

TOPIC #13

**NATURAL
CLIMATIC FORCING**

Part I (wrap up)
&
Part II

(p 70 in Class Notes)

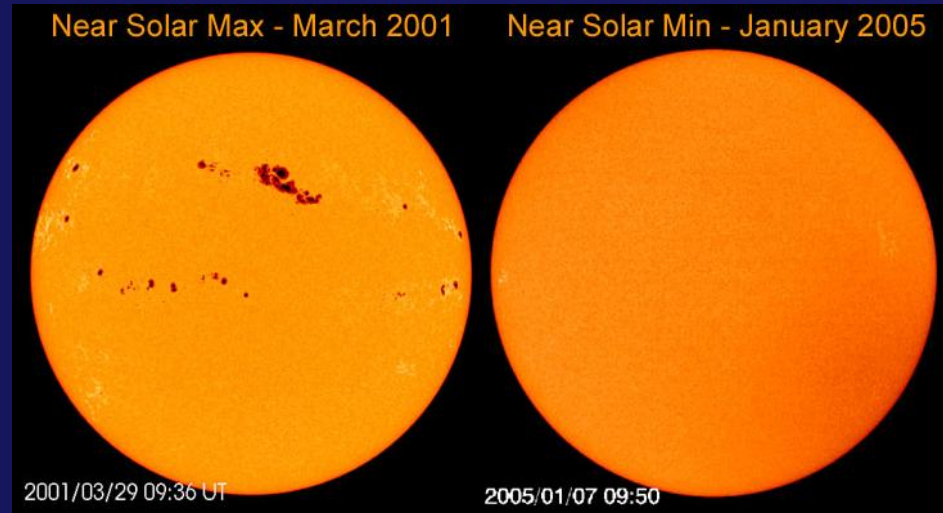
The 3 main drivers of
NATURAL CLIMATIC FORCING:

1) ASTRONOMICAL FORCING

2) SOLAR FORCING ←

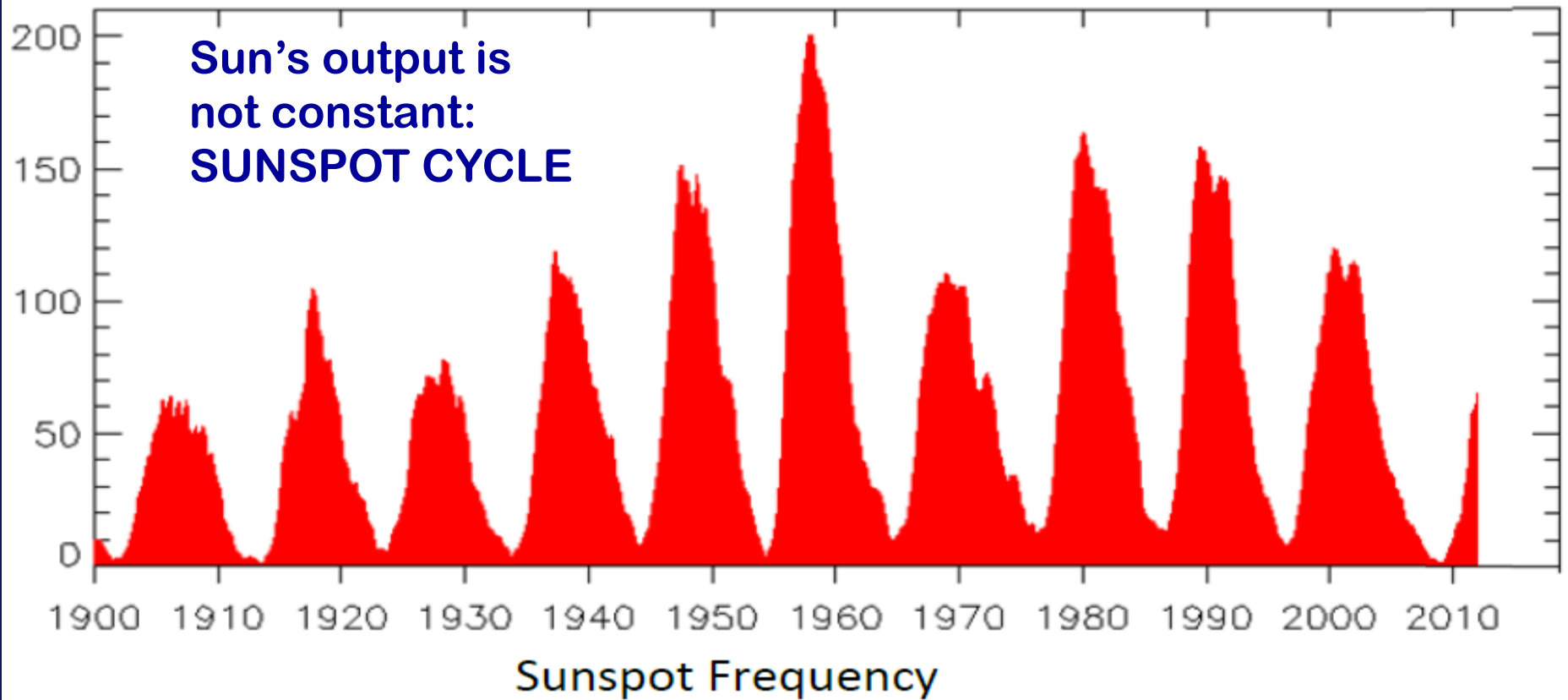
3) VOLCANIC FORCING

ANOTHER POSSIBLE NATURAL FORCING: **SOLAR VARIABILITY**



Sunspot maxima
= **MORE** solar
brightness
(warmer temps)

Sunspot minima
= **LESS** solar
brightness
(cooler temps)



http://www.sidc.be/sunspot-index-graphics/sidc_graphics.php

Sunspot maxima
= **MORE** solar
brightness
(warmer temps)

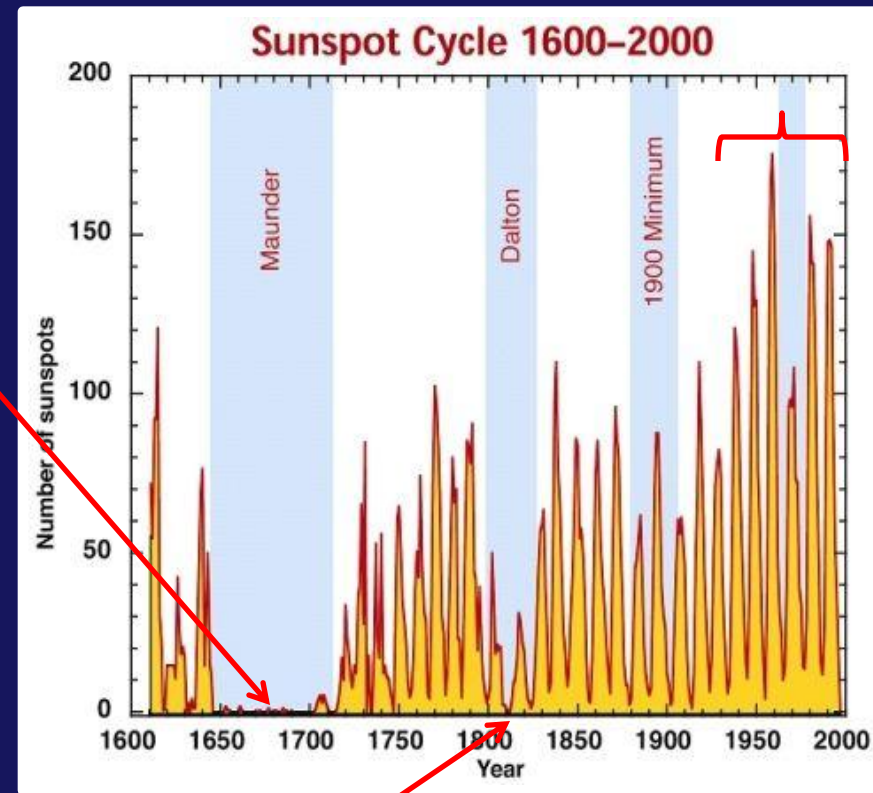
Sunspot minima
= **LESS** solar
brightness
(cooler temps)

Maunder Minimum (cooler) (1645 -1715)

linked to “Little Ice Age”
period of 1600-1800

(Also a period of lots of volcanic
eruptions (next forcing topic)

Uncertainties remain about the
MECHANISM that links the Sun’s
drop in brightness to the lower
temperatures on the Earth

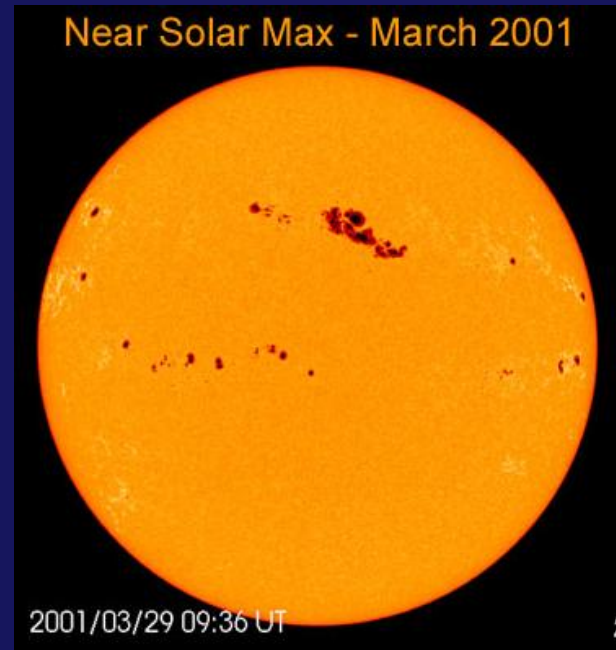


Dalton Minimum (1795 – 1825)

-- was also cooler, BUT, lots of large eruptions then too

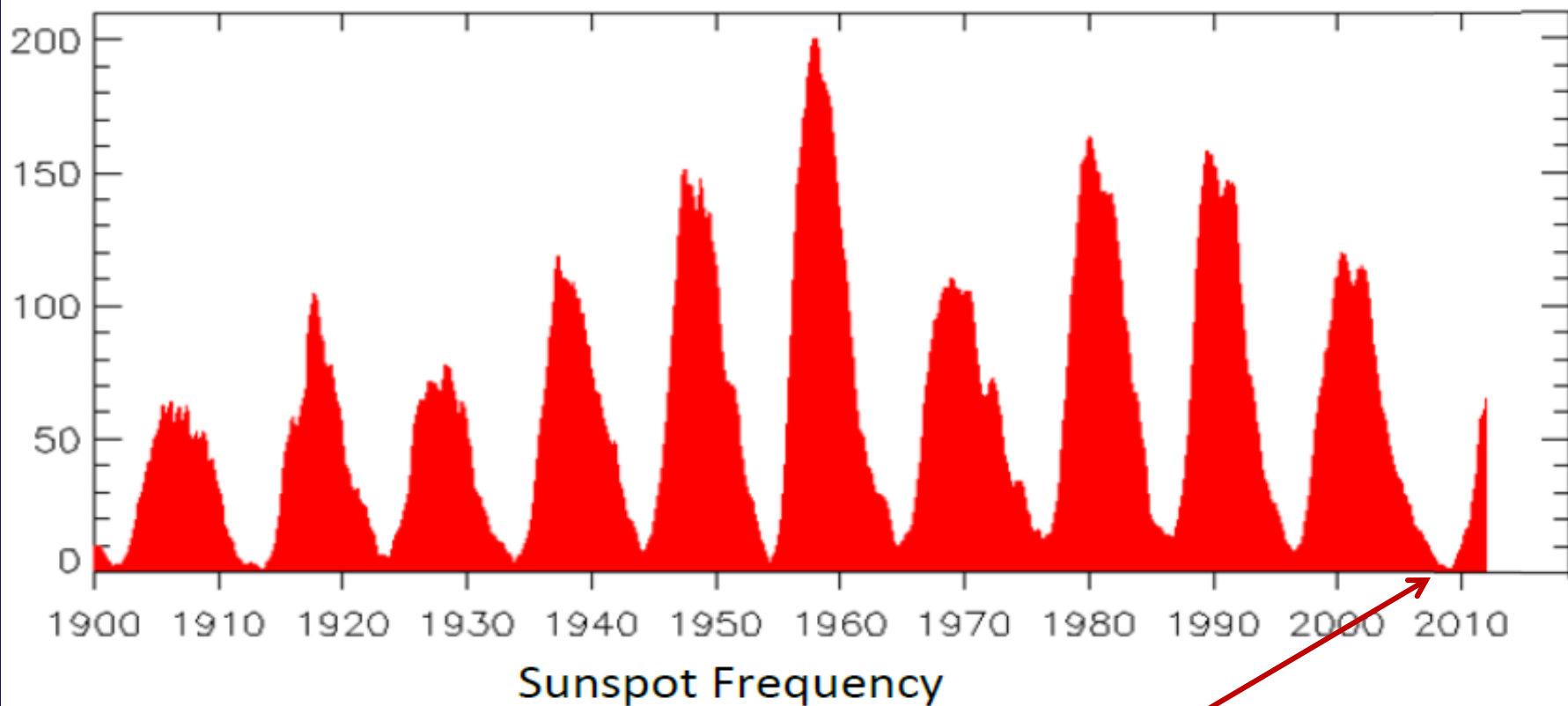
Since the Dalton Minimum, the Sun gradually
brightened to the “**Modern Maximum**” (max in 2001)

During the recent
“Modern Maximum”
the increase in
solar brightness
accounted for only:



- **about ½ of the temperature increase since 1860, and**
- **less than 1/3 since 1970**

The rest has been attributed to **greenhouse-effect warming** by most experts in solar forcing.



Recently we were in a **SOLAR MINIMUM**

– *this caused some (controversial) interest because:*

- minimum seemed unusually long
- number of “spotless” days has not been equaled since 1933
- the vigor of sunspots (in terms of magnetic strength and area) has greatly diminished
- **Speculation: are we going into another Maunder-like period?**
Or **Will normal activity return within the year?**

Scientist Predicts Ice Age Within 10 Years



Not by Fire but by Ice
THE NEXT ICE AGE - NOW!

University of Mexico expert says lack of solar activity to cause significant cooling that will last over half a century

Paul Joseph Watson
Prison Planet
Tuesday, August 19, 2008

As evidence builds of the earth entering a dramatic cooling trend, another scientist has gone public with his conviction that we are about to enter a new ice age, rendering warnings about global warming fraudulent and irrelevant.

