TOPIC #15

Paleoclimate & Short Term Climatic Variability

pp 91 - 104 in Class Notes

&

TOPIC #16

Volcanism & Natural Climatic Forcing

(The Climatic Effects of Explosive Volcanism)

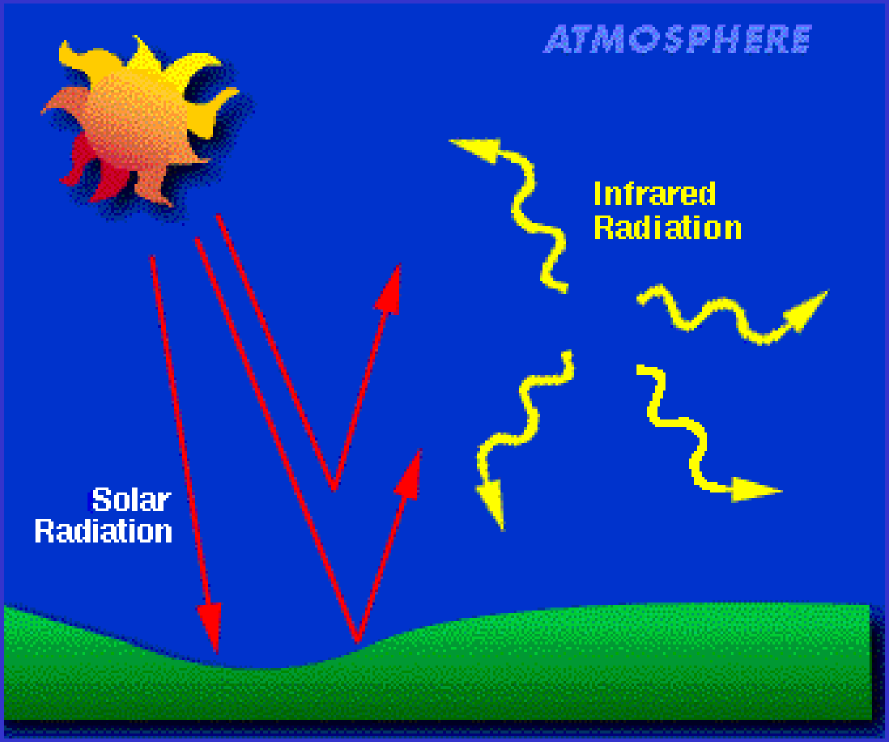
pp 105 - 110 in Class Notes

Topic #16 begins with Slide #35

All things are connected. Whatever befalls the earth, befalls the children of he earth.

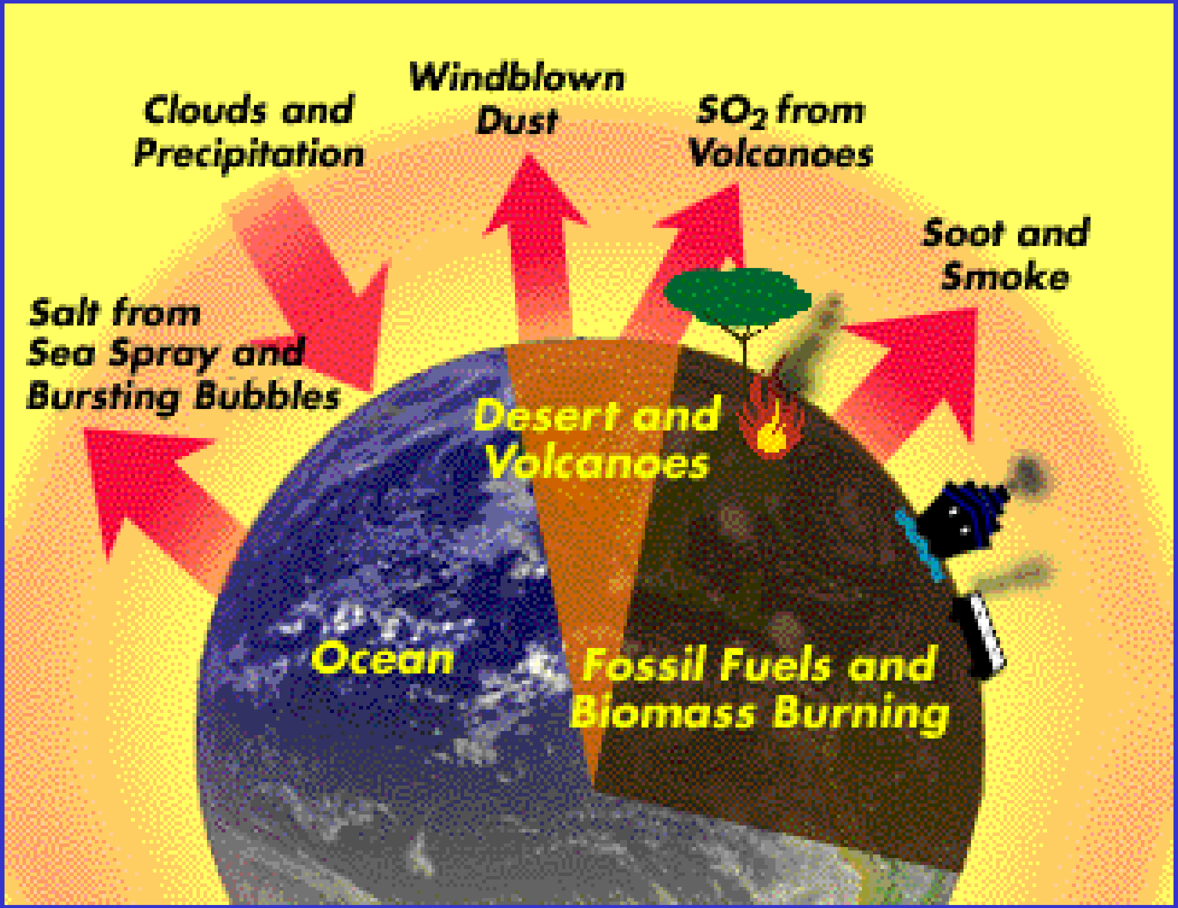
~ Chief Seattle

ENERGY BALANCE (review)



Global climate change / climate variability are due to changes in this balance that are "FORCED"

FORCING = a persistent disturbance of a system;
a longer term disturbance than a perturbation



ANTHROPOGENIC FORCING

Human-Enhanced GH Effect

vs.

NATURAL CLIMATIC FORCING

Earth-Sun orbital relationships, changing land-sea distribution (due to plate tectonics), volcanic eruptions, solar variability

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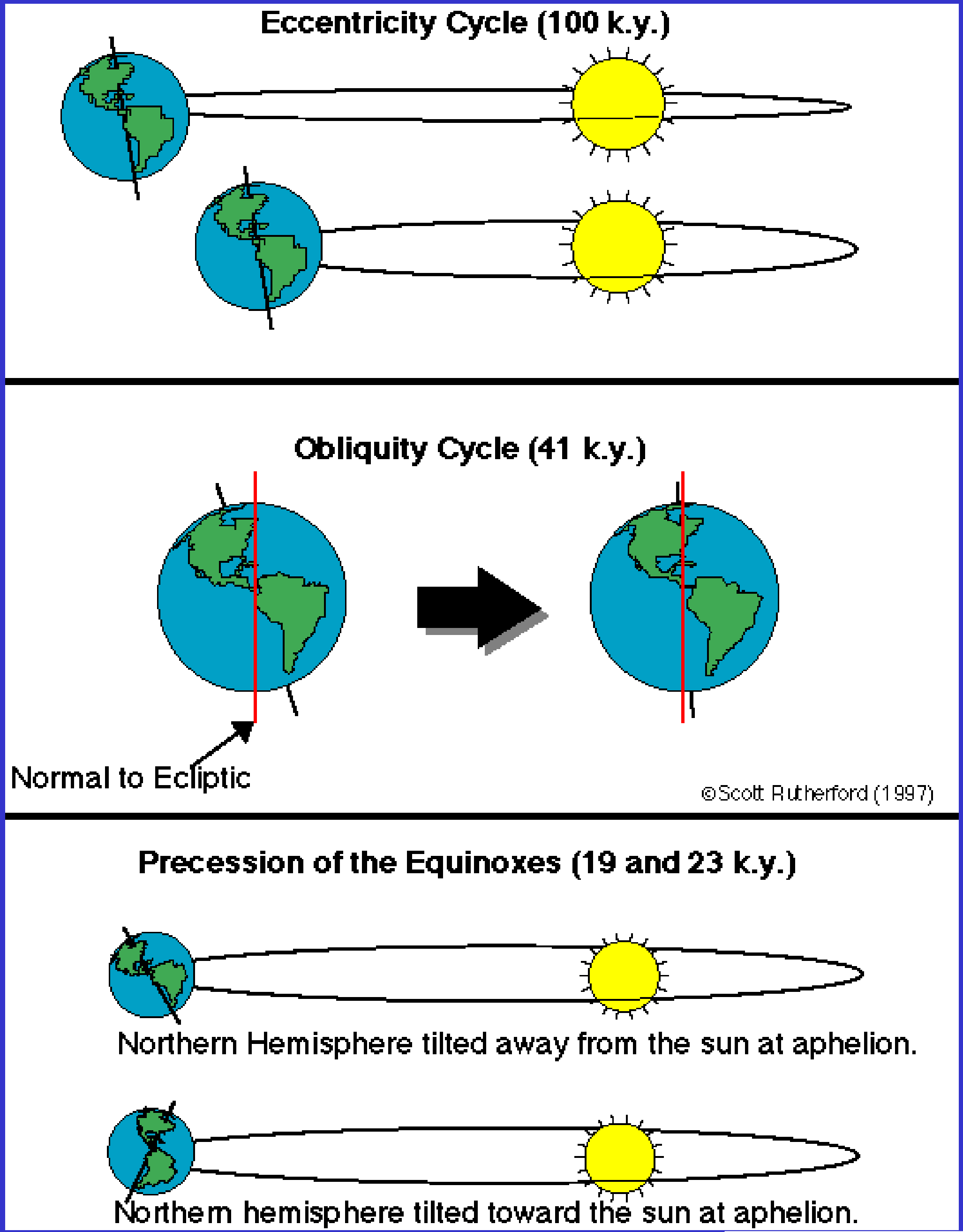
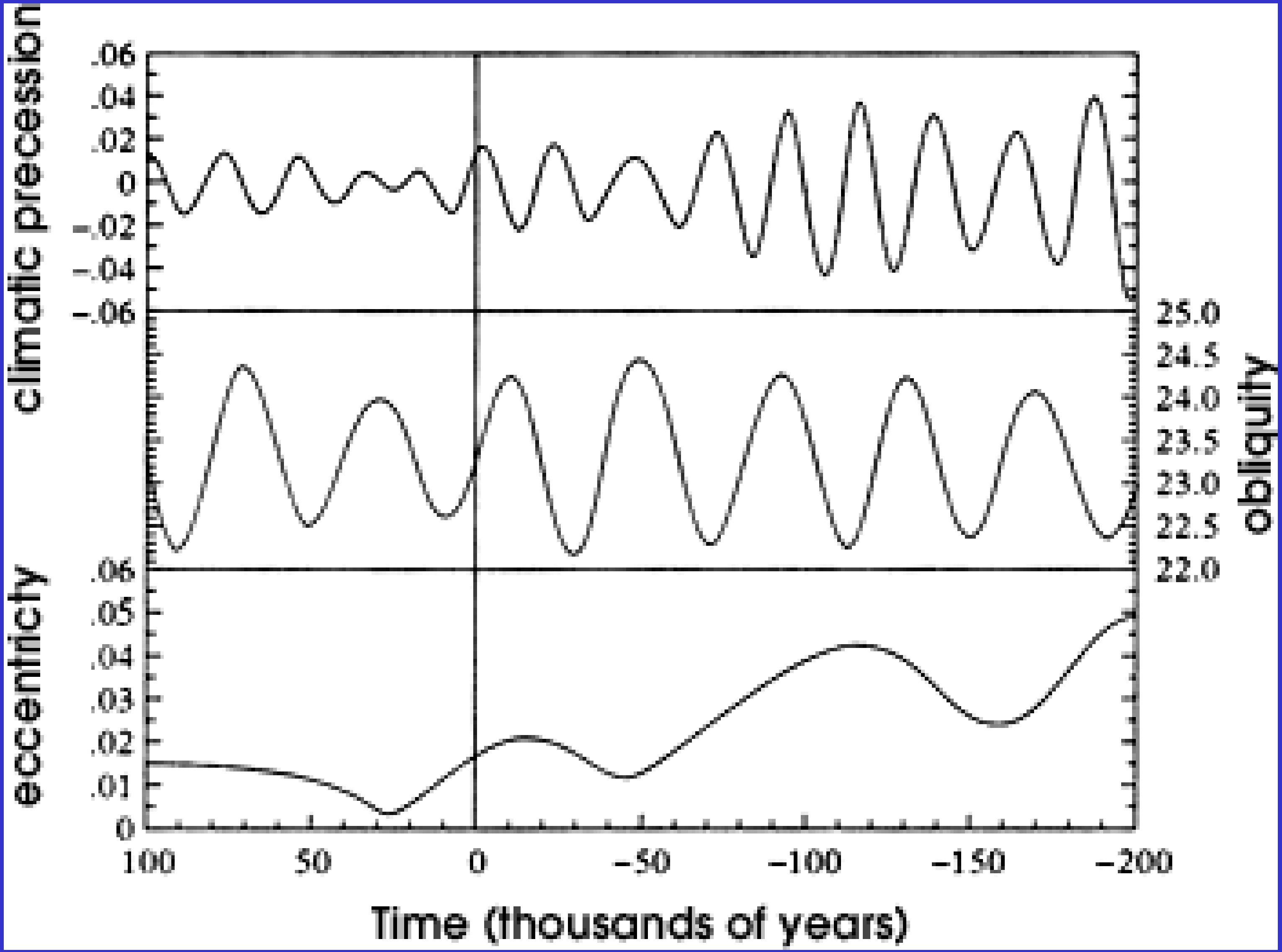
Earth-Sun Orbital Relationships

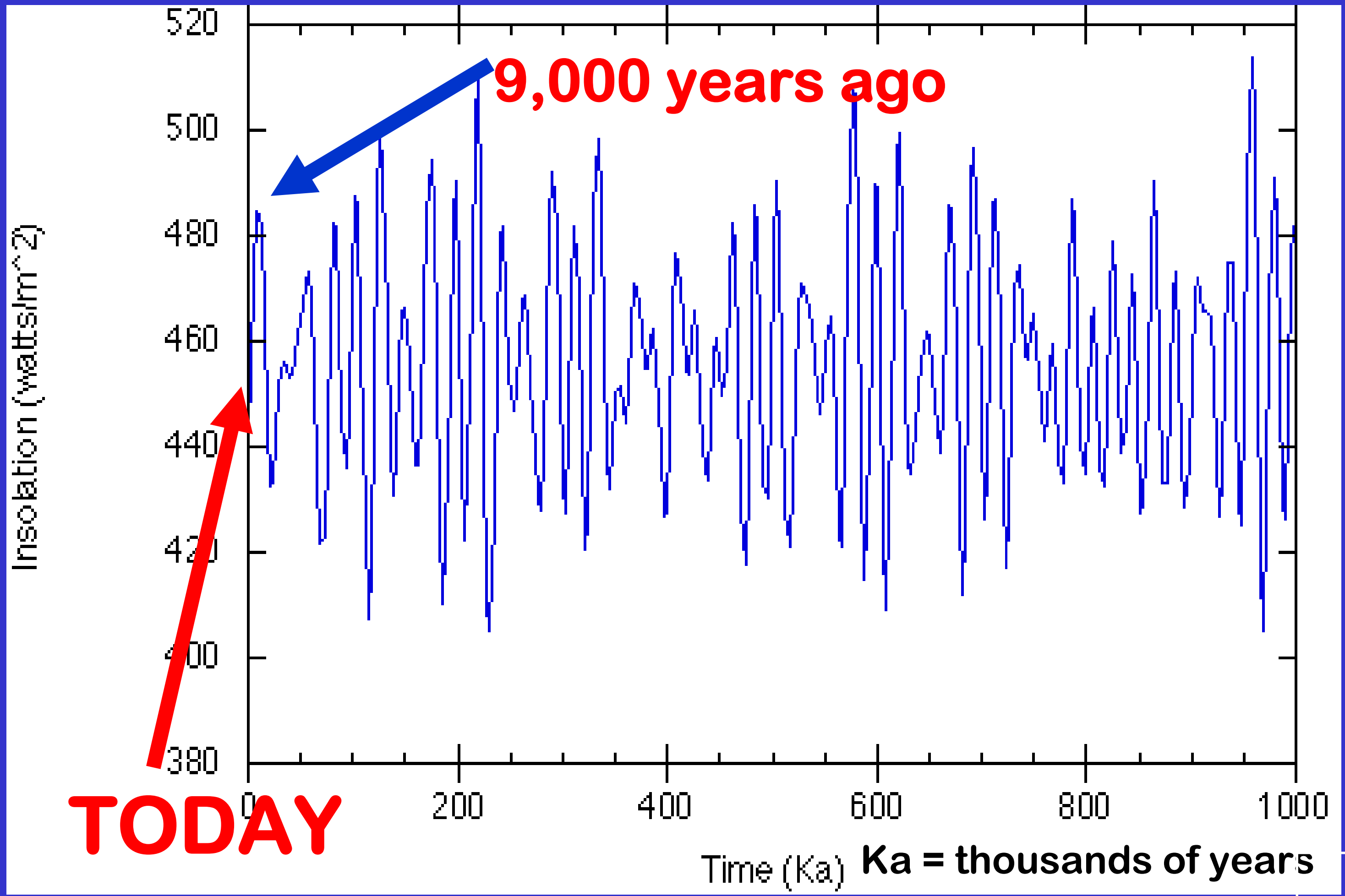
"astronomical climate forcing"

Drives natural climate variability (ice ages, etc.) on LONG time scales (geologic time, past 10,000 to 100,000 years, etc., etc.)




climatic precession
.06
.04
.02
0
-.02
-.04
-.06
obliquity
25.0
24.5
24.0
23.5
23.0
22.5
22.0
eccentricity
.06
.05
.04
.03
.02
.01
0
100
50
0
-50
-100
-150
-200
Time (thousands of years)

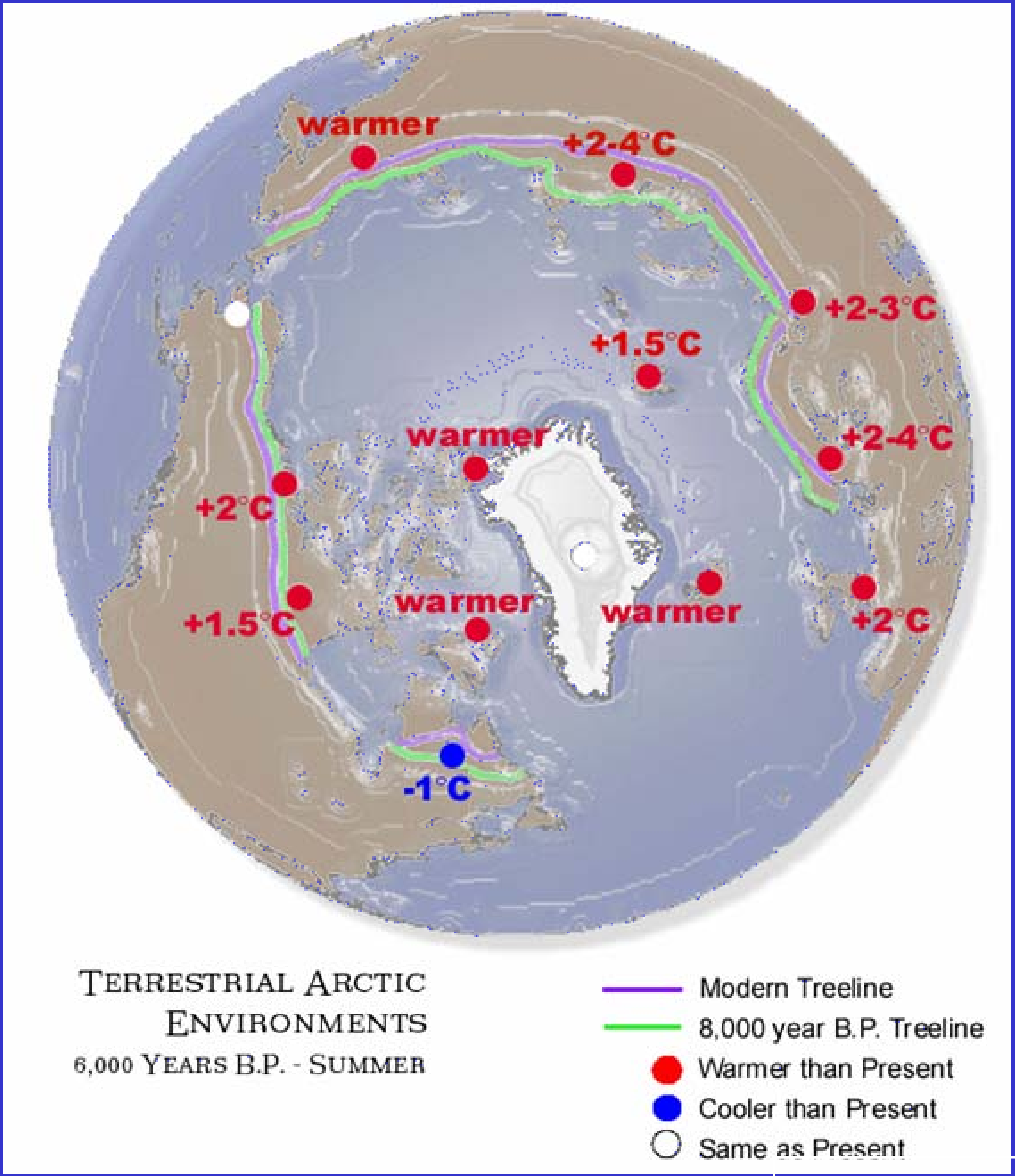
SOLAR INSOLATION calculated for 65 °N latitude from the present to 1 million years ago. In the Northern Hemisphere, peak summer insolation occurred about 9,000 years ago when the last of the large ice sheets melted. Since that time Northern Hemisphere summers have seen less solar radiation.

