Temperature and Humidity

Overview

Water vapor is a very important gas in the atmosphere and can influence many things like condensation and the formation of clouds and rain, as well as how hot or cold it feels at the surface. Different regions typically contain different amounts of water vapor and this can drastically affect the climate across these regions. Water vapor is also a necessary tool in forecasting, therefore the measurement of the amount of water vapor in the air is standard for most weather observation stations (along with temperature and wind properties). The following activities will help you become familiar with the different ways in which meteorologists express water vapor amounts as well as how to measure it.

Theory

The amount of water vapor in the air can vary greatly on regional scales and must be measured at weather stations. There are several ways to measure and express this moisture content. One is using a psychrometer, which measures the dry bulb (actual air) temperature and what is called a wet-bulb temperature. This is done by placing a wet material over one of the temperature sensors and ventilating it, causing the temperature to drop due to evaporation of the water from the material. If the air is dry, the evaporation will be stronger and so the temperature will drop more than if the air was humid. Therefore, the difference of the dry and wet bulb temperatures can be an indication of how much water vapor is in the air.

Other ways to express water vapor include the relative humidity, dew point temperature and partial pressure of water vapor (the amount of pressure the water vapor would have if it alone occupied a parcel of air (i.e. vapor pressure)). If enough of these quantities are known, they can be used along with a table of temperature and saturation vapor pressure (the partial pressure of water vapor necessary to reach saturation, or 100% relative humidity) to calculate unknown quantities of moisture content and temperature. Computation of these quantities for different regions can illustrate that water vapor varies greatly on a regional scale and that relative humidity can be a good measure of how humid it feels but not necessarily of the actual water vapor content.

Relative humidity is dependent on the temperature and the vapor pressure (p_v) of the air. Using temperature to find saturation vapor pressure (p_v^*) (i.e. table 2), one can compute the relative humidity as:

$$\frac{p_v}{p_{v*}} * 100\%$$

Keep in mind that not only will this quantity change if the moisture content is altered, but if the vapor pressure (the actual amount of water vapor in the air) remains the same, the relative humidity will be affected by a change in temperature.

How does humidity affect temperature?

CMMAP

Reach for the sky.

Overview

When travelers discuss the different climates they have experienced, many will agree that the summers in Texas are much less comfortable than Colorado despite the fact that the summer highs for these regions are very similar - generally within a few degrees of each other. So why the difference? We've all heard that "it's a dry heat" in Colorado but what does that mean? How does the lack of humidity in Colorado make a 32°C day seem more bearable than a 32°C day in Texas?

Theory

In this activity, your students will be constructing a whimsical psychrometer or wet bulb/dry bulb thermometer. The psychrometer was invented by Dr. Adolf Aßmann in the late 19th century and enables atmospheric scientists to measure how much moisture is in the air. In this experiment, one probe of the thermometer will be shielded from radiation and moisture inside the apparatus while the other will be in a humid environment exposed to moving air. This will cause the latter probe to record a lower temperature than the former. When the water in the stuffed animal (or Humidibeast) evaporates, it must absorb energy. This

Necessary materials:

- An indoor/outdoor thermometer
- Small stuffed animal
- Rubber bands
- Water
- Small fan
- Chart of relative humidity and dew points based on wet bulb/dry bulb temperature differences

The chart included with this experiment is adapted from the relative humidity tables courtesy of NOAA (http://www.wrh.noaa.gov/sto/rhtbl.php). To read the chart, locate the wet bulb temperature on the horizontal and the dry bulb temperature on the vertical. Where they intersect you will see two numbers. The first number is the dew point and the second is the relative humidity. All temperatures are in Celsius.

leaves the temperature probe cooler. The amount of water evaporated from the Humidibeast depends on the moisture content of the ambient air. By measuring the two temperatures, we can determine the *relative humidity* of the air. Relative humidity is the percentage of water that is actually in the air compared to how much water the air could possibly hold at a certain temperature.

$$RH = \frac{\text{Amount of water in the air}}{\text{Amount of water the air } could \text{ hold}} \times 100$$

This is also called the dew point: the temperature at which the air becomes saturated and water vapor condenses into liquid forming dew.

The indoor/outdoor thermometer takes two readings: one of the "wet" temperature and one of the "dry."

Doing the Experiment

Soak the Humidibeast thoroughly with water and use the rubber bands to secure one probe of the indoor/outdoor thermometer to it so the animal's hide covers the sensor*. Set up the fan so that it blows across the animal, encouraging evaporation. Have students observe the difference in temperature readings between the wet and dry. Once the two temperatures have reached a stable point, have students record the values and disassemble their equipment. If the two values are very different then the relative humidity is low meaning that more of the water in the Humidibeast could (and did) evaporate. If, however, the values are closer together then we know that the relative humidity was rather high and the air could not hold any more moisture. When students have resumed their seats, have them use the provided chart to determine the relative humidity and dew point temperature. Discuss how this might vary in different parts of the world or other times of the year.

