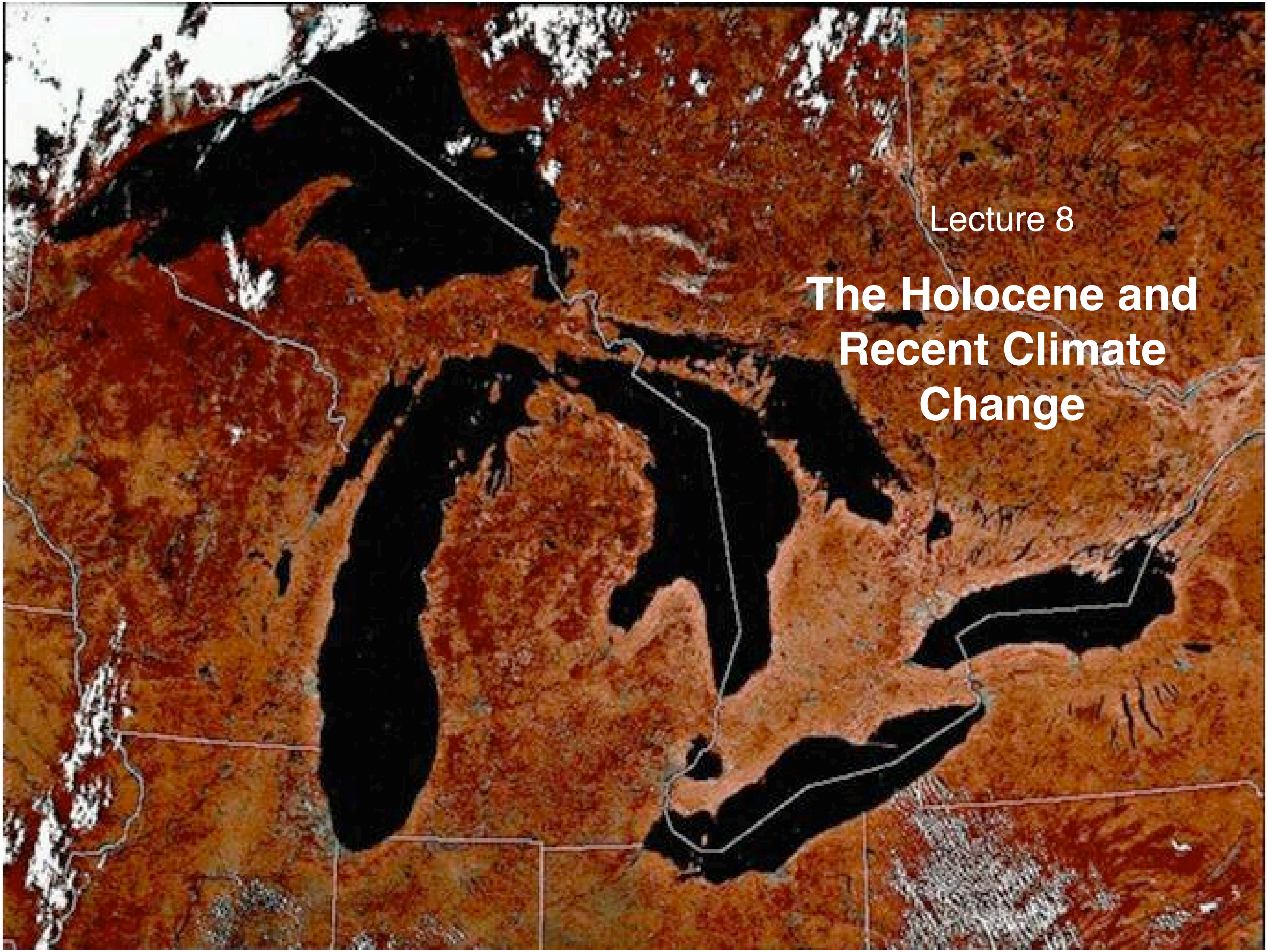


Lecture 8

The Holocene and Recent Climate Change

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. This had a number of impacts:

