Space Weather Handout

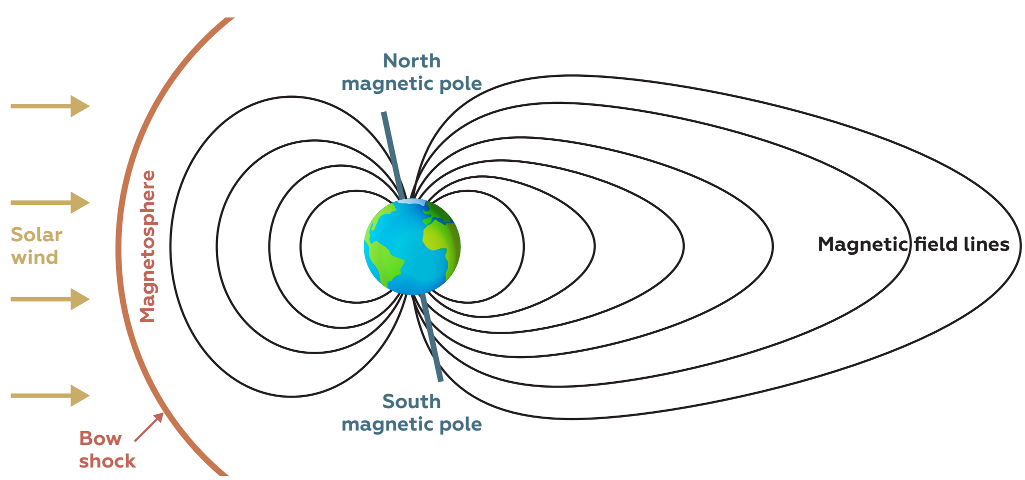
Although most of us think of weather as something that happens in the Earth's atmosphere, it turns out that activity on the surface and in the atmosphere of our Sun can also cause its own dramatic kind of weather.

Solar Wind

Because the outer layers of the Sun are so hot, atoms and parts of atoms leave the Sun at speeds that average almost a million miles per hour. (That sounds outrageously fast if a car were driving at that speed, but it's easier to get tiny protons and electrons moving that fast.) We call this flow of material the *solar wind*. As it moves through the whole solar system, some of it streams toward the Earth. Most of the solar wind is made of charged particles: electrons, protons, and alpha particles (the nuclei of helium atoms).

When the charged particles reach our planet, they are caught up in the magnetic zone around the Earth and spiral around. This *magnetosphere* (the zone of our magnetic field) around Earth keeps most of the charged particles from reaching us (see figure below). The only place the magnetic field can lead particles from the solar wind toward Earth is at our north and south magnetic poles. There, the magnetic field comes in and goes out of our planet, and the Sun's fast moving particles can hit the top of our layer of air.

When the solar wind particles collide with air molecules, they cause them to "jiggle" (vibrate) and give off light. Tourists like to go to the northern and southern regions of the Earth and watch the resulting glowing curtains of light high in the atmosphere. We call this an *aurora* (or the northern lights and southern lights).



A diagram of Earth's magnetic field

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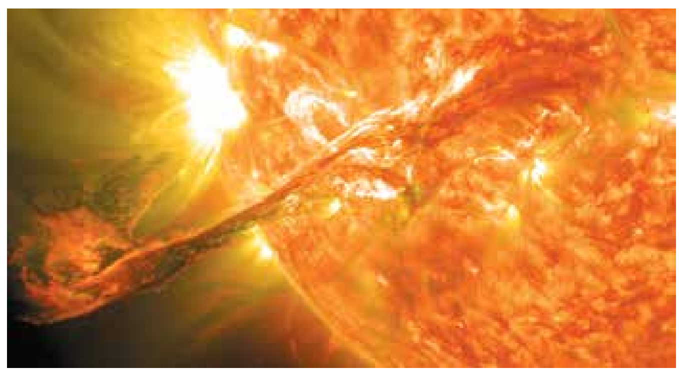
Solar Storms

In addition to its steady wind, the Sun can also have "storms" in its upper layers. These storms are the result of the sudden release of a lot of magnetic energy, and they can fling huge numbers of particles into space at once. Such storms are more likely to happen during times when the Sun has more sunspots on its surface, a time known as solar maximum.

There are a number of ways in which we see increased activity (storms) on the Sun. When there is a flare, a small part of the Sun gets much brighter as both energy and particles are released. In a *coronal mass ejection* (CME), huge bubbles of charged particles are flung from the Sun in one particular direction. A large CME can contain billions of tons of charged particles and take a few days to travel the distance from the Sun to the Earth. Luckily, most CMEs don't happen to be going in our direction, and they travel onward through our solar system without affecting us. But every once in a while, a CME turns out to be flung directly toward Earth and then our cosmic neighborhood (and particularly our magnetosphere) is overloaded with all its energetic particles.



A 2012 CME seen with NASA's Solar Dynamics Observatory spacecraft.
(The colors are enhanced.)

When a storm from the Sun reaches the Earth, auroras can be seen farther south in the Northern Hemisphere and farther north in the Southern Hemisphere. Even more significant, all those extra charged particles set up large currents of electricity in the Earth's upper atmosphere (particularly in the layer called the ionosphere).

