Climate Changes & Global Warming

- *Global Climate Change Impacts in the United States* ed. Thomas R. Karl, Jerry M. Melillo and Thomas C. Peterson, Cambridge Press (2009)

http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/full-report/about-this-report

- *Ecological Impacts of Climate Changes* report by Committee on Ecological Impacts of Climate Changes, National Research Council (2008)

http://dels.nas.edu/dels/rpt_briefs/ecological_impacts.pdf

- *The Science and Politics of Global Climate Change: A Guide to the Debate* by Andrew E. Dessler and Edward A. Parson, Cambridge University Press (2006)

- *Understanding and Responding to Climate Change* – Highlights of National Academies Report (2008)

http://dels.nas.edu/dels/rpt_briefs/climate_change_2008_final.pdf

Key Findings

- Global warming is unequivocal and primarily human-induced
- Climate changes are underway and are projected to grow
  - Widespread climate-related impacts are occurring and are expecting to increase
  - Climate change will stress water resources, crop & livestock production, human health
  - Coastal areas are at increasing risk from sea-level rise and storm surge
- Tipping points will be reached , leading to irreversible changes: need immediate responses and making the right choices

Radiation

Thermal energy emitted by matter as a result of vibrational and rotational movements of molecules, atoms and electrons. The energy is transported by electromagnetic waves (or photons). Radiation requires no medium for its propagation, therefore, can take place also in vacuum. All matters emit radiation as long as they have a finite (greater than absolute zero) temperature. The rate at which radiation energy is emitted is usually quantified by the modified Stefan-Bolzmann law:

$$EA = q = \frac{dQ}{dt} = \varepsilon \sigma A T_b^4$$

where the emissivity, ε , is a property of the surface characterizing how effectively the surface radiates compared to a "blackbody" ($0<\varepsilon<1$). E=q/A (W/m^2) is the surface emissive power. σ is the Stefan-Boltzmann constant ($\sigma=5.67 \times 10^{-8}$ $W/(m^2K^4)$). Tb is the absolute temperature of the surface (in Kelvin).

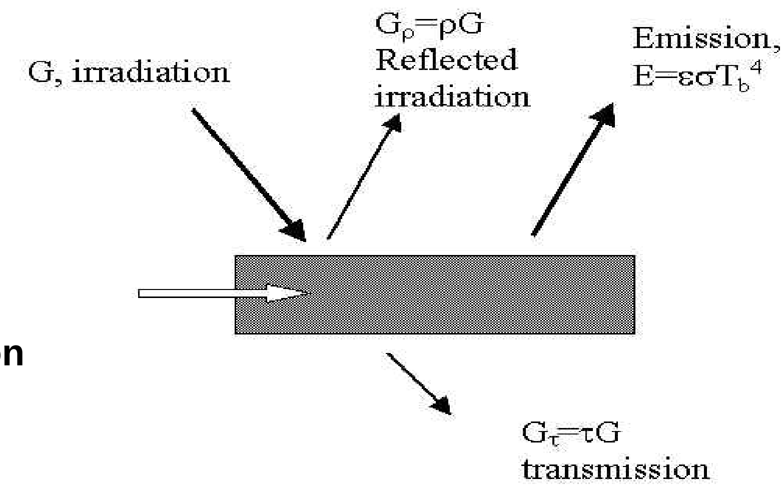
Radiation (cont.)

Blackbody: is an ideal surface which emits the maximum possible thermal radiation at a given temperature.

Irradiation (G): All incoming radiation that is incident on the surface. It can then be transmitted, absorbed or reflected from the surface. $G = G_{trans} + G_{abs} + G_{ref} = \tau G + \alpha G + \rho G$

Where τ, α and ρ represent transmissivity, absorptivity and reflectivity, respectively. $\tau + \alpha + \rho = 1$

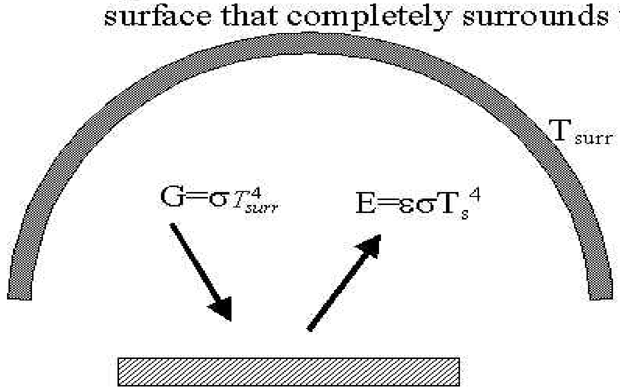
Radiation (cont. 2)



$G_\alpha=\alpha G$
Absorbed irradiation

Net radiation energy exchange:
$q''_{net} = q/A = \alpha G - E = \alpha G - \varepsilon\sigma T_b^4$

Special case: a small surface inside a much large isothermal surface that completely surrounds the small one



$q''_{net} = \varepsilon\sigma T_s^4 - \alpha G$
if $\varepsilon = \alpha$ (a gray surface)
$= \varepsilon\sigma(T_s^4 - T_{surr}^4)$

Radiation (cont. 3)

Electromagnetic radiation spectrum
Thermal radiation spectrum range: 0.1 to 100 mm
It includes some ultraviolet (UV) radiation and all visible (0.4-0.76 μm) and infrared radiation (IR).

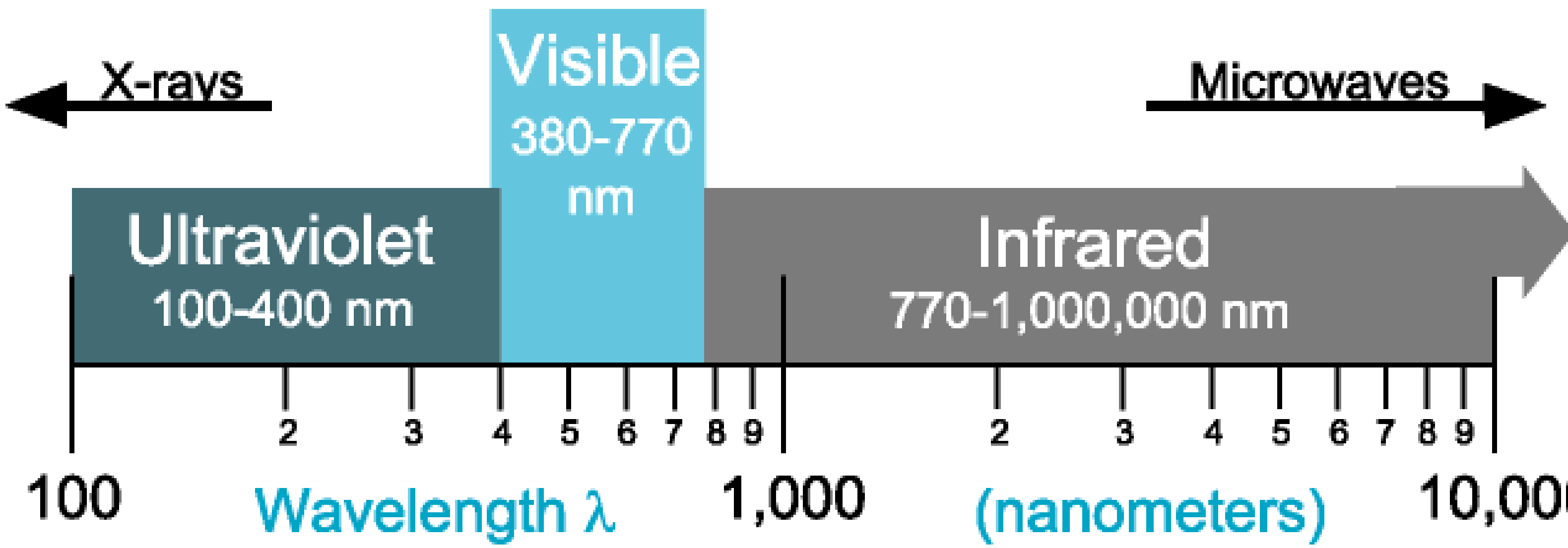


Fig. 1.1 The optical portion of the electromagnetic spectrum

Radiation (cont. 4)

The Planck Distribution

The Planck law describes theoretical spectral distribution for the emissive power of a black body. It can be written as

$$E_{\lambda,b} = \frac{C_1}{\lambda^5\left[\exp(C_2/\lambda T) - 1\right]}$$

where C_1=3.742x10^8 (W.μm^4/m^2) and C_2=1.439x10^4 (μm.K) are two constants. The planck distribution is shown in the following figure as a function of wavelength for different body temperatures.

Spectral blackbody emissive power

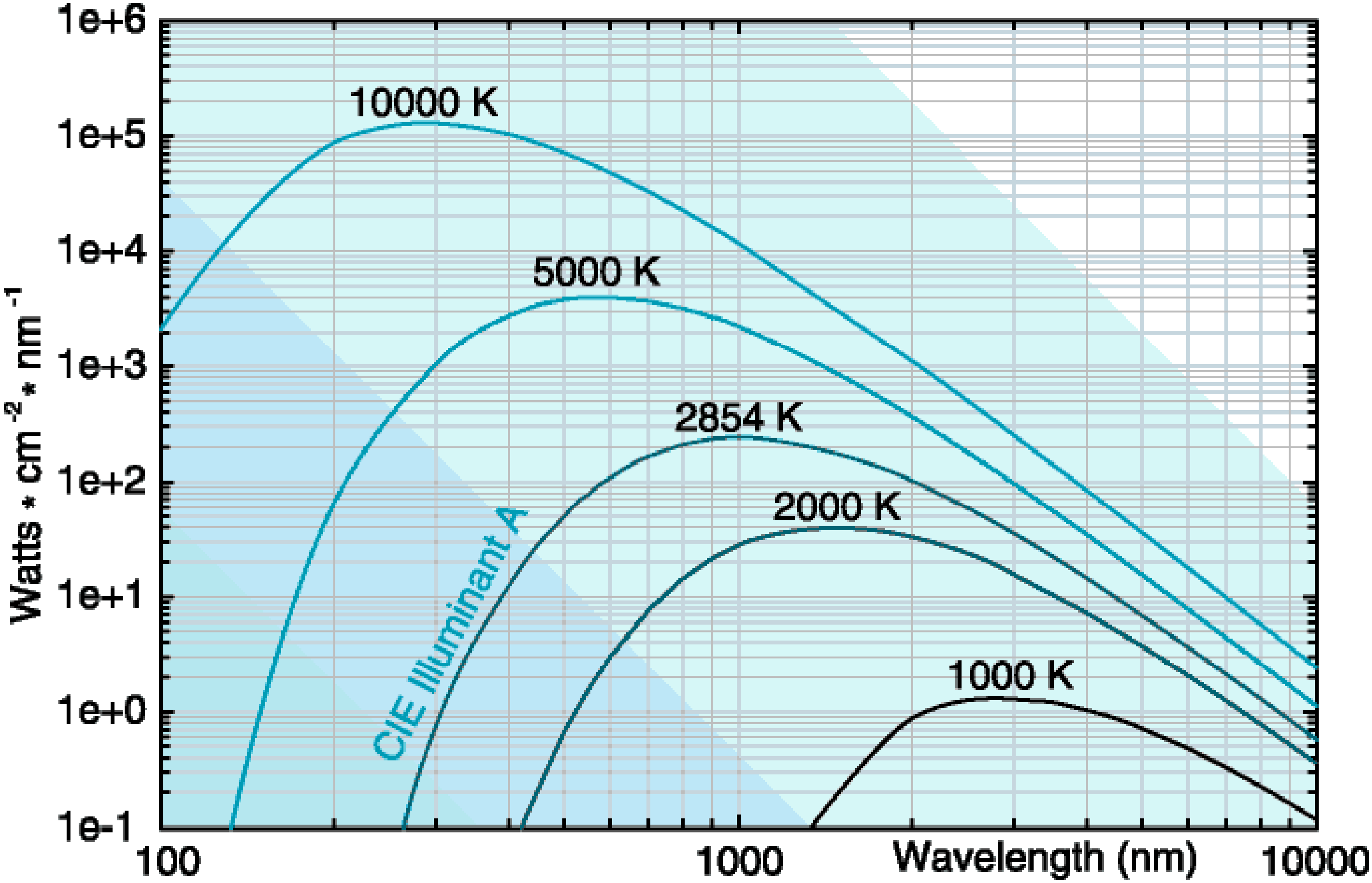


Fig. 5.1 Blackbody radiation at several color temperatures.

Planck Distribution

- At given wavelength, the emissive power increases with increasing temperature

- As the temperature increases,more emissive energy appear at shorter wavelengths

- For low temperature (<800 K), all radiant energy falls in the infrared region and is not visible to the human eyes. That is why only very high temperature objects, such as molten iron, can glow.

