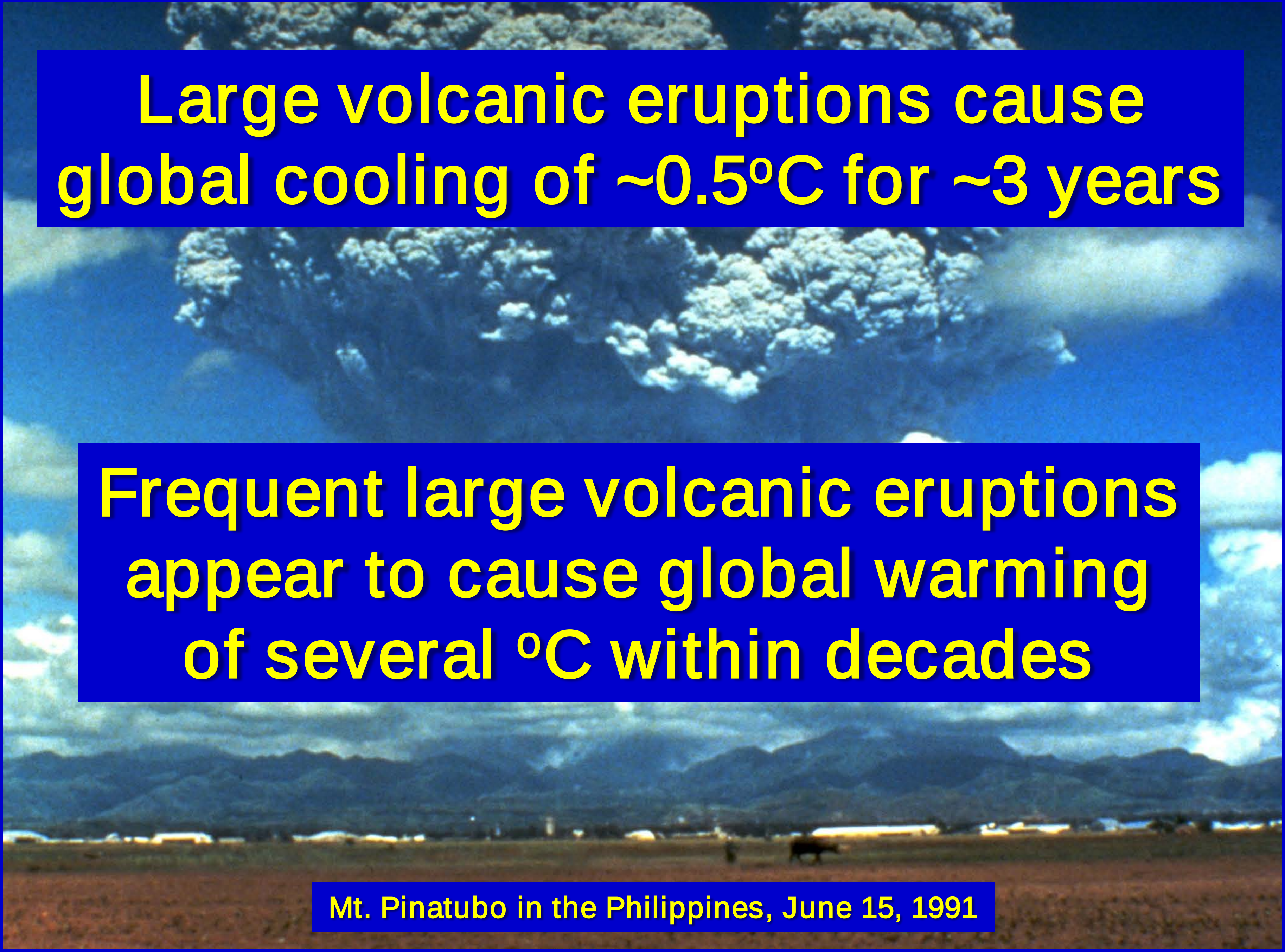


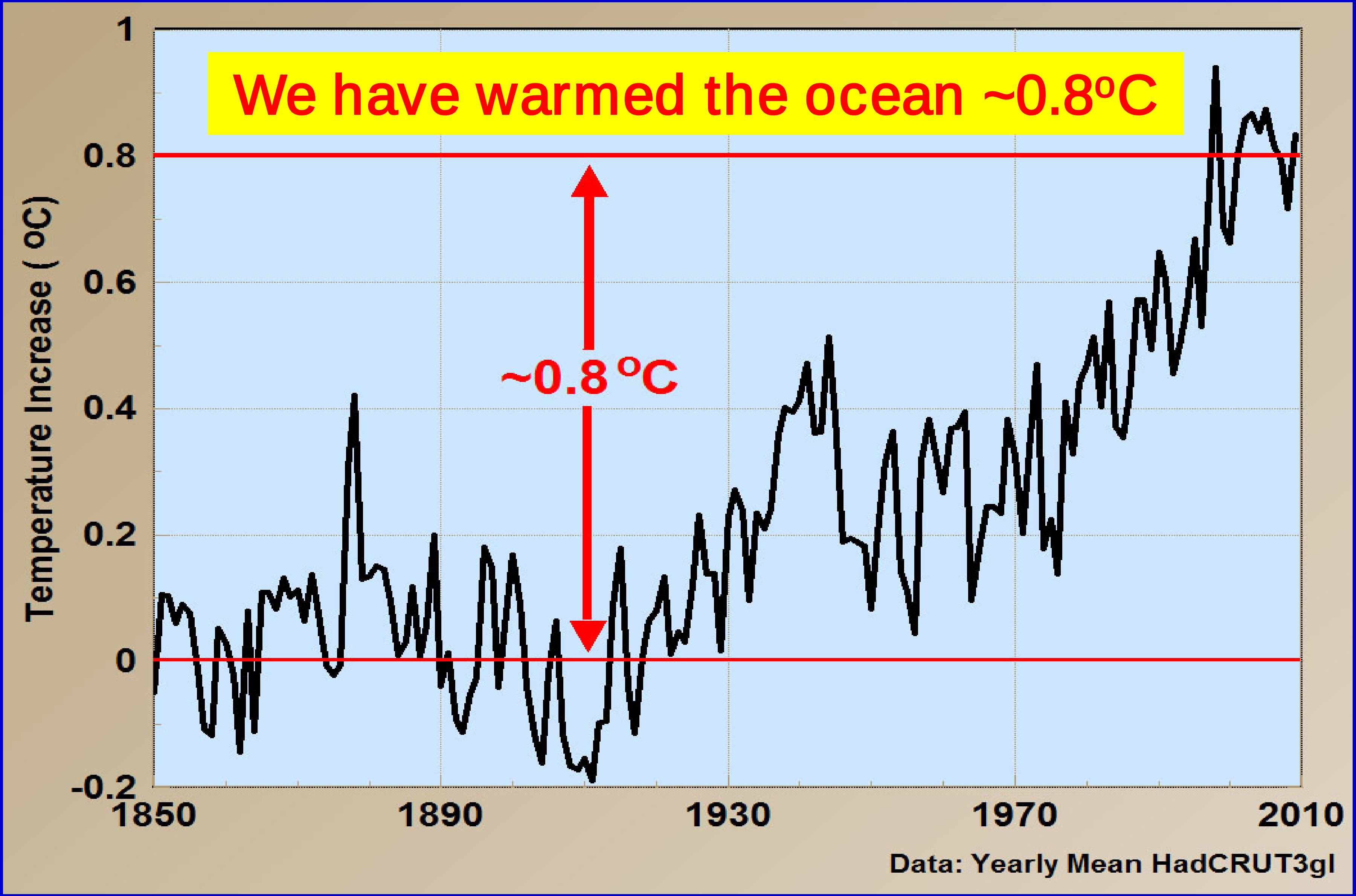
Understanding Volcanoes May Be the Key to Controlling Global Warming

Society of Vacuum Coaters
April 19, 2010

Peter L. Ward
U. S. Geological Survey, Retired
Teton Tectonics
Jackson, Wyoming
peward@wyoming.com


Large volcanic eruptions cause global cooling of ~0.5ºC for ~3 years
Frequent large volcanic eruptions appear to cause global warming of several ºC within decades
Mt. Pinatubo in the Philippines, June 15, 1991

Global Warming in the 20th Century



Why?

Scientists say

Man caused global warming by emitting greenhouse gases, primarily carbon dioxide and methane

Climate deniers say

It happened before and it will happen again!
It is only natural, not manmade!

Science versus Belief

We Will Explore Two New Observations

1. Evidence that global warming in the past was initiated by large, nearly continuous emissions of sulfur dioxide (SO_2) from volcanoes over decades and that this happened 14 times in the last 46,000 years

2. Evidence that global warming in the 20th century was initiated by large, continuous emissions of sulfur dioxide (SO_2) by humans burning fossil fuels, especially coal

INITIATED LARGE CONTINUOUS

But Peter, That Is Preposterous!!

1. SO_2 erupted into the strato-sphere by large volcanic eruptions typically cools the earth for ~3 years

James Hansen, NASA

2. The atmospheric concentration of CO_2 is 387 ppmv while the concentration of SO_2 is much less than 90 ppbv, 3 to 4 orders of magnitude less

3. CO_2 lasts ~100 years in the atmosphere while SO_2 lasts only days to weeks

SO_2 simply cannot be an important greenhouse gas absorbing infrared energy

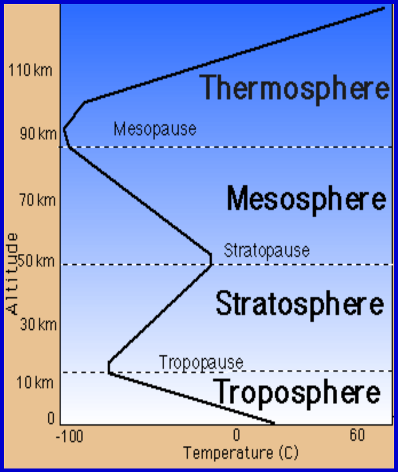
“This paper is almost irresponsible in its disregard for known science.”

Anonymous Reviewer
November 2008

Photons from the sun make life on earth possible

"Solar ultraviolet radiation plays a decisive role in almost all aspects of the chemistry of the atmosphere."

