Atmospheric Composition and the Greenhouse

12.340 Global Warming Science
February 23, 2012
Dan Cziczo

A Little About Myself…

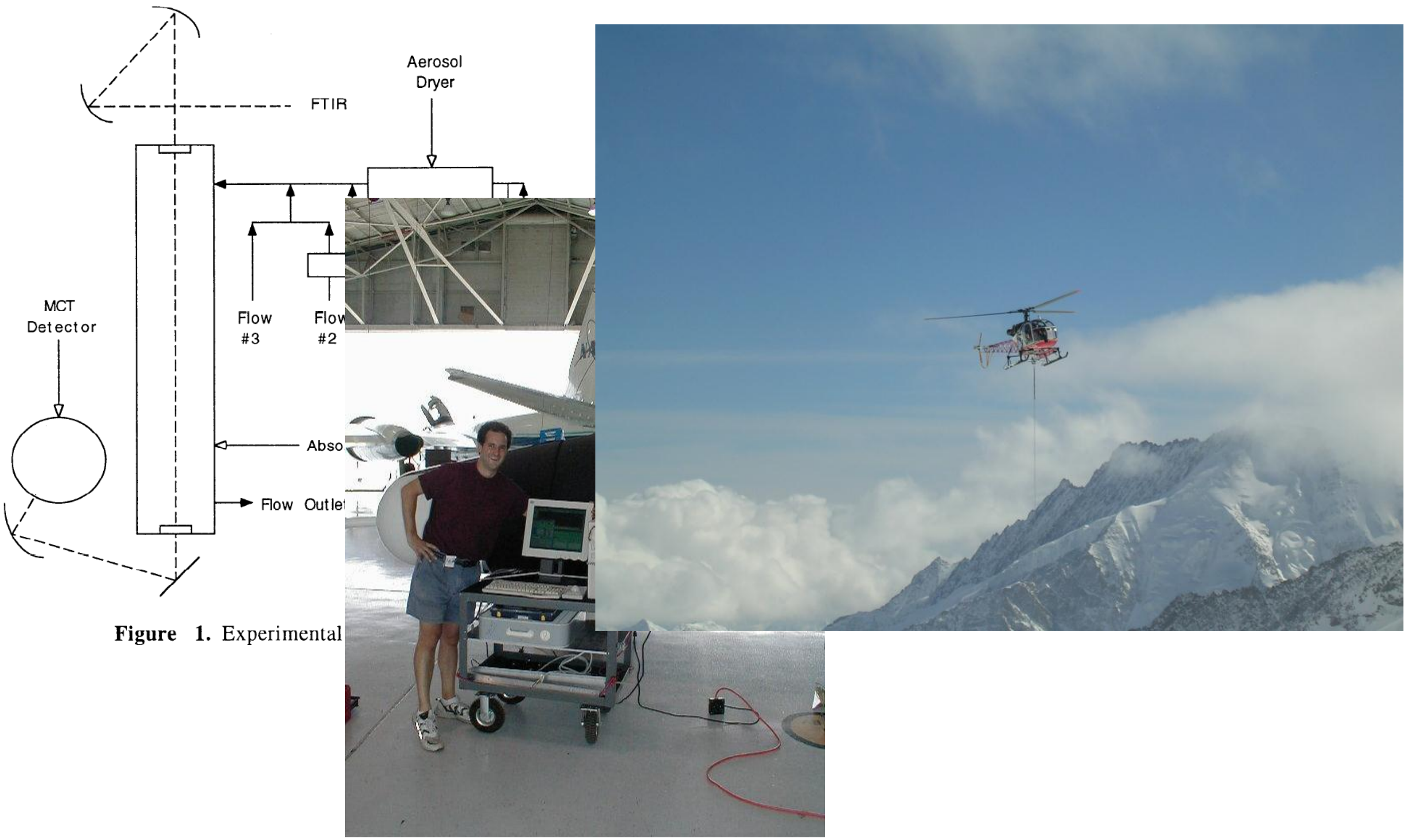


Figure 1. Experimental

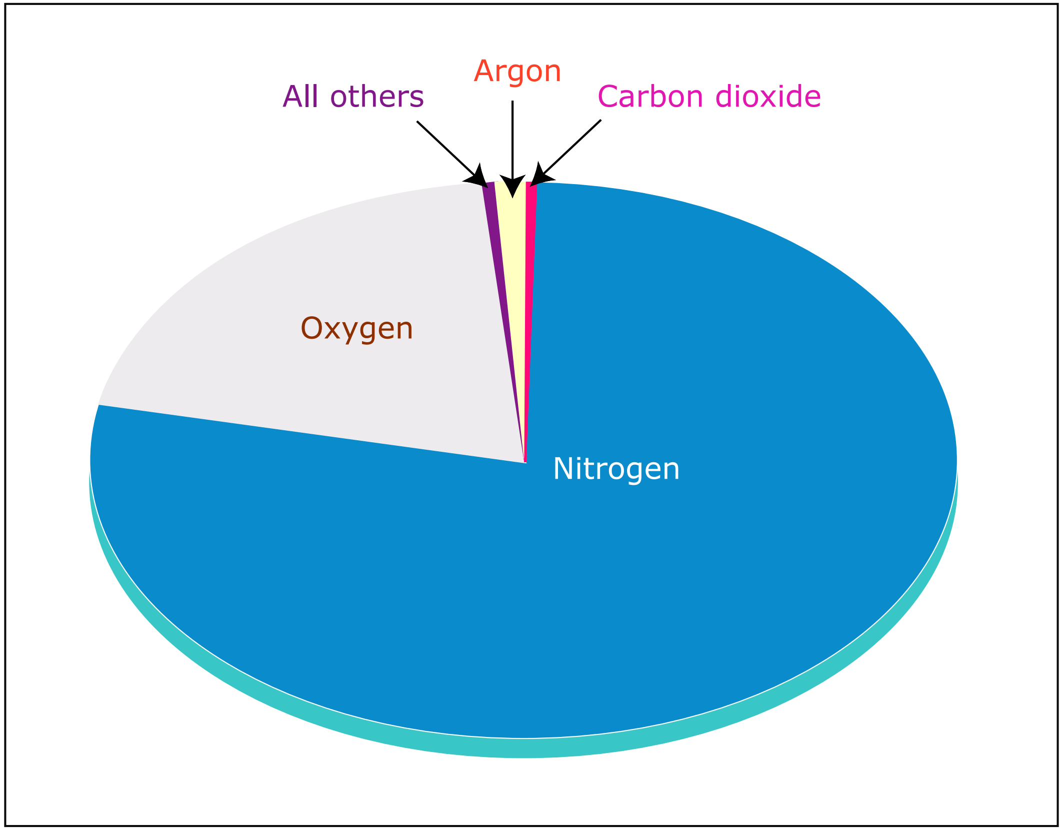
Today's Class

- Why are atmospheres important?
  - -Bare rocks and blankets (the greenhouse concept)

- What are the Earth's greenhouse gases? Where are they from?

- Paleo versus modern greenhouse levels

Recap



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Early Atmosphere
Probably H_2, He
- Likely lost to space early

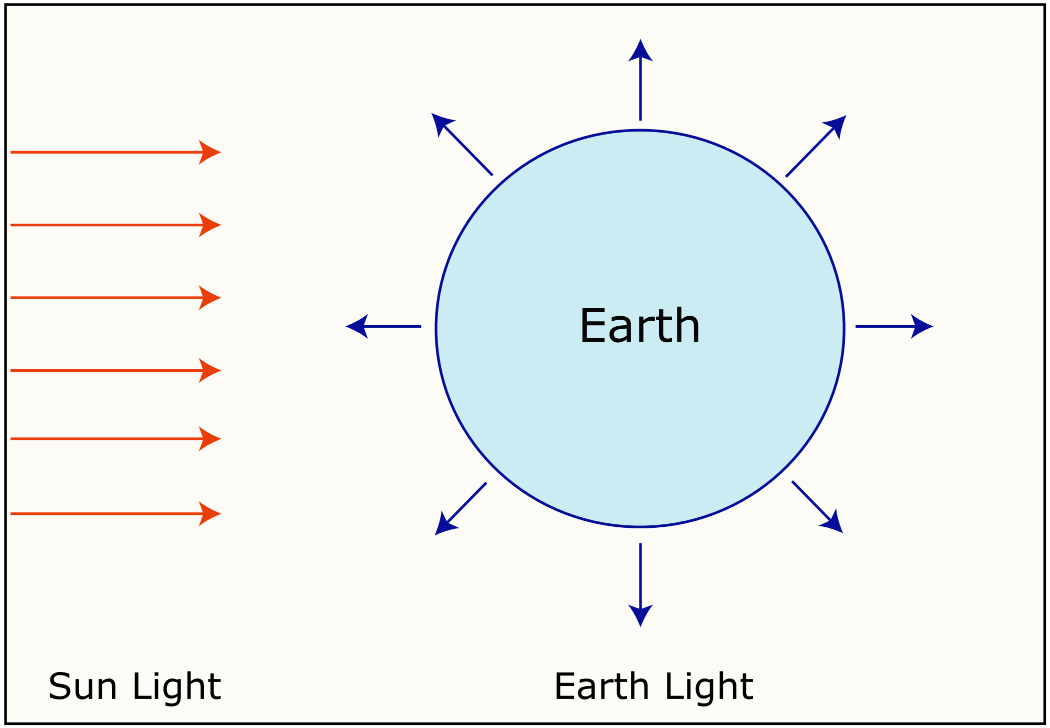
Later Atmosphere
- Volcanic out gassing + impacts
: H_2O, CO_2, SO_2, CO, S_2, Cl_2, N_2, H_2, NH_3, and CH_4

O_2 ?