- Sun can be approximated as a blackbody at 5800 K

Solar Irradiation

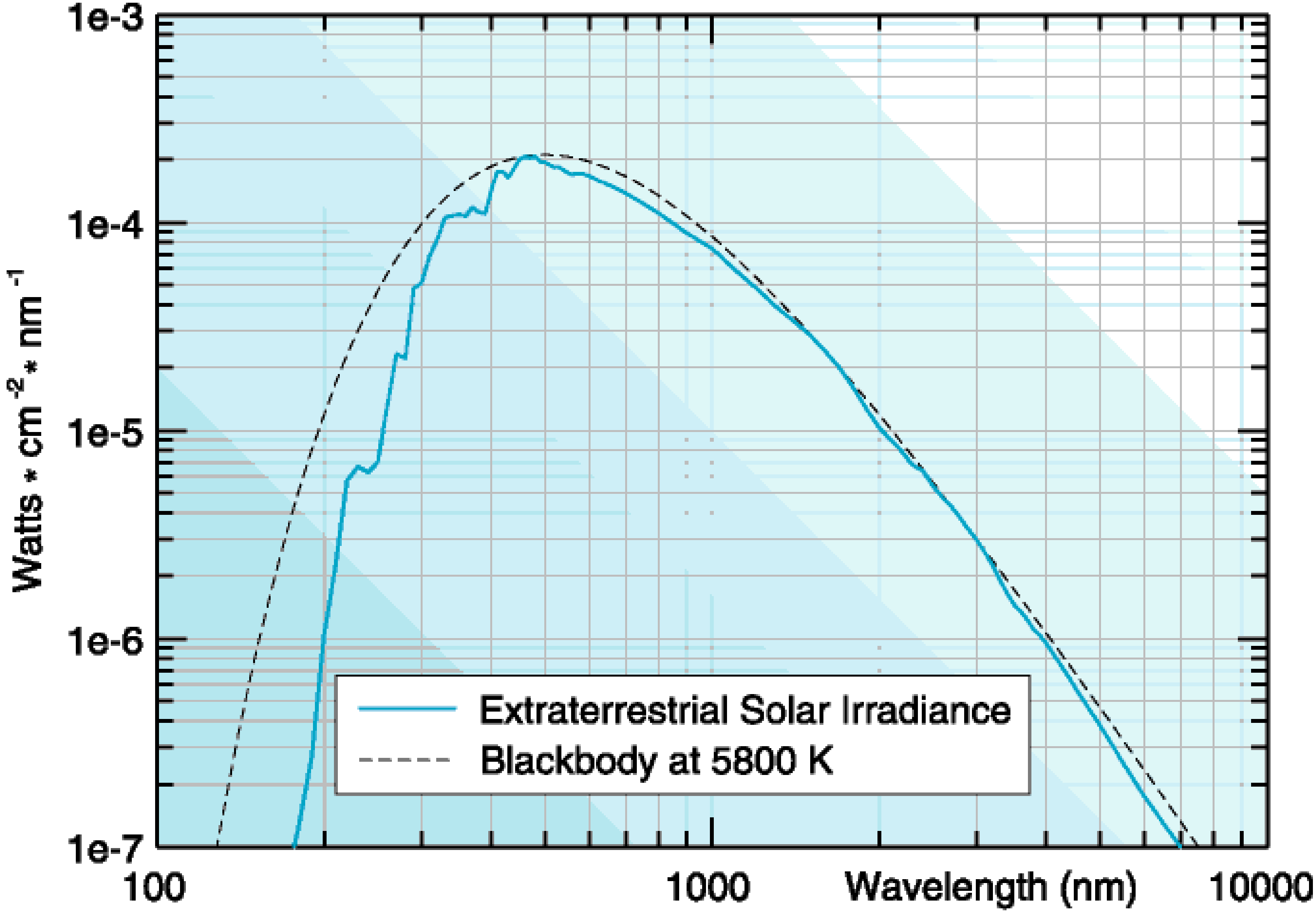
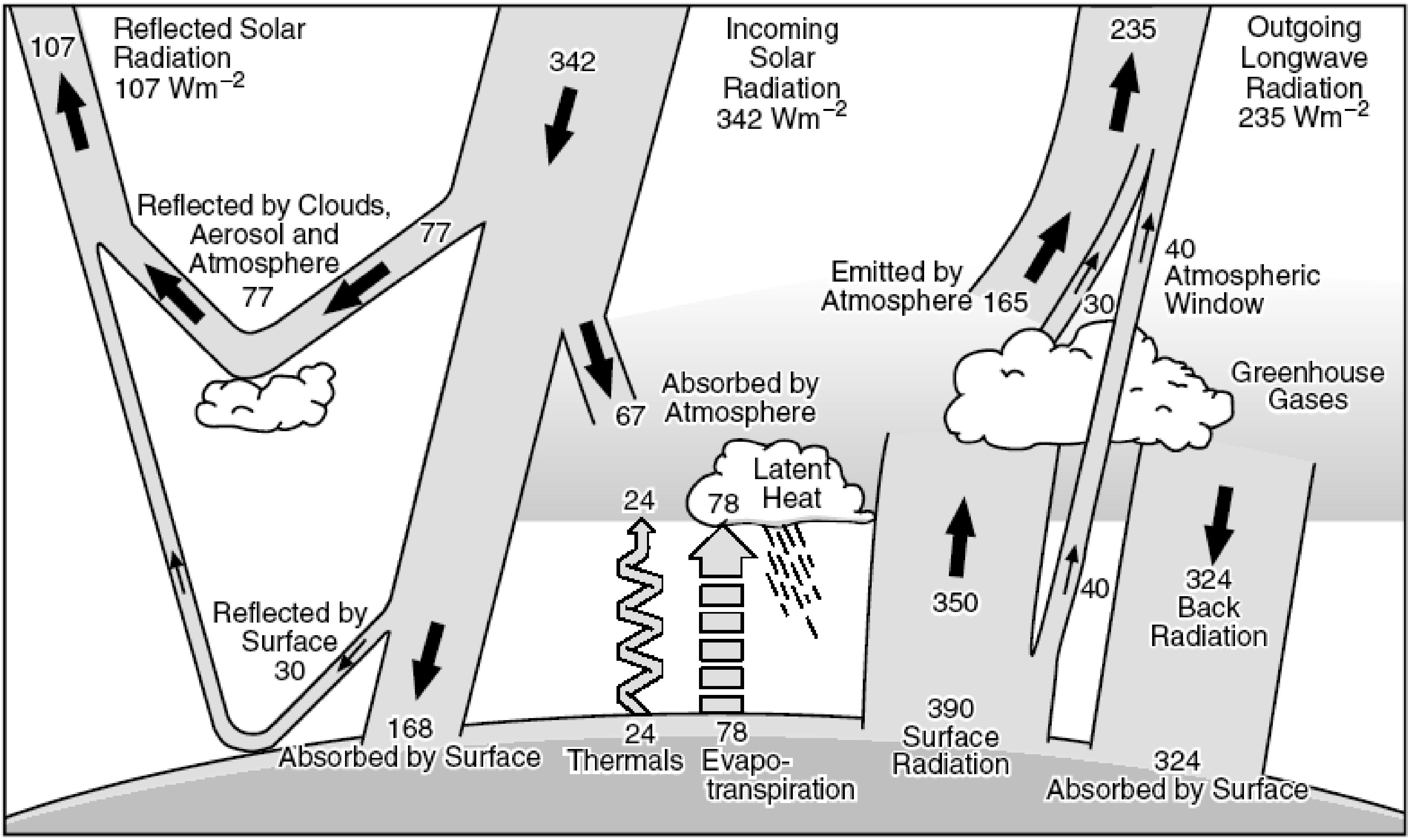


Fig. 5.7 Extraterrestrial solar irradiance compared to a blackbody.

Greenhouse Effect, Global Energy Balance

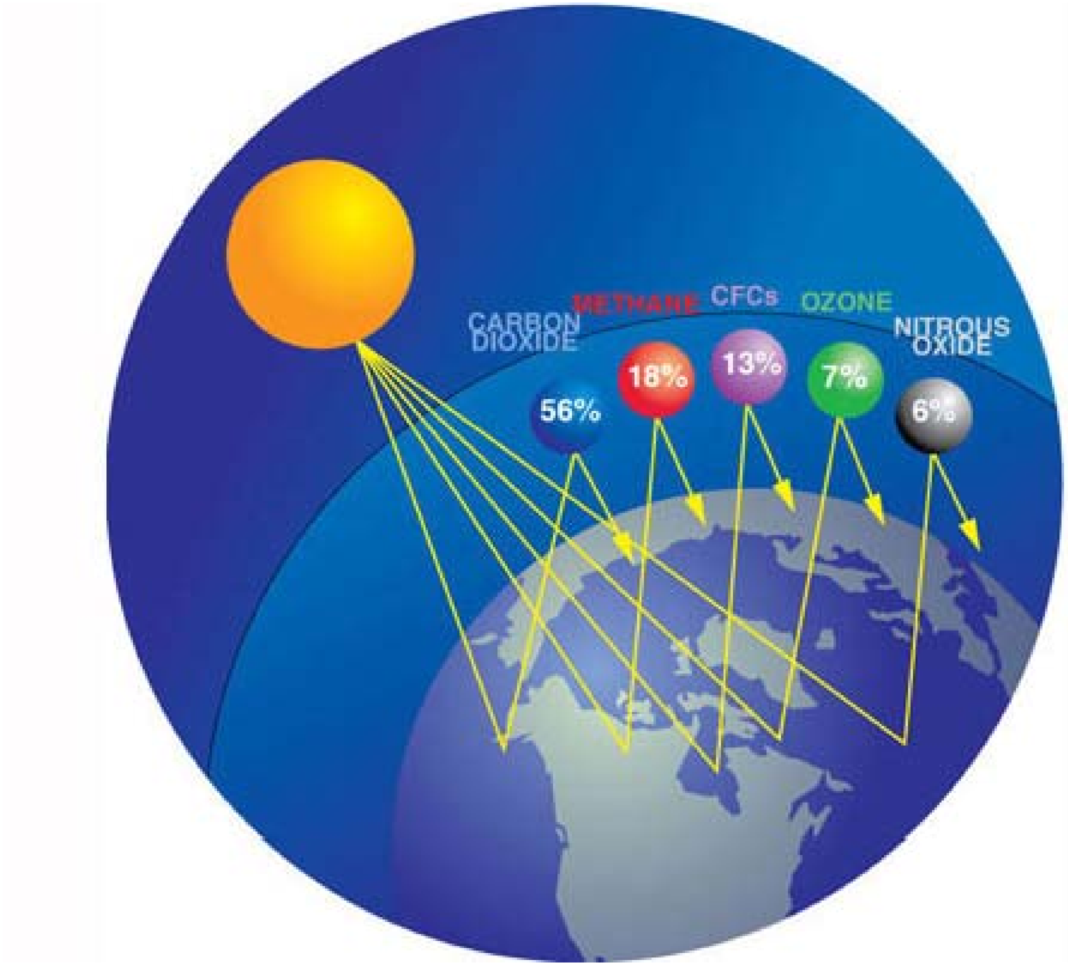


Natural Greenhouse Effect & Global warming

Table 12.3. Estimated Percentages of Natural Greenhouse Effect and Global Warming Temperature Changes Due to Greenhouse Gases and Particulate Black Carbon since the mid-1800s

Compound Name	Formula	Current Total Tropospheric Mixing Ratio (ppmv) or Loading (Tg)	Natural Percentage of Current Total Mixing Ratio or Loading	Anthropogenic Percentage of Current Total Mixing Ratio or Loading	Percentage of Natural Greenhouse Effect Temperature Change Due to Component	Percentage of Global Warming Temperature Change Due to Component
Water vapor	$H_2O(g)$	10,000	>99	<1	88.9	0
Carbon dioxide	$CO_2(g)$	370	75.7	24.3	7.5	46.6
Black carbon (BC)	$C(s)$	0.15–0.3 Tg	10	90	0.2	16.4
Methane	$CH_4(g)$	1.8	39	61	0.5	14.0
Ozone	$O_3(g)$	0.02–0.07	50–100	0–50	1.1	11.9
Nitrous oxide	$N_2O(g)$	0.314	87.6	12.4	1.5	4.2
Methyl chloride	$CH_3Cl(g)$	0.0006	100	0	0.3	0
CFC-11	$CFCl_3(g)$	0.00027	0	100	0	1.8
CFC-12	$CF_2Cl_2(g)$	0.00054	0	100	0	4.2
HCFC-22	$CF_2ClH(g)$	0.00013	0	100	0	0.6
Carbon tetrachloride	$CCl_4(g)$	0.00010	0	100	0	0.3

