The Threat to the Planet*

Dark and Bright Sides of Global Warming

Jim Hansen

17 January 2008

Center for Global and Regional Environmental Research

University of Iowa

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

Status of the Matter

1. A Knowledge Gap

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

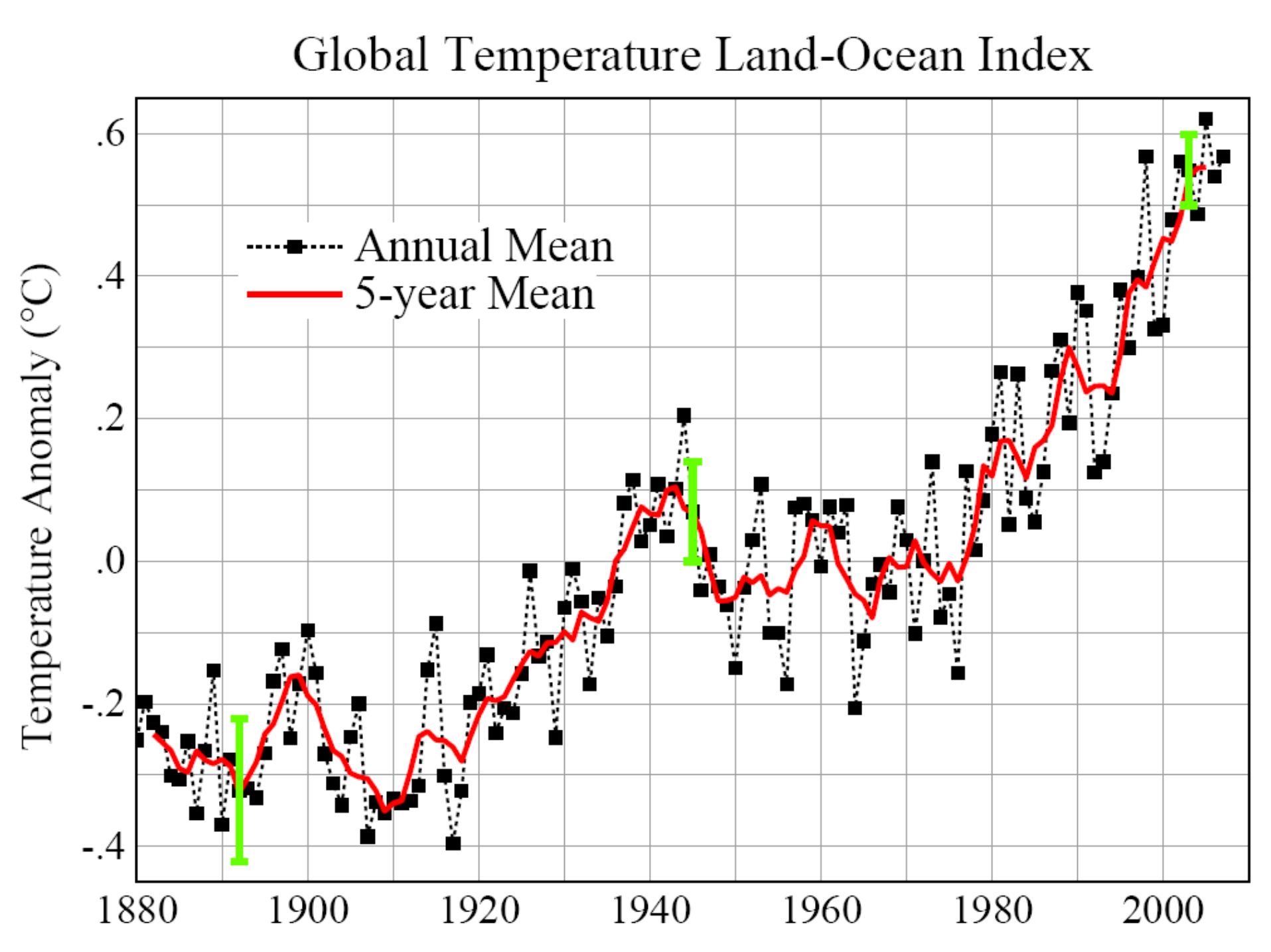
2. A Planetary Emergency

- Positive Feedbacks Predominate
- Climate Inertia → Pipeline Effect

Danger: Tipping Points → Different Planet

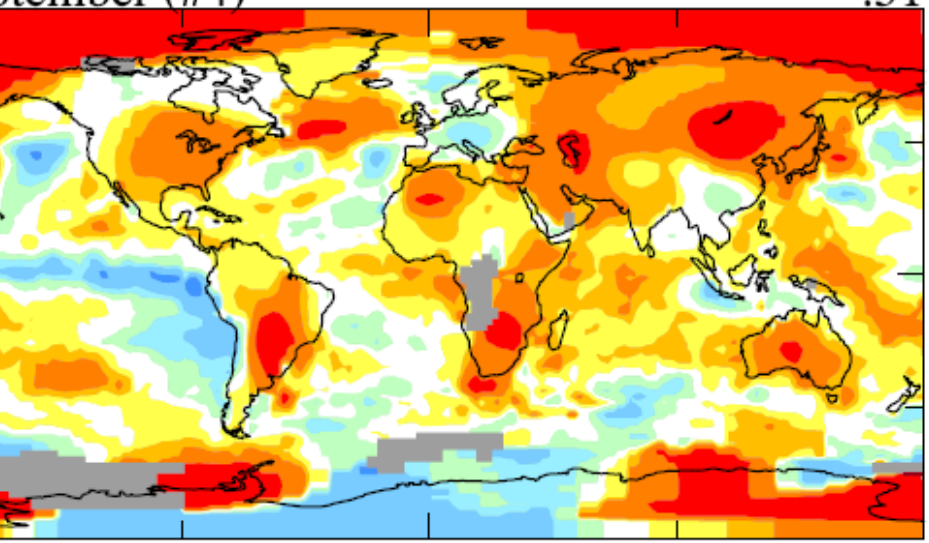
3. Good News in Bad News: Opportunity

- CO_2 350-450 ppm technically feasible
- Fewer Pollutants → + Health, Agriculture
- Low CO_2 Limit → less Ocean Acidification
- Special Interests → Need Public's Help!

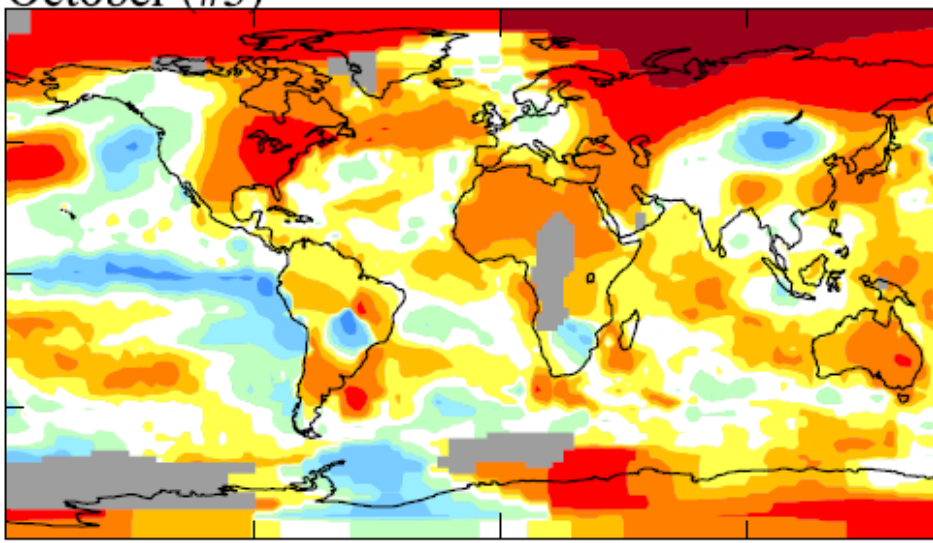

Global Temperature Land-Ocean Index
Annual Mean
5-year Mean
Temperature Anomaly (°C)
.6
.4
.2
.0
-.2
-.4
1880
1900
1920
1940
1960
1980
2000

2007 Surface Temperature Anomalies (°C) [Base Period 1951-80]

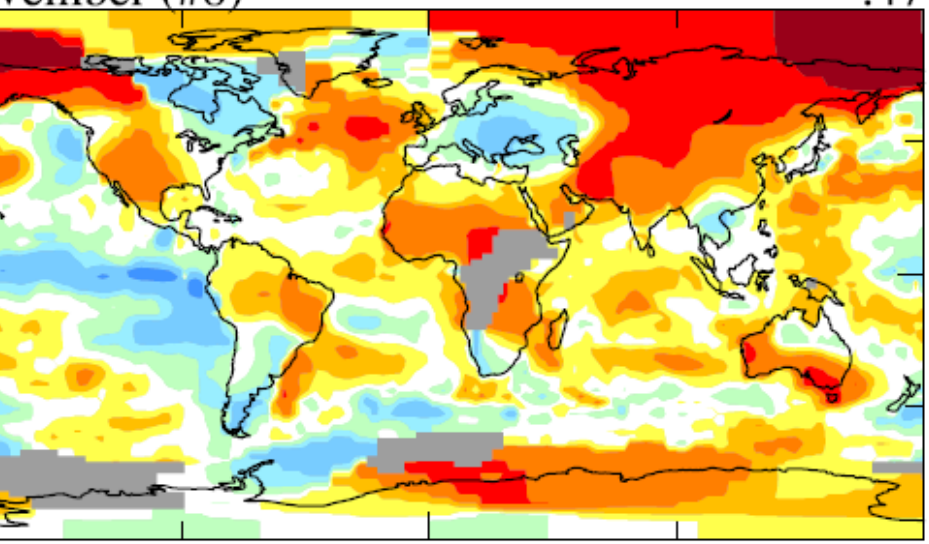
ptember (#4) .51



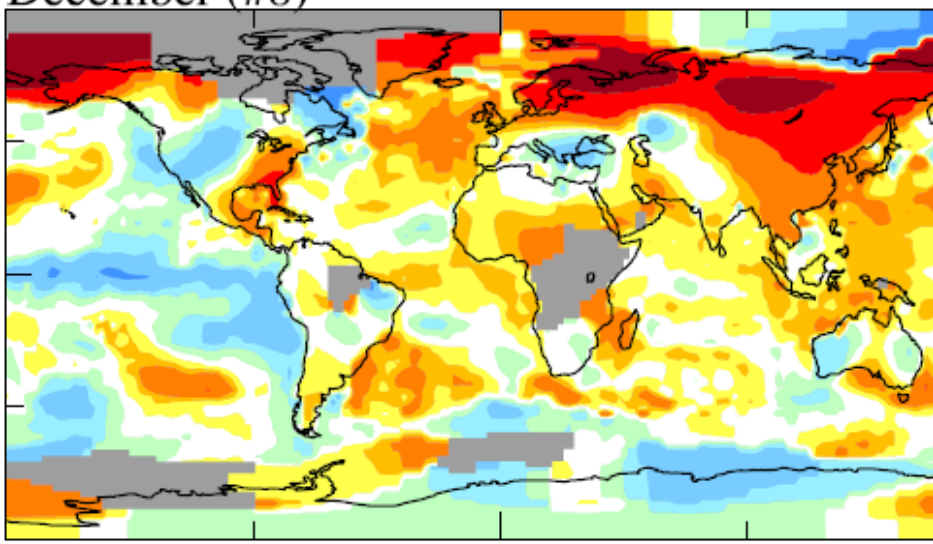
October (#5)



vember (#8) .47



December (#8)

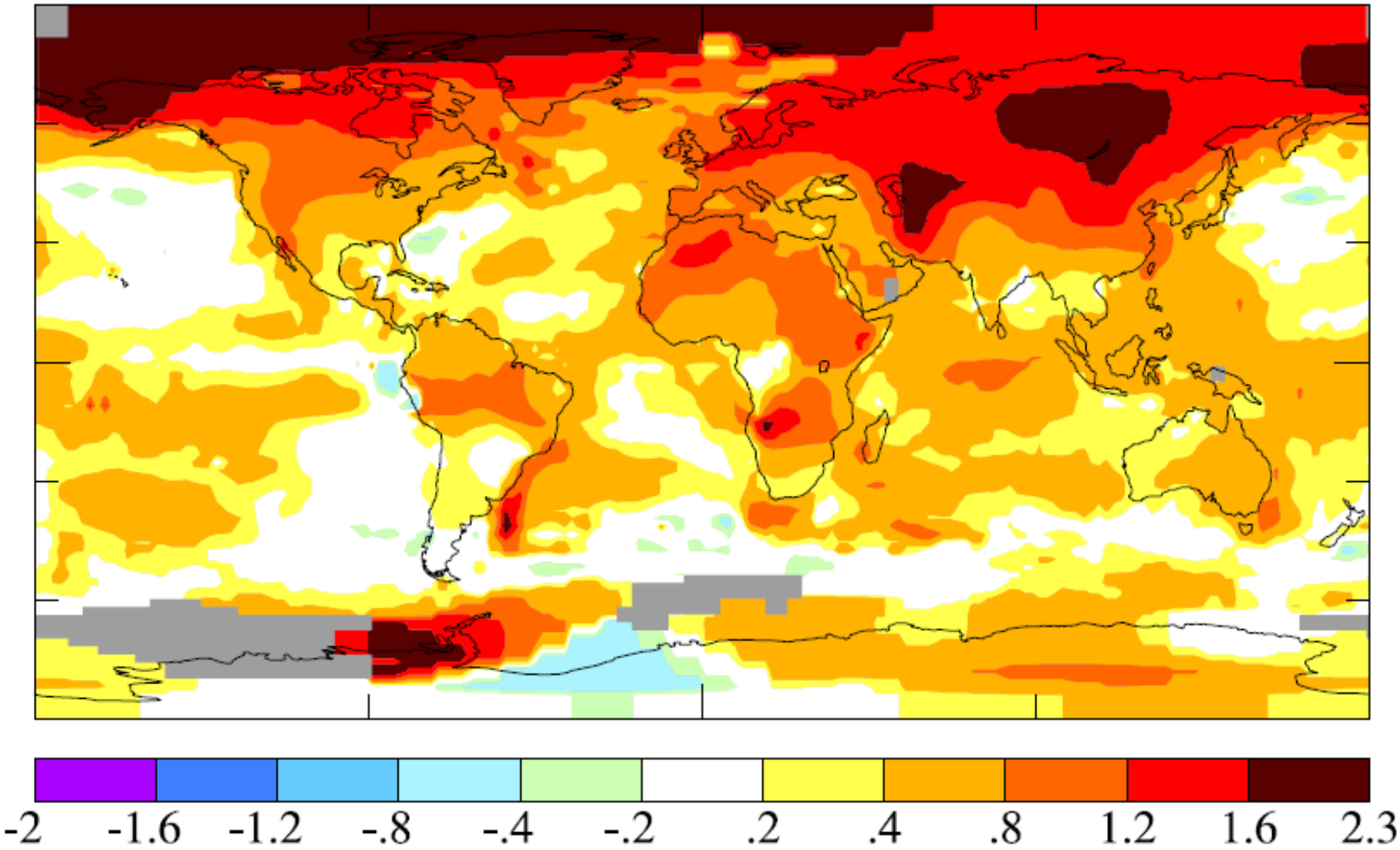


-5 -2 -1 -.6 -.2 .2 .6 1 2 5 8

-6 -5 -2 -1 -.6 -.2 .2 .6 1 2 5

2001-2007 Mean Surface Temperature Anomaly (◦C)

Base Period = 1951-80, Global Mean = 0.54



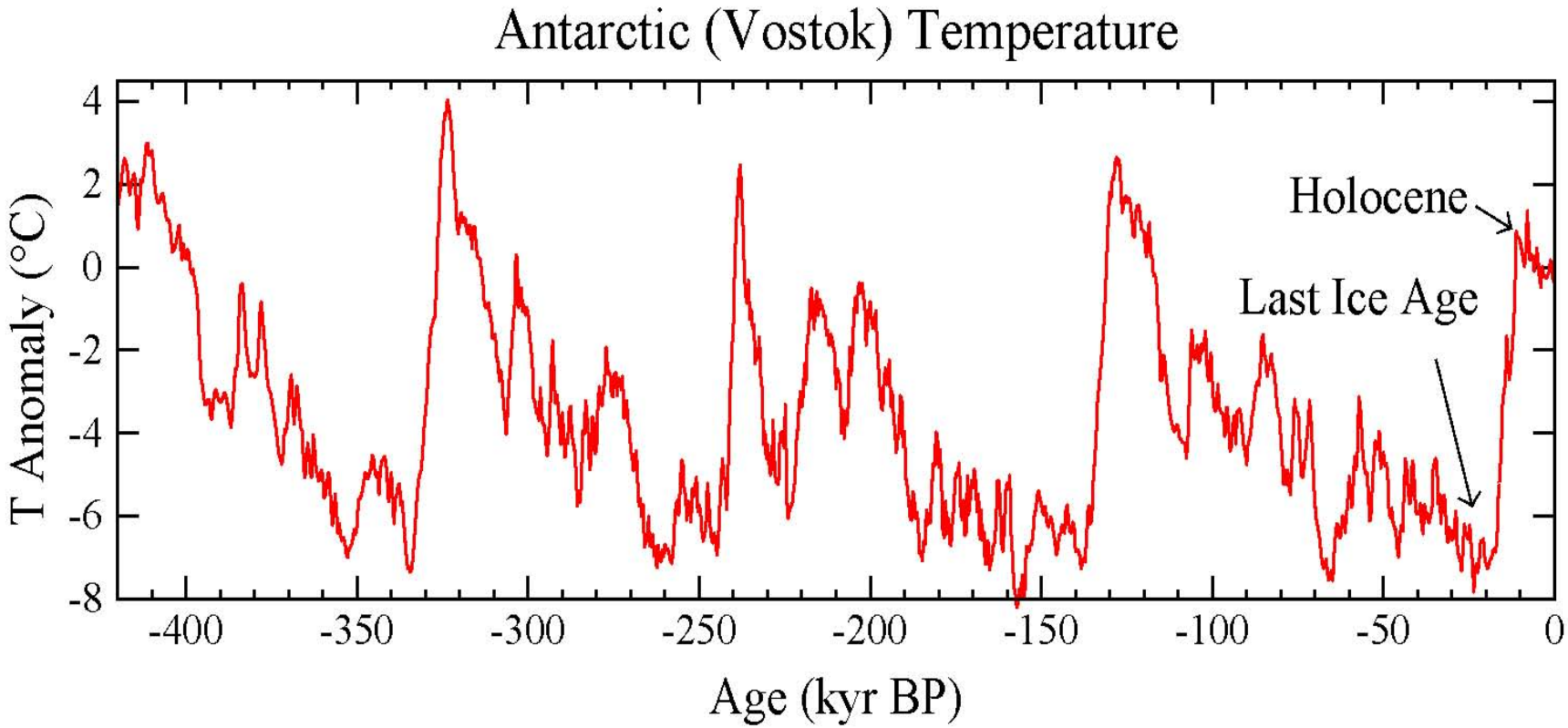
Warming in the Pipeline?
Tipping Points?

Isn't this just some sort of "theory"?

Do we really need to wrestle with global warming?

There have been huge climate changes in the past.

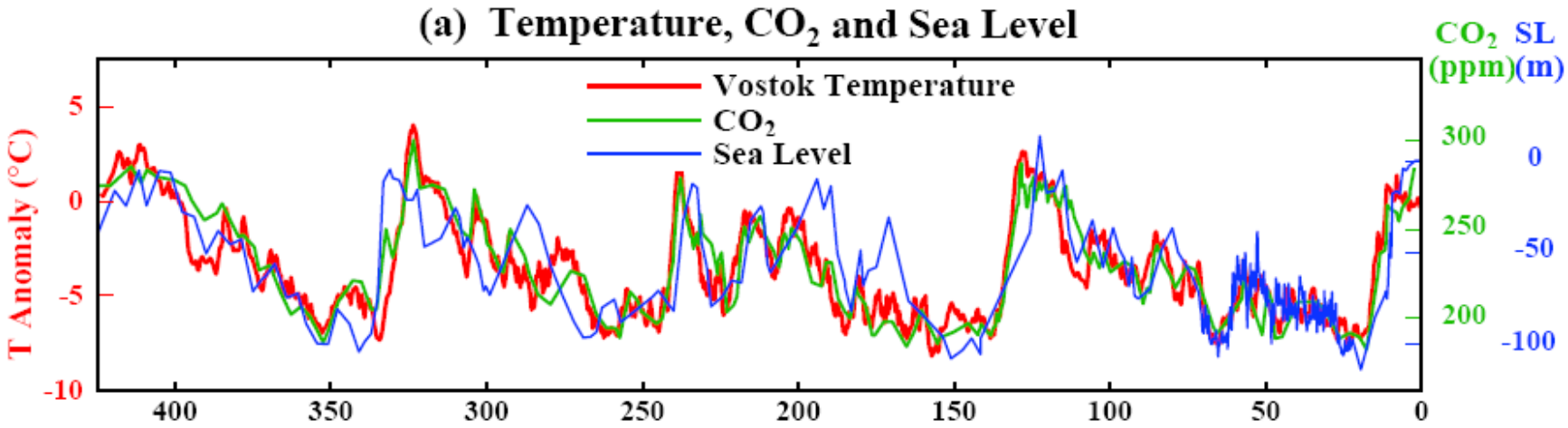
Isn't it arrogant to say that the present climate is the best?



Earth's history provides most important information on global warming.

Recorded human history occurs within the Holocene warm period.

