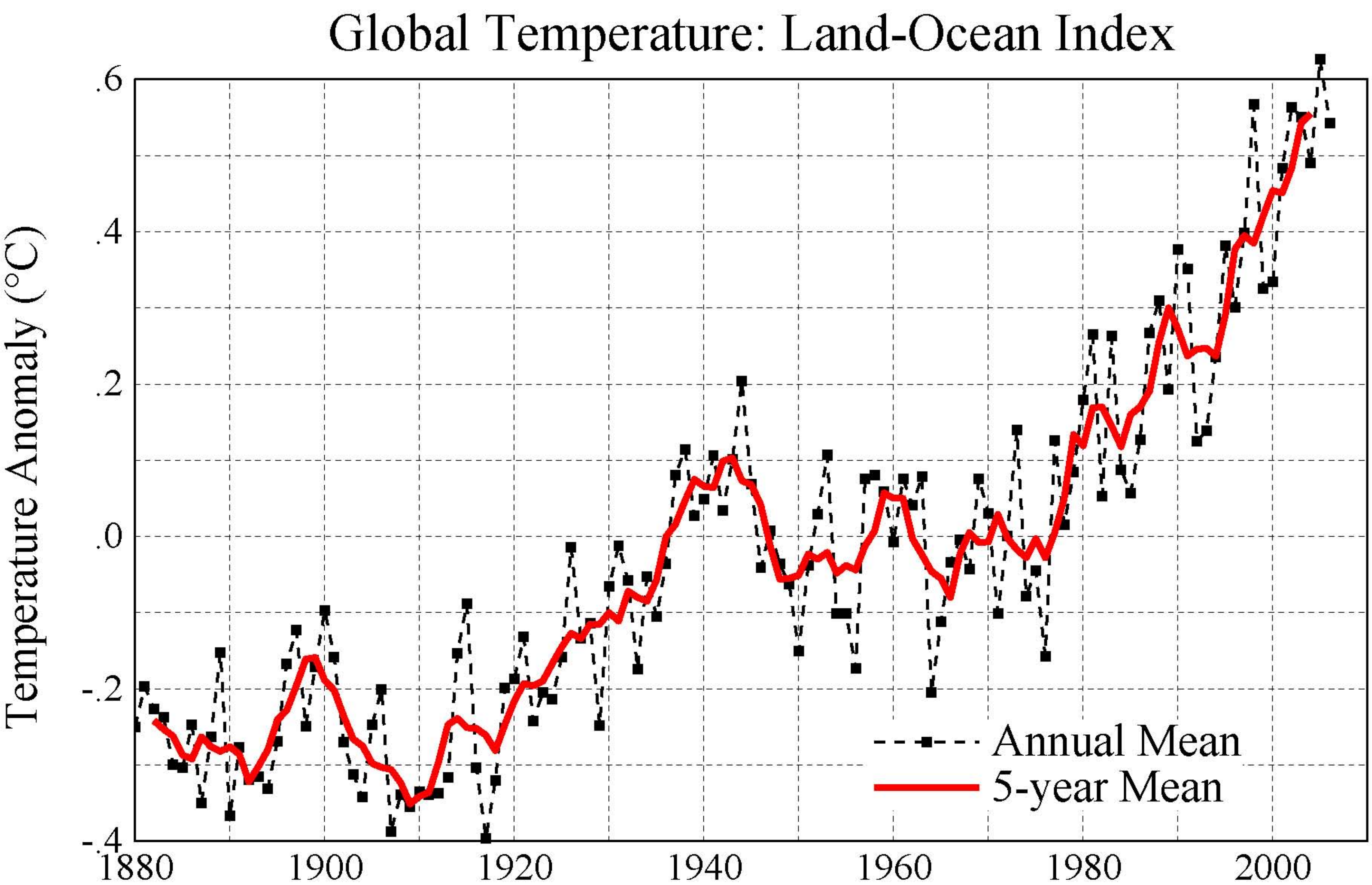
U.S. District Court: Vermont

Auto Dealers & Manufacturers versus Vermont Agency of Natural Resources

Declaration of James E. Hansen

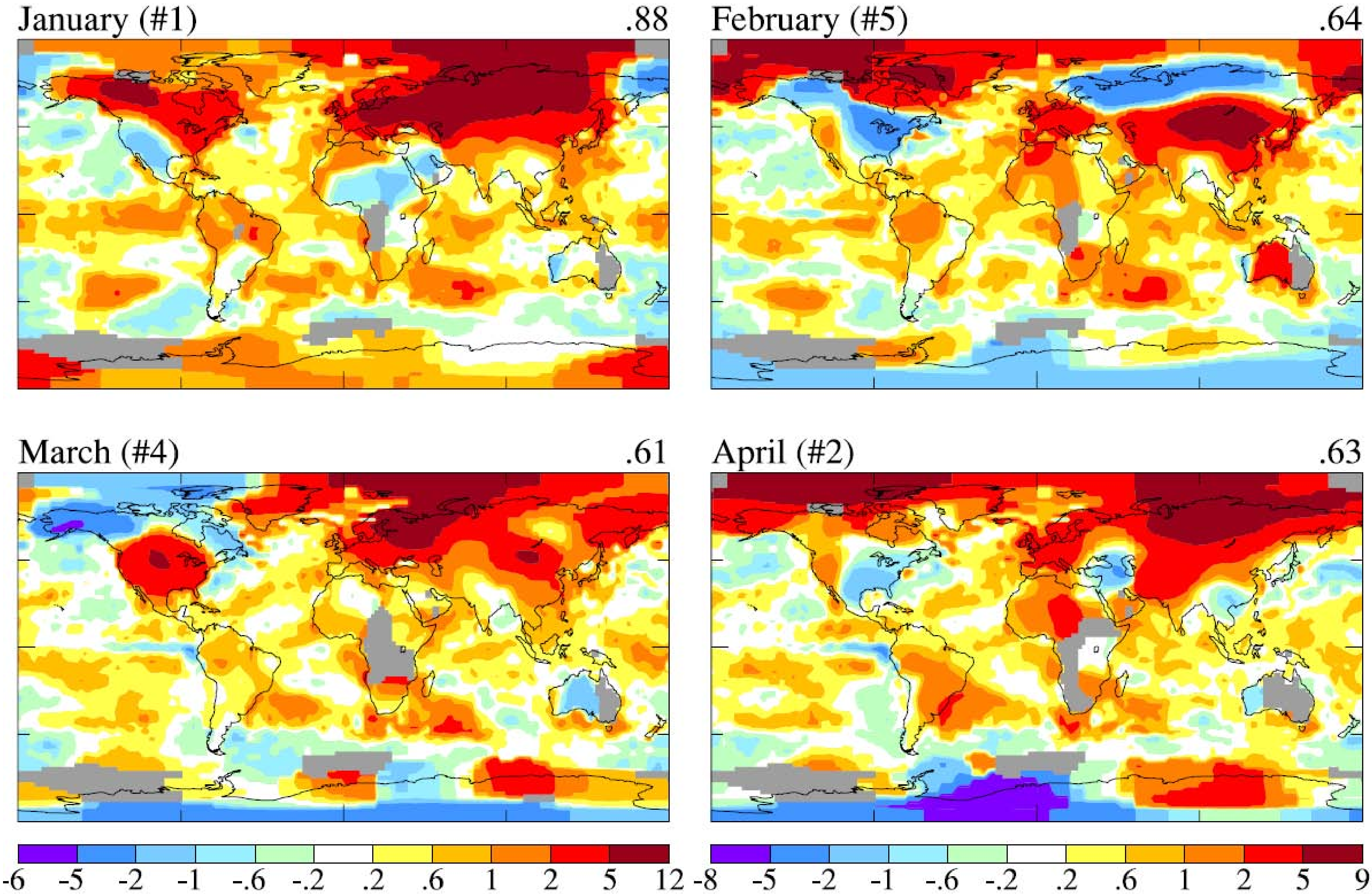
03 May 2007

Burlington, Vermont



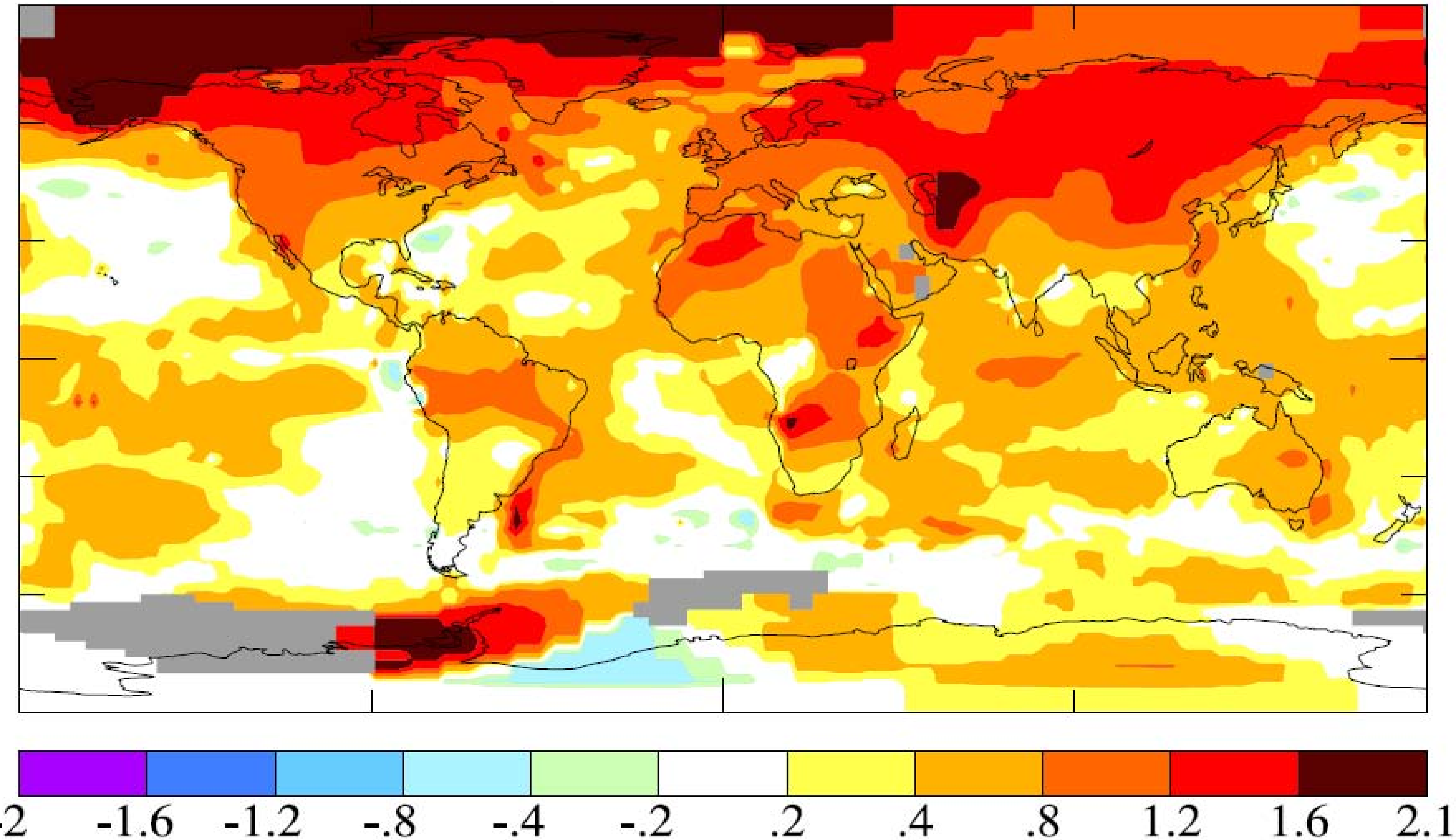
Global Temperature: Land-Ocean Index
Temperature Anomaly (°C)
.6
.4
.2
.0
-.2
-.4
1880
1900
1920
1940
1960
1980
2000
Annual Mean
5-year Mean

