EOSC 112: Lecture Summary: Friday, September 7

Text Coverage: Chapter 3 pp. 34-40

- A key question for Chapter 3: What determines the surface temperature of the earth?
- Expand this question to: What determines the surface temperature of the inner planets? (Mercury, Venus, Earth (plus Moon), Mars).
- Need to understand the absorption, emission and reflection of radiation by the surface and the atmosphere.
- Start with some basic concepts: wavelength, frequency, energy, power, flux

Specific example – show satellite image of ship tracks (enhanced cloud cover) at 3.7 microns (μm) wavelength.

(Digression: a human hair has a diameter of about 100 μm. The typical radius for a cloud droplet in a white puffy cloud is about 10 μm. Dark, heavy clouds have many droplets with diameters large than 100 μm, and large raindrops are about 1000 μm (1 mm). The interactions between light waves and matter (whether a photon is scattered, absorbed, or transmitted) depends on the relative size of the photon and the object doing the scattering.

The formulae on p. 36 of the text relate the wavelength λ, the wavespeed c and the frequency ν via $\lambda\nu$=c.

Example (check yourself) = for λ=3.7 μm,c= 3.0×10^8 $\mathrm{m\,s^{-1}}$ the photon frequency ν is: $\nu = c/\lambda = 81 \times 10^{12}/s$ or $81 \times 10^{12} s^{-1}$. Where the unit s^{-1} is ("per second") is called a "Hertz" and abbreviated Hz.

(Note: it is often convenient to write units with a negative superscript instead of a division sign. Thus "meters per second per second" can be written either as " m/s/s or $\mathrm{m\,s^{-2}}$.)

What is the energy of these 3.7 micron photons?

- Einstein was the first to come up with the idea that light could be considered a particle ("photon") as well as a wave. How much energy does a 3.7 μm photon have?
- Using the Einstein/Planck equation from p. 36:

  Energy $E = h\nu$, where h, Planck's constant is given in the text as 6.63×10^{-34} $\mathrm{J\,s}$ (Joule-seconds).

  So E (3.7 μm) = 5.37×10^{-20} Joules (try this).

- *Digression on units*: How to remember the units used to report energy, power, radiative flux?

- Start with Newton's second law:

  F=ma

  What are the units for this? (*mass* × *acceleration*).

  So force has units of $\mathrm{kg\,m\,s^{-2}}$ – called a *Newton*.

  From here, you need to remember that work and energy have the same units and that

  work = *force* × *distance*

  So the units of energy (Joules) are = force × distance = $\mathrm{kg\,m\,s^{-2}} \times \mathrm{m}$ or $\mathrm{kg\,m^2\,s^{-2}}$, abbreviated J.

- From here we can get units for power:

  power=energy/time = J/s = Watts (W)

  and flux:

  flux=energy/time/area = Watts/m/m = $\mathrm{W\,m^{-2}}$

- Note: it's handy to cancel units as if they were variables in an equation – these kind of *unit checks* can quickly uncover mistakes in a calculation.

An example showing unit cancellation :

You go to Seattle and find a job paying $US 3000/month What is your salary in Canadian dollars/hour?

- Step 1: convert to Canadian:

  3000 $US/month × 1.54$Canadian/$US = 4615 $Canadian/month

  or in exponential notation:

  $3000\ \mathrm{\$US\,month^{-1}} \times 1.54\ \mathrm{\$Canadian\,\$US^{-1}} = 4615\ \mathrm{\$Canadian\,month^{-1}}$

- Step 2: convert from months to hours, note how weeks and months cancel in conversion

  $4615\ \mathrm{\$Canadian\,month^{-1}} \times (4\ \mathrm{weeks\,month^{-1}} \times 40\ \mathrm{hours\,week^{-1}})^{-1} = 28.84\ \mathrm{\$Canadian\,hour^{-1}}$

This works the same for flux × area = power:

- $300\ \mathrm{W\,m^{-2}} \times 2\ \mathrm{m^2} = 600\ \mathrm{W} = 600\ \mathrm{J\,s^{-1}}$

End units digression

- Show electromagnetic spectrum – Figure 3-3 – note that we are blind to the majority of the electromagnetic spectrum. Note also that photons with short wavelengths ($\lambda < 0.3\,\mu$m) (high frequency, high energy) are called "hard" photons, because they hit capillaries, burst them and cause bleeding (sunburn), hit cells and cause mutations (skin cancer), etc.

Next look at **Blackbody radiation (p. 39)**.

- All objects with temperatures > 0 K emit photons
- The wavelength, frequency, and hence energy of these photons depends on the temperature.

- At any time an object is emitting photons of many different wavelenghts. The flux emitted at each wavelength is predicted by the *Planck function* (Fig. 3-7).

- The peak of value of the Planck function is the wavelength of most of the emitted photons (λ_{max}).

- If you know the temperature T of a blackbody, then you know its Planck function and its $\lambda_{max} = 2898\ \ \mu\mathrm{m}\,\mathrm{K/T}$. This is *Wien's Law.* (In words: "The hotter the object, the more energetic (shorter wavelength, higher ν), its emitted photons.)

- The average surface temperature of the sun is 5780 K, which puts its $\lambda_{max} \approx 0.5\ \ \mu$m (check). The average surface temperature of the earth is 288 K, which gives it a $\lambda_{max} \approx 10\ \ \mu$m.

- This means that for the purposes of this course, solar photons ($\lambda < 3\ \ \mu$m and terrestrial photons $\lambda > 3\ \ \mu$m can be considered separately.

- This separation is somewhat hidden by Figure 3-8, which gives the Planck functions for the sun and the earth. It looks like the sun overwhelms the earth at all wavelengths, but the figure doesn't take into account the large distance between the sun and earth. This is shown a little better here.

Finish with a picture of the "A-train" – three satellites that will fly in formation, launch date set for 2004. Each satellite observes the atmosphere/surface at a different set of wavelengths: AQUA (visible and infrared to look at surface – plants, ocean color, rocks, clouds), followed by Picasso-CENA (short-wave visible laser to look at smog/haze), followed by Cloudsat (1 mm wavelength radar to look at cloud drops and raindrops).