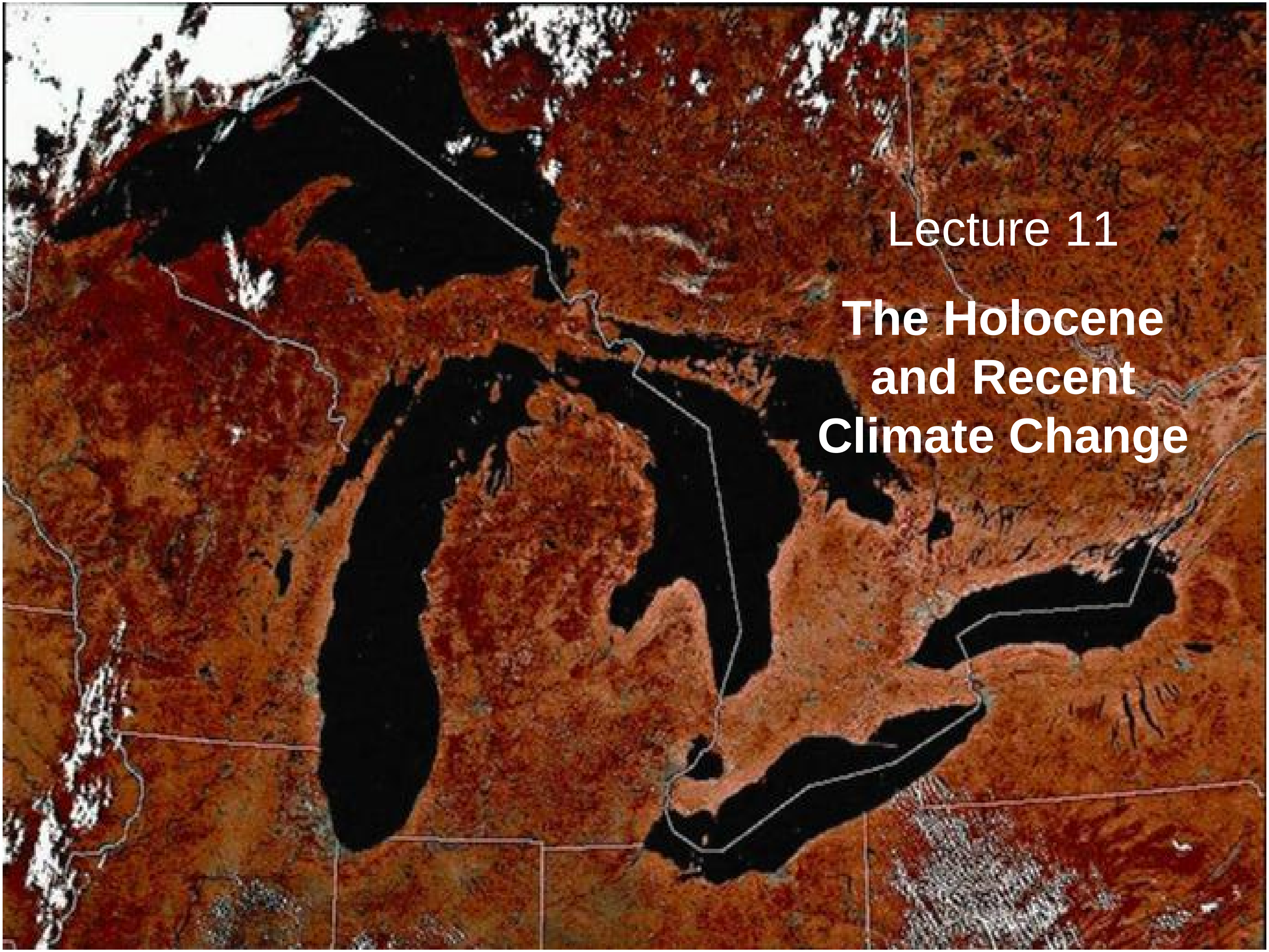
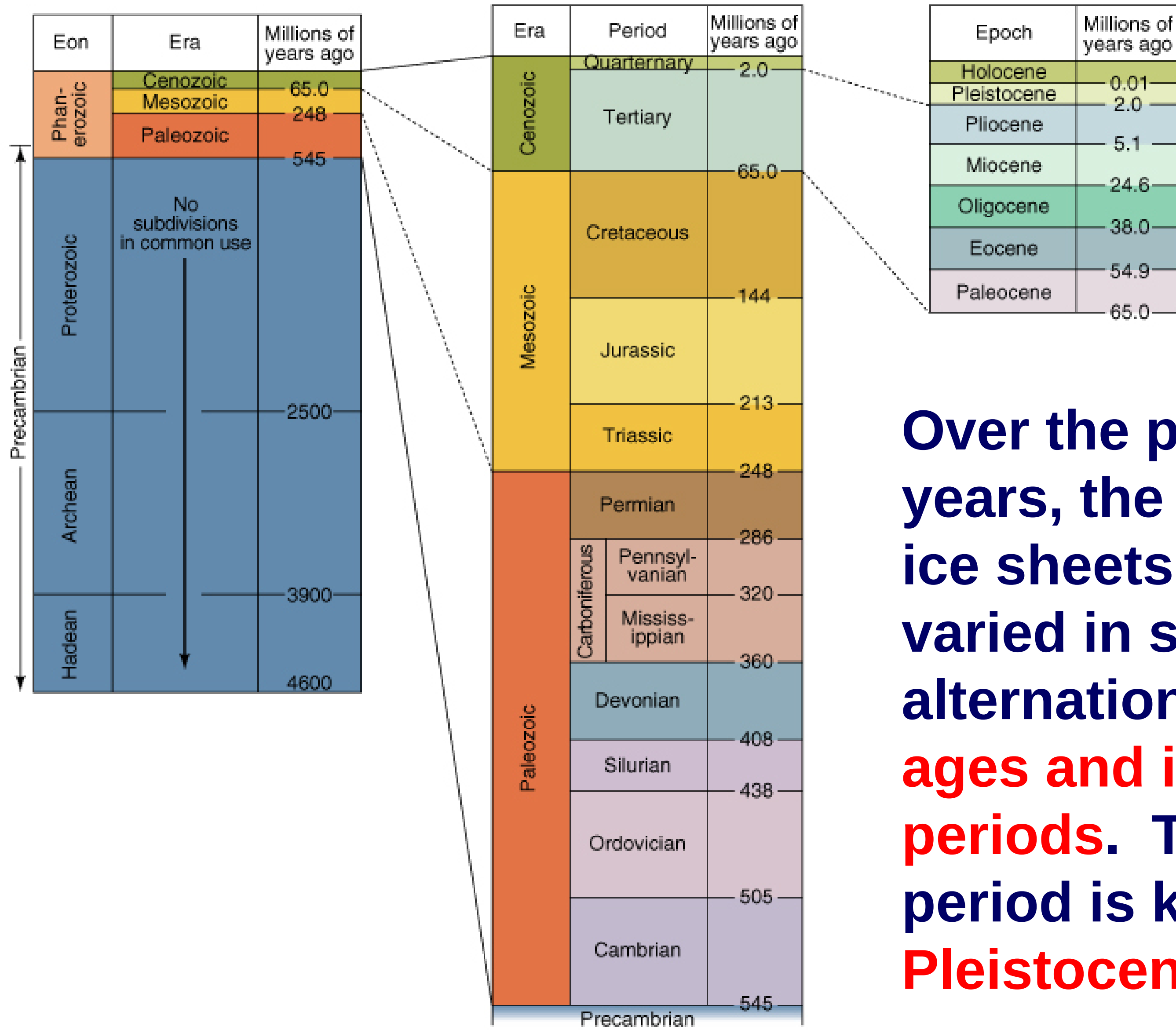


Lecture 11

The Holocene and Recent Climate Change



Over the past 2 million years, the Earth has had ice sheets which have varied in size, causing alternations between ice ages and interglacial periods. This entire time period is known as the Pleistocene.

The Holocene : Recovery from the last ice age

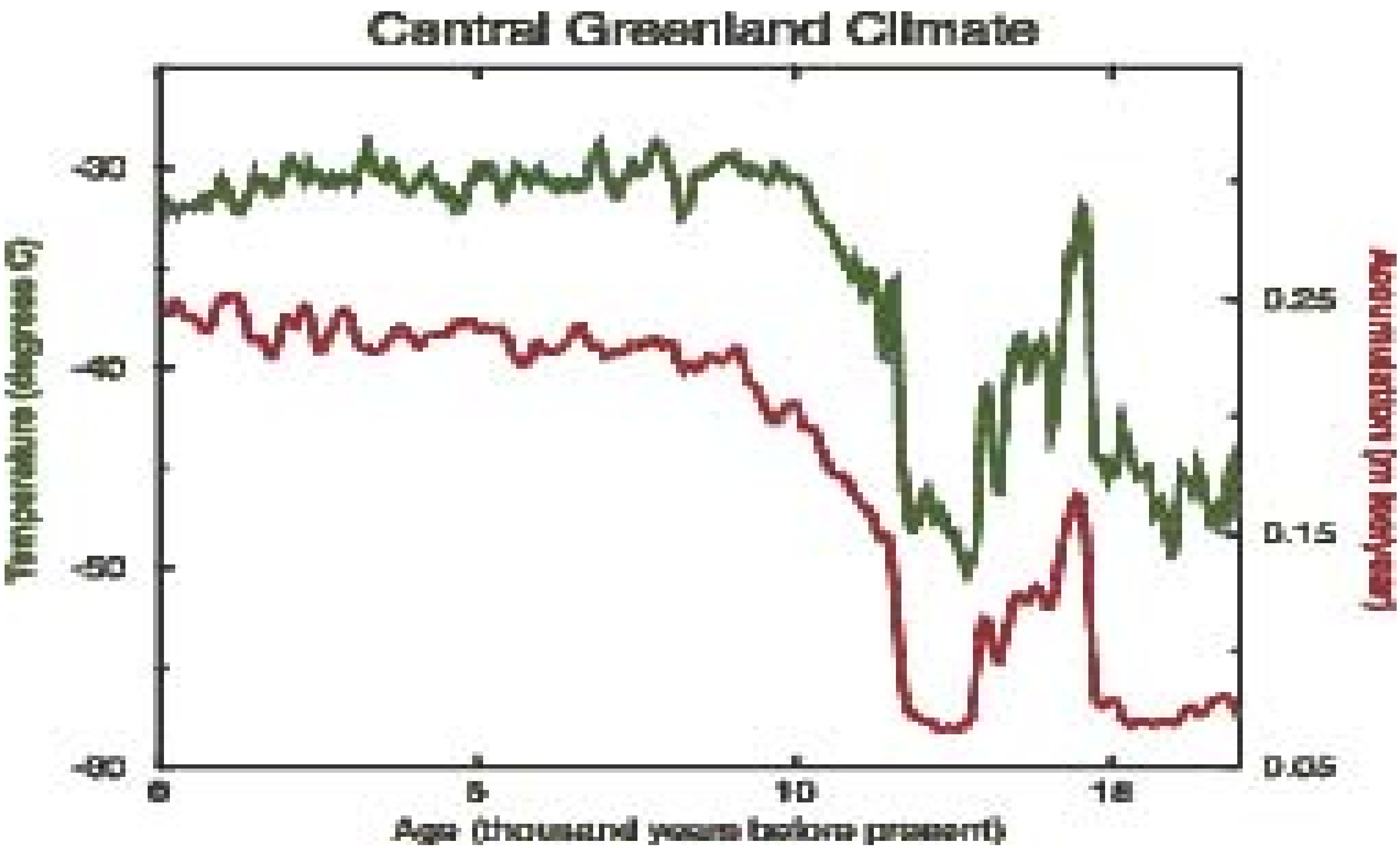
About 15,000 years ago, the earth began to warm and the huge ice sheets covering much of North America and Eurasia began to melt, leading to a number of impacts:

(1) lake formation in regions left behind by glaciers.

