# Climate change: Lecture 2

Greenhouse gas effect

## Anthropogenic GHG emissions

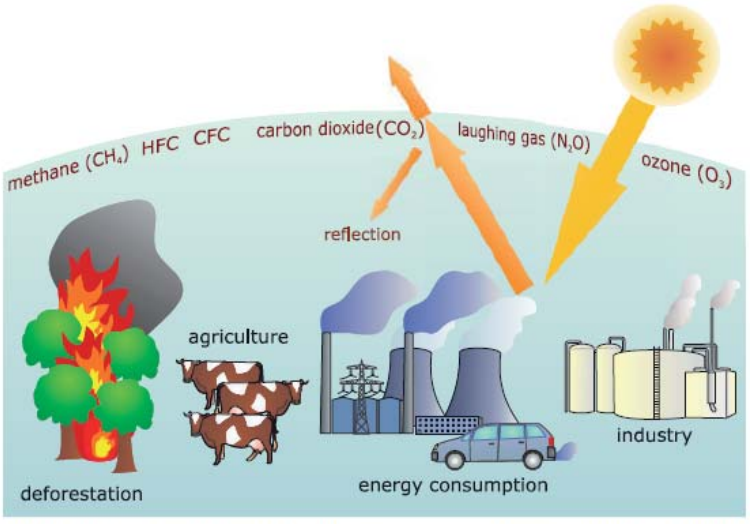
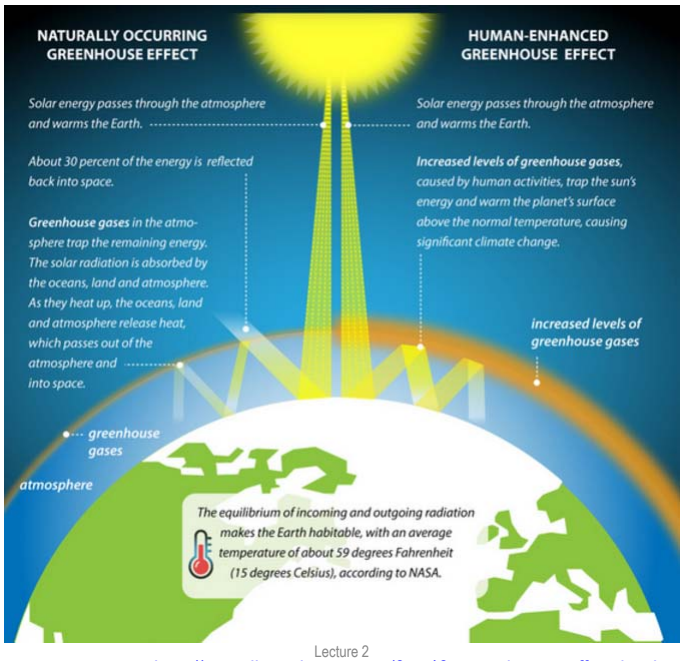



**Figure 2.6** Causes of anthropogenic greenhouse effects due to human activities.

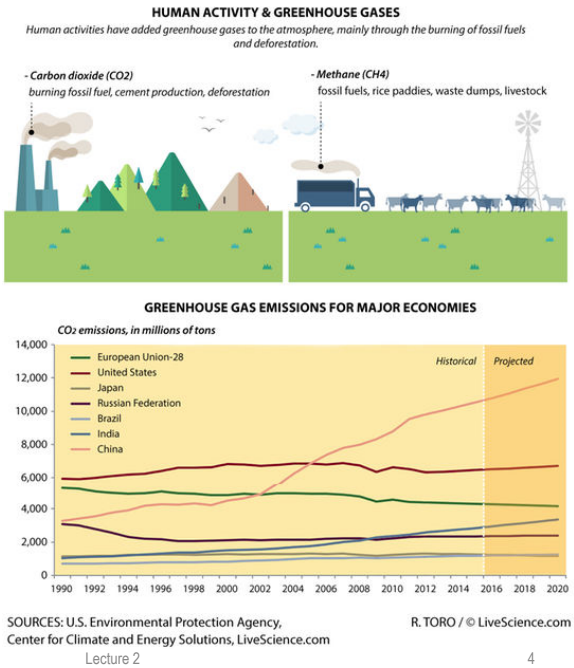





http://www.livescience.com/37743-greenhouse-effect.html

# Greenhouse gases

If global warming continues unchecked, it will cause significant climate change, a rise in sea levels, increasing ocean acidification, extreme weather events and other severe natural and societal impacts, according to NASA, the EPA and other scientific and governmental bodies.