Death Of Sunspot Activity To Herald New Ice Age



... predicts two degree drop in temperatures over next two decades
... windles

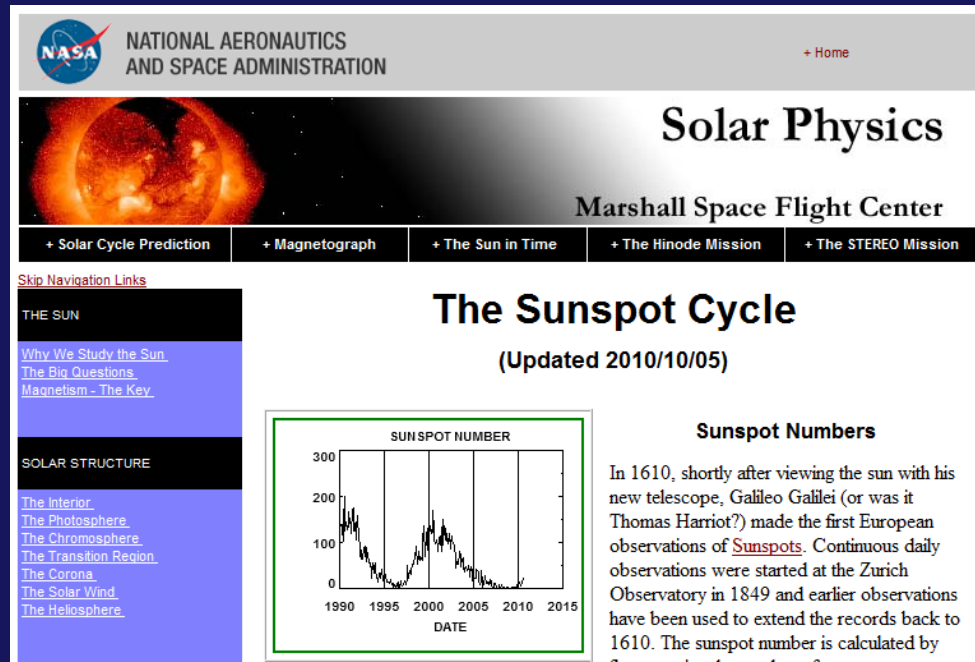
... en measuring sun cycles for over 200 years predicts that global
... degrees over the next two decades as solar activity grinds to a halt
... down, potentially heralding the onset of a new ice age.

... d politicized bodies like the IPCC scaremonger about the
... the poor and middle class pay CO2 taxes, both hard
... ence points to a clear cooling trend.

... - active period in over 11,000 years, the **last 10 years have**
... trend as temperatures post-1998 leveled out and are now

So what happened?

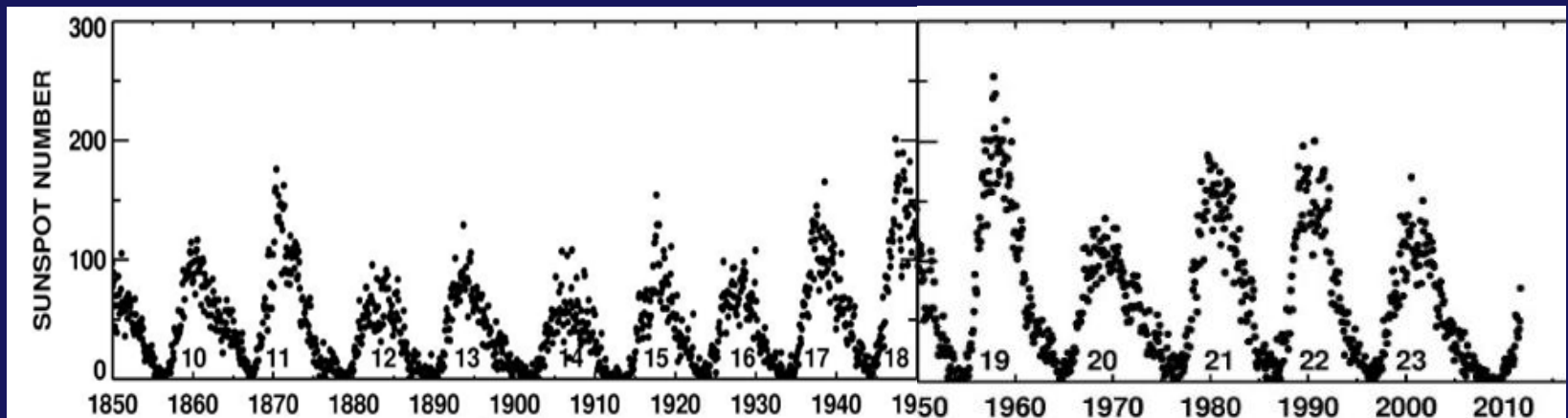
Forget the return of an Ice Age . . .
Brightness is increasing again . . .



The screenshot shows the NASA Solar Physics website. At the top left is the NASA logo and the text 'NATIONAL AERONAUTICS AND SPACE ADMINISTRATION'. To the right is a '+ Home' link. Below this is a banner image of the Sun with the text 'Solar Physics' and 'Marshall Space Flight Center'. A navigation bar contains links: '+ Solar Cycle Prediction', '+ Magnetograph', '+ The Sun in Time', '+ The Hinode Mission', and '+ The STEREO Mission'. On the left is a 'Skip Navigation Links' section with two categories: 'THE SUN' (with links for 'Why We Study the Sun', 'The Big Questions', and 'Magnetism - The Key') and 'SOLAR STRUCTURE' (with links for 'The Interior', 'The Photosphere', 'The Chromosphere', 'The Transition Region', 'The Corona', 'The Solar Wind', and 'The Heliosphere'). The main content area is titled 'The Sunspot Cycle (Updated 2010/10/05)'. It features a line graph of 'SUN SPOT NUMBER' from 1990 to 2015, showing a clear cyclical pattern with peaks around 1995, 2000, and 2005. To the right of the graph is a text block titled 'Sunspot Numbers' which states: 'In 1610, shortly after viewing the sun with his new telescope, Galileo Galilei (or was it Thomas Harriot?) made the first European observations of Sunspots. Continuous daily observations were started at the Zurich Observatory in 1849 and earlier observations have been used to extend the records back to 1610. The sunspot number is calculated by'.

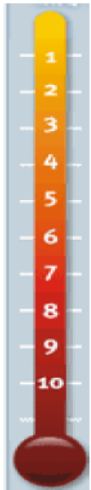
Good webpage on sunspots:

<http://solarscience.msfc.nasa.gov/SunspotCycle.shtml>



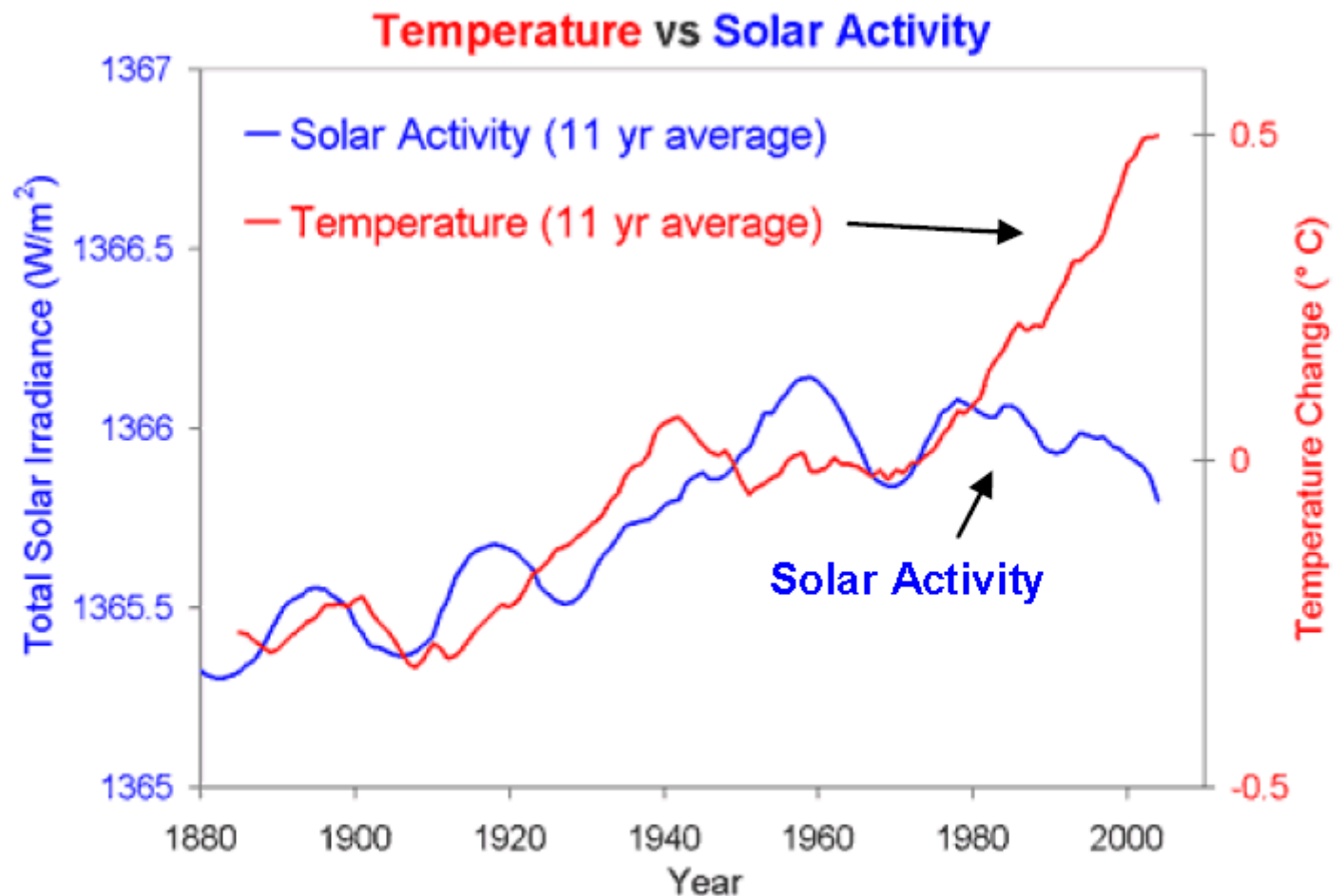
SEE ALSO: http://www.sidc.be/sunspot-index-graphics/sidc_graphics.php

Indicator Interlude . . .

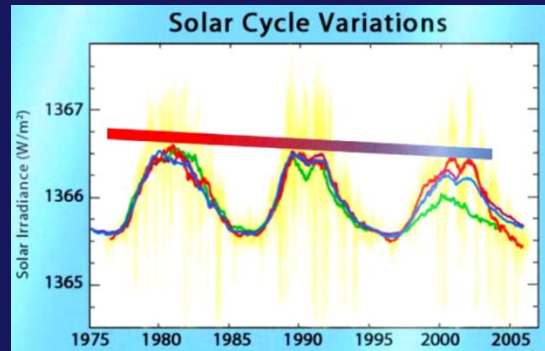


**Denier
Argument #2:**

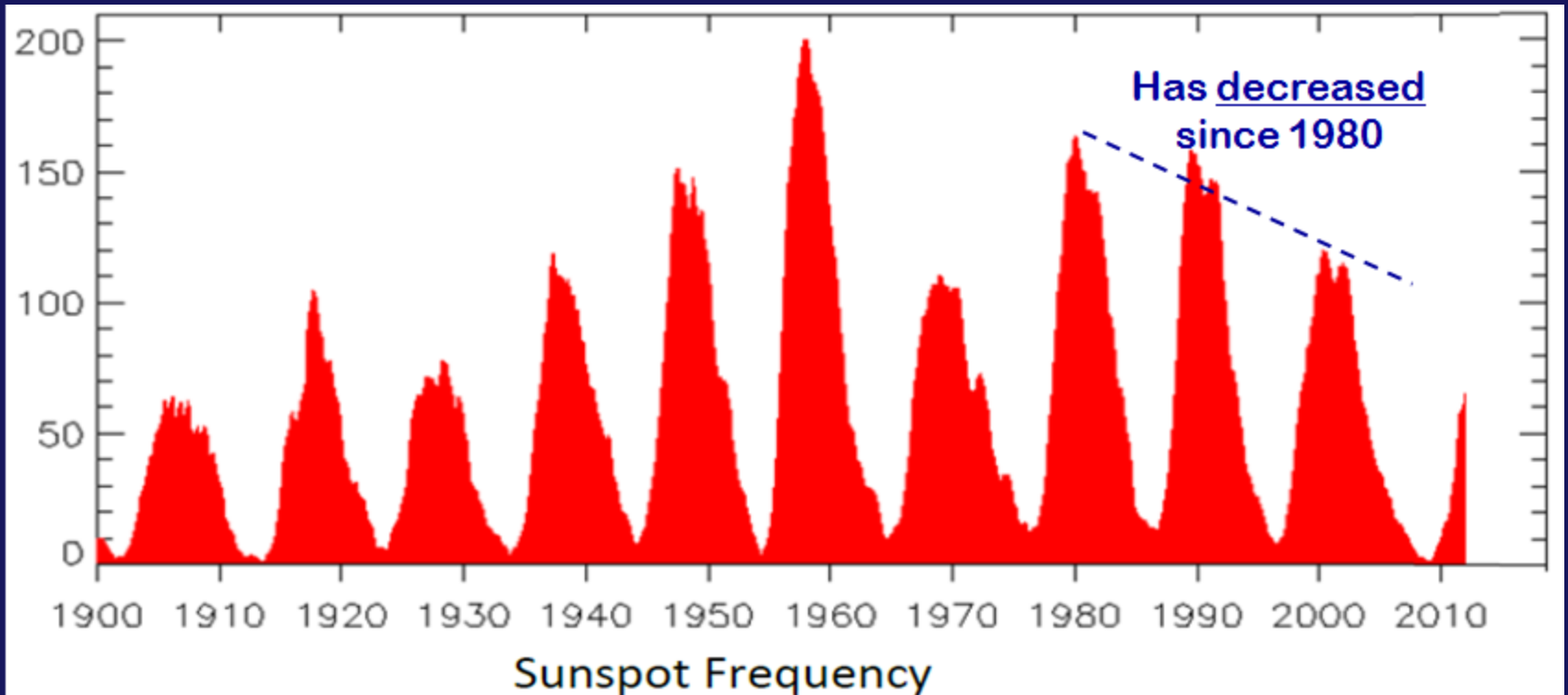
"It's the Sun"



Global temperature ([NASA GISS](#)) and Total solar irradiance (1880 to 1978 from [Solanki](#), 1979 to 2009 from [PMOD](#)).



← “Clearing the Air”
in Lesson 2





INDICATOR
INTERLUDE . . .

The Greenhouse
Warming Signature:
*"Increasing CO₂ warms
the Troposphere and
cools the Stratosphere"*



What would a SOLAR Warming Signature look like?