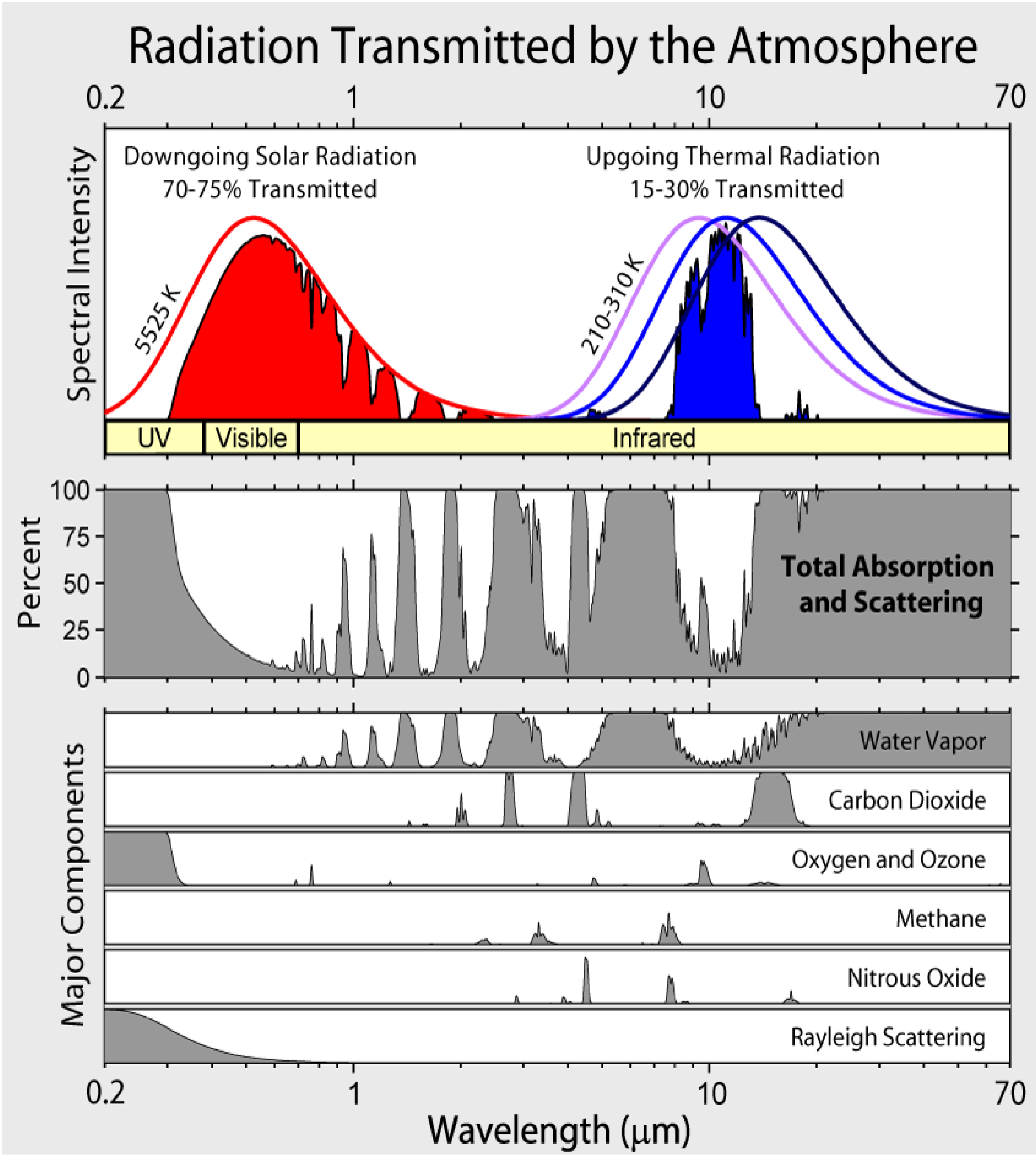
Anthropogenic Greenhouse Gases (GHGs)



- Carbon dioxide, CO_2: human-induced 80% fossil fuels, 20% deforestation
- Methane, CH_4: livestock, mining, fossil fuels, compost in landfills
- Nitrous oxide, N_2O: fertilizer and fossil fuels
- Halocarbon, CFCs: refrigeration, A/C, industrial processes
- Ozone, O_3 (7%)
- Water vapor: most important GHGs

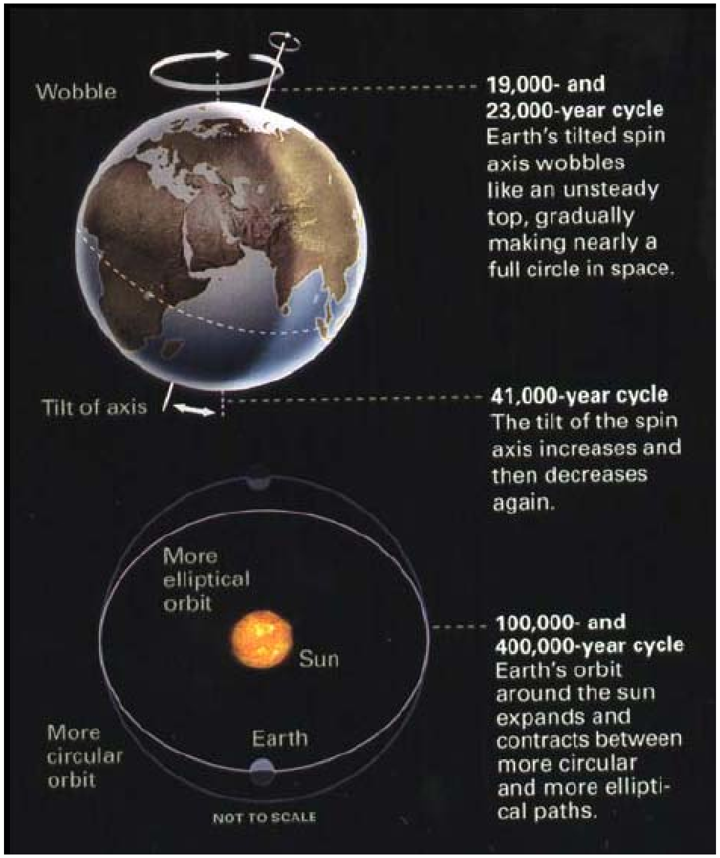
Courtesy Marian Koshland Science Museum of the National Academy of Sciences

http://www.koshland-science-museum.org

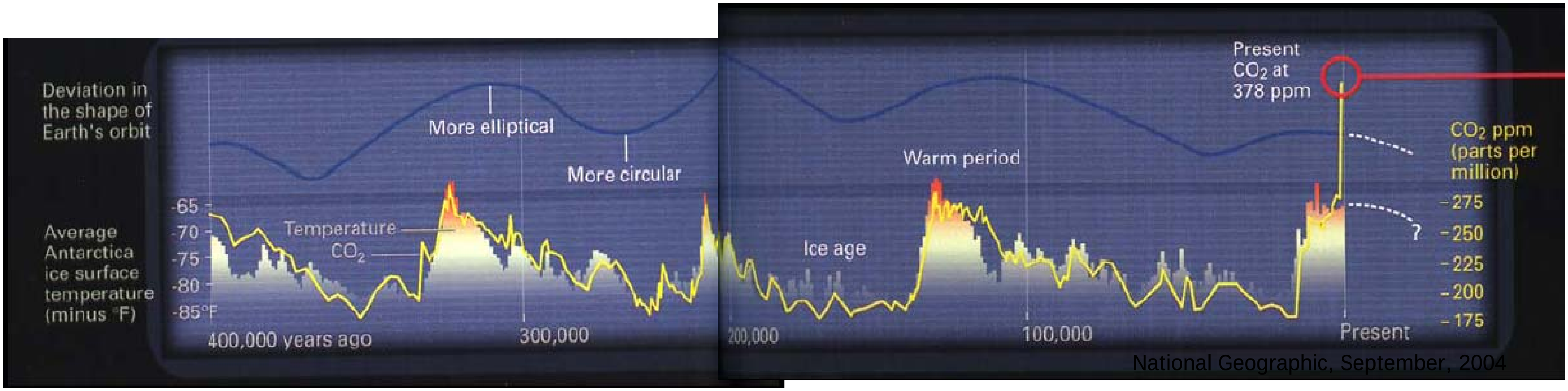


Atmospheric absorption and scattering at different electromagnetic wavelengths. The largest absorption band of carbon dioxide is in the infrared

Milankovitch Cycles

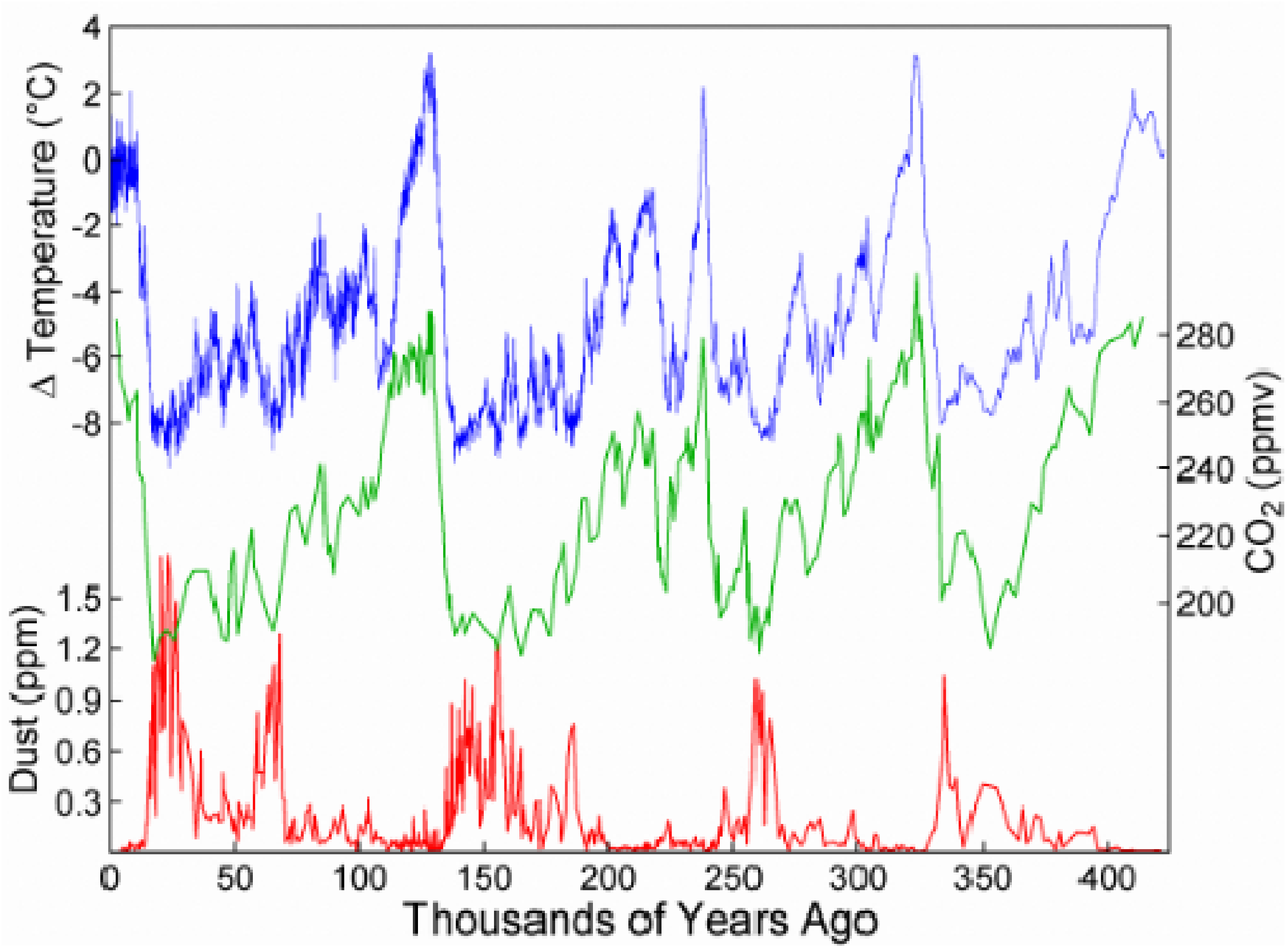


Caused by gravitational attraction between planets of the solar system and Earth due to changes in the eccentricity of the Earth's orbit, obliquity of the Earth's axis and precession of the Earth's axis of rotation.