# Atmosphere

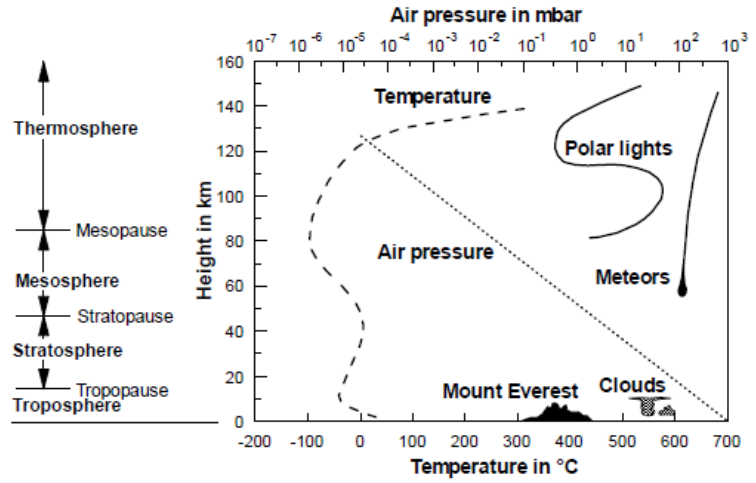



**Fig. 2.4** Cross-section through the atmosphere (see /2-2/)



**Table 2.1** Composition of the air (see /2-2/)

| | | |
|---|---|---|
| Components independent from time and space | | |
| nitrogen ($N_2$) | | 78.08 vol. %; 75.53 mass % |
| oxygen ($O_2$) | | 20.95 vol. %; 23.14 mass % |
| argon (Ar) | | 0.93 vol. %; 1.28 mass % |
| further noble gases (He, Ne, Kr, Xe) | | traces |
| Components dependent on time and space | | |
| steam ($H_2O$) | | depending on meteorological conditions up to 4 % |
| carbon dioxide ($CO_2$) | | 0.03 vol. %; 0.05 mass %; tendency currently increasing |
| admixtures | | |
| gases | ozone ($O_3$) | from the high atmosphere |
| | radon (Rn) | from radioactive soil respiration |
| | sulphur dioxide ($SO_2$) | from e.g. volcanoes, post-volcanic activities |
| | carbon monoxide (CO) | oxidizes into carbon dioxide ($CO_2$) in the short term |
| | methane ($CH_4$) | from e.g. animal digestion, anaerobic fermentation |
| | VOC | from plants |
| Aerosols | gaseous aerosols | from gaseous reactions (sulphates, nitrates etc.) |
| | dust | for example plain, desert, or volcano dust |
| | plant ash | from forest and steppe fires |
| | sea water salt | transferred into the air with breaking wave crests |
| | biomass | for example micro-organisms, pollen |

mass % mass percentage; vol. % volume percentage.

# GHG emitters

**Table 2.1** The ten countries on earth with the highest energy-related carbon dioxide emissions. Status: 2006. Data: IEA (International Energy Agency, 2008).