(2) sea level rise.

(3) colonization of formerly glaciated regions by vegetation, and huge changes in the ecology of other regions due to the overall global-scale warming.

About 14,000 years ago, the warming trend was reversed in the North Atlantic, ushering in the period known as the Younger Dryas. This relatively cold period lasted about 2,000 years. The North Atlantic climate warmed very abruptly about 12,000 years ago, and has been relatively stable since then.



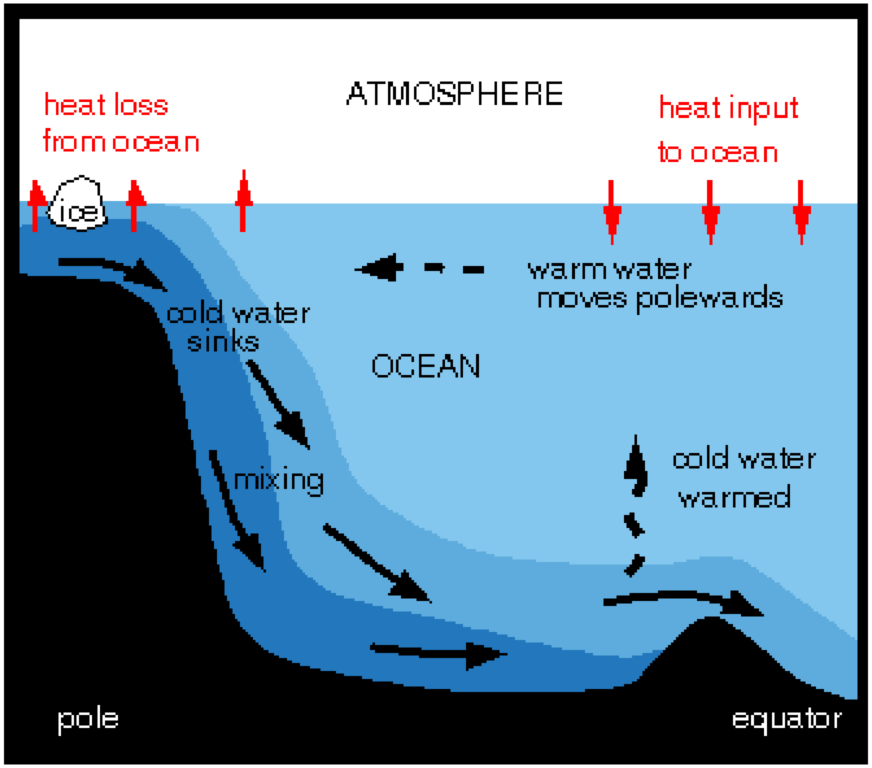
The Younger Dryas was probably caused by a massive flooding of the North Atlantic by freshwater outflow from the melting ice sheets.

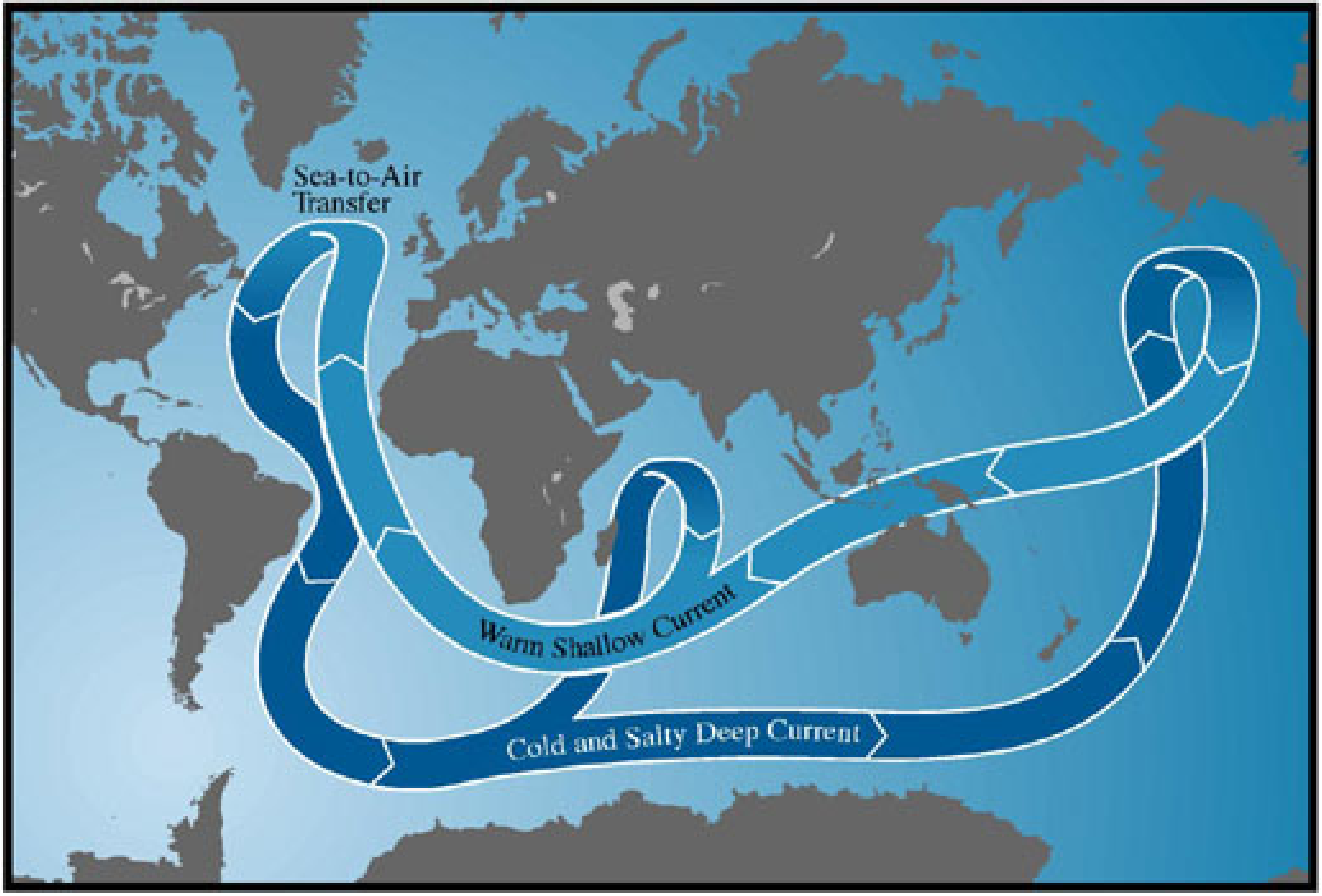
Studies with numerical models of the climate system indicate that a large meltwater pulse could cause a shutdown of the thermohaline circulation and cooling of the magnitude observed.

As we have noted in a earlier lecture, the thermohaline circulation transports warm water from the tropics to the northern North Atlantic, maintaining warm temperatures in this region.

Current evidence indicates the Younger Dryas was probably confined to the North Atlantic, consistent with the thermohaline shutdown mechanism.

North Atlantic thermohaline circulation

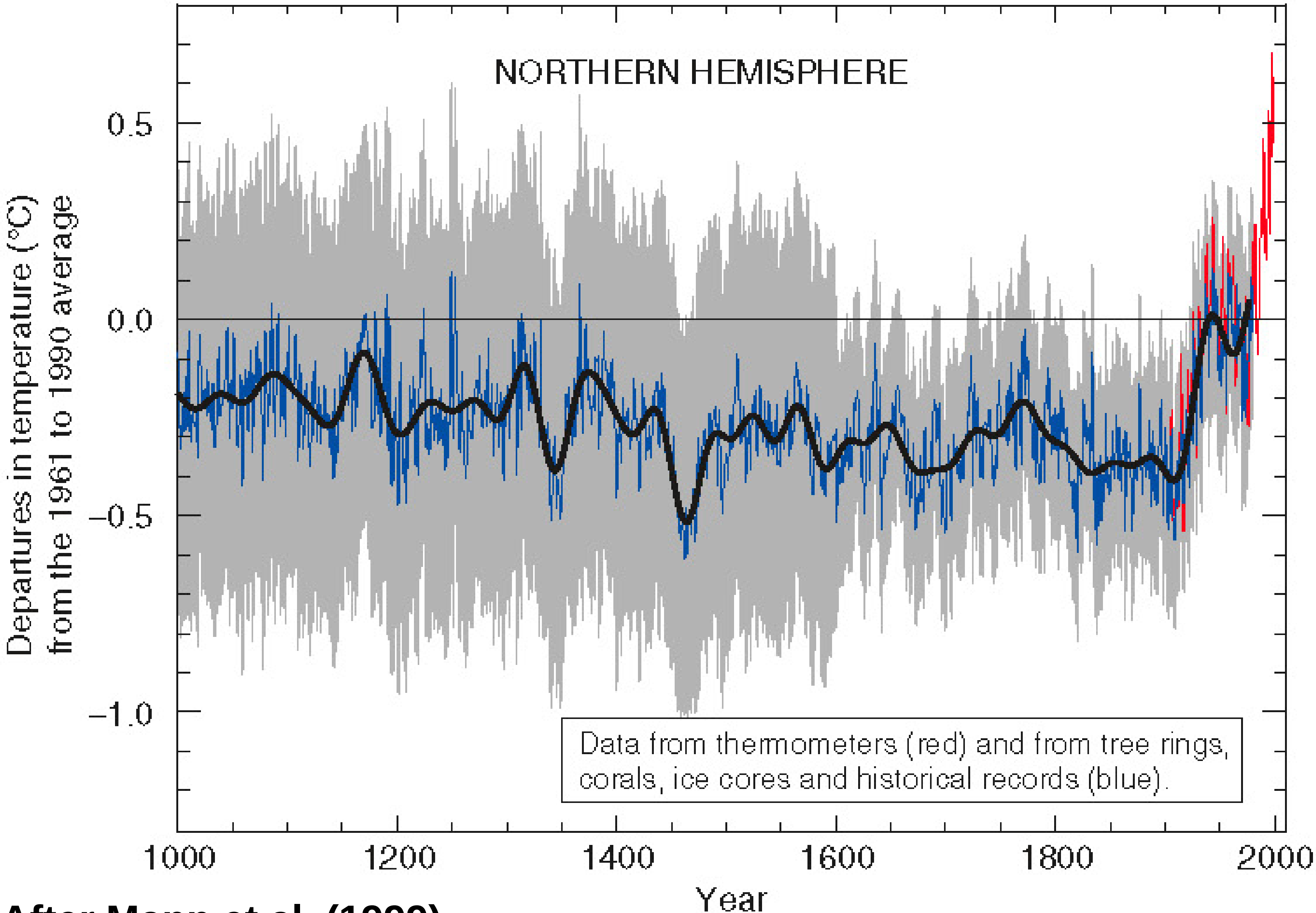




Because of its high salinity, North Atlantic water is more susceptible to sinking than other waters with the same temperature. This is therefore a major sinking region of the global thermohaline circulation. The Southern Ocean is also a site of deep convection. All of the deep water of the entire ocean originates in one of these two regions.