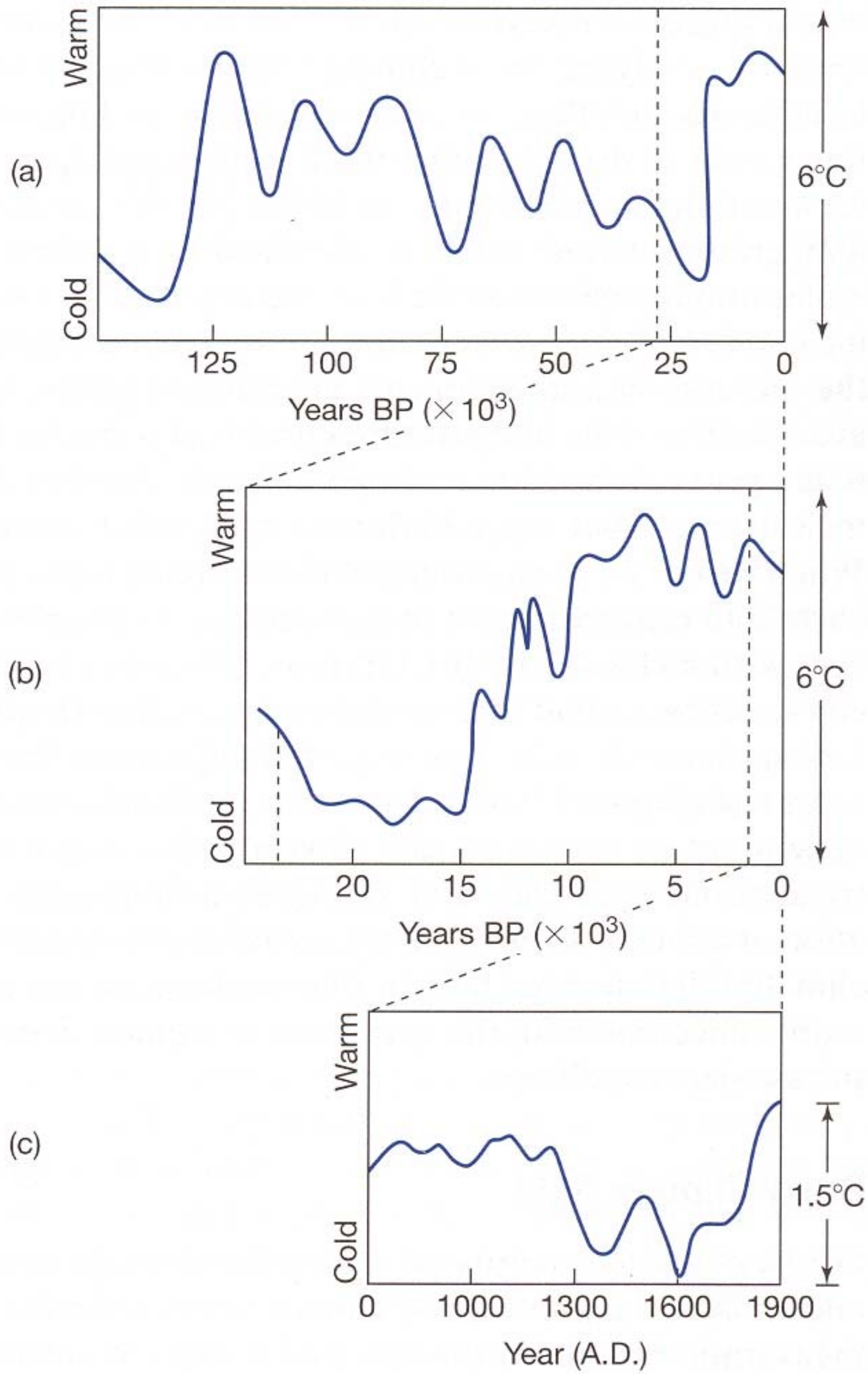


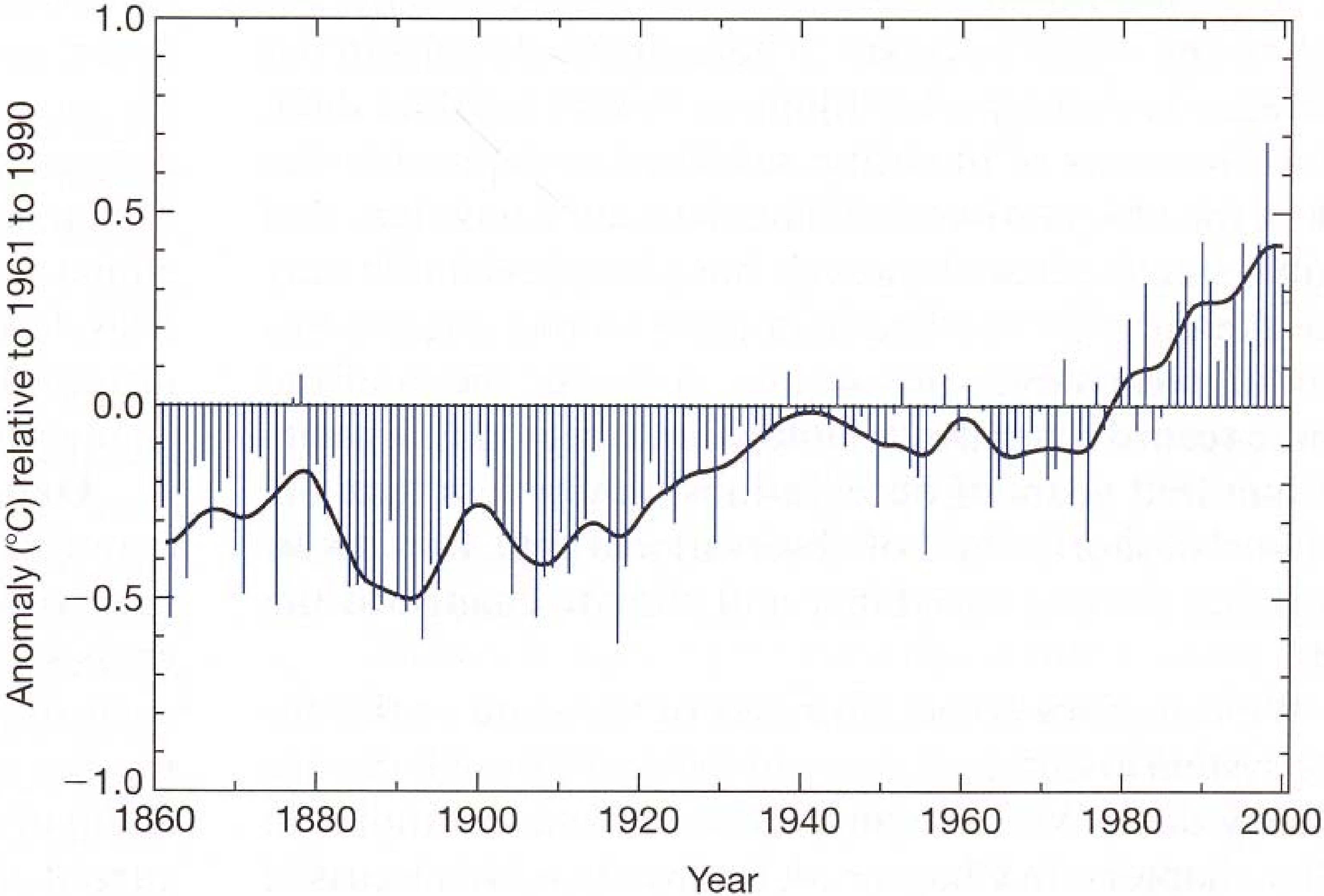
Mid-Holocene warm period
(~ 6,000 years ago)

Generally warmer than today, but only in summer and only in the northern hemisphere.

Cause = "astronomical" climate forcing




(a)
Warm
Cold
6°C
125
100
75
50
25
0
Years BP (× 10³)
(b)
Warm
Cold
6°C
20
15
10
5
0
Years BP (× 10³)
(c)
Warm
Cold
1.5°C
0
1000
1300
1600
1900
Year (A.D.)


1.0
0.5
0.0
−0.5
−1.0
Anomaly (°C) relative to 1961 to 1990
1860
1880
1900
1920
1940
1960
1980
2000
Year
(d)

SHORT-TERM CLIMATE VARIABILITY

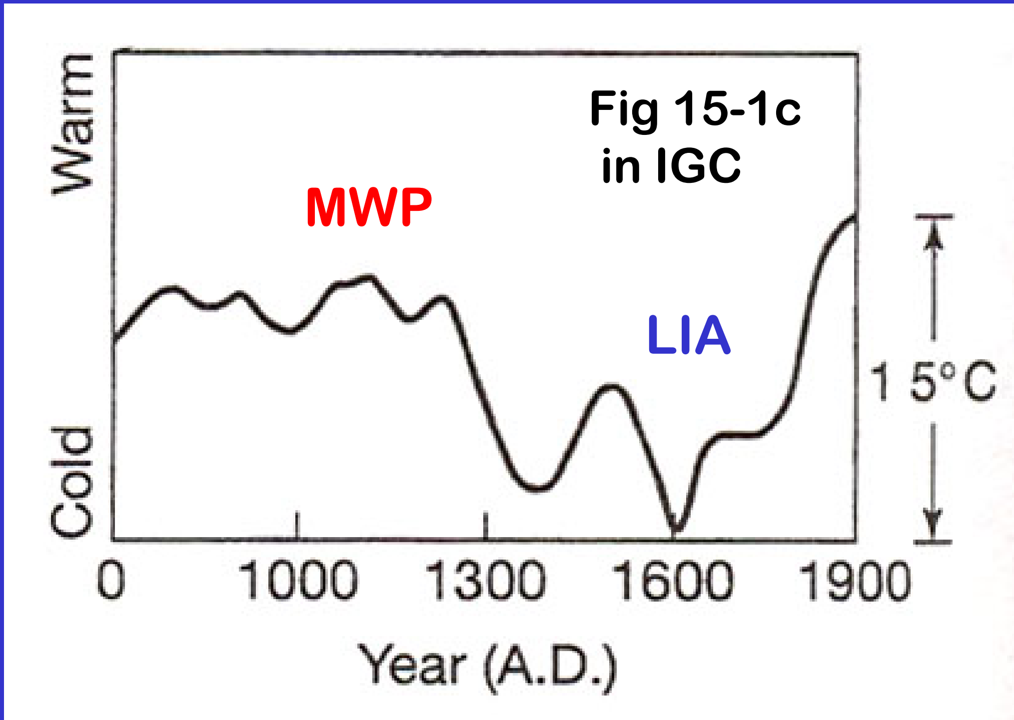
(century, decade, inter-annual time scales of the last 10,000 years)

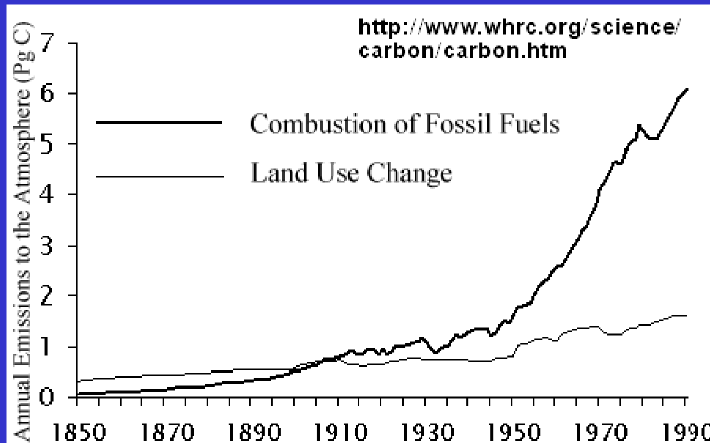
Medieval Warm Period (MWP)

9th-14th centuries
(800-1300)

Little Ice Age (LIA)

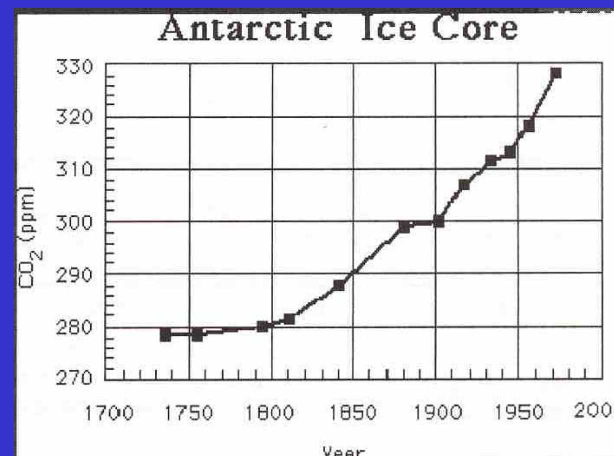
15th – 19th centuries
(1400-1800)
esp. 1600 -1800





GRAPH A

The darker line is emissions of carbon into the atmosphere from burning of fossil fuels; the lighter line is emissions due to land use change (e.g. deforestation, etc.). Which process emits more carbon into the atmosphere and how do the trend compare over time?



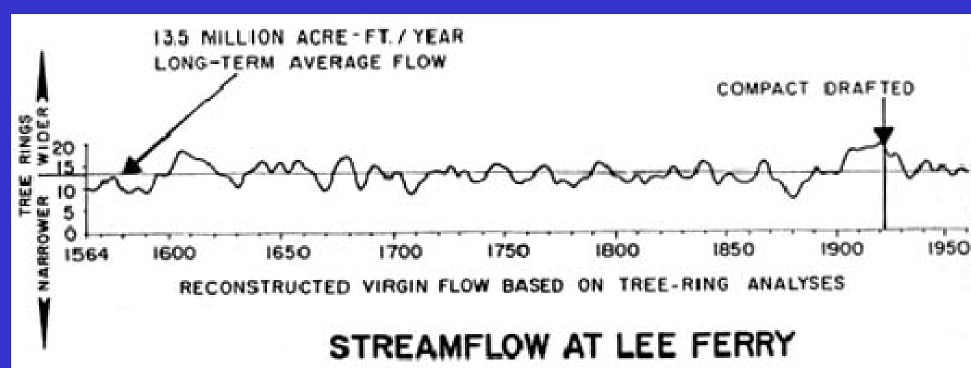
GRAPH B

This one shows carbon dioxide captured over time in Antarctic ice cores.

Does the trend agree with graph of CO_2 in the atmosphere? (see Graphs A)

GRAPH C

This one shows long term streamflow variations in the Colorado River -- the graph is based on a reconstruction of the flow using tree rings. How does the first part of the 20th century compare to the 1600s, 1700s and 1800s?



RESPONDER TIME!!

Q1 The Little Ice Age is:

1. a period during Medieval times when Europe was exceptionally warm, and Greenland was much warmer than today

2. a period characterized by cooler temperatures, a higher frequency of volcanic eruptions, fewer sunspots and episodic cold spells from the 1500s to mid-1800s.

3. a mid-Holocene period (5,000 - 6,000 years ago) when cooling was concentrated in summer and only in the Northern Hemisphere due to orbital effects between the Earth and Sun

4. a period in the early part of the 20th century which was significantly cooler than the most recent warming we have seen in the years 1960-2000.

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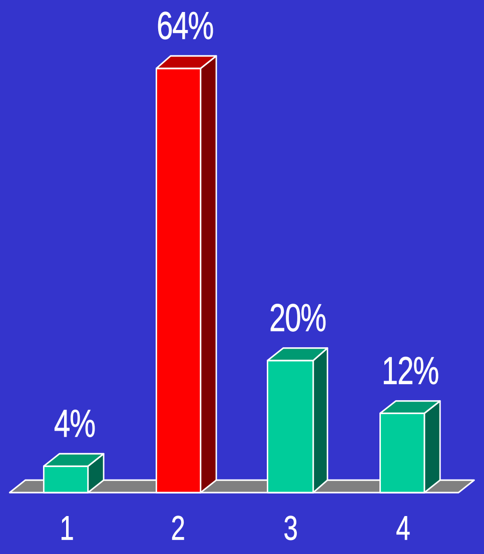
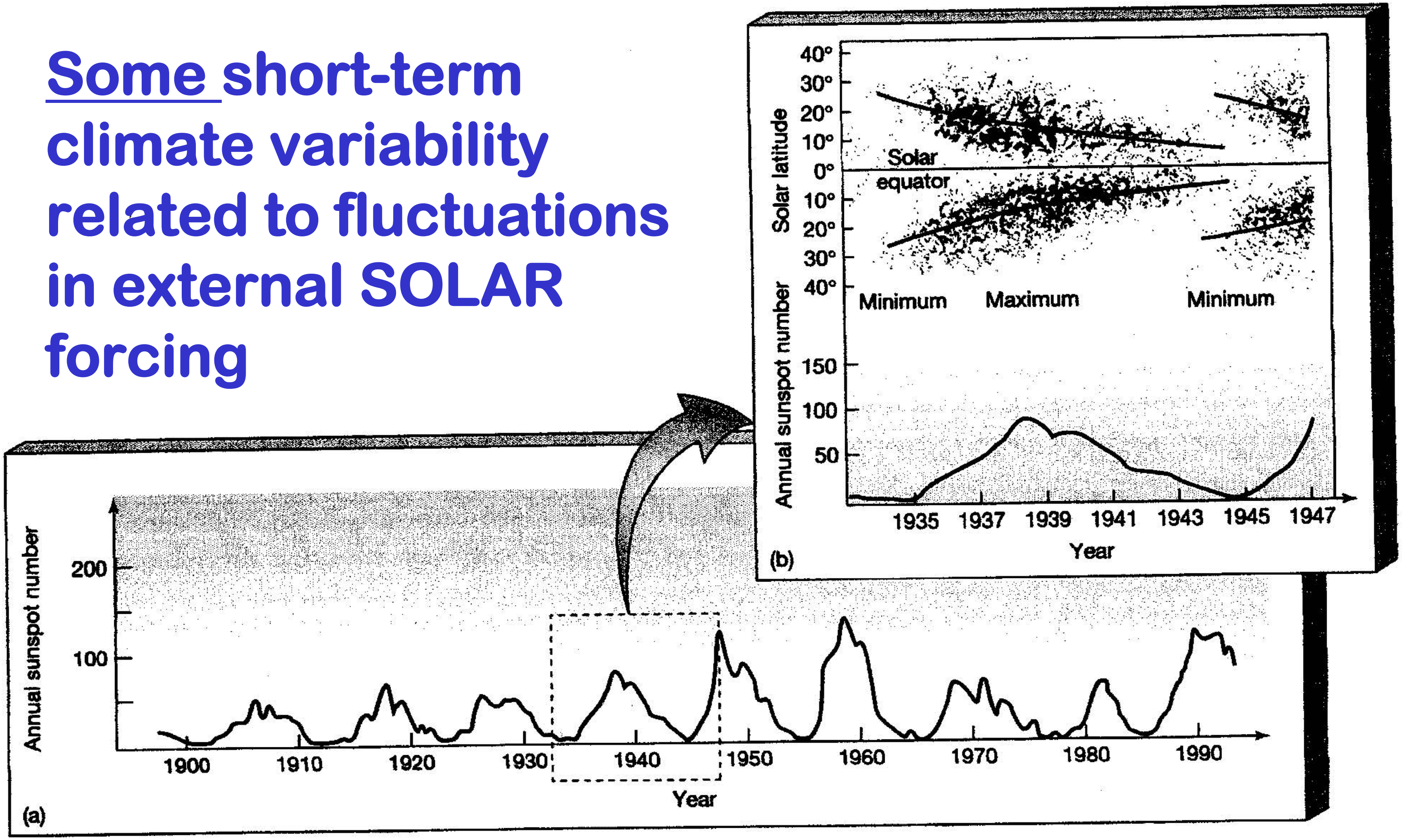


BEGIN ANSWERING NOW!

Some short-term climate variability related to fluctuations in external SOLAR forcing



Sunspot cycles (quasiperiodic)

sunspot minima = LESS solar brightness

Maunder Minimum (1645-1715) linked to "Little Ice Age" (1600-1800)

But uncertainties remain . . . .????

what MECHANISM transfers

brightness drop → lower temperatures

Dalton Minimum (1795 – 1825)

-- also cooler

-- lots of large eruptions then too

Since the Dalton Minimum, the Sun has gradually brightened – we are now in the "Modern Maximum."

BUT . . .
increase in solar brightness during the current "Modern Maximum" accounts for only:

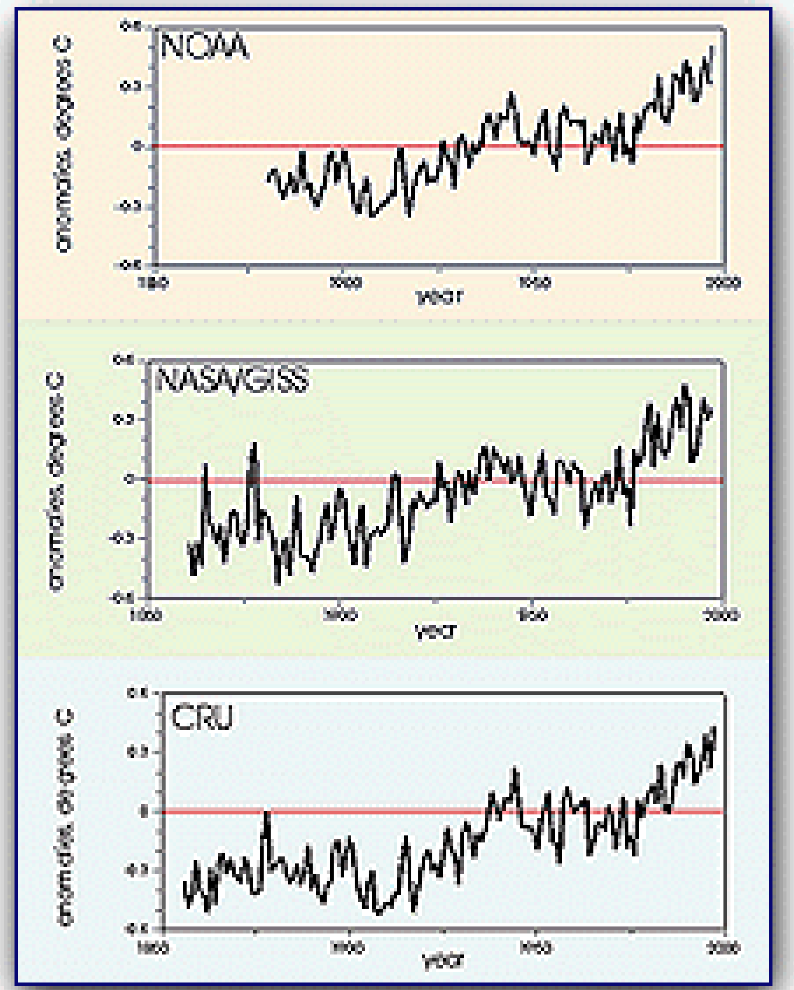
- about ½ of the temperature increase since 1860, and
- less than 1/3 since 1970

The rest is attributed to greenhouse-effect warming by most experts in solar forcing.

DETECTING GLOBAL WARMING:

INSTRUMENTAL RECORD

Thermometer-based Temperature Trends



GLOBAL TEMPERATURE ANOMALIES
SOURCES: NOAA, NASA/GISS, AND CRU

To make an incontrovertible case about the role that humans play in global warming, what do scientists need?

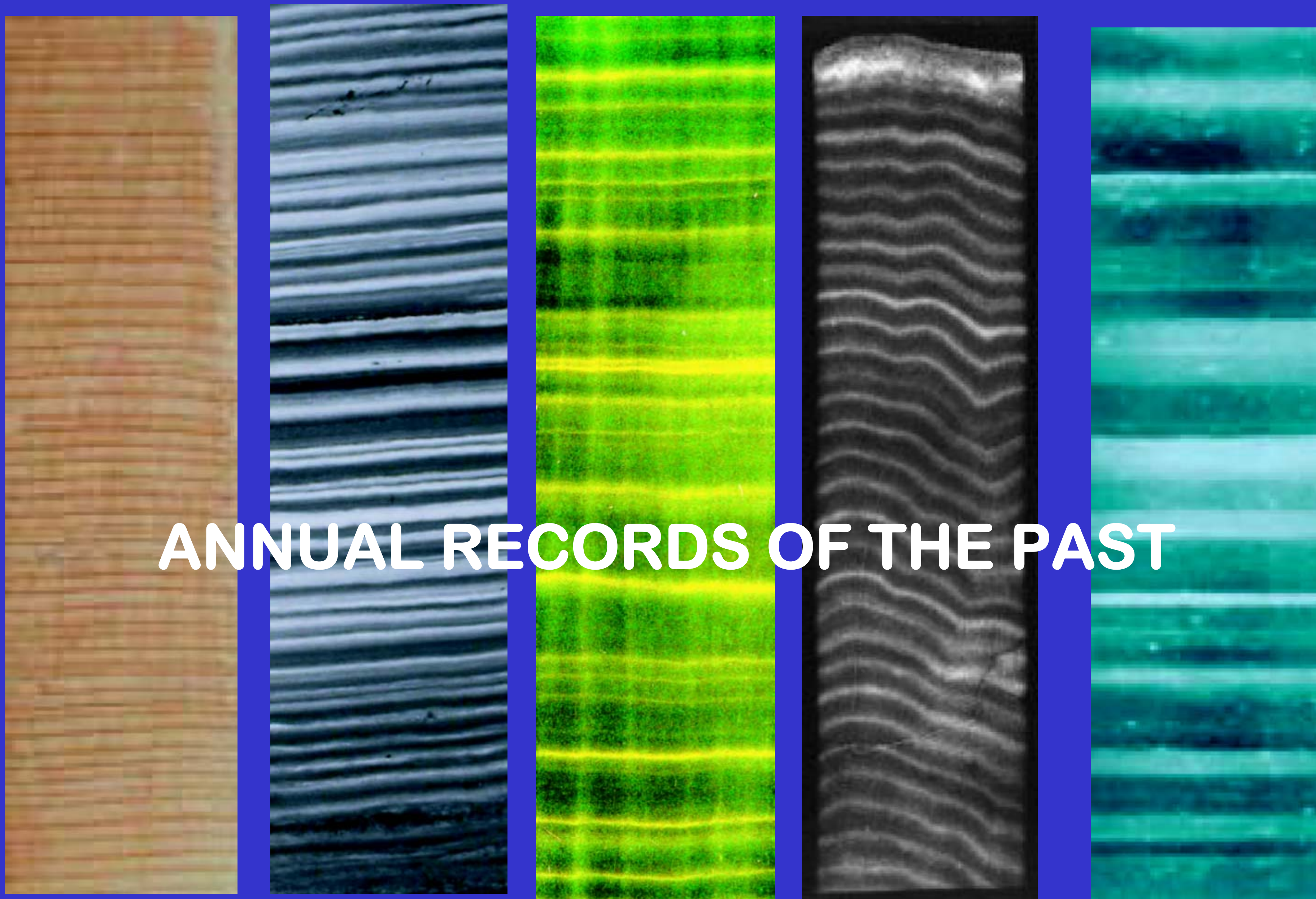
(1) a long-term temperature record, i.e., centuries

(2) over a large part of the globe

(3) To be able to say:

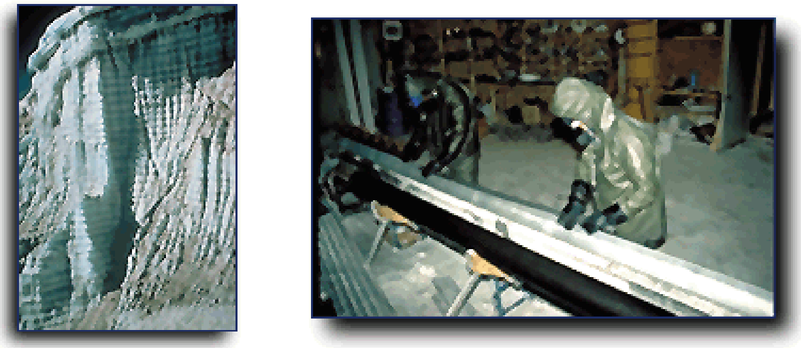
“What's the average been for several hundred years, and is this a significant departure from that?”

