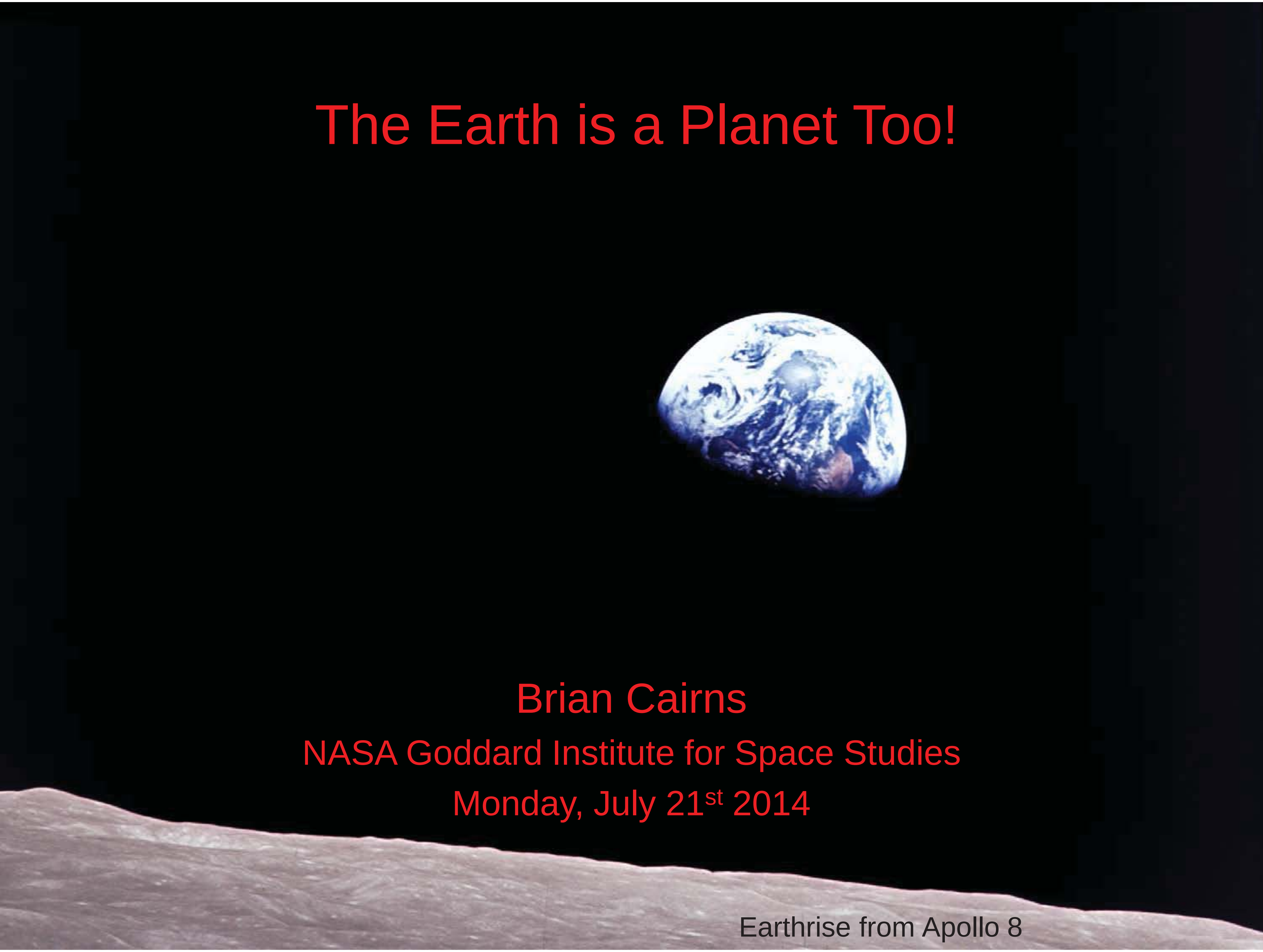
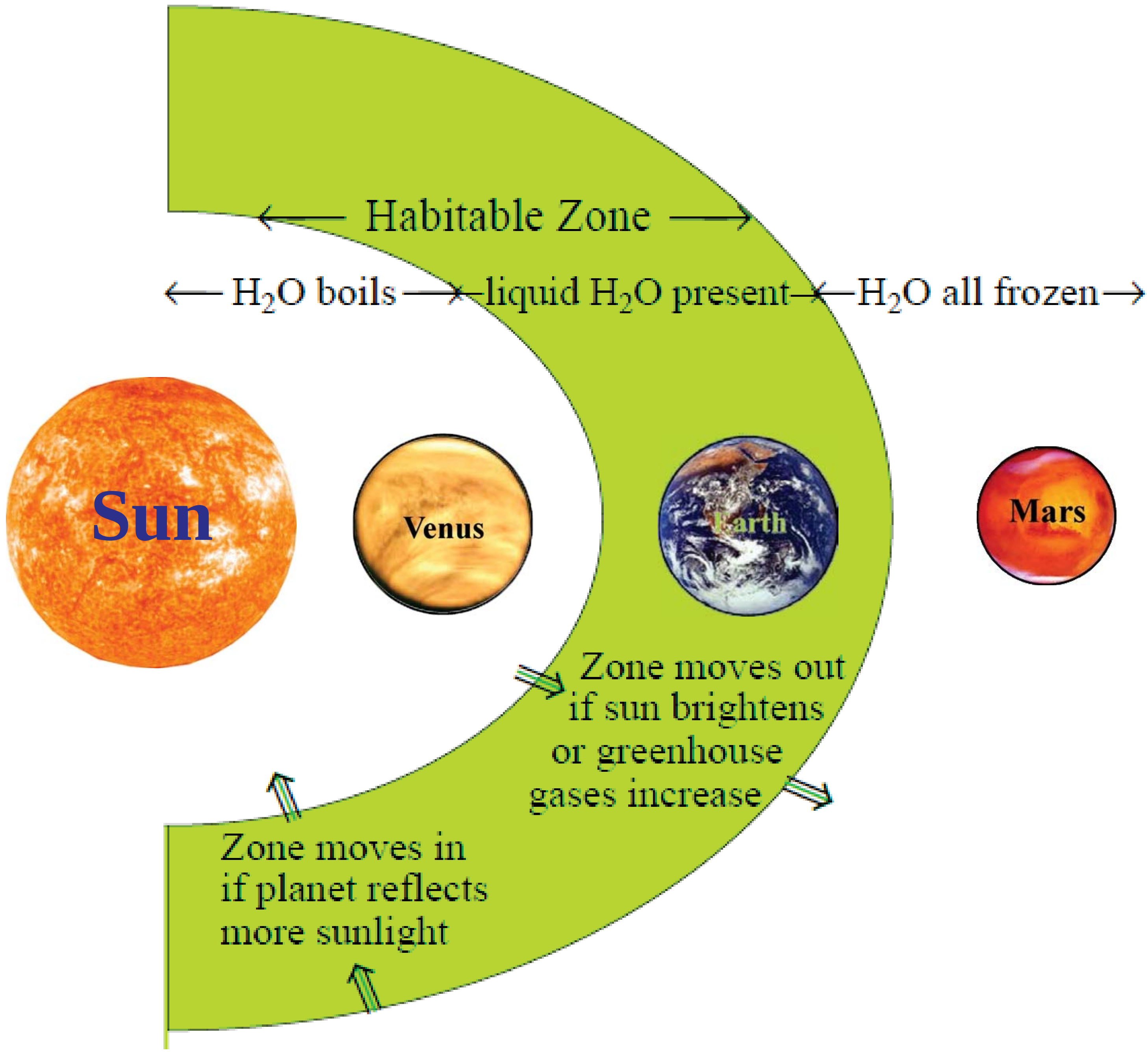
The Earth is a Planet Too!



Brian Cairns
NASA Goddard Institute for Space Studies
Monday, July 21st 2014

Earthrise from Apollo 8

NASA Goddard Institute for Space Studies



When the solar system formed, the sun was 30% dimmer than today and Venus had an ocean. As the sun brightened, a runaway greenhouse effect caused the Venus ocean to boil away.

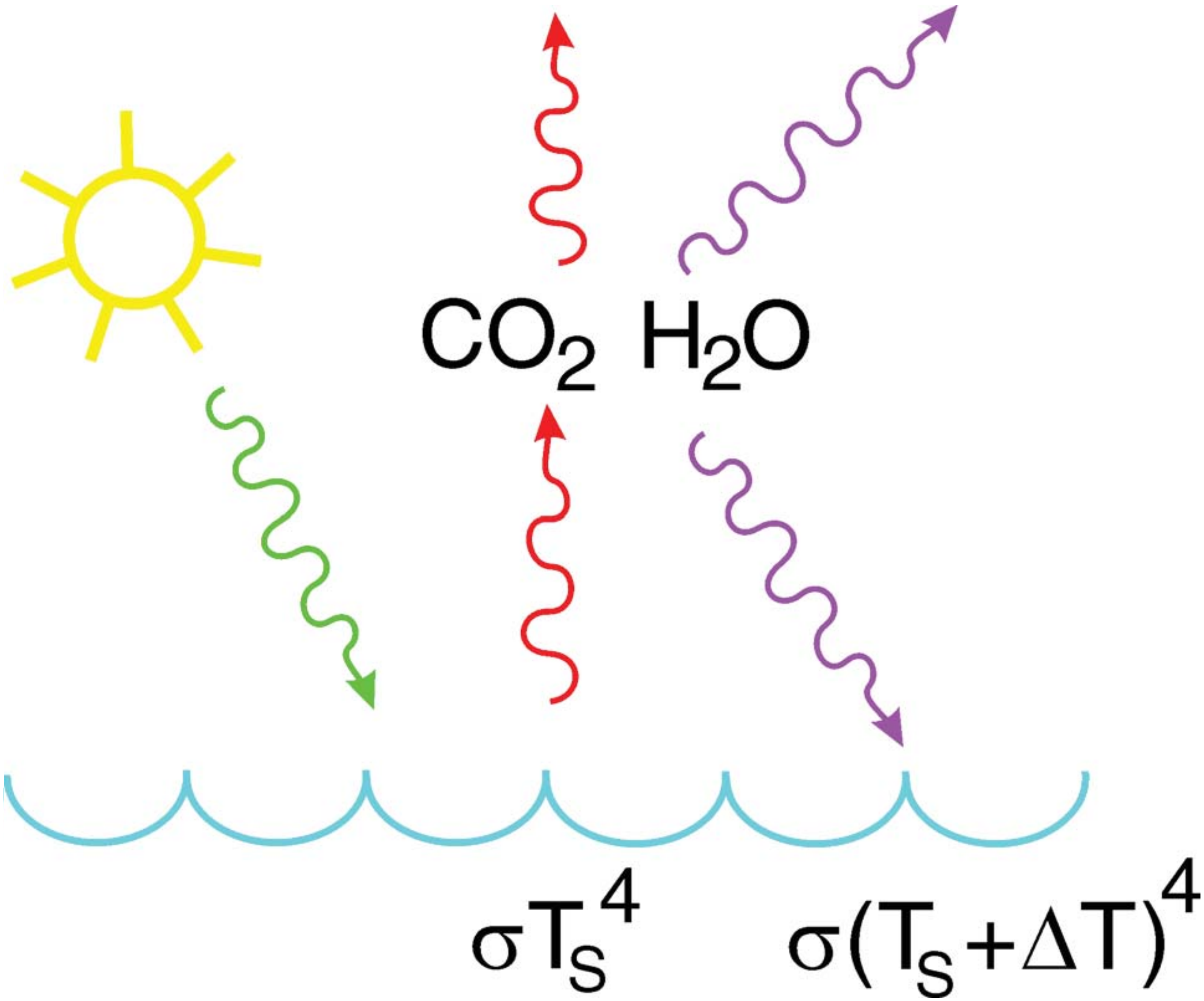
At times when Earth was younger, the sun less bright, and atmospheric CO_2 less, Earth froze over ("snowball Earth").

Earth is in the sweet spot today.

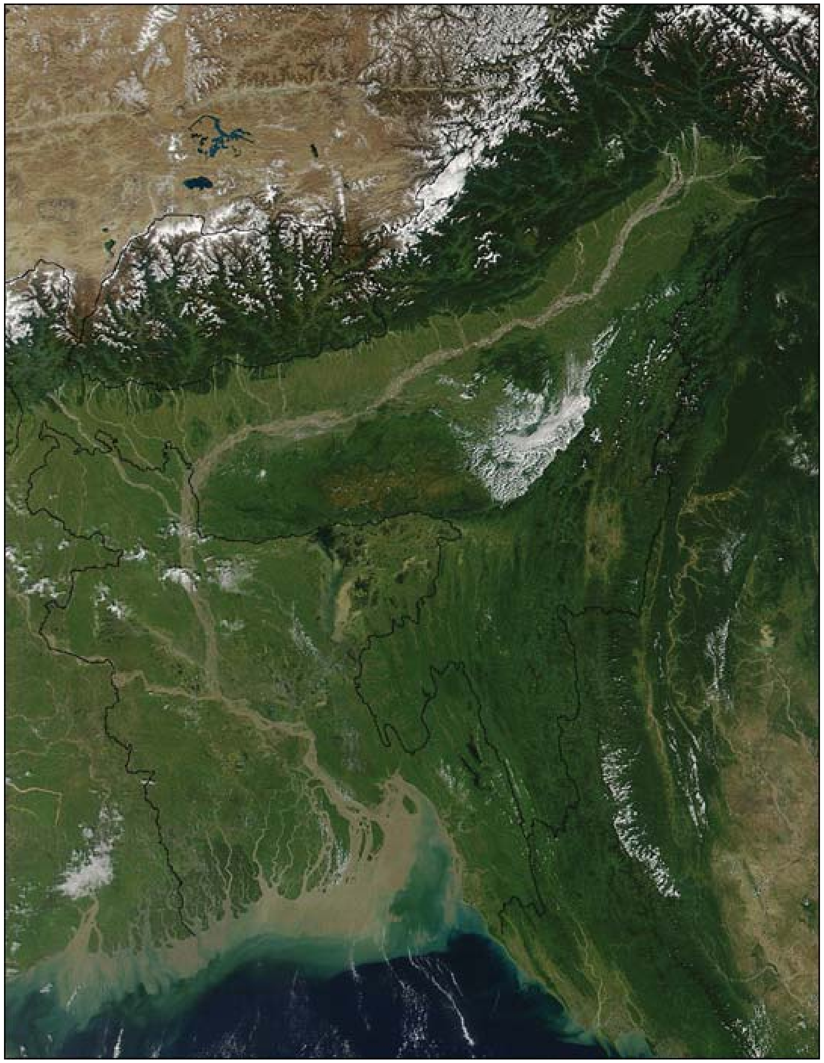
	Mars	Earth	Venus
Temperature	-50°C	+15°C	+450°C
Greenhouse Effect	a few degrees	~30°C	~470°C

Venus is closer to sun than Earth is, but cloud-covered Venus absorbs only 25% of incident sunlight, while Earth absorbs 70%. Venus is warmer because it has a thick carbon dioxide atmosphere causing a greenhouse effect of several hundred degrees.