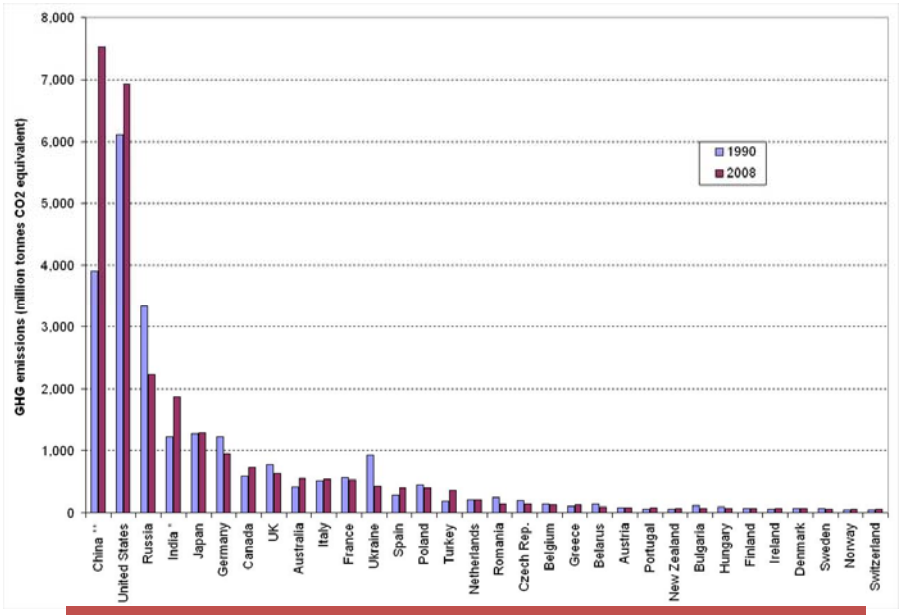
| Country | Mll. t $CO_2$ | Mll. Inhab. | t $CO_2$/ Inhab. | Country | Mll. t $CO_2$ | Mll. Inhab. | t $CO_2$/ Inhab. |
|---|---|---|---|---|---|---|---|
| 1. USA | 5697 | 299 | 19.00 | 6. Germany | 823 | 82 | 10.00 |
| 2. China | 5606 | 1312 | 4.27 | 7. Canada | 539 | 33 | 16.52 |
| 3. Russia | 1587 | 143 | 11.14 | 8. Great Britain | 536 | 61 | 8.86 |
| 4. India | 1250 | 1110 | 1.13 | 9. South Korea | 476 | 48 | 9.86 |
| 5. Japan | 1213 | 128 | 9.49 | 10. Italy | 448 | 59 | 7.61 |
| **World** | **28 003** | **6546** | **4.28** | 133. Mozambique | 2 | 20 | 0.08 |



## WORLD $CO_2$ EMISSIONS STATISTICS IN 2010

| S.N. | Country | Mtoe CO2 |
|---|---|---|
| 1 | China | 7 366 |
| 2 | United States | 5 380 |
| 3 | India | 1 626 |
| 4 | Russia | 1 585 |
| 5 | Japan | 1 058 |
| 6 | Germany | 754 |
| 7 | South Korea | 545 |
| 8 | Canada | 522 |
| 9 | United Kingdom | 491 |
| 10 | Saudi Arabia | 452 |

Source:: http://yearbook.enerdata.net/2010-energy-consumption-data.html#/2010-CO2-emissions-data-from-fuel-combustion.html




http://www.climatechangeconnection.org/emissions/GlobalchangesinGHG.htm



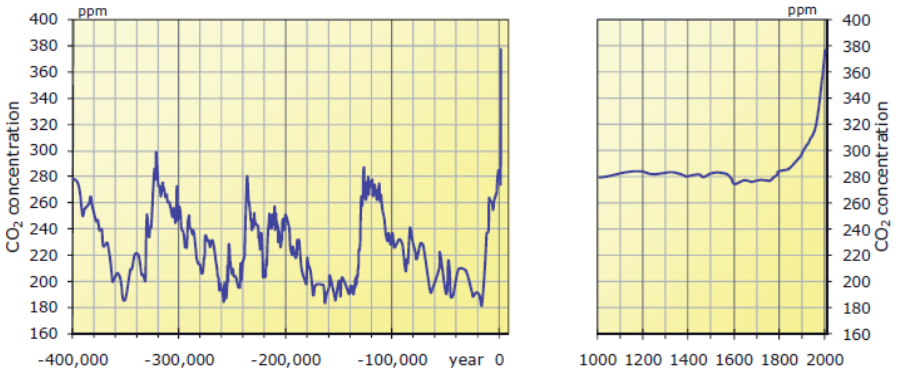



**Figure 2.7** Development of carbon dioxide concentration in the atmosphere over the last 400 000 years and in the recent past. Data: CDIAC, cdiac.ornl.gov.