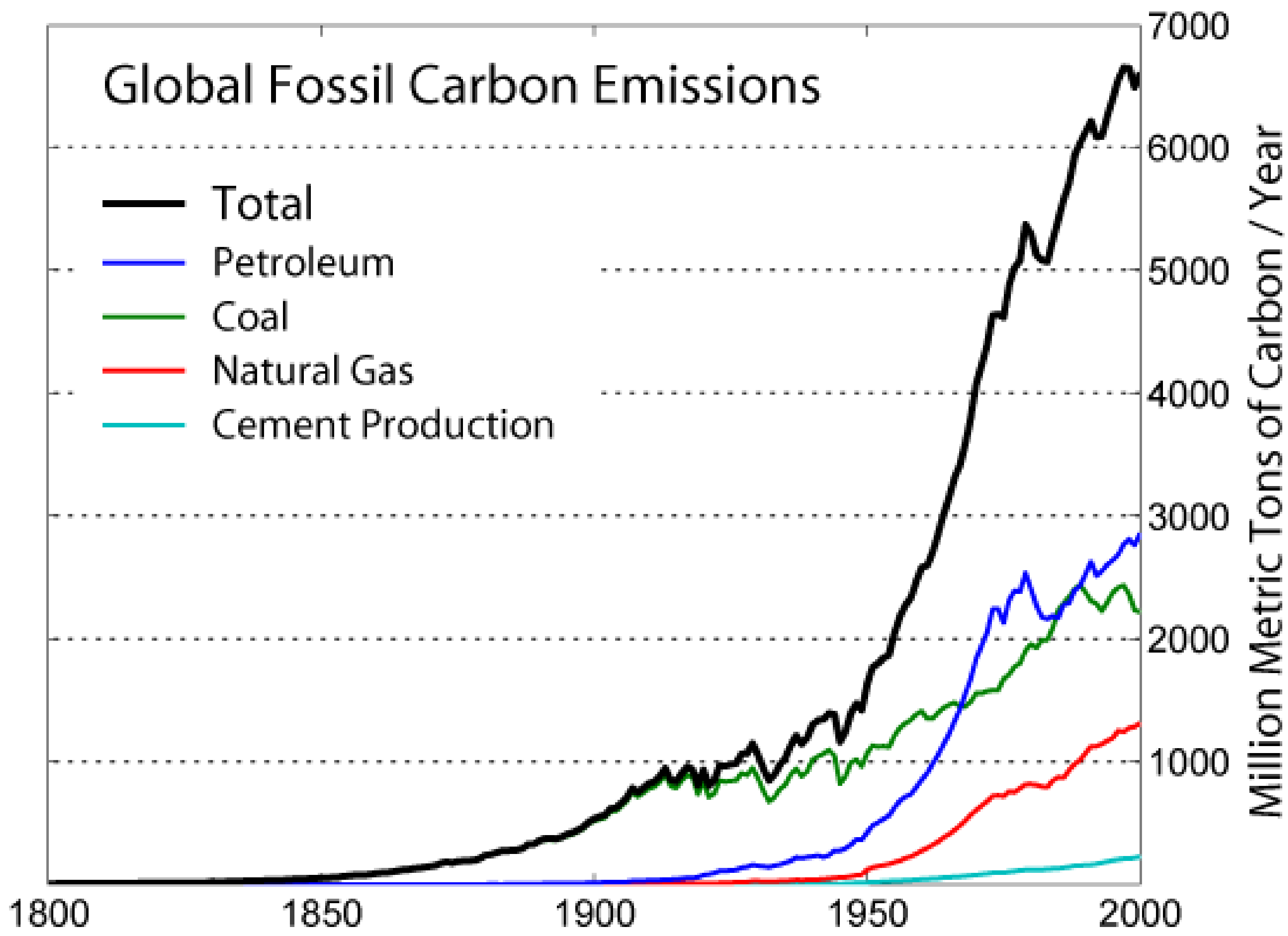
National Geographic, September, 2004

Correlation Between GHGs and Global Temperature Rise

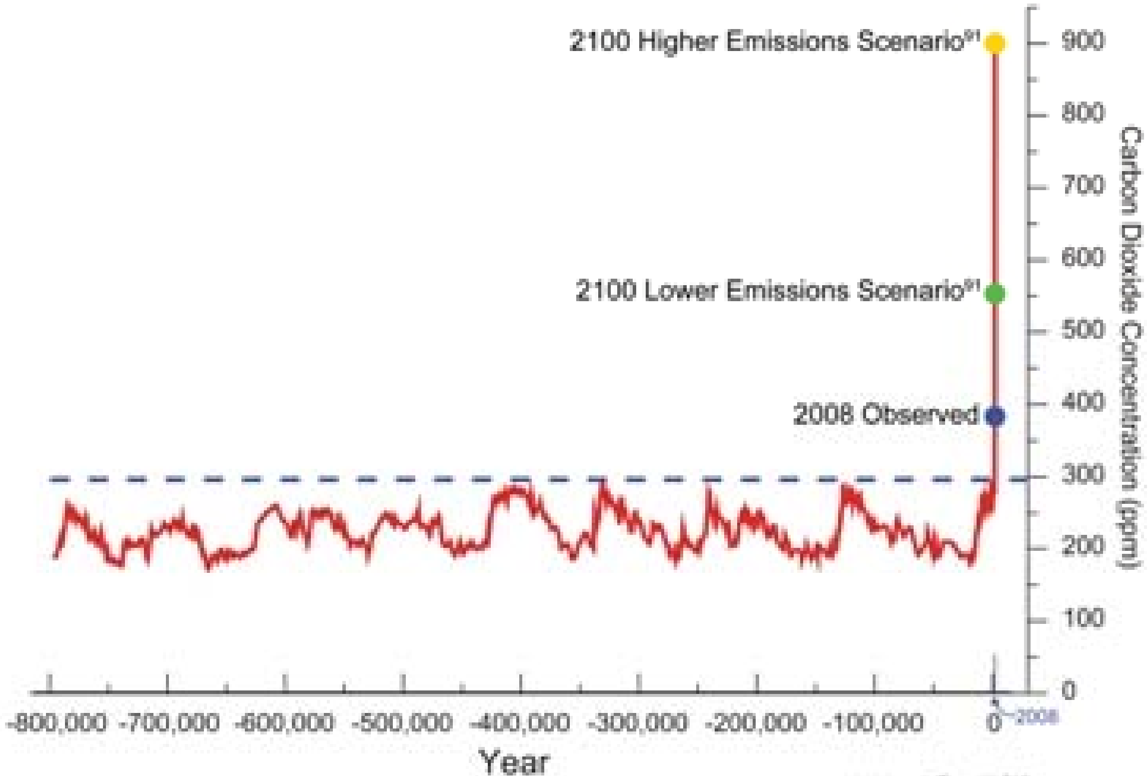


- These are the results from the Vostok ice shelves in Antarctica. The blue line and the green line are correlated: blue is temperature, green is CO_2. The measurements gauge average temperature and CO_2 level for the past 420,000 years. Ref: J.R. Petit et.al, Nature, 399, 3, June 1999, 429 - 436

Global Carbon Dioxide Emission 1751-2000



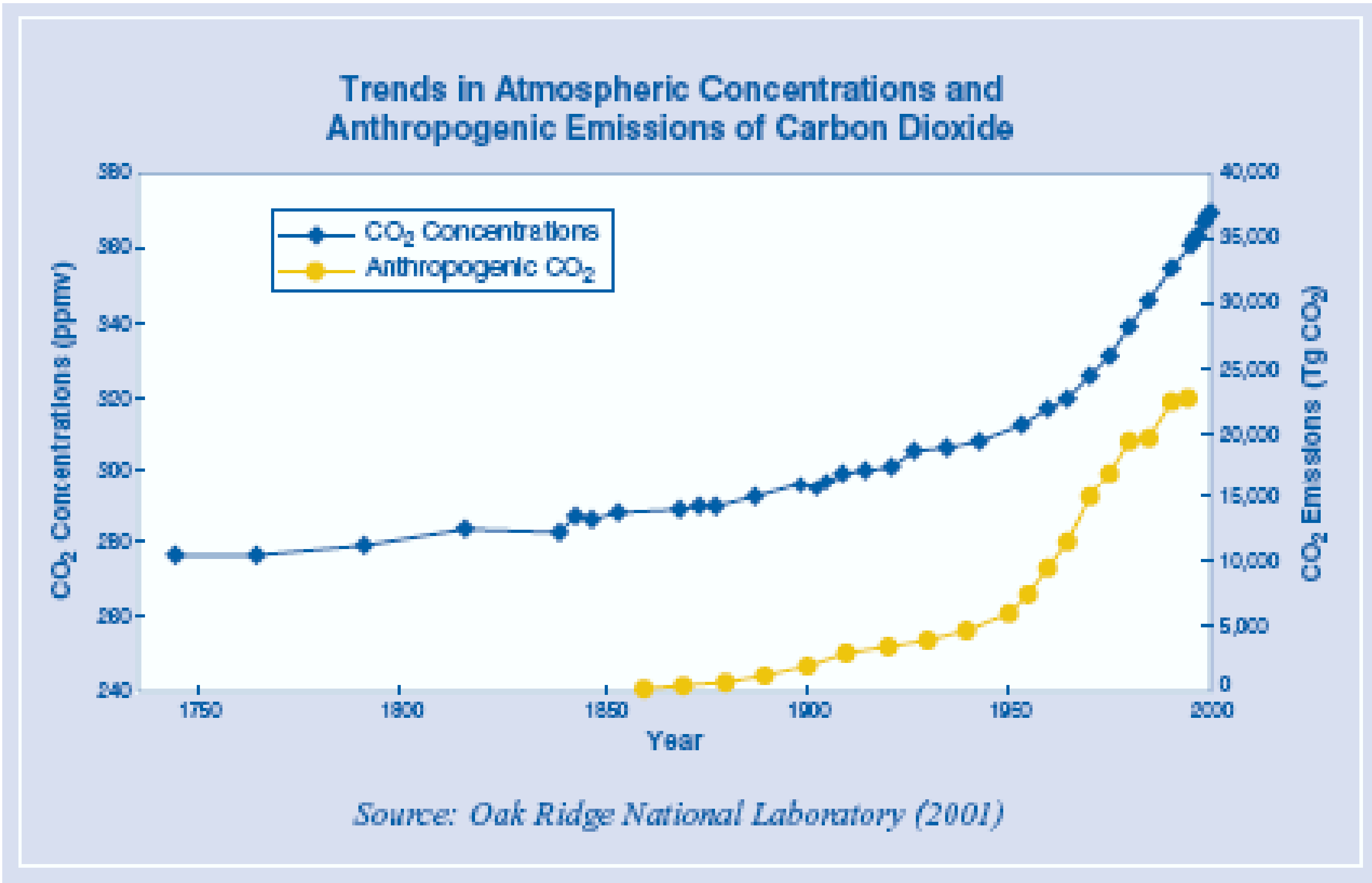
800,000 Year Record of CO_2 Concentration Record



Analysis of air bubbles trapped in an Antarctic ice core extending back 800,000 years documents the Earth's changing carbon dioxide concentration. Over this long period, natural factors have caused the atmospheric carbon dioxide concentration to vary within a range of about 170 to 300 parts per million (ppm). Temperature-related data make clear that these variations have played a central role in determining the global climate. As a result of human activities, the present carbon dioxide concentration of about 385 ppm is about 30 percent above its highest level over at least the last 800,000 years. In the absence of strong control measures, emissions projected for this century would result in the carbon dioxide concentration increasing to a level that is roughly 2 to 3 times the highest level occurring over the glacial-interglacial era that spans the last 800,000 or more years.

- Analysis of air bubbles trapped in an Antarctic ice core
- Range between 170-300 ppm for the past 800,000 yr
- Present concentration is 385 ppm
- Expect to increase to 550 or 900 ppm in the absence of strong control measures

Human Activities Have Led to Large Increase of Greenhouse Gases (GHGs)