Temperature, CO_2 and Sea Level



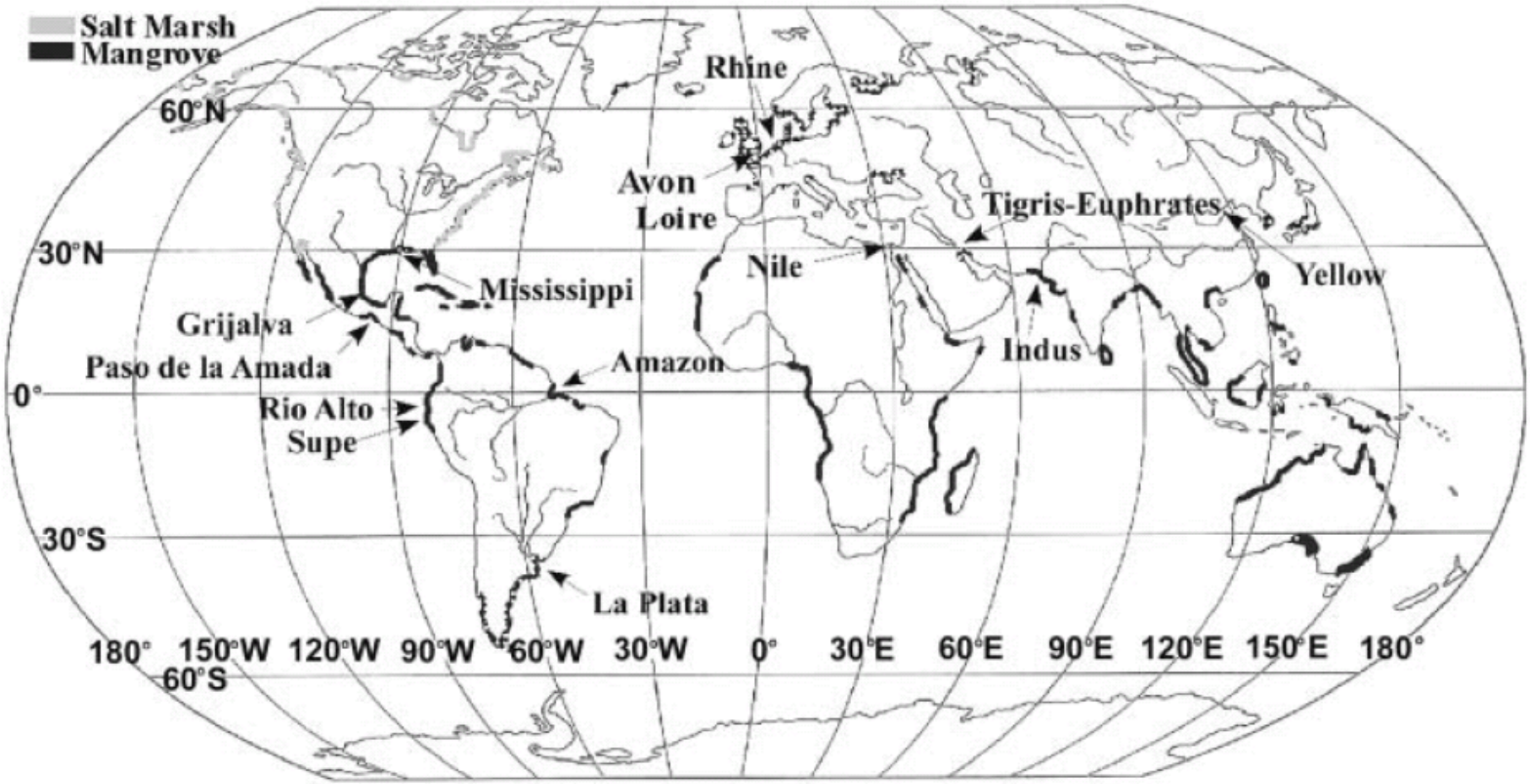
Sea level variations ~400 feet; unusually stable for past 7000 years.

Atmospheric CO_2 variation due to exchange among surface reservoirs.

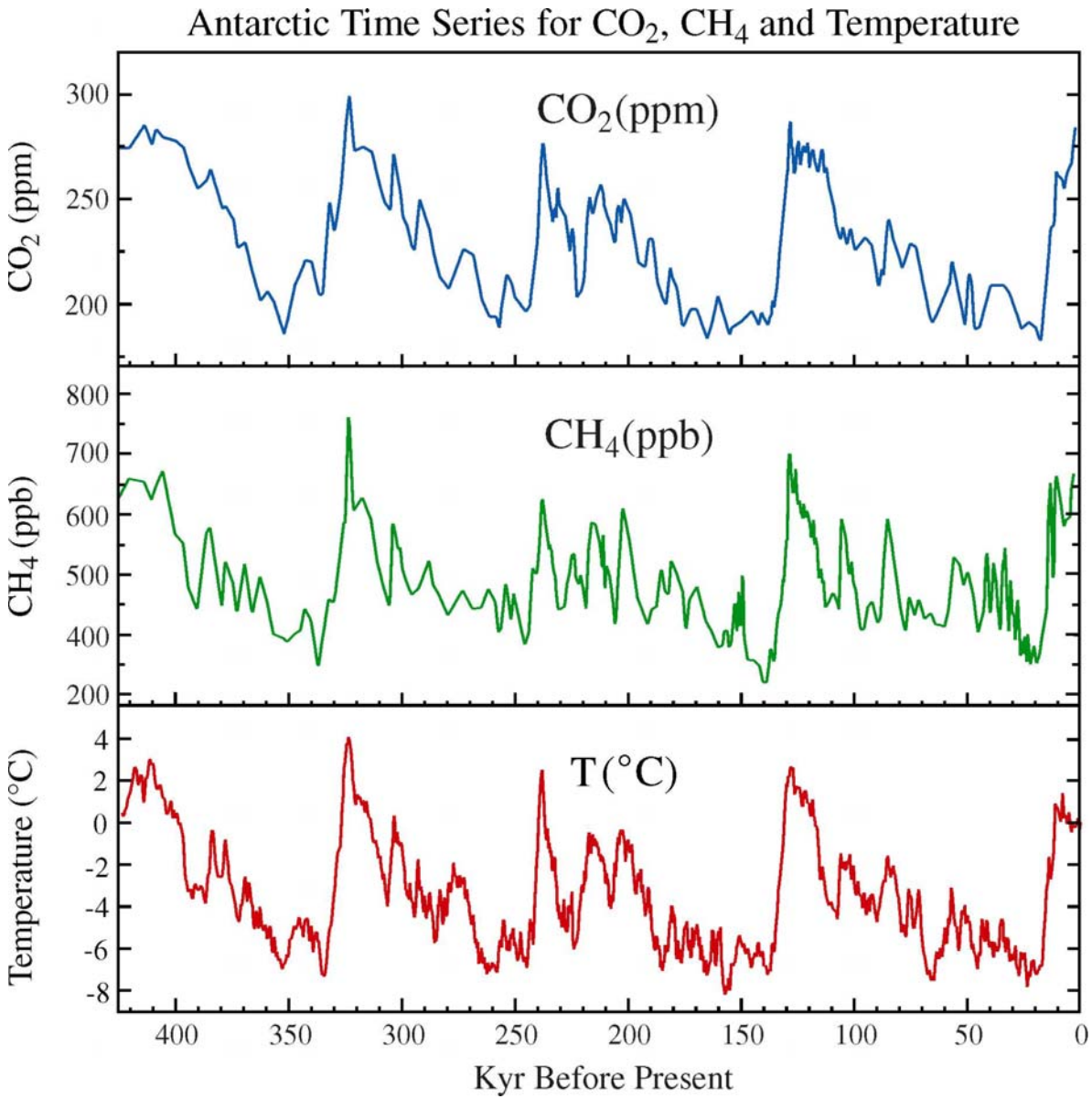
Drive for these large climate change is perturbations of Earth's orbit.

Fig. .3a. "Climate change and trace gases", Hansen et al. Phil. Trans. Roy. Soc. A, 365, 1925, 2007

Emergence of Urban Societies 7000-5000 yr BP



Distribution of early urban societies. Coastal mangroves and salt marshes shown by dark and light shades. (Day, J.W. et al., Emergence of complex societies after sea level stabilized, *EOS Trans. AGU*, **88**, 169-170, 2007).



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.

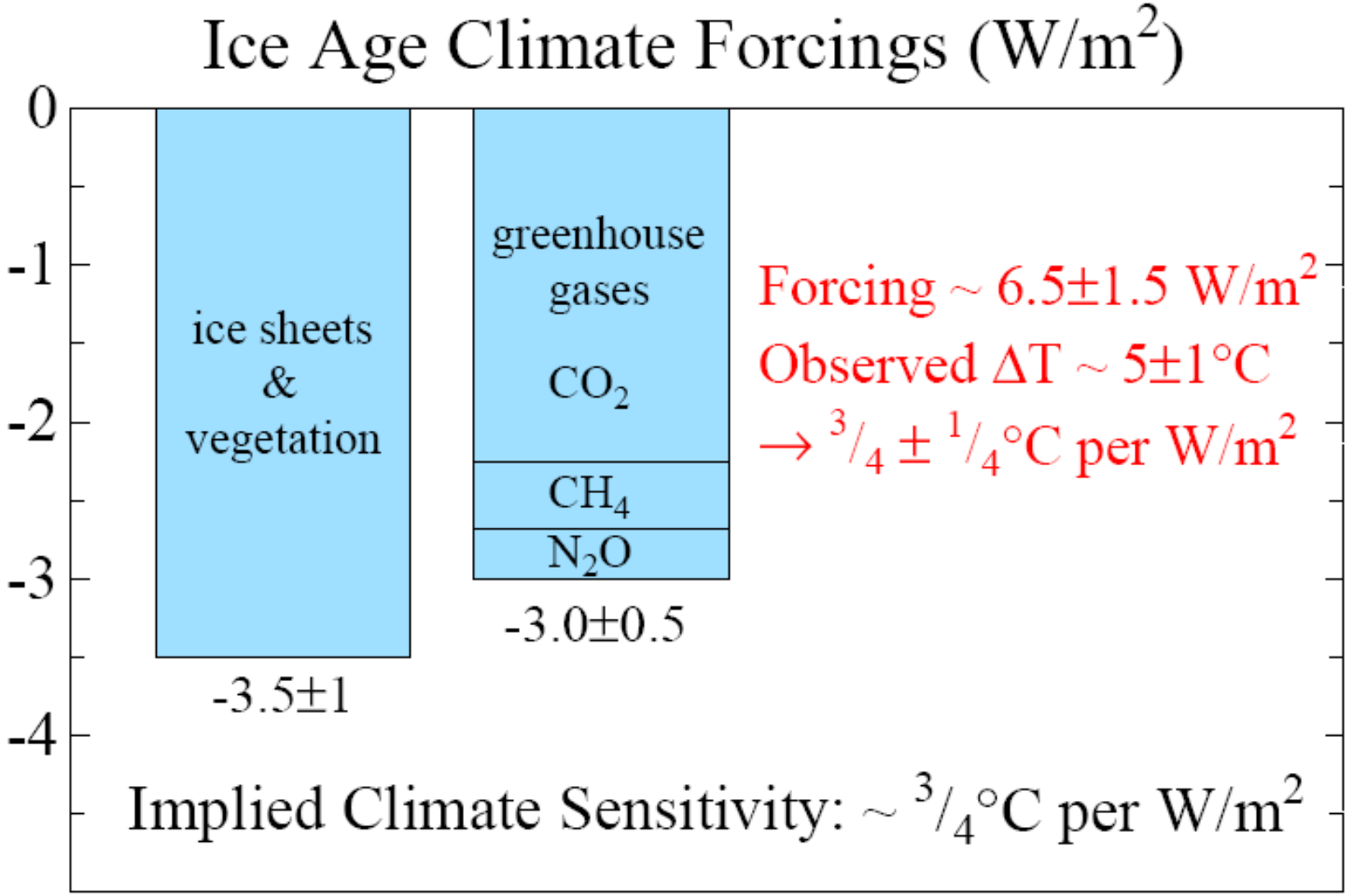
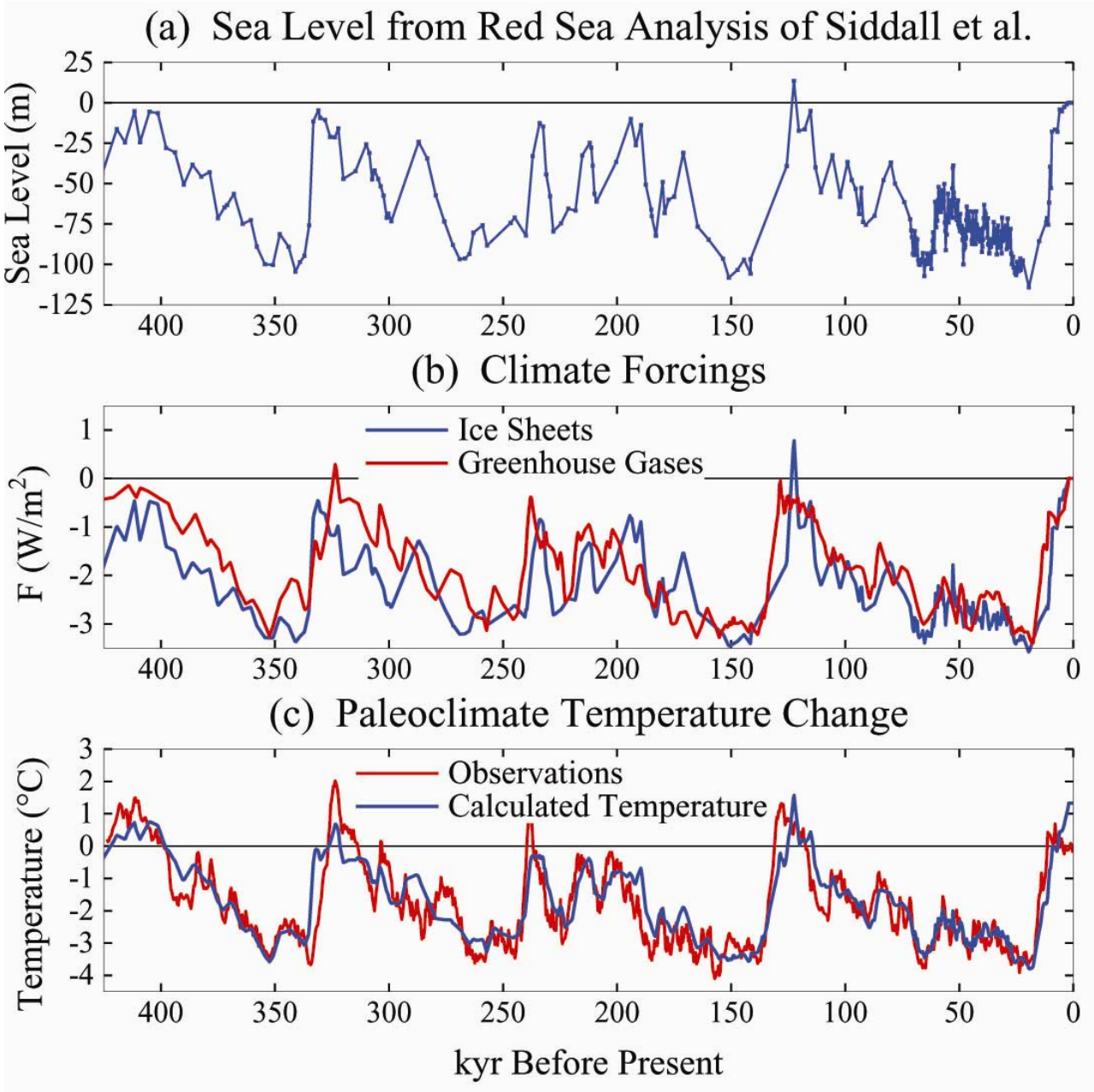
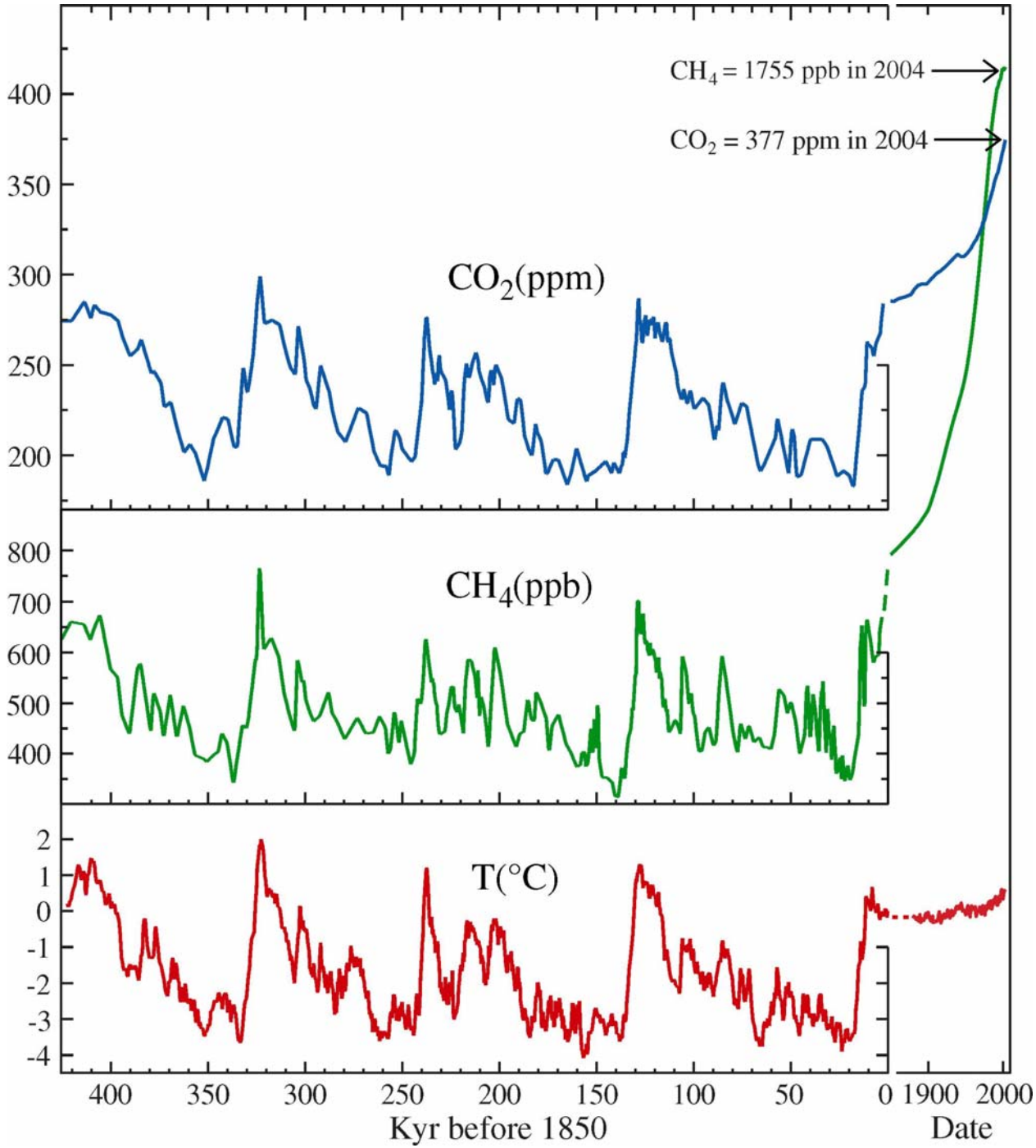


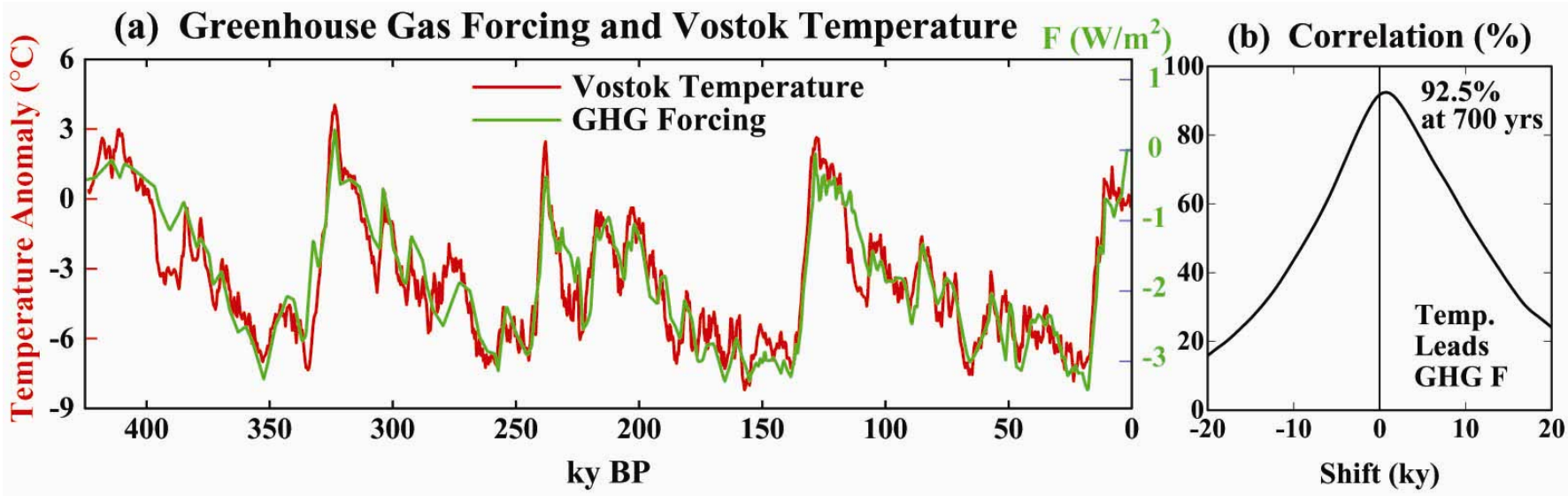
Fig. S2. Climate forcings during ice age 20 ky BP, relative to the present (pre-industrial) interglacial period.

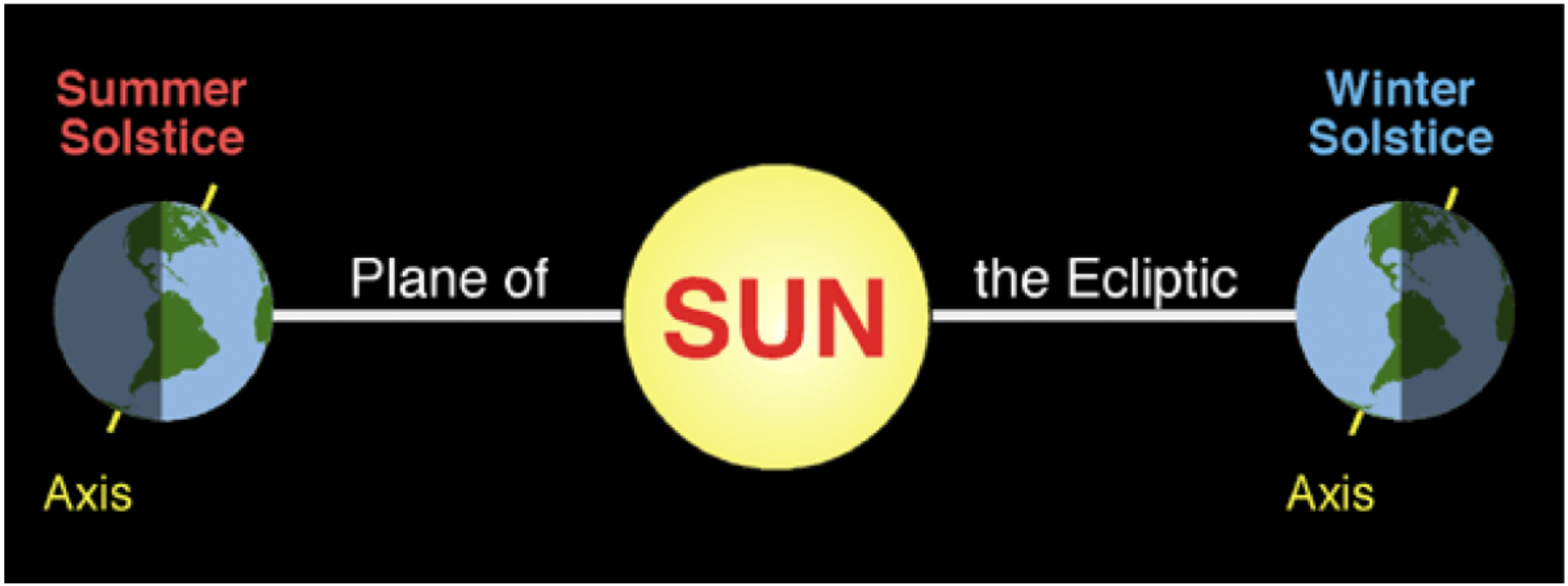

(a) Sea Level from Red Sea Analysis of Siddall et al.
Sea Level (m)
25
0
-25
-50
-75
-100
-125
400
350
300
250
200
150
100
50
0
(b) Climate Forcings
F (W/m^2)
Ice Sheets
Greenhouse Gases
1
0
-1
-2
-3
(c) Paleoclimate Temperature Change
Temperature (°C)
Observations
Calculated Temperature
3
2
1
0
-1
-2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

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.

