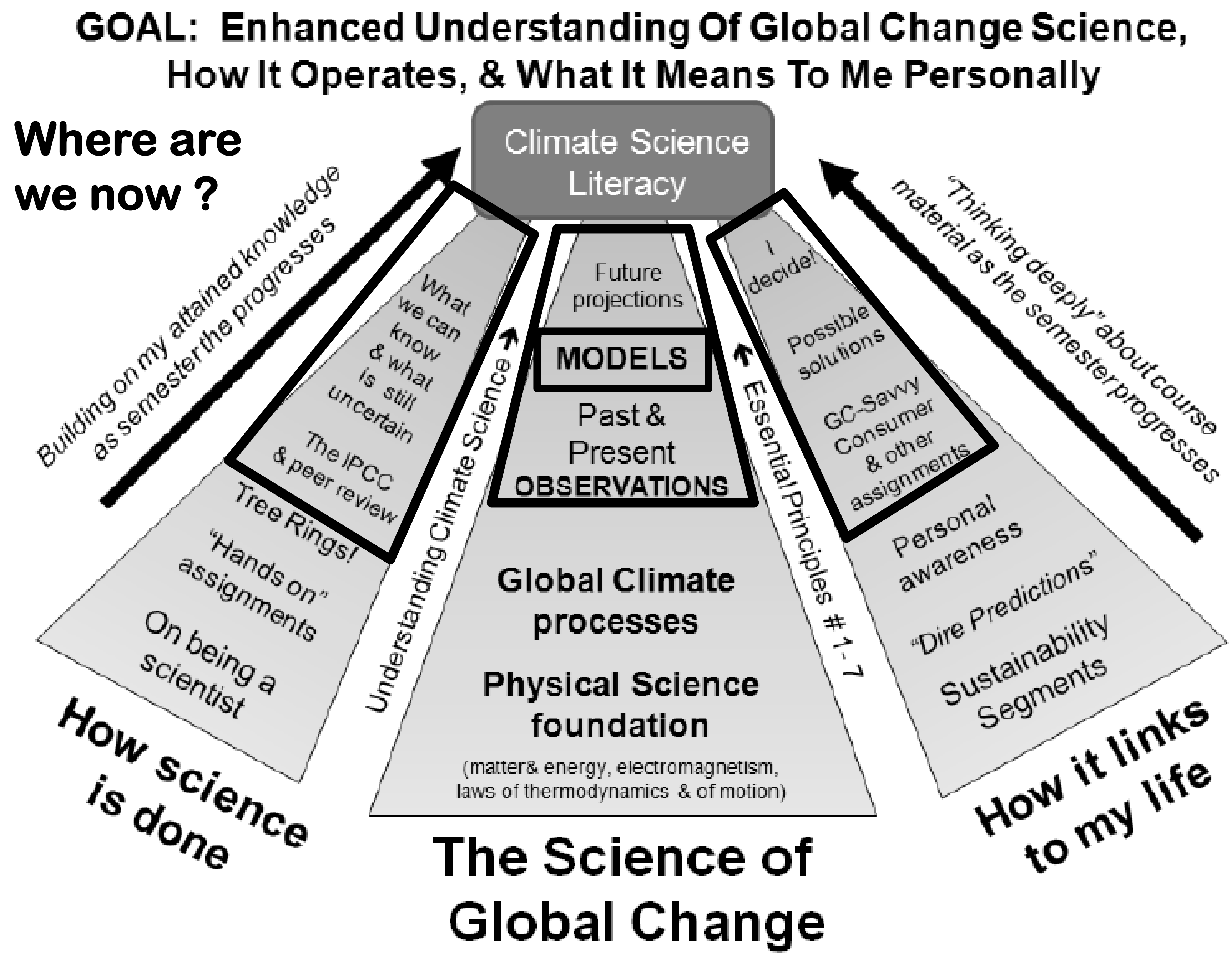
TOPIC # 16
GLOBAL WARMING & ANTHROPOGENIC FORCING

TODAY's 3 KEY CONCEPTS:

- Carbon / Forests / Deforestation
- Computer Model Evidence for
  Anthropogenic GW Forcing
- Tying it all together w/
  RADIATIVE FORCING GRAPHS


GOAL: Enhanced Understanding Of Global Change Science, How It Operates, & What It Means To Me Personally
Where are we now ?
Climate Science Literacy
Building on my attained knowledge as semester the progresses
'Thinking deeply' about course material as the semester progresses
What we can know & what is still uncertain
The IPCC & peer review
Tree Rings!
"Hands on" assignments
On being a scientist
How science is done
Understanding Climate Science
Future projections
MODELS
Past & Present OBSERVATIONS
Global Climate processes
Physical Science foundation
(matter& energy, electromagnetism, laws of thermodynamics & of motion)
The Science of Global Change
Essential Principles # 1-7
I decide!
Possible solutions
GC-Savvy Consumer & other assignments
Personal awareness
"Dire Predictions"
Sustainability Segments
How it links to my life

TOPIC # 16
GLOBAL WARMING & ANTHROPOGENIC FORCING

Part A - CARBON RESERVOIRS & FLUXES: Natural vs. Anthropogenically Enhanced

(or How does all that "C" get into the atmosphere??)

Class Notes pp 83

"I'm extremely concerned that the Earth has a chronic disease, and that chronic disease is CO_2 syndrome, it's something that's creeping on us.

We have plenty of fossil fuel so it's going to continue to get worse, and it's going to affect every aspect of life on the planet, from food production to drinking water to coastlines to the plight of the poor in the tropics, and so forth."

~Wally Broecker , Paleoclimatologist

CO_2 & CARBON RESERVOIRS

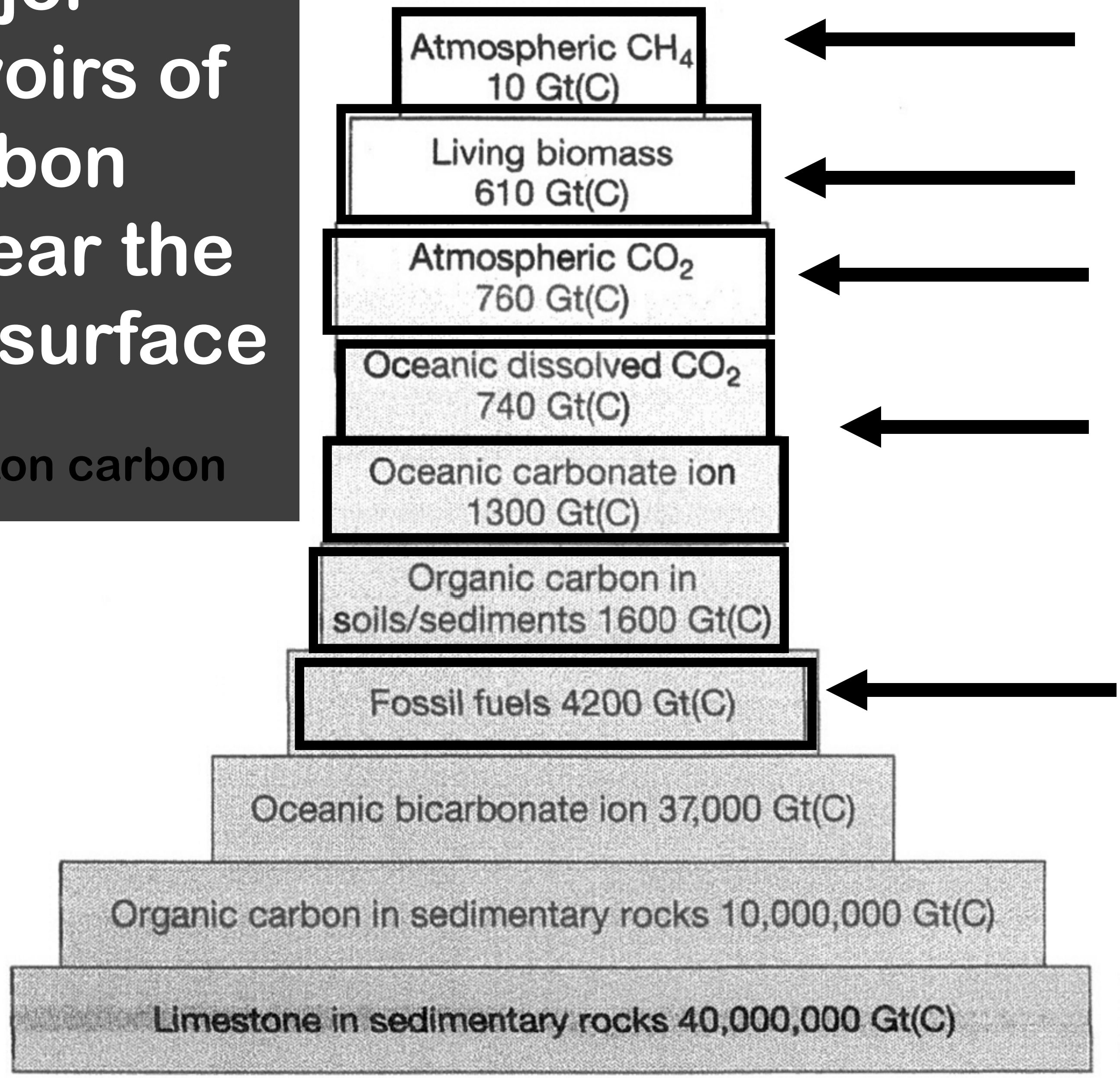
CO_2 in the atmosphere is one place CARBON resides in the Earth-Atmosphere system.

Where else is carbon located and how does it move (flux) from one reservoir to another?

☺

Major Reservoirs of Carbon at or near the Earth's surface

Gt (C) = gigaton carbon



p 83

Amount of carbon is expressed in units of Gtons (gigatons) of carbon: GT(C)

Amounts represent the MASS OF CARBON ATOMS ONLY, not other atoms to which C is attached (e.g. CO_2)

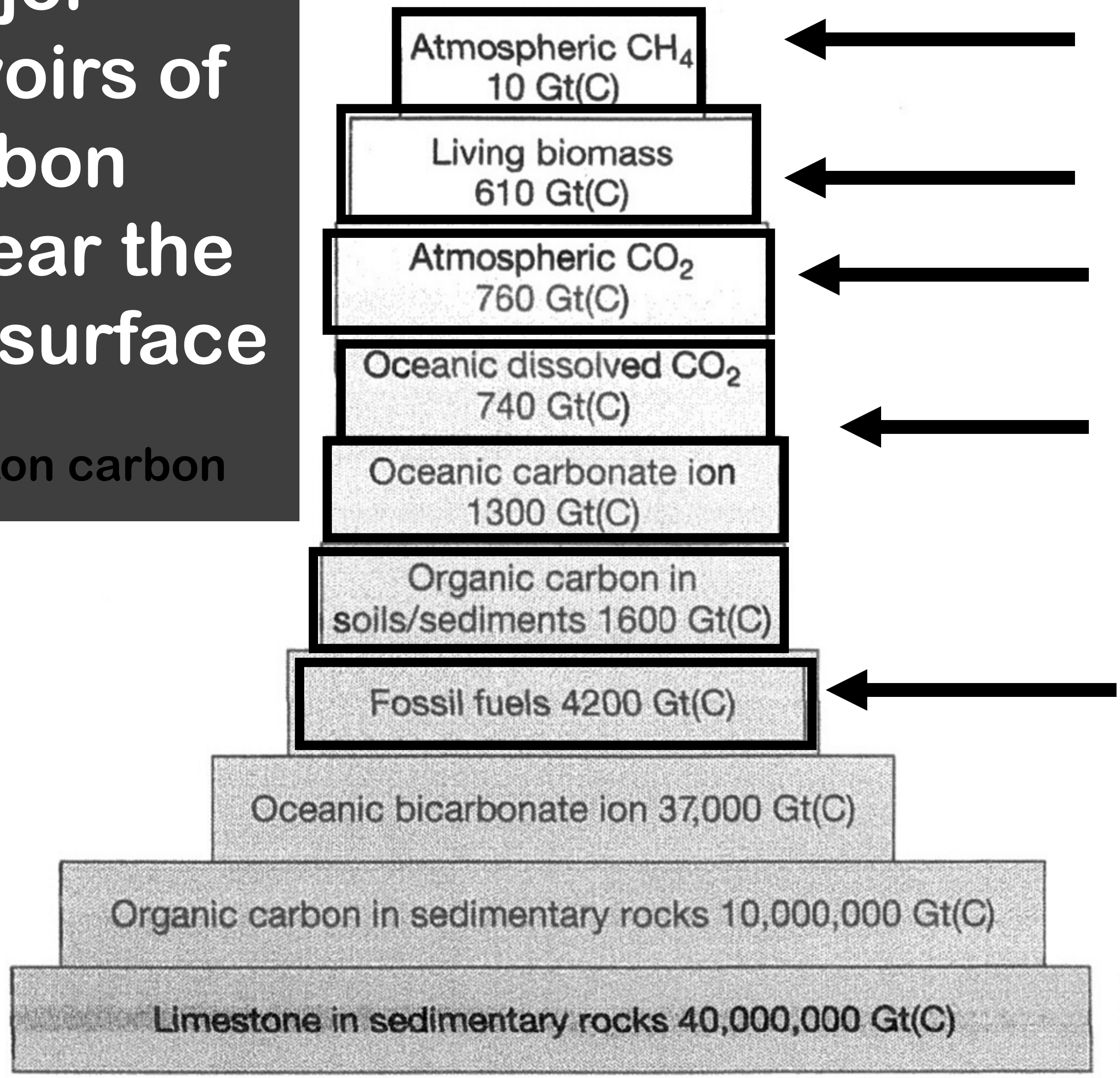
One gigaton is . . .

- **Greater than the mass of all the humans on the planet**

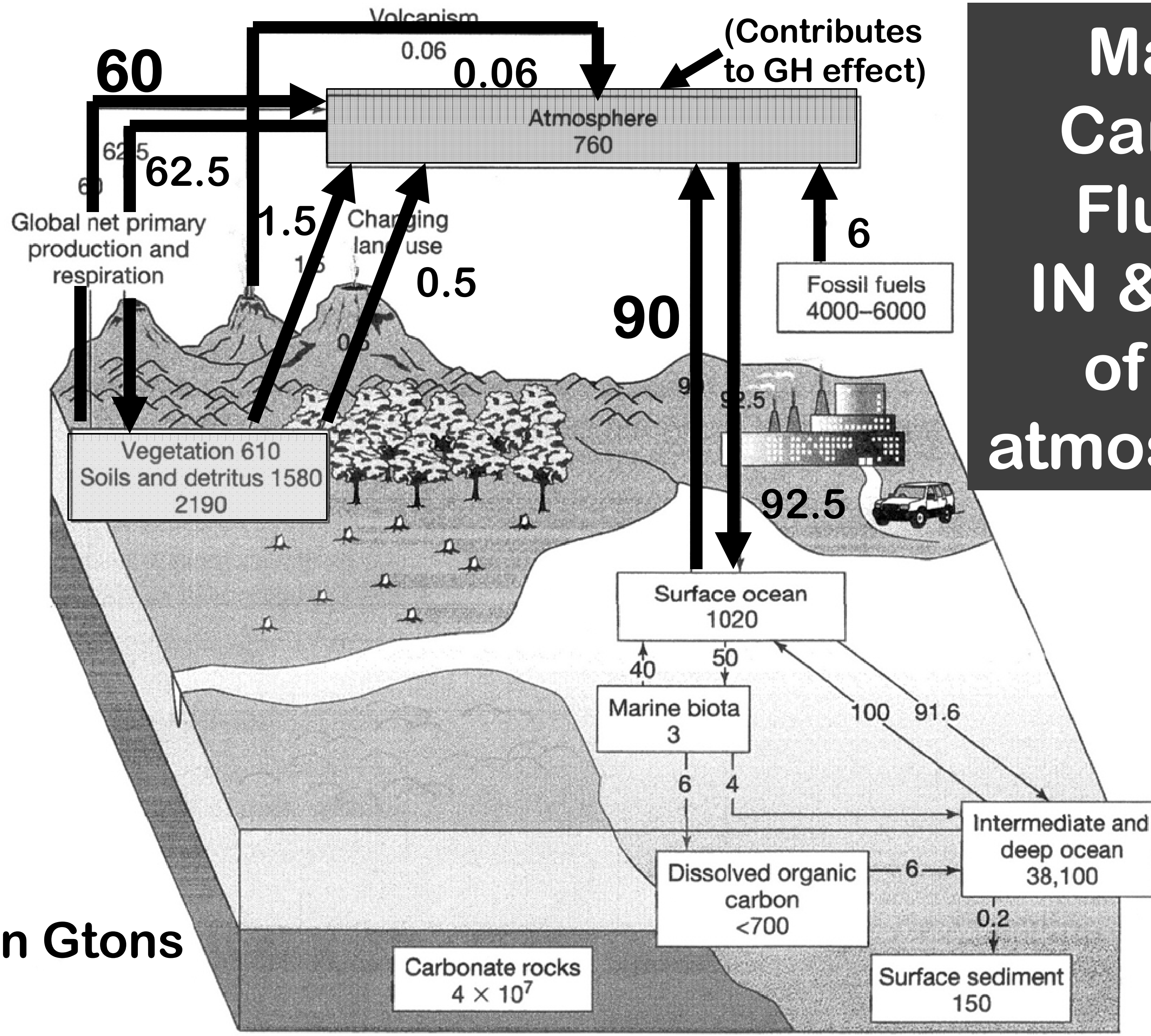
☺

Major Reservoirs of Carbon at or near the Earth's surface

Gt (C) = gigaton carbon



Major Carbon Fluxes IN & OUT of the atmosphere

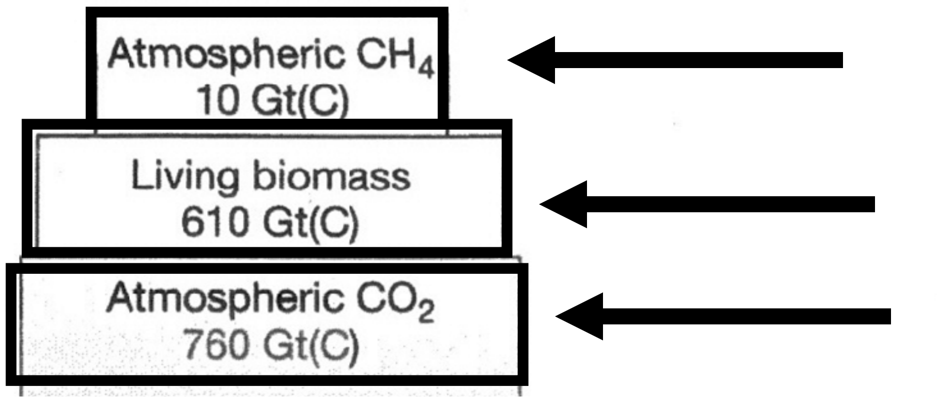


In Gtons

p 83

Biomass = the total mass of organic matter in living organisms in a particular reservoir.

(Definition on p 84)



The total amount of carbon in LIVING BIOMASS = 610 Gt

↔

The total amount of carbon in the ATMOSPHERIC CARBON RESERVOIR = 770 Gt (760 Gt is in CO_2 gas)

p 83

How does CARBON “flux” FROM the biosphere INTO the atmosphere?

1. Trees take in carbon dioxide during photosynthesis.

2. Trees release carbon dioxide during photosynthesis.

3. Trees release carbon dioxide into the atmosphere during respiration.

NATURAL FLUXES INTO & OUT OF THE ATMOSPHERIC CARBON RESERVOIR related to BIOMASS = respiration & photosynthesis

FLUX from PLANT INTO ATMOSPHERE:

Respiration: $CH_2O + O_2 \longrightarrow CO_2 + H_2O.$

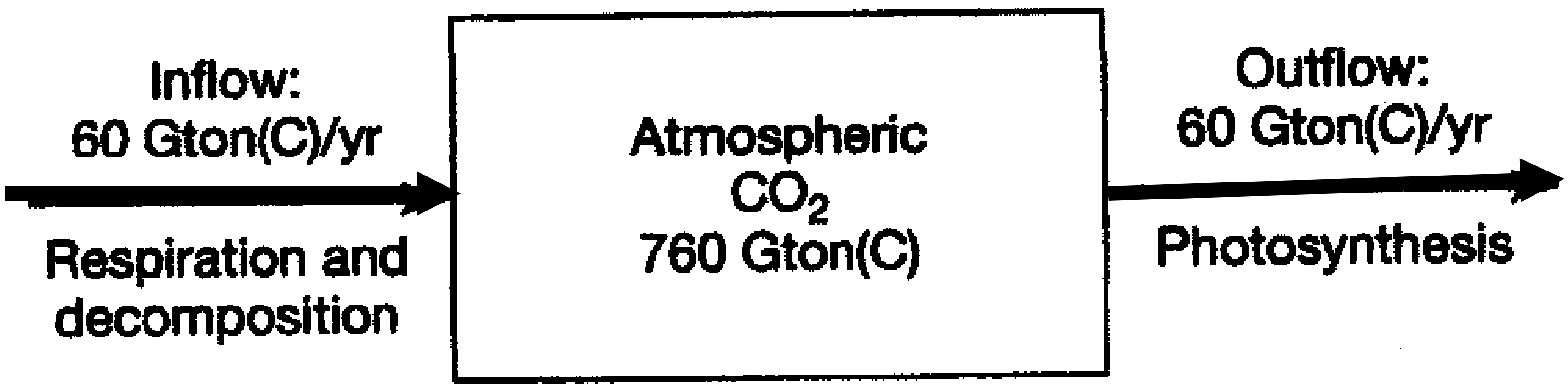
carbohydrate | oxygen gas | carbon dioxide | water

FLUX <u>OUT OF ATMOSPHERE</u> into PLANT:

Photosynthesis: (Primary Production) $CO_2 + H_2O \longrightarrow CH_2O + O_2.$

carbon dioxide | water | carbohydrate | oxygen gas

The Atmospheric Carbon Reservoir

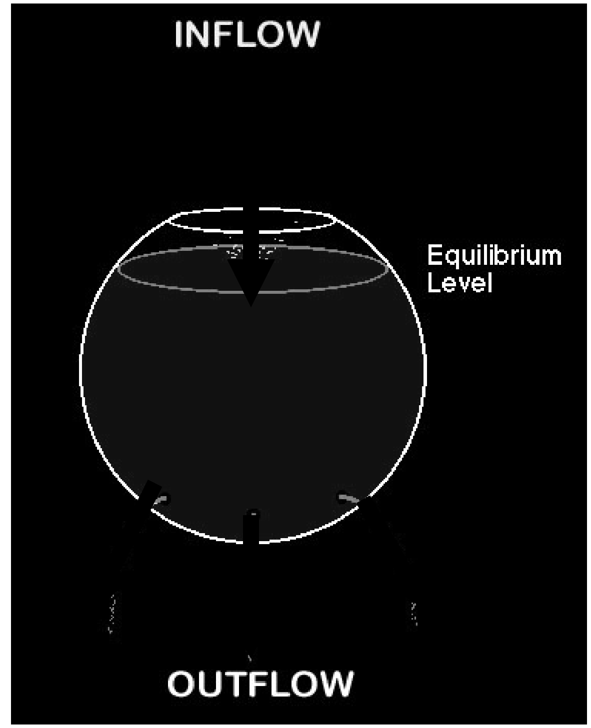


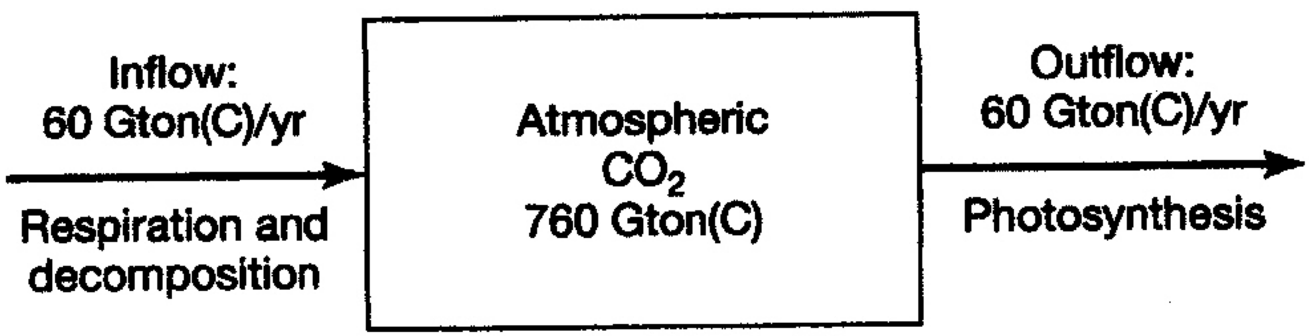
showing inflows and outflows (fluxes)

. . . leads to a

STEADY STATE

In the atmospheric CO_2 “reservoir”





Where have we a STEADY STATE before?

