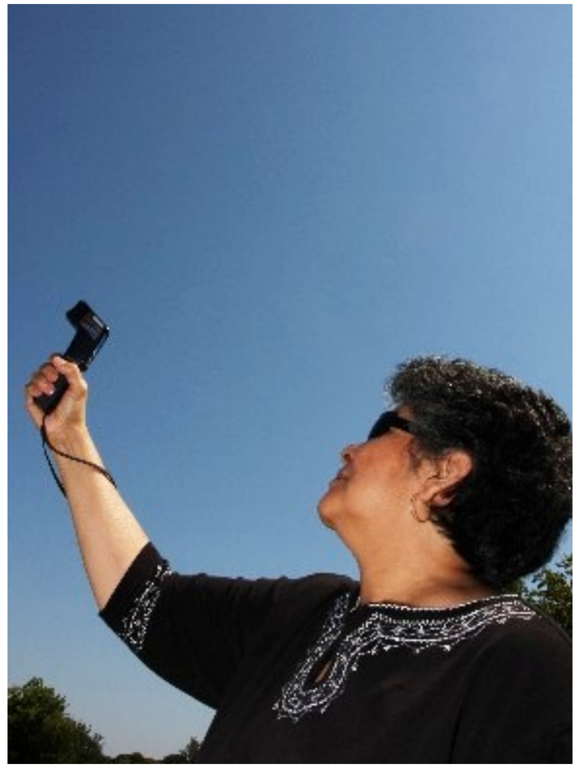
Measuring the Temperature of the Sky and Clouds

Web Id:P18

Purpose: In this project you will learn about the greenhouse effect by measuring the temperature of the sky and clouds far overhead with an infrared thermometer.



Measuring the temperature of the sky (27 F or -3 C). Image courtesy of Forrest M. Mims III

Sunlight warms the Earth, which then emits the energy it absorbs as thermal (infrared) radiation that we perceive as heat. This process is important, for if the Earth did not release the energy it absorbed from the sun, the Earth would become excessively warm. Life as we know it would be unable to survive.

If the Earth did not have an atmospheric blanket, most of the radiation absorbed during the day would be radiated into space at night. The Earth would be so cold that the oceans would freeze! Fortunately, our atmosphere has plenty of water vapor, which strongly absorbs some of the infrared rays radiated from the soil, rocks, oceans and cities below. Thanks to water vapor, the Earth remains warm enough for life to exist.

Age Range: 14 to adult

Time Required: In under half an hour you can measure the temperature of the sky and clouds and learn how clouds tend to stabilize the temperature on the ground below. You can learn much more by spending a few hours reviewing this project, visiting the links it lists and performing some experiments of your own.

Background:
Sunlight warms soil, rocks, plants, roads, buildings and bodies of water, all of which then emit the solar energy they absorb in the form of thermal (infrared) radiation that we perceive as heat. If there were no atmosphere, the Earth surface would release as much

energy to space as it receives from the sun. But that would keep the Earth much too cold for life as we know it to exist.

The atmosphere is why the Earth is warm enough to support life, for it contains water vapor, a gas that strongly absorbs infrared radiation. This water vapor is the key to why the Earth is warm enough to support life. According to the National Oceanic and Atmospheric Administration, removing water vapor from the atmosphere would reduce the average temperature of Earth to 0 degrees F! The oceans would be frozen solid. The Irish scientist John Tyndall was among the first to explain this, and in 1863 he wrote,

Aqueous vapour [water vapor] is a blanket, more necessary to the vegetable life of England than clothing is to man. Remove for a single summer night the aqueous vapour from the air which overspreads this country, and you would assuredly destroy every plant capable of being destroyed by a freezing temperature. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost.

You can find this and more of John Tyndall's wisdom on pp. 417-418 of his book Heat.

