Wednesday 13 September, 2017
10:30-11:30, Class#07

0) Project Choice with rough outline **due Friday Sept 22**

1) Review from last class & clarification

2) Do board example of radiation balance, OLR slides

3) Today's topics

- global heat transport
- role of ocean and atmosphere

Review

- Describe the key properties of electromagnetic spectrum of the Shortwave (solar) and Longwave (terrestrial) radiation that are relevant for climate?
- What is a radiative equilibrium model of the earth’s climate?
- Overall what is the impact of clouds on the earth’s climate? Why?

Blackbody

- Electrical burner that is on is an example of black body radiation. But when it is at room temperature, still emits light (just IR). (photo)
- If a chunk of matter has oscillators that vibrate and interact with light at all possible frequencies, it is a blackbody. The light emitted by a blackbody is called blackbody radiation.
- Solids and liquids at earths surface are good blackbodies but gases are not (interact with only a few frequencies), **Like a piano with missing strings.**
- **"A blackbody is like a musical instrument with all the notes."** **[David Archer, "Global Warming: Understanding the Forecast" Chapter 2]**

Blackbody

- Boltzman's equation tells us how energy is radiated from an object and gives us the emission temperature.
- A hot object emits more light than a cold object. (see IR picture)

Spectrum of outgoing Longwave (InfraRed) Radiation

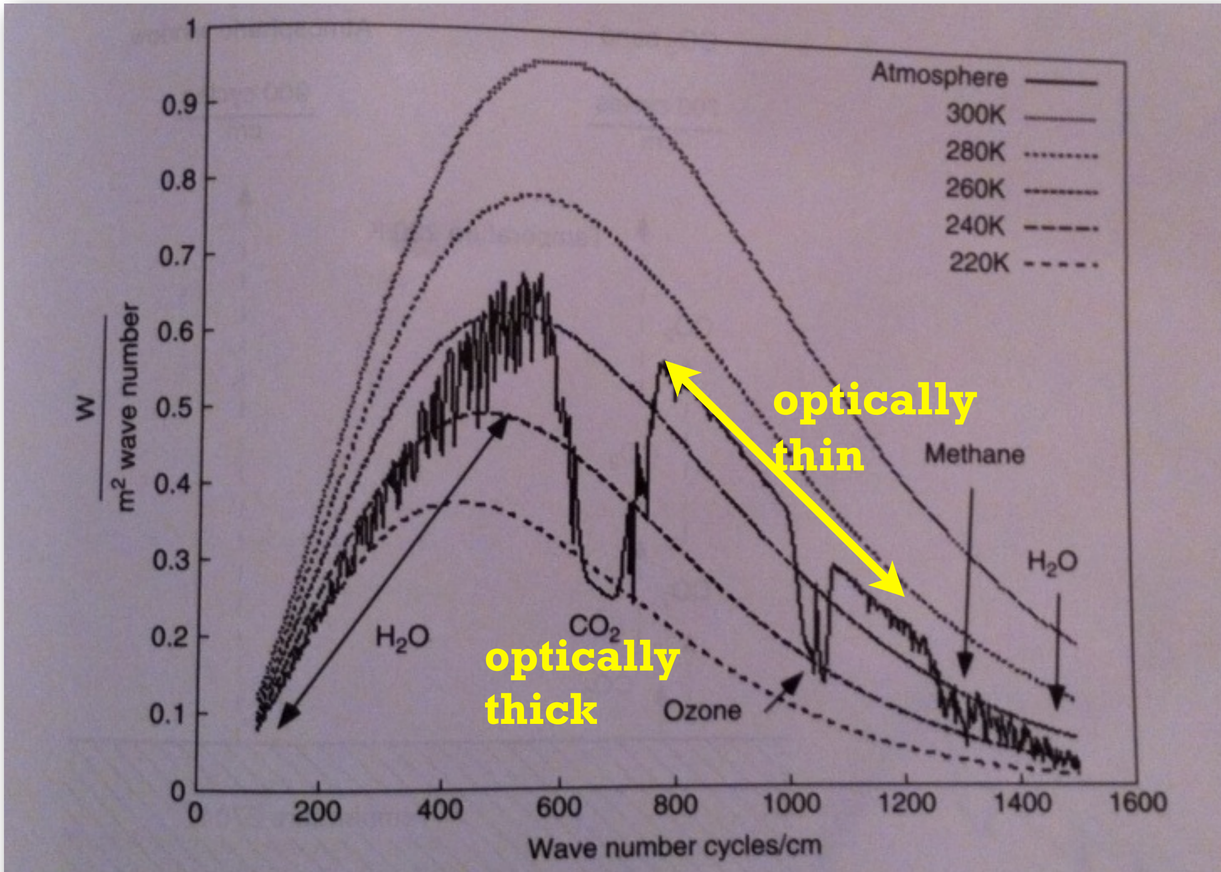


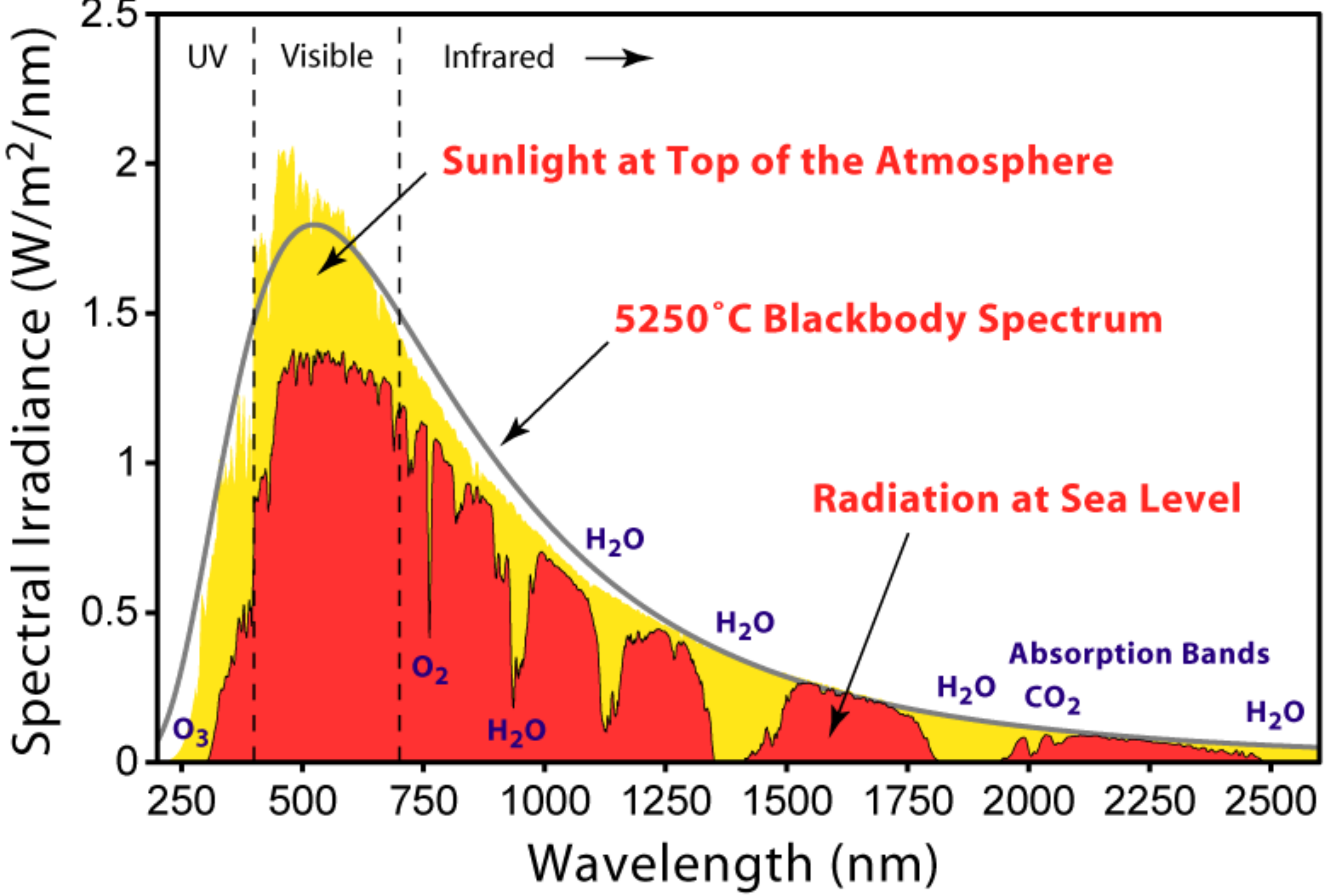
Figure 4-3 The *solid line* is a model-generated spectrum of the infrared light escaping to space at the top of the atmosphere. For comparison, the *broken lines* are blackbody spectra at different temperatures. If the Earth had no atmosphere, the outgoing spectrum would look like a blackbody spectrum for 270 K, between the 260 K and 280 K spectra shown. The atmospheric window is between about 900–1,000 cm^{-1}, where no gases absorb or emit infrared light. CO_2, water vapor, ozone, and methane absorb infrared light emitted from the ground and emit lower-intensity infrared from high altitudes, where the air is colder than at the surface.

