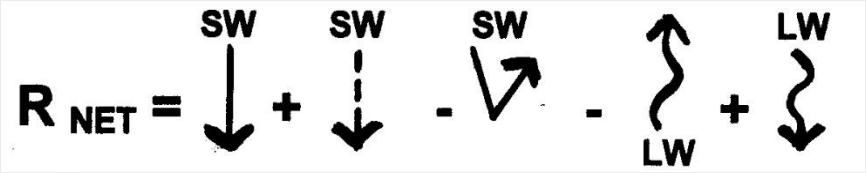
WRAP UP
of
PREVIOUS TOPICS . . . .

G-5
APPLYING THE ENERGY BALANCE ANSWERS

p 58

The LEFT side of the equation:

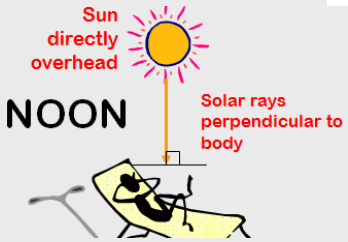


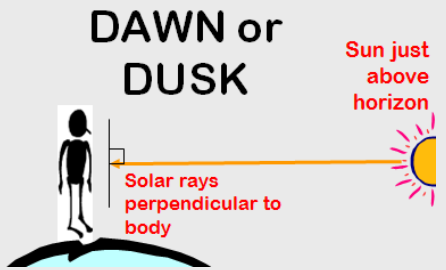
1. SW gases of atmosphere scatter shorter blue wavelengths

2. SW

3. SW

4. Noon: more SW & dusk: more SW





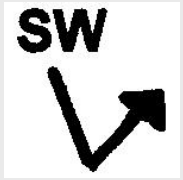
5. LW + LW together = the Greenhouse Effect

6. 

(dust, thicker atmosphere scatters longer red/orange wavelengths)

7. 

radiates day & night; camera senses IR

8. 

9. 

leads to distinct shadows, while diffuse SW 

radiation does not

10. 

All wavelengths of visible part of spectrum are scattered & transmitted in a colored spectrum by raindrops

11. Attempt to increase absorption & reduce 

into eyes; reduces glare

12. More 

is absorbed, leads to more 

which can then warm up car

The RIGHT Side of the Equation:

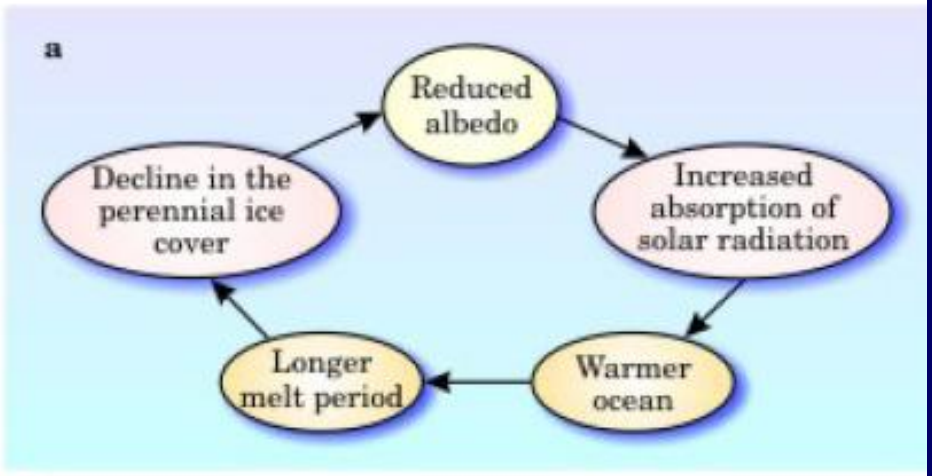
= H + LE + G

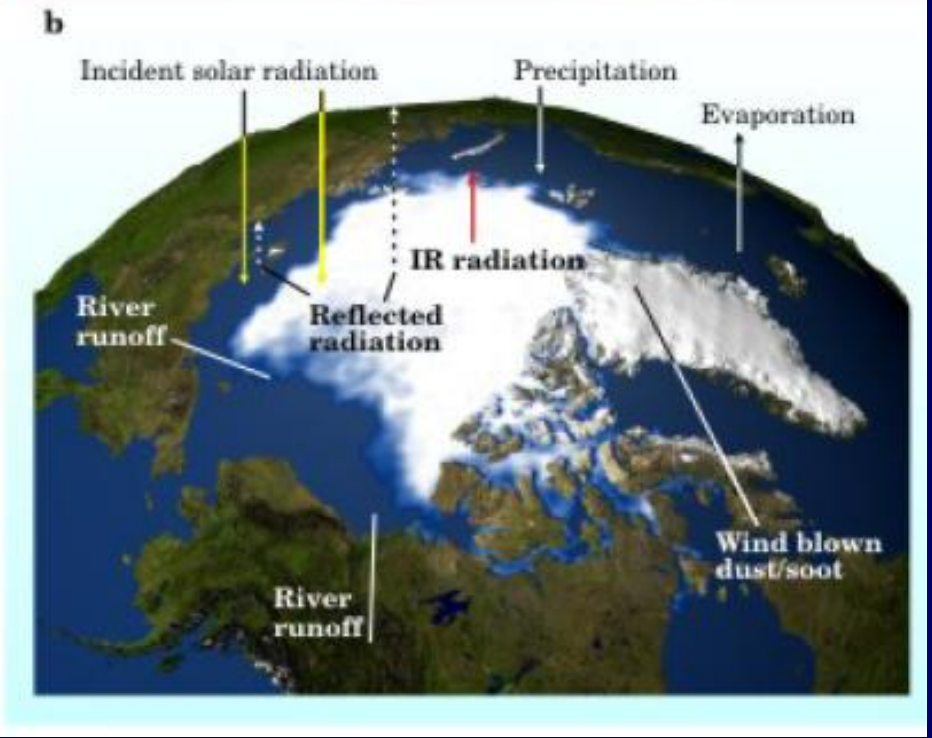
13. H Hot air (less dense than surrounding cool air) rises in a convection current & lifts balloon

14. Wet mud evaporates from pig & cools him: LE
also heat from pig's body is conducted into soil: G

15. June is hot & dry in Tucson. Dry, hot air can "hold" more water vapor, so water in cooler pads is evaporated easily. Hence more energy goes into LE instead of H This cools the house!

REMEMBER FEEDBACK LOOPS:
Is this one positive or negative?





BONUS POINT CHALLENGE WRAP UP

NOW – on the back of the paper, in your group, complete the feedback loop on page 65 by linking the components with the proper coupling arrow symbols as used in the SGC text

p 65

albedo

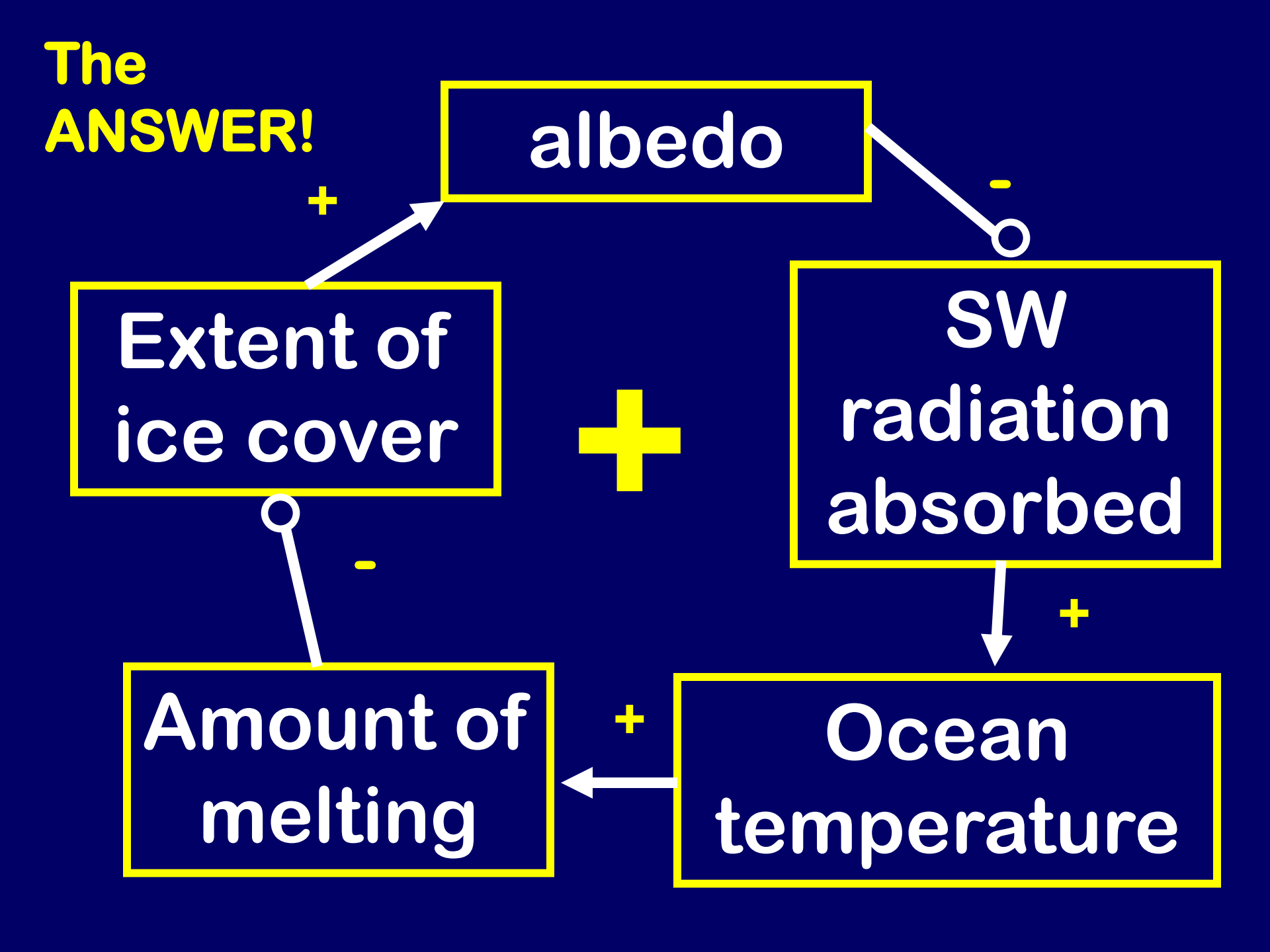
START HERE

Extent of ice cover

SW radiation absorbed

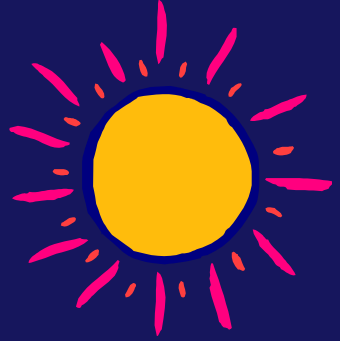
Amount of melting

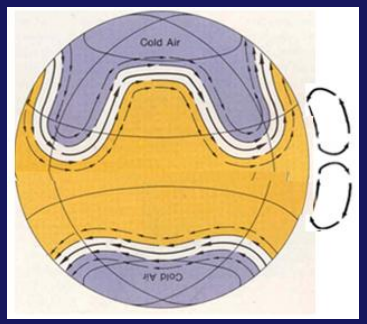
Ocean temperature


The ANSWER!
albedo
+
-
Extent of ice cover
SW radiation absorbed
+
-
+
Amount of melting
+
Ocean temperature

TOPIC #12

Wrap Up on GLOBAL CLIMATE PATTERNS





SW + SW - SW - LW + LW = R_{NET} = H + LE + G

Ultimate source of energy is the SUN (SW)

LW energy is radiated in & out by EARTH & Atmosphere

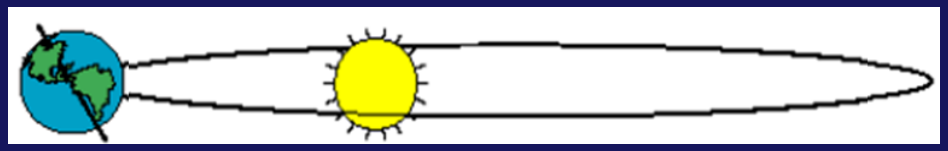
Any NET (leftover) energy

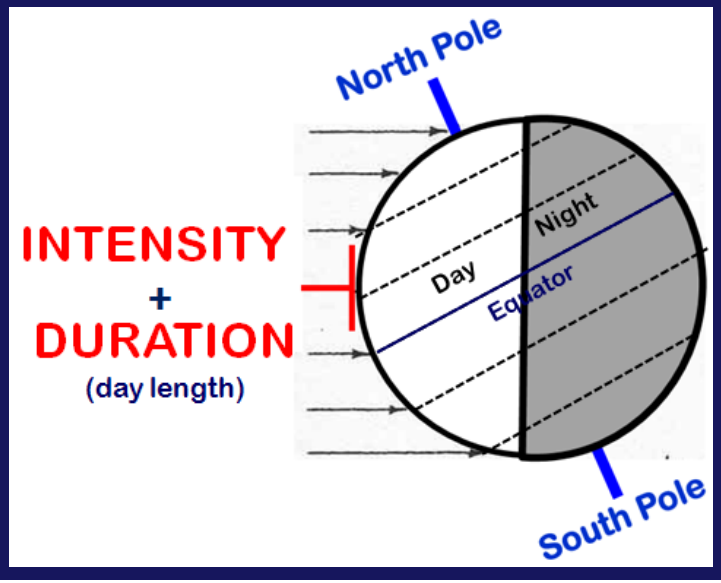
Goes into the HEAT TRANSFER processes that drive **WEATHER & CLIMATE !**

Review

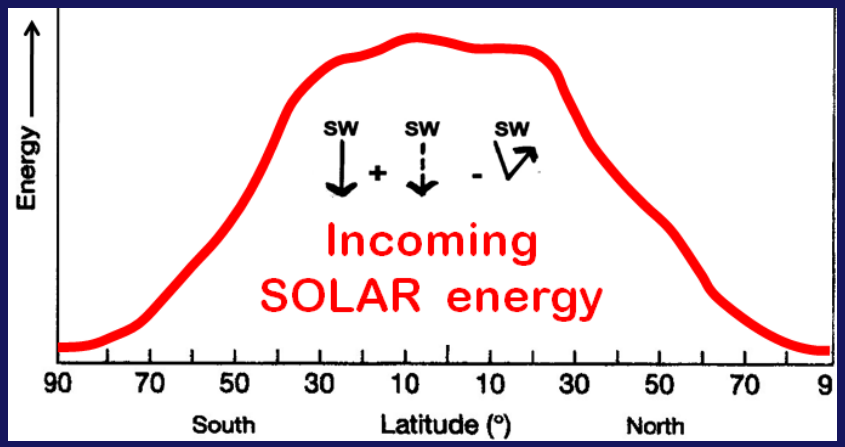
Earth-Sun Relationships
(Astronomical Forcing):

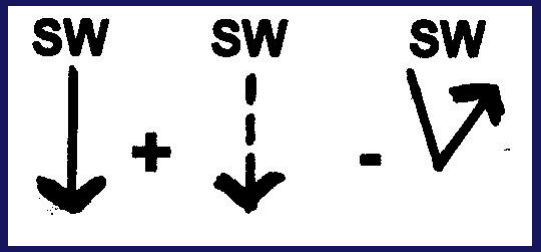
Review





This determines the **LATITUDAL & SEASONAL** DIFFERENCES of what comes **IN** from the SUN and is **absorbed** . . .

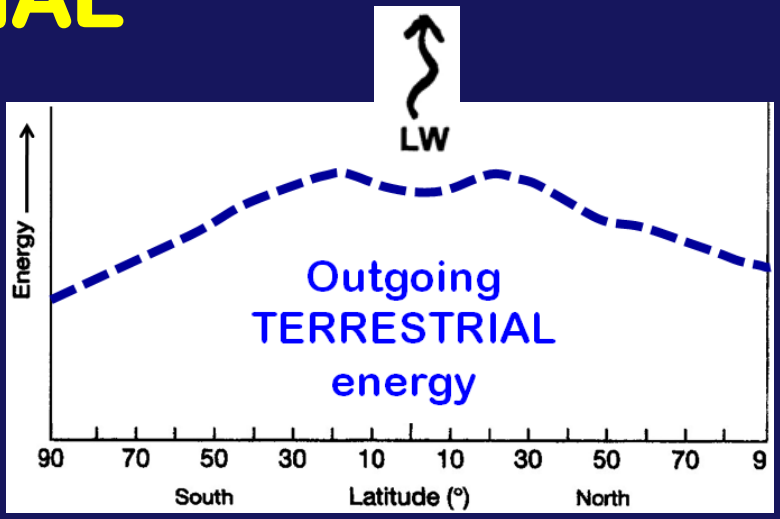


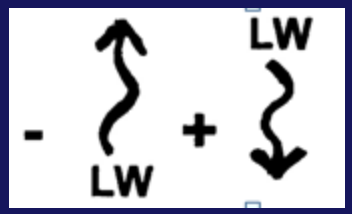


. . at each latitude
To **WARM** the Earth

Earth + Atmosphere Temperature & the Greenhouse Effect

This determines the **LATITUDINAL & SEASONAL DIFFERENCES** of what goes **OUT** from the EARTH . . .

