How Volcanism Controls Climate Change

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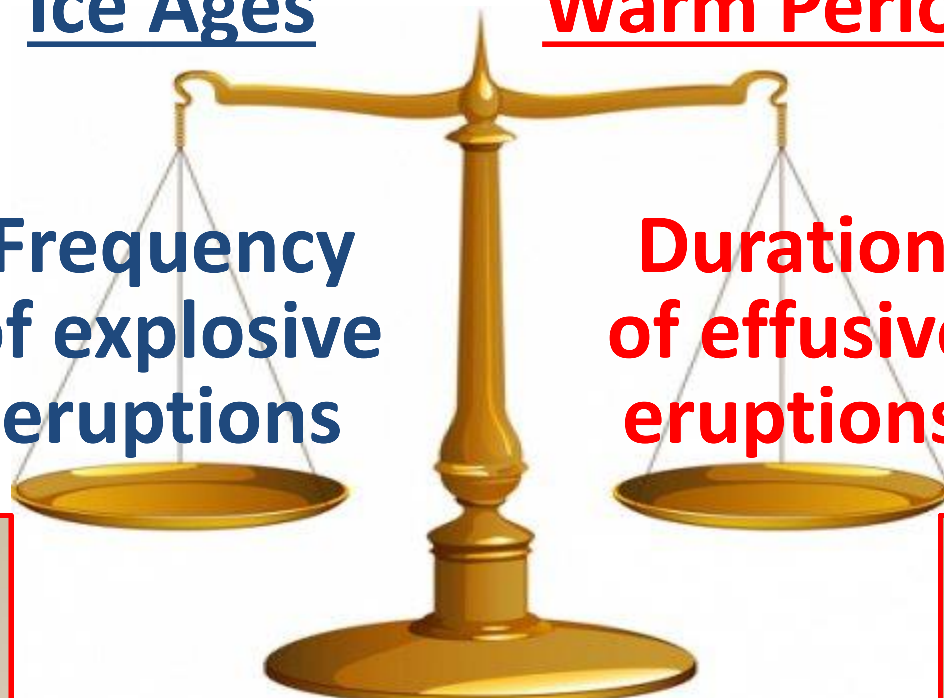
Fundamental Conclusion

Large, explosive, volcanic eruptions cool Earth
Small, effusive, basaltic eruptions warm Earth

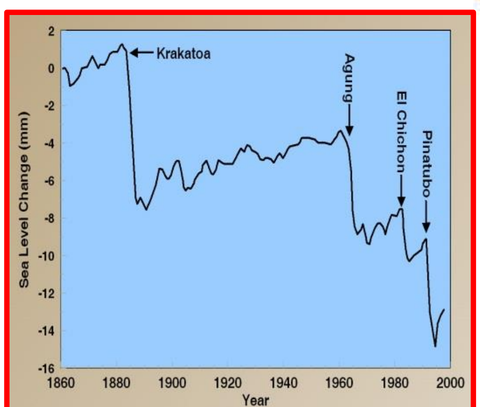
Ice Ages

Warm Periods



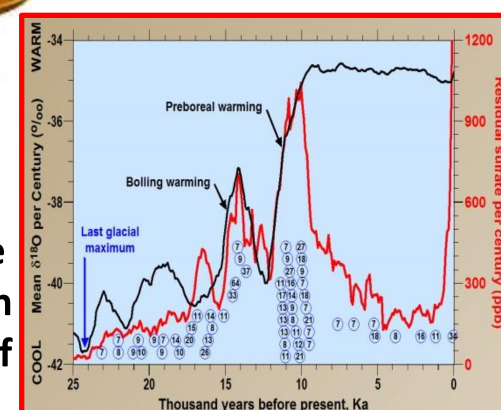
Frequency of explosive eruptions

Duration of effusive eruptions

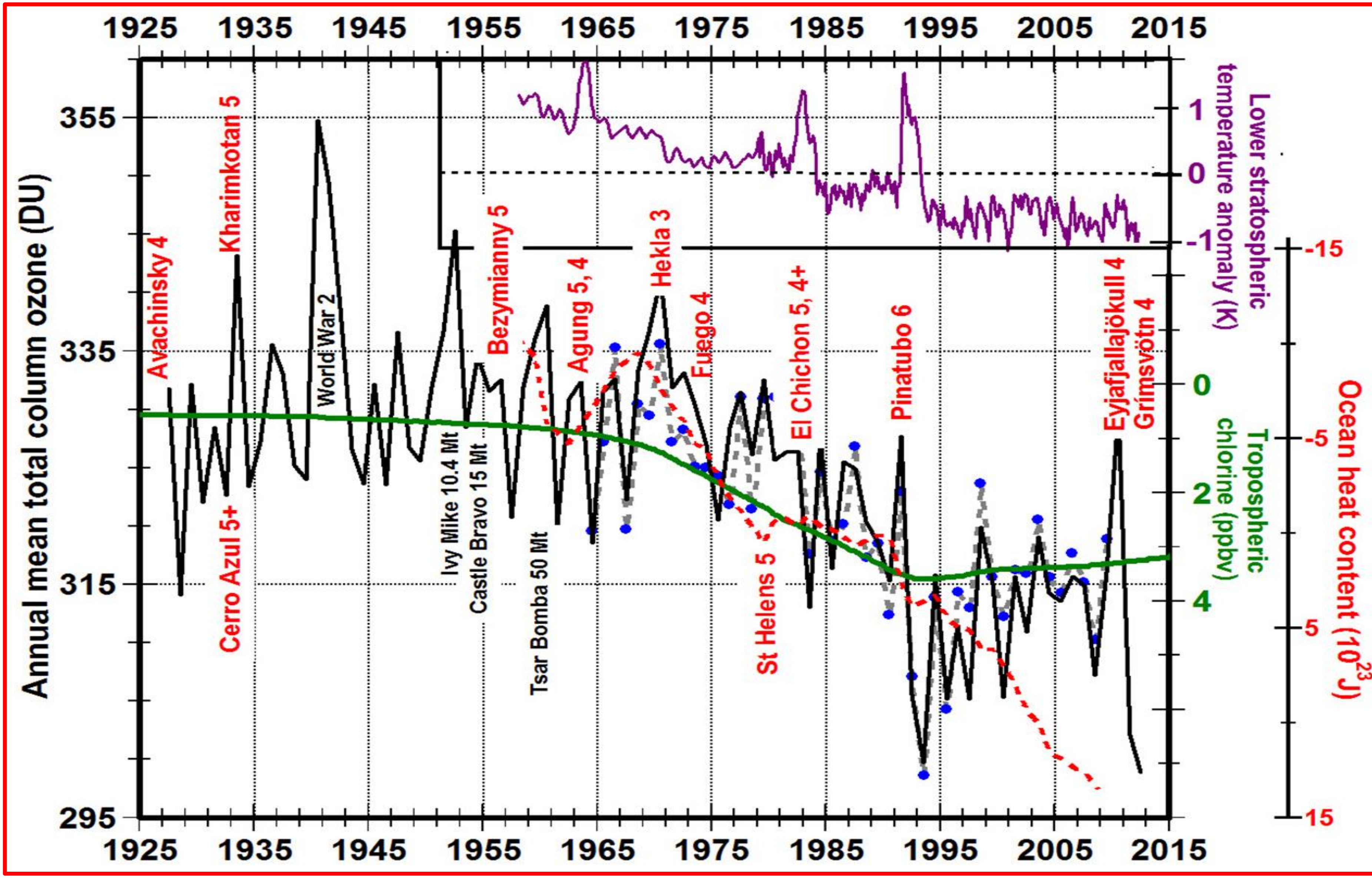


Cumulative effect of explosive eruptions on ocean temperature modeled as sea level

Continuous effusive basaltic volcanism in Iceland at the end of the ice age



(1) Humans depleted stratospheric ozone ~3% for a century
Each volcanic eruption depletes ozone ~6% for a decade



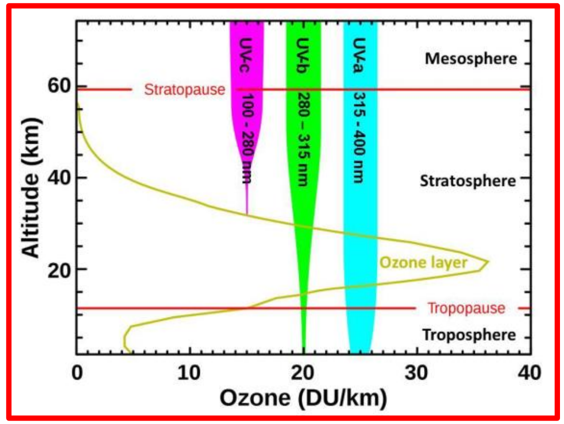
(2) Ozone depletion allows more UV-b to warm Earth