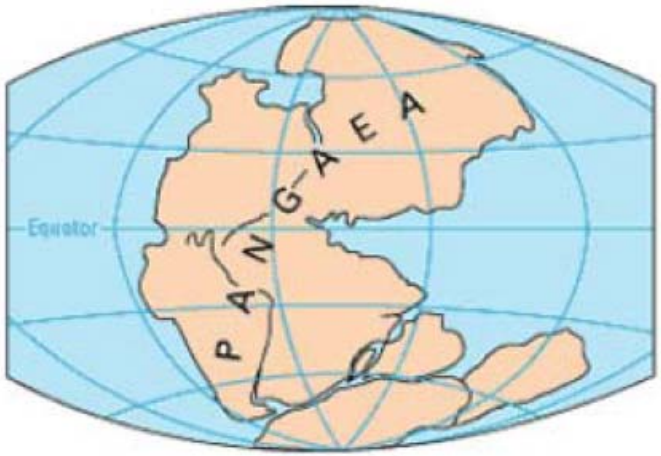

(a) Greenhouse Gas Forcing and Vostok Temperature
Temperature Anomaly (°C)
F (W/m²)
Vostok Temperature
GHG Forcing
6
3
0
-3
-6
-9
1
0
-1
-2
-3
400
350
300
250
200
150
100
50
0
ky BP
(b) Correlation (%)
100
80
60
40
20
0
92.5%
at 700 yrs
Temp.
Leads
GHG F
-20
-10
0
10
20
Shift (ky)


Summer
Solstice
Winter
Solstice
Plane of
the Ecliptic
SUN
Axis
Axis

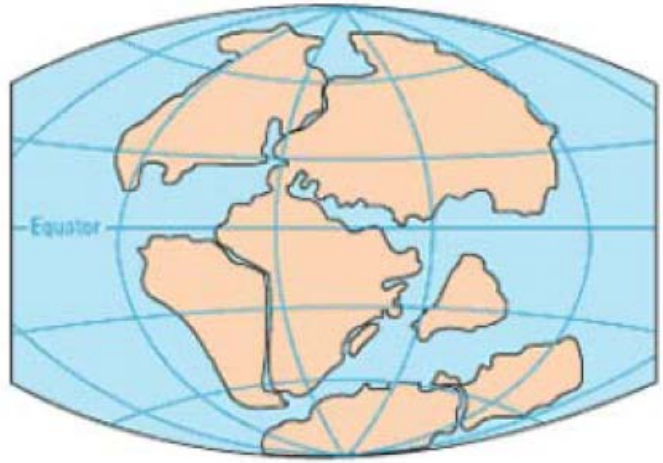
Implications of Pleistocene Climate Change

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

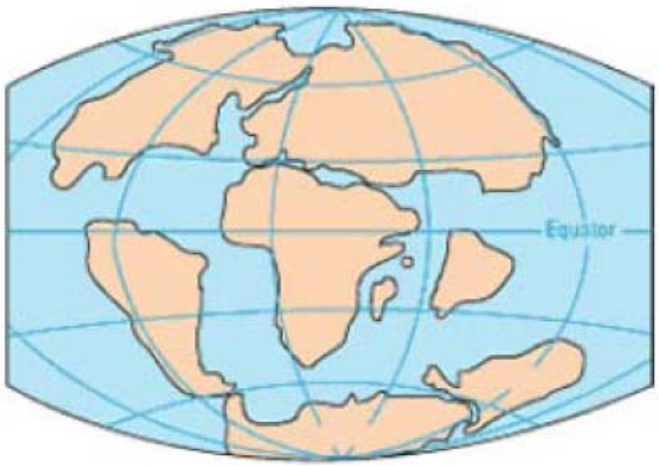
Continental Drift



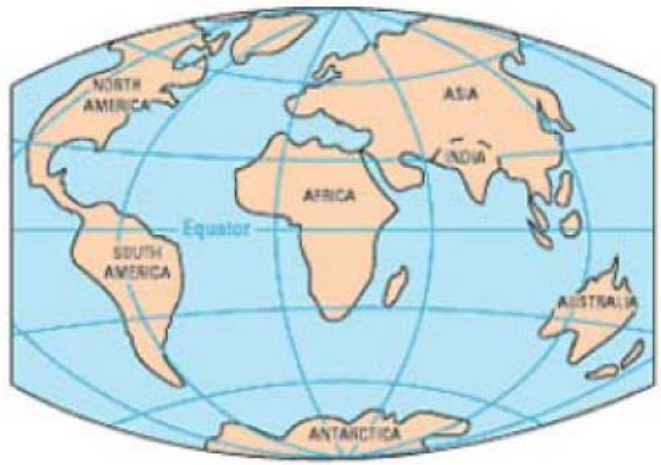
End of Permian (250 My BP)



End of Jurassic (145 My BP)



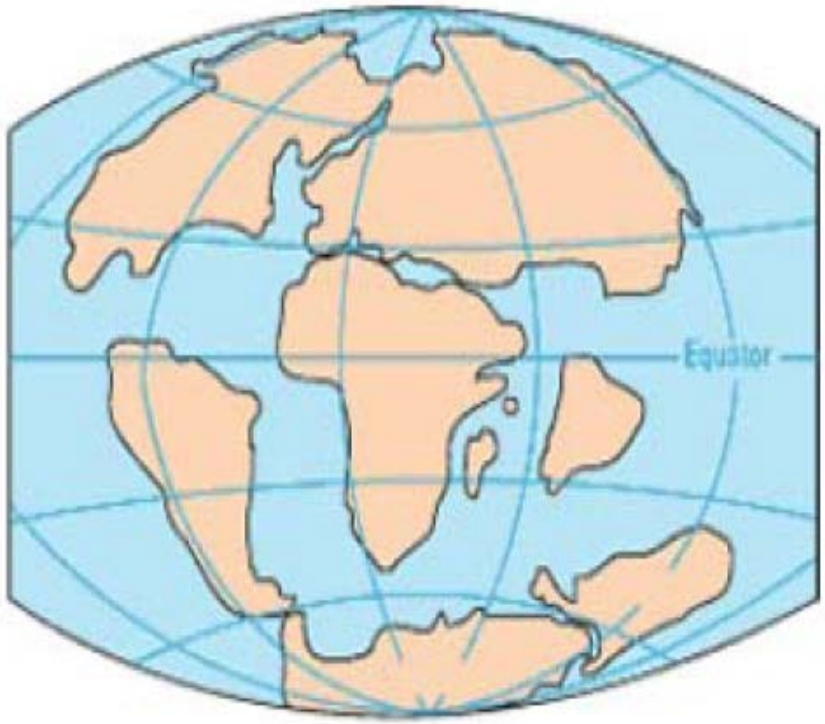
End of Cretaceous (65 My BP)



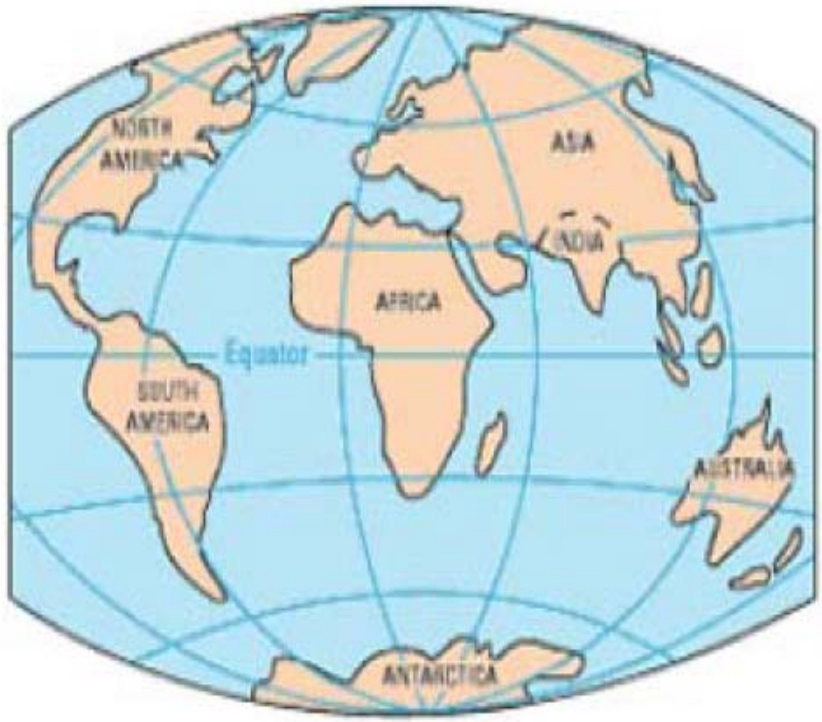
Present Day

Fig. 1 “Global Warming: East-West Connections”(adapted from Keller&Pinter, 1996)

Cenozoic Era



65 Million Years Ago



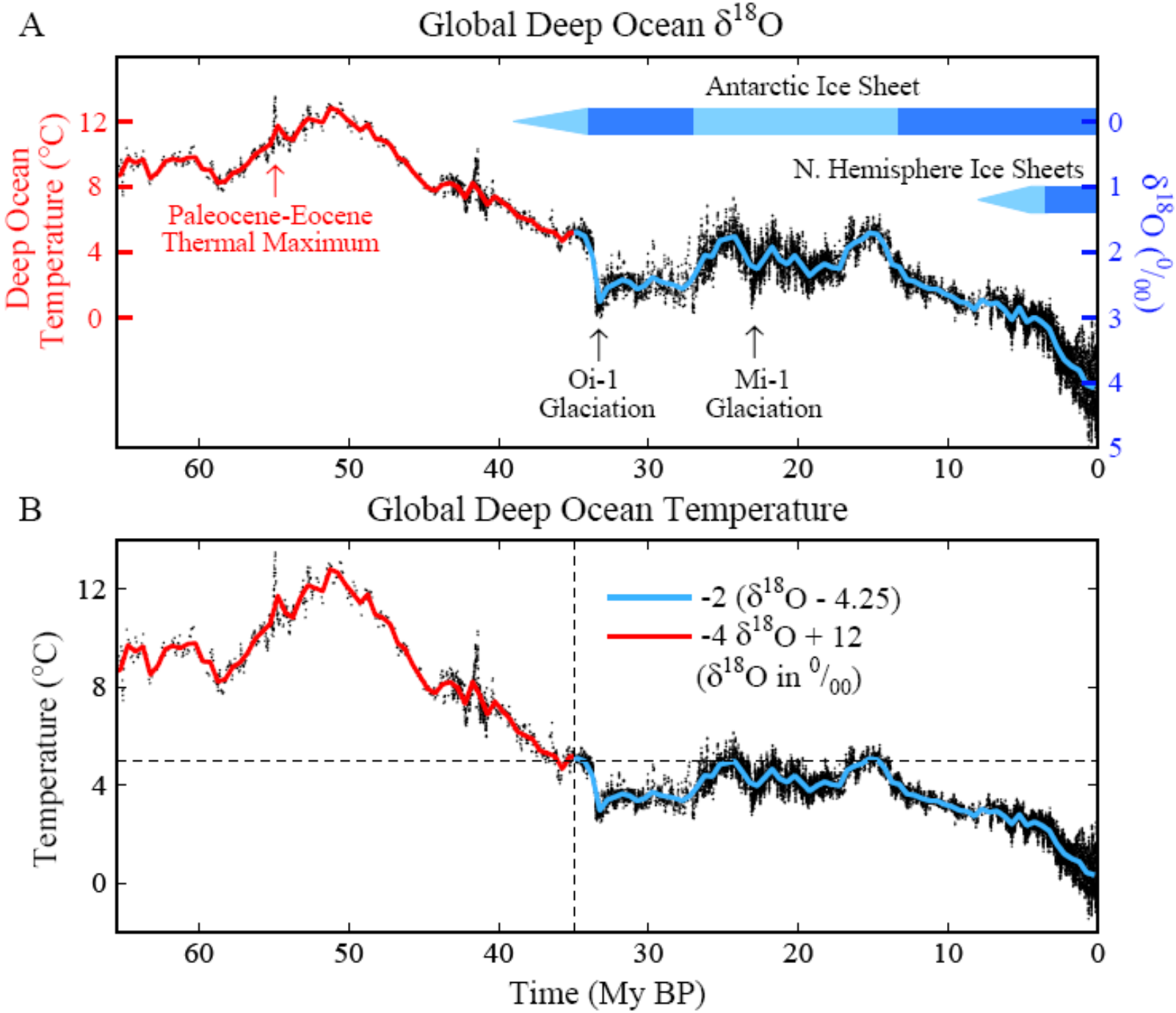
Present Day

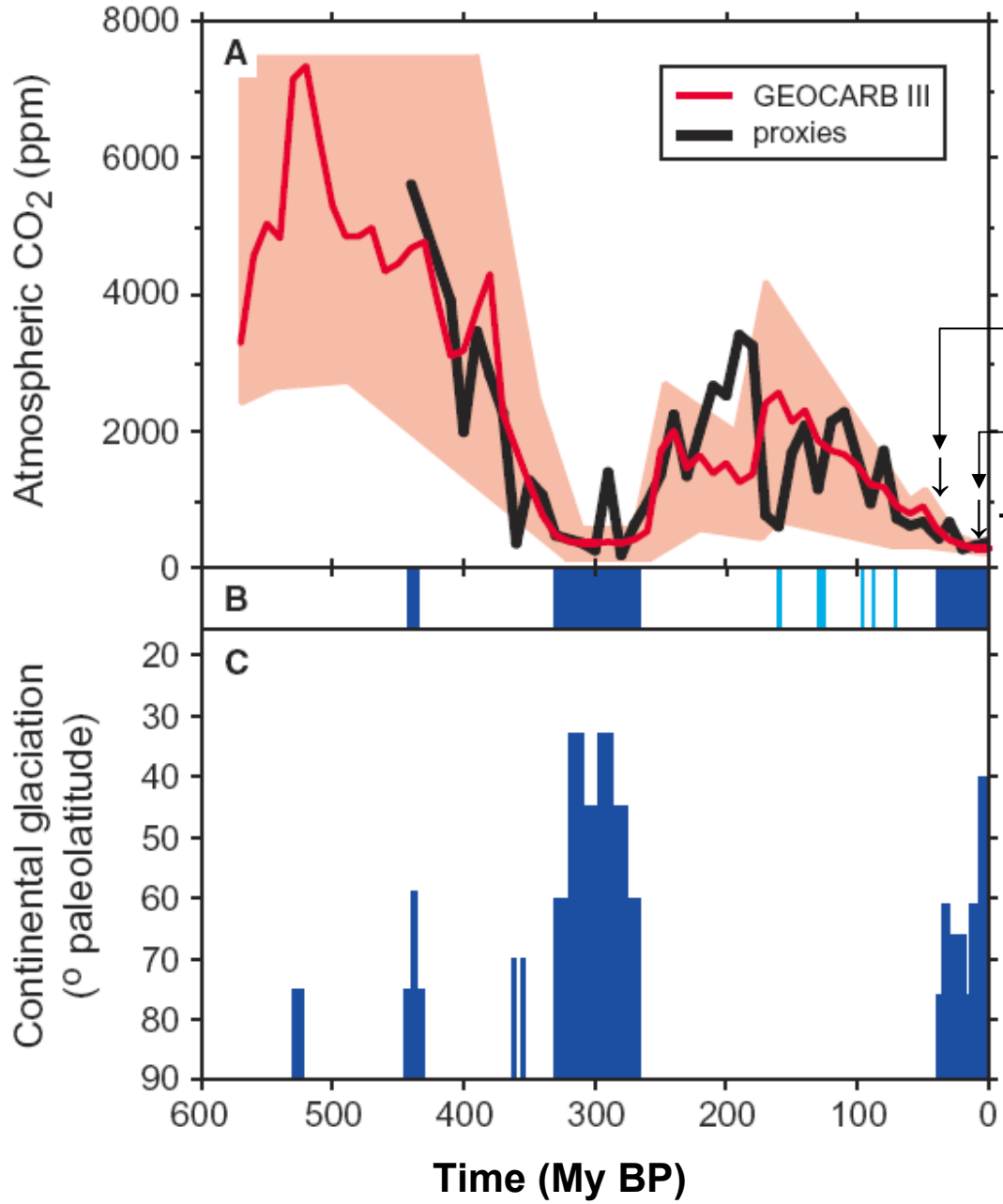
Global Climate Forcings

External (solar irradiance): +1 W/m^2

Surface (continent locations): <1 W/m^2

Atmosphere (CO_2 changes): > 10 W/m^2


A
Global Deep Ocean $\delta^{18}O$
Antarctic Ice Sheet
N. Hemisphere Ice Sheets
Deep Ocean Temperature (°C)
12
8
4
0
Paleocene-Eocene Thermal Maximum
Oi-1 Glaciation
Mi-1 Glaciation
$\delta^{18}O$ (‰)
0
1
2
3
4
5
60
50
40
30
20
10
0
B
Global Deep Ocean Temperature
-2 ($\delta^{18}O$ - 4.25)
-4 $\delta^{18}O$ + 12
($\delta^{18}O$ in ‰)
Temperature (°C)
12
8
4
0
60
50
40
30
20
10
0
Time (My BP)



Antarctic Glaciation (34 My BP)
CO_2 amount: 400-500 ppm

Pliocene (3.5 My BP)
Sea Level ~ +25 m
CO_2 amount 300-400 ppm

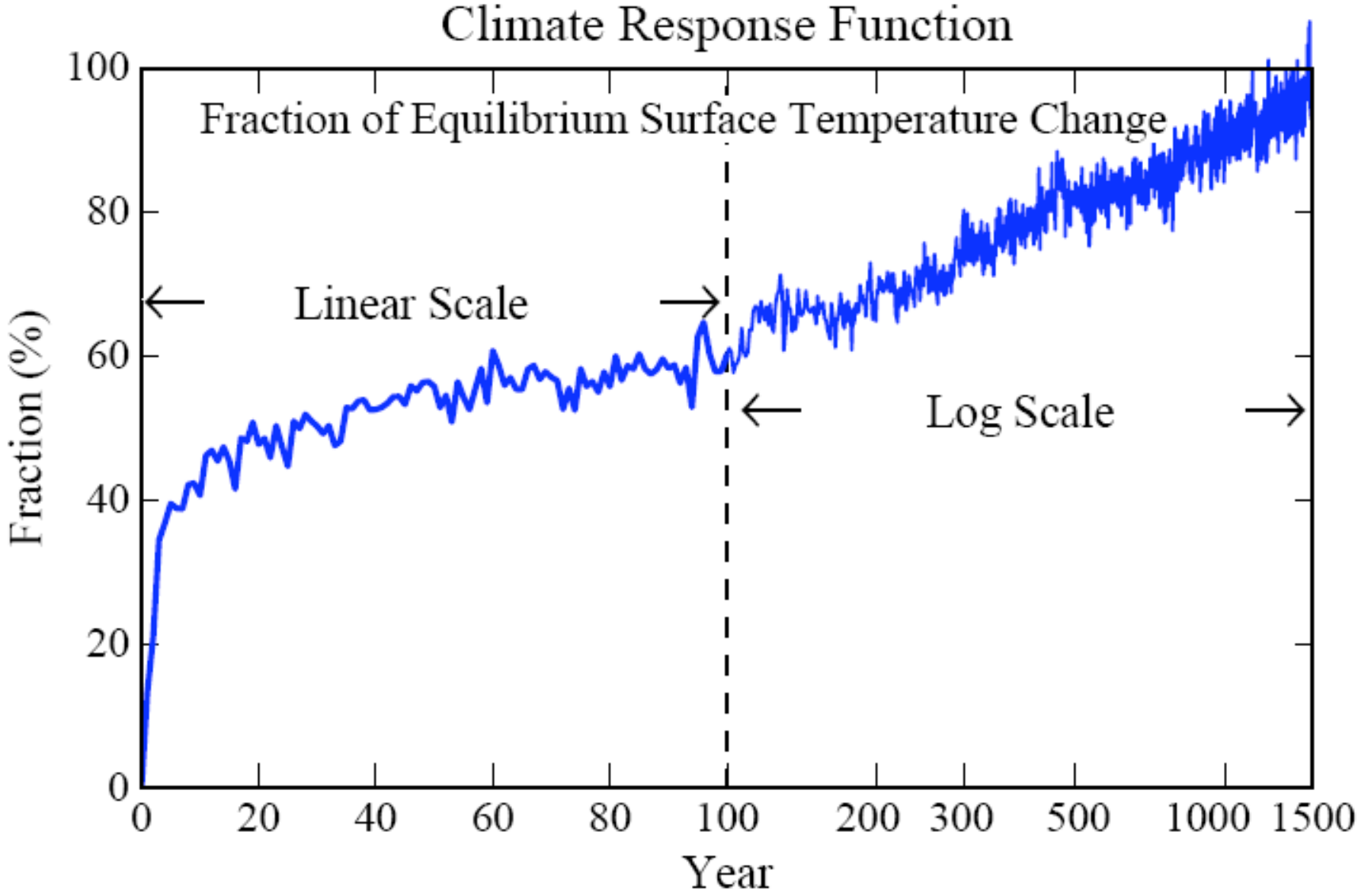
Summary: Cenozoic Era

1. **Dominant Forcing: Natural ΔCO_2**
   - Rate ~100 ppm/My (0.0001 ppm/year)
   - Human-made rate today: ~2 ppm/year

