Space Science : Atmosphere
Greenhouse Effect
Part-5a

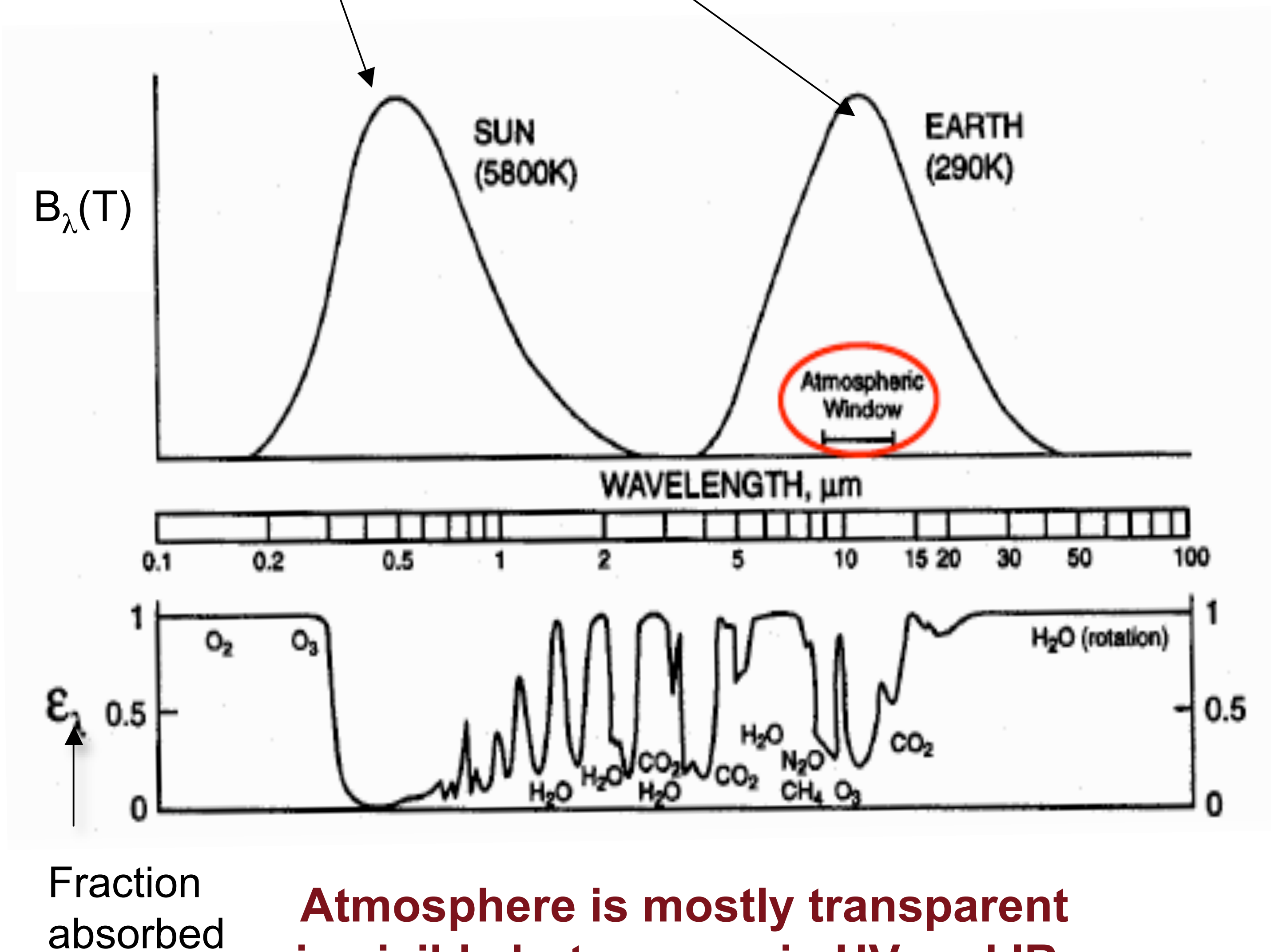
Solar + Earth Spectrum
IR Absorbers
Grey Atmosphere
Greenhouse Effect

Radiation: Solar and Earth Surface

$B_\lambda(T)$ Planck Ideal Emission

Integrate over wave length and angles to get total emission from a surface

$F_{IR} = \sigma T^4$; Stephan Boltzmann



Atmosphere is mostly transparent in visible but opaque in UV and IR; IR window 8-13um

GRAY ATMOSPHERE

(Transparent vs. Gray)

Partially absorbing in IR but
absorption is independent of frequency
over the range of relevant frequencies

Process

Surface heated by visible

Warm surface emits IR

~ 3 – 100 μm
peak ~ 15 μm

IR absorbed by
CO_2, O_3, H_2O, etc.

Remember why not O_2 and N_2 ?

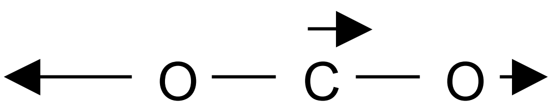
Vibrational Bands

CO_2 (IR active?)

