Volcanoes and Climate since 1960: what does the Moon have to say ?

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This is the large print edition for senior scientists.

Why ?

To assess the magnitude and effect of any climate forcing (solar), other major climate forcings (volcanoes, greenhouse gases, oceans, …) must also be assessed.

Today it's volcanoes.

About the project. First, it needs a name and an acronym.

Lunar Aerosol Climate Experiment

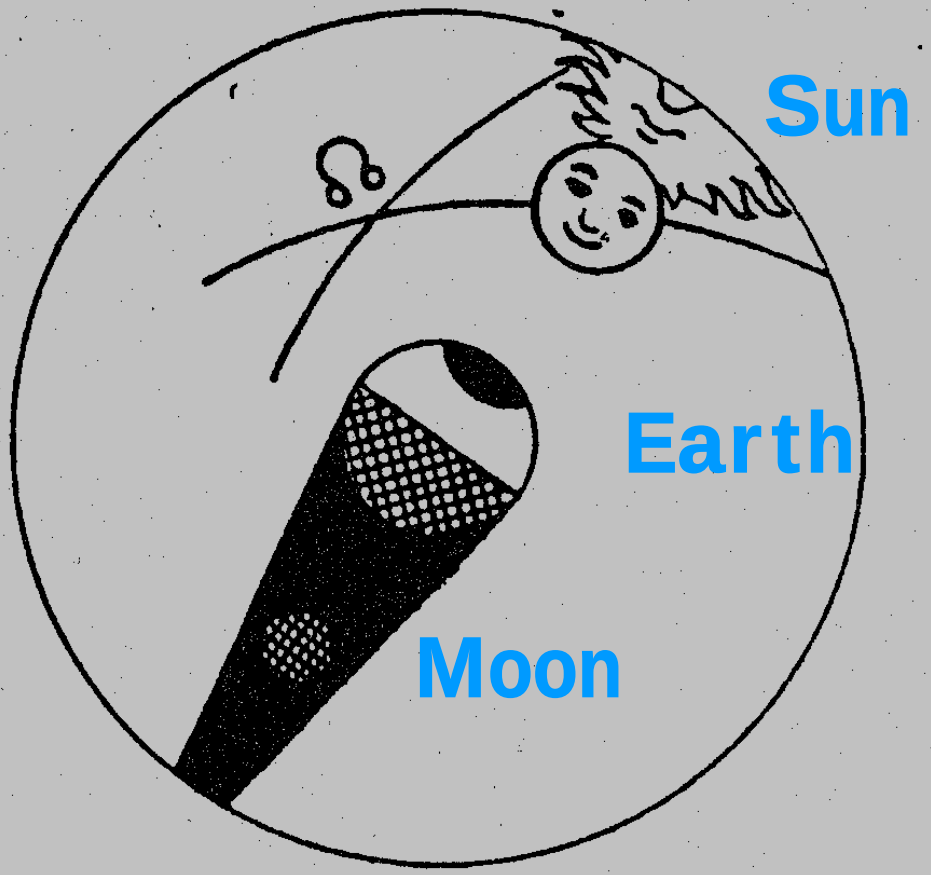
LUNACE

The LUNACE satellite (since renamed MOON) was launched around 4.5 billion BC by a Mars-size impactor. No air dropped Pegasus rockets here !

It did, however, take much longer for the satellite to reach the proper orbit.

"On time and on budget"

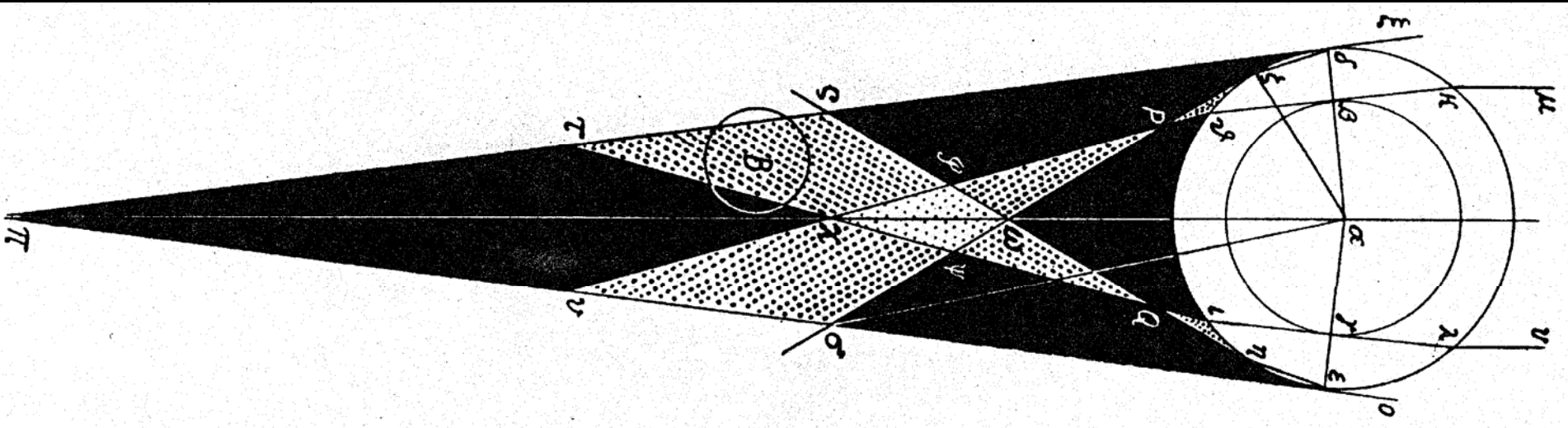
Now, about once per year on average, a Lunar Eclipse occurs when the Moon passes through the Earth's shadow.