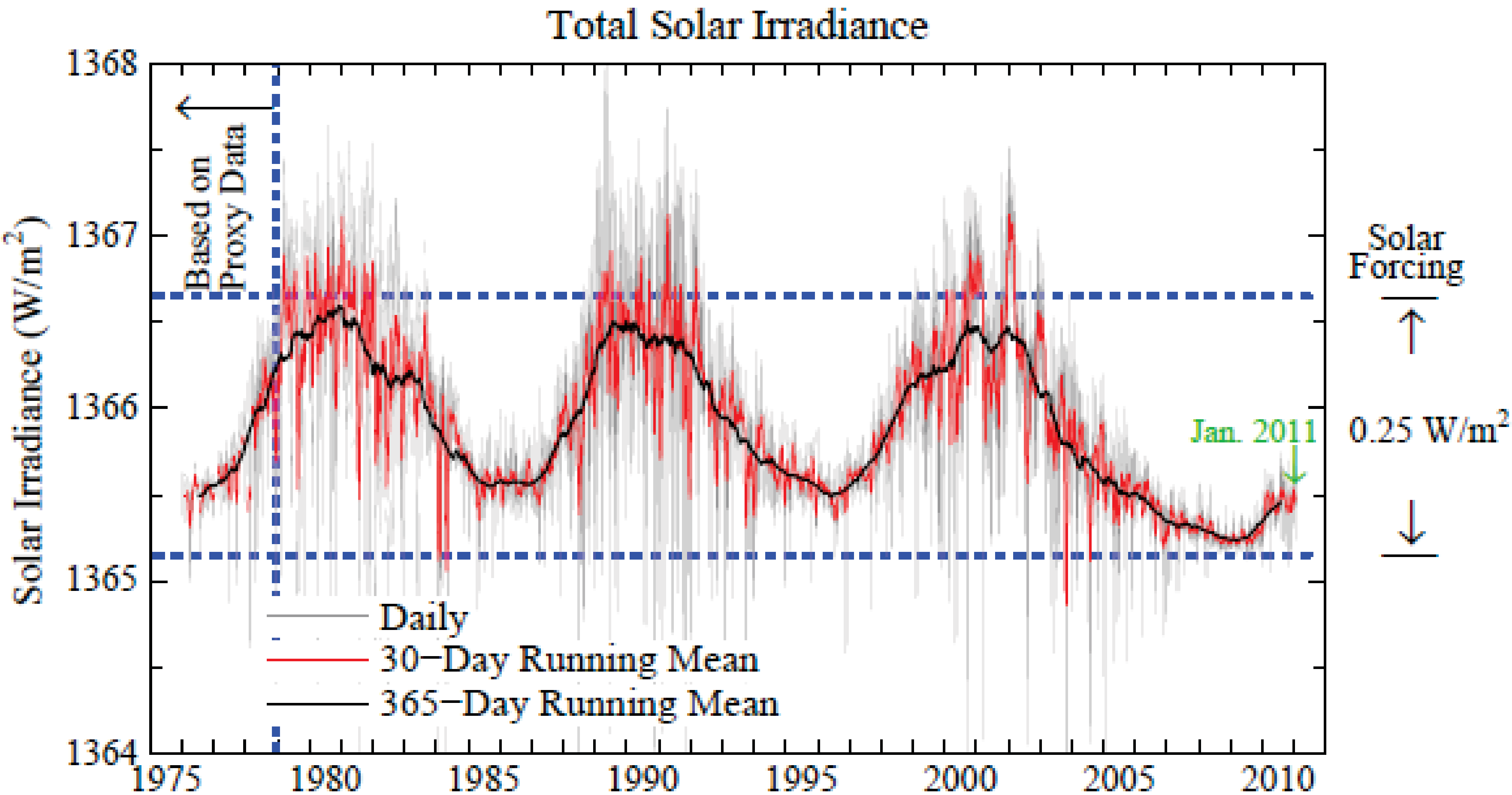
The Greenhouse Effect

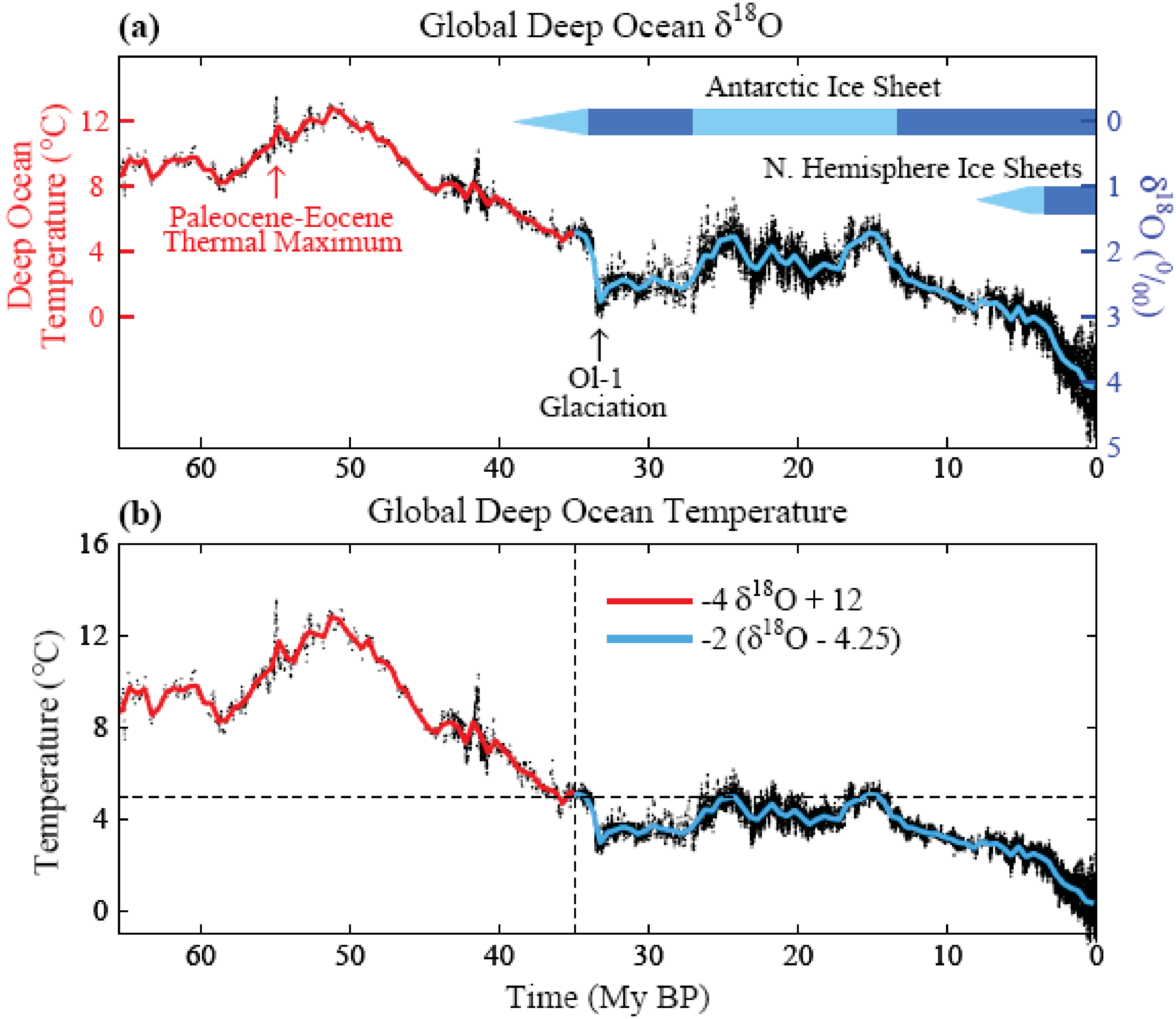


Albedo Effect



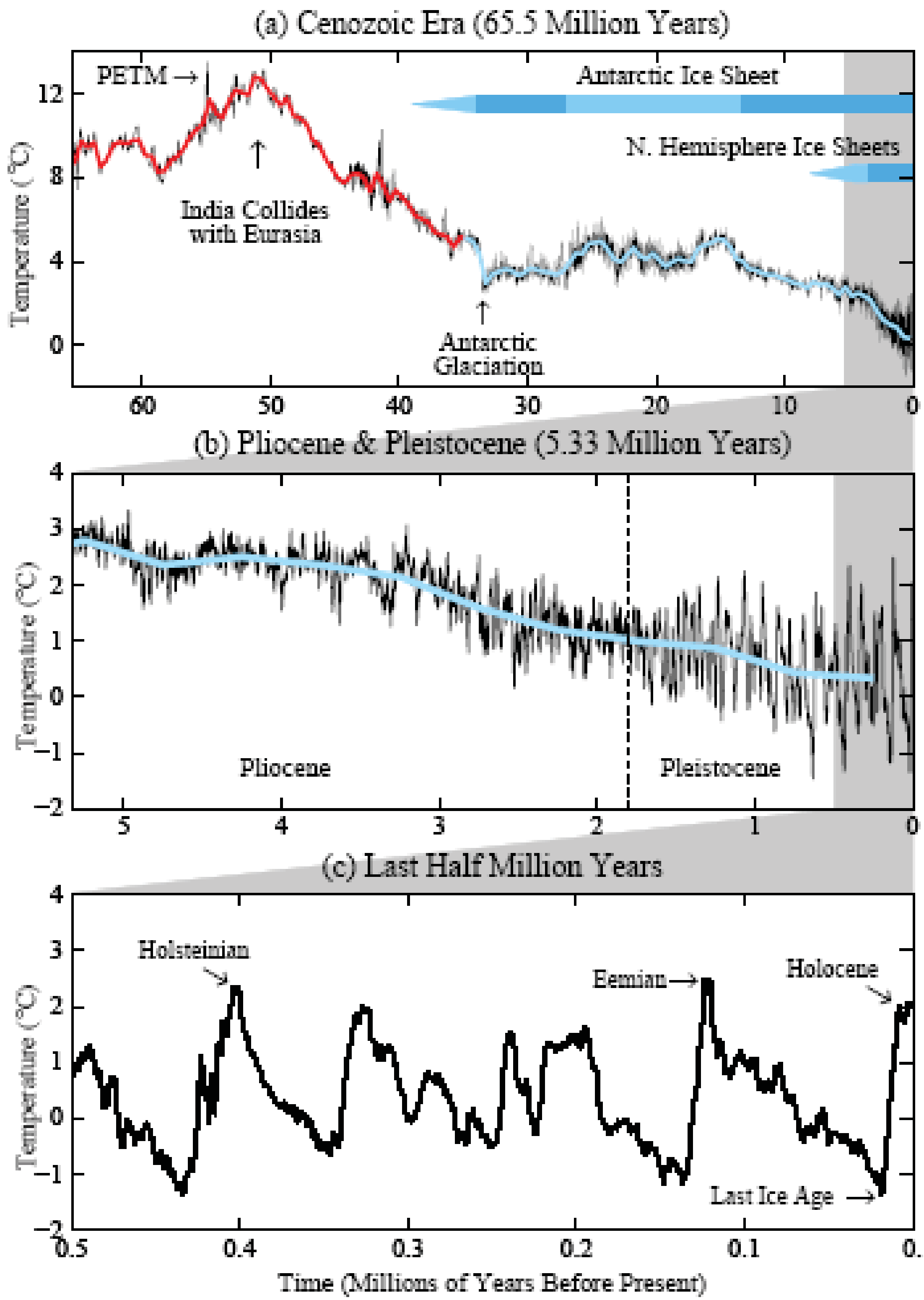
Solar Brightness Effect

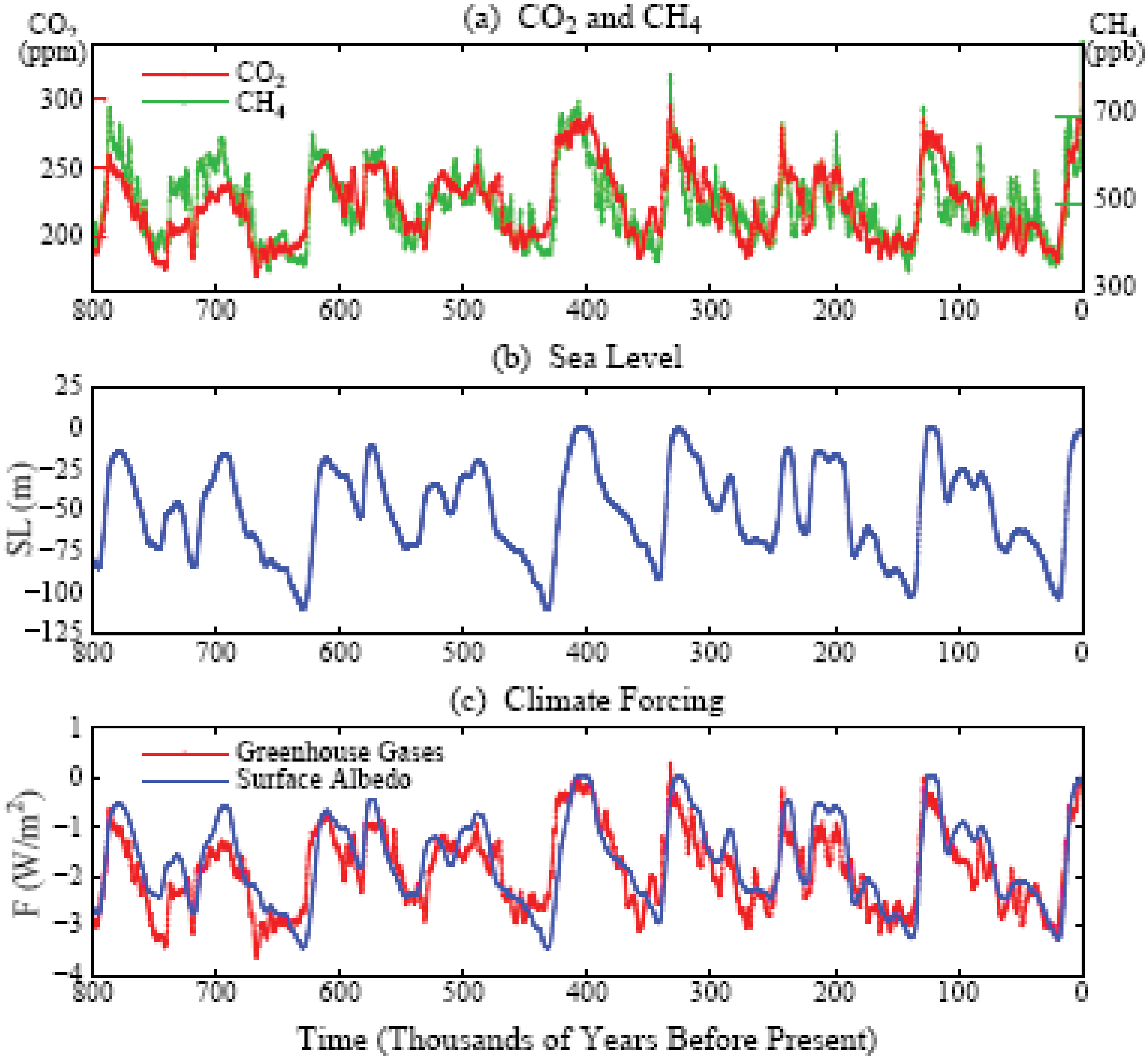


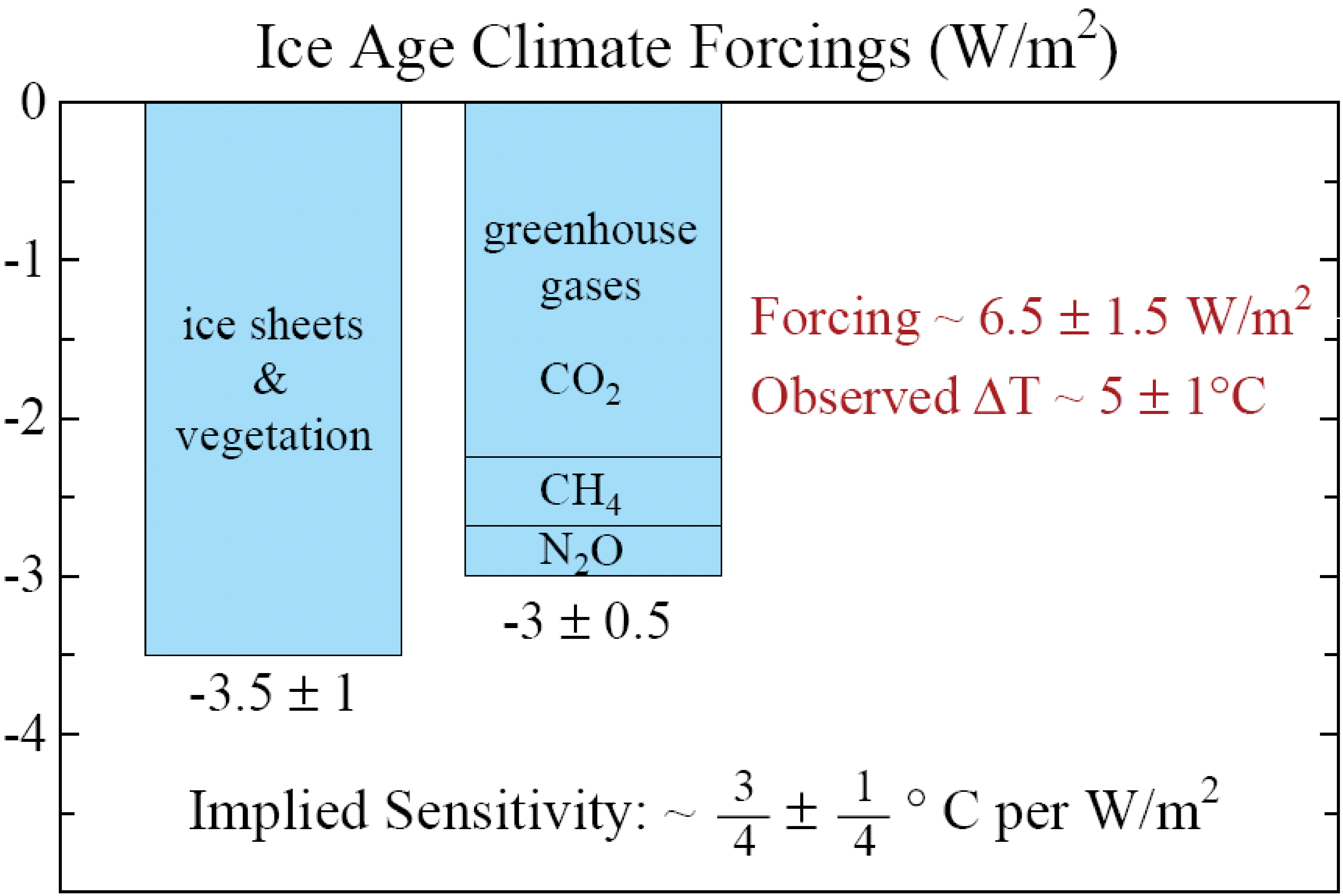


(a) ^{18}O in foram shells, and (b) inferred deep ocean temperature.

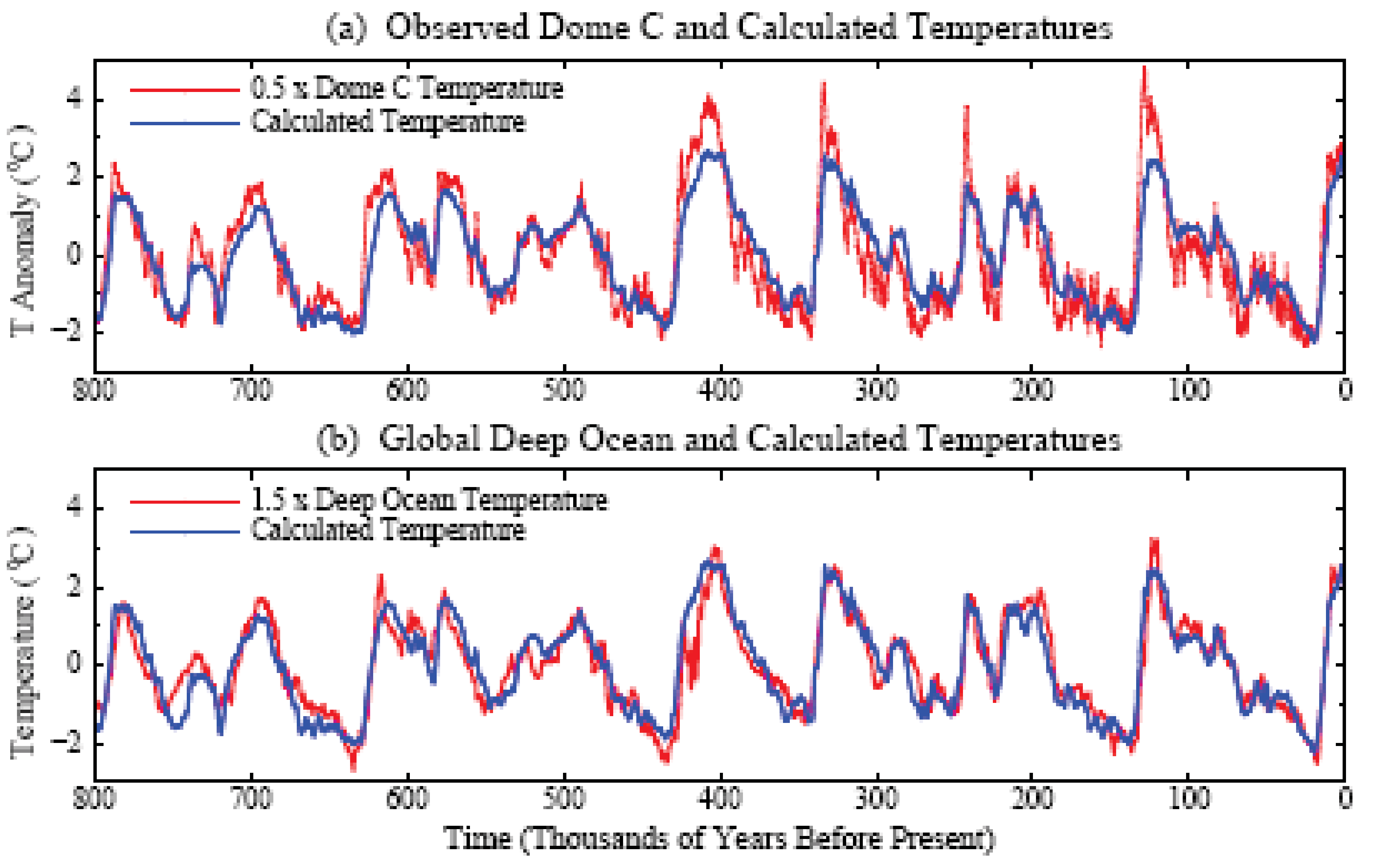
Source: Target Atmospheric CO_2, Hansen *et al.*, *Open Atmos. Sci. J.*, **2**, 217-231, 2008.

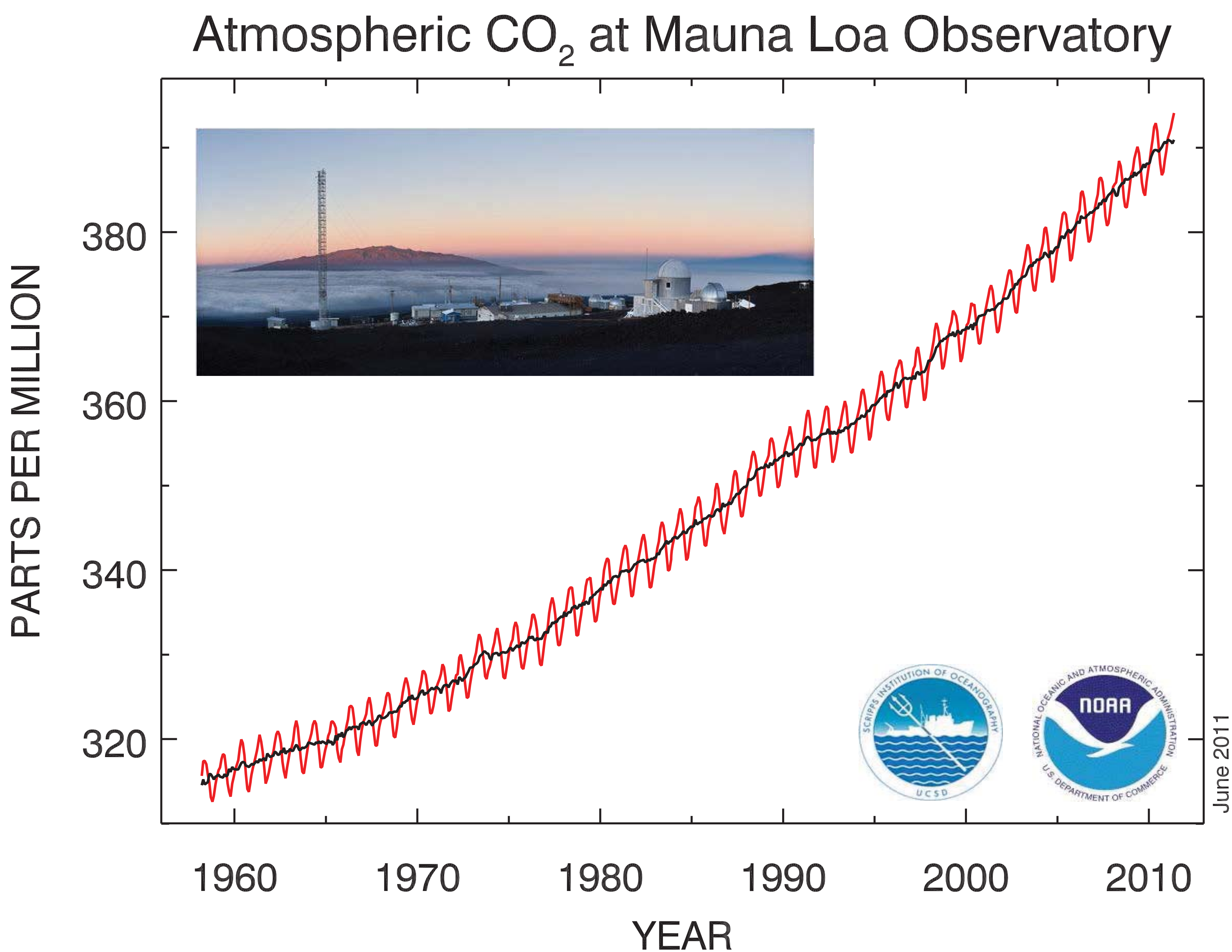

(a) Cenozoic Era (65.5 Million Years)
PETM →
Antarctic Ice Sheet
N. Hemisphere Ice Sheets
India Collides with Eurasia
Antarctic Glaciation
Temperature (°C)
(b) Pliocene & Pleistocene (5.33 Million Years)
Pliocene
Pleistocene
Temperature (°C)
(c) Last Half Million Years
Holsteinian
Eemian
Holocene
Last Ice Age
Temperature (°C)
Time (Millions of Years Before Present)


(a) CO_2 and CH_4
CO_2 (ppm)
CH_4 (ppb)
CO_2
CH_4
300
250
200
700
500
300
800
700
600
500
400
300
200
100
0
(b) Sea Level
SL (m)
25
0
−25
−50
−75
−100
−125
(c) Climate Forcing
F (W/m^2)
Greenhouse Gases
Surface Albedo
1
0
−1
−2
−3
−4
Time (Thousands of Years Before Present)



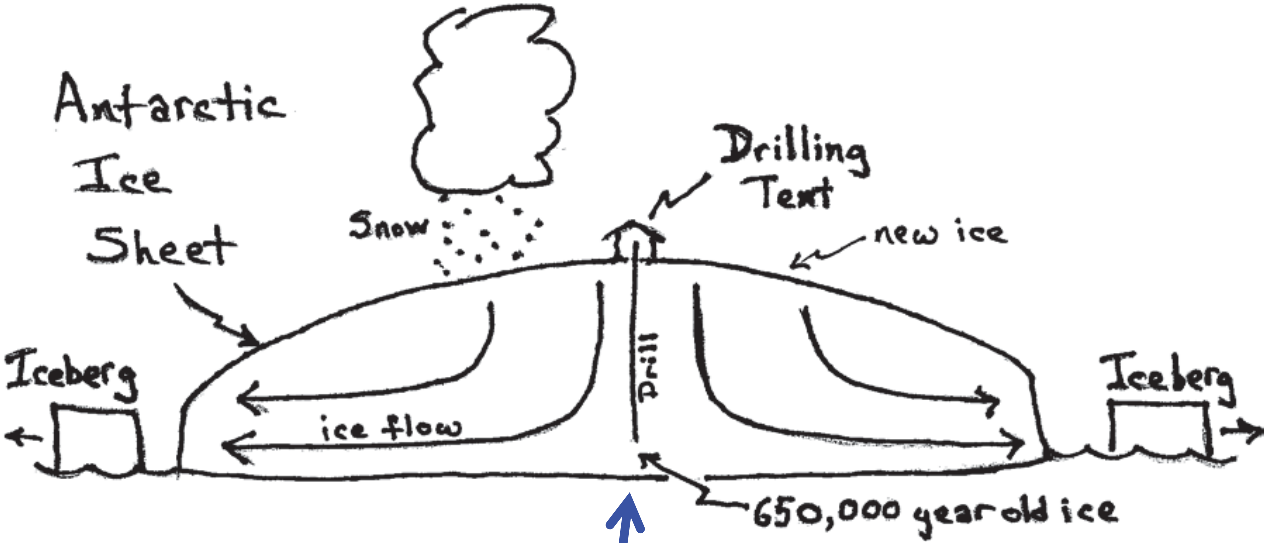
Climate forcings during ice age 20 ky BP, relative to the present (pre-industrial) interglacial period.

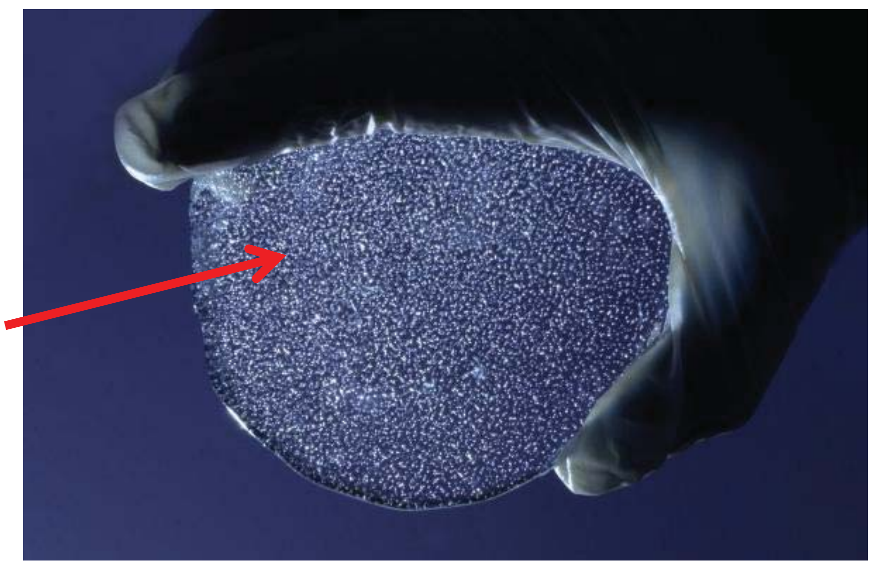

(a) Observed Dome C and Calculated Temperatures
0.5 x Dome C Temperature
Calculated Temperature
T Anomaly (°C)
4
2
0
−2
800
700
600
500
400
300
200
100
0
(b) Global Deep Ocean and Calculated Temperatures
1.5 x Deep Ocean Temperature
Calculated Temperature
Temperature (°C)
4
2
0
−2
800
700
600
500
400
300
200
100
0
Time (Thousands of Years Before Present)



http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_full

CO_2 From Old Ice Bubbles



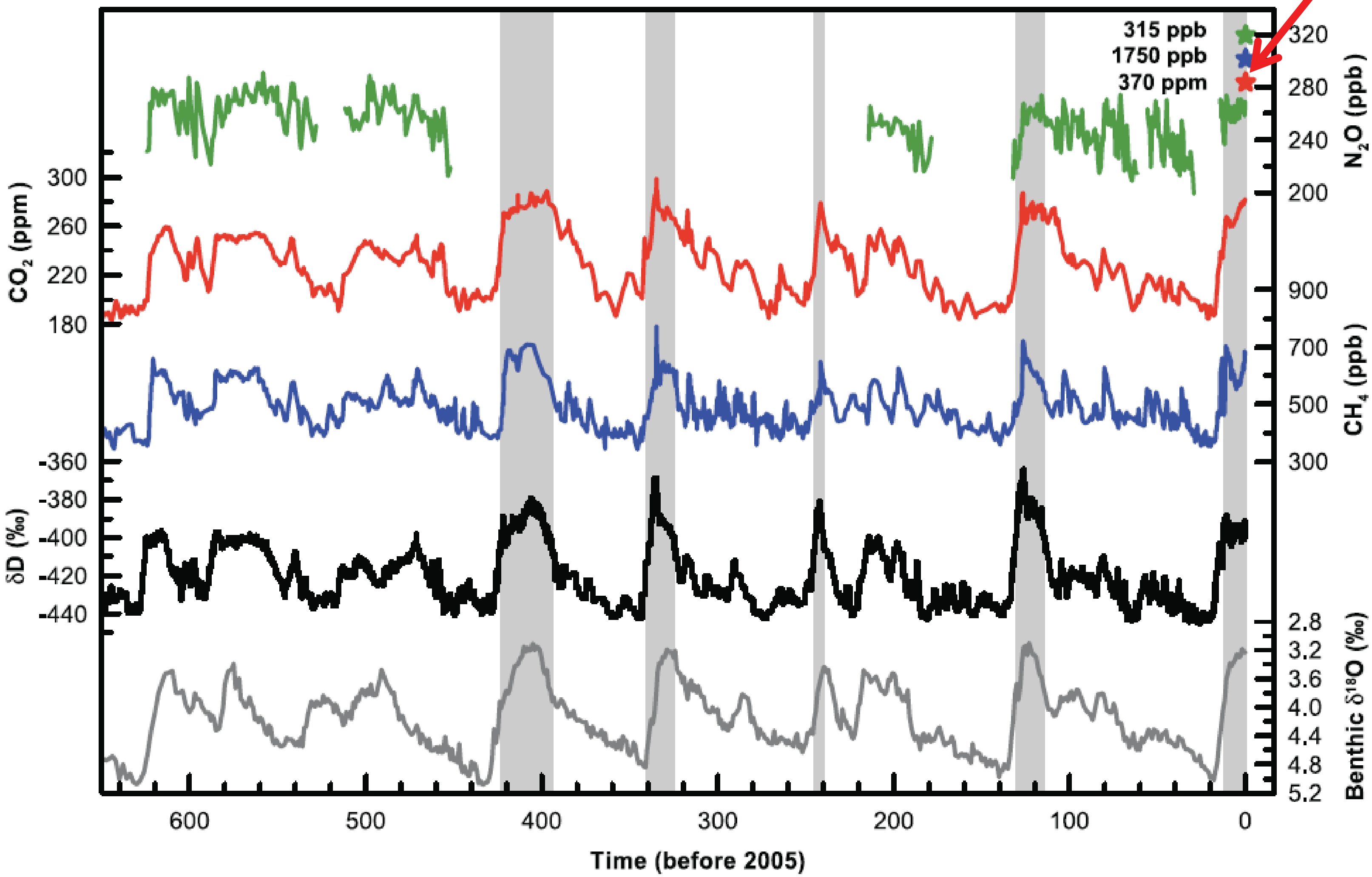


The white specks are bubbles of very old air trapped in the ice.

