(Dr. Liu)

Question 1:

45 min. Assume that the mass absorption coefficients at 15 μm for the layer from 1000 to 950 mb is $k_{v,m,1}$ and that for the layer from 250 to 200 mb is $k_{v,m,2}$. We further assume that $k_{v,m,1}$ and $k_{v,m,2}$ are constants within their corresponding layers and in unit of $(kg\ m^{-2})^{-1}$. We know that the mixing ratio, r, of CO_2 is approximately a constant up to about 100 km. Answer the following questions ($1\ mb = 100\ Pascal = 100\ kg\ m^{-1}\ s^{-2}$, $g = 9.8\ m\ s^{-2}$):

1) For a clear-sky atmosphere, write the expression of optical depth at 15 μm for each of the above two layers as a function of mass absorption coefficient and CO_2 mixing ratio.

2) Which of the two layers has a larger transmission at 15 μm and why?

3) Explain the principle of temperature profile retrieval using satellite observations near 15 μm.

MET 5471 Satellite Remote Sensing

1. Cloud optical depth (τ) is a parameter used in models (radiative transfer models and GCMs) to represent the radiative property of clouds. In the visible wavelength, τ is related to cloud liquid water path (W) and effective radius (r_e), where W is the vertical integrated liquid water content and r_e is defined by

$$r_e = \frac{\int_0^\infty n(r) r^3 dr}{\int_0^\infty n(r) r^2 dr},$$

and n(r) is the droplet size distribution, and r is the cloud droplet radius.

(1) Derive the expression of τ as a function of W and r_e.

(2) Based on this equation, when viewing from space, a cloud should look darker or brighter (clouds with larger τ are brighter), if

(2a) it gains more liquid water but no change in r_e (for example, because the cloud moves to a warmer area);

(2b) droplets become smaller (r_e decreases) but no change in W (for example, because the cloud moves to a more polluted area)?

Dr. Liu
Choose ONE from the following 2 questions (~45 min each):

1. MET 5471

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2. GENERAL

2. As a first order approximation, the mean temperature of the Earth is determined by the distance between the Sun and the Earth. Satellite-observed incoming solar flux at the top of the atmosphere is S_{sun} (~1368 W m^{-2} on average, it is called solar constant). Let us assume that the Earth and the Sun are blackbodies and are in radiative equilibrium. Consider the solid Earth and its atmosphere as one system. Derive the expressions of

(a) the mean temperature of the Sun; and
(b) the mean temperature of the Earth system if it reflects 1/3 of the incoming solar radiation back to space (this ratio is called planetary albedo).

Assume the following constants are known:
R_{sun}: the radius of the Sun
D_{se}: the distance between the Sun and the Earth
σ: Stefan-Boltzmann constant
S_{sun}: Solar constant

From Dr. G. Liu **[Each question takes ~30 min]**

1. Surface brightness:

Let us assume three different kinds of flat surfaces, ocean (open water), first-year sea ice, and multiple-year sea ice covered by a thin layer of snow, all at the same temperature (~ 0°C). Answer the following questions (assuming that the instrument viewing geometry do not change when surface changes, ignore atmospheric emission/absorption):
(1) Measuring by a 12 μm wavelength radiometer, which surface has the warmest brightness temperature and which has the coldest brightness temperature? Why?
(2) Measuring by a 1 cm wavelength radiometer, which surface has the warmest brightness temperature and which has the coldest brightness temperature? Why?
(3) Measuring by 0.64 μm wavelength radiometer during daytime, which surface appears brighter, and which appears darker? Why?

2. Weighting Function:

Consider retrieving temperature profile from satellite measurements near the absorption line of a vertically well-mixed gas (e.g., O_2). At a given wavelength, assume that the mass absorption coefficient, k_a, is a constant with respect to height, the mixing ratio of the gas is r_a, and the acceleration of gravity is g. Using hydrostatic equation, derive the pressure, p_{max}, at which the weighting function is the maximum when the satellite sensor views at nadir. (Hint: weighting function peaks at optical depth being 1.) Discuss how the P_{max} varies when the sensor's wavelength is moved closer or further away from the absorption line's center.