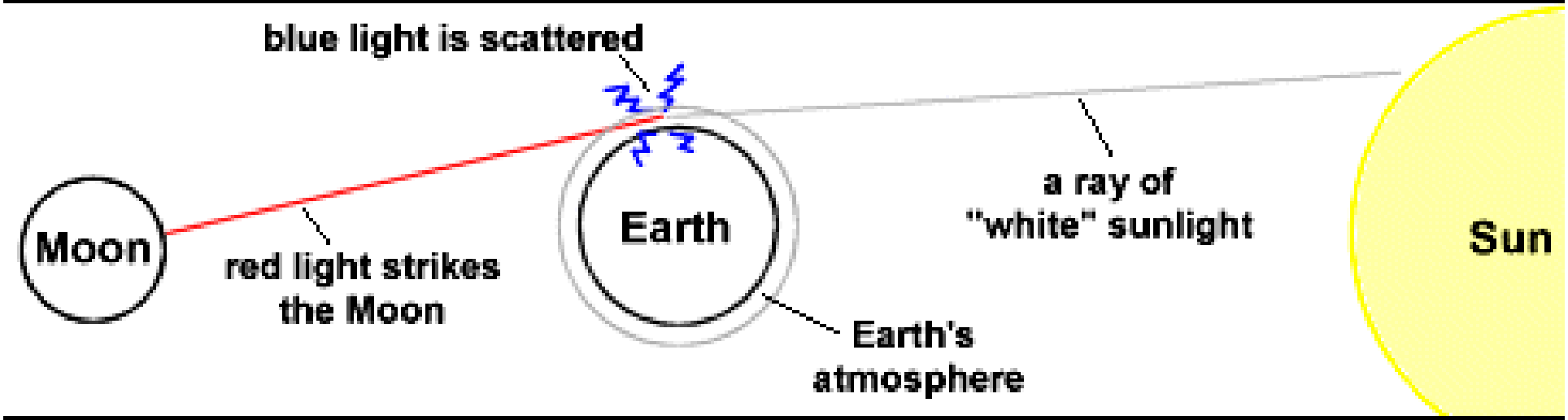
Johannes Kepler

1571-1630

Kepler's diagram of light from the sun (coming from the left) being refracted into the Earth's umbra and onto the Moon.
(Astronomiae pars Optica, 1604)



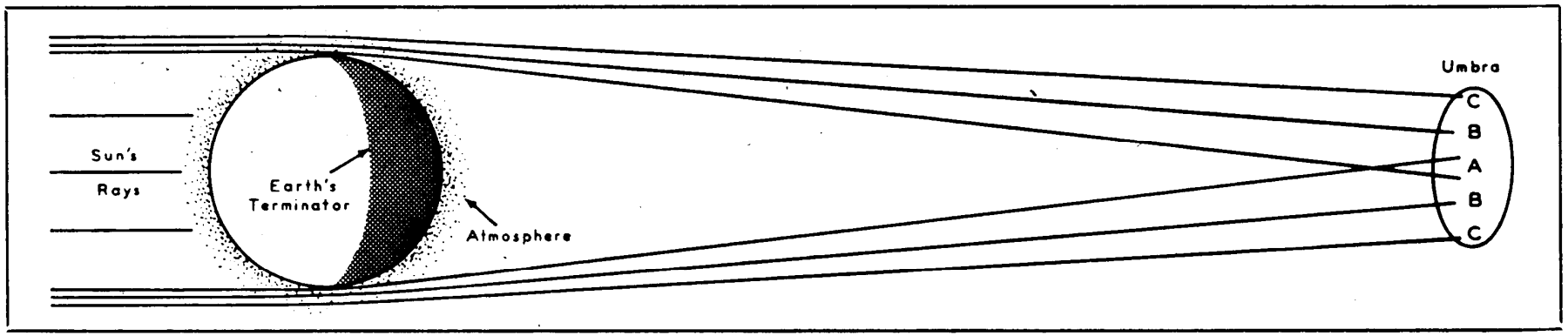
The sunlight is reddened by scattering by “mists and smoke” in the Earth’s atmosphere (Kepler).



1967: Surveyor III views an eclipse of the Sun by the Earth… from the Moon!

From Earth, we see a lunar eclipse

Most of the sunlight that illuminates the moon during an eclipse passes through the stratosphere



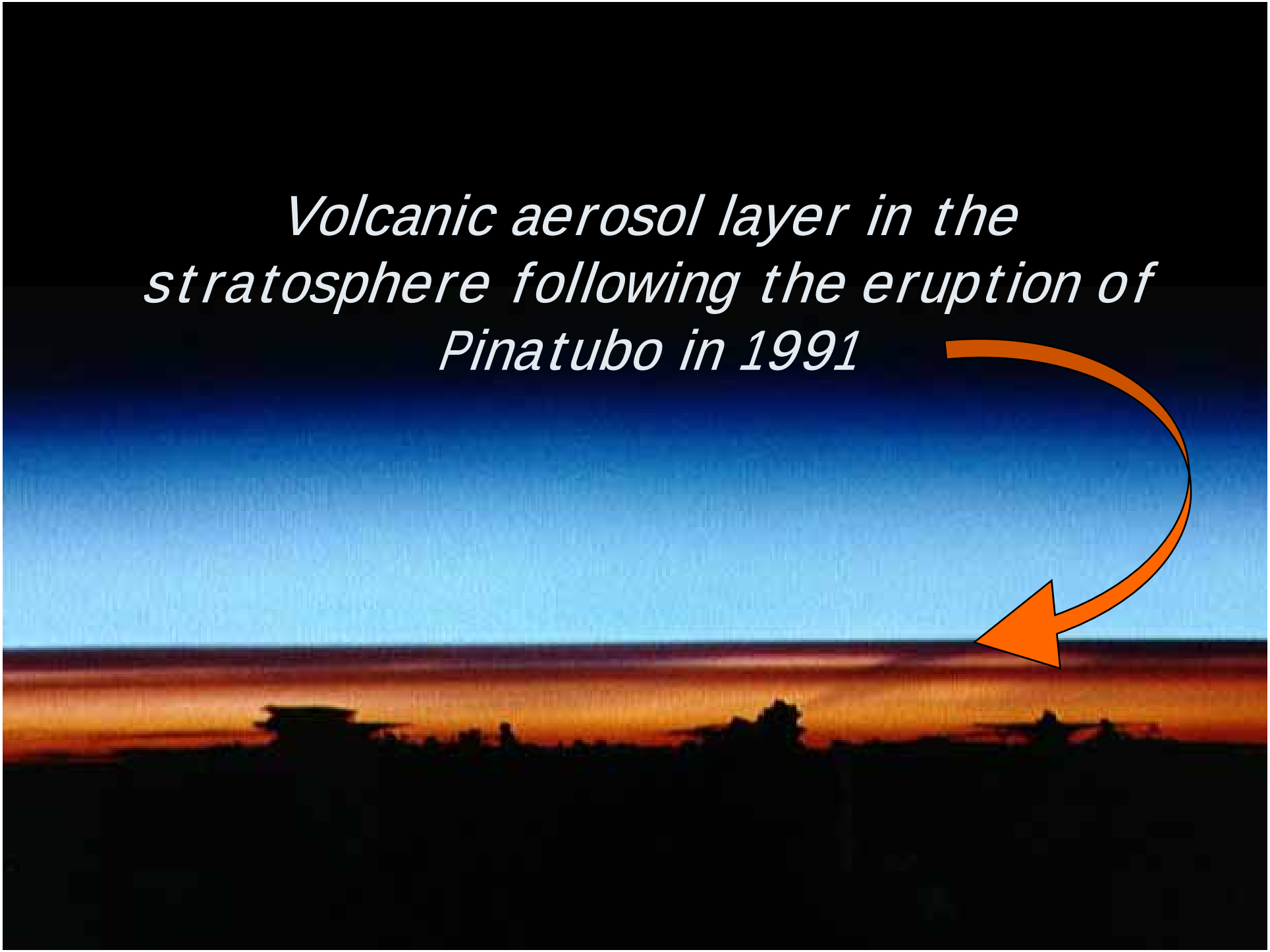
Sunlight is refracted by the earth's atmosphere into the umbral shadow, as seen here. A, B, and C, respectively, are parts of the shadow that are illuminated mainly by rays that pass through the lower, middle, and upper atmosphere.

