Reducing Our Carbon Footprint: Frontiers in Climate Forecasting

Bill Collins

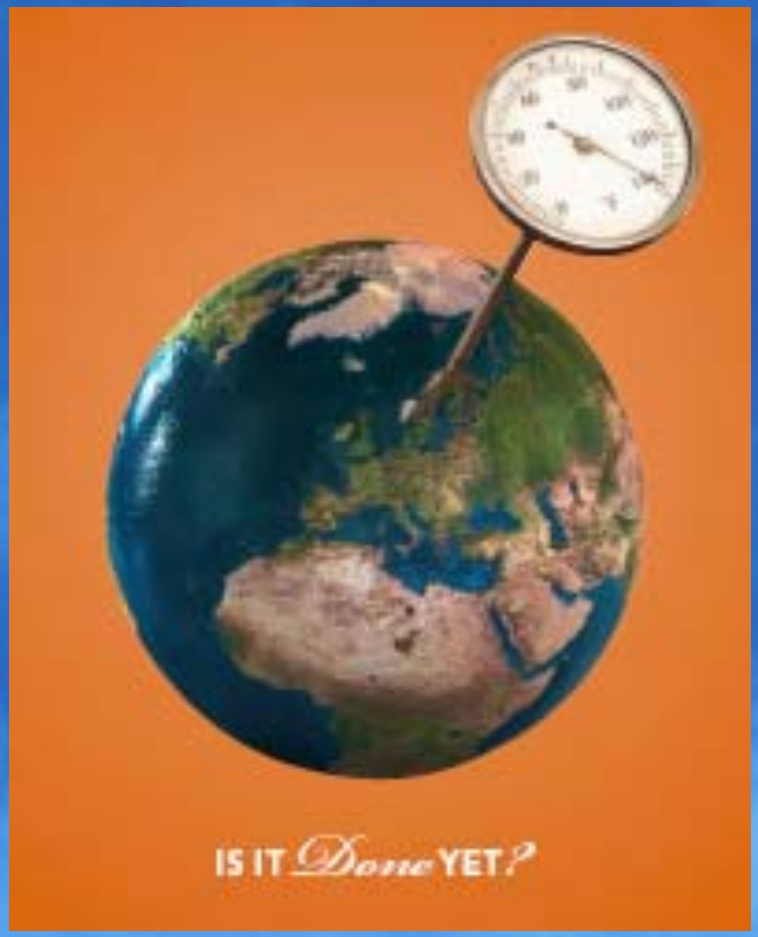
Lawrence Berkeley National Laboratory and UC Berkeley

SCIENCE at the THEATER

Berkeley Repertory Theatre

October 22, 2007

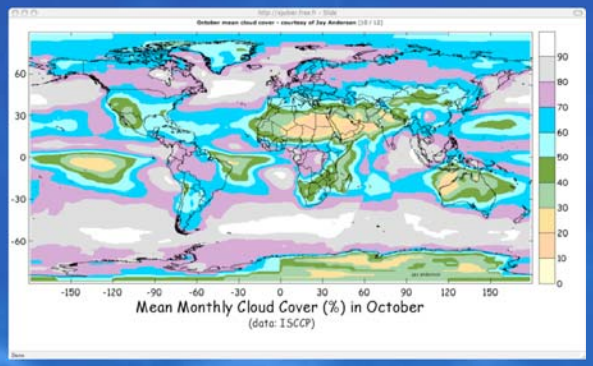
Central Questions about our Future Climate



- What is climate?
- How is it changing now?
- What causes these changes?
- What could happen next?
- Can we avoid harmful warming?

What are Weather and Climate?

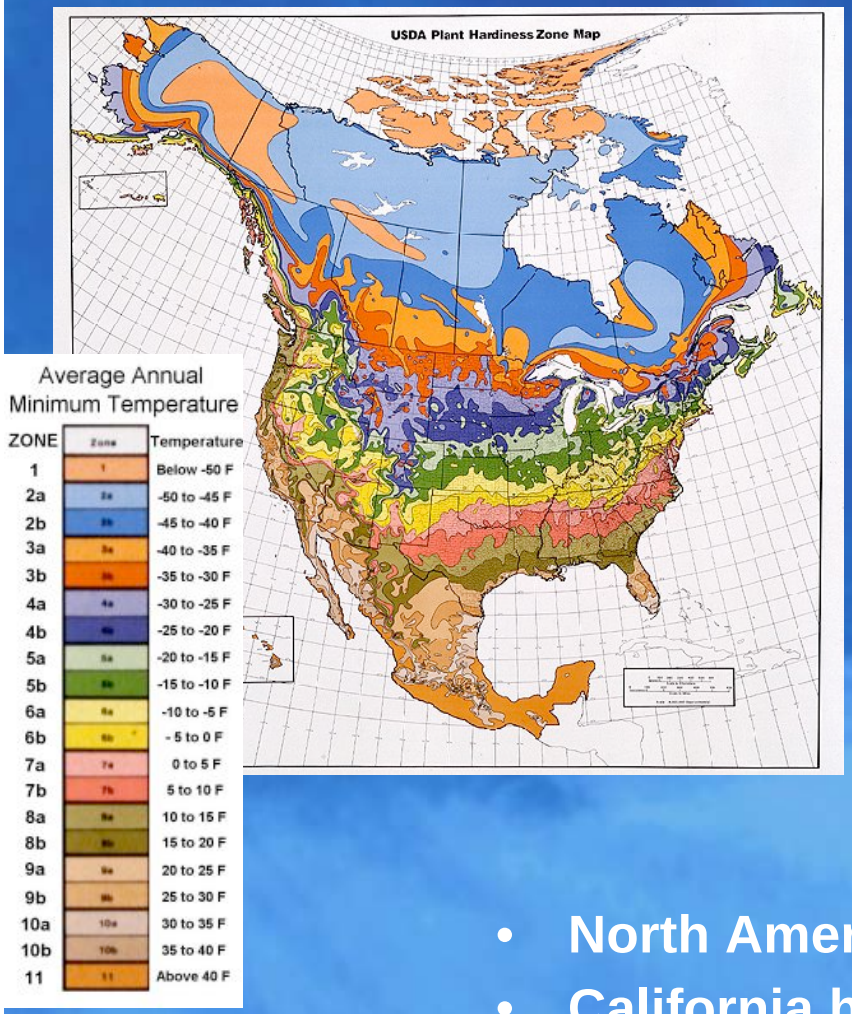
Weather refers to the current atmospheric conditions at a particular time and place.



Climate refers to the general weather patterns expected in a given area.

"Climate" basically mean the large-scale weather patterns in time and space (e.g., an Ice Age climate or a tropical climate).

Climate of North America



- North America has 11 zones.
- California has 3 zones.

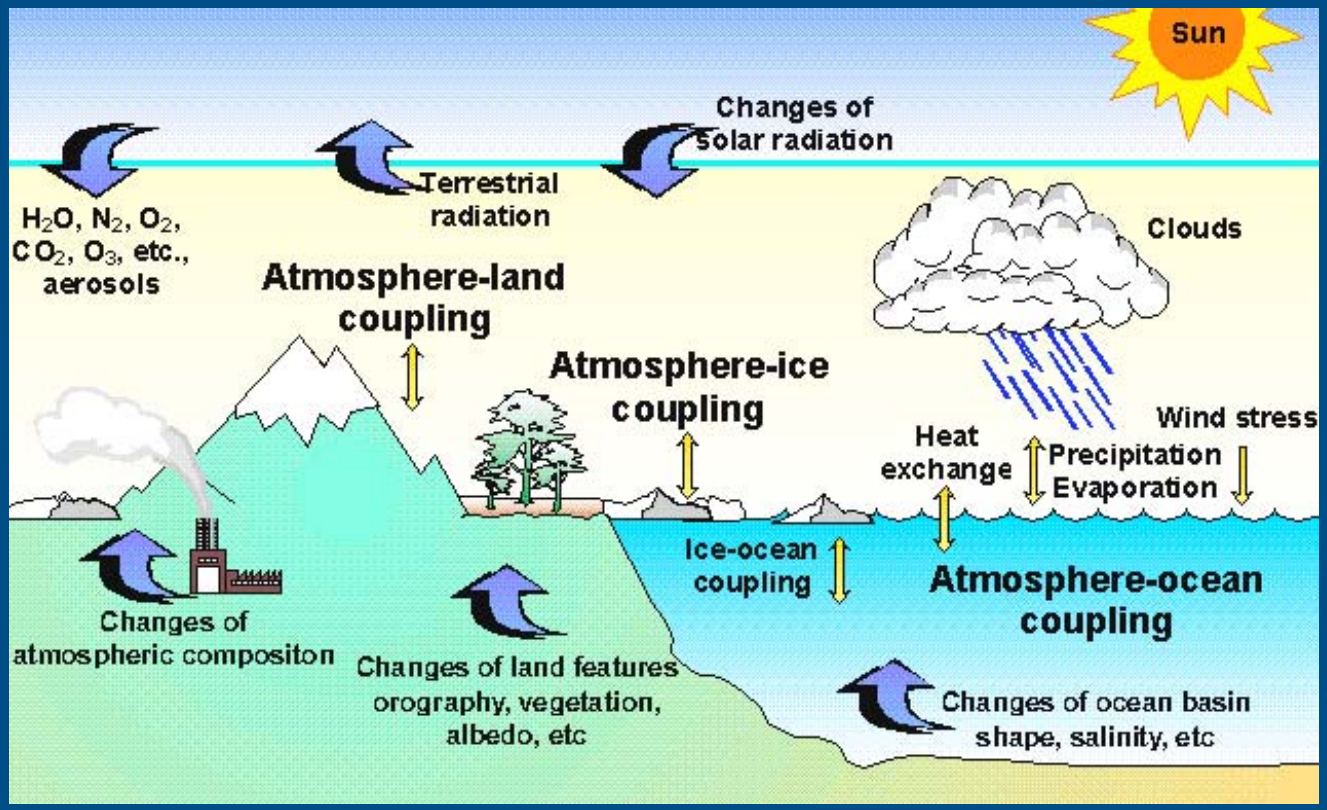
Climate Stability: European Vineyards from Roman Times Remain the Same Today

Cornas, Northern Rhone, France
Vineyards from Roman or earlier times

Van Gogh, Vineyard at Auvers, 1890

Key Questions about the Climate System

- What changes have occurred?
- How well are the past and present climates understood?
- What changes could lie ahead?



Observations:

- Temperatures
- Precipitation
- Snow / Ice cover
- Sea level
- Circulation
- Extremes

Simulations:

- Natural variation
- Forcing Agents
- Global climate
- High impact events
- Stabilization

Observations vis-à-vis Simulations

Timeline: Paleo & Instrumental Periods — The Present — The Future

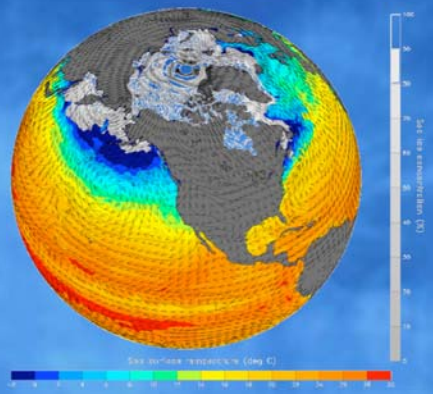
Tools to Study Climate Change

- **Past: Proxy records (distant past)**

  Examples: fossils, ice cores, tree rings, pollen

- **Present: Sensors and indicators**

  Examples: satellites and ground instruments



- **Future: Models**

  Examples: computer models

Clues to Earlier Climates

Tree rings

When trees flower

Ice cores

Harvest production

Observations of the Present Climate

Balloons

Local

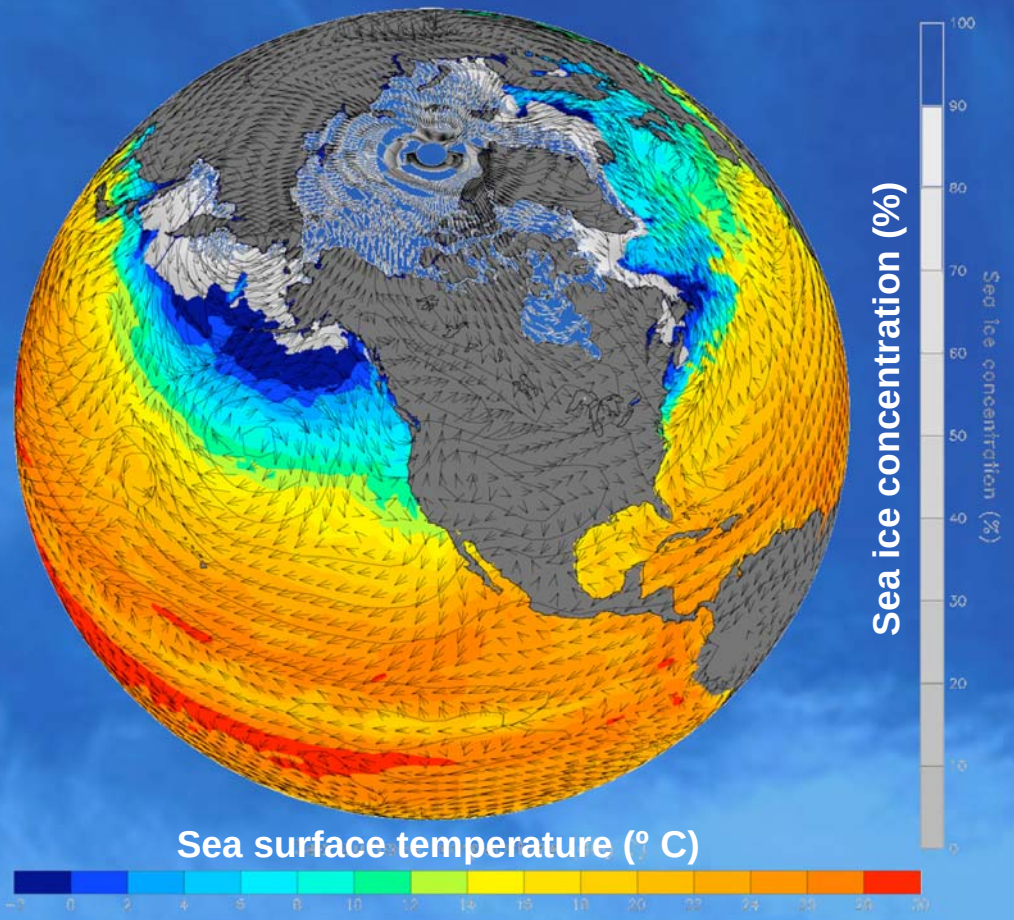
Aircraft

Regional

Satellites

Global

What is a Climate Model?



