Pinatubo
June 12, 1991

Three days before major eruption of June 15, 1991

Dr. Alan Robock

Satellites, Weather and Climate Module 8b:

Air Quality - Volcanoes

SWAC

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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

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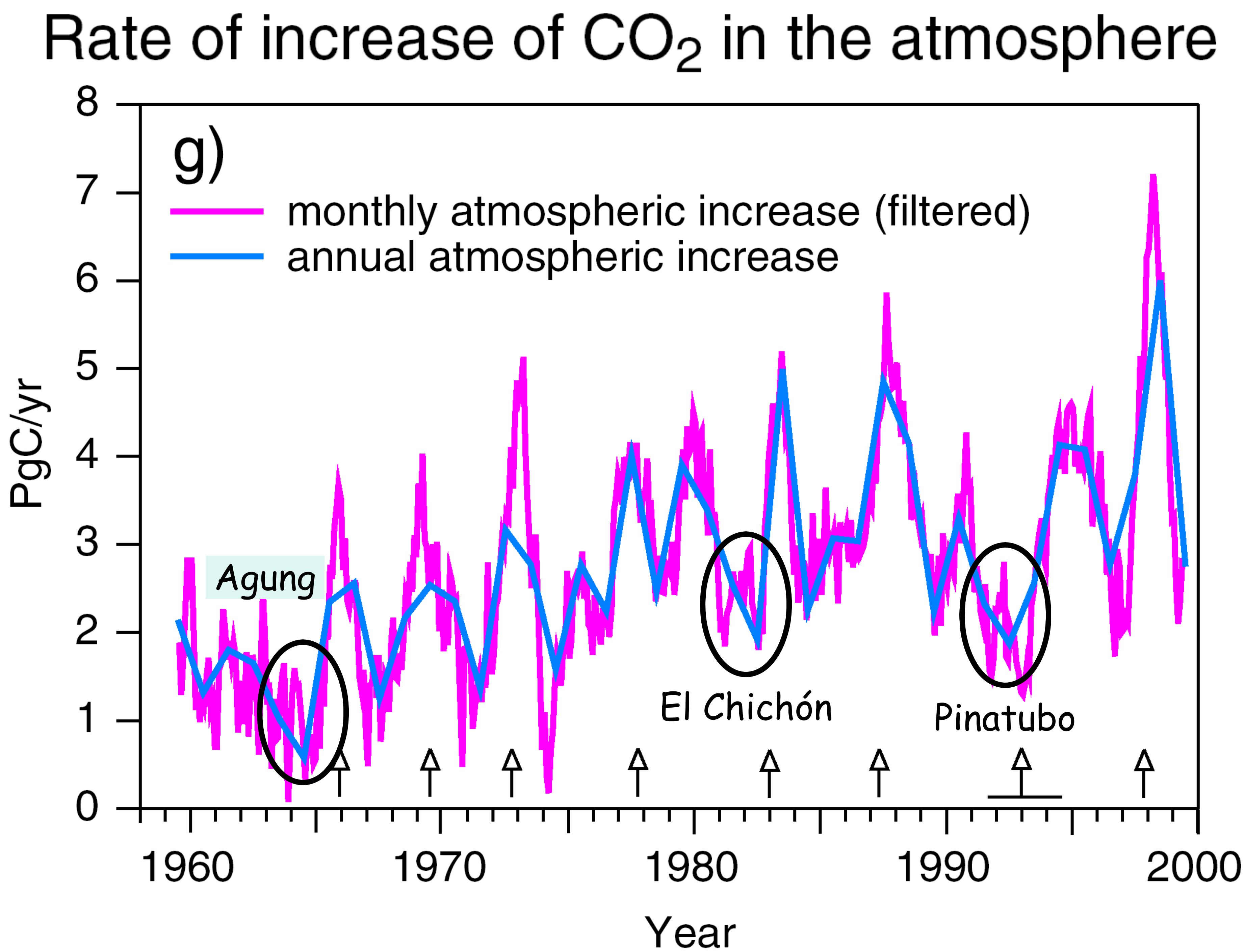
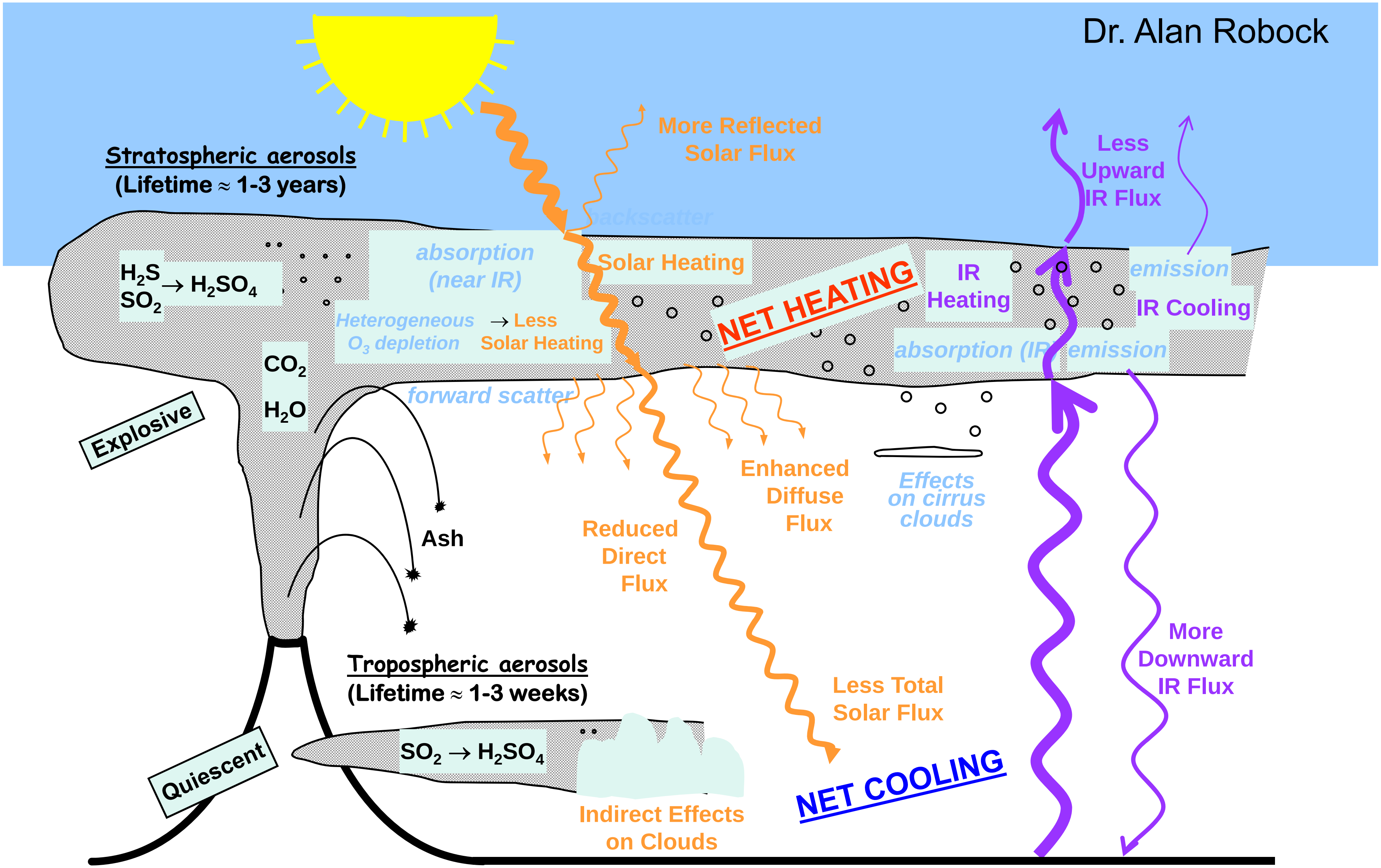
Gaseous emissions from volcanoes

- nitrogen (1%)
- water vapour (80%)
- carbon dioxide (12%)
- sulphur dioxide & other gases (12%)


Rate of increase of CO_2 in the atmosphere
g)
monthly atmospheric increase (filtered)
annual atmospheric increase
PgC/yr
Year
Agung
El Chichón
Pinatubo
0
1
2
3
4
5
6
7
8
1960
1970
1980
1990
2000