... which is where volcanic aerosols concentrate and persist for years after an eruption.

Put "dirt" in the stratospheric light path, and the eclipse becomes darker.

The stratosphere is normally a very clear place.

Volcanic aerosol layer in the stratosphere following the eruption of Pinatubo in 1991



Dec. 9, 1992 – after Pinatubo

Eruptions the size of Pinatubo occur once in a blue moon.

The blue is caused by ozone absorption of red light in the upper stratosphere. Light passing through the middle and lower stratosphere was absorbed by the sulfate aerosol.

Dec. 30, 1982 – after El Chichon


Dec. 30, 1963 – after Agung
The darkest eclipse since 1816.

Comparison of two eclipses

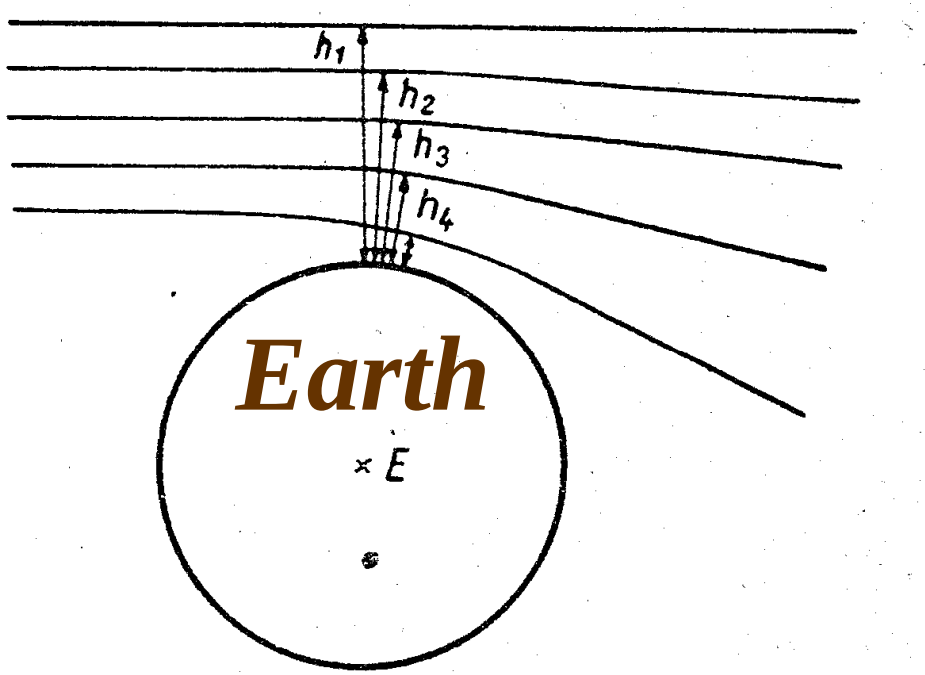
1972 (left), 1982 (after el Chichon, right)

taken with the same telescope, film, and exposure

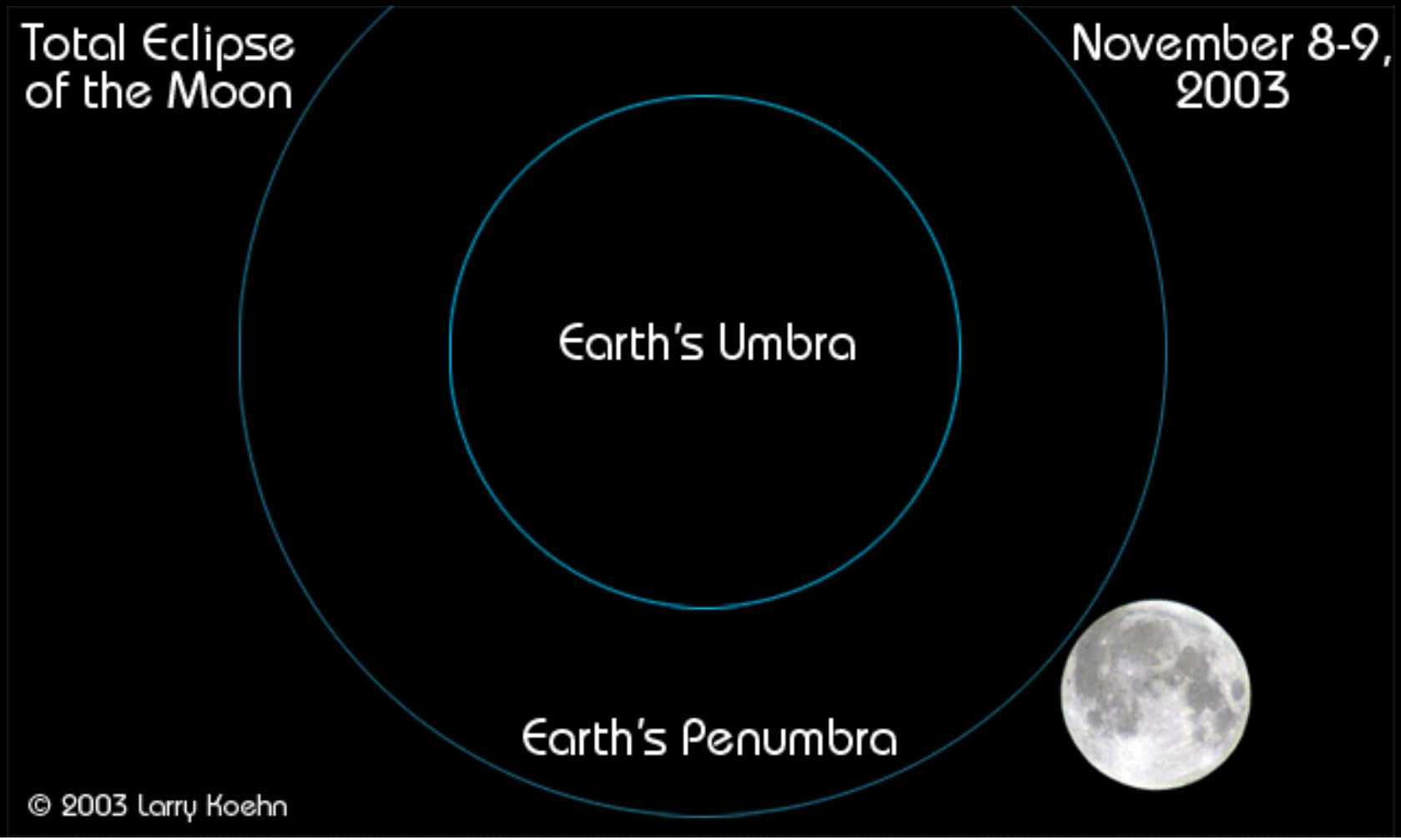
The eclipse on the left is 400 times brighter than the one on the right.

