

**TOPIC # 15**  
**GLOBAL WARMING &**  
**ANTHROPOGENIC**  
**FORCING**

Part B

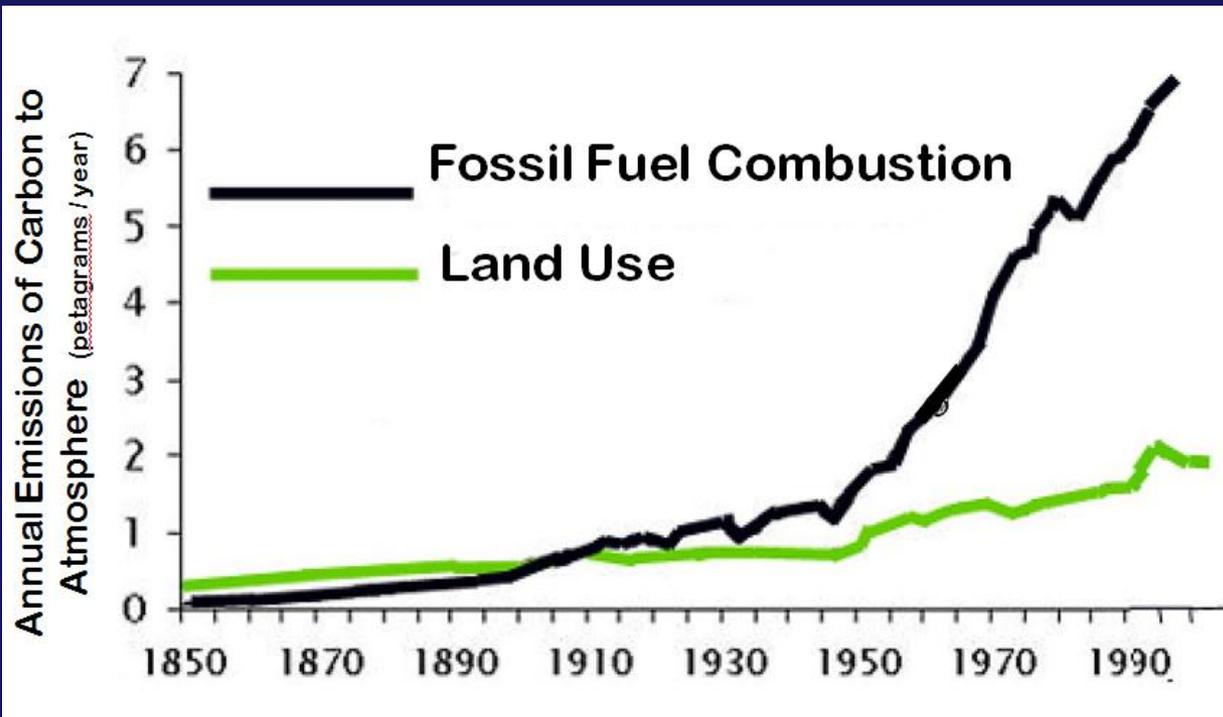
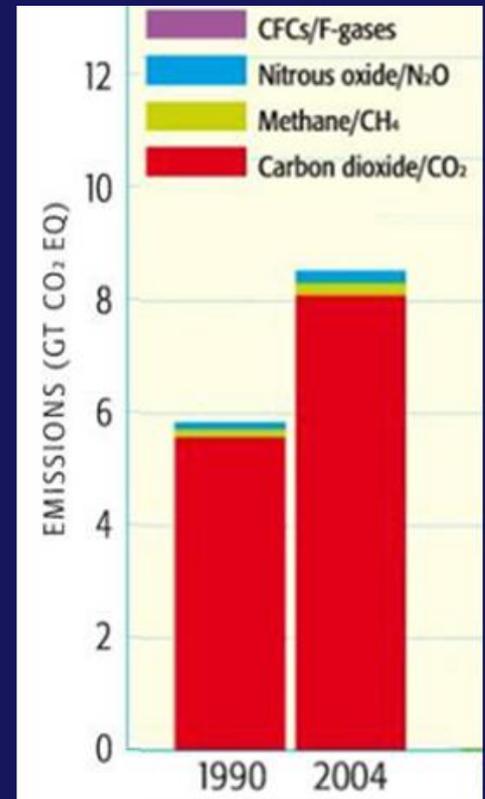
*The Key To It All:*

**SORTING OUT THE RADIATIVE**  
**FORCINGS OF CLIMATE**

Class Notes p 83



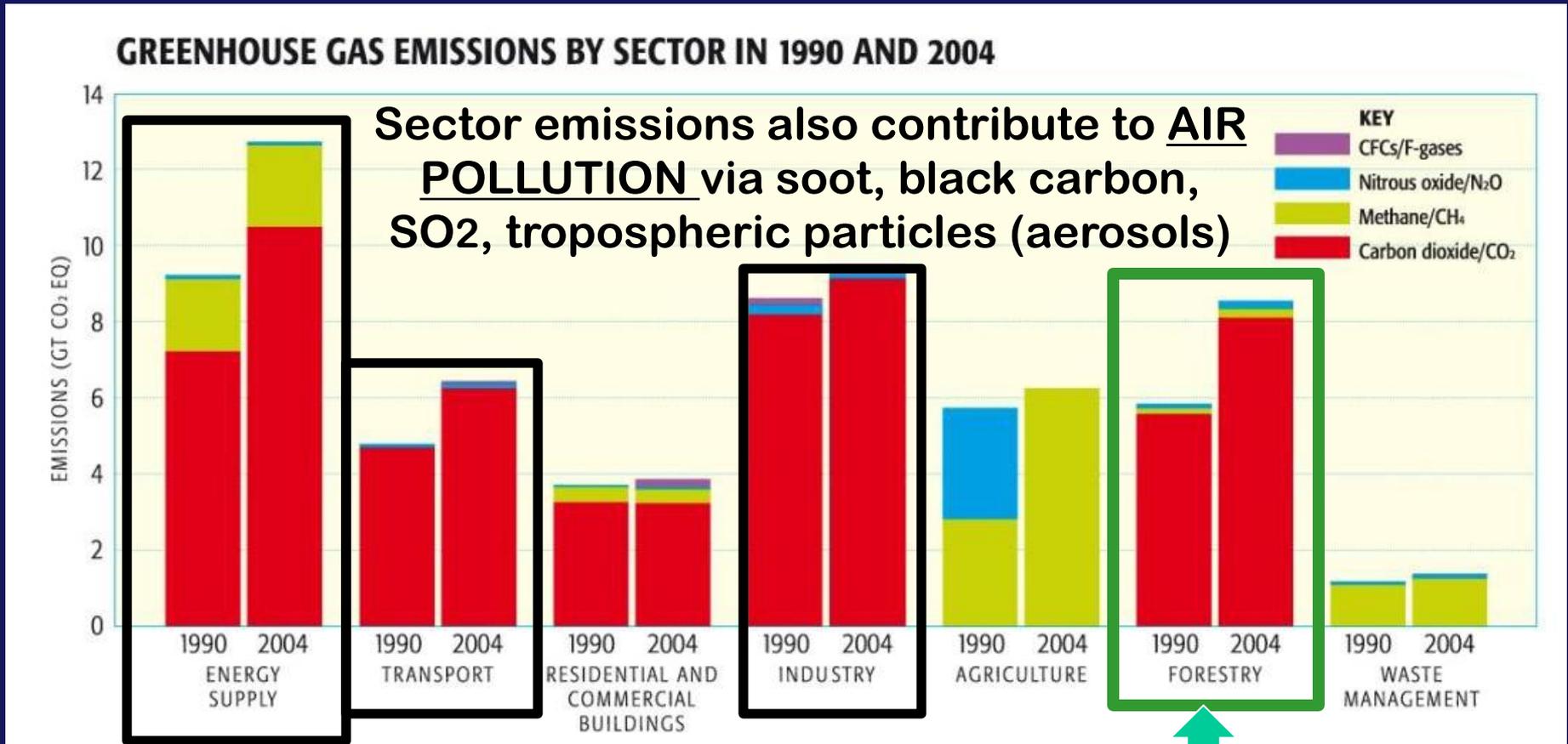
# Greenhouse Gas emissions from Forestry → (Deforestation, biomass burning)



GHG's, soot, SO<sub>2</sub>



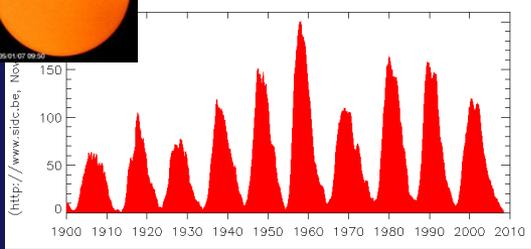
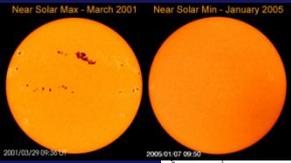
# Where do all those OTHER Greenhouse Gas emissions come from?



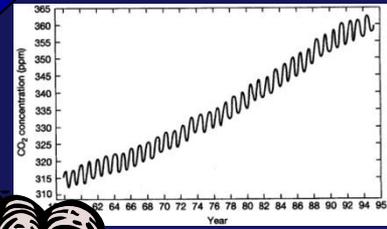
see 159  
in *Dire Predictions*

**CO<sub>2</sub> emissions from DEFORESTATION & BIOMASS BURNING**

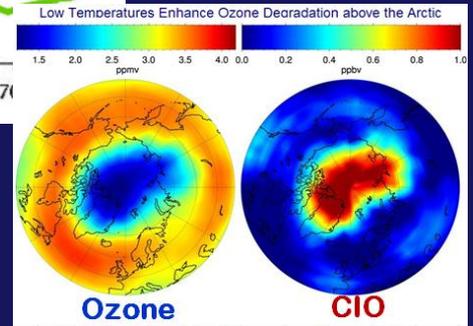
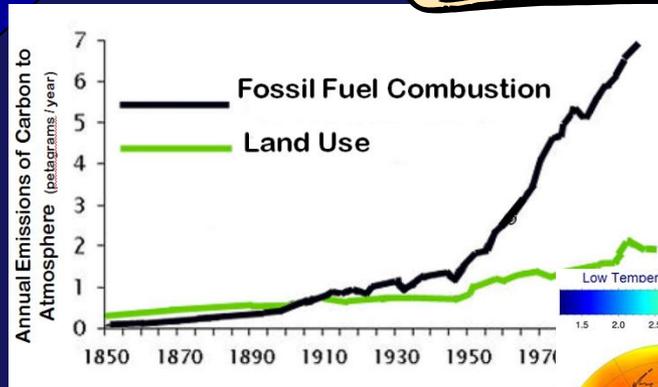
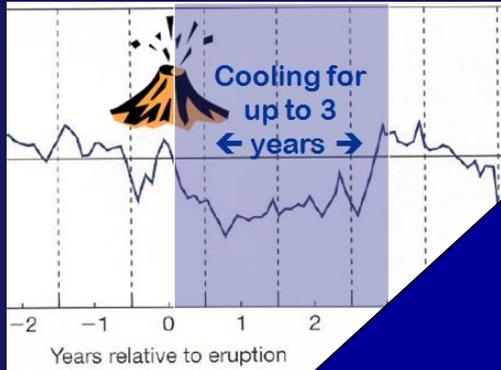
# NATURAL FORCING



