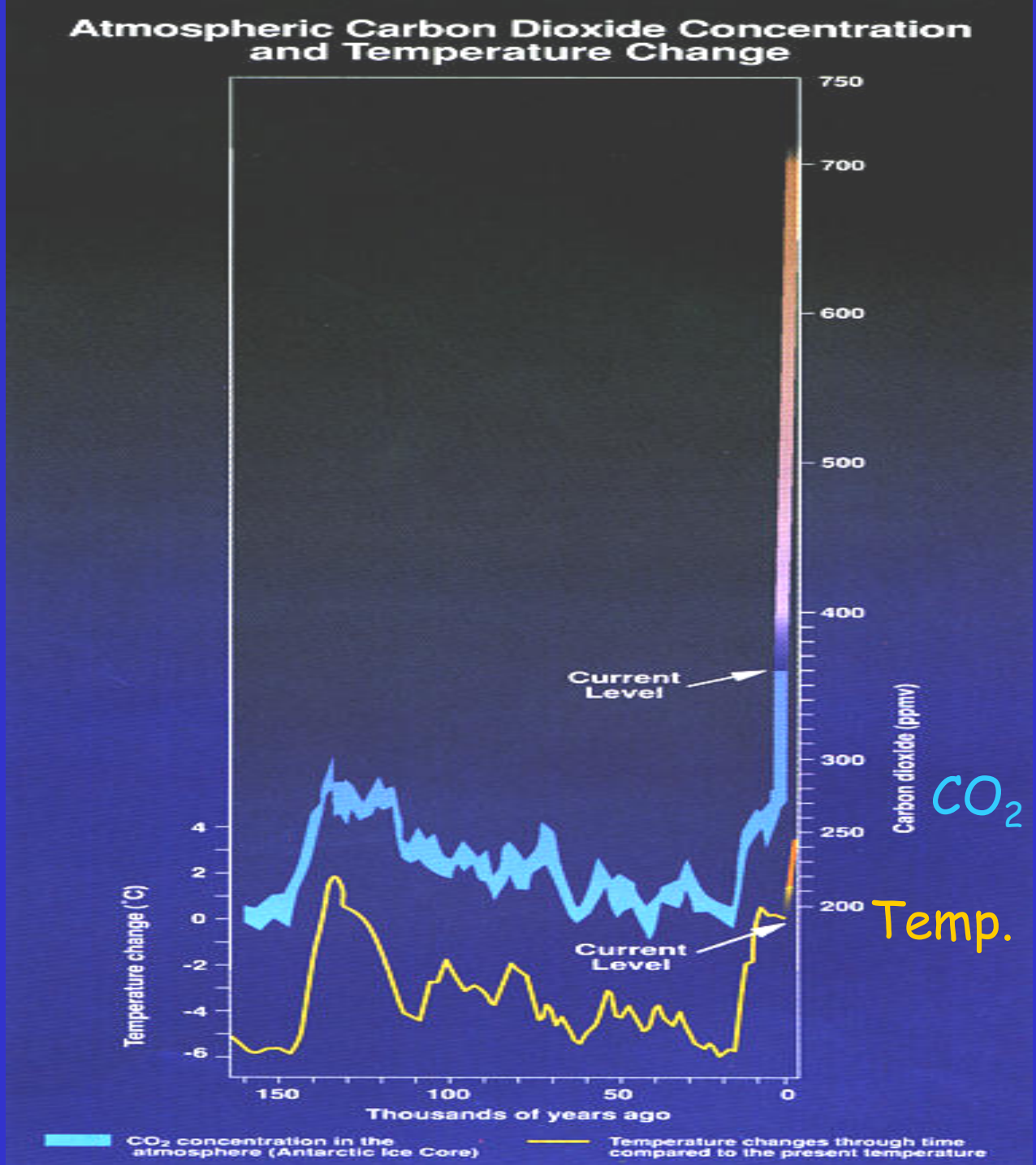
Holland et al., GRL, 2006

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.

