Global Warming:
The Threat to the Planet*

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2007 Leo Szilard Lecture

American Physical Society
Jacksonville, FL

***Any statements relating to policy are personal opinions**

Status of the Matter

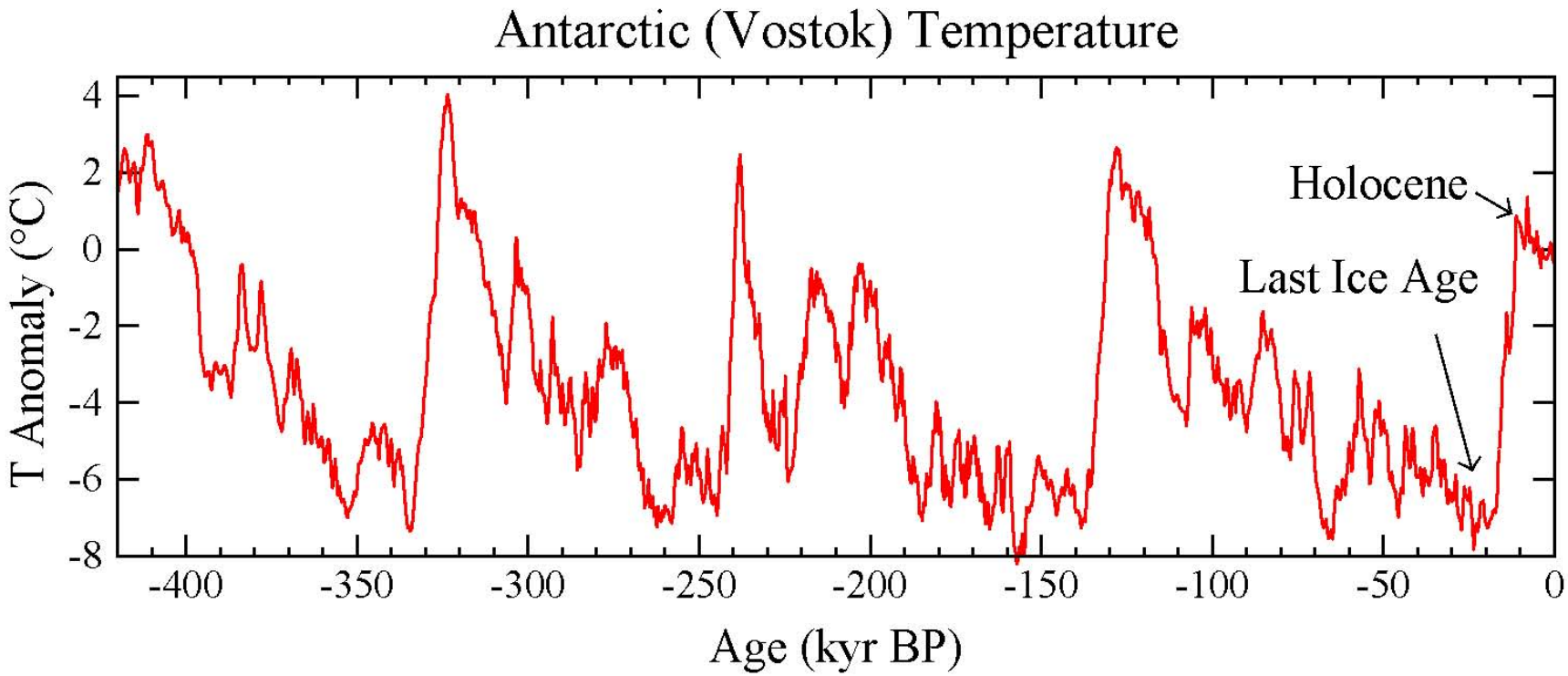
1. A Knowledge Gap

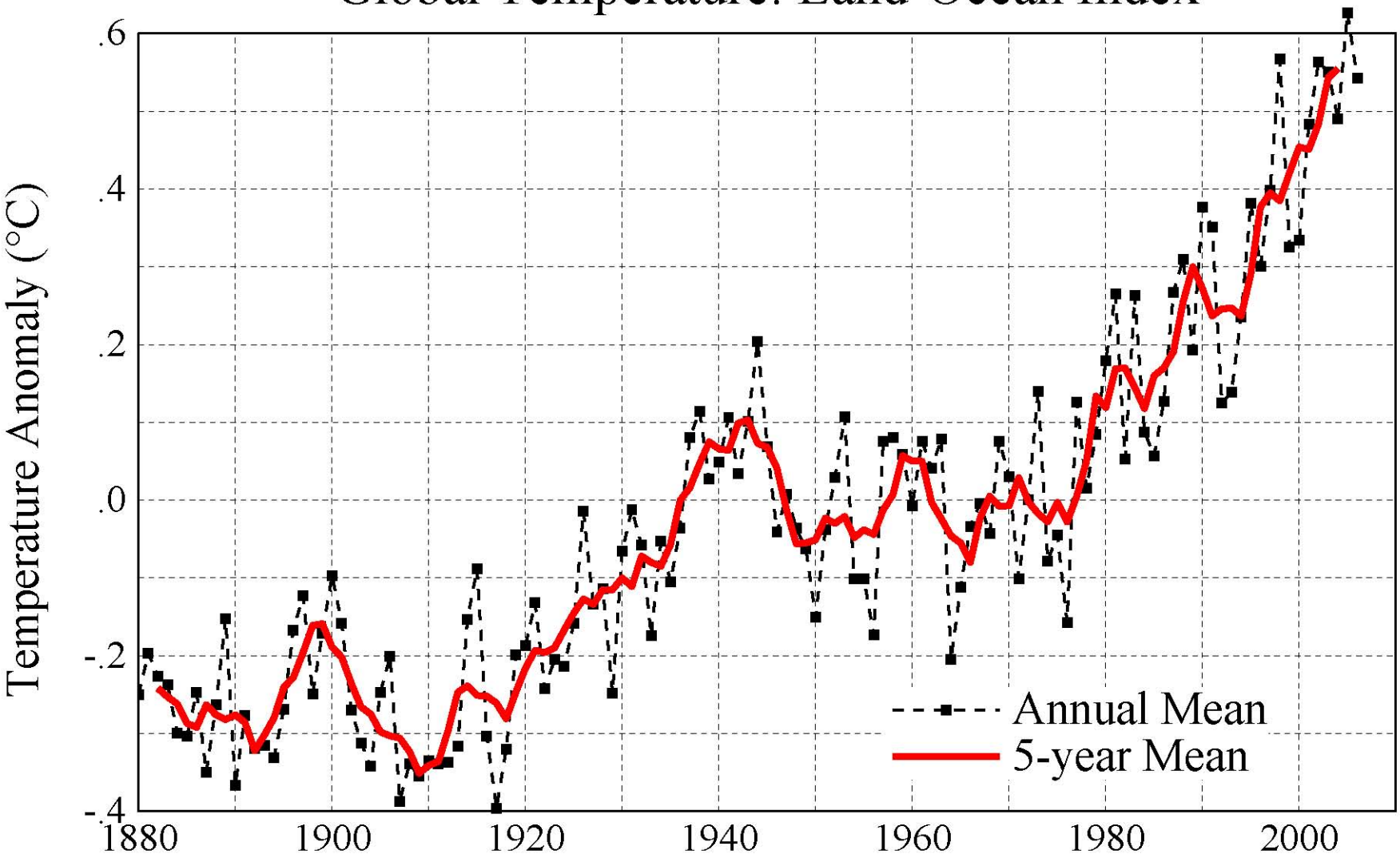
- What is Understood (scientists)
- What is Known (public/policymakers)