Summing Up

If you are taking a walk in the park on a warm summer day, your body will attempt to thermally regulate itself by sweating. When the sweat evaporates it leaves your skin cooler - you are in essence a Humidibeast yourself in this situation. If, however, the relative humidity is already very high then less of the sweat will be able to evaporate since the air can not hold much more moisture. In this case, your body will not be able to cool itself and you will feel much warmer. This is why the a hot summer day in Colorado doesn't seem as severe as the same temperature day in Texas.

For More Information

CMMAP, the Center for Multiscale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

*No Humidibeasts were harmed in the development or execution of this experiment.

Part 1: Measuring humidity - Inside vs. Outside

LSOP Exercise - How does humidity affect temperature?

1. Soak the Humidibeast thoroughly with water and use the rubber bands to secure one probe of the indoor/outdoor thermometer to it so the animal's hide covers the sensor.

2. Set up the fan so that it blows across the animal, encouraging evaporation.

3. Observe the difference in temperature readings between the wet and dry.

4. Once the two temperatures have reached a stable point, record the values.

5. Subtract the temperature of the wet beast from that of the dry one.

6. Use Table 1 to figure out the relative humidity.

Inside Observations:
Dry Bulb Temperature: _____
Wet Bulb Temperature: _____
Relative Humidity: _____

Outside Observations:
Dry Bulb Temperature: _____
Wet Bulb Temperature: _____
Relative Humidity: _____

Discussion:

• In your groups discuss how this might vary in different parts of the world or other times of the year.

• Did you expect it to be more drier inside or outside? Why?

• Why is the wet-bulb temperature a good measure of how cool human skin can become?

• Why do hot and humid summer days usually feel hotter than hot and dry summer days?

Part 2: Calculating Moisture Content

For the second part of the activity, you will calculate and compare moisture parameters for different regions.

Background Information

There are many different ways to measure water vapor in the atmosphere, the most common include dew point and wet bulb temperatures, relative humidity, vapor pressure. The following definitions and relationships will prove useful in this 2nd activity:

- Dew point Temperature (T_d): the temperature air would have to be cooled to in order for saturation to occur. The dewpoint temperature assumes there is no change in air pressure or moisture content of the air.

- Dry Bulb Temperature (T): the actual air temperature

- Wet Bulb Temperature (T_w): the lowest temperature that can be obtained by evaporating water into the air at constant pressure. T_w is between the actual temperature and the dew point.

- Vapor Pressure (p_v): the air's total water vapor content (in terms of the amount of pressure that the water vapor molecules exert). -- good measure of the total amount of WV in the air

- Saturation vapor pressure (p_{v*}): describes how much water vapor is necessary to make the air saturates at a any given temperatures. It is the pressure that the water vapor molecules would exert if the air were saturated with vapor at a given temperature. The point at which the water will condense because the parcel can't 'hold' any more water vapor. It is dependent on the temperature of the air only and can be calculated using Table 2.

- Relative Humidity (RH): the amount of water vapor actually in the air divided by the amount of water vapor the air can hold. Relative humidity is expressed as a percentage and can be computed in a variety of ways. One way is to divide the actual vapor pressure by the saturation vapor pressure and then multiply by 100 to convert to a percent.

Note: Because of the relationship between vapor pressure, saturation vapor pressure and relative humidity, in Table 2:

dew point temperature - corresponds with the actual vapor pressure of the air
actual temperature - corresponds to the saturation vapor pressure.

Answer the following questions:
These questions are designed to enhance your understanding of water vapor content and its regional variations. You will need to reference Table 2.

1. What are the vapor pressure, saturation vapor pressure, and relative humidity? If the temperature is 29°C and the dew point temperature is 13°C.

2. What are the vapor pressure, saturation vapor pressure, and air temperature? If the dew point temperature is 10°C and a relative humidity of 50%.

3. What are the air temperature, vapor pressure, and relative humidity? If the dew point temperature is 10°C and a saturation vapor pressure is 35mb.

4. Find the relative humidity of two cities:

   a. City A has an actual vapor pressure of 6mb and a saturation vapor pressure of 41mb.

   b. City B has an actual vapor pressure of 6mb also, but a saturation vapor pressure of 18mb.

   c. Which city has a higher surface temperature? How can you tell?

5. Phoenix has a surface temperature of 35°C and RH of 15%, while Fairbanks has a surface temperature of 4°C and RH of 80%. Which of these cities has a higher water vapor content? (hint: make sure to calculate it, don't just trust your instinct)

Summing Up

Now you should know that moisture can vary greatly in the atmosphere and plays an important role in regional climate and weather forecasting. Also, don't judge a book by it's cover, remember that relative humidity isn't always the best indication of the actual water vapor content in the air.