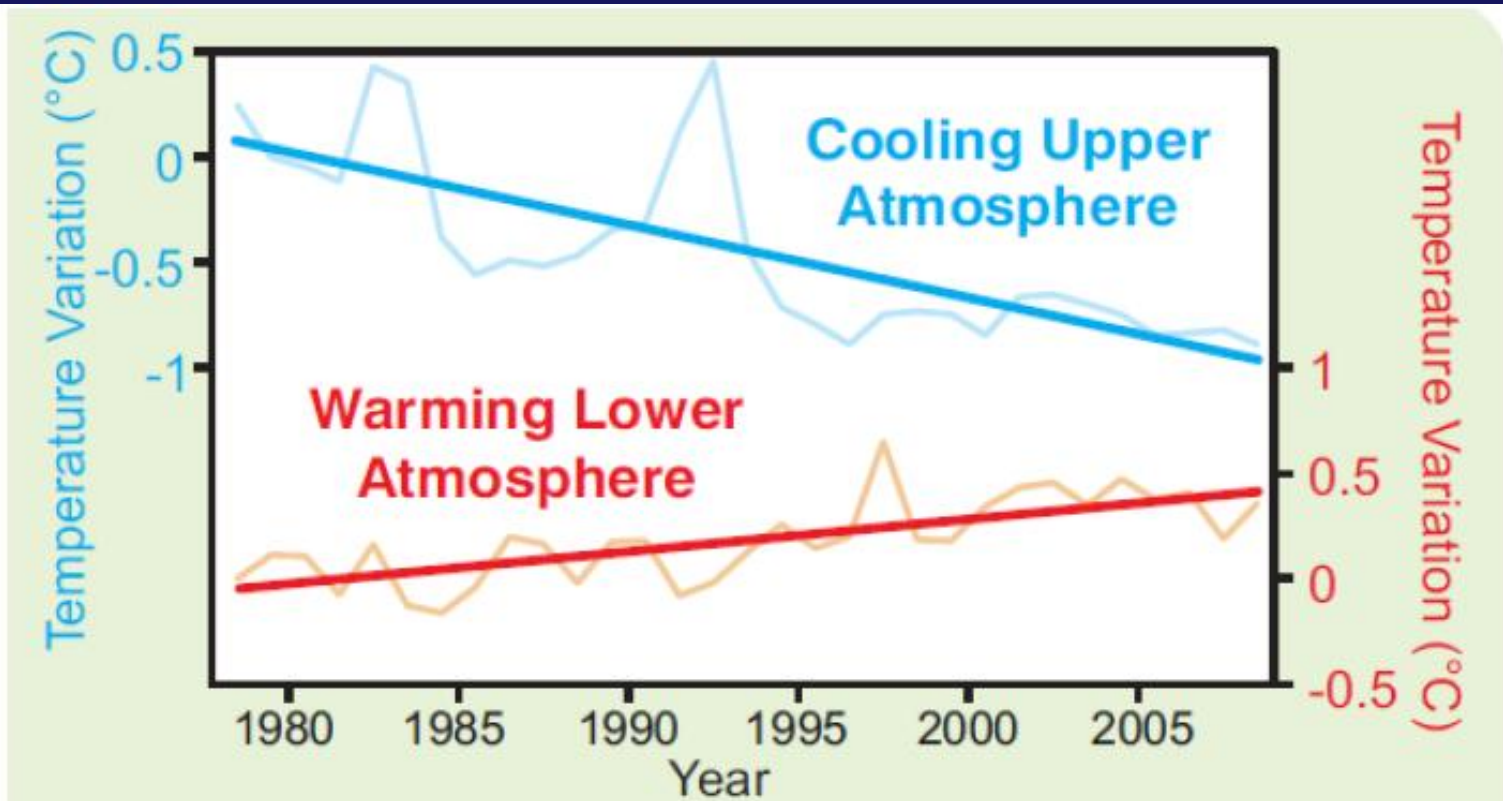
From page 39

Solar Signature: would be the opposite!!

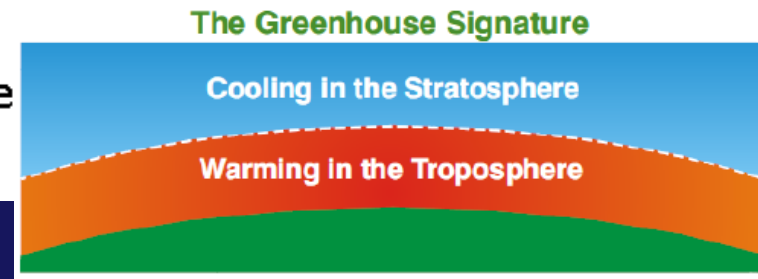
WARMING in the upper atmosphere
& **COOLING** in the Troposphere

Review

What has been observed since 1980?



Temperature variations (degrees C) in the upper (stratosphere) and lower (troposphere) atmosphere (measured by satellites)



Next we will focus on the
third main driver of
NATURAL CLIMATIC FORCING:

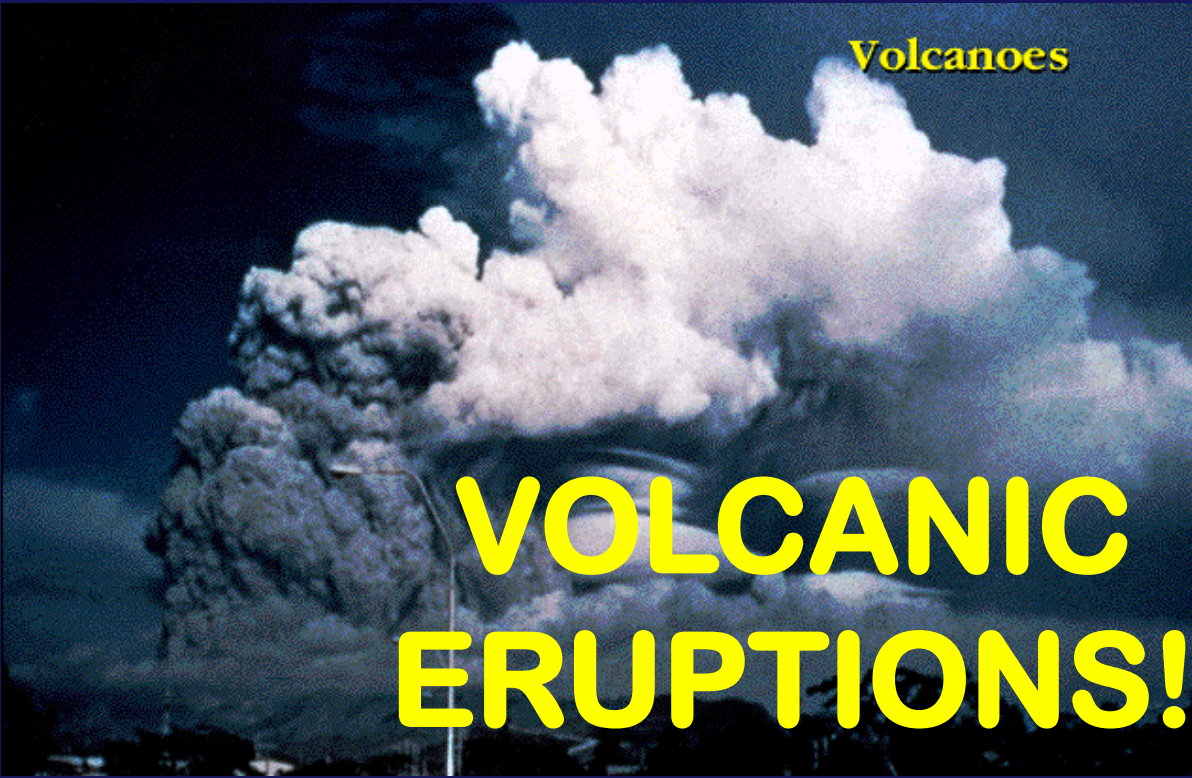
1) ASTRONOMICAL FORCING

2) SOLAR FORCING

3) VOLCANIC FORCING ←

Volcanoes

VOLCANIC ERUPTIONS!



**Volcanoes are one way the
Earth gives birth to itself.**

~Robert Gross

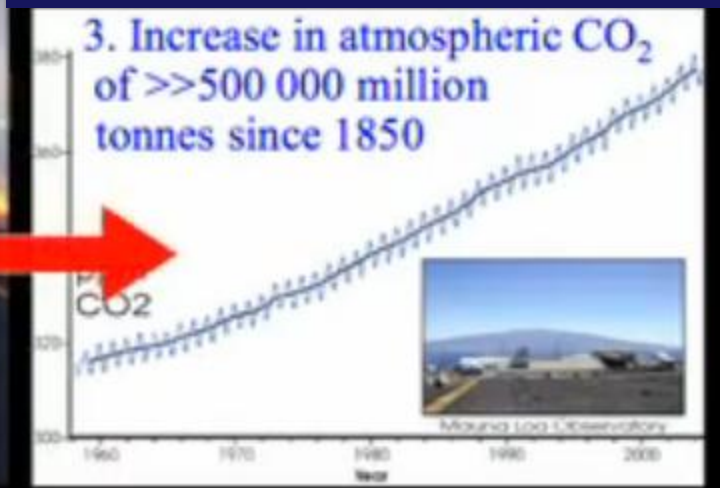
Volcanic eruptions contribute to the **natural Greenhouse Effect** by adding CO₂ into the atmosphere:

Volcanic “outgassing” of CO₂ into atmosphere

0.06 Gtons



Is CO₂ emitted by volcanoes an important natural cause of the recent global warming observed?



Q1 – Are volcanic eruptions an important cause of recent **global warming**?

1 – YES! The **CO2** they give off is a key cause of the enhanced GH Effect

2 – NO! It's the ash (not CO2) that volcanic eruptions eject that is important & it causes global cooling not warming.

3- NO! The **CO2** that volcanic eruptions emit is a natural part of the carbon cycle and it **balances out**

Q1 – Are volcanic eruptions an important cause of recent **global warming**?

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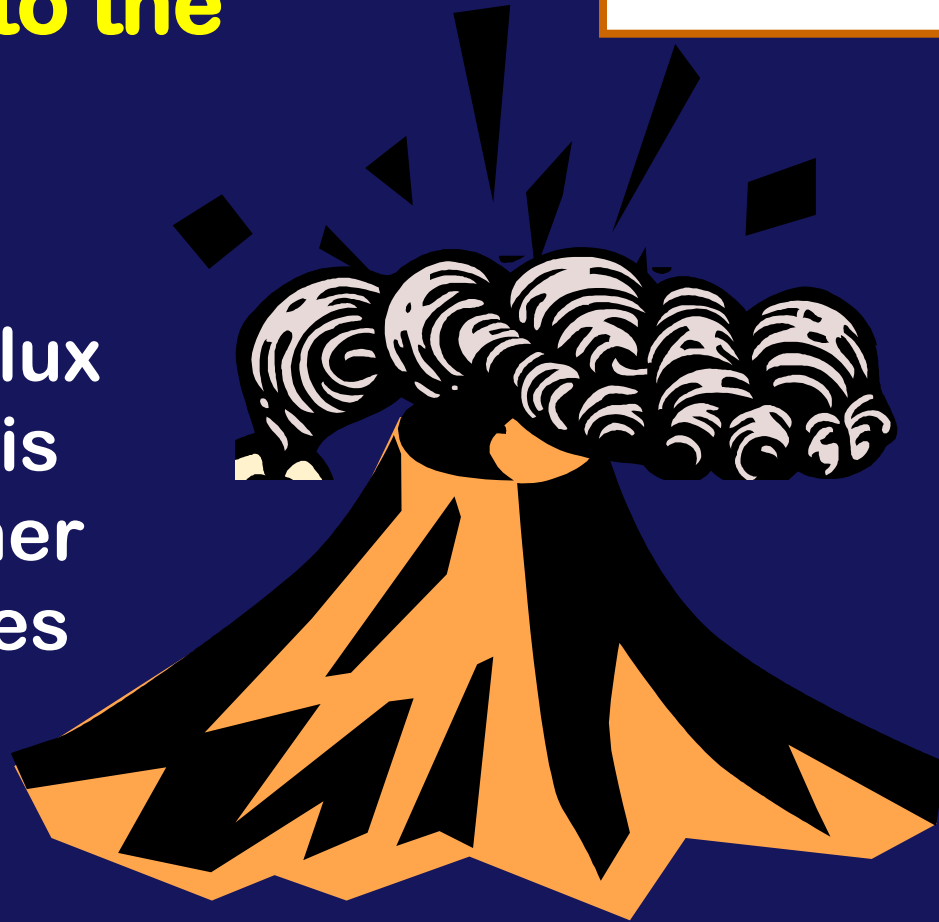
3- NO! The **CO2** that volcanic eruptions emit is a natural part of the carbon cycle and it **balances out**

Carbon flux from
volcanic eruptions
**What about the
CO₂ emitted into the
atmosphere?**

Over time, this
natural carbon flux
balances out & is
absorbed by other
natural processes
in the carbon
cycle

**Volcanic outgassing
of CO₂
into atmosphere**

0.06 Gtons

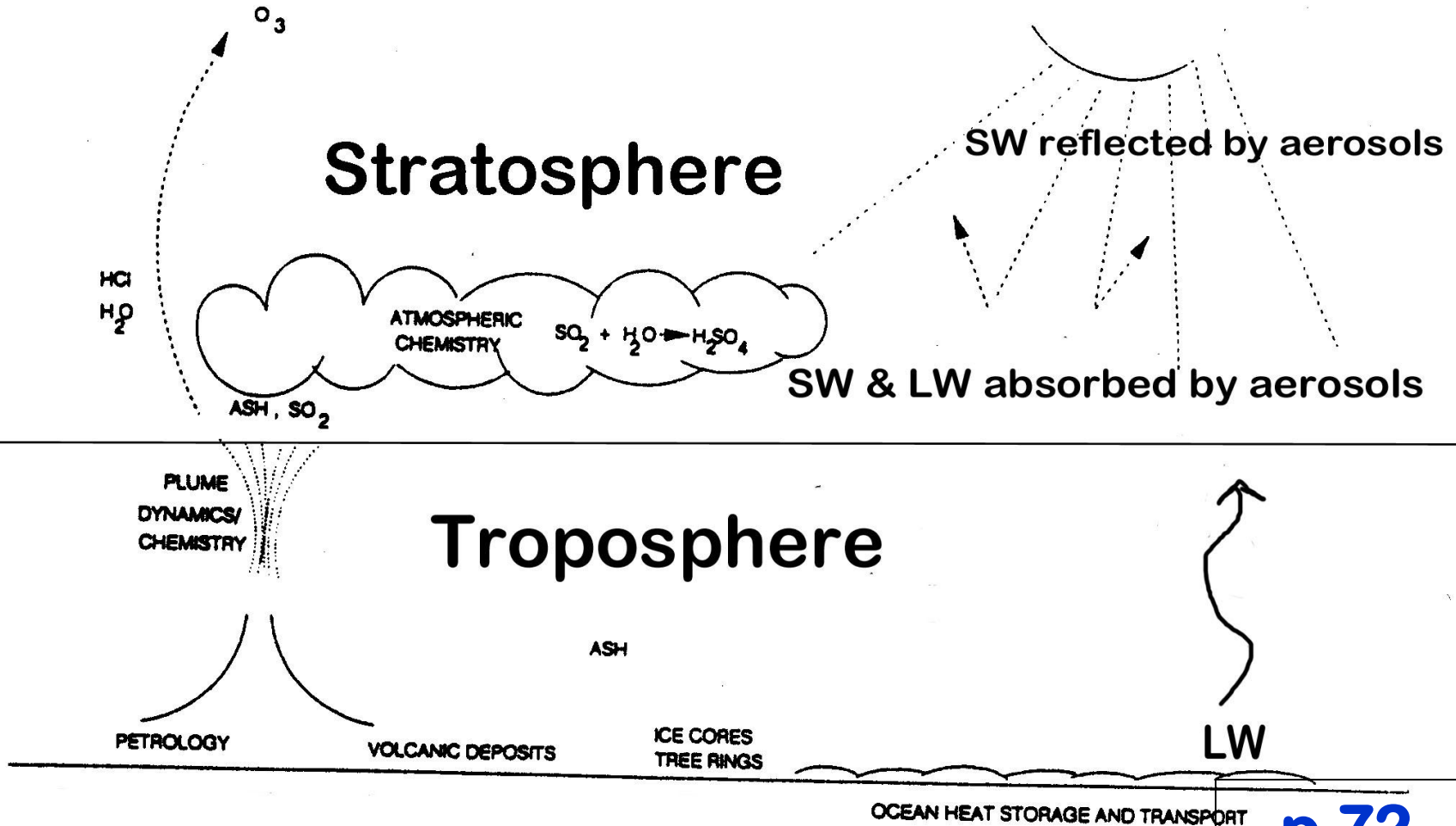


But eruptions can have a
more direct
climatic effect
under certain conditions . . .



