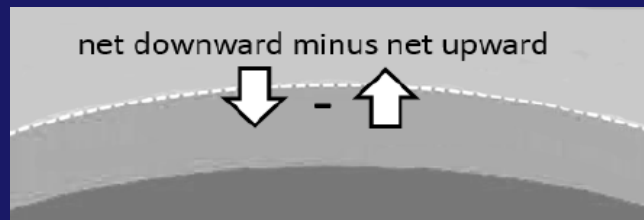


# TOPIC # 15

## GLOBAL WARMING & ANTHROPOGENIC FORCING (cont.)

### Part B

## RADIATIVE FORCING



Class Notes pp 89

# THE KEY TO IT ALL:

## RADIATIVE FORCING

(linked to the Energy Balance!)

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

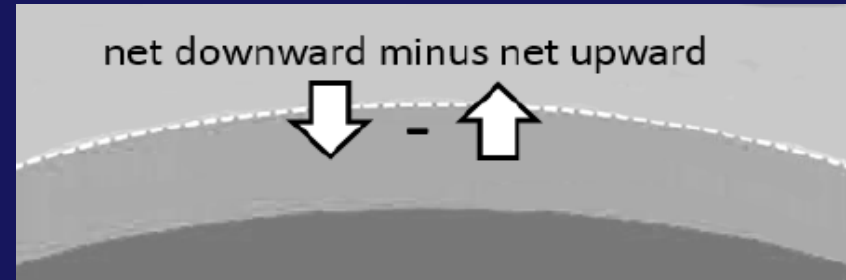
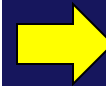
expressed in Watts per square meter ( $\text{Wm}^{-2}$ ) = ENERGY!

(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!

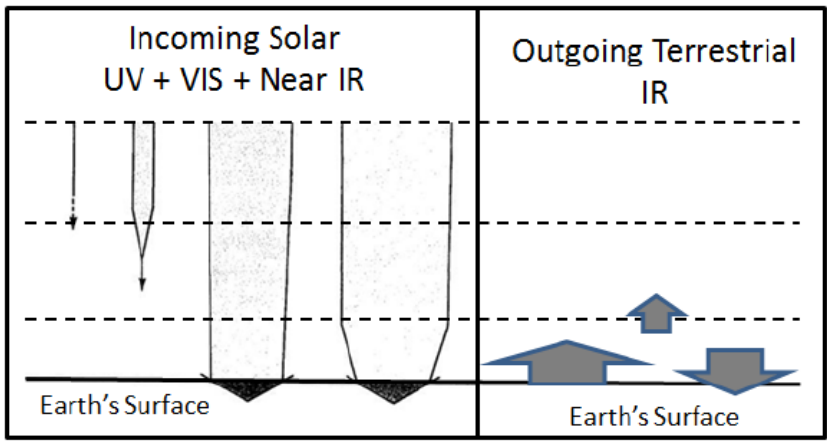
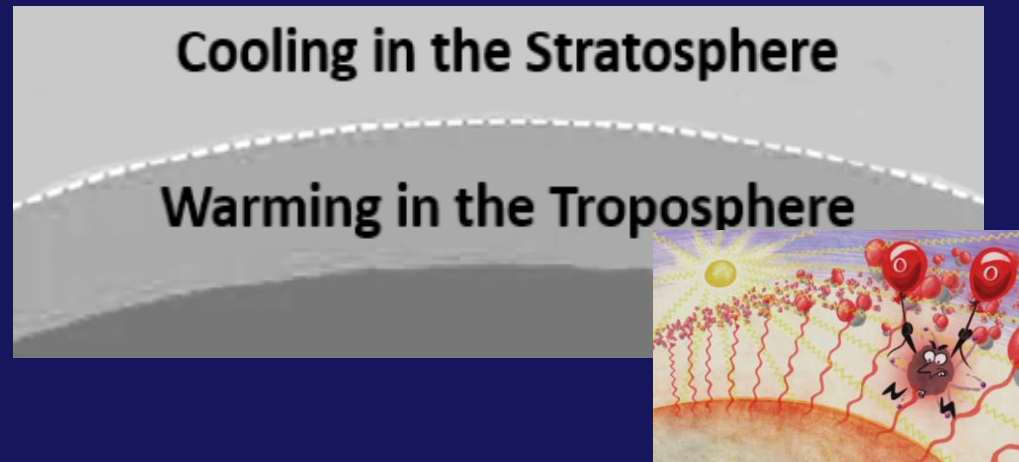
$$R_{NET} = \begin{array}{c} \text{SW} \\ \downarrow \\ \text{SW} \\ \downarrow \\ \text{SW} \\ \searrow \\ \text{LW} \\ \uparrow \\ \text{LW} \\ \downarrow \end{array} + \begin{array}{c} \text{SW} \\ \downarrow \\ \text{LW} \\ \downarrow \end{array} - \begin{array}{c} \text{SW} \\ \searrow \\ \text{LW}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



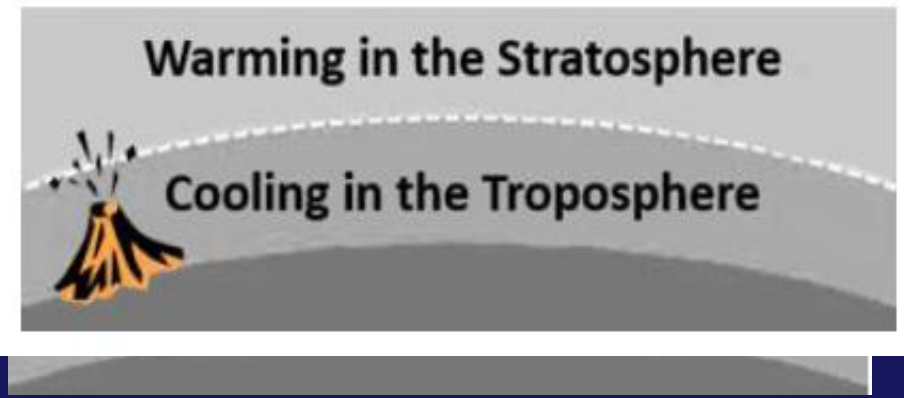
It's an index of the degree to which different factors (like GHG's) INCREASE or DECREASE the amount of energy that accumulates in the TROPOSPHERE!

**Radiative Forcing (RF)** - Radiative forcing is the change in the net, downward (incoming) minus upward (outgoing), **irradiance** (expressed in  $W/m^2$ ) at the *tropopause* due to a change in an external driver of *climate change*, such as, for example, a change in the concentration of *carbon dioxide* or the output of the Sun.

# Greenhouse Warming Signature



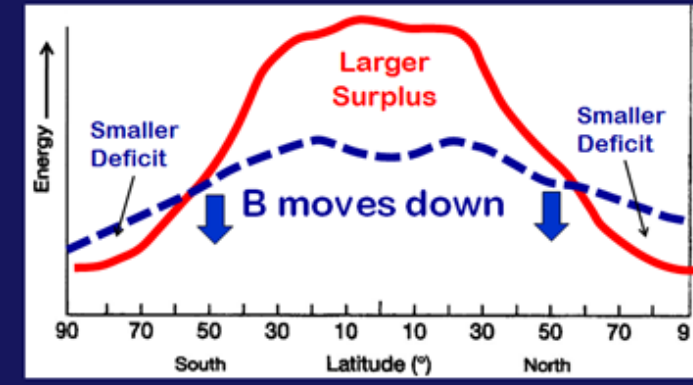
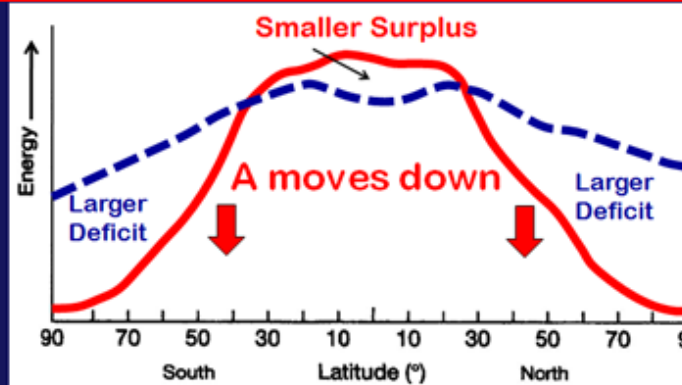
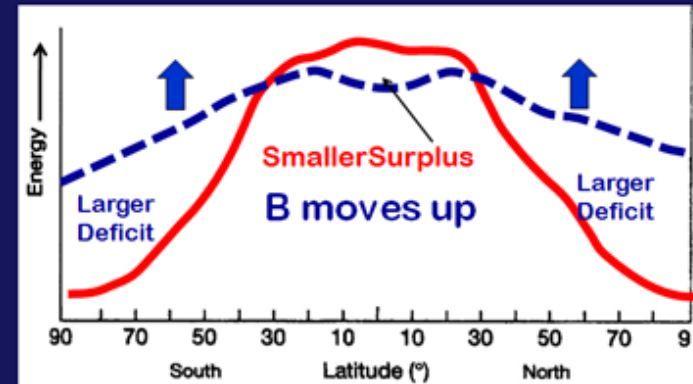
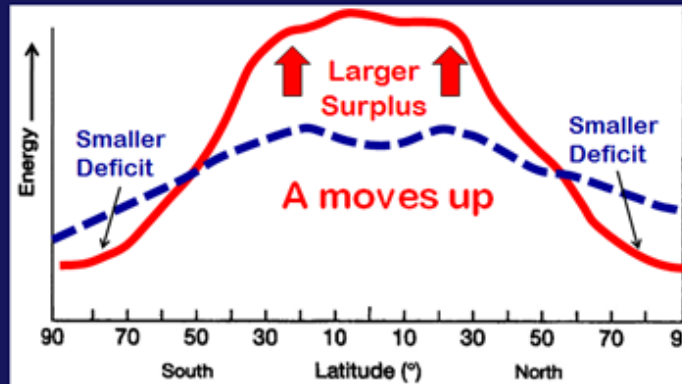
## The Volcanic Aerosol Signature:



**Review -- see p 39**

# G-6 Volcanism Activity:

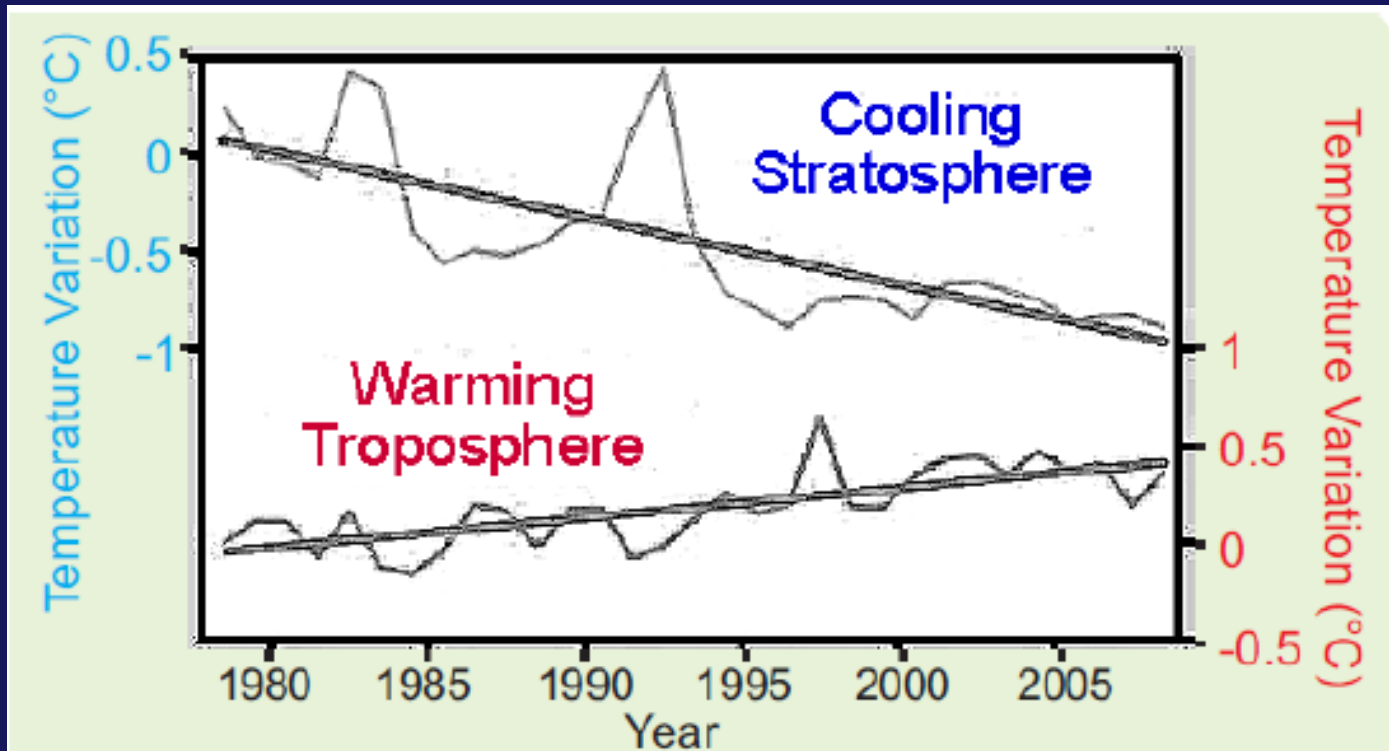
Show how the energy balance would change if a major volcanic eruption occurred:



**WHICH ONE IS RIGHT ?**

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

# Here's what's been happening in recent decades:



Graphs showing temperature variations (degrees C)  
in the stratosphere and troposphere  
(*measured by satellites*)

**RADIATIVE FORCING** = a measure of the influence a factor has in altering the balance of **incoming** ↓ and **outgoing** ↑ energy in the Earth-atmosphere system

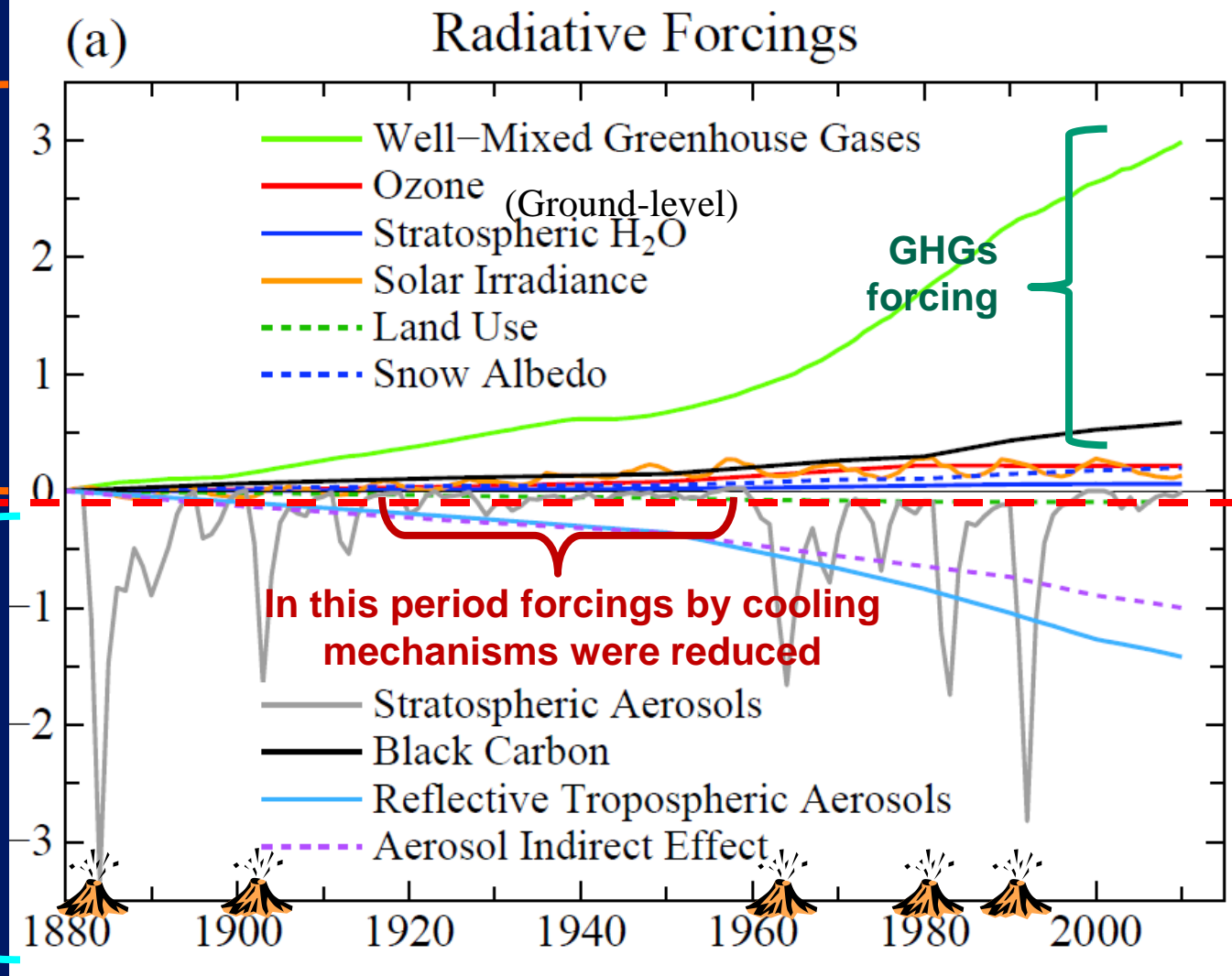
- ✓ It is an index of the importance of a factor as a potential climate change mechanism.
- ✓ It is expressed in Watts per square meter ( $\text{W}/\text{m}^2$ )
- ✓ *Another def:*  
the change in net downward ↓ minus upward ↑ irradiance (in  $\text{W}/\text{m}^2$ )  
at the tropopause  
due to a change in an **external driver of climate**.

