EOSC 112: Lecture Summary: Monday, September 10

Text Coverage: Chapter 3 pp. 41-43 – Planetary energy balance

- Review – last lecture key points (see Sept. 7 summary)
- Add one more graph – the measured Planck function for the big bang.

  Key features:

  - The Cosmic Background Explorer was so good that you can't see the error bars in this comparison with a 2.73 K Planck function.
  - It's remarkable that Planck's equation, which has no *free parameters* (fudge factors) should so completely describe something Planck knew nothing about.
  - Because Planck's law works so well here, we have a very good idea of the temperature of the big bang.
- *Minor point:* Note the units on the y-axis of the Planck function in text figure 3-8 or here – these are called "distribution density units" of $\mathrm{W\,m^{-2}\,\mu m^{-1}}$. As discussed in class, the y-axis has to have these units if the area under the Planck function is equal to the flux , i.e. the area under the curve has to look like a height (y-axis) times a width (x-axis) and the units of height × width in this case are $\mathrm{W\,m^{-2}\,\mu m^{-1}} \times \mathrm{\mu m} = \mathrm{W\,m^{-2}}$.
- It follows from the Planck function (although we don't show it in this course), that the total area depends only on the temperature. This is the total flux emitted across a flat surface by a blackbody of temperature T:

  $F(\mathrm{W\,m^{-2}}) = \sigma T^4$ (Stefan-Boltzman law, p. 40)

  where $\sigma = 5.67 \times 10^{-8}\ \mathrm{W\,m^{-2}\,K^{-4}}$ is the *Stefan-Boltzman constant*
- Armed with the Stefan-Boltzman law, we can calculate the flux at the sun's surface, knowing that the surface temperature of the sun is 5780 K (in real life, things are actually reversed – we infer the surface temperature of the sun from measurements of its flux F_{sun}).

  $F_{sun} = \sigma \times (5780\ \mathrm{K})^4 = 6.3 \times 10^7\ \mathrm{W\,m^{-2}}$
- We know that energy (Joules) are conserved, so if these photons are not absorbed then they must all wind up passing through a sphere with the radius of the Earth's orbit. The total number of photons leaving the surface of the sun in a second can be calculated given that the radius of the sun is $R_{sun} = 7 \times 10^8$ m. This total power is called the *solar luminosity* L_{sun}

  $L_{sun} = F_{sun} \times 4\pi(R_{sun})^2 = 3.89 \times 10^{26}\ \mathrm{W}$

  It is this quantity, L_{sun} that remains the same for each of the planets.
- By the time these photons reach Earth, they are spread out over a much bigger sphere, with a radius of 1 AU = $R_{sun-earth} = 1.5 \times 10^{11}$ m.

  So the flux arriving at Earth's orbit is:

  $S = L_{sun}/(4\pi(R_{sun-earth})^2) = 1370\ \mathrm{W\,m^2}$

- S is called the *solar constant* and is different for every planet. You can calculate it for any planet given the planet's distance from the sun and the sun's luminosity.

- In words you can describe the solar constant S as the flux hitting the top of the atmosphere at high noon. Note that not all of this energy is absorbed by the atmosphere/ocean/surface however. A significant fraction of the radiation is reflected and doesn't change the temperature at all. The fraction of the incoming solar flux that is reflected back to space is called the *Albedo* and represented by the symbol A. It has no units (because it is a ratio of reflected flux/incoming flux and the units cancel).

- So a more reasonable value of S for the Earth would be include it's average albedo A=0.3:
  $S_{received} = (1 - A)S = (1 - 0.30)1370\,\mathrm{W\,m^{-2}} = 959\ \ \mathrm{W\,m^{-2}}$

- What happens to this energy? In the Earth's case it gets spread around the entire planet, so that the north and south (which don't receive as much as the equator), don't get too far from the global average temperature. Note also that one half of the Earth is always dark, so that $S_{received}$ is large overestimate for the amount of sunlight received by the entire planet over the course of a year. A more accurate value for the power received from the sun by the Earth is:

  $S \times (1 - A) \times \pi(R_{earth})^2$ (Watts)

  i.e. it's the disk of the earth (with area $\pi(R_{earth})^2$) rather than the whole sunlit hemisphere (with area $2\pi(R_{earth})^2$)) that is intercepting the solar beam. (See textbook figures 3-4 and p. 37 and 4-3 p. 61)

  But remember that you need to spread this over both sides of the planet, so that the actual, annually averaged shortwave flux received by the earth is given by:

$$\frac{\text{received flux}}{\text{earth area}} = \frac{(1 - A) \times S \times \pi(R_{earth})^2}{4\pi(R_{earth})^2} = \frac{(1 - A)S}{4} \approx 240\,\mathrm{W\,m^{-2}} \tag{1}$$

  (show this with your calculator)

  It is this number, $S_{avg} = 240\ \ \mathrm{W\,m^{-2}}$ that we need to keep in mind when we ask how big a difference humanity is making to the Earth's energy budget.

- In the lab we refer to this as $S_{avg} = (1 - A)S/4$. It is S_{avg} that the planet needs to shed by emission in order to keep an even temperature. The only way it can shed the incoming shortwave radiation is by longwave emission of flux $F_{earth} = \sigma T_e^4$ (p. 42). We call T_e the *effective radiating temperature.*

- For the earth, balancing F_{earth} and S_{avg} gives:

$$\sigma T_e^4 = (1 - A)S/4 = 240\ \ \mathrm{W\,m^{-2}} \tag{2}$$

  or:

$$T_e = \left(\frac{(1 - A)S}{4\sigma}\right)^{1/4} = \left(\frac{240}{\sigma}\right)^{1/4} = 255\ \ \mathrm{K} \tag{3}$$