How the Climatic Effect Occurs through **the ENERGY BALANCE** of course!

ozone destruction hastened by chemical reactions on aerosol surfaces



Large volcanic eruptions inject sulfur gases, water vapor, HCL into the stratosphere:

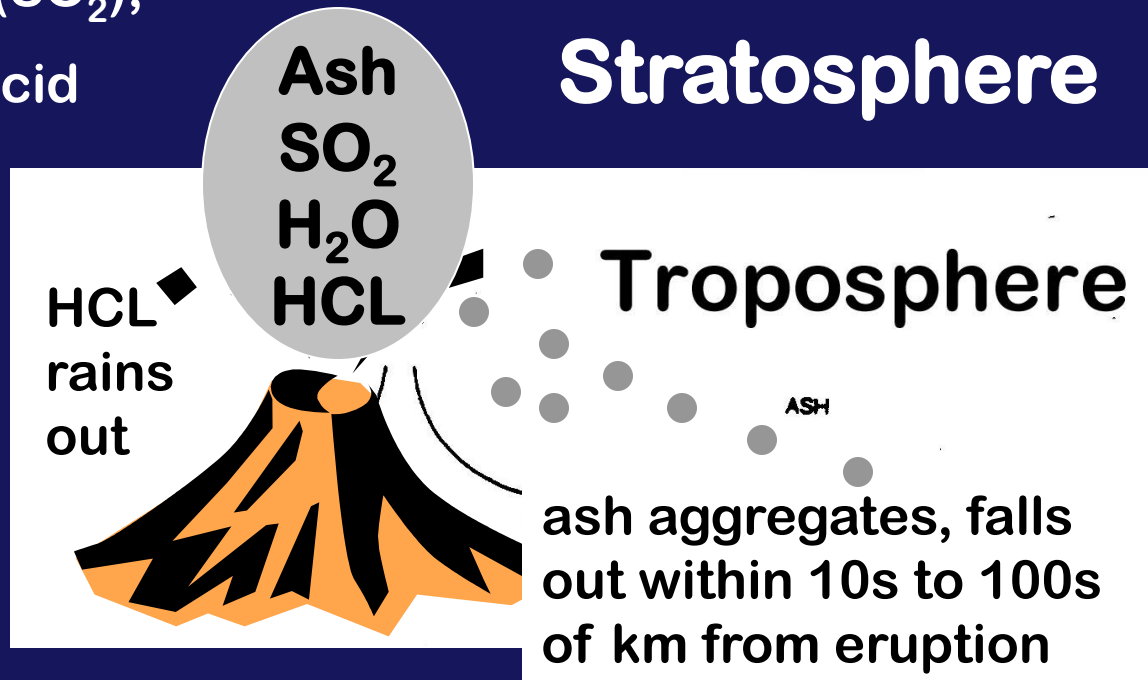
water vapor (H_2O)

sulfur dioxide (SO_2),

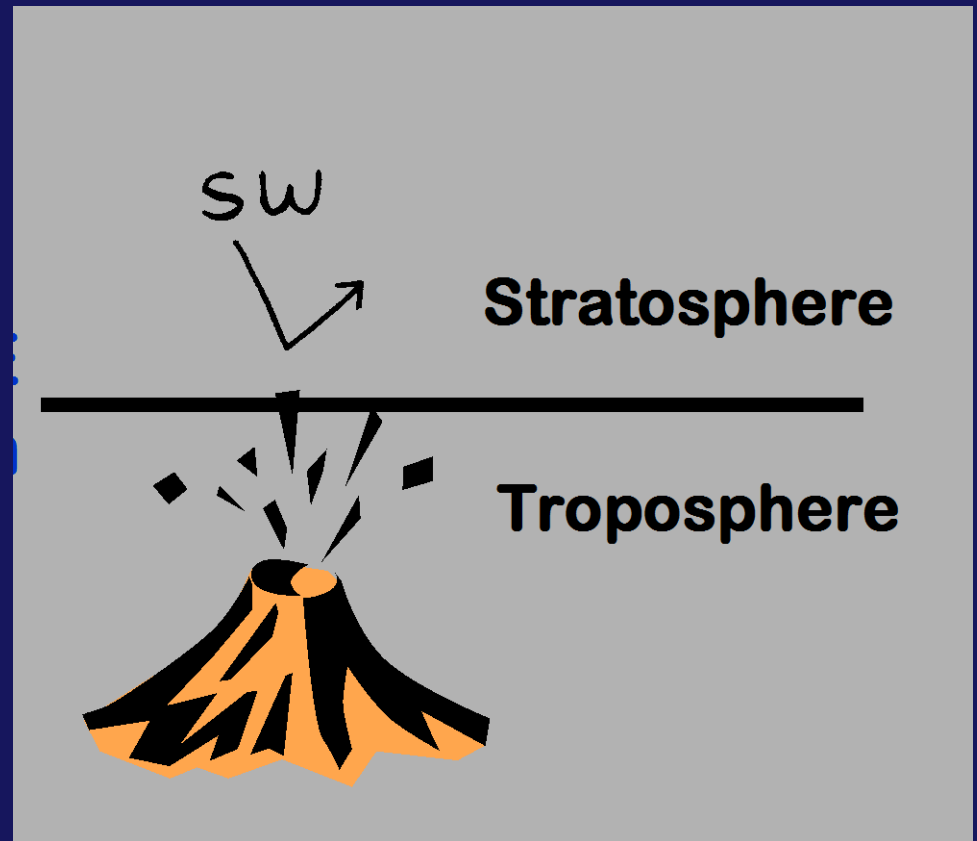
hydrochloric acid
(HCl)

mineral ash

into the
stratosphere

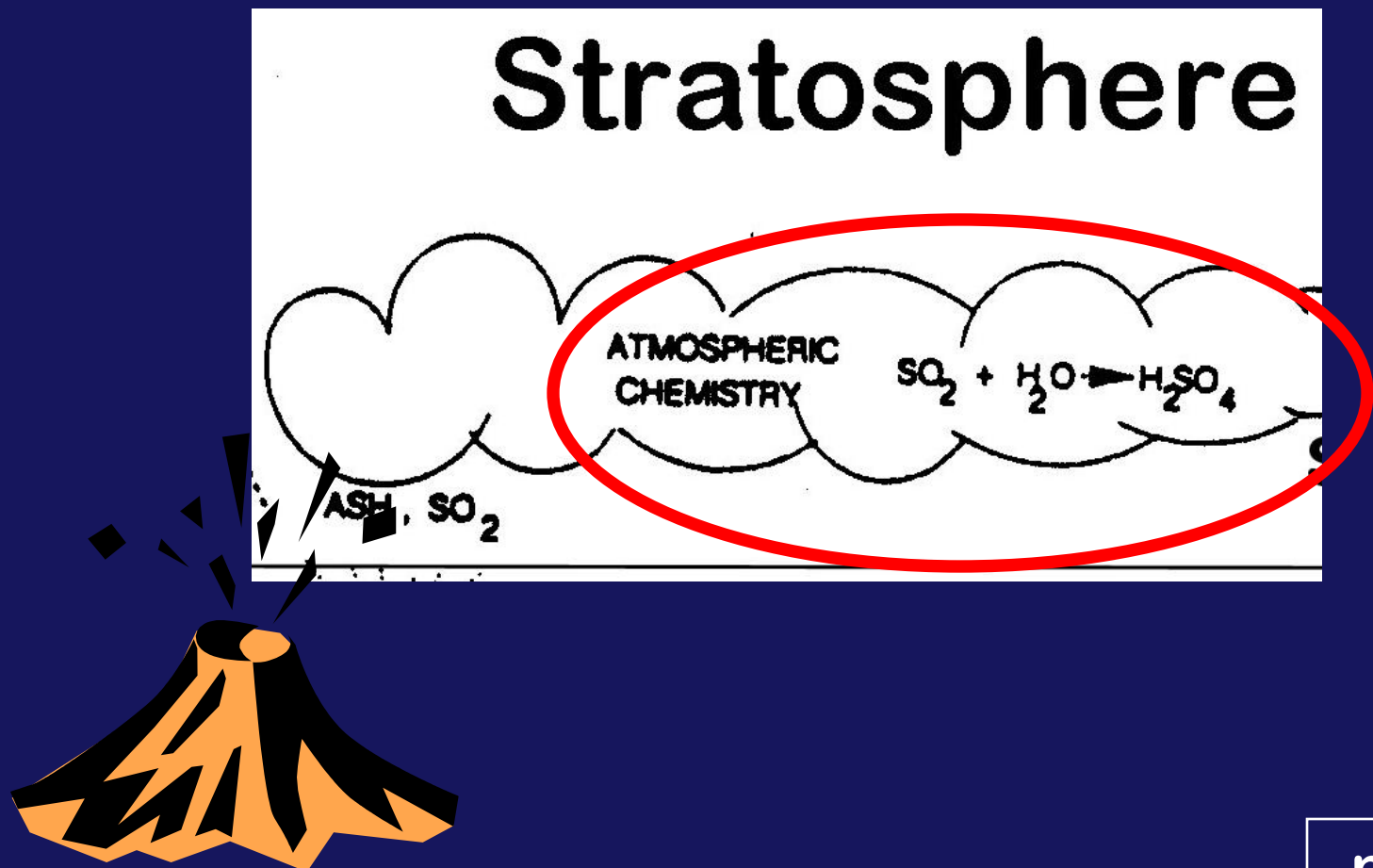


Albedo of ejected ASH in the **STRATOSPHERE** is not the reason for cooling after an eruption!
(most ash falls out early)

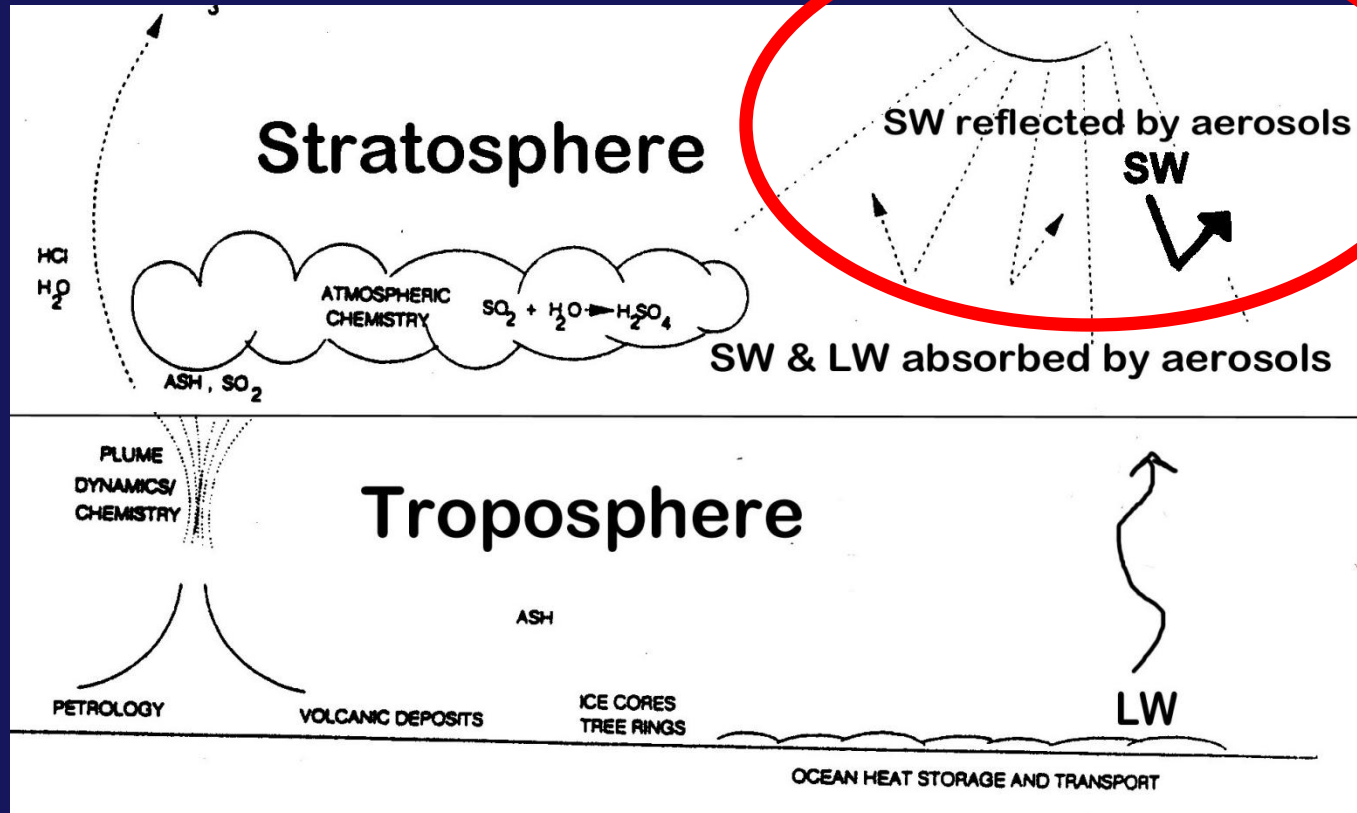


What **DOES** reflect the incoming shortwave radiation after an eruption?