# RADIATIVE FORCINGS ARE THE KEY TO WHAT'S GOING ON!

**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<sup>2</sup>) 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

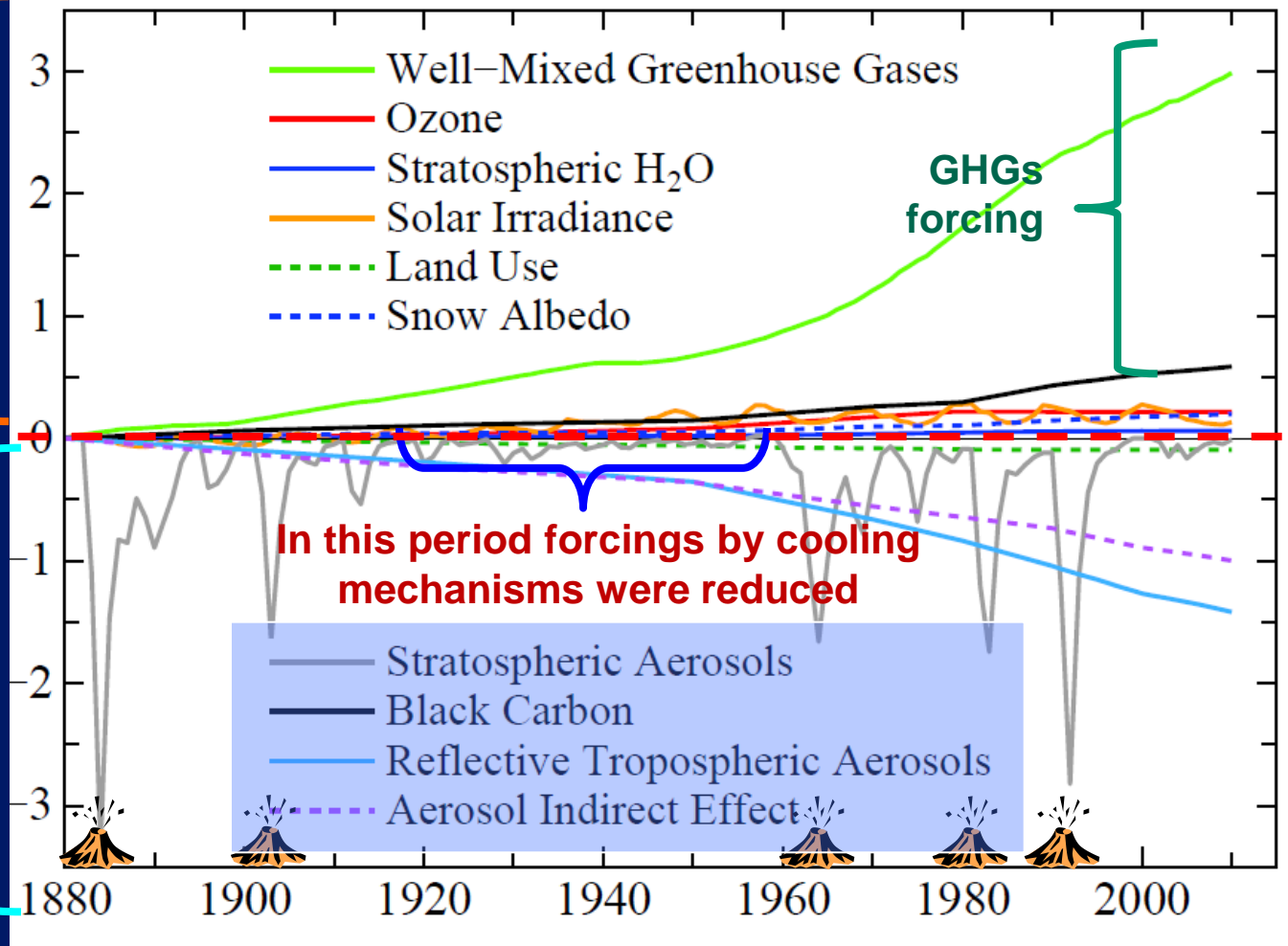
Jet Trails, 2007

Photographic artist, Chris Jordan

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

Forcing by mechanisms that cause warming

Forcing by mechanisms that cause cooling





# 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 segments link:

[http://services.oia.arizona.edu/MediaServices/katie/dimming\\_the\\_sun.wvx](http://services.oia.arizona.edu/MediaServices/katie/dimming_the_sun.wvx)




[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

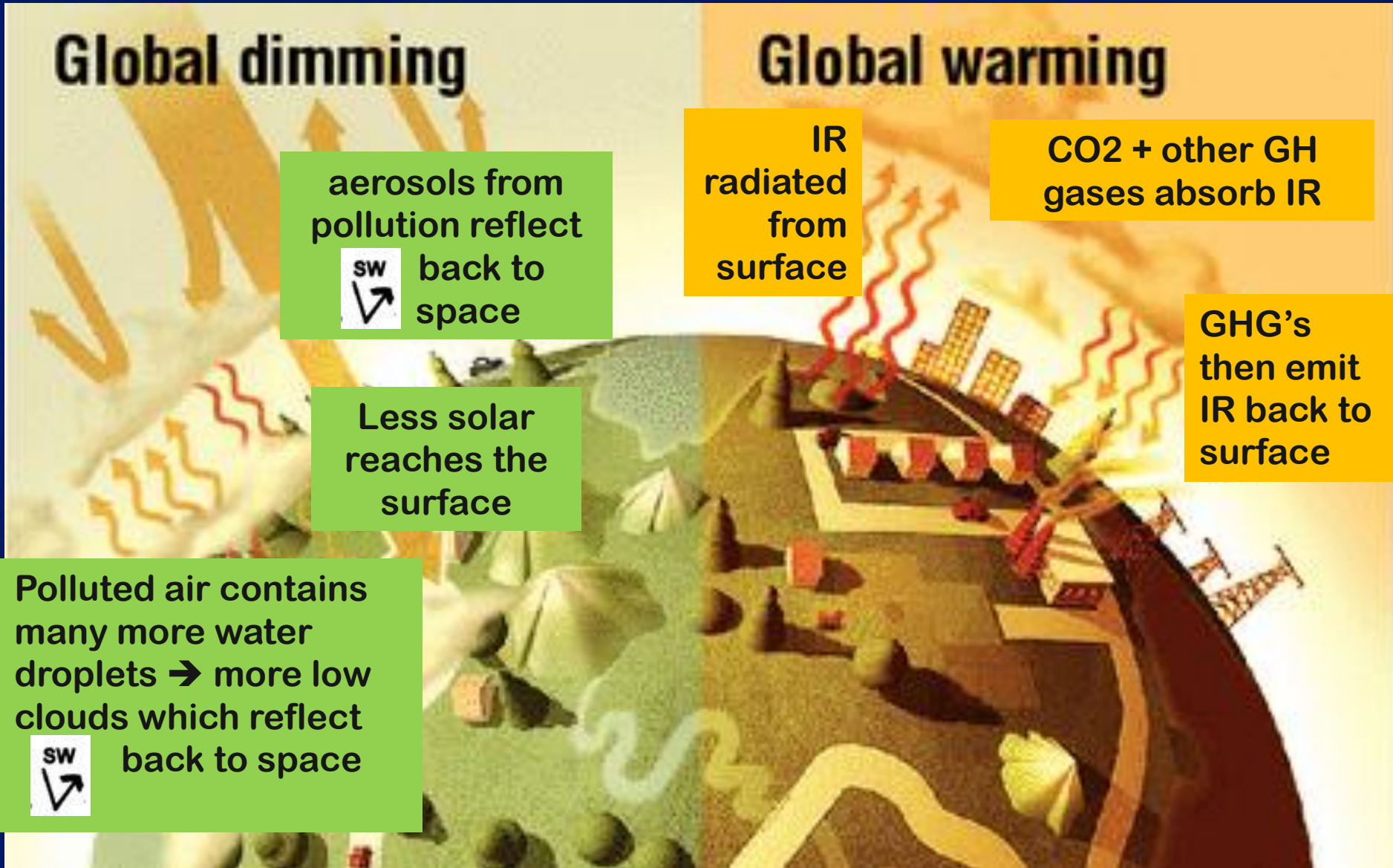
Polluted air contains many more water droplets → more low clouds which reflect  
 back to space

## Global warming

IR radiated from surface

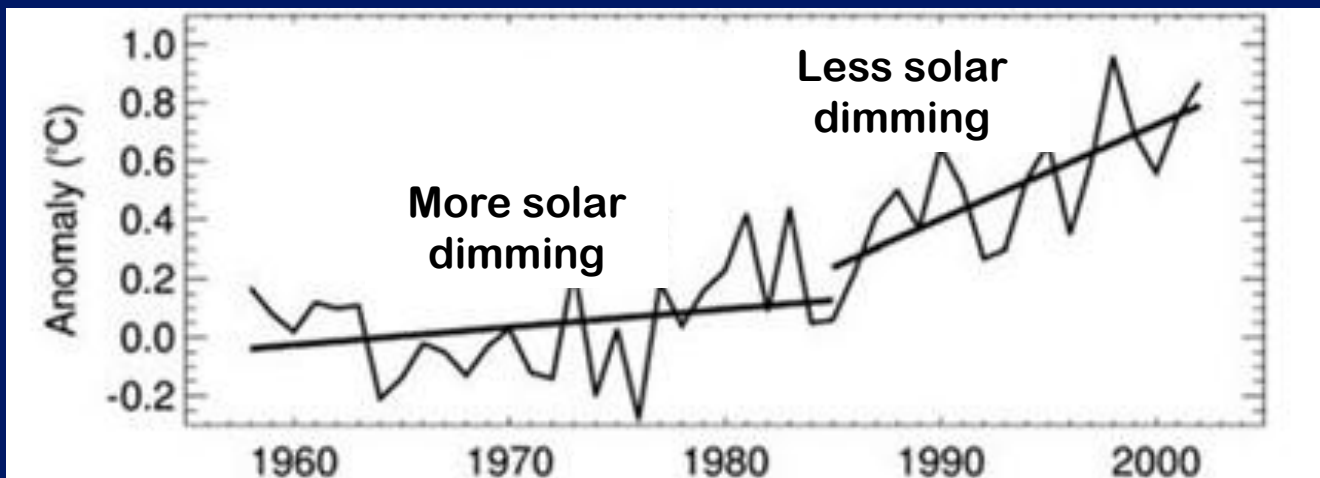
CO<sub>2</sub> + other GH gases absorb IR

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*

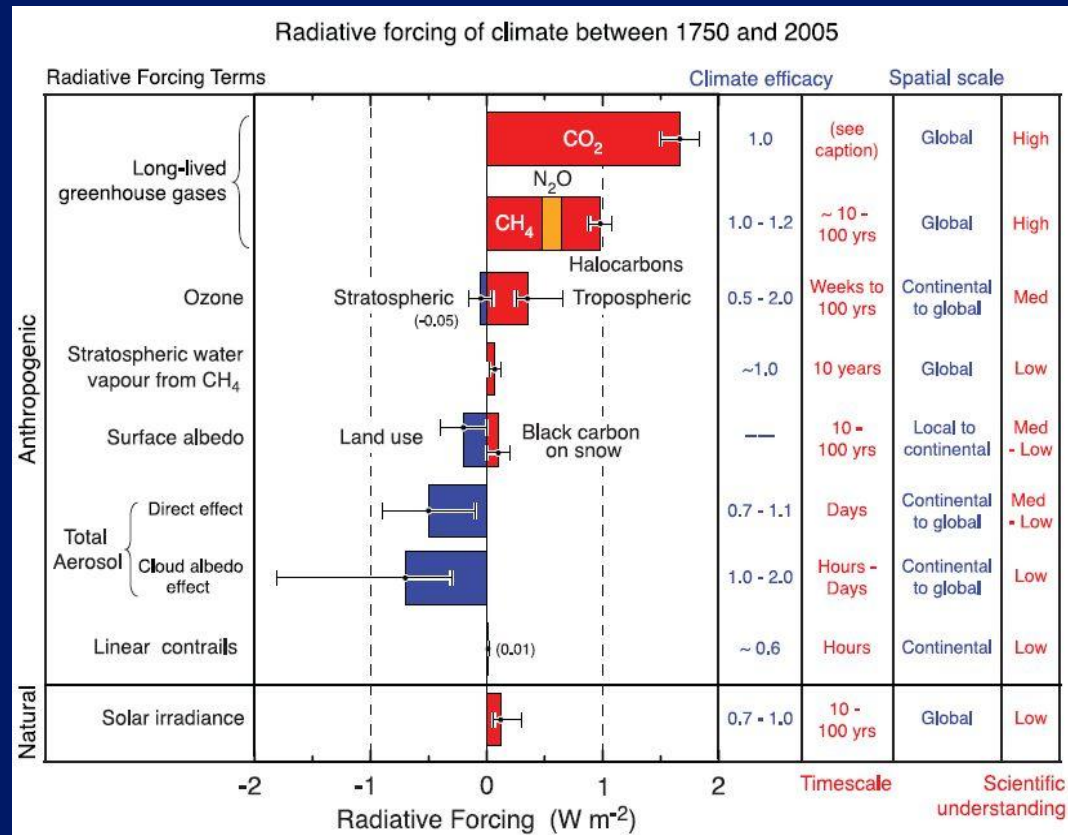
**Clean Air  
Act of 1990**  
*EPA more implementation +  
enforcement authority;  
increased emphasis on  
cost-effectiveness*