- Synthesis of our knowledge
- Tool for predicting the future
- Tool for understanding the past
- Numerical “parallel Earth”

Climate Change: The International View

UN climate change studies (1998-present):

Intergovernmental Panel on Climate Change (IPCC)

IPCC periodic assessments:

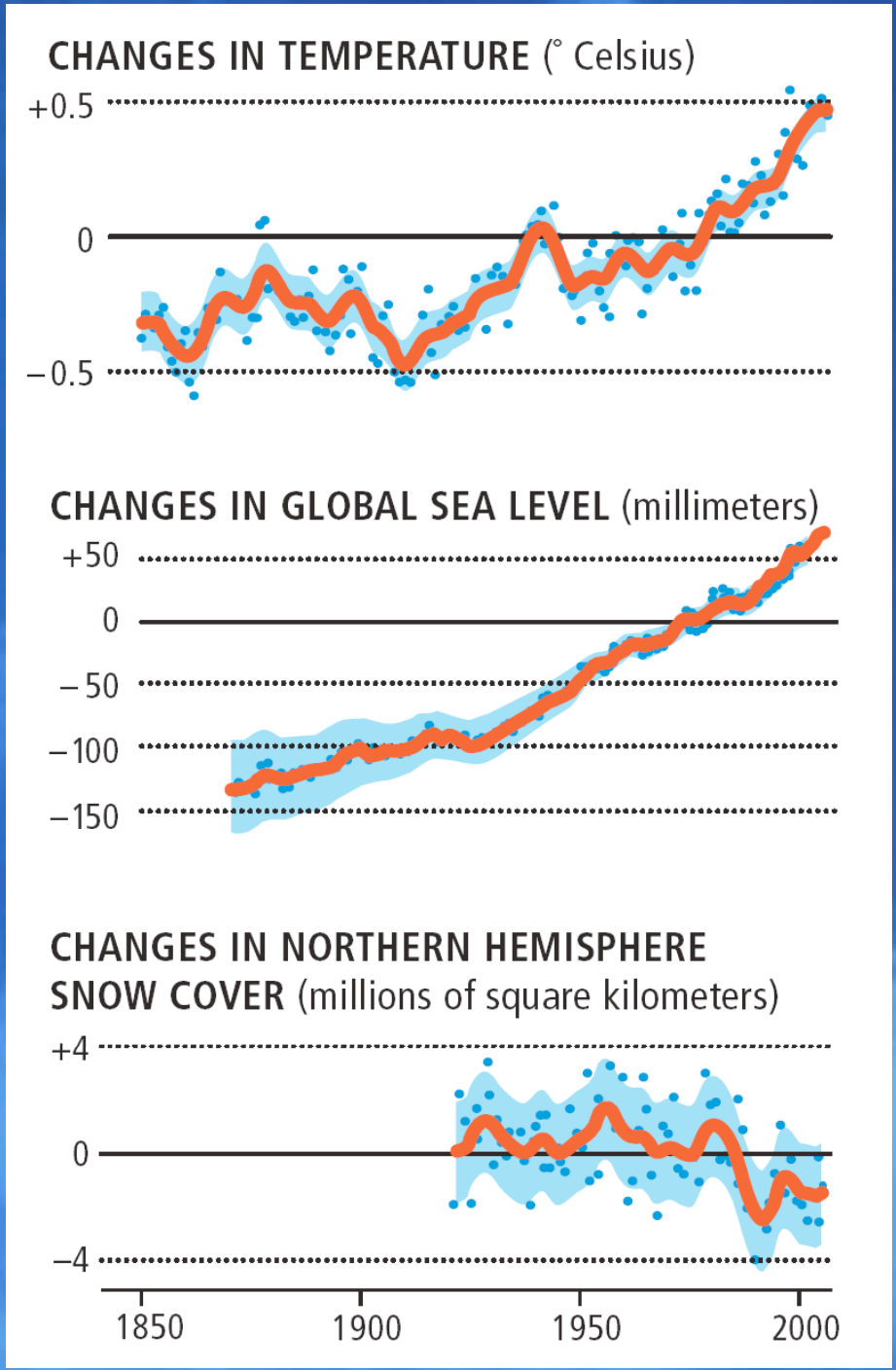
- ***State of the science***
- ***Impacts on plants, animals, and human societies***
- ***Options to slow or halt climate change***

2007 Peace Prize awarded jointly to former Vice President Al Gore, Jr. and the IPCC

Evidence for Physical Climate Change

Grinnell Glacier, Montana, 1938

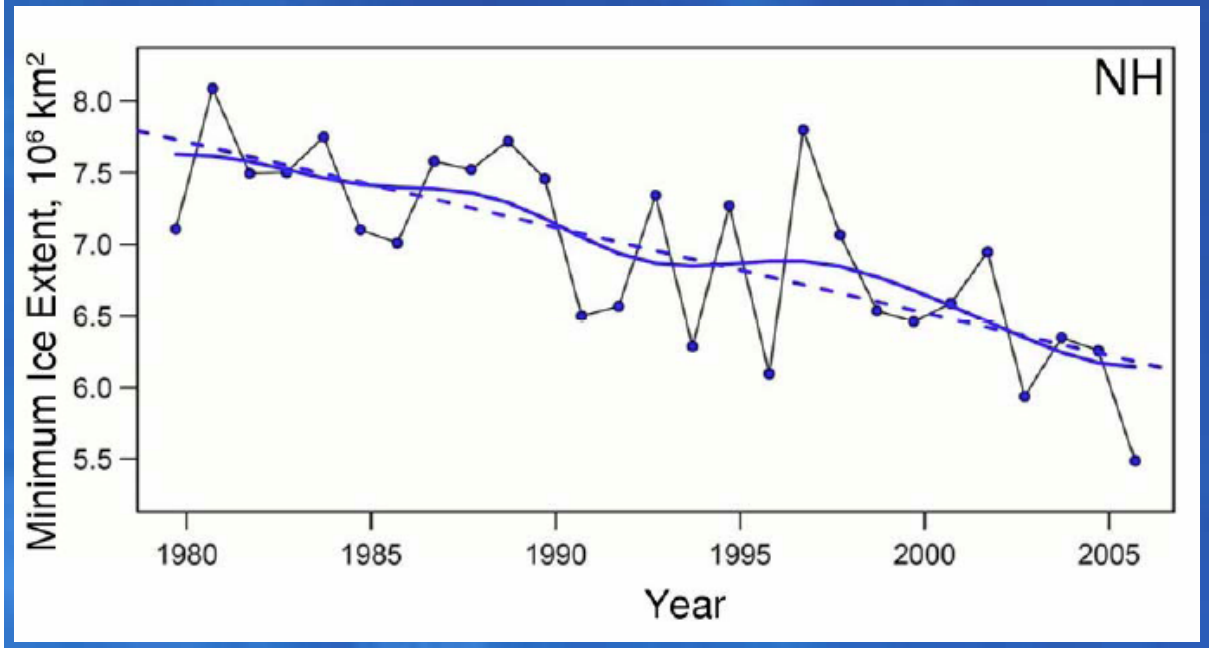
Grinnell Glacier, Montana, 2005



Current Findings

- ***The global temperature has risen by 1.5 degrees.***
- ***The sea level has risen by 10 inches.***
- ***Northern Hemisphere snow cover has decreased.***

Reductions in Arctic Sea Ice



Arctic sea ice, 1979

Arctic sea ice, 2005

- Arctic summer sea ice extent is shrinking at a rate of 7.5% per decade.

The New York Times

October 1, 2007

Science

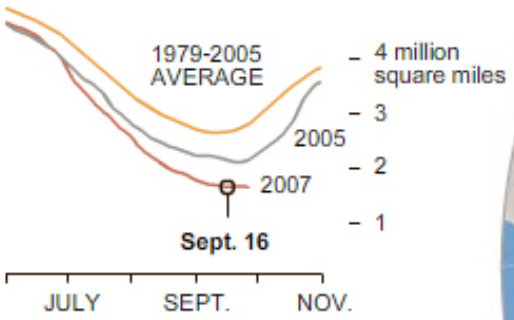
Sea Ice in Retreat

This summer saw a record-breaking loss of Arctic sea ice.

SUMMER SEA ICE

This summer saw a record-breaking loss of Arctic sea ice. Experts attribute the changes to the interaction of wind, weather, ice drift, ocean currents and greenhouse gases.

