Volcanic Eruptions and Climate

What are the connections?

Preconceived notions

- 1) High latitude volcanic eruptions don’t significantly affect climate-only near equatorial eruptions
- 2) There is no good way to use historical observations to date volcanic eruptions
- 3) Frost rings in trees are the most effective method of discerning the climate affect of volcanic eruptions.

THE ERUPTION OF MOUNT TAMBORA

APRIL 1815

EXPELLED INTO THE ATMOSPHERE

24 MI³ (100 KM³) OF ASH, PUMICE, AND AEROSOLS

60 MEGATONS OF SULFUR

"YEAR WITHOUT A SUMMER"

1816

AVERAGE GLOBAL TEMPERATURE REDUCED BY

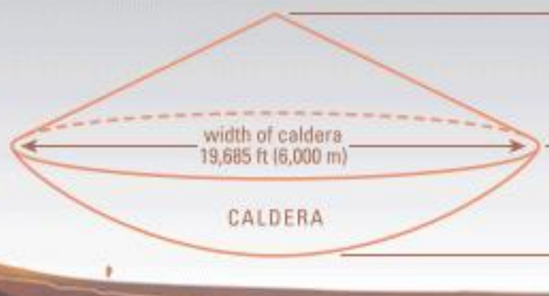
5.4 °F

5.4 °F = 3 °C

FACTS & FIGURES

- Stratovolcano
- Forms the entire 37.3-mi- (60-km-) wide Sanggar peninsula on Sumbawa island, Indonesia
- Largest observed eruption in recorded history
- Measure of 7 on the volcanic explosivity index (VEI)

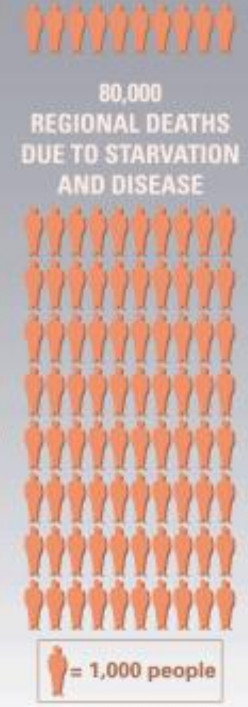
VOLCANO DIMENSIONS



CASUALTIES

10,000 LOCAL DEATHS FROM INITIAL ERUPTION

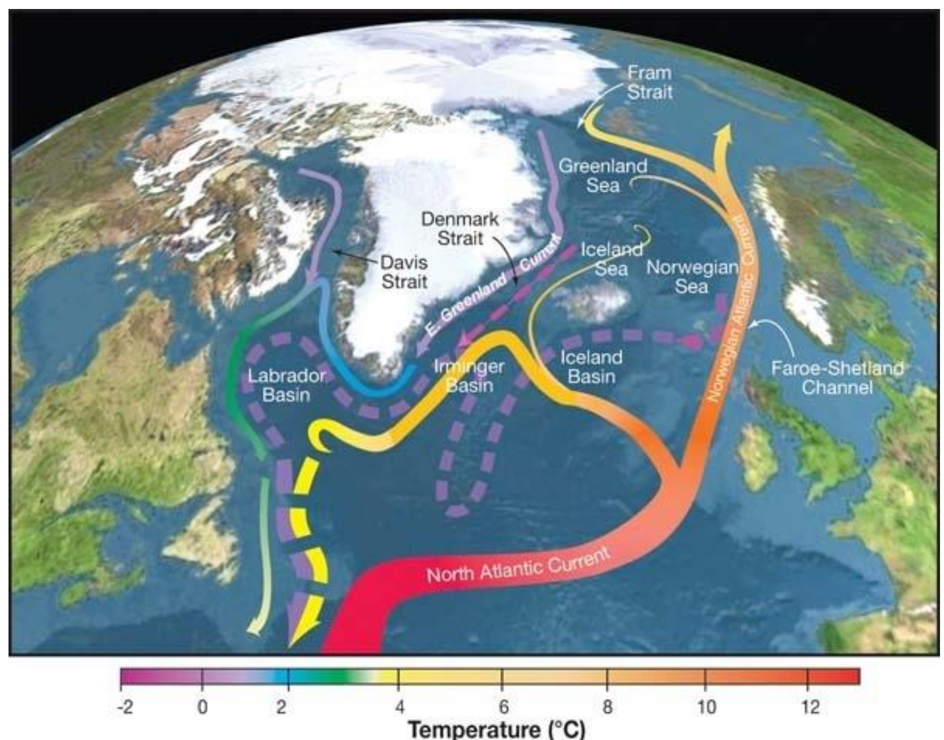
80,000 REGIONAL DEATHS DUE TO STARVATION AND DISEASE



Summit Caldera of Tambora

Little known facts about Tambora

- 1) **reduced** ice in the north Atlantic in 1816 and 1817- indirectly responsible for many deaths in the British search for a NW passage in 1818. How?-drought from cold weather reduced fresh water on top and
- AMOC brought in
- warm salty water
- and melted the ice.

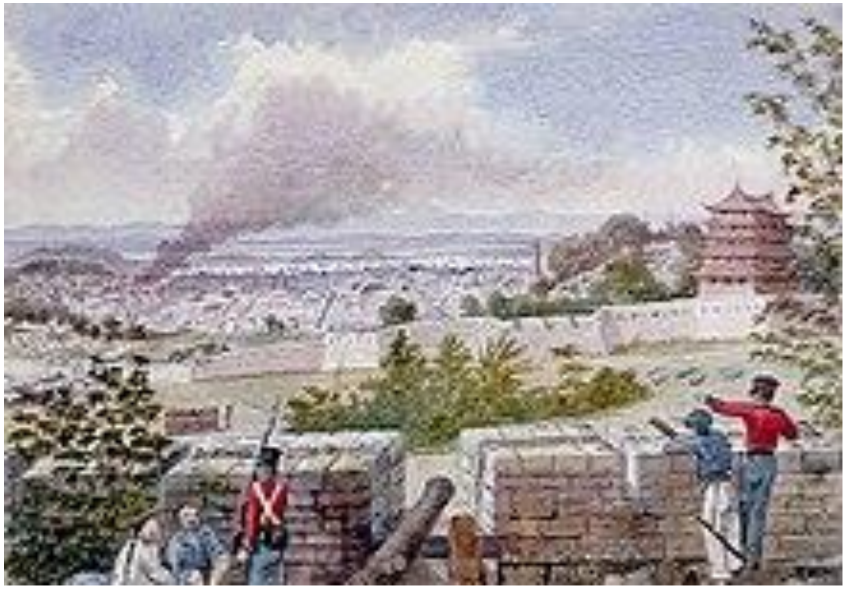


Little Known Facts about Tambora

- 2) produced cholera mutation in India and subsequent spread of cholera across the globe

Little Known Facts about Tambora

- 3) starvation in China caused farmers to start growing opium as a cash crop. Eventual result: The golden triangle and the opium wars.



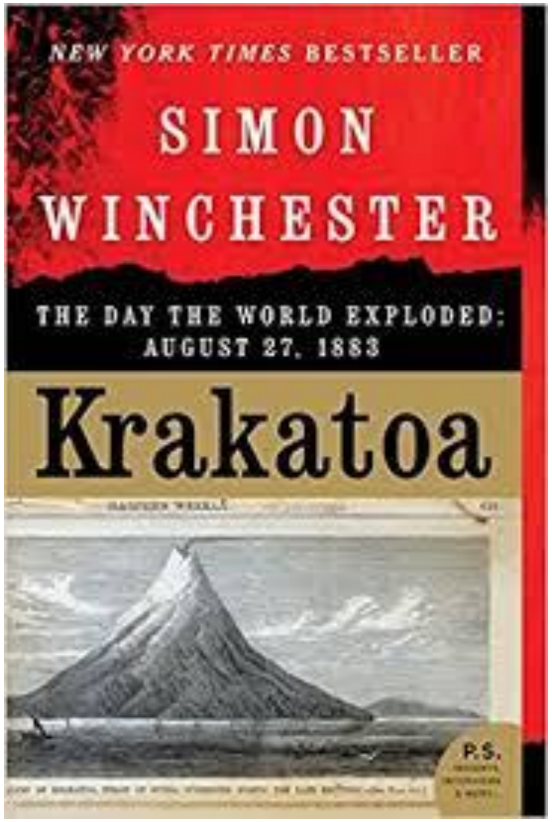
Little Known Facts about Tambora

- 4) Although it was cold and rainy in much of Europe, the Russians had good weather and a great harvest. This saved much of the British
- Empire from starvation.

