How the Rate of Volcanism Initiated the Medieval Warm Period and Controlled Its Periods of Drought

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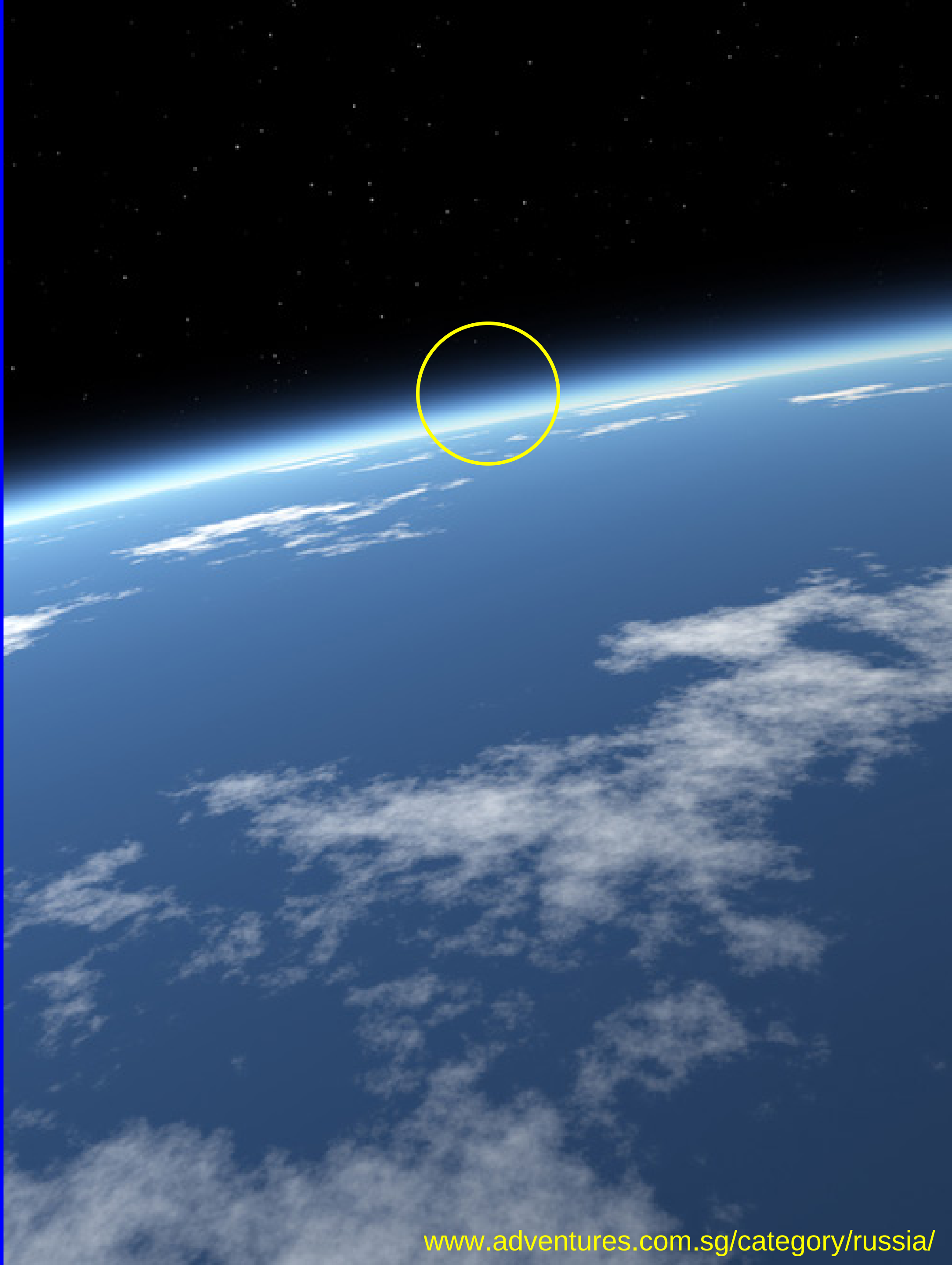
Earth's atmosphere is a thin blanket that warms the Earth.