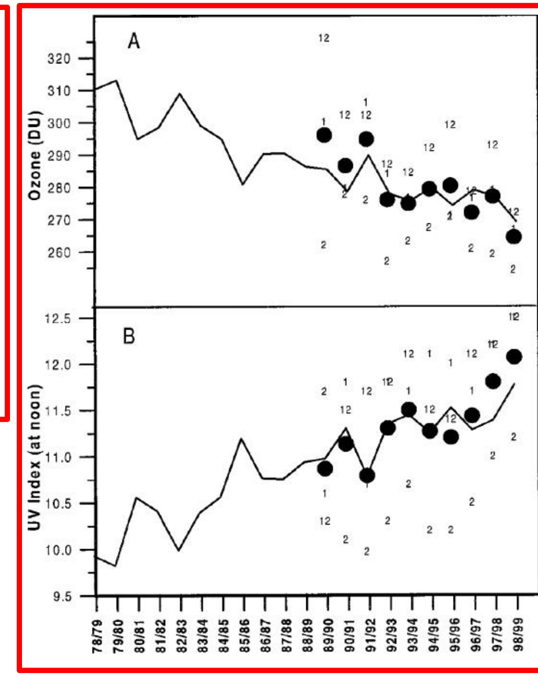
Ozone depletion:

a) Cools the lower stratosphere (purple line above)

b) Raises the height of the tropopause

c) Warms the ocean





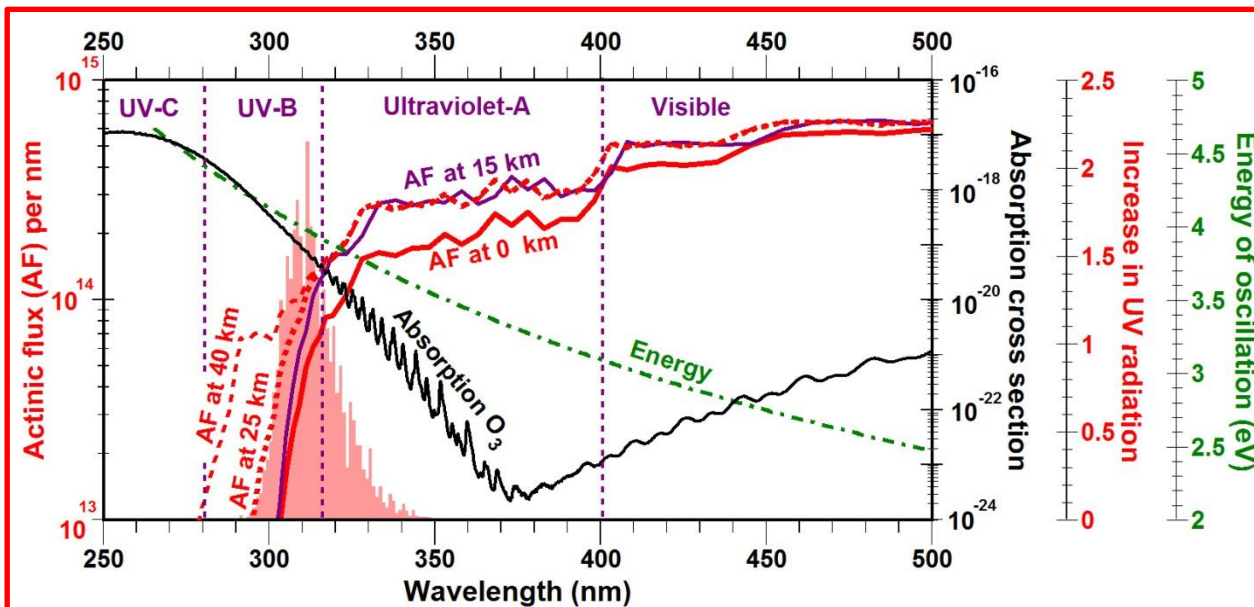
Observed decrease in ozone and increase in the ultraviolet index at noon in Lauder, New Zealand

McKenzie et al. (1999)

A 50% decrease in total column ozone increases the amount of ultraviolet radiation reaching Earth's surface by ~2 W m^{-2} between 290 and 340 nm (red shaded area) when Sun is directly overhead

AF = actinic flux of solar radiation at altitudes of 0, 15, 25, and 30 km

Madronich (1993)

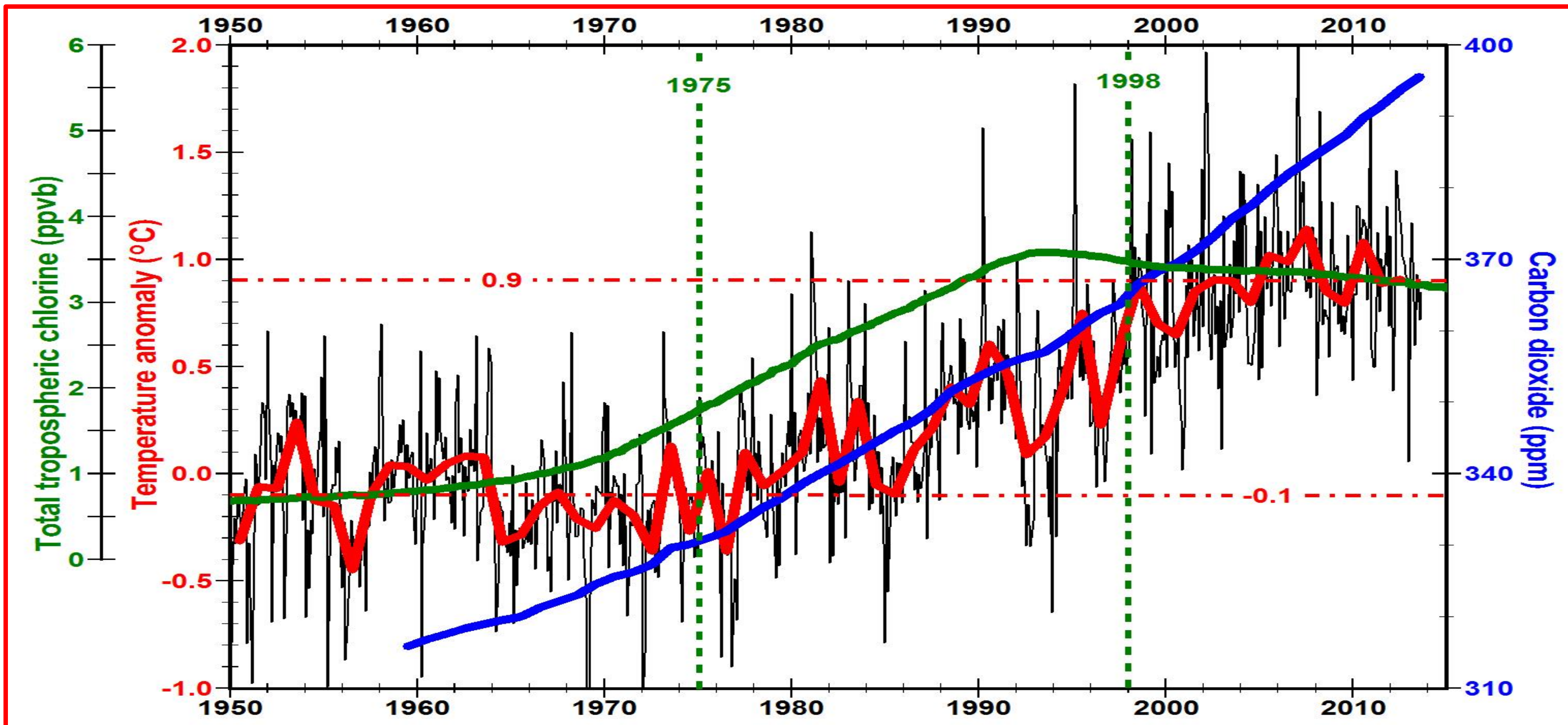


(3) 3% depletion of ozone by humans appears to have caused global warming of up to 1°C 1975-1998

a) Anthropogenic chlorine (green line) increased rapidly between 1970 and 1992 when the Montreal Protocol led to decreased production

b) Mean monthly (black line) and annual (red line) temperatures in the northern hemisphere (HadCrut4-NH) rose 1°C between 1975 and 1998

c) Meanwhile, CO_2 has been increasing at increasing rates for more than a century