Ocean Formation ?

Lutgens and Tarbuck, *The Atmosphere*, 8th edition

Planetary Temperature



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Let's start by assuming the Earth is a rock heated by the sun with no greenhouse gases

Unless otherwise specified: Archer, Global Warming

‘Bare Rock’

Energy in = energy out

$F_{in} = F_{out}$ (Watts)

From Archer: Intensity = W/m^2

$F_{in}[W] = I[W\ m^{-2}] \times (1-\alpha) \times Area[m^2]$

What is I? What is albedo?

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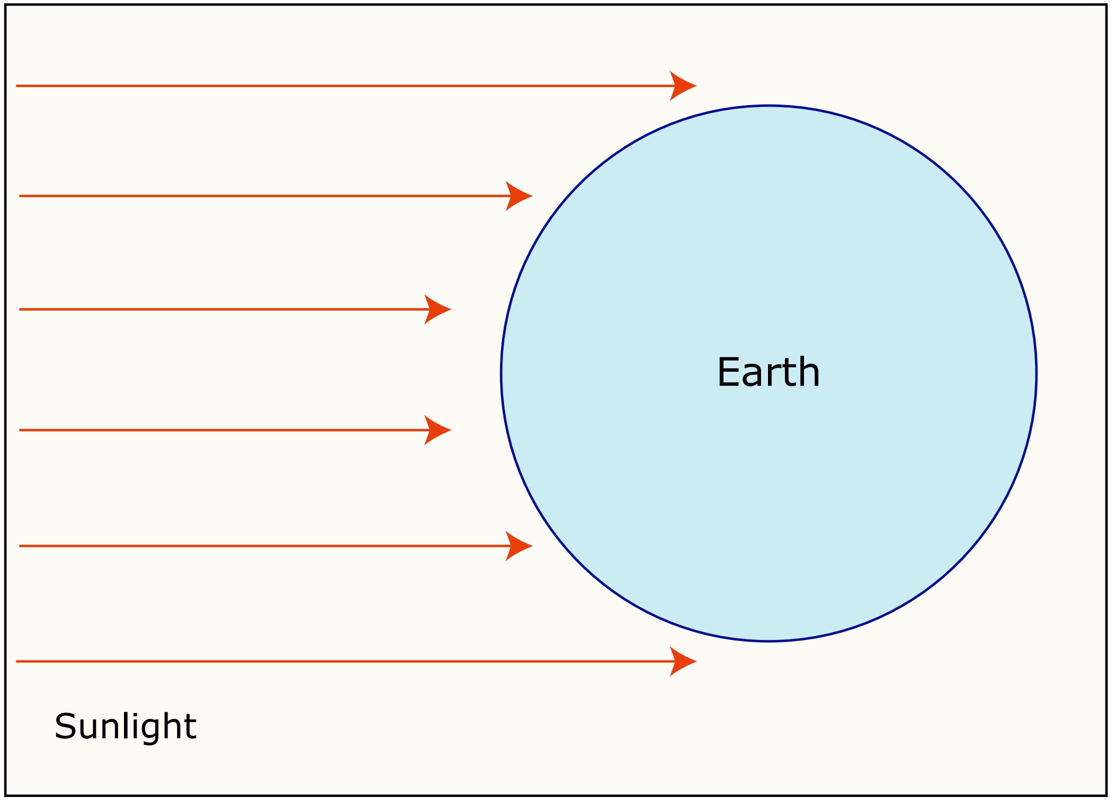
F_{in}



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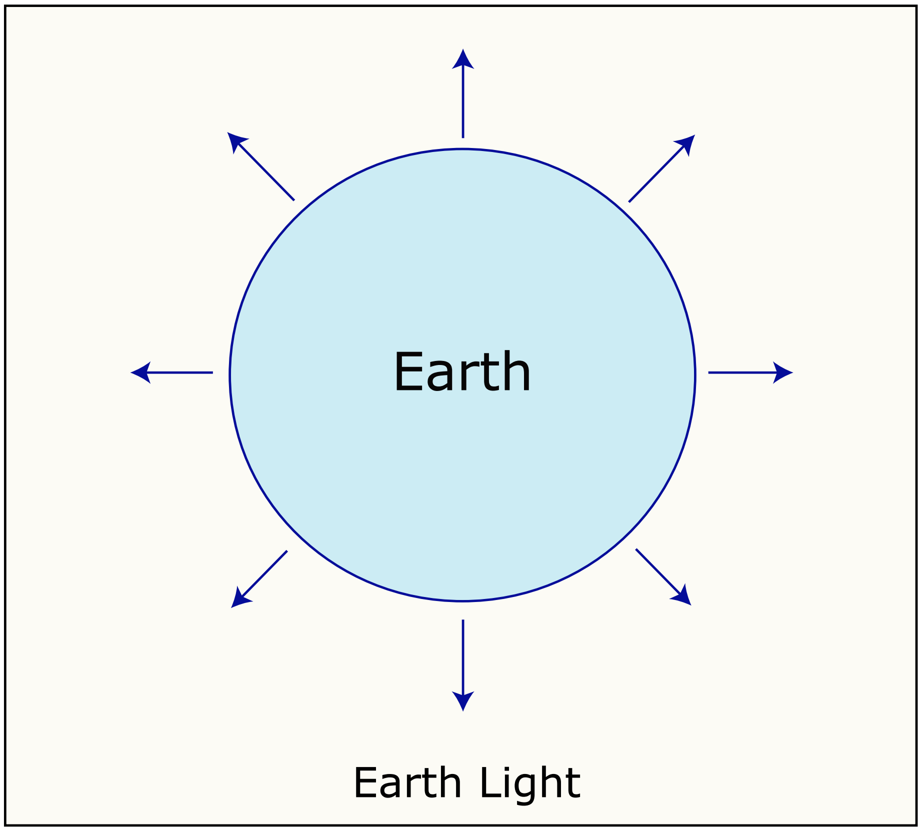
Area = πr^2 (why not $4\pi r^2$?)

$F_{in} = I_{in} \times (1-\alpha) \times \text{Area}$

$F_{in} = I_{in} \times (1-\alpha) \times \pi r^2$

Fig 3-1

F_{out}



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Stephan-Boltzmann Equation

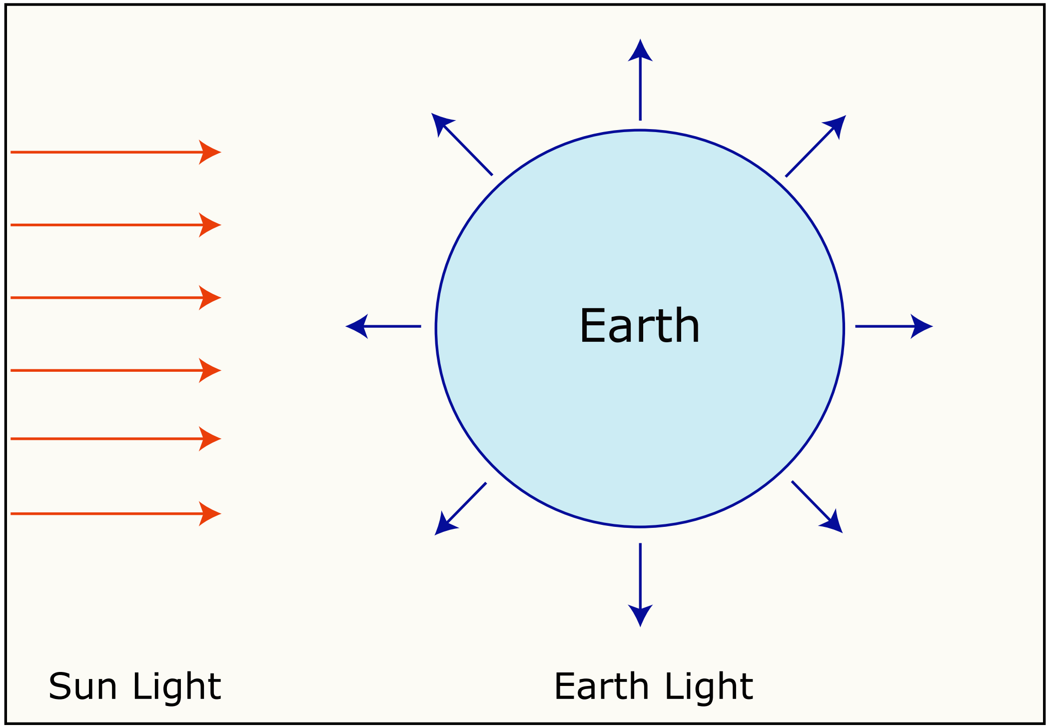
$F_{out} = I_{out}$ x Area

$I_{out} = \varepsilon\sigma T^4$

Area = $4\pi r^2$ (why not πr^2?)

