

THE PHYSICAL BASIS FOR EARTH'S CLIMATE SYSTEM

This Investigation is the same as AMS Climate Studies' Current Climate Studies 1 from Preview Week. Participants only need to complete the Current Climate Studies once.

Do Now:

1. Print this file, if directed by your instructor.
2. Read the *Weekly Climate News* file, print if directed to do so by your instructor.
(**Note:** Check the AMS Climate Studies website during the week as breaking climate news stories may have been added.)

To Do Investigation:

1. Reference: Chapter 1 in the *AMS Climate Studies* text.
 2. Complete Investigations 1A and 1B in the *AMS Climate Studies Investigations Manual* as directed by your instructor.
 3. Complete this online-delivered *Current Climate Studies* activity if directed by your instructor.
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Introduction:

Welcome to the first of a series of *Current Climate Studies* which will be delivered in alignment with the other weekly components of this climate science course. Collectively, the course components are directed towards helping you build your own *learning progression* in which webs of interconnected ideas concerning Earth's climate system grow and deepen over time. This will enable you to become a more informed citizen on the science and societal issues of climate, climate variability, and climate change. [Learning progressions are descriptions of the successively more sophisticated ways of thinking that evolve as individuals learn about a topic over an extended period of time.]

The Physical Bases of Earth's Climate System:

Climate is commonly described by the properties (for example, temperature and precipitation) throughout the atmosphere in a set of long-term atmospheric statistics, **but it is also much more**. Climate, climate variability, and climate change result from complex mass and energy flows, transformations, and feedbacks that are perpetually taking place on wide ranging space and time scales. This course focuses on building understandings of the physical bases of Earth's climate system. These encompass the forcing agents and mechanisms as well as the boundary conditions imposed by such factors and the internal dynamics of the system.

In a broad sense, Earth's climate can be regarded in terms of the mean (average) physical state of an energy-driven system. In physics, the term *system* refers to an arbitrarily enclosed portion of the physical universe (e.g., the Earth system) which may contain matter, energy, or both. A system is separated from its environment by a **boundary** (e.g., for many purposes, the boundary separating the Earth system and surrounding space can be considered as being located at the top of the atmosphere). The state of a system is determined by the observable properties of the matter and/or energy within the system.

The sealed terrarium in **Figure 1** demonstrates a physical system. The glass jar delineates the boundary separating the system from its environment. The air-tight terrarium can be described as a *closed* system because it does not exchange matter with its surroundings. However, it does exchange radiant energy with the environment (i.e., sunlight). Our Earth exhibits similar system characteristics.



Figure 1. Sealed terrarium
[Apartment Therapy Media]

1. The term *system* is a powerful concept in science as it focuses on a portion of the physical universe chosen for analysis. The system may contain [***matter***](***energy***)(***both matter and energy***).

Systems may be described as **closed** or **open**. A closed system does not exchange matter with its surroundings while an open system can. Both closed and open systems exchange energy with their environment. Earth's climate system is considered a closed system because there is almost no exchange of matter between Earth and space. At the same time, Earth exchanges energy with surrounding space in the form of radiation. It intercepts radiant energy from the Sun and it radiates infrared (heat) radiation to space. The subsystems of Earth's climate system (atmosphere, hydrosphere, geosphere, and biosphere) are open systems, as both matter and energy can be exchanged between them. The transfer of matter or energy across a system boundary will cause changes inside the system, leading to a change in the physical state of the system.

2. A brighter, more intensely radiating sun would be expected to change the state of Earth's climate system by raising Earth's average global temperature because of the [***decrease***](***increase***) in the rate of incoming solar radiation transferred across the boundary between surrounding space and Earth.
3. The global water cycle in which water circulates through the Earth System, including flow from ocean to atmosphere to land and back to the ocean, demonstrates that the several sub-systems of Earth's climate system are [***closed***](***open***) systems.

Specifying conditions at a system's boundary is essential to scientific inquiry. **Boundary conditions**, a term drawn from mathematics, refer to information such as the magnitude

and direction of flows of energy and mass at system boundaries. Applied to Earth's climate system and its subsystems, specifying the values at systems' boundaries makes it possible to create mathematical models of climate.

- Knowing the conditions at the boundary separating ocean and atmosphere subsystems is another example of how boundary conditions contribute to determining the state of Earth's climate system and its subsystems. At the boundary between the ocean and atmosphere, called the air/sea interface, acquisition of observational data (e.g., surface weather data, water temperature) can lead to determination of the magnitude and direction of [*matter*]*(energy)**(both matter and energy)* transfer across that boundary.

Our global climate is fundamentally the story of the energy from the Sun received by Earth being absorbed, deflected, stored, transformed, put to work, and eventually emitted back to space. Climate describes the slowly varying aspects of Earth's climate system. Climate encompasses the broad array of weather conditions and impacts that arise from the interplay of the subsystems of Earth's climate system in response to this energy flow.

The relative amounts of incoming and outgoing energy on a global basis determine whether or not Earth is in a steady-state condition, cooling, or warming. As a closed system, Earth is sustained by the continuous gains and losses of energy. It can be assumed to have a balanced steady-state condition whenever its properties (e.g., temperature) do not vary when averaged over time.