(4) Large, explosive eruptions form aerosols in the stratosphere cooling Earth ~0.5°C for ~3 years

But also deplete ozone leading to warming during mid to late winter

Lower tropospheric temperature anomalies from December 1991 to February 1992 after the eruption of Mt. Pinatubo in June 1991

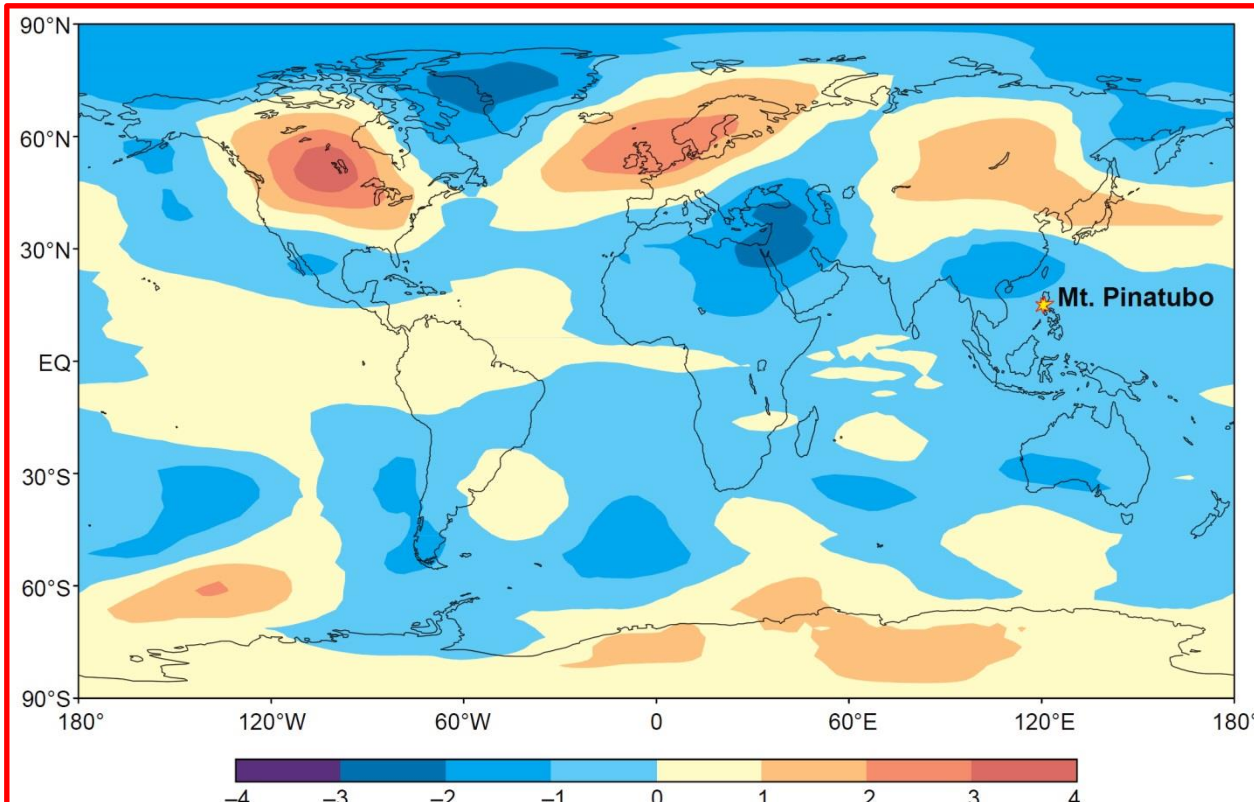
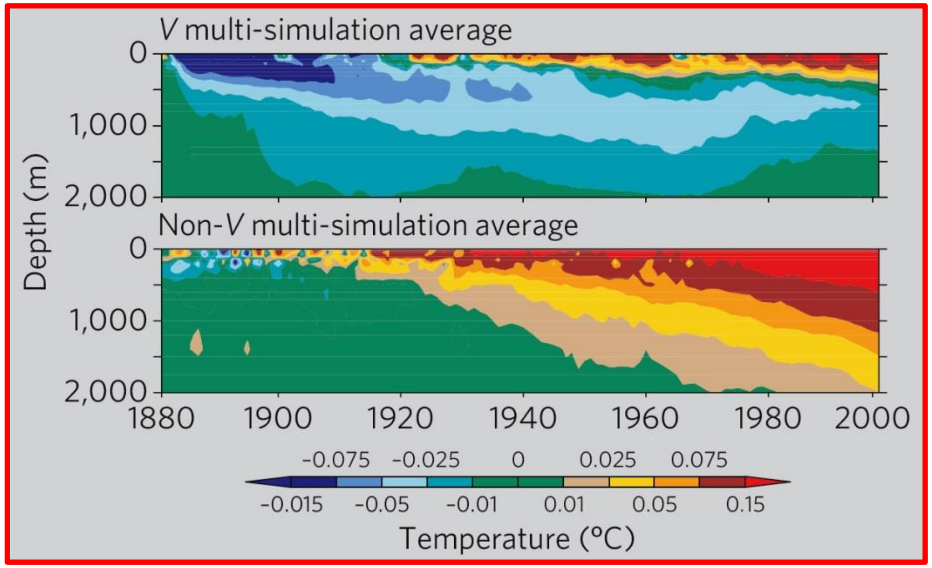


Figure from Robock, 2002

(5) Large eruptions every decade or so increment Earth into ice ages

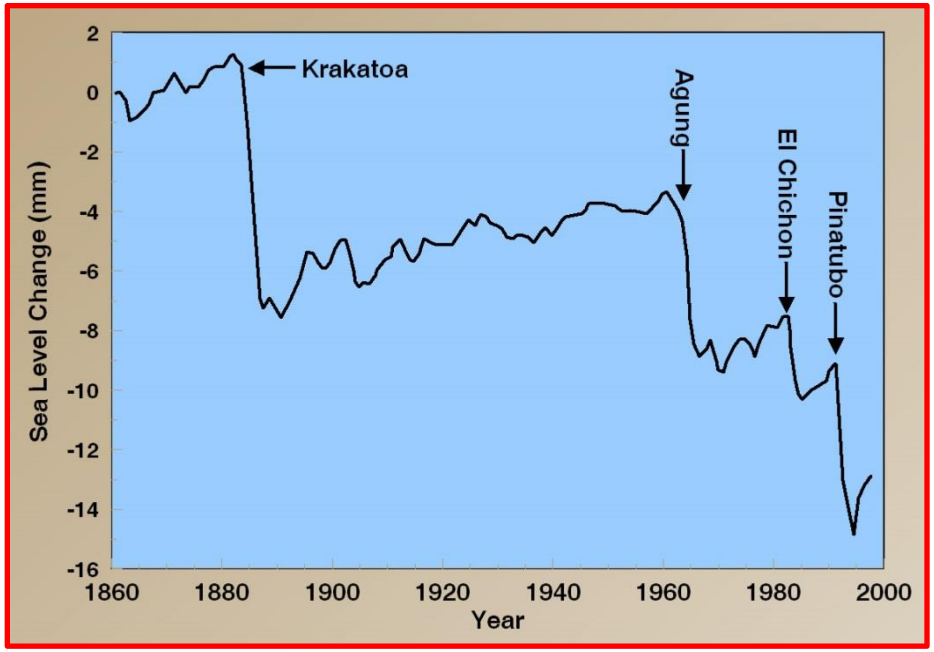
Atmospheric cooling following eruption of Krakatoa in 1883 persists in modeled ocean temperatures for a century shown with (upper) and without (lower) volcanic forcing

Gleckler et al., 2006



Modelled annual global-mean sea level change due to cooling following 4 major volcanic eruptions