The climate since the Younger Dryas

(b) the past 1,000 years



After Mann et al. (1999)

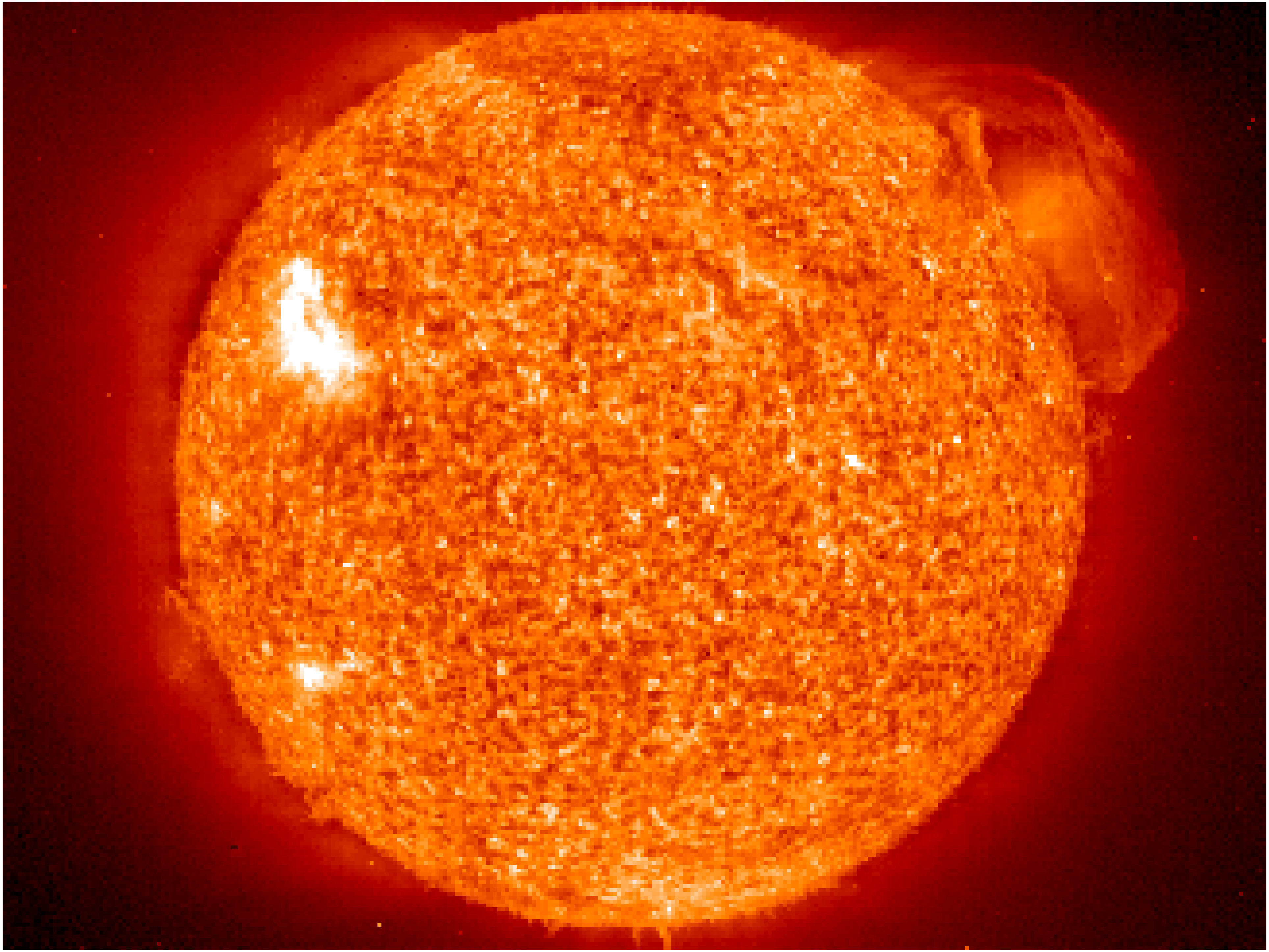
To understand the details of the recent climate record, we need to understand the possible sources of Holocene Climate variability external to the atmosphere-ocean system:

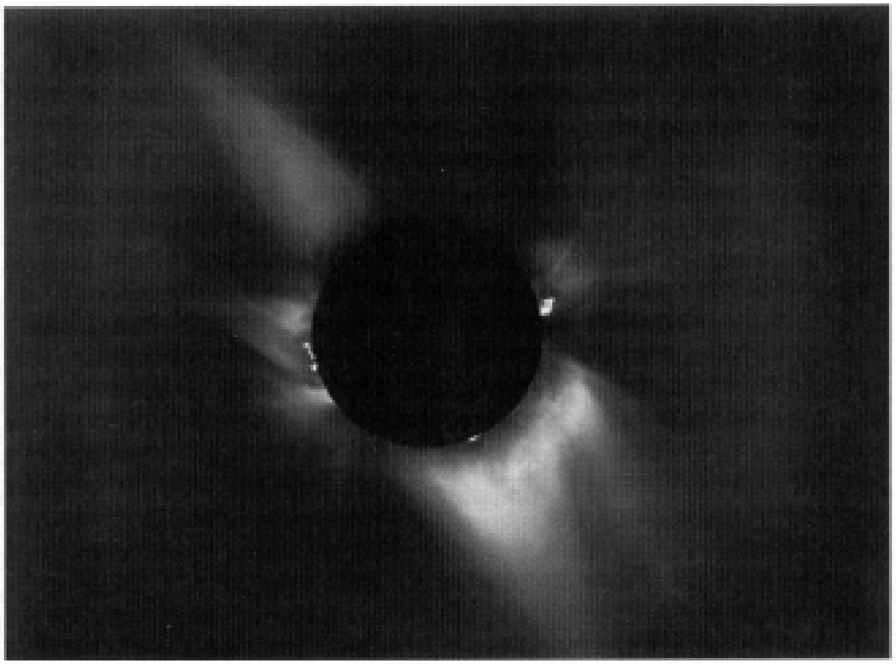
(1) Solar Variability, which can alter the radiation the Earth receives.

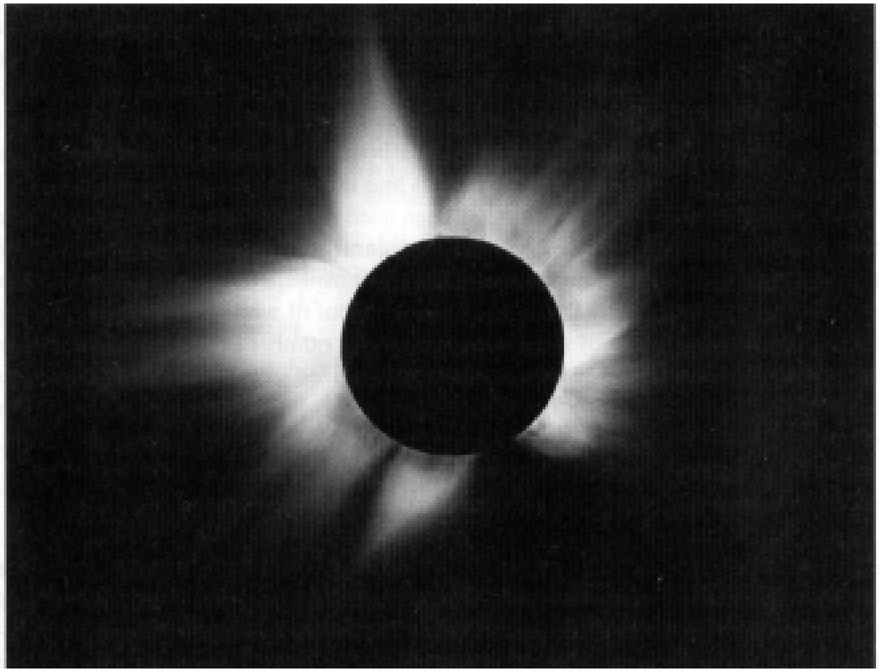
(2) Changes in aerosols, including volcanic aerosols, dust, and soot (black carbon).

(3) Increases in greenhouse gases.

