Using Fluid Dynamics Computer Simulations to Model Properties of Earth's Atmosphere

Lesson Objectives:

1. Determine how dew point is used to determine the height of clouds in Earth's atmosphere.
2. Utilize fluid dynamics models to simulate the motions of air that forms clouds.
3. Collect and analyze data from a weather balloon for comparison with computer model simulations.

Standards:

State STEM Standards Connecticut: Use content-specific tools and software (Grades 9 - 12)

ITEEA Standards: The Nature of Technology: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

NGSS Standards:

- Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. (Grades 9 - 12)
- Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.(Grades 9 - 12)

CCSS Standards: Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

Grade Level

Targeted for Grade 11, but could work for grades 7-12

Unit Vocabulary

- Dew Point – the temperature air must be cooled for air to become saturated, causing condensation to occur.
- Adiabatic – Changes in temperature caused ONLY by changes in pressure, movement of heat is ignored.
- Lapse Rate – The rate air temperature changes as it moves vertically through the atmosphere.
- Lifted Condensation Level (LCL) – the height in Earth's atmosphere where condensation begins causing condensation to occur.

Classroom Lesson

Initiation

Place the class into small groups (2-3) and have them discuss the following questions:

1) What are clouds made of? How do they form?
2) How does temperature change as you go up into Earth's atmosphere? Why?
3) What does a meteorologist mean when they say the atmosphere is "very unstable"?

Lesson Activities

1) Introduce students to the concept of adiabatic changes in temperature and lapse rates. Use worksheet as a guide, review ways that air can rise (Orographic Lifting, Frontal, and Convection). In small groups, have students complete the worksheet and review with the whole class.
2) Have students write out work to sample problems on the board.
3) Using program, have students input scenarios from worksheet.

Lesson Worksheet

Background: For clouds to form in Earth's atmosphere, air must rise to carry water vapor up into the atmosphere. As we have already learned, temperature generally decreases with height in Earth's atmosphere. Once air cools to its dew point, condensation occurs causing cloud droplets to form. There are 3 main ways in which air can be causes to rise:

1) Orographic Lifting – Air moving towards a mountain has nowhere to go but up.
2) Convection – Heating from the sun warms air near Earth's surface. This air becomes less dense than surrounding air, rises, and cools.
3) Frontal – An atmospheric boundary forms where two different air masses meet. The warmer air mass tends to be less dense than the colder air mass, causing it to rise above.

The level at which clouds form is called the **Lifted Condensation Level (LCL)**, which is the height where rising air has cooled to its dew point. To determine this height, we must first know the temperature and dew point at the Earth's surface. We use the **Dry Adiabatic Lapse Rate (DALR)** to determine how air's temperature should change with height. This has a value of about 10^{o} C/1000 m (5.5^{o} F/1000 feet). Once the air has cooled to its dew point condensation begins, and the lapse rate changes. This is due to the latent heat of condensation releasing energy to the surroundings. The rate is about 5^{o} C/1000 m (3.3^{o} F/1000 feet) and is called the **Wet Adiabatic Lapse Rate (WALR).**

Practice: Complete the following in relation to *Figure 2* on the next page.

1) Fill out the diagram below for the heights indicated as air is lifted over a mountain. Remember to use the DARL until temperature and dew point are the same. Then use the WALR.
2) Once air has reached the top of the mountain it can descend the backside of the mountain (Called the Leeward side). Because all the moisture has been precipitated out, air will sink at the DALR. Fill in the indicated heights to determine the temperature at sea level on the backside of the mountain.
3) In Meteorology, stability is used to describe if air will have the tendency to rise or sink. We can launch a weather balloon to determine how temperature actually changes with height, and plot this information on a graph. The rate of temperature change with altitude is known as the Environmental Lapse Rate.