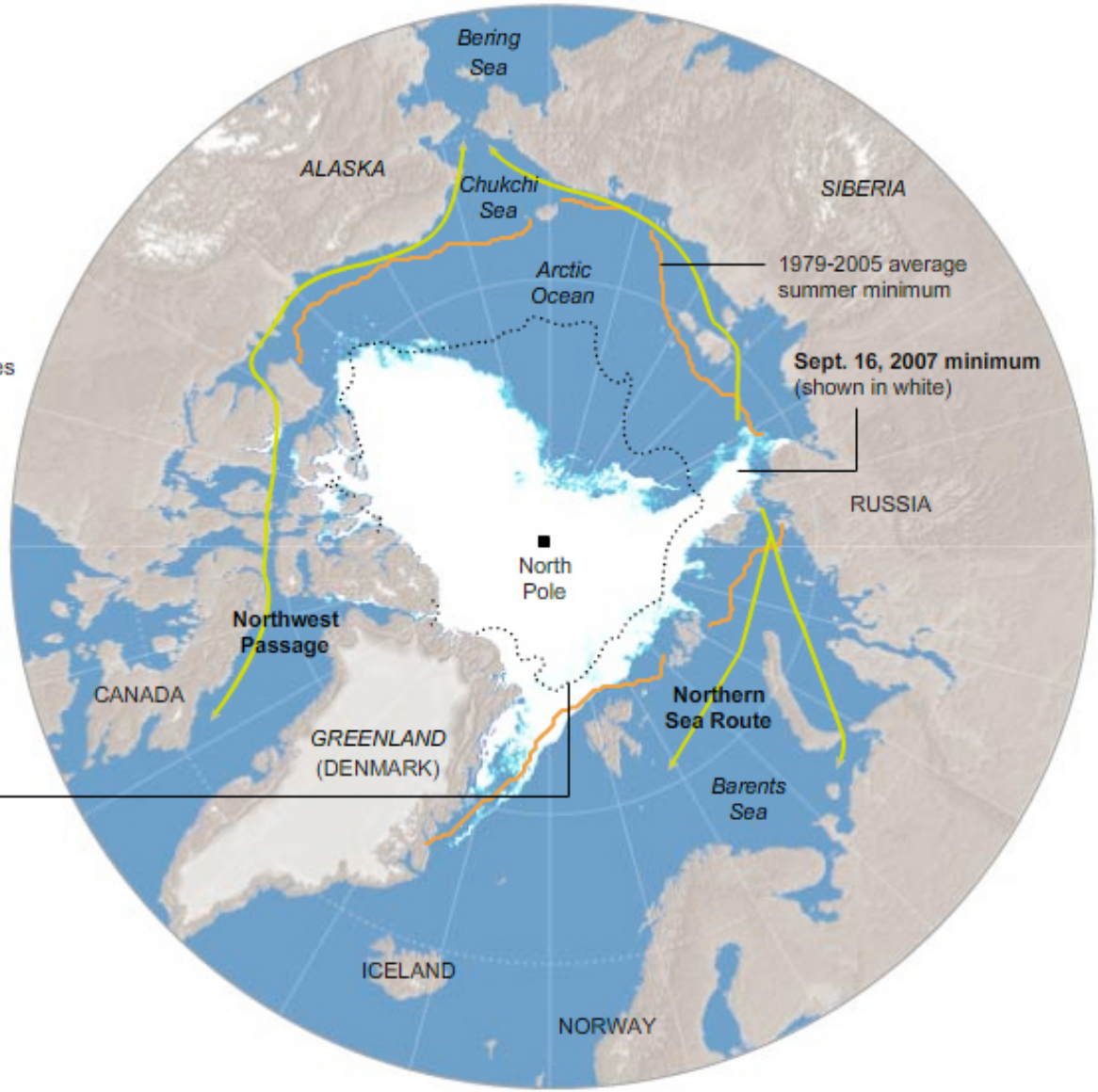
SUMMER SEA ICE EXTENT*



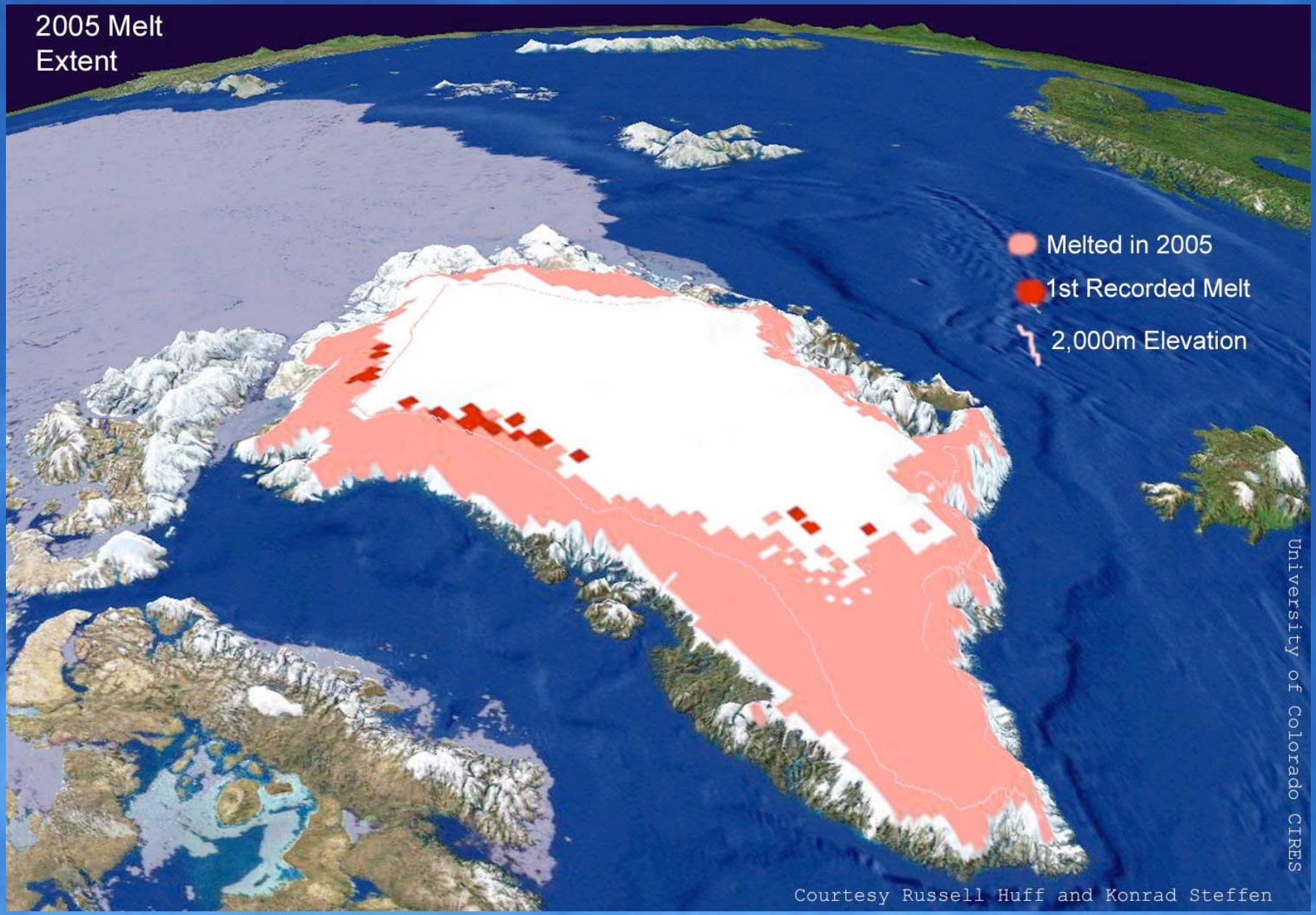
**Sea ice extent is the area of ocean covered by at least 15 percent ice.*

PERENNIAL SEA ICE

Ocean within this boundary had been covered with ice year-round since satellite records began in 1979. This summer was the first time that part of the perennial sea ice was open water.



Reductions in Greenland Sea Ice



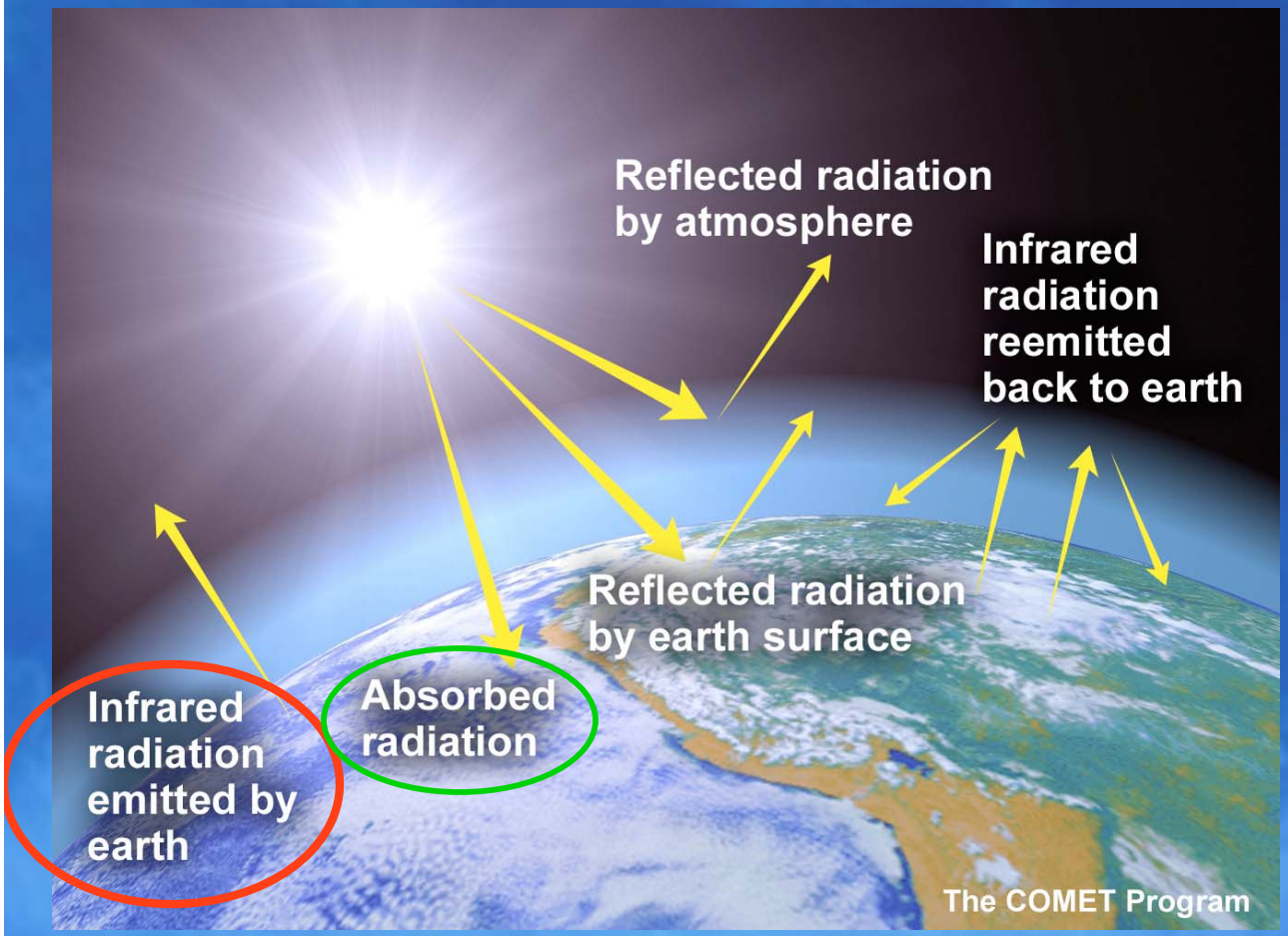
http://cires.colorado.edu/science/groups/steffen/greenland/melt2005/

Permafrost Melt – Drunken Forest, Alaska

Houses undermined by melting Permafrost

What is Causing the Climate to Change?

Imbalance of Energy for the Earth



Energy input/output:

- *Sunlight*
- *Heat*

Steady climate:

Balance in energy

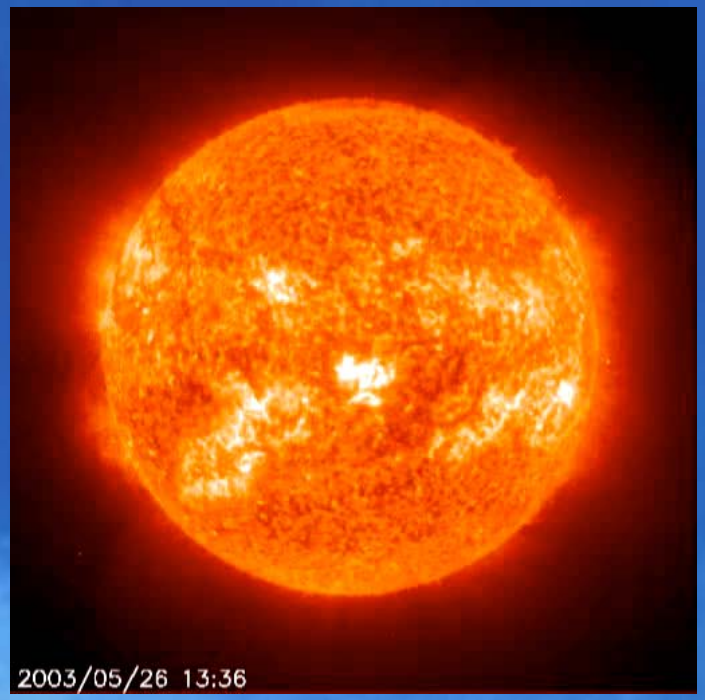
Changing climate:

Imbalance in energy

Natural Climate Forcing

Radiative forcing is an externally imposed change in the energy budget of the Earth's climate system

