Make a Thundershower

**A quick teacher's guide is given at the end of this document*

This guide goes with the "Make a Thundershower" applet created by Tom Whittaker and Steve Ackerman with Weather Wise. The Weather Wise page is at http://profhorn.meteor.wisc.edu/wxwise/ The "Make a Thundershower" applet can be found at

http://profhorn.meteor.wisc.edu/wxwise/thermo/tstm.html.

A second, more advanced applet can be found at

http://profhorn.meteor.wisc.edu/wxwise/thermo/thermogram.html

This applet can be used to teach about thunderstorm development. Resources that you can use to learn and teach about thunderstorms include

NOAA National Weather Service JetStream Online School for Weather

http://www.srh.noaa.gov/jetstream/matrix.htm

University of Illinois WW2010

http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/svr/home.rxml

Millersville University—Guide to read Skew-T charts (upper air soundings). This will help you understand concepts related to atmospheric instability which leads to thunderstorm development.

http://www.atmos.millersville.edu/~lead/SkewT_Home.html

Benchmarks

SC912.E.7.6 - Relate the formation of severe weather to the various physical factors.

Background Information for the Applet

(Special note—I left out the degrees Celsius symbol $^{o}$C because it is causing difficulty with the formatting)

The graph on the left shows the temperature (red) and the dew point temperature (blue) of the atmosphere at various pressure levels. The purple line is the temperature of an individual air parcel as it rises through the atmosphere. The temperatures are plotted on the x-axis and the pressure levels of the atmosphere are plotted on the y-axis. The units for temperature are degrees Celsius (C) and millibars (mb) for pressure. The cloud is shown on the right hand side. You are able to change the temperature and the dew point of the atmosphere and see how it affects the thunderstorm.

This table shows the temperature and dew point at the various pressure levels.

| Pressure Level (mb) & Standard Atmospheric Height (meters) | Temperature (C)--Red Line | Dew Point Temperature (C)--Blue Line |
|---|---|---|
| 100 (16,000 meters) | -55 | -60 |
| 150 | -55 | -60 |
| 200 (12,000 meters) | -55 | -60 |
| 300 (9000 meters) | -40 | -60 |
| 400 | -30 | -50 |
| 500 (5000 meters) | -20 | -38 |
| 600 | -11 | -30 |

| | | |
|---|---|---|
| 700 (3000 meters) | -10 | -20 |
| 850 (1500 meters) | 2 | -15 |
| 900 | 12 | -10 |
| 1000 (100 meters) | 20 | 10 |
| 1010 | 20 | 15 |

(Pressure levels were obtained from http://weather.unisys.com/upper_air/details.php)
This guide will allow you to show the applet and guide students towards an understanding of the necessary atmospheric conditions for thunderstorms to form. Answers for the guiding questions are given in **bold**.

Part 1—Practice Reading the Graph

Orient the students on how to read the graph. Point out that the atmospheric temperature is given in red and the dew point temperature is in blue. Ask

1. What is the temperature of the atmosphere at these pressure levels?

1010 mb **(20 C)**, 1000mb **(20 C)**, 900 mb **(12 C)**, 700 mb **(-10 C)**, 500 mb **(-20 C)**, 300 mb **(-42 C)**

Explain that the dew point is the temperature at which air has to be cooled to to become saturated with water vapor. When the air temperature cools to the dew point water vapor will condense and become liquid water vapor and form a cloud. The closer the dew point temperature is to the air temperature the more water vapor is in the air.

2. At which levels would you expect there to be moist air? **(1010, 1000 mb)**

3. At what pressure level is the cloud base? **(850 mb)**
4. At what pressure level is the cloud top? **(between 625 and 600 mb)**

Explain that cumulus clouds form when air rises, cools, and the water vapor condenses to form cloud droplets.

