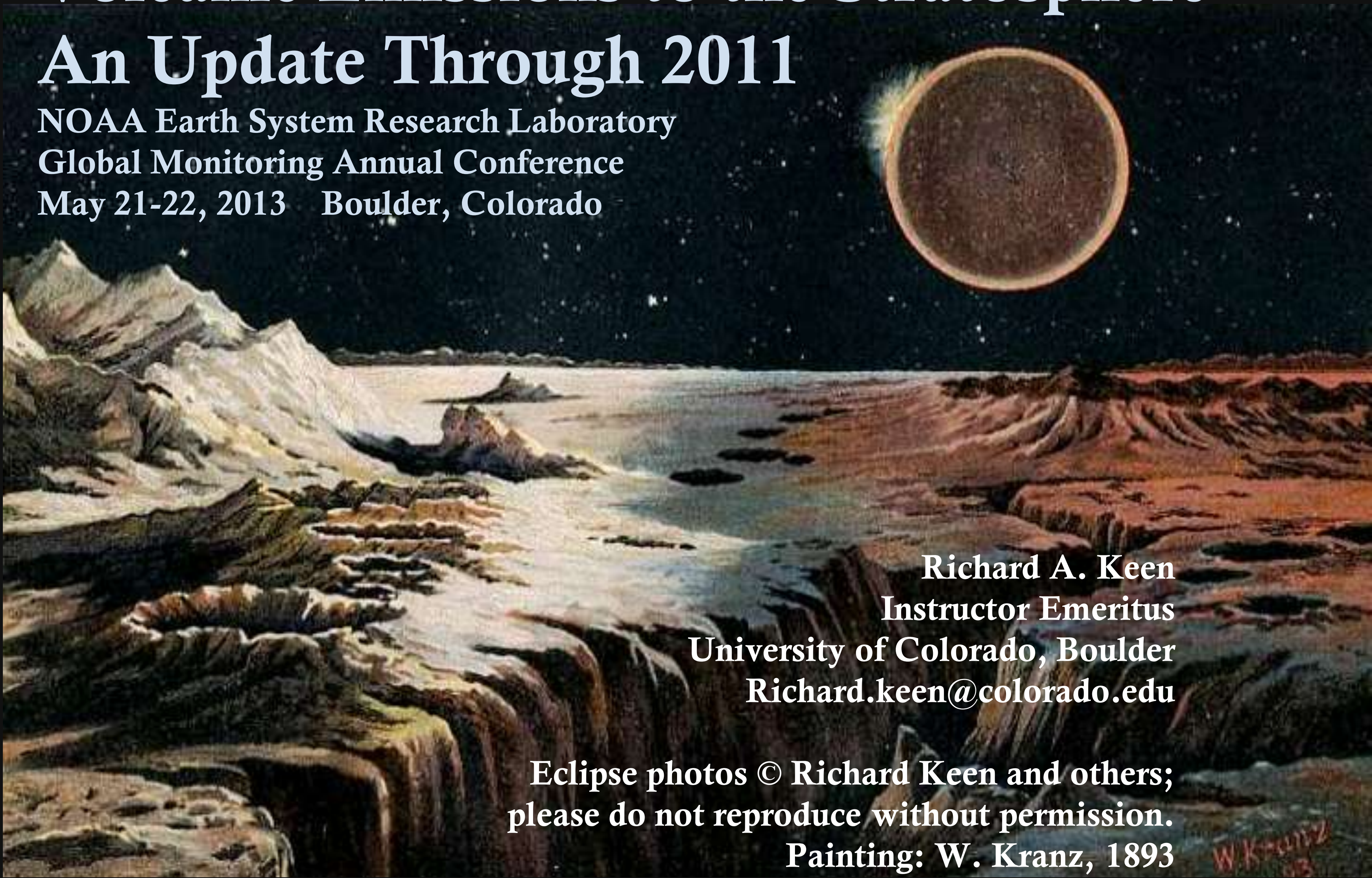
Earth (and Lunar) Based Observations of Volcanic Emissions to the Stratosphere – An Update Through 2011

NOAA Earth System Research Laboratory
Global Monitoring Annual Conference
May 21-22, 2013 Boulder, Colorado