99% of the air is within 30 km of the earth's surface

0.5% of the earth's radius

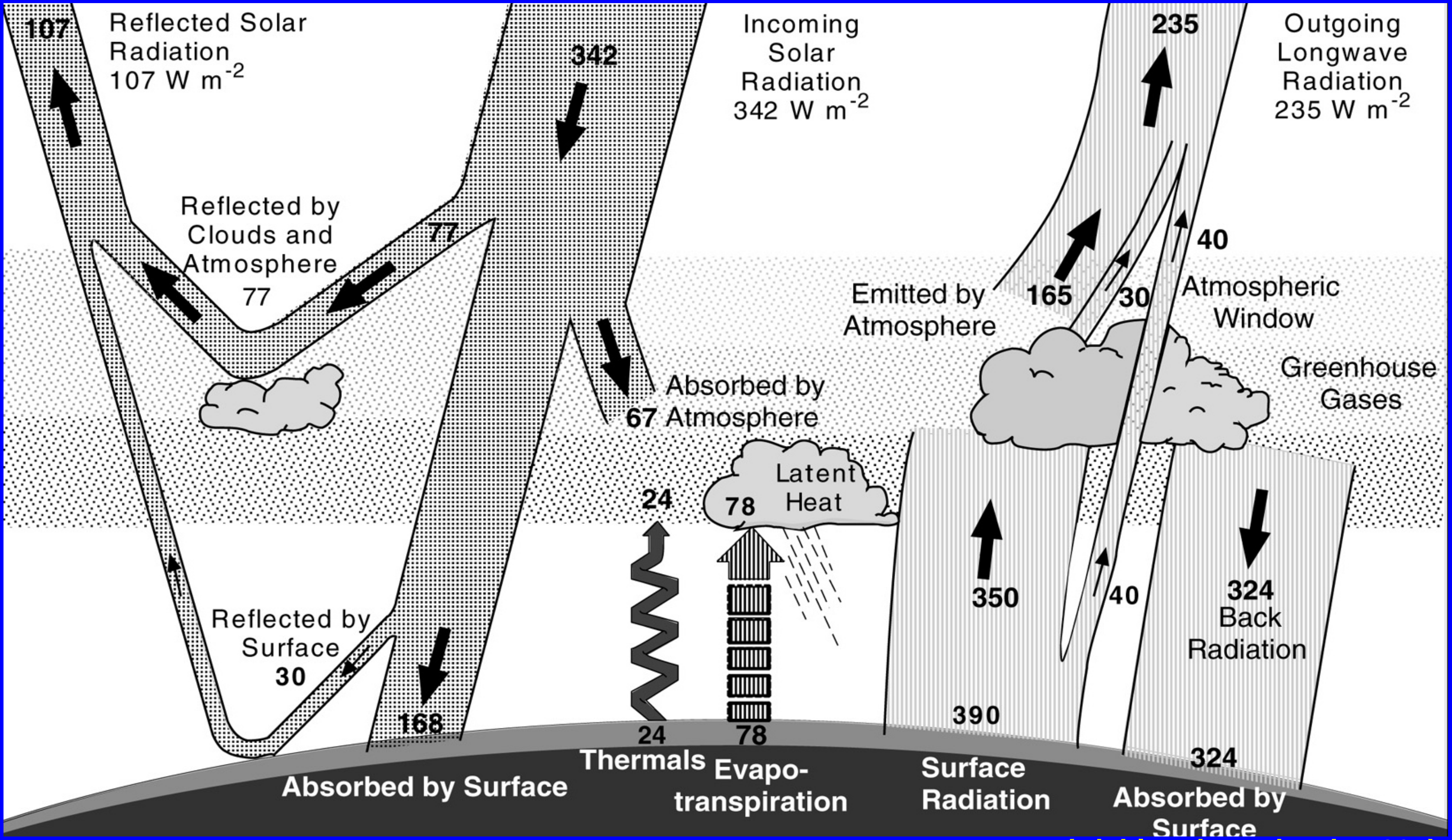
If no atmosphere, then the surface temperature would be -19^{o}C (-2^{o}F)



www.adventures.com.sg/category/russia/

Small changes in gas chemistry and cloud content can modulate large changes in solar and radiated energy flow.