Source: http://www.epa.gov/globalwarming/publications/emissions

Radiative Forcing Components

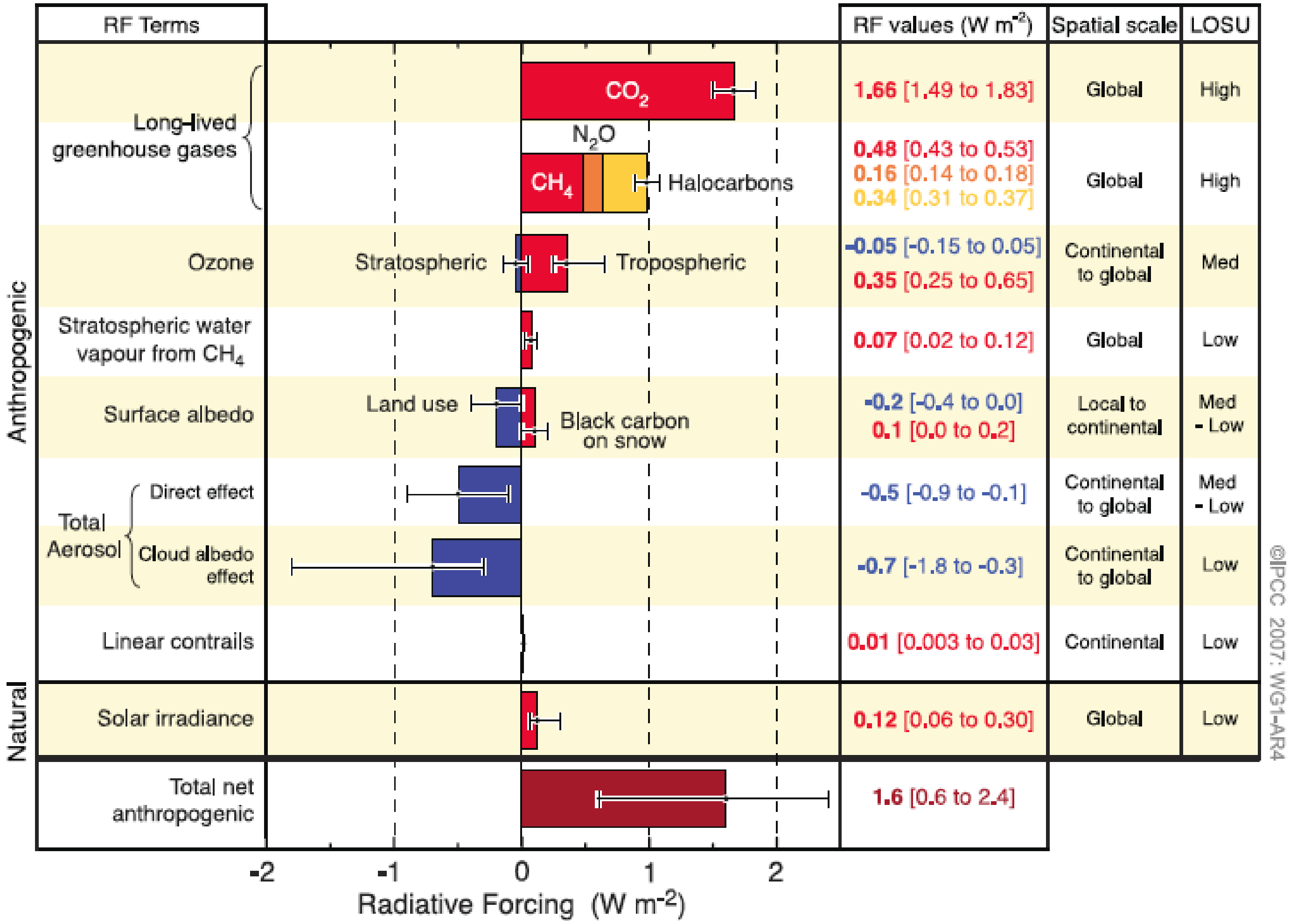
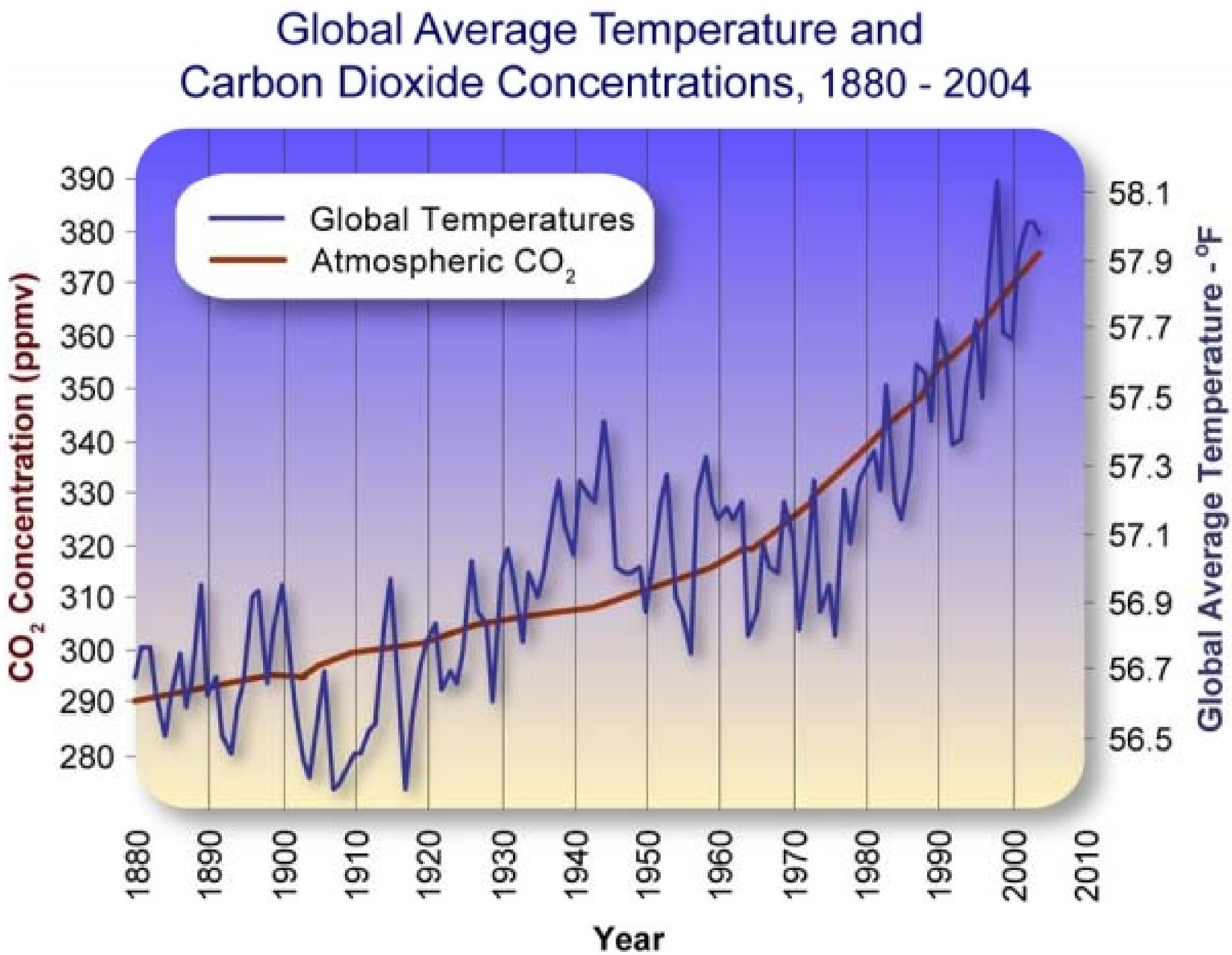
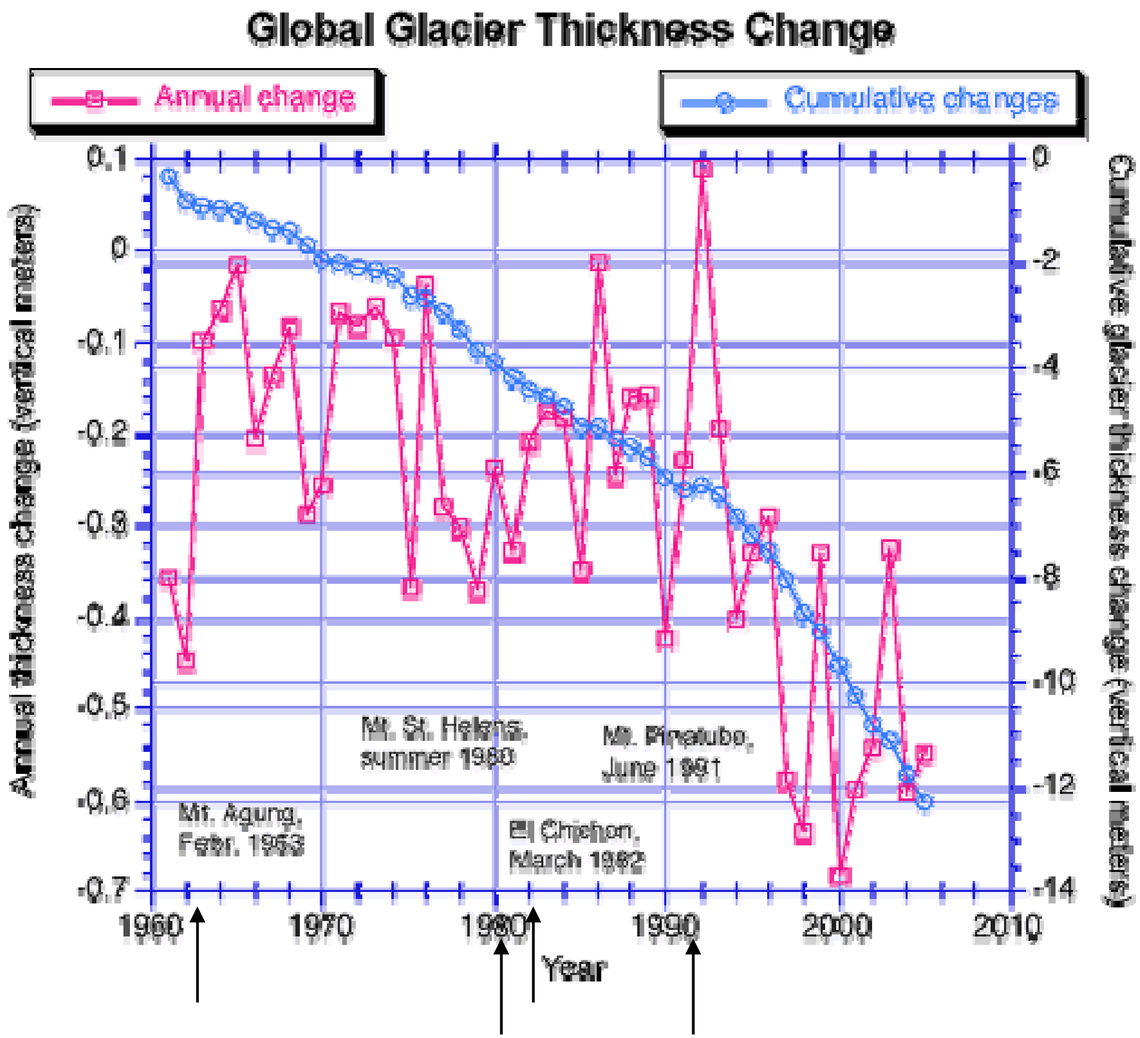


Figure SPM.2. *Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. The range for linear contrails does not include other possible effects of aviation on cloudiness. {2.9, Figure 2.20}*

Global Average Temperatures are Rising



Year to year fluctuations in temperature are due to natural processes, such as the effects of El Ninos, La Ninas, and the eruption of large volcanoes



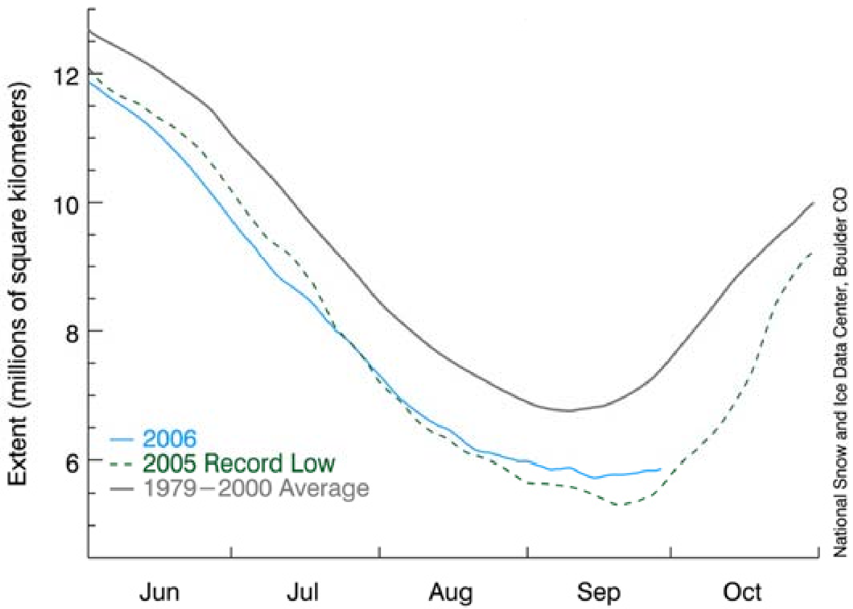
Global Glacier Thickness Change: This shows average annual and cumulative glacier thickness change, measured in vertical meters, for the period 1961 to 2005. Image courtesy of Mark Dyurgerov, Institute of Arctic and Alpine Research, University of Colorado, Boulder.

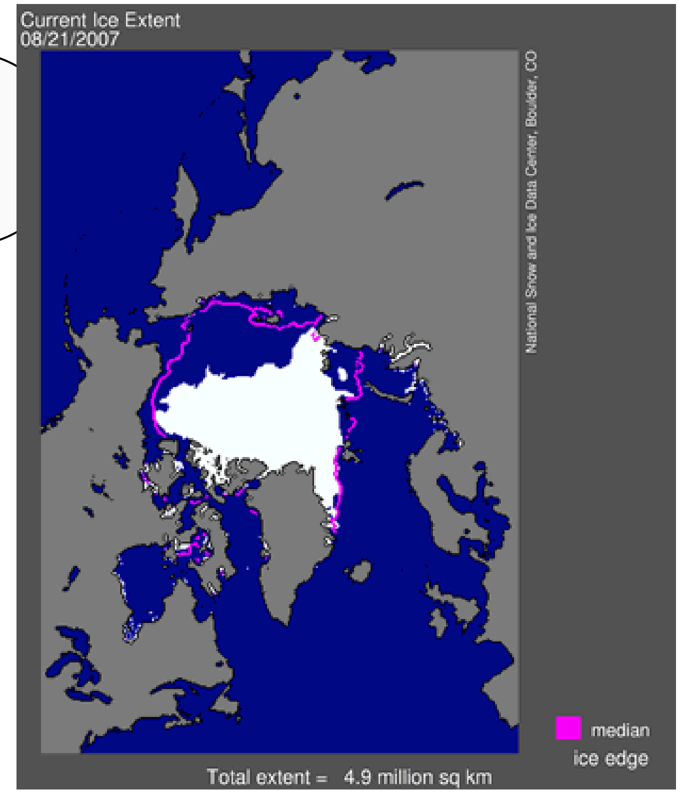
Glacier Retreat

Muir Glacier, photographed by William O. Field on 13 August 1941 (left) and by Bruce F. Molnia on 31 August 2004 (right).

- **1941-2004 comparison:** Glacier Bay National Park and Reserve's White Thunder Ridge as seen on August 13, 1941 (left) and August 31, 2004 (right). Muir Glacier has retreated out of the field of view, Riggs Glacier has thinned and retreated significantly, and dense new vegetation has appeared. Muir Glacier was more than 2,000 feet thick in 1941. 2004 USGS photo by B. F. Molnia; 1941 photo by W. O. Field. See Repeat Photography of Glaciers in the Glacier Photograph Collection to access this and other photograph pairs.