Humans Overwhelm Slow Geologic Changes

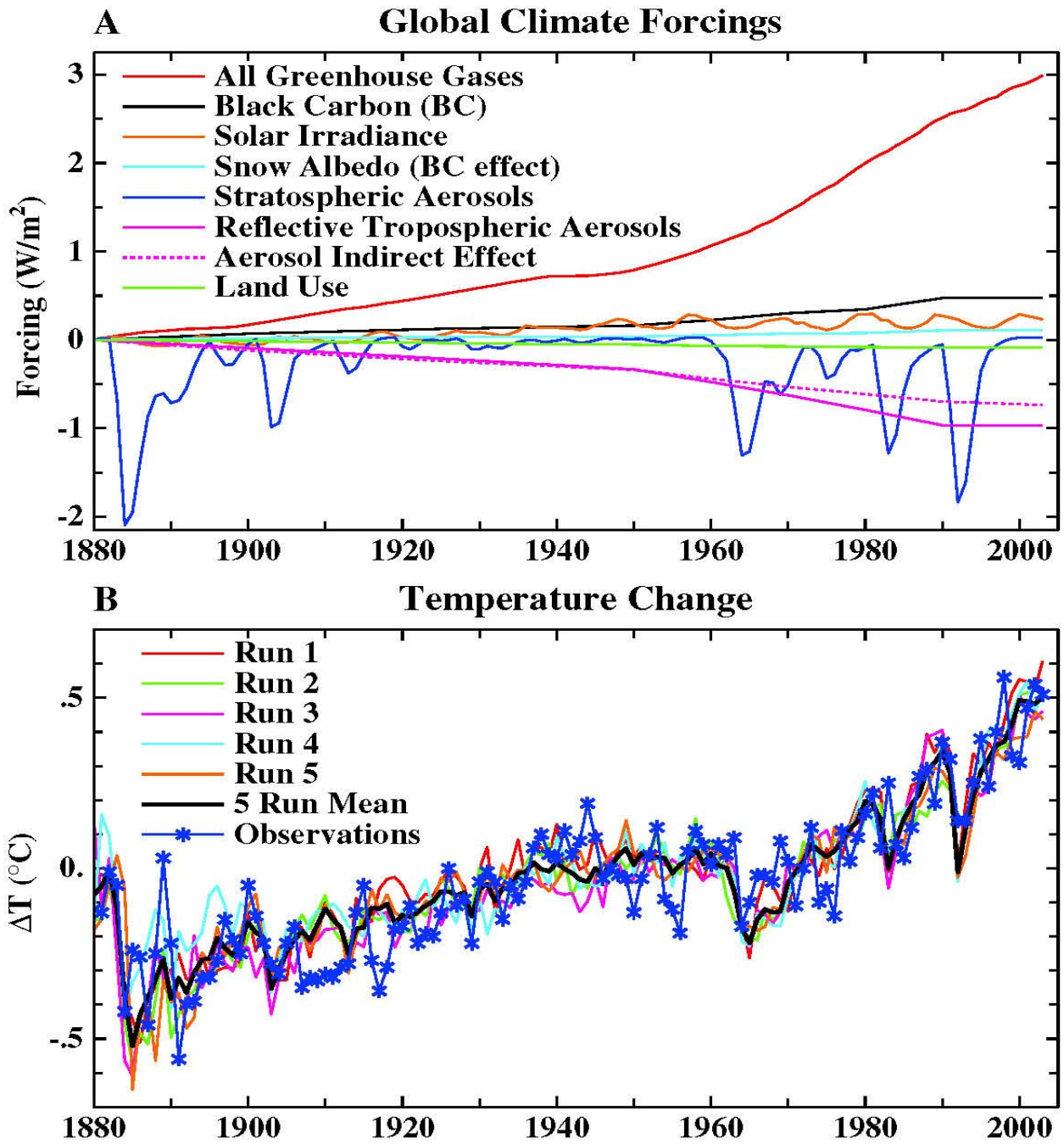
2. **Climate Sensitivity High**
   - Antarctic ice forms if CO_2 < ~450 ppm
   - Ice sheet formation reversible

Humans Could Produce "A Different Planet"


Climate Response Function
Fraction of Equilibrium Surface Temperature Change
Linear Scale
Log Scale
Fraction (%)
Year
0
20
40
60
80
100
0
20
40
60
80
100
200
300
500
1000
1500

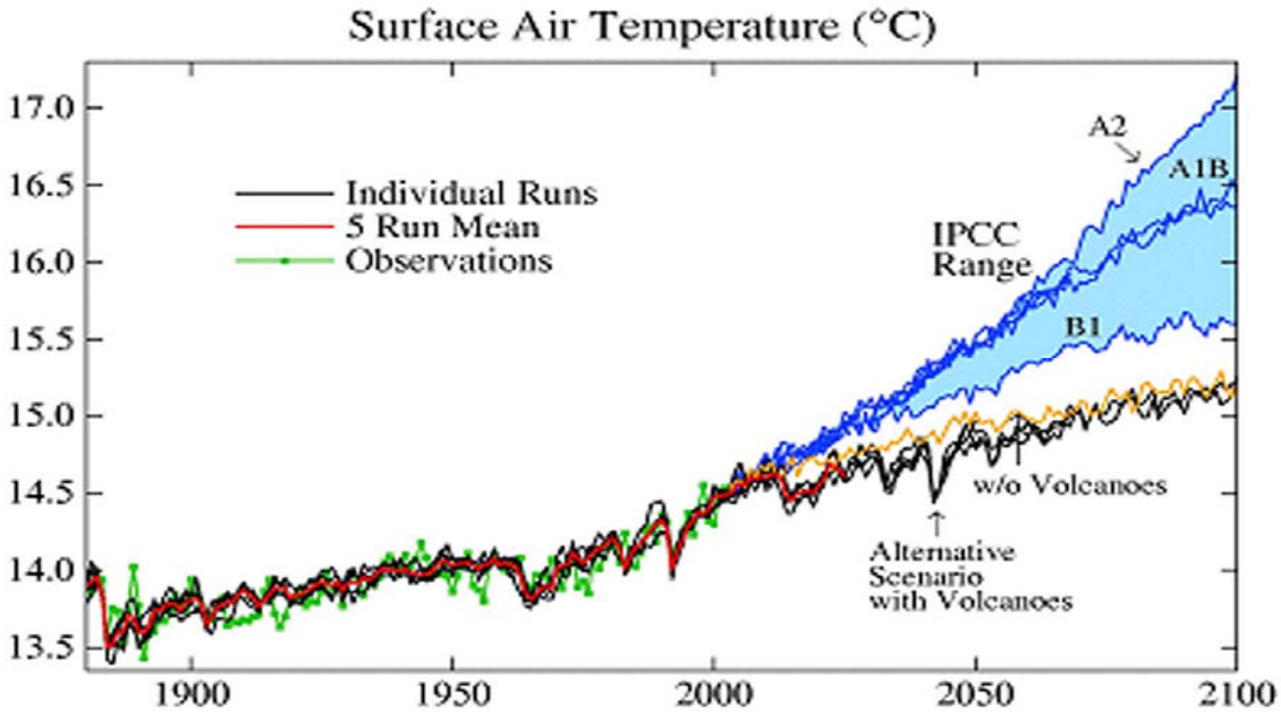
(A) Forcings used to drive climate simulations.

(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/m²

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

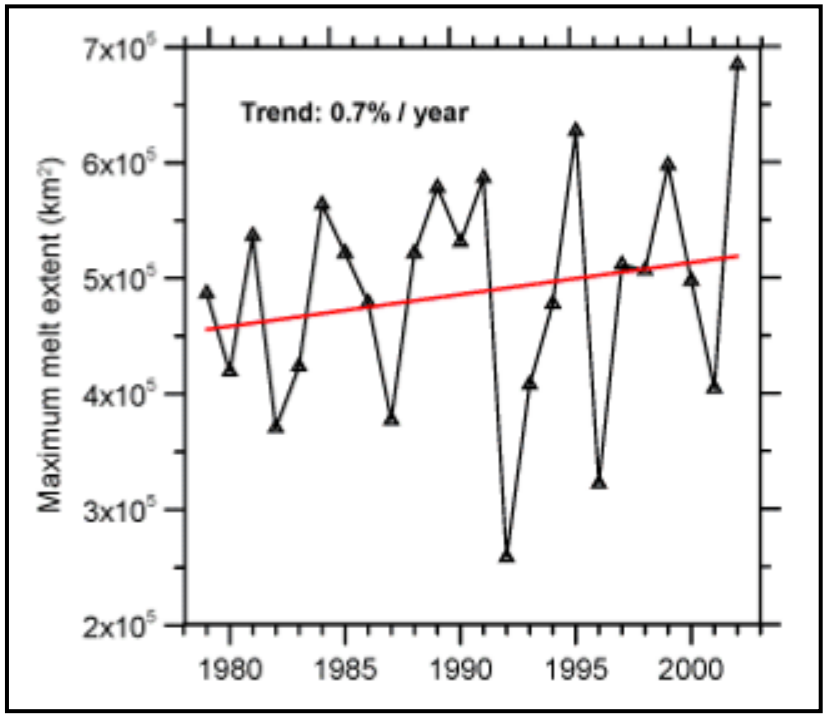
Extermination of Animal & Plant Species

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

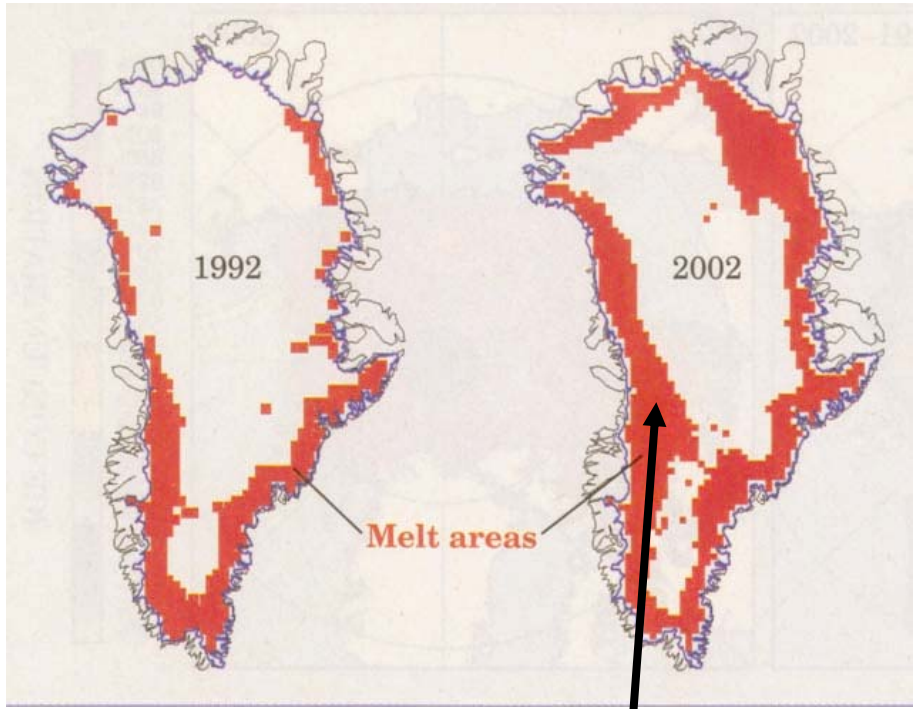
Regional Climate Disruptions

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

Increasing Melt Area on Greenland



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

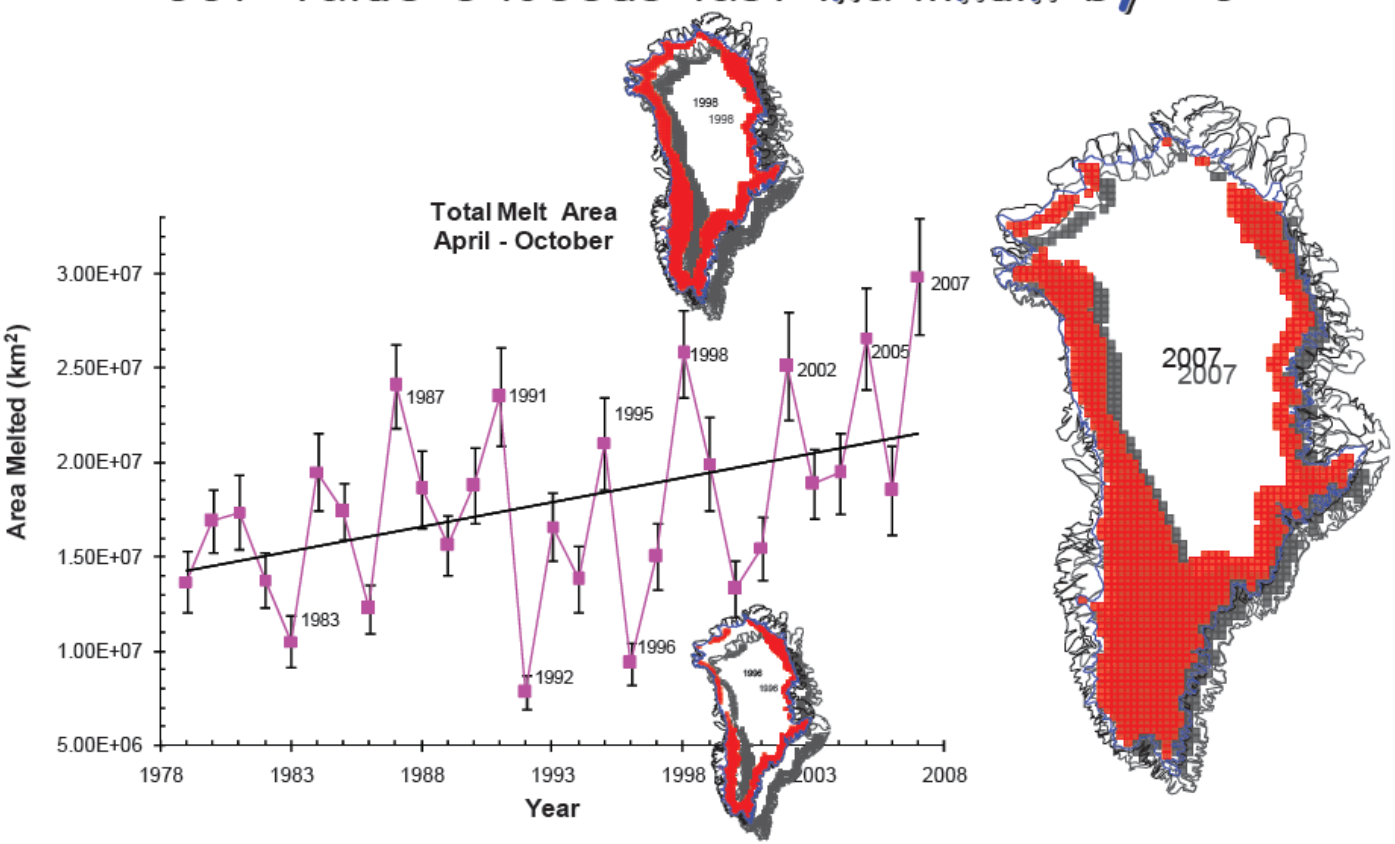


70 meters thinning in 5 years

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

Source: Waleed Abdalati, Goddard Space Flight Center

Greenland Total Melt Area –
2007 value exceeds last maximum by 10%



Konrad Steffen and Russell Huff, CIRES, University of Colorado at Boulder

Surface Melt on Greenland

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

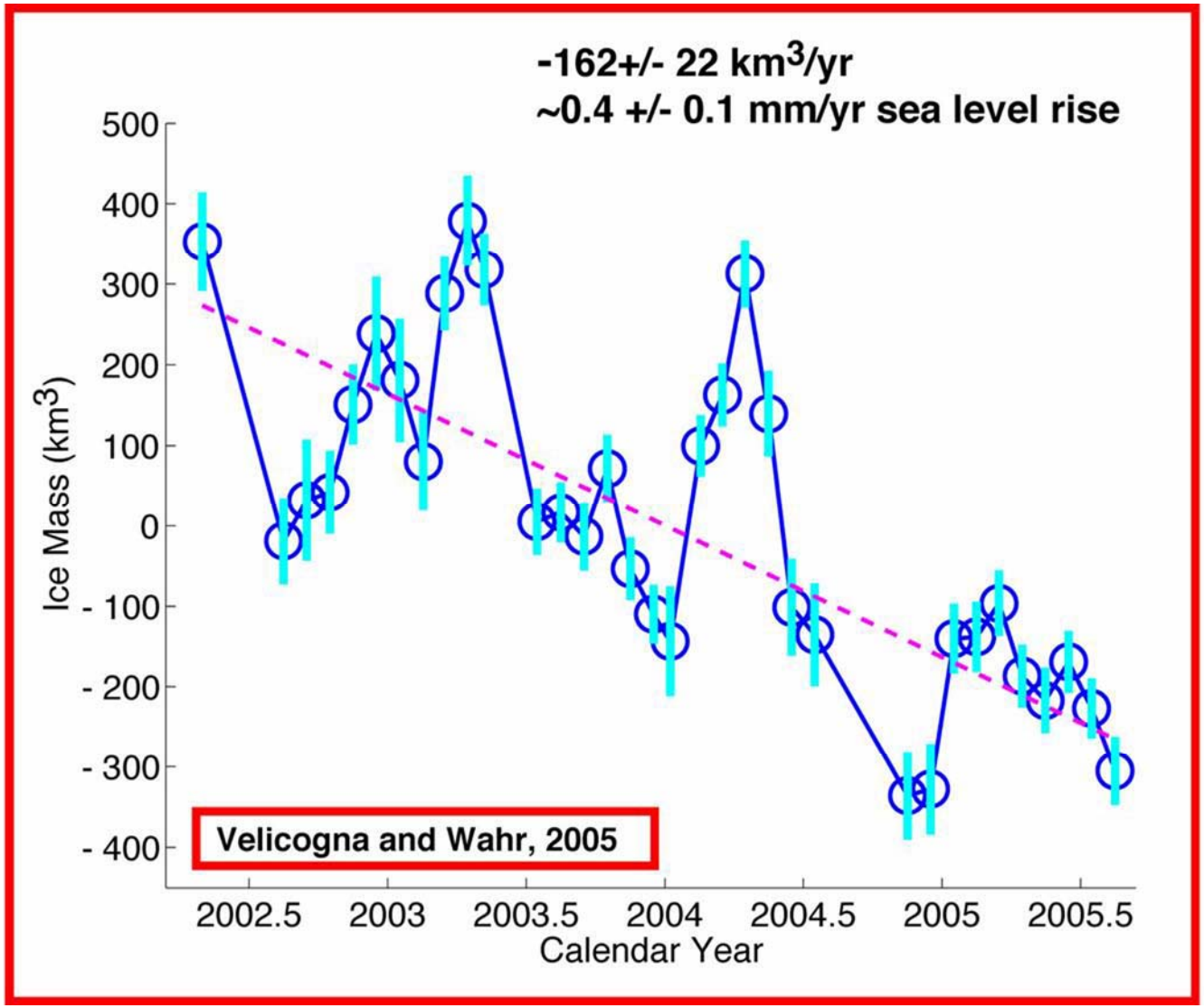
Source: Roger Braithwaite, University of Manchester (UK)

Jakobshavn Ice Stream in Greenland

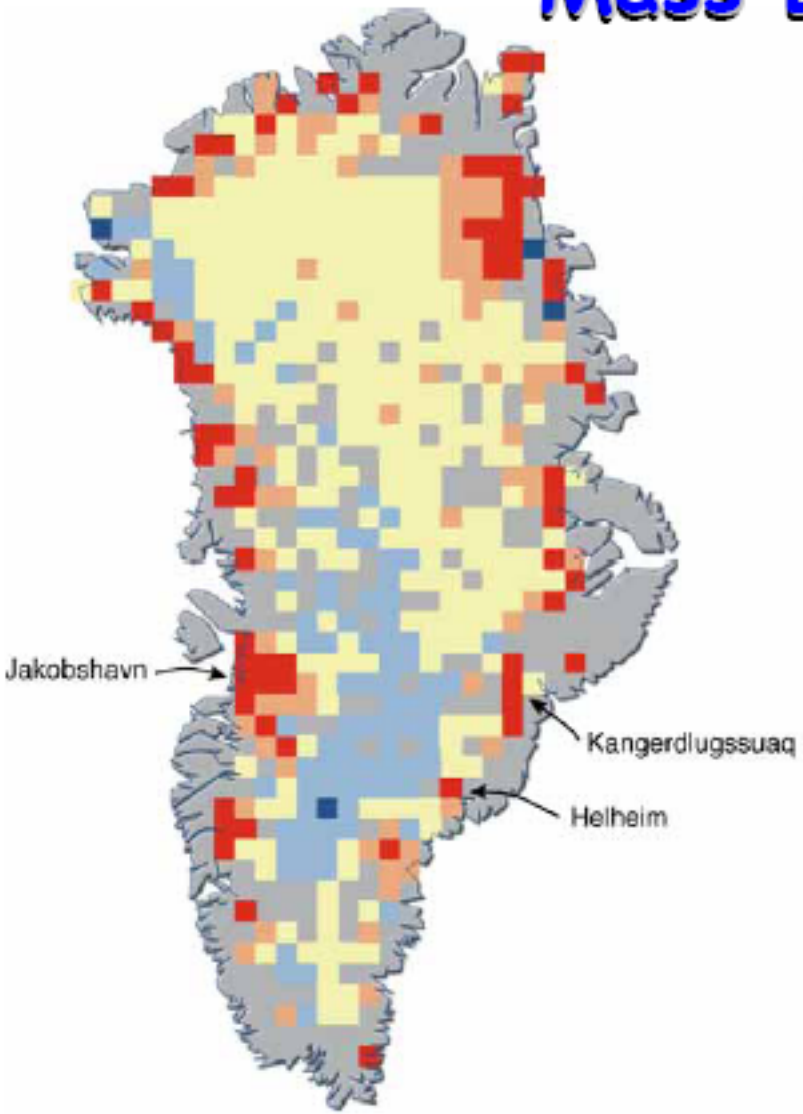
Discharge from major Greenland ice streams is accelerating markedly.

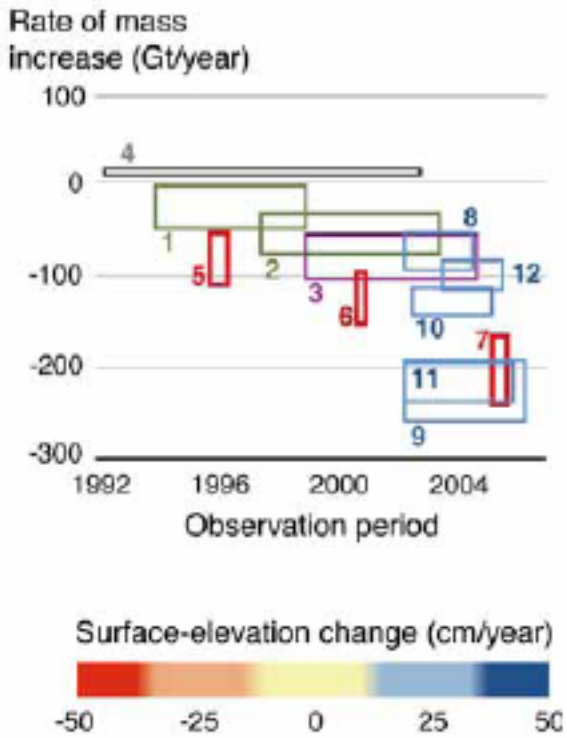
Source: Prof. Konrad Steffen, Univ. of Colorado

Greenland Mass Loss – From Gravity Satellite



Mass Balance of Greenland



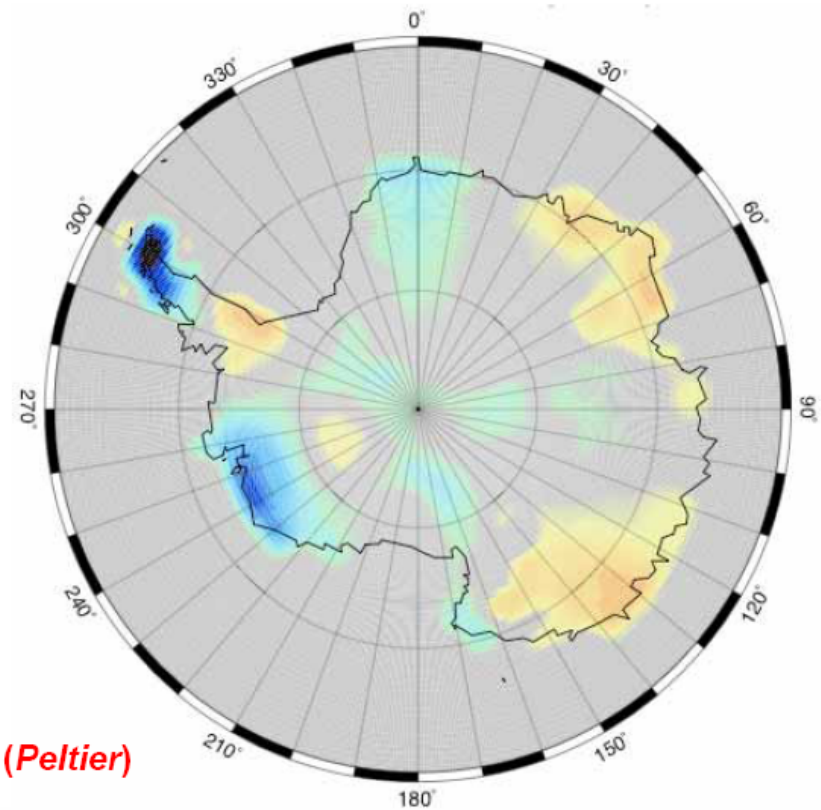


365 Gt/year = 1 mm SLR

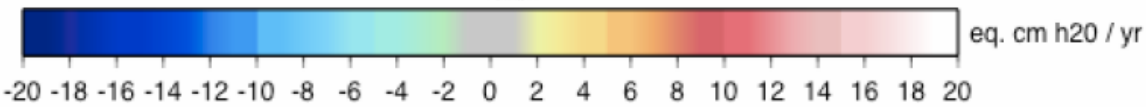
Greenland ice-sheet: rate of change from airborne laser-altimeter surveys (green), airborne/satellite laser-altimeter surveys (purple), mass-budget calculations (red), temporal changes in gravity (blue).