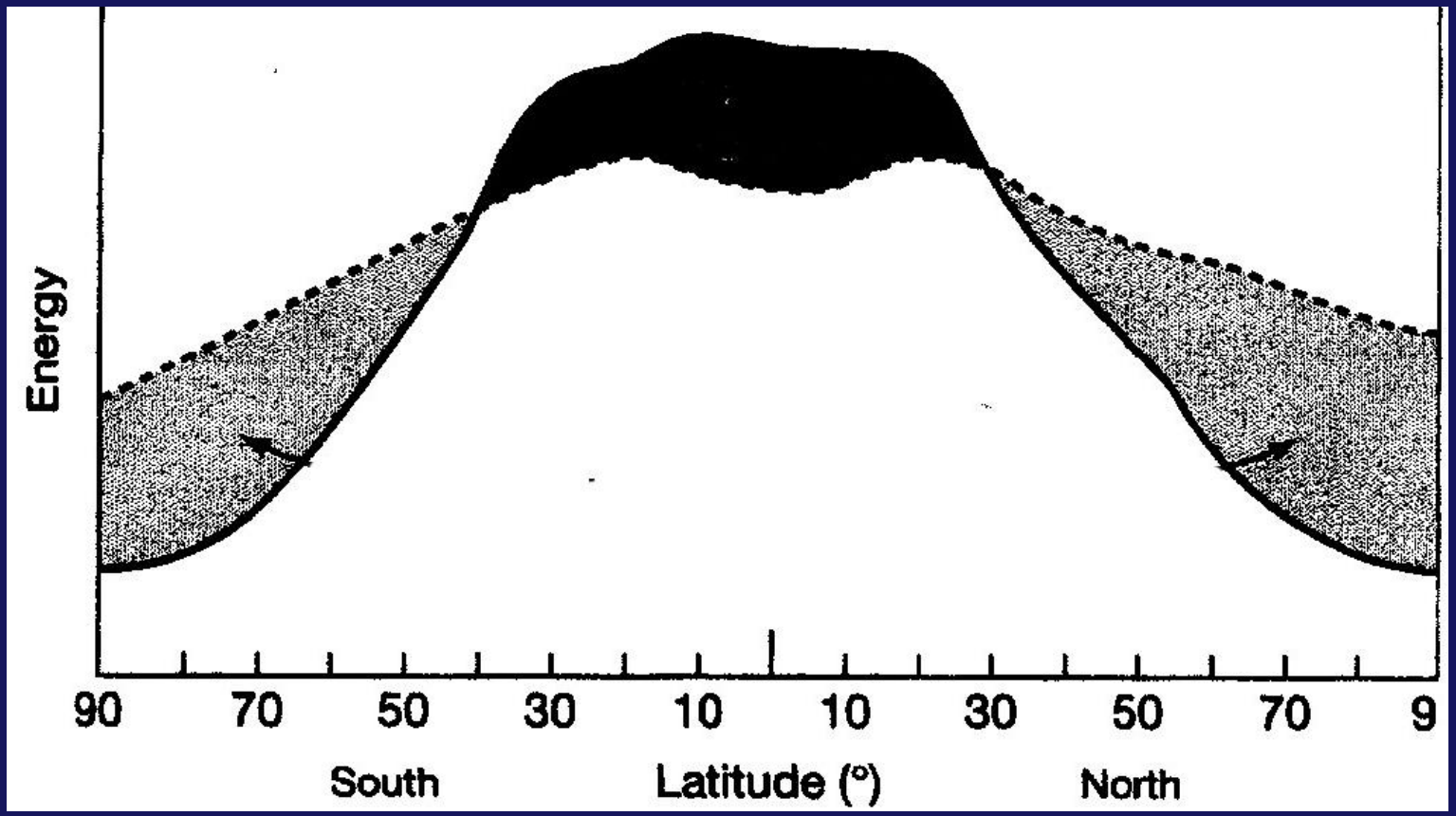




. . at each latitude

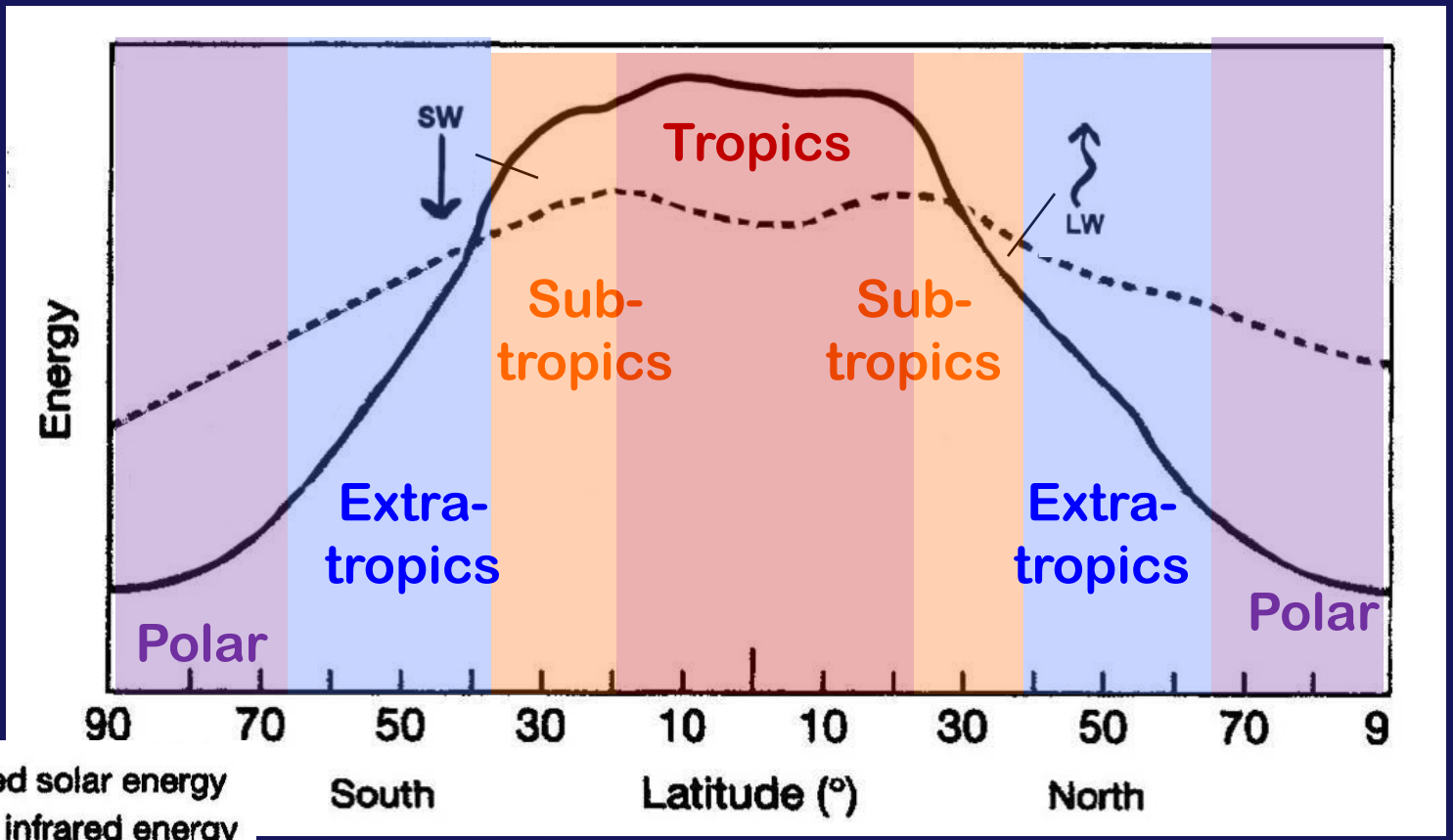
To COOL the Earth

Put them together . . . .

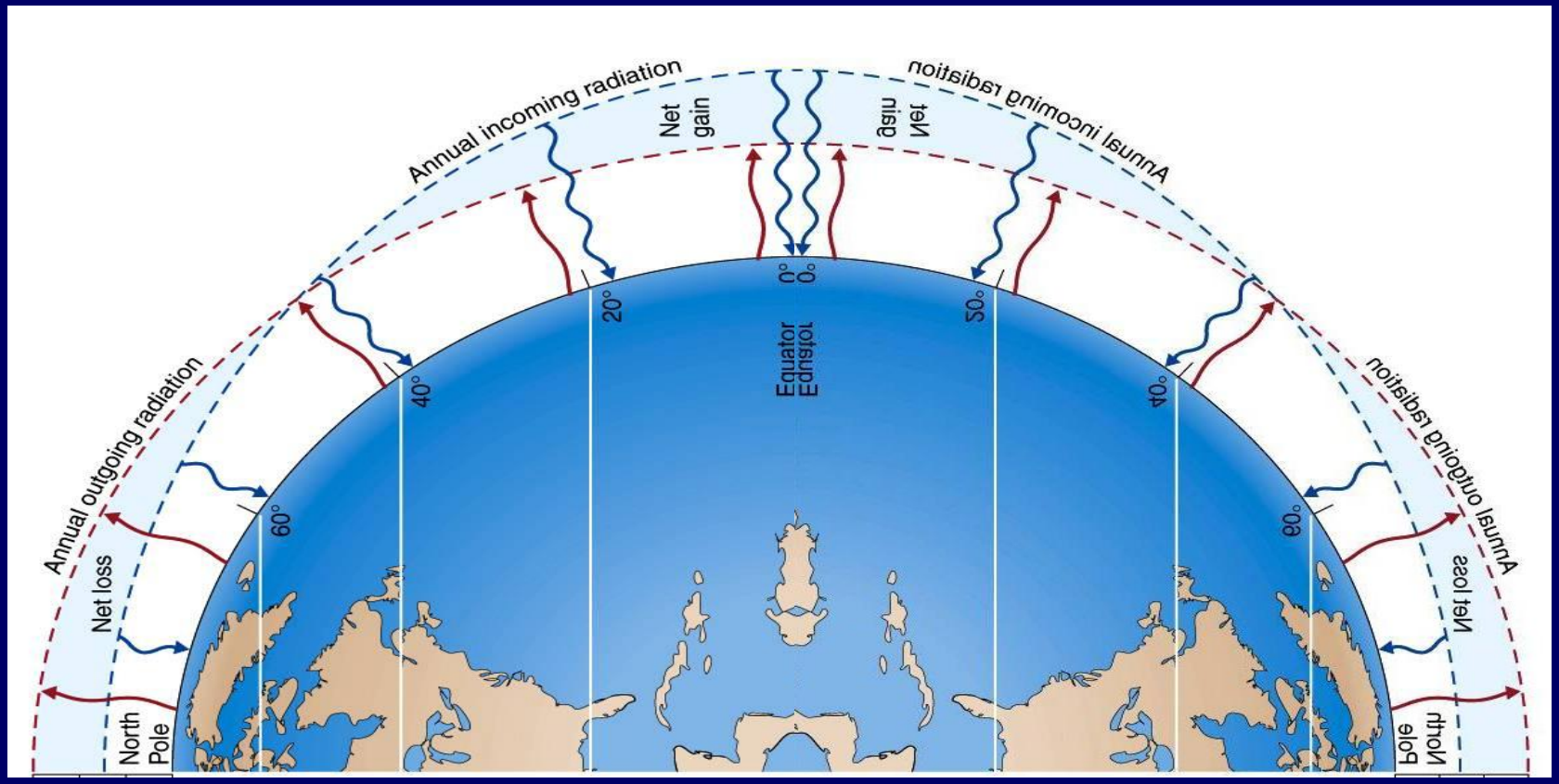


ENERGY BALANCE & CLIMATE REGIONS

(wrap up)

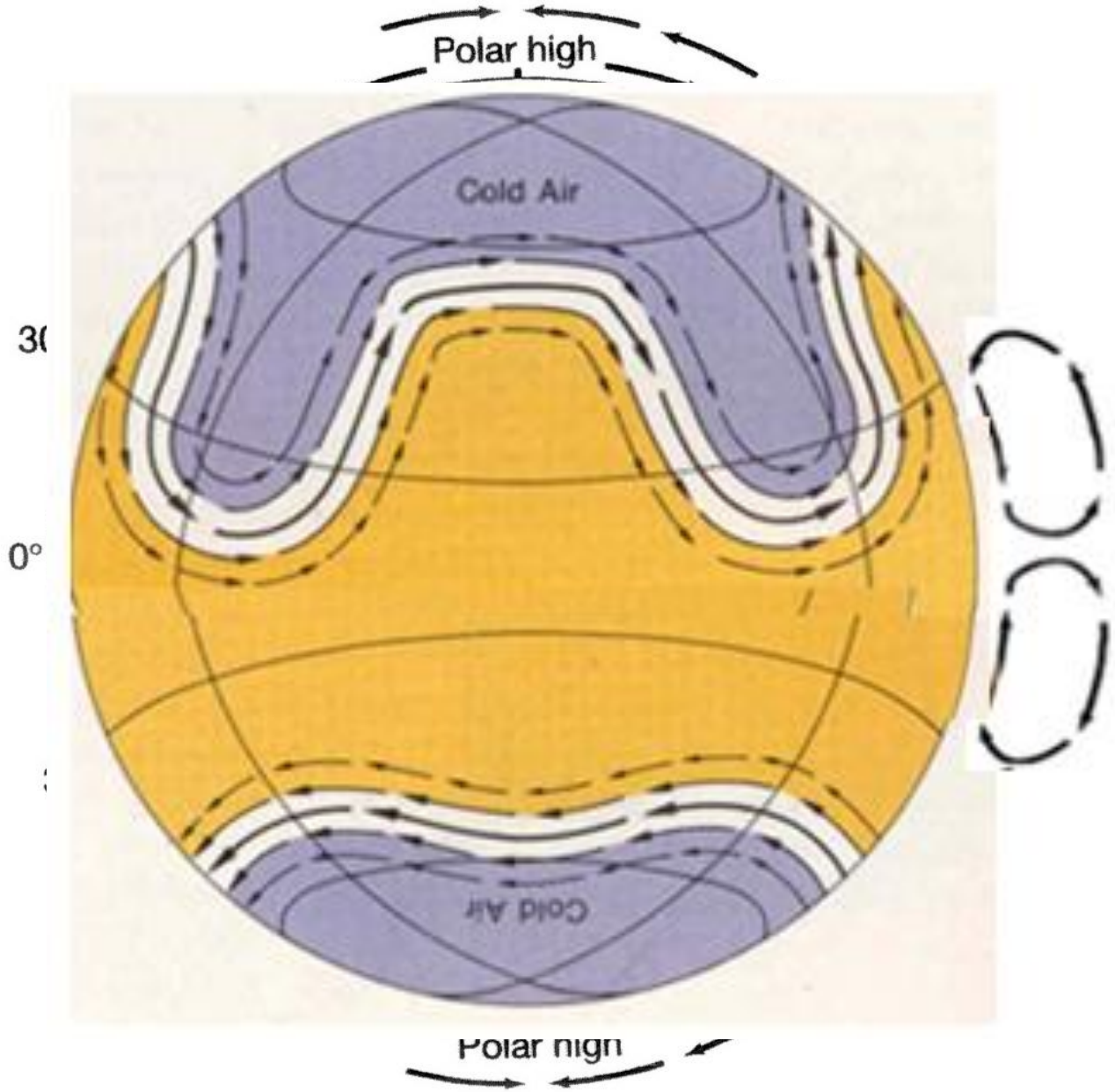


Global climate patterns are determined (in part) by regions of surplus and deficit in the **ENERGY BALANCE**



POLE **EQUATOR** **POLE**

Now lets look at a Pole to Pole Transect

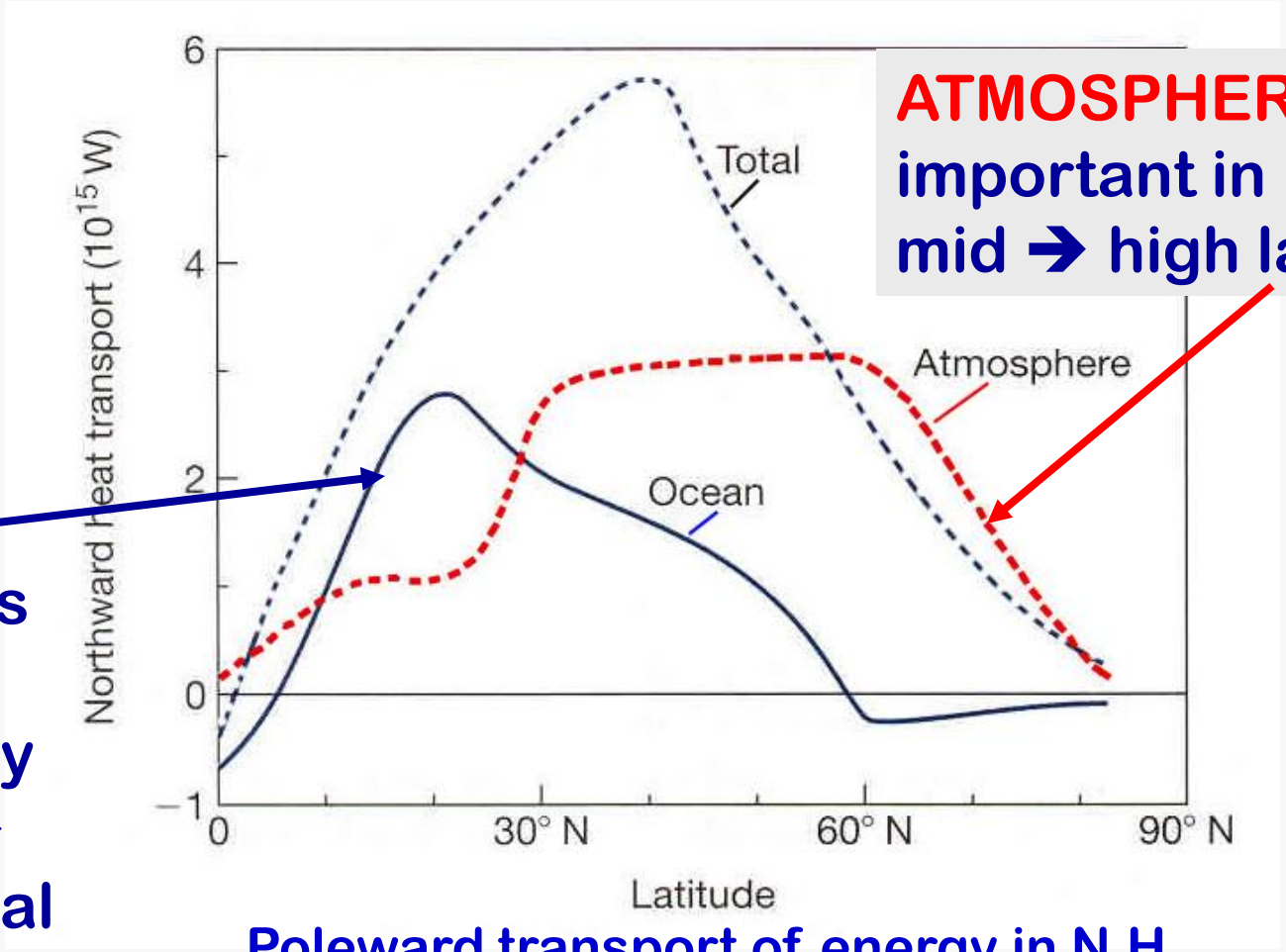


ROSSBY WAVES

HADLEY CELLS

ROSSBY WAVES

Both ATMOSPHERE & OCEAN play important roles in BALANCING OUT ENERGY SURPLUS & DEFICIT AREAS:



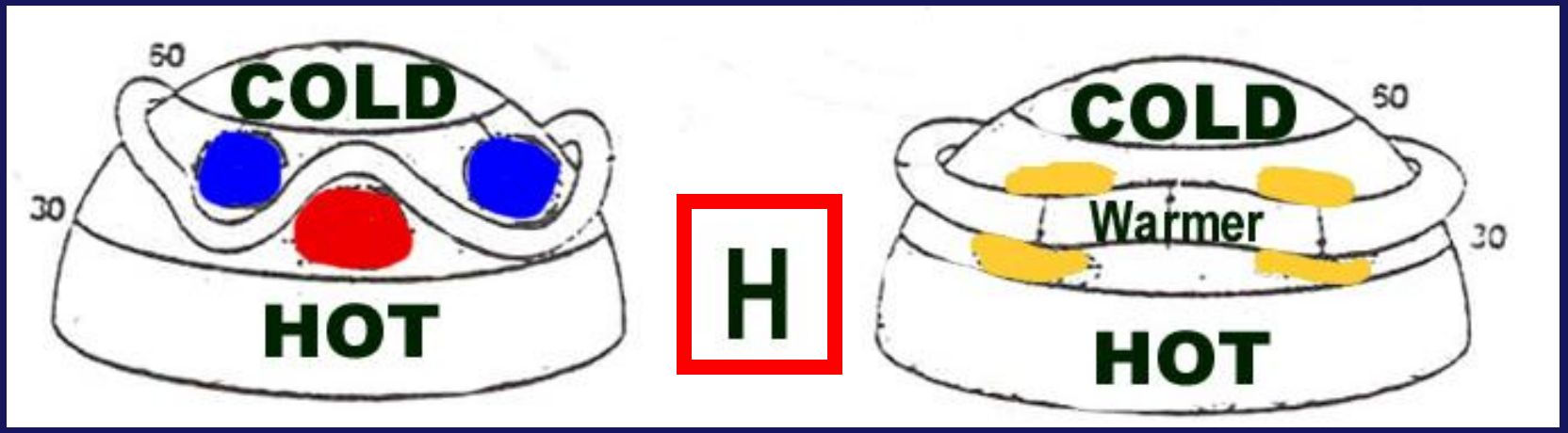
ATMOSPHERE more important in mid ➔ high latitudes

OCEAN transports MOST of the energy in LOW ➔ subtropical latitudes

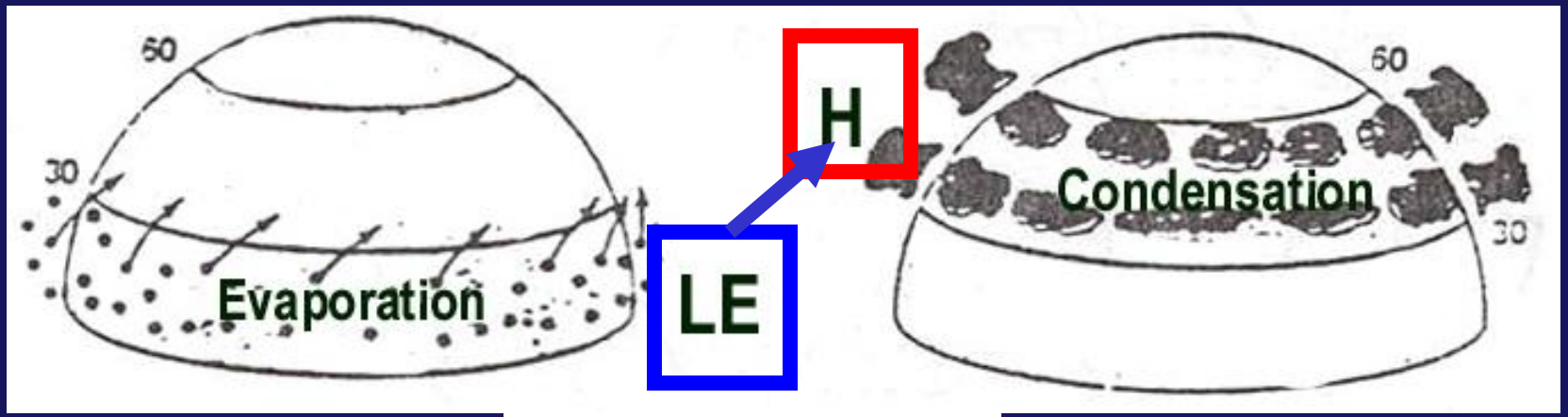
Poleward transport of energy in N.H.

Energy is transported from areas of surplus to deficit via:

H (sensible heat)



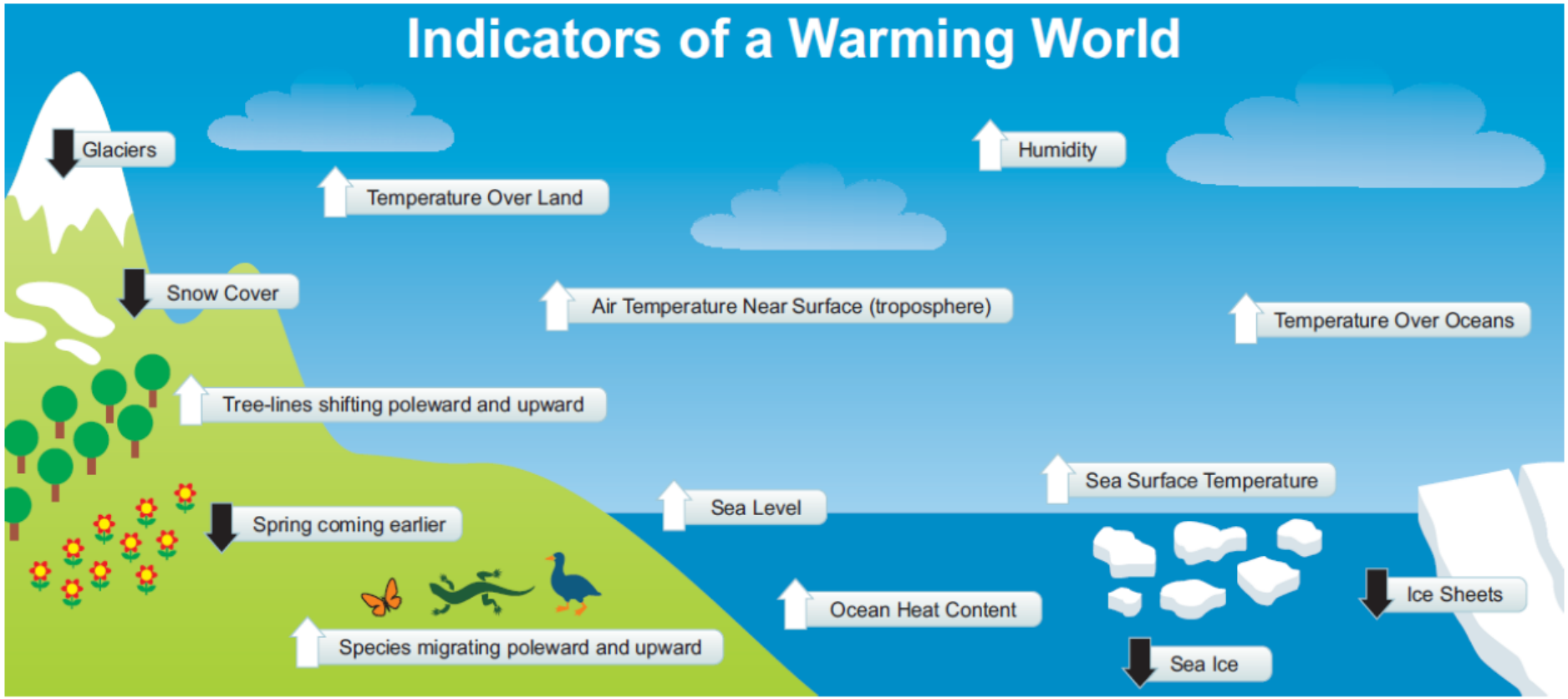
& LE (Latent Energy)



H + LE

To ponder . . . .