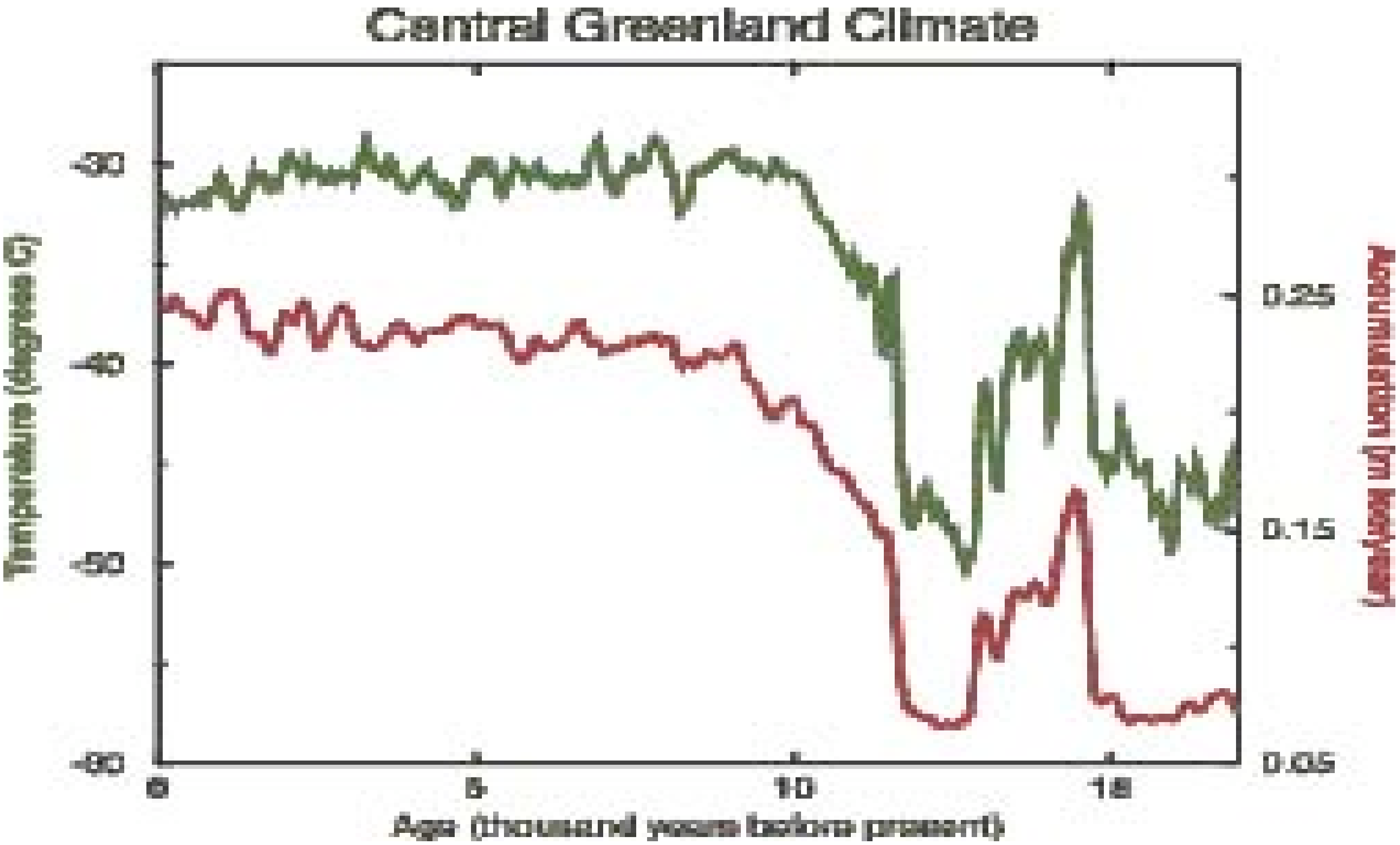
(1) lake formation in regions left behind by glaciers

(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.

The period since the great ice sheets melted is known as the **Holocene**

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.



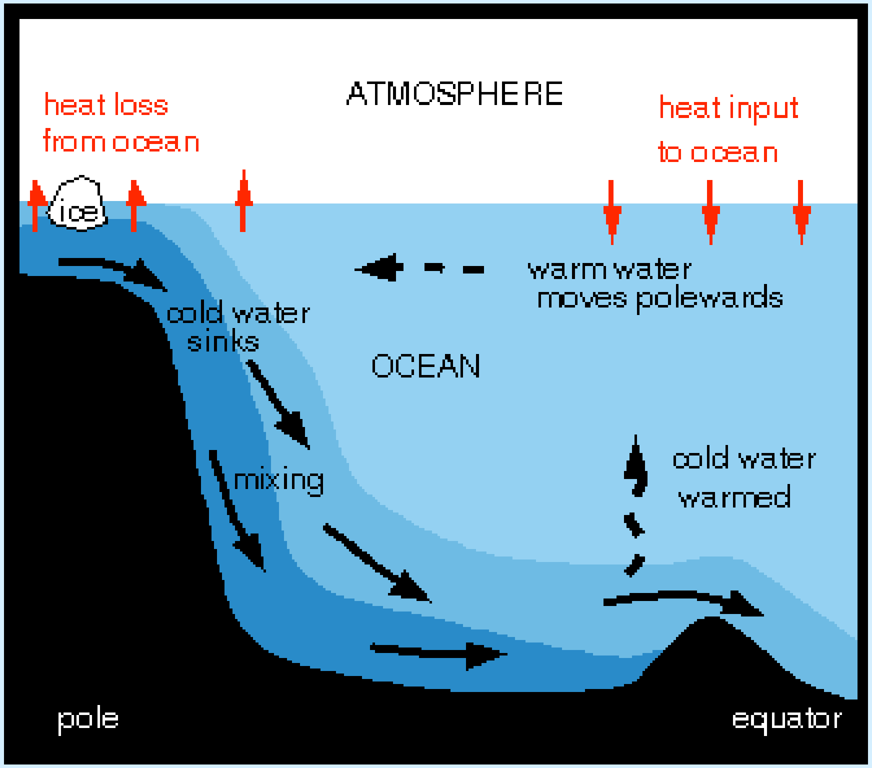
The Younger Dryas was probably caused by a massive flooding of the North Atlantic by freshwater outflow from the melting ice sheets.

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.

