# Two Centuries of Volcanic Aerosols Derived from Lunar Eclipse Records, 1805-2019

## Global values from Lunar Eclipse observations

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About once per year on average,
a Lunar Eclipse occurs when the Moon passes through the Earth's shadow.
At these times we can measure the effect of volcanoes on Earth's climate.

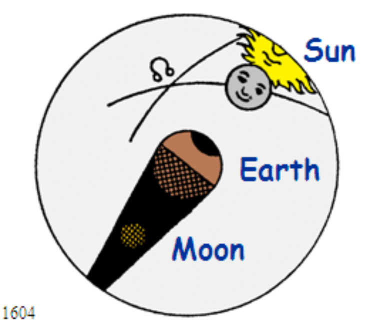
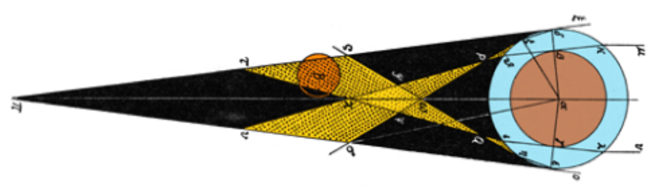
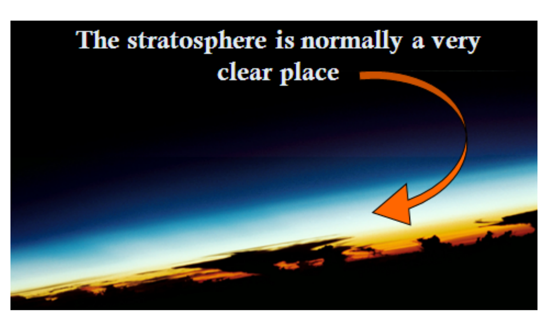


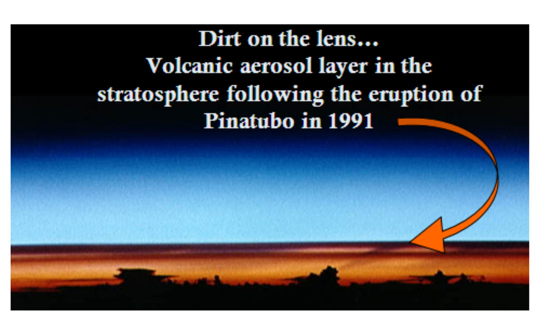

Diagram: Kepler, 1604

Sun light (coming from the right) is refracted (like a lens) into the Earth's umbra and onto the Moon during a lunar eclipse.
From J. Kepler, "Astronomiae pars Optica" (1604)

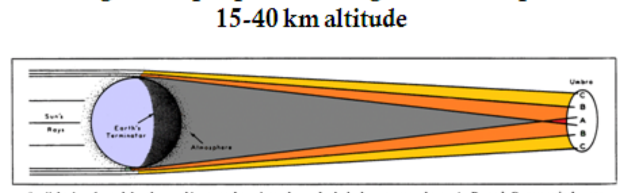


Kepler wrote that sunlight is reddened & dimmed as it passes through "mists and smoke" in the Earth's atmosphere (mostly stratosphere, we now know), causing the eclipsed moon to appear orange, red, or darker.




Most of the sunlight that illuminates the moon during an eclipse passes through the stratosphere 15-40 km altitude




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.

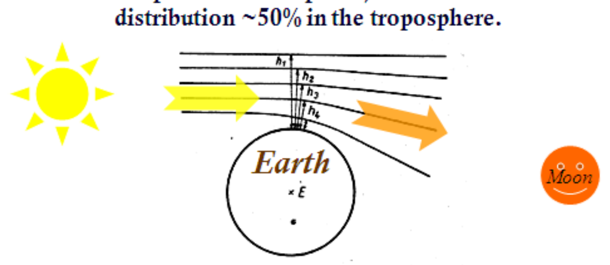
... which is where volcanic aerosols concentrate and persist for years after an eruption.
Put "dirt" in the stratospheric light path, and the eclipse becomes darker.

**Lunar Eclipse:**
Calculate a "predicted" brightness for a clear atmosphere.

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.

Observe the actual brightness, then calculate the amount of volcanic stuff from the difference.





About once per year, on average, the moon is totally eclipsed; the moon is then illuminated by sunlight refracted into the umbra, primarily by the stratosphere. Stratospheric aerosols can affect the brightness of the eclipsed moon, and climatically significant, visible-band, global aerosol optical depth (AOD) can be directly measured from the difference between observed and predicted brightness.