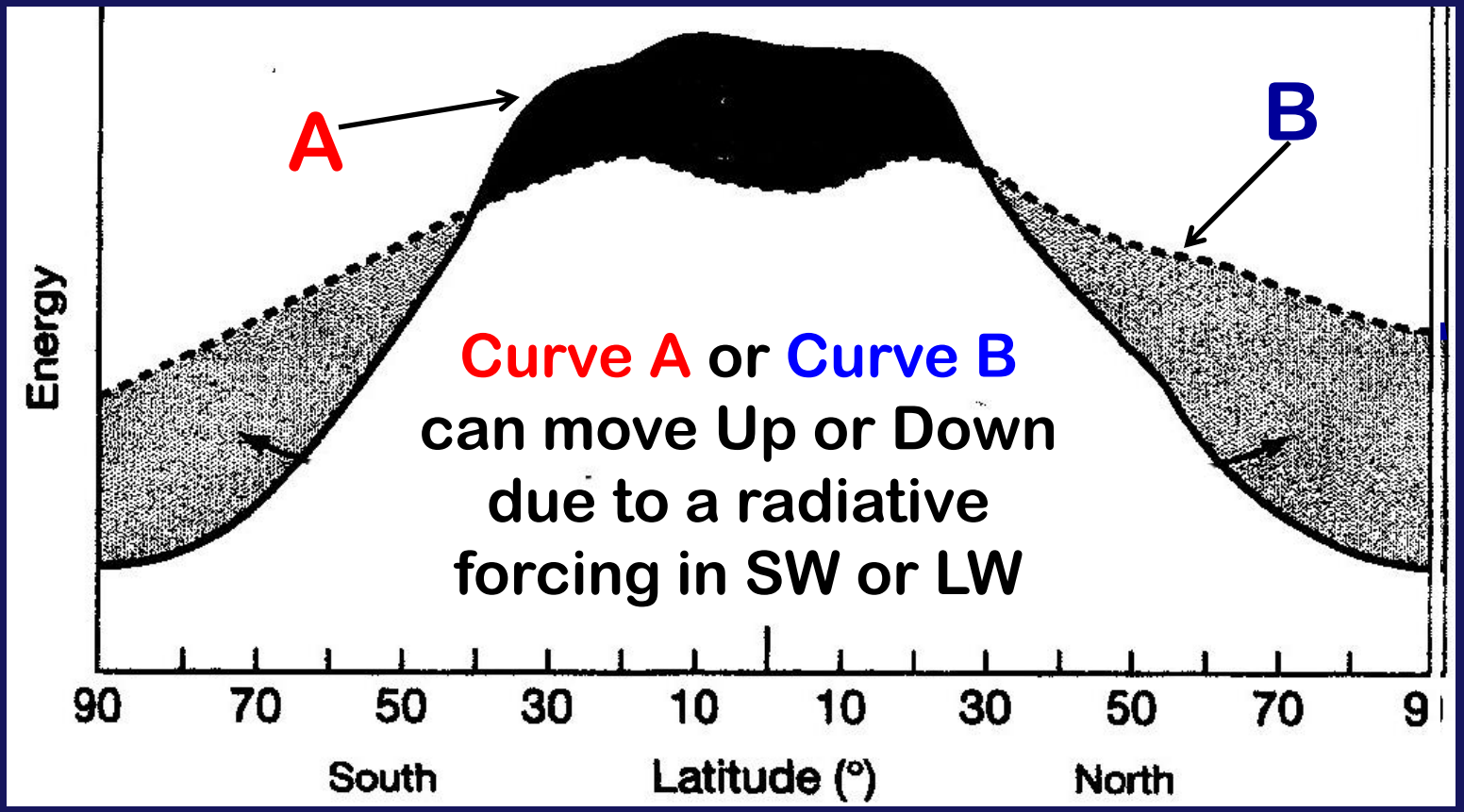
RECAP: Can you explain how each of the processes involved in these climate change indicators would occur with a warming world?



TOPIC #13

NATURAL CLIMATIC FORCING

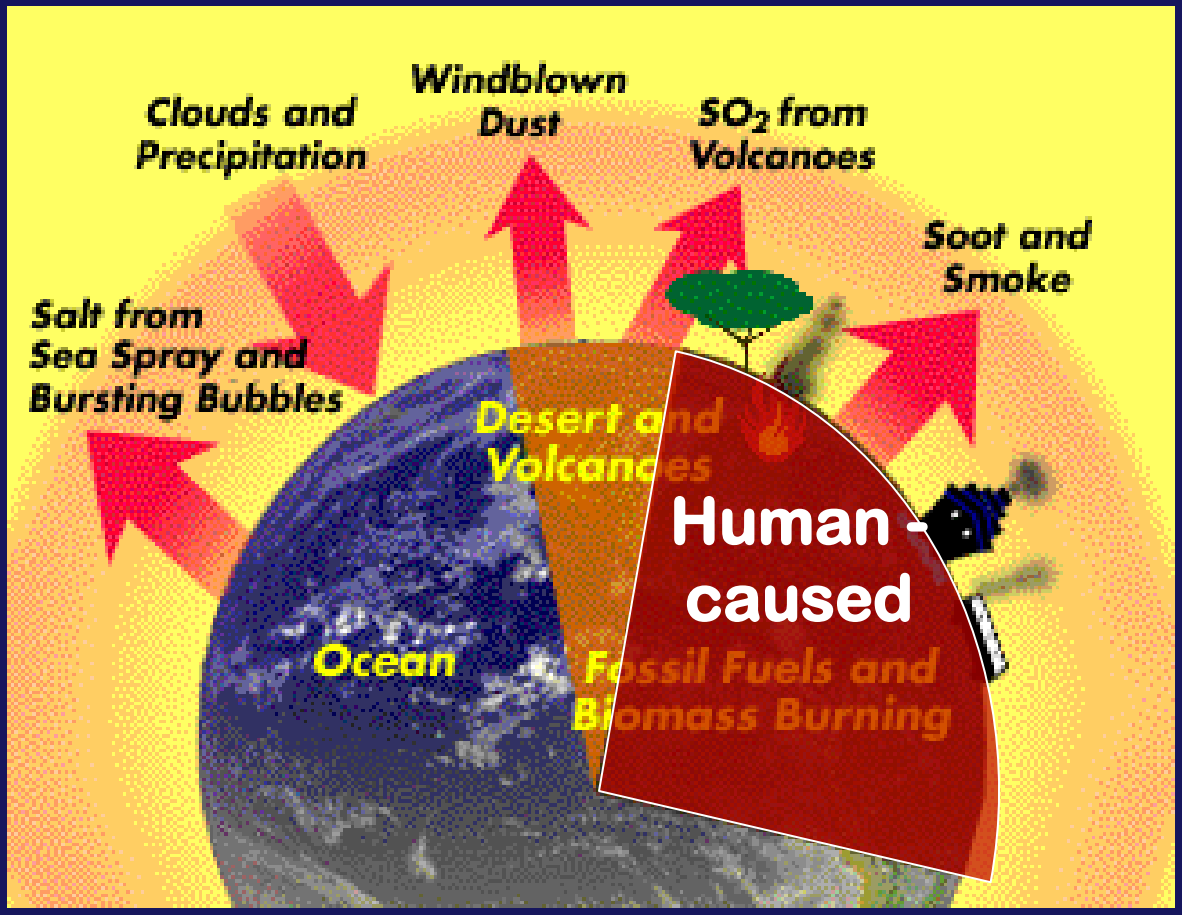
Global climate variability and change are caused by changes in the ENERGY BALANCE that are "FORCED"



CURVE A SW + SW - SW

CURVE B LW LW

FORCING = a persistent disturbance of a system



(a longer term disturbance than a perturbation)

NATURAL CLIMATIC FORCING

vs.

ANTHROPOGENIC FORCING

Natural Climatic Forcing = changes due to natural earth-atmosphere-sun processes

- **Earth-Sun orbital relationships**
- **Solar variability**
- Changing land-sea distribution
  (over long time scales: due to plate tectonics)
- **Volcanic eruptions**

also: internal atmosphere-ocean variability (i.e., El Nino & La Nina), clouds, dust, etc

Anthropogenic Climatic Forcing = changes due to human causes or enhancement of the processes involved

- Enhanced Greenhouse Effect due to fossil fuel burning
- Land use changes due to human activity (deforestation, urbanization, etc.)
- Soot and aerosols from industry
- Chemical reactions in stratosphere involving human-made compounds (ozone depletion)

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

~ Chief Seattle

The 3 main drivers of NATURAL CLIMATIC FORCING:

1) ASTRONOMICAL FORCING

2) SOLAR FORCING

3) VOLCANIC FORCING

The 3 main drivers of NATURAL CLIMATIC FORCING:

1) ASTRONOMICAL FORCING ←

2) SOLAR FORCING

3) VOLCANIC FORCING

Changes in Solar "Astronomical" Forcing have driven natural climate variability (ice ages, etc.) on LONG time scales (5,000 to 1 million years)

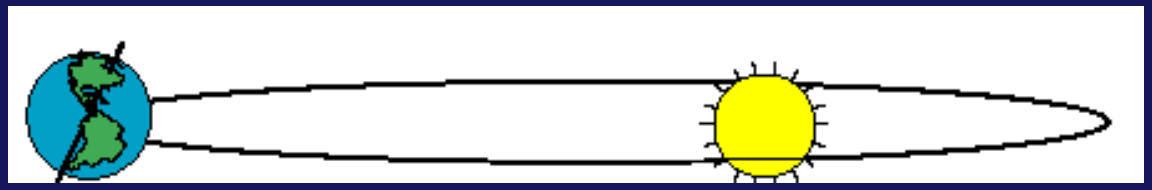
What has varied over time?

#1 OBLIQUITY OF EARTH'S AXIS

#2 ECCENTRICITY OF EARTH'S ORBIT

 # 3 Timing of Seasons in Relation to Orbit: "PRECESSION OF THE EQUINOXES"

Q1. What is being represented by this diagram ?

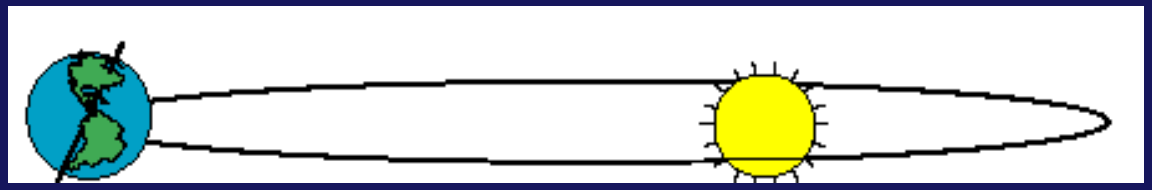


1 - One of the Equinoxes, where every latitude on Earth experiences 12 hours of daylight and 12 hours of darkness.

2 - Northern Hemisphere winter.

3 -Northern Hemisphere summer.

Q1. What is being represented by this diagram ?



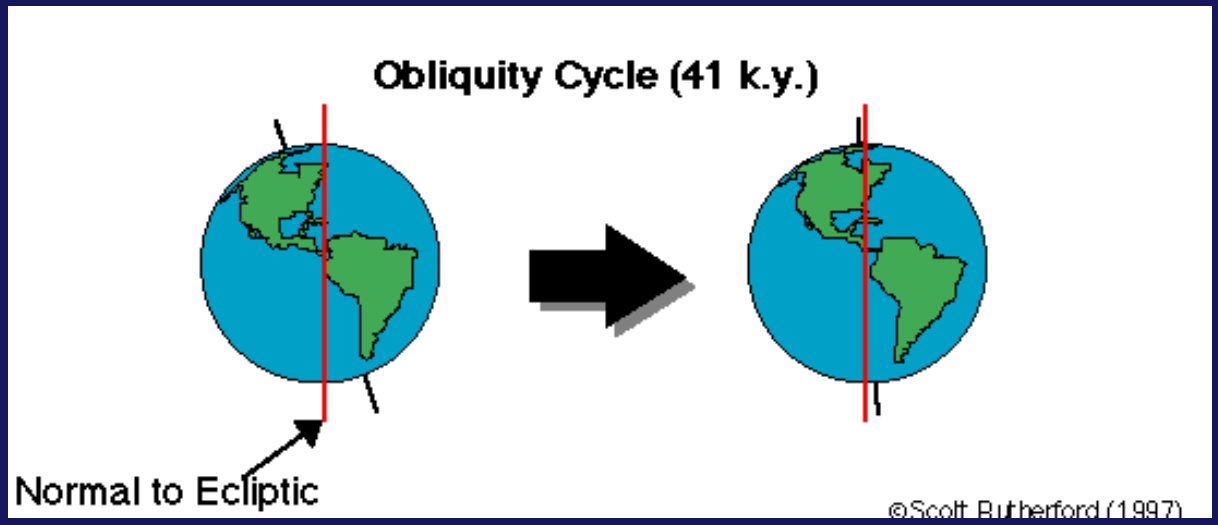
1 - One of the Equinoxes, where every latitude on Earth experiences 12 hours of daylight and 12 hours of darkness.

2 - Northern Hemisphere winter.

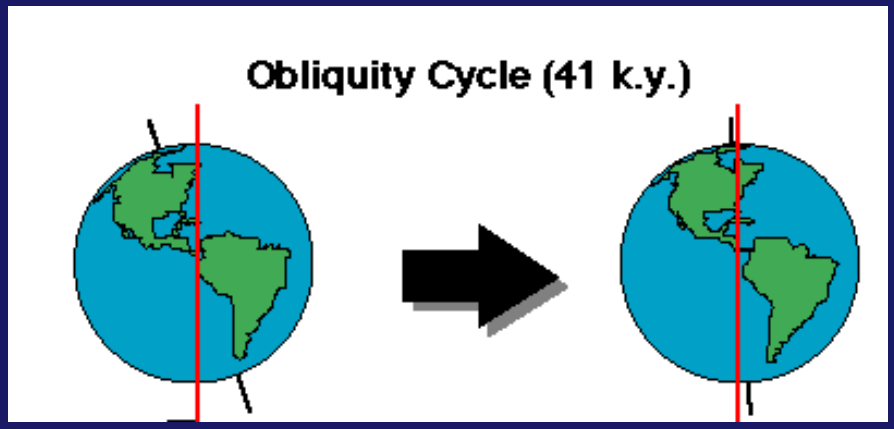
3 -Northern Hemisphere summer.

1. OBLIQUITY OF EARTH'S AXIS

- axis "tilts" 23.5 degrees from plane of ecliptic
- causes the seasons
- has varied in the past from more "tilted" to more "vertical" (~24.5 ^{o} to ~ 22.5 ^{o})



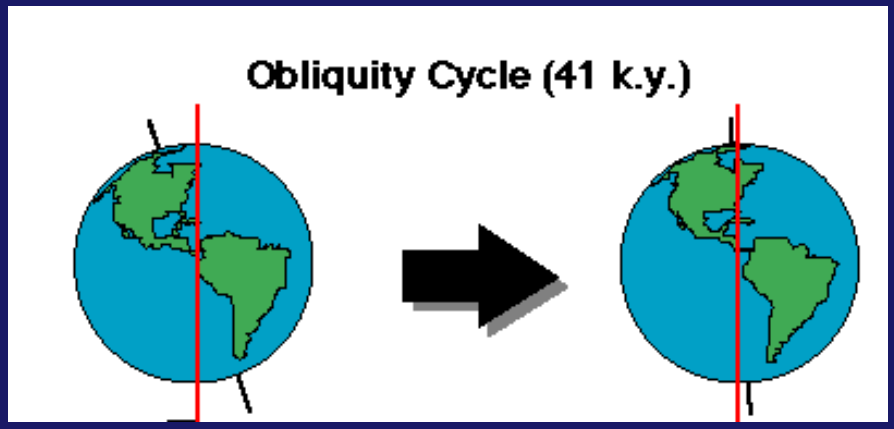
Q1 How do you think global climate would change with less of a tilt?



1 – The <u>difference</u> in annual temperature between polar and tropical latitudes would be GREATER

2 – The <u>difference</u> in annual temperature between polar and tropical latitudes would be LESS

Q1 How do you think global climate would change with less of a tilt?



1 – The <u>difference</u> in annual temperature between polar and tropical latitudes would be GREATER

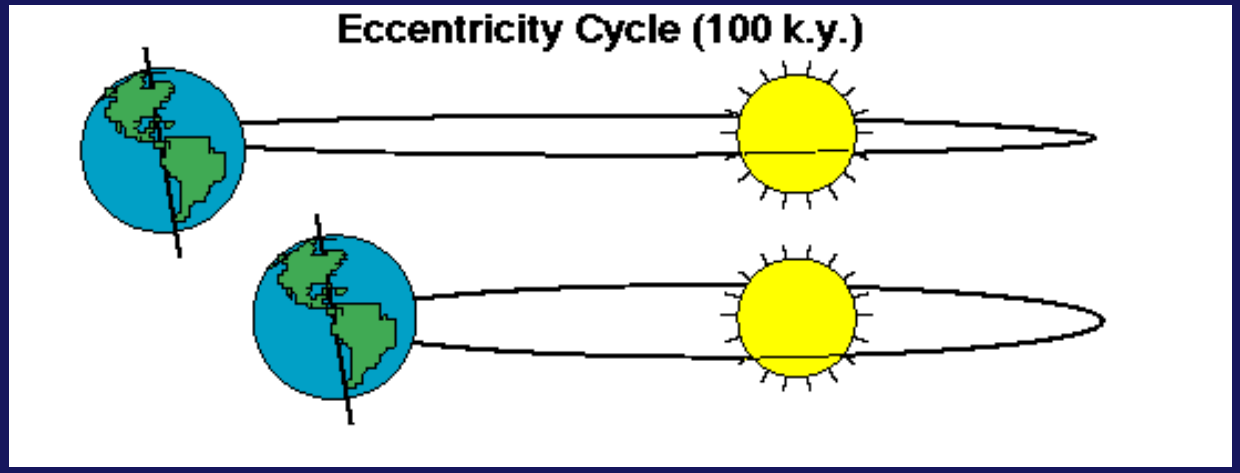
2 – The <u>difference</u> in annual temperature between polar and tropical latitudes would be LESS

2. ECCENTRICITY OF ORBIT

- Earth's orbit around sun is not symmetrical

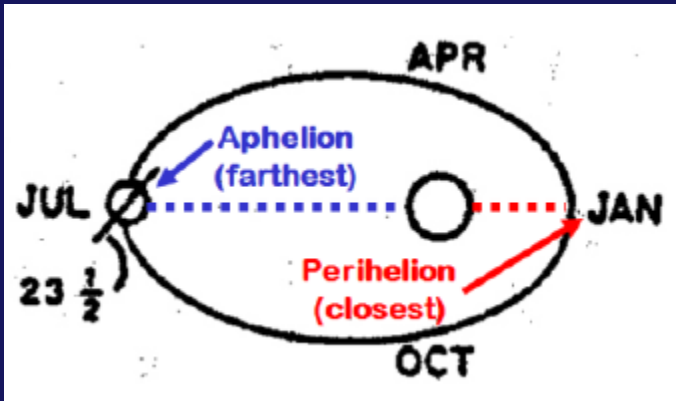
- Has varied in the past from more circular => elliptical shape

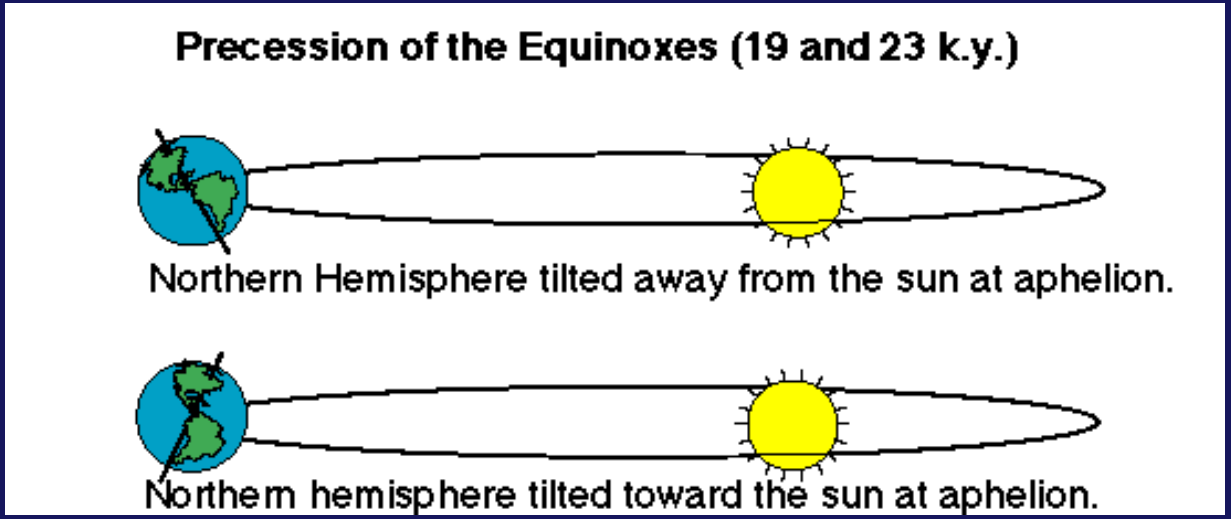
(more "eccentric!")