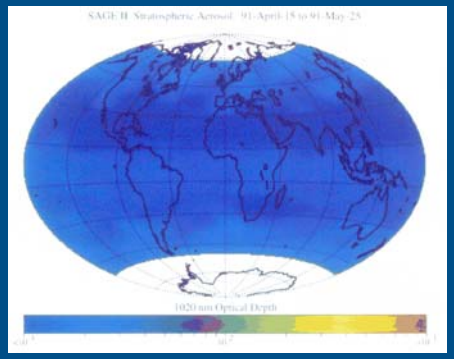
Volcanic Eruptions



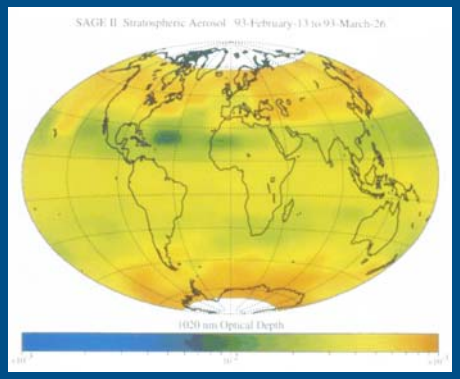
The Sun

Cooling Effect of Volcanoes

Mount Pinatubo, 1991

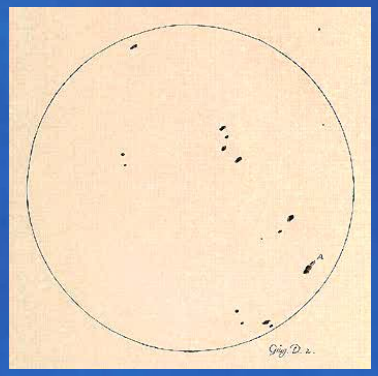


Reflection before: little aerosol in upper atmosphere

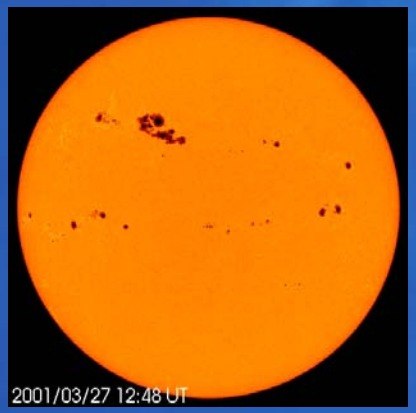


Reflection after: yellow sulfate

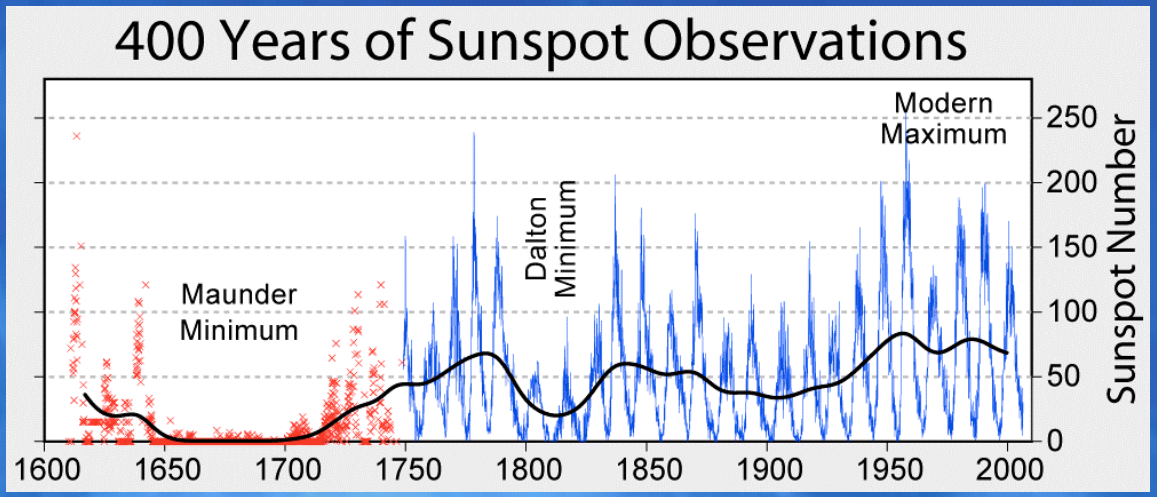
Changes in the Sun and Sunlight

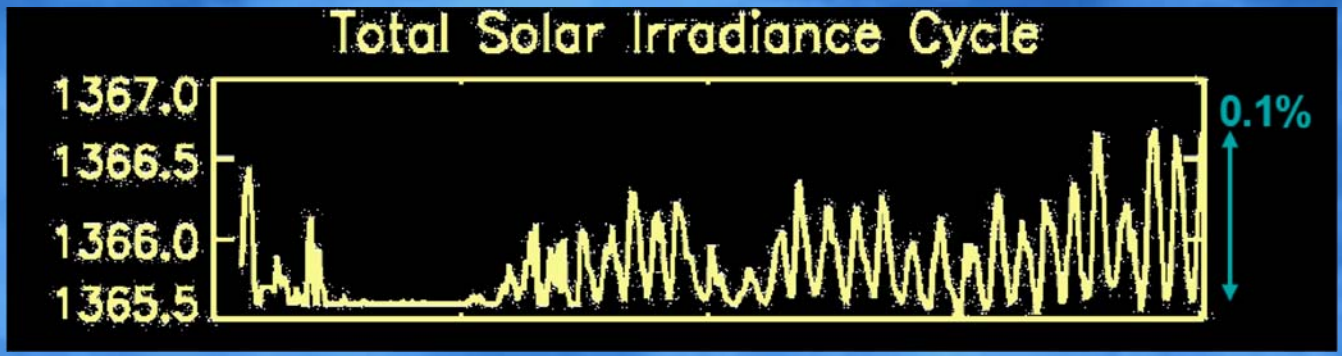


Sunspots by Galileo



Sunspots by NASA

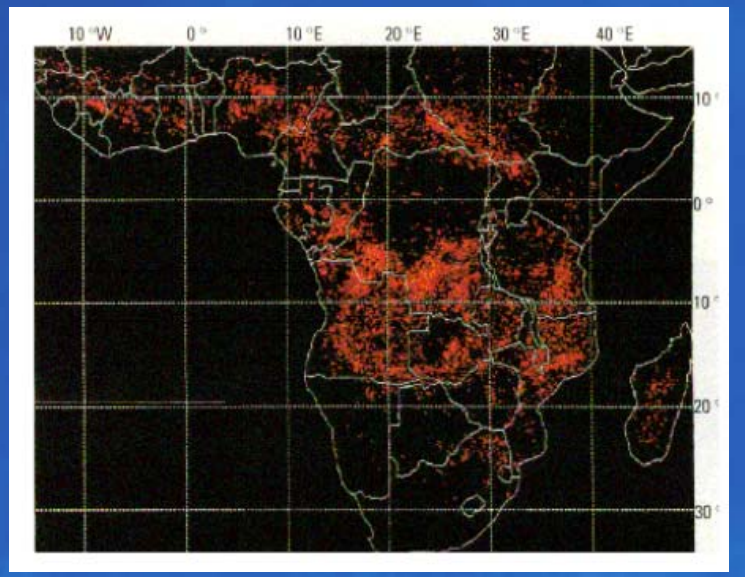




Man-Made Climate Forcing

Industry

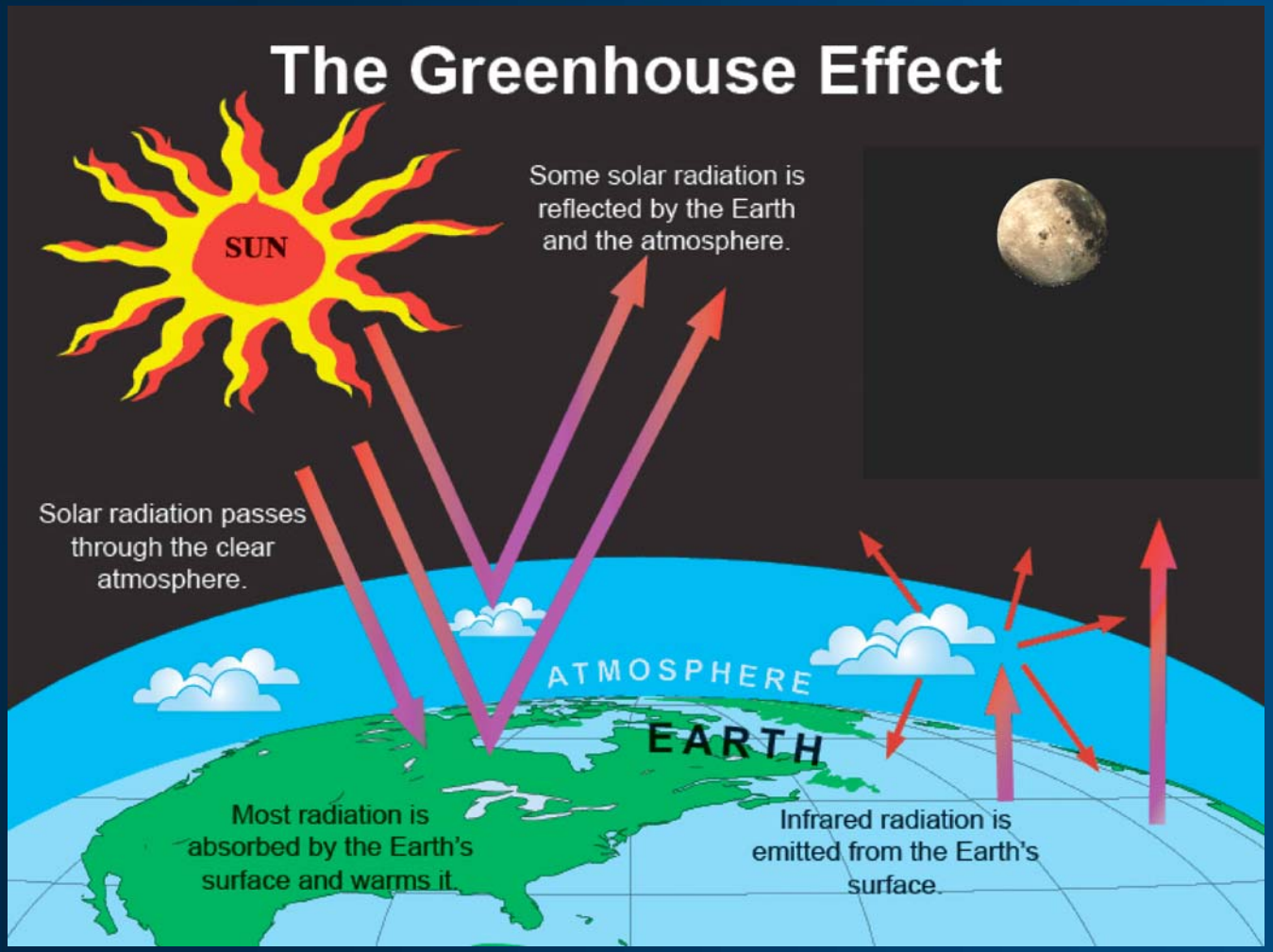
Transportation



Hot spots from African forest combustion

Fires

Earth's Atmosphere is Like a Blanket



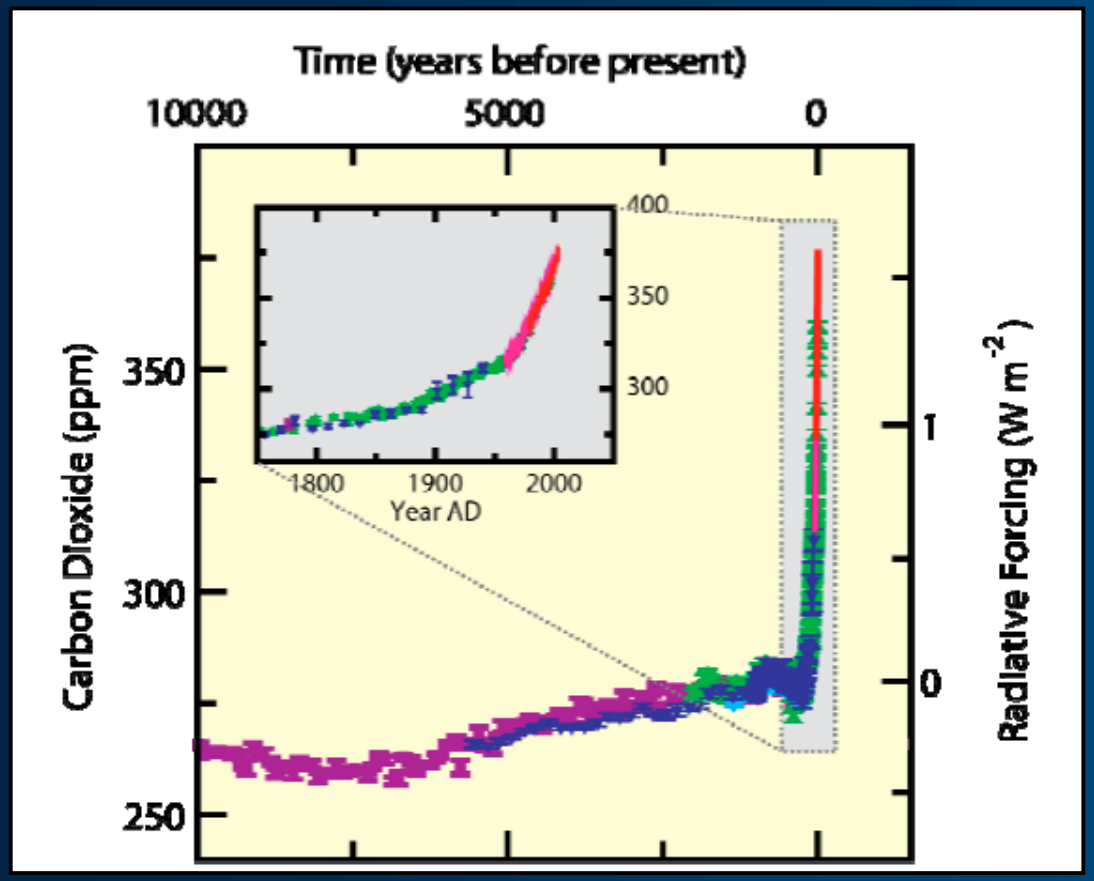
The greenhouse effect makes Earth habitable.

Greenhouse gases cause this effect.

We are increasing greenhouse gases.

This is increasing the heat trapped in the climate system.

Carbon Dioxide: Stability and Change

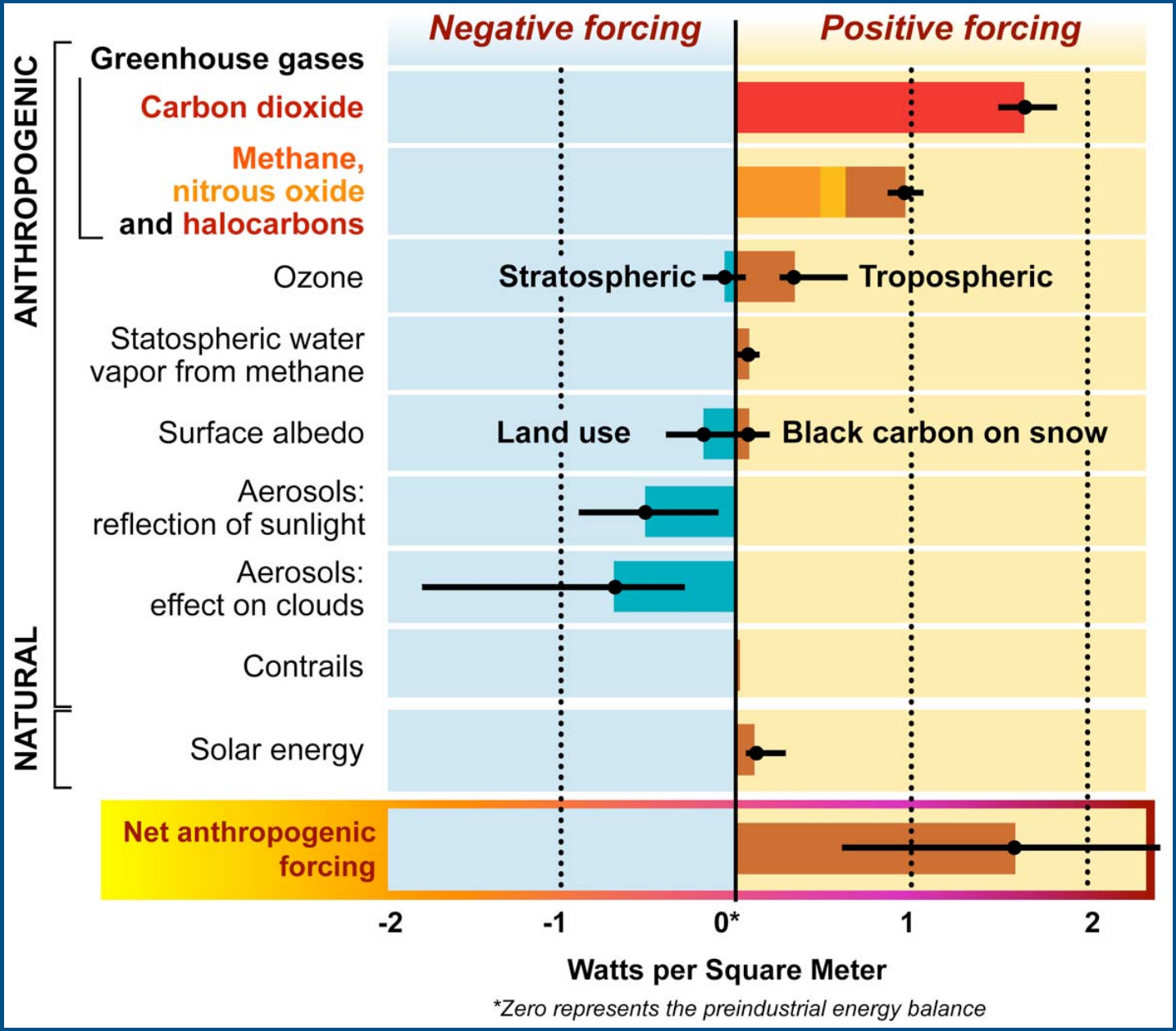


Carbon dioxide is the most important greenhouse gas.