You can use an infrared thermometer to see the impact of water vapor on warming the atmosphere. The temperature in outer space approaches absolute zero, which is -273 degrees Celsius. But you will measure a much warmer temperature if you point an infrared thermometer at the sky directly overhead (the zenith). Depending on the season and your location, the temperature will likely be near or below zero degrees Celsius. While this is very chilly, it's far from being as cold as absolute zero. The difference is caused mainly by water vapor in the sky that has become warm by absorbing infrared radiation emitted by the Earth below. The warmed water vapor returns some of the infrared back to the Earth, and this helps keep the Earth warmer than space.

The ability of water vapor to warm the Earth is called the the greenhouse effect. Like a closed car on a hot day, a greenhouse warms the plants inside by trapping air heated by the sun. The natural greenhouse effect is based on a different phenomenon, for air is not trapped and is free to circulate. The sun warms the planet, which emits some of the heat as infrared radiation. Water vapor absorbs and traps some of this radiation, thus, warming the atmosphere. Carbon dioxide, methane and other gases that absorb infrared also contribute to the greenhouse effect, and they and water vapor are collectively known as greenhouse gases.

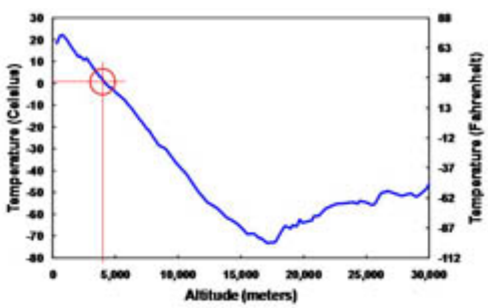
Photographs by Forrest M. Mims III.

The two images above show an infrared thermometer pointed at the sky overhead (left) and a cumulus cloud (right) a few minutes apart on the same day. The sky temperature is just above freezing (34 degrees Fahrenheit or 1 degree Celsius). The cloud temperature is considerably warmer (65 degrees F or 18 degrees C). The cloud is warmer because it is much lower in the sky than the portion of the clear sky being measured at left.

The difference between the extreme cold of outer space and what you measure when you point an infrared thermometer at the sky is caused mainly by the water vapor in the atmosphere, which is warmed as it absorbs infrared emitted by the Earth. Water vapor strongly absorbs the infrared radiation emitted by the Earth.

Nearly all the water vapor in the atmosphere is found in the troposphere, the layer of the atmosphere between the surface and around 10 to 15 kilometers. The troposphere is where weather occurs. When an infrared thermometer is pointed straight up at the sky, it measures the temperature through a cone-shaped column of the troposphere. This means that the “sky temperature” indicated in the photo at left above represents the infrared brightness of the sky. For the purpose of this project, the “sky temperature” can be thought of as an average of the temperature between the ground and the upper troposphere where water vapor is much less abundant. Therefore, the “sky temperature” is really not the temperature of the sky but a number that indicates that the sky is much warmer than space and cooler than cumulus clouds. For this project, let’s call the temperature of the sky indicated by an infrared thermometer the “apparent temperature.”

The apparent sky temperature measurements in the photographs above were made in South-Central Texas on September 21, 2008. The temperature of the sky measured by a weather balloon launched from Del Rio, Texas, that morning (about 277 kilometers or 172 miles away) is shown by the blue line in the graph below.



The apparent temperature measured by the infrared thermometer is indicated by the circle, which corresponds to the temperature of the air at an elevation of about 4,000 meters. The temperature below 4,000 meters is warmer than the temperature above 4,000 meters. This explains why the infrared thermometer measures an “average” temperature that demonstrates the decline of temperature with elevation.

Note how the temperature falls sharply until an altitude of about 17,500 meters (57,415 feet). The temperature then begins to rise. This change marks the tropopause, the border between the troposphere, which is where most water vapor resides, and the very dry stratosphere above. The temperature increase in the stratosphere is caused by the ozone layer, which is warmed when it absorbs ultraviolet sunlight. View a lesson on radiosonde data that shows the troposphere.