Incoming Solar Radiation = Outgoing Reflected Solar + Longwave Radiation



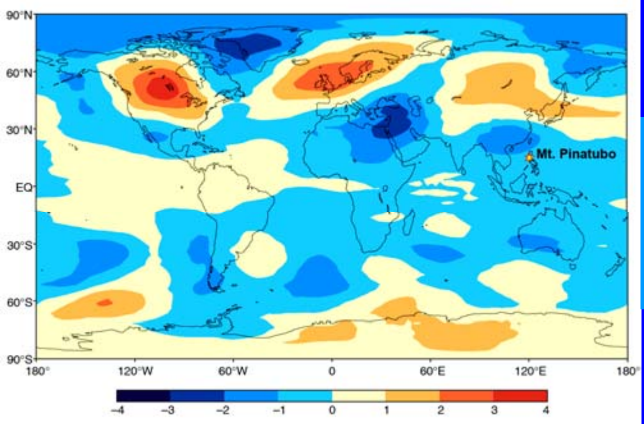
(Kiehl and Trenberth, 1997)

An occasional large volcanic eruption cools the Earth for several years but uses up ozone.

Pinatubo (1991) (VEI = 6), the largest volcanic eruption in 87 years,

Erupted 20 Mt SO_2 and 491 Mt H_2O forming an aerosol layer between 20 and 23 km high that was 99% pure H_2SO_4 and H_2O

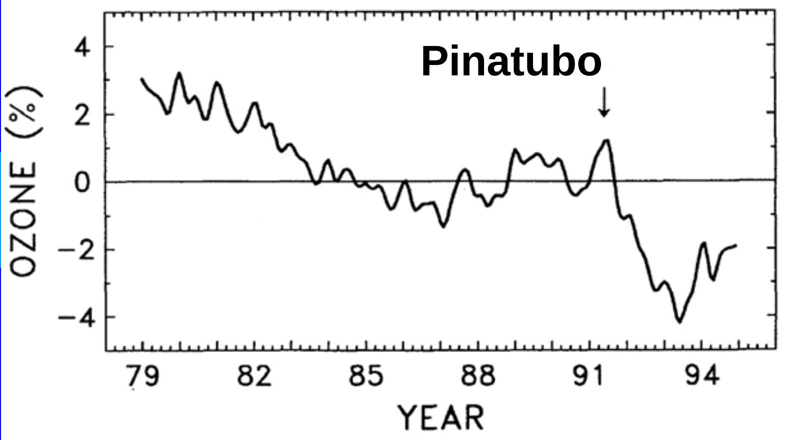
The aerosol reflected sunlight, lowering world temperatures 0.4°C over 3 years with some winter warming over continents.



Temperature changes in the lower troposphere during first winter after the eruption (Robock, 2002)

Reducing Ozone to lowest known level since satellite measurements began

TOMS Satellite global mean anomaly less Quasi-Biennial-Oscillation (Randel et al., 1995)



$$\frac{\text{Mass } SO_2 + H_20}{\text{Mass Atmosphere}} = \frac{20 + 491}{5.15 * 10^9} = 99.3 \text{ ppb}$$

The oxidizing capacity of the atmosphere is limited.

1. Pollutants of the atmosphere are removed primarily by oxidation and then rain

2. Oxidation is caused primarily by OH, H_2O_2 and O_3, which are in limited supply

3. OH forms primarily from ozone by photodissociation in the near-ultra-violet

$O_3 + hv \rightarrow O(^1D) + O_2$

$O(^1D) + H_2O \rightarrow OH + O$ (Thompson, 1992)

