NATURAL CLIMATIC FORCING

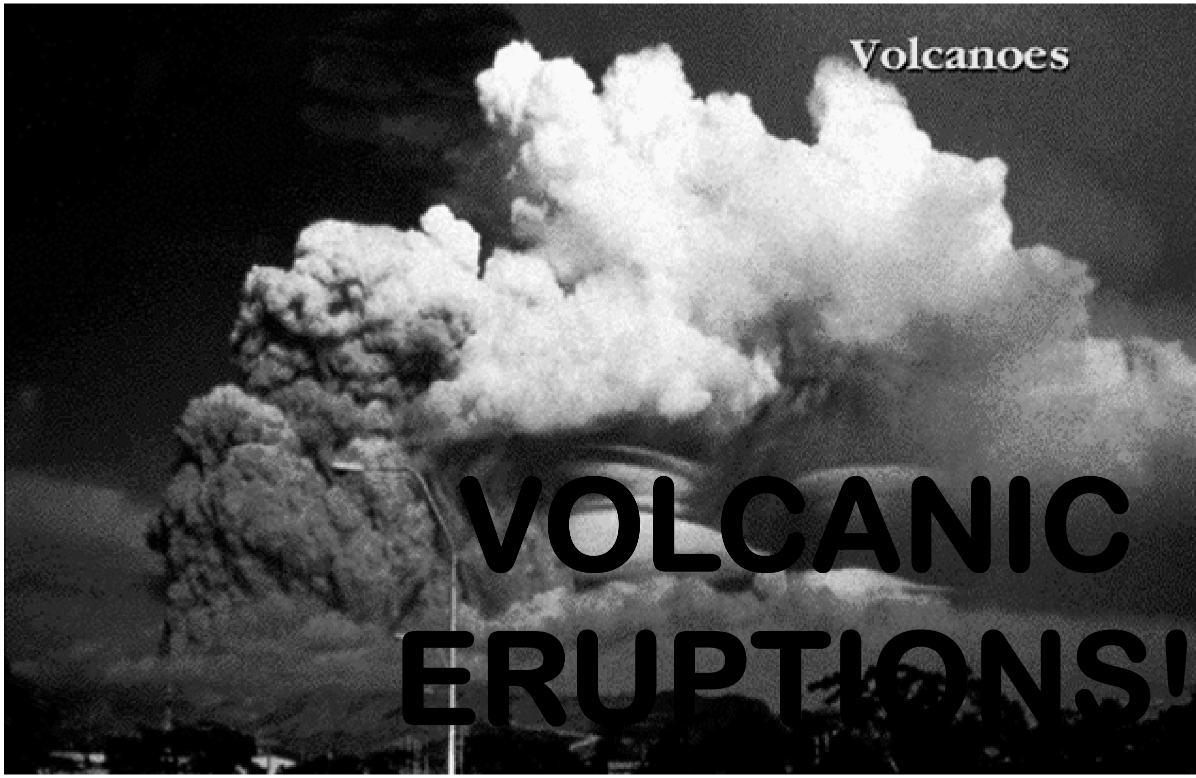
Earth-Sun orbital relationships, changing land-sea distribution (due to plate tectonics), solar variability & VOLCANIC ERUPTIONS

vs.

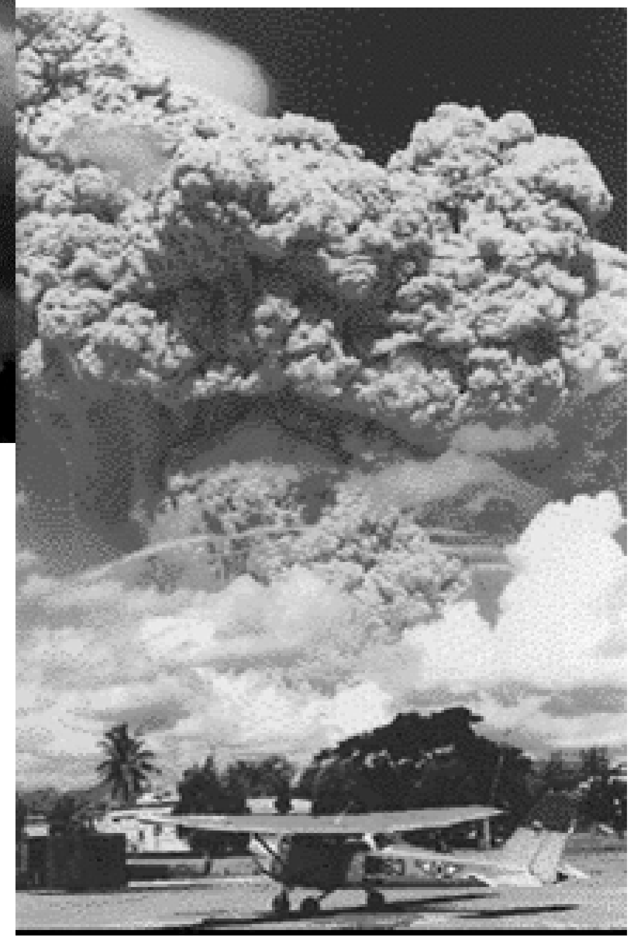
ANTHROPOGENIC FORCING

Human-Enhanced GH Effect, contribution of catalysts for OZONE DEPLETION

review



VOLCANIC ERUPTIONS!



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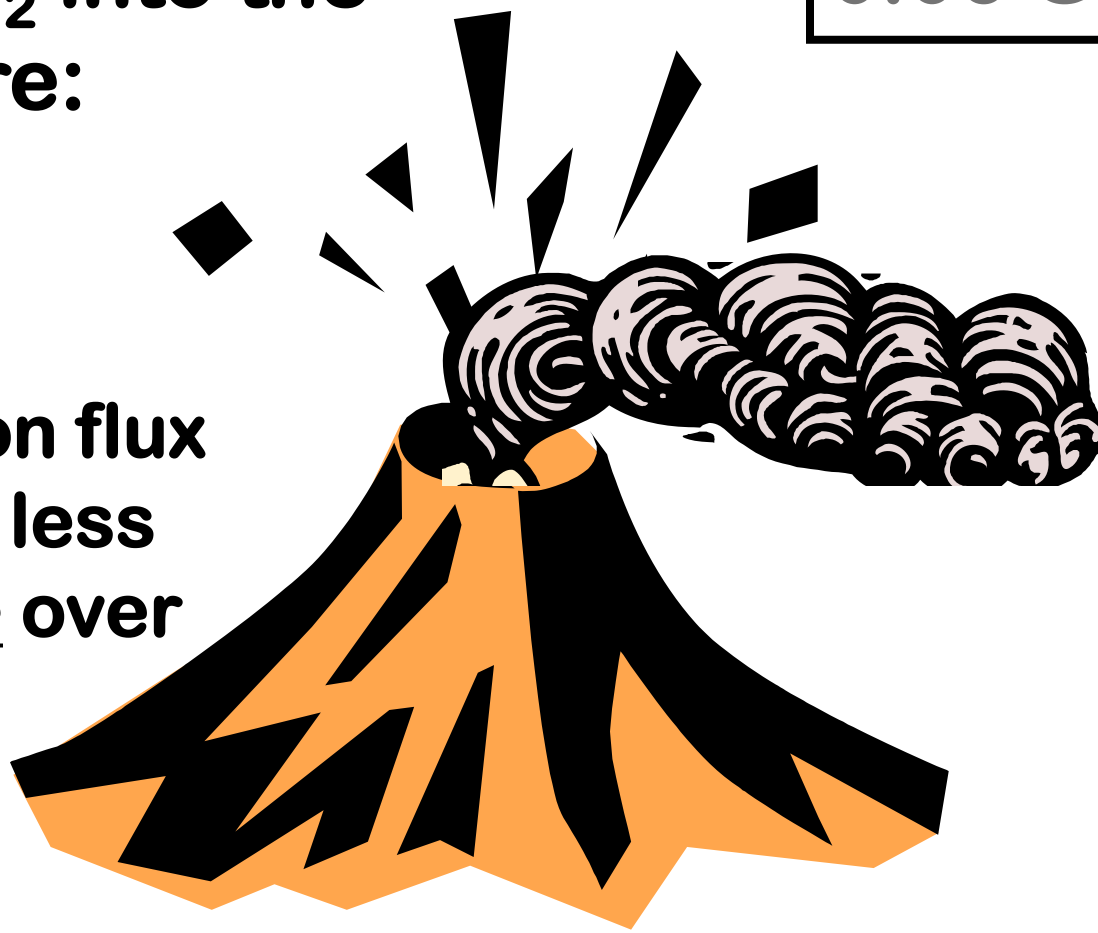
Volcanoes are one way the Earth gives birth to itself.

~Robert Gross

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

Volcanic outgassing of CO_2 into atmosphere

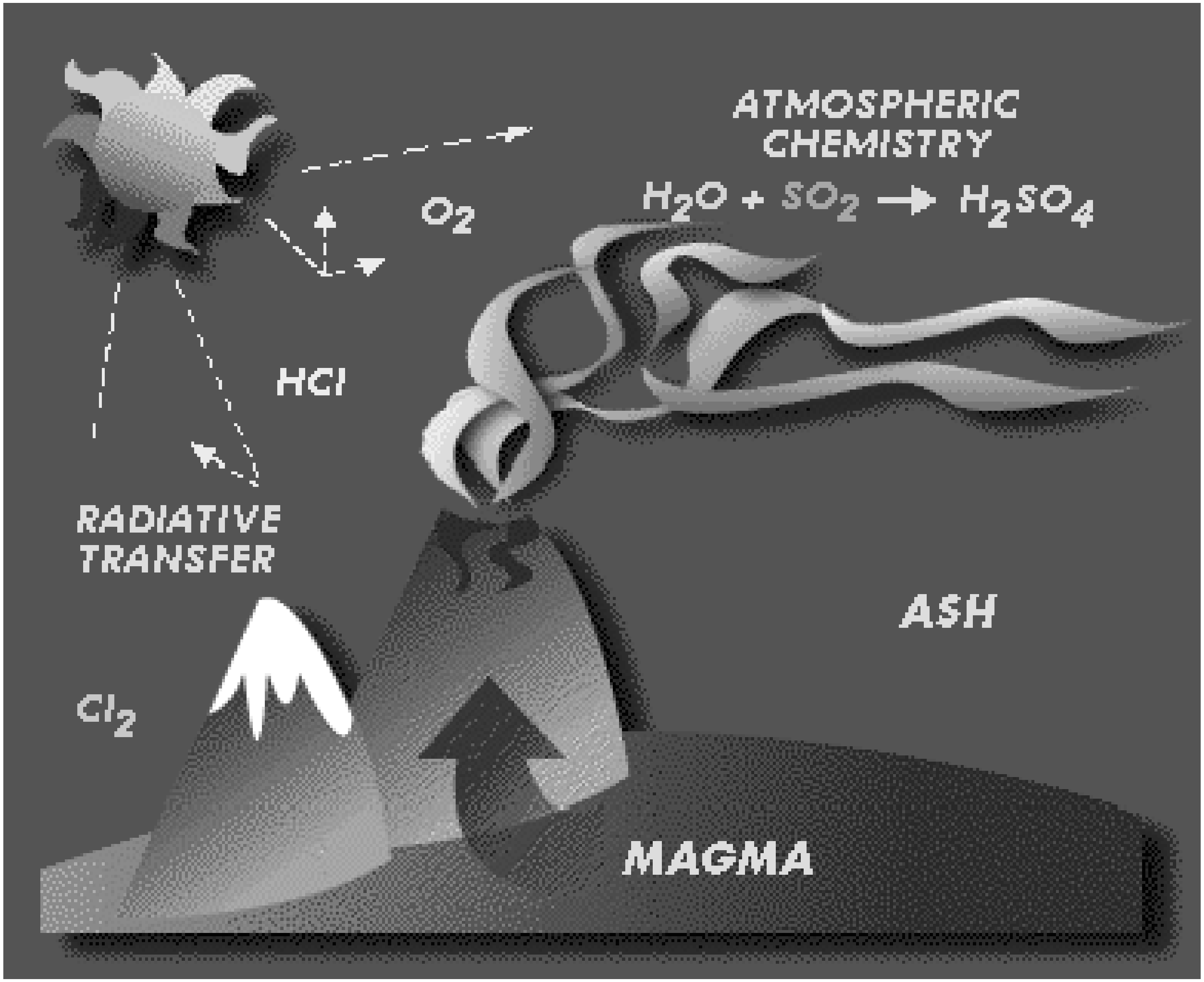
0.06 Gtons



This carbon flux is more or less <u>in balance</u> over time

☺

Eruptions can also have a more direct climatic effect under certain conditions:



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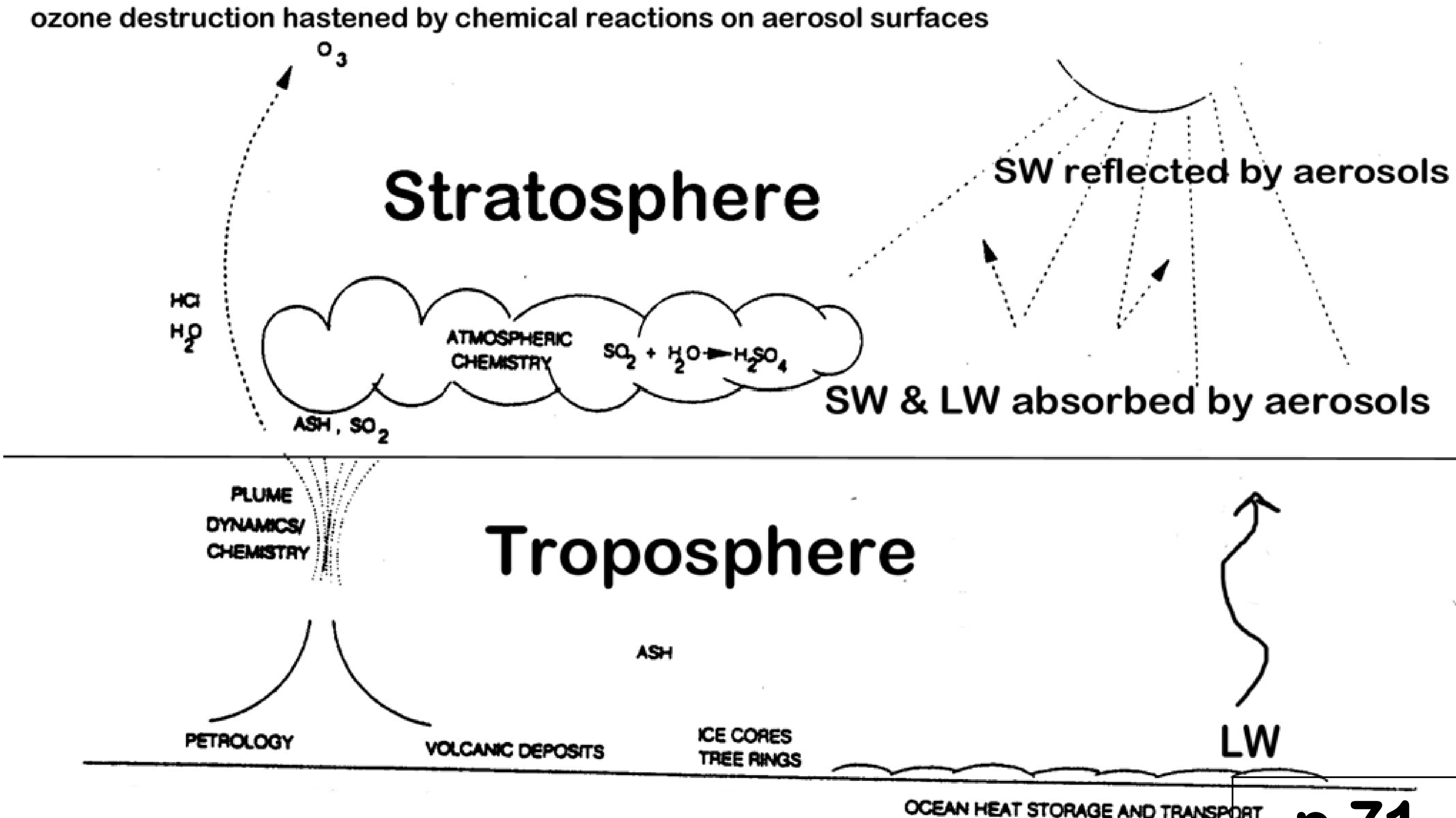
How the Climatic Effect Occurs . . . . through the ENERGY BALANCE of course!