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

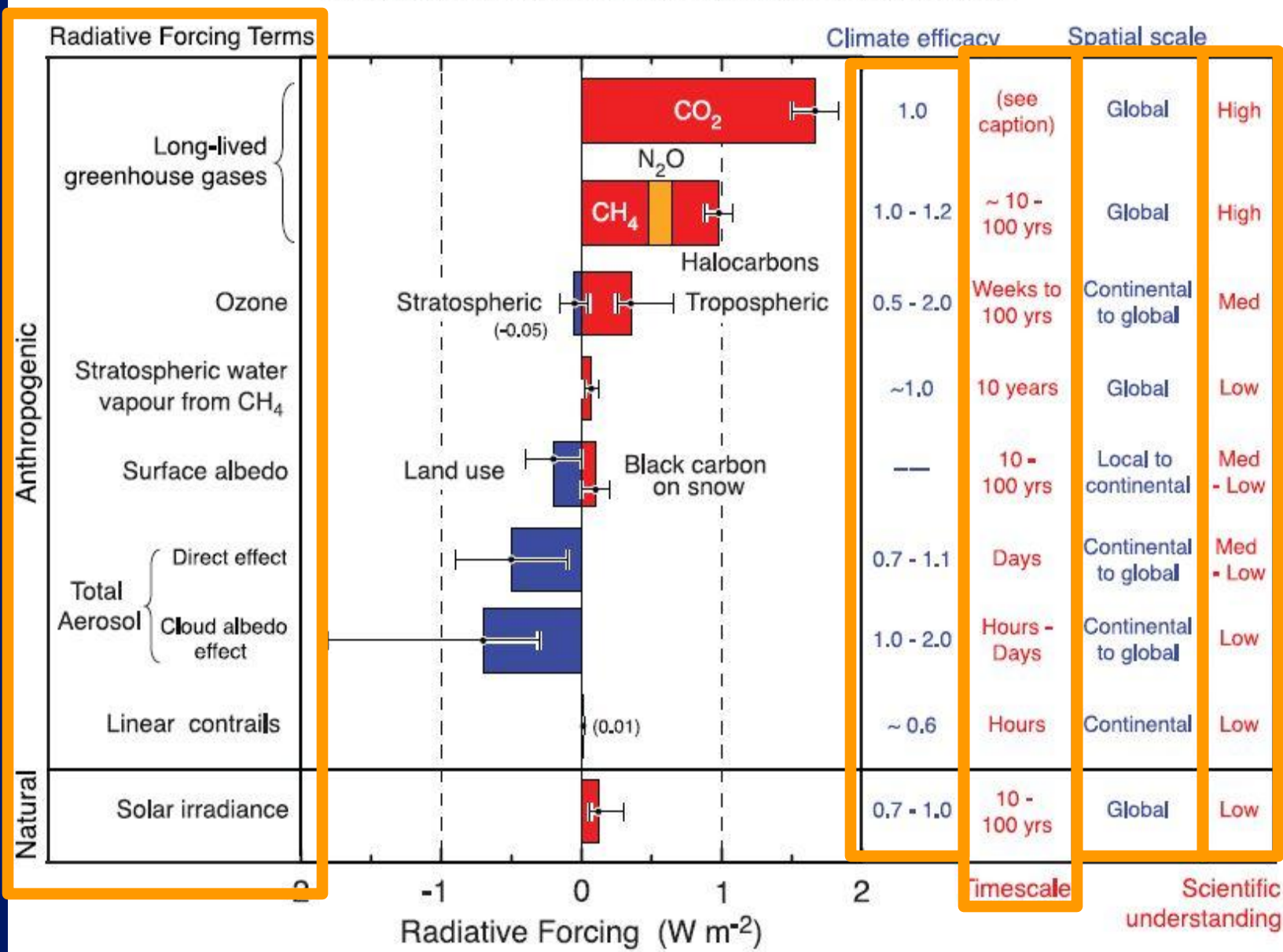


# The Key To It All:

## RADIATIVE FORCING OF CLIMATE

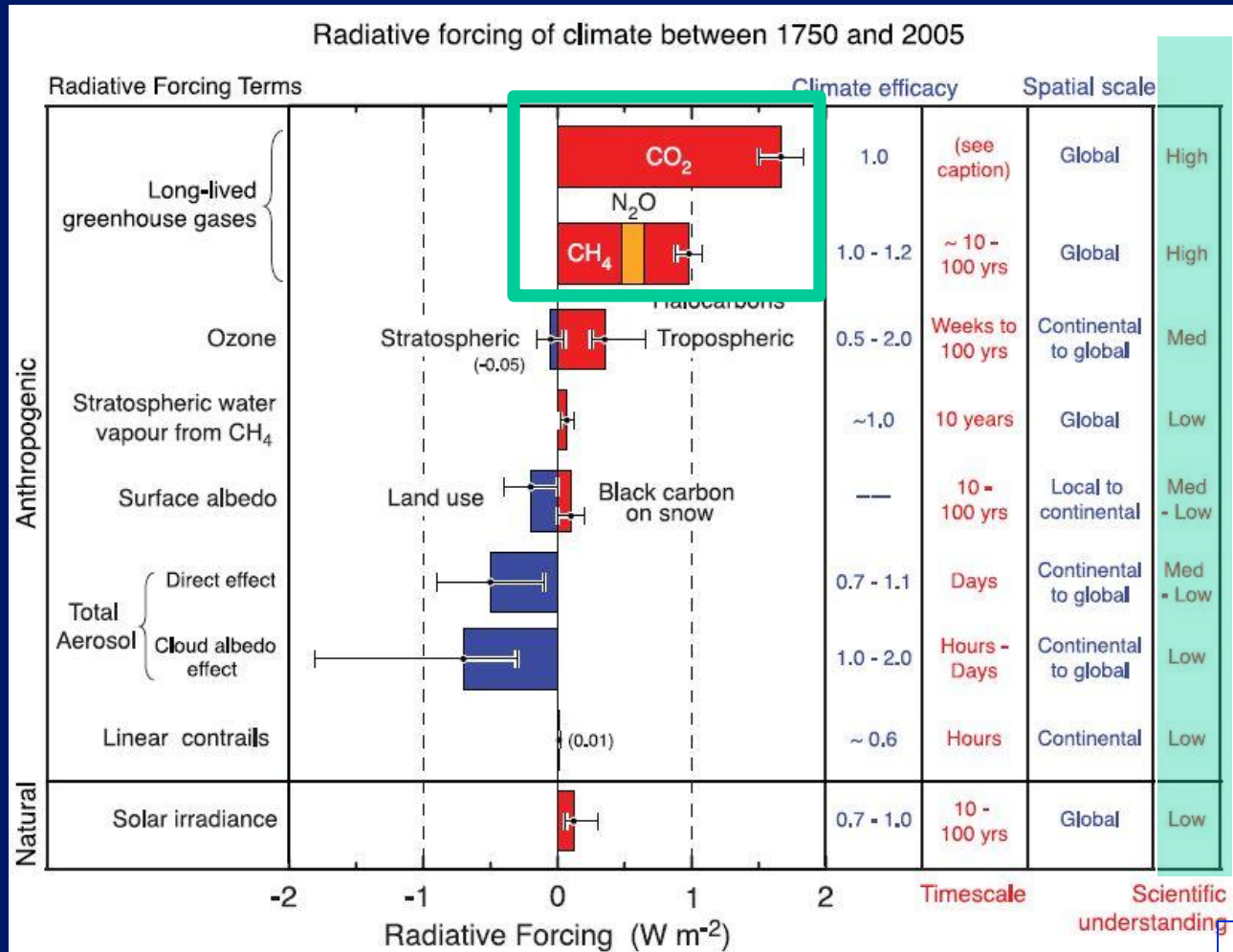


# Radiative forcing of climate between 1750 and 2005



**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**.

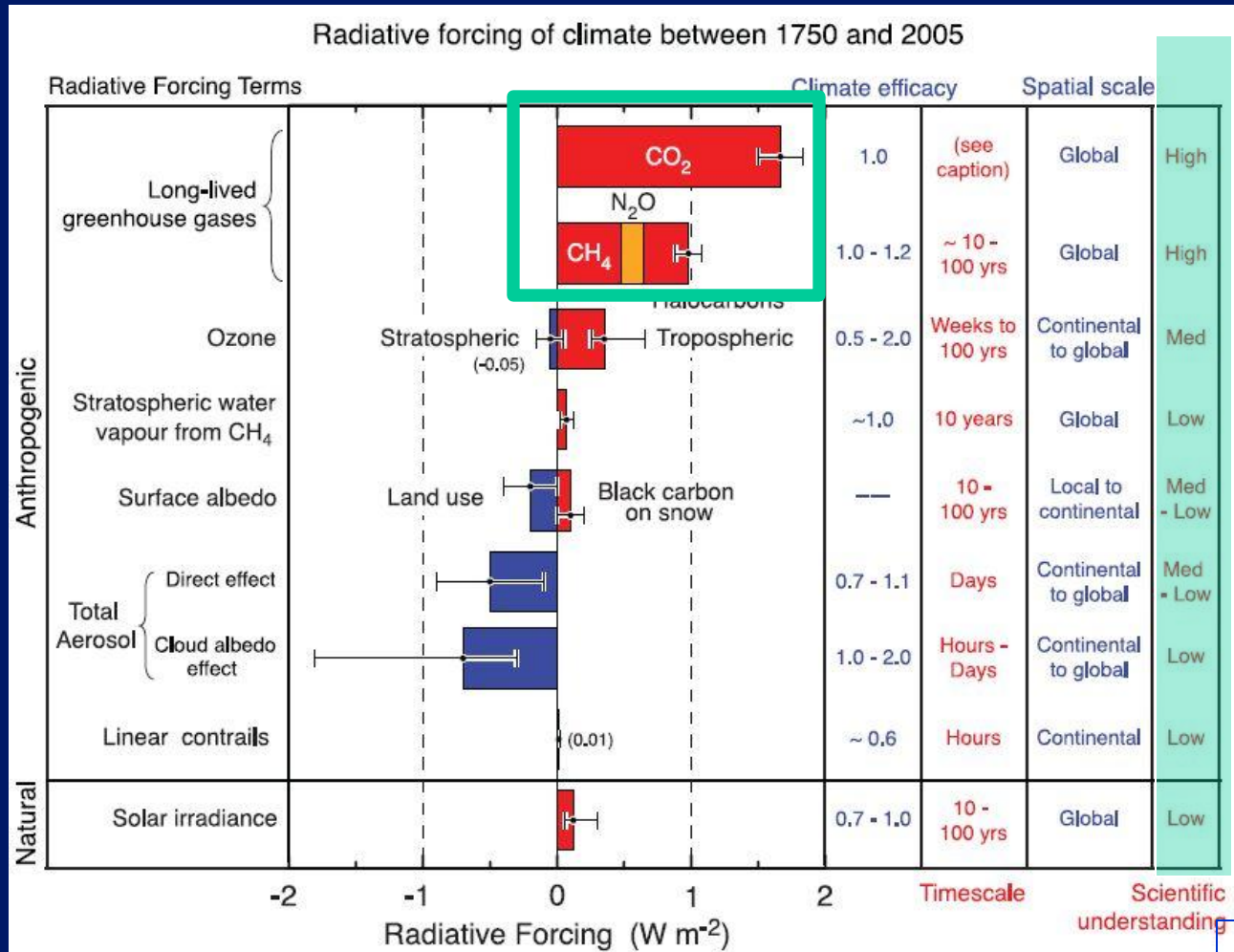
1. TRUE
2. FALSE





**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**.

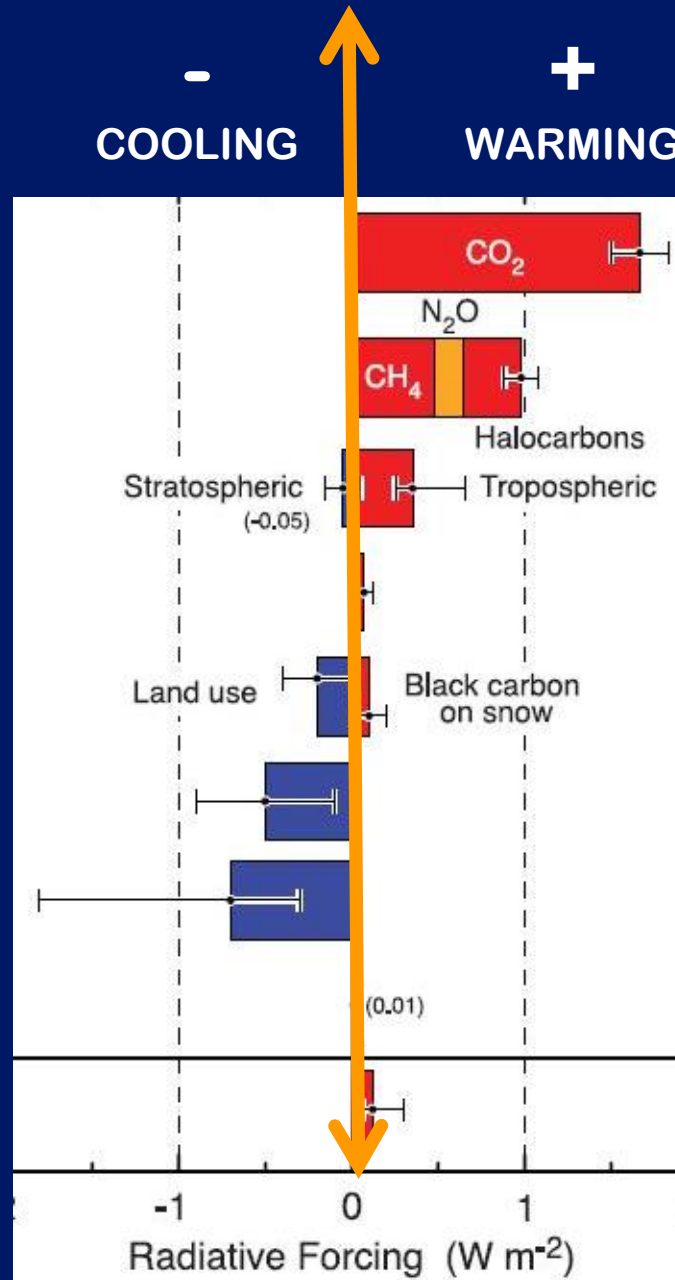
**1. TRUE**  
**2. FALSE**



# WHAT TO KNOW:

If the forcing is NEGATIVE (to left of line)

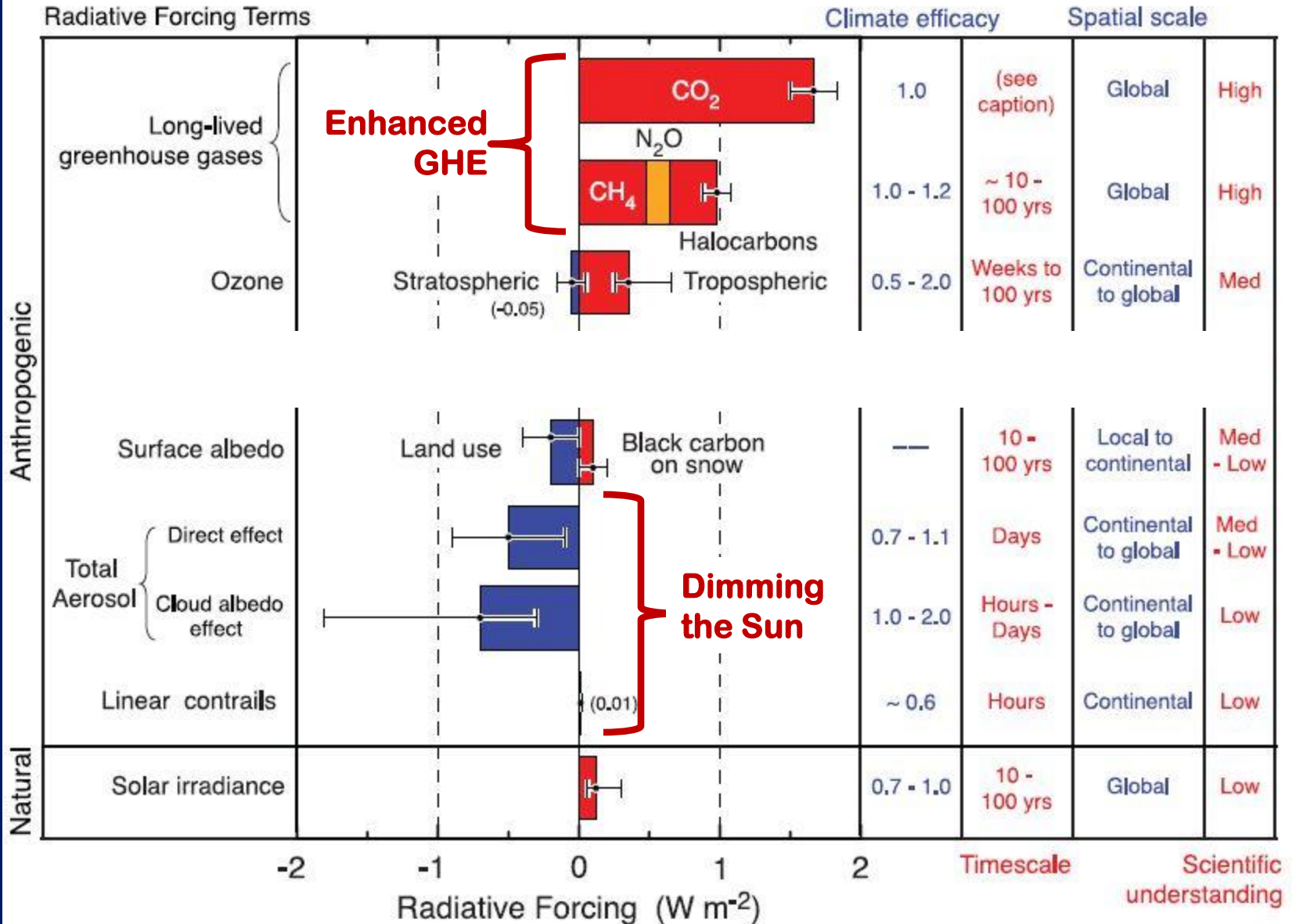
it means that an increase in that gas or factor contributes to **COOLING** in the troposphere.