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Stratospheric aerosols
(Lifetime ≈ 1-3 years)
More Reflected Solar Flux
backscatter
Less Upward IR Flux
H_2S SO_2 → H_2SO_4
absorption (near IR)
Solar Heating
NET HEATING
IR Heating
emission
IR Cooling
Heterogeneous O_3 depletion → Less Solar Heating
absorption (IR) emission
CO_2
H_2O
forward scatter
Explosive
Ash
Enhanced Diffuse Flux
Effects on cirrus clouds
Reduced Direct Flux
More Downward IR Flux
Tropospheric aerosols
(Lifetime ≈ 1-3 weeks)
Less Total Solar Flux
SO_2 → H_2SO_4
Quiescent
NET COOLING
Indirect Effects on Clouds

Local impact – water vapour

- cooling of water vapour → cloud of water and ash above & downwind of volcano

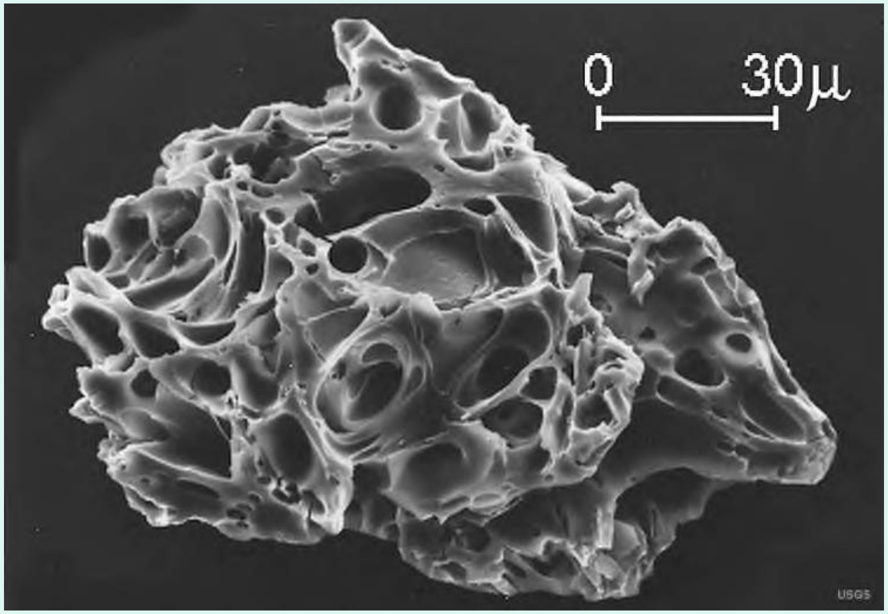
- ↪ decrease in daytime temperature
- increase in nighttime temperature

Local impact

- gas and ash carried > 20-30km up (by heat and explosive energy)
- advection of plume by prevailing winds - heavier particles settle out
- stable stratosphere - lightweight particles long residence time

- volcanic plume in tropical stratosphere spreads laterally and poleward in both hemispheres (most major volcanoes equatorward of 30°)

Volcanic ash



After Pinatubo, Clark Air Force Base
25 km from volcano

Photo by R. P. Hoblitt, June 15, 1991

After Pinatubo, Cubi Point Naval Air Station, 40 km from volcano

U.S. Navy photograph by R. L. Rieger

Dust Veil Index

- measure of turbidity of atmosphere
- reduction in radiation due to dust & aerosols in the years after eruption

  - depletion of radiation following the eruption
  - temperature variations following the eruption
  - the amount of solid material dispersed as dust after an eruption

AEROSOLS AND CLIMATE CHANGE - Netscape 6

http://www.geo.arizona.edu/palynology/geos462/23clim...

DVI

The **D**UST **V**EIL **I**NDEX (H.H. Lamb, 1970, 1977, 1983)
comparison value: Krakatau DVI = 1000

DVI = 0.97 · R·E·t

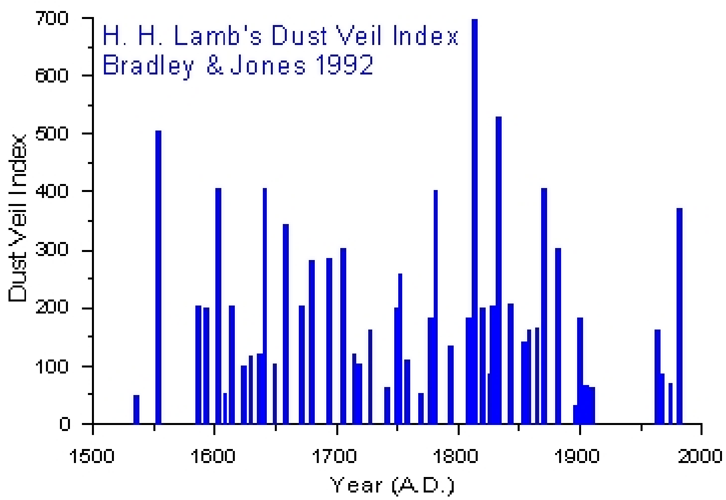
- **R** = % radiation decr.
- **E** "latitude factor: from 1.0 for lat. 20N - 20S to 0.3 for lat. 42 - 90 N,S
- **t** = months duration

DVI = 52.5 · T·E·t

- **T** = ^{0}C temperature lowering

DVI = 4.4 · q·E·t

- **q** = km^{3} dust in atm.



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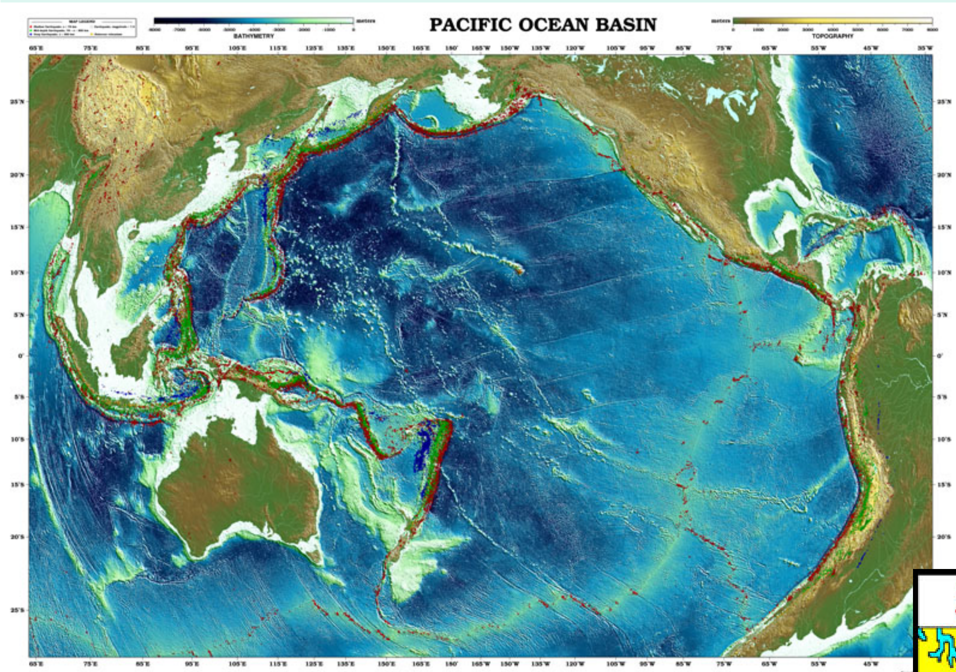
Global impact

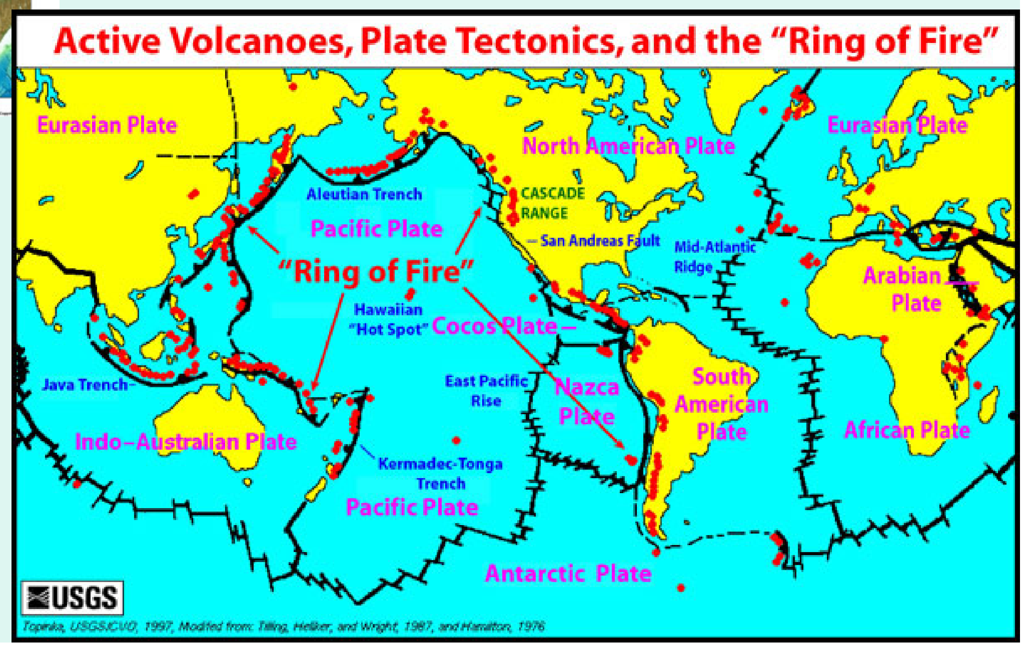
- large and explosive
- large volumes of sulphur gases
- penetration of gases and ash into the stratosphere
- location of stratospheric penetration and time of year must be conducive for upper level advection