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

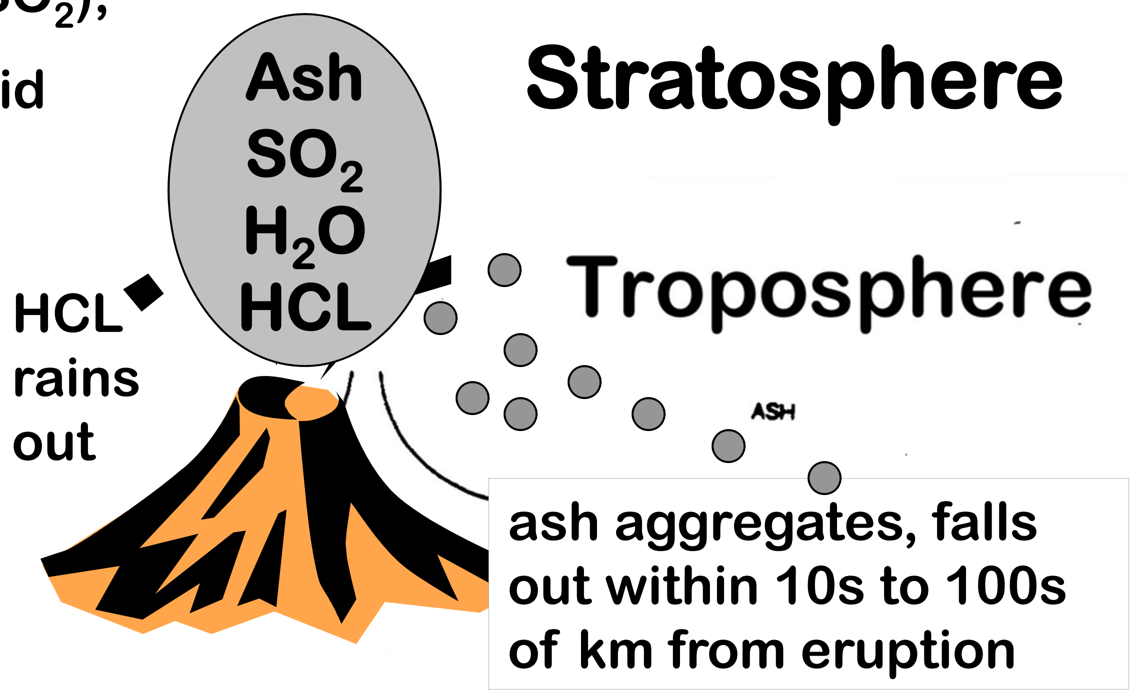
water vapor (H_2O)

sulfur dioxide (SO_2),

hydrochloric acid (HCl)

mineral ash

into the stratosphere



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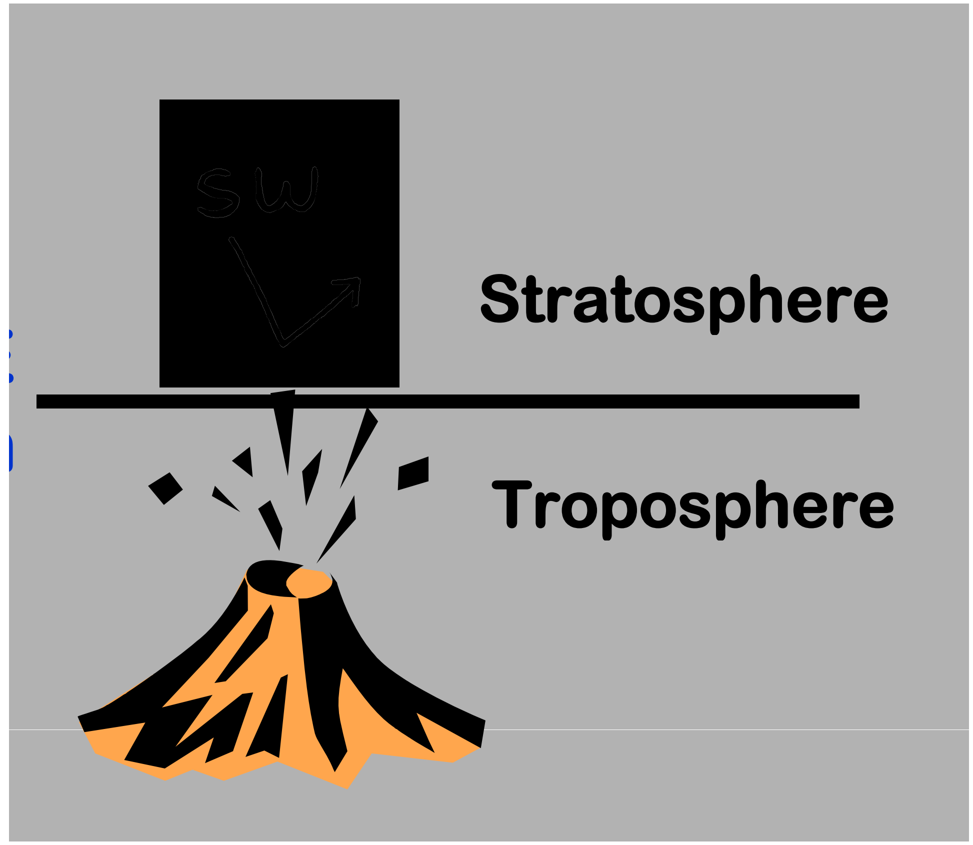
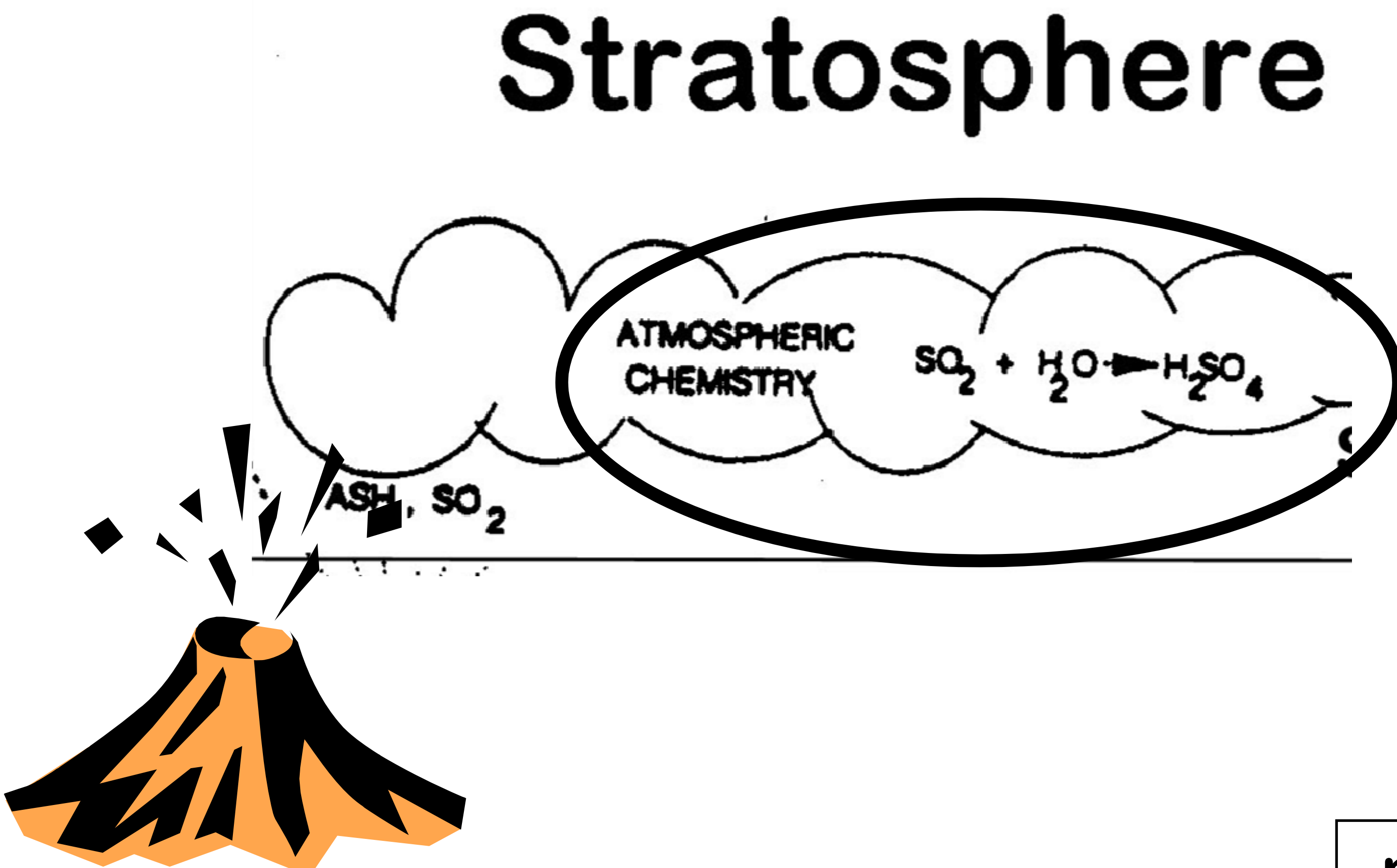
Albedo of ejected ASH in the STRATOSPHERE is *not* the reason for cooling after an eruption! (most ash falls out early)



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

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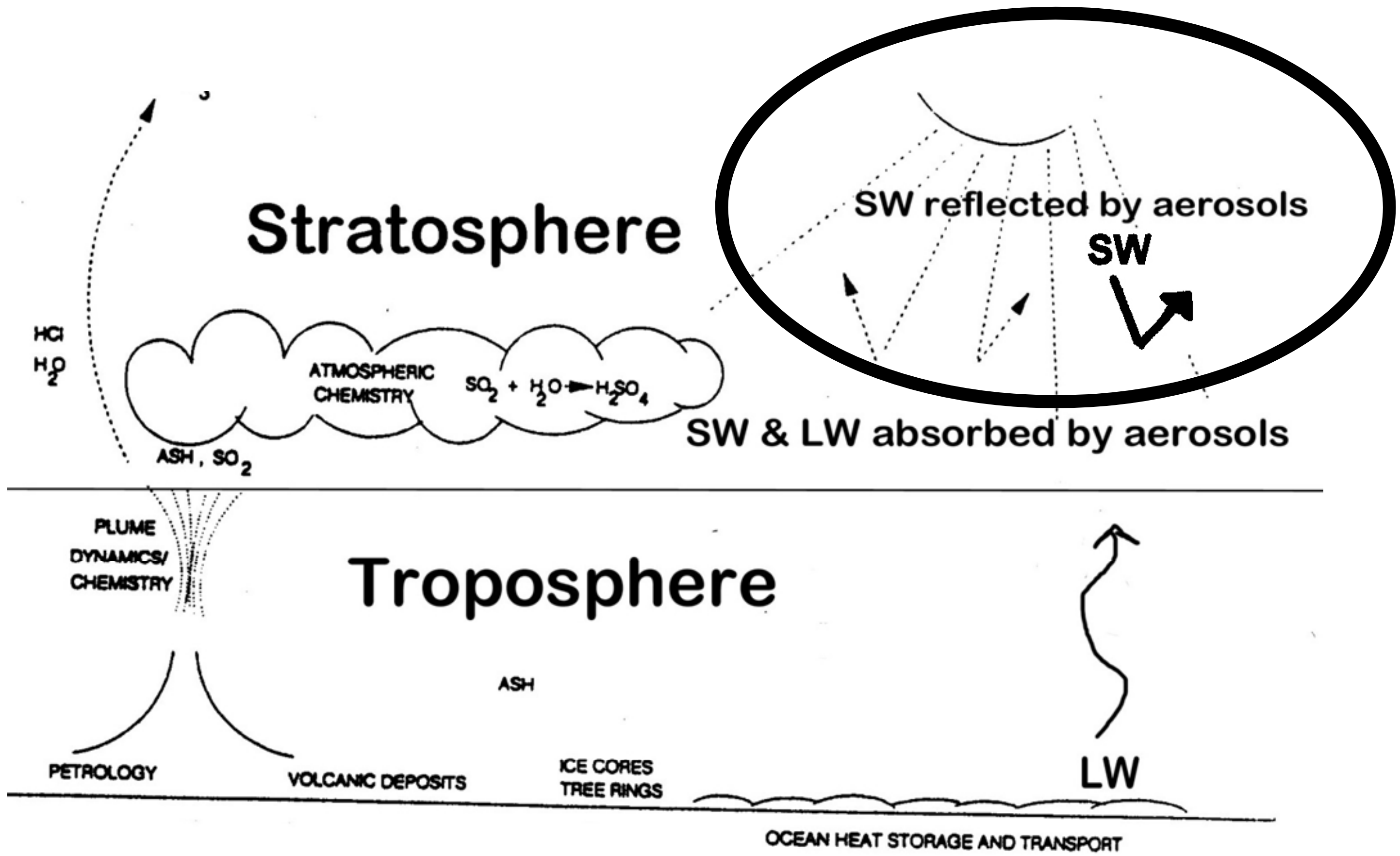
the sulfate aerosols *reflect* some of the incoming solar SW radiation back to space, cooling the troposphere below



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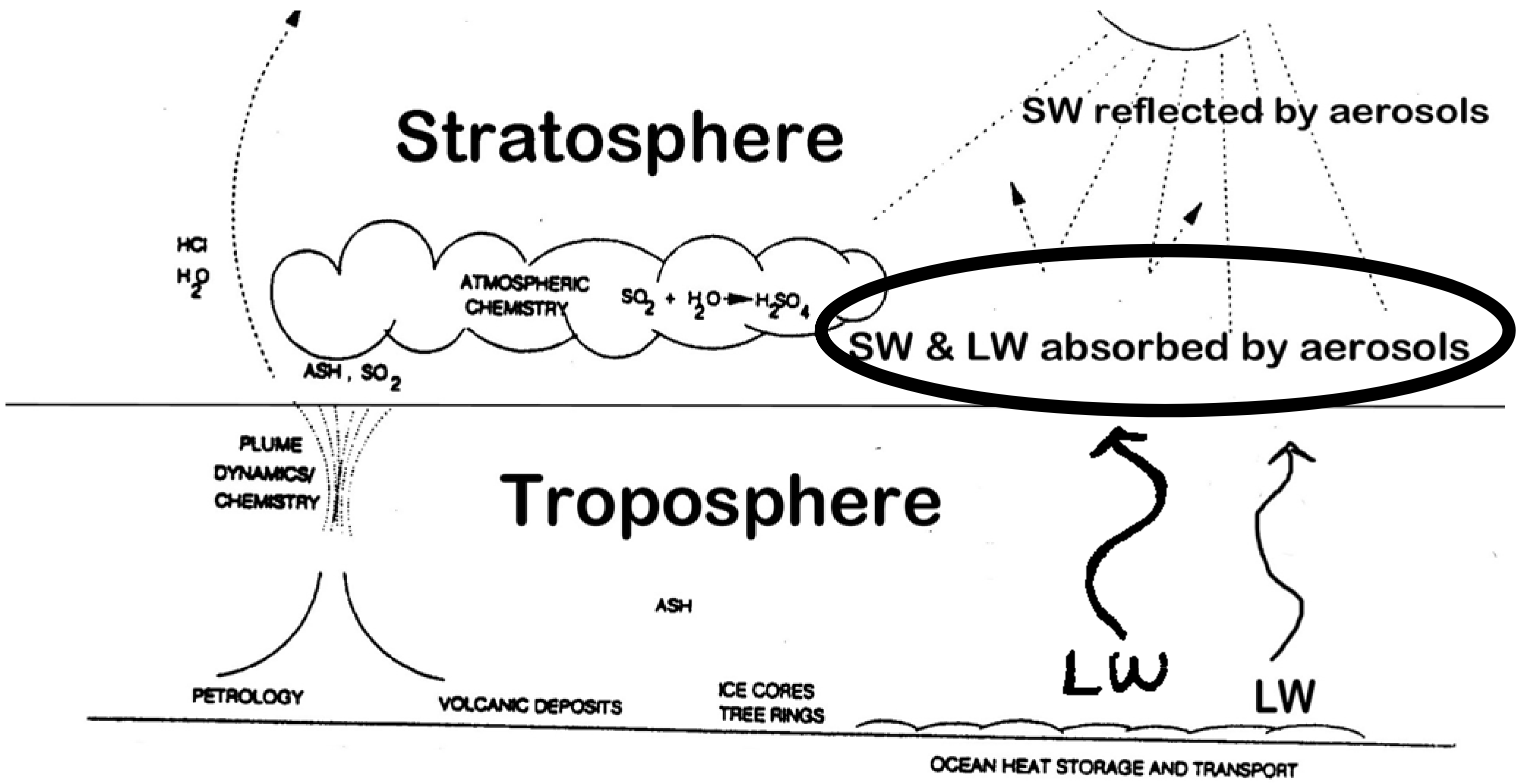
BUT - the aerosols also ABSORB certain wavelengths of the incoming SW radiation and some of the Earth's outgoing LW radiation, this warms the <u>stratosphere</u> **(not the troposphere)**