Eruption of Krakatau 1883

Little Known Facts about Krakatau

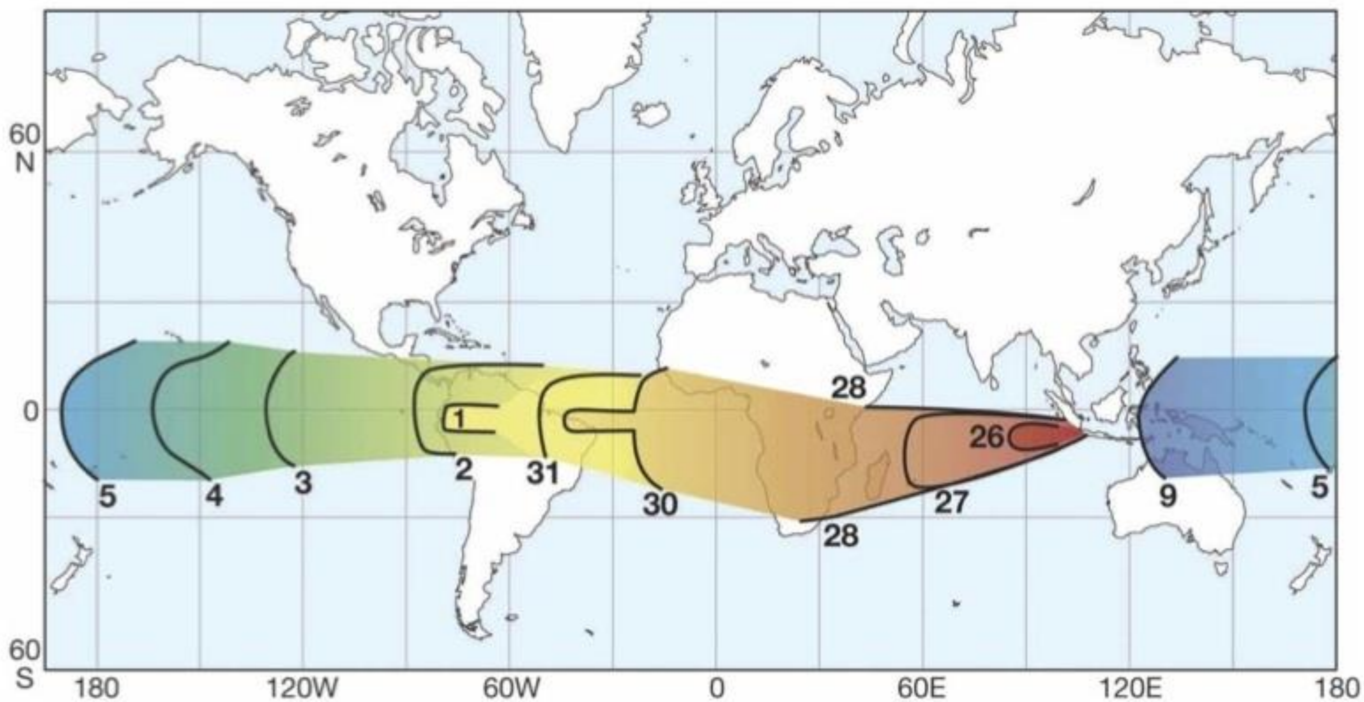
- 1) Eruption produced a tsunami



Little Known Facts about Krakatau- 2) loudest sound in human history

Little Known Facts About Krakatau-1883

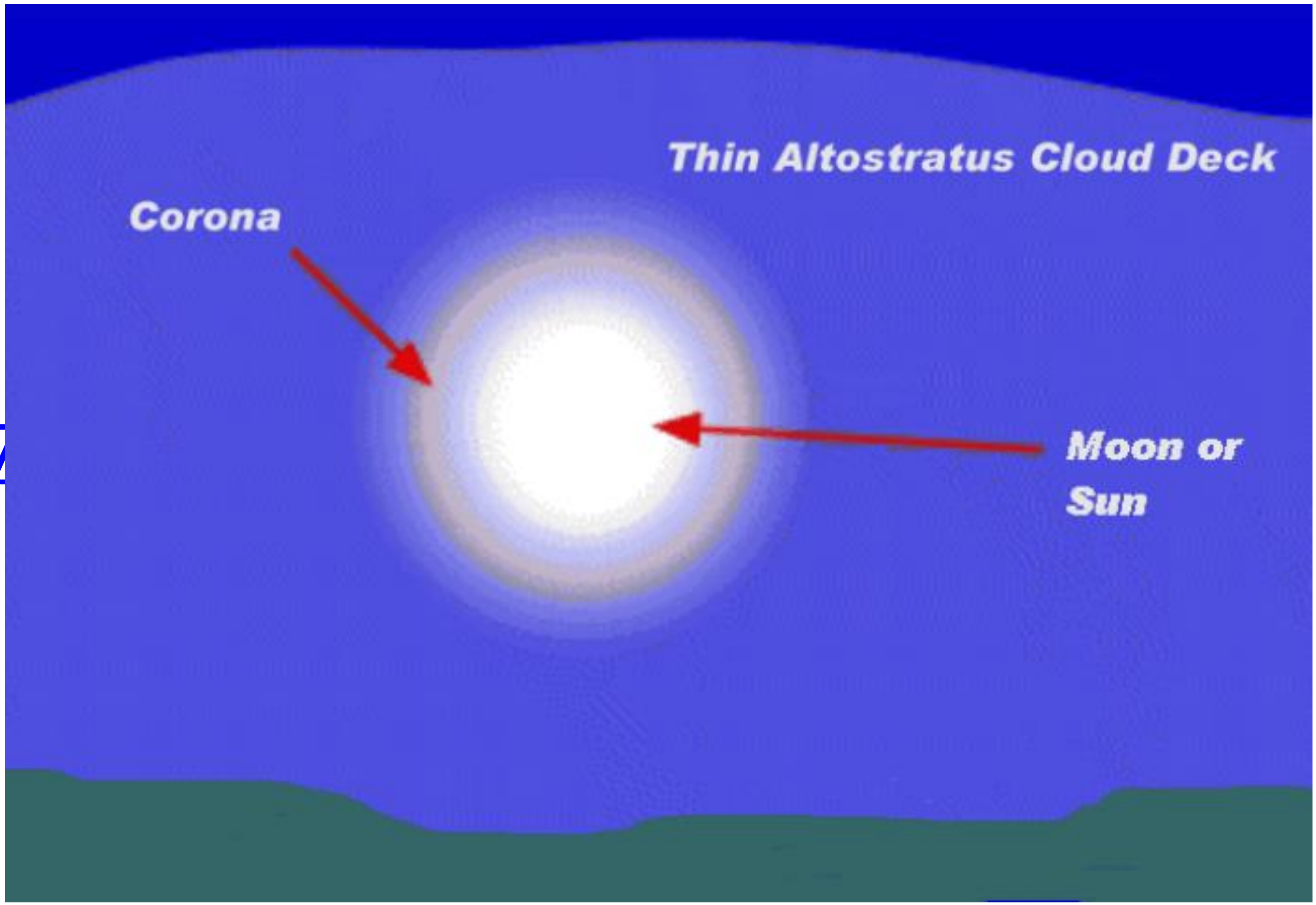
- 3) Produced not just red suns but blue and green suns all around the tropics.



Little Known Facts- Krakatau 1883
4) First observations of Bishops ring

Fig. 2 The Reverand Sereno Edward Bishop in an 1888 photo (reproduced from Hawaiian Mission Children's Society (1901)).

Krakatau-1883
Appearance of Bishops ring



Krakatau 1883-tsunami-runup in meters

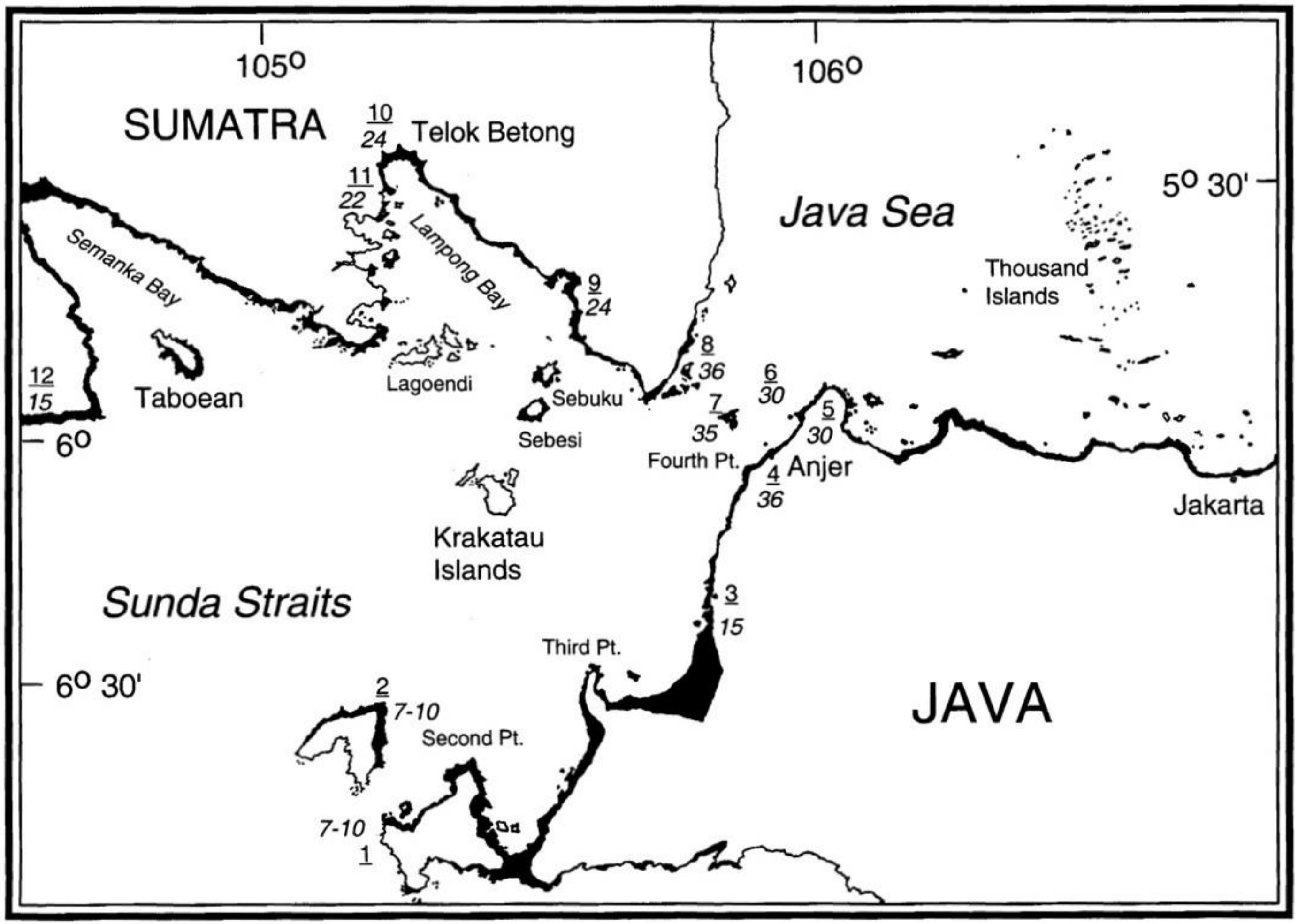
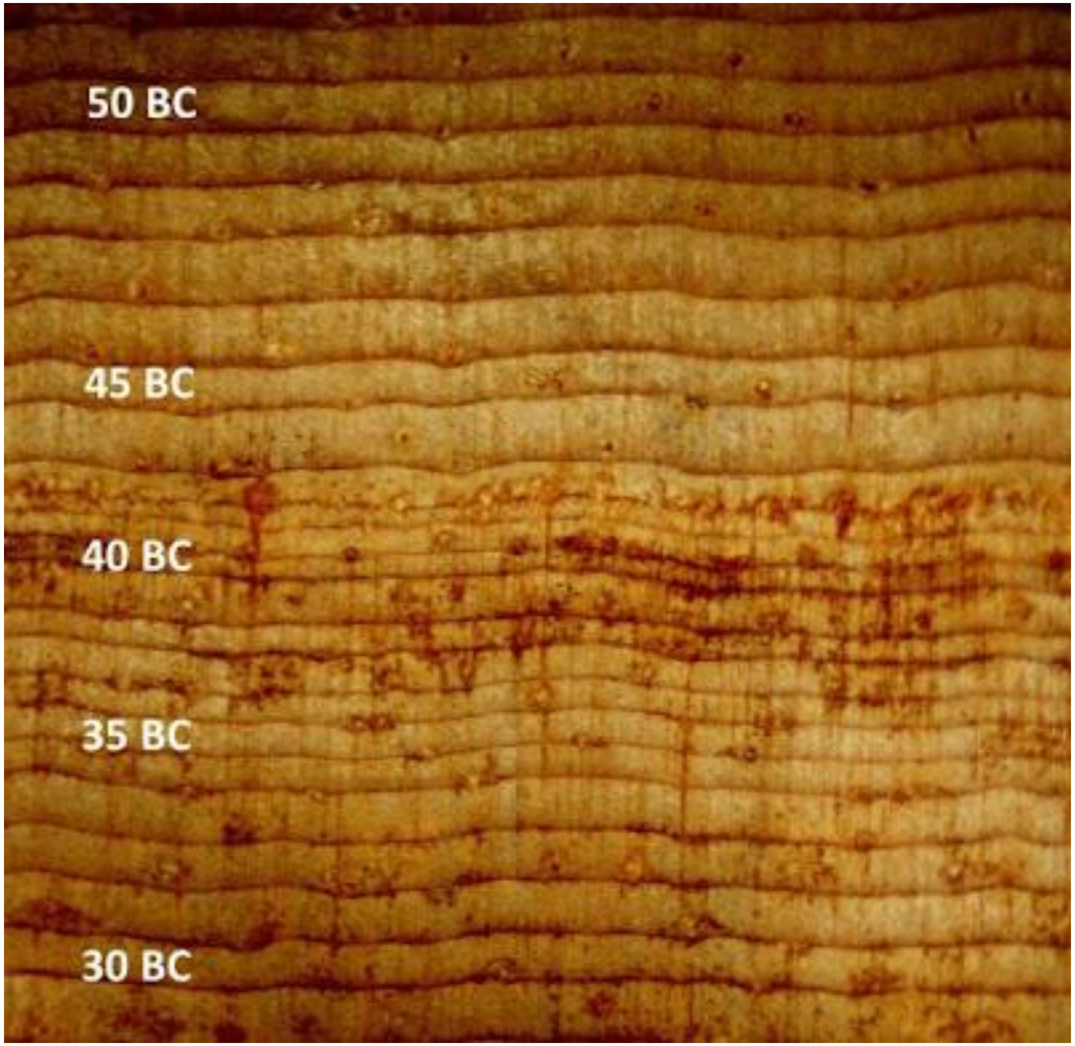


Figure 3. Area of shoreline inundated by tsunamis (black zones) during the 1883 eruption of Krakatau, adapted from Verbeek (1885). Underlined numbers are locations referred to in Table 1 and numbers in italics are the maximum tsunami run-up heights (meters) from Verbeek (1885).

