GE510 Physical Principles of the Envt

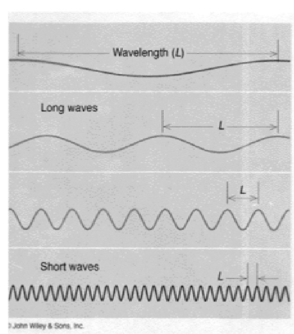
Earth's Energy Balance:

1. **Types and key properties of energy**
2. **Blackbody radiation revisited and Wein's displacement law**
3. **Transformations of the sun's radiant energy by earth**
4. **Adding up the numbers: the global energy budget**

1A. Types of energy:

-**Electromagnetic (incoming solar, outgoing thermal radiation)**

E(photon) = h/lambda



-- **Mechanical (potential; kinetic; wind, ocean currents)**

-- **Chemical (photosynthesis, life)**

-- **Thermal (conductive heat transfer)**

1B: Key properties of energy:

-**Conservation of energy: it all must add up!**

-**Interconvertible among types (e.g. heat can be converted into light and vice versa)**

-**Power (watts) = energy expended (joules) per time (sec)**

-**Blackbody radiation is just that conversion of thermal into electromagnetic (light) and vice versa. Let's revisit…**

1B: Key properties of energy:

Becoming comfortable with power units:

-**How much power does a human give off?**

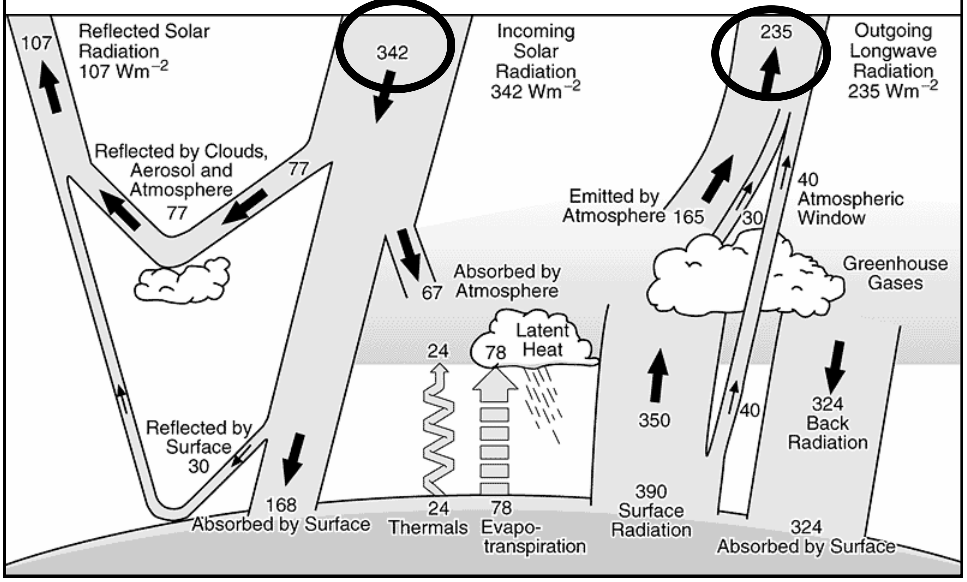
1B: Key properties of energy

Table 4 Powers of Continuous Phenomena

Energy flows	Power
Global intercept of solar radiation	170 PW
Wind-generated waves on the ocean	90 PW
Global gross primary productivity	100 TW
Global Earth heat flow	42 TW
Worldwide fossil fuel combustion	10 TW
Florida Current between Miami and Bimini	20 GW
Large thermal power plant	5GW
Basal metabolism of a 70-kg man	80 W

2. Revisit the concept of blackbody radiators.

Let's start with earth inputs and outputs…

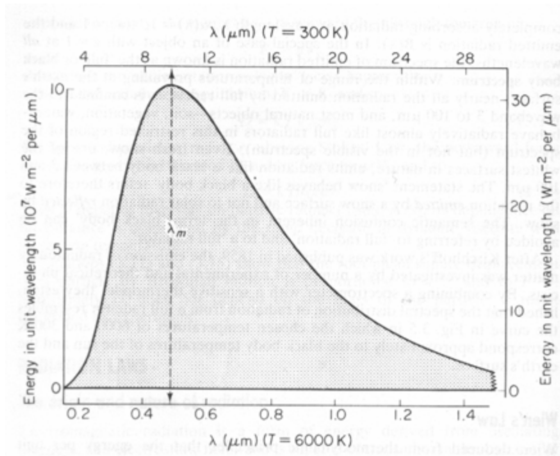


Here's what radiation from an ideal blackbody looks like, for both an 'earth-like' and 'sun-like' object. Note that the peak occurs at different wavelengths.