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.

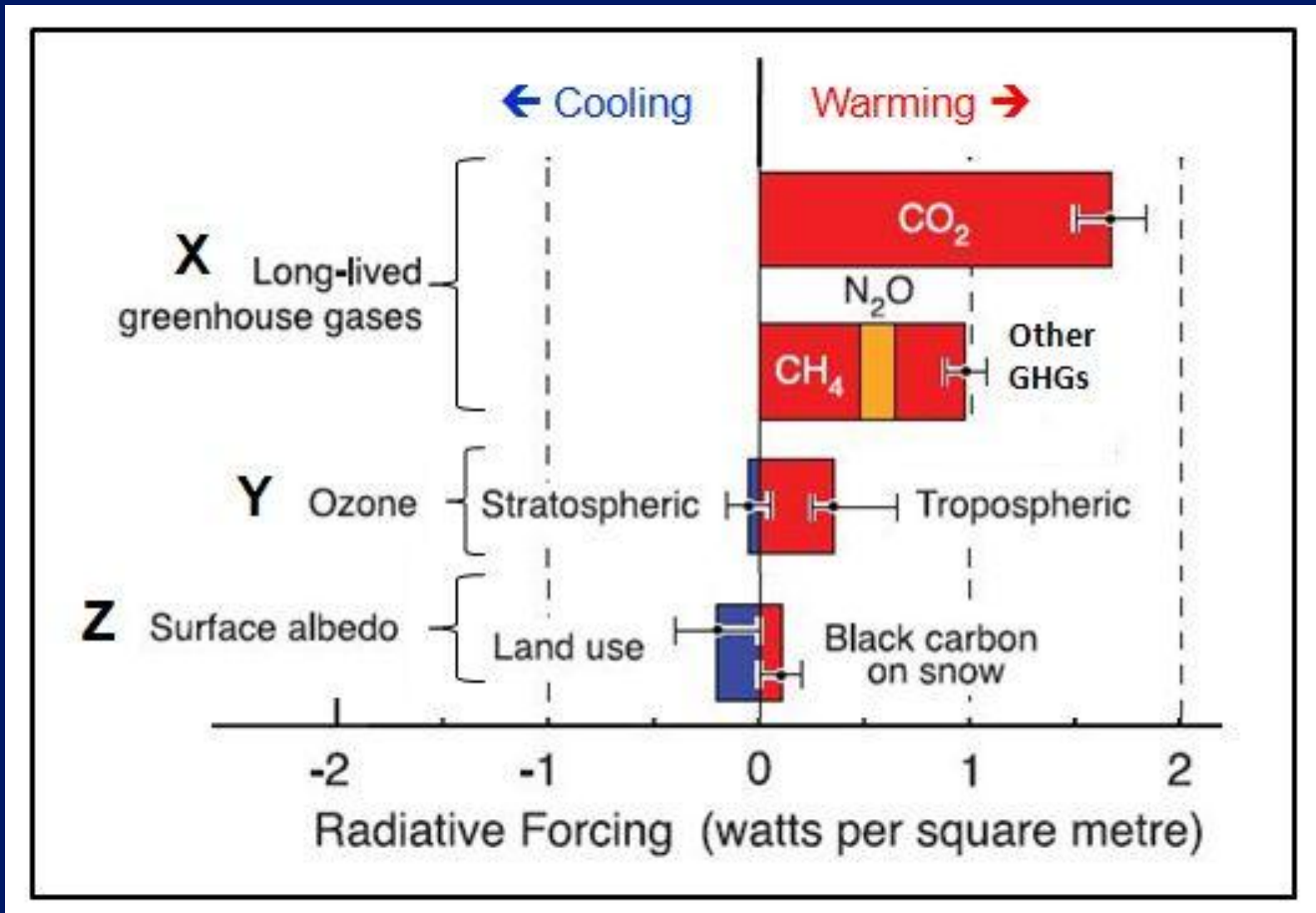
# Radiative forcing of climate between 1750 and 2005



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

**Q -ALL of the forcing mechanisms shown here (X, Y, & Z) are linked to anthropogenic activity in some way:**

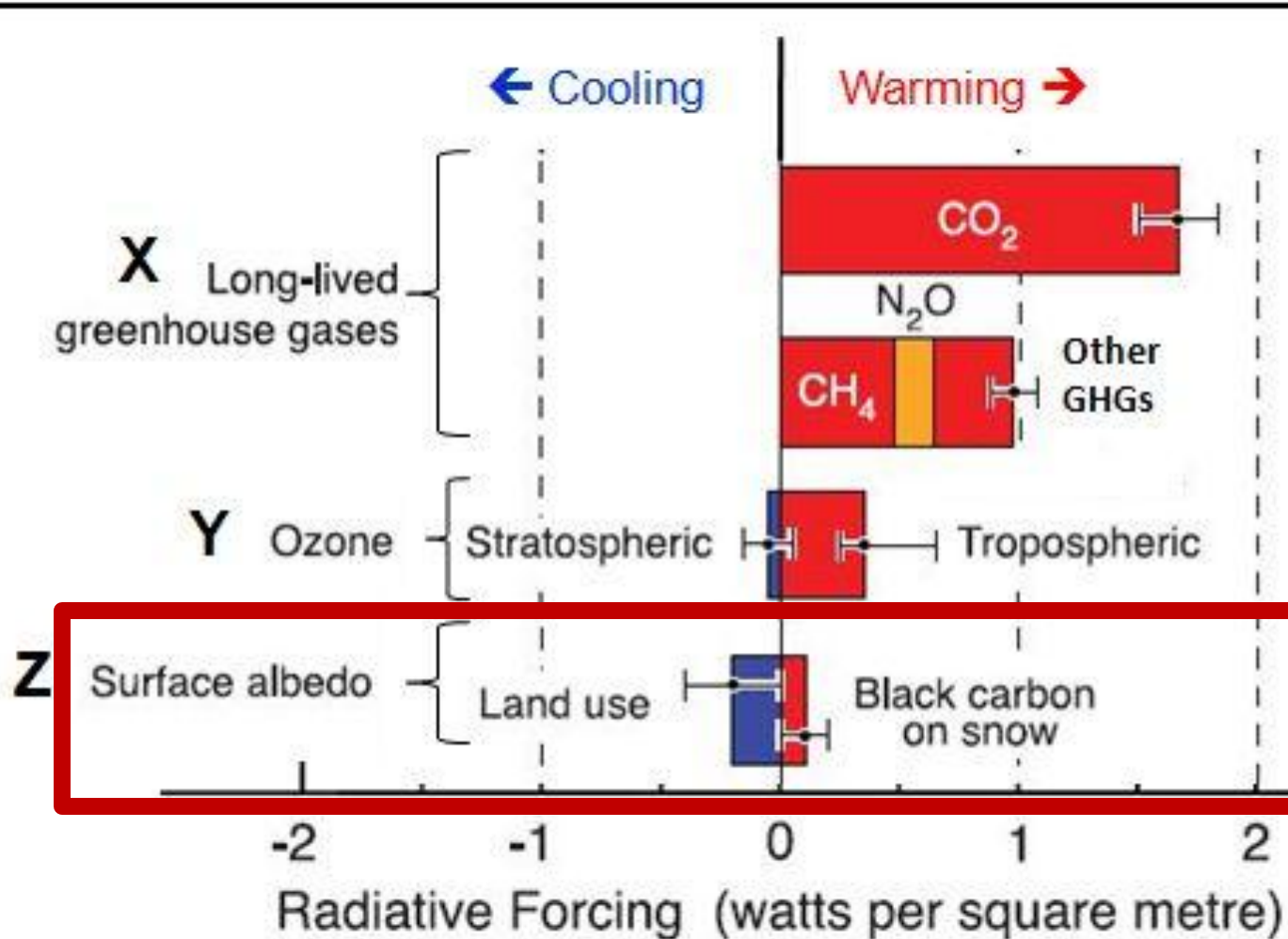
**1. TRUE      2. FALSE**



Q -ALL of the forcing mechanisms shown here (X, Y, & Z) are linked to anthropogenic activity in some way:

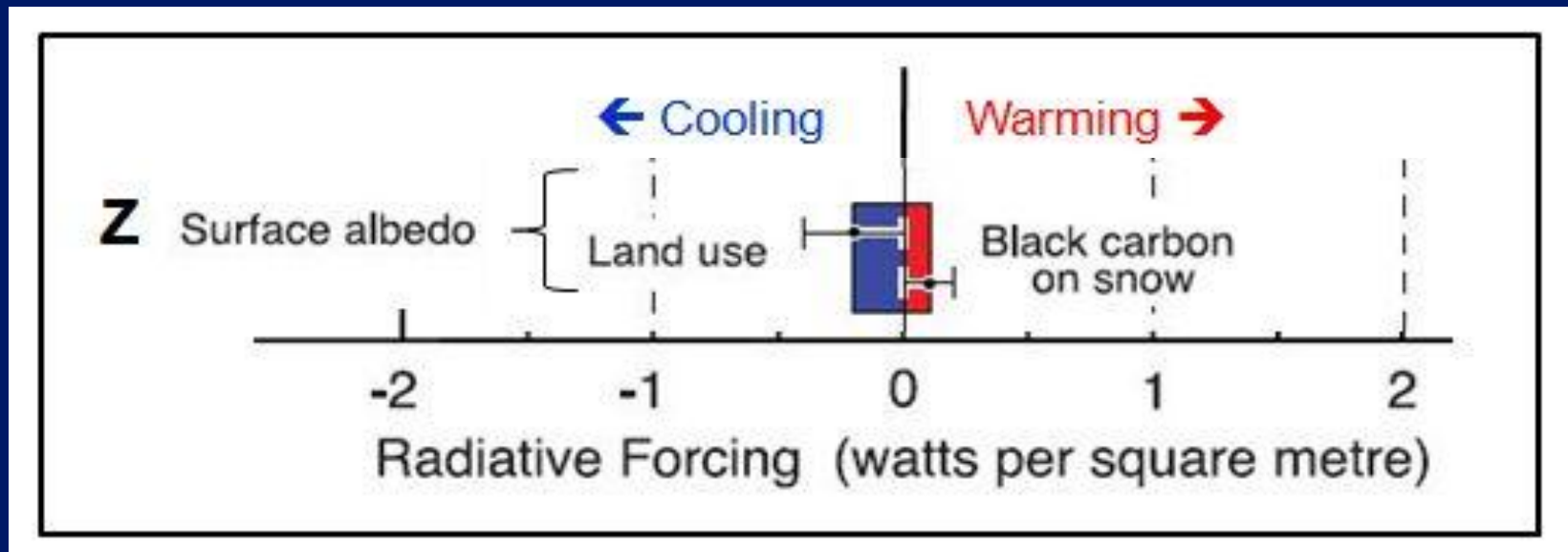
1. TRUE

2. FALSE



**Q** -The figure shows that **forcing mechanism Z** (Land-use as indicated by albedo) leads to **COOLING** . . . . The reason for this is that **cooling** occurs when surface albedo *increases* and hence **MORE** energy is **absorbed**.

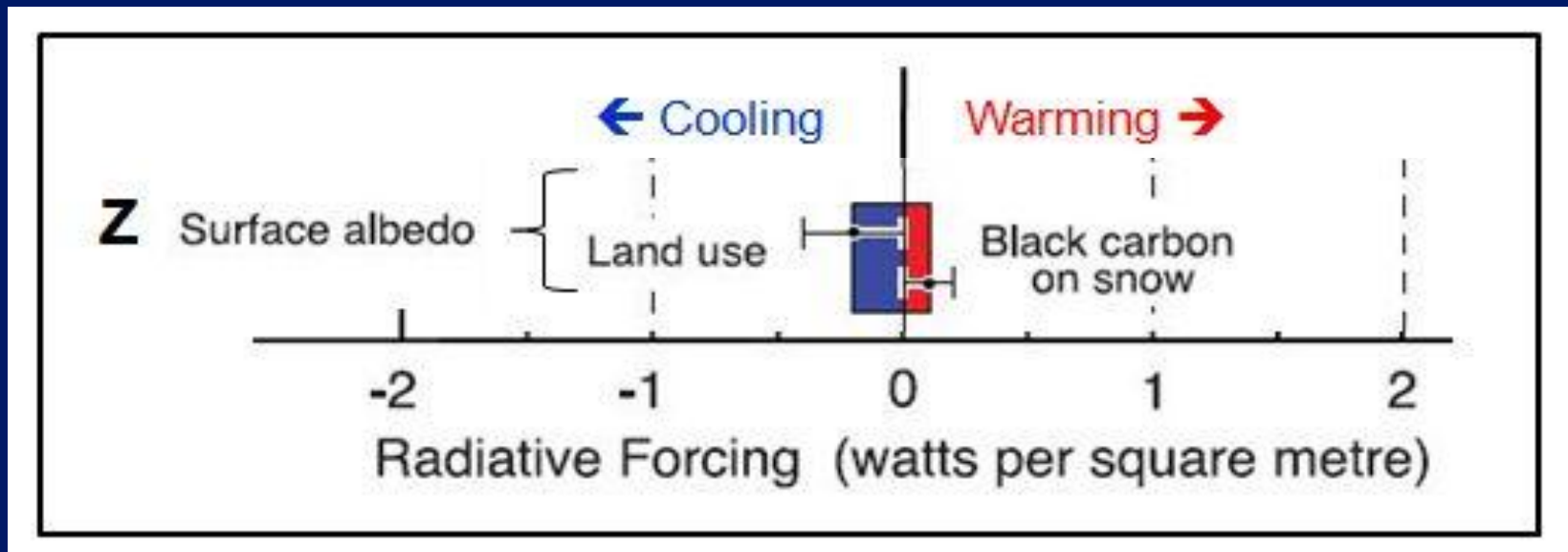
TRUE or FALSE?



**LESS** energy is absorbed!

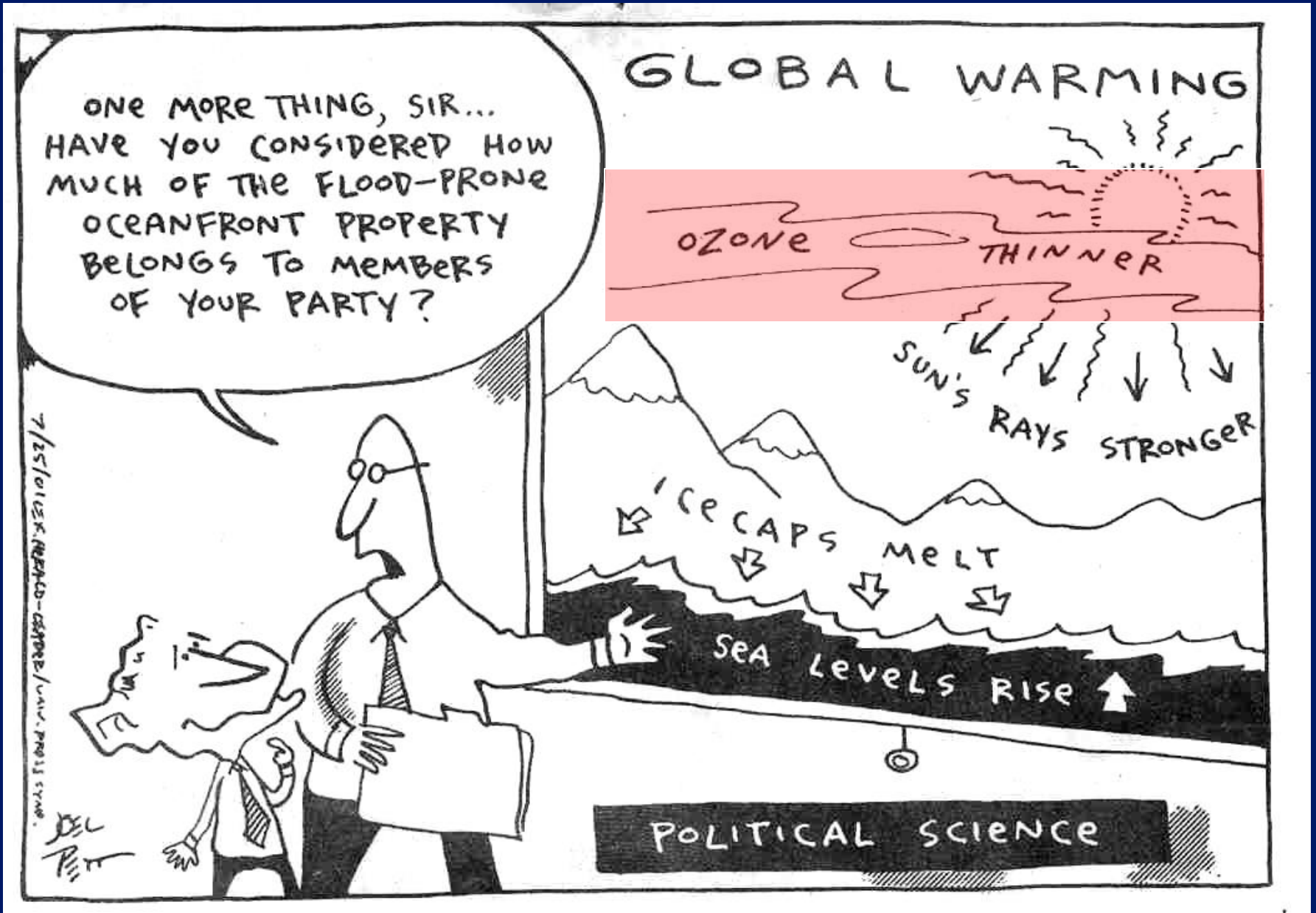
**Q** -The figure shows that **forcing mechanism Z** (Land-use as indicated by albedo) leads to **COOLING** . . . . The reason for this is that **cooling** occurs when surface albedo *increases* and hence **MORE** energy is **absorbed**.