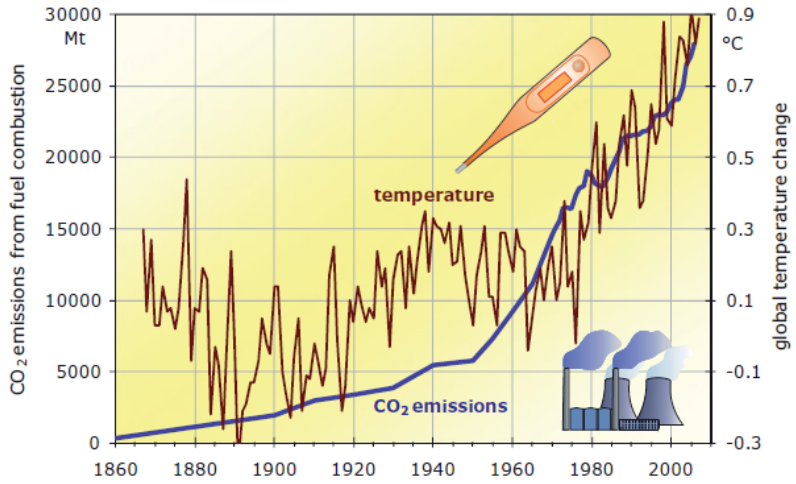



**Figure 2.8** Progression of energy-related $CO_2$ emissions and global changes in temperatures since 1860.



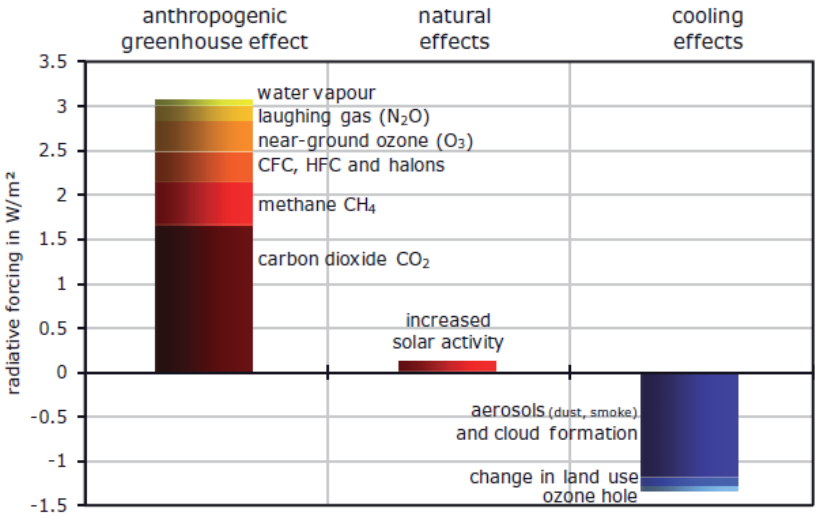


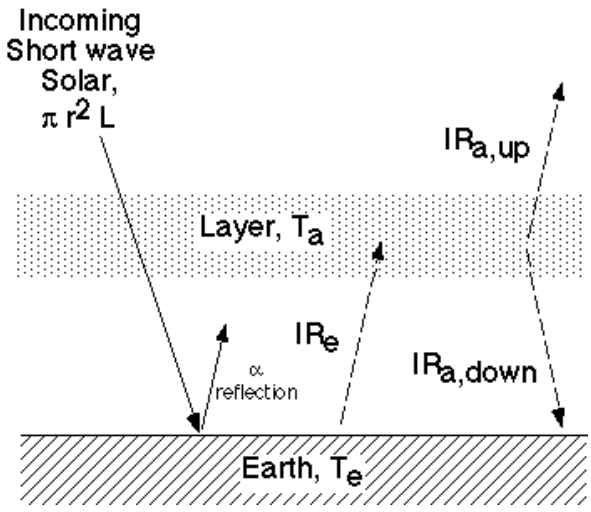

**Figure 2.9** Causes of global warming. Data: IPCC (Intergovernmental Panel on Climate Change, 2007), www.ipcc.ch.

# ALBEDO

- Albedo: reflection coefficient can range from 0 (no reflection) to 1 (100% reflection).
- On average earth has an albedo of 0.3 in the visible range.
- A (visible) = 0.3: 1/3rd from earth's surface, 2/3rd from atmosphere.
- A (IR) ~ 0



Simplified scheme of the Earth radiation balance




L – solar constant (1367 W/m^2)

## EARTH AS A BLACK BODY (Zeroth Order Model)

- Solar Flux Ω = 1,372 W/m$^2$ (at a point directly under the sun)
- Average Flux = Ω/4 (Average over day and night and over all latitudes)
- Surface area: $4\pi R^2$; Perpendicular are (disc) = $\pi R^2$
- Stefan-Boltzman Law describes the relationship between temperature of black bodies and their rate of radiation
- $F = \sigma T^4$