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 (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6)
- Provisions for "flexible" market mechanisms: international trading system, credits, etc.
- 175 countries have ratified
- Protocol was ratified; took effect Feb 16, 2005.
- US withdrew in 2001. In 2004 US emissions were 16% (20%) over 1990 levels for GHG (CO_2).

What about a carbon tax?

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.

Cap and Trade: 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.

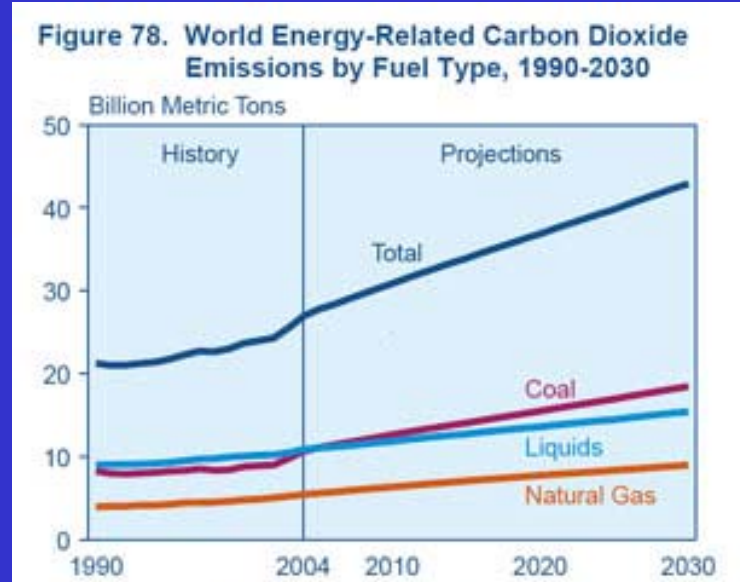
Recent trends: May 2007

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 (560 new plants from 2002 to 2006 and 113 GigaWatts of coal fired power). (200 MW each)

Far from decreasing carbon dioxide emissions, the trend is much worse than "business as usual" and higher than A1FI.

Raupach et al 2007 PNAS

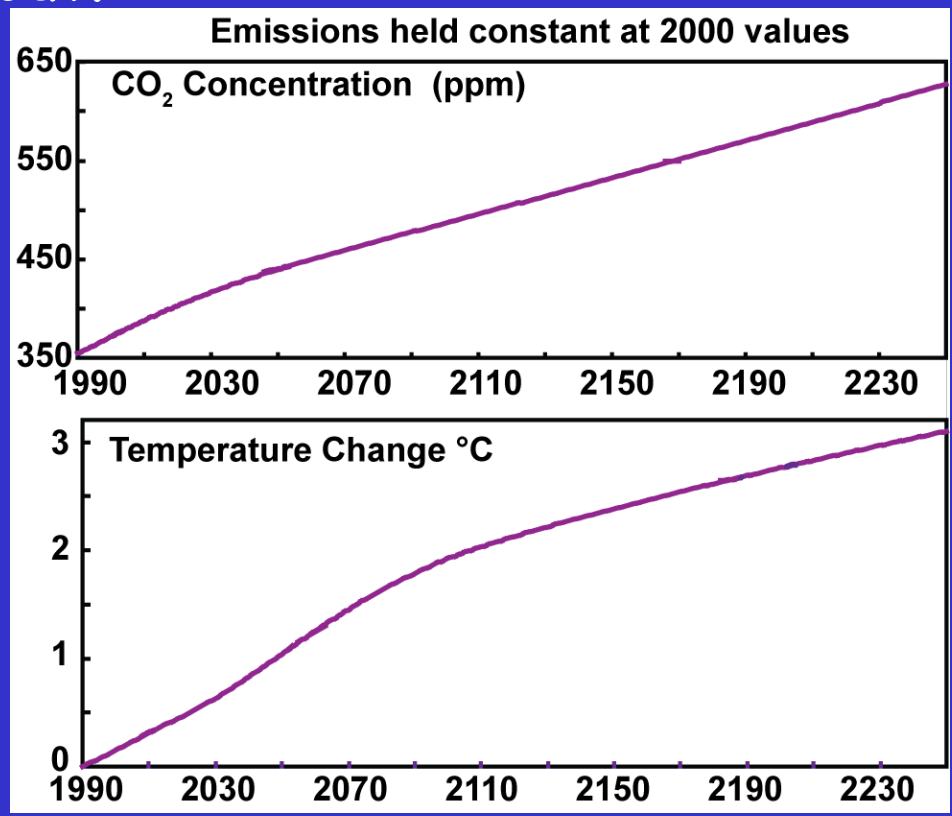
In 2030 global emissions will likely be up by 59% relative to 2004 according to the U.S. Energy Information Administration in its annual International Energy Outlook in May 2007.



