Global Warming affects us all: What must be done?

Kevin E Trenberth
NCAR

- 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.

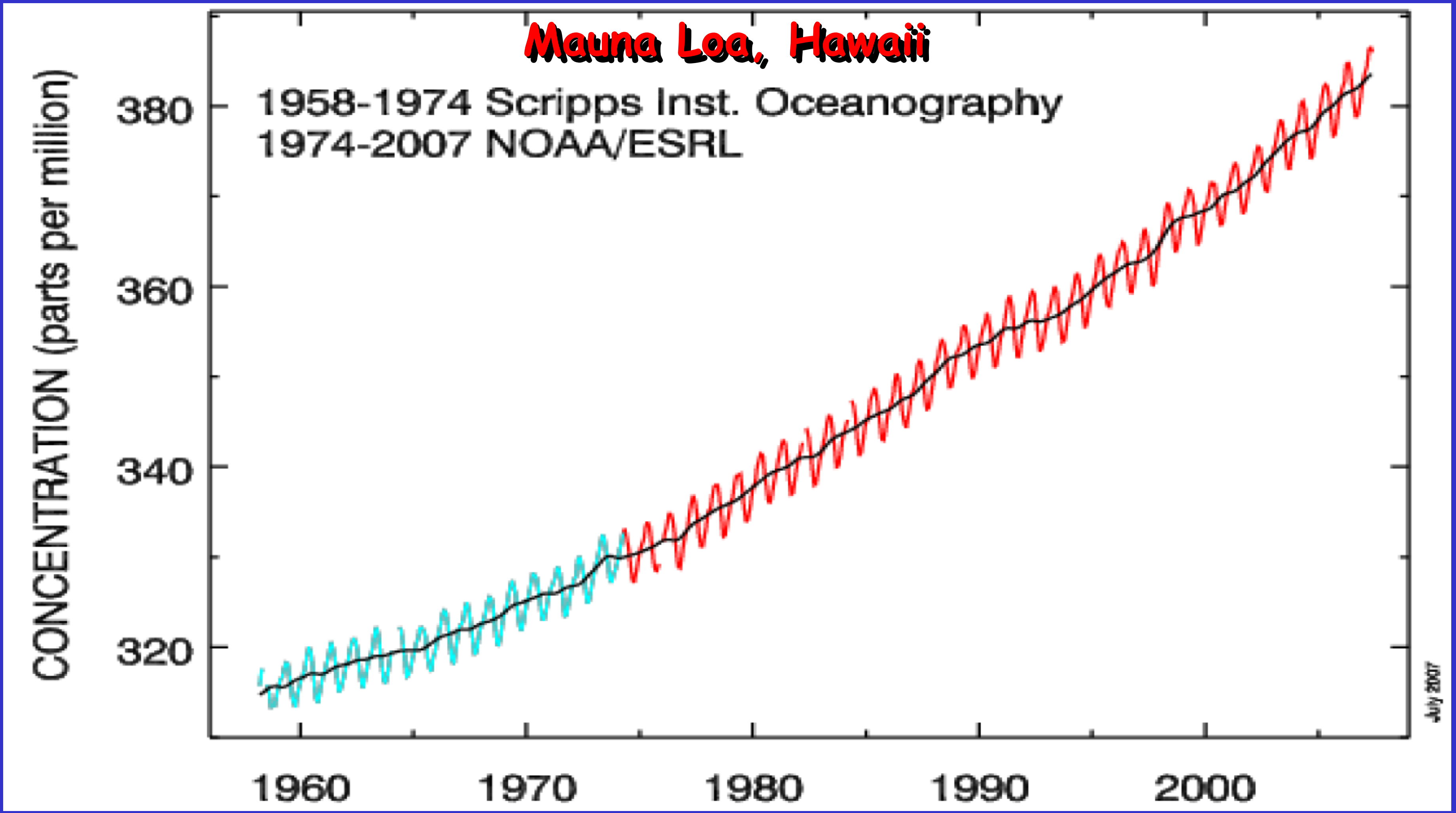
Photo Credit/Crédit photographique: Dan Crosbie

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.

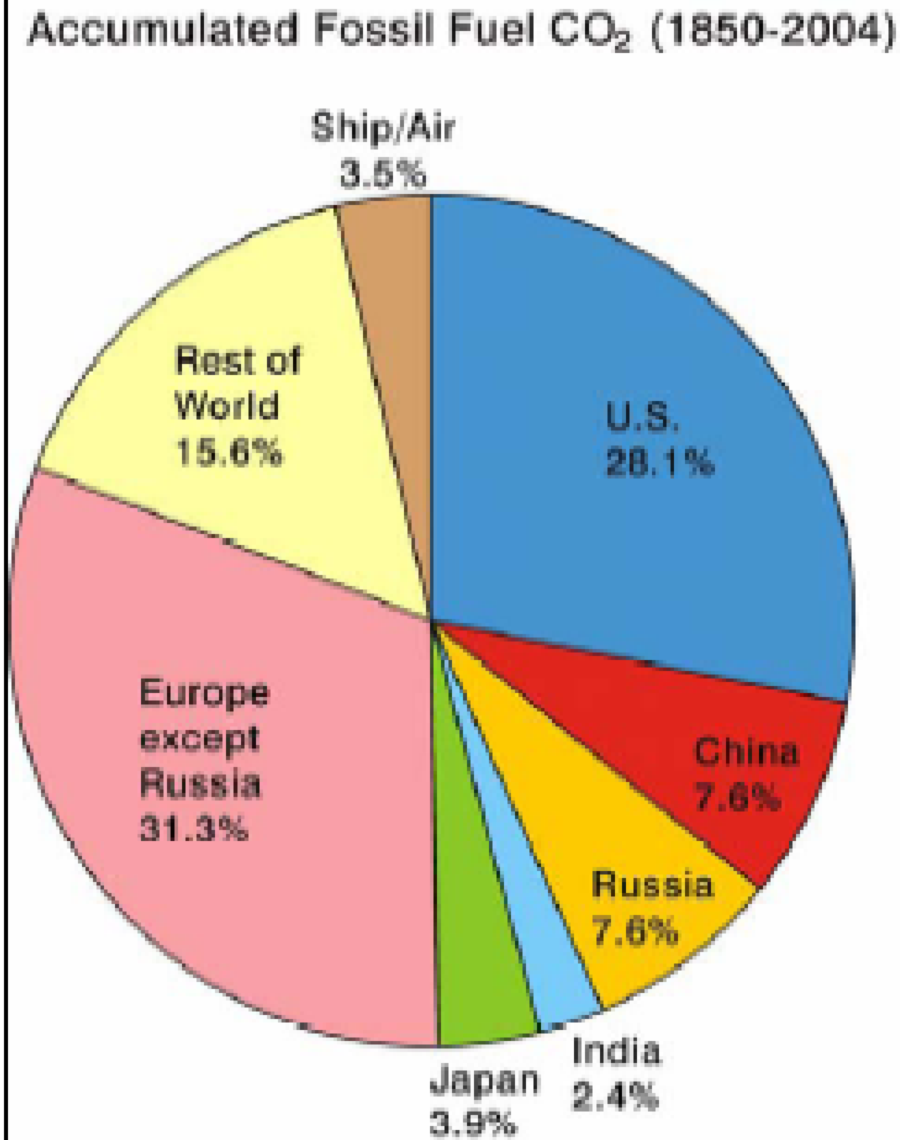
The atmosphere is a dumping ground for all nations for pollution of all sorts. Some lasts a long time and is shared with all. **One consequence is global warming!**