Characteristic emission spectra from blackbody radiator

Total energy (integral under curve) = $\varepsilon\sigma T^4$

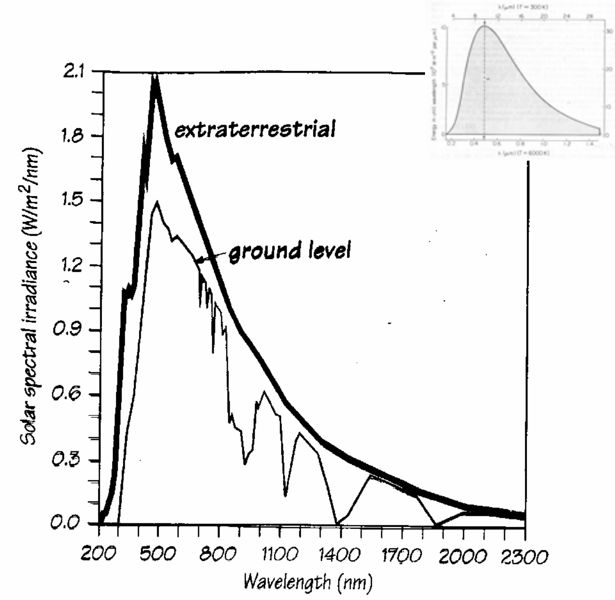
This is the Stefan-Boltzmann Law



Are the earth and sun remotely like these idealized blackbody radiators?

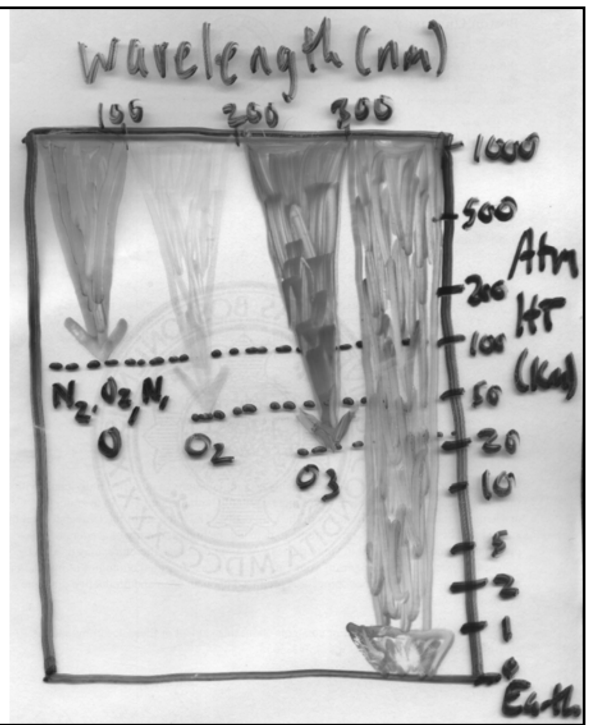
Not a bad approximation for solar radiation received at top of atmosphere.

Ground level spectra has 'holes' in it: why?



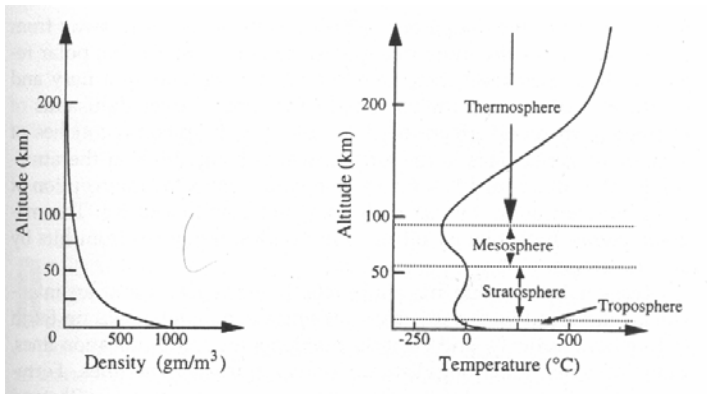
Extraterrestrial and ground-level spectra of solar radiation.

- **Different molecules absorb incoming solar radiation at different vertical zones of the atmosphere. This causes the natural temperature profile.**
- **About 20% of total incoming solar radiation is absorbed in the atmosphere, 30% reflected, 50% reaches earth's surface.**



This is what causes the thermal structure of the atmosphere.