Symmetric Stretch

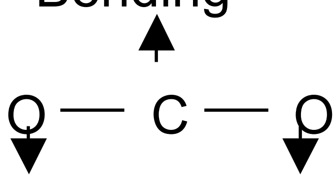
7.46 μm (N)

Asymmetric Stretch



4.26 μm (Y)

Bending

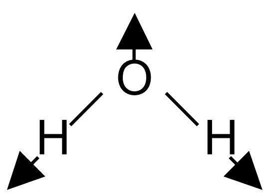


15.0 μm (Y)

Near IR peak

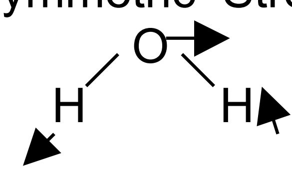
H_2O

Symmetric Stretch



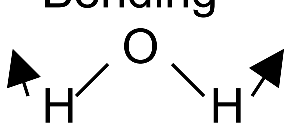
2.73 μm (Y)

Asymmetric Stretch



2.66 μm (Y)

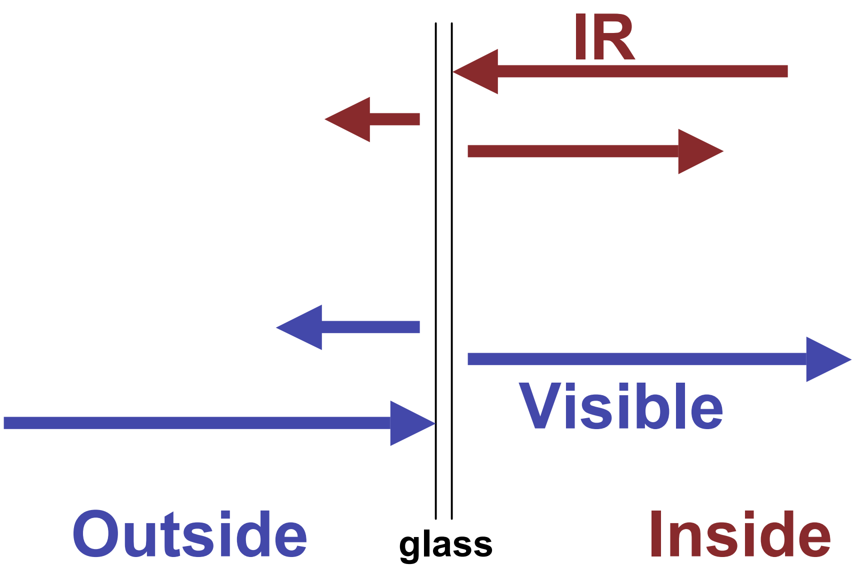
Bending



6.27 μm (Y)

You can have combination bands or 2 vib. levels

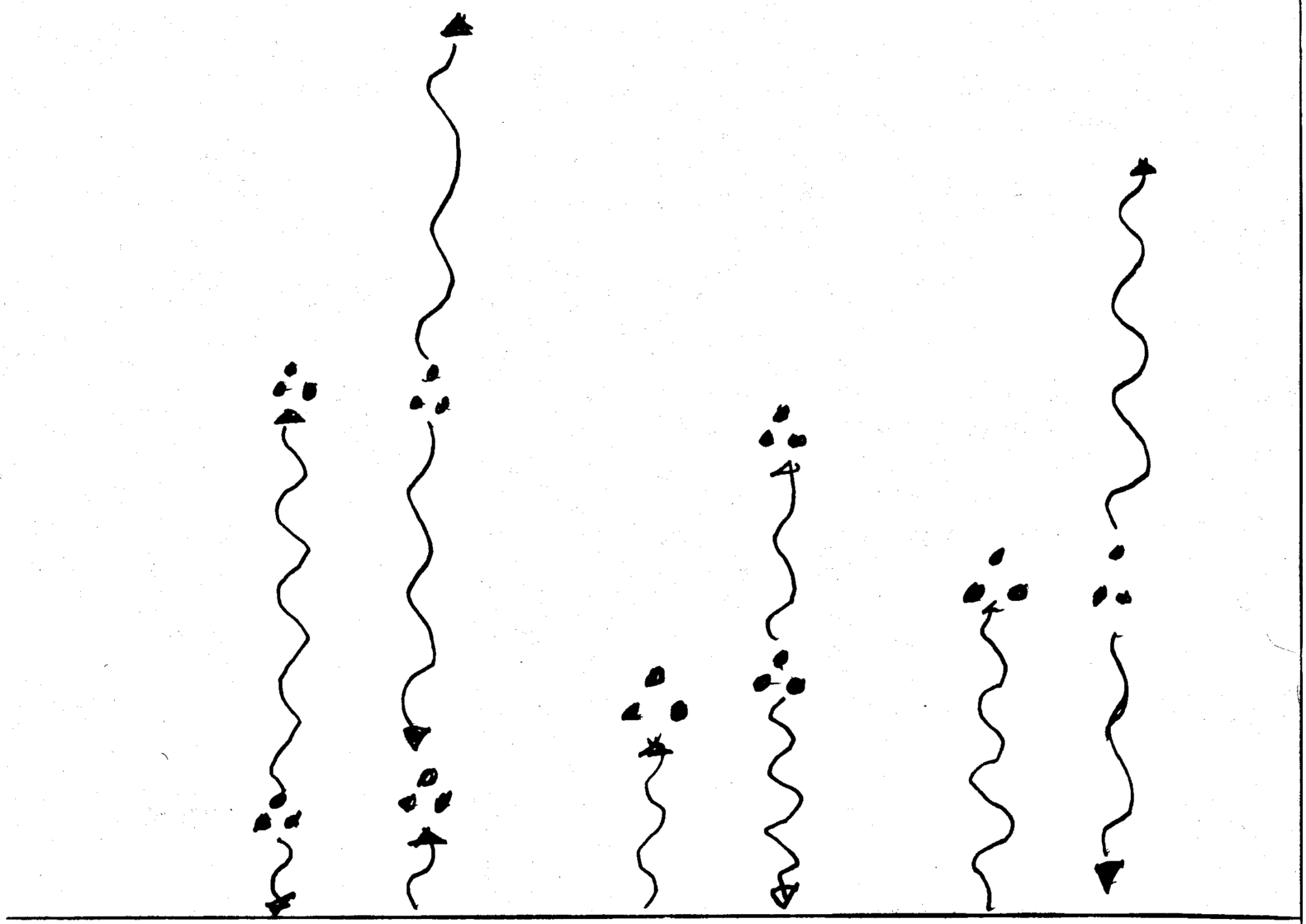
A Real Green House



How do you get IR out equal to
Visible light absorbed inside:
RAISE T

Note: For a real green house
convection may be as important:
i.e. glass a thermal barrier