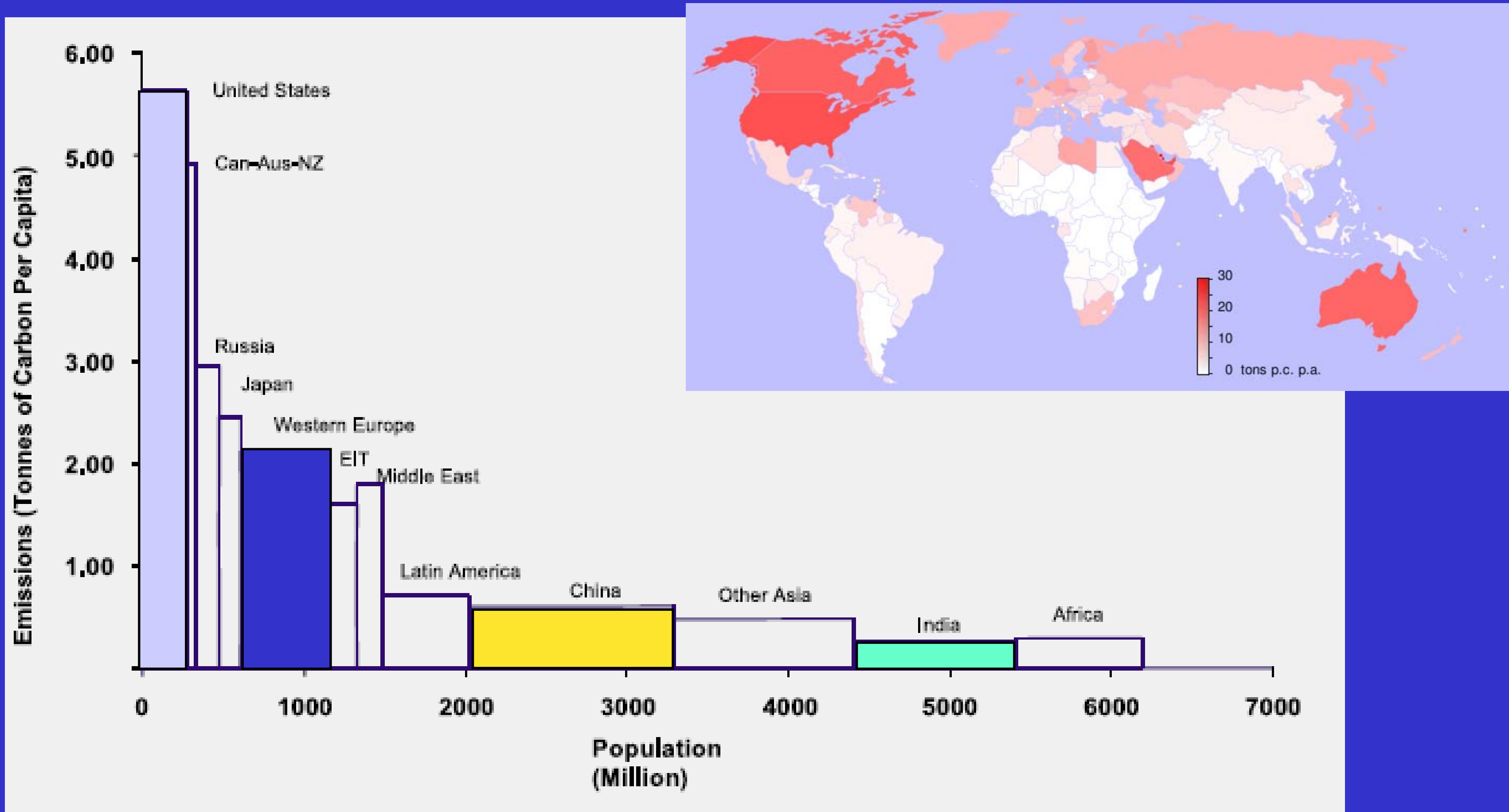
Changing atmospheric composition: CO_2



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

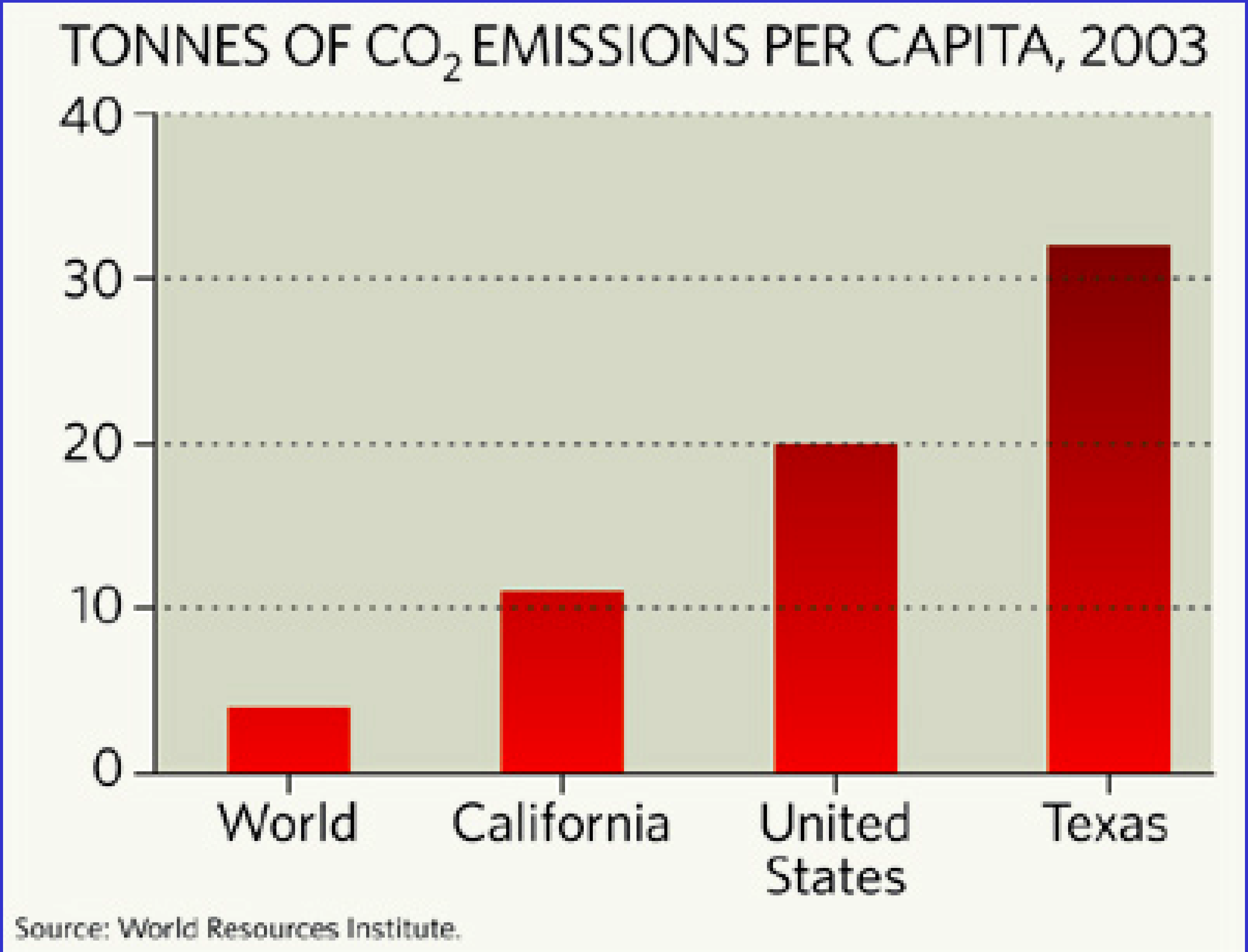
Fossil Fuel CO_2 Emissions





CO_2 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.

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
- Ocean acidity

Decrease in:

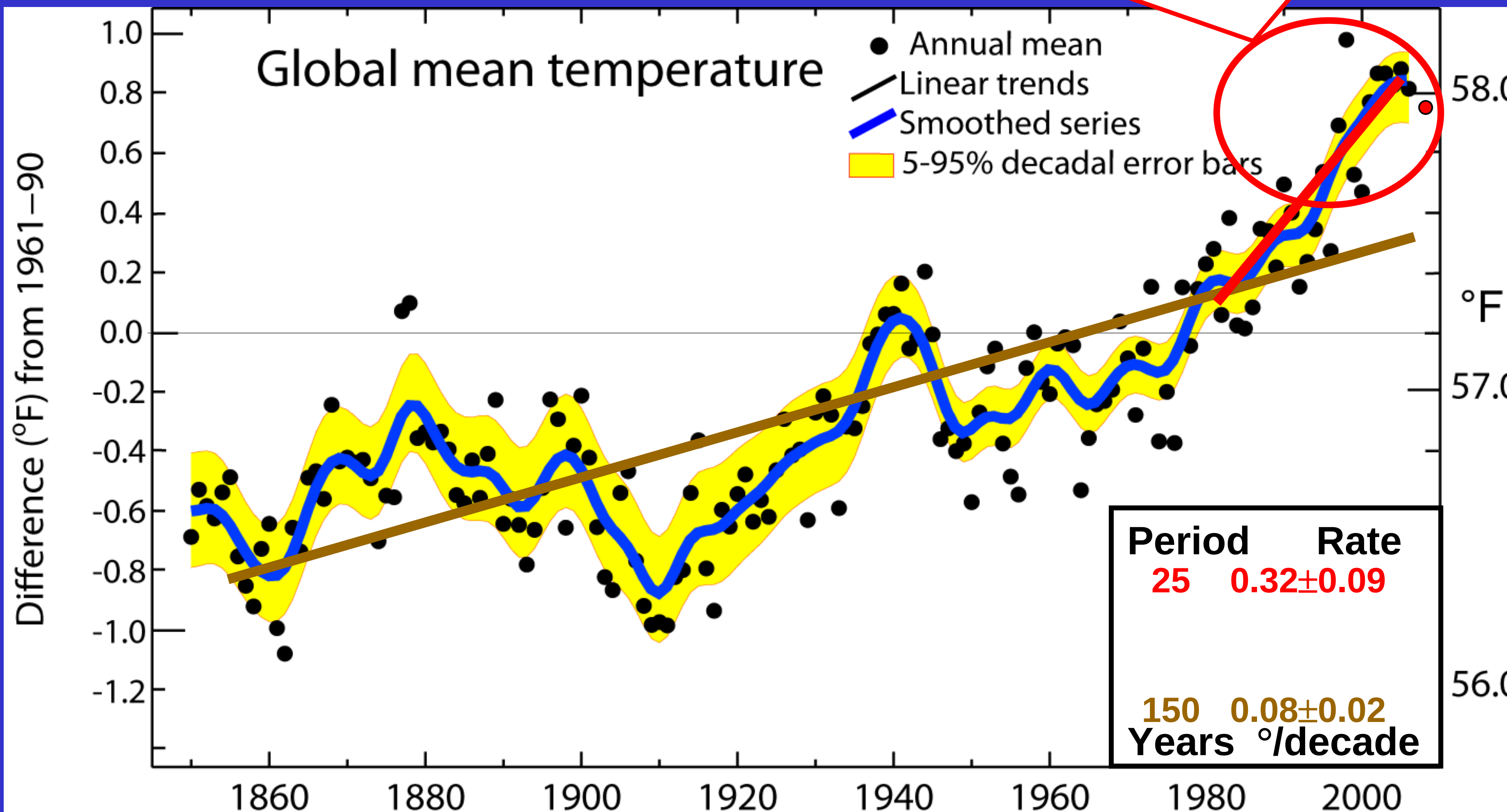
NH Snow extent
Arctic sea ice
Glaciers
Cold temperatures

