Atmospheric Sciences 321: Science of Climate
Final Examination Study Guide
The final examination will consist of similar questions

Multiple Choice Questions:

1. What fraction of the solar radiation that arrives at the top of the atmosphere is absorbed in the atmosphere?
a) 70%, b) 50%, c) 30%, d) 20%, e) 10% Answer: ___d__

2. What fraction of the solar radiation that arrives at the top of the atmosphere is absorbed at the Earth's surface?
a) 70%, b) 50%, c) 30%, d) 20%, e) 10% Answer: ___b__

3. What fraction of the solar radiation that is absorbed at the Earth's surface is used to evaporate water?
a) 70%, b) 50%, c) 30%, d) 20%, e) 10% Answer: __b___

4. How large is the rate of terrestrial radiation emission from the Earth's surface compared to the solar radiation that arrives at the top of the atmosphere, globally averaged?
a) 150%, b) 110%, c) 70%, d) 50%, e) 10% Answer: __b___

5. What fraction of the terrestrial radiation emission from the Earth's surface escapes to space without being absorbed by the atmosphere?
a) 70%, b) 50%, c) 30%, d) 20%, e) 10% Answer: ___e__

6. At what latitude and during what season is the daily-averaged insolation at the top of the atmosphere the greatest?
a) Equator at Equinox, b) Equator on Jan. 5, c) South pole on Dec. 21,
d) North pole on June 21, e) South Pole on June 21. Answer: __c___

7. The two most important greenhouse gases are:
a) CO_2 and CFCs, b) CO_2 and CH_4, c) CO_2 and H_2O, d) CO_2 and SO_2 Answer: ___c__

8. The last interglacial period comparable to today's occurred about,
a) 20,000, b) 41,000, c) 125,000, d) 160,000 years ago. Answer: ___c__

9. The total solar radiance varies with the 11-year solar cycle with an amplitude of
a) 11%, b) 2%, c) 1%, d) 0.1%, e) 0.01% Answer: ___d__

10. Ice ages are more likely when the obliquity or tilt angle of Earth's rotation is,
a) smaller, b) larger than average. Answer: ___a__

11. Ice ages are more likely when wintertime, northern hemisphere insolation is,
a) smaller, b) larger than average. Answer: ___b__

12. The energy balance in the troposphere is an 'approximate' balance between the two largest terms which are, a) heating by ozone and cooling by emission from water vapor, b) heating by ozone and cooling by emission from carbon dioxide, c) heating by condensation of water and cooling by longwave emission from water vapor, d) heating by absorption of solar radiaton by water vapor and cooling by longwave emission from water vapor.

Answer: __c___

13. The last glacial period occurred about,
a) 20,000, b) 41,000, c) 125,000, d) 160,000 years ago. Answer: __a___

14. A change in eccentricity from 0.0 to 0.04 would change the annual mean insolation by about, a) 8%, b) 4%, c) 0.4%, d) 0.08% , e) 0.04% Answer: ___d__

15. The symbolic formula for the energy balance of the atmosphere is given below. In the blank space under each symbol write the number of Watts per square meter that each term contributes to the annually and globally averaged atmospheric energy balance, accurate to within 10 Wm^{-2}. (5pts)

$$\frac{\partial E_a}{\partial t} = R_a + LP + SH - \Delta F_a$$

__0___ = ___−100_+____80___+___20____− __0____

Short Essay Answers:

1. Explain why a barely visible cirrus cloud at 15km in the tropical atmosphere tends to warm the climate, while a fog bank off the coast of Oregon during July tends to cool the climate.

A high thin cloud has only a small effect on reflected shortwave, because its albedo is small. It can still have an effect on longwave, though, since clouds are more opaque in the infrared. Also, high clouds are very cold, compared to the surface, and so they have a large greenhouse effect.

2. The difference between the daily maximum temperature and the daily minimum temperature is observed to be declining with time at many locations around the world. Explain how human activities may be modifying the atmosphere in ways that might be causing this trend. Give at least two changes we are making and explain how they affect the diurnal range of temperature.