<u>Key findings</u>:

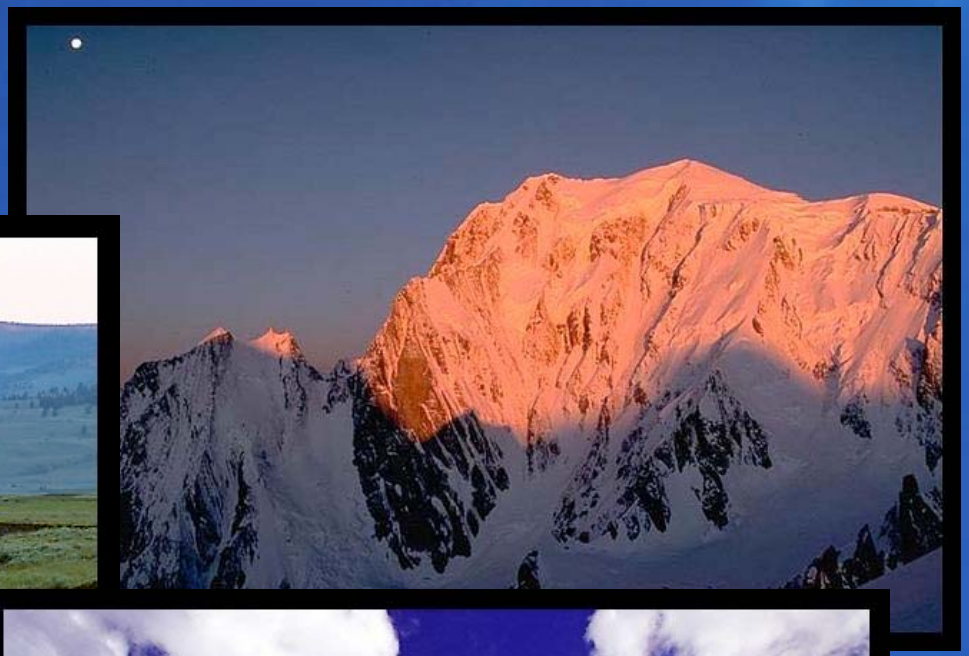
- ***The amount was constant for almost 10000 years.***
- ***The amount has risen in the industrial age.***

Changes to the Earth's Energy Balance



Climate Change: A Thought Experiment

Climate Models



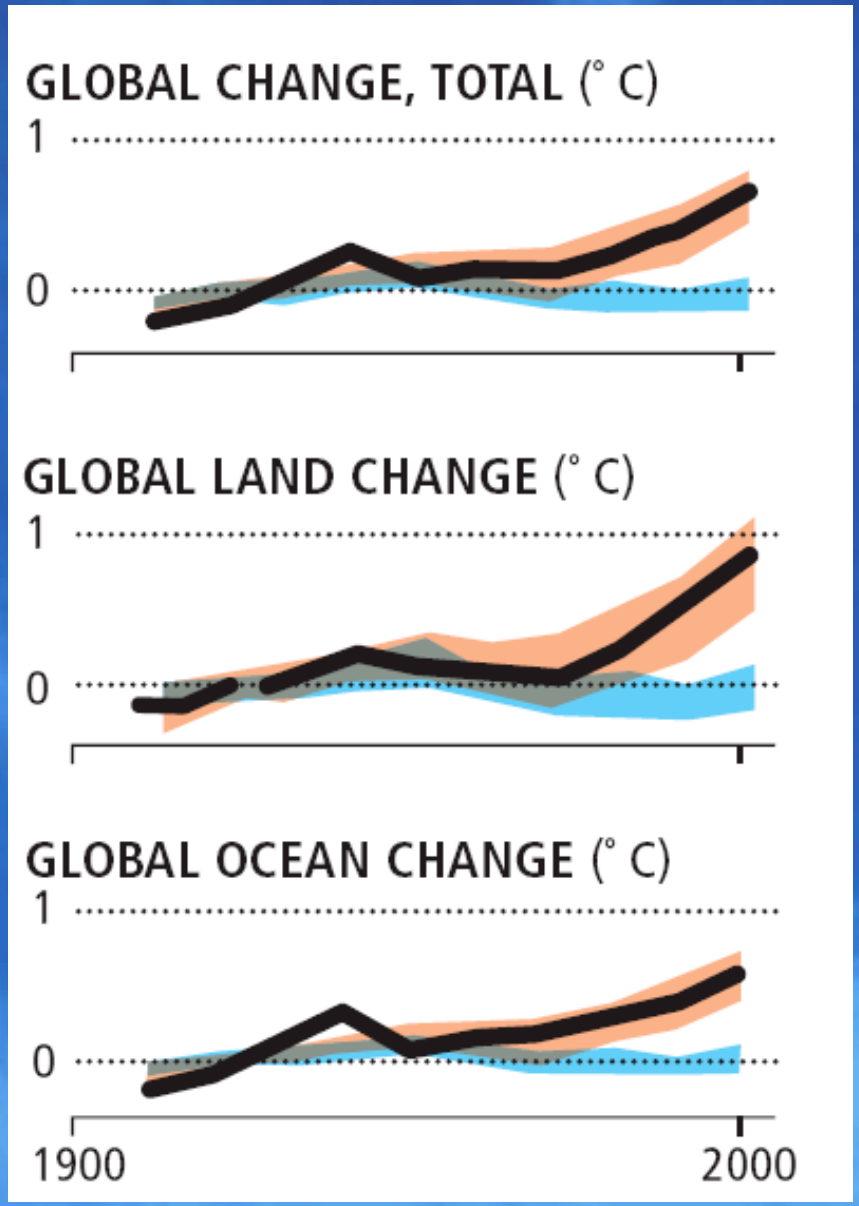
Earth without Humans

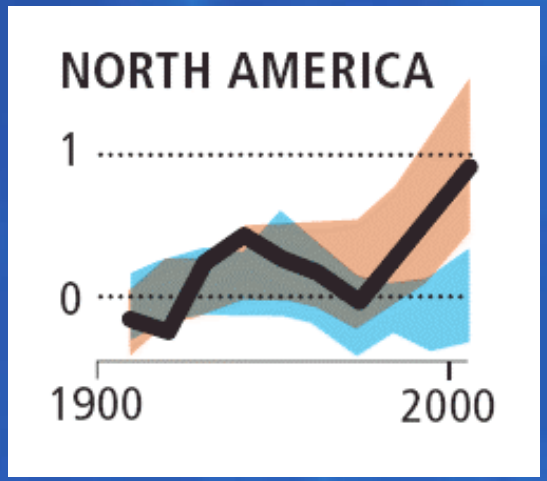
Climate Change: A Thought Experiment

Climate Models

Earth with Humans

Attribution of Climate Change





natural forcings

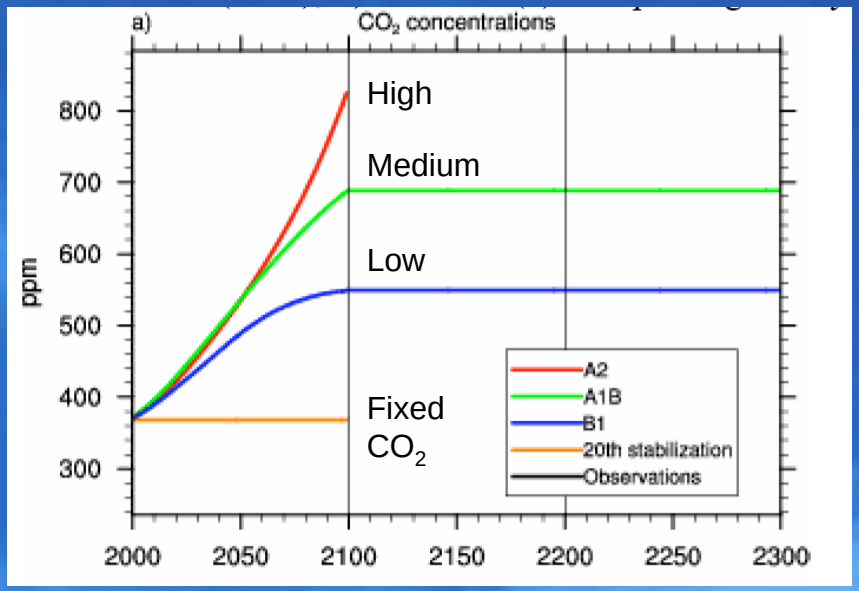
natural and manmade forcings

observations

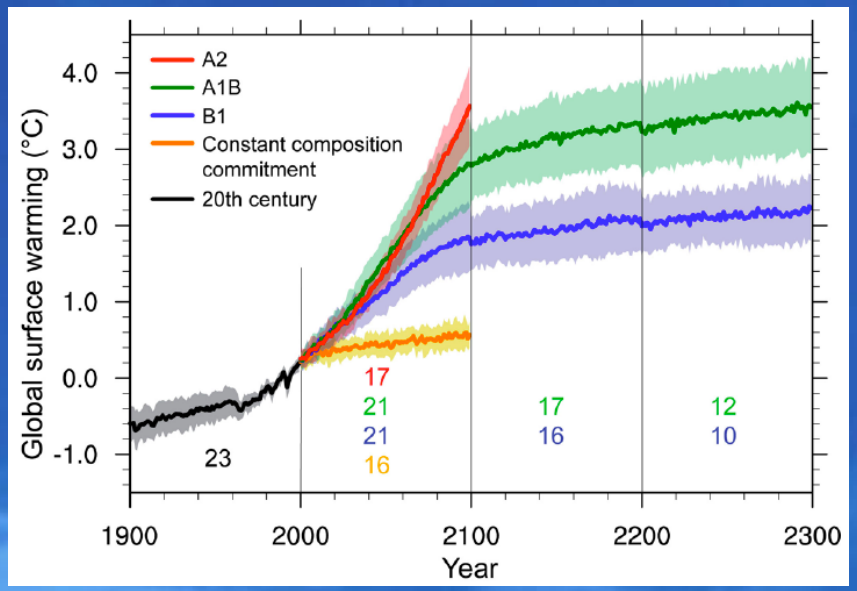
Result: It's very likely people are causing recent warming.

Projections for global temperatures

Emissions Scenarios



Global Temperature Projections

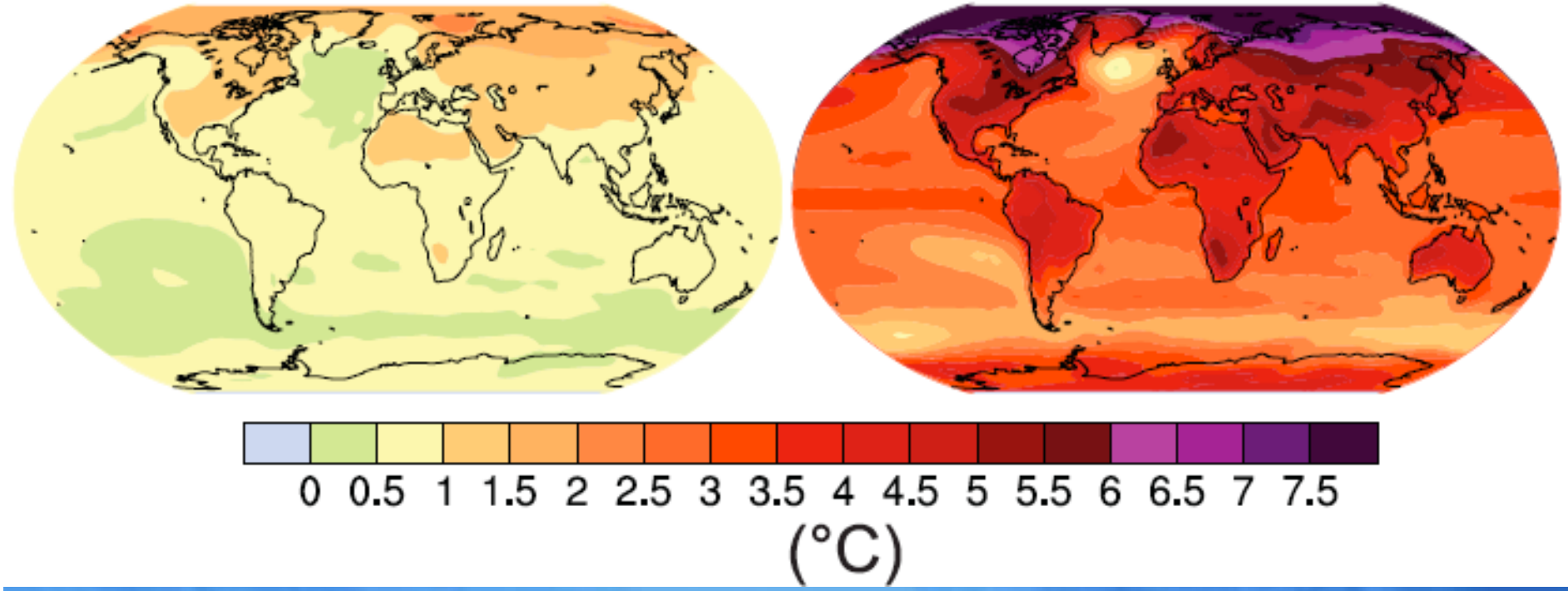


- Global temperatures could increase by 1.7 to 3.2 ºK.

