Lecture 26: Historical Climate: Volcanoes and Sunspots

Source: Ch 16, 303-305A

Prof. Alan Robock's presentation

Historical Climate: Volcanoes and Sunspots

• How do volcanoes affect climate?

• Name two important volcanic eruptions in the past two hundred years.

• How do sunspots affect climate?

• In what way do sunspot cycles before the 20^{th} century imply a Sun-climate connections?

Famous Volcanic Eruptions

Santorini, 1628 BC

Etna, 44 BC

Lakagígar, 1783

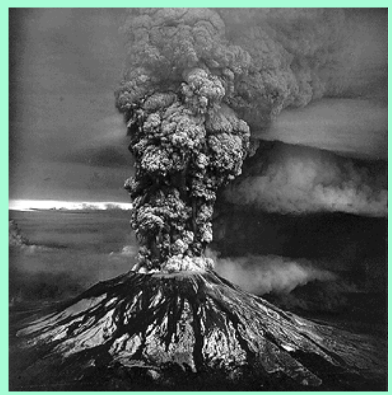
Tambora, 1815

Toba, 71,000 BP

Krakatau, 1883

Pinatubo, 1991

El Chichón, 1982



St. Helens, 1980

Agung, 1963

Major volcanic eruptions of the past 250 years

Volcano	Year	VEI	d.v.i/E_{max}	IVI
Lakagígar [Laki craters], Iceland	1783	4	2300	0.19
Unknown (El Chichón?)	1809			0.20
Tambora, Sumbawa, Indonesia	1815	7	3000	0.50
Cosiguina, Nicaragua	1835	5	4000	0.11
Askja, Iceland	1875	5	1000	0.01*
Krakatau, Indonesia	1883	6	1000	0.12
Okataina [Tarawera], North Island, NZ	1886	5	800	0.04
Santa María, Guatemala	1902	6	600	0.05
Ksudach, Kamchatka, Russia	1907	5	500	0.02
Novarupta [Katmai], Alaska, US	1912	6	500	0.15
Agung, Bali, Indonesia	1963	4	800	0.06
Mt. St. Helens, Washington, US	1980	5	500	0.00
El Chichón, Chiapas, Mexico	1982	5	800	0.06
Mt. Pinatubo, Luzon, Philippines	1991	6	1000	—

Volcanic Eruptions

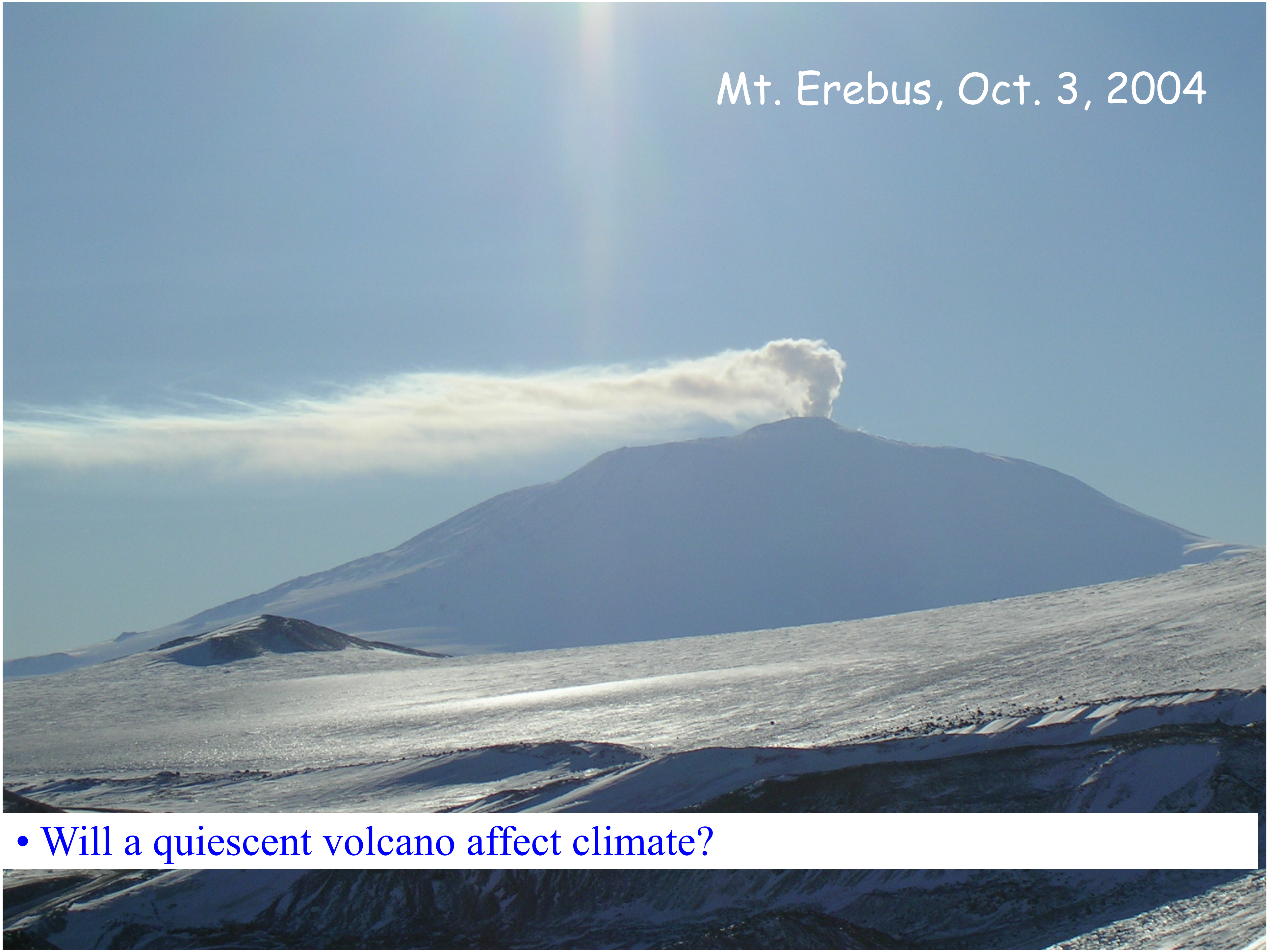
- Will hot lava flows produce warming effects?