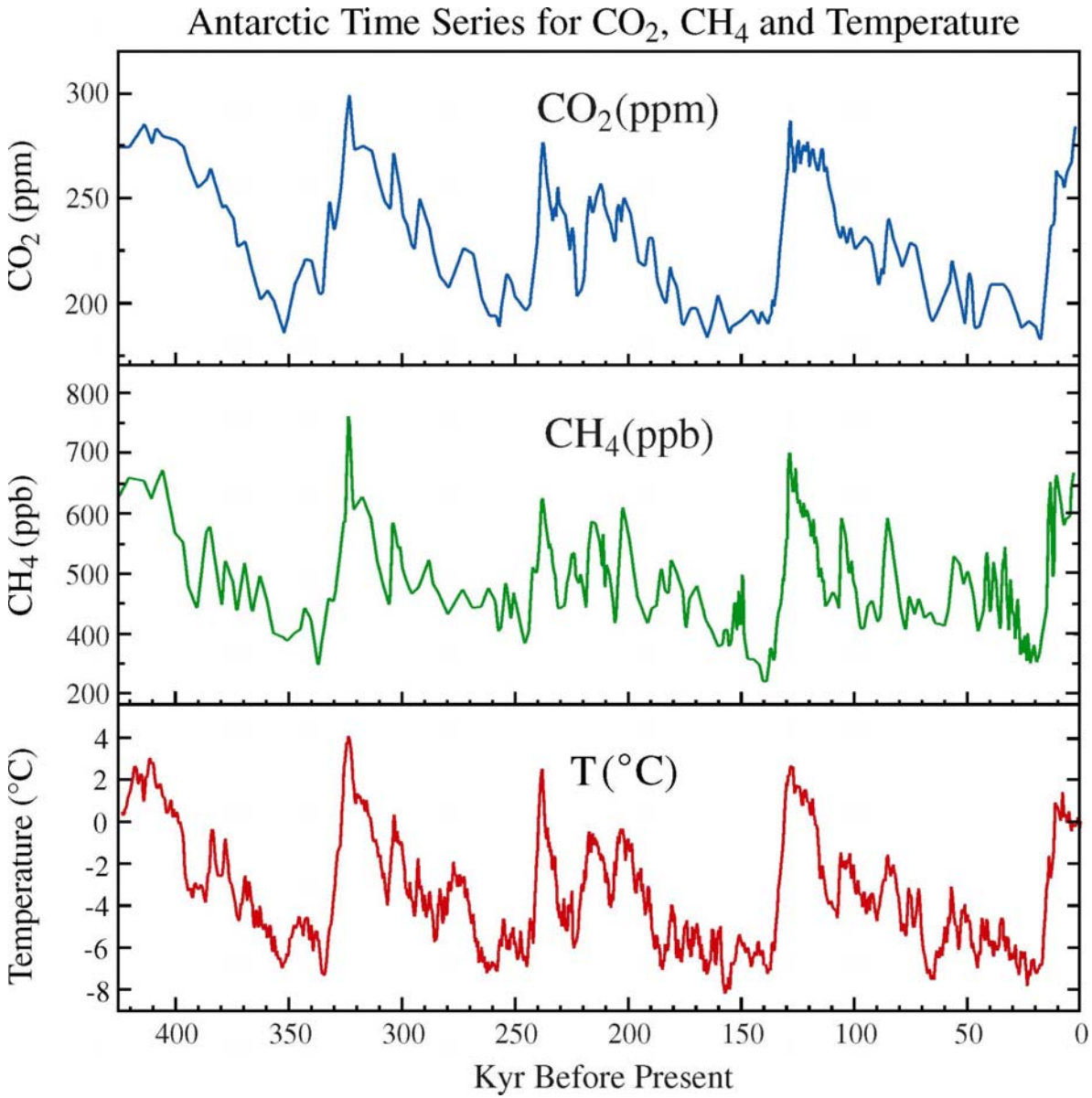
2. The Climate Crisis

- Positive Feedbacks Predominate
- Climate Inertia → Pipeline Effect

Danger:Tipping Point→Different Planet


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

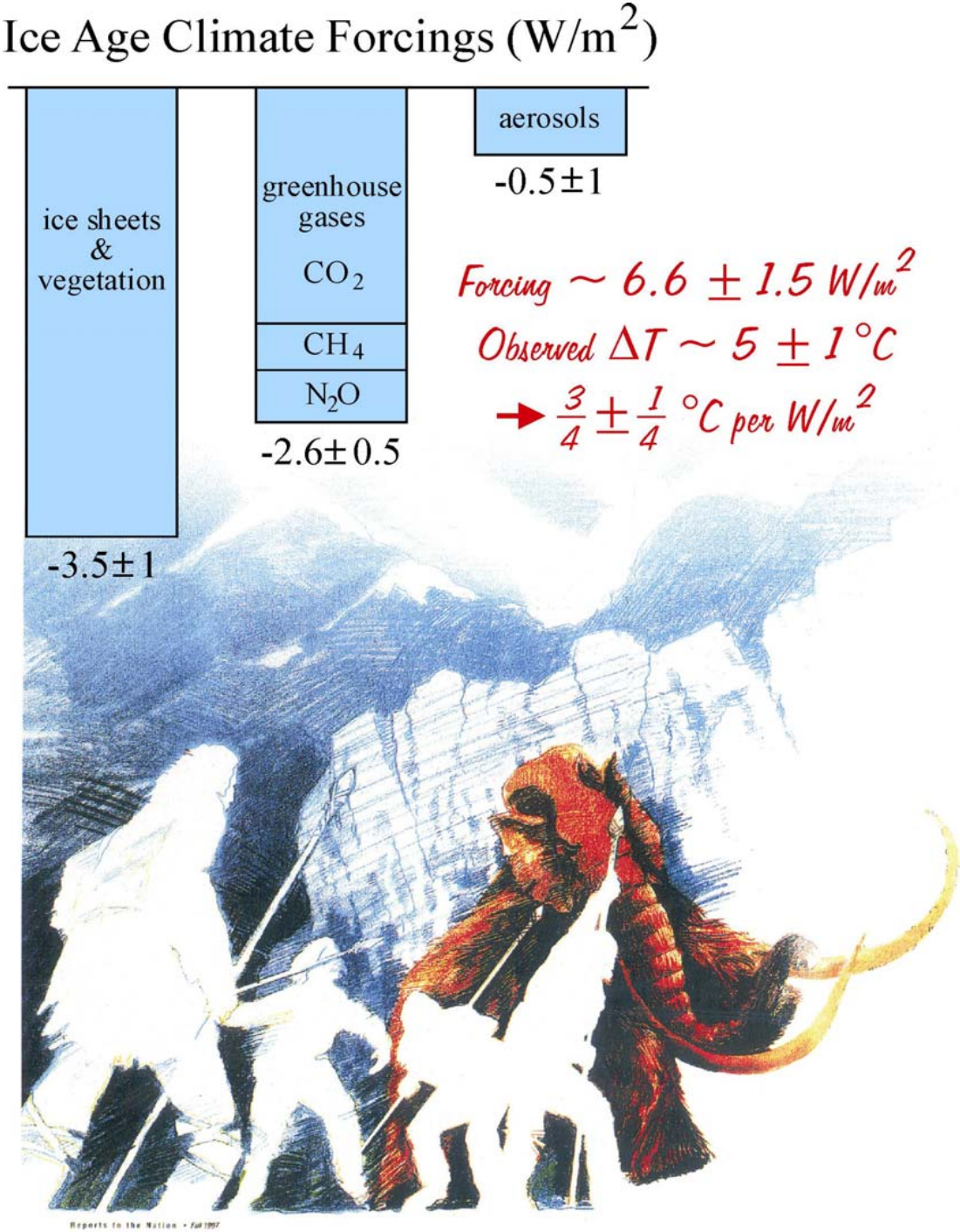

Global Temperature: Land-Ocean Index
Temperature Anomaly (°C)
.6
.4
.2
.0
-.2
-.4
1880
1900
1920
1940
1960
1980
2000
Annual Mean
5-year Mean



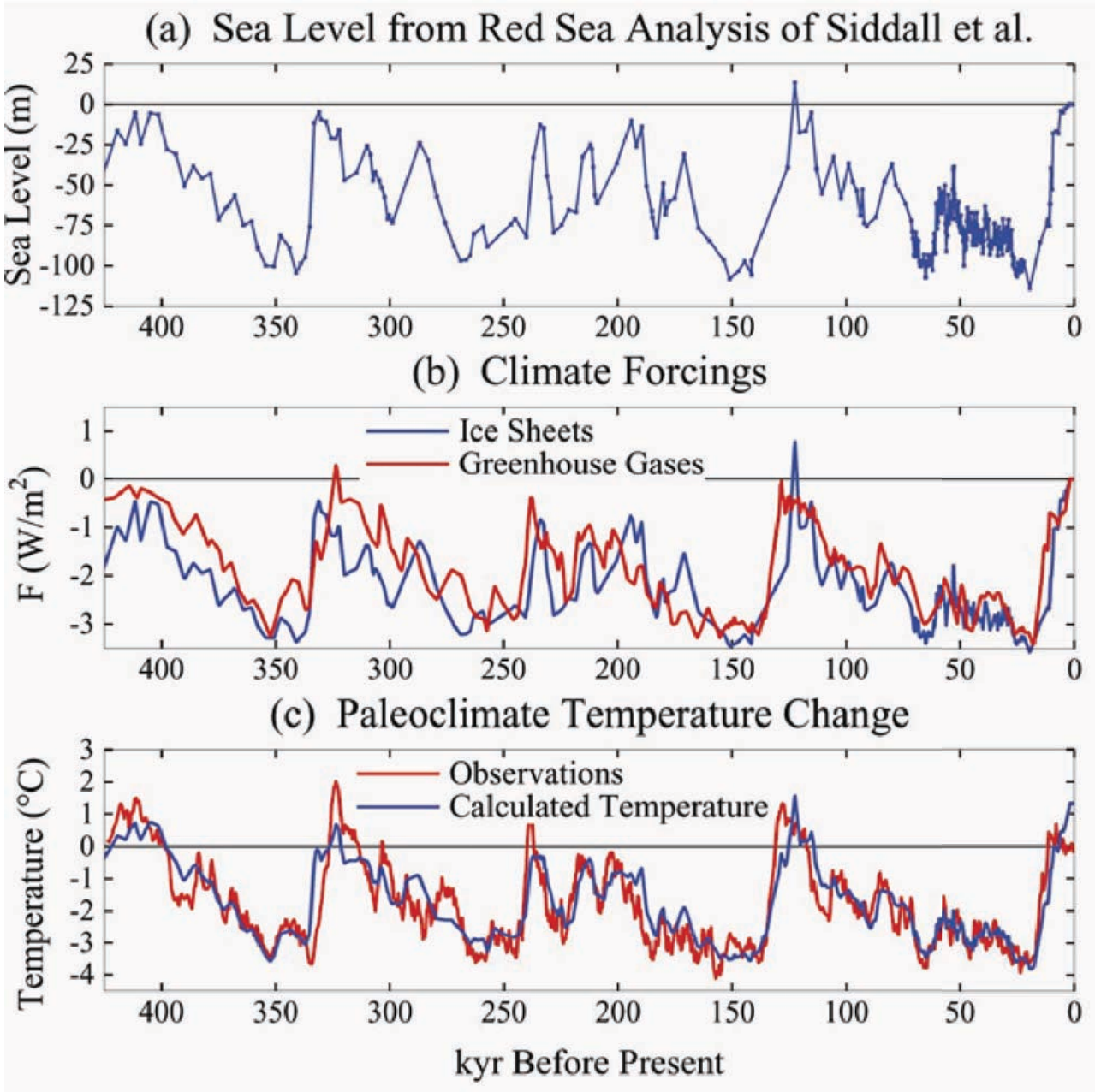
CO_2, CH_4 and temperature records from Antarctic ice core data

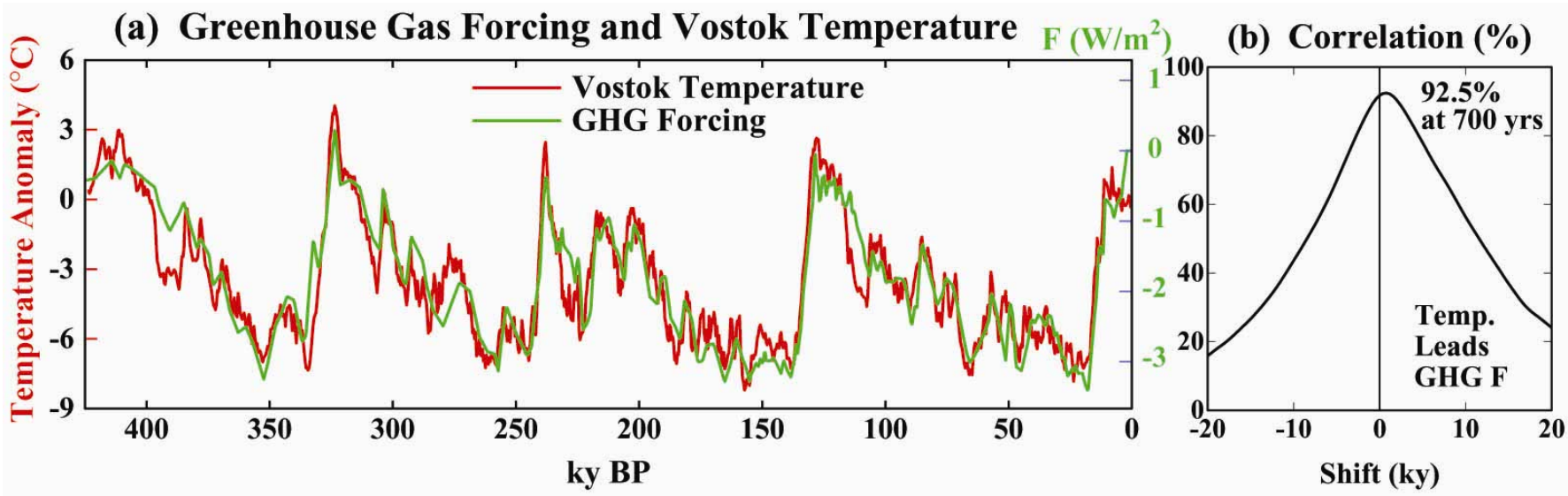
Source: Vimeux, F., K.M. Cuffey, and Jouzel, J., 2002, "New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction", *Earth and Planetary Science Letters*, **203**, 829-843.