Table 1.
Relative humidities based on wet and dry bulb temperature differences.

Dry Bulb Temperature (°C)	Temperature Difference (dry bulb − wet bulb, °C)									
	1	2	3	4	5	6	7	8	9	10
10	88	77	66	55	44	34	24	15	6	−
11	89	78	67	56	46	36	27	18	9	−
12	89	78	68	58	48	39	29	21	12	−
13	89	79	69	59	50	41	32	22	15	7
14	90	79	70	60	51	42	34	25	18	10
15	90	81	71	61	53	44	36	27	20	13
16	90	81	71	63	54	46	38	30	23	15
17	90	81	72	64	55	47	40	32	25	18
18	91	82	73	65	57	49	41	34	27	20
19	91	82	74	65	58	50	43	36	29	22
20	91	83	74	67	59	53	46	39	32	26
21	91	83	75	67	60	53	46	39	32	26
22	91	83	76	68	61	54	47	40	34	28
23	92	84	76	69	62	55	48	42	36	30
24	92	84	77	69	62	56	49	43	37	31
25	92	84	77	70	63	57	50	44	39	33

Table 2.
Saturation vapor pressure as a function of air temperature

Temperature (°C)	Saturation vapor pressure (mb)
2	6.9
4	8.4
7	10.2
10	12.3
13	14.8
16	17.7
18	21.0
21	25.0
24	29.6
27	35.0
29	41.0
32	48.1
35	56.2
38	65.2
41	76.2
43	87.8
46	101.4
49	116.8
52	134.2

Answer Key

1. What are the vapor pressure, saturation vapor pressure, and relative humidity? If the temperature is 29ºC and the dew point temperature is 13ºC.

Actual vapor pressure of air (p_v) = 14.8mb (corresponds to T_d = 13ºC in Table 2)

Saturation vapor pressure (p_v^*) = 41mb (corresponds to T = 29ºC in Table 2)

Relative Humidity (RH) = $\dfrac{p_v}{p_v^*} \times 100\% = \dfrac{14.8mb}{41mb} \times 100\% = .36 \times 100\% = 36\%$

2. What are the vapor pressure, saturation vapor pressure, and air temperature? If the dew point temperature is 10ºC and a relative humidity of 50%.

Actual vapor pressure of air (p_v) = 12.3mb (corresponds to T_d = 10ºC in Table 2)

Use RH and p_v to find saturation vapor pressure:

$$\frac{50\%}{100\%} = 0.5 = \frac{p_v}{p_v^*} = \frac{12.3mb}{p_v^*} \rightarrow p_v^* = \frac{12.3mb}{0.5} = 24.6mb$$

Air Temperature $\approx$ 20ºC (round from nearest corresponding p_v^* in Table 2)

3. What are the air temperature, vapor pressure, and relative humidity? If the dew point temperature is 10ºC and a saturation vapor pressure is 35mb.

Air Temperature = 27ºC (corresponds to p_v^* = 35mb in Table 2)

Vapor Pressure (p_v) = 12.3mb (corresponds to T_d = 10ºC in Table 2)

RH = $\dfrac{12.3mb}{35mb} \times 100\% = 35\%$

4. Find the relative humidity of two cities:

   a. City A has an actual vapor pressure of 6mb and a saturation vapor pressure of 41mb.

   RH = $\dfrac{6mb}{41mb} \times 100\% = 14.6\%$

   b. City B has an actual vapor pressure of 6mb also, but a saturation vapor pressure of 18mb.

   RH = $\dfrac{6mb}{18mb} \times 100\% = 33.3\%$

c. Which city has a higher surface temperature? How can you tell?
City A has a higher surface temperature because it has a higher saturation vapor pressure.

5. Phoenix has a surface temperature of 35ºC and RH of 15%, while Fairbanks has a surface temperature of 4ºC and RH of 80%. Which of these cities has a higher water vapor content? (hint: make sure to calculate it, don't just trust your instinct)

Phoenix:
$$p_v^* = 56.2mb$$
$$\frac{p_v}{p_v^*} = \frac{RH}{100\%} = 0.15 = \frac{p_v}{56.2mb} \rightarrow p_v = 56.2mb \times 0.15 = 8.43mb$$

Fairbanks:
$$p_v^* = 8.4mb$$
$$p_v = 8.4mb \times 0.8 = 6.72mb \quad \text{(using same calculation as in Phoenix)}$$

Therefore, Phoenix actually has a higher moisture content than Fairbanks even though it has a lower relative humidity.

This is also why it feels very dry in houses during winter; the air gets warmed up but no moisture is added, hence the numerator in the RH fraction remains the same while the denominator increases, reducing the relative humidity.