Driving Question: What is Earth’s climate system and what are the empirical and dynamic definitions of climate?

Educational Outcomes: To identify some of the many reasons for studying Earth’s climate system. To learn more about the workings of Earth’s climate system and become more aware of the significance of climate, climate variability, and climate change for our well being wherever we live.

Objectives: AMS Climate Studies is an innovative study of Earth’s climate system that promises to deliver new understandings and insights into the role of climate in our individual lives and the broader society. The AMS Climate Paradigm presented in this Investigation employs an Earth system science approach.

After completing this investigation, you should be able to:

- Describe Earth’s climate system and its interacting components.
- Describe, compare and contrast the complementary empirical and dynamic definitions of climate.
- Explain the AMS Climate Paradigm.

An Earth System Approach:

AMS Climate Studies employs an Earth system perspective. A view of the Earth system as seen from space is presented in Figure 1. The image shown is a visible light full-disk view from a U.S. weather satellite positioned about 36,000 km (22,300 mi) above the equator in South America at 75 degrees W longitude. The satellite remains at that location relative to Earth’s surface because it makes a full revolution around the planet as Earth makes one rotation in the same direction. Being geostationary, the satellite provides a continuous view of the same underlying surface. Successive images from this vantage point provide animations of whatever can be seen moving across Earth’s surface, including the boundaries, called terminators, which separate the illuminated day side and dark night side of our planet.

Examine Figure 1, noting the outlines of land masses. The center of the disk is the point on Earth directly under the satellite from which this image was acquired. Place a dot on the image to represent this sub-satellite point and draw a horizontal line, representing the equator, through the point and extended to the edges of the Earth disk. Approximately one-third of Earth’s surface can be seen from the satellite.

1. Figure 1 is a view of the Earth system with the edge of the disk marking the boundary between Earth and the rest of the universe. It is evident from the sharpness of the edge between Earth and space that the atmosphere must be a thin layer compared to Earth’s diameter. Since the full disk appears sunlit in this visible image, the local time at the subsolar point must be near \([\text{noon}]\)(sunset)(sunset).
2. Compare land and ocean surfaces in this view. As would be seen from other vantage points in space as well, Earth’s surface is [(more) (less)] water than land.

Figure 1 is a static view of Earth’s climate system. For a view of it in motion, go to: http://www.ssec.wisc.edu/data/geo/index.php?satellite=east&channel=vis&coverage=fd&file=.jpg&imgoranim=8&anim_method=flash, or http://www.ssec.wisc.edu/data/geo/index.php?satellite=east&channel=vis&coverage=fd&file=.jpg&imgoranim=8&anim_method=jsani

Short Cuts! Please note that all web addresses appearing in these investigations are available on the course website by clicking on “Investigations Manual Web Addresses”. Under the particular Investigation heading, click on the link shown. The website above also can be accessed via QR coding presented at the right.
You are viewing the University of Wisconsin Space Science and Engineering Center (SSEC) website from which Figure 1 was acquired. The animation that appears is composed of eight recent full-disk images from the GOES East satellite, most acquired at three-hour intervals with the latest being only a few hours old. View the animation that essentially covers one day as it repeats through several cycles. To look at individual images or to slow down the animation, use the control bar above the image. First, click on “stop”. Then click successively on the step-forward (>) button while noting the progression of day and night on Earth’s surface as the rotating planet intercepts the radiant energy from the distant Sun.

3. Half of Earth’s surface is in sunlight and half in darkness. The sunlit portion in the image shows the part of Earth in the satellite’s field of view that is receiving energy from outside the Earth system. The animation shows that the solar energy coming into the Earth system at any location is \((\text{continuous, constantly illuminating the surface})\) \((\text{received in pulses, alternating between periods of sunlight and no sunlight})\).

4. The time of each image is printed across the top, after the date. Stop the animation at the 1745 UTC image, the same time of day as the Figure 1 image. Compare it with Figure 1. The major observable differences in the two images arise from the Earth system’s \((\text{land surfaces})(\text{ocean surfaces})(\text{atmosphere})\).

Because these images are visible light images (essentially conventional black and white photographs), features are distinguished by the variation and quality of reflected sunlight. Generally, the brighter (whiter) the feature, the greater the reflection of solar radiation directly back to space. Conversely, darker areas indicate greater absorption of the incoming solar energy.

5. Generally, the image shows that \((\text{land surfaces})(\text{water surfaces})(\text{cloud tops})\) are places where the greatest amount of incoming solar energy is absorbed into the Earth system.

On the SSEC Geostationary Satellite Images browser menu to the left, click on the Imager Channel “Longwave IR 10.7 μm” button. Here you are viewing images of “heat” radiation emitted by the Earth system out to space. In these IR images, the darker areas represent those places where outgoing heat radiation to space is greater, and lighter areas denote less outgoing heat radiation. Essentially, these are images of temperature. The darker the shading, the higher the temperature of the surface from which the radiation is being emitted and the greater the rate at which heat energy is being lost to space.

6. Comparison of the IR animation with the visible light animation shows that the Earth system emits IR to space \((\text{continuously})(\text{only on the night side of Earth})\).