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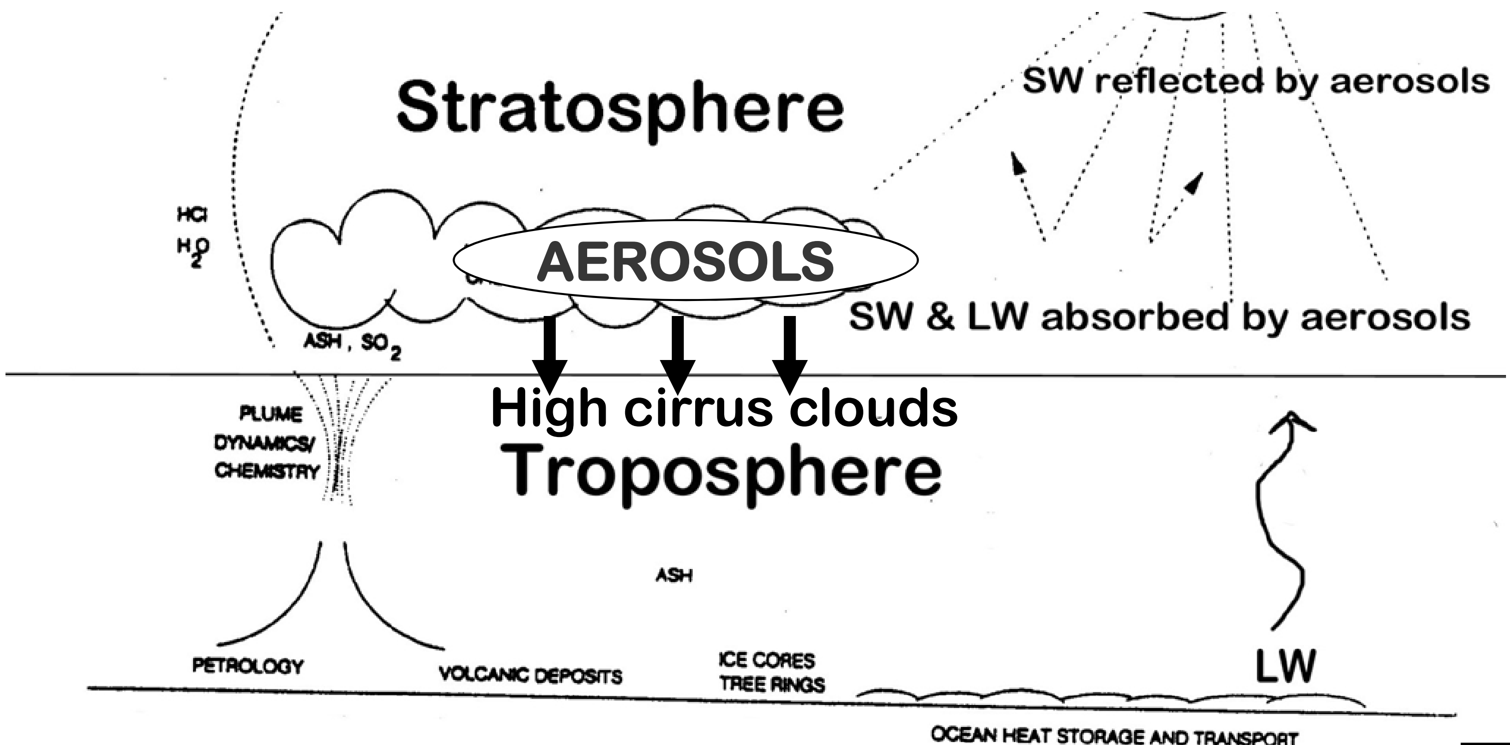
Then, as the aerosols settle into the upper troposphere, they may serve as nuclei for cirrus (high) clouds, further affecting the Earth's radiation balance *

* either absorbing or reflecting, depending on the cloud's albedo and other factors



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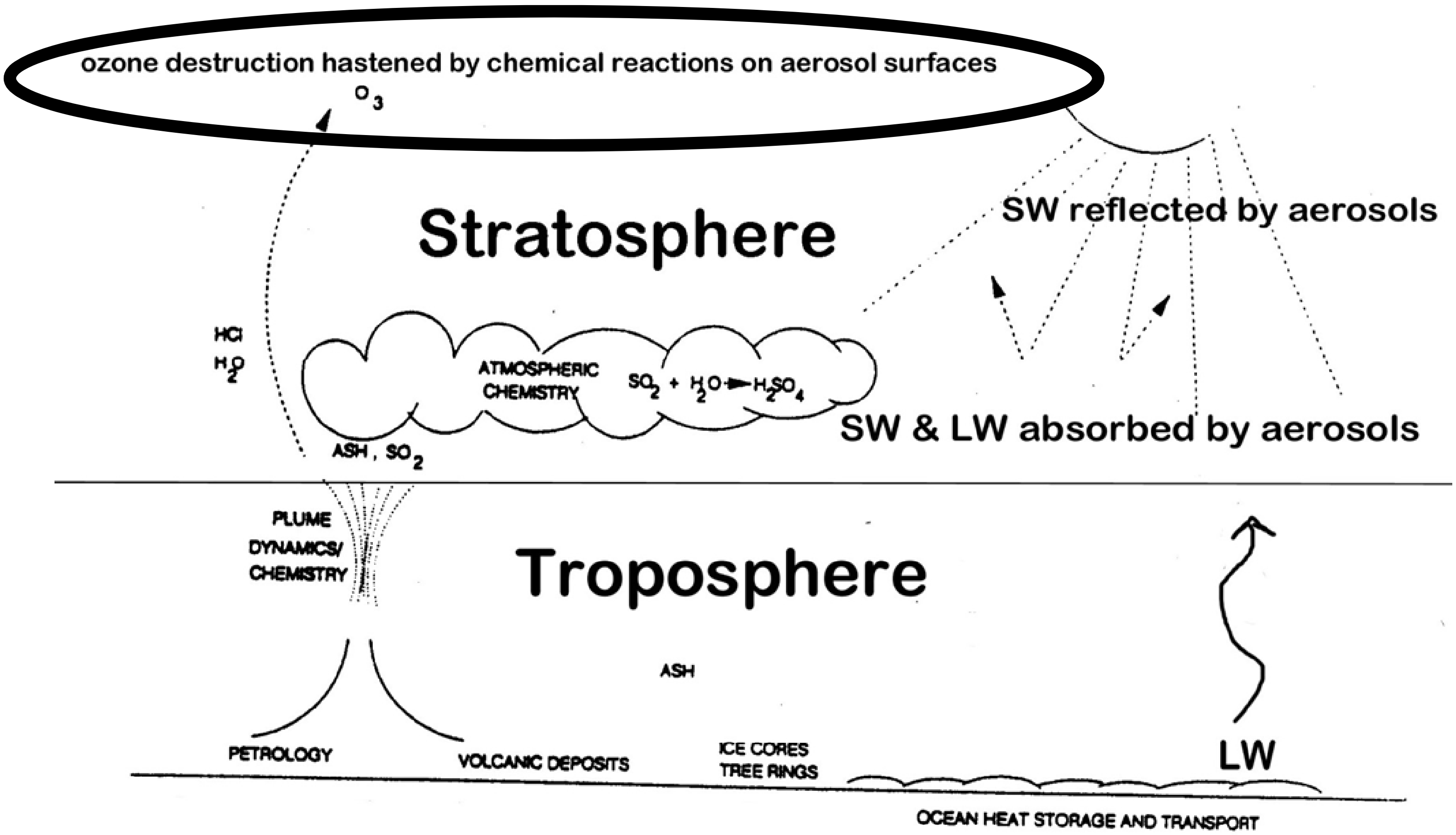
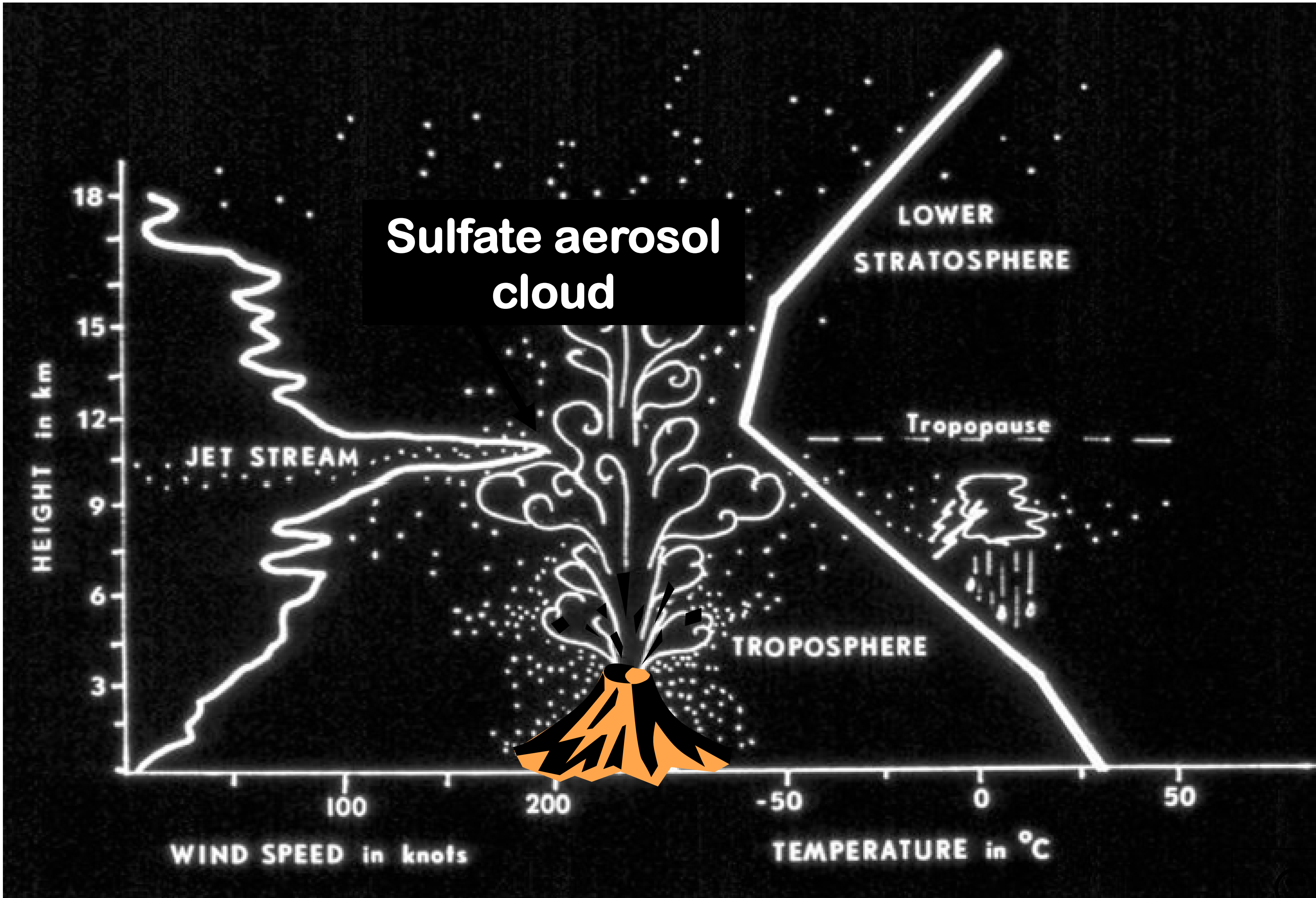
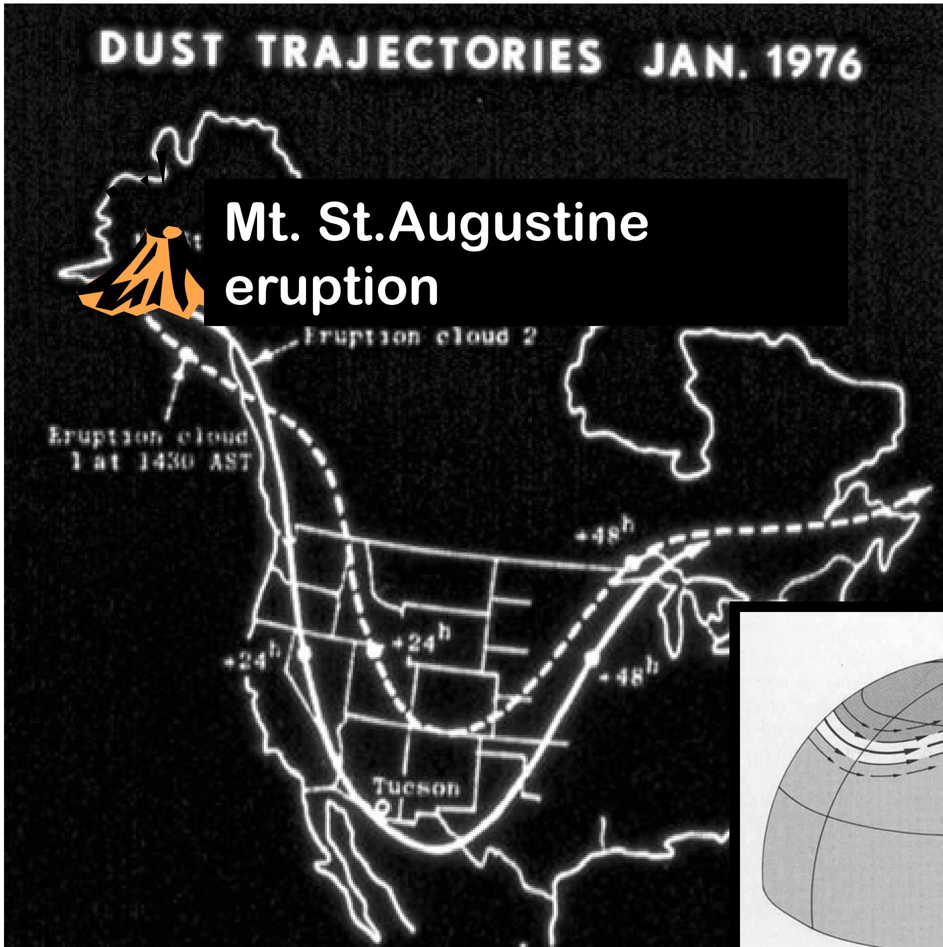
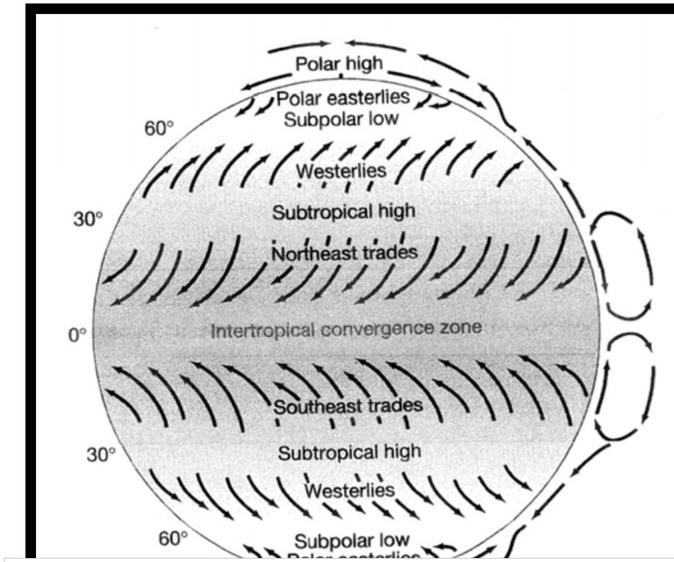
Chemical effects of the sulfate aerosol cloud can also produce responses in the climate system through OZONE destruction (Topic #13)



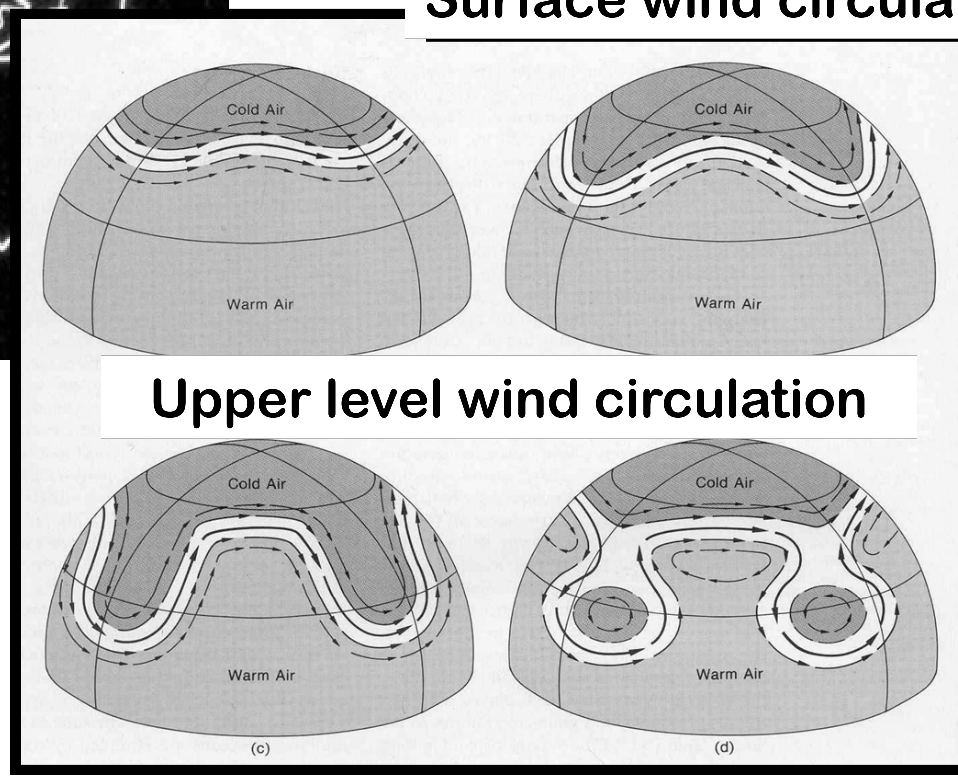
How do eruption effects become GLOBAL??







Surface wind circulation

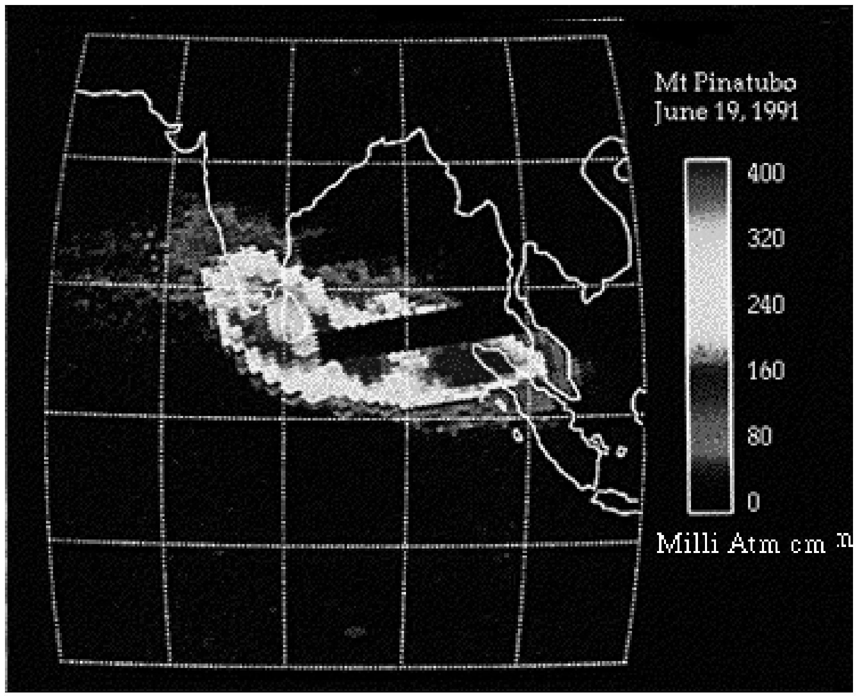


Upper level wind circulation

Through the atmospheric circulation!

