Welcome to ATMS 111 Global Warming

http://www.atmos.washington.edu/2010Q1/111

Censored

Spotted by Jennifer Le

Today

Review and Finish up The Greenhouse Effect - RG p 21-30

A rogues gallery of greenhouse gases

Why shouldn't water vapor be in the rogues gallery

What is the role of aerosols?

Homework 1 is open and due Friday at 11:55pm. Enrollment Key is noodle

Tuesday

Quiz , similar to homework 1 plus new topics today. See homework 2 problems 1-7 for practice too.

BRING A SCANTRON SHEET. Available at the bookstore.

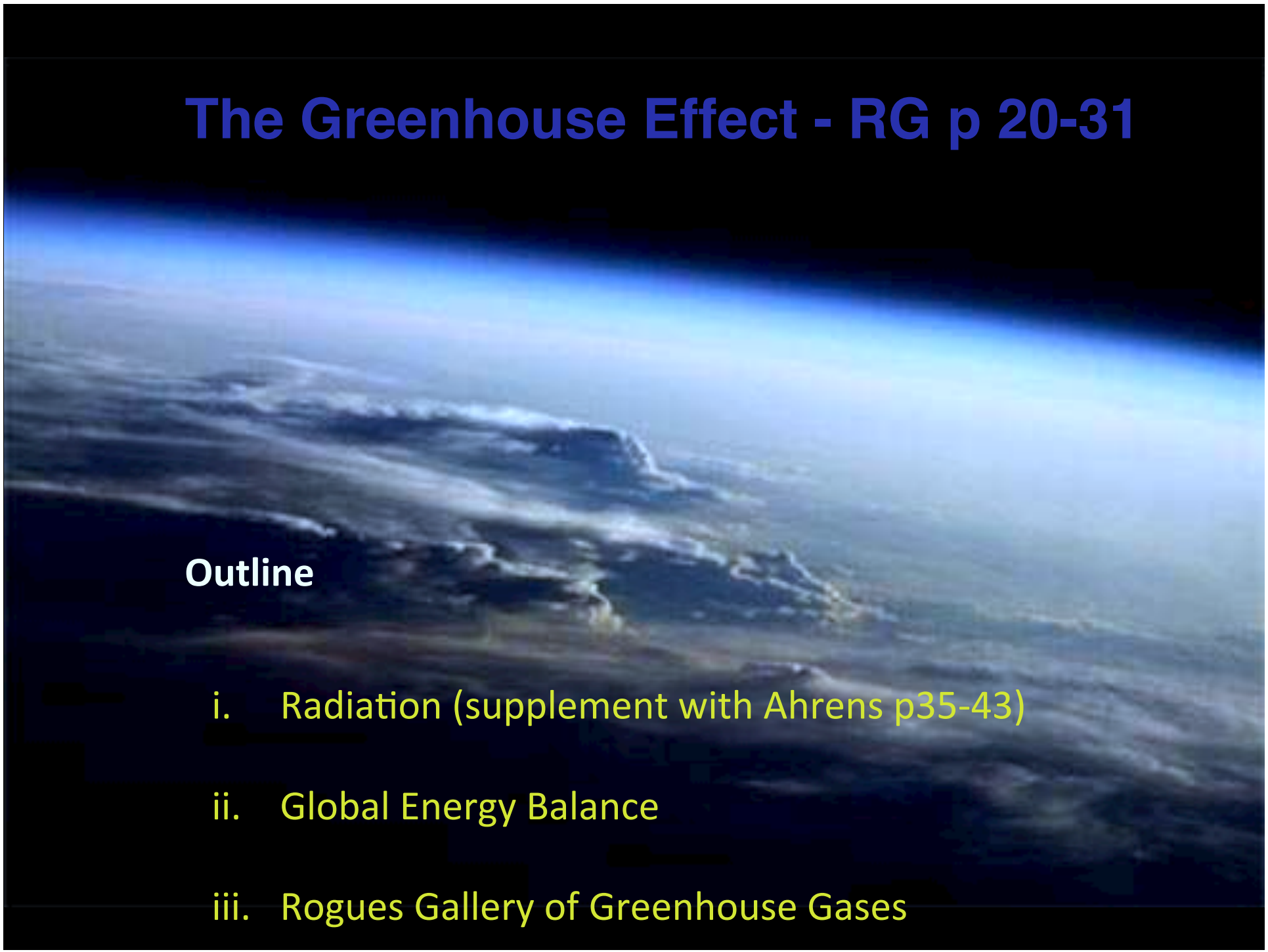
BRING A #2 PENCIL

Lectures on line

http://www.css.washington.edu/course/ATMS111A

with UW Net ID

The Greenhouse Effect - RG p 20-31

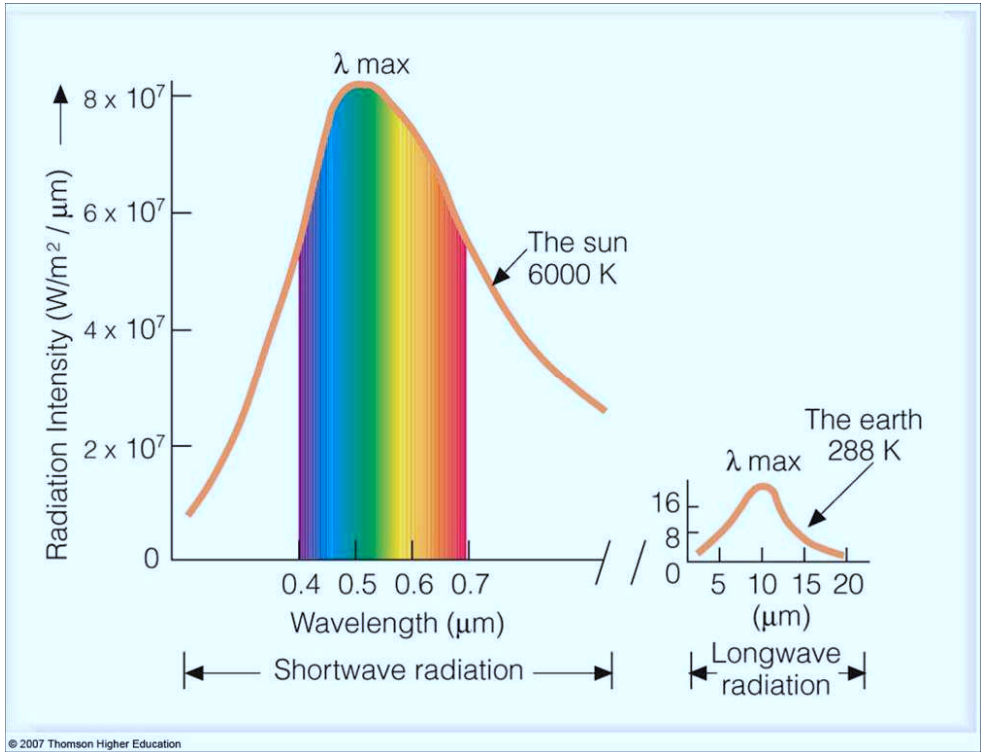


Outline

i. Radiation (supplement with Ahrens p35-43)

ii. Global Energy Balance

iii. Rogues Gallery of Greenhouse Gases



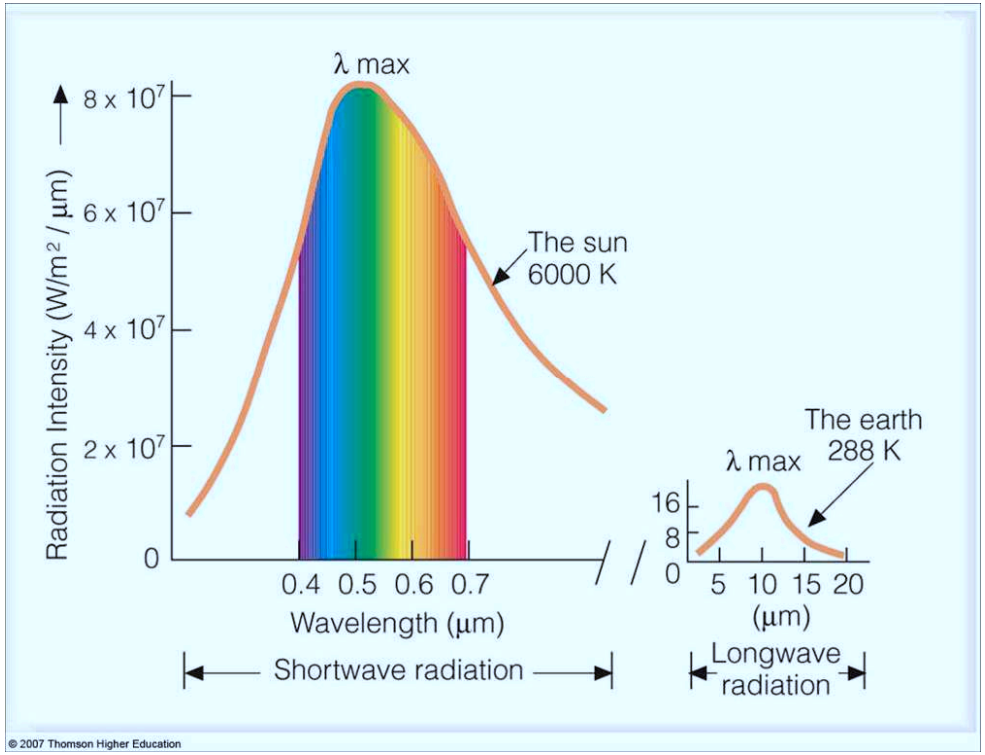
Warmer objects emit radiation at lower wavelengths

Wien's Law

$$\lambda_{max} = \frac{2897 \mu m\ K}{T}$$

λ = wavelength
T = temperature in Kelvin

Had numbers reversed in lecture on Tues.
lecture notes on line are corrected



Warmer objects also emit at greater intensity, or flux F (summed over all wavelengths)

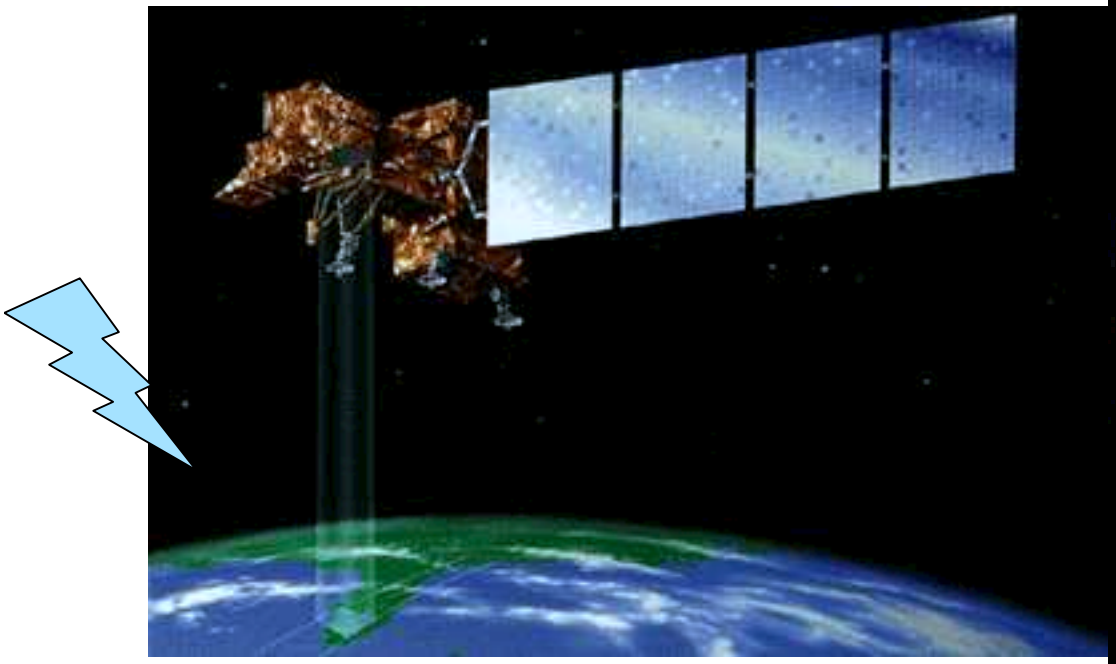
Stefan-Boltzmann Law

$$F = \sigma T^4$$

Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ W/m^2/K^4

T = temperature of black-body in Kelvin


INFRARED




The land color is fake

Planetary Energy Balance

At Equilibrium (a steady climate):