ε = 'emissivity', $0<\varepsilon<1$

'Bare Rock'



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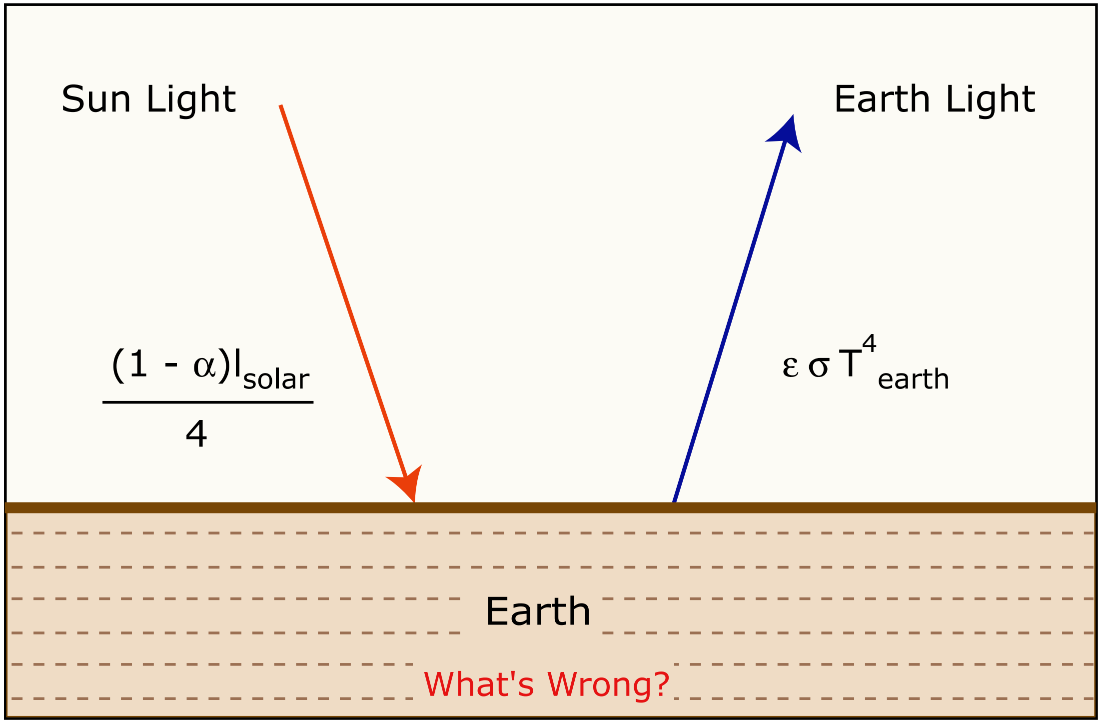
$$4\pi r_{earth}^2 \varepsilon \sigma T_{earth}^4 = \pi r_{earth}^2 (1-\alpha) I_{in}$$

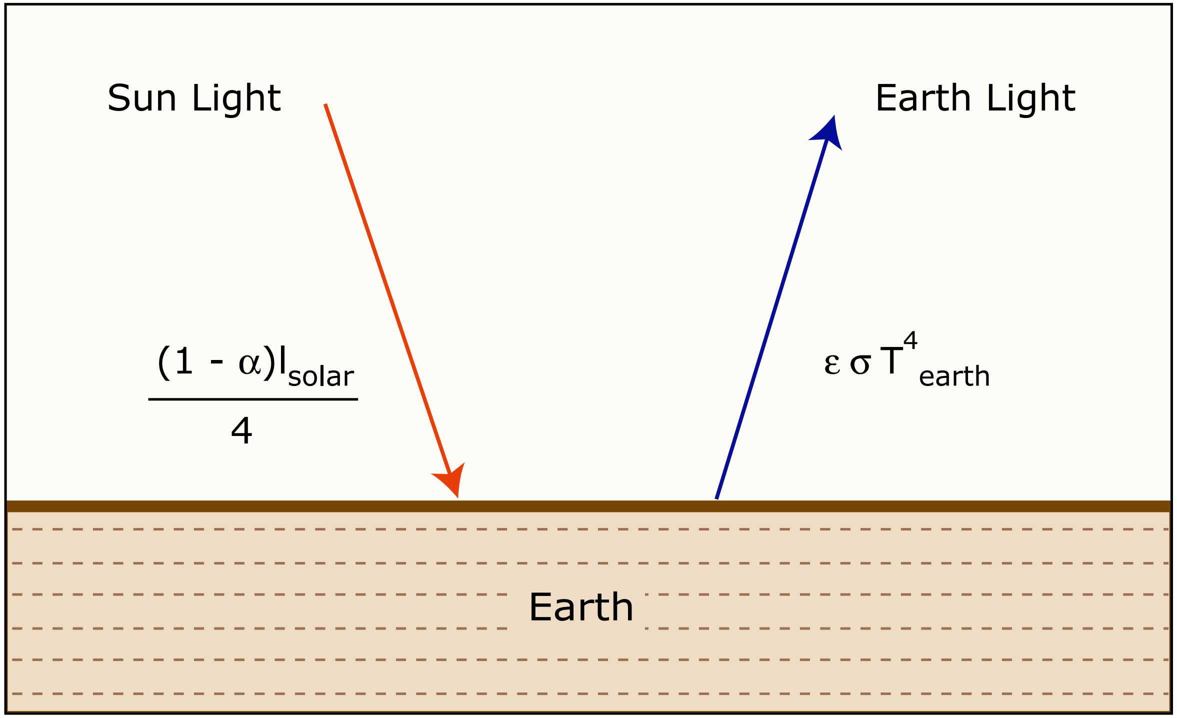
$$T_{earth} = [(1-\alpha) I_{in} / 4\varepsilon\sigma]^{1/4}$$



Planet	α (%)	T (K)	I_{solar} (Wm^{-2})
Venus	71	240	2600
Earth	33	251	1350
Mars	17	216	600

Image by MIT OpenCourseWare.

Let's Add an Atmosphere



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$F_{out} = 4\pi r_{earth}^2 \varepsilon \sigma T_{earth}^4$

Define $I_{out} = \varepsilon \sigma T_{earth}^4$ [W m^{-2}]

$F_{in} = \pi r_{earth}^2 (1-\alpha) I_{in}$

Define $I_{in} = (1-\alpha) I_{in}/4$

1 Layer

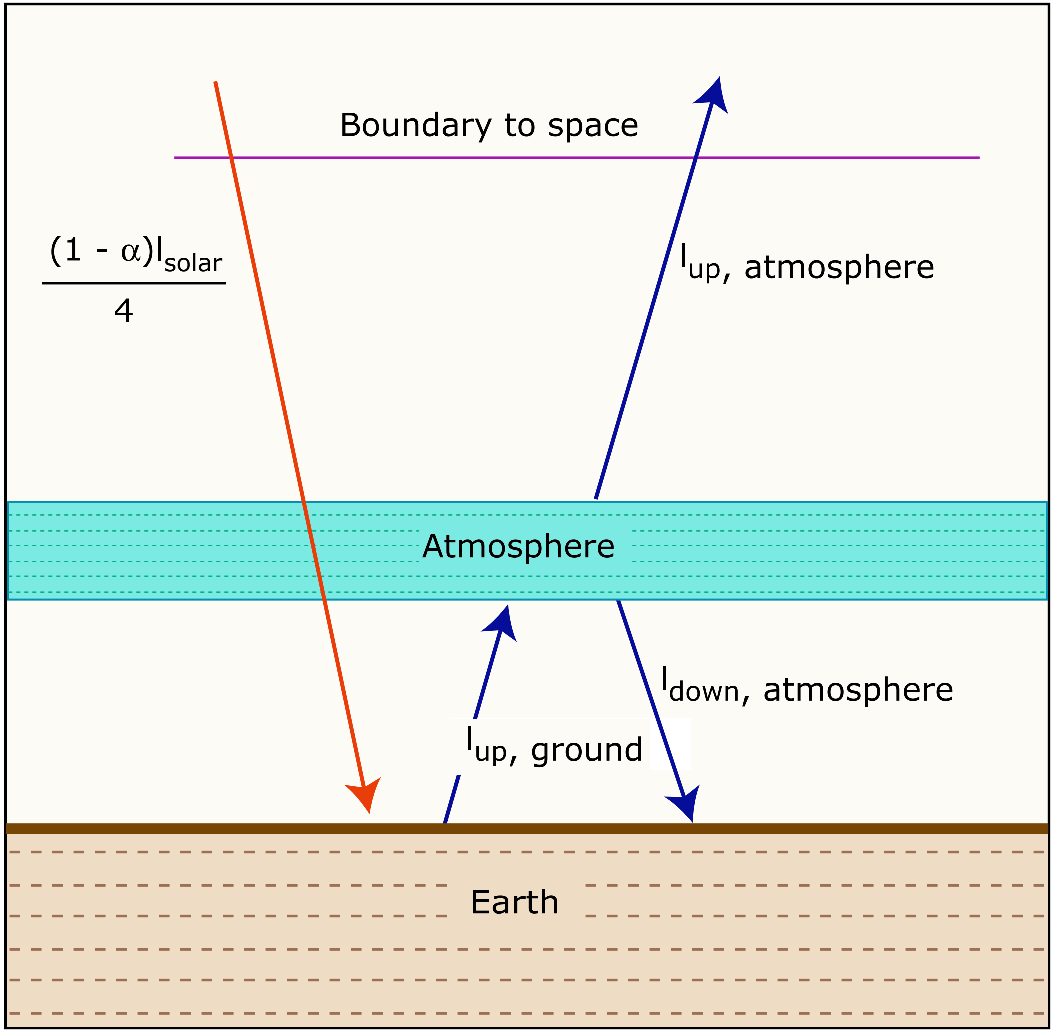


Image by MIT OpenCourseWare.