Using records of 147 lunar eclipses published in the recent and historic literature, observations communicated directly from observers around the globe, and 31 eclipses observed by the author, the AOD time series now extends from 1805 to 2019. Some climatically significant implications of the AOD record:

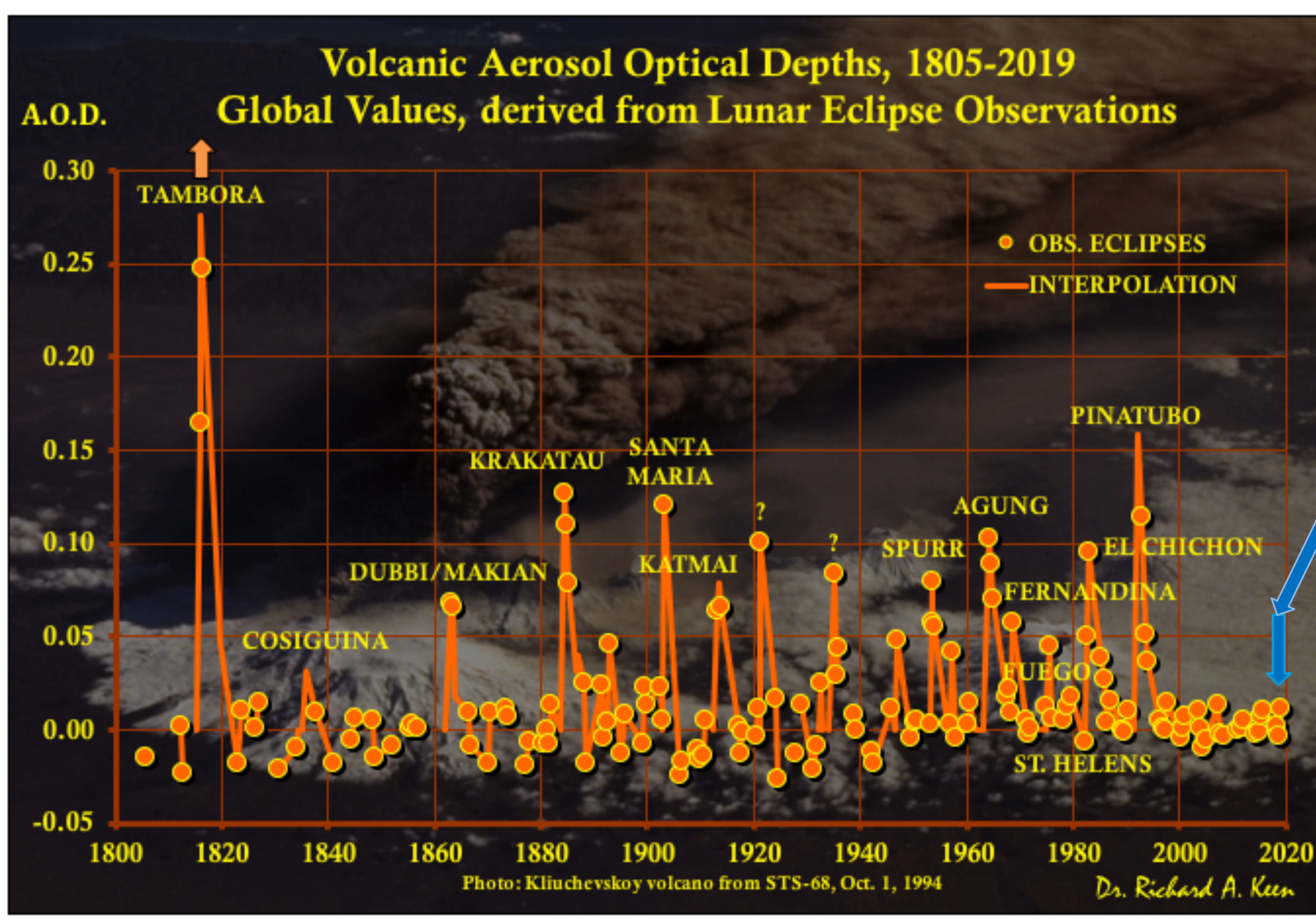
1. There was more volcanic effect on the climate during 1915-1962, and less from 1820-1882, than previously determined by Dust Veil and Volcanic Explosivity Indices and other estimates. The largest DVI event, Cosigüina in 1835, is demoted to a minor event in the eclipse AOD record.