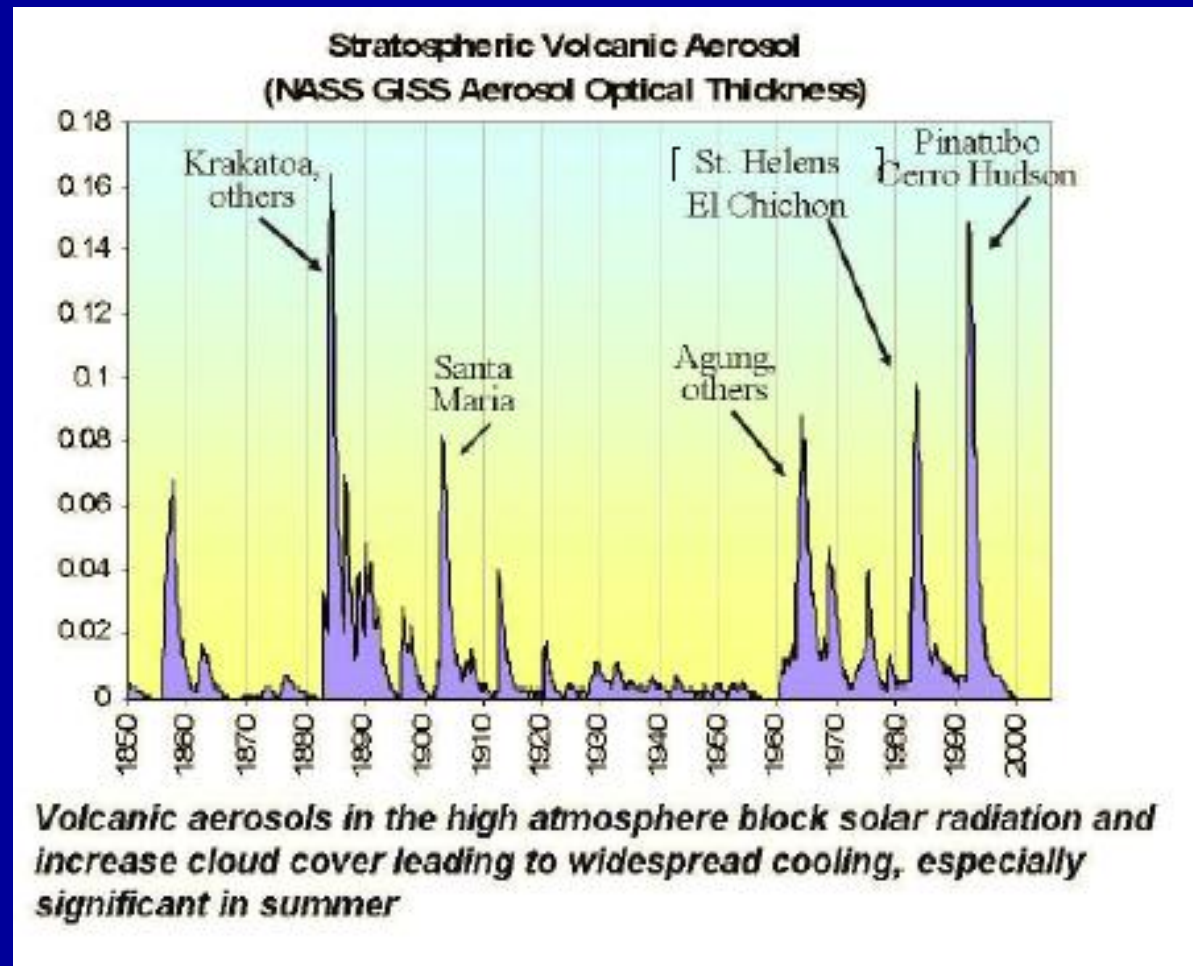
SO₂ remains gaseous and is eventually converted to **sulfuric acid** (H₂SO₄) which condenses in a mist of fine particles called **sulfate aerosols**.



the sulfate aerosols *reflect* some of the incoming solar SW radiation back to space, **cooling the troposphere below**



Volcanic aerosols in stratosphere from sulfur dioxide gases in eruption can **REFLECT** back incoming solar radiation → global cooling

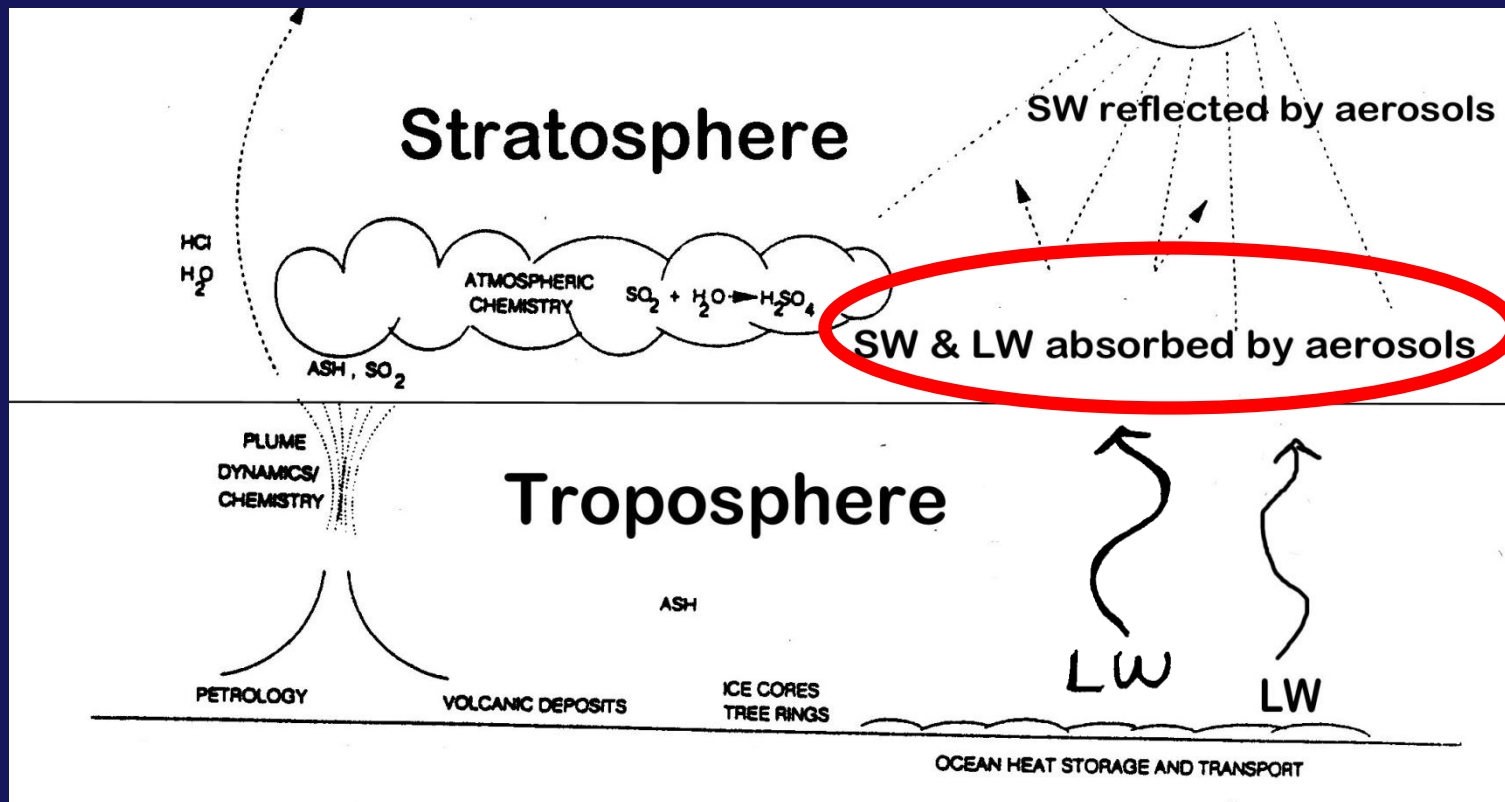


Graph is on
p 73 in Class
Notes

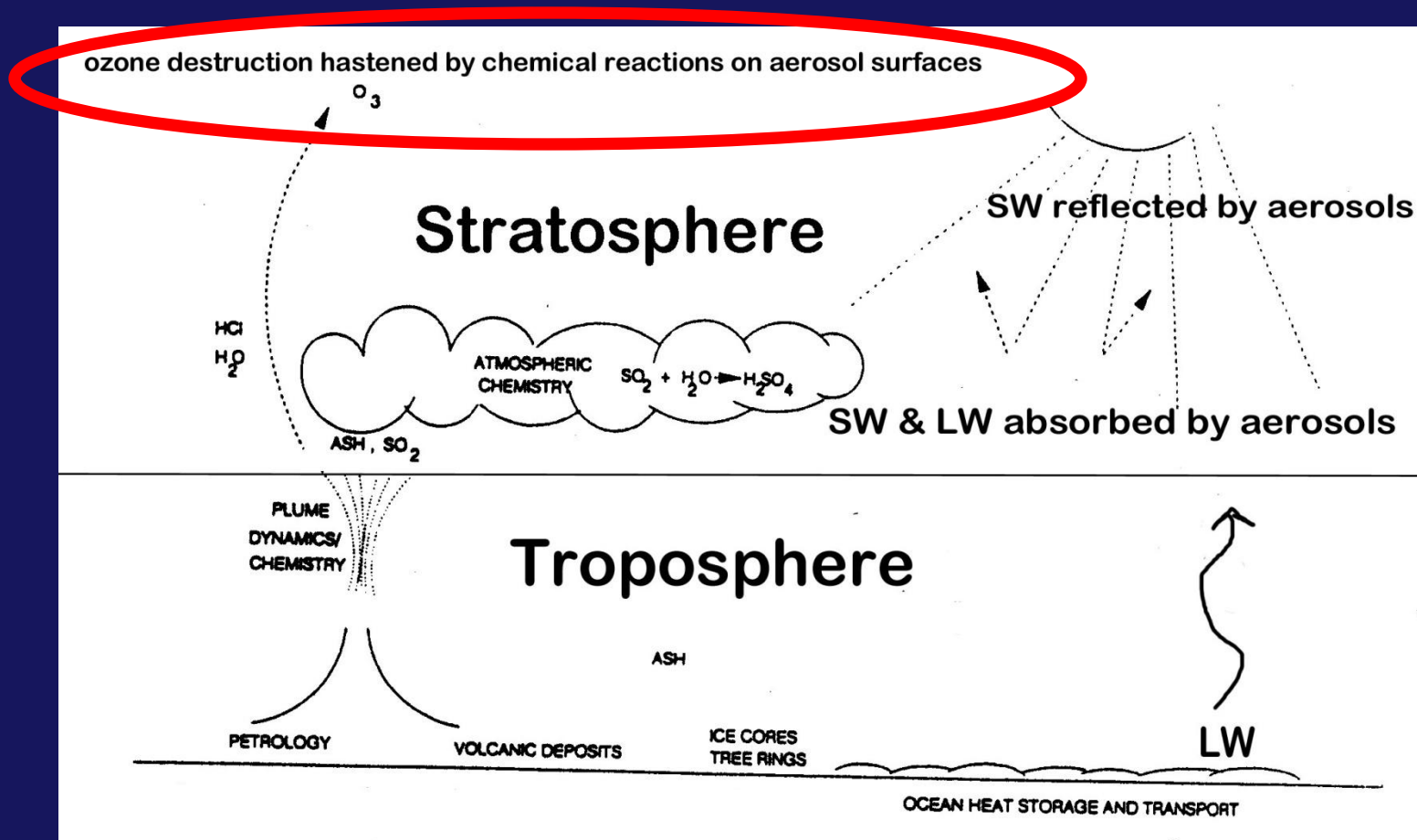
**SOME MAJOR
VOLCANIC
ERUPTIONS
OF THE PAST
250 YEARS:**

Laki (Iceland)	1783
El Chichon? (Mexico)	1809
Tambora (Indonesia)	1815
Cosiguina (Nicaragua)	1835
Krakatau (Indonesia)	1883
Agung (Indonesia)	1963
El Chichon (Mexico)	1982
Mt Pinatubo (Philippines)	1991

BUT - the aerosols **in the stratosphere** also **ABSORB** certain wavelengths of the incoming SW radiation and some of the Earth's outgoing LW radiation, this **warms the stratosphere** (not the troposphere)



Chemical effects of the sulfate aerosol cloud can also produce responses in the climate system through **OZONE destruction** (Topic #14)



Q2 - How can an eruption in one spot on earth have a **GLOBAL COOLING effect?**

1- The cold air from the eruption's local cooling effect gets circulated to other locations around the globe by winds

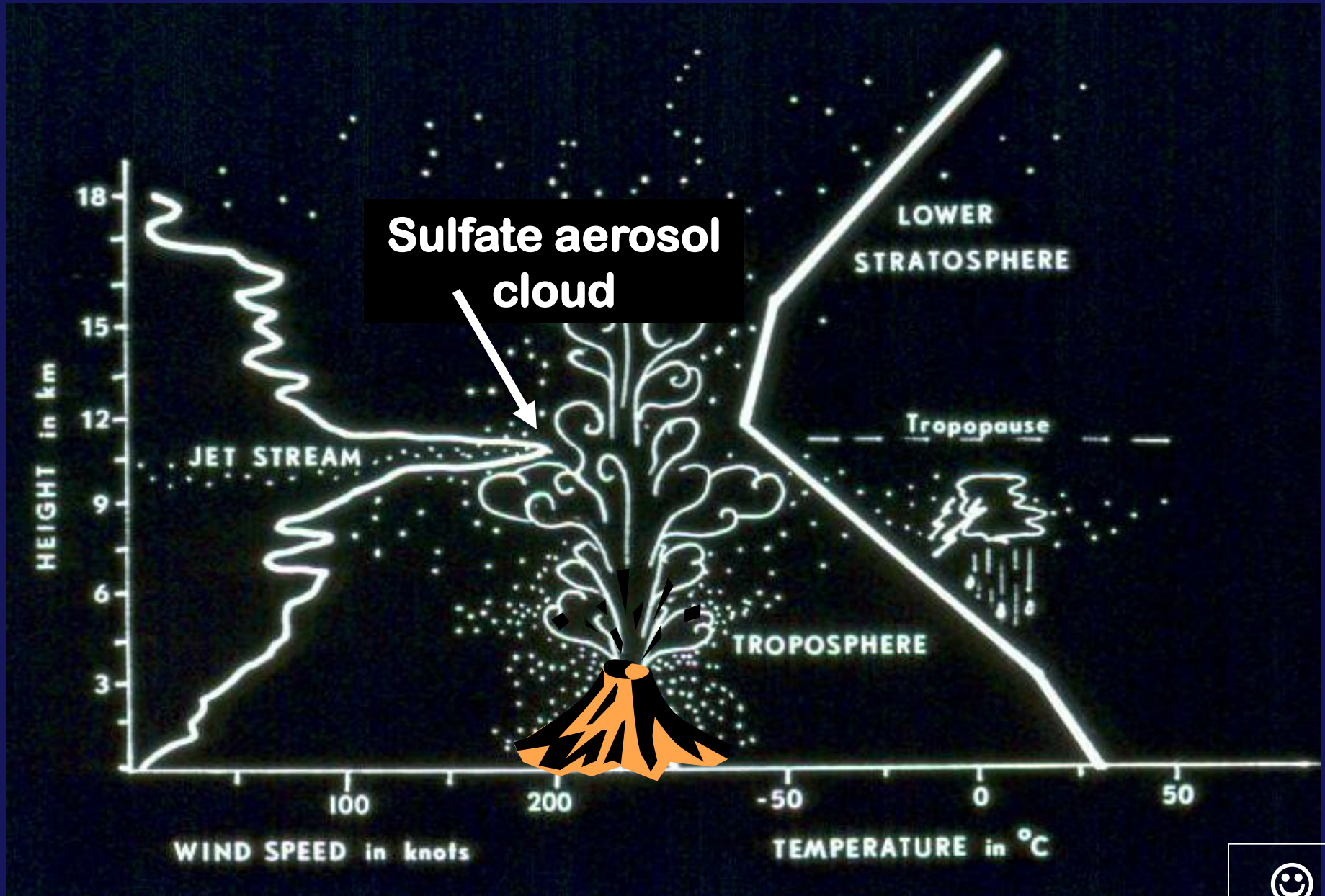
2 – The aerosols in the stratosphere get circulated around the globe by winds , which influences the radiation balance globally

Q2 - How do you think an eruption in one spot on earth have a GLOBAL COOLING effect?

