TOPIC #12

NATURAL CLIMATIC FORCING – Part II

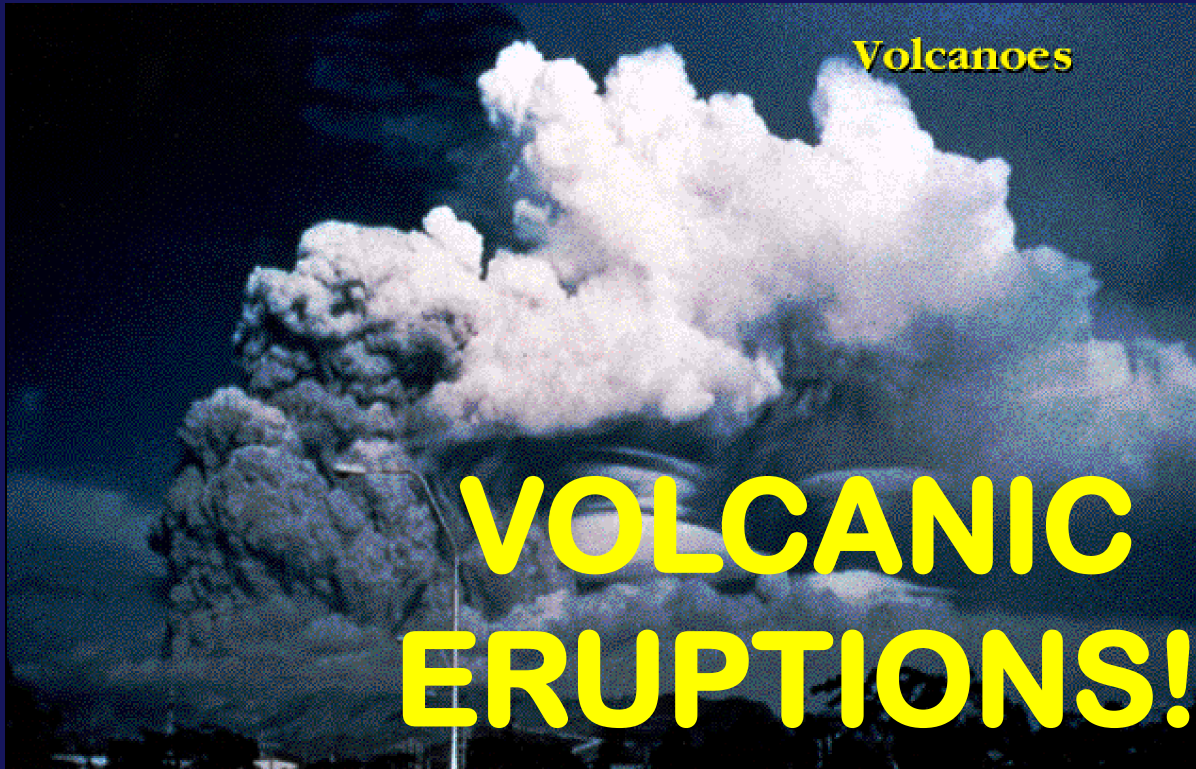
(p 72 in Class Notes)

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

1) ATRONOMICAL FORCING

2) SOLAR FORCING

3) VOLCANIC FORCING ←



VOLCANIC ERUPTIONS!

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Volcanoes are one way the Earth gives birth to itself.

~Robert Gross

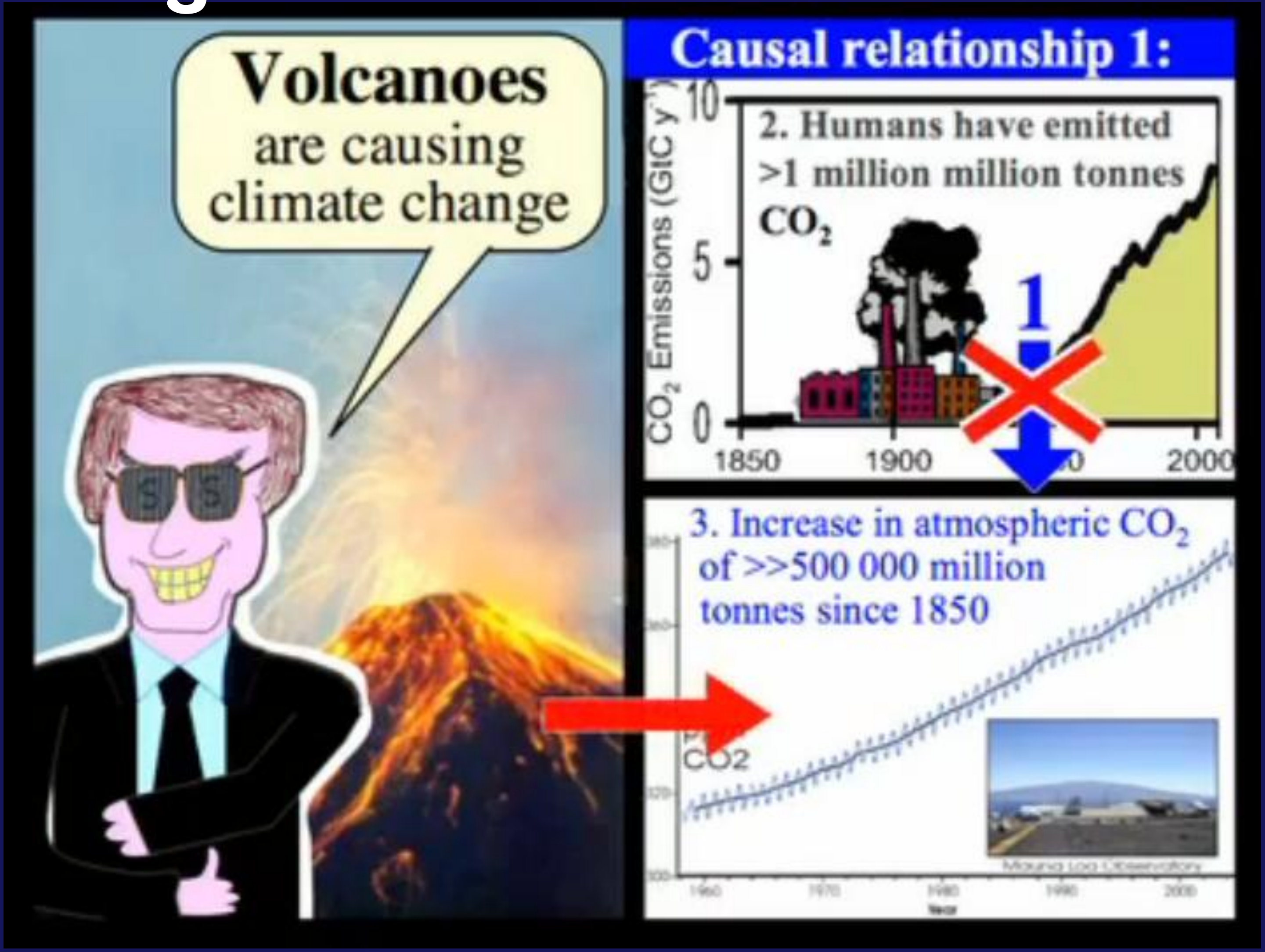
Volcanic eruptions contribute to the natural Greenhouse Effect by adding CO_2 into the atmosphere:

Volcanic outgassing of CO_2 into atmosphere

0.06 Gtons

☺

CO2 emitted by volcanoes is an important natural cause of the recent global warming observed! Or is it?



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

1 – YES! The CO_2 they give off is a key cause of the enhanced GH Effect

2 – NO! It's the ash (not CO_2) that volcanic eruptions eject that is important & it causes global cooling not warming.

3- NO! The CO_2 that volcanic eruptions emit is a natural part of the carbon cycle and it balances out

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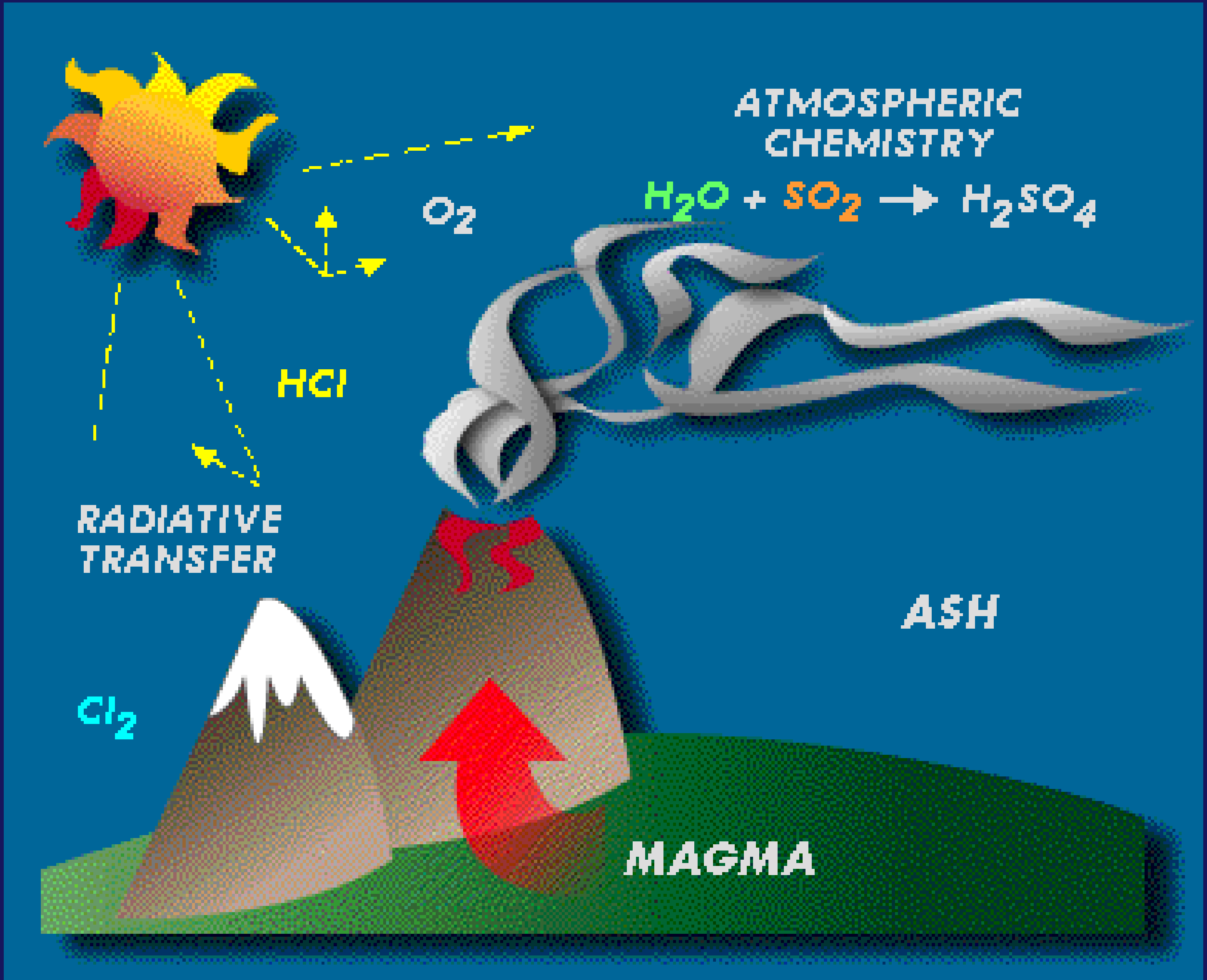
Volcanic eruptions contribute to the natural Greenhouse Effect by adding CO_2 into the atmosphere:

Volcanic outgassing of CO_2 into atmosphere

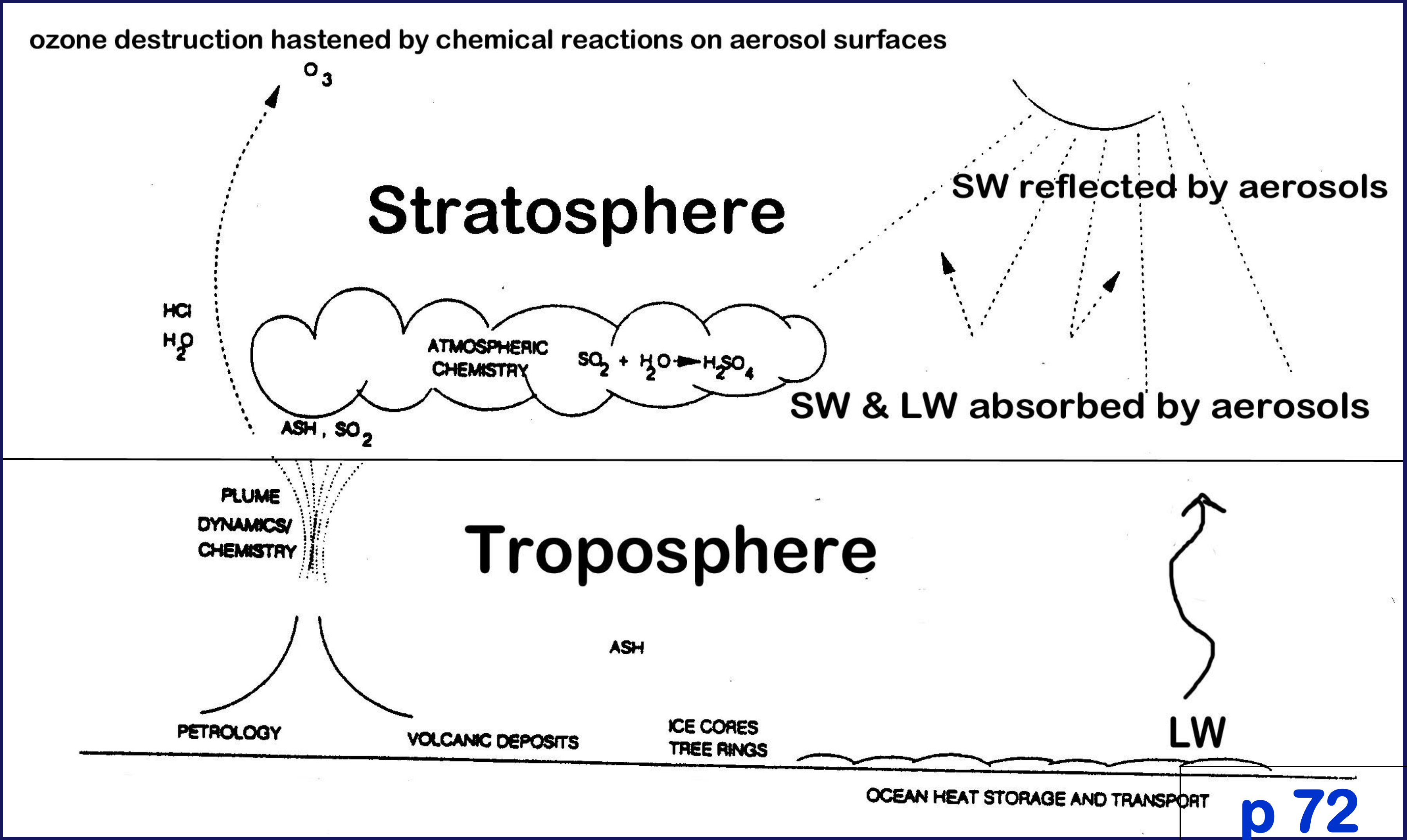
0.06 Gtons

This carbon flux is in balance over time & absorbed by natural processes in the carbon cycle