First, calculate the bending and attenuation of sunlight passing at different altitudes, to predict the amount of light reaching various parts of the umbra.

Include refraction, scattering, and absorption by clear air in the stratosphere & mesosphere, and an assumed cloud distribution ~50% in the troposphere.



The brightness of the moon depends on its path through the umbra and distance from the Earth. Knowing the geometry of the eclipse, we can predict the moon's brightness (assuming no volcanic aerosols).

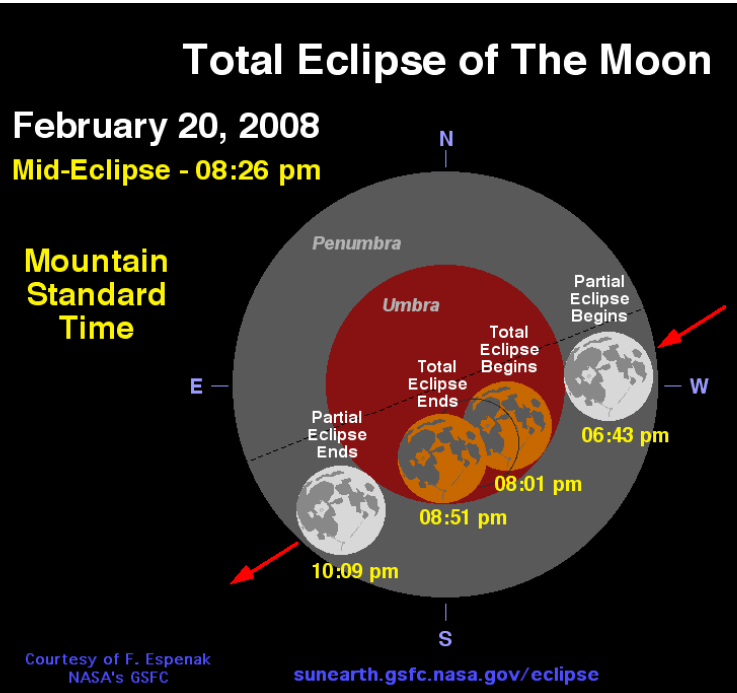


Next, observe the brightness of the eclipse with eye or photometer (or find old observations in the literature).

Then, compare the observed brightness (in stellar magnitudes) of each eclipse with the predicted brightness.

The difference is due mostly to volcanic aerosols, and can be converted into an aerosol optical thickness.

Due to the grazing path length along the limb of the Earth, the dimming of the moon is roughly 40 times the optical depth of the aerosol layer.