CO_2 In Bubbles From Antarctic Ice

Today, the concentration of CO_2 is 392 ppmv. During other warm interglacials, CO_2 was around 280 ppmv, and as low as 180 ppmv during cold glacial climates.

Concentration in Year 2000. Today's value is over 390 ppmv.

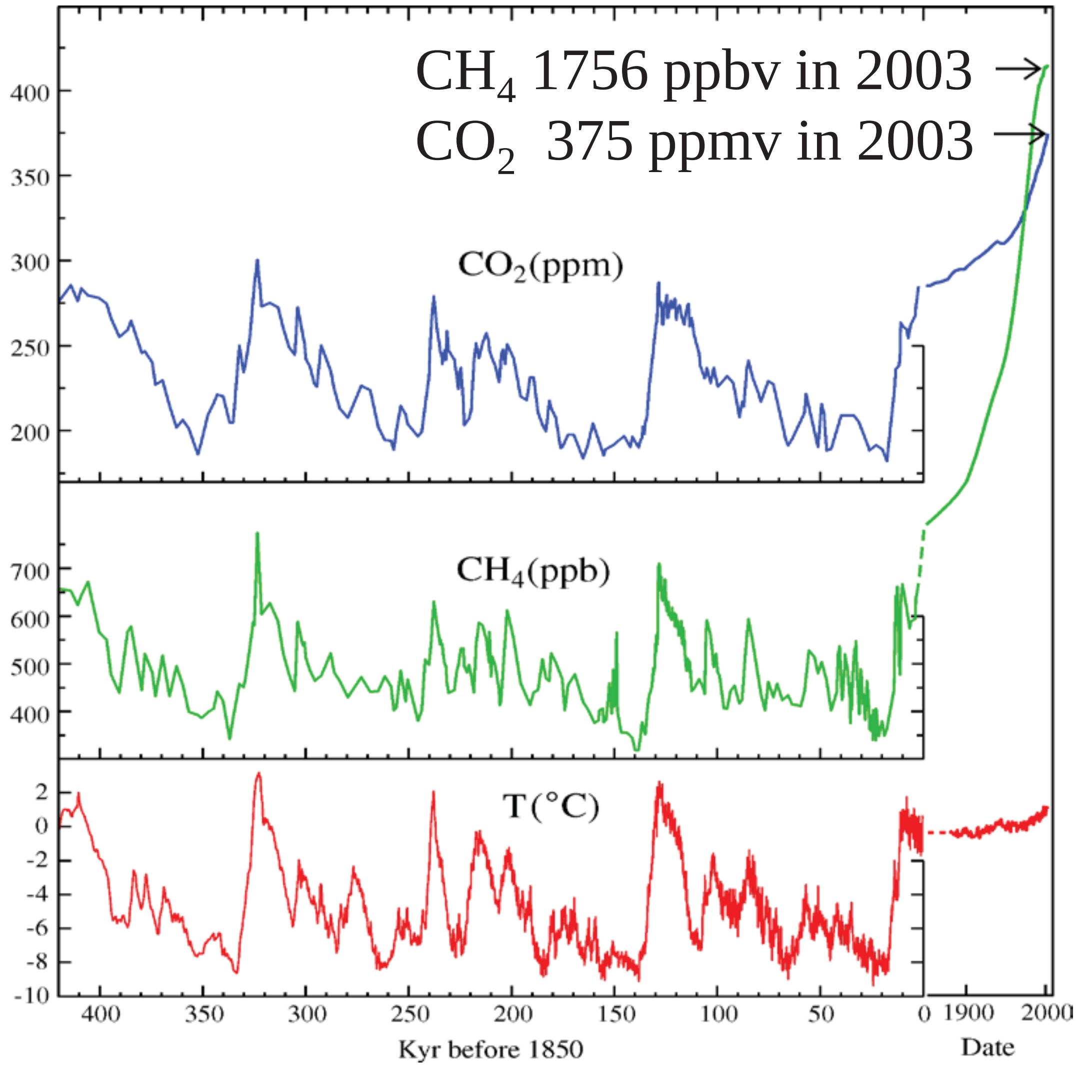


Black curve shows temperature variations in Antarctica

Gray curve varies with the size of the continental ice sheets (like Greenland and Antarctica)

Sea level drops by about 100-120 meters (about 400 feet) during cold glacial climates because the water is locked up in the ice sheets.

Greenhouse gases and temperature over the past 450,000 years.

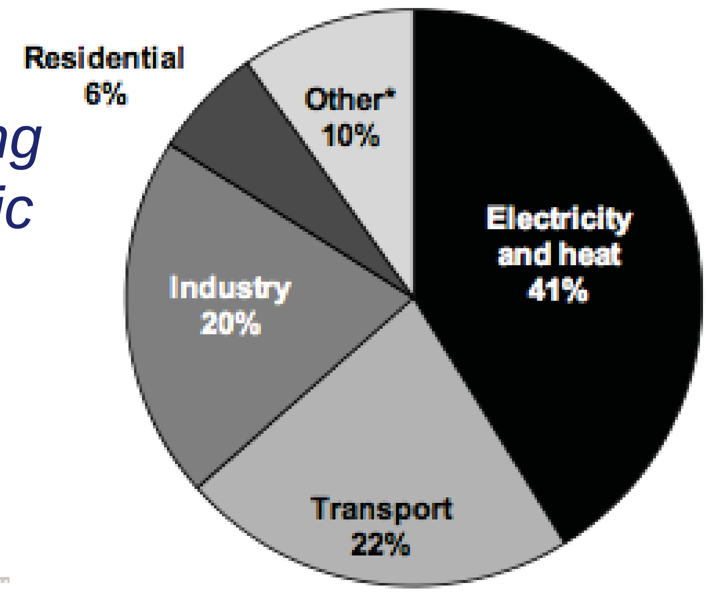


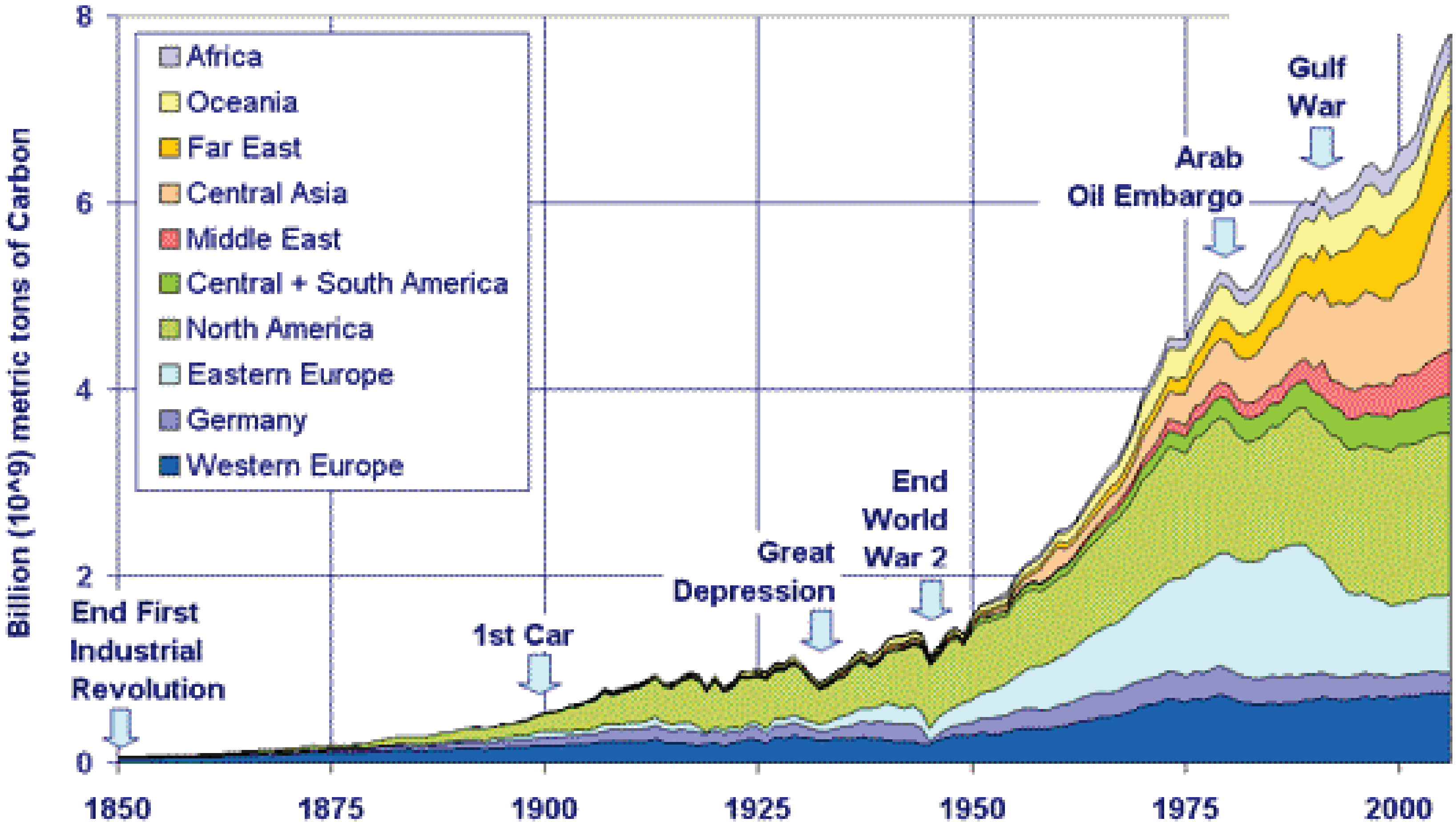
- Temperature and greenhouse gas levels follow each other closely through ice age cycles.
- Today, greenhouse gas levels are unprecedented compared to the last 450,000 years.

Zero temperature: 1880-1899 mean.

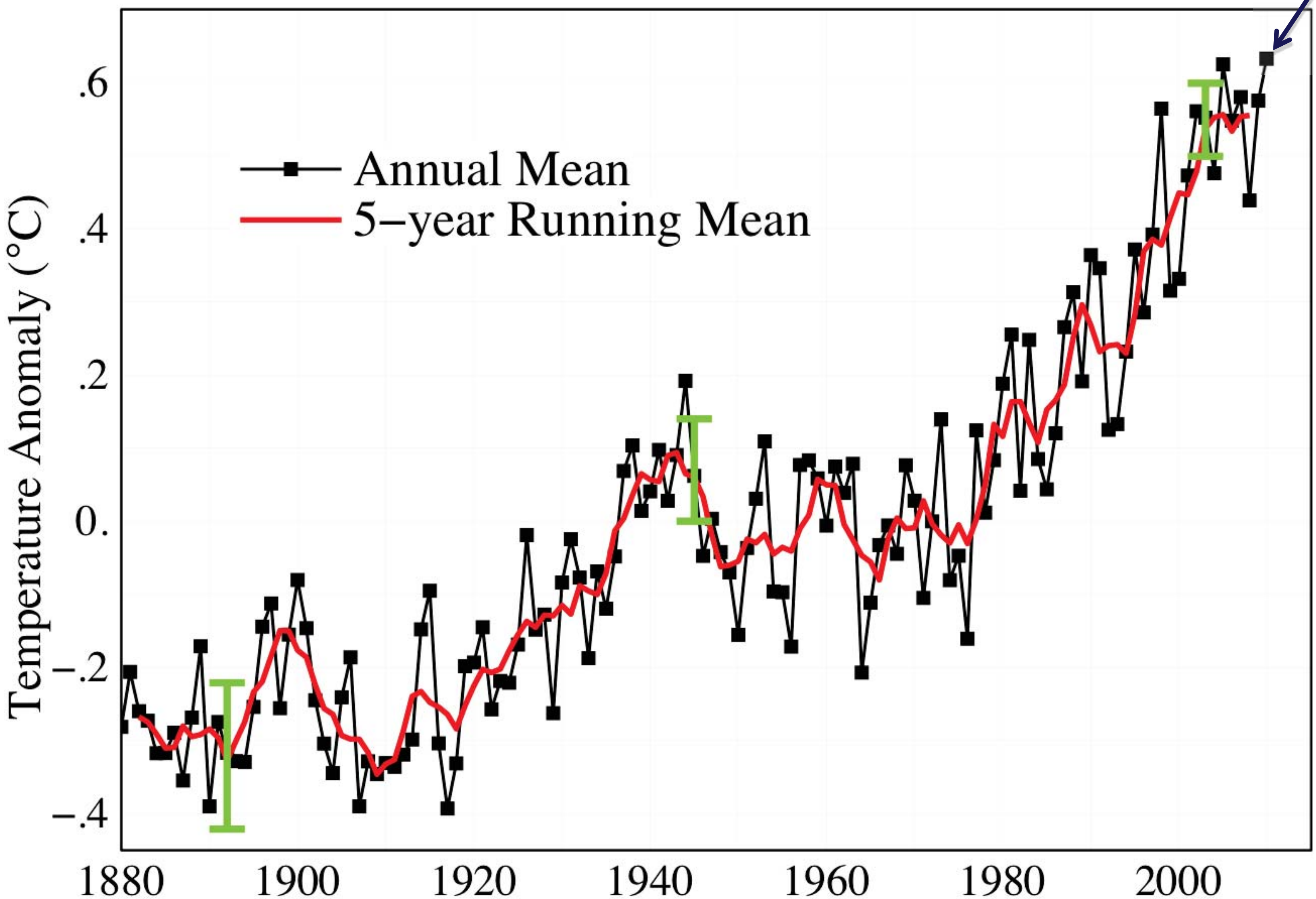
Hansen, *Clim. Change*, **68**, 269, 2005.

Human-sourced CO_2 is single biggest factor leading to an increased greenhouse effect and atmospheric warming. Carbon emissions into the atmosphere continue to rise due to a variety of sources.





Global Surface Air Temperature



2010

Green shows our uncertainty in global average due to missing observations.

Anomaly is computed relative to the average between 1950 and 1980.

http://data.giss.nasa.gov/gistemp

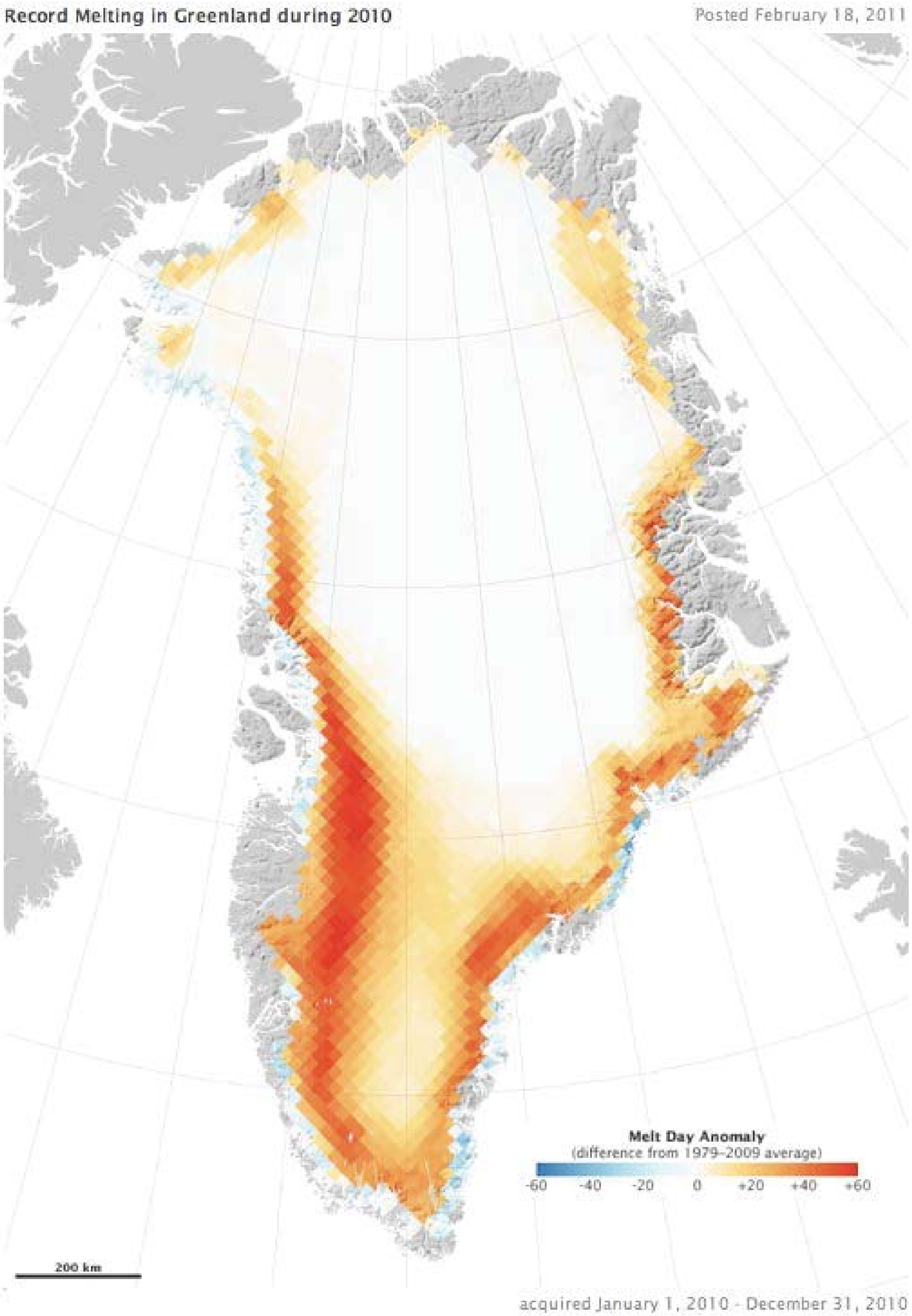
Melting Glaciers Show 20th Century Warming

Athabasca Glacier, Canadian Rockies

Rhone Glacier, French Alps

Recent photos by Gary Braasch

Rongbuk Glacier (North Slope of Mt. Everest)

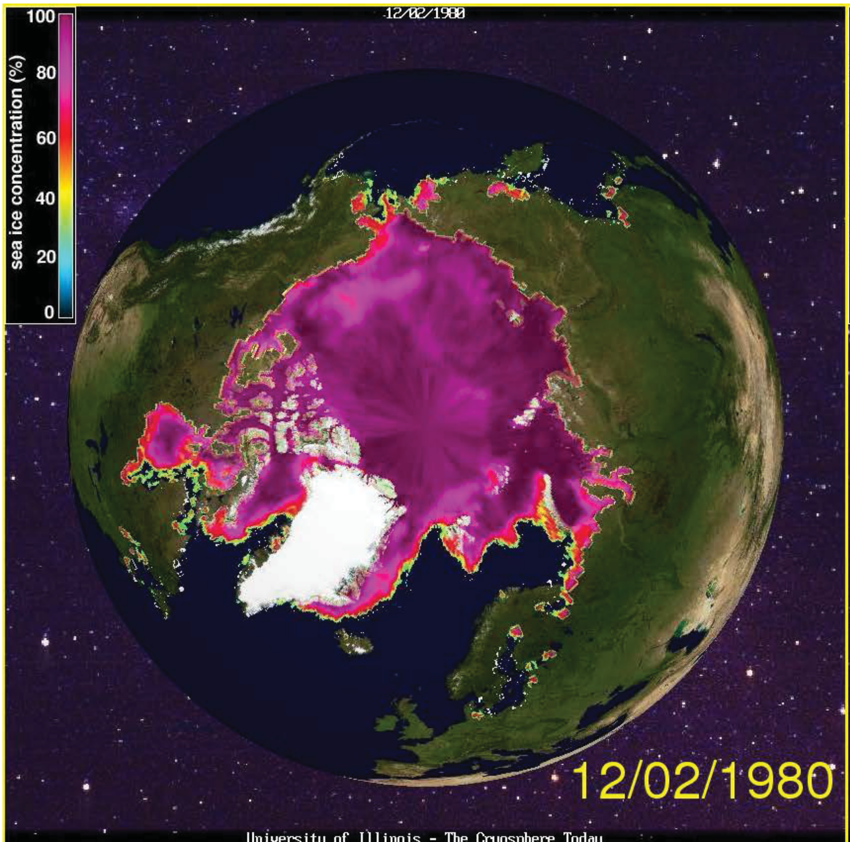


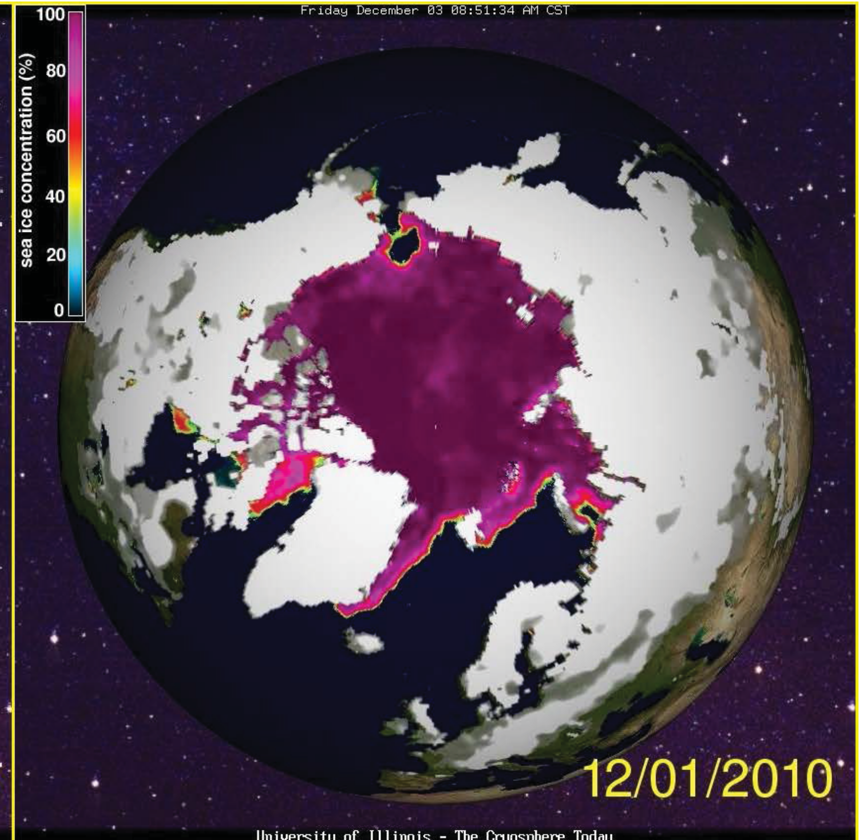
Ice Sheet Melting in 2010

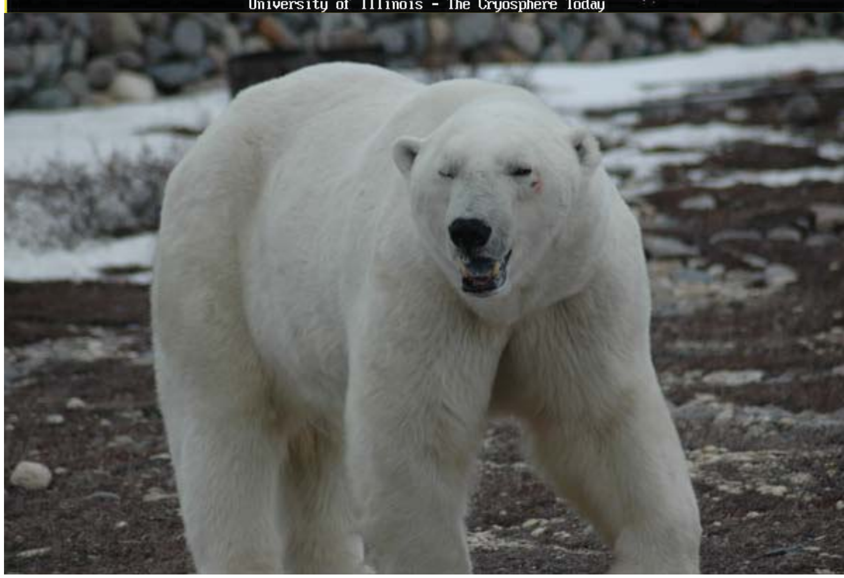
- Melt days measure for how many days the ice surface is covered by a layer of meltwater.
- The coastal region where the surface of the ice sheet melts during the summer is expanding toward higher elevations in the interior of Greenland due to warming.
- The meltwater that runs into the ocean raises sea level.

