Lab 5 for GEOL 1147 (Introduction to Meteorology Lab)

I. Introduction

Humidity is a measure of the amount of water vapor present in the atmosphere, at a given time and location. Meteorologists use a number of different variables to represent the amount of moisture in a given sample of air. The use of so many different variables to represent the same basic measurement may seem strange, but each of the humidity variables that will be presented in this lab has their own advantages and disadvantages.

The humidity variables used in this lab include:

- Vapor pressure
- Saturation vapor pressure
- Relative humidity
- Dewpoint
- Wet-bulb temperature

II. Review of Terms

Saturation: A given sample of air (an air parcel) is said to be saturated when the rate of evaporation from a flat surface of water into the parcel is exactly equal to the rate of water vapor condensation onto the water surface, from the air parcel. In the atmosphere any addition of water vapor to a sample of air that is already saturated will result in condensation and the formation of clouds or fog. Therefore, when an air parcel is referred to as "saturated," the air contains the maximum amount of water vapor possible at the prevailing temperature, without condensation occurring.

Vapor pressure (e): The vapor pressure is the pressure exerted by the water vapor molecules in a sample of air. The water vapor pressure contributes to the overall pressure similarly to the pressure contributions from the other gases present (nitrogen, oxygen, argon, etc.)

Saturation vapor pressure (e_s): The saturated vapor pressure is the contribution to the total pressure from the water vapor molecules in a sample of air that is saturated. A given air parcel will have separate values for the vapor pressure and the saturation vapor pressure associated with it. The vapor pressure is a measure of the amount of water vapor *actually* in the air parcel, while the saturation vapor pressure is a measure of the *maximum* amount of water vapor the air parcel could hold at its current temperature. (Remember that the saturation vapor pressure increases as the temperature of the air parcel increases. When the air parcel is saturated the vapor pressure will equal the saturation vapor pressure.

Relative humidity (RH): The relative humidity is a measure of how close the air is to being saturated and is the ratio of the actual vapor pressure to the saturation vapor pressure. (Relative humidity is also given by the ratio of the mixing ratio to the saturation mixing ratio). Because the relative humidity is calculated based on the actual amount of water vapor in an air parcel and the maximum amount of water vapor an air parcel could hold (which depends on the temperature of the air parcel) *the relative humidity will change if either the amount of water vapor present changes or the temperature changes*. This is an important idea to understand. It means that the relative humidity cannot be used when comparing the actual amount of water vapor present at two different locations or times (since the temperature may not have been the same when the two relative humidity measurements were made). If you are interested in comparing the actual amount of water vapor present at two different locations, other humidity variables such as the vapor pressure, dewpoint, or wet-bulb temperature must be used.

Dewpoint (T_d): The dewpoint (or dewpoint temperature) is the temperature to which a sample of air must be cooled at constant pressure in order to become just saturated. By cooling an air sample, the saturation vapor pressure will decrease. If the air is cooled enough, the actual vapor pressure will become equal to the saturation vapor pressure and the air sample will be saturated.

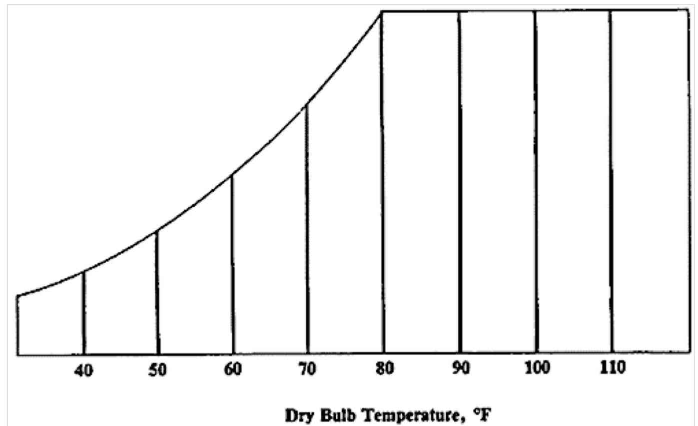
Wet-bulb temperature (T_w): The wet-bulb temperature is the temperature a wetted thermometer bulb measures when exposed to a steady stream of air. The wet-bulb temperature will be measured in this lab with a *sling psychrometer*.

III. Determination of Humidity Variables

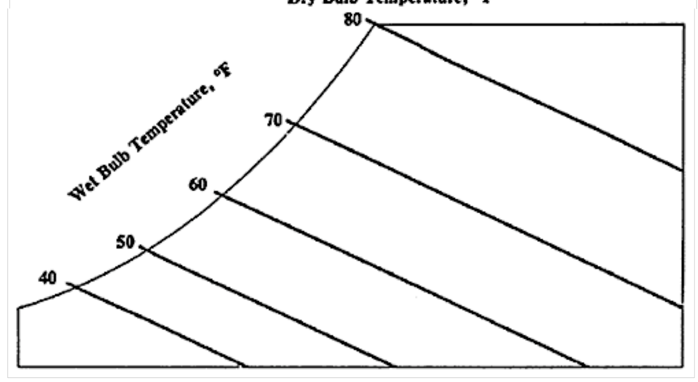
The humidity variables can be determined using a simplified **psychrometric chart**, which graphically illustrates the relationships between air temperature and relative humidity.

