What makes a gas, a greenhouse gas?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

Greenhouse gases and their role in climate change has become a heated topic of discussions, news reports, magazine articles and books. There are many different types of gas molecules in the atmosphere. Why are some greenhouse gases and others not?

Necessary materials:

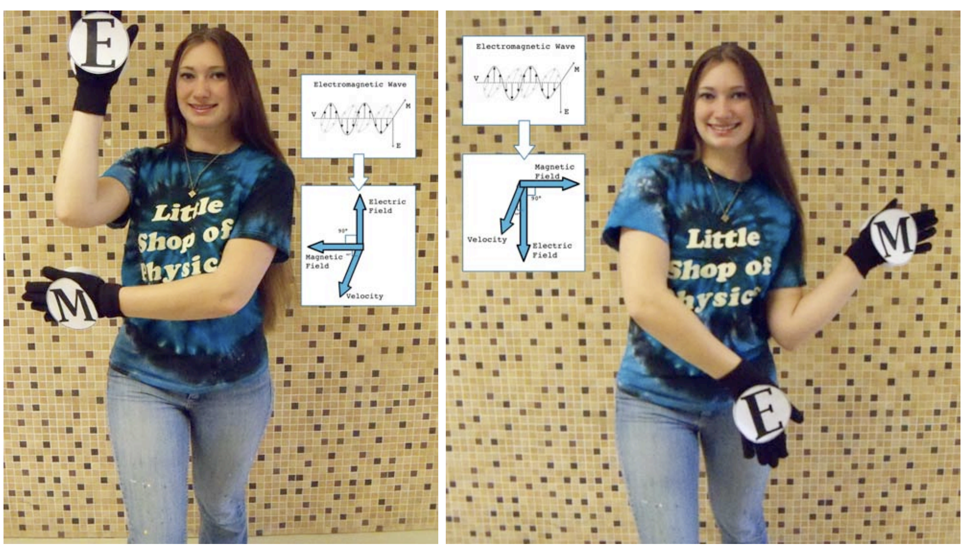
- A large open area for your students to move about freely in groups of 2 and then 3
- 2 gloves–one marked E on both sides and one marked M on both sides
- Stickers, hats, wigs, or other ways to designate what type of atom each student is portraying.

Check out Scott Denning, Professor of Atmospheric Science at Colorado State University, and education director of CMMAP demonstrating the "dances" of atmospheric molecules at

http://changingclimates.colostate.edu/movies/scott_denning_796kbits.

Theory

The earth's atmosphere is composed of a variety of gases–in fact, 99% of the Earth's atmosphere consists of two gases: nitrogen (N_2), which makes up 78%, and oxygen (O_2) which accounts for 21%. The other 1% is a mix of argon, neon, ozone, carbon dioxide, water vapor, methane and other trace gases.

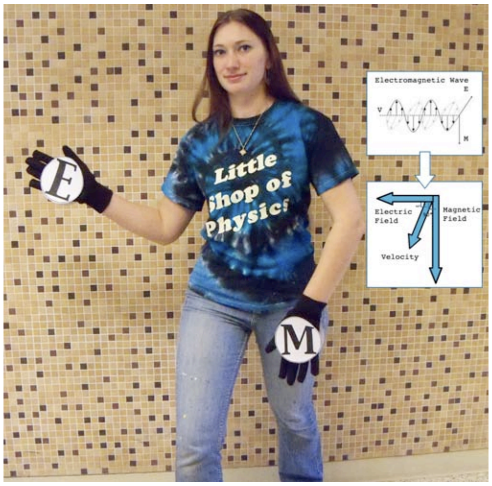


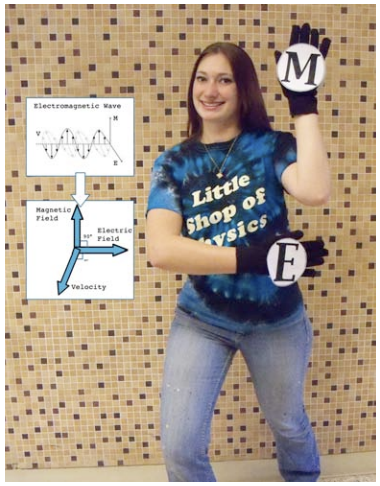
In this simulation of an electromagnetic wave, the wave is traveling out of the page toward you. The electric field is oriented up and down, as the magnetic field moves from side to side.