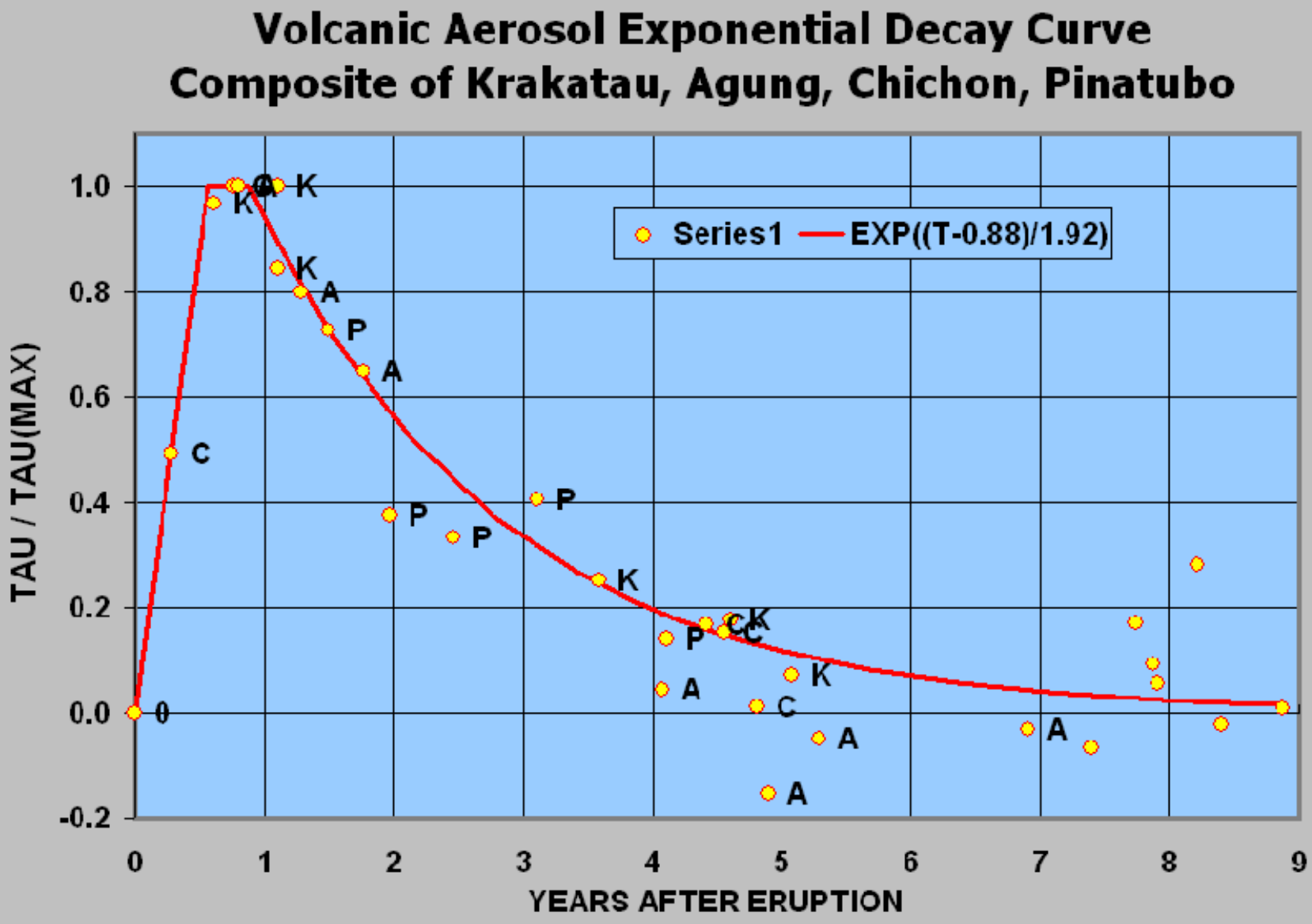


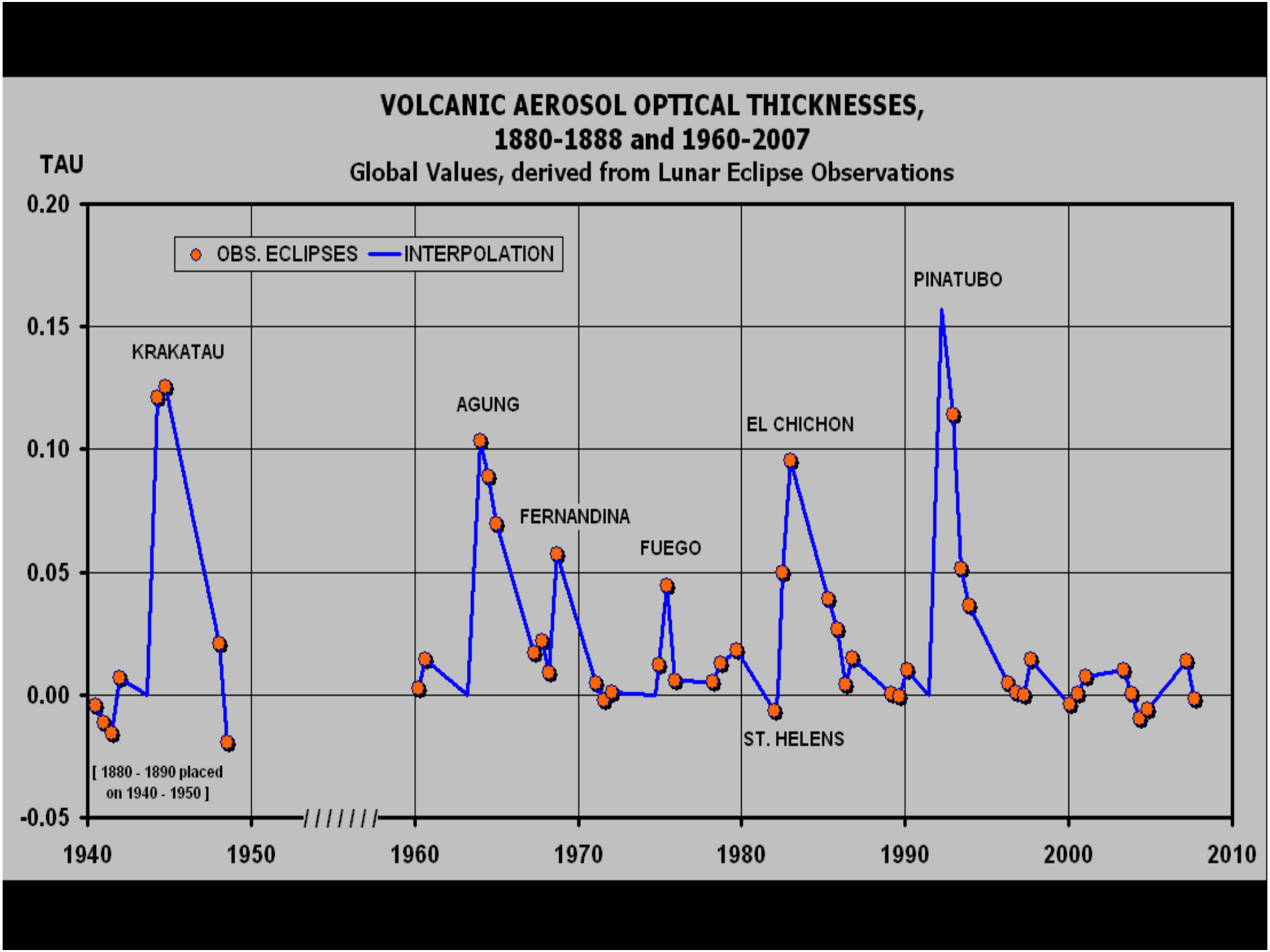
Some adjustments

Eclipses can favor the northern or southern hemisphere, as can volcanoes.

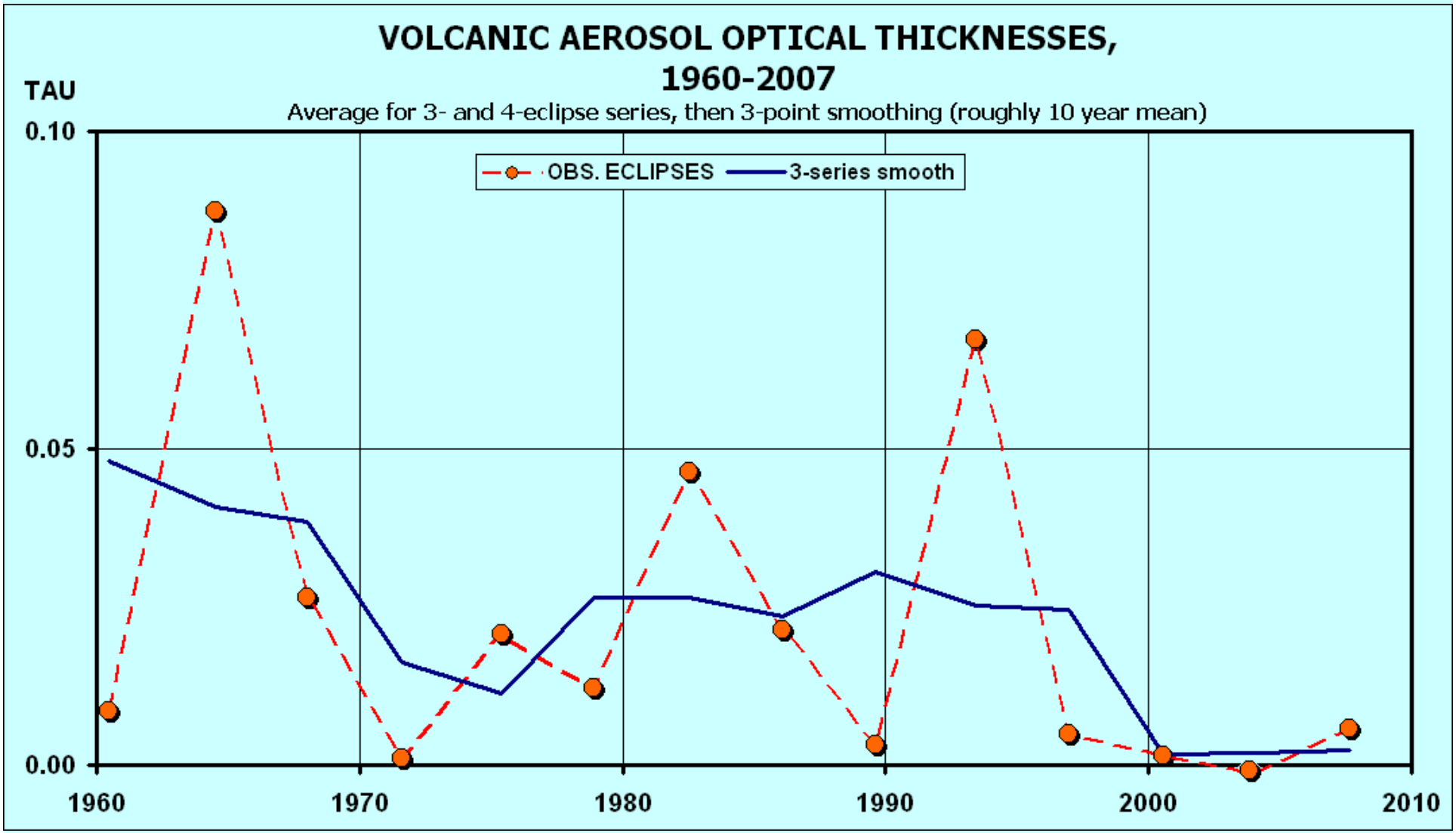
A “hemispheric bias” factor of 0.8 is applied when the eclipse and volcano favor the same hemisphere, and 1/0.8 for opposite hemispheres.