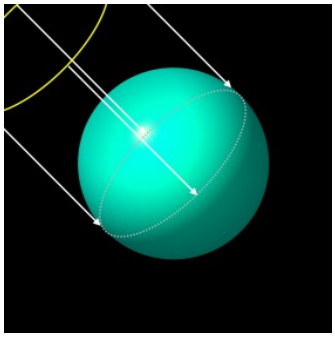
  F is radiant energy output (units energy per unit time per unit area)

  T is the absolute temperature of the object in Kelvins

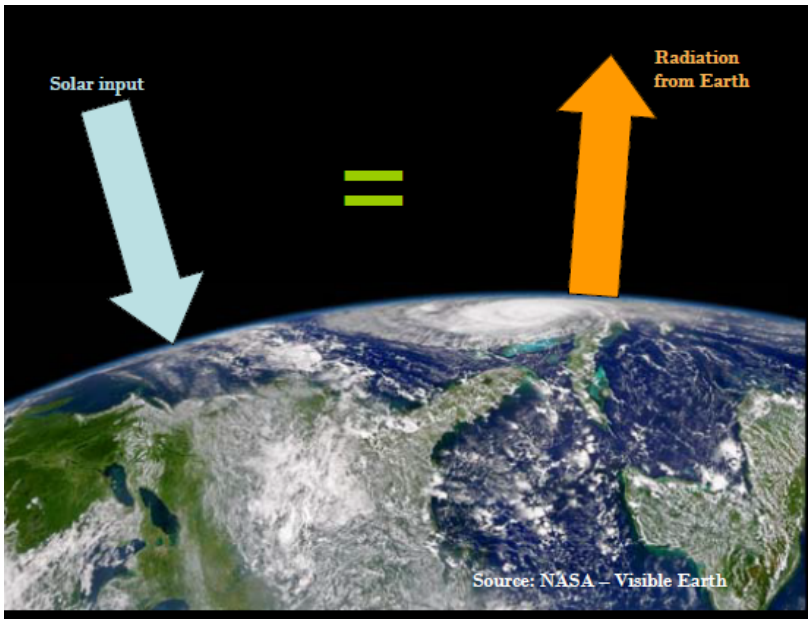
  $\sigma = 5.67 \times 10^{-8}$ J/m$^2$ sec K$^4$
- $F_{in} = \Omega/4$; $F_{out} = a\Omega/4 + \sigma T^4$
- $T^4 = (1\text{-}a)\ \Omega/4\sigma$
- Black body temperature of the earth, $T_o$ = 255K



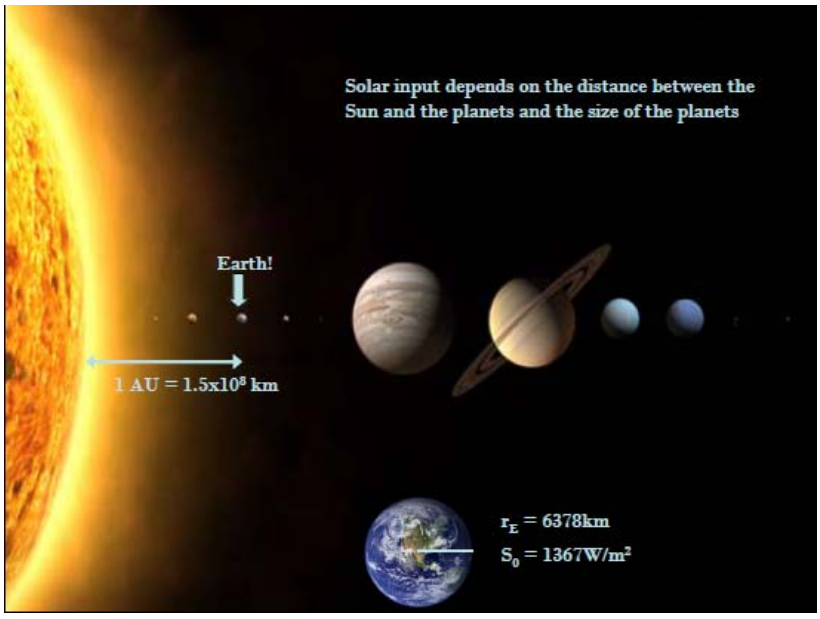
## Why is it one quarter?



