Overview of Climate Science

This overview of climate science is written to support the development of a K-14 climate education plan for the Pacific Islands Climate Education Partnership (PCEP). It aims to help people understand the main ideas involved in climate science, and how that climate science content is organized in the PCEP website.

In order to understand climate, we need to know a lot about how our planet works. While our planet is very complex, there are a few big ideas that can help us understand the most important things that we need to know about planet Earth. The biggest of these ideas is to think about our planet as a system. In fact, there is a whole area of science that is called Earth System Science.

In Earth System Science, we study planet Earth as a system. Whenever we study any kind of system, we learn that it is made of parts. We also learn that the parts of the system connect in specific ways to make the system work as a whole. We generally discover that the system as a whole has properties that are qualitatively different than the properties of its parts. For example, a car is a system made of parts such as brakes, an engine, wheels, doors, a fuel tank and a battery. The car has the property of being able to transport people rapidly from one place to another. It also has other system properties such as a fuel efficiency, being able to go 35 miles on a gallon of gasoline. No individual part of the car can transport people or get 35 miles per gallon of gasoline.

Similarly, planet Earth is a system. It is made of parts, such as the atmosphere, the oceans, and the solid sphere that scientists call the geosphere. These parts are the physical stuff that make up our planet. Just like a car, our planet has properties that none of its parts have. Climate is one of the most important of these Earth system properties. Earth's global climate is a feature of the planet as a whole. As we will be learning, the interactions of the parts of the Earth system play significant roles in determining the climate at specific locations as well as the climate for the planet as a whole.

The climate science content in the PCEP website is organized into five major topics:

- **Earth System Science**
- **Earth's Matter**
- **Energy and the Earth System**
- **Earth's Biosphere (life)**
- **Earth's Climate.**

Each of those topics has a number of subtopics associated with it that help explain that topic in much more detail. In this overview, we are focusing on the five main topic areas. Resources within the PCEP website can help you explore each of these topics in even greater detail.

Earth System Science

We have already introduced Earth System Science as the interdisciplinary way that scientists investigate and discover how the parts of the Earth system work together. Earth system scientists measure key features of our planet such as the temperature at thousands of different locations in the atmosphere and oceans. They use powerful computers to analyze enormous amounts of data and to understand how our planet works, what changes are happening now, and what changes are likely to happen in the future.

One reason that it is very helpful to think about planet Earth as a system is that we have learned a lot about systems and how they change. For example, in many systems, a small change in one part of a system can cause very large changes in the whole system. It can be hard to predict what changes will happen to the whole system when one or more of its parts change. This feature is particularly true for a complicated system like planet Earth.

Because there are now so many human beings and we have very powerful technologies, humans are now making major changes to many parts of the Earth system. These changes are affecting the climate in local areas, large regions, and the planet as a whole.

Just as the parts of the Earth system affect the climate, the climate itself affects the parts of the Earth system. So changes in the parts cause the climate to change, and that changing climate then affects the parts and cause further changes in the climate. These kinds of loops of change are called feedback loops. Some kinds of feedback loops can cause the changes to become larger and larger, and some kinds of feedback loops can stabilize the system. With respect to climate, we worry about feedback loops that make the changes become larger. We are grateful for feedback loops that stabilize the climate. These kinds of feedback loops influence how much Earth's climate will change and how fast it will change.

There are different ways that we can classify the parts of the system. For this website, we are classifying the parts as Earth's Matter, Earth's Energy and Earth's Life. We classify in this way because it reveals three important principles that help us understand global climate change. The three principles are summarized below, and are described in more detail in their respective sections of this overview document.

Matter Cycles: Each of the elements that is vital for life exists on Earth in a closed loop of cyclical changes. From a systems point of view, Earth is essentially a closed system with respect to matter.

Energy Flows: The functioning of our planet relies on a constant input of energy from the Sun. This energy leaves the Earth system in the form of heat flowing to outer space. From a systems point of view, Earth is an open system with respect to energy.

Life Webs: A vast and intricate web of relationships connects all of Earth's organisms with each other and with the cycles of matter and the flows of energy. From a systems point of view, Earth is a networked system with respect to life.

Humans are making very significant changes to Earth's cycles of matter, particularly the carbon cycle. These changes are altering the flows of energy into, within and out of the Earth system. These changes to the flows of energy are changing Earth's climate locally and globally. Changes to climate affect the web of life, including us.

<u>Earth's Matter</u>

For climate science, we especially want to know about forms of matter that interact with the flows of energy into, within and out of the planet. For example, carbon dioxide and water vapor are gases in the atmosphere that keep heat longer within the Earth system. As a result, Earth's climate is warmer than it would be without these heat-trapping greenhouse gases.