☺

SOME DEFINITIONS:

Respiration =

biochemical process
living organisms take up O_2,
consume organic matter,
RELEASE CO_2, heat, & H_2O

Decomposition =

breakdown of organic matter
by bacteria and fungi,
RELEASES CO_2 to the atmosphere

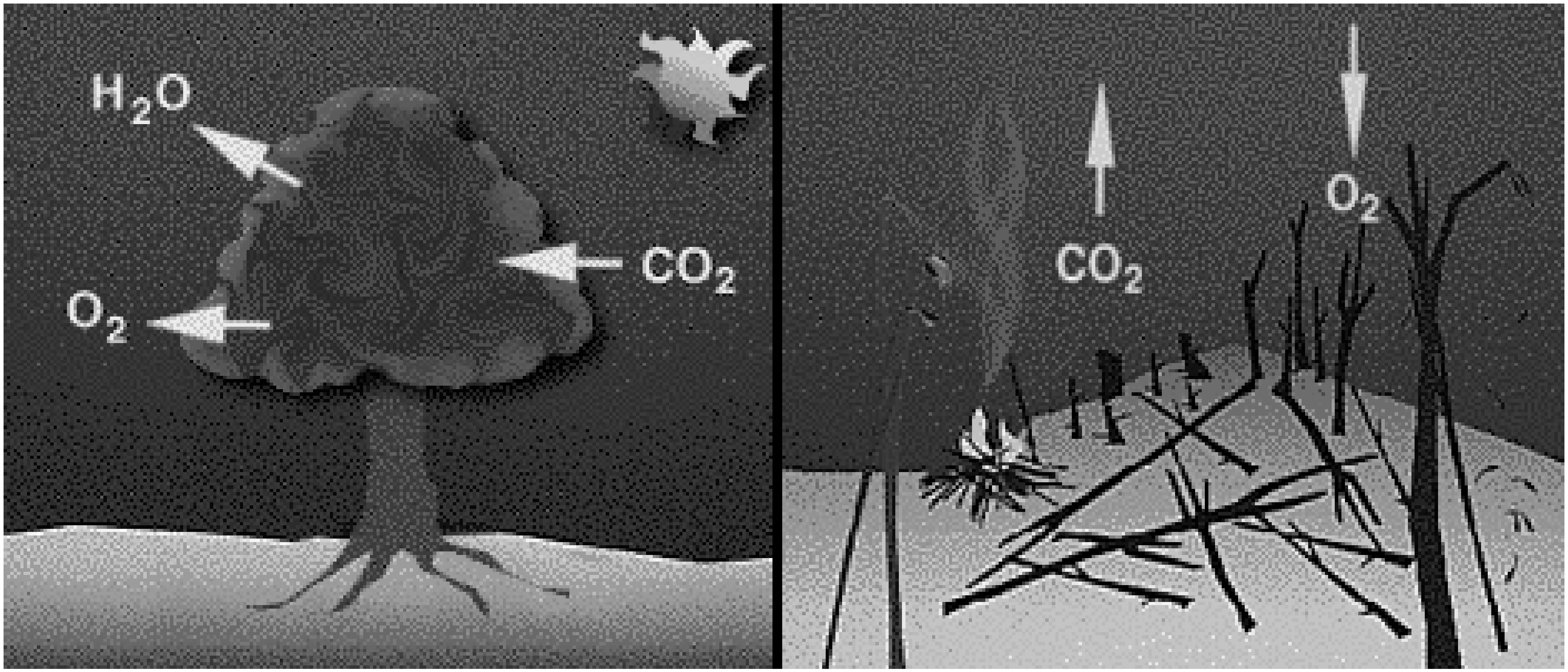
Photosynthesis =

manufacture of carbohydrates & O_2
from CO_2 and H_2O
in the presence of chlorophyll
sunlight as the energy source.

Oxygen is *released* in the process.

Solar energy → chemical energy

(Part of chemical energy is stored in living tissues & used by other organisms (consumers) that cannot use solar energy directly.)



Photosynthesis

Respiration, Burning of Biomass, & Decomposition

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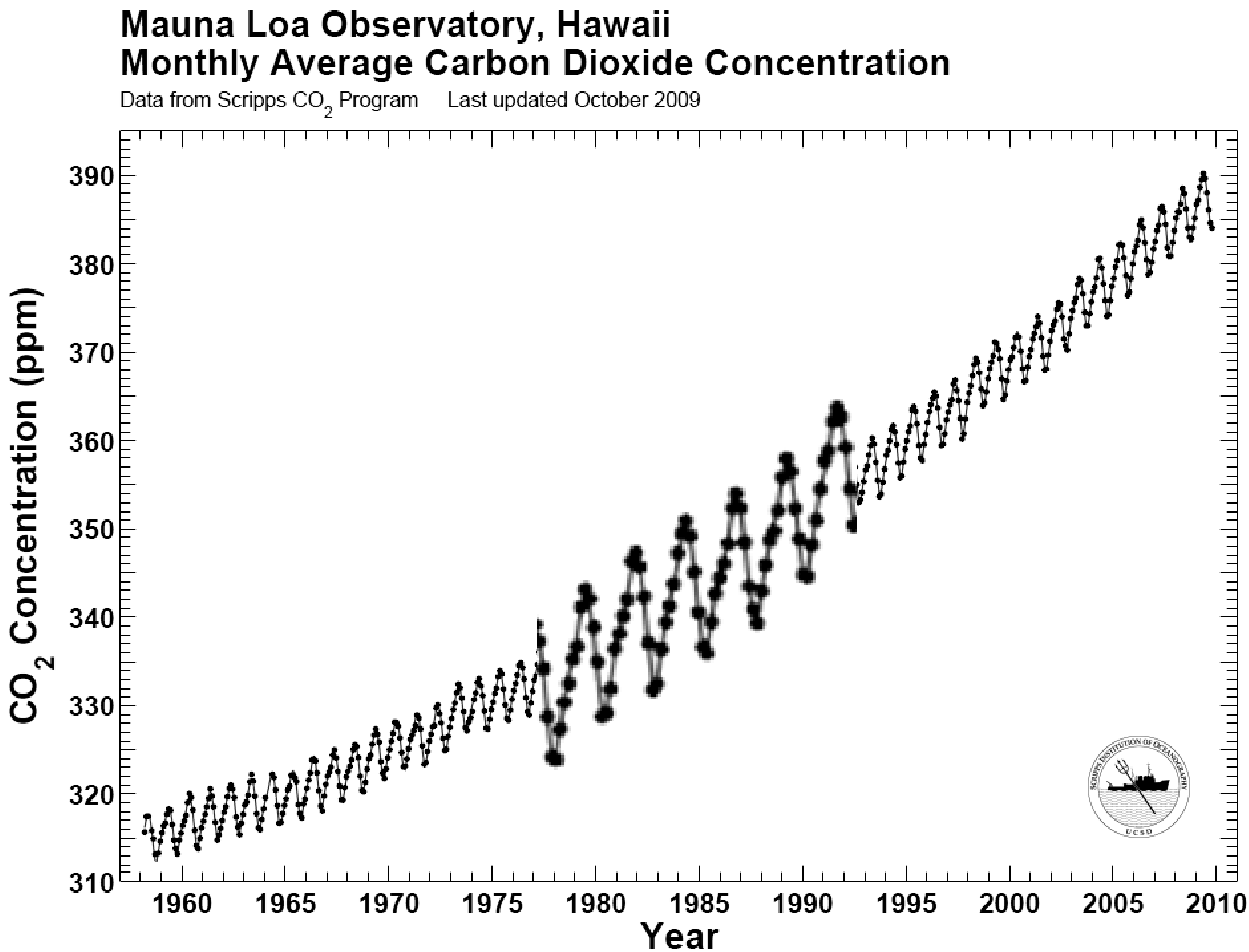
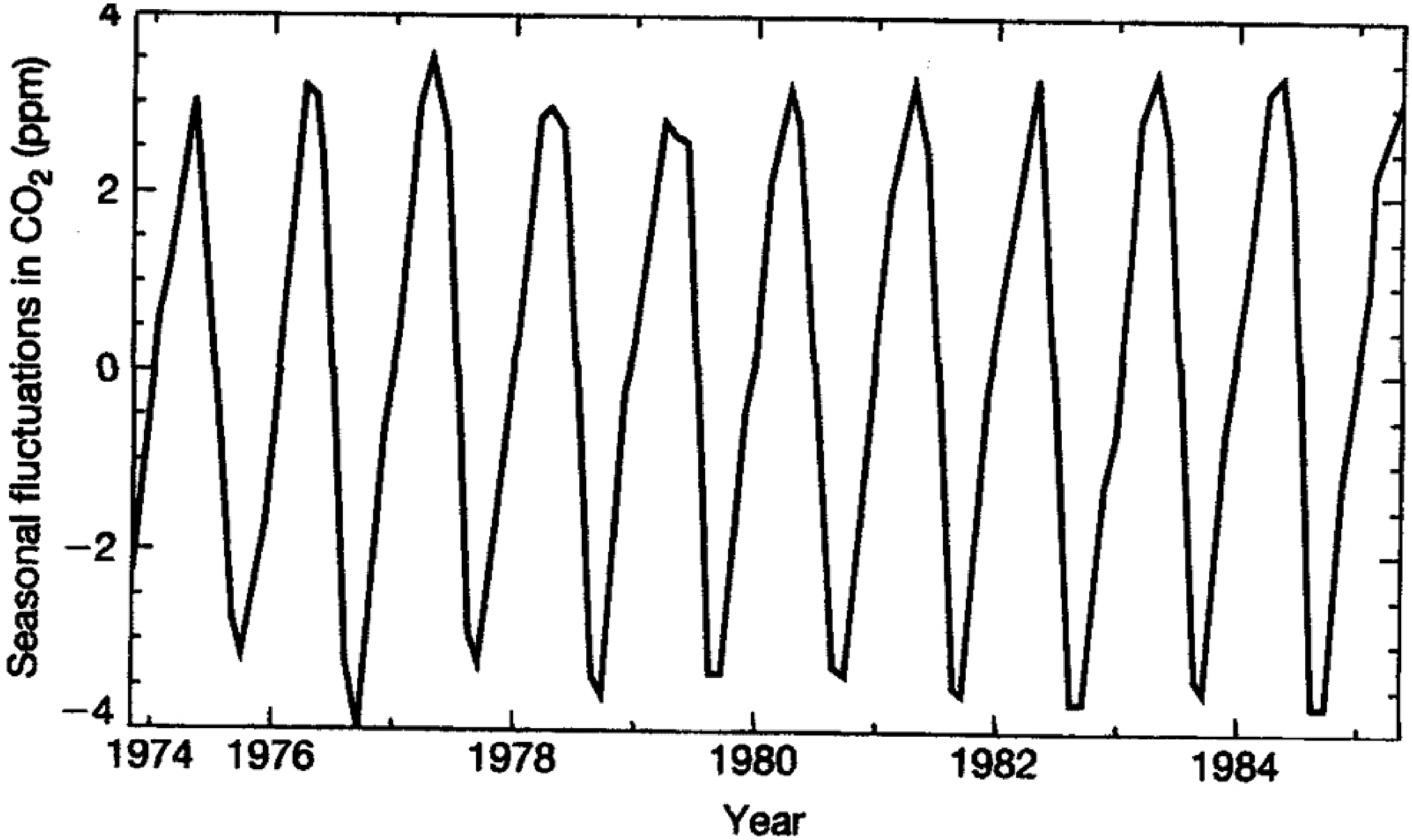
WHAT ABOUT THOSE ZIG-ZAGS IN THE KEELING CURVE?



CLOSE-UP VIEW:



Trend due to anthropogenic increases has been removed.

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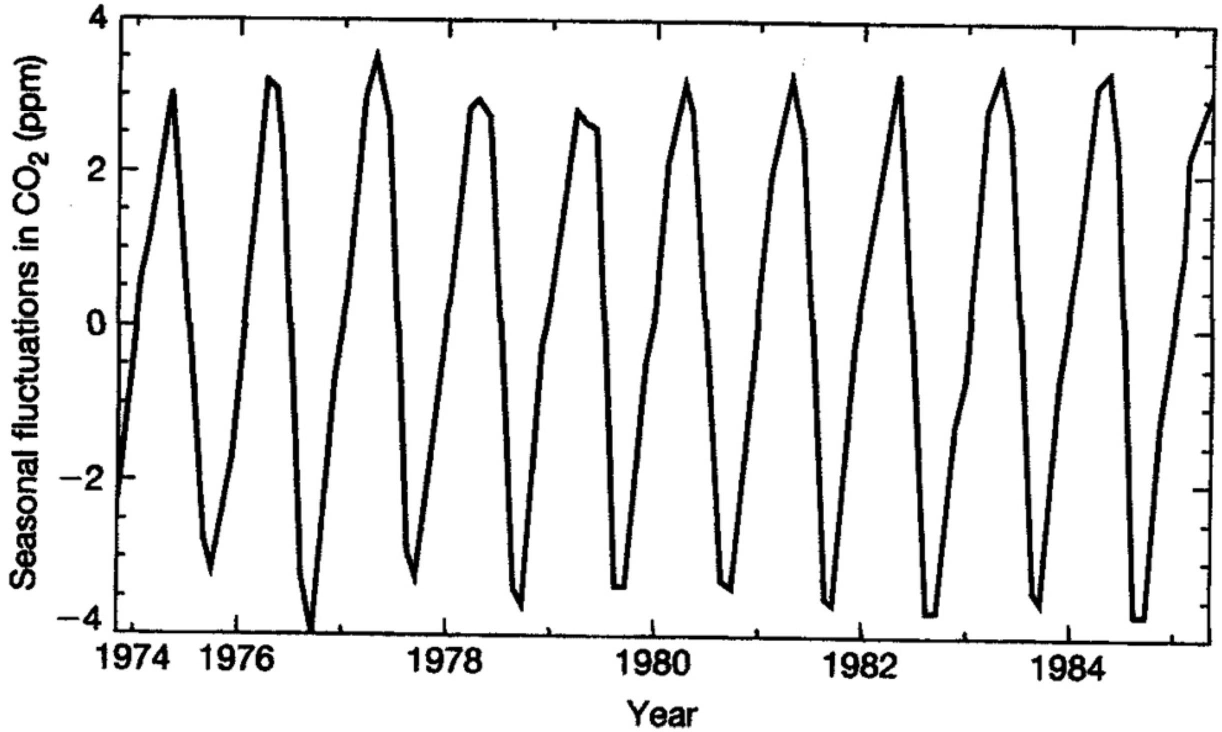
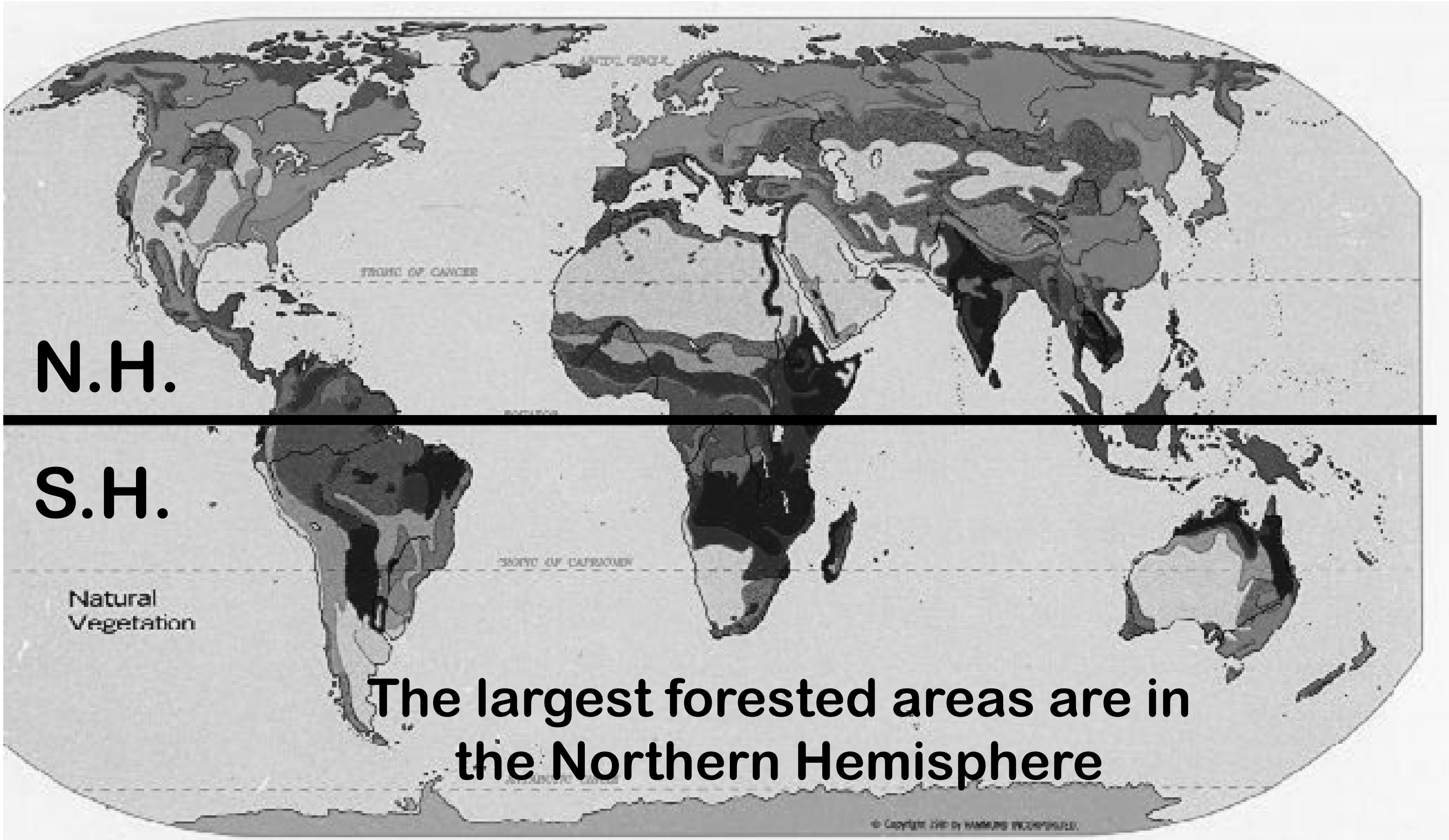


Oscillations represent seasonal fluctuations driven by the balance between respiration & photosynthesis

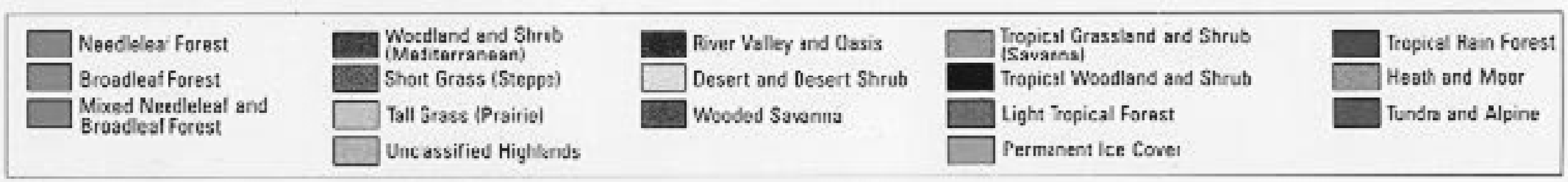
(dominated by Northern Hemisphere forests)

p 84



The largest forested areas are in the Northern Hemisphere

GLOBAL VEGETATION PATTERNS



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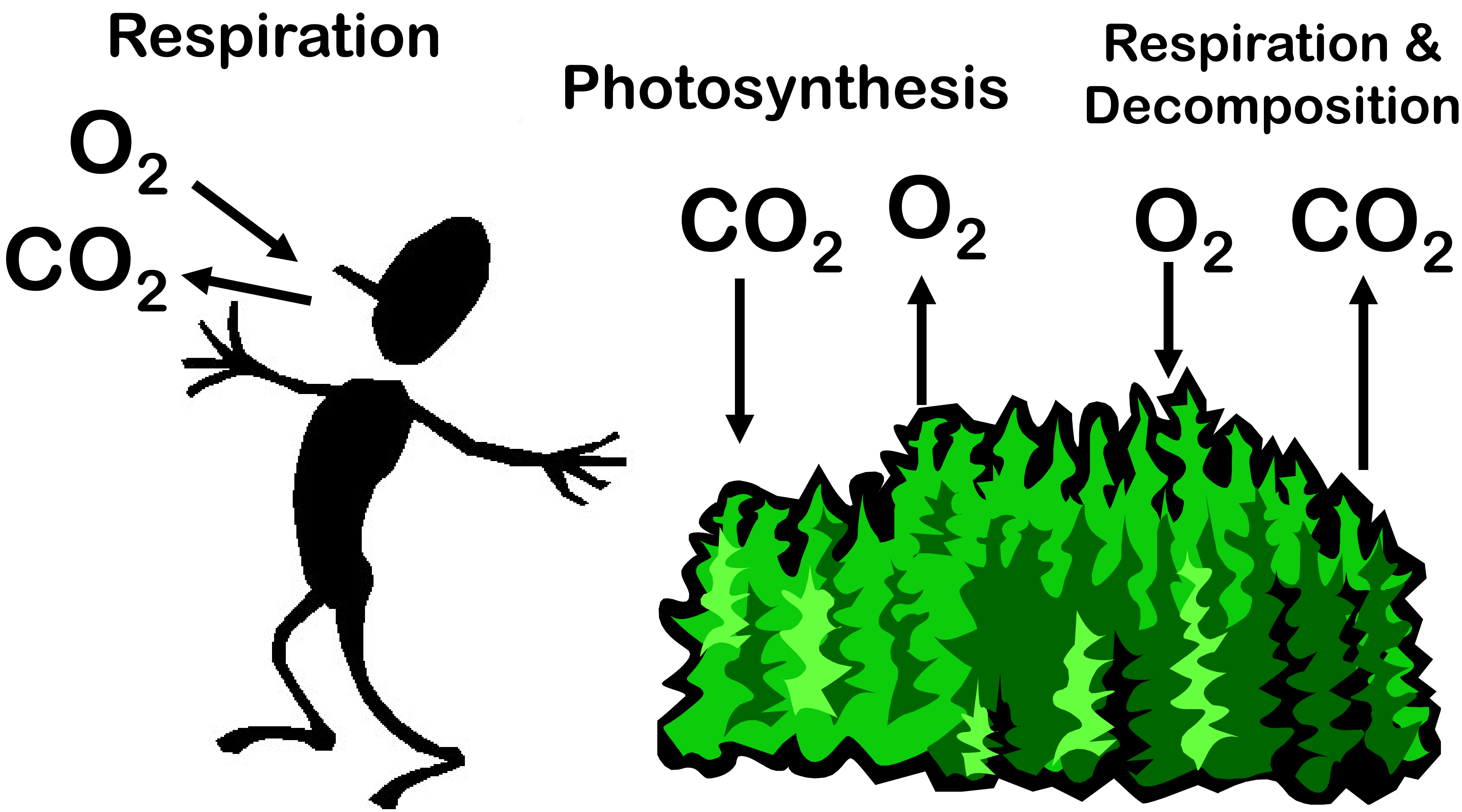
“Breathing” -- ANIMALS vs. PLANTS



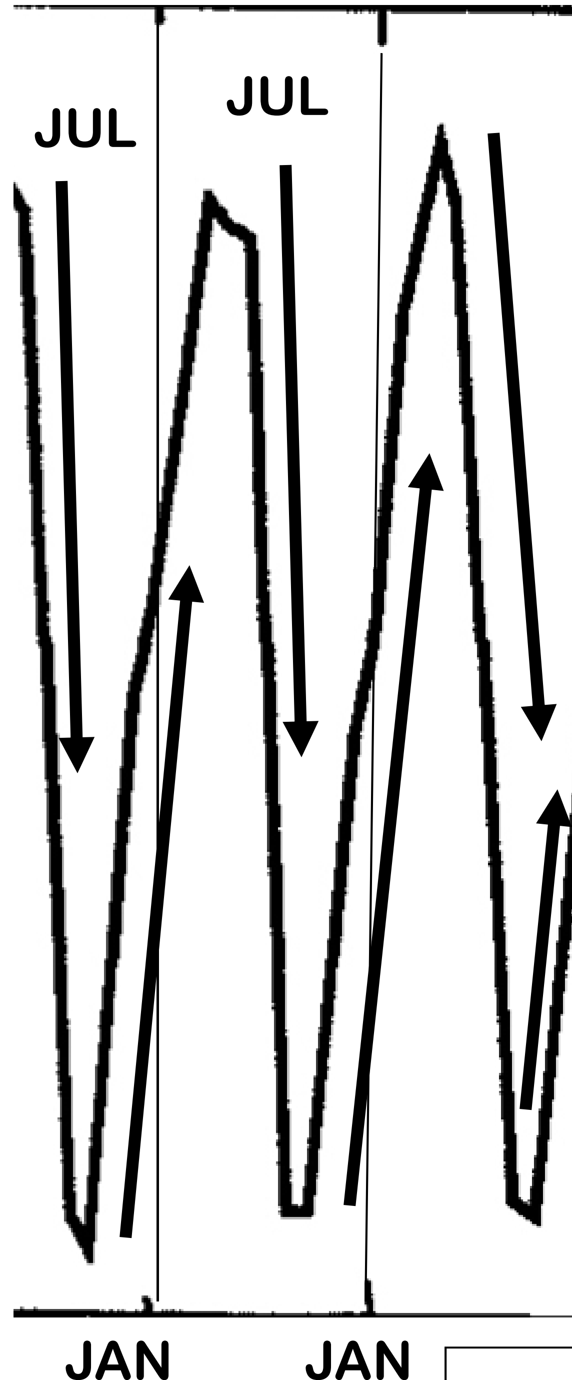
Tick marks are at January of each year:

Photosynthesis > Respiration
(CO_2 goes down in SUMMER as forests "breathe in" more CO_2)

Respiration > Photosynthesis
(CO_2 levels rise in FALL/WINTER as forests "breathe out" more CO_2)

Photosynthesis > Respiration
(CO_2 goes down in summer)

Respiration > Photosynthesis
(CO_2 levels rise in fall/winter)



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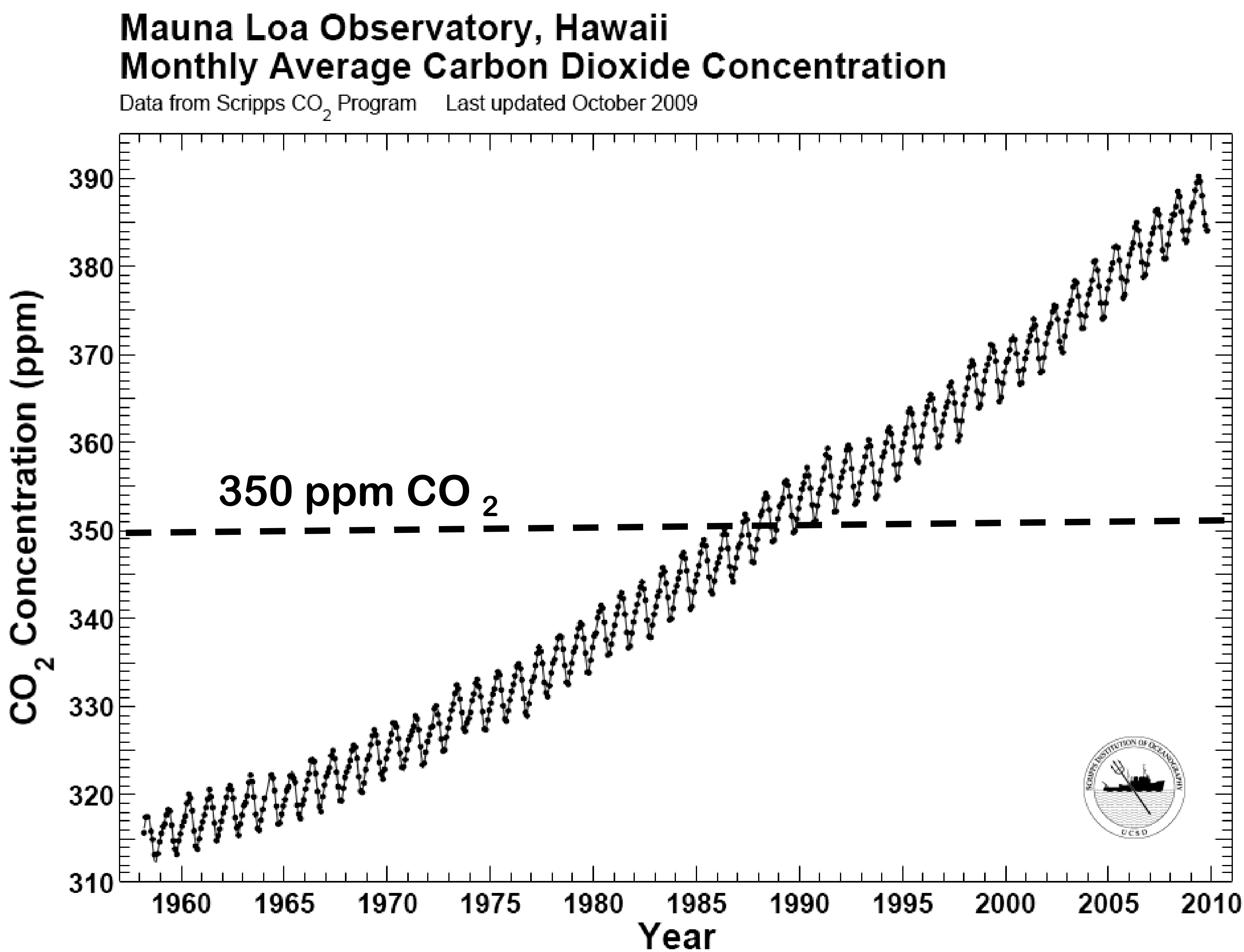
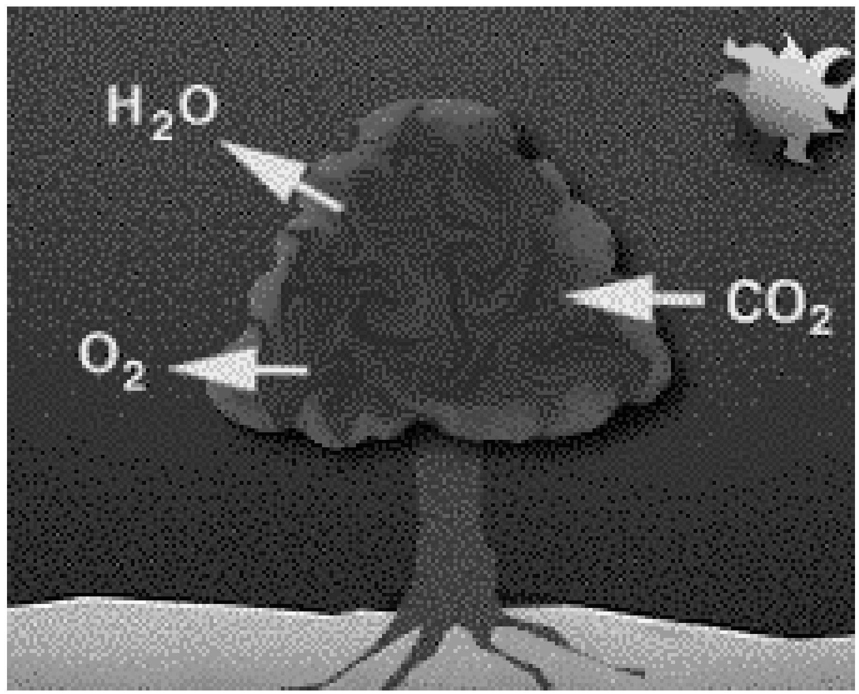

Mauna Loa Observatory, Hawaii
Monthly Average Carbon Dioxide Concentration
Data from Scripps CO2 Program Last updated October 2009
350 ppm CO 2
CO2 Concentration (ppm)
Year
310
320
330
340
350
360
370
380
390
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

review

BUT IS ALL THE EXTRA CO_2 A BAD THING???

PLANTS DEPEND ON CO_2!!!



Photosynthesis: $CO_2 + H_2O \longrightarrow CH_2O + O_2$.

(**Primary Production**) — **carbon dioxide**, **water**, **carbohydrate**, **oxygen gas**

☺

YOU TUBE!

http://www.youtube.com/watch?v=0_VmMIbWKoo

With rising CO2 levels:

• Some plant species continue to increase photosynthesis (C3)

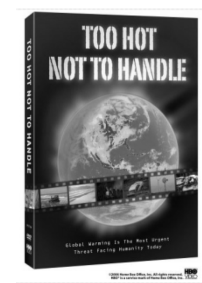
• others do NOT (C4)

•Some plants can respond readily to higher CO2 levels

• Other plants can make only <u>limited</u> responses

Hence with Increased CO2 :

• some plant species will be stronger, more prolific, and may overwhelm those less able to benefit



WE ARE ALREADY SEEING POLLEN INCREASES FROM RAGWEED & OTHER PLANTS

And . . . there may be consequences we don't yet know !!

☺

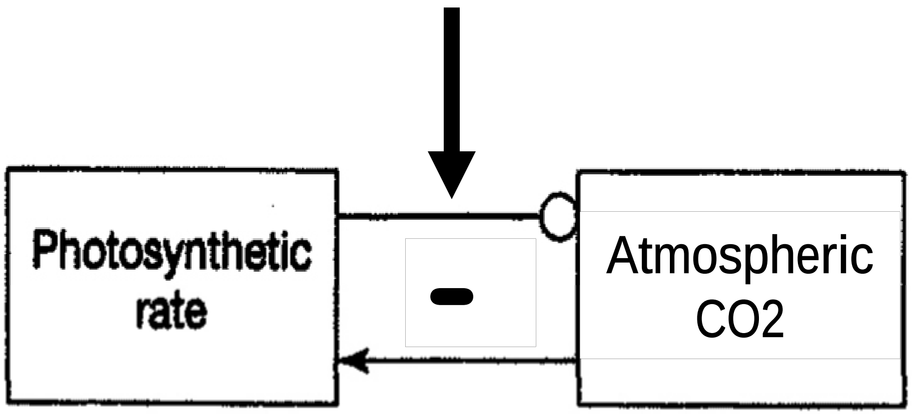
Greater atmospheric CO_2 concentration

➔ enhanced photosynthesis (due to "CO_2 Fertilization")

➔ more CO_2 being assimilated by plant from the atmosphere

➔ less atmospheric CO2

What kind of FEEDBACK LOOP?

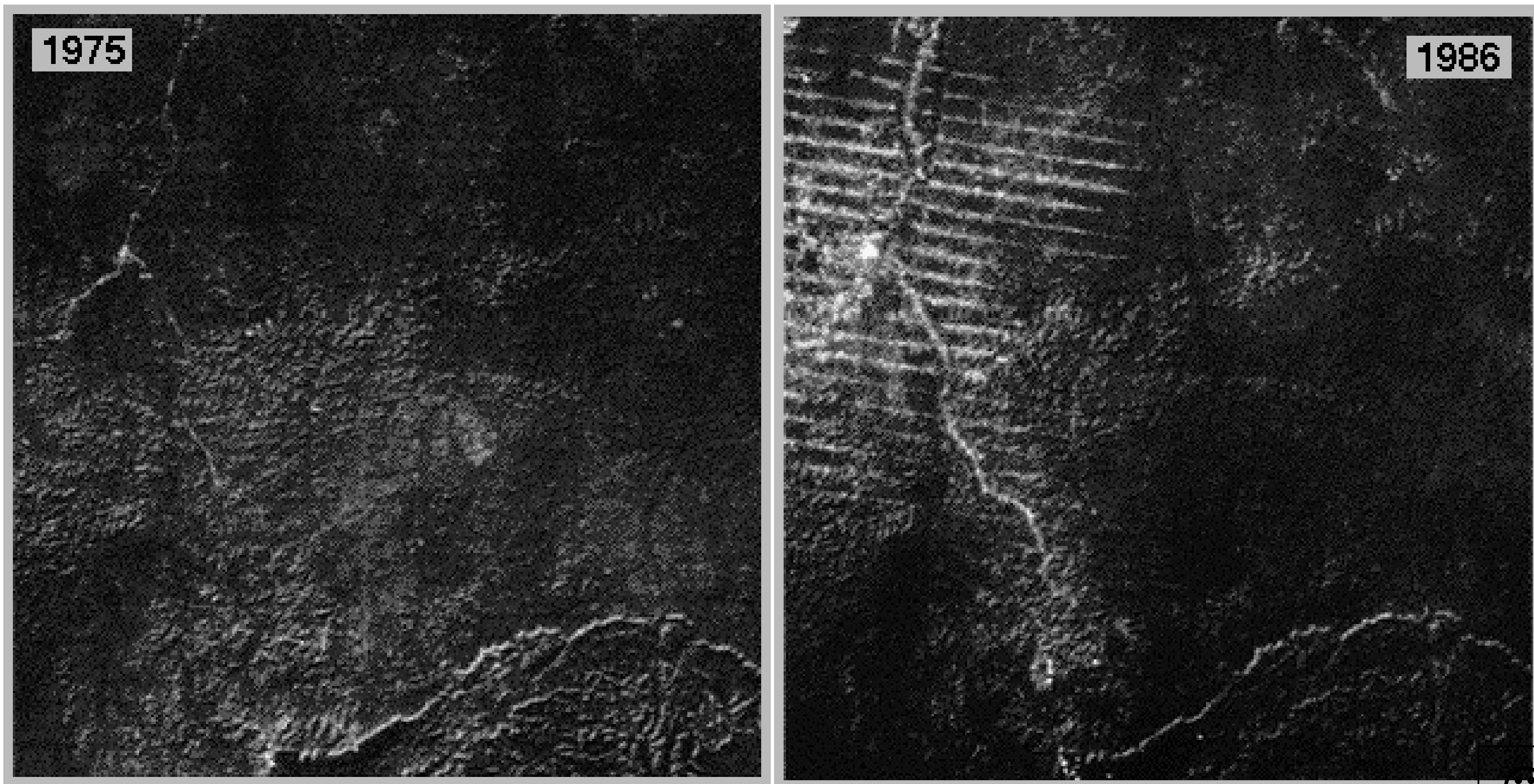


Negative & self-regulating!

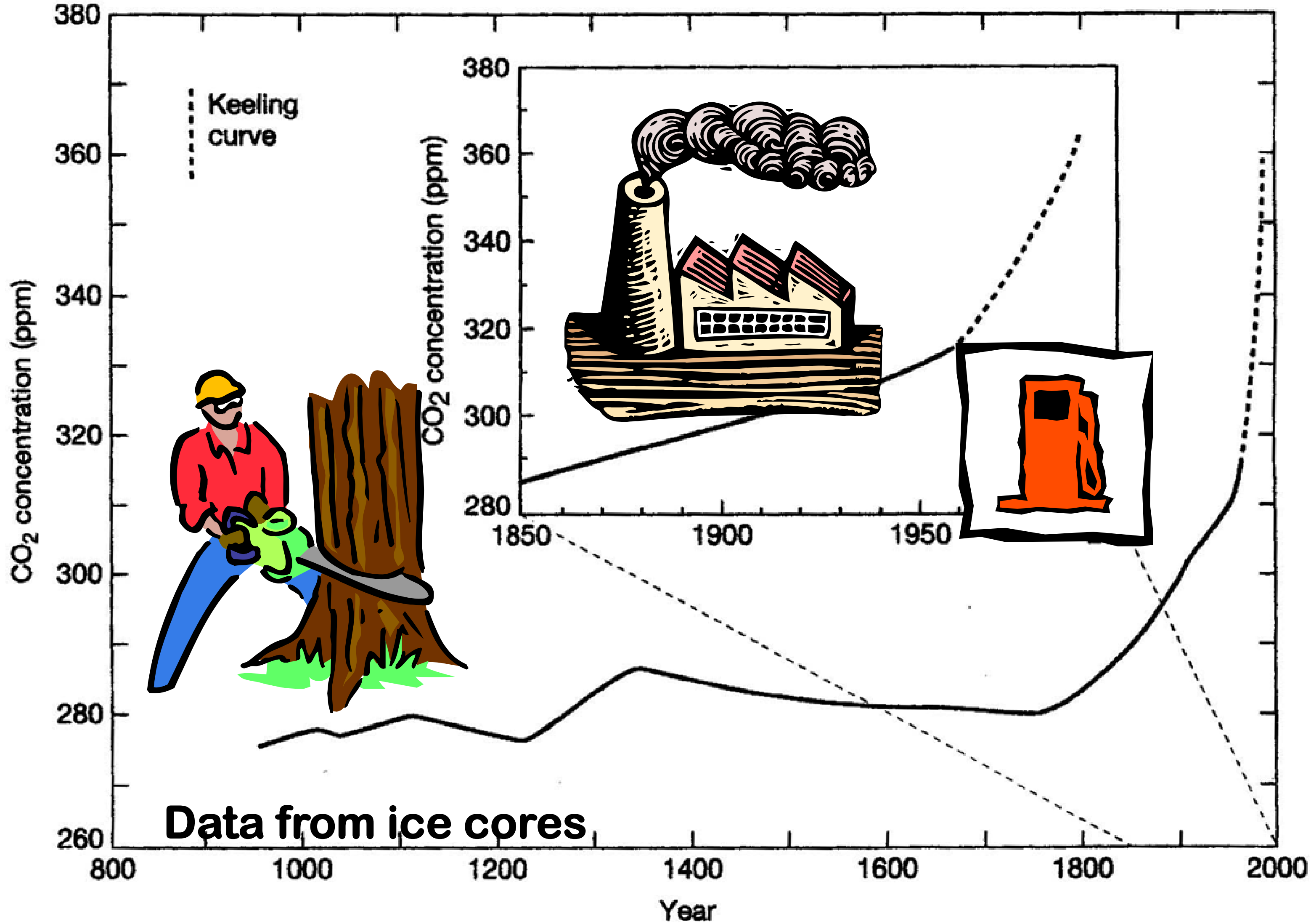
. . . but the jury is still out on how well this negative feedback loop can counteract HUGE anthropogenic influxes of CO2

☺

LAND USE CHANGES:
Deforestation practices increase burning & decomposition of large areas of forest

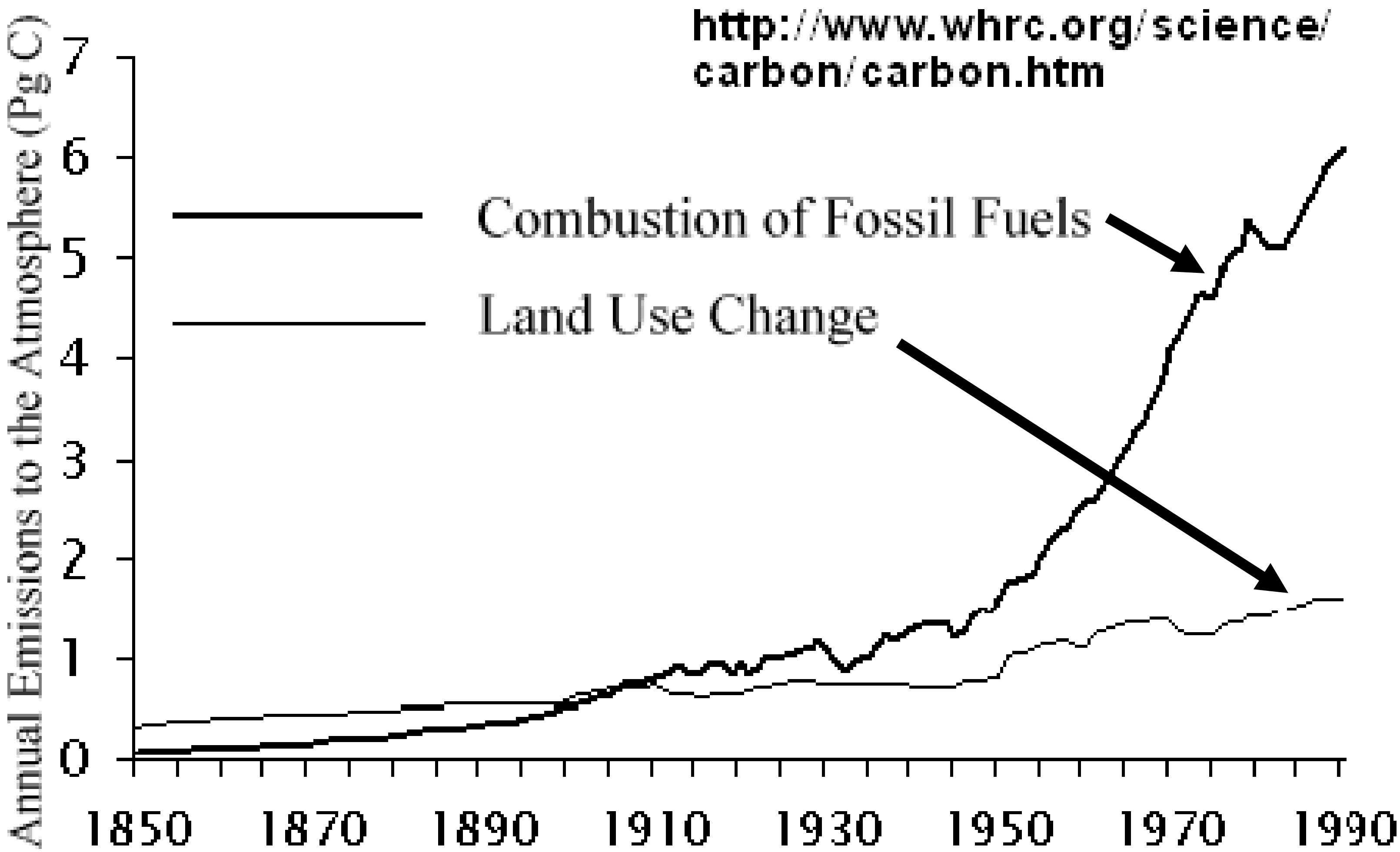


CARBON DIOXIDE: Trends



Review

Time Series Graph comparison of two ways CARBON gets into atmosphere:



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The New York Times

OP-ED COLUMNIST

Trucks, Trains and Trees

November 11, 2009

By THOMAS L. FRIEDMAN

"Imagine if you took all the cars, trucks, planes, trains and ships in the world and added up their exhaust every year. The amount of carbon dioxide, or CO2, all those cars, trucks, planes, trains and ships collectively emit into the atmosphere is actually less than the carbon emissions every year that result from the chopping down and clearing of tropical forests in places like Brazil, Indonesia and the Congo. "

"We are now losing a tropical forest the size of New York State every year, and the carbon that releases into the atmosphere now accounts for roughly 17 percent of all global emissions contributing to climate change. "

http://www.nytimes.com/2009/11/11/opinion/11friedman.html

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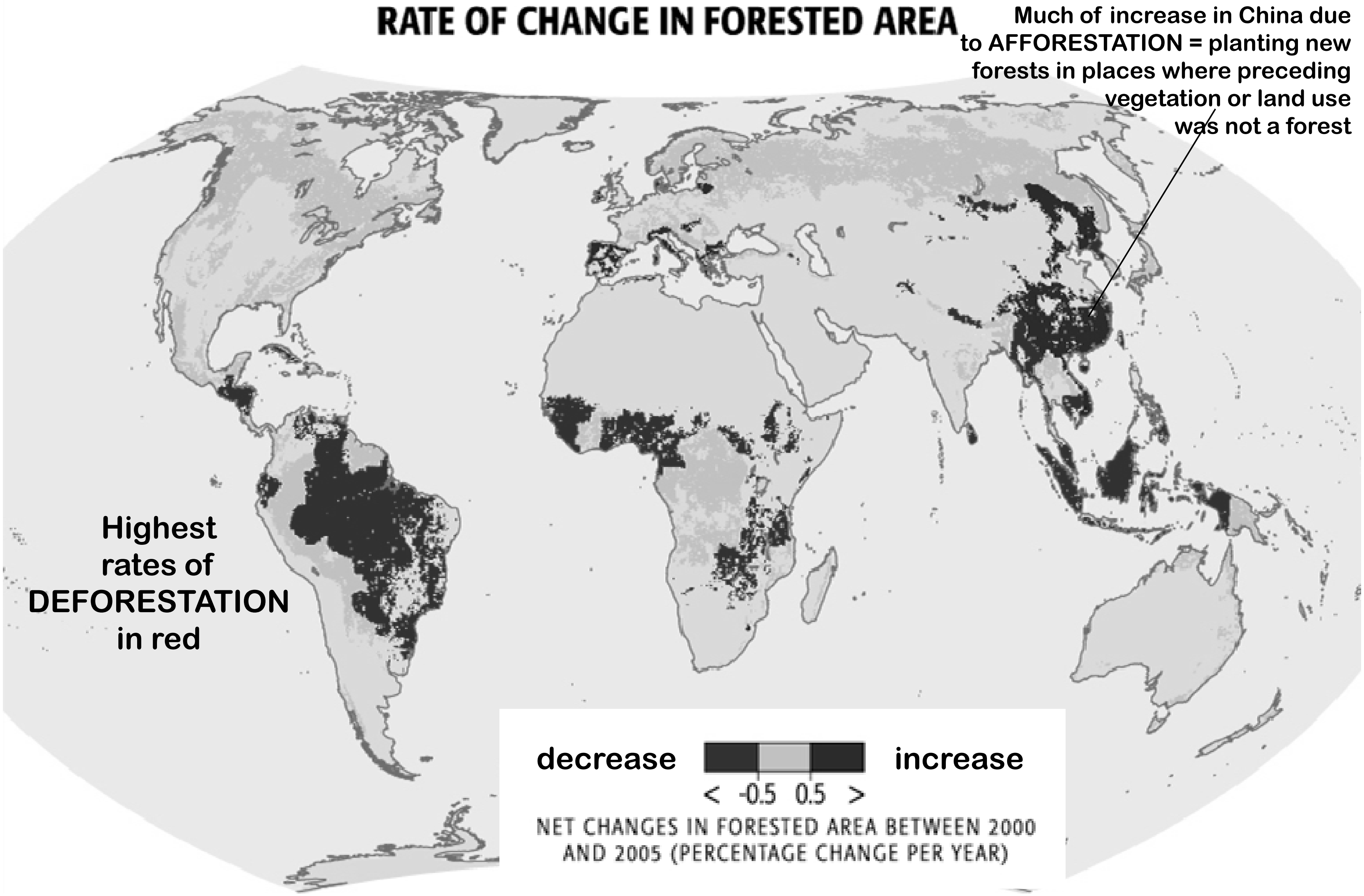