Sources (corresponding to numbers on rectangles): 1 and 2 Krabill and others 200016 and 2004[; 3 Thomas and others 200617; 4 Zwally and others 20055; 5 to 7 Rignot and Kanagaratnam 200618; 8 and 9 Velicogna and Wahr 2005[and 2006b; 11 Chen and others 2006]; 10 Ramillien and others 200632; 12 Luthke and others 2006[

Antarctica Ice Sheet Hi-Res Mascon Solution
Spatial pattern of trend



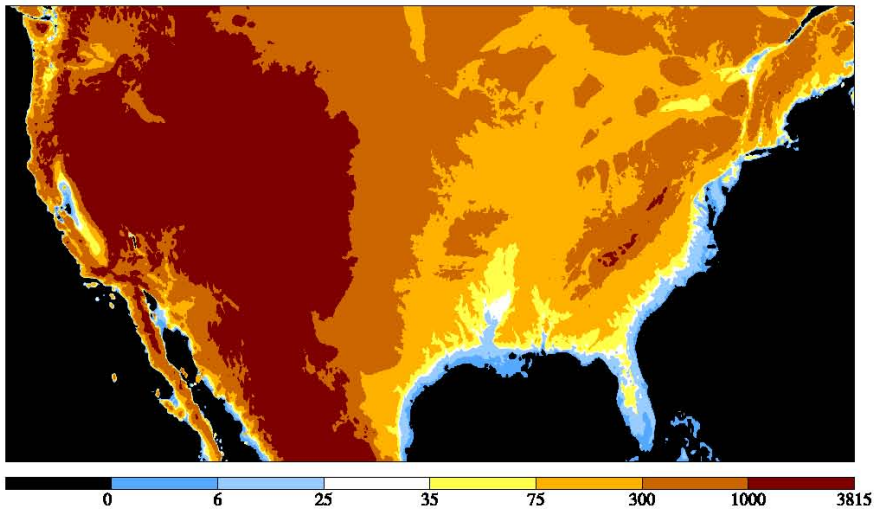
Trend - ICE5G GIA (*Peltier*)



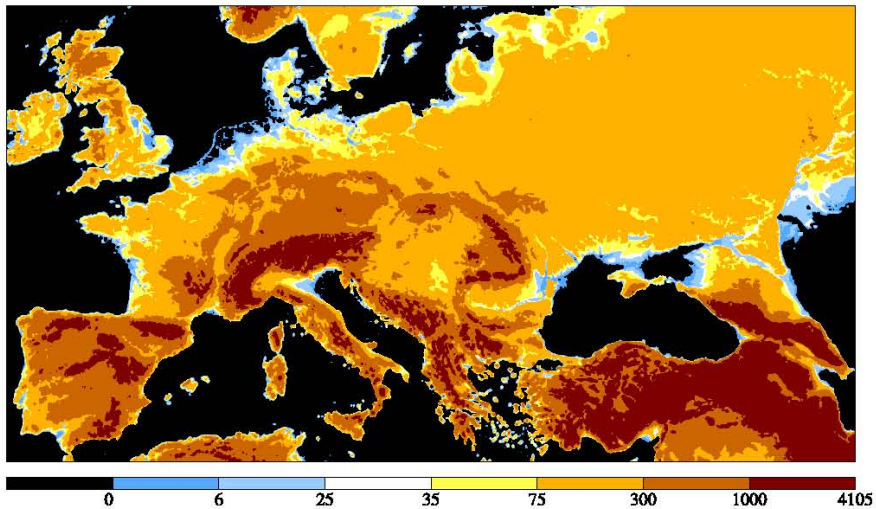
S.B. Luthcke et al., NASA GSFC, code 698

Areas Under Water: Four Regions

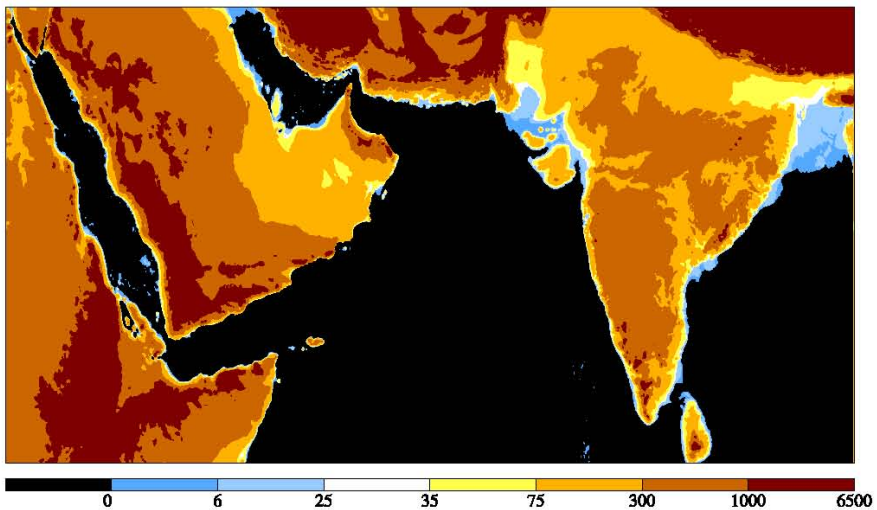
U.S. Area Under Water



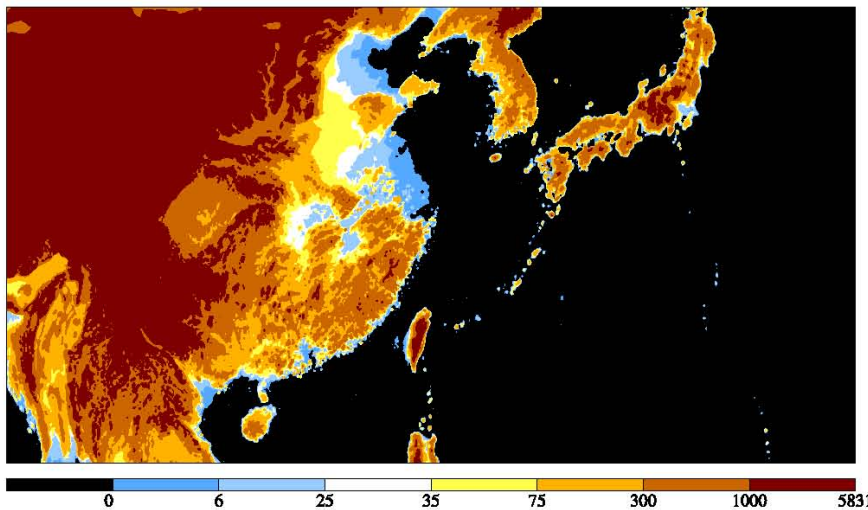
Europe Area Under Water

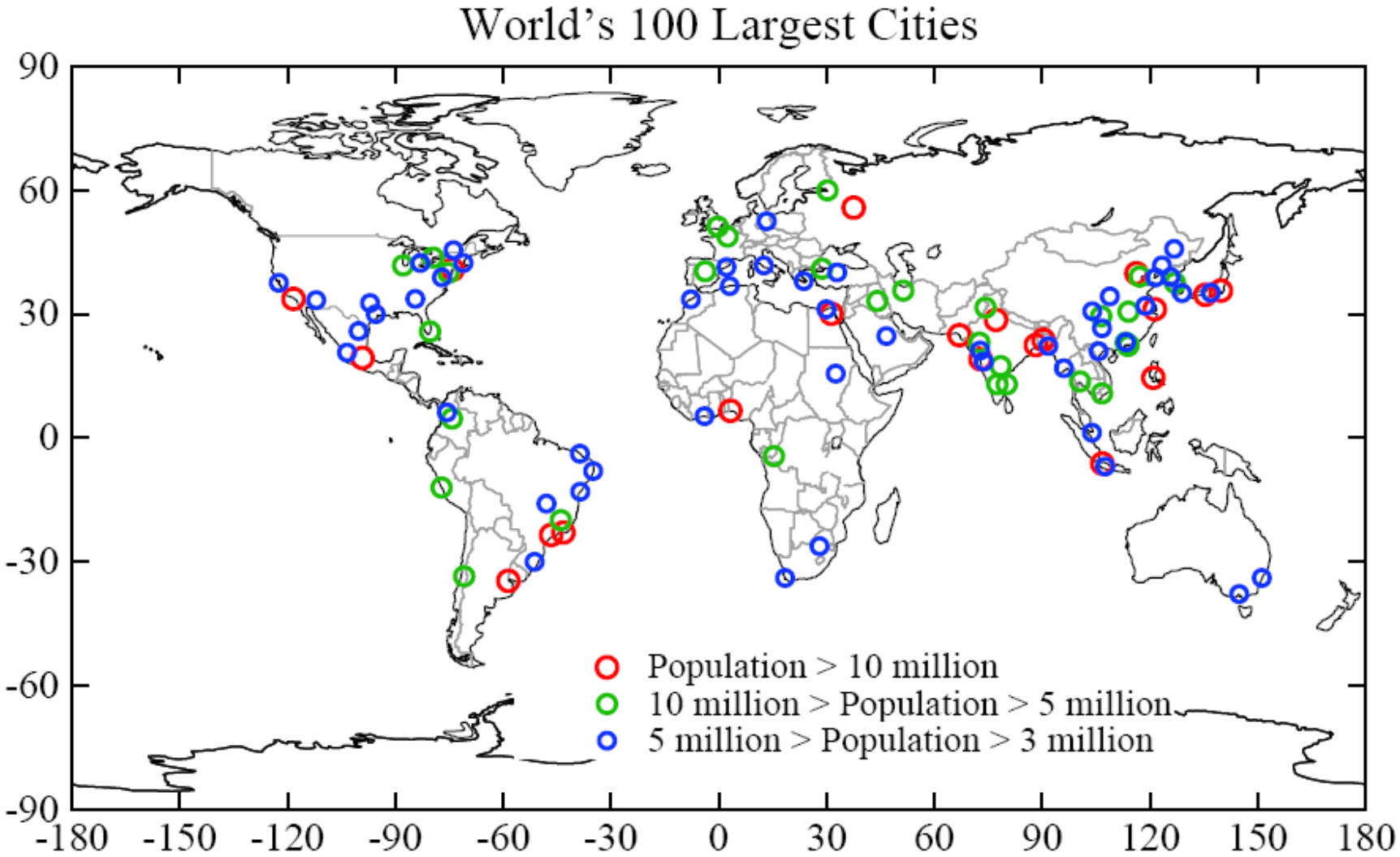


Central Asia: Area under Water



Far East: Area under Water




World's 100 Largest Cities
90
60
30
0
-30
-60
-90
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180
Population > 10 million
10 million > Population > 5 million
5 million > Population > 3 million

Arctic Change:

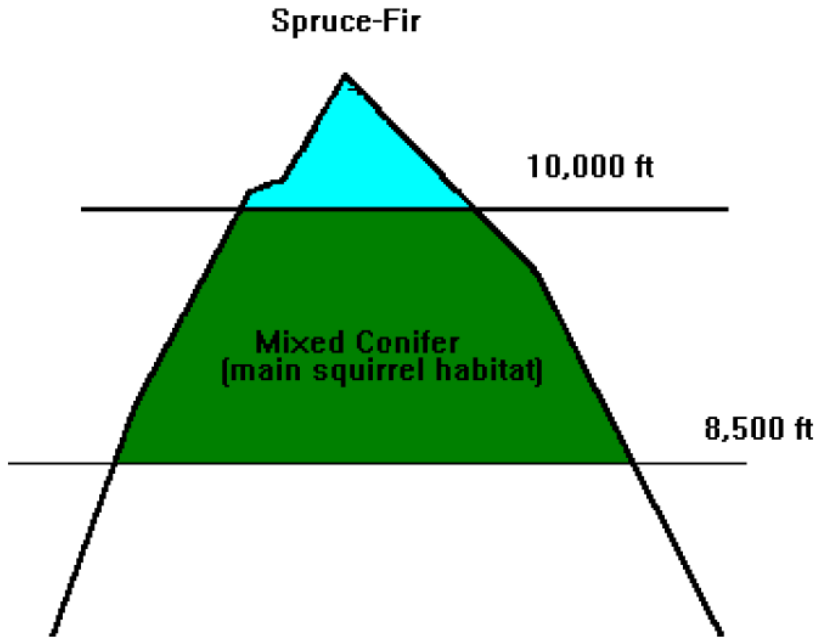
Future loss of Arctic sea ice could result in a loss of 2/3 of the world's polar bears within 50 years.

Source: U.S. Geological Survey
www.usgs.gov/newsroom/special/polar%5Fbears/

Images:
Sea Ice: Claire Parkinson & Robert Taylor
Polar Bears: Unknown

Mt. Graham Red Squirrel

Mount Graham Red Squirrel (Credit: Claire Zugmeyer)



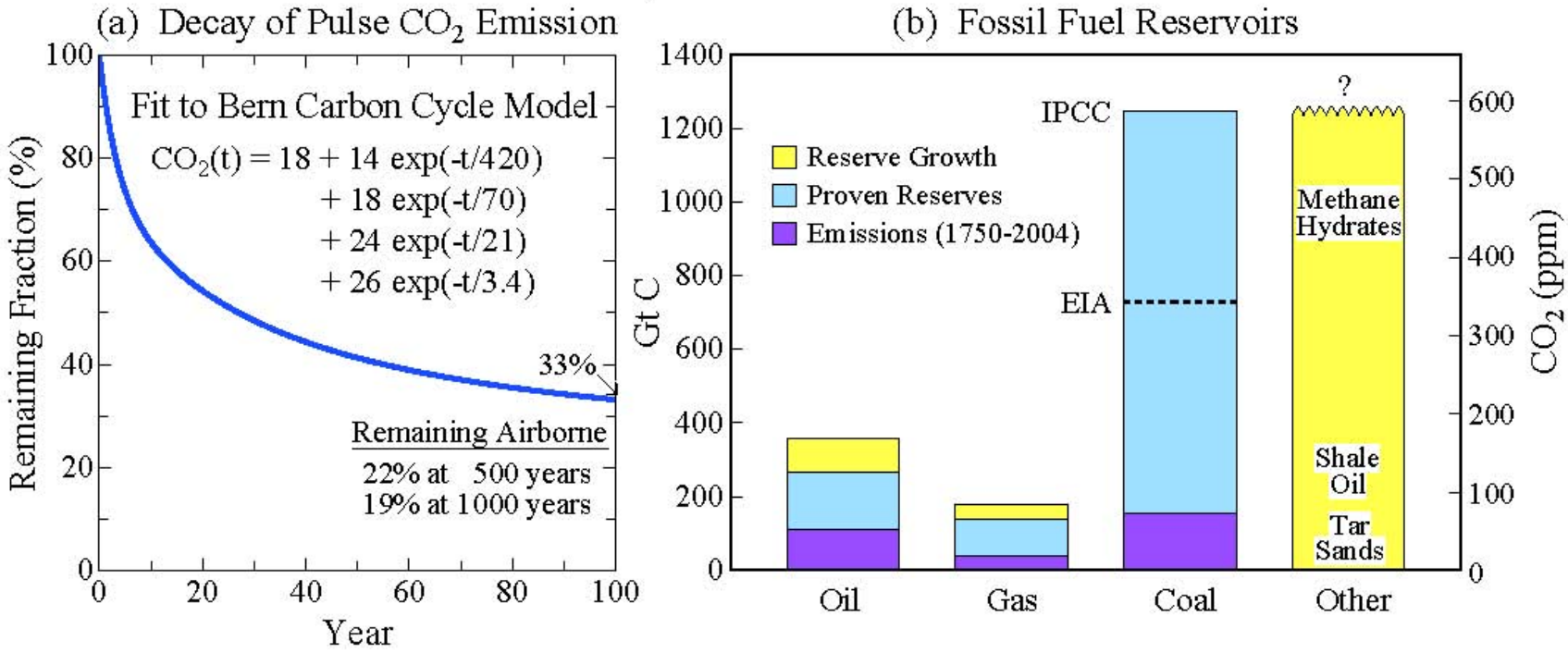
Survival of Species

1. **"Business-as-Usual" Scenario**
   - Global Warming ~ 3ºC
   - Likely Extinctions ~25-50 percent
2. **"Alternative" Scenario**
   - Global Warming <1ºC
   - Likely Extinctions <10 percent

How Many Species to Survive Bottleneck?

Climate Feedbacks → Scenario Dichotomy

Carbon Cycle Constraints

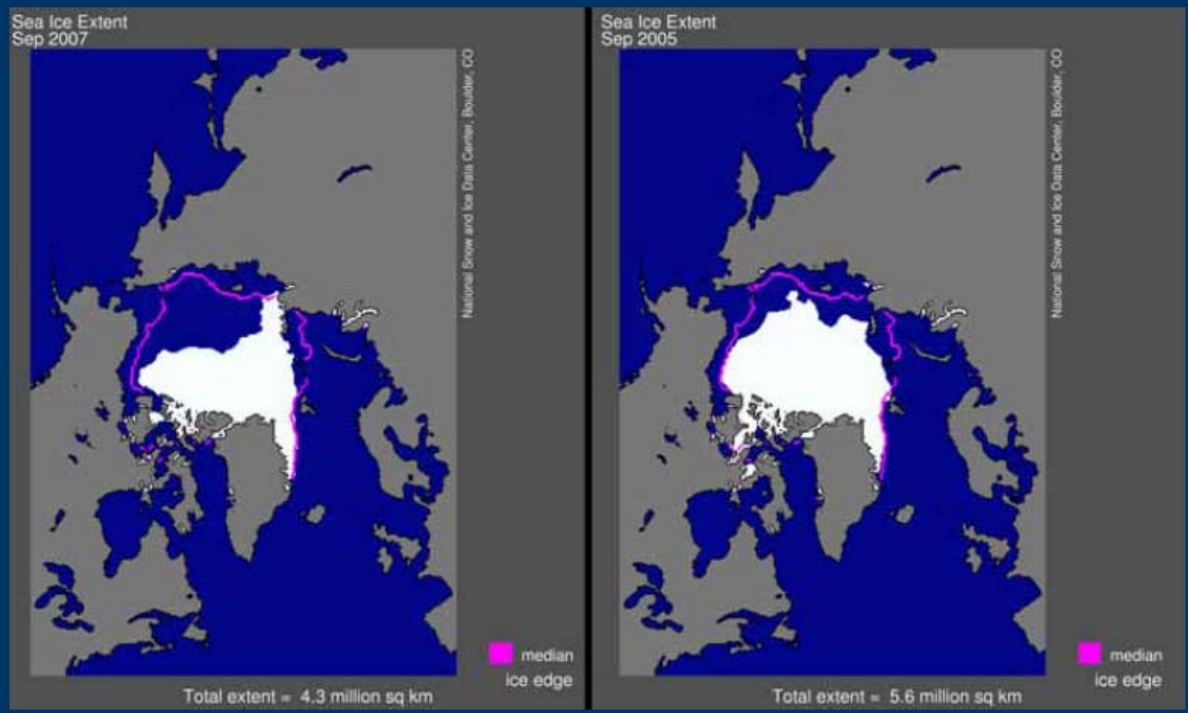


Define a "Target CO_2": Why?

1. **Public Needs to Know**
   - For Energy Policies
   - CO_2 Long-Lived (1/5 > 1000 years)
2. **Flaws in 'Dangerous Level' Approach**
   - Standard of Proof too Great
   - Levels Defined can be Absurd
     'Burning Embers' → +3°C Dangerous!!!
   - If 450 ppm is Dangerous, is 449 ppm o.k.?