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



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



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

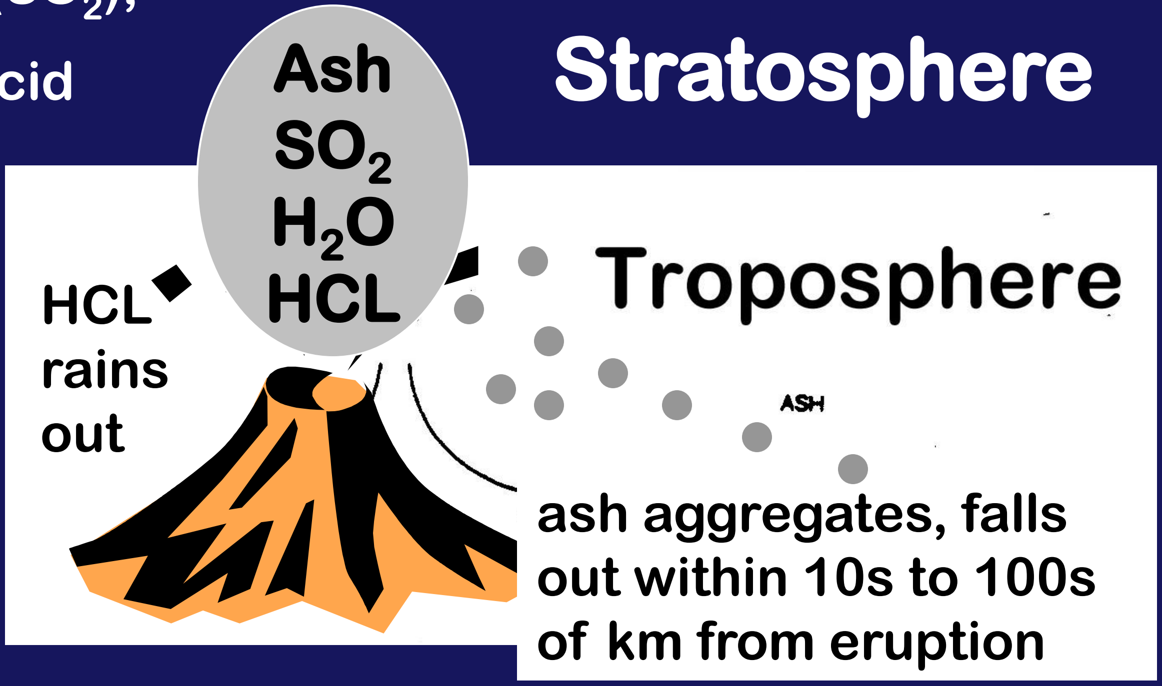
water vapor (H_2O)

sulfur dioxide (SO_2),

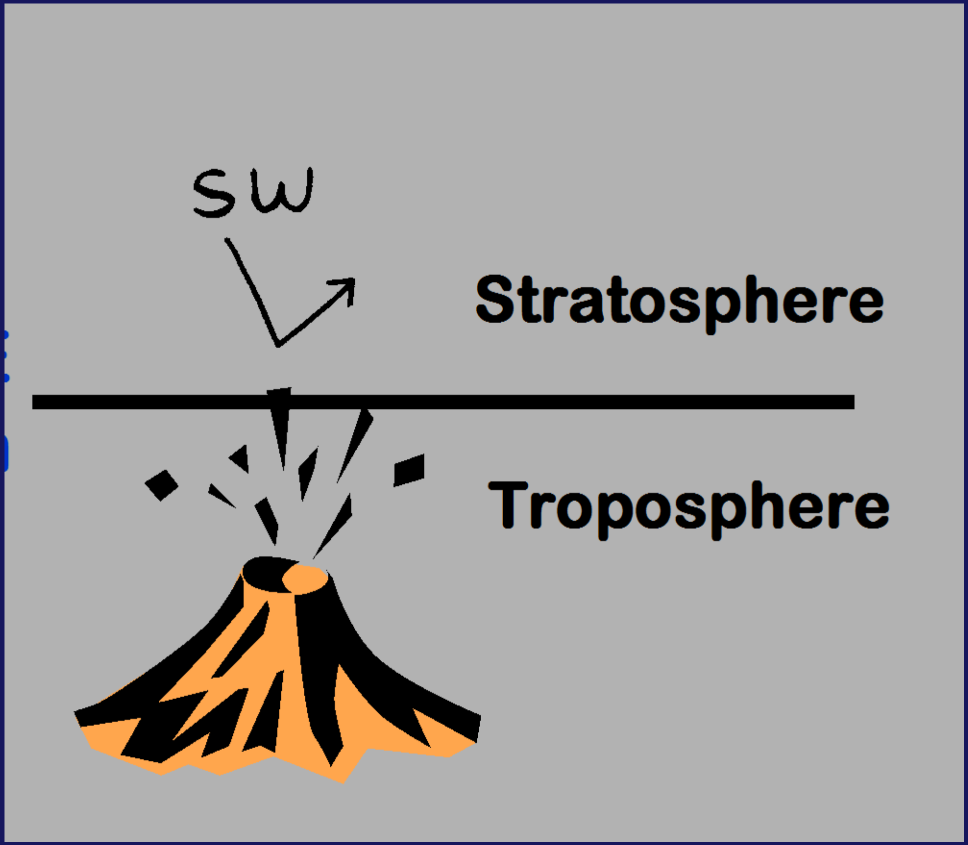
hydrochloric acid (HCl)

mineral ash

into the stratosphere

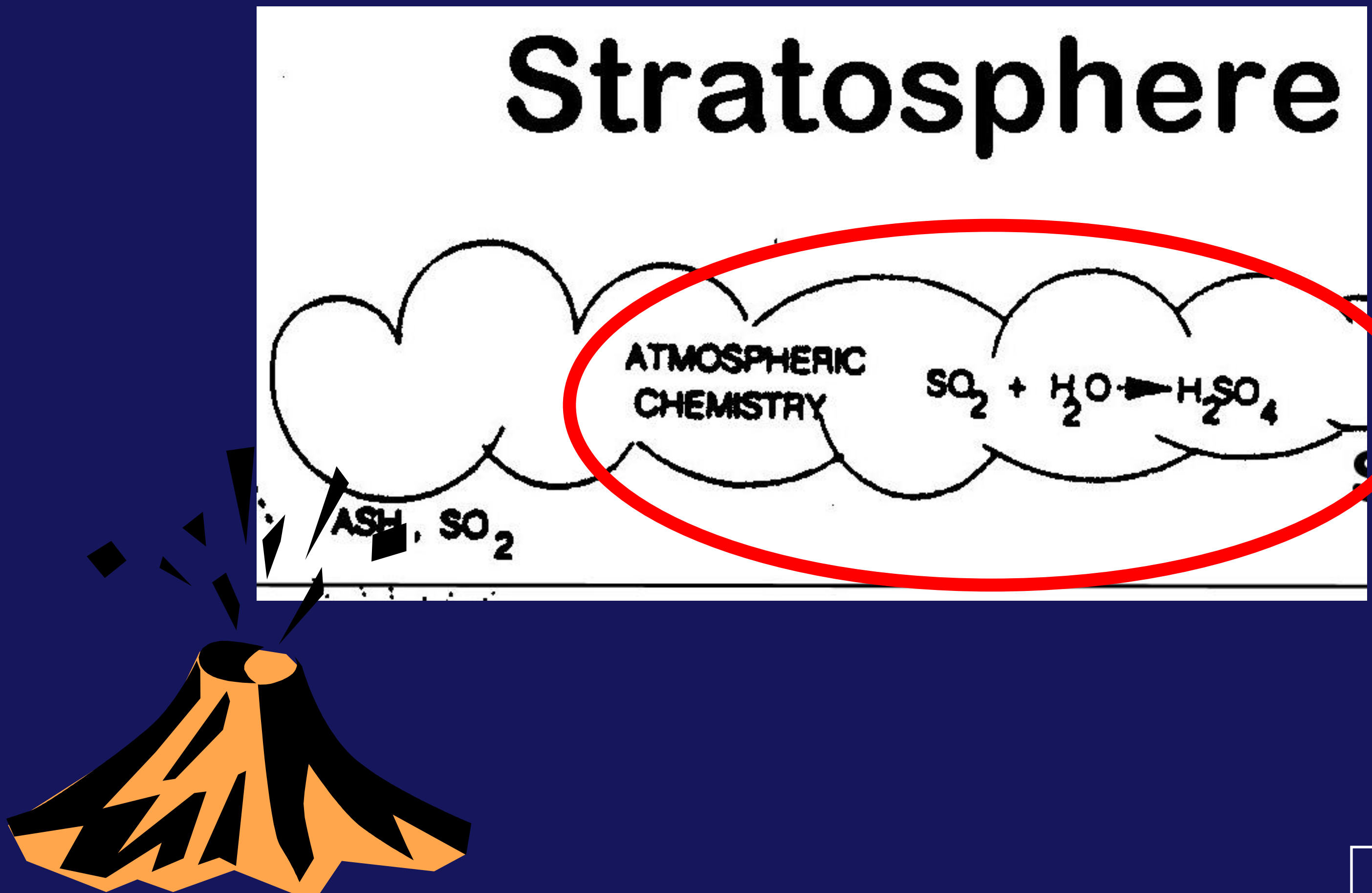


Albedo of ejected <u>ASH</u> in the STRATOSPHERE is *<u>not</u>* the reason for cooling after an eruption! (most ash falls out early)



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

SO_2 remains gaseous and is eventually converted to sulfuric acid (H_2SO_4) which condenses in a mist of fine particles called sulfate aerosols.