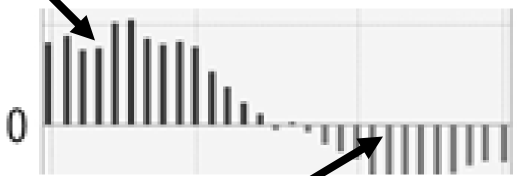
Much of increase in China due to AFFORESTATION = planting new forests in places where preceding vegetation or land use was not a forest

Highest rates of DEFORESTATION in red

Figure on p 175 in *Dire Predictions*

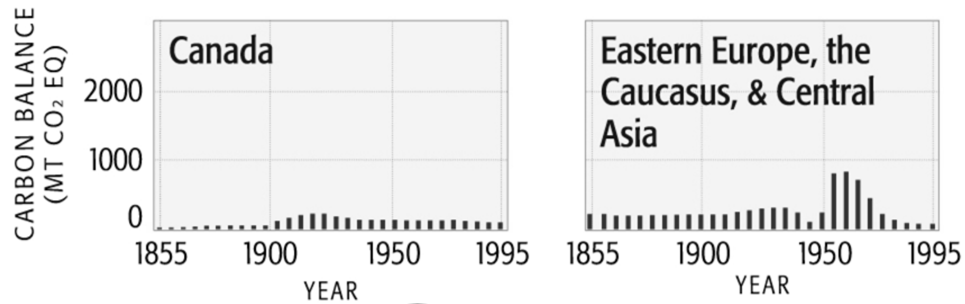
Data Source: UN / FAO Global Forest Assessment Report
http://www.fao.org/forestry/fra/41555/en/

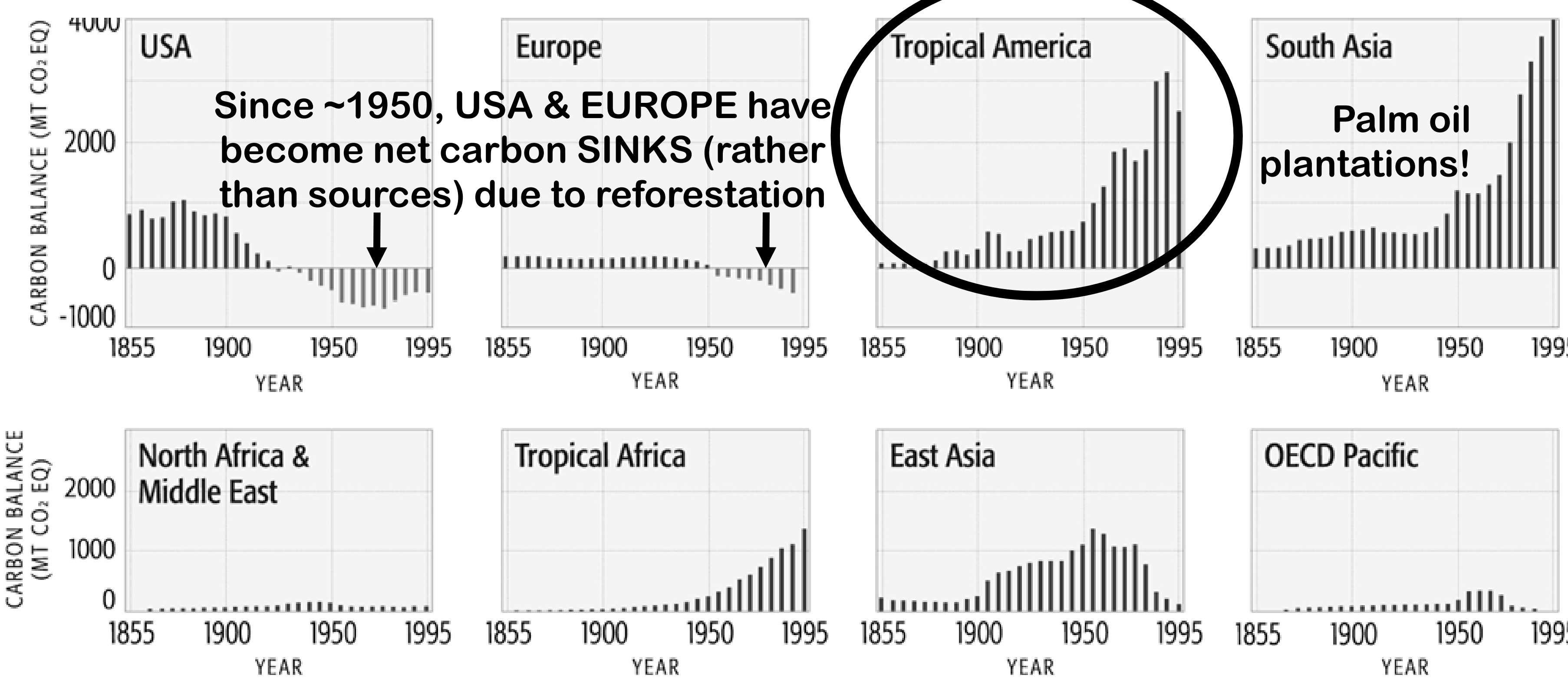
Forest carbon emissions INTO the atmosphere (+)



- Forest uptake of carbon OUT OF the atmosphere (-)

HISTORICAL TRENDS IN FOREST CARBON EMISSIONS AND UPTAKE





from pp 174-175 in *Dire Predictions*

Some good news? . . .

Amazon deforestation at record low

ABC News

By Richard Reynolds

Posted Fri Nov 13, 2009 2:35pm AEDT

Brazil has announced that deforestation in the Amazon basin has fallen to its lowest level since records began 21 years ago.

The report comes from Brazil's space agency, which monitors deforestation with satellites.

The organisation is considered credible and often contradicts the Brazilian Government when it makes outlandish claims about deforestation.

The agency claims that in the year to August, only 7,000 square kilometres of forest has been cut down.

That level is a 45 per cent reduction on the previous year.

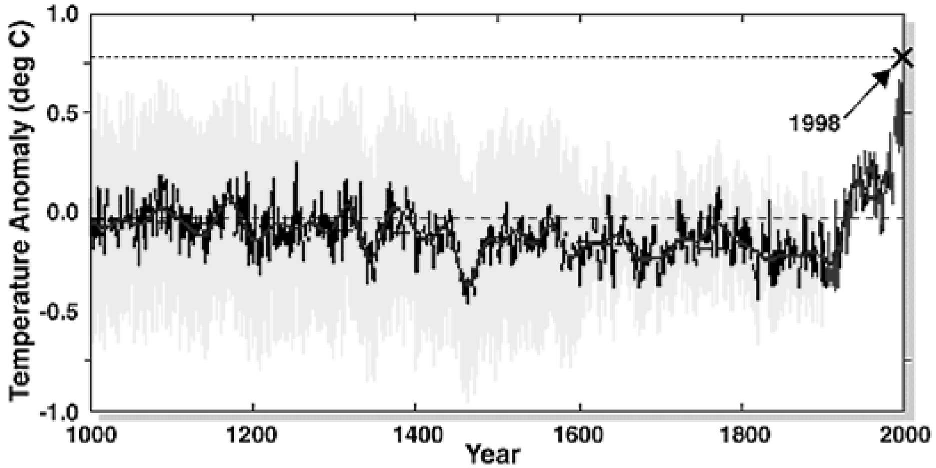
Brazilian President Lula da Silva has promised a reduction in deforestation and is using that to pressure the leaders of major nations to reduce greenhouse gas emissions.

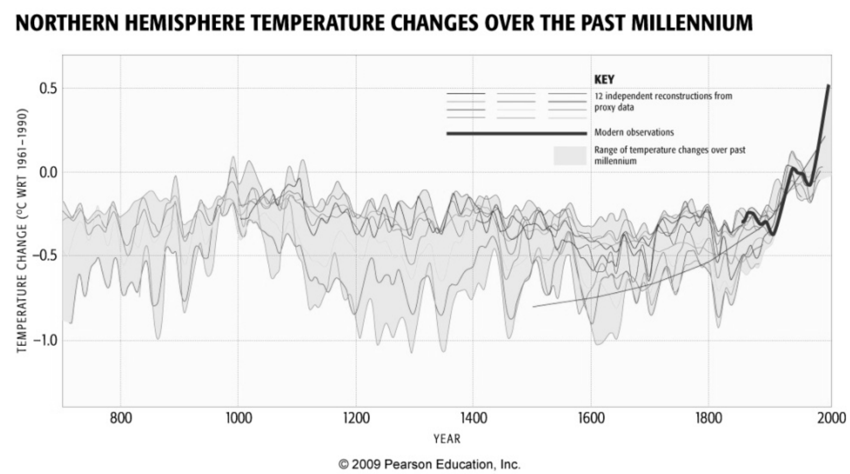
This comes ahead of the UN conference on climate change next month in Copenhagen.

thtp://www.abc.net.au/news/stories/2009/11/13/2742229.htm

TOPIC # 16, PART B: Evidence from Natural Archives

(Covered in class last Thursday)

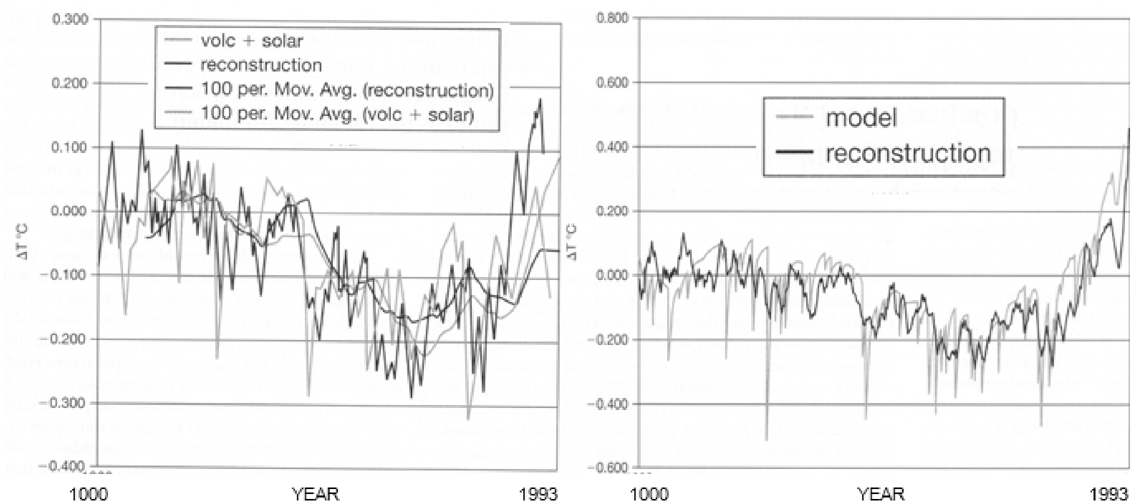




Class Notes pp 86

TOPIC # 16, PART C: Evidence from Natural vs. Anthropogenic Model Comparisons

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

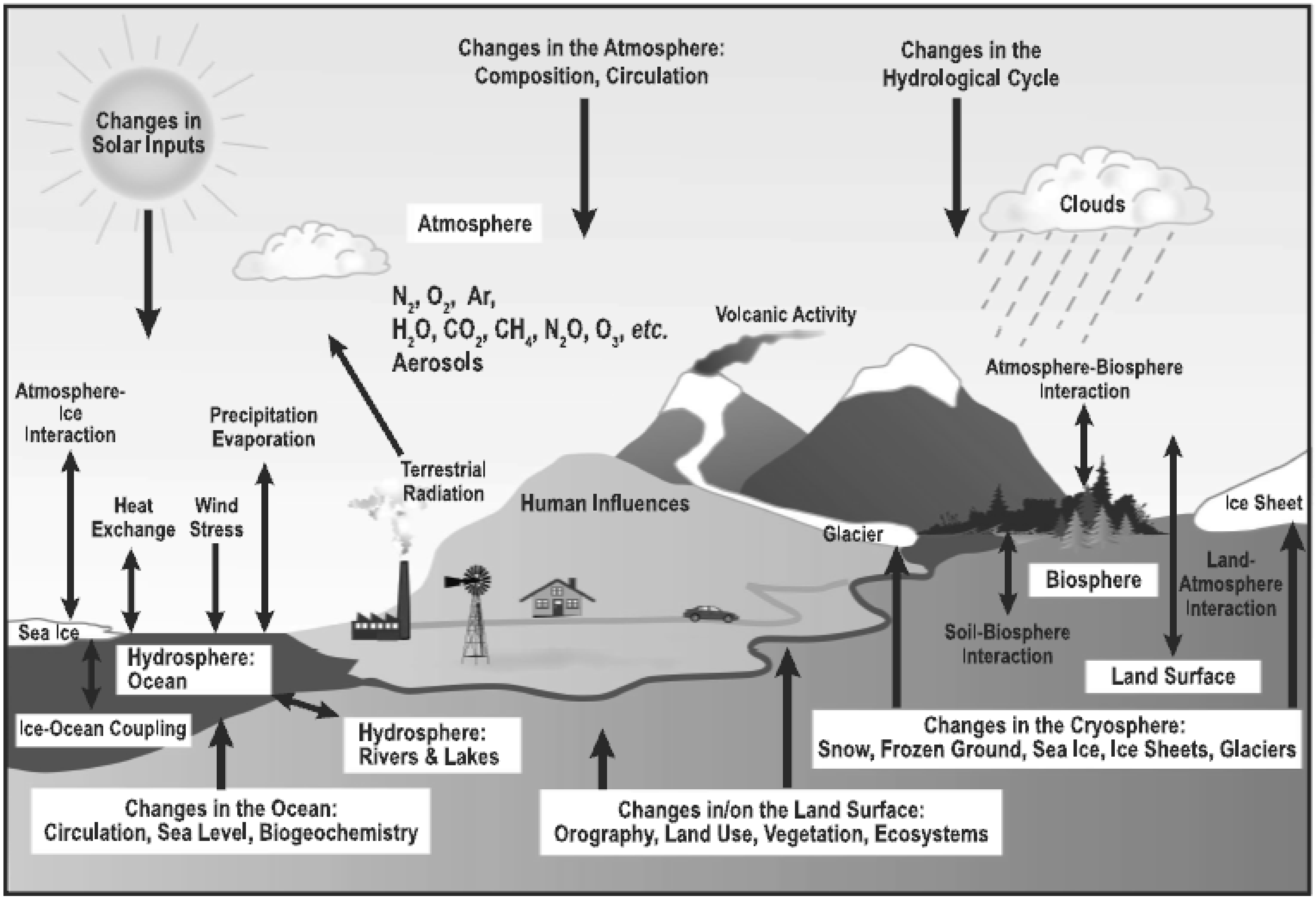


Forced with solar orbital variations & volcanic eruptions only
anthropogenic GHGs not included
(model does not capture recent warming)

Forced with solar orbital variations, volcanic eruptions, & greenhouse gas concentrations
(a much better fit → evidence for anthropogenic GHG forcing)

Class Notes pp 87

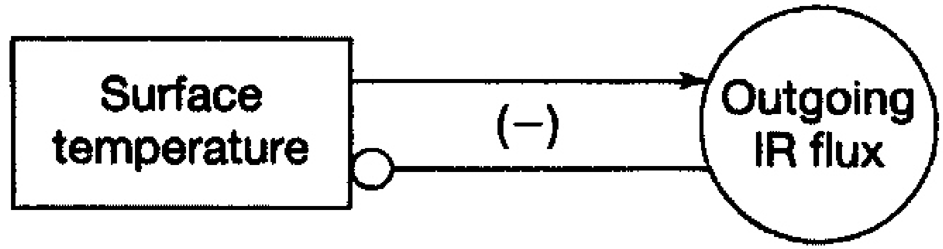
Modeling The Climate System: A Brief Look

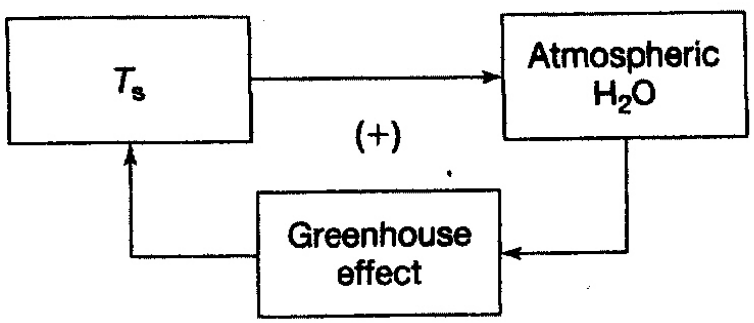


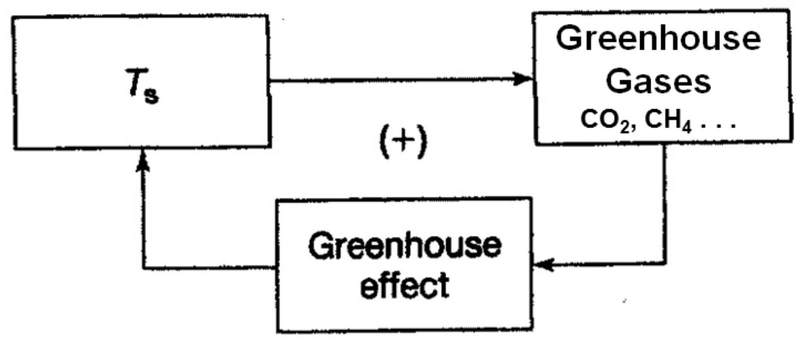
Flip back to p 60

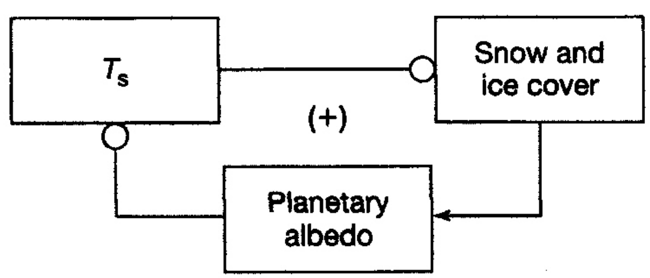
MULTIPLE FEEDBACKS

(e.g., snow / ice, water vapor, clouds, etc.)









Review

DIFFERENT TYPES OF MODELS:

- **Energy Balance Model**
  (EBM)
- **Radiative Convective Model**
  (RCM)
- **General Circulation Model**
  (GCM)

Increasing complexity

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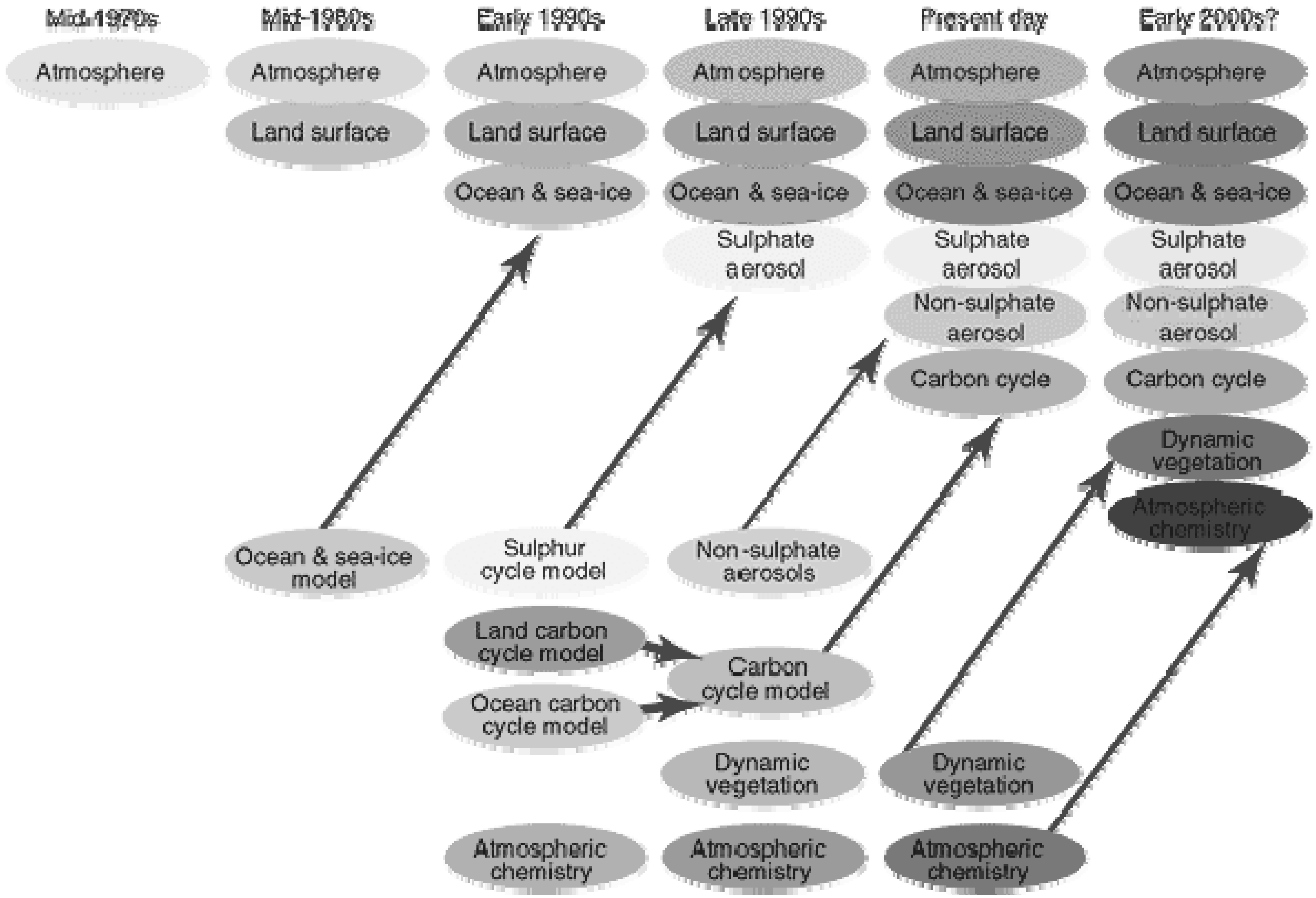
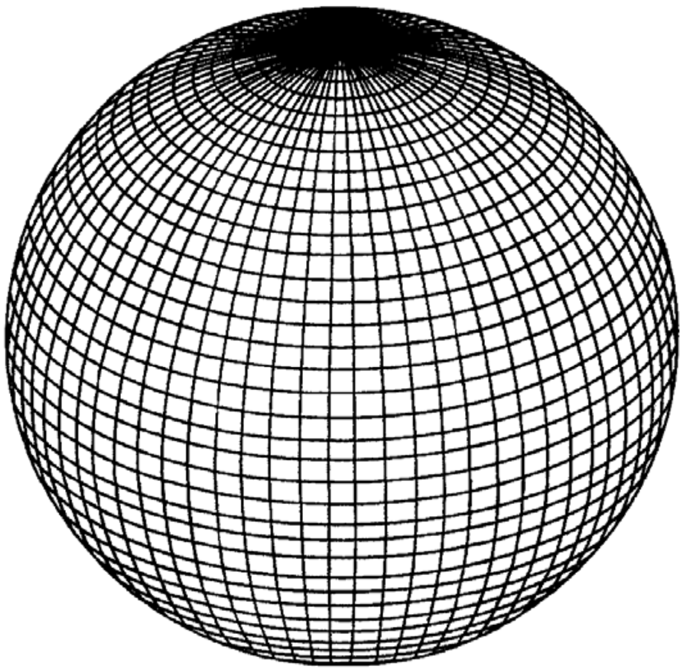
The Development of Climate models, Past, Present and Future



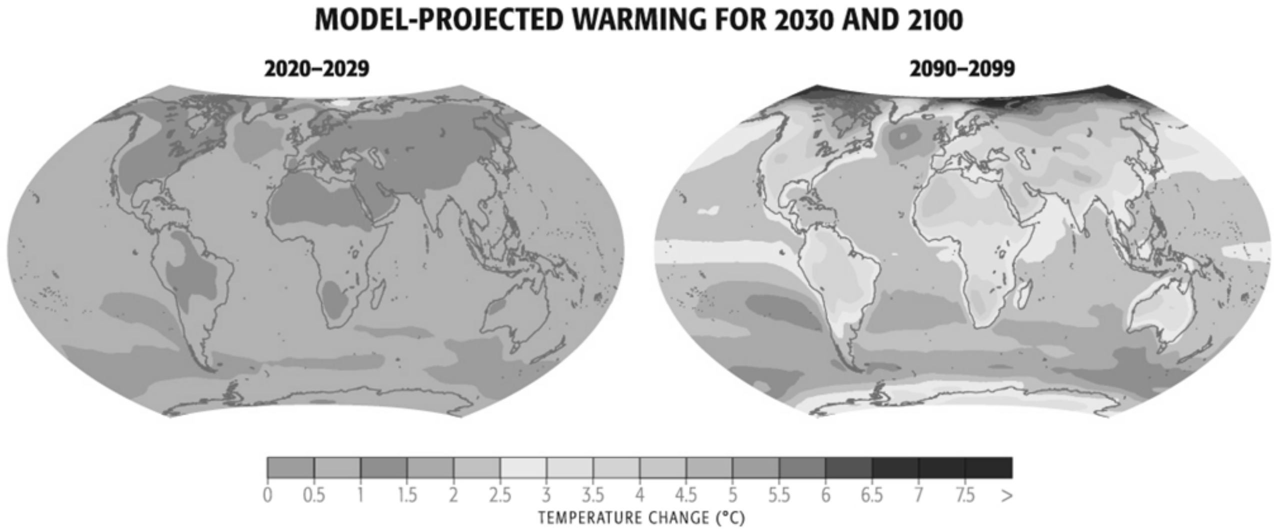
GCM models compute atmospheric pressure, velocity, density, and water vapor as functions of time

for EACH GRID BOX in a latitude-longitude grid covering the entire Earth in the horizontal dimension,

and as many as 20 LAYERS(!) of the atmosphere in the vertical dimension.