IR Emission and Absorption



Ground Emits

Primarily triatomc molecules absorb and re-emit: vibrational and rotational states

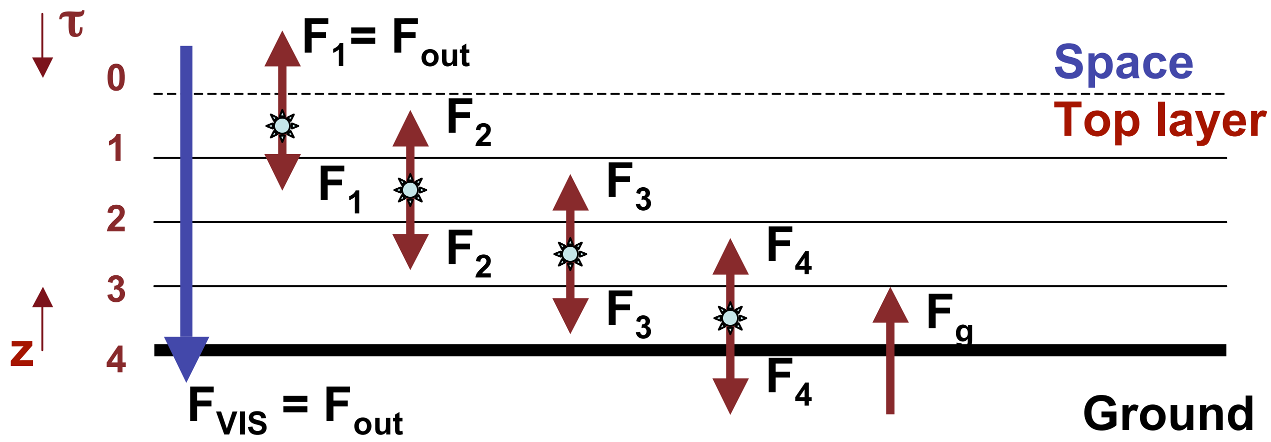
To determine T we assume excited molecules heat locally by collisions.

CO_2(v=1) + M --> CO_2(v=0) + M + K.E.

Also at a given T (CO_2 excited and can emit)

CO_2(v=0) + M --> CO_2(v=1) + M - K.E.

Goody + Walker (Simple Model)



I chose an atmosphere 4 layers thick in the IR

Each layer is $\tau_{IR} = 1$ thick

It would absorb $(1 - e^{-1})$ ~63% of the flux from the layer above and below

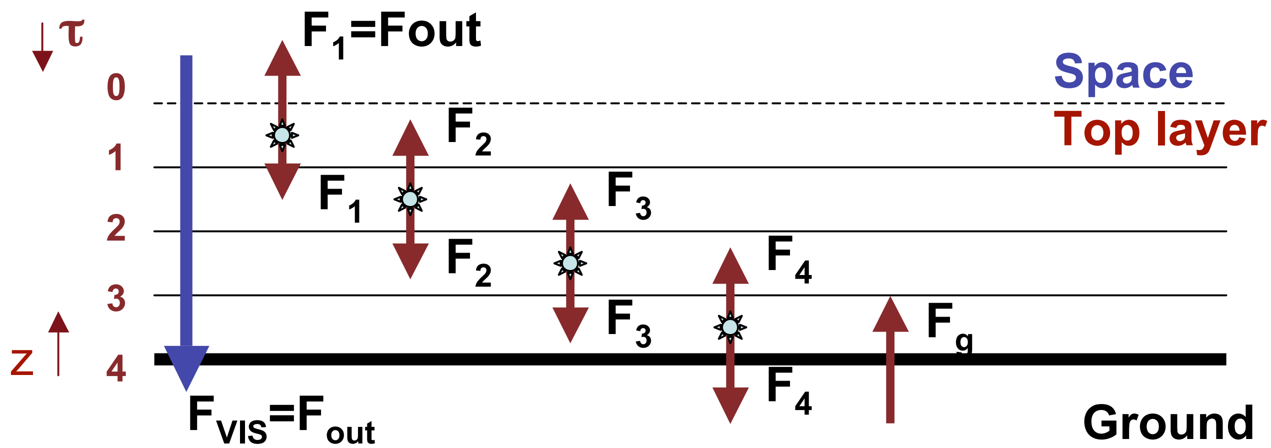
(we''ll assume 100% for simplicity)

We will also assume that each layer emits like a perfect emitter: σT^4, where T is its temperature

The surface is heated by the sun and it emits

Note: heat balance $F_{vis(} = F_{out} = \sigma T_e^4$

(simple Greenhouse cont.)