In the case of Pinatubo, the first eclipse was 18 months after the eruption. Tau was extrapolated backward using this composite decay curve.

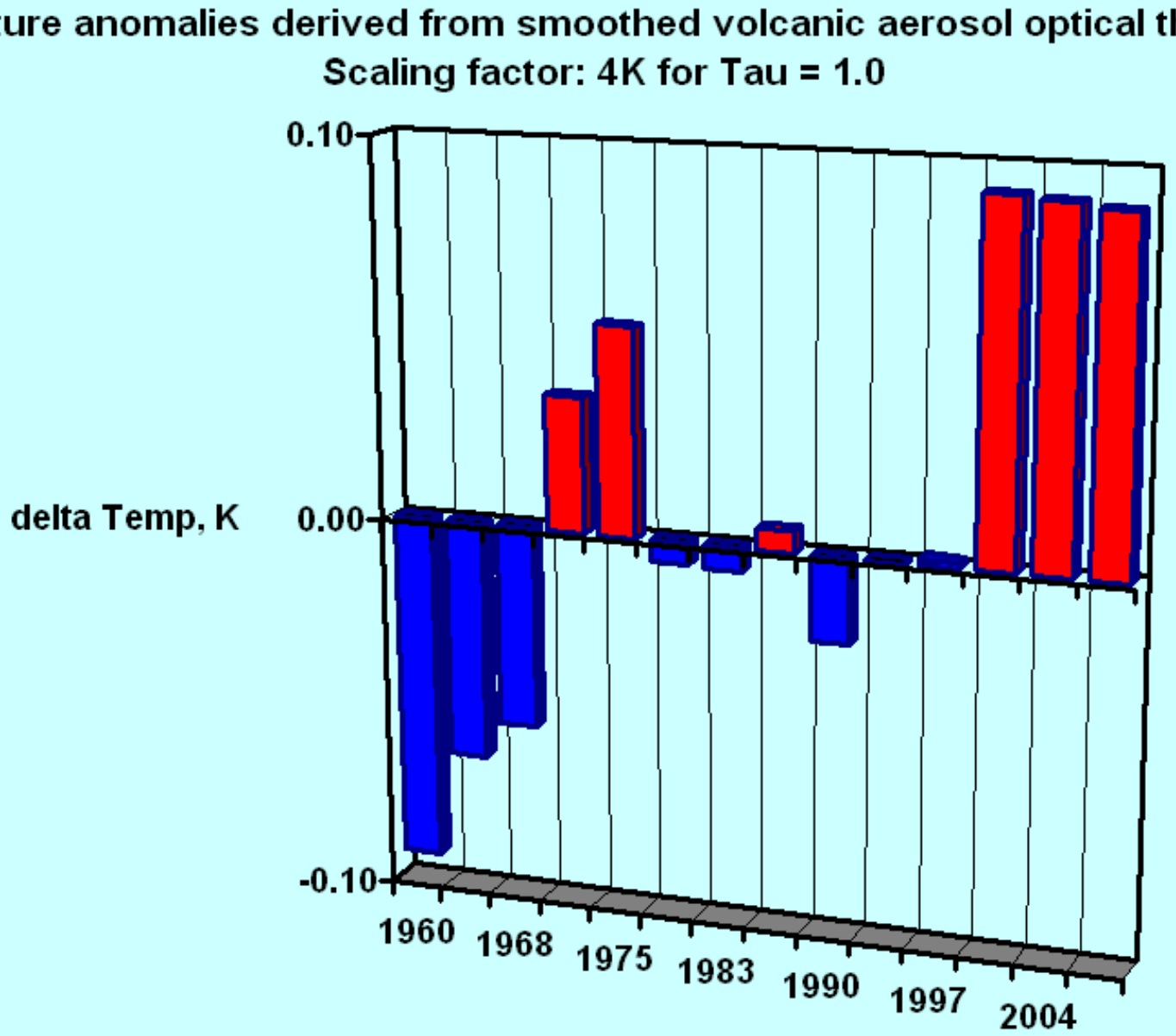



VOLCANIC AEROSOL OPTICAL THICKNESSES,
1880-1888 and 1960-2007
Global Values, derived from Lunar Eclipse Observations
TAU
0.20
0.15
0.10
0.05
0.00
-0.05
OBS. ECLIPSES
INTERPOLATION
KRAKATAU
AGUNG
FERNANDINA
FUEGO
EL CHICHON
ST. HELENS
PINATUBO
[1880 - 1890 placed
on 1940 - 1950]
1940
1950
1960
1970
1980
1990
2000
2010

Eclipses occur in groups of 3 or 4 at 6-month intervals, separated by ~2 years with no eclipses.
Averaging these groups gives:



Convert the optical depths to global temperature anomalies:



Take home thoughts:

1. The lunar eclipse record indicates a clear stratosphere over the past decade, contributing a warming of 0.1 to 0.2 K over the previous four decades (a forcing change of about ½ W/m^2).