Grant W. Petty, 2006, in his book
A First Course in Atmospheric Radiation



The origin of oxygen

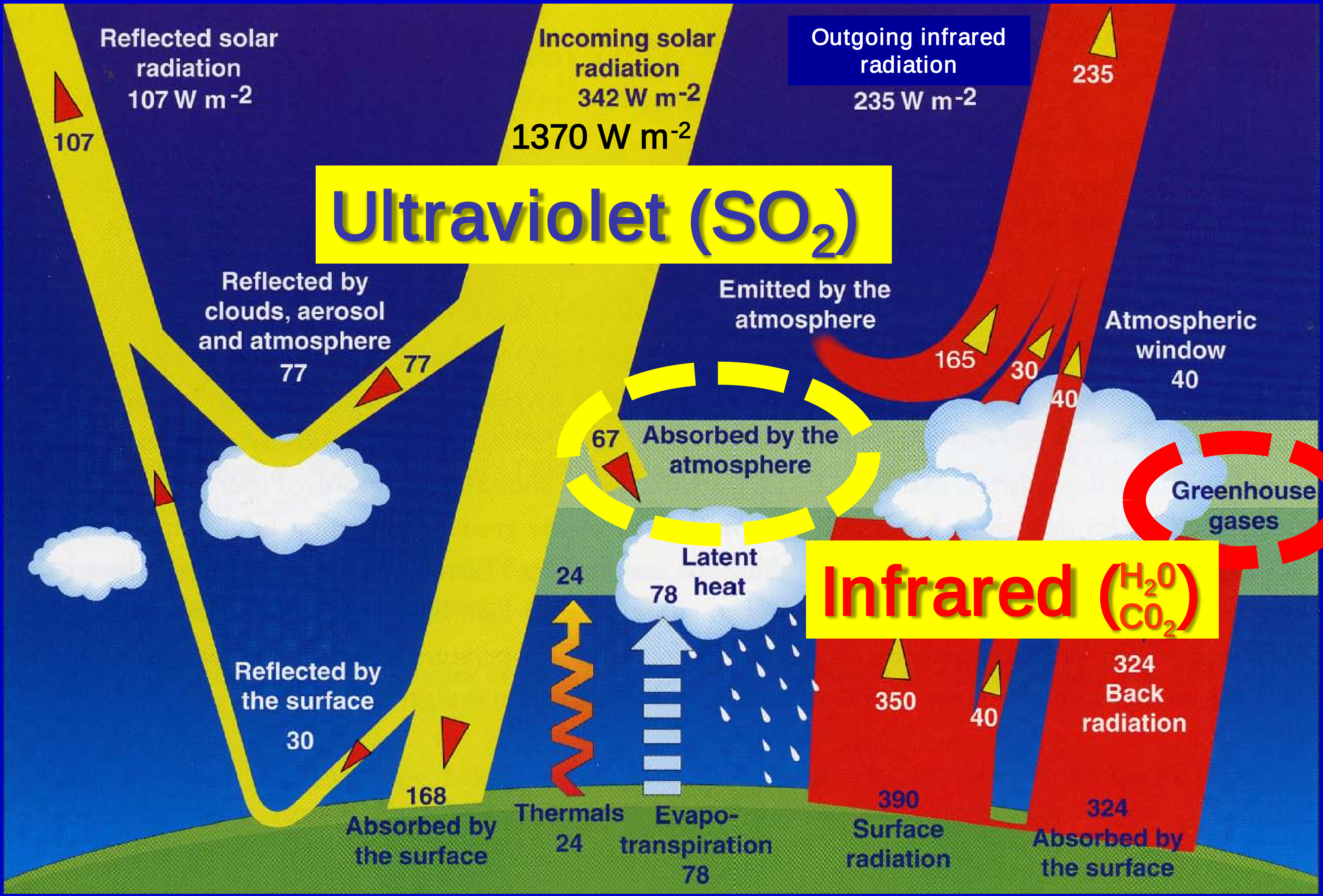
The origin of ozone

The primary structure of the atmosphere

The oxidation of pollutants

The primary initiator of global warming

Energy Budget of the Atmosphere



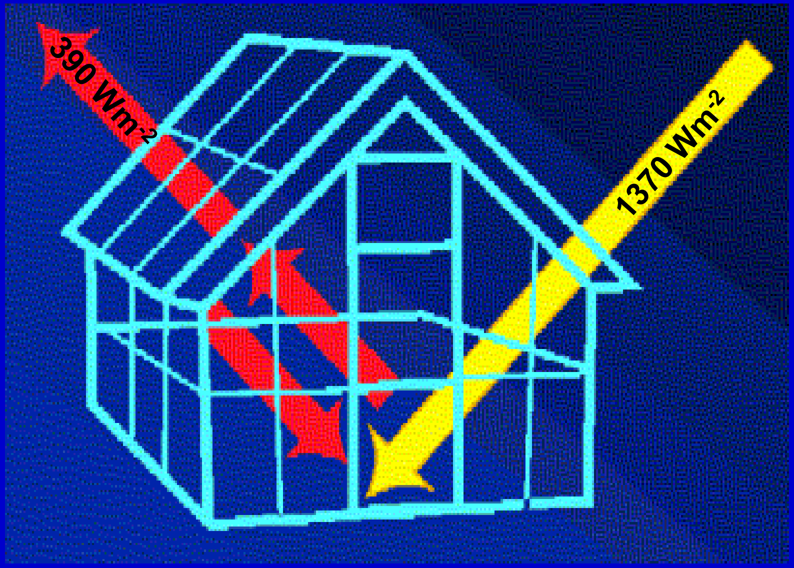
Based on Kiehl and Trenberth (1997)

Greenhouse Gases

Solar Absorbing Gases

Infra-
red

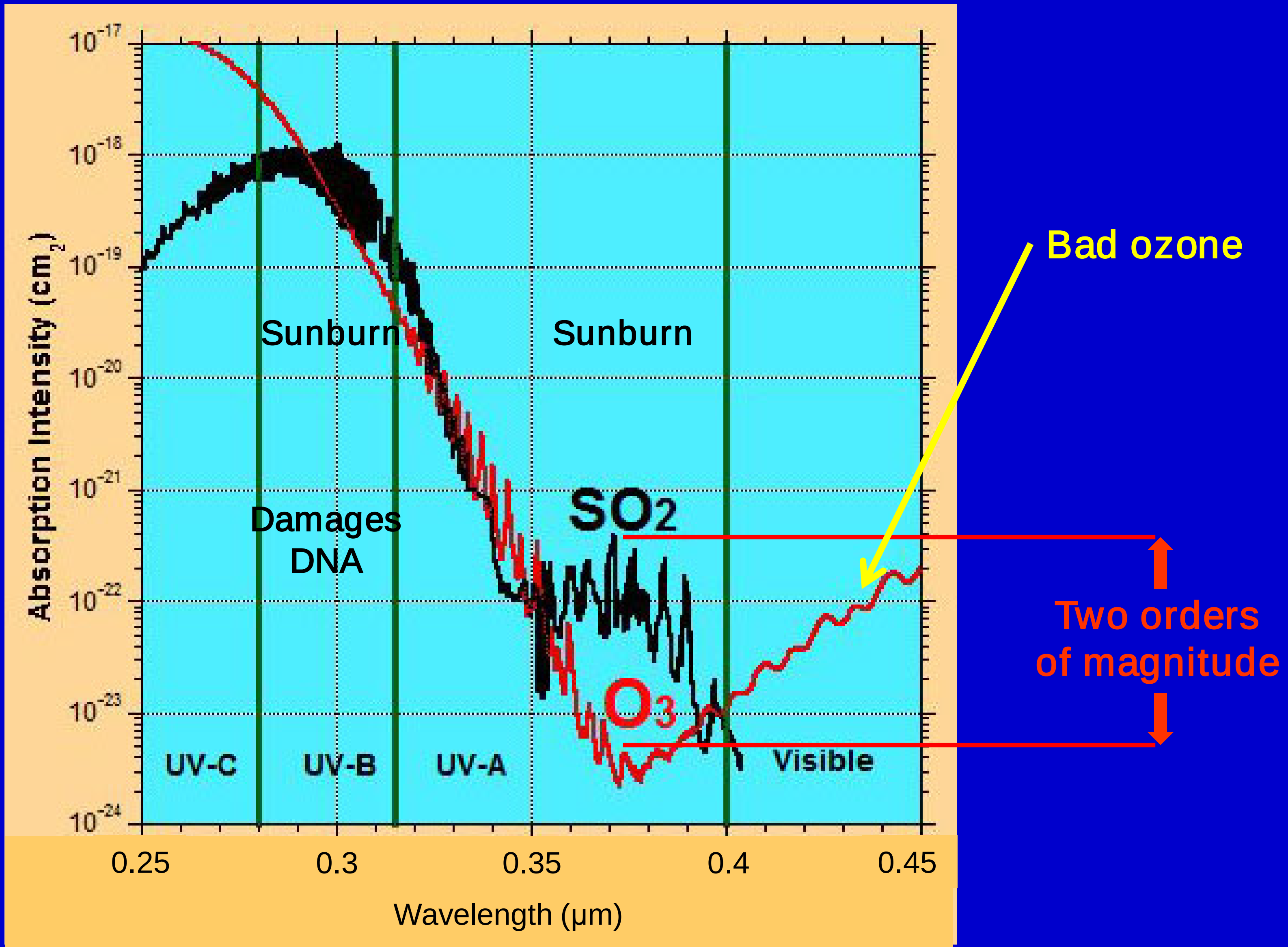
Visible &
Ultra-
violet

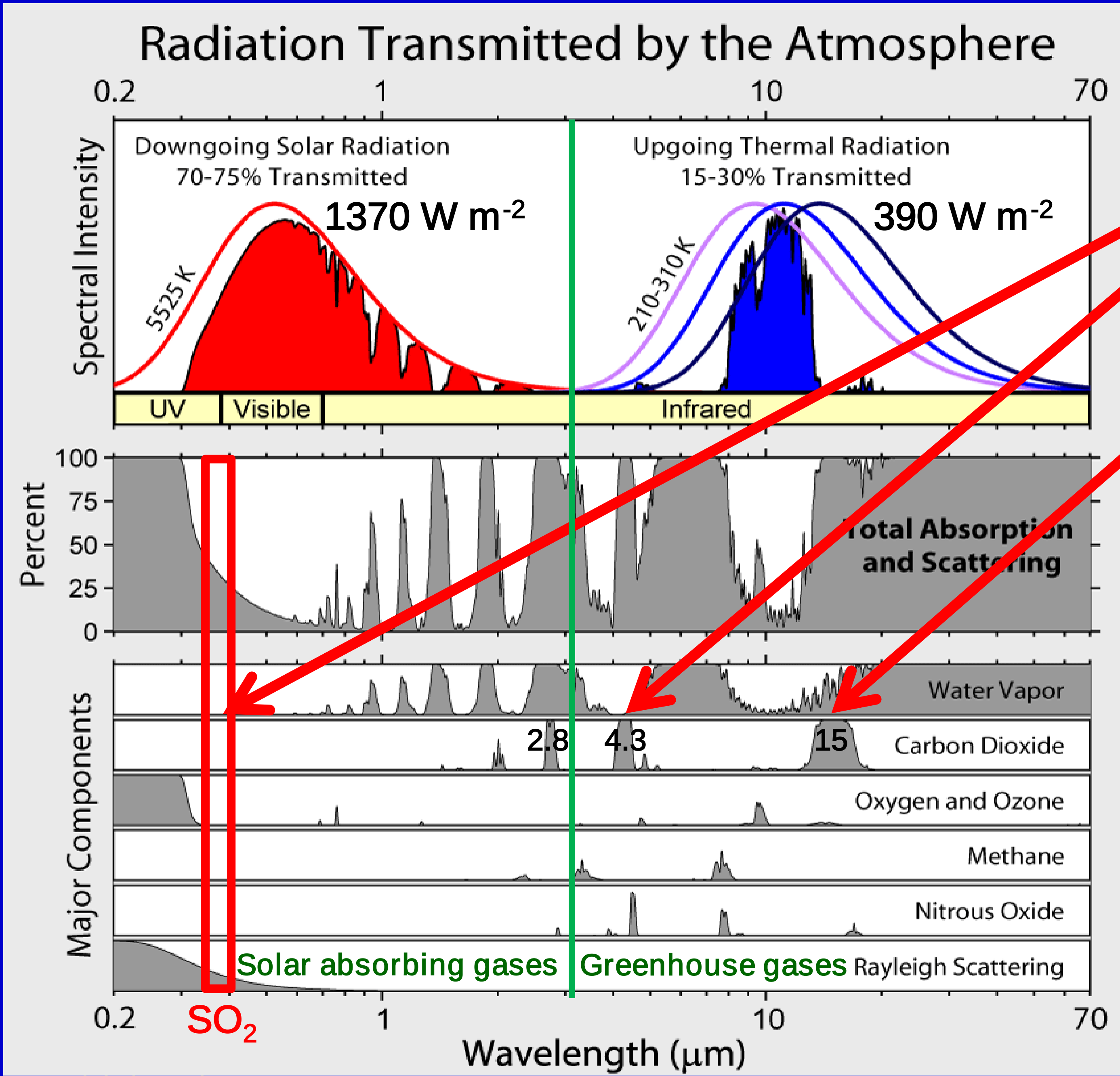


A cloudy night feels warmer than a clear night

A bright sun feels hotter than a cloudy sun

SO_2 Absorbs Strongly in UV-A





www.globalwarmingart.com

Energy of a photon

$E = h\nu = hc/\lambda$ Joules

$$\frac{E(0.37\ \mu m)}{E(4.3\ \mu m)} = 12$$

$$\frac{E(0.37\ \mu m)}{E(15.0\ \mu m)} = 41$$

Concentrations

H_2O = 0 to 2%

CO_2 = 0.0385%

CO_2 = 385,000 ppbv

CH_4 = 1,700 ppbv

NO_2 = 35 ppbv

O_3 = 10 ppbv

SO_2 = 1 to 93 ppbv

Heat generated is proportional to

Energy In times

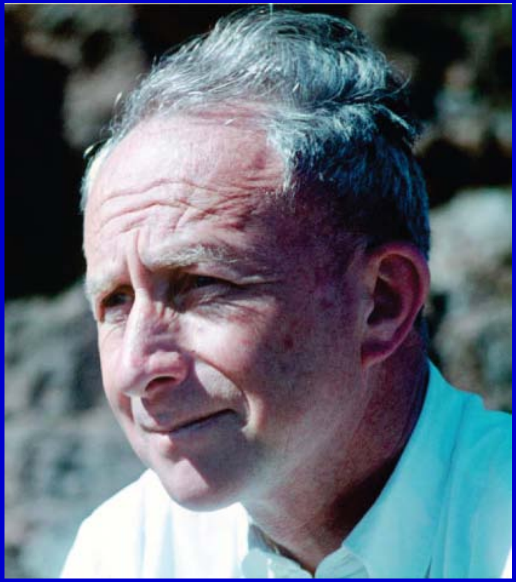
Absorption Intensity times

Concentration

Christian E. Junge

widely regarded as
the father of
atmospheric chemistry

wrote in 1960:

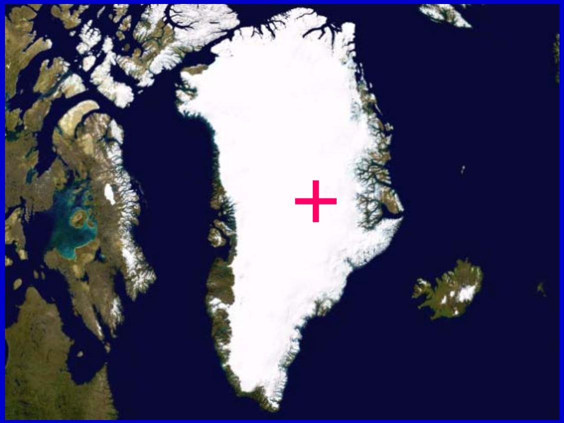


"Sulfur is one of the trace substances which is always found in the atmosphere, even in the most remote areas."

"Sulfur, as an important atmospheric constituent, has received very little attention."