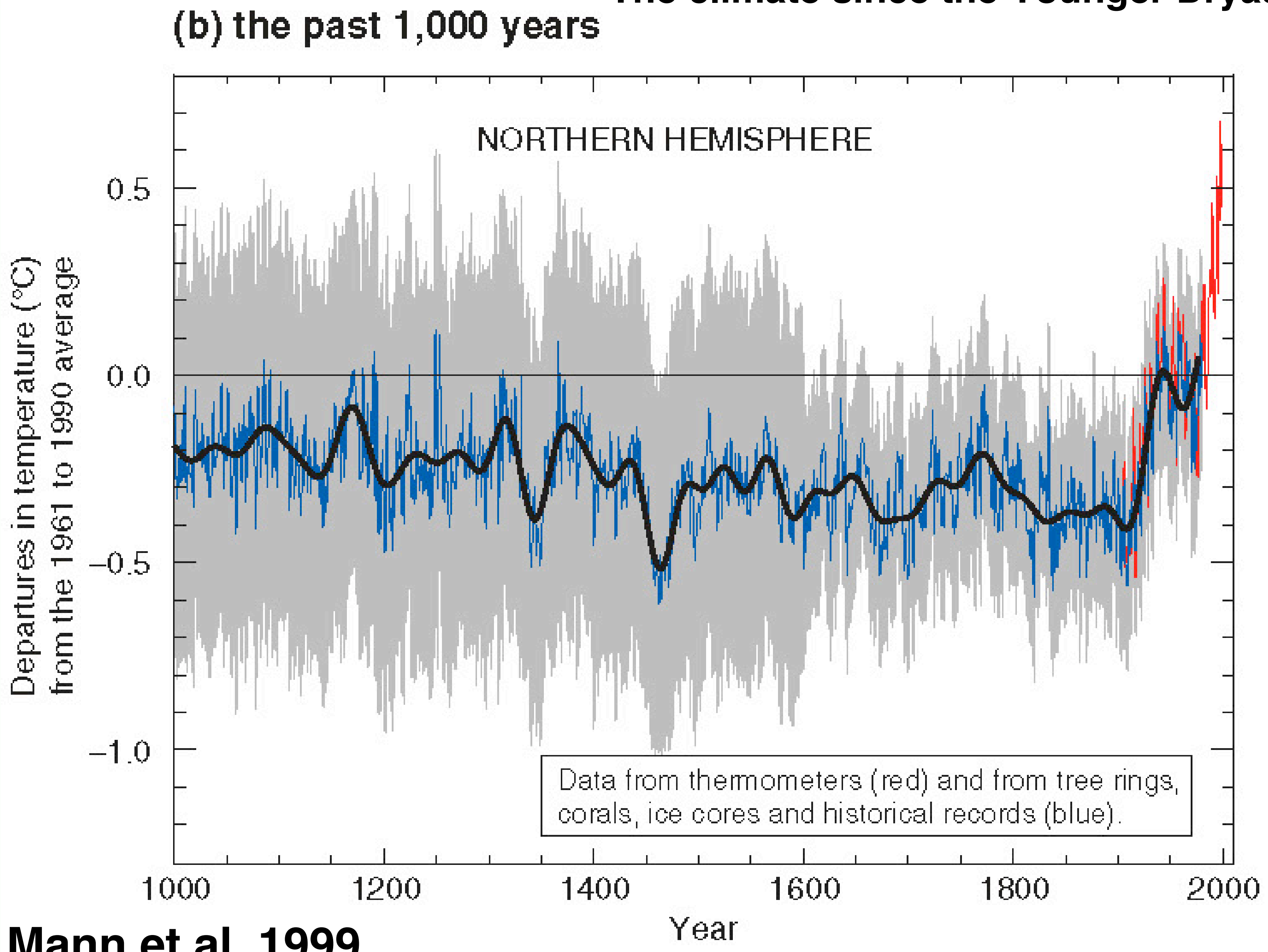
As we have noted in earlier lectures, the thermohaline circulation transports warm water from the tropics to the northern North Atlantic, maintaining warm temperatures in this region.

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

North Atlantic thermohaline circulation



The climate since the Younger Dryas



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) <u>Changes in aerosols</u>, including volcanic aerosols, dust, and soot.

(2) <u>Solar Variability</u>, which can alter the radiation the earth receives.

(3) <u>Increases in greenhouse gases</u>.

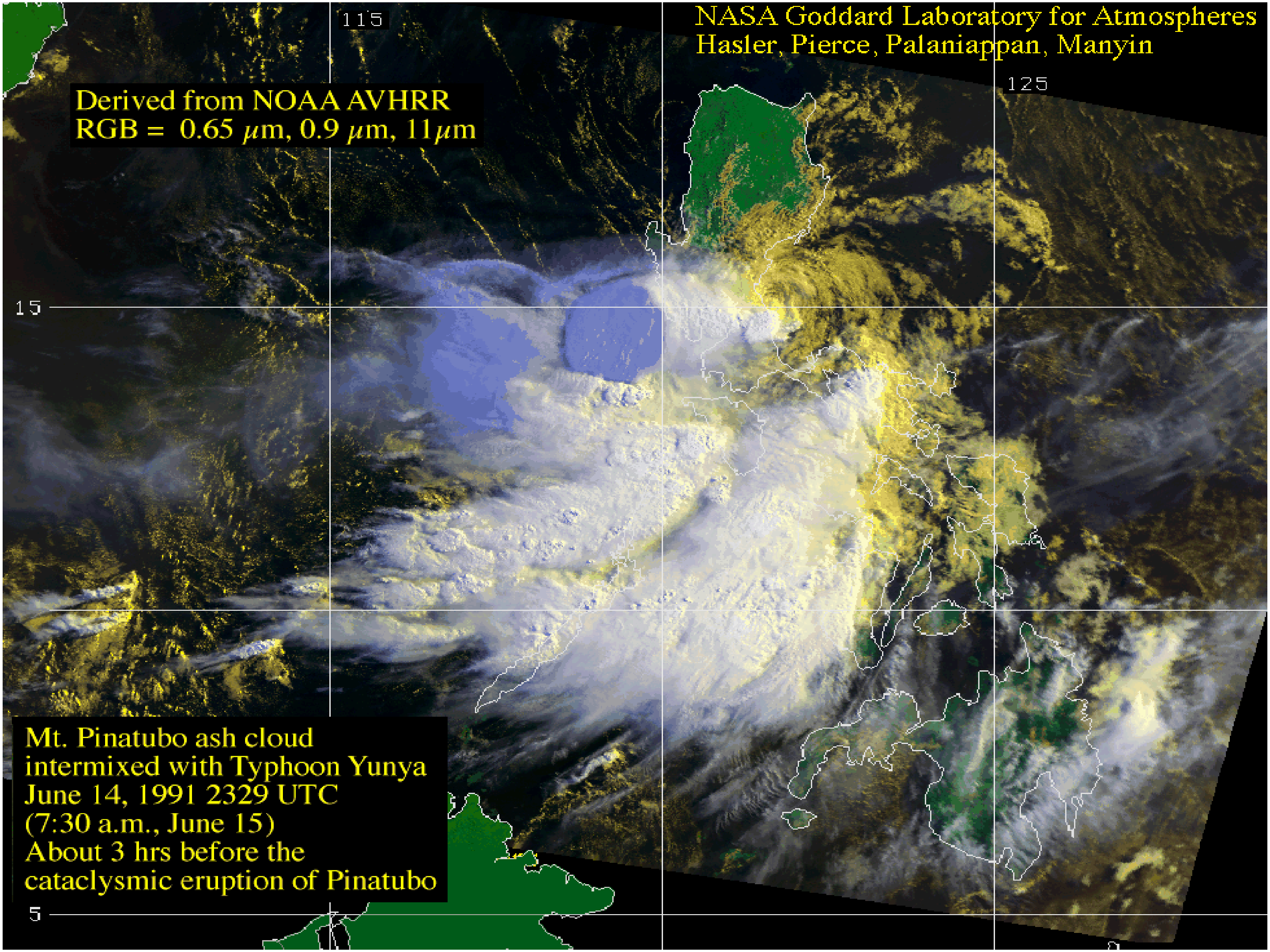
The atmosphere-ocean system also generates variability on its own, and we will consider this issue in the next lecture.