3. Cloud brightness

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(1) Derive the expression of τ as a function of W and r_e.
(2) Based on this equation, when viewing from space, a cloud should look darker or brighter (clouds with larger τ are brighter), if

(2a) it gains more liquid water but no change in r_e (for example, because the cloud moves to a warmer area);

(2b) droplets become smaller (r_e decreases) but no change in W (for example, because the cloud moves to a more polluted area)?

Thermodynamics (Liu)

At times, ski resorts have to make artificial snow to keep skiers happy. Imagine that you are the manager of a ski resort who has to decide how deep the artificial snow must be at sunrise in order to have at least some snow on the ground until sunset. Here are the conditions. The snow temperature is 0°C all the time, and the snow density (ρ) is always 0.2 g/cm^3. The sun rises at 7 a.m. and sets at 5 p.m. During daylight hours, there is a mean incoming flux, F, of 500 W/m^2. Artificial snow has an albedo of 0.6. The latent heat of fusion is 3.3×10^5 J/kg. Assume that melting is caused only by the "warmth" of the Sun, and that melted water runs off immediately.

(a) Discuss the energy balance of the snow layer, and write the energy balance equation.

(b) Estimate how deep the snow must be at sunrise (7 am) to last until sunset (5 pm).

Radiation (Liu)

The equilibrium temperature of the Earth is determined by the radiation output of the Sun and the distance between the Earth and the Sun. Assume that both the Sun and Earth radiate as "black bodies" at temperatures of 6000 K and 300 K, respectively.

(a) If we measure the spectrally-integrated radiative fluxes at the surfaces of the Sun and the Earth, what is the ratio of the two fluxes?

(b) If we know that solar radiation peaks around 0.5 μm wavelength, at what wavelength does terrestrial radiation peak?

(c) If you were Superman, how far would you hav eto push the Earth away from the Sun (in terms of a percentage of the current distance between the Sun and Earth) in order to cancel a 1 percent (3 K) increase in the Earth's temperature associated with global warming?

(d) Bonus question: Near the wavelengths where most meteorological radars operate, i.e., several millimeters to several centimeters, where the Rayleigh-Jeans approximation holds, what is the ratio of the spectral radiances of the Sun and the Earth?

Radiative Transfer

III.

a. Write the differential equation of radiative transfer for the diffuse intensity in a plane, parallel atmosphere in which both thermal AND solar radiation are important. Be sure to define your source function precisely in terms of the Planck function, solar parameter, scattering phase function, and other terms. Be sure to identify every term used in your equation(s). (10 min)

b. ***Outline*** how you would solve the above equation for the upwelling flux at the top of the atmosphere and the downwelling flux at the surface using the two-stream and the Eddington approximations. Be sure to point out what quantities you need to know and the approximations necessary to find the solutions. (15 min)

c. Consider the atmosphere to be an isothermal layer of temperature T_a which is in local thermodynamic equilibrium. Only absorption and thermal emission occur in the longwave portion of the spectrum, and the atmospheric flux emissivity (absorptivity) is denoted as ε. In the shortwave portion of the spectrum, the atmosphere absorbs radiation with absorptivity A (no scattering). The atmosphere is irradiated from above with a point source of solar radiation of irradiance F_o with the spectral radiant output of our sun. The atmosphere overlays a surface of temperature T_S. The surface is spectrally black in the longwave and it has a flux reflectivity A_S in the shortwave. This surface loses sensible and latent heat to the atmosphere in an amount SL.

1. By considering the surface-atmosphere system to be in instantaneous energy balance, derive expressions for T_a and T_s in terms of ε, A_S, A, F_o and SL (20 minutes).
2. Suppose the atmosphere is composed of but CO2, O3, CH4, and N2O (i.e., no water vapor). Discuss how and why T_a and T_s under these conditions would compare with the values expected with more Earth-like conditions. (10 minutes)
3. Again, assume the atmosphere is composed of but CO2, O3, CH4, and N2O (i.e., no water vapor) and to have the thermal properties derived in a. From your knowledge of the spectroscopy of these gases, sketch the spectral distributions of the vertically downward directed longwave specific intensity at the earth's surface, the vertically upward directed longwave specific intensity at the top of the atmosphere, and the vertically downward directed direct (parallel beam) solar irradiance at the earth's surface. On the longwave diagrams, be sure to sketch and label Plank function curves representative of the various temperatures along with the intensity curves. For the shortwave, please sketch the distribution of solar irradiance at the top of the atmosphere in addition to the other curve. (5 minutes)

(Dr. Ellingson)

Thermodynamics and Cloud Physics

I. Stating the assumptions made, derive the equation for the saturated adiabatic lapse rate Γ_s for Earth's atmosphere. Be sure to identify all terms and symbols.