Divide atmosphere into IR thick layers: $\tau_{IR} \sim 1$

Energy balance in each layer

0 $\quad F_1 = F_{out} = \sigma\, T_e^4$

Out = In

1 $\quad 2\,F_1 = F_2 \quad \rightarrow \quad F_2 = 2\,F_1 = 2\,F_{out}$

2 $\quad 2\,F_2 = F_1 + F_3 \quad \rightarrow \quad F_3 = 2\,F_2 - F_1 = 3\,F_{out}$

3 $\quad 2\,F_3 = F_2 + F_4 \quad \rightarrow \quad F_4 = 2\,F_3 - F_2 = 4\,F_{out}$

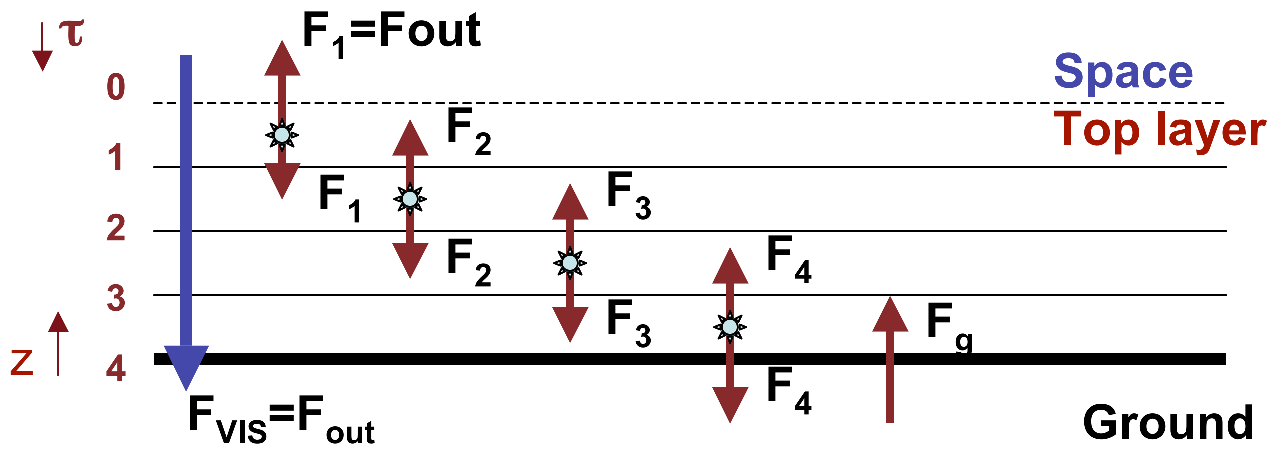
4 $\quad 2\,F_4 = F_3 + F_g \quad \rightarrow \quad F_g = 2\,F_4 - F_3 = 5\,F_{out}$

Note: can write $\mathbf{F_g = [\,1 + \text{number of layers}\,]\,F_{out}}$

$$\sigma T_g^4 = \sigma T_e^4\,[\,1 + \tau_g\,]$$

$$\tau_g = \text{number of IR layers}$$

(simple Greenhouse cont.)



Divided atmosphere into IR layers: $\tau_{IR} \sim 1$

We find : $\mathbf{F_g = [\,1 + \text{number of layers}\,]\,F_{out}}$

$$\sigma T_g^4 = \sigma T_e^{\,4}\,[\,1 + \tau_g\,]$$

Ground layer (gives the same result)

$g \quad F_{vis} + F_4 = F_g \;\rightarrow F_g = F_{viz} + 5\,F_{out}$

Since $F_{viz} = F_{out} = \sigma T_e^4$, then get the same result

$\therefore$ drop σ: $\quad \underline{\underline{\mathbf{T_g^4 = T_e^{\,4}\,[\,1 + \tau_g\,]}}}$

How Many Layers on Earth

$\tau_g \approx 2$

Using T_e = 250K

Implies

T_g = 330 K ! No Way

Again - it is clear that at the surface
convection is important
but it gives ~ 288K too cold

Greenhouse + Convection determine surface T

(Note F_4 - -air above surface
we have to do a little more carefully)

<u>Before Finishing</u>: can make an estimate

If $\tau_g \approx 2 \approx \sigma_{abs} f_{abs} N$

Using $N = 2 \times 10^{25}$ mol/cm^2 (see early lecture)

$f_{abs} = 1\%$ (H_2O, CO_2, O_3 ....)

$\sigma_{abs} \approx 10^{-23}$ cm^2

IR absorbers have small cross sections relative to UV

VENUS (Problem for set 3)

T_e = 232 T_g = 750

Therefore: τ_g^* = ?

Then: Use cross section from previous slide, pure CO_2

Find column: N_{CO2} = ?

GREEN HOUSE EFFECT

H_2O	$+21\,K$
CO_2	$+\ 7\,K$
O_3	$+\ 2\,K$
$\text{Other}(N_2O, CH_4, \cdots)$	$+\ 3\,K$
	$33\,K$

$$Te \quad + \quad \Delta T$$

$$255\,K \; + \; 33\,K \; = \; 288\,K$$

$$\text{Note: Increase } O_3 \Rightarrow \begin{array}{l} z > 30K \quad \text{increase } T \\ z < 25K \quad \text{decrease } T \end{array} \; !$$

Double CO_2? ($\sim 30\%$ increase since 1800)