Earth is made of solid stuff, liquid stuff, and gas stuff. We are most familiar with the solid ground upon which we walk and build our social structures. This thin outer layer of Earth's solid matter is called the crust. The geosphere is a more inclusive scientific term that takes into account the vast majority of Earth's solid stuff that exists underneath the crust. Earth's geosphere is arranged somewhat like a layer cake. The thin layer of crust overlies 6,300 km of rock and metals.

The region directly below the crust is called the mantle, and it makes up the largest volume of Earth's interior. Earth's core, made mostly of iron and a small amount of nickel, is directly below the mantle. The core has an outer liquid part and an inner solid part. The liquid iron in the outer core is main source of Earth's magnetic field.

With respect to global climate, the solid Earth exerts two main influences. The positions of mountains and continents influence the patterns of how energy circulates within the Earth system. The other influence happens when volcanoes and other natural processes eject matter into the air. Once the matter is in the atmosphere, it can change Earth's climate by reflecting sunlight back to outer space, absorbing some of the sunlight, or by interfering with the escape of heat from the planet.

Since air readily moves from one place to another (wind is air that is moving), the atmosphere plays a very large role in moving different forms of matter and energy around the planet. Changes to the atmosphere can happen very quickly and can have very profound effects on local and global climate.

The atmosphere is a thin blanket of air that surrounds Earth. It is mainly composed of nitrogen (78%), oxygen (21%) and other gases including argon and carbon dioxide. The atmosphere also contains varying amounts of water vapor.

Scientists characterize four different layers of the atmosphere, which differ from each other in their location. The troposphere, the layer closest to the ground, starts at the Earth's surface and extends to about 15 kilometers (9 miles) high. This part of the atmosphere is the most dense and has the most matter. Almost all weather is in this part of the atmosphere.

The oceans cover about 70% of Earth's surface, which is why our planet looks blue from outer space. The oceans have more than 97% of Earth's water. Even though they are present in smaller amounts than the liquid water, the gas and solid forms of water (water vapor and ice) are very important parts of Earth's matter.

All three phases of water (solid, liquid, and gas) play important roles in Earth's climate and these roles are different from each other. The oceans stores huge amounts of heat, and also transport thermal energy around the planet. Water vapor in the air keeps heat longer in the Earth system. Water in the form of solid ice reflects incoming sunlight back to outer space. Since reflected light does not heat the planet, the larger the amount of ice, the cooler the planet is.

Water on Earth continuously changes its physical state and location in a series of changes that we know as the water cycle. The water cycle is important because water is vitally important to life and to how our planet works. The water cycle is also important educationally because it helps us realize that matter is essentially a closed system on our planet. The matter that we have stays here and keeps cycling within the Earth system.

For any specific cycle, we want to know about its reservoirs, the places where the matter exists. We learn where the matter exists in terms of location, physical state and chemical form. For example, the atmosphere is a reservoir of the carbon cycle; it has carbon in the forms of carbon dioxide and methane gases. We also investigate how the matter moves from one reservoir to another. For example, in the water cycle, water evaporates from the ocean and goes into the atmosphere.

The water cycle involves changes in physical state. Water in all parts of the water cycle is the familiar H_2O molecule, sometimes as a liquid, sometimes as a gas, and sometimes as a solid. The water cycle does not involve chemical changes.

Carbon atoms on Earth also constantly move around the planet in a cycle. Unlike the water cycle, the carbon cycle involves chemistry. Carbon is combined with different atoms in the different parts of the carbon cycle. For example, carbon in the air is mostly in the form of carbon dioxide gas. Carbon in the ocean is present as a dissolved salt that includes carbon, hydrogen and oxygen. Carbon under ground as oil is present as a liquid that is made of carbon and hydrogen atoms combined in molecules. Carbon in plants is found as sugar molecules.

The carbon cycle is very important to us since Earth's life is based on the chemistry of carbon. It is also important to us because the carbon cycle is deeply connected to Earth's climate. When we burn fossil fuels, carbon moves from under the ground into the atmosphere. This carbon dioxide in the atmosphere is a greenhouse gas that traps heat energy longer in the Earth system.

Nitrogen atoms on Earth also constantly move around the planet in a cycle. Like the carbon cycle, the nitrogen cycle involves chemistry. Nitrogen is combined with different atoms in the different parts of the nitrogen cycle. For example, most of Earth's nitrogen is in the form of nitrogen gas in the air. Nitrogen in living organisms is mostly found in very large molecules such as proteins. As with the carbon cycle, human changes to the nitrogen cycle are putting gases into the atmosphere that trap heat energy longer in the Earth system.