2. Lunar eclipses are beautiful and informative. Be sure to watch the next one in two weeks.

3. If you do observe the eclipse and get a number, do let me know !
(thanks from me and the entire LUNACE team)

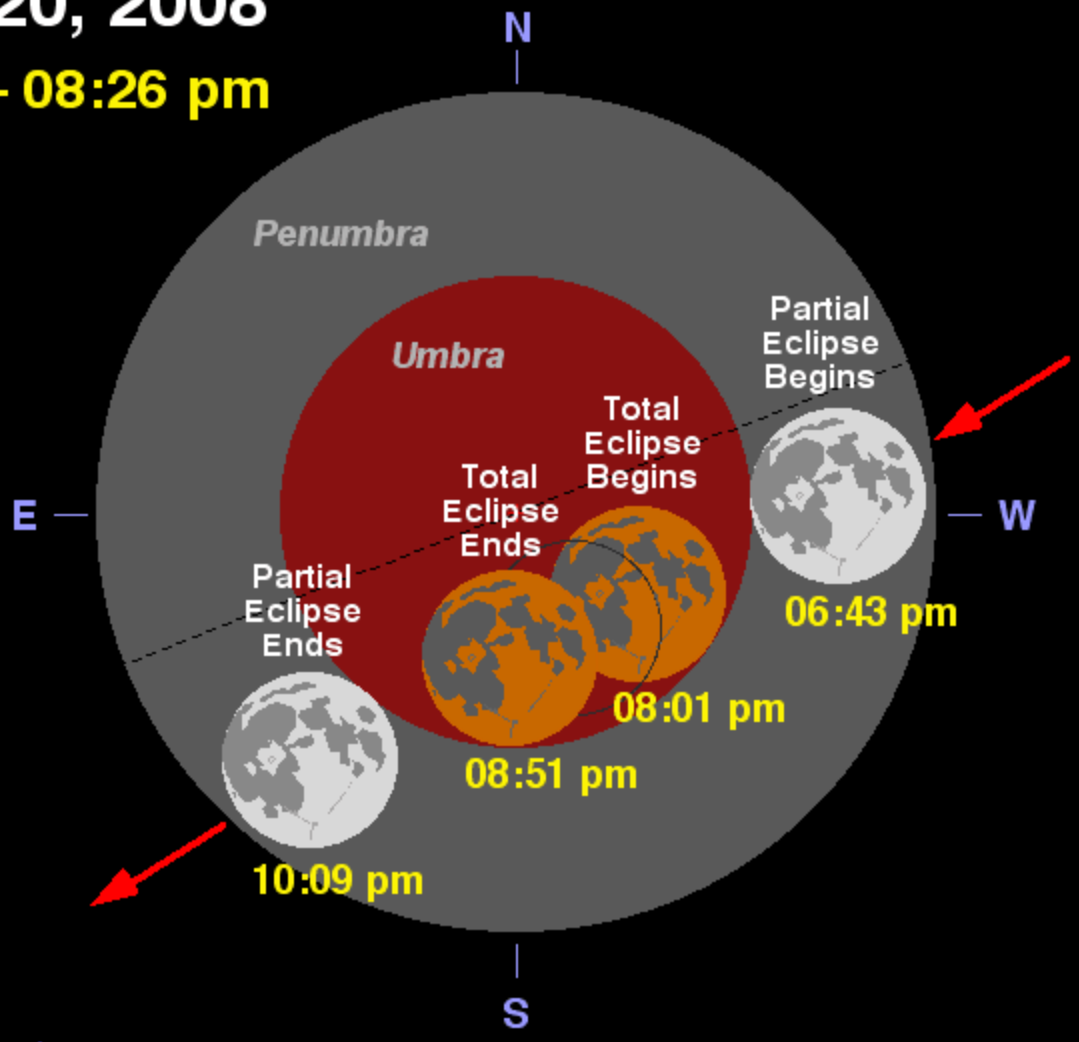
Next eclipse:

Total Eclipse of The Moon

February 20, 2008

Mid-Eclipse - 08:26 pm

Mountain Standard Time



Courtesy of F. Espenak
NASA's GSFC

sunearth.gsfc.nasa.gov/eclipse

Thanks to eclipse observers in:

Australia

Brazil

Jordan

Netherlands

New Zealand

Norway

Portugal

Slovakia

Slovenia

South Africa

Spain

Sweden

United Kingdom

United States

United Arab Emirates

Venezuela

Kwakiutl dancing to restore an eclipsed moon, c.1914, Edward Curtis (1868 – 1952)

Surface-Based Observations of Volcanic Emissions to the Stratosphere

Dave Hofmann, John Barnes, Ellsworth Dutton, Terry Deshler, Horst Jäger, Richard Keen, and Mary Osborn