A key idea in climate change research is the concept of

RADIATIVE FORCING

This allows us to quantify the importance of the various factors that have potential to change climate. It is defined as the radiation change in W/m^2 at the tropopause due to the forcing agent (e.g. increase in greenhouse gases)

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.



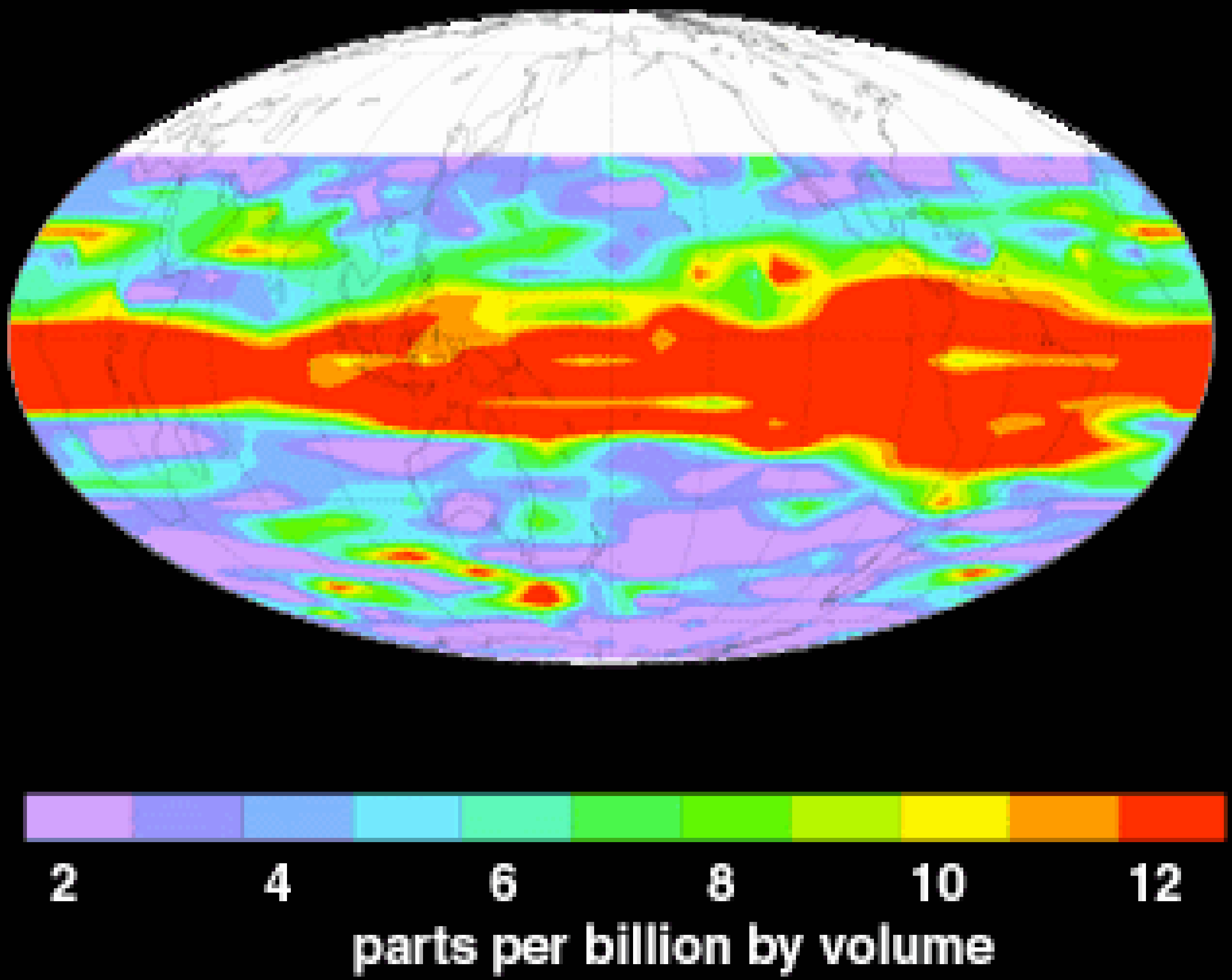
NASA Goddard Laboratory for Atmospheres
Hasler, Pierce, Palaniappan, Manyin