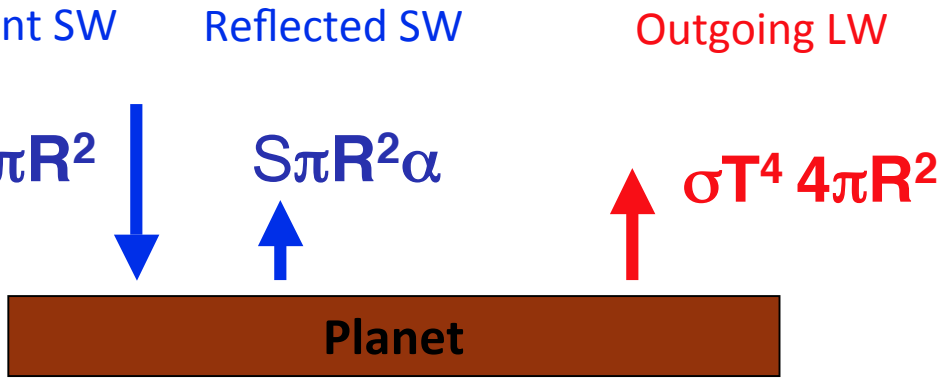
Energy Flux in = Energy Flux out

Absorbed solar energy = Heat energy lost to space

$$F_{IN} = F_{OUT}$$

If something knocks a planet out of energy balance,
the planet WILL warm or cool to eliminate the imbalance.

Model of Planet with No Atmosphere - Model A



$$F_{IN} = F_{OUT}$$

$$S\pi R^2 (1-\alpha) = \sigma T^4 \, 4\pi R^2$$

Balance of total Fluxes

$$\frac{S}{4}(1-\alpha) = \sigma T^4$$

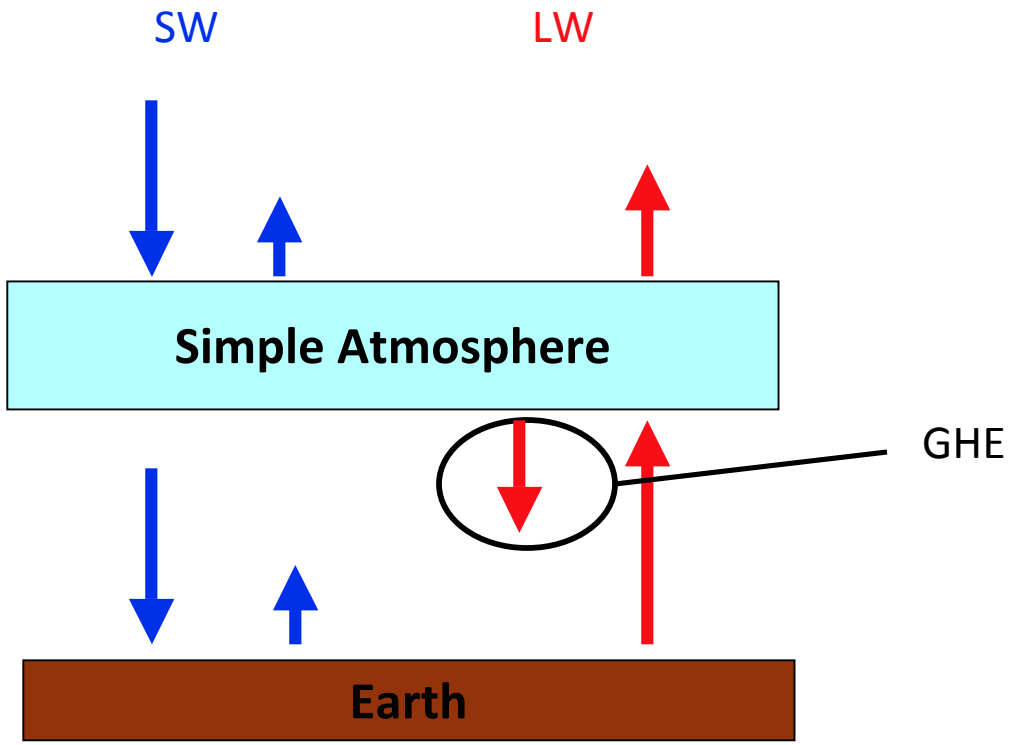
Balance of Fluxes per unit area

Model A

$$T = \sqrt[4]{\frac{S(1-\alpha)}{4\sigma}}$$

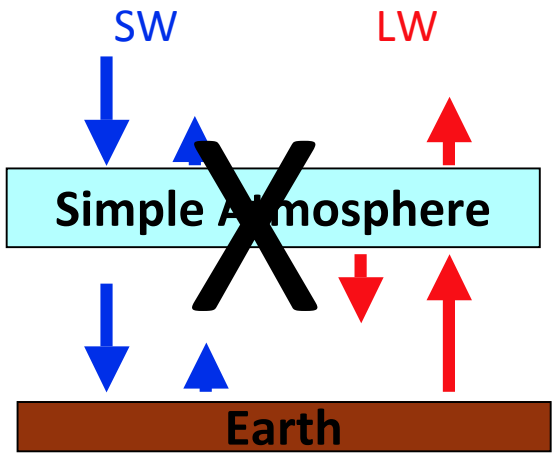
Model A, solved for T

Earth with a Simple 1-Layer Atmosphere Model B



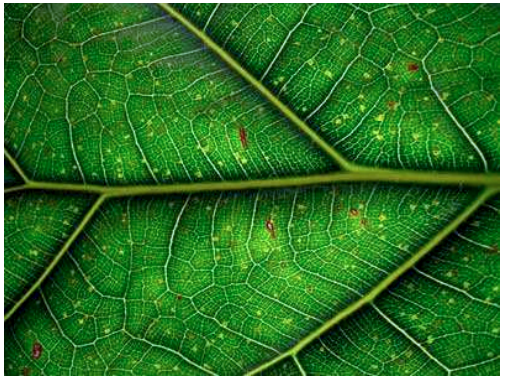
Take ATMS 211 or see optional reading for equations

Enhanced or Anthropogenic GHE

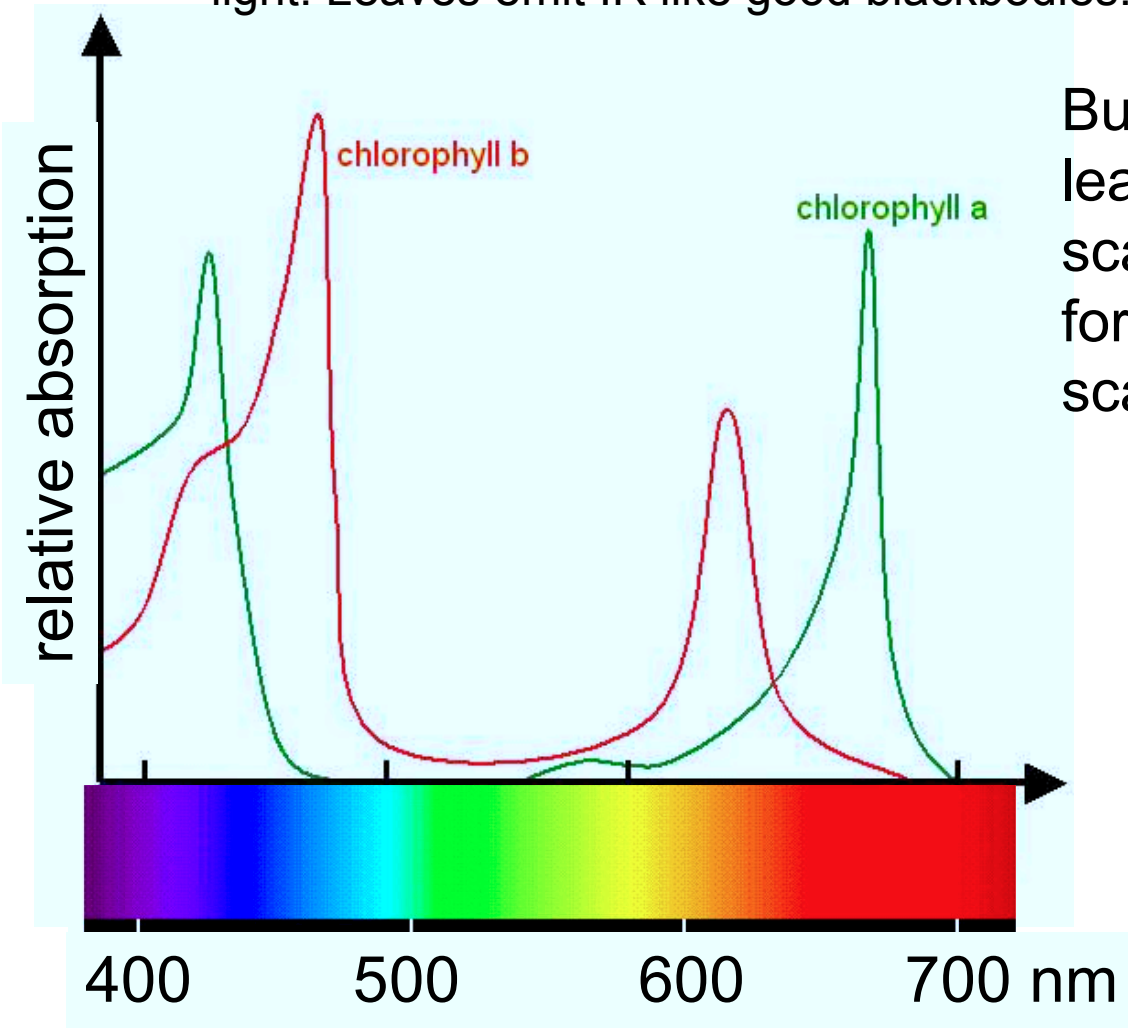


Even Model B is too simple because it doesn't change if there are more GHGs

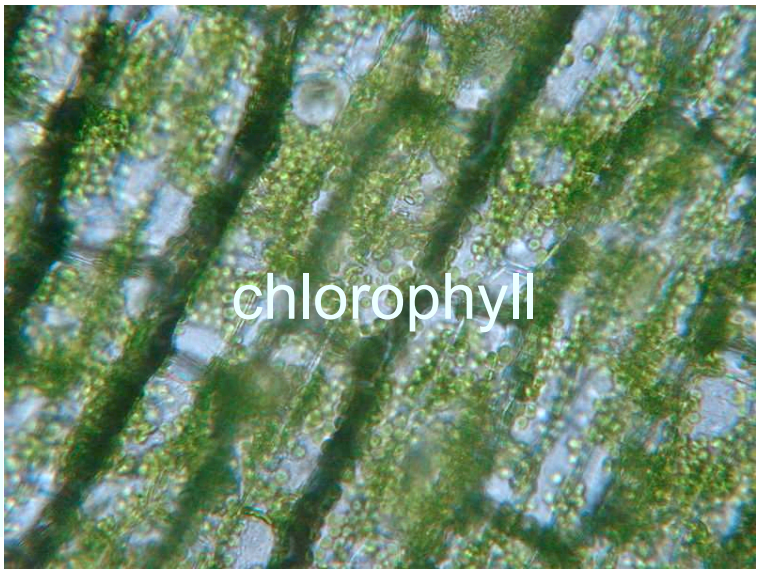
Selective absorption occurs in leaves, as well as GHG



Note: here we are considering *visible* light. Leaves emit IR like good blackbodies.