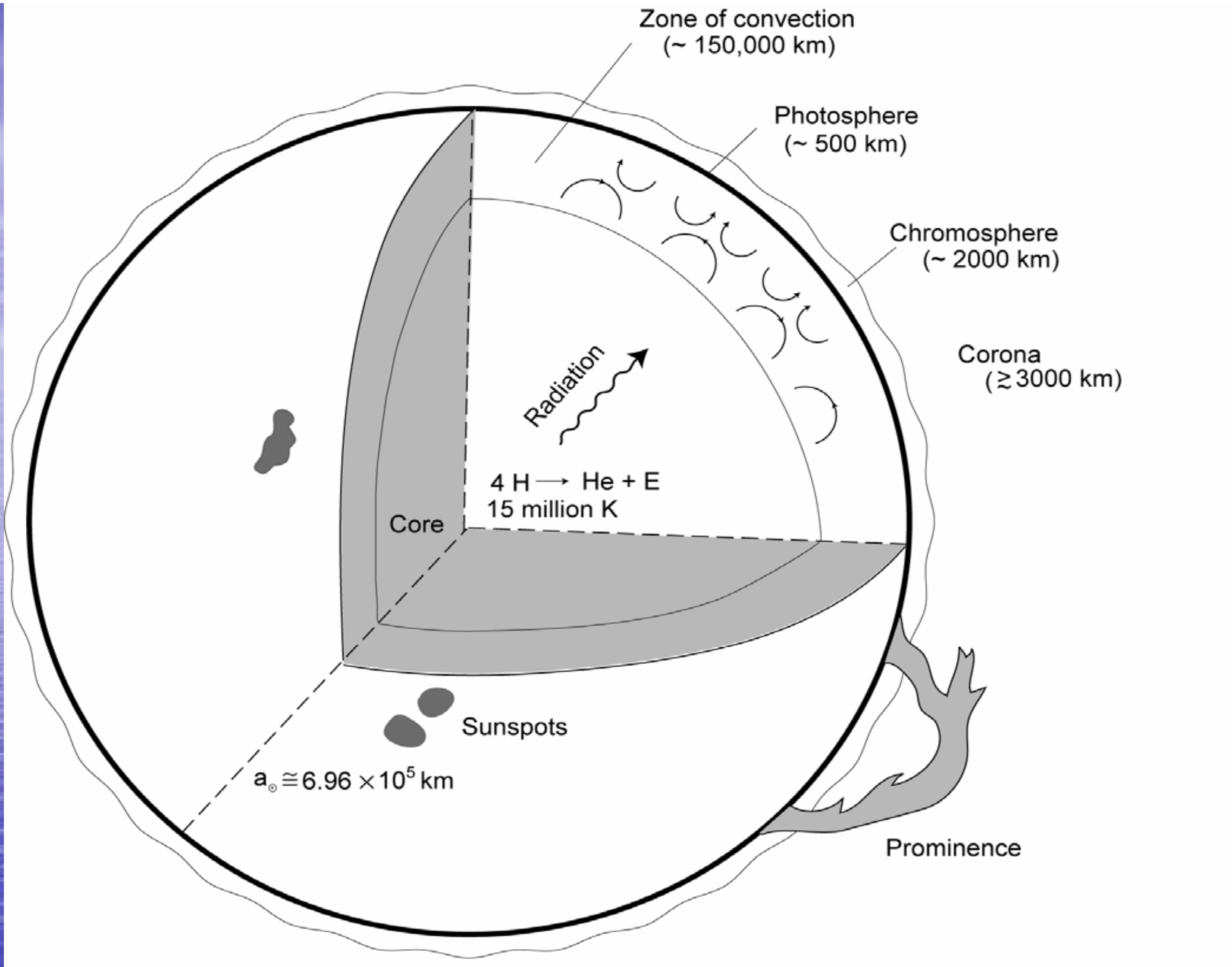
The atmosphere-ocean system also generates variability on its own.



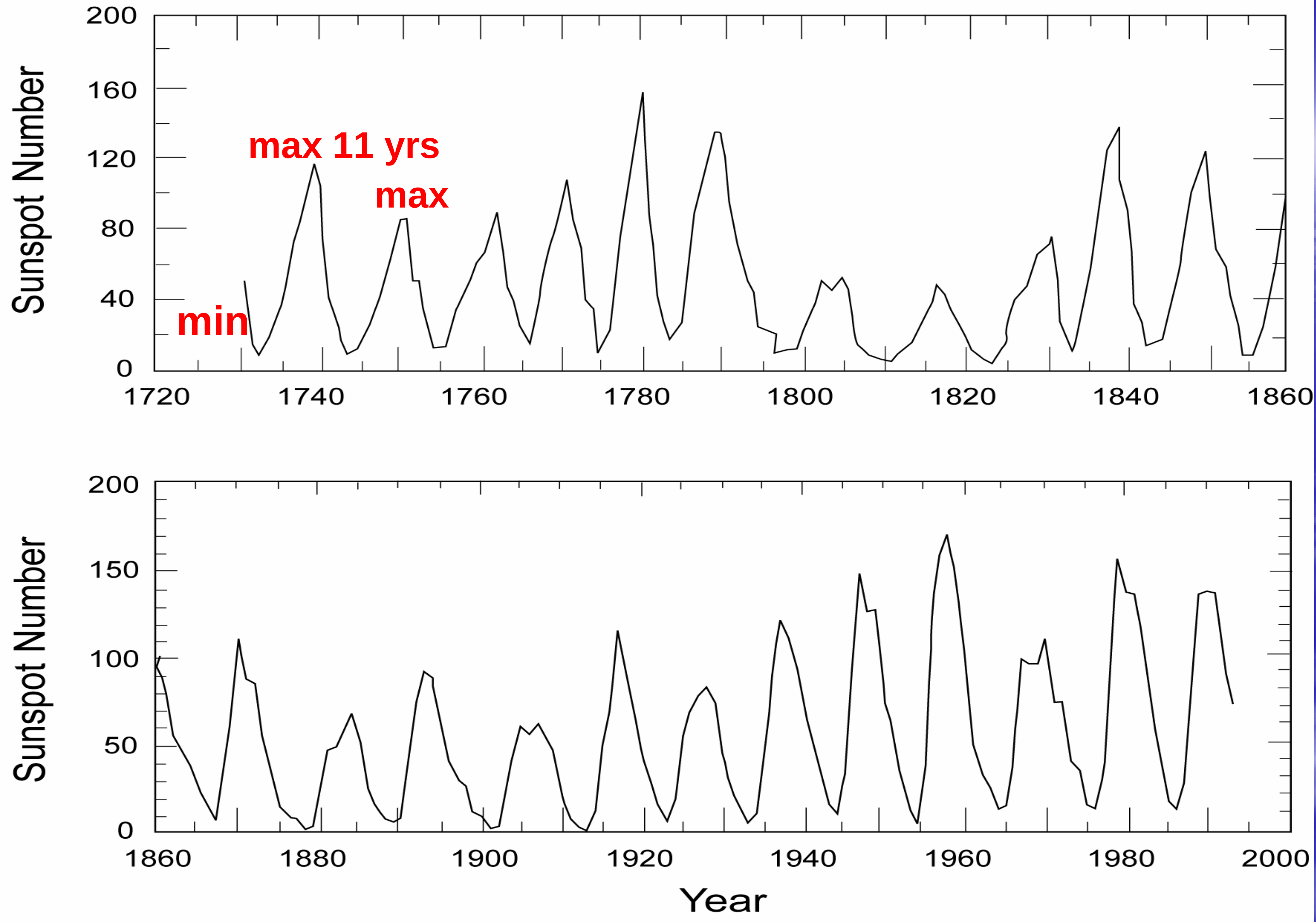




The Left picture is the total solar eclipse of July 11, 1991, photographed from Mauna Loa, Hawaii. The right picture is the solar corona during the total eclipse of March 7, 1970. Features are visible at a distance of about 4.5 solar radii or 3 million kilometers (courtesy of Rhodes College and High Altitude Observatory, Boulder, Colorado).



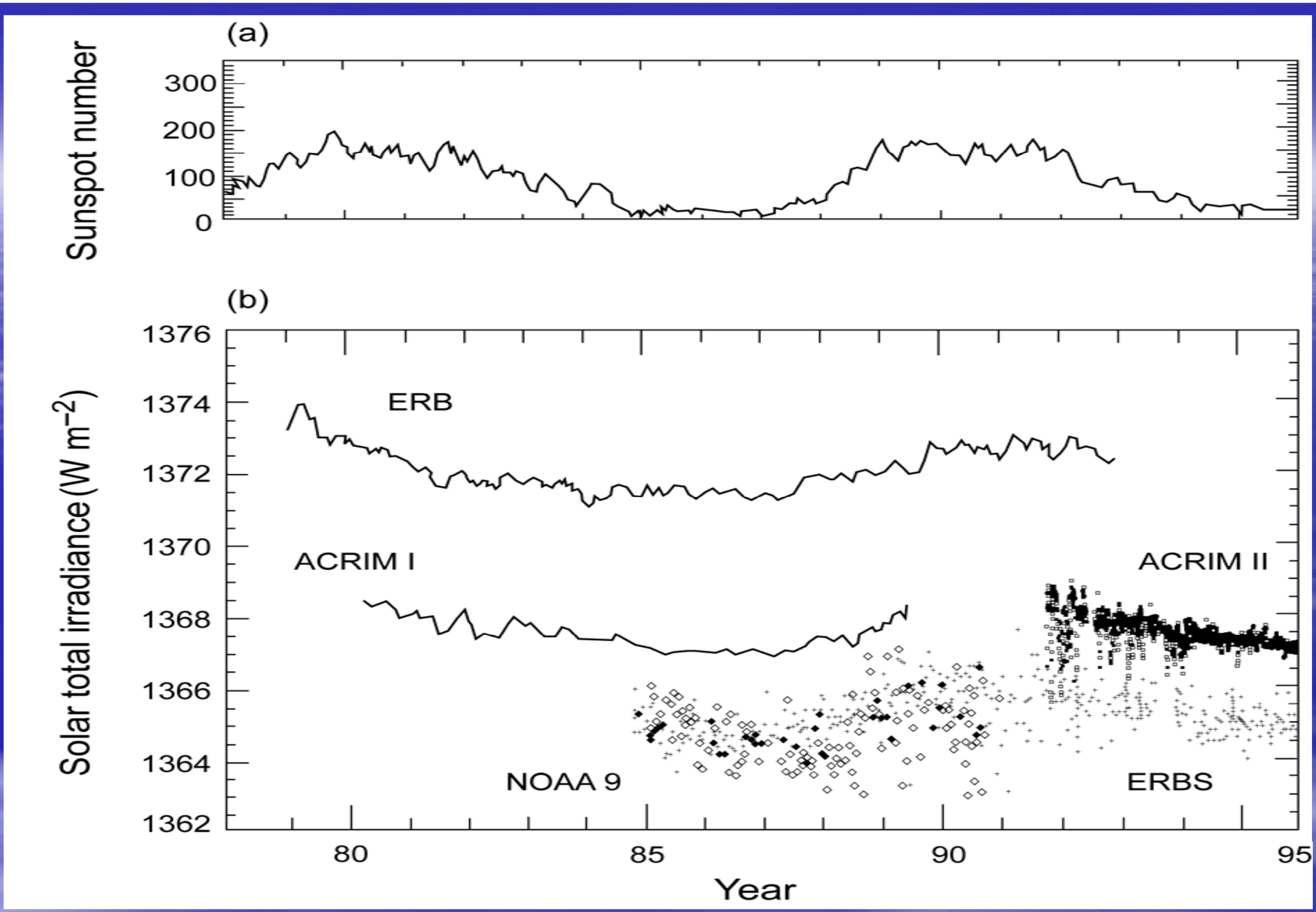
A cross section of the sun illustrating the solar interior and atmosphere. The solar interior includes the core with a temperature of about 1.5 x 10^7 K, the radiation zone, and the convective zone. The solar atmosphere includes the photosphere, the chromosphere, and the corona. The former two layers are exaggerated for illustration purpose.