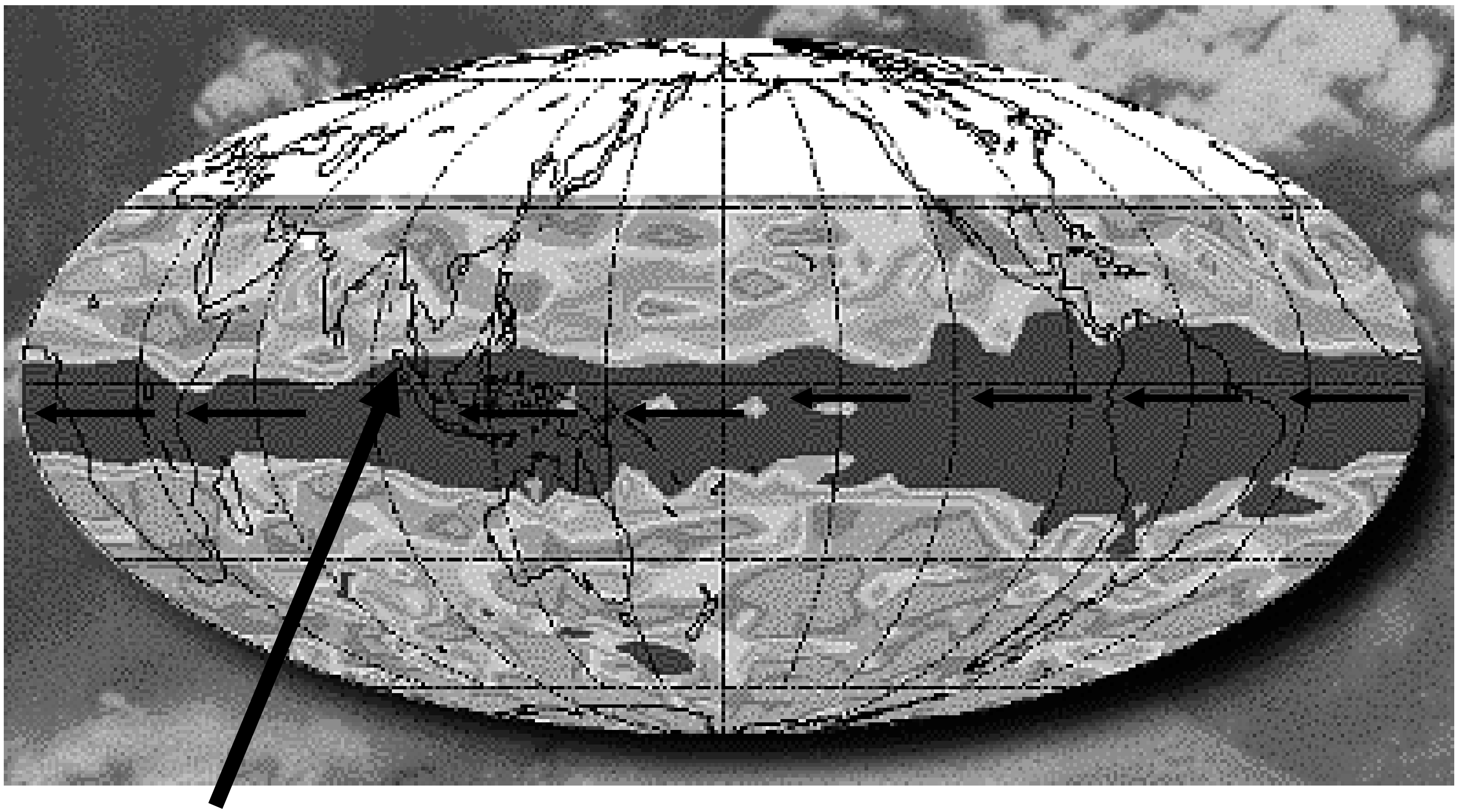
☺

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

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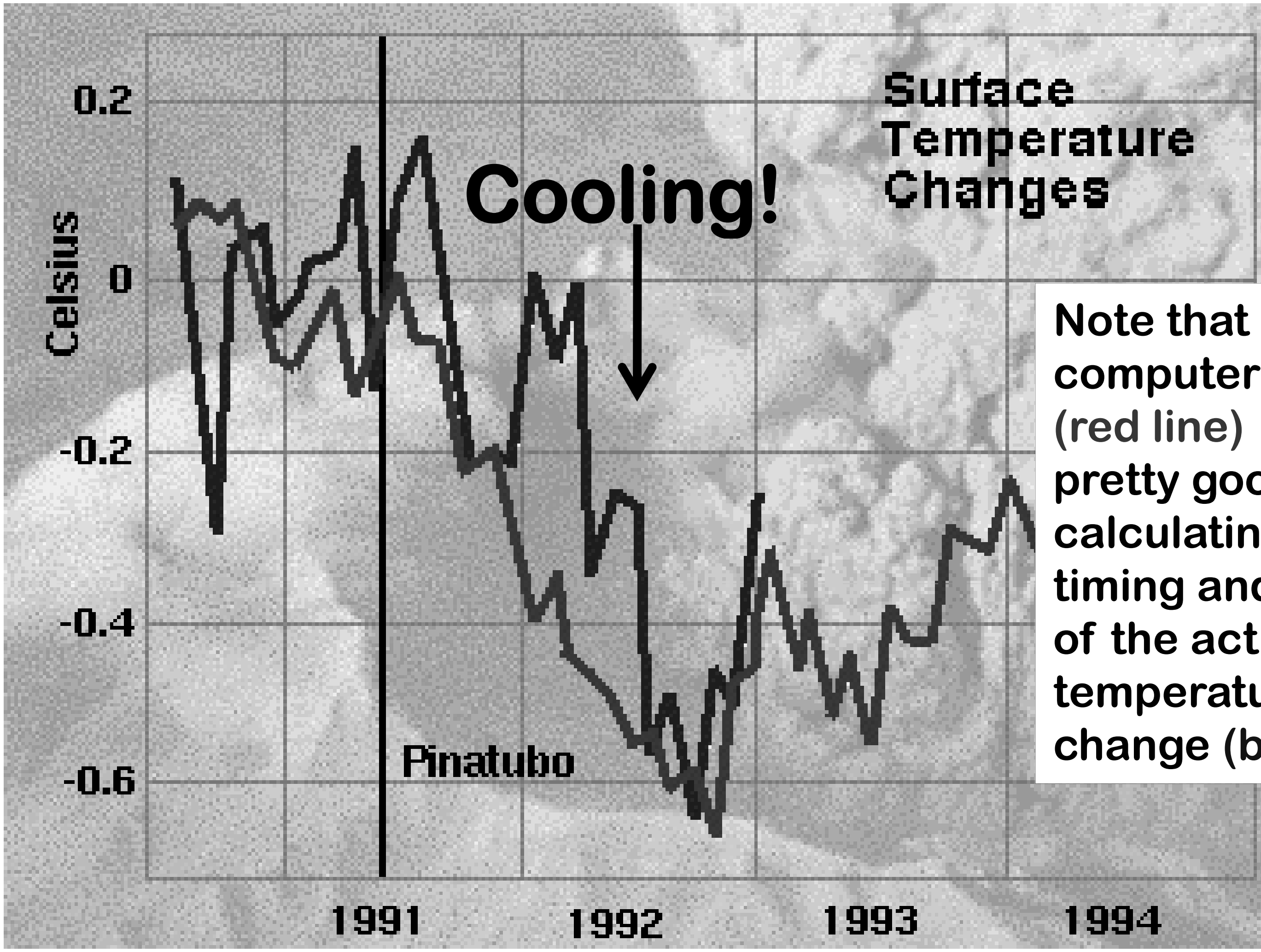
Mt Pinatubo eruption June 1991

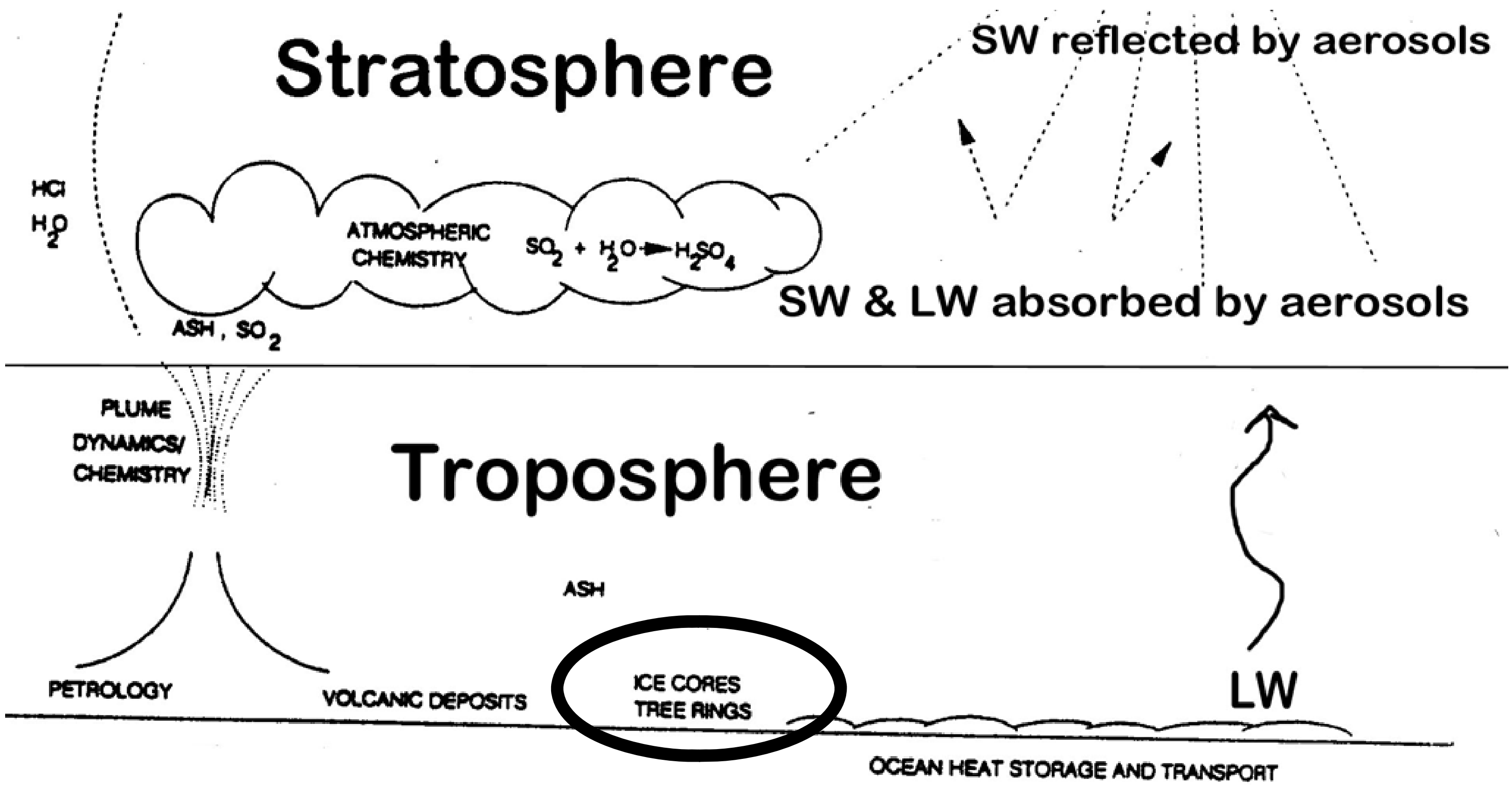


Note that the computer model (red line) did a pretty good job of calculating the timing and amount of the actual temperature change (blue line).

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!



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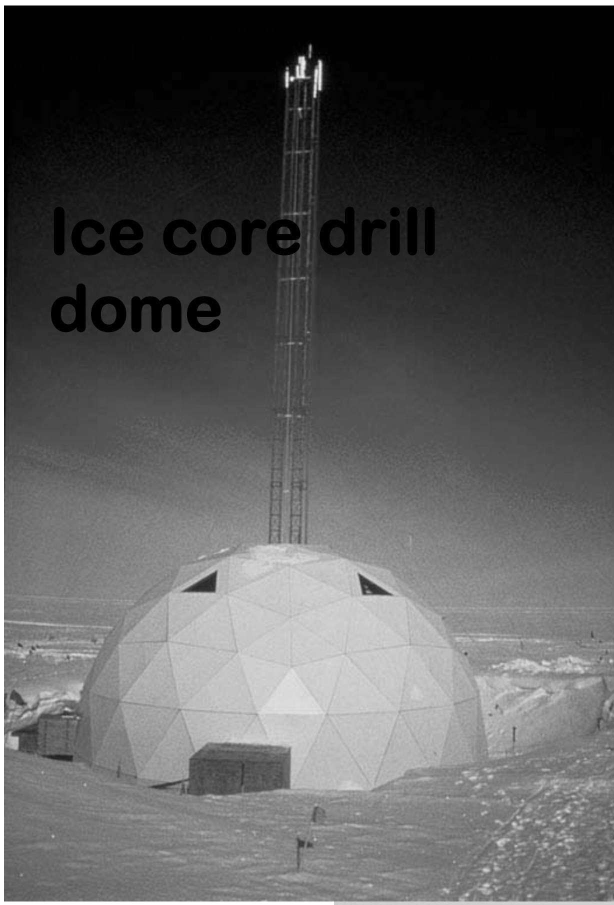
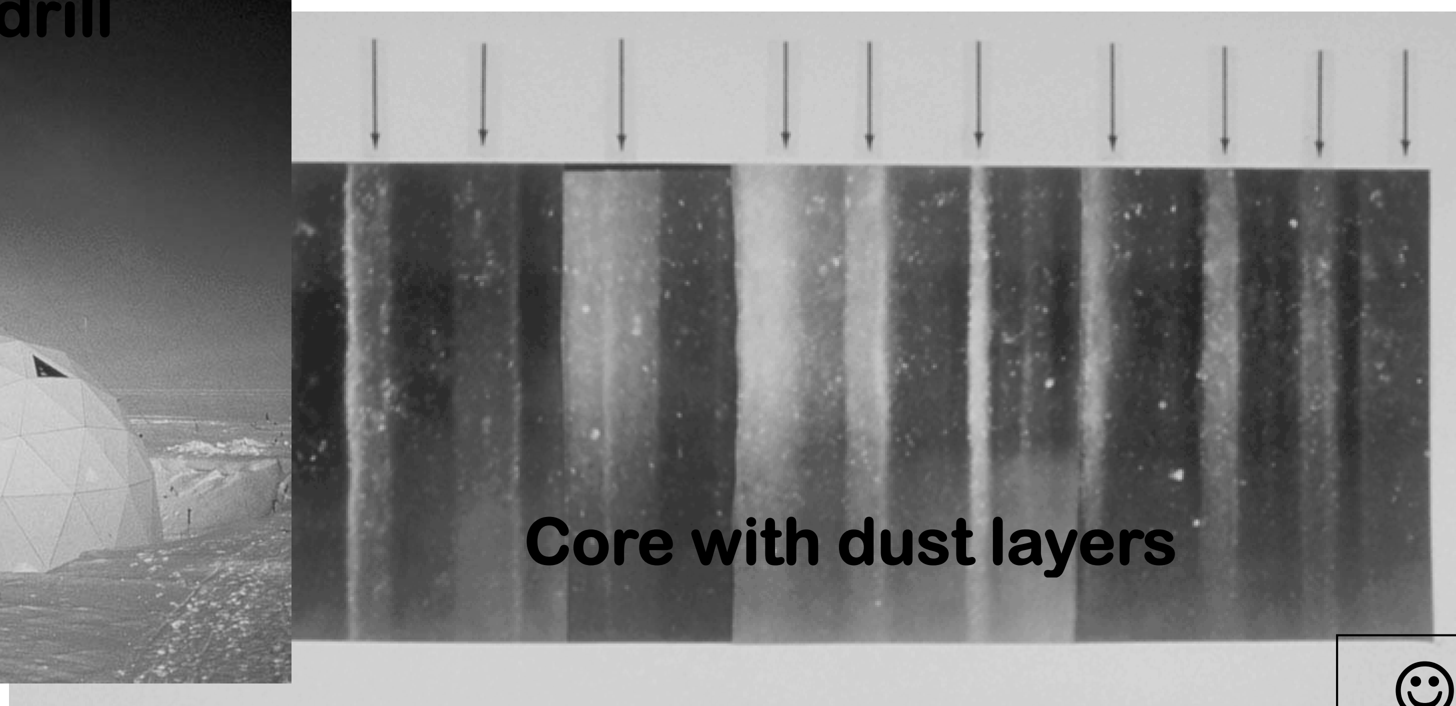
ICE CORES