The energy from the sun travels to the earth in the form of electromagnetic waves and warms it up. The earth in turn cools itself off by radiating long wavelengths of thermal radiation back to space.

Certain gases in the atmosphere absorb these outgoing electromagnetic waves.

This is very important; with no such greenhouse gases, the planet





Now the magnetic field is oriented up and down, and the electric field moves from side to side.

would be a giant ice ball with an average temperature of -18 ˚ Celsius, or 0 ˚ Fahrenheit. Life as we know it would not exist! The greenhouse gases are able to absorb the thermal radiation and send some of the energy back down to earth. But why are some gases able to do this and others not? It turns out that a molecule that has the capability of vibrating in different ways can absorb different wavelengths. It then can emit heat back to warm the earth.

Doing the Experiment

Before doing this experiment, label one glove or sign with an E on both sides, and then label another one with an M on both sides. Put on the gloves or hold the signs and practice portraying an electromagnetic wave–having one letter go from side to side while the other letter is going up and down. This is a bit trickier than it looks.

Gather your students in a large open area so they can spread out as needed. Explain to them that they are going to act out 4 different molecules that are part of the Earth's atmosphere and discover which ones are greenhouse gases and which ones are not.

N_2 & O_2

Have your students break into pairs and lock arms together to simulate the chemical bonds between them. Each molecule pair can be facing in any direction, but they are to stand still. Tell one half of the class that

N_2 is a molecule with equal charge sharing. Neither atom has a net charge. There is little interaction with electromagnetic waves.

O_2 is also a molecule with equal charge sharing. Neither atom has a net charge. There is little interaction with electromagnetic waves.

they represent nitrogen molecules and the other half that they are oxygen molecules. Explain that these two types of molecules are like two balls on a stick, and that they don't have a net positive or negative charge.

Put on the two gloves that are labeled E and M and tell them that you are portraying an electromagnetic wave. The wave is traveling straight ahead of you. If the individual atoms in the molecule have a net positive charge, they will be pulled in the direction of the electric field (the E on the glove). If they have a net negative charge they will be pulled in the opposite direction.

Use the gloves and have the E and M move back and forth vertically and horizontally as seen in the pictures above. What happens to the N_2 and O2 molecules? Not much! The individual atoms don't have a net positive or negative charge, so they don't interact with the electric field, and neither do the molecules. Net result: *Electromagnetic waves don't interact with the major components of the atmosphere, so the atmosphere is transparent.*

CO_2

Now have the students break into groups of 3. Explain that they are going to portray carbon dioxide molecules. The carbon atom is in the middle with a slight positive charge and there is an oxygen atom on each side with a slight negative charge. Each group of 3 students should lock arms and stand in a line. Simulate an electromagnetic wave and demonstrate with one of your groups of 3 before having your whole group join in the simulation. Here are suggested EM wave movements to try.

H_2O

Have your students stay in their groups of 3 and tell them that they are now going to act out H. Oxygen is in the center and has a slight negative charge. Each hydrogen atom locks an arm with the oxygen and positions him/ herself at a 45% angle to the oxygen atom, but 90 degrees from the other hydrogen atom. The hydrogen atoms have a slight positive charge. Demonstrate with one of your groups of 3 how H_2O has many ways to vibrate due to it's shape. If the electric field points down, the O can go up as the two H drop down. If the electric field points up, the two H can go up as the O drops down.

The H_2O molecule can spin, twist & more.

Explain to your class that different vibrations allow a molecule to absorb different wavelengths. The molecule then emits these wavelengths in all directions, with the result that some are sent back down to earth warming the planet. Greenhouse gases have this quality. Discuss which of the four molecules were greenhouse gases. Explain that even though H_2O is a more powerful greenhouse gas than CO_2, water vapor only exists in the lower layers of the atmosphere, where CO_2 exists throughout.

An interesting activity to try is to have 78% of your students act as N_2, 21% as O_2, and then have several in the mix depicting a CO_2 or water vapor molecule as you wield the electric field glove. It might give your students a sense of how powerful greenhouse gas molecules are–even though they make up less than 1% of the atmosphere.