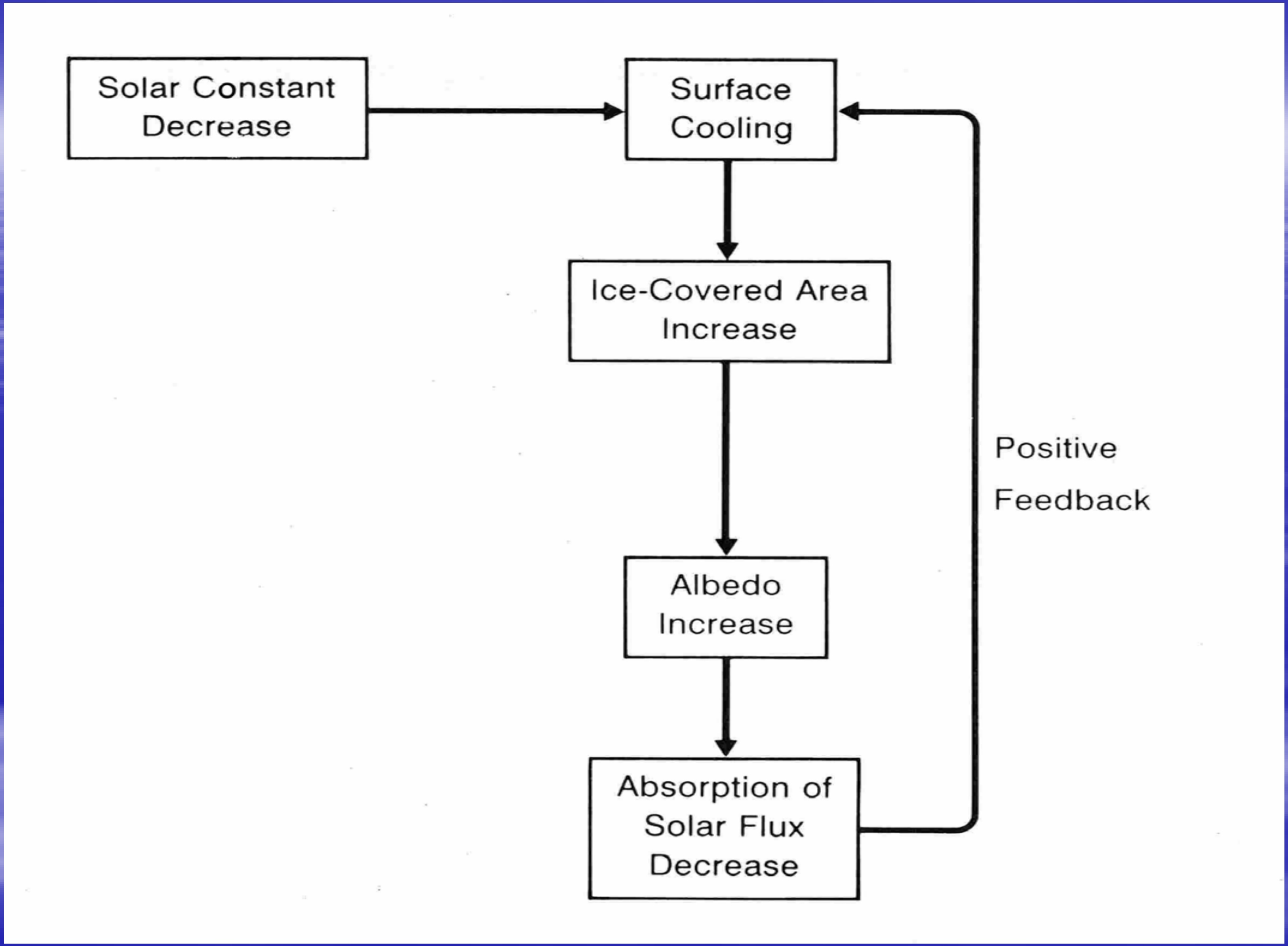
Variability of the sunspot number as function of year. Results from 1730 to 1976 are taken from Eddy (1976), while these after 1976 are from Lean and Rind (1998).

Sunspots

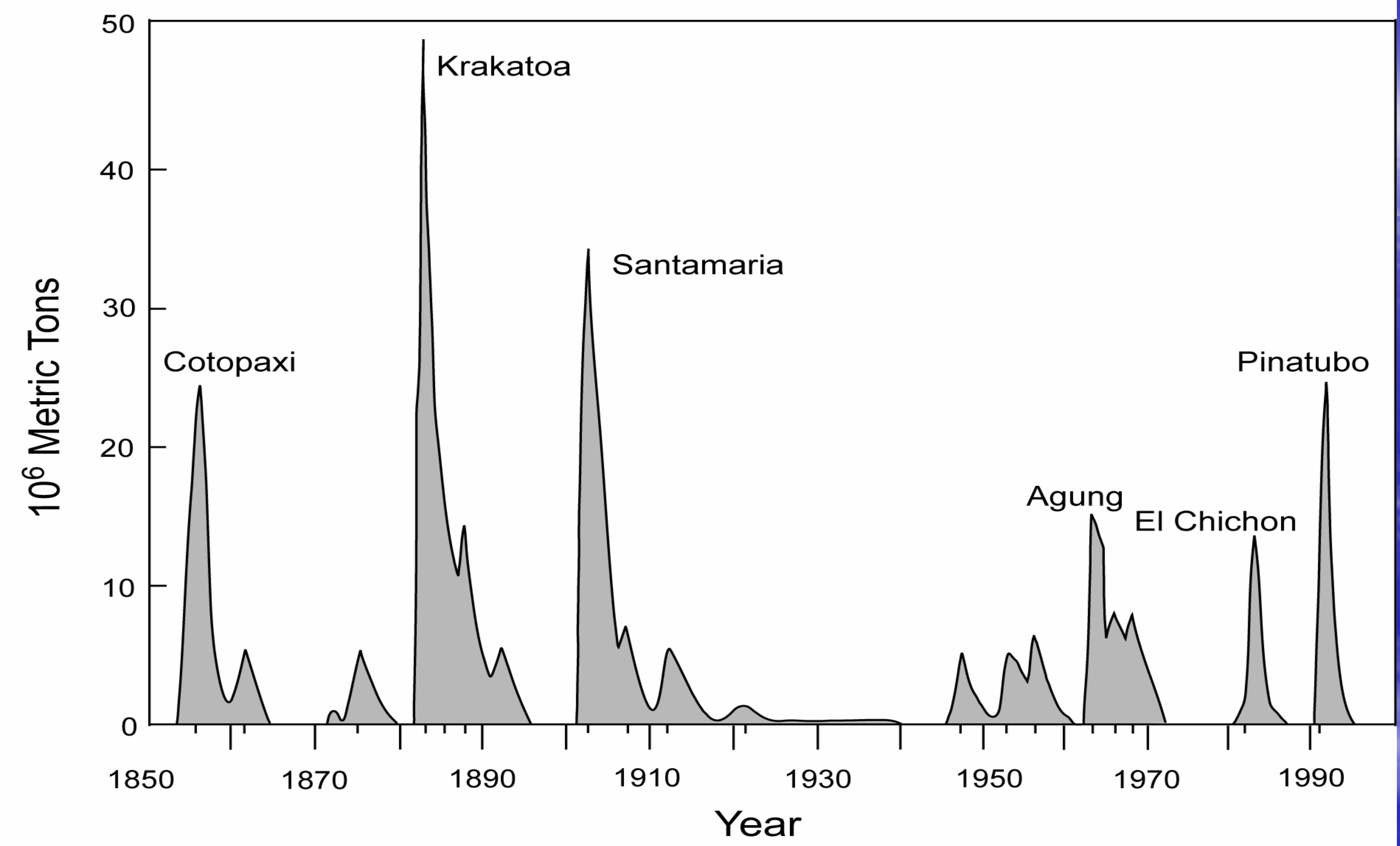
When there are more sunspots (dark regions, ~ 4000 K), faculae (bright emission areas) also develop. As a consequence, the radiation coming from the sun is slightly increased (solar constant is increased). Solar activity follows an 11 year cycle, with significant variation from cycle to cycle. Based on astronomical records, we can reconstruct the history of sunspot activity back to 1600 or so, when there appears to be a sustained minimum in the number of sunspots. It has been hypothesized that the cooler climate during this period is due to reduced solar activity.



Solar activity variations from 1978 to 1996 illustrated by (a) the sunspot number and (b) changes in total solar irradiance. The results were obtained from the ERB radiometer on the Nimbus-7 satellite, ACRIM I on the Solar Maximum Mission (SMM) satellite, ACRIM II on the UARS, and the ERBE program (NOAA-9 and ERBS). The solid lines are 81-day running means of the daily data. Solar total irradiance increases during times of maximum solar activity relative to its levels in the intervening activity minimum. The differences in absolute irradiance levels among various measurements are of instrumental origin (data taken from Lean and Rind, 1998).

