The Greenhouse Effect

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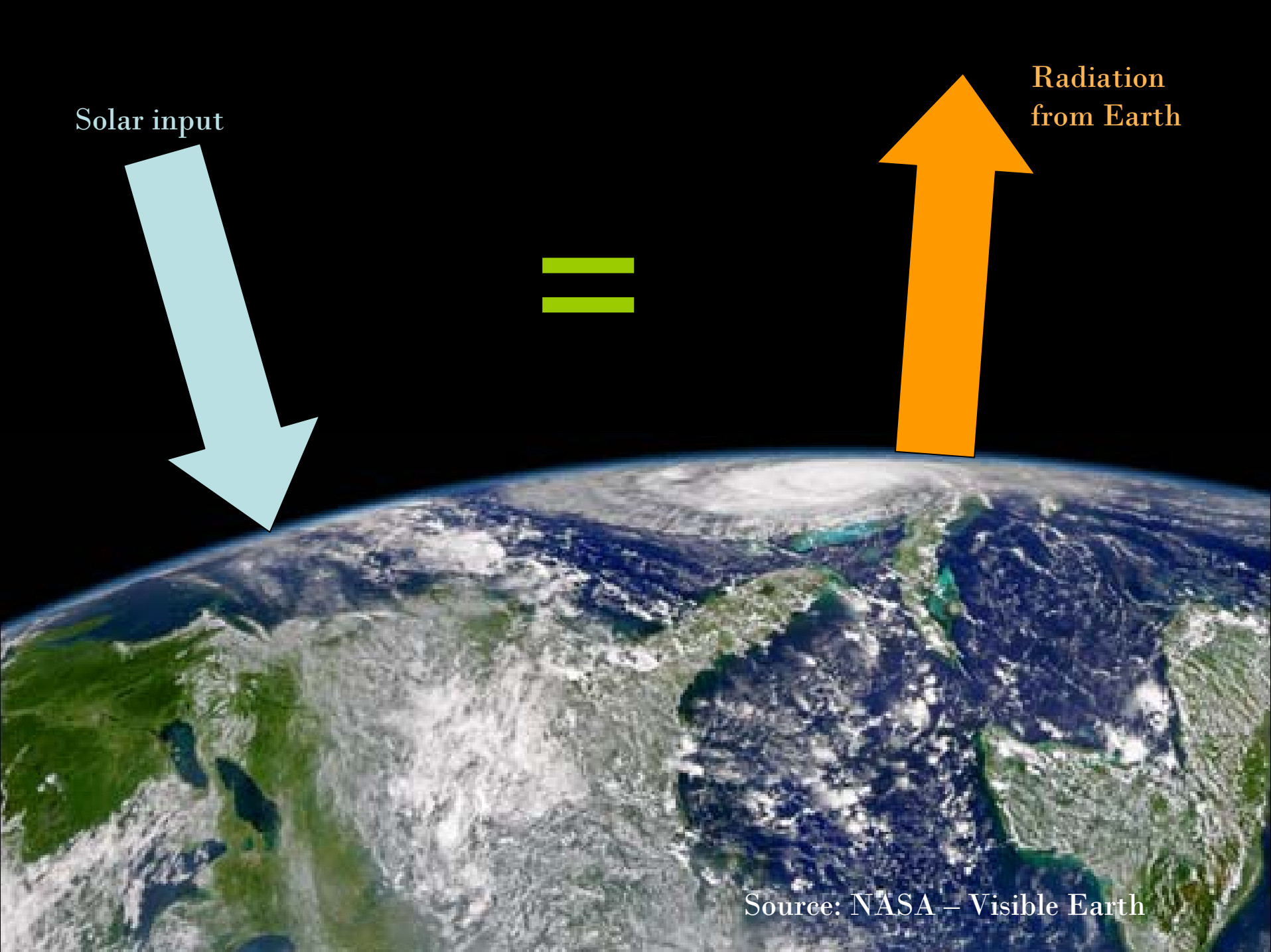
Global Warming: Problems & Solutions

17 September, 2007

What to cover today:

- How do we calculate the Earth's surface temperature?
- What makes a gas a greenhouse gas and how does the increasing greenhouse gases in the atmosphere cause global warming?


Solar input
=
Radiation
from Earth
Source: NASA – Visible Earth

Solar input depends on the distance between the Sun and the planets and the size of the planets

Earth!