“And that's very difficult to do.” (James Trefil, physicist)


Tree rings
Lake varves (sediments)
Speleothems (from cave)
Coral (annual growth)
Ice Core
ANNUAL RECORDS OF THE PAST

"PROXY" DATA or NATURAL ARCHIVES of CLIMATE

Corals

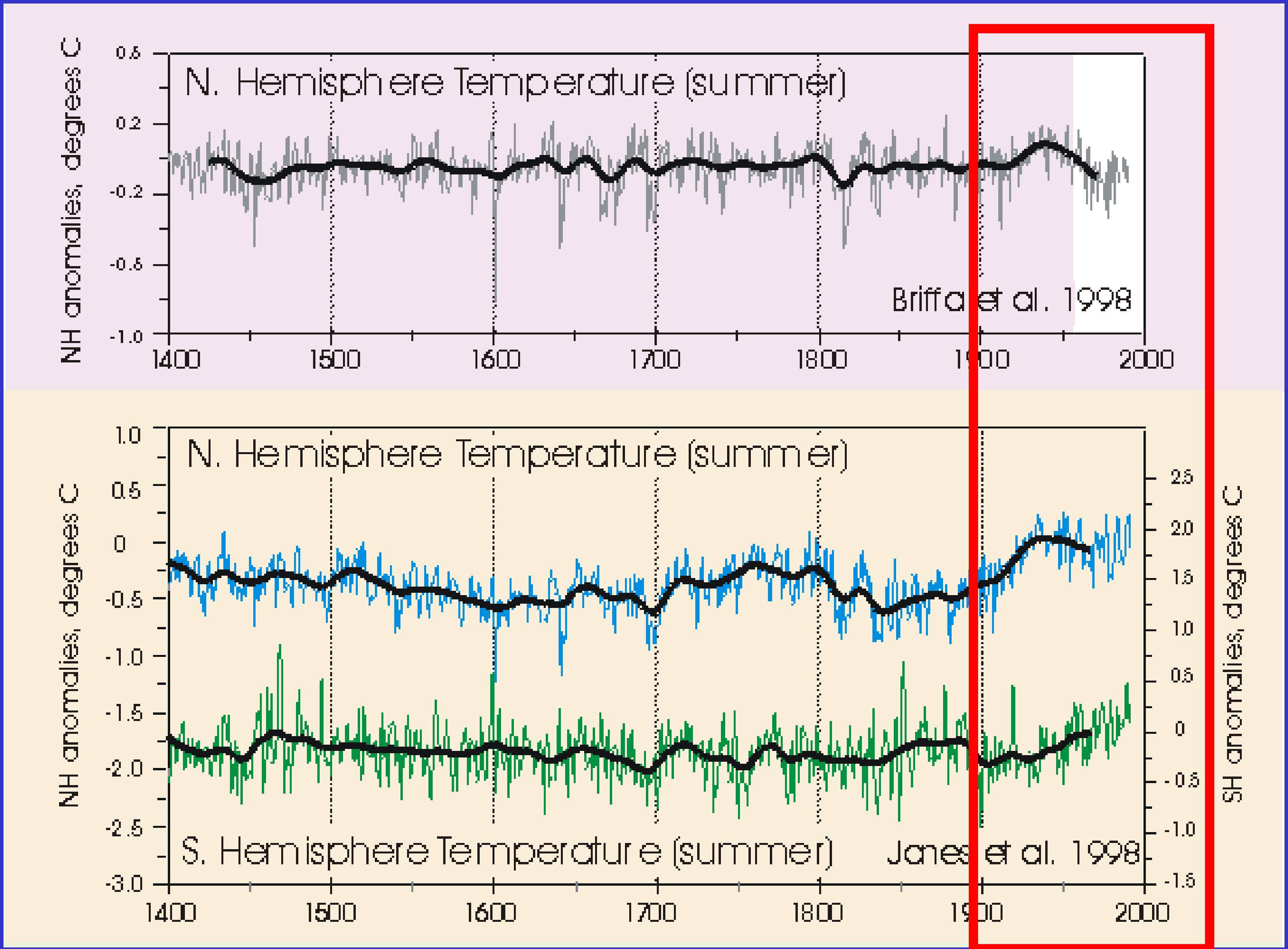


Ice cores

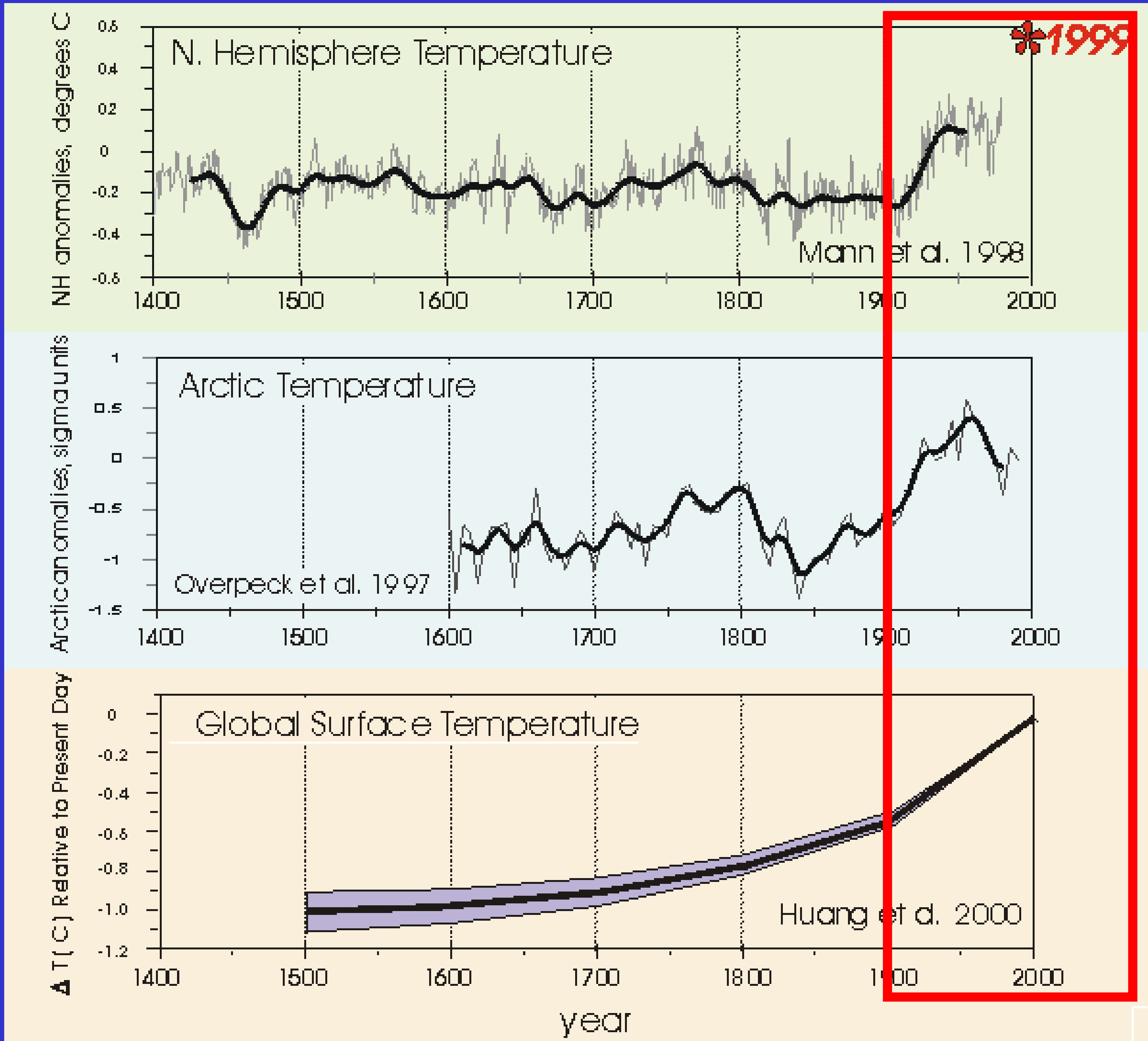
Lake, bog & ocean sediments

Pollen

Temperature Variability over the Last 400 -1000 years:



Each record reveals that 20th century is the warmest!



*1999
N. Hemisphere Temperature
Mann et al. 1998
NH anomalies, degrees C
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1400
1500
1600
1700
1800
1900
2000
Arctic Temperature
Overpeck et al. 1997
Arctic anomalies, sigma units
1
0.5
0
-0.5
-1
-1.5
Global Surface Temperature
Huang et al. 2000
Δ T(C) Relative to Present Day
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
year

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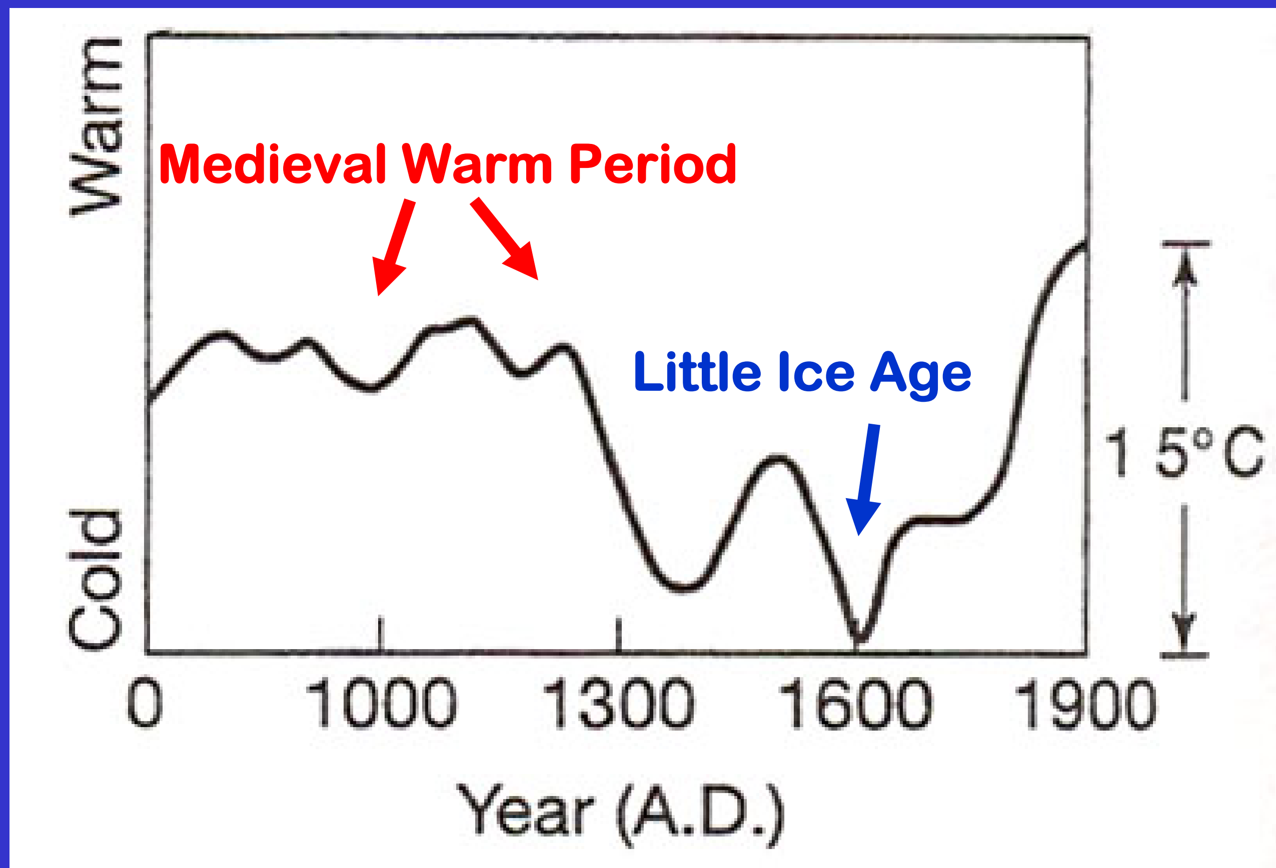
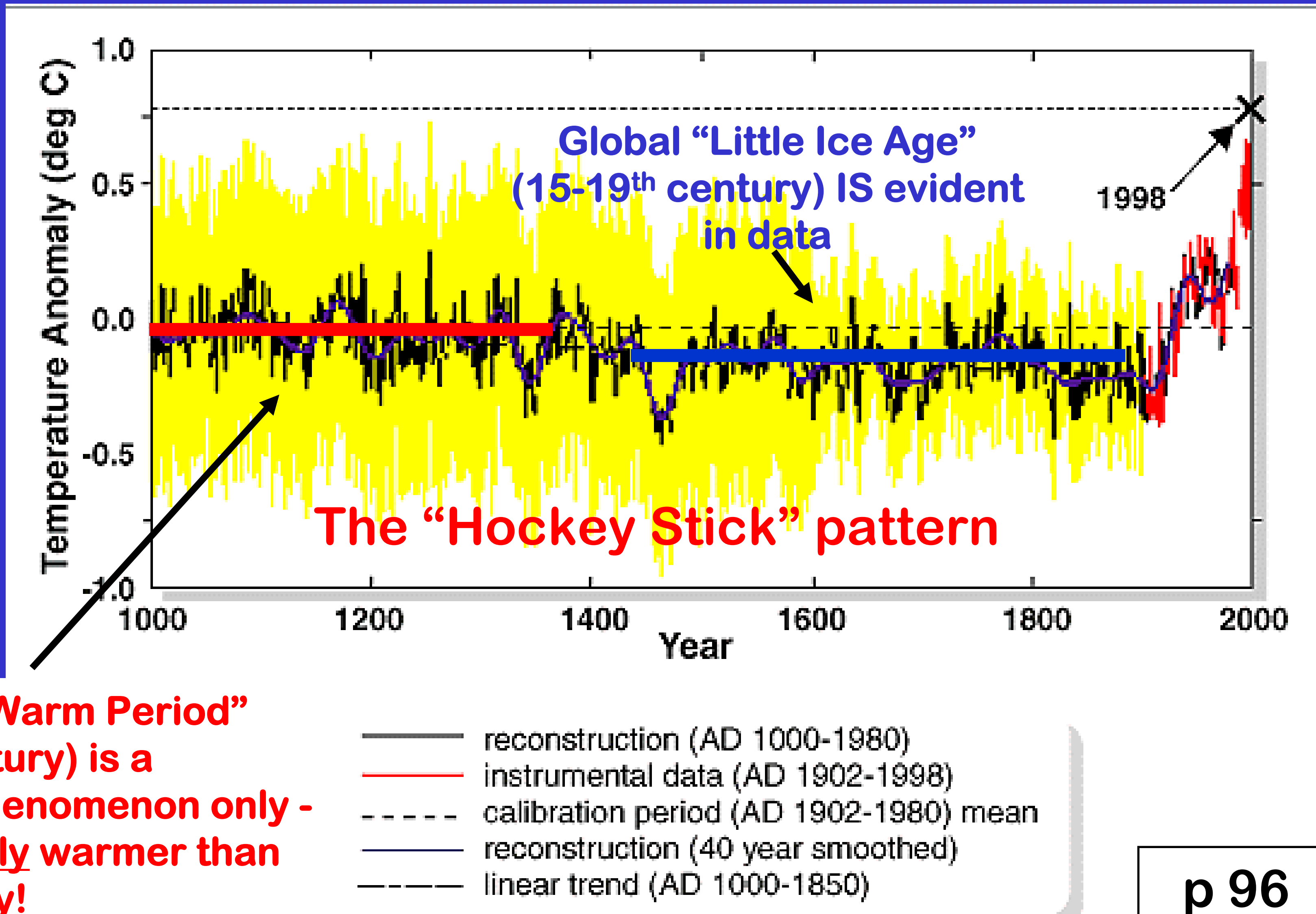
Mean temperature change estimates from historical documents (emphasis on North Atlantic region)

Fig 15.1 in IGC on Short-Term Climatic Variability



KEY GRAPH! Temperature change over the last 1000 years from multi-proxy records: shows there is NO period of global or hemispheric temperatures warmer than the 20th century

1902 -80 global mean



"Medieval Warm Period" (9-14th century) is a regional phenomenon only - - not globally warmer than 20th century!

The latest peer-reviewed paleoclimatic studies appear to confirm that the global warmth of the 20th century may not necessarily be the warmest time in Earth's history (over geologic time scales)

-- what is unique is that the warmth is global and cannot be explained by natural forcing mechanisms.

-- but the controversy continues!!!

More on this debate later!!

SO WHAT ABOUT GLOBAL COOLING??

What explanations do we have for periods of the past 1000 years when the temperature was much cooler, such as the Little Ice Age (1500s – 1800s)?

☺

Q2 - What NATURAL mechanisms can be linked to global COOLING???

1. Asteroid impacts
2. Volcanic eruptions
3. An INCREASE in the # of sunspots
4. All of the above

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1. Asteroid impacts
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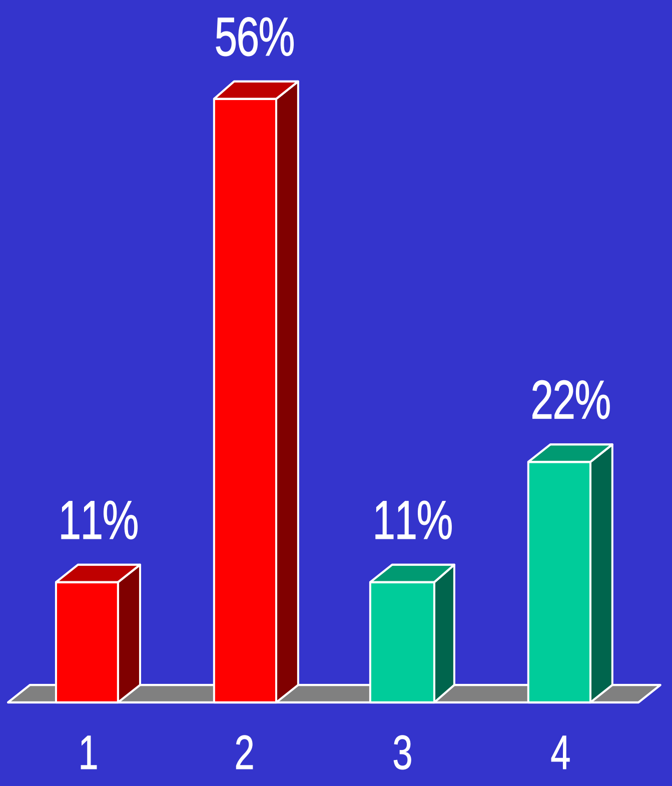
4. All of the above

BEGIN ANSWERING NOW!

NOT choice #3 -- The correct answer for #3 would be: a DECREASE in # of sunspots => decrease in solar brightness



SO WHAT ABOUT GLOBAL COOLING??

What explanations do we have for periods of the past 1000 years when the temperature was much cooler, such as the Little Ice Age (1500s – 1800s)?

1) Reduction in solar brightness

2) climatically effective explosive volcanic eruptions

Recall: SOLAR BRIGHTNESS VARIATIONS

Maunder Sunspot Minimum (1645-1715) linked to "Little Ice Age" (1600-1800)

→ But uncertainties remain about what MECHANISM transfers the brightness drop into lower temperatures.

Dalton Sunspot Minimum (1795 – 1825) also cooler, but lots of large eruptions then as well.

Since the Dalton Minimum, the Sun has gradually brightened – we are now in the "Modern Maximum."

Review: p 95

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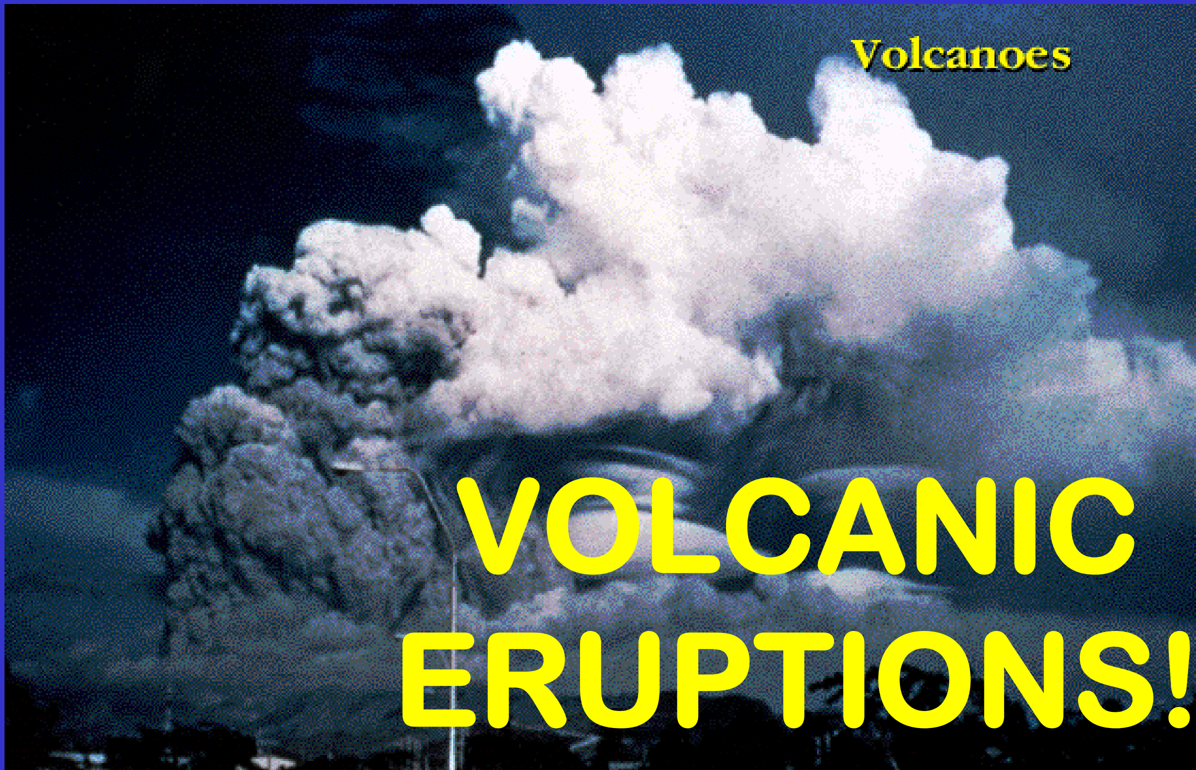

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Volcanoes are one way the Earth gives birth to itself.