Fire fountains from Kilauea volcano in Hawaii

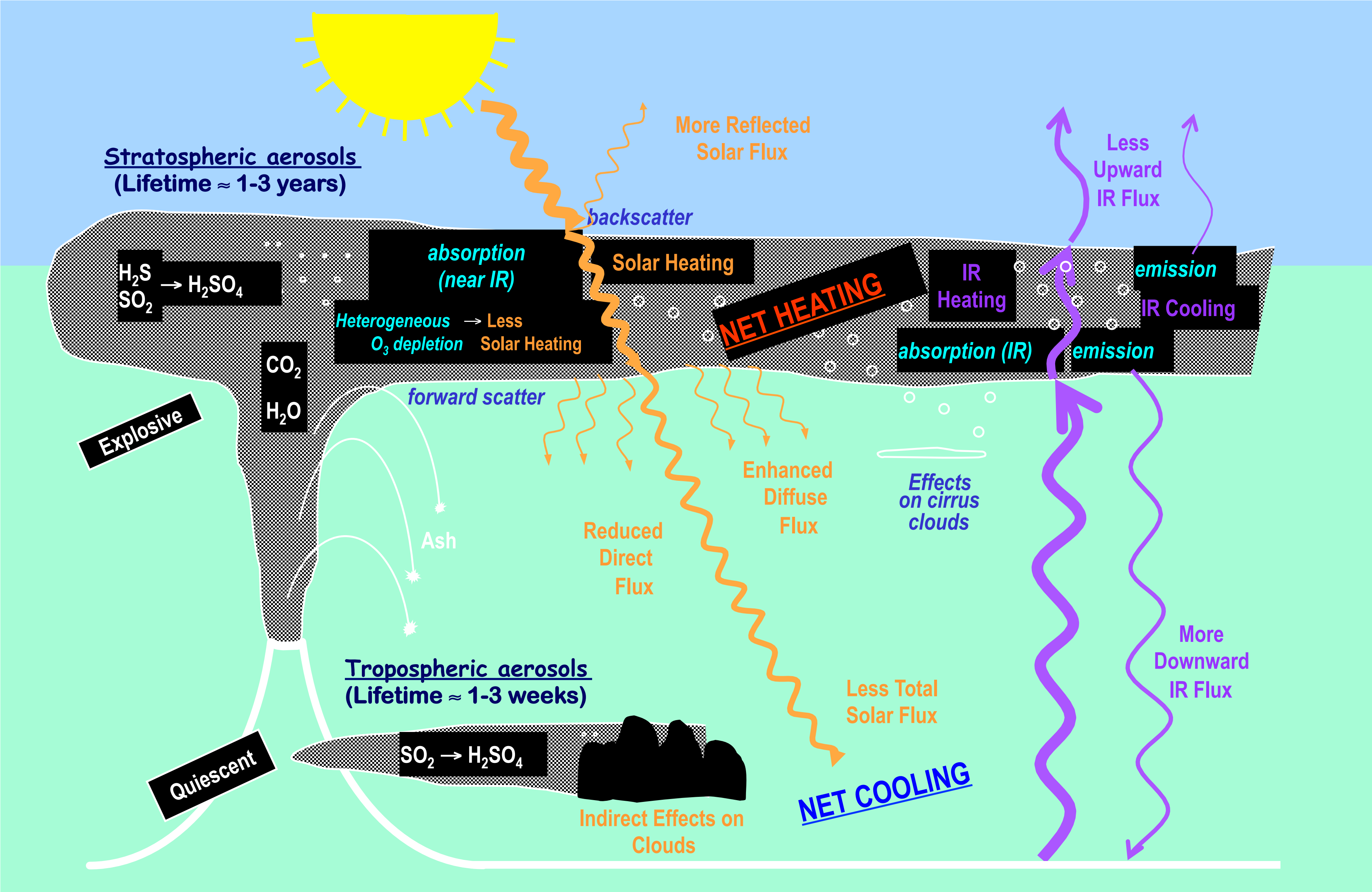
- Will forest fires and smokes caused by volcanoes affect climate?

Laki, Iceland, erupted 1783-1784

• Will beautiful landscapes created by volcanic eruptions affect climate?



• Will a quiescent volcano affect climate?



How does volcano affect climate?

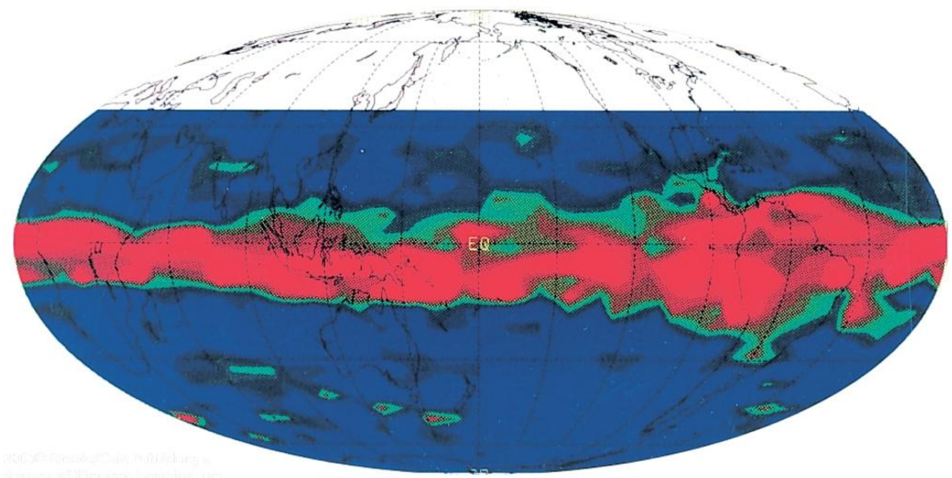
Tropospheric & Stratospheric Aerosols

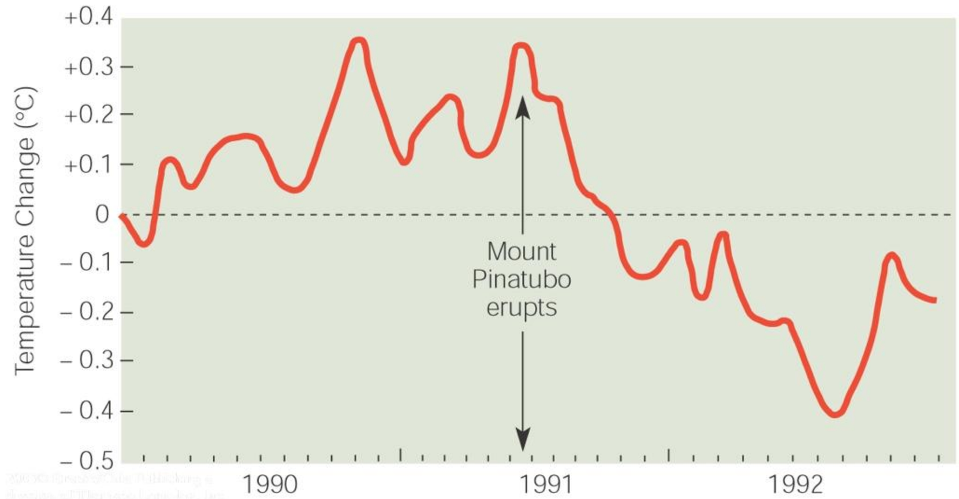
Auto emissions and wild land fires are 2 sources that emit aerosols into the troposphere that reduce incoming radiation and have a net cooling effect on earth's surface.

Volcanic eruptions push aerosols into the stratosphere.

Large eruptions, such as Mt. Pinatubo, have been linked to significant cooling episodes.