Derived from NOAA AVHRR
RGB = 0.65 μm, 0.9 μm, 11μm

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

SO_2 injected into the statosphere by Pinatubo Volcano

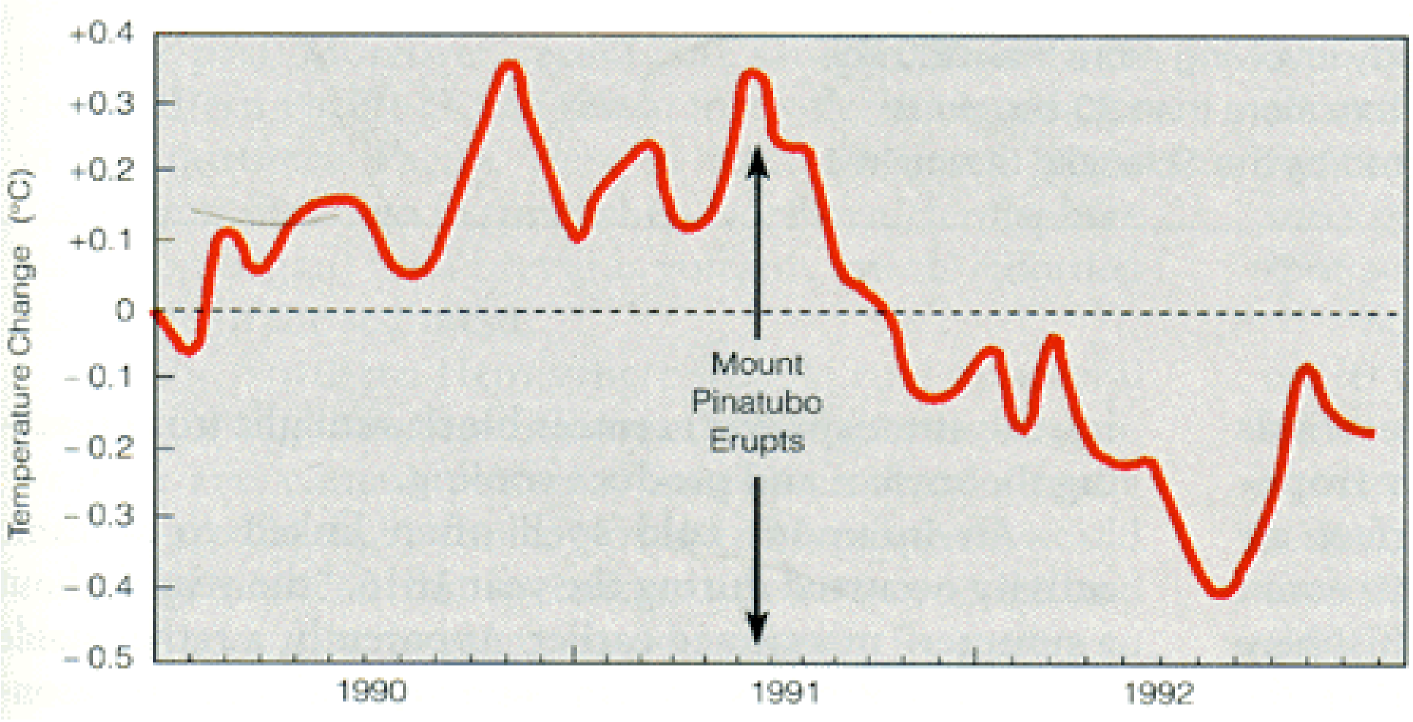
Measured by MLS on 21 Sep 1991, for layer at 26 km; from *Read et al., GRL 20, 1299* (1993)



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 5°C.