II. A saturated parcel of air with a temperature of 0°C initially located at the surface near Detroit, Michigan USA (elevation about 200 m above mean sea level) was found to be transported psuedo-adiabatically on a near-surface path to Thomas, West Virginia (elevation about 1 km above mean sea level) and then to College Park, Maryland (elevation about 15 m above mean sea level). Estimate the temperature and the relative humidity of the air parcel when it reached Thomas, WV and College Park, MD.

Atmospheric Radiation Ellingson

This question is to be answered using information gleaned from Figures 1, 2, and 3 on the attached sheet. The figures show spectra of the vertically downward radiance (downwelling specific intensity) incident on the surface as calculated by a line-by-line radiation model using measured or climatological data as input.
The spectra shown in Figure 1 are for the coldest and warmest days at Barrow, Alaska during 1986. Figs. 2 and 3 show comparisons between spectra calculated for the coldest day with subarctic winter conditions and the warmest day with subarctic summer conditions, respectively.

a. Consider the curve labeled 'February 28, 1986' in Fig. 1. Explain the causes for the various spectral features. That is, what are the causes for the major bumps and wiggles between 0 - 500, 500 - 800, 800 - 1200, and 1200 -2000 cm^{-1}?

b Consider the curve labeled 'July 9, 1986' in Fig. 1. Discuss the causes for the similarities and differences between this curve an that labeled 'February 28, 1986' for the intervals 0 - 500, 500 - 800, 800 - 1200, and 1200 -2000 cm^{-1}.

c. From your knowledge of climatology, atmospheric spectroscopy and thermodynamic structure, discuss the reasons for similarities and differences between the spectra shown in Fig. 2 for the intervals 0 - 500, 500 - 800, 800 - 1200, and 1200 -2000 cm^{-1}.

d. Approximate the difference in the downwelling flux for the spectra given in Fig. 1. Be sure to show your work.

e. Suppose a black cloud was added to each atmospheric profile used in Fig. 1 at a level just above the surface, but at the temperature of the surface. What would be the approximate change in the longwave downward flux at the surface for each profile? What would you expect to happen in this were to occur? Be sure to show your work. Feel free to make sketches on the figures.

Fig. 1. - Clear-sky downwelling radiance spectra at the surface for Barrow, Alaska (71°20'N, 156°00'W)

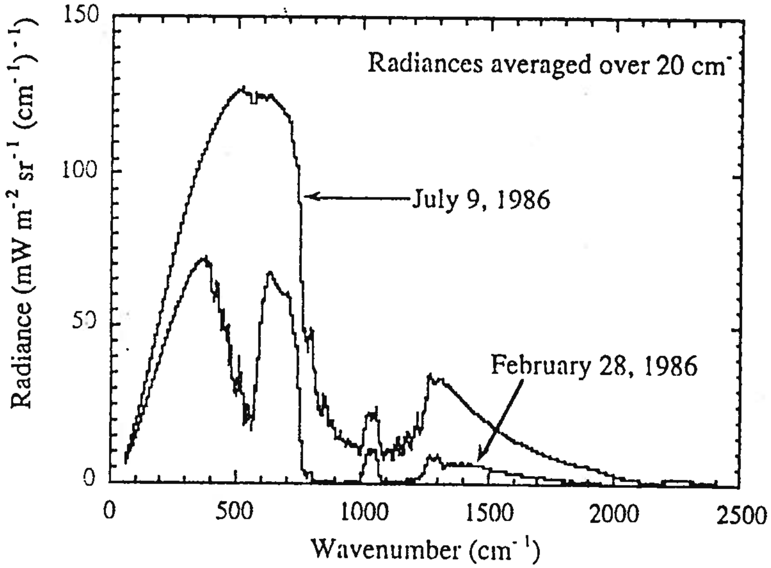


Fig. 2. - A comparison between calculations using the climatological subarctic winter sounding and the sounding from Barrow, Alaska with the coldest surface temperature in 1986