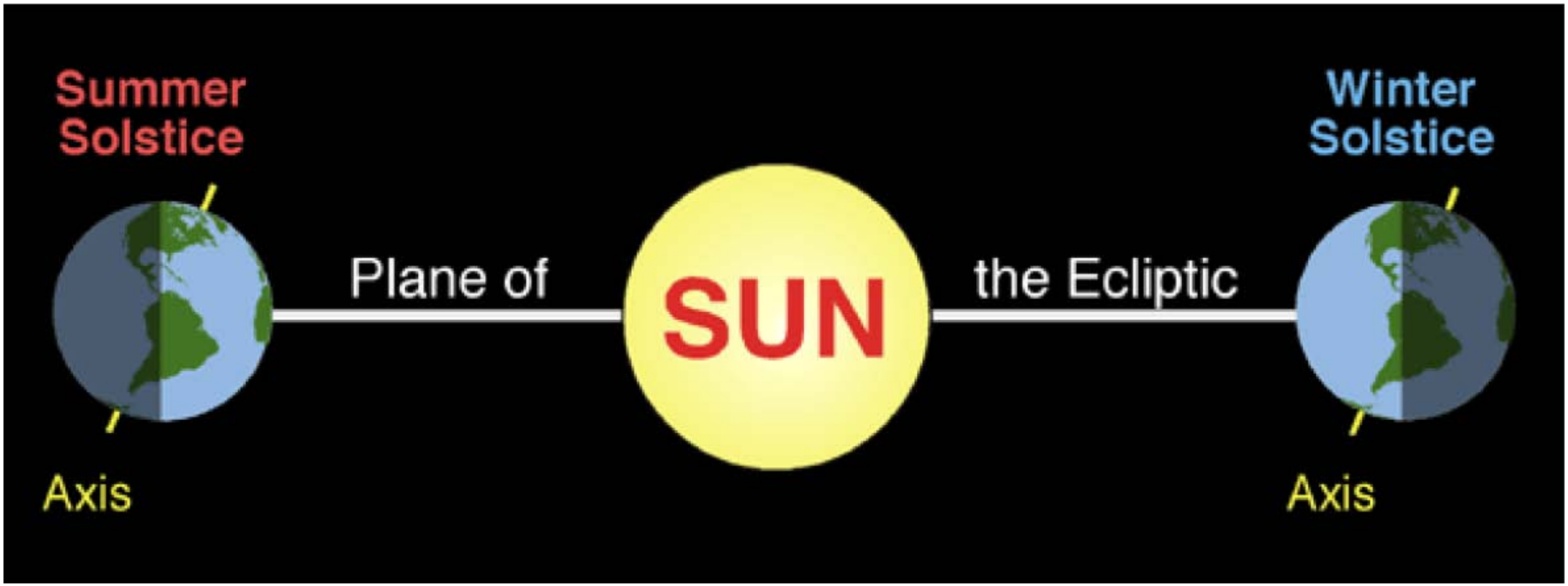
Ice Age Forcings Imply Global Climate Sensitivity ~ ¾°C per W/m^2.



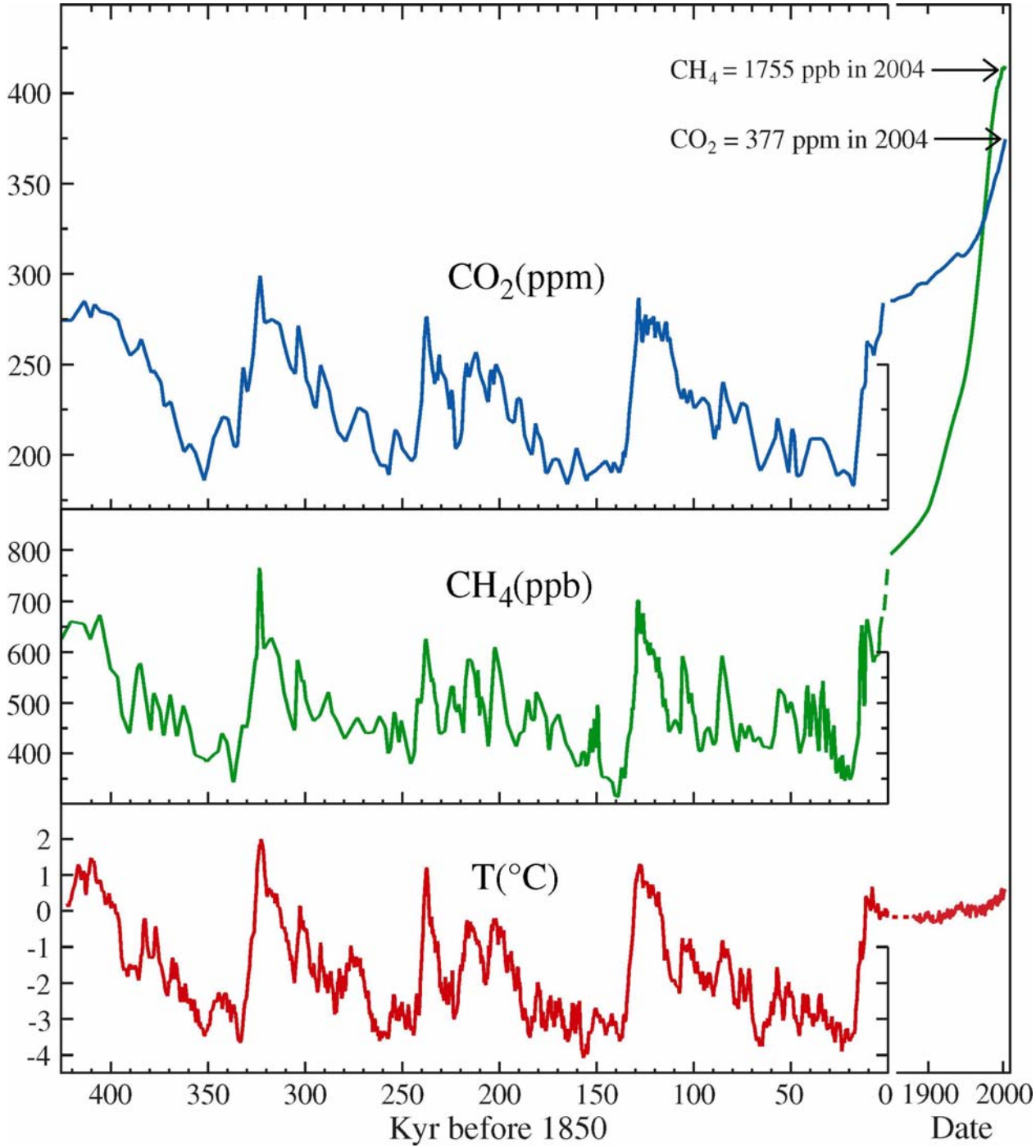
Source: Hansen et al., *Natl. Geogr. Res. & Explor.*, **9**, 141, 1993.


(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 (%)
100
80
60
40
20
0
92.5%
at 700 yrs
Temp.
Leads
GHG F
-20
-10
0
10
20
Shift (ky)


Summer
Solstice
Winter
Solstice
Plane of
the Ecliptic
SUN
Axis
Axis

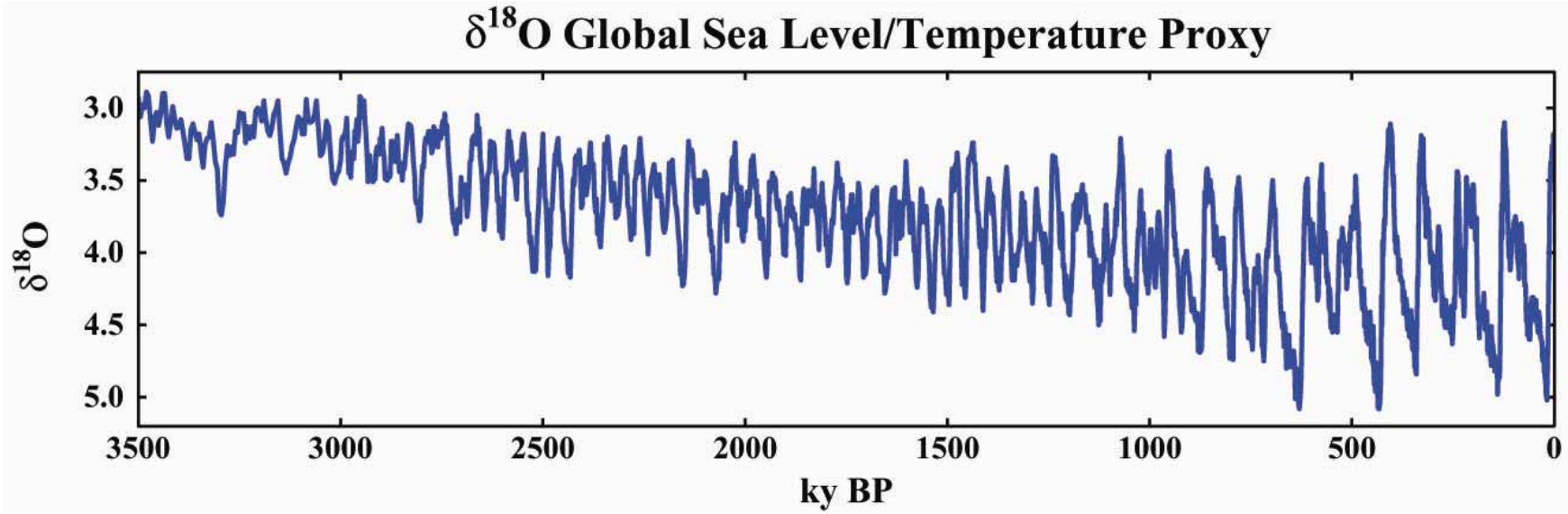
CO_2,CH_4 and estimated global temperature (Antarctic ΔT/2 in ice core era) 0 = 1880-1899 mean.