(*Sulfur in the atmosphere* , JGR:65 p. 227)

Junge predicted that amounts of $SO_4^=$ (oxidized SO_2) measured in the snow in Greenland should show a linear increase since 1915 proportional to increasing SO_2 pollution

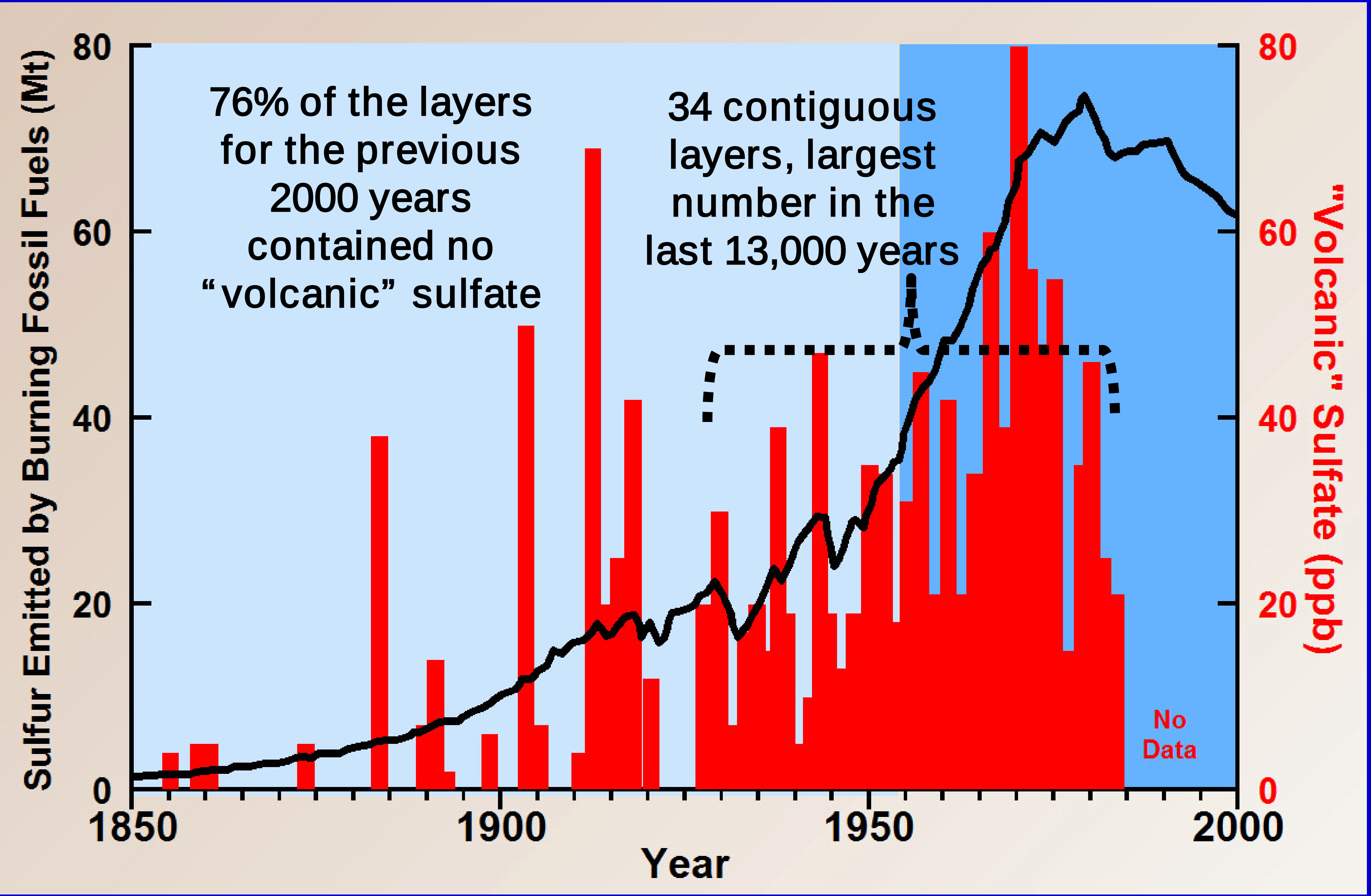


Junge emphasized that his data were "noisy and limited" and that they did not show the expected relationship

He concluded that

1. "Either the estimates are inaccurate"
2. "Or industrial SO_2 is washed out so rapidly that no substantial fraction penetrates into the Arctic"

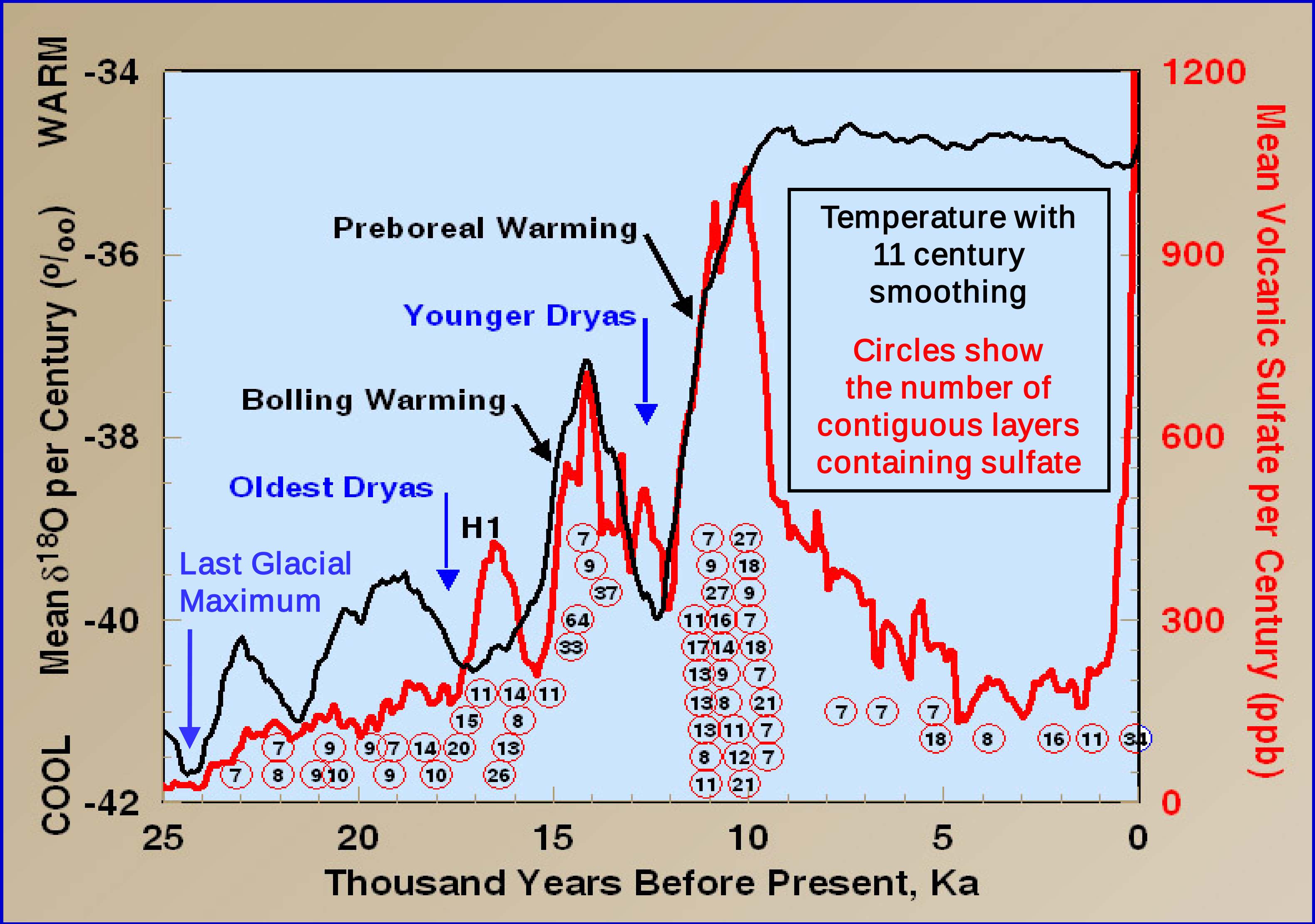
Sulfate Measured in Greenland



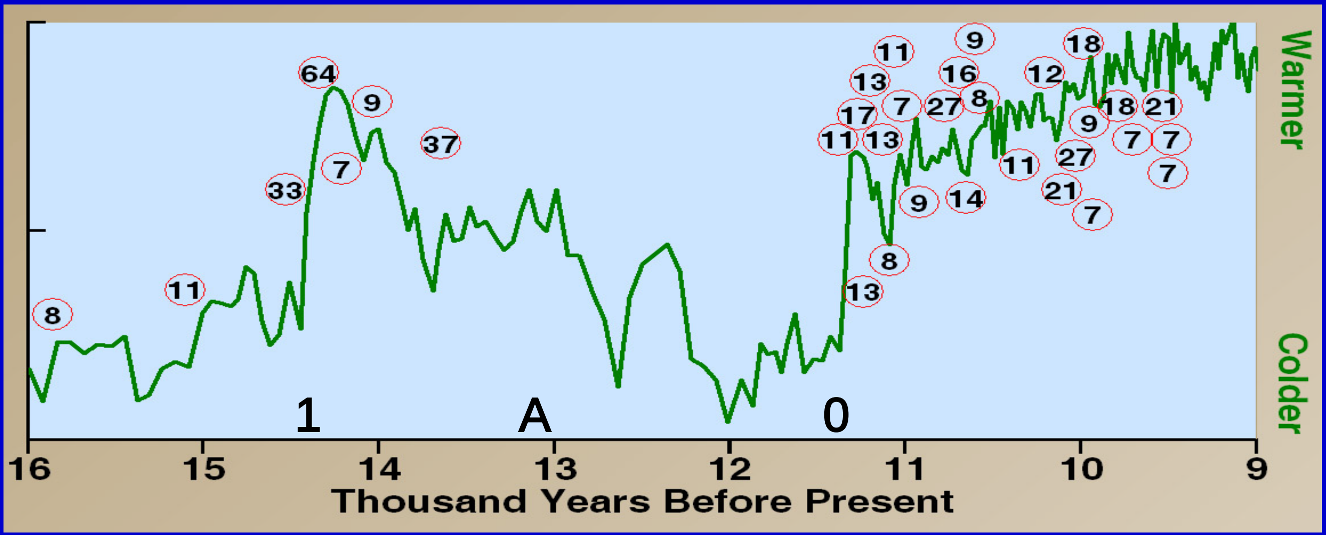
Smith et al. 2004

Zielinski et al. 1996

High Rates of Volcanism Are Contemporaneous with Rapid Warming



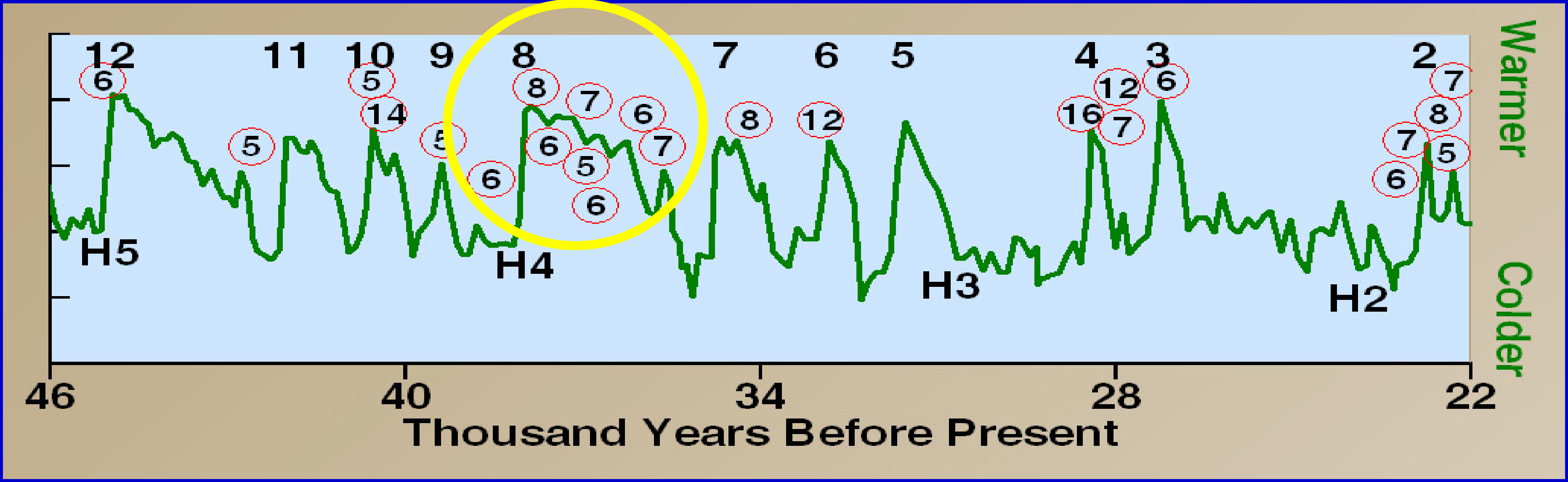
Warming Vs Contiguous Layers with Sulfate