TRUE or FALSE?



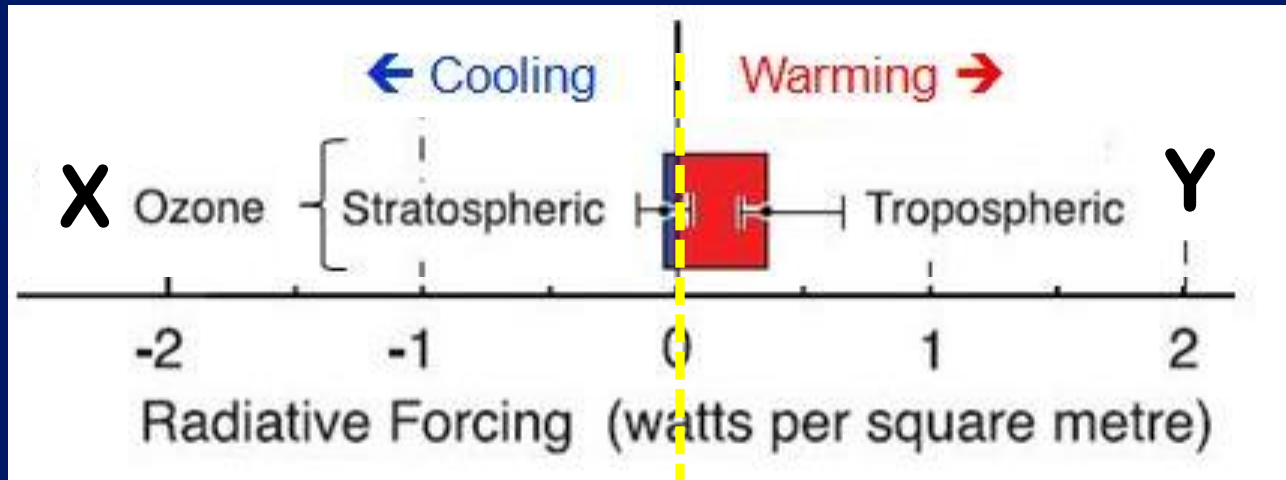
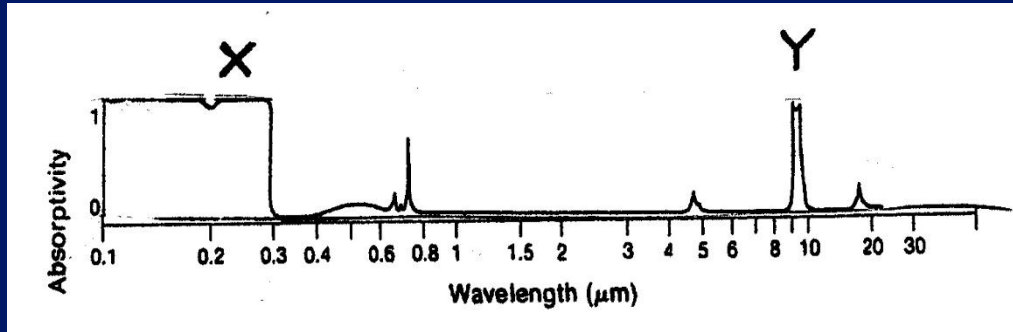
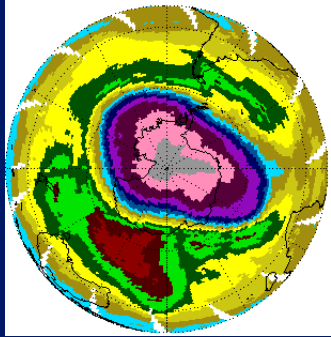
**LESS** energy is absorbed!

# REVIEW OF A COMMON MISCONCEPTION!





# OZONE'S DUAL PERSONALITY!

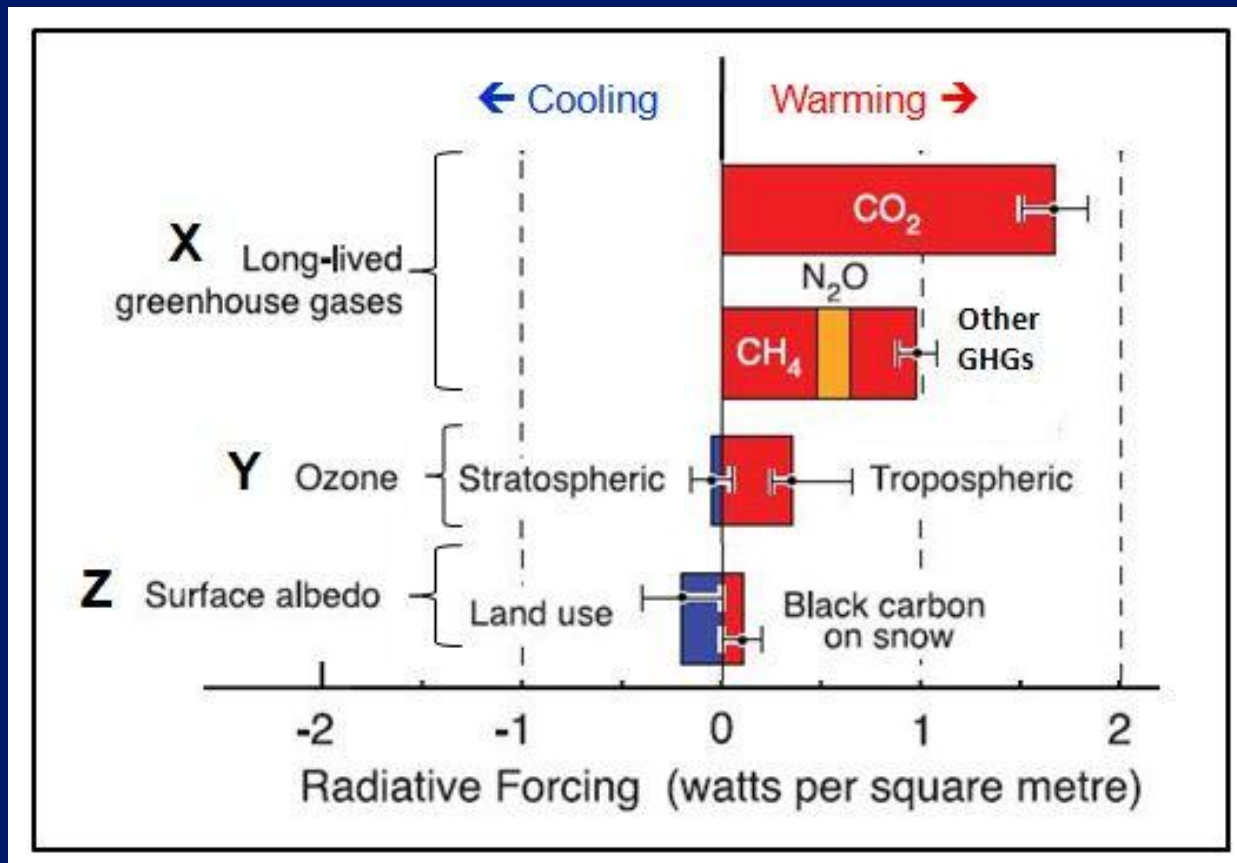


An INCREASE of Stratospheric Ozone will absorb more UV in the stratosphere → less UV getting into the troposphere → a COOLER Troposphere

An INCREASE of Tropospheric (ground-level) Ozone will add to the Greenhouse Effect → more IR staying in the troposphere → a WARMER Troposphere

**Q -According to the figure which forcing mechanism has a GREATER influence on global temperature?**

**Stratospheric OZONE OR Tropospheric OZONE**

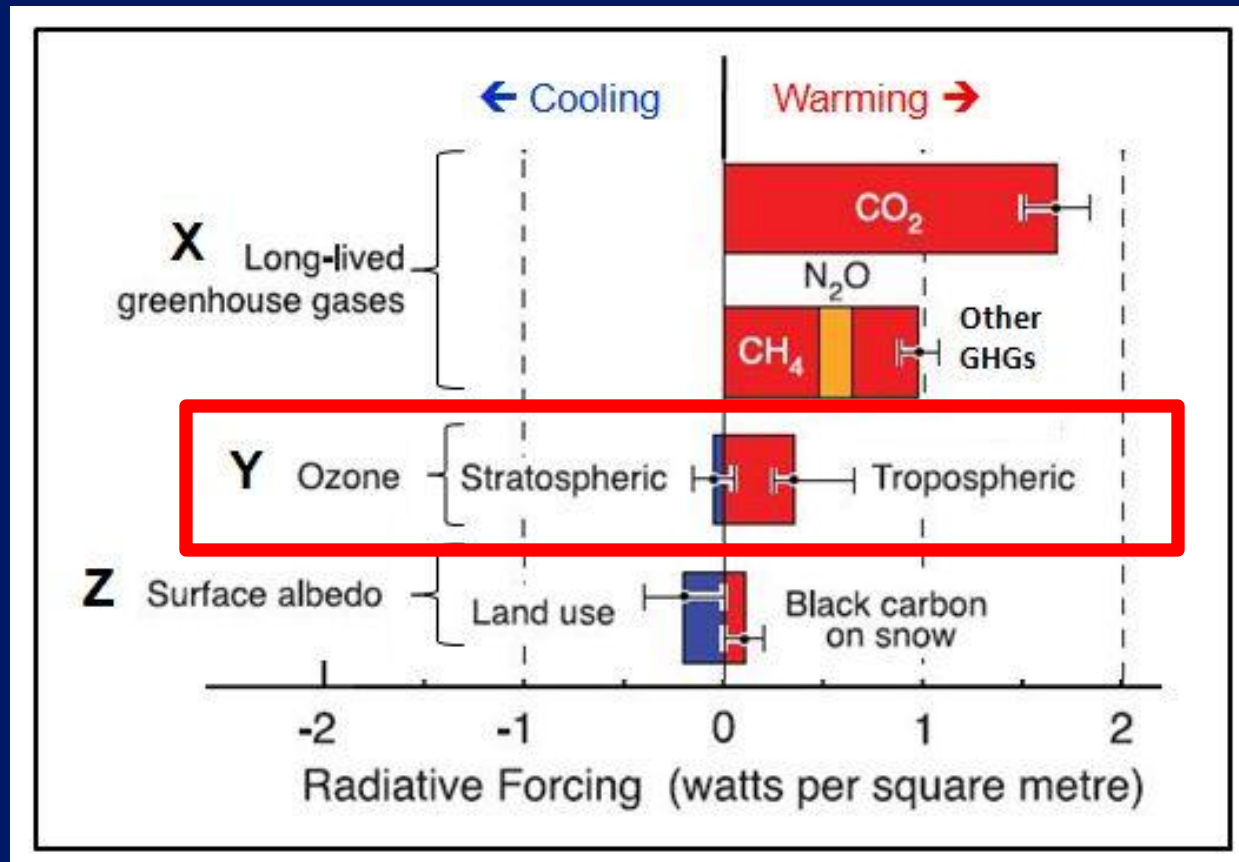


Q -According to the figure which forcing mechanism has a GREATER influence on global temperature?