Global Warming

The **Kyoto Protocol** basically calls for a **freeze** on emissions to 1990 levels for developed countries. Similarly, the Montreal Protocol for ozone depletion initially called for a freeze on CFC emissions and only later was this changed to a phase out.

A freeze on emissions means that concentrations of carbon dioxide continue to increase. Climate continues to change, temperatures rise and sea level continues to rise.



Global Warming

We can slow global warming down!

Disruption arises more
from rapid change than from the climate per se.

Mitigation effects mainly payoff beyond 2050.

So we **must** adapt to climate change:
we will adapt, whether unplanned (disruptive untold damage and loss of life), autonomously, or planned.

Many things yo

- Use energy efficient

Going
Green

Many things you can do:

- Walk, bicycle
- Drive less, and drive fuel efficient vehicles
- Use biofuels

Many things you can do:

- Do not over heat or over cool:
- Set thermostat to 76°F in summer
- Set to 66°F in winter (82°F in Japan)
- Wear a sweater

Many things you can do:

- Use solar power:
- Dry your clothes on the clothes line
- Some HOAs ban clothes lines: clothes lines are environmentally beautiful

Many things you can do:

- Insulate your house etc:

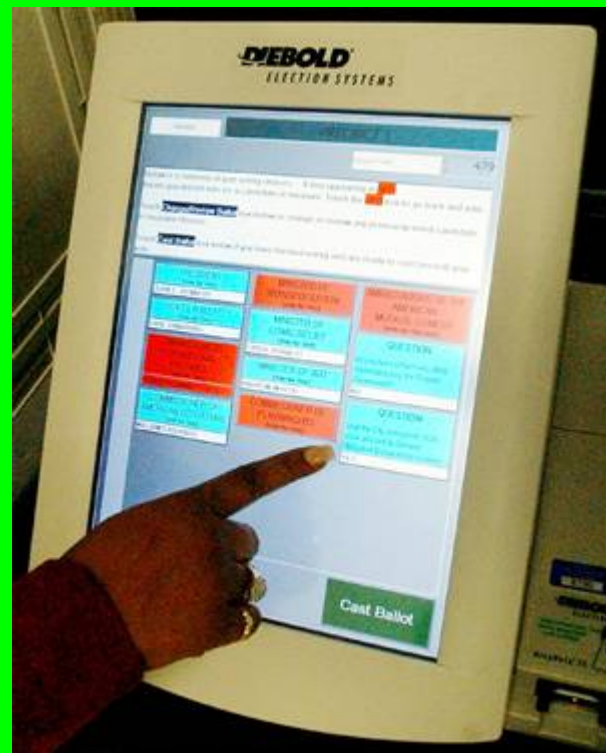
Many things you can do:

- Use renewable energy
- Reduce coal fired power (unless carbon capture and storage employed)

Many things you can do:

- VOTE!
- Vote for responsible candidates

- **Most important!**



Our house

The Challenge:
Sustainable Management of an Ever-Changing Planet

BIZARRO

BY DAN PIRARO