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Significance: Water vapor in the sky is responsible for the natural greenhouse effect that keeps the Earth warm enough for life to exist. Clouds formed from water vapor play a major role in controlling the temperature of the Earth. The activities in this project demonstrate that the open sky, while very cool, is much warmer than space and that cumulus clouds are much warmer than the sky.
Project Links:

- Learn all about infrared thermometers.
- Why does it get colder on clear nights than on cloudy nights? Find out with this experiment from the Little Shop of Physics at Colorado State University.
- Klaus-Dieter Gruner of Raytek has written an excellent survey of infrared thermometry. Some of this is written at an advanced level, but it's worth a look: Principles of Non-Contact Temperature Measurement.
- Find out about temperature and how thermometers work.
- Learn about an infrared instrument that scientists use to measure the temperature of the sky and clouds.
- Read a scientific article about using an infrared detector to monitor clouds.
- Make an infrared cloud detector.
- Very Advanced Information: Learn more about infrared.

Supplies Needed:

1. Non-Contact Infrared (IR) Thermometer. This is an electronic thermometer that uses a heat sensor installed inside a plastic housing to measure the temperature of objects from a distance. Infrared thermometers measure the temperature across an area known as the field of view or look angle, an invisible cone between the instrument and the object or substance whose temperature is being measured. A look angle of 1:1 means that 1 meter away the thermometer "sees" a spot 1 meter across. For best results use an infrared thermometer with a look angle of at least 6:1. This means that 1 meter away the thermometer "sees" a spot 1/6 meter across.

Many different kinds of IR thermometers are available from industrial suppliers and online dealers. The least expensive at the time this writing are around $45 (less from some discount sites). A key feature to look for is the look angle, which describes the cone viewed by the IRT. A 6:6 look angle means the instrument sees a 6 foot diameter circle when held 6 feet away from an object. The range of the IRT, especially the minimum temperature, is also important for this project. Gun-style infrared thermometers are easier to use, since you can point the thermometer where you like while watching the temperature display. You can find many infrared thermometers by searching online.

Caution: When using an IR thermometer equipped with a laser, switch the laser off if possible. If the laser cannot be switched off, place a small piece of dark tape over its port to block the beam. When using the IR thermometer with the laser switched on, never point the laser at anyone or at a shiny surface. Never point the laser beam at your eyes! Always keep an infrared (IR) thermometer in a protective case to protect it from dust and to keep from scratching its readout. If it did not come with a case, you can store it in a clean sock.

An IR thermometer is operated simply by pointing it at anything whose temperature is to be measured. Press the power button to activate the thermometer and read the temperature from the display. Most infrared thermometers will allow you to switch between Celsius and Fahrenheit scales. Various IR thermometers have different operating controls, so be sure to read the instrument's instructions. Most IR thermometers have a "hold" mode. This allows you to point the thermometer at an object, measure its temperature and read the temperature when it is convenient.

Test the IR thermometer by pointing it at your hand, your clothing, a book and a light bulb, and notice the temperature differences. Next, point the IR thermometer at the floor and then at the ceiling. Warm air is lighter and rises. Thus, the ceiling will usually be warmer than the floor.

2. Notebook or Spreadsheet. Pencil or pen and notebook or, alternatively, a clip board with a spreadsheet arranged like this:

NAME:
PLACE:

DATE	**TIME**	**SKY TEMPERATURE**	**CLOUD TEMPERATURE**	**SKY (CLEAR, HAZY, CLOUDS, ETC.)**

Note: Mention of commercial products and suppliers does not imply that they are endorsed by NASA or the author. You can find many sources for conventional and IR thermometers at retail stores and by searching the web.