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Painting: W. Kranz, 1893

Continuing results of the…

Lunar Aerosol Climate Experiment

LUNACE

Previous update, through 2001

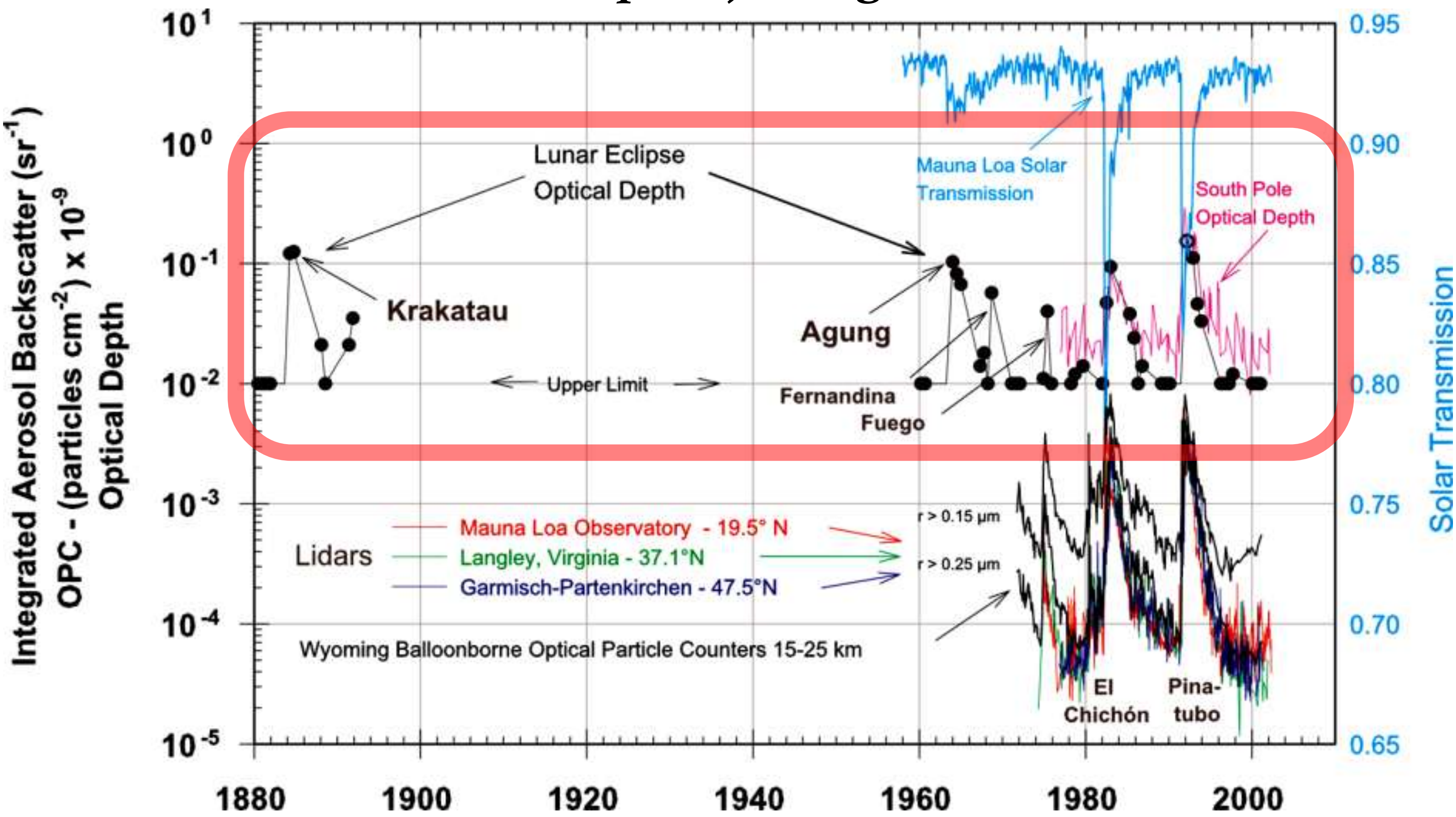


Plate 8. *Summary of long-term stratospheric aerosol records….*

From: 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

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.

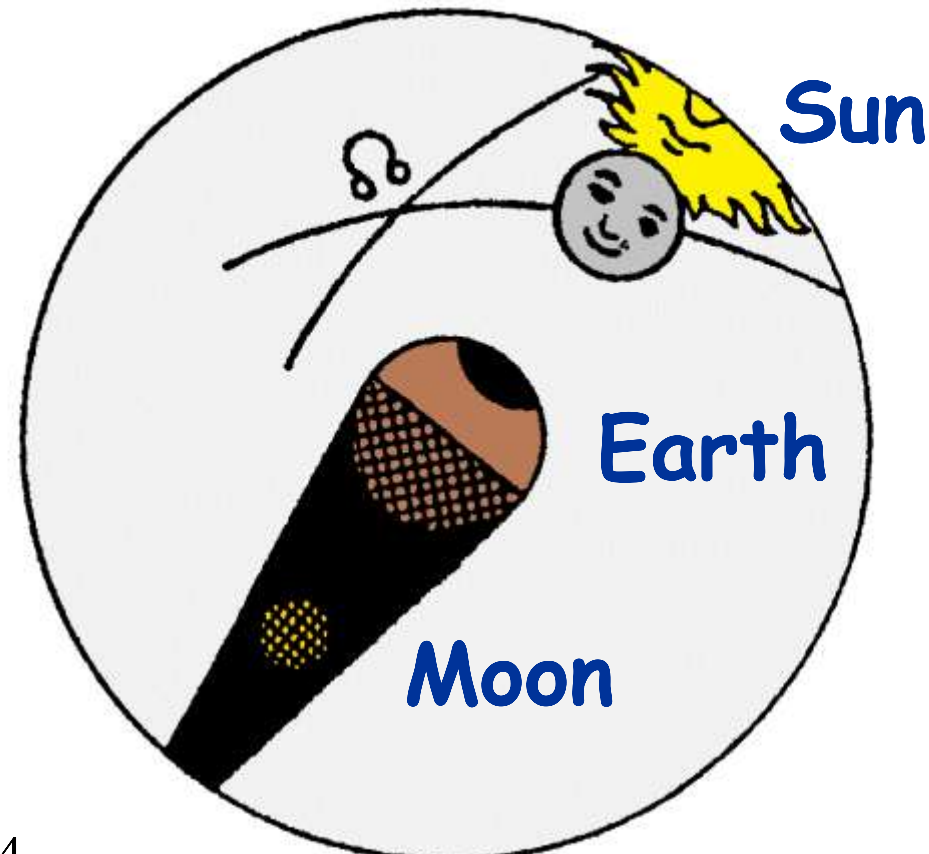
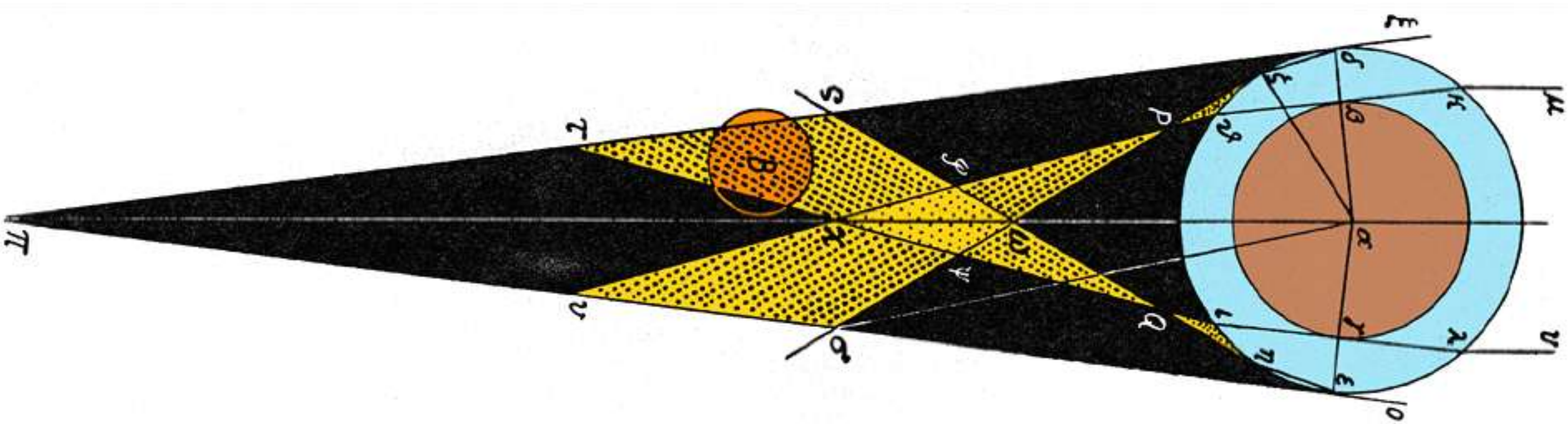