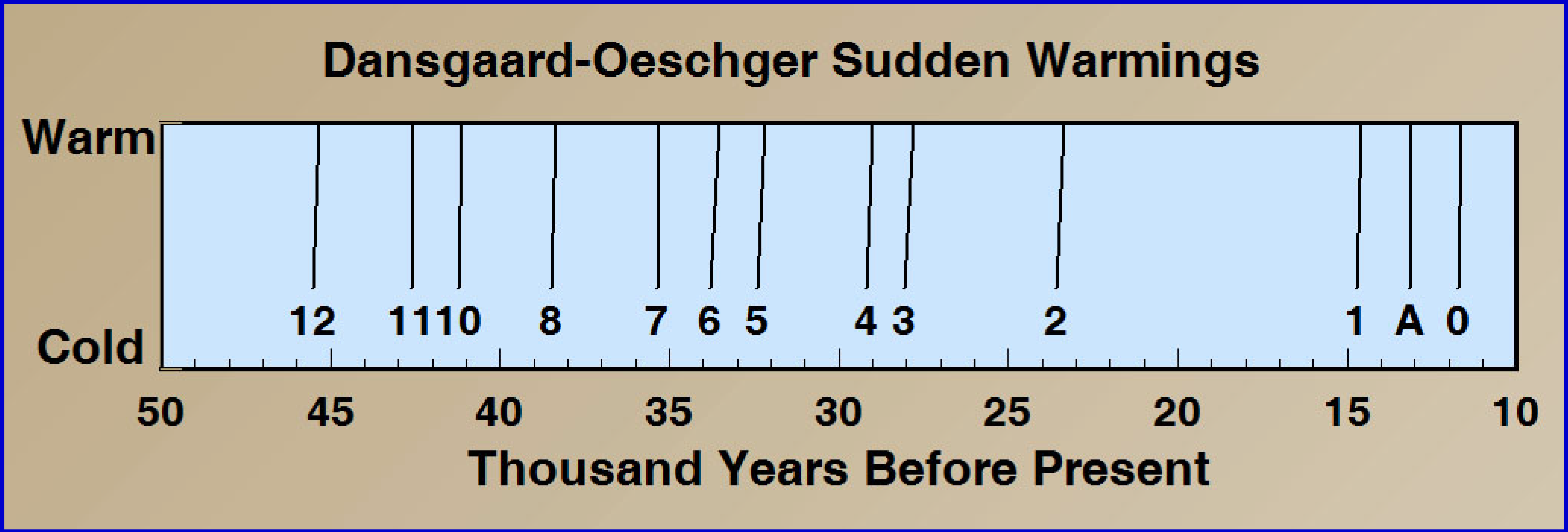


Circles include the number of contiguous layers containing sulfate

Paleolithic Revolution

Numbers are Dansgaard-Oeschger Events



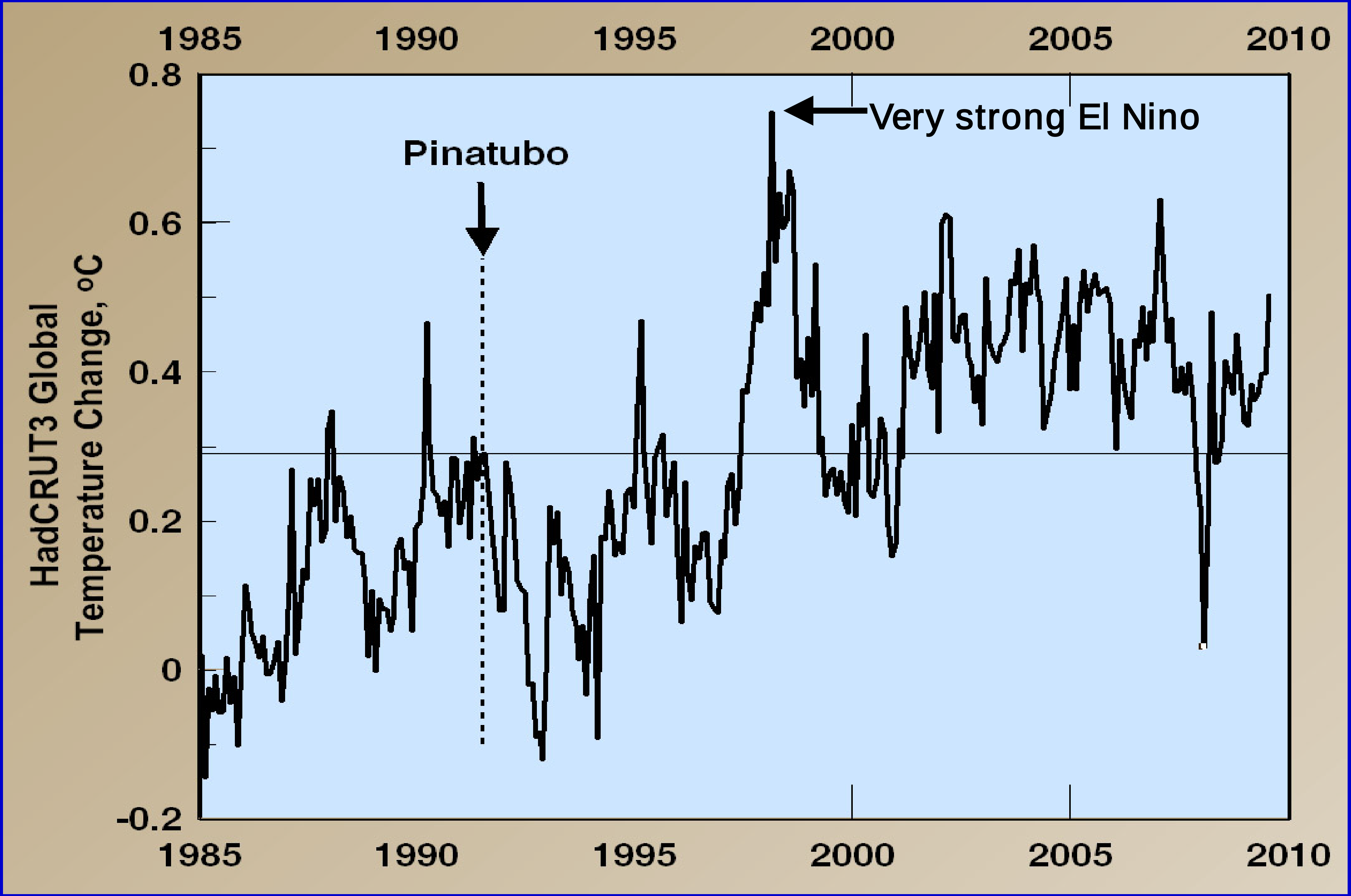


A few decades every 2500 years

Only 5.8% of the time

Mt. Pinatubo, Philippines, 1991

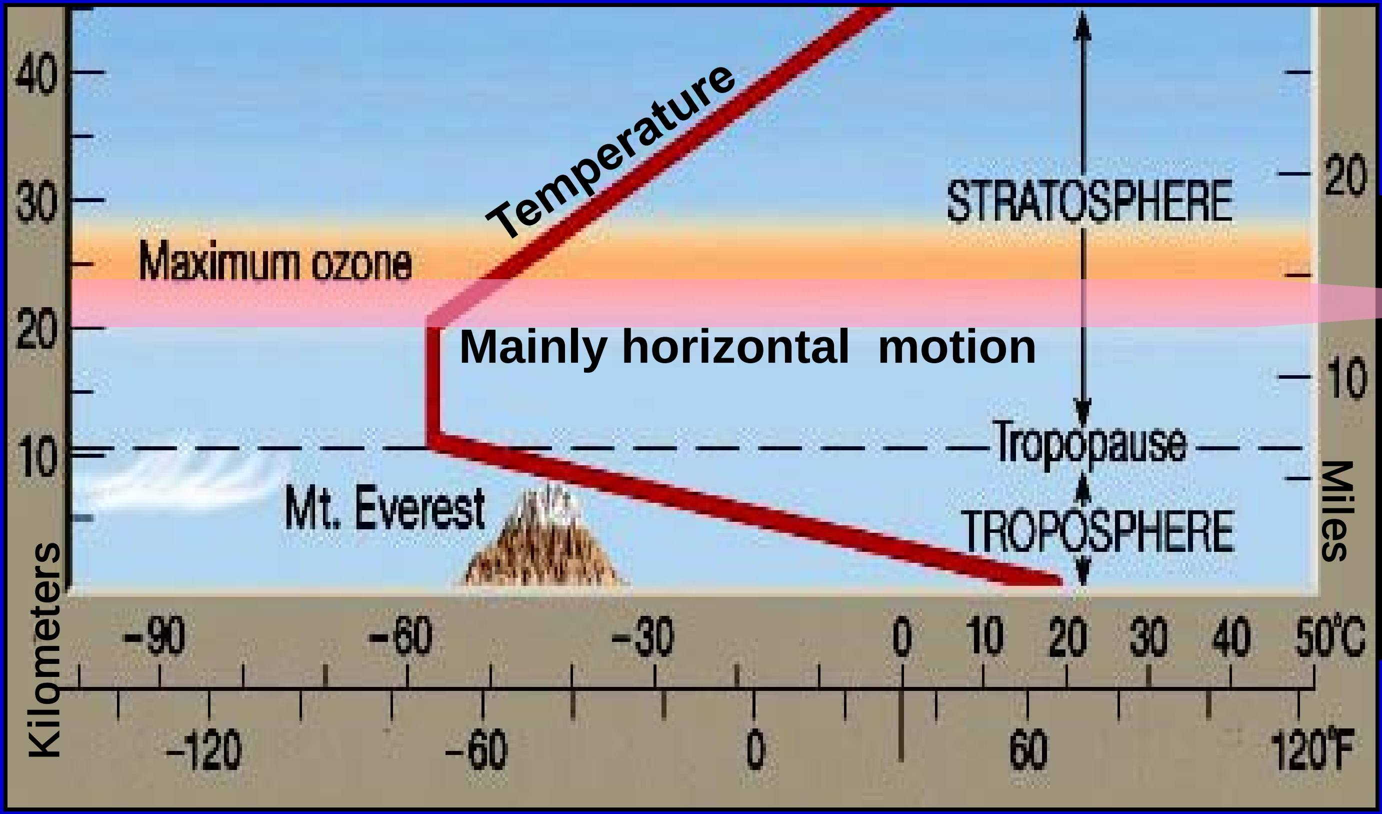
Temperature Drop After Pinatubo



Large Volcanic Eruptions Form Aerosols

A gaseous suspension of fine solid or liquid particles

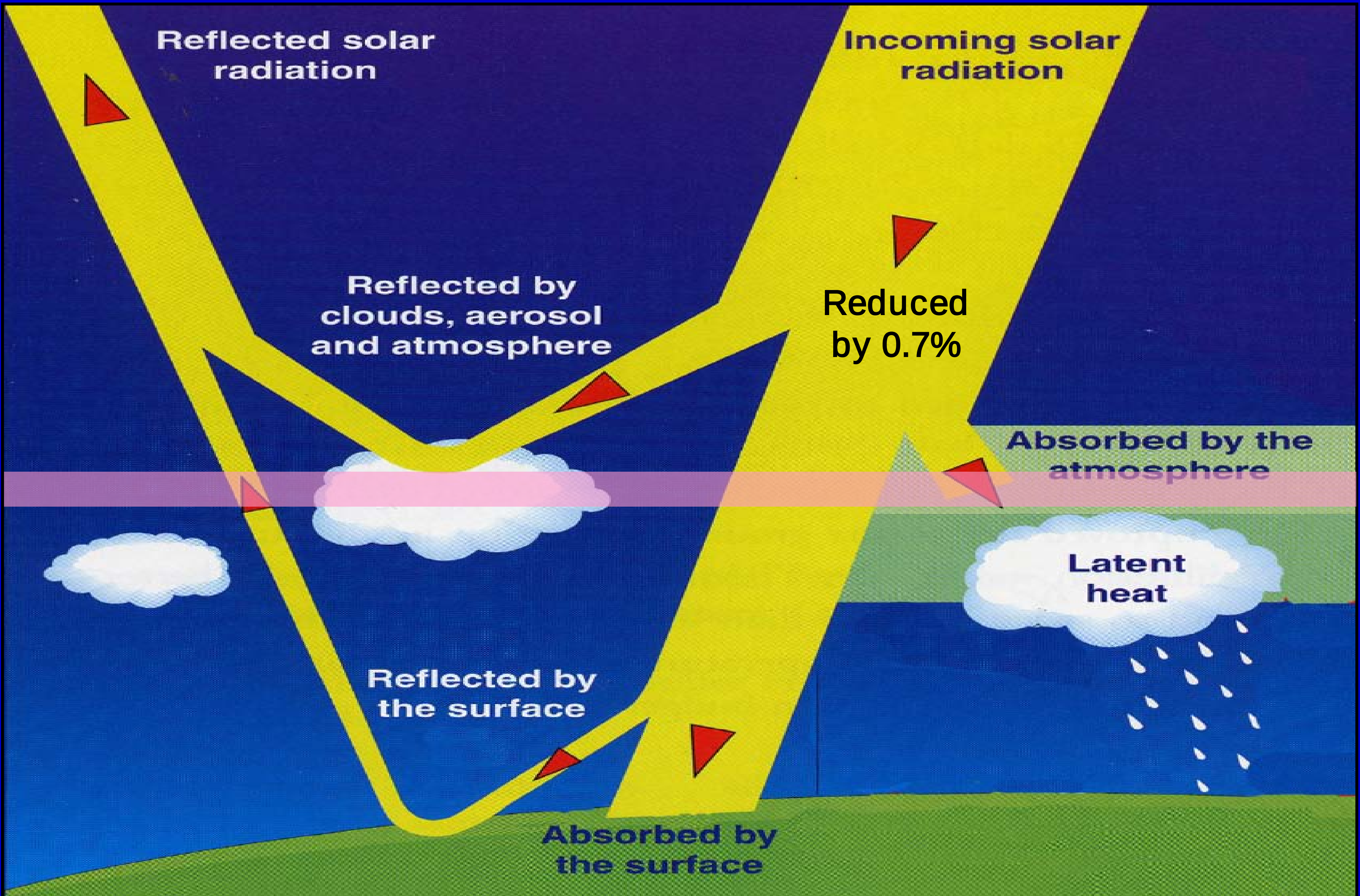
17 megatons of SO_2 erupted from Pinatubo formed an aerosol 20 to 23 kilometers high that was 99% pure sulfuric acid + water.