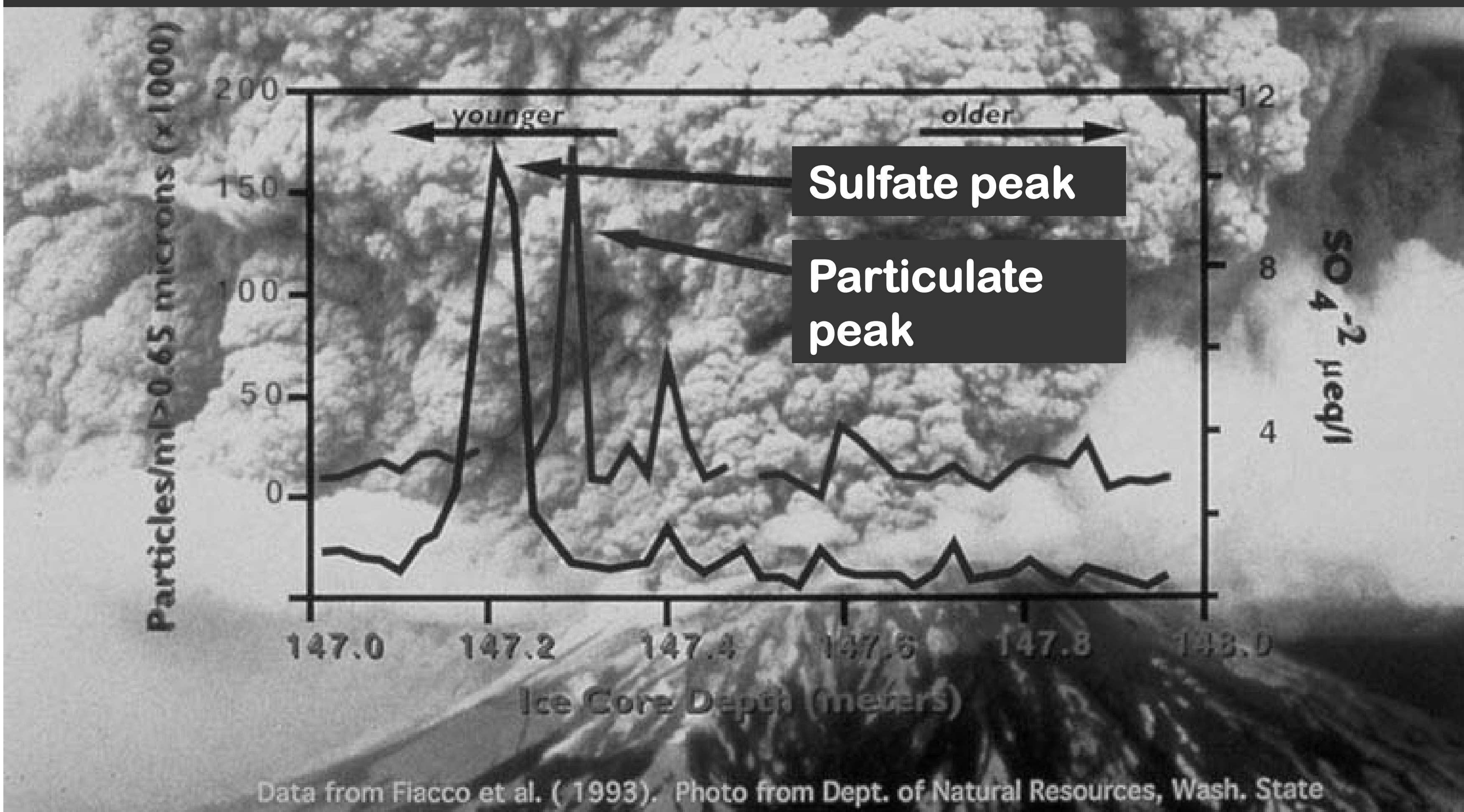

Field conditions


Examining core


Ice core drill
dome


Core with dust layers

The 1479 A.D. eruption of Mount St. Helens appears as a peak in particle concentration & sulfate records in ice cores from Greenland



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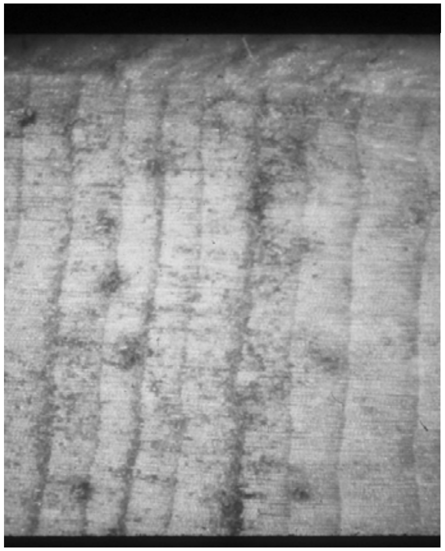
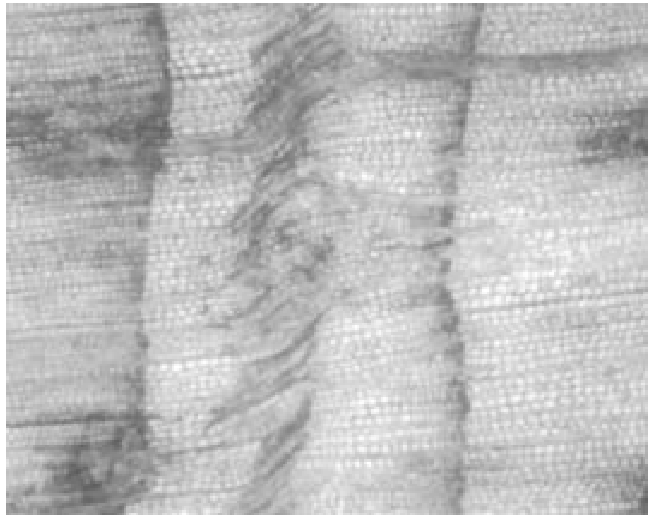
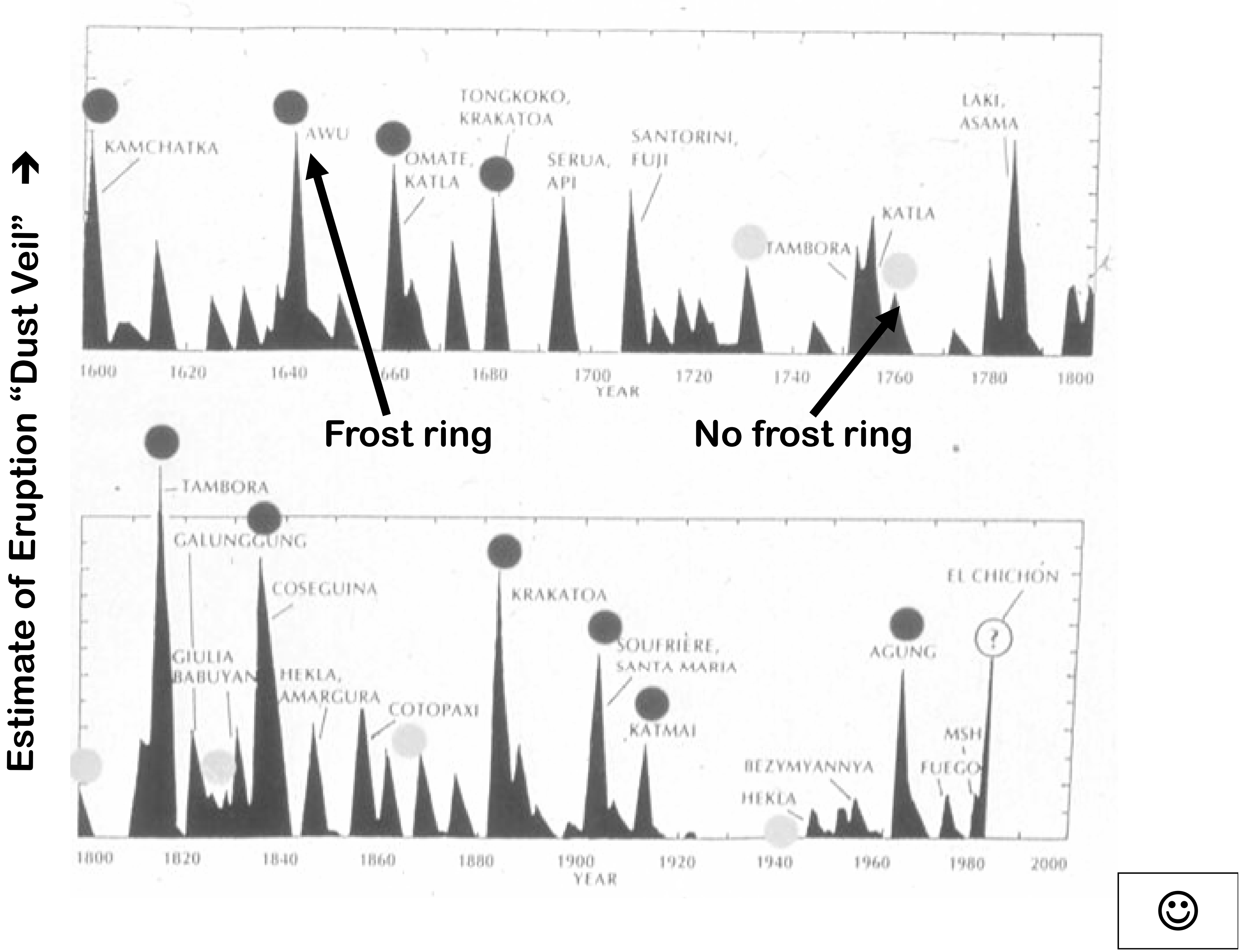
TREE RINGS

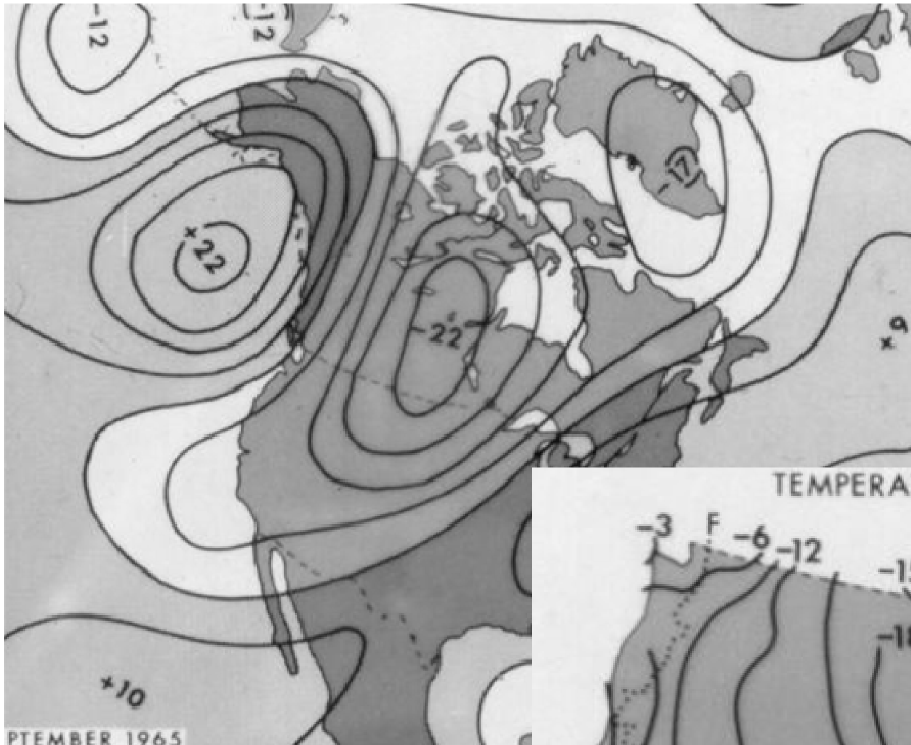


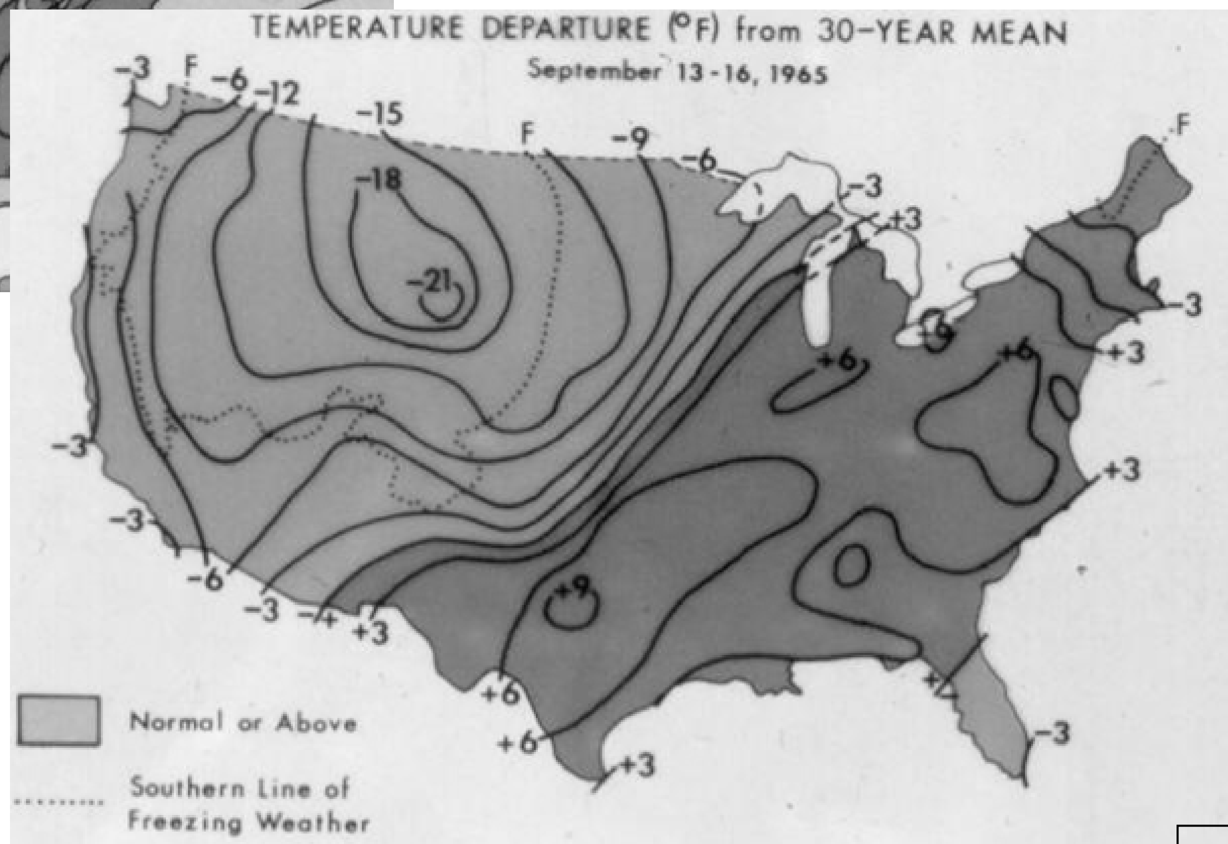


Eruption – Tree Ring Connection via FROST RINGS


Estimate of Eruption "Dust Veil"
KAMCHATKA
AWU
OMATE, KATLA
TONGKOKO, KRAKATOA
SERUA, API
SANTORINI, FUJI
TAMBORA
KATLA
LAKI, ASAMA
1600
1620
1640
1660
1680
1700
1720
1740
1760
1780
1800
YEAR
Frost ring
No frost ring
TAMBORA
GALUNGGUNG
COSEGUINA
GIULIA
BABUYAN
HEKLA, AMARGURA
COTOPAXI
KRAKATOA
SOUFRIÈRE, SANTA MARIA
KATMAI
BEZYMYANNYA
HEKLA
AGUNG
EL CHICHON
?
MSH
FUEGO
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
YEAR
☺

Agung eruption 1963 ➔ frost ring response in 1965





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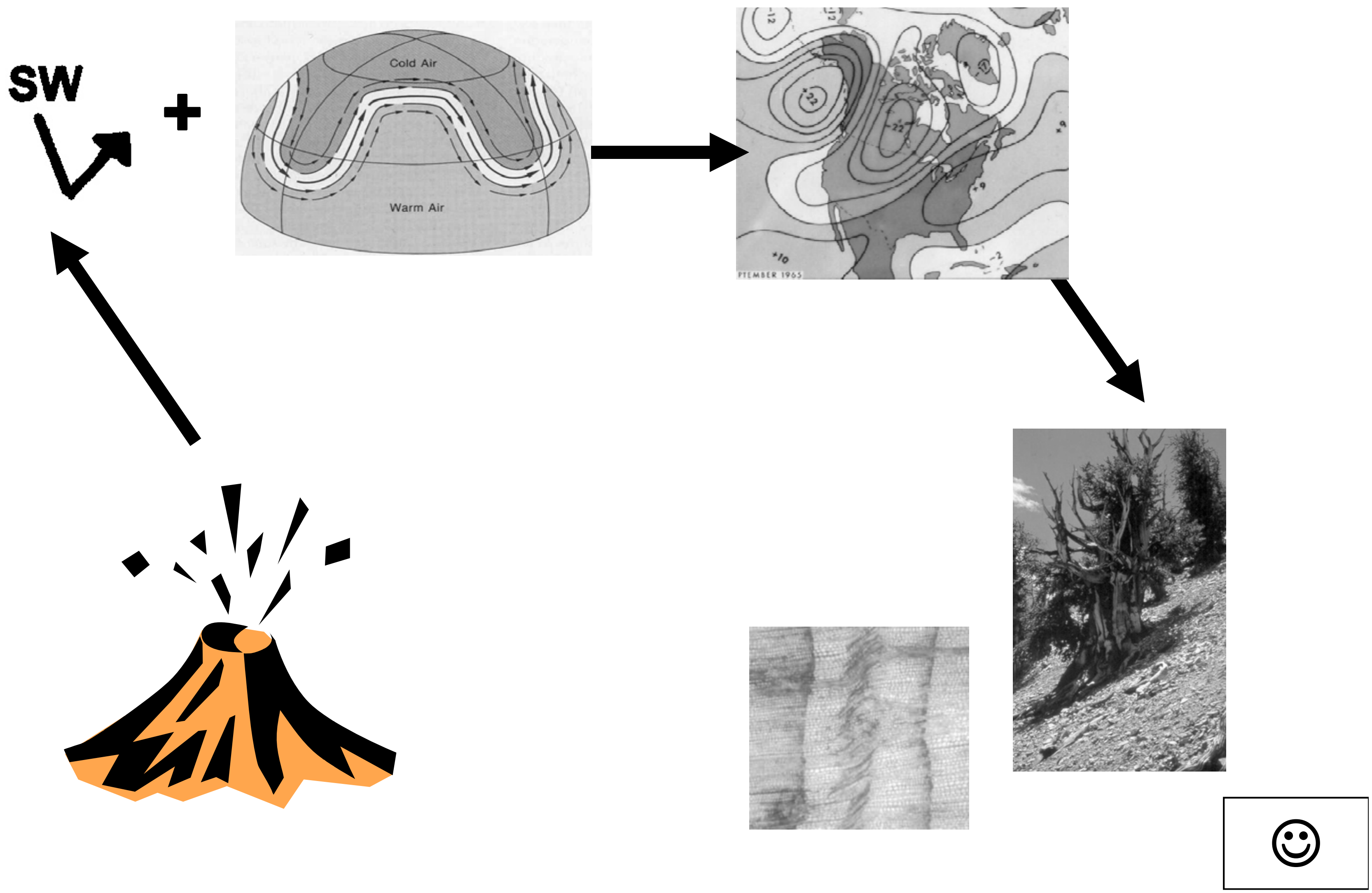
Energy Balance Effects & Global Atmospheric Circulation



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 <u>Low Latitude</u> eruptions are more climatically effective and have more of a 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.