Effects on Earth Technology

The extra electricity introduced by a big solar storm can affect many parts of our lives, which are more and more dependent on electricity and delicate instruments like computers. Electricity is supplied to homes and businesses by local and national networks (called the *electric power grid*). Large currents in our atmosphere can overload the power grid and cause electrical blackouts around the local area. Because the grid connects many regions together, such blackouts can sometimes also affect other parts of the country and the continent.

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Up in space, the extra flow of charged particles can penetrate computers and other electronic parts in our orbiting satellites. This can lead to computers giving the wrong instructions to the satellite instruments or even to permanent damage when there is a strong storm. Engineers now shield sensitive satellite instruments with protective coverings so they aren't as easily damaged.

Solar storms can also interfere with long-distance communications on our planet. To reach distant places, we often bounce radio waves off the ionosphere, which can act like a mirror, reflecting waves to other parts of the Earth. But if this mirror is disturbed, communications can't get through. Communications problems are especially dangerous for airplanes, which fly up in the atmosphere and need to keep in touch with flight controllers around the world.

There is also concern about how astronauts in orbit aboard the International Space Station (ISS) would be affected by a major CME coming in their direction. So far, no such event has threatened humans inside the ISS. When there is the prediction of a solar storm, astronauts are advised to go to sections of the ISS that offer greater shielding.

Monitoring Space Weather


The Solar Dynamics Observatory

Because storms from the Sun can be dangerous for human activities, NASA and the National Oceanic and Atmospheric Administration (NOAA) carefully monitor the Sun and the space weather it causes. NASA has a number of satellites in space to keep regular track of what the Sun is doing. The most recent of these (launched in 2010) is the Solar Dynamics Observatory, which monitors the Sun's output not just in visible light, but in ultraviolet light and x-rays, too.

NOAA's Space Weather Prediction Center (in Boulder, Colorado) keeps track of what's happening on the Sun 24 hours a day, seven days a week. If they see conditions that signal a storm coming, they alert military and civilian agencies so that airlines, power grid operators, and others who depend on electricity, satellites, and long-distance communications can take precautions.

For more information, print out the NOAA booklet Space Weather from *www.swpc.noaa.gov/sites/default/files/images/u33/swx_booklet.pdf*.

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A History of Solar Storms

On September 1, 1859, amateur astronomer Richard Carrington noticed a bright flare on the Sun. Although Carrington didn't know it then, that flare also came with a powerful CME pointed directly at the Earth. To make things worse, there had been an earlier CME that had "cleared a path" in the steady wind of particles from the Sun, and so the second CME found fewer particles in its way between the Sun and Earth than normal and got here with unusual speed and power.

On September 2, a huge solar storm arrived at Earth. As the Earth's magnetosphere was overloaded by charged particles, dramatic effects were seen all around our planet. Auroras were visible the next evening as far south as Hawaii and the Caribbean, and these northern lights were so bright, some people woke up in the middle of the night thinking it was already day. Some even reported being able to read a newspaper in the middle of the night by their light.

This was the time in history when the telegraph—a machine and network for sending coded messages over electrical wires—was spreading all over the United States. Rival companies were stringing up wires on telegraph poles for sending messages between people and companies. (You could say this was the oldest form of an internet.) The charged particles descending through our atmosphere in 1859 got into the telegraph system, and some telegraph operators reported sparks coming out of their instruments, while others saw sparks flying from the telegraph wires overhead. The episode is now called the Carrington event in honor of the person who first connected it with activity on the Sun.

Today, we are far more dependent on electricity than we were in 1859. We had a taste of what can happen in our modern world when a milder geomagnetic storm hit the Earth in March of 1989. Auroras were visible in both Canada and the United States. Electricity and lights went out in Montreal and other parts of Quebec, leaving Montreal's underground system of pedestrian walkways dark until backup lights could come on. The radar at the airport in Dorval stopped working for a while. Elsewhere, people reported their electric garage doors opening and closing randomly.

It just so happened that the Space Shuttle Discovery went into space on March 13 that year, just as the storm was arriving, and the astronauts reported some strange readings on their instruments. A number of satellites already in space reported damage to their electronic instruments because of the surge of electrically charged particles that hit them.

Three-Dimensional Learning Exposed

3D LE

Many of the experiences in this book emphasize three-dimensional learning when coupled. The best example in this chapter is the combination of Experience 3.4, "Discover the Sunspot Cycle," and Experience 3.7, "What Else Cycles Like the Sun?"

These two experiences use Earth- and space-based data that students analyze to discover patterns in the number of sunspots observed over many years. This information is then compared with data characterizing other phenomena. Students find that some of them are related to the level of sunspot activity (e.g., geomagnetic activity) and some are not (e.g., stock market activity).

We encourage you to find time during these experiences to point out to students how they are engaged in the science practices and crosscutting concepts, especially how what they are doing resembles the practices of scientists—analyzing and interpreting data that have been carefully gathered.

In addition to three-dimensional learning, the experiences in this chapter also make extensive use of mathematics concepts identified in the *Common Core State Standards*, including basic algebra, proportional reasoning, and graphing skills. Reading, writing, and speaking skills are required in many of the experiences, as students use informational text and the results of observations they have made to produce and deliver presentations arguing for their perspectives or ideas.