Pacific Ring of Fire



http://www.geoware-online.com/GeowarePacificOceanBasinMap.jpg

http://oceanexplorer.noaa.gov



Impact of SO_2

Chaiten eruption

- large amounts in the stratosphere
- $SO_2 + H_2Ov \rightarrow$ sulphuric acid drops which reflect sunlight back to space $\rightarrow$ lowering of surface temperature
- sulphate aerosol $\rightarrow$ brilliant red and orange sunsets for months to years after major eruption (couple years residence time)

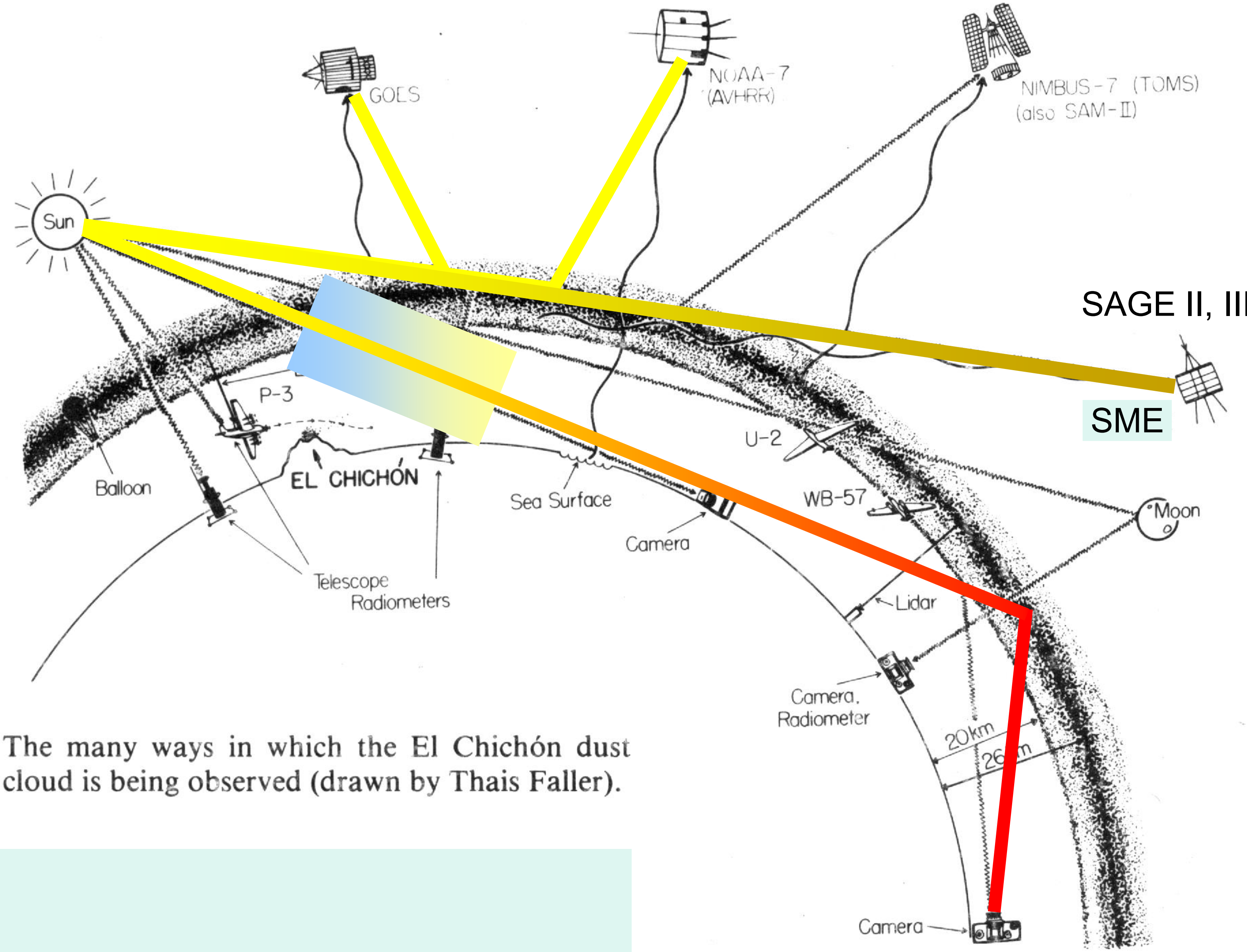
El Chichón, 1982

Sunset

Madison, Wisconsin

May, 1983

Photograph by Alan Robock



The many ways in which the El Chichón dust cloud is being observed (drawn by Thais Faller).

Robock (1983)

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August 30, 1984

August 8, 1991

These two photos show the Earth's limb at sunset before and after the Mt. Pinatubo eruption. The first view (STS41D-32-14) shows a relatively clear atmosphere, taken August 30, 1984. Astronauts were looking at the profiles of high thunderstorms topping out at the tropopause at sunset; different atmospheric layers absorbed the last rays of light from the sun as the spacecraft moved eastward.

The same type of photograph (STS043-22-23) was taken August 8, 1991, less than two months after the Pinatubo eruption. Two dark layers of aerosols make distinct boundaries in the atmosphere. The estimated altitude of aerosol layers in this view is 20 to 25 km.

http://earthobservatory.nasa.gov/Study/AstronautPinatubo/astronaut_pinatubo2.html

Types of eruptions

- explosive vs. quiet
- function of gas release at eruption and ease with which gas escapes from erupting molten rock

- gases dissolved at high pressures and temperatures deep within earth
- sudden release when molten rock reaches surface