The cycles of matter teach us one of our three Earth System Science principles. From a systems point of view, Earth is essentially a closed system with respect to matter. Each of the chemical elements that is vital for life exists on Earth in a closed loop of cyclical changes.

Energy and the Earth System

Energy enters the Earth system in the form of sunlight. About 30% of that input solar energy is immediately reflected t outer space and does not heat the planet. Different features of Earth reflect different percentages of the incoming solar energy. Snow, ice and clouds typically reflect about 80% of the sunlight that shines on them. In contrast, land and ocean typically much less of the incoming solar energy, and absorb the rest. Overall 30% of the incoming solar energy is immediately reflected back to outer space and does not heat the planet.

The remaining 70% of the input solar energy is absorbed and heats the planet. The absorbed solar energy circulates within the Earth system via wind and ocean currents. Eventually it leaves the Earth system by flowing in the form of heat radiating to outer space.

Under stable conditions, the amount of energy that leaves the Earth system tends to equal the amount of energy entering the Earth system. Earth's global energy budget can be significantly affected by changes to how much energy enters the Earth system, how the energy circulates within the system, and how energy leaves the Earth system. Changes to Earth's global energy budget can have large effects on the global climate and regional climates.

Tropical areas close to the equator absorb much more solar energy than polar locations. As a result of this imbalance, heat energy flows within the Earth system from the warmer equatorial areas to the colder temperate and polar areas. The atmosphere and the oceans play important roles in circulating this heat energy. The patterns of heat circulation by winds and ocean currents determine many climatic conditions around the planet.

Water has a much greater capacity to absorb heat energy than do gases or solid Earth. As a result of its great size and its high heat capacity, the oceans store most of Earth's absorbed solar energy. The oceans play several role in absorbing and storing large amounts of heat energy, and in circulating that heat energy from the tropics toward the poles.

Heat energy leaves the Earth system by radiation. Warmer objects radiate infrared heat energy to their cooler surroundings. We directly experience this phenomenon when we feel the heat coming from a boulder or a cliff wall that has been heated by the Sun.

At the scale of our planet, Earth radiates heat to the deep cold of outer space. This radiating energy must pass through the atmosphere before it can leave the Earth system. Greenhouse gases in the atmosphere, such as water vapor and carbon dioxide, absorb this heat energy. The extra energy makes these gas molecules vibrate and then they radiate the energy that they have absorbed. Often, the energy simply gets passed to nearby greenhouse gas molecules. This movement of energy in Earth's lower atmosphere keeps the heat energy longer within the Earth system before it eventually escapes to outer space.

Without the greenhouse effect, Earth would be a frozen planet that would not support life as we know it. However, human activities have increased the amount of greenhouse gases. Strong evidence indicates that this increase in atmospheric greenhouse gases is already changing Earth's climate, and threatens to cause much larger changes during this century.

Earth's Biosphere

The biosphere is the system of all of life on our planet. In addition to the living organisms, the biosphere also includes organisms that have died but not yet completely decomposed. We tend to identify Earth's organisms with the plants and animals with which we are familiar. Most of us will never see or directly know about the vast majority of organisms that live on our planet. The biosphere includes all life on land, in water, and under the ground. In addition to plants and animals, it includes fungi, protists, bacteria and viruses.

Organisms live within ecosystems. An ecosystem includes the organisms that live in a particular location, their relationships with each other, and their interactions with the physical and chemical parts of their environment. Different ecosystems have a similar pattern of organization. They all require a source of energy and a group of organisms (producers) that can capture that energy and store it in chemical form. All the other organisms in the ecosystem depend either directly or indirectly on these producers for their food.

Biodiversity refers to the number and kinds of organisms that live on our planet. All of Earth's organisms are connected with each other and with Earth's cycles of matter and flows of energy in a vibrant web of life. We still have much to learn about Earth's biodiversity, how it is affected by climate, and how it affects climate.

Plants and animals in different parts of the planet are very different from each other. These differences are not random. Instead, they have distinct patterns that are closely related to the local temperature and water cycle patterns. In other words, the patterns are directly connected to local climate.

Scientists group distinct communities of organisms that live together on land under the same environmental conditions into categories called biomes. There are seven commonly recognized biomes, often named on the basis of one or more main plant types that grow there. Examples of biomes are coniferous forests, rainforests, deserts, grasslands and tundra.

An ecosystem that is located in a body of water is called an aquatic ecosystem. There are two main types of aquatic ecosystems, those that are based in ocean environments (marine ecosystems) and those that are based in lakes, rivers and ponds (freshwater ecosystems). Aquatic ecosystems account for slightly less than half of the total photosynthesis that occurs on Earth.