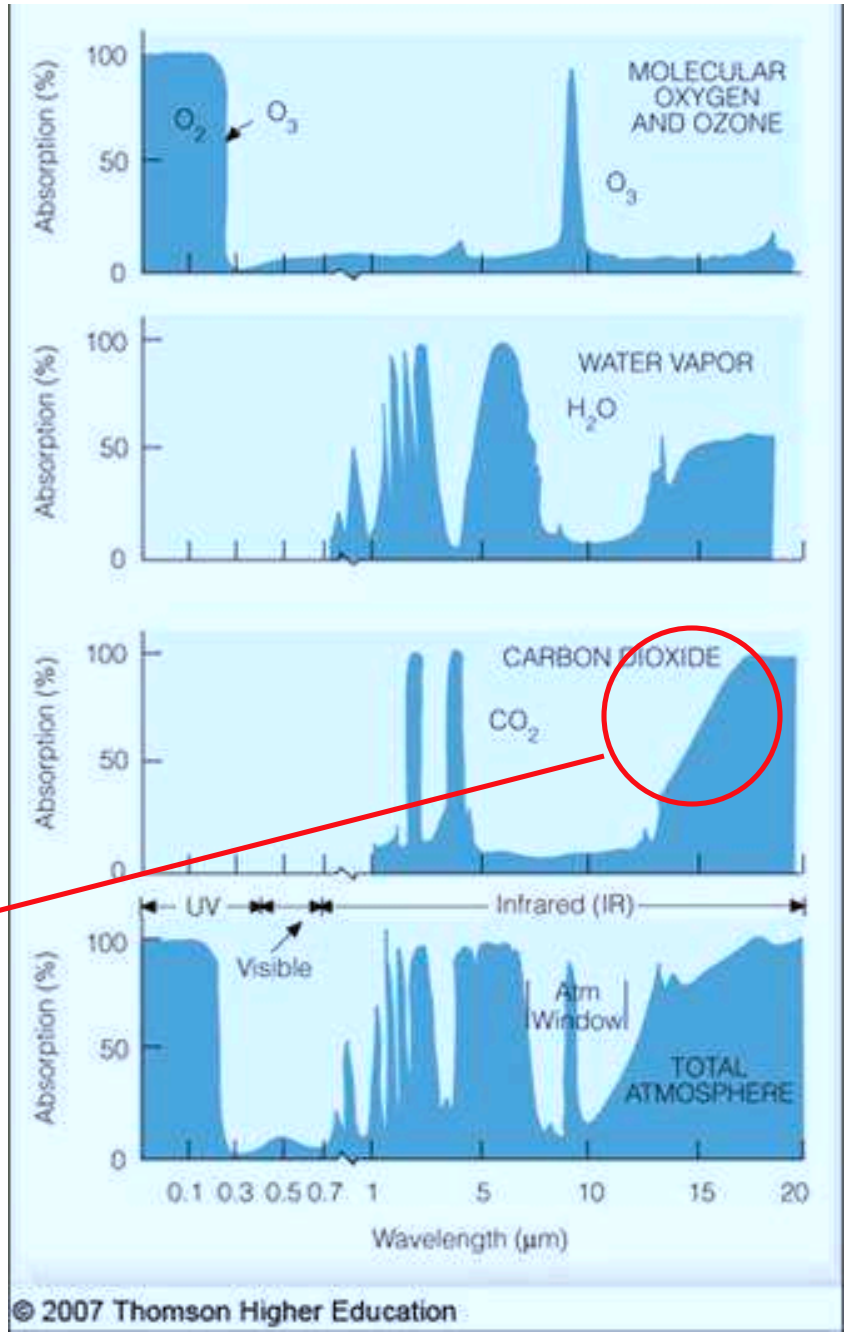


But non-absorbed light on leaves is mostly back scattered (or reflected), while for GHGs it is mostly forward scattered (or transmitted)

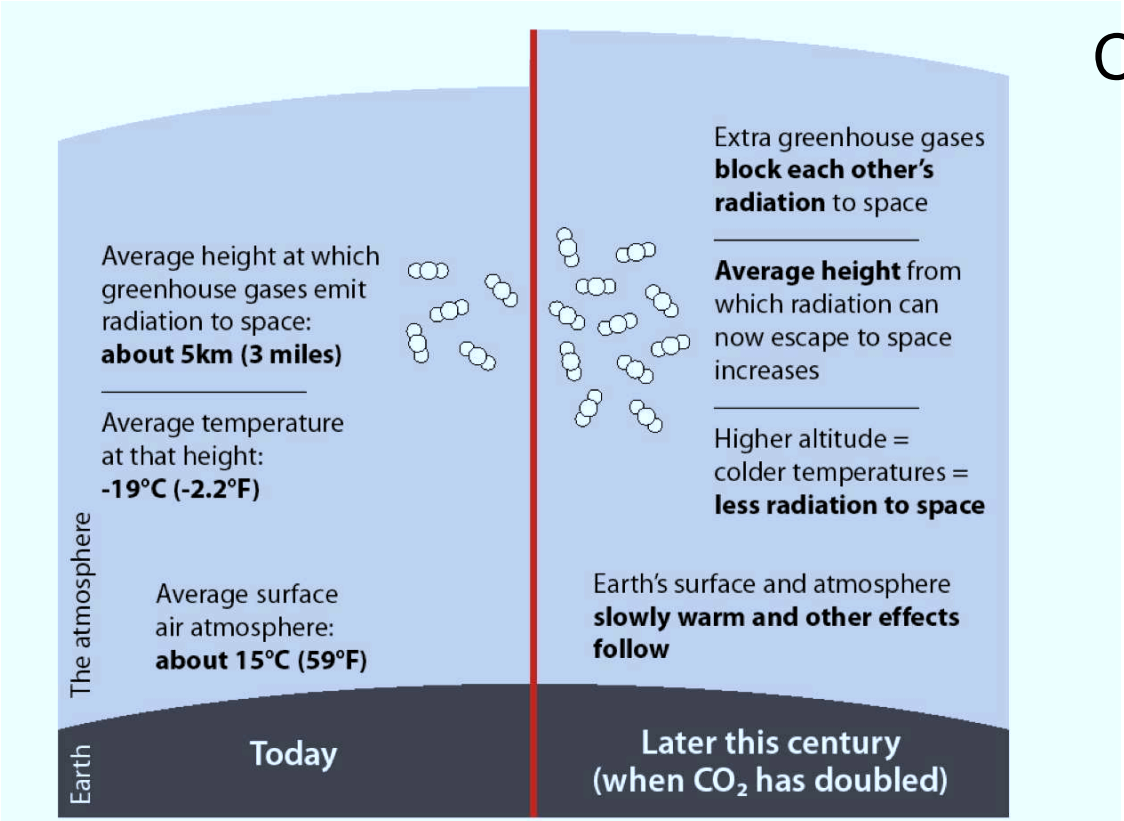


GHGs are selective absorbers, not good black bodies. They transmit almost all visible and some IR, especially in the "atmospheric window"

Adding more CO2 to the atmosphere increases absorption where it is ~30-90%



Too much of a good thing? The Anthropogenic GHE



Crucial 4 steps

1

2

3

RG p24

4) The Earth must warm to compensate for the lowered radiation to space - Nature seeks to eliminate the imbalance.

The atmosphere height (troposphere specifically) moves up, but this is not a major factor driving surface warming.

Relative contribution to the GHE

(the natural one)

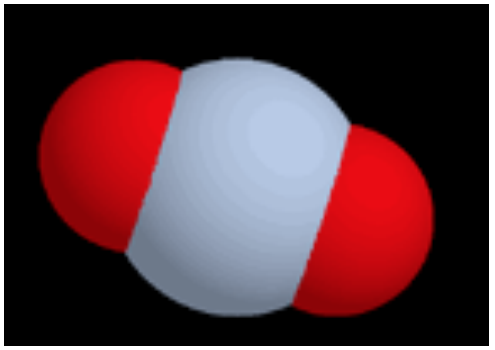
According to Ahrens

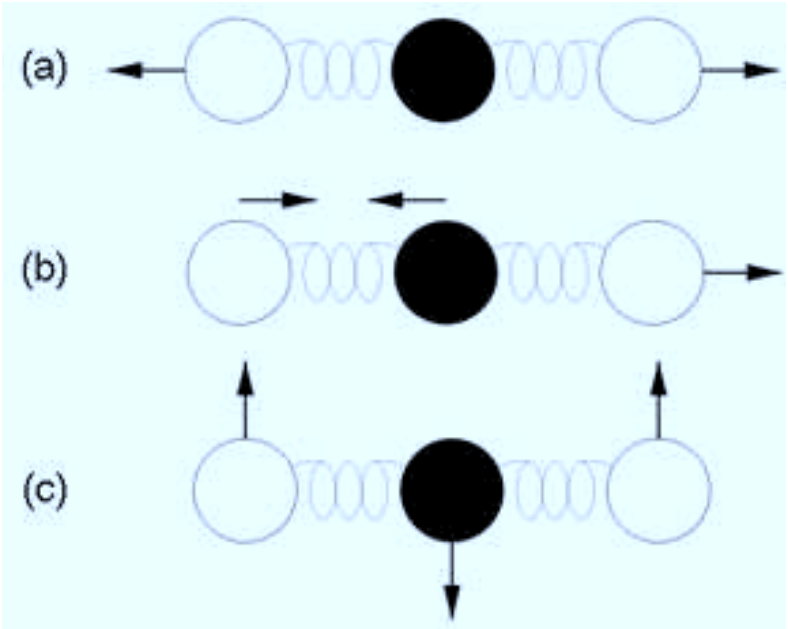
H2O is 60%
CO2 is 26%
the rest is 14%

These numbers are computed by running a radiative transfer model with all important GHG and then again removing the gas.


ROGUES
GALLERY
of greenhouse gases

What's special about GHGs?





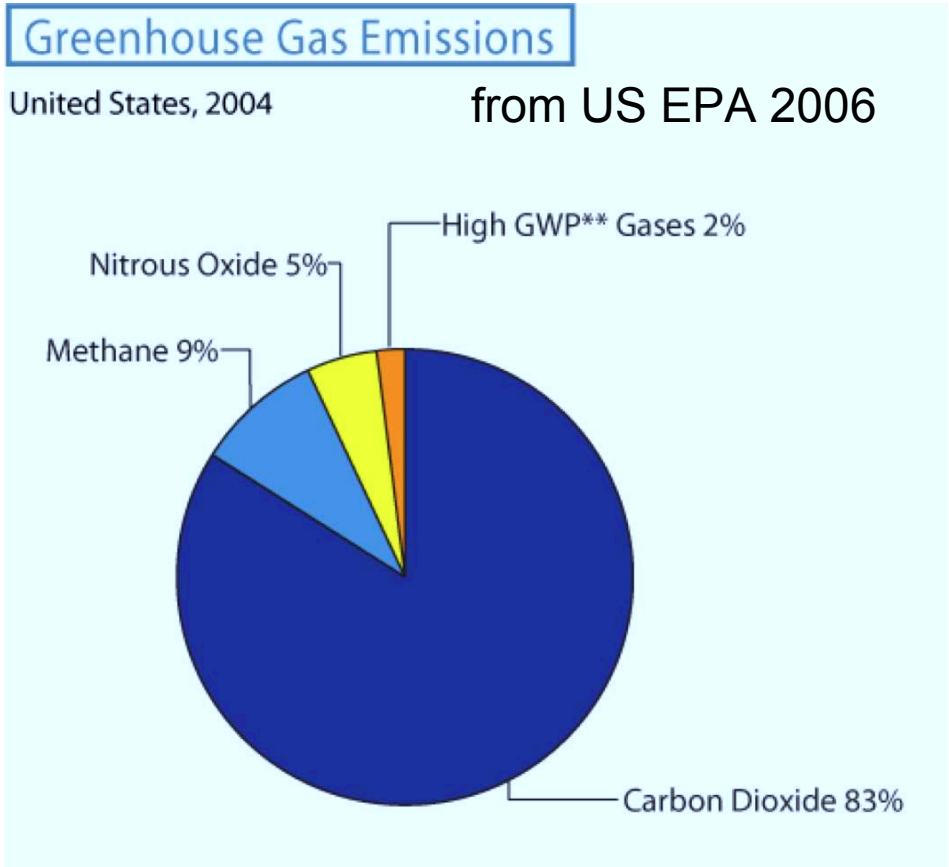
IR inactive (too symmetric)

vibrations are excited by IR,
which breaks the axial symmetry

Can O_2 or N_2 be GHGs?