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

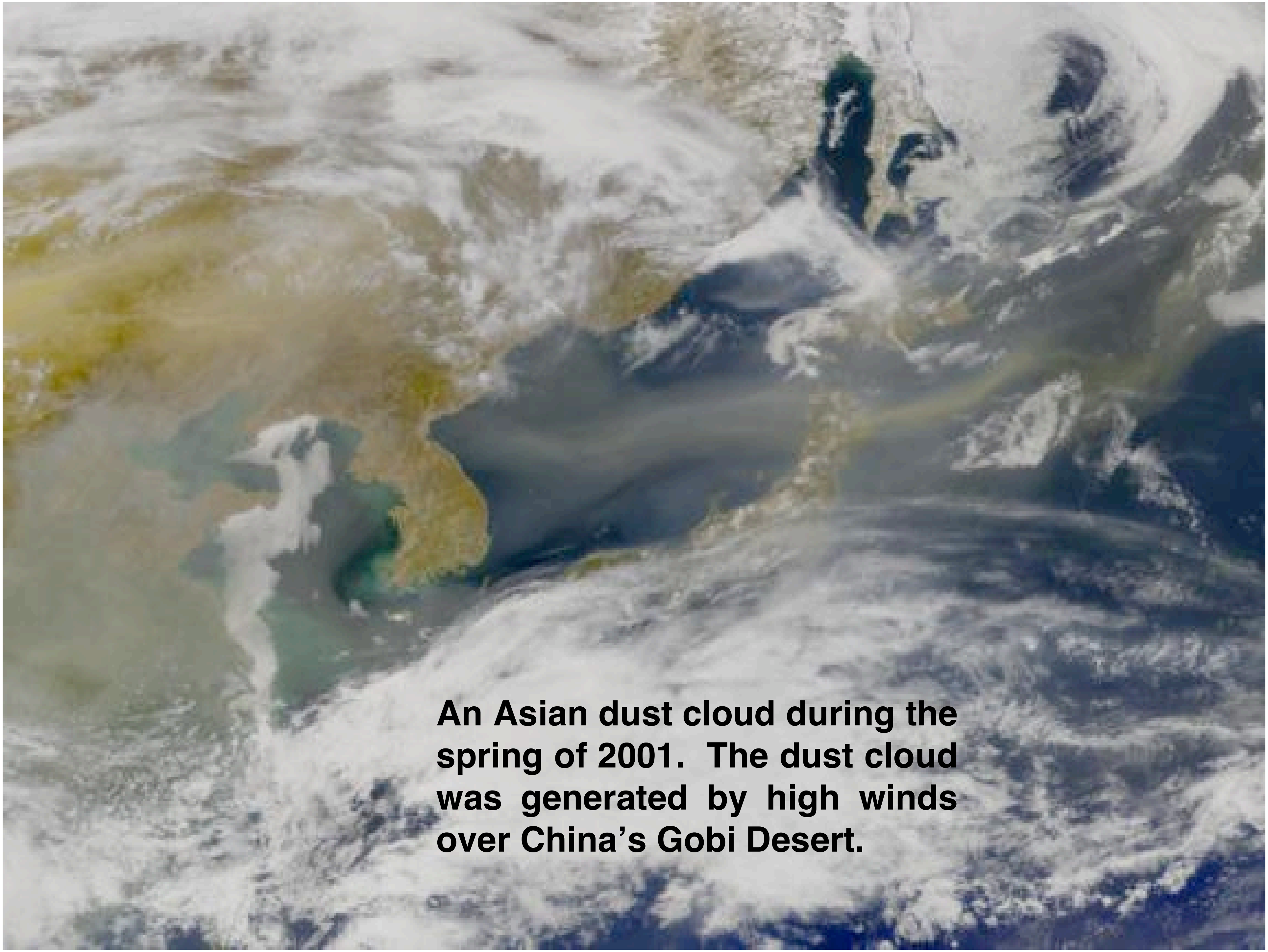


Observed global air temperature anomaly associated with the Mt. Pinatubo eruption in 1991. (from Ahrens, Meteorology Today)

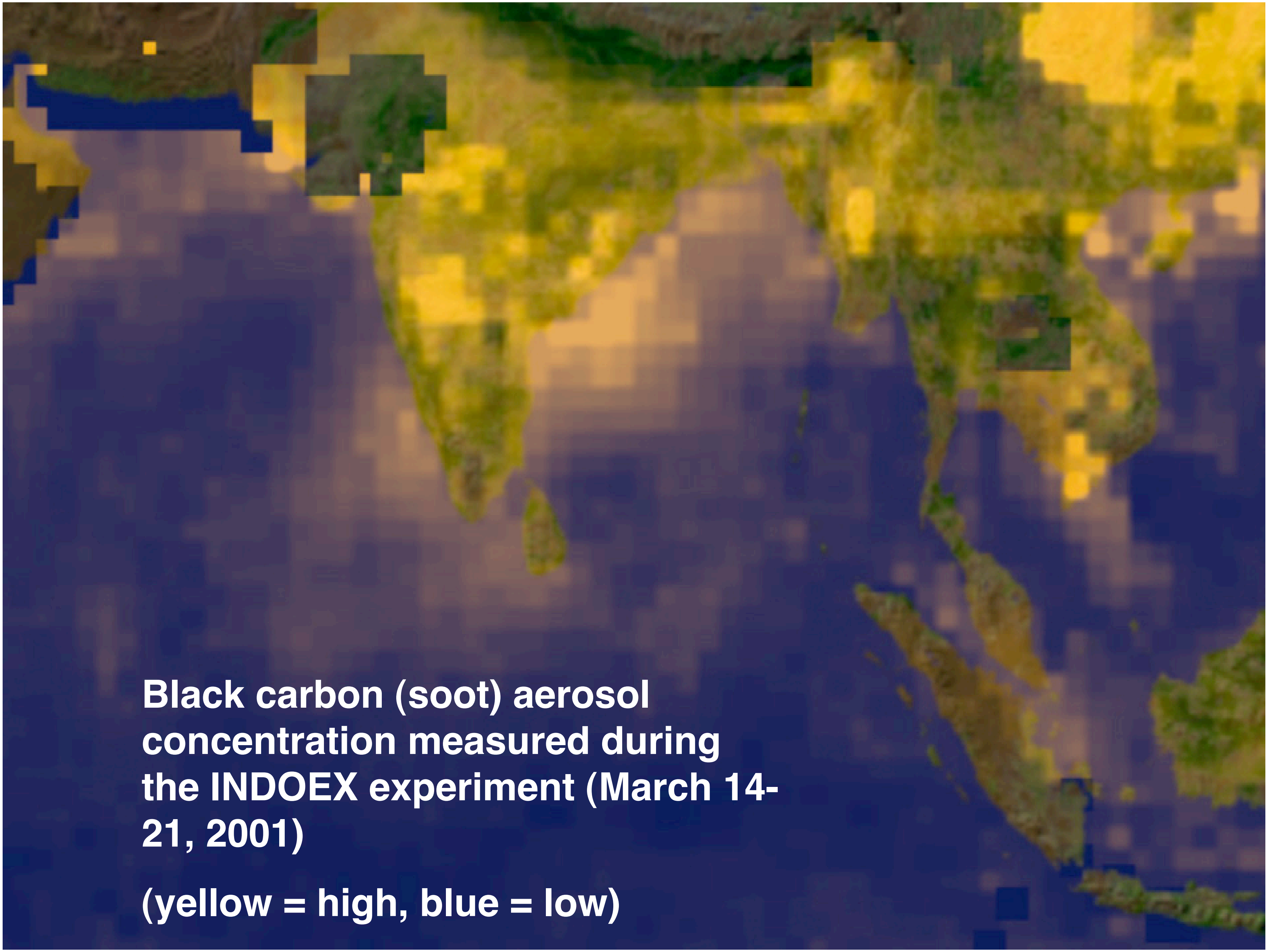
In the case of the 1991 Mt. Pinatubo eruption, the sulfate aerosol cloud resulted in a radiative forcing of about -0.5 W/m^2, which lasted for a few months. This coincided with a global cooling on the order of a few tenths of degree C, which lasted a year or so.

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 5°C.