This is because the full energy does not vertically hit the full Earth surface, but only the cross section of the Earth. We know that half of the Earth is always in the night and the sun radiation under a low angle is weaker. Since the cross section of a sphere is one fourth of the surface of a sphere the total energy on the Earth surface is R = 1/4 L = 342 W/m$^2$. (L is solar flux = 1367 W/m$^2$)

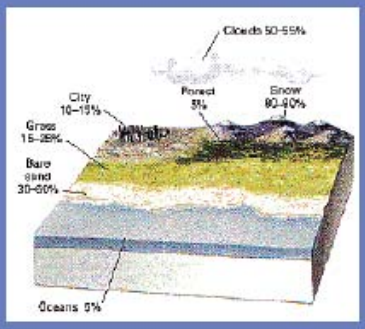

Solar input
Radiation from Earth
Source: NASA – Visible Earth




Solar input depends on the distance between the Sun and the planets and the size of the planets
Earth!
1 AU = 1.5x10⁸ km
$r_E$ = 6378km
$S_0$ = 1367W/m²

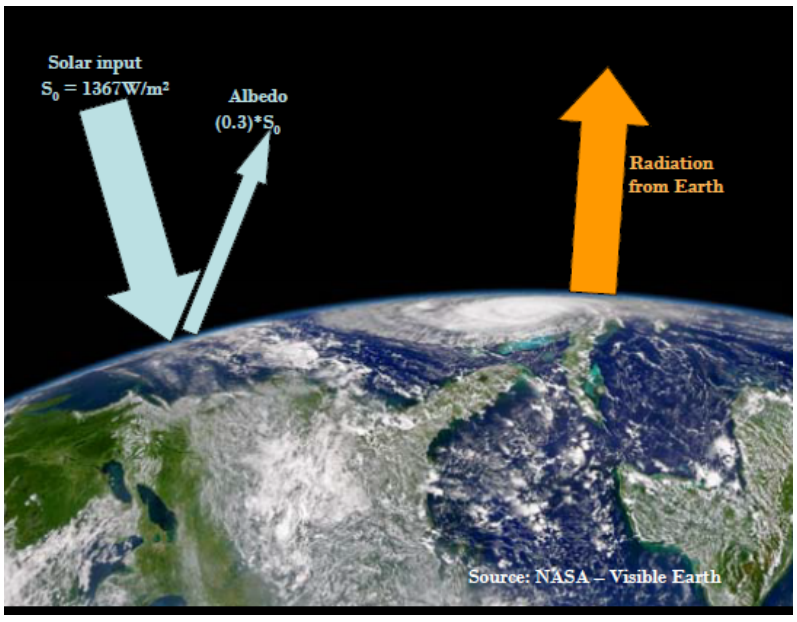
## Is that all?

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





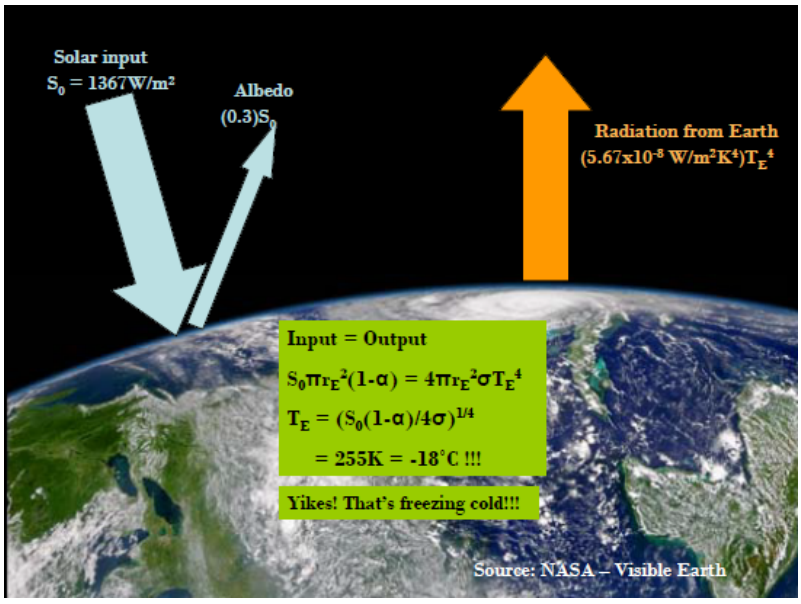
The amount of radiation emitted is proportional to the surface temperature of that body…