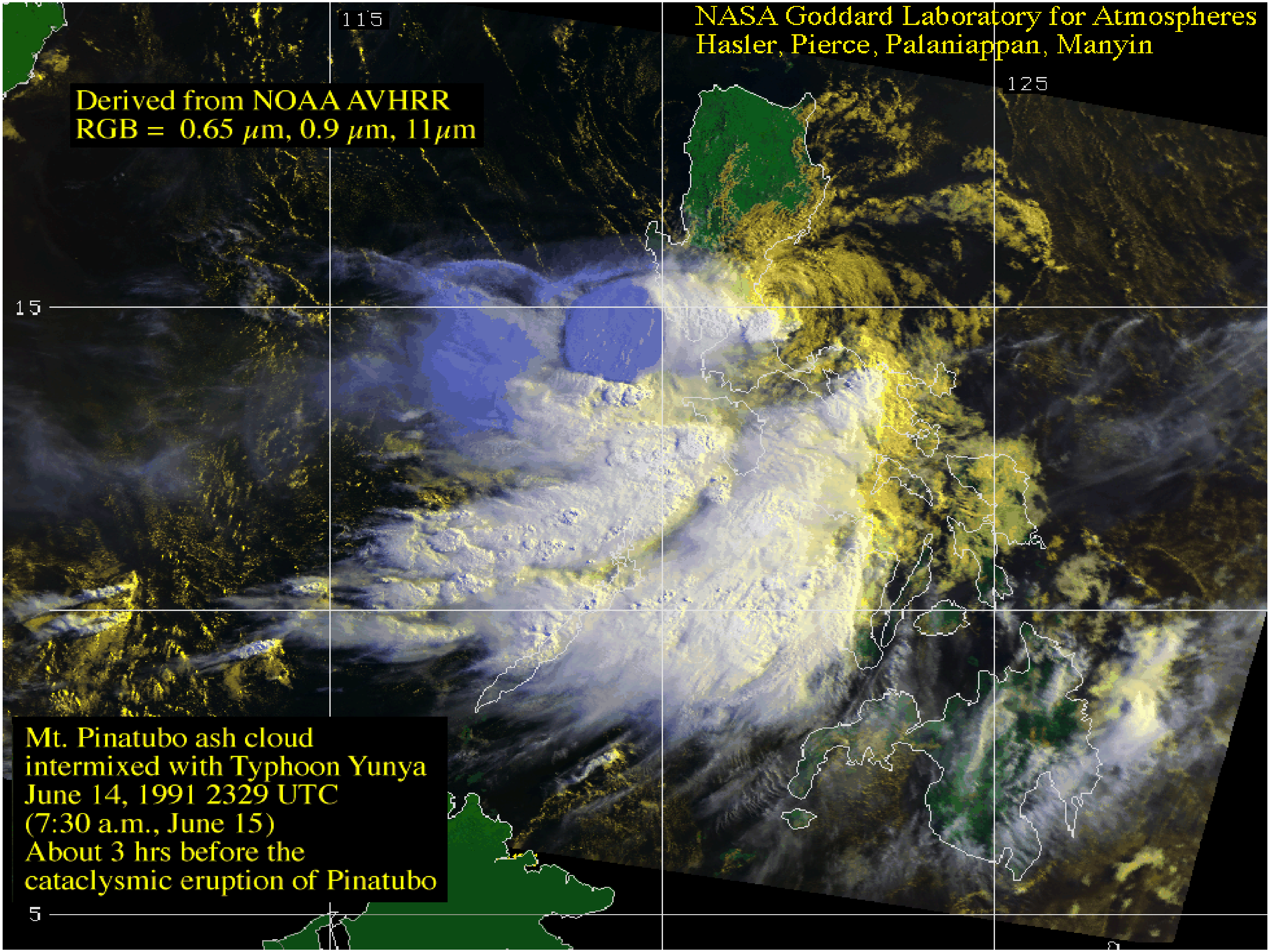


An illustration of the ice-albedo feedback due to the radiative perturbations of the solar constant.

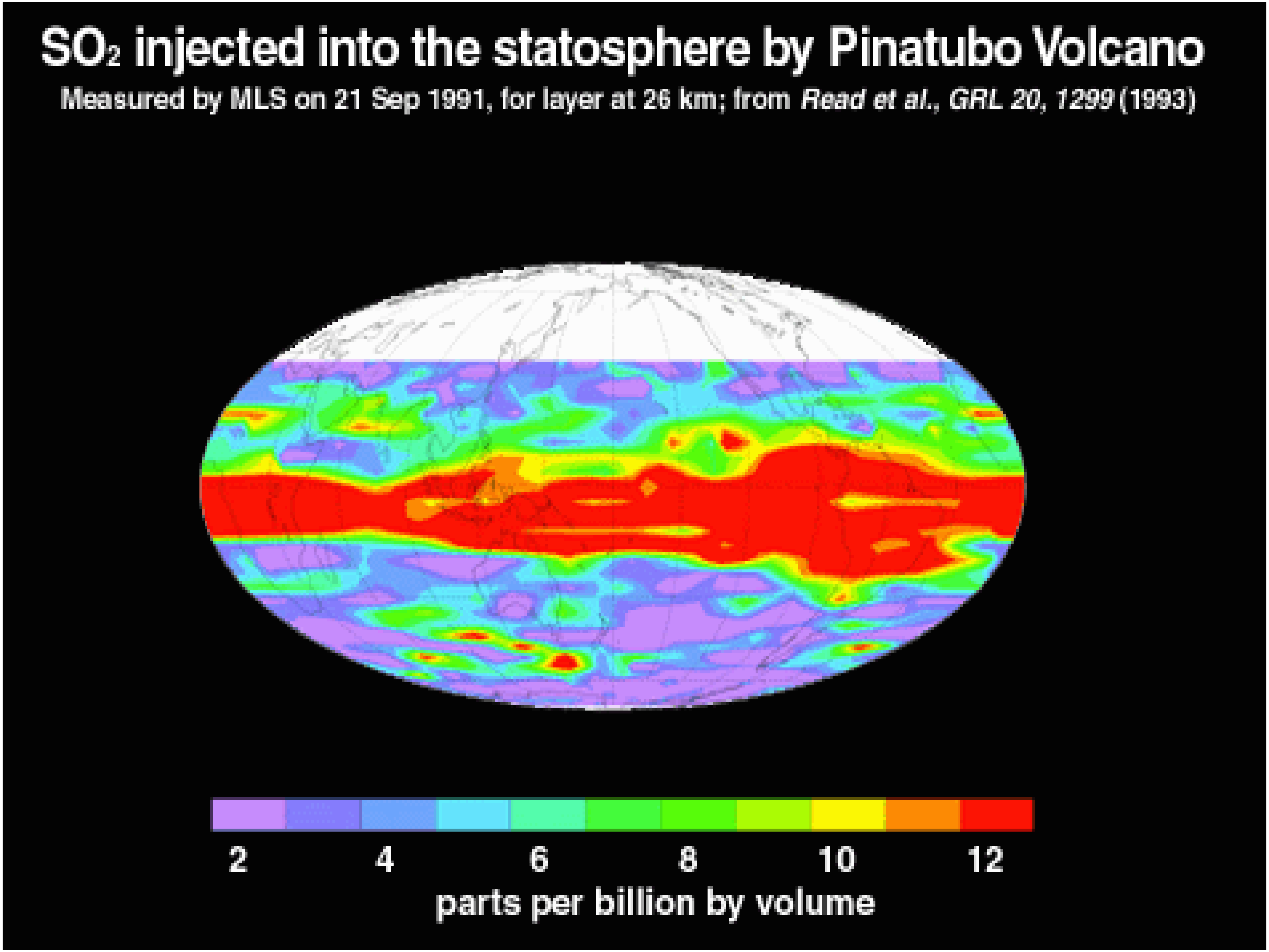


Estimated chronology of annual average global aerosol loading by volcanic activity from 1850 to 2000. Major volcanic episodes are indicated in the diagram (data taken from *Man's Impact on the Climate*, 1971; Sato et al., 1993).


Volcanoes spew enormous amounts of material into the atmosphere, including sulfur dioxide, which is transformed in the atmosphere into sulfate aerosols. These aerosols reflect sunshine.



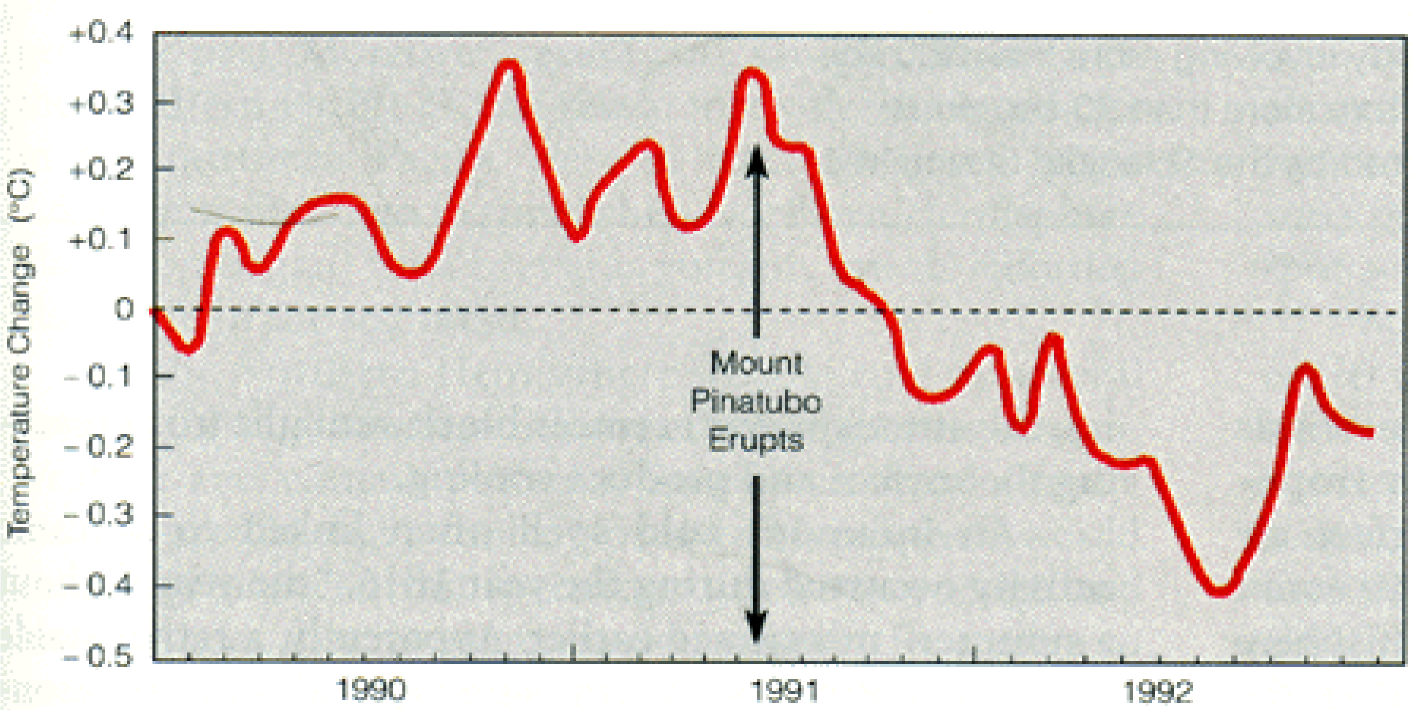
NASA Goddard Laboratory for Atmospheres
Hasler, Pierce, Palaniappan, Manyin
Derived from NOAA AVHRR
RGB = 0.65 μm, 0.9 μm, 11μm
115
125
15
5
Mt. Pinatubo ash cloud
intermixed with Typhoon Yunya
June 14, 1991 2329 UTC
(7:30 a.m., June 15)
About 3 hrs before the
cataclysmic eruption of Pinatubo


SO2 injected into the statosphere by Pinatubo Volcano
Measured by MLS on 21 Sep 1991, for layer at 26 km; from Read et al., GRL 20, 1299 (1993)
2
4
6
8
10
12
parts per billion by volume