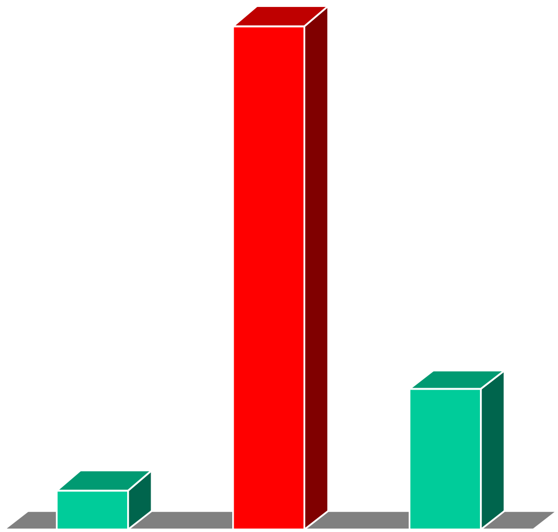
Q3 Why do you think Low Latitude eruptions are more climatically effective and have more of a effect?

BEGIN ANSWERING NOW!

1. Because the temperature is warmer in tropical latitudes and hot air rises.

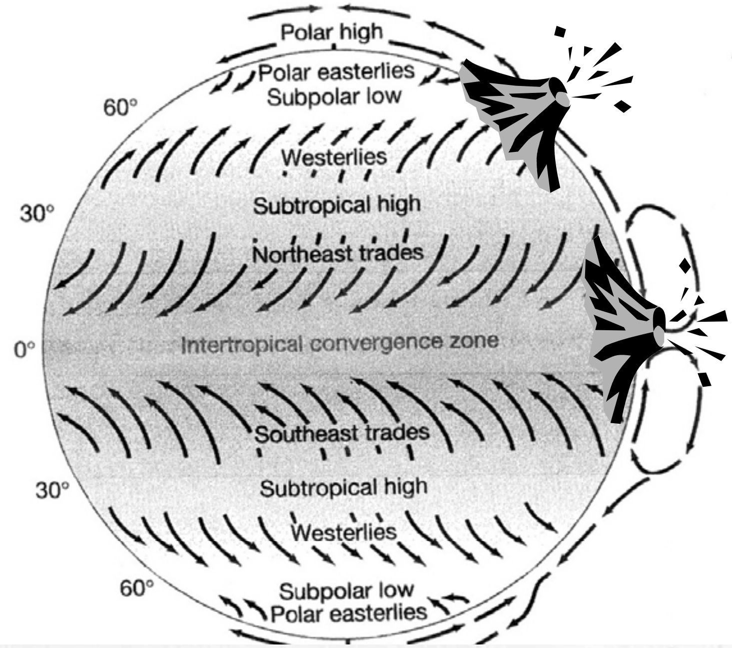
2. Because the Hadley Cell circulation can distribute the volcanic aerosols into both hemispheres if the eruption occurs near the equator.

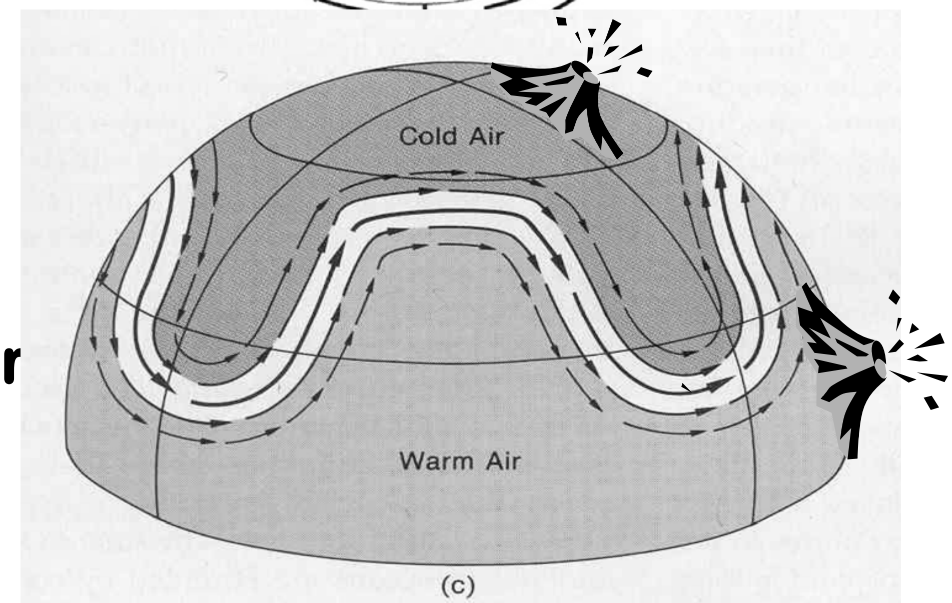
3. Because the tropopause is lower over Low Latitudes and hence its easier for aerosols to get injected into the stratosphere where they will not be rained out.



- 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 mor 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.

Major tropical eruption:

- <u>Stratospheric heating</u> is larger in the tropics ➔ enhanced pole-to-equator temperature gradient, esp. in winter.

N.H. winter ➔ enhanced gradient produces a stronger polar vortex ➔ stationary wave pattern of tropospheric circulation resulting in winter warming of NH continents.

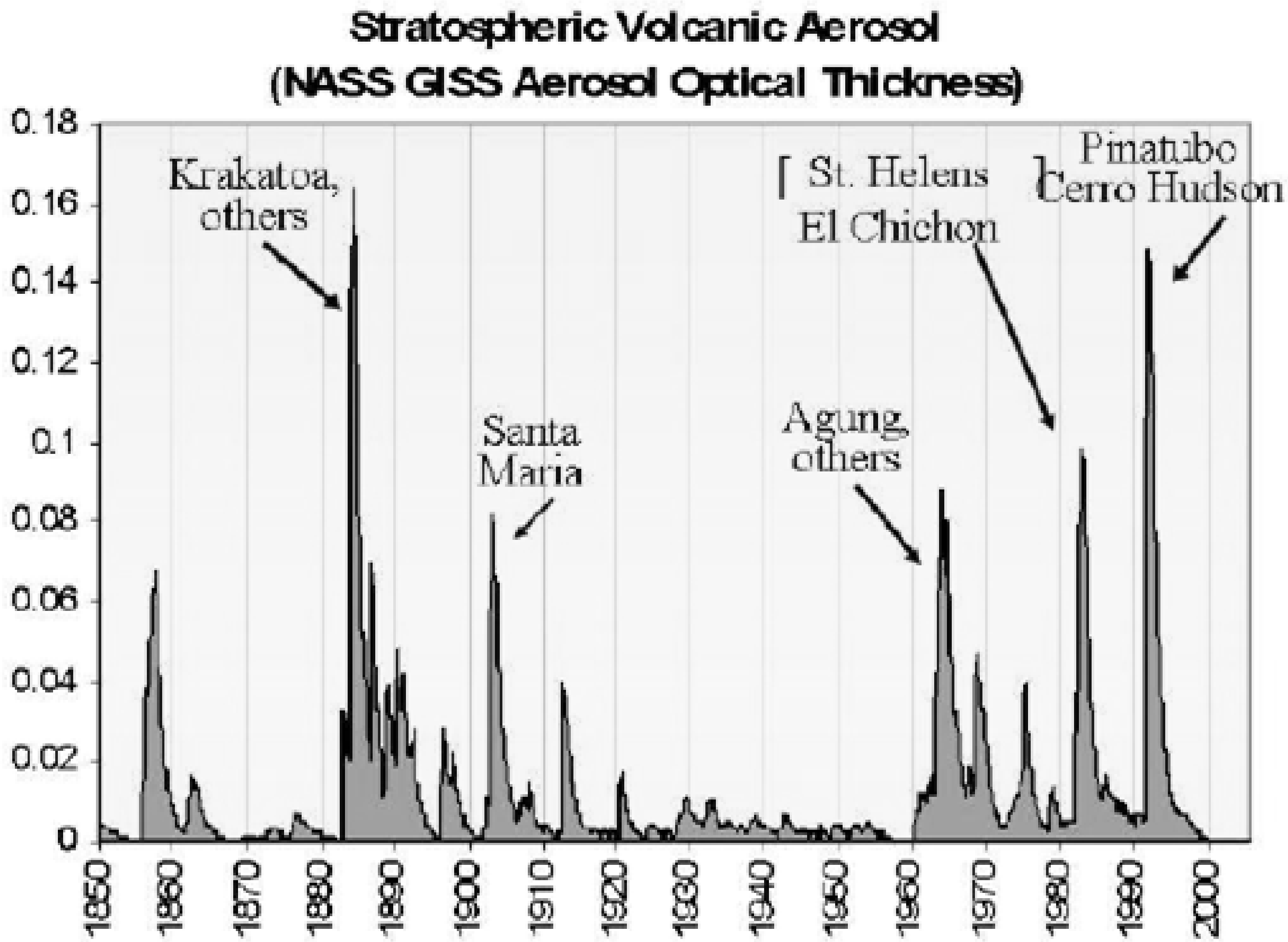
HOW MUCH TROPOSPHERIC COOLING CAN OCCUR AND HOW LONG DOES IT LAST?

- **Individual large eruptions can result in a 1-to-3 year cooling of average surface temperatures of 0.3 to 0.7° C.**

  Tambora in 1815
  Krakatau in 1883
  Agung in 1963
  El Chichon in 1982

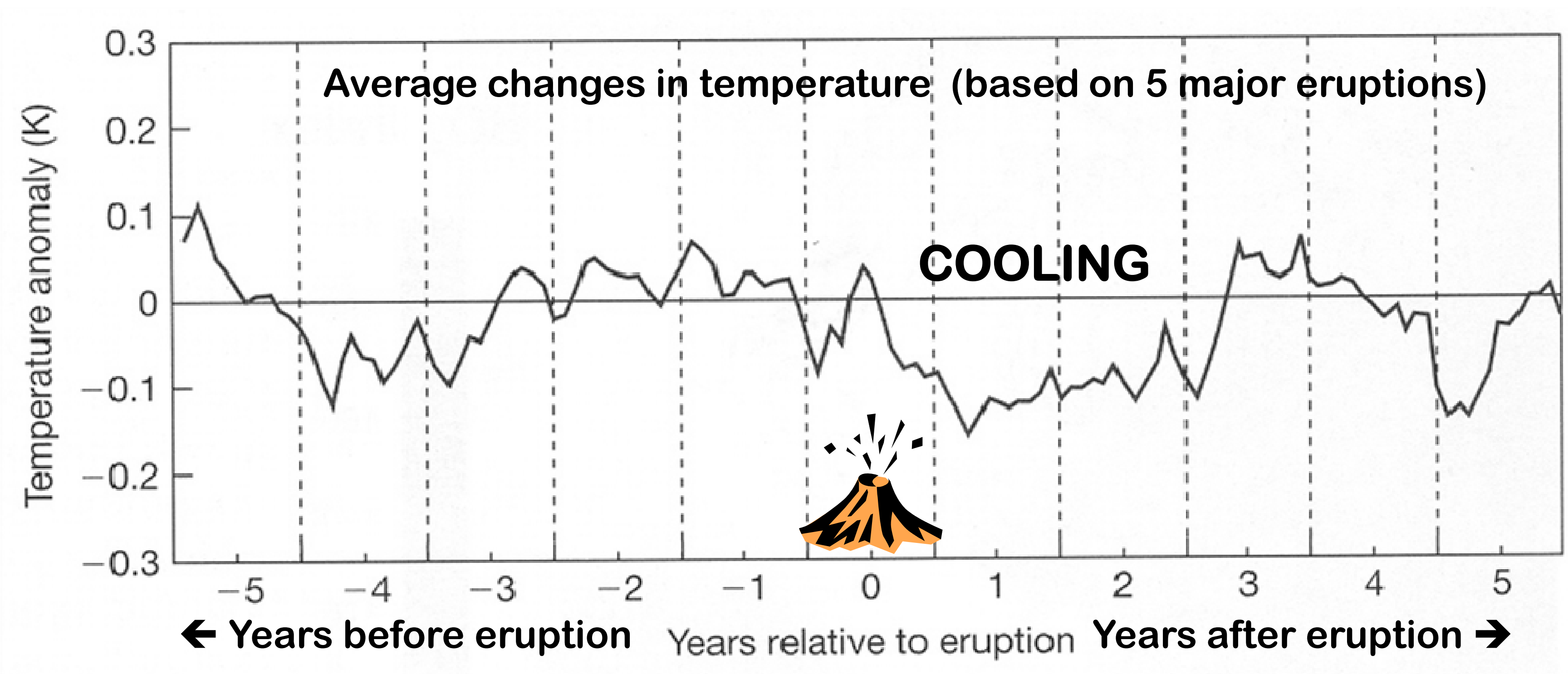
HOW IMPORTANT IS EXPLOSIVE VOLCANISM AS A FORCING MECHANISM FOR PAST AND FUTURE CLIMATE CHANGES?

- 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.



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

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

Eruption	Year	Magma Erupted (km^3)	Stratospheric Aerosol (Mt) S.H.	Stratospheric Aerosol (Mt) N.H.	Petrologic Estimate (Mt) H_2SO_4	Petrologic Estimate (Mt) HCl	N.H. ΔT
Tambora (8°S)	1815	50	150	150	52	220	-0.4 to -0.7
Krakatau (6°S)	1883	10	30-38	55	2.9	3.8	-0.3
Santa Maria (15°N)	1902	9	22	<20	0.6	0.4	-0.4
Katmai (58°N)	1912	15	0	<30	12.0	4.0	-0.2
Agung (8°S)	1963	0.6	30	20	2.8	1.5	-0.3
Mount St. Helens (46°N)	1980	0.35	0	—	0.08	0.04	0 to -0.1
El Chichón (17°N)	1982	0.3-0.35	<8	12	0.07*	—	-0.2
Pinatubo (15°N)	1991	5(±1)	—	20-30	~0.3*	—	-0.5

IMPORTANT: a dash — means that NO INFORMATION IS AVAILABLE, NOT a value of zero!

THINK-PAIR –SHARE UNGRADED GROUP ACTIVITY!