Temperature

kidsgeo.com

Aerosols Reflect Sunlight



Effects of Pinatubo

Surface temperature ↓ 0.5^{o}C for 3 years

Therefore global water vapor ↓ 3% and precipitation ↓ 3 SD

Ocean temperature ↓ and thus sea level ↓

Diffuse radiation ↑ and thus photosynthesis ↑ 23%

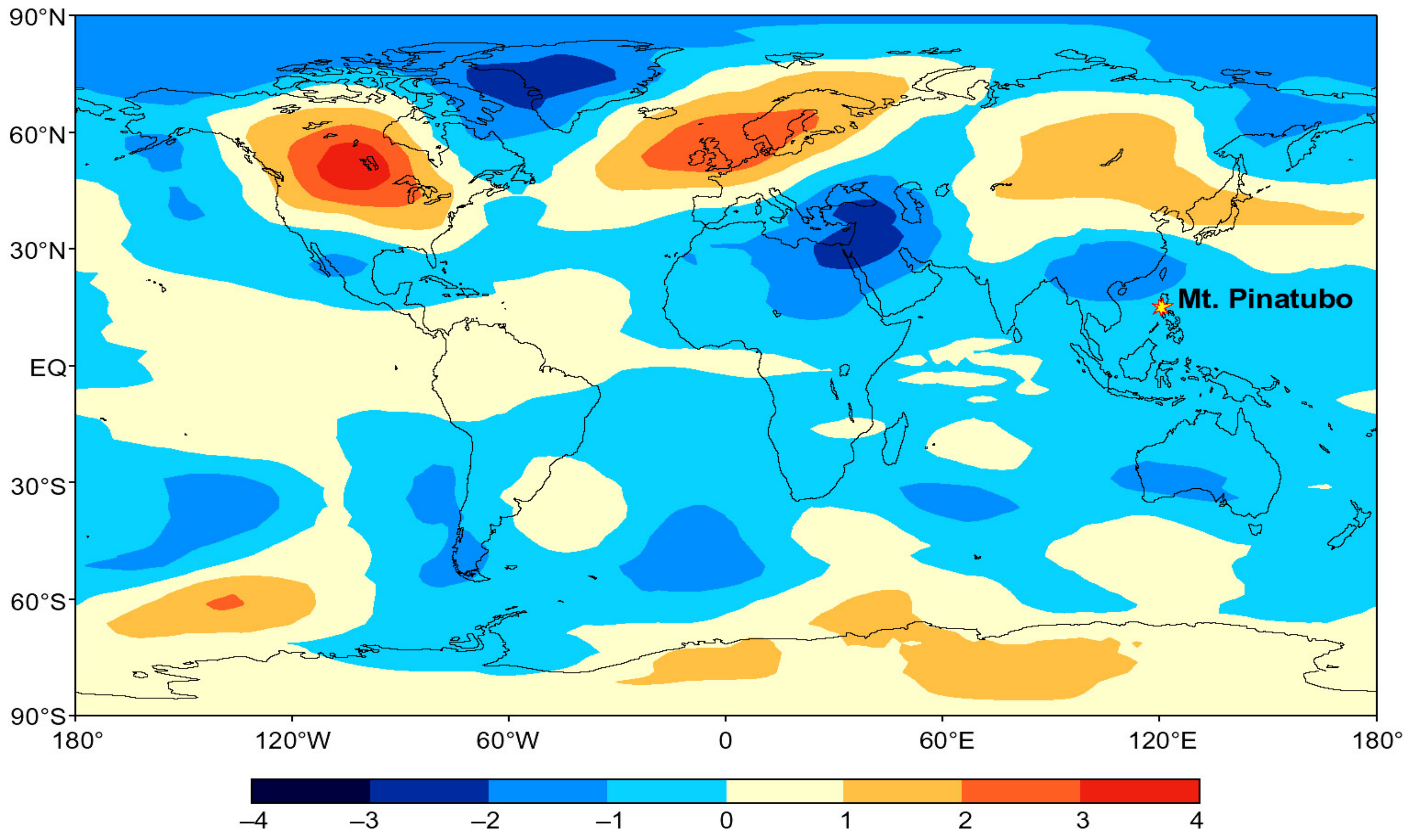
Therefore carbon dioxide ↓

Ozone ↓ 5%   Ozone hole ↑ 17%

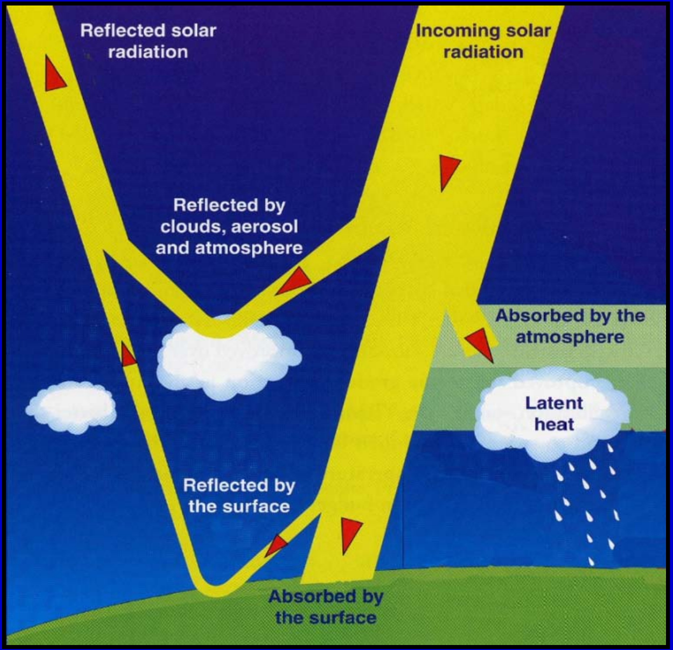
OH ↓ 10% for year and thus oxidizing capacity ↓

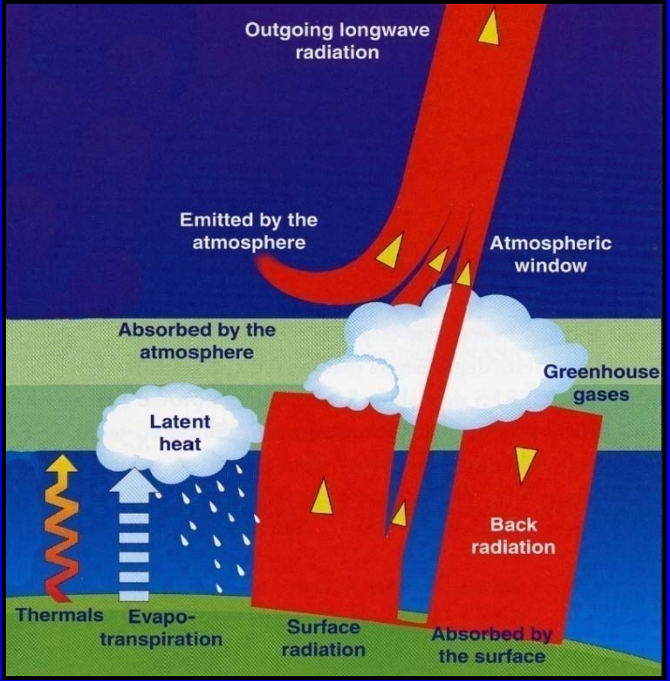
Therefore Methane ↑ Carbon monoxide ↑ Ethane ↑

Winter Temperatures Were Actually Higher Over Northern Continental Land Masses



Robock (2002)





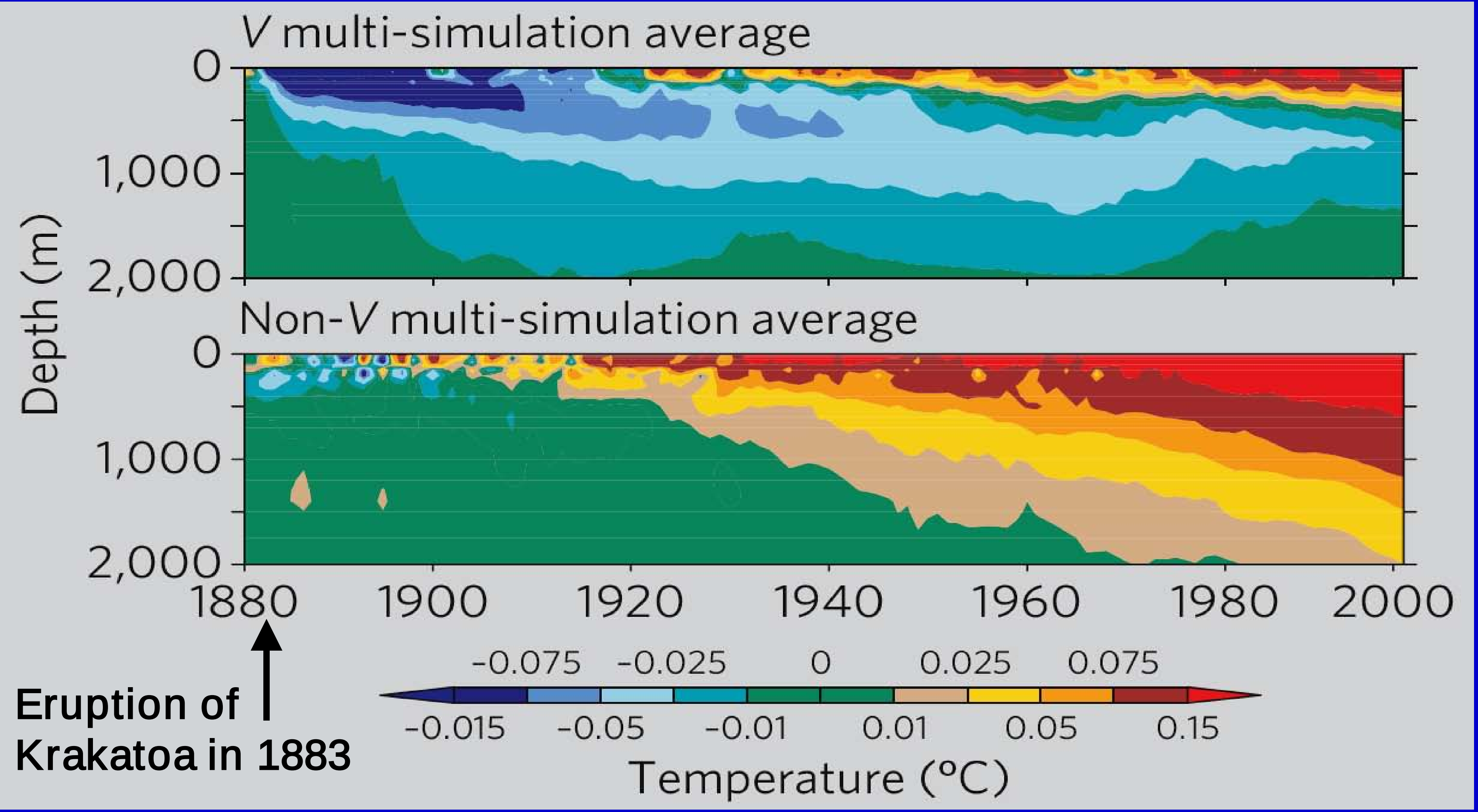
Volcanic Aerosols Have the Greatest Effect in Summer

When the sun is more directly overhead

But Greenhouse Gases May Become Dominant in Winter

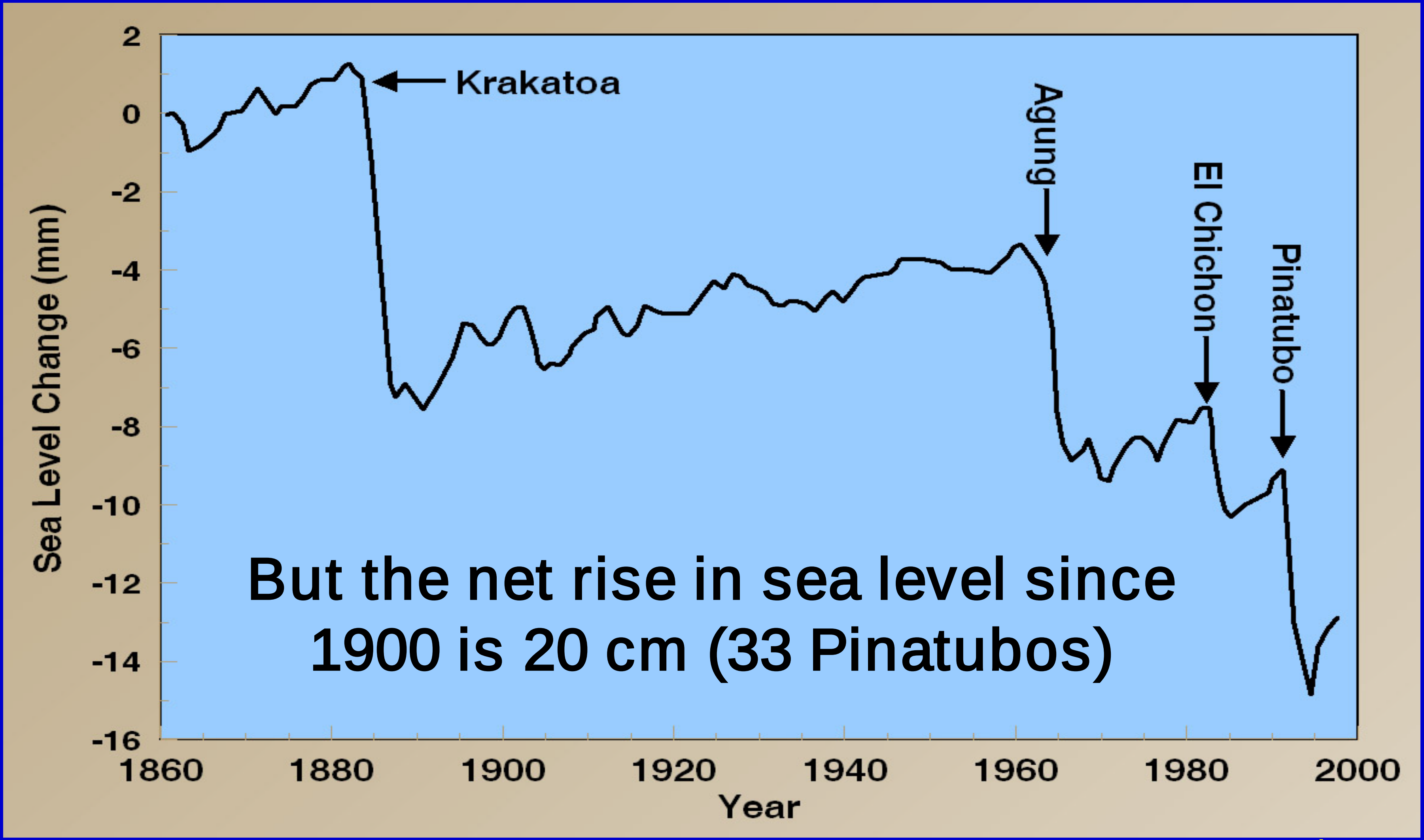
And greenhouse gases will accumulate and become even more dominant if new eruptions occur before the greenhouse gases are removed