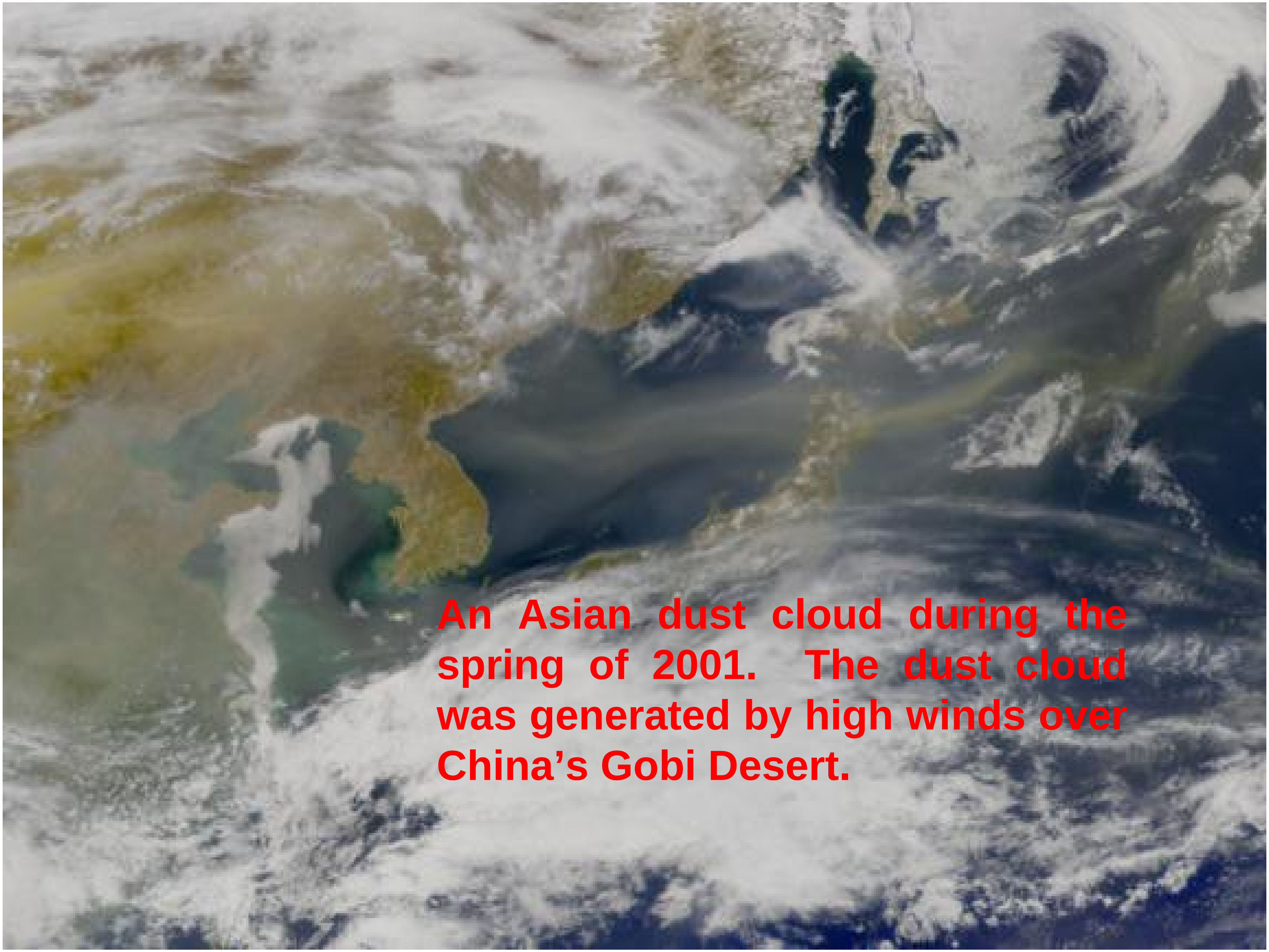
In the case of the 1991 Mt. Pinatubo eruption, the sulfate aerosol cloud resulted in a radiative forcing of about -0.5 W/m^2, which lasted for a few months. This coincided with a global cooling on the order of a few tenths of degree C, which lasted a year or so.

Other historical volcanic eruptions are also associated with anomalies in the climate record. The most noteworthy is the enormous 1815 eruption of the Tambora volcano. This is referred to as the "year without a summer" in Europe and North America. The cooling effect was probably on the order of 5ºC.

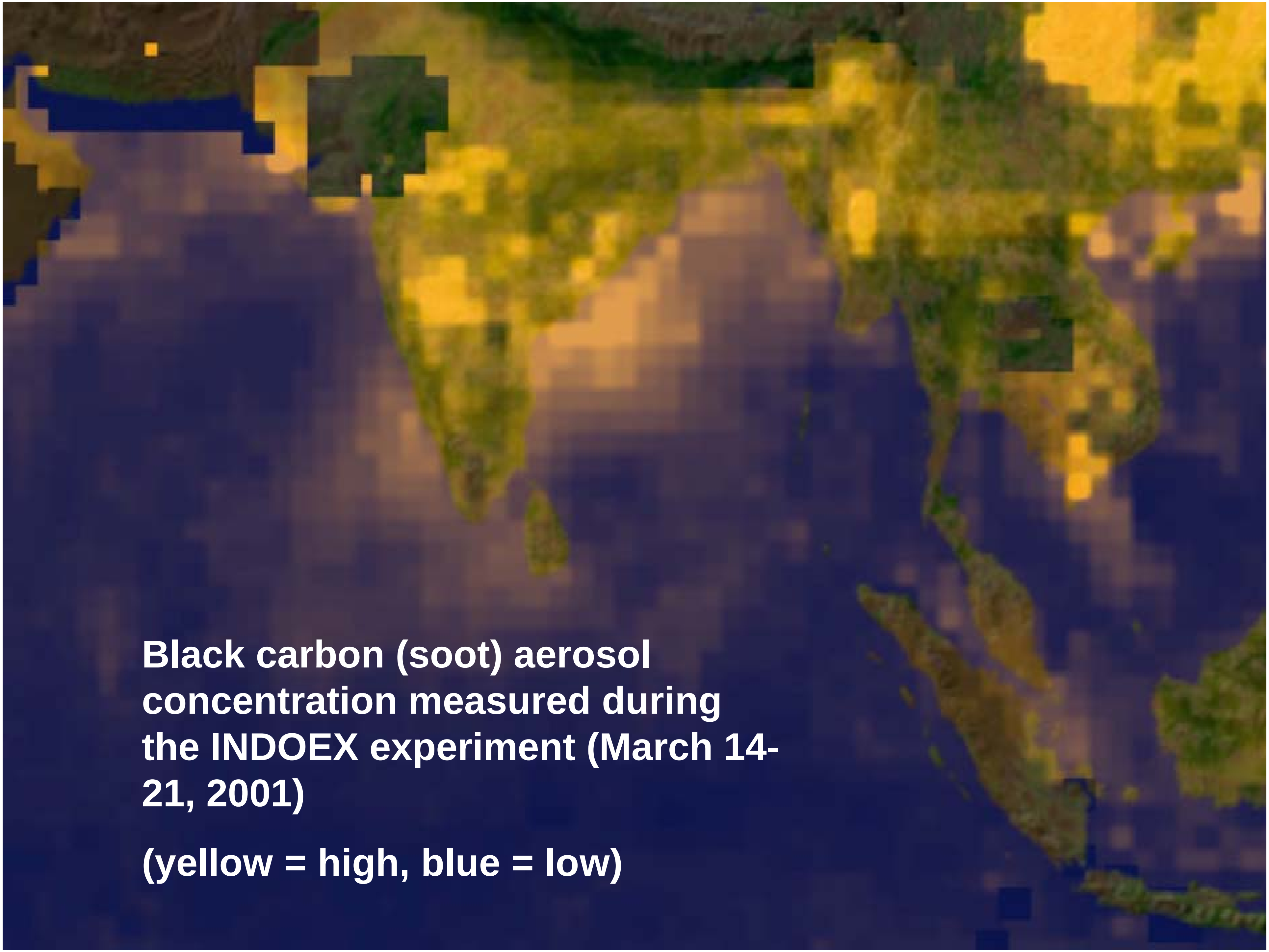
However, the global cooling effects of the volcanic eruptions we are familiar with last at most a few years.



Observed global air temperature anomaly associated with the Mt. Pinatubo eruption in 1991. (from Ahrens, Meteorology Today)



An Asian dust cloud during the spring of 2001. The dust cloud was generated by high winds over China's Gobi Desert.

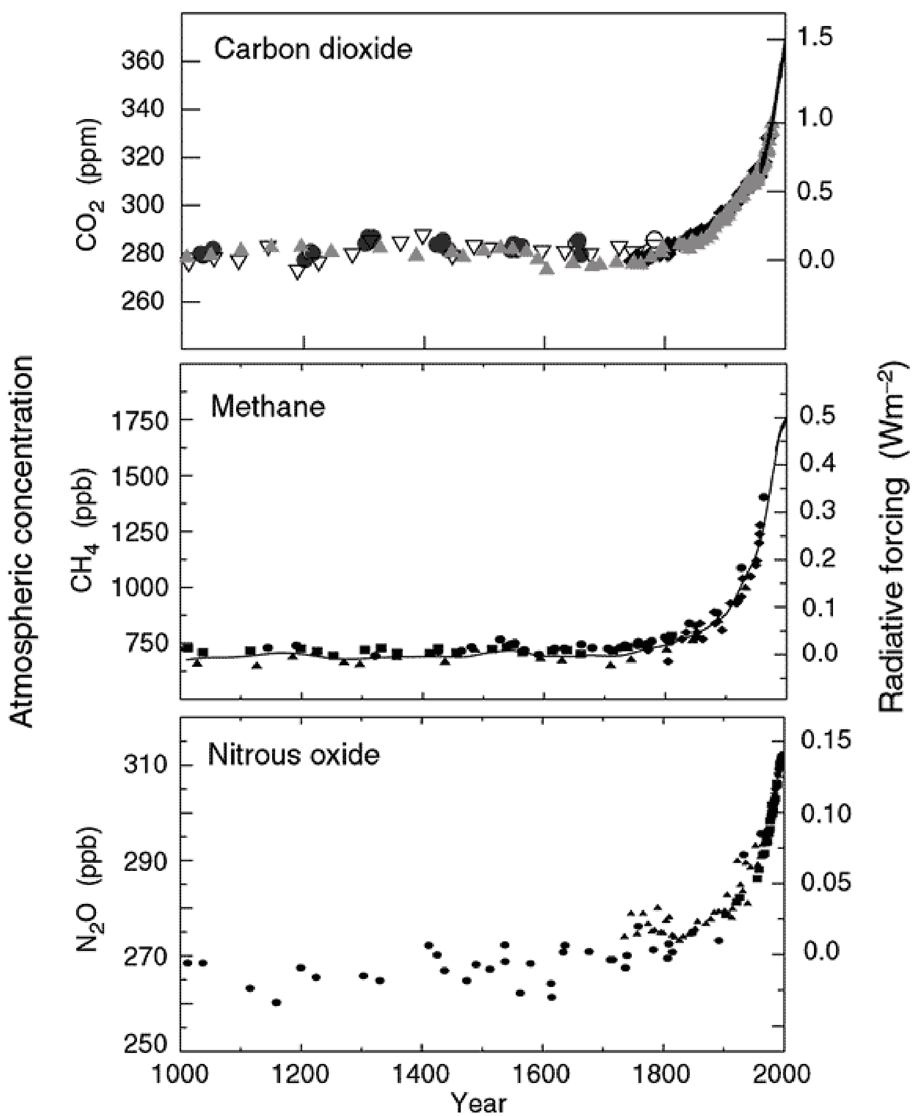


Black carbon (soot) aerosol concentration measured during the INDOEX experiment (March 14-21, 2001)