[Archer 2011, based on model]

- **Theoretical Blackbody spectra for various temperatures from 220-300K.**
- **Jagged line is IR spectrum at TOA.**
- **Few gases that absorb along yellow arrow of spectrum. (Atmospheric window). Follows warmer curve.**
- **Around 700 cycles/cm, the spectra follows cooler curve, due to bending vibration of CO_2 (absorbs at this frequency and emits at lower intensity).**
- **Figure constructed so area under curve proportional to total energy flux.**
- **CO_2 versus CH_4 absorption?**

location & jaggedness…

Solar Radiation Spectrum



This figure was prepared by Robert A. Rohde

Solve for temperature of surface and atmosphere.

Board-problem

Absorbed=Emitted

Simple energy balance model
Assume
- **LW blackbody**
- **Solar transparent**

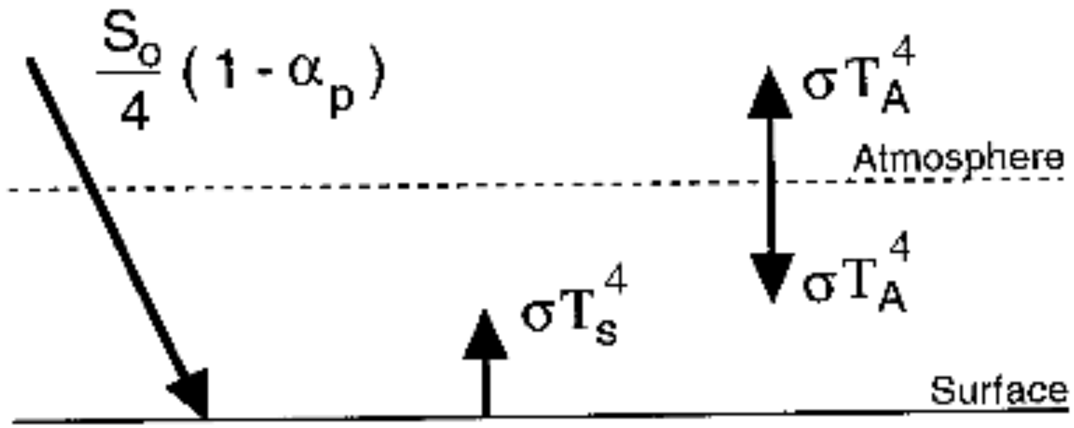


Fig. 2.3 Diagram of the energy fluxes for a planet with an atmosphere that is transparent for solar radiation but opaque to terrestrial radiation.

Hartmann, 1994

$$\frac{S_0}{4}(1-\alpha_p) = \sigma T_A^4 = \sigma T_e^4$$

Energy Balance TOA

$T_e = T_a = 255K$

$$\sigma T_S^4 = 2\sigma T_A^4$$

Energy Balance of Atmosphere

$$\frac{S_0}{4}(1-\alpha_p) + \sigma T_A^4 = \sigma T_S^4$$

Energy Balance of Surface

T_S= is ~20% warmer= 303.2K

Develop Radiative Model for 2 layers, answers in red

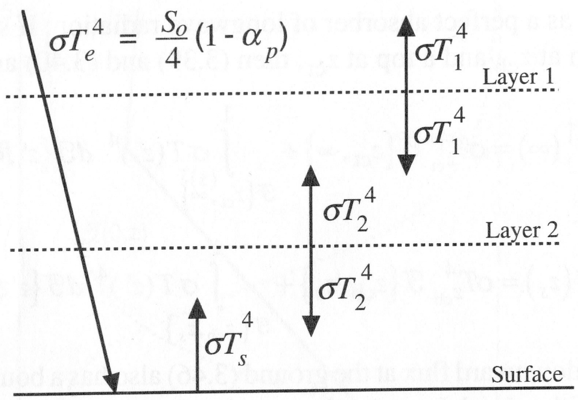


Fig. 3.10 Diagram of simple two-layer radiative equilibrium model for the atmosphere–Earth system, showing the fluxes of radiant energy.