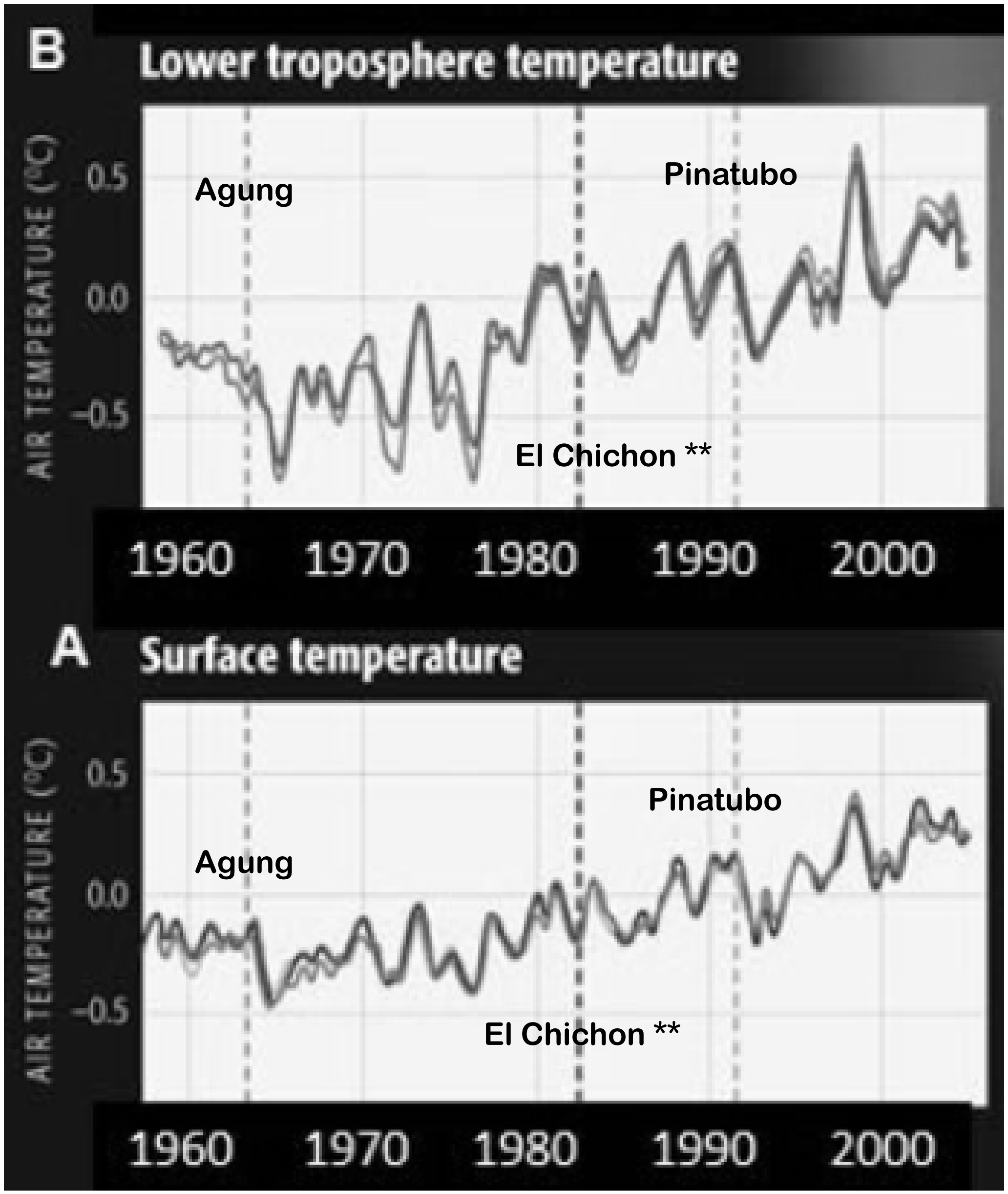
P.S. This is one of my favorite questions to ask on the FINAL EXAM!!!!

#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)



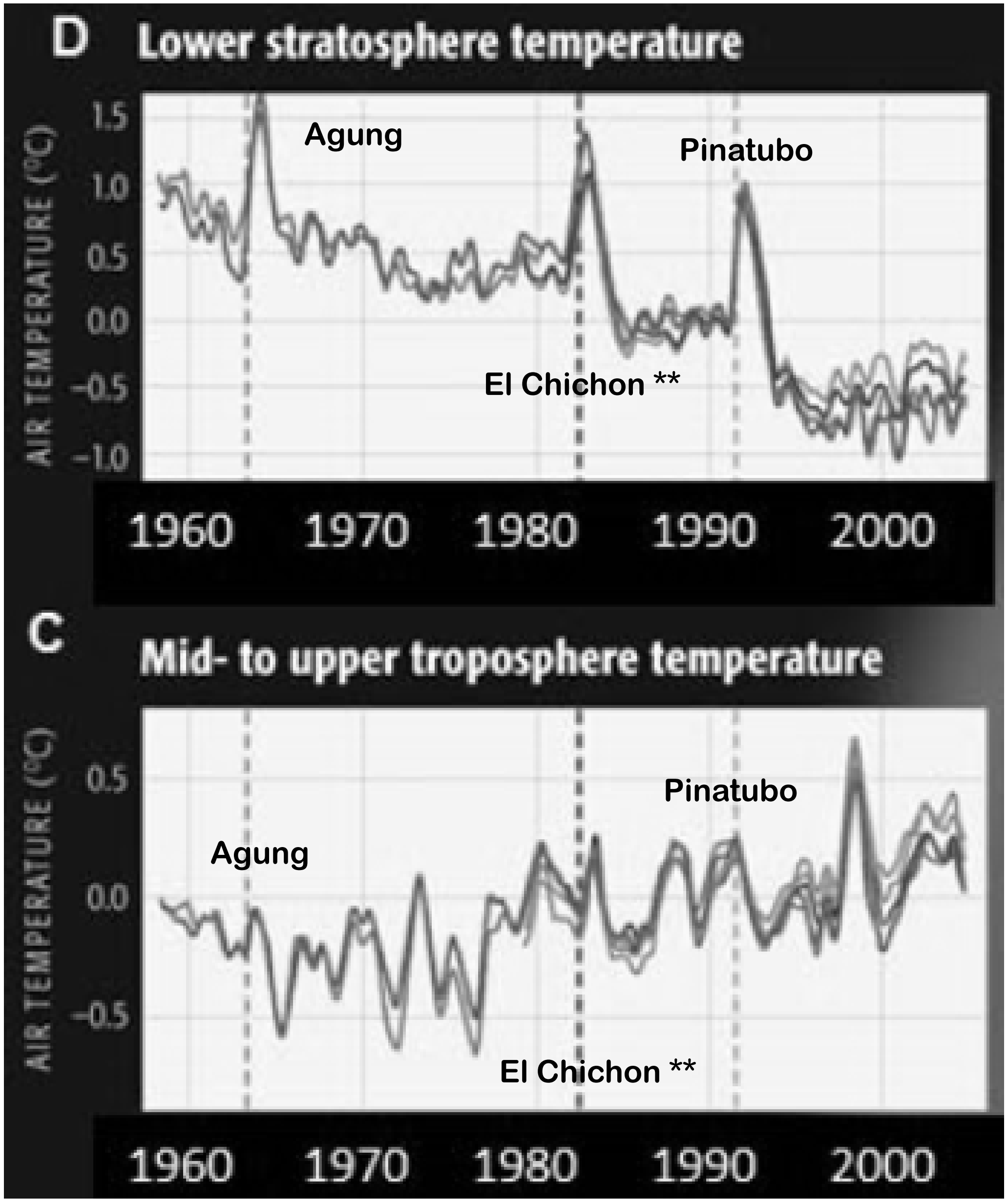
#3. Which levels show a COOLING and which show a WARMING immediately after the eruption?

** 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)

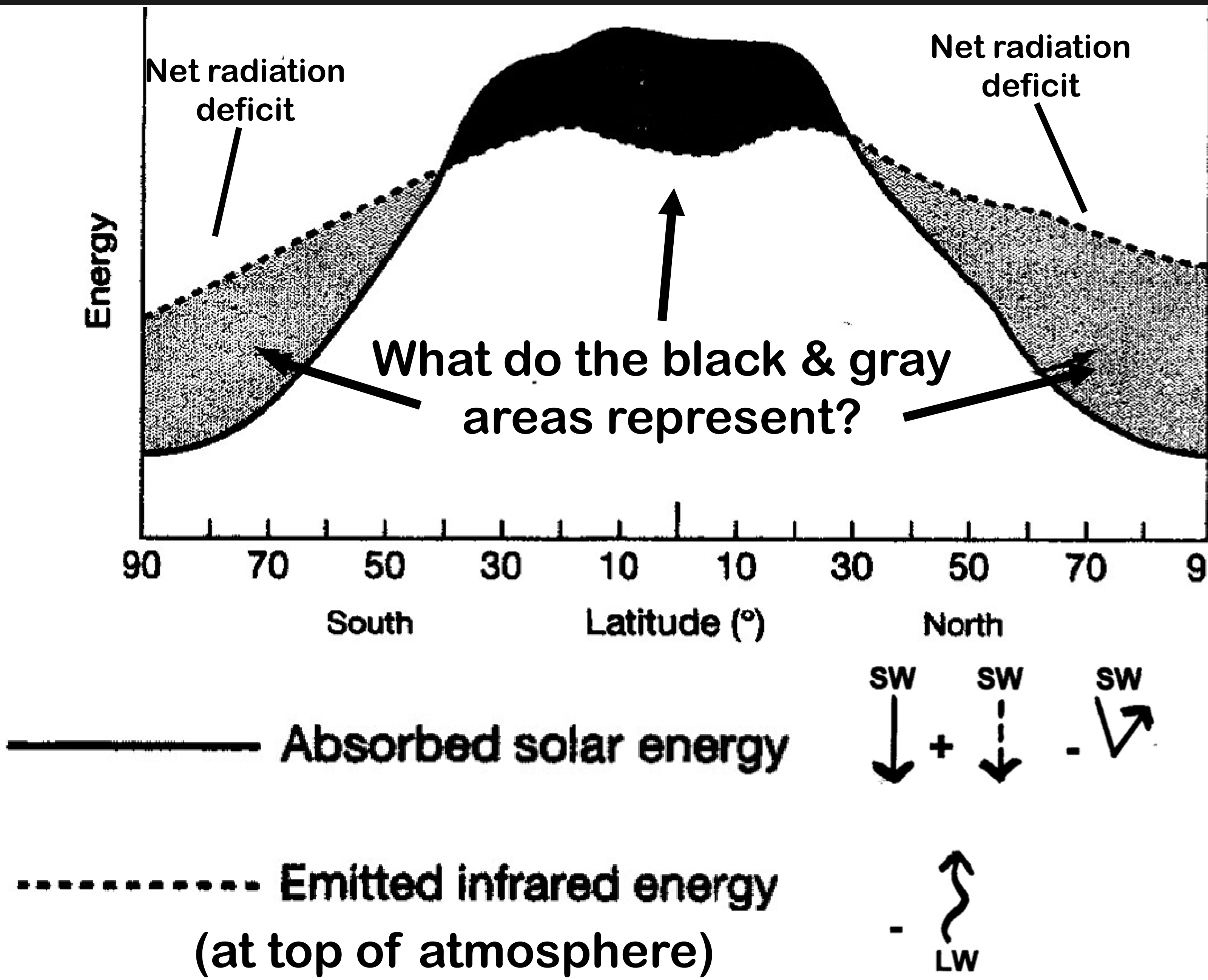


#4. Explain WHY each level's TEMPERATURE responded as it did to the Agung & Pinatubo eruptions?

(by referring to the Radiation Balance)

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

REMEMBER THIS IMPORTANT GRAPH?



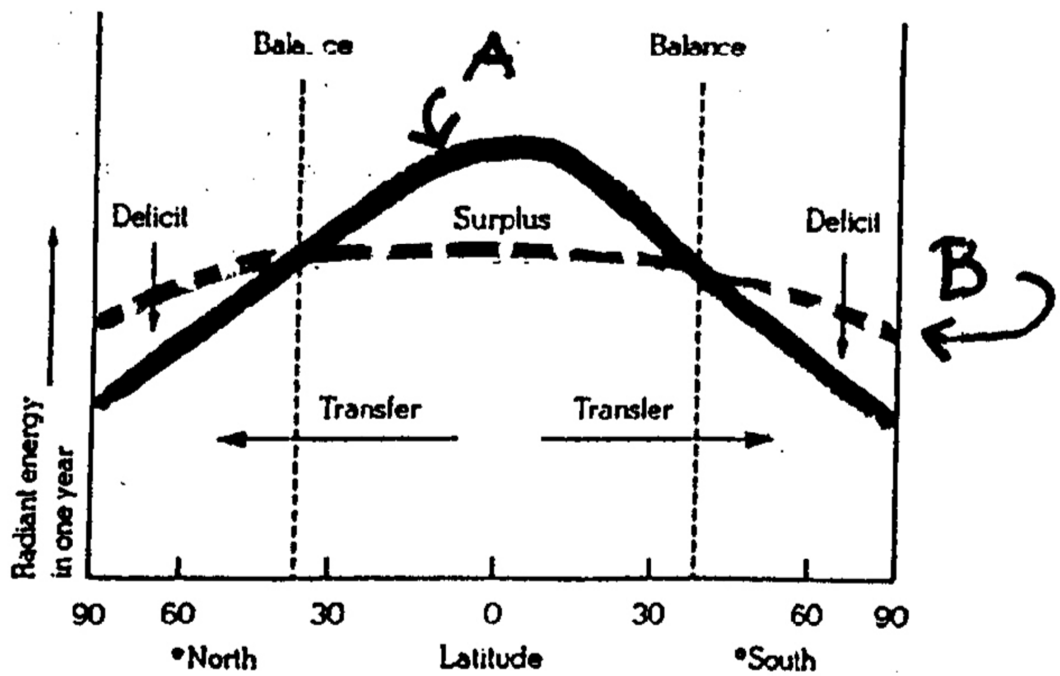
A = incoming SW (solar) radiation

Absorbed solar energy　SW + SW - SW

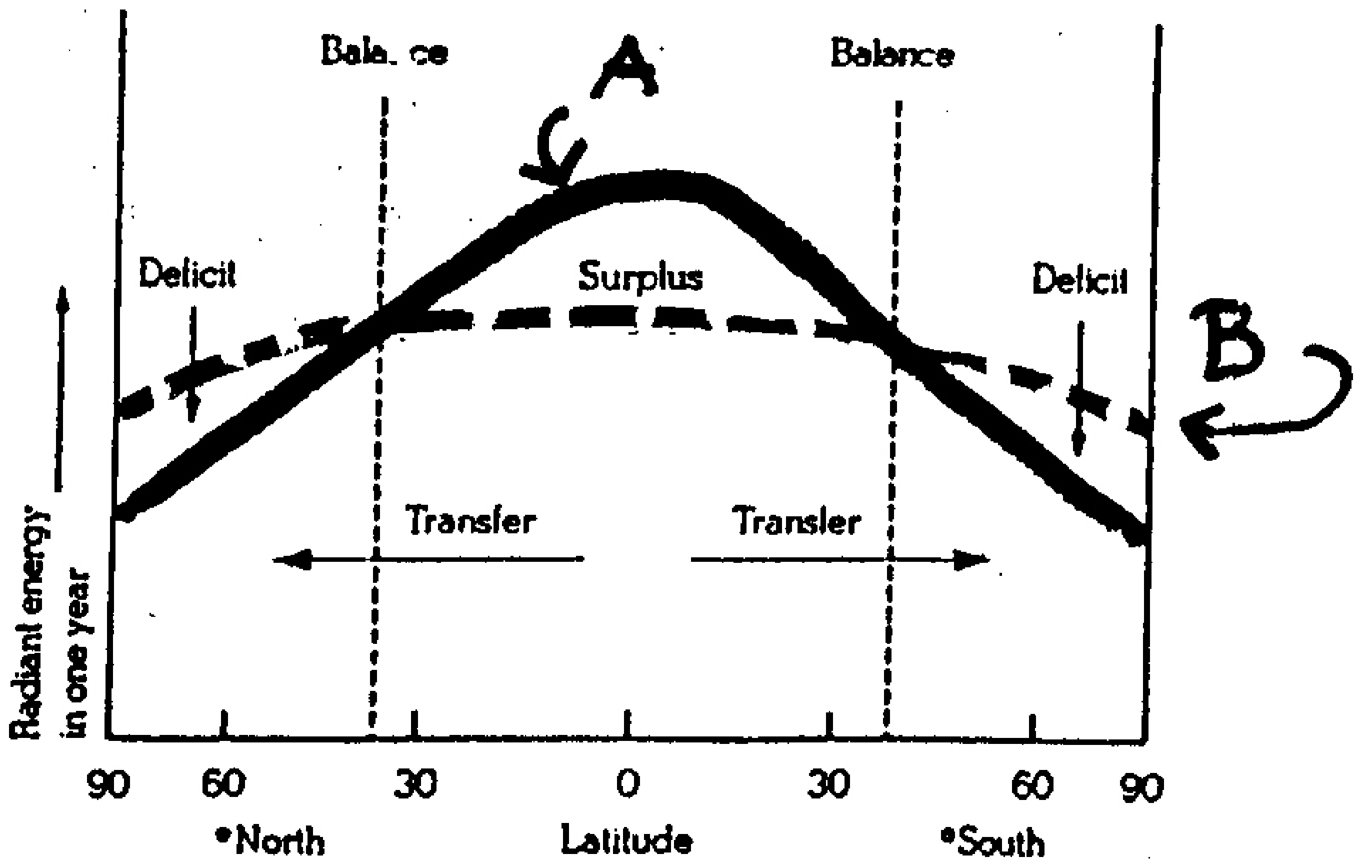
B = outgoing LW (terrestrial) radiation

Emitted infrared energy　- LW

(at top of atmosphere)



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



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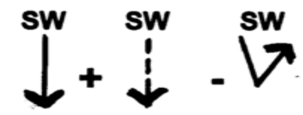
Assume:

- **that the eruption produces a long-lived <u>aerosol veil</u> in the stratosphere over <u>both</u> hemispheres**