The Balance:

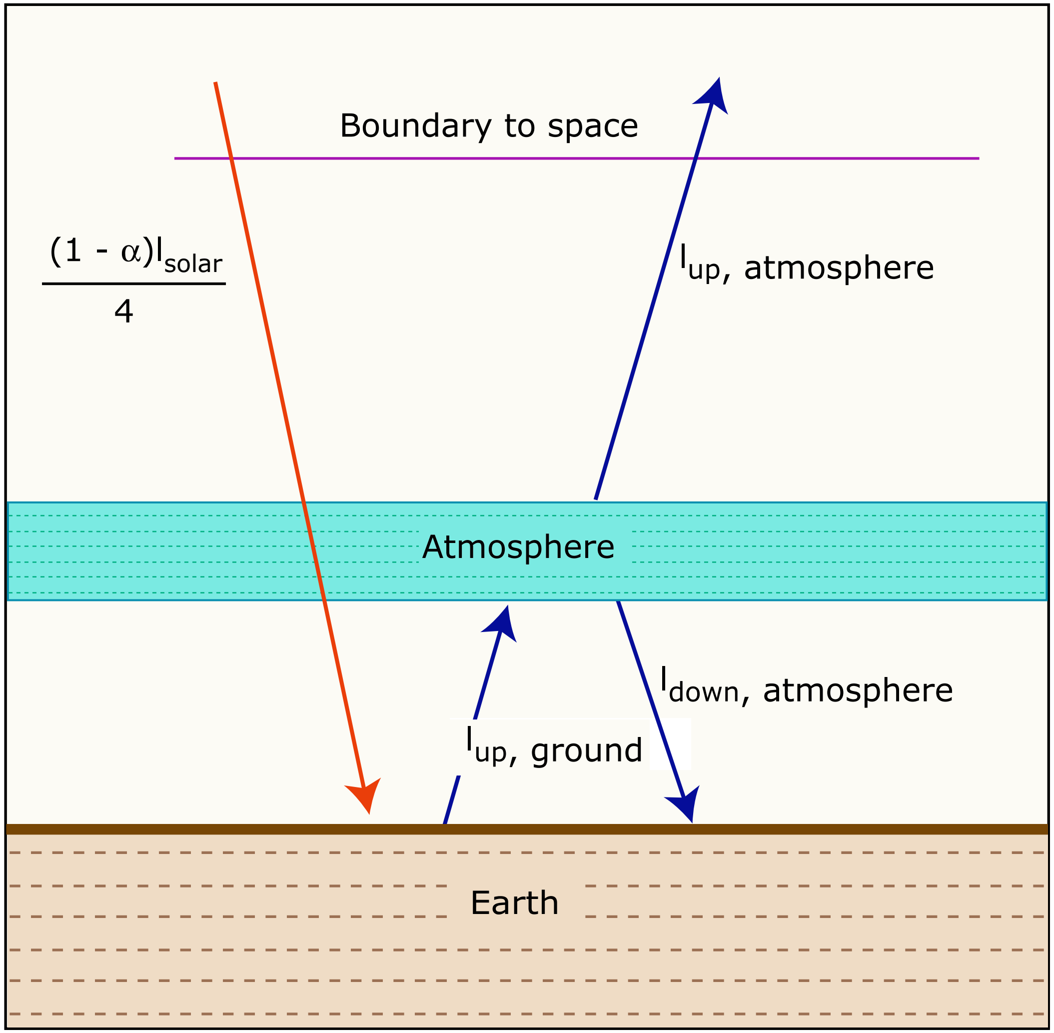
$I_{in,solar} = = (1\text{-}\alpha)I_{in}/4$

$I_{up,ground} = \varepsilon\sigma T_{grnd}^{4}$

$I_{up,atmosphere} = \varepsilon\sigma T_{atm}^{4}$

What is T_{grnd}?

1 Layer



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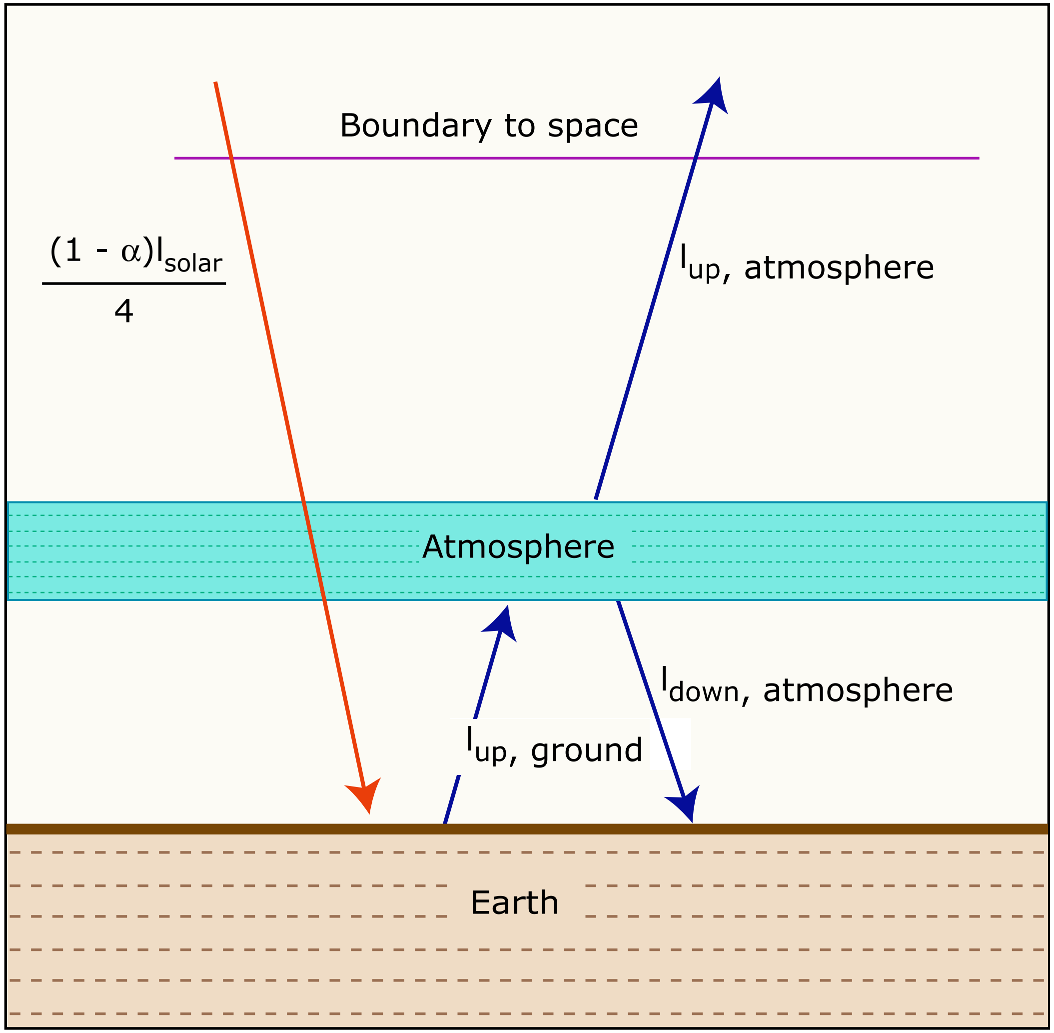
The atmosphere is like the bare rock:

$I_{up,atm} = I_{in,solar}$

$\varepsilon\sigma T_{atm}^4 = (1-\alpha)I_{solar}/4$

$T_{atm} = [(1-\alpha)I_{in}/4\varepsilon\sigma]^{1/4}$

1 Layer



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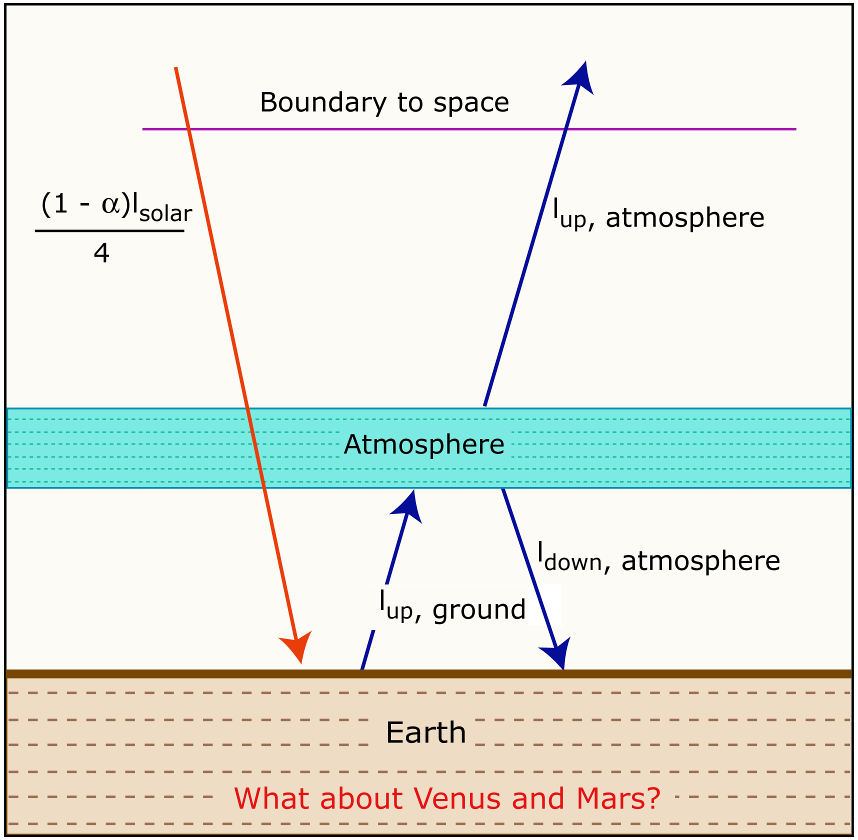
And the ground is now warmer:

$I_{up,atm} + I_{down,atm} = I_{up,grnd}$

$2\varepsilon\sigma T_{atm}^4 = \varepsilon\sigma T_{grd}^4$

$T_{grd} = [2]^{1/4}\, T_{atm}\ (\sim 1.2 T_{atm})$

$T_{grd} = [(1-\alpha) I_{solar}/2\varepsilon\sigma]^{1/4}$



Planet	α (%)	T (K)	$T_{observed}$ (K)	$T_{1\ layer}$ (K)	I_{solar} (Wm^{-2})
Venus	71	240	700	285	2600
Earth	33	251	295	303	1350
Mars	17	216	240	259	600

Image by MIT OpenCourseWare.

If It Wasn’t For Greenhouse Gases We Wouldn’t Be Here!

(or we’d look a lot different)

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The image is from Ruddiman, W. F., 2001. *Earth's Climate: past and future*. W.H. Freeman & Sons, New York.

"Runaway Greenhouse"

"The Goldilocks Effect"

Earth's Atmosphere

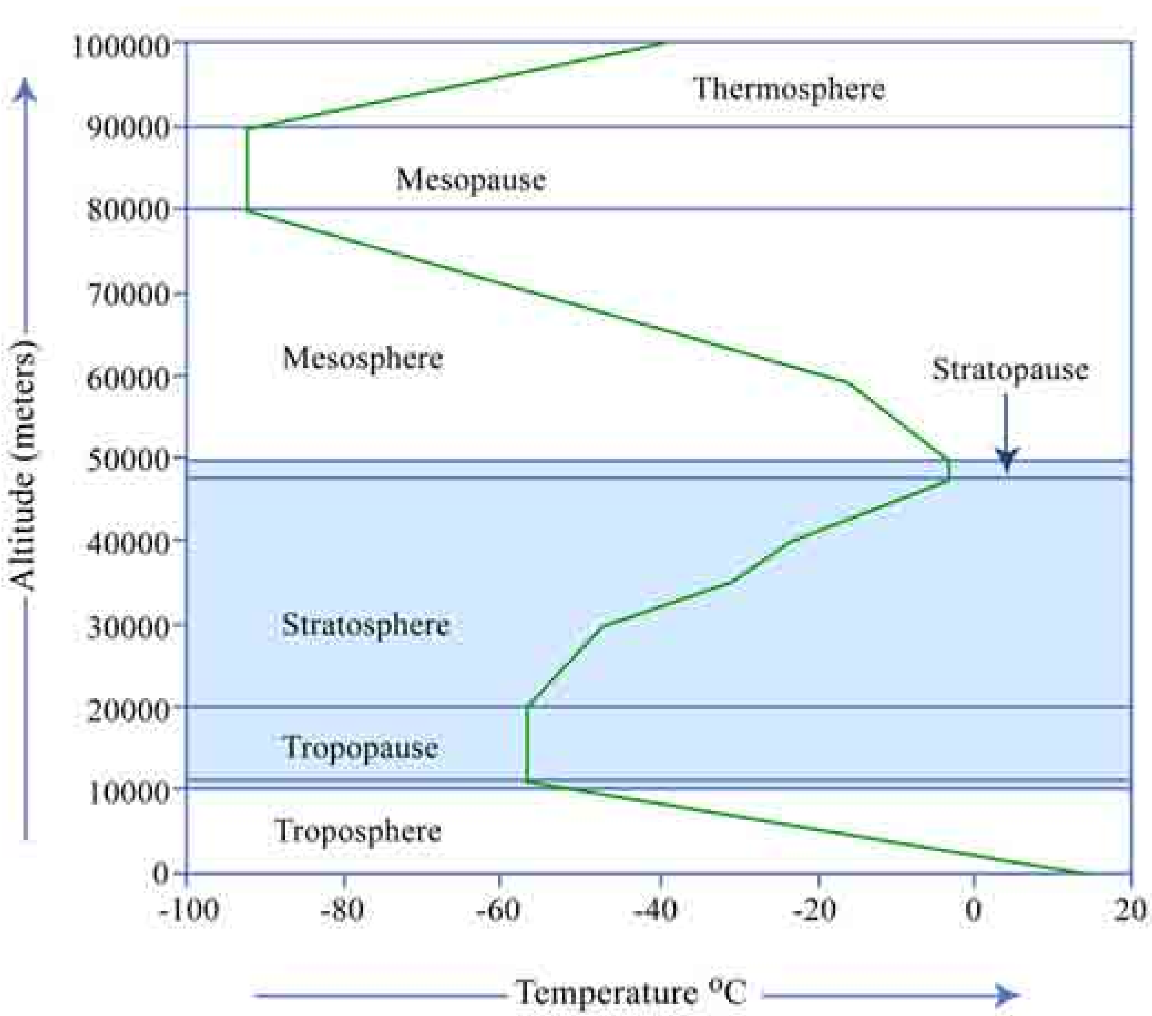

Figure by MIT OpenCourseWare.

The Earth's atmosphere can be mimicked by a 1 layer atmosphere but is much more complex

Greenhouse Gases

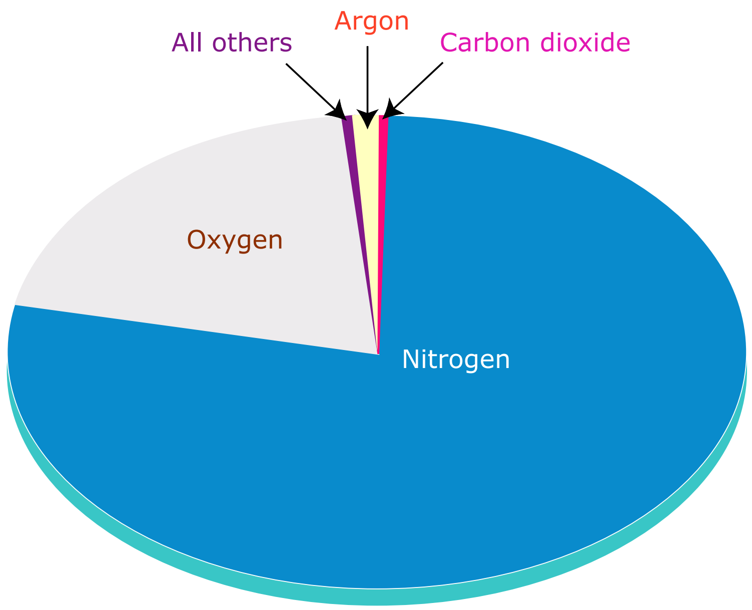

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Table: Principal gases of dry air

Constituent	Percent by volume	Concentration in Parts Per Million(PPM)
Argon (Ar)	0.934	9,340.0
Carbon dioxide (CO_2)	0.036	360.0
Helium(He)	0.000524	5.24
Hydrogen (H_2)	0.00005	0.5
Krypton (Kr)	0.000114	1.14
Methane (CH_4)	0.00015	1.5
Neon (Ne)	0.00182	18.2
Nitrogen (N_2)	78.084	780,840.0
Oxygen (O_2)	20.946	209,460.0

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figure and table fron Lutgens and Tarbuck, The *Atmosphere*, 8th edition)