Katmai/Novarupta eruption 1912 little known facts

- 1) two volcanoes not one erupted

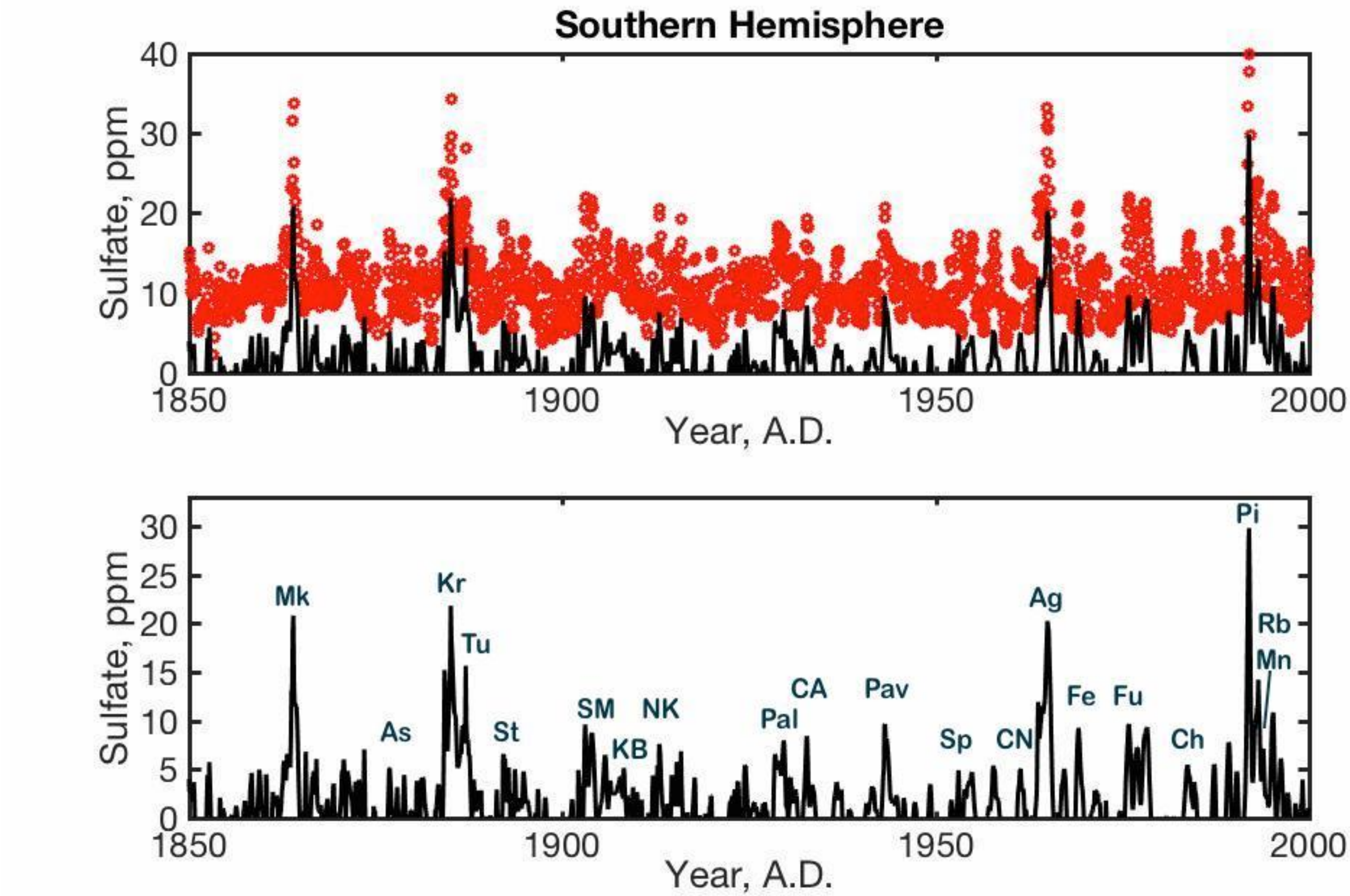
Novarupta/Katmai 1912- little known facts- 2) Eruption produced frost rings.



Novarupta/Katmai 1912- little known facts- 3) visible atmospheric effects only to about 30°N

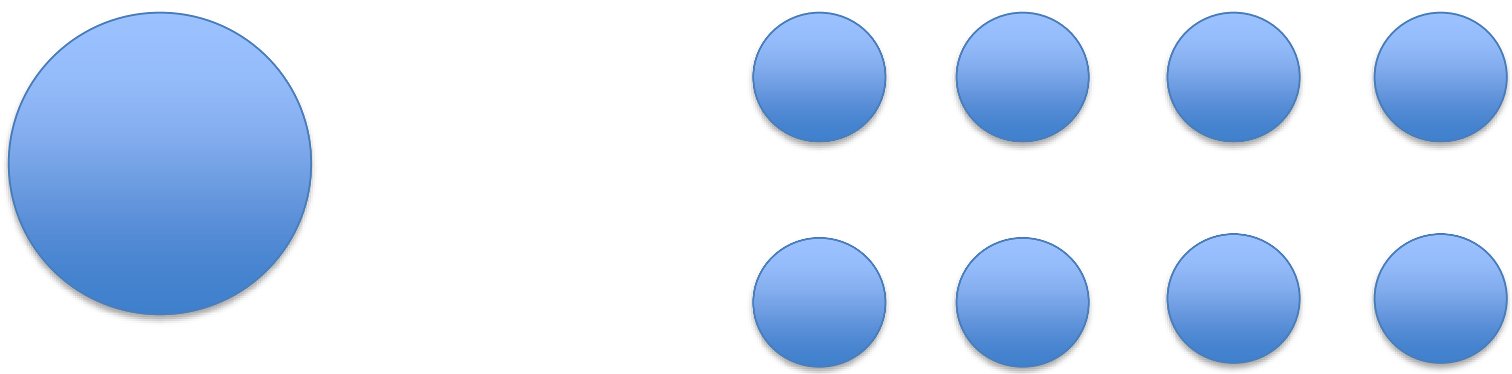
Optical depth-measure of atmospheric disturbance to light from a volcanic eruption.

Novarupta/Katmai 1912- little known fact-4) deposited sulfate in Antarctica



Problem: How can you get sulfate deposition and no optical effects?

- Answer-change particle sizes during transport
- Double particle diameter-change concentration 8 times plus reduce optical effect 2 times. Overall increase in apparent brightness of sun, moon or stars: 16 times.



Particle size change during transport

- Most literature has found little evidence for particle size changes during transport-But can only make observations in places where can see optical effects AND only need a small change in average particle size to produce big effects on optical depth.

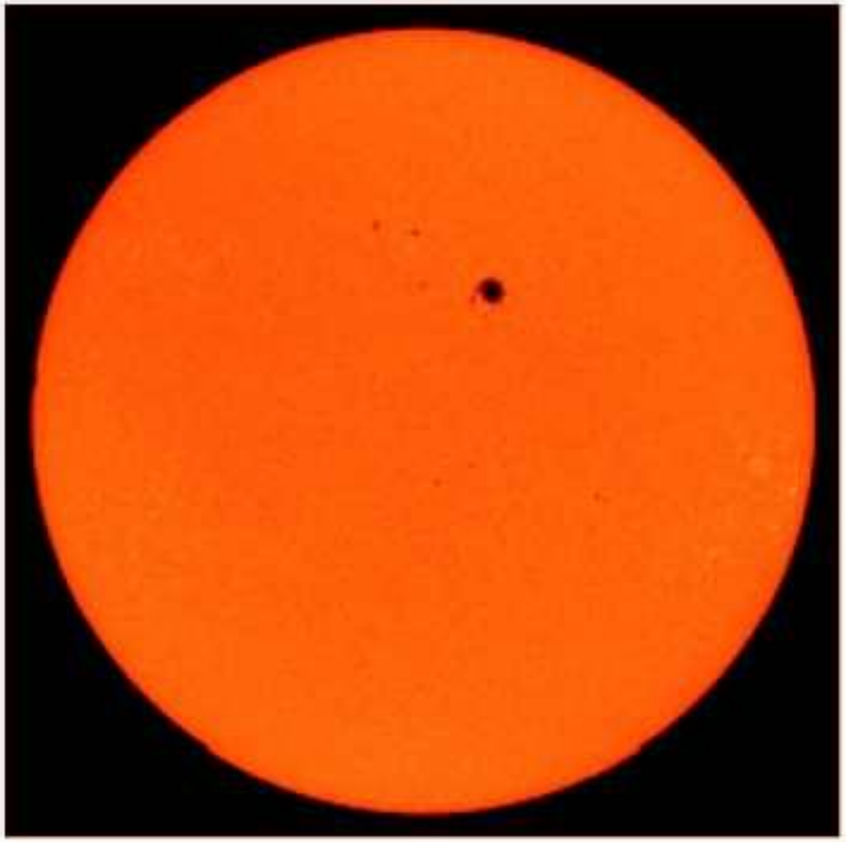
Work on Volcanic Eruptions

- Question: When does the maximum optical effect occur relative to the time that sulfate is deposited in ice cores?

- Motivation: Ancient eruptions-location and size are unknown. Only data are observations of stars, sun, moon, tree rings, and optical effects like Bishops Ring.

How do we know the time of maximum optical effect from Tambora in 1815?

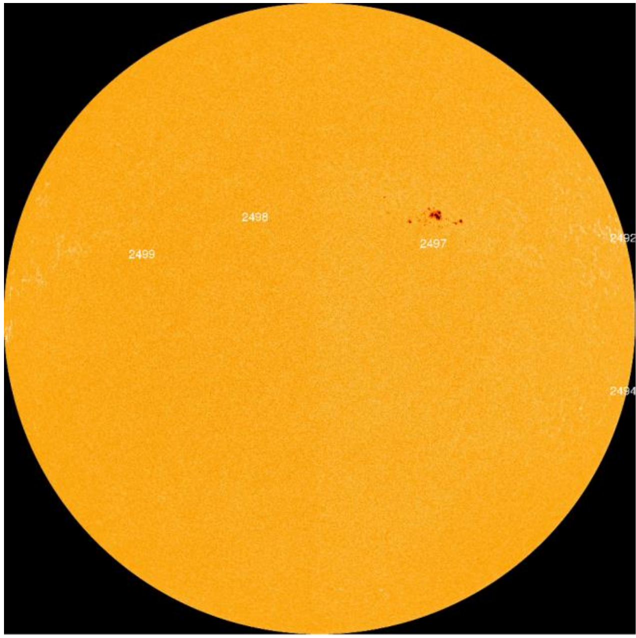
- Observed sunspots with the naked eye over North America-
- May 3rd-May 10th,
- 1816 also
- June 11th, 1816
-



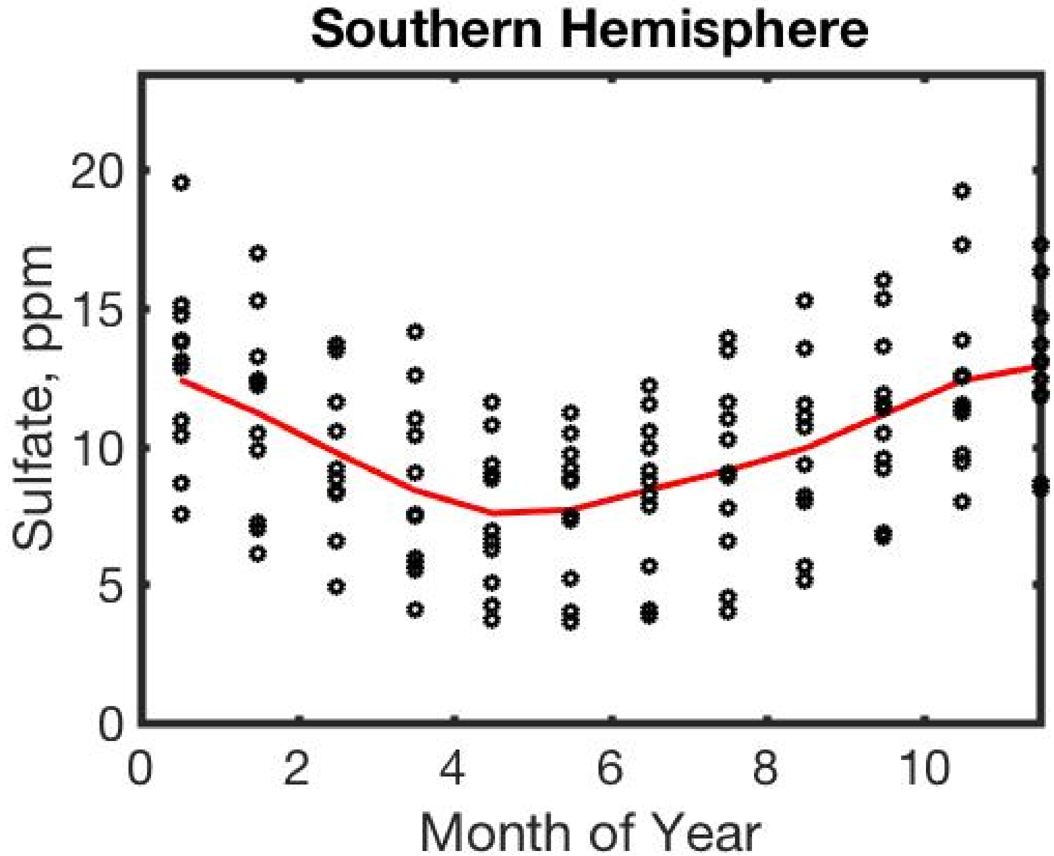
Another mystery solved: How could ancient Chinese astronomers see sunspots without telescopes or filters?