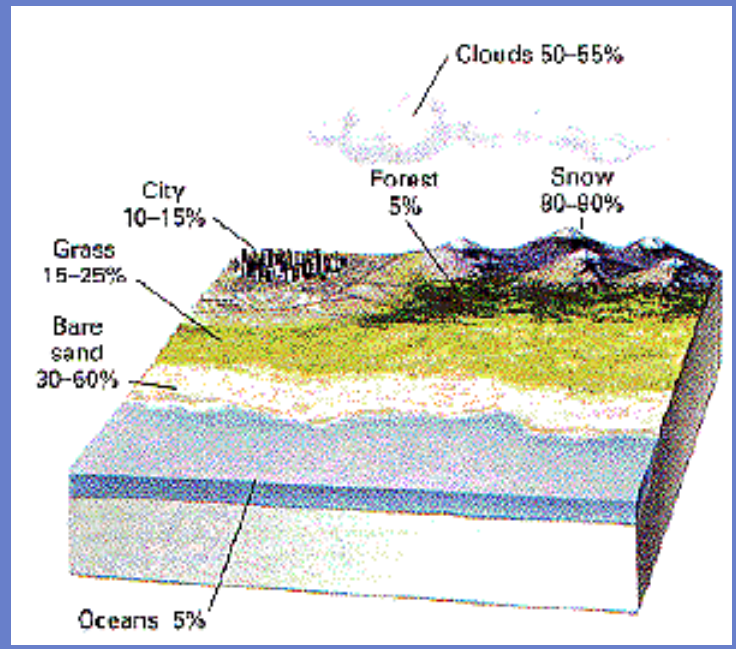
1 AU = 1.5×10^8 km

$r_E = 6378\text{km}$

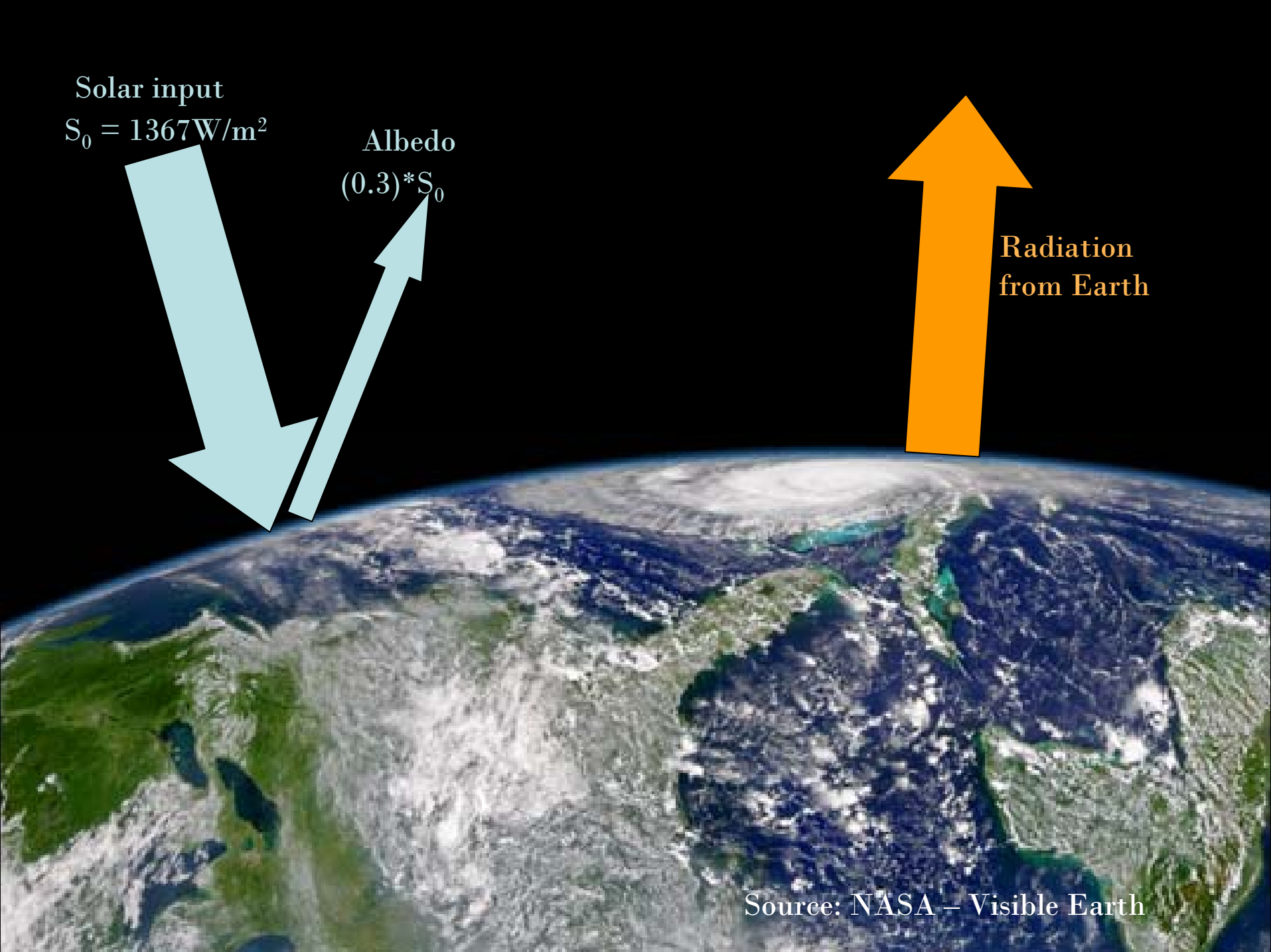
$S_0 = 1367\text{W/m}^2$

Is that all?

It turns out that not all incoming solar radiation is absorbed at Earth's surface. Part of it is directly reflected from clouds, the surface itself, and air molecules. This reflectance of solar input is called **albedo**; the present value for Earth is about 0.3.



http://www.geo.lsa.umich.edu/~crlb/COURSES/117-IntroductiontoGeology/Lec23/lec23.html