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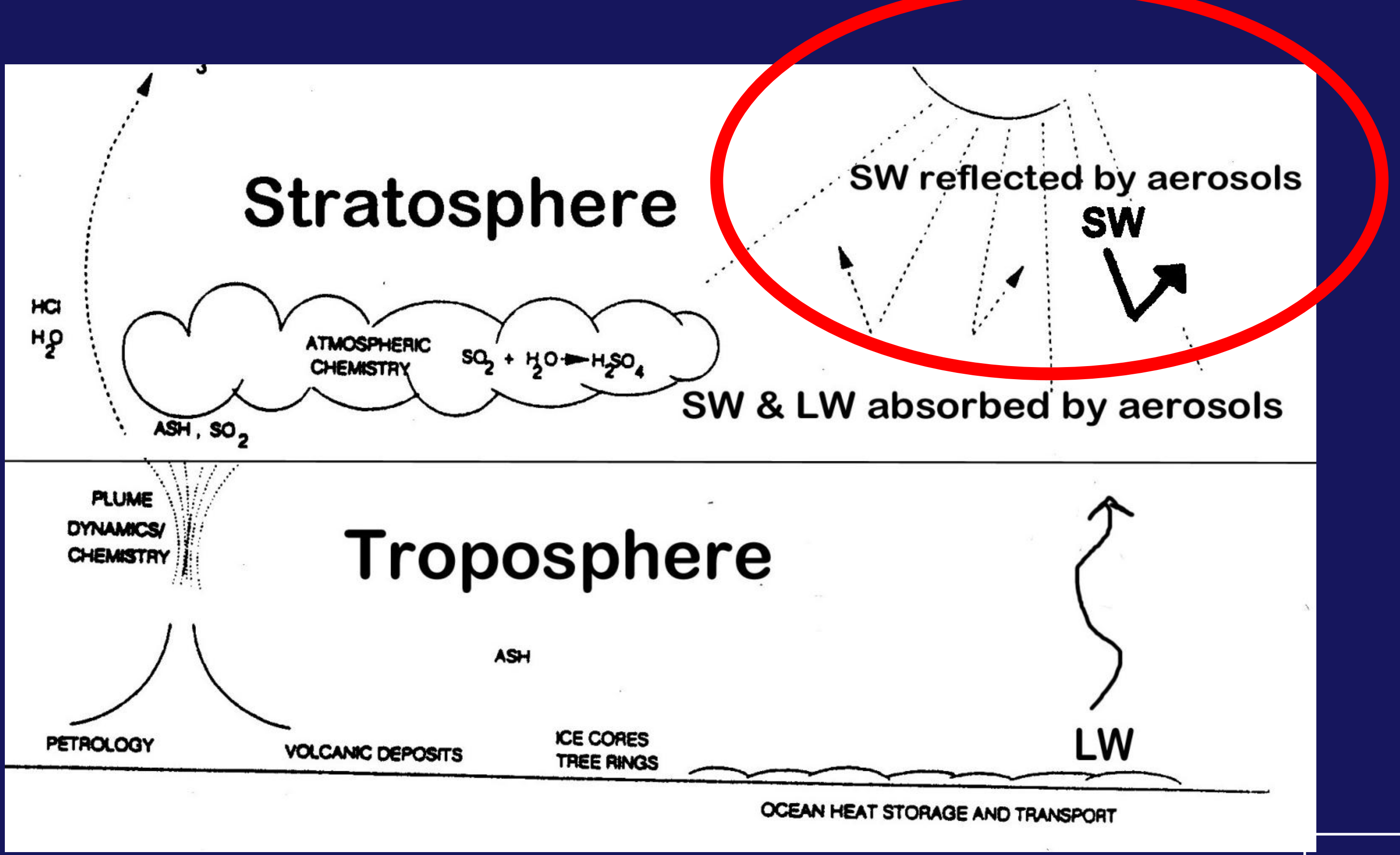
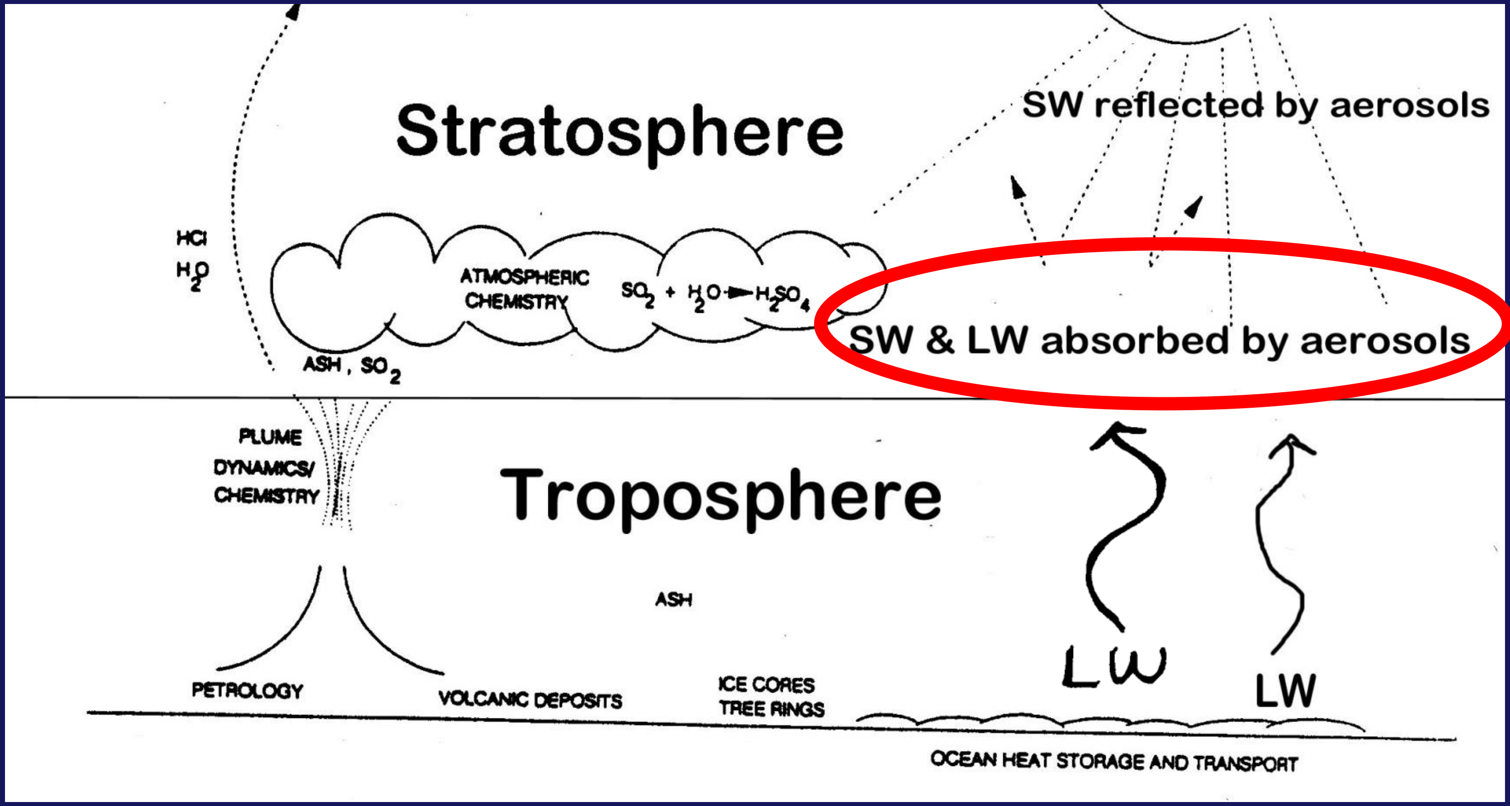
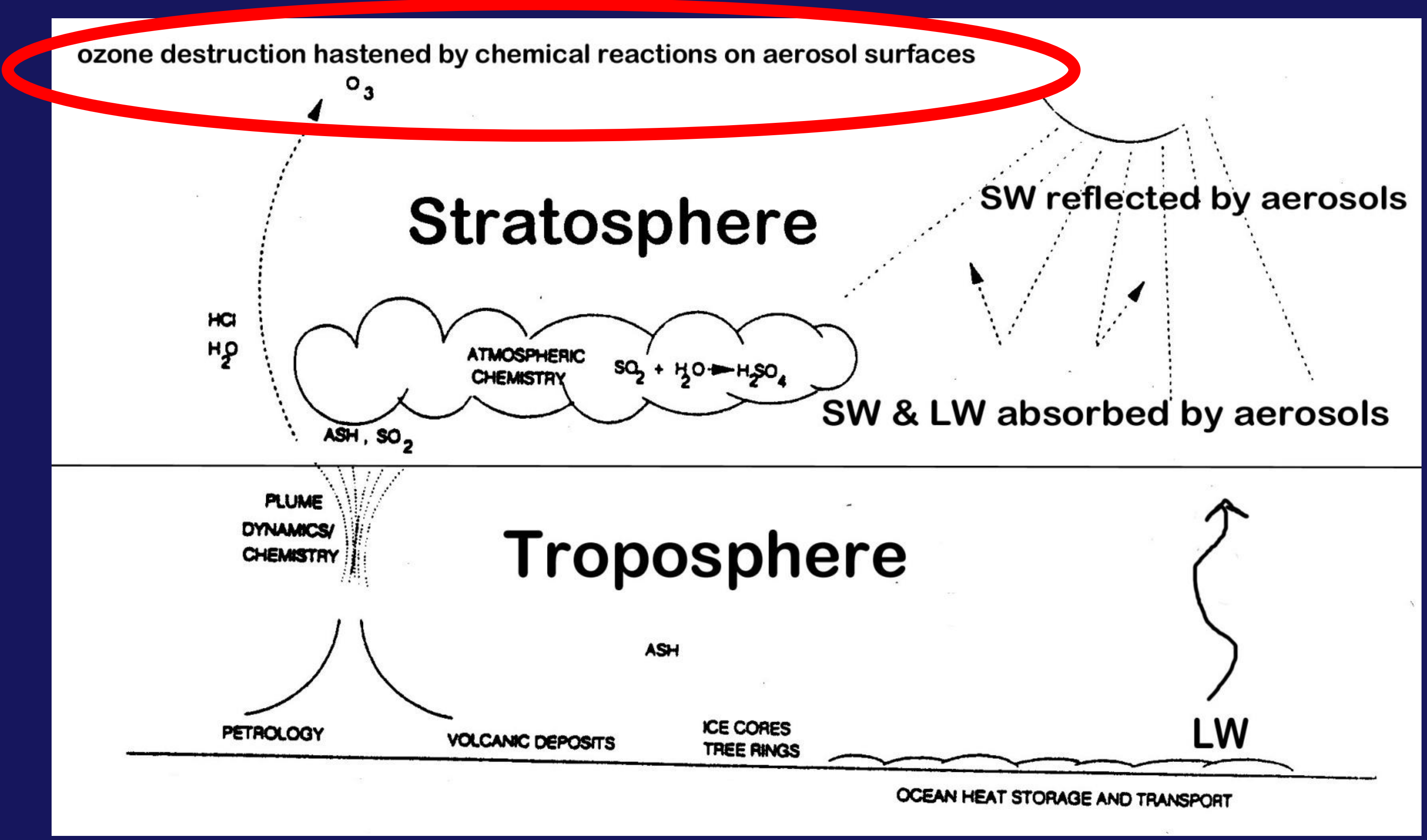
the sulfate **aerosols** ***reflect*** some of the incoming solar SW radiation back to space, **cooling the troposphere below**



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 #13)



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

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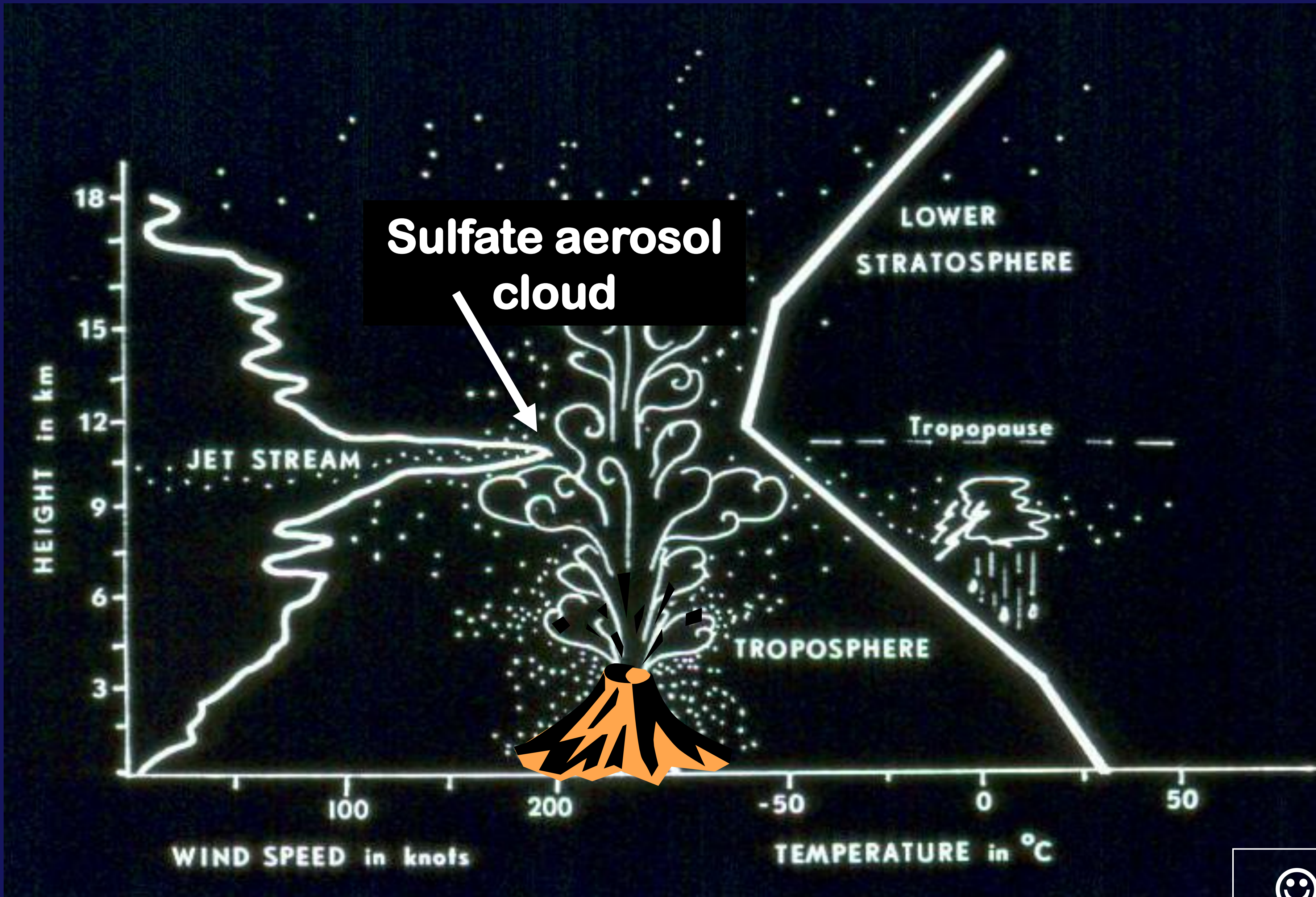
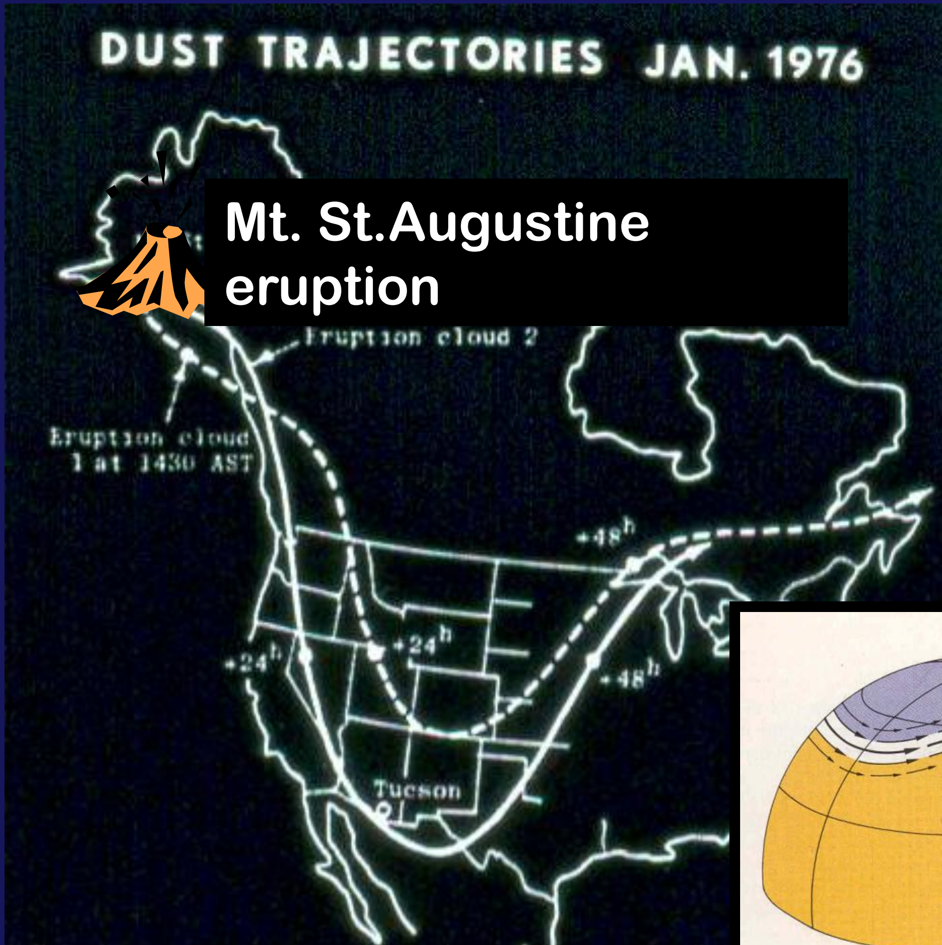
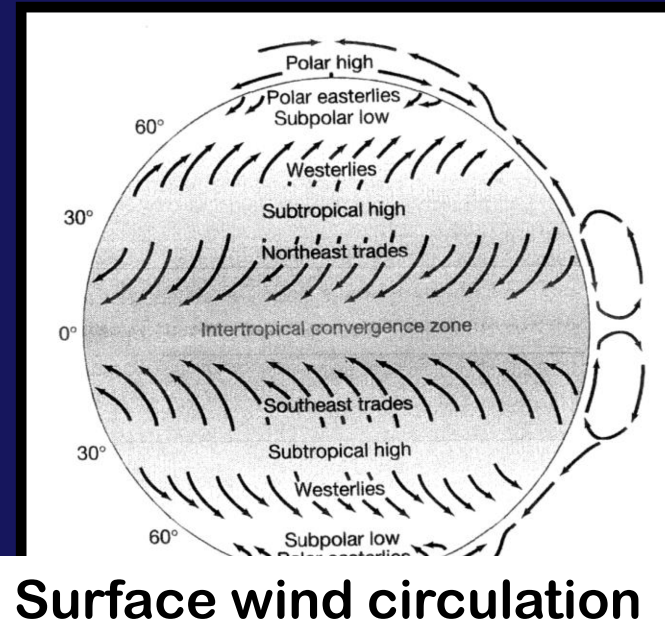
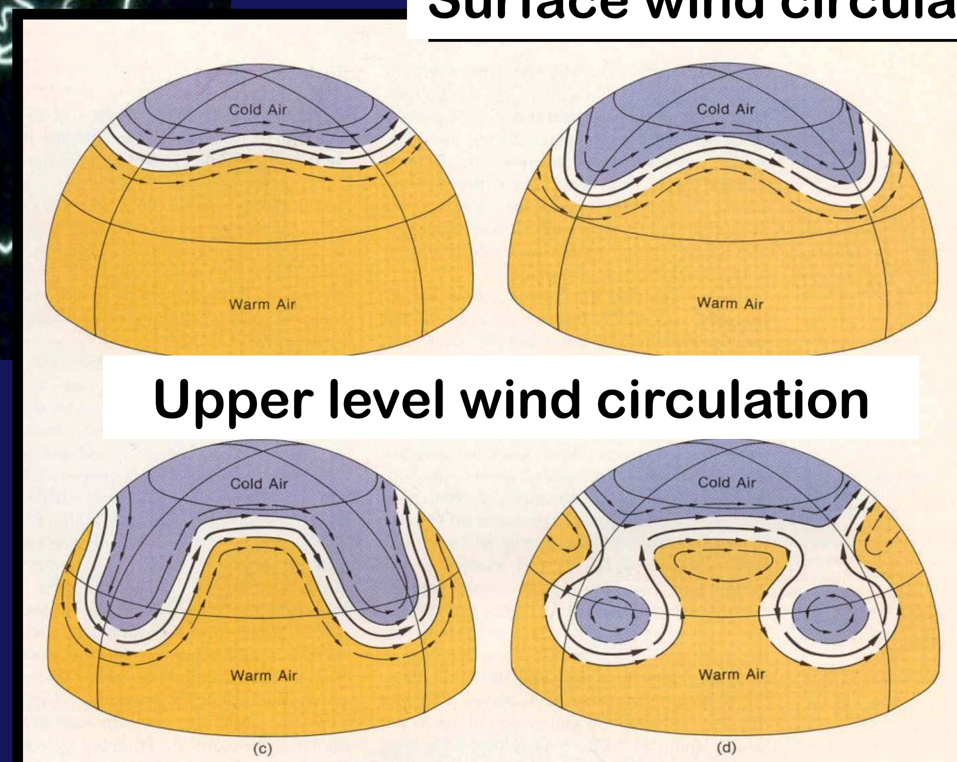
How an eruption's effects can become GLOBAL:



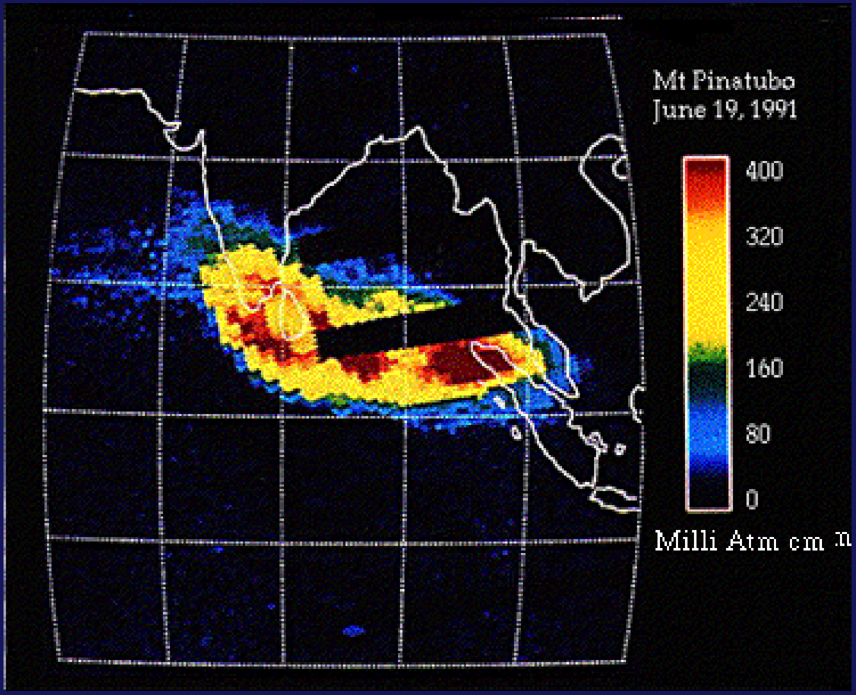






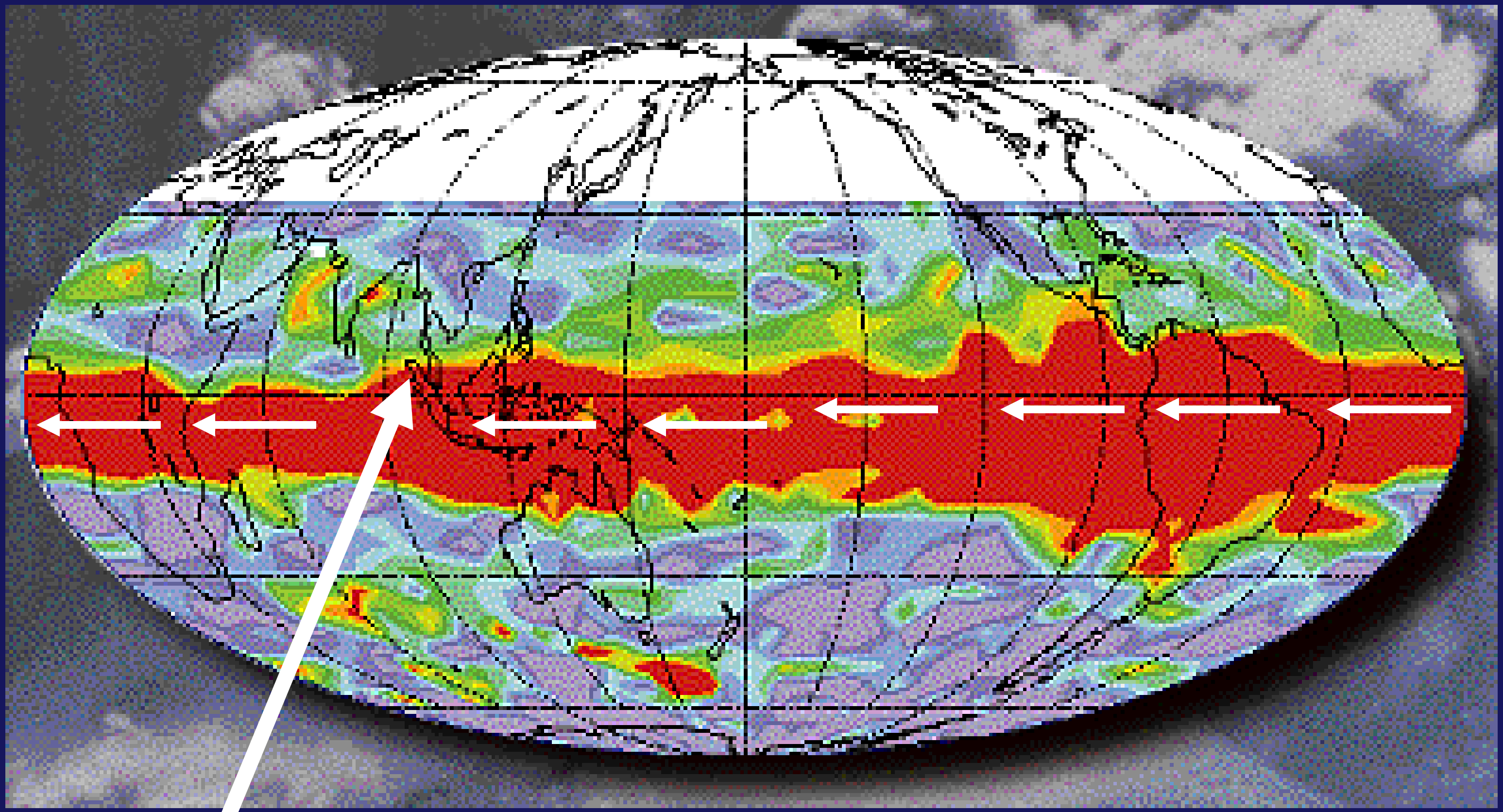
Through the atmospheric circulation!

Mt Pinatubo Eruption in the Philippines, June, 1991



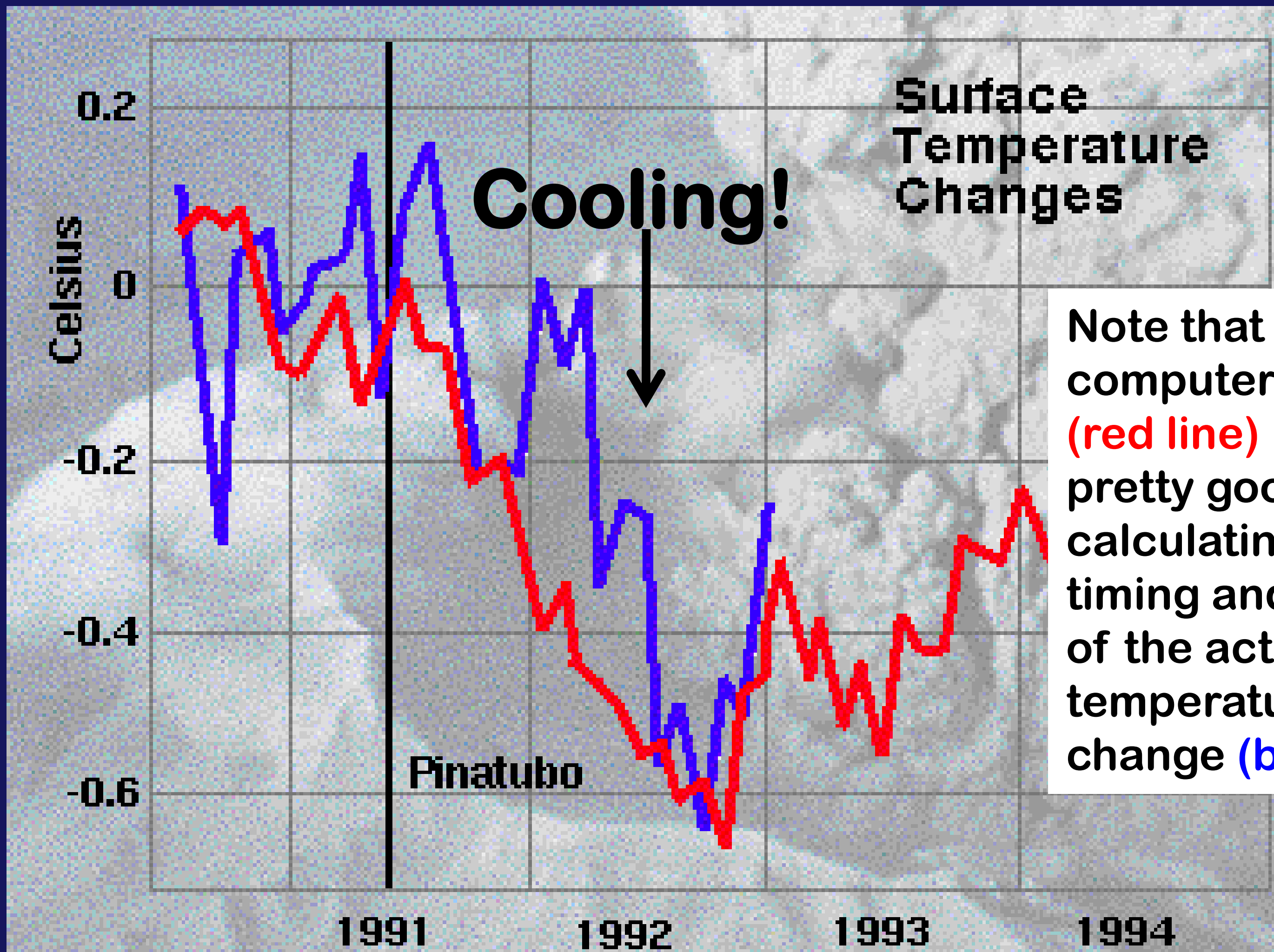
Satellite-derived image of
sulfur dioxide thickness in the atmosphere
red = higher thickness

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



Mt Pinatubo

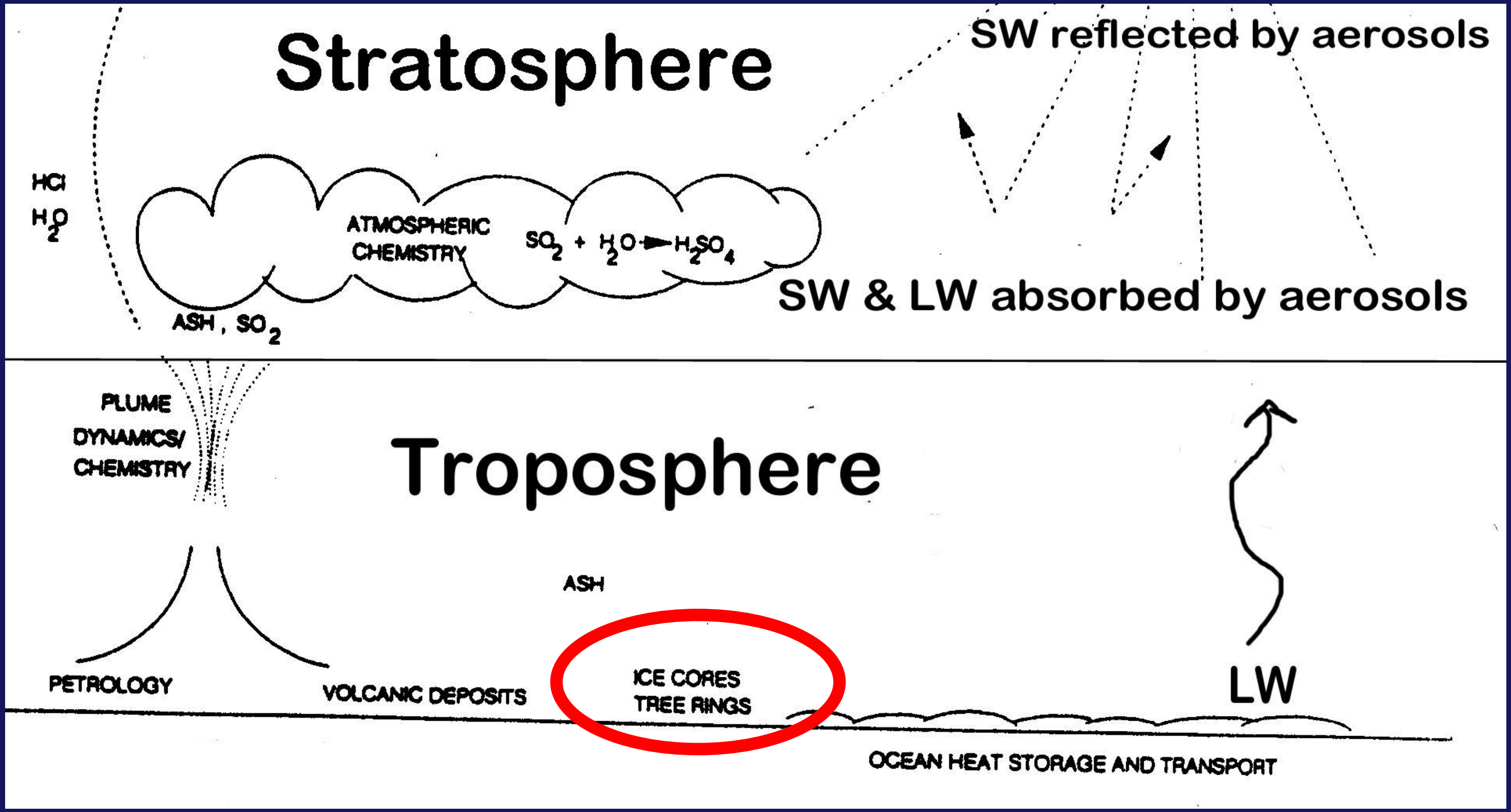
Mt Pinatubo eruption June 1991



Note that the computer model (red line) did a pretty good job of calculating the timing and amount of the actual temperature change (blue line).