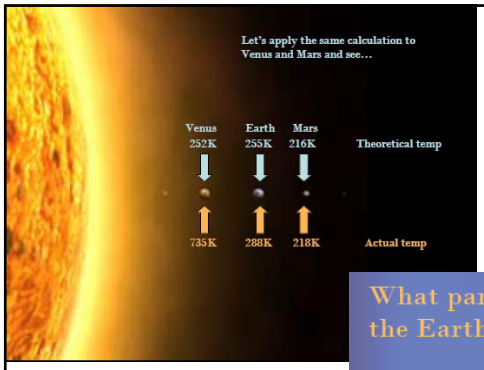
radiation emitted = $\sigma T_E^4$

$\sigma \equiv$ Stephan-Boltzmann constant

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








## 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**

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

$= 615\ W/m^2$

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

$= 228K = -45°C$ !!!

**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:

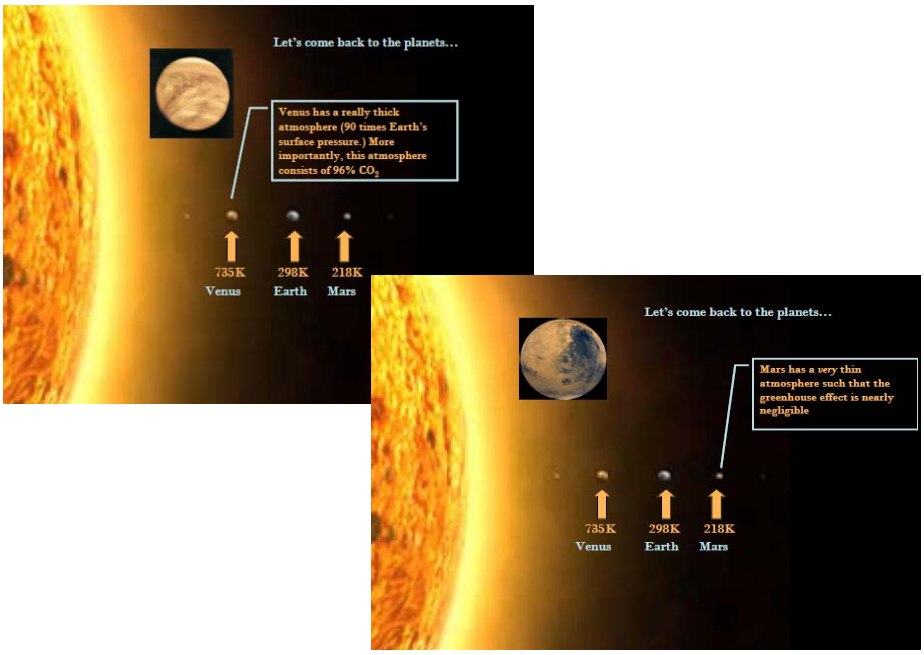
solar input 1367 $W/m^2$

greenhouse effect 945 $W/m^2$

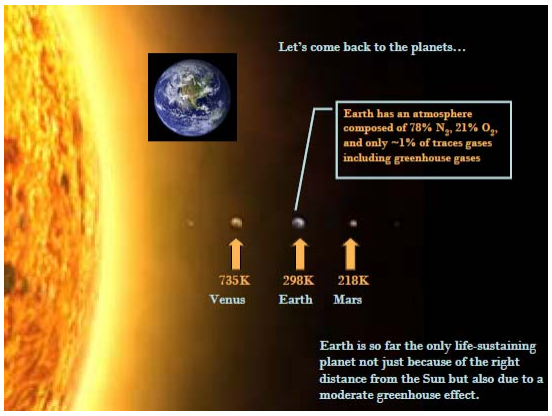
## Thankfully, greenhouse gases also save the day!

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!