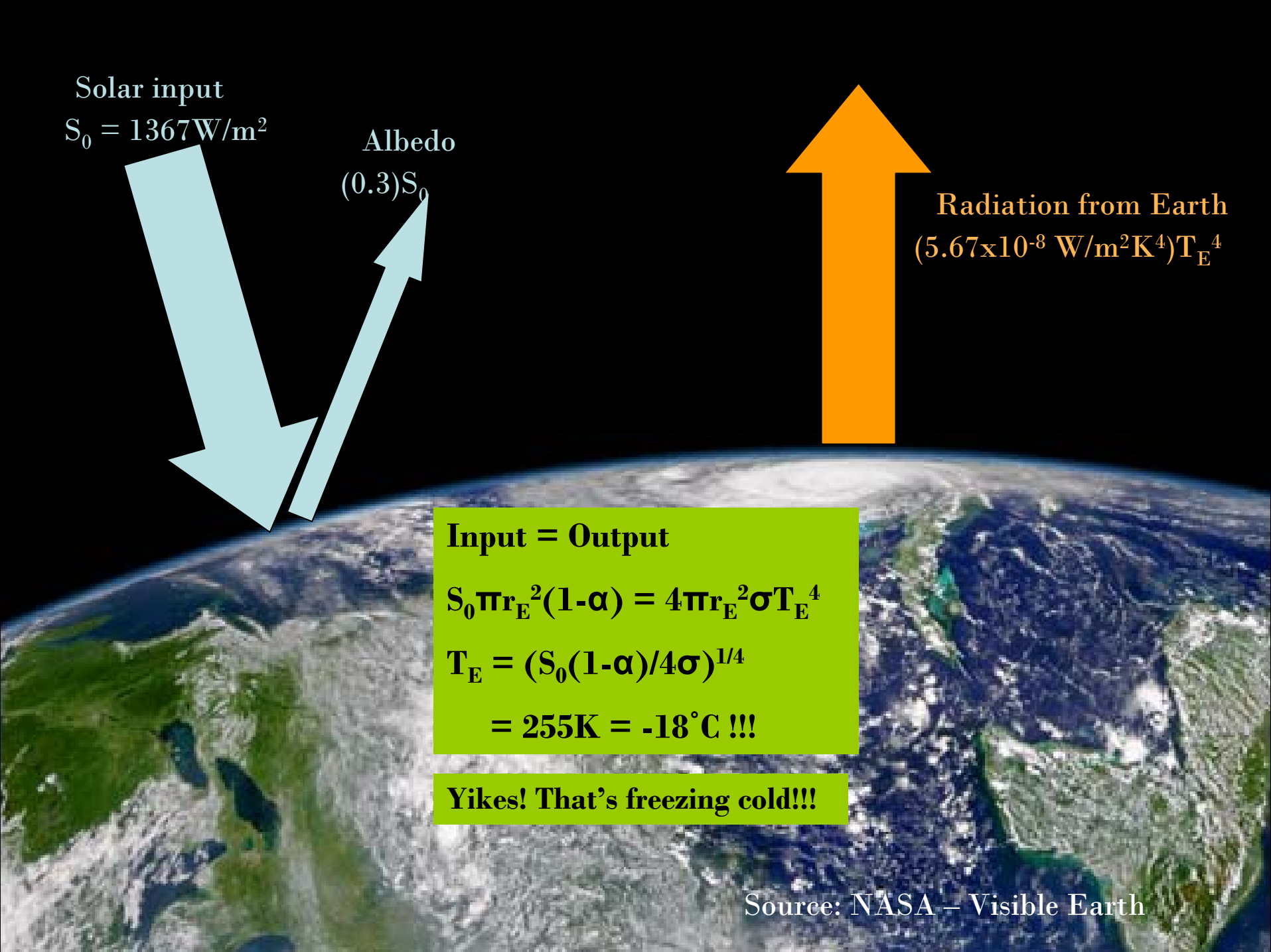

Solar input
$S_0 = 1367 W/m^2$
Albedo
$(0.3)*S_0$
Radiation
from Earth
Source: NASA – Visible Earth

The amount of radiation emitted is proportional to the surface temperature of that body…