No two points always lie on a line,
if the same atoms its symmetric

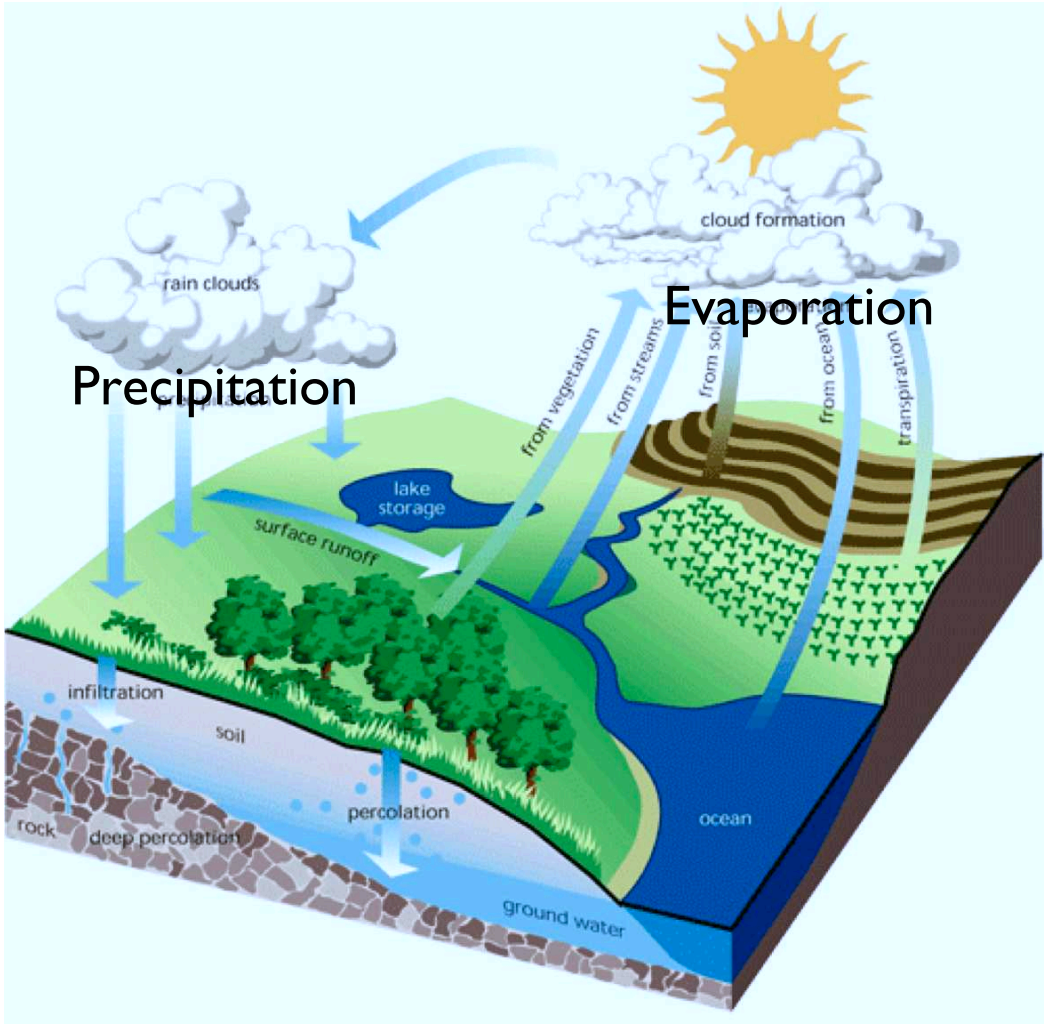
If only two atoms they must differ, like NO.
Three or more atom gases are usually GHGs



All these GHG are emitted by human activities.

Humans can’t directly alter water vapor, so can it be a rogue?

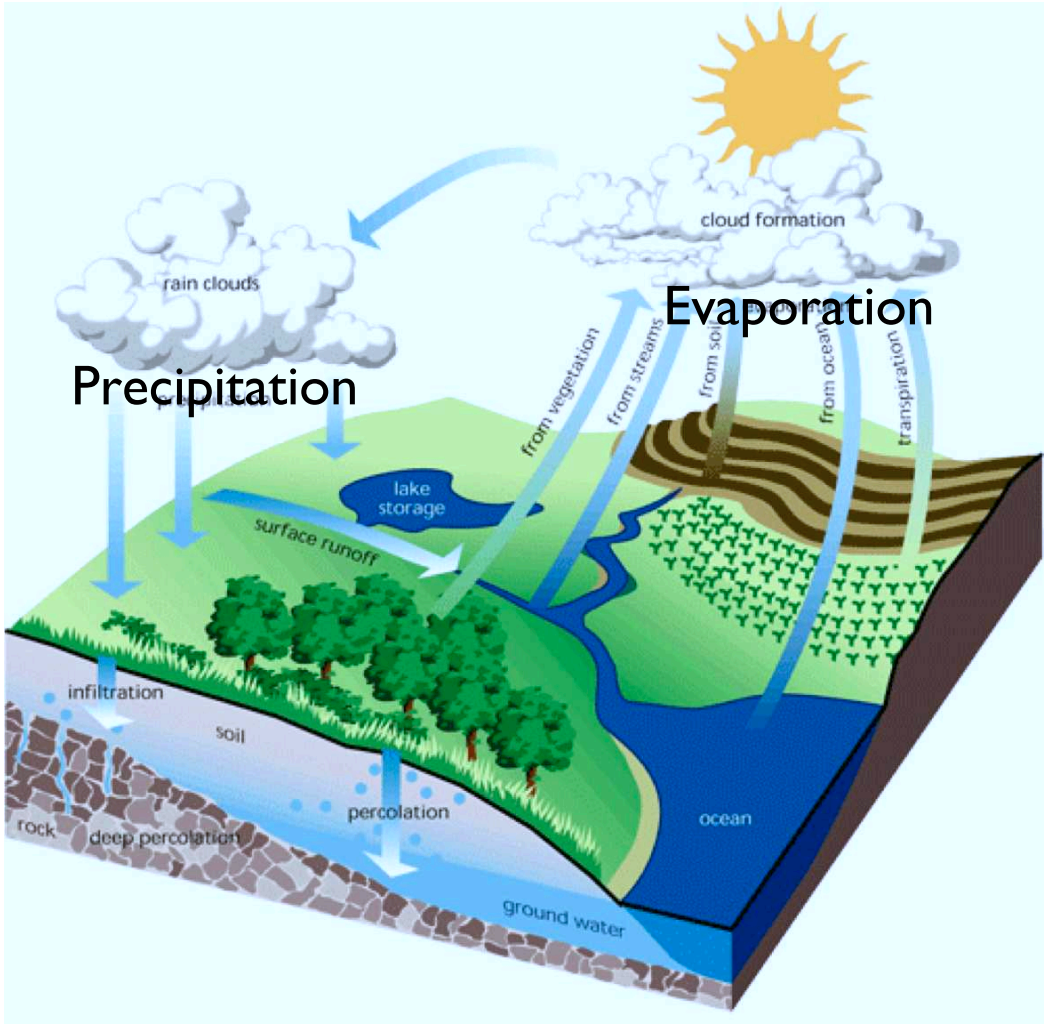
What determines H_2O concentration?



In the global average
Evaporation = Precipitation

$$E = P$$

What determines H_2O concentration?

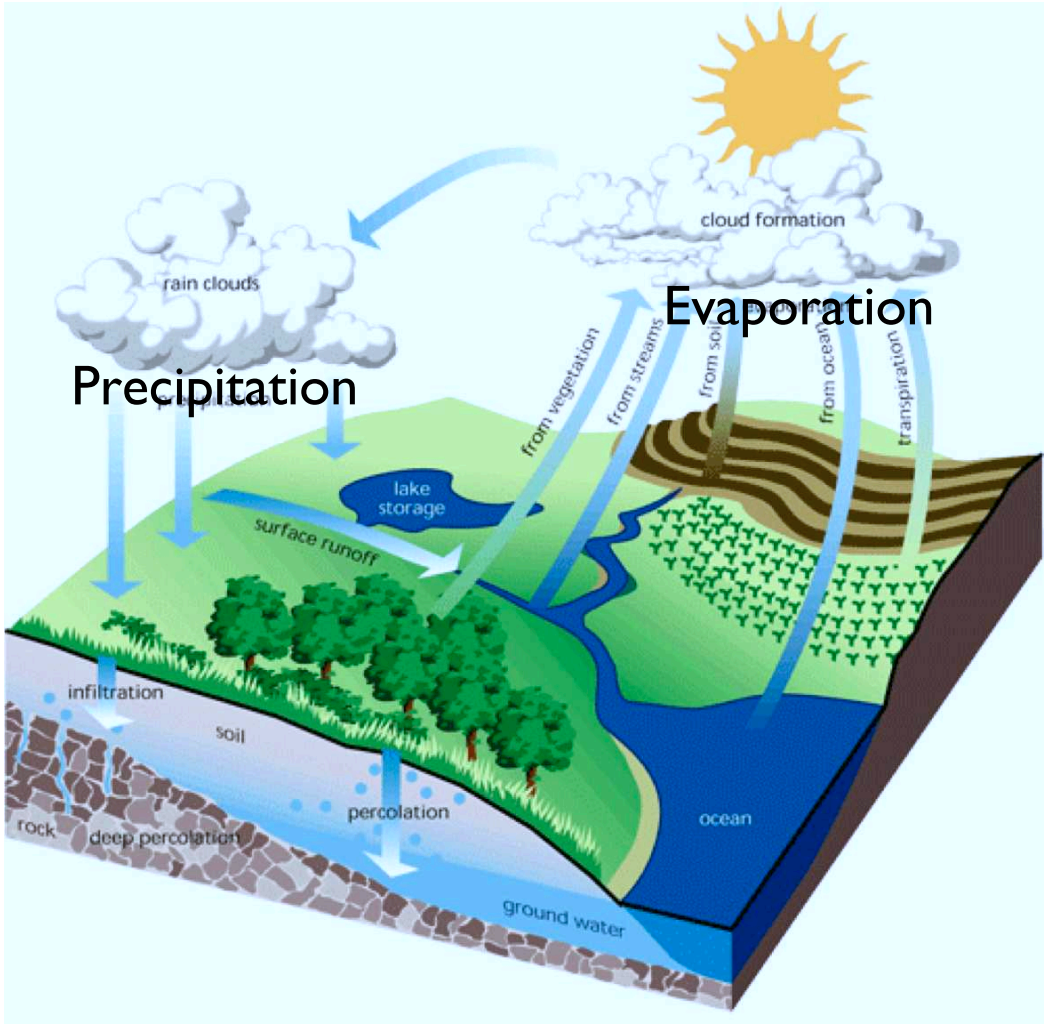


Imagine a "thought experiment". Take all the water vapor out of the atmosphere. What happens at first?