Figure 1 displays decadal averages of Earth's global temperature changes based on the 1901-2000 period record. The last decade covers the ten-year period from 2000 through 2009.

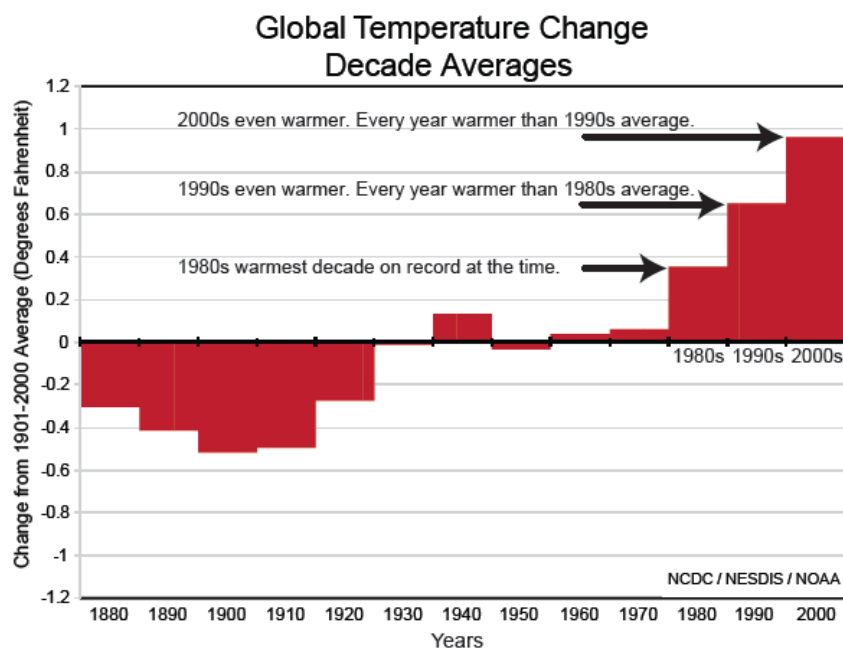


Figure 1. Decadal average global temperature change. [Arndt, D. S., M. O. Baringer, and M. R. Johnson, Eds., 2010: State of the Climate in 2009. *Bull. Amer. Meteor. Soc.*, **91** (6), S1-S224]

- Figure 1 shows that 1980-89 was the warmest decade on record to that time. The 1990-99 decade was even warmer, and 2000-09 was warmest of all. This indicates that, during these three decades, Earth's climate system [~~did~~~~(did not)~~] exhibit a steady state condition.

The resulting changes in climate, due to variations in such factors as solar radiation and atmospheric composition, are described in terms of **radiative forcing**. As defined by the Intergovernmental Panel on Climate Change (IPCC), radiative forcing is a measure of the influence a climate factor has in *altering* the balance of incoming and outgoing energy at the boundary between Earth system and space.

- Radiative forcing arises from the change in the radiative energy budget of Earth's climate system due to [~~(differences between the incoming radiant energy and the outgoing radiant energy)~~~~(changes only in the rate of incoming radiant energy)~~~~(changes only in the rate of total outgoing radiation)~~], and is measured in Watts per square meter (W/m^2).

The magnitudes of the various radiative climate forcings and the directions they act are measured at the upper atmospheric boundary (the tropopause, where the troposphere and overlying stratosphere meet, is actually assumed to be the boundary), and are among the *boundary conditions* of Earth's climate system. **Specifying the values of the interactions at system boundaries make it possible to use numerical computer models to predict future states of the climate system.**

The solar radiation intercepted by Earth is a primary climatic boundary condition. It is the major external forcing that acts on Earth's climate system. If the flow of solar energy intercepted by Earth changes, then a change in a major Earth-system boundary condition occurs. The Earth responds with a change in the emission of infrared (heat) radiation as its climate system adjusts to achieve global radiative equilibrium with space. That can be expected to produce changes in the amount of energy residing in the Earth system. This, in turn, brings about other changes such as an alteration in the prevailing atmospheric circulation pattern, and so on. The net result is climate change.

Starting with Investigation 1B, the *AMS Conceptual Energy Model (AMS CEM)* is employed to investigate basic concepts, including climate forcings and boundary conditions, underlying these global-scale flows of energy to and from Earth. The *AMS CEM* allows you to track the paths that units of energy might take as they enter, move through, and exit an imaginary planetary system according to simple rules applied to different scenarios. We will refer back to the *AMS CEM* as this course investigates the flow of energy in the real Earth climate system.

Summary:

The goal of this course is to assist you in the development of an in-depth Earth's climate system learning progression. It will be built on learning statistical characterizations of climate as well as fundamental scientific understandings of Earth's climate, climate variability, and climate change from a systems perspective. What you learn can start you, as an informed citizen, on a path leading to global-scale contributions towards devising and implementing strategies for sustainable development and long-term stewardship of Earth.

If directed by your instructor, place the answers to this Current Climate Studies on the **Current Climate Studies Answer Form** linked from the *AMS Climate Studies website*.

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