- The psychrometric chart has lines for *dry bulb temperature*, *wet bulb temperature, dewpoint*, *water vapor pressure* and *relative humidity.*

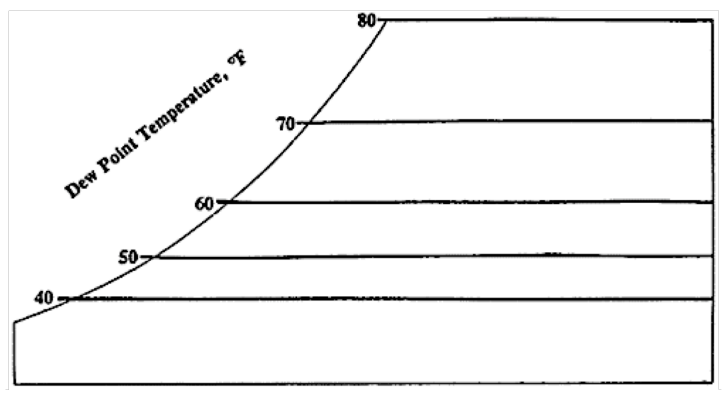
The <u>*dry bulb temperature*</u> (T), measured by an ordinary thermometer, is plotted along the horizontal bottom chart axis. Vertical lines are lines of constant dry bulb temperature.



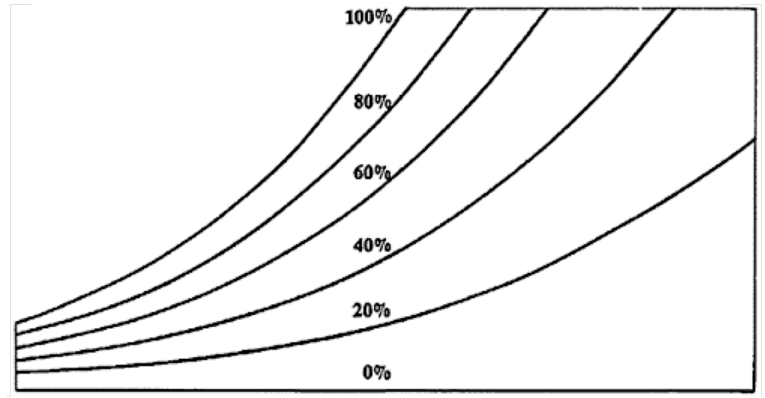
<u>*Wet bulb temperature*</u> (T_w) is plotted along the curved upper left boundary of the chart. The lines sloping down from 'top left' to 'bottom right' are lines of constant wet bulb temperature.



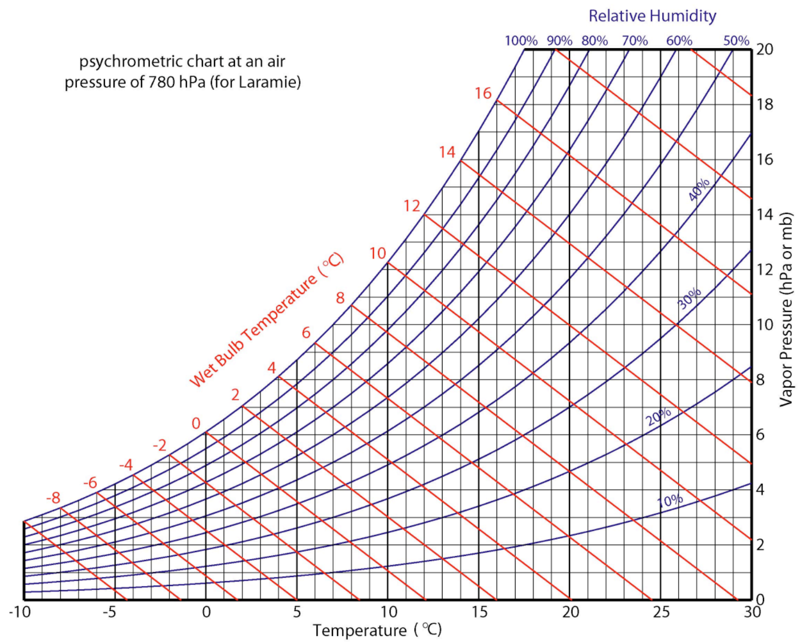
<u>*Dewpoint*</u> (T_d) uses the same numerical scale as wet bulb temperature; the horizontal lines represent constant dewpoint.



Lines of constant *relative humidity* (RH) curve upwards from the lower left to the upper right of the chart.



Vapor pressure (e) (or on some charts, water vapor mixing ratio) is plotted on the vertical right hand axis and is represented by horizontal lines. Therefore any given horizontal line specifies a saturation (dew point) temperature and the corresponding saturation vapor pressure at that temperature.