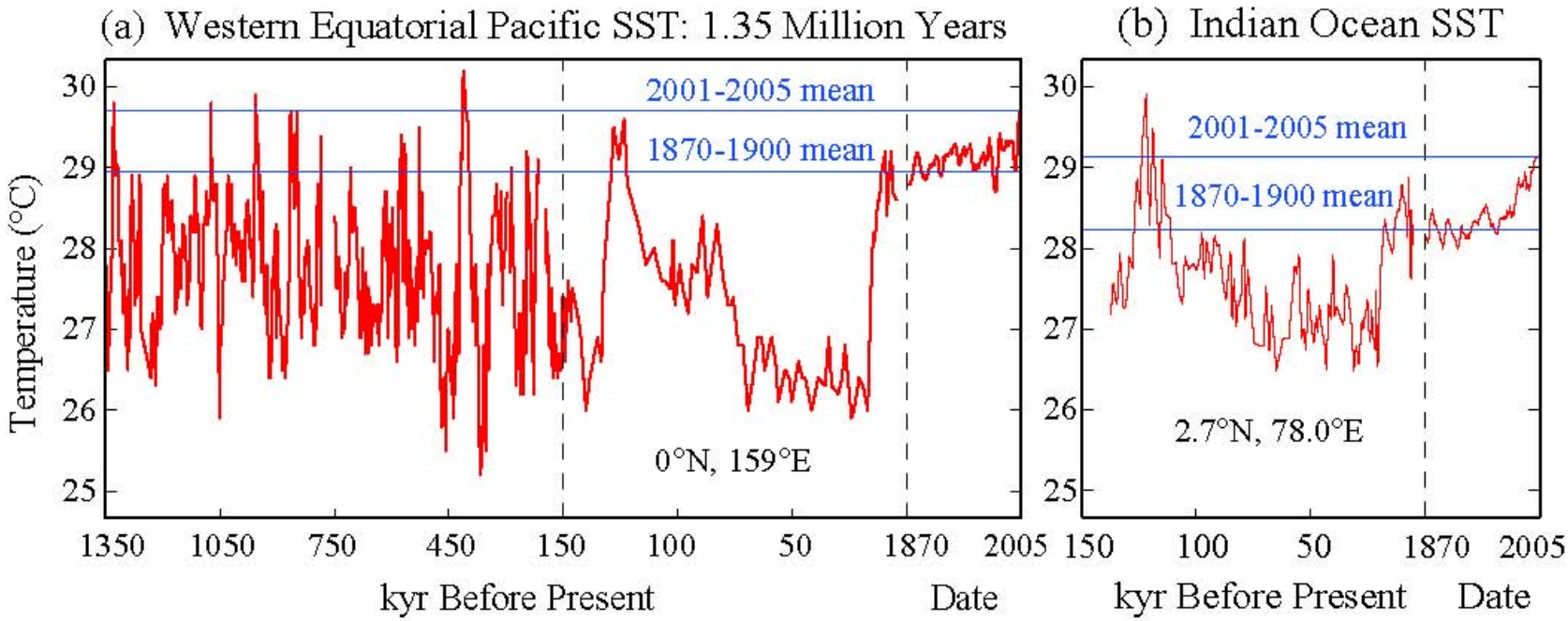
Source: Hansen, *Clim. Change*, **68**, 269, 2005.

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.



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.


(a) Western Equatorial Pacific SST: 1.35 Million Years
(b) Indian Ocean SST
Temperature (°C)
30
29
28
27
26
25
2001-2005 mean
1870-1900 mean
0°N, 159°E
2.7°N, 78.0°E
1350
1050
750
450
150
100
50
1870
2005
kyr Before Present
Date

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

Extermination of Animal & Plant Species

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

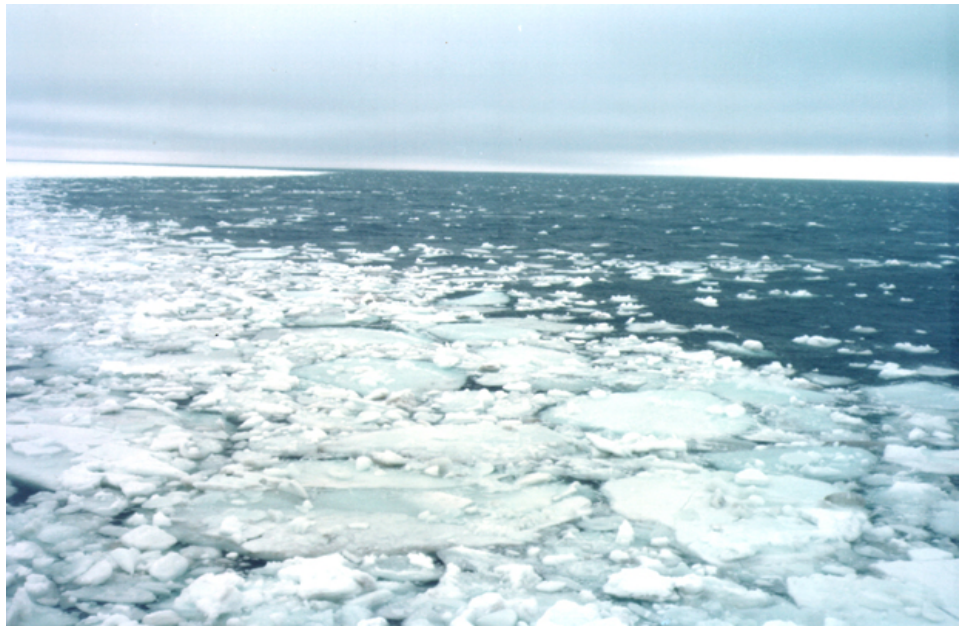
Ice Sheet Disintegration: Global Sea Level

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

Regional Climate Disruptions

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

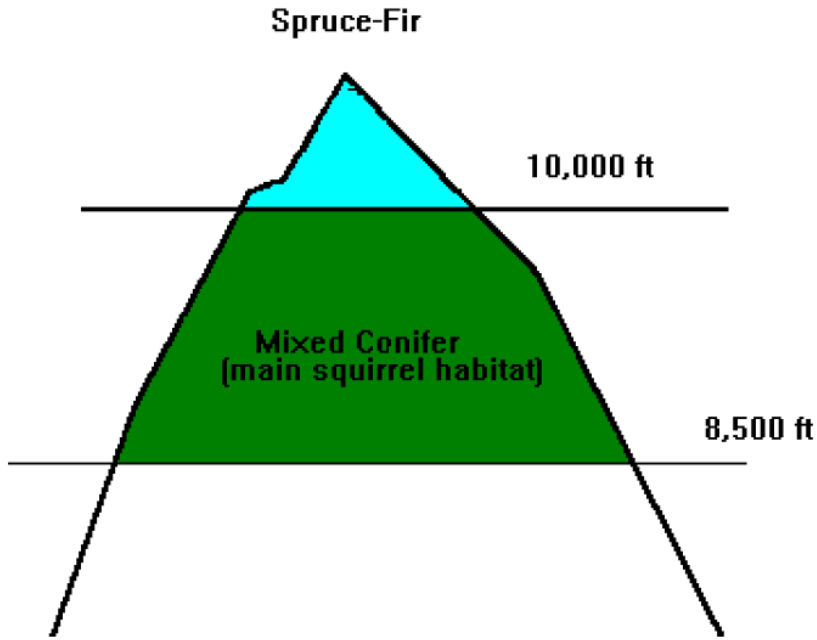
Arctic Climate Impact Assessment (ACIA)



Sources: Claire Parkinson and Robert Taylor

Mt. Graham Red Squirrel

Mount Graham Red Squirrel (Credit: Claire Zugmeyer)

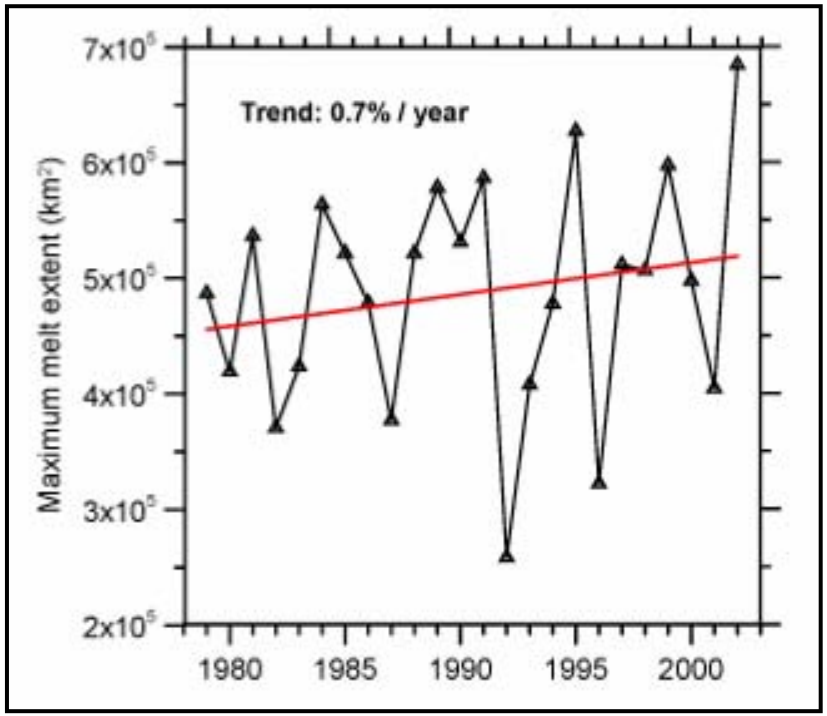


Survival of Species

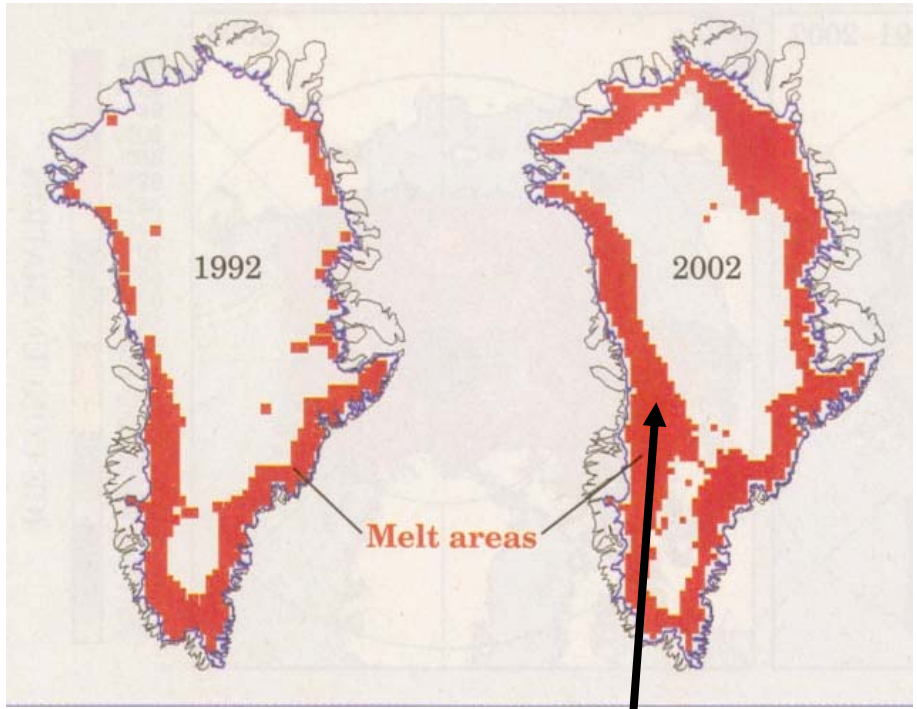
1. **"Business-as-Usual" Scenario**
   - **Global Warming ~ 3ºC**
   - **Likely Extinctions ~ 50 percent**
2. **"Alternative" Scenario**
   - **Global Warming ~ 1ºC**
   - **Likely Extinctions ~ 10 percent**

Climate Feedbacks → Scenario Dichotomy

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.