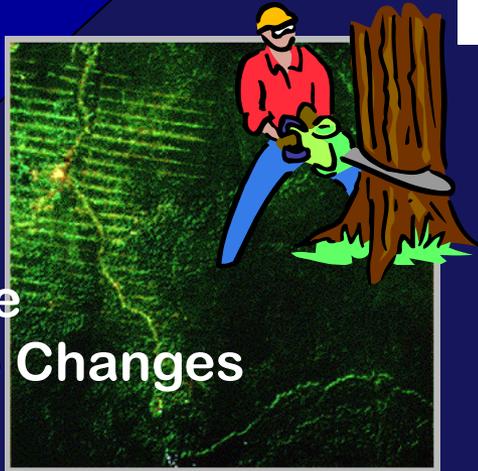
Solar output variations, sunspots



GHG's, soot, SO<sub>2</sub>



Volcanic eruptions

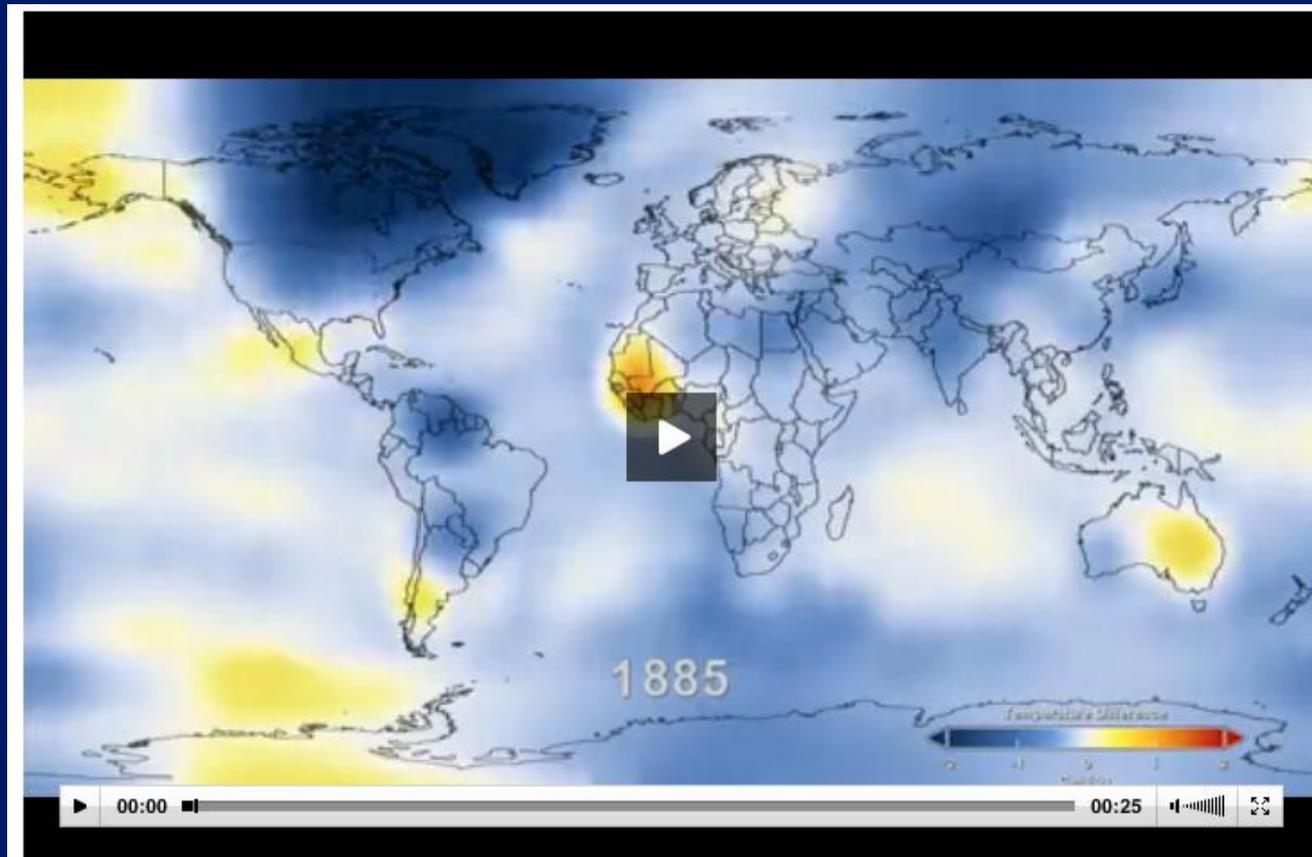


Surface Albedo Changes

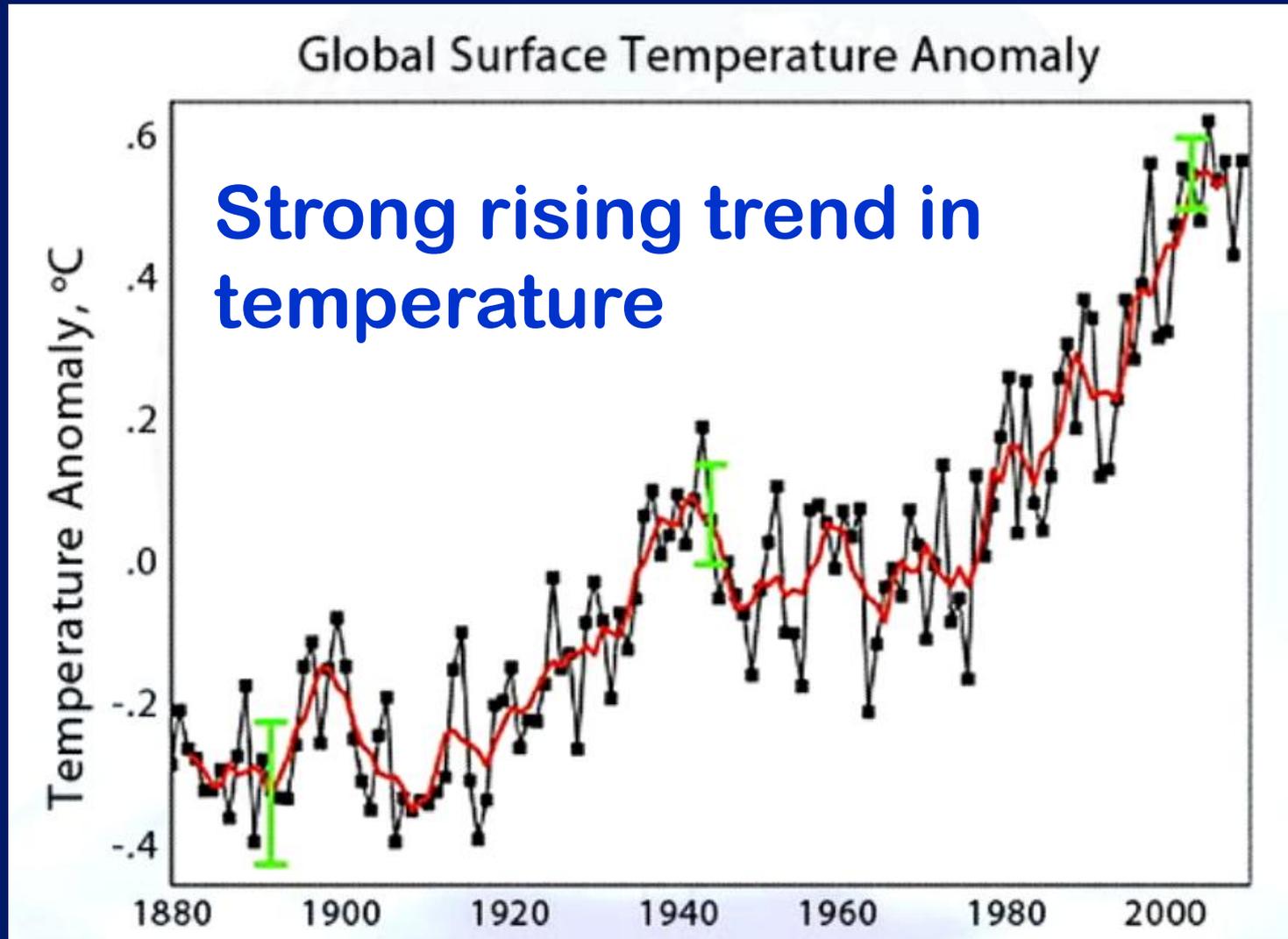
# ANTHROPOGENIC FORCING



# A Century of GLOBAL WARMING in 26 seconds



<http://www.biologicaldiversity.org/news/center/articles/2012/nasa-01-19-2012.html>



*Today's topic:*

## RADIATIVE FORCING

(linked to the Energy Balance!)

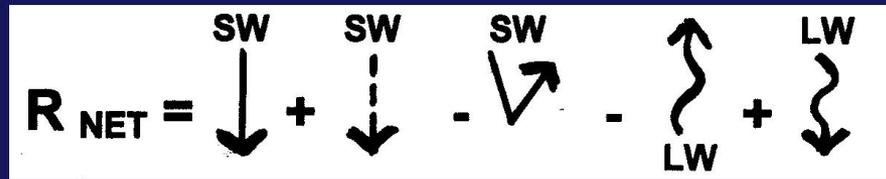
$$R_{\text{NET}} = \begin{array}{c} \text{SW} \\ \downarrow \\ \text{+} \\ \text{SW} \\ \downarrow \\ \text{-} \\ \text{SW} \\ \nearrow \\ \text{-} \\ \text{LW} \\ \uparrow \\ \text{+} \\ \text{LW} \\ \downarrow \end{array}$$

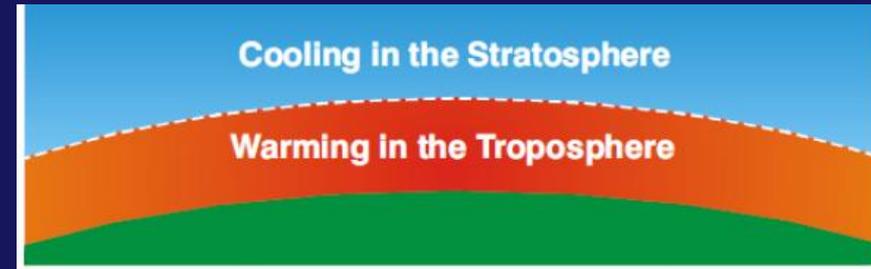
expressed in Watts per square meter ( $\text{Wm}^{-2}$ ) = ENERGY!