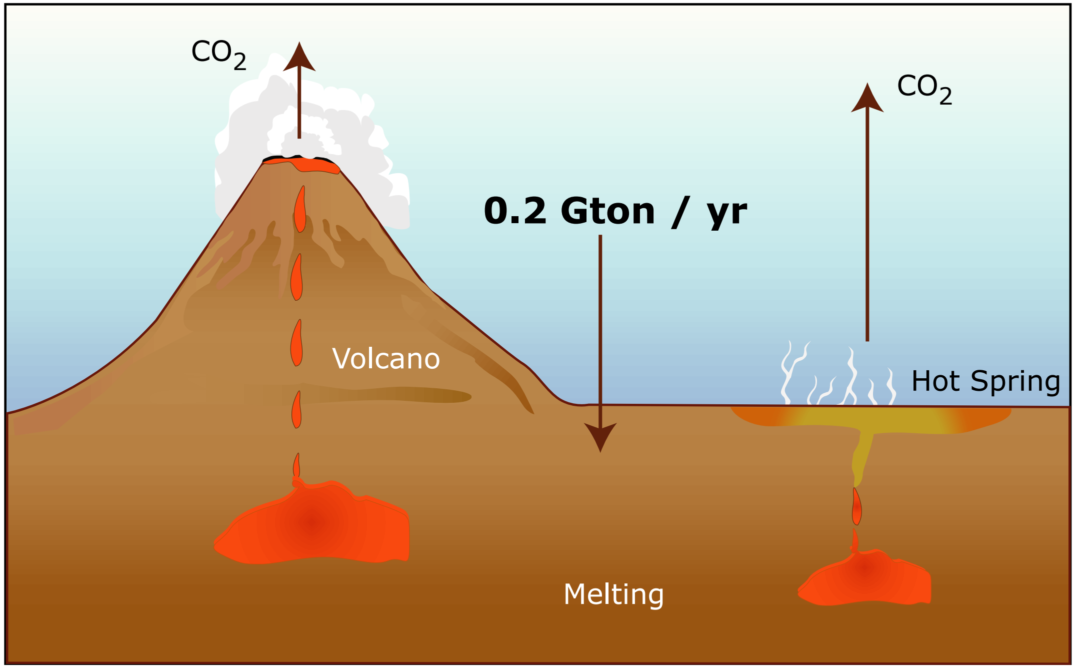
Carbon dioxide, methane and nitrous oxide are natural (as well as anthropogenic)

More on CO_2 in a moment.

Methane (CH_4) – from wetlands, grazing animals, termites, and other sources

Nitrous Oxide (N_2O) – from denitrifying bacteria

Where Do Greenhouse Gases Come From (and go)?



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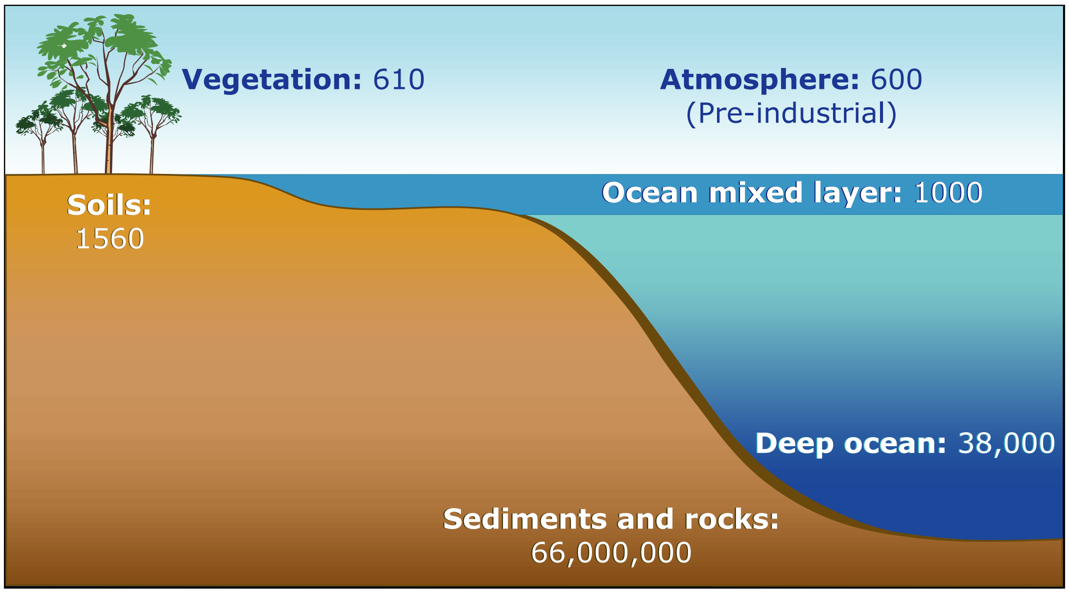
$H_2O + CO_2 \rightarrow H_2CO_3$ (soil)

$H_2CO_3 + CaSiO_3 \rightarrow CaCO_3 + SiO_2 + H_2O$

Ruddiman,2001

Greenhouse Gases



A Major carbon reservoirs (gigatons; 1 gigaton = 10^{15} grams)

Image by MIT OpenCourseWare.

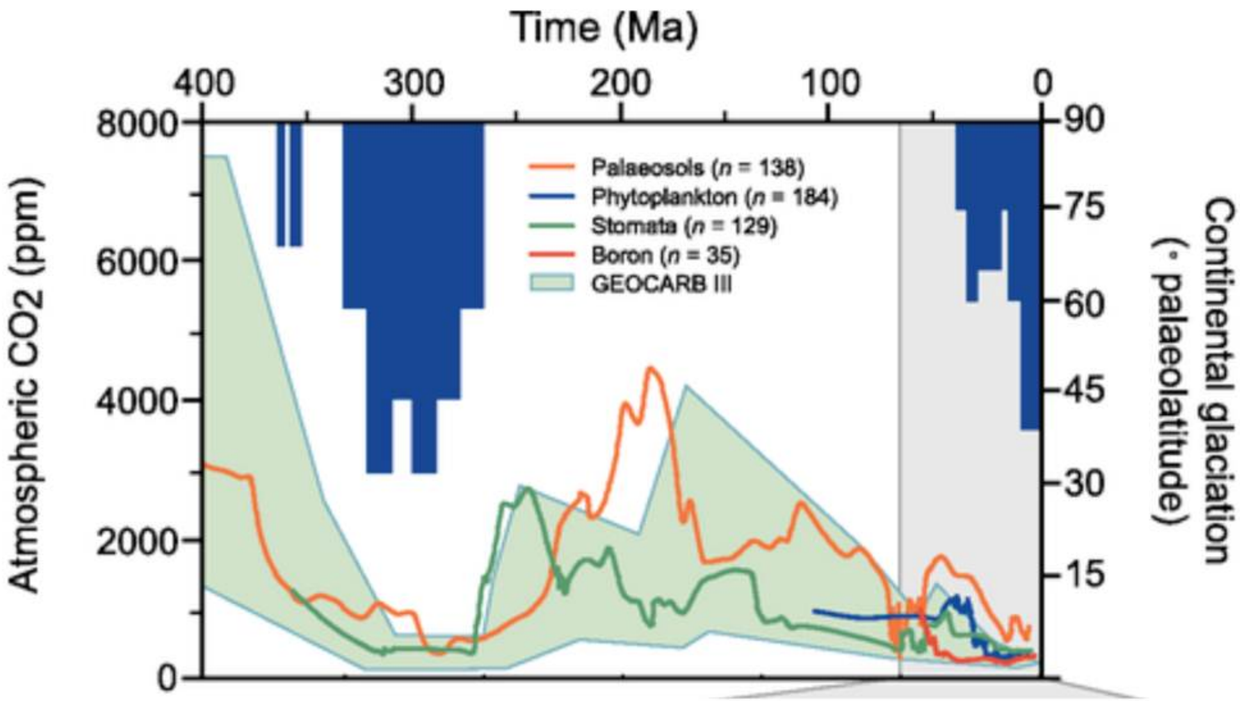
What if volcanoes stopped?

Concept of lifetime:

Abundance (Gton) /Emission (Gton/yr)= Lifetime (yr)