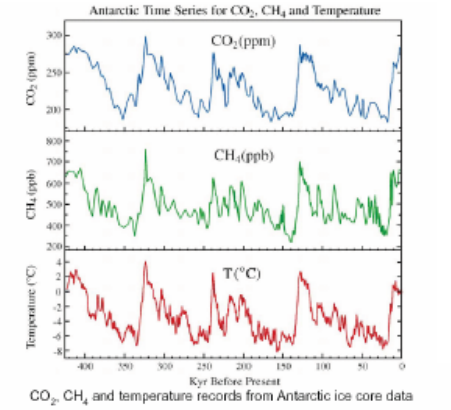



Lecture 2 25




Lecture 2 26

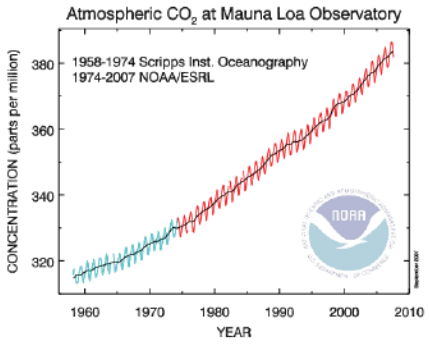
## Past atmosphere




$CO_2$, $CH_4$ and temperature records from Antarctic ice core data

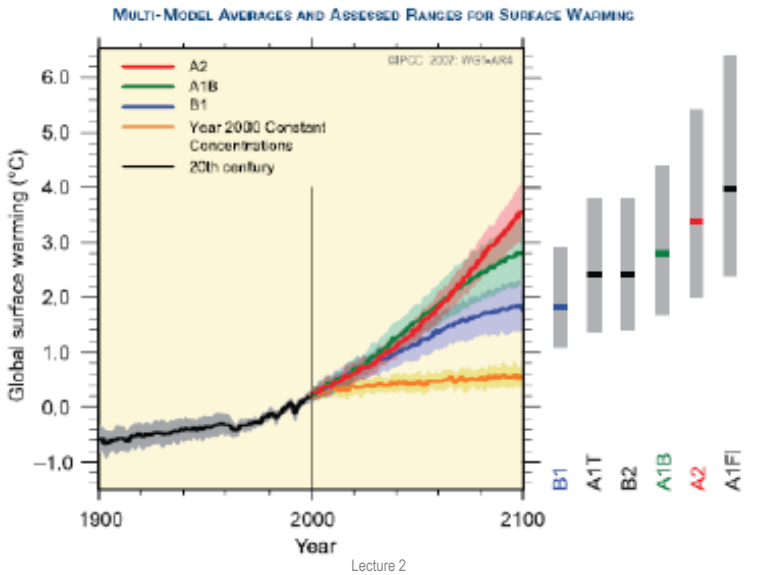
*Source:* Vimeux, F., K.M. Cuffey, and Jouzel, J., 2002. "New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction". *Earth and Planetary Science Letters*, **203**: 829-843.

## Past atmosphere






## Future atmosphere



## Sources of greenhouse gas

| GHG | Sources |
|---|---|
| $CO_2$ | Natural: ocean, volcano, decomposition<br>Anthropogenic: fossil fuel burning, exhaust |
| $CH_4$ | Natural: aerobic decomposition (wetland, cows, etc.)<br>Anthropogenic: fossil fuel burning, agriculture |
| $N_2O$ | Natural: soil and ocean<br>Anthropogenic: fertilizer (nitrification of ammonium) |
| CFC/ HCFCs | Natural: x<br>Anthropogenic: refrigerant, aerosol propellent |
| $O_3$ | Natural: photolysis<br>Anthropogenic: NOx + VOC |
| $SF_6$ | Natural: x<br>Anthropogenic: insulator for high voltage equipment |



## Earth surface temperature considering GHG emissions

- Incoming energy from sun:
  (1-a)*S*π*r^2 (energy absorbed)
- Outgoing energy from the earth:
  4*π*r^2*ε*σ*T^4 (Energy emitted), ε – emissivity
- (1-a)*S*π*r^2 = 4*π*r^2*ε*σ*T^4
- (1-a)*S = 4*ε*σ*T^4
- T^4 = (1-a)*S/(4*ε*σ), by taking S=1367W/m^2 and ε=0.612 we get
- T^4 = 6.89E+09 K^4
- T = 288.15 K = 15.15°C

# Conclusions

- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.
- An increase in global temperature will lead to global climate change.
- Not all the climate changes will in the end be adverse. While some parts of the world experience more frequent or more severe droughts, floods or significant sea level rise, in other places crop yields may increase due to the fertilising effect of carbon dioxide.
- Increasing demand of energy leads to more consumption of fossil fuels which ultimately increases the emission of greenhouse gas to the atmosphere.



# Homework

- Reading materials:
- Chapters 2 and 3 from ebooks on
  - Energy and climate
  - Global warming