IPCC Summary for Policy Makers, 2007

21st Century Change in Temperature

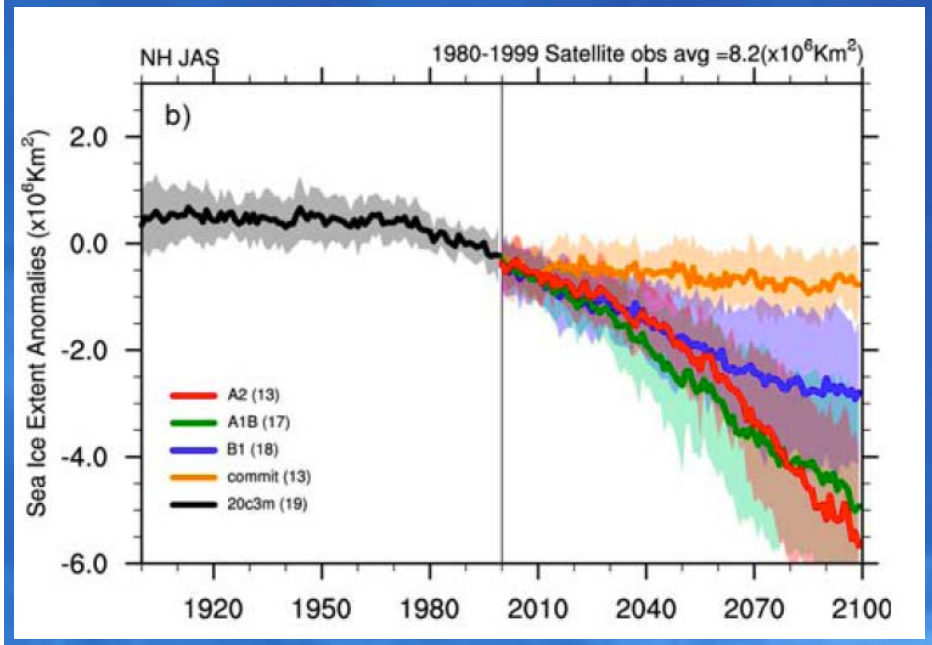
Near-term (2020) → Future (2099)
High Emissions

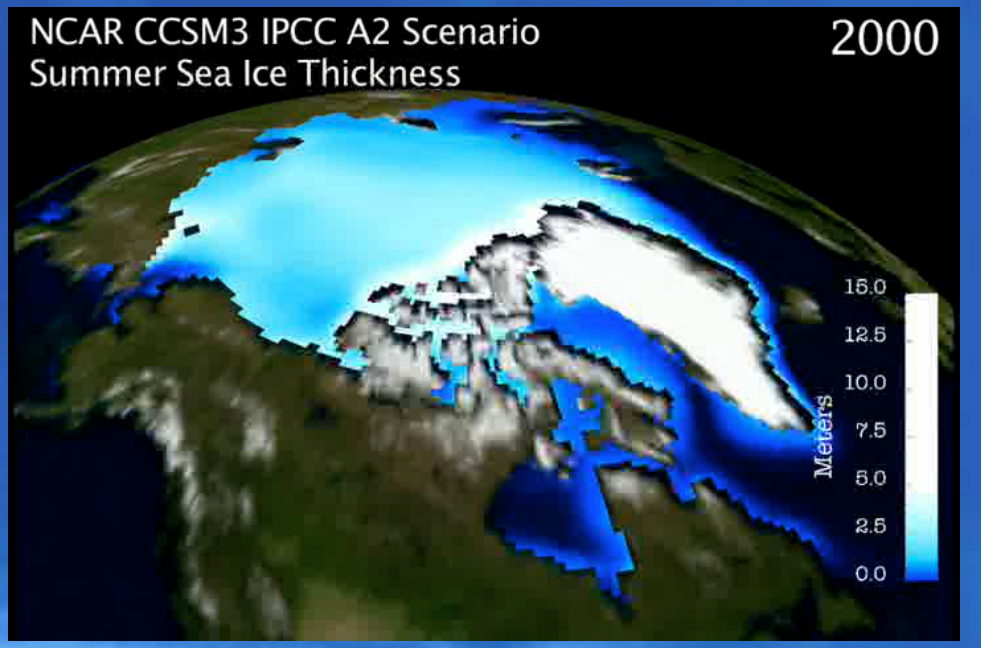


Roughly 2/3 of warming by 2030 is from historical changes.
Warming by 2030 exceeds 20th C natural variability by >2x.

IPCC Summary for Policy Makers, 2007

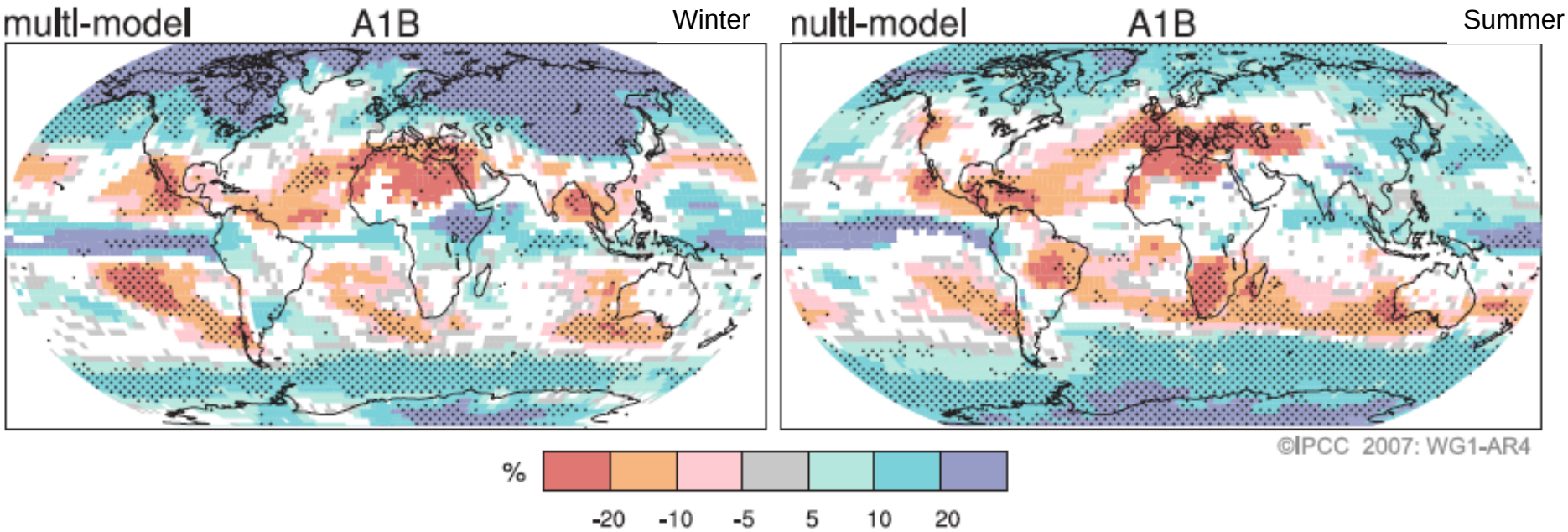
Further reductions in Arctic sea ice





21st Century Change in Precipitation

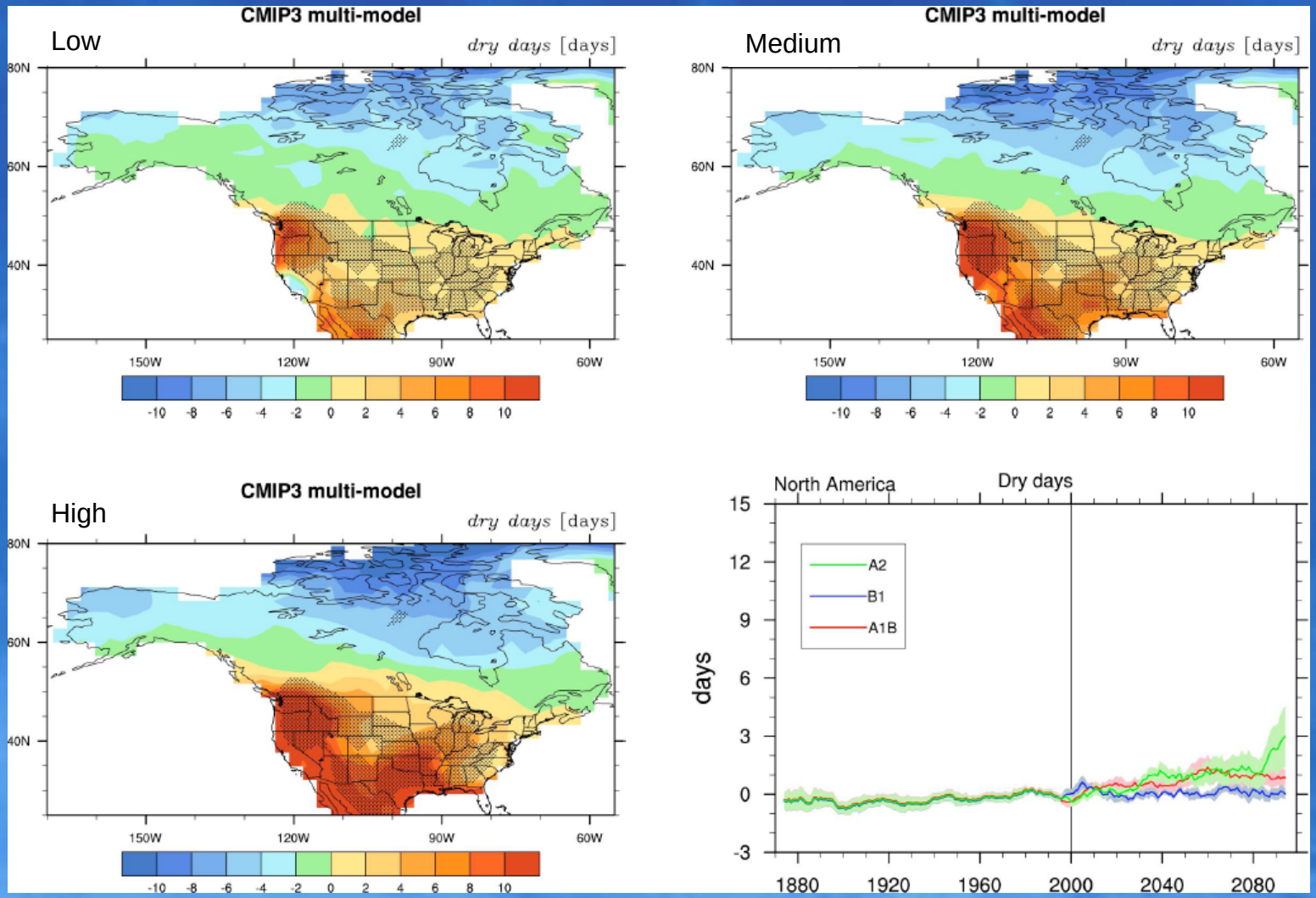
Summer and Winter 2099
Medium Emissions



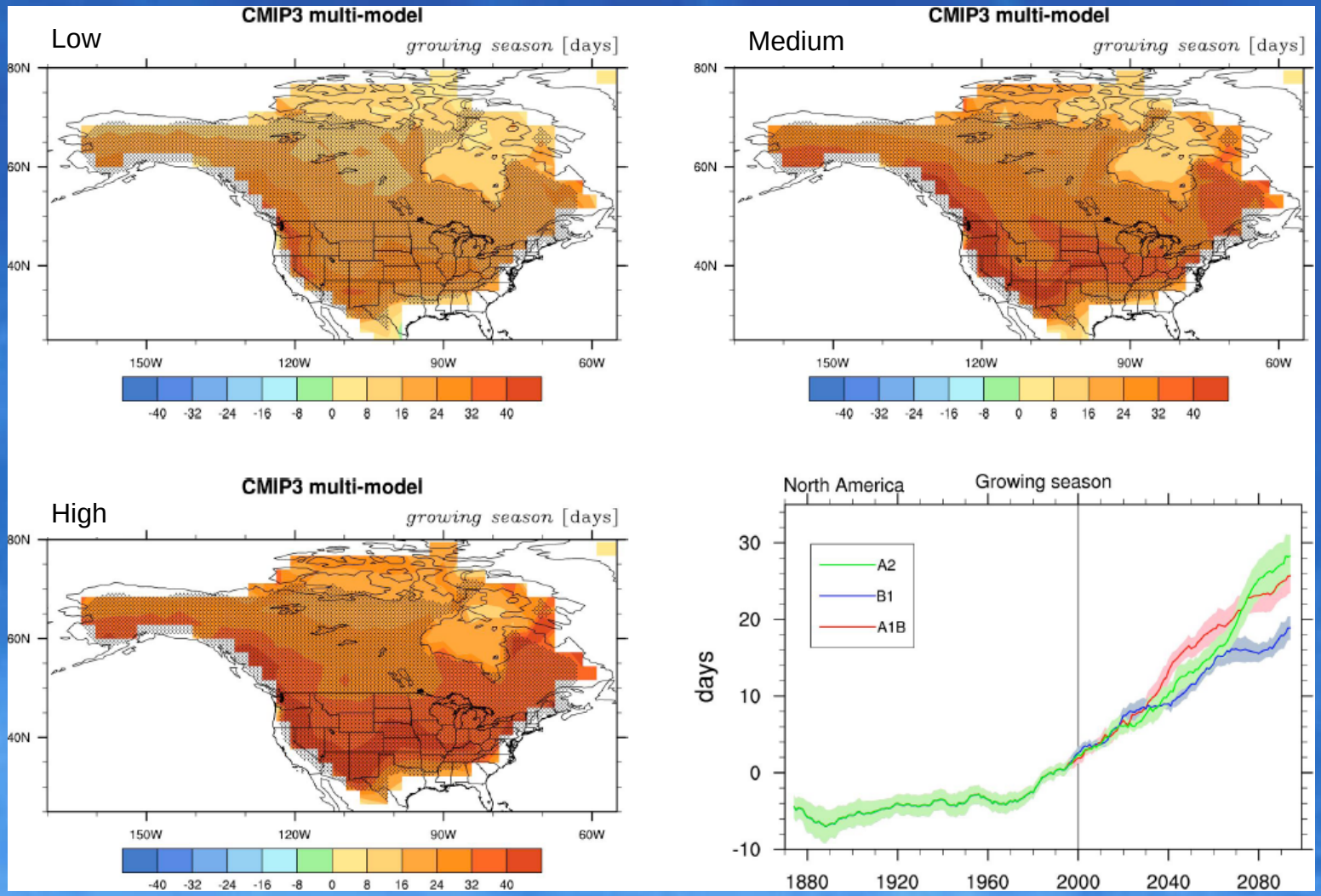
- Extratropical storm tracks are projected to move poleward.
- Increases in the amount of precipitation are very likely in high latitudes, while decreases are likely in most subtropical land regions

