Objectives

The AMS’ *A Changing Climate in a Changing World* Paradigm presented in this investigation employs an Earth system science approach and is used throughout our study of the climate system as we uncover new understandings and insights into the role of climate in our individual lives and the broader society.

After completing this investigation, you should be able to:

- Identify reasons for studying Earth’s climate system.
- Describe Earth’s climate system and its interacting components.
- Describe, compare, and contrast the complementary empirical and dynamic components of climate.
- Explain the AMS *A Changing Climate in a Changing World* Paradigm.

An Earth System Approach

A view of the Earth system as seen from space is presented in **Figure 1**.
Figure 1. Visible light image of Earth from NOAA GOES East satellite at 1145 UTC on 18 April 2018. The time was 7:45 AM EDT, 6:45 AM CDT, 5:45 AM MDT, 4:45 AM PDT. [NOAA STAR, Link 1A-1]

**Figure 1** 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 dividing line (terminator) separating the sunlit and night portions of our planet.

Examine Figure 1, noting the superimposed outlines of land masses. The center of the disk is the point on Earth directly under the satellite from which this image was acquired. Imagine a dot in the center of the image representing this sub-satellite point and a horizontal line, depicting the equator, through the point and extended to the edges of the Earth disk. Because the geostationary satellite is astronomically close to Earth, approximately one-third of our planet’s surface can be observed from the satellite’s position. The satellite’s field of view extends to about 60 degrees North and South Latitudes and 60 degrees of longitude east and west from the sub-satellite point along the equator.
1. Compare expanses of land and ocean surfaces in this Figure 1 view. As would be seen from other vantage points in space as well, Earth’s surface shows ________.
   
a. less water than land  
b. equal water and land  
c. more water than land  

2. Figure 1 is a view of the Earth system with the sunlit edge of the disk marking the boundary between Earth and the rest of the universe. The full disk is not sunlit in this visible image (e.g., much of Northern Hemisphere is in darkness). If fully illuminated, the disk’s edge would appear circular. It is evident from the sharpness of the edge between sunlit portions of Earth and space that the atmosphere must be a very ________ layer compared to Earth’s diameter.
   
a. thick  
b. thin  

Figure 1 is a static view of Earth’s climate system. For a view in motion, go to Link 1A-1. You are viewing the National Oceanic and Atmospheric Administration’s (NOAA) GOES-East Image Viewer website from which Figure 1 was acquired. The animation that appears is typically composed of twenty-four recent full-disk images from the GOES East satellite, most acquired at fifteen-minute intervals with the latest being within about half an hour. View the animation that essentially covers a repeating several-hour period. To look at individual images or to slow down the animation, use the controls above the image. First, click on “Pause.” Then click successively on the Previous/Next buttons while noting the progression of day and night on Earth’s surface as the rotating planet intercepts the radiant energy from the distant Sun. An animation period of up to 96 images (24 hours) may be chosen to view.

3. At any instant, half of Earth’s total surface area is in sunlight and half in darkness. The sunlit portion in each image shows what part of Earth in the satellite’s field of view is receiving energy from outside the Earth system. The animation shows that at any location observable from the geostationary satellite, the solar energy arriving on Earth is ________.
   
a. continuous, constantly illuminating the surface  
b. received in pulses of varying intensities, alternating between periods of sunlight and no sunlight  

4. The time of each image is displayed above the image(s) along with the date. From a maximum length loop if necessary, Pause the animation at or near 1145 UTC, the same time of day as the Figure 1 image. Compare it with Figure 1. The major observable differences in the sunlit portions of the two images arise from reflection of light from the Earth system’s ________.
   
a. atmosphere  
b. land surfaces  
c. ocean surfaces  

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 back to space. Conversely, darker areas in sunlit areas indicate greater absorption of the incoming solar energy.
5. The image shadings infer that ________ are generally where the least amount of incoming solar energy is absorbed into the Earth system.
   a. cloud tops  
   b. land surfaces  
   c. water surfaces

On the NOAA GOES-East Image Viewer menu bar at the top of the page, click on “Full Disk Views,” then “Band 14 – IR: Longwave.” Here you are viewing images of “heat” radiation emitted by the Earth system out to space. In these infrared radiation (IR) images, the darker areas represent those places where outgoing heat radiation to space is greater, and lighter gray 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. A gray/color scale is displayed below the images. Very cold temperatures are further color-coded to enhance the generally highest and coldest cloud tops. These are often associated with storm activity.

6. Comparison of the IR animation with the visible light animation (Band 1 or 2) shows that the Earth system emits IR to space ________.
   a. during both night and day  
   b. only during day  
   c. only during night

7. Step through the IR animation for a period of time lasting a day or more and look for broad, essentially cloud-free places where shading changes most over the period of a day, that is, they alternate between dark shading (meaning they reach relatively high temperatures) and light shading (meaning cooler temperatures). These locations are generally ________ surfaces.
   a. land  
   b. water

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 ________.
   a. sunrise  
   b. mid-day  
   c. midnight

In summary, you have been introduced to the Earth, 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 energy arriving as sunlight, flowing through the Earth system, and returning to space as infrared radiation, is Earth’s climate system.
Weather, Climate, and Climate Change

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

Weather investigates 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 occurrence and its variability are determined by energy and mass flows through the Earth system.