Gregory et al., 2006



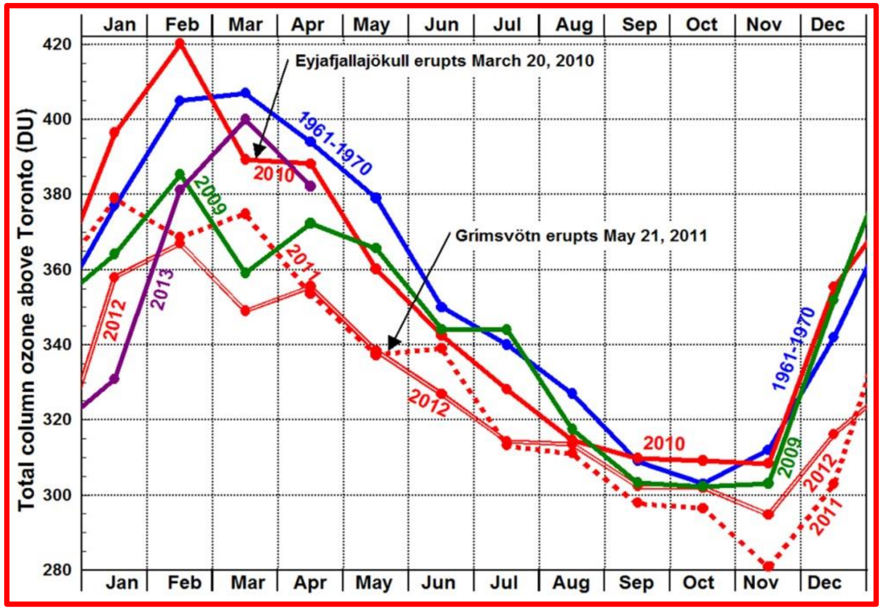
(6) <u>Small, effusive, basaltic eruptions deplete ozone but do not form stratospheric aerosols causing net warming</u>

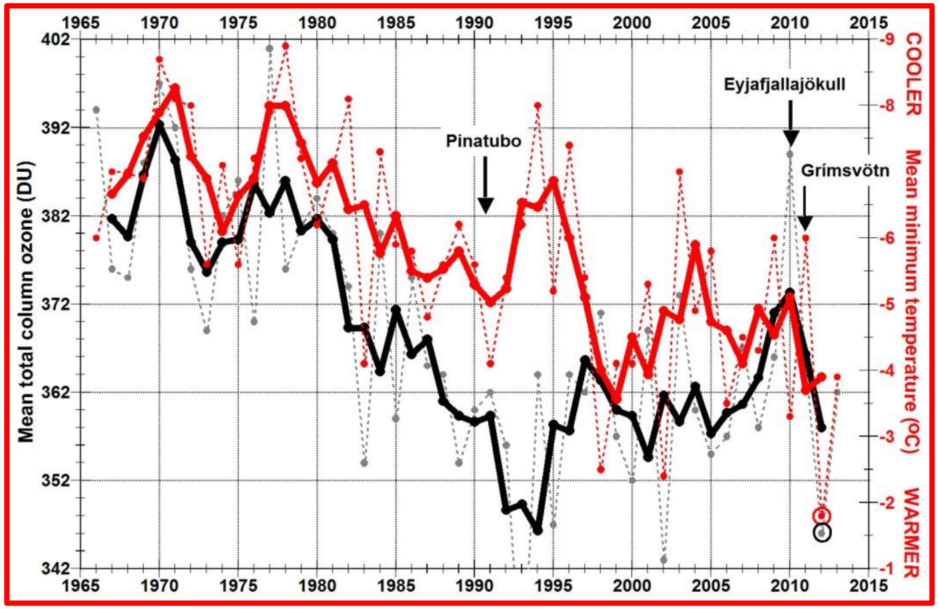
Effusive, basaltic eruptions tend to last for years, centuries, even hundreds of thousands of years, depleting ozone for long periods

(7) Ozone depletion caused by humans and by the effusive volcanoes Eyjafjallajökull (2010) and Grímsvötn (2011) appears to have caused major warming and drought in 2012

Total column ozone above Toronto, Canada, in November, 2011, was 12% below the average for Novembers in 1961 through 1970 and has remained unusually low throughout 2012

When mean total column ozone measured during the months of December through April in Toronto Canada decreases, mean minimum temperature for the same months typically warms except following the eruption of Pinatubo

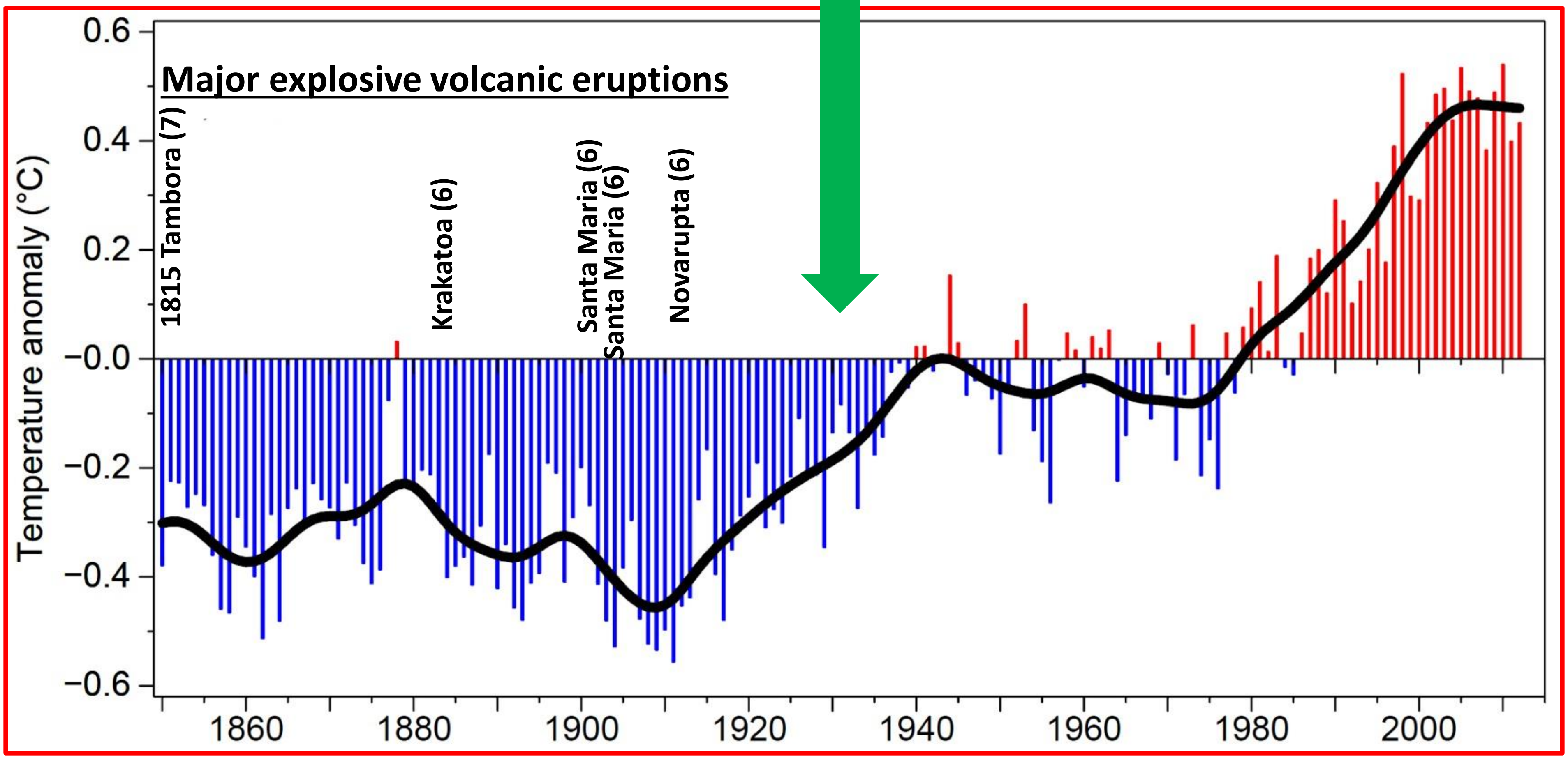




(8) Dust Bowl caused by an unusual sequence of small volcanic eruptions from 1929 through 1933?