Cooling For 3 Years Lasts Much Longer in the Ocean



Gleckler et al. 2006

Modeled Cumulative Sea Level Change Due to Volcanic Activity

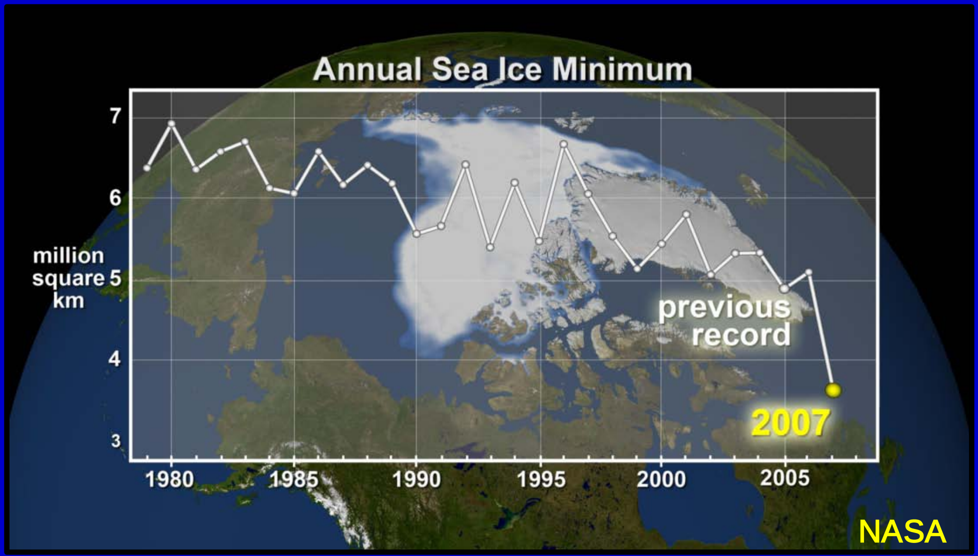


Gregory et al., 2006

A Change in the Mean Temperature of the Earth Means a Change in the Mean Temperature of the Ocean

The upper 3 m (10 ft) of the ocean stores as much heat as the whole atmosphere

The average depth is 3,790 meters (12,430 feet)



Effects of Pinatubo

All of these effects were caused by adding 17 Mt SO_2 plus sufficient water primarily to the lower stratosphere

A mere 3.4 parts per billion

But concentrated between 17 and 25 km (17%) and thus 20 parts per billion

Why Was the Aerosol So Effective?

Ozone layer formed by effects of UV light on O_2

17 Mt SO_2 erupted into the vicinity of the ozone layer

SO_2 oxidized by OH created from ozone by UV

Up to 921 Mt H_2O erupted simultaneously

H_2SO_4 has a very low vapor pressure

Aerosol concentrated by temperature inversion

Horizontal winds in stratosphere spread SO_2 efficiently

Covered 42% of the earth within 2 months

These factors typically not effective in troposphere

Eruption of Lakigigar, Iceland 1783, VEI = 4

14.7 km^3 basalt from a 27 km long fissure

122 Mt SO_2 (5 times Pinatubo) 80% in the troposphere

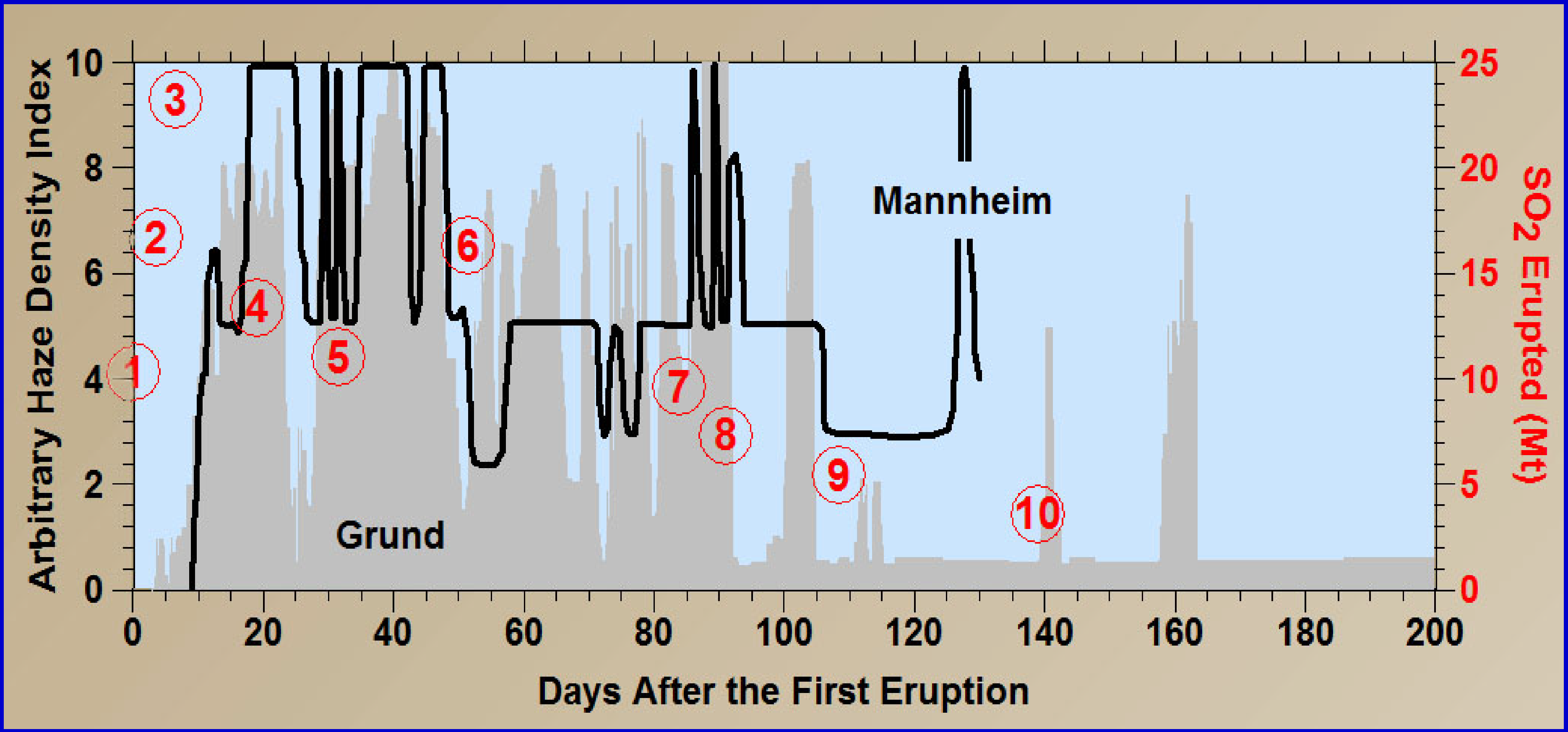
Trees, crops damaged by H_2SO_4 in Iceland, Scandinavia, Italy

>47,000 people killed from respiratory problems and famine

Lakigigar

Eyjafjallajökull (March 2010)

A Dry Fog or Haze Settled Over Europe



Grund, Iceland, NNW 80 mi (130 km)

Mannheim, Germany, ESE 1400 mi (2250 km)

Haze is Common in Polluted Cities

Kuala Lampur, Malaysia

Laki haze:

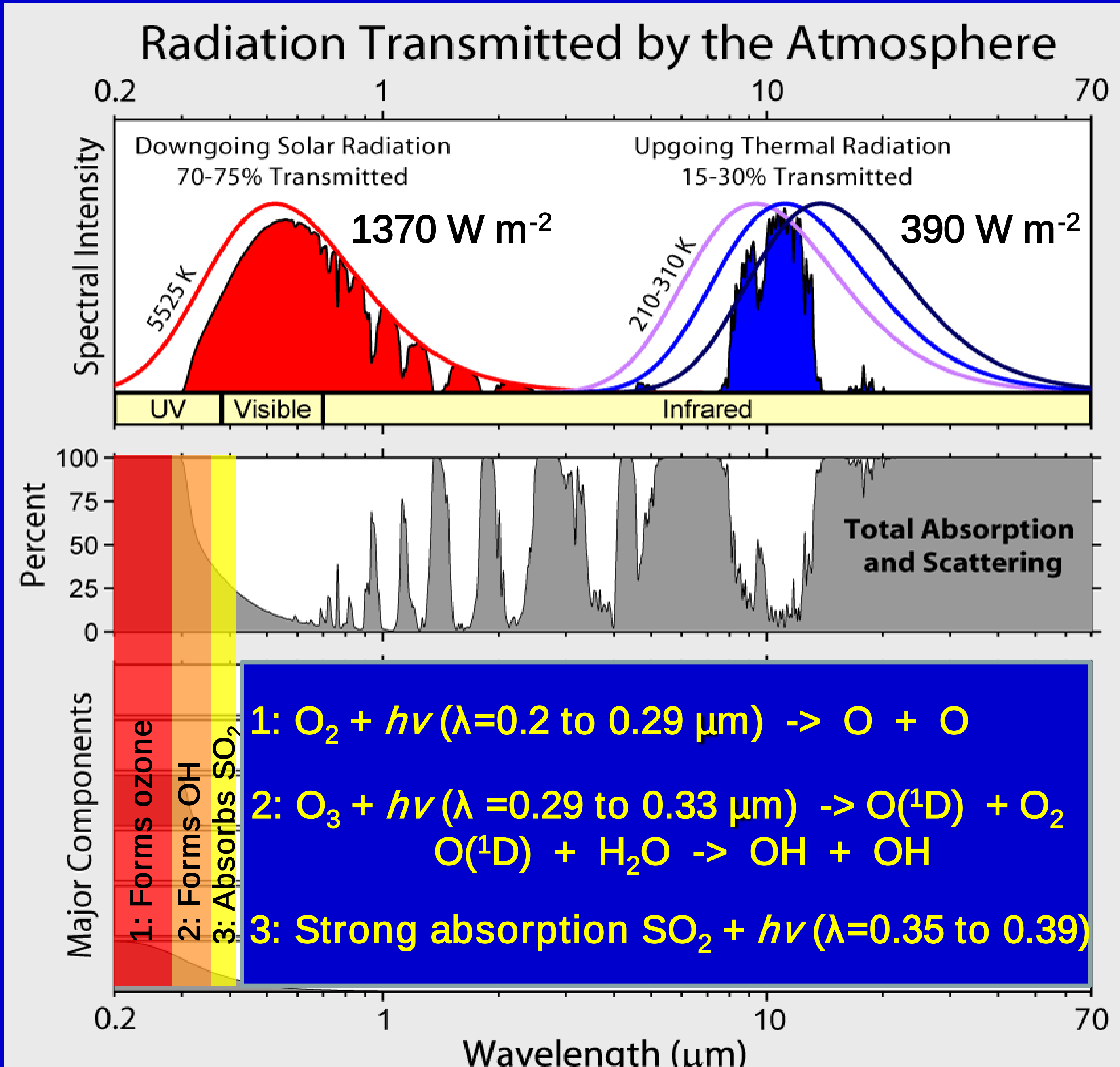
Noticeable smell of SO_2 (burnt match)

Severe irritation to respiratory passages

Severe sulfuric acid damage to vegetation

Dimmed sunlight

Raised daytime temperatures 3°C



1: $O_2 + h\nu$ (λ=0.2 to 0.29 μm) -> O + O

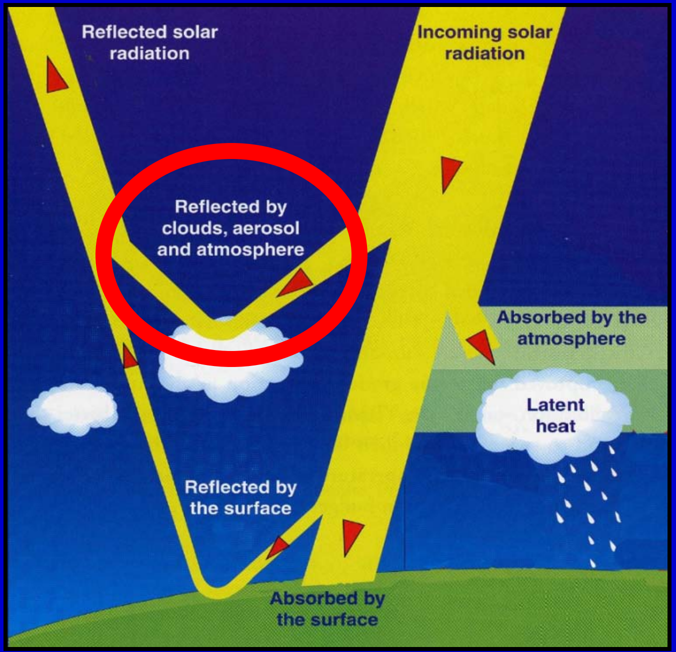
2: $O_3 + h\nu$ (λ =0.29 to 0.33 μm) -> $O(^1D) + O_2$

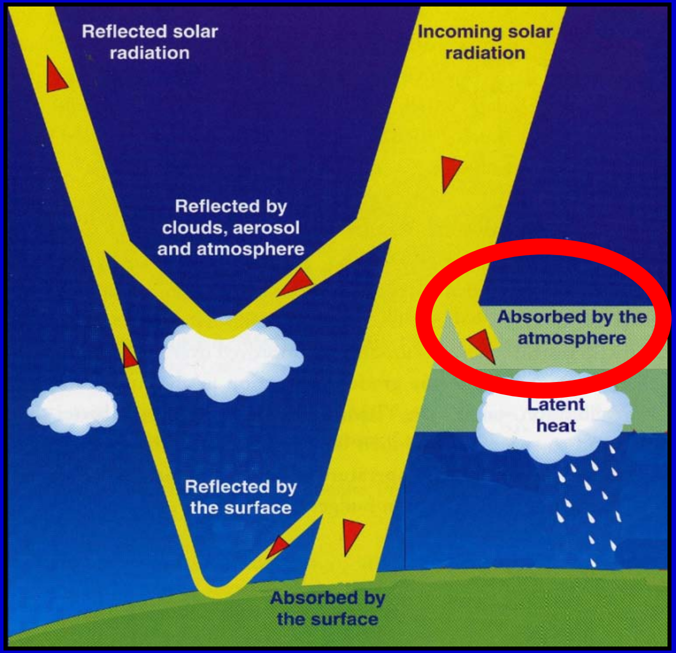
$O(^1D) + H_2O$ -> OH + OH

3: Strong absorption $SO_2 + h\nu$ (λ=0.35 to 0.39)

"Solar ultraviolet radiation plays a decisive role in almost all aspects of the chemistry of the atmosphere."

