Climate Studies

# THE PHYSICAL BASIS FOR EARTH'S CLIMATE SYSTEM/ VISITING GLOBAL CLIMATE CHANGE AND IMPACTS STUDY RESOURCES / WHAT DO WE KNOW? HIGHLIGHTS AND KEY FINDINGS ABOUT CLIMATE AND CLIMATE CHANGE

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## THE PHYSICAL BASIS FOR EARTH'S CLIMATE SYSTEM

**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 properties (for example, temperature and precipitation) throughout the atmosphere in a set of long-term atmospheric statistics, **but it is 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 outer extent 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** is an example of a physical system. The glass jar represents 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 comes in and heat energy goes out). Our Earth exhibits similar system characteristics.

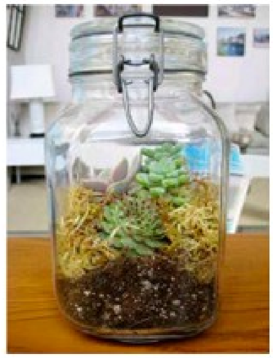

Figure 1.

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 environments. Earth's climate system is generally 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, cryosphere, 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 because the increase in the rate of incoming solar radiation transferred across the boundary between surrounding space and Earth leads to a **[(*lower*)(*higher*)]** global average temperature.
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 make it possible to create mathematical models of climate.

4. 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 these energy flows.

**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 global properties (e.g., temperature) do not vary when averaged over time.

**Figure 2** displays changes of decadal averages of Earth's global temperature from that of the 1901-2000 period record. The last decade covers the ten-year period from 2000 through 2009.

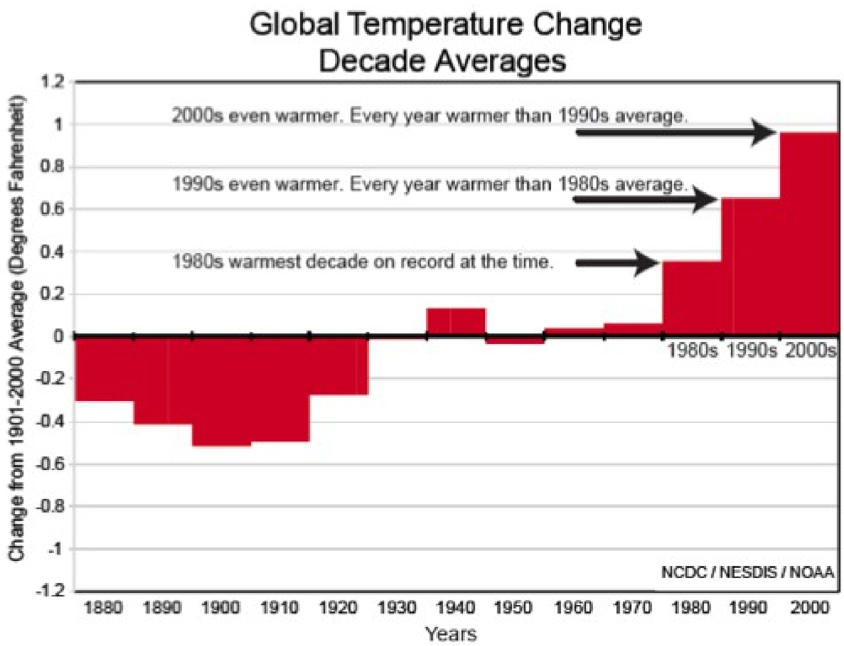


Figure 2.

Decadal average global temperature changes. [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]

5. Figure 2 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 the Earth system and space.

6. 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*)]**. This forcing 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. 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.

Beginning in Investigation 1, the ***AMS Conceptual Energy Model*** (***AMS CEM***) is employed to investigate basic concepts 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.

# VISITING GLOBAL CLIMATE CHANGE AND IMPACTS STUDY RESOURCES

## *Climate Studies* Conceptual Structure:

The course ***Climate Studies (Earth's Climate System)*** is uniquely structured. It is organized conceptually along two themes that are carried forward concurrently as the course proceeds. The first and primary theme of the course is a systematic study of climate, climate variability, and climate change, encompassing the fundamentals of modern climate science. These fundamentals include the spatial variations in climate as a response to many interacting forcing agents, or mechanisms, both internal and external to the Earth system.