GCM’s can predict not only HOW MUCH CHANGE IN TEMPERATURE might occur due to an enhanced greenhouse effect



but also ***WHERE*** the changes are likely to manifest themselves.

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All of the calculations are based on physical principles such as the 1st law of thermodynamics and Newton’s 2nd law of motion.

Some models “couple” the ocean and atmosphere for better results.

The models are so complex that they require hundreds of hours of computing time on a supercomputer!

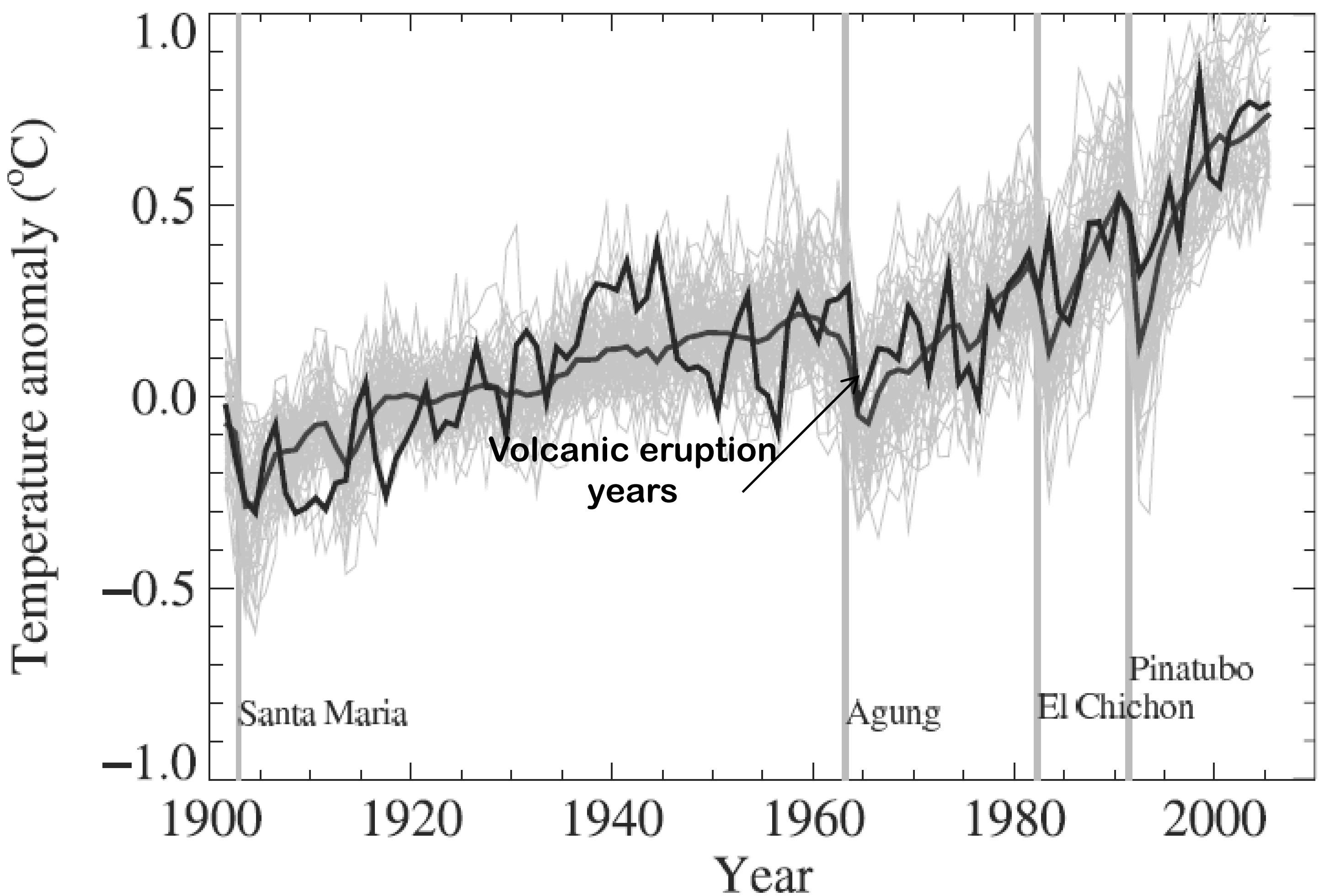
But even such sophisticated models cannot predict processes, such as cloud feedback mechanisms, that occur at scales smaller than a grid box.

Hence the inability to model processes like cloud radiational effects in detail, leads to UNCERTAINTIES and differences in the estimates produced by different GCMs.

However, even with their uncertainties, GCMs can give good results and fairly reliable estimates of the RANGE of EXPECTED CHANGE in the atmosphere (e.g. global temperature increase) due to GHG forcing.

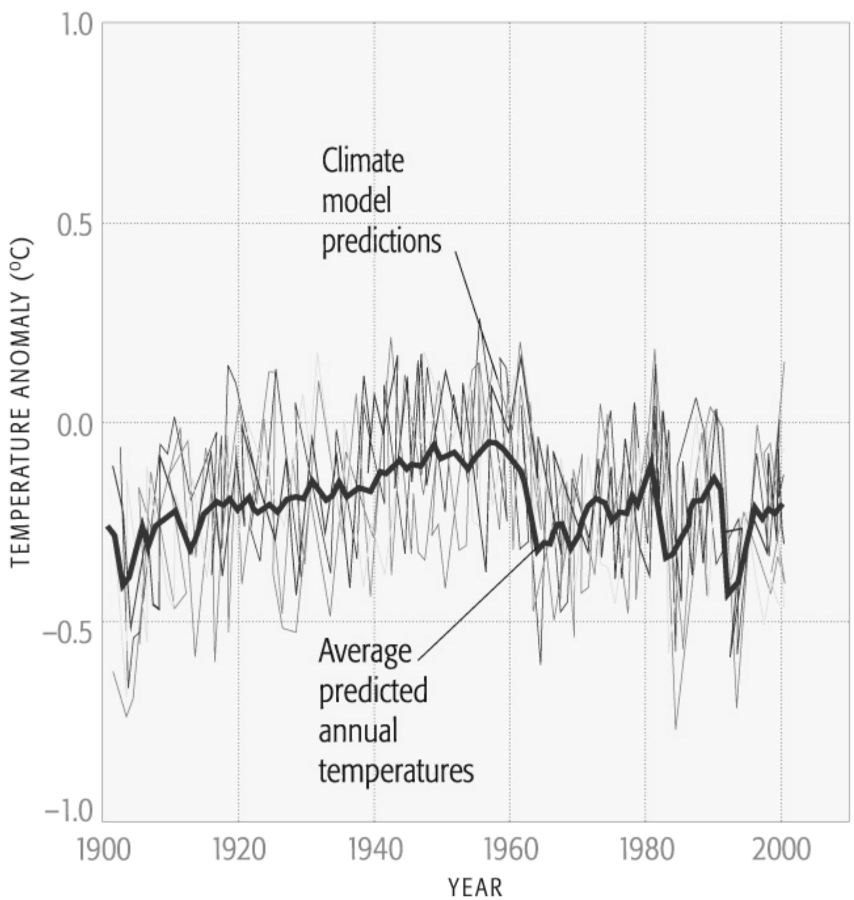
How Good are the Models?

GLOBAL MEAN TEMPERATURE from OBSERVATIONS = black line
Model simulations = yellow lines (58 runs from 14 different models!)
Mean of model runs = red line

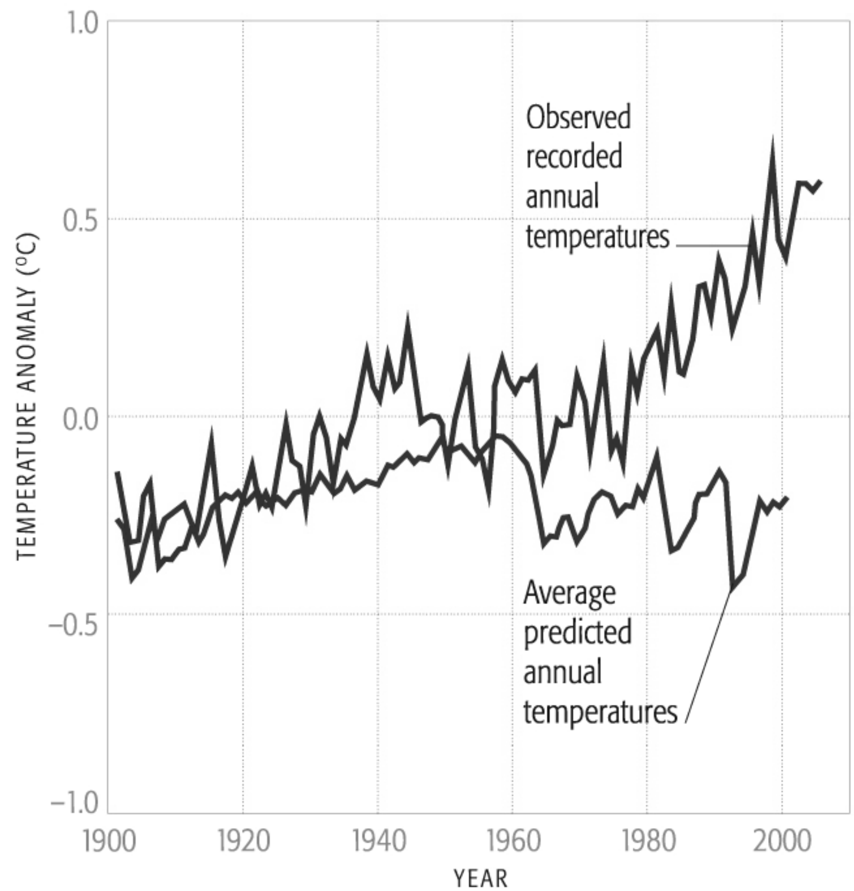


Modeled Temperature with Natural Forcing Only

PREDICTED/OBSERVED CLIMATE TRENDS
Predicted temperature trends from models, taking into account the impacts of natural forces alone

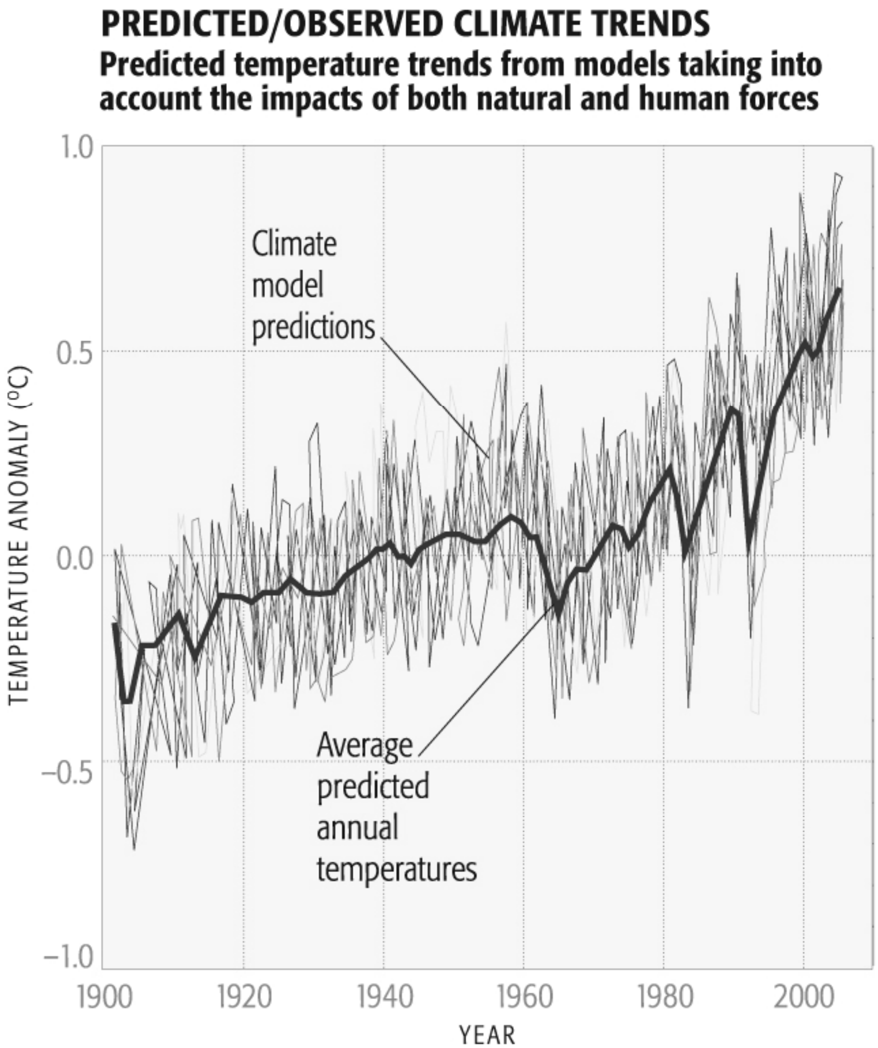


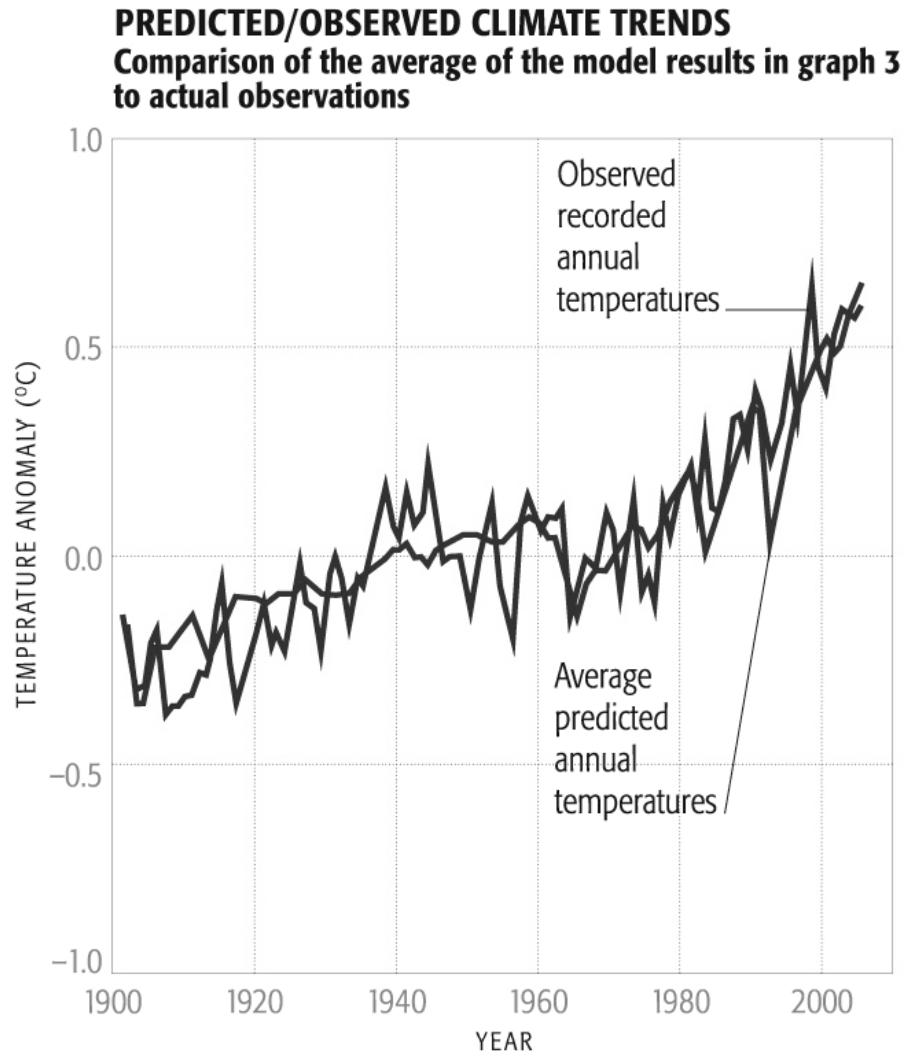
PREDICTED/OBSERVED CLIMATE TRENDS
Comparison of the average of the model results in graph 1 to actual observations



From <u>Dire Predictions</u> pp 68-69

Modeled Temperature with Natural & Anthropogenic Forcing



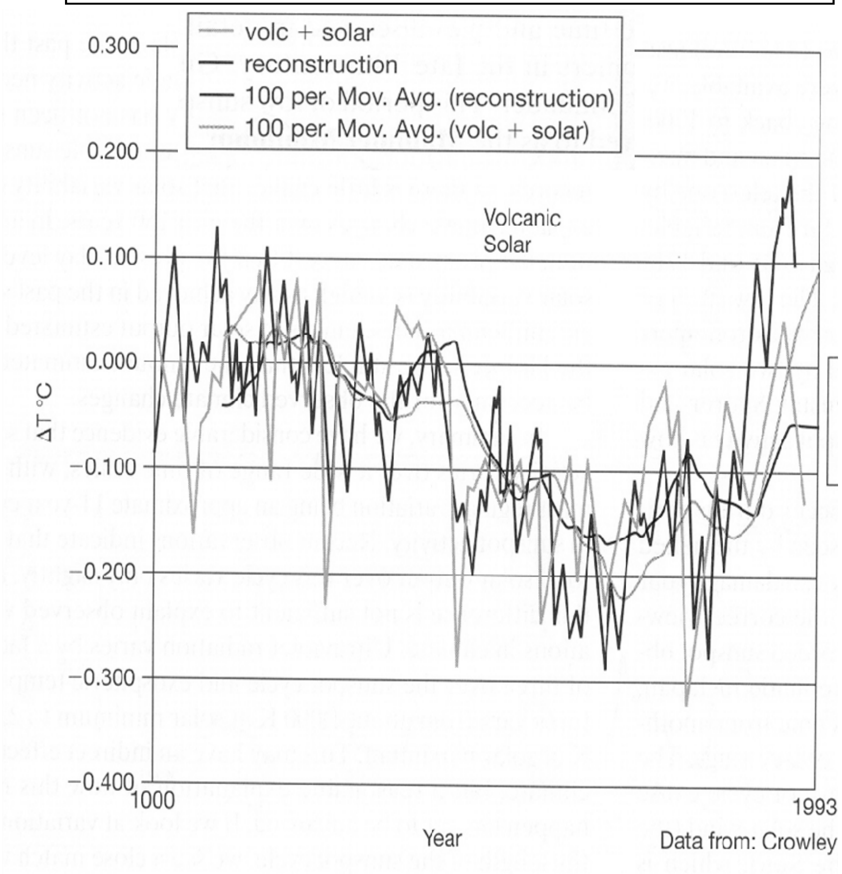


From Dire Predictions pp 68-69

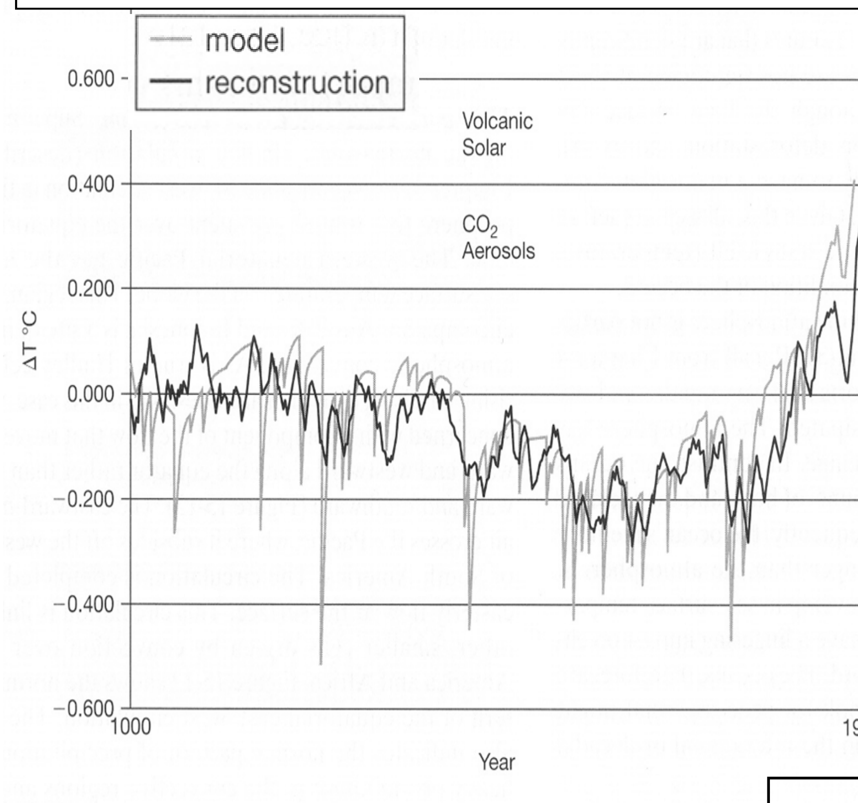
COMPUTER MODEL "FORCING" EXPERIMENT

1000-year Reconstruction of Northern Hemisphere temperatures w/ Modeling Results of an Energy Balance Model Forced in Different Ways

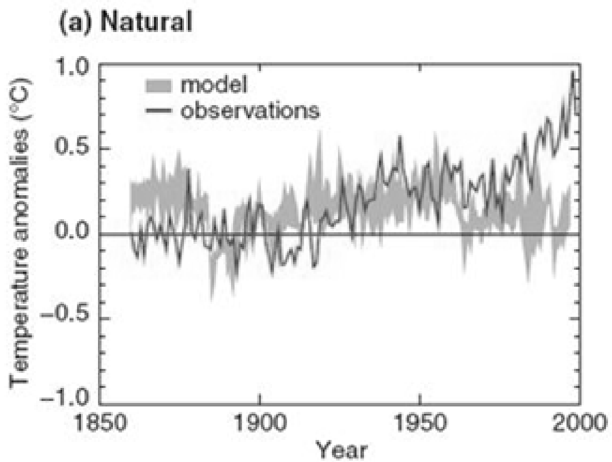
Forced with orbital variations & volcanic eruptions