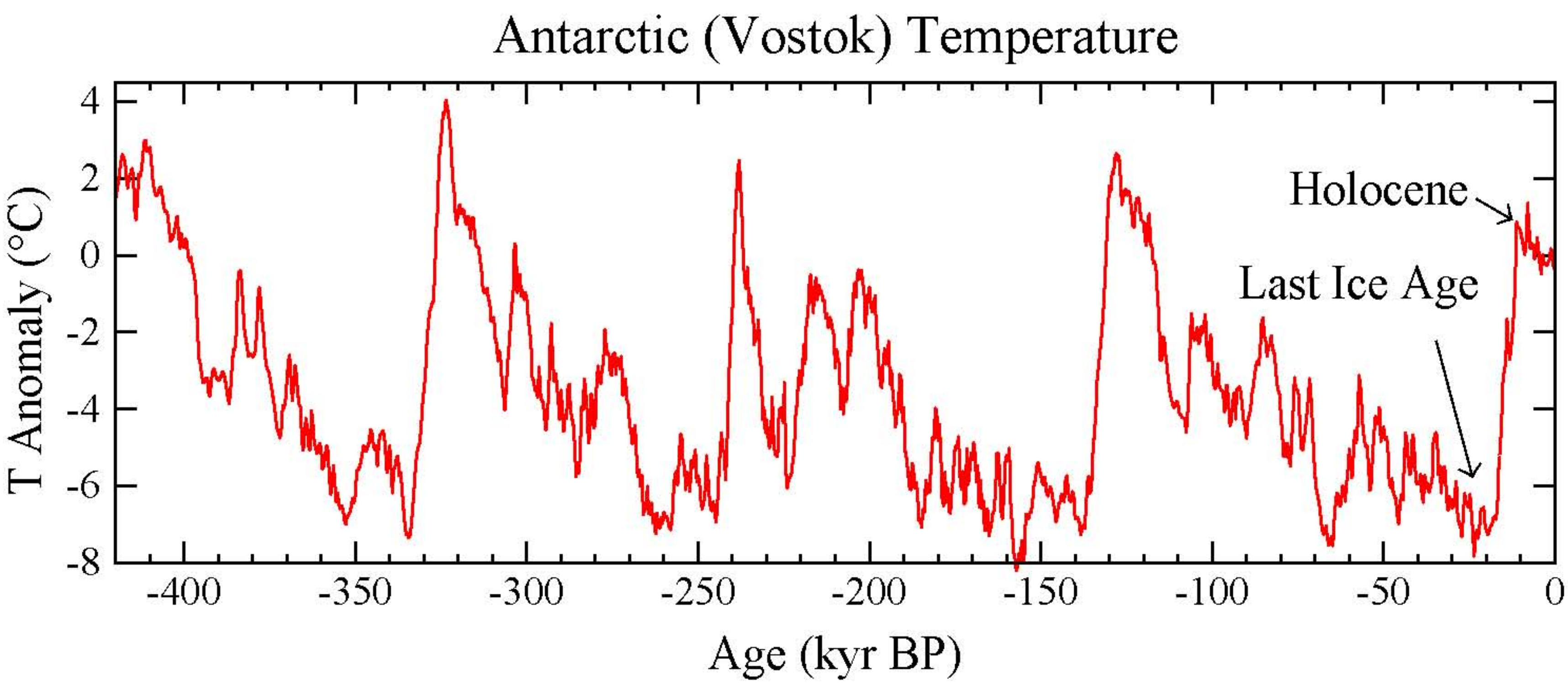
2007 Surface Temperature Anomalies (^{o}C) [Base Period 1951-80]



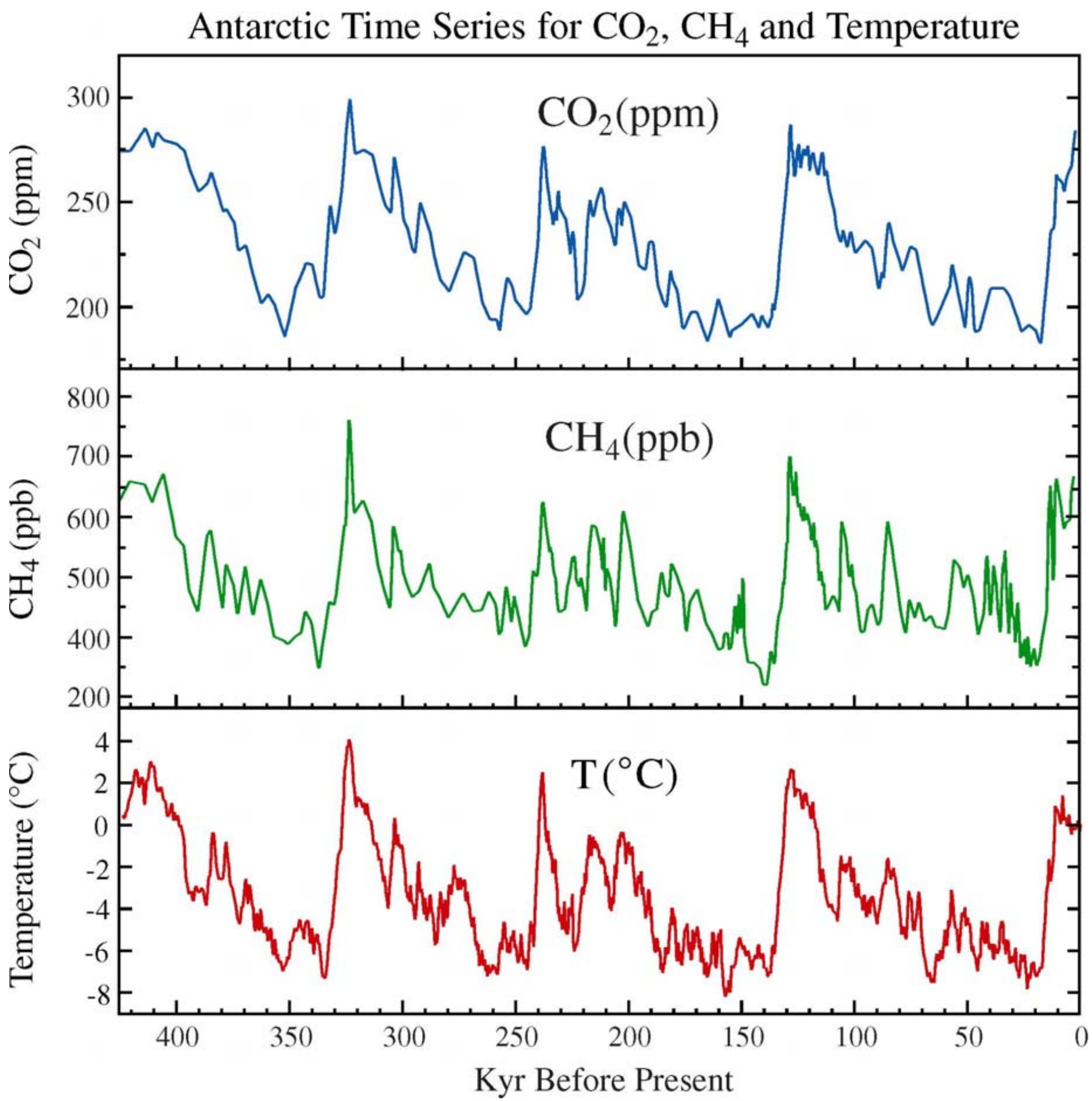
2001-2006 Mean Surface Temperature Anomaly (°C)

Base Period = 1951-1980 Global Mean = 0.54



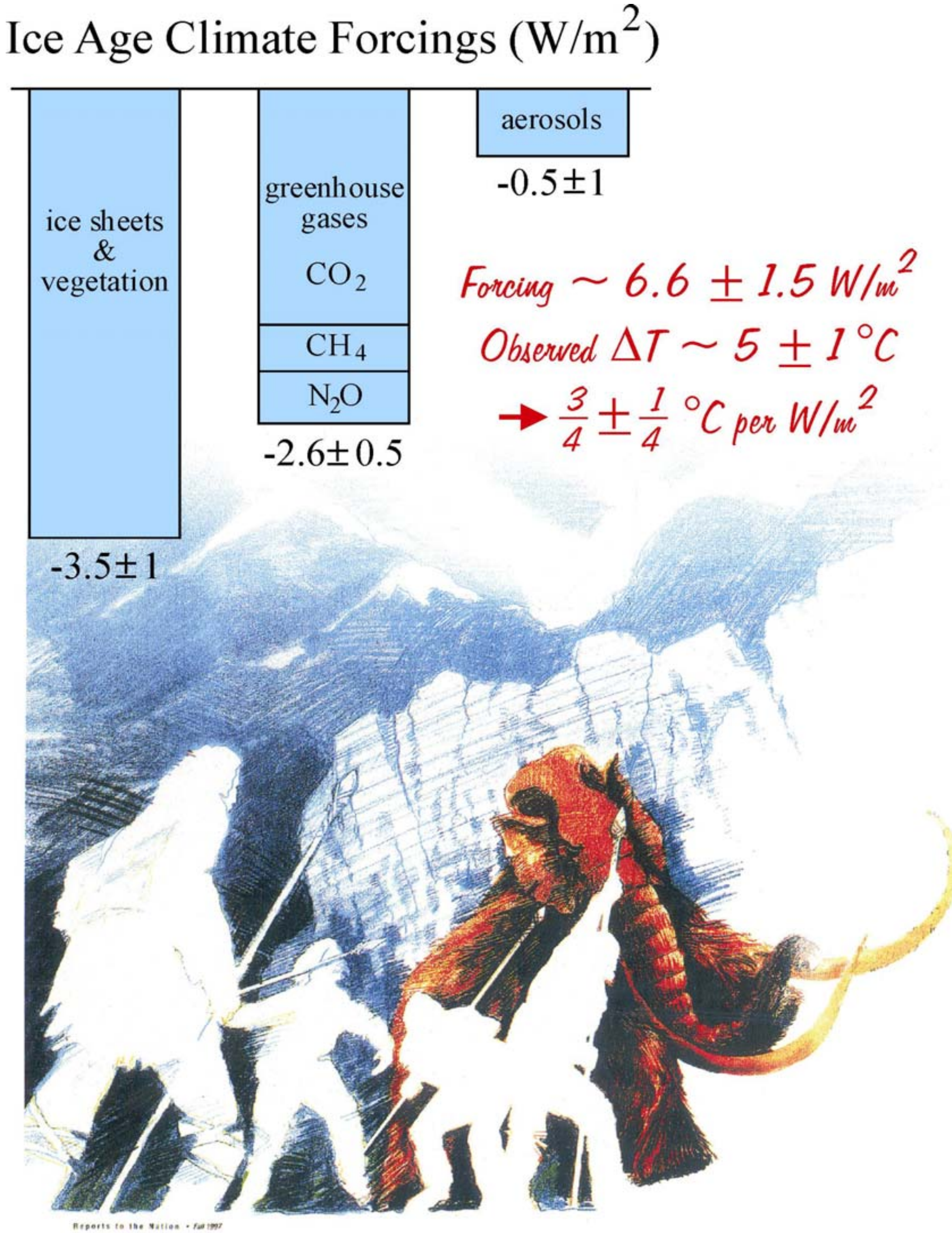


Antarctic (Vostok) Temperature
T Anomaly (°C)
4
2
0
-2
-4
-6
-8
-400
-350
-300
-250
-200
-150
-100
-50
0
Age (kyr BP)
Holocene
Last Ice Age



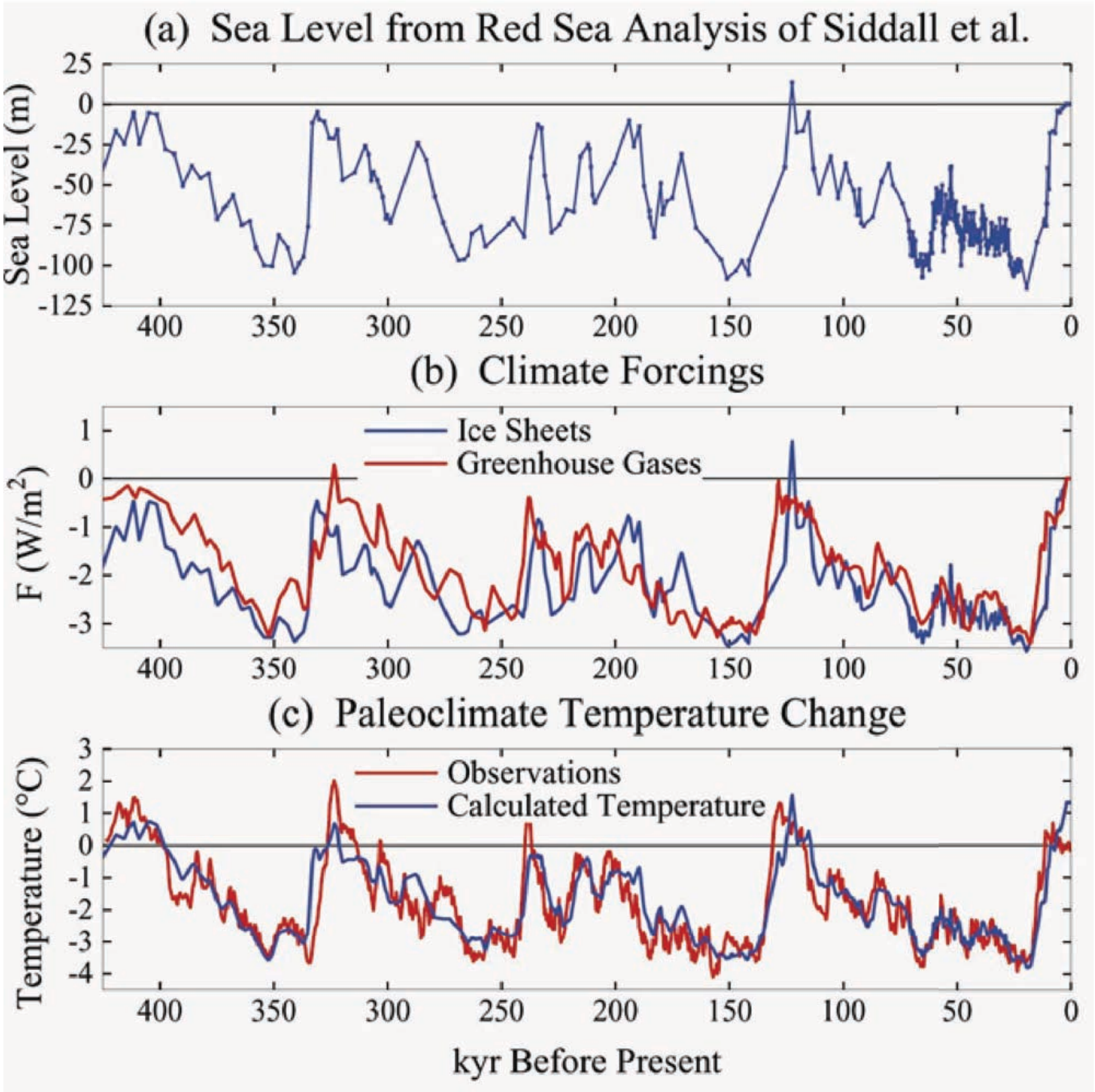
CO_2, CH_4 and temperature records from Antarctic ice core data