The second theme focuses on climate change and impacts from the perspective of findings reported by the U.S. Global Change Research Program (USGCRP), International Panel on Climate Change (IPCC), U.S. National Academies, U.S. National Aeronautics and Space Administration (NASA), U.S. National Oceanic and Atmospheric Administration (NOAA), the AMS/NOAA *State of the Climate* reports, and the August 2012 *AMS Information Statement on Climate Change*. ***Climate Studies*** shares a common foundation with these entities, relying on the latest authoritative scientific information. The ultimate goal of this second theme is to inform decision makers and members of the public (including you) as they strive to develop effective policies in response to vulnerabilities arising from climate variability and climate change.

## Climate Change and Impacts:

**There is unequivocal evidence of global warming.** The AMS/NOAA *State of the Climate in 2012* is the most recent of a continuing series, led by NOAA and published by AMS, which documents the status of Earth's climate system based on compiled observed data. A total of 384 scientists from 52 countries analyzed data on close to 50 climate indicators for the Year 2012 report. Their findings confirm that the preponderance of climate indicators, including rising levels of atmospheric carbon, rising sea levels, and melting of Arctic sea ice, show a warming Earth. In terms of global surface temperature, 2012 was in alignment with a relative plateau of annual values spread over more than a decade which included the 10 warmest years on record, all of which occurred since 1998.

NASA's Goddard Institute for Space Studies (GISS) has reported that 2012 was the ninth warmest year since 1880, continuing a long-term trend of global warming. With the exception of 1998, the nine warmest years in the 132-year record have occurred since 2000. The years 2010 and 2005 rank as the hottest years. The global surface average temperature in 2012 was 58.3 oF (14.6 oC). The average global surface temperature has risen about 1.4 Fo (0.8 Co) since 1880.

**Climate continually evolves.** There is no doubt that over time climate has changed, is changing, and will continue to change. Against this backdrop, there is a growing sense of urgency arising from the mounting evidence of climate change taking place now, and the impact such change is having, and will have, on people and ecosystems.

In the scientific community, there is essentially total agreement that the observational evidence showing global warming is undeniable, and almost universal consensus that it is primarily human induced. The U.S. National Academies, in its *America's Climate Choices, Advancing the Science of Climate Change, 2011 Edition*, reviewed the current scientific evidence regarding climate change. The report points out on page 1 that "there is a strong, credible body of evidence, based on multiple lines of research, documenting that climate is changing and that these changes are in large part caused by human activities. While much remains to be learned, the core phenomenon, scientific questions, and hypotheses have been examined thoroughly and have stood firm in the face of serious scientific debate and careful evaluation of alternative explanations." And also that:

"**Climate change is occurring, is caused largely by human activities and poses significant risks for–and in many cases is already affecting–a broad range of human and natural systems."**

There is similar concurrence that the current scientific understanding of climate change justifies taking steps to prepare for climate change and to slow it. The major purpose of this particular ***Current Climate Studies*** is to introduce you to the most widely-recognized science-based information sources on climate change and its impacts. These sources are firmly based on scientific research findings reviewed, interpreted, and reported by hundreds of independent climate scientists, dozens of non-governmental scientific organizations (including the AMS), and scores of governmental agencies including 13

U.S. Federal departments and agencies via USGCRP. The ***Climate Studies*** course is science based and promotes no political viewpoint. It is left to the informed learner to employ scientific knowledge when considering possible policies and actions directed toward addressing climate and climate change issues.

## The AMS/NOAA *State of the Climate* Reports:

The *State of the Climate in 2012* is the 23rd annual edition of NOAA's *State of the Climate* series of observation-based assessments of Earth's climate system. The annual reports, each published midway through the subsequent year, provide the most current overview of what is happening to the world's climate. The information they provide helps to advance understanding of the climate system and build confidence in climate projections.

On the course website, in the Climate Information section, click on "State of the Climate 2012". On the next page, brief introductions summarize the highlights of the report, which can be accessed under the Supplemental and Summary Materials heading by clicking on "State of the Climate in 2012: Highlights".

1. The major reservoir of heat in the climate system is the world ocean. According to the Highlight's section, the globally averaged heat stored in the top 2300 ft (700 m) of the ocean remained near record high levels in 2012, while overall **[(*decreases*) (*increases*)]** occurred between depths of 2300 ft (700 m) to 6600 ft (2000 m) and even in the deep ocean from 2011 to 2012.
2. One strong indicator of climate change has been the phenomenon of "Arctic amplification". According to the Highlights section, the Arctic's average surface temperature in recent decades has increased at a rate about **[(*the same as*)(*twice*) (*triple*]** the rate of warming at lower latitudes.