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

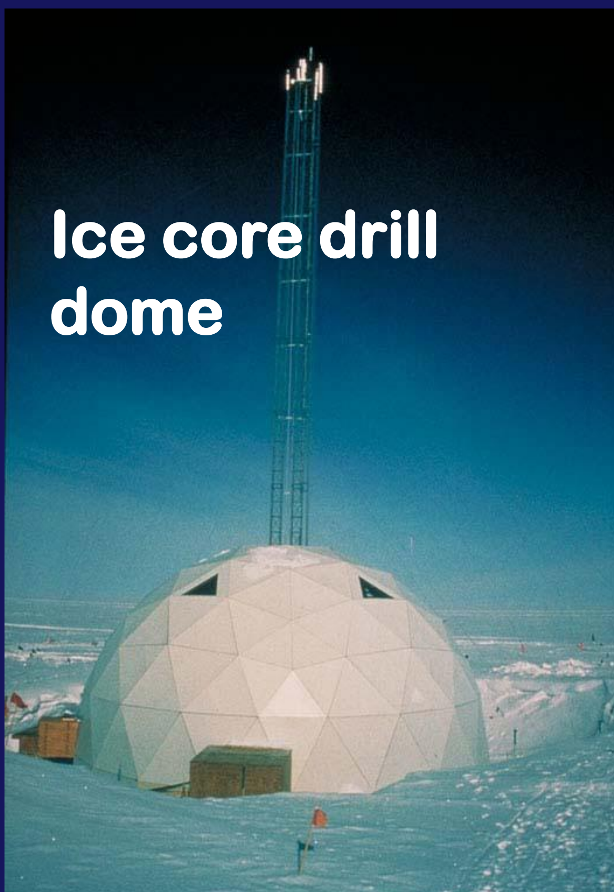
Major volcanic eruptions are infrequent events, but their climatic effects can be recorded over long time periods in ICE CORES & TREE RINGS!



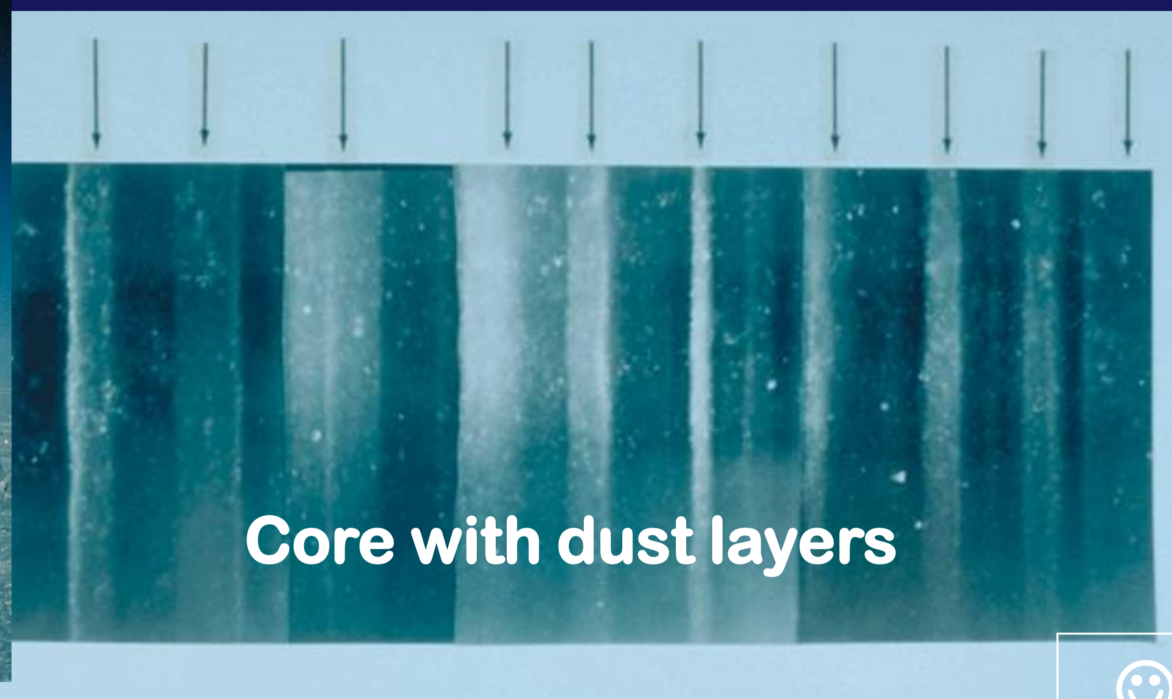
ICE CORES

Field conditions

Examining core

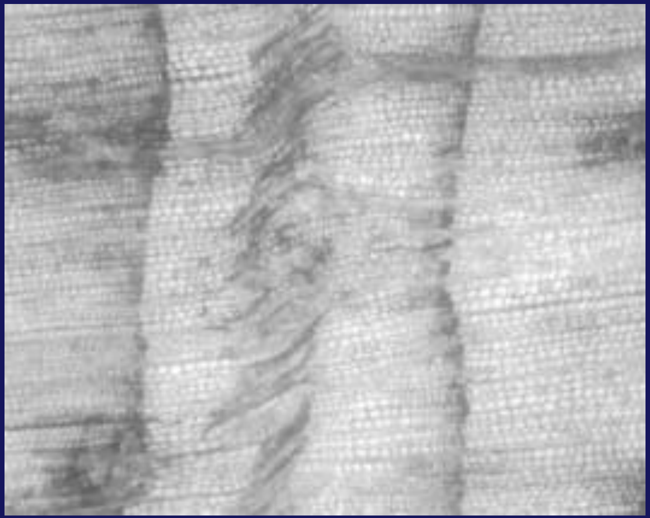


Ice core drill dome



Core with dust layers

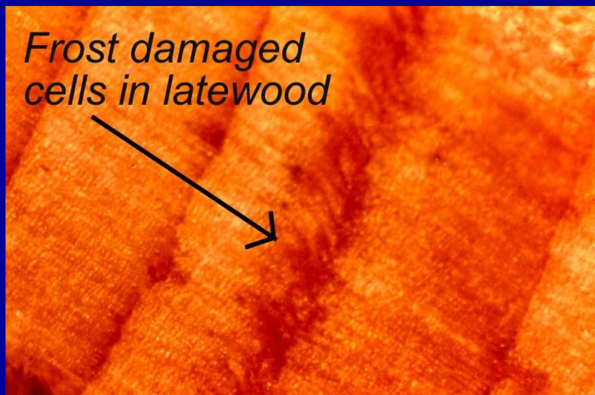
TREE RINGS

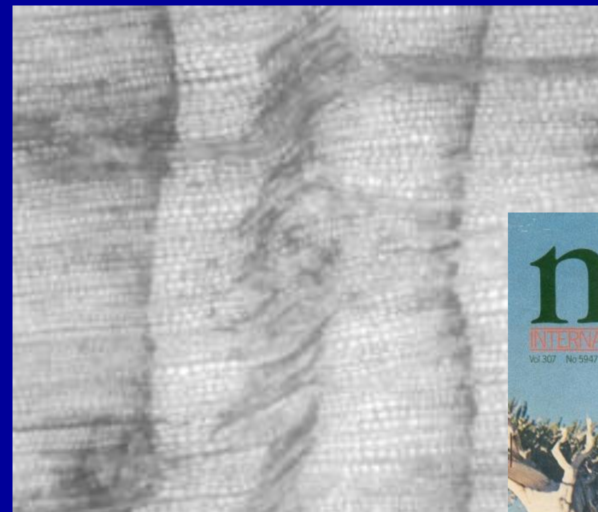


Severe <u>local</u> frost damage can be recorded in Tree Rings:

FROST RINGS

ABOUT FROST RINGS:



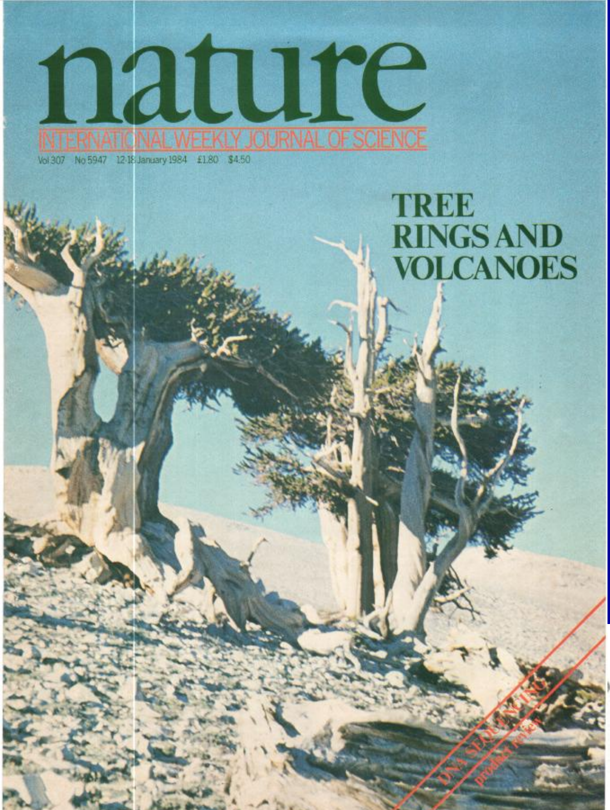


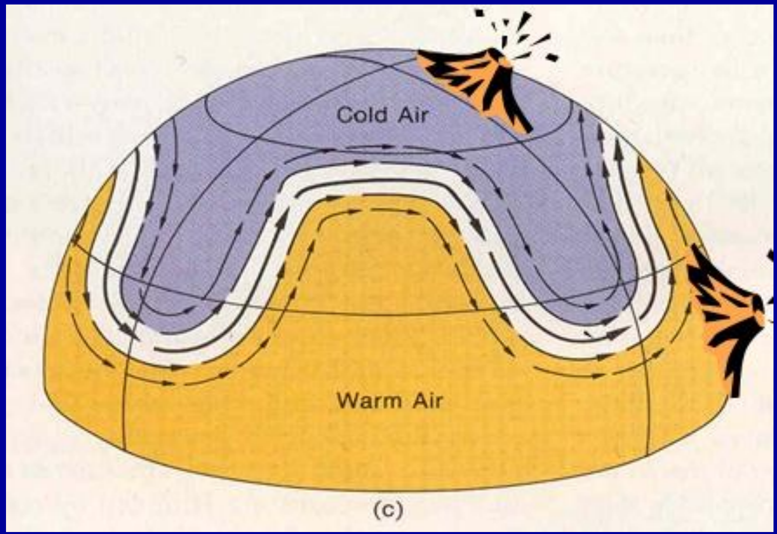
Produced by a severe freeze occurring DURING the tree's growing season :

2 nights < - 5^{o} C
intervening day 0^{o} C

Growing season for <u>high</u> elevation bristlecone pines = June – Aug, continues into September during cooler years (growth is slower during cool summers) and makes them more susceptible to an early frost

Have been linked to global cooling after major volcanic eruptions !!





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

Frost rings in trees as records of major volcanic eruptions

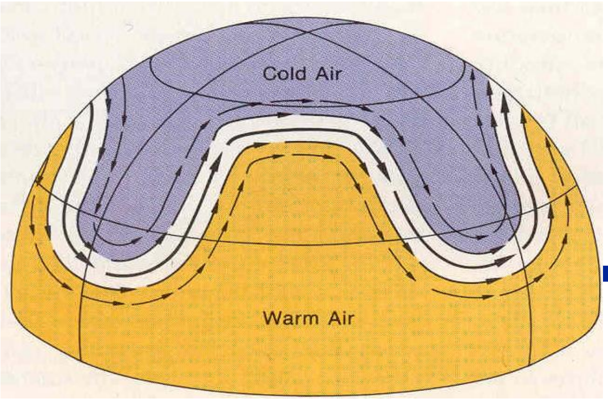
Valmore C. LaMarche Jr* & Katherine K. Hirschboeck†

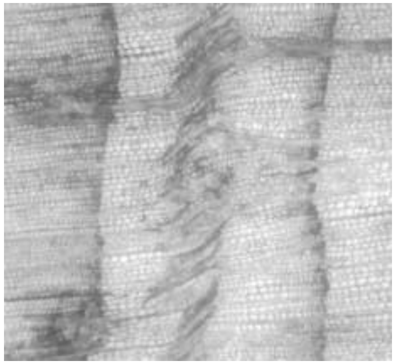
* Laboratory of Tree-Ring Research and † Department of Geosciences, University of Arizona, Tucson, Arizona 85721, USA

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.

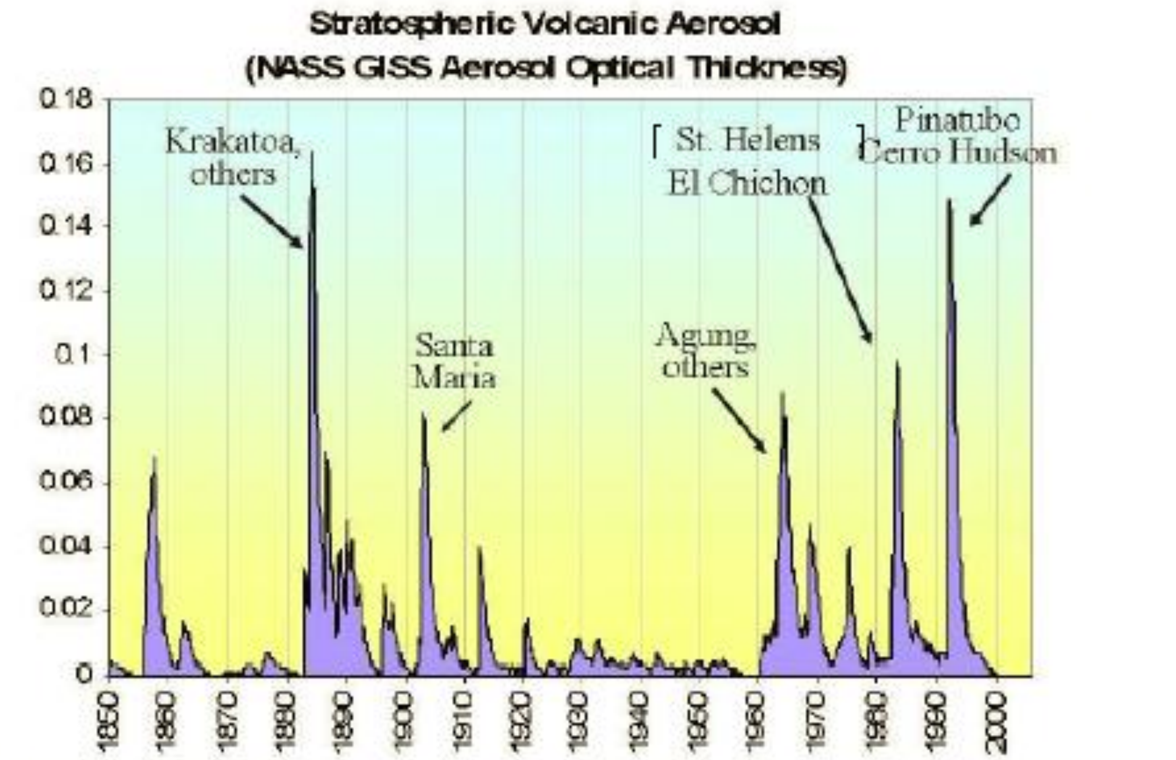
Energy Balance Effects & Global Atmospheric Circulation

+





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



Volcanic aerosols in the high atmosphere block solar radiation and increase cloud cover leading to widespread cooling, especially significant in summer

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

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 its easier for aerosols to get injected into the stratosphere where they will not be rained out.