Summing Up

In this kinesthetic activity, students will have an opportunity to act as different molecules in the earth's atmosphere. They will experience why certain molecules are so good at absorbing and emitting thermal radiation and others are not.

For More Information

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

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

How does the atmosphere keep the earth warmer?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

The earth cools by radiation. That's the only way that the earth can exchange energy with space. But the atmosphere is not transparent to the far infrared that the earth emits, and so the earth is warmer than it would otherwise be.

Theory

We can simulate the energy exchange of the earth and the atmosphere with space by using a stack of glass plates for this simple reason: Glass is transparent to the visible light and the near infrared emitted by the sun (and the lamp!), but opaque to the far infrared, the thermal radiation, emitted by the earth. So energy gets in but can't get out—at least not so easily.

Necessary materials:

- Four identical pieces of glass (You can use glass from the same size picture frames.)
- We use 4 clear rubber feet on the bottom of each piece of glass as spacers.
- Spray one side of one glass plate with flat black paint.
- Infrared thermometer
- Desk lamp with an incandescent or halogen bulb

We purchased our frames at a dollar store, which made them quite reasonable!

Doing the Experiment

We'll start with a simple experiment that shows how the atmosphere keeps the earth warmer. This can be done as a demo, but is more effective when small cooperative groups work to collect data and then compare with others. Once you set the experiment up, you'll need to let the lamp shine on the stack of plates for 20 minutes.

SAFETY NOTE I: The desk lamp with the incandescent or halogen bulb can get very hot. Be sure students are careful when working around the lamp

SAFETY NOTE II: The glass plates have sharp edges, so students need to be especially careful when moving and lifting the plates. You may want to keep the picture frames on each glass plate and put the rubber feet on the frames instead.

- Have your students make a stack with the 4 glass plates. They should put the black painted glass plate at the bottom of the stack. Place the desk lamp over the stack of glass plates and discuss how close you want the light bulb to be to the top of the stack.Turn the desk lamp on and let it shine on the stack of plates for approximately 20 minutes.
- While you are waiting for the experiment to be ready, model for your class, what they will be doing once they begin. Explain to your students that they are setting up a model of layers of the atmosphere. Show them how they will have to work as a group to conduct this experiment. There will be four jobs per group. One student will turn off the desk lamp and turn it away so that it doesn't keep

warming the plates with infrared radiation. The second student uses an infrared thermometer immediately to measure the temperature of the top plate, while the third student records that temperature, while the fourth student pulls the top plate off. The process is repeated by students 2, 3, and 4 until they have measured the temperature of all the plates in the stack. We recommend that you have a group of students practice this, so they all realize how quickly they have to do this. The plates start cooling immediately, so the quicker they are, the better.

- While you are still waiting for the experiment to be ready, have students predict what they think will happen with the temperatures. Which plate do they think will be the warmest? The coolest? etc.
- Conduct the experiment and have students report and compare their data. Discuss what they think is happening. They will probably find that the bottom plate is the warmest, the one above a little cooler, and the one above that cooler yet. How about the very top plate? This will depend on the light source. Why might this be?
- This will be a great place to explain how the glass plates are like layers of the atmosphere. The visible and near infrared radiation from the lamp (sun) can pass through the layers, but once this energy is absorbed by the earth (the black plate) the radiation emitted is thermal radiation and is a longer wavelength. It cannot pass through the layers as easily, so the earth gets warmer.

Activity Variation 1

- Put two glass plates painted black on a table. Put a desk lamp over them.
- Turn on the desk lamp and leave it on for at least 5 minutes.
- As soon as you turn off the desk lamp, use the infrared thermometer to take a temperature of both black plates and record.
- Immediately place a clear glass plate over one of the black plates.
- Wait one minute, remove the extra frame, and then take the temperature of both black plates again and record.
- Quickly put the extra frame back on the black felt frame and repeat the procedure again.

Activity Variation 2

- Have one student hold up his/her hand and take the temperature of the hand and record.
- Have another student hold a glass plate in front of the student's hand. Use the infrared thermometer to take the temperature again and record. The temperature reading of the hand with the glass plate in front should be much cooler.
- Discuss what they think is happening.

Summing Up

This is a good simulation that can show how the layers of the atmosphere keep the earth warmer than it would otherwise be.