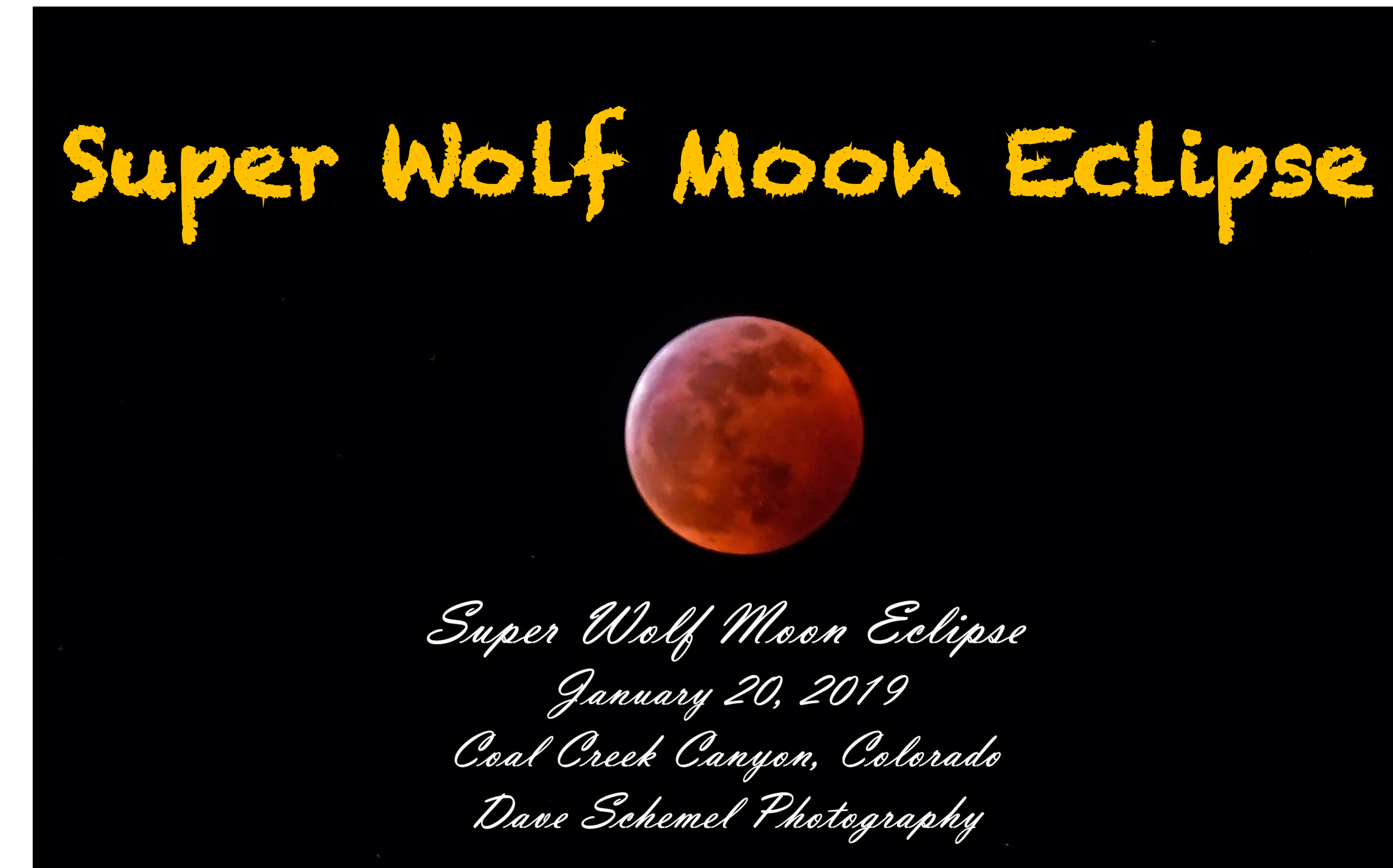
2. There have been no climatically significant volcanic eruptions since Pinatubo, 28 years ago. This is the longest period without a major climatically significant volcano in the past two centuries.