(def) a measure of the influence a factor has in altering the balance of **incoming & outgoing energy** in the Earth-atmosphere system

... more specifically →

# Radiative Forcing is based on the ENERGY BALANCE at the TROPOPAUSE!

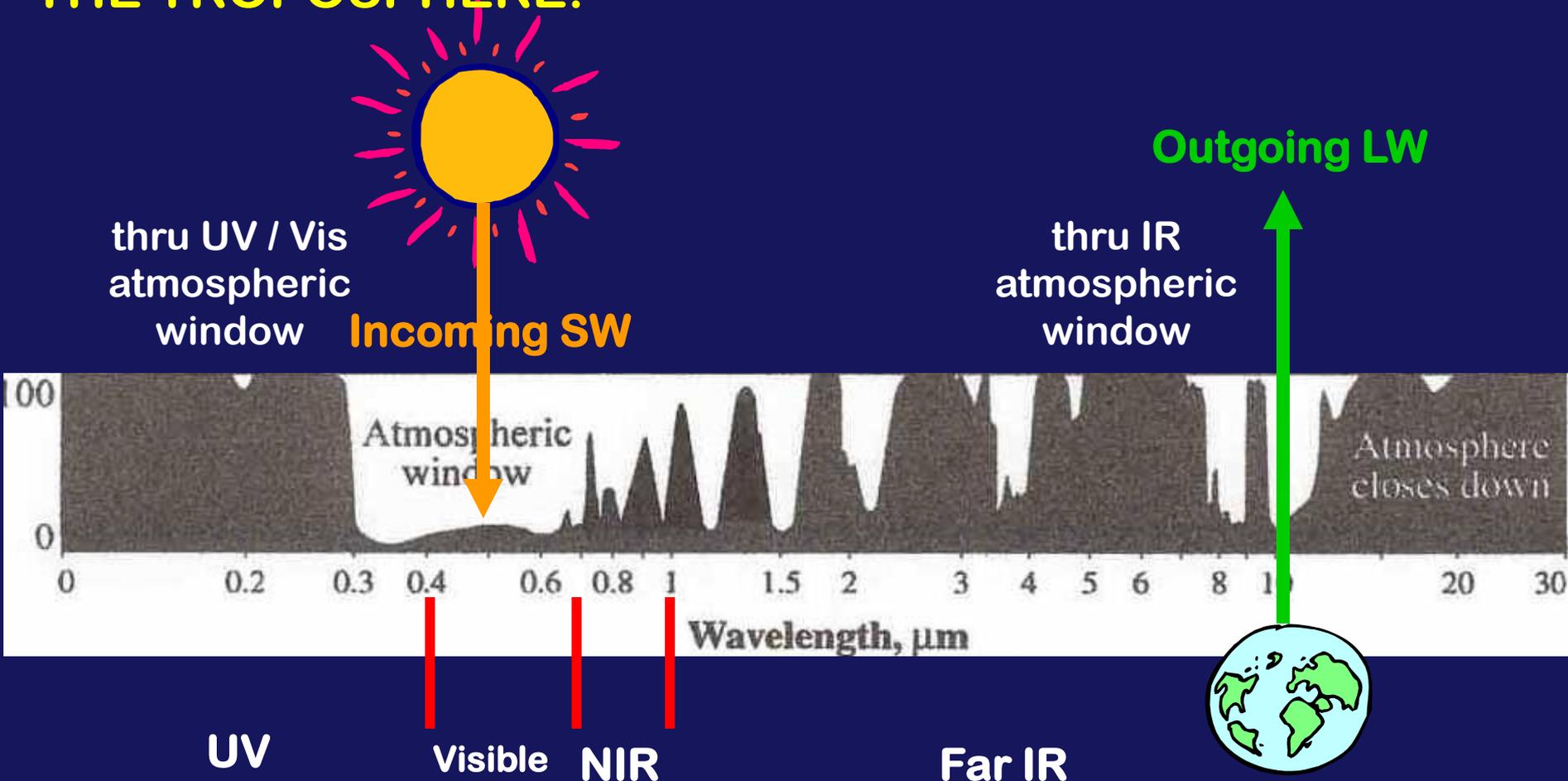
$$R_{NET} = \downarrow_{SW} + \downarrow_{SW} - \nearrow_{SW} - \uparrow_{LW} + \downarrow_{LW}$$
A diagram illustrating the components of radiative forcing. It shows the equation  $R_{NET} = \downarrow_{SW} + \downarrow_{SW} - \nearrow_{SW} - \uparrow_{LW} + \downarrow_{LW}$ . The first two downward arrows represent incoming solar radiation (SW). The third upward arrow represents outgoing solar radiation (SW). The fourth upward wavy arrow represents outgoing longwave radiation (LW). The fifth downward wavy arrow represents incoming longwave radiation (LW). A yellow arrow points from this diagram to the right.



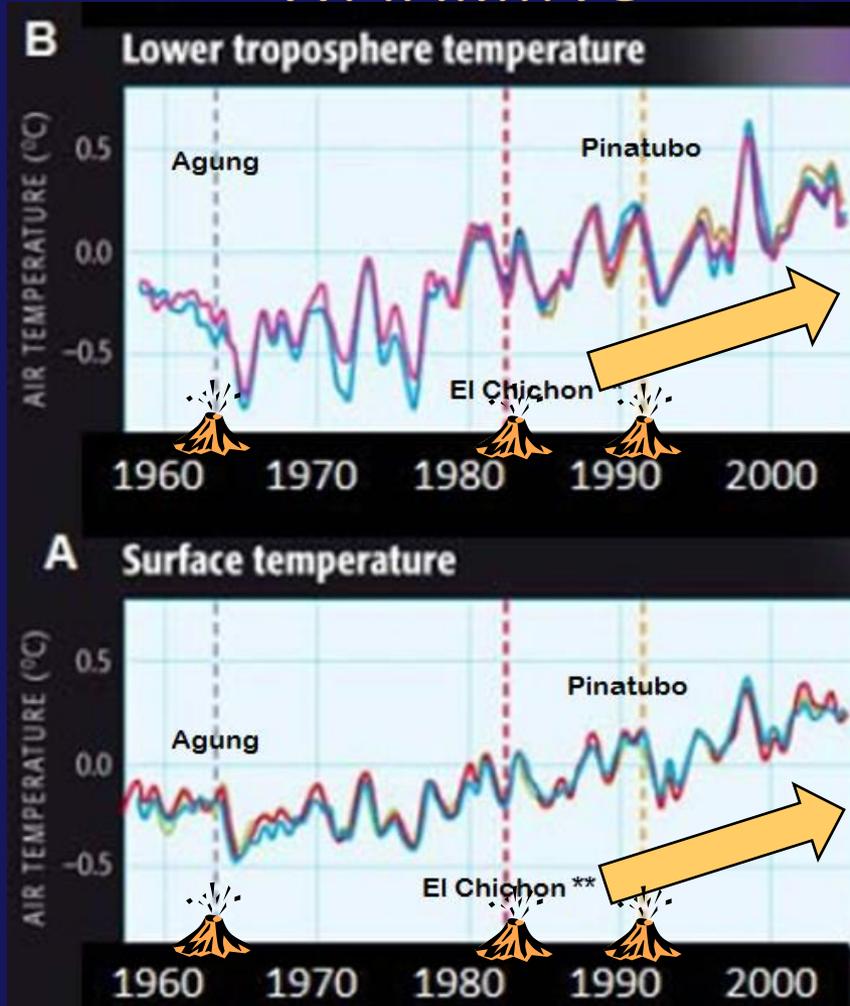
It's an index of the degree to which different factors (like GHG's) INCREASE or DECREASE the amount of energy that accumulates in the TROPOSPHERE!

# Review: Absorption curve for the "Whole Atmosphere"

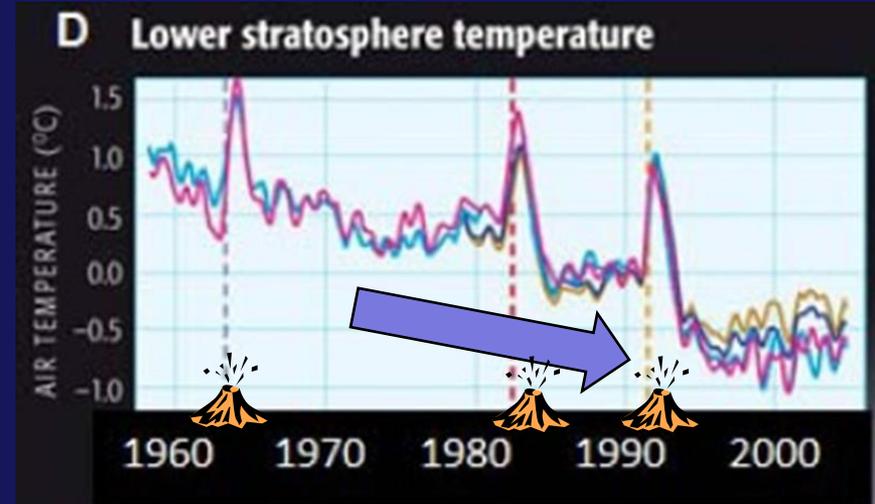
OVERALL BALANCE AT THE TROPOSPHERE: Incoming - Outgoing



*Over Last 4 decades:*  
**TROPOSPHERIC  
WARMING**



*Over Last 4 decades:*  
**STRATOSPHERIC  
COOLING**



*After eruptions:*  
**STRATOSPHERIC WARMING**

Long-term **TREND**  
is due to  
**ANTHROPOGENIC  
FORCING**

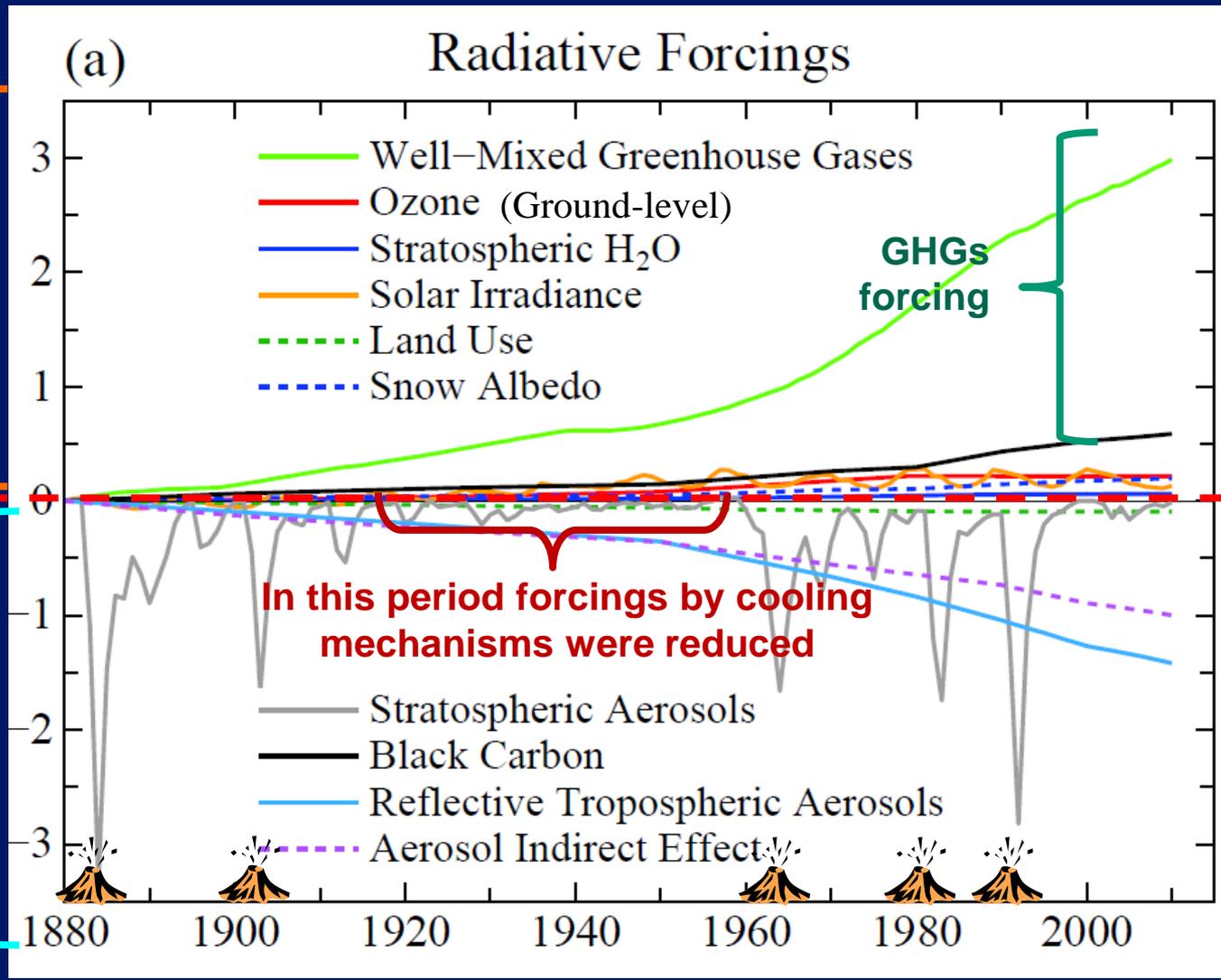
*After eruptions:*  
**TROPOSPHERIC COOLING** (unless an El Niño year)