Stratospheric OZONE

OR

Tropospheric OZONE

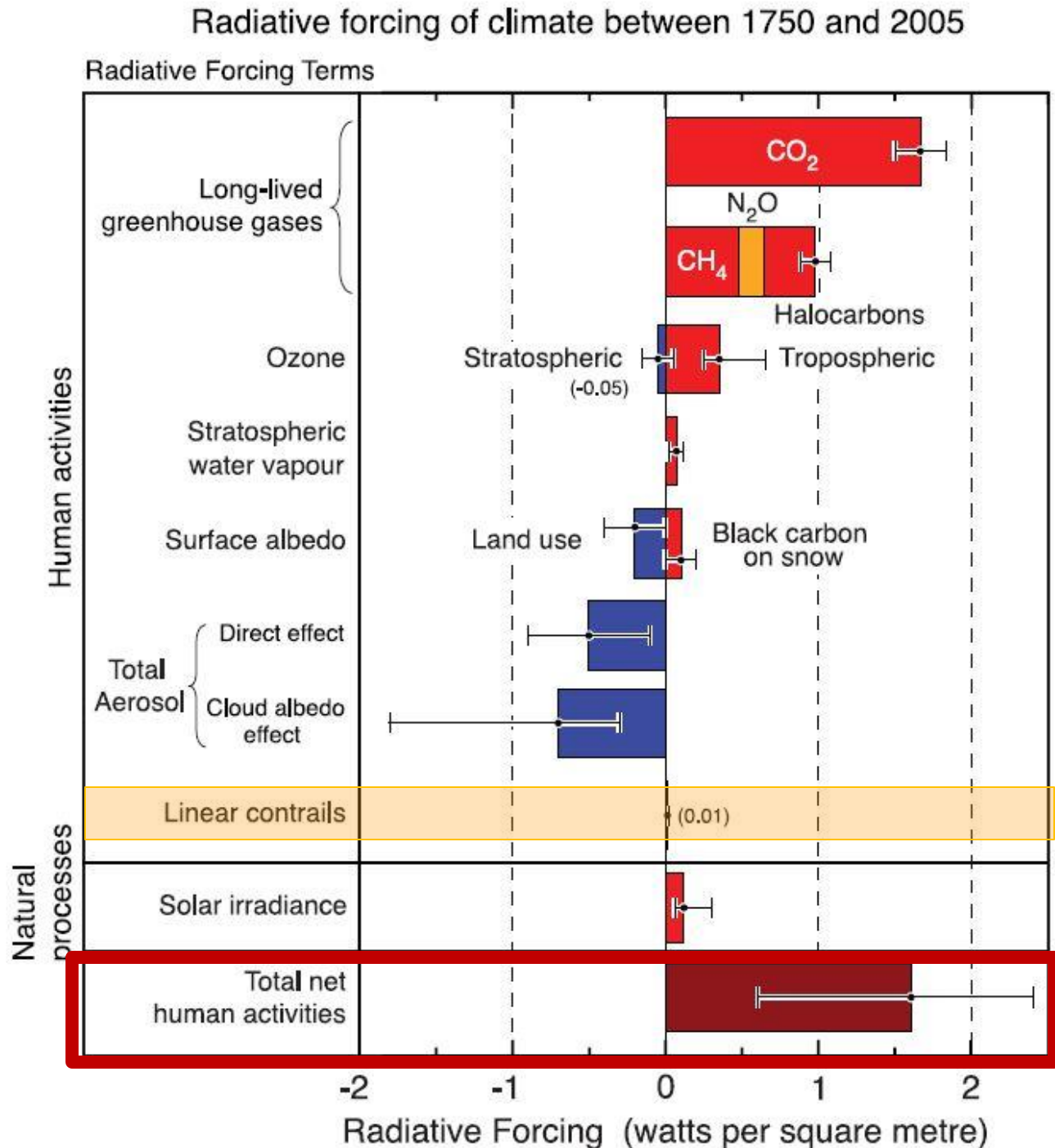


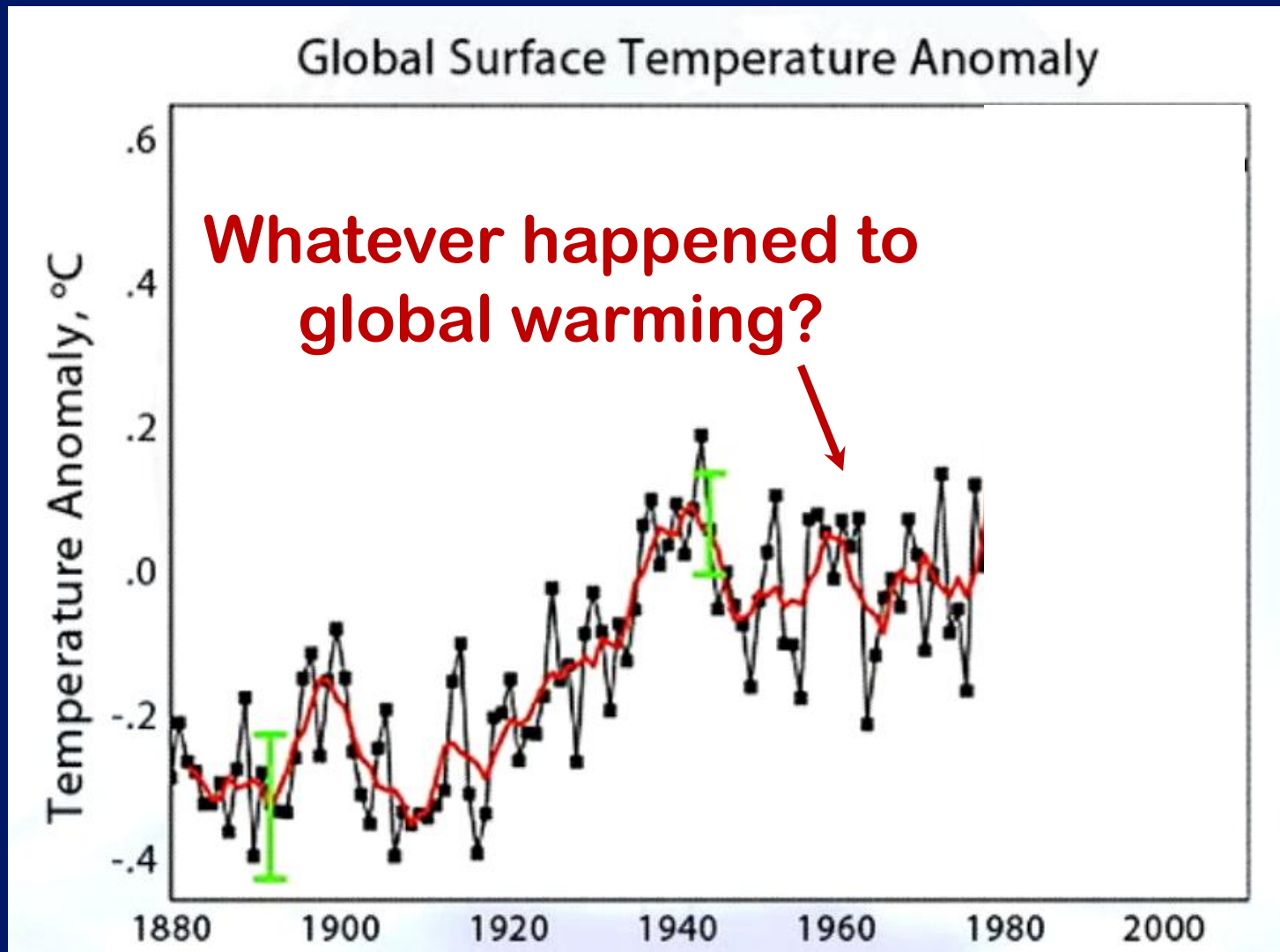
Therefore, the Stratospheric Ozone Hole is NOT the main cause of global warming!

Climate Change  
2007 - IPCC  
The Physical  
Science Basis  
Working Group 1  
Report

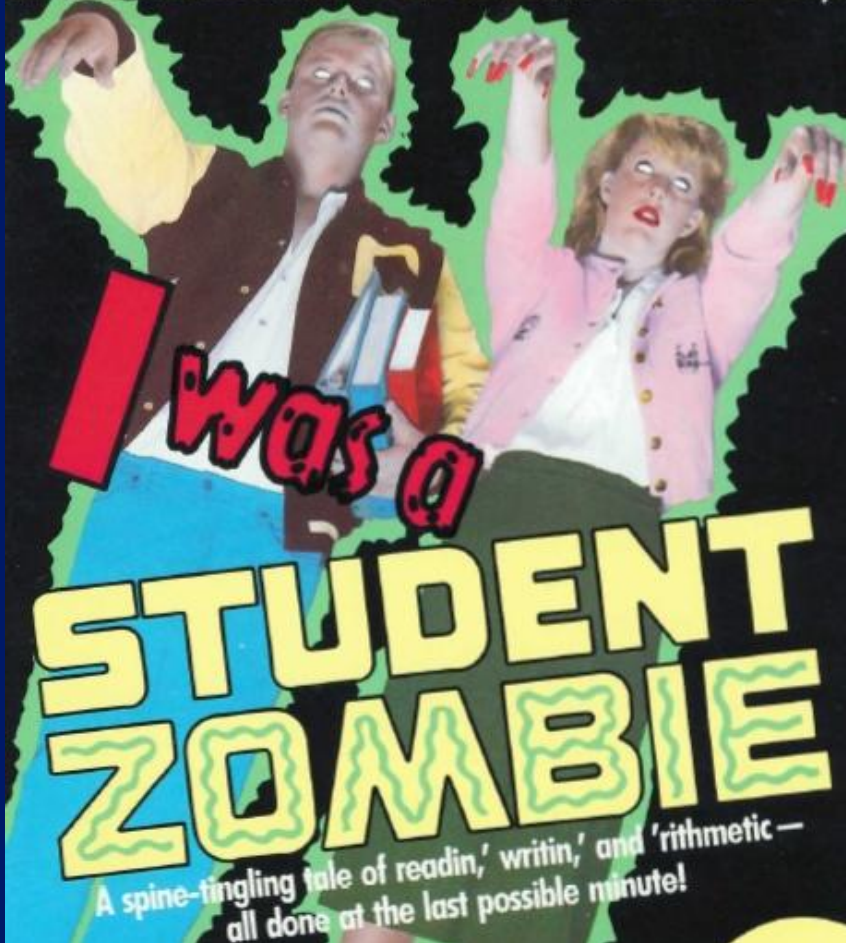
FAQ 2.1

How do Human  
Activities  
Contribute to  
Climate  
Change and  
How do They  
Compare with  
Natural  
Influences?





It's happening right now...in YOUR town...  
in YOUR school...in YOUR class...in YOUR BRAIN!

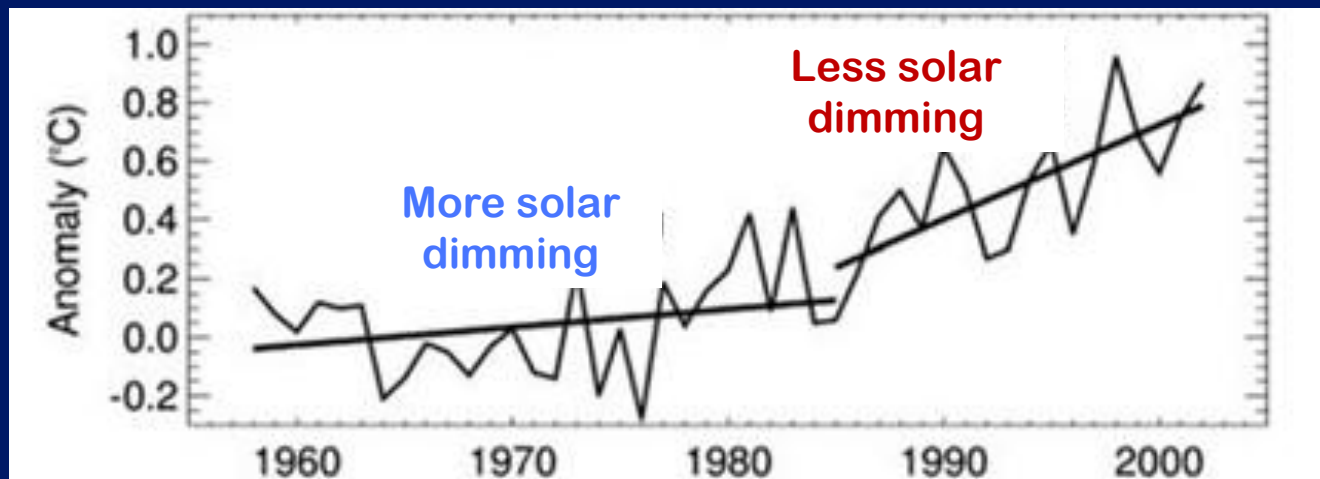


# Mini ZOMBIE BREAK !

<http://www.youtube.com/watch?v=D4Z0S9yRTyw>

# 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)



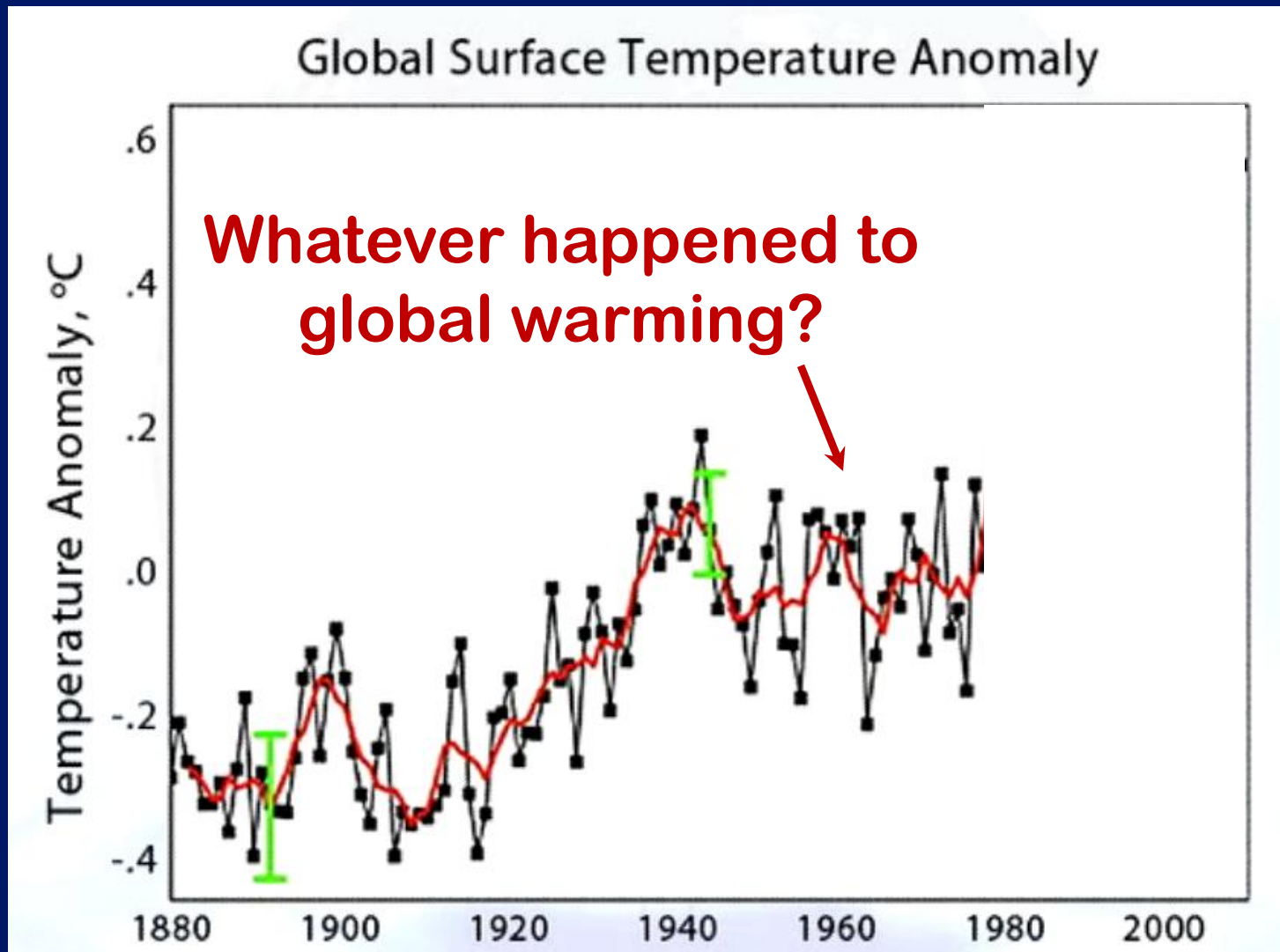
*Thick-cloud  
air pollution common;  
health problems, deaths*



**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*





# CLIMATE CHANGE:

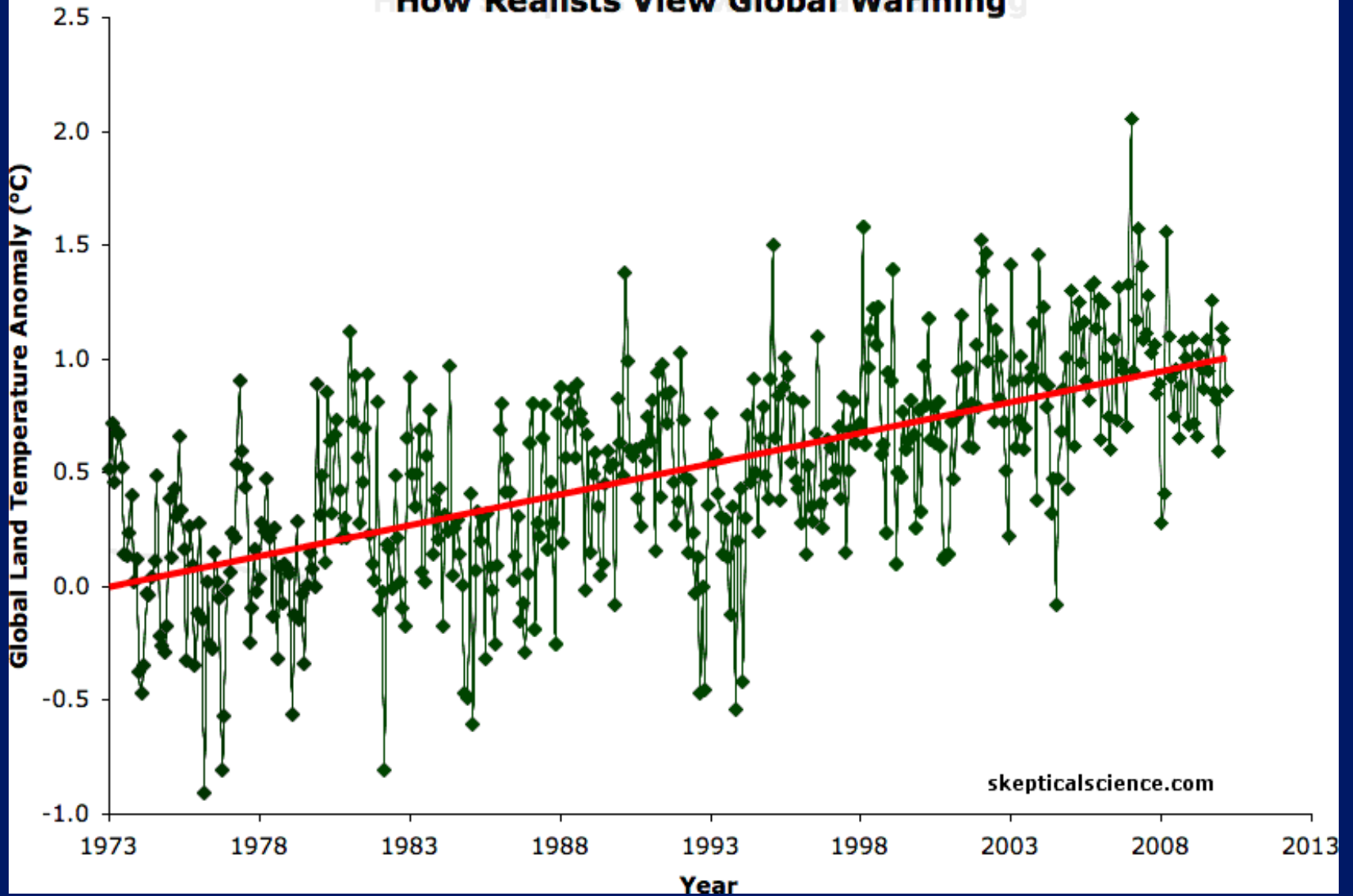
## WHAT'S CAUSING IT?