Precipitation, P = 0 (no rain)

Evaporation, E is big because the air is dry

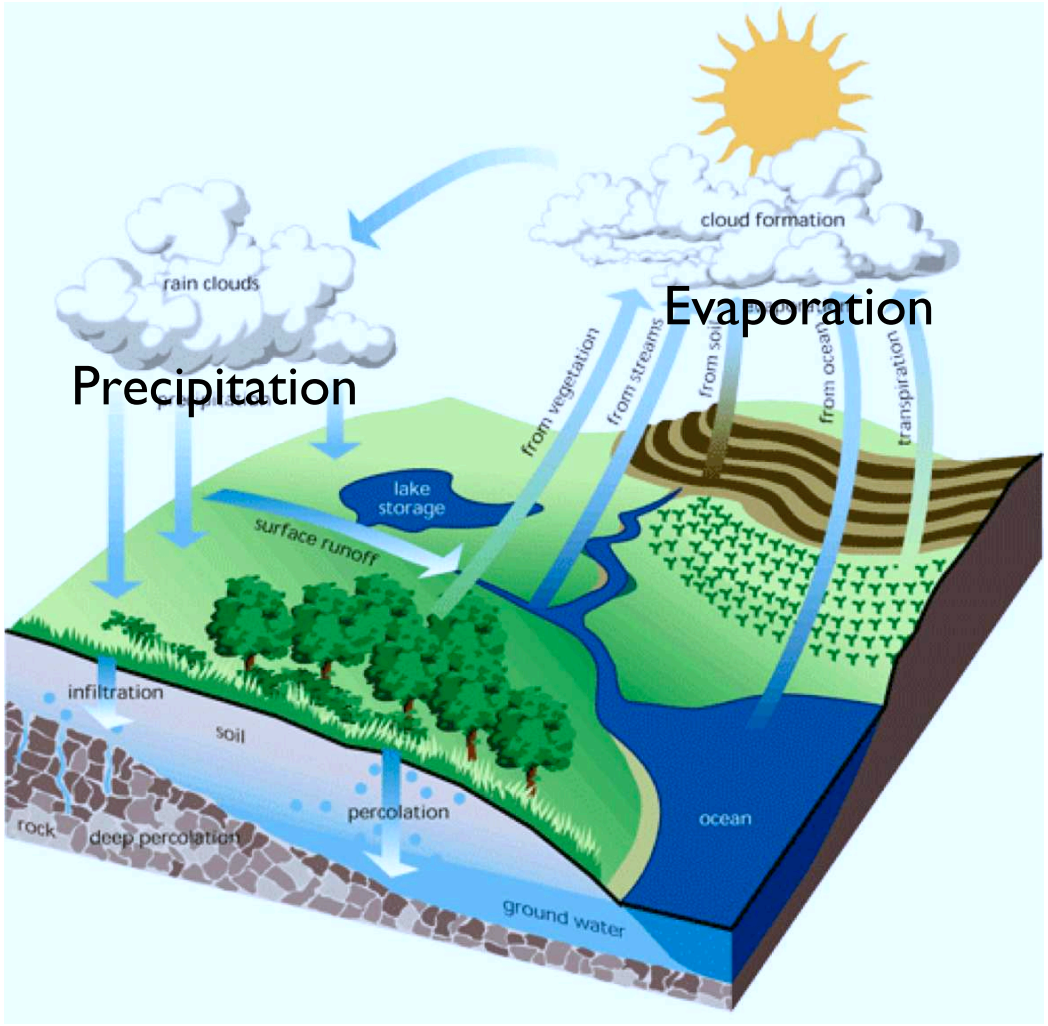
What determines H_2O concentration?



The air is moistening, but not yet back to normal. Now what?

E > P

What determines H_2O concentration?



Eventually,

$$E = P$$

It takes about 10 days for this to happen in nature

Water vapor is part of a Feedback, it is not Forcing

Human activities doe not directly influence water vapor.

We do not consider it a “forcing” for global warming.

It is part of the system…

But does it influence global warming?

In other words, does it feedback on the system?

What determines H_2O concentration?

Leaky bucket analogy

source is evaporation

bucket is the atmosphere, containing water vapor

leak is precipitation

How full the bucket is matters

Imagine a partially full bucket, pictured here as a glass.
This represents the present climate.

The fraction it is full is like the **relative humidity**

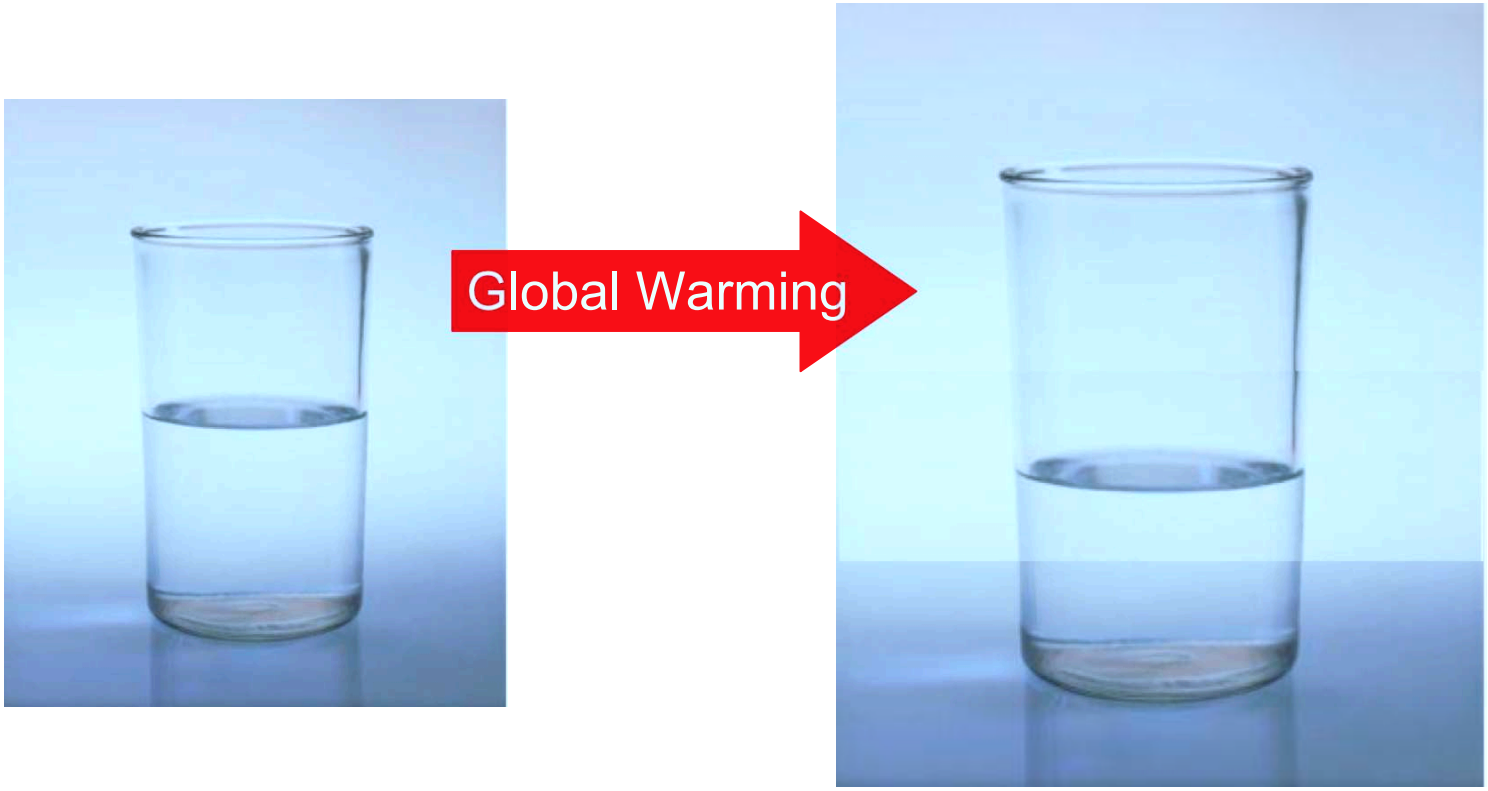
$$= \frac{\text{actual water vapor concentration}}{\text{water vapor concentration at saturation}}$$

If the glass were full, the atmosphere would be saturated.
In reality it is not full.

So what happens under global warming?

As the climate warms the concentration at saturation increases at a rate of 7% per degree C.

This increase in capacity is like making the glass bigger.



But will it contain more water???

So what happens under global warming?

Will there be more water in the glass - by which we mean more water vapor in the atmosphere - just because the capacity is greater?

Constant relative humidity assumption

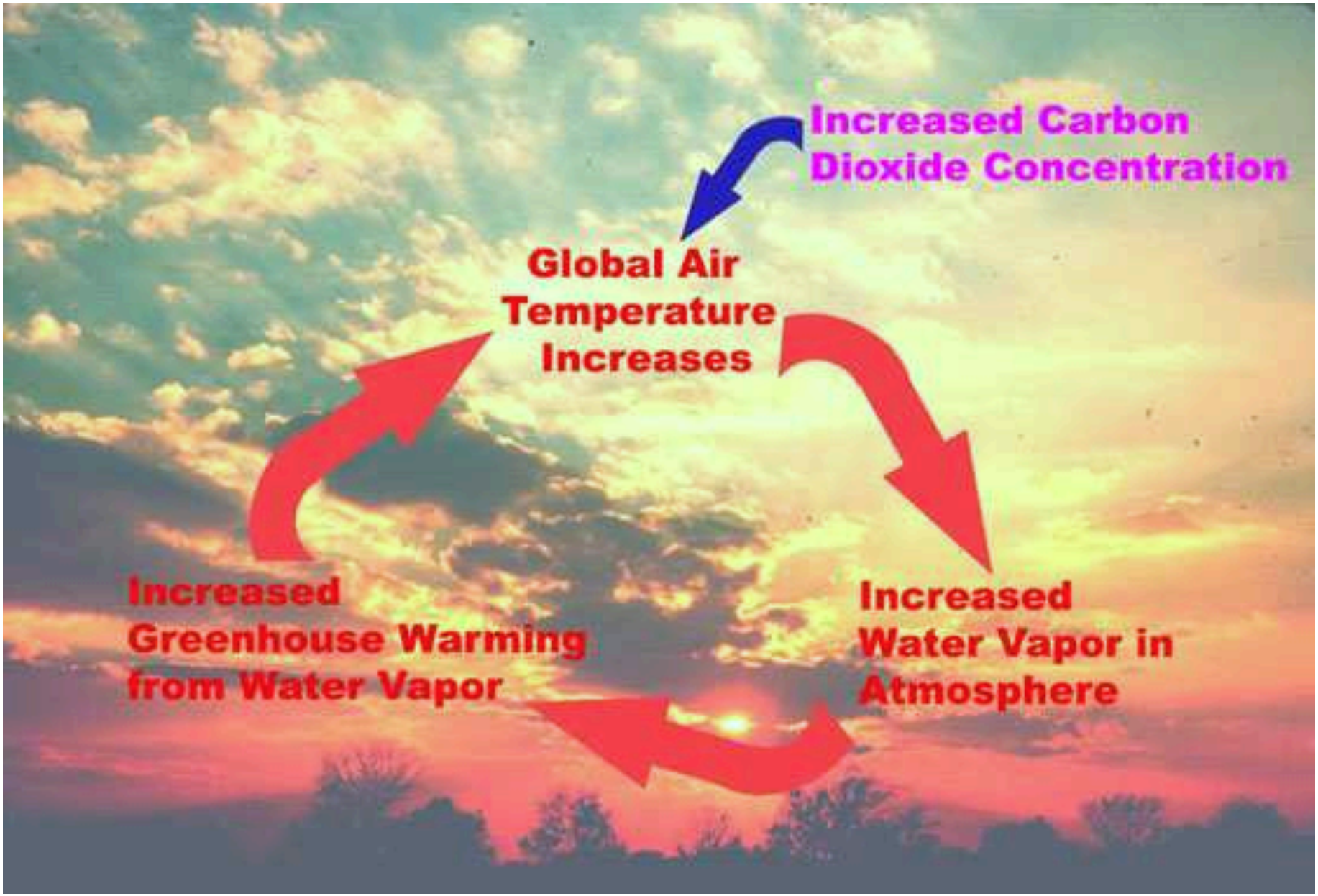
Constant Water Vapor Concentration assumption