# RADIATIVE FORCINGS . . . Flip back to p 71

**ABOVE THE 0 LINE:**  
Forcing by mechanisms that cause warming in the troposphere

0 line = 1880 value

**BELOW THE 0 LINE:**  
Forcing by mechanisms that cause cooling in the troposphere



**Effectiveness of various global climate forcings ( in  $W/m^2$ ) relative to their 1880 value**

(figure from NASA GISS <http://data.giss.nasa.gov/modelforce/>)



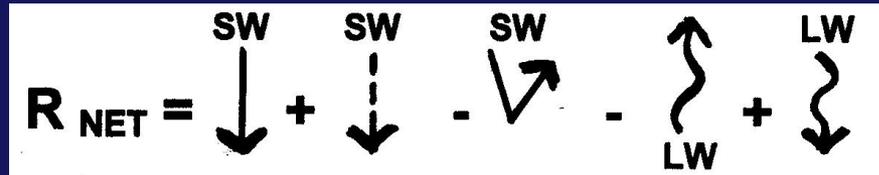
11,000 jet trails in 8 hours  
33,000 in 24 hours

Jet Trails, 2007

Photographic artist, Chris Jordan

# RADIATIVE FORCING

(based on the Radiation Balance at the Tropopause!)

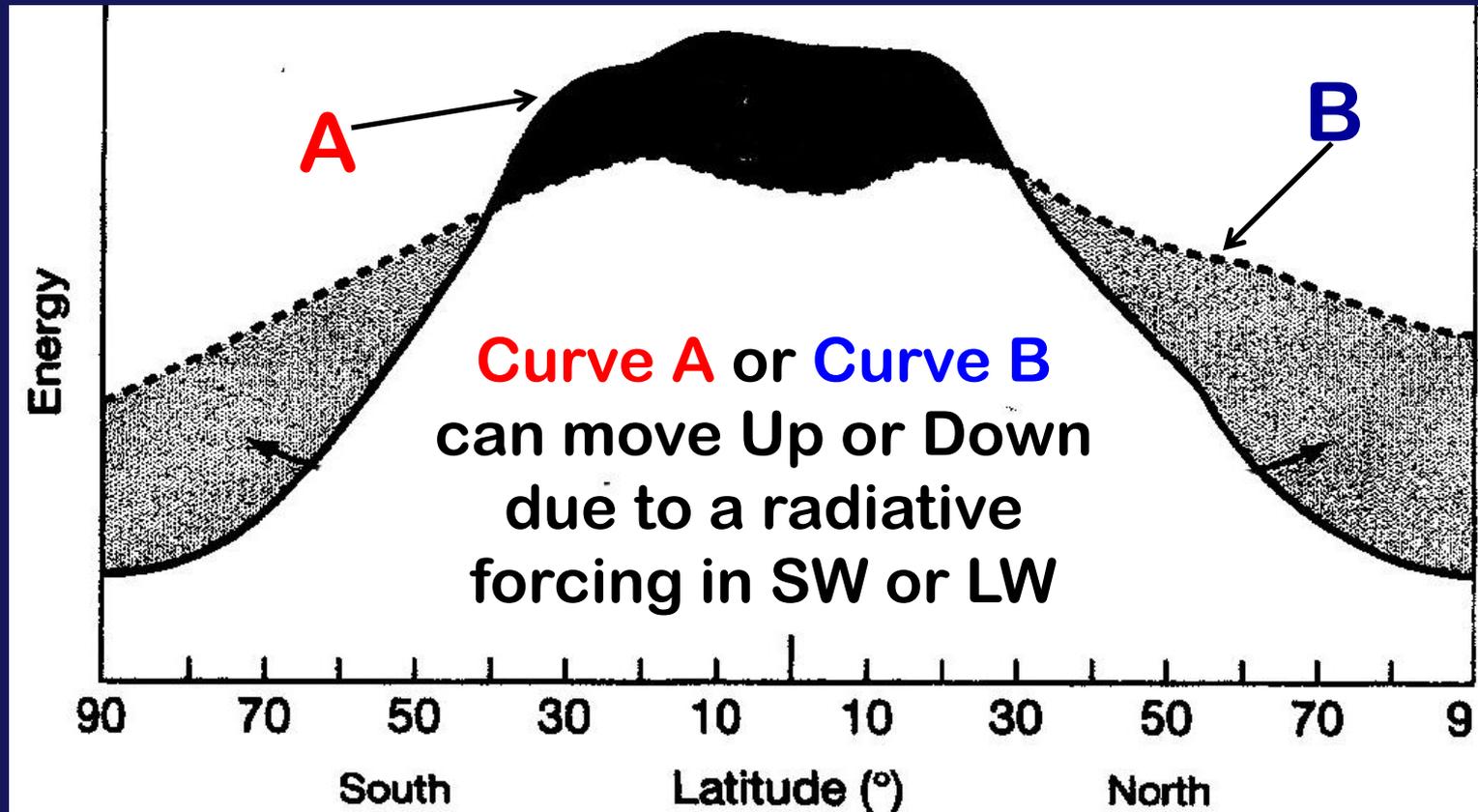
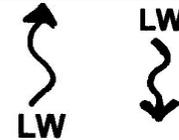
$$R_{\text{NET}} = \downarrow_{\text{SW}} + \downarrow_{\text{SW}} - \uparrow_{\text{SW}} - \uparrow_{\text{LW}} + \downarrow_{\text{LW}}$$
The diagram shows the equation R\_NET = [solid arrow down labeled SW] + [dashed arrow down labeled SW] - [solid arrow up labeled SW] - [wavy arrow up labeled LW] + [wavy arrow down labeled LW]. The arrows represent different radiative fluxes: incoming shortwave radiation (SW) and outgoing longwave radiation (LW).

= an index of the importance of different factors (e.g. GH gases) for increasing or decreasing the amount of energy that accumulates in the TROPOSPHERE!

**CURVE A**



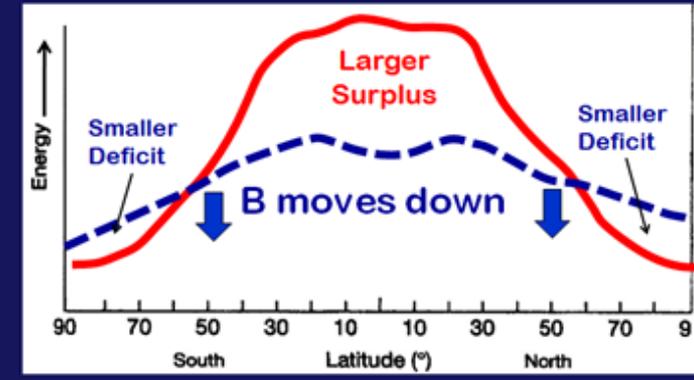
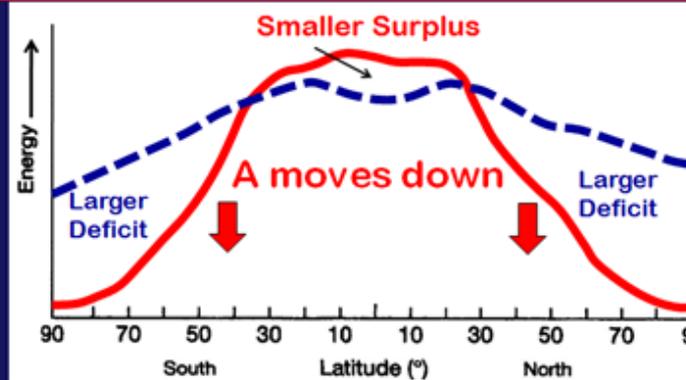
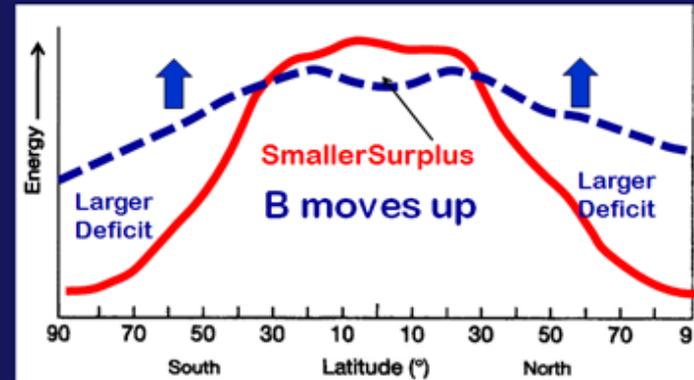
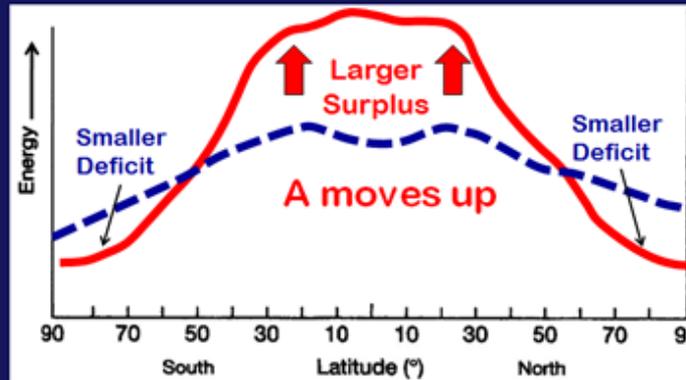
**CURVE B**