Rapid Loss of Arctic Sea Ice

2007 Sea ice extent compared to previous record set in 2005

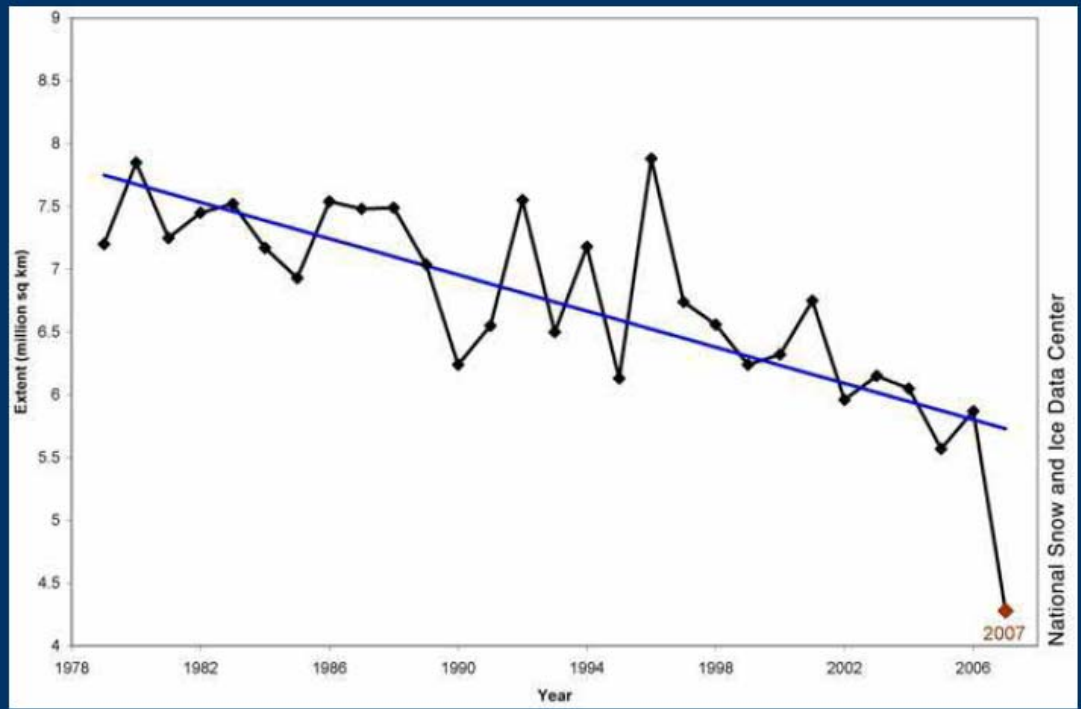


Mark Serreze, Julienne Stroeve, Walt Meier, Ted Scambos, Marika Holland, Jim Maslanik, Stephanie Renfrow, Matt Savoie

NSIDC

2007 Sea ice conditions in context

September Sea Ice Extent (1979–2007)



September 2007
4.28 million km^2

Mark Serreze, Julienne Stroeve, Walt Meier, Ted Scambos, Marika Holland, Jim Maslanik, Stephanie Renfrow, Matt Savoie

NSIDC

Arctic Sea Ice Criterion*

1. **Restore Planetary Energy Balance**

   → CO_2: 385 ppm → 325-355 ppm

2. **Restore Sea Ice: Aim for -0.5 W/m^2**

   CO_2: 385 ppm → 300-325 ppm

Range based on uncertainty in present planetary energy imbalance (between 0.5 and 1 W/m^2)

*Assuming near-balance among non-CO_2 forcings

Sea Level Criterion*

1. **Prior Interglacial Periods**

   → CO_2 ~ 300 ppm

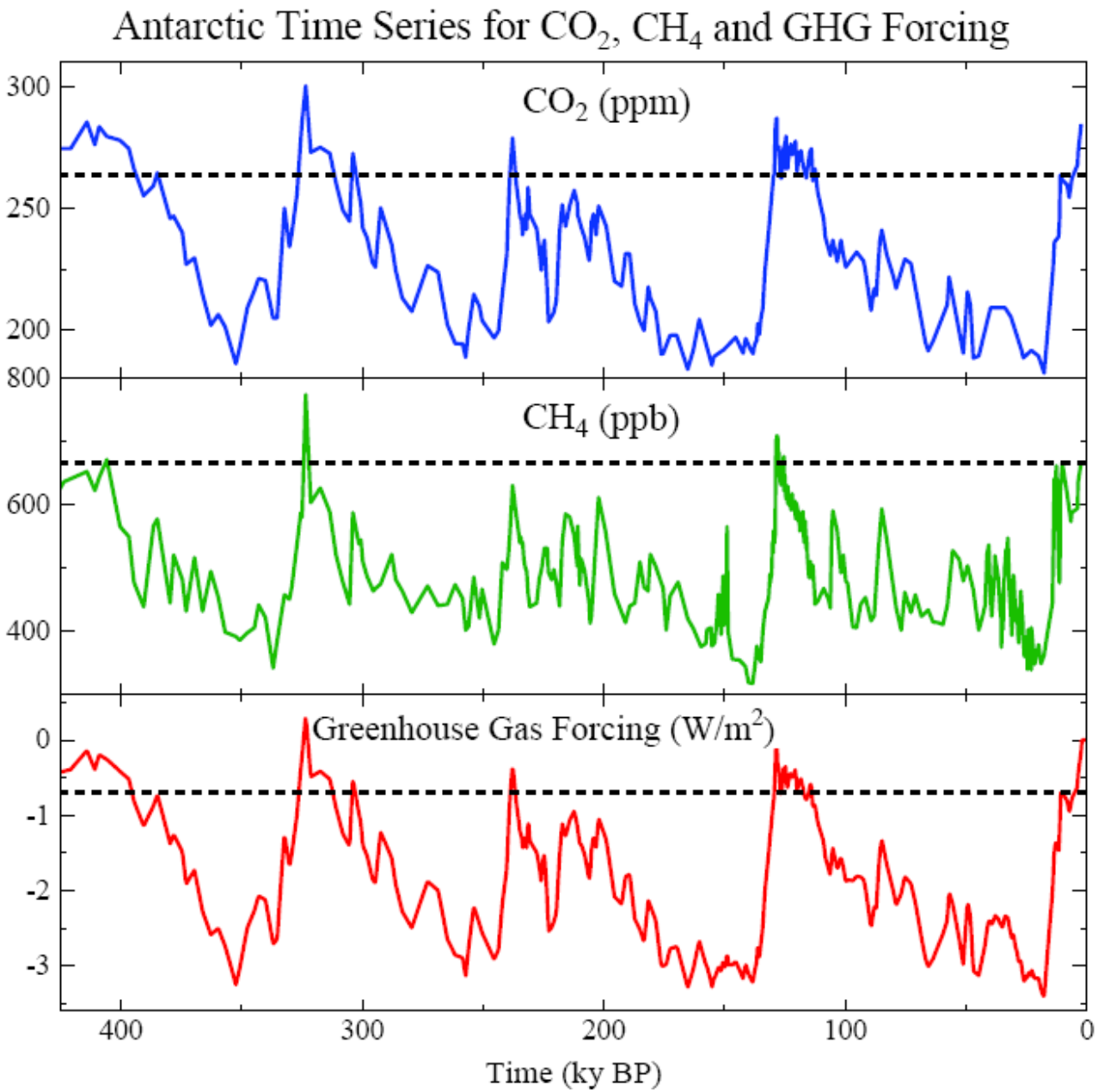
2. **Cenozoic Era**

   → CO_2 ~ 300 ppm

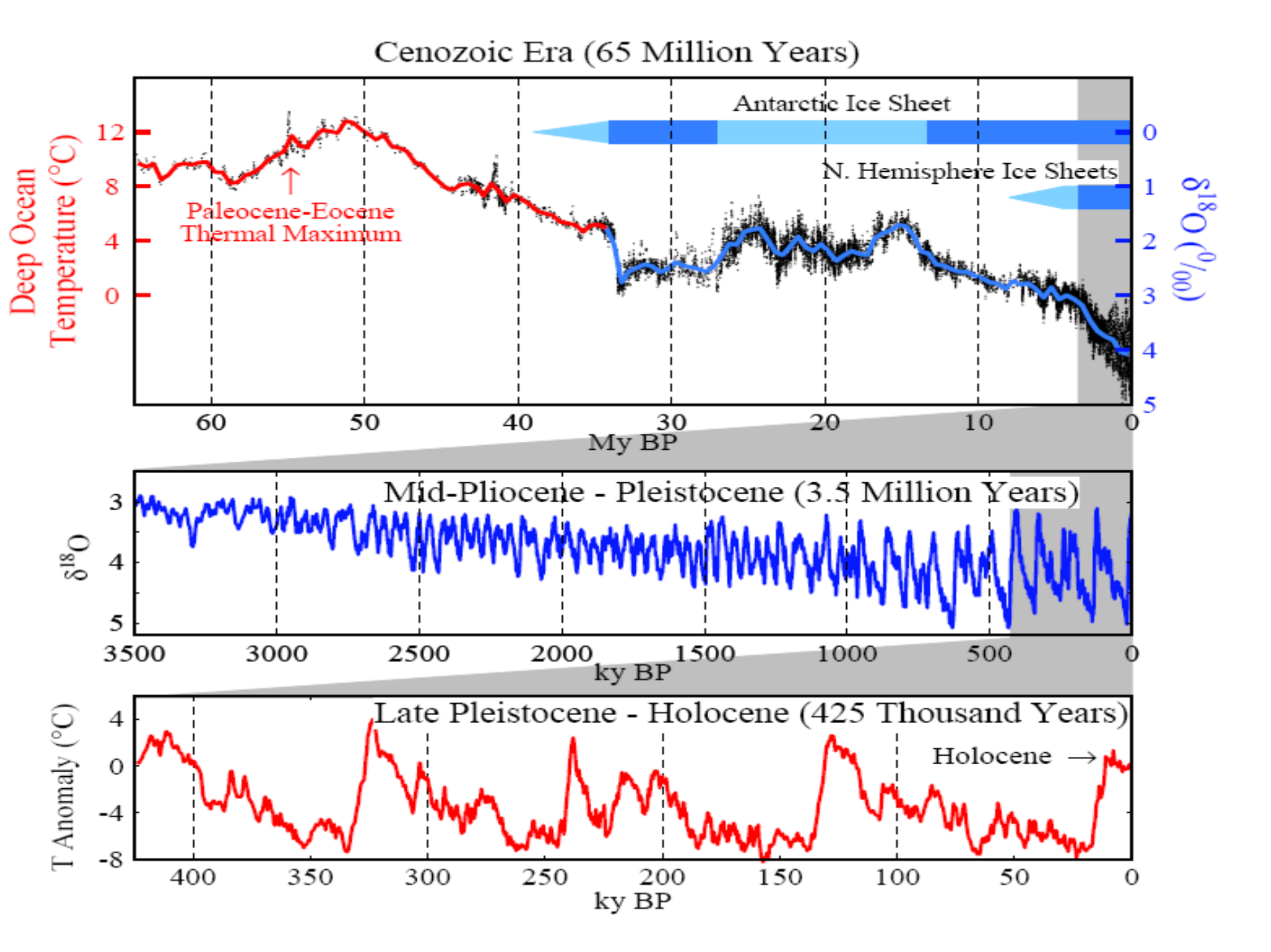
3. **Ice Sheet Observations**

   → CO_2 < 385 ppm

*Assuming near-balance among non-CO_2 forcings



Dashed lines: Early Holocene maxima.


Cenozoic Era (65 Million Years)
Deep Ocean Temperature (°C)
12
8
4
0
Paleocene-Eocene Thermal Maximum
Antarctic Ice Sheet
N. Hemisphere Ice Sheets
0
1
2
3
4
5
δ18O (‰)
60
50
40
30
20
10
0
My BP
Mid-Pliocene - Pleistocene (3.5 Million Years)
δ18O
3
4
5
3500
3000
2500
2000
1500
1000
500
0
ky BP
Late Pleistocene - Holocene (425 Thousand Years)
T Anomaly (°C)
4
0
-4
-8
Holocene →
400
350
300
250
200
150
100
50
0
ky BP

Pier on Lake Mead.

Lake Powell

Regional Climate Criterion*

1. **Restore Planetary Energy Balance**

   CO_2: 385 ppm → 325-355 ppm

2. **Restore Climate: Aim for -0.5 W/m^2**

   CO_2: 385 ppm → 300-325 ppm

Range based on uncertainty in present planetary energy imbalance (between 0.5 and 1 W/m^2)

***Assuming near-balance among non-CO_2 forcings**

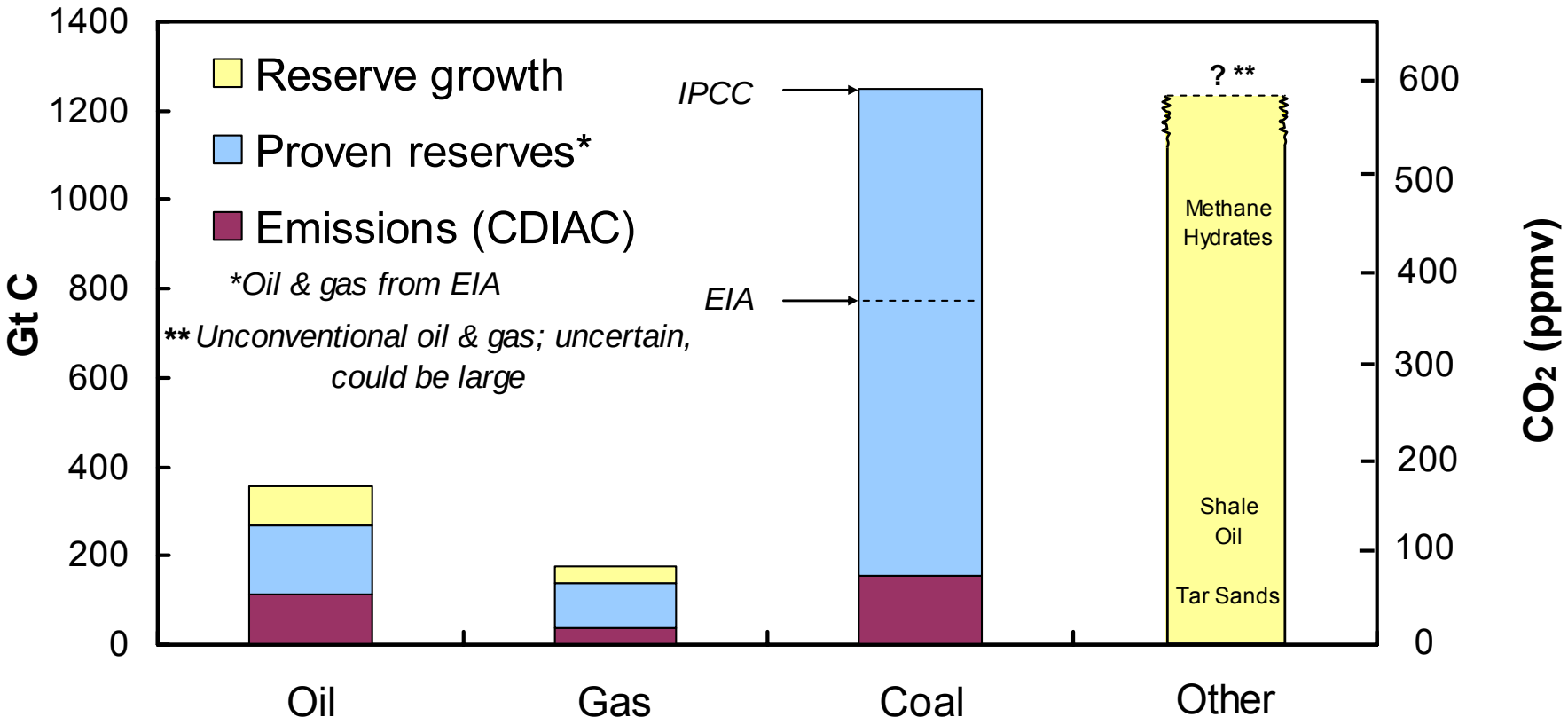
Assessment of Target CO_2

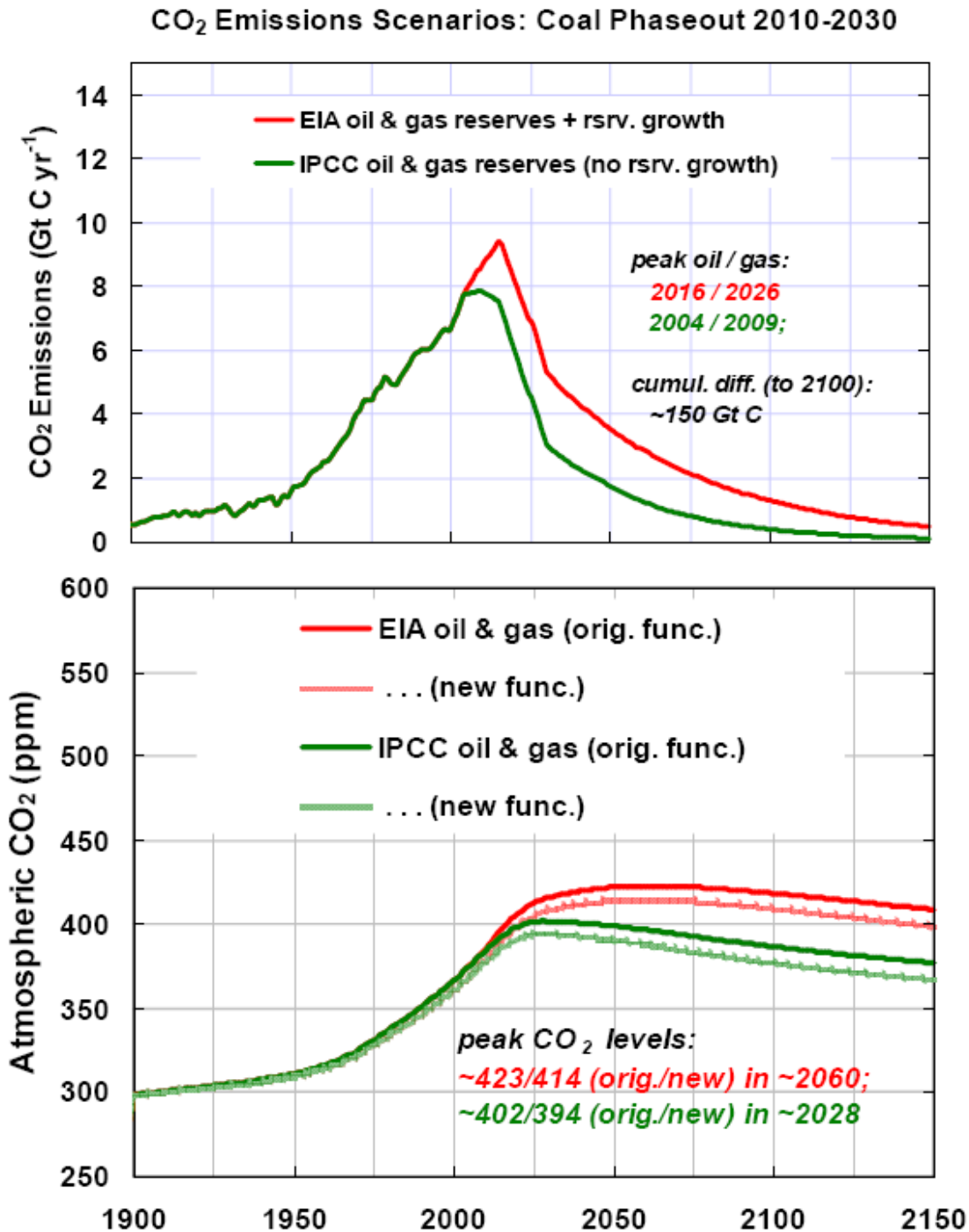
Phenomenon	Target CO_2 (ppm)
1. Arctic Sea Ice	300-325
2. Ice Sheets/Sea Level	~300
3. Shifting Climatic Zones	300-350
4. Alpine Water Supplies	300-350
5. Avoid Ocean Acidification	~300

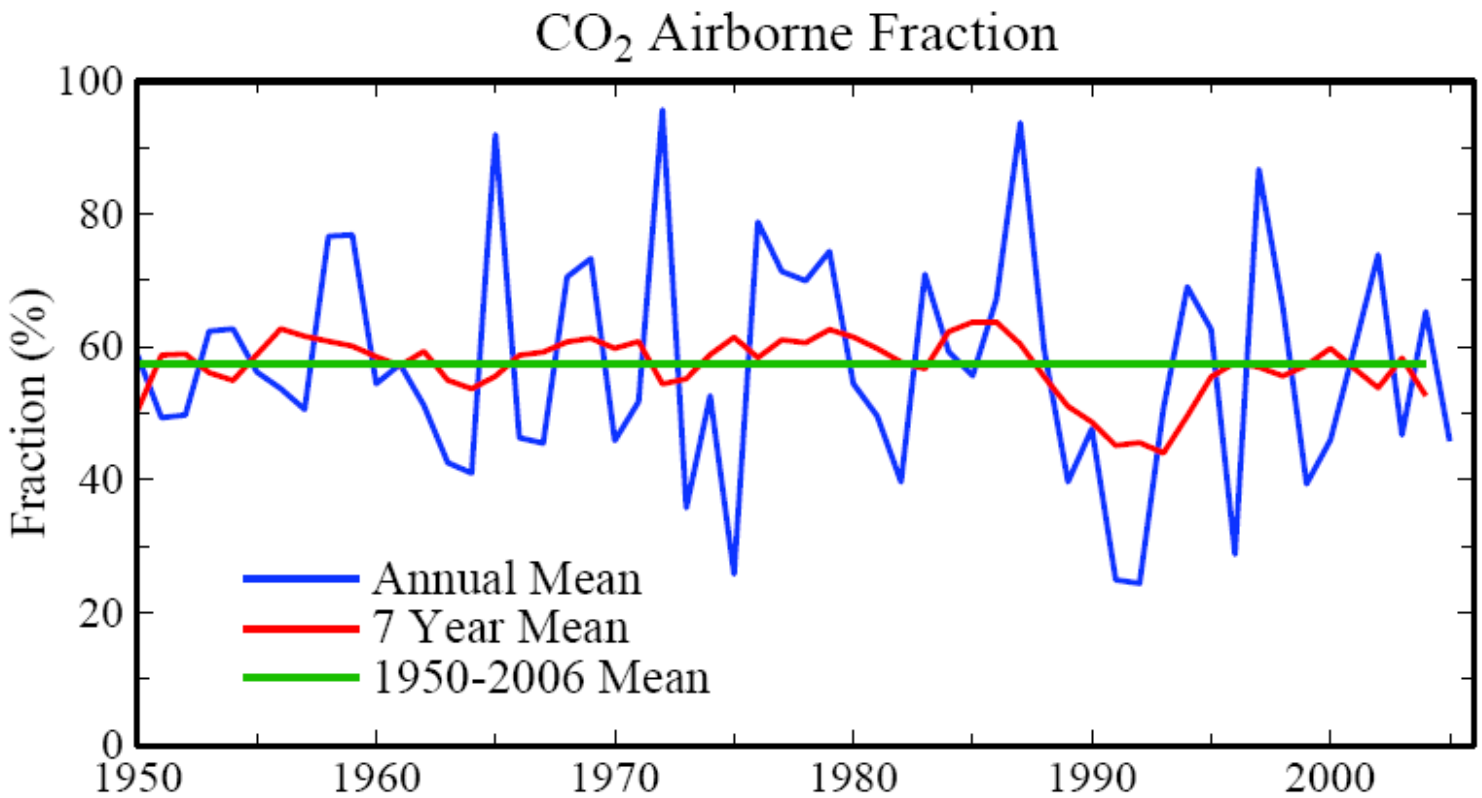
→ **Initial Target CO_2 = 300-350***

*350 ppm assumes CH_4, O_3, Black Soot decrease

Fossil Fuel Reservoirs and 1750–2004 Emissions




CO_2 Emissions Scenarios: Coal Phaseout 2010-2030
CO_2 Emissions (Gt C yr^{-1})
EIA oil & gas reserves + rsrv. growth
IPCC oil & gas reserves (no rsrv. growth)
peak oil / gas:
2016 / 2026
2004 / 2009;
cumul. diff. (to 2100):
~150 Gt C
Atmospheric CO_2 (ppm)
EIA oil & gas (orig. func.)
. . . (new func.)
IPCC oil & gas (orig. func.)
. . . (new func.)
peak CO_2 levels:
~423/414 (orig./new) in ~2060;
~402/394 (orig./new) in ~2028
1900
1950
2000
2050
2100
2150


CO_2 Airborne Fraction
Fraction (%)
100
80
60
40
20
0
1950
1960
1970
1980
1990
2000
Annual Mean
7 Year Mean
1950-2006 Mean

Target CO_2: 300-350 ppm

Technically Feasible

(but not if business-as-usual continues)

Quick Coal Phase-Out Critical

(long lifetime of atmospheric CO_2)
(must halt construction of any new coal plants that do not capture & store CO_2)

Basic Conflict

Fossil Fuel Special Interests

vs

Young People & Nature (Animals)

Fossil Interests: God-given fact that all fossil fuels will be burned (no free will)

Young People: Hey! Not so fast!
Nice planet you are leaving us!