The most used "denier" arguments about the causes and effects of climate change

From: <http://www.skepticalscience.com/>



# How Realists View Global Warming



From: [skepticalscience.com](http://skepticalscience.com)

... and now

How do we KNOW  
that the recent global  
warming is due primarily  
to human activities  
and not just  
natural climate forcing?

# TOPIC # 15, PART C:

## Evidence from Natural Archives

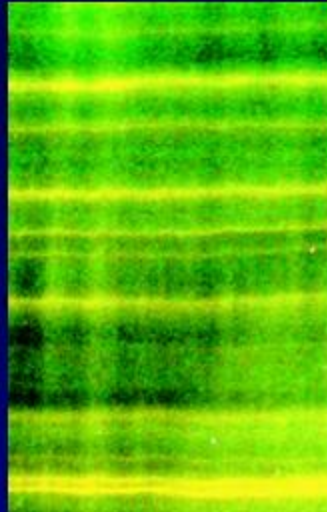
Tree rings



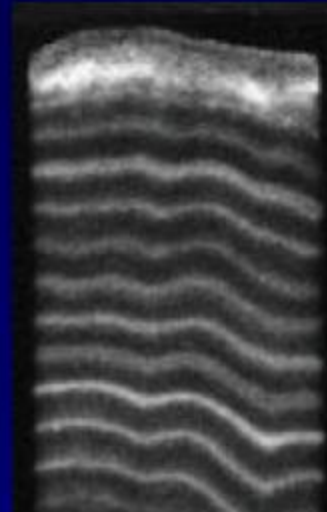
Lake varves  
(sediments)



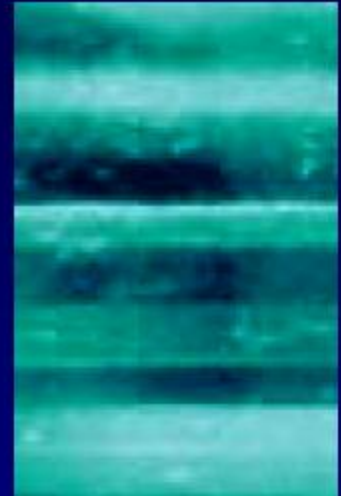
Speleothems  
(from cave)



Coral  
(annual growth)



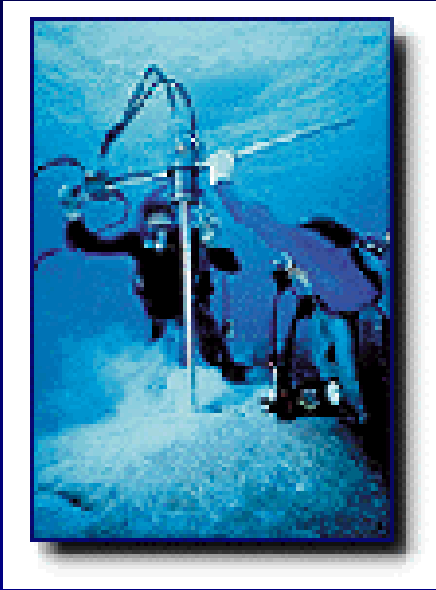
Ice Core



*"The farther backward you can look,  
the farther forward you are likely to see."*

*- Winston Churchill*

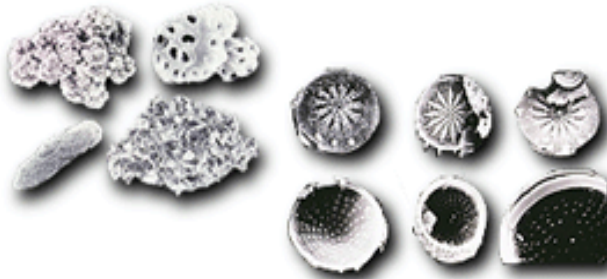
# “PROXY” DATA or NATURAL ARCHIVES of CLIMATE



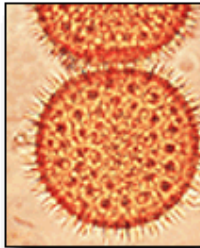
Corals



Ice cores



Lake, bog &  
ocean  
sediments



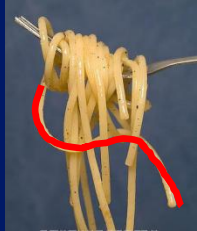
Pollen



Tree rings!

# 3 "iconic" graphs of GLOBAL CLIMATE CHANGE . . .

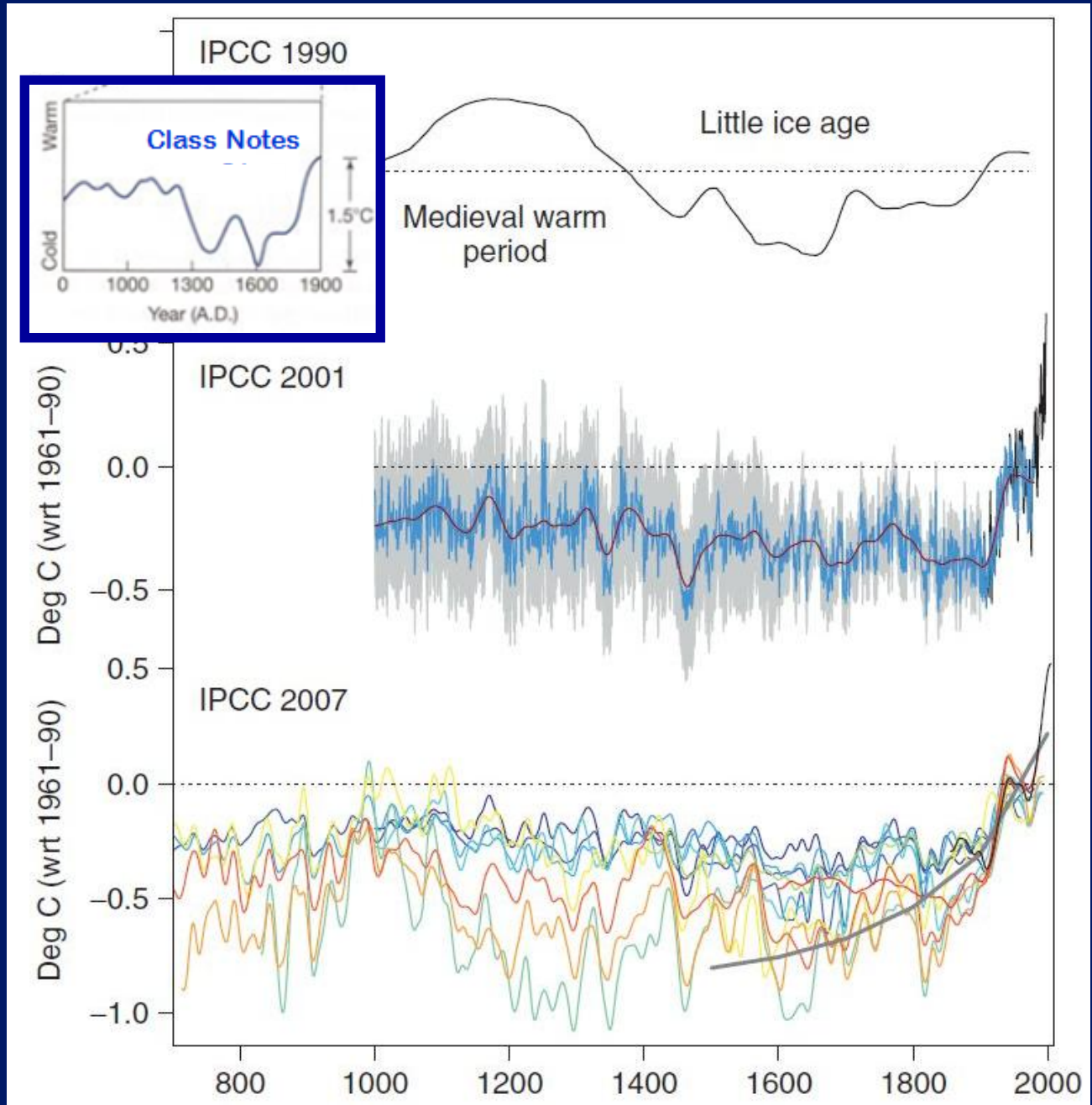
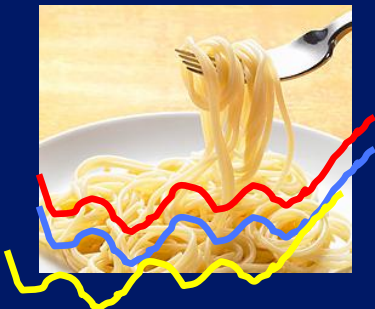
## The "Noodle"



## The "Hockey Stick"



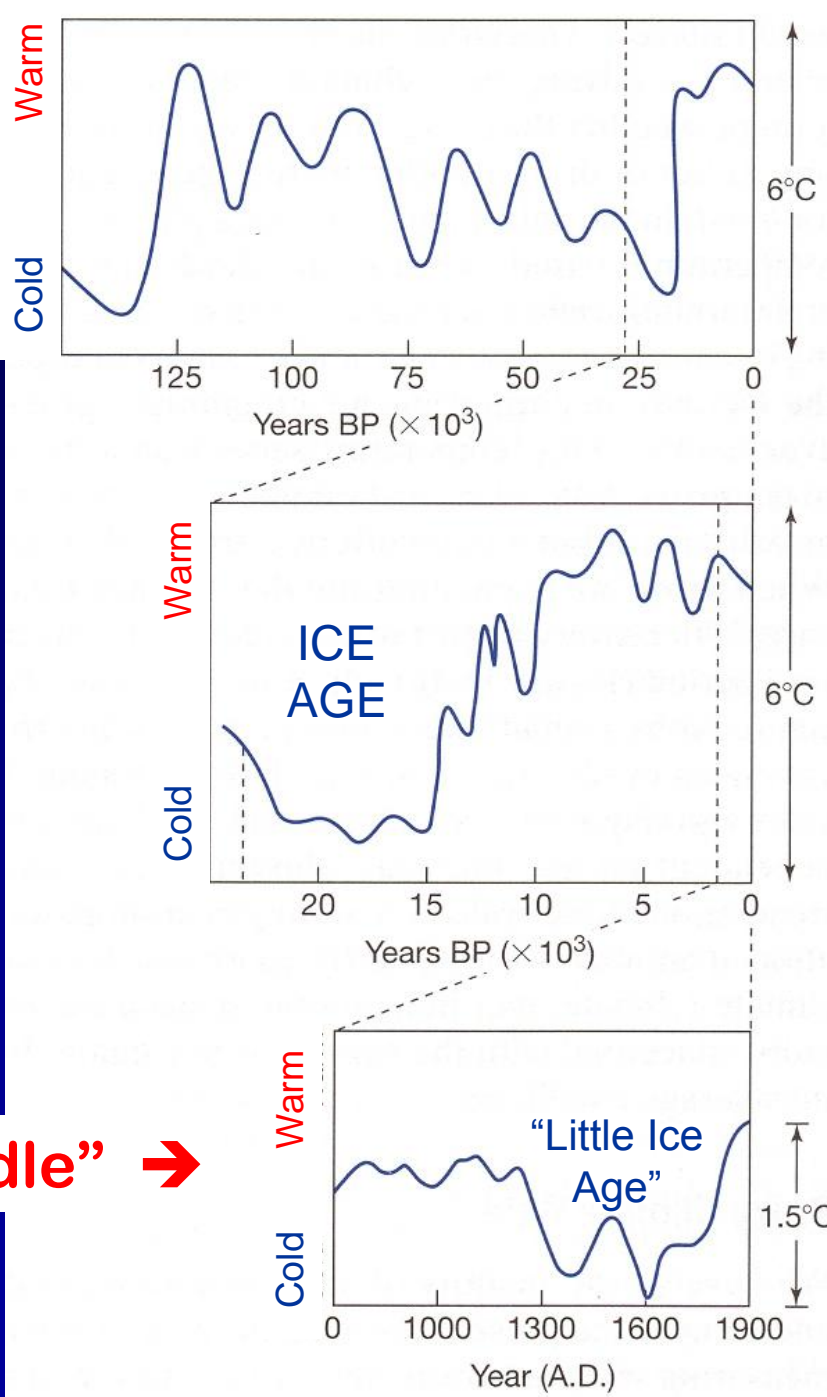
## The "Spaghetti Plate"



**Review:**  
**from p 17 of**  
**Class Notes:**

**Estimates of**  
**Mean Global**  
**Temperature**  
**Change --**  
**based on**  
**various types**  
**of archives**

**The “Noodle”** →



**deep-sea**  
**sediments**

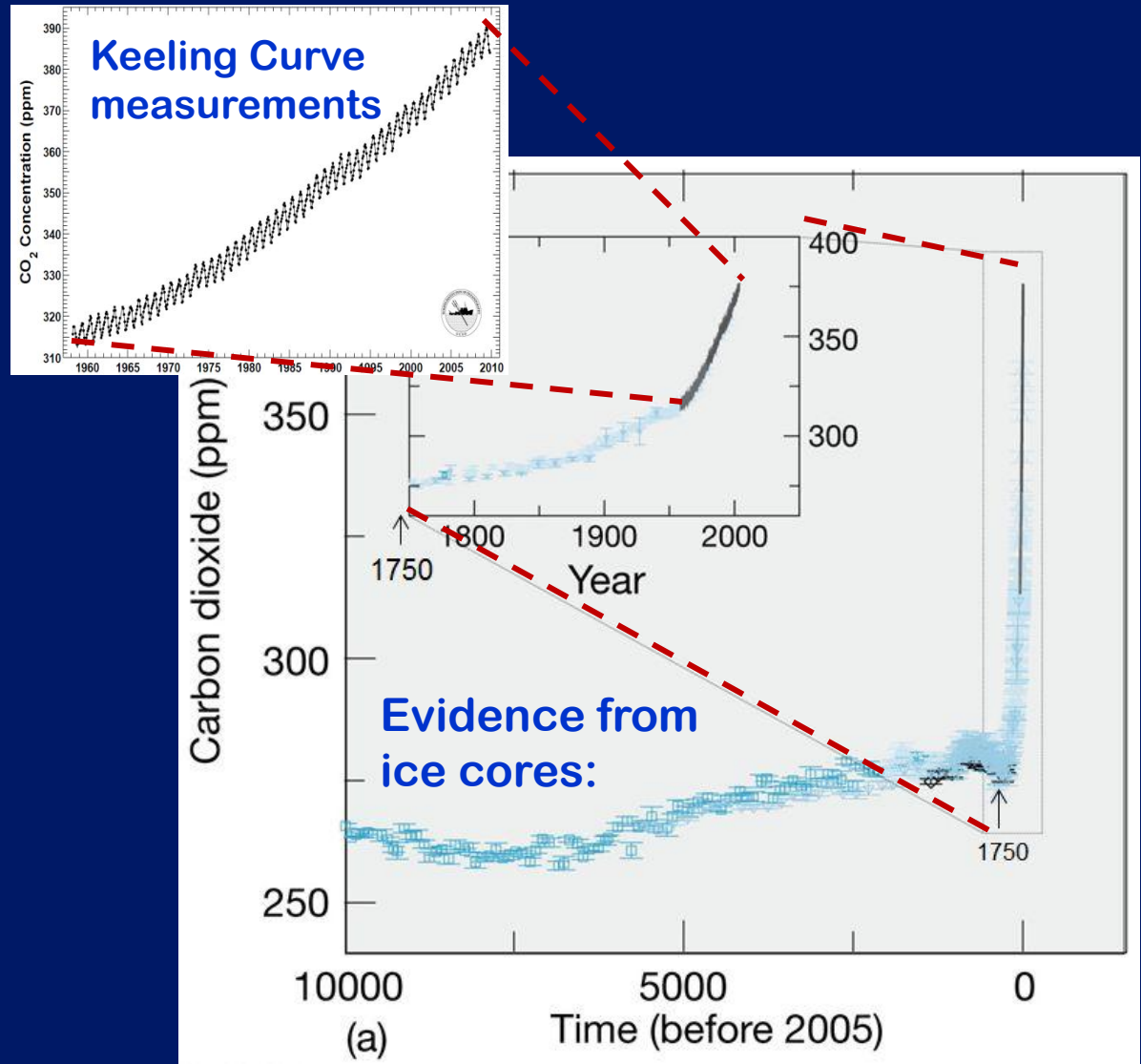
**pollen data &**  
**alpine glaciers**

**historical**  
**documents**

(emphasis on the North  
Atlantic region)