~Robert Gross

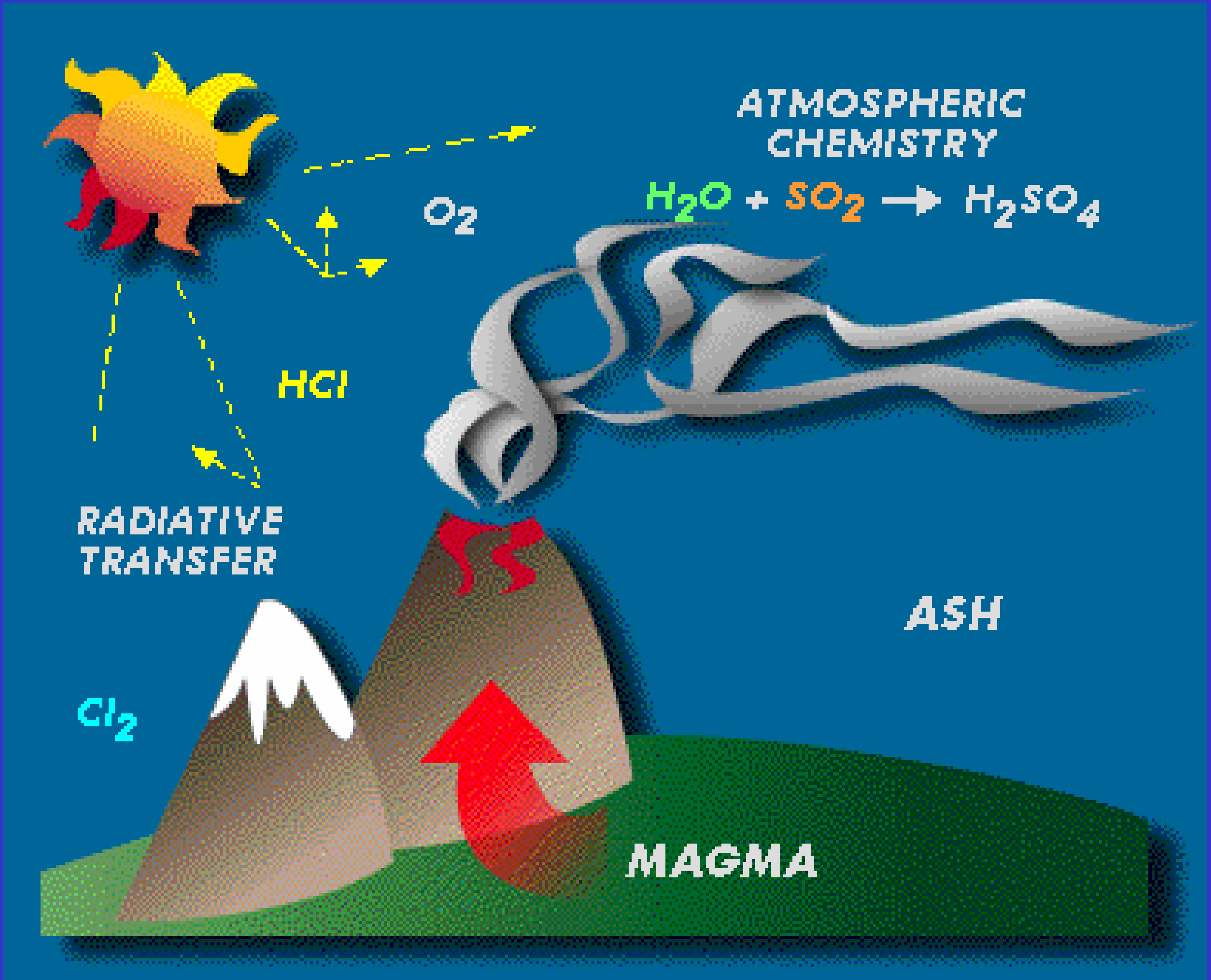
Volcanic eruptions contribute to the natural carbon cycle by adding CO_2 into the atmosphere:

Volcanic outgassing of CO_2 into atmosphere

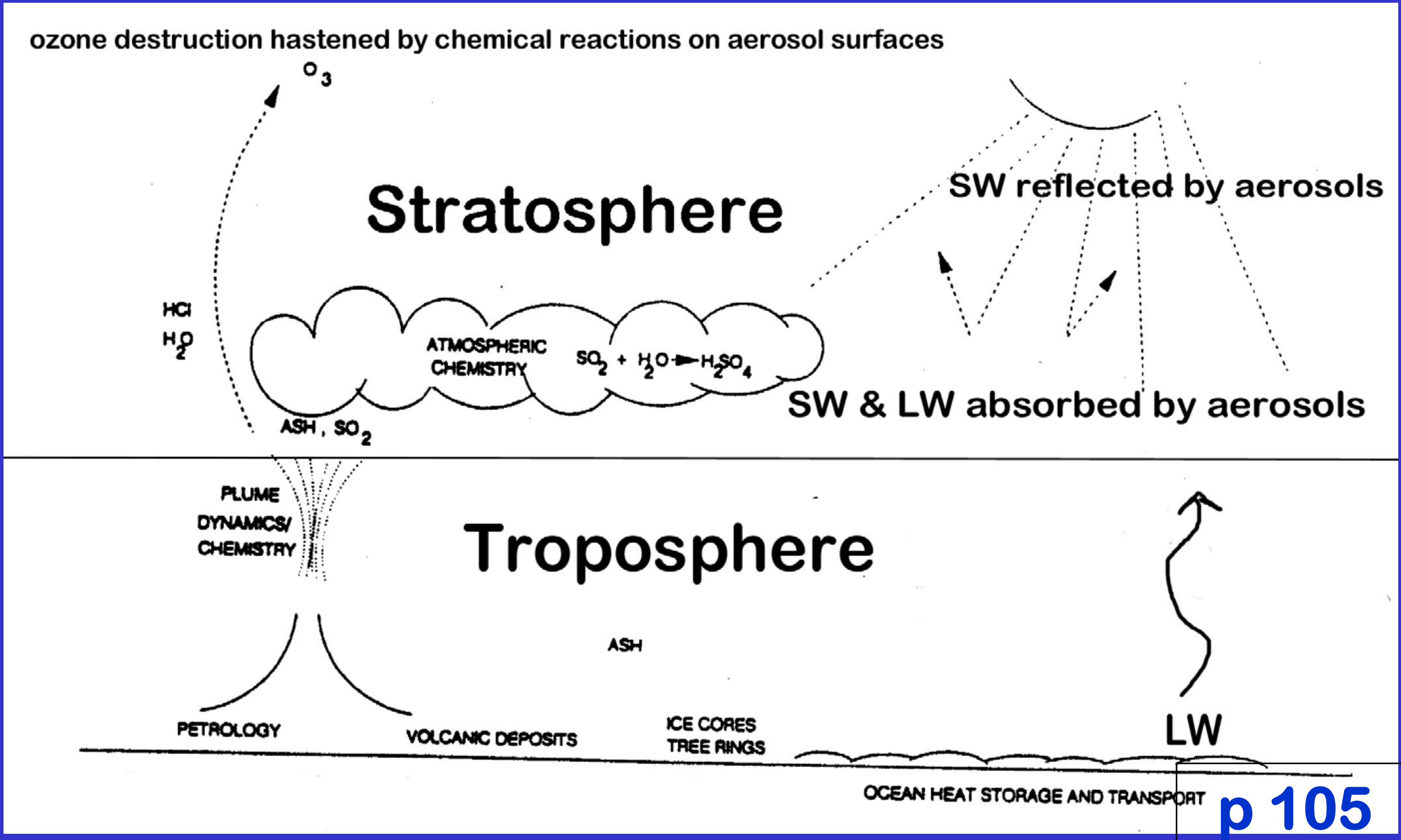
0.06 Gtons

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:



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)

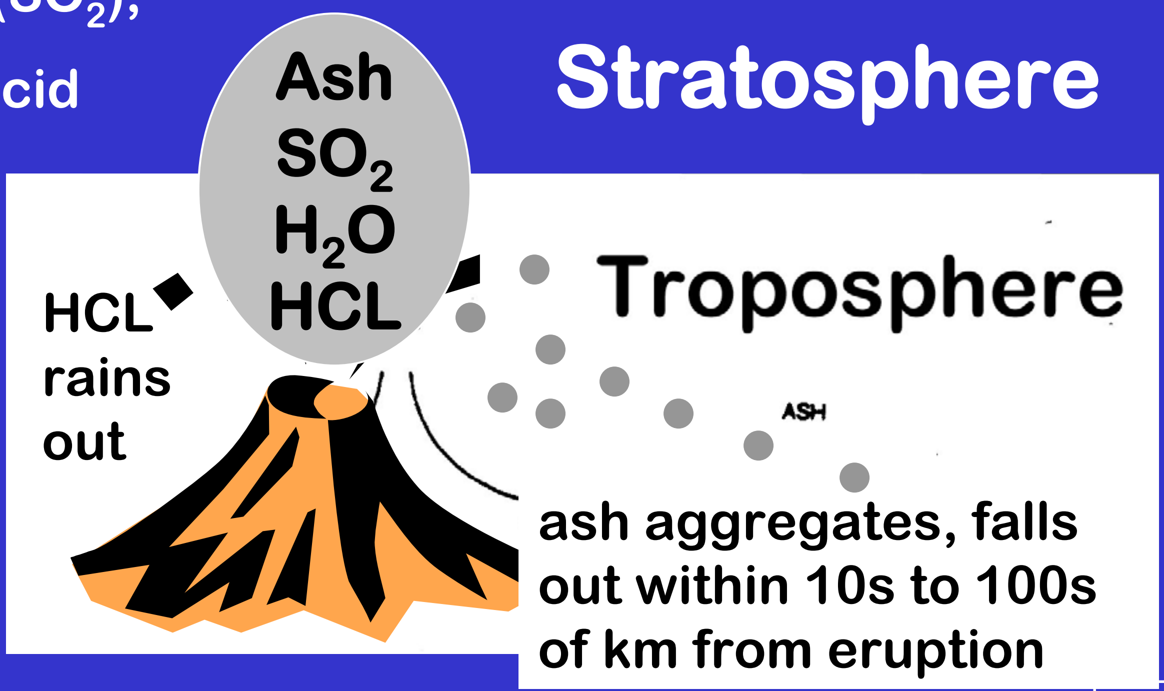
sulfur dioxide (SO_2),

hydrochloric acid (HCl)

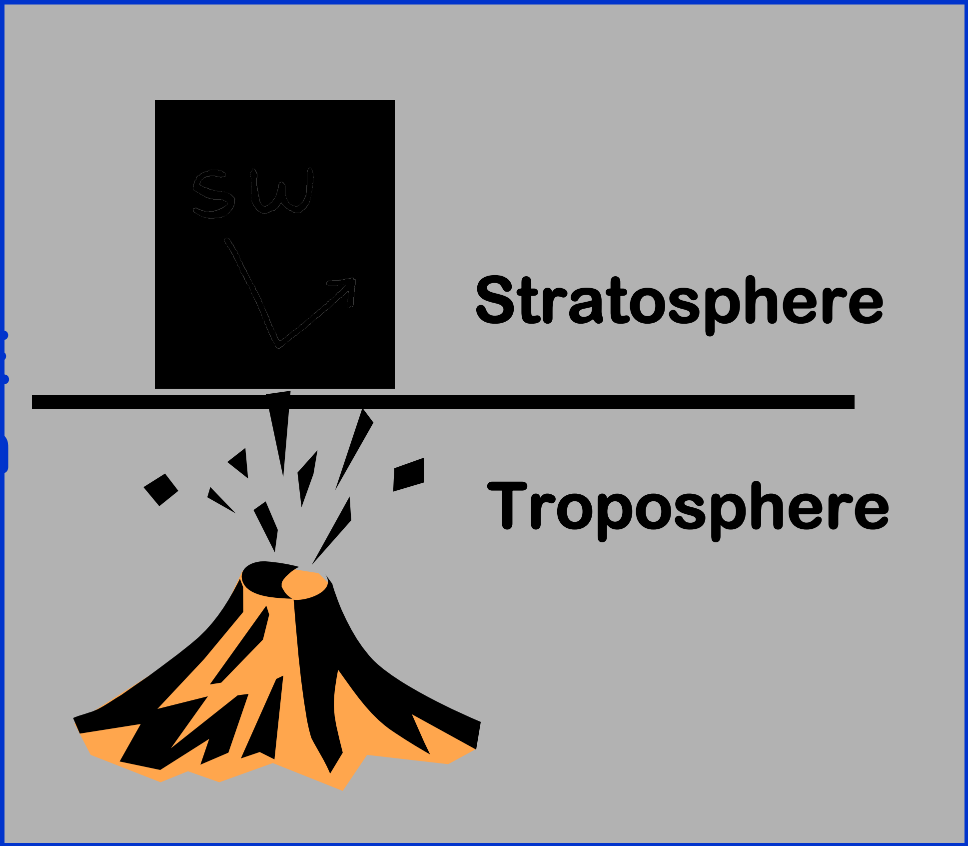
mineral ash

into the stratosphere

↑

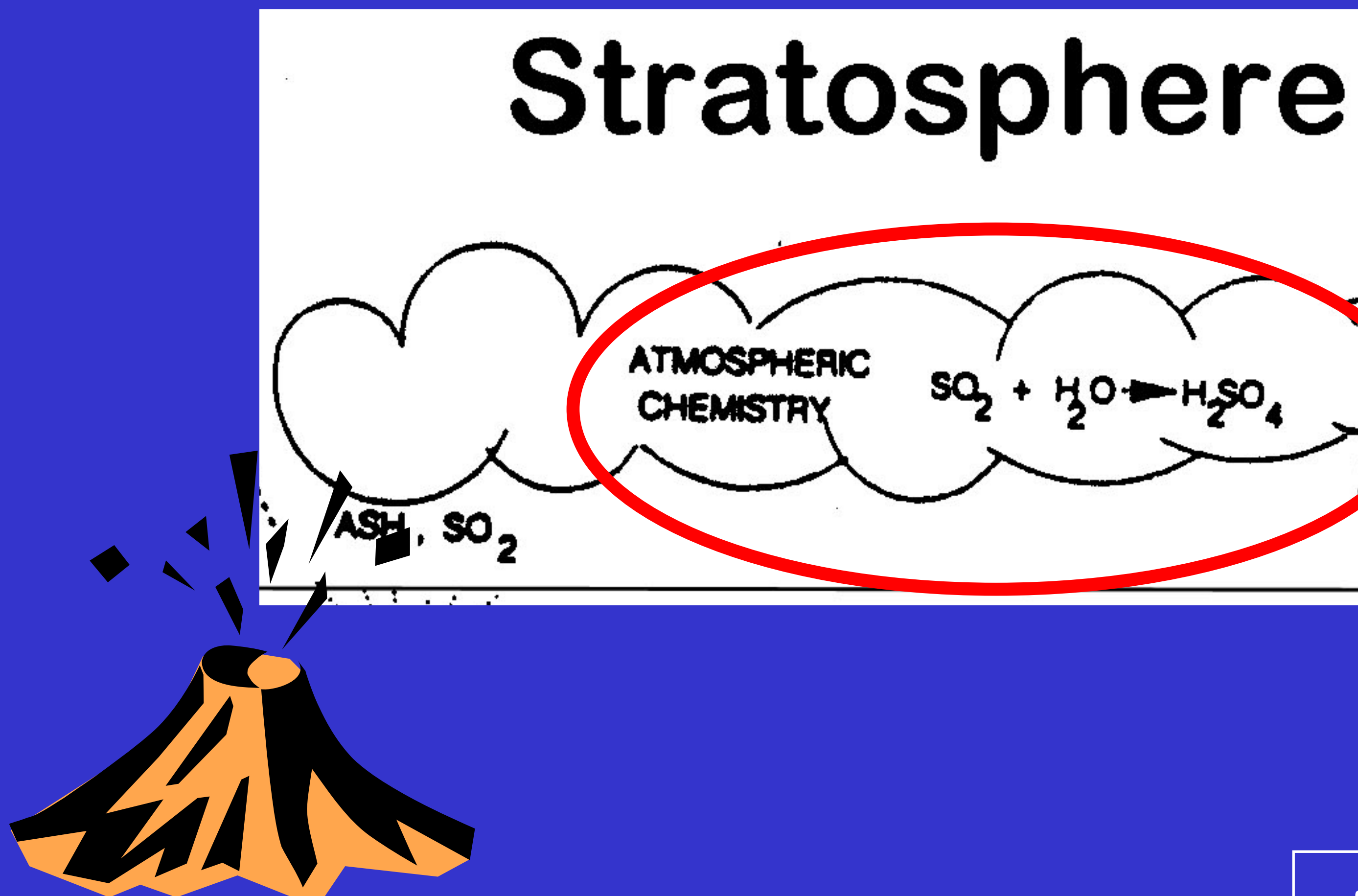


Albedo of ASH in the STRATOSPHERE is *not* the reason for cooling after an eruption! (most ash falls out early)



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 **(sulfate aerosols).**



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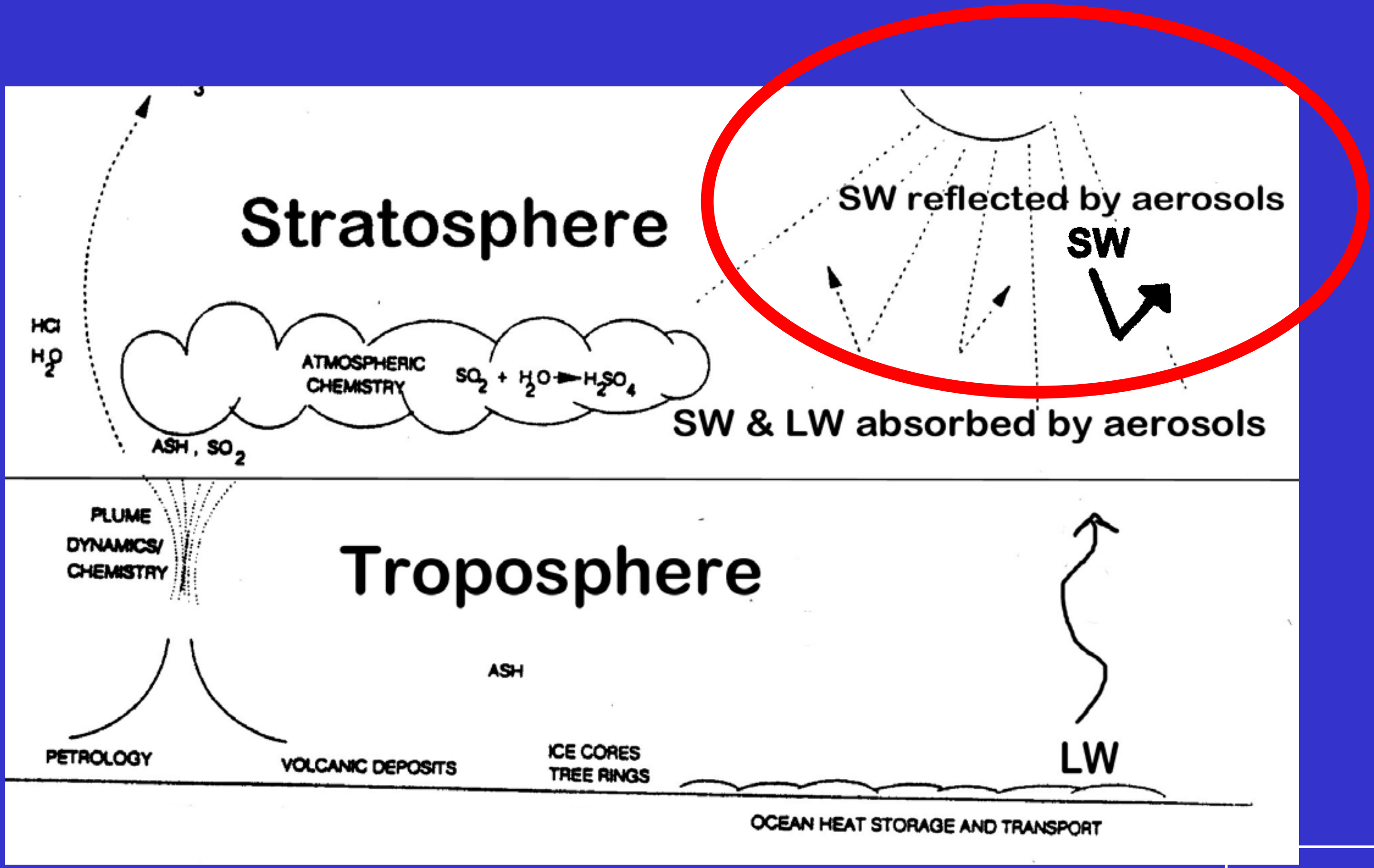
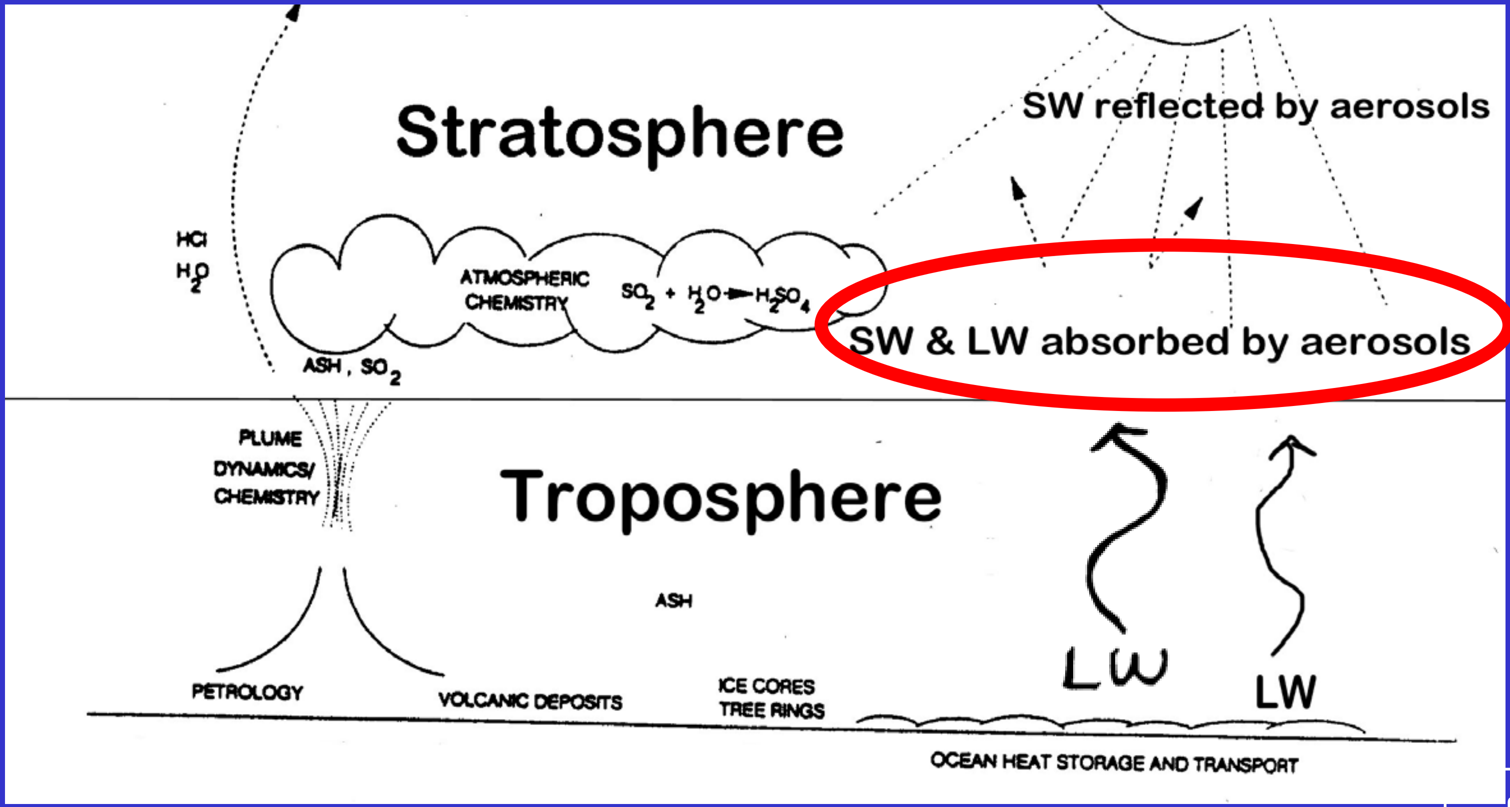
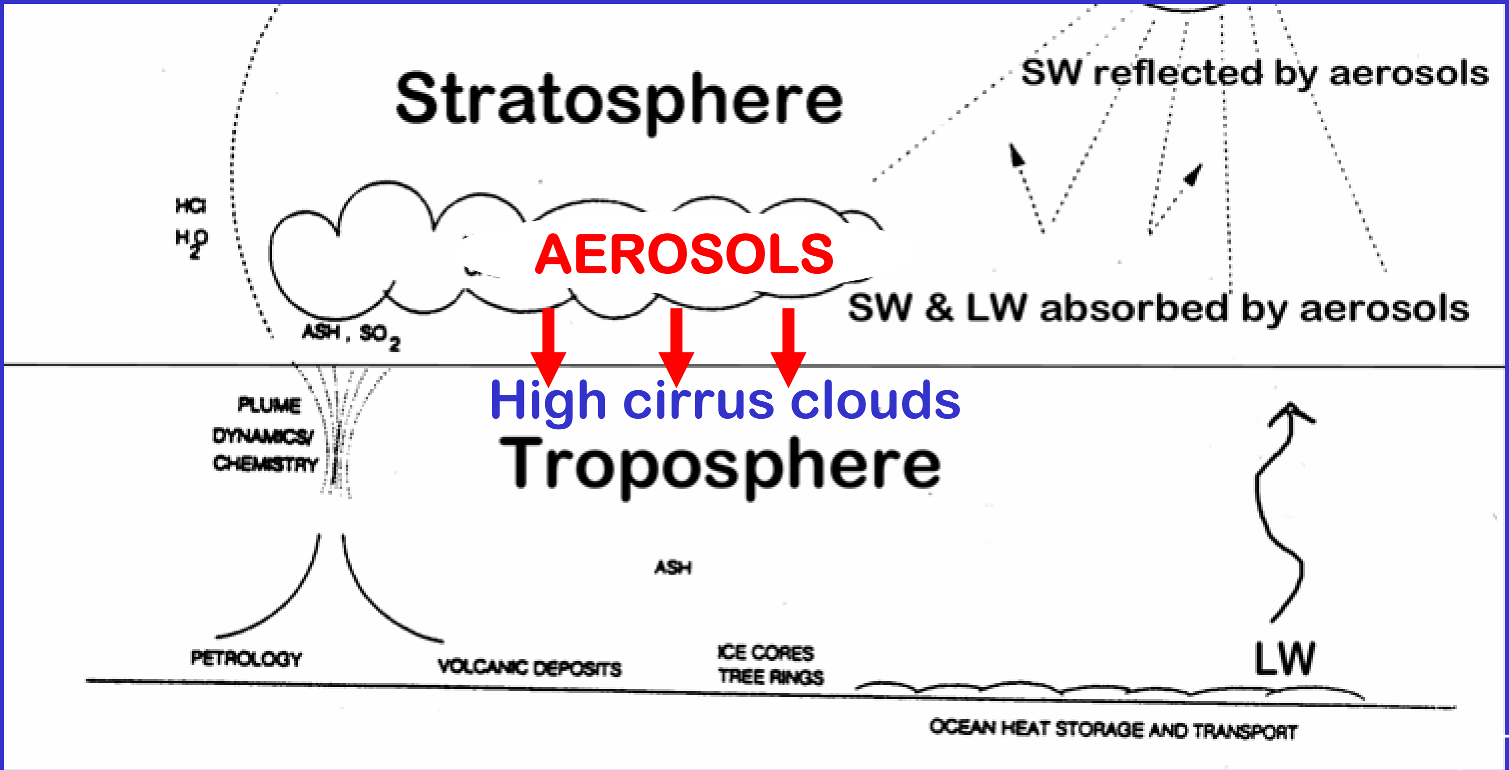
the sulfate aerosols *reflect* some of the incoming solar SW radiation back to space, cooling the troposphere below