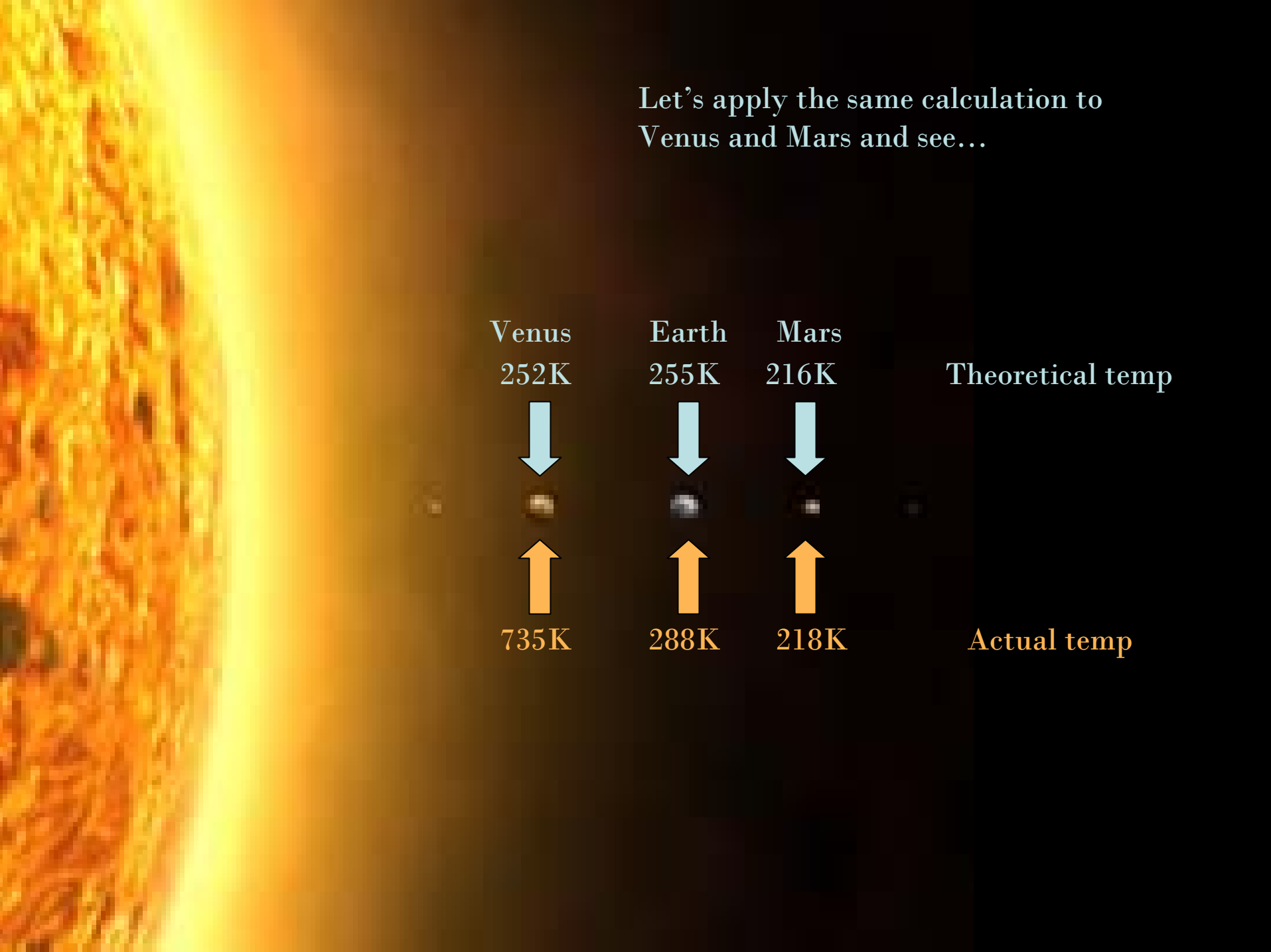
radiation emitted = σT_E^4

$\sigma \equiv$ Stephan-Boltzmann constant

$= 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$


Solar input
$S_0 = 1367 W/m^2$
Albedo
$(0.3)S_0$
Radiation from Earth
$(5.67x10^{-8} W/m^2K^4)T_E^4$
Input = Output
$S_0\pi r_E^2(1-\alpha) = 4\pi r_E^2\sigma T_E^4$
$T_E = (S_0(1-\alpha)/4\sigma)^{1/4}$
$= 255K = -18^{\circ}C$!!!
Yikes! That's freezing cold!!!
Source: NASA – Visible Earth

Let's apply the same calculation to Venus and Mars and see…



What parameters do we need to calculate the Earth's average surface temperature?

- Solar input (depends on distance from Sun and size of planet)
- Albedo (depends on landform and cloud cover)
- Blackbody assumption (perfect absorption and perfect emission)
- Greenhouse effect

Wait a second, there is another twist!

About 25% of the incoming solar radiation is absorbed by various gases like H_2O, CO_2, O_2, and O_3 before it hits the surface. So the calculation would be:

Input = Output

$$S_0(1 - \alpha - \text{atmos absorption}) = 4\sigma T_E^4$$

$$= 615 \text{ W/m}^2$$

$$T_E = (S_0(1 - \alpha - \text{atmos absortion})/4\sigma)^{1/4}$$

$$= 228\text{K} = -45^\circ\text{C}$$!!!

Opps… that's going the wrong direction!

Thankfully, greenhouse gases also save the day!

We know the average surface temperature of Earth is about 15°C, by back calculation we see:

$4\sigma(T_E)^4 = 4\sigma(288K)^4 = 1560\ W/m^2$

GH Effect = $1560\ W/m^2 - 615\ W/m^2 = 945\ W/m^2$

Let us compare:

solar input	$1367\ W/m^2$
greenhouse effect	$945\ W/m^2$

Thankfully, greenhouse gases also save the day!

The greenhouse effect is HUGE ! From the "no atmosphere" model of -18°C to an observed average surface temp of 15°C, it is a +33°C effect !

Furthermore, if this were linear then we would get 1°C increase for every 7 W/m^2. Thankfully this is not the case, but adding more greenhouse gases into the atmosphere still poses an appreciable amount of warming to Earth!

Let's come back to the planets…

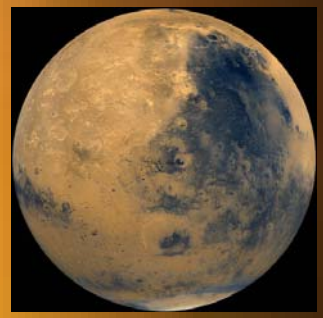
Venus has a really thick atmosphere (90 times Earth's surface pressure.) More importantly, this atmosphere consists of 96% CO_2

735K Venus

298K Earth

218K Mars

Let's come back to the planets…



Mars has a *very* thin atmosphere such that the greenhouse effect is nearly negligible

735K
Venus

298K
Earth

218K
Mars

Let's come back to the planets…

Earth has an atmosphere composed of 78% N_2, 21% O_2, and only ~1% of traces gases including greenhouse gases