**top graph on p 91**

# The CO<sub>2</sub> “Hockey Stick” Graph . . .

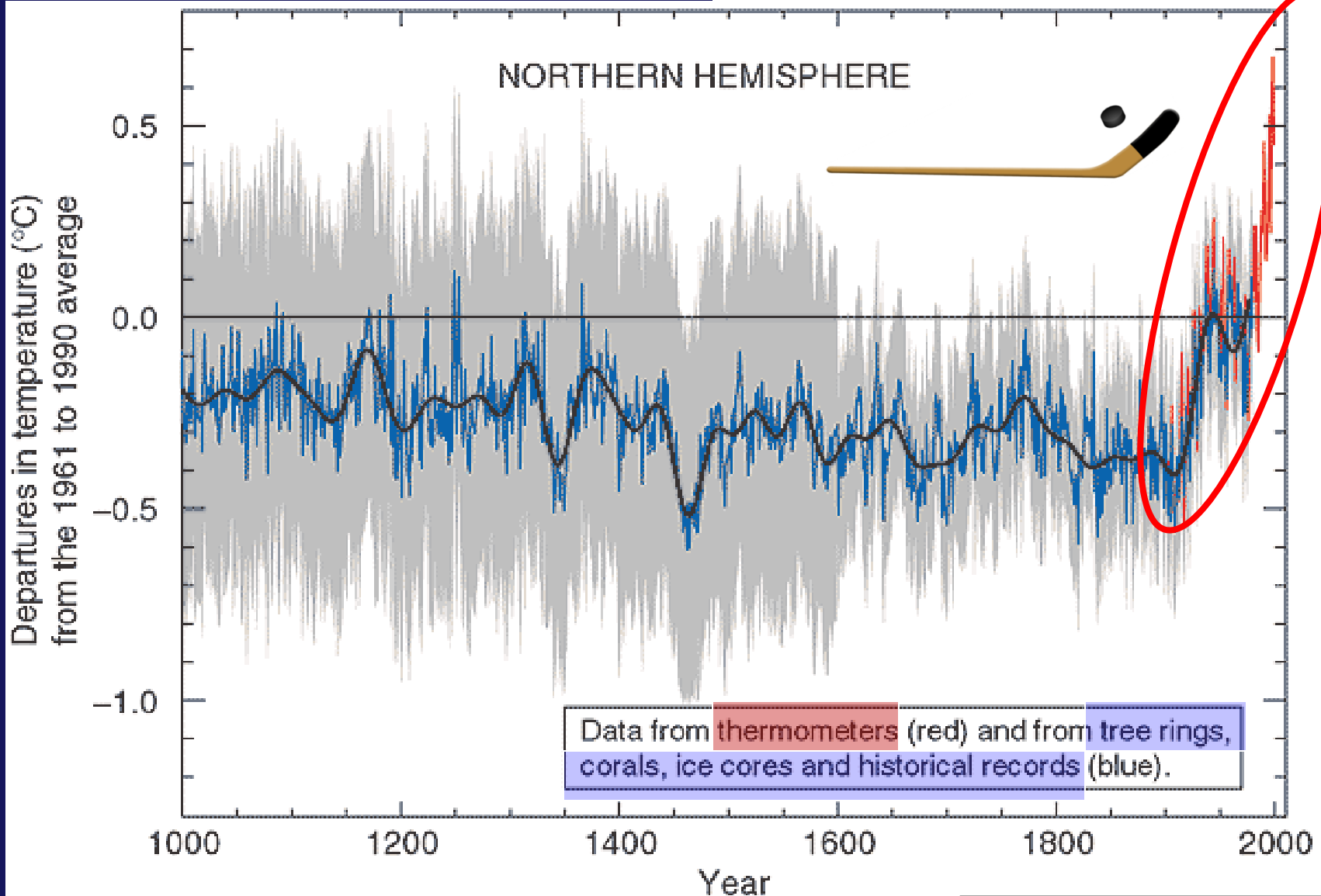


SGC E-Text  
Chapter 1  
Fig 1-3a



# The Temperature “Hockey Stick” Graph

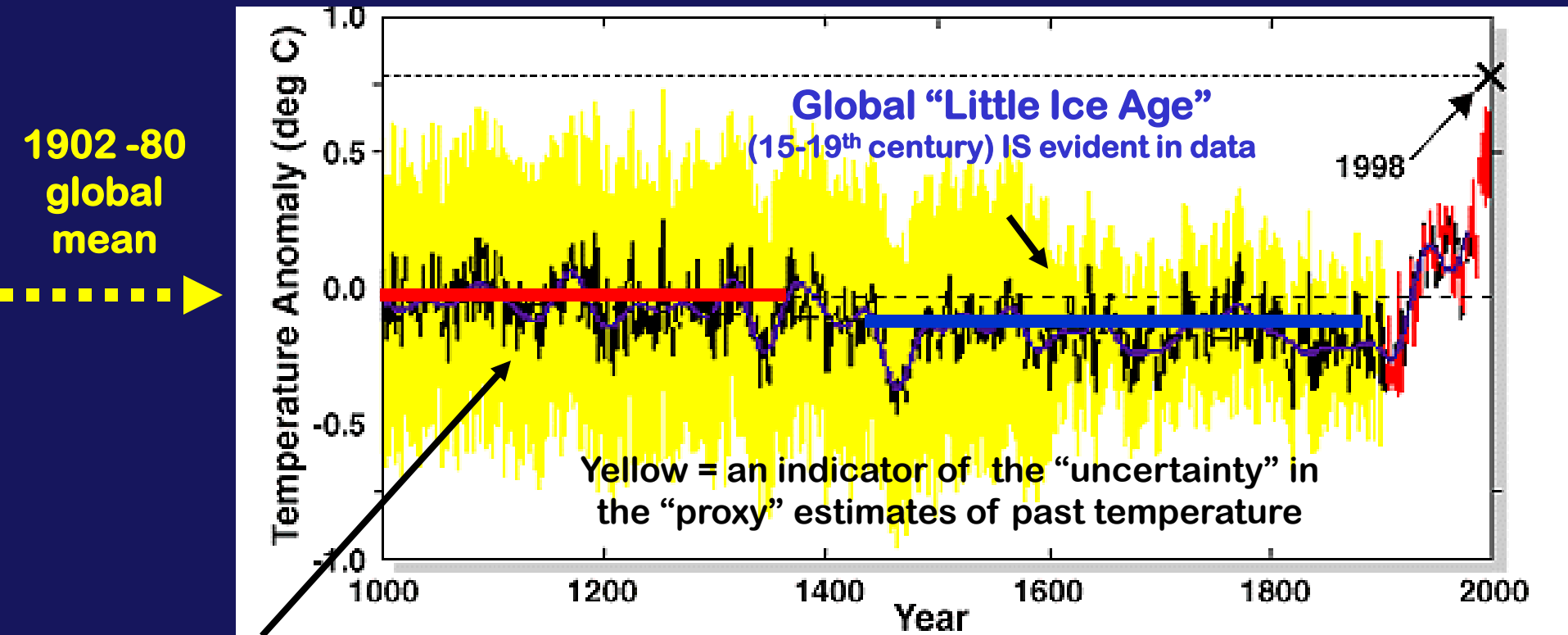
“proxy” data +  
thermometer records



middle graph on p 91

# The Temperature Hockey Stick Graph (another view)

Temperature change over the last 1000 years from multi-proxy records: shows there is **NO period** of global or hemispheric temperatures **warmer than the 20<sup>th</sup> century**



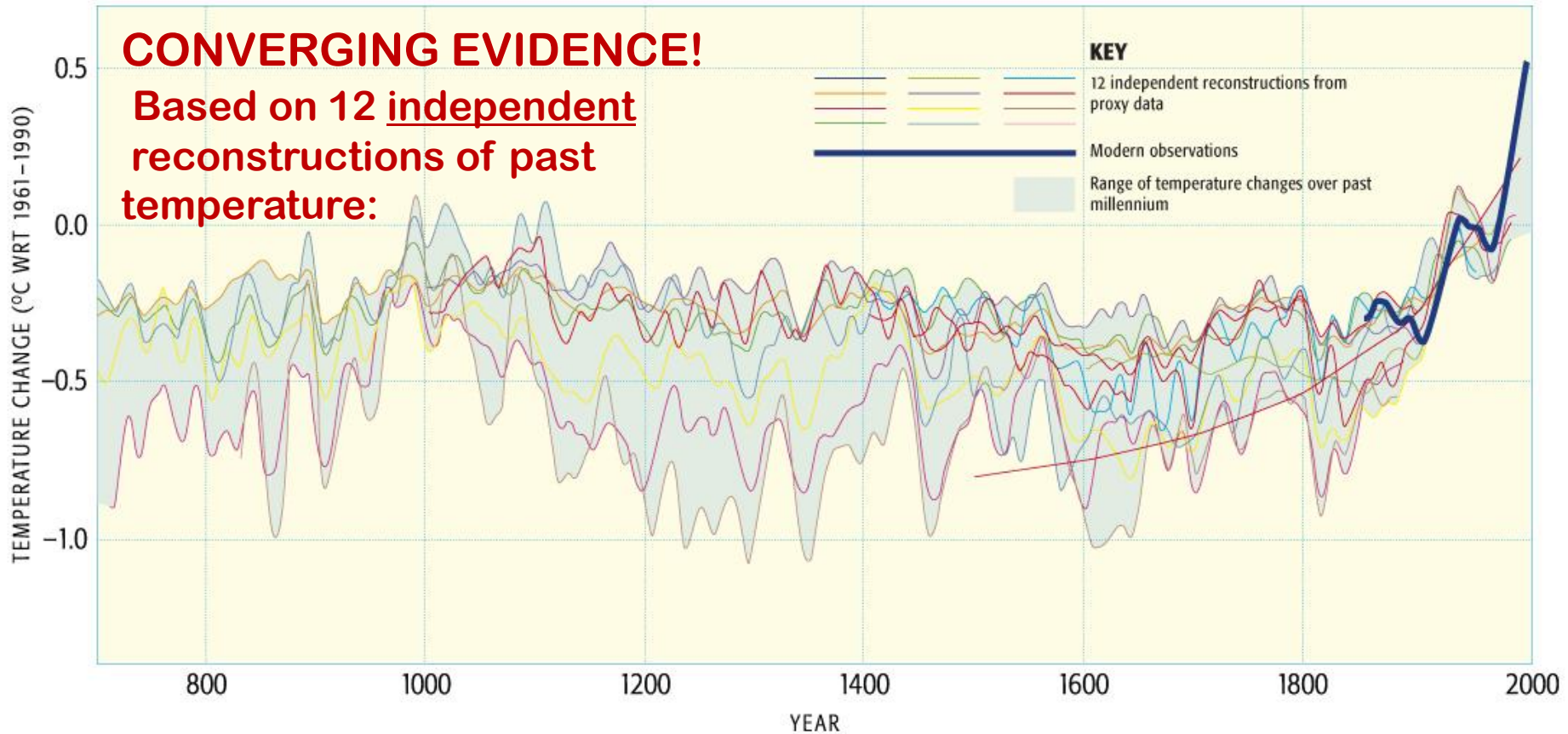
**"Medieval Warm Period"** (9-14<sup>th</sup> century) not very evident (more of a regional phenomenon)

- reconstruction (AD 1000-1980)
- instrumental data (AD 1902-1998)
- - - calibration period (AD 1902-1980) mean
- reconstruction (40 year smoothed)
- - - linear trend (AD 1000-1850)

Another version

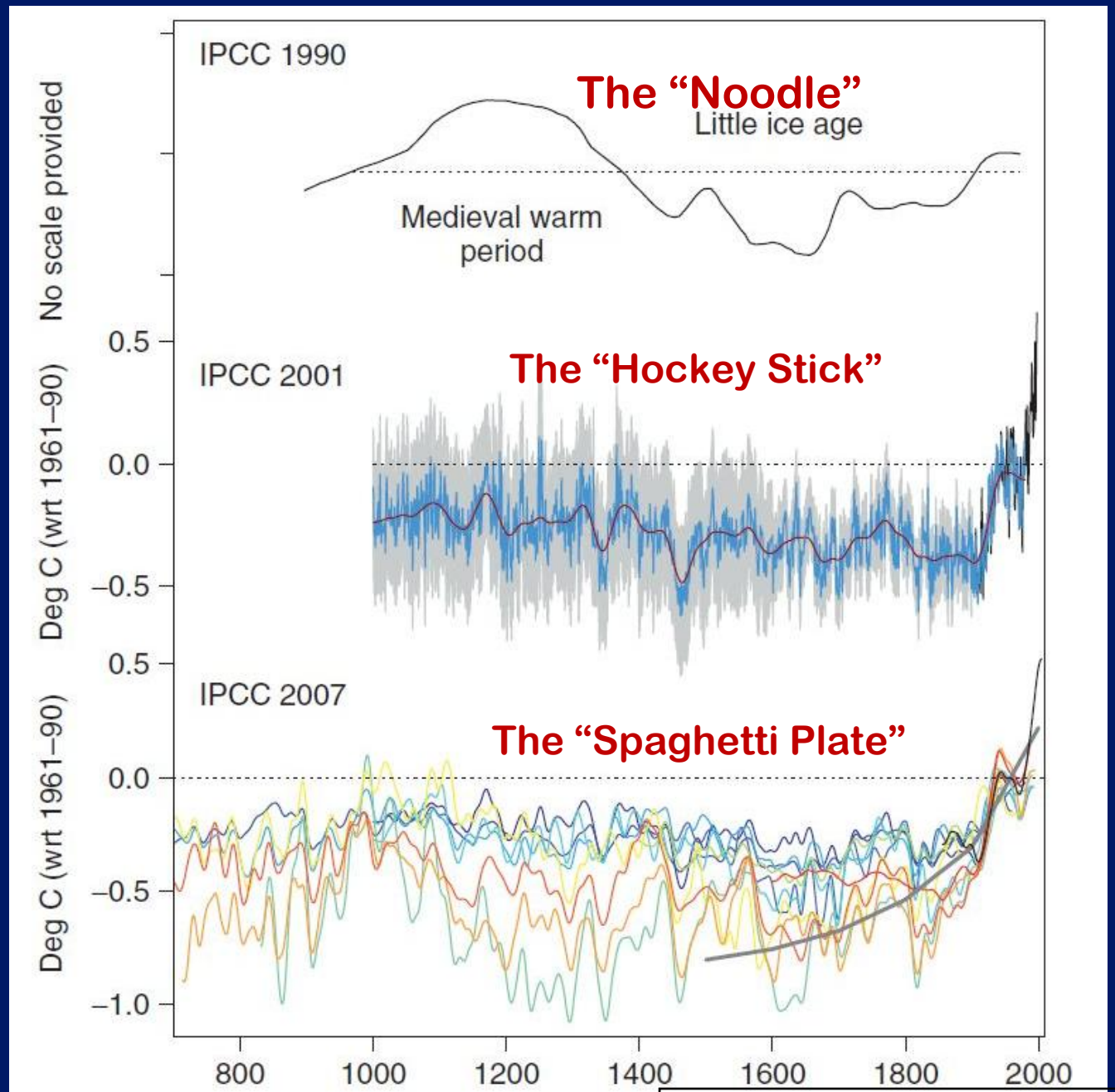
# The Temperature “Spaghetti Plate” Graph

## NORTHERN HEMISPHERE TEMPERATURE CHANGES OVER THE PAST MILLENNIUM



The general “Hockey Stick” shape has stood the test of time, despite intense scrutiny and debunking attempts!

# The Scientific Process “in action”



All 3 graphs on p 91

**GROUP  
TIME!!**

**VOTE** on which question to debate &  
**SIGN UP** for a role today!

*WITHIN YOUR GROUP, EACH STUDENT WILL  
SELECT FROM ONE OF THE FOLLOWING ROLES:*

1. **Climate Scientist \*\*** (each group should have one!)
2. **Global Warming Denier \*\*** (each group should have one!)
3. Corporate Manager/ Multinational Executive
4. Environmental Non-Governmental Organization (NGO)
5. Coal, Oil, Gas or Mining Interest -- executive or worker
6. Insurance or Re-Insurance Company Executive (e.g., see [LINK](#))
7. Working Class American
8. Upper-class American
9. Renewable Energy Small Business Leader (e.g. Solar panels)
10. Automotive or Transportation Executive, Business or Dealer
11. Resident of Tuvalu ( Pacific island nation in danger )  
or other Developing Country (you select)

**GOOD LUCK GETTING YOUR  
PROJECT SLIDES IN  
TOMORROW NIGHT!**

**SEE YOU NEXT  
TUESDAY!**