Lab 6 for GEOL 1147 (Introduction to Meteorology Lab)

1.Introduction

Dry Adiabatic Processes

Adiabatic processes are those in which an air parcel does *not* exchange heat energy with its surroundings. The temperature of a parcel undergoing an adiabatic process can nevertheless change, if its pressure changes. In the atmosphere, parcel pressure changes usually result from rising or sinking motions of the parcel. Thus, parcels that sink are warmed by adiabatic compression, while those that rise undergo decompressional adiabatic cooling.

As an air parcel rises in the atmosphere it moves upward into regions of lower pressure (since pressure always decreases as you move to higher elevations). As the pressure decreases, the air parcel expands, because initially the pressure inside the air parcel is slightly greater than the pressure outside the air parcel. This is similar to how a bag of chips that you've bought at lower elevation expands when you bring it up unopened to Laramie, where the atmospheric pressure is lower. In order for the parcel, or the bag of chips, to expand, energy must be used. Where does this energy come from? Since no energy is exchanged between the parcel and the environment in an adiabatic process, the energy must come from the thermal energy contained by the air molecules within the parcel. Therefore if energy is used to allow the parcel to expand, the thermal energy, and hence the temperature, of the parcel decreases. In summary, the temperature of a rising air parcel decreases, even though there is no exchange of heat energy between the parcel and the environment, because the air molecules have to give up some of their energy to allow the parcel to expand. The air parcel continues to expand until the pressure inside is exactly equal to the pressure of the surrounding air. (When an air parcel sinks in the atmosphere, the pressure of the surroundings increases, the parcel is compressed, and the temperature inside the parcel increases).

The *dry* adiabatic process is an adiabatic process in which no change of phase of water vapor occurs. The fact that it is termed 'dry' does not mean that the parcel does not contain any water vapor, only that the water vapor in the air parcel does not experience any change of phase. For a dry adiabatic process the temperature of a rising air parcel always decreases at a constant rate of 9.76°C/km. This rate of temperature change is known as the **dry adiabatic lapse rate** (a lapse rate is just the rate of temperature change with change in altitude). For a sinking air parcel, the temperature will increase at the same dry adiabatic lapse rate. These changes of temperature with changes in height (and pressure) are represented on the thermodynamic diagram by solid green lines, which slope upwards and to the left. These lines are referred to as **dry adiabats**.

The use of dry adiabats to describe dry adiabatic processes is straightforward. First locate the point on the diagram (given by the temperature and pressure) that represents the initial state of the air parcel. For rising motion, follow the dry adiabat that intersects the initial temperature and pressure intersection point, upwards and to the left, until you arrive at the new pressure of the air parcel. Now read the new temperature corresponding to the intersection point of the dry adiabat and the final pressure. Note that if the initial state of the air parcel does not lie exactly on a dry adiabat, a path that is parallel to the nearest dry adiabat is followed to describe the process. Sinking motions can be described in the same way, except that the dry adiabat is followed down and to the right on the diagram.

What about the moisture contained in the air parcel during a dry adiabatic process? As mentioned above, the amount of water vapor in the air parcel will not change during a dry adiabatic process, since no phase changes occur, so the mixing ratio of the air parcel (obtained knowing the initial dewpoint) remains constant during the process. However, the dewpoint decreases slightly with decreasing pressure at higher altitudes. Following the mixing ratio line upwards that passes through the initial dewpoint allows the decreasing value of the dewpoint (for rising motion) to be tracked.

How does the saturation mixing ratio of the air parcel change during dry adiabatic ascent? The saturation mixing ratio is determined by the air parcel's temperature and pressure. Since the temperature of the air parcel decreases for rising motion, the corresponding saturation mixing ratio will also decrease (because as the air temperature decreases the amount of moisture needed to saturate the air decreases).

As an air parcel rises in a dry adiabatic process, notice that the temperature of the air parcel decreases more rapidly than the rate at which the dewpoint decreases. Therefore, if an air parcel is lifted sufficiently, the temperature and the dewpoint will become equal, and the air parcel will become saturated. Also note that while the saturation mixing ratio of the air parcel decreases during ascent, the actual mixing ratio remains constant. Obviously if the air parcel is lifted sufficiently, the actual mixing ratio and saturation mixing ratio will become equal, and the air parcel will become saturated.