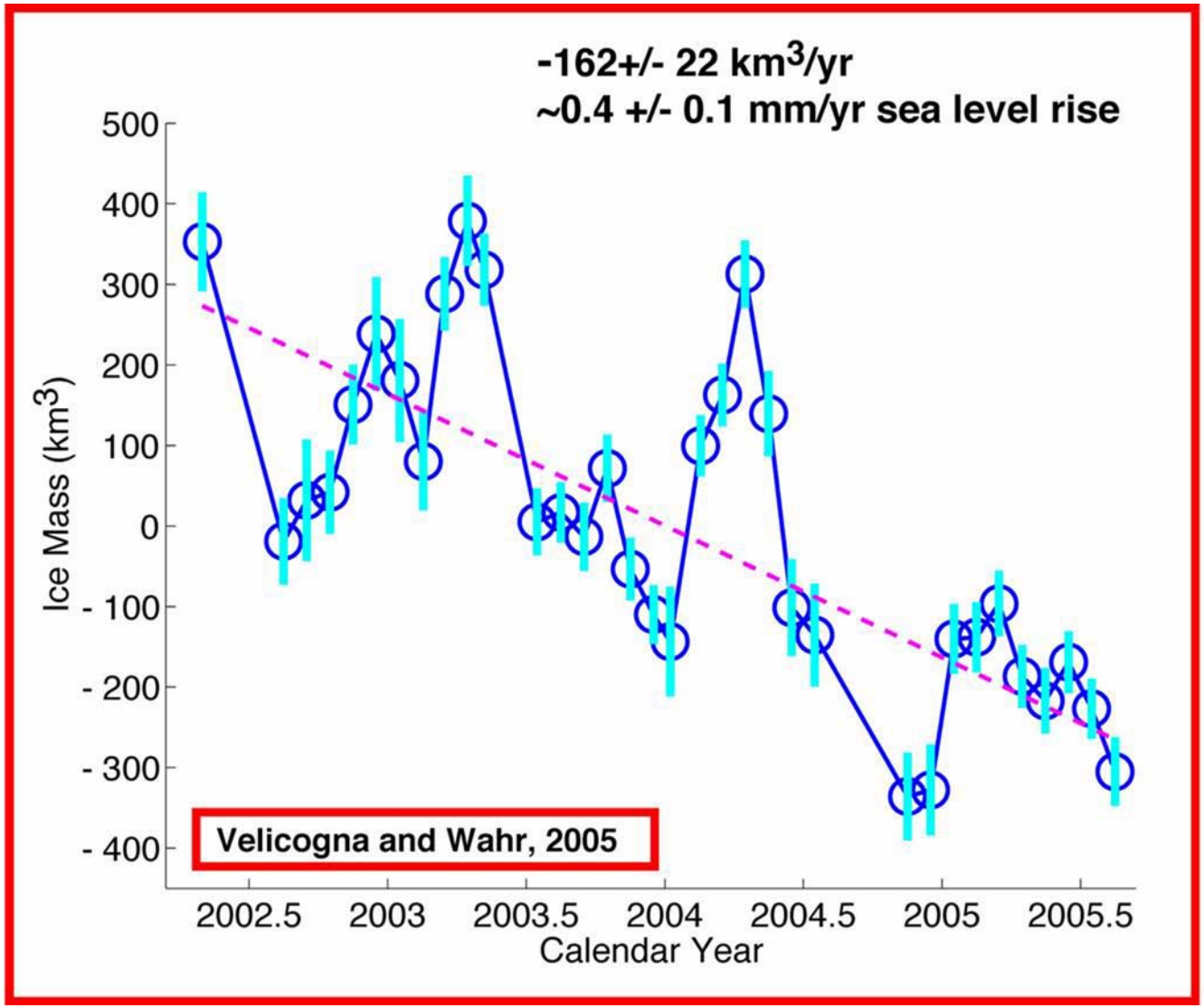
Source: Roger Braithwaite, University of Manchester (UK)

Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.

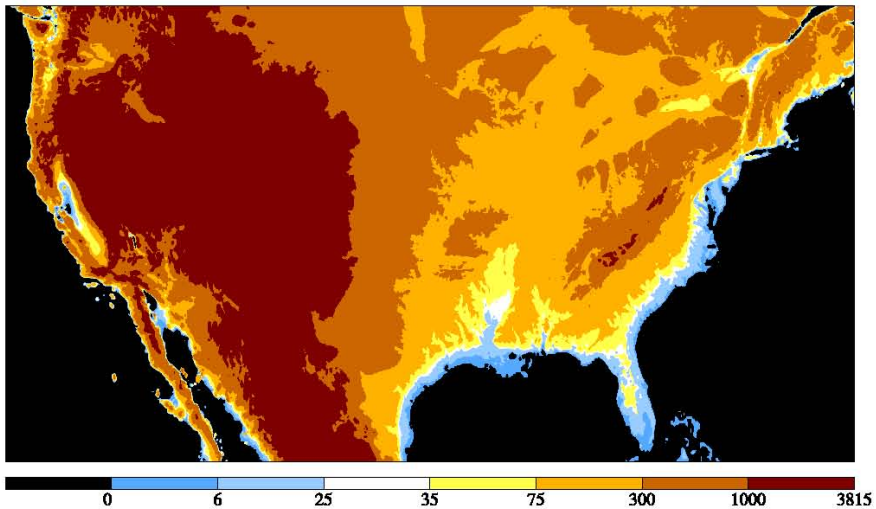
Source: Prof. Konrad Steffen, Univ. of Colorado