735K Venus

298K Earth

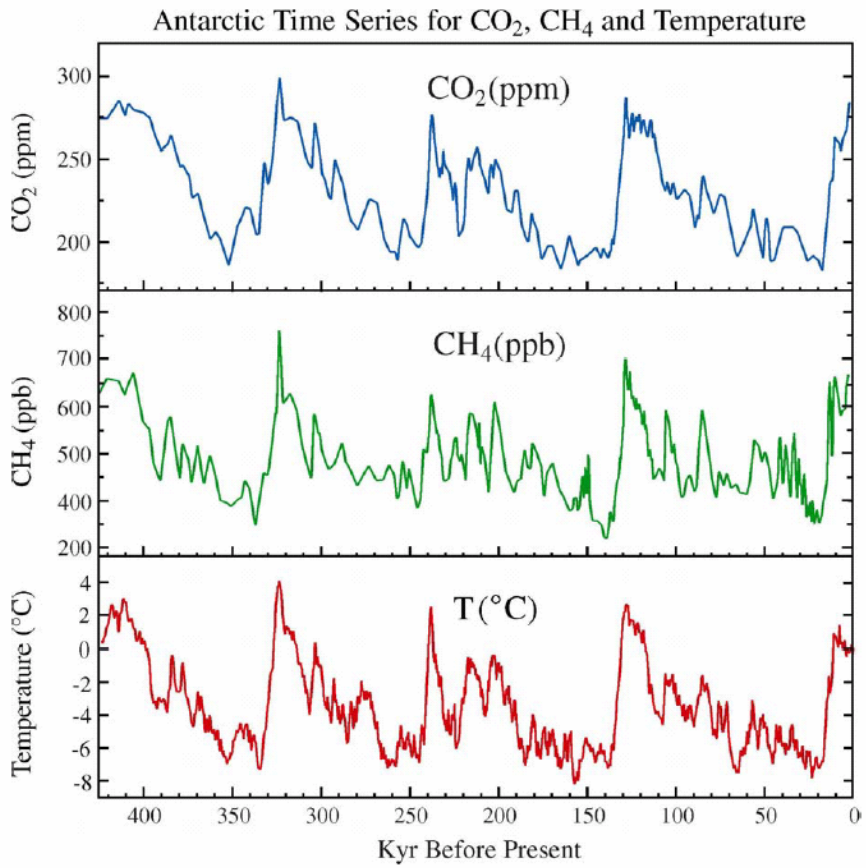
218K Mars

Earth is so far the only life-sustaining planet not just because of the right distance from the Sun but also due to a moderate greenhouse effect.

That was a lot of math…

Now what ?!