Photo Credit/Crédit photographique: Dan Crosbi

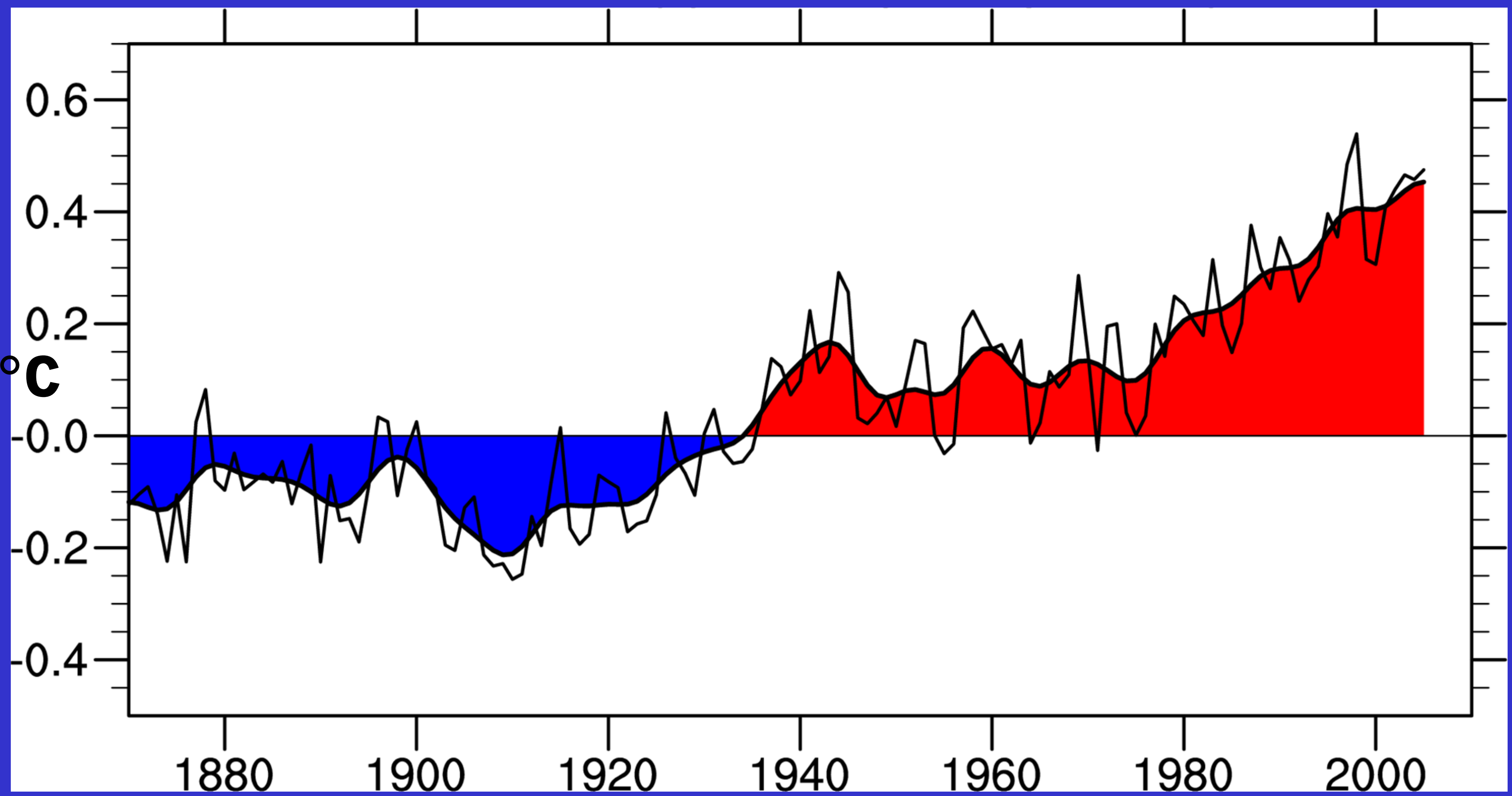
Global mean temper

Warmest 13 years:

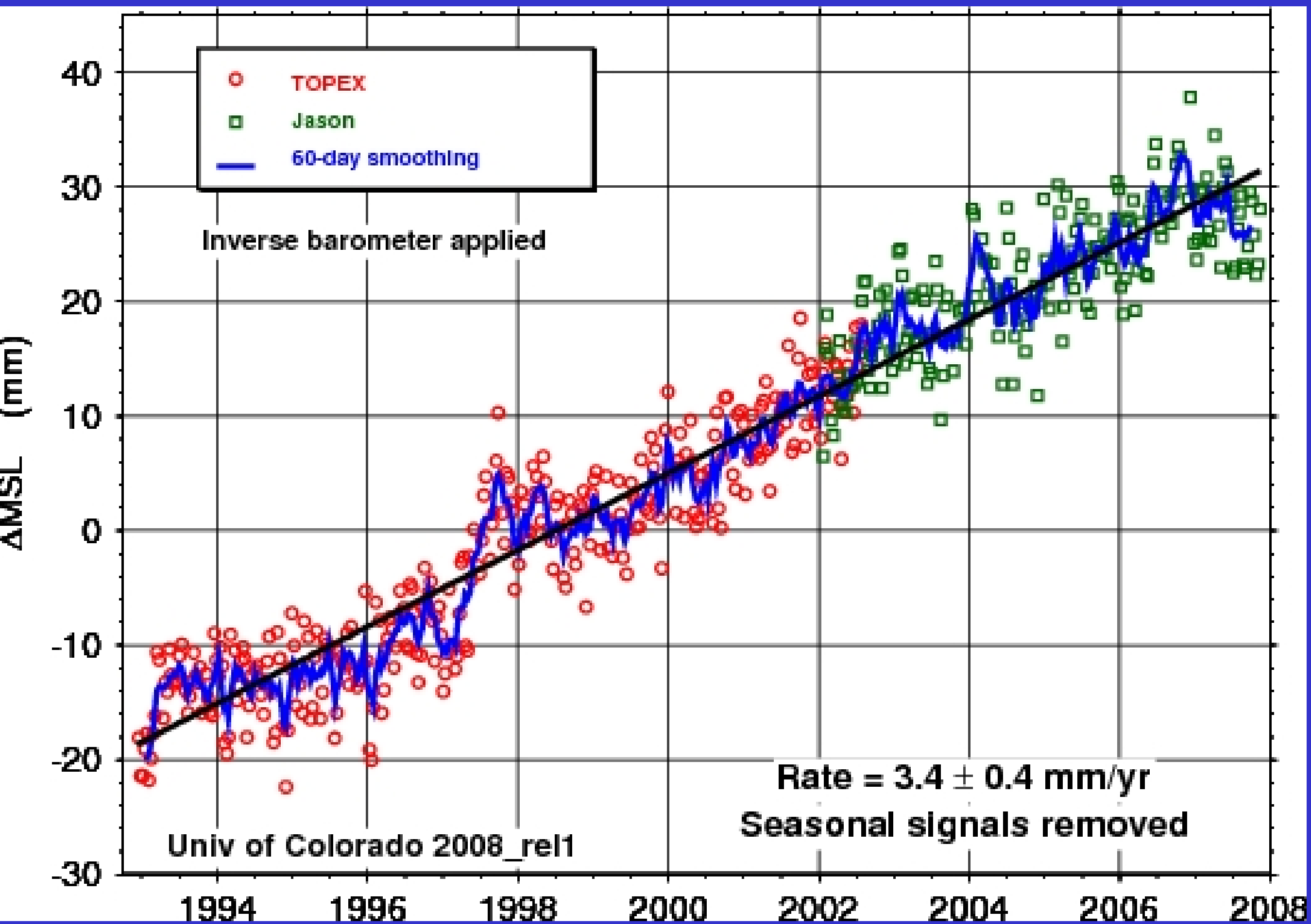
1998,2005,2003,2002,2004,2006,
2001,2007,1997,1995,1999,1990,2000



Global SSTs are increasing: base period 1901-70



Sea level is rising:
from ocean expansion and melting glaciers



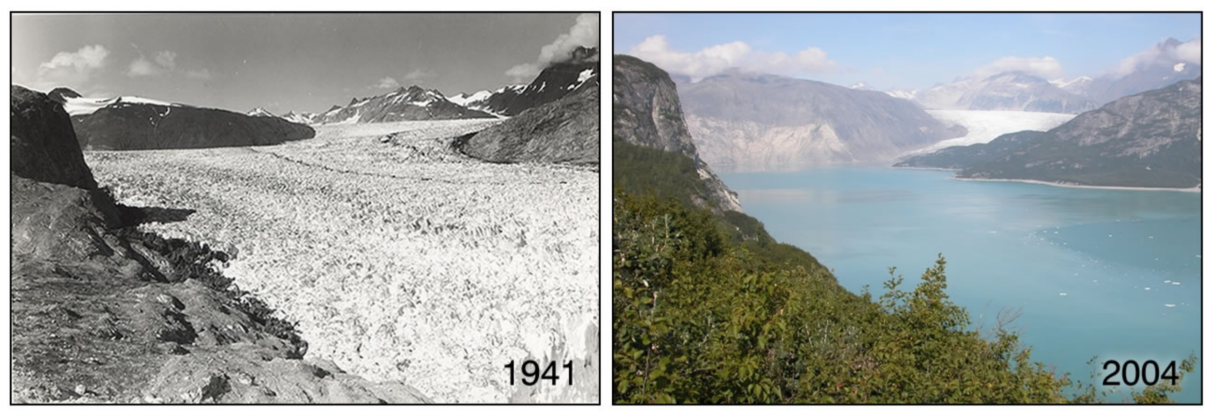
Since 1992 Global sea level has risen 48 mm (1.9 inches)

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

Steve Nerem

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

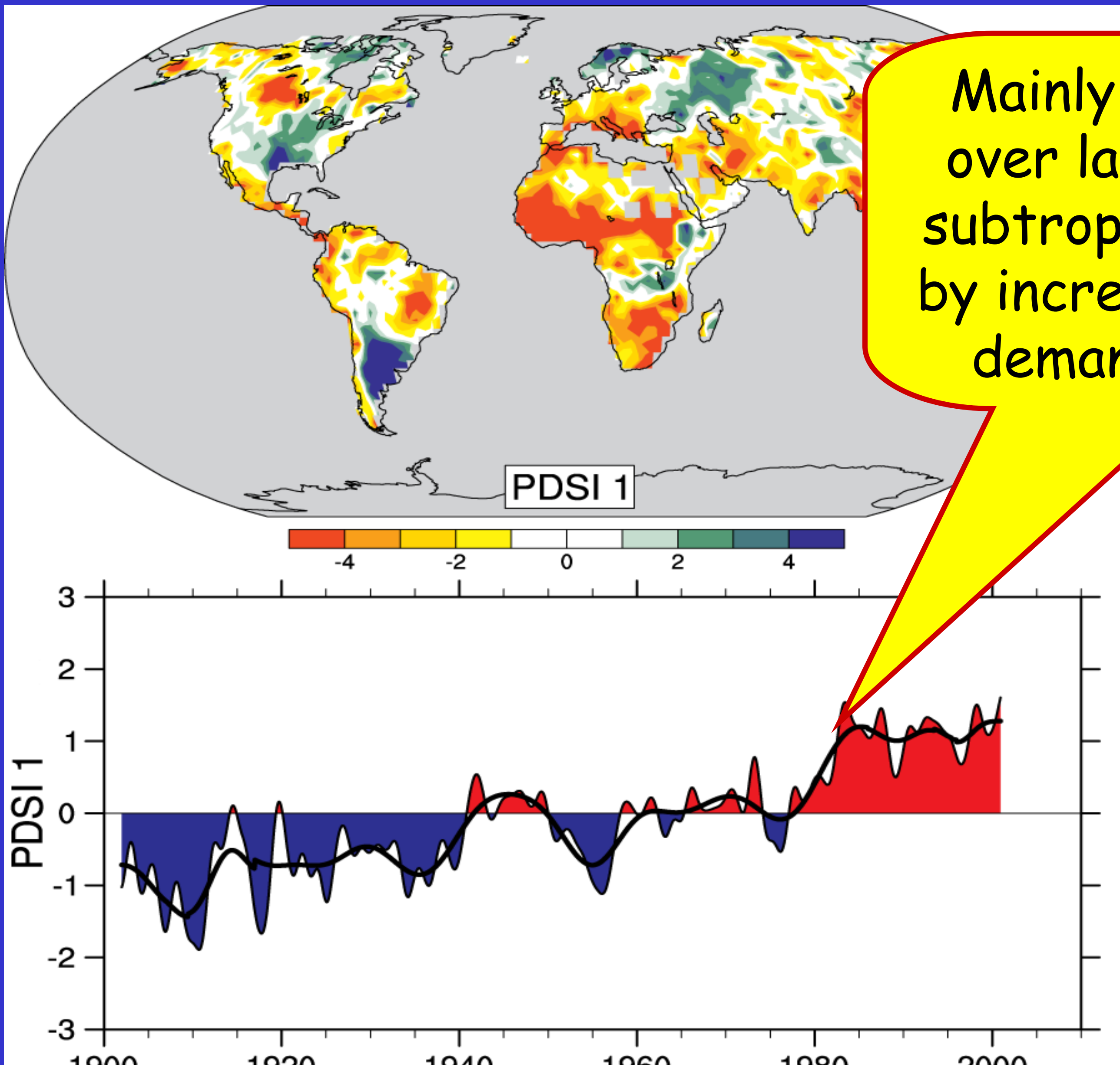
Alpine glacier, Austria

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.