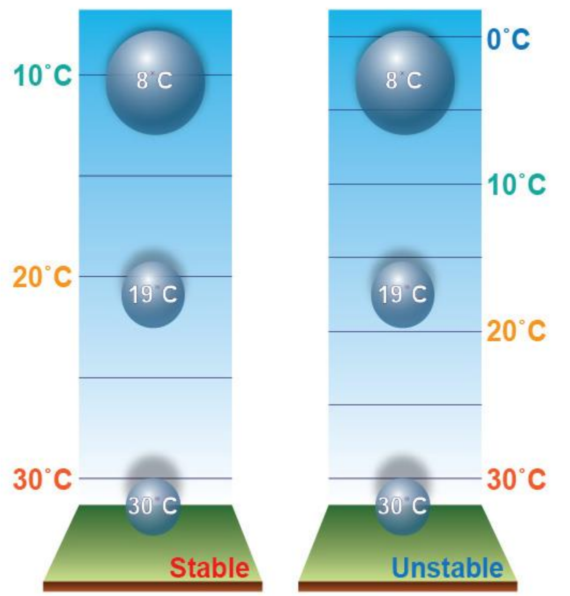


Figure 1

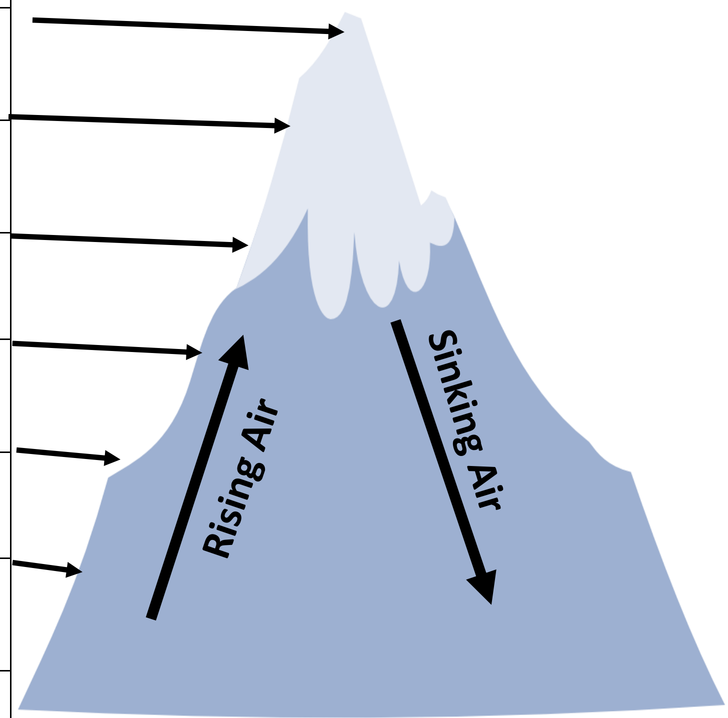
Source: https://www.weather.gov/jetstream/parcels

Stable Air – Air will tend to be cooler and more dense than the environment, so it will tend to remain still or sink. (See Figure 1)
Unstable Air – Air will tend be warmer and less dense than the environment, and have the tendency to rise.

Figure 2

Temp	Height
	3000 m
	2500 m
	2000m
	1500 m
	1000 m
	500 m
	0 m (Sea level)

Surface Dew Point = 10 C



Temp	Height
	3000 m
	2500 m
	2000m
	1500 m
	1000 m
	500 m
	0 m (Sea level)

<u>Analysis:</u> Complete the following questions.

1) You look up into the sky and notice some puffy cumulus clouds. Calculate the LCL of these clouds if the surface temperature is 15 C with a dew point of 7 C.
2) Determine how high in the atmosphere the temperature should be at freezing (0^{o} C). Explain which lapse rate you used and why.
3) Air at the top of a 3,500 m mountain has a temperature of -10^{o} C. What will be the air's temperature if the air descended to an altitude of 800 m?
4) A weather balloon is launched and measures and environmental lapse rate of 6.5^{o} C/1000 m. If air at Earth's surface has a temperature of 10^{o} C and the air rise 1000 m, what will be its temperature? Is this air stable or unstable?
5) Would you expect a strong thunderstorm to occur is a stable or unstable atmosphere? Why? *Hint: What does a cumulonimbus cloud look like?*

Extension

1) There is also something called the dew point lapse rate, which means the dew point decrease at a rate of 2^{o} C/1000 m. Go back to analysis question #1 and see if you can determine what would be the real LCL by taking this into consideration.

2) Do some research about how rain shadow deserts form. Give an example of where on Earth a rain shadow desert exists and explain how it relates to lapse rates.

End of lesson worksheet

Closure

Review Student work as a whole class. Have students submit exit tickets of the initiation questions.