Knowing the values of any two of the above five parameters fixes the intersection point of the lines for those two parameters on the chart, and allows the values of the other three parameters, whose lines pass through that point, to be determined. For example, if T = 23°C and T_d = 4.5°C, then T_w must be 12°C, RH must be 30%, and the actual vapor pressure 8.4 hPa (equal to the saturation vapor pressure at the dewpoint).

IV. The Thermodynamic Diagram

The thermodynamic diagram is an important tool for meteorologists. It can be used to determine the static stability of the atmosphere, and thereby help to determine whether or not clouds will develop and what form those clouds subsequently take, as well as allowing other processes involving the vertical movement of air to be visualized.

The diagrams graphically represent physical processes that can also be described by a series of equations. However, it is easier to visualize these processes graphically, rather than relying on tedious calculations. In this lab you will learn to use thermodynamic diagrams to describe a number of processes in the atmosphere, and to determine the stability of the atmosphere. In the following lab we will again use thermodynamic diagrams to investigate cloud formation processes.

Thermodynamic diagrams are used to describe the state of the atmosphere. The state of an air parcel can be characterized by values of temperature and pressure, and a moisture variable. The horizontal and vertical lines on the thermodynamic diagram are used to describe an air parcel's pressure and temperature, respectively. The vertical lines on the diagram (isotherms) are labeled in degrees Celsius and are plotted at 10°C intervals. The horizontal lines are lines of constant pressure (isobars). The pressure values plotted adjacent to these lines decrease as you move up the graph, the same way that pressure decreases as you move upwards in the atmosphere. For practice, make sure that you can find the following points on the diagram: T = 0°C and p = 700 mb (located near the center of the diagram); T = 30°C and p = 1000 mb (located near the lower right side of the diagram).

The final variable required to describe the state of an air parcel is a moisture content variable. Lines of constant mixing ratio are plotted as blue dashed lines which slope upwards and to the left on the diagram included with this lab. The mixing ratio of an air parcel is the mass of water vapor contained in the parcel for each kilogram of dry air in the air parcel.

The mixing ratio lines are actually used to describe two characteristics of the air parcel. The mixing ratio line which passes through the point defined by the parcel temperature and pressure describes the *saturation* mixing ratio, r_s, of the air parcel. The saturation mixing ratio is analogous to the saturation vapor pressure discussed in the humidity lab, in that it is a measure of the maximum amount of water vapor that can be held in the air parcel at a given temperature and pressure. The mixing ratio line that passes through the intersection point of the parcel pressure and *dewpoint* is that of the *actual* mixing ratio, r, a measure of the actual amount of water vapor contained in the air parcel. Therefore an unsaturated air parcel at a given pressure level is characterized by *two* points on the thermodynamic diagram, one given by the parcel temperature and pressure, and the other by the parcel dewpoint and pressure. If the air parcel is saturated then the temperature and dewpoint are equal, and only *one* point is required to describe the state of the air parcel on the diagram.

From the saturation mixing ratio and the actual mixing ratio, the relative humidity, RH, can be determined using the formula:

$$RH = \frac{r}{r_s} \cdot 100\%$$

Often the state of an air parcel will not be located exactly at the intersection of the temperature, pressure, or mixing ratio lines printed on the diagram, and therefore you will need to interpolate between the plotted lines. Don't worry about being over precise. You should be able to estimate the temperature to better than one degree Celsius, the pressure to within 10 mb, and the mixing ratio to within 0.1 to 1 g/kg depending on your location on the graph (the spacing between mixing ratio lines is not constant).

IV. Exercises

1. List the five humidity variables.

2. Name the five lines displayed on a thermodynamic diagram.

3. What does the term *adiabatic* mean?

4. What is the numerical value of the dry adiabatic lapse rate?

5. Why is the rate of temperature decrease for moist adiabatic ascent less than for dry adiabatic ascent.

6. For each of the following problems, plot the required points on the thermodynamic diagram included at the end of the lab manual and label the point with the problem number. It is advisable to **use a pencil**, so that you can easily erase errors.

6a. Locate the points which describe the following air parcel state (mark these points on your thermodynamic diagram):

$T = -15°C$, $T_d = -25°C$, and $p = 600$ mb

6b. What is the mixing ratio of this air parcel?

6c. What is the saturation mixing ratio of this air parcel?

6d. Use the formula on the previous page to calculate the relative humidity of the air parcel.

7a. Locate the points which describe the following air parcel state (mark these points on your thermodynamic diagram):

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

7b. What is the mixing ratio of this air parcel?

7c. What is the saturation mixing ratio of this air parcel?

7d. What is the relative humidity of the air parcel?

8a. Locate the points which describe the following air parcel state (mark these points on your thermodynamic diagram):

$$T = 0°C,\ T_d = -15°C,\ \text{and}\ p = 800\ \text{mb}$$

8b. What is the mixing ratio of this air parcel?

8c. What is the saturation mixing ratio of this air parcel?

8d. What is the relative humidity of the air parcel?

STUVE THERMODYNAMIC DIAGRAM