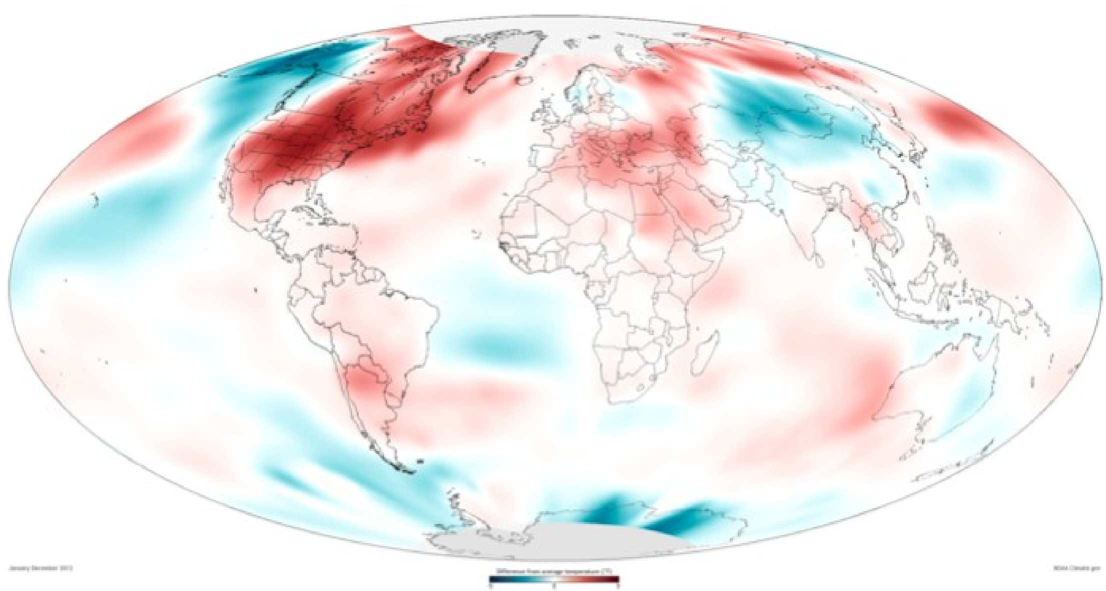

Figure 1.

2012 land and ocean surface temperature anomalies based on 1981-2010 average), deep red represents the warmest and deep blue the coldest. [NOAA]

3. A temperature anomaly is the deviation of temperature from the long-term average value for the same location. **Figure 1** displays land and ocean surface temperature anomalies in 2012 compared to average 1981-2010 temperatures. According to Figure 1, places with the greatest warming in 2012 relative to the 1981-2010 average were at **[(*higher southern*)(*tropical*)(*higher northern*)]** latitudes.
4. In 2012, the U.S. experienced its warmest year of surface temperatures on record. The global pattern of 2012 surface temperature anomalies seen in Figure 1 shows that the midsection of the contiguous U.S. had about the **[*lowest*)(*about average*) (*highest*)]** compared to the rest of the

planet.

On the NOAA *State of the Climate 2012* website, in the Full Report section, you can download the full report. The publication is extremely valuable as an annual survey of observational data on the changing state and behavior of the physical climate system. It does not provide attribution, forecasts, scenarios, or projections.

NOAA's National Climate Data Center (NCDC) also publishes *State of the Climate, National Overview* on a monthly and annual schedule. Go to http://www.ncdc.noaa.gov/sotc/national. The page that appears will describe the U.S. climate for the latest full month. Near the top of the page select the settings for "National Annual Review" report, "2012", and "Annual", and then click on "Submit".

5. The 2012 Annual Report announced that in 2012 the contiguous U.S. experienced an average annual temperature of 55.3 oF. It was **[(*3.2*)(*5.2*)(*7.3*)]** Fahrenheit degrees (Fo) above the 20th century average, and the warmest year in the 1895-2012 period of record. The 2012 value was 1.0 Fo warmer than the 1998 average annual temperature, the previous record warm year.

6. Scroll through the 2012 Annual Report to survey the kinds of information it contains. The only state with a dedicated section in the report is **[(*Hawaii*)(*Texas*)(*Alaska*)]**.

## The National Academies:

The **U.S. National Academies** (including the National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council) act as advisors to the nation on Science, Engineering, and Medicine. In response to a request from the U.S. Congress, the National Academies have conducted a program called *America's Climate Choices*.

On the climate studies website, go to the Societal Interactions and Climate Policy section and click on "America's Climate Choices" (or go directly to http://nas- sites.org/americasclimatechoices/). There, under Summaries & Booklets, click on "Climate Change: Evidence, Impacts, and Choices". Click on "Click here to download a high-resolution PDF of the booklet."