Ask students----
What do you think causes air to rise in the first place? **(Possible answers might include low pressure systems, or perhaps the air was initially warmer than the surrounding air).**

Use the analogy of hot air balloons to explain about rising air in the atmosphere. Hot air balloons are able to rise in the atmosphere because the air inside is warmer and less dense than the surrounding air. In the atmosphere air parcels—small blobs of air within the atmosphere (sort of like hot air balloons)--are constantly rising and sinking in convection currents. Convection currents form when individual air parcels are warmed by the Earth's surface, rise, cool off, and sink. A good analogy for convection is boiling water. The pot of water is the atmosphere and the rising bubbles are like the air parcels. However, these convection currents are generally limited to the lowest 1 kilometer of the atmosphere (the boundary layer). Explain that unlike hot air balloons, air parcels don't have a burner to heat them up so that they can rise. When air parcels are rising they are actually cooling off.

Ask the students--
5.How can an air parcel rise to make a thunderstorm when it is cooling off?

Tell the students that they will follow an individual air parcel as it rises from ground level through the atmosphere as it becomes a cloud and eventually a thunderstorm (note a thunderstorm is made up of many rising air parcels). Direct the students to look at the graph of the temperatures. The purple line is the temperature of an air parcel as it is rising through the atmosphere. If you look closely the purple line is actually a little cooler than the red line (atmospheric temperature)--the air parcel is slightly cooler than the surrounding atmosphere but it is rising. Air parcels can rise despite being cooler than the surrounding atmosphere if they get a little help. Air can sometimes be lifted by a passing low pressure system, when a cold or warm front passes by, the afternoon sea breeze, outflow from a nearby thunderstorm, or by subtle convergence (coming together) of the wind.

Ask the students
6.Which of these can cause the air to rise? Circle all that apply **(low pressure, high pressure, a cold front, the sea breeze)**

Continue explaining--As the air parcel rises it will continue to cool off because it is expanding. Notice that at 875 mb level the air parcel is now warmer than the environment. Since the air parcel is now <u>warmer</u> than the environment is able to rise on its own. It has now reached the level of free convection.

7. At the level of free convection the air parcel is now (colder/**warmer**) than the environment.

Explain that as the air parcel is rising it continues to cool off. It is still able to rise because it is **warmer** than the surrounding atmosphere. The key for this to happen is that the air parcel cools off at a slower rate than the change in temperature of surrounding atmosphere with height. It turns out that when unsaturated (no liquid water yet ) air rises it cools at of 9.8C for every 1000 meters or approximately 10C per km. In technical terms this is known as the dry adiabatic lapse rate. So if an air parcel starts off at 18C and rises 2 km in the atmosphere it will have cooled off to approximately -2C.

8. Air parcels are able to rise because they are (cooler/**warmer**) than the surrounding atmosphere.

9. If a parcel of air has a temperature of $26^{o}$C at the surface, what will its temperature be after it rises 3 km in the atmosphere? (**-4C**).

Continue with--The air parcel continues to rise past the level of free convection because it is warmer than the environment. As the air parcel rises it will eventually cool off enough so that the water vapor in that parcel will condense and become liquid water. This is marked by the box on the purple line at approximately the 850 mb pressure level (or about 1500 meters). This is known as the **lifting condensation level** and this marks the cloud base.

9. The point in the atmosphere where the air parcel becomes a cloud is known as the lifting (vaporization/**condensation**) level.

The air parcel will continue to rise because it is still warmer than the environment. As it is rising the water vapor will condense into liquid cloud drops (making a cloud). This has a very important effect on the air parcel. When water vapor condenses it releases heat energy (this is known as latent heat). This heat release offsets some of the cooling that is experienced by the air parcel. The air parcel will continue to cool off, but at a slower rate. This rate is around 4C per km in the lower atmosphere and about 6-7C per km in the upper atmosphere. We can approximate this as 5C per km. This is known as the **saturated adiabatic lapse rate**.

10. Imagine a saturated air parcel that has a temperature of -4C is lifted from 1500 m in the atmosphere to 3500 m in the atmosphere. What will its temperature be? (-14C)

The air parcel, which is now a cloud, will continue to rise until it becomes cooler than the environment.

11. At what pressure level will the air parcel stop rising? **(600mb or just below it)**
12. At what pressure level is the cloud top? **(600 mb or just below it)**

Direct students that the cloud top corresponds to where the air parcel became cooler than the environment.