Mt. Pinatubo Eruption & Impact

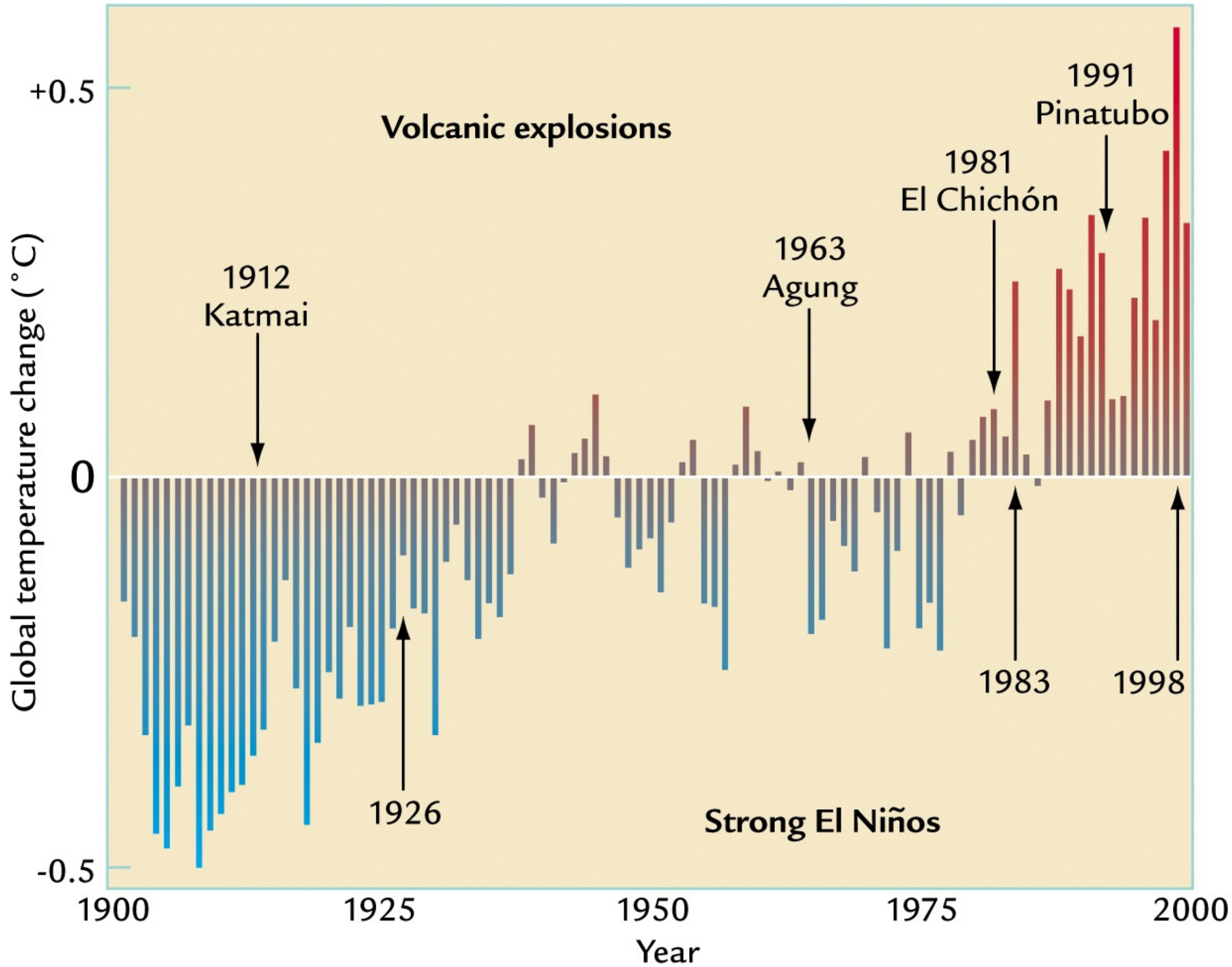


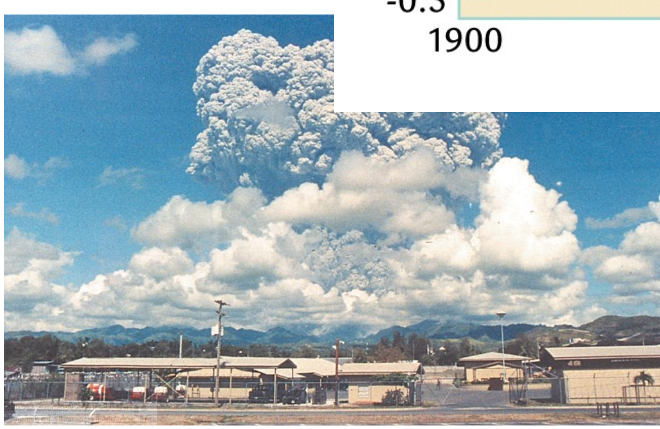


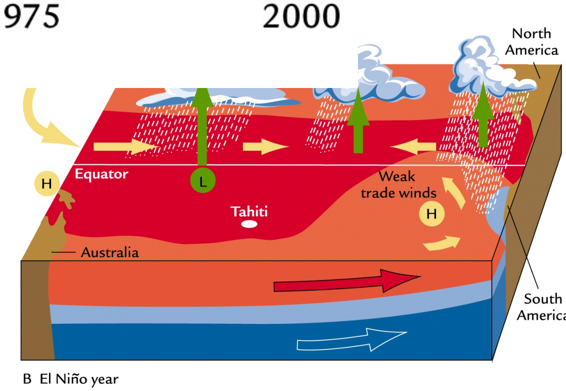
Three months after the June 1991 eruption of this Philippine volcano, much of the 20 million tons of ejected sulfur dioxide had been directed by zonal stratospheric winds and girdled the equator.

Recorded changes in air temperature indicates the volcanic impact on climate.

Brief Episodes of Volcanic Cooling and El Nino Warming







Volcanoes produced the atmosphere and the oceans

Volcanic emissions

N_2 remains N_2

CO_2 → photosynthesis → O_2

H_2O → photosynthesis

H_2O → condensation → oceans

N_2 and O_2: 99% of atmosphere

EFFECTS OF LARGE EXPLOSIVE TROPICAL VOLCANOES ON WEATHER AND CLIMATE

EFFECT/MECHANISM	BEGINS	DURATION
1. Enhance or reduce El Niño? Tropospheric absorption of shortwave and longwave radiation, dynamics	1-2 weeks	1-2 months
2. Reduction of diurnal cycle Blockage of shortwave and emission of longwave radiation	Immediately	1-4 days
3. Summer cooling of NH tropics, subtropics Blockage of shortwave radiation	Immediately	1-2 years
4. Reduced tropical precipitation Blockage of shortwave radiation, reduced evaporation	Immediately	~1 year
5. Reduced Sahel precipitation Blockage of shortwave radiation, reduced land temp., reduced evaporation Weaker African monsoon	1-3 months	1-2 years