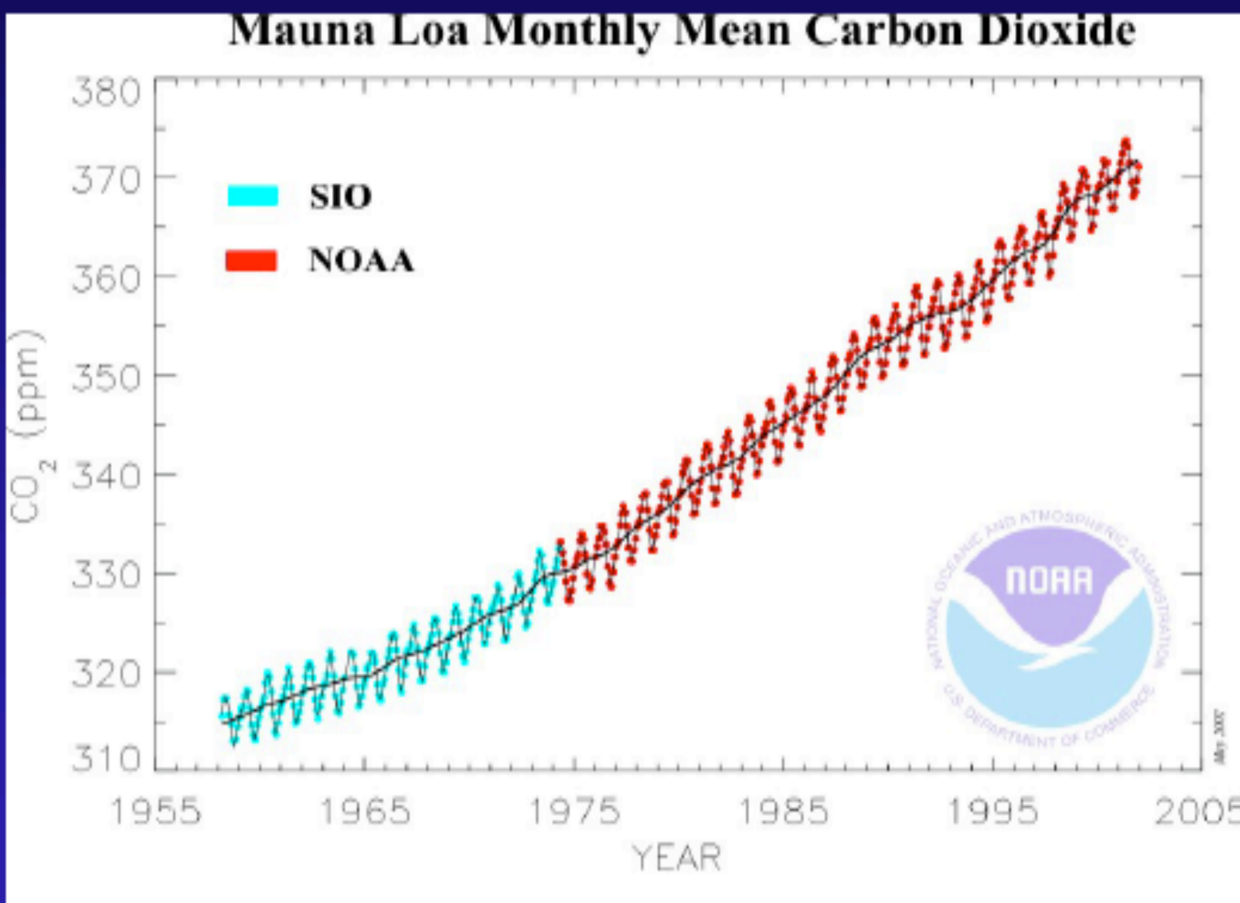
$$\Delta T = 2.5 - 5\,K \; ! \quad \text{ATMOSPHERE ONLY}$$

$$= 1 - 2\,K \; ! \quad \text{ATMOSPHERE + OCEAN}$$

We will come back when we discuss atmospheric evolution to discuss: Reservoirs for carbon and Time Constants

