The Calbuco Chronicle:

Volcanic aerosols in the post-Pinatubo stratosphere

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Background: What is a Lunar eclipse

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.

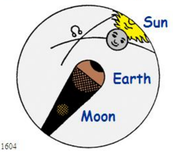
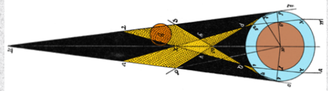


Diagram: Kepler, 1604

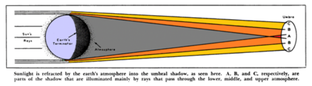
Sun light (coming from the right) is refracted (like a lens) into the Earth's umbra and onto the Moon during a lunar eclipse.
From J. Kepler, "Astronomiae pars Optica" (1604)



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.

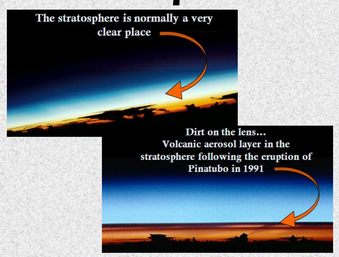
How volcanoes affect eclipses

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.

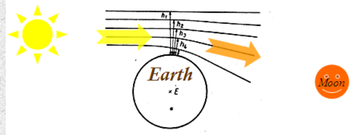


Calculating the amount of volcanic aerosol

Calculated

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.



Observed minus Calculated

After calculating the brightness of an eclipse for a clear, volcanic aerosol free atmosphere, go out and observe the eclipse. The brightness of the eclipse, in stellar magnitudes, can be observed with eye or photometer. Or, find observations in the literature.

The difference, Observed minus Calculated, is caused 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 40x the aerosol optical depth.

The volcanic record ,1880 to 2002. Krakatau, Agung, el Chichon, Pinatubo

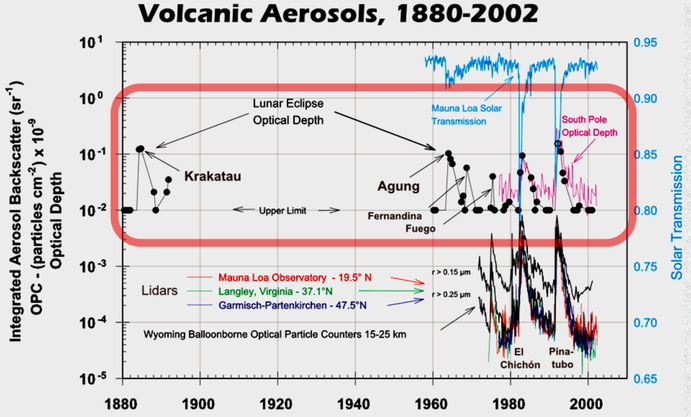


Plate 8. Summary of long-term stratospheric aerosol records….
From: Hofmann, Keen et al., 2004: "Surface-Based Observations of Volcanic Emissions to the Stratosphere", in Volcanism and the Earth's Atmosphere, Geophysical Monograph 139, American Geophysical Union

Summary Abstract

The brightness of the moon during a total lunar eclipse depends on, among other things, the presence of volcanic aerosols in the stratosphere. Following the eruptions of Agung, Chichon, and Pinatubo in 1963, 1982, and 1991, the effect was striking, and allowed accurate determination of globally averaged aerosol optical depths (AOD) from each volcano. The most recent lunar eclipse, on 28 September 2015, was seen by many observers to be about 33 percent dimmer than predicted (for an aerosol free stratosphere). While initially this slight dimming was thought to be within the range of observational error, sightings of "volcanic twilights" around the time of the eclipse suggested that the dimming was volcanic in origin.

