AIAA AEROSPACE MICRO-LESSON

Easily digestible Aerospace Principles revealed for K-12 Students and Educators. These lessons will be sent on a bi-weekly basis and allow grade-level focused learning. - AIAA STEM K-12 Committee.

CLOUDS

Water is key to life on Earth and it exists all around us. Where can you see water? You can see it in lakes, rivers, and oceans. It comes out of a faucet, into a glass for you to drink or into your bath. And it falls from the sky as rain, snow, sleet, or in other forms. But how does it get there? Can you see it? Look up! If you see a cloud, you are looking at water in the sky. But even on a clear day, there is water all around, mixed into the air, as a vapor.

Next Generation Science Standards (NGSS):
* Discipline: Earth's Systems.
* Crosscutting Concept: Scale, proportion, and quantity.
* Science & Engineering Practice: Asking questions and defining problems.

GRADES K-2

NGSS: Energy: Make observations to determine the effect of sunlight on Earth's surface.

What is water? If I asked you for some, where would you get it? You might go fill a glass of water from the sink. That is liquid water. Water can also be a solid, called ice, which you might put in the water to make it cold. But water also can be an invisible vapor which you cannot see. Some of the water breaks away from the liquid or ice and flies into the air. The amount of water that has escaped into the air is called humidity. If I ask you for some water, you can just cup your hands together. There! You have some in your hands, mixed in with the air!

Most of the water in Earth's air comes from the sun heating lakes, oceans, and rivers. The heat of the sun gives the water energy, and the more energy it gets, the more of it can escape into the air. As this invisible water rises up into the sky, it cools and loses energy. When it has cooled enough, it starts to turn back into liquid water, and the little drops of water stick to little bits of dust and dirt in the air. Those tiny drops of water, high in the sky, are clouds! Millions of tiny drops of liquid water floating in the air!

You can make a model of this right on your desk. In the activity linked to, the boiling water creates humid, moist air in the jar, a jar with a lot of water vapor. When you put the ice on top, it cools the water vapor, just like it would if it rose up into the sky. The water vapor wants to turn back into a liquid.

GRADES K-2 (CONTINUED)

Why do you need the hair spray in the activity? When the water vapor cools, it can't turn back into a liquid unless it has something to stick to so it can collect together. Hair spray is an *aerosol*, which means it is made of tiny bits of solid or liquid, like dust. This gives the water vapor something to stick together on to form drops. In Earth's air, smoke, dust, pollution, and other aerosols are carried by the air, and they help clouds to form.

When the clouds are lifted high enough that the drops grow so big the air can't hold them anymore, the drops of water fall down as rain, or if it is cold enough, as snow. The movement of water evaporating from the ground or oceans into the atmosphere, condensing into clouds, and falling back to the ground or ocean is called the *water cycle*. Another activity that illustrates the water cycle can be found here.

GRADES 3-5

NGSS: Earth's Systems: Represent data in tables and graphical displays to describe typical weather conditions expected during a particular season.

Have you ever looked up in the sky and watched the clouds? Perhaps you have looked at their shapes and imagined they were different animals or objects. An elephant. Or a boat. Did you know different types of clouds have names? And that you can tell a lot about the weather by looking at the type of clouds overhead.

Most clouds are formed when moist air—air that has water mixed into it—is lifted into the sky and cools. Sometimes it is lifted very fast. Other times it is lifted slowly. Clouds may be low to the ground or high in the sky. They may be spread out, or lumped together. All these shapes tell you something about how they formed, and what they are called.

This site has pictures and names of different cloud types.

Some clouds are formed at weather fronts. Perhaps you've seen a weather chart with the red and blue lines on it? Weather fronts are where big areas of warm and cool air are pushing into each other. When this happens, some air is lifted up, and clouds form. Air that is lifted rapidly forms big lumpy *cumulus* clouds, which often result in quick and wet rainstorms. Air that is lifted slowly forms wide, spread-out *stratus* clouds, which make long, gentle showers. If the air rises really fast, you get *cumulonimbus* clouds—thunderstorms!

GRADES 3-5 (CONTINUED)

Clouds can form in other ways, too. In the southern United States, in the summer, the heat of the sun can make the air rise fast enough to form clouds and afternoon rain showers. This happens a lot in Florida. (Note that the video is a four-hour time-lapse view of four hours compressed into a minute and a quarter. If you go outside and watch a thunderstorm form it does not look like that.) In mountainous states and on islands, winds can push air up the side of a mountain, forming clouds at the top that disappear on the other side. (This also is a time-lapse video.)