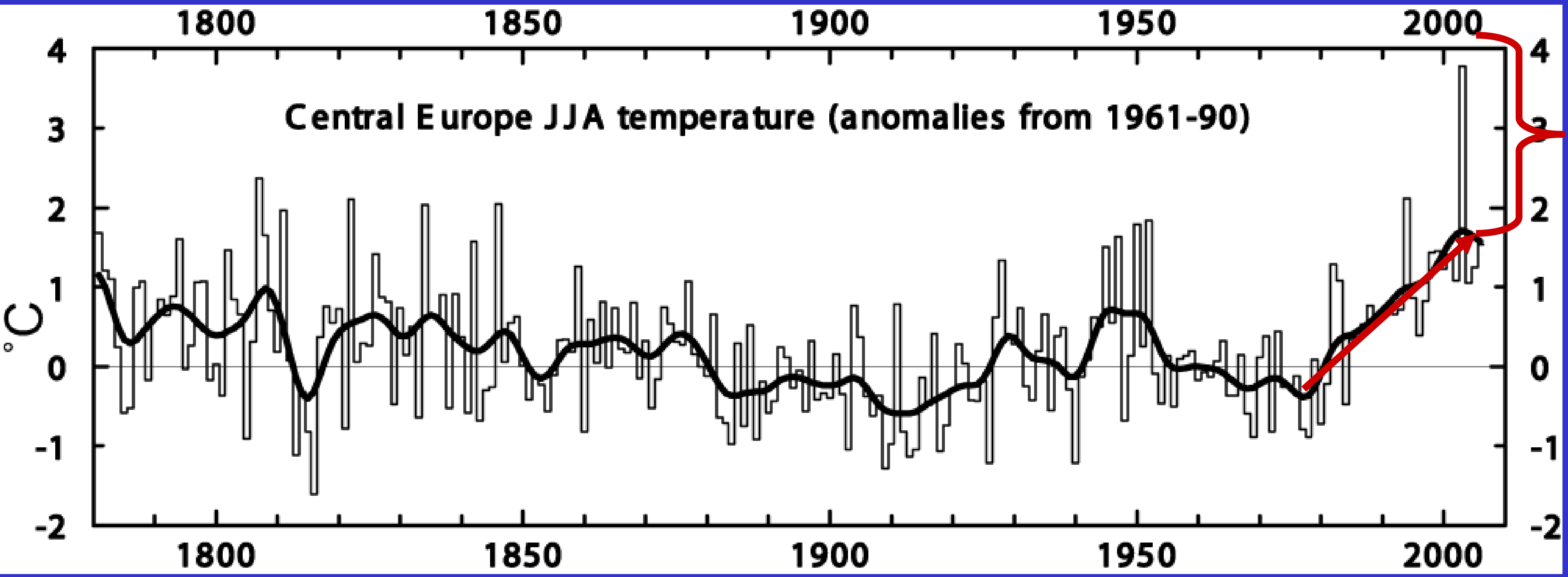
The time series (below) accounts for most of the trend in PDSI.

IPCC

Heat waves and wild fires

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

Heat waves are increasing: an example

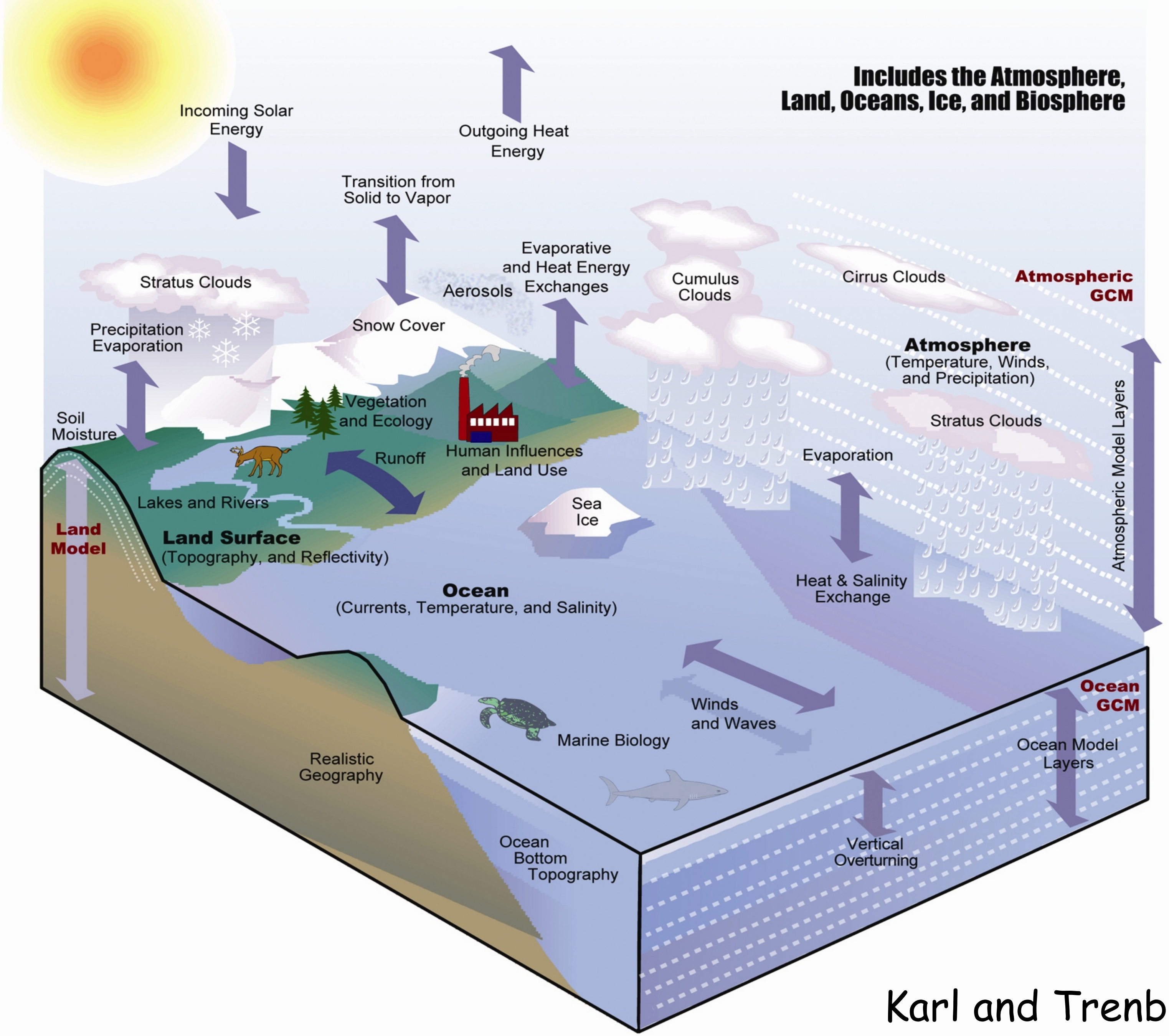


Extreme Heat Wave
Summer 2003
Europe
30,000 deaths

Trend plus variability?