H_2O in the atmosphere as Positive Feedback

Constant relative humidity assumption

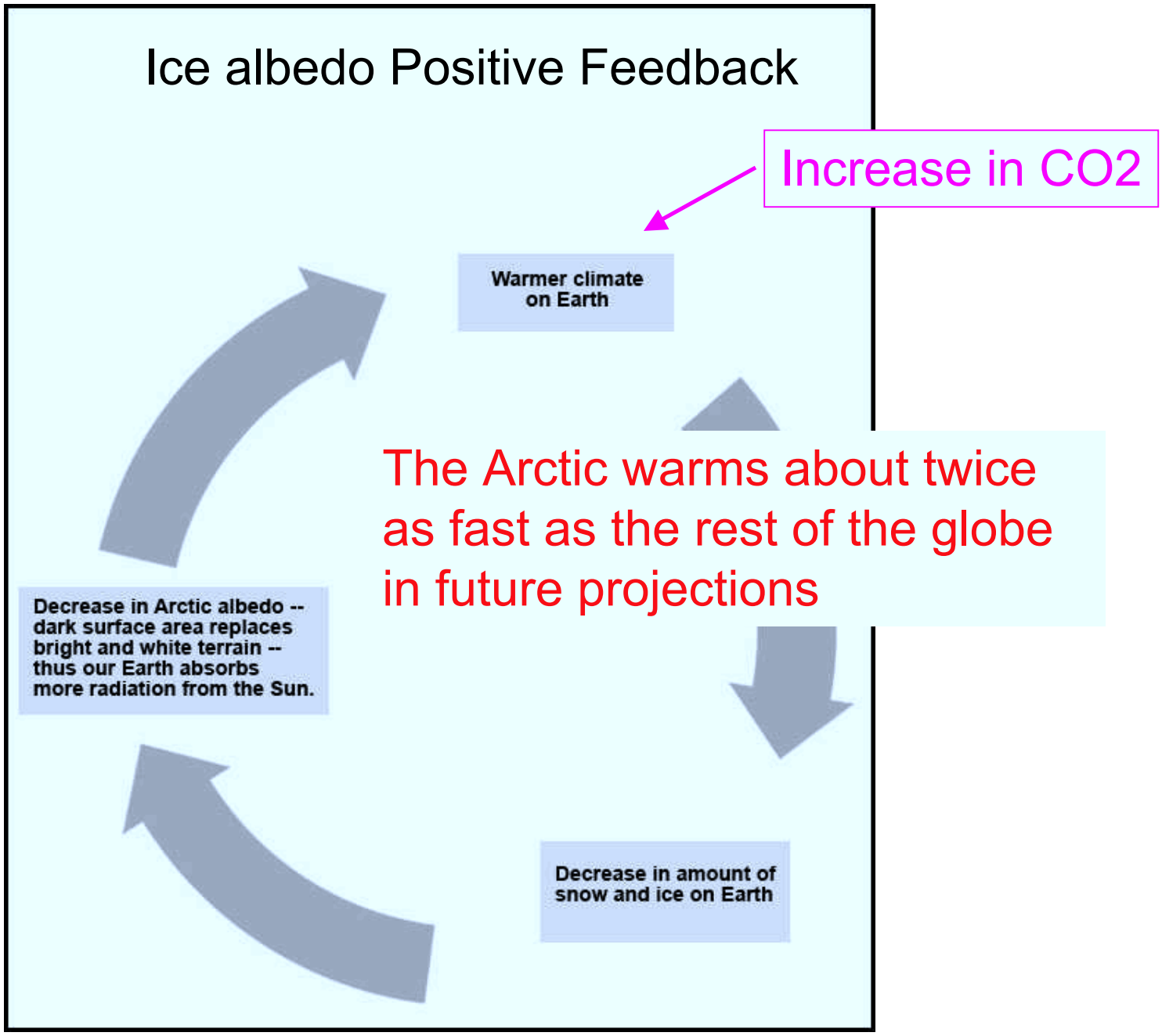
If warming increases the amount of water vapor in the atmosphere, the Earth will warm even more, because water vapor is a GHG too.

Water vapor positive feedback

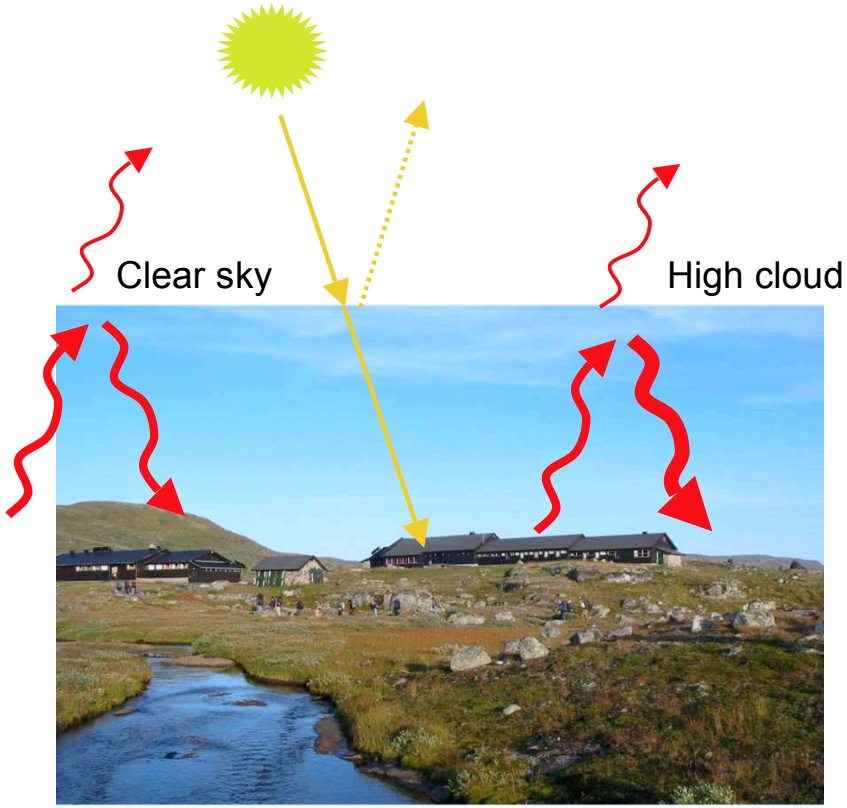


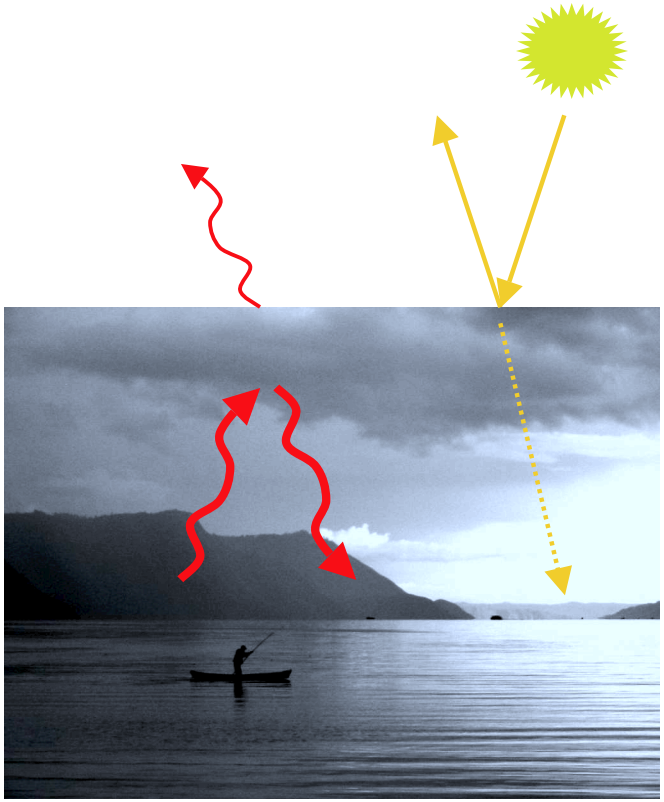
Sea Ice (in the Arctic) has a high albedo

Can you think of a positive feedback involving sea ice?


Ice albedo Positive Feedback
Increase in CO2
Warmer climate on Earth
The Arctic warms about twice as fast as the rest of the globe in future projections
Decrease in amount of snow and ice on Earth
Decrease in Arctic albedo -- dark surface area replaces bright and white terrain -- thus our Earth absorbs more radiation from the Sun.

Clouds and Climate





High (thin) Clouds Warm

Low (thick) Clouds Cool

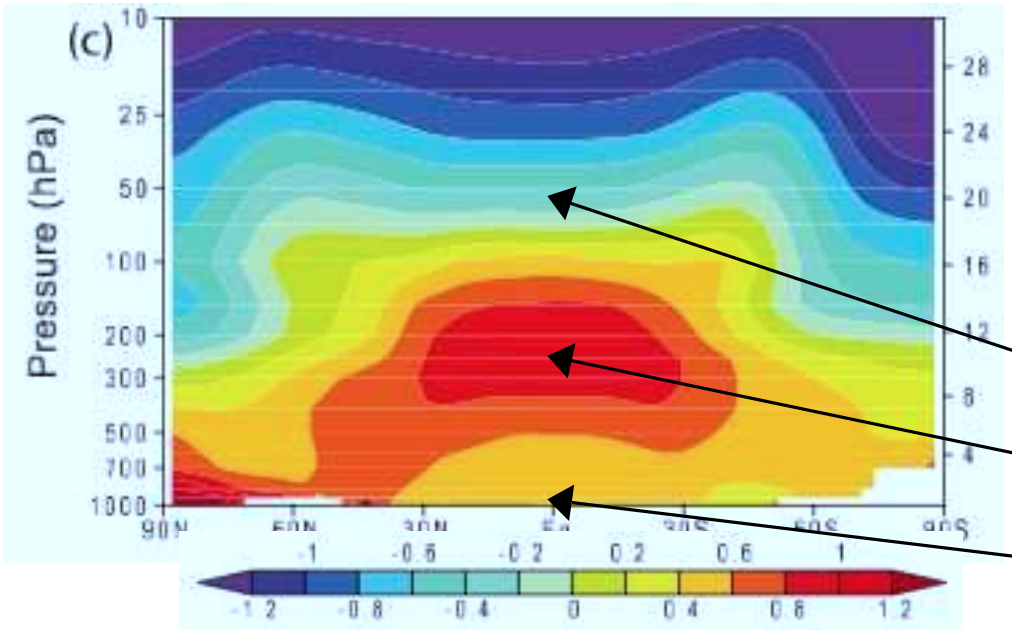
In today's climate, *the net effect of clouds is to cool the planet* (albedo affect wins over greenhouse effect)

Cloud feedback from global warming?

More of these …. ...and/or… … less of these?

Near agreement that low clouds cool less as CO_2 rises, which makes a positive feedback. But amplitude is very uncertain.