Greenland Mass Loss – From Gravity Satellite

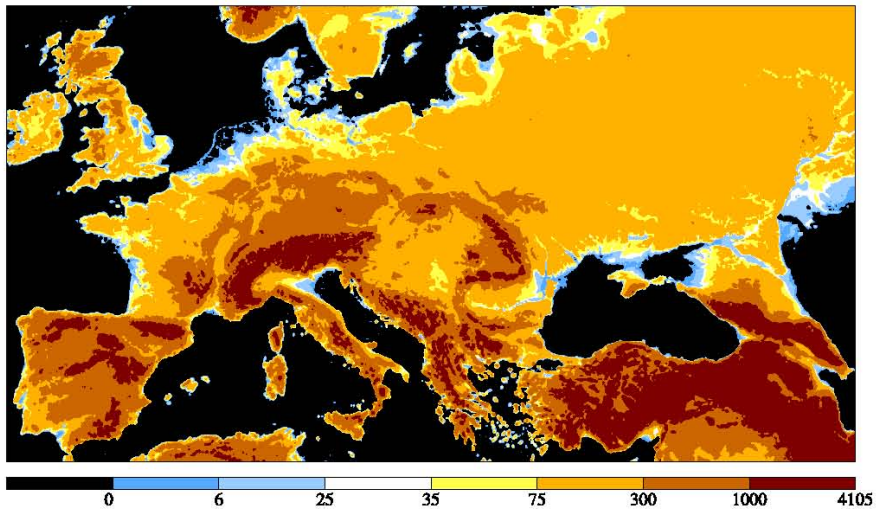


Areas Under Water: Four Regions

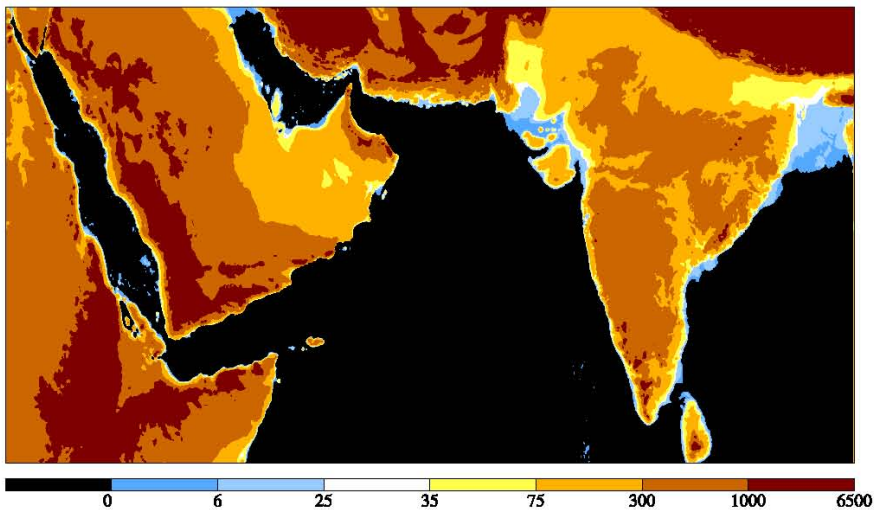
U.S. Area Under Water



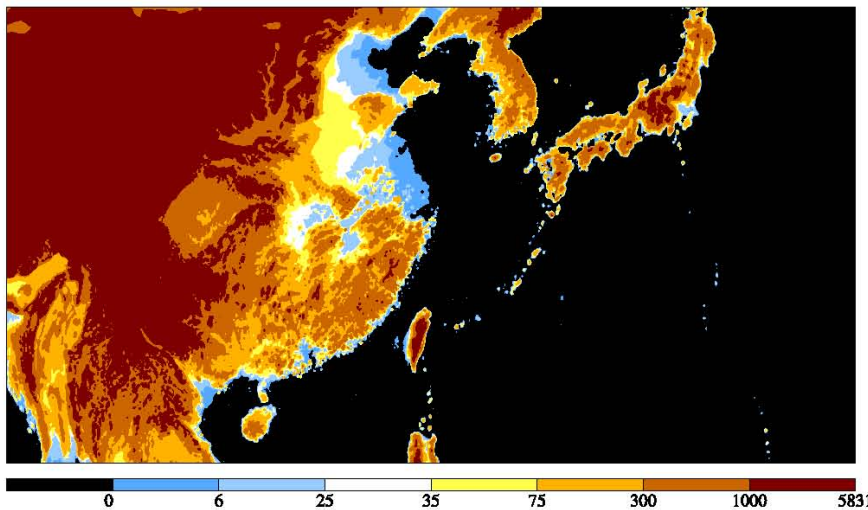
Europe Area Under Water



Central Asia: Area under Water



Far East: Area under Water

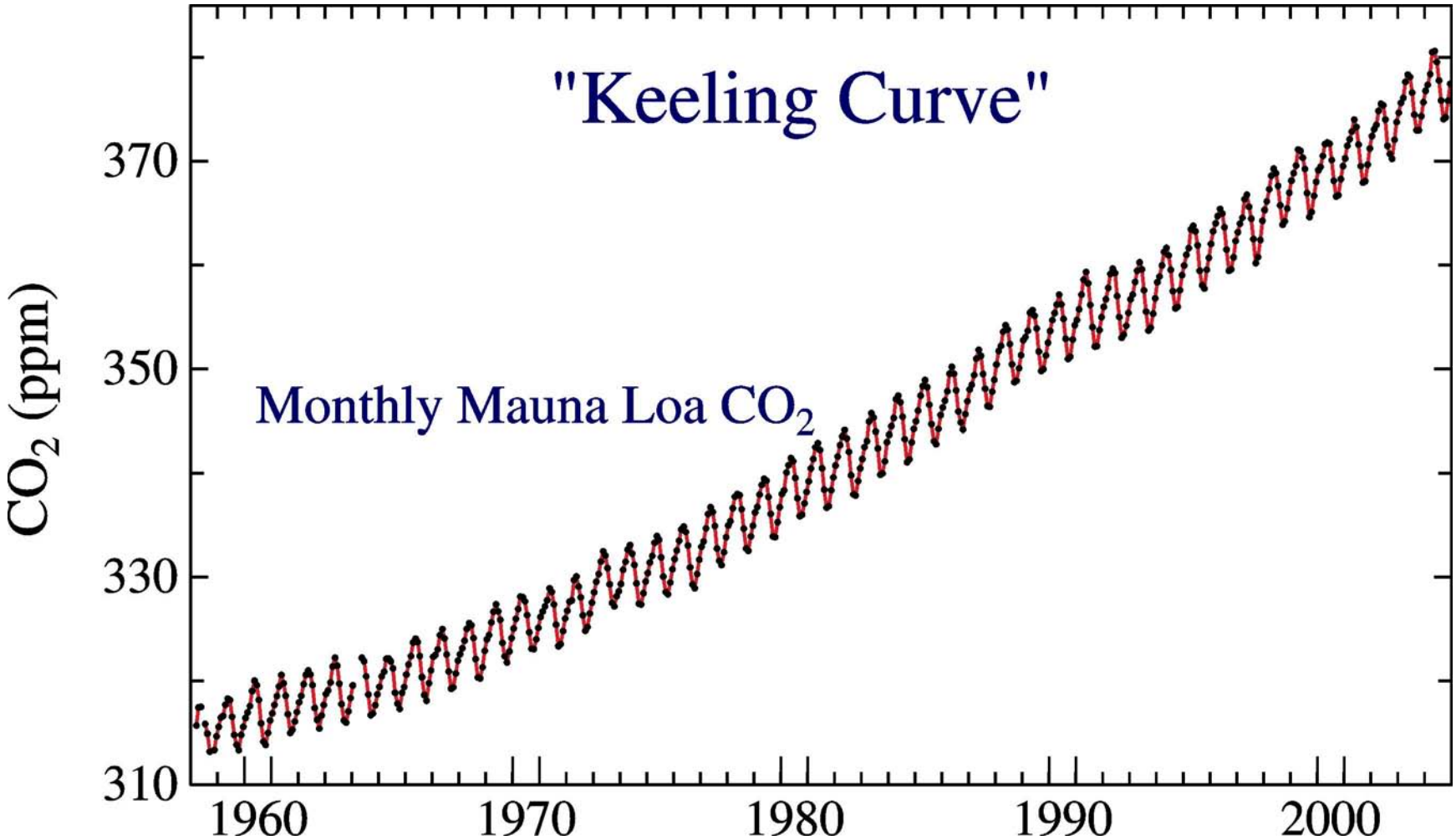


Summary: Ice Sheets

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

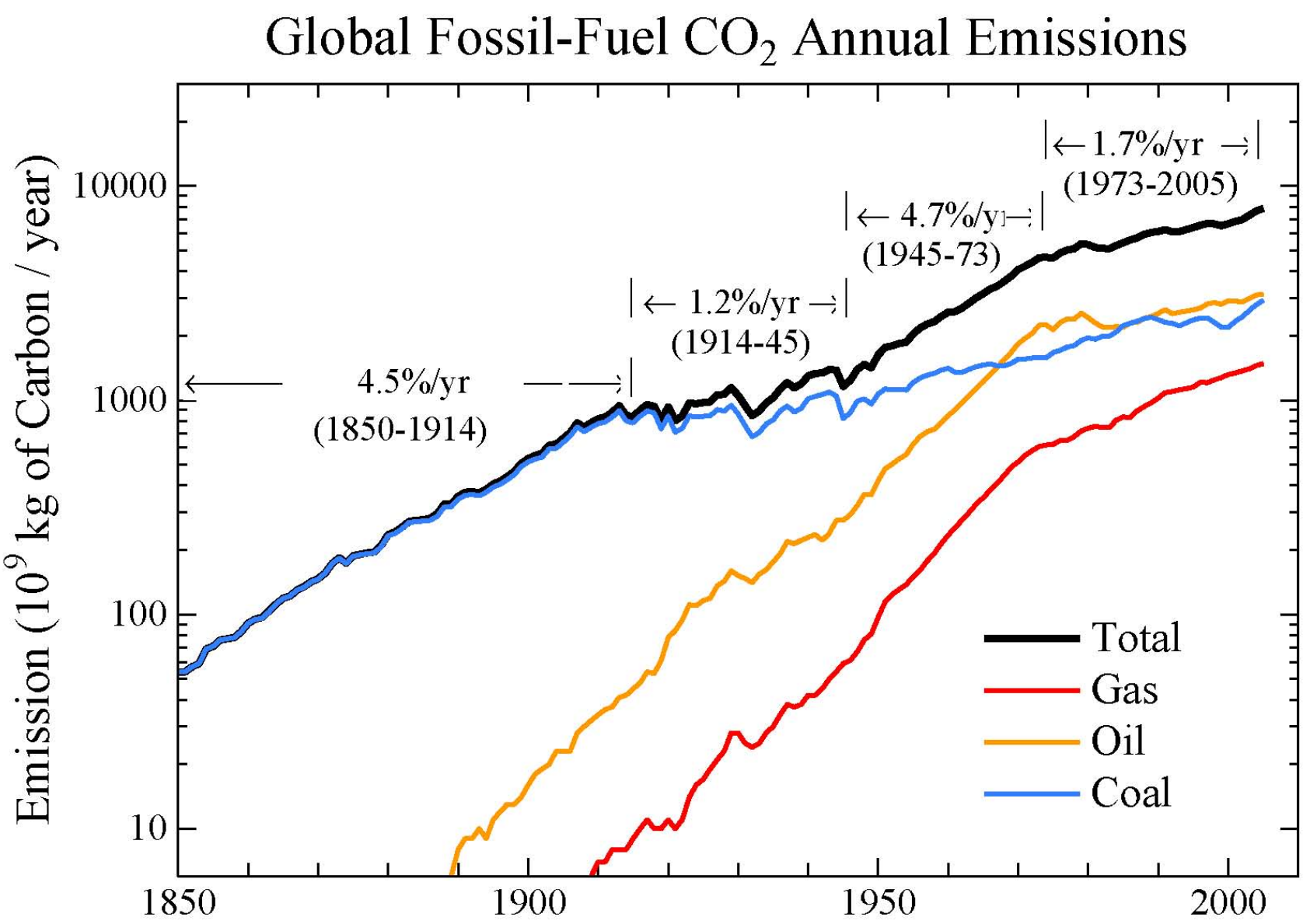
2. **Ice Sheet Disintegration Starts Slowly but Multiple Positive Feedbacks Can Lead to Rapid Non-Linear Collapse**