Further lifting of the air parcel above the level of saturation would result in a supersaturated condition if condensation did not occur, since the temperature would be less than the dewpoint, and the actual mixing ratio would become greater than the saturation mixing ratio. We know that significantly supersaturated conditions are not common in the atmosphere, so continued lifting beyond the height at which saturation occurs must be accompanied by condensation (a change of phase of water vapor). The height at which the air parcel just reaches saturation is known as the condensation level (CL) (sometimes referred to as the Lifting (or Lifted) Condensation Level (LCL)). For continued lifting beyond the CL we can no longer describe the change of state of the air parcel by the dry adiabatic process, but instead must turn to the moist adiabatic process, which describes the change of state of the air parcel as condensation of water vapor occurs.

Moist Adiabatic Processes

The moist adiabatic process describes changes of temperature, dewpoint, mixing ratio, and saturation mixing ratio for a saturated air parcel that is rising. For this process the temperature and dewpoint are equal, as are the mixing ratio and saturation mixing ratio. Cooling associated with the ascending motion results in condensation. Moist adiabatic processes are represented on the thermodynamic diagram by the red saturated adiabats, which curve up to the left.

The rate of temperature decrease for a moist adiabatic process is less than that for a dry adiabatic lapse rate, because as water vapor condenses it releases latent heat. The latent heat that is released provides some of the energy needed for the expansion of the air parcel, so that not as much of the thermal energy of the air parcel is required to cause the parcel to expand. The temperature of the parcel therefore decreases at a slower rate than in a dry adiabatic process.

Remember that for moist adiabatic processes the state of the air parcel is described by only one point, since the temperature and dewpoint are equal at saturation. As the saturated air parcel rises, the temperature decreases, but so does the mixing ratio. The mixing ratio decreases because in parallel with the temperature decrease, water vapor condenses to form liquid water (or ice), so that the parcel's water vapor content goes down.

II. Exercises

In this section of the lab you will explore both dry and moist adiabatic processes using your thermodynamic diagram.

1. Locate the points that describe the following air parcel state (mark these points on your thermodynamic diagram):

$T = 30°C$, $T_d = 13°C$, and $p = 1000$ mb

1a. Start with the air parcel described above. Lift this air parcel from its initial pressure of 1000 mb to a pressure of 900 mb. Mark the new temperature, dewpoint, and pressure as well as the lines used to get to these points on your thermodynamic diagram. Label these points.

1b. What is the new temperature and dewpoint at a pressure of 900 mb?

1c. What is the mixing ratio at 900 mb?

1d. Has the mixing ratio changed from its value at 1000 mb? Why or why not?

1e. What is the saturation mixing ratio at 900 mb?

1f. Has the saturation mixing ratio changed from 1000 mb to 900 mb? Why or why not?

1g. Calculate the relative humidity of the air parcel at 900 mb.

1h. How has the relative humidity of the air parcel changed from the value at 1000 mb?

1i. Now continue lifting the air parcel until it reaches its CL. Mark the point representing the condensation level on the diagram.

1j. What is the pressure of the air parcel at the CL?

1k. What is the temperature of the air parcel at the CL?

1l. What is the dewpoint of the air parcel at the CL?

1m. What is the mixing ratio of the air parcel at the CL?

1n. What is the relative humidity of the air parcel at the CL?

1o. Finally, lift the air parcel from the CL to a pressure of 500 mb. Mark this point on the diagram.

1p. What is the temperature of the air parcel at 500 mb?

1q. What is the mixing ratio of the air parcel at 500 mb?

1r. How is the mixing ratio of the air parcel at 500 mb different from the mixing ratio of the air parcel at the CL? What has happened to this water vapor between the CL and 500 mb?

2. Locate the points that describe the following air parcel state (mark these points on your thermodynamic diagram):

$T = 0°C$, $T_d = -15°C$, and $p = 800$ mb

2a.Start with the air parcel described above. Lift this air parcel from its initial pressure of 780 mb to its CL. Mark this point on your thermodynamic diagram.

2b. What is the pressure of the air parcel at the CL?

2c. What is the temperature of the air parcel at the CL?

2d. What is the dewpoint of the air parcel at the CL?

2e. What is the mixing ratio of the air parcel at the CL?

2f. Finally, lift the air parcel from the CL to a pressure of 500 mb. Mark this point on the diagram.

2g. What is the temperature of the air parcel at 500 mb?

2h. What is the mixing ratio of the air parcel at 500 mb?

2i. How is the mixing ratio of the air parcel at 500 mb different from the mixing ratio of the air parcel at the CL? What has happened to this water vapor between the CL and 500 mb?