7. Step through the IR animation for several cycles and look for broad, essentially cloud-free places where shading changes most, that is, they alternate between dark shading (meaning they reach relatively high temperatures) and light shading (meaning cooler temperatures) over the period of a day. These locations are \((\text{land})(\text{water})\) surfaces.
8. Stop the IR animation on the image with places shaded darkest and note the time of the image. Switch to the visible imagery by going to the browser menu and stopping the animation at the same time. The comparison shows that the highest surface temperatures occur within a few hours of local \([\text{midnight}](\text{sunrise})(\text{mid-day})\).

In summary, you have been introduced to the Earth system, the receipt of sunlight into the Earth system from space (incoming energy), and the emission of IR (heat) from Earth to space (outgoing energy).

That part of our planet (including the atmosphere, ocean, land, biosphere and cryosphere) subjected to solar energy flowing into, through, and out of the Earth system, is \textit{Earth’s climate system}.

\textbf{Weather, Climate and Climate Change:}

Fundamental to an understanding of weather, climate and climate change, is the recognition that the Earth’s climate system is a complex system of energy flow, as alluded to by animations of visible and IR full-disk views of Earth. The observable impacts of the energy flows (and the associated mass flows) are embodied in the descriptions of weather and climate.

\textit{Weather} is concerned with the state of (i.e., conditions in) the atmosphere and at Earth’s surface at particular places and times. Weather, fair or stormy, is not arbitrary or capricious. Both its persistence and its variability are determined by energy and mass flows through the Earth system.

\textit{Climate} is commonly thought of as a synthesis of actual weather conditions at the same locality over some specified period of time, as well as descriptions of weather variability and extremes over the entire period of record at that location. Climate so defined can be called \textit{empirical}, i.e., dependent on evidence or consequences that are observable by the senses. It is empirical as it is based on the descriptions of weather observations in terms of the statistical averages and variability of quantities such as temperature, precipitation and wind over periods of several decades (typically the three most recent decades).

Climate can also be specified from a \textit{dynamic} perspective of the Earth environment as a system. The definition of Earth’s climate system must encompass the hydrosphere including the ocean, the land and its features, the biosphere, and the cryosphere including land ice and snow cover, which increasingly interact with the atmosphere as the time period considered increases. While the transitory character of weather results from it being primarily an atmospheric phenomenon, \textit{climate exhibits persistence arising from it being essentially an Earth system phenomenon}.

From the dynamic perspective, climate is ultimately the story of solar energy intercepted by Earth being absorbed, scattered, reflected, stored, transformed, put to work, and eventually emitted back to space as infrared radiation. As energy flows through the Earth system,
it determines and bounds the broad array of conditions that blend into a slowly varying persistent state over time at any particular location within the system.

Whereas the empirical approach allows us to construct descriptions of climate, the dynamic approach enables us to seek explanations for climate. Each has its powerful applications. In combination, the two approaches enable us to explain, model and predict climate and climate change. In this course we will treat climate from the two complementary perspectives.

9. In its definition of climate, the AMS Glossary of Meteorology, 2nd. ed., 2000, states that climate “… is typically characterized in terms of suitable averages of the climate system over periods of a month or more, taking into consideration the variability in time of these average quantities.” This definition is derived from an empirical perspective.

10. The AMS Glossary’s definition continues: “… the concept of climate has broadened and evolved in recent decades in response to the increased understanding of the underlying processes that determine climate and its variability.” This expanded definition of climate is based on a dynamic perspective.

11. Local climatic data, including records of observed temperature, precipitation, humidity, and wind, are examples of empirically derived information.

12. The determination of actual climate change, also from the AMS Glossary, (“any systematic change in the long-term statistics of climate elements sustained over several decades or longer”) is based primarily on evidence provided from an empirical perspective.

13. Also from the AMS Glossary, “Climate change may be due to natural external forcings, such as changes in solar emission or slow changes in Earth’s orbital elements; natural internal processes of the climate system; or anthropogenic (human caused) forcing.” This is a statement derived from a dynamic perspective.

14. Scientific predictions of such an altered state of the climate (i.e., climate change) must be based on treating Earth’s climate system from an empirical perspective.

Earth’s Climate System (ECS) Paradigm:

Utilizing a planetary-scale Earth system perspective, this course explores Earth’s climate system. In pursuing this approach, understanding is guided and unified by a special paradigm:
15. It is implied in the *AMS Climate Paradigm* that components of Earth’s climate system (e.g., atmosphere, hydrosphere, cryosphere, geosphere, and biosphere) interact in a(n) [(random)(orderly)] way as described by natural laws.

16. This interaction of Earth system components through natural laws would imply a(n) [(dynamic)(empirical)] perspective for climate studies.

17. The ocean as an Earth system component and player in atmosphere/ocean energy and mass distributions suggest it is a [(minor)(major)] part of biogeochemical cycles (e.g., water cycle, carbon cycle) operating in the Earth system.

18. According to the *AMS Climate Paradigm*, our understanding of Earth’s climate system is incomplete. Nonetheless, it states that the risks associated with climate change call for the development and implementation of [(sustainable development strategies) (long-term stewardship of our Earthly environment) (both of these)].
Summary:

In this course we will investigate climate, climate variability, and climate change through complementary empirical and dynamic approaches guided by the *AMS Climate Paradigm*.

Please note that Figure 1 and all other Investigations Manual images are also available on the course website. To view these images, click on the “Investigations Manual Images” link on the website, go to the row containing the appropriate investigation name, and then select the appropriate figure within that row. For example, to view Figure 1 online, go to the row labeled “1A” and then select “Fig. 1”.