4. Oxidation of SO_2 is limited primarily by availability of OH and H_2O

$SO_2 + OH + M \rightarrow HOSO_2 + M$

$HOSO_2 + O_2 \rightarrow SO_3 + HO_2$

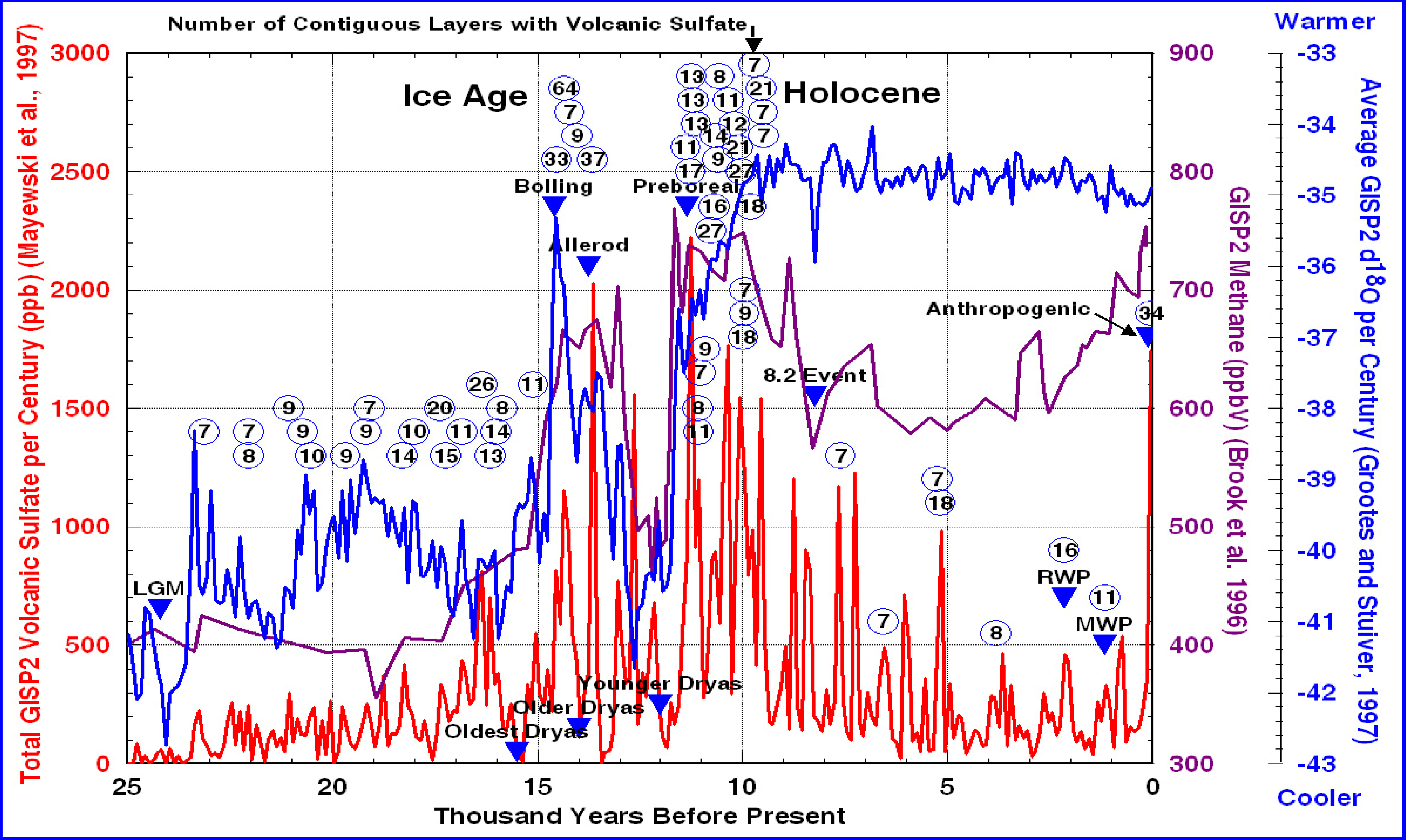
$SO_3 + H_2O \rightarrow H_2SO_4$ (Coffey, 1996)

5. Pinatubo e-folding time for this reaction = 35 days (Bluth et al., 1992)

6. Atmospheric methane is inversely proportional to oxidizing capacity

$CH_4 + OH \rightarrow CH_3 + H_2O$ (Lifetime 9.6 years) (Wikipedia/Methane)