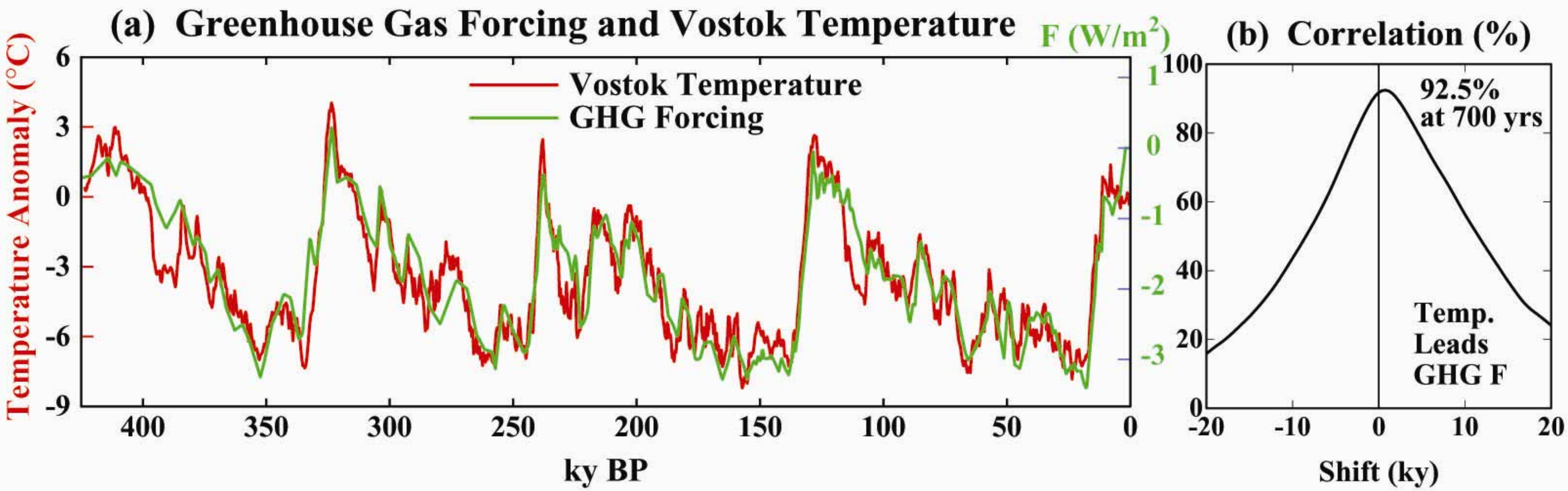
Source: Vimeux, F., K.M. Cuffey, and Jouzel, J., 2002, "New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction", *Earth and Planetary Science Letters*, **203**, 829-843.



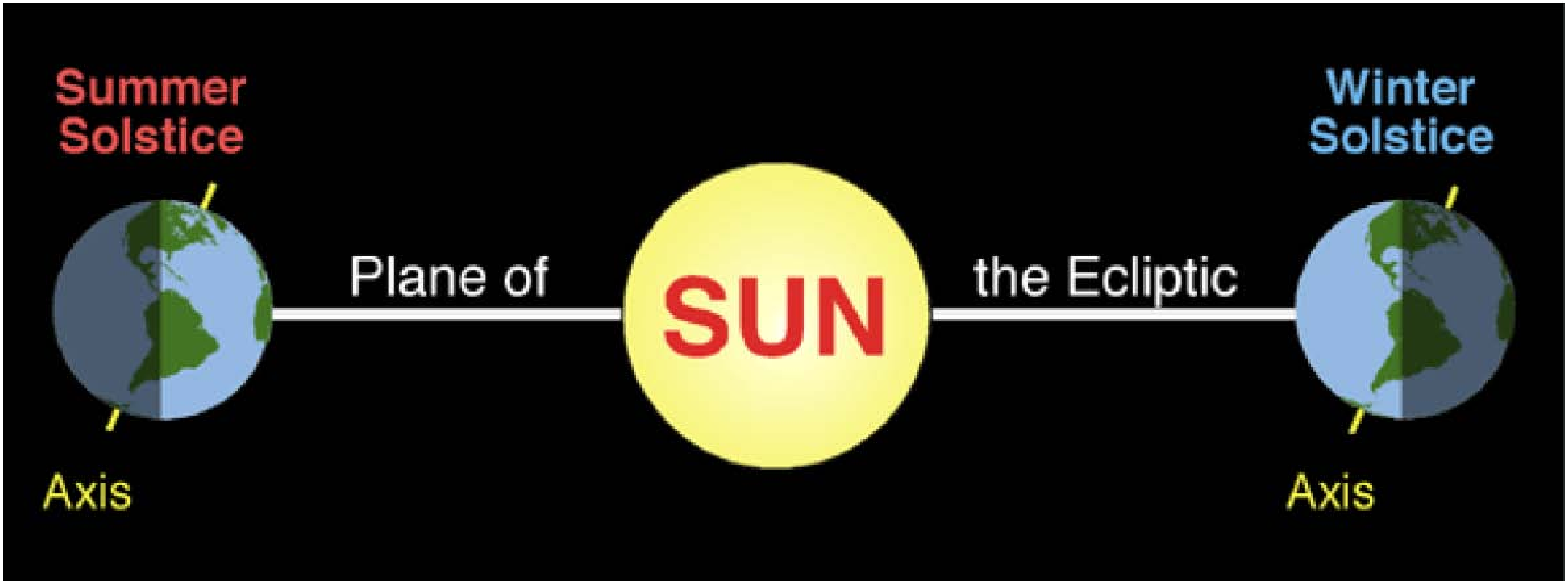
Ice Age Forcings Imply Global Climate Sensitivity ~ ¾°C per W/m².

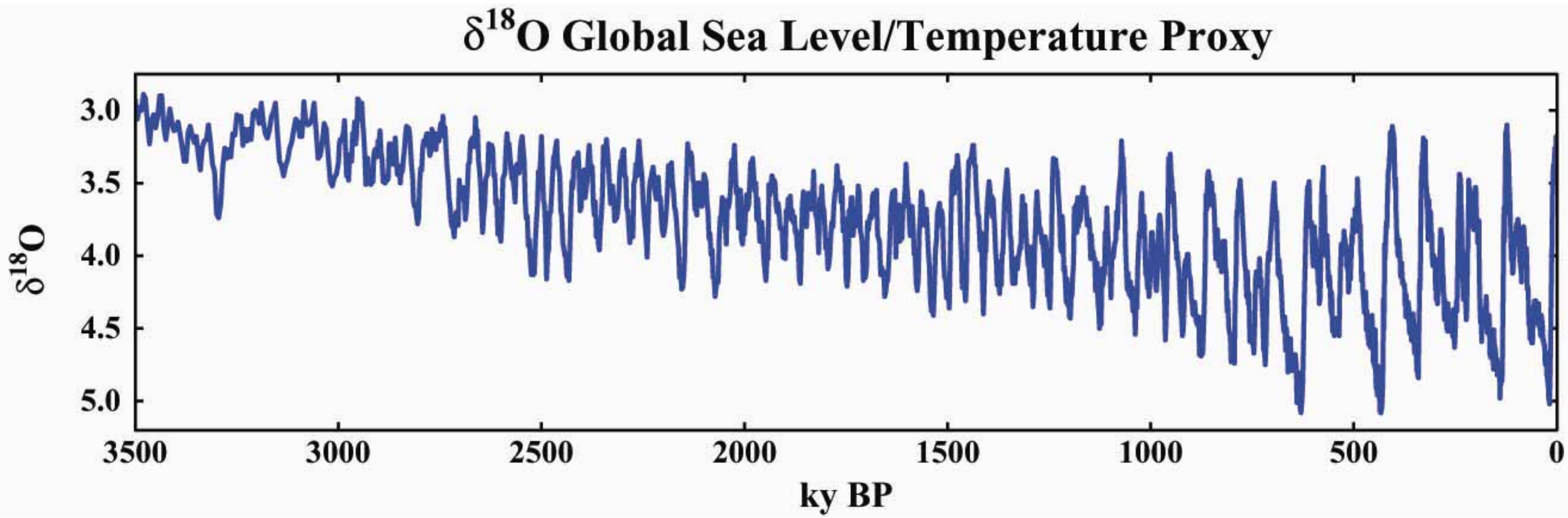
Source: Hansen et al., *Natl. Geogr. Res. & Explor.*, **9**, 141, 1993.


(a) Sea Level from Red Sea Analysis of Siddall et al.
Sea Level (m)
25
0
-25
-50
-75
-100
-125
400
350
300
250
200
150
100
50
0
(b) Climate Forcings
F (W/m^2)
Ice Sheets
Greenhouse Gases
1
0
-1
-2
-3
(c) Paleoclimate Temperature Change
Temperature (°C)
Observations
Calculated Temperature
3
2
1
0
-1
-2
-3
-4
kyr Before Present



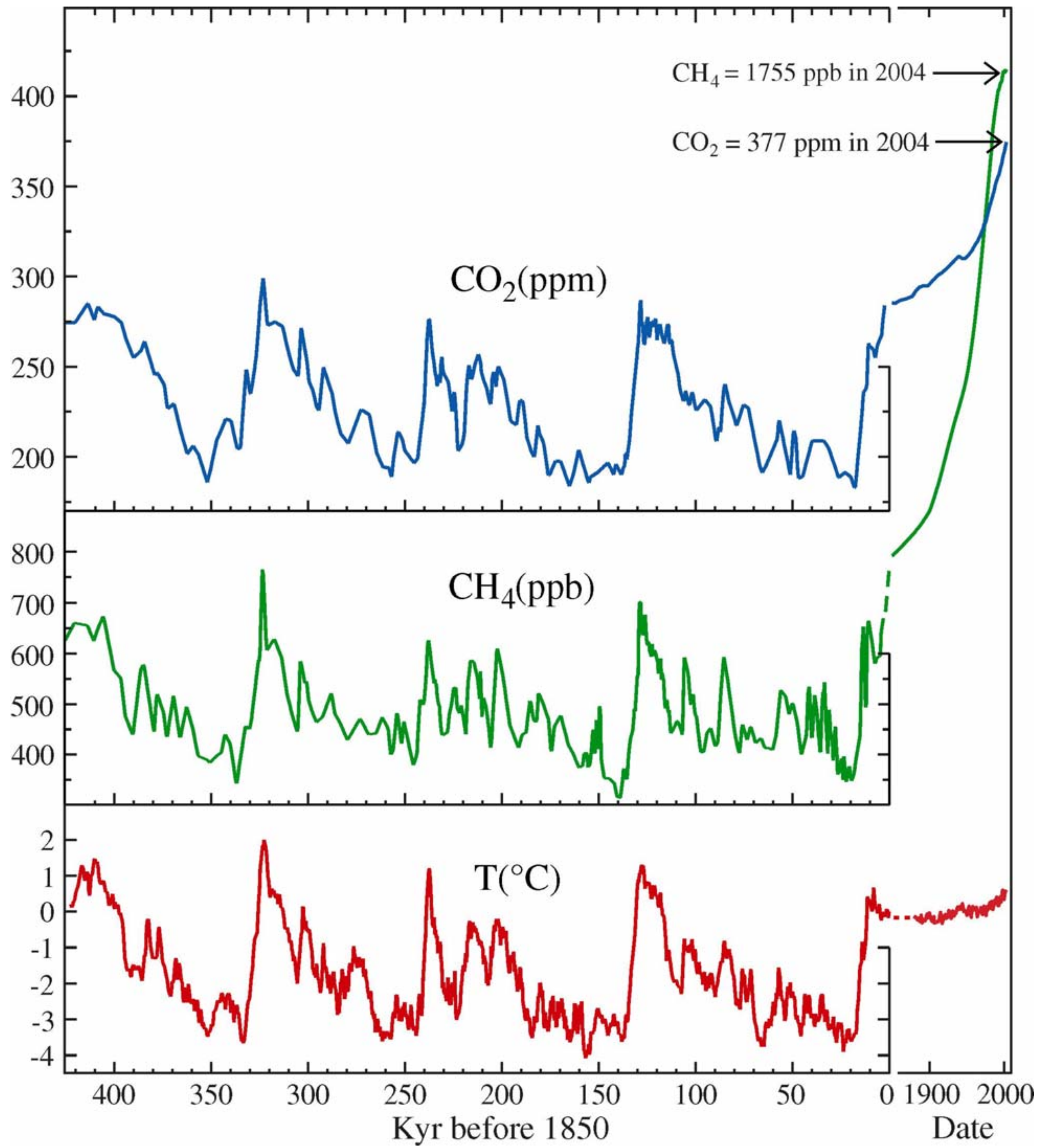
(a) Greenhouse Gas Forcing and Vostok Temperature
Temperature Anomaly (°C)
F (W/m²)
Vostok Temperature
GHG Forcing
6
3
0
-3
-6
-9
1
0
-1
-2
-3
400
350
300
250
200
150
100
50
0
ky BP
(b) Correlation (%)
92.5%
at 700 yrs
Temp.
Leads
GHG F
100
80
60
40
20
0
-20
-10
0
10
20
Shift (ky)


Summer
Solstice
Winter
Solstice
Plane of
SUN
the Ecliptic
Axis
Axis



Proxy record of Plio-Pleistocene (3.5 million years) temperature and ice volume. Based on oxygen isotope preserved in shells of benthic (deep ocean dwelling) foraminifera.