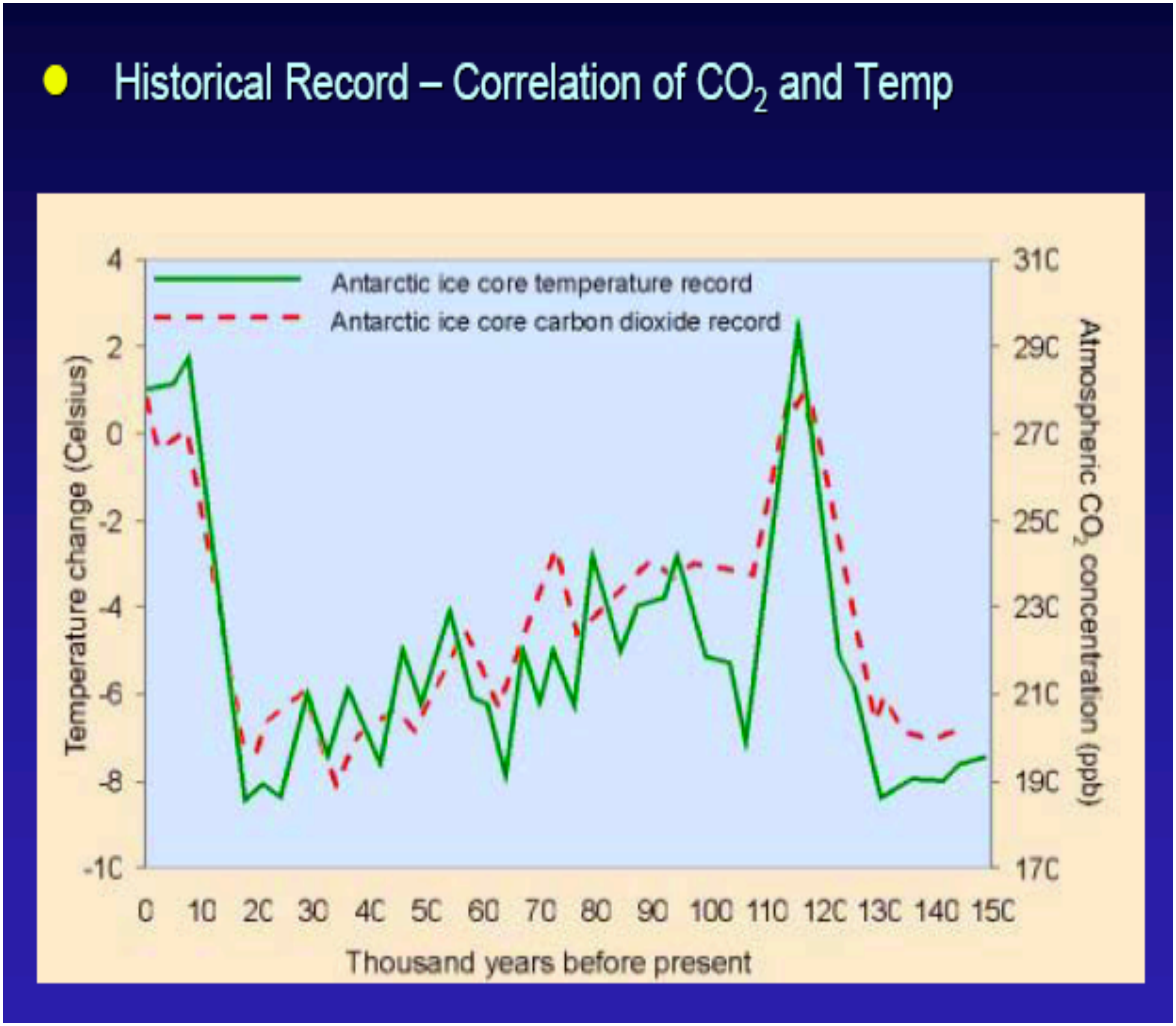
Carbon concentration vs. time

- Increase from 280 ppm (1860) to 370 ppm (present) – 31% increase
  - Note: 370 ppm = 0.0370%



Atmospheric carbon dioxide monthly mean mixing ratios. Data prior to May 1974 are from the Scripps Institution of Oceanography (SIO, blue), data since May 1974 are from the National Oceanic and Atmospheric Administration (NOAA, red). A long-term trend curve is fitted to the monthly mean values. Principal investigators: Dr. Pieter Tans, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678, ptans@cmdl.noaa.gov, and Dr. Charles D. Keeling, SIO, La Jolla, California, (616) 534-6001, cdkeeling@ucsd.edu.