Lapse Rate Feedback
Negative Feedback from Larger Warming Aloft



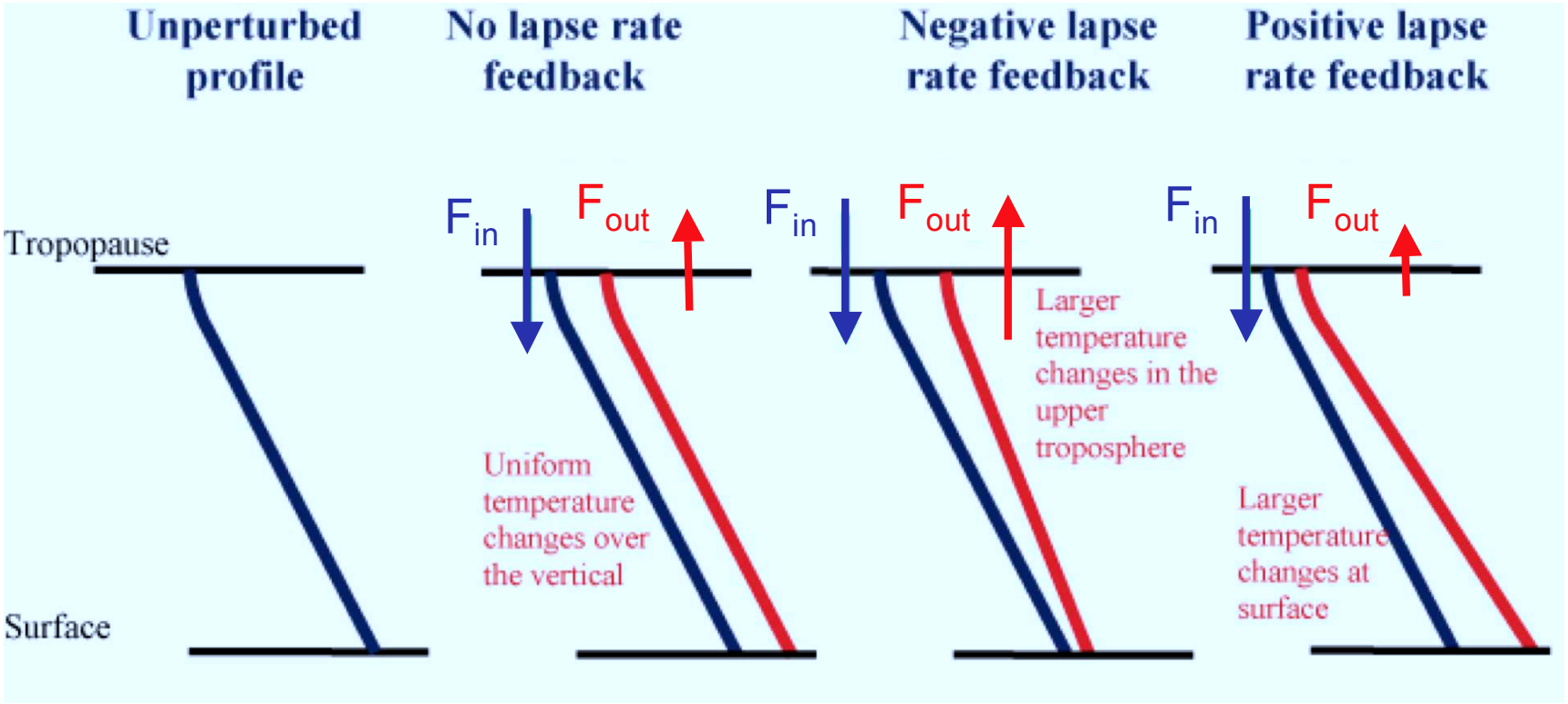
In degree C per century

Simulated zonal temperature change (1890-1999) in one climate model

- -0.5C strato
- +1C tropo
- +0.5C surface

Lapse rate = rate of temperature decrease with height

In which case has the planet warmed enough to remove the imbalance caused by the perturbation (eg CO2)?



GWP

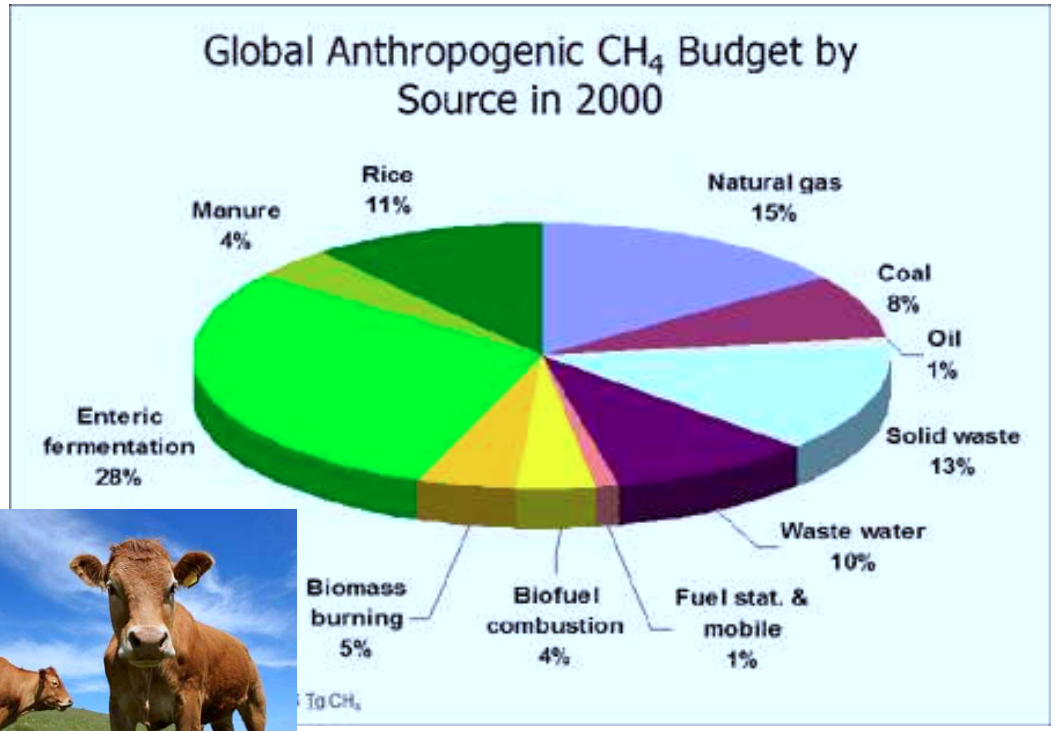
German Wirehaired Pointer

of greenhouse gases

Greenhouse Warming Potential

Warming per molecule of gas

weighted by residence time in the atmosphere



Methane CH_4 is higher than CO_2, but there is much less in the atmosphere (which is why its GWP is so high)

Aerosols (Particles)

Sulfate aerosols are whitish: they serve to increase the Earth's planetary albedo

Carbon particles are black: they decrease it

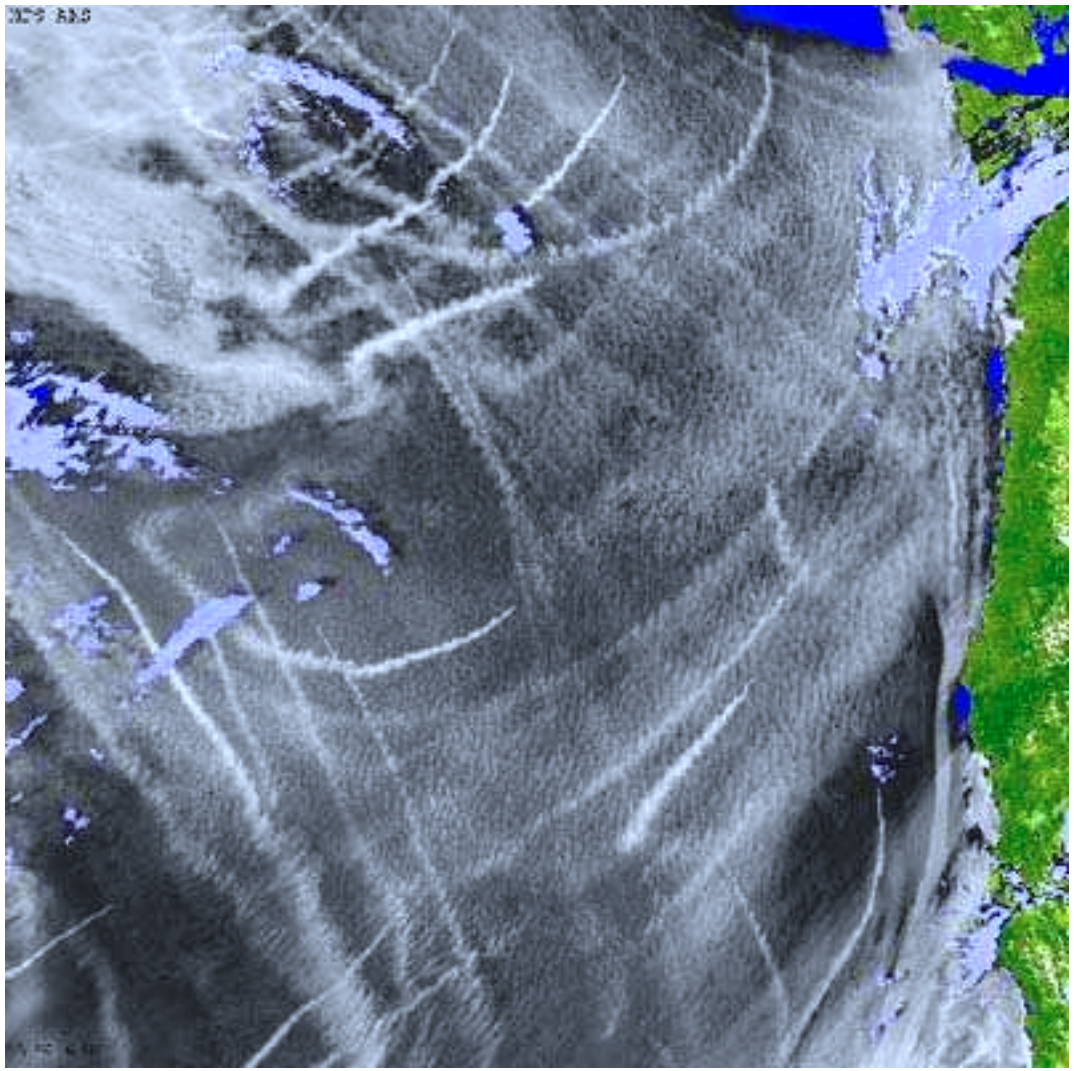
Volcanic eruptions are a major natural source of aerosols. Most take 1-3 years to fall out.

Burning is a major source of aerosols

Aerosol forcing: direct effect

Aerosol haze (here from east coast) reflect sunlight back to space and cool. They fall out over a few days.

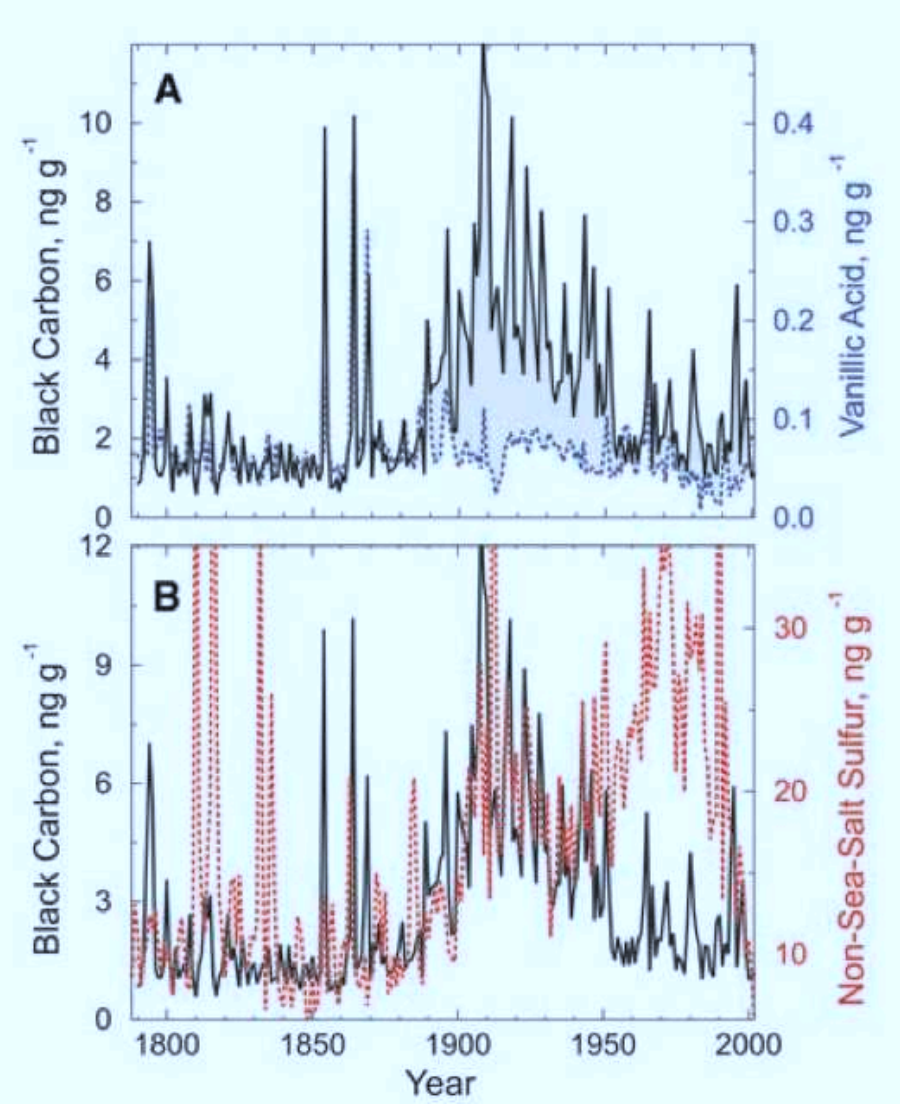
Aerosol forcing: indirect effect or "Cloud Albedo Effect"



Aerosols from ship's smoke stacks can brighten clouds by seeding droplets

Black carbon (BC) on snow causes melting, but is it increasing?