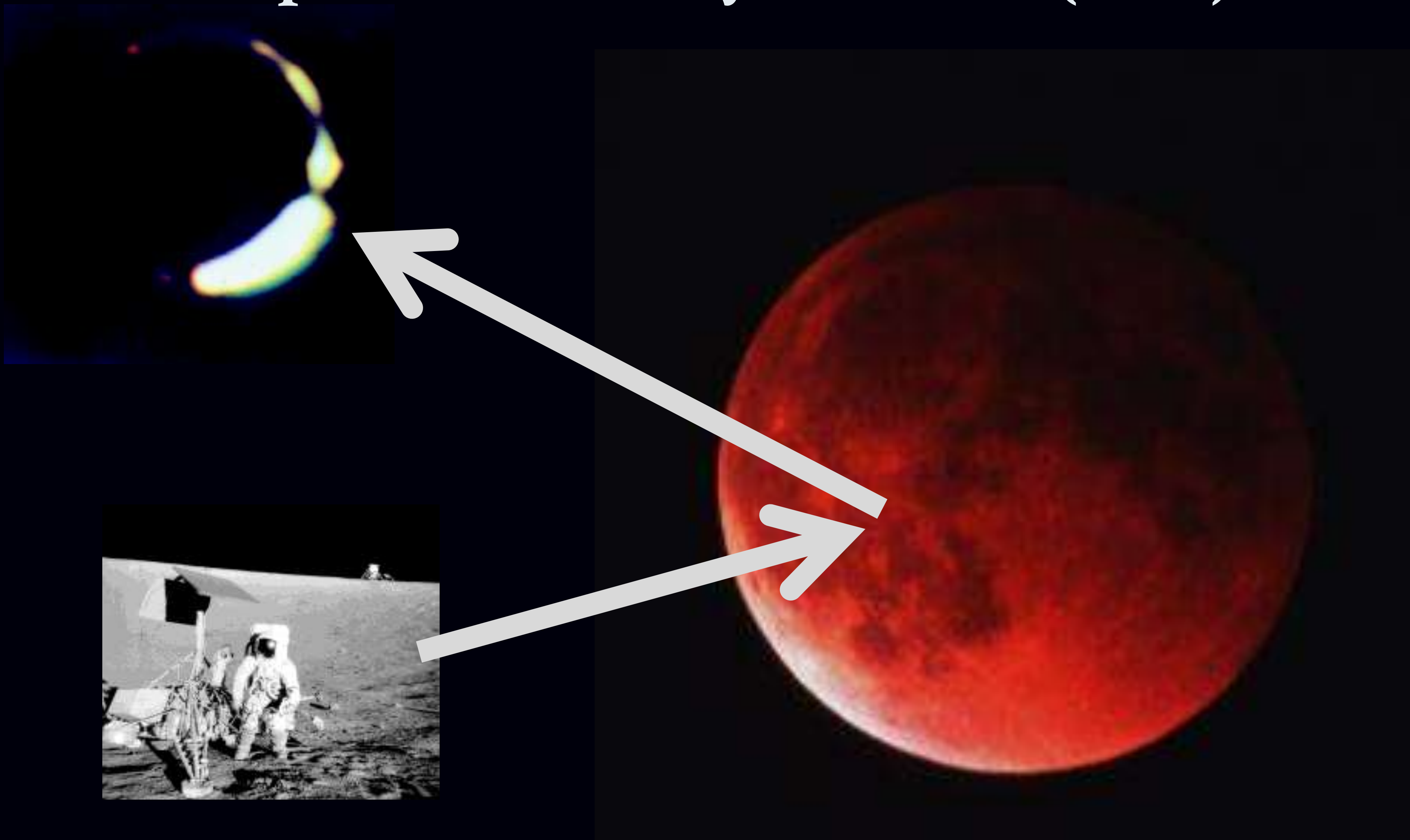
Diagram: Kepler, 1604

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)