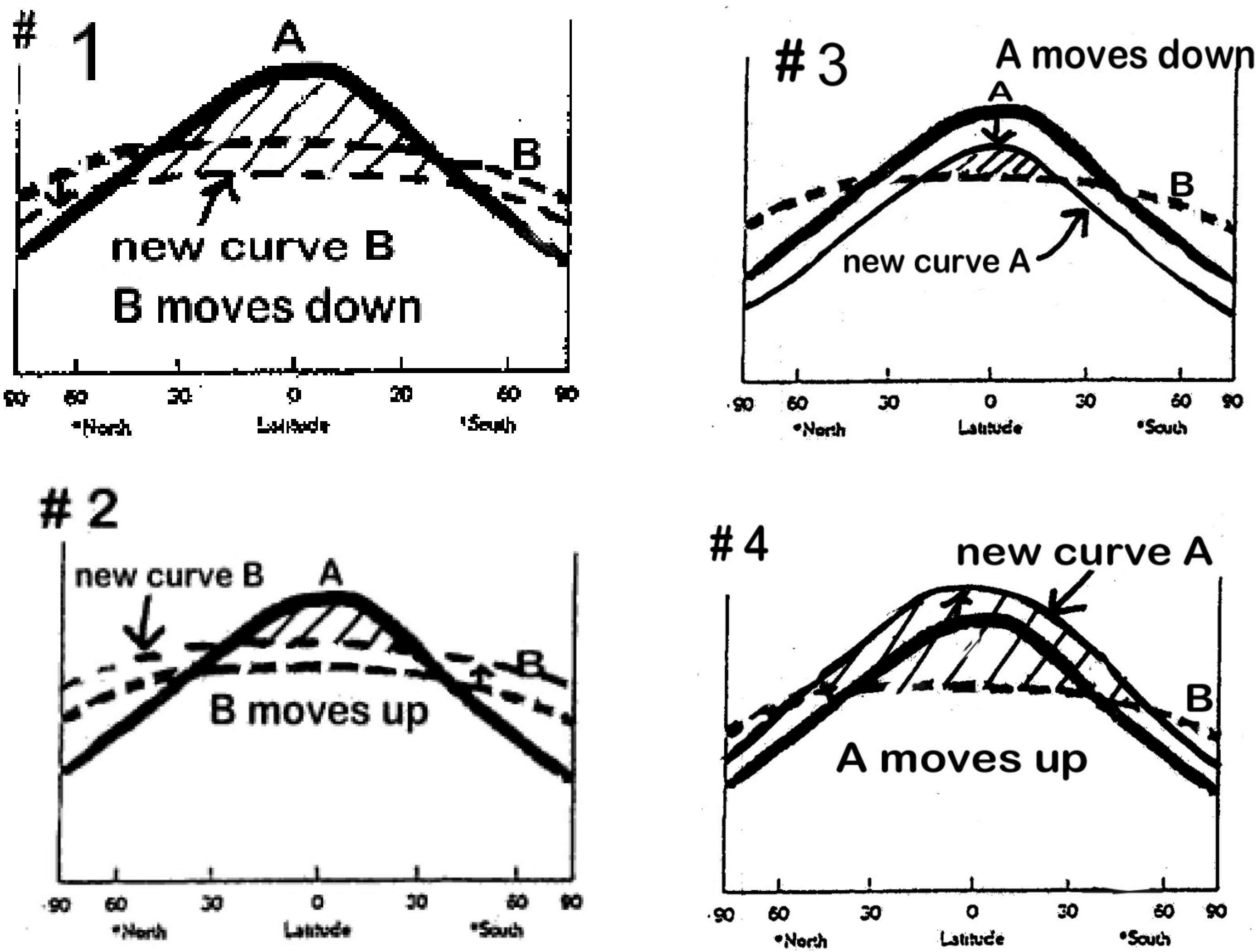
- **that this veil <u>reflects</u> large amounts of incoming solar radiation back to space *before* it enters the troposphere's earth-atmosphere system shown in the graph.**

- ***Hint: you do not need to worry about stratospheric warming for this question.***

IF CURVE B is affected: 

If CURVE A is affected: 

Four scenario's are possible for how you should sketch the new graph:



THE ANSWERS!

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

#1 Low latitude eruption → both hemispheres

#2 Large amount of eruptive material (50 sq km!)

#3 Aerosol cloud was HUGE and went into both hemispheres equally

#4 Sulfuric acid (H_2SO_4) content was very large

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

#1 High latitude – could only affect part of Northern Hemisphere

#2 Low sulfur content (also, low volume, didn't get to S. Hemisphere, etc.)

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3 HOW did the temperature at the 4 levels respond to the Agung and Pinatubo eruptions?

#4 EXPLAIN WHY – referring to Radiation Balance?

<u>Level A (Surface)</u> – Cooled

Why? 

by sulfate aerosols in stratosphere and therefore less SW got into troposphere to be absorbed by Earth's surface

<u>Level B (Lower Troposphere)</u> – Cooled

Why? 

by stratospheric aerosols => less SW absorbed at surface <u>and</u> in troposphere,

ALSO: less 

radiated up into troposphere from the cooler Earth's surface

Level D (Lower Stratosphere) – Warmed immediately after both eruptions

Why? Sulfate aerosols in the stratosphere absorbed some wavelengths of incoming SW and heated up, they also absorbed some of the Earth's outgoing LW as it radiated up out of the troposphere

Level C (Mid-Upper Troposphere) –
After Agung: warmed briefly, then cooled;
After Pinatubo: cooled

Why? A transitional layer with some processes like those in Layer B and Layer D: sulfate aerosols reflected some SW and absorbed some SW plus outgoing LW

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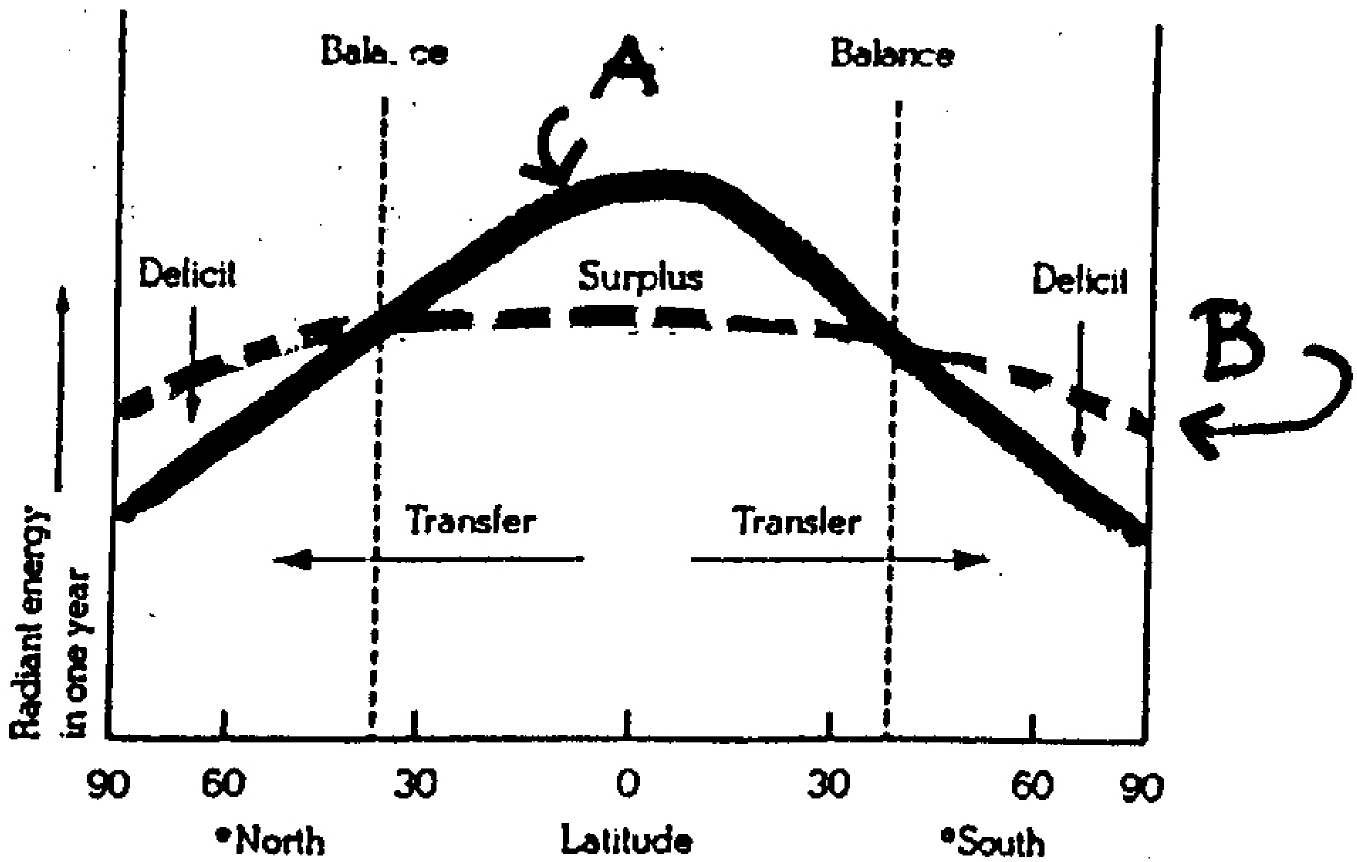
TO SUMMARIZE: 2 KEY POINTS

- **Major eruptions with a long-lived sulfate aerosol veil REFLECT incoming solar radiation back to space BEFORE it enters the mid- & lower troposphere or gets to the Earth's surface, hence the troposphere & surface get COOLER after an eruption.**

- **The aerosols in the stratosphere can also ABSORB some wavelengths of incoming SW and outgoing LW, so that the stratosphere WARMS slightly after an eruption.**

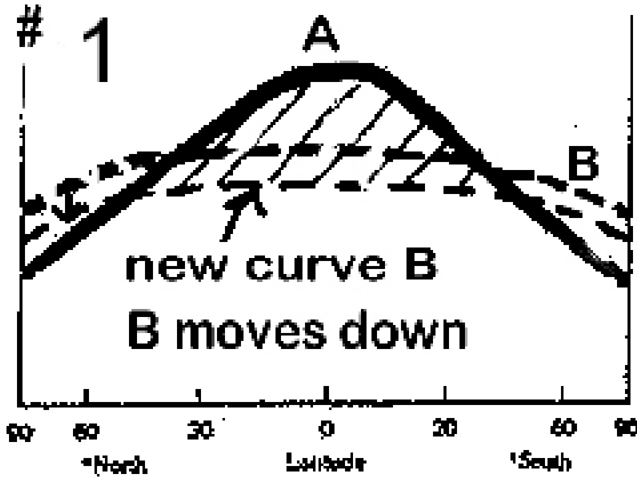
SKETCH A NEW CURVE A OR NEW CURVE B to show how the energy balance would change if a major volcanic eruption occurred .

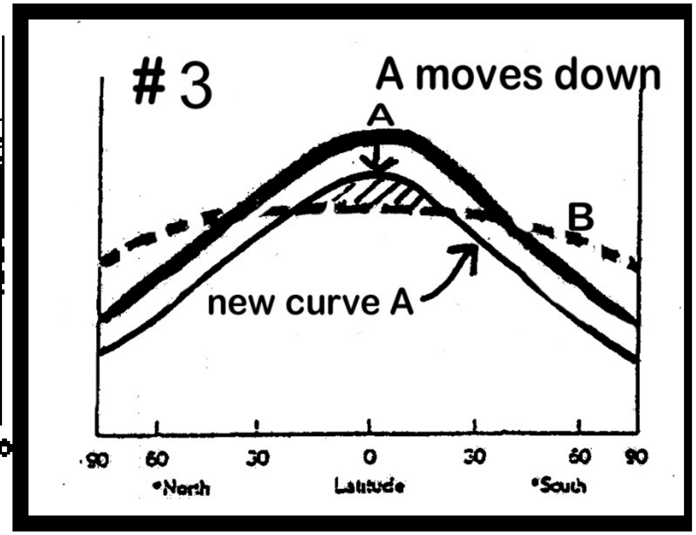


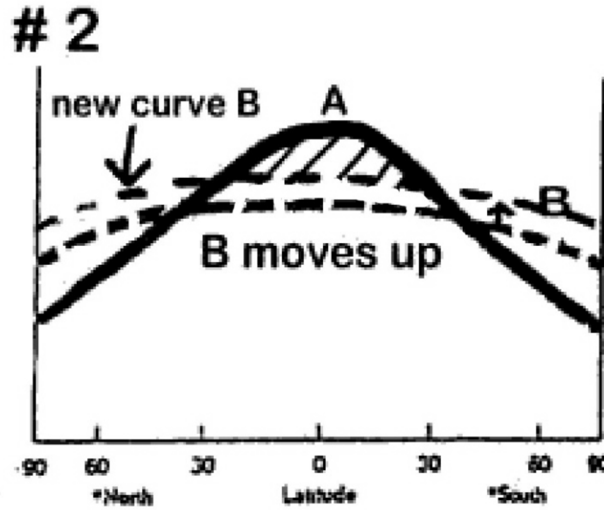
WHICH ONE IS RIGHT?

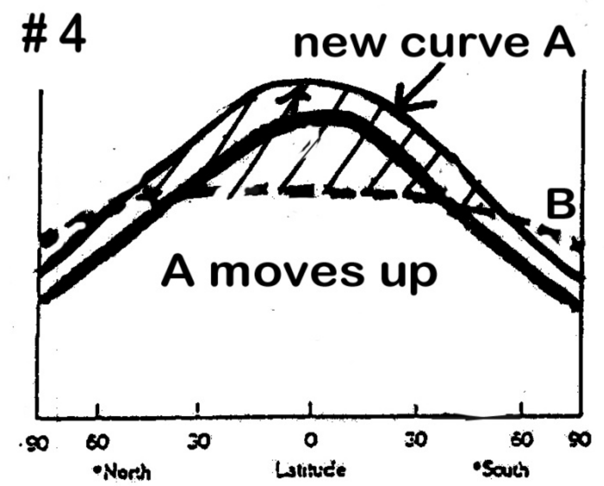
Does the change affect CURVE A or CURVE B?

Show how the energy balance would change if a major volcanic eruption occurred .

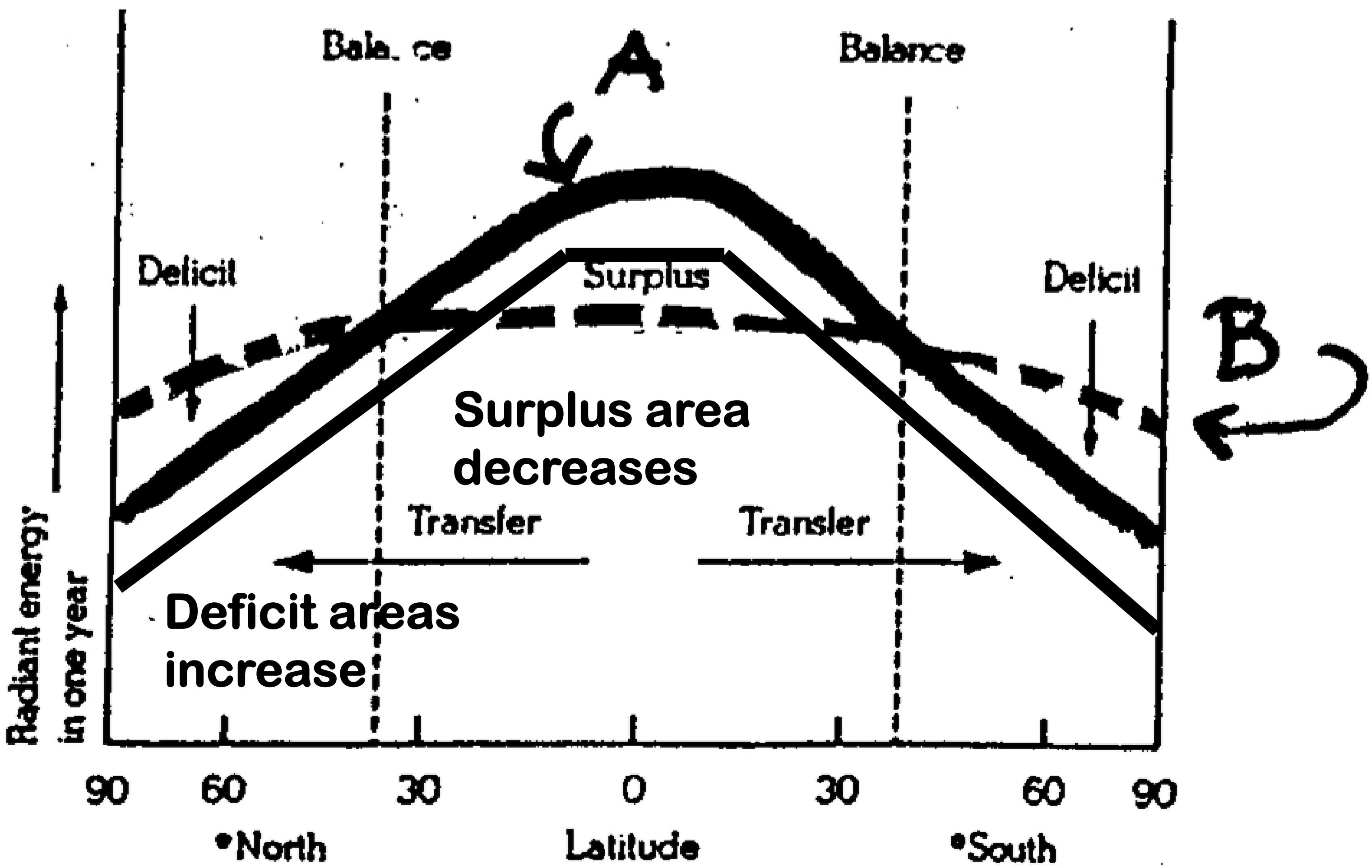








A moves down, & B stays ~ same; eventually B will also move down a bit due to cooler Earth temps and less outgoing LW



The End . . . but

Why a red sunset after an eruption???