Grant W. Petty, 2006





SO_2 in the Stratosphere

SO_2 absorbs sunlight, warming the stratosphere

OH (formed by UV acting on O_3) oxidizes SO_2 to form an aerosol within months

The aerosol reflects, absorbs and scatters sunlight, cooling the earth

SO_2 in the Troposphere

Oxidized very slowly by OH and H_2O_2 because less UV and O_3 are available

Absorbs sunlight, warming the troposphere

Sulfur Cycle

Natural Emissions	Sulfur Mt/year
Oceanic, DMS	15-35
Oceanic, H_2S	2.9
Oceanic, OCS	0.3
Oceanic, CS_2	0.2
Continental Biogenic	0.2
Biomass Burning	0.1
Volcanic Background	8-20
Total	**27-59**

Volcanic Eruptions	Sulfur Mt
El Chichón, 1982	3.5
Pinatubo, 1991	8.5
Tambora, 1815	60
Laki, 1783	**61**
Toba, ~74,000 BP	>570

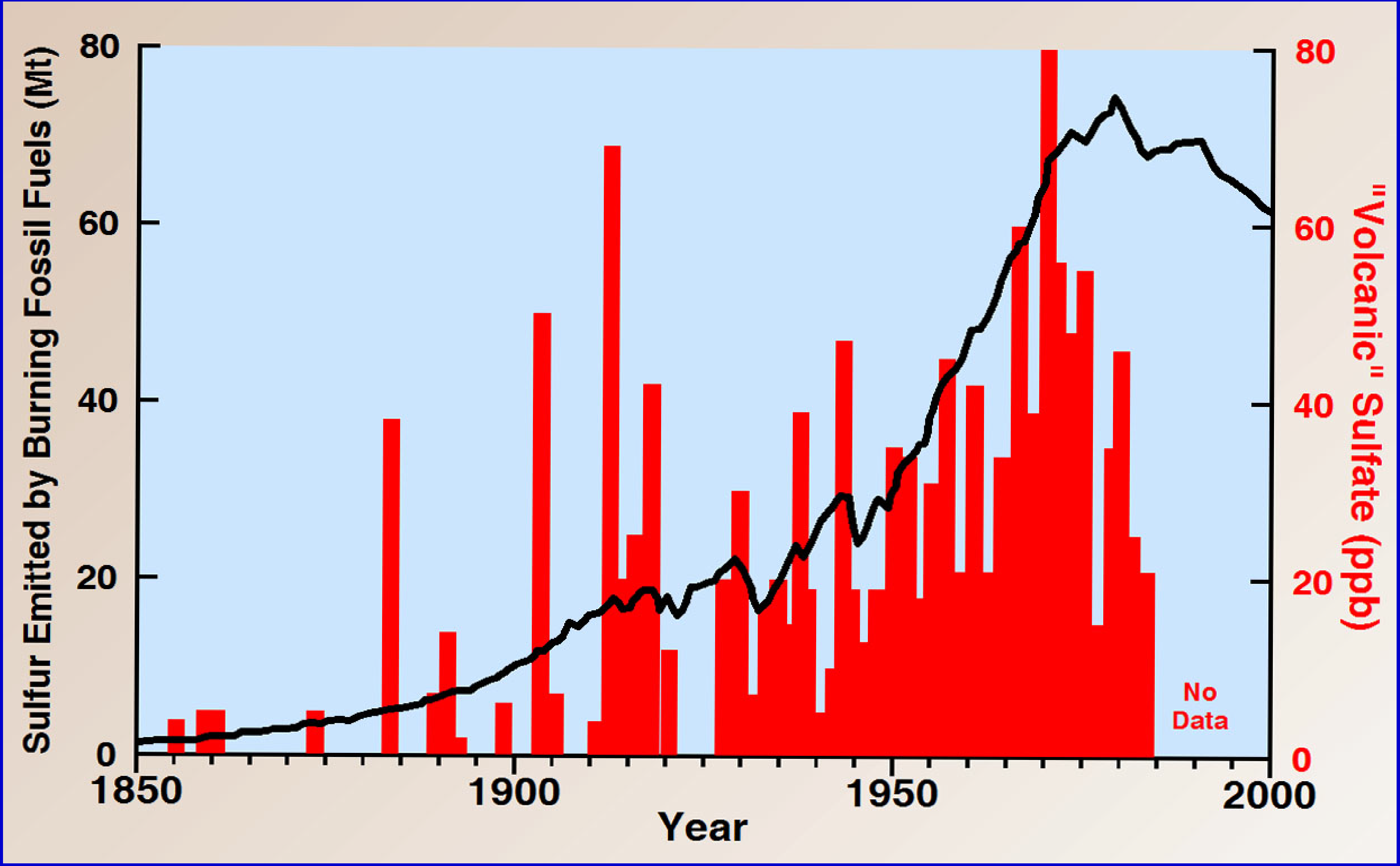
Anthropogenic Emissions	Sulfur Mt/year
2000	62
1979	**75**
1965	57
1950	32
1900	10
1850	1.5
Biomass burning	2.1

In 1979:

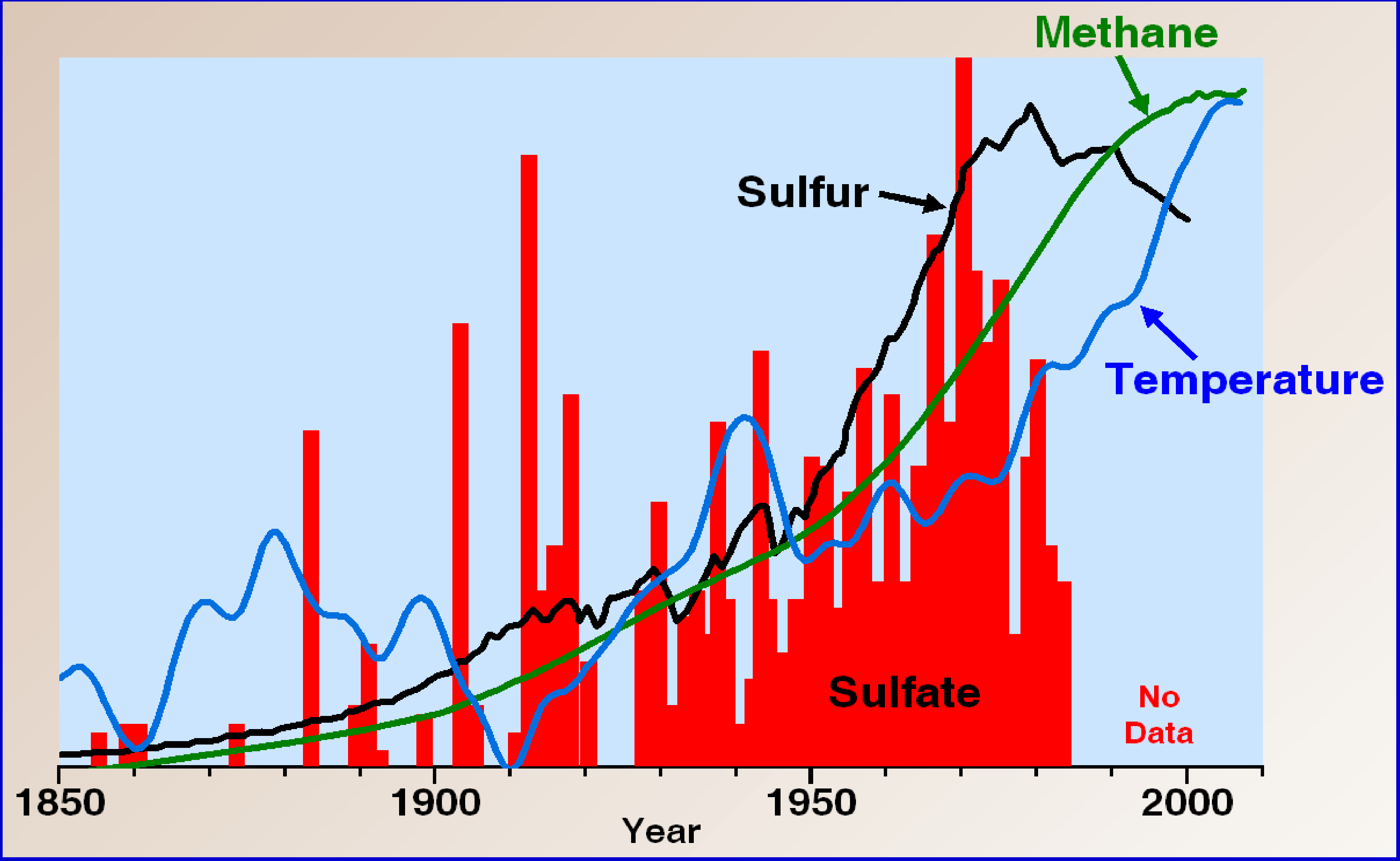
Anthropogenic emissions of SO_2 were 130% to 280% larger than the total natural emissions

Anthropogenic emissions of CO_2 and CH_4 were only 36% and 16% larger than the total natural emissions

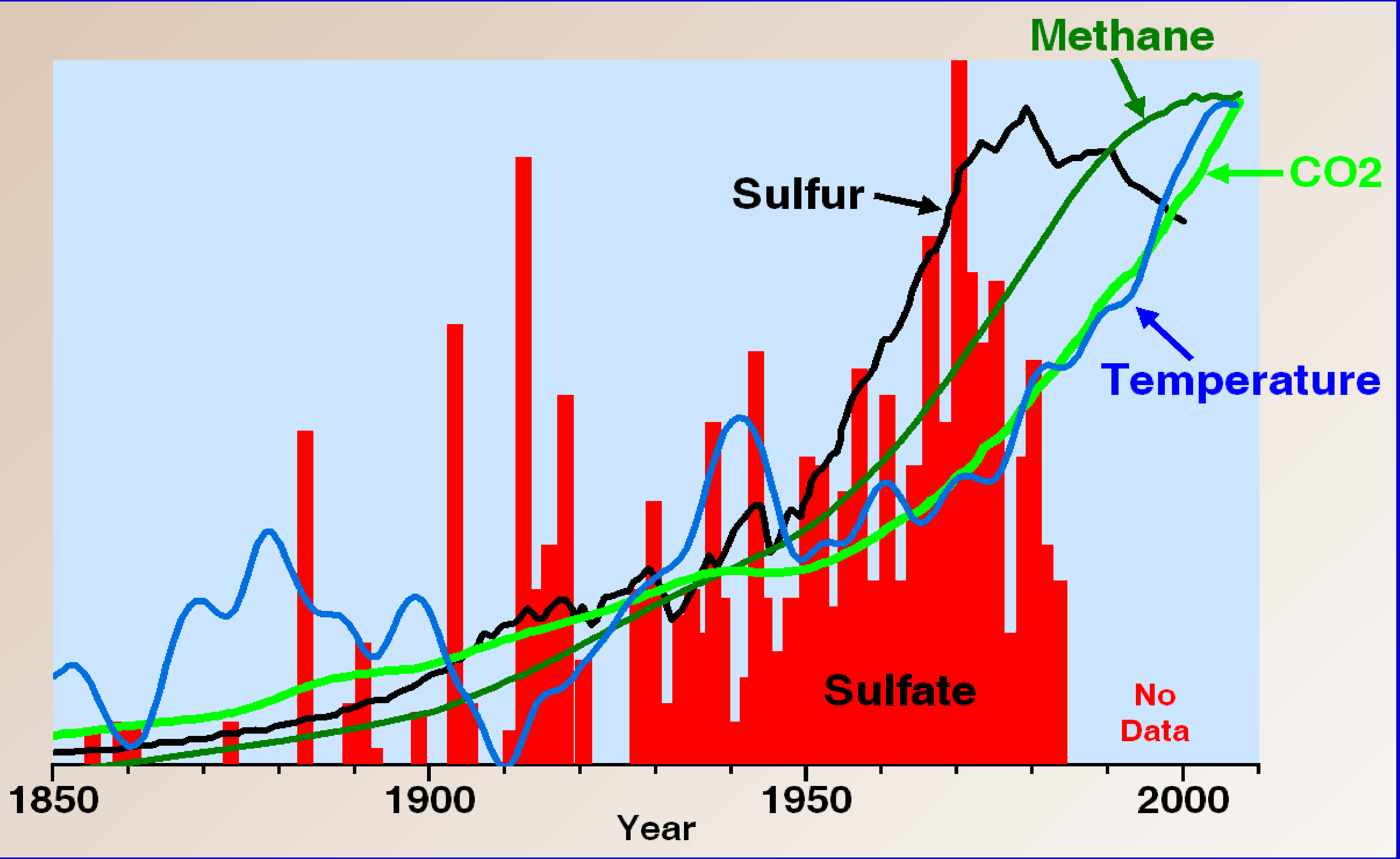
Sulfate in Greenland Changed Up and Down in Phase With Known Sulfur Emissions



Decrease in Sulfur Followed by Less Growth in Methane and Temperature



Meanwhile CO_2 Shows No Change!