**ENERGY BALANCE CHANGES  
IN THE TROPOSPHERE**

# G-5 Volcanism Activity:

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

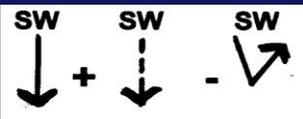
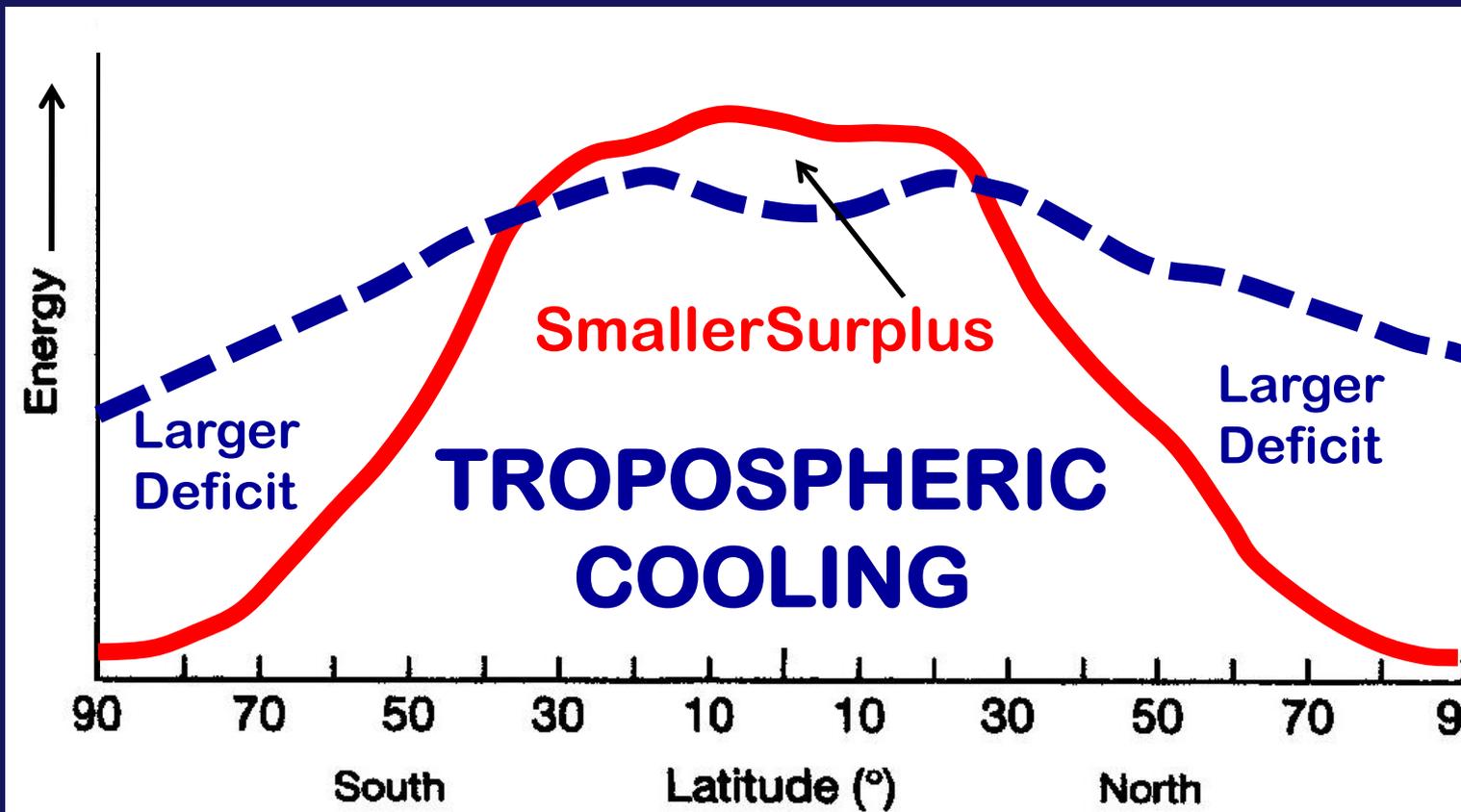
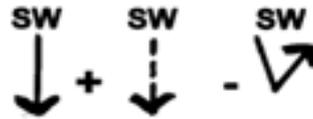


**WHICH ONE IS RIGHT ?**

**Does the change affect CURVE A or CURVE B?**

**IF CURVE A**

**moves down:**

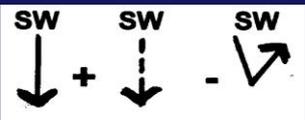
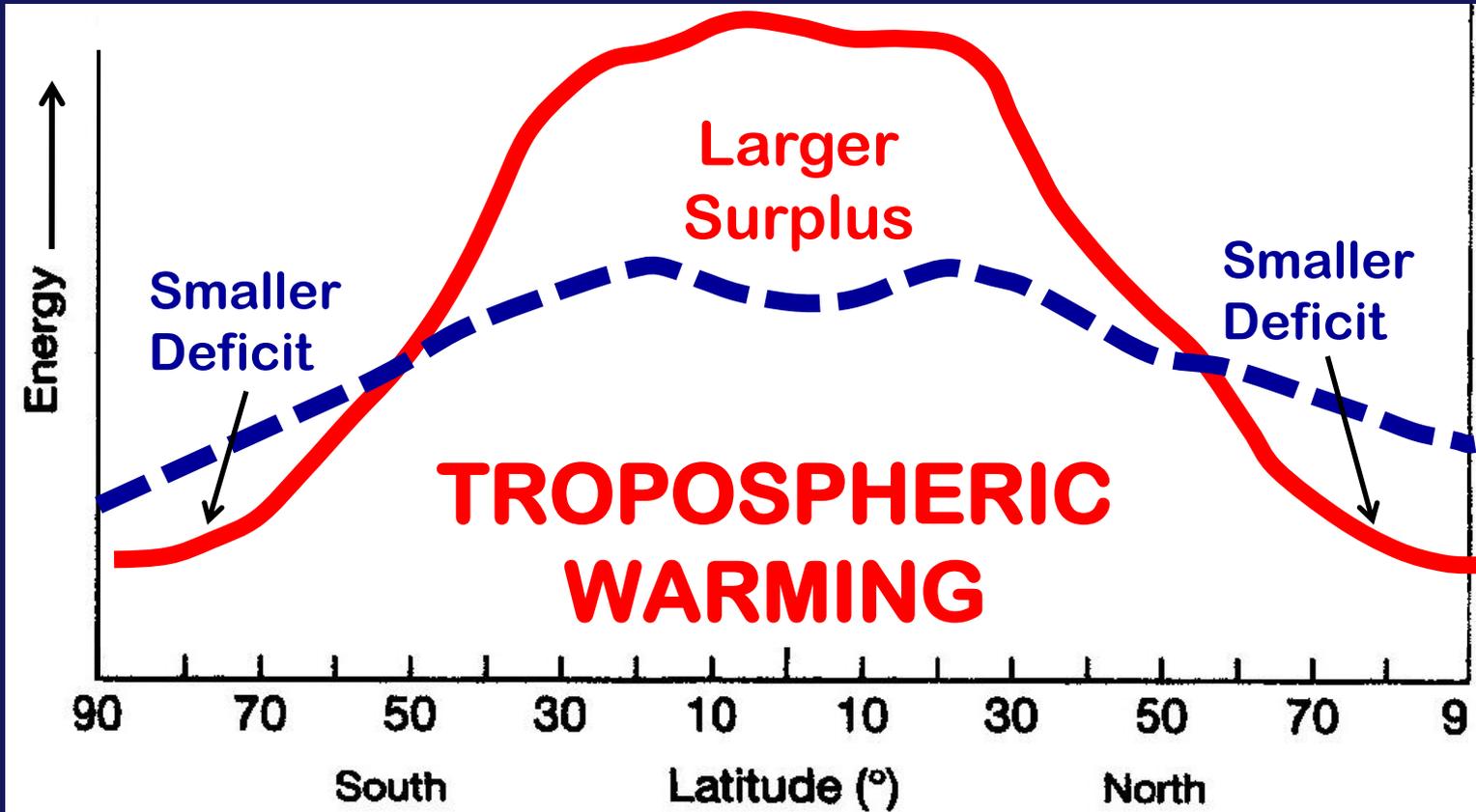
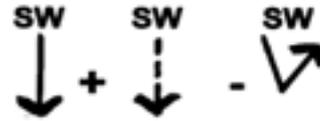


If incoming energy represented by Curve A is reduced (A curve goes down)

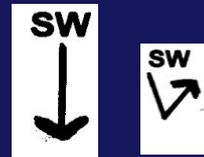
**HOW?** Albedo increases due to Eruption, Deforestation, Sulfur Aerosols, etc.



**IF CURVE A**  
**moves up:**

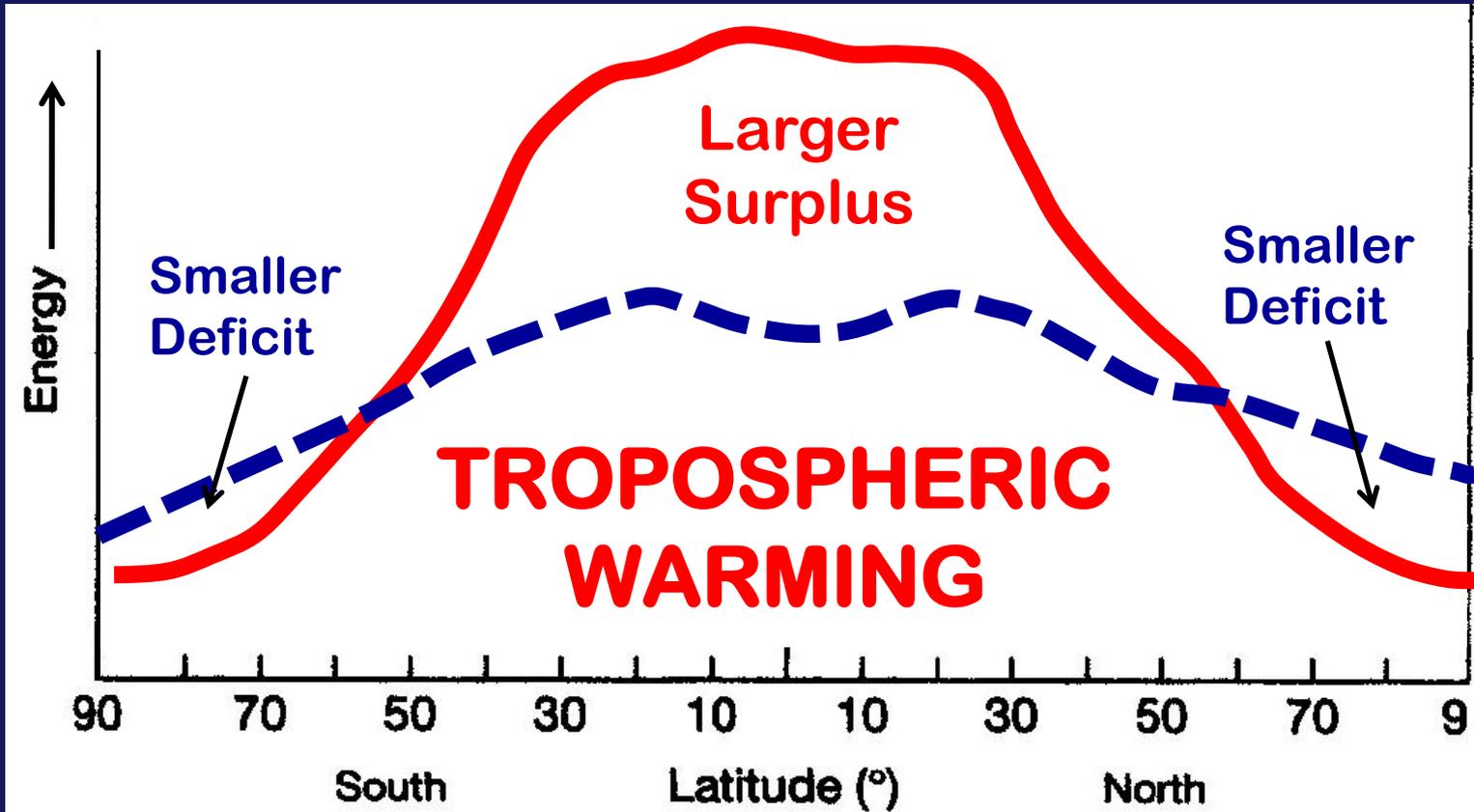
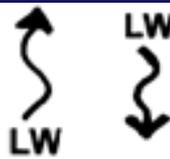