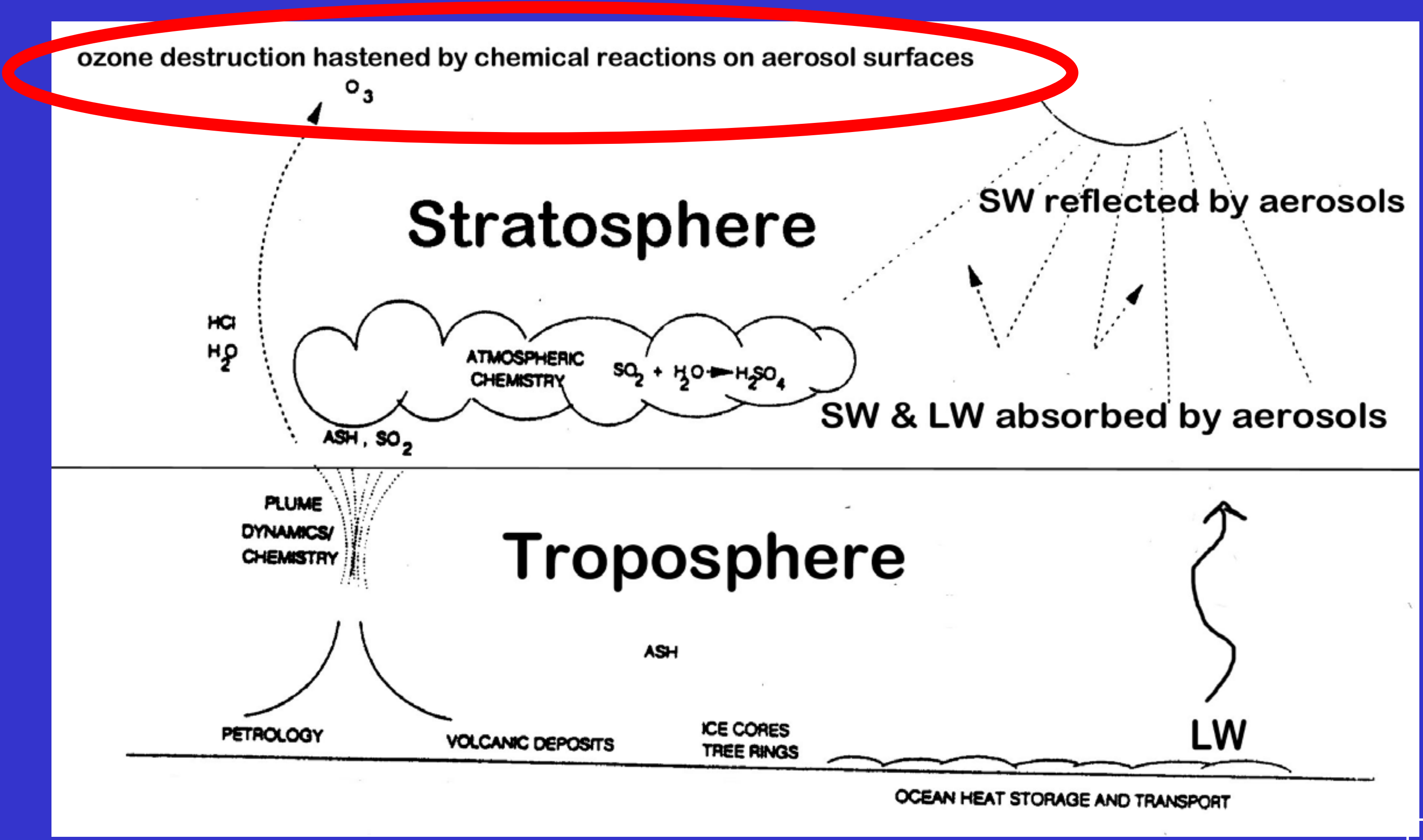
BUT - the aerosols also **ABSORB** certain wavelengths of the incoming SW radiation and some of the Earth's outgoing LW radiation, this **warms the stratosphere** (not the troposphere)



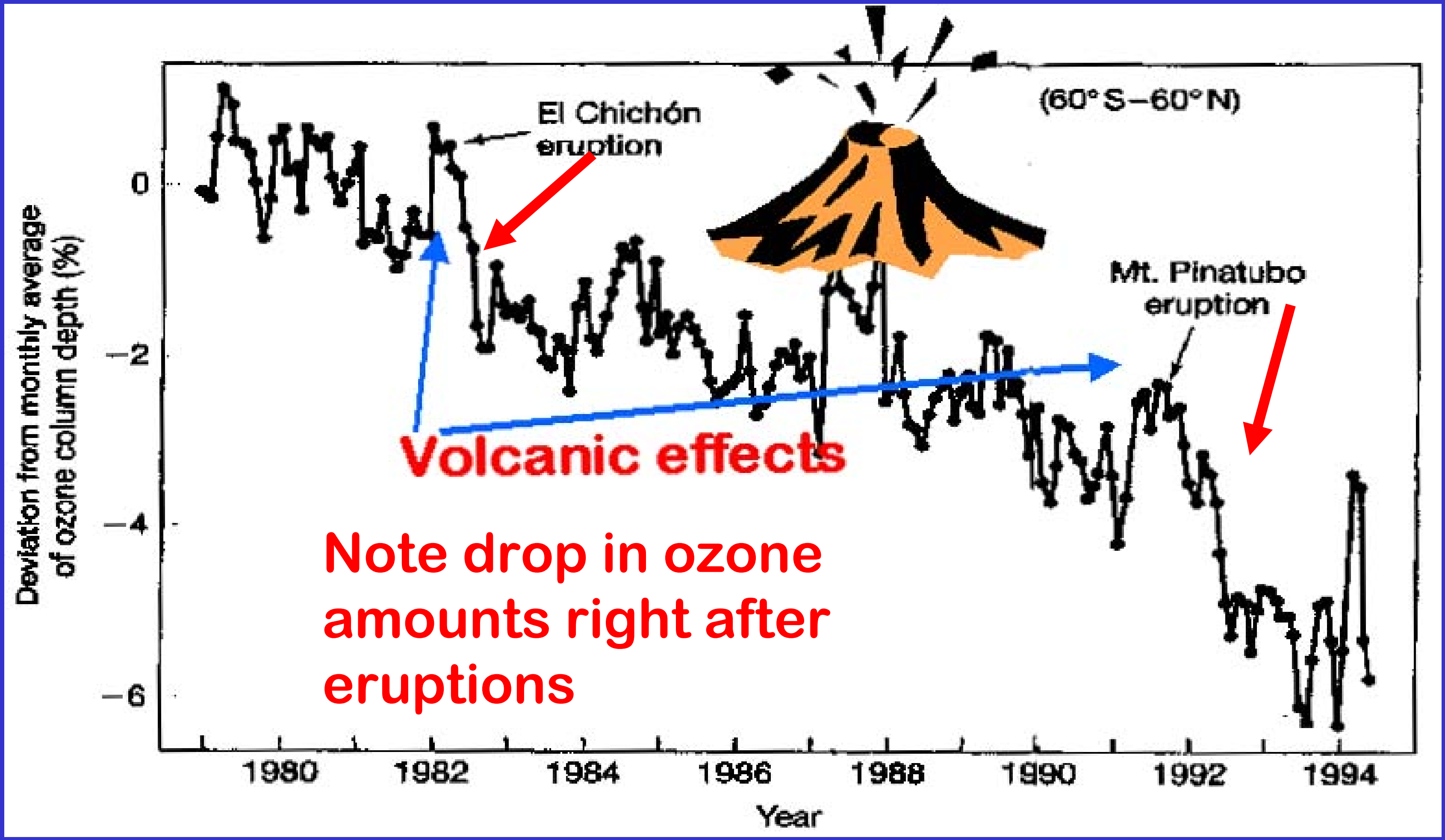
Then, as the **aerosols settle** into upper troposphere, they may serve as nuclei for **cirrus (high) clouds**, further affecting the Earth's radiation balance.



Chemical effects of the sulfate aerosol cloud can also produce responses in the climate system through OZONE destruction



OZONE & ERUPTIONS



Stratospheric ozone is destroyed by photochemical reactions that take place on the surfaces of the sulfate aerosols

- When chlorine compounds resulting from the breakup of chlorofluorocarbons (CFCs) in the stratosphere are present
- the sulfate particles change the stratospheric nitrogen balance
- which leads to increased reactive chlorine, which then reduces ozone.

The reduction in stratospheric OZONE:

- lowers (UV) absorption of the incoming solar SW in the stratosphere
- reduces the radiative heating in the lower stratosphere
- BUT the net effect is still HEATING in the stratosphere.

(This volcanic effect on ozone levels is only important in recent decades because it depends on CFCs)

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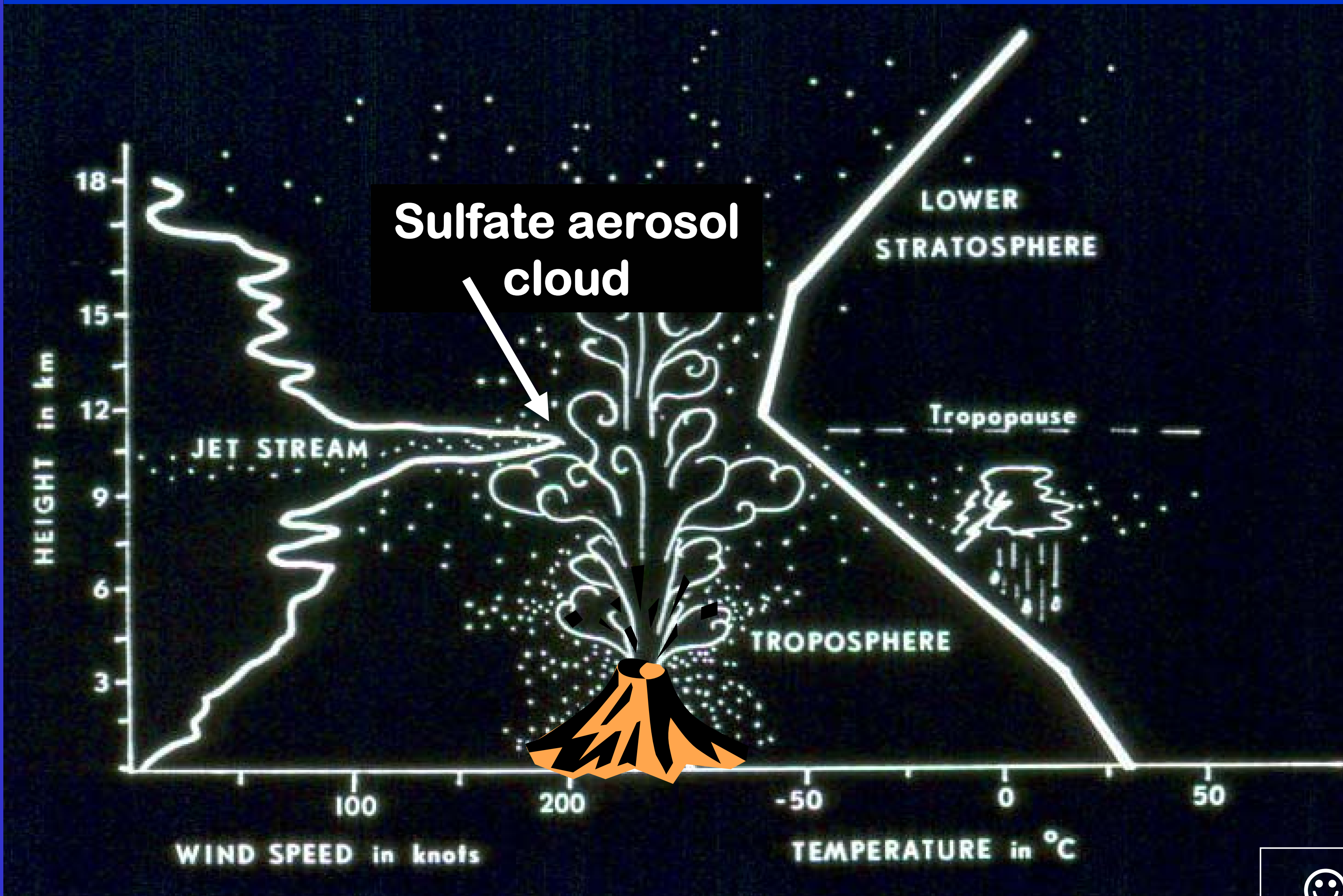
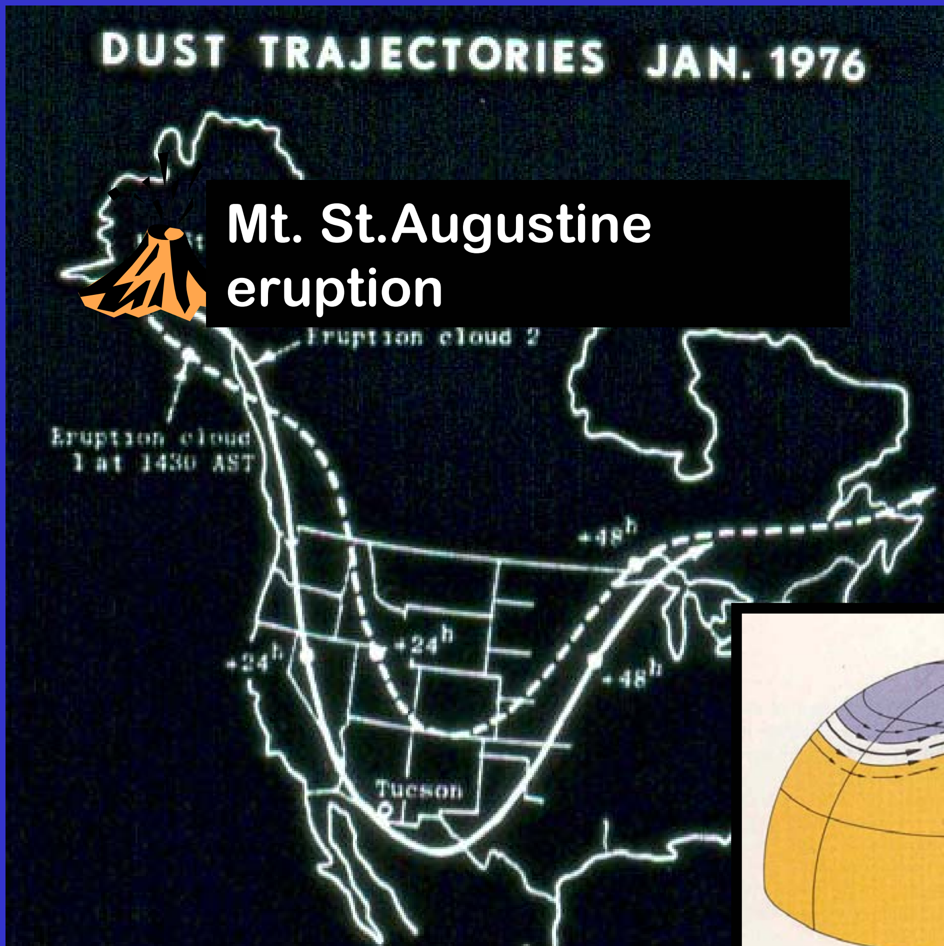
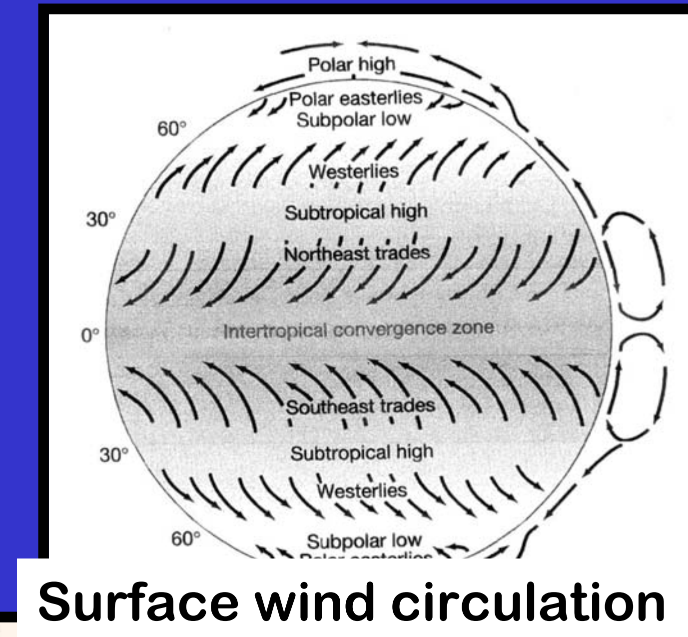
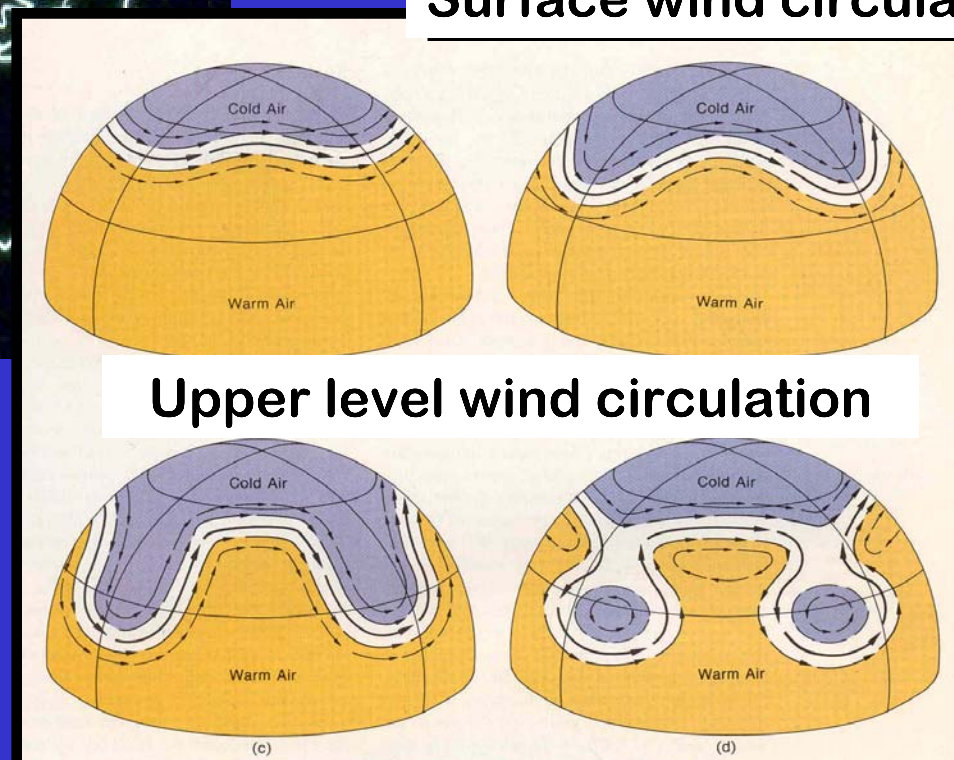
How do eruption effects become GLOBAL??





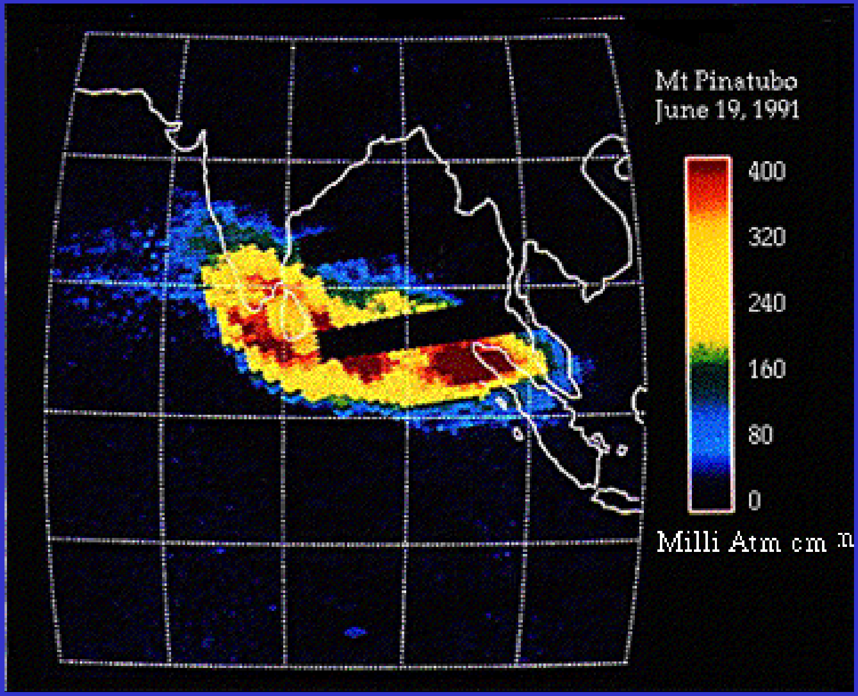




Through the atmospheric circulation!