- 1) lots of blowing dust in China in fall, winter and early spring- makes it possible to see sunspots with the naked eye

- 2) sometimes volcanic eruptions obscured the atmosphere and made it possible to see sunspots without telescopes or filters



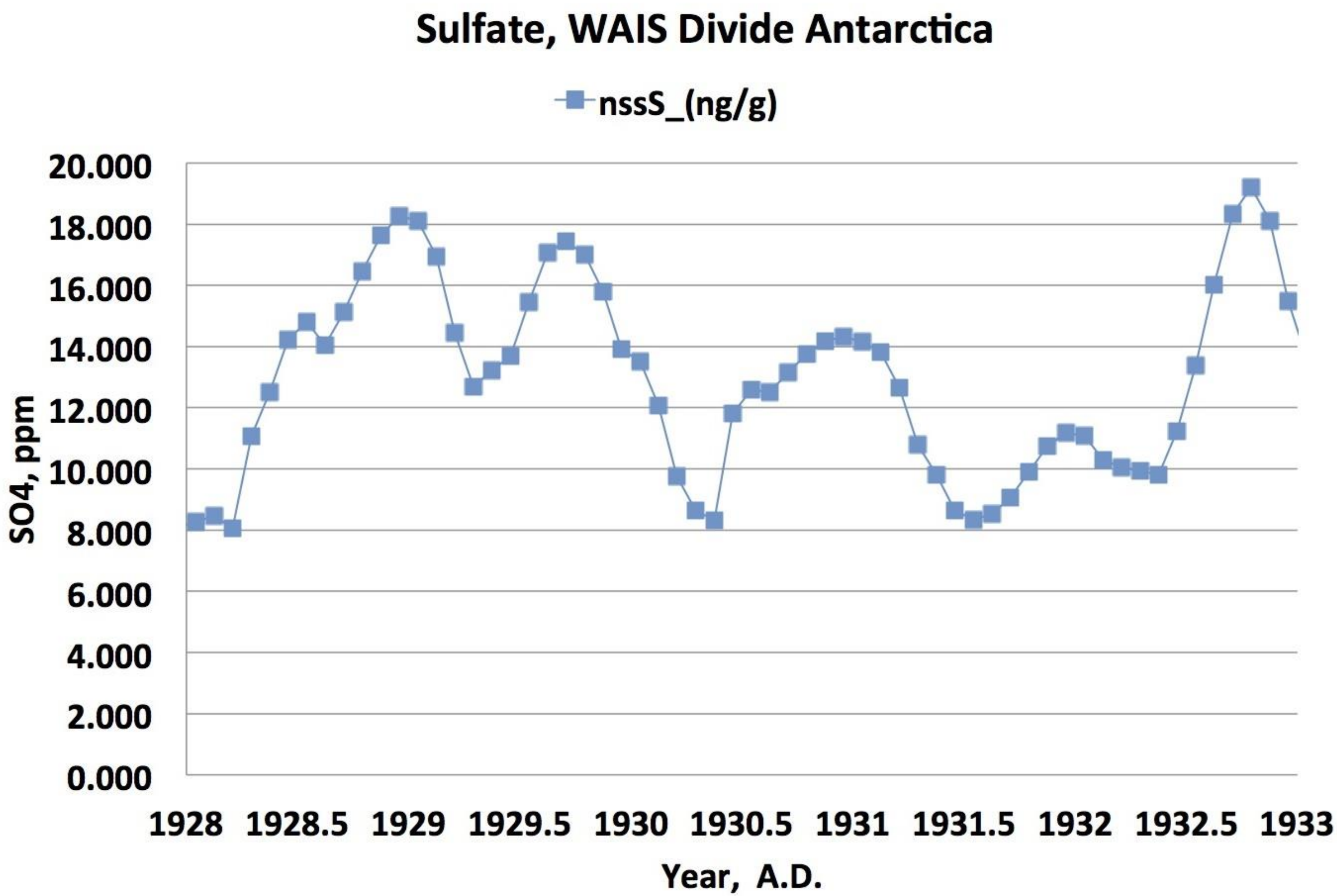
How to get volcanic sulfate data-southern hemisphere ice cores



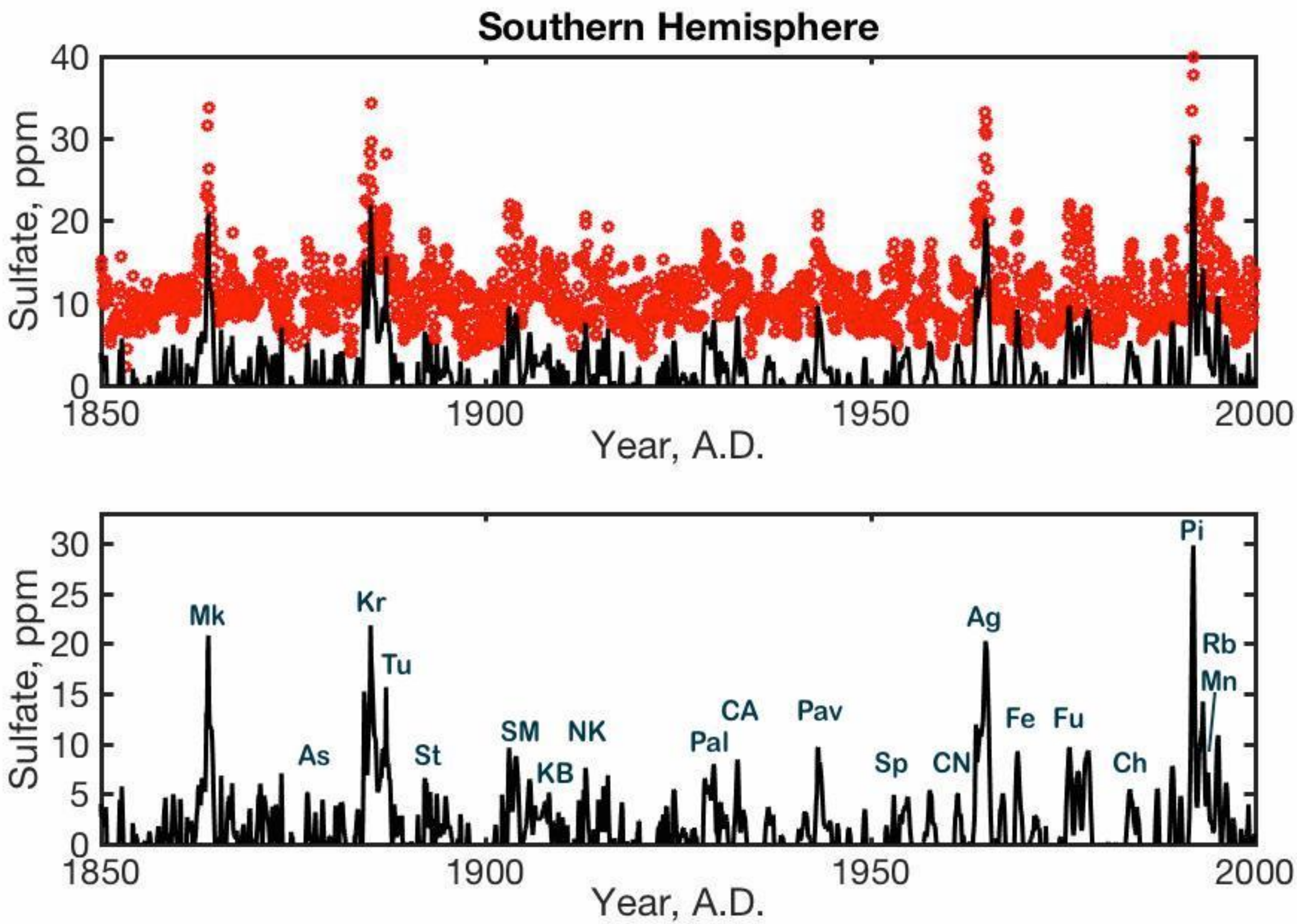
- Looked at sulfate in years with no volcanism-
- More sulfate in winter- southern hemisphere summer.

Source of sulfate seasonal signal-MSA-methanesulfonic acid

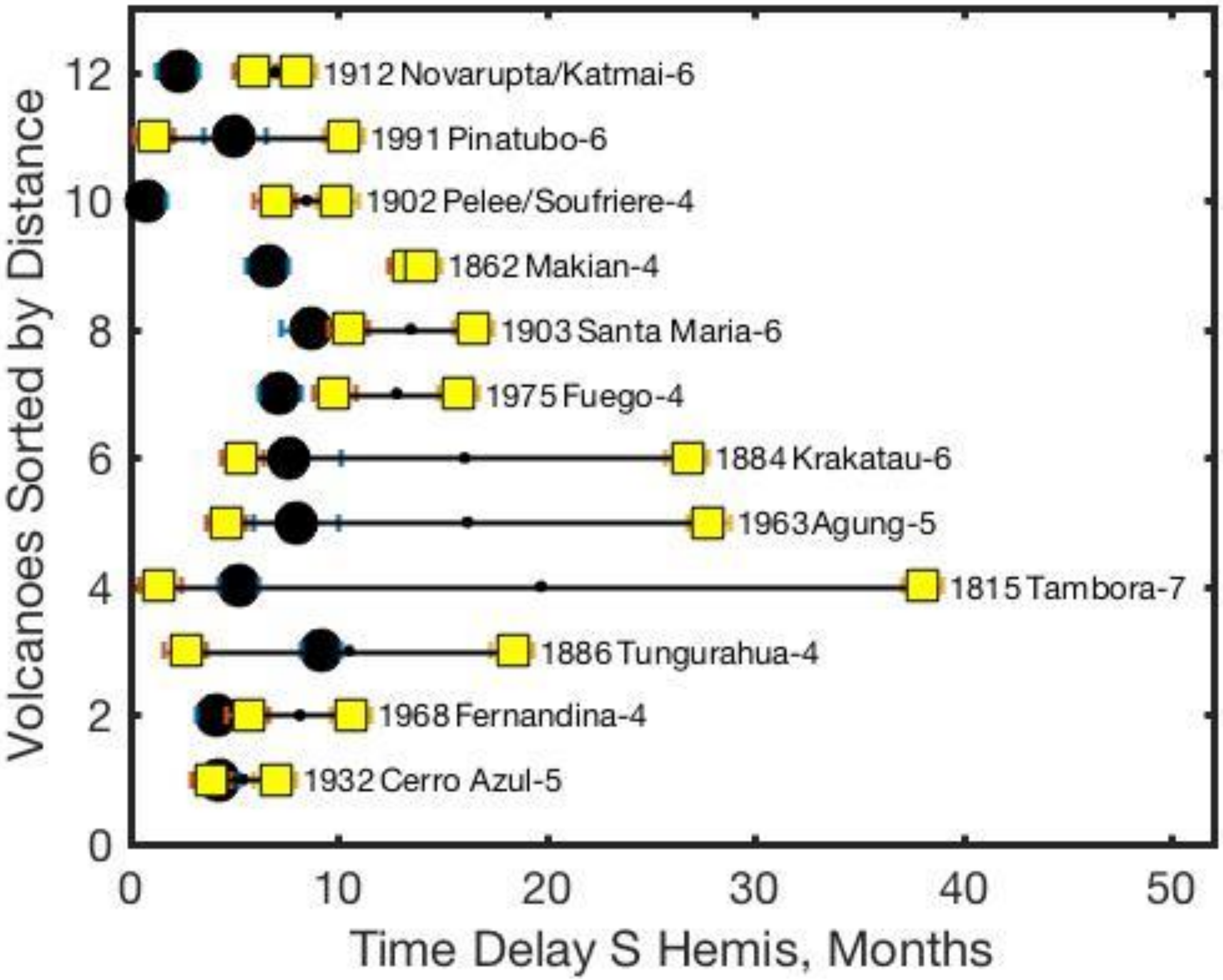
- Related to biological activity-variable from year to year