One effect is increased greenhouse gases in the atmosphere, which would affect the cooling at night. Another effect is the addition of aerosols by humans, which reduces the solar heating,e ither directly or by making the clouds brighter by distributing the water over more drops.

3. Give two reasons why tiny amounts of trace gases like CFC-11 and CFC-12 can significantly affect the radiative energy balance of Earth, even if they do not influence ozone. That is, what about their radiative properties is important for climate?

    1. *They are extremely efficient at absorbing infrared radiation.*
    2. *They do so at wavelengths in the water vapor window, where the natural atmosphere is fairly transparent to infrared*

4. Explain the process whereby dense deep water is formed in the far North Atlantic Ocean.
   Warm salty water is brought poleward in the Gulf Stream Extension and cooling in the Norwegian Sea area. Cold, Salty water is very dense.

5. Explain the relationship between the Younger Dryas Event, the thermohaline circulation of the North Atlantic Ocean, and the melting of the ice sheets.
   The Younger Dryas was a return to cold conditions as the climate started to warm after the last ice age. The idea is that the North American Ice Sheet began to break apart and sent a flotilla of ice bergs and fresh water into the North Atlantic, possibly through the release of an ice dam. This put fresh water into the North Atlantic, which caused the thermohaline circulation to slow down, providing less ocean heating in the far North Atlantic, and causing a return to much colder conditions for a while.
6. Explain why when you increase the solar constant in a global climate model by 2%, the largest warming is in the polar regions in winter.

This has to do with sea ice. See middle paragraph of page 278.

7. Use angular momentum conservation to explain why Earth has zonally-averaged surface easterlies in the tropics and surface westerlies in middle latitudes.
   See chapter 6
8. Explain why when you double the carbon dioxide concentration of the atmosphere, the surface WARMS, and the stratosphere COOLS.
   See chapter 12 relating to Fig. 12.8
9. Give three reasons why marine stratocumulus clouds are so important for climate and may have a role in climate sensitivity.
   1. Cover large area, 2. Are over ocean, so albedo contrast is very large so they are strong net coolers and a small change in their area coverage or optical depth can make a big difference, 3. They appear to be sensitivity to both climate change and aerosols.
10. How much has the methane concentration increased in the atmosphere since preindustrial times? How do you know? Give three reasons why methane may have increased?
    Page 325.
11. Why does Antarctic Bottom Water have more nutrients than North Atlantic Bottom Water??
    It comes from intermediate depths, instead of from the surface where plankton consume all the nutrients.
12. Explain what the Younger Dryas Event was, and speculate about what caused it.
    See question 5.

13. How do we know for sure that the increase in atmospheric carbon dioxide during the last 100 years has come from fossil fuel burning?

See page 322 and class notes

14. What three characteristics of a volcanic eruption can make it more important for climate? Explain.

See lecture notes.

15. What does the ^{18}O ratio in an ice core tell us about past climates?

The temperature above the ice when the snow fell

16. What are the orbital parameters, on what times scales do they vary, and how does each affect the insolation at the top of the atmosphere?

See chapter 11.

17. Explain why when the double CO_2 the upper tropical troposphere warms more than the surface in many climate models.

Moist adiabatic lapse rate is less than dry adiabatic lapse rate, moreso as the climate warms.

Problem Solving: Show all work. Show units. Underline answer. Formulas and constants are given on last page

1. If the Earth north of 30N loses 75Wm^{-2} of energy to space in the annual average, what is the annual average northward flux of energy in the atmosphere and ocean across 30˚N? Give your answer in petaWatts (10^{15} Watts). Hint: One quarter of the surface area of the earth is north of 30N.

Multiply average TOA flux times area of polar cap.

2. A parcel of air starts at the equator with a relative zonal velocity of zero and moves to 50˚N conserving angular momentum. What will be its zonal relative velocity when it gets to 50˚N?

See homework

3. A 1 km thick layer of the stratosphere at about 55 km altitude has a longwave emissivity of $1x10^{-4}$. It absorbs solar radiation at the rate of 0.05 Wm^{-2}. If the OLR is 250 Wm^{-2}, what is the radiative equilibrium temperature of this layer?