ARTIC SEA ICE EXTENT

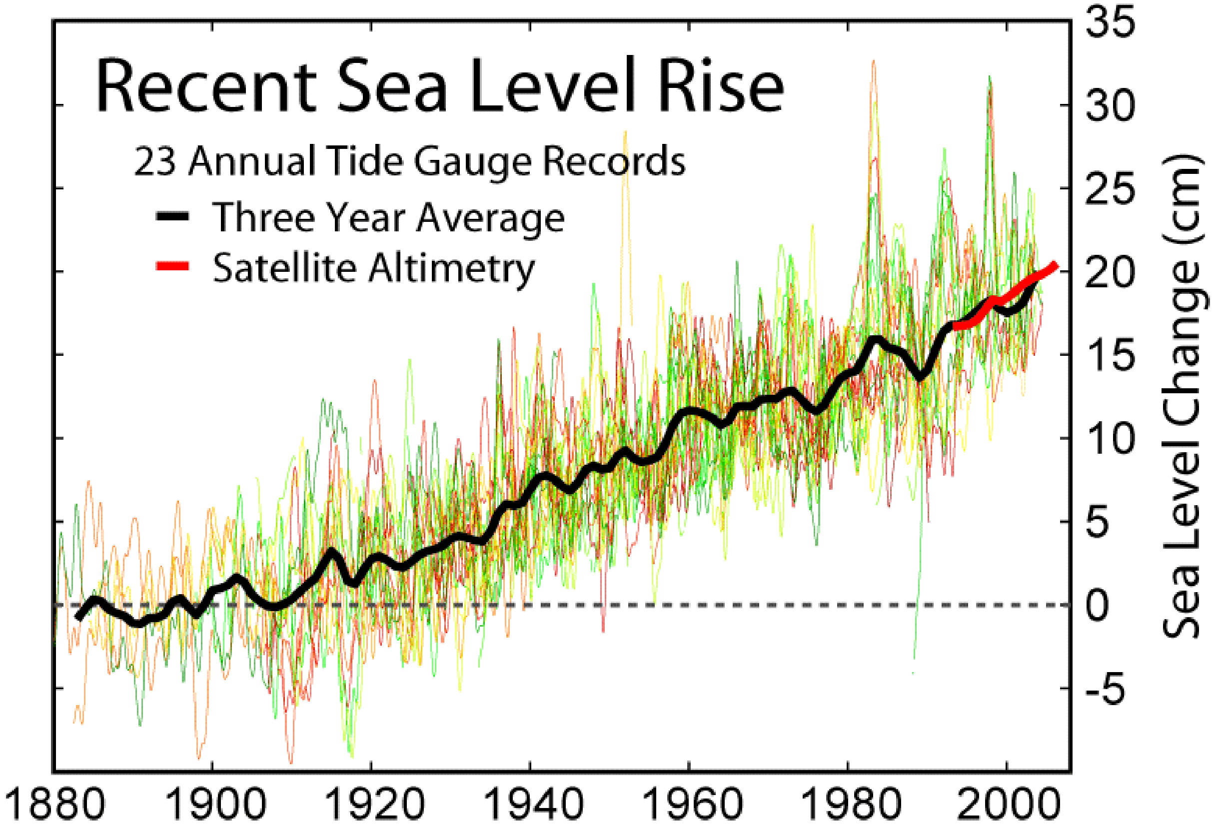




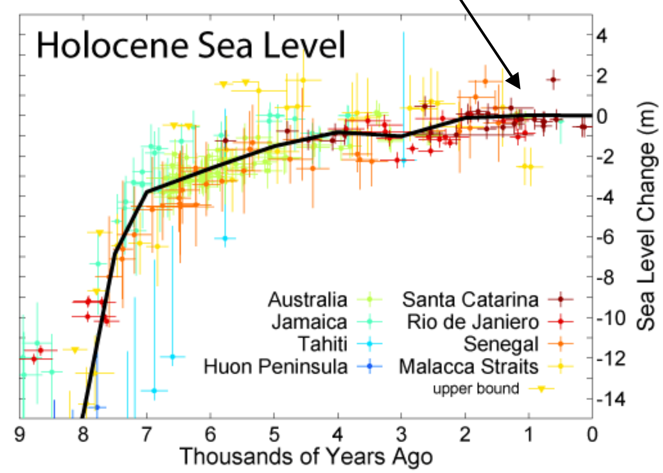
“Weather patterns in 2007 indicate that the sea ice could be reduced to a lower level than in 2005. "The Arctic is experiencing an unprecedented sixth consecutive year with much less sea ice than normal," the bulletin continued. The NSIDC also warned that "this year's sea ice melt season may herald a new and steeper rate of decline.” (NSIDC)

Figure 1 provides a map of sea ice extent for August 21, 2007. Sea ice extent now stands at 4.92 million square kilometers (1.89 million square miles). The magenta line shows the median August sea ice extent based on data from 1979 to 2000.

Sea Level is Rising



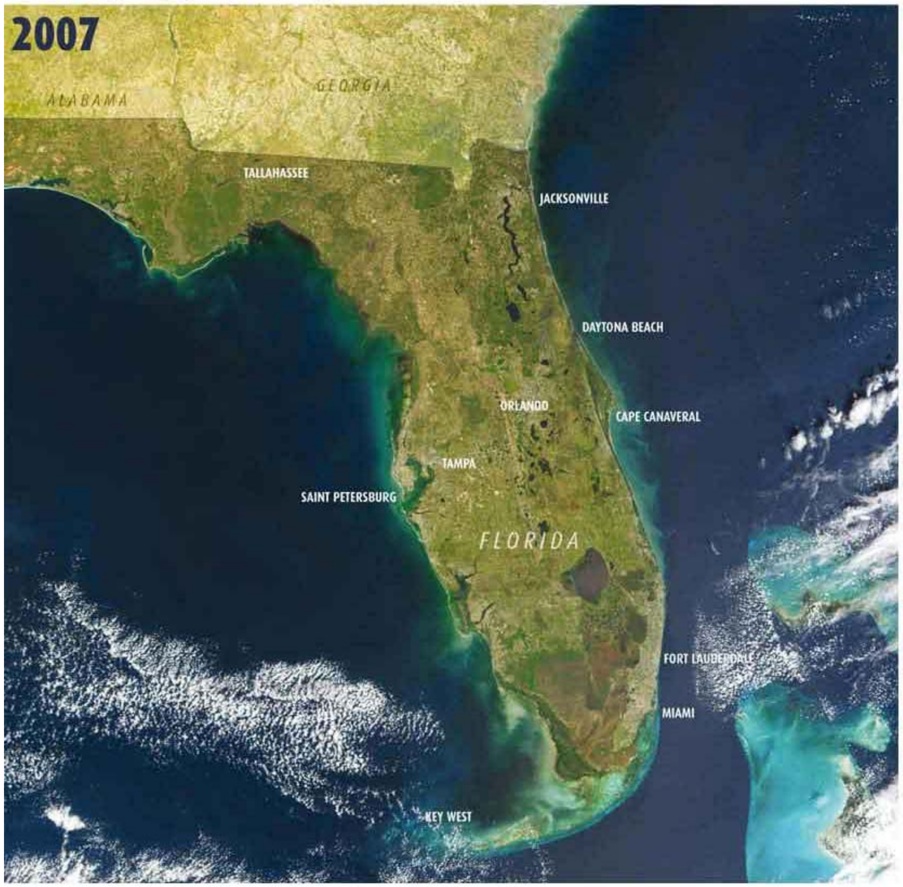
Relatively constant for the past 2000 yrs

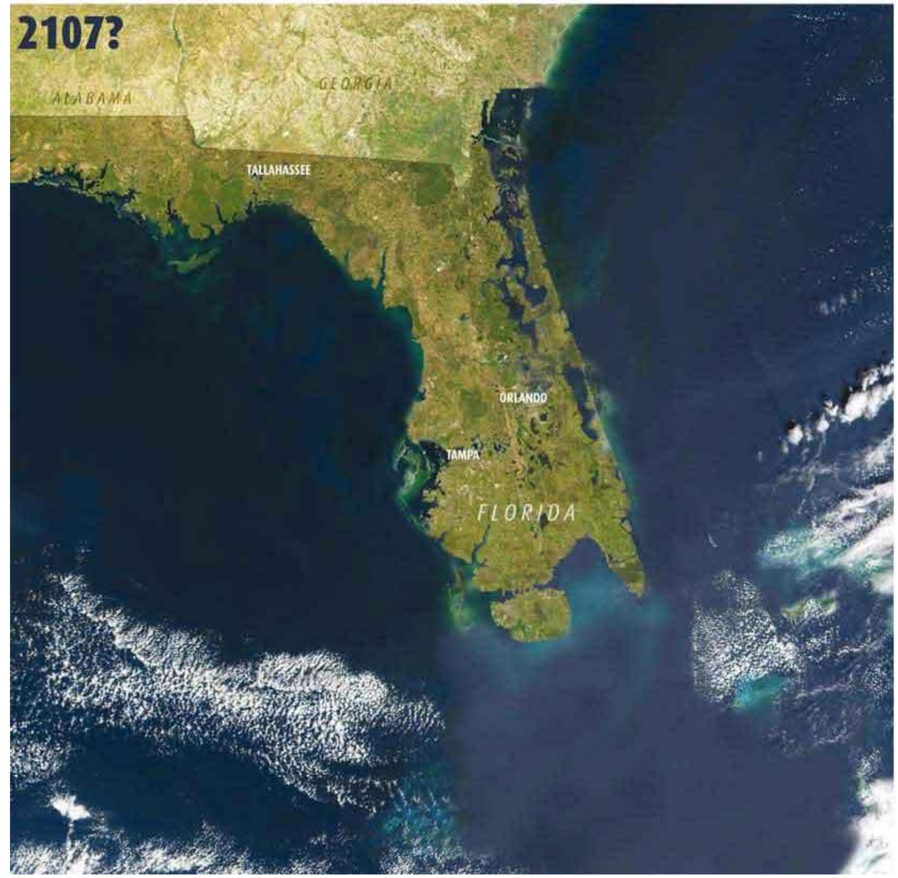


- Water expands as it warms
- Warming leads to the melting of glaciers and ice sheets

Image created by Robert A. Rohde / Global Warming Art":
http://www.globalwarmingart.com/wiki/File:Recent_Sea_Level_Rise_png

Seal Level Rise - Florida

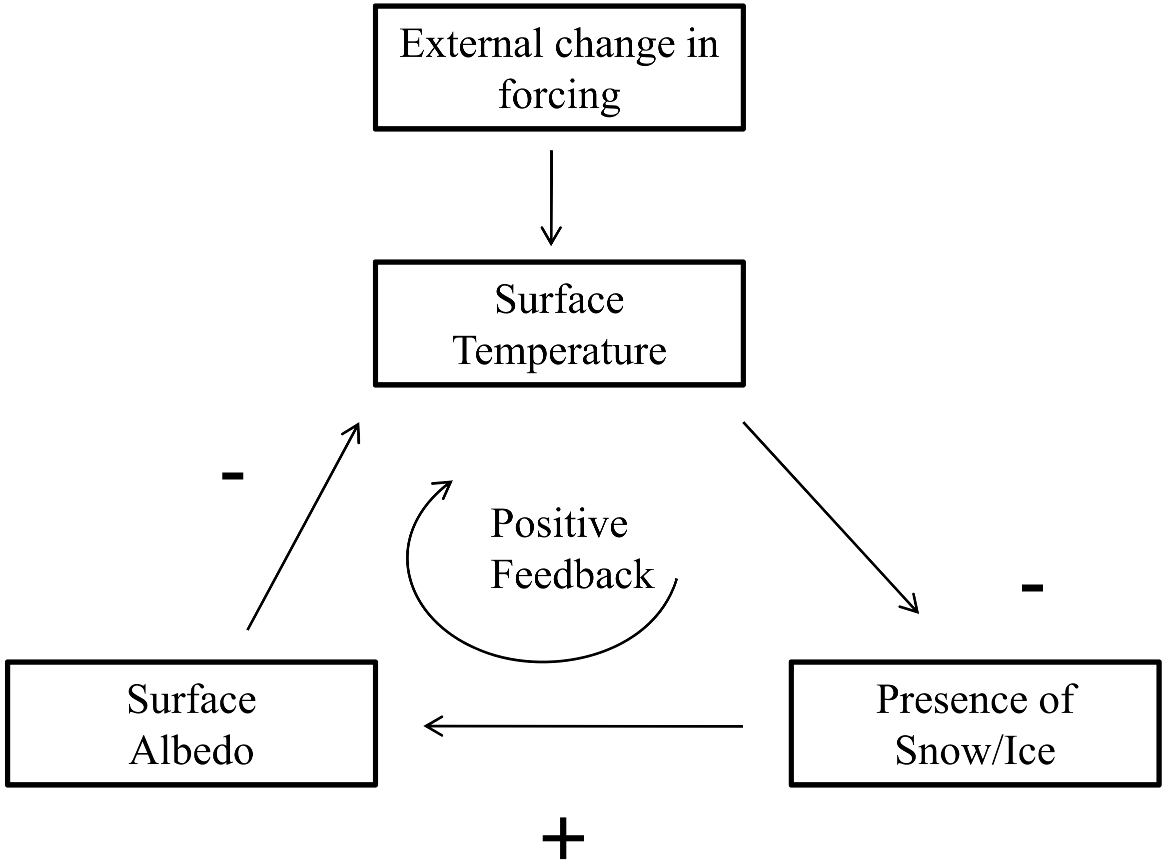




Sea Level Rise: 5m

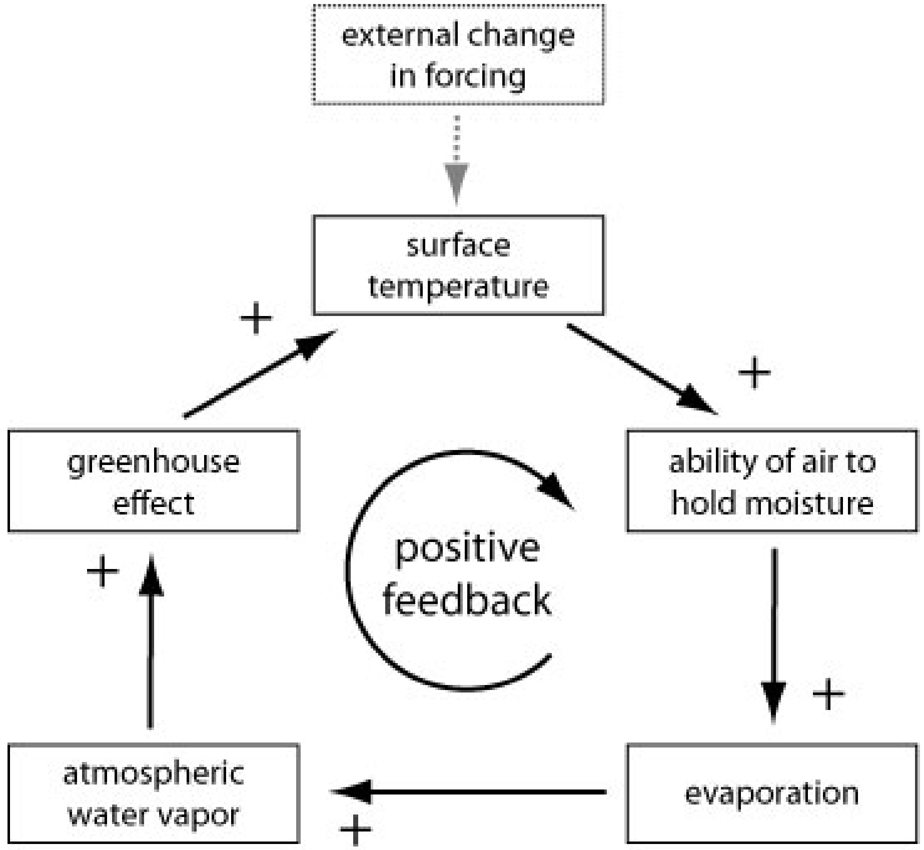
Source:**Huge sea level rises are coming – unless we act now**• 25 July 2007•NewScientist.com news service•**James Hansen**