Result after take out seasonal signal from MSA-Southern Hemisphere



Using Southern Hemisphere Data



Optical Depth versus Time-Pinatubo

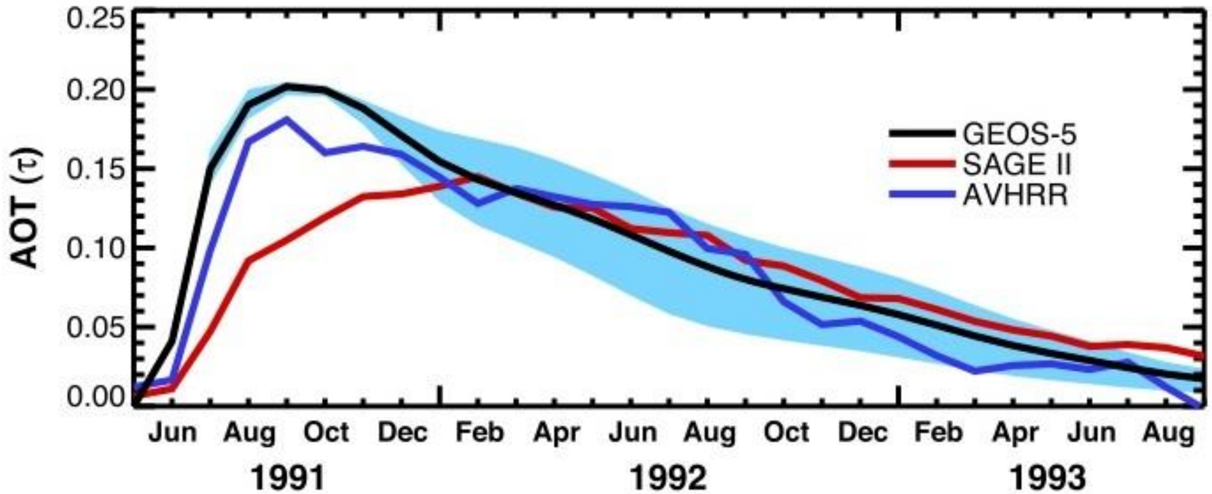
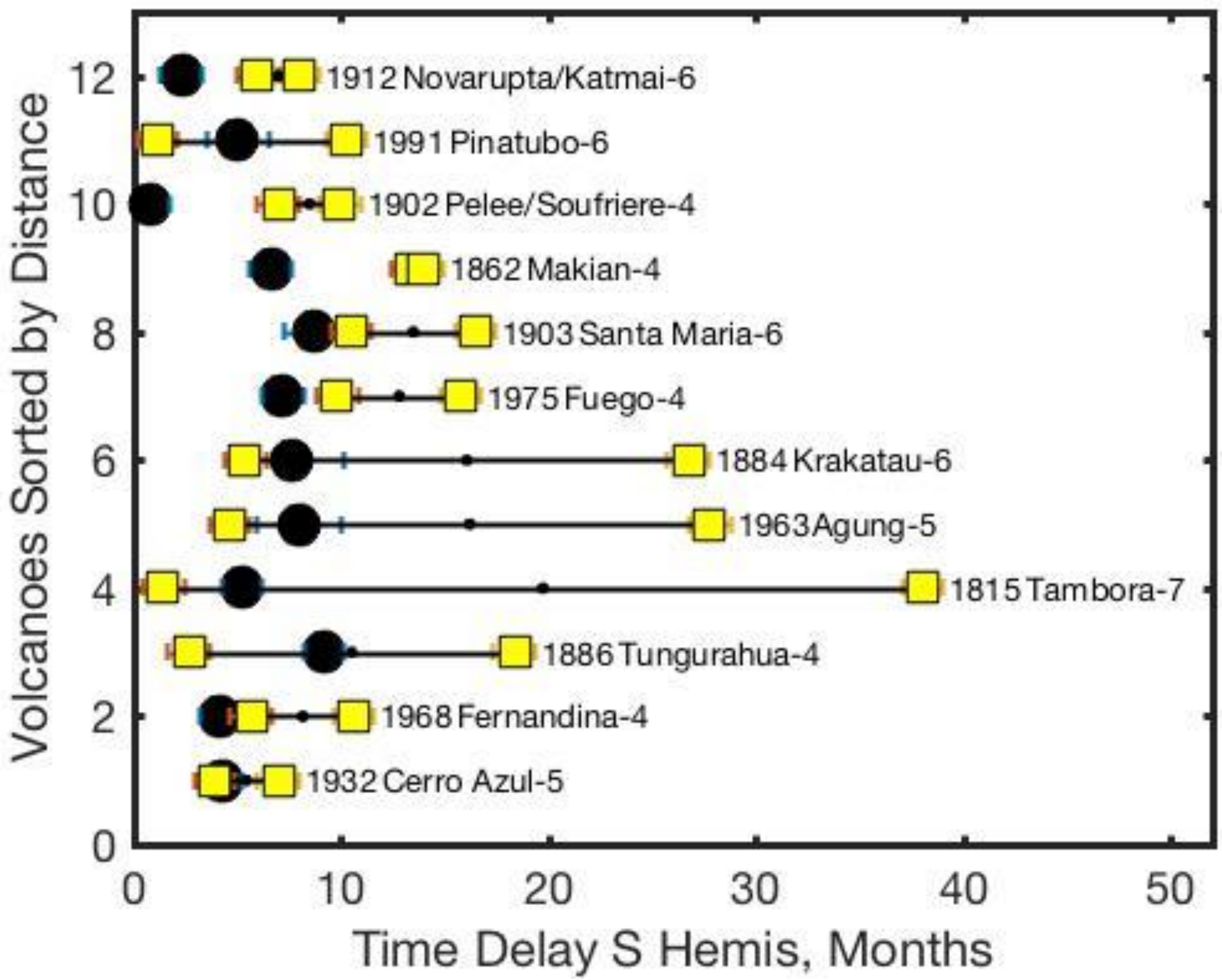


Figure 1. Global mean of the visible aerosol optical thickness as simulated by GEOS-5 (experiment REF, black line) and as derived by Stratospheric Aerosol and Gas Experiment II (SAGE II; red line), and Advanced Very High Resolution Radiometer (AVHRR; blue line) data. Background values have been removed from the AVHRR data. The blue shaded area shows the variability of the ensemble.

Sorted by Distance- Bottom-Closer
Top Further Away- Pinatubo is different- Why?

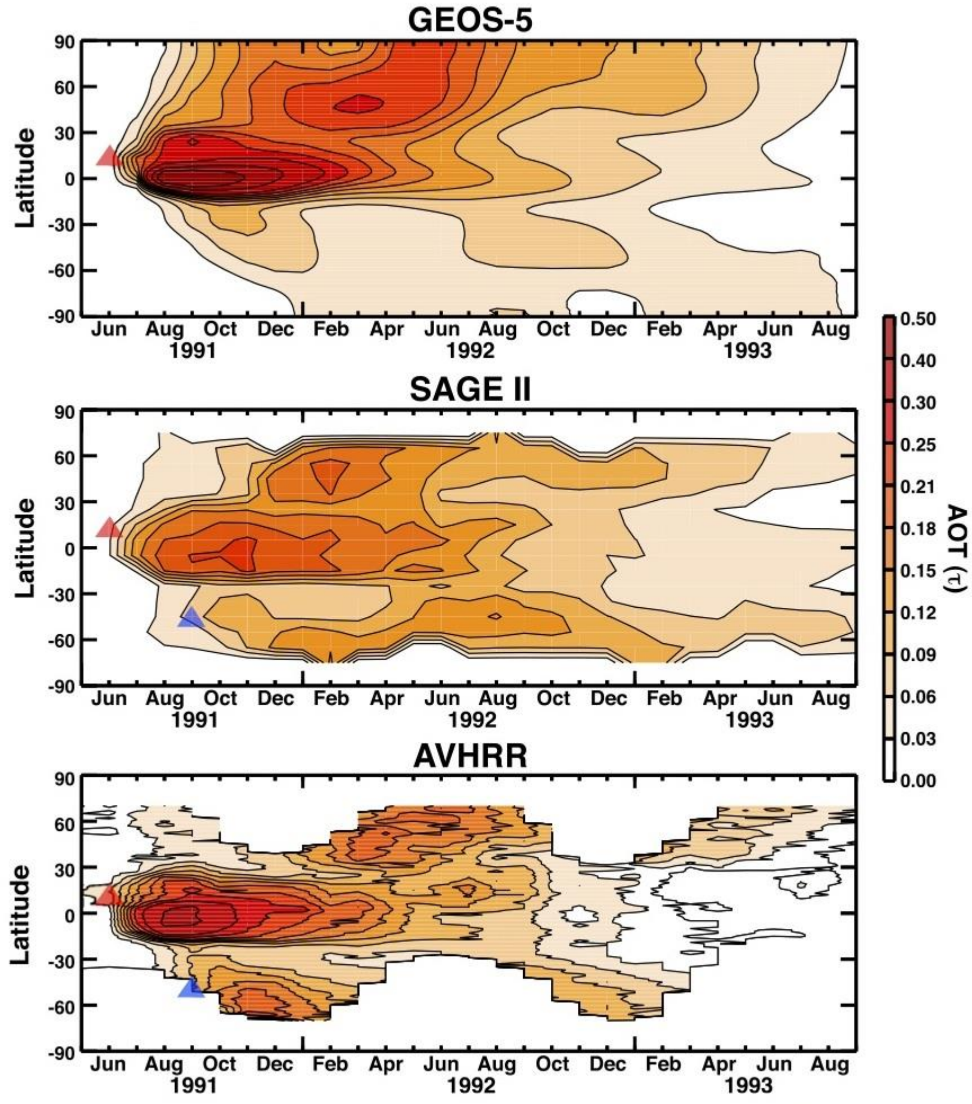


Speed of Transport versus Eruption Southern Hemisphere

Eruption Date	Volcano	Velocity, km/hr	VEI
1932.27	Cerro Azul	1.80	5
1912.43	Novarupta/Katmai	3.54	6
1902.35	Pelee/Soufriere	2.13	4
1991.46	Pinatubo	14.63	6
1968.45	Fernandina	2.12	4
1974.78	Fuego	1.45	4
1902.82	Santa Maria	1.37	6
1886.03	Tungurahua	4.30	4
1883.65	Krakatau	2.60	6
1963.21	Agung	2.92	5
1861.99	Makian	1.08	4
1815.27	Tambora	9.45	7