Since the oceans cover more than 70% of Earth's surface, marine ecosystems greatly outnumber freshwater ecosystems in terms of amounts and kinds of different organisms. Major marine ecosystems include coral reefs, estuaries, salt marshes, intertidal, and hydrothermal vents.

Within an ecosystem or a biome, the organisms that live in a particular location generally affect the physical environment in which they live. Some of these interactions can have major effects on the local climate.

On a global scale, organisms are a key part of the global carbon cycle. Organisms influence the atmospheric concentrations of two very important greenhouse gases (carbon dioxide and methane) by engaging in the processes of photosynthesis, respiration, and digestion.

Because there are now so many human beings and we have very powerful technologies, humans are now making major changes to many parts of the Earth system. The overwhelming consensus of scientific studies on climate indicates that human activities are already affecting global climate. As a result of increasing greenhouse gas concentrations resulting from the burning of fossil fuels and other industrial and agricultural practices, human activities are very likely to have caused most of the observed increase in global average temperatures since the latter part of the 20th century.

Earth's Climate

Global climate refers to the conditions of climate averaged over the entire planet for a particular period of time. Some confusion and uncertainties occur because we tend to focus on what if happening in our particular location at the current time. Global climate takes into account the entire planet over a longer period of time than a particular season or year. Key indicators of global climate include a wide variety of temperature measurements, precipitation indicators, amounts of sea ice, and timing of seasons.

Climate is not the same thing as weather. Weather is the minute-by-minute variable condition of the atmosphere on a local scale. Climate is a conceptual description of an area's average weather conditions and the extent to which those conditions vary over long time intervals. Climate descriptions can refer to areas that are local, regional, or global in extent.

Climate naturally varies over years and decades. Extreme care and many different kinds of measurements are needed to distinguish between this natural variability and climate change caused by human activities. Frequency, strength and locations of extreme weather events, such as tropical cyclones, are important and dramatic aspects of weather, climate and climate change.

The most important determining factor for the climate at a particular location is its latitude and the time of the year. At any given latitude, variations occur due to other factors such as altitude, proximity to a large body of water, ocean currents, and wind patterns. It is more difficult to predict climate patterns for a particular region than it is for the planet as a whole.

Seasonal variations and multi-year cycles (e.g., the El Nino Southern Oscillation) that produce warm, cool, wet, or dry periods across different regions are a natural part of climate variability. These variations do not represent climate change.

Scientific observations indicate that global climate has changed in the past, is changing now and will change in the future. The magnitude and direction of change are not the same at all locations on Earth.

In recent decades, changes to Earth's climate have been unusually large and rapid. Natural processes do not explain the extent of these changes. The only explanation that is consistent with all available evidence is that human activities are playing an increasing role in climate change.

Our understanding of the climate system and our projections for the future are based on a huge number and a very wide range of environmental measurements. For example, scientists use instruments on satellites, buoys, and weather stations to collect data from different depths of the ocean, different layers of the atmosphere, and the surface of the Sun. In addition to gathering today's climate data, scientists learn about past climates by using natural records, such as tree rings ice cores, and sedimentary layers. They also investigate past climate by analyzing historical observations, such as native knowledge and personal journals. Taken together, all these and other sources show that Earth's average temperature is now warmer than it has been for at least the past 1,300 years.

Sophisticated computer models play a very significant role in understanding the climate system and predicting climate in the future. Essentially all scientific climate models based on current and future greenhouse gas emissions in this century predict that there will be greater changes in global climate and more severe climate impacts. The major differences in the predictions are the extent of the changes and how soon they will happen. The predictions from the existing computer systems are not as detailed about a specific location, such as a country of city, as they are about the planet as a whole or a large region of the planet.

There are a wide variety of careers related to local, regional, and global climate. Just considering basic scientific research, there are a wide variety of careers in basic research about the causes and consequences of weather and climate phenomena, In part, this variety is due to the interdisciplinary nature of Earth system science, the complexities of the climate system, and the global nature of the issue.

There are also many careers that are related to climate mitigation, that is, activities to potentially reduce the extent of climate change. Some of these careers involve scientific and engineering research, but most of them involve implementing or promoting green technologies and social activities, such as wind power and energy efficiency improvements. Other climate careers involve adapting to the consequences of the climate change that is already happening and that will happen in the future. As this website documents, unfortunately there are projected to be a wide variety of climate impacts. As a result, there will be many different career opportunities to help people and societies adapt as well as possible to these changes.