At TOA:

$$\frac{S_0}{4}(1-\alpha_p) = \sigma T_e^4 = \sigma T_1^4$$

$T_e = T_1 = 255K$

Key to developing equations: Absorbed = Emitted

Energy Balance in Layer 1: $\sigma T_2^4 = 2\sigma T_1^4$ $T_2 = 303.3K$

Energy Balance in Layer 2: $\sigma T_1^4 + \sigma T_s^4 = 2\sigma T_2^4$

$T_s = 335K$

Energy Balance at Surface:

$$\frac{S_0}{4}(1-\alpha_p) + \sigma T_2^4 = \sigma T_s^4$$

Solar augmented by atmospheric radiation

Simple Radiative Equilibrium Model Analysis on board

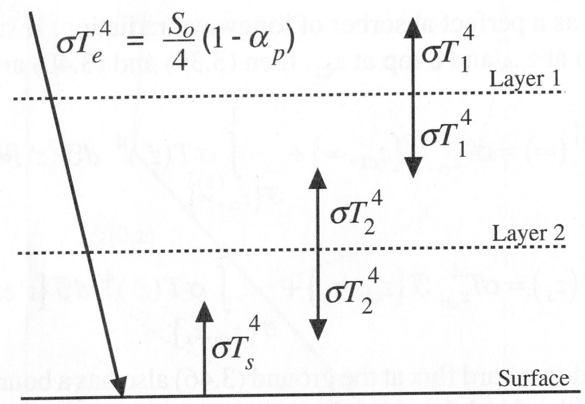


Fig. 3.10 Diagram of simple two-layer radiative equilibrium model for the atmosphere–Earth system, showing the fluxes of radiant energy.

Solve for surface temperature, work out the math yourselves

$$T_s^4 = 3\left(\frac{\frac{S_0}{4}(1-\alpha_p)}{\sigma}\right) = 3T_e^4$$

A model of n layers has this relationship:

$$T_s = \sqrt[4]{n+1}\,T_e$$

n=0, T_e=255K then T_s=255K

n=1, T_e=255K then T_s=303K

n=2, T_e=255K then T_s=335K

- **Surface too hot… Radiative equilibrium not great approximation for surface temperature since heat removed by sensible and latent fluxes are ignored here.**
- **The more layers you add the hotter the surface gets. This heat has to be taken away from the surface by processes other than radiation!**