7. Peruse the booklet, published in summer 2012, for an objective science-based introduction to climate change. On pages 3 and 4, it is mentioned that Earth's average surface temperature has increased by more than 1.4 Fo (0.8 Co) over the past century. The booklet points out that this is greater than the average temperature difference between Washington, DC and **[(*Richmond, VA*)(*Raleigh, NC*) (*Charleston, SC*)]**, which experience significantly different climates.

## Intergovernmental Panel on Climate Change (IPCC):

An unprecedented worldwide effort was established in 1989 to face the risks of climate change, particularly those produced by human action. The **Intergovernmental Panel on Climate Change (IPCC)** is the leading body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences.

The IPCC assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to understanding climate change. Thousands of scientists from around the world voluntarily contribute to its work. Review is essential to the IPCC process, ensuring an objective and complete assessment of current information. Because of its scientific and intergovernmental nature, the IPCC embodies a unique opportunity to provide rigorous and balanced scientific information to decision makers and the public. The fourth IPCC assessment report (AR4), *Climate Change 2007*, was endorsed by 189 of the 194 UN member states, including the U.S.

8. Go to the course website and, under the Links section, click on “WMO/UNEP IPCC”. Information about *Climate Change 2007* can be found by

clicking on “Fourth Assessment Report” appearing near the middle of the screen. The report consists of four volumes: a Synthesis Report and three IPCC Working Groups (WG) Reports. Click on the “Synthesis Report” cover image. Then, under Contents, click on “Summary for Policymakers”. This Summary, often abbreviated as SPM, provides a succinct overview of the AR4’s contents. Click on “1. Observed changes in climate and their effects”. It states that “Warming of the climate system is unequivocal.” It bases this statement on observations of **[(*increases in global average air and ocean temperatures*)(*widespread melting of snow and ice*)**

**(*rising global average sea level*)(*all of these*)]**.

9. Return to the WMO/INEP IPCC website, and this time click on “Fourth Assessment Report”, and then on “The Physical Science Basis” cover image. Under Contents, click on “1. Historical Overview of Climate Change Science”. Here you can read in detail of the emergence of climate change science. In the historical overview Section 1.3.1: The Human Fingerprint on Greenhouse Gases, it is stated that “The high-accuracy measurements of atmospheric $CO_2$ concentration, initiated by Charles David Keeling in **[(*1786*)(*1937*)(*1958*)]**, constitute the master time series documenting the changing composition of the atmosphere. These data have iconic status in climate science as evidence of the effect of human activities on the chemical composition of the atmosphere.”
10. Return to the WMO/INEP IPCC website, and under Fifth Assessment Report near the middle of the screen, read the text under the heading AR5 Synthesis Report to the right. There, it is reported that work on the IPCC Fifth Assessment Report (AR5) is well underway. Descriptive material about the AR5 report indicates that more than **[(*70*)(*50*)(*800*)]** highly qualified experts are working on the report. Click on “more information ...” and then on “AR5 Authors List” to note nationalities and institutional affiliations.

The IPCC assessment reports and related technical reports provide a solid, objective foundation for investigating global climate change based on the expertise of hundreds of lead authors and thousands of expert reviewers. The reports have gained wide acceptance throughout the scientific community and among policy makers. The AR5 is presently scheduled to be completed during the 2013/2014 time period, with the initial report, *WGI: The Physical Science Basis*, released in September 2013. For the latest information about IPCC WGI, go to www.ipcc-wg1.unibe.ch/.

## United States Climate Change Assessment:

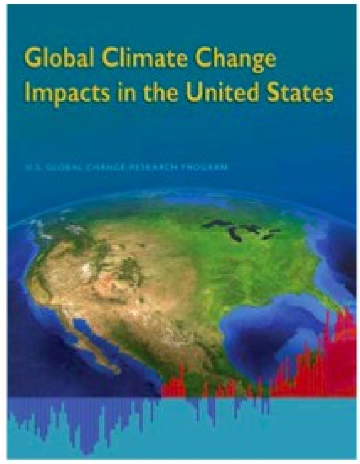


Figure 2.

Cover of USGCRP state of knowledge report, June 2009.

[USGCRP]

The **U.S. Global Change Research Program** (**USGCRP**), the combined effort of 13 Federal departments and agencies, is a comprehensive and integrated United States research program that assists the nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change. **Figure 2** displays the cover of its *Global Climate Change Impacts in the United States* report. This state of knowledge report summarizes the science of climate change and impacts of climate change on the United States, now and in the future. The report presents climate-related impacts for various societal and environmental sectors and regions across the country.