3a. Locate the points that describe the following air parcel state. Mark these points on your thermodynamic diagram.

$$T = 30°C,\ T_d = 21°C,\ p = 800 \text{ mb}$$

3b. Find the mixing ratio, saturation mixing ratio, and relative humidity for the points given in problem 3a.

3c. Lift the air parcel described in problem 3a from 800 mb to 750 mb. Mark the new temperature and dewpoint.

3d. What is the temperature and dewpoint at 750 mb?

3e. Lift the air parcel from problem 3c to the CL. Label this point as 3e.

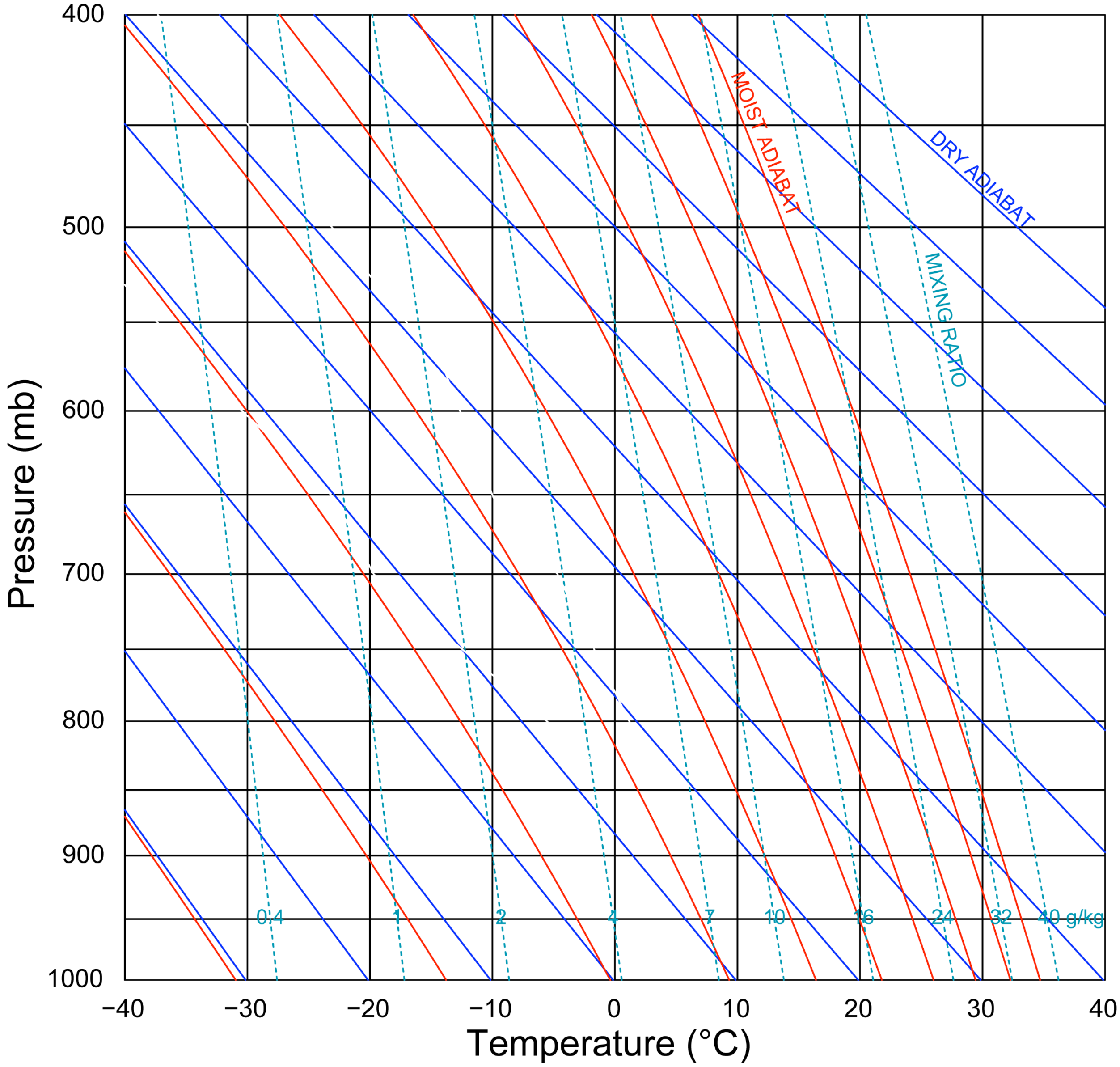
3f. What is the pressure, temperature and dewpoint at the CL?