Ruddiman,2001

Greenhouse Gases Record



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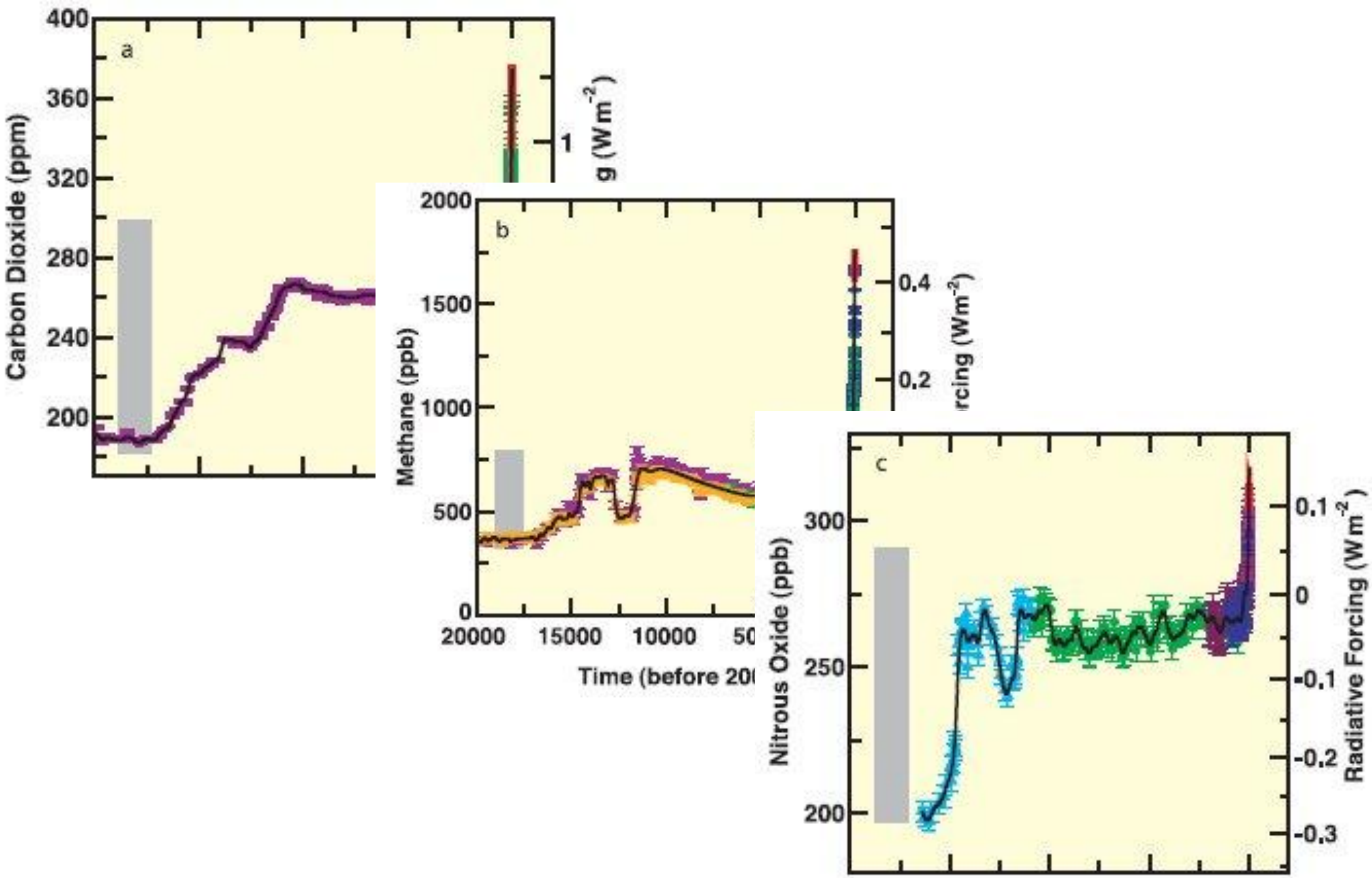
http://www.nature.com/ngeo/journal/v4/n7/fig_tab/ngeo1186_F1.html

Paleo Changes in GGs



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Greenhouse Gases

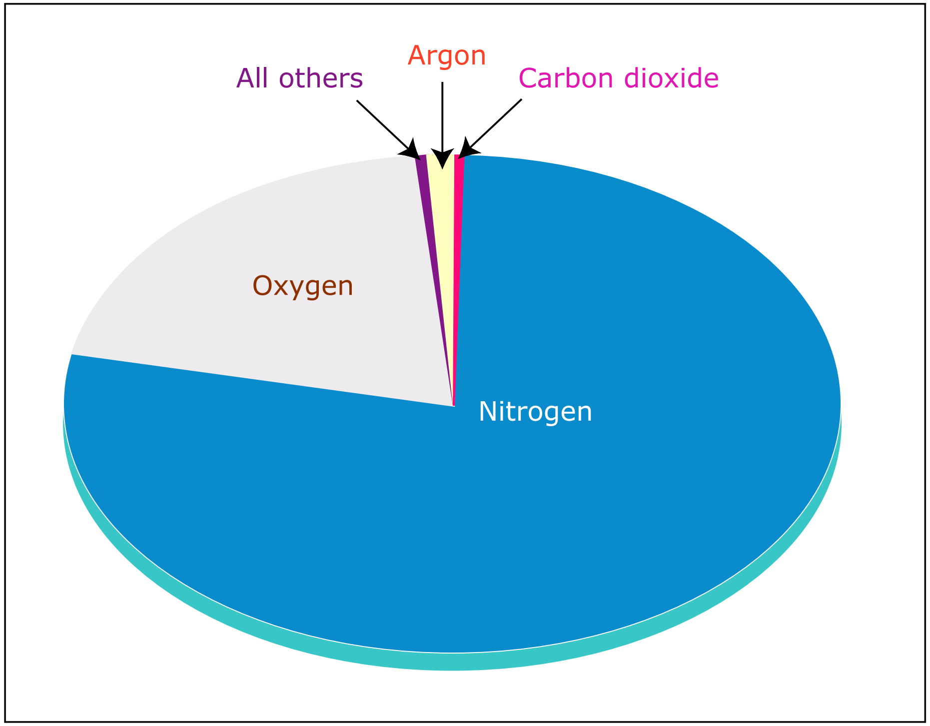

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figure and table fron Lutgens and Tarbuck, The *Atmosphere*, 8th edition)

Table 2.1. *Present-day concentrations and RF for the measured LLGHGs. The changes since 1998 (the time of the TAR estimates) are also shown.*

	Concentrations[b] and their changes[c]		Radiative Forcing[d]	
Species[a]	2005	Change since 1998	2005 (W m^{-2})	Change since 1998 (%)
CO_2	379 ± 0.65 ppm	+13 ppm	1.66	+13
CH_4	1,774 ± 1.8 ppb	+11 ppb	0.48	-
N_2O	319 ± 0.12 ppb	+5 ppb	0.16	+11

Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Table 2.1. Cambridge University Press. Used with permission.

Modern CO2

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Put In Perspective

1 Tg = 1 million metric tons = 10^9 Kg = 10^{12} g

Added CO_2 per year (man made) is ~9000 Tg (9 Gigatons)

This is out of 700 Gtons of CO_2 in the atmosphere at any given time

Methane is about 60%/40% anthropogenic/natural

N_2O is about 40/60%

Greenhouse Gases

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CH_4 and Nitrous Oxide Global Emissions - IPCC

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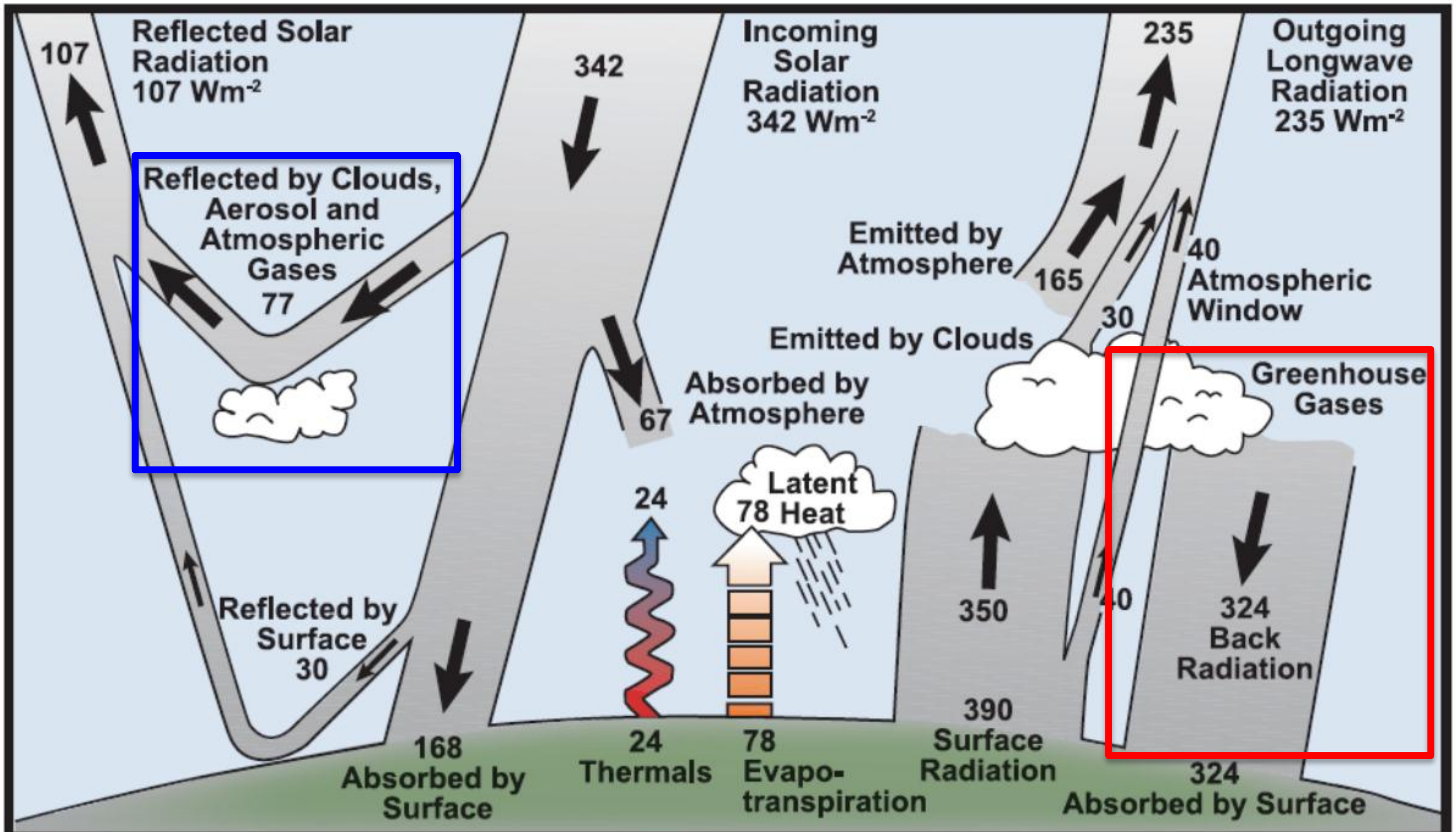
The Other Greenhouse Gases

(more in Lecture 13)

Gas	Global Warming Potential
Carbon Dioxide	1
Methane	72
Nitrous Oxide	289
CFC-12	11000
HCFC-22	5160
Sulphur Hexafluoride	16300

Implication?