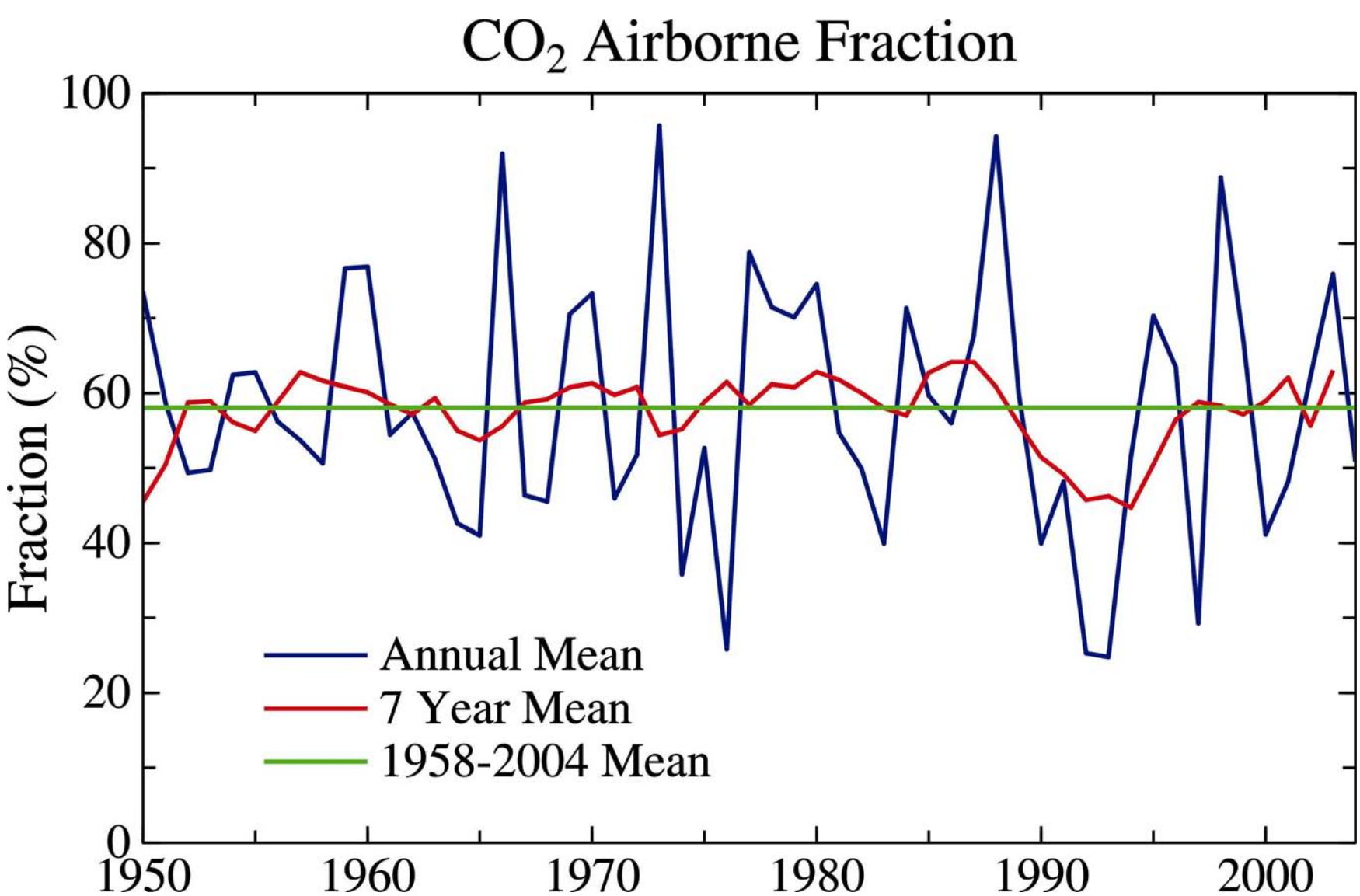
3. **Equilibrium Sea Level Rise for ~3C Warming (25±10 m = 80 feet) Implies the Potential for Us to Lose Control**



Atmospheric CO_2 measured at Mauna Loa, Hawaii.

Source: NOAA Climate Monitoring and Diagnostic Laboratory

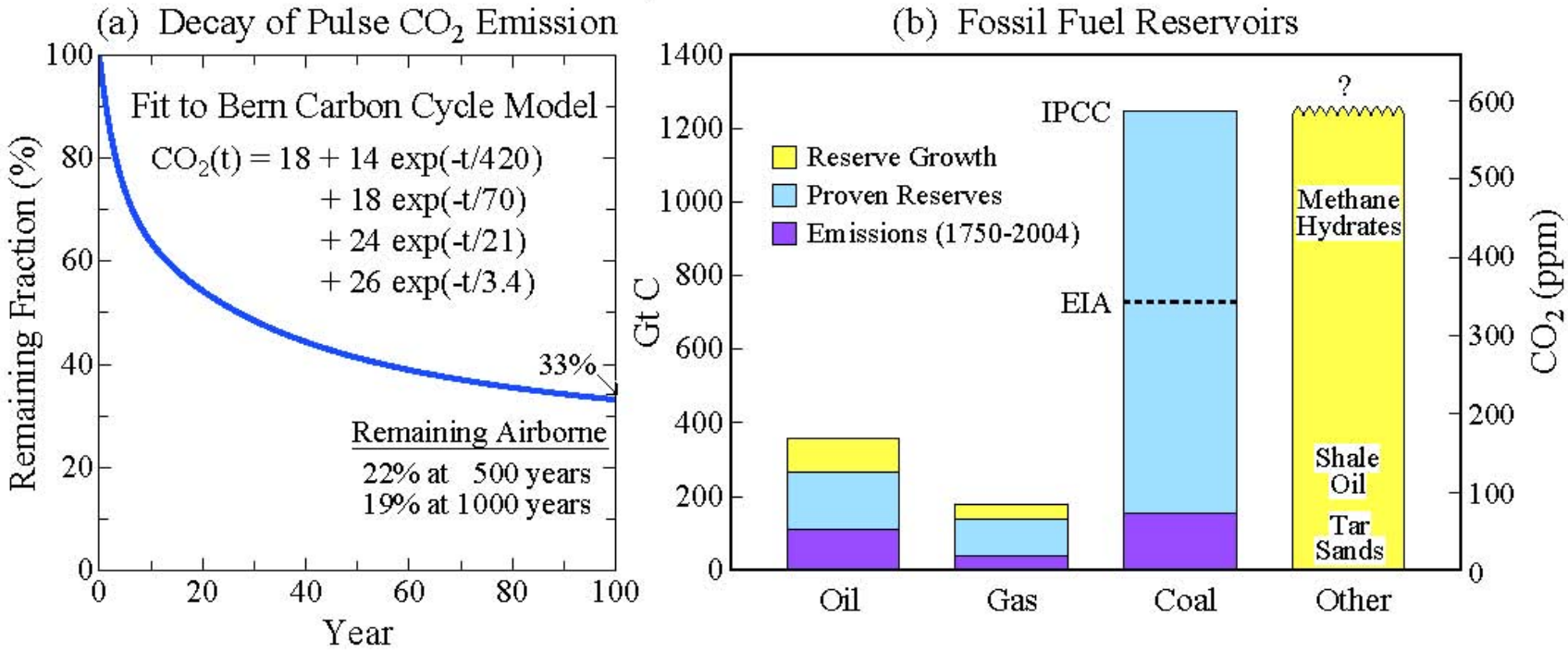

Global Fossil-Fuel CO_2 Annual Emissions
Emission (10^9 kg of Carbon / year)
10000
1000
100
10
1850
1900
1950
2000
4.5%/yr
(1850-1914)
1.2%/yr
(1914-45)
4.7%/yr
(1945-73)
1.7%/yr
(1973-2005)
Total
Gas
Oil
Coal



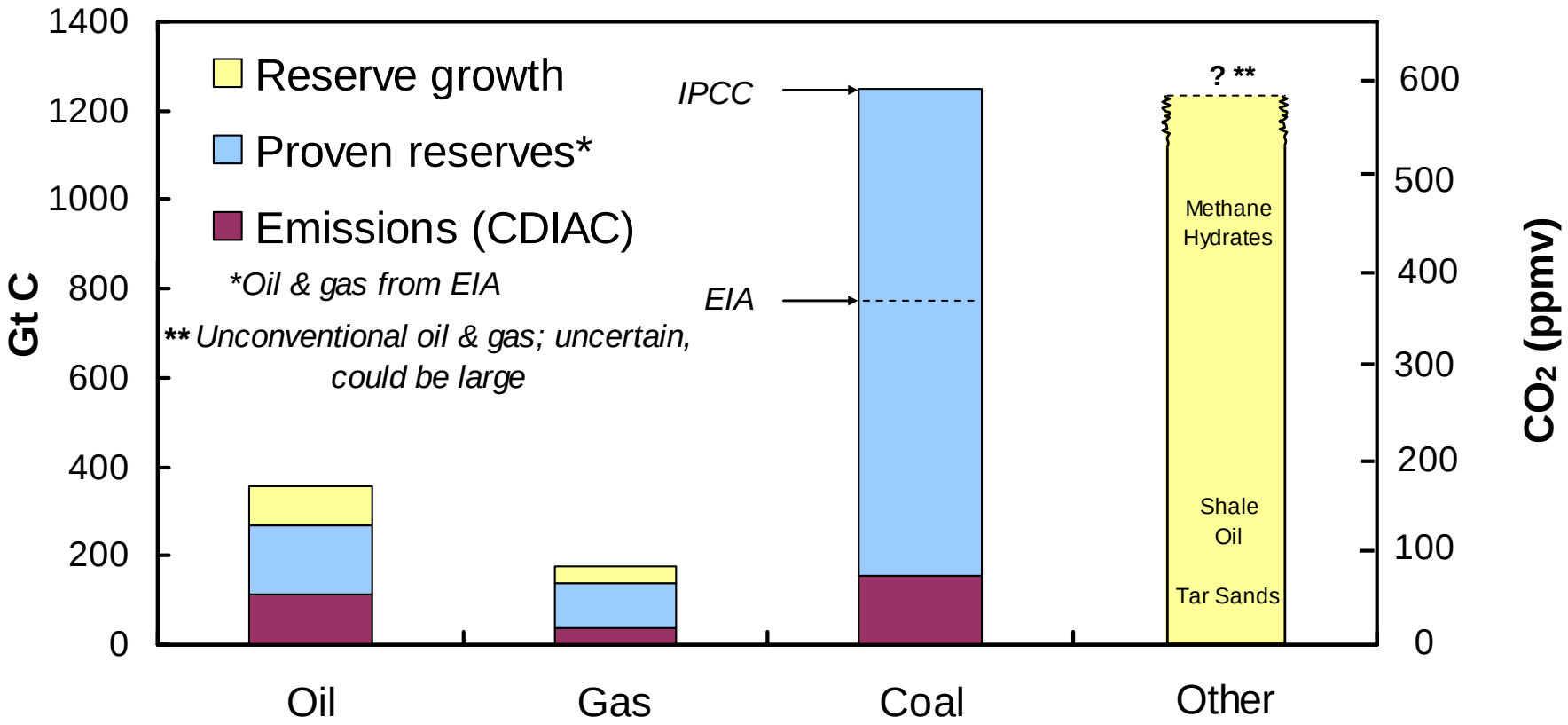
CO_2 airborne fraction, i.e., ratio of annual atmospheric CO_2 increase to annual fossil fuel CO_2 emissions.