For More Information

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

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

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What is a "model"?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

The physics of how the atmosphere works is quite simple, described with some very straightforward equations. The behavior of the atmosphere itself, though, is quite complex, and can't e expressed in a series of simple equations. Building up from the very simple concepts of a physical theory to the complicated behavior of a real physical system is the job of a *model*. The best way to learn what a model is is simple to create one, which we will do in this exercise.

Necessary materials:

- Chips or tokens
- 4 copies of the Heat Exchange Model sheet

Students will work in groups of four for this activity, one student representing each "cell" in the model.

Theory

Climate models start with physical theories: How air moves, how water behaves, how radiation transports energy. They then break the earth's atmosphere down into pieces—cells—and then compute what happens in each cell based on these physical theories. Cells exchange energy and matter with each other based on the physics of the transfer of matter and energy. The net result is a simulation of what the actual atmosphere might do. We can illustrate this idea by doing a very, very simple model for a piece of the atmosphere, as described below.

The design of the CMMAP logo tells us something about the model being developed by the center.

Doing the Experiment

Start with a simple simulation:

- Have each element start with 20 tokens—meaning a temperature of 20.
- Now run the model for 10 turns. How do the temperatures change?
- Now, continue the simulation; keep running it, having students keep track of the temperature.

At some point, the model will stabilize; all of the elements will remain at the same temperature for each turn. How long does it take to reach this point? This is the final temperature profile that the model predicts for the atmosphere. Just as for the real atmosphere, the earth is warmer than the lower atmosphere and the temperature drops as you go higher.

The model breaks down at the high end, though: In fact, the stratosphere is hotter than the lower atmosphere. That's because the stratosphere is heated by the sun, something our model doesn't consider. But we can fix this! You should try "tweaking" the model a bit to get a more realistic result. You could add another layer to the atmosphere, and then have space give some energy to the highest level each turn—say 3 tokens to earth and 1 token to the upper atmosphere.

- How does this alter the predicted temperature profile?

You could also do an open-ended discussion of how this model could be made more realistic. What elements would you add?

Summing Up

This is a very simple model, but it captures the key elements of what a model is and does. And it can be made more complex.

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Setting up and Running the Model

Setting up the Model

Four people are needed to run the model. Each person represents one segment of the model: One is the earth, one is the lower atmosphere, one is the upper atmosphere and one is space. The four people sit in a row, in order, just as the different segments appear in relation to each other:

Earth   Lower Atmosphere   Upper Atmosphere   Space

Each element can exchange energy to the adjacent element:

- The earth exchanges energy with the lower atmosphere.
- The lower atmosphere exchanges energy with the earth and with the upper atmosphere.
- The upper atmosphere exchanges energy with the lower atmosphere and with space.
- Space exchanges energy with the upper atmosphere.

In addition, the earth gets energy directly from space.

How much energy is exchanged depends on the temperature: If an element is hotter, it gives off more energy.

Running the Model

During each "turn" each element exchanges energy with other elements. The energy transfered depends on the temperature of each element.

The earth, lower atmosphere and upper atmosphere each get some tokens. Each person puts his or her tokens on the model sheet, a copy of the following page, in order from the bottom. The first uncovered square gives the temperature and the energy to be transferred.

During one "turn", each element exchanges energy with the other elements:

- The earth exchanges energy with the lower atmosphere. The amount transfered is determined by the temperature of the earth. If the temperature is 20, then 3 tokens are transferred to the lower atmosphere.
- The lower atmosphere exchanges energy with the earth and with the upper atmosphere. If the temperature is 20, then 3 tokens are transferred to earth and 3 are transferred to the upper atmosphere.
- The upper atmosphere exchanges energy with the lower atmosphere and with space. If the temperature is 20, then 3 tokens are transferred to the lower atmosphere and 3 are transferred to space.
- Space gives 3 tokens to the earth—because energy from the sun heats the earth directly.

Each element places the newly received tokens and then determines the new temperature. This temperature is used for determining the energy transferred during the next "turn."