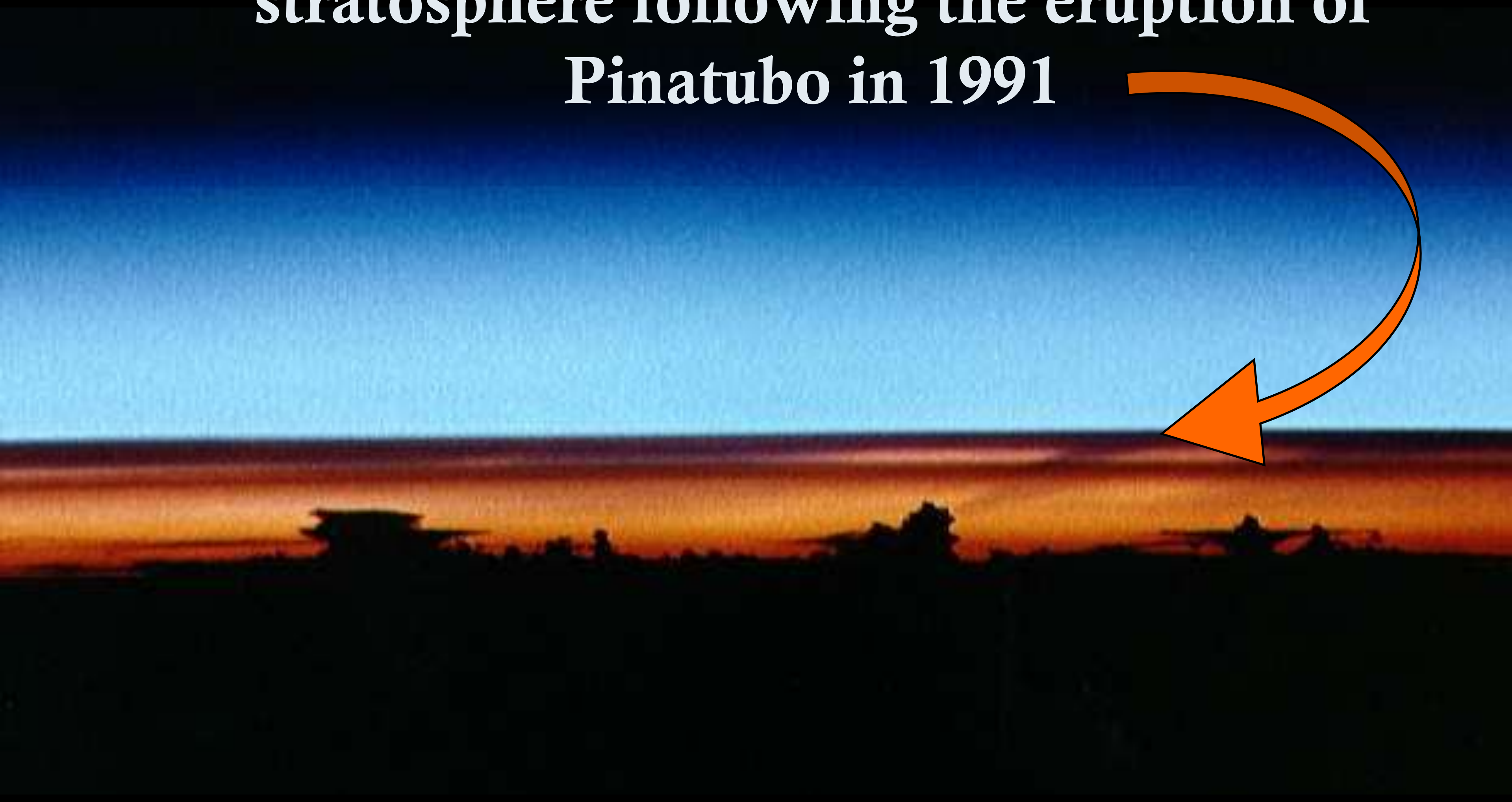
According to Kepler, sunlight is reddened & dimmed as it passes through "mists and smoke" in the Earth's atmosphere (stratosphere, mostly), causing the eclipsed moon to appear orange, red, or darker.

From Earth, we see a lunar eclipse. From the moon, Surveyor III views an eclipse of the sun by the Earth (1967)



Dirt on the lens…

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



Dark Eclipses

Dec. 9, 1992 – after Pinatubo

Dec. 30, 1982 – after El Chichon

Dec. 30, 1963 – after Agung - darkest since 1816.