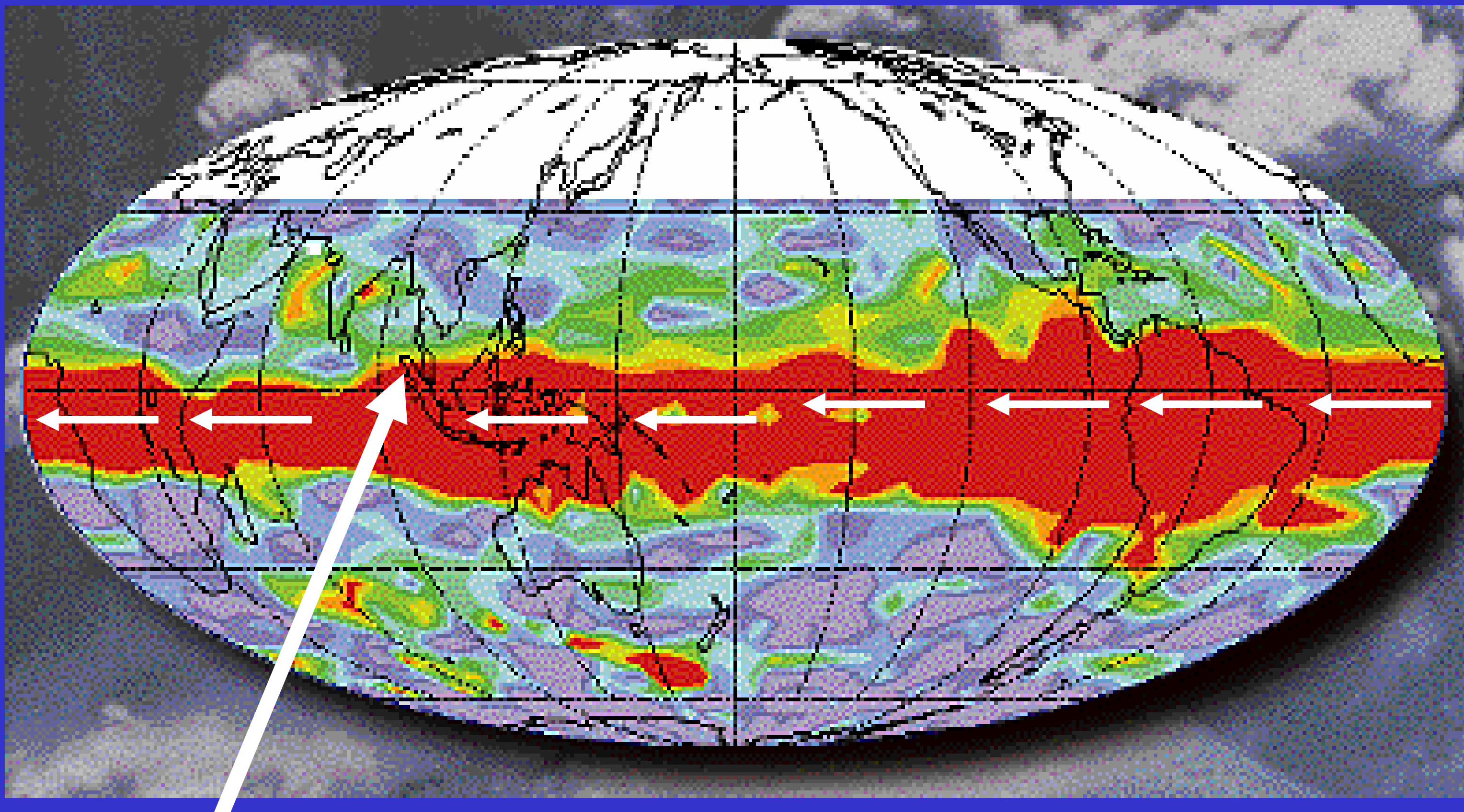
☺

Mt Pinatubo Eruption in the Philippines, June, 1991



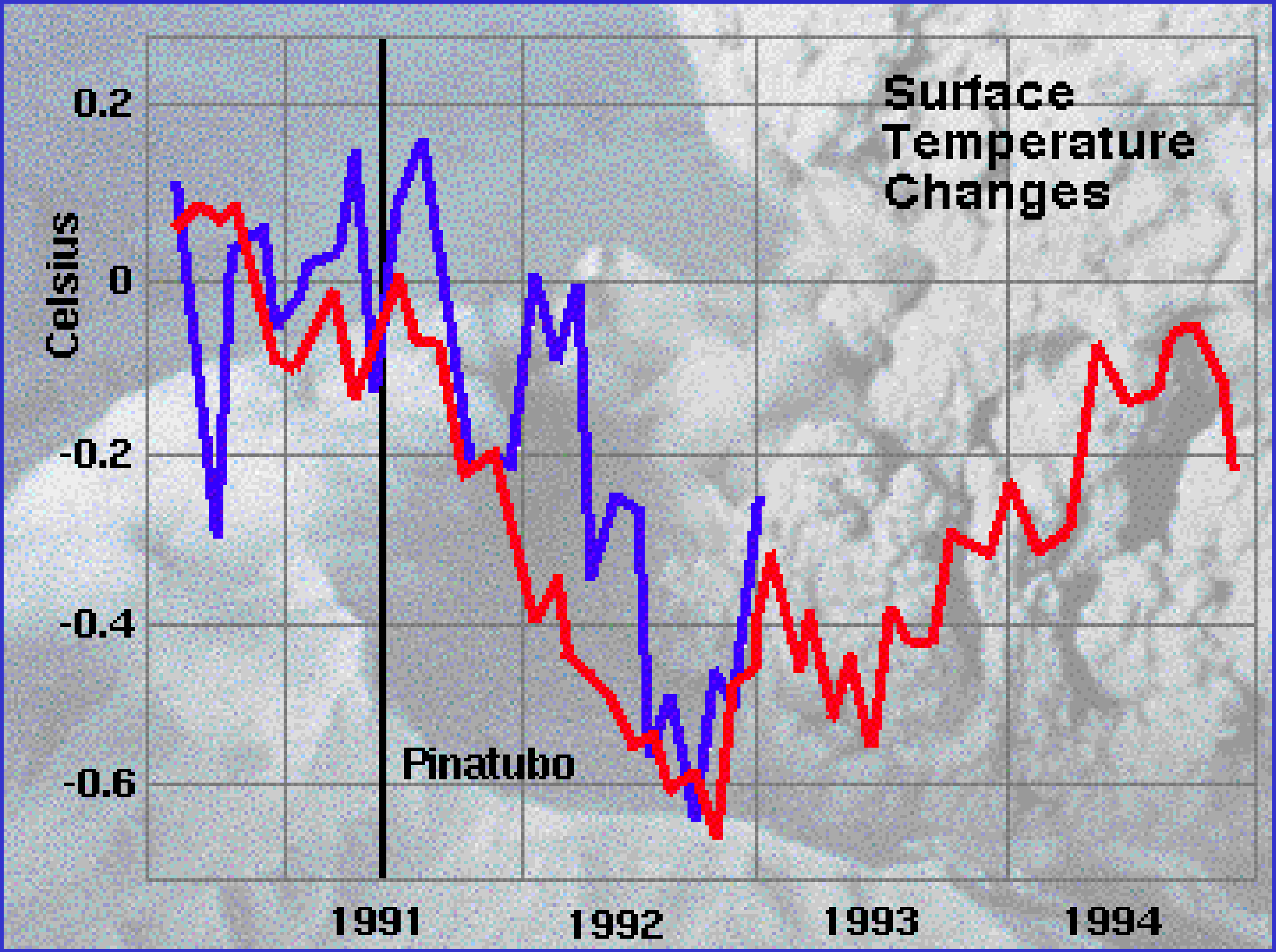
Satellite-derived image of
sulfur dioxide thickness in the atmosphere
red = higher thickness

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



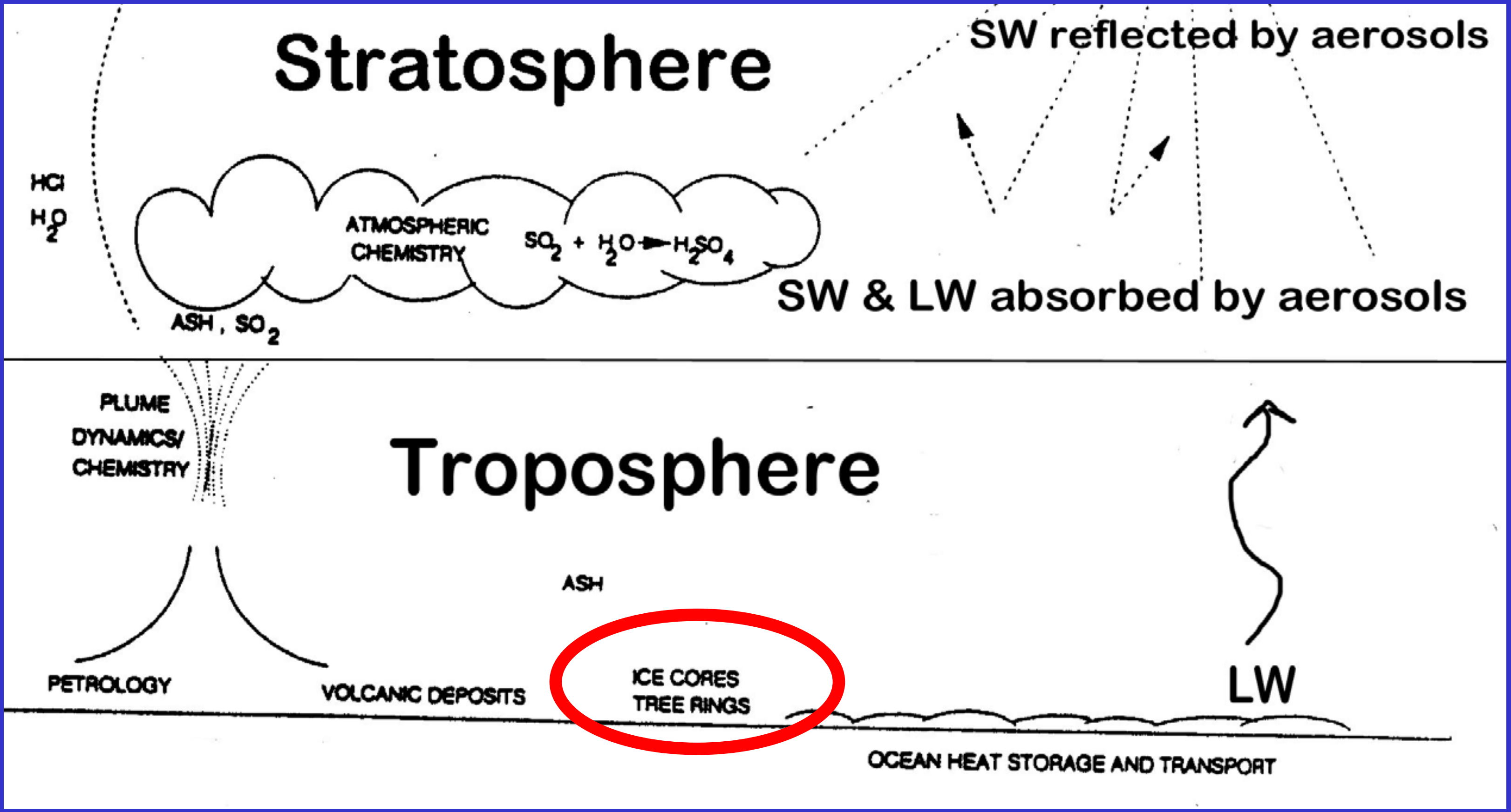
Mt Pinatubo

Mt Pinatubo eruption June 1991



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

Volcanic eruptions & their climatic effects can be recorded in ICE CORES & TREE RINGS!

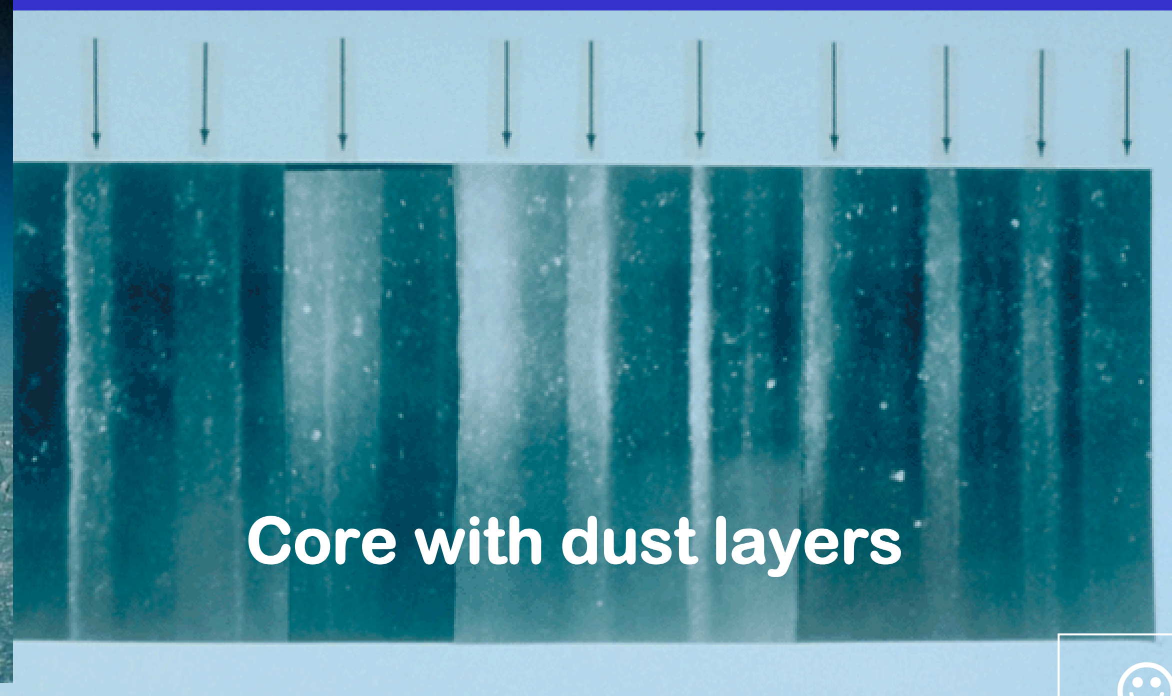


ICE CORES

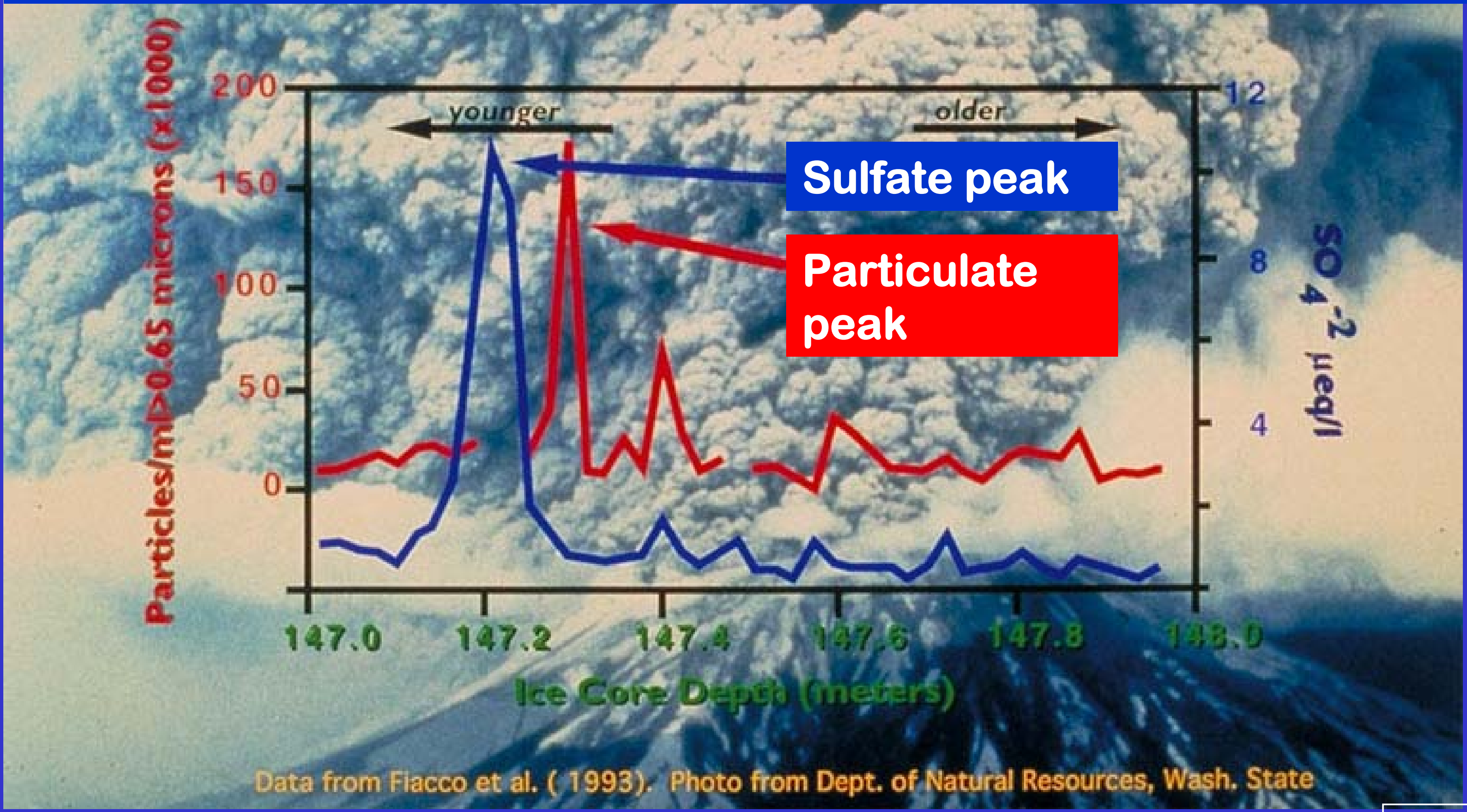

Field conditions


Examining core

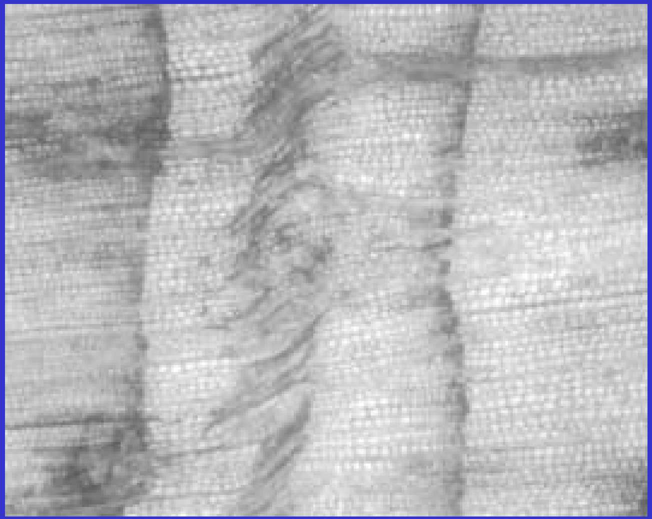

Ice core drill
dome


Core with dust layers

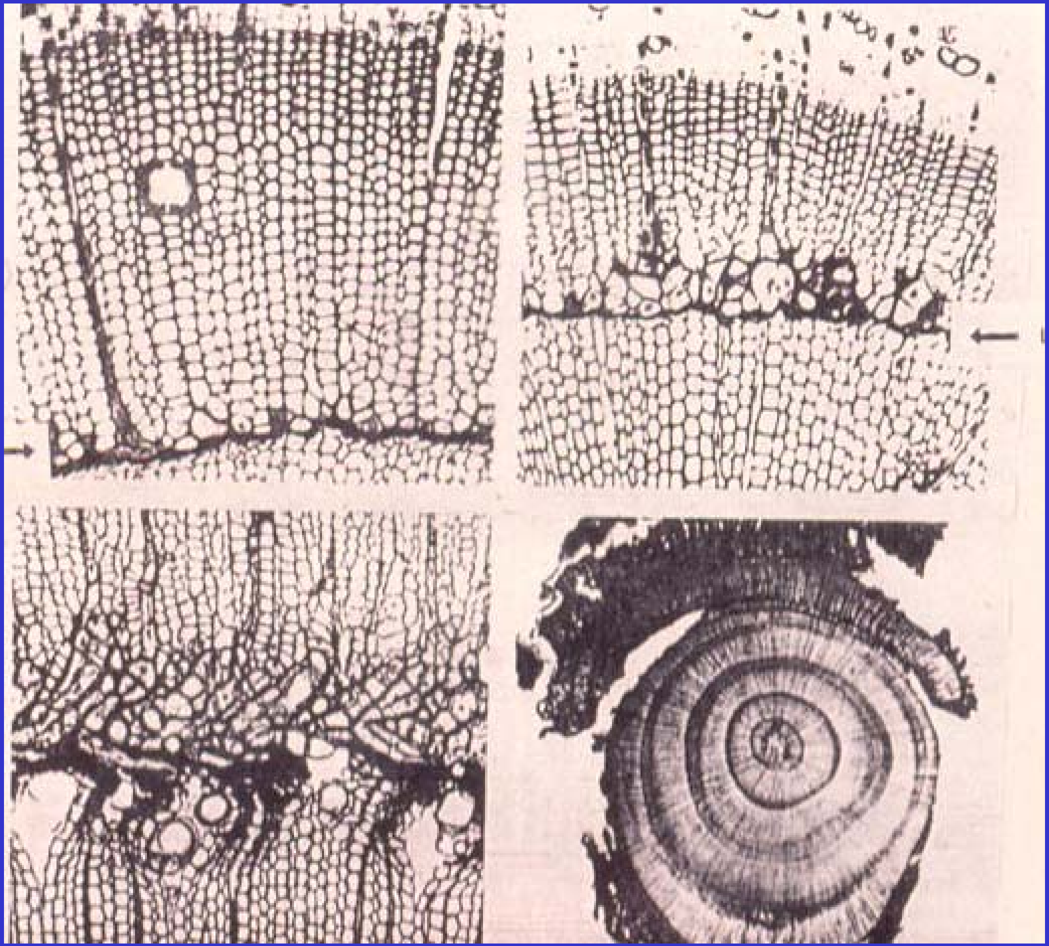
The 1479 A.D. eruption of Mount St. Helens appears as a peak in particle concentration & sulfate records in ice cores from Greenland