Temperature 35 Transfer 7	Temperature 36 Transfer 8	Temperature 37 Transfer 9	Temperature 38 Transfer 10	Temperature 39 Transfer 11
Temperature 30 Transfer 5	Temperature 31 Transfer 6	Temperature 32 Transfer 6	Temperature 33 Transfer 6	Temperature 34 Transfer 7
Temperature 25 Transfer 4	Temperature 26 Transfer 4	Temperature 27 Transfer 5	Temperature 28 Transfer 5	Temperature 29 Transfer 5
Temperature 20 Transfer 3	Temperature 21 Transfer 3	Temperature 22 Transfer 4	Temperature 23 Transfer 4	Temperature 24 Transfer 4
Temperature 15 Transfer 2	Temperature 16 Transfer 3	Temperature 17 Transfer 3	Temperature 18 Transfer 3	Temperature 19 Transfer 3
Temperature 10 Transfer 2	Temperature 11 Transfer 2	Temperature 12 Transfer 2	Temperature 13 Transfer 2	Temperature 14 Transfer 2
Temperature 5 Transfer 1	Temperature 6 Transfer 1	Temperature 7 Transfer 1	Temperature 8 Transfer 1	Temperature 9 Transfer 2
Temperature 0 Transfer 1	Temperature 1 Transfer 1	Temperature 2 Transfer 1	Temperature 3 Transfer 1	Temperature 4 Transfer 1

What is a feedback?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

The earth's climate is a complex system that is determined by a variety of forces and *feedbacks*. The concept of feedback is central to an understanding of the science and the everyday experience of the climate.

Necessary materials:

Feedback Activity

- 4 small cups: 2 attached at the base, 2 attached at the mouth
- 1 track

The parts for this activity can be purchased at any grocery store (2 oz cups) or hardware store (angle iron or L channel).

Theory

Here's an example of feedback at work: in areas that receive lasting snow in the winter, the season change from fall to winter is much less sudden than the change from winter to spring. A warmer fall will gradually fade into the lasting snow of winter, as opposed to the rapid change from winter to spring. This rapid change is due to a *positive feedback*. Snow reflects most of the light that hits it; bare ground absorbs it. Warming a snow-covered landscape melts snow, meaning more sunlight is absorbed, meaning higher temperatures, meaning more warming, meaning more snow melts, meaning more ground is exposed… and so on. The positive feedback means a quick switch from a snowy cold winter to the bare ground and balmy temperatures of spring. The positive feedback takes a small swing in temperature and amplifies it.

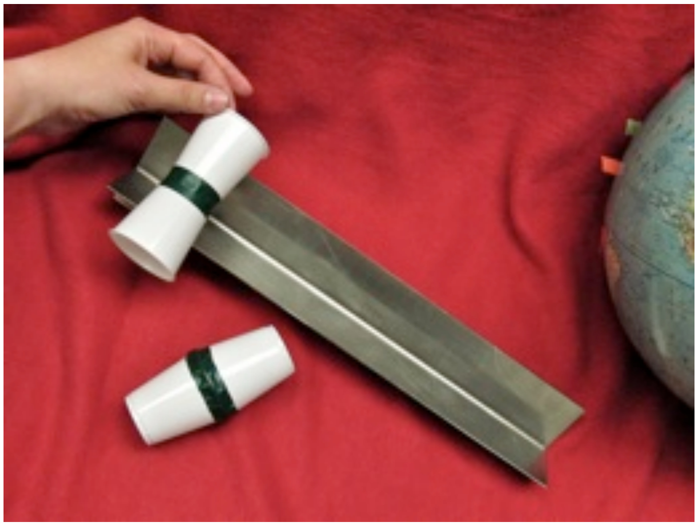
On the other hand, a *negative feedback* will work to damp out a change. Here's an example: as incoming solar radiation warms the ocean, water evaporates and rises. As the vapor rises it cools and condenses to form clouds. These low clouds reflect incoming radiation. Less radiation means less warming—meaning less evaporation and fewer clouds.... The negative feedback is a stabilizing force.