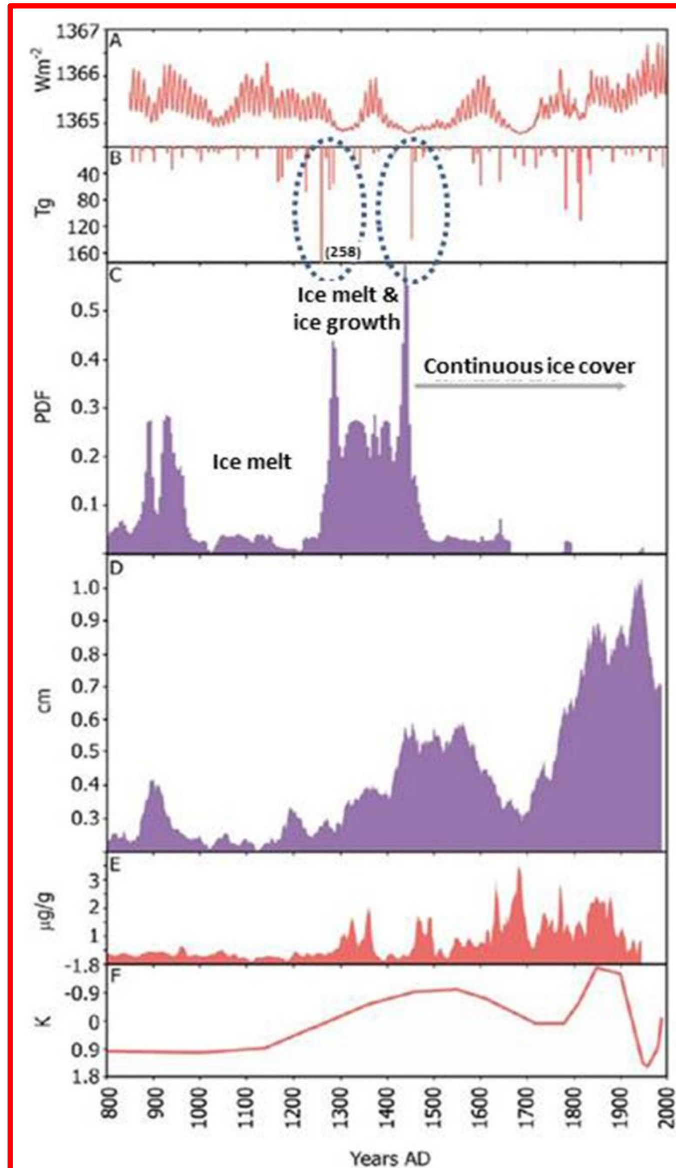
Kuchinoerabujima (Japan) 1933 (4)
Suoh (Indonesia) 1933 (4)
Kharimkotan (Kurile) 1933 (5)
Cerro Azul (Chile) 1932 (5+)

Fuego (Guatemala) 1932 (4)
Aniakchak (Alaska) 1931 (4+)
Kliuchevskoi (Kamchatka) 1931 (4)
Komaga-Take (Japan) 1929 (4)



(9) Little Ice Age caused by explosive volcanism?

Global sulfate aerosol loadings (B) were highest at the beginning of the Little Ice Age in 1275 to 1300 AD and during a major intensification between 1430 and 1455 AD (C)



A. **Total solar irradiance**
B. **Global stratospheric sulfate loadings**
C. **Ice cap expansion dates**
D. **30-year running mean varve thickness in Hvítárvatn sediment core**
E. **Arctic Ocean sea ice recorded in a sediment core on the north Iceland shelf**
F. **Temperature anomalies over southern Greenland**

From Miller et al., 2012

(10) Medieval Warm Period caused by effusive volcanism?

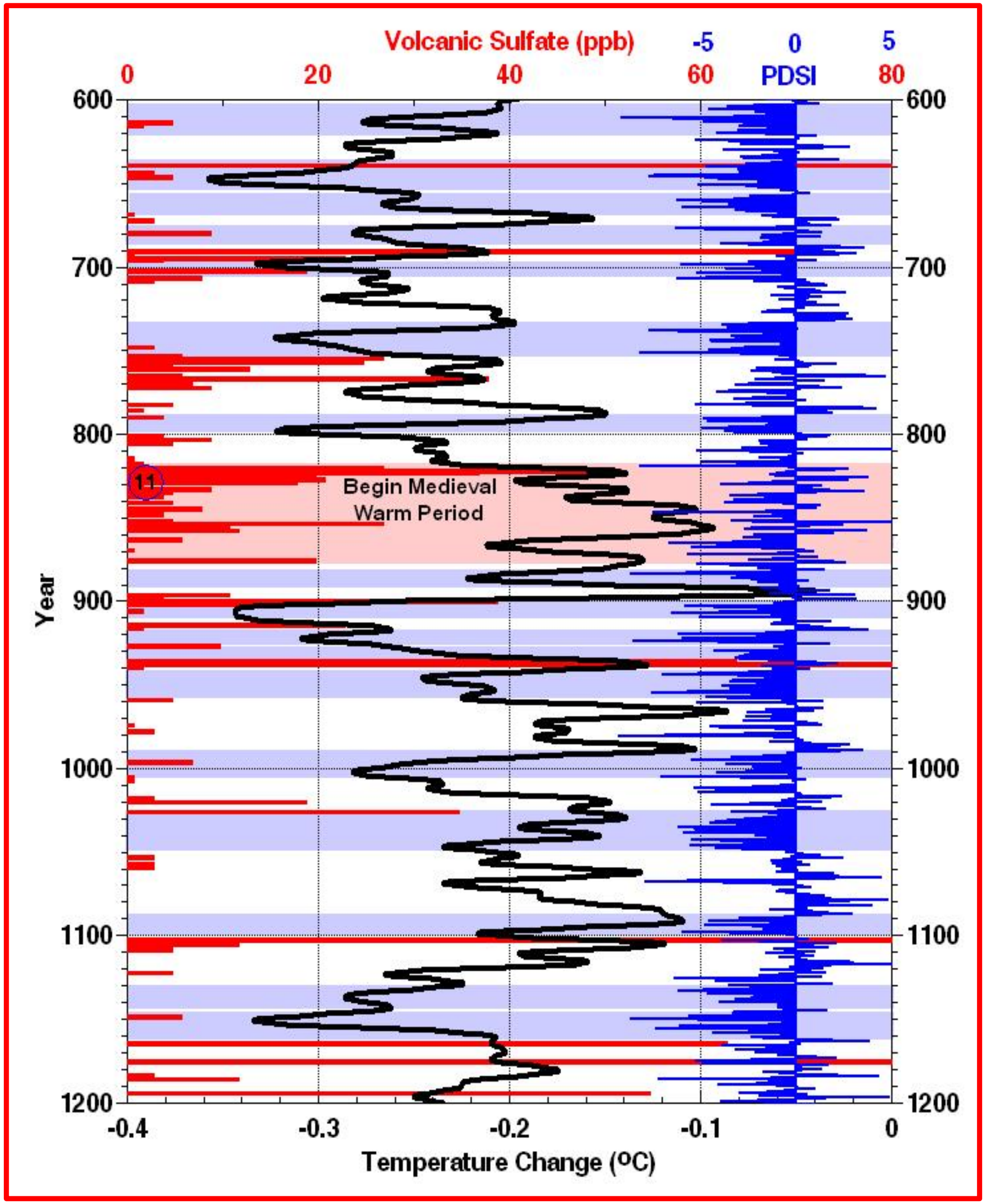
The Medieval Warm Period (820 to 1120 AD) began with a burst of volcanism

Black line is temperature change based on multiple proxies

Red bars are volcanic sulfate anomalies in the GISP2 borehole

Blue circle shows when 11 contiguous layers had sulfate anomalies, coinciding exactly with the increase in temperature

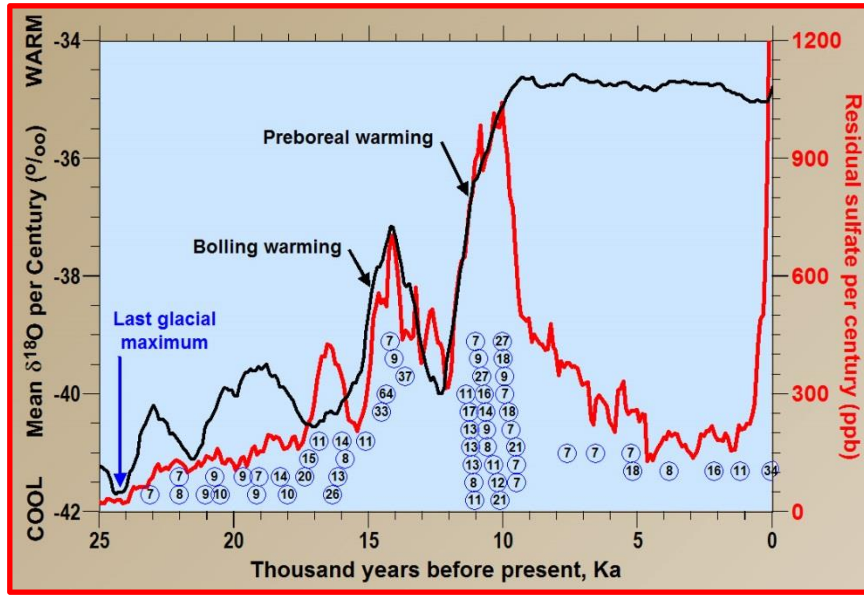
The Palmer Drought Severity Index (PDSI) is shown in blue for southeastern Utah. Negative numbers are drought; positive numbers imply rain. Times of extended drought (shaded blue) tend to be times with little or no evidence of volcanism