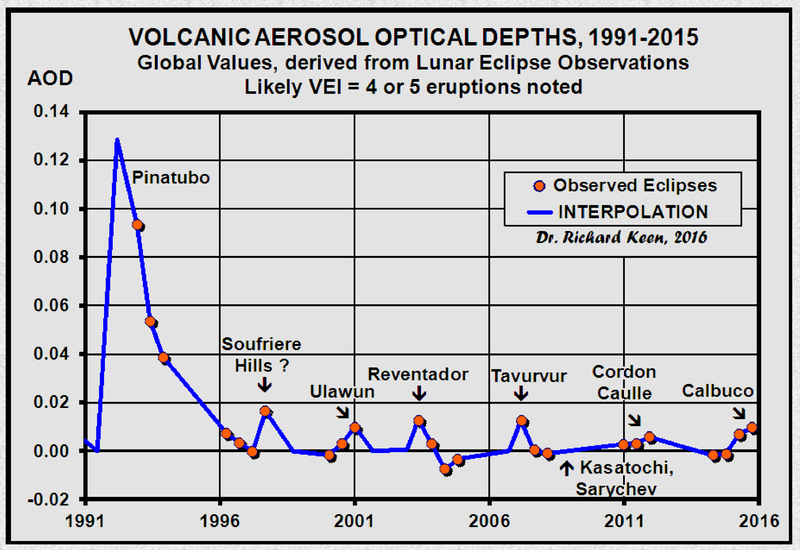
The source of the aerosols was traced to the eruption of Calbuco in Chile five months earlier. The global AOD derived from the eclipse observations, 0.010, is close to the value by Steve Albers (NOAA) derived from twilight observations.

The detection of Calbuco in the eclipse record suggests that other events with small AOD in the 0.010 range could be found (keeping in mind the likely uncertainties could be half this value). Six such events are tentatively identified in the post-Pinatubo era. It should be noted that because of the timing of lunar eclipses - with occasional gaps of two years - other similar AOD events may have "slipped through the cracks" and were not detected.

R. Keen, Volcanic Aerosol Climate Forcing, 1979-2015
www.esrl.noaa.gov/gmd/publications/annual_meetings/2015/posters/P-48.pdf
T. Phillips, Lunar Eclipse Detects Global Cooling (but only a little)
www.spaceweather.com/archive.php?view=1&day=06&month=10&year=2015
S. Albers, Volcanic Twilight Sky
laps.noaa.gov/albers/allsky/twilight_volcanic.html

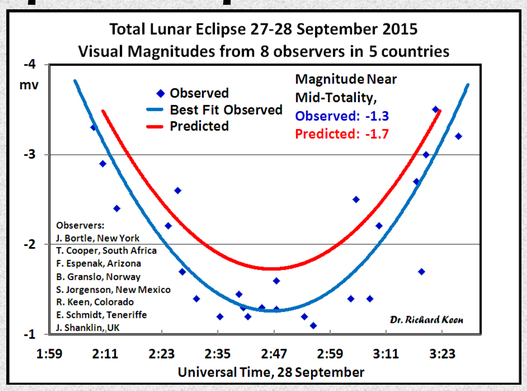
Aerosols from other volcanoes since Pinatubo

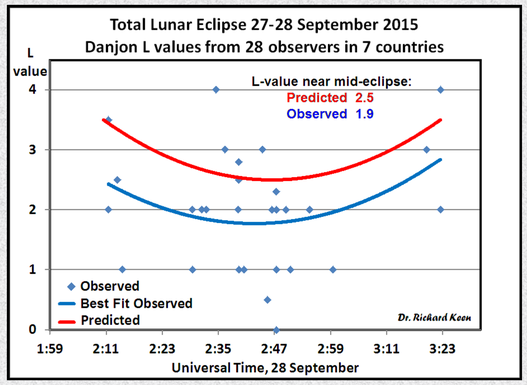
The 33 percent dimming of the September 2015 eclipse computes to a globally averaged AOD of 0.010, +/- 0.005. Identification of the enhanced AOD with Calbuco suggests that other AOD events since 1995 may be identified with similarly sized eruptions (Volcanic Explosivity Index VEI = 4 or 5)



The Lunar Eclipse of 28 September 2015

Well observed by dozens of observers on four continents. Objective visual magnitude measurements (right) and subjective Danjon scale appearance ratings (below) consistently recorded the eclipse to be slightly dimmer (about 33%) than predicted by a clear sky model.





The culprit: Volcano Calbuco in Chile

Thanks to tips from Steve Albers (NOAA) and Helio Vital (Brazil), who noted the VEI=4 eruption in April 2015 and observed volcanic twilights afterwards, suggesting the presence of a stratospheric aerosol layer.

Implications for climate: the "Pause" since 1998

Since 1998 there has been little or no warming of the surface and lower troposphere of the Earth's atmosphere. It has been suggested that this lack of warming could be due to increasing background stratospheric aerosols, or several "small" volcanic aerosol events. However, over the past 20 years, stratospheric AOD has declined by an insignificant trend of 0.002, removing stratospheric aerosols as a contender for the cause of the pause.