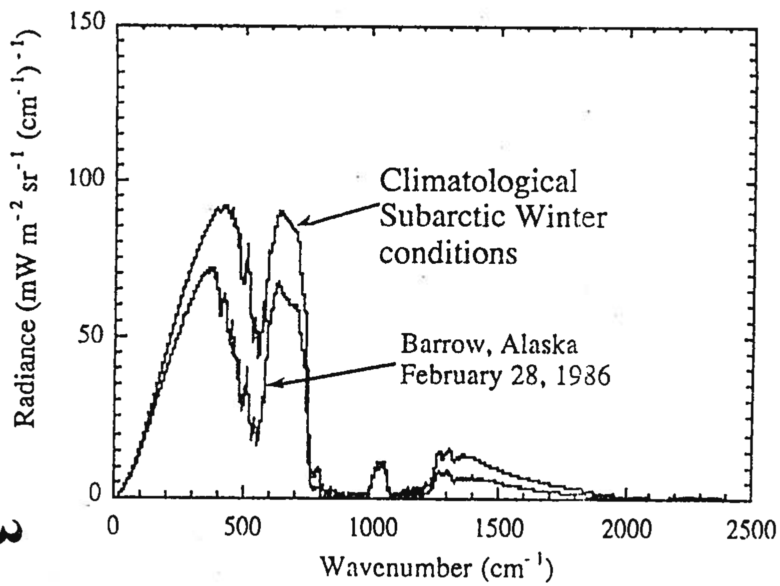
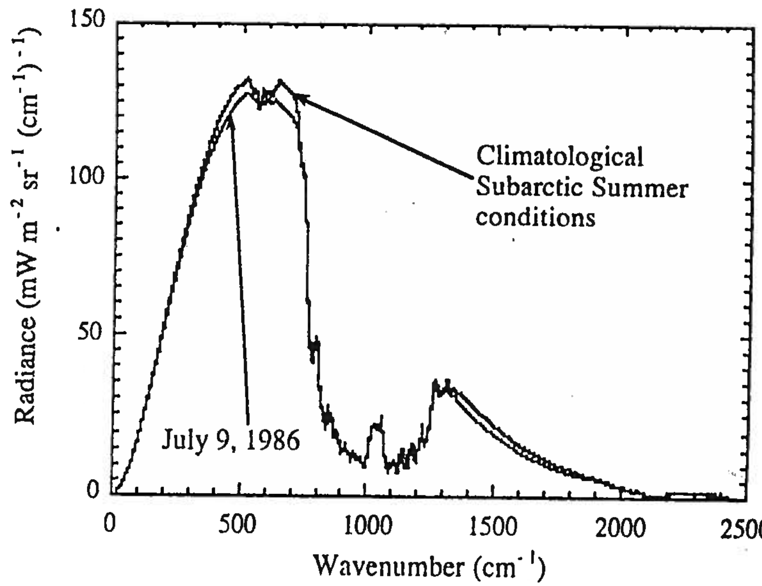


Fig. 3. - A comparison between calculations using the climatological subarctic summer sounding and the sounding from Barrow, Alaska with the warmest surface temperature in 1986



(Dr. Ellingson)

Selected Aspects of Longwave Radiation

Suppose you were given the task of developing a new longwave radiation model for use in a general circulation model that could calculate the effects of atmospheric gases on fluxes to within 1 W/m^2 at all levels of the atmosphere. Describe how you would develop such a model. In your description, include discussions of the important physics, the gases you would include, the mathematical techniques you might use, the reasons for selecting these techniques, and the methods you might use for checking the accuracy of the techniques selected. Be sure to give specific details of the important physics and mathematics.

Dr. Ellingson

Below is a question that might be given to the one student who has taken the radiation class - 5421.

Suppose you were give the task of designing the computer code to calculate atmospheric profiles of long-and-shortwave radiative fluxes and heating rates in a present day general circulation model. Describe:
1. the physics that must be taken into account,
2. the techniques/approximations that you might make in order to parameterize the physics discussed in 1,
3. the quantities that must be known in order to perform the calculations, and
4. the manner by which you might check the accuracy of your completed model.
The responses to the material above should be at the level consistent with Meteorology 5421. That is, your answer should include both mathematical equations and written descriptions. For example, you should certainly include a mathematical statement of the equation of radiative transfer along with its general solution and information to illustrate your knowledge of the important differences between short-and-long wave radiation. Similar mathematics and verbal descriptions are required for the complete answer.