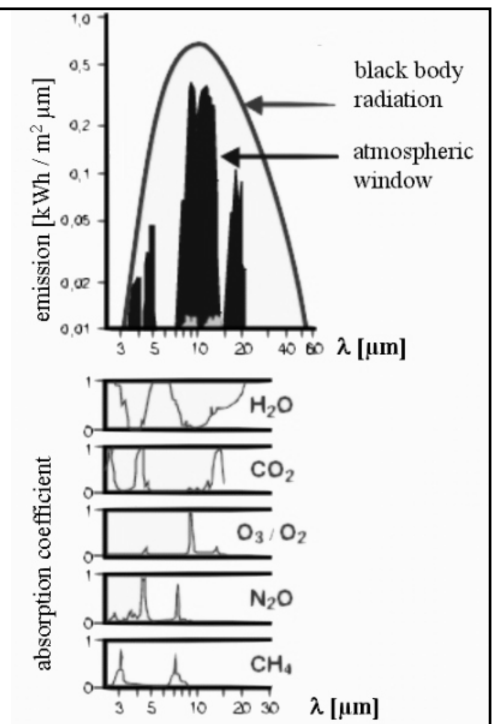
- **Atmosphere divided vertically by its temperature zones**
- **Troposphere: heated from below**
- **Stratosphere: zone of increased temperature – mostly due to ozone absorption and re-radiation**
- **Thermosphere: O, O2, N, N2 absorb high energy photons and re-radiate**



Earth follows the envelope of an ideal blackbody, but with some significant gaps – these blocked spectral ranges constitute the radiant 'congestion' caused by atmospheric greenhouse gases.

Here we see where these greenhouse gases absorb.

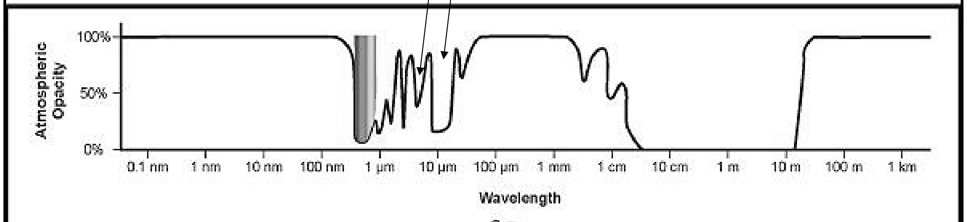
We need to keep the 'atmospheric window' clean to stay cool.



More on the atmospheric window:

Key point: most of the naturally occuring atmospheric gases are transparent to thermal (longwave) radiation. They let those thermal rays pass downward and upward.

This provides an atmospheric 'window' by which heat radiation from earth's surface and troposphere can escape to outer space.



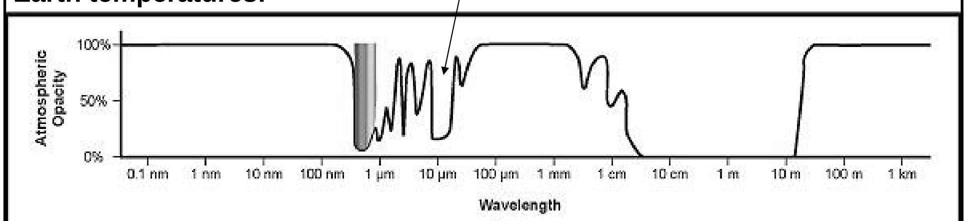
Aside: what is the 'temperature' of 10 um infrared radiation?

There is a law called 'Wein's Displacement Law' that relates temperature of a blackbody radiator to wavelength

T(kelvin) = 2897 / λmax(um)

So in the center of one of the windows below, we have T = 289.7K
T(celsius) = T(kelvin) –273; so 290-273 = 17^{O}C

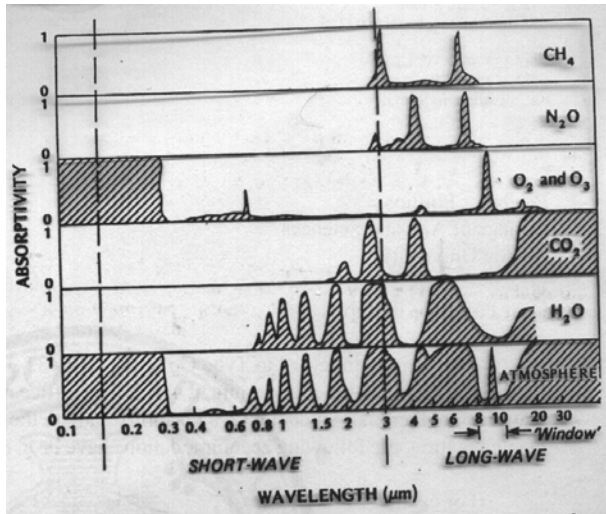
This is a precariously opened Window, right around comfortable Earth temperatures!



Greenhouse gases 'crowd' out the window, preventing thermal radiation from escaping to outer space.

Note how CO2 pushes into the atmospheric window.