CO_2,CH_4 and estimated global temperature (Antarctic ΔT/2 in ice core era)
0 = 1880-1899 mean.

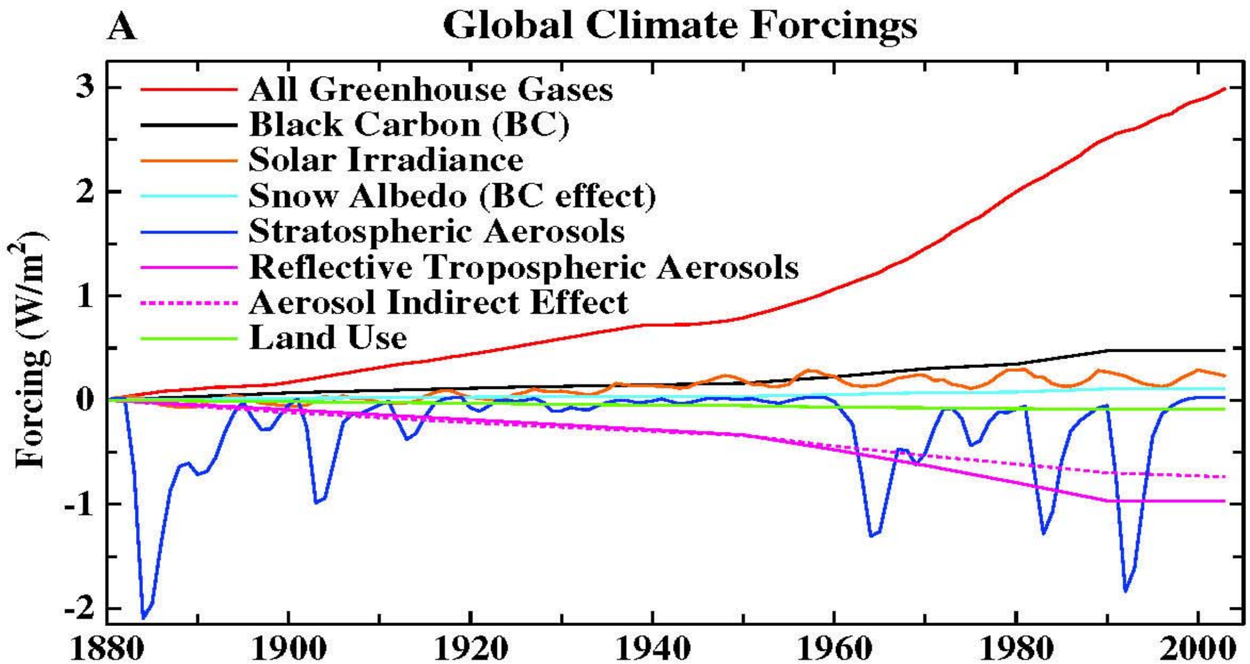


Source: Hansen, *Clim. Change*, **68**, 269, 2005.

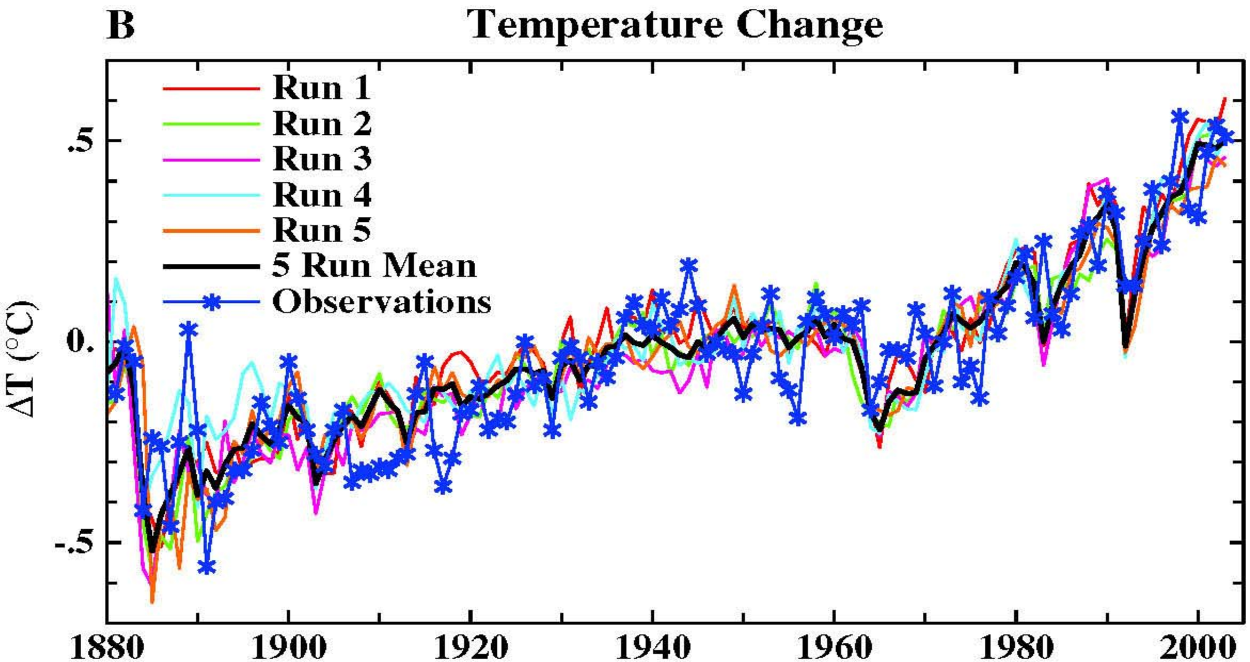
Implications of Paleo Forcings and Response

1. **Chief mechanisms for paleoclimate change GHGs & ice sheet area, as feedbacks.**
2. **Chief instigator of climate change was earth orbital change, a very weak forcing.**
3. **Climate on long time scales is very sensitive to even small forcings.**
4. **Human-made forcings dwarf natural forcings that drove glacial-interglacial climate change.**
5. **Humans now control global climate, for better or worse.**

(A) Forcings used to drive climate simulations.

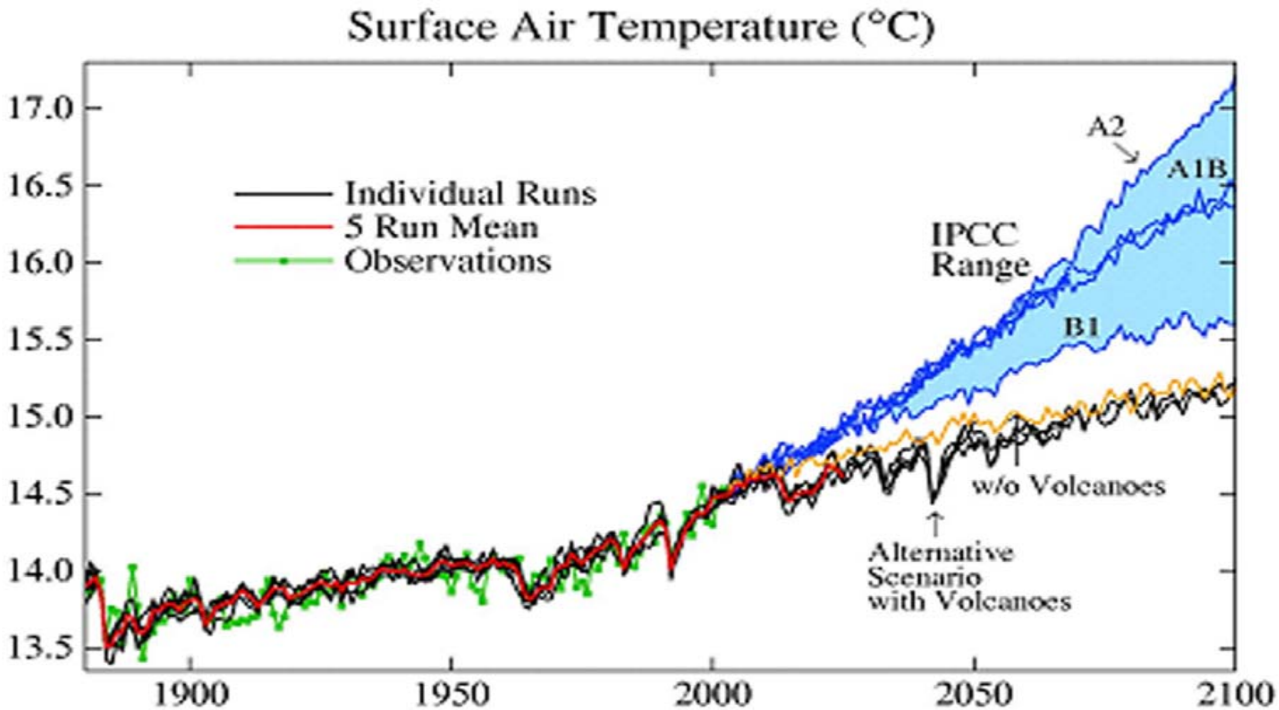


(B) Simulated and observed surface temperature change.



Source: Earth's energy imbalance: Confirmation and implications. *Science* **308**, 1431, 2005.

21st Century Global Warming



Climate Simulations for IPCC 2007 Report

► **Climate Model Sensitivity 2.7-2.9°C for $2xCO_2$**
(consistent with paleoclimate data & other models)

► **Simulations Consistent with 1880-2003 Observations**
(key test = ocean heat storage)

► **Simulated Global Warming < 1°C in Alternative Scenario**

Conclusion: Warming < 1°C if additional forcing ~ 1.5 W/m^2

Source: Hansen et al., *to be submitted to J. Geophys. Res.*

United Nations
Framework Convention on Climate Change

Aim is to stabilize greenhouse gas emissions…

"…at a level that would prevent dangerous anthropogenic interference with the climate system."