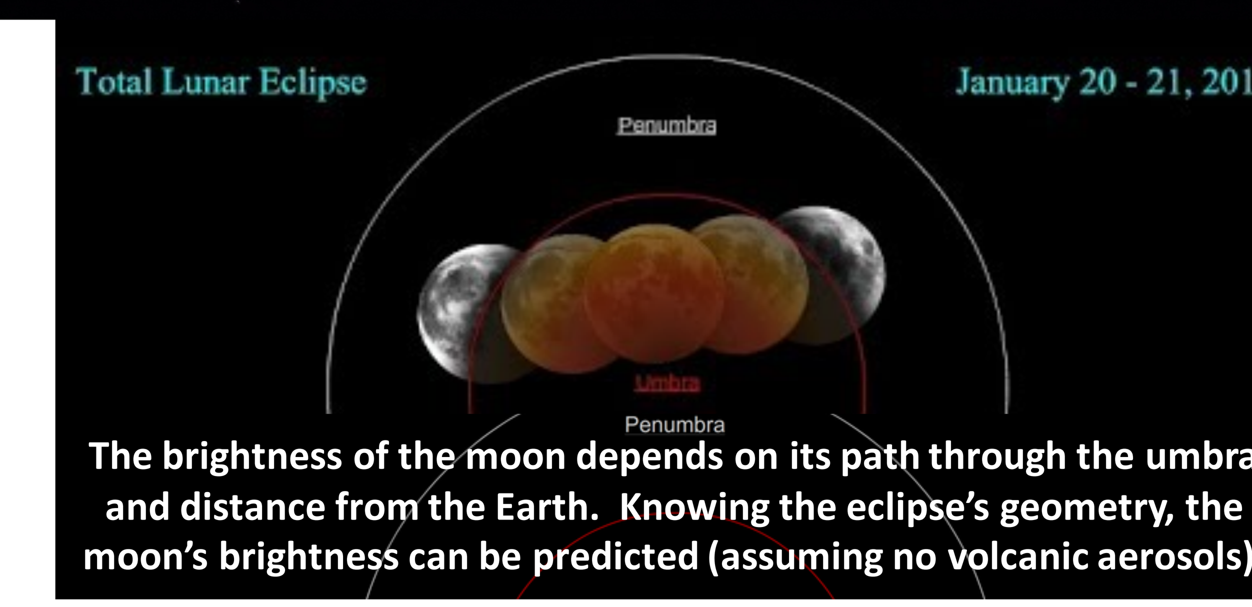
3. A continuum of smaller volcanic eruptions since Pinatubo has maintained a steady activity level, with no detectable trend in stratospheric AOD. The most recent, Ambae in 2018, produced an AOD of just 0.01.

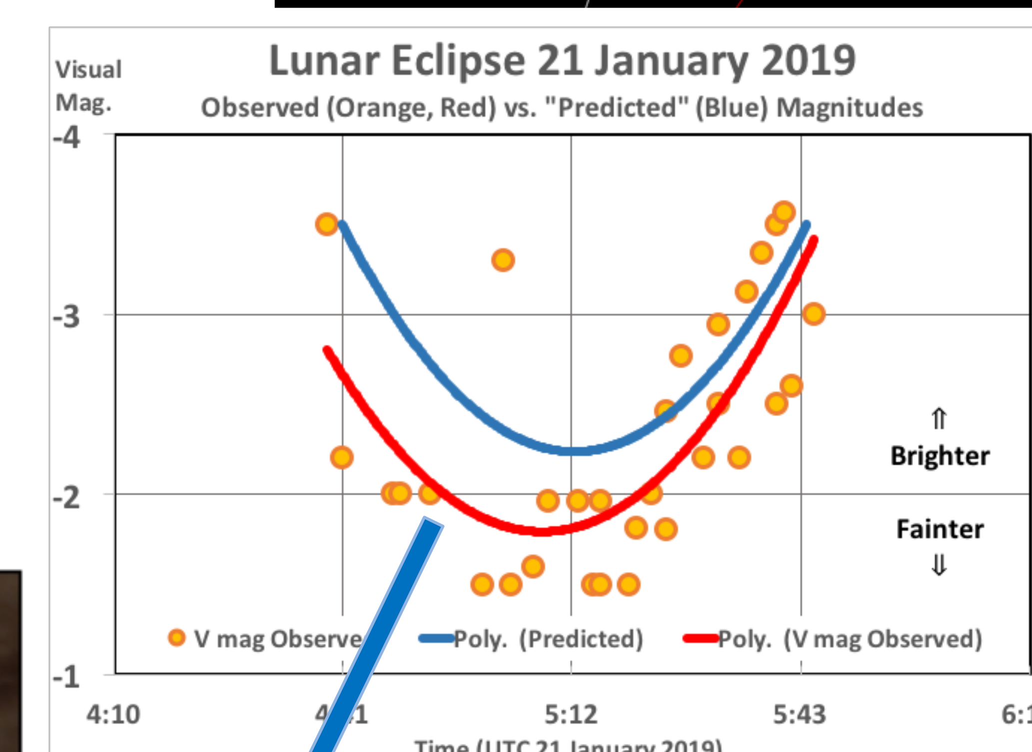
4. The average volcanic AOD for 1996–2018 is 0.002, compared to 0.041 for the previous 14 years. According to Hansen et al. (2002), this corresponds to an increase of forcing of +0.82 W/m. For comparison, forcing increase due to $CO_2$ and other GHG during the same interval is less, at +0.62 W/m2.