Carbon Concentration Long Term

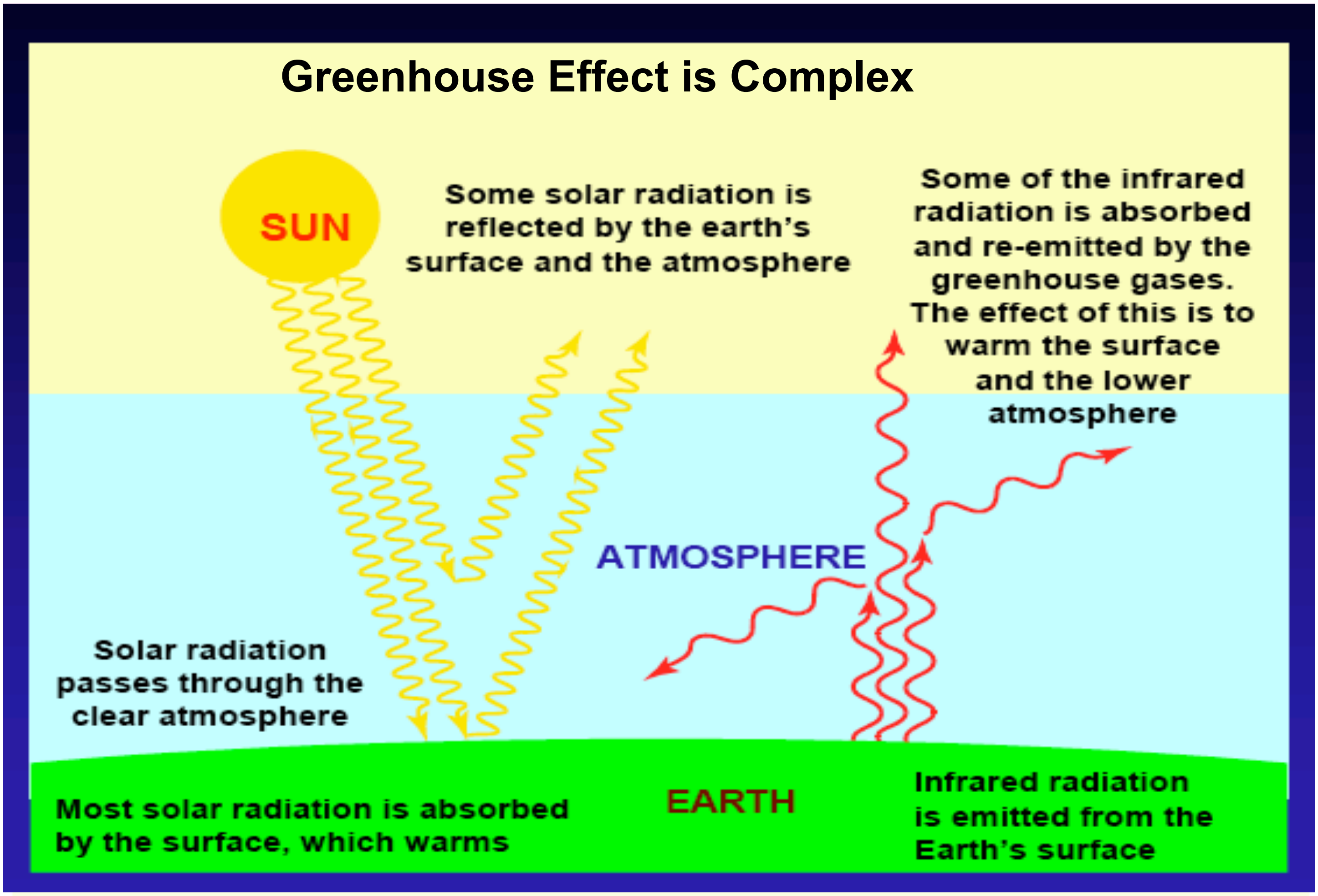


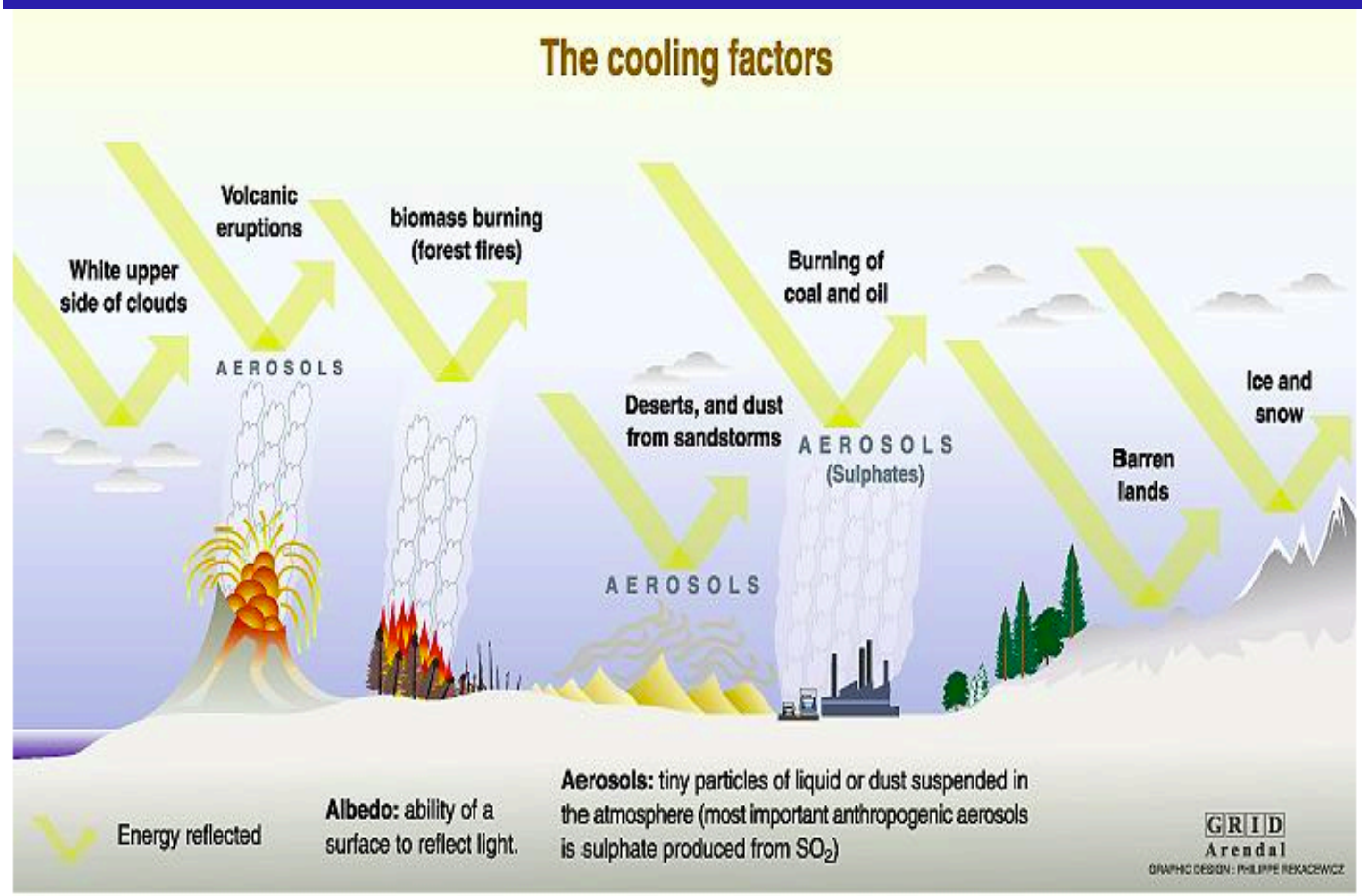
Later we will look at the carbon cycle

- Carbon Dioxide, CO_2
  - Contributes 60% of warming
- Trace Gases (100 –1000 times less)
  - Contribute 40% of warming
  - Methane, CH_4 (15-30% of warming)
  - Nitrogen Oxides, NO_x (up to 15% of warming)
  - Chlorofluorocarbons, CFCs (12% of warming)

However,

- Molecule for molecule, CO_2 is less efficient than other greenhouse gases because its atmospheric concentration is high and hence its absorption bands are nearly saturated.
- Over a 100-year time horizon, reducing SF_6 emissions by 1 kg is as effective from a greenhouse perspective as reducing CO_2 emissions by 24,900 kg.