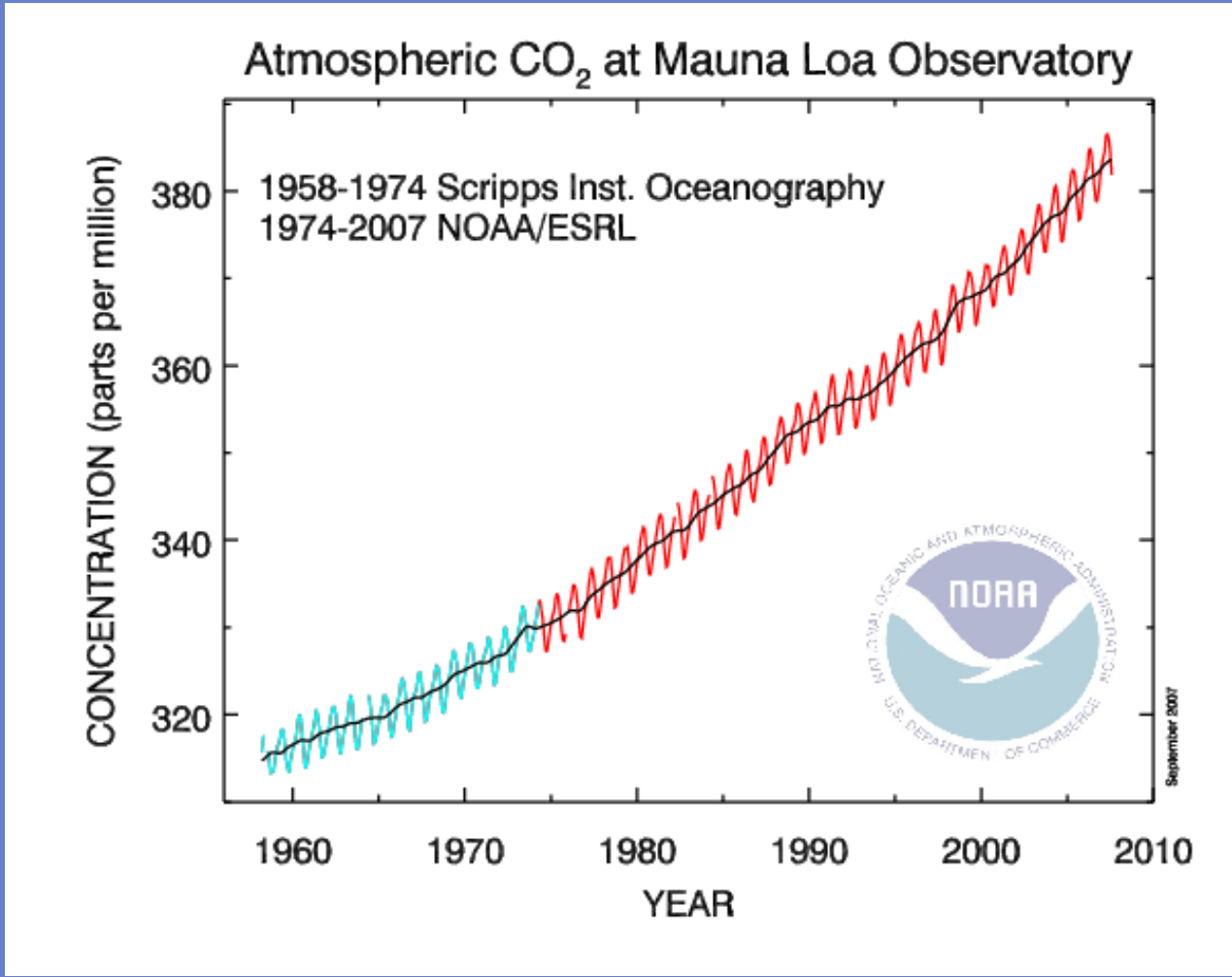
Past atmosphere



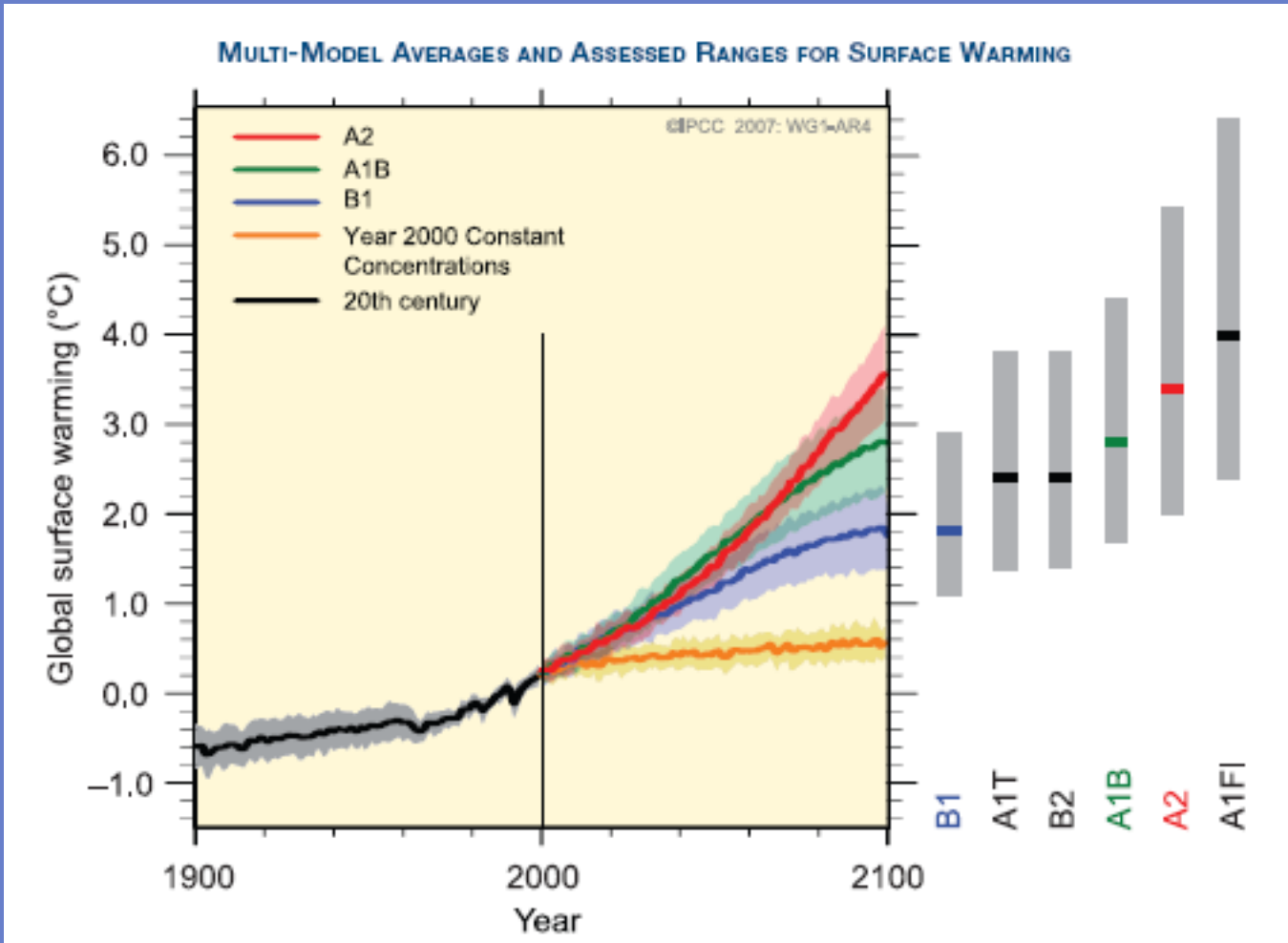
CO_2, CH_4 and temperature records from Antarctic ice core data

Source: Vimeux, F., K.M. Cuffey, and Jouzel, J., 2002, "New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction", *Earth and Planetary Science Letters*, **203**, 829-843.