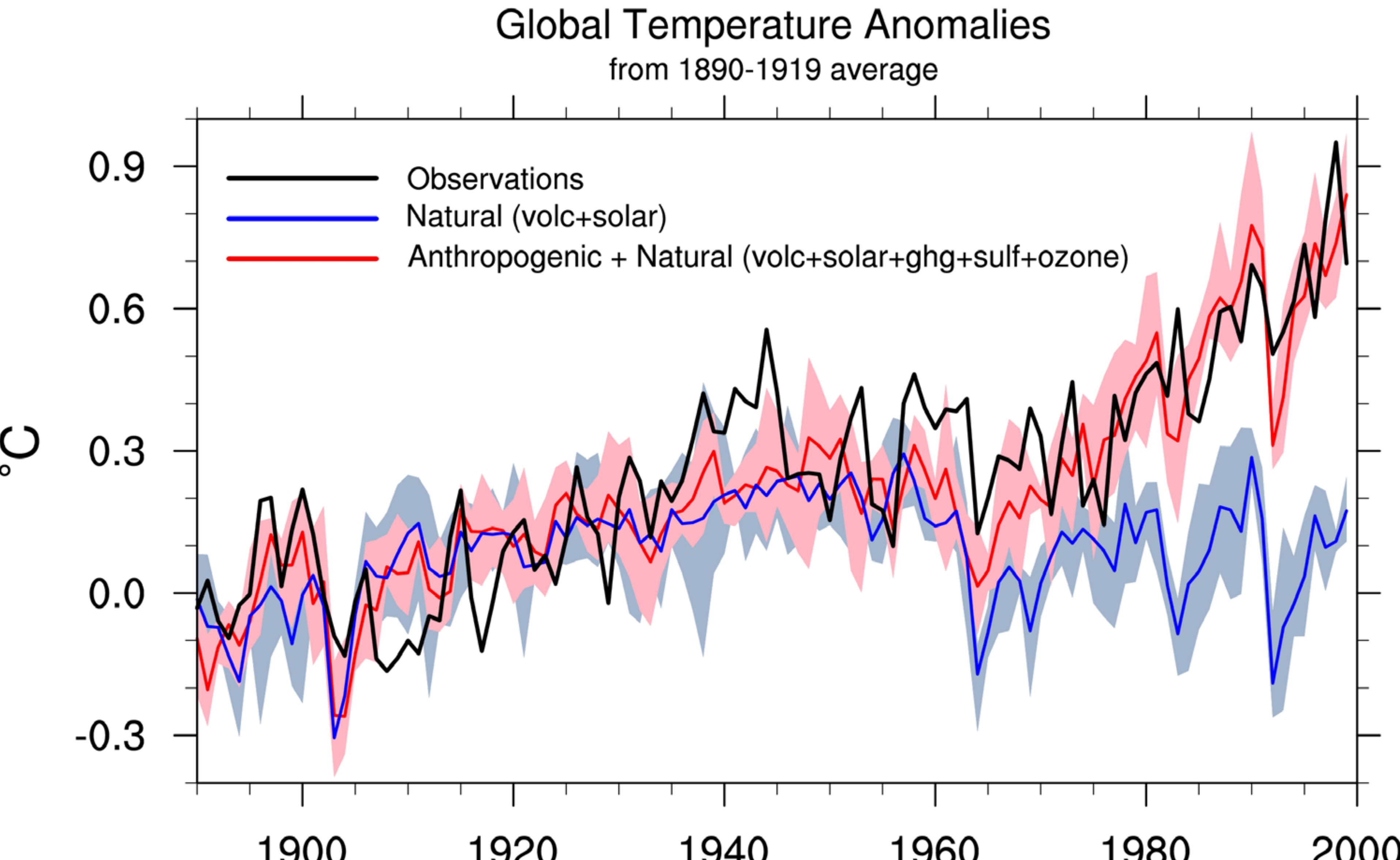
IPCC

Modeling the Climate System



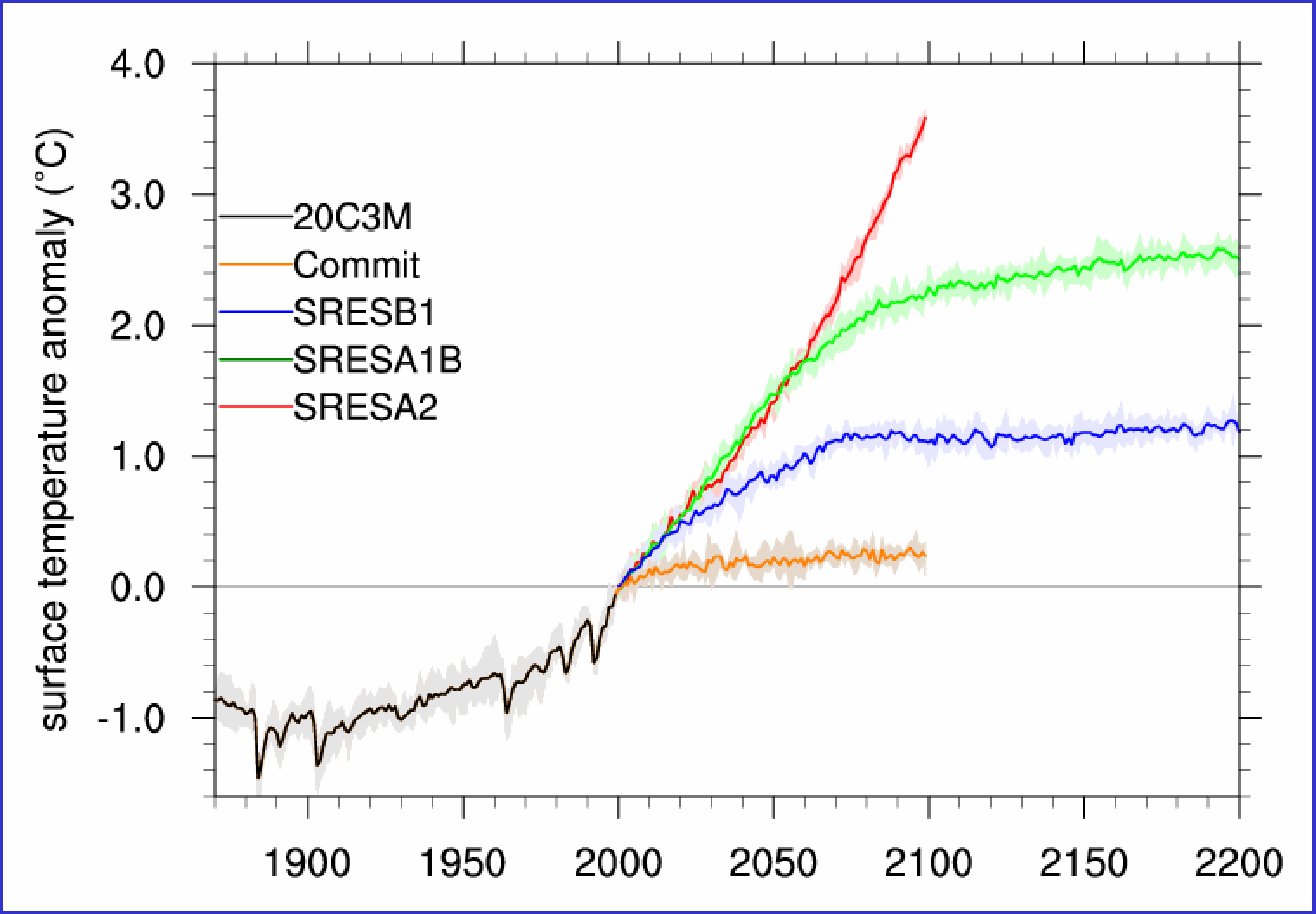
Karl and Trenberth 2003

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



Meehl et al, 2004: J. Climate.

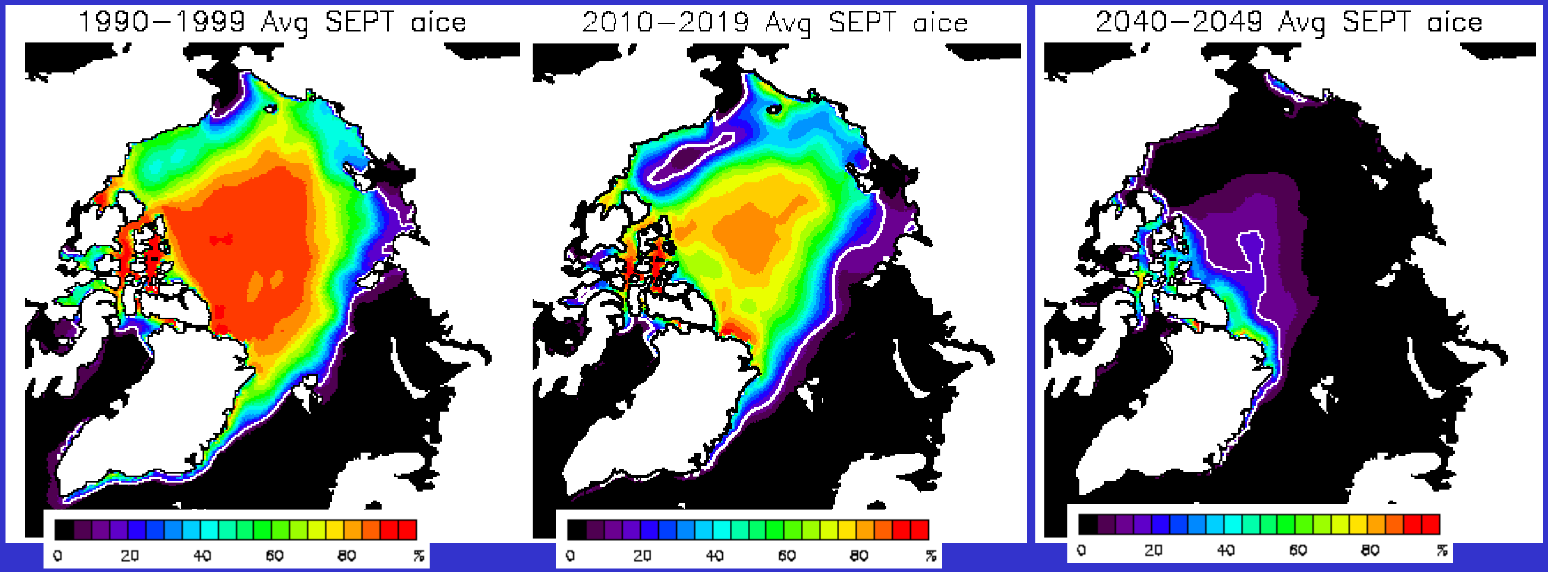
The movie simulation is replaced by global mean values