If incoming energy  
represented by Curve A is  
increased (A curve goes up)



**HOW? Albedo decreases  
and / or solar input  
increases**

If **CURVE B**  
moves down

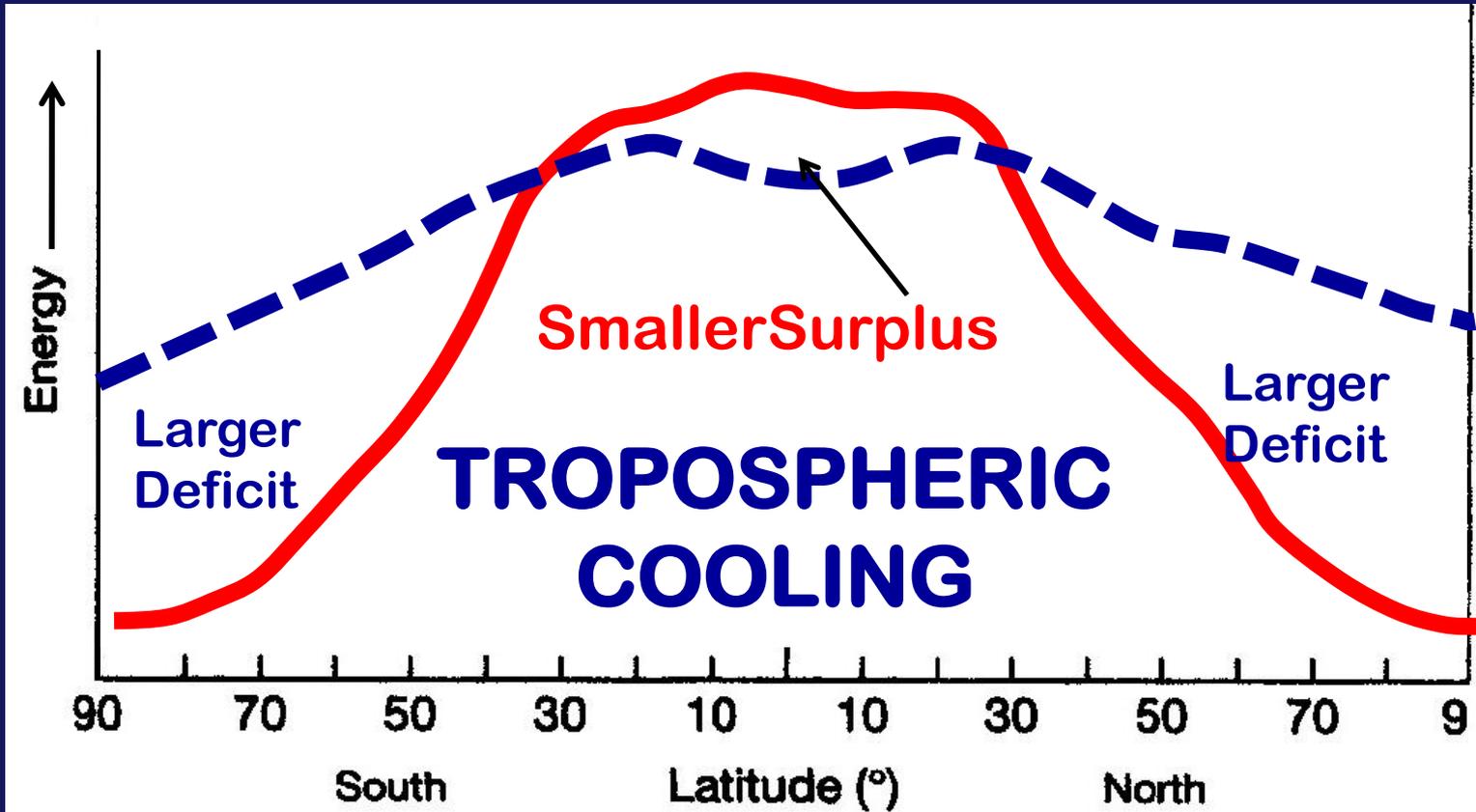
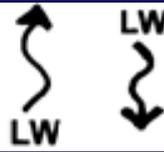


If outgoing energy represented by Curve B is reduced (B curve goes down)

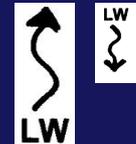


**HOW?**  
**GHG's increase & keep more LW in!**

If **CURVE B**  
moves up:



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



**HOW?**  
**GHG's decrease**  
**& allow more**  
**LW out!**



# MOVIE TIME!



“New evidence that **AIR POLLUTION** has masked the full impact of global warming suggests the world may soon face a heightened climate crisis.”

**Program website link – See D2L to watch it!**



[http://www.pbs.org/wgbh/nova/transcripts/3310\\_sun.html](http://www.pbs.org/wgbh/nova/transcripts/3310_sun.html)

# Global Solar Dimming effect is about half as strong as Global Warming

## Global dimming

aerosols from pollution reflect back to space



Less solar reaches the surface

Polluted air contains many more water droplets → more low clouds which reflect back to space

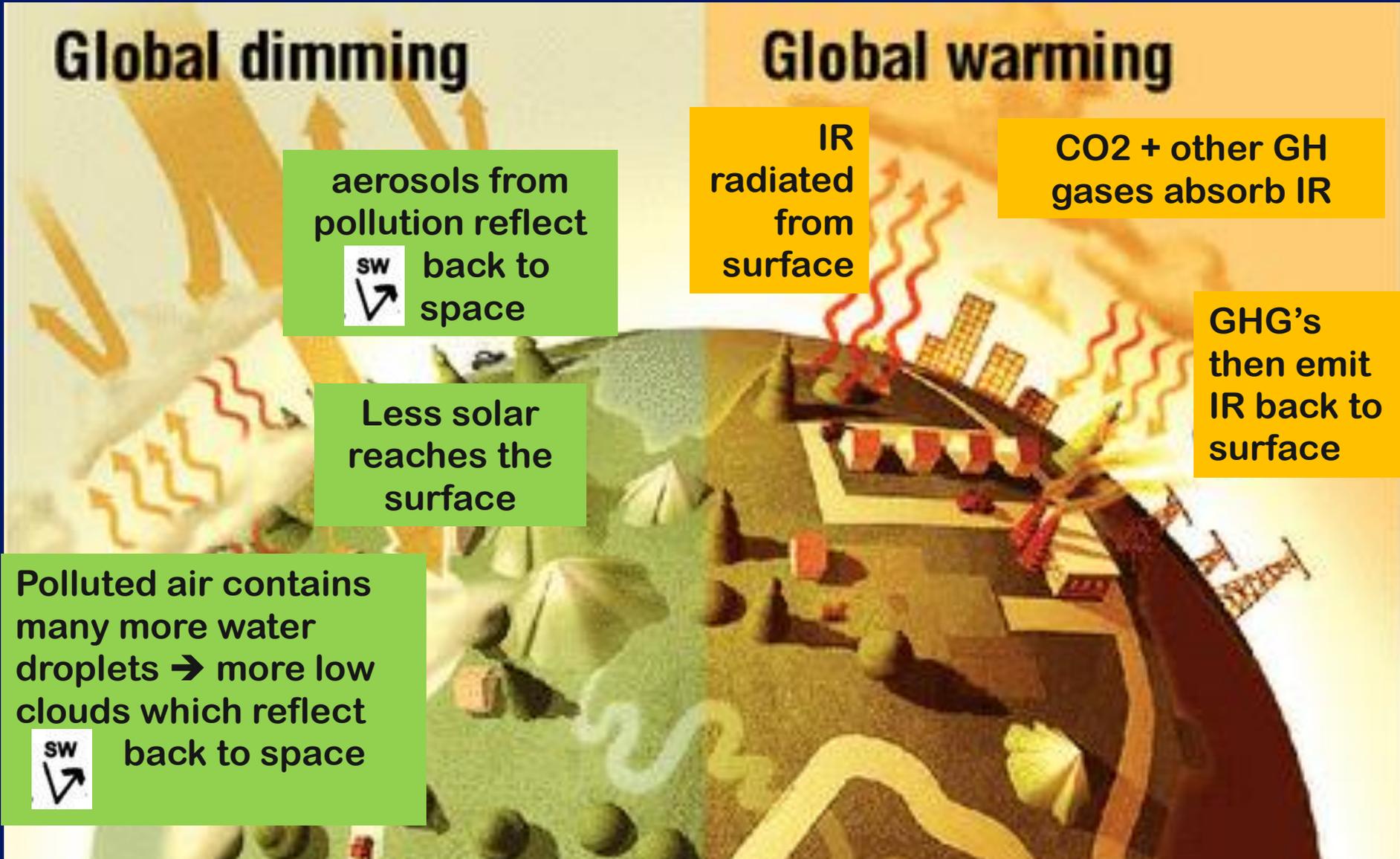


## Global warming

IR radiated from surface

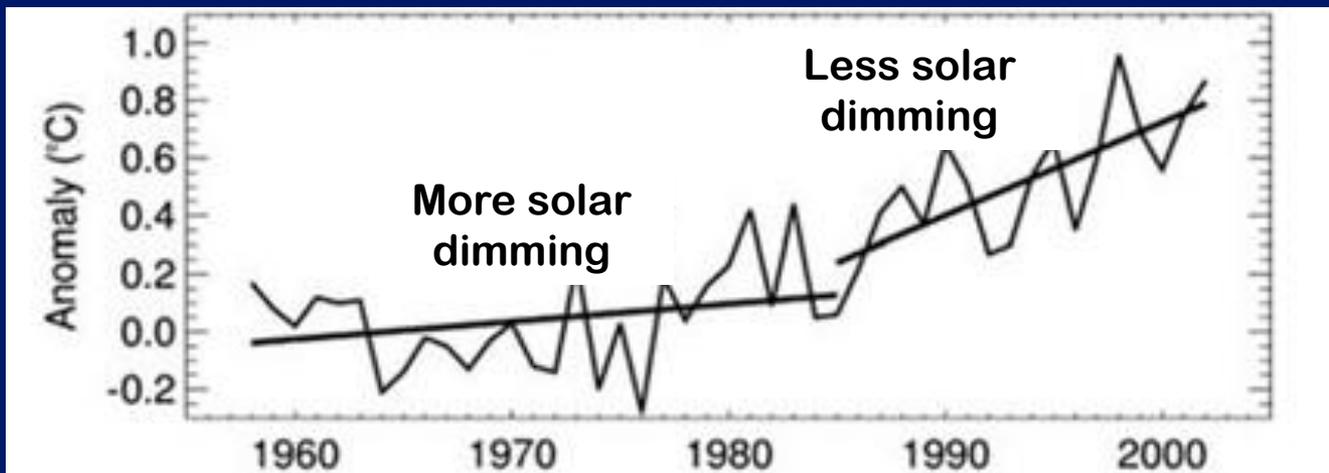
CO<sub>2</sub> + other GH gases absorb IR

GHG's then emit IR back to surface



# Solar Dimming may have “masked” the intensity of warming from the Enhanced GH Effect . . . until recently!

Average Temperature Change  
over Global Land Surfaces (1958 – 2002)