Procedure:

The temperature of the air and everyday objects is usually given using the Fahrenheit or Celsius scale. In the Celsius scale, The freezing point of water is 0 degrees and the boiling point of water is 100 degrees (at sea level). In the slightly older Fahrenheit scale, the freezing point is 32 degrees and the boiling point is 212 degrees. Scientists and people in most countries use the Celsius scale. While the Fahrenheit scale is going out of style, its advantage is that it provides nearly twice the resolution of the Celsius scale. Both Celsius and Fahrenheit scales are used in the projects that follow.

Here are the formulas for converting between Celsius (T_C) and Fahrenheit (T_F):

Celsius (T_C) = (5/9) x ((T_F) – 32)

Fahrenheit (T_F) = (9/5 x (T_C)) + 32

Here are spreadsheet formulas you can use for making these conversions:

To convert (T_F) to (T_C), type this formula into spreadsheet cell B5: =(5/9)*(A5-32) (where A5 or any other cell location is the cell containing T_F).

To convert (T_C) to (T_F), type this formula into spreadsheet cell B6: =(9/5*A6)+32 (where A6 or any other cell location is the cell containing T_C).

Be sure to test these formulas after you enter them. Type 212 into cell A5, and cell B5 should read 100. Type 100 into cell A6, and cell B6 should read 212.

Various online calculators like this oneallow you to convert from Fahrenheit to Celsius or Celsius to Fahrenheit.

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Science Project Ideas:

You can use an infrared thermometer to learn much about the sky and various kinds of clouds. These experiments can be done at any time of the day or night. Always use care when using an infrared thermometer outdoors, in public places and around strangers who may be unfamiliar with what you are doing. Be careful to avoid touching objects that are so hot they might burn you. Here are some projects you can try:

1. Measure Sky and Cloud Temperature with an IR Thermometer.

The apparent temperature of the sky measured by an infrared thermometer provides basic information about the greenhouse effect.

Warning: Never point a laser pointer at a person, car, truck or airplane!

Project: Go outdoors and point an IR thermometer straight up at the open sky and write the time and temperature in a notebook. Repeat this procedure for a cloud that is overhead or nearly so.

What did you observe? What was the difference in the sky and cloud temperature?

Repeat your measurements at various angles around the sky. What happens to the temperature as you point the IR thermometer closer to the ground?

If the infrared thermometer is equipped with a laser pointer, be sure to switch it off during this experiment.

2. Investigate Cloud Temperature with an IR Thermometer.

The dew point is the temperature at which water vapor in the air condenses as moisture. Morning dew on grass means that the night time temperature fell to or below the dew point. Fog means the temperature of the air is at the dew point. When warm air loaded with water vapor rises in the sky, it cools and condenses into clouds when the temperature of the air falls to the dew point.

Project: Is there a relationship between the the dew point and the temperature of the bottom of cumulus clouds measured with an infrared thermometer? The temperature of cumulus clouds measured for this project was very close to the dew point. What are your results? To find out, measure the temperature of overhead cumulus clouds once a day for at least 10 days. On days when you measure clouds, check with your local US Weather

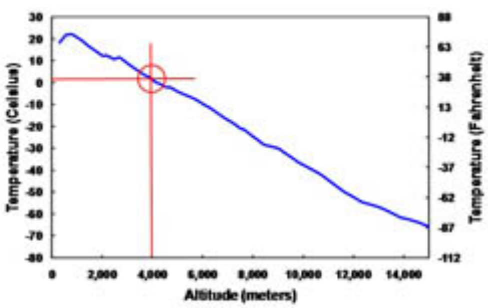
Service officeto find the dew point. Enter your data into a computer spreadsheet and make a graph to compare the dew point and the cloud temperature. You can go further by making a scatter graph and selecting the trendline feature. Then select the R squared function to determine the degree of agreement between your cloud measurements and the dew point. The closer the R2 is to 1, the better the agreement.

Going Further: Does this method work with fog? Does it work with clouds other than cumulus clouds?

More Going Further: You can estimate the altitude of the base of cumulus clouds at this cloud base calculator.