"Free Will" Alternative

1. **Phase Out Coal CO_2 Emissions**
   - by 2020/2030 developed/developing countries
2. **Rising Carbon Price**
   - discourages unconventional fossil fuels & extraction of every last drop of oil (Arctic, etc.)
3. **Soil & Biosphere CO_2 Sequestration**
   - improved farming & forestry practices
4. **Reduce non-CO_2 Forcings**
   - reduce CH_4, O_3, trace gases, black soot

What are the Chances?

Fossil Interests: have influence in capitols world-wide

Young People: need to organize, enlist others (parents, e.g.), impact elections

Animals: not much help (don't vote, don't talk)

The Big Tipping Point

If the (human/energy) system reaches a point such that positive feedbacks cause a rapid change

It is possible. We have to figure out how to live w/o fossil fuels some-day anyhow – why not sooner?

☺ but animals can't do it

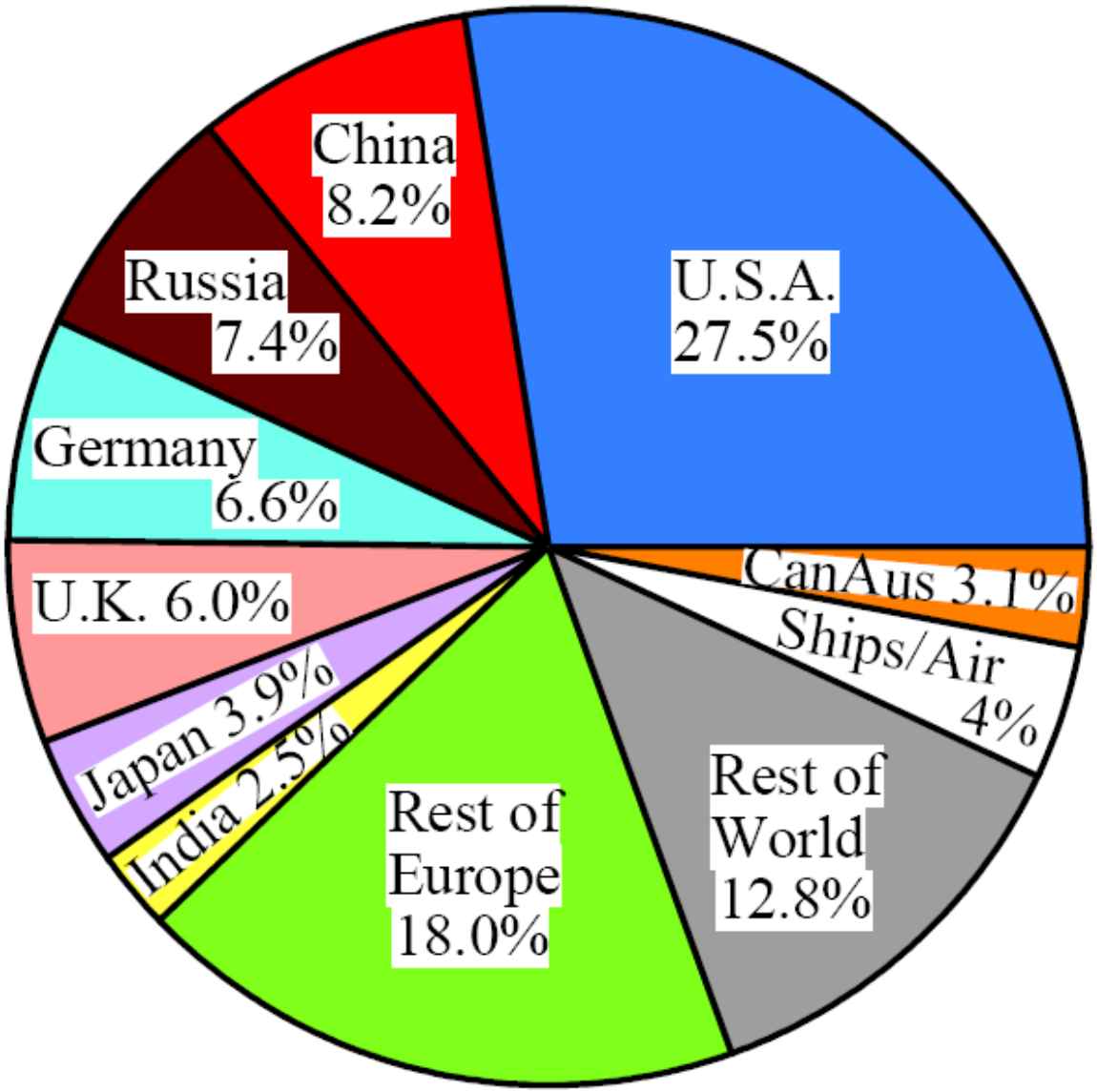
Outline of Solution

1. Coal only in Powerplants w Sequestration
   Old Technology 'Bulldozed' in Decades
2. Stretch Conventional Oil & Gas
   Via Incentives (Cap or Tax) & Standards
   No Unconventional F.F. (Tar Shale, etc.)

---

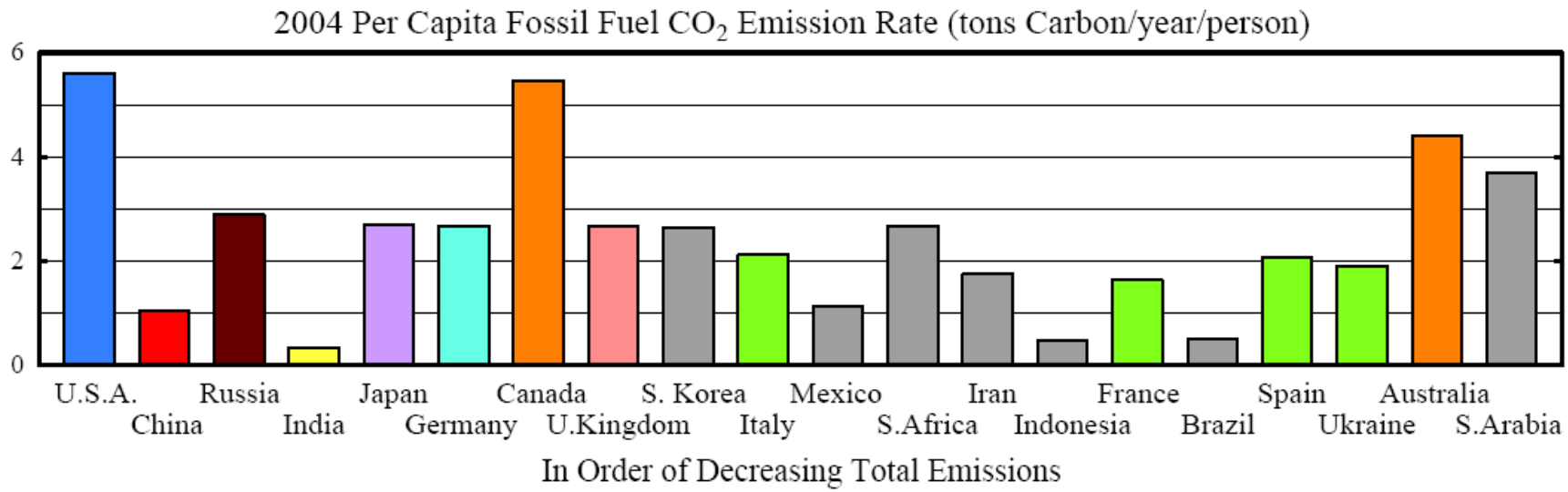
3. Reduce non-CO_2 Climate Forcings
   Methane, Black Soot, Nitrous Oxide
4. Draw Down Atmospheric CO_2
   Agricultural & Forestry Practices
   Biofuel-Powered Power-Plants

1751-2006 Cumulative Fossil Fuel CO_2 Emissions



Update of Figure 10(e) of “Dangerous human-made interference with climate”

Per Capita Carbon Emissions

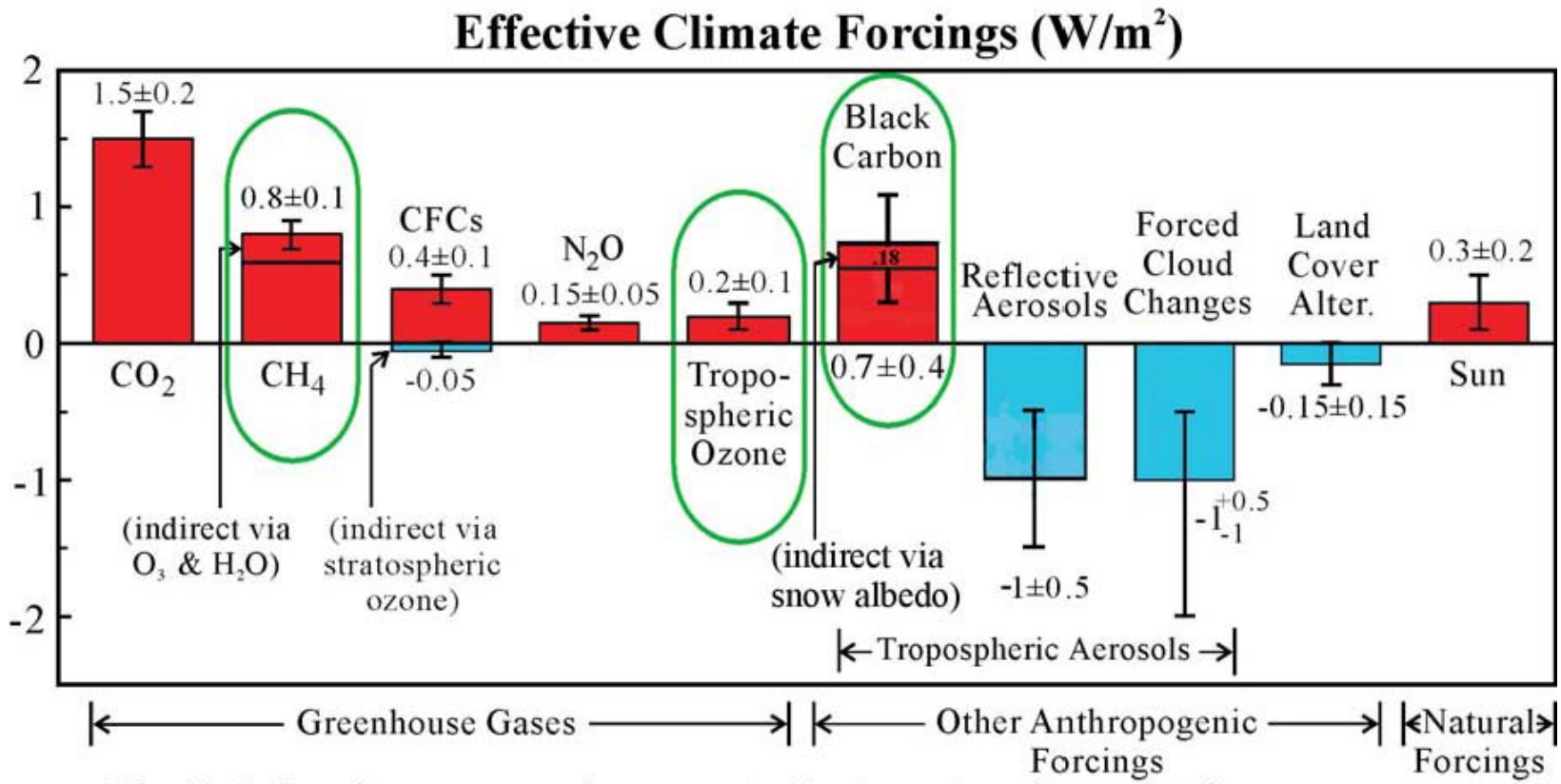


Update of Figure 10(g) of “Dangerous human-made interference with climate”

Why Stretch Supplies-Carbon Price

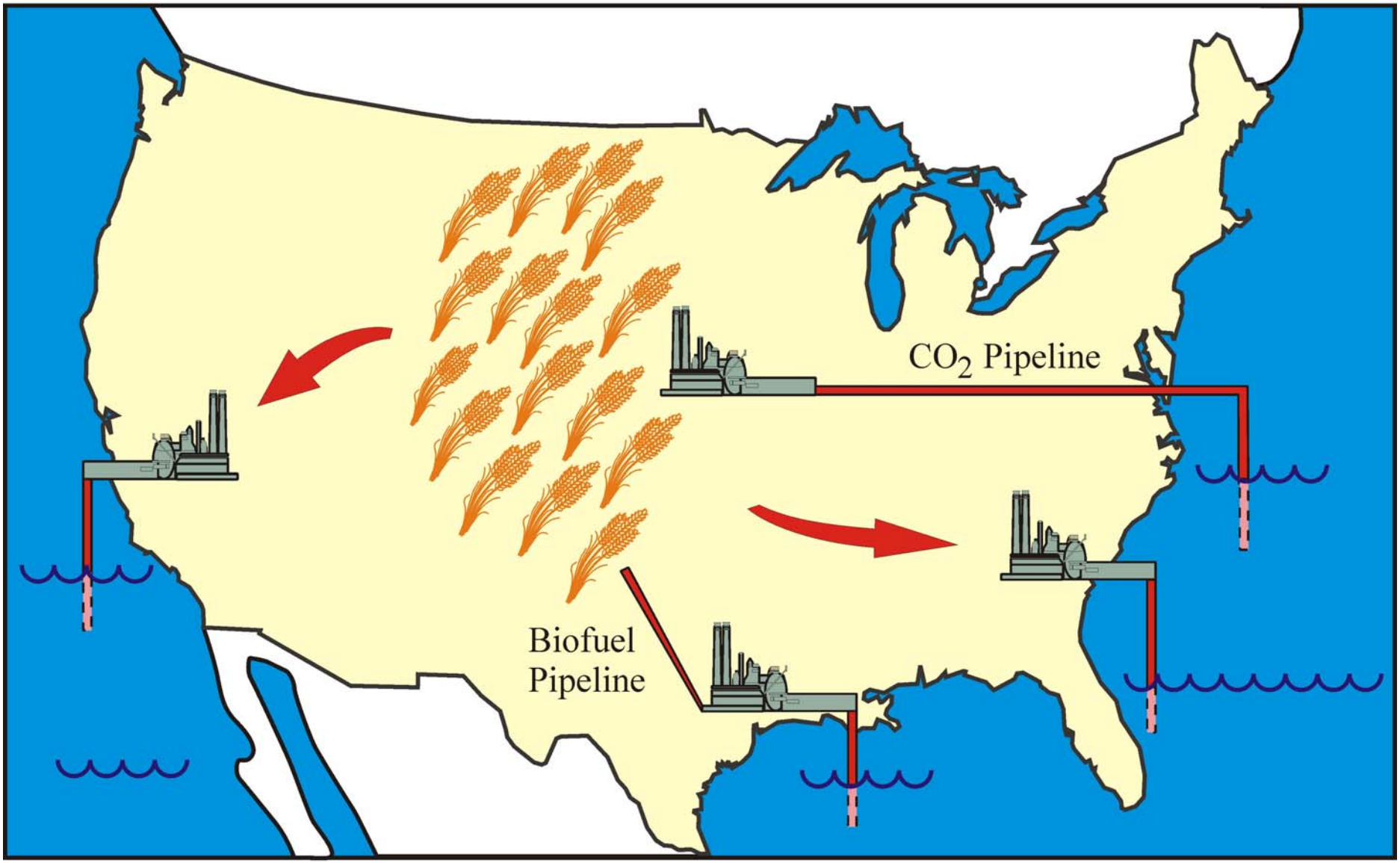
Wean from Fossil Fuel Addiction

- Fossil fuels finite – future energies cleaner – advantageous to get there sooner, good hi-pay jobs in U.S. → gradually increasing carbon price
- Carbon price can be fair & revenue neutral: cap & trade, carbon rations, carbon tax, etc.
- Irrational desperate addict: squeeze every drop from tar shale, Arctic nature preserves, decapitate mountains – some FF should be left in the ground!
- Even addicts have a brain – our behavior suggests special role of special interests – our addiction will not be solved by politicians w/o encouragement – our democracy still functions – let's use it!

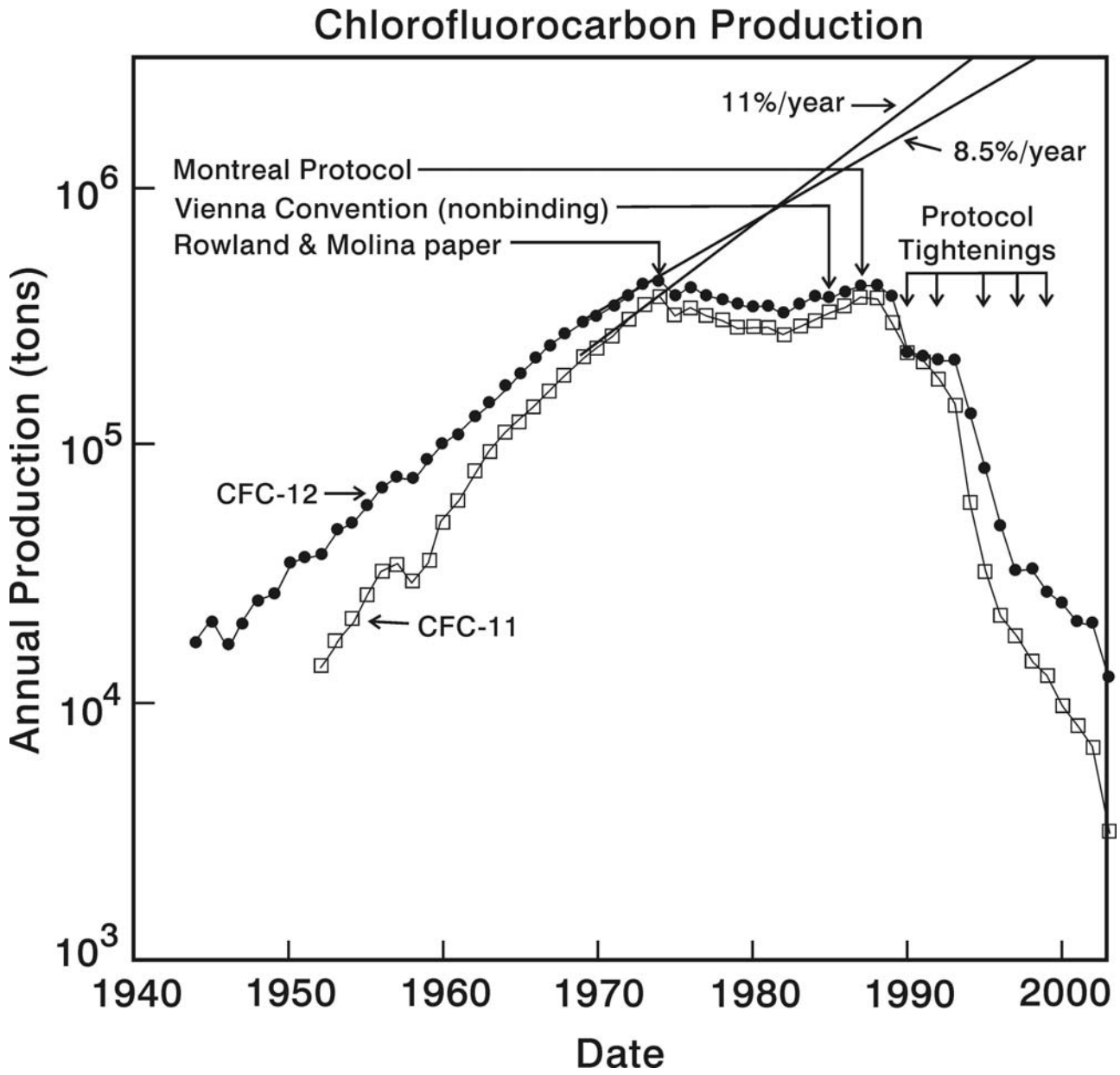


Circled forcings are prime contributors to air pollution.

Biofuel Negative-CO_2 Power Plants



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


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

Ozone Success Story

↑1. **Scientists**: Clear warning

↑2. **Media**: Transmitted the message well

3. **Special Interests**: Initial oposition, but forsook disinformation, pursued advanced technologies

↑↑4. **Public**: quick response; spray cans replaced; no additional CFC infrastructure built

↑5. **Government**: U.S./Europe leadership; allow delay & technical assistance for developing countries

Global Warming Story

↓1. **Scientists**: Fail to make clear distinction between climate change & BAU = A Different Planet

↓2. **Media**: False "balance", and leap to hopelessness

↓↓3. **Special Interests**: Disinformation campaigns, emphasis on short-term profits

↓4. **Government**: Seems affected by special interests; fails to lead – no Winston Churchill today

↓5. **Public**: understandably confused, uninterested

As it appears that the world may pass a tipping point soon, beyond which it will be impossible to avert massive future impacts on humans and other life on the planet:

Who Bears (Legal/Moral) Responsibility?

1. Scientists?
2. Media?
3. Special Interests?
4. Politicians?

5a. Public?

5b. Children/Grandchildren?

Who Will Pay?

Urgent Action Needed:

Moratorium on New Coal Powerplants

- Plant Lifetime ~ 50-75 Years
- Sequestration Technology ~10 Years Away
- Efficiency, Renewables in Interim
- Need to Remove Barriers to Efficiency

Citizens Must Stand Up

- Coal Industry is Very Powerful
- Congress Unlikely to Act Decisively

Declaration of Stewardship for the Earth and all Creation

1. **Moratorium on Dirty Coal**
   I will support a moratorium on coal-fired power plants that do not capture and sequester CO_2 .

2. **Price on Carbon Emissions**
   I will support a fair, gradually rising, price on carbon emissions, reflecting costs to the environment. Mechanisms to adjust price should be apolitical and economically sound.