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

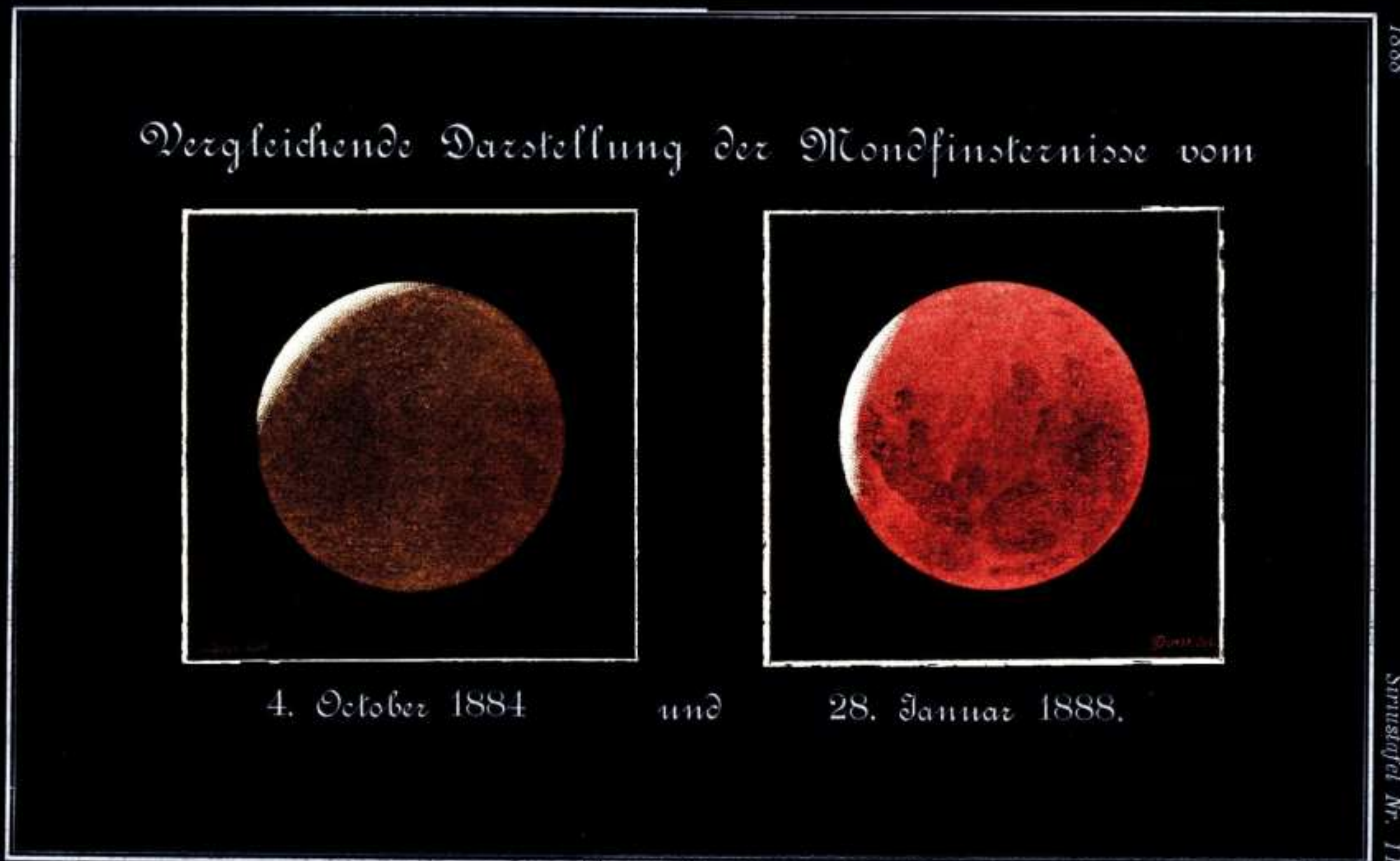
The blue is caused by ozone absorption of red light in the upper stratosphere. Light passing through the middle and lower stratosphere was absorbed by the sulfate aerosol.

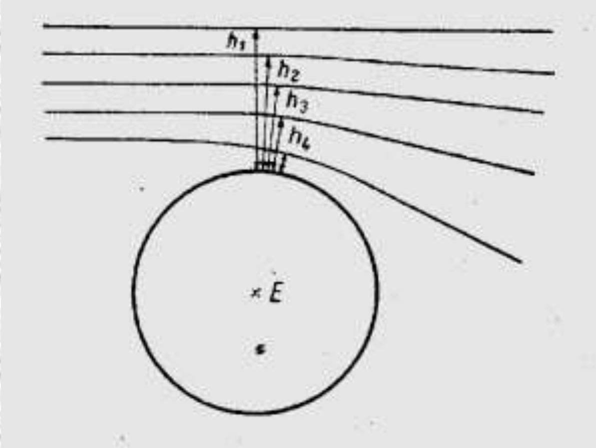
Comparison of two eclipses

1972 (clear stratosphere, left), 1982 (after el Chichon, right) taken with the same telescope, film, and exposure, by the same photographer.

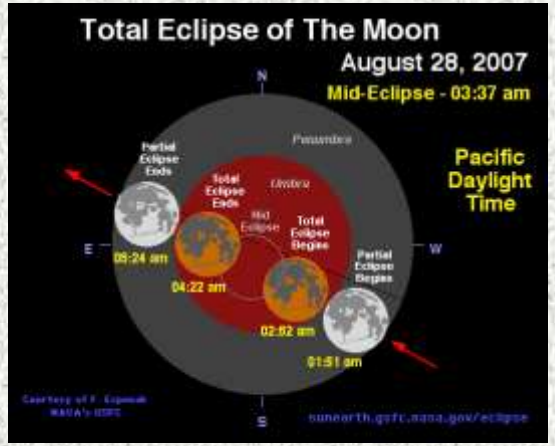
The 1972 eclipse is 400 times brighter than the 1982 "el Chichon" eclipse.

Comparison of two eclipses
1884 (after Krakatoa, left), 1888 (right)