The Earth's Energy Balance



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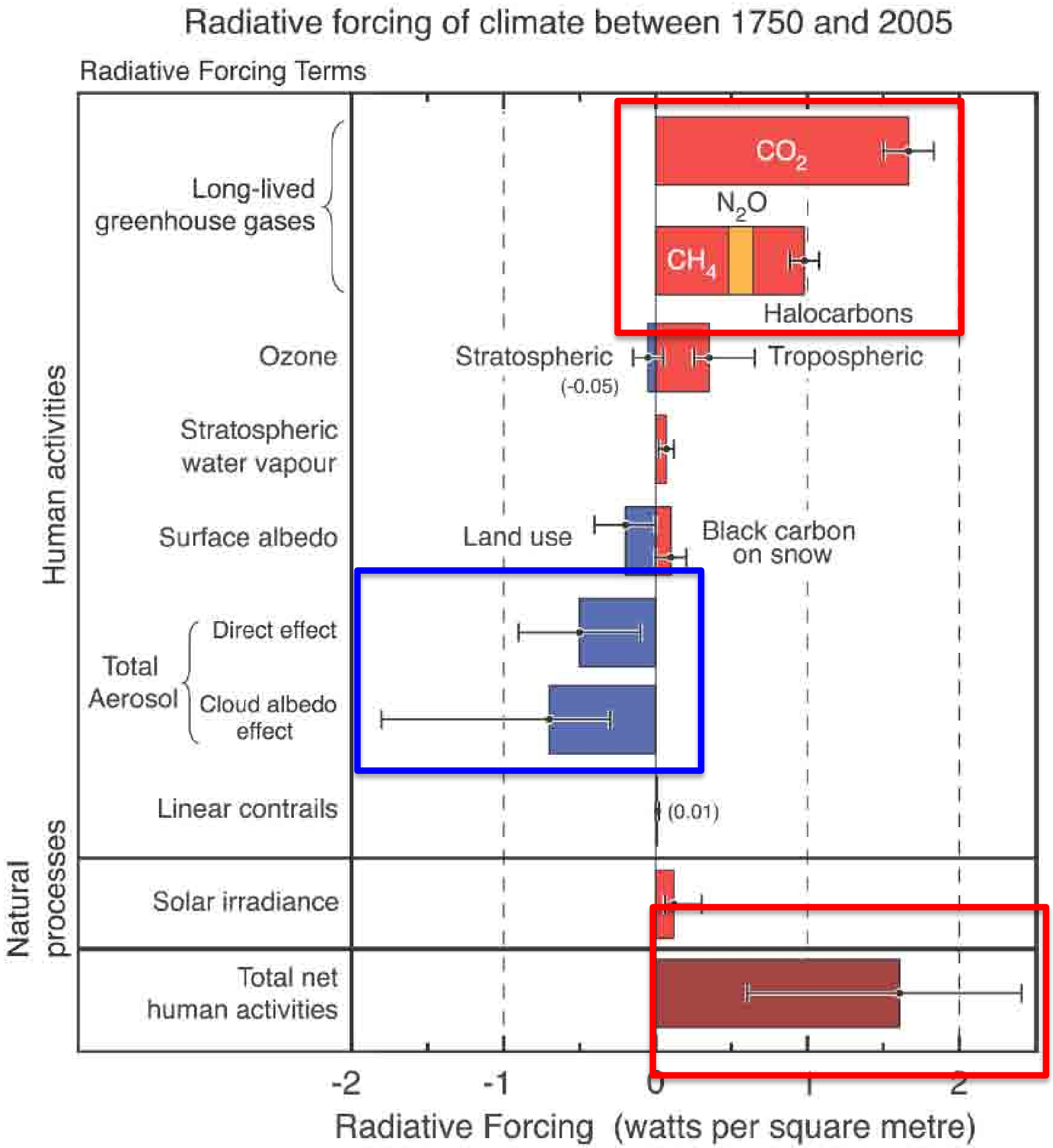

Solar Irradiance ~ 1350 W/m^2

(more in Lecture 15)

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No Models! (ok, a little modeling)

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http://onlinelibrary.wiley.com/doi/10.1029/2009JD012105/full

(more in Lecture 15,17,18)

Anthropogenic CO_2 and a Delayed Ice Age?

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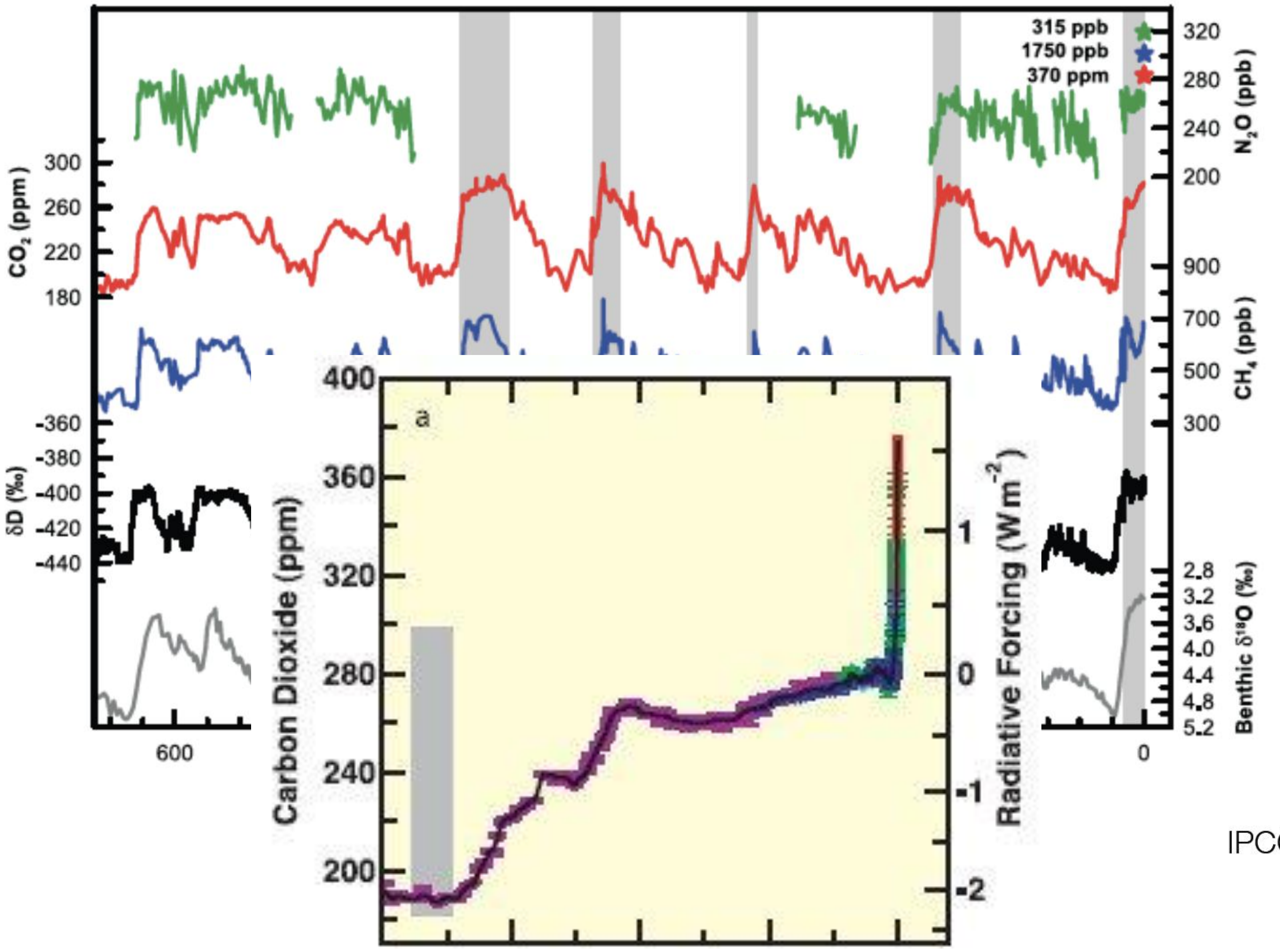
Anthropogenic CO2 and a Delayed Ice Age?



Problems?

- Adaptation (extinction)?
- Increase drought
- Increasingly sever storms
- Sea level rise / lost land
- Increased disease
- Increased conflict over resources

IPCC AR4

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Recap

- The concept of greenhouse gases and why they are important (necessary!)

- The important natural and anthropogenic greenhouse gases

- Paleo versus modern greenhouse levels

References

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Beerling D. J., & Royer, D. Convergent cenozoic CO_2 history, Nature Geoscience, 4, 2011.

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