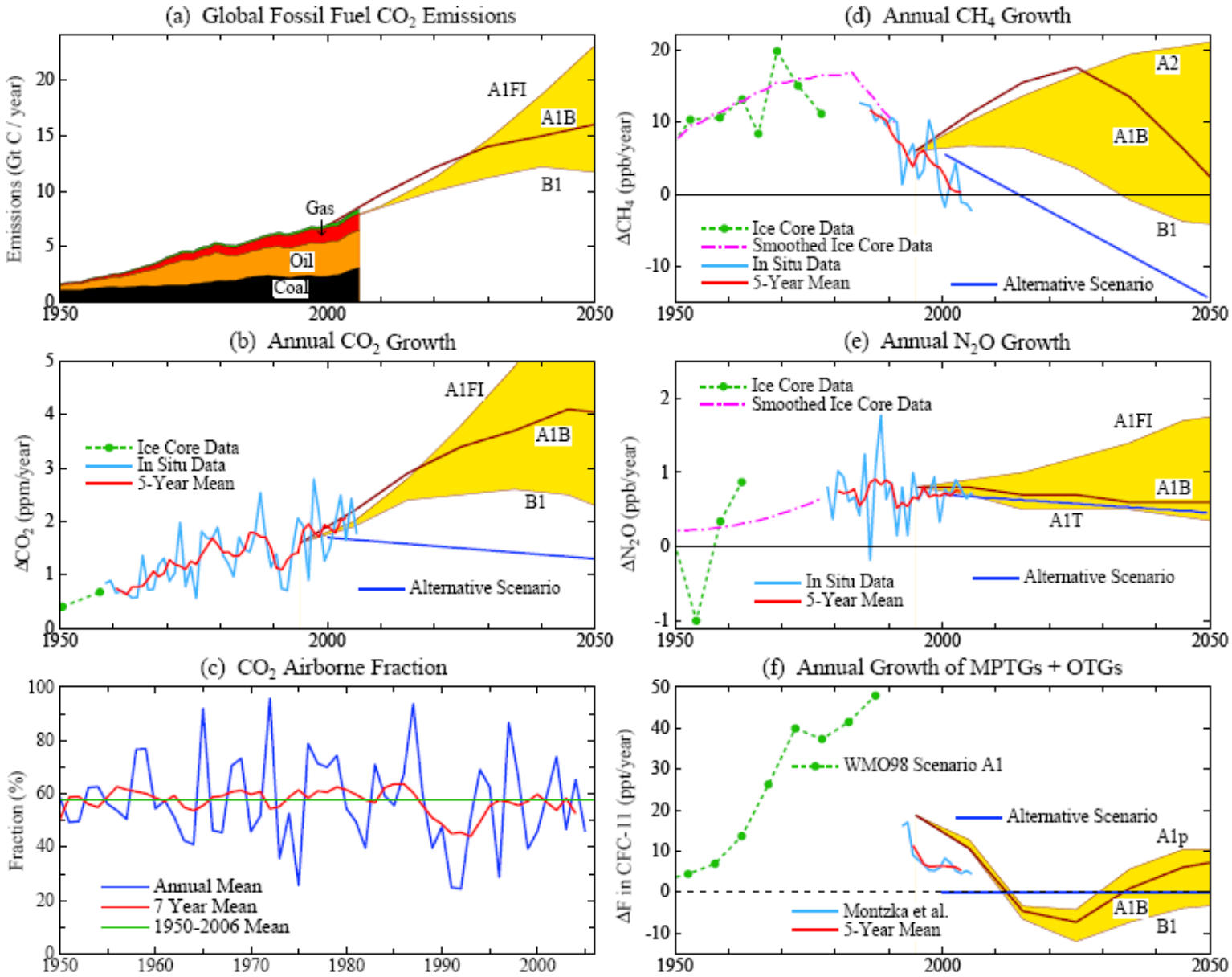
3. **Energy/Carbon Efficiency Incentives & Standards**
   I will support rules to reward utilities based on efficiencies (not amount of energy sold), and higher standards for buildings, vehicles, etc.

Status of the Matter

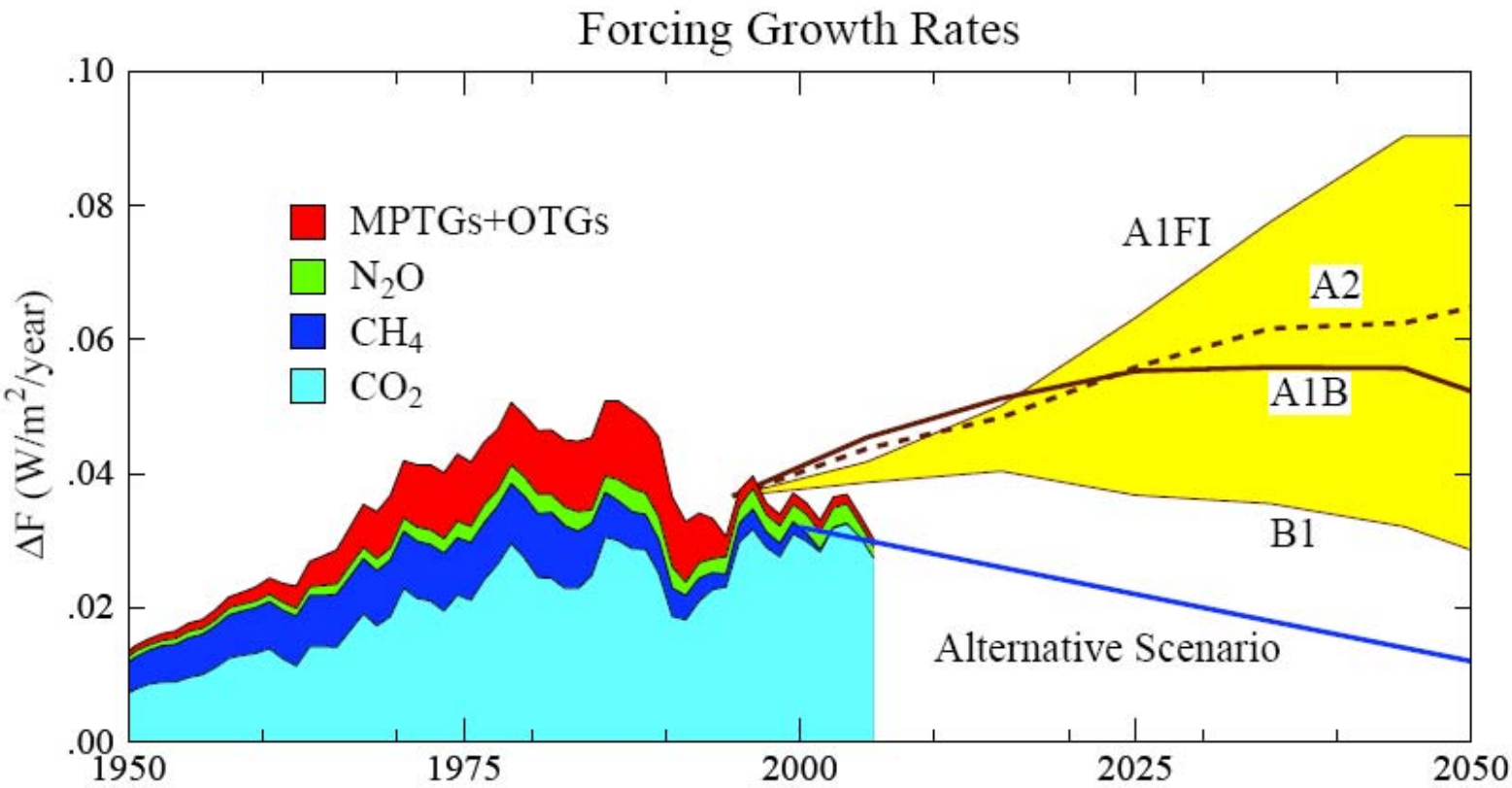
1. **Climate Situation Clear, not Communicated Well**
   - Positive Feedbacks Coming into Play,
   - Tipping Points are Near,
   - Real Potential to Lose Control

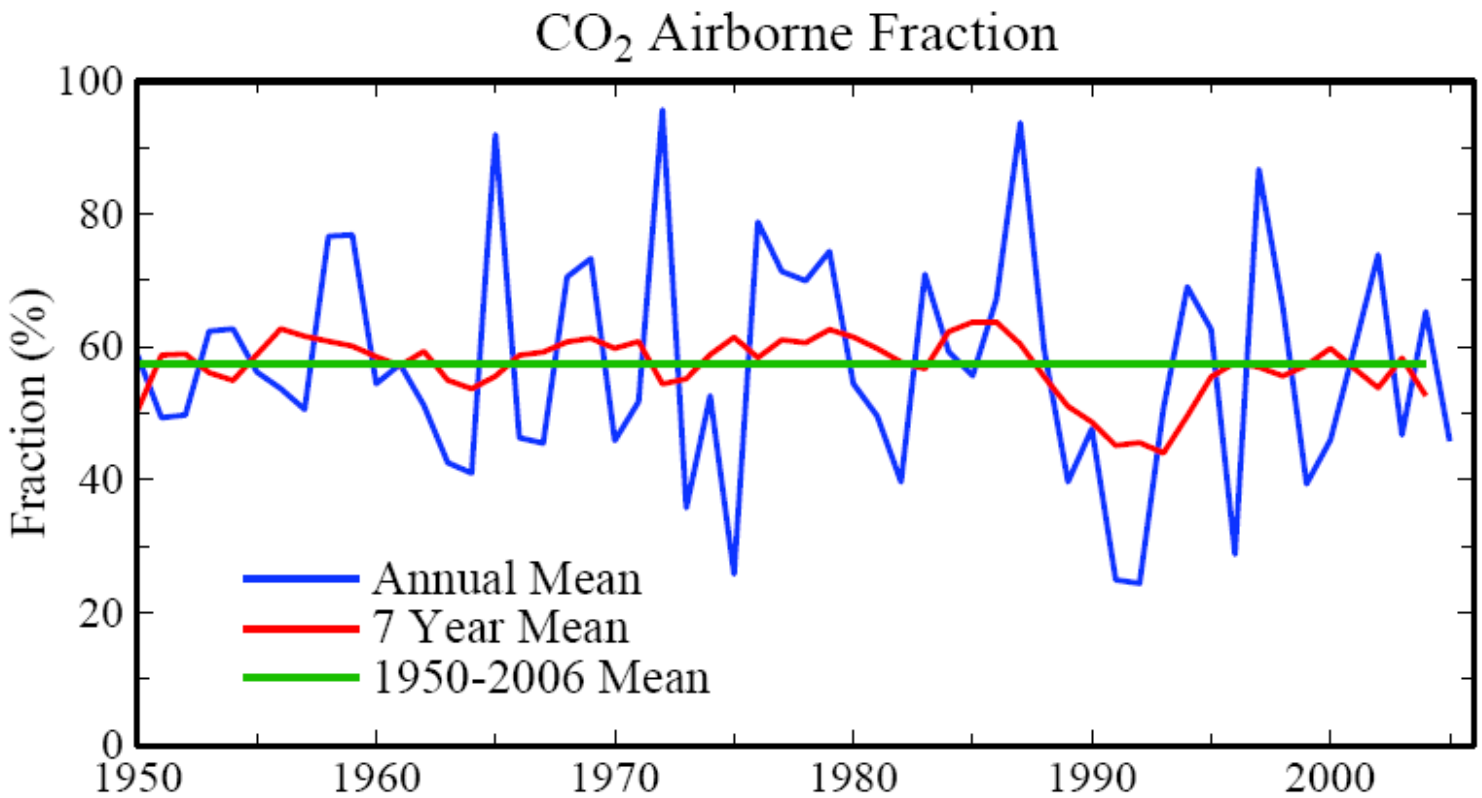
2. **Solution is Feasible**
   - Peak Oil will occur, Coal Moratorium in West now
   - Moratoriumn in10 years in Developing Countries,
   - Dirty Coal Phase-Out by 2050 → CO_2 <450 ppm
   - Carbon Price, Reduce Pollution, Draw Down CO_2

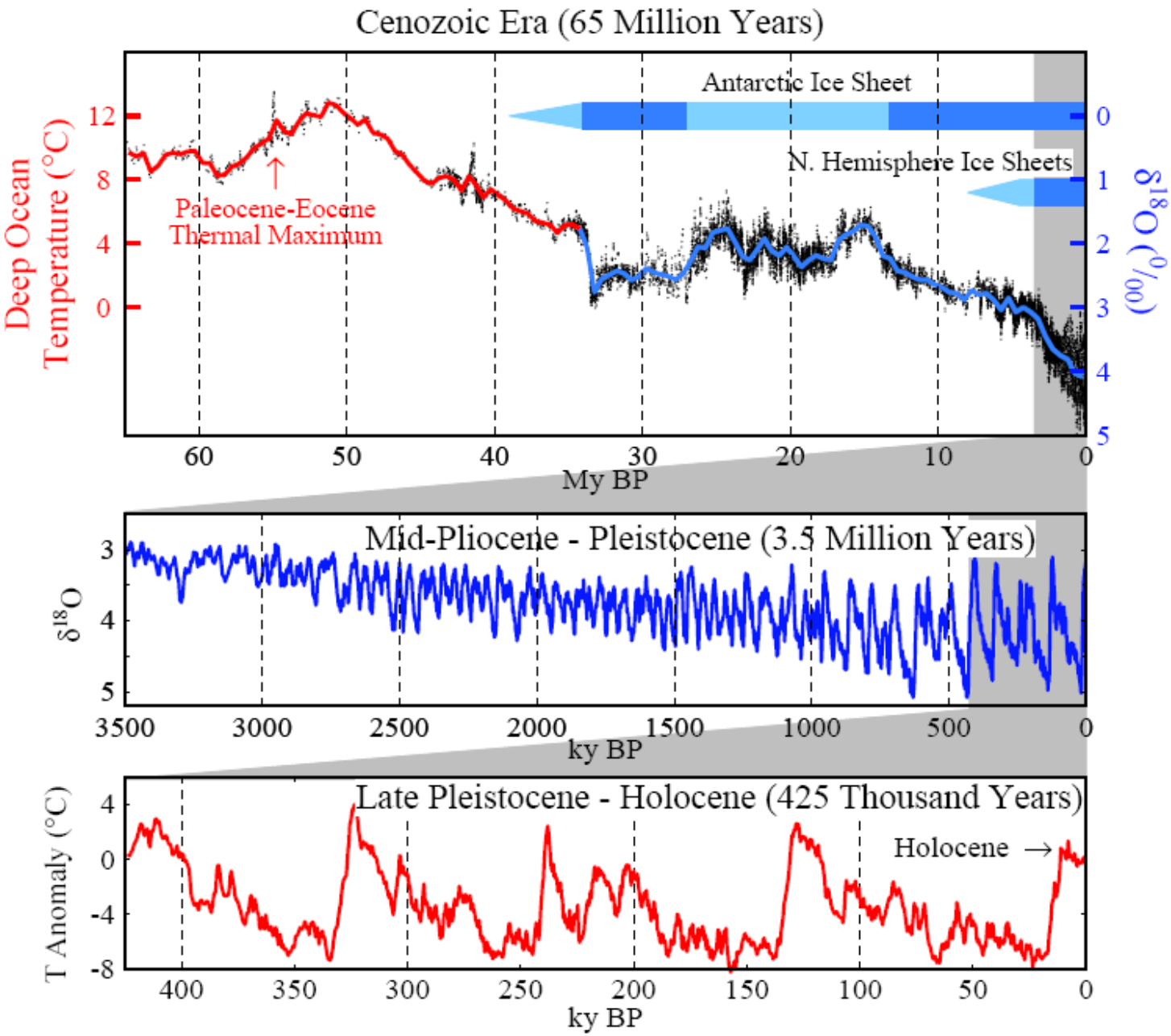
3. **Side Benefits are Great**
   - High-Tech, High-Pay Jobs
   - Energy Independence
   - Clean Atmosphere, Clean Water


(a) Global Fossil Fuel CO_2 Emissions
Emissions (Gt C / year)
A1FI
A1B
B1
Gas
Oil
Coal
(b) Annual CO_2 Growth
ΔCO_2 (ppm/year)
Ice Core Data
In Situ Data
5-Year Mean
Alternative Scenario
(c) CO_2 Airborne Fraction
Fraction (%)
Annual Mean
7 Year Mean
1950-2006 Mean
(d) Annual CH_4 Growth
ΔCH_4 (ppb/year)
A2
Smoothed Ice Core Data
(e) Annual N_2O Growth
ΔN_2O (ppb/year)
A1T
(f) Annual Growth of MPTGs + OTGs
ΔF in CFC-11 (ppt/year)
WMO98 Scenario A1
A1p
Montzka et al.
1950
1960
1970
1980
1990
2000
2050

Climate Forcing by Long-Lived Greenhouse Gases




CO_2 Airborne Fraction
Fraction (%)
100
80
60
40
20
0
1950
1960
1970
1980
1990
2000
Annual Mean
7 Year Mean
1950-2006 Mean


Cenozoic Era (65 Million Years)
Deep Ocean Temperature (°C)
12
8
4
0
Paleocene-Eocene Thermal Maximum
Antarctic Ice Sheet
N. Hemisphere Ice Sheets
0
1
2
3
4
5
δ18O (‰)
60
50
40
30
20
10
0
My BP
Mid-Pliocene - Pleistocene (3.5 Million Years)
δ18O
3
4
5
3500
3000
2500
2000
1500
1000
500
0
ky BP
Late Pleistocene - Holocene (425 Thousand Years)
T Anomaly (°C)
4
0
-4
-8
Holocene →
400
350
300
250
200
150
100
50
0
ky BP

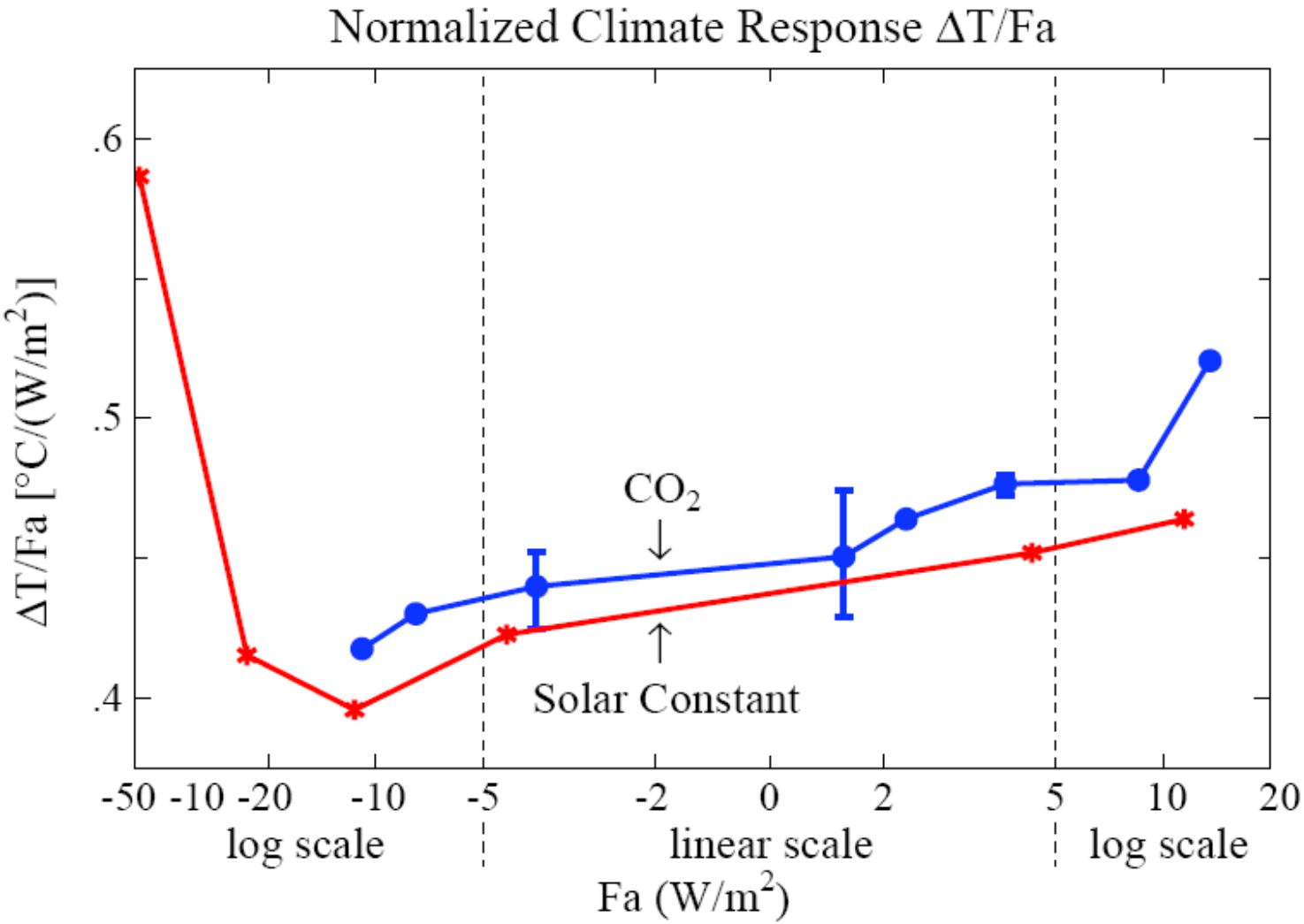
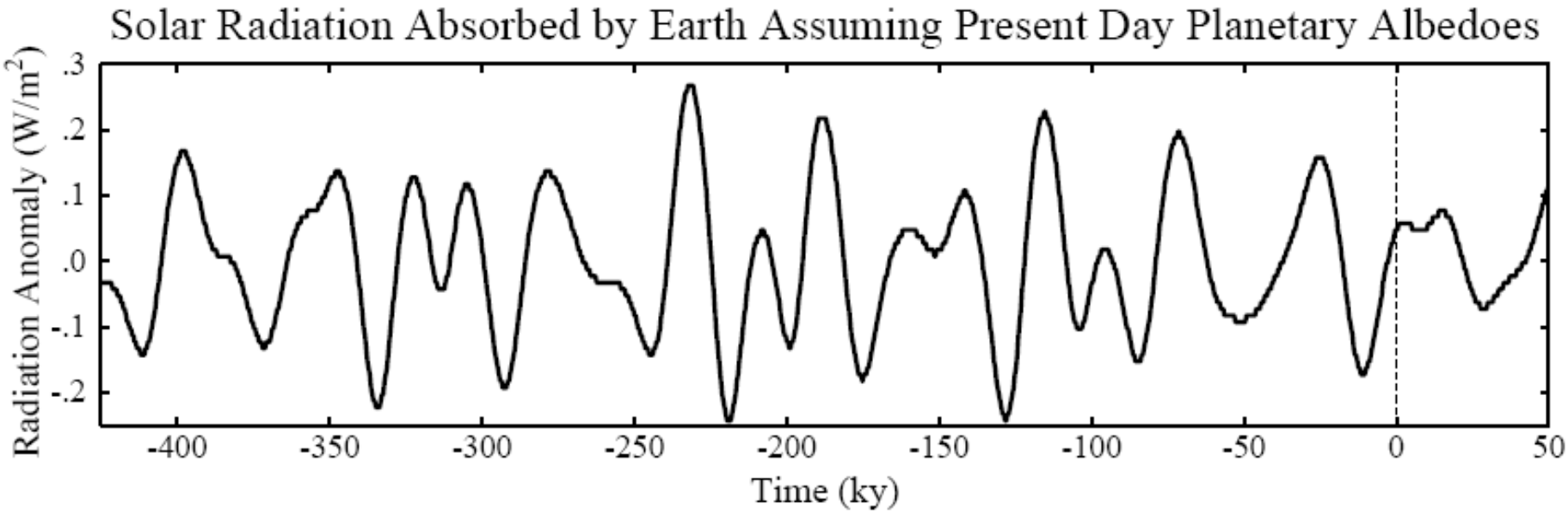


Fig. S1. Global surface air temperature change (5) after 100 years (mean of years 81-120) in simulations with the Goddard Institute for Space Studies (GISS) modelE (S1) as a function of climate forcing for changes of solar irradiance and atmospheric CO_2. Fa is the standard adjusted climate forcing (5). Results here are extracted from Figure 25(a) of (5).


Solar Radiation Absorbed by Earth Assuming Present Day Planetary Albedoes
Radiation Anomaly (W/m2)
.3
.2
.1
.0
-.1
-.2
-400
-350
-300
-250
-200
-150
-100
-50
0
50
Time (ky)