3. Graph the Temperature of the Sky Overhead.

The Background section above describes apparent sky and cloud temperature measurements made from South-Central Texas on September 21, 2008, and the temperature measured by a weather balloon launched from Del Rio, Texas, the same day. The graph below shows the temperature measured by the weather balloonfrom the ground to the upper troposphere when an infrared thermometer indicated a sky temperature just above freezing (34 degrees or 1 degree C).



Project: You can make similar graphs for your sky measurements. Here's how:

Ideally, measure the apparent sky temperature within an hour or two before or after a weather balloon flight. Weather balloons are launched from weather stations around the world at 0 Zulu and 12 Zulu. "Zulu" means Coordinated Universal Time (UTC). UTC is the same time everywhere on Earth. Thus, when it is 10:30 UTC in Colorado, it's 10:30 UTC in Australia. You can find the UTC for your location by clicking here.You will see the graphic below:

Notice the list of places below the map (Samoa, Hawaii-Aleutian, etc.) To find the UTC, click on "UTC" at the end of this list. To find your local time, click on your time zone. By finding your local time and UTC, you can determine how to convert your local time into UTC. For example, when the UTC is 12:00 hours, in the Central Time Zone (light blue central States in the map above) the local time is 06:00 AM. This means that the UTC is Central Standard Time – 6 hours. For Daylight Saving Time, the UTC is Central Daylight Time – 5 hours. The Navy has posted an online table herethat converts the main US time zones (Pacific, Mountain, Central and eastern) into UTC.

If you live in one of the four US time zones, here are the times when weather balloons are launched each day:

UNITED STATES	STANDARD TIME		DAYLIGHT SAVING TIME	
TIME ZONES	0Z (00:00 UTC)	12Z (12:00 UTC)	0Z (00:00 UTC)	12Z (12:00 UTC)
PACIFIC	4 p.m.	4 a.m.	5 p.m.	5 a.m.
MOUNTAIN	5 p.m.	5 a.m.	6 p.m.	6 a.m.
CENTRAL	6 p.m.	6 a.m.	7 p.m.	7 a.m.
EASTERN	7 p.m.	7 a.m.	8 p.m.	8 a.m.

Go to this University of Wyoming web site to find the closest weather balloon site to your location. When you see the following map, click on the site closest to your location.

You will next see a table of the most recent weather balloon flight from the location you selected. For example, here is the data from the first kilometer of a balloon flight from Del Rio, Texas. (This flight reached 32 km before the balloon burst and the instruments parachuted down to Earth.)

72261 DRT Del Rio Observations at 12Z 03 Oct 2008

PRES	HGHT	TEMP	DWPT	RELH	MIXR	DRCT	SKNT	THTA	THTE	THTV
hPa	m	C	C	%	g/kg	deg	knot	K	K	K
976.0	314	18.2	13.5	74	10.06	80	7	293.4	322.3	295.1

964.0	421	22.0	16.0	69	12	120	10	298.3	333.4	300.4
943.2	610	22.5	14.9	62	11.45	190	15	300.6	334.6	302.7
925.0	780	23.0	14.0	57	10.98	205	22	302.8	335.6	304.8
912.0	903	23.4	12.4	50	10.01	205	24	304.5	334.7	306.3
910.9	914	23.4	12.2	50	9.92	205	24	304.5	334.5	306.3
884.0	1175	22.2	8.2	41	7.77	192	21	305.9	329.8	307.4

The data highlighted in blue in the table above is what you can use to make a graph like the one above. The first blue column is the height above the ground in meters. The second blue column is the temperature in degrees Celsius. For an explanation of what weather balloons measure, scroll down to the bottom of any data page for links to descriptions of the data columns.

Save the table you select as a text file (e.g., skytemp.txt). Then upload this file into a computer spreadsheet. You can then make a scatter graph to display the data as it's displayed above.