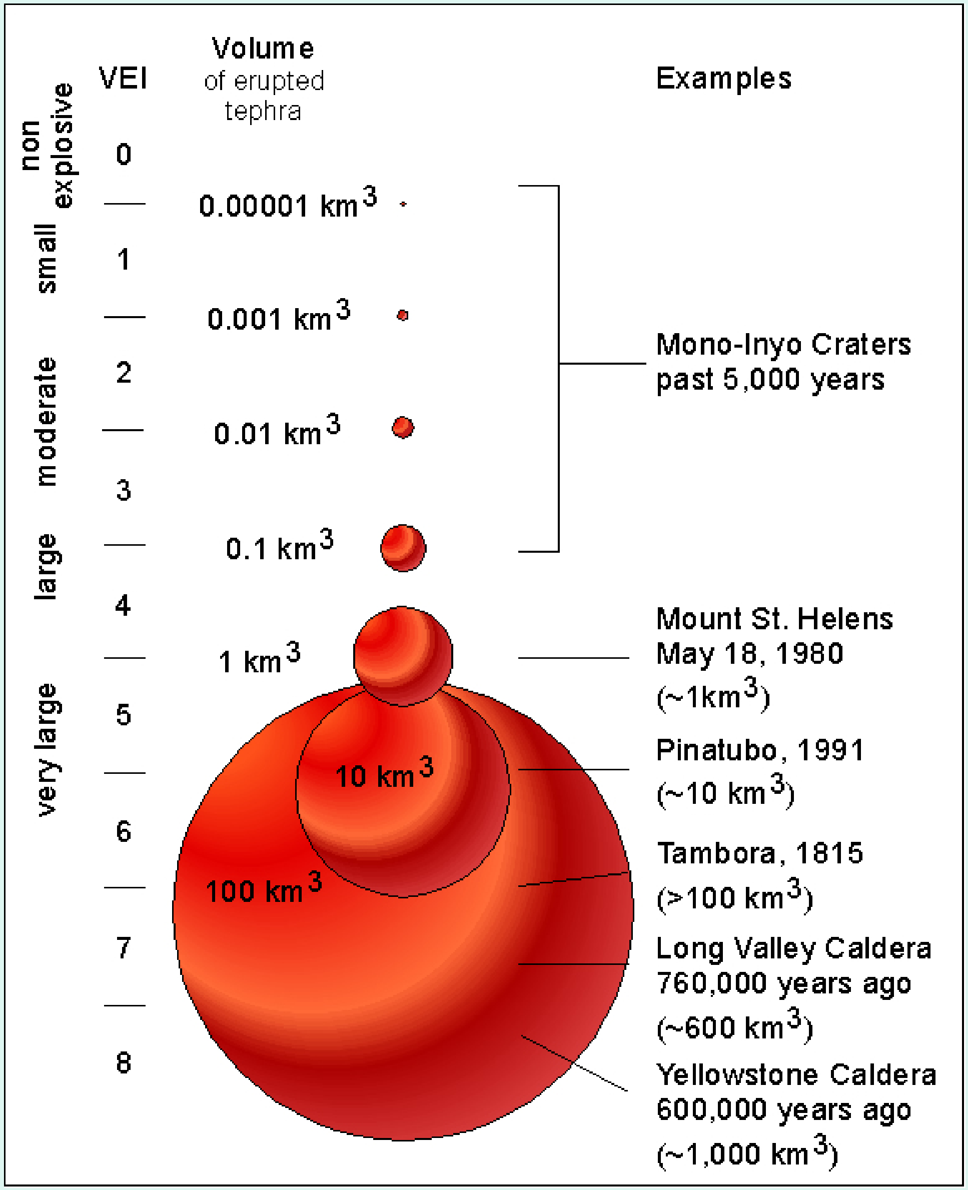
Types of eruptions

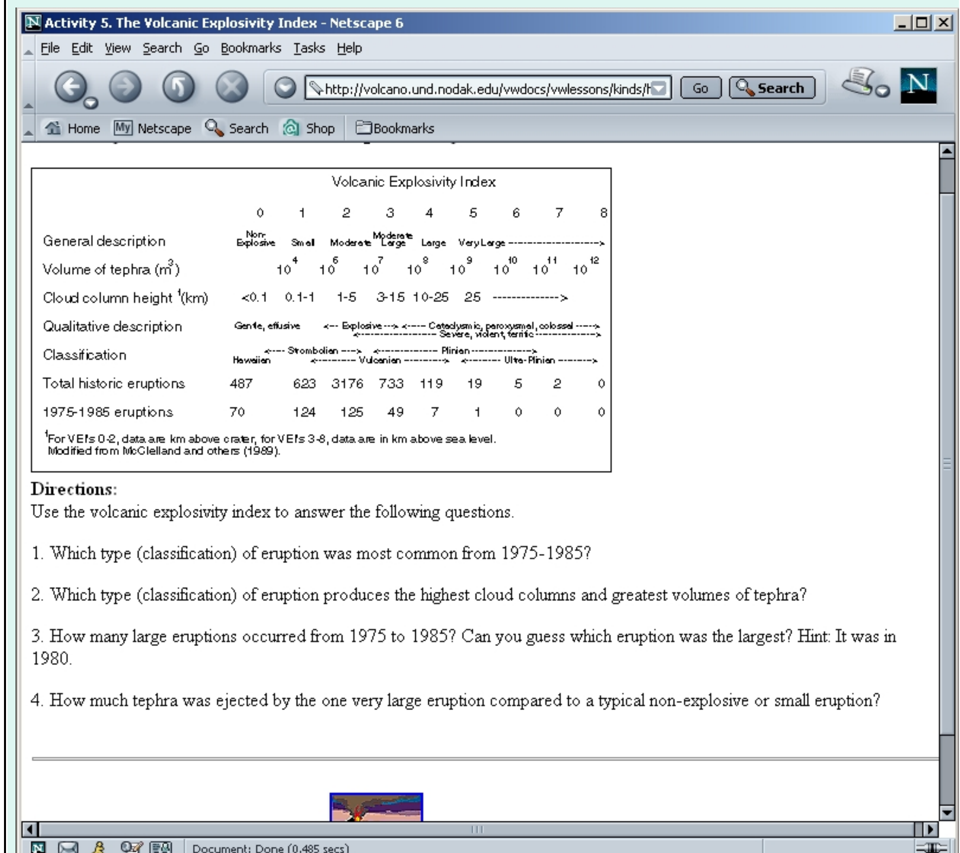
- steam (most abundant), carbon dioxide, sulphur gases (SO_2 and hydrogen sulphide), hydrochloric acid gas, nitrogen

- Hawaiian lavas low in dissolved gases
- Pacific Ring of Fire volcanoes higher gas content

Volcanic explosivity index

- measures the impact
- volume of products, eruption cloud height, duration in hours and qualitative observations
- open ended scale
  - 0 for non- explosive eruptions
  - 8 for history's largest explosive eruption
  - Strombolian and Vulcanian eruptions are the most common
  - Plinian and ultraplinian eruptions generate the greatest cloud column heights
  - The volume of Hawaiian and Strombolian eruptions is 10^4 m^3 or less
  - Very large eruptions produce one million m^3 more tephra than non-explosive or small eruptions.





Volcanic Explosivity Index

	0	1	2	3	4	5	6	7	8
General description	Non-Explosive	Small	Moderate	Moderate-Large	Large	Very Large ------------------>			
Volume of tephra (m^3)		10^4	10^6	10^7	10^8	10^9	10^{10}	10^{11}	10^{12}
Cloud column height [1] (km)	<0.1	0.1-1	1-5	3-15	10-25	25 ------------>			
Qualitative description	Gentle, effusive		<-- Explosive -->	<---- Cataclysmic, paroxysmal, colossal ----> <---------------- Severe, violent, terrific ------------>					
Classification	Hawaiian	<--- Strombolian ---> <--------- Vulcanian --------->		<------------ Plinian ------------>		<-------- Ultra-Plinian -------->			
Total historic eruptions	487	623	3176	733	119	19	5	2	0
1975-1985 eruptions	70	124	125	49	7	1	0	0	0

[1] For VEI's 0-2, data are km above crater, for VEI's 3-8, data are in km above sea level.
Modified from McClelland and others (1989).

Directions:
Use the volcanic explosivity index to answer the following questions.

1. Which type (classification) of eruption was most common from 1975-1985?

2. Which type (classification) of eruption produces the highest cloud columns and greatest volumes of tephra?

3. How many large eruptions occurred from 1975 to 1985? Can you guess which eruption was the largest? Hint: It was in 1980.

4. How much tephra was ejected by the one very large eruption compared to a typical non-explosive or small eruption?

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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 Maria, 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	—

NOTABLE GLOBAL ERUPTIONS

Iceland

- 1783
- 25 km long crack - large amount of basalt → largest single flood of lava eruptions in history
- huge emissions of volcanic gases
- severe winter in Europe 1783-1784

- Tambora - 1815
- Krakatau - 1883
  - (both followed by drop in temp of 1-2°C in next 1-2 years)

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1783-84 Laki Eruption in Iceland (8 June 1783 – 7 February 1784)