Metrics for “Dangerous” Change

Ice Sheet Disintegration: Global Sea Level

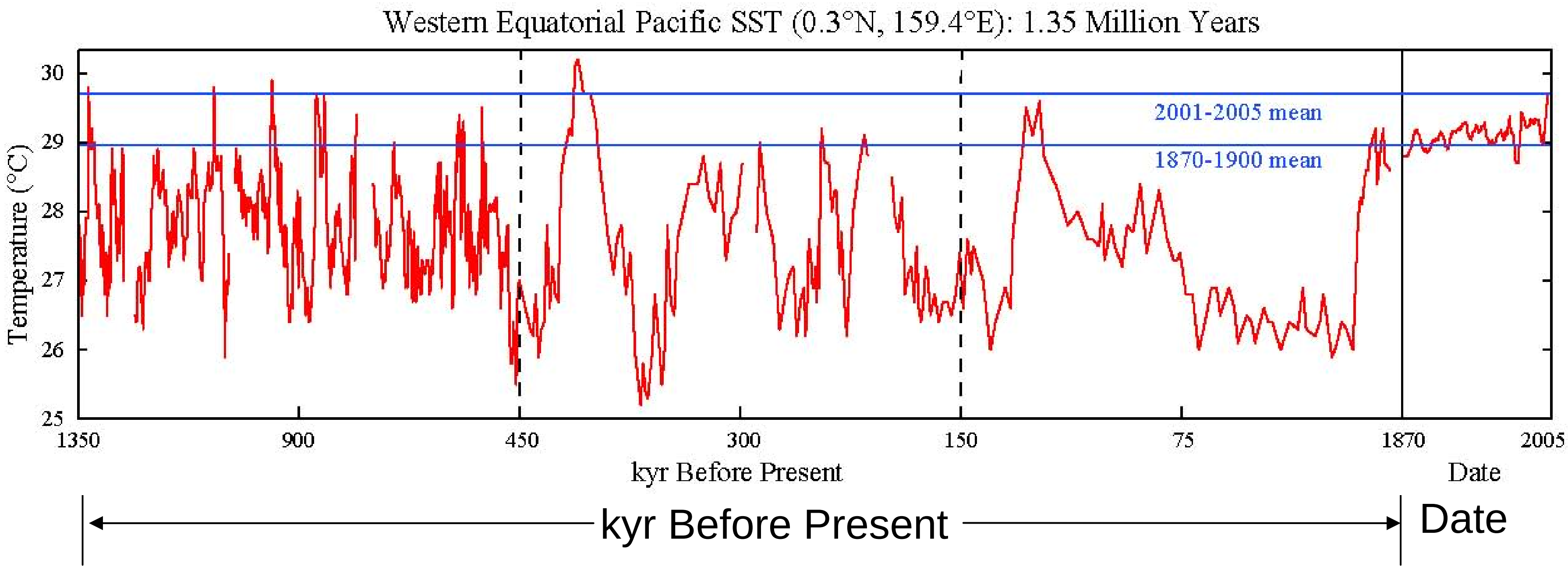
1. Long-Term Change from Paleoclimate Data
2. Ice Sheet Response Time

Extermination of Animal & Plant Species

1. Extinction of Polar and Alpine Species
2. Unsustainable Migration Rates

Regional Climate Disruptions

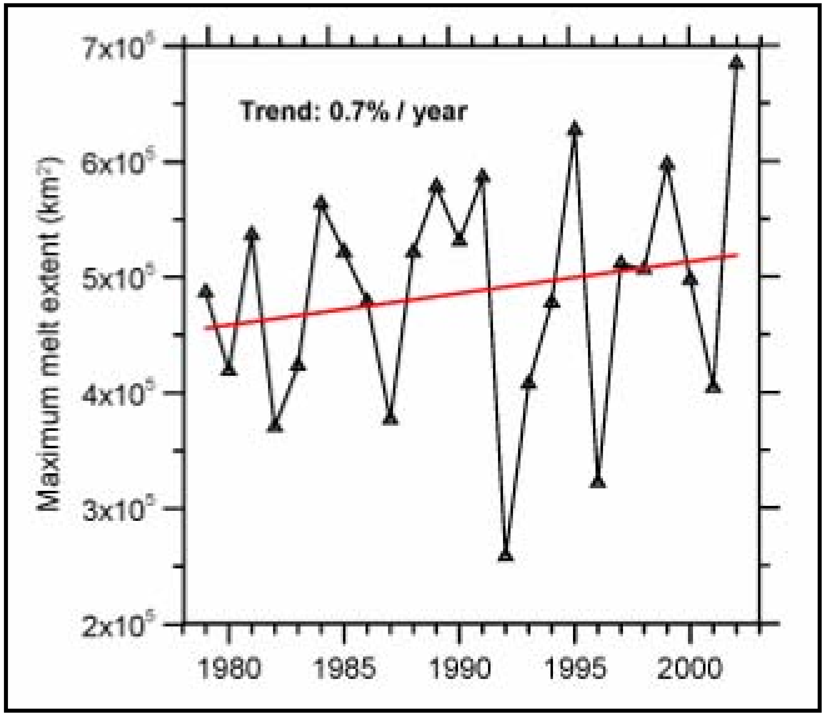
1. Increase of Extreme Events
2. Shifting Zones/Freshwater Shortages

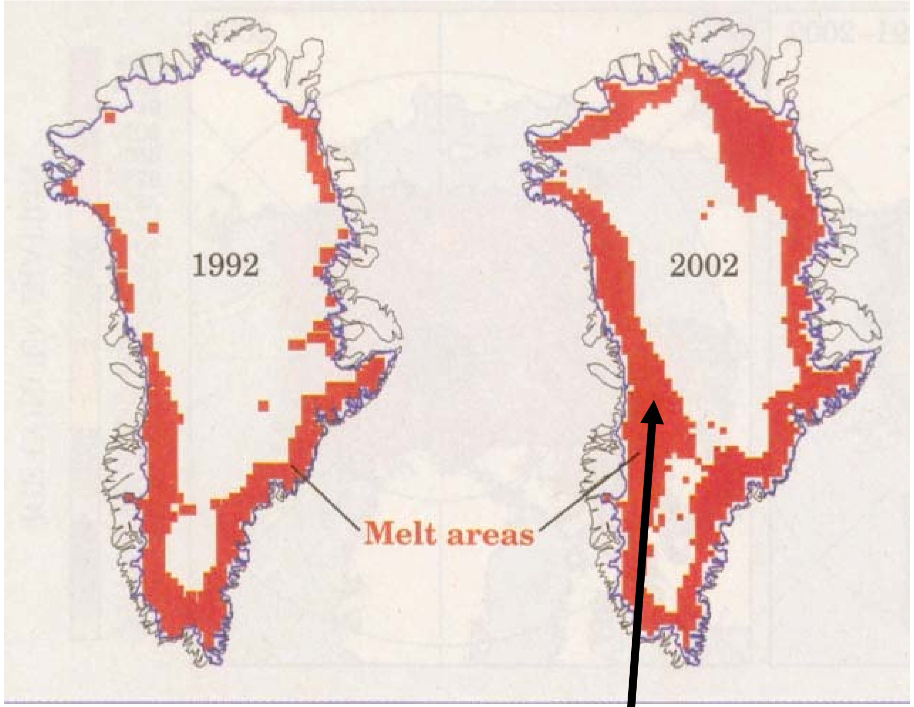


SST in Pacific Warm Pool (ODP site 806B, 0°N, 160°E) in past millennium. Time scale expanded in recent periods. Data after 1880 is 5-year mean.

Source: Medina-Elizalde and Lea, ScienceExpress, 13 October 2005;data for 1880-1981 based on Rayner et al., *JGR*, **108**, 2003, after 1981 on Reynolds and Smith, *J. Climate*, **7**, 1994.

Increasing Melt Area on Greenland





- 2002 all-time record melt area
- Melting up to elevation of 2000 m
- 16% increase from 1979 to 2002

70 meters thinning in 5 years

Satellite-era record melt of 2002 was exceeded in 2005.

Source: Waleed Abdalati, Goddard Space Flight Center

Surface Melt on Greenland

Melt descending
into a moulin,
a vertical shaft
carrying water
to ice sheet base.

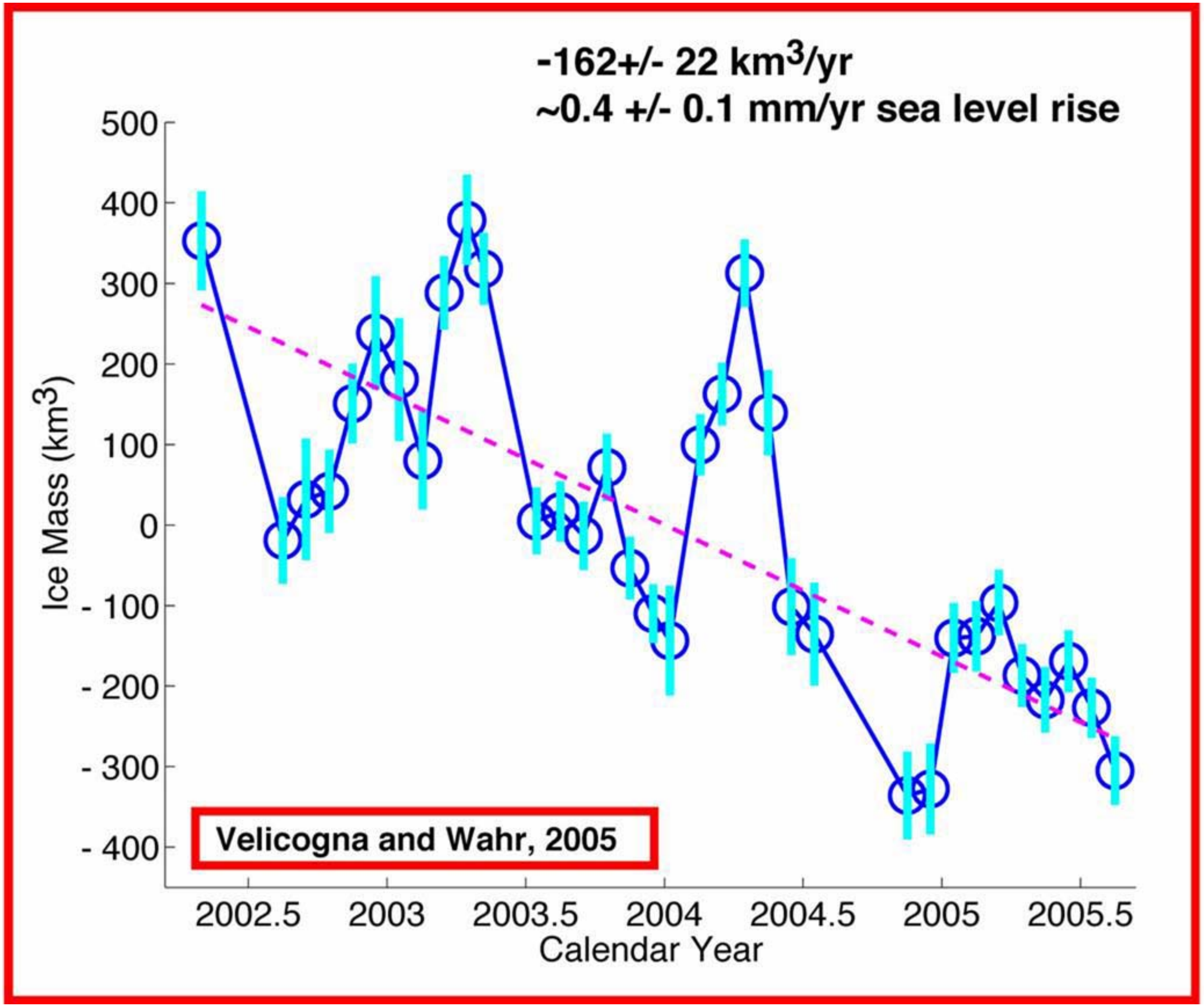
Source: Roger Braithwaite,
University of Manchester (UK)

Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.

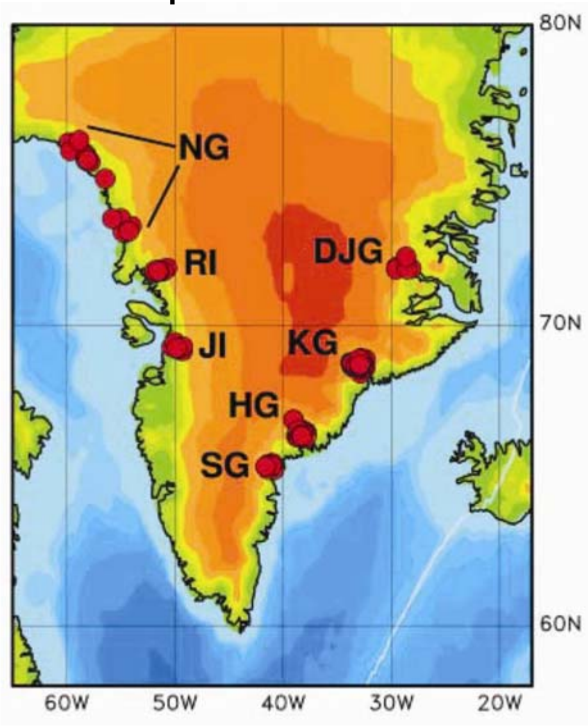
Source: Prof. Konrad Steffen, Univ. of Colorado

