Assignment VIII, PHYS 308
Fall 2014
Due 11/14/14 at start of class

This homework will be worth double! Make sure to spend a good chunk of time with this homework. I normally drop your lowest homework assignment each semester, and I will this semester as well – but not this one. Take some time with this!

NOTE: Please leave your answers in terms of actual numbers (with appropriate units) when possible. Please provide full, legible, easy to follow solutions to the following problems. I can't give you credit if I can't follow your reasoning. Extensive exposition on your thought process or strategy is always appreciated.

1. The saturation vapor pressure over liquid water for air at -20 Celcius is right about 1.280 mbar. At the same temperature, the saturation vapor pressure over ice is about 1.033 mbar.

   a) We'll use $G = 7.7 \times 10^{-11}$ m^2/s in the condensational growth equation. How long would it take a supercooled liquid water drop to grow from 20 micron *diameter* to twice its starting *VOLUME* if the environmental vapor pressure is 1.281 mbar?

   b) Let's use the same value of G for ice. (It actually isn't the same – but it is reasonably close-ish, and we'll keep it the same to keep the analysis simple). How long would it take a spherical ice crystal to grow from 20 micron *diameter* to twice its starting *VOLUME* if the environmental vapor pressure is 1.281 mbar?

   c) How long (in days) would it take for the 20 micron diameter supercooled water droplet to grow to the size of a raindrop (diameter 1 mm) under the same conditions as in part (a) above?

   d) How long (in hours) would it take for the 20 micron diameter spherical ice crystal to grow to the size of a raindrop (diameter 1 mm) under the same conditions as in part (b) above?

2. In class, we argued that the condensation process tends to cause a distribution of droplet sizes to become less dispersed (narrower). This is because small droplets grow faster than large droplets, and ultimately allows the small drops to partially "catch up" to the larger ones. At some point, we will (or have) talked about gravitational coagulation, which follows this basic form:

$$\frac{\partial m}{\partial t} \propto \begin{cases} r^6 & \text{for} 10 \leq r \leq 50 \mu \text{ m} \\ r^3 & \text{for} r \gtrsim 50 \ \mu\text{m} \end{cases}$$

Based on this, figure out if gravitational coagulation should cause a size distribution should become narrower or wider.

3. The largest difference between the saturation vapor pressure of liquid water and the saturation vapor pressure of ice occurs near about -14C. Thus, this is the regime where you would expect supersaturations with respect to ice to be largest and you would get most rapid growth of ice crystals by deposition.

   a) If a mixed phase cloud is exposed to a situation where the air is at -14C and supersaturated with respect to ice but subsaturated with respect to supercooled liquid water (as in the Bergeron-Findeisen process), what sort of ice crystal habit would you expect to find a lot of?

   b) If a mixed phase cloud is exposed to a situation where the air is at -14C and supersaturated with respect to both ice and supercooled liquid water, what sort of ice crystal habit would you expect to find a lot of?

   c) What ice crystal habit would you expect in cirrus clouds that somehow have lots of water vapor?

   d) Where might you expect to find a needle habit?

4. We've been studying the dynamics and growth patterns of atmospheric particulates for over two months now, and – whenever you talk about a topic for that long – it sometimes is hard to make sure you have an appropriate understanding of the "big picture". I've tried to emphasize this, but this question is really devoted to seeing how good of a job we've done.

   The average middle-school level understanding of precipitation development goes something like this: water evaporates from the ocean surface, then condenses into clouds, and finally falls back down as rain. We now can say a whole lot more about this process. Describe – in detail – the different processes that occur starting from surface evaporation and continuing on through to the arrival of a fully grown raindrop on the ground.

   I'm expecting a well organized essay with a great deal of detail here. I seriously expect you to spend a few hours on just this question, which is one of the reasons why you are getting an extra week for this assignment. Please type your solution to this problem. Although there is no formal required page length, a 3-5 page answer would be appropriate.

   The intended audience for your essay would be someone who has a degree in Physics, but no background in atmospheric stuff. (Think of your classmates who have never had an atmospheric class).

   Your essay should discuss all of the following topics: homogeneous nucleation, heterogeneous nucleation, Köhler Theory, Deliquescence/Efflurescence, condensational growth, coagulation (perhaps in a variety of contexts), ice nucleation, the Bergeron-Findeisen process, and Saffman-Turner theory. However, the essay is not just a definition of these different phenomena. You are trying to tell a coherent story about the processes water goes through as it grows in the atmosphere.