Present atmosphere

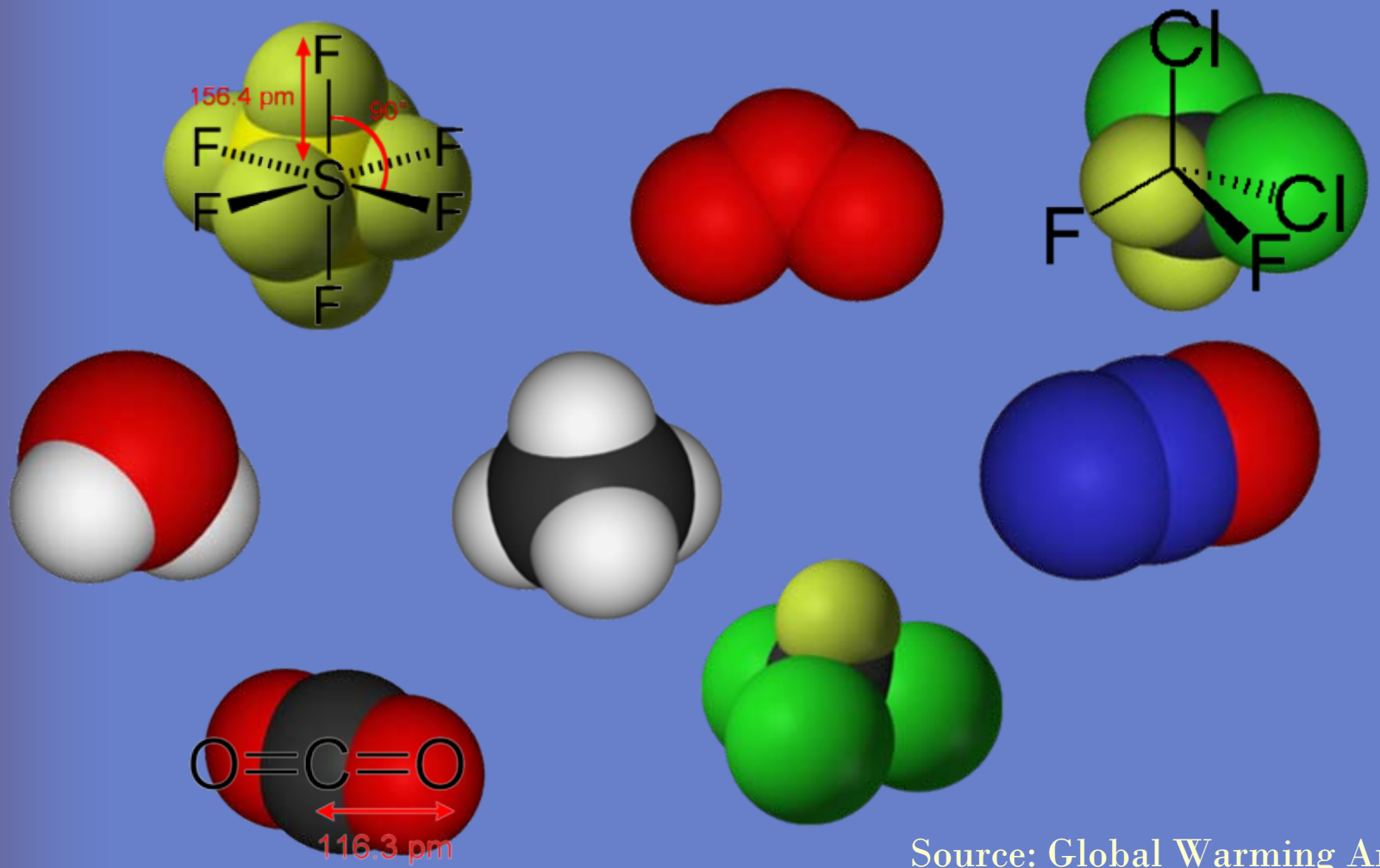


Future atmosphere?



Source: IPCC AR4

What are greenhouse gases?



Source: Global Warming Art

What are greenhouse gases?

Greenhouse gases can effectively absorb radiation emitted from the Earth's surface. Such absorption excites molecules to vibrate and rotate and sometimes change their *dipole moment*.

Symmetric and linear molecules like O_2 and N_2 do not have a dipole moment (and cannot produce one).

Dipole Moment

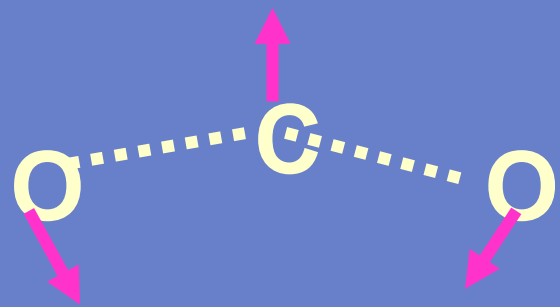
- Amount of charge separated by distance
- There needs to be a change in dipole moment- a change of charge for a molecule to interact with the energy radiating from Earth's surface (electromagnetic radiation)

What are greenhouse gases?

ν_1 **symmetric**

ν_2 **bending**

15 μm



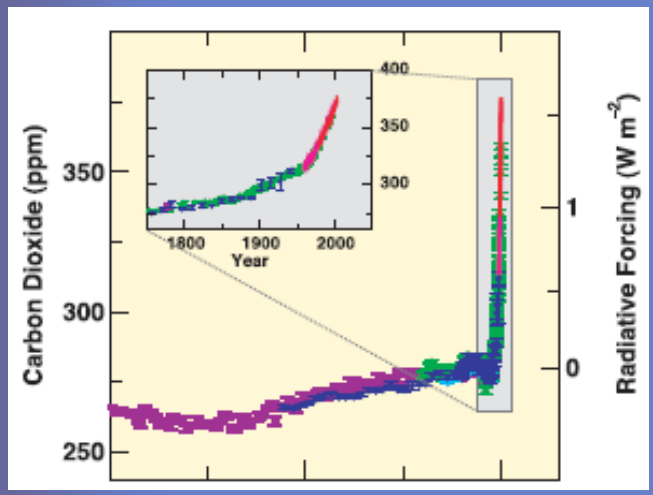
ν_2 **asymmetric**

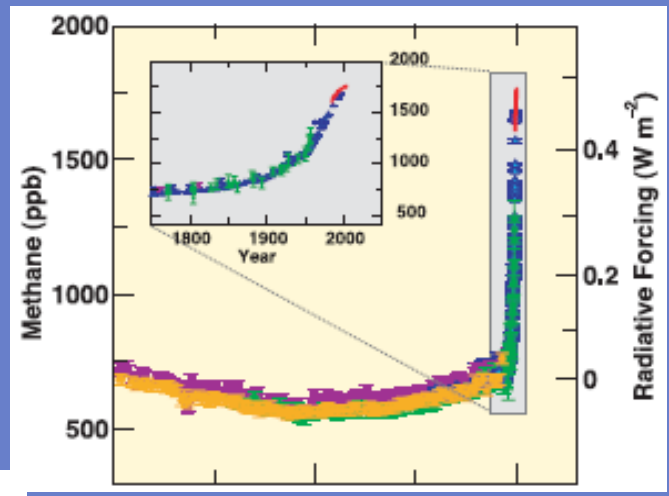
4.3 μm

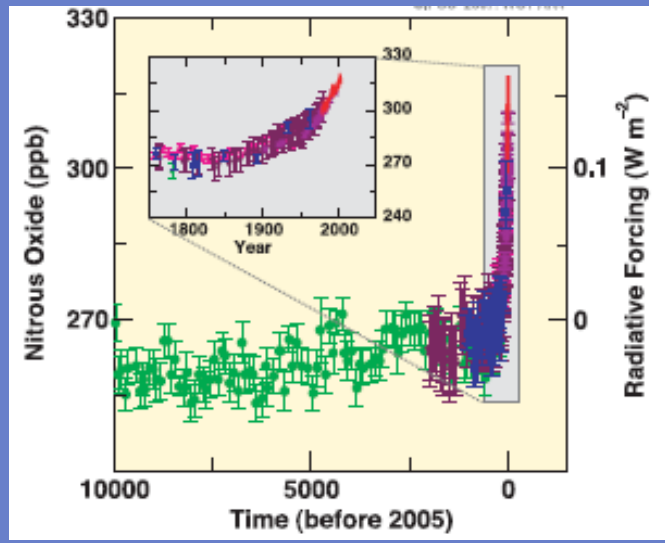
Sources of greenhouse gases:

CO_2	Natural: ocean, volcano, decomposition Anthropogenic: fossil fuel burning, exhaust
CH_4	Natural: aerobic decomposition (wetland, cows) Anthropogenic: fossil fuel burning, agriculture
N_2O	Natural: soil and ocean Anthropogenic: fertilizers (nitrification of ammonium)
CFCs / HCFCs	Anthropogenic: refrigerant, aerosol propellant
O_3	Natural: photolysis Anthropogenic: NOx + VOCs

Concern?







Source: IPCC AR4

Acknowledgement

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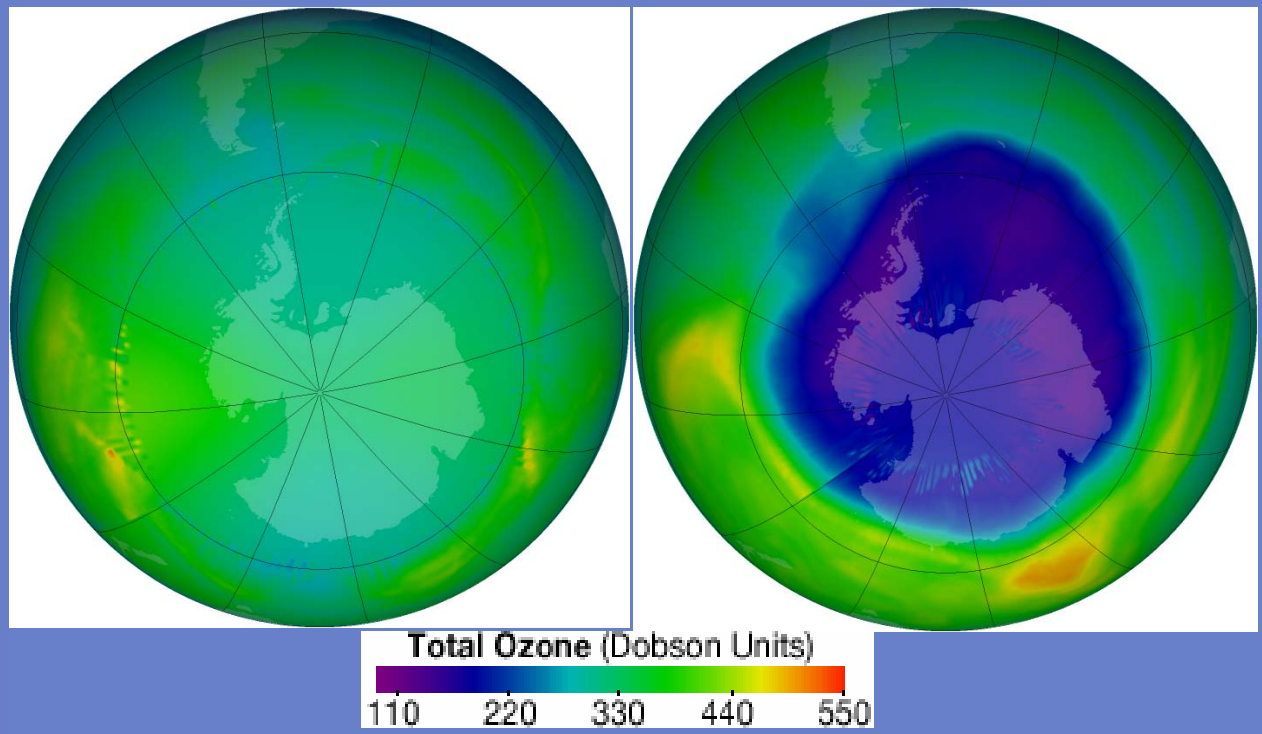
Discussion

If we cannot predict the weather for more than 10 days, why should we believe in models that predict our climate 50 years from now?

Trends!

Is global warming also caused by the ozone hole, which is allowing more harmful and intense UV radiation to penetrate through?



13 July, 2007

13 September, 2007

Source: NASA – Ozone Hole Watch

Overlap between O_3 hole and GW

- Some of the most prominent ozone destructive chemical species, Chlorofluorocarbons (CFCs, entirely man-made), are also greenhouse gases (change in dipole moment!)

- Hydro-chlorofluorocarbons (HCFCs, also man-made), the replacement for CFCs, are less destructive to ozone but are still potent greenhouse gases

Stratospheric Ozone

- CFCs are now banned, but due to long life-time they will be around for another half a decade or so. The ozone hole still occurs during Antarctic spring but is hopefully on its way to shrink.

- We don't need to regenerate ozone. Ozone in the stratosphere is naturally produced and when we are not "poking" it as much it will gradually recover.

Two types of Ozone

- Ozone in the stratosphere (upper atmosphere) absorb harmful UV and is thus good, but that is also where most ozone loss occurs.

- Ozone in the troposphere (lower atmosphere) is a form of smog / pollution generated by NOx and VOCs and thus is bad. (BTW ozone is toxic- it causes breathing difficulties, lung tissue damage, and damages rubber and some plastics)