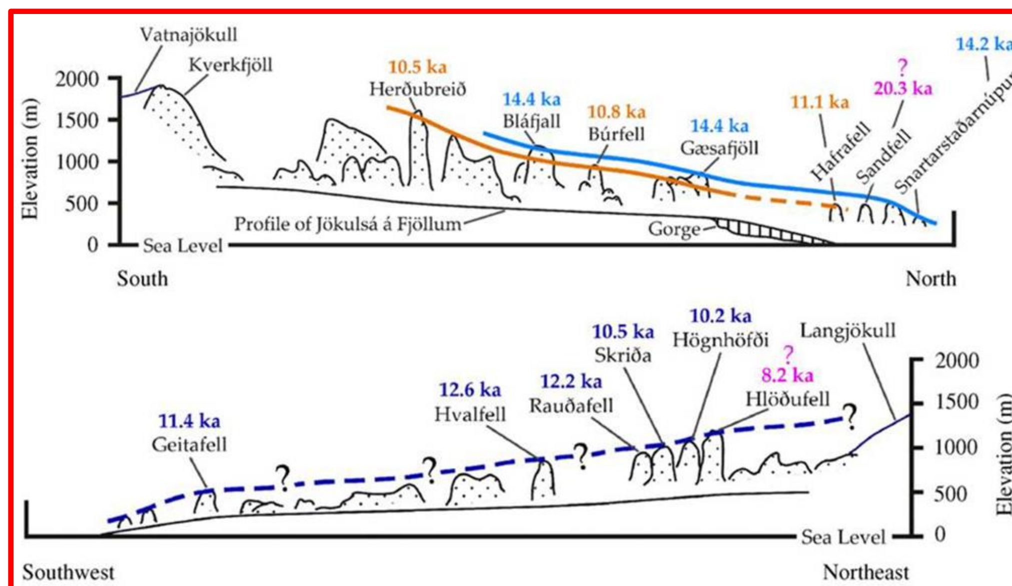
(11) The end of the last ice age caused by effusive volcanism in Iceland from 11,700 to 9,800 years BP?

Basaltic volcanism was substantial and relatively continuous in Iceland during the Bolling and Preboreal warmings

12 of the 13 dated table mountains or tuyas in Iceland experienced their final eruptive phase during the last deglaciation




A table mountain formed by eruption of basalt under ice.



^3He exposure ages & schematic ice surface at end of last ice age

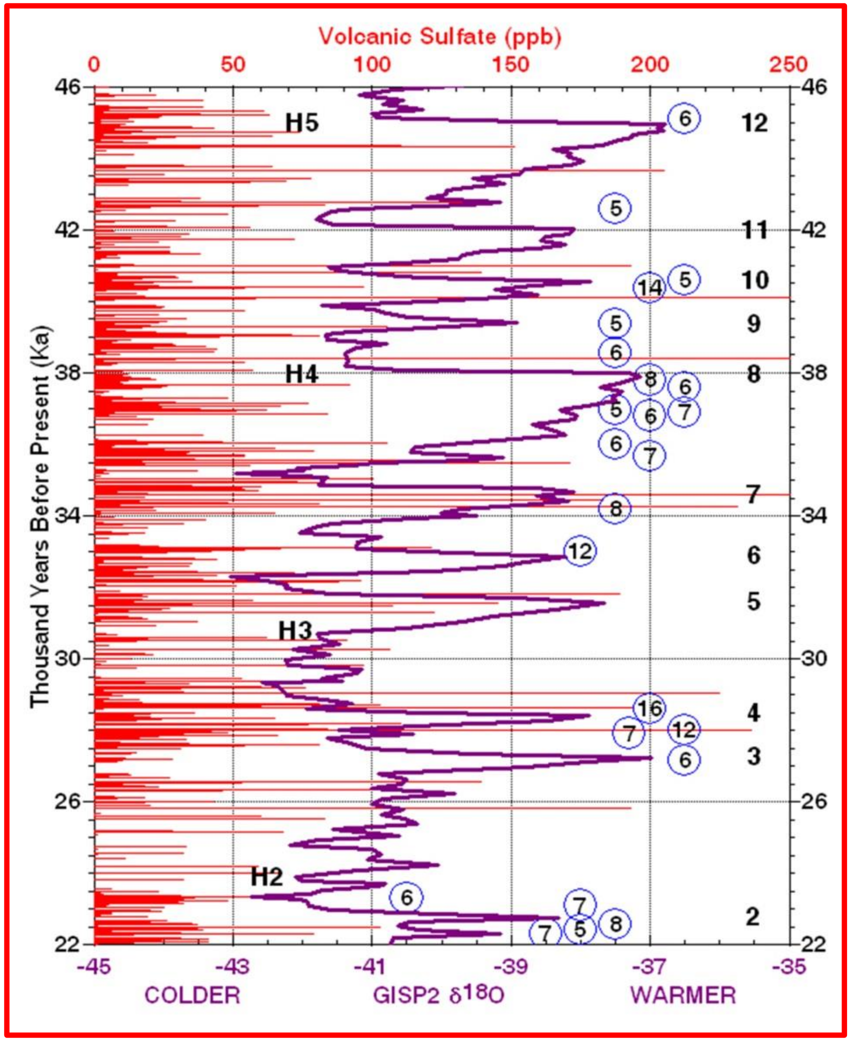
from Licciardi, Kurz, and Curtice, 2007

(12) Dansgaard-Oeschger sudden warmings caused by effusive volcanism primarily in Iceland?

25 times in the last 120,000 years, local temperatures in Greenland rose 10 to 16°C in less than 40 years, returning to ice-age conditions within a century or more

Data from the GISP2 borehole: purple line shows the proxy for paleotemperature, red bars volcanic sulfate, and circled numbers are the number of contiguous layers containing substantial volcanic sulfate

Sudden onset of warming appears contemporaneous with major volcanism. As volcanism wanes, the heat content of the ocean cools Earth back into the ice-age

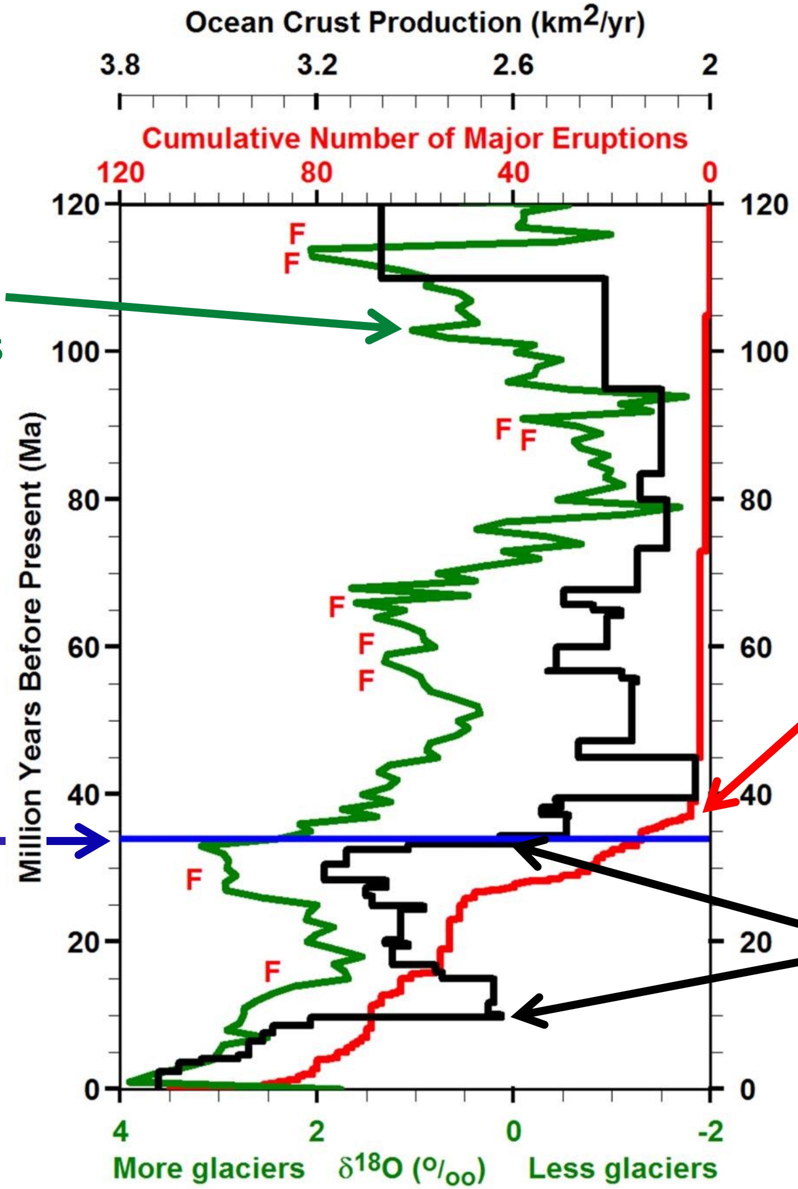


Circled numbers are number of contiguous layers with volcanic sulfate showing continuity of volcanism