IPCC Summary for Policy Makers, 2007

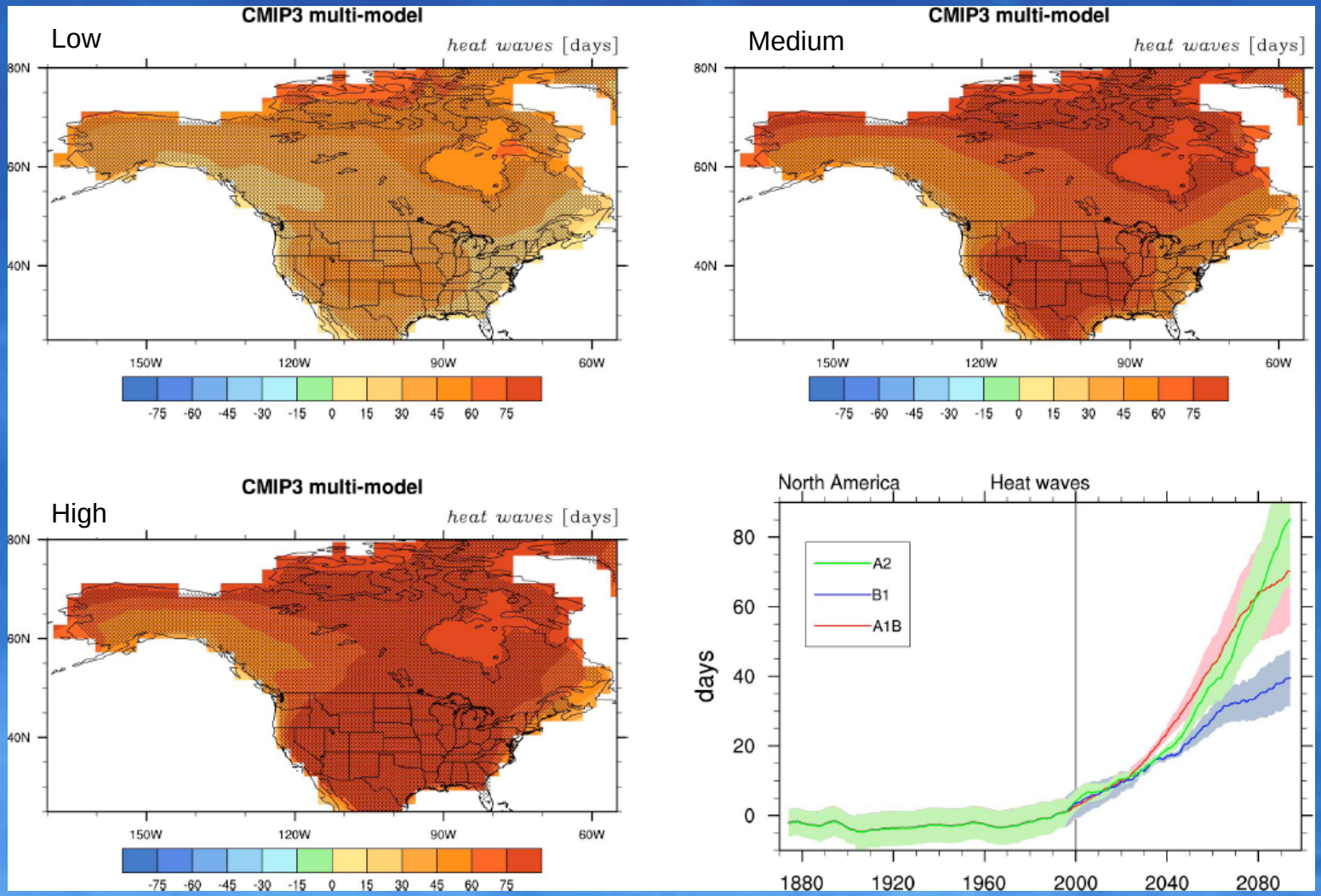
Maximum Number of Dry Days
North America



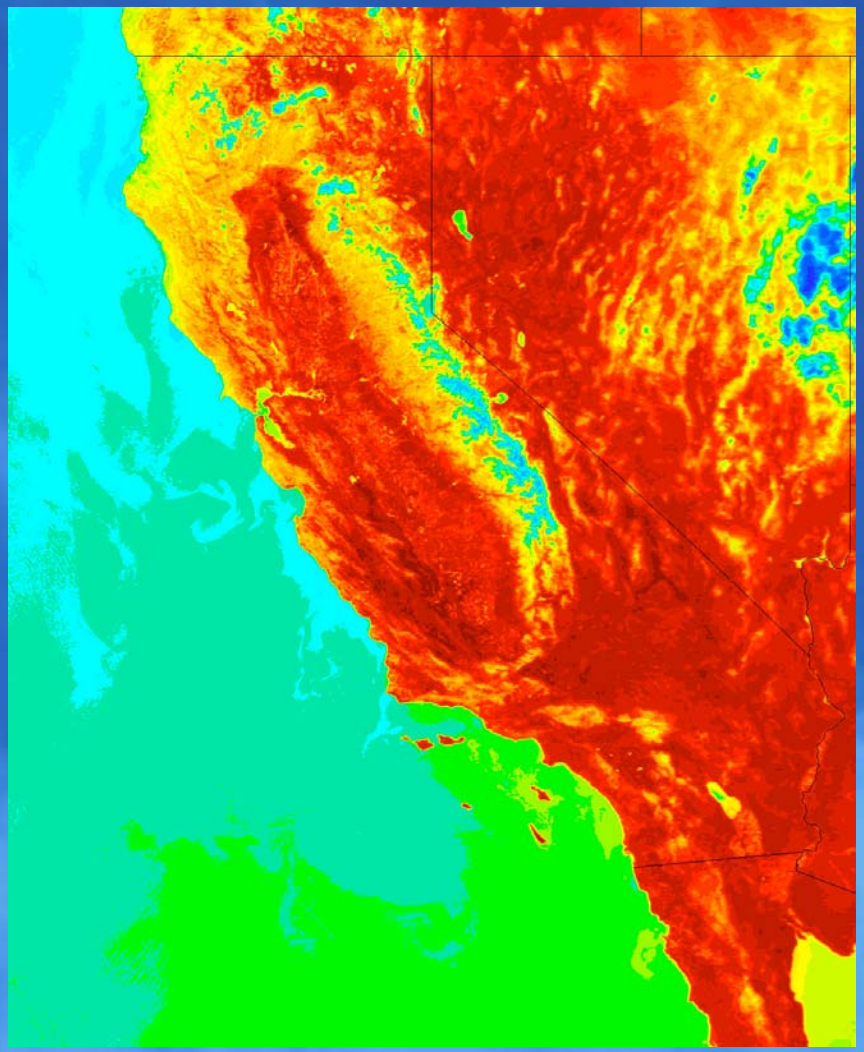
Growing Season Length
North America



Heat Wave Duration
North America

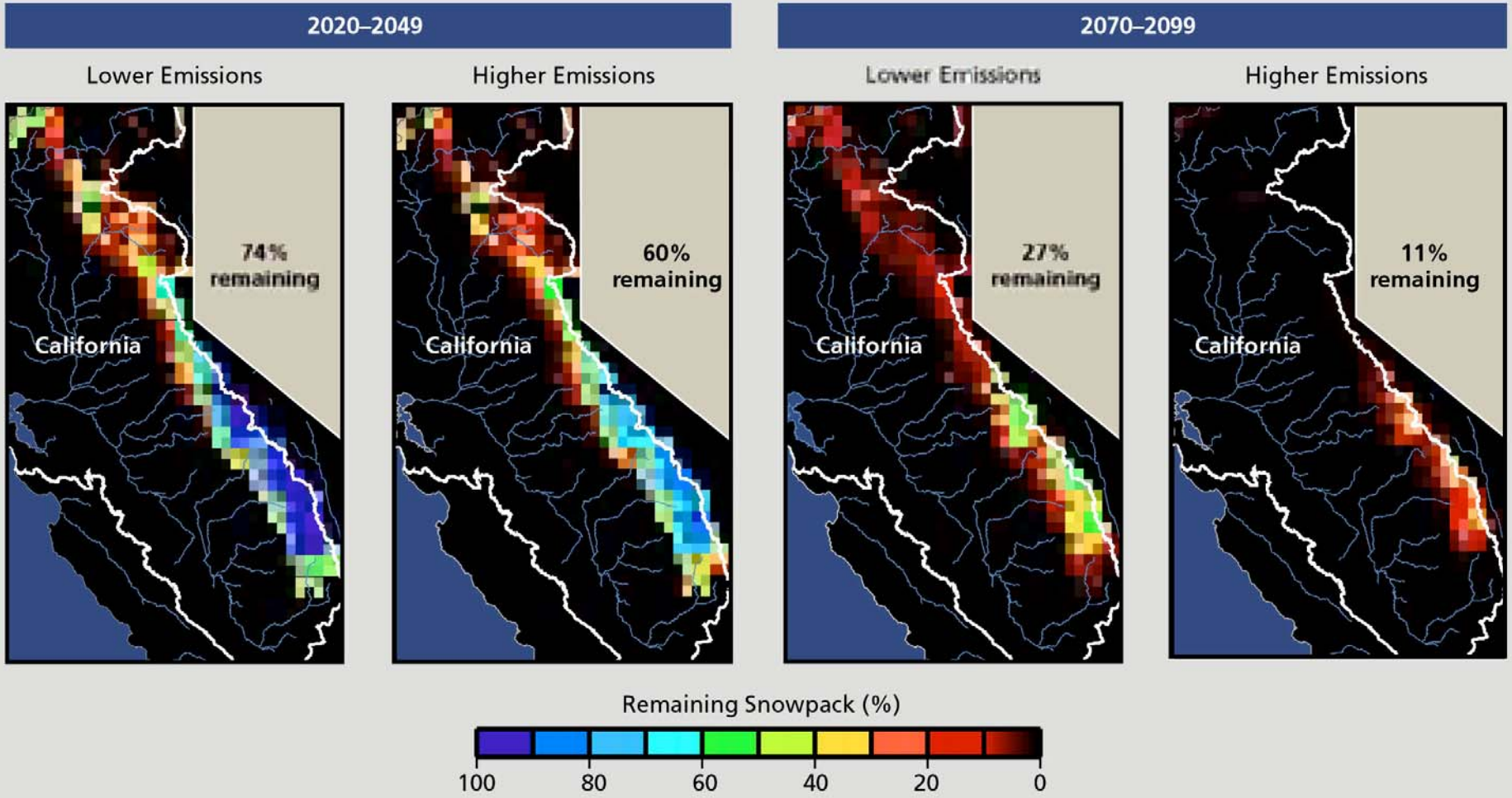


Extreme Temperature Range
North America



Heat wave in Southern California (surface temperature image) May 2, 2004:
Record-breaking temperatures broiled much of California, as an ongoing spring heat wave plagued the region. According to the AP, 16 areas in Southern California set new record highs for the day ... downtown Los Angeles 97 °F (36 C), and Long Beach, 102 °F (39 C). Baked in the summer sun, the land had reached sizzling hot temperatures, nearing 150 °F (70 C) when the Moderate Resolution Imaging Spectroradiometer (MODIS) flew over on the Aqua satellite at 2:20 pm, US Pacific time. Land temperatures are often higher than air temperatures.

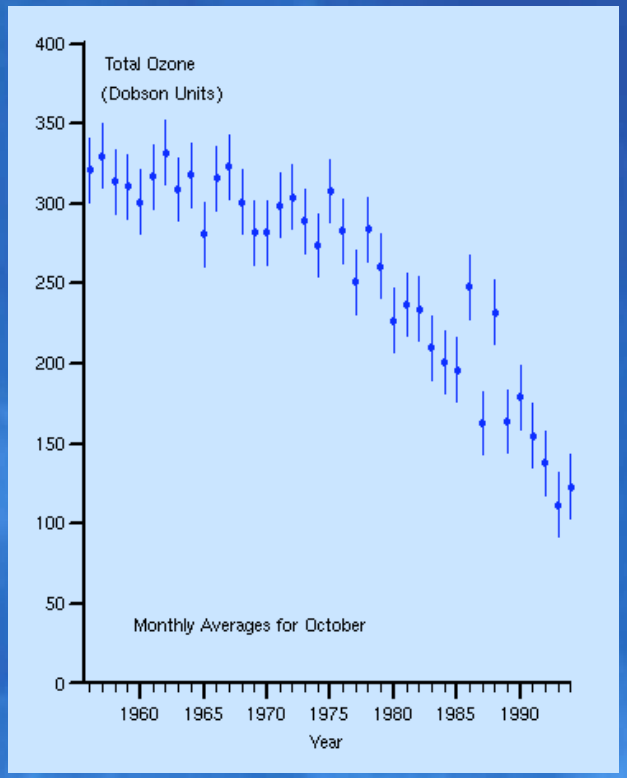
Projections of Sierra snow-pack and implications for water

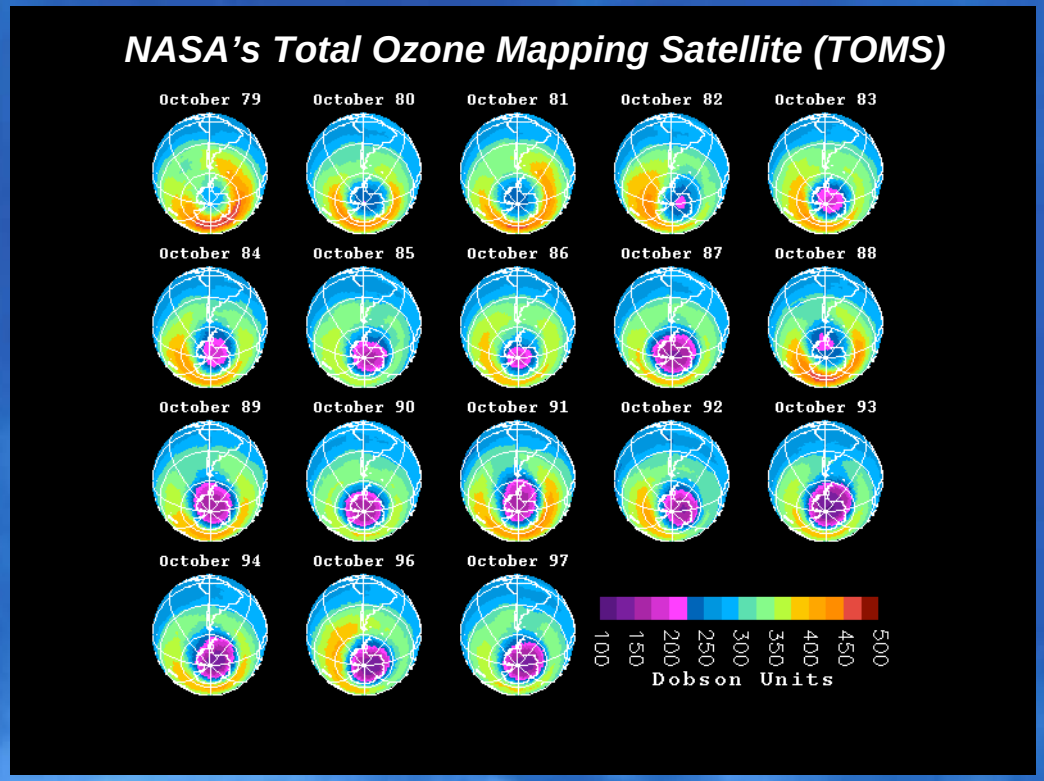


Conclusions on the state of the science

- We are changing the chemistry of the atmosphere.
- It is very likely these changes heat the Earth.
- Scientists are certain the climate is warming.
- Continued emissions will amplify this warming, with serious consequences for many regions.
- The warming will continue for <u>centuries.</u>