EFFECTS OF LARGE EXPLOSIVE TROPICAL VOLCANOES ON WEATHER AND CLIMATE

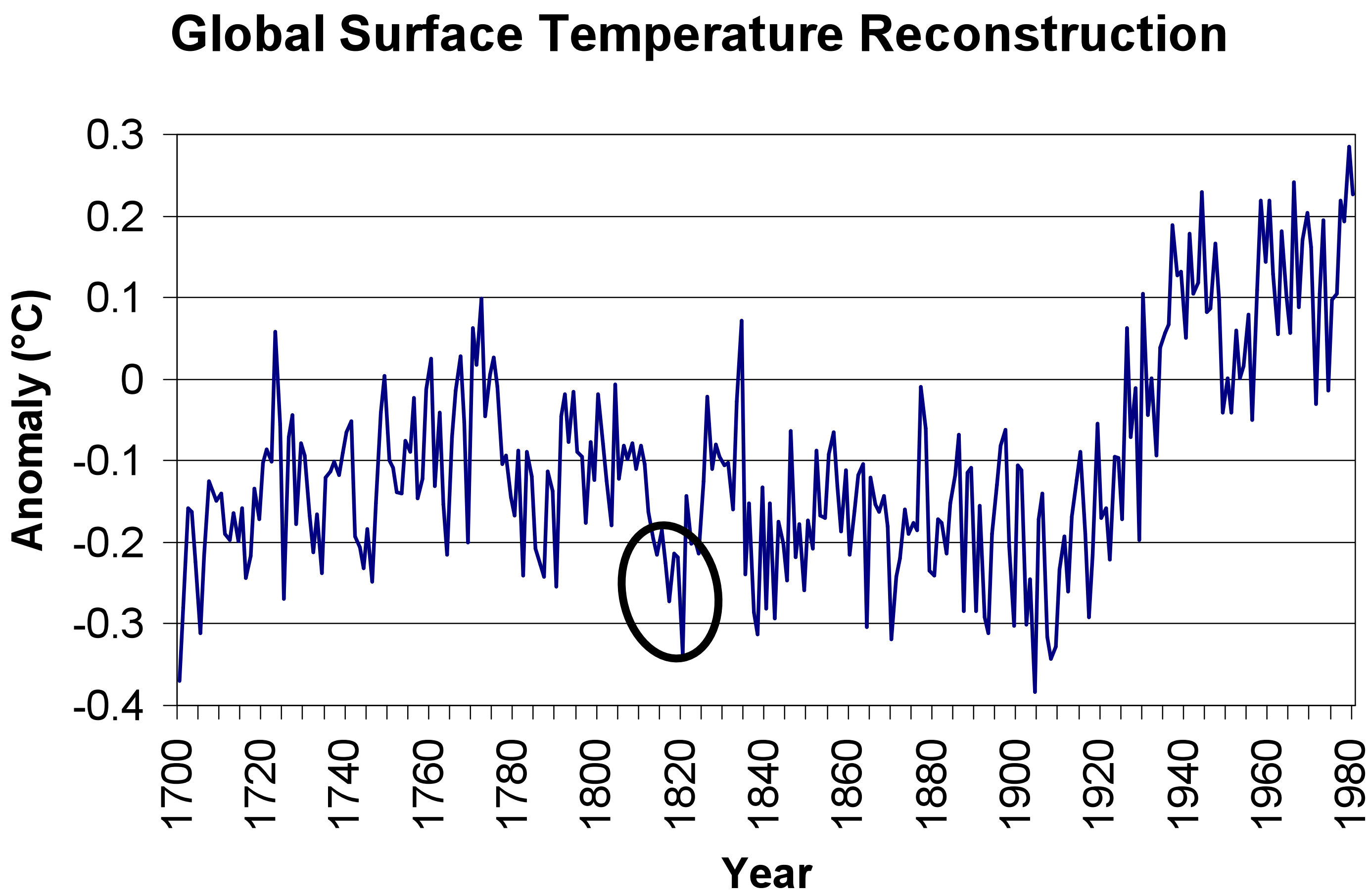
EFFECT/MECHANISM	BEGINS	DURATION
6. Ozone depletion, enhanced UV Dilution, heterogeneous chemistry on aerosols	1 day	1-2 years
7. Global cooling Blockage of shortwave radiation	Immediately multiple eruptions:	1-3 years 10-100 years
8. Stratospheric warming Stratospheric absorption of shortwave and longwave radiation	Immediately	1-2 years
9. Winter warming of NH continents Stratospheric absorption of shortwave and longwave radiation, dynamics	½-1½ years	1 or 2 winters

EFFECTS OF LARGE EXPLOSIVE HIGH-LATITUDE VOLCANOES ON WEATHER AND CLIMATE

EFFECT/MECHANISM	BEGINS	DURATION
High latitude eruptions:		
10. Cooling of continents Blockage of shortwave radiation	Immediately	1-2 years
11. Reduction of Indian summer monsoon Continental cooling, reduction of land-sea temperature contrast	½-1 year	1 or 2 summers
12. Reduction of African summer monsoon Continental cooling, reduction of land-sea temperature contrast	½-1 year	1 or 2 summers
13. Reduction of Nile River flow Reduced monsoon precipitation	½-1 year	1-2 years

Tambora, 1815, produced the "Year Without a Summer" (1816)

Tambora in 1815, together with an eruption from an unknown volcano in 1809, produced the "Year Without a Summer" (1816)



Mann et al. (2000)