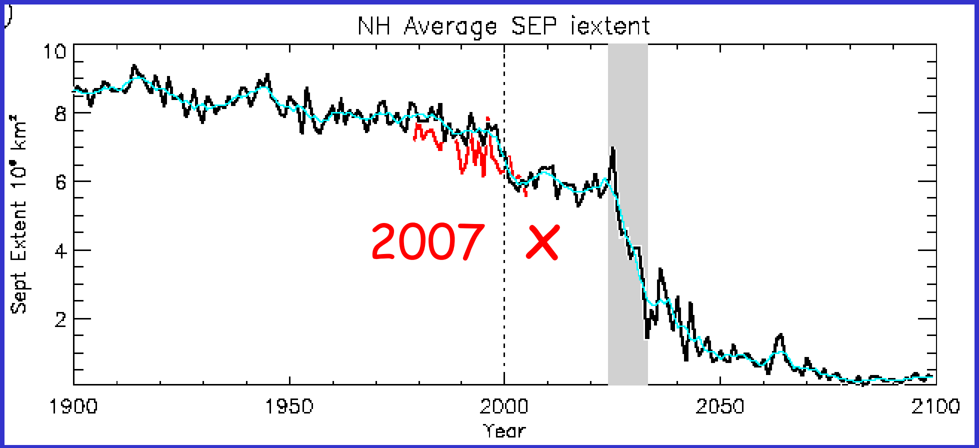


Arctic sea ice disappears in summer by 2050

Already 2007 lowest on record by 22%

Abrupt Transitions in Summer Sea Ice

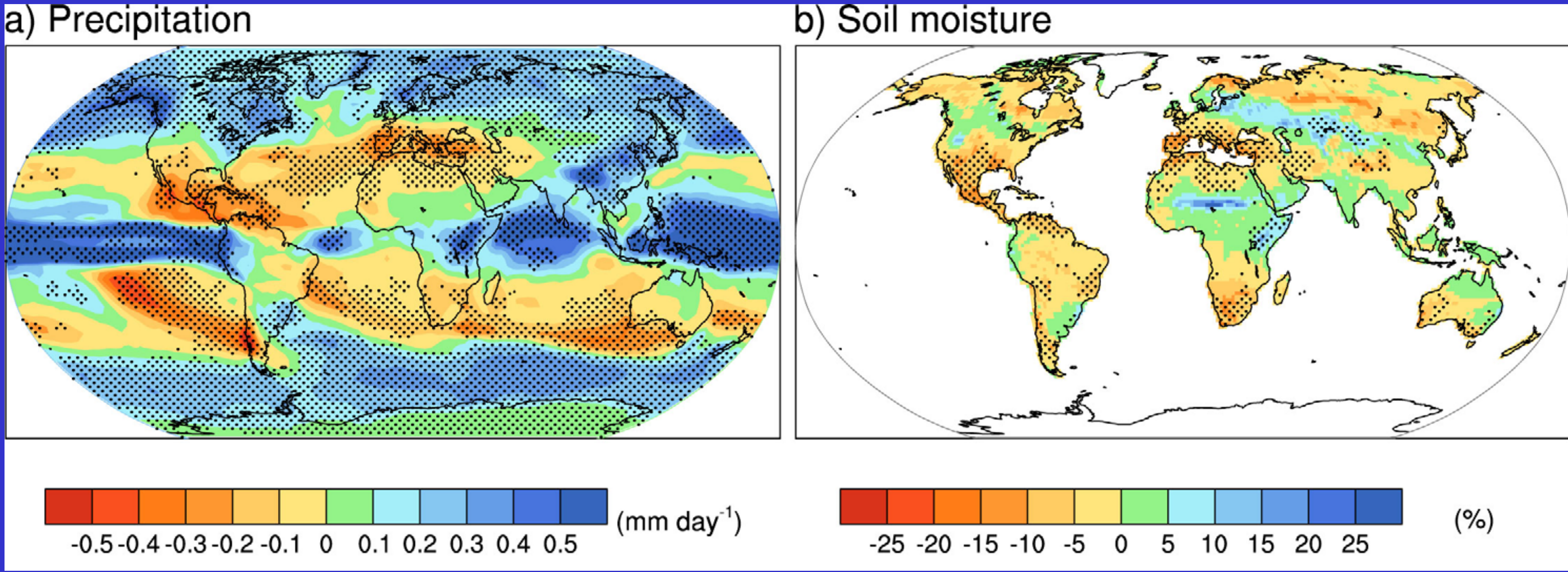




- Gradual forcing results in abrupt Sept ice decrease
- Extent decreases from 80 to 20% coverage in 10 years.
- Relevant factors:
  - Ice thinning
  - Arctic heat transport
  - Albedo feedback

Holland et al., GRL, 2006

Projected Patterns of Precipitation Change 2090-2100

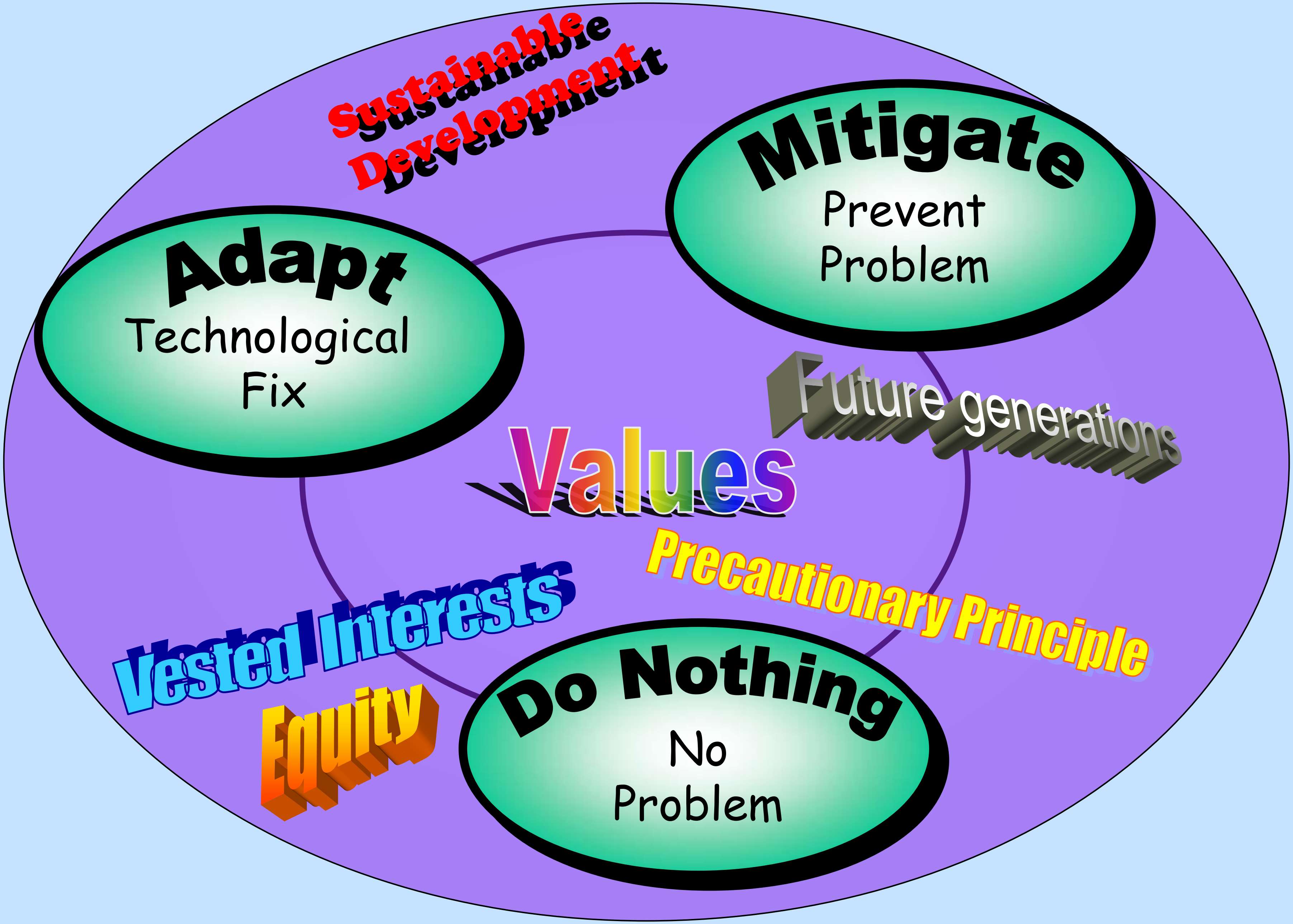


Combined effects of increased precipitation intensity and more dry days contribute to mean precipitation changes

IPCC

Global warming is happening!

Global Warming Actions



Mitigation:

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.
- 176 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.

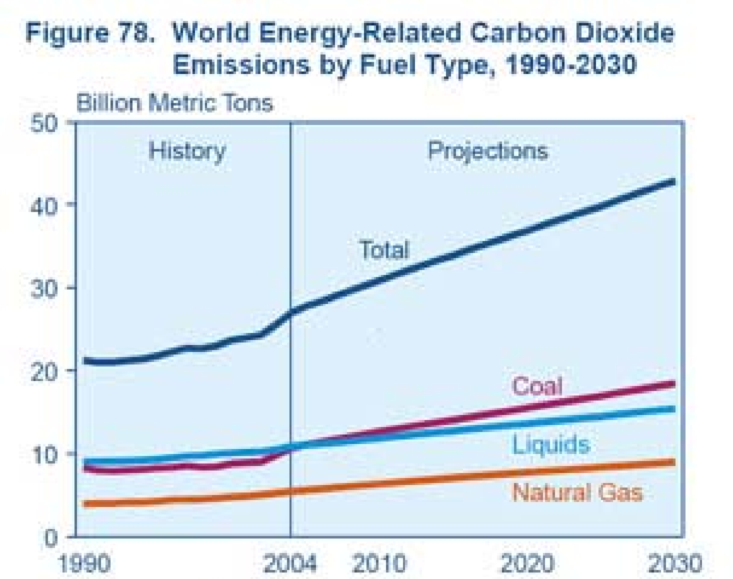
Recent trends: May 2007

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

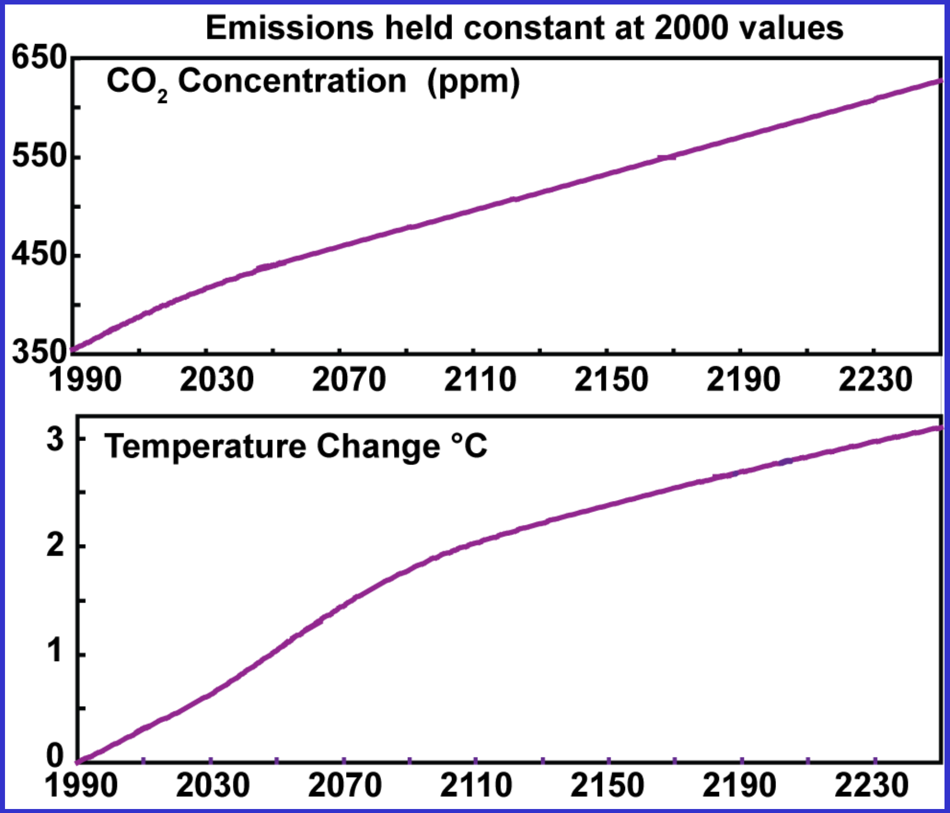
In 2030 global emissions will likely be up by 59% relative to 2004 according to the U.S. Energy Information Administration in its annual International Energy Outlook in May 2007.



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

A freeze on emissions means that concentrations of carbon dioxide continue to increase.

We can slow global warming down!
Disruption arises more
from rapid change than from the climate per se.

Mitigation effects mainly payoff beyond 2040.
So we <u>must</u> adapt to climate change:
we will adapt, whether unplanned (disruptive untold damage and loss of life), autonomously, or planned.