O – C

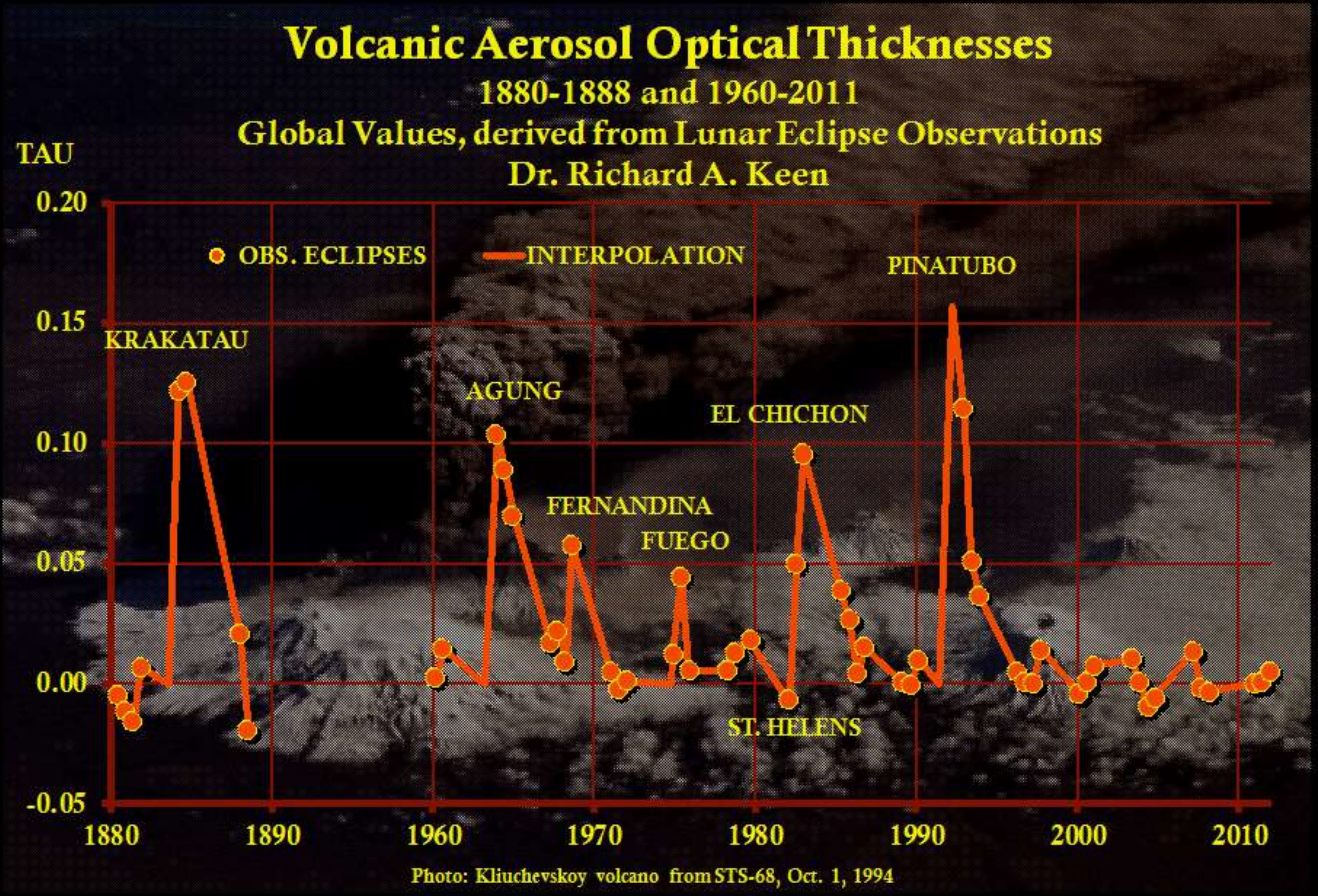


Calculate the brightness of the eclipse, using refraction, scattering, and absorption by clear stratosphere & mesosphere, and ~50% cloudiness in the troposphere. Results vary with the exact location and distance of the moon during the eclipse.

Observe the brightness of the eclipse (in stellar magnitudes) with eye or photometer (or find old observations in the literature).

Observed minus Calculated 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 40x the aerosol optical depth.


Volcanic Aerosol Optical Thicknesses
1880-1888 and 1960-2011
Global Values, derived from Lunar Eclipse Observations
Dr. Richard A. Keen
TAU
0.20
0.15
0.10
0.05
0.00
-0.05
OBS. ECLIPSES
INTERPOLATION
KRAKATAU
AGUNG
FERNANDINA
FUEGO
EL CHICHON
PINATUBO
ST. HELENS
1880
1890
1960
1970
1980
1990
2000
2010
Photo: Kliuchevskoy volcano from STS-68, Oct. 1, 1994

17- year averages: 1996-2012 minus 1979-1995

Climate forcing = –21*AOD (Hansen et al., 2002; IPCC 2001)

GHG from http://www.esrl.noaa.gov/gmd/aggi/index.html

ΔT (C) = 0.185*Δ(forcing, W/m^2), from Δ(forcing) = $\Delta(\sigma T^4)$

Aerosol Optical Depth AOD	τ	ΔT from σT^4
AOD 1979-1995	0.035	
AOD 1996-2012	0.002	
AOD change	– 0.033	
AOD forcing change	+0.71 W/m^2	+0.13 C
Total GHG forcing change (ESRL, 2012)	+0.57 W/m^2	+0.11 C
CO_2 forcing change (ESRL, 2012)	+0.41 W/m^2	+0.08 C
MMTS Global Temp.		+0.27 C

- **Some conclusions:**
- **The Globe has warmed +0.27 C over the past 34 years (first 17 years vs last 17 years).**
- **Based on simple radiative calculations (no water vapor feedbacks, etc.), the clear stratosphere after 1995 is responsible for half of this warming (+0.13 C).**
- **Increasing Total GHG can explain about ¾ of the remainder, or about +0.11 C. Of this, CO_2 contributes about +0.08 C.**
- **The combined effects of Volcanic aerosols and Total GHG are sufficient to explain most of the observed Warming with no additional feedback effects.**

Shameless plug…

"Because of its global stratospheric integrating properties, the lunar eclipse technique is perhaps the most definitive for defining the global effect of volcanic eruptions on the stratospheric aerosol."

"Observations for most eclipses exist back to about 1800. Completing this unique record of the effects of volcanic eruptions on the global stratosphere over a 200 year period is a goal worth pursuing."