Greenland Mass Loss – From Gravity Satellite

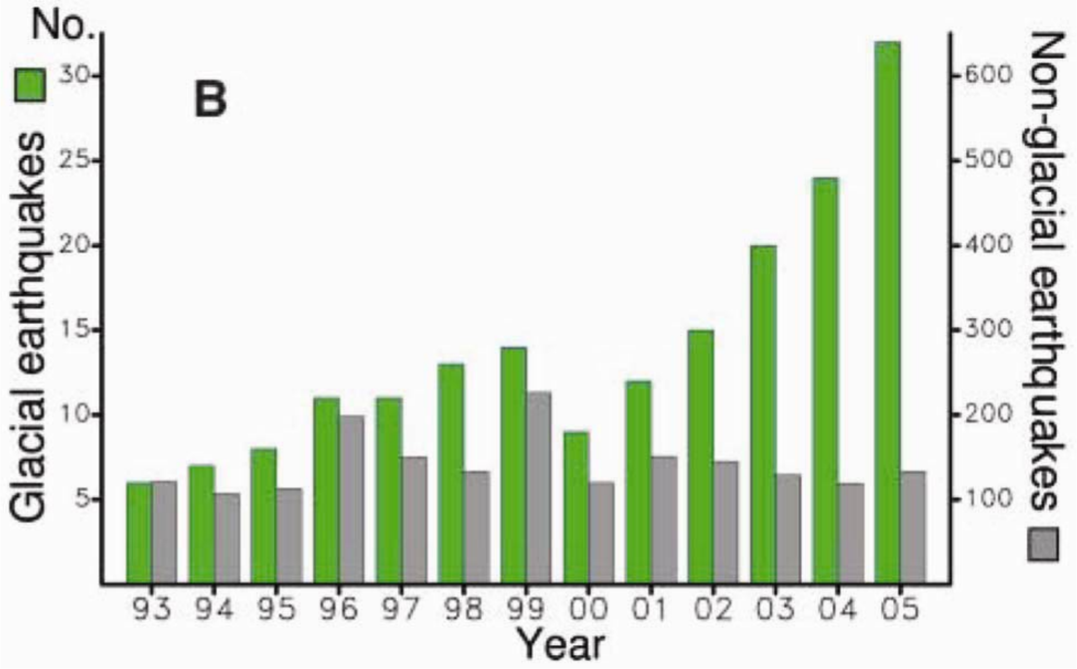


Glacial Earthquakes on Greenland

Earthquake Locations



Annual Number of Quakes*



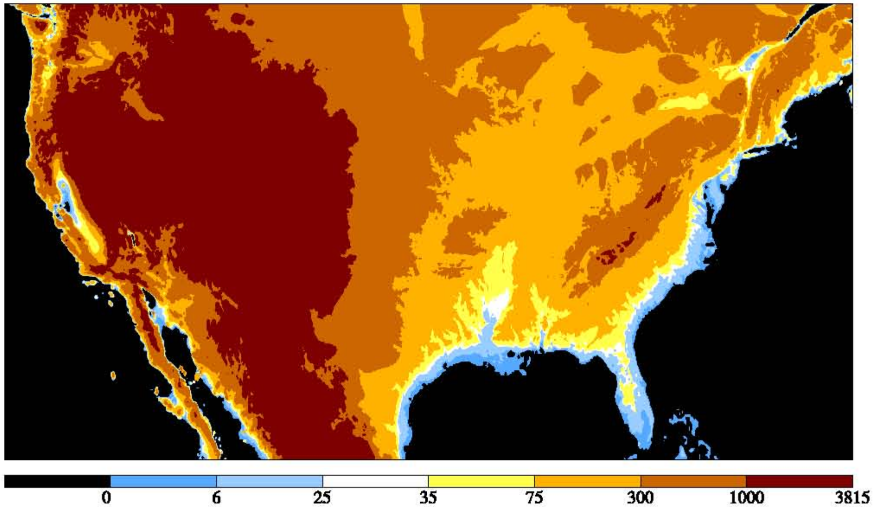
* 2005 bars capture only first 10 months of 2005

Location and frequency of glacial earthquakes on Greenland. Seismic magnitudes are in range 4.6 to 5.1.

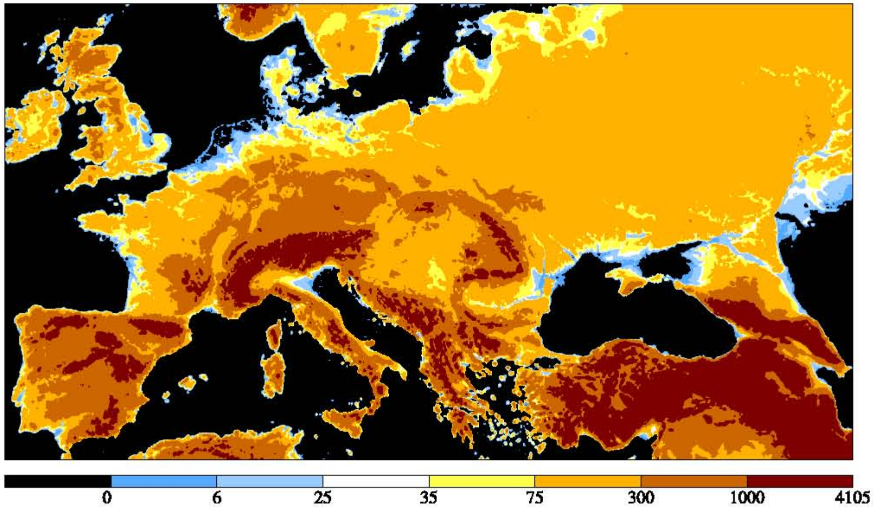
Source: Ekstrom, Nettles and Tsai, *Science*, **311**, 1756, 2006.

Areas Under Water: Four Regions

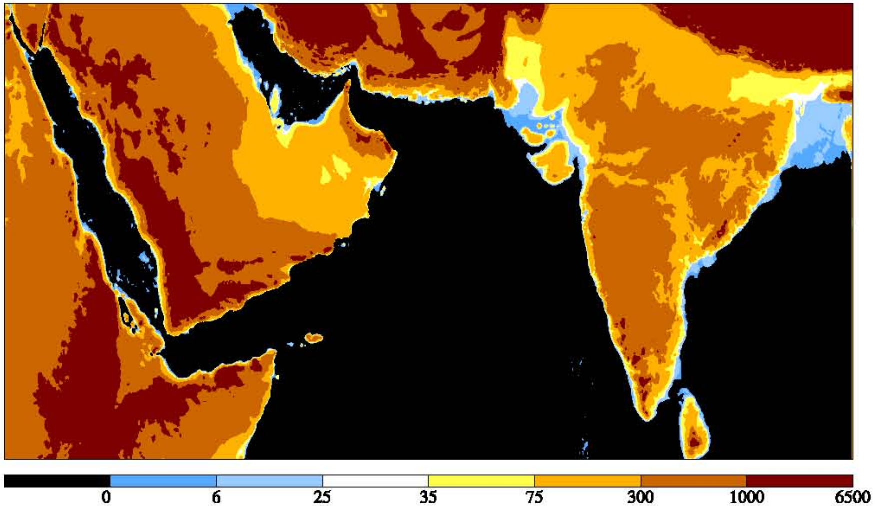
U.S. Area Under Water



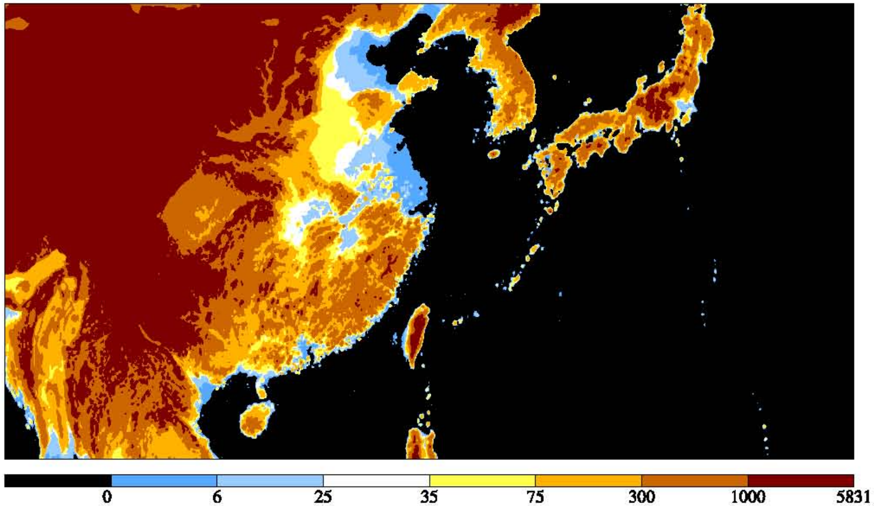
Europe Area Under Water



Central Asia: Area under Water



Far East: Area under Water



Paleoclimate Sea Level Data

1. **Rate of Sea Level Rise**

   - Data reveal numerous cases of rise of several m/century (e.g., MWP 1A)

2. **"Sub-orbital" Sea Level Changes**

   - Data show rapid changes ~ 10 m within interglacial & glacial periods

Ice Sheet Models Do Not Produce These

Summary: Ice Sheets

1. Human Forcing Dwarfs Paleo Forcing and Is Changing Much Faster

2. Ice Sheet Disintegration Starts Slowly but Multiple Positive Feedbacks Can Lead to Rapid Non-Linear Collapse

3. Equilibrium Sea Level Rise for ~3C Warming (25±10 m = 80 feet) Implies the Potential for Us to Lose Control

Extermination of Species

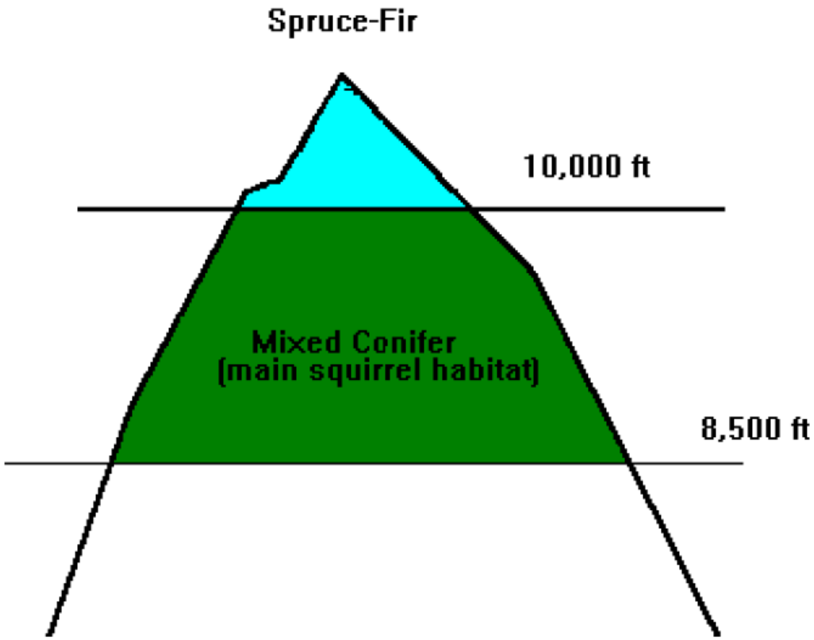
(a.k.a. decrease of biological diversity)

1. Distributions of plants and animals reflect climate
2. Extinctions occurring due to a variety of stresses
3. Added stress of climate change forces migrations
4. Some paths blocked by natural/human barriers
5. Migrations (~6 km/decade) < isotherm movement
6. Non-linear because of species extinctions

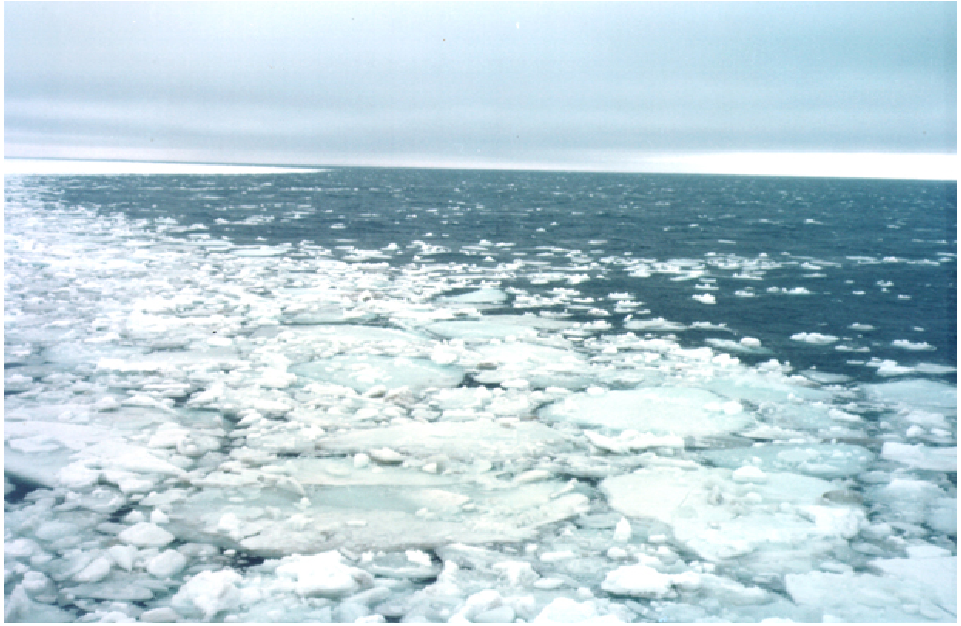
→ large difference between BAU/alternative scenarios