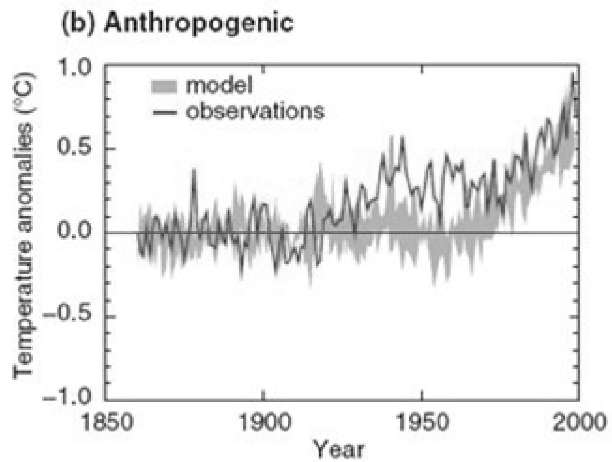
Forced with orbital variations, volcanic eruptions, & greenhouse gas concentrations



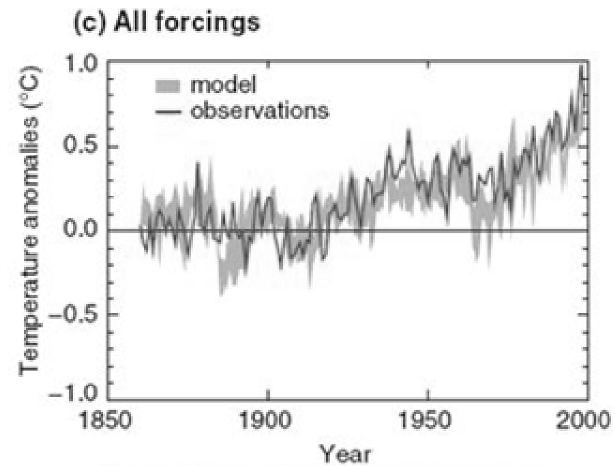
SEPARATING OUT NATURAL vs. ANTHROPOGENIC FORCING



Gray = Model-derived temperatures based on forcing by **solar variations and volcanism** only
Red = Observed temperatures



Gray = Model-derived temperatures based on forcing **by human emissions of GHGs** and **pollution** only
Red = Observed temperatures

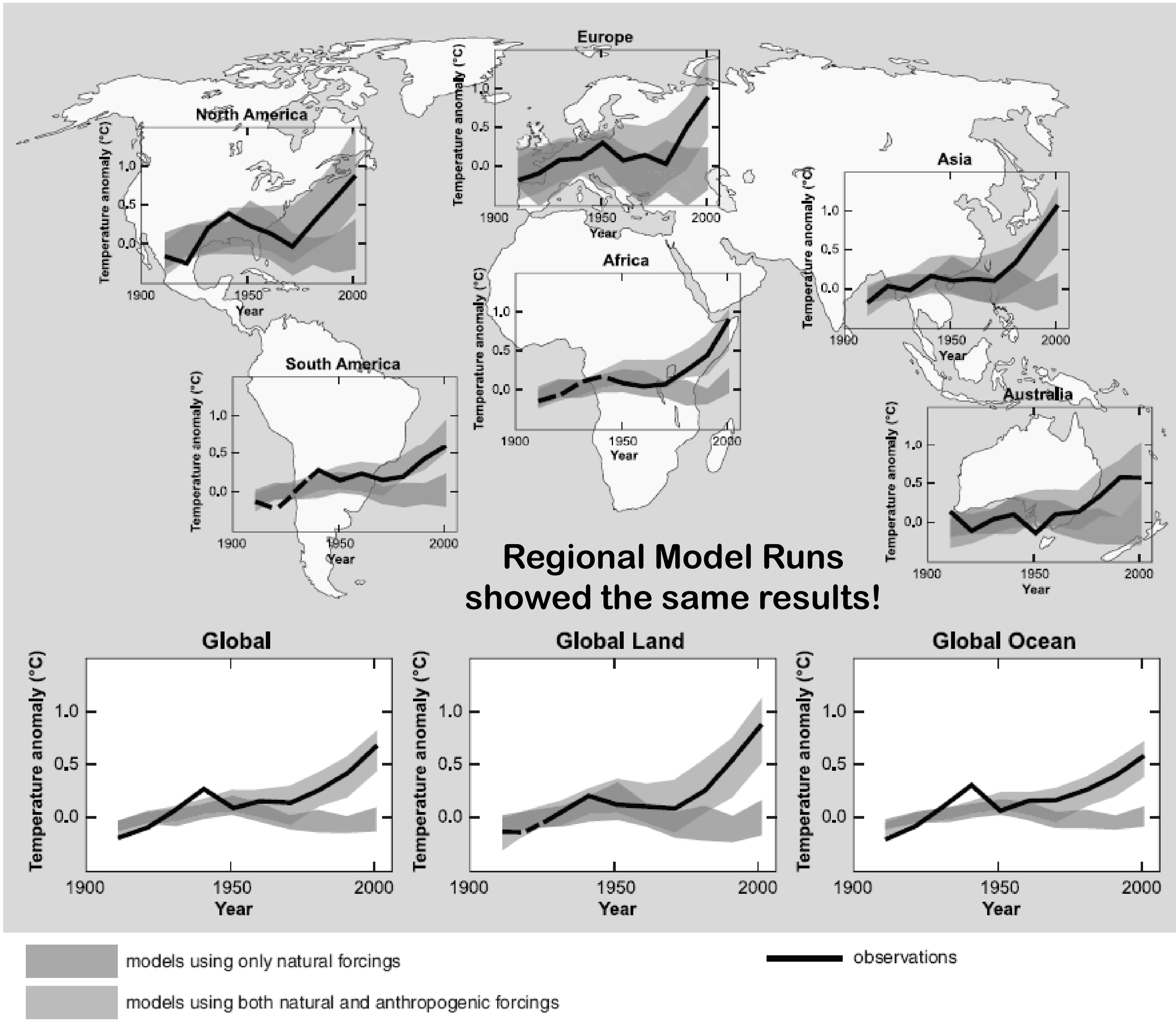


Gray = Model-derived temperatures based on forcing by BOTH **natural and anthropogenic** factors
Red = Observed temperatures

From SGC-II Ch. 9

☺

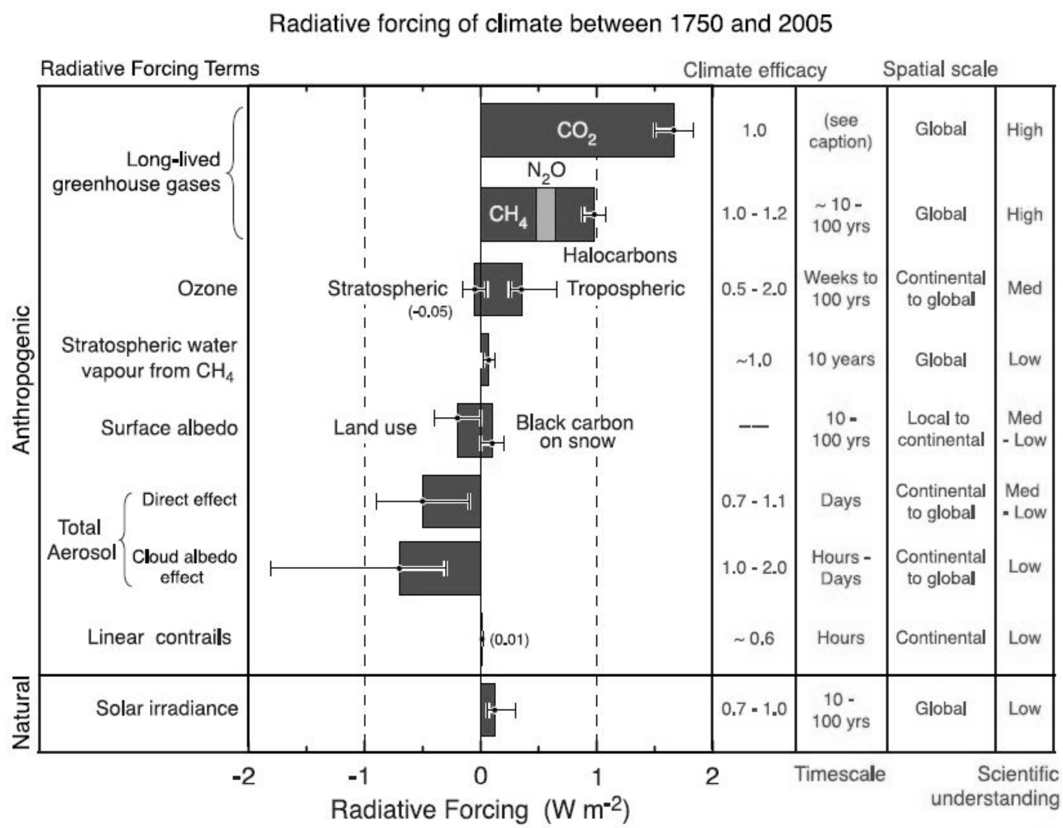
Global and continental temperature change



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

The Key To It All:

RADIATIVE FORCING OF CLIMATE



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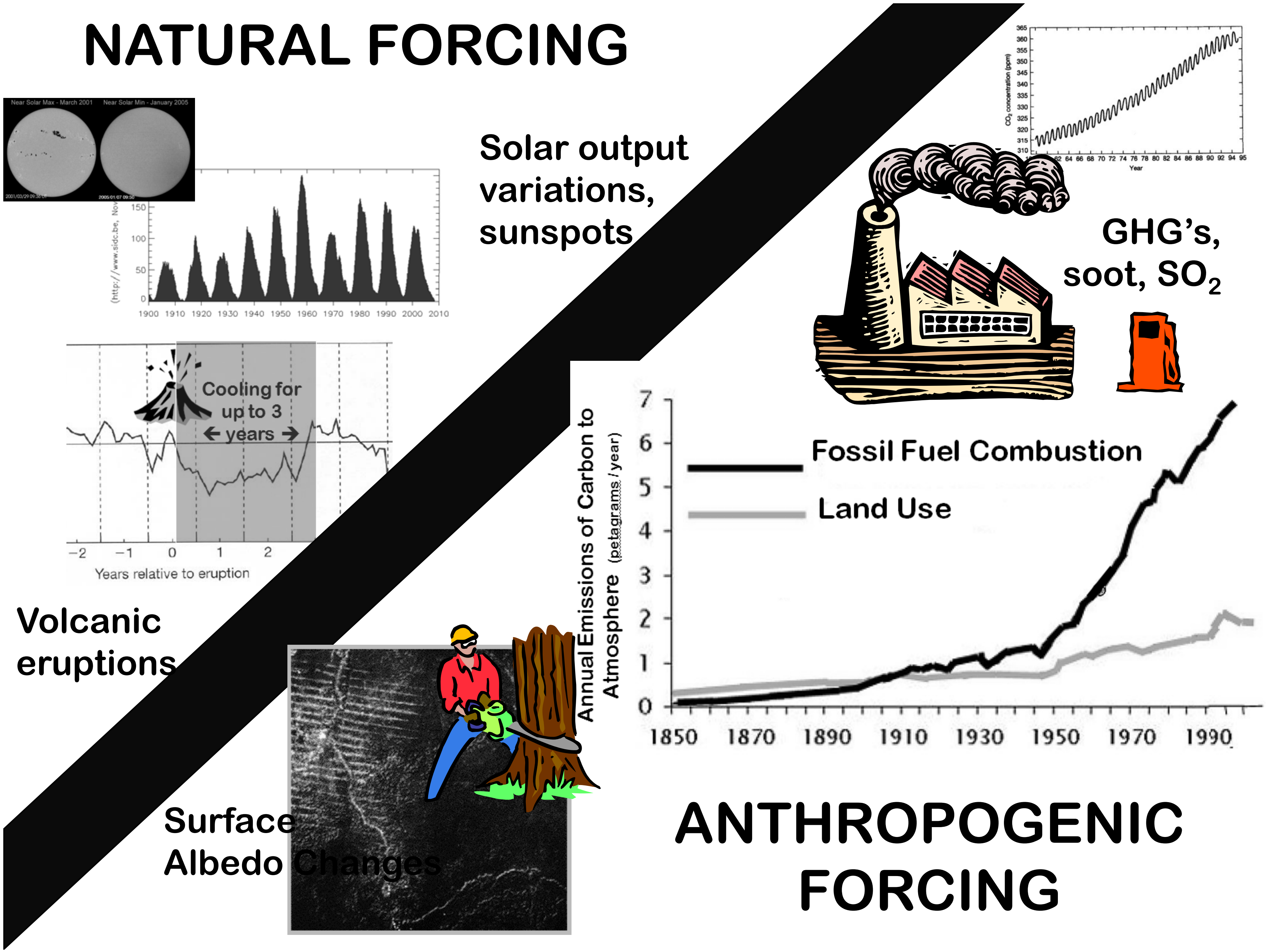
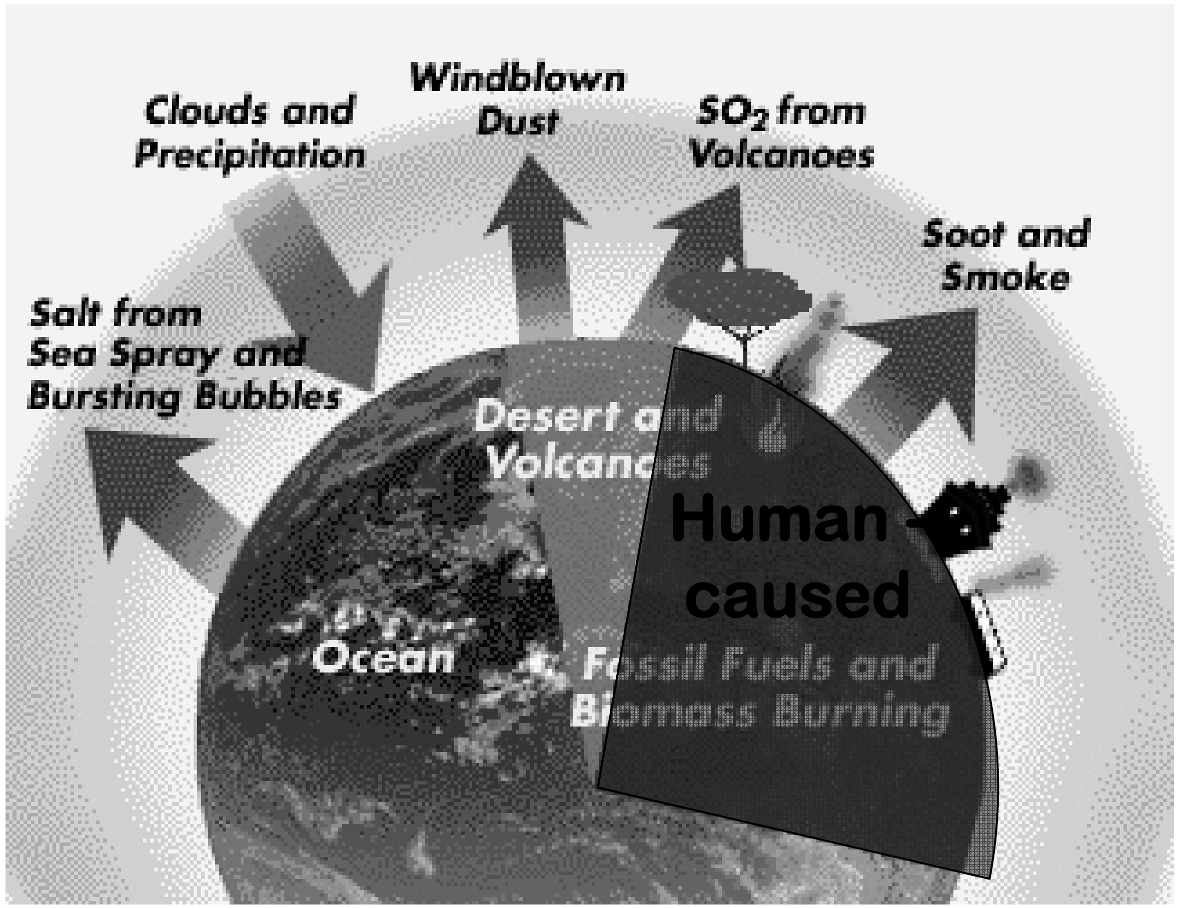


NATURAL FORCING
Near Solar Max - March 2001
Near Solar Min - January 2005
150
100
50
0
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Solar output variations, sunspots
Cooling for up to 3 years
−2 −1 0 1 2
Years relative to eruption
Volcanic eruptions
Surface Albedo Changes
GHG's, soot, SO_2
Year
Annual Emissions of Carbon to Atmosphere (petagrams / year)
0 1 2 3 4 5 6 7
Fossil Fuel Combustion
Land Use
1850 1870 1890 1910 1930 1950 1970 1990
ANTHROPOGENIC FORCING

FORCING = a persistent disturbance of a system



(a longer term disturbance than a perturbation)

review

Now we will focus on:

<u>RADIATIVE</u> FORCING

(linked to Radiation Balance!)

$$R_{NET} = \overset{SW}{\downarrow} + \overset{SW}{\downarrow} - \overset{SW}{\nearrow} - \underset{LW}{\uparrow} + \overset{LW}{\downarrow}$$

(expressed in Watts per square meter (Wm^{-2})

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

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RADIATIVE FORCING
(linked to Radiation Balance!)

$$R_{NET} = \overset{SW}{\downarrow} + \overset{SW}{\downarrow} - \overset{SW}{\nearrow} - \underset{LW}{\uparrow} + \overset{LW}{\downarrow}$$

It’s an index of the importance of the factor as a potential climate change mechanism!

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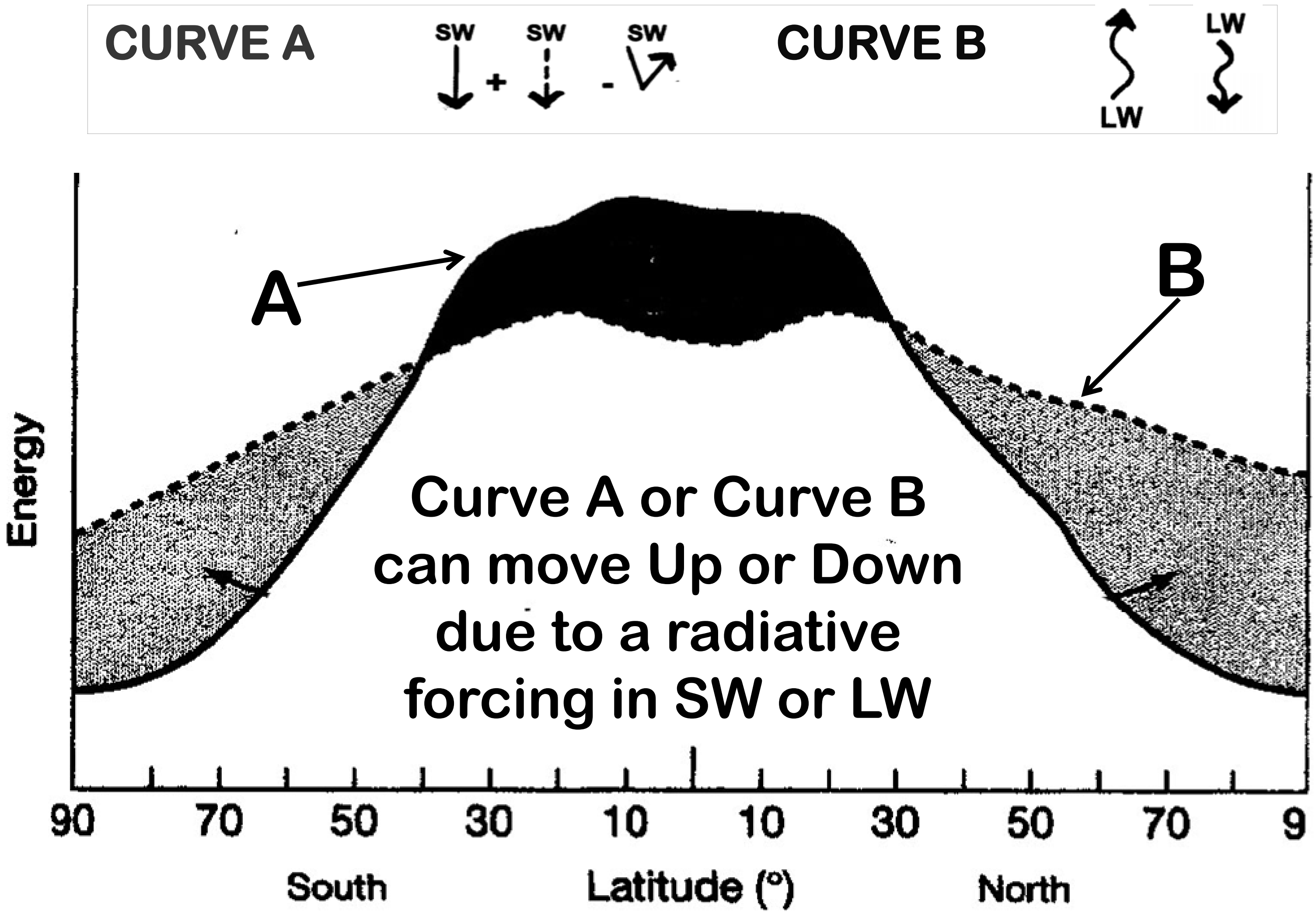
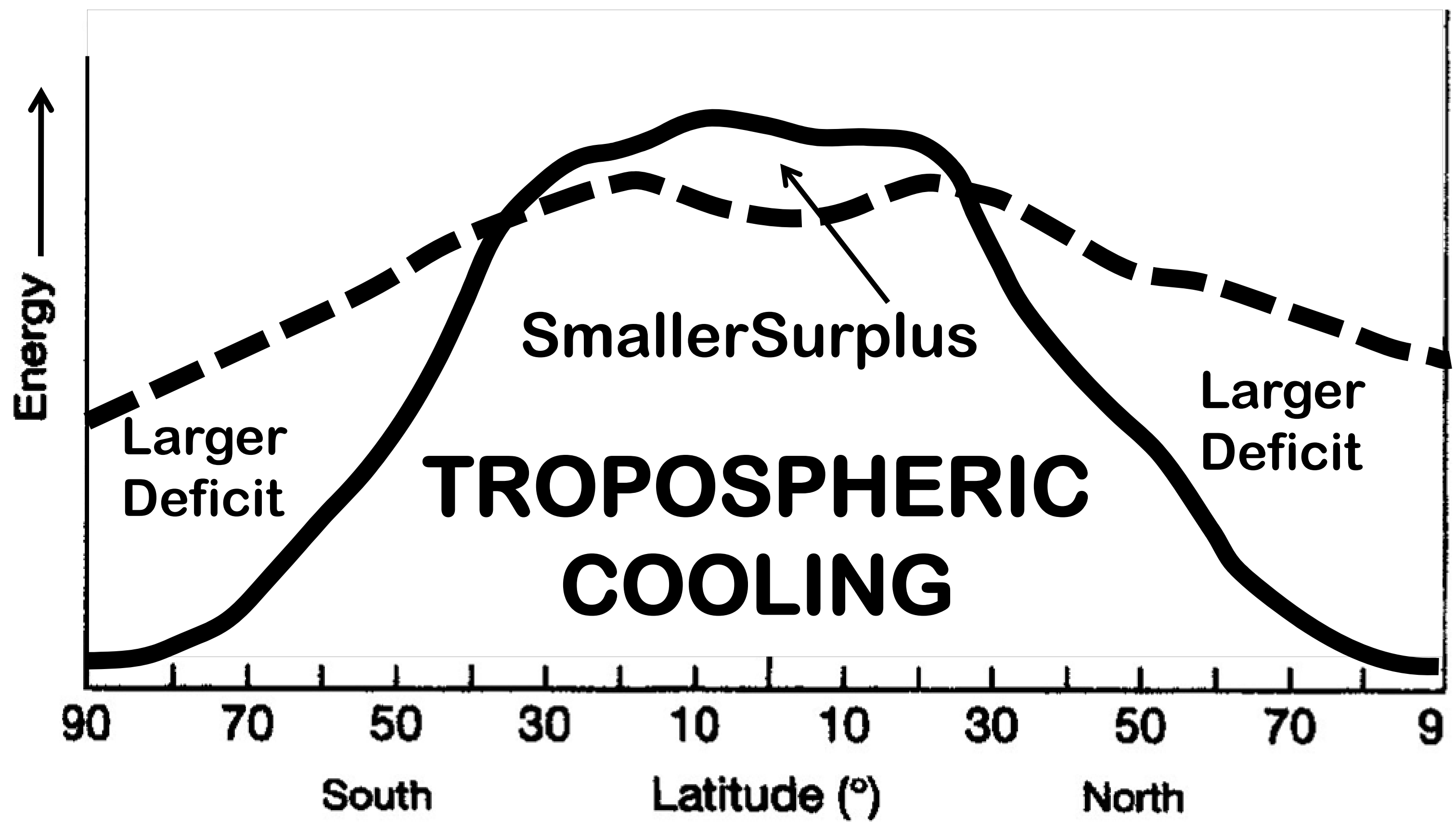