But What About CO_2?

Man is adding ~8.4 Gt C/year or ~23 Mt C/day

The 1991 Pinatubo eruption added up to 234 Mt CO_2 or 63 Mt C

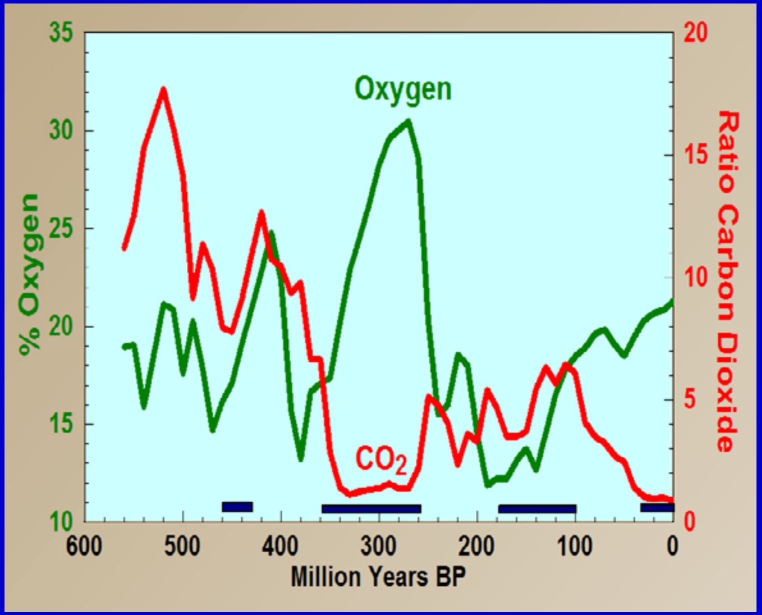
CO_2 is a greenhouse gas with an atmospheric concentration of 387 ppmv, increasing by 1.4 ppmv per year

CO_2 is removed from the atmosphere by

1. Photosynthesis in plants
2. Weathering of silicate rocks
3. Solubility in water (greater at lower temperatures)
4. Conversion by ocean organisms to tissues and hard body parts

CO_2 is added to the atmosphere by

1. Respiration by plants & animals
2. Decay of plants and animals
3. Combustion of organic material
4. Production of cement
5. Volcanic eruptions



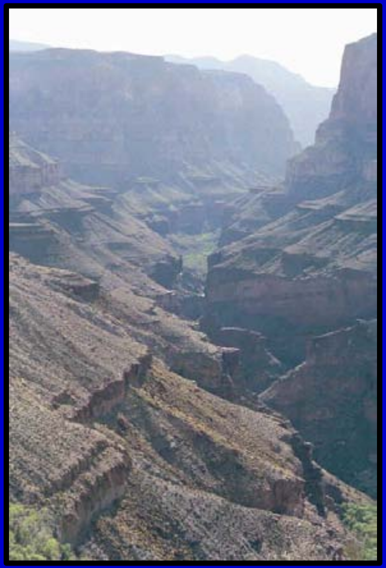
Berner, 2006, GEOCARBSULF

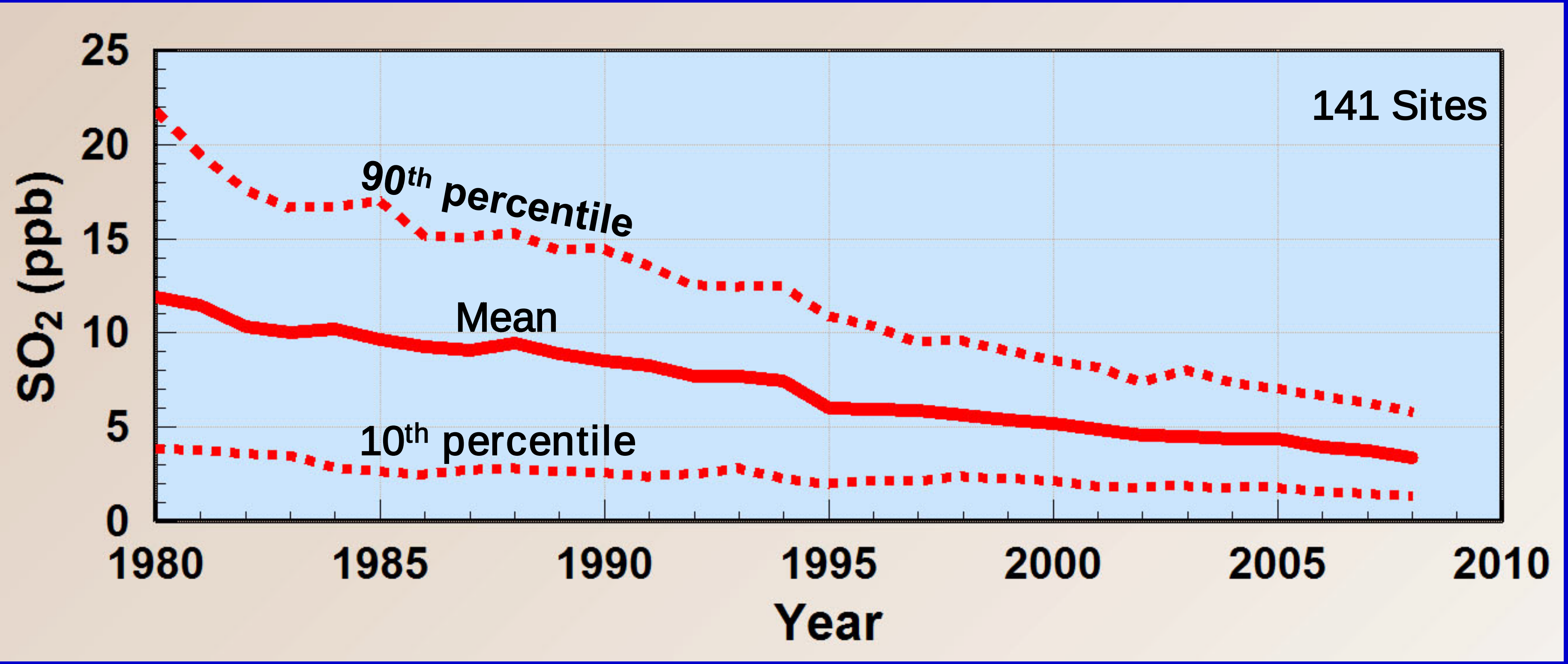
SO_2 in the United States

71% Decrease in the national average from 1980 to 2008

Highest in the East

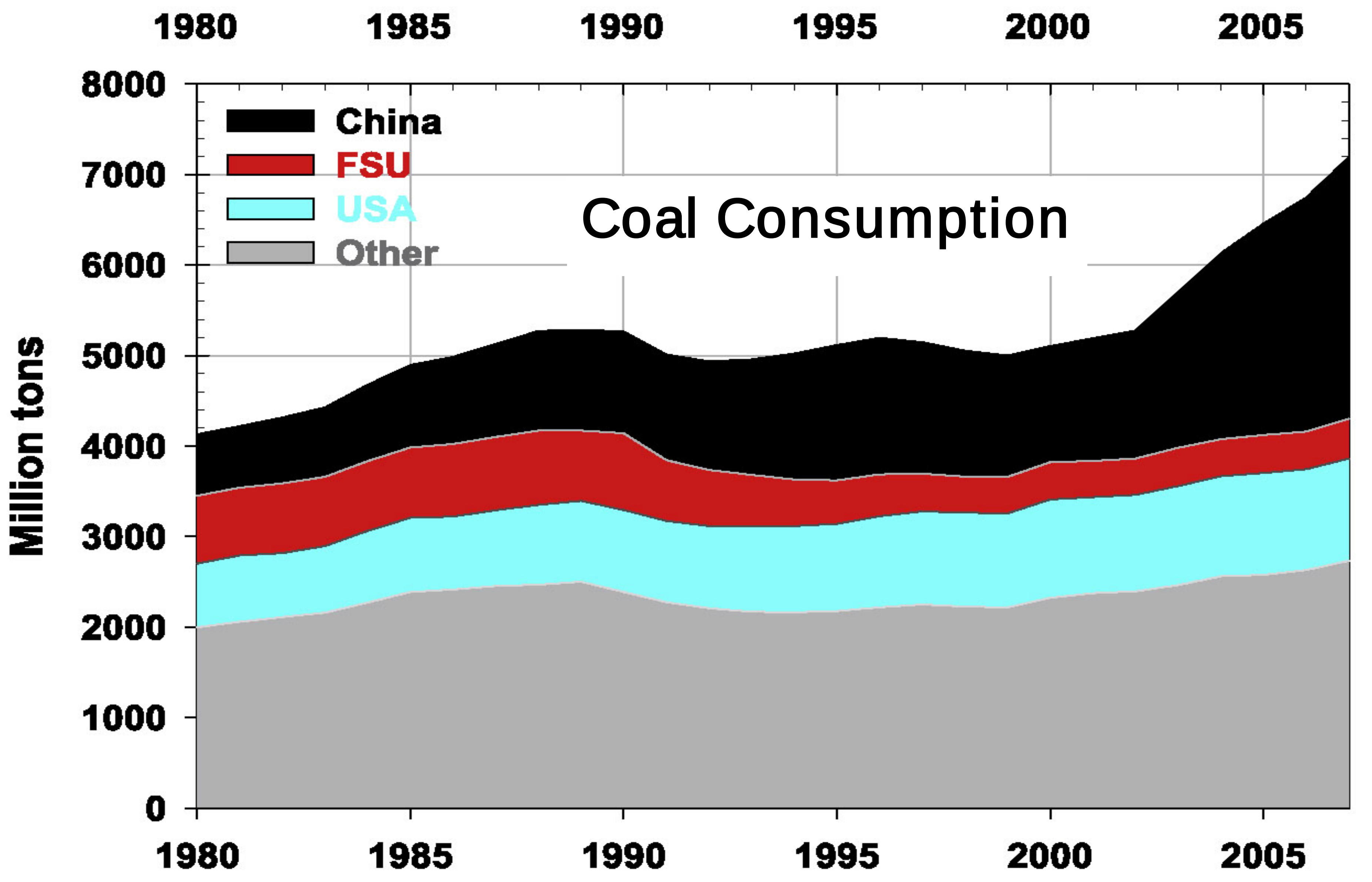
But strong in the Grand Canyon





US EPA

But SO_2 Emissions Are Rising Again



Conclusions

Sulfate levels in ice cores from central Greenland are observed to be unusually high during:

- A: 14 short periods of rapid global warming between 46,000 and 11,000 BP (Dansgaard-Oeschger) implying short high rates of major volcanism
- B: The period of most rapid global warming during the 20th century when anthropogenic emissions of sulfur were greatest

Much of the older sulfate can be traced via trace elements to volcanoes in 5Iceland and elsewhere

20th century sulfate can be traced in similar ways to smokestacks in northern Europe and northwestern Asia with sporadic contributions from central North America

The sources of SO_2 are different, but the mechanism is the same

Humans caused 20th century warming

Conclusions (Continued)

SO_2 absorbs photons from the sun very strongly at wavelengths in the UV-A range just above 0.35 µm

Photons below 0.35 µm form O_3 and OH and rarely reach the troposphere

Photons in the 0.35-0.39 µm range are the most energetic from the sun to reach the lower troposphere

This energy is turned into heat when SO_2 is present

SO_2 from Laki volcano in 1783 heated Europe 3^{o}C

Anthropogenic emissions of SO_2 were 130% to 280% larger than the total natural emissions

Anthropogenic emissions of CO_2 and CH_4 were only 36% and 16% larger than the total natural emissions

The Primary Conclusion

The primary initiator of

global warming

appears to be

solar absorbing gases
(dominantly SO_2)

not greenhouse gases
(dominantly H_2O and CO_2)

The Importance of SO_2 is Good News!!

We know how to reduce SO_2 emissions

We have done it very successfully in North America, Europe and Japan since 1979

The Clean Air Act in the United States

We can scrub it from smoke stacks and burn fuels in ways that reduce emissions

China has an aggressive program to reduce SO_2, but not aggressive enough

Reducing SO_2 emissions will also reduce both acid rain and premature life loss

Let's get on with the job!

Sulfur dioxide initiates global climate change in four ways

2009
Thin Solid Films, Volume 517, Pages 3188-3203

Peter L. Ward
U.S. Geological Survey Retired
Teton Tectonics
Jackson, Wyoming
peward@wyoming.com

www.tetontectonics.org









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