Climate: It's All About the Sun!!! Or, Is It?
Chris Fairall, NOAA ESRL

- Introduction, background on climate system
- Black body radiation basics
- The sun vs earth as blackbodies
- Mean radiative balance of the earth
- Greenhouse effect made (deceptively) simple
- Tropics vs poles
- Global circulations
- The sun vs CO2: A global warming question

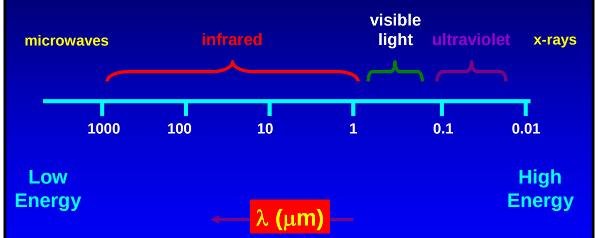
Introduction, background on climate system

- The Earth climate system maintains a balance between solar energy absorbed and IR (blackbody) energy radiated to space.
- The so-called *Greenhouse* effect distributes the temperature in the atmosphere so that the surface is much warmer than the mean radiative temperature.
- Currents and Winds redistribute the heat within the System – principally cooling the equatorial regions and warming the poles.

Blackbody Radiation/ Planetary Energy Balance

*Electromagnetic Spectrum
*Blackbody radiation – temperature
*Sun's heat at the earth
*Earth's blackbody radiation to space
*Planetary radiation temperature of Earth
*Surface temperature of Earth

Electromagnetic Spectrum



Blackbody Radiation

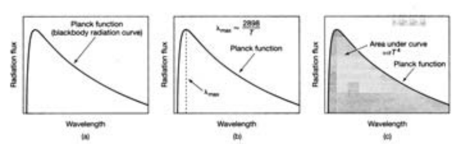


FIGURE 3-7
(a) The Planck function, or blackbody radiation curve; (b) Wien's law; (c) the Stefan-Boltzmann law.

Blackbody radiation—radiation emitted by a body that emits (or absorbs) with maximum efficiency at all wavelengths

Greybody radiation —radiation emitted by a body that emits (or absorbs) with efficiency ε (0 to 1.0) at all wavelengths
ε is called the EMISSIVITY

Basic Laws of Radiation

1) All objects emit radiant energy.

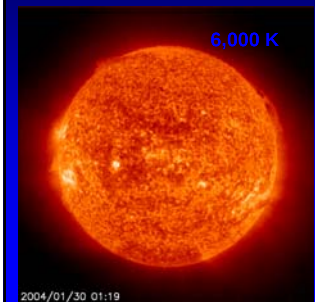
2) Hotter objects emit more energy than colder objects. The amount of energy radiated is proportional to the temperature of the object raised to the fourth power.

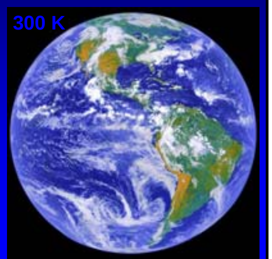
➡ This is the Stefan Boltzmann Law

$$F = \sigma T^4$$

F = flux of energy (W/m^2)
T = temperature (K)
$\sigma = 5.67 \times 10^{-8}$ W/m^2K^4 (a constant)

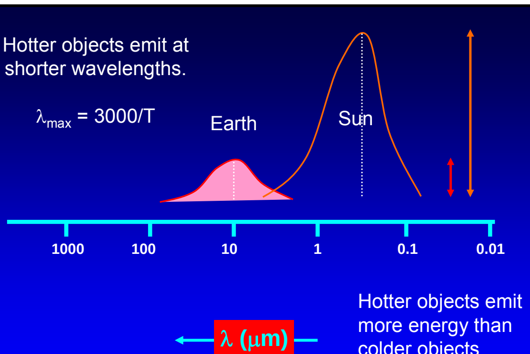
We can use these equations to calculate properties of energy radiating from the Sun and the Earth.





Hotter objects emit at shorter wavelengths.