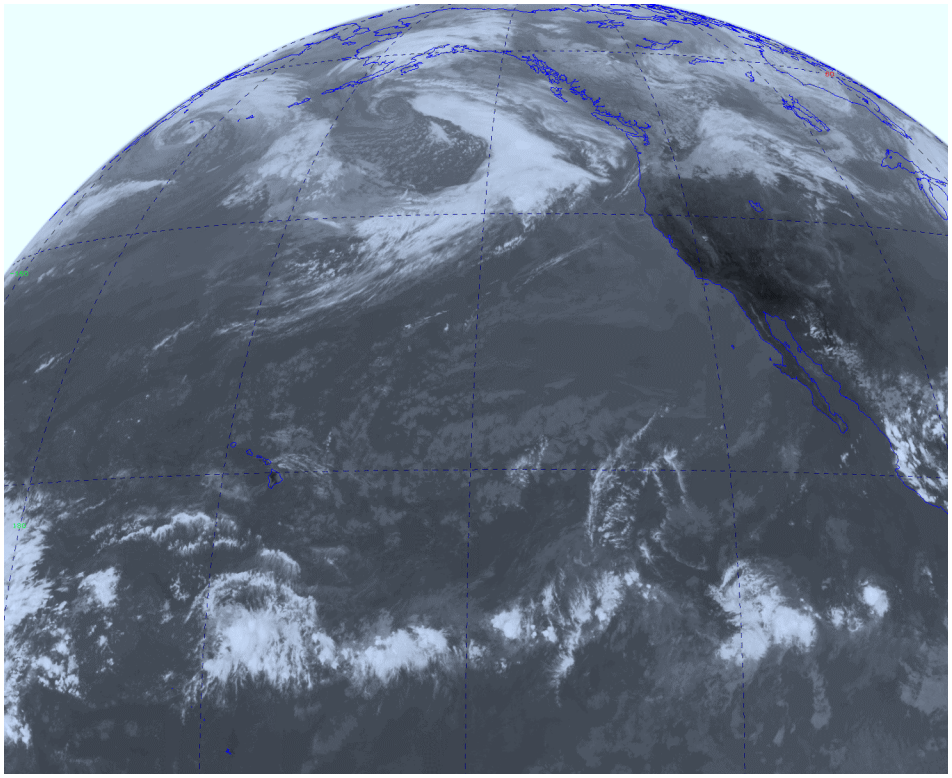
And is it anthropogenic?



proxy for forest fires - shows when BC is natural

sulfur - shows when BC was industrial or volcanic… BUT after 1950 BC was scrubbed from smoke stacks. Sulfur removal took until the 1970 Clean Air Act.

Data from Greenland snow



Adding more GHG is a little like adding more high clouds.

Less heat escapes, so

F_{OUT} decreases

Imagine the CO2 Level Doubled Instantly

Less heat escapes, so

F_{OUT} decreases

"Radiative Forcing"

$$\Delta F = F_{IN} - F_{OUT} = 3.7\ W/m^2$$

(estimated to within a few tenths)

Global Warming Theory

$$\Delta T = \lambda \Delta F$$

Note:
Δ: common symbol to refer to change in some quantity

ΔF: radiative forcing (change in energy balance)
ΔT: response (change in surface temperature)
λ: climate sensitivity (everything else)

λ: does not represent the wavelength of light here!

Run a Climate Model with Double CO2

$$\Delta T = \lambda \, \Delta F$$

Run model until the ocean comes into equilibrium with the atmosphere and find ΔT is about 2-4.5 deg C.

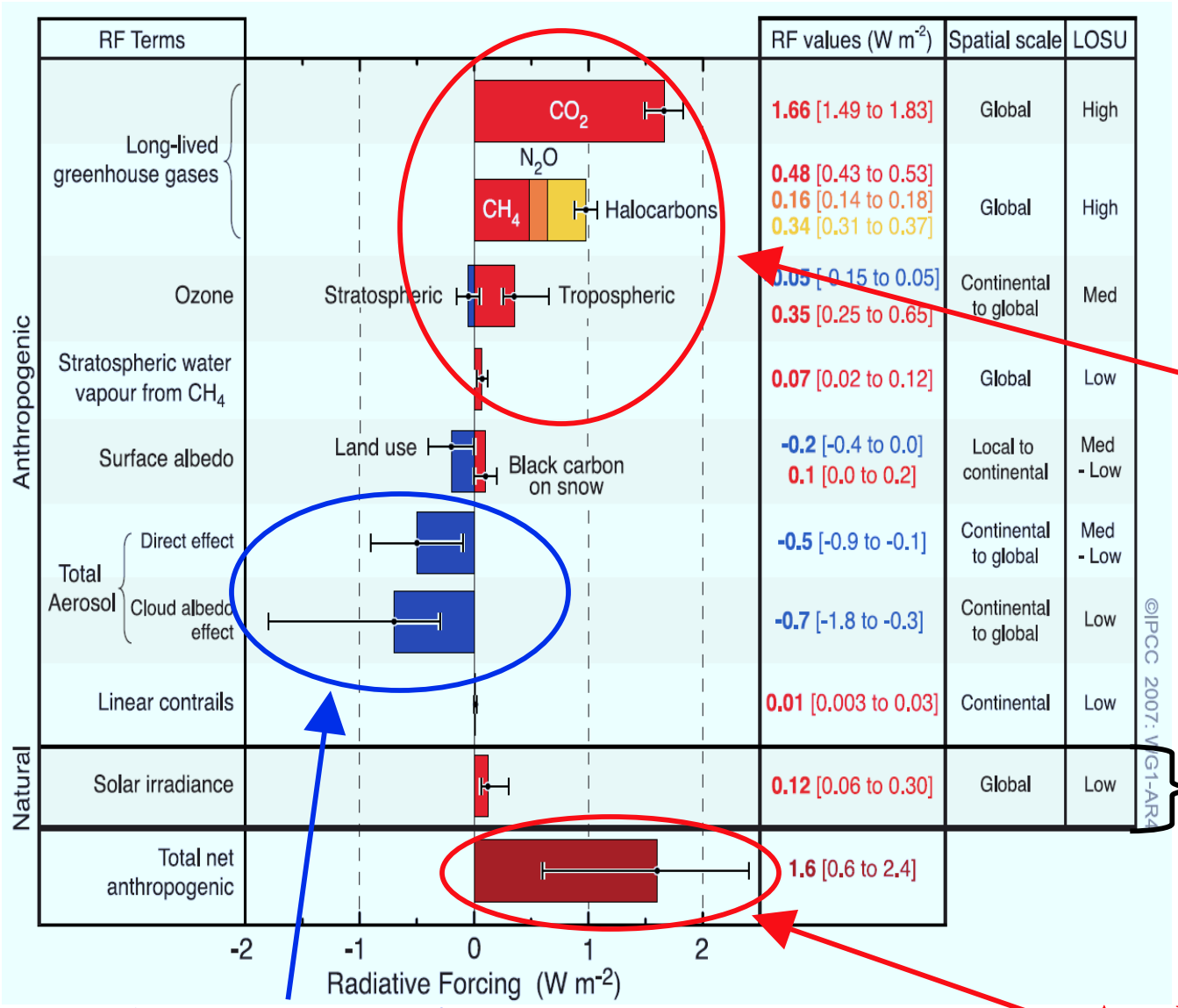
So λ is ?

$$\lambda = \Delta T / \Delta F = 2/3.7 \text{ to } 4.5/3.7$$
$$= 0.54 \text{ to } 1.2 \ \ \mathrm{K} / (\mathrm{W/m^2})$$

The next slide shows the climate radiative forcing ΔF due to a wide range of human activities and some natural forcings as well: all at present with reference to the time of the industrial revolution.

It is from the IPCC 2007 Summary for Policy Makers

Forcing In 2005 relative to preindustrial



GHGs

Sun

Anthropogenic Aerosols

Total Anthropogenic Forcing

Summary of GHE

Radiation is emitted and absorbed from matter over a range of wavelengths: Visible from the Sun and IR from the Earth.

IR radiation is not seen by our eyes, so matter with Earth-like temperature are invisible without visible light to reflect off their surface.

Temperature and wavelength at the peak of the radiation spectrum are inversely related via Wien's Law. Glowing blue indicates a hotter object than one glowing red.

The radiative flux (or intensity) from blackbodies (the sun and Earth's surface) can be computed from the Stefan-Boltzmann Law.

Summary of GHE

IR satellite images help us understand that colder (whiter in the image) matter is higher in the sky.

The planet seeks to be in energy balance. When out of balance, the planet will cool or warm as needed to return to balance.

The GHE warms the surface from downward IR emitted by GHGs, in addition the outgoing IR flux to space is less than the IR flux emitted from Earth's surface.

The anthropogenic GHE is from an increase in GHGs, which raises the average height from which radiation can escape to space. At higher altitudes, the gases are colder, so outgoing IR is lowered. The planet must warm to return the planet to radiative balance.

Summary of GHE

We can interpret any perturbation to the climate system as a radiative imbalance. This is known as "forcing" or ΔF

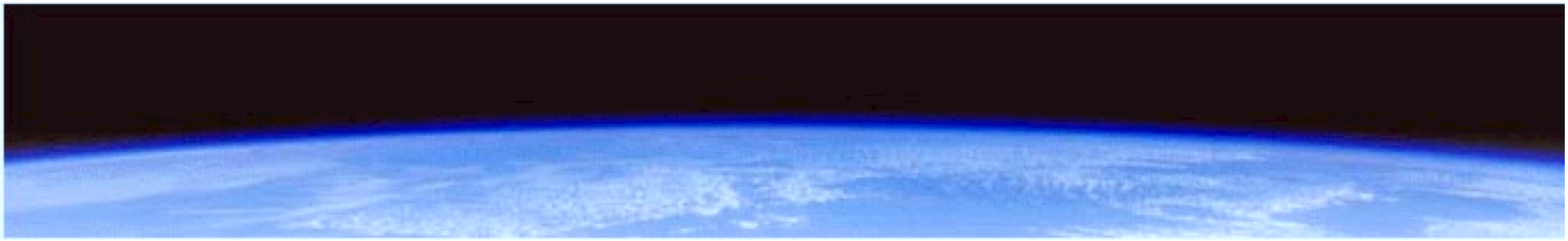
Water vapor is part of a feedback, not a forcing

Other major feedbacks are from ice, clouds, and lapse rate

Aerosols are another major forcing

The temperature change at equilibrium (once balance is restored) is ΔT

The climate sensitivity parameter is $\lambda = \Delta T / \Delta F$



Class Web Site:

http://www.atmos.washington.edu/2010Q1/111