The two-cup devices and track

Doing the Experiment

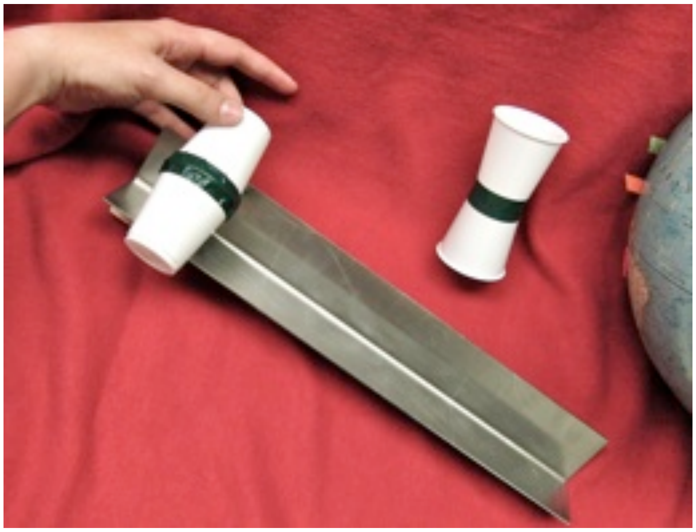
Begin the lesson with an explanation of feedback. You might ask your students for examples of positive and negative feedback they have experienced in the earth system and elsewhere.

Explain to the class that this exercise will model positive and negative feedbacks. Set up the track on a flat surface and avoid vibrations. Show the two-cup devices to the class and ask them to explain the difference between them—in particular the size of the cup where it touches the track. The diameter of one cup device starts out at a maximum and gets smaller as you move from the center outward along the long axis. The other device is quite the opposite.



A positive feedback

Ask students to observe as you (or a volunteer student from your class) rolls the base-to-base cup device down the ramp. The cup should be placed, centered, at the very top of the ramp and allowed to roll freely by the force of gravity alone without any additional pushing. Notice that this device falls off the ramp before reaching the bottom. This is a positive feedback. It works to amplify any small deviation from straight rolling: a small turn to one side rapidly increases in magnitude. Now repeat this with the mouth-to-mouth cup device. This one stays firmly on the ramp. If it starts to roll to the side, the motion will correct itself so that the cup stays put. This is a negative feedback; any deviation from straight rolling damps out as the cups swivels in the opposite direction, and the cup quickly turns enough to roll right off the ramp.



A negative feedback

Summing Up

Positive and negative feedbacks often have a different meaning to the general public, with positive viewed as a good thing, and negative, not so. As mentioned above, positive feedbacks in the climate system can amplify fluctuations in the climate system and are often viewed with apprehension.

For More Information

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What’s the difference between weather and climate?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

That’s a good question! Sometimes the words get used almost synonymously, but there’s a real difference. And we can illustrate the difference with a pack of M&Ms.

Necessary materials:

- Bags of M&M candy, “fun size”, or:
- Beads of a mix of colors and/or shapes

Other types of candy will work as well, of course. You just need a little bag of candy with many—but not too many—different kinds of candy in the bag. If you choose not to use candy, beads make a very nice substitute.

Theory

Weather is what it is doing *right now*. It might be raining, it might be sunny.

Climate is a bit harder to define. Here are a couple of characteristics:

- Climate describes the range of what you might expect in a given location—the limits of what the weather might be. In Fort Collins, where we are, it might be cold in March or it might be hot. It might be 25°F or it might be 75°F. But it’s never 0°F or 100°F in March.
- Climate describes average weather. On any given day, it might be hot in Denver and cool in Miami, but, on most days, it’s hotter in Miami than it is in Denver.
- Climate describes long-term trends. If it’s cold for a few days, that’s weather. If it’s an ice age, that’s climate.

The expected range of M&Ms in the bag is the climate. What actually comes out is the weather.

In Colorado, our weather is pretty changeable. It might be rainy one minute and sunny the next. But our climate is pretty stable. It’s warm in the summer, cool in the winter, and, overall, pretty dry.

Doing the Experiment

This is a pretty quick experiment. It’s more of a demonstration, but one that is interactive and informative, and one that has a candy treat at the end.

Define a different type of weather for each color of candy. Orange might be cool and cloudy, blue hot and sunny. Use your imagination!

Give each group a bag of candy. Each bag will represent the weather in Colorado (or wherever you are!) for a series of days in March for a particular year. You might even assign years—one bag represents 1996, one 2000...

Ask each group to tear open a corner of their bags, and tip out one piece of candy. That's the weather on March 1. Now, ask each group what they got. In some groups (that is, in some years...) the M&M is orange (March 1 was cool and cloudy); in others, it's blue (March 1 was hot and sunny.) That's weather. On a given day in a given year, you just can't predict what the weather will be.