Activity: Fluid Dynamics Simulation

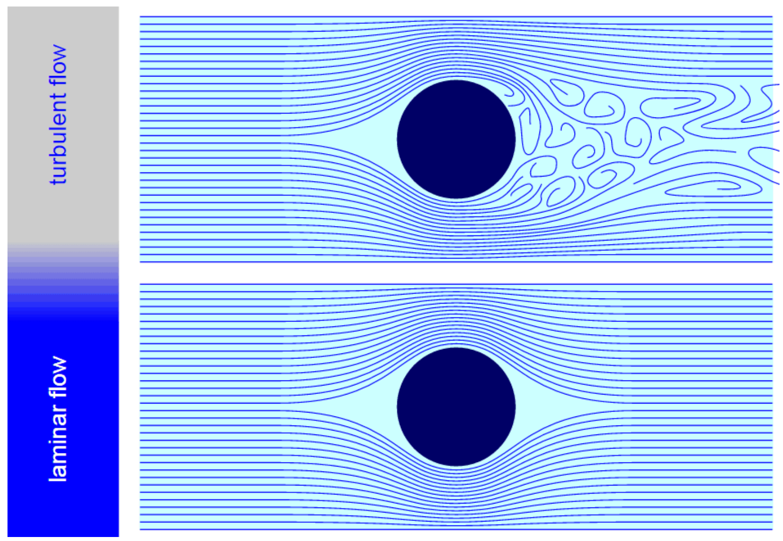
Required Program:

Initiation: Have the students in groups discuss the following questions:

1) Have you ever experienced turbulence in a plane? What does it feel like?
2) How does warm air behave? Why?
3) How would a bubble of air rising into surrounding air that is warmer behave? What if the surrounding air was colder?

Background: A fluid is a form of matter that can flow. This includes gases and liquids because the atoms are free to flow. Convection is a form of heat transfer that occurs only in fluids. While we can generalize the motions of a fluid when heated, it is difficult to model these motions perfectly because the motions of fluids can turbulent.

Because many motions in our atmosphere is related to turbulent flows such as convection, we can use simulations to model how bubbles of air moving upward (called thermals) behave.



Procedure.

1) Open the simulation and click on bubble and run the simulation. Write a statement describing how temperature affects the motion of the bubble.
2) Reset the simulation. Change the lapse rate and run the simulation. Explain what you observe.
3) Repeat step #2 but change to a new lapse rate. Explain what you observe.

Analysis:

1) How should the temperature of rising air change? Why?
2) Does the bubble show laminar or turbulent flow? Explain how you know by giving examples.
3) How should a bubble of air move if it rises into an environment that is colder than the bubble? What if the environment is warmer?
4) **Can you make the bubble rise faster? How?**
5) A *temperature inversion* is where air's temperature increases with altitude instead of decreasing. How would this affect the motion of air rising into the inversion?
6) Severe thunderstorms are characterized by strong convection in the atmosphere. Why do airline pilots try to avoid strong thunderstorms whenever possible?

Extension: Do some research on Sigmets. Explain how they relate to this activity.

Activity: Balloon Launch

Important Notes:

- Balloon and GoPro are anticipated to be purchased using Joule Fellow classroom supply fund at https://www.highaltitudescience.com/products/eagle-pro-near-space-kit.
- As an alternative, students could build their own weather balloon if time permits. For the scope of this lesson, the purpose is to use balloon data to compare results of fluid dynamic computer simulations
- Weather balloon will have to be retrieved using GPS tracking service at https://www.findmespot.com/shop/.

Pre-launch day: Teachers should consult local weather forecasting resources to determine a date for optimal launch and retrieval of balloon. Depending on atmospheric winds, retrieval could require driving over a hundred miles. Reviewing forecast resources, decide with the whole class on a day that will be best for the balloon launch. You may want to begin at https://www.aviationweather.gov/windtemp

Balloon Launch day:

1) Check to ensure flight computer and all instrumentation is working correctly per manufacturer directions. Review flight manual for FAA recommendations. Make sure when you launch you are in an open area with not large buildings or trees nearby.
2) Launch the balloon per manufacturer directions. Using a laptop track balloon using GPS service.
3) Locate balloon once it has returned to Earth's surface. Download data as a .csv file and share with students. Students should complete the provided analysis activities.
4) Make some observations of the current sky. Note the presence of clouds, and surface observations (temperature, dew point, wind speed/direction, and surface pressure.

Balloon Analysis Questions.

1) Using the spreadsheet, create a graph showing how temperature and pressure change with altitude.
2) Calculate the LCL using the temperature and dew point at time of balloon launch. How does this compare with the data from the camera footage?
3) Determine the environmental lapse rate for the balloon (change in temperature/change in height). Explain if the lapse rate is consistent all the way up through the atmosphere.
4) If possible, estimate the height of the tropopause. Explain how you would know this is the tropopause? How should this influence the vertical motion of air?
5) Using the fluid dynamic model, input at least 3 different sections of atmosphere into the model using the bubble simulation. Explain how air should move within that section of atmosphere.