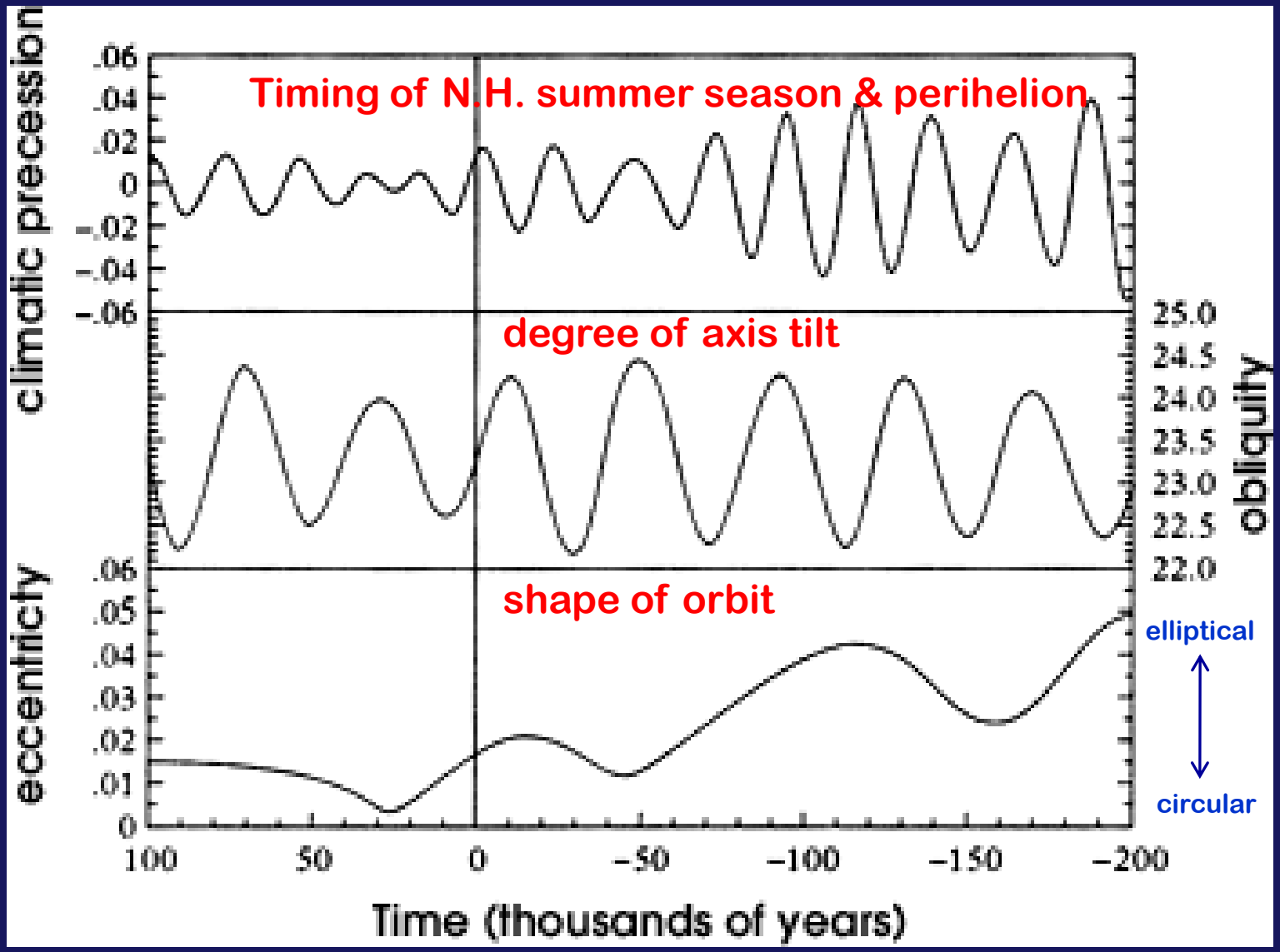
3. PRECESSION OF THE EQUINOXES
(Timing of Seasons in Relation to Orbit)

Currently the Earth is <u>closest to the Sun</u> (perihelion) in Jan & <u>farthest</u> (aphelion) in July. This has varied in the past.

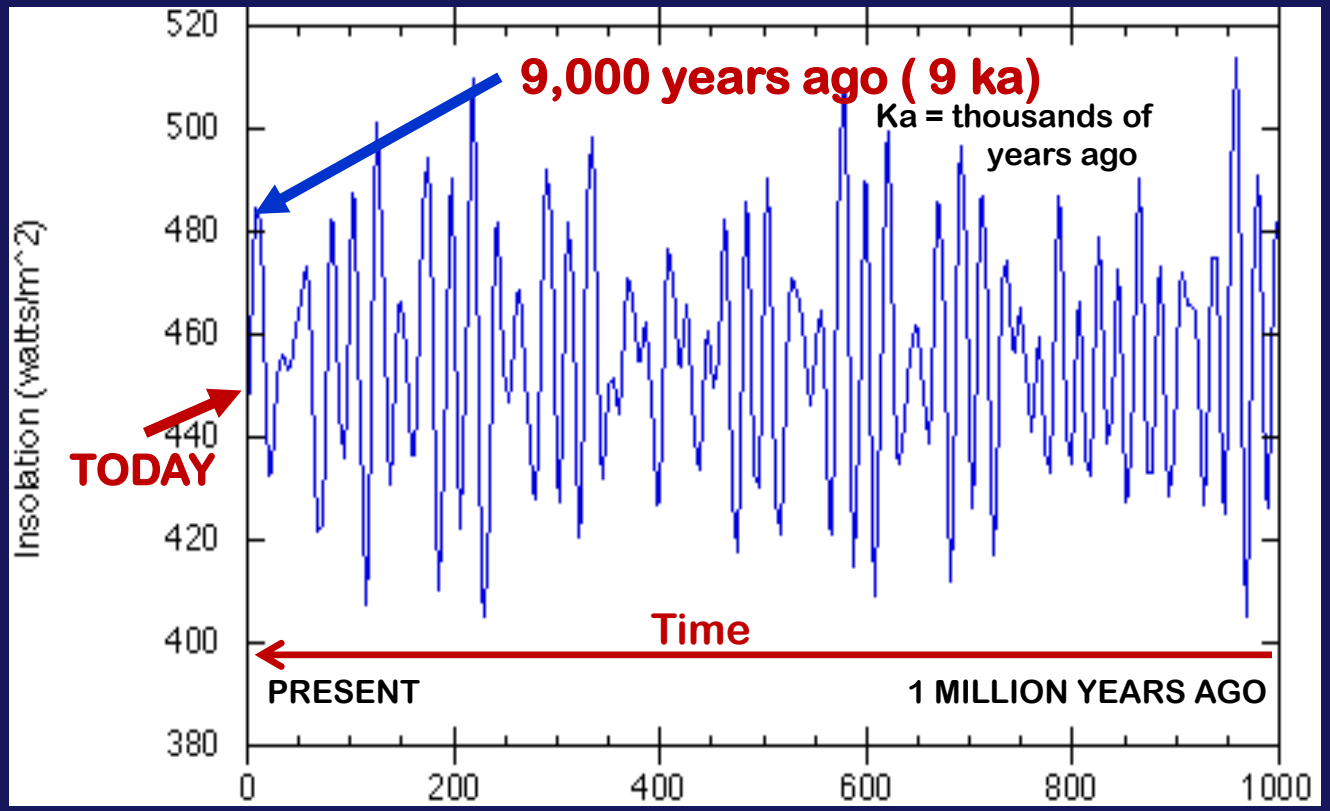




the Future ← TODAY → the Past *(in thousands of years)*



Summarizing graph of SOLAR INSOLATION calculated for 65 ° N latitude from the present to 1 million years ago based on "ASTRONOMICAL CLIMATE FORCING"



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In the Northern Hemisphere, peak summer insolation occurred about 9,000 years ago when the last of the large ice sheets melted.

Since then N. H. summers have seen **LESS** solar radiation.

INDICATOR INTERLUDE

Denier Argument #1:

"Climate's changed before"

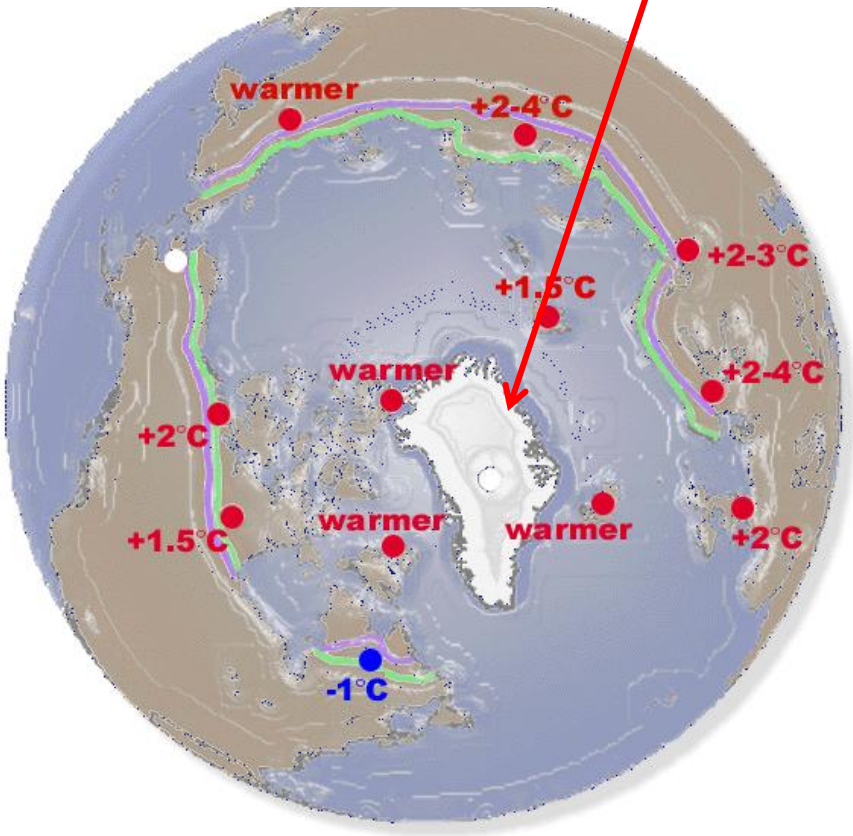
Mid-Holocene warm period
(~ 6,000 years ago)

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

Cause =

"astronomical climate forcing"

Global warming "deniers" often point out how warm Greenland was in the past :



Top p 76

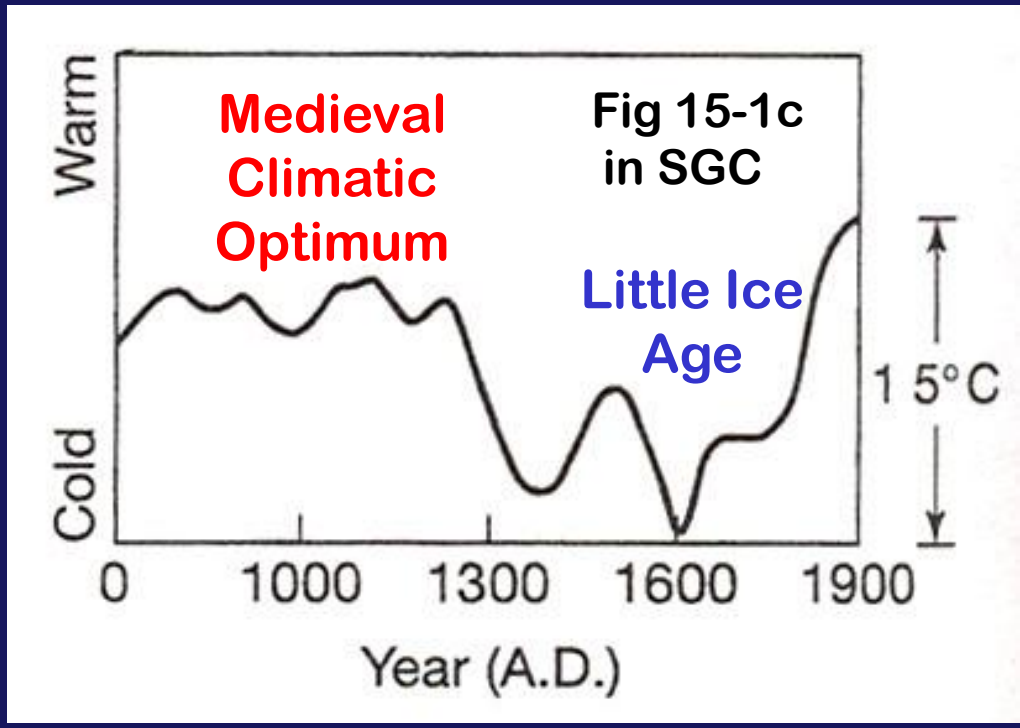
Other notable "naturally forced" climate changes of the more recent past:

Medieval Warm Period (MWP)

"Medieval Climatic Optimum"

9th-14th centuries (800-1300)

(regionally most evident in Europe)



Little Ice Age (LIA)

15th – 19th centuries (1400-1800)

esp. 1600 -1800 (evidence found globally)

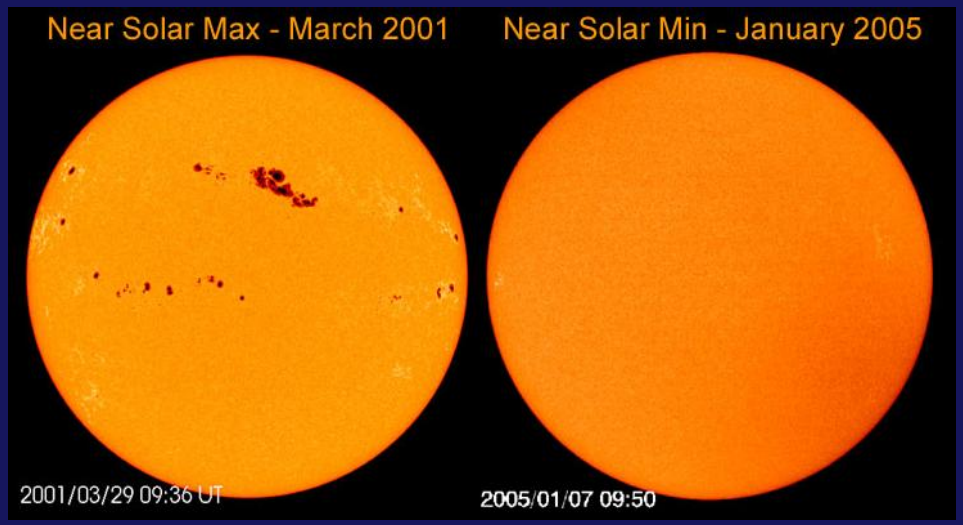
The 3 main drivers of NATURAL CLIMATIC FORCING:

1) ASTRONOMICAL FORCING

2) SOLAR FORCING ←

3) VOLCANIC FORCING

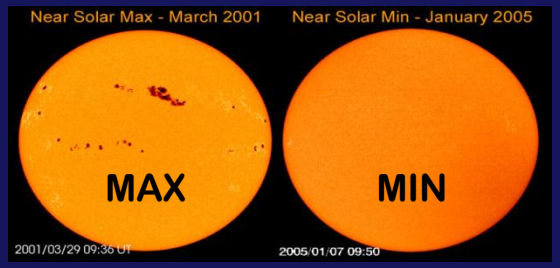
ANOTHER POSSIBLE NATURAL FORCING: SOLAR VARIABILITY

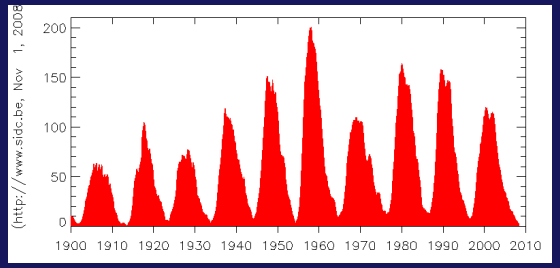


Sunspot maxima = MORE solar brightness (warmer temps)

Sunspot minima = LESS solar brightness (cooler temps)

ANOTHER POSSIBLE NATURAL FORCING: SOLAR VARIABILITY





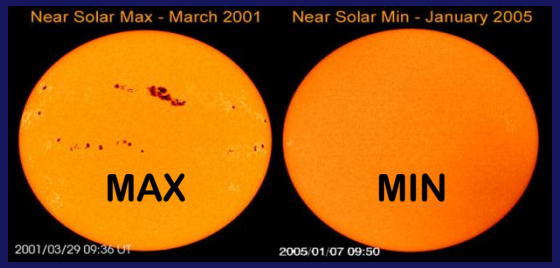
Q2 – During SUNSPOT Maximum periods:

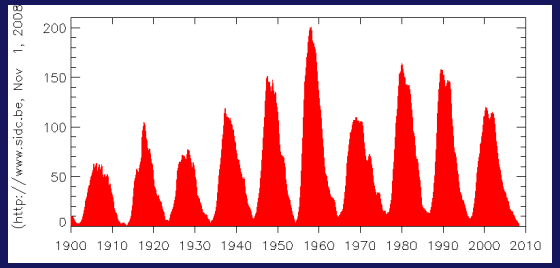
1. The sun is darker so it gives off less energy and global cooling is likely.