- Dave Hofmann, 2004,

Surface-Based Observations of Volcanic Emissions to the Stratosphere

Goal worth pursuing: fill in the blanks

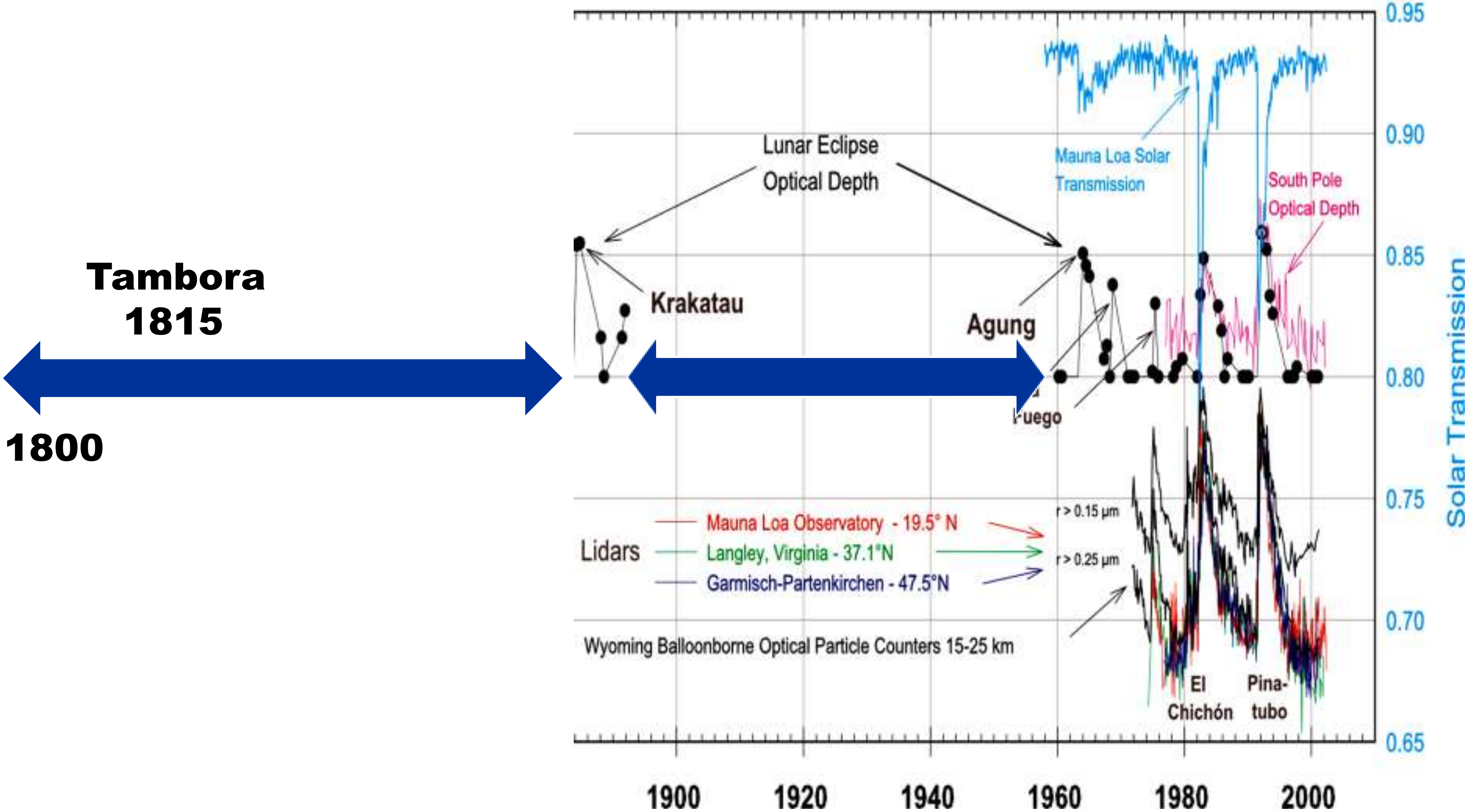


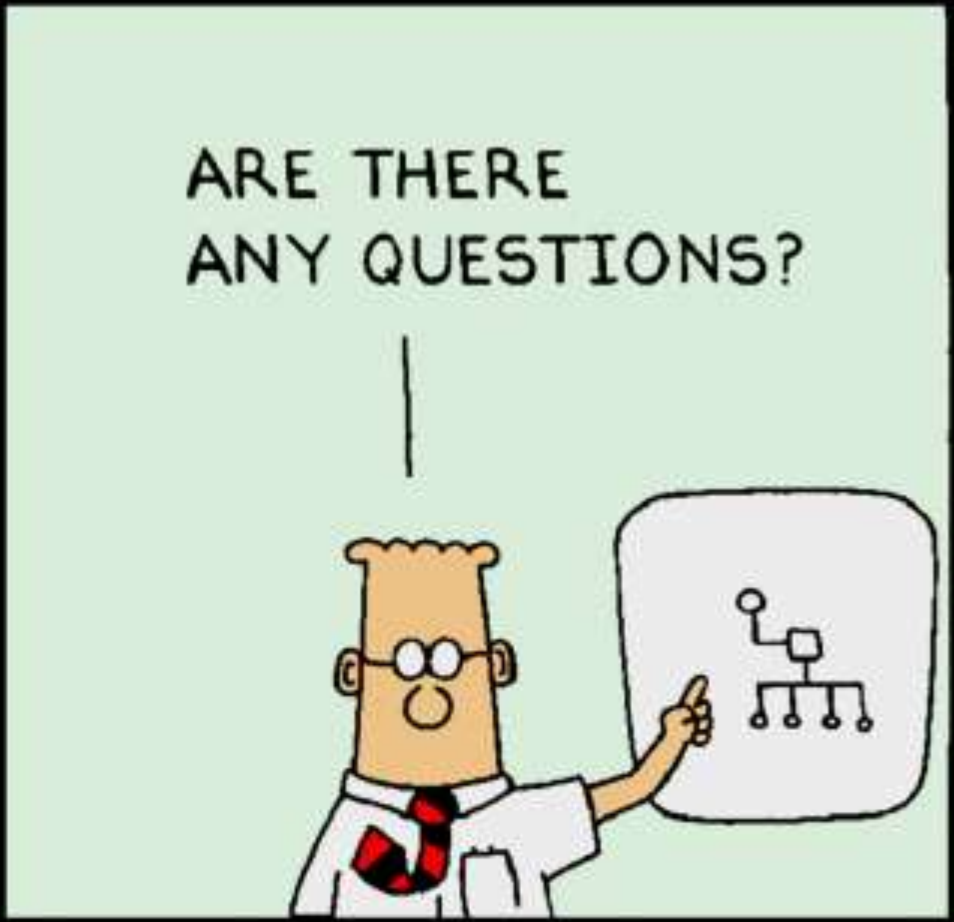
Plate 8. *Summary of long-term stratospheric aerosol records….*

