Homework 3 Solutions

1. Clouds are formed by condensation of water vapor. Water vapor molecules need a surface to condense on in order to form cloud droplets. Hence, atmospheric aerosols that are water soluable are necessary for the formation of clouds.

2. The fog formed is radiation fog. It is produced by Earth's radiational cooling and forms best on clear and calm nights. The radiational cooling causes a temperature inversion, in which there is cooler air near the surface and warmer air above. When the temperature cools to the dew point temperature in the inversion and the relative humidity is 100%, condensation occurs and a fog forms. The fog typically persists until there is enough heating of the ground to break the inversion. In California during the wintertime sometimes the inversion and associated Tule fog persists for days and days because the sunlight is too weak to break the inversion, thus making winters in the Central and San Joaquin Valleys very foggy and miserable.

3. See the descriptions of the clouds within the cloud lecture.

4. a) Infrared cloud images are used to distinguish between high and low clouds. The typical grayscale color scheme in infrared satellite imagery makes warm temperatures appear darker and cold temperatures appear lighter. As the tops of low clouds are warmer than those of high clouds, warm low clouds are appear darker and the cold high clouds lighter. b) Visible cloud images are used to distinguish thick clouds from thin clouds. Because thick clouds have a higher reflectivity than thin clouds, they appear brighter.

5. An adiabatic process is one in which there is no exchange of heat with the surrounding environment. For a rising, unsaturated air parcel, as the parcel of air rises it will expand, due to the decrease in pressure of surrounding air, and cool. The rate of cooling is approximately 10 degrees Celsius per kilometer and this is referred to as the dry adiabatic lapse rate. For a rising saturated air parcel, in which the relative humidity is 100%, water vapor will begin to condense, adding heat to the surrounding environment. The heat added during the condensation process offsets some of the cooling due to expansion, so the rate of cooling is approximately 6 degrees Celsius per kilometer, and this is referred to as the moist adiabatic lapse rate.

6. Clouds that occur in stable atmospheres are generally the stratus-type clouds, which are flat and spread out; clouds that occur in unstable atmospheres are the cumuliform-type clouds, which are puffy and vertically developed. The greater the amount of instability, the more vertically developed the cloud will be. In the case of a mature cumulonimbus (thunderstorm) cloud, the instability extends through nearly all the troposphere. The stability of the atmosphere can be determined by the environmental lapse rate. There are three possibilities: 1) Absolutely stable: environmental lapse rate less than moist adiabatic lapse rate (6 degrees C per km). In this situation, a lifted parcel of air will be cooler than its surrounding environment and sink. 2) Absolutely unstable: environmental lapse rate greater than the dry adiabatic lapse rate (10 degrees C per km). In this situation, a lifted parcel air of air will be warmer than its surrounding environment and tend to rise. This actually rarely happens in the atmosphere. 3) Conditionally unstable: environmental lapse rate in between moist and dry adiabatic lapse rates. In this situation, a lifted parcel of air will be warmer than its surrounding environment and tend to rise ONLY if

condensation is occurring. The occurrence of condensation is therefore almost always a necessary condition for atmospheric instability.

7. Thunderstorms typically form in the afternoon during the monsoon in Arizona because this is the hottest part of the day, and surface heating makes the atmosphere more unstable. Storms form over the mountains because the mountains are locally warmer than the surrounding air, causing the air to rise up the mountain slopes and form convective clouds. The flat base of a thunderstorm cloud, or the lifting condensation level, defines the point where a lifted parcel of air has cooled to its dew point temperature after rising dry adiabatically from the surface. After reaching this point, a parcel of air will continue to rise at the moist adiabatic lapse rate and condense water vapor to form a cumuliform cloud. A rising parcel may reach the top of the troposphere in a cumulonimbus cloud if conditional instability extends through the depth of the troposphere. A parcel cannot go beyond this point, though, because the environmental temperature begins to increase in the stratosphere. So the rising parcel in the cumulonimbus cloud will start to be cooler at this point and sink, forming the flat, spread out anvil top of the cloud. The directional orientation of the anvil is a good indication of the upper level winds.