11. Go to the climate studies website and scroll down to the Societal Interactions and Climate Policy section. Click on "US Global Change Impacts Report". Scroll down to page 7 of the Report, to the section titled About this Report. According to the What is this report? paragraph, the overall goal of the publication is to better inform **[(*climate science researchers*)(*public and private decision making at all levels*)]**.
12. On the next page in the same About this Report section, it states that "While the primary focus of this report is on the impacts of climate change in the United States, it also deals with some of the actions society is already taking or can take to respond to the climate challenge." These actions fall into the category(ies) of **[(*mitigation*) (*adaptation*)(*both mitigation and adaptation*)]**.

The USGCRP is currently completing its next *National Climate Assessment* which is scheduled to be published in 2014. Up-to-date information on the report, including a preliminary draft of the report, is available at: http://assessment.globalchange.gov.

**Summary:** We will be returning to these and other information sources as this course progresses. The USGCRP reports, AMS/NOAA *State of the Climate in 2012*, the National Academies' 2012 *Climate Change: Evidence, Impacts, and Choices* booklet, and the IPCC *WGI: The Physical Science Basis* report will act as the primary references for the conceptual theme of this course as we investigate climate change and impacts.

# WHAT DO WE KNOW? HIGHLIGHTS AND KEY FINDINGS ABOUT CLIMATE AND CLIMATE CHANGE

## What Do We Know From the Observational Record?

Change in the state of Earth's climate system is evidenced by changes in its mean surface air temperature. The global temperature record from 1880 to 2012 based on NASA's Goddard Institute for Space Studies (NASA GISS) analyses is displayed in **Figure 1** in terms of temperature anomalies (deviations) in Celsius degree units relative to the 1951-1980 mean temperature. Draw a horizontal line on the graph at the .0 Celsius degree temperature anomaly value representing the 1951-1980 long-term mean for reference.

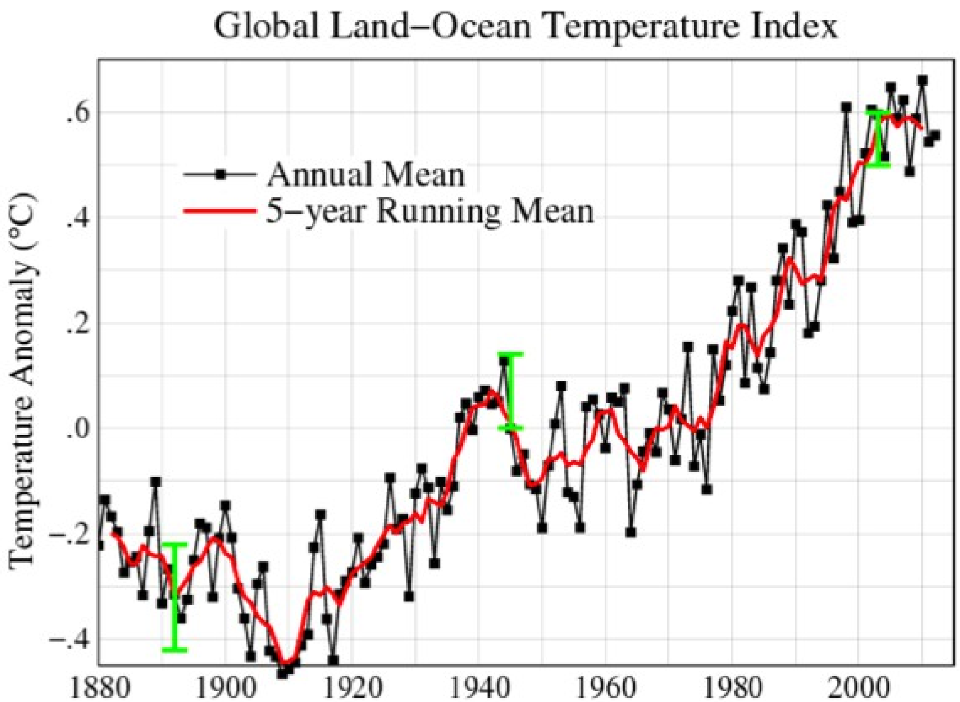


Figure 1.

Global temperature anomalies from 1880 to 2012 based on the 1951-1980 average. Black line connects annual mean anomaly values. Red line denotes 5-year mean or moving average. [NASA GISS]

1. Figure 1 shows that since about 1910 the trend of Earth's mean surface air temperature was generally, although not consistently, upward. The figure also shows that annual global land-ocean temperatures so far in the 21st century have all been among the highest of record. In the last decade of record (from 2003 to 2012), annual mean temperatures, while variable from to year, were generally **[(*rising*)(*falling*)(*level within a range of less than two-tenths of a degree*