2. The sun sunspots indicate active solar flares and the sun gives off more energy leading to warmer periods.

3. There is no link between solar activity and global warming.

ANOTHER POSSIBLE NATURAL FORCING: SOLAR VARIABILITY





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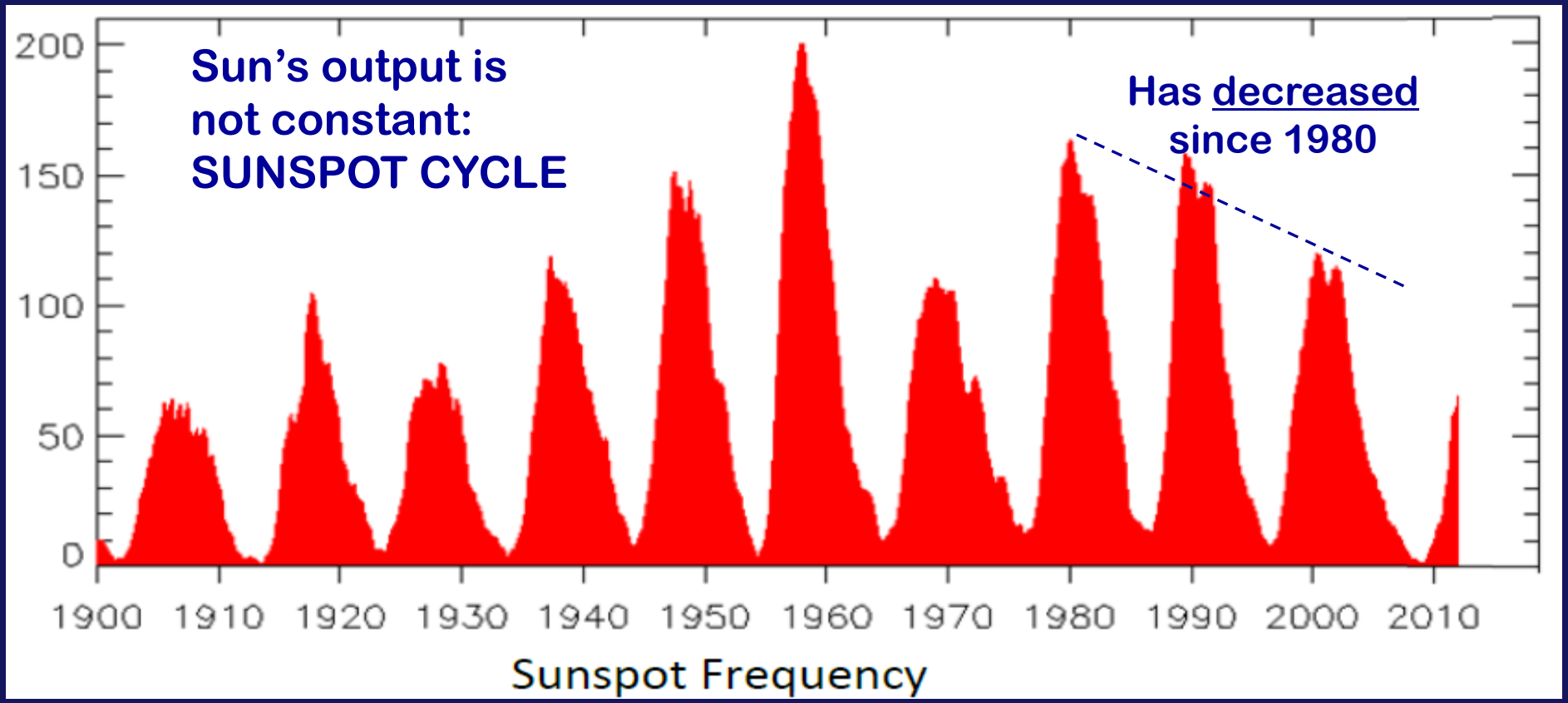
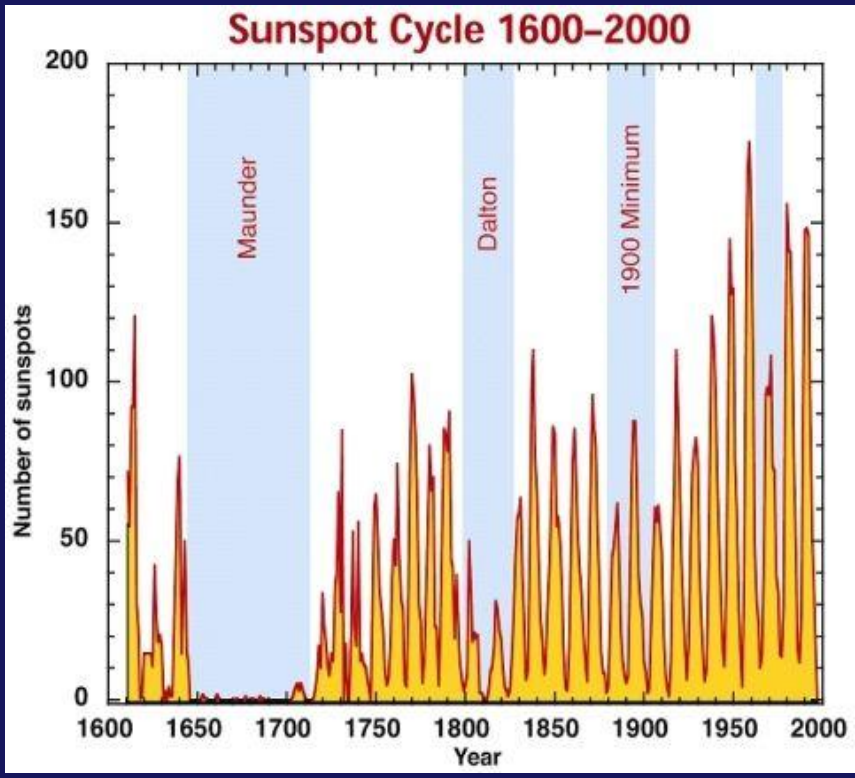


http://www.sidc.be/sunspot-index-graphics/sidc_graphics.php

Sunspot maxima = MORE solar brightness (warmer temps)

Sunspot minima = LESS solar brightness (cooler temps)

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



But uncertainties remain!
What's the MECHANISM that links the Sun's drop in brightness to the lower temperatures on the Earth?

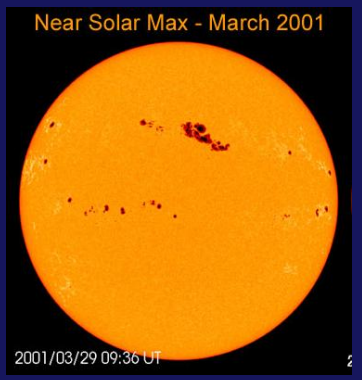
Dalton Minimum (1795 – 1825)

-- was also cooler

-- BUT, lots of large volcanic eruptions then too

Since the Dalton Minimum, the Sun has gradually brightened , e.g., **"Modern Maximum"** (in 2001)

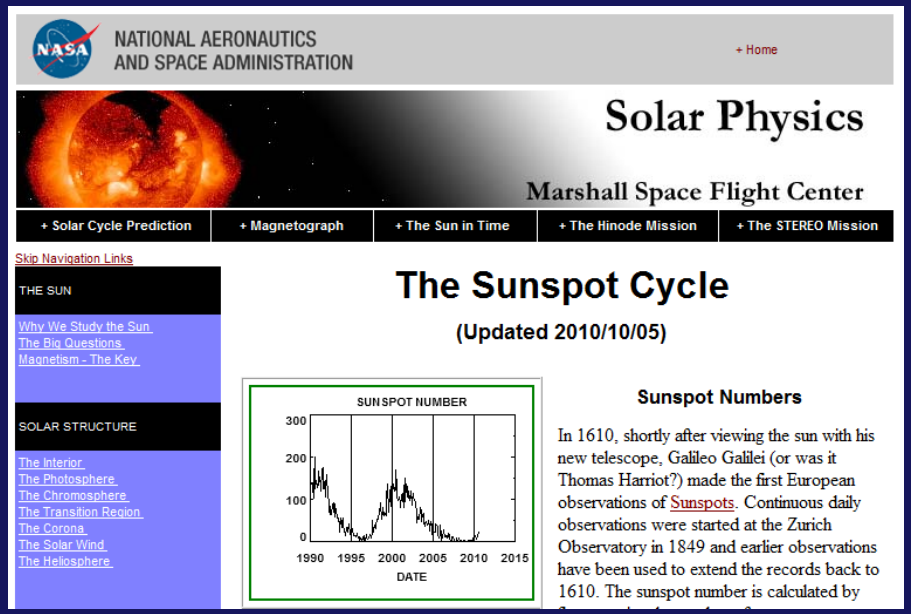
BUT . . .
The increase in solar brightness during the recent "Modern Maximum" accounted for only:



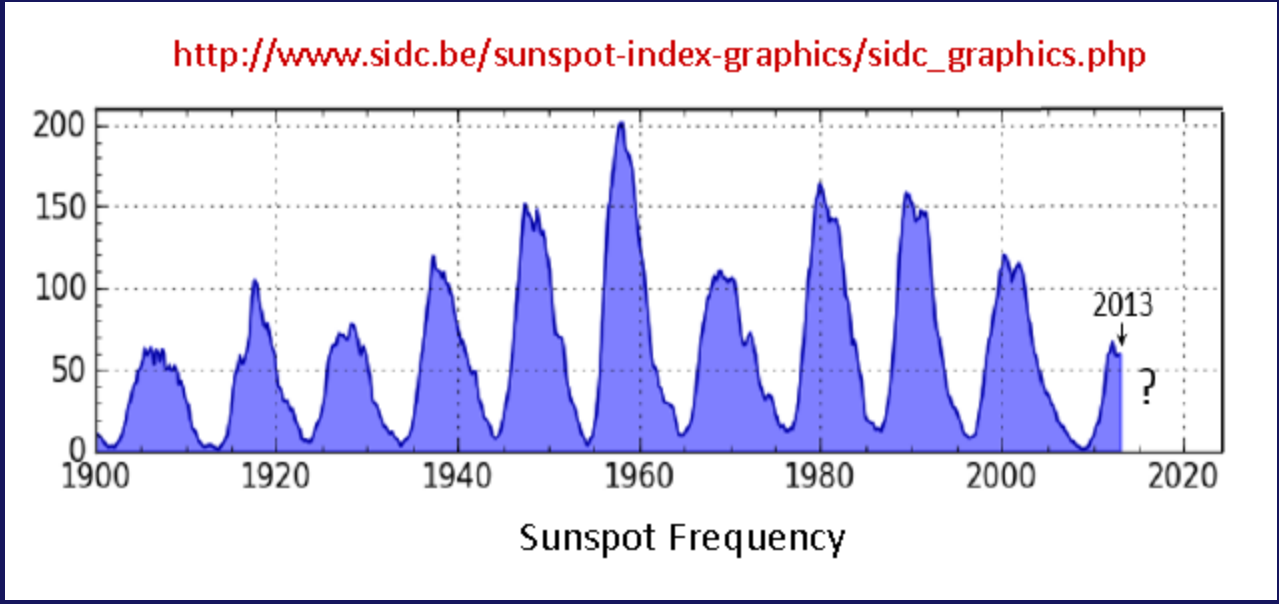
- **about ½ of the temperature increase since 1860**, and
- **less than 1/3 since 1970**

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

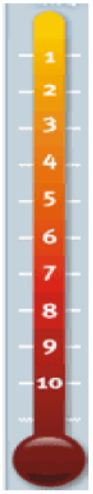
What is happening today?



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



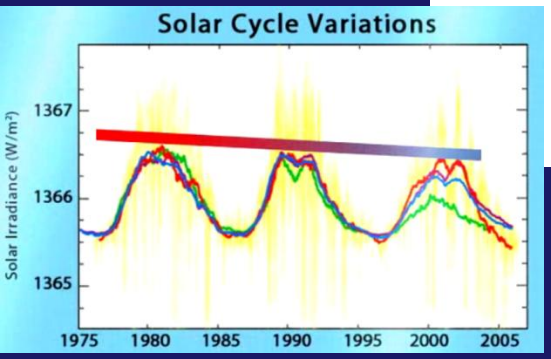
SEE ALSO: http://www.sidc.be/sunspot-index-graphics/sidc_graphics.php

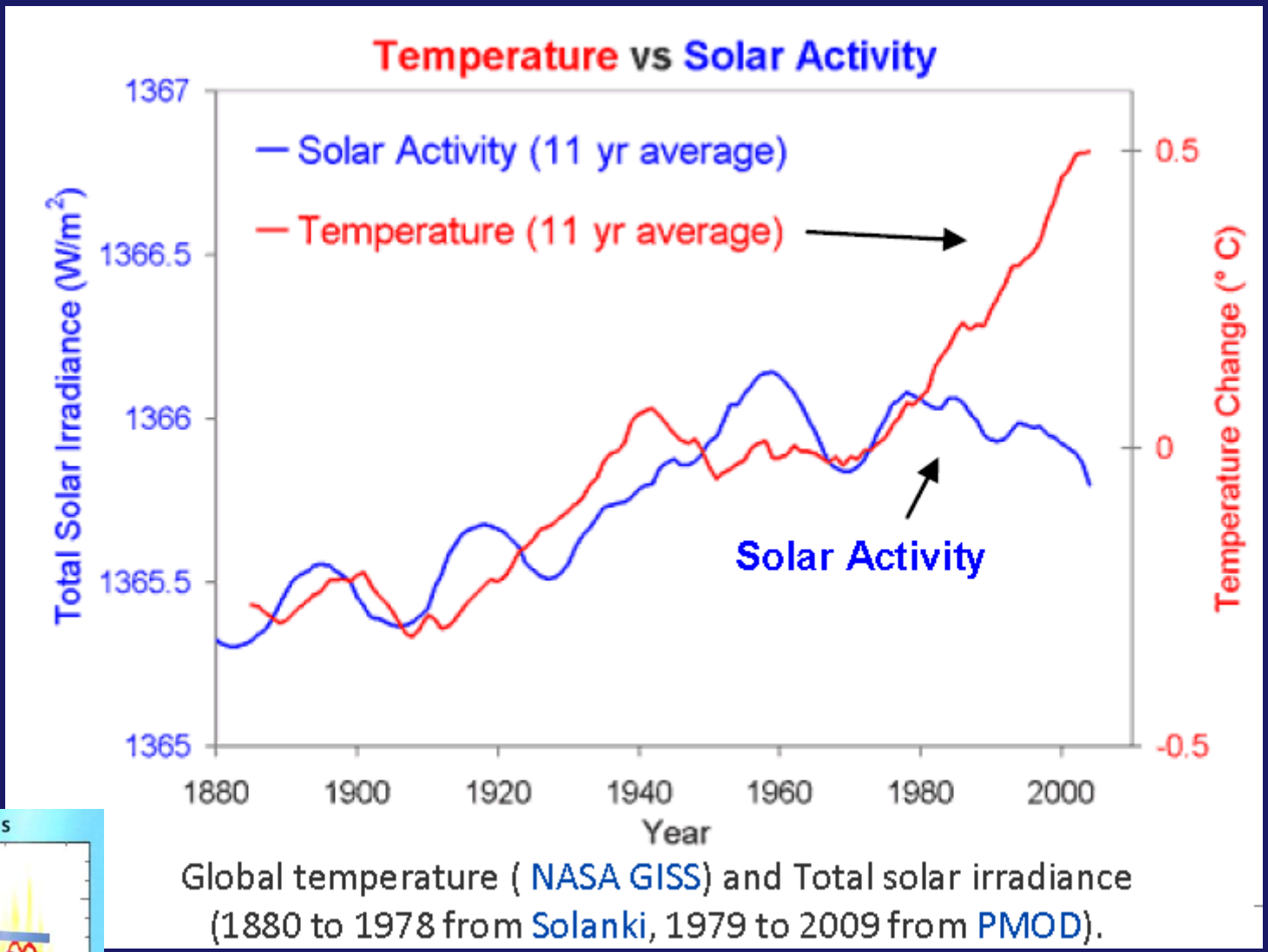


Indicator Interlude . . .

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

The Greenhouse Signature

What would a SOLAR Warming Signature look like?

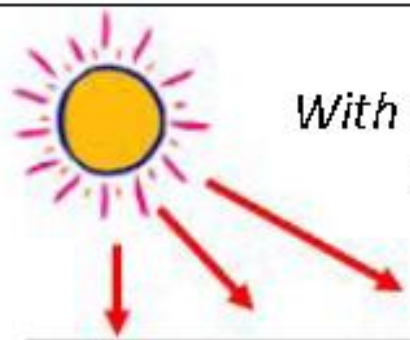
INDICATOR INTERLUDE . . .

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

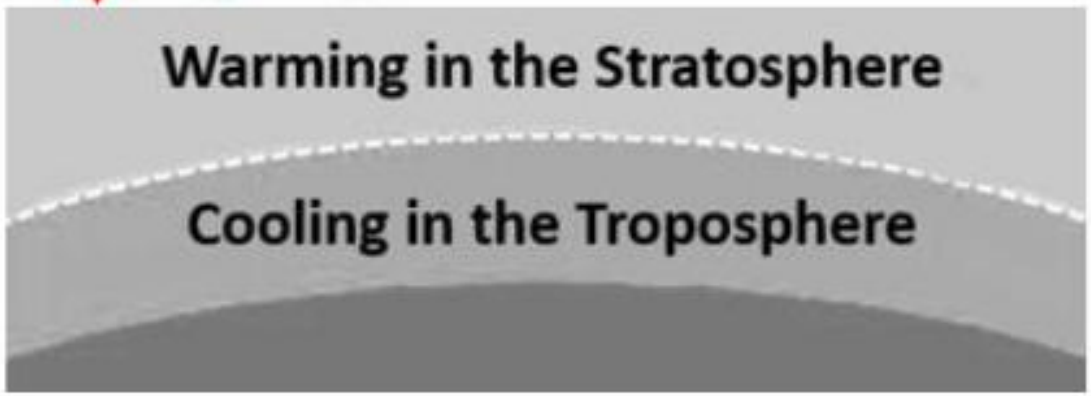
Solar Signature:
= Warming in the upper atmosphere & cooling in the Troposphere . . .

Review p 39

The Solar Irradiance Signature:

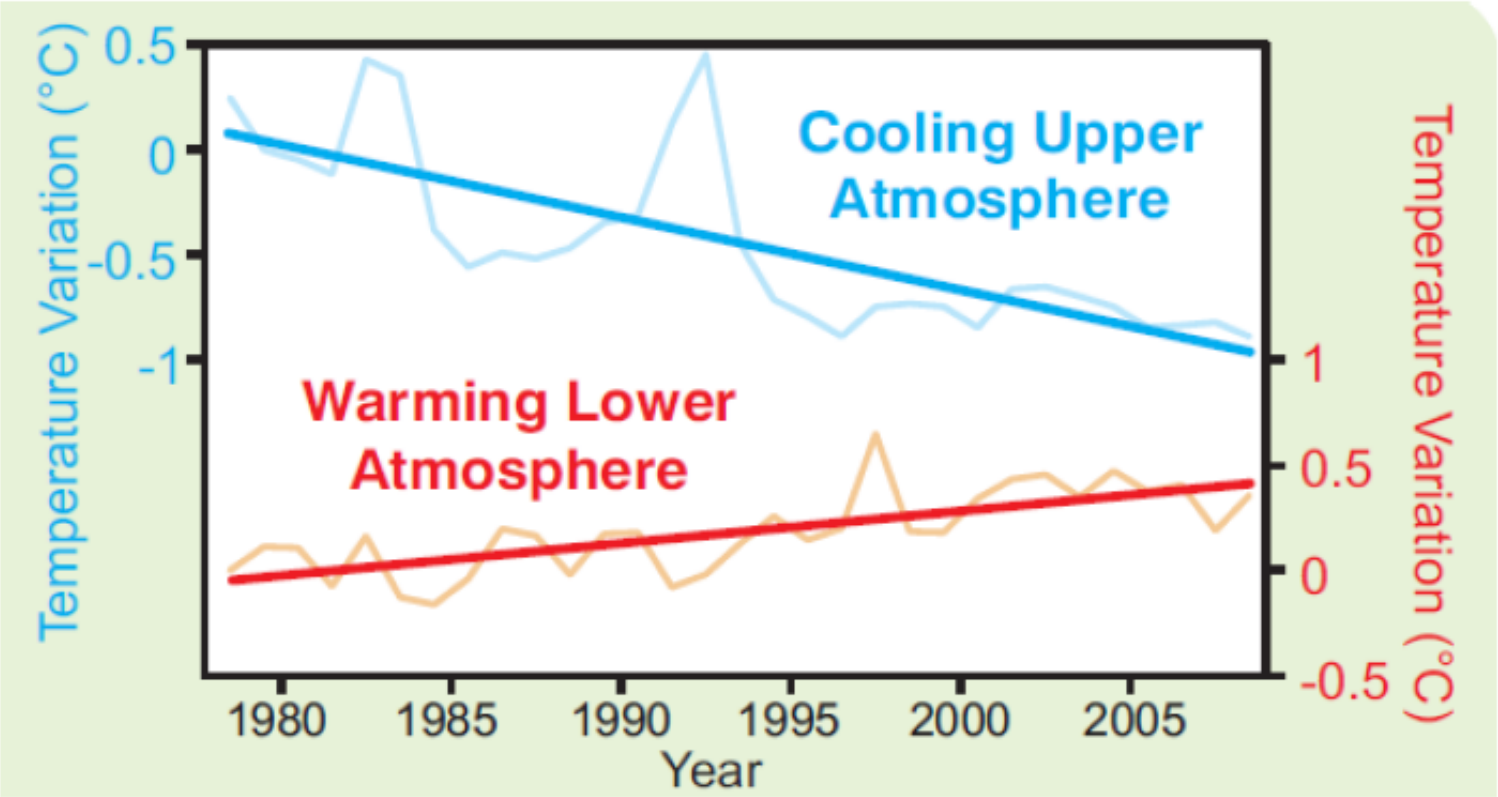


With increased Solar Activity we would expect to see "top down" warming:

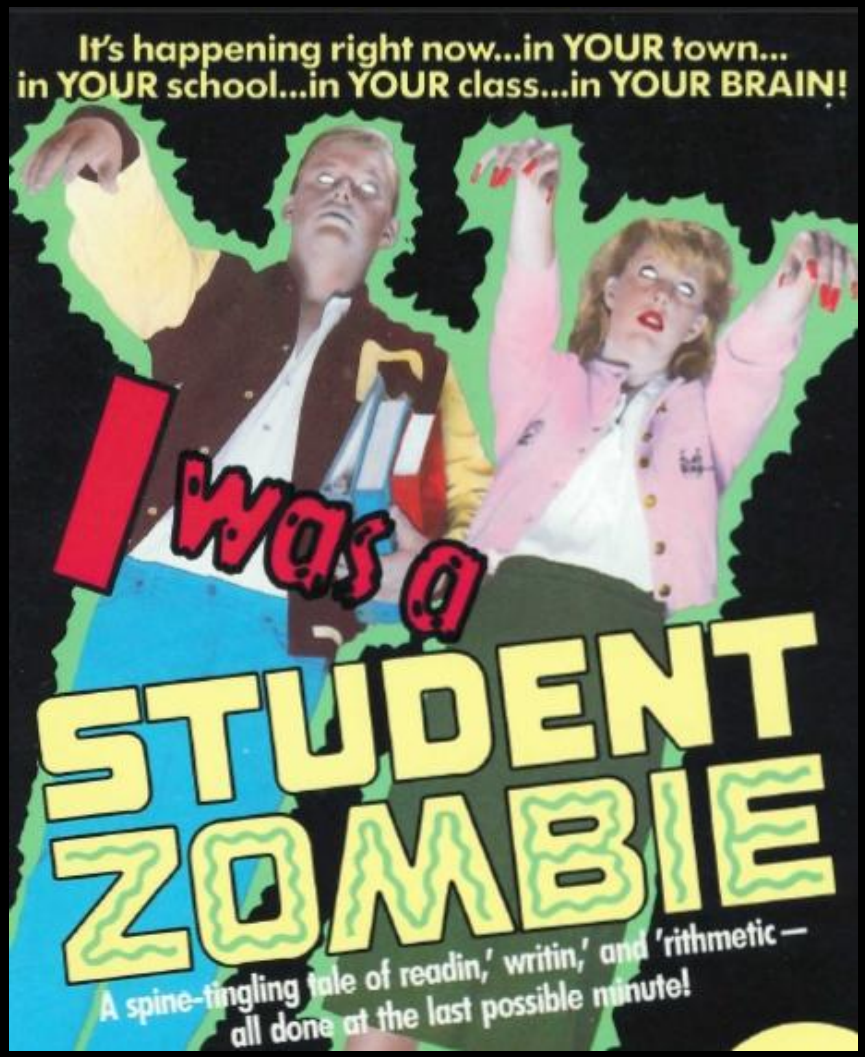


Solar Signature = Warming in the upper atmosphere & cooling in the Troposphere . . .