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

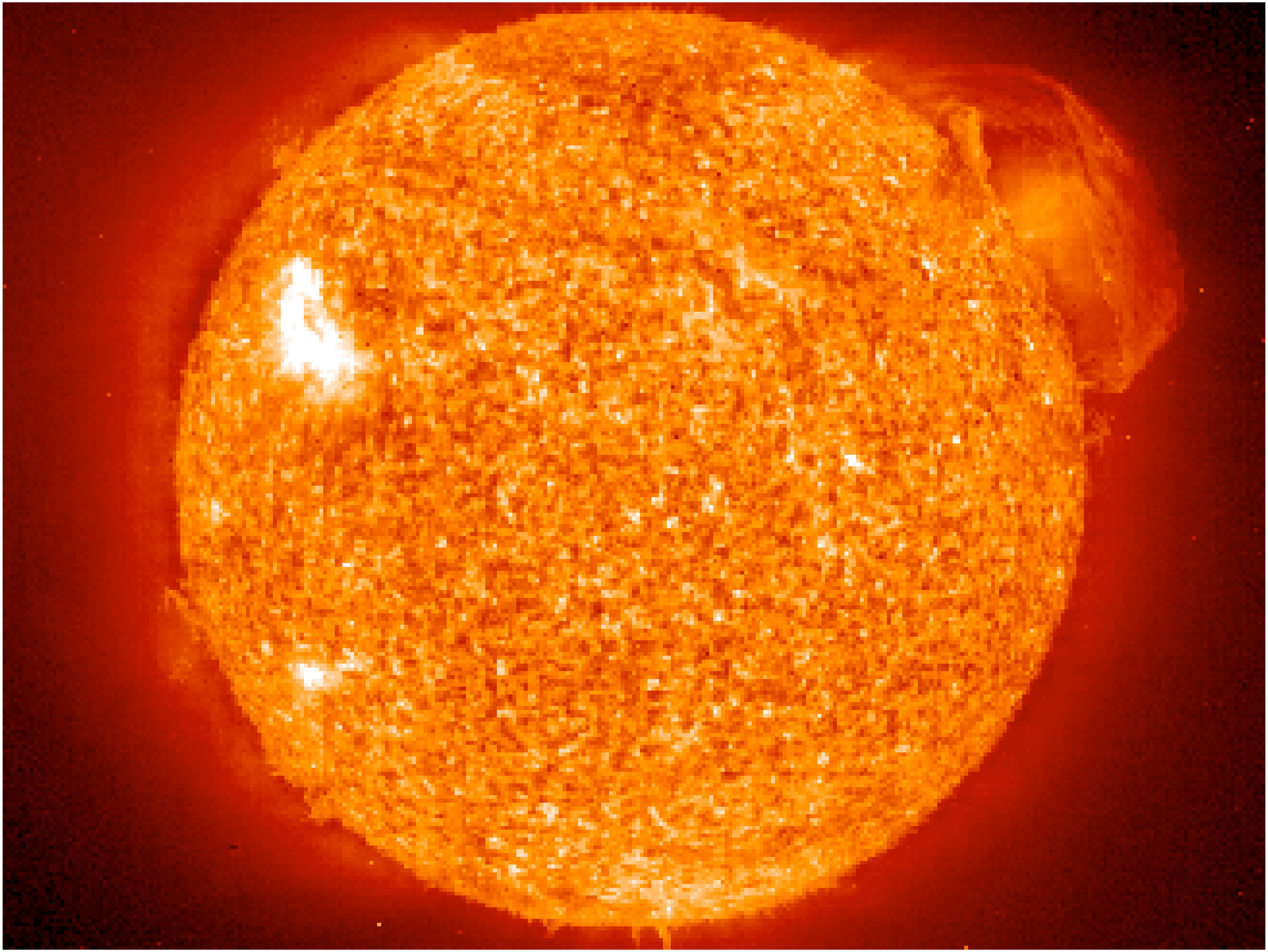


An Asian dust cloud during the spring of 2001. The dust cloud was generated by high winds over China's Gobi Desert.