1- The cold air from the eruption's local cooling effect gets circulated to other locations around the globe by winds

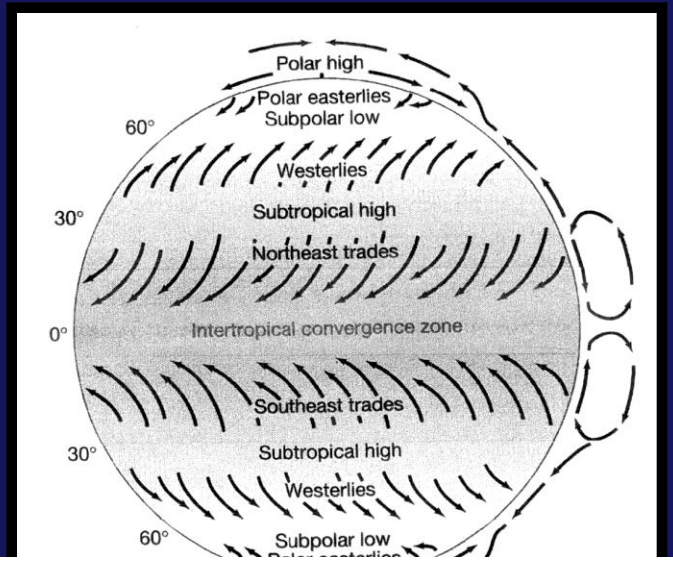
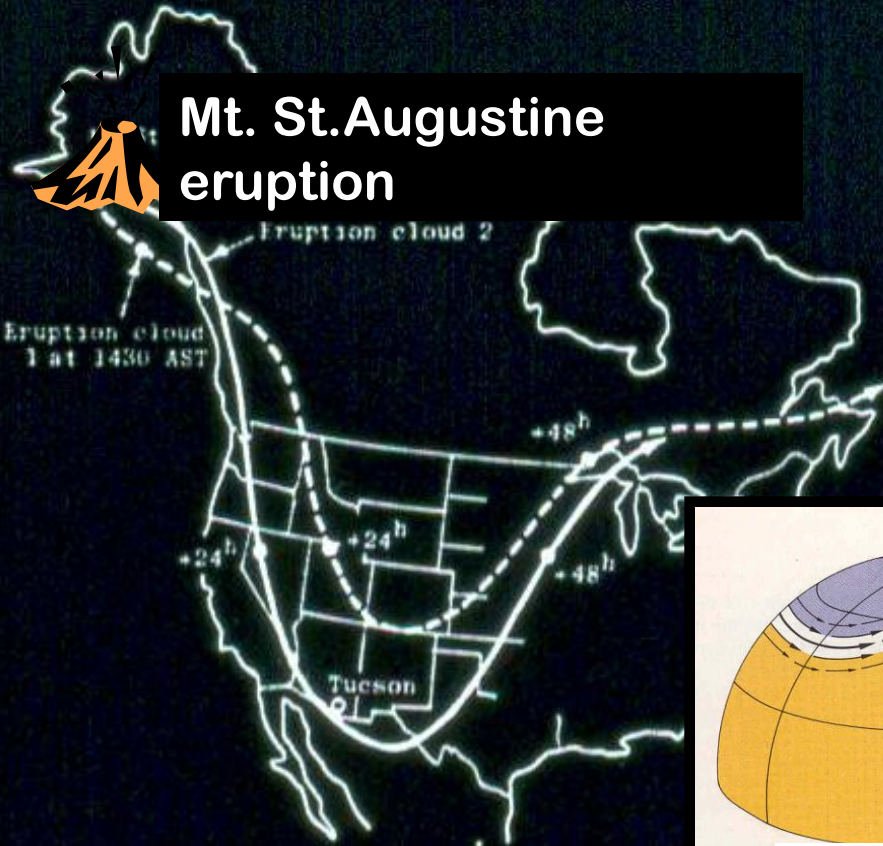
2 – The aerosols in the stratosphere get circulated around the globe by winds , which influences the radiation balance globally

How an eruption's effects can become GLOBAL:

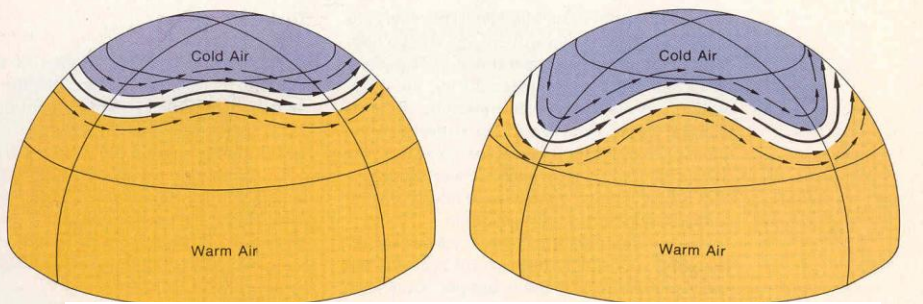


DUST TRAJECTORIES JAN. 1976

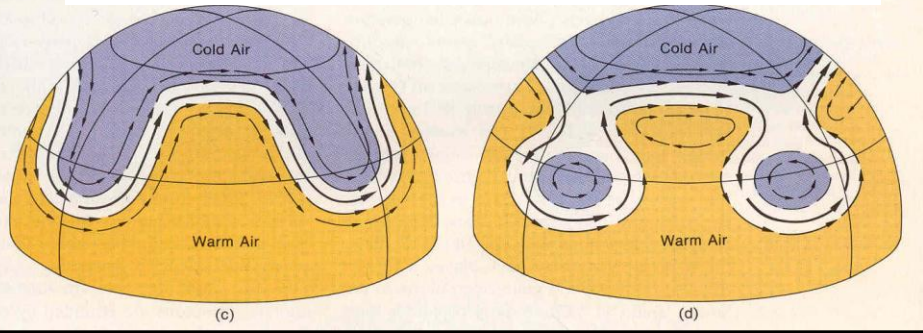
Mt. St. Augustine eruption



Surface wind circulation



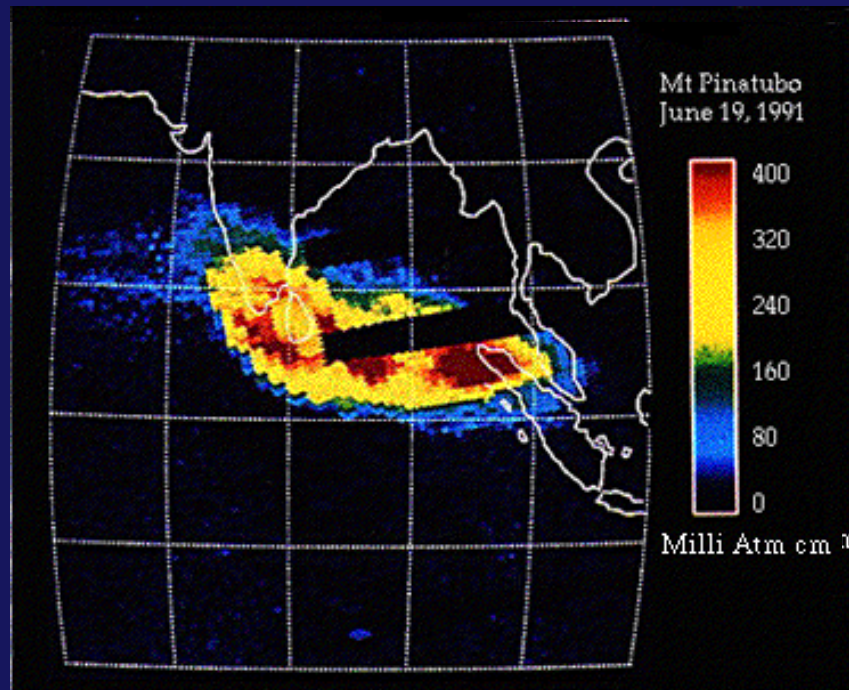
Upper level wind circulation



Through the atmospheric circulation!



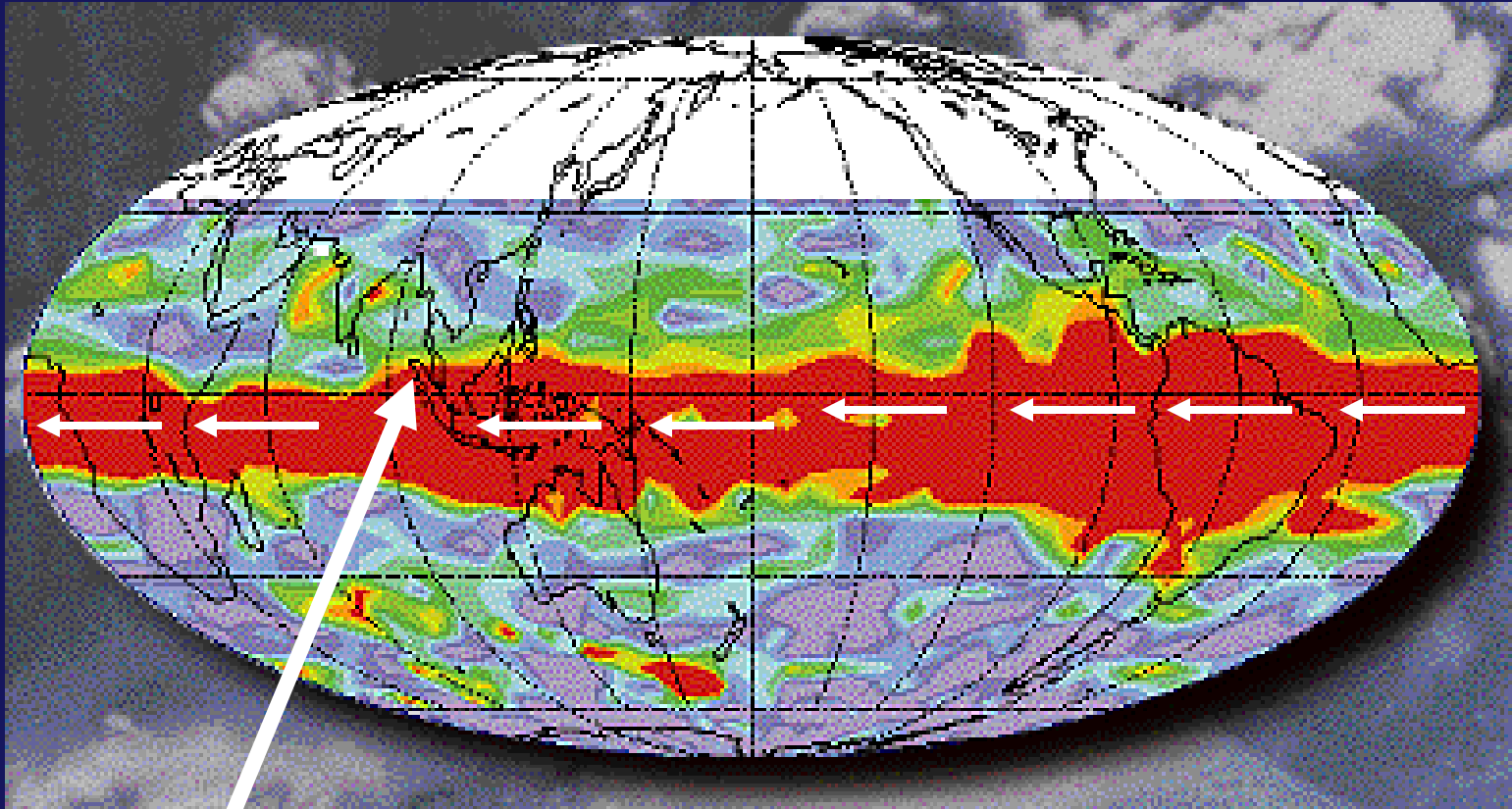
Mt Pinatubo Eruption in the Philippines, June, 1991



Satellite-derived image of
sulfur dioxide thickness in the atmosphere
red = higher thickness



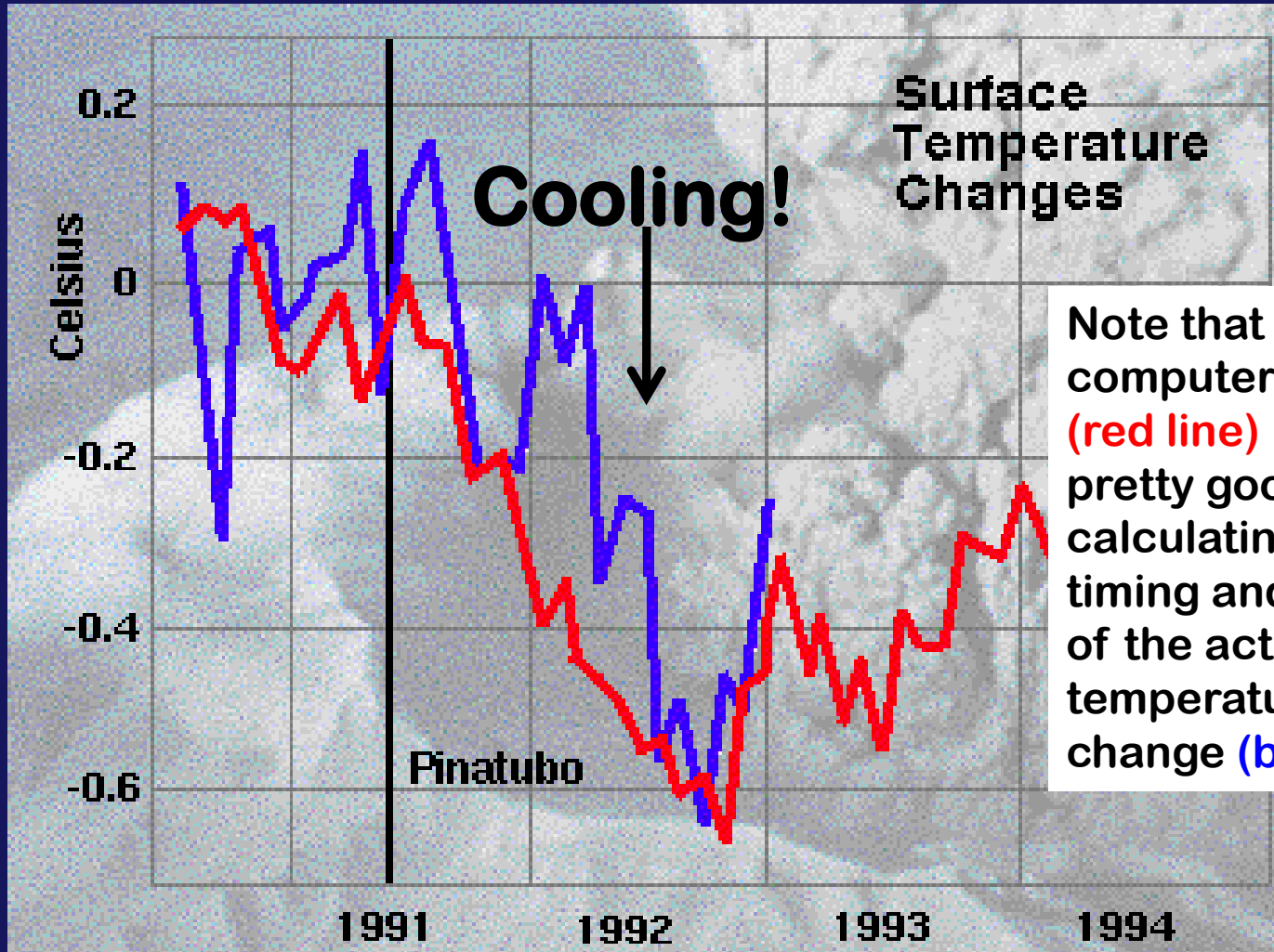
By Sept 21, 1991 increased levels of sulfur dioxide had dispersed worldwide