Long defined as the average of weather plus information on extremes at a particular location over a period of time, climate has taken on a more comprehensive definition as the state of the climate system as a whole. The concept of climate has broadened in recent decades as understandings of the underlying processes that determine climate and its variability have increased. The state of Earth’s climate system, composed of atmosphere, hydrosphere, cryosphere, geosphere, and biosphere, results from internal and external influences, mutual interactions, and feedbacks. Climate is fundamentally the journey of the Sun’s energy received on Earth as it is deflected, stored, transformed, put to work, and eventually emitted back to space.

Climate has been traditionally 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 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).

The definition of climate has expanded in meaning to describe the state of the climate system as a whole. This specifies a dynamic perspective of the Earth environment. 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, climate exhibits persistence arising from it being essentially an Earth system phenomenon arising from boundary conditions. In this modern definition of climate, weather results from climate.

It is from this dynamic perspective that climate is ultimately the story of the intercepted solar energy being absorbed, scattered, reflected, stored, transformed, put to work, and eventually emitted by Earth 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 a(n) ________ perspective.

a. dynamic  
b. empirical

10. The AMS Glossary’s definition of climate continues with “…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(n) ________ perspective.

a. dynamic  
b. empirical

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

a. dynamically  
b. empirically

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 a(n) ________ perspective.

a. dynamic  
b. empirical

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(n) ________ perspective.

a. dynamic  
b. empirical

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 a(n) ________ perspective.

a. dynamic  
b. empirical

**The AMS *A Changing Climate in a Changing World* Paradigm**

Utilizing a planetary-scale Earth system perspective, this course explores Earth’s climate system. In pur-
suing this approach, understanding is guided and unified by a special overarching paradigm:

The AMS

A Changing Climate in a Changing World

Paradigm

Climate, traditionally defined as the average of weather plus information on extremes at a particular location over a period of time, has expanded in meaning to describe the state of the climate system as a whole. The state of Earth’s climate system, composed of atmosphere, hydrosphere, cryosphere, geosphere, and biosphere, results from internal and external influences, mutual interactions, and feedbacks. Climate is fundamentally the journey of the Sun’s energy received on Earth as it is deflected, stored, transformed, put to work, and eventually emitted back to space. Earth’s climate system establishes the environmental conditions and sets the boundaries of weather that determine where life, including people, can exist.

Climate is inherently variable, but is currently changing at rates unprecedented in recent Earth history. The warming of Earth’s climate system is unequivocal and is most certainly caused in large part by our relentless burning of fossil fuels for energy and in the altering of the characteristics of Earth’s surface. These human activities have become significant drivers of global environmental change, linking human systems to our planet’s biophysical systems. This linkage positions climate change as part of a complex, coupled human/natural system. Unlike all other life on this planet, humans’ ability to think informs us through science studies of our impact on climate. With this understanding comes the capability of making choices and taking actions to mitigate this impact and to adapt.

Rapid climate changes heighten the vulnerabilities of societies and ecosystems, impacting biological systems, water resources, food production, energy demand, human health, and national security. These vulnerabilities are global to local in scale, calling for increased understanding and surveillance of the climate system and its sensitivity to imposed changes. Scientific research on key climate processes, expanded monitoring, and improved modeling capabilities increase our ability to project the future state of the climate. Climate change is not an isolated problem, but occurs with concurrent environmental change and societal developments which affect our vulnerability and strategies for responding. Although incomplete, our current understanding of the climate system and the far-reaching risks associated with the negative impacts of climate change require dialog between scientists and the broader community for the immediate preparation and implementation of adaptation and mitigation strategies aimed at sustainable development and long-term stewardship of Earth.

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) ________ way as described by natural laws.

a. chaotic
b. random
16. This interaction of Earth system components through natural laws would imply a(n) ________ perspective for climate studies.
   a. dynamic
   b. empirical

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

18. According to the AMS Climate Paradigm, modern climate and climate change are the results of a ________ system.
   a. biophysical
   b. human
   c. coupled human/natural

19. 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 ________.
   a. long-term stewardship of our Earthly environment
   b. sustainable development strategies
   c. both of these

**Summary**

Climate, traditionally defined as the average of weather and the extremes at a particular location over a period of time, has expanded to describe the state of the climate system as a whole. Climate is variable and changing, yet is currently shifting at rates unparalleled in recent Earth history. Rapid climate change heightens the vulnerabilities of societies and ecosystems, calling for increased understanding and surveillance of the climate system. In this course we will investigate climate, climate variability, and climate change through complementary empirical and dynamic approaches guided by the AMS Climate Paradigm.