Tell the students that you are going to adjust the temperature of the environmental air (the red line) to see what effect it has on our cloud. Move the temperature at 600 mb to -20C.

13. What happened to the cloud? **(It grew taller).**
14. At what level did the air parcel stop rising? **(At about 525 mb)**
15. Why did the air parcel stop rising? (It became cooler than the surrounding atmosphere)
16. What is the level of the new cloud top? (**At about 525 mb**)

Adjust the temperature of the environmental air again. Move the temperature at 500 mb to -30C.

17. What happened to the cloud? **(It grew taller)**
18. The cloud was able to rise because air parcel was (**warmer**/cooler) than the surrounding atmosphere.

Explain that in this simulation we were able to change the environmental air temperature to see how it effects the growth of the cloud. In reality the temperature of the environmental air does not change like this during the day. The air temperature at the different levels may change by a few degrees over the course of a few days. This can happen if an upper level disturbance passes by.

Summarize this key point--So far this simulation shows one of the necessary conditions for thunderstorms to develop: **instability**. The key for thunderstorm formation is that change in height of the atmospheric temperature has to be less than the air parcel's. If the change in temperature with height of the atmosphere is less than -10 $^{\circ}$C per km then the atmosphere is considered absolutely unstable. This rarely happens though. Typically for thunderstorms to develop the atmosphere will have a change in temperature with height less than -10 $^{\circ}$C/km but greater than -4 $^{\circ}$C/km (the saturated adiabatic lapse rate). This is known as conditional instability or an unstable atmosphere. In this situation a dry unsaturated air parcel will have a hard time rising (unless it gets a little help) but a moist saturated air parcel will be able to rise because its rate of cooling is less than the atmosphere.

19. Thunderstorms can develop if the atmosphere is (stable/**unstable**)

Part3—What can stop thunderstorms?

Ask students: “Now that we have gone over some of the basics of how thunderstorms form what do you think can stop thunderstorms from forming? “ (Sample answers may include that the air at the surface is too cold to rise, there may not be enough moisture in the atmosphere, there might not be lift to get the air parcels going, the atmosphere warms with height)

Reset the atmosphere to its original conditions (hit refresh). Change the temperature at the 850 mb level (the third level) from 2C to 20C.

20. What happened when we increased the 850 mb temperature? **(No cloud this time)**
21. Why do you think this happened? (**Sample answers might include that air parcel is not able to rise because the rising air parcel became colder than the enviromen**t).

The reason why the cloud was not able to form is because the rising air parcel encountered a layer of air that was warmer than the air parcel. Between the 900 and 850 mb levels the temperature of the atmosphere actually increased. This is known as an **inversion**. Inversions can happen just before sunrise when the air closest to the ground cools quickly. This is why we don't see cumulus clouds early in the morning in the summer. Inversions can also happen when air is sinking in a high pressure system. This is why we sometimes don't get thunderstorms in the summer when there is higher pressure in the area. Finally above the troposphere the temperature of the atmosphere begins increasing in the stratosphere. Thunderstorms typically stop growing when they reach the tropopause, the boundary between the troposphere and stratosphere.

22. A layer in which the atmospheric temperature increases with height is known as an (instability/**inversion**)

Reset the atmosphere again to its original conditions (hit refresh). This time adjust the moisture in the lower levels of the atmosphere by decreasing the dew point. Set the dew point at the second level to 0C and at the first level to 5C.

23. What happened to the cloud? **(It shrank)**
24. Why do you think this happened? (**There is less moisture in the atmosphere to work with**)

By decreasing the dew point temperature we are changing the amount of moisture in the low levels of the atmosphere. Rising air parcels will have less water vapor in them. As the parcel rises all of the water vapor condenses out and we are unable to get deep clouds. You can show the opposite of this by changing the dew point of the first level to 18 $^{\circ}$C and the second level to 10 $^{\circ}$C. You will notice that the cloud got bigger.