http://earthobservatory.nasa.gov/IOTD/view.php?id=49338

Shrinking Arctic Sea Ice





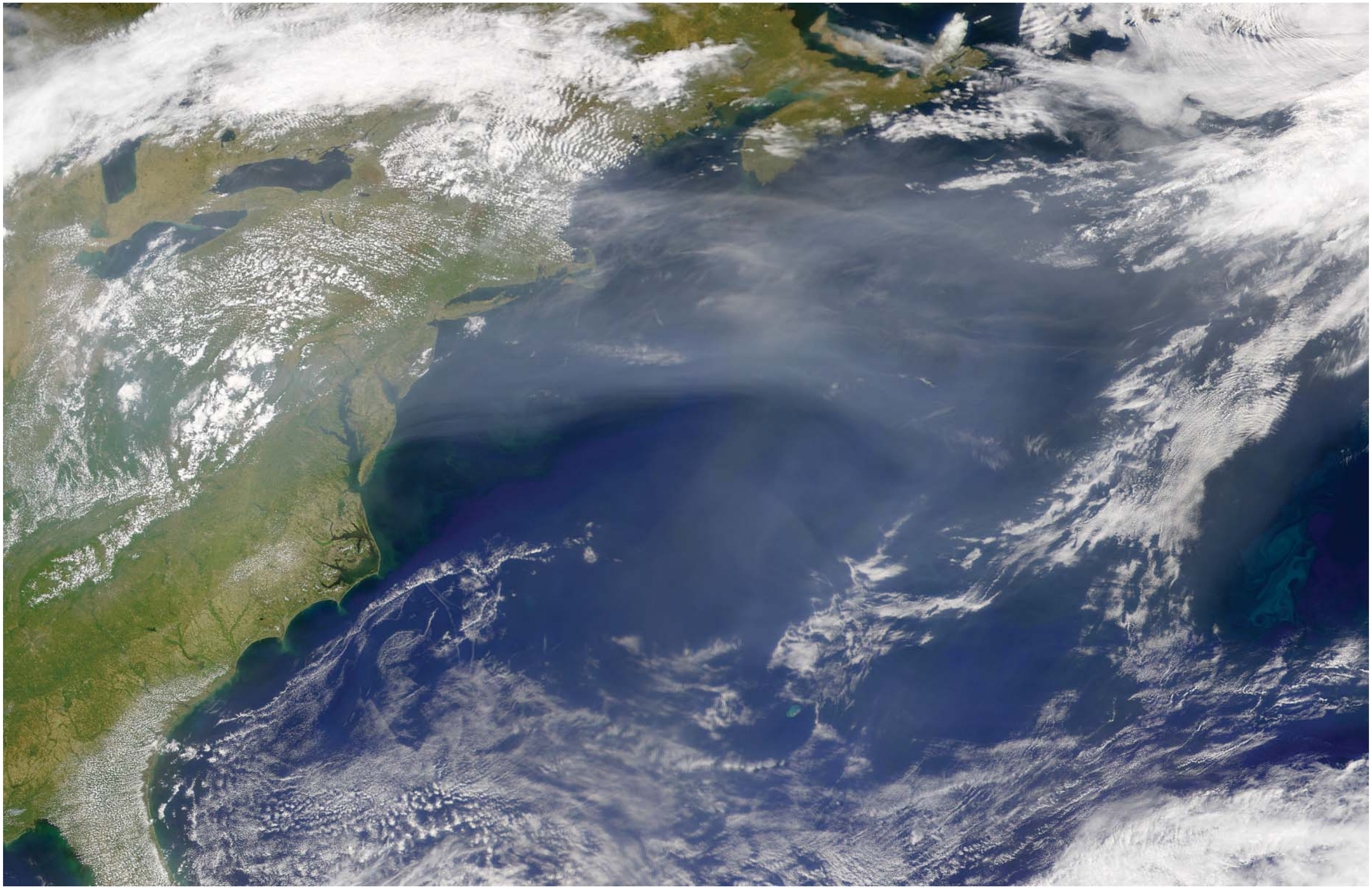


Bears in Churchill Bay: photos by Gavin Schmidt

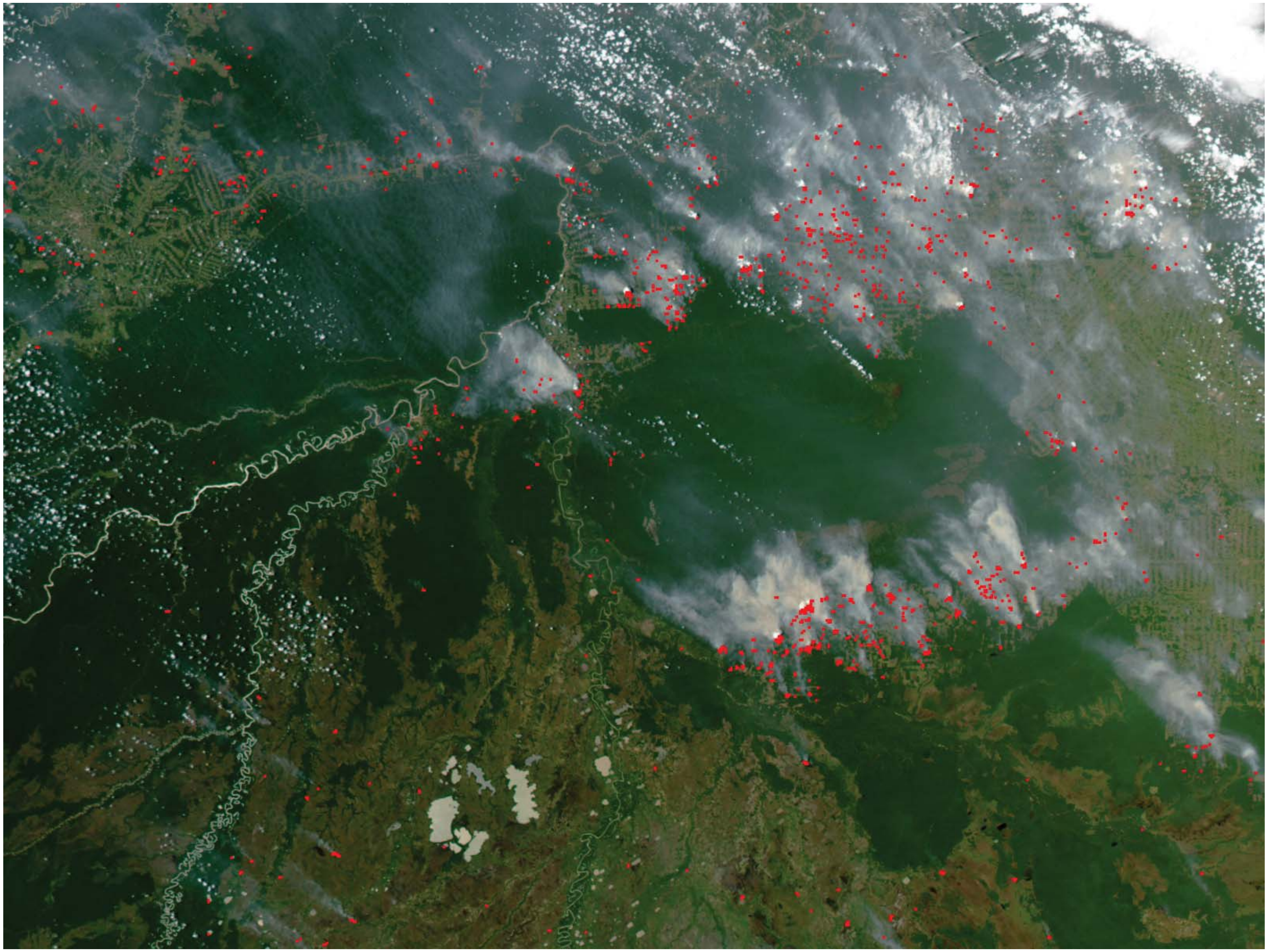
Other Changes In Atmospheric Composition Since the Industrial Revolution: Sulfate Aerosols

- Power plants burning high-sulfur coal produce SO_2, which mixes with cloud droplets to produce reflective sulfate droplets and acid rain.

Cooling Increases When the Bright Sulfate Layer Extends Over the Dark Surface of the Atlantic

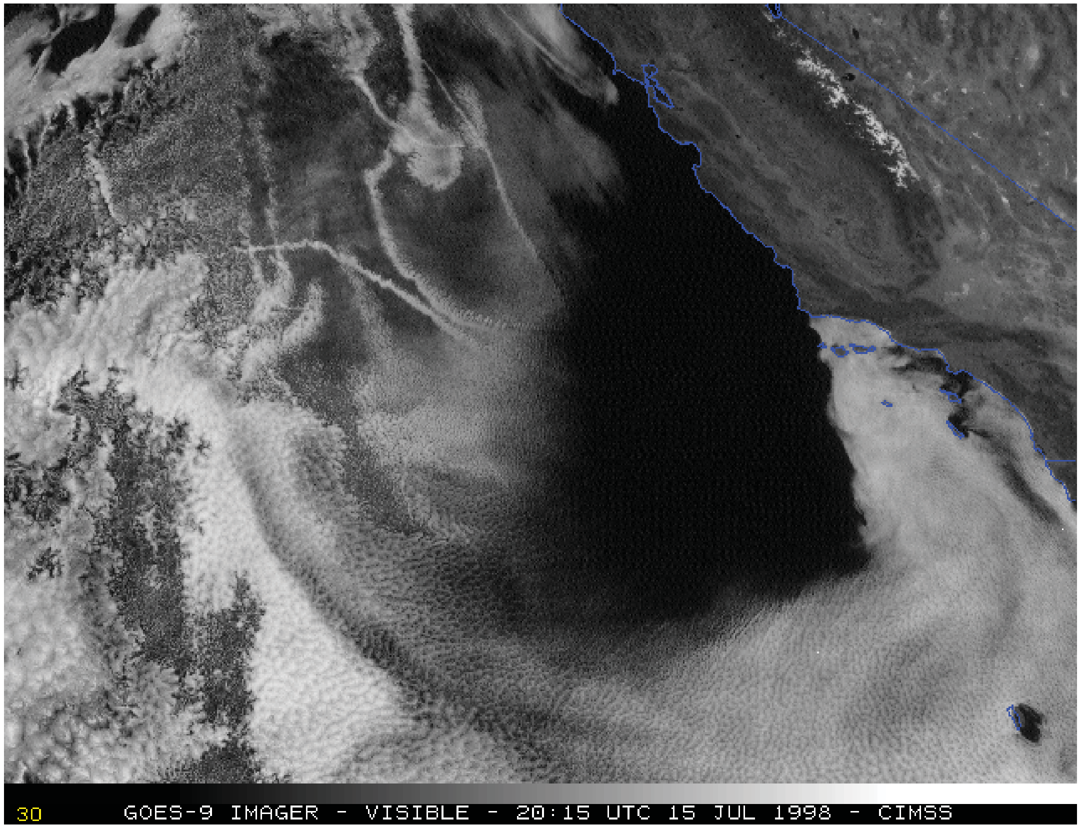


Fires to Clear Farmland in Brazil



The Aerosol Indirect Effect

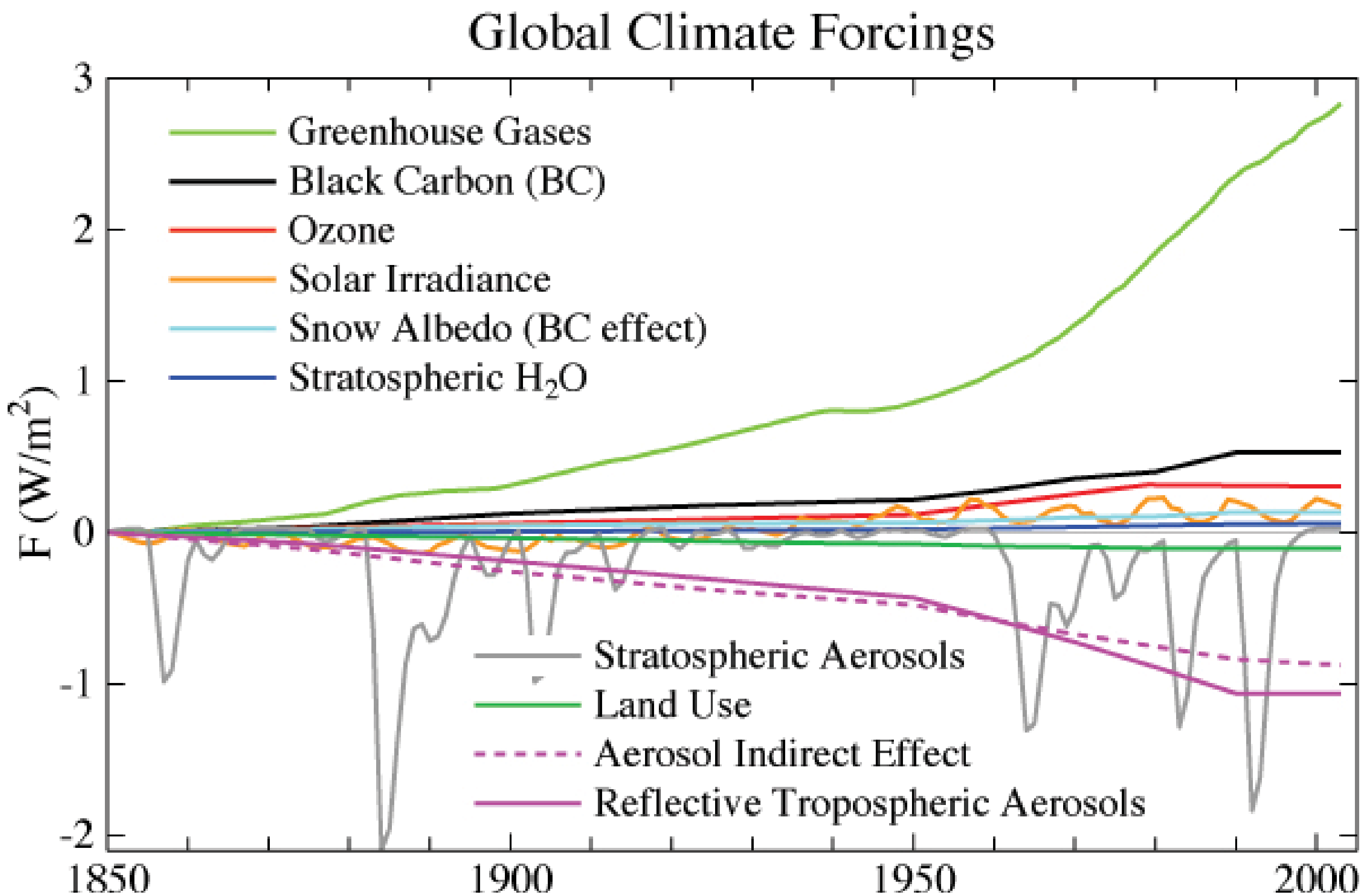
- 1st aerosol indirect effect: smaller cloud droplets create brighter clouds.
- 2nd aerosol indirect effect: smaller cloud droplets require more collisions to create droplets large enough to precipitate. Clouds last longer.



www.cimss.ssec.wisc.edu/goes/misc/980715.html

⇒ Which aerosols are effective cloud condensation nuclei?
Sulfate droplets are hydrophilic; many soil minerals are hydrophobic.

Variations in Global Radiative Forcing Since 1850

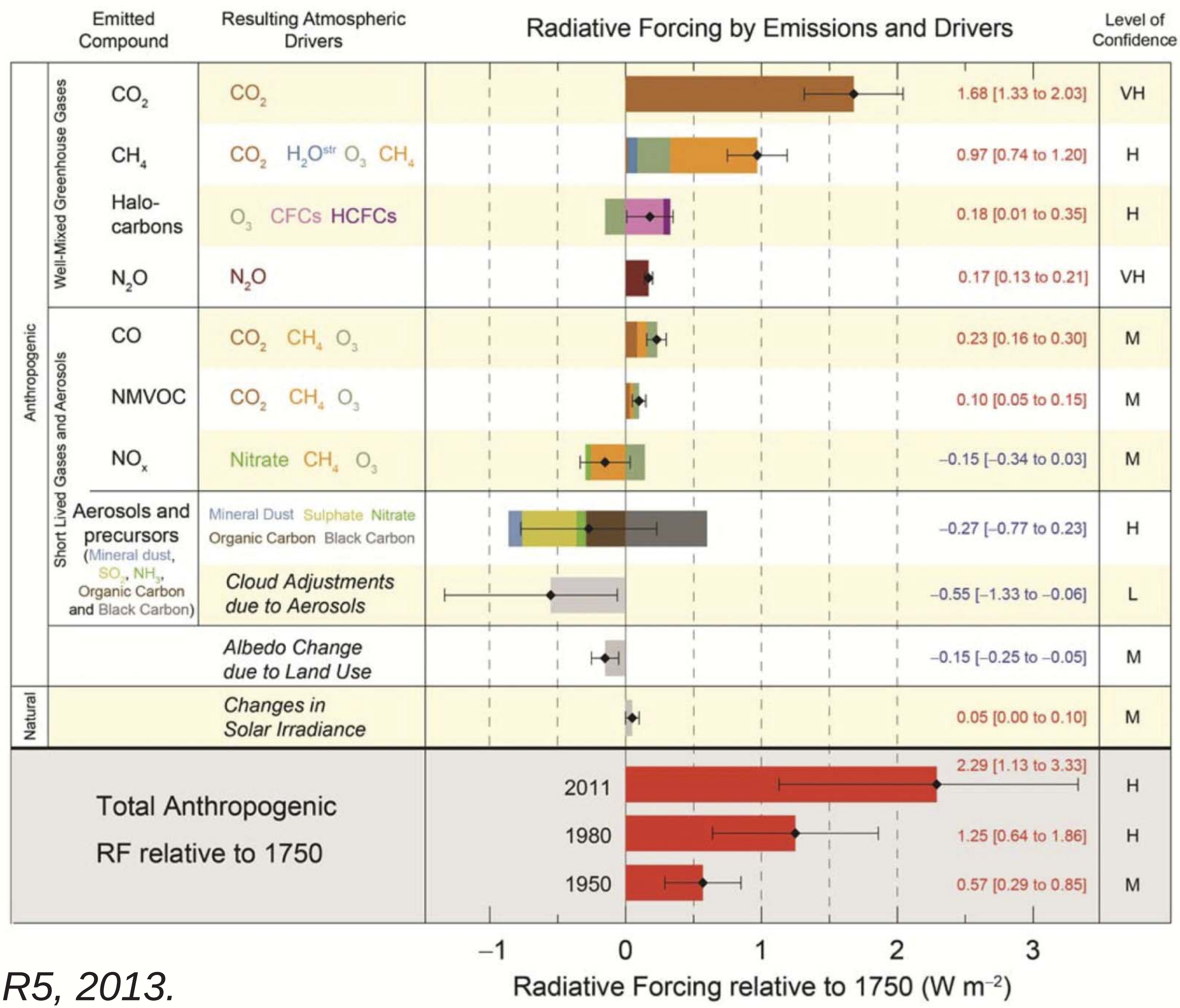


Based upon measured and modeled changes in atmospheric composition and solar output.

Hansen et al., *Atmos. Chem. Phys.,* 2006

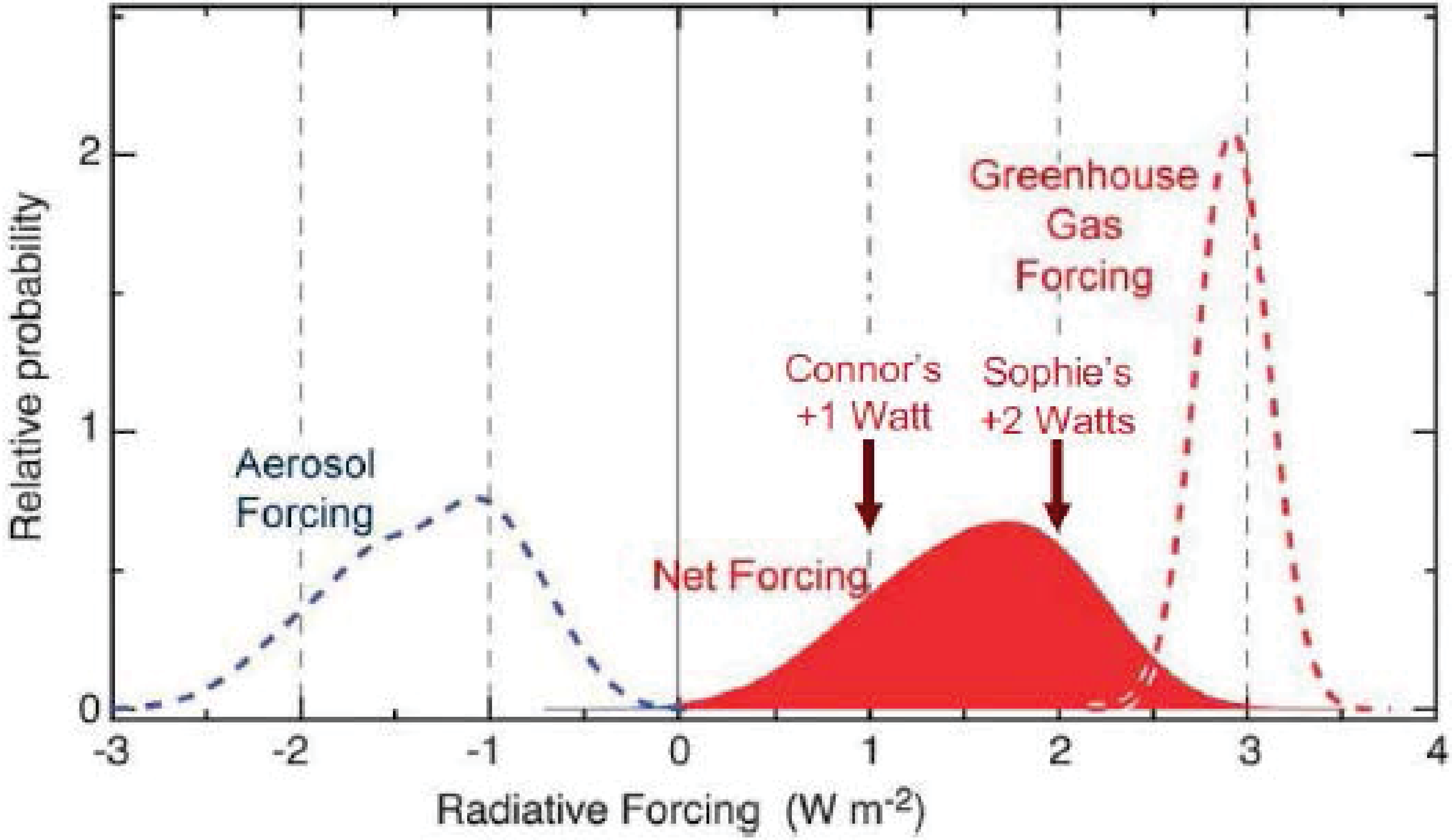
GHG and other climate forcers summarized by surface watts/m^2

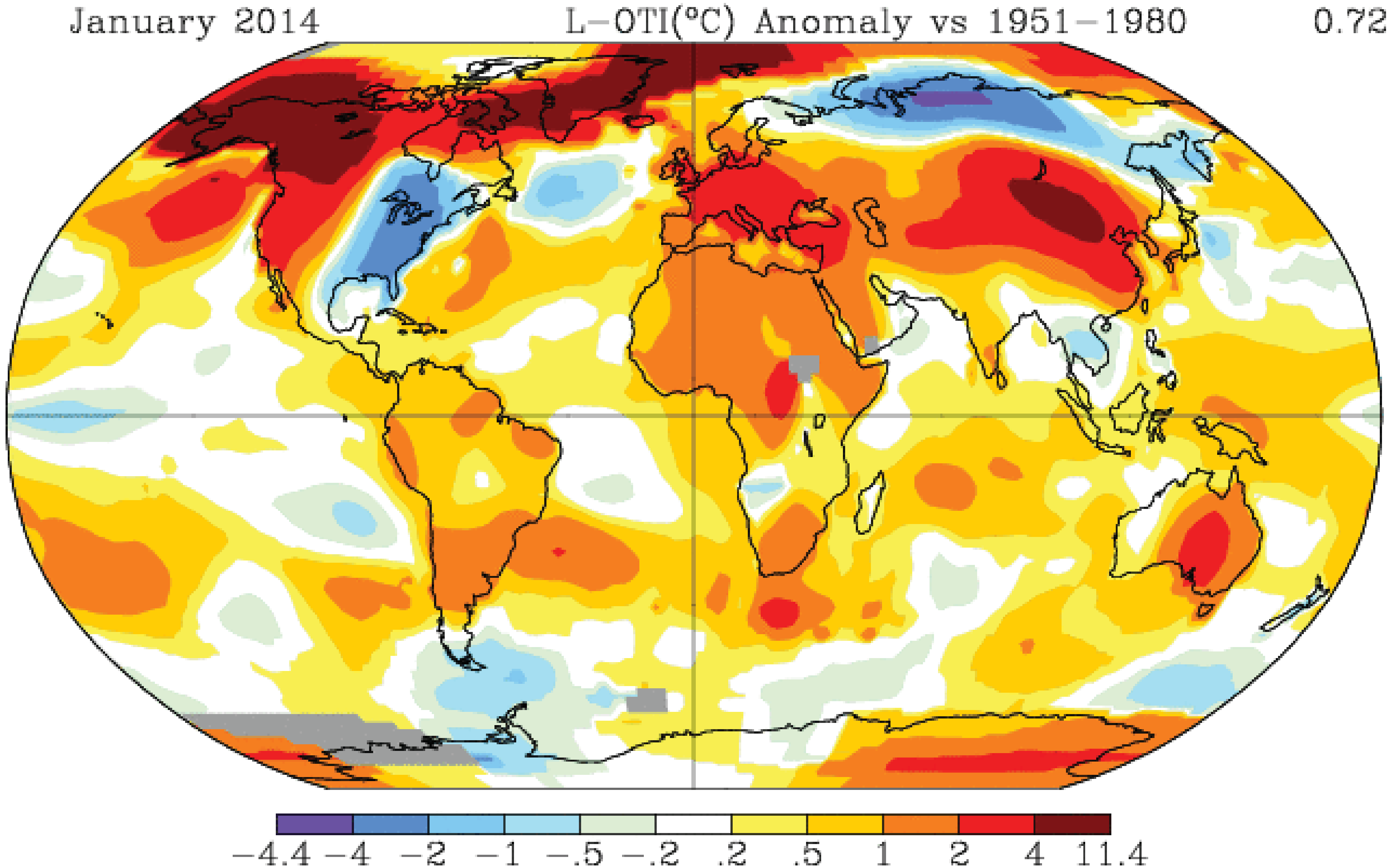
(GHGs absorb outgoing heat and radiate back to surface.)