Now, have each group pour out all of their candy and count: How many orange? How many blue? You'll find that there are some differences between groups, but the differences are reasonably small. Some groups may get a larger percentage orange candy, others will get more blue. But no one will get all orange or all blue! If you look at the weather over a longer period of time, patterns start to emerge. You are starting to pin down the climate....

Now, compute an average number for each color in all of the bags. This is climate, the average weather, what you expect. If you give someone a fresh bag, you can't predict the weather—whether the next candy out of the bag will be blue or orange—but you can predict *trends* in the weather. You can say, with confidence, that there won't be 10 orange candies in a row. That would be very unlikely!

If you want a nice extension, you can compare different types of candy. Give some of your groups M&Ms, some of them another kind of candy. That would correspond to different climates.

When you are done, ask your students the question we started with: What is the difference between weather and climate?

Summing Up

This is really a demonstration, but we have found it helpful in demonstrating the difference between the unpredictable fluctuations of the weather and the long-term predictable average of the climate.

For More Information

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

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

If you can't predict the weather, how can you predict the climate?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

This is a very good question. Here's the one word answer: Chaos.

Necessary materials:

- Calculator

You can also do this exercise with a computer running a spreadsheet.

Theory

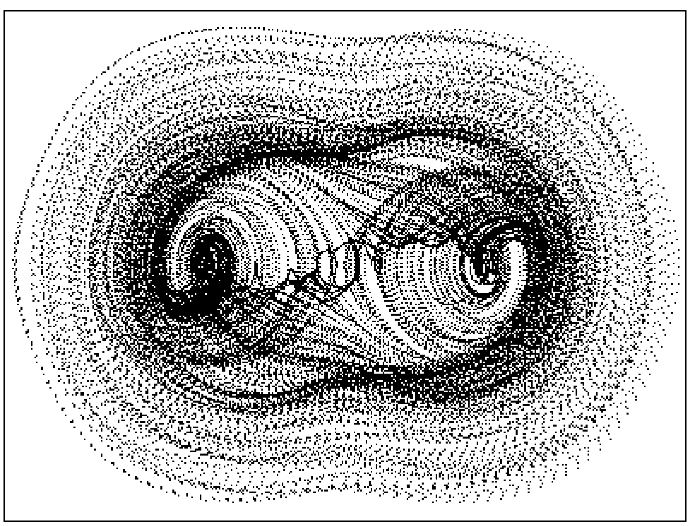
Contrary to popular usage, "chaos" doesn't mean randomness. Systems—like the atmosphere—that are chaotic are unpredictable in some ways but follow certain well-defined patterns. This is the essence of chaos, and rather than trying to explain this seeming contradiction, it's easier to just explore a system that seems like it should be quite regular but is actually chaotic.

Doing the Experiment

We are going to compute successive values of an iterative equation—one in which you use one value to compute the next value. Here's the equation we use:

$$x_{n+1} = (1 - x_n)(x_n)\lambda$$

λ is a parameter that can be varied. We are going to use 3.87 here. We are going to compute successive values with a calculator. To simplify, we have a recipe that tells how to compute these values:



This is a graph of the velocity (vertical axis) vs. the position (horizontal axis) of a pendulum undergoing chaotic motion.

1) Pick a value for the parameter for the equation.

1) Take your starting value. We'll call this x_1. Press STO on the calculator to put it into memory.

2) Now, we need to compute the next value, x_2. Press the following keys:

- 1-RCL= (compute 1-x_n)
- ×RCL= (multiply by x_n)
- ×3.87= (multiply by 3.87)
- STO (put the result in memory for the next round)

3) Record the value and do Step 2 again.

And just keep doing Steps 2 and 3.

The big question is this: What do the results mean? Here are two trends to notice:

- Each value seems random, but there are trends. In particular, notice the “high, low, medium” sets of values. You’ll often—but not always—see this type of trend.
- Small changes in this initial value don’t make much difference in the initial rounds, but make a big difference later. That’s “sensitivity to initial conditions,” one of the hallmarks of chaos.

The values are quite unpredictable on a short scale, but there are some very clear trends that are quite stable. Weather and climate!

Summing Up

This simple experiment does have a lot to tell us about chaos and, ultimately, the difference between weather and climate.

For More Information

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