ENERGY BALANCE CHANGES IN THE TROPOSPHERE

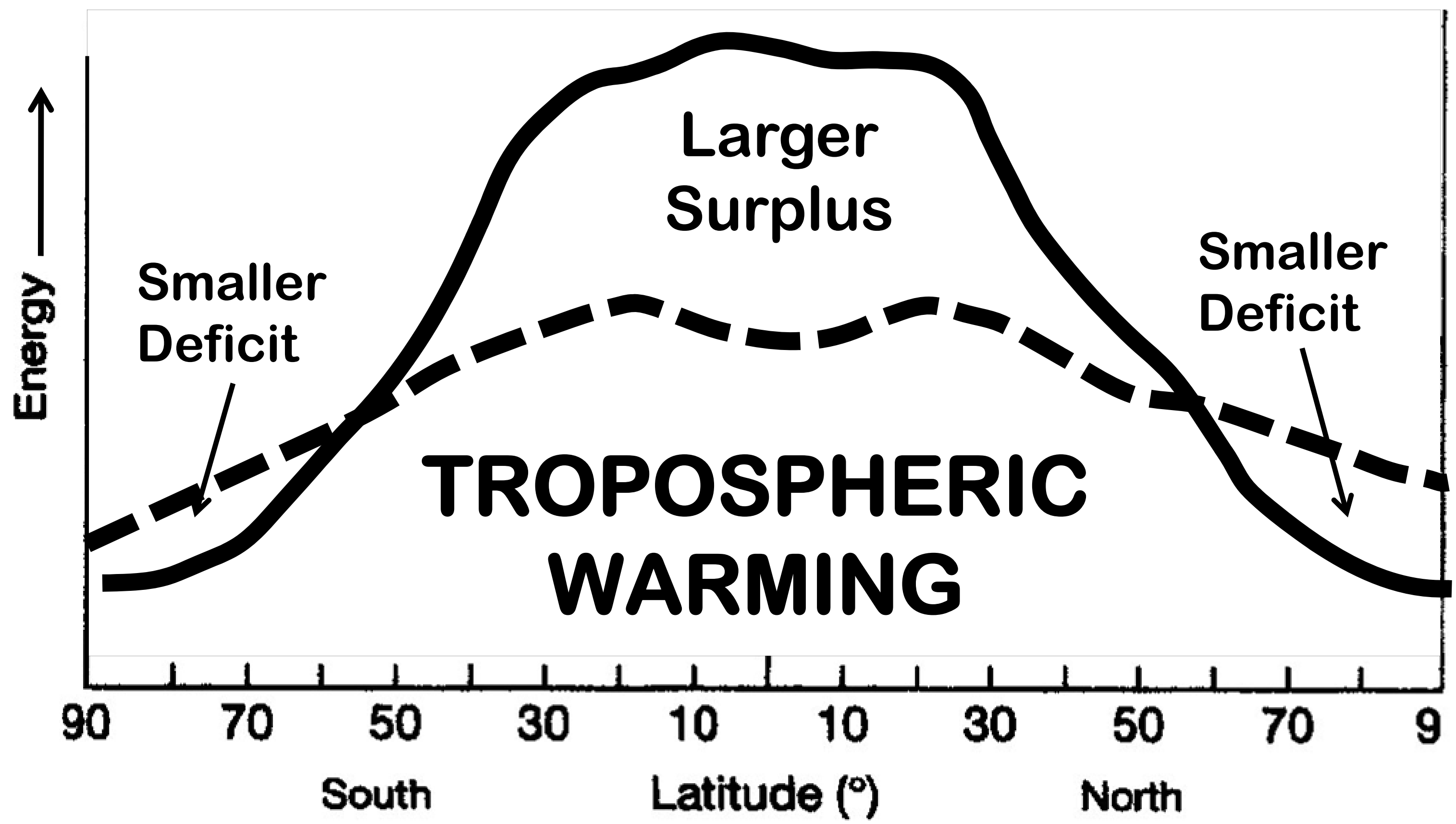
IF CURVE A moves down: $\overset{SW}{\downarrow} + \overset{SW}{\downarrow} - \overset{SW}{\nearrow}$



$\overset{SW}{\downarrow} + \overset{SW}{\downarrow} - \overset{SW}{\nearrow}$ **If incoming energy represented by Curve A is reduced (A curve goes down)**

HOW? Albedo increases due to Eruption, Deforestation, Sulfur Aerosols, etc. $\overset{SW}{\downarrow}$ $\overset{SW}{\nearrow}$

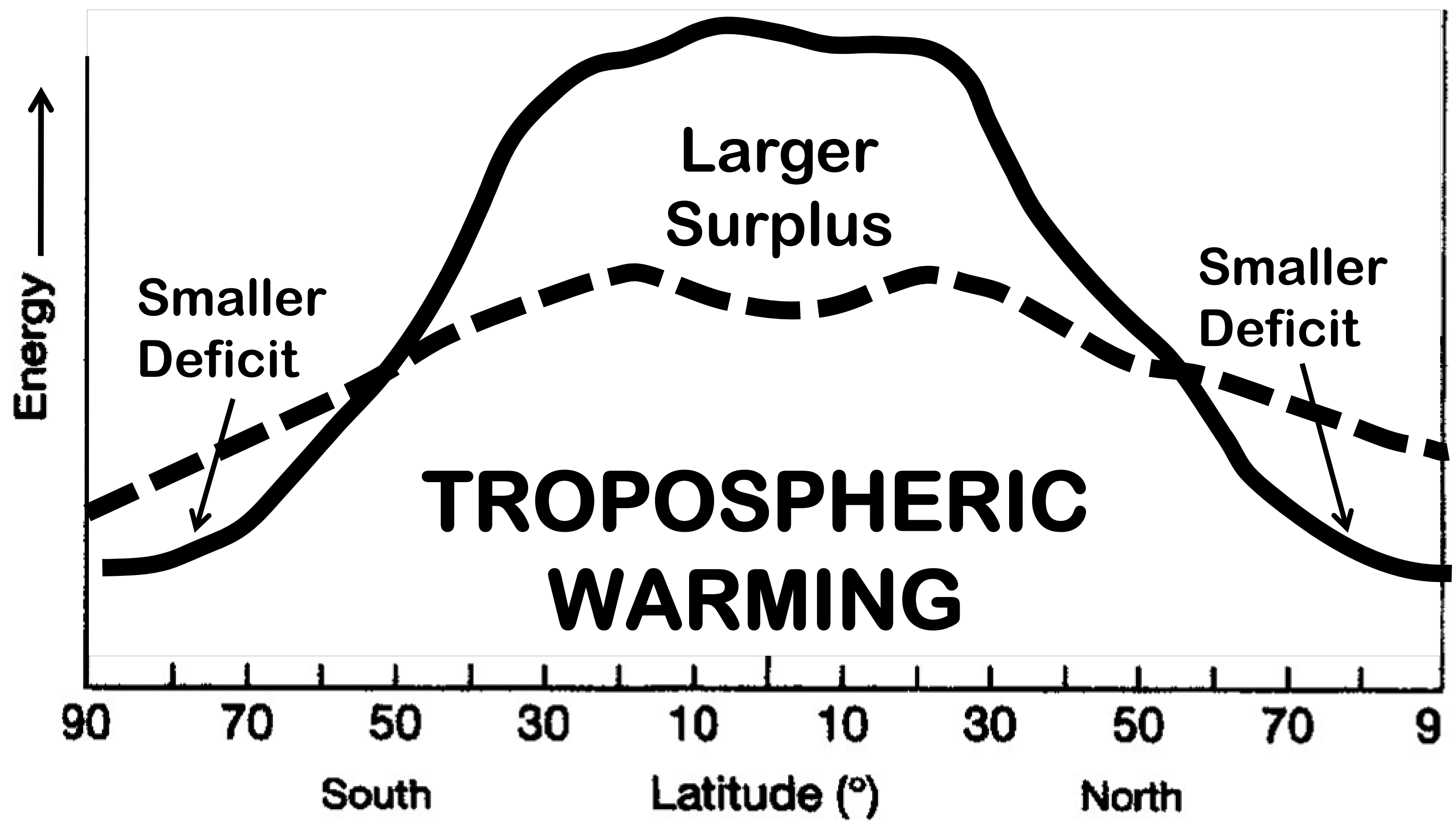
If CURVE B moves down



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

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

IF CURVE A moves up: SW ↓ + SW ↓ - SW ↗

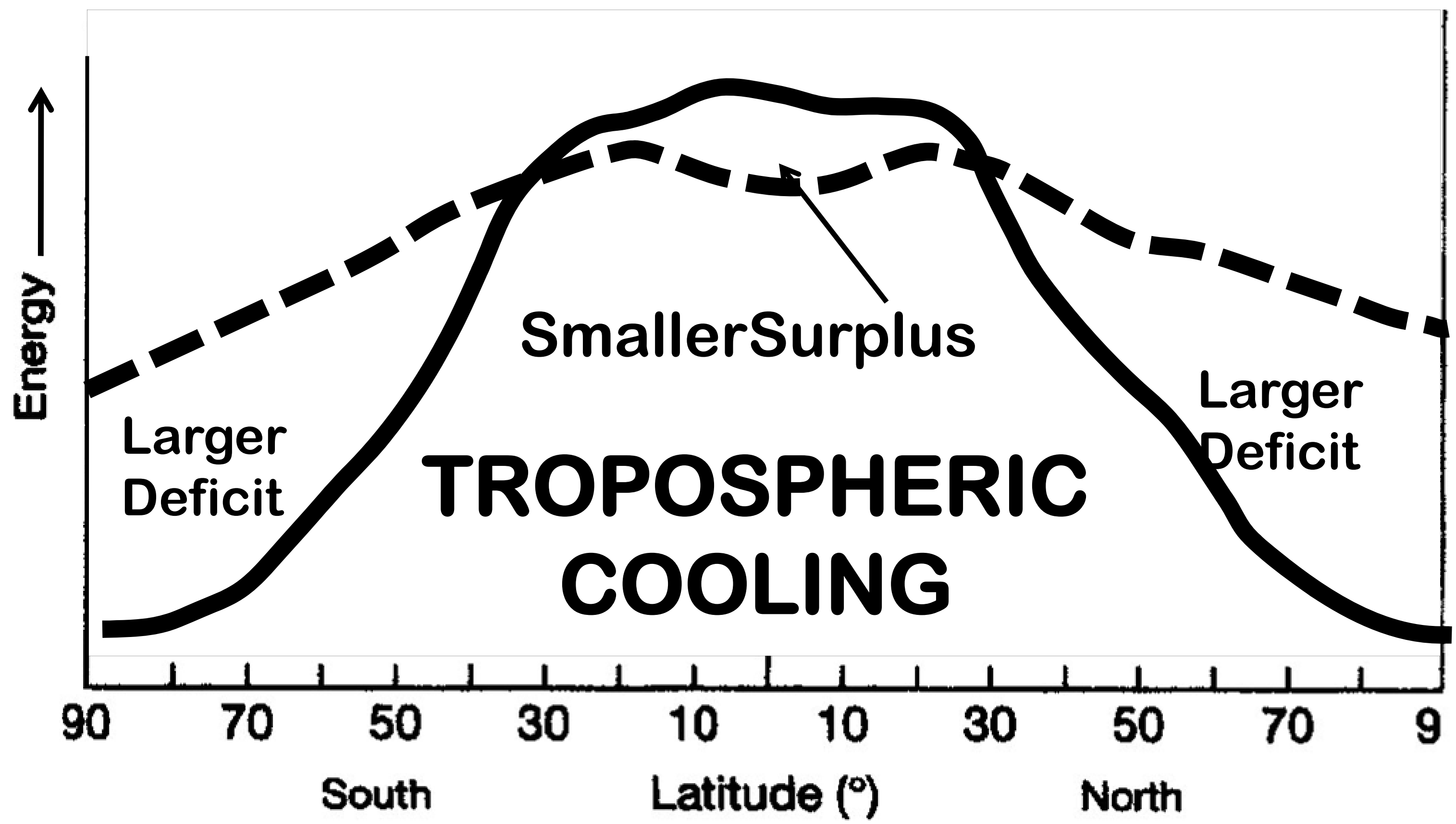


SW ↓ + SW ↓ - SW ↗ **If incoming energy represented by Curve A is increased (A curve goes up)**

HOW? Albedo decreases and / or solar input increases

SW ↓ SW ↗

If CURVE B moves up: LW LW

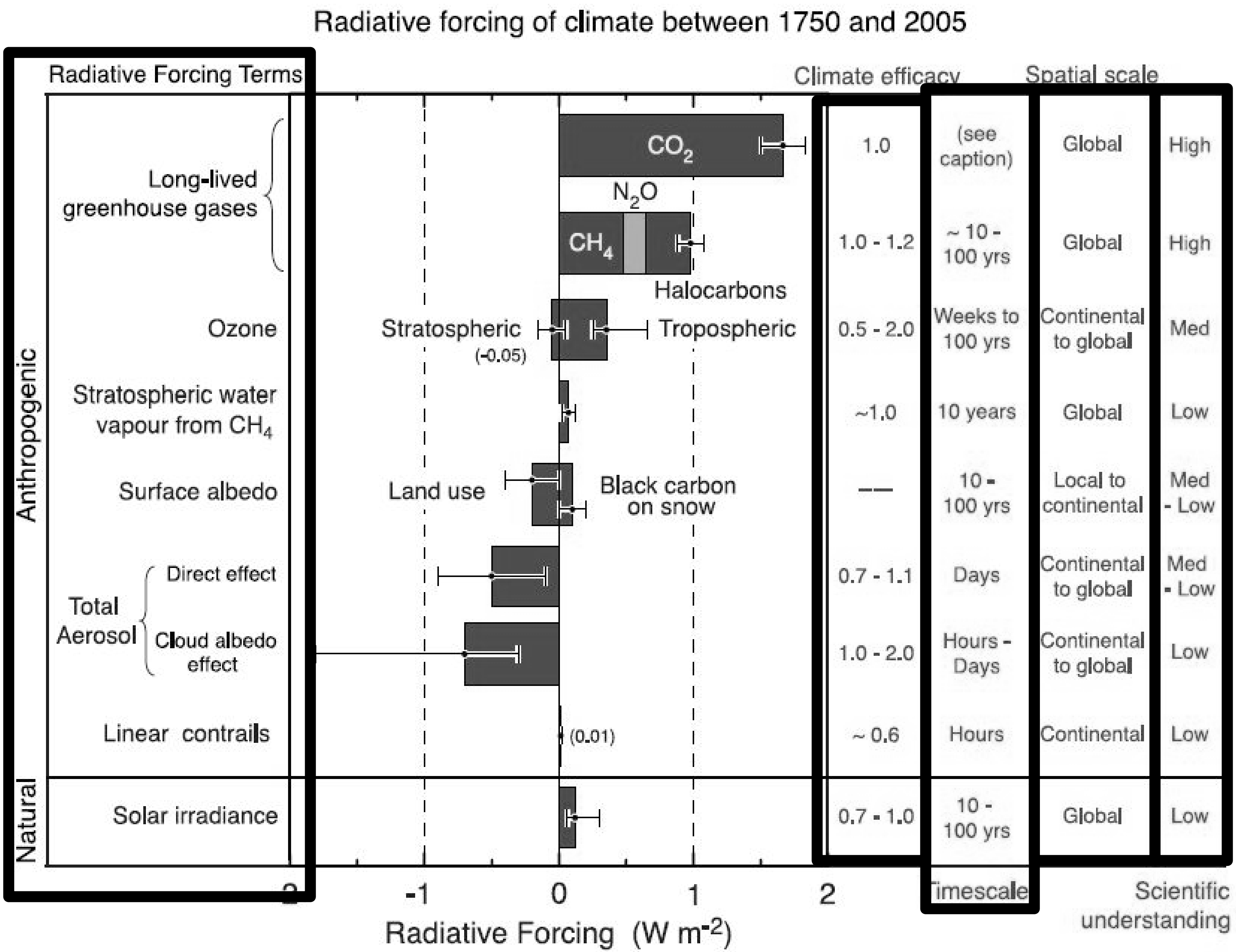


LW

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

LW LW

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



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

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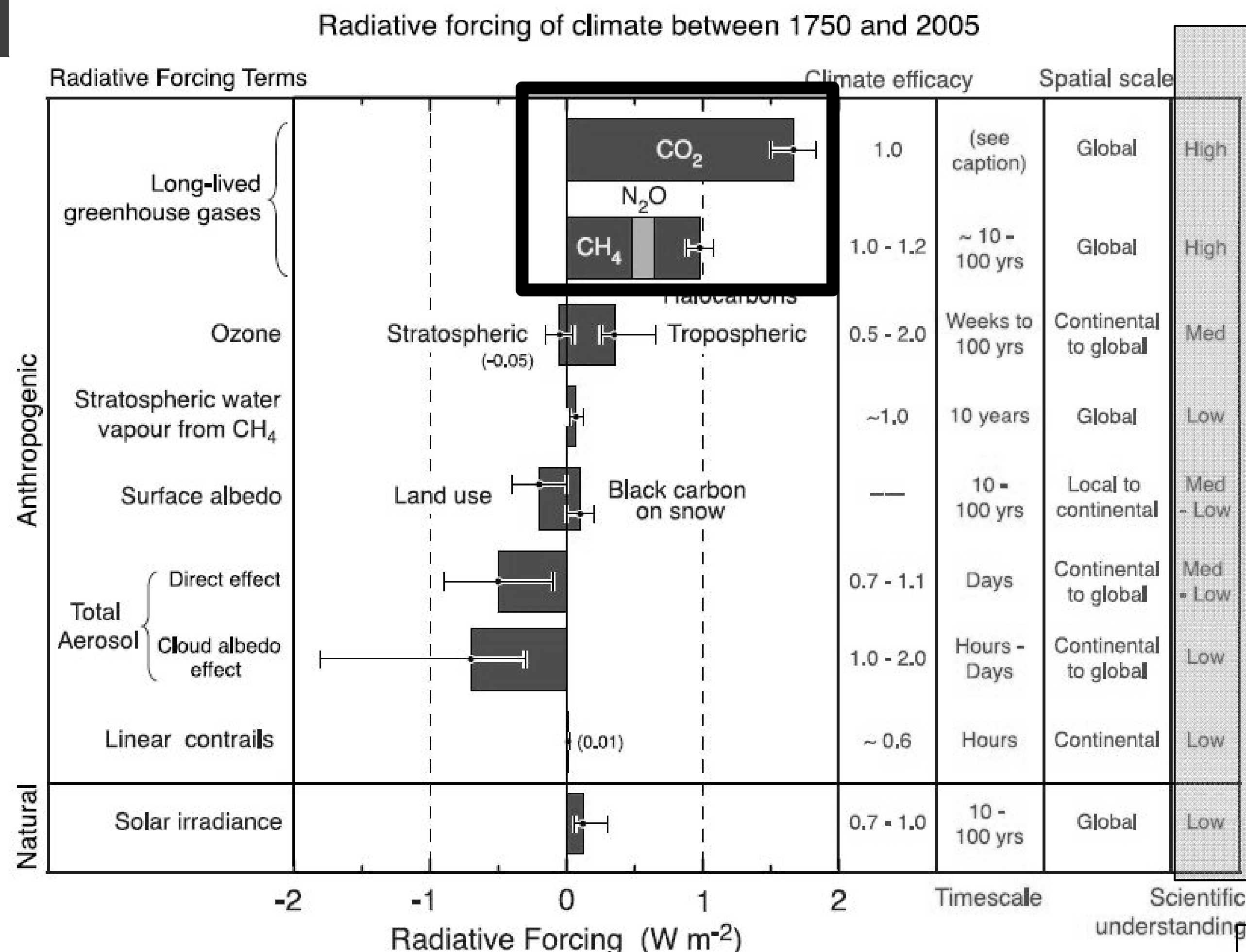
The figure shows that the forcing mechanism that is ***BEST*** understood by scientists is also the one that leads to the greatest climatic impact.

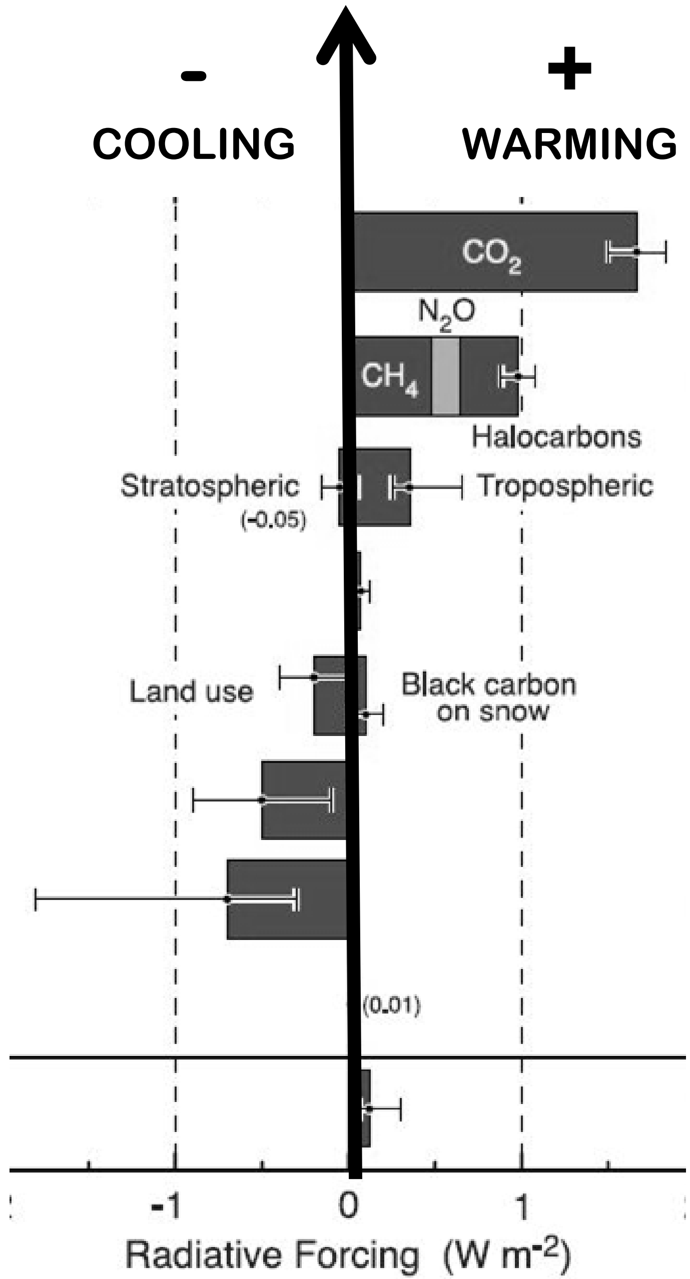
1. TRUE
2. FALSE



p 90

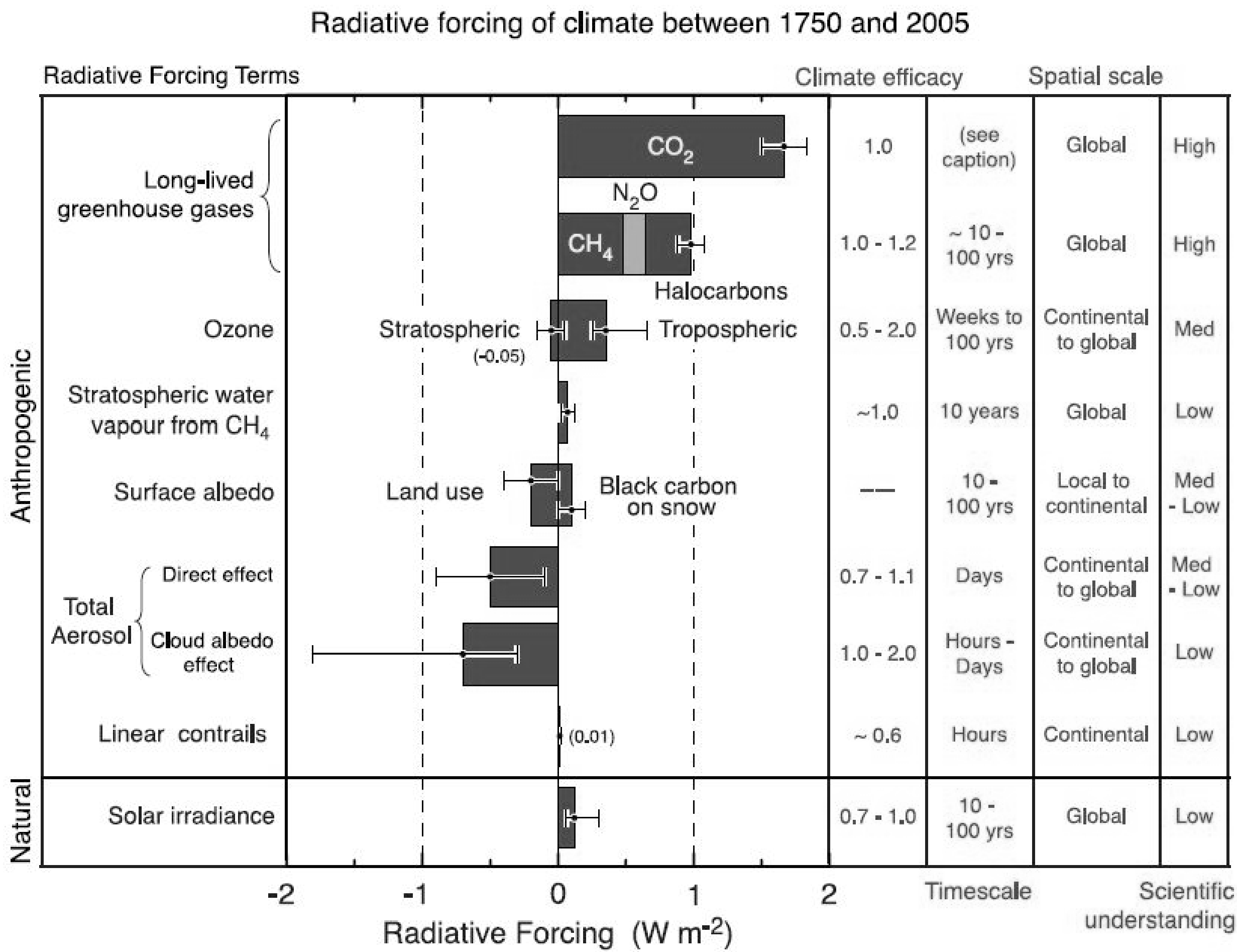
If the forcing is **NEGATIVE**
(to left of line)