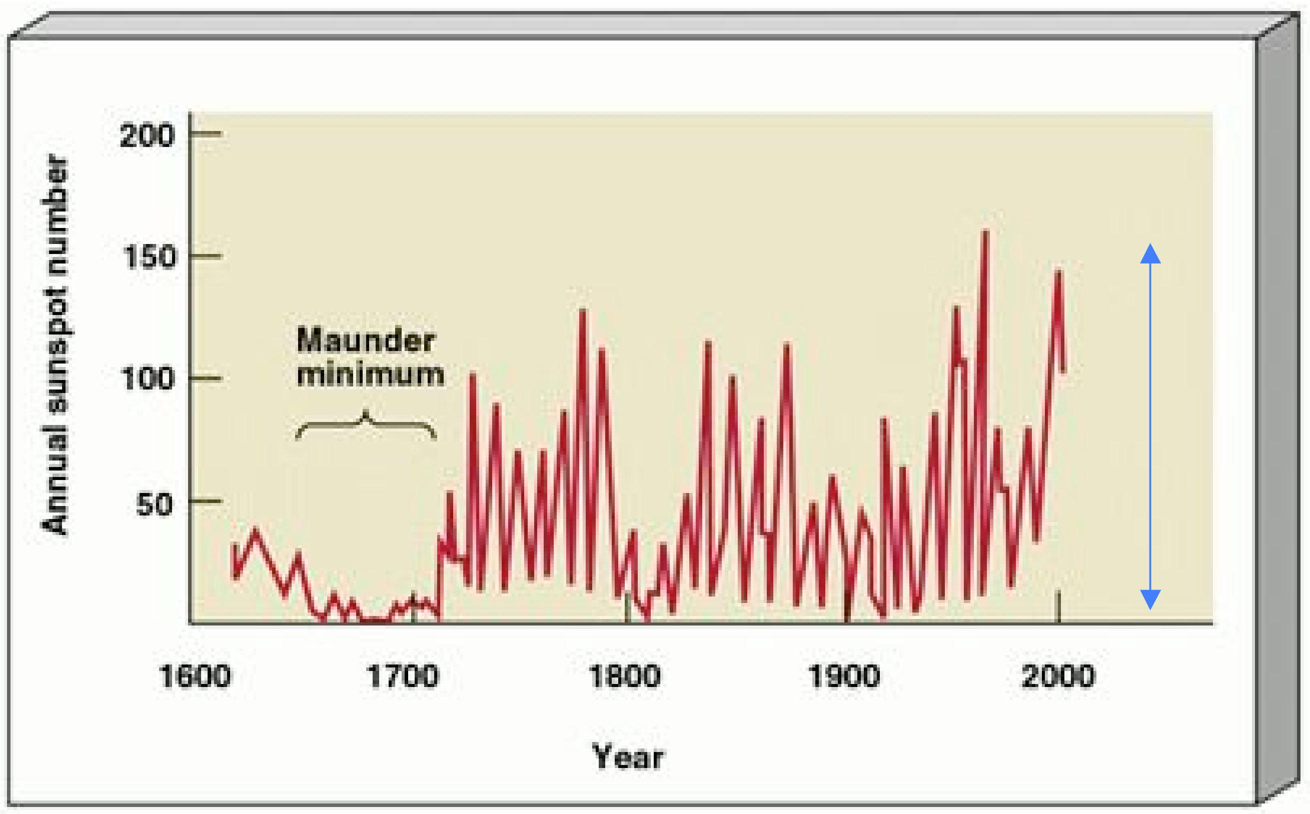


Black carbon (soot) aerosol concentration measured during the INDOEX experiment (March 14-21, 2001)

(yellow = high, blue = low)



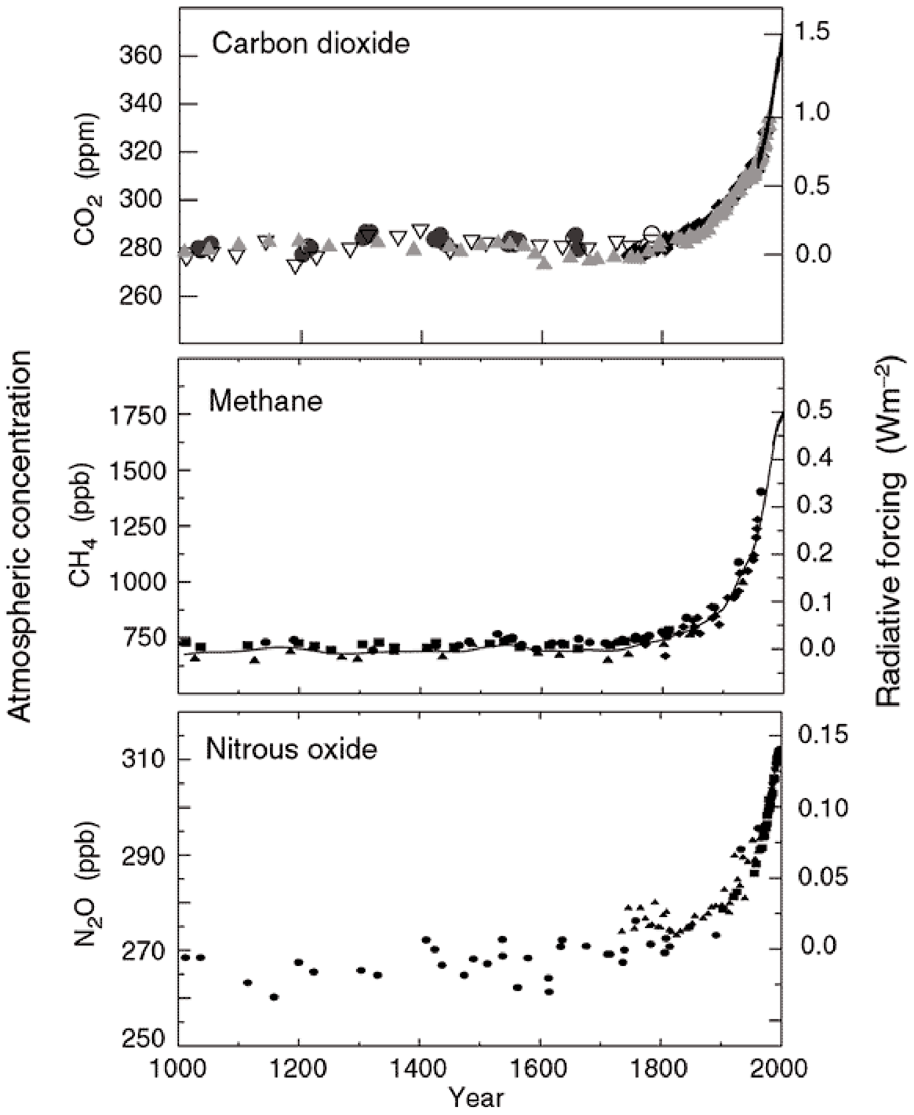
When there are more sunspots, the radiation coming from the sun is slightly increased. Solar activity follows an 11 year cycle, with some variation from cycle to cycle. Based on astronomical records, we can reconstruct the history of sunspot activity back to 1600 or so, when there appears to be a sustained minimum in the number of sunspots. It has been hypothesized that the cooler climate during this period is due to reduced solar activity.



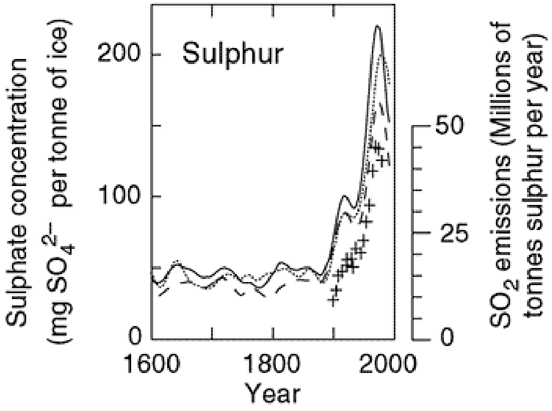
However, the difference in incoming sunshine between times of maximum and minimum solar activity is only on the order of a few tenths of a watt per meter squared, which is unlikely to generate a large climate anomaly by itself.

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.

A key idea in climate change research is the concept of

RADIATIVE FORCING

This allows us to quantify the importance of the various factors that have potential to change climate. It is defined as the radiation change in W/m^2 at the tropopause due to the forcing agent (e.g. increase in greenhouse gases)

The global mean radiative forcing of the climate system for the year 2000, relative to 1750