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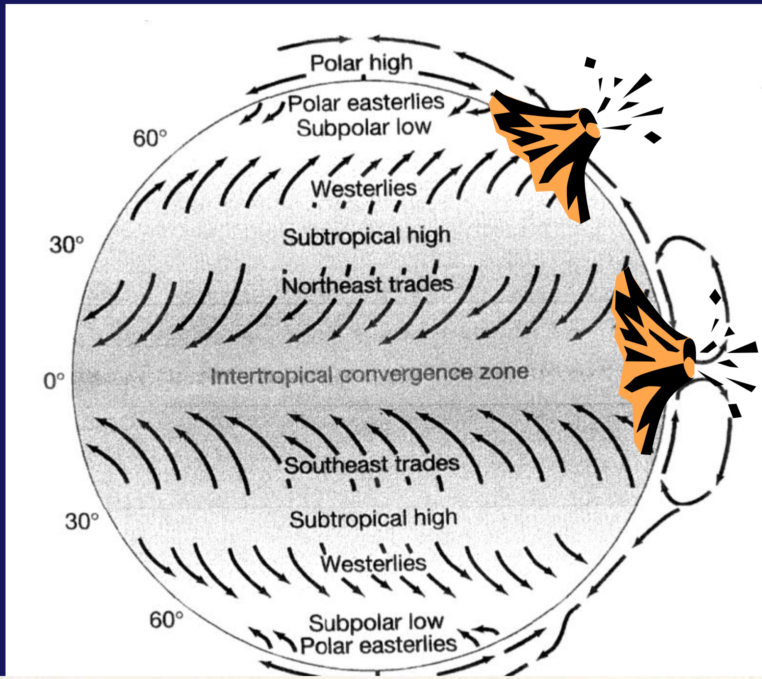
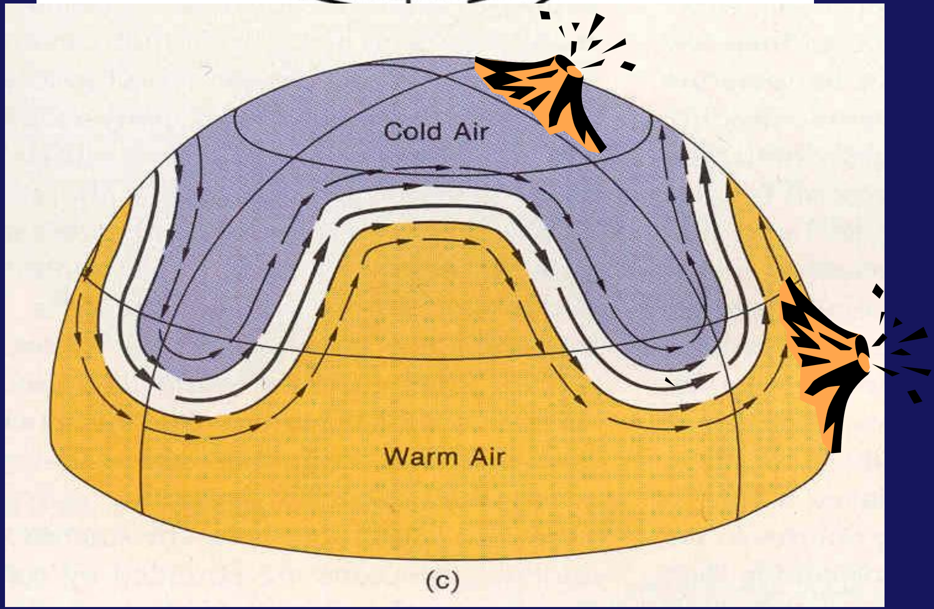
- The GEOGRAPHIC LOCATION of the erupting volcano influences the climatic effectiveness of an eruption because of the General Circulation of the Atmosphere.

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





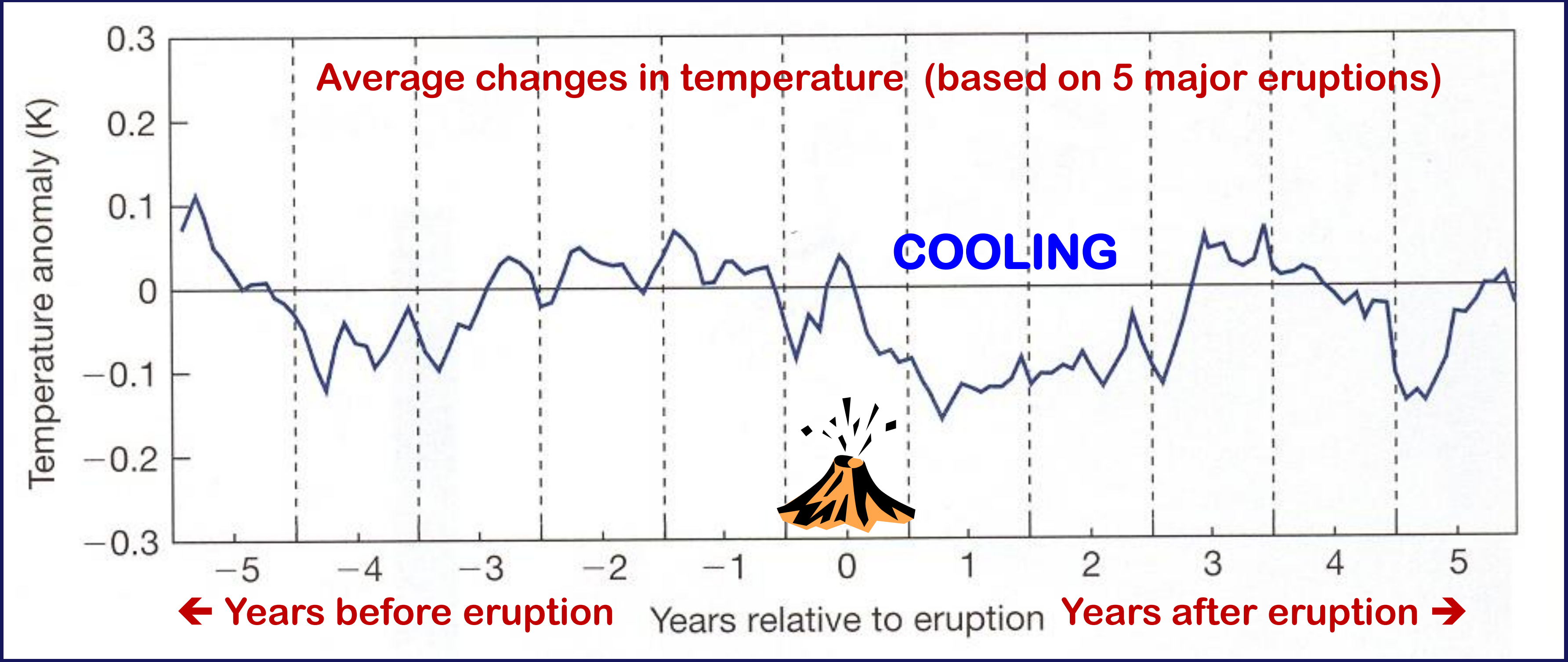
HOW DO REGIONAL CLIMATES RESPOND TO AN EXPLOSIVE ERUPTION?

In general, explosive eruptions warm the stratosphere and cool the troposphere, especially during the summer season.

HOW IMPORTANT IS EXPLOSIVE VOLCANISM AS A FORCING MECHANISM FOR PAST AND FUTURE CLIMATE CHANGES?

- interdecadal climate change ("Little Ice Age")
- Individual years, such as 1816, the "Year without a Summer" after the eruption of Tambora in 1815
- Link not always conclusive – e.g., El Nino at same time, etc.

Typical Global Cooling Pattern after a Volcanic Eruption



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

Comparison Table of Eruptions

Latitude

How much magma → how big an eruption

How much aerosol got into each hemisphere

Sulfur-rich if high H_2SO_4

Estimated N.H. temperature change °C

COMPARISON TABLE OF ERUPTIONS

Eruption & Latitude	Year	Amount of Magma Erupted (km^2)	Stratospheric Aerosol (Mt) S.H.	Stratospheric Aerosol (Mt) N.H.	H_2SO_4 estimate (Mt)	Estimated N.H. Temp change (°C)
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,
<u>this does not mean the</u> value is zero!

G-5 ACTIVITY ON VOLCANISM & CLIMATE

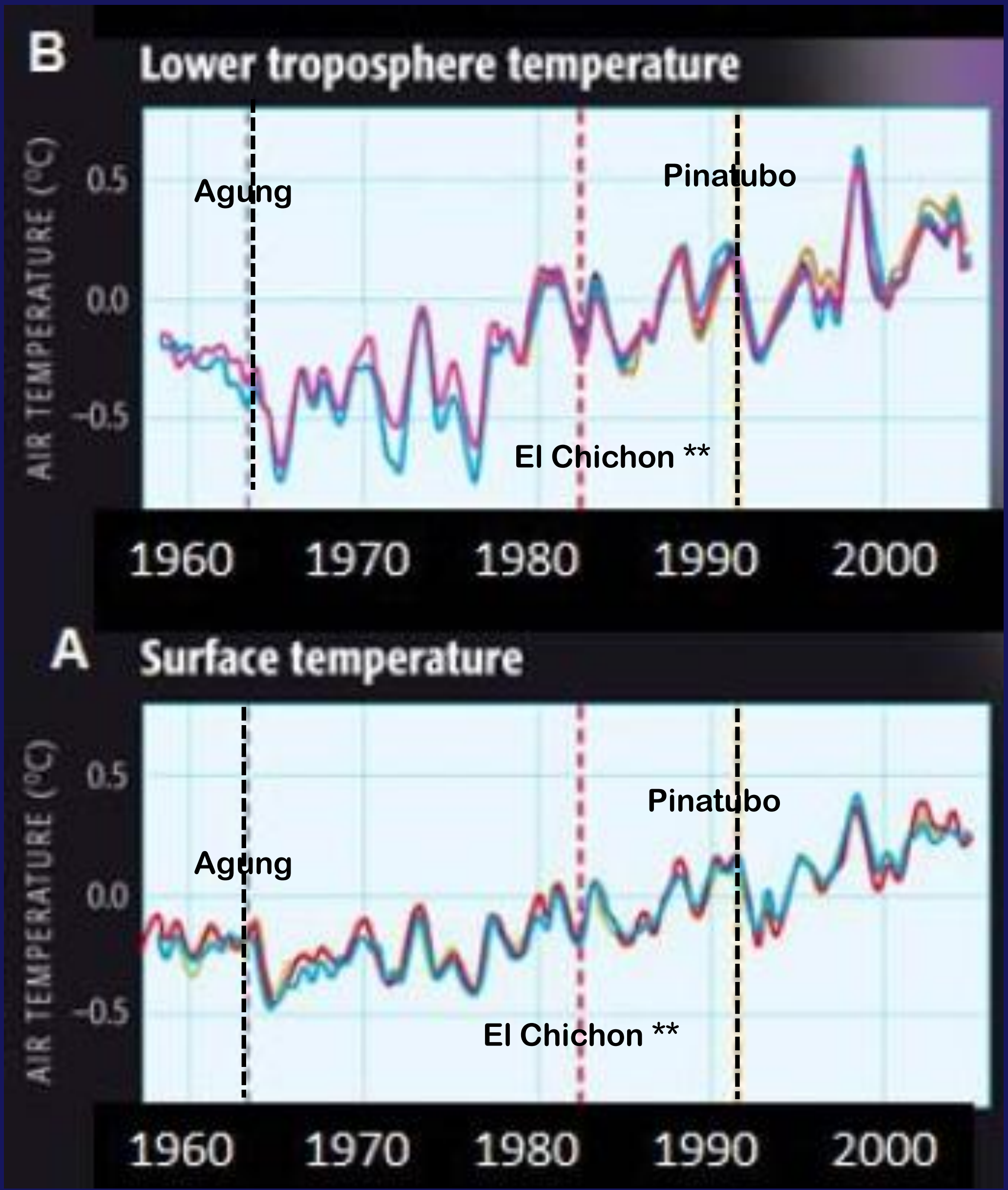
P.S. This is one of my favorite questions to ask on the FINAL EXAM!!!!

#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:

Write in the ERUPTIONS at top of page

Agung (1963) Pinatubo (1991)



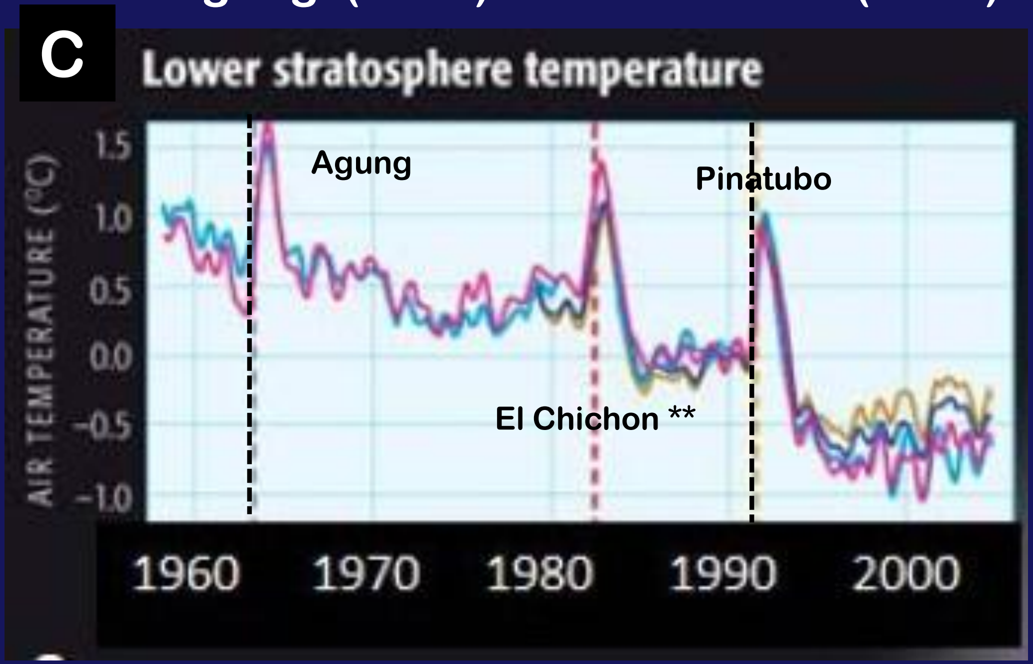
#3. Which levels show a COOLING and which show a WARMING immediately after the eruption?

** NOTE: At the time of the El Chichon eruption, there was warming taking place due to a strong El Nino, hence the temperature change after this eruption shows a different response.