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

Carbon Cycle Constraints



Fossil Fuel Reservoirs and 1750–2004 Emissions



Status of CO_2

Pre-industrial Amount: **280 ppm**

Present Amount: **382 ppm**

Maximum Allowable ≤ **450 ppm**

Rate of Change: **+2 ppm/year (and growing)**

→ **Maximum Likely To Be Exceeded**

→ **'Geoengineering' May Be Needed!**

Science & Implications

1. Warming >1°C Risks 'Different Planet'

- Maximum CO_2 ~450 ppm (maybe less!)
- CO_2 limit slightly more, if non-CO_2 ↓

2. Quarter of CO_2 Stays in Air "Forever"

- Eventual Vehicles must be Zero-CO_2 (renewable, hydrogen from nuclear or solar, etc.)
- Eventual Power Plants must be Zero-CO_2

3. Gas + Oil Use Most of 450 ppm Limit

- Coal/unconventional must sequester CO_2
- Gas + Oil supplies must be stretched

Methods to Reduce CO_2 Emissions

1. **Energy Efficiency & Conservation**
   - More Efficient Technology
   - Life Style Changes
2. **Renewable & CO_2-Free Energy**
   - Hydro
   - Solar, Wind, Geothermal
   - Nuclear
3. **CO_2 Capture & Sequestration**

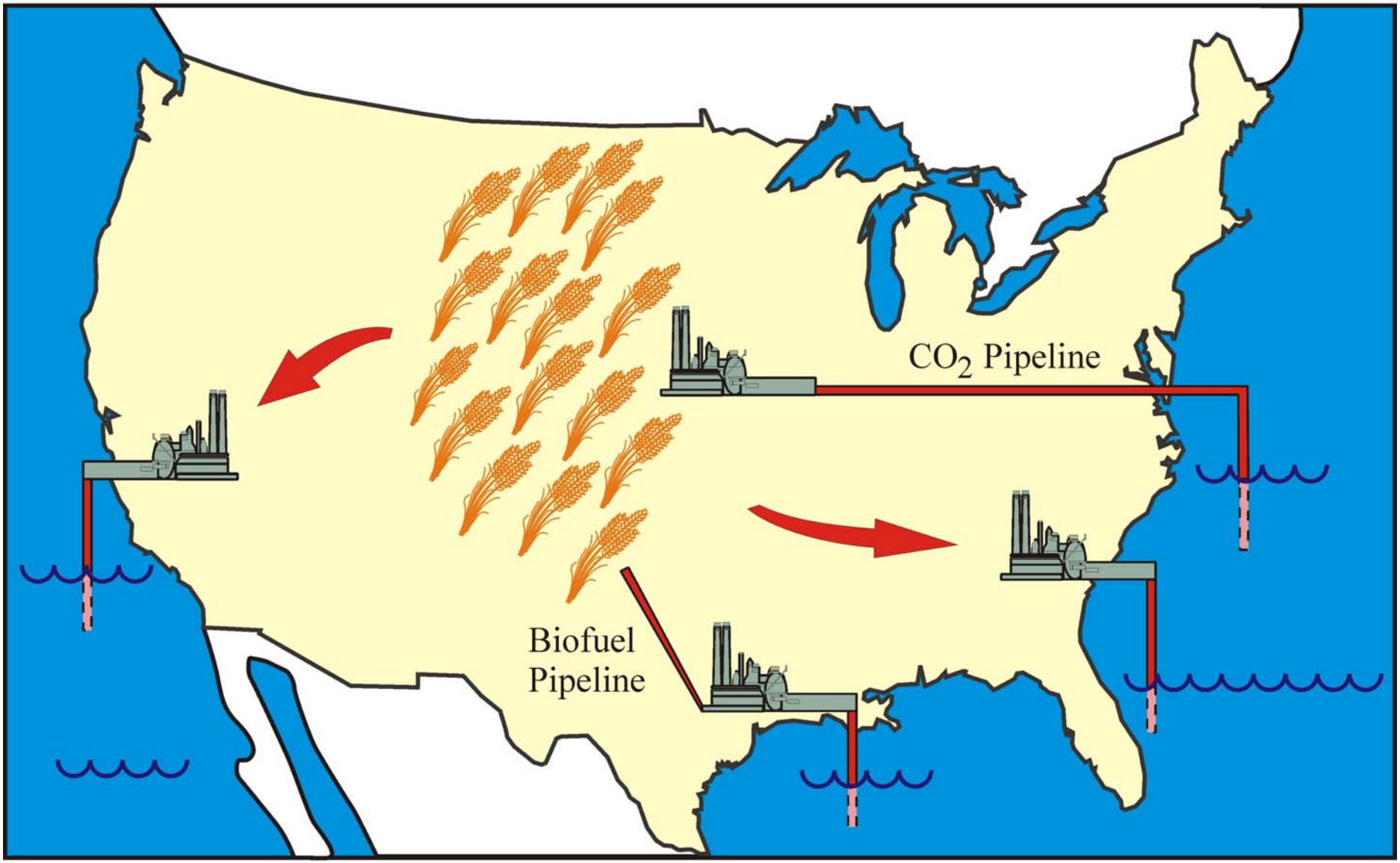
→ **No Silver Bullet**

→ **All Three are Essential**

Outline of Solution

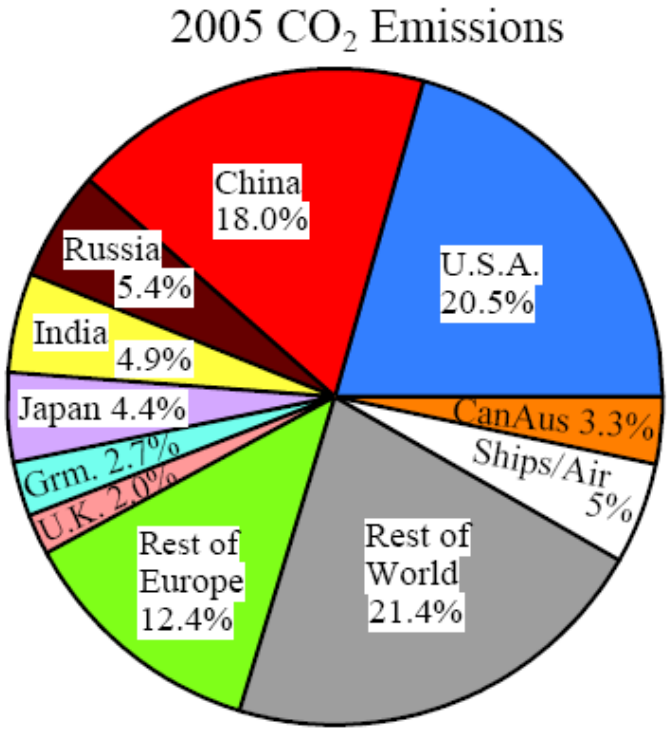
1. **Coal only in Powerplants w Sequestration**
   - **Phase-out old technology. Timetable TBD**
2. **Stretch Conventional Oil & Gas**
   - **Via Incentives (Carbon tax) & Standards**
   - **No Unconventional F.F. (Tar Shale, etc.)**
3. **Reduce non-CO_2 Climate Forcings**
   - **Methane, Black Soot, Nitrous Oxide**
4. **Draw Down Atmospheric CO_2**
   - **Agricultural & Forestry Practices**
   - **Biofuel-Powered Power-Plants**

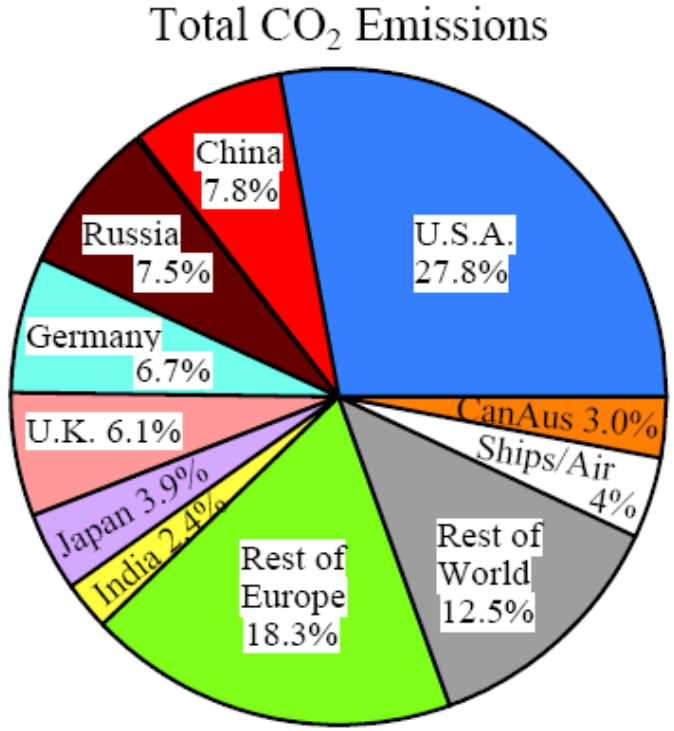
Biofuel Negative-CO_2 Power Plants

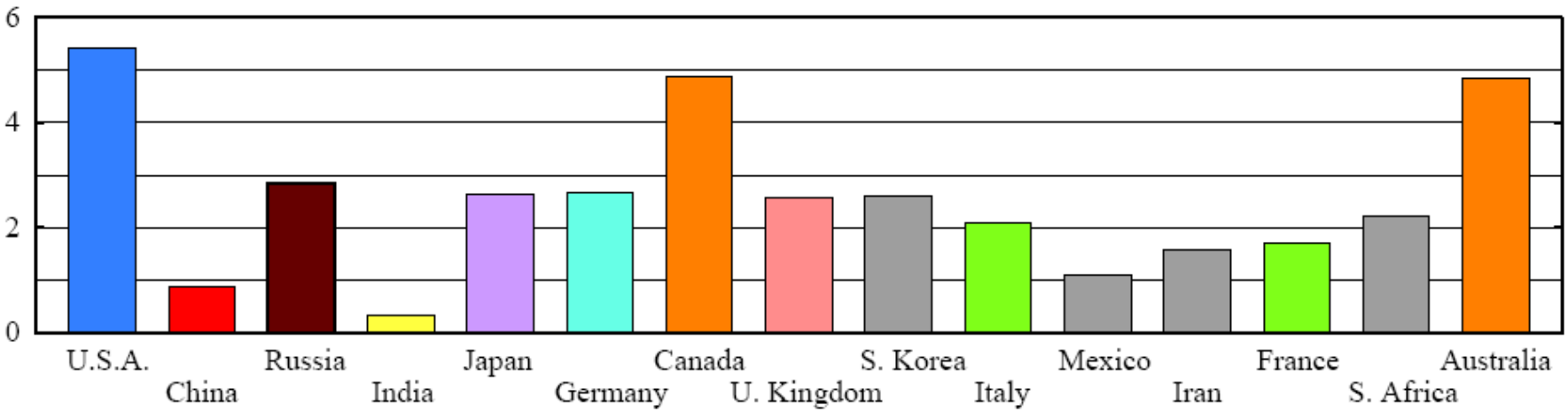


Cellulostic Biofuels Electrical Power Generation
Fail-Safe CO_2 Sequestration in Deep-Sea Sediments

Responsibility for CO_2 Emissions and Climate Change







Per Capita Fossil Fuel CO_2 Emissions in Order of Total Emissions