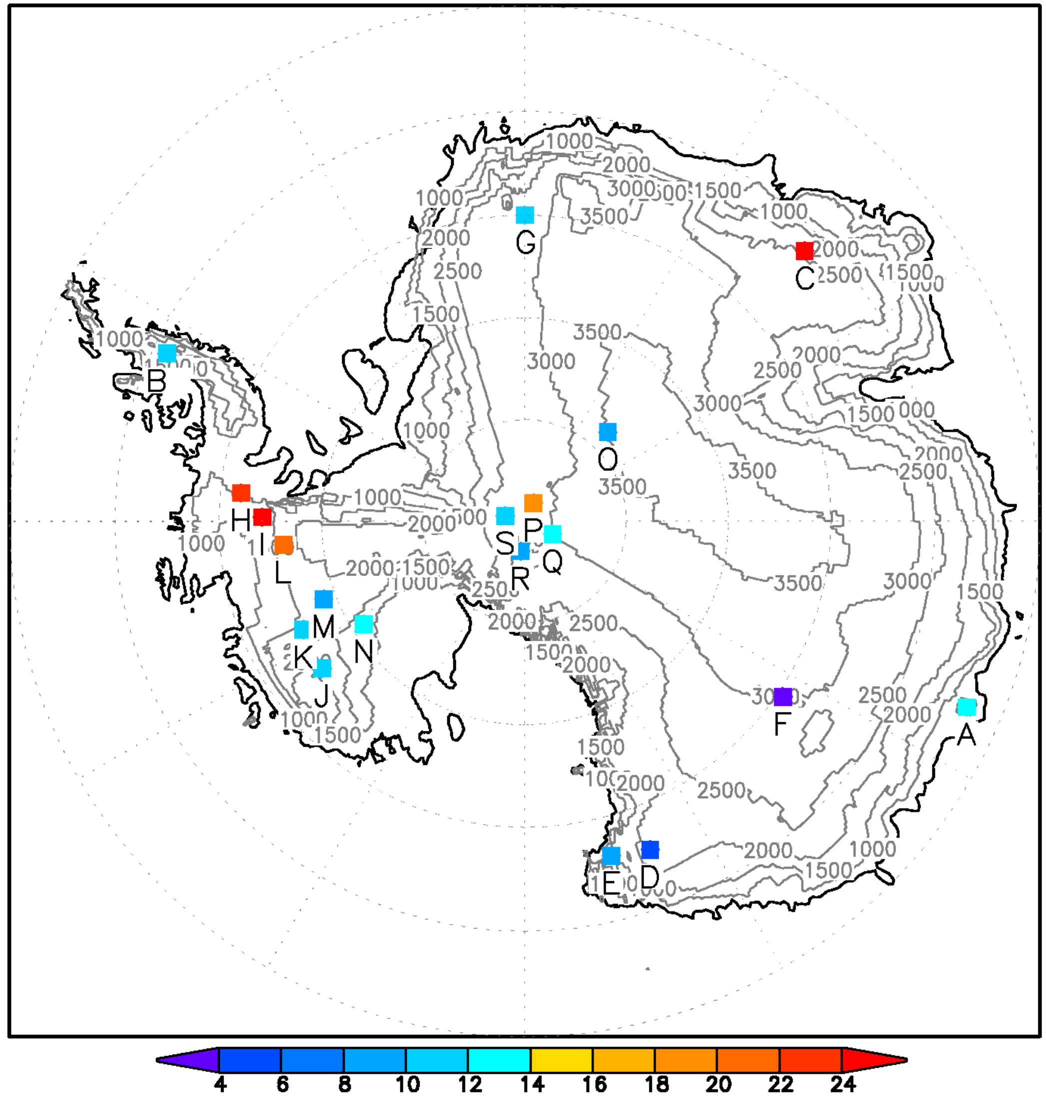
The Pinatubo Bears

In the summer of 1992 the ice on Hudson Bay melted almost a month later than normal.

"That had a dramatic effect on the bears," Ian Stirling says. "They were bigger, they were heavier, they had more cubs, the cubs survived better. And the cubs that were born in that year, we call them the Pinatubo bears, because so many of them survived from that particular year class."

Volcanic sulfate in ice cores gives record of past climate forcing from volcanic eruptions

Krakatau Deposition (kg/km²) in Antarctica



A–LawDome B–Dyer C–G15 D–TalosDome E–HercNeve
F–DomeC G–DMLB32 H–SipleStn I–ITASE015 J–ITASE005
K–ITASE004 L–ITASE013 M–ITASE001 N–ITASE991 O–PlateauRm
P–SP2001c1 Q–SP95 R–PS1 S–PS14

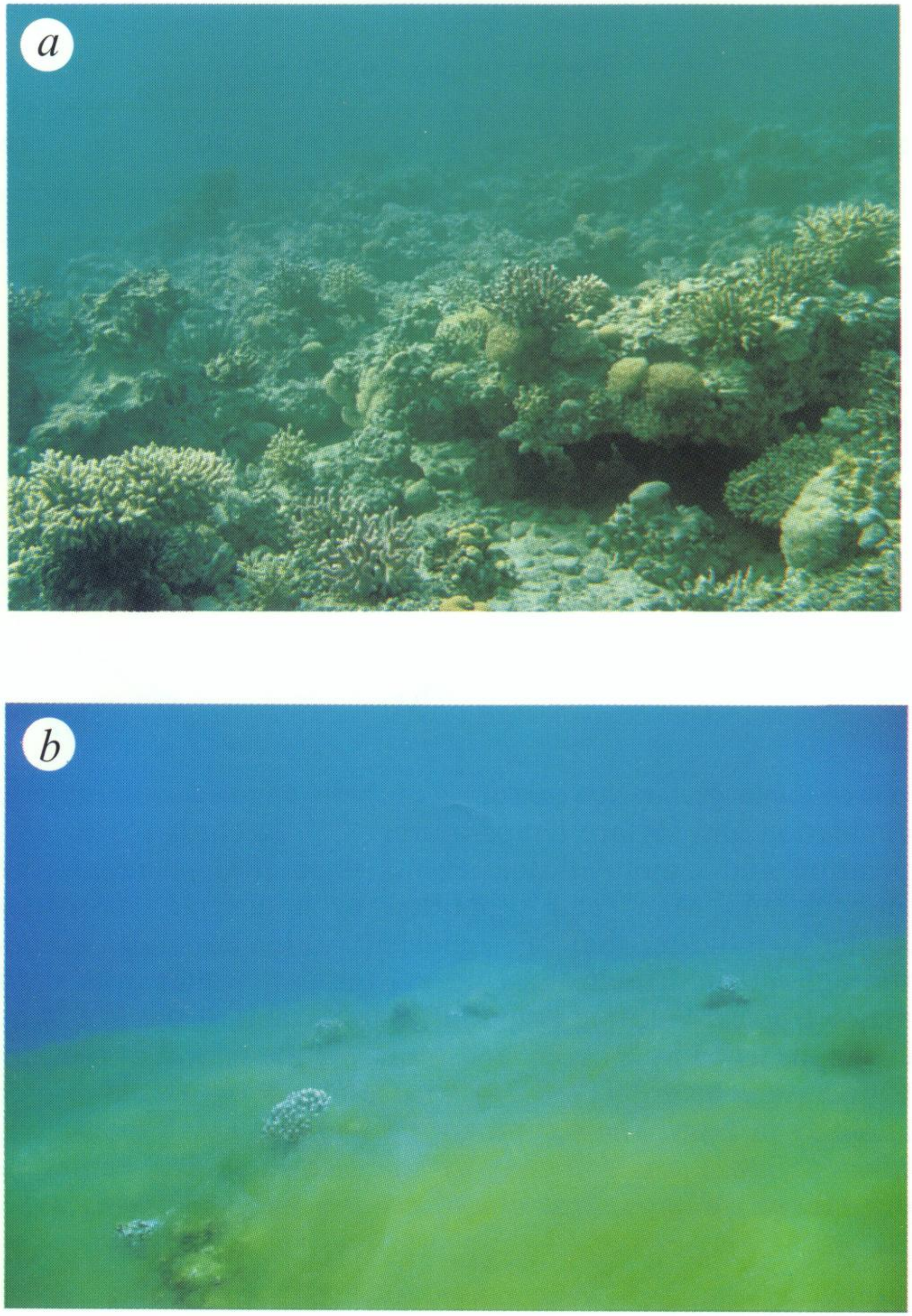
Site J, K, P, Q, S, R are slightly relocated to avoid overlapping.

Genin et al. (1995) found coral death in the Red Sea in the winter following the Pinatubo eruption.