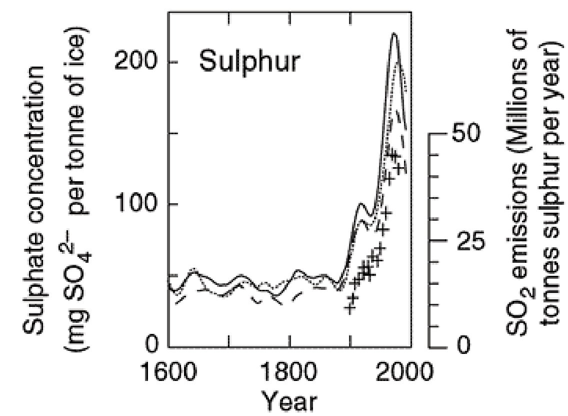
(yellow = high, blue = low)

Indicators of the human influence on the atmosphere during the Industrial Era

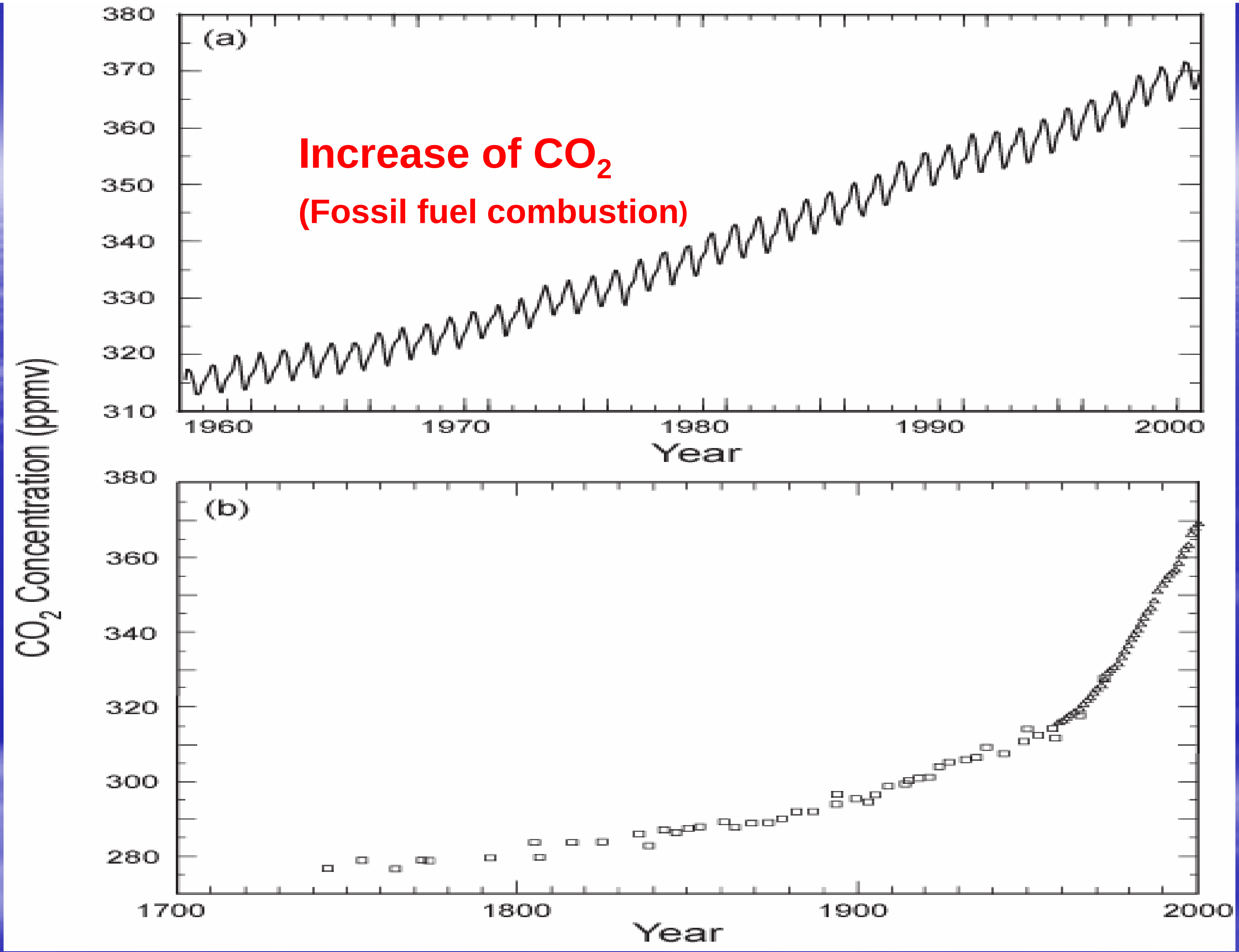
(a) Global atmospheric concentrations of three well mixed greenhouse gases



(b) Sulphate aerosols deposited in Greenland ice



According to records of past atmospheric composition in ice cores, greenhouse gases, including carbon dioxide, methane, and nitrous oxide, have increased during the industrial era. So have sulfate aerosols.



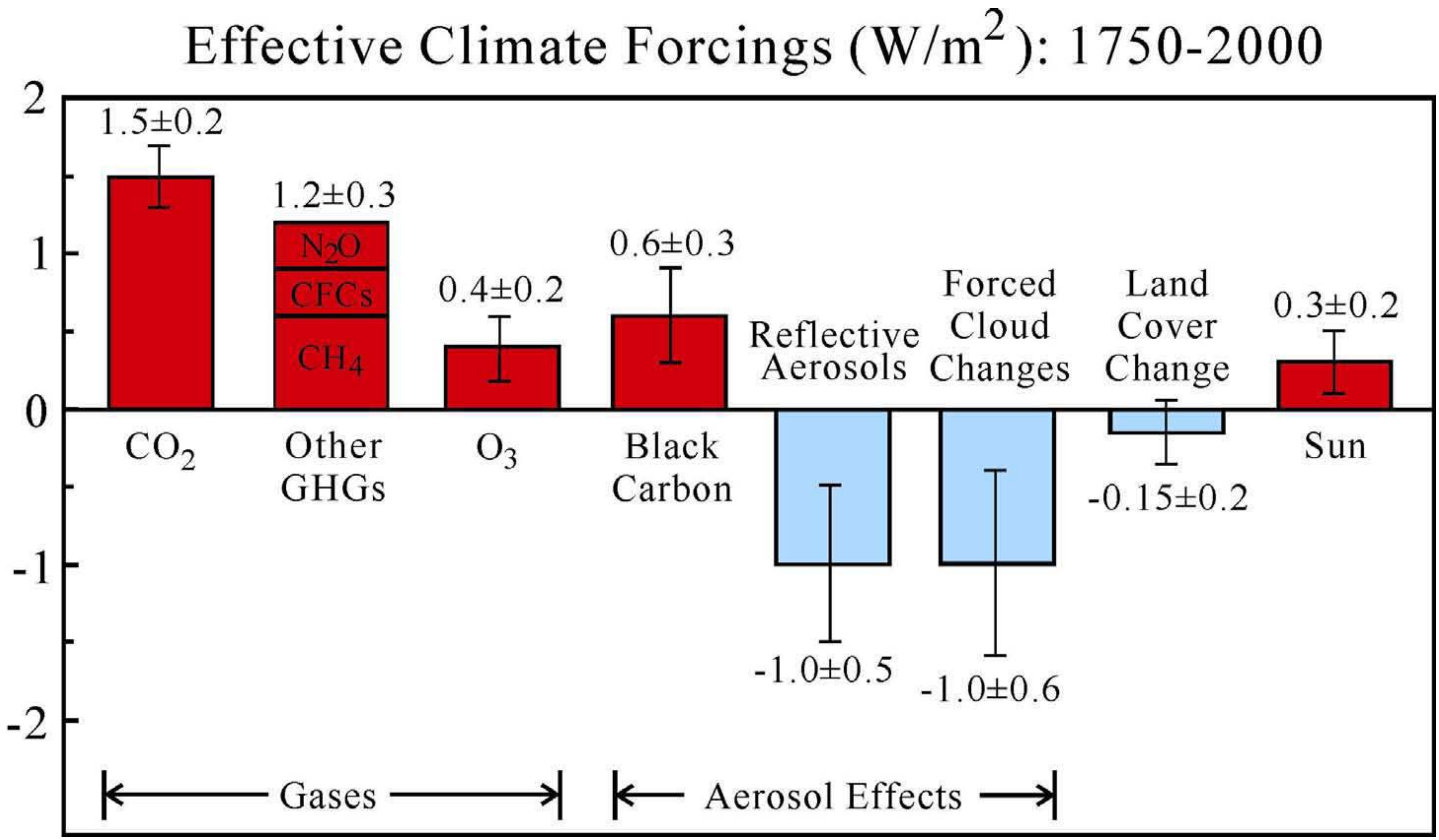
Concentration of atmospheric CO_2 at Mauna Loa Observatory, Hawaii, expressed as a mole fraction in parts per million of dry air for the period 1958-2000 (courtesy of Pieter Tans, Geophysical Monitoring for Climate Change, Environmental Research Laboratory, National Oceanic and Atmospheric Administration). (b) Atmospheric CO_2 concentration for the past 250 years as indicated by measurements in air trapped in ice core from Antarctica determined by Neftel et al. (1985) and extended to the present using the Mauna Loa recorded displayed in (a).

Climate Radiative Forcing

(1) Net Flux at TOP (pristine atmosphere)

(2) Net Flux at TOP (polluted atmosphere)

Radiative Forcing (W/m^2) = (2) – (1) = Gain of Radiative Flux in Earth-Atmosphere



Climate forcing agents in the industrial era. "Effective" forcing accounts for "efficacy" of the forcing mechanism

Source: Hansen et al., JGR, **110**, D18104, 2005.