$\lambda_{max} = 3000/T$



Hotter objects emit more energy than colder objects

$F = \sigma T^4$

	T (K)	λ_{max} (μm)	region in spectrum	F (W/m²)
Sun	6000	0.5	Visible (green)	7×10^7
Earth	300	10	infrared	460

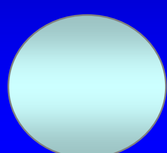
Solar Radiation and Earth's Energy Balance

Planetary Energy Balance

- We can use the concepts learned so far to calculate the radiation balance of the Earth
- **Some Basic Information:**

  Area of a circle = πr^2

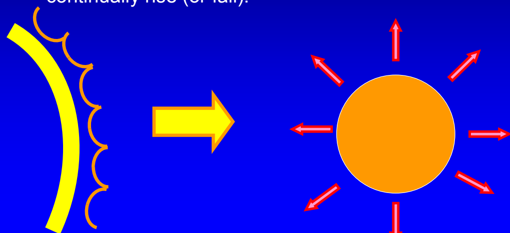
  Area of a sphere = $4 \pi r^2$



Energy Balance:

The amount of energy delivered to the Earth by the SUN is equal to the energy lost to space from the Earth by Blackbody (IR) radiation

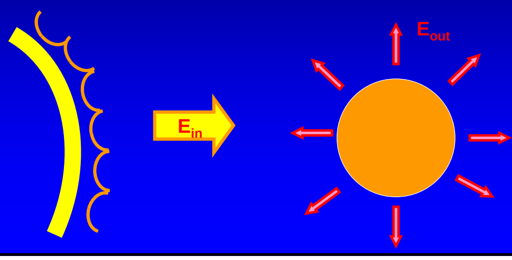
Otherwise, the Earth's temperature would continually rise (or fall).



Energy Balance:

Incoming energy = outgoing energy

$E_{in} = E_{out}$



Solar Radiative Flux at the Earth

$$S_0 = \frac{\sigma T_{sun}^4 * r_{sun}^2}{r_{s-e}^2}$$

S_o is the **solar constant** for Earth

It is determined from the flux at the surface of the Sun and by the distance between Earth (r_{s-e} = 1.5 x 10^{11}m) and the Sun's radius, r_{sun} =2.3 x 10^9m .

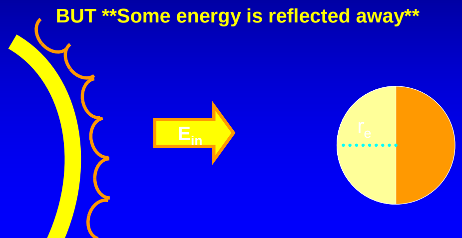
S_o = **1368 W/m²**

How much solar energy is absorbed in the Earth System?

Assuming solar radiation covers the area of a circle defined by the radius of the Earth (r_e)

$E_{in} = S_o$ (W/m²) x π r_e^2 (m²)

BUT **Some energy is reflected away**

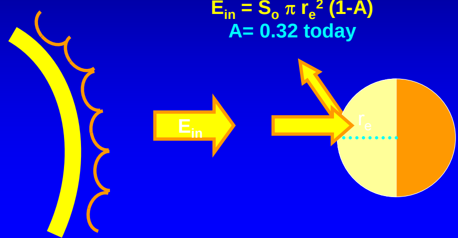


How much solar energy is absorbed into the Earth's Climate System?

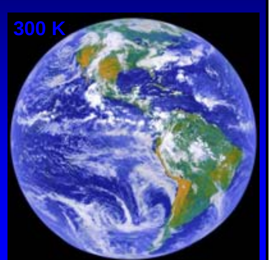
Albedo (A) = % energy reflected away by clouds, aerosols, and the surface

$$E_{in} = S_o \pi r_e^2 (1-A)$$

A= 0.32 today



How much energy does the Earth emit?



How much energy does the Earth emit?