Cooling induced mixing, bringing nutrients which produced an algae bloom, which smothered the coral.

a. Dec. 15, 1994 (normal)

b. April 6, 1992 (after Pinatubo)



El Chichón, 1982

Sunset

Madison, Wisconsin

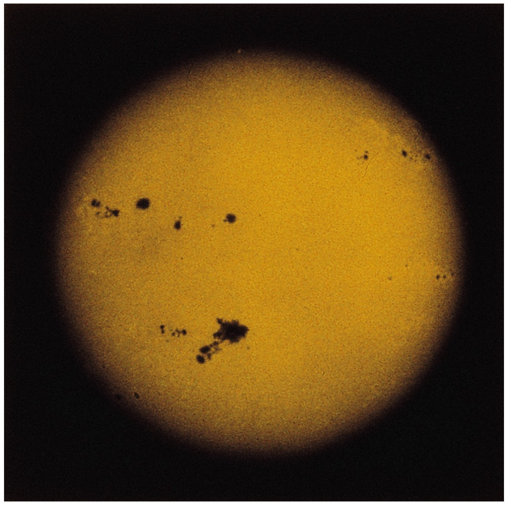
May, 1983

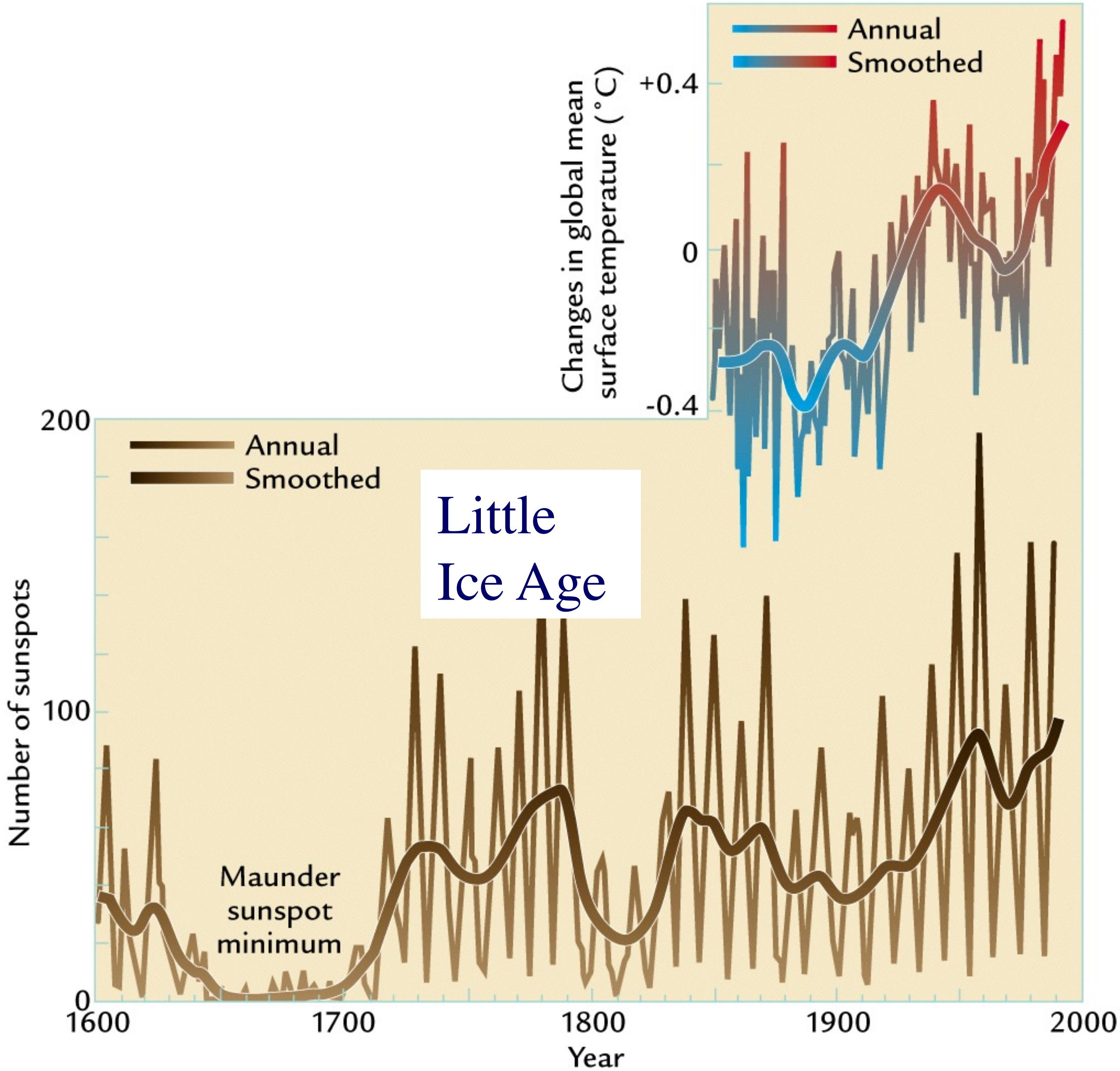
Photograph by Alan Robock

- How do sunspots affect climate?

- In what way do sunspot cycles before the 20th century imply a Sun-climate connections?