Volcanism and the Earth's Atmosphere
Geophysical Monograph 139

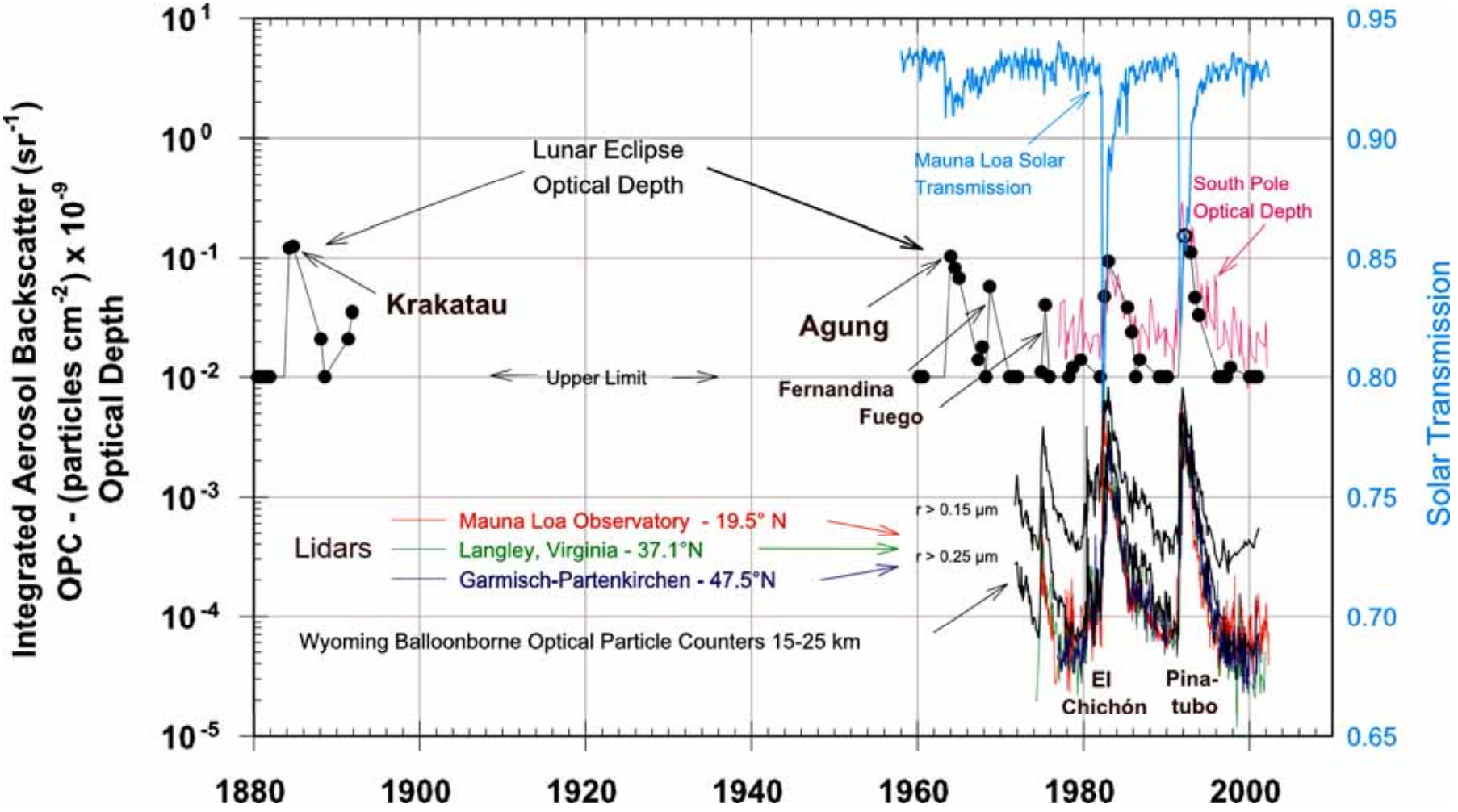
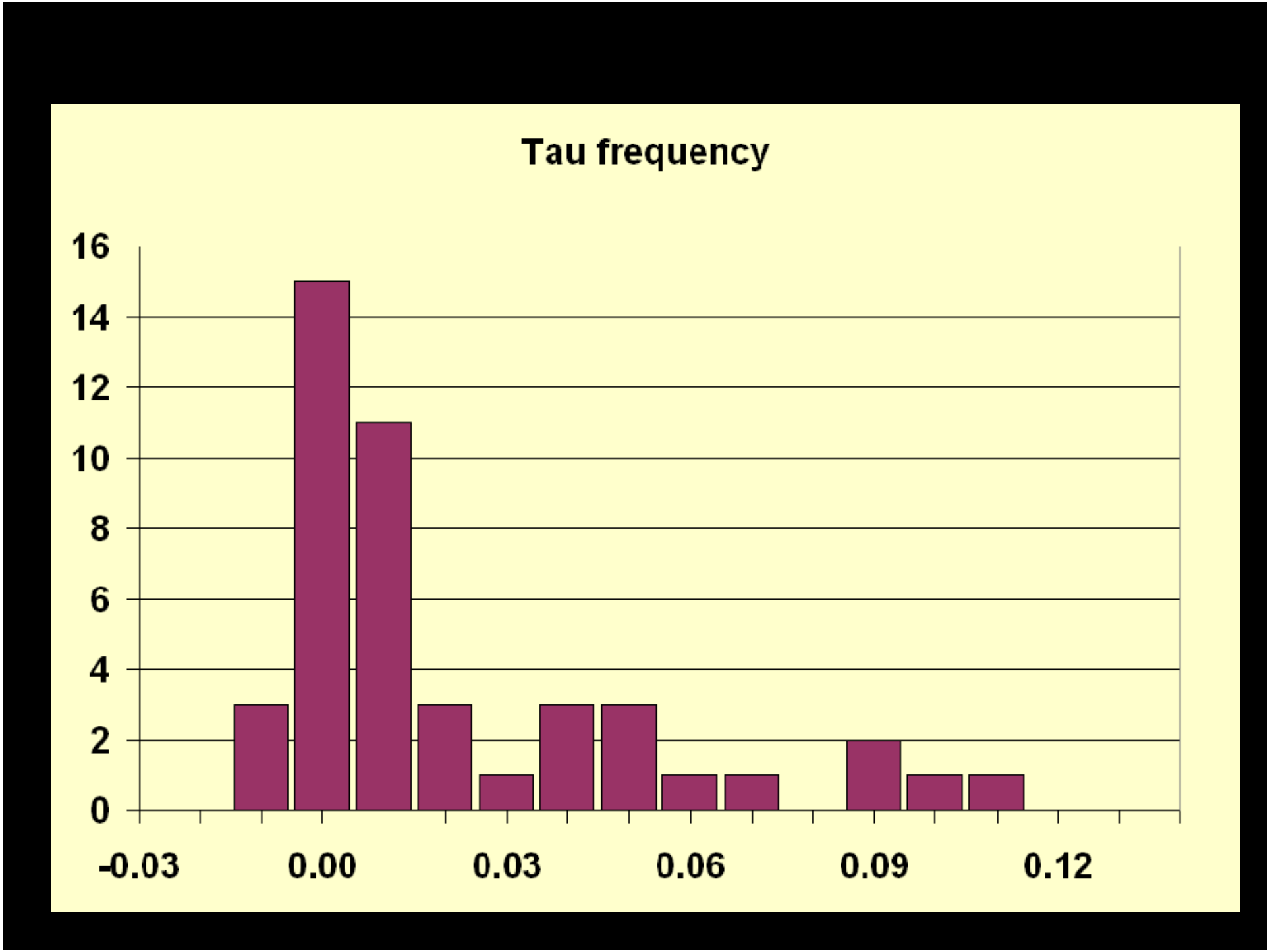


Plate 8. *Summary of long-term stratospheric aerosol records including three lidars, at Mauna Loa Observatory (Hawaii), Langley Research Center (Virginia), and Garmisch-Partenkirchen (Germany); balloon borne particle counters at Laramie, Wyoming, solar visible transmission at Mauna Loa Observatory; aerosol optical depth at South Pole Station and lunar eclipse optical depth, which is a globally-integrating technique.*

Table 1. Volcanic Eruption Data and Lunar Eclipse Derived Maximum Optical Depth

Volcano Name	Major Eruption Date	Volcanic Explosive Index *	Max Optical Depth
Krakatau	**1883-08-27**	**6**	**0.13**
Agung	**1963-03-17**	**4**	**0.10**
Fernandina	**1968-06-11**	**4**	**0.06**
Fuego	**1974-10-10**	**4**	**0.04**
El Chichón	**1982-04-03**	**5**	**0.09**
Pinatubo	**1991-06-15**	**6**	**0.15**

* *Simkin and Siebert* [1994]


Tau frequency
16
14
12
10
8
6
4
2
0
-0.03
0.00
0.03
0.06
0.09
0.12