TREE RINGS



Eruption – Tree Ring Connection via FROST RINGS



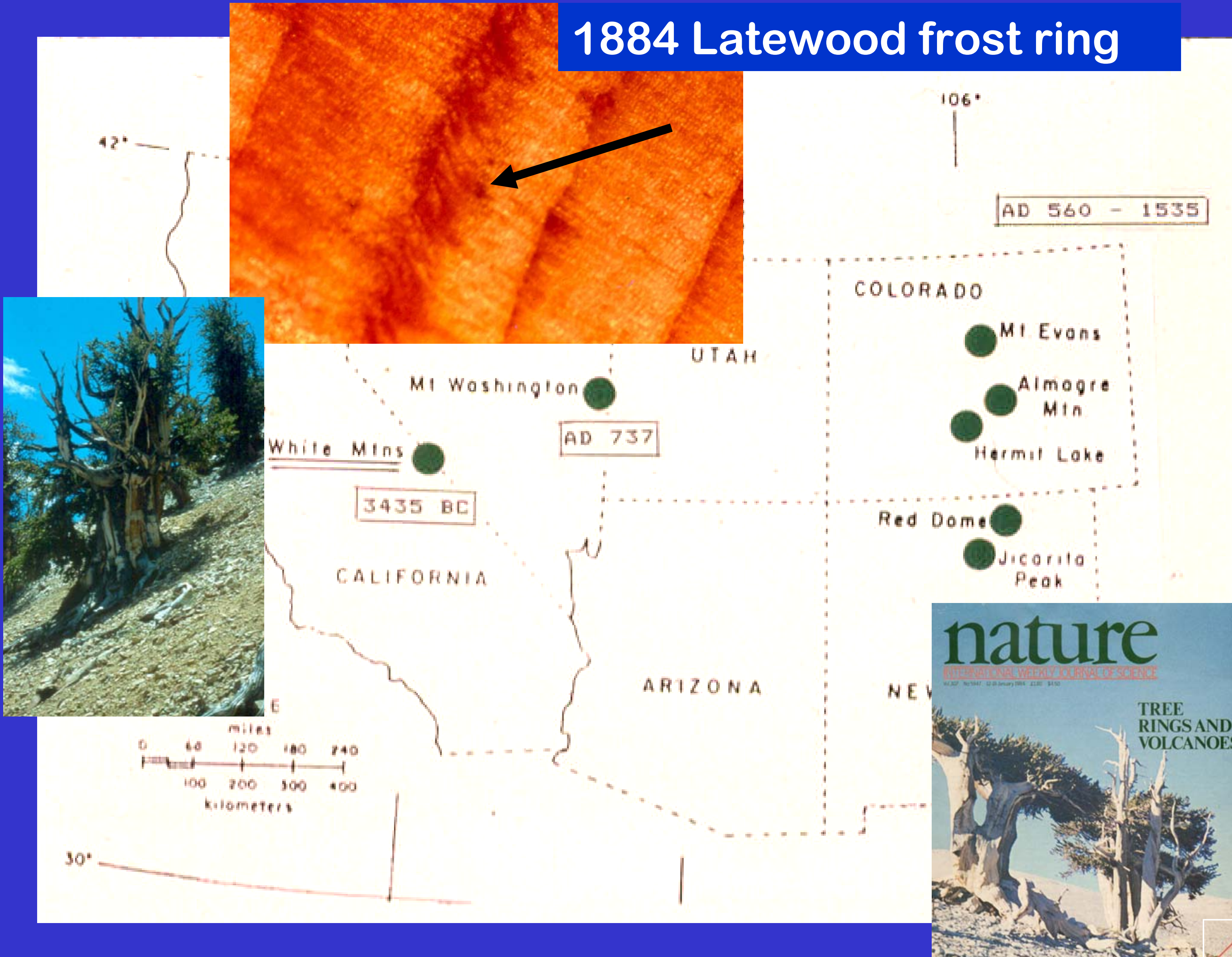
When severe freeze occurs DURING the tree's growing season ➔ "frost rings"

2 nights < - 5° C
intervening day 0° C

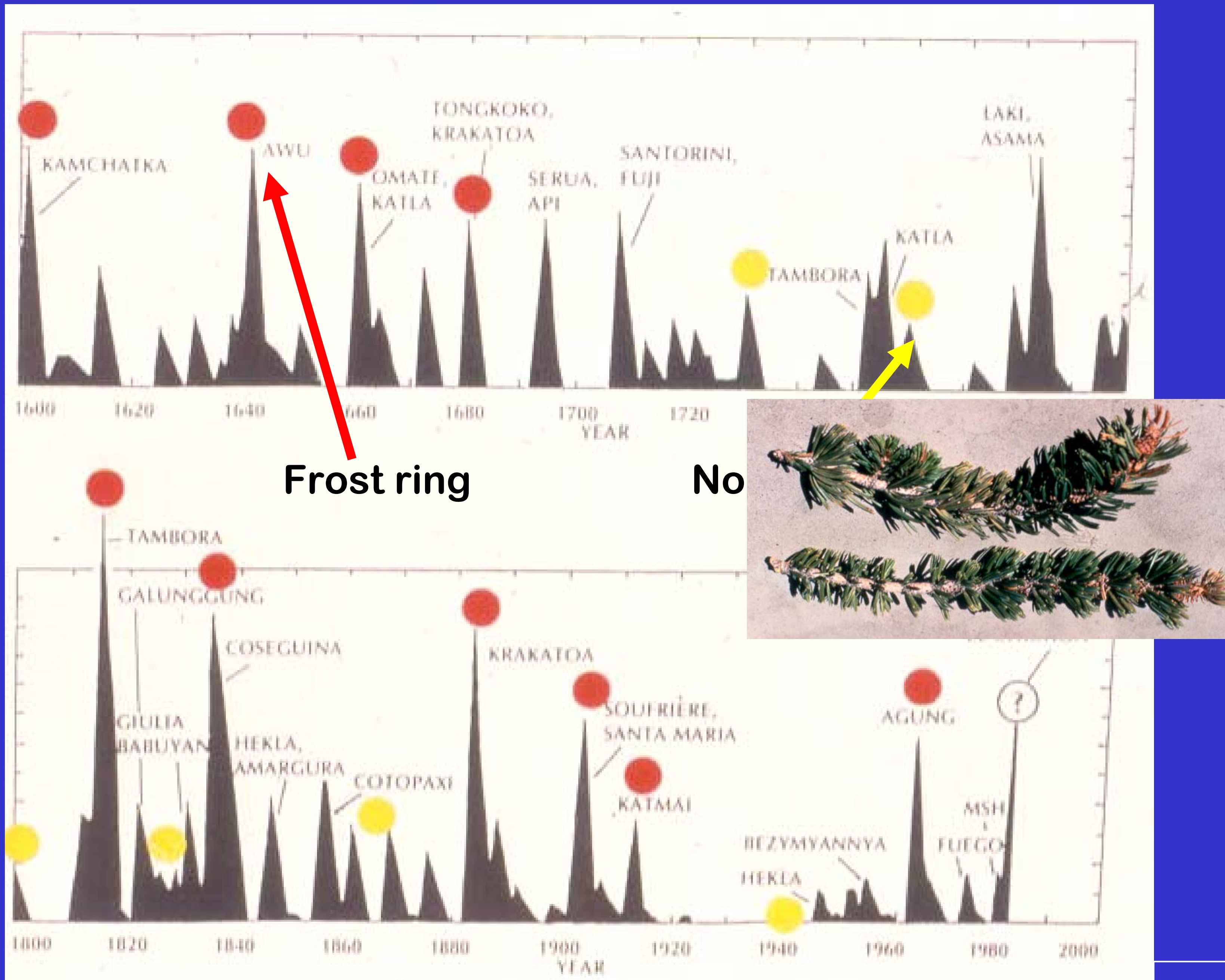
Growing season for high elevation bristlecone pines = June – Aug, continues into September during cooler years (growth slower during cool summers) makes them more susceptible to early frost

☺

1884 Latewood frost ring



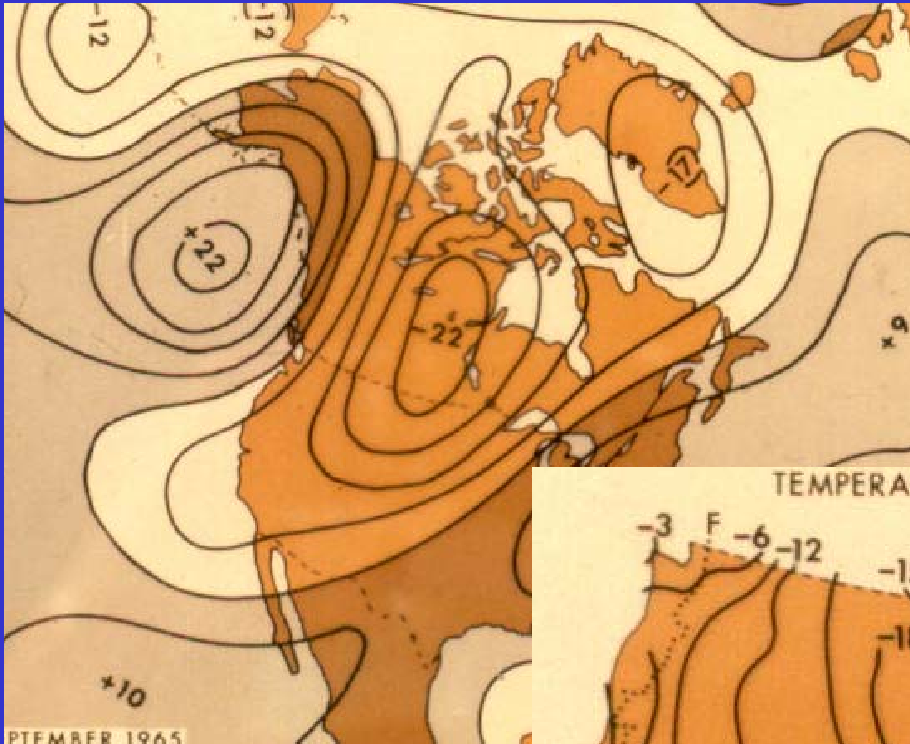
Estimate of Eruption “Dust Veil” →

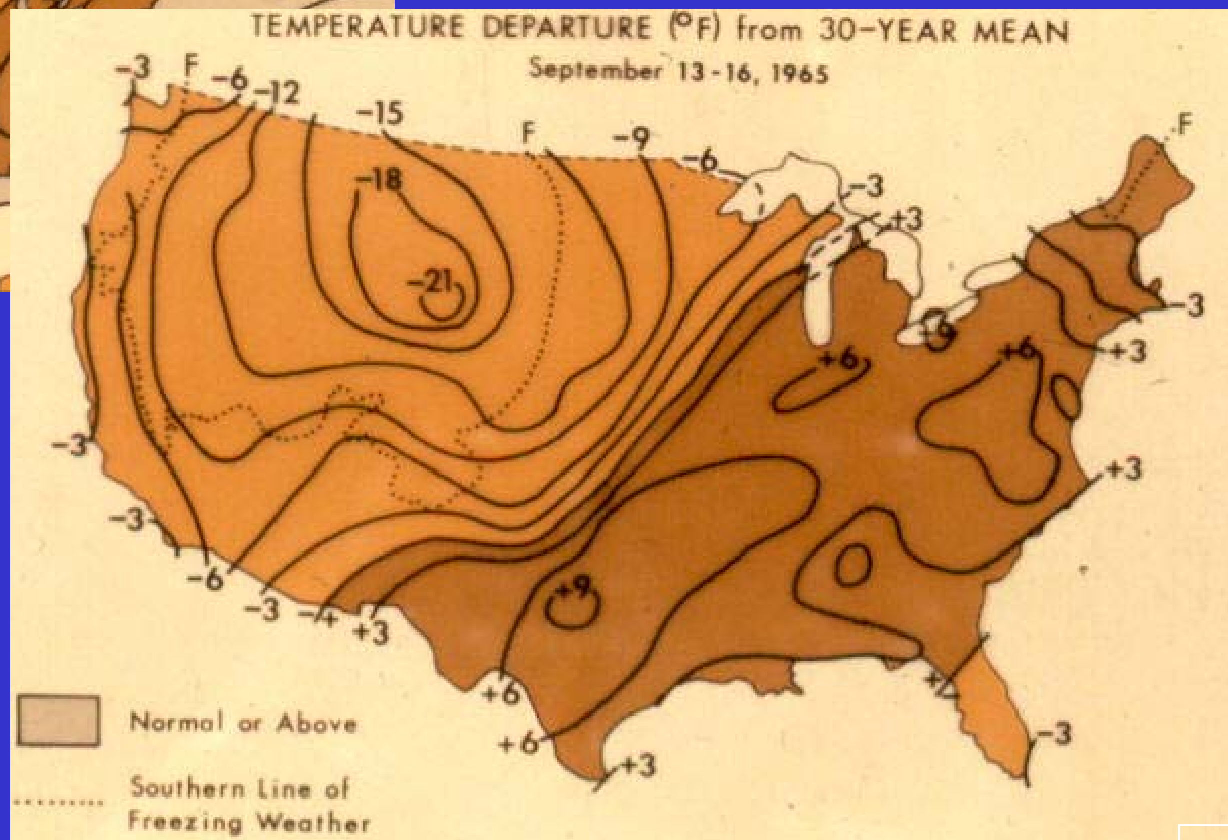


Frost ring

No

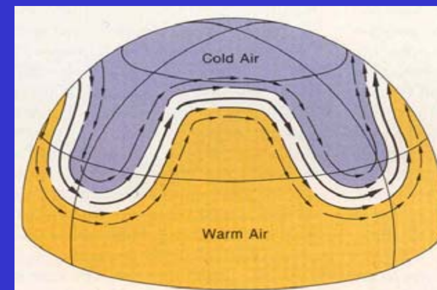
Agung eruption 1963 → frost ring response in 1965

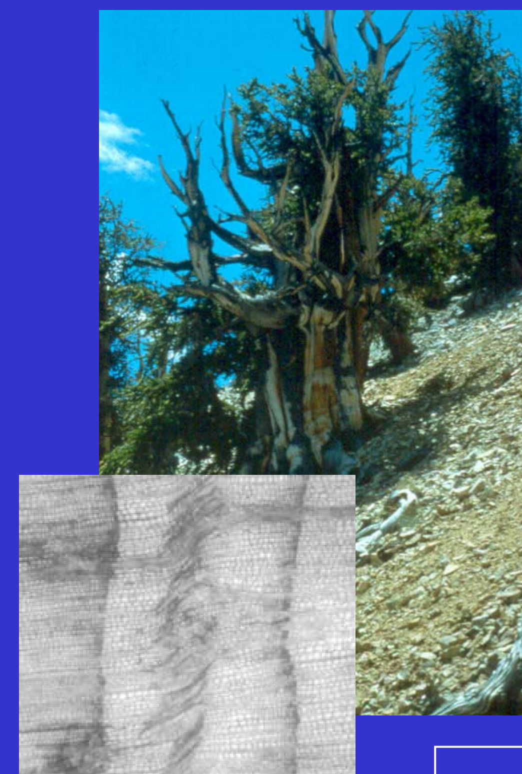




Energy Balance Effects & Global Atmospheric Circulation

+





WHICH ERUPTIONS ARE THE MOST CLIMATICALLY EFFECTIVE?

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

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Q3 Why do you think Low Latitude 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.

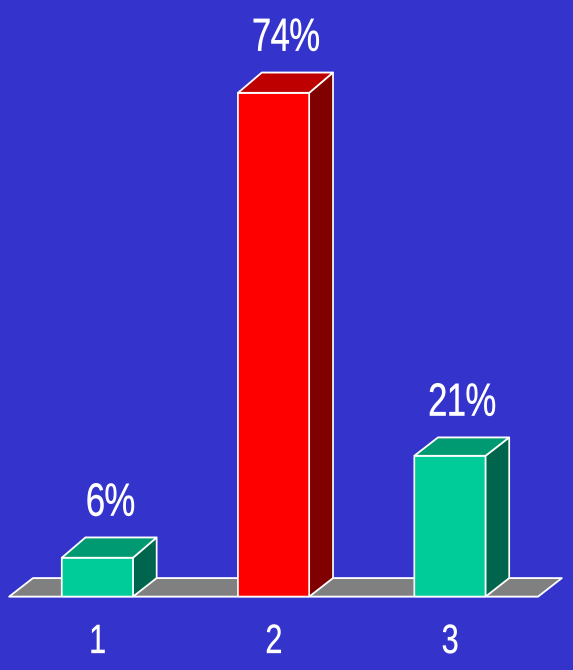
Q3 Why do you think Low Latitude eruptions are more climatically effective and have more of a effect?

BEGIN ANSWERING NOW!

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

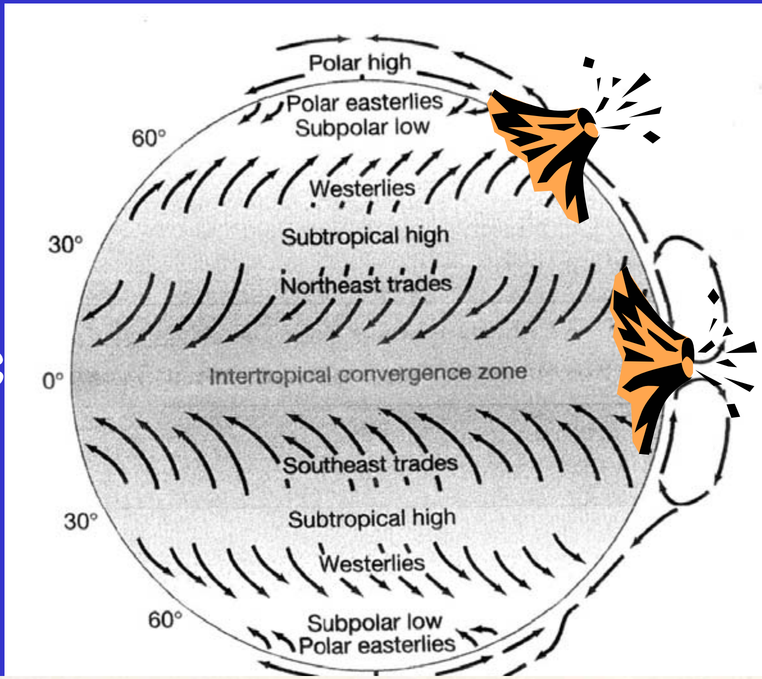
2. Because the Hadley Cell circulation can distribute the volcanic aerosols into both hemispheres if the eruption occurs near the equator.

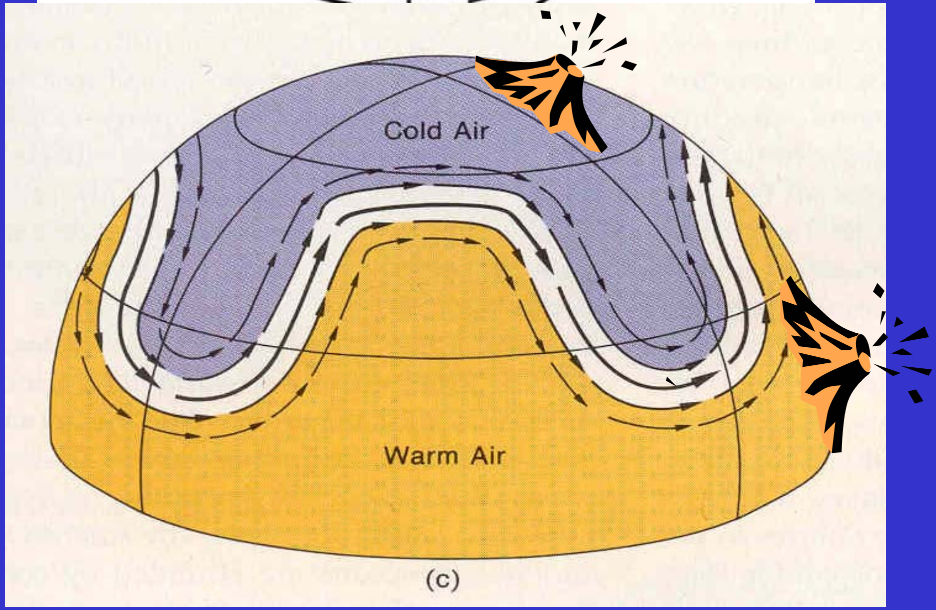
3. Because the tropopause is lower over Low Latitudes and hence its easier for aerosols to get injected into the stratosphere where they will not be rained out.



- 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 more broadly & in both hemispheres**





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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.

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Major tropical eruption:

- Stratospheric heating 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.

COOLING AFTER AN ERUPTION

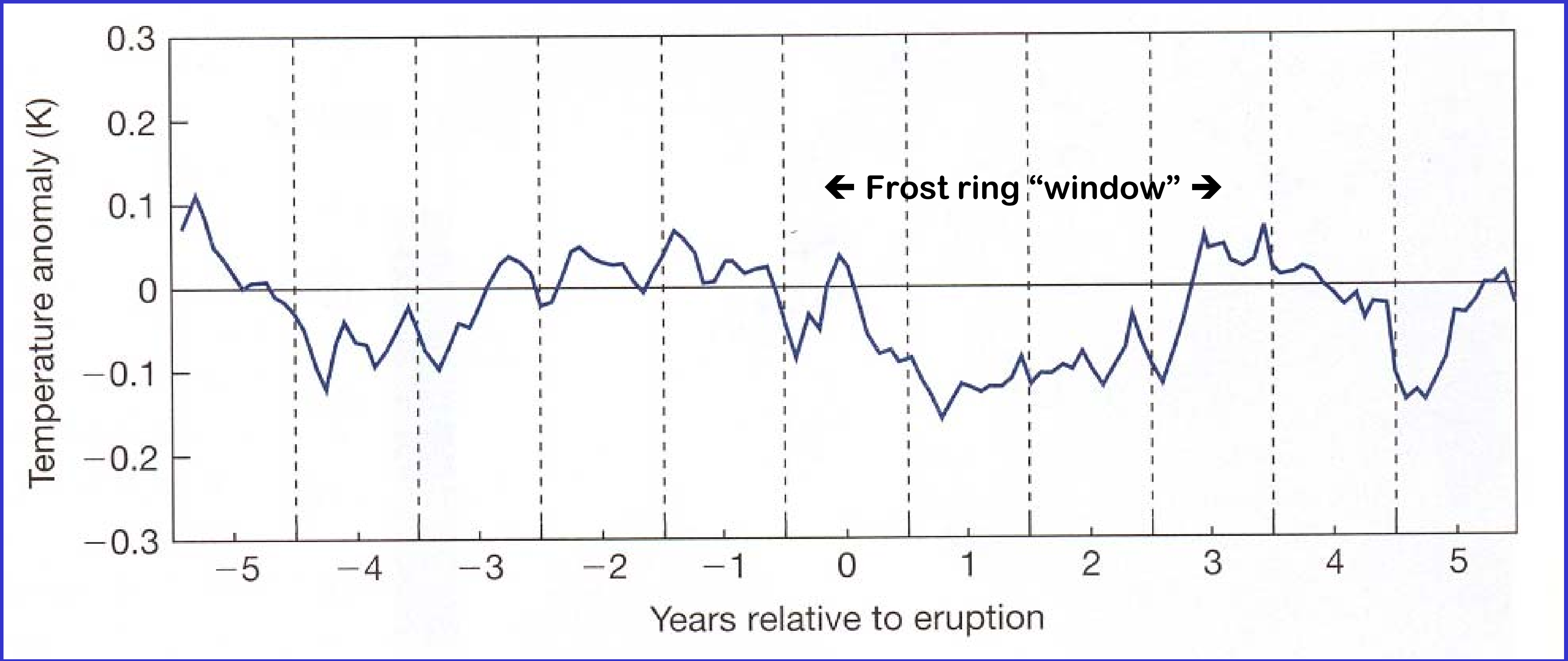
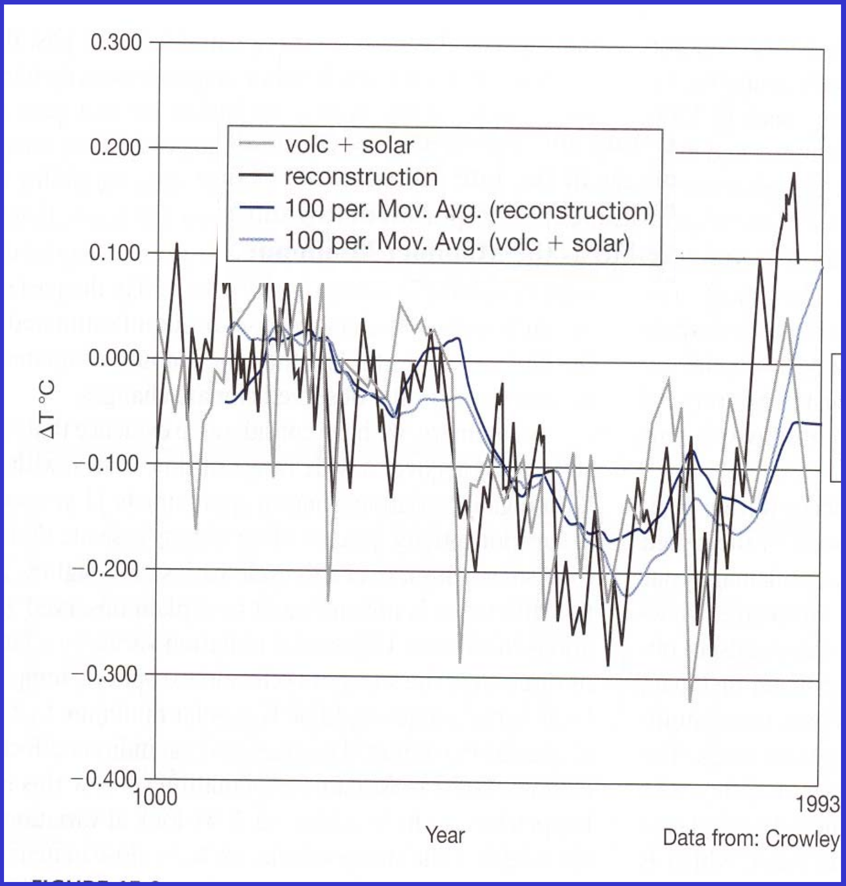