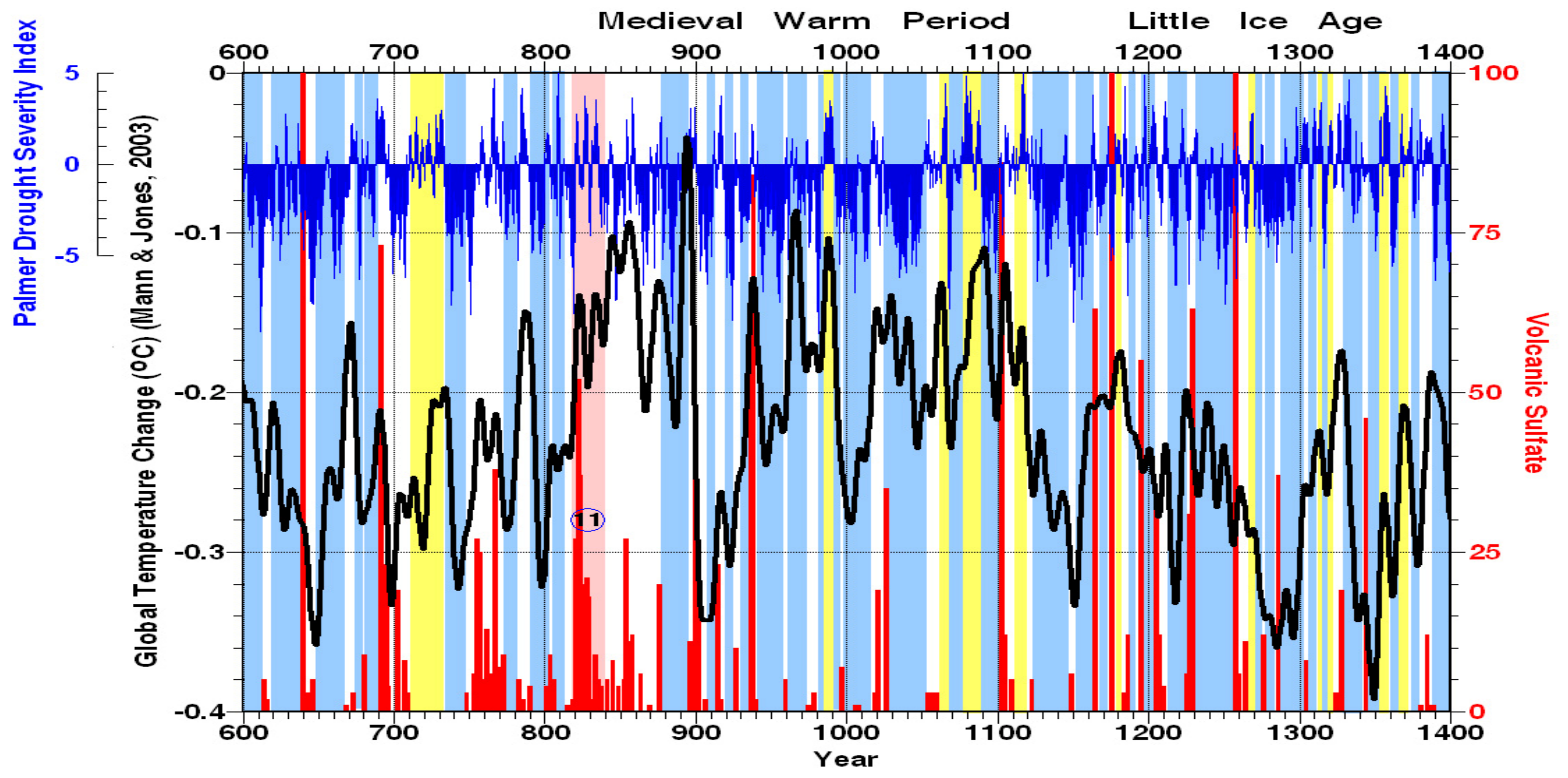
Periods of greatest global warming coincide with times when seven or more contiguous layers of snow in Greenland contain volcanic sulfate.



1. Onset of Medieval Warm Period coincides with 11 contiguous layers of volcanic sulfate from 818.2 to 837.8 = 19.6 years.