E_{out} = F x (area of the Earth)

$F = \sigma T^4$

Area = $4 \pi r_e^2$

$$E_{out} = (\sigma T^4) \times (4 \pi r_e^2)$$

Energy Balance:

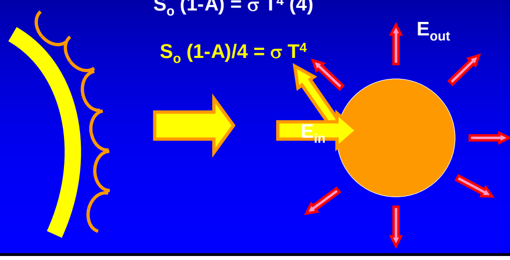
$$E_{in} = E_{out}$$

$$E_{in} = S_o \pi r_e^2 (1\text{-}A)$$

$$E_{out} = \sigma T^4 (4 \pi r_e^2)$$

$$S_o (1\text{-}A) = \sigma T^4 (4)$$

$$S_o (1\text{-}A)/4 = \sigma T^4$$



Planetary Blackbody Temperature

$$T = \left[\frac{S_O (1 - A)}{4\sigma} \right]^{1/4}$$

If we know S_o and A, we can calculate the temperature of the Earth. We call this the equivalent Blackbody temperature (T_{space}). It is the temperature we would expect if Earth System radiates to SPACE like a blackbody.

This calculation can be done for any planet, provided we know its solar constant and albedo.

So What is the Earth's Radiative Temperature?

$$T = \left[\frac{S_O (1 - A)}{4\sigma} \right]^{1/4}$$

So = 1368 W/m^2
A = 0.33
σ= 5.67 x 10^{-8}

T^4 = 4.23 x 10^9 (K^4)

Tspace = 252 K

DANG, That is Hot!!

Earth's Planetary BB Temperature:

T_{space} = 252 K Kelvin

(^oC) = (K) – 273 Centigrade

T_{exp} = (252 - 273) = -21 ^oC

(which is about -4 ^oF)

DANG, That is Cold!!

Is the Earth's surface really -18 ^oC?

NO. The surface temperature is warmer!

The observed ground temperature (T_g) is 15 ^oC, or about 59 ^oF.

The difference between observed and blackbody temperatures (ΔT):

$$\Delta T = T_g - T_{space}$$

ΔT = 15 - (-21)

ΔT = + 36 ^oC

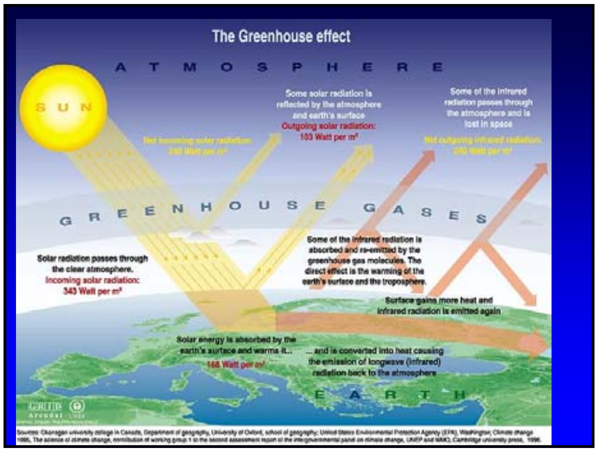
Earth's "Greenhouse" Warming

ΔT = + 36 ^oC
In other words, the Earth is 33 ^oC warmer than expected based on black body calculations and the known input of solar energy.

This extra warmth is what we call the GREENHOUSE EFFECT.

It is a result of warming of the Earth's surface by the absorption and re-emission of IR radiation by molecules in the atmosphere.

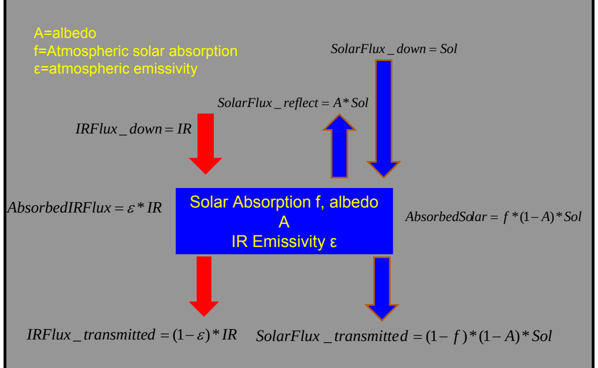
The atmosphere is warm at the surface (15 C) cold in the middle (-4 C) and very, very cold near the top (-100 C).