8. The flat base of the cumulonimbus cloud defines the lifting condensation level (see answer to previous question), so the temperature of the air will equal the dew point temperature and the relative humidity will be 100% there. Because there is no condensation occurring below the cloud, no atmospheric moisture has been removed between the cloud base and the surface. Therefore it may be assumed that the dew point temperature at the base of the cloud is the same as that of the surface (20 degrees C). So, to calculate the surface air temperature, assume that a parcel of air descends dry adiabatically from the cloud base to the surface, warming at the dry adiabatic lapse rate of 10 degrees C per kilometer. This yields a final surface temperature of 30 degrees C. In actual point of fact, the dew point temperature does decrease slightly with height due to the decrease in atmospheric pressure, and the rate of this decrease is approximately 2 degrees C per kilometer (this was not explicitly discussed in class lecture). Applying this additional assumption to the problem yields a cloud base temperature of 18 degrees C and a final surface temperature of 28 degrees C. So either 30 degrees C or 28 degrees C is acceptable as a correct answer to this question.

9. In areas of the cloud that are above freezing, the collision-coalescence is the main factor role in producing precipitating raindrops. In this process, large cloud droplets fall faster and collide and coalesce with smaller, more slowly falling cloud drops in their path. This merging of cloud droplets causes a rapid growth of cloud drops to raindrops. A typical cumulonimbus cloud produces precipitation within minutes or hours after this process begins.

10. The Bergeron process refers to the rapid growth of ice crystals in the presence of supercooled cloud drops. Because the saturation vapor pressure over ice is lower than the saturation vapor pressure over water, there are a relatively greater number of water vapor molecules over the liquid water drops than over the ice crystals. Because of this difference (or gradient) in water vapor, the water vapor molecules tend to be drawn towards the ice crystals, so the liquid water drops evaporate and shrink and the ice crystals grow. This process is most effective where the difference in saturation vapor pressure between water and ice is greatest, about -12 degrees C. At this temperature, ice crystals in precipitating clouds tend to be the largest, forming complex snowflake shapes.

11. Hail is produced in a cumulonimbus cloud when graupel, or large frozen raindrops, or just about any particles act as embryos that grow by accumulating supercooled liquid droplets by accretion. The size of hail is related to the strength of the updraft in the cloud. Stronger updrafts allow hail to stay suspended in a cumulonimbus cloud longer and continue to grow. The biggest hail typically occurs in the strongest, most severe thunderstorms, such as those in the central U.S. Hail typically occurs in summer thunderstorms, whereas the other forms of frozen precipitation occur mainly in winter from more stable clouds (e.g. nimbostratus). Snow will occur when the temperature profile in the lower atmosphere (about 3000 m above the ground) is below freezing throughout. The "wintry mix" type precipitation (sleet and freezing rain) will occur if there is an intervening layer of warm air above freezing to melt precipitating particles on their descent and then refreeze them before they hit the ground.

12. The height, or thickness, of a column of air is dependent on the surface pressure and the temperature. As the temperature decreases with increasing latitude, on average, the height of a given layer also tends to decrease with increasing latitude.

13. The ideal gas law states that pressure is proportional to density and temperature. Assume the air pressure in the room and the refrigerator are the same. When the balloon is place in the refrigerator, the temperature of the air inside will drop and its density will increase. Since the air occupies less volume, the balloon deflates. When the balloon is removed from the refrigerator, the air temperature will rise and the density of the air will decrease. Since the air will occupy more volume, the balloon will inflate.

14. The Galileo thermometer works on the principle of buoyancy. The thermometer consists of a tube filled with a fluid and glass balls with colored liquid suspended in the fluid. Each of the glass balls have different metal weights attached to them. As the temperature of the air changes, the density of the fluid in the thermometer increases (temperature decreases) or decreases (temperature increases). If the density of a weighted ball is greater than that of the fluid it displaces, it will sink, analogous to a stable parcel of air in the atmosphere. If the density of the weighted ball is less than that of the fluid it displaces, then it will float, analogous to an unstable parcel of air in the atmosphere. When the thermometer is at the upper (lower) limit of its temperature range, all the balls will sink (float).

15. There are two key points to this experiment: 1) Release of the pressure in the bottle causes the air to expand and cool adiabatically. This occurred in both experiments with and without the match. 2) When the air temperature cools to the dew point temperature, vapor particles condense to the cloud condensation particles provided from the smoke from the match stick.