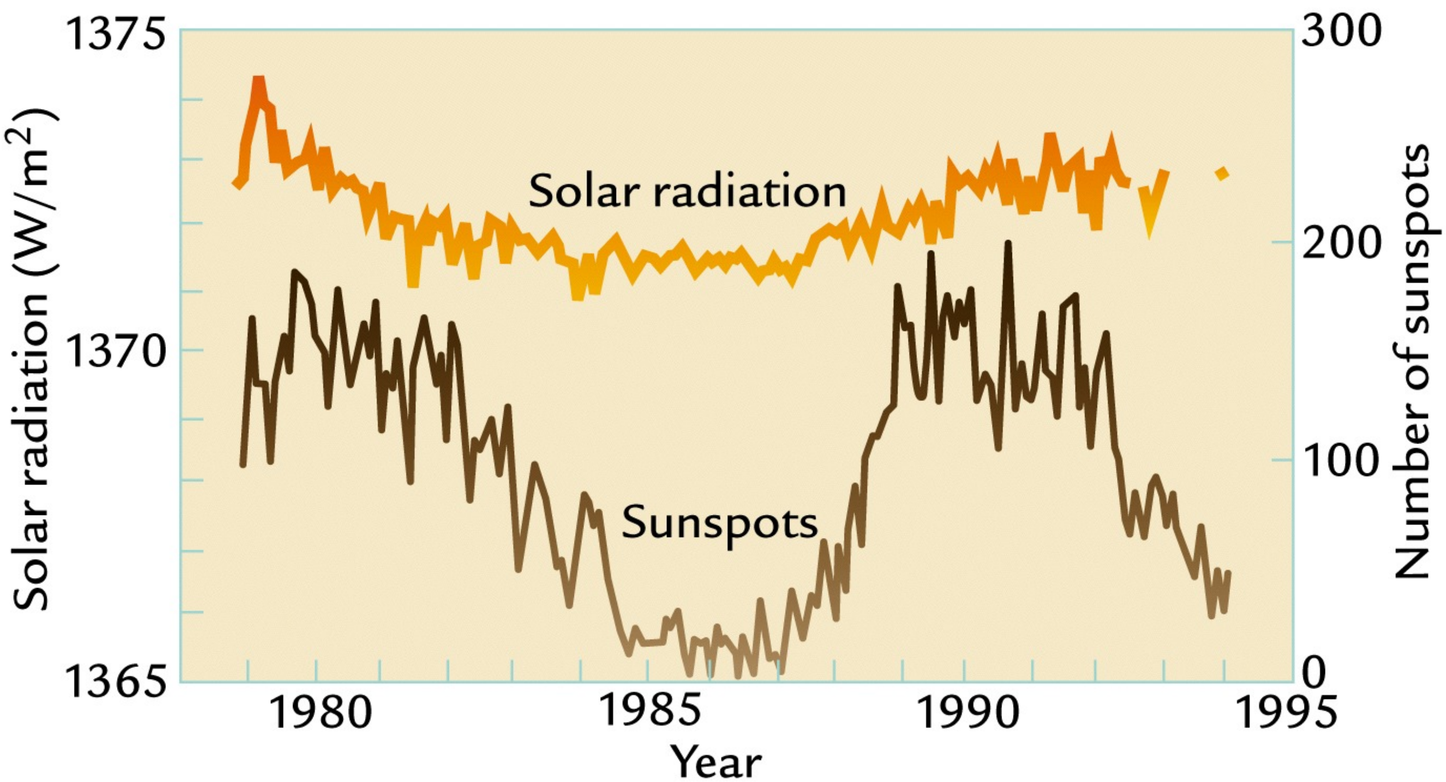
Sunspot History from Telescopes



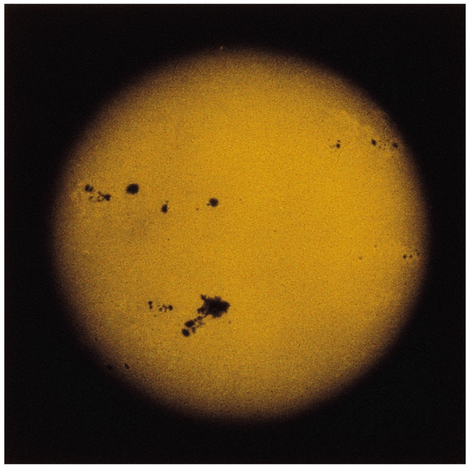


The telescope records show:
11-year sunspot cycle,
The Maunder minimum.

Climate Change and Variations in Solar Output



More sunspots, stronger solar emissions from the Sun's polar regions and from the bright margins of sunspots.



Third Assessment Report of the IPCC (2001): General circulation model results

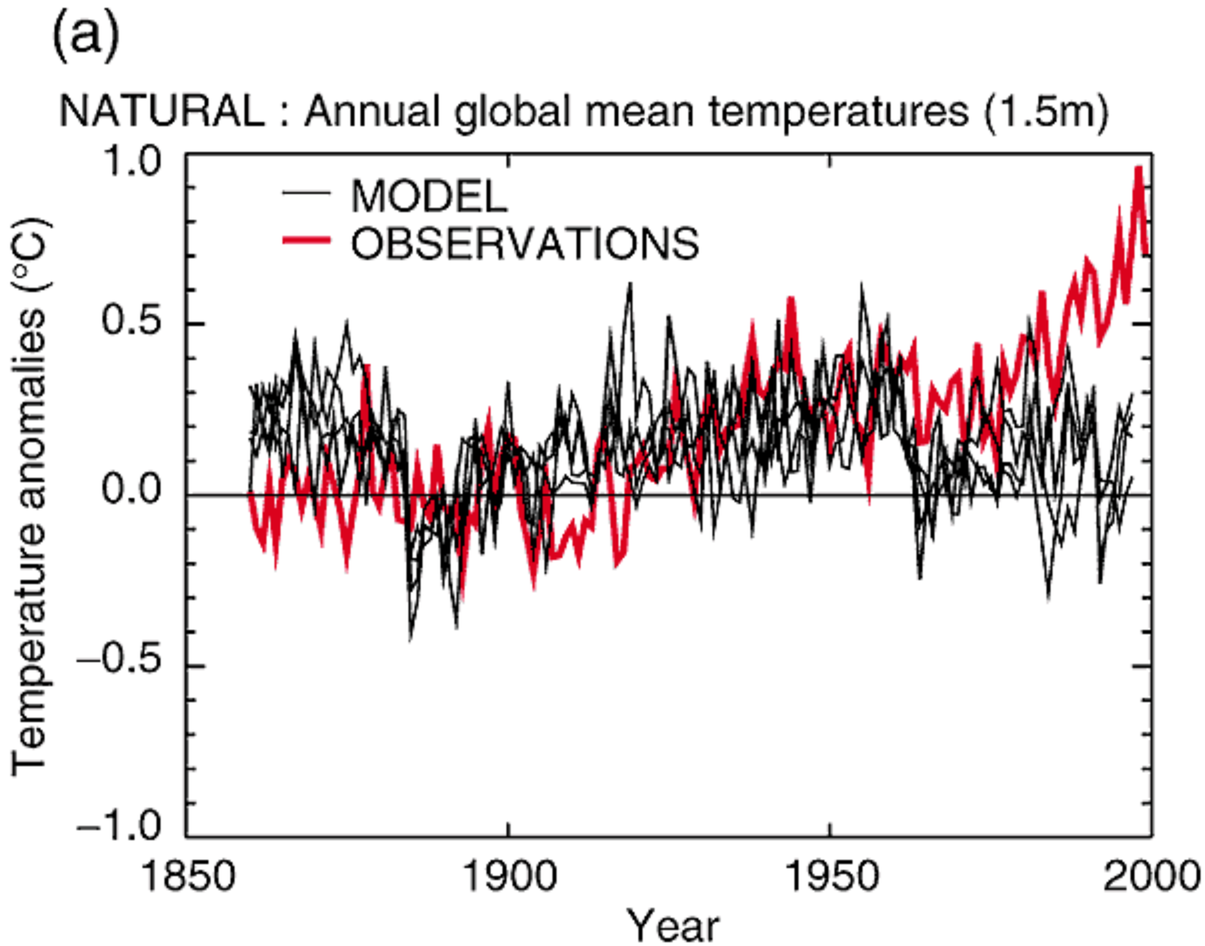
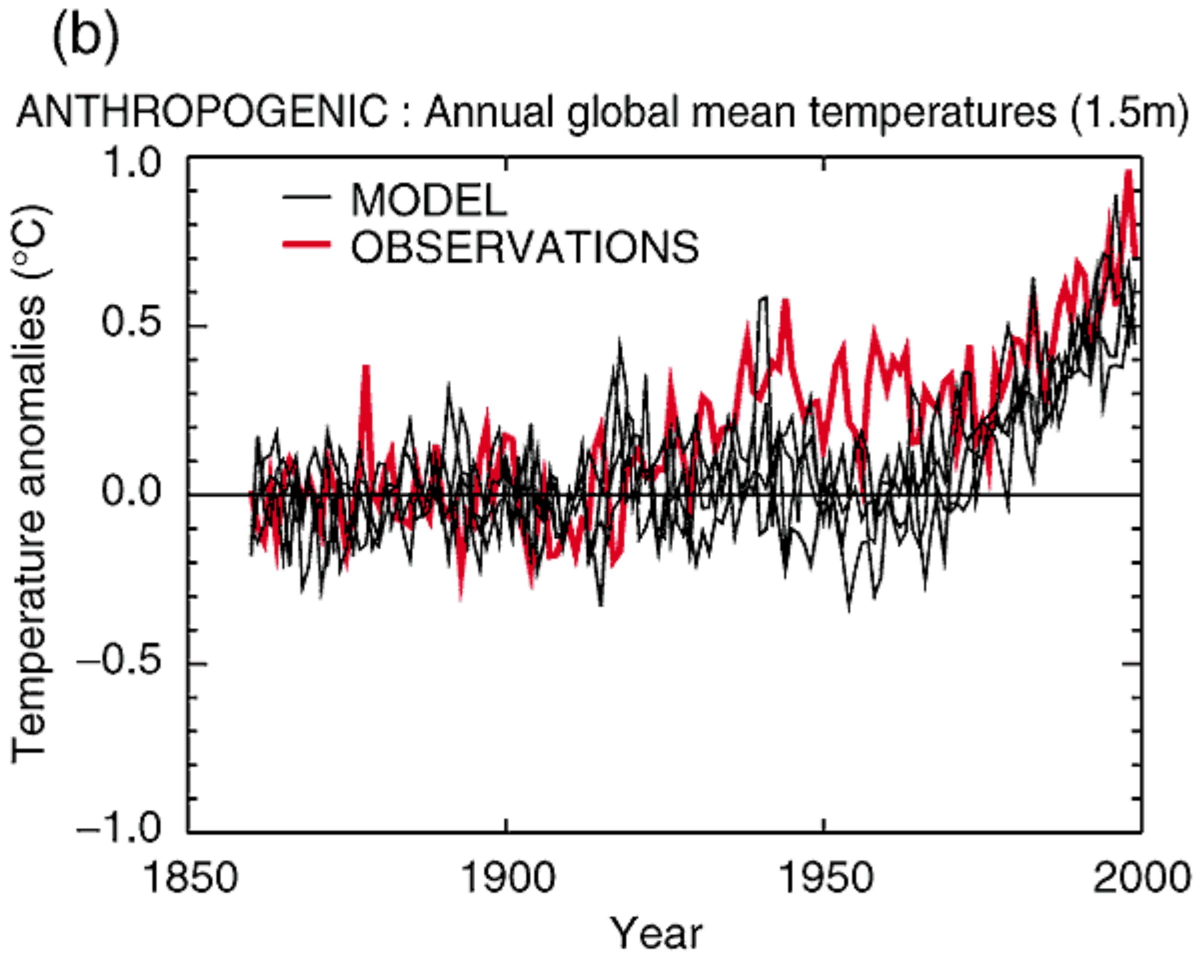