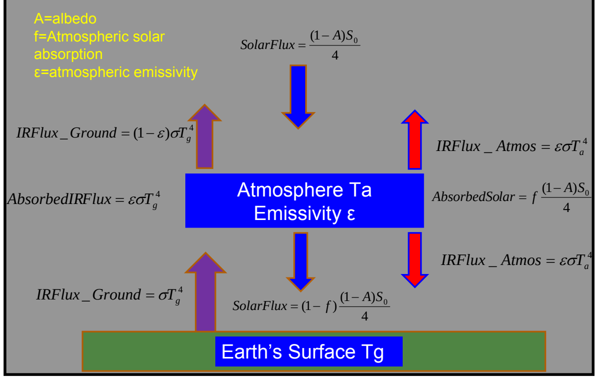
Greenhouse Effect is the Result of the Solar and IR Transmission Properties of the Atmosphere

- The **solar flux** is *moderately* scattered and *weakly* absorbed in the AIR. Thus, the sun principally passes through the atmosphere and HEATS the SURFACE.
- **IR** flux is *strongly* absorbed and emitted by 'greenhouse gases': water vapor, CO2, Ozone, Methane.
- Solar photons absorbed in the system are **never** re-emitted as solar photons. Their heat may be conducted, convected, or re-emitted in the IR.
- The process of adjacent layers emitting and absorbing radiation from each other is important.
- Vertical mixing by turbulence, clouds, storms, etc is a complicating factor.

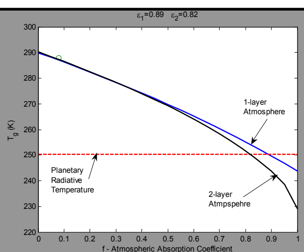
Bulk Radiative Transfer in the Atmosphere



Simplified (??)Energy Balance of Earth-Atmosphere System



$$T_g = \left[\frac{(2-f)(1-A)S_0}{(2-\varepsilon)4\sigma}\right]^{1/4}$$

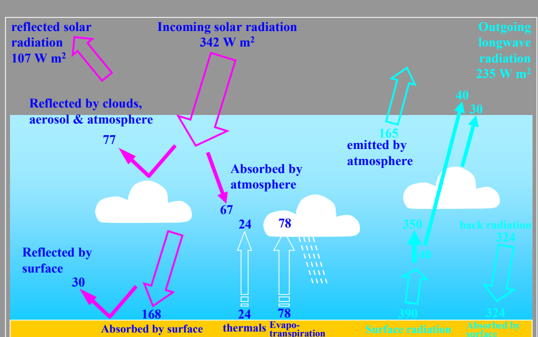


Geenhouse Effect Analogies:

*Greenhouse

*Driving across Boulder

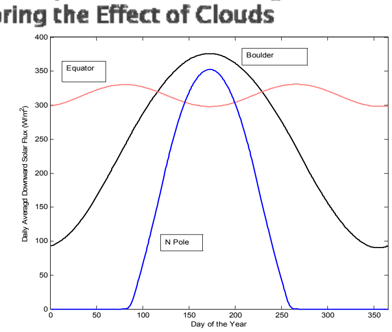
*Cup O' Dirt



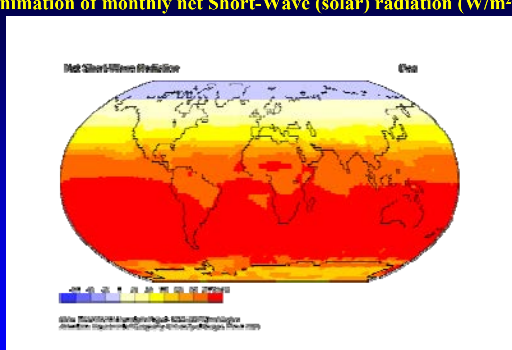
Contributions to global ocean-atmosphere energy budget

	Energy Flux (W m^{-2})
Solar radiation	**230**
Rate of kinetic energy dissipation	2
Photosynthesis	-0.1
Geothermal heat flux	*0.06*
World energy production (fossil fuels)	*0.02*