Pinatubo Eruption Cloud

- Went south first and what else?
- Top: Model
- Middle: Data1
- Bottom: Data2



Pinatubo lateral movement of sulfate

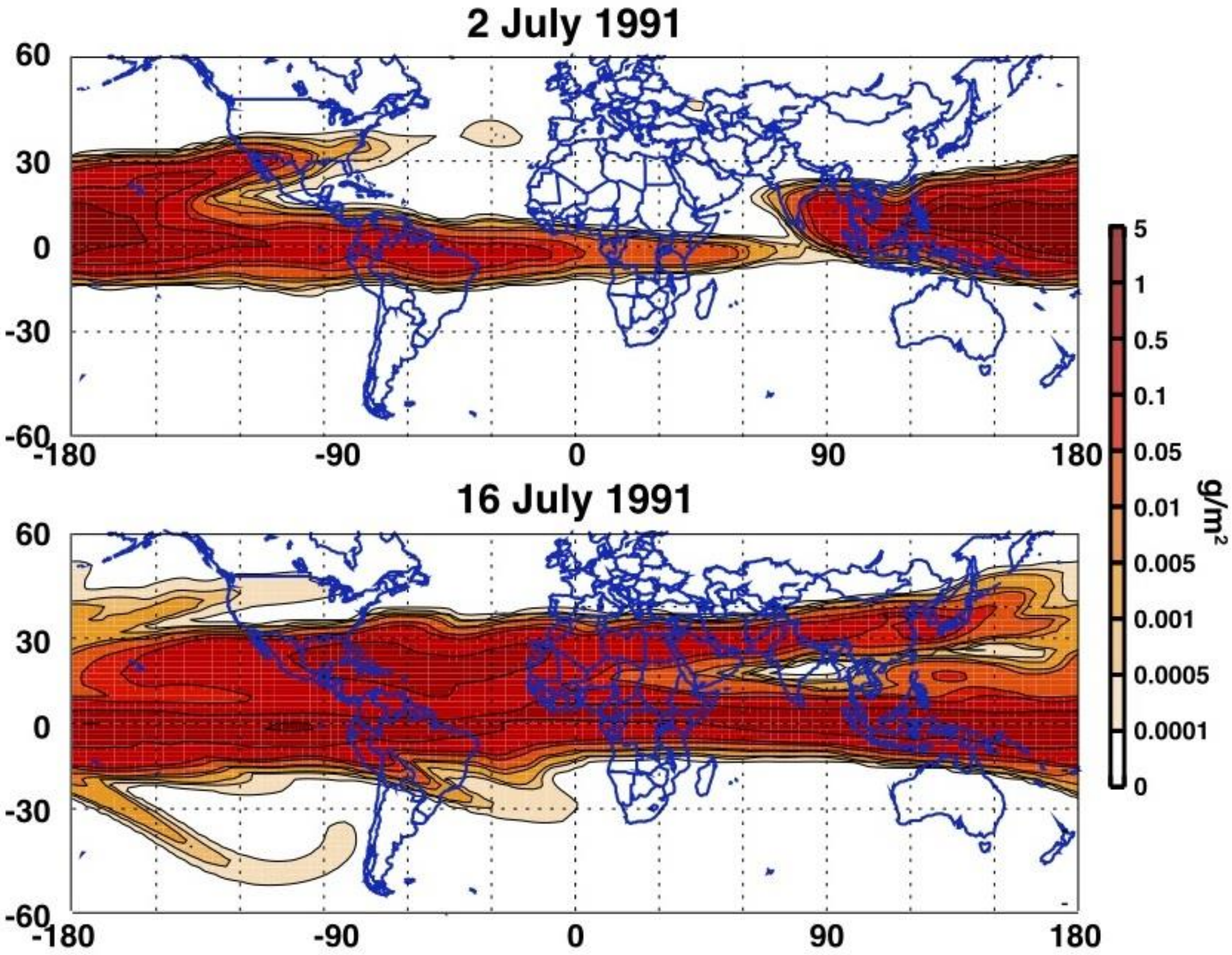
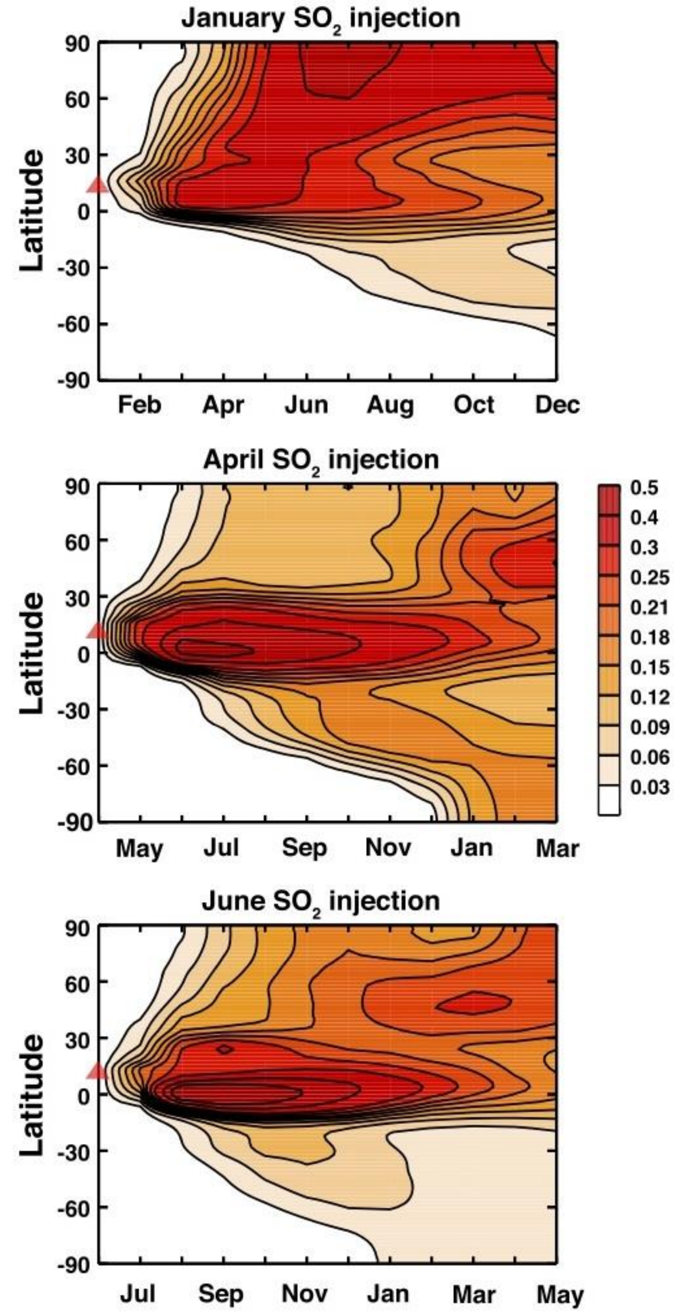


Figure 5. Horizontal distribution of simulated SO_4 column mass (experiment REF) between 30 hPa and the top of the atmosphere on (top) 2 July 1991 and (bottom) 16 July 1991.

Pinatubo seasonality of sulfate movement



Speed of Transport South vs. Season- Some NH Winter Effect

Eruption Dat	Volcano	Velocity	VEI
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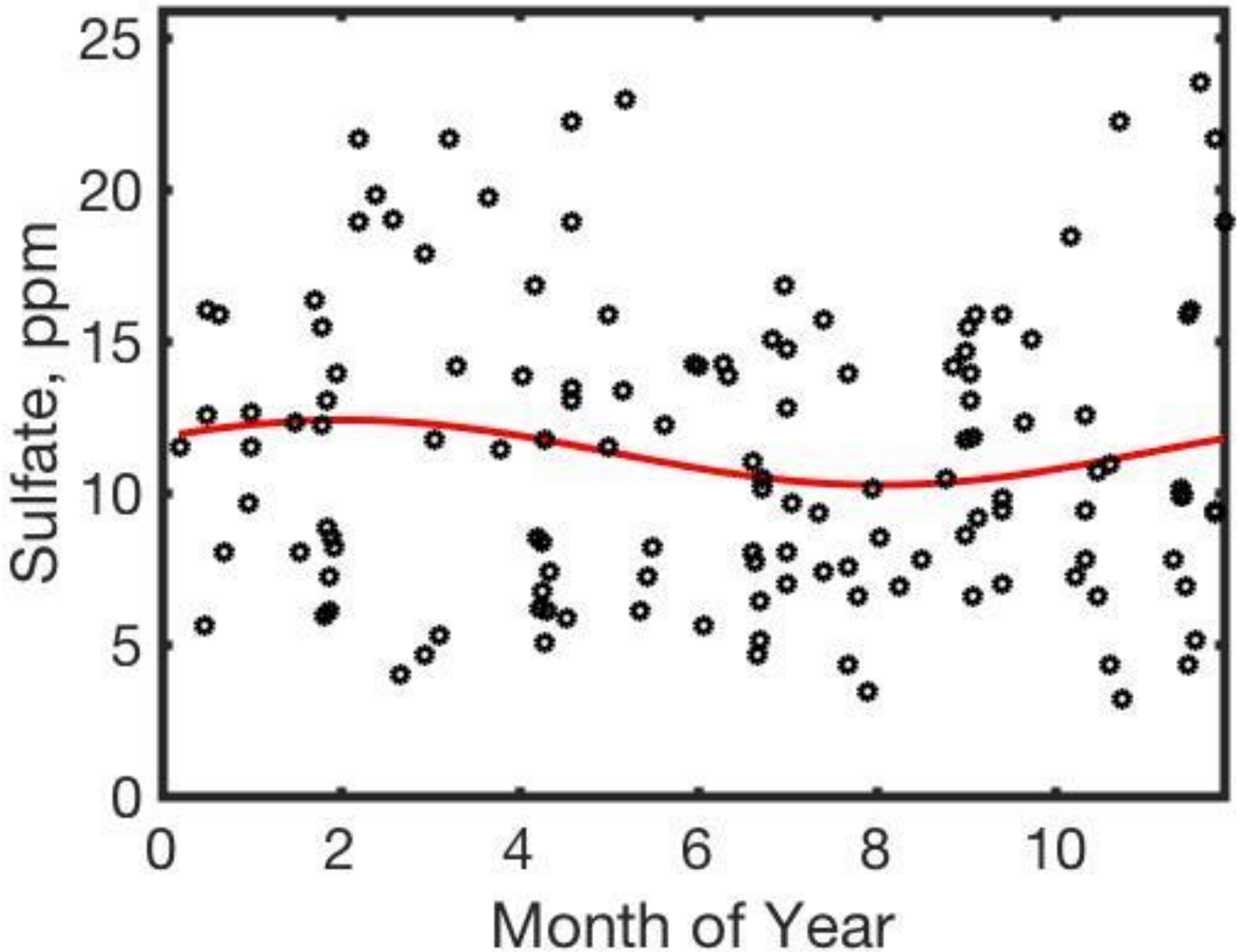
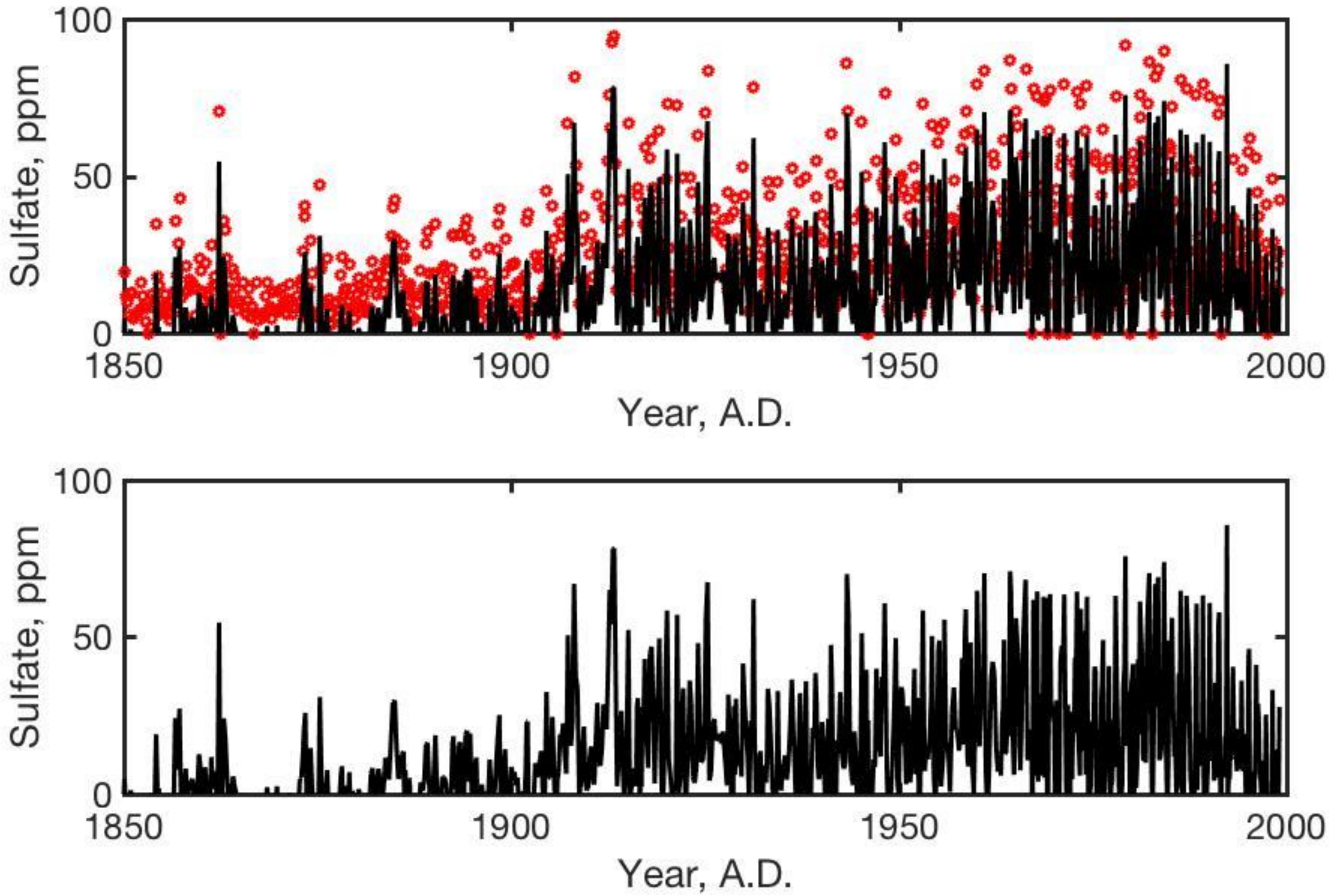
Northern Hemisphere Background Fit