Mt Pinatubo



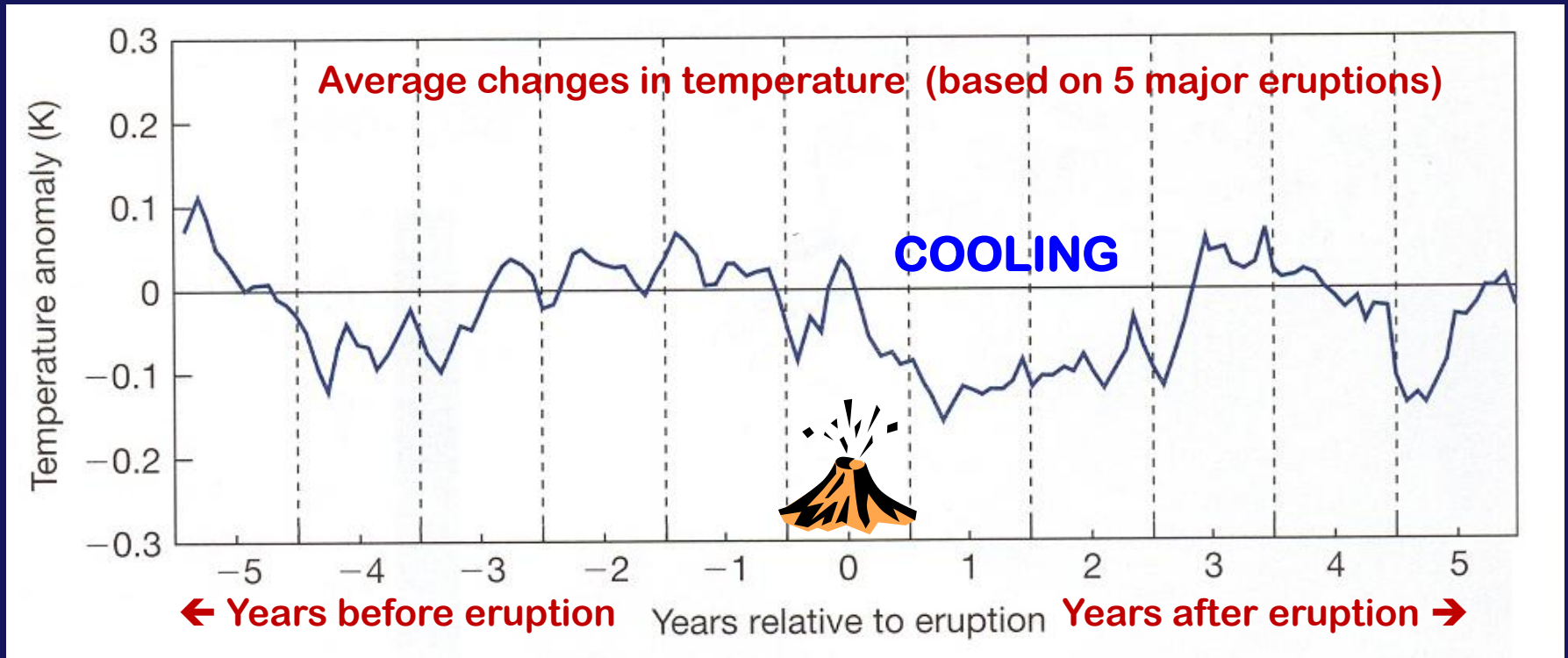
Mt Pinatubo eruption June 1991



Blue line = observed temperature change after eruption
Red line = modeled temperature change after eruption



Typical Global Cooling Pattern after a major explosive Volcanic Eruption

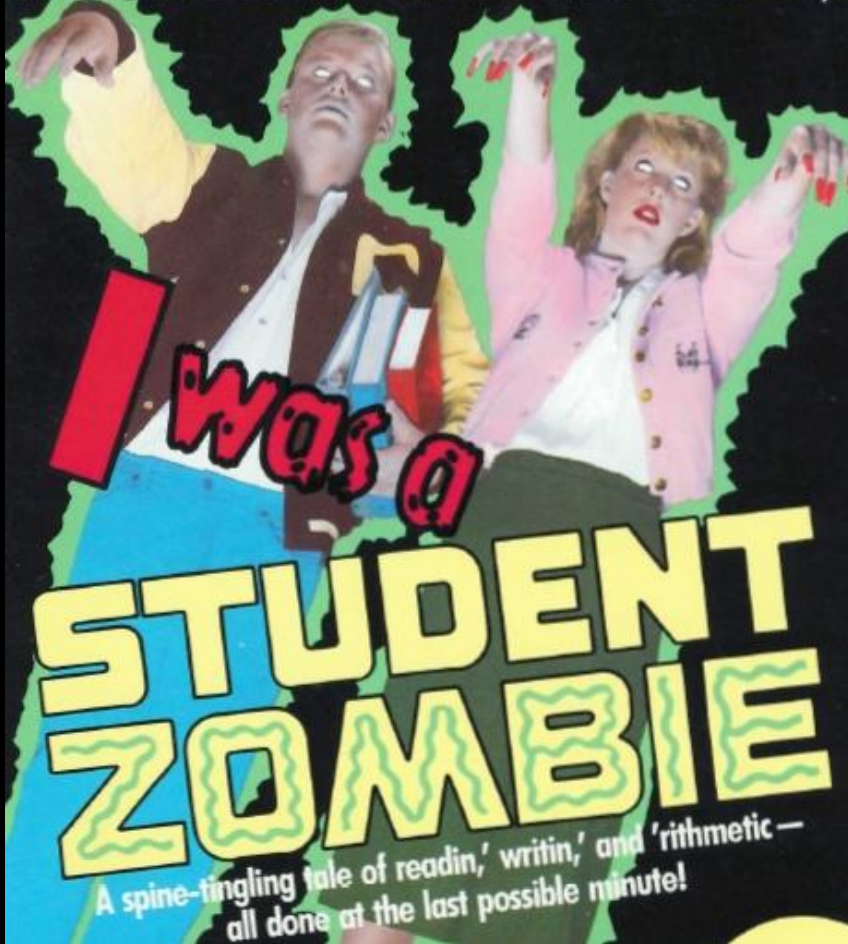


This graph shows the global mean temperature changes for years before (-) and after a large eruption (at year zero)

WHICH ERUPTIONS ARE THE MOST CLIMATICALLY EFFECTIVE?

- **EXPLOSIVE**
- **high SULFUR content in magma**
- **whose eruption clouds inject into the STRATOSPHERE**
- **Low Latitude Eruptions**

It's happening right now...in YOUR town...
in YOUR school...in YOUR class...in YOUR BRAIN!



**I Was a
STUDENT
ZOMBIE**

A spine-tingling tale of readin,' writin,' and 'rithmetic —
all done at the last possible minute!

**ZOMBIE
BREAK !**

The Greenhouse effect is represented by which symbol?

1. This one: 

2. This one: 

3. This one: 

4. H + G

5. None of the above

The Greenhouse effect is represented by which symbol?

1. This one: 

2. This one: 

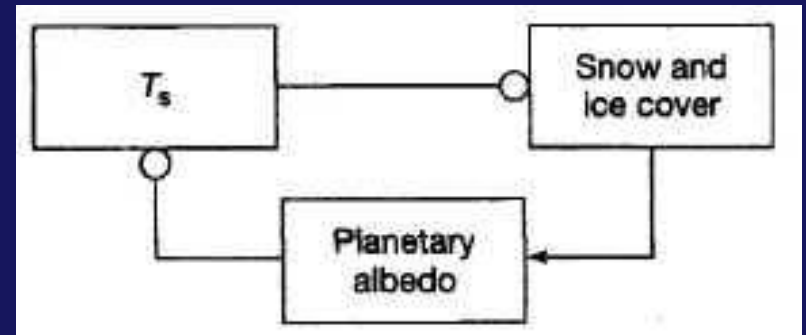


3. This one: 

4. H + G

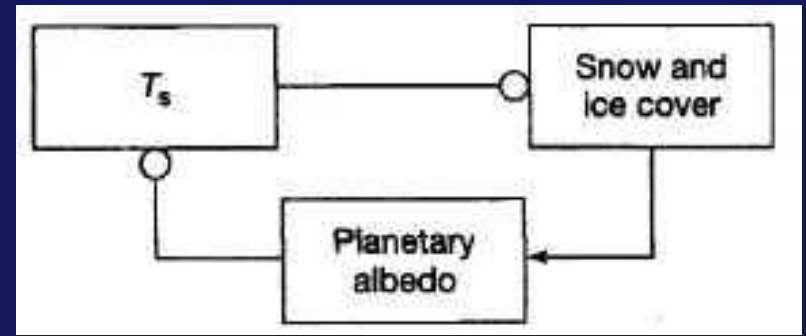
5. None of the above

What will this feedback loop will lead to:



1. A self-regulated return to an equilibrium state
2. An ice age followed by a warm period.
3. A self-amplifying change in the Earth's surface temperature
4. A runaway Greenhouse Effect!

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This is likely to occur during a sunspot cycle with a **MAXIMUM of sunspots**

- 1. Decreased solar brightness and cooling on Earth**
- 2. Increased solar brightness and warming on Earth**
- 3. Glacial advances**
- 4. More volcanic eruptions**

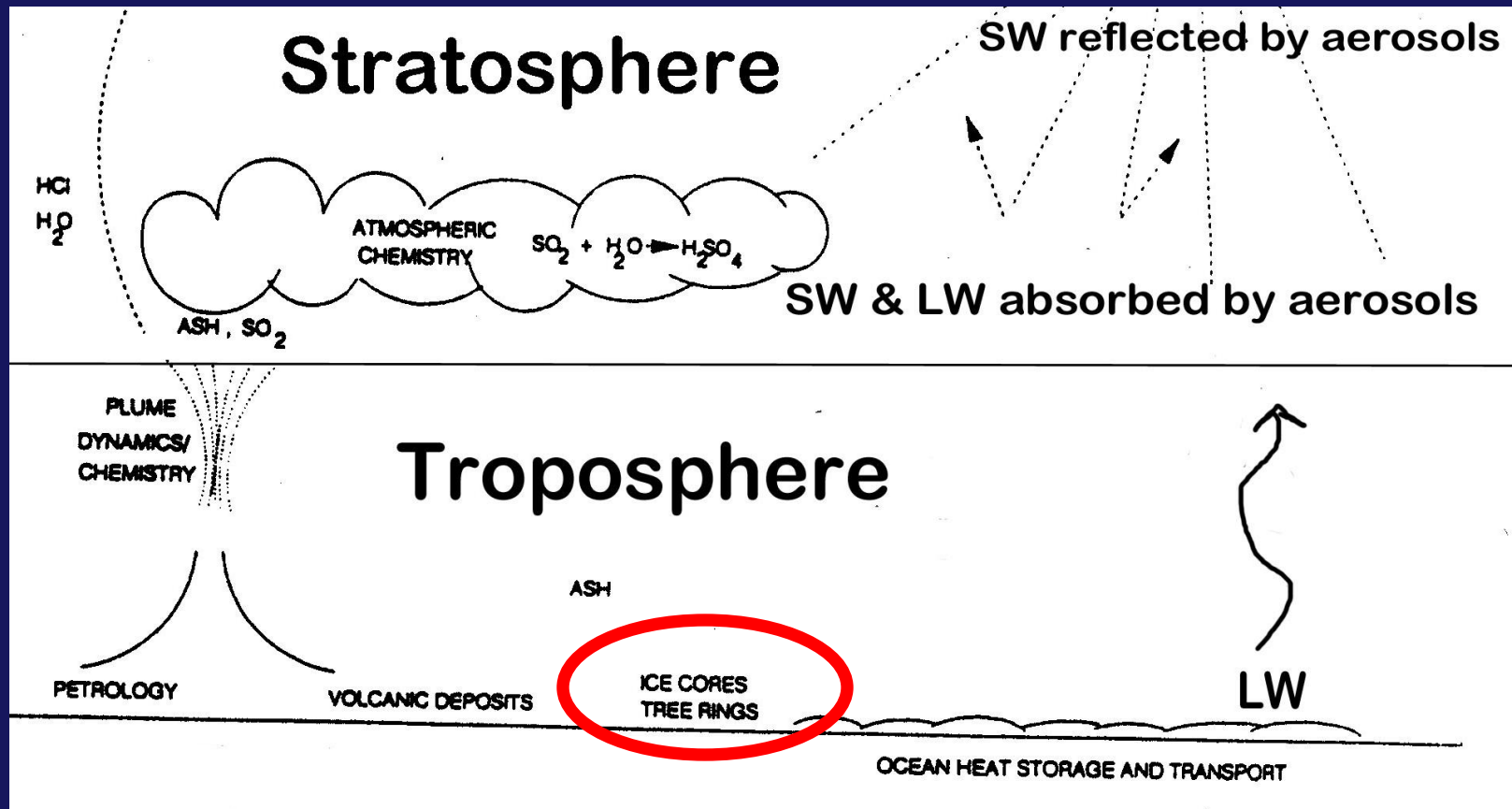
This is likely to occur during a sunspot cycle with a **MAXIMUM** of sunspots

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2. Increased solar brightness and warming on Earth
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**Back to:
VOLCANISM & CLIMATE**

Major volcanic eruptions are infrequent events, but their climatic effects can be recorded over long time periods in **ICE CORES & TREE RINGS!**



Field conditions

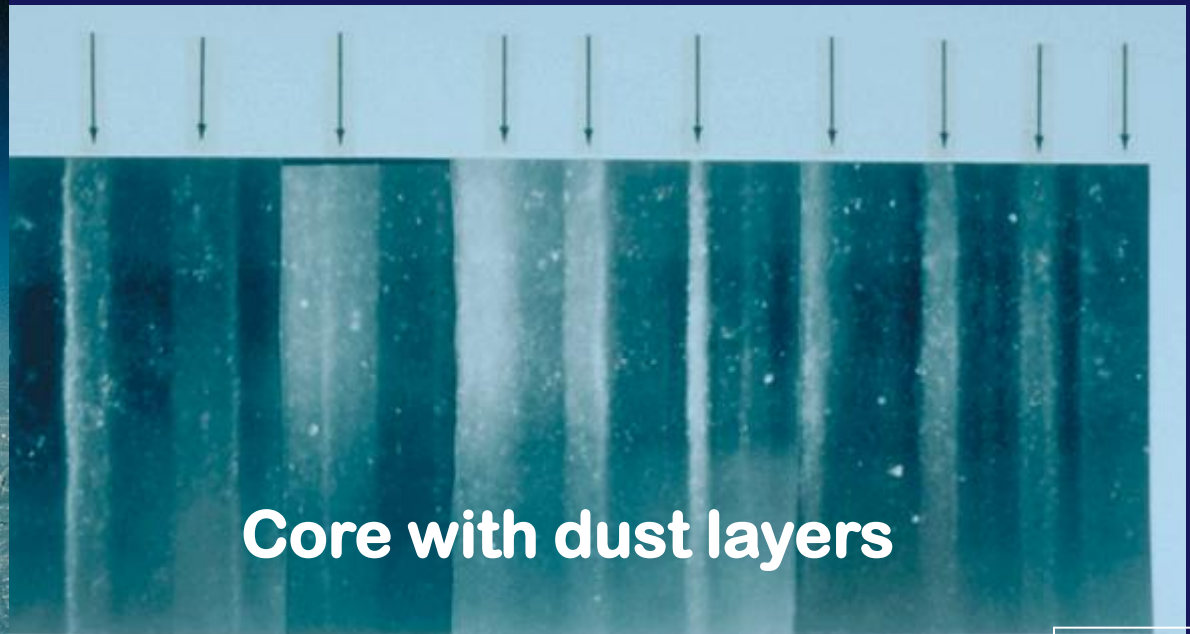
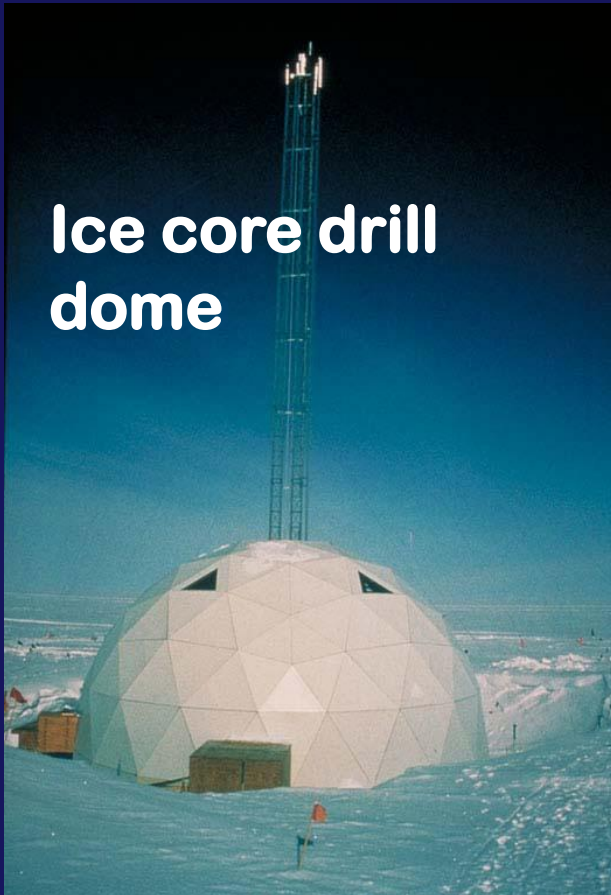