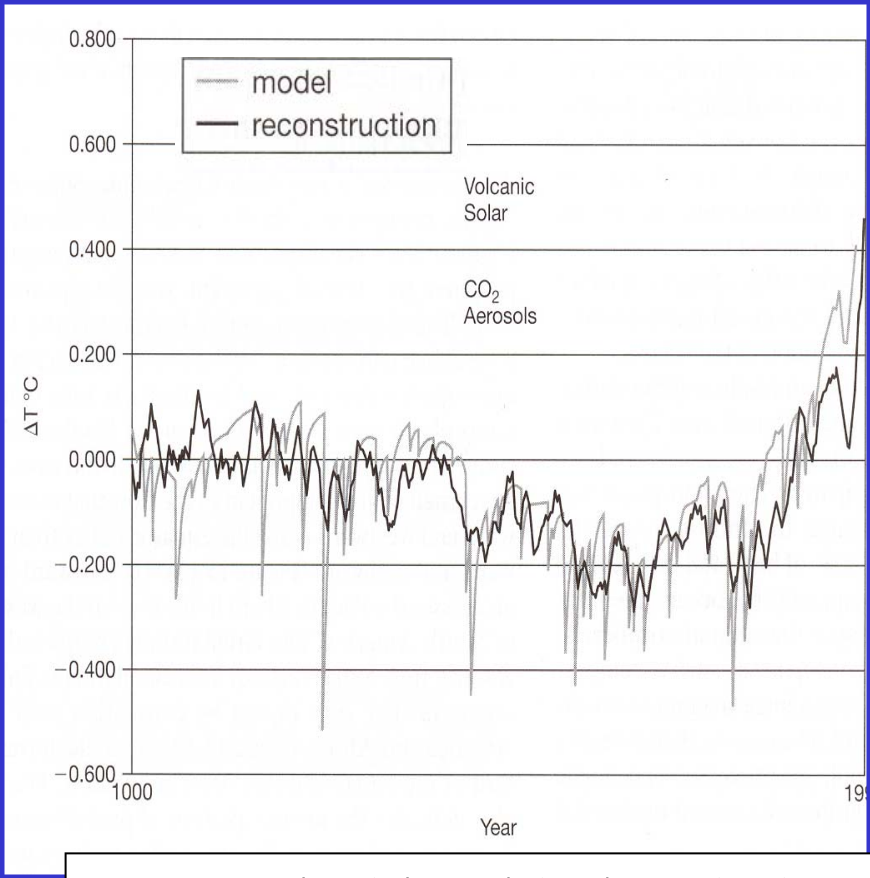
FIGURE 15-6

Cooling due to volcanic eruption: The global mean temperature changes for 5 years preceding and following a large volcanic eruption (at year zero). The temperatures are the average changes noted for five major eruptions: Krakatau, August 1883; Santa Maria, October 1902; Katmai, June 1919; Agung, March 1963; and El Chichón, April 1982. The effects of ENSO (discussed later in this chapter) on temperatures have been removed. (After A. Robock and J. Mao, 1995. The Volcanic Signal in Surface Temperature Observations. *Journal of Climate*, 8:1086–1103.)

1000-YEAR RECONSTRUCTION OF NORTHERN HEMISPHERE TEMPERATURES w/ MODELING RESULTS OF AN ENERGY BALANCE MODEL FORCED IN DIFFERENT WAYS



Forced with orbital variations & volcanic eruptions



Forced with orbital variations, volcanic eruptions, & greenhouse gas concentrations

GROUP ASSIGNMENT G-6

ACTIVITY ON VOLCANISM & CLIMATE

Same as pp 109-110 in CLASS NOTES

DIRECTIONS: Split into two small subgroups – one G-6 handout for each, work in pairs or in your subgroup . . . filling in the answers on pp 109 -110 in you NOTES packet, then transfer the best answers to the SUBGROUP FORM & sign your names.

Comparison Table of Eruptions

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

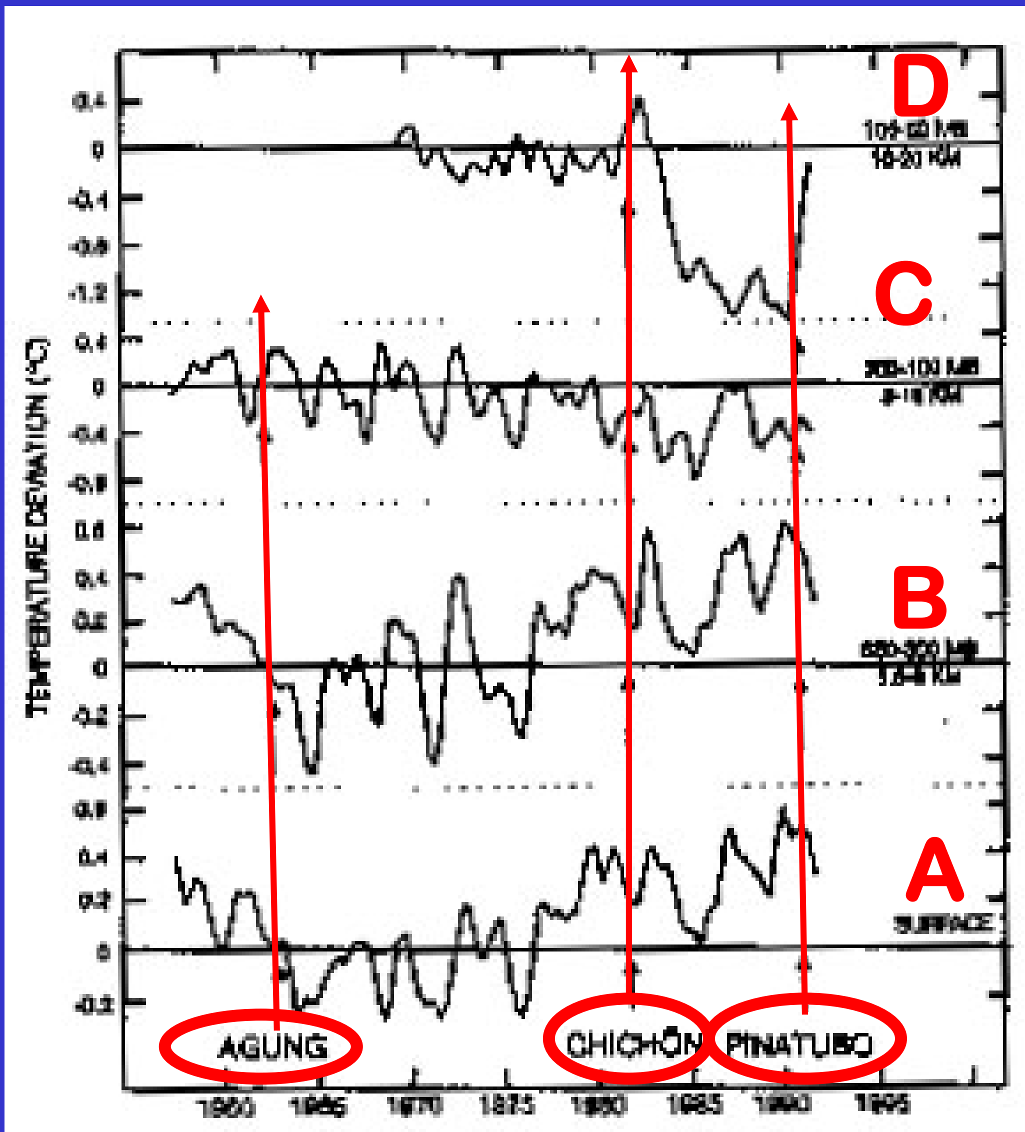
Latitude

How much magma → how big an eruption

How much aerosol got into each hemisphere

Sulfur-rich if high H_2SO_4

Which levels show a COOLING & which show a warming?



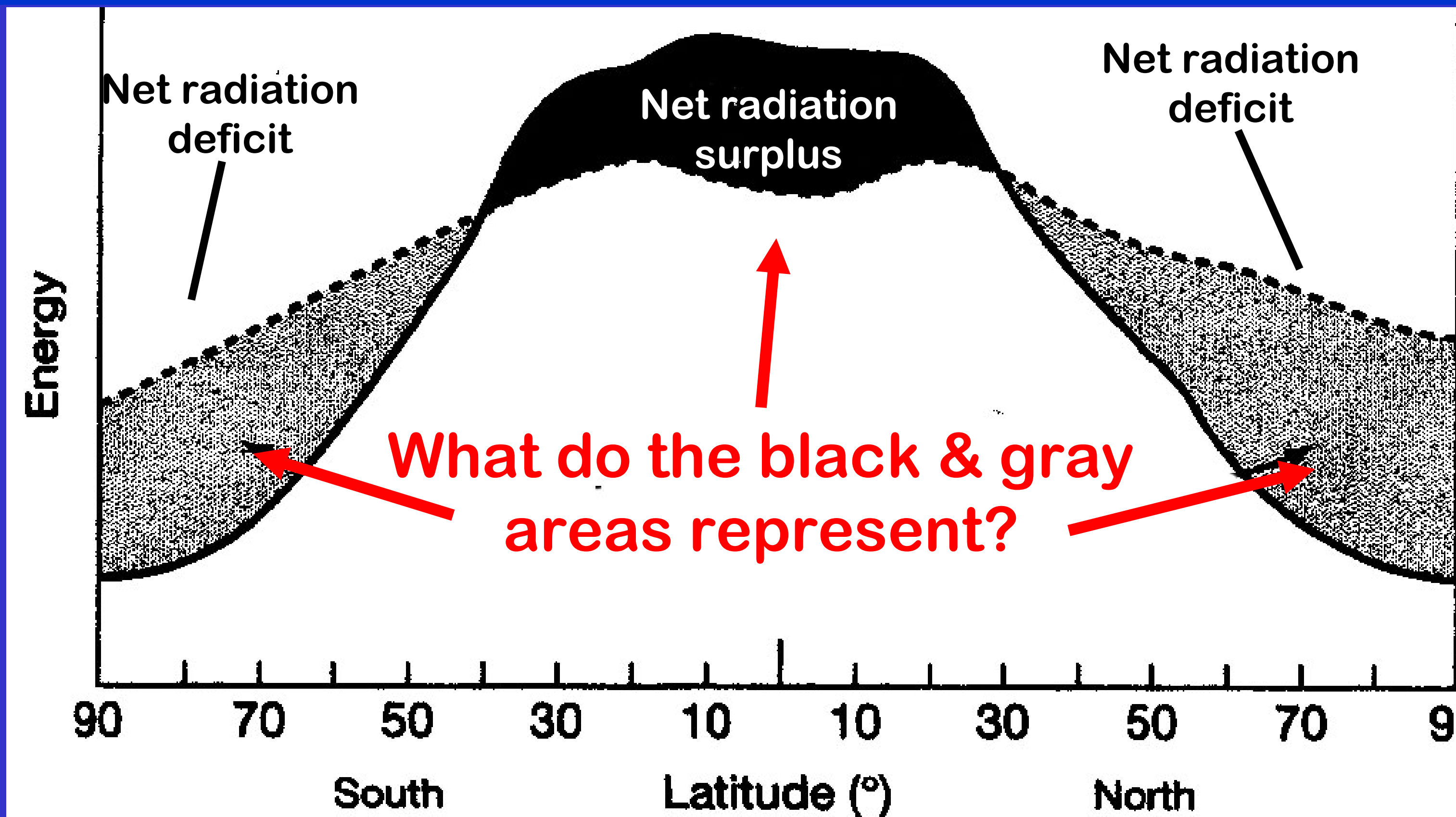
D - Lower Stratosphere

C – Tropopause level

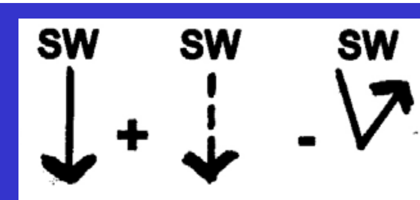
B - Mid-troposphere

A -Earth’s surface

REMEMBER THIS IMPORTANT GRAPH?



——————— Absorbed solar energy

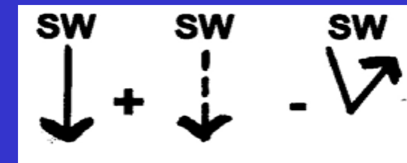


- - - - - - - - - - - - Emitted infrared energy

(at top of atmosphere)

A = incoming SW (solar) radiation

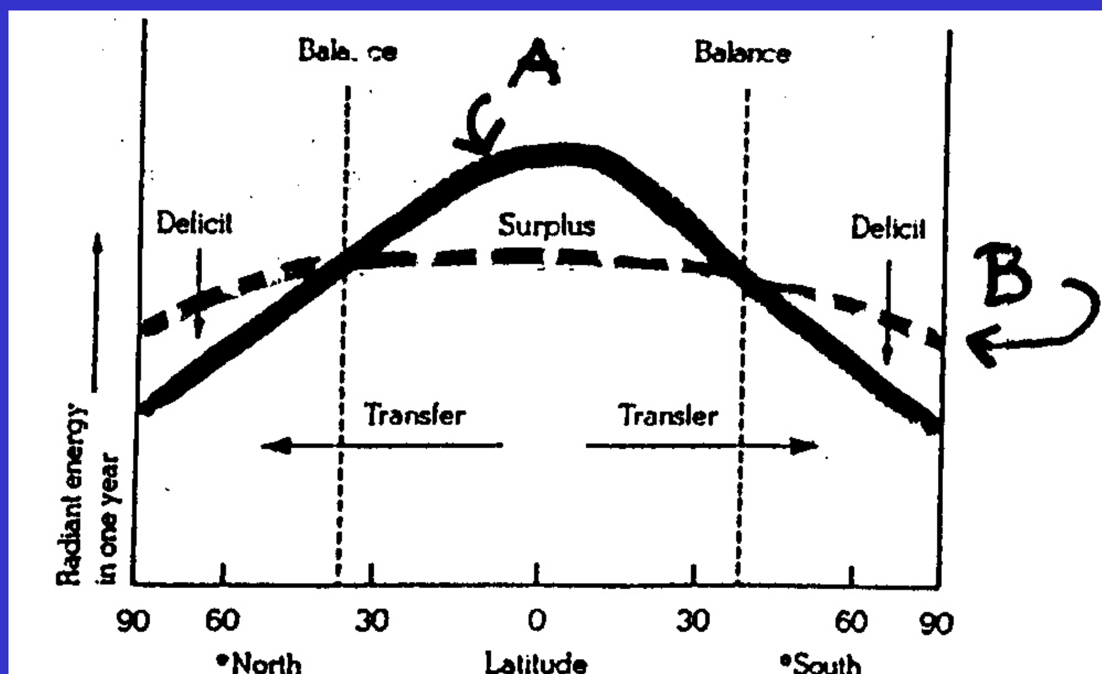
——————— Absorbed solar energy



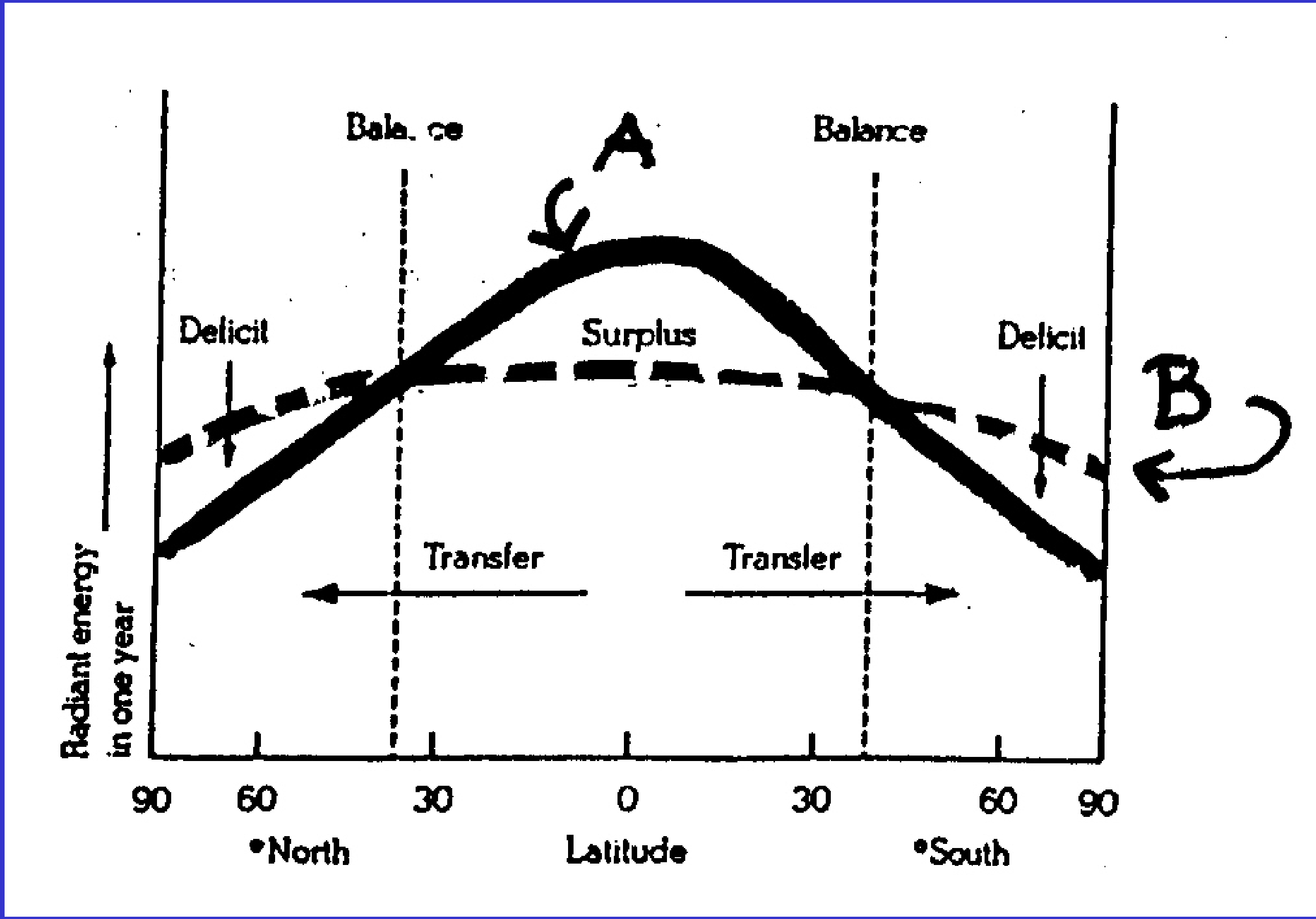
B = outgoing LW (terrestrial) radiation

- - - - - - - - - - - - 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 .



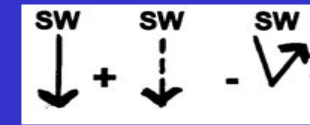
Assume:

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

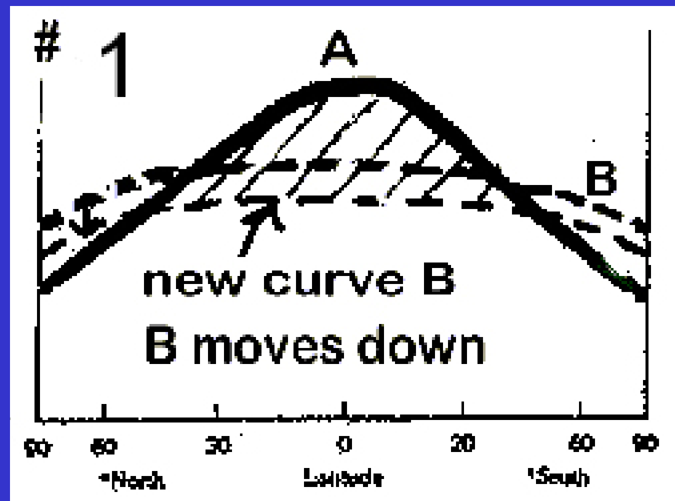
- **that this veil reflects large amounts of incoming solar radiation back to space *before* it enters the troposphere’s earth-atmosphere system shown in the graph.**

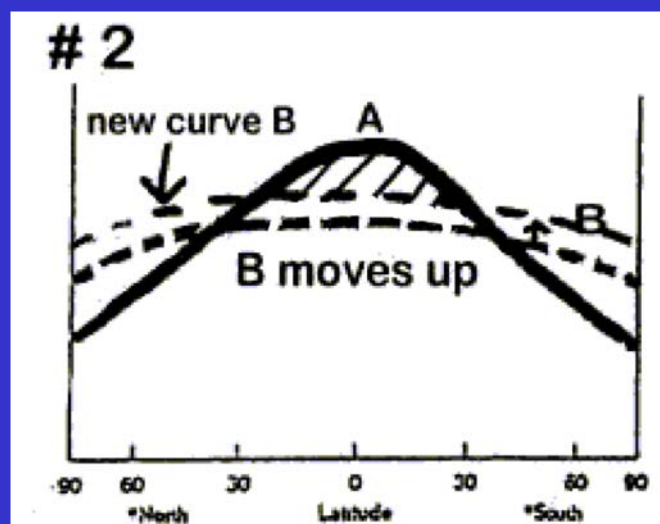
- ***Hint: you do not need to worry about stratospheric warming for this question.***

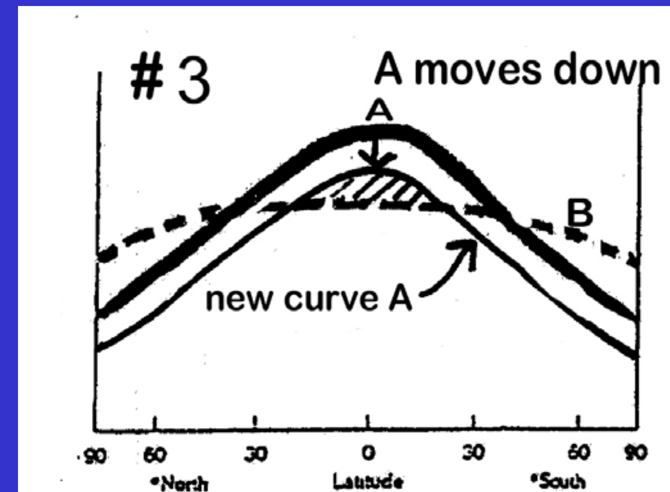
IF CURVE B is affected: 

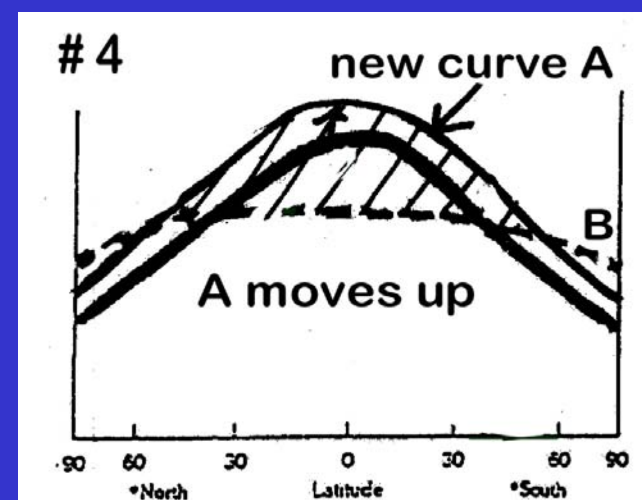
If CURVE A is affected: 

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









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

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

. . . We ran out of time, so the G-6 Assignment will take place before or after Test #3 on Thursday.