(13) Onset of major glaciation at 33.9 Ma caused by a major increase in the rate of explosive volcanism?

$\delta^{18}O$ measured in shells of foraminifera, a proxy for mean paleotropical sea-surface temperature and global ice volume with lowest temperatures and more glaciers to the left. The range in temperatures is approximately 7 °C.

First major accumulation of Antarctic ice



F = flood basalts

Rapid increase in the cumulative number of major explosive eruptions

Rapid increase in rate of ocean crust production

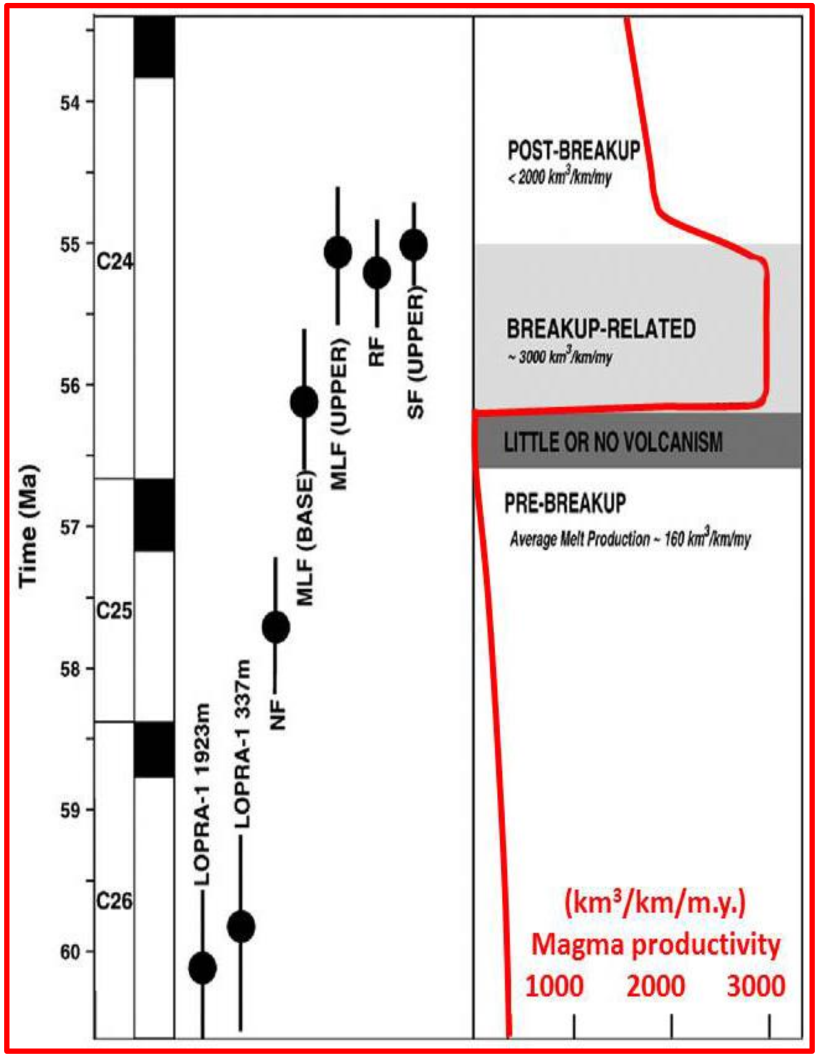
(14) Paleocene-Eocene Thermal Maximum caused by a major increase in effusive, basaltic volcanism?

The PETM was a brief period of extreme global warming beginning around 56.1 Ma as subaerial extrusion of basalts related to the opening of the Greenland-Norwegian Sea suddenly increased to rates greater than 3000 km^3 per kilometer of rift per million years

Global surface temperatures rose 5 to 9°C within a few thousand years

Sea surface temperatures near the North Pole increased to 23°C

Southwest Pacific sea surface temperatures rose rapidly to 34°C, cooling back to 21°C over seven million years



From Storey et al., 2007, Zeebe et al., 2009, Sluijs et al., 2006, and Bijl et al., 2009

(15) Extreme warming and mass extinctions caused by massive flood basalts?

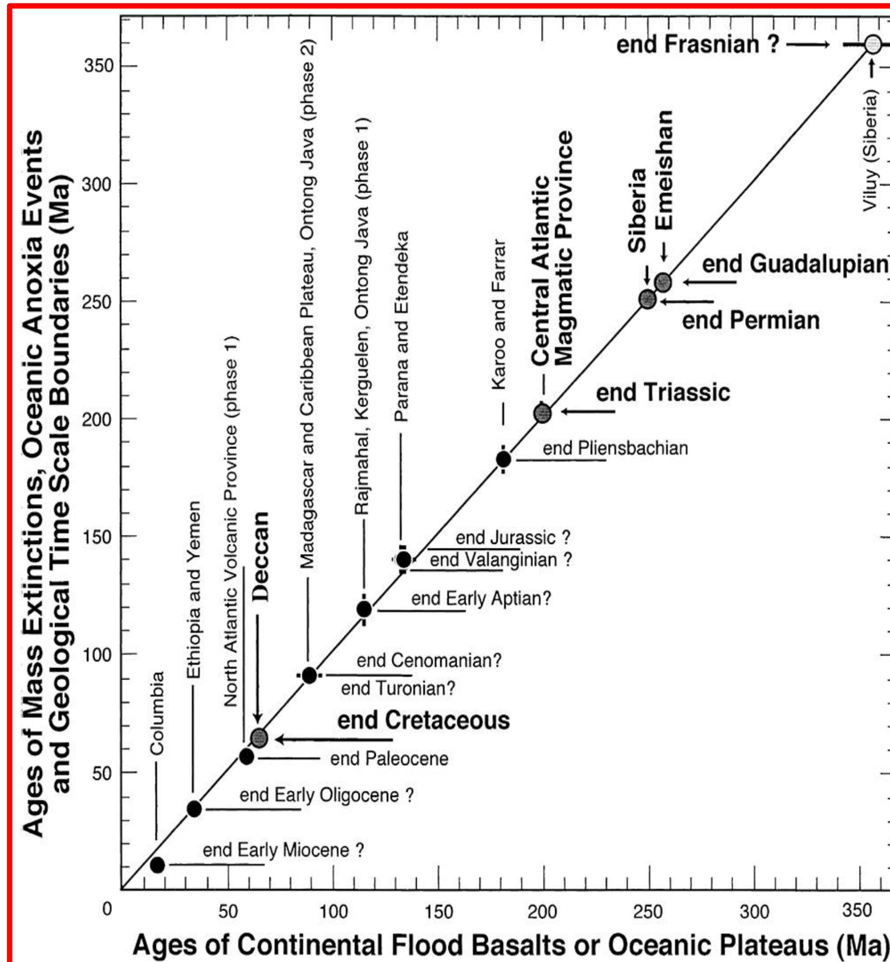
Major effusive eruptions of flood basalts are contemporaneous with mass extinctions

Around 250 Ma, >3 million km³ of basalt was extruded in Siberia over an area of at least 5 million km² (62% of the contiguous 48 United States) possibly in less than 670,000 years