IPCC AR5, 2013.

Greenhouse Gas, Aerosol & Net Climate Forcing





No one experiences the globally averaged temperature.
Jan 2014 was 4th warmest Jan on record, but eastern US cold.

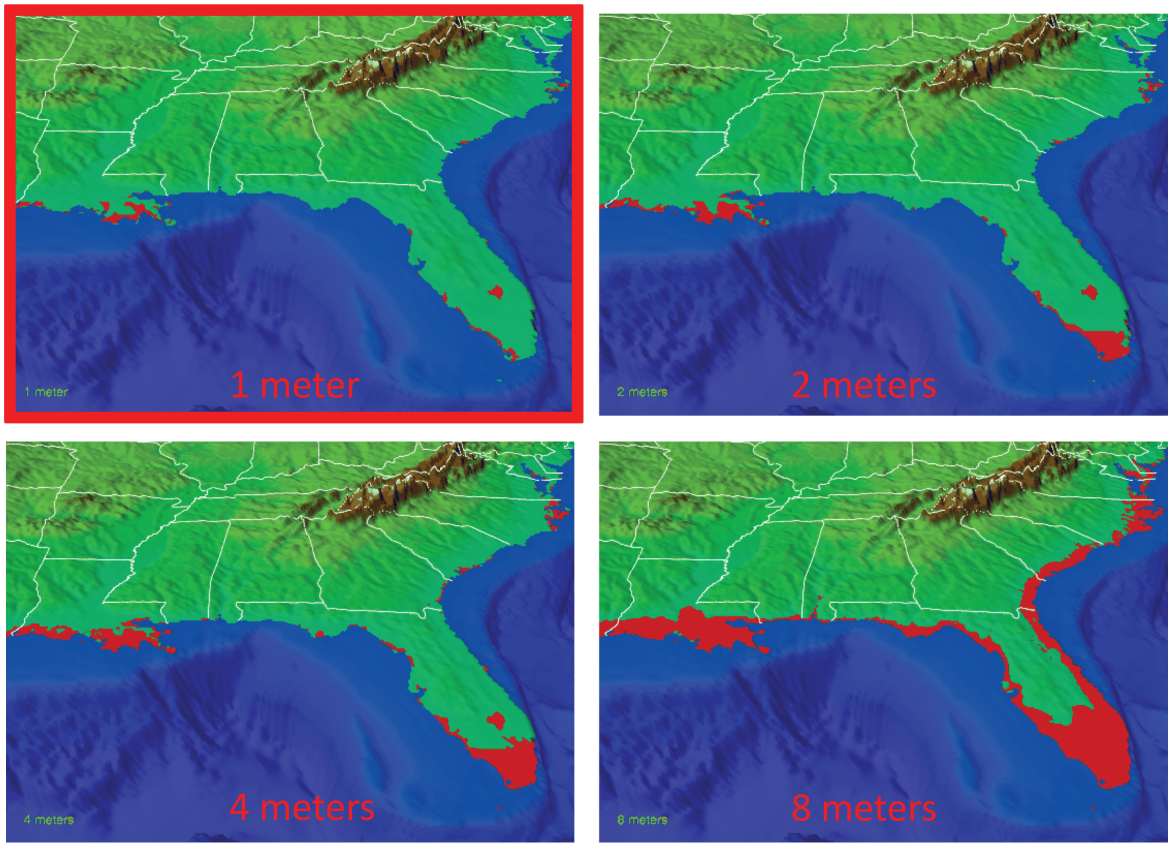
Regional Drought
Due to Permanent Shifts In the Storm Tracks

Pier on Lake Mead

The dry subtropics are expected to expand poleward as the planet warms. However, changes to the storm tracks are still difficult to predict, and some regions will become wetter.

Sea Level Will Rise in the 21st Century Due To:

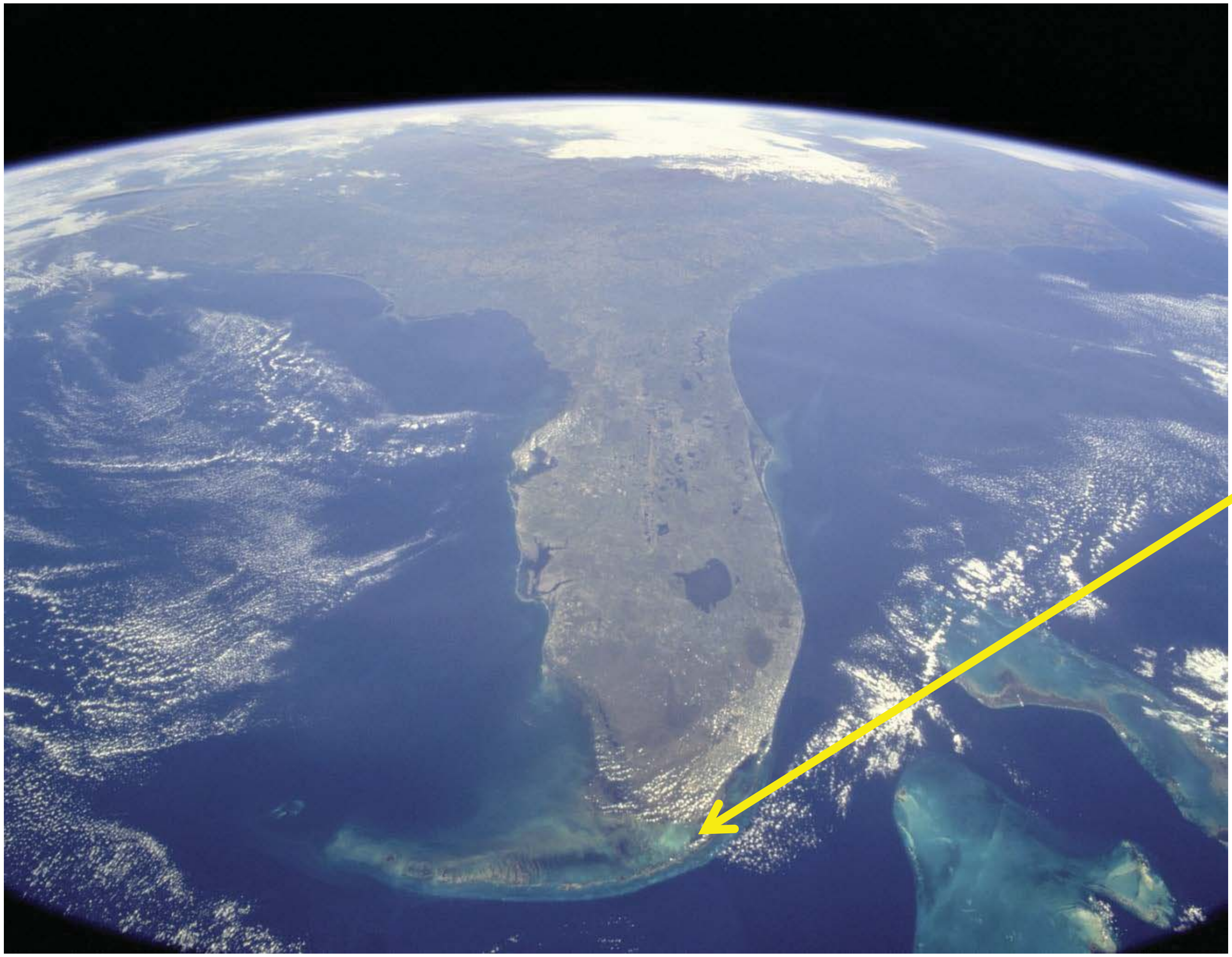
- Thermal expansion of sea water (warm water is less dense and takes up more space),
- Tectonic sinking (on the margins of former continental ice sheets, e.g. coastal mid-Atlantic).
- Melting of glaciers and land ice (but not sea ice, due to Archimedes principle)
- The total is highly uncertain but probably one meter by 2100.

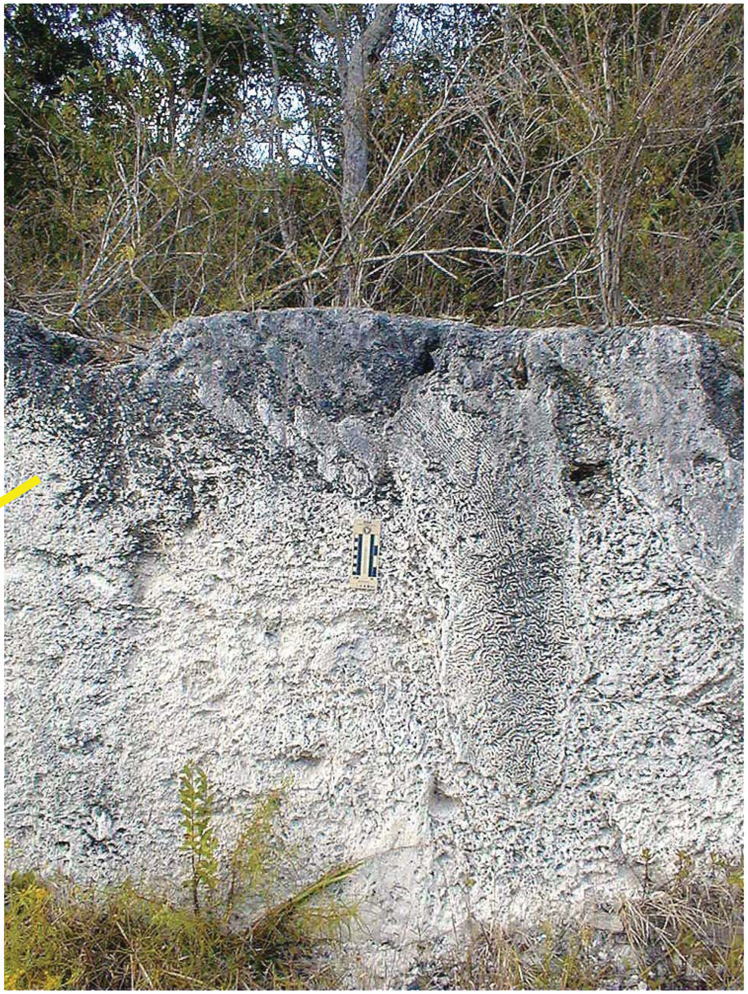


Coastal inundation for 1, 2, 4, and 8 meters of sea level rise.

http://www.gfdl.noaa.gov/~tk/climate_dynamics

Melting of Greenland and West Antarctic Ice Sheets?

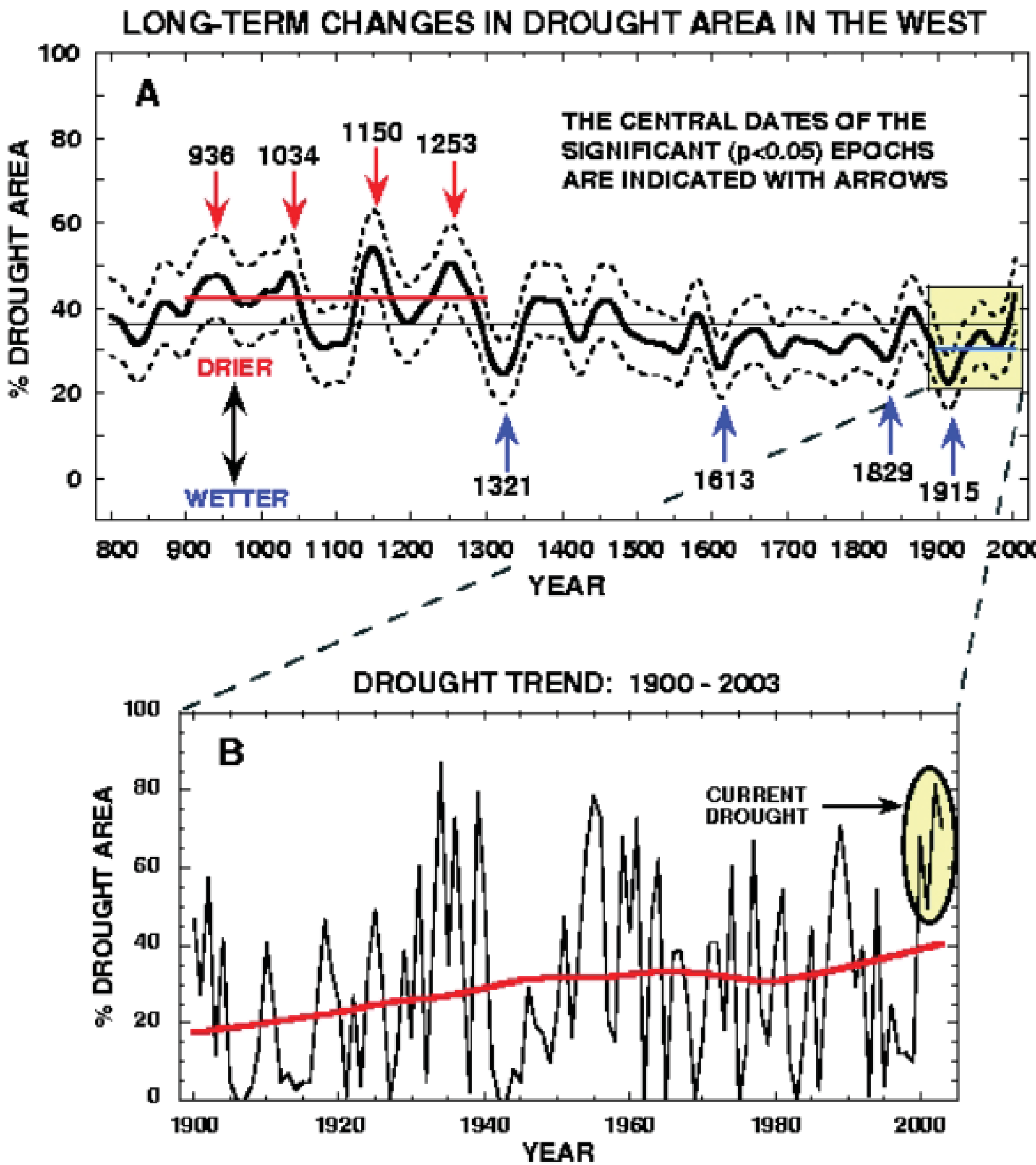




- Windley Key is a former coral reef about 5 meters above sea level. This reef formed in shallow water during the Last Interglacial about 128,000 years ago.
- A number of reefs worldwide suggest that sea level was 5 meters higher during the Last Interglacial, when the temperature over Greenland was 3^{o}C warmer.
- By 2100, Greenland is expected to warm by 2-4^{o}C.

What are the concerns for the Western US?

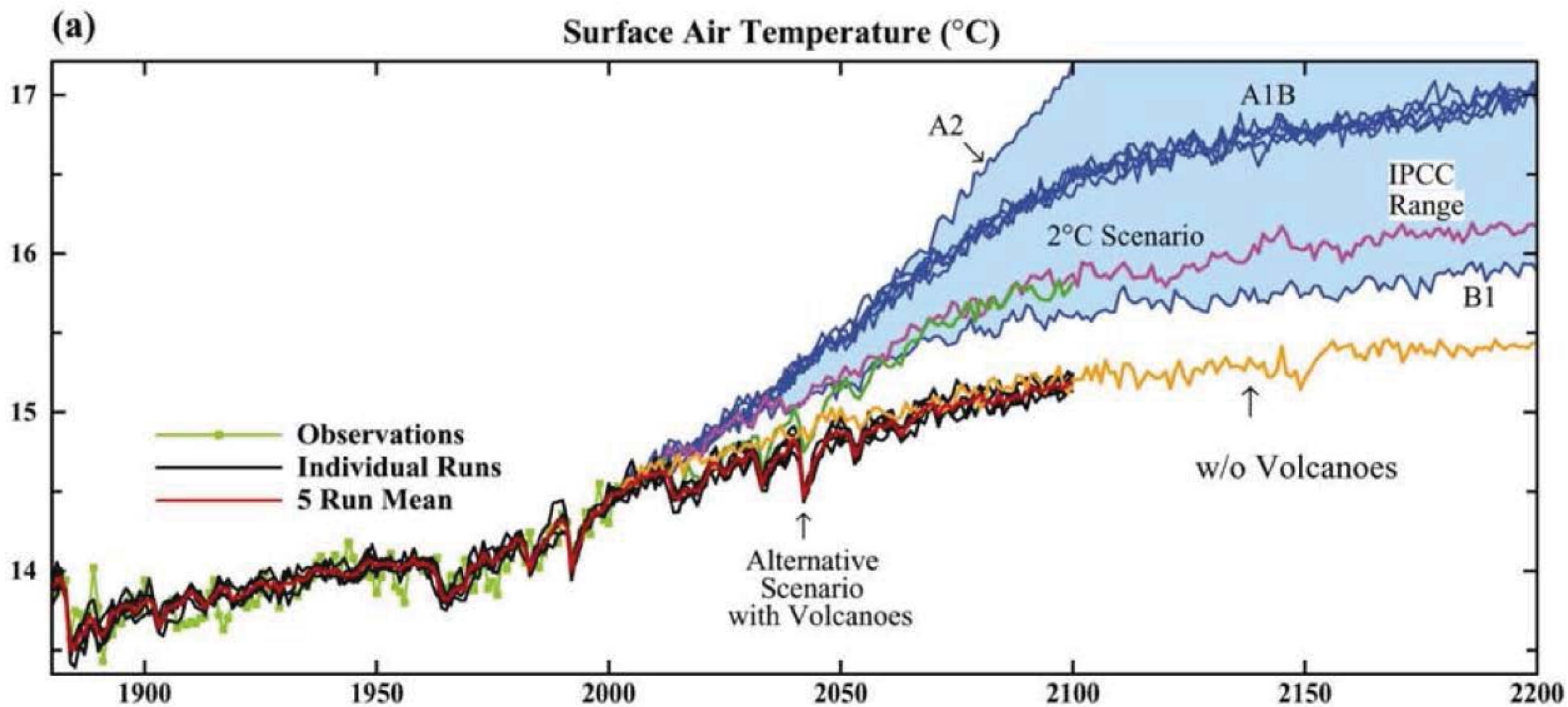
- Dead trees trunks in river beds and lakes show that water levels were much lower during the Medieval era in the west.
- Historically, droughts in the western US have been as intense as recent ones and have lasted longer.



The Earth At Night

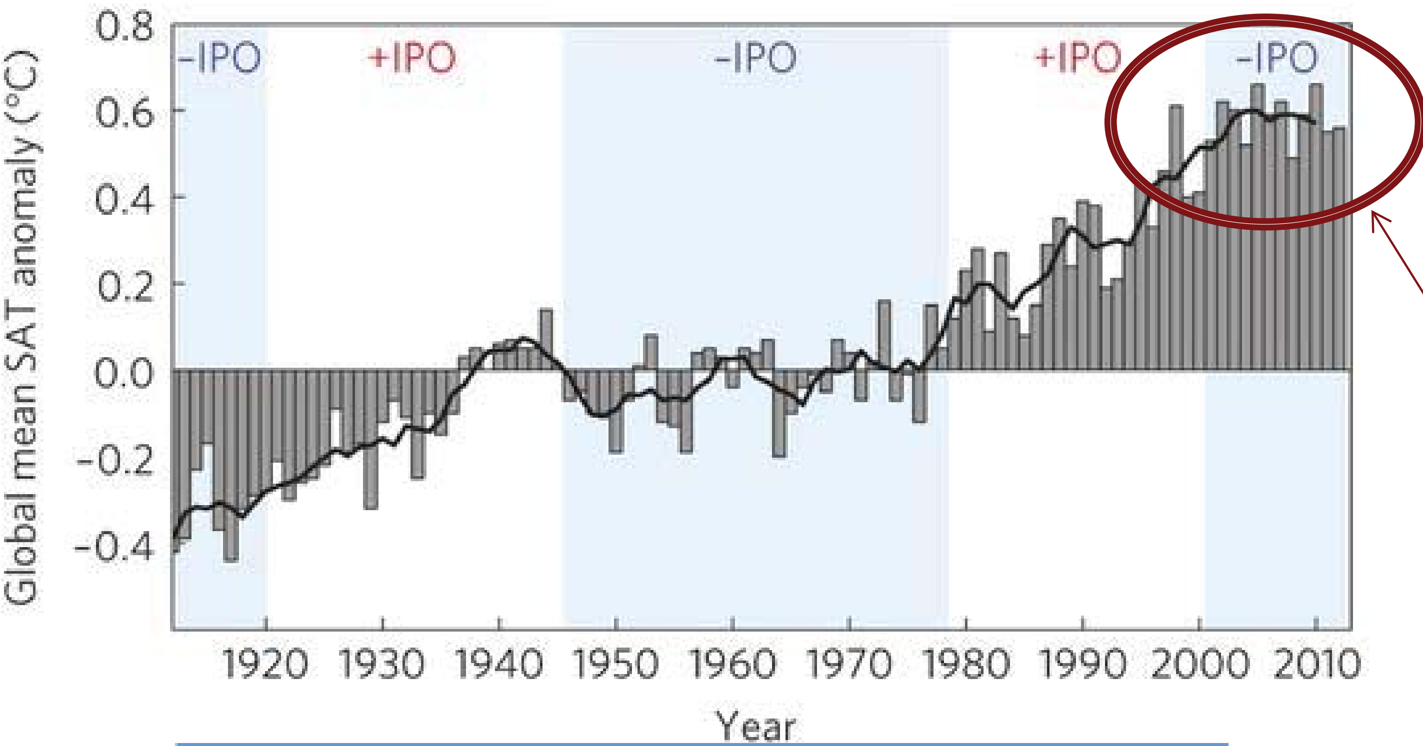
- Only 1 billion people (out of the current global population of 6 billion) have a 'first world' lifestyle with cars, refrigeration, A/C, etc.
- Challenge: how do we create energy to improve the lives of the other 5 billion people without further increasing the greenhouse gas concentration in the atmosphere?