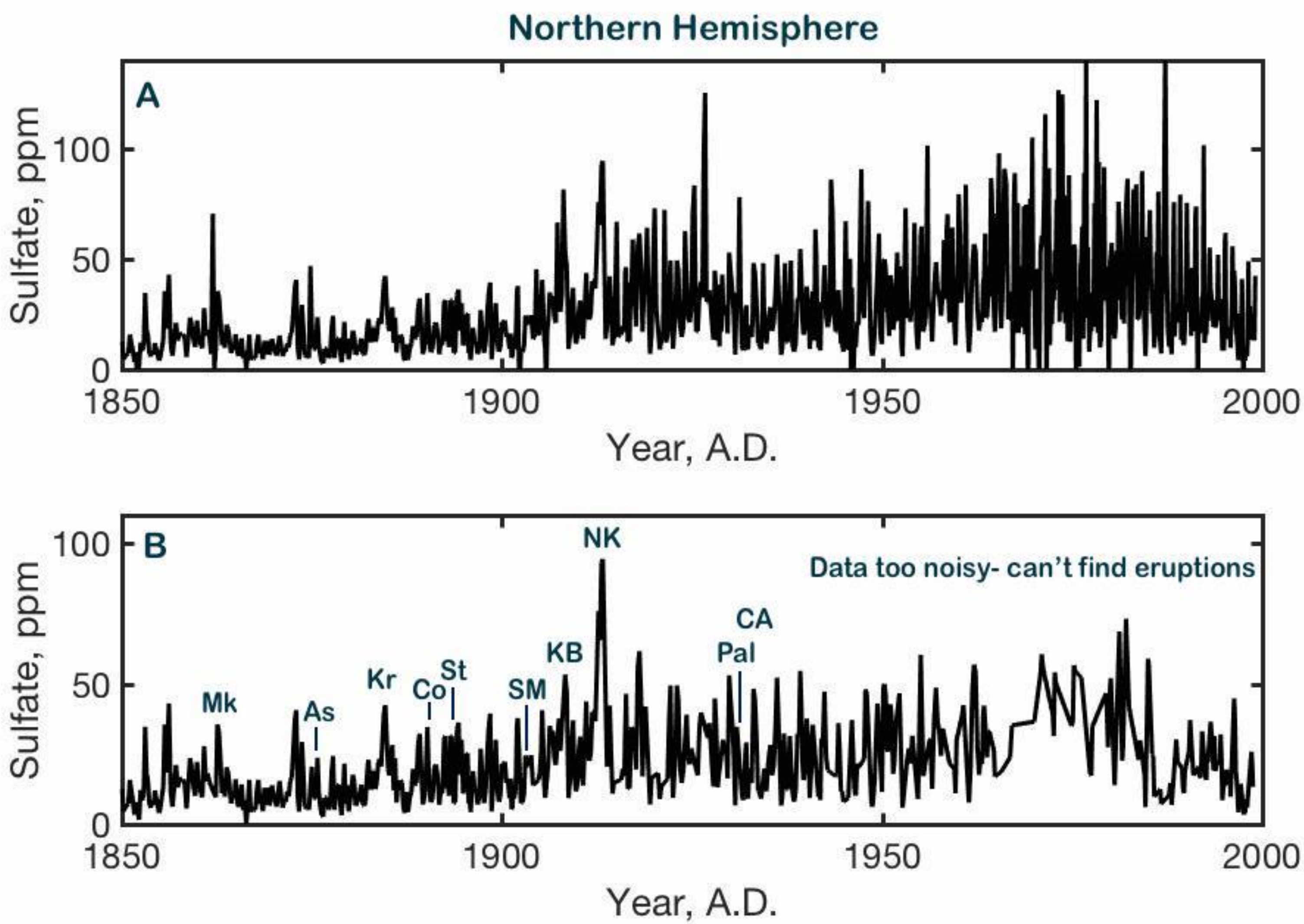
Northern Hemisphere Sulfate from Greenland Ice Sheet- very noisy



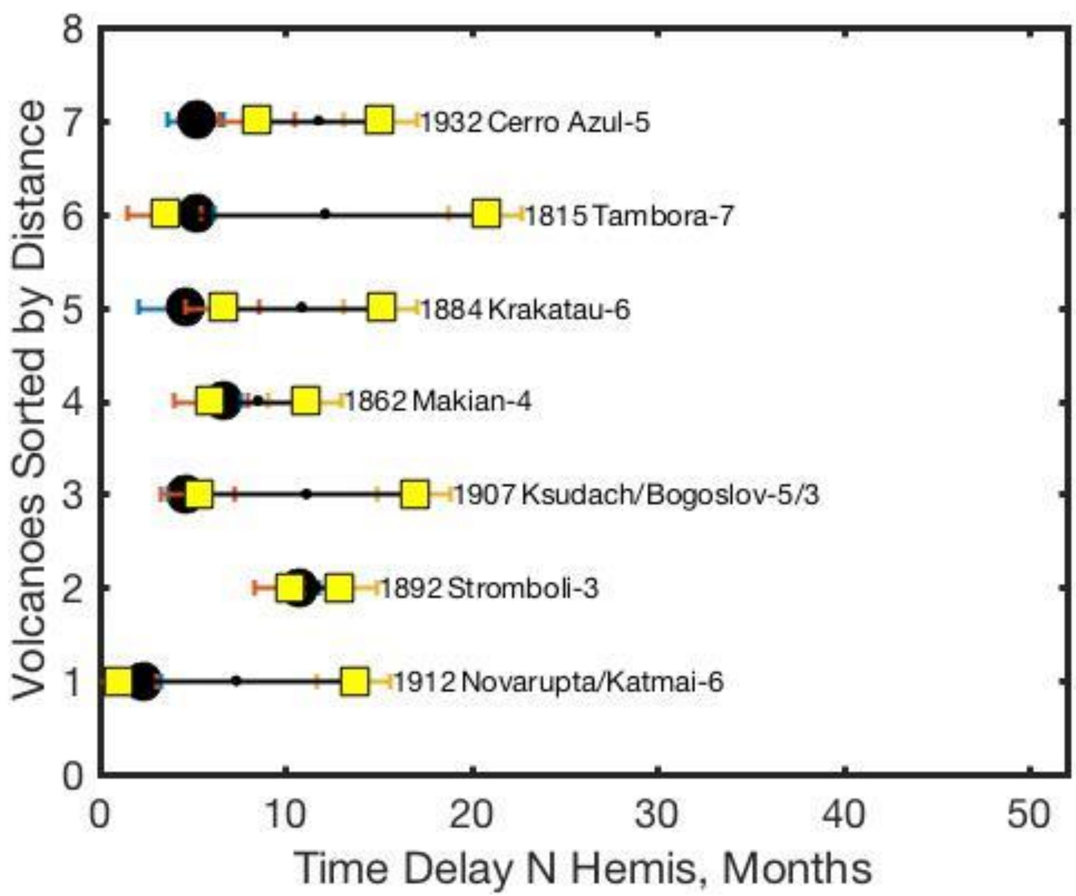
Why Data is Noisy

- 2) Continents affect cycles
- 3) Dust (and sulfate) coming from Chinese deserts (and mines) that are burning coal.
- 4) New strategy, take out sudden peaks in sulfate and also subtract a uniform average background sulfate of about 15 ppm.

Better Northern Hemisphere Sulfate



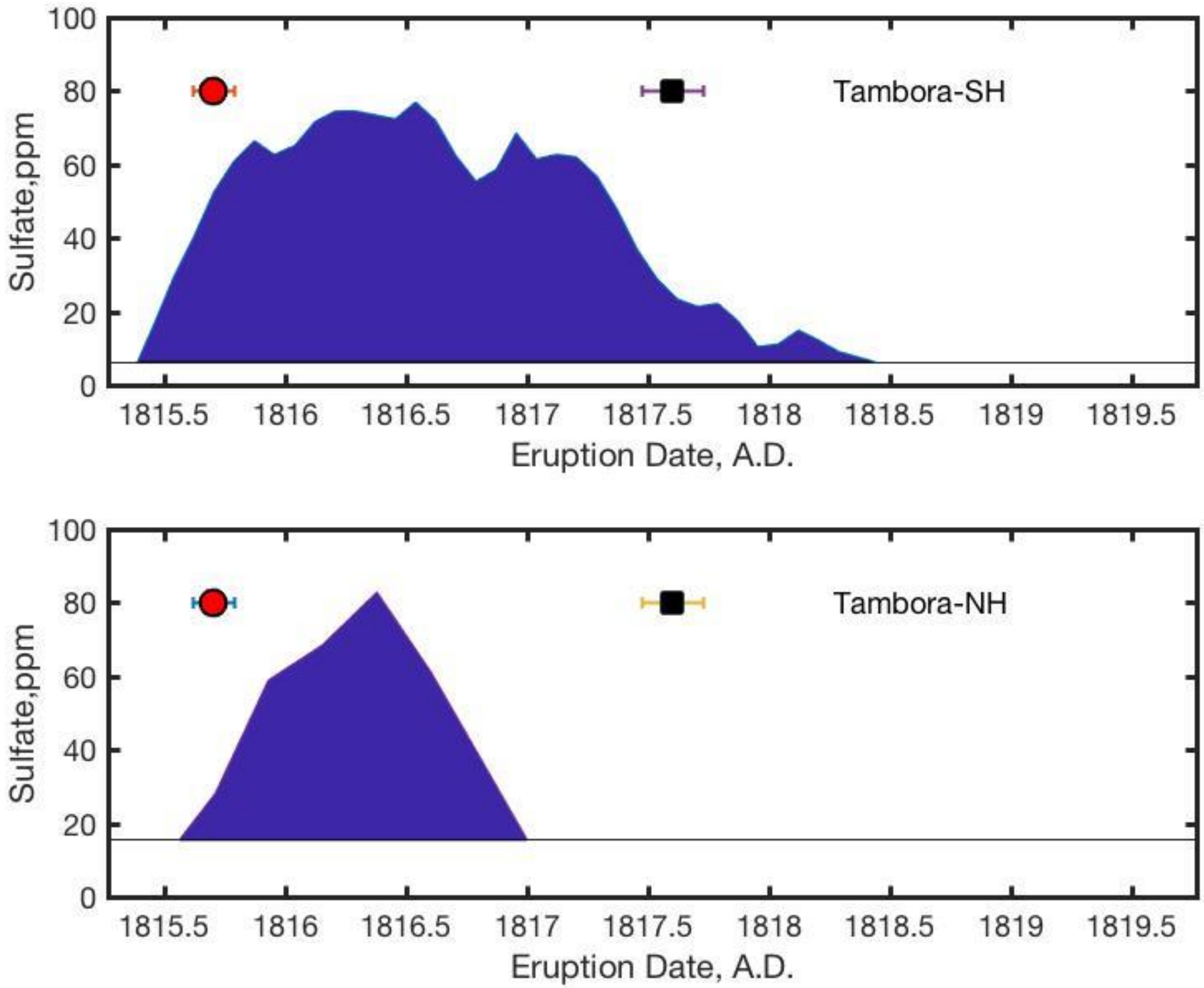
Result Northern Hemisphere-sorted by distance from volcano