Note how CH4 absorbs farther to the left than the atmospheric window at 10 um (17^{O}C) - how then can it act as a greenhouse gas?



Note how CH4 absorbs farther to the left than the atmospheric window at 10 um (17^{O}C) (I.e. at hotter temperatures) - how then can it act as a greenhouse gas?

The answer lies in the fact that blackbody radiators radiate over a range of wavelengths – so earth surface radiation, with a peak e.g. at 17^{O}C, also contains a range of other wavelengths, including those that CH4 absorbs.

Characteristic emission spectra from blackbody radiator

Total energy (integral under curve) = $\varepsilon\sigma T^4$

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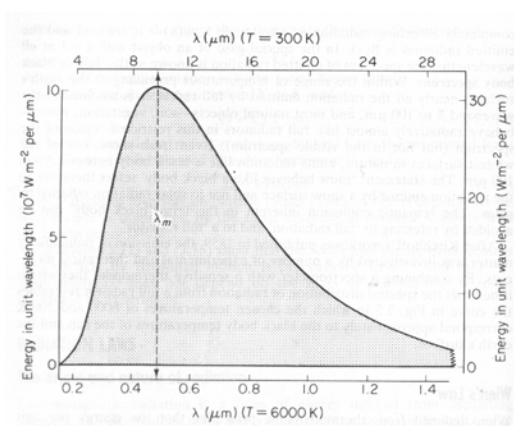
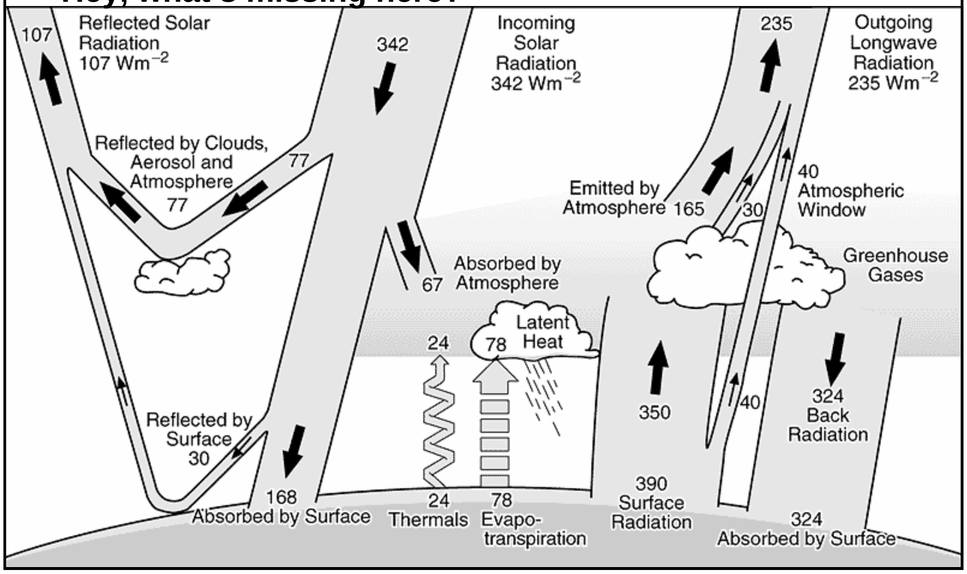
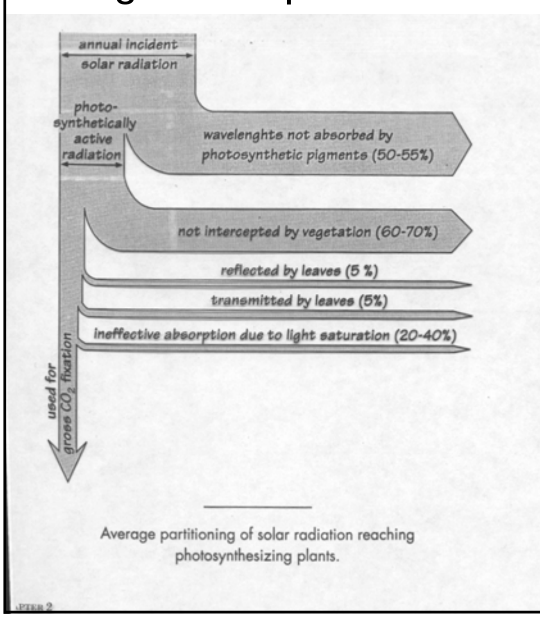


3. Transformations of the Sun's Radiant Energy by Earth

Hey, what's missing here?



Photosynthesis does not directly transform a significant portion of incoming solar radiation



Average partitioning of solar radiation reaching photosynthesizing plants.

Does this mean life doesn't impact earth's energy balance?

4. Adding up the numbers: the global energy budget