25. The air temperature and pressure in two cities are both 20C and 1010 mb. City A has a dew point of 5C while City B has a dew point of 17C.

a. Which city has more moisture in the atmosphere? **(B)**
b. In which city would you expect very shallow cumulus clouds? **(A)**

Part 4—Super-charging the thunderstorms

Adjust the temperatures and dew points (respectively) to the following values at these levels

1010 mb  30C/27C
1000 mb  28C/25C
900 mb   20C/-10C
300 mb   -55C/-60C
200 mb   -60C/-60C

Keep the rest of the levels the same.

There will be dramatic changes in the thunderstorm.

Explain that this is an over exaggeration of what happens in the atmosphere but it illustrates some of the key elements that affect thunderstorm development.

In the lower levels of the atmosphere it is very warm and humid.  This is shown by the high values of the air temperature and dew point at the 1010 and 1000 mb levels in the boundary layer.

There is a steep lapse rate above the 1000 mb level.  The temperature of the atmosphere is decreasing rapidly with height.  Severe thunderstorms typically form when there are steep lapse rates in the atmosphere and very cold temperatures in the middle levels of the atmosphere.

The thunderstorm is able to rise until it reaches a level where the air rising air parcels are cooler than the atmosphere.  This is at about the 240 mb level.  When the rising air parcels reach this level they will spread out to form the anvil top of the thunderstorm.

**Summarize the necessary conditions for thunderstorm development**--
*Warm air temperatures in the lower levels of the atmosphere.
*Plenty of water vapor in the lower levels of the atmosphere as well.  Have a deep layer of moisture throughout all levels will promote thunderstorm development as well.  Dry conditions will often hinder thunderstorm development.
*An unstable atmosphere where the temperature decreases rapidly with height anywhere between -4C/km and -10C/km.  Temperatures decrease with height in the atmosphere but if the decrease is sufficient then thunderstorms can form.
*The absence of an inversion in the low levels of the atmosphere that would stop the thunderstorms from forming (sometimes inversions can actually help severe thunderstorms form—they allow heat and humidity to collect in the low levels and later on this inversion or cap can be broken with some lift from an upper air disturbance).

26.  What are some of the necessary conditions for thunderstorms and severe weather to develop? (Unstable atmosphere, warm moist air in the low levels, the atmospheric temperature decreases with height)

Quick Teacher's Guide

Go over these points--

1. The red line shows the temperature of the atmosphere.
2. The blue line shows the dew point of the atmosphere.

3. The purple line shows the temperature of a rising air parcel. The square marks where the parcel becomes saturated and the cloud forms (at about 825 mb)

4. The air parcel is able to rise because it is warmer than the environment. As it rises it cool off, but the air parcel is able to rise because as long as the atmosphere cools off at a <u>faster rate</u> allowing the air parcel to be warmer than the atmosphere.

5. Air parcels cool at a rate of 9.8 C/km when they are dry and anywhere from 4-7C km when they are saturated. The dry cooling occurs below the cloud and the moist cooling occurs when at the cloud layer. This transition is marked by the box on the purple line.

6. The air parcel stops rising when it becomes cooler than the environment. This occurs at about 625 mb. This is also the cloud top.

7. Adjust the temperatures at 600, 500, 400, and 300 mb to the left (cooler). The cloud grows taller each time. The air parcel is able to rise because it is now warmer than the surrounding atmosphere. The surrounding atmosphere is cooling off at a faster rate than the air parcel. This illustrates one of the necessary conditions for severe weather—atmospheric instability.

8. Adjust the temperatures at the bottom two levels to 30C and the dew points to about 25C. The thunderstorm grows. This is illustrates another necessary condition for severe weather—moisture. The closer the temperature and dew point are to each other indicates a higher amount of humidity (moisture) in the atmosphere. A warm-moist conditions in the low levels of the atmosphere promote thunderstorm development. The warmer and more moist the air is the less dense it is and it is easier for this air to rise.

9. Put the brakes on the thunderstorm. Move the temperature at 850mb to 20C. This is an inversion. The temperature of the atmosphere increases with height over a short vertical distance. This layer of air is warmer than the rising air parcel and the air parcel will stop rising. Inversions can limit thunderstorm growth, but they can also allow heat and humidity to build in the low levels which can lead to severe thunderstorms later in the day if a lifting mechanism comes along.