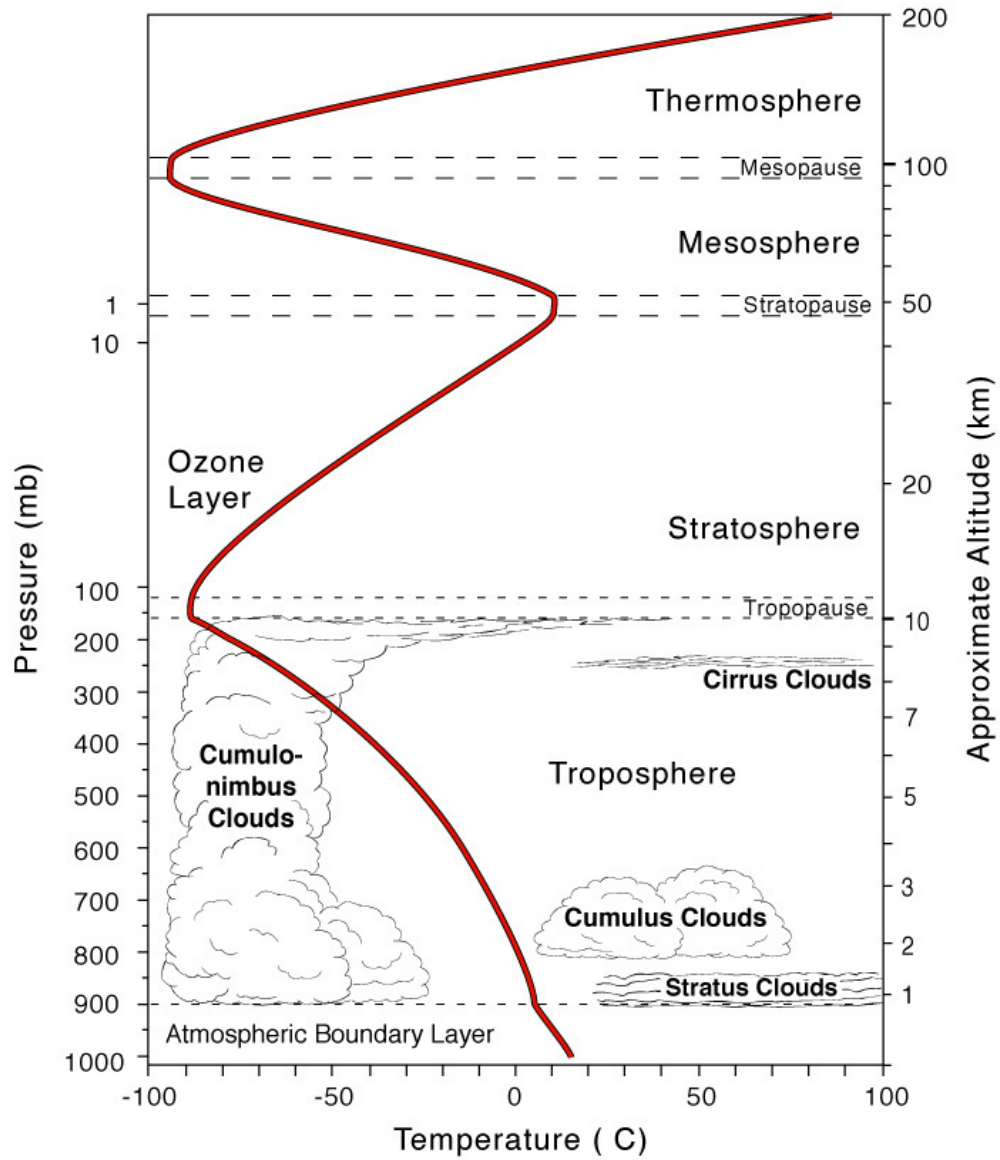
Lapse Rate

- **Lapse Rate is the rate of temperature decrease with height.**

$$\Gamma = -\frac{\partial T}{\partial z}$$

- **Temperature decreases with height on global average 6.5 K/km.**

- **Temperature inversion is when the temperature increases with height.**



[Neelin 2011]

Shortcomings of the Radiative Equilibrium Model

Pg 62-63 Hartmann

Add a thin upper layer to model at stratosphere and a thin layer next to surface. Solve our model for T at each level getting:

Ts=355K

Tsa=320K

T2=303K

T1=255K

Tstrat=214K

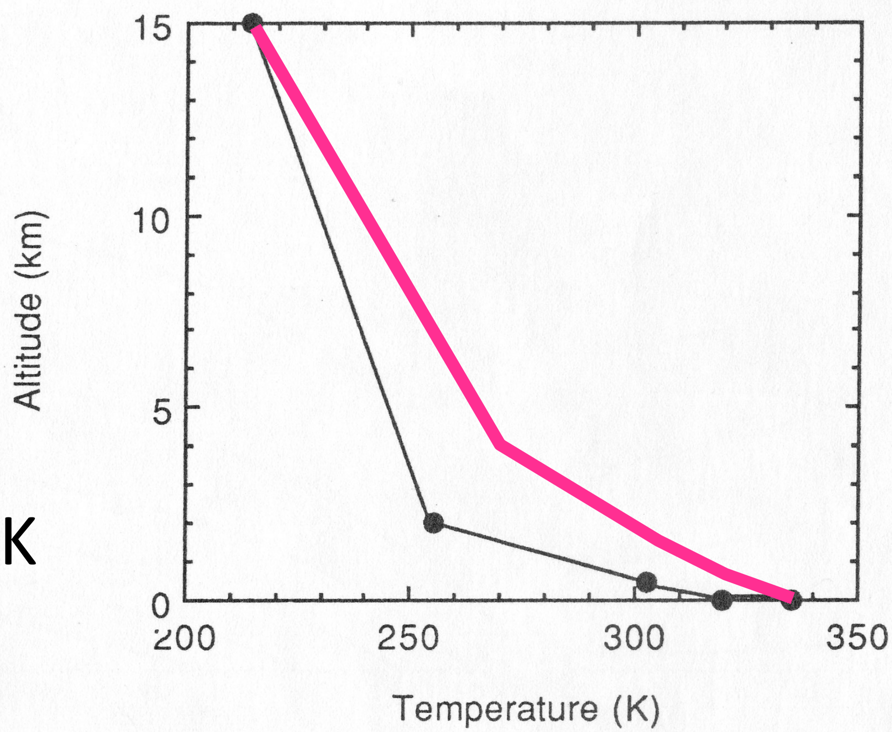


Fig. 3.11 Plot of temperature profile obtained from the simple two-level atmosphere radiative equilibrium model.

Hot air rises! Hot air under cooler air is unstable! Unstable ==> the air turns over/ mixes.

R-E model gives large temperature difference between surface and the thin layer of atmosphere above it. Need to add heat transport due to conductive and convective heat transport.

Hartmann, 1994