Adaptation to climate change

- Assess vulnerability
- Devise coping strategies
- Determine impacts of possible changes
- Plan for future changes

Requires information

The climate is changing: It is likely to continue to change!
Regardless of the success of mitigation actions:

We need a comprehensive information system to:

- Observe and track the climate changes and forcings as they occur.
- Analyze global products (with models)
- Understand the changes and their origins
- Validate and improve models
- Initialize models; predict future developments
- Assess impacts regionally: on environment, human activities and sectors such as agriculture, energy, fisheries, water resources, etc.

Such a system will be invaluable regardless of magnitude of global warming

T et al 2003

Weather prediction

- Weather prediction is a problem of predicting the future evolution of the atmosphere for minutes to days to perhaps 2 weeks ahead.
- It begins with observations of the initial state (and their uncertainties) and analyses into global fields, then use of a model of the atmosphere to predict all of the future evolution of the turbulence and eddies for as long as is possible.
- Because the atmosphere is a chaotic fluid, small initial uncertainties or model errors grow rapidly in time and make deterministic prediction impossible beyond about 2 weeks.

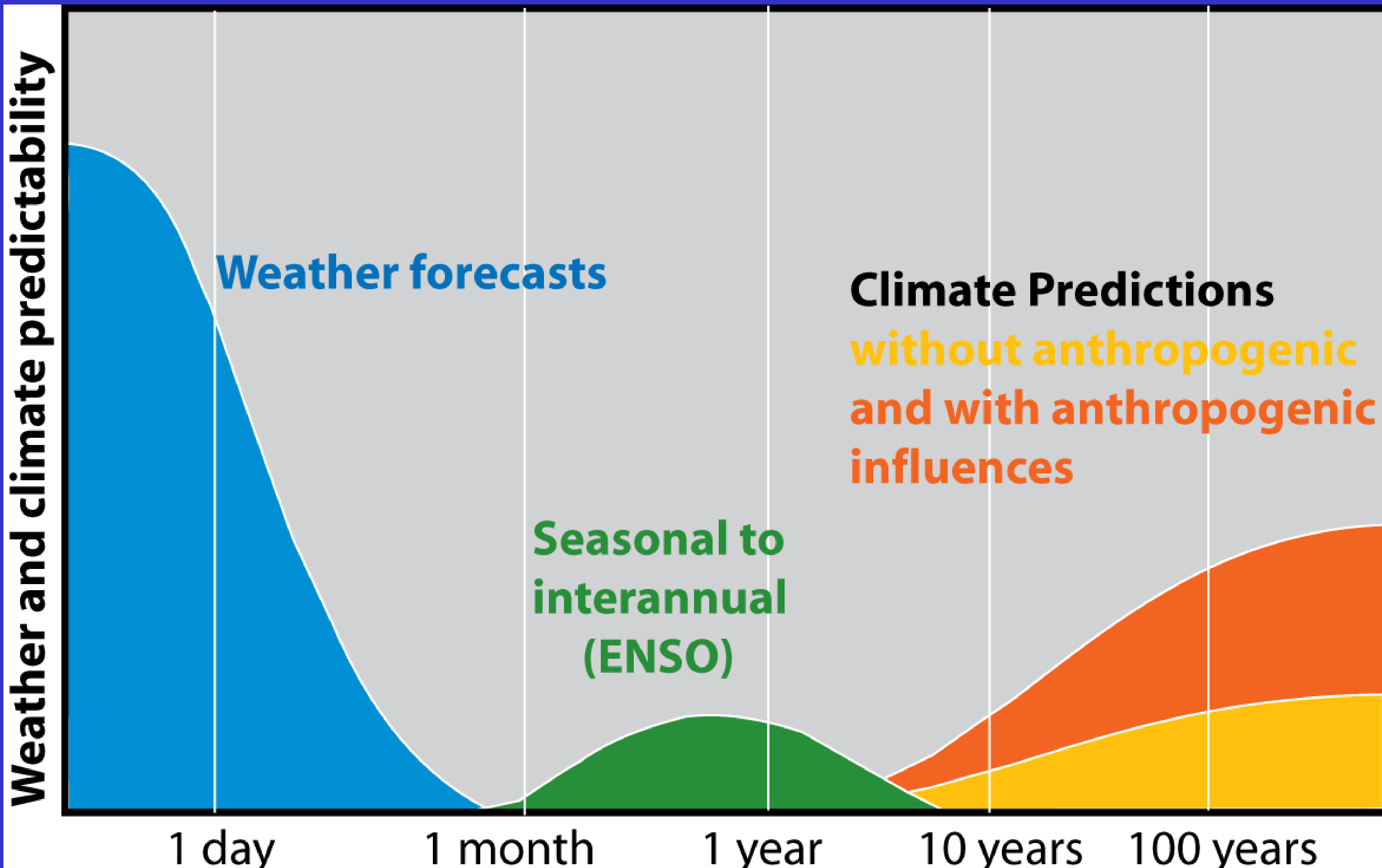
Climate prediction

- Climate prediction is a problem of predicting the patterns or character of weather and the evolution of the entire climate system.
- It is often regarded as a "boundary value" problem. For the atmosphere this means determining the systematic departures from normal from the influences from the other parts of the climate system and external forcings (e.g., the sun).
- The oceans and ice evolve slowly, providing some predictability on multi-year time scales.
- But because there are many possible weather situations for a given climate, it is inherently probabilistic.
- Human influences are now the main predictable climate forcing.

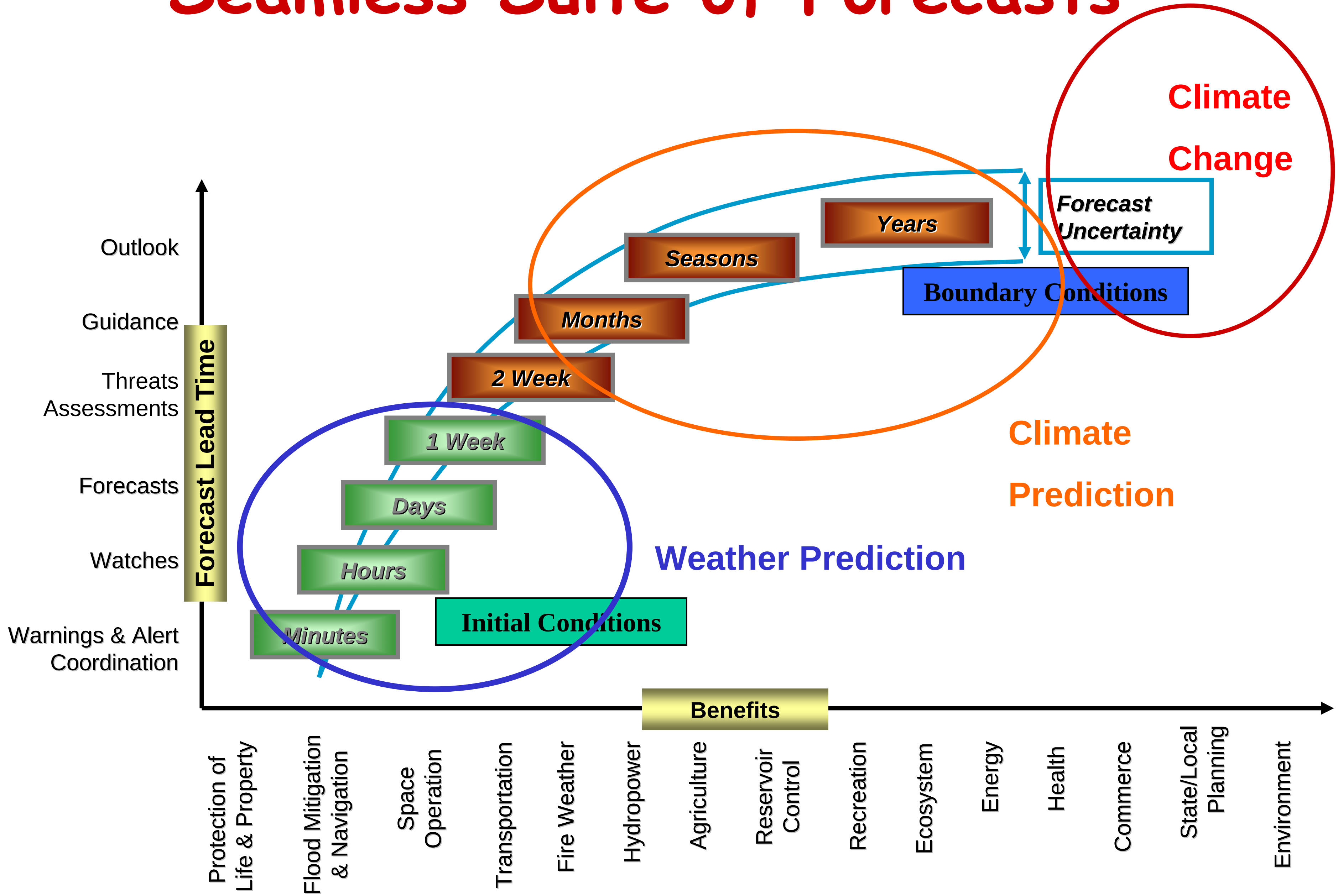
Weather and climate prediction

- As the time-scale is extended, the influence of anomalous boundary forcings grows to become noteworthy on about seasonal timescales.
- The largest signal is El Niño on interannual time scales.
- El Niño involves interactions and coupled evolution of the tropical Pacific ocean and global atmosphere. It is therefore an <u>initial value</u> problem for the ocean and atmosphere.
- In fact all climate prediction involves initial conditions of the climate system, leading to a seamless (in time) prediction problem.

Predictability of weather and climate



Seamless Suite of Forecasts



Progress in NWP and climate modeling

There have been no *revolutionary* changes in weather and climate model design since the 1970s.

- Same dynamical equations, with improved numerical methods
- Comparable resolution
- Similar parameterizations
- A modest extension of the included processes

And the models are somewhat better.

Meanwhile, computing power is up by a factor of a **million**.

- Model resolution has increased.
  - Horizontal resolution has quadrupled (at most).
  - The number of layers has tripled.
- More processes have been introduced.
- Parameterizations have become a little more elaborate.