Tipping Point: Positive Feedbacks
(1) The Snow/Ice Albedo Feedback



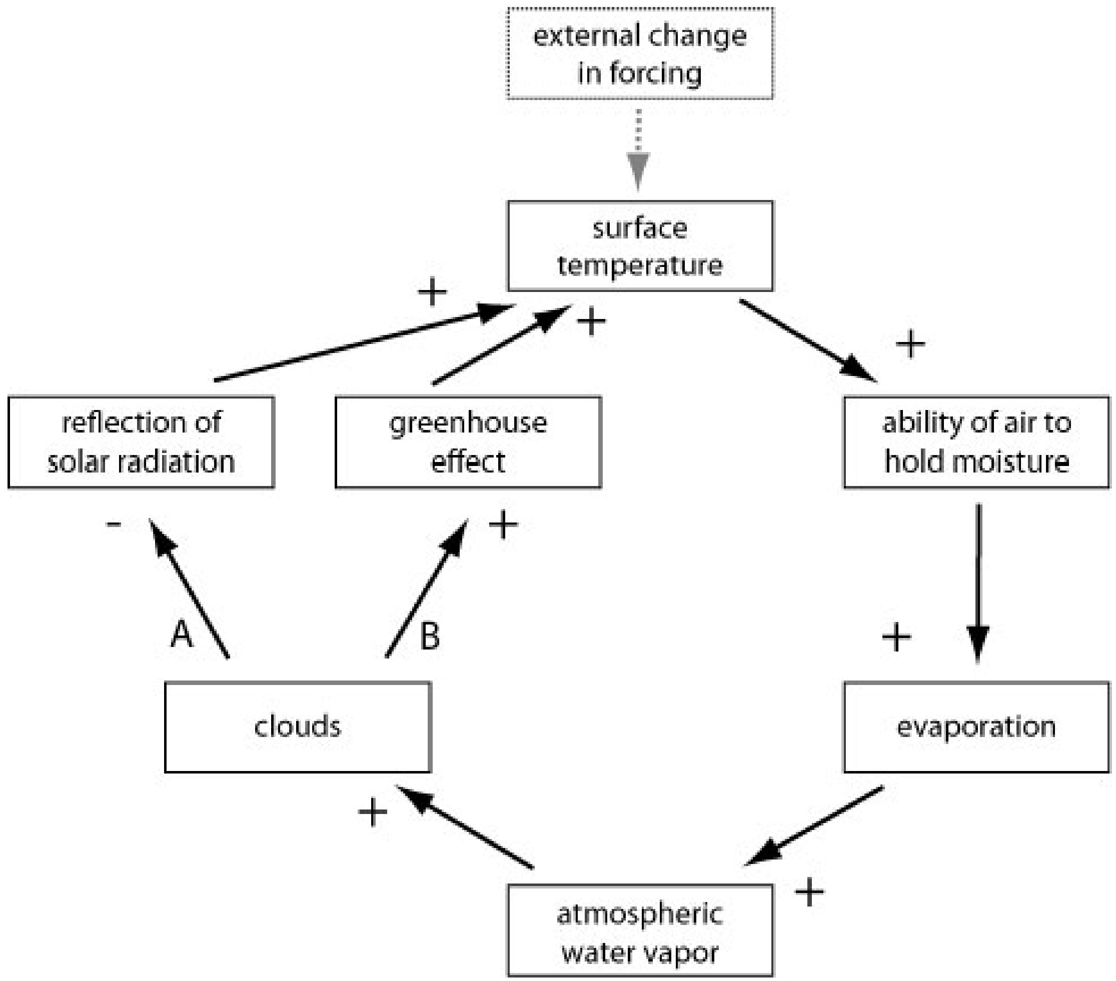
An external change that warms the surface reduces the presence of snow, lowers the surface albedo, thereby amplifying the warming (a positive feedback).

(2) The water vapor feedback



An external change that warms the surface heats the lower atmosphere. Since warmer air can hold more moisture, this enhances surface evaporation and the amount of water vapor in the atmosphere. More water vapor results in a stronger atmospheric greenhouse effect, thereby amplifying the initial change (a positive feedback).

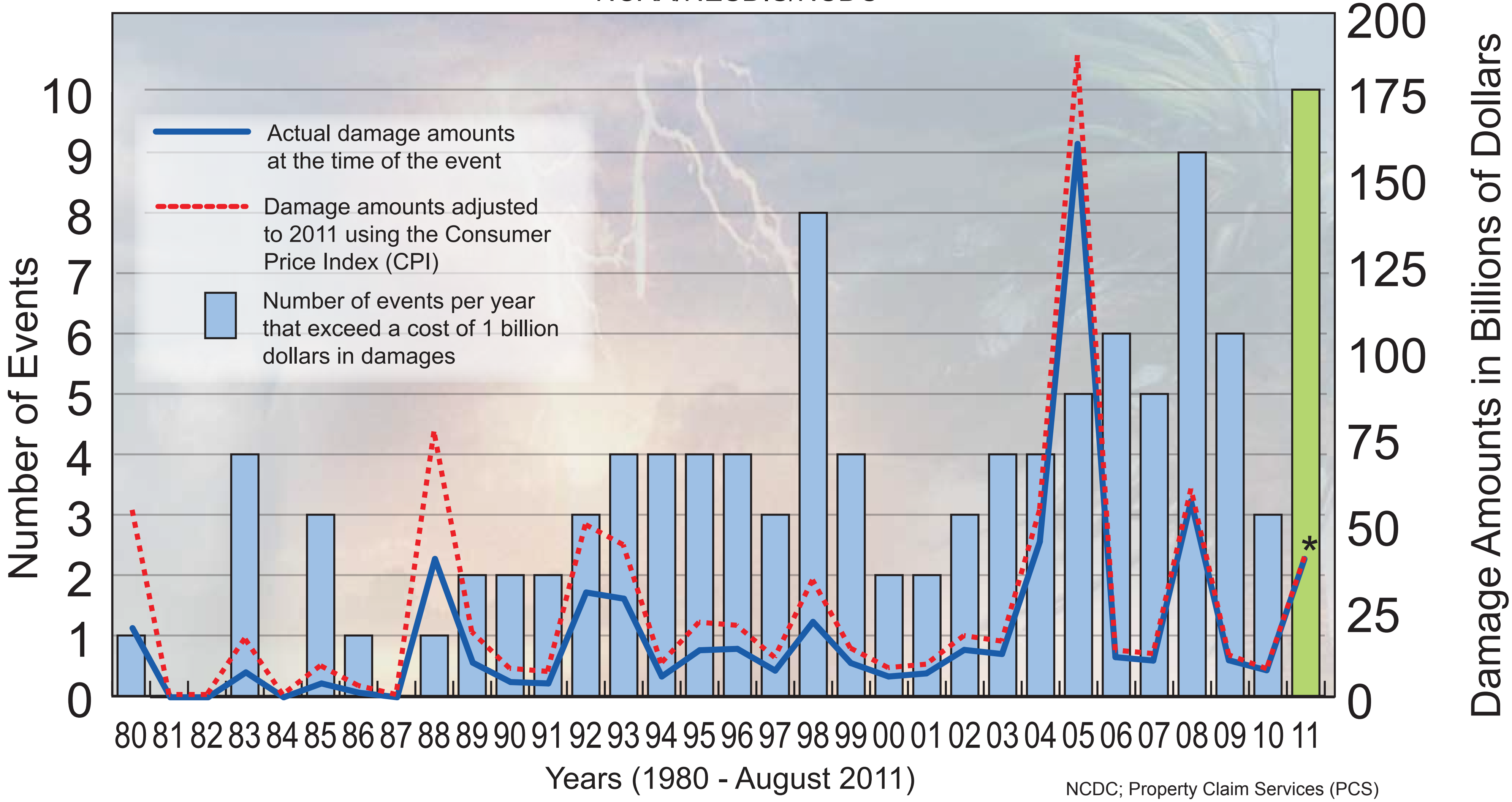
(3) Cloud Feedback



More water vapor in the atmosphere can result in more clouds. Depending on the balance of increased cloud cover on shortwave reflection (path A) or increased greenhouse forcing (path B), cloud feedbacks can form both, positive and negative feedback loops on surface temperature.

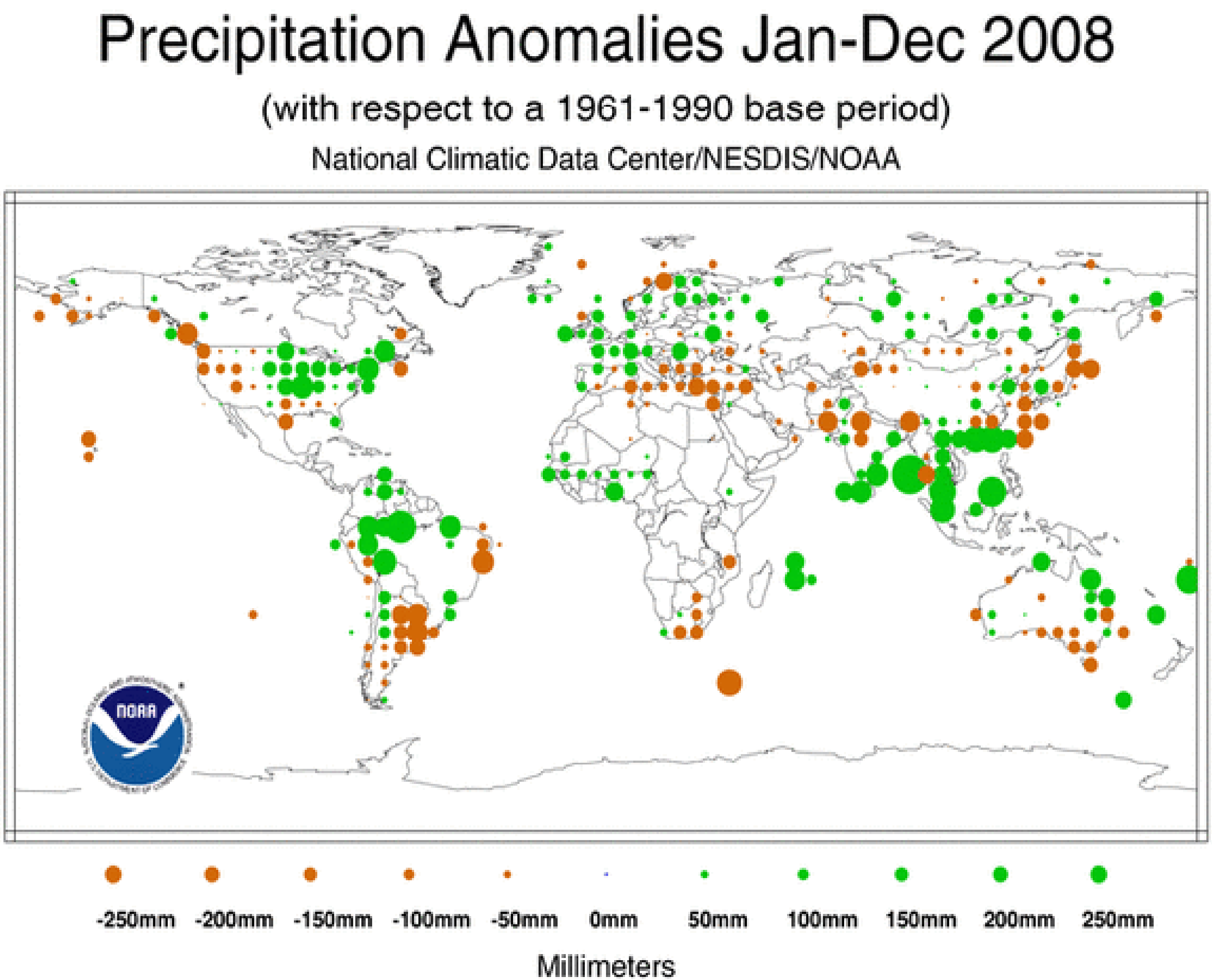
Billion Dollar U.S. Weather/Climate Disasters
1980 - August 2011