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



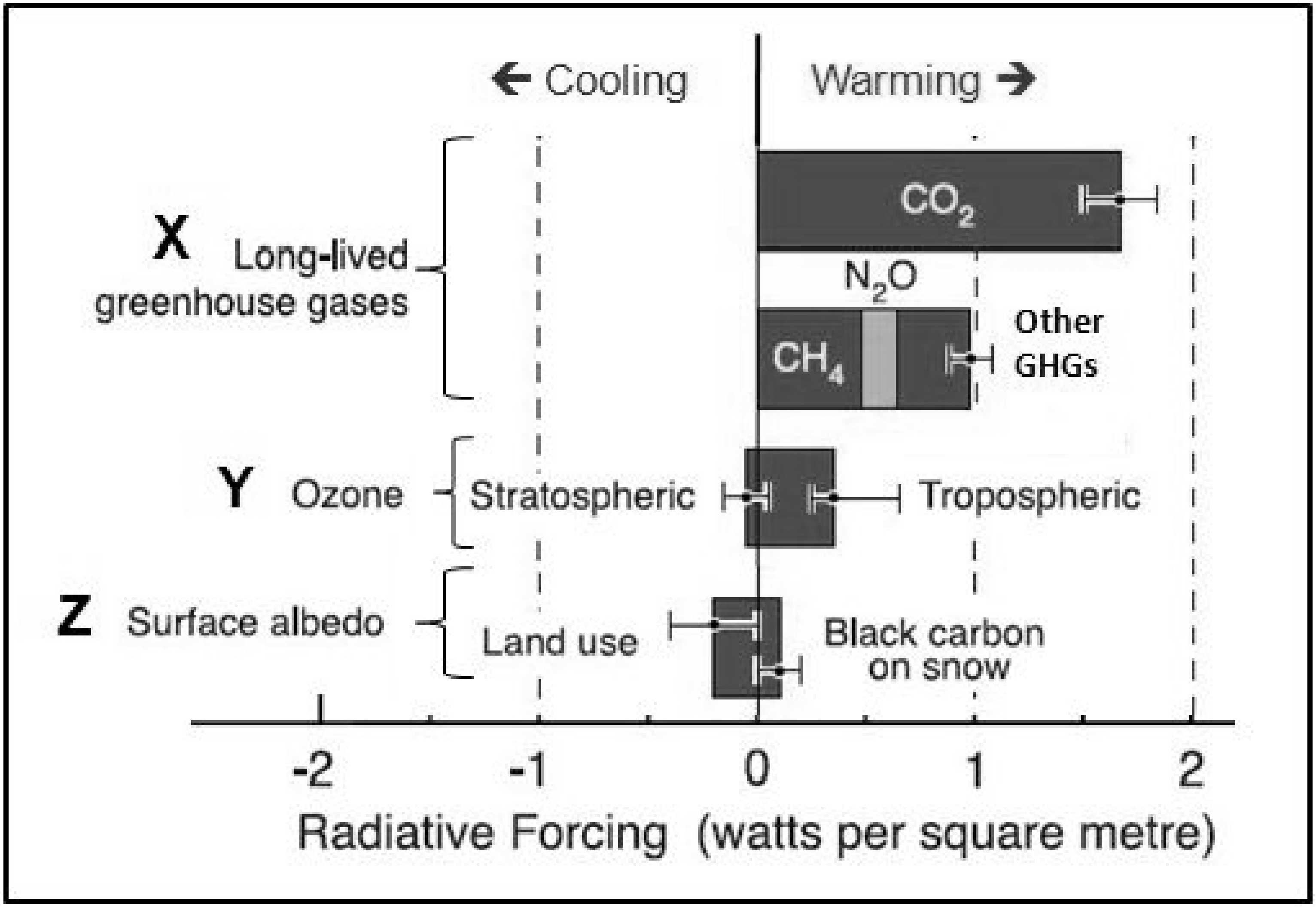
If the forcing is **POSITIVE**
(to right of line)

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



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

ALL of the forcing mechanisms shown here (X, Y, & Z) are linked to anthropogenic activity in some way: $\boxed{\text{1. TRUE}}$ 2. FALSE

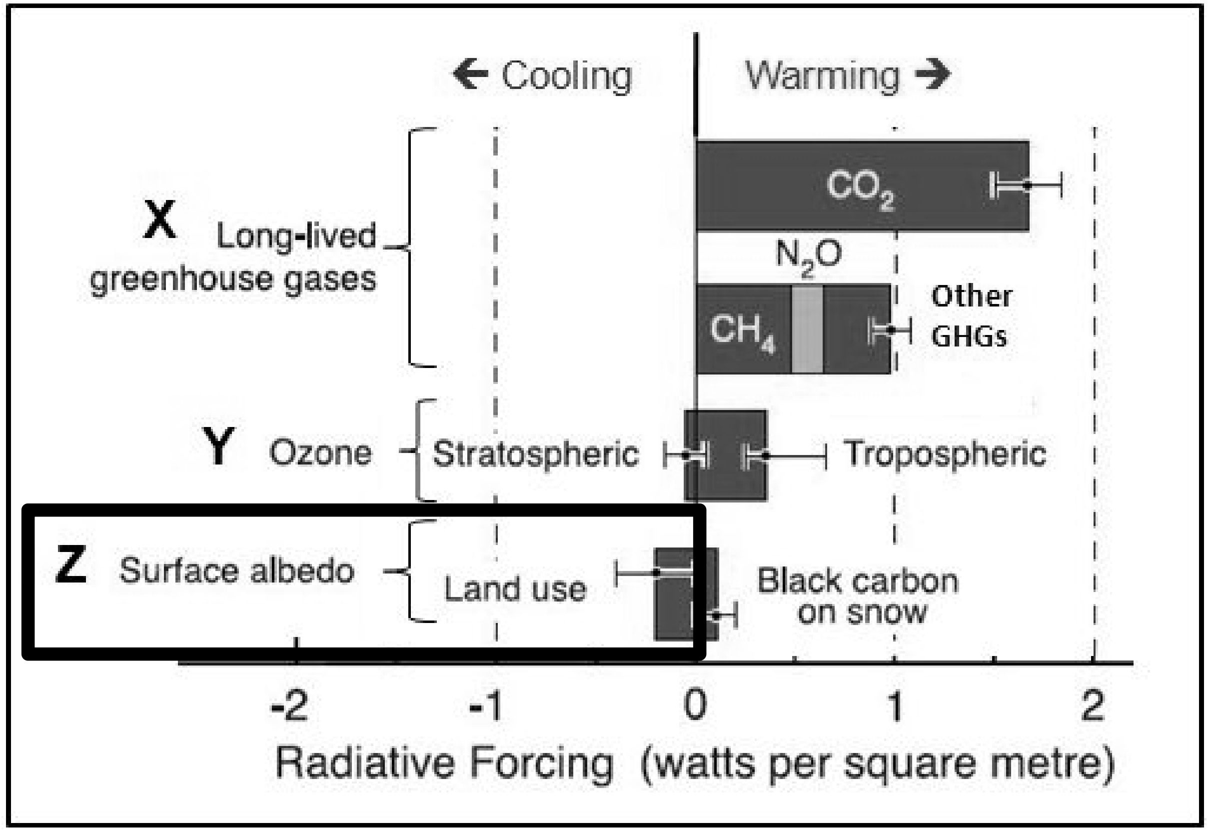


The figure shows that forcing mechanism Z (Land-use as indicated by albedo) leads to <u>COOLING</u>. . .

1. TRUE
2. FALSE

. . . The <u>reason</u> for this is that cooling occurs when surface albedo *increases* and hence <u>MORE</u> energy is absorbed.

TRUE or FALSE?



<u>LESS</u> energy is absorbed!

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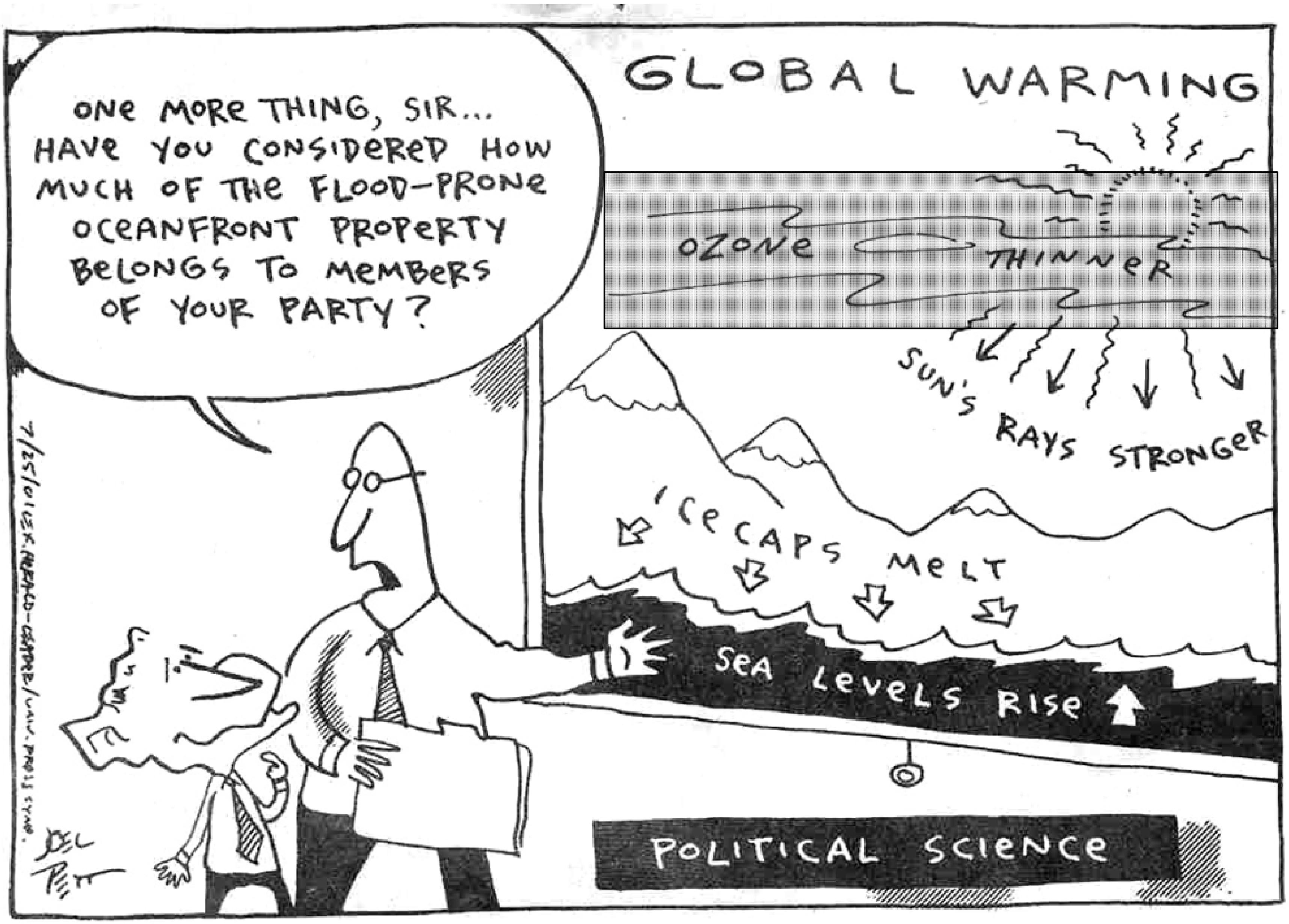
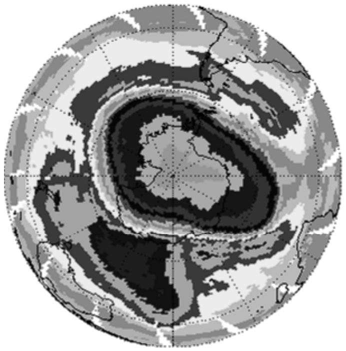
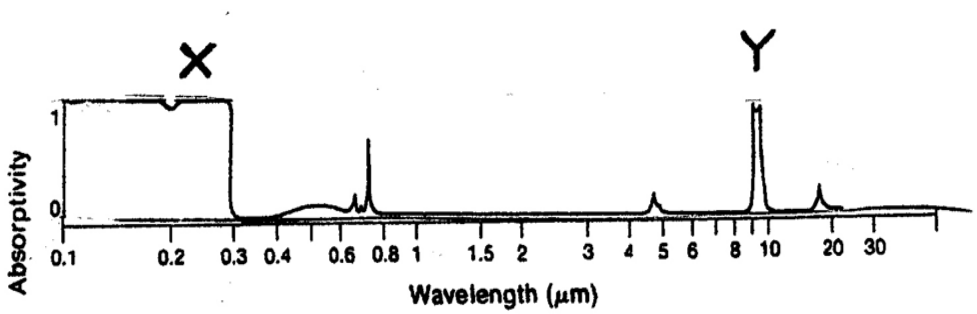
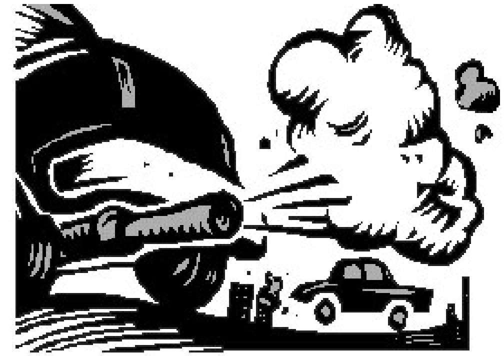
A COMMON MISCONCEPTION!

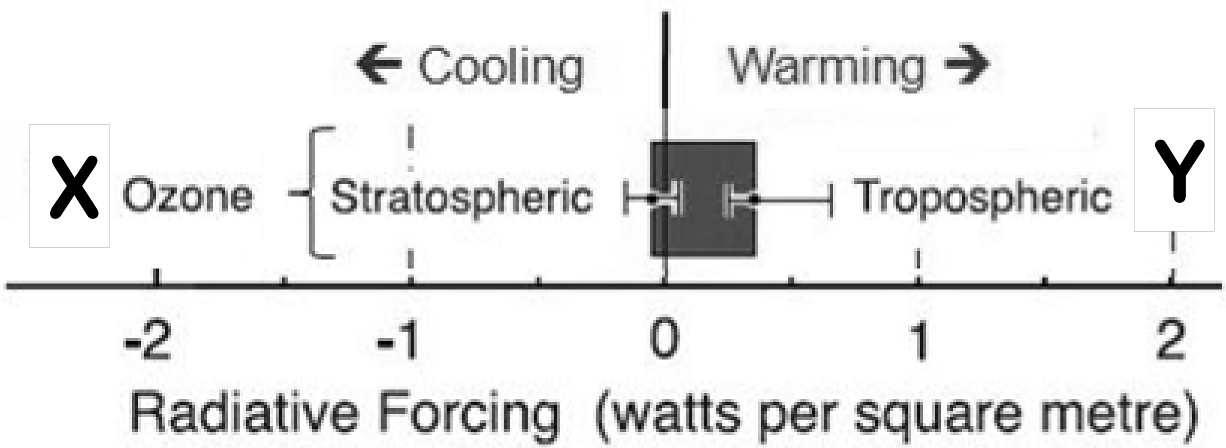


OZONE'S DUAL PERSONALITY!



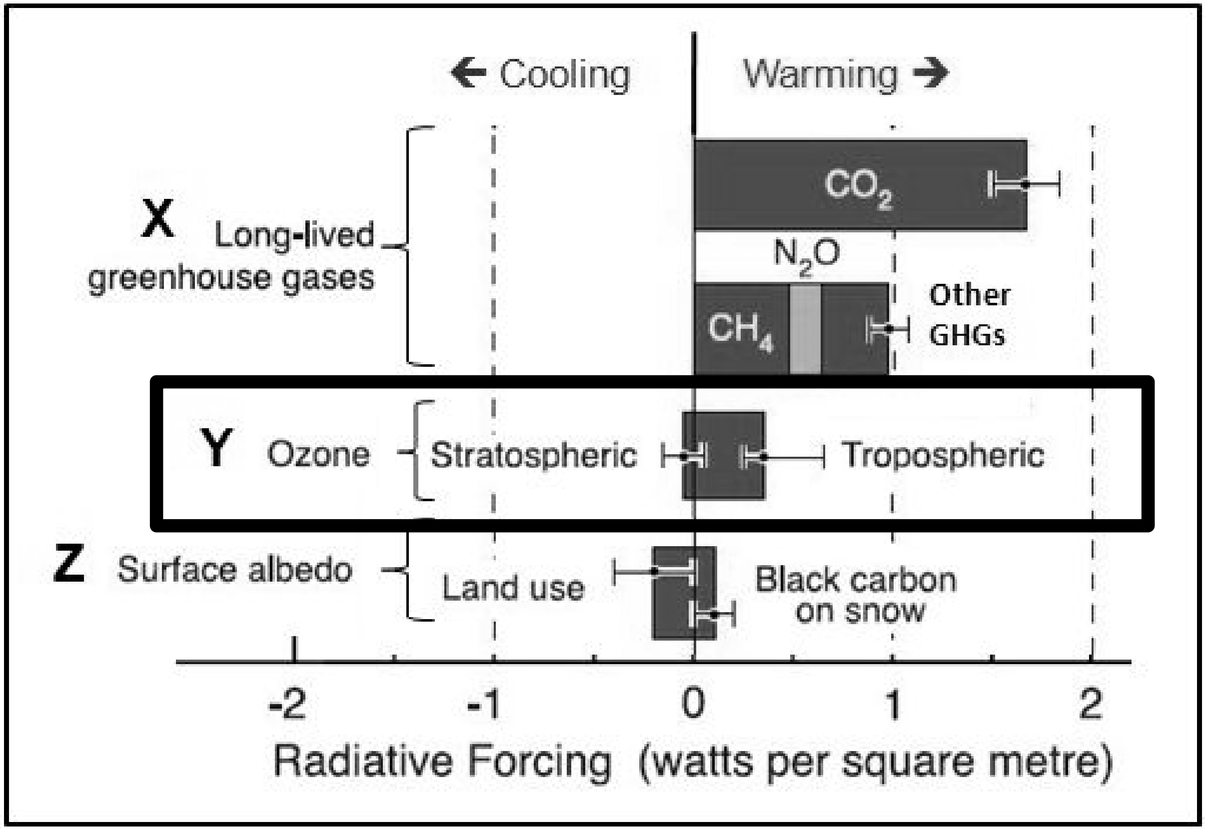






According to the figure which forcing mechanism has a GREATER influence on global temperature?

Stratospheric OZONE OR Tropospheric OZONE

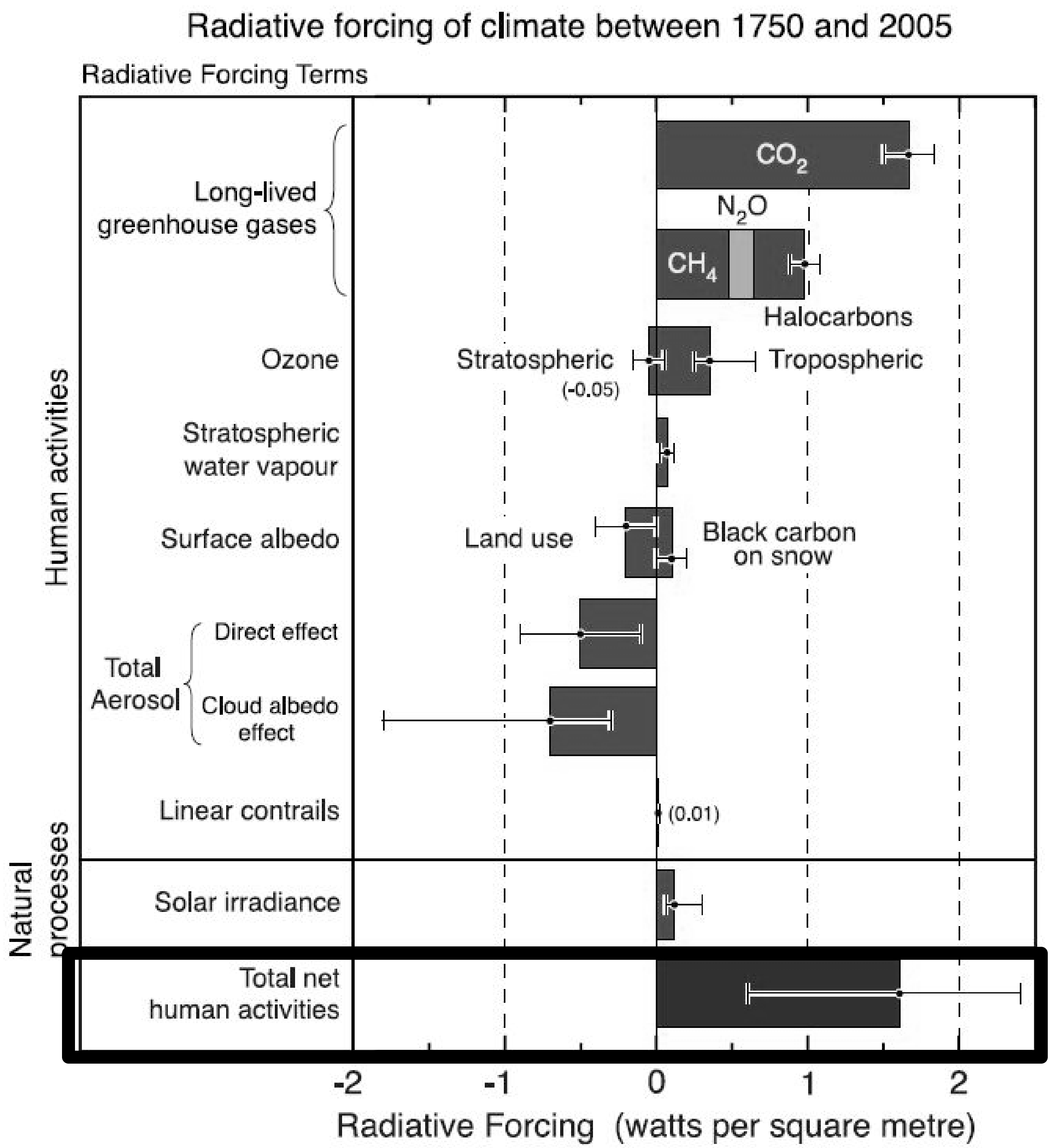


The OZONE HOLE IS NOT THE <u>MAIN</u> CAUSE FOR GLOBAL WARMING!

FAQ 2.1

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

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



Study hard for
Test #4 !

See you on
Thursday . . . .