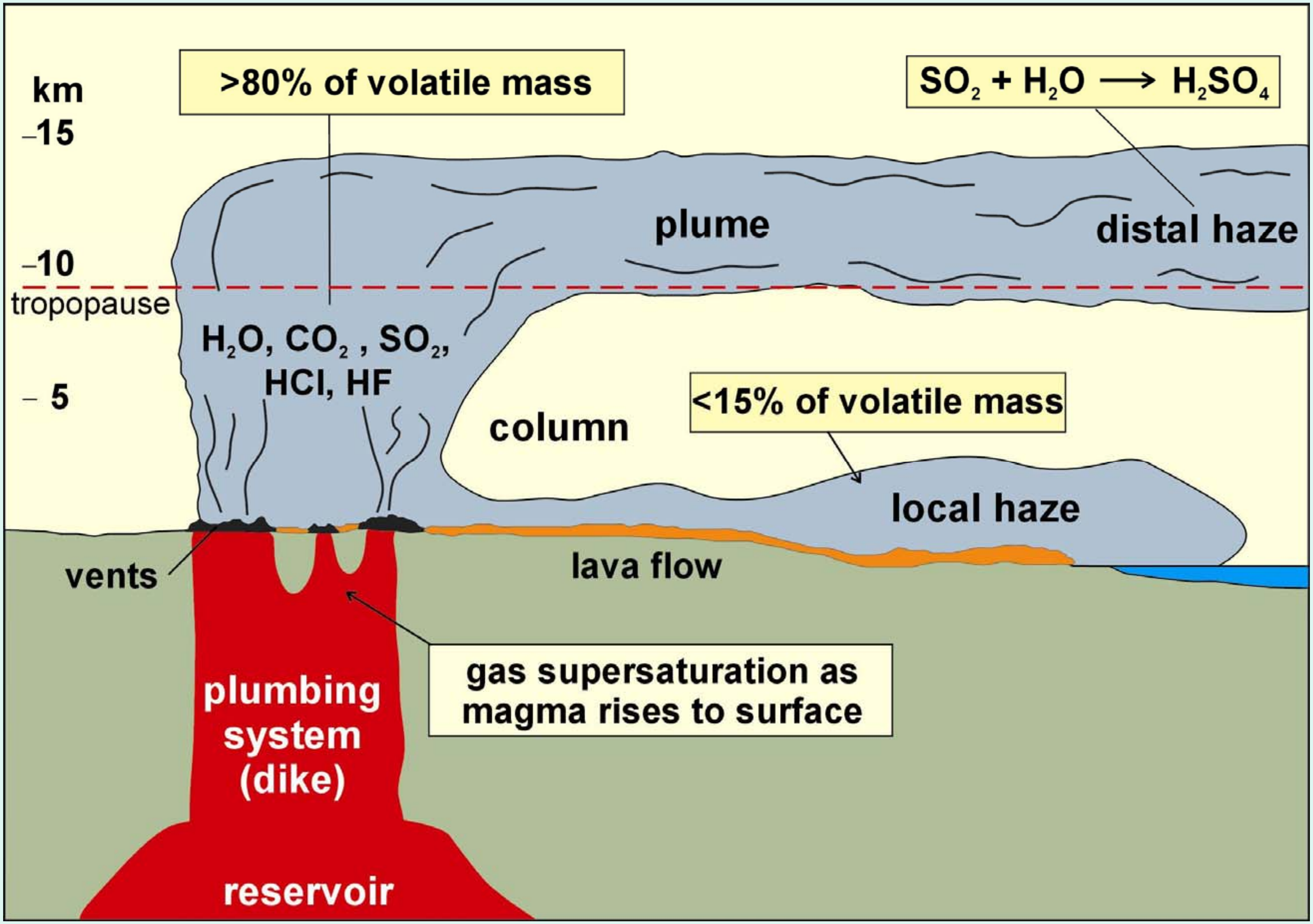
Second largest flood lava eruption in historical time

Iceland's biggest natural disaster

Lava = 14.7 km^3
Tephra = 0.4 km^3

WVZ, EVZ, NVZ are Western, Eastern and Northern Volcanic Zones

Fig. 1 from Thordarson and Self (2003)



Laki eruption was both tropospheric and stratospheric.

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Fig. 3 from Thordarson and Self (2003)

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Figure 128. Portrait of Benjamin Franklin by Pierre H. Alix after Charles A.P. van Loo. National Portrait Gallery, Smithsonian Institution, Washington, D.C.

Franklin (1784)

During several of the summer months of the year 1783, when the effect of the sun's rays to heat the earth in these northern regions should have been greatest, there existed a constant fog over all Europe, and great part of North America. This fog was of a permanent nature; it was dry, and the rays of the sun seemed to have little effect towards dissipating it, as they easily do a moist fog, arising from water. They were indeed rendered so faint in passing through it, that when collected in the focus of a burning glass, they would scarce kindle brown paper. Of course, their summer effect in heating the earth was exceedingly diminished.

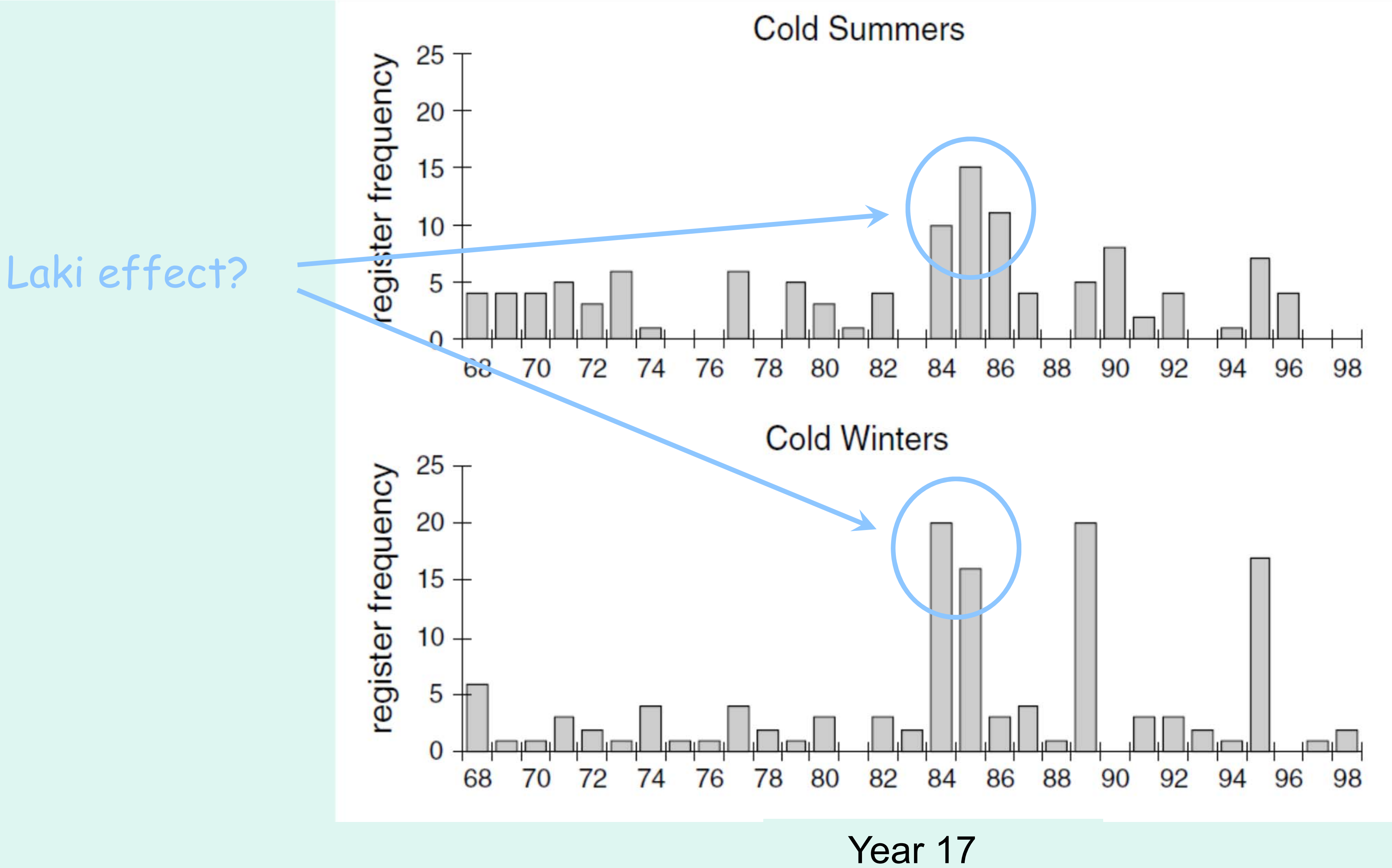
Hence the earth was early frozen,

Hence the first snows remained on it unmelted, and received continual additions.

Hence the air was more chilled, and the winds more severely cold.

Hence perhaps the winter of 1783-4, was more severe, than any that had happened for many years.

The cause of this universal fog is not yet ascertained. Whether it was adventitious to this earth, and merely a smoke, proceeding from the consumption by fire of some of those great burning balls or globes which we happen to meet within our rapid course round the sun, and which are sometimes seen to kindle and be destroyed in passing our atmosphere, and whose smoke might be attracted and retained by our earth; or whether it was the vast quantity of smoke, long continuing to issue during the summer from Hecla in Iceland, and that other volcano which arose out of the sea near that island, which smoke might be spread by various winds, over the northern part of the world, is yet uncertain.



Frequency distribution of cold summers, cold winters, and cold years in Europe and eastern United States during the period 1768 to 1798.