See homework problem 12-4 and Figure 12.8.

4. Suppose the climate system has a heat capacity equivalent to that of an oceanic mixed layer 200 meters deep. A virus attacks the ocean which results in an instantaneous doubling of atmospheric carbon dioxide, that remains constant forever. This doubling causes an instantaneous decrease in the OLR loss at the top of the atmosphere of 4 Wm^{-2}. If the climate feedback parameter is 1.0 ˚K/(Wm^{-2}), how much warmer will the climate be after 35 years and after 70 years?

See homework problem 12-5 and equations 12.3 to 12.9.

5. A parcel of air starts at 30˚S with a relative zonal velocity of zero and moves across the equator to 50˚N conserving angular momentum. What will be its zonal relative velocity when it gets to 50˚N?

See Chapter 6 homework.

6. By what percentage would total solar irradiance (the solar constant) need to decrease in order to offset a greenhouse gas forcing of 4Wm^{-2} ? Show all work.

Use dQ = dS/4 (1-albedo), where dS is the change in TSI.

7. If the Earth north of 60˚N loses 100Wm^{-2} of energy to space in the annual average, what is the annual average northward flux of energy in the atmosphere and ocean across 60˚N? Give your answer in petaWatts (10^{15} Watts). Hint: The area northward of latitude ϕ is $area = 2\pi a^2 (1.0 - \sin\phi)$

   Multiply average TOA flux times area of poleward cap and make sure you get the direction right, northward or southward.

8. A parcel of air starts at 20˚S with a relative westerly zonal velocity of 20ms^{-1} and moves across the equator to 60˚N conserving angular momentum. What will be its zonal relative velocity when it gets to 60˚N?

   See homework 6-4

9. A volcanic eruption produces a cloud of aerosols at 20 km altitude. The cloud of aerosols reflects 0.5% and absorbs 0.5% of the direct downward solar radiation incident on it. Use global mean radiative equilibrium calculations to estimate how much the surface temperature would change in response to the introduction of the stratospheric aerosol cloud. You may assume that the troposphere can be represented by two layers that are black bodies for terrestrial radiation, but transparent for solar radiation.

   Assume that both the absorbed and reflected energy is lost to the system, since the solar radiation absorbed way up is lost to space before it can much affect the surface.

10. What is the solar zenith angle at noon at winter solstice at 30N?

    At noon the solar zenith angle is the latitude minus the declination angle.

Formulas and Constants: Not all are needed

radius of Earth = 6.37x10^{6}m. Stefan-Boltzmann constant $\sigma = 5.67\times10^{-8}$ Wm^{-2}K^{-4}.

Specific heat of air at constant pressure $c_p = 1004$ JK^{-1}kg^{-1}, $\pi = 3.1415926$

rotation rate of Earth $\Omega = 7.292\times10^{-5}$ s^{-1} $S_{O_3} + \varepsilon\sigma T_e^4 = 2\varepsilon\sigma T_{strat}^4.$

Angular Momentum = $M = (\Omega a \cos\varphi + u) a \cos\varphi$ $\frac{\partial T}{\partial t} = \frac{-1}{\rho c_p}\frac{\partial F}{\partial z}$

Density of water = 1000 kg m^{-3} Area of a sphere = $4\pi r^2$

Latent heat of vaporization = 2.5 x 10^6 J K^{-1} kg^{-1} $\overline{C}_A = c_p \frac{p_s}{g}$

Specific heat of liquid water at 0˚C = 4218 J K^{-1} kg^{-1} $\overline{C}_O = \rho_w c_w d_w$

$c\frac{\partial T'}{\partial t} + \lambda_R^{-1} T' = Q'$ $T' = \lambda_R Q_o \left\{1 - e^{-t/\tau_R}\right\}$

$S_{O_3} + \varepsilon\sigma T_e^4 = 2\varepsilon\sigma T_{strat}^4.$

Volume of a sphere = $4/3\pi r^3$

$\tau_R = c\,\lambda_R$

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

$e = mc^2$

$E_\nu = nh\nu$

$\overline{Q}^{\text{Annual}} \propto \left(1 - e^2\right)^{-1/2}$