There are other ways clouds form. Sometimes it's not from air moving up, but from air moving sideways or from the land underneath it cooling it. This is how fog is formed. *Radiation* fog forms when calm, moist air is cooled by the ground underneath cooling at night. This is most common in the fall and early winter. *Advection* fog is formed when moist air from the ocean or a lake is blown over cold ground, as happens on the California coast.

The next time you are outside, look up and think about why the clouds look the way they do. How were they made? And what do you think the weather will be like tomorrow, or later this week, based on the clouds you can see?

GRADES 6-8

NGSS: Earth's Systems: Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.

Have you heard the term *humidity*? You may have heard someone say, "It's hot, but it's a dry heat." Or, "I can't bear it outside, it's just too humid!" What does this mean?

Humidity is a measure of how much water vapor is in the air. It is usually given as a percent, for example, "60% humidity," and this refers to *relative humidity*. *Relative humidity* is technically the ratio of the partial pressure of water vapor relative to the equilibrium vapor pressure of water at a given temperature. If you haven't heard those terms in chemistry class, don't worry. What it means is that the *relative humidity* is a measure of how much water is in the air as compared to how much water could be in the air at the given temperature. The actual amount of water vapor in the air is called the *absolute humidity*. The *absolute humidity* is measured as a mass of water vapor in a given volume of air. The hotter the air, the more water can exist as a vapor, and vice versa. This is why your air conditioner drips water: the cooled air coming out of the air conditioner

GRADES 6-8 (CONTINUED)

can't hold as much water vapor as the warmer air going in, so the rest falls out into the drip pan.

Humans, like most mammals, cool our bodies by evaporation. Dogs, cats, and many other mammals use their tongues, but humans sweat. Our skin releases water all over our body, and as this water escapes into the air it takes some heat with it. Some scientists theorize that our ability to sweat gave our ancestors the ability to run down other animals until they overheated and collapsed, called *persistence hunting*. Many animals can run faster than a human, but few can run for as long a time or distance. The ability of our sweat to cool us depends a lot on how fast water can evaporate from our skin. And that depends on how much water is already in the air.

When someone says, "it's a dry heat" (often heard in the Southwest U.S. or Texas), they mean the air is hot, but the relative humidity is low. Because the air is so dry, sweat evaporates quickly, and so their body is able to cool itself easily. In a humid place like Florida or Georgia, where the humidity may be 90%, sweat cannot evaporate quickly because there is already so much water in the air. So it is more difficult to stay cool.

However, overly dry air is not all good. Very low humidity dries out your skin and nose. In the winter, even very humid cold air outside becomes dried out when heated inside a building. Most people are comfortable with a relative humidity between 50% and 60%.

You may have heard the term *dew point* as well. The *dew point* is the temperature the air must be cooled to become *saturated* with water vapor, i.e. when it can hold no more. (At this point the *relative* humidity is 100 percent.) When air is cooled to a temperature lower than the dew point, some of the water vapor will condense to form liquid water, called dew. If the temperature is below freezing, the water vapor condenses out as frost. If this happens up in the sky, the dew forms around aerosols suspended in the air and becomes clouds. In fact, you can make an estimate of how high clouds are based on surface measurements of temperature and dew point, and assuming a rate of cooling with altitude.

Pilots pay close attention to dew point because frost formation on aircraft can be deadly. This is known as *icing* and it occurs when aircraft fly through visible moisture that is at or just below freezing temperature (32 deg F / 0 deg C). Ice can build up rapidly on the wings and fuselage, ruining the shape that gives lift and adding extra weight.

GRADES 6-8 (CONTINUED)

Even though airliners are equipped with deicing gear to mitigate ice formation, they still avoid flying at altitudes and in conditions where ice formation is likely. And other aircraft, such as small general aviation planes, cannot fly if icing is likely.