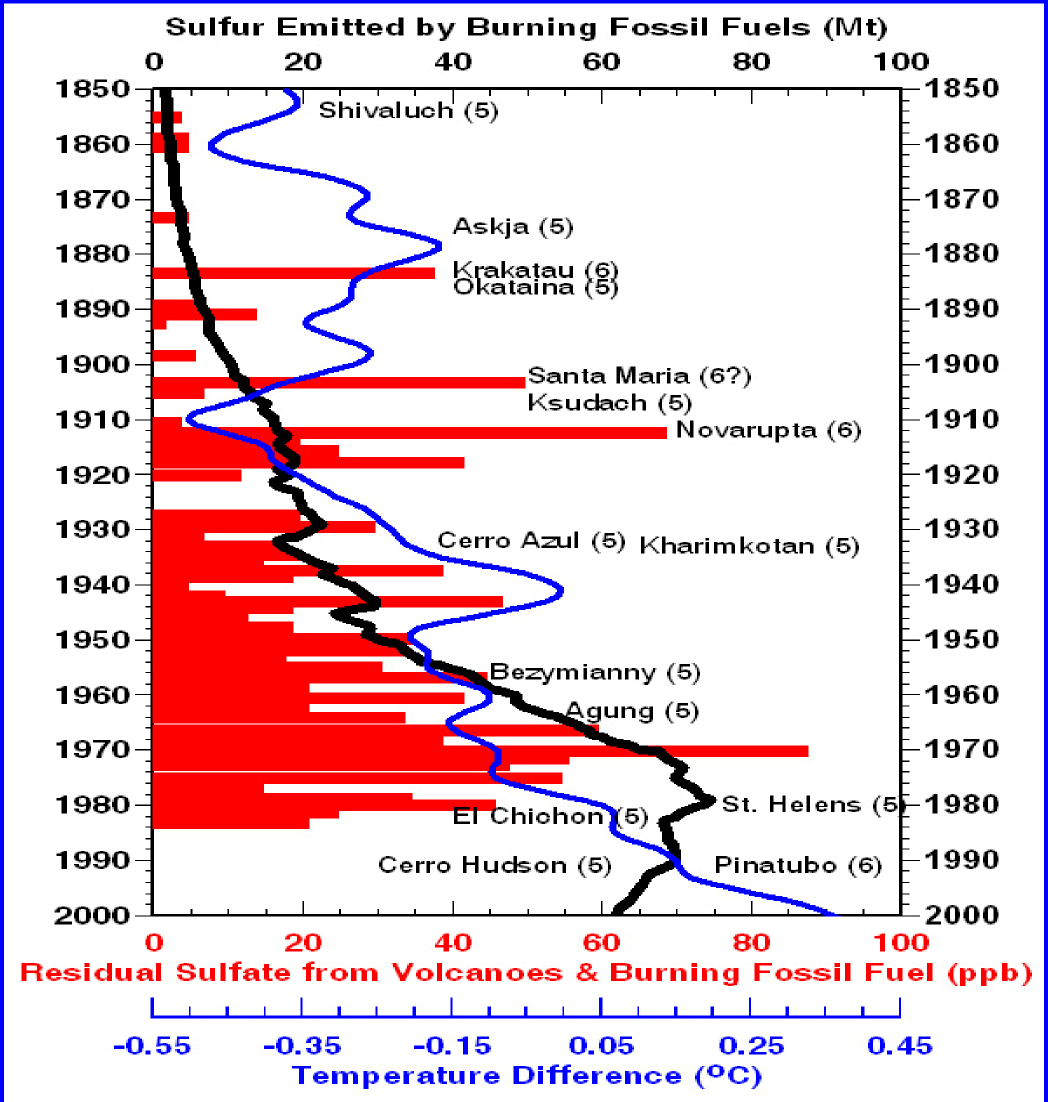
2. Most large volcanic eruptions are followed by cooling for a few years.

3. Most periods of no volcanic activity (blue) coincide with periods of prolonged drought. Exceptions are shown in yellow.



PDSI for SE Utah, North American Drought Atlas, Cook & Krusic, 2004

Sulfur emitted by humans burning fossil fuels is depositing sulfate in Greenland equivalent to one major volcanic eruption per year.



Sulfur Emitted by Burning Fossil Fuels (Smith et al., 2004)

Global Temperature Changes (Brohan et al., 2006)

Volcanic Sulfate GISP2 (Mayewski et al., 1997)

Volcanic Eruptions (VEI) (Simkin & Siebert, 1994)

The Four Cardinal Rates of SO_2

	Rate of SO_2 Emission	Eruption Rate	Effect	Cause
1	**Low**	No large eruptions for decades	Cooling and decadal droughts	Lack of significant SO_2 allows the oxidizing capacity of atmosphere to be restored, purging all greenhouse gases and pollutants, reducing the insulating capacity of the atmosphere and inhibiting rain.
2	**Moderate**	1 large eruption (VEI>=6) every few decades or longer	Cooling	Erupted SO_2 forms sulfuric acid layer in the lower stratosphere, reflecting heat from the sun typically for three years
3	**High**	More than 1 large eruption each year for decades	Global warming	Erupted SO_2 uses up the oxidizing capacity of the atmosphere causing greenhouse gases and other pollutants to accumulate
4	**Extreme**	More than 100,000 large flood basaltic eruptions in less than one million years	Extreme global warming and mass extinctions	Erupted SO_2 causes extreme global warming and acid rain over tens of thousands of years

3. High rates correlate uniquely with the onset of the Roman, Medieval, and Current Warming Periods as well as the end of the Ice Age.

2. Moderate rates correlate with cooling for a few years after single eruptions.

1. Low rates correlate with major droughts in southeastern Utah.

Role of El Niño, La Niña, and other ocean currents.   Need for detailed modeling.

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