Mt. Graham Red Squirrel

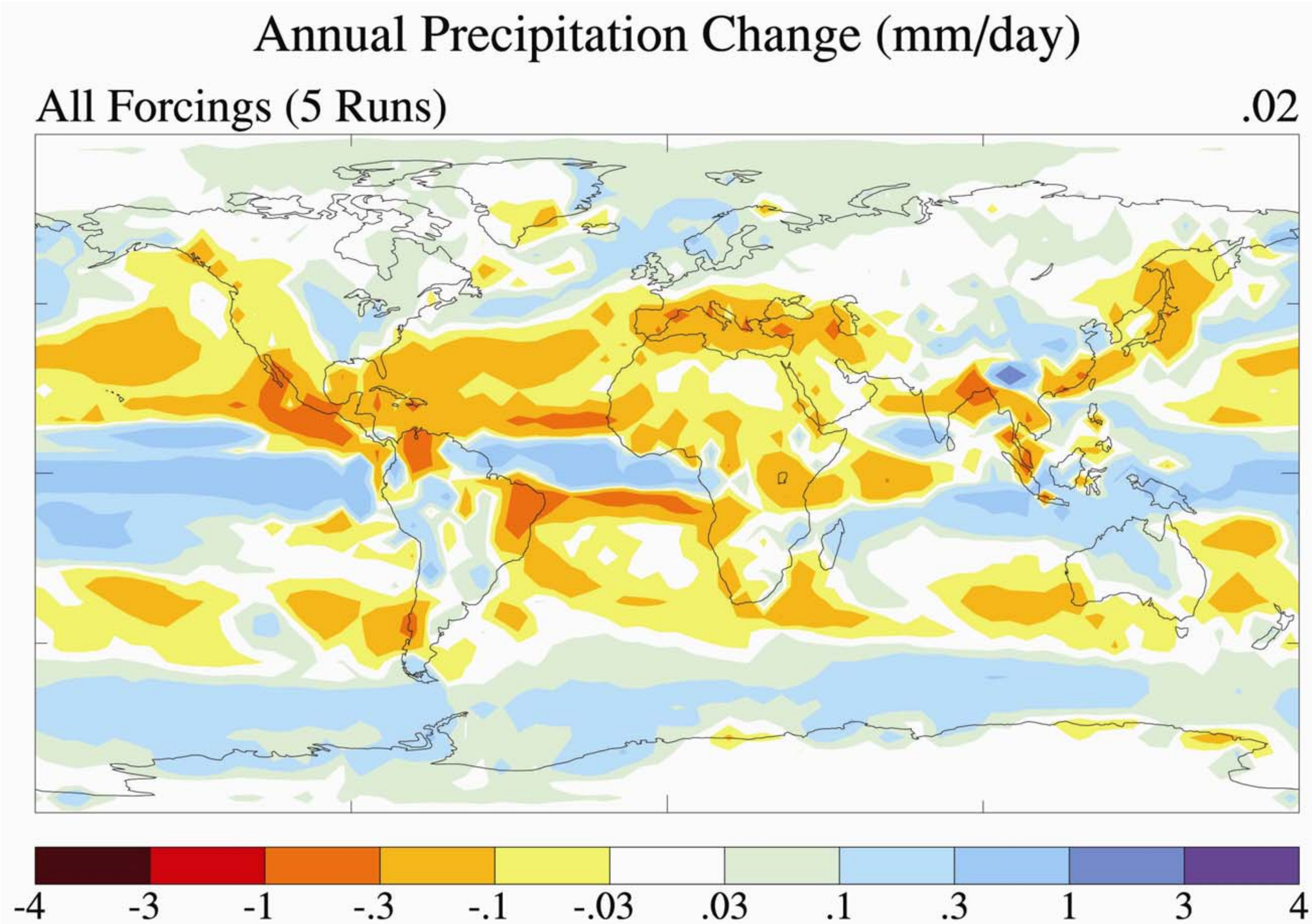
Mount Graham Red Squirrel (Credit: Claire Zugmeyer)



Arctic Climate Impact Assessment (ACIA)



Sources: Claire Parkinson and Robert Taylor



Simulated precipitation change in response to climate forcings estimated for 1880-2000.
Source: Hansen et al., *JGR* **110**, D18104, 2005.

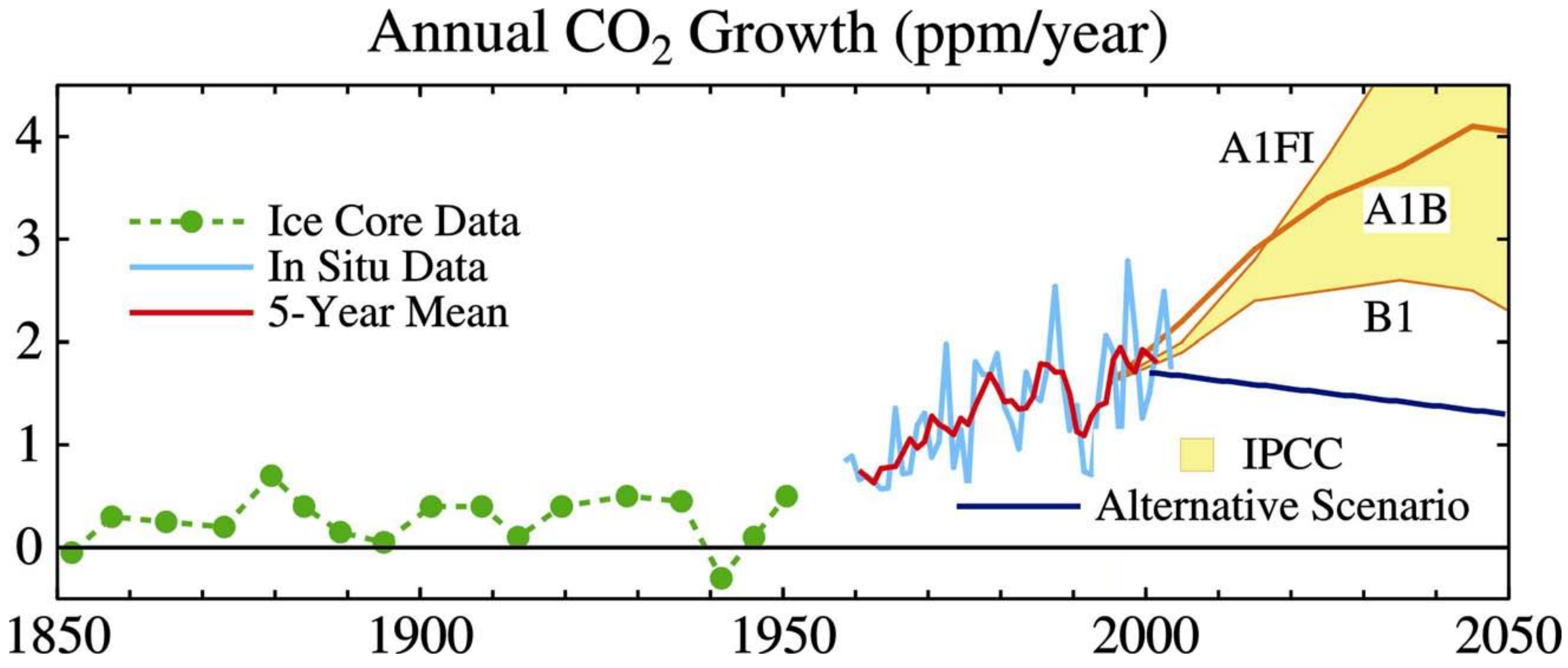
Expected Precipitation Changes

1. **Increased Precipitation**
   - Tropical Rain-Belt over Ocean
   - Polar Regions

2. **Increased Drought in Subtropics**
   - Western United States
   - Mediterranean Region
   - Parts of Africa/Southern Australia