GRADES 9-12

NGSS: Earth's Systems: Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

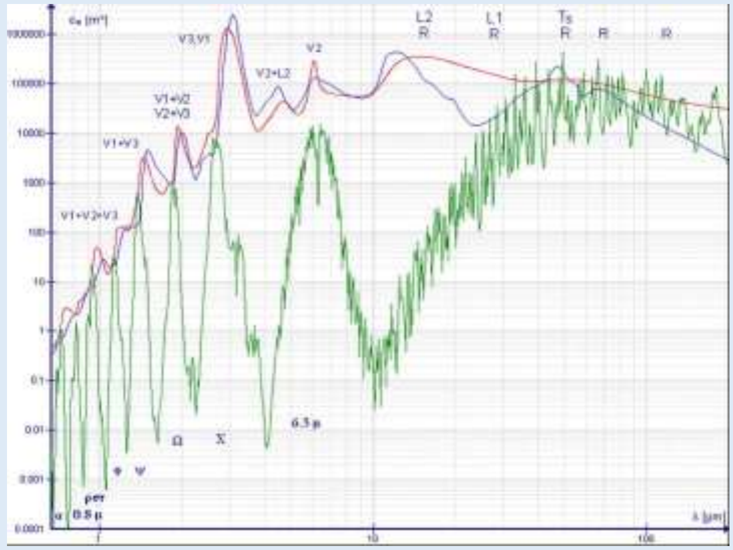
Clouds play a crucial role in governing the climate of any place on the Earth. The climate, which is simply the long-term weather at any place, is described in terms of its temperatures and levels of precipitation. The role that clouds play in precipitation is obvious; without clouds, there is no rain or snow. Clouds' role in regulating temperature, however, is equally important although less obvious.

Any place on the Earth receives its warmth from the radiation of the Sun. Before the radiation can reach the Earth's surface, however, it must pass through the atmosphere. If the atmosphere over a given spot has clouds in it, the clouds will block most of the Sun's radiation. The clouds will absorb some of the radiation; they will let a little bit of it through to the Earth's surface; but they will reflect most of it back out into space. This is why on an overcast day the temperature will often not increase much through the day. (This is also why the planet Venus appears so much brighter in the sky than Mercury or Mars: apart from being larger, it is covered completely by clouds which reflect the Sun's radiation very efficiently.) Where there are no clouds, most of the radiation, which is in the visible part of the electromagnetic spectrum, passes through the atmosphere easily.

During the night, the Earth's surface radiates its warmth away into space. (It does this during the day as well, but the effect is overwhelmed by the radiation it receives from the Sun.) Before it can get to space, however, this radiation must pass through the atmosphere as the incoming radiation had to. Most of the Earth's radiation, however, is in the infrared part of the spectrum. Water vapor in the atmosphere absorbs infrared radiation much more effectively than it absorbs visible light. Clouds also block the radiation. This is called the "greenhouse effect" and makes the Earth significantly warmer than it would be if it had no atmosphere. It also explains why, on a cloudy night, the temperature often does not drop by much and why a bowl of water left outside overnight in the Sahara desert may have a film of ice on it in the morning.

Grades 9-12 (continued)

Scientists have quantified how a substance absorbs or transmits light as its *absorptivity*, or *attenuation coefficient*. The *absorptivity* of a material is a measure of the fraction of light of a given frequency (or wavelength), which governs the color of the light, that is absorbed while passing a given distance through the material. The figure to the right, taken from Wikipedia, shows the attenuation coefficient of ice (in blue), liquid water (in red), and water vapor (in green) as a function of the light's wavelength. Notice that the axes in this graph are logarithmic scales, meaning that for every unit of length that you move up or to the right, the value of the variable increases by a factor of ten. The wavelengths that correspond to visible light are on the extreme left end of the graph, where the attenuation coefficient is quite small. The water vapor in the atmosphere lets the visible light through easily (which is why we can see long distances with our eyes) but blocks most of the infrared radiation.



Cameras on satellites often take pictures with different wavelengths of light outside the visible portion of the spectrum. To allow us to see the pictures easily, they are then given "false colors" for display purposes. While water vapor blocks radiation in most of the infrared spectrum, there are some specific frequencies which it does not block. Clouds, which scatter visible light badly, do not scatter infrared light and so the infrared pictures can see through them directly down to the Earth's surface. This can be very handy when the satellite operators want to see what is going on at the surface on a cloudy day.

Sixty Years Ago in the Space Race:

March 5: The American Explorer II failed to reach orbit when the fourth stage did not ignite.