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Fig. 11 from Thordarson and Self (2003)

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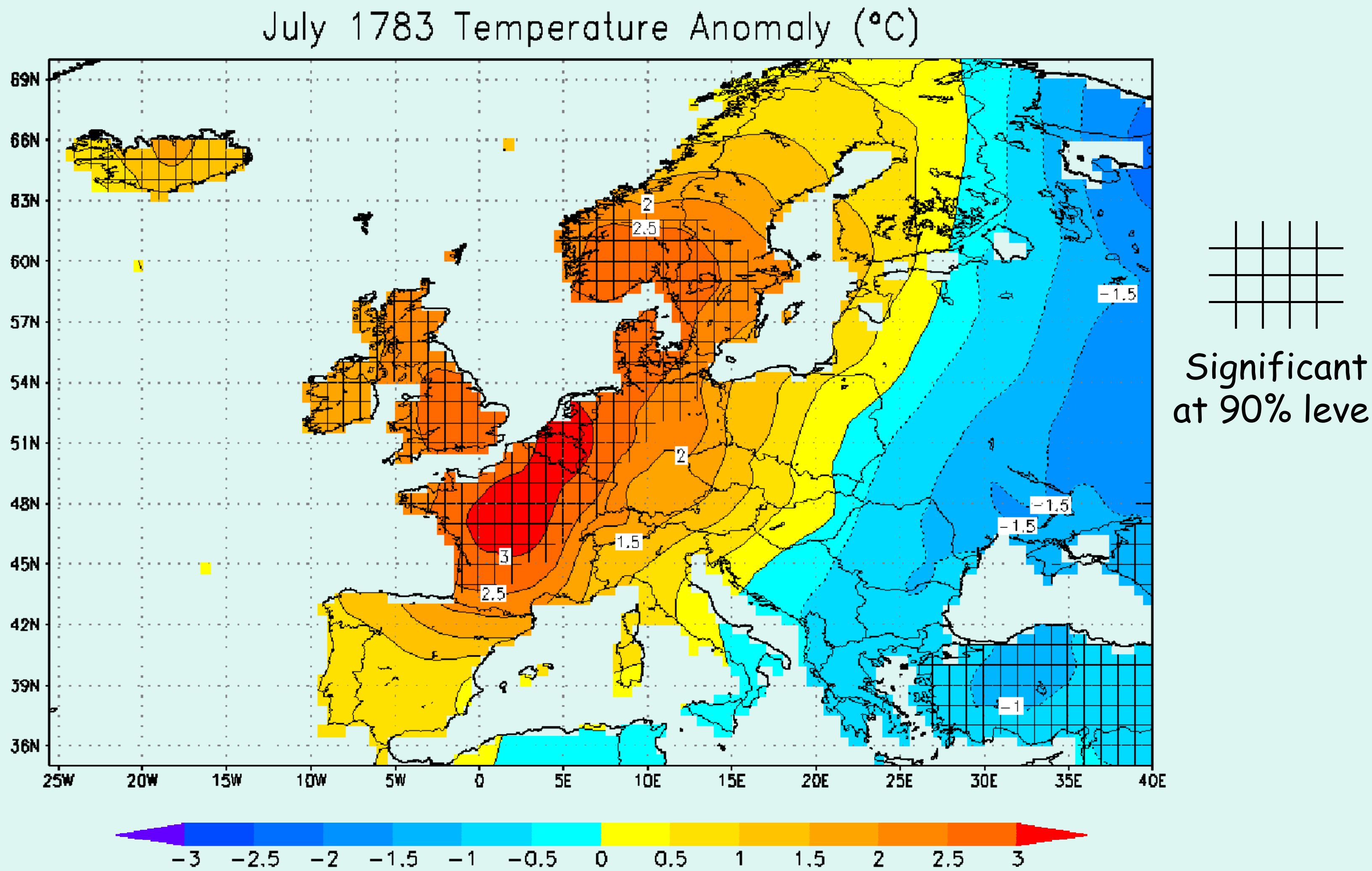

Reconstruction from Luterbacher et al. (2004)

Anomalies based on 31 yr mean, 1770-1800

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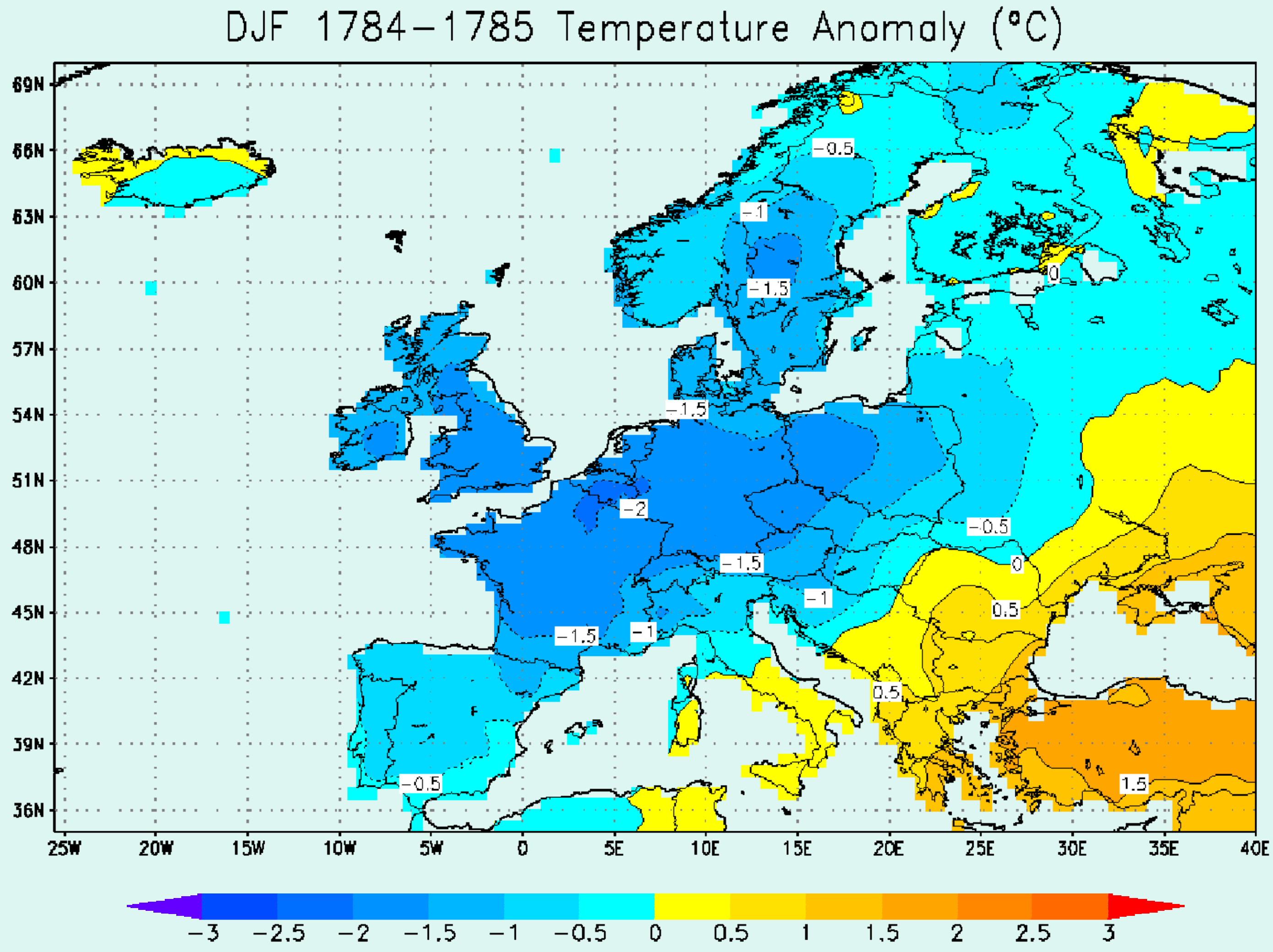

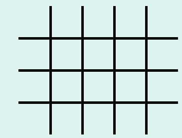

Significant at 90% level

Reconstruction from Luterbacher et al. (2004)