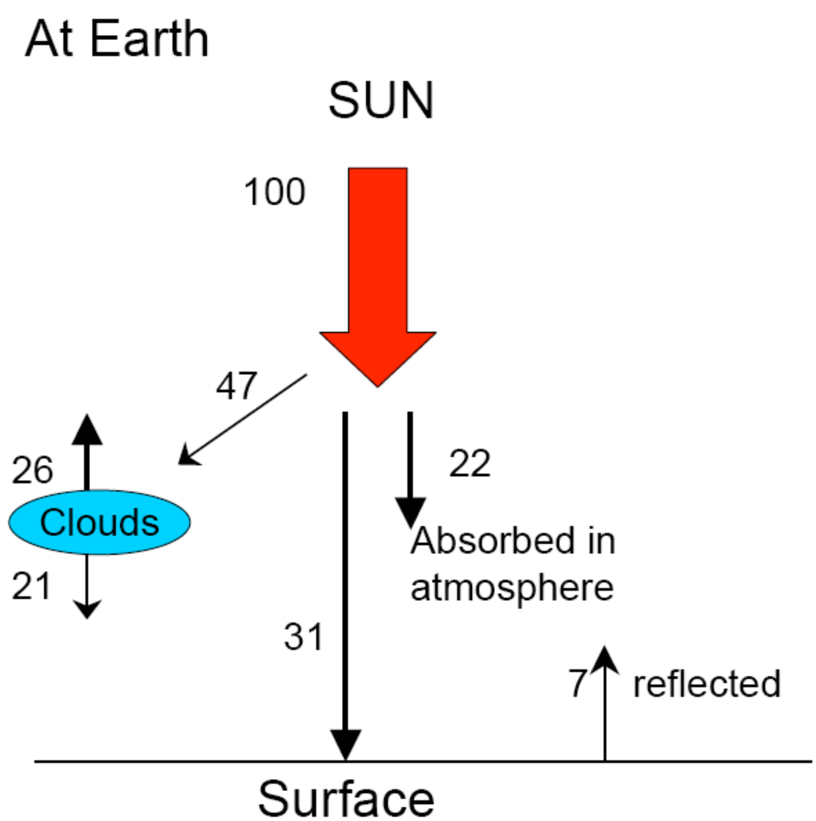

Greenhouse Effect is Complex
SUN
Some solar radiation is reflected by the earth's surface and the atmosphere
Some of the infrared radiation is absorbed and re-emitted by the greenhouse gases. The effect of this is to warm the surface and the lower atmosphere
ATMOSPHERE
Solar radiation passes through the clear atmosphere
Most solar radiation is absorbed by the surface, which warms
EARTH
Infrared radiation is emitted from the Earth's surface


The cooling factors
White upper side of clouds
Volcanic eruptions
biomass burning (forest fires)
Burning of coal and oil
AEROSOLS
Deserts, and dust from sandstorms
AEROSOLS (Sulphates)
AEROSOLS
Barren lands
Ice and snow
Energy reflected
Albedo: ability of a surface to reflect light.
Aerosols: tiny particles of liquid or dust suspended in the atmosphere (most important anthropogenic aerosols is sulphate produced from SO_2)
GRID Arendal
GRAPHIC DESIGN : PHILIPPE REKACEWICZ

PLANETARY ENERGY BALANCE

G+W fig 3-5

Incoming solar radiation



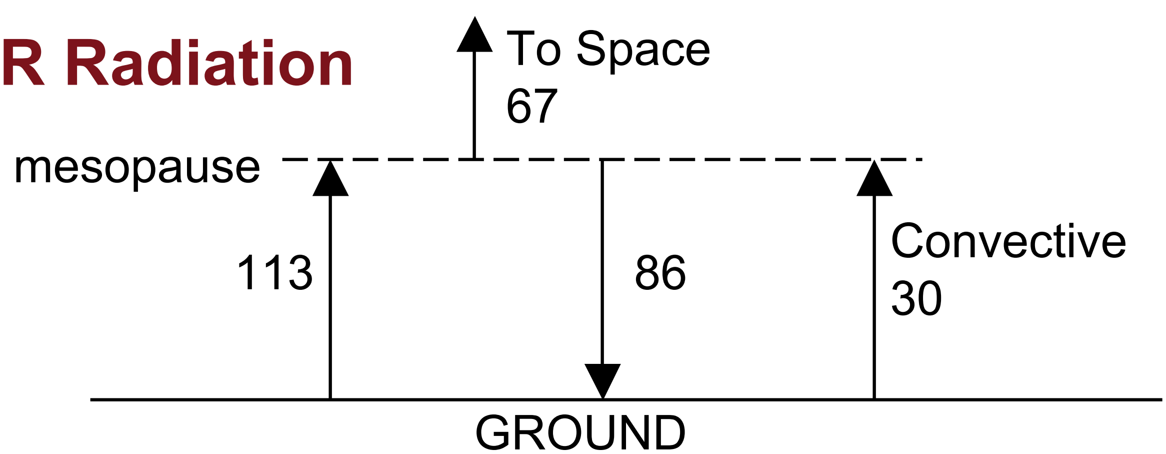
Absorbed

Clouds	21
Atmos.	22
Ground	24
	67

Back to space

Reflect	Ground	7
Clouds		26
Albedo		33

IR Radiation



#5a Summary

Things you should know

Planck Radiation Law
IR Molecules
Greenhouse Effect
Surface temperature