NOAA/NESDIS/NCDC

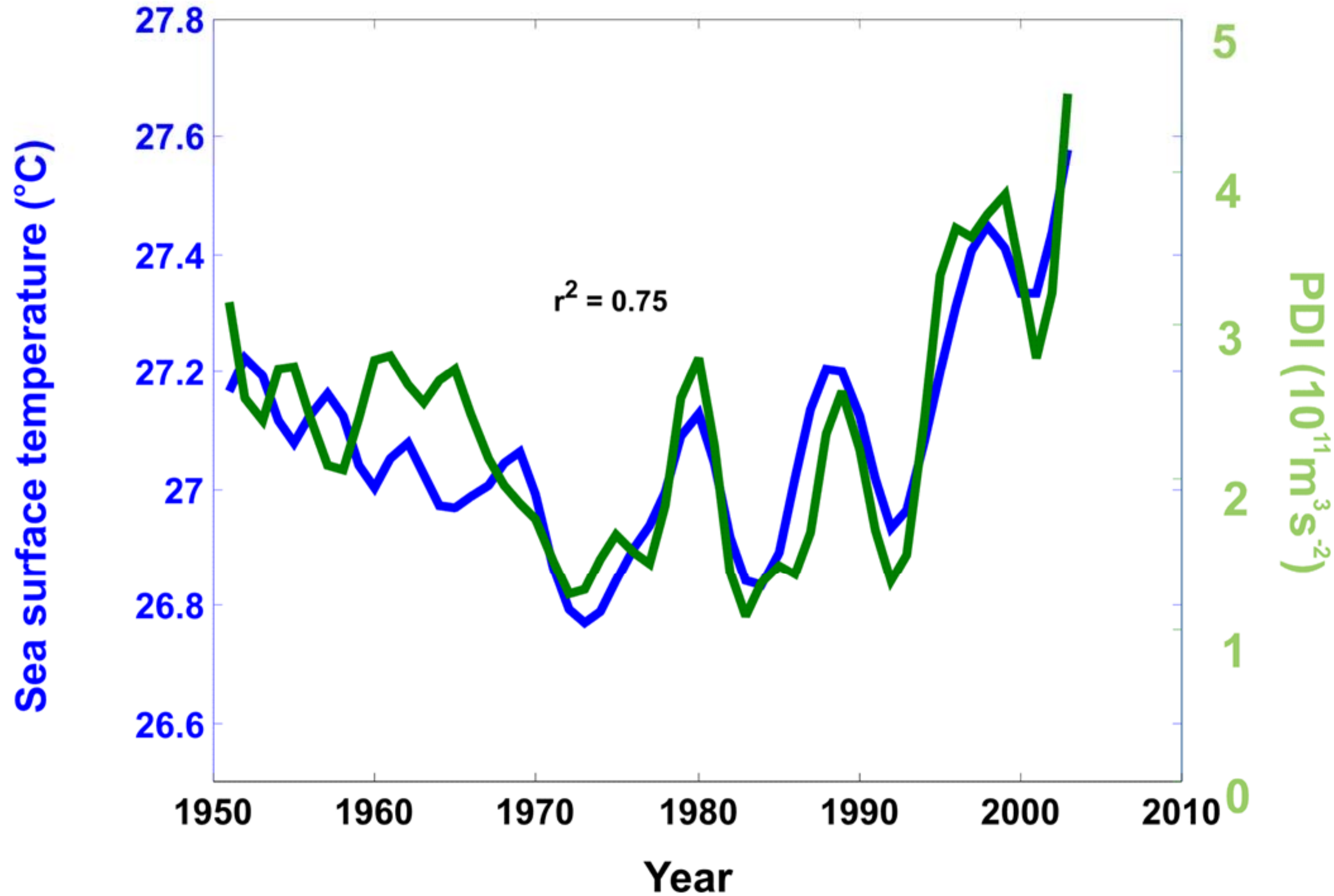


* This damage amount does not take into account the losses from Hurricane Irene

Extreme Events (Global precipitation)

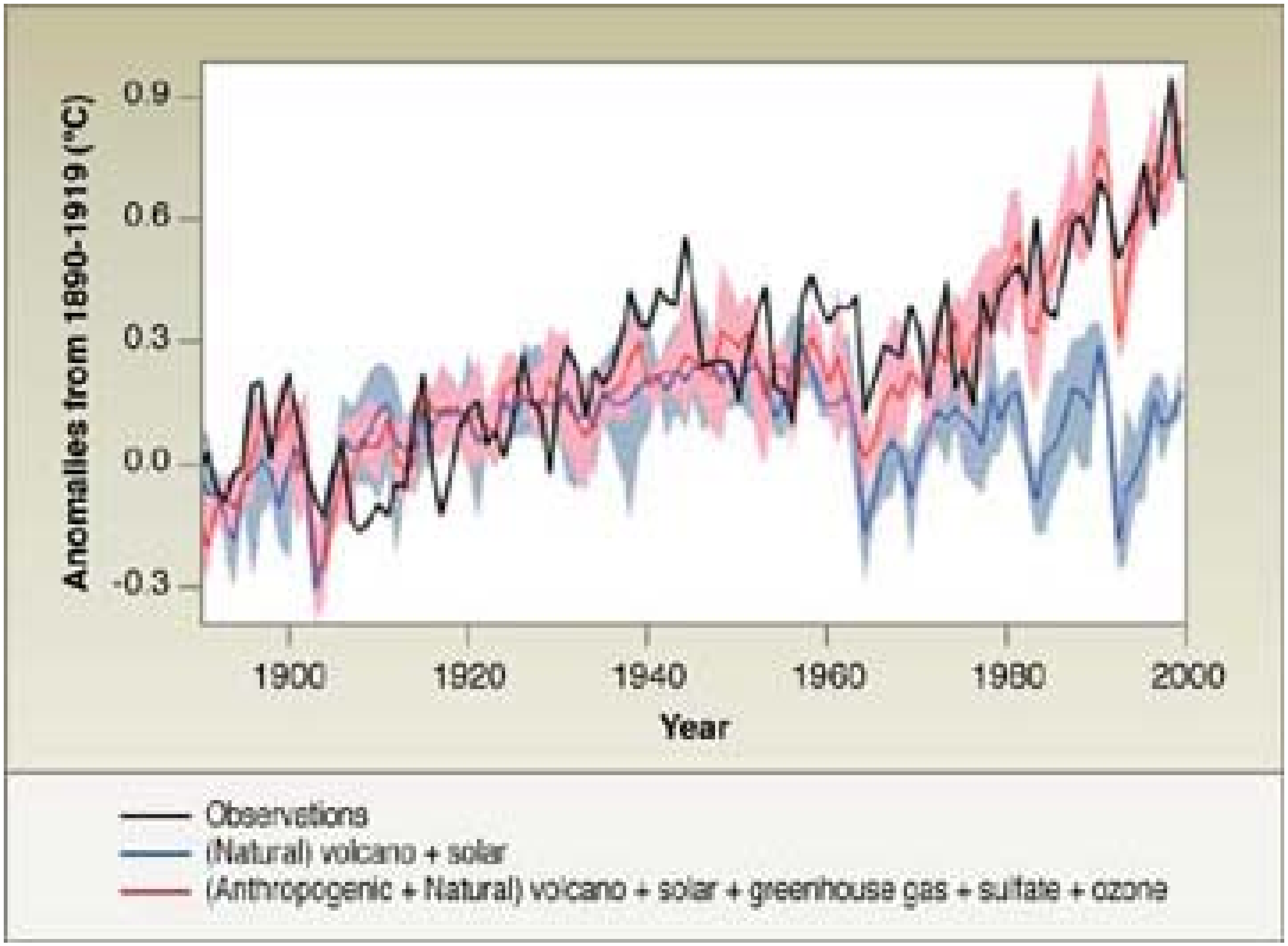


Correlation Between Sea Surface Temperatures and Hurricane Power in the North Atlantic Ocean



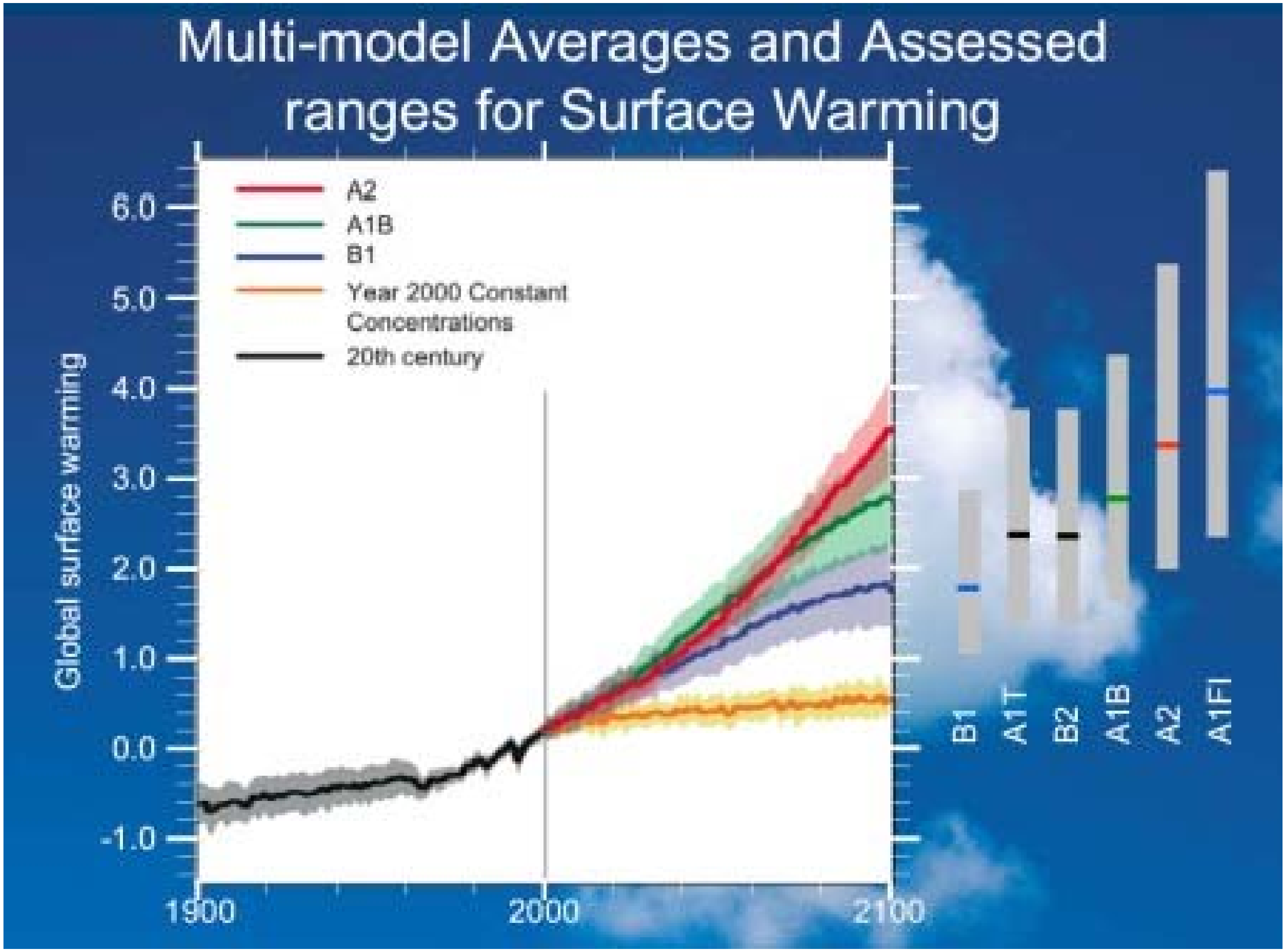
It is premature to conclude that human activity--and particularly greenhouse warming--has already had a discernible impact on Atlantic hurricane activity.
It is likely that greenhouse warming will cause hurricanes in the coming century to be more intense on average and have higher rainfall rates than present-day hurricanes.

Climate Model can Separate Human and Natural Influences on Climate



Without human influences, temperature over the past century would actually first warmed and then cooled slightly over recent decades

Future Prediction of Global Surface Temperature



Worst scenario (A2), temperature will rise 3.6°C by year 2100

Multiple Lines of Evidence for a Human Influence on Global Climate

- Basic physical understanding of greenhouse effects, how climate responds to increase in GHGs
- Indirect estimates of climate changes over the last 1,000 to 2,000 years, indicating unusual global surface temperature pattern.
- Broad, qualitative consistency between observed changes in climate and the computer model simulations
- Extensive statistical evidence from "fingerprint" studies. Models can capture not only present-day climate, but also key features of past climate changes

Expected Climate Changes

- Rising global temperature
- Changing precipitation patterns
- Currently rare extreme events are becoming more common
  - Droughts and floods, heat waves, stronger storms/hurricanes
- Sea level will continue to rise
  - Ranging from 8 inches to 3 to 4 feet by 2,100
- Abrupt climate change possible
  - Rapid ice sheet collapse → sea-level rise
  - Abrupt release of methane from thawing of frozen soils, from the sea floor, and from wetlands
  - The operation of the ocean current