Anomalies based on 31 yr mean, 1770-1800

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

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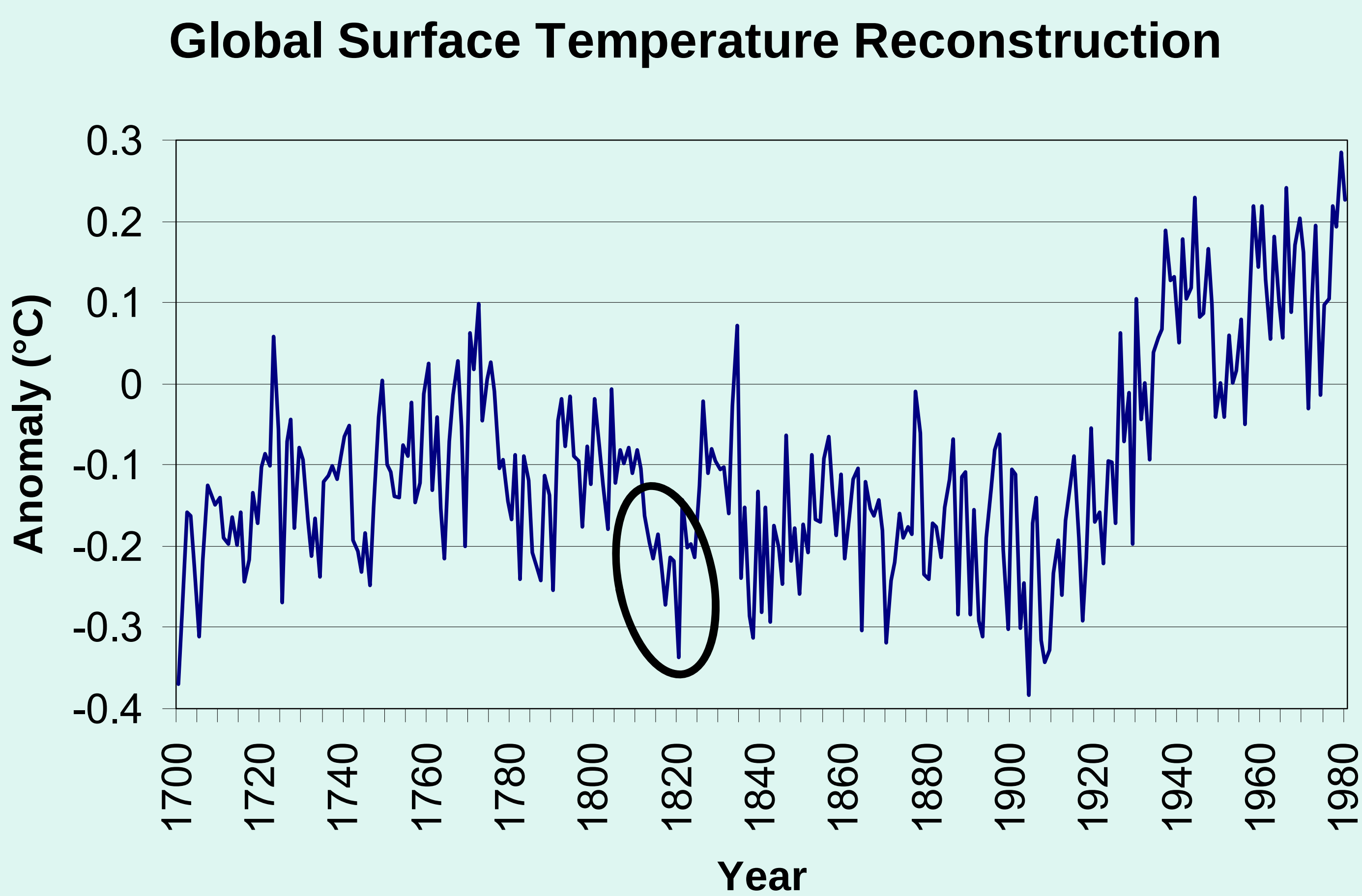

Mann et al. (2000)

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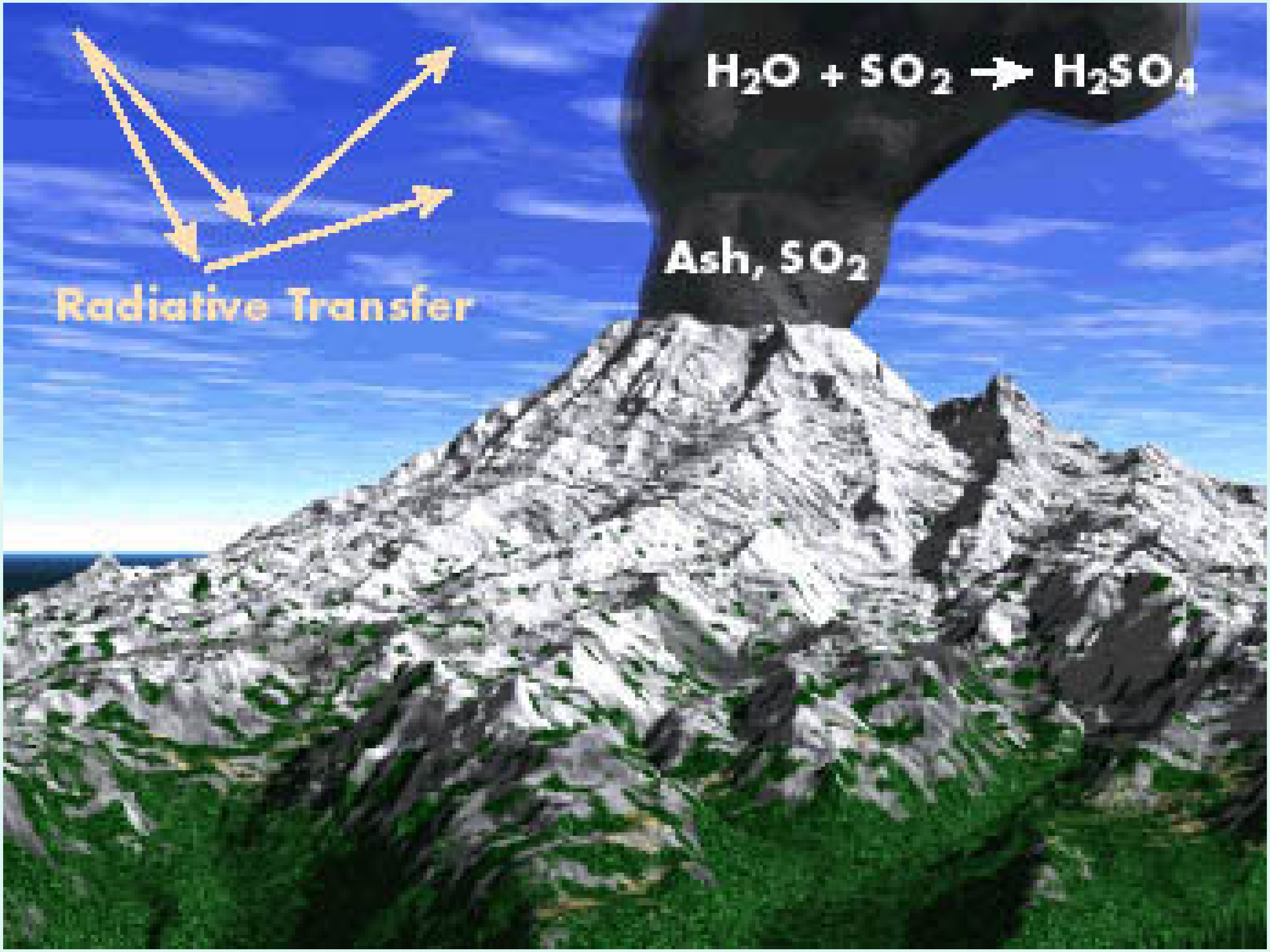
Tambora, 1815, produced the "Year Without a Summer" (1816)

"Darkness"
by Byron

I had a dream, which was not all a dream.
The bright sun was extinguish'd, and the stars
Did wander darkling in the eternal space,
Rayless, and pathless, and the icy earth
Swung blind and blackening in the moonless air;
Morn came and went—and came, and brought no day,
And men forgot their passions in the dread
Of this their desolation; and all hearts
Were chill'd into a selfish prayer for light:
And they did live by watchfires—and the thrones,
The palaces of crowned kings—the huts,
The habitations of all things which dwell,
Were burnt for beacons; cities were consumed,
And men were gather'd round their blazing homes
To look once more into each other's face; . . .



http://terra.nasa.gov/FactSheets/Aerosols/

Case study – Mt. St. Helens

- devastated 150 sq. miles of prime forest
- cloud of volcanic gas and ash rose vertically 14 miles for more than 8 hours
- 2-3 inch ashfall covered central WA
- dark ash cloud reached east coast within 3 days
- no global impact