Observed And Projected Surface Air Temperature



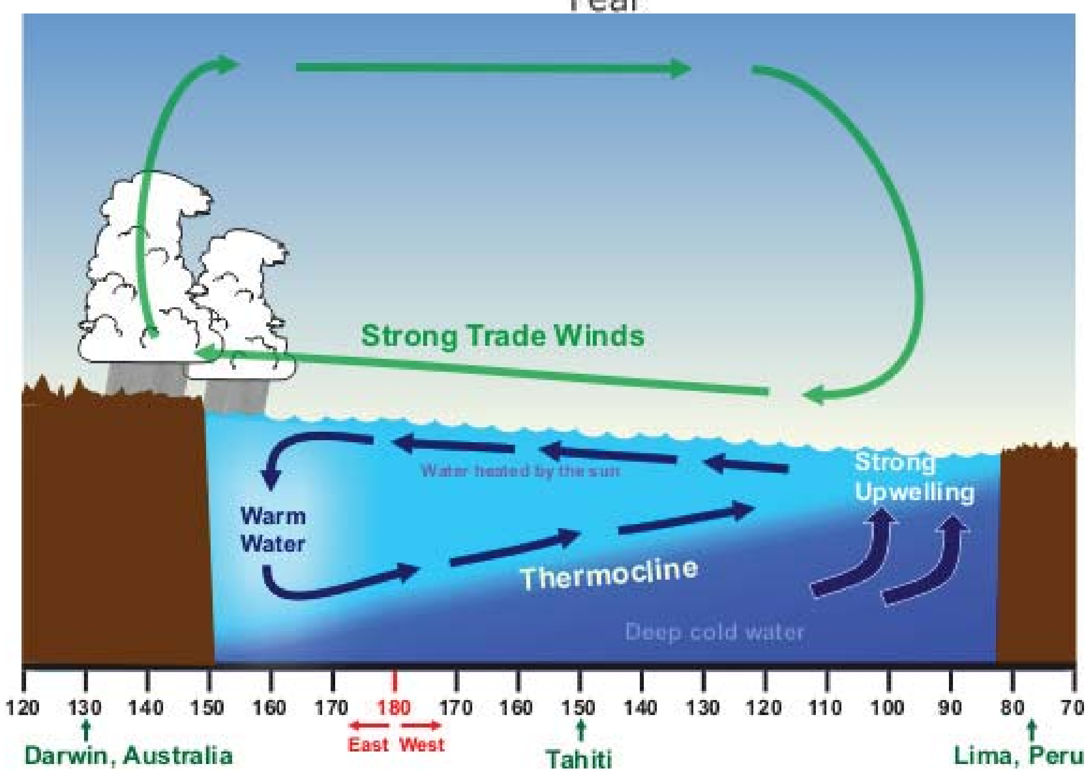
Hansen et al., *Atmos. Chem. Phys.,* 2006

- How much warming we expect depends upon how much CO_2 we add to the atmosphere during the coming century.



Superposed on warming trend are fluctuations at different timescales. Some due to radiative forcing, some to internal climate variability.

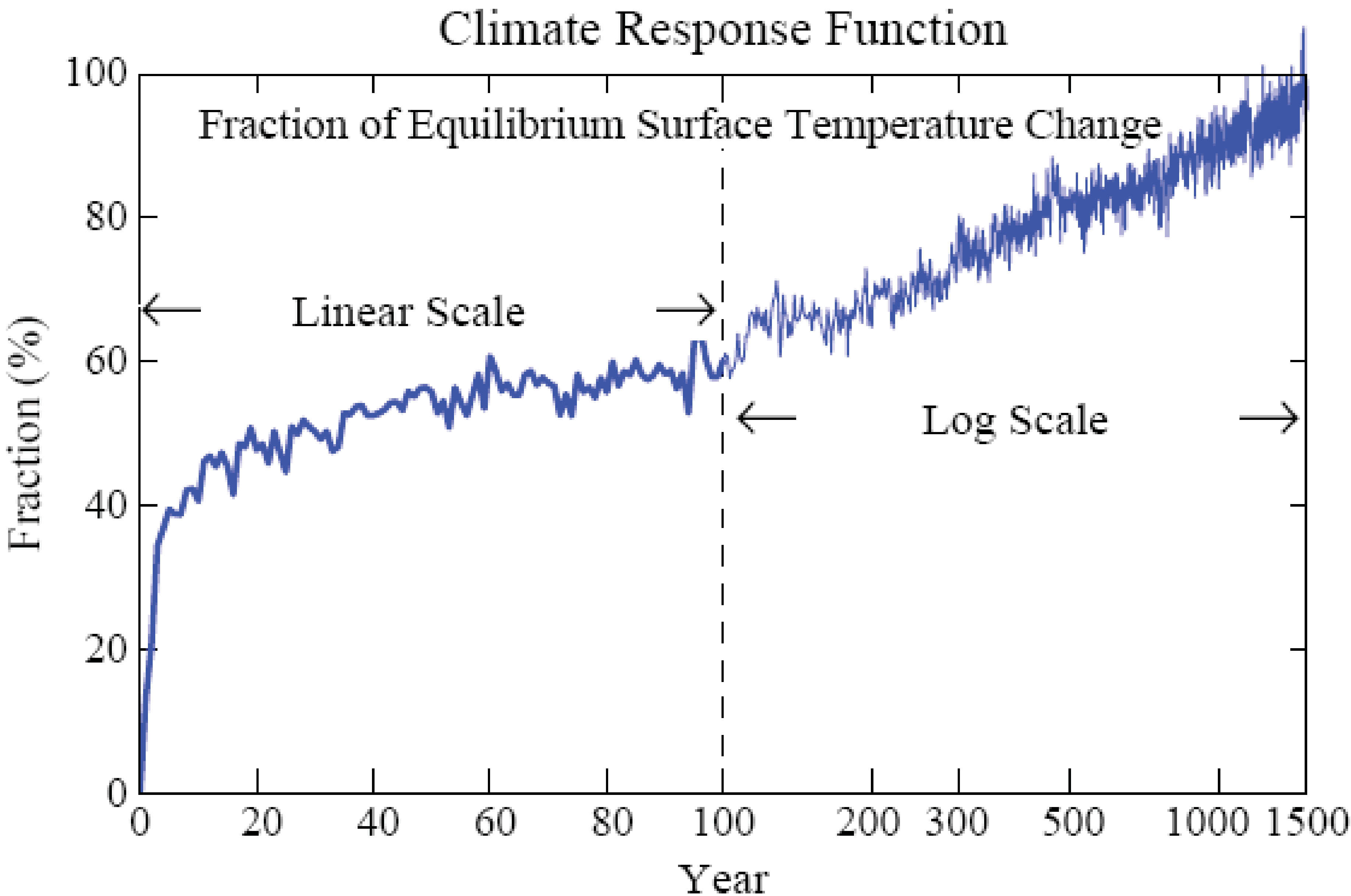
Slowdown of warming in past decade, even though GHG concentrations increase unabated.



Strengthening of trade winds in tropical Pacific exposes cold water in east, which takes up atmospheric heat. (*England et al., Nature, 2014*) Essentially, prolonged La Nina state.

Rapid increase in Asian aerosol cooling ~1/3 of the slowdown (*Schmidt et al., Nature Geosci, 2014*.)

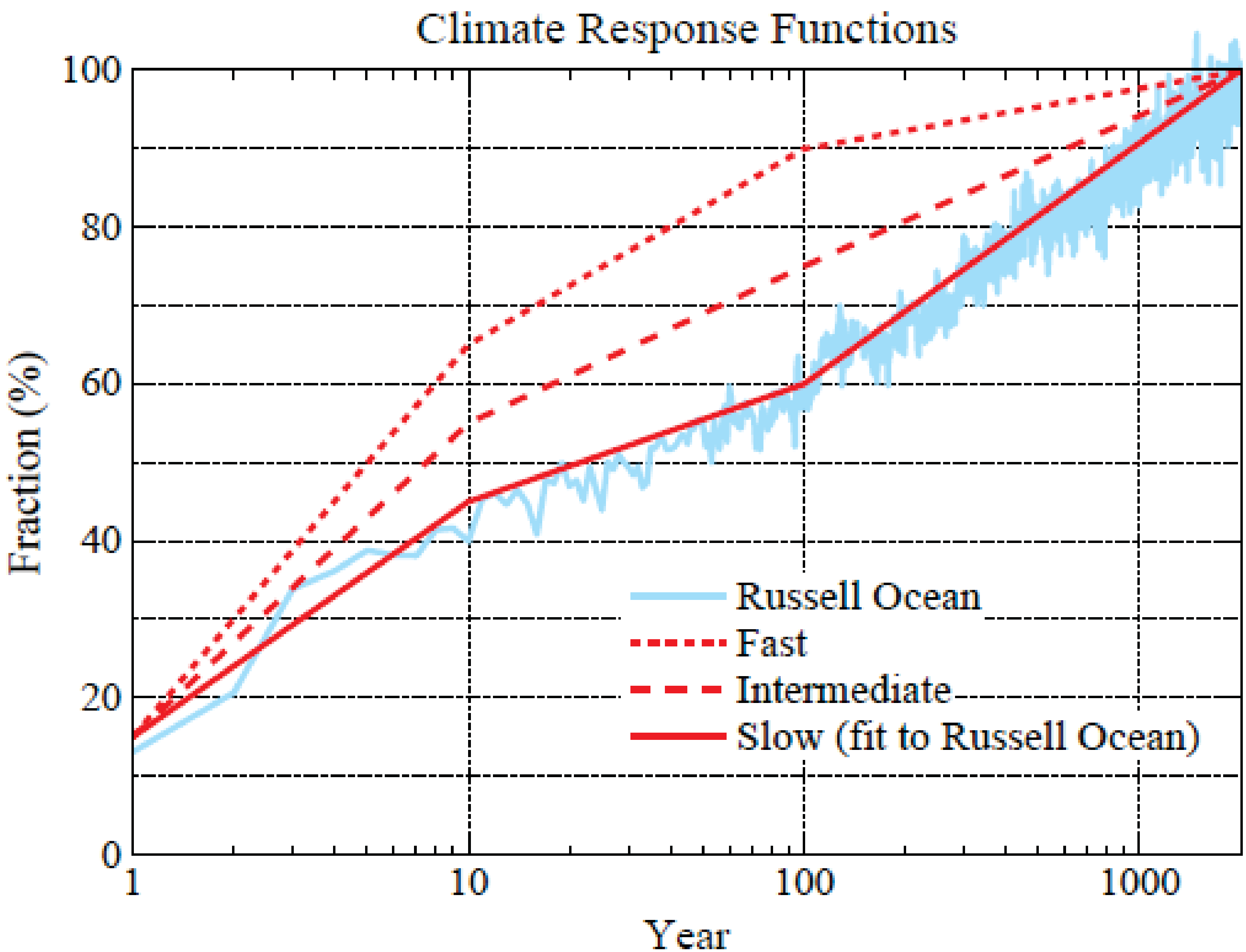
How Long?



- Climate models are “sluggish” in responding – is this right?

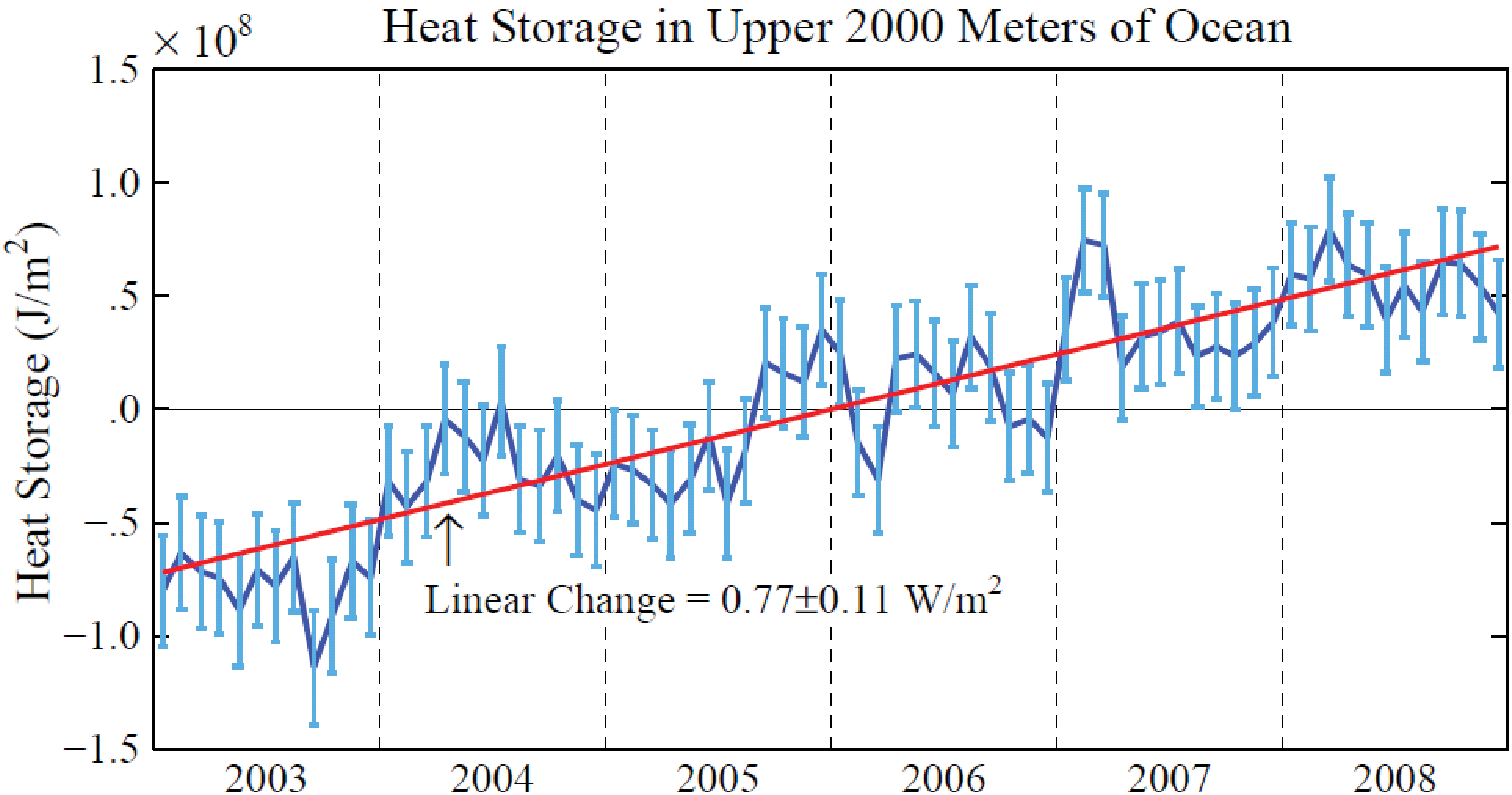
Source: Target Atmospheric CO_2, Hansen *et al.*, *Open Atmos. Sci. J.*, **2**, 217-231, 2008.

How Long?



- Current models mix heat too deep too quickly (e.g. Russell Ocean) based on measurements of heat in the deep oceans.

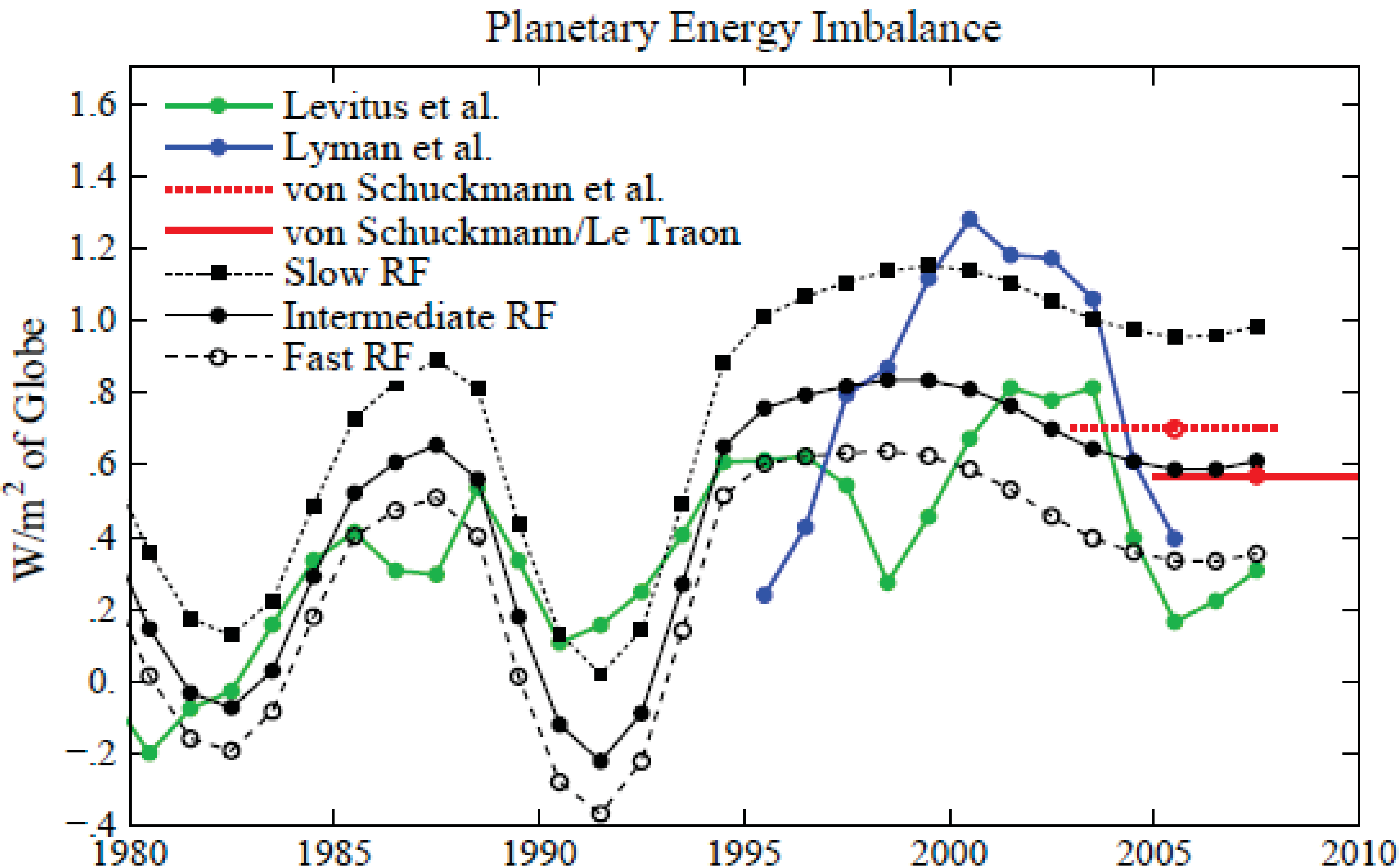
How Long?



- Two tuning knobs to get the right temperature over the last century: aerosol forcing and climate response time.
- But we also need to get the right amount of heat into the ocean which amounts to getting the residual energy imbalance right.

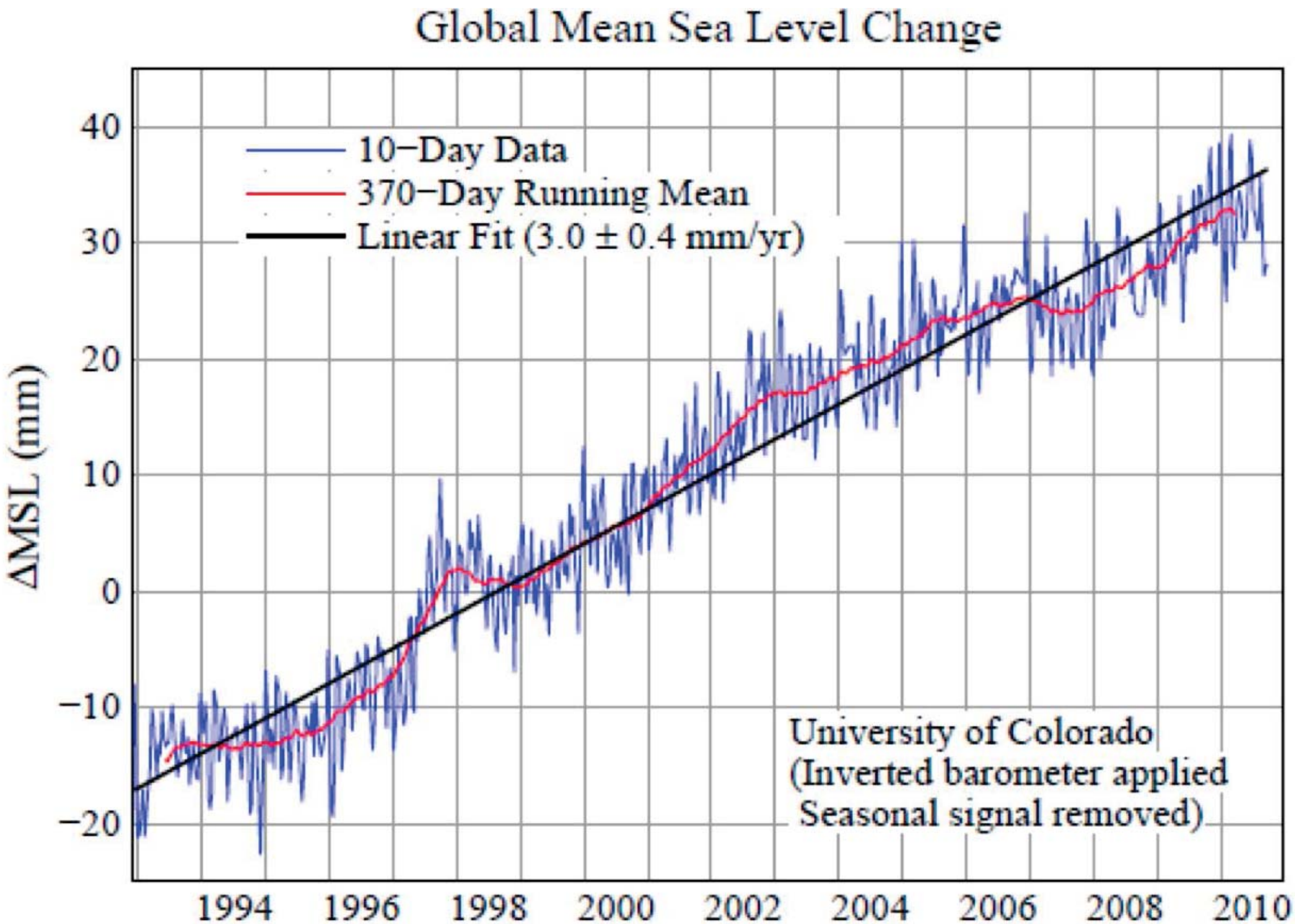
Data source: von Schuckmann *et al. J. Geophys. Res.* **114**, C09007, 2009, doi:10.1029/2008JC005237.

How Long?



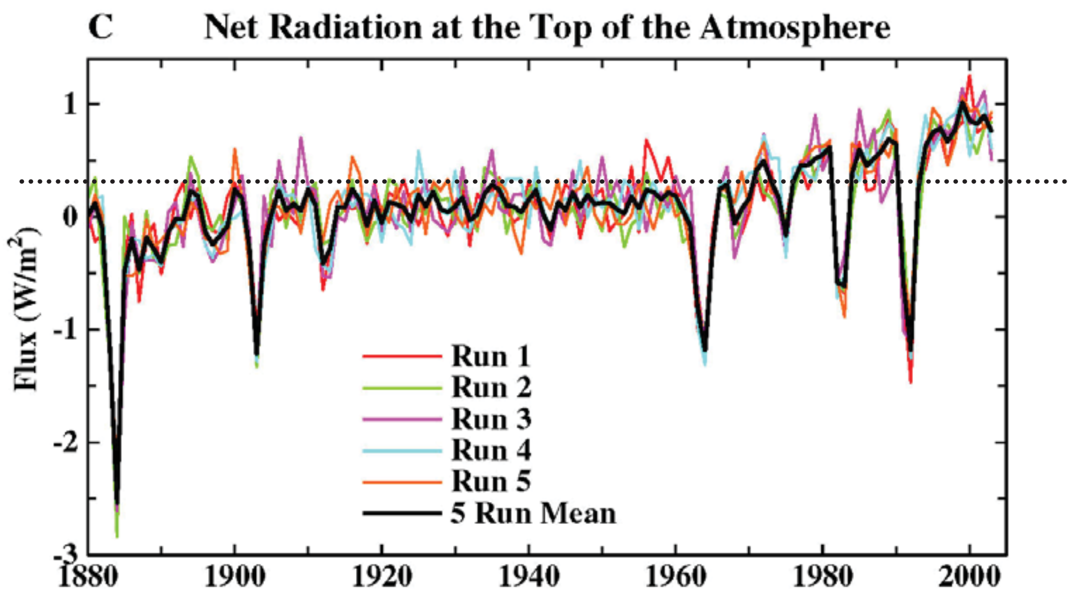
- Evidence points to -1.6 ±0.3 Wm^{-2} from aerosols and a faster (labelled intermediate here) response than is present in current coupled climate models.

Consistency?