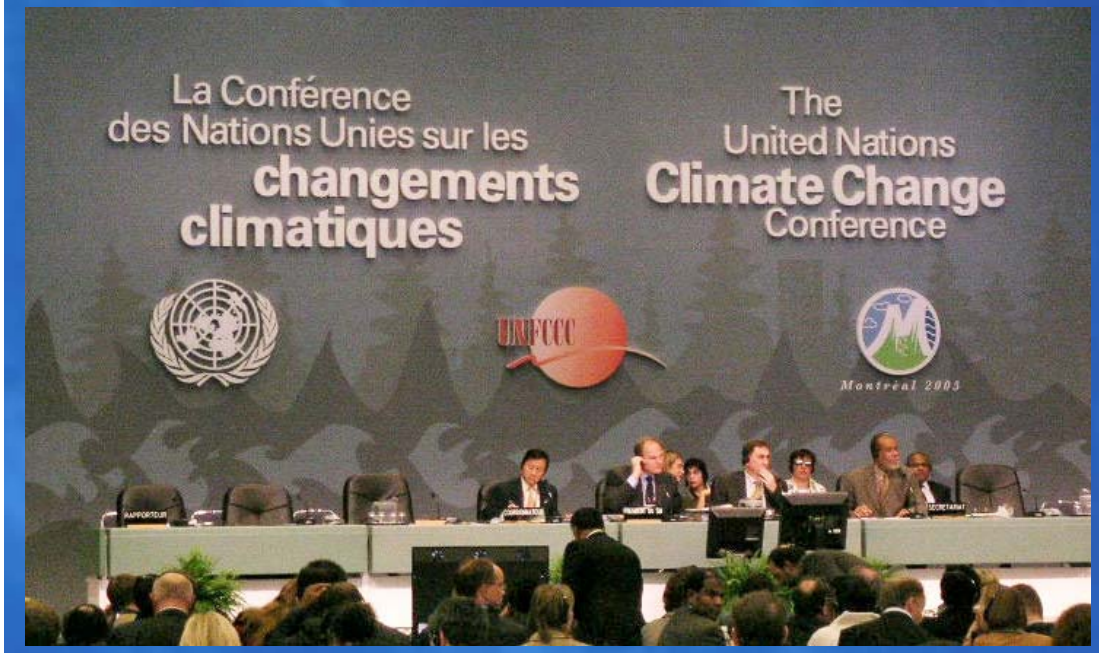
The ozone hole: a mitigation success story

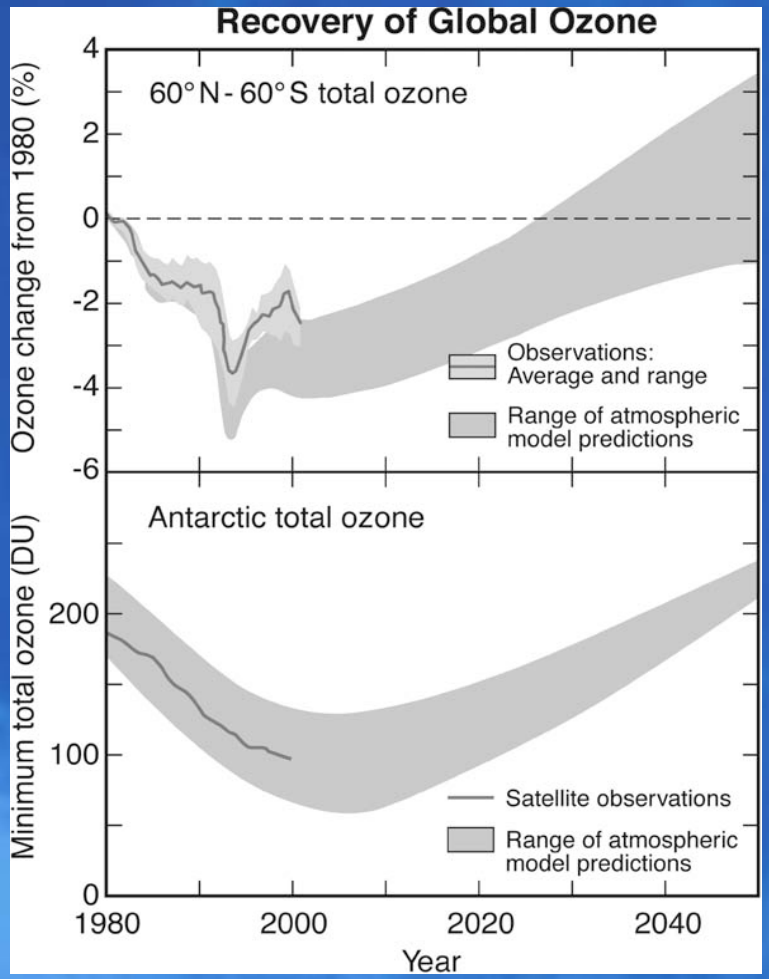


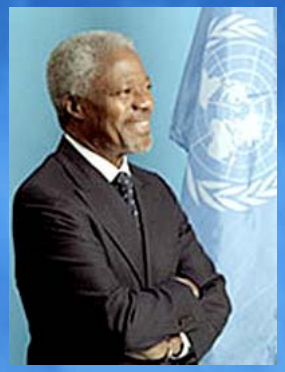


- Ozone protects life on Earth from harmful UV.
- Depletion of ozone by CFCs is a real threat.
- International assessments led to action.

Projected recovery of ozone due to the Montreal protocol







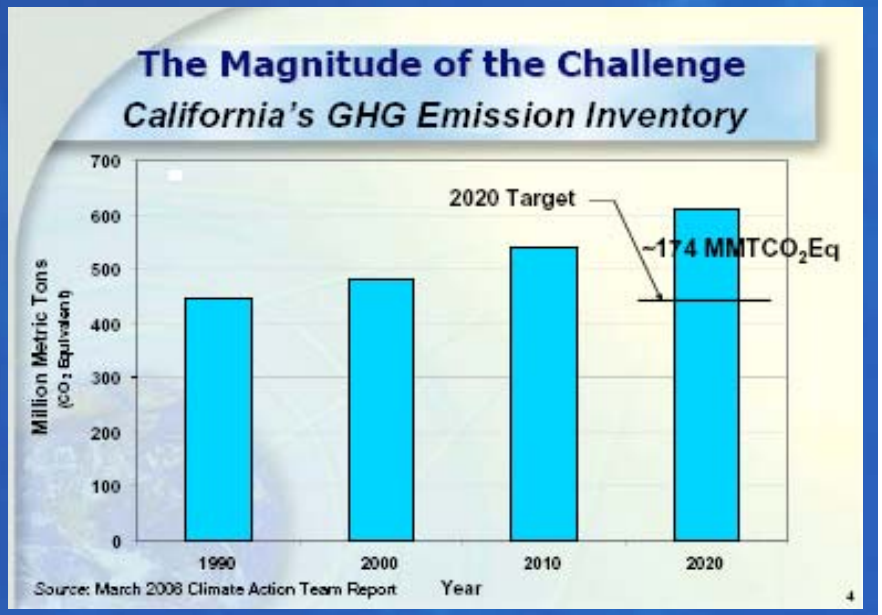
"Perhaps the single most successful international agreement to date…"

Kofi Annan

California's Actions to Slow Climate Change

- The AB32 law requires California GHG emissions to be reduced to 1990 emission levels by 2020.
- AB32 establishes comprehensive program of regulatory and market mechanisms to achieve reductions of greenhouse gases (GHG).

September 2006
Gov. Schwarzenegger Signs AB32 Legislation to Reduce Greenhouse Gas Emissions

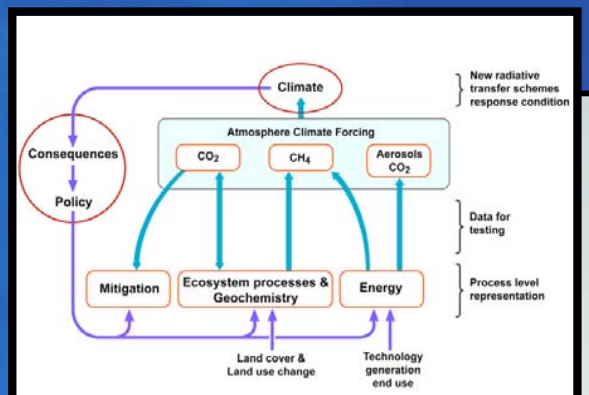


Berkeley Lab and UC Berkeley

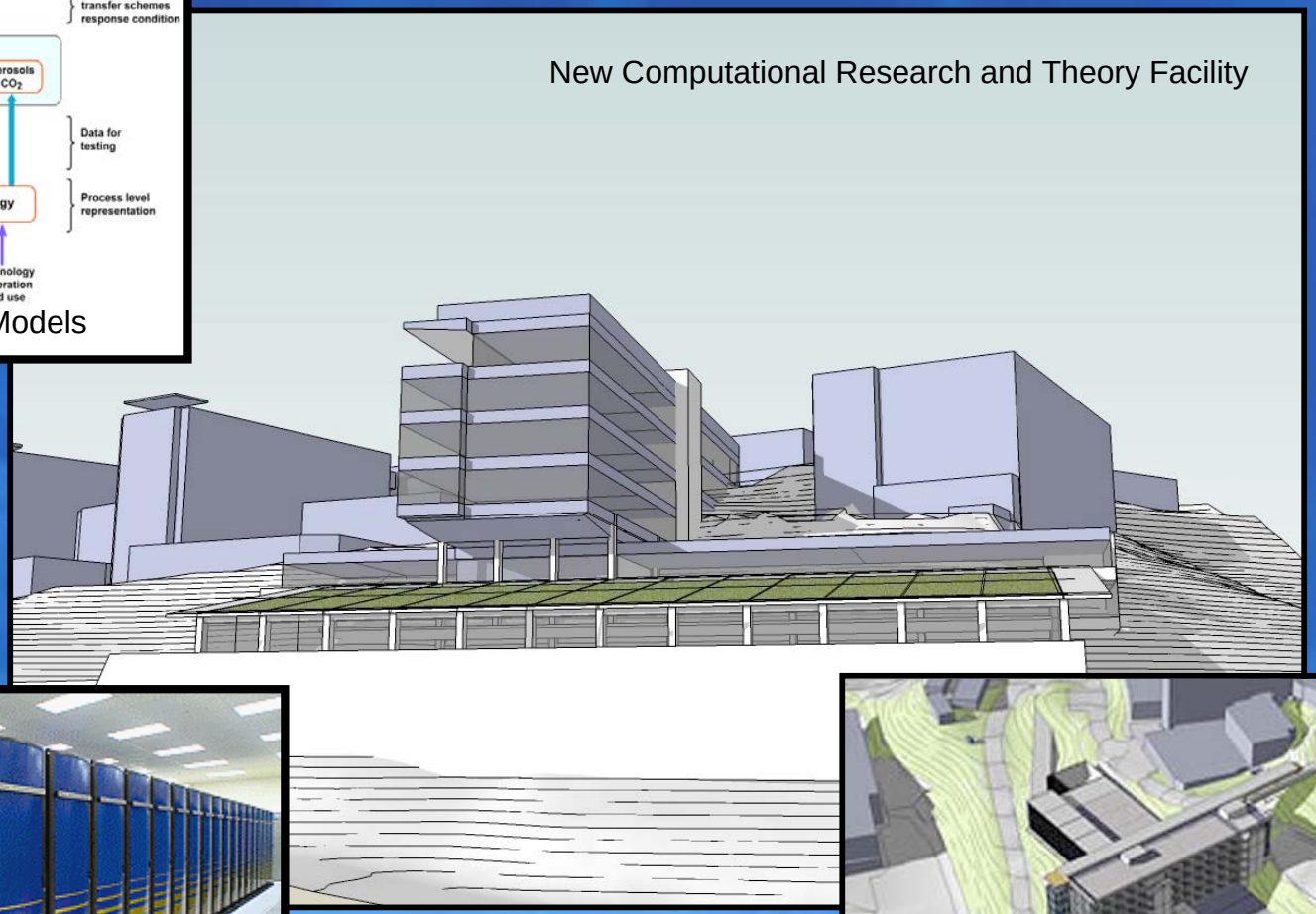
Groups are advancing climate models in:

- Earth Sciences (LBNL)
- Earth & Planetary Sciences (UCB)
- Computing (LBNL/UCB)
- Environmental Energy Technologies (LBNL)

LBNL efforts to support climate forecasts:
World-class supercomputers



New Earth System Models



New Computational Research and Theory Facility

Options for Action

- We have many options to reach these goals.
- We have the technology to start now.

Options for Action

- We *can* reduce greenhouse gases.
- We *can* slow down global warming.

Berkeley Passes Measure G, Greenhouse Gas Emission Reduction Ordinance, by 81% in November 2006

Tesla Roadster, San Carlos, CA.

We need to start NOW.