What has been observed since 1980?



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



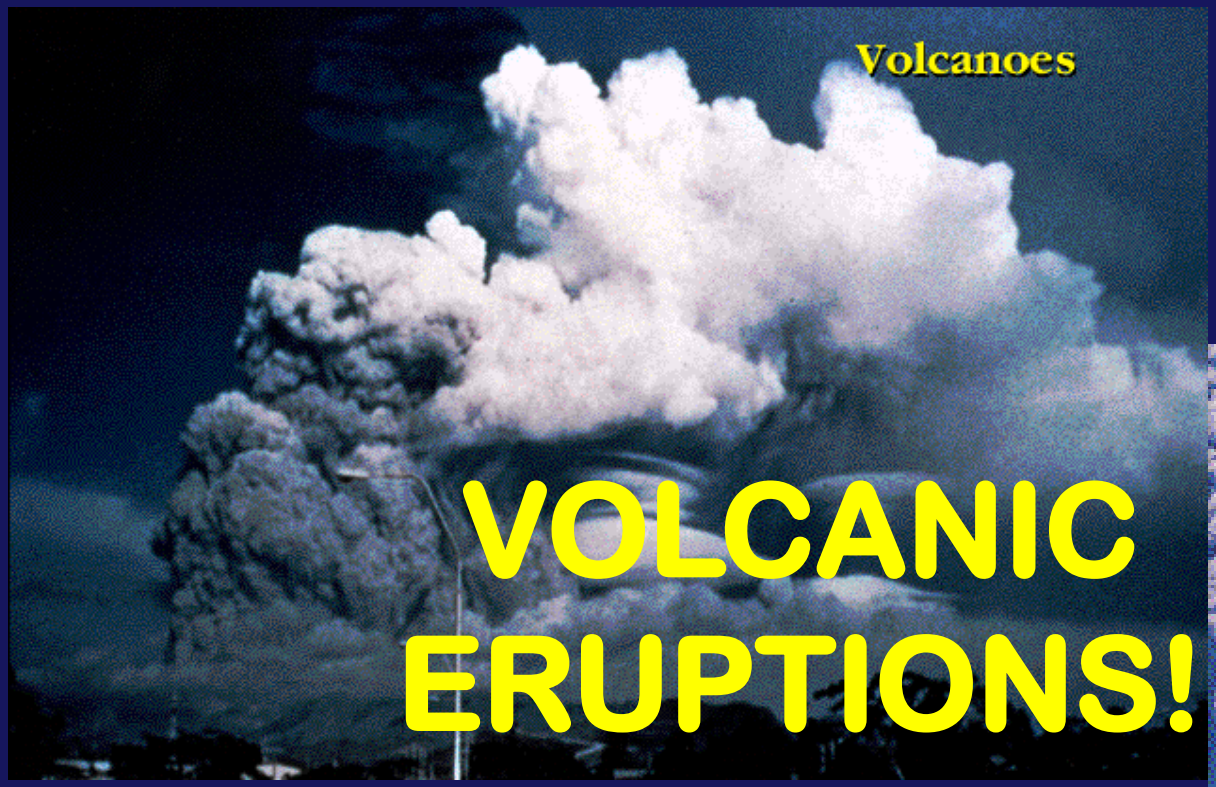
ZOMBIE BREAK !

TEXAS SHOWDOWN

Google and Microsoft's newest rivalry: renewable energy

http://qz.com/143251/google-and-microsofts-newest-rivalry-renewable-energy/

Texas wind farm operators are feeling lucky. *Robert Nickelsberg/Getty*



VOLCANIC ERUPTIONS!

Volcanoes are one way the Earth gives birth to itself.

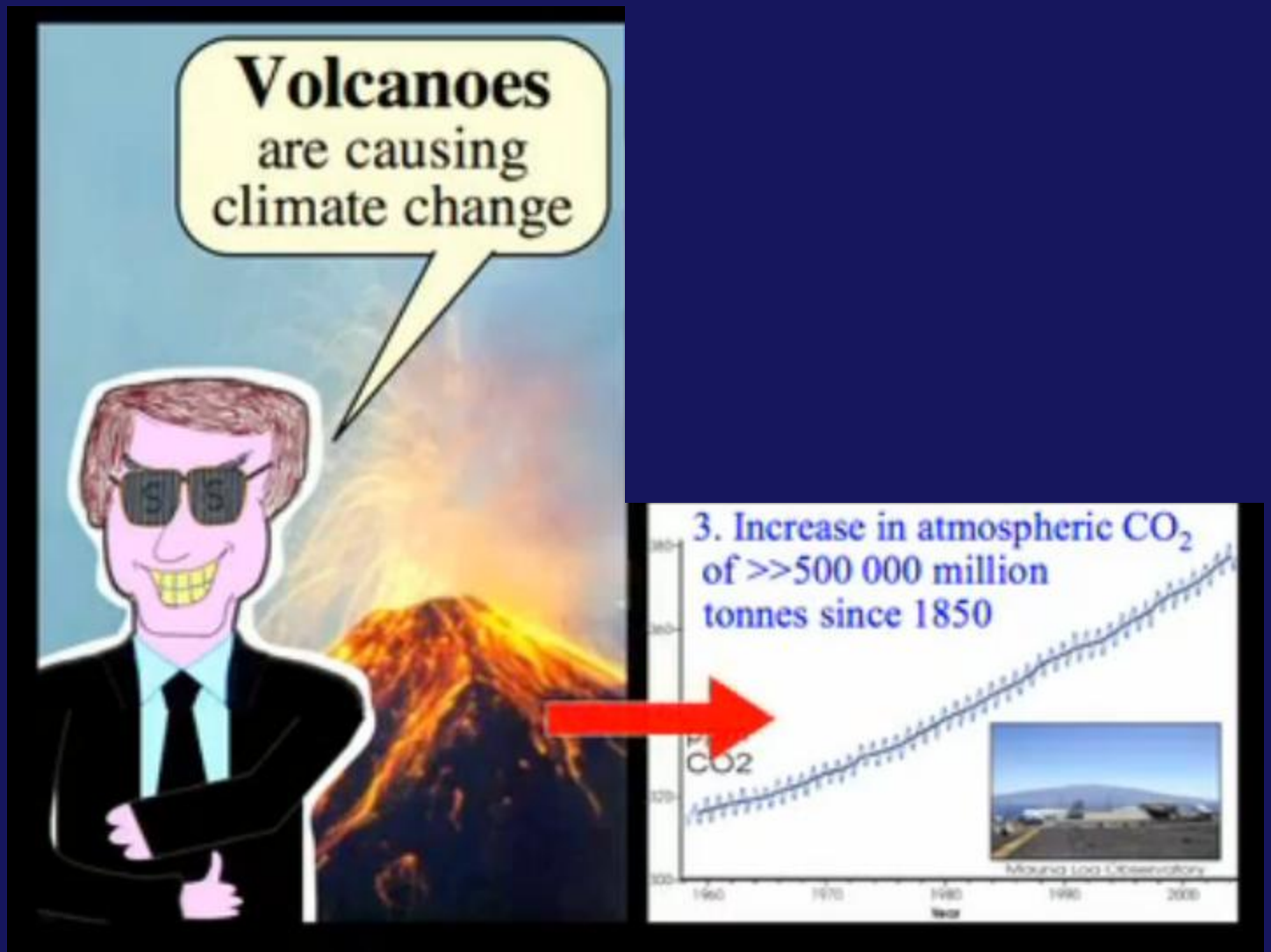
~Robert Gross

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

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



Q3 – 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

Q3 – Are volcanic eruptions an important cause of recent global warming?

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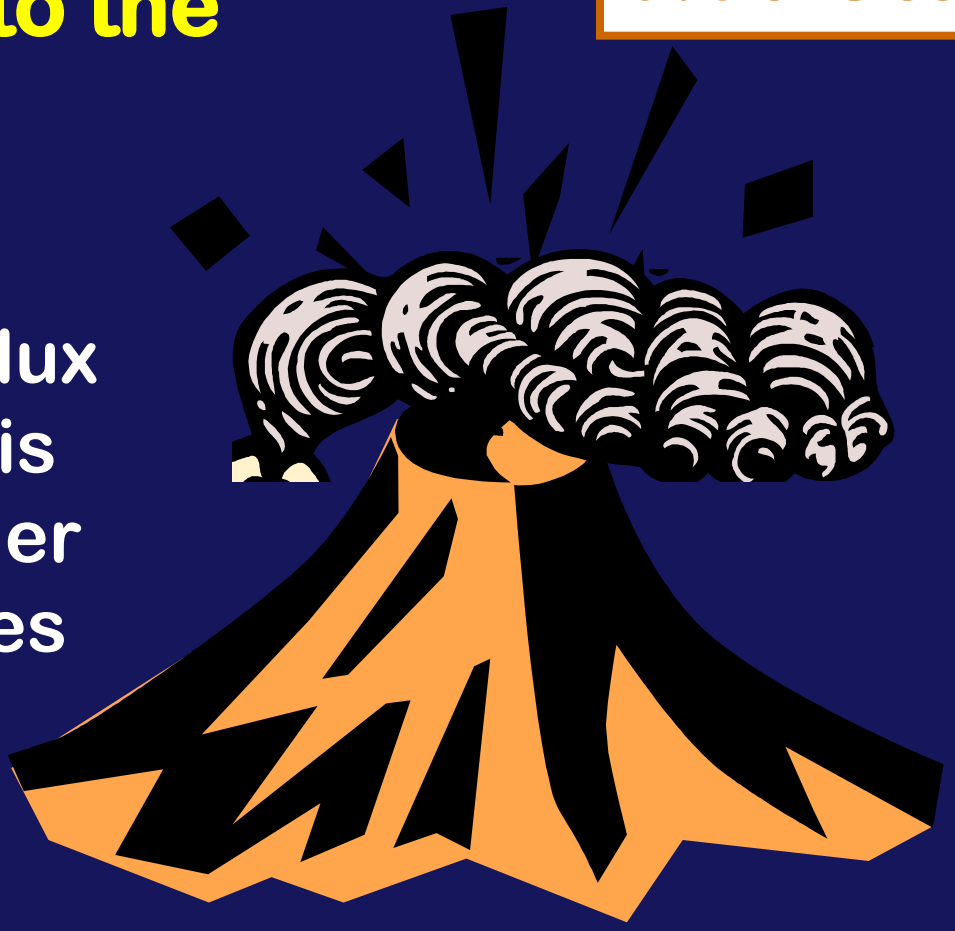
Carbon flux from volcanic eruptions
What about the CO_2 emitted into the atmosphere?

Volcanic outgassing of CO_2 into atmosphere

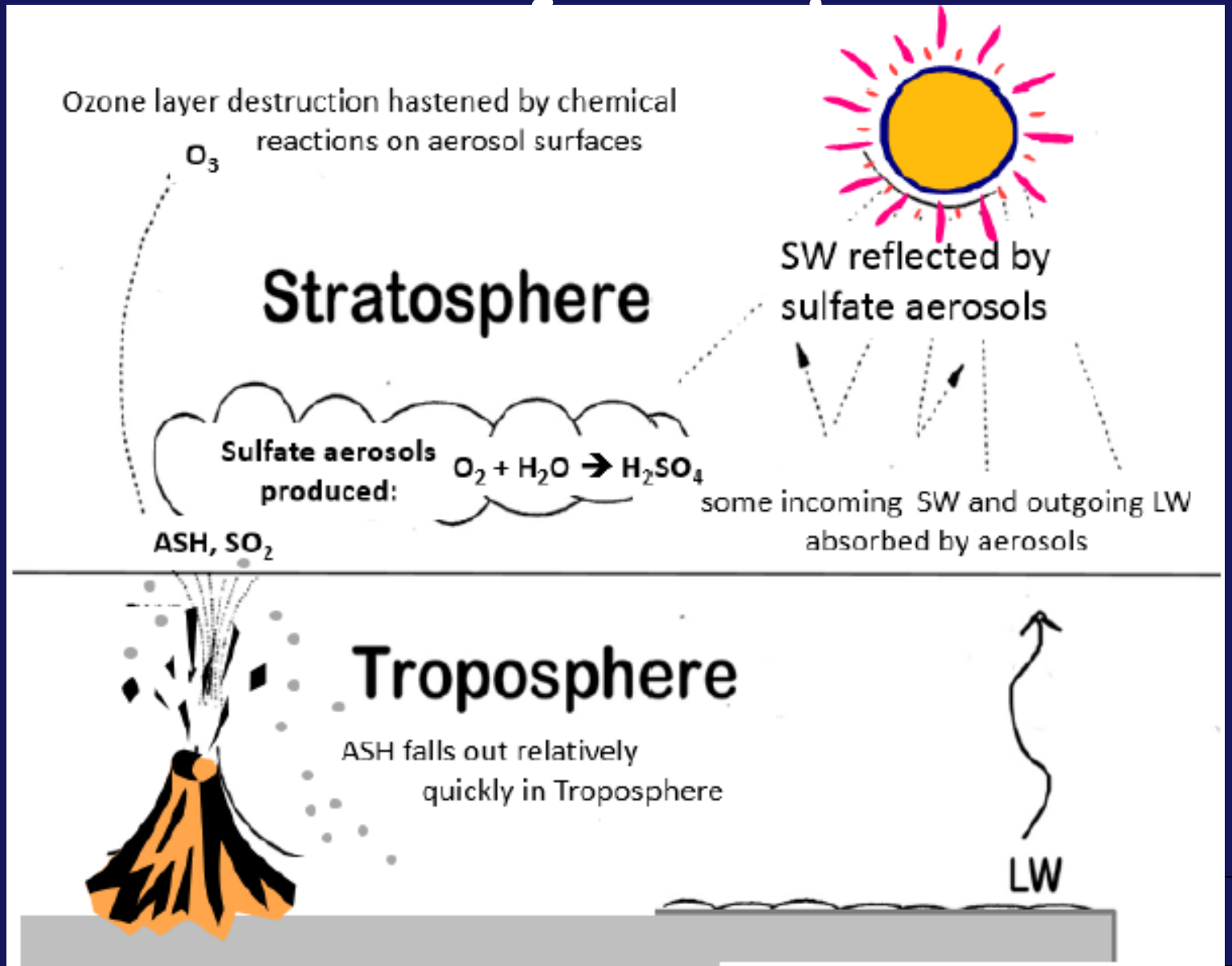
0.06 Gtons



Over time, this natural carbon flux balances out & is absorbed by other 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



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

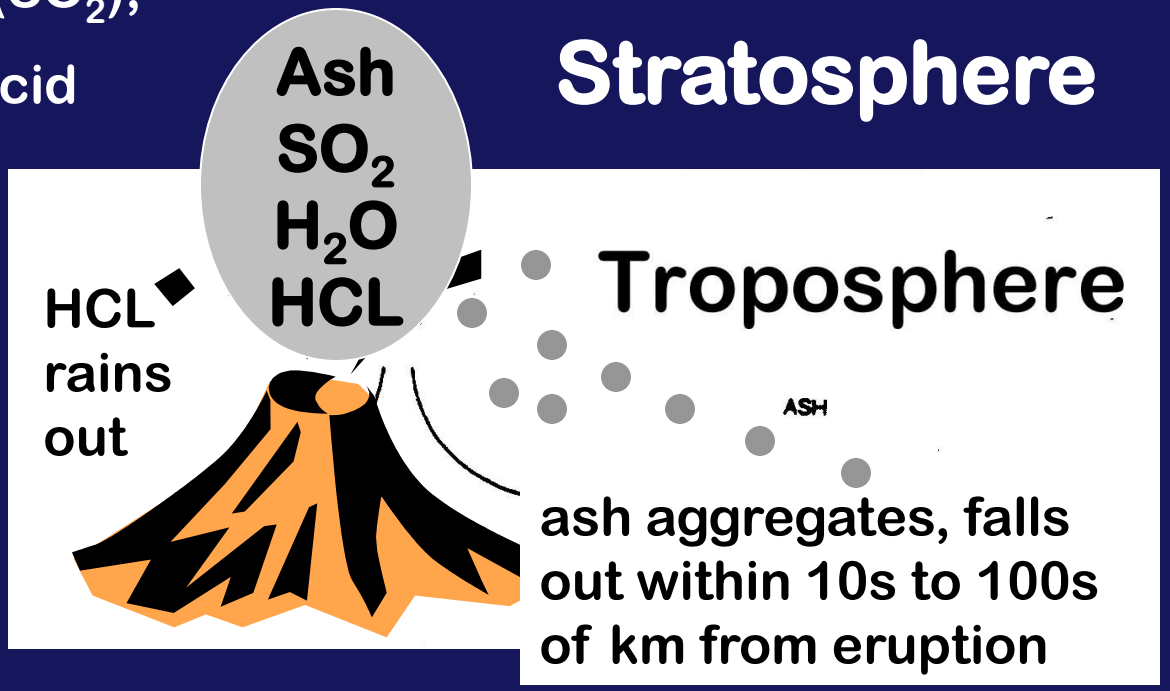
water vapor (H_2O)

sulfur dioxide (SO_2),

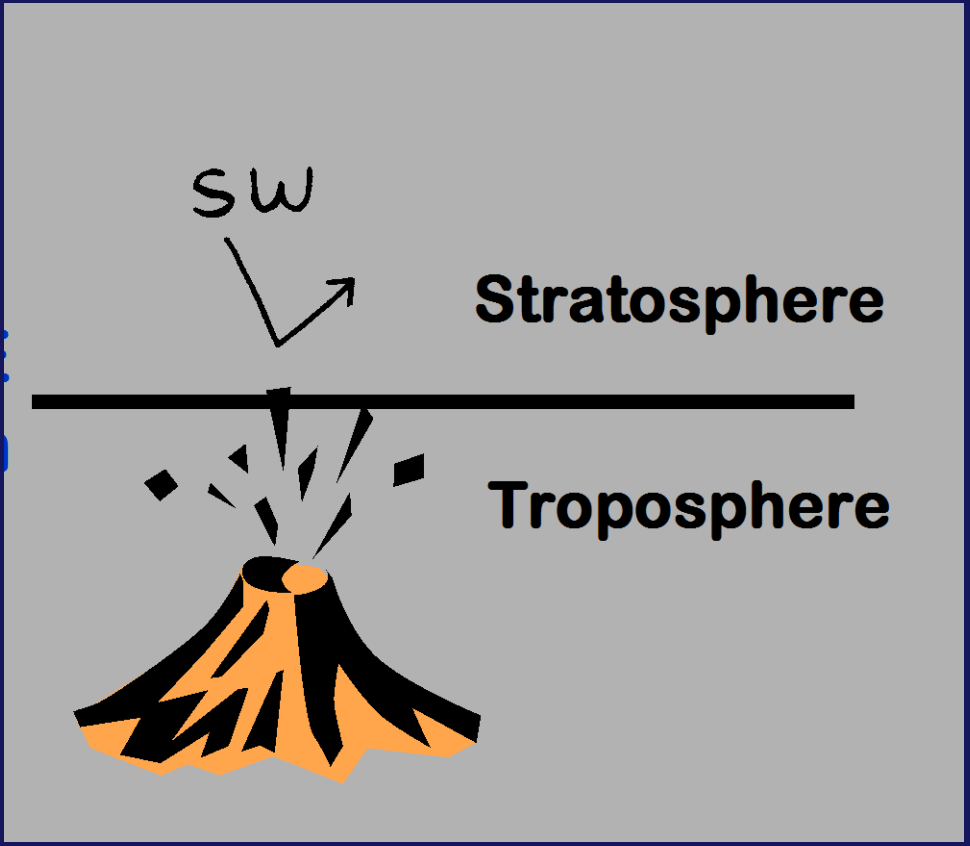
hydrochloric acid (HCl)

mineral ash

into the stratosphere

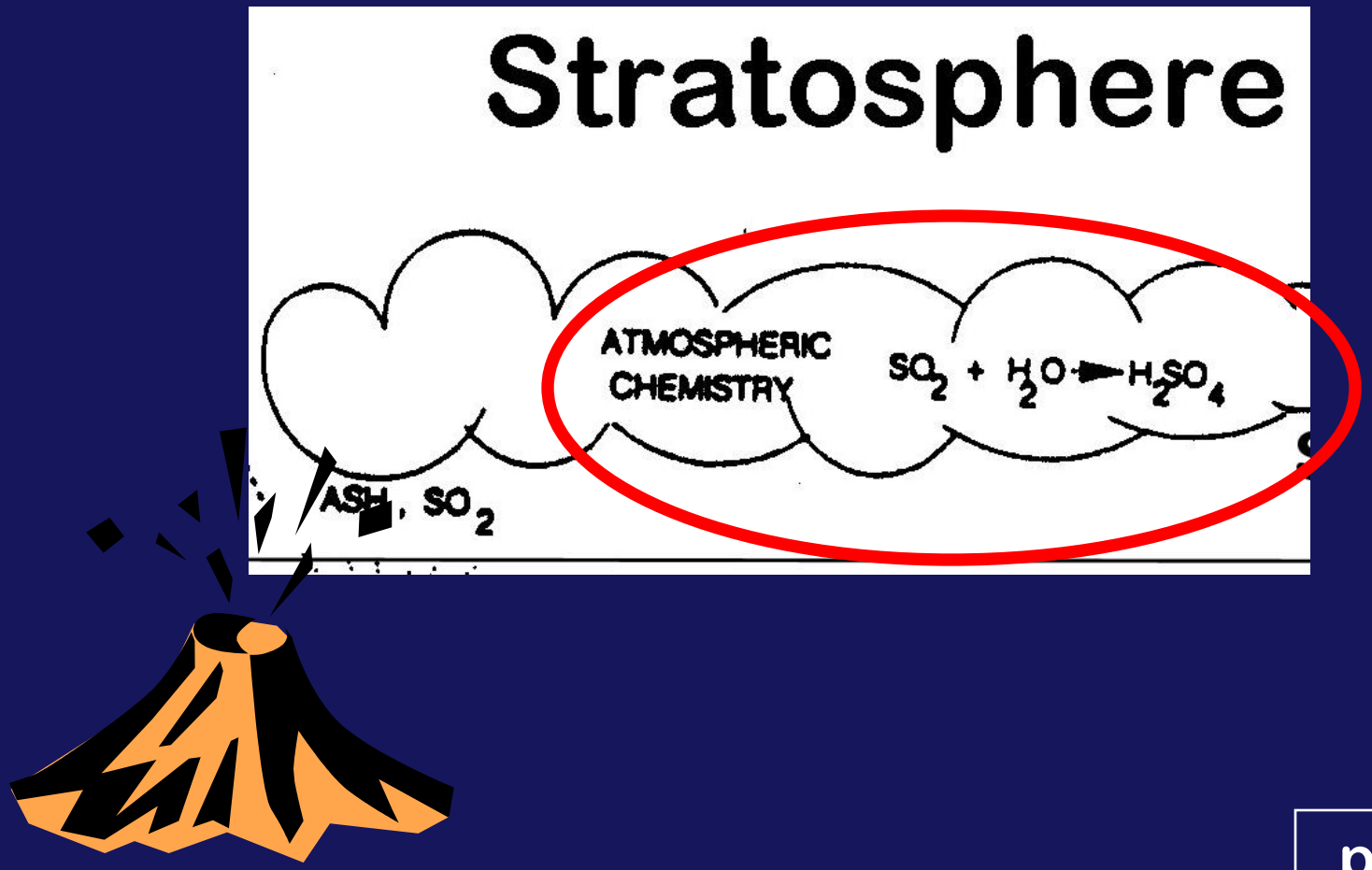


Albedo of ejected ASH in the STRATOSPHERE is *not* the reason for cooling after an eruption!
(most ash falls out early)