When ANSWERING # 3 & #4 – focus on Agung & Pinatubo only

Write in the ERUPTIONS at top of page

Agung (1963) Pinatubo (1991)

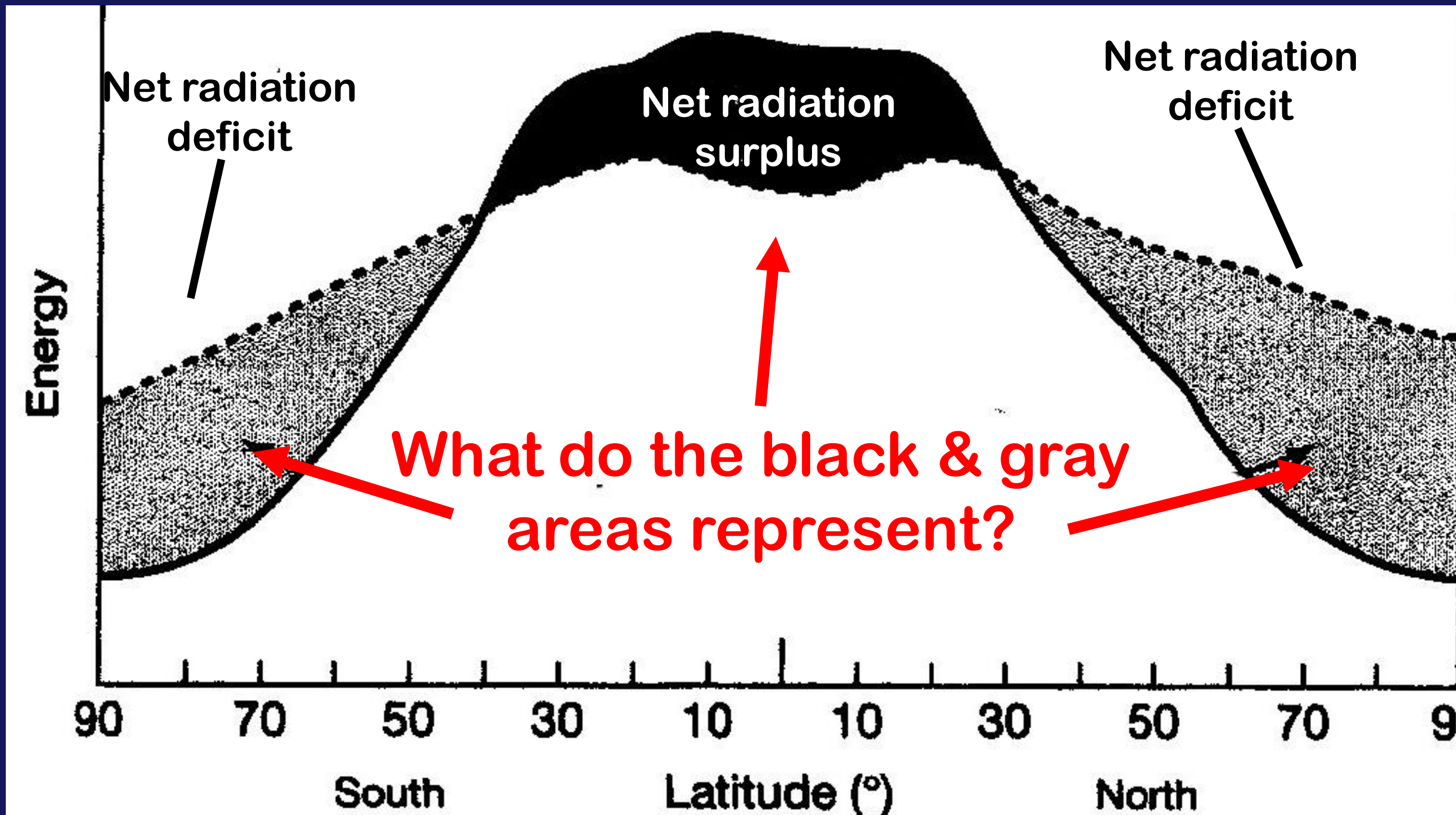


#4. Explain WHY each level's TEMPERATURE responded as it did to the Agung & Pinatubo eruptions?

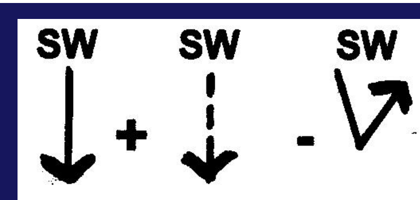
(by referring to the Radiation Balance)

When ANSWERING # 3 & # 4 – focus on Agung & Pinatubo only

REMEMBER THIS IMPORTANT GRAPH?



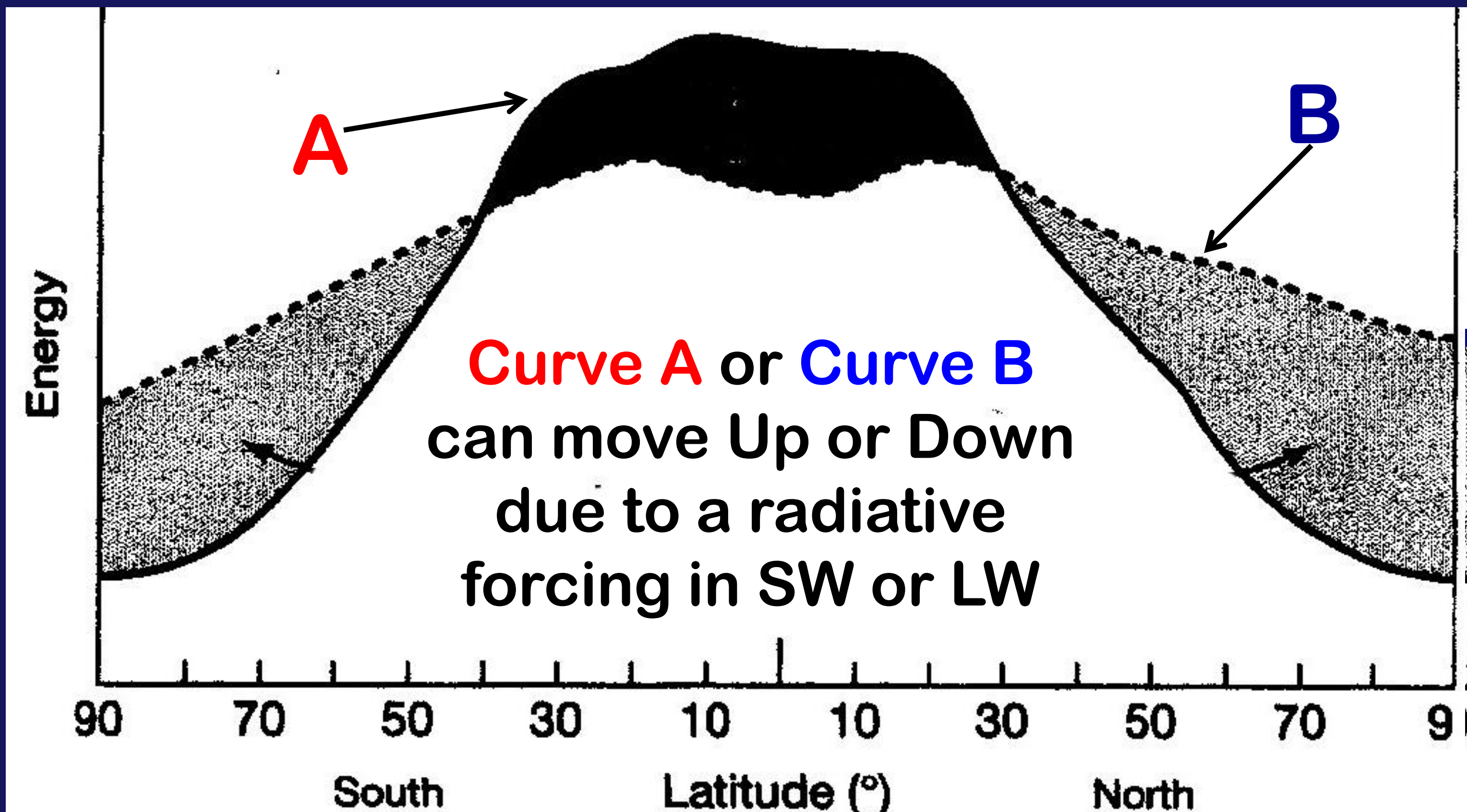
Absorbed solar energy

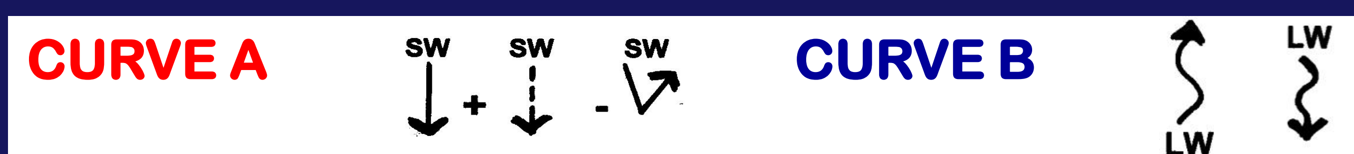


Emitted infrared energy

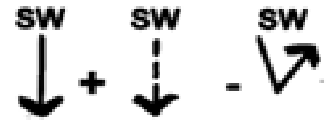
(at top of atmosphere)

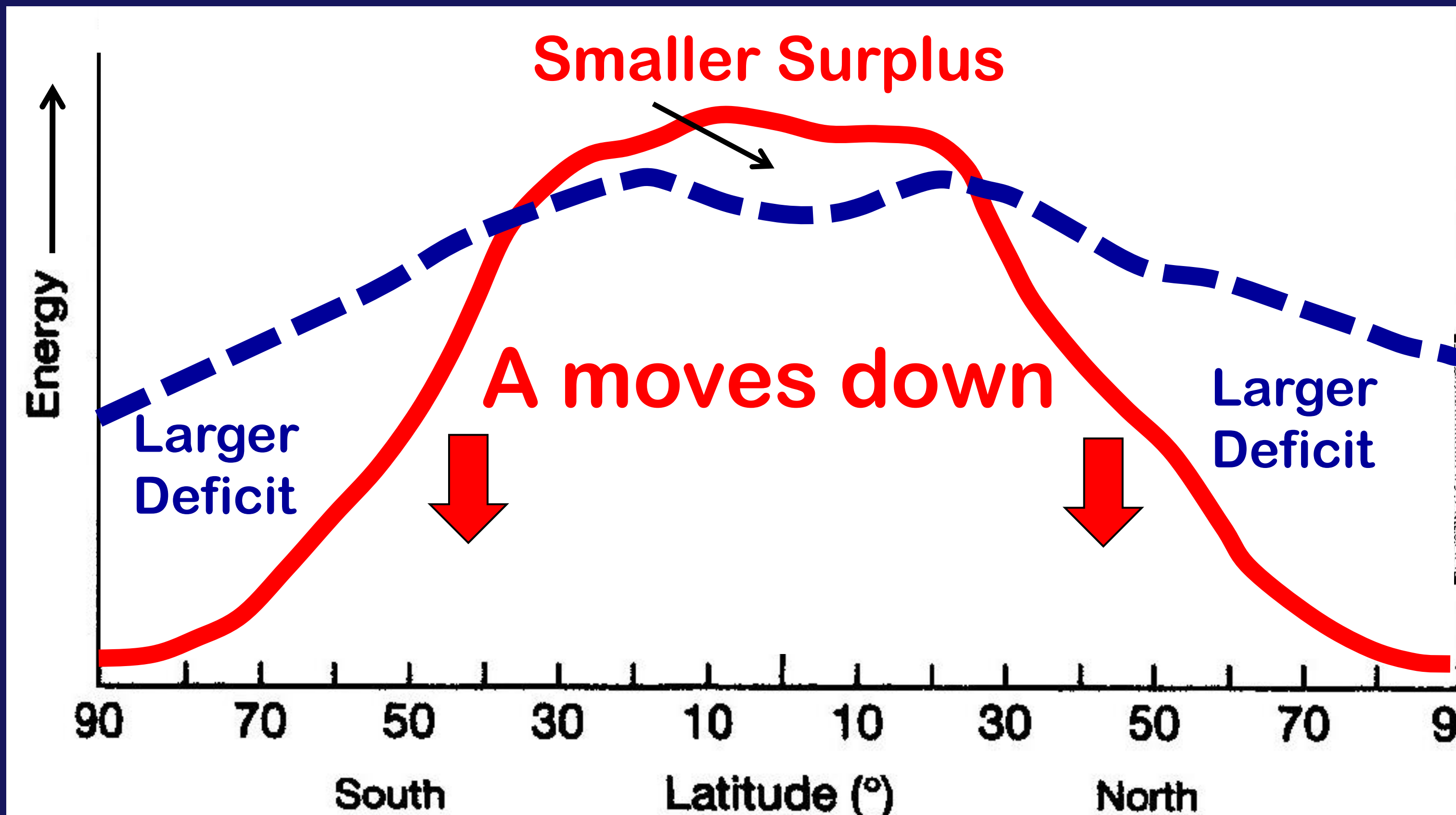
SKETCH A NEW CURVE A OR NEW CURVE B to show how the energy balance would change if a major volcanic eruption occurred .

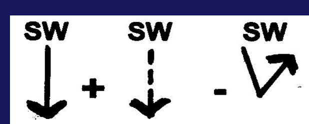




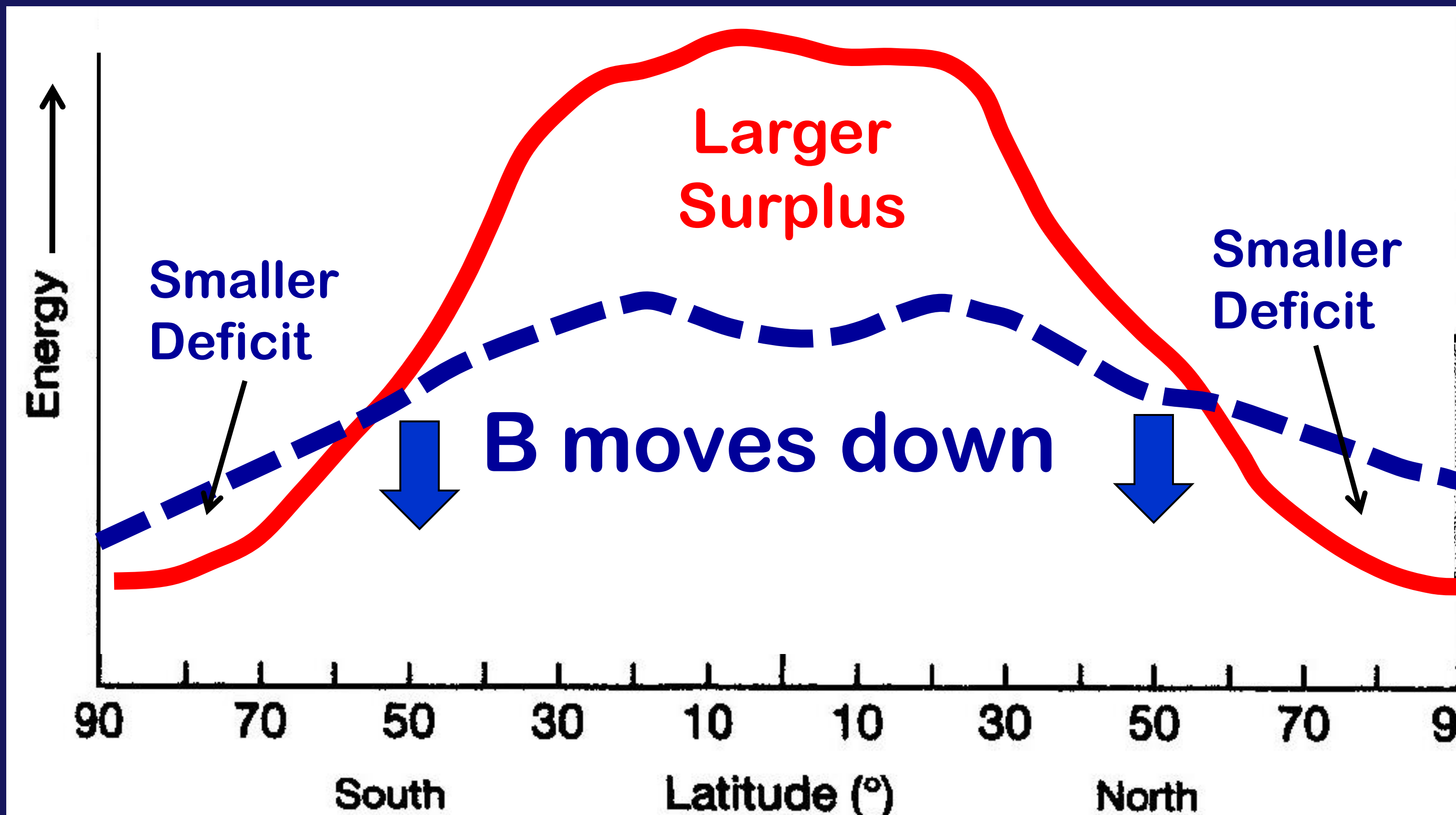
IF CURVE A moves down:





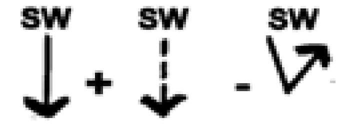


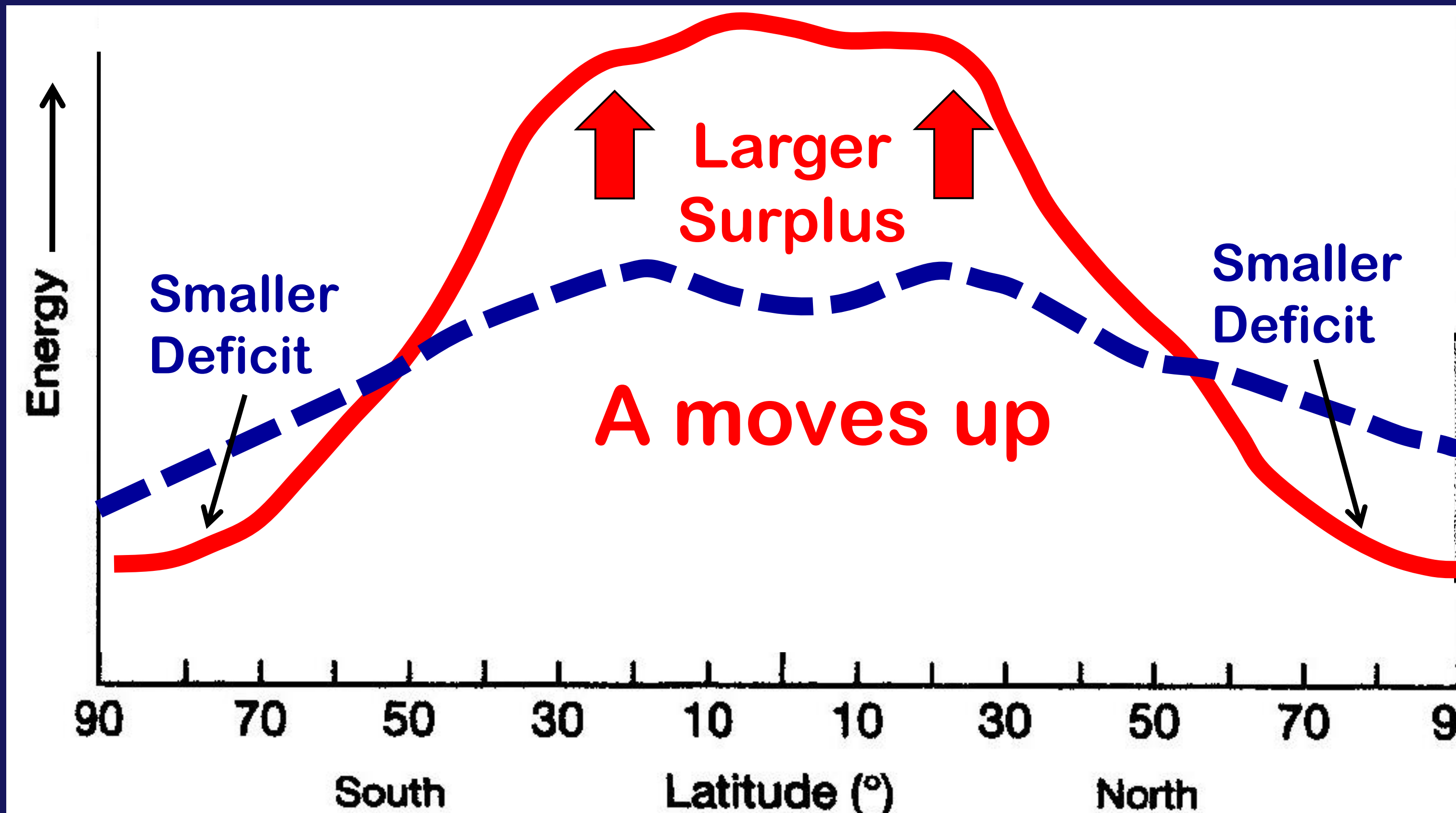
If incoming energy represented by Curve A is reduced (A curve goes down)

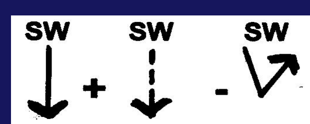


If outgoing energy represented by Curve B is reduced (B curve goes down)

IF CURVE A moves up:

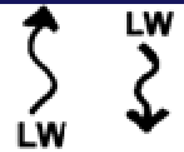


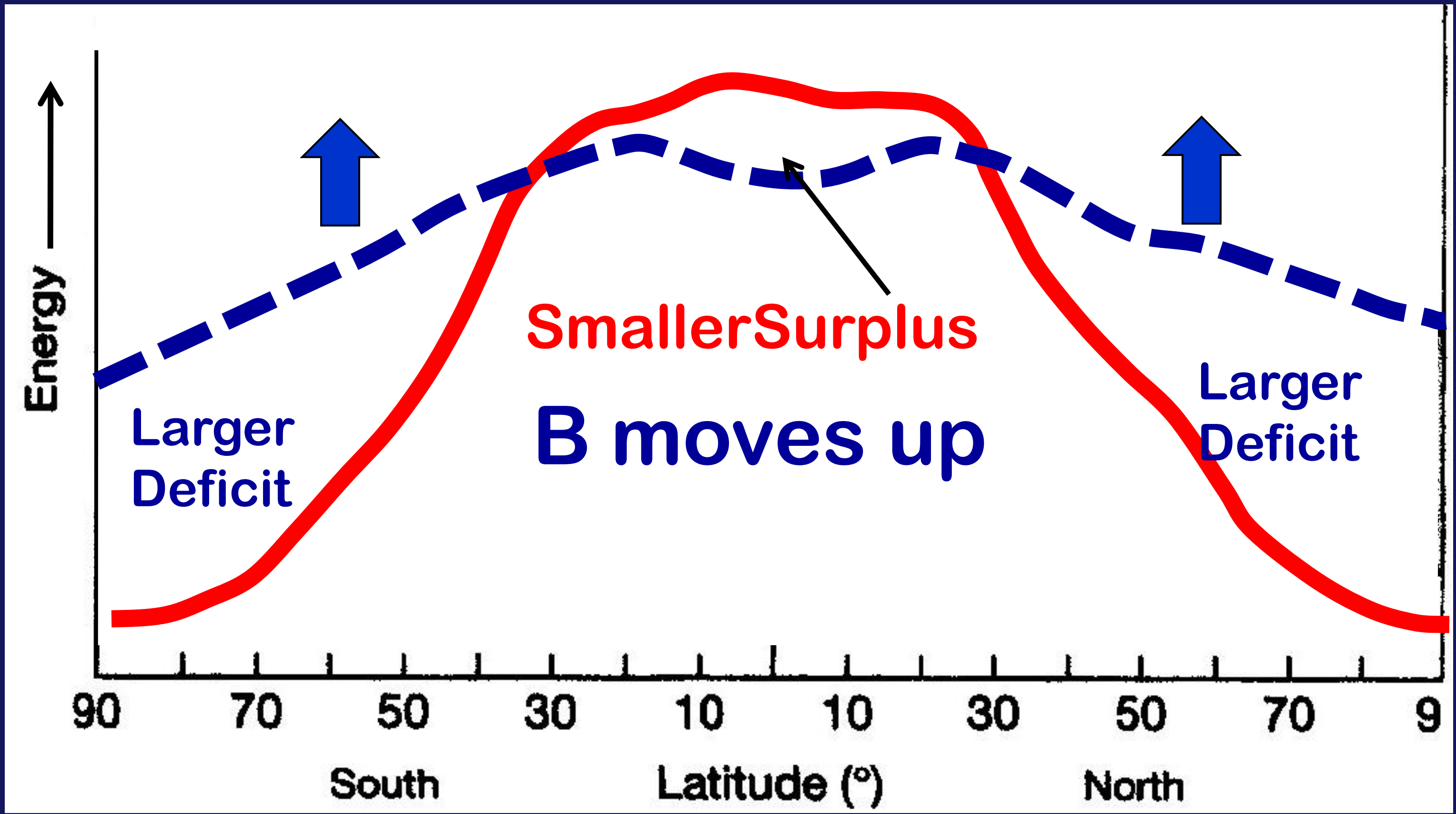




If incoming energy represented by Curve A is increased (A curve goes up)

If CURVE B moves up:



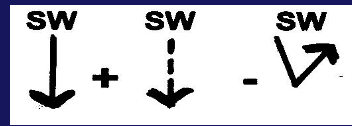


If outgoing energy represented by Curve B is increased (B curve goes up)

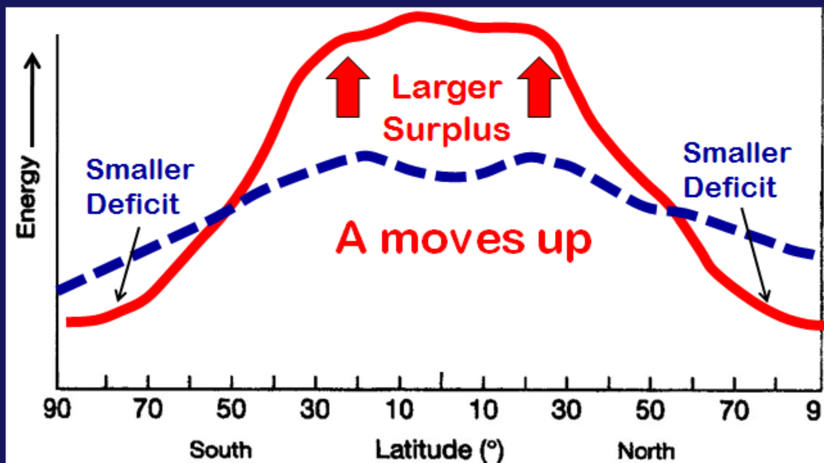
Assume:

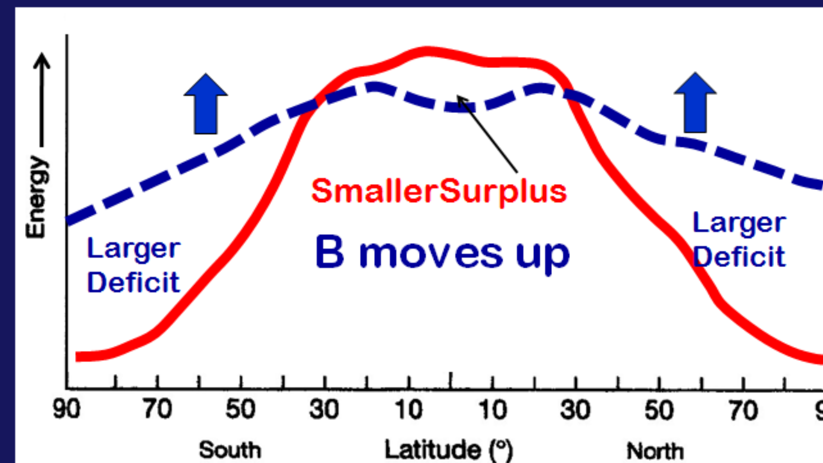
- that the eruption produces a long-lived aerosol veil in the stratosphere over both hemispheres
- that this veil reflects large amounts of incoming solar radiation back to space *before* it enters the troposphere's earth-atmosphere system shown in the graph.
- *Hint: you do not need to worry about stratospheric warming for this question.*

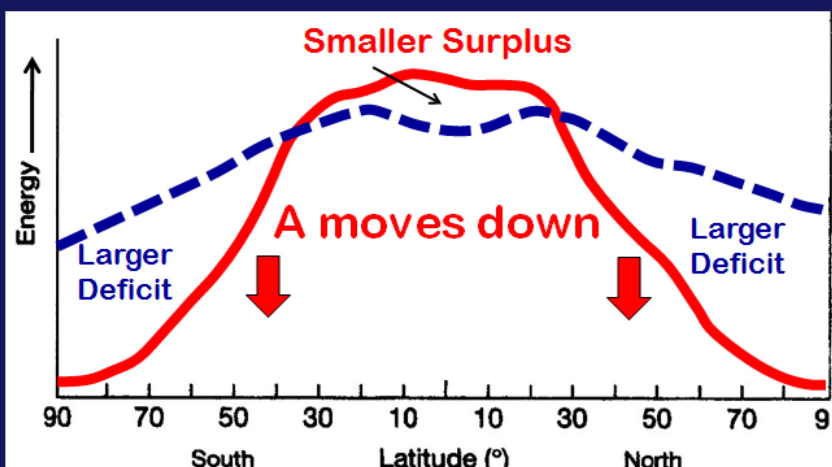
IF CURVE A is affected:

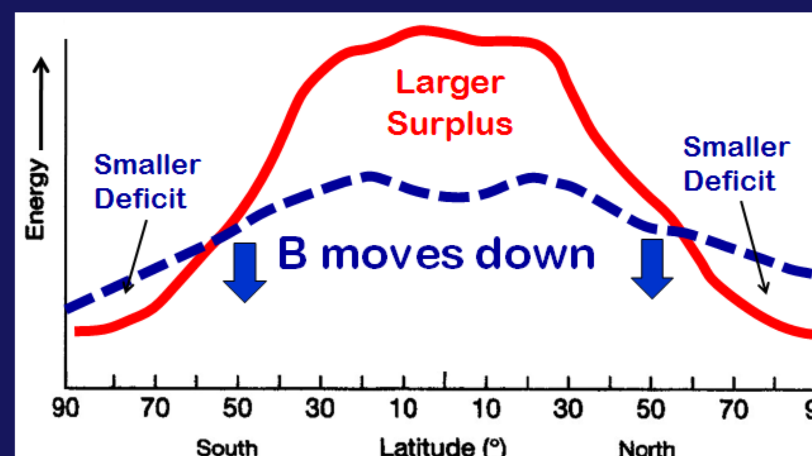


If CURVE B is affected:









Four scenarios are possible for how you should sketch the new graph