Mt. St. Helens, May 28, 1980

Case study – El Chichon

- spring 1982
- cold spells, heat waves, droughts, floods

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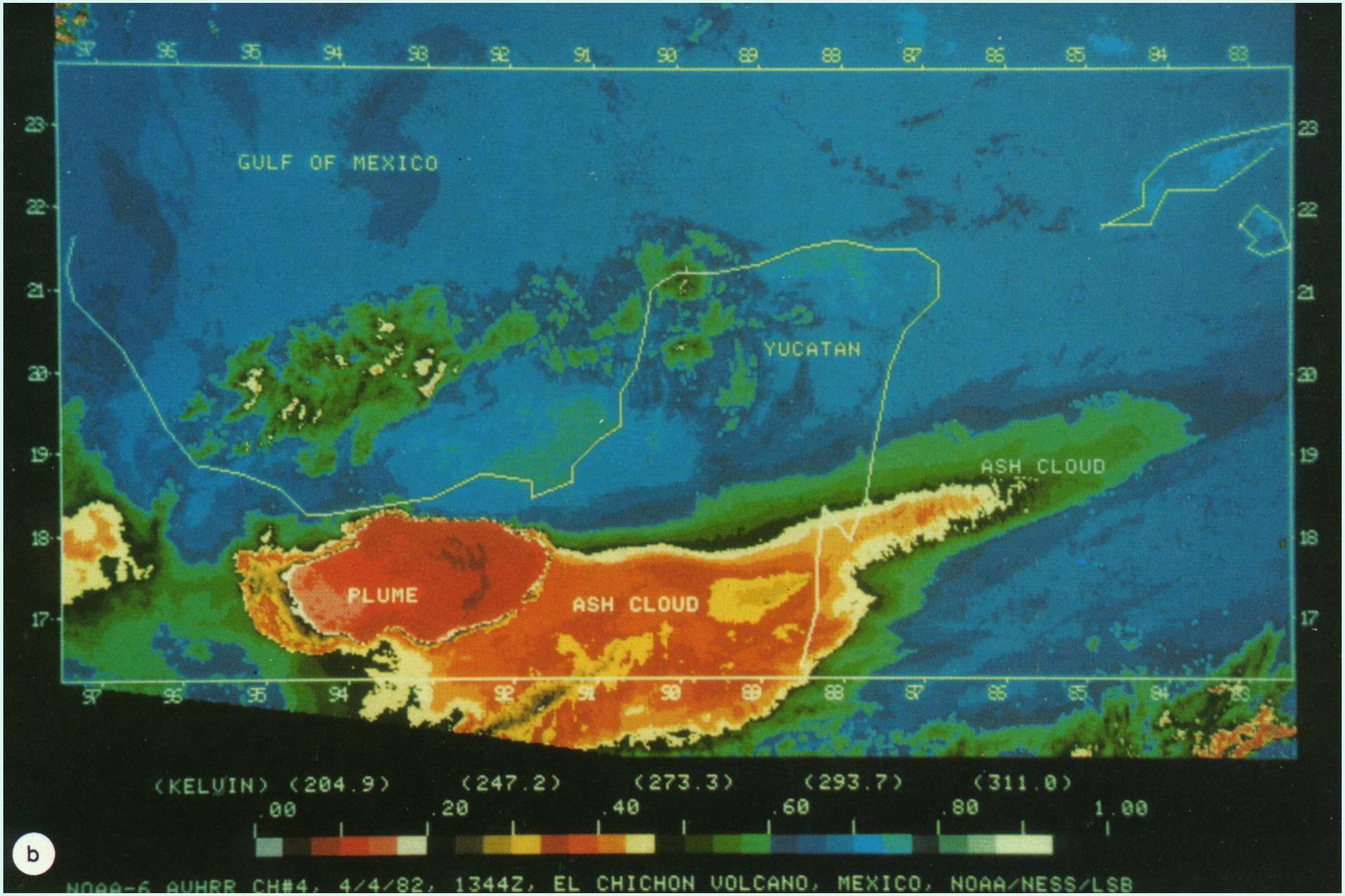
El Chichón, 1982



Matson (1984)

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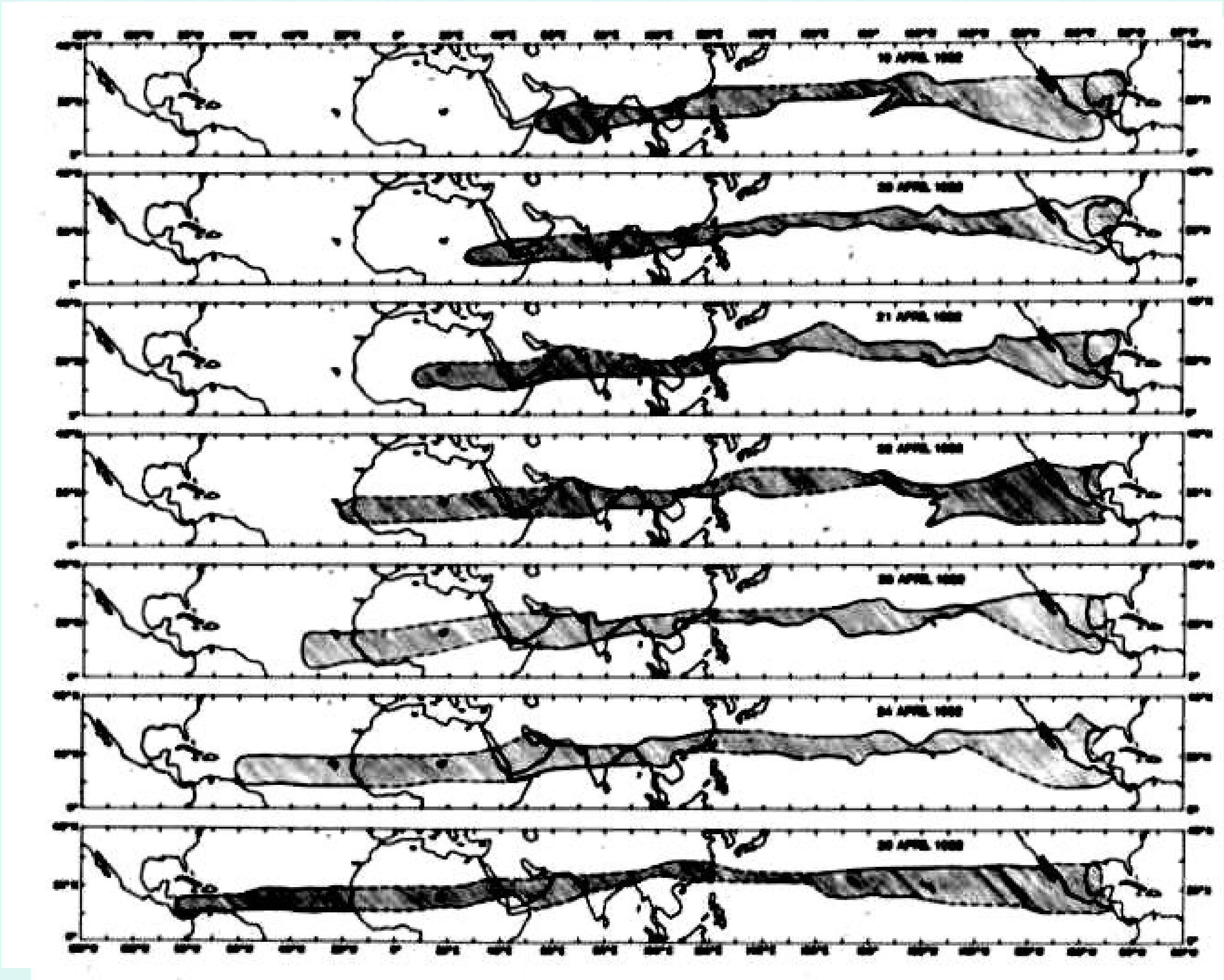
El Chichón, 1982



(Robock and Matson, 1983)

Case study – Mt. Pinatubo

- erupted on June 16, 1991
- SO_2 shot 100,000 feet into the air
- SO_2 emissions twice as much as El Chichón in April 1982, 20 times Mt. St. Helens in May 1980
- vivid sunset 1991 and 1992
- 10% decrease in tropical oceanic rainfall for 1.5 years
- 4.7% more solar radiation reflected
- cool summer 1992
- colder than average winter 1992-1993 in US