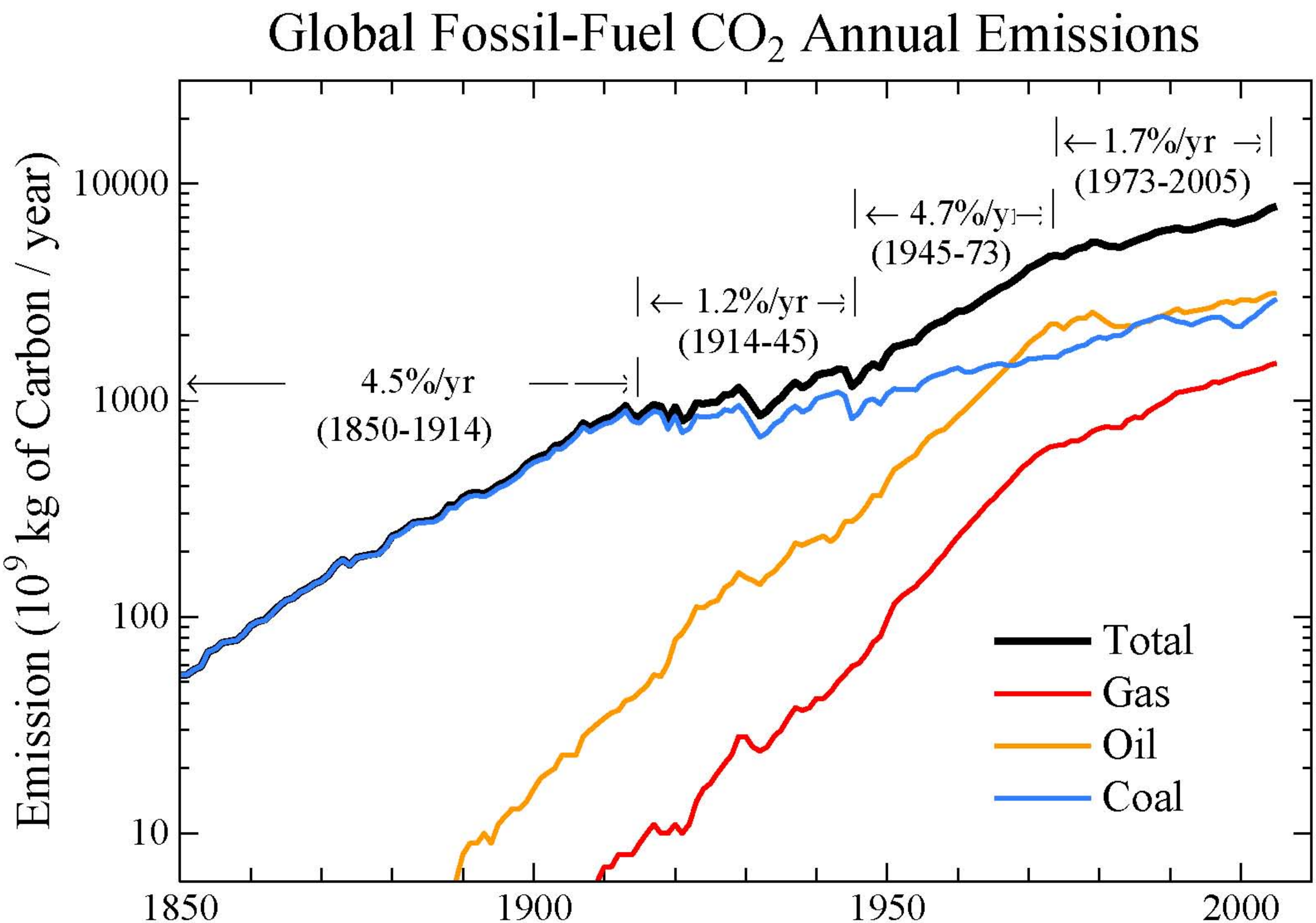
BAU → Super-Drought in U.S. West

Increased Extremes & Fire Intensity

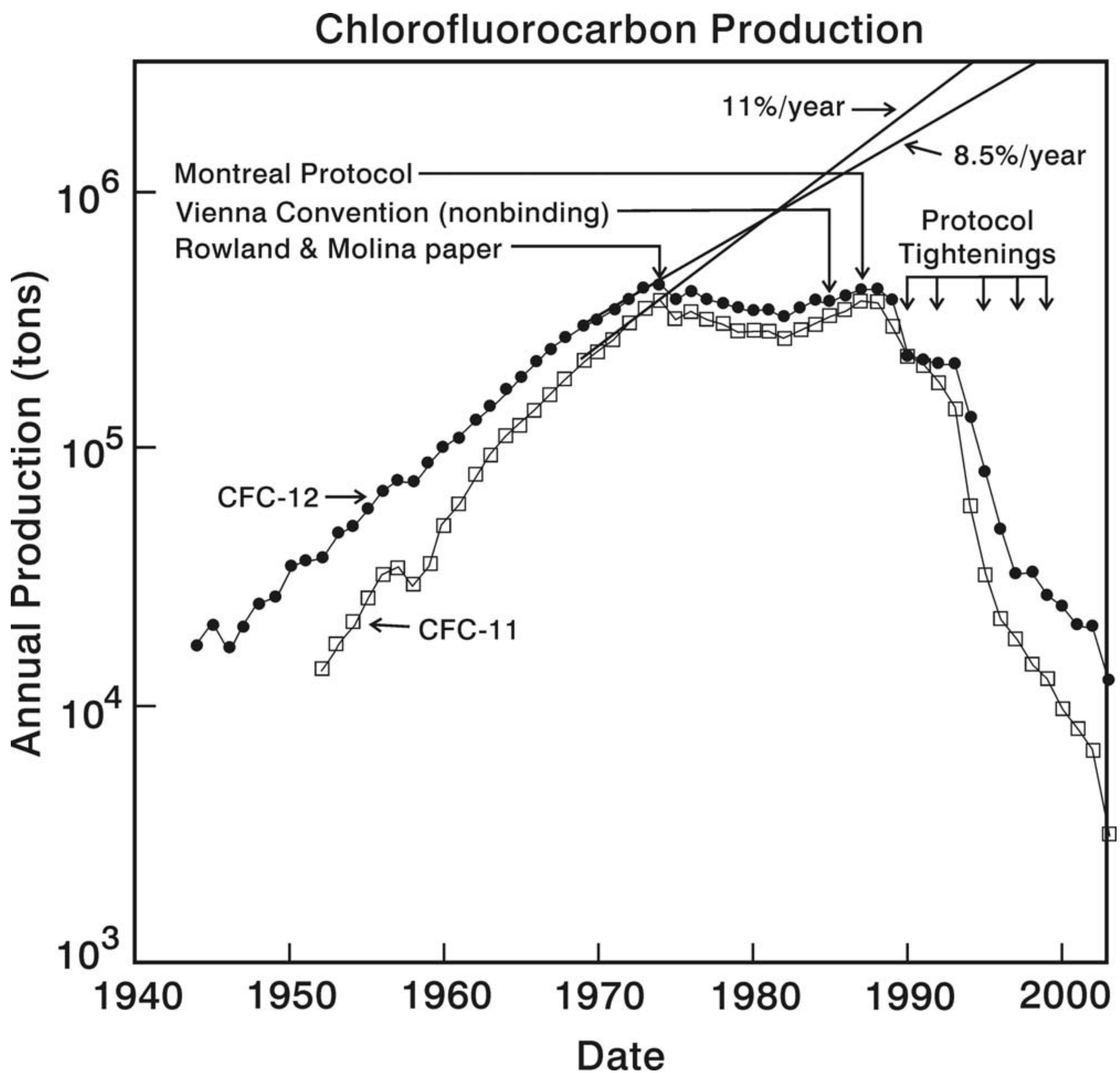


Growth rate of atmospheric CO_2 (ppm/year).

*Source: Hansen and Sato, PNAS, **101**, 16109, 2004.*

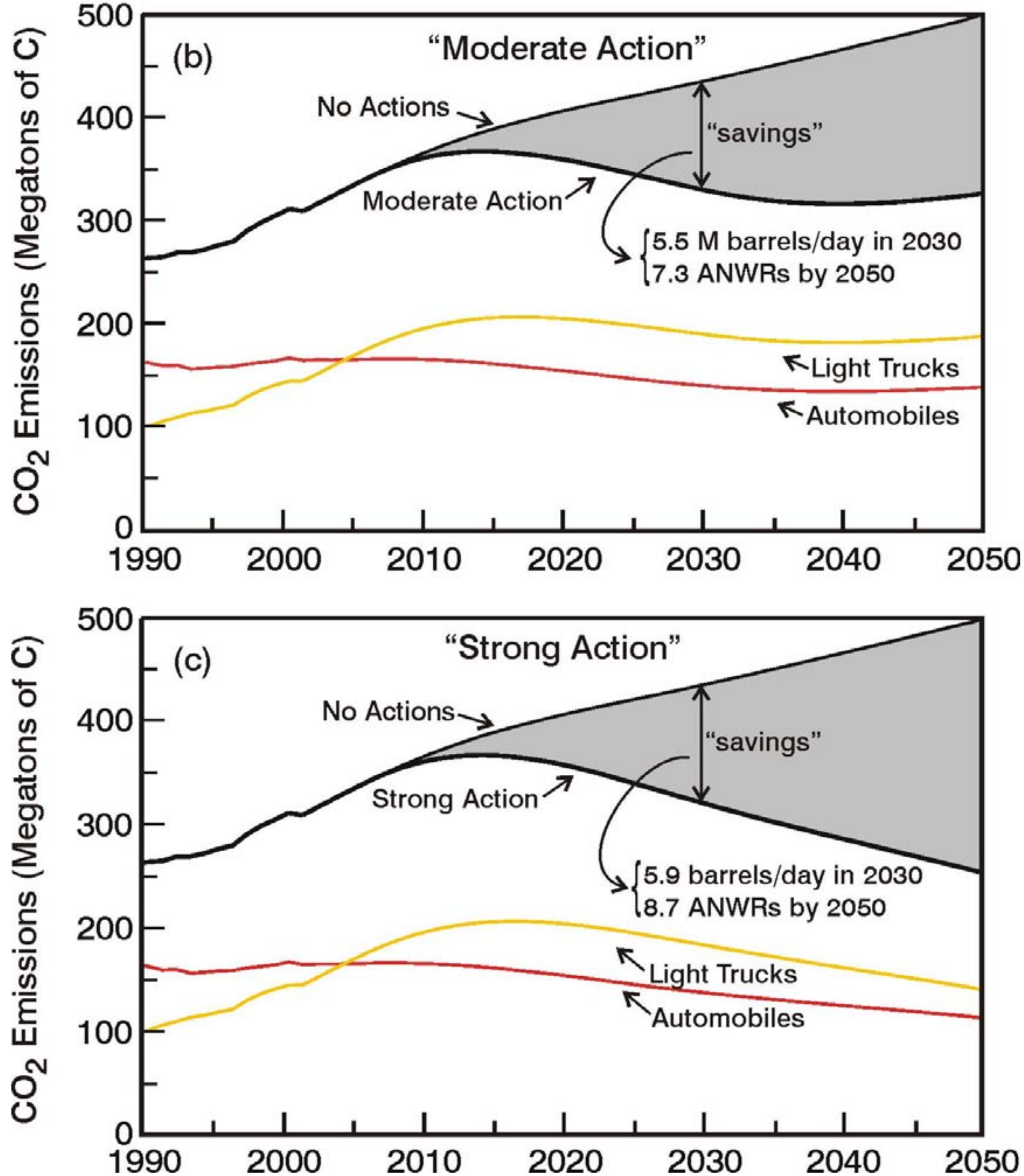


Global Fossil-Fuel CO2 Annual Emissions
Emission (10^9 kg of Carbon / year)
10000
1000
100
10
1850
1900
1950
2000
4.5%/yr
(1850-1914)
1.2%/yr
(1914-45)
4.7%/yr
(1945-73)
1.7%/yr
(1973-2005)
Total
Gas
Oil
Coal


Chlorofluorocarbon Production
11%/year
8.5%/year
Montreal Protocol
Vienna Convention (nonbinding)
Rowland & Molina paper
Protocol Tightenings
CFC-12
CFC-11
Annual Production (tons)
10^6
10^5
10^4
10^3
1940
1950
1960
1970
1980
1990
2000
Date

U.S. Auto & Light Truck CO_2 Emissions

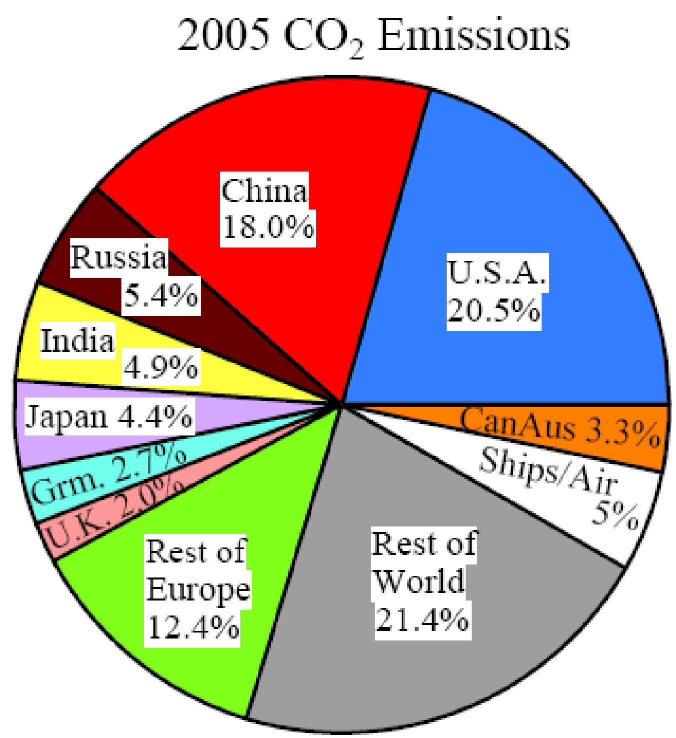
"Moderate Action" is NRC "Path 1.5" by 2015 and "Path 2.5" by 2030.

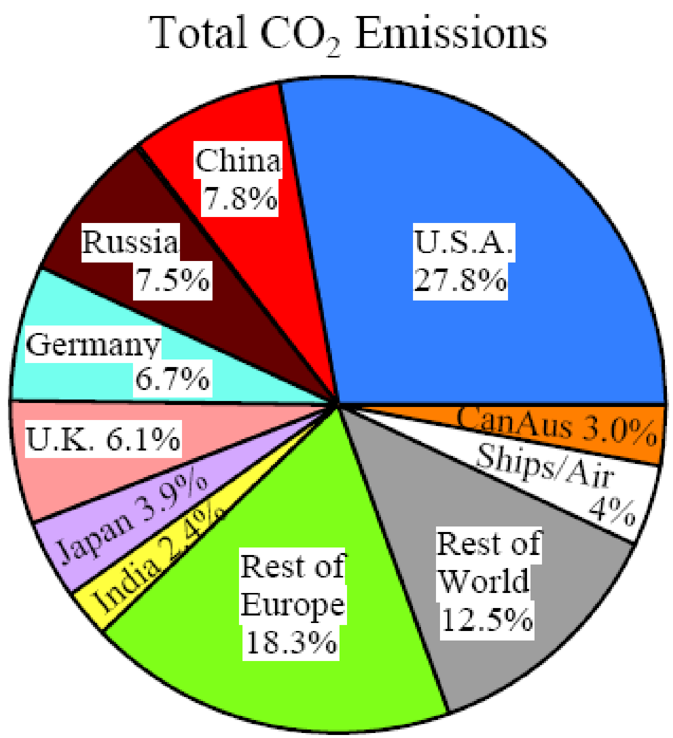


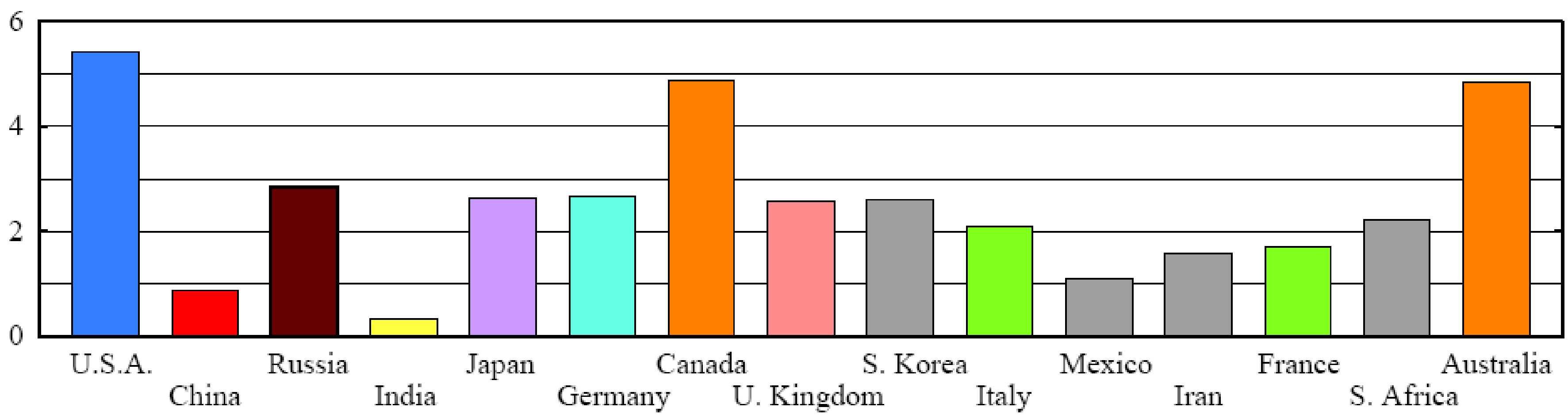
"Strong Action" adds hydrogen-powered vehicles in 2030 (30% of 2050 fleet). Hydrogen produced from non-CO_2 sources only.

Source: On the Road to Climate Stability, Hansen, J., D. Cain and R. Schmunk., *to be submitted*.

Responsibility for CO_2 Emissions and Climate Change







Per Capita Fossil Fuel CO_2 Emissions in Order of Total Emissions

Summary: Is There Still Time?

Yes, But:

- **Alternative Scenario is Feasible,**

  But It Is Not Being Pursued

- **Action needed now.**

  A decade of Business-as-Usual eliminates Alternative Scenario