ICE CORES



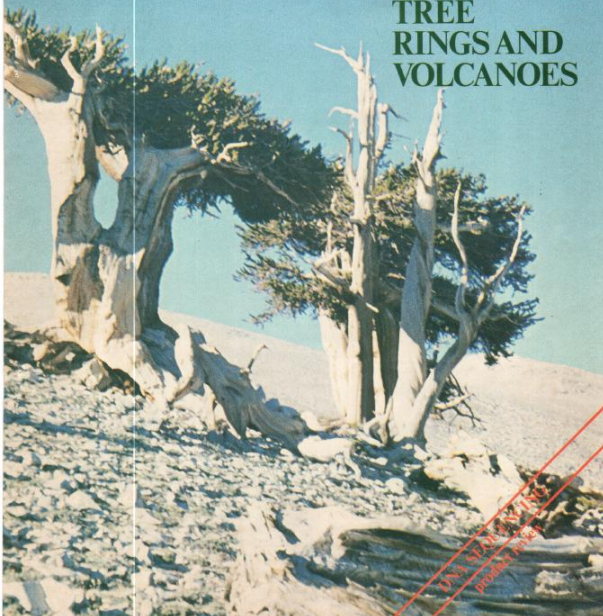
Examining core

Ice core drill dome



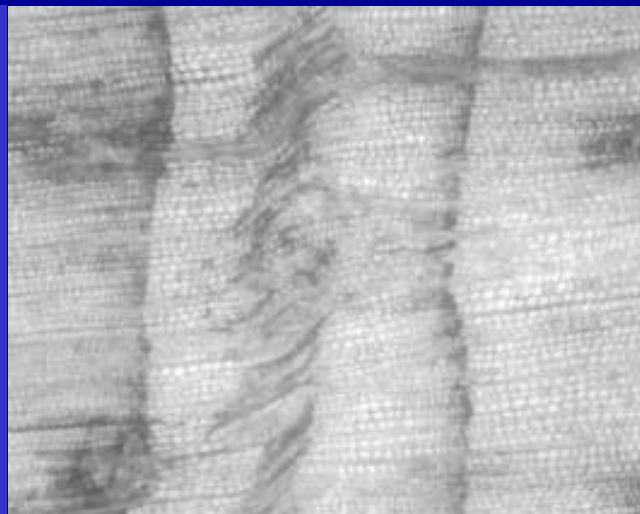
Core with dust layers





TREE RINGS AND VOLCANOES

Frost rings in bristlecone pine have been linked to global cooling after major volcanic eruptions !!



Printed from Nature, Vol. 307, No. 5946, pp. 121-126, 12 January, 1984

© Macmillan Journals Ltd., 1984

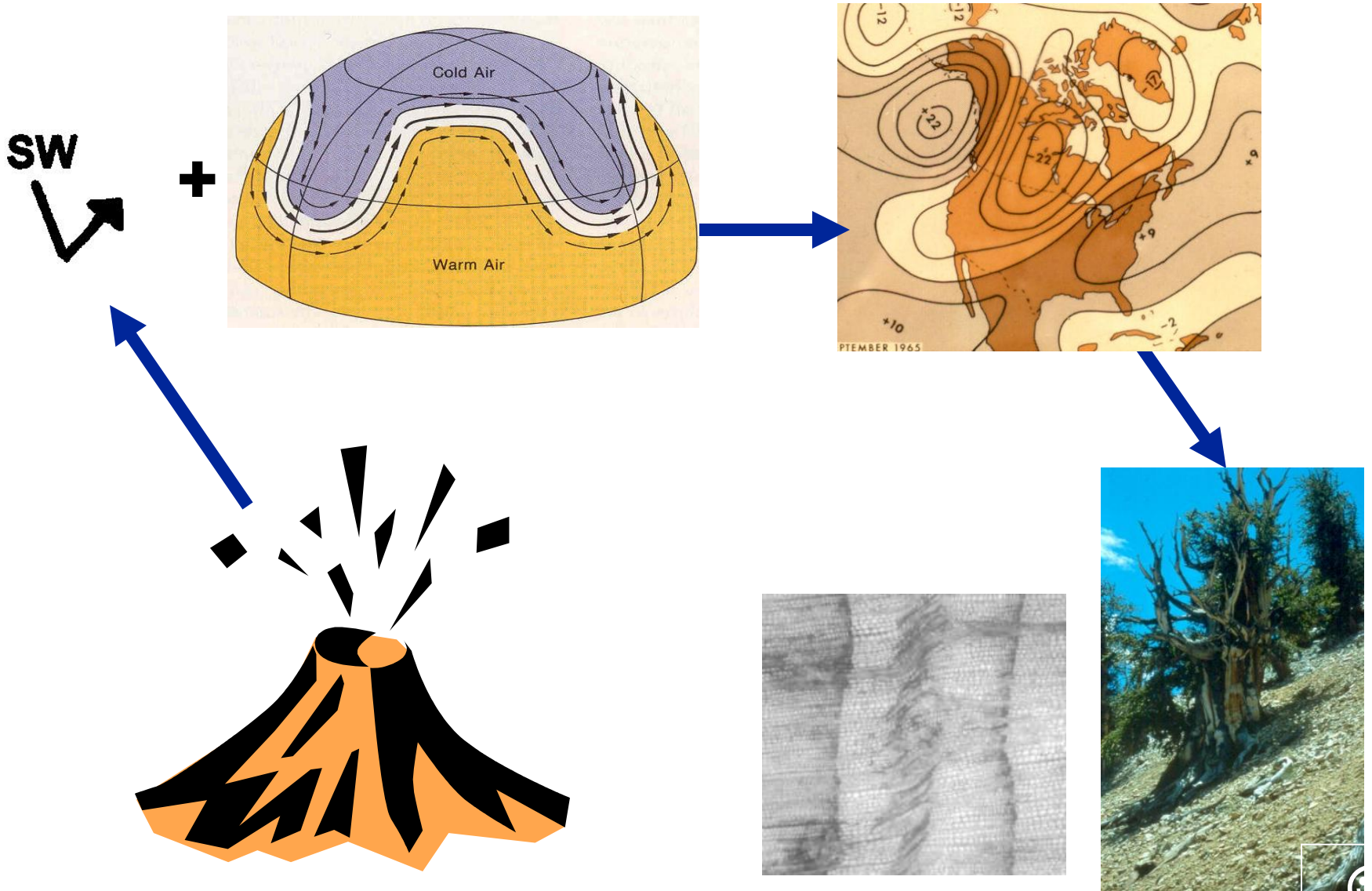
Frost rings in trees as records of major volcanic eruptions

Valmore C. LaMarche Jr* & Katherine K. Hirschboeck†

* Laboratory of Tree-Ring Research and † Department of Geosciences, University of Arizona, Tucson, Arizona 85721, USA

New data about climatically-effective volcanic eruptions during the past several thousand years may be contained in frost-damage zones in the annual rings of trees. There is good agreement in the timing of frost events and recent eruptions, and the damage can be plausibly linked to climatic effects of stratospheric aerosol veils on hemispheric and global scales. The cataclysmic proto-historic eruption of Santorini (Thera), in the Aegean, is tentatively dated to 1628–26 BC from frost-ring evidence.

HOW IT WORKS: Combo of Energy Balance Effects & Global Atmospheric Circulation



WHICH ERUPTIONS ARE THE MOST CLIMATICALLY EFFECTIVE?

- **EXPLOSIVE**
- **high SULFUR content in magma**
- **whose eruption clouds inject into the STRATOSPHERE**
- **Low Latitude Eruptions** ←

Q3 - Why do you think Low Latitude eruptions are more climatically effective and have more of an effect?

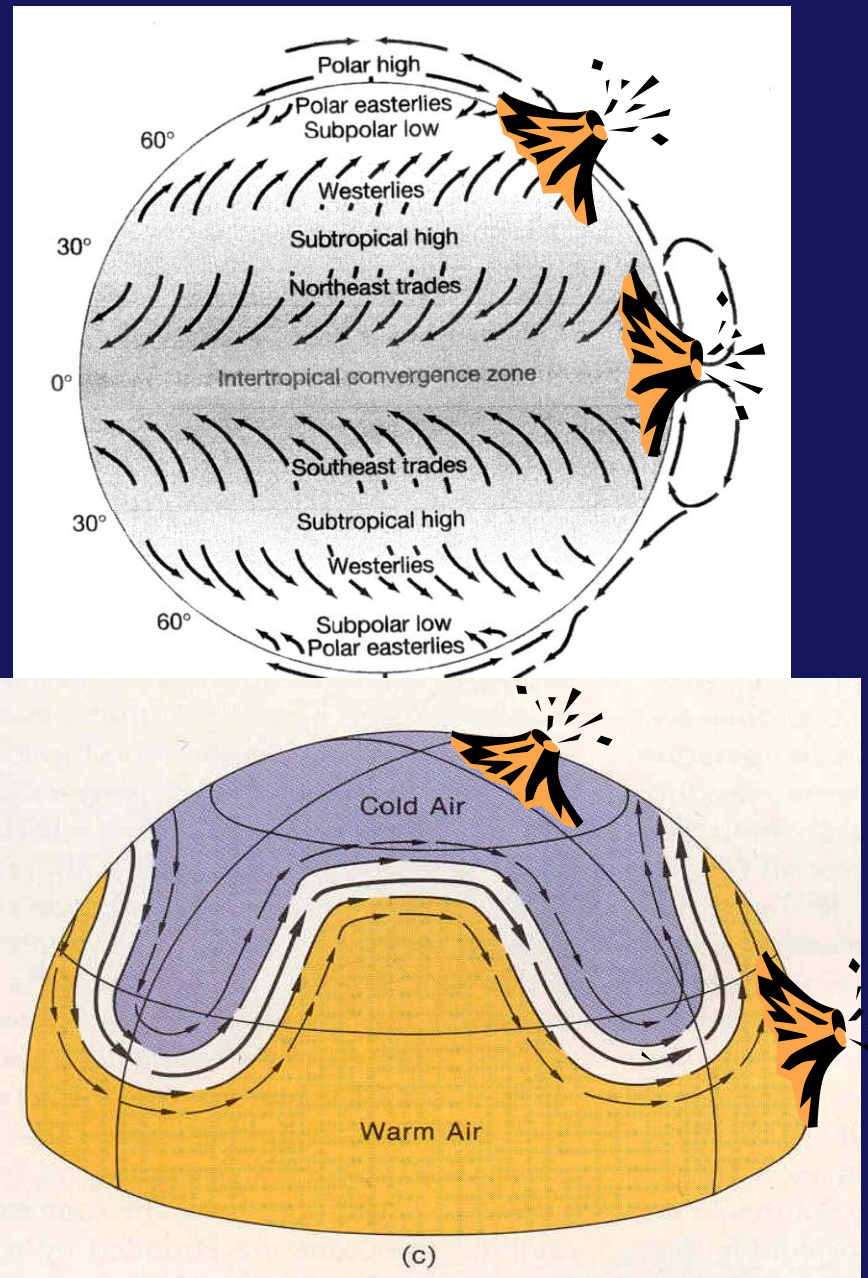
1. Because the temperature is warmer in tropical latitudes and hot air rises.
2. Because the Hadley Cell circulation can distribute the volcanic aerosols into both hemispheres if the eruption occurs near the equator.
3. Because the tropopause is lower over Low Latitudes and hence it's easier for aerosols to get injected into the stratosphere where they will not be rained out.

Q3 - Why do you think Low Latitude eruptions are more climatically effective and have more of an effect?

1. Because the temperature is warmer in tropical latitudes and hot air rises.
2. Because the Hadley Cell circulation can distribute the volcanic aerosols into both hemispheres if the eruption occurs near the equator.
3. Because the tropopause is lower over Low Latitudes and hence it's easier for aerosols to get injected into the stratosphere where they will not be rained out.

- The **GEOGRAPHIC LOCATION** of the erupting volcano influences the climatic effectiveness of an eruption because of the **General Circulation of the Atmosphere**.

- **Low latitude eruption clouds get circulated more broadly & in both hemispheres**



**See box on p 73
for a good summary of
which eruptions are
CLIMATICALLY EFFECTIVE**

G-5 ACTIVITY ON VOLCANISM & CLIMATE

**Introduction today . . .
we'll complete it in
upcoming class**

Comparison Table of Eruptions

Estimated N.H.
temperature
change °C

Latitude

How much
magma → how
big an eruption

How much
aerosol got into
each hemisphere

Sulfur-rich
if high
H₂SO₄

COMPARISON TABLE OF ERUPTIONS

Eruption & Latitude	Year	Amount of Magma Erupted (km ²)	Stratospheric Aerosol (Mt)		H ₂ SO ₄ estimate (Mt)	Estimated N.H. Temp change (°C)
			S.H.	N.H.		
Tambora (8°S)	1815	50	150	150	52	-0.4 to -0.7
Krakatau (6°S)	1883	10	~34	55	2.9	-0.3
Santa Maria (15°N)	1902	9	22	<20	0.6	-0.4
Katmai (86°N)	1912	15	0	<30	12	-0.2
Agung (8°S)	1963	0.6	30	20	2.8	-0.3
Mt St. Helens (46°N)	1980	0.3	0	no info	0.08	0 to -0.1
El Chichón (17°N)	1982	~ 0.3	<8	12	0.07	-0.2
Pinatubo (15°N)	1991	~ 5	no info	~25	~0.3	-0.5

(Large eruption if
lots of magma)

(How much got into
each hemisphere)

(Sulfur-rich
if high)

**IMPORTANT: if
NO INFORMATION IS AVAILABLE,
this does not mean the value is zero!**

#1. List 4 reasons why Tambora in 1815 resulted in the largest GLOBAL cooling:

2. Give at least two reasons why the eruption of Mt St. Helens was NOT a very climatically effective eruption:

P.S. This is one of my favorite questions to ask on the FINAL EXAM!!!! Try to do it on your own now and be ready to do it as a group later.

STUDY HARD
For **TEST #3 !**

See you on Friday!