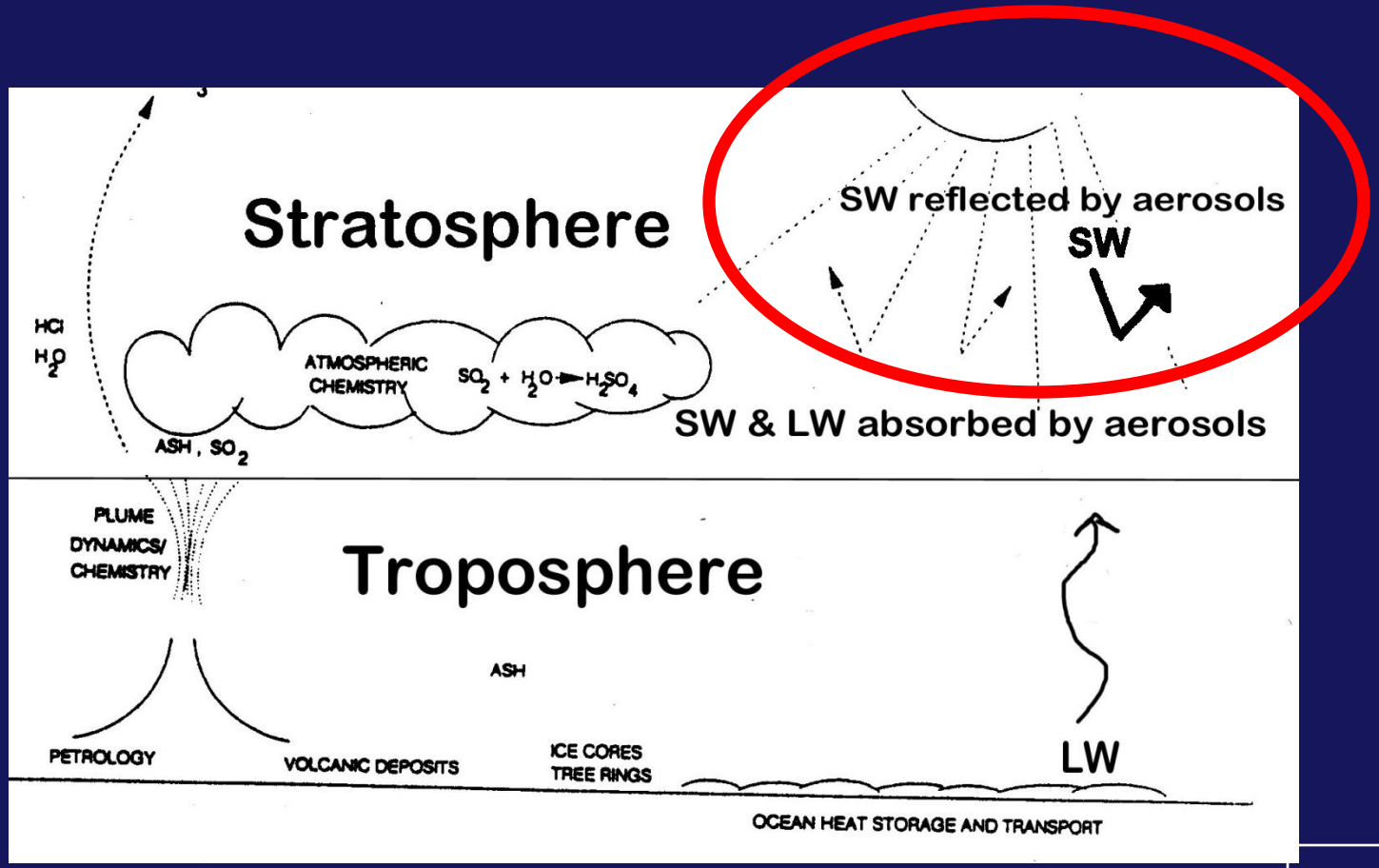


What *DOES* reflect the incoming shortwave radiation after an eruption?

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.**

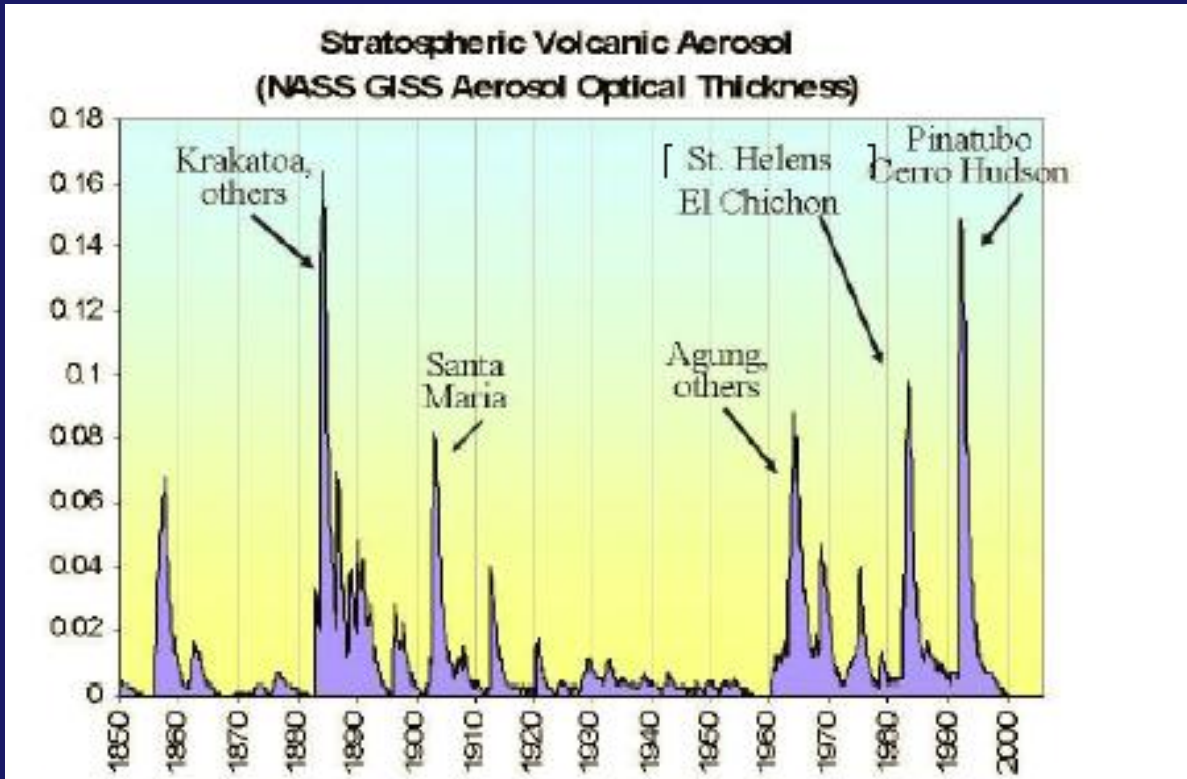


the sulfate aerosols *reflect* some of the incoming solar SW radiation back to space, cooling the troposphere below



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

Graph is on p 79 in Class Notes

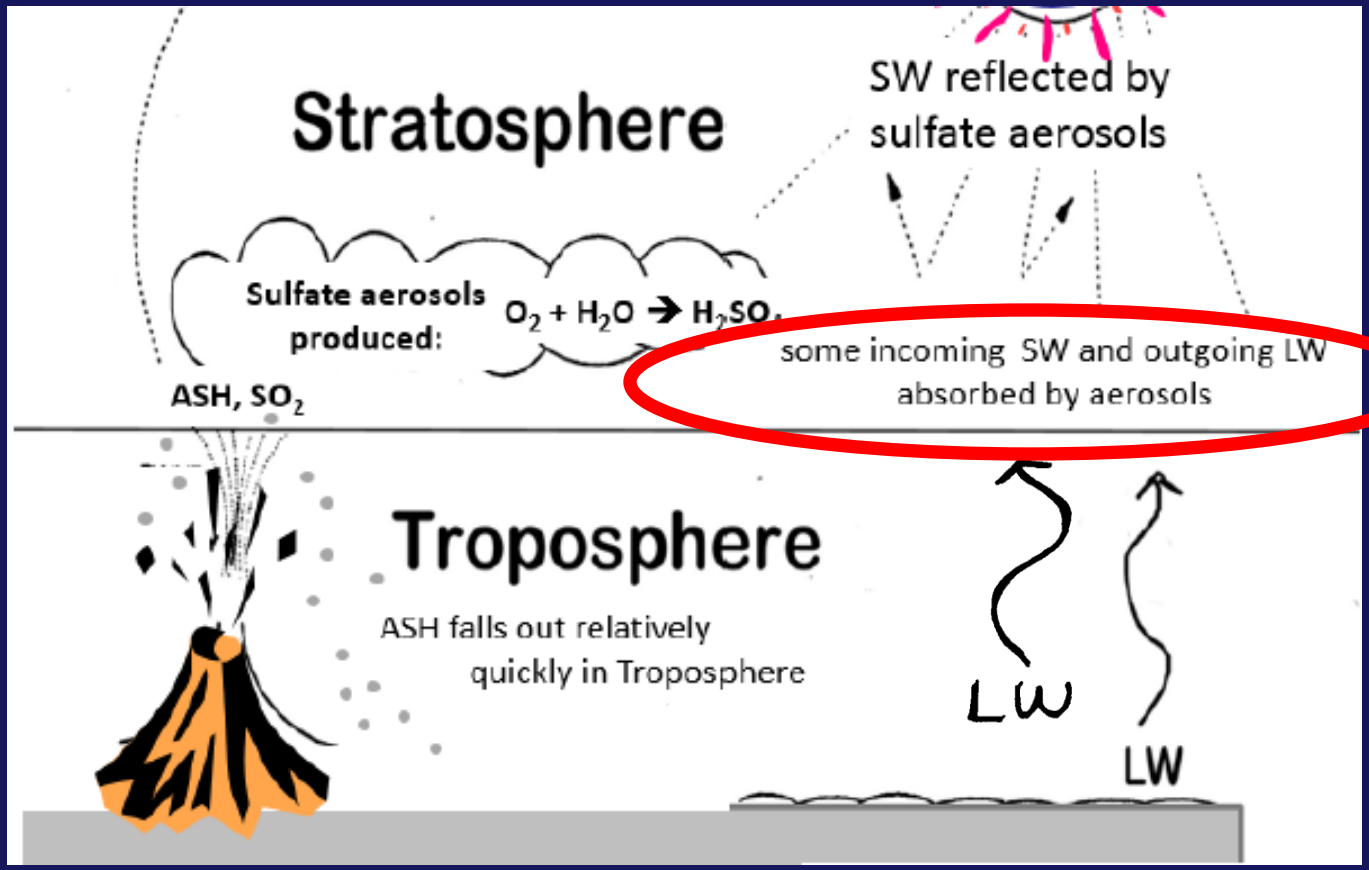


Volcanic aerosols in the high atmosphere block solar radiation and increase cloud cover leading to widespread cooling, especially significant in summer

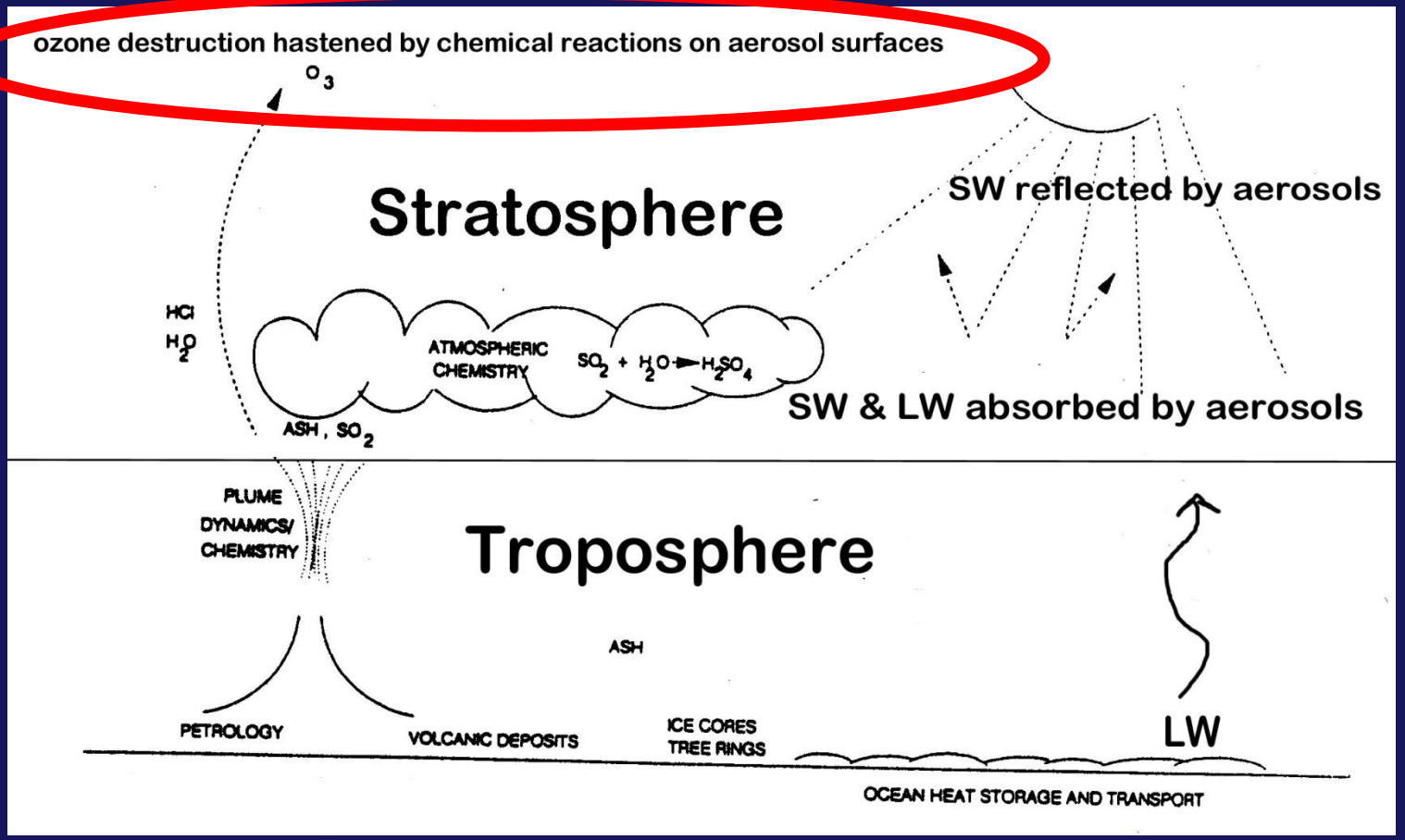
SOME MAJOR VOLCANIC ERUPTIONS OF THE PAST 250 YEARS:

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)



Q24- 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

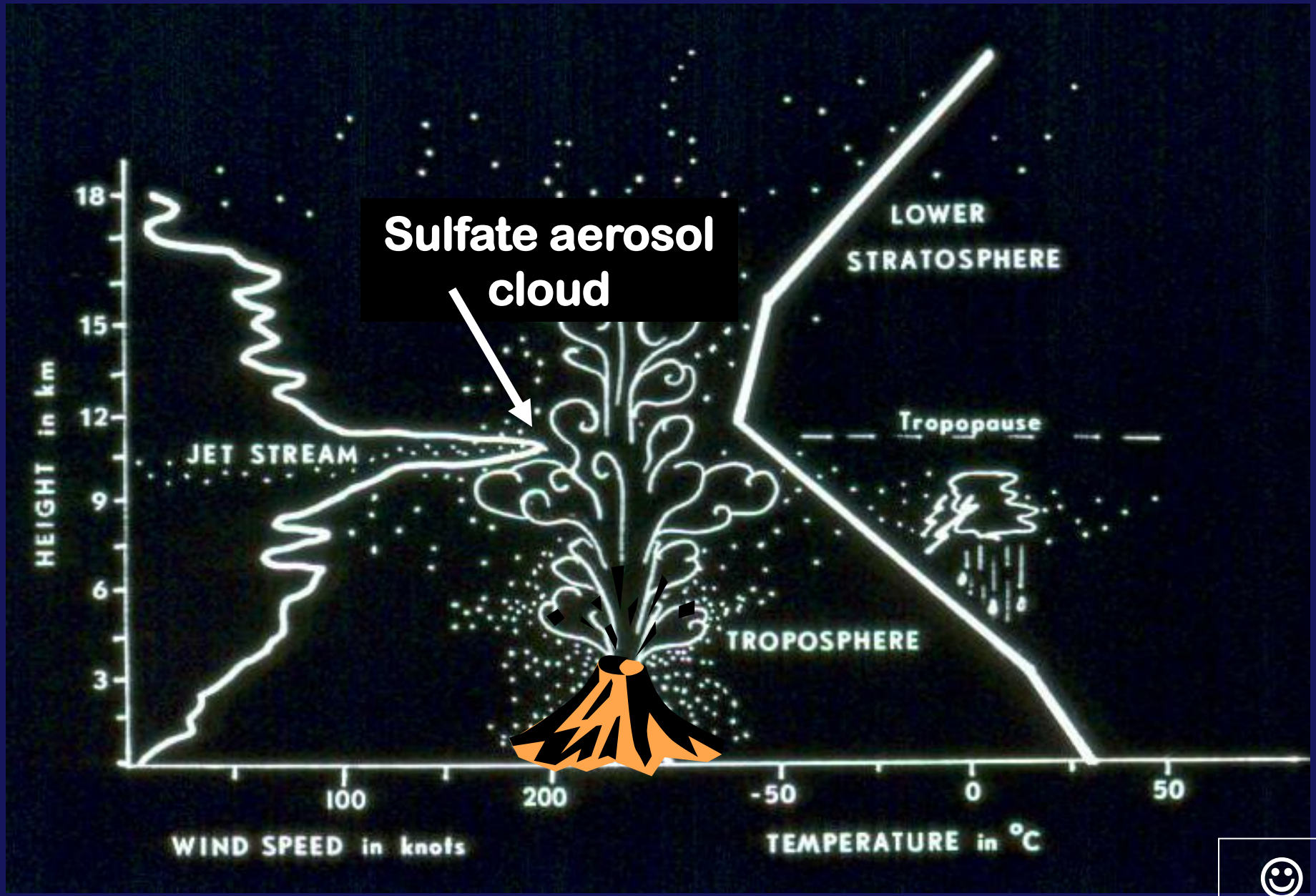
2 – The aerosols in the stratosphere get circulated around the globe by winds , which influences the radiation balance globally

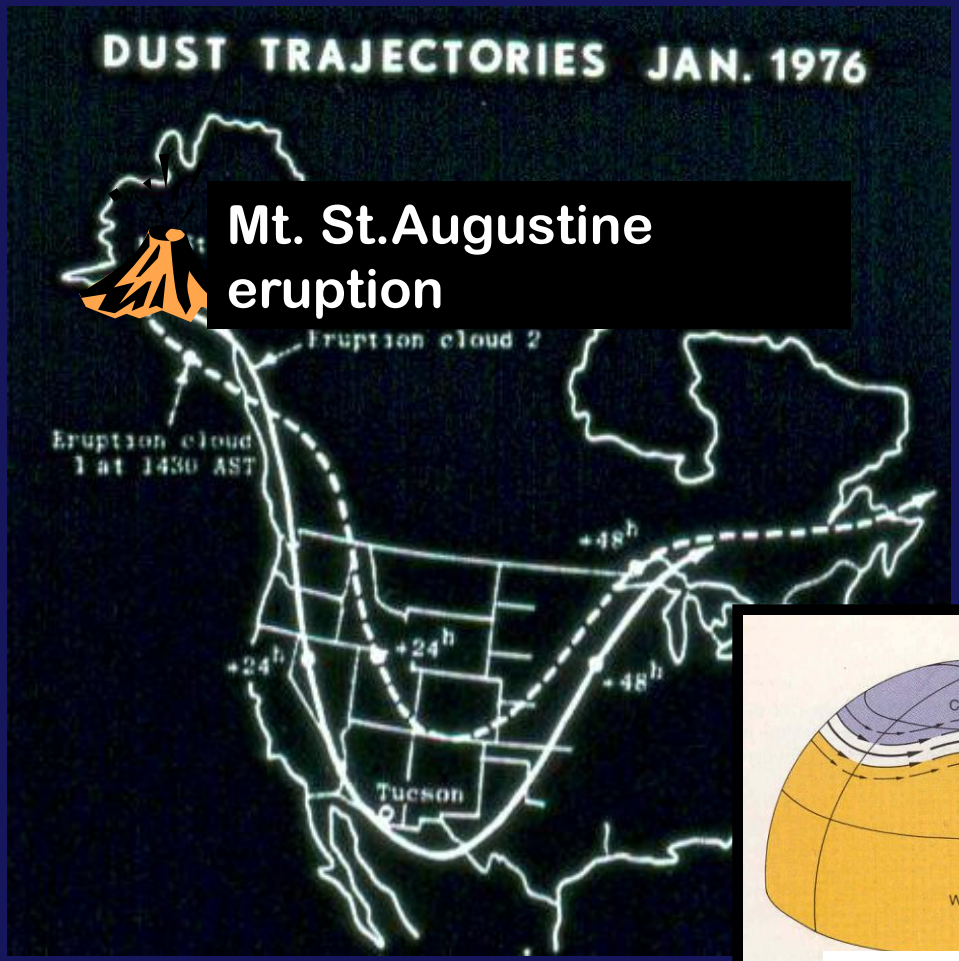
Q4 - How do you think an eruption in one spot on earth have a GLOBAL COOLING effect?