} Factor of 1000

- Longer runs
- More runs: ensembles

} Factor of 1000

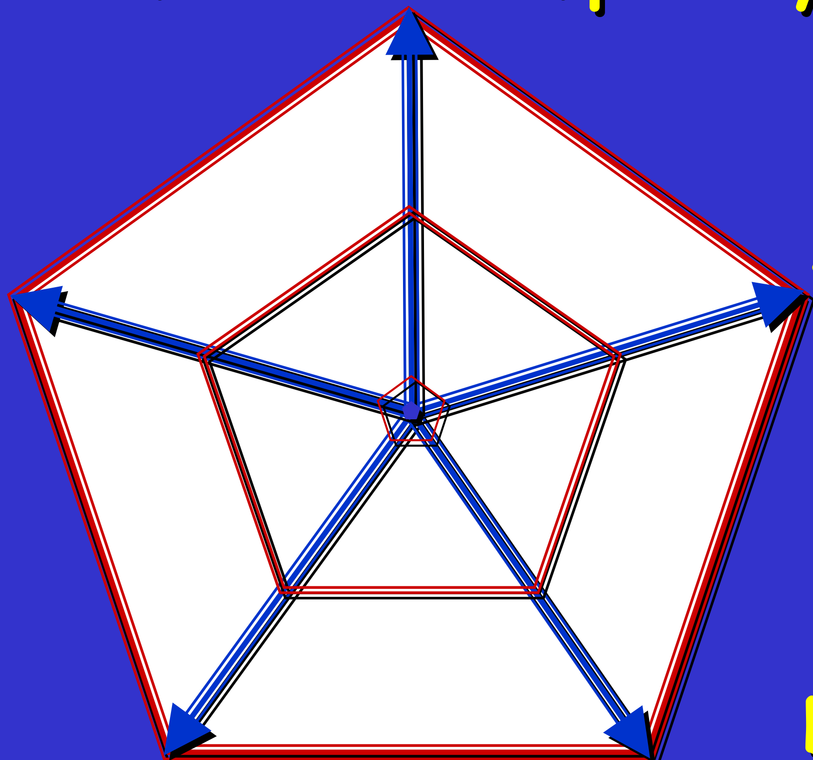
Adapted from D. Randall (CSU)

5 Dimensions of Climate Prediction

(Tim Palmer, ECMWF)

Simulation complexity

Resolution



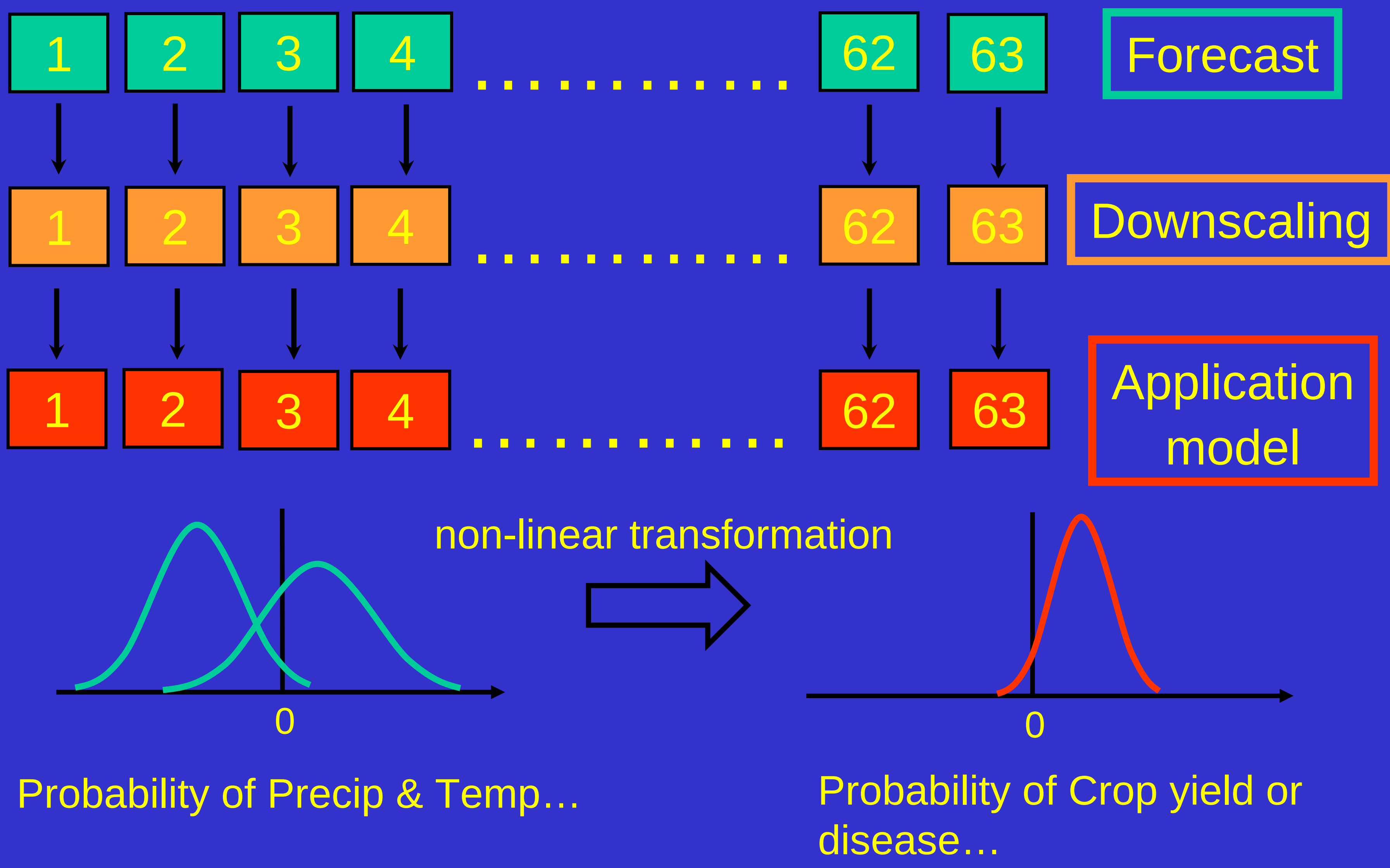
Timescale

Ensemble size

Data assimilation/
initial value forecasts

All require much greater computer resource
and more efficient modeling infrastructures

End-to-end Forecast System



Future needs: A climate information system

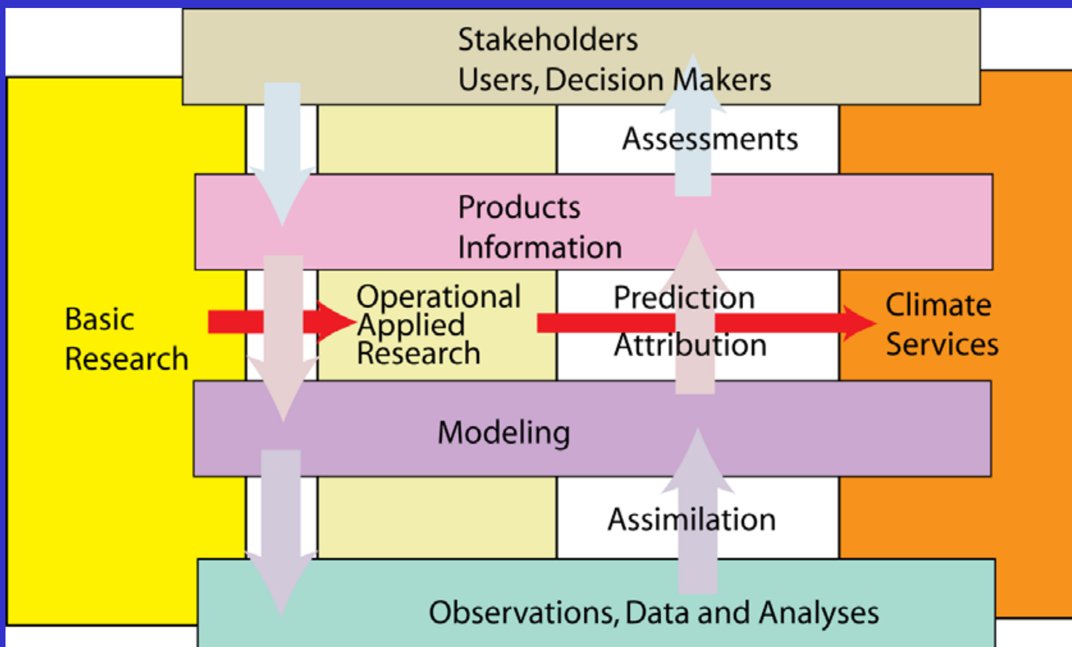
- Observations: in situ and from space
- Data processing and analysis
- Data assimilation and model initialization
- Better, more complete models
- Ensemble predictions: many time scales
- Statistical models: applications
- Information: regional, sectoral

Imperative
A climate information system

- ☺ Observations: forcings, atmosphere, ocean, land
- ☺ Analysis: comprehensive, integrated, products
- ☺ Assimilation: model based, initialization
- ☺ Attribution: understanding, causes
- ☺ Assessment: global, regions, impacts, planning
- ☺ Predictions: multiple time scales
- ☺ Decision Making: impacts, adaptation

An Integrated Earth System Information System

Climate Information System



Trenberth, 2008 WMO Bulletin

***Nature* 6 December 2007**

Forecast for 2020 (in 2019)?

New **environmental** forecast products will be feasible

Melting permafrost

Major fires

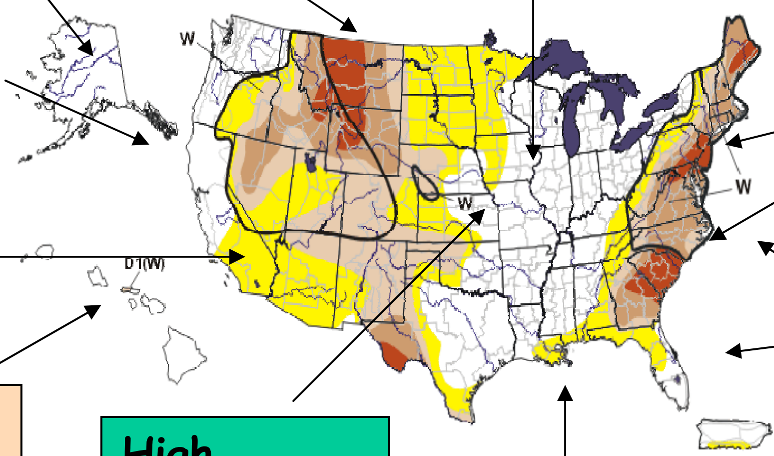
Agricultural production at 50%, blowing dust

Health warning: Limit outdoor activities; expect brownouts

Major fisheries regime change likely

Air quality alerts: 75% of days

Swimming and Fishing prohibited



Frequent flooding and Asian dust threats continue

High danger of toxic CO2 releases

Expect fisheries downturn; health threats

21 Tropical storms: 10 above normal

African bacteria alerts

Possible Threats for Summer 2020:

Drought, hot, dry & unhealthy

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)

The Challenge:
Sustainable Management of an Ever-Changing Planet