From: 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

Thanks from the entire LUNACE team to eclipse observers in …

Antarctica
Australia
Brazil
Canada
Cyprus
Czech Republic
Germany
India
Iran
Italy
Japan
Jordan
Mexico
Namibia
Netherlands
New Zealand
Norway
Portugal
Russia
Saudi Arabia
Slovakia
Slovenia
South Africa
Spain
Sweden
Tanzania
United Kingdom
United States
United Arab Emirates
Venezuela

… who will help observe upcoming eclipses in 2014 (April & October) and 2015 (April & September)



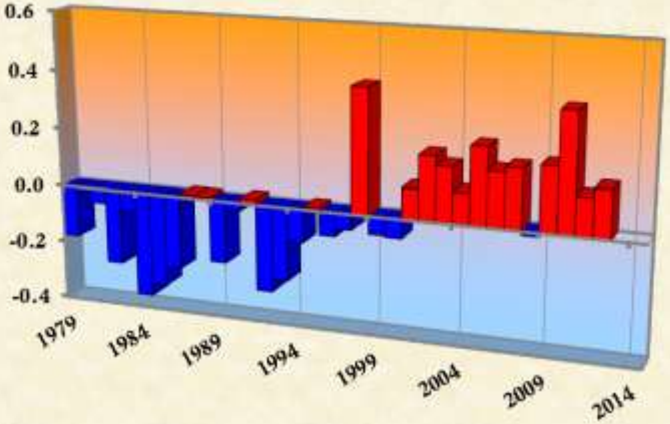
If not, enjoy these extra slides with a little more information.

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

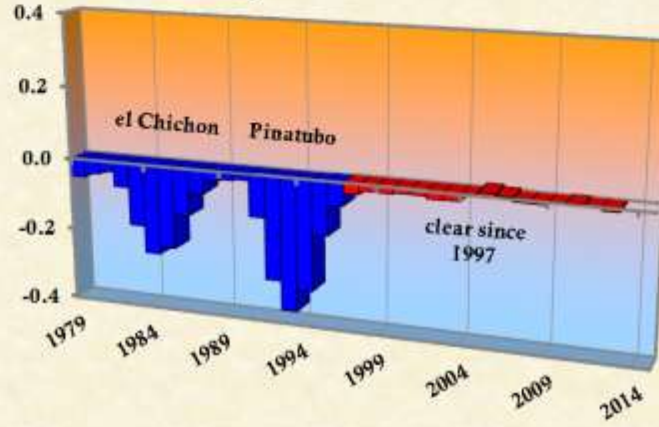
Volcano Name	Major Eruption Date	Volcanic Explosive Index *	Max Optical Depth
Krakatau	**1883-08-27**	**6**	**0.13**
Agung	**1963-03-17**	**4**	**0.10**
Fernandina	**1968-06-11**	**4**	**0.06**
Fuego	**1974-10-10**	**4**	**0.04**
El Chichón	**1982-04-03**	**5**	**0.09**
Pinatubo	**1991-06-15**	**6**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

* *Simkin and Siebert* [1994]

MSU Global Temperatures, 1979 to 2012
degrees C relative to 34-year mean.

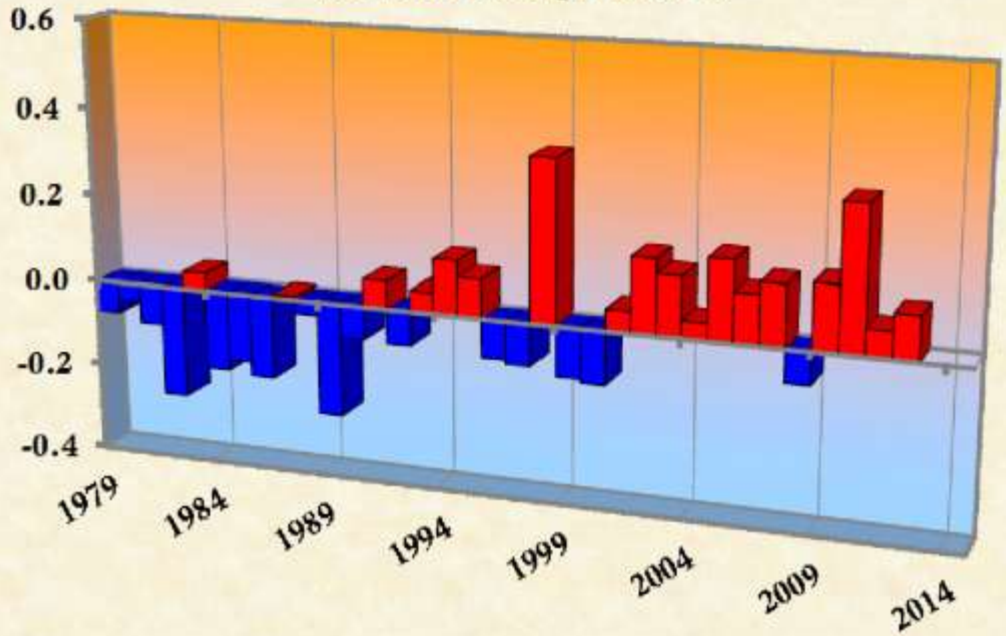


Volcanic cooling from el Chichon (1982)
and Pinatubo (1991), degrees C. 3-year smoothed.
Scaling factor: 3.87C for Tau = 1.0



MSU Global Temperatures minus calculated volcanic cooling

MSU Global Temperatures, 1979 to 2012
degrees C relative to 34-year mean.
Volcanic cooling removed.



An eclipse may occur more than a year after an eruption. Volcanic Optical Depth (Tau) can be extrapolated backward using this composite decay curve.