Low-latitude surface seawater temperatures rose 8°C

Lethally hot temperatures exerted a direct control on extinction and recovery

Massive depletion of ozone and prolonged exposure to enhanced UV radiation



From: Courtillot and Renne, 2003, Reichow et al., 2009, Joachimski et al., 2012, Sun et al., 2012, Beerling, 2007, Svensen et al., 2009, Visscher et al., 2004

(16) Earth's energy balance

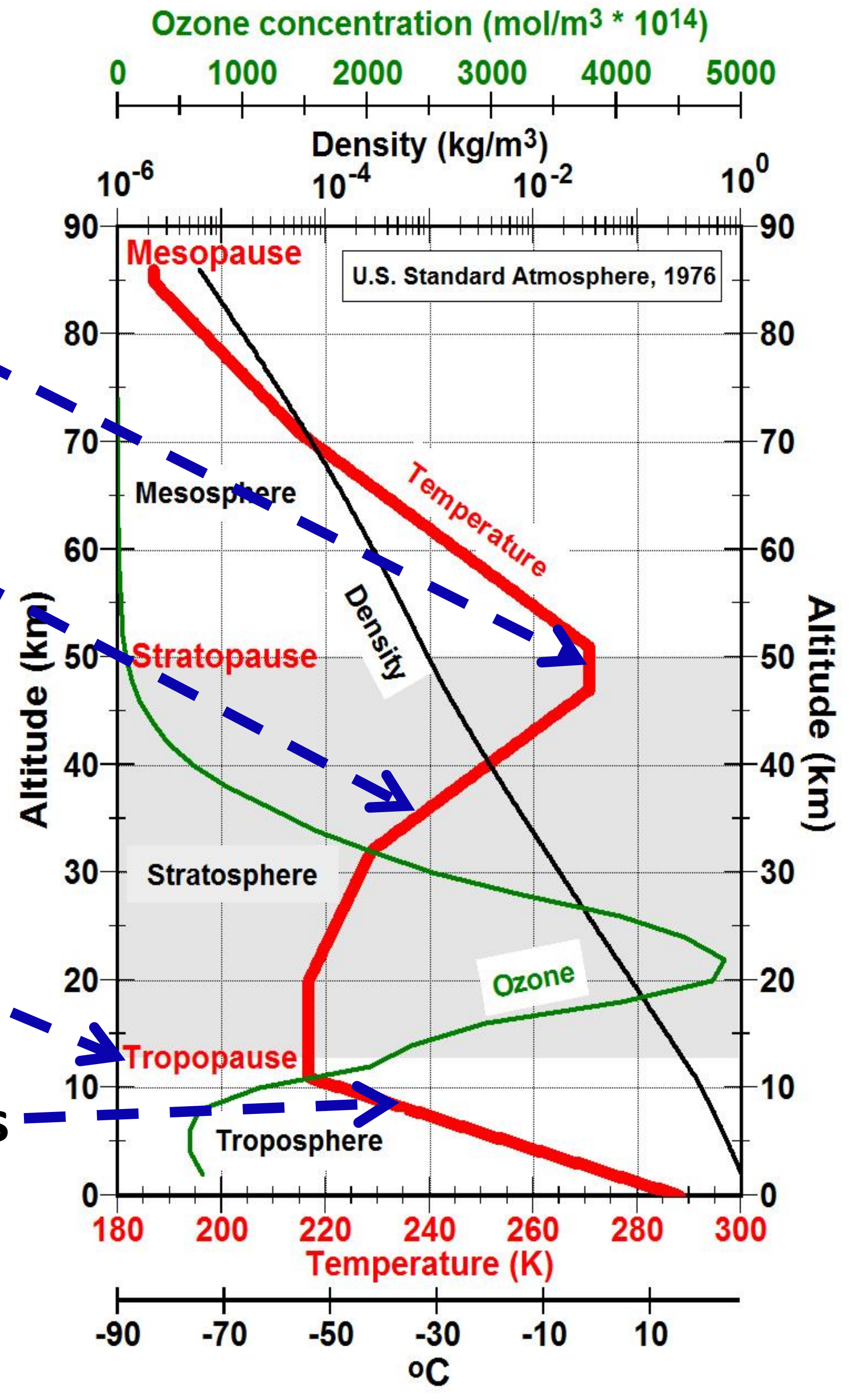
The stratopause is the surface radiating heat into space

Heat rises through the stratosphere and is increased by heat generated by the photodissociation of O_2 and O_3

The tropopause is the boundary between the troposphere warmed from below by a sun-warmed Earth and the stratosphere heated from above by solar ultraviolet radiation causing photodissociation

Flow of heat away from Earth in the troposphere is dominantly by convection shown in weather systems

Greenhouse gases only affect radiation and are therefore are not very important for the flow of heat through the troposphere



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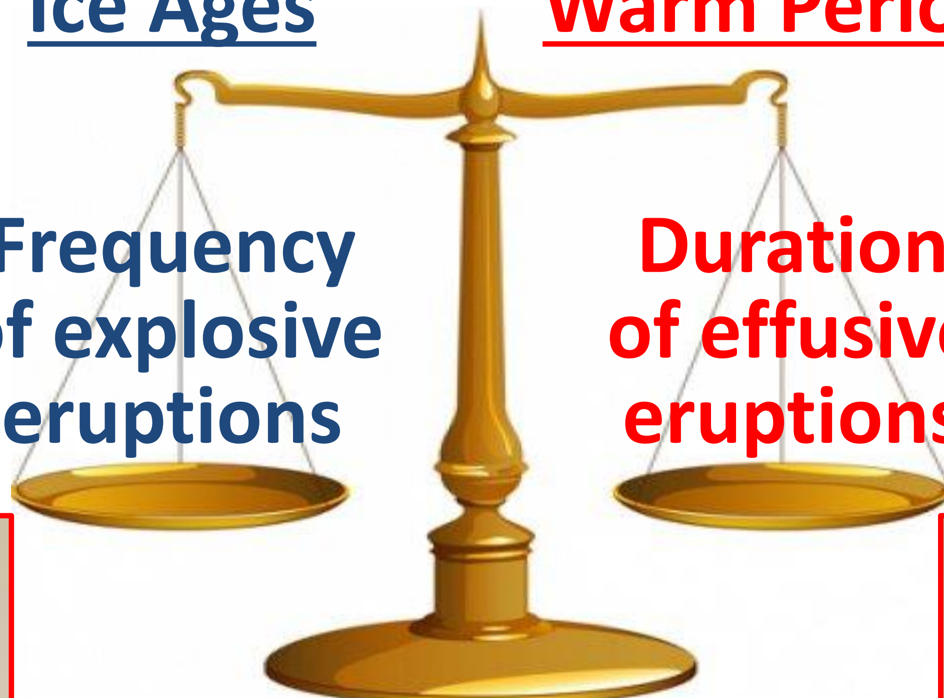
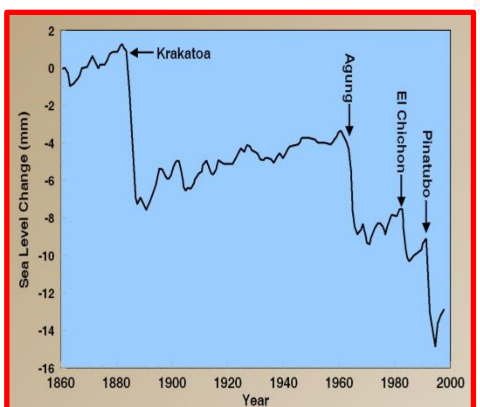
Ice Ages | **Warm Periods**



Frequency of explosive eruptions

Duration of effusive eruptions



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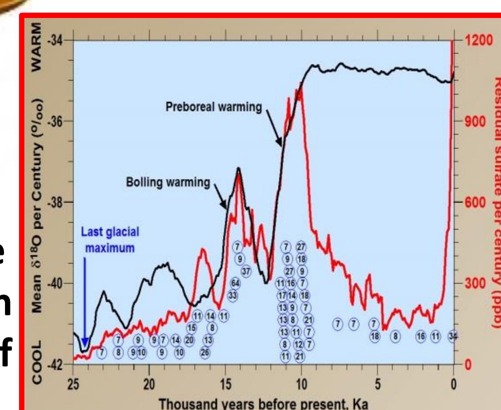

More information

I am working on a major website that explains the ozone depletion theory of global warming in considerable detail.

This will to be made public along with a new published paper by February, 2014.

If you would be willing to provide feedback on how clearly the website answers your questions and provide any technical comments that come to mind, please contact me for the address and password at peward@wyoming.com or 307-413-4055.