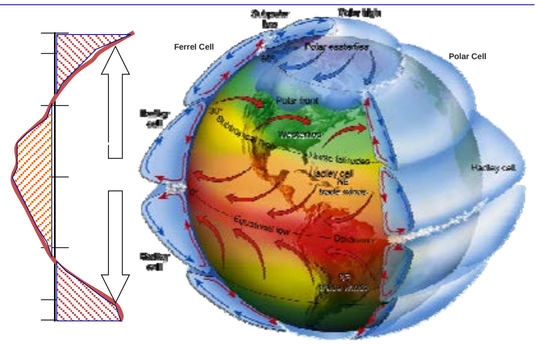
Annual Cycle of Solar Heating vs Latitude Ignoring the Effect of Clouds



Animation of monthly net Short-Wave (solar) radiation (W/m^2)



Revision



Why is Ocean The Big Boss?
It has 10,000 times the mass of the Atmosphere.

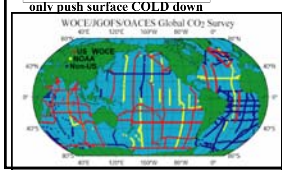
How long would it take 5 W/m² to warm the atmosphere 1 C?

15 days

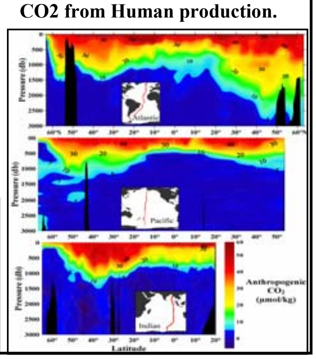
How long would it take 5 W/m² to warm the ENTIRE ocean 1 C?

80 years

BUT – It is very, very difficult to push surface heat down into the ocean. In fact, you can only push surface COLD down



How do we know? We can trace CO2 from Human production.



Google Search "Solar ClimateWarming Hoax" : 30,100 hits

Used in UK 2007 TV Show 'The Great Global Warming Swindle'
http://www.channel4.com/science/microsites/G/great_global_warming_swindle/

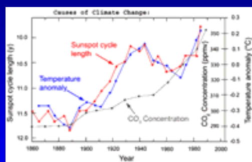


Figure from DeFreitas Article

BULLETIN OF CANADIAN PETROLEUM GEOLOGY
VOL. 50, NO. 2 (JUNE, 2002), P. 297-327

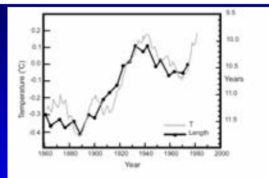


Fig. 22. Eleven-year running means of solar activity, in terms of the sunspot cycle length (years), compared with global temperature (T) based on the work of Friis-Christensen and Lassen (1991). The global temperature is the same as that used by IPCC (Jones, 1988; Jones et al., 1986).

***Use sunspot cycle length, not solar flux**
***Graphs stop in 1980**

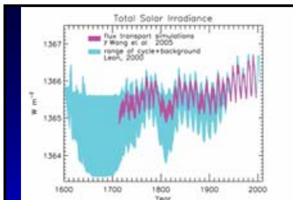


Figure 2.17. *Reconstructions of the total solar irradiance time series starting as early as 1600. The upper envelope of the shaded regions shows irradiance variations arising from the 11-year activity cycle. The lower envelope is the total irradiance reconstructed by Lean (2000), in which the long-term trend was inferred from brightness changes in Sun-like stars. In comparison, the recent reconstruction of Y. Wang et al. (2005) is based on solar considerations alone, using a flux transport model to simulate the long-term evolution of the closed flux that generates bright faculae.*

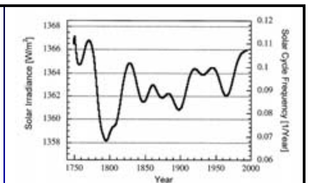


Fig. 7. Sun melody. Frequency modulation of the sunspot Schwabe cycle (14 y low-pass filter).

$$T_g = \left[\frac{(2-f)(1-A)S_0}{(2-\varepsilon)4\sigma}\right]^{1/4}$$

F=0.08 ε=0.89 σ=5.67E-8 A=0.34

S_0=1366.5 W/m^2 Tg=14.84 C

S_0=1365 W/m^2 Tg=14.76 C Change = 0.08 C

S_0=1362 W/m^2 Tg=14.60 C Change = 0.24 C

What Has Happened Since 1980?