Finally, mark on the graph the apparent sky temperature you measured with an infrared thermometer to see the altitude at which that temperature was measured during the balloon flight. As discussed above, this does not mean that you measured the temperature at only that altitude. Instead, you measured what might be described as an average temperature up to that altitude and beyond.

Note: The University of Wyoming upper air web site includes an archive of past balloon flights. This is handy if you make some sky temperature measurements on days when you don't have access to a computer.

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Project Ideas continued

4. Measure the Temperature Across the Entire Sky.

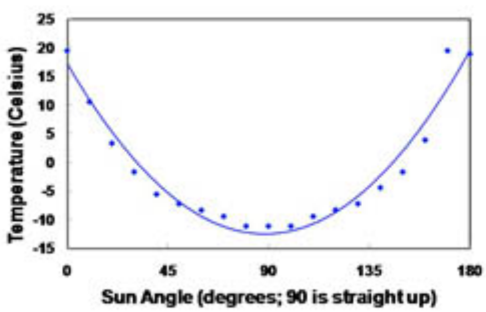
The apparent temperature of the sky straight overhead (the zenith) is cooler than when an IR thermometer is pointed at lower angles in the sky. This is because the IR sensor in the thermometer is looking through more water vapor when the instrument is at an angle away from the vertical. Here, for example, is a scan across the entire sky from East (0 degrees) to West (180 degrees) near midnight when no clouds were present.

DATE: 03 Oct 2008	TIME: 11:27 p.m.
SKY CONDITION: Totally clear.	

ANGLE (90 is zenith)	SKY TEMPERATURE (Celsius)
0	19.4
10	10.6
20	3.3
30	-1.7
40	-5.6
50	-7.2
60	-8.3
70	-9.4
80	-11.1
90	-11.1

100	-11.1
110	-9.4
120	-8.3
130	-7.2
140	-4.4
150	-1.7
160	3.9
170	19.4
180	18.9

Here's a graph that shows the data in the table above:



The blue diamonds represent the actual temperature measurements. The blue line represents the best curve though the data points.

Project: This project is best done with two people in a place where you have a full view across the sky. You will need an infrared thermometer and an angle indicator such as the Johnson Pitch and Angle Locator.

Use a computer to make a simple spreadsheet like the one above or draw a similar spreadsheet on a sheet of paper. Place your spreadsheet on a clipboard and take it and an IR thermometer and a protractor outdoors to measure the temperature across the sky every 10 degrees.

Hold the angle indicator against the side of the infrared thermometer so that the top of the thermometer is even with the top edge of the angle indicator. You will need to experiment with the best way to hold them together.

While one person points the infrared thermometer at 10 degree intervals across the sky, the second person should write down the temperature at each interval. Some IR thermometers have a hold feature that freezes the temperature reading on the readout when a button is pressed. This feature is very handy if a partner is not available.

Enter your measurements into a computer spreadsheet to make a graph like the one above.

Study your graph. Do the two sides of the scan across the sky match fairly evenly? Why does the sky become warmer near the horizon? What happens when clouds are in the sky? Why?

Questions:

1. True or false: On the same day, the temperature of the blue sky measured by an infrared thermometer is warmer than the temperature of a cumulus cloud. Explain your answer.

2. Explain the dew point.

3. True or false: The temperature of a cumulus cloud is related to the dew point. Explain your answer.

4. True or false: A weather balloon can measure air temperature at an altitude of 30 kilometers or greater. Explain your answer.

5. When measured with an infrared thermometer, the sky temperature is coolest: (a) straight overhead, (b) at an angle of 30 degrees away from straight overhead, or (c) at an angle parallel with the ground.

Going Further:

Learn about emissivity to better understand how an infrared thermometer works. Can you provide a scientific explanation of what an infrared thermometer is really measuring when pointed at the sky and clouds?

Project Idea contributed by Forrest M. Mims III, Geronimo Creek Observatory, Texas

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