3g. What is the mixing ratio, saturation mixing ratio, and relative humidity at the CL?

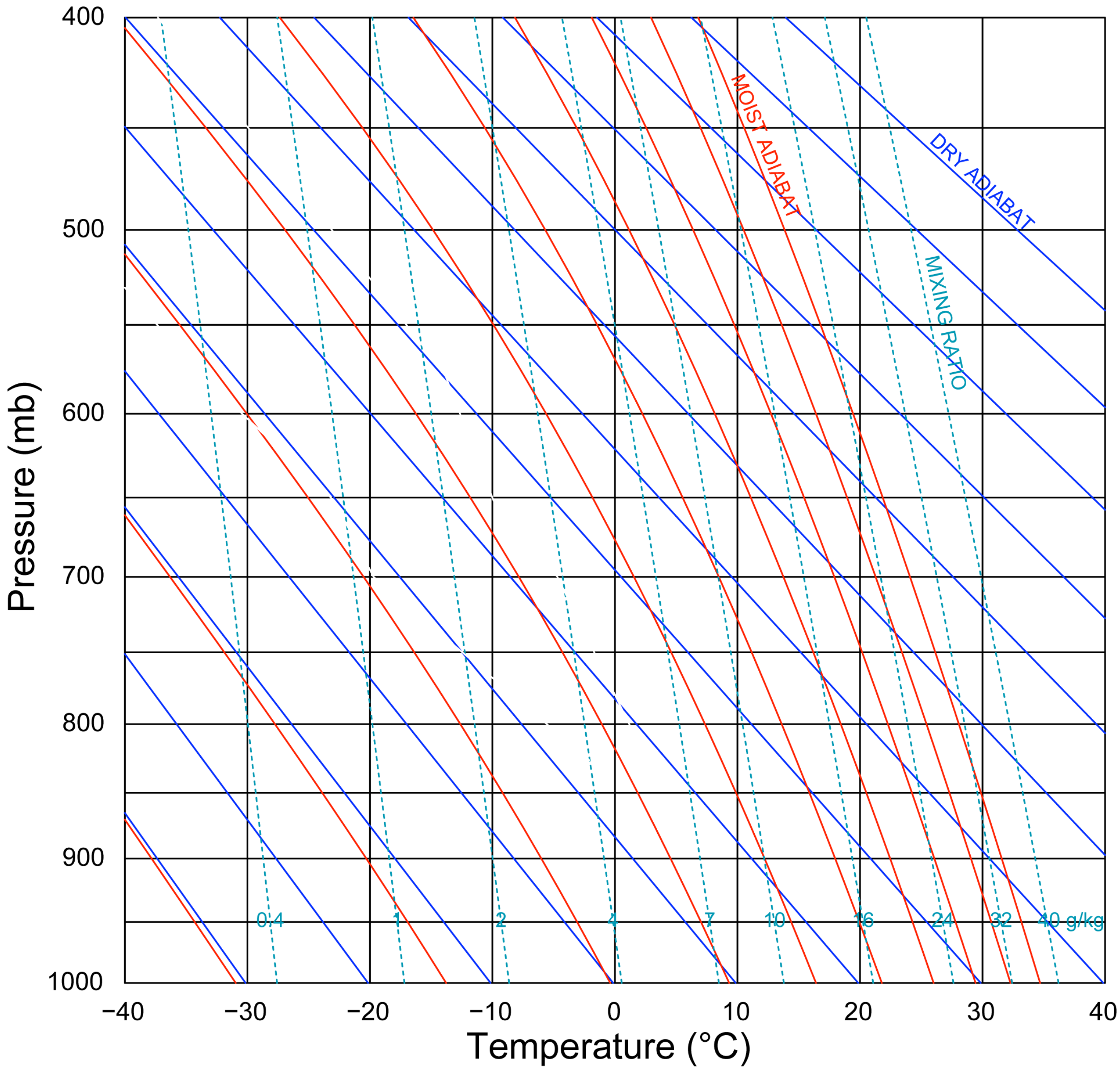
3h. Continue lifting this air parcel to a pressure of 600 mb. Label this point 3h.

3i. What are the temperature, dewpoint, and relative humidity at 600 mb?

STUVE THERMODYNAMIC DIAGRAM



STUVE THERMODYNAMIC DIAGRAM



STUVE THERMODYNAMIC DIAGRAM