Fig. 12-7

Third Assessment Report of the IPCC (2001): General circulation model results



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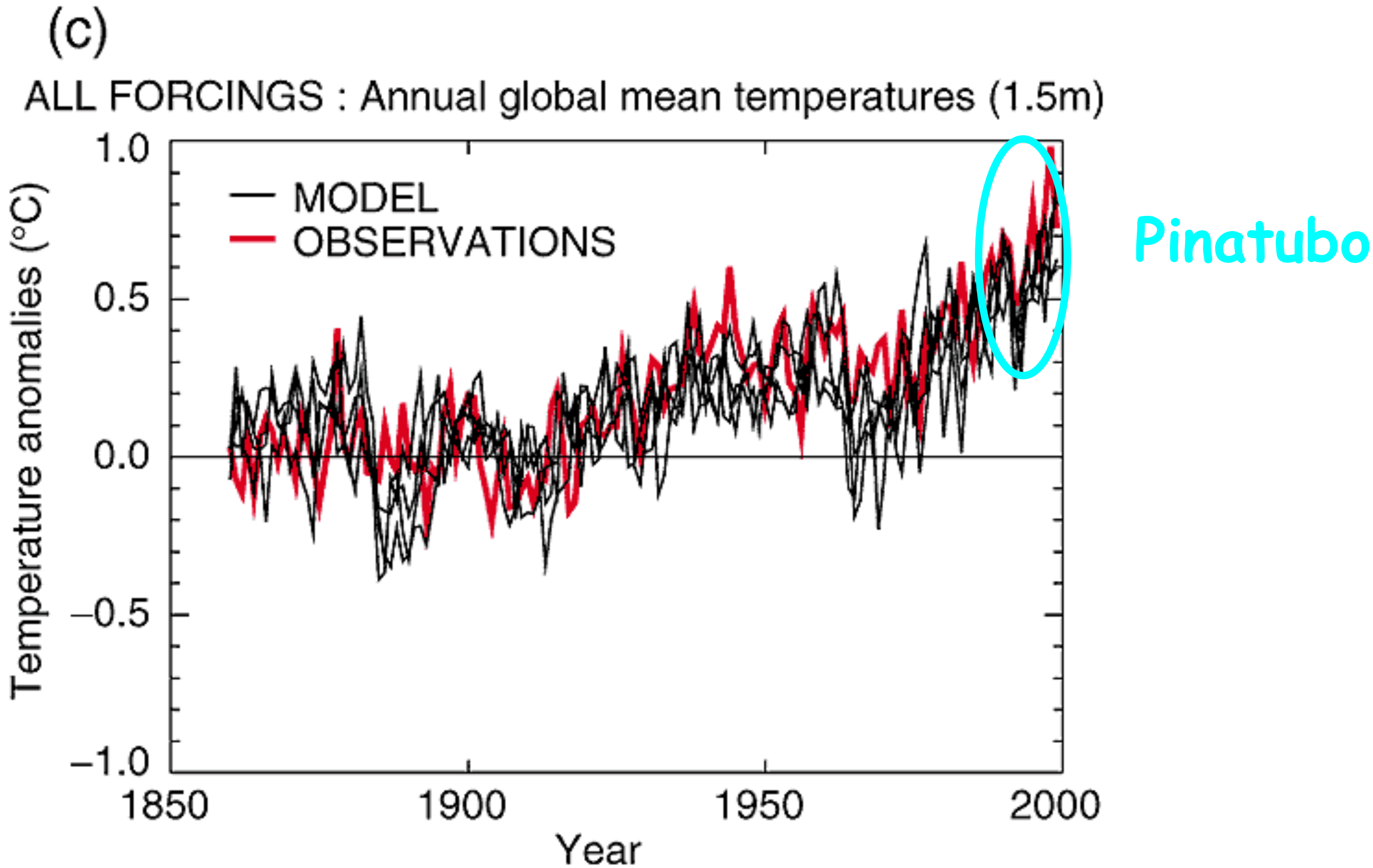

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