*Thick-cloud  
air pollution common;  
health problems, deaths*



**Clean Air  
Act of 1970**  
*stronger law;  
EPA established  
later that year*

**Clean Air  
Act of 1990**  
*EPA more implementation +  
enforcement authority;  
increased emphasis on  
cost-effectiveness*

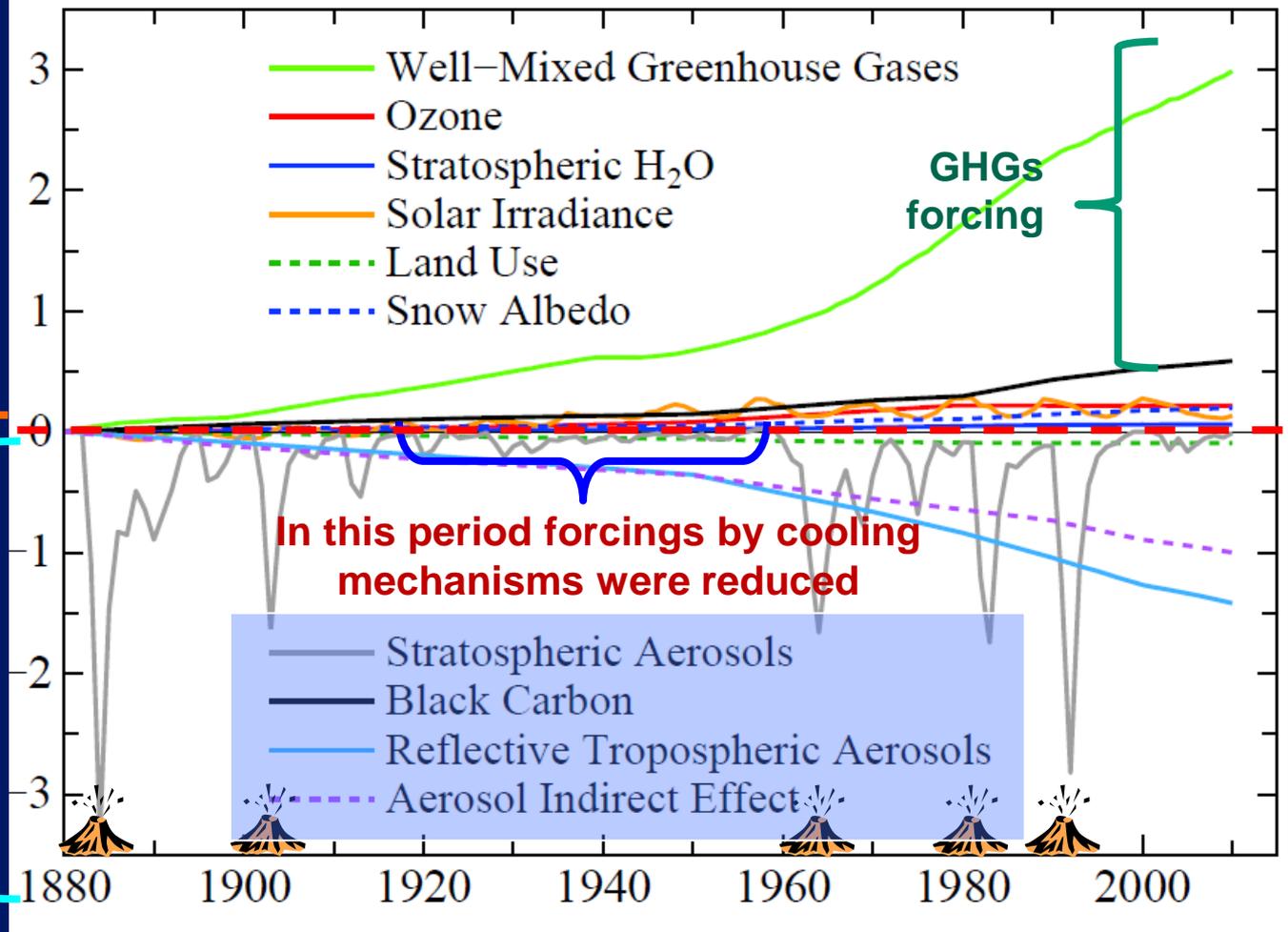
**Clean Air Act of 1963**  
*funding to study health effects; federal  
+ state laws promote clean air*



# How pollution & other human influences affect **RADIATIVE FORCINGS** . . .

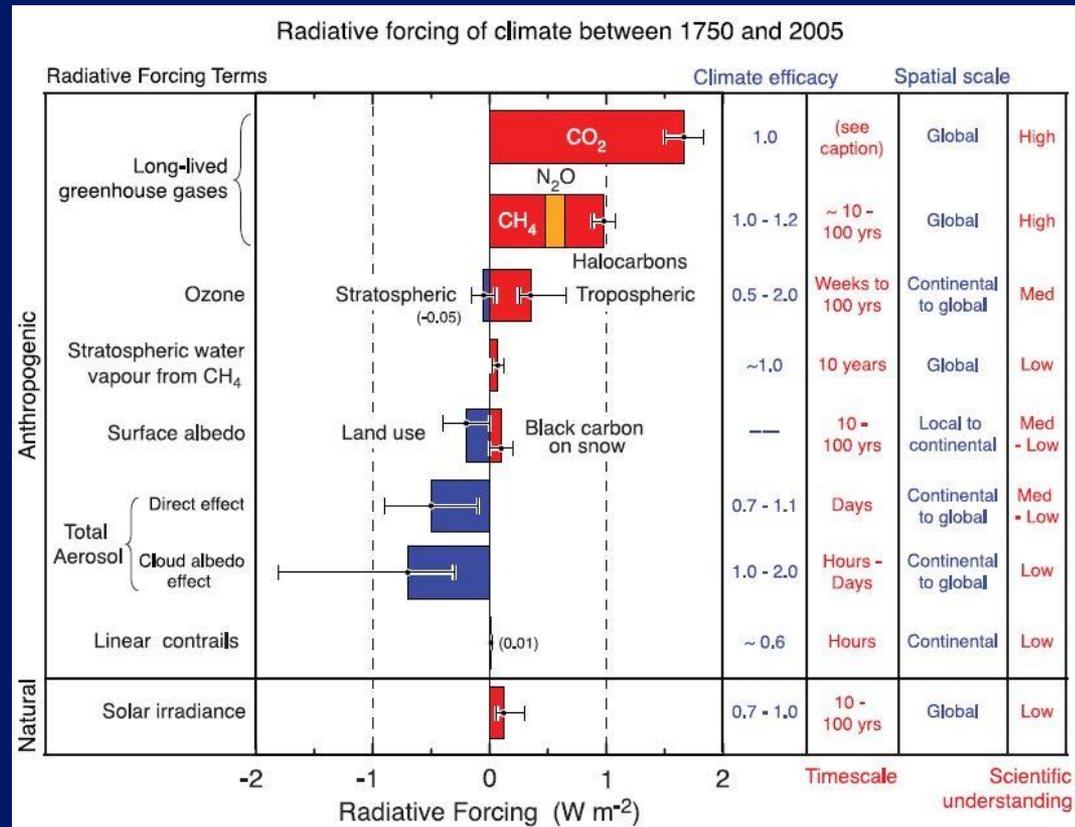
Forcing by mechanisms that cause warming