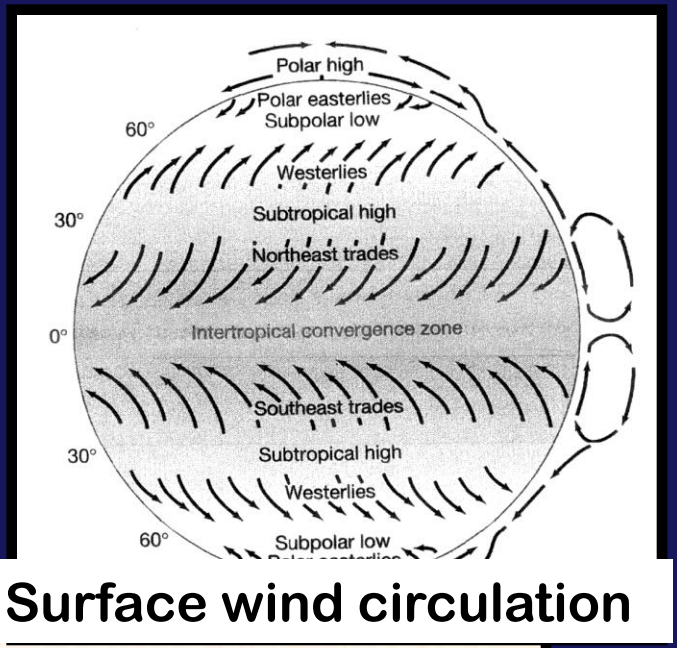
1- The cold air from the eruption's local cooling effect gets circulated to other locations around the globe by winds

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

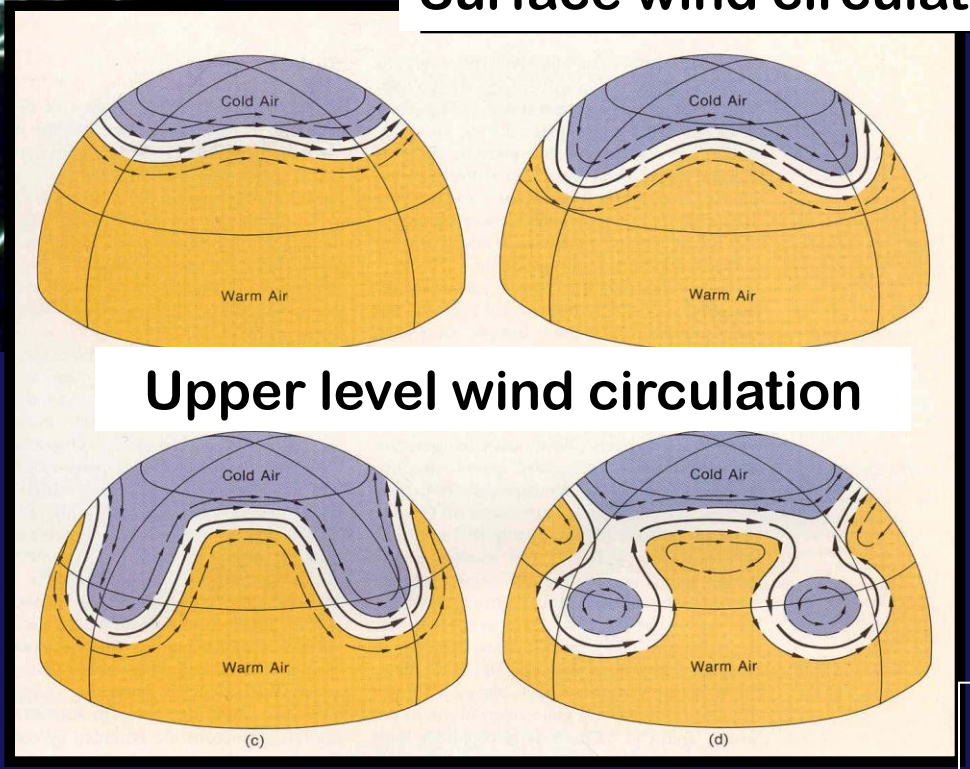
How an eruption's effects can become GLOBAL:





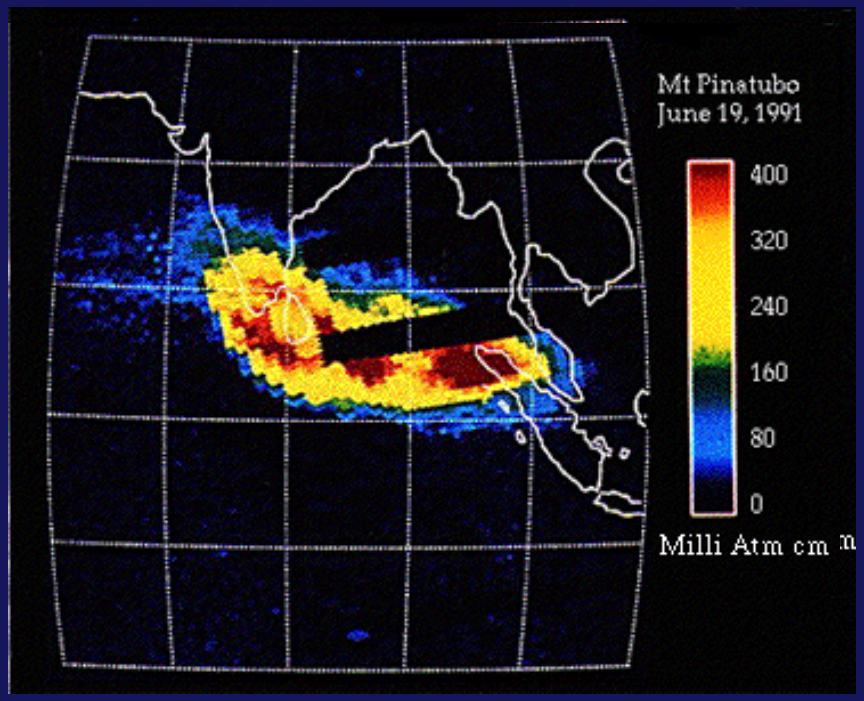


Surface wind circulation



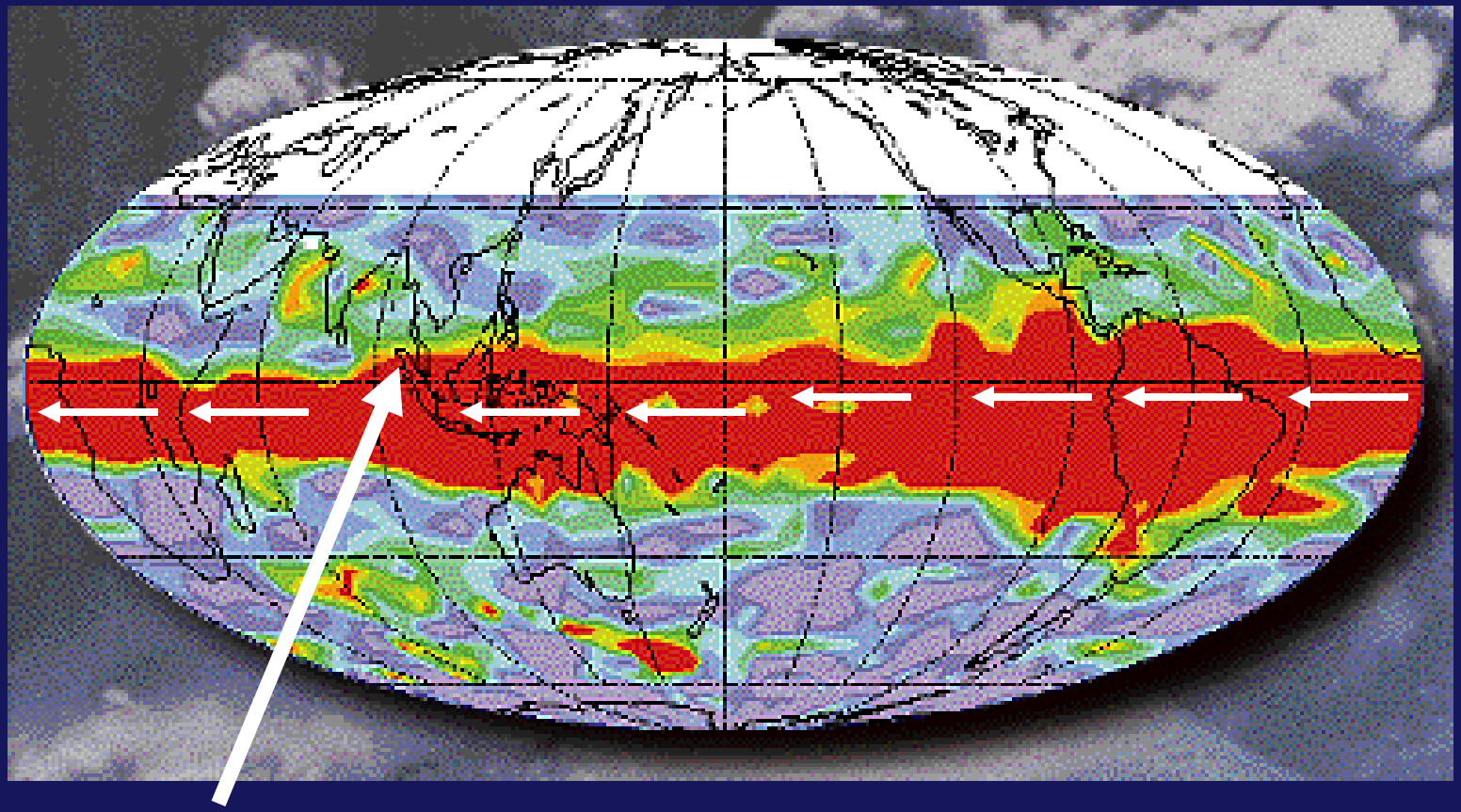
Through the atmospheric circulation!

Mt Pinatubo Eruption in the Philippines, June, 1991



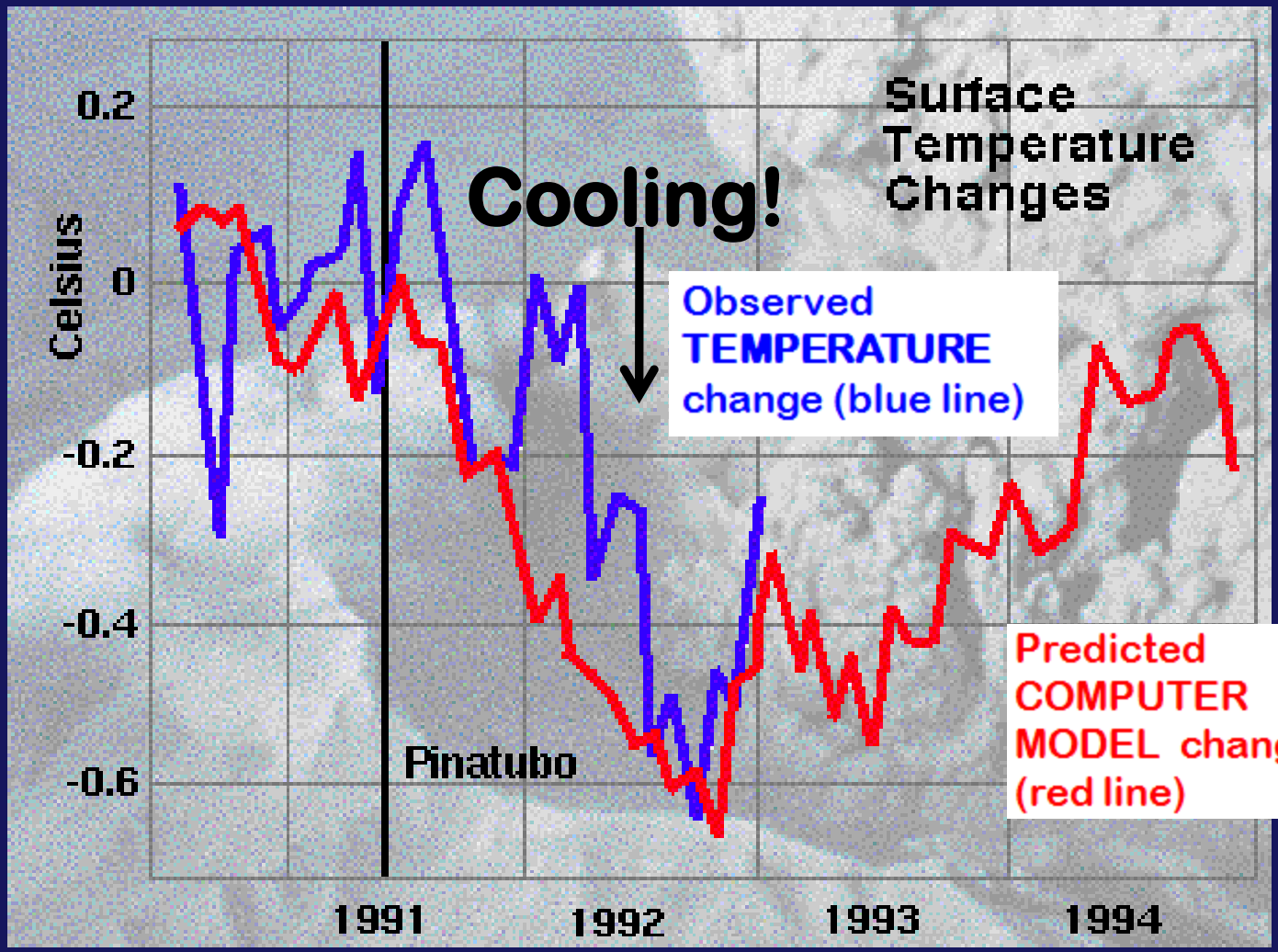
Satellite-derived image of
sulfur dioxide thickness in the atmosphere
red = higher thickness

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

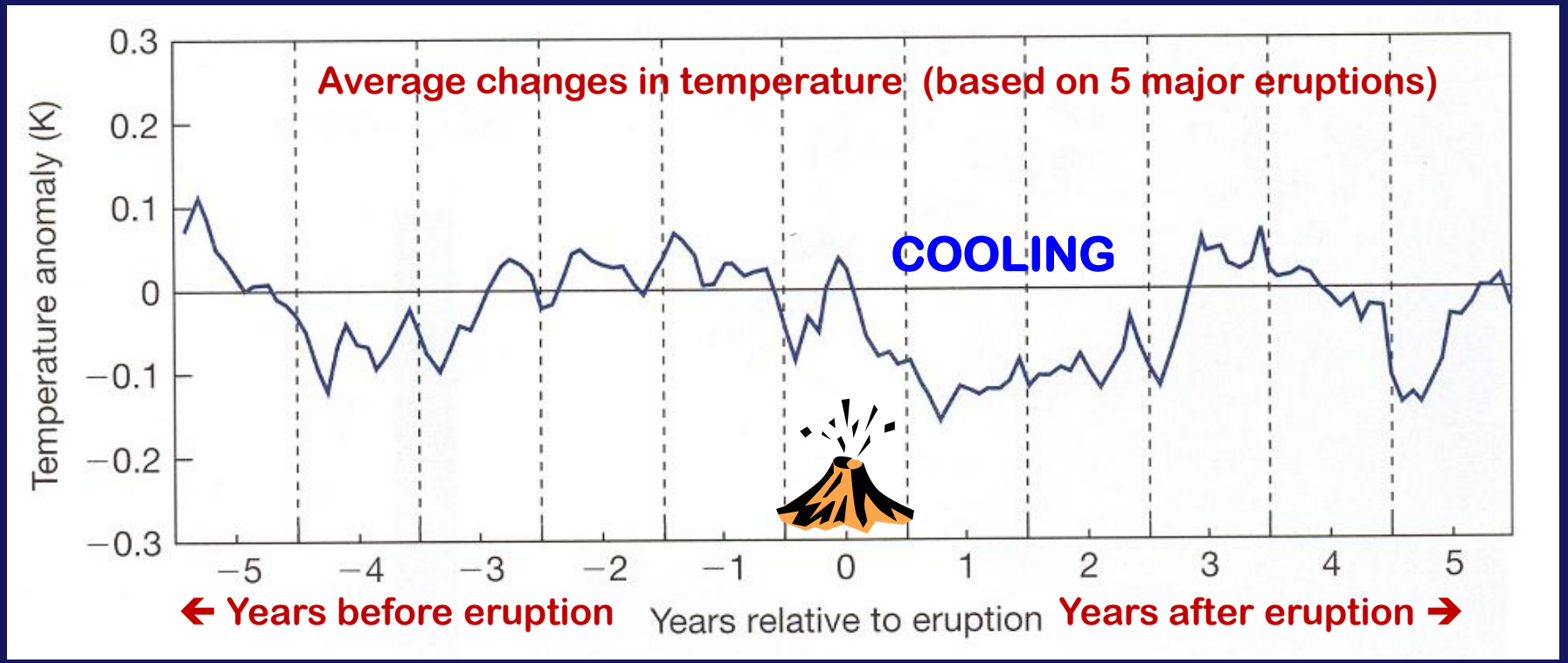


Mt Pinatubo

Mt Pinatubo eruption June 1991



Typical Global Cooling Pattern after a major explosive Volcanic Eruption



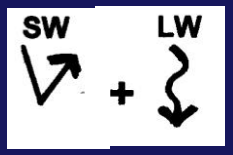
This graph shows the global mean temperature changes for years before (-) and after a large eruption (at year zero)

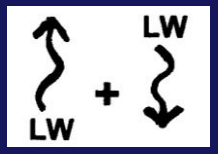
WHICH ERUPTIONS ARE THE MOST CLIMATICALLY EFFECTIVE?

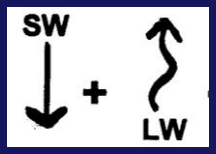
- EXPLOSIVE
- high SULFUR content in magma
- whose eruption clouds inject into the STRATOSPHERE
- Low Latitude Eruptions

QUICKIE
TEST #3 REVIEW:

Q5. The Greenhouse effect is represented by which symbol?

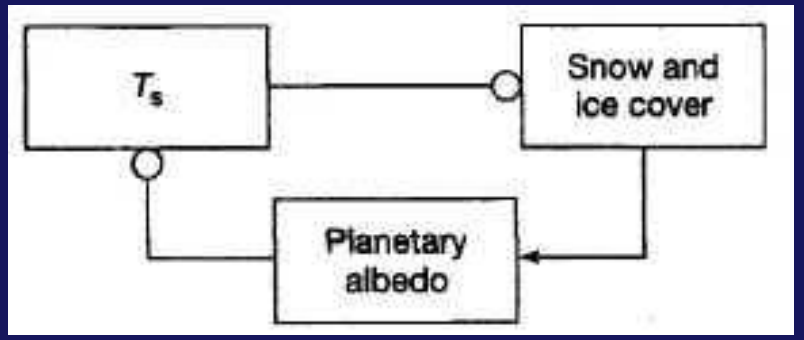
1. This one: 

2. This one: 


3. This one: 

4. H + G
5. None of the above

Q6. 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!

Q7. 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

SEE YOU ON THURSDAY!