Figure 1. Global Volcanic Aerosol Optical Depth from Lunar Eclipse observations, 1805-2019

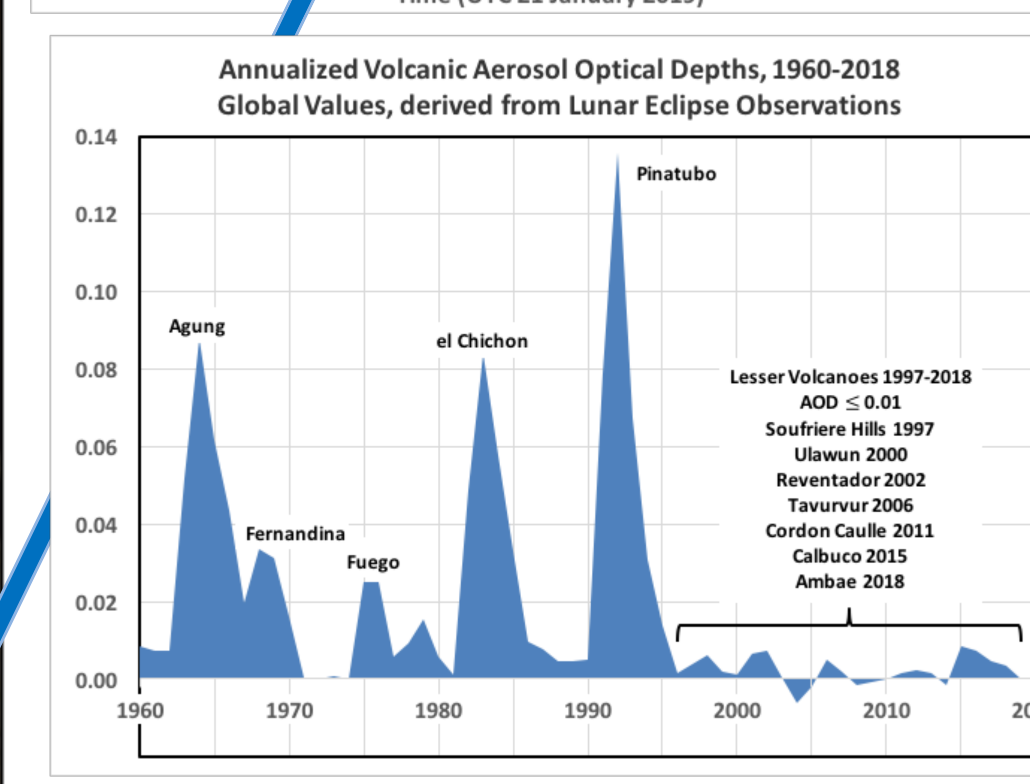



**Observed brightnesses (left) ran about half a magnitude fainter, or about 40% dimmer, than the prediction. This computes to an AOD of about 0.01, likely due to the eruption of Ambae volcano on Vanuatu 6 months earlier.**




**Since 1960 every eclipse has been observed, allowing computation of annual mean AOD.**

**After Pinatubo, relatively minor eruptions like Ambae and others have been climatologically insignificant.**

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No animals, students, or retired faculty were harmed in this research.

References:

- Hofmann et al. (2004) "Surface-Based Observations of Volcanic Emissions to the Stratosphere", in Volcanism and the Earth's Atmosphere, Geophysical Monograph 139, American Geophysical Union.
- Keen (1983) "Volcanic Aerosols and Lunar Eclipses", Science, 2 December 1983: 1011-1013. [DOI:10.1126/science.222.4627.1011] http://www.sciencemag.org/content/222/4627/1011.