Forcing by mechanisms that cause cooling

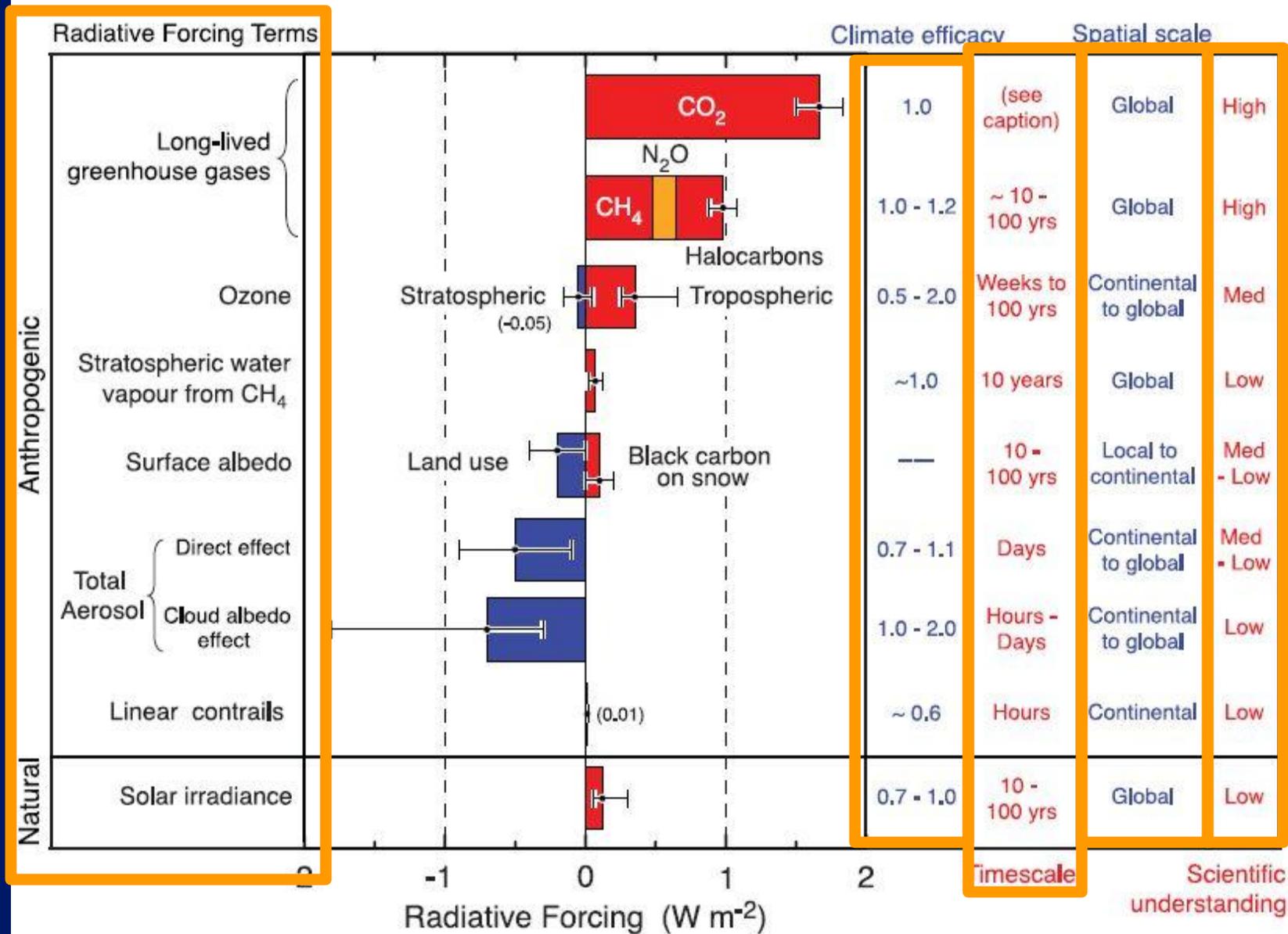


# The Key To It All:

## RADIATIVE FORCING OF CLIMATE

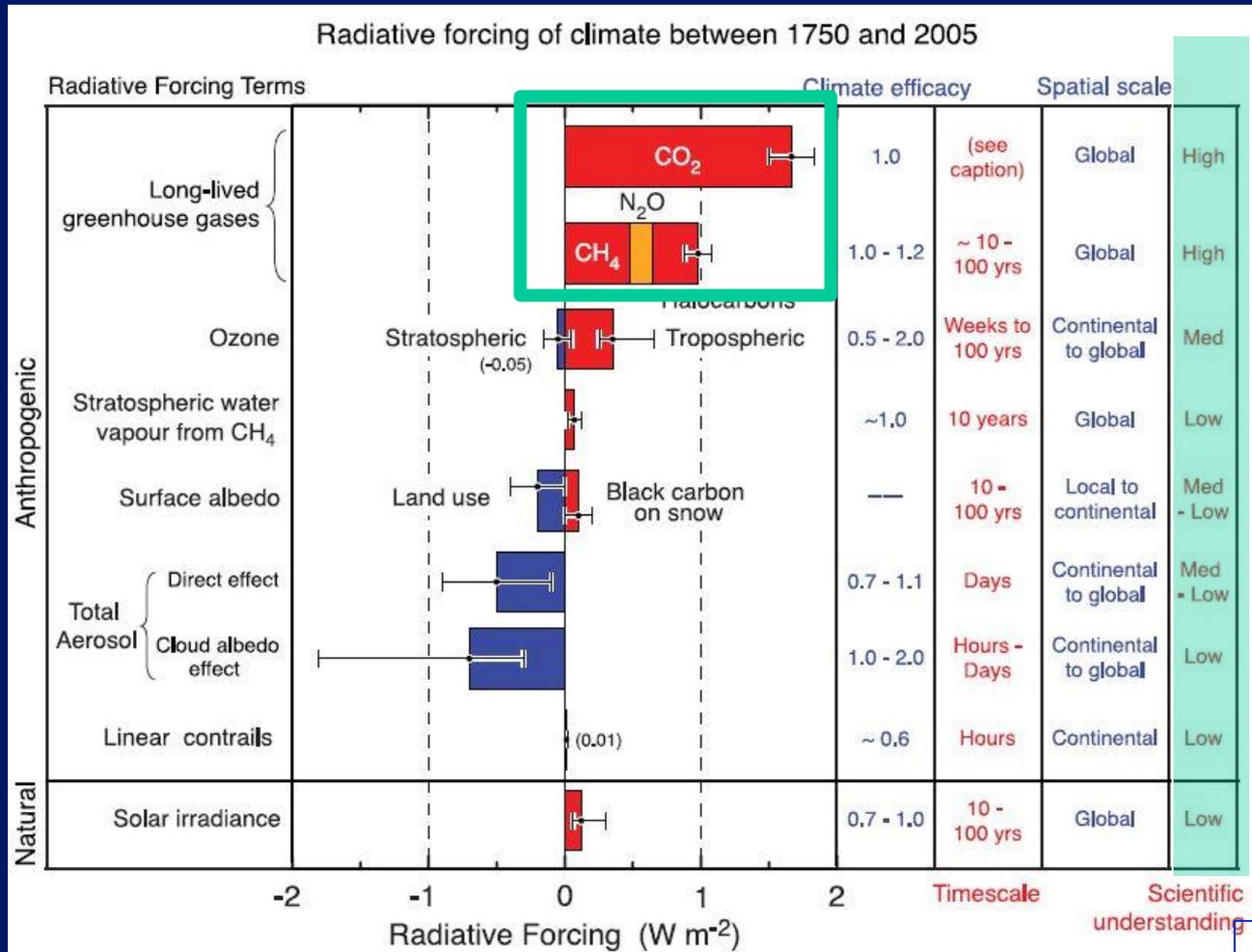


# Radiative forcing of climate between 1750 and 2005



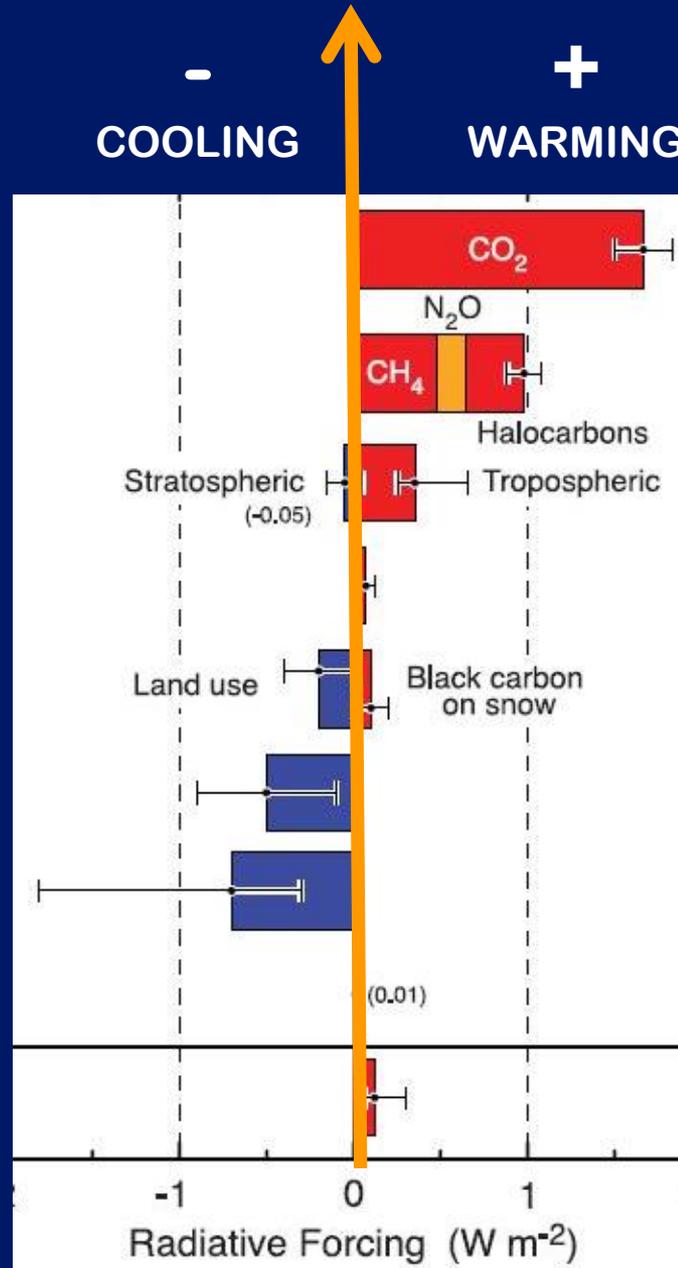
Q1- The figure shows that the forcing mechanism that is BEST understood by scientists is also the one that leads to the greatest climatic impact.

1. TRUE  
2. FALSE



If the forcing is NEGATIVE (to left of line)

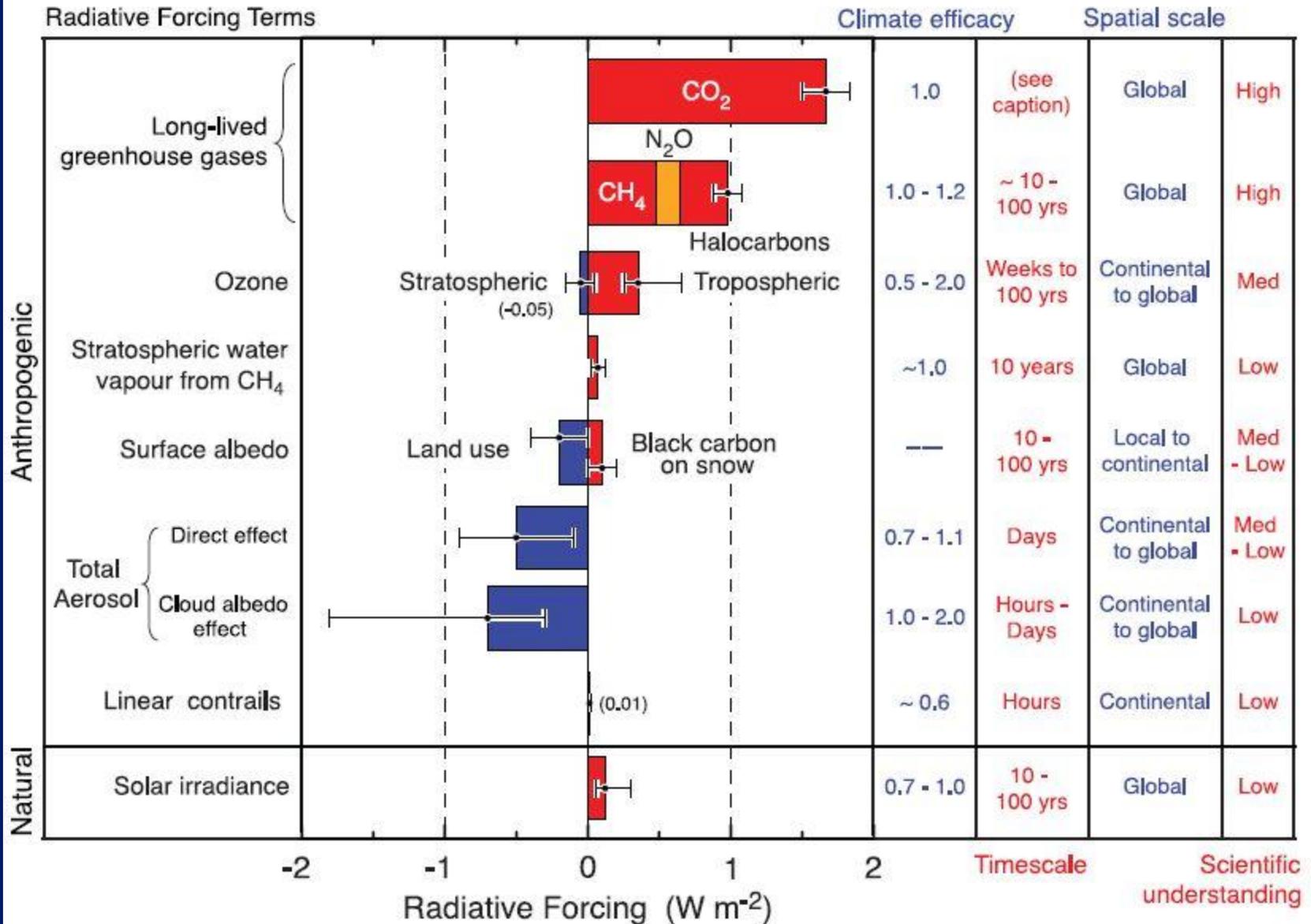
it means that an increase in that gas or factor contributes to **COOLING** in the troposphere.



If the forcing is POSITIVE (to right of line)

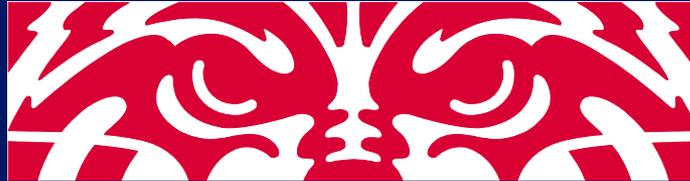
it means that an increase in that gas or factor contributes to **WARMING** in the troposphere.

# Radiative forcing of climate between 1750 and 2005



SOURCE: IPCC 2007 WG-1 Synthesis Report Summary for Policymakers

**HAVE A GREAT  
WEEKEND!**



**GO CATS !**

**Don't forget your last online  
Climate Basics Tutorial  
1-4 on Intro to Modelling!**