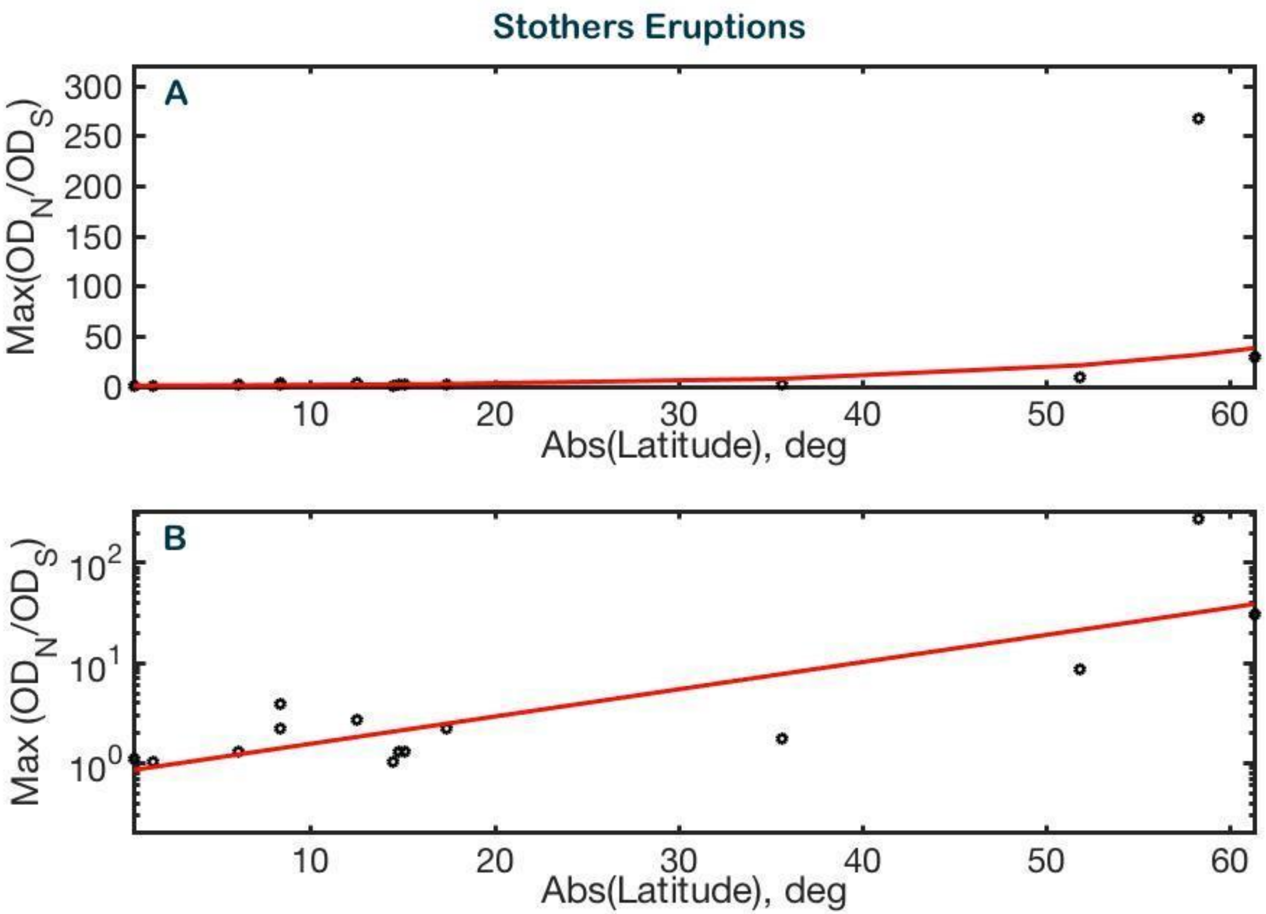
Summary Optical Depths

- Nearby volcanoes- maximum optical depth occurs before sulfate deposition starts
- (Sulfate is obscuring the atmosphere and later falls out).
- More distal volcanoes-maximum optical depth overlaps with early part of sulfate deposition but is never more than halfway through the time of overall sulfate deposition.

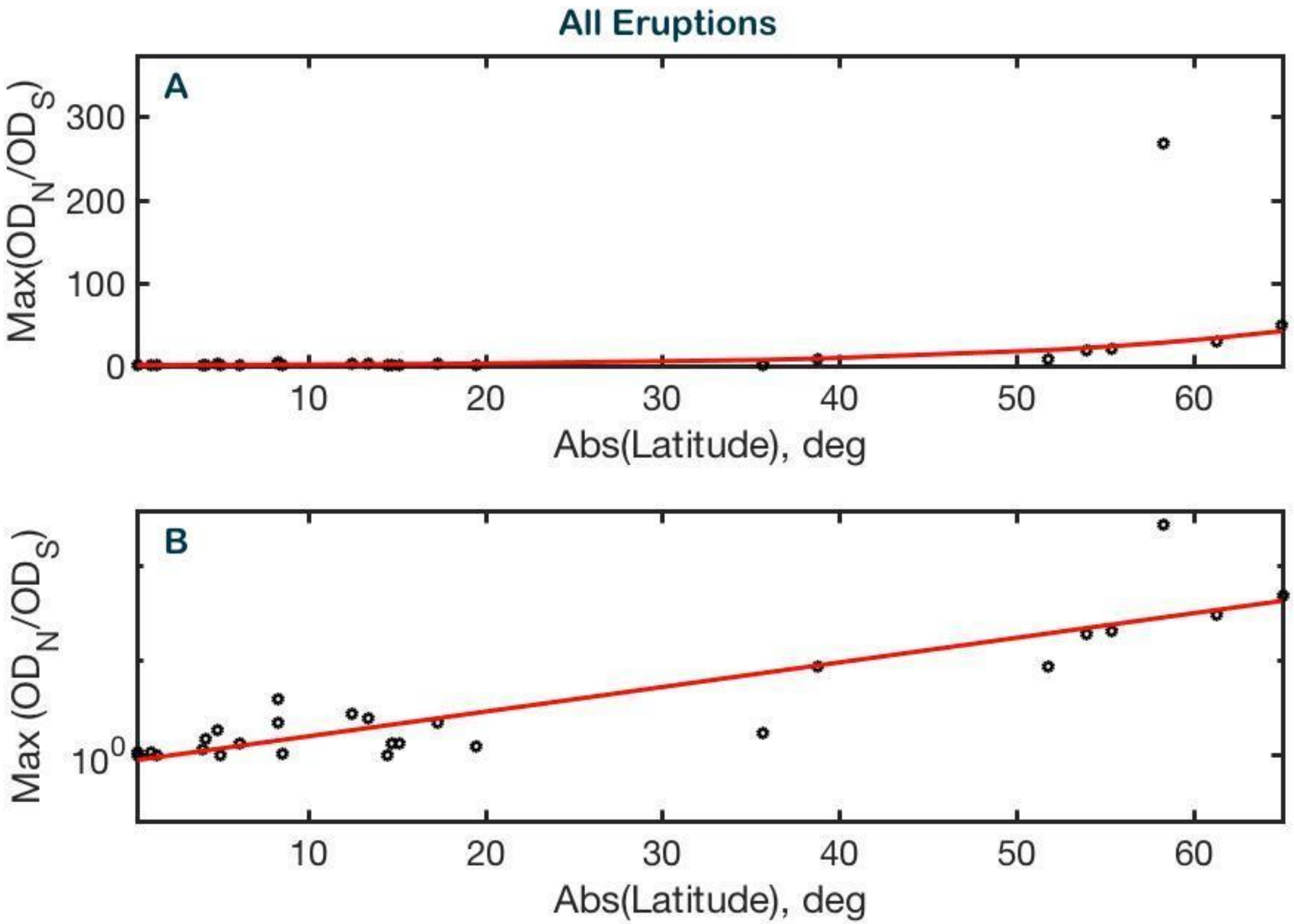
Results for Tambora- Maximum Optical Depth is early, frost ring is late



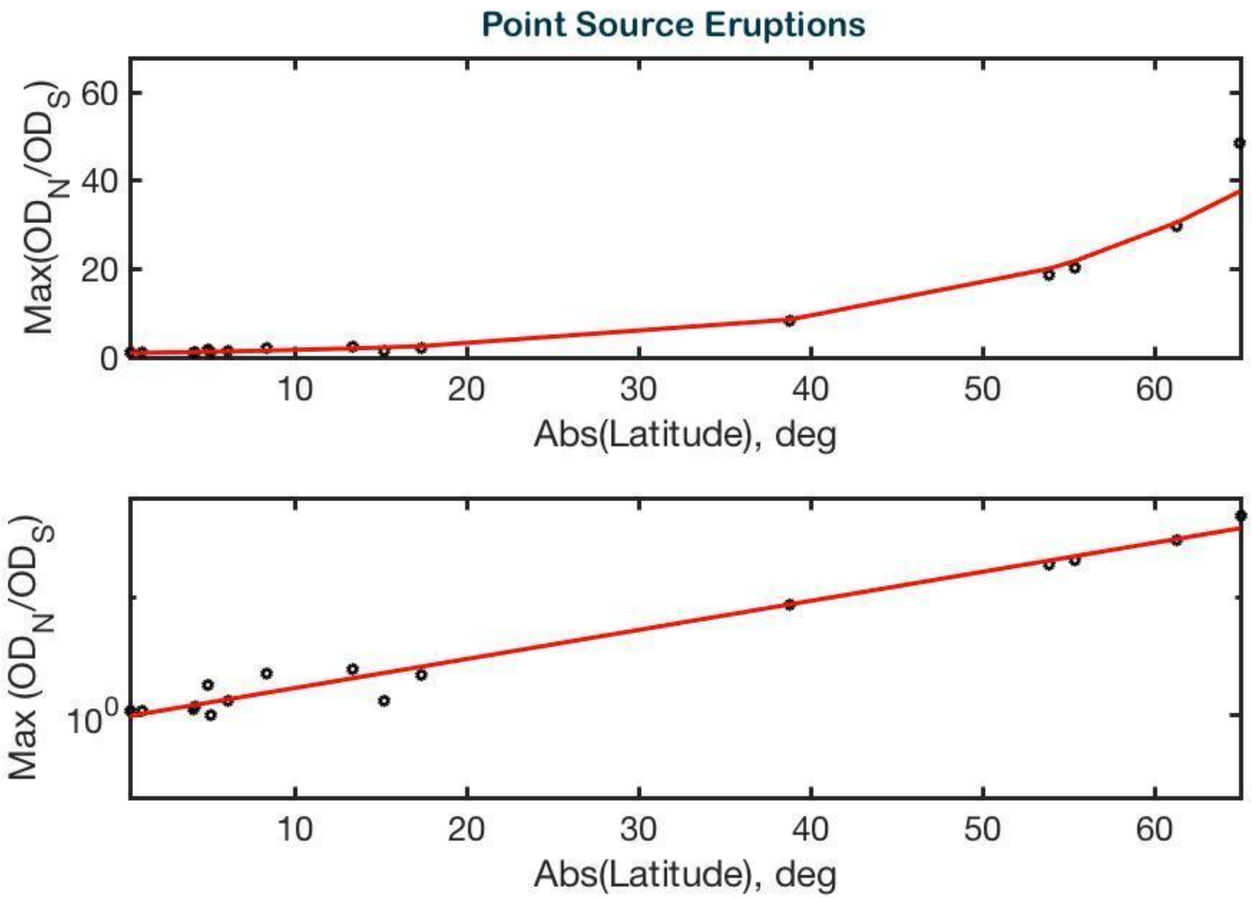
How to determine latitude of source volcano- part 1-ratios of optical depth $R2 = 0.69$



How to determine latitude of source volcano from ratios of optical depth R2=0.79



How to determine latitude of source volcano- best for point source eruptions R^2=0.97

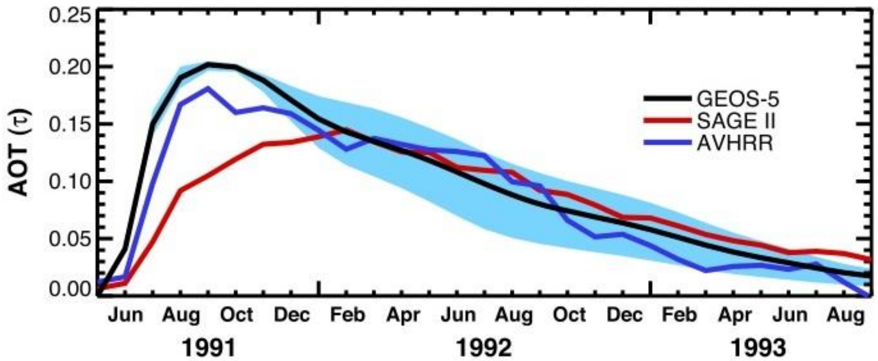


Conclusions

- 1) High latitude eruptions can produce frost rings
- 2) Maximum optical depth occurs before midpoint of sulfate deposition. Exact time difference depends on speed of travel of sulfate and distance to volcano
- 3) Frost rings can occur two years after an eruption with no frost ring one year after an eruption- light rings may be better to use as they average over several months rather than a few days.

Time Scale for mid-sixth century

- Maximum optical depth was between March 15th 536 and June 537- most likely 5 months after March 15th or around August 15th, 536 A.D.



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More than half of sulfate deposition occurred after August 15th, 536 A.D. Likely time of sulfate peak is fall 536 to spring 537 A.D. This fits Abbott et al., 2014 timescale for GISP2 ice core. Timescale based on independent historical data.