- Two sources of sea level rise, expanding water, melting ice
- The observed increase in sea level is consistent with the measurements of ice melt and the estimates of ocean heat storage on which our estimates of climate response are based

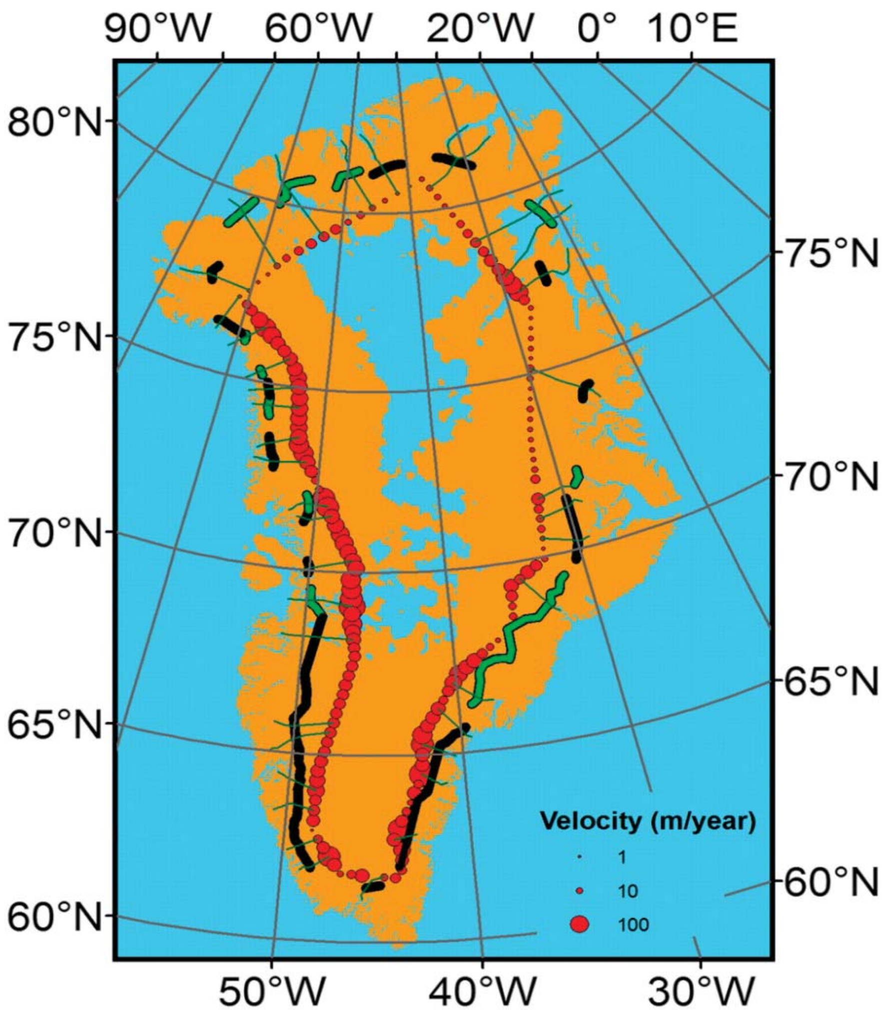
Should We Wait to Stop Global Warming?



Hansen et al., *Sci.* (2005)

- Climate Inertia: We can expect another 0.6ºC in the next few decades as the atmosphere adjusts to today's atmospheric composition. Sea level will continue to rise another 0.5 m due to thermal expansion over the next few centuries, in addition to any rise due to melting of the ice sheets.
- Inertia of Energy Infrastructure: Power plants have lifetimes of several decades, so what we build today will determine strongly influence future greenhouse gas emission. More drastic changes will be required the longer we wait to introduce new energy technologies.

Pfeffer et al, Science, 2008: Extrapolate accelerating flow through marine-based glacier gates (Greenland, Antarctica) to 2100 to bound dynamic component SLR.

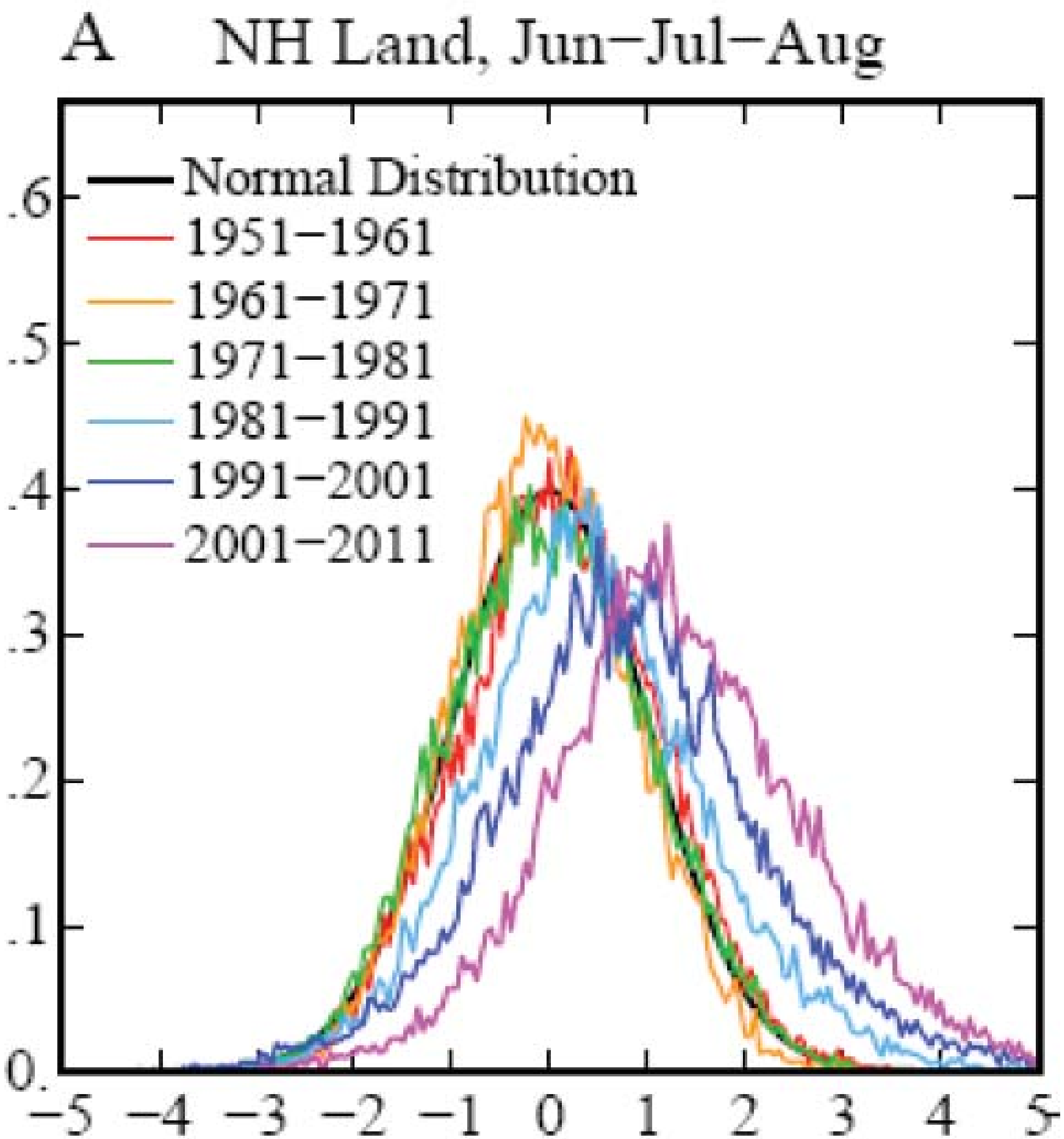


	SLR equivalent (mm)		
	Low 1	Low 2	High 1
Greenland			
Dynamics	93	93	467
SMB	71	71	71
Greenland total	165	165	538
Antarctica			
PIG/Thwaites dynamics	108		394
Lambert/Amery dynamics	16		158
Antarctic Peninsula dynamics	12		59
SMB	10		10
Antarctica total	146	128	619
Glaciers/ice caps			
Dynamics	94		471
SMB	80		80
GIC total	174	240	551
Thermal expansion	300	300	300
Total SLR to 2100	785	833	2008

IPCC no dynamic ice loss: 40-90 cm

With dynamic ice loss: 80-200 cm

Warming climate: effect on frequency of extreme events



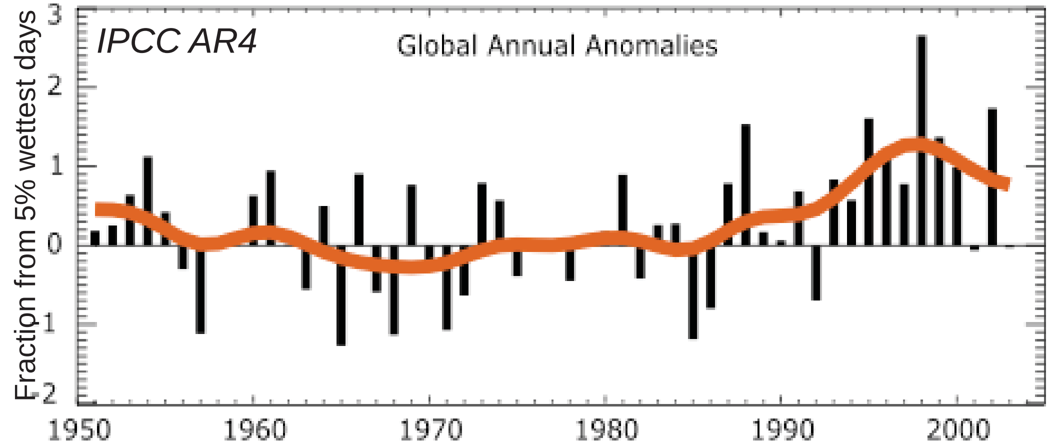
Standard deviations from 1951-1961 mean

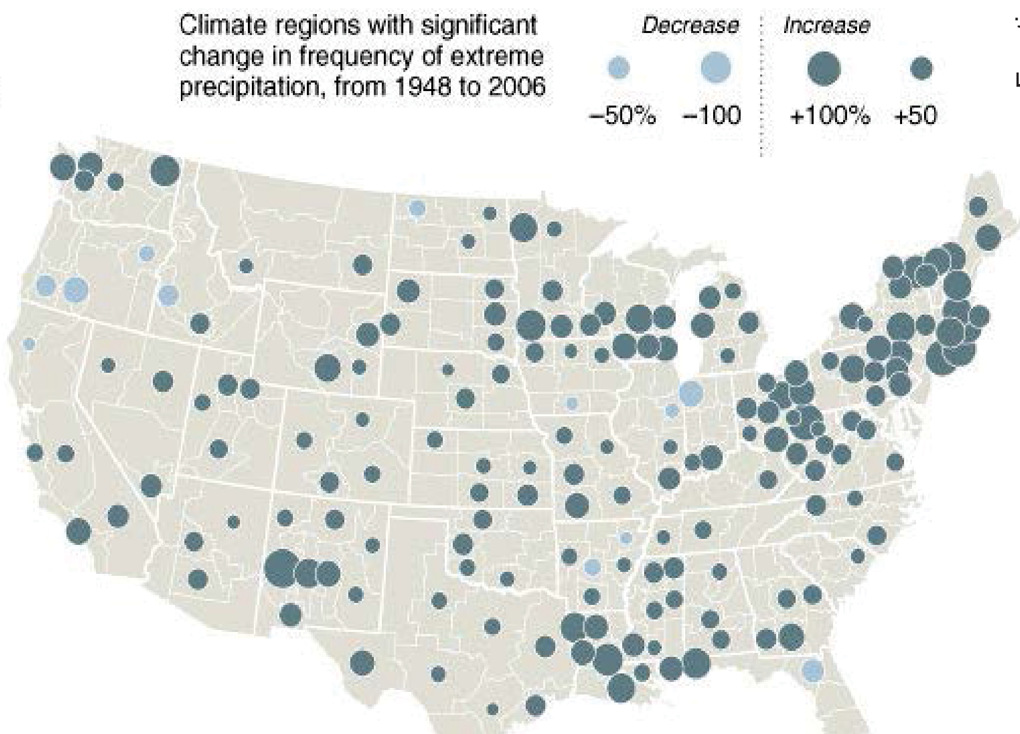
A small shift in the mean of a distribution causes a larger fractional change in the tails.

- *More heat records*
- *More extreme droughts*
- *More extreme rainfall*

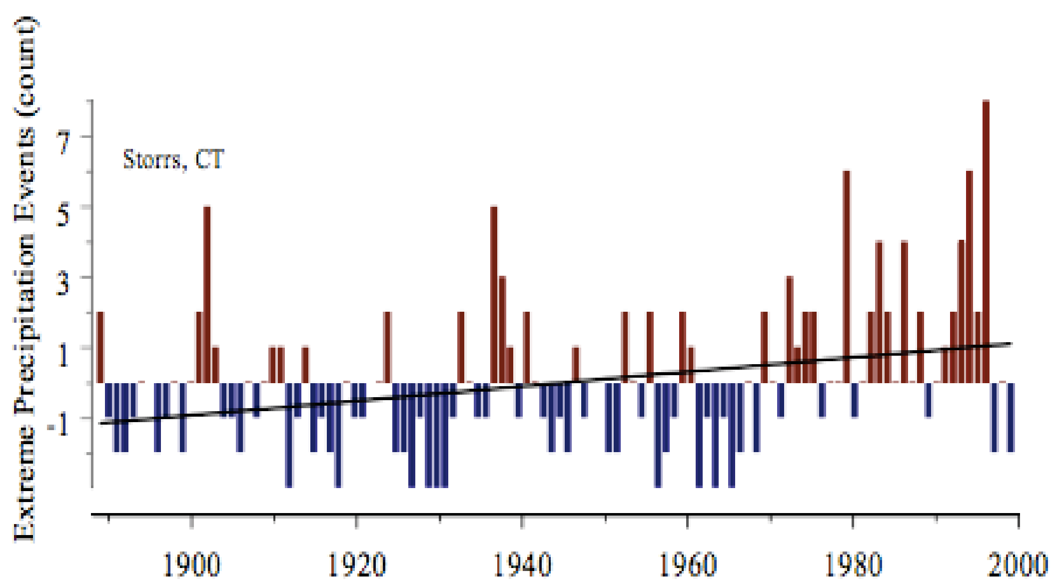
Example of this general statement for NH summer overland surface-air temperature. *Hansen et al., PNAS, 2012.*

***Extreme Precipitation**: Warmer air results in more vigorous hydrologic cycle.*
Warm air holds more water. Water-vapor condensation is fuel for storms.
More intense rainfall events.





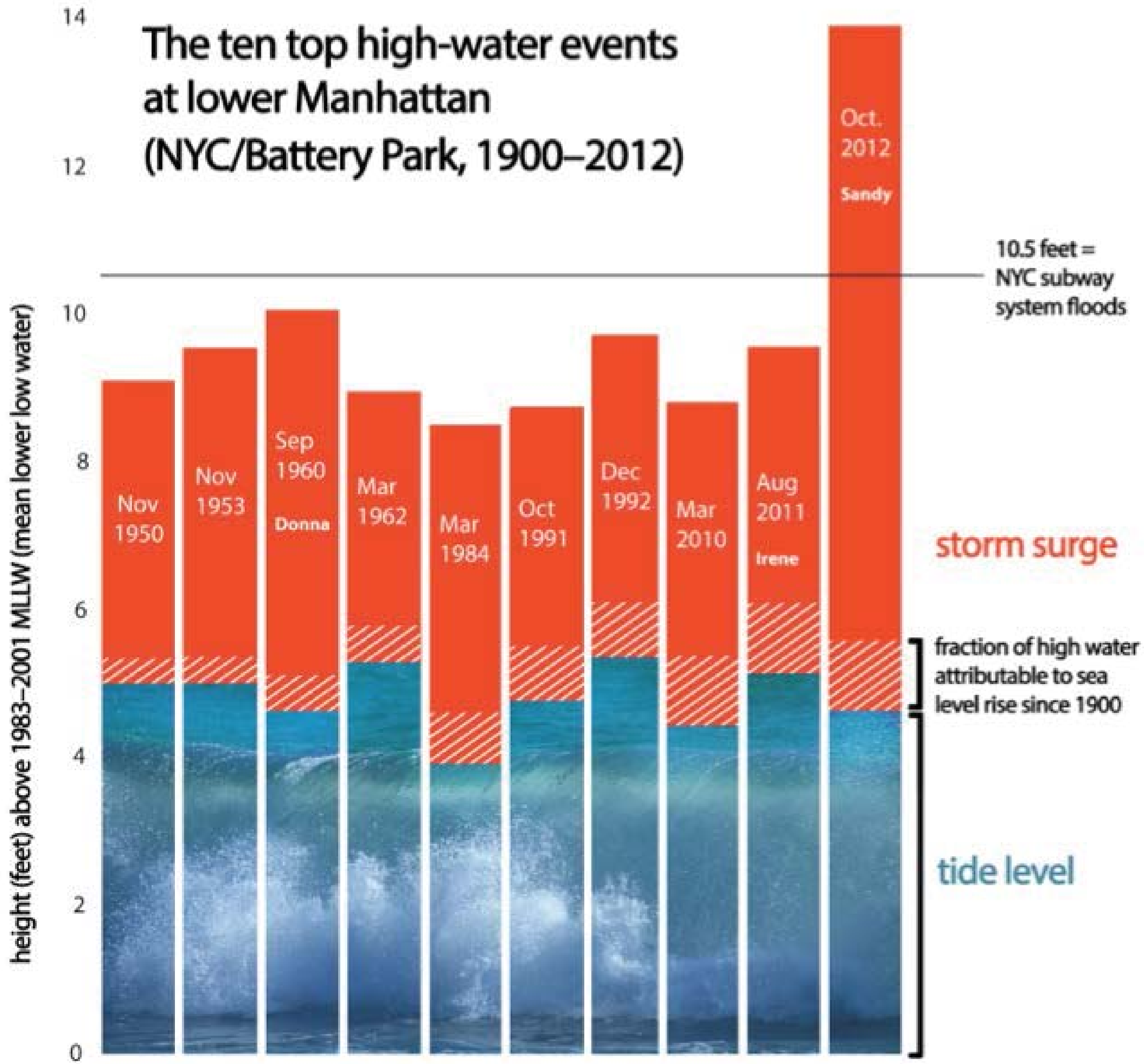
Madsen and Figdor, Environment America, 2007



Example of changing frequency of extreme events: Sea-level rise and coastal flooding

Gustav, New Orleans, 2008

Sandy, NJ shore, 2012



Sandy shifts from 1000-year flood to 350-year flood late this century, mostly due to 1m sea-level rise. Absolute values highly model dependent, lots of uncertainty. But large increase in frequency with sea-level rise robust.

The following slides were provided to me by Drew Shindell and are a summary of:

Measures to Limit Near-Term Climate Change and Improve Air Quality

The UNEP/WMO Integrated Assessment of Black Carbon and Tropospheric Ozone

and

Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security

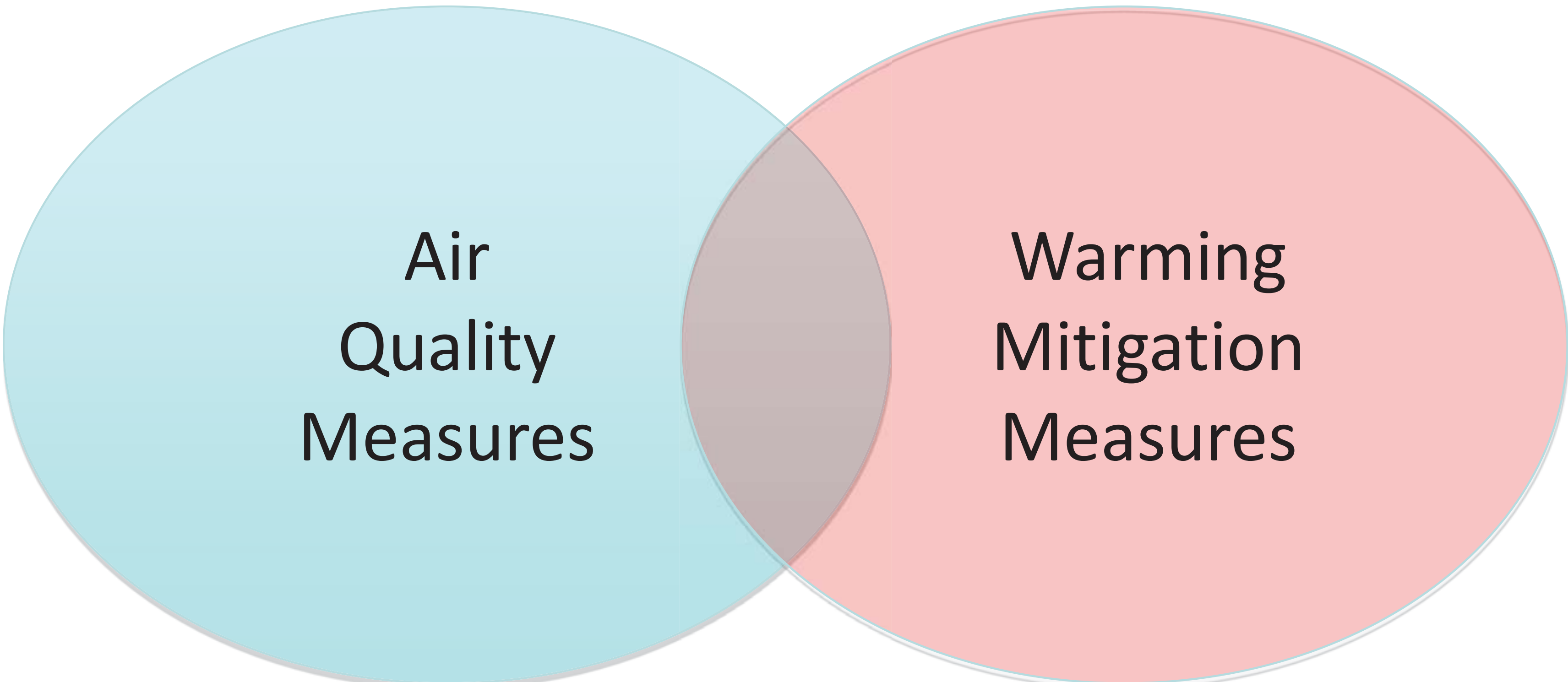
Drew Shindell, NASA GISS, Chair/Lead author

Vice-Chairs: **Frank Raes**, Joint Research Centre, European Commission; **V. Ramanathan**, Scripps Institution of Oceanography; **Kim Oanh**, Asian Inst. Technology, Thailand; **Luis Cifuentes**, Catholic University of Chile

~50 contributors, over 100 reviewers

UNEP/WMO coordinators: Volodymyr Demkine/Liisa Jalkanen

Objectives



Screening of ~400 measures

Emission Control Measures in the Analysis

- ranked mitigation measures by the net global warming potential (GWP) of their emission changes (CO, CH_4, BC, OC, SO_2, NO_X, VOCs, and CO_2) and picked the top measures

'Methane measures'

– extraction and long-distance transport of fossil fuels

– waste management; municipal, landfills & wastewater

– agriculture; livestock manure & intermittent rice aeration

‘BC Measures’: those that reduce emissions of black carbon and co-emissions (e.g. OC, CO)

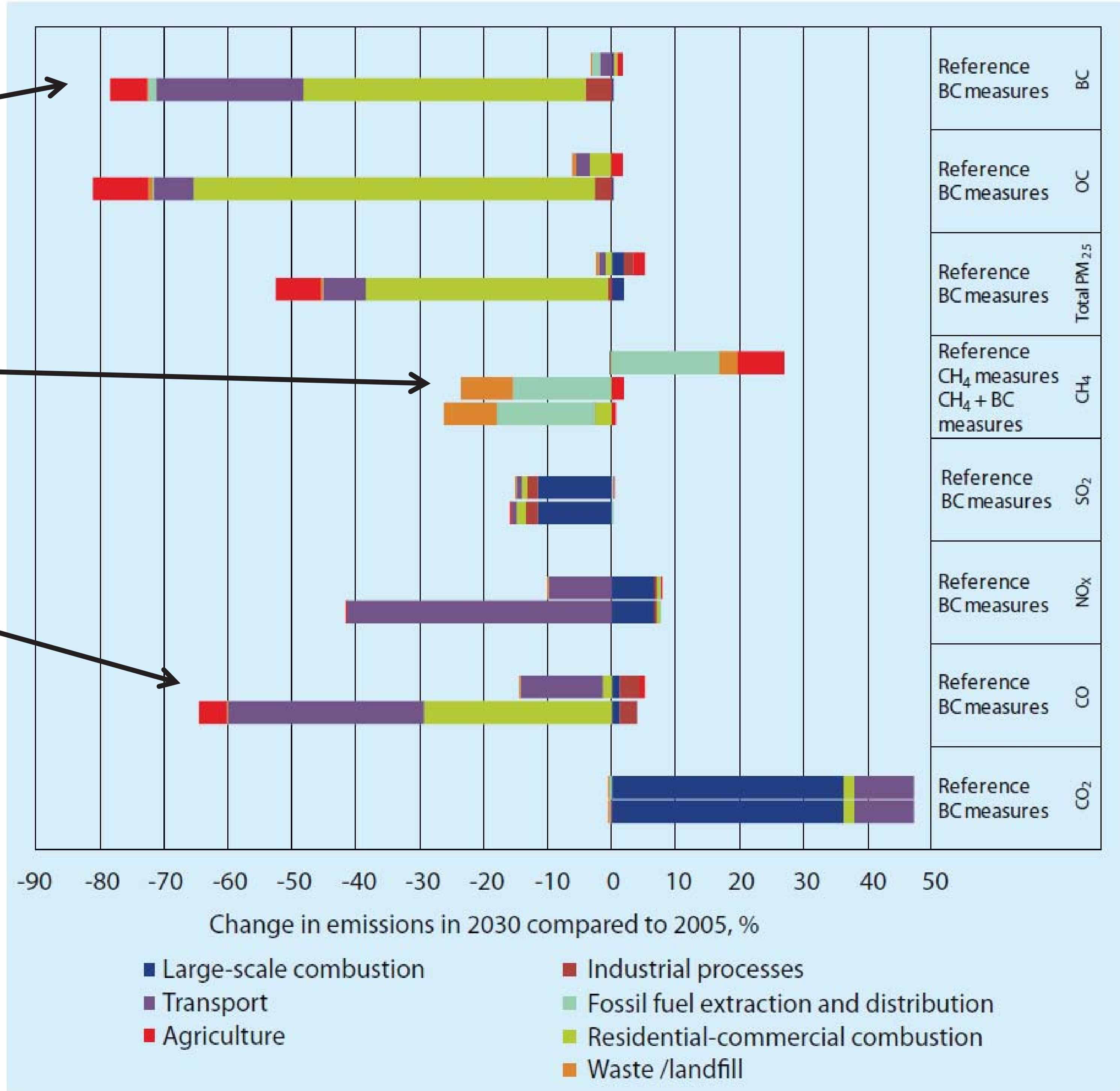
- Diesel vehicles (particle filters+)
- Coal briquettes replacing coal in residential stoves
- Pellet stoves & boilers replacing residential wood burning in Industrialized countries
- Clean-burning cookstoves in developing countries
- Modern brick kilns
- Modern coke ovens
- Ban of open burning of agricultural waste

Effect of measures on emissions projected in 2030 relative to 2005

9 BC measures reduce ~80% of BC

Reference: CH_4 increases
7 CH_4 measures reduce ~25% of CH_4 (2005); or ~ 40% relative to 2030

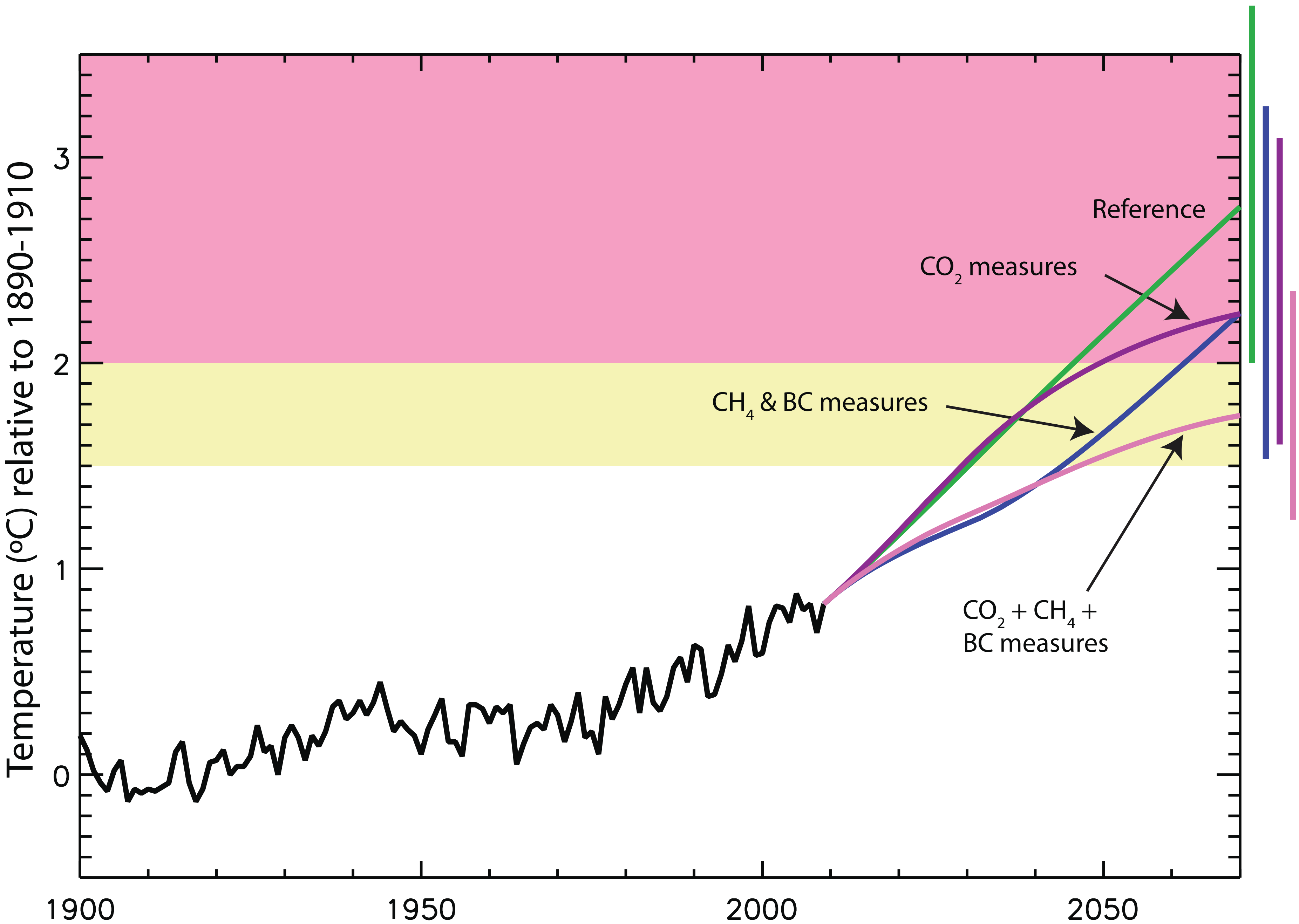
BC measures reduce CO



Methane and BC measures vs CO_2 measures

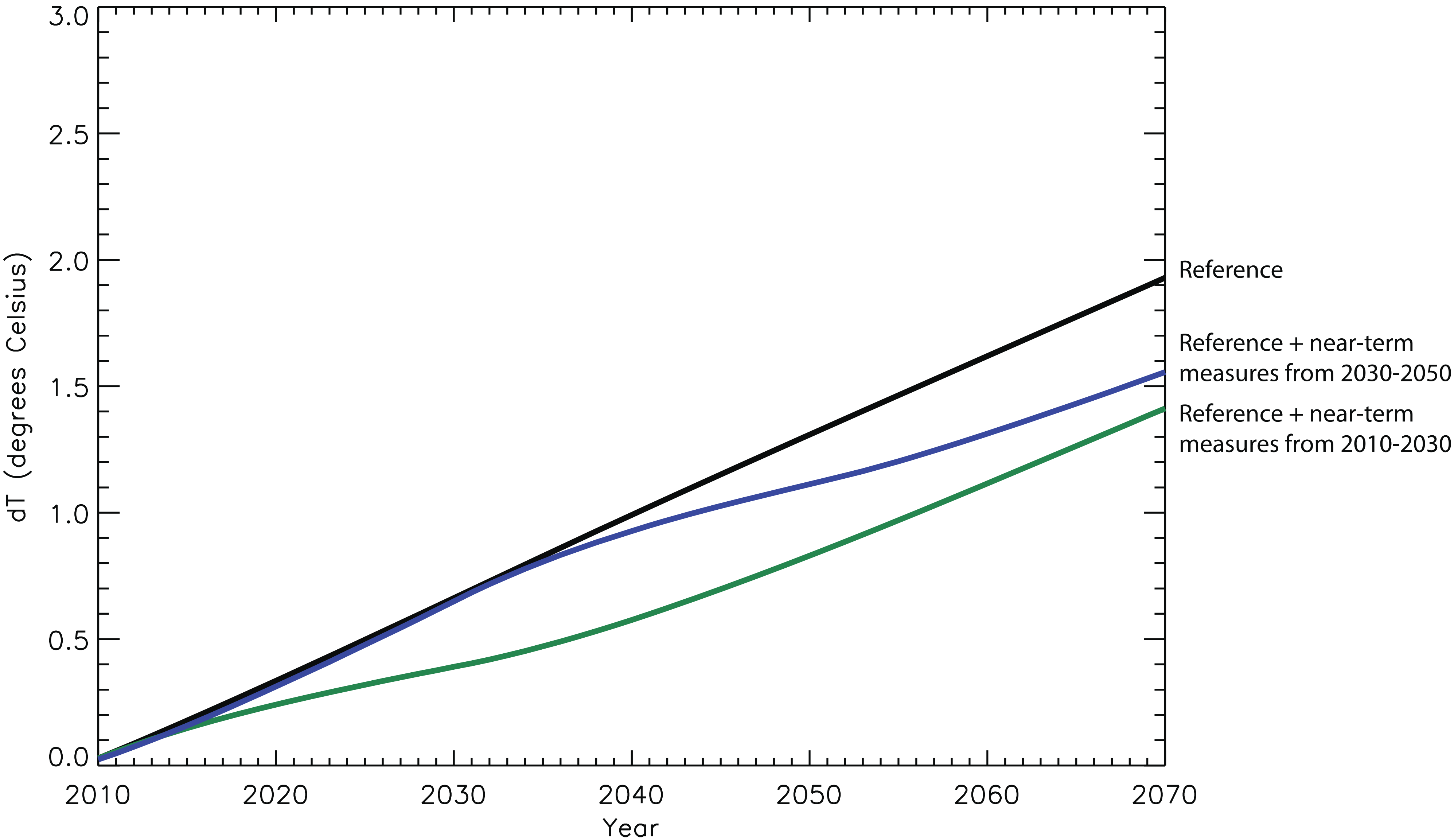
- CO_2 measures target power plants and heavy industry
- Methane and BC measures largely target other sectors
- Even for transportation, which emits substantial CO_2 and BC/OC/CO, diesel particulate filters impact the latter but not CO_2
- Emissions control measures for CO_2 and methane/BC would be more related in a world with very substantial shifts to low carbon (e.g. electric cars/public transport) or with certain regulatory/behavioral changes that were not examined (e.g. fuel economy) by this study.

Global Temperature Change (hybrid of results from GISS and ECHAM models and assessment of literature) added to the historical record

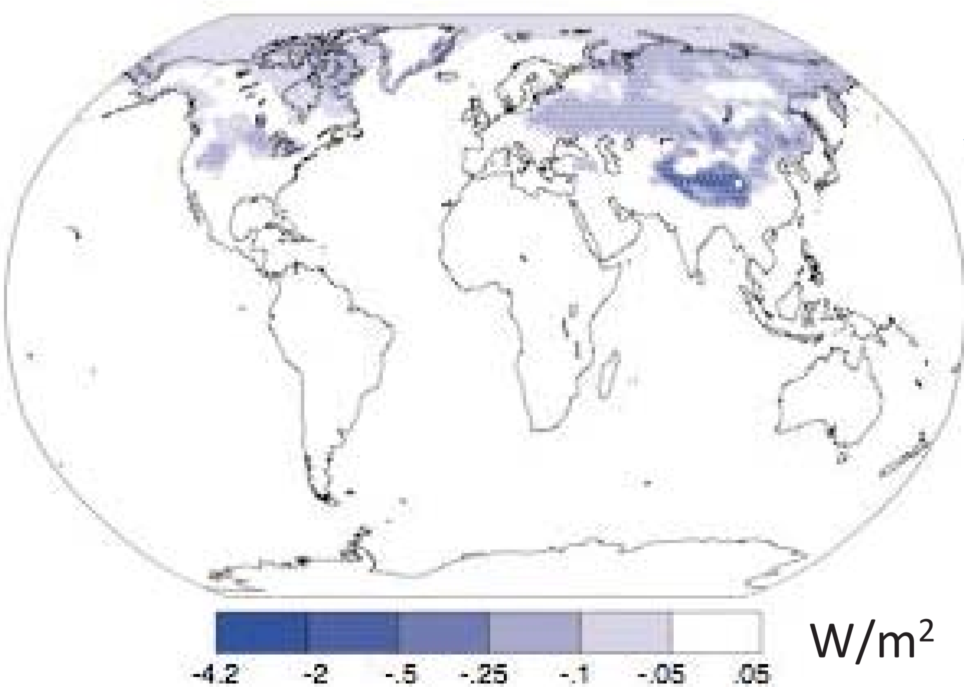


Phasing in measures early gives strong near-term benefit

Early action relative to late has little long-term impact (peak warming governed by CO_2)



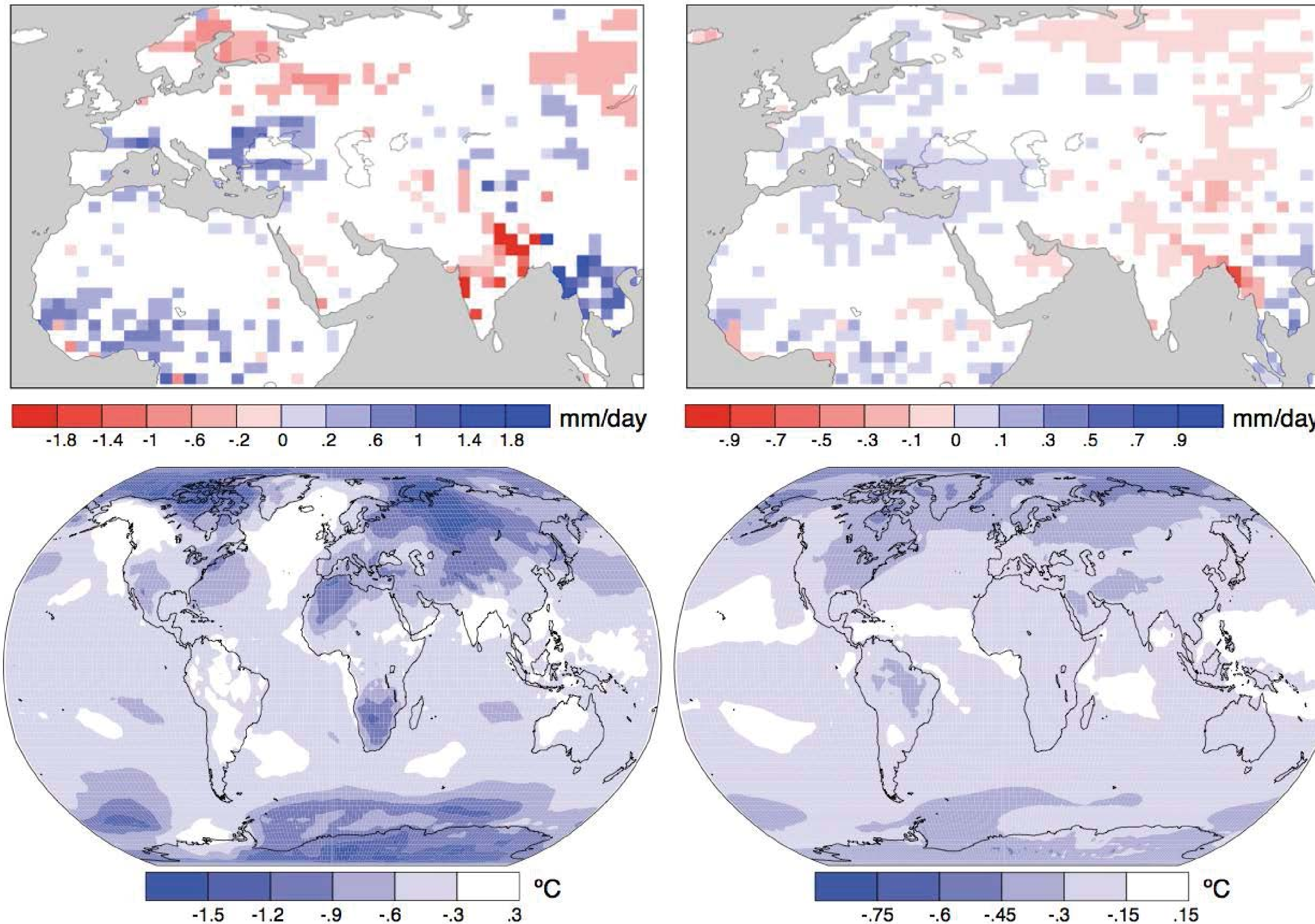
Mitigation of Regional Climate Changes



RF due to BC darkening snow & ice

Assessment estimated this would reduced Arctic warming by 0.7 ^{o}C by 2040 compared to the reference scenario, with measures taken 2010-2030. Mitigating ~2/3 of projected 1.2 ^{o}C warming.

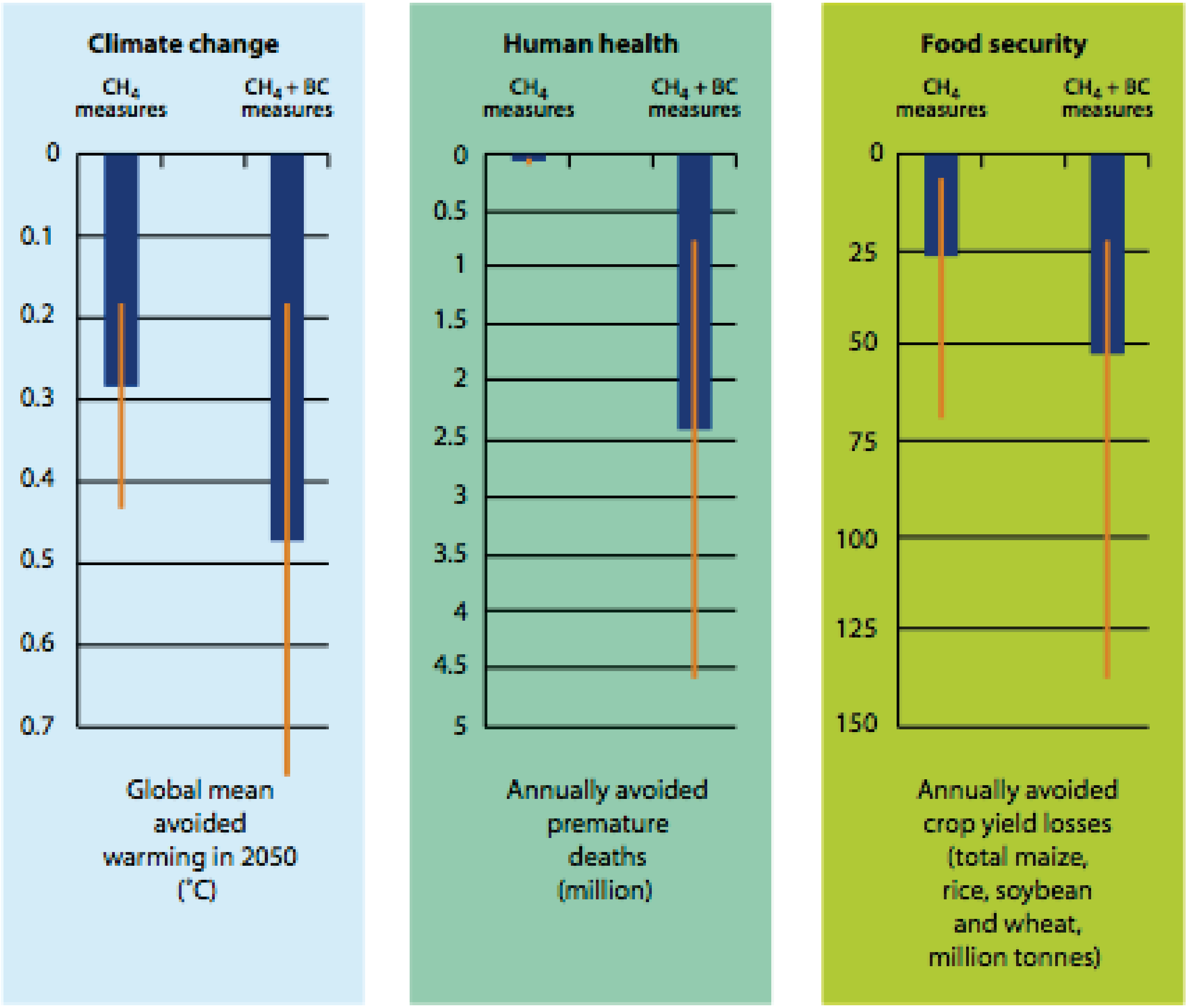
Mitigation of Regional Climate Changes



Global mean response quite consistent with simple estimates.

Impact of the Measures on Health and Crop yields

- Models give **$PM_{2.5}$ and ozone concentrations** for health and crop yield impact assessment
- Concentration-response relationships from literature used to evaluate global impacts



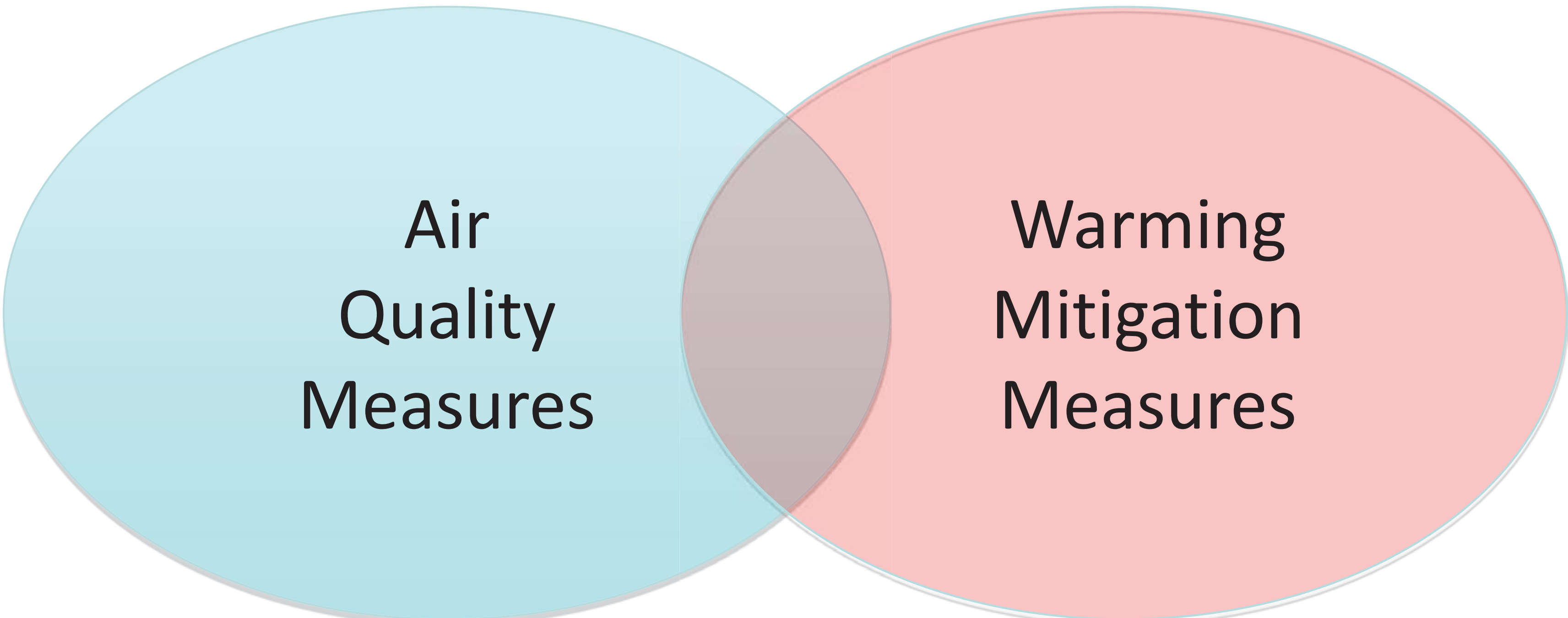
Air quality benefits for 2030 and beyond.

Health & crop benefits greatest in regions that reduce emissions.

Comparison of Methane & BC Measures' Impacts

- Methane measures
  - Large benefits for global climate & agriculture
  - Comparatively small benefits for human health
  - Virtually certain

- BC Measures
  - Probable large global climate benefit, large uncertainty
  - Substantial regional climate benefits: water, cryosphere
  - Large health and agricultural benefits
  - High confidence in regional climate and air quality benefits



Number of measures in overlap zone is small, effects nonetheless large

Policies to Implement the Measures

- **The identified measures are all currently in use in different regions around the world to achieve a variety of environment and development objectives.**

- **Much wider and more rapid implementation is required to achieve the full benefits identified in this Assessment.**

- Many **measures achieve cost savings** over time. However, initial capital investment could be problematic, necessitating additional strategic support and investment.

CDM funded coal mine methane project in China

Loans for efficient charcoal stoves in Ghana

Policy world response: Climate and Clean Air Coalition

U.S. DEPARTMENT OF STATE
DIPLOMACY IN ACTION

"The UN Environment Program has determined that reducing these pollutants can slow global warming by up to a half degree Celsius by 2050."

"UNEP has identified a package of 16 major actions… Every one of the actions has already been applied somewhere, and so we know they work.
Every one is based on existing technology, and fully half of them are considered low-cost interventions. So when you put all these factors together, they add up to an important opportunity that we cannot miss."

Policy world response

The New York Times

"A Second Front in the Climate War"

hindustantimes

"Simple measures could reduce global warming, save lives"

The south Asian countries of India, Bangladesh and Nepal would see the biggest reductions in premature deaths.

"There is no way to effectively address climate change without reducing carbon dioxide, the most dangerous, prevalent, and persistent greenhouse gas. It stays in the atmosphere for hundreds of years. So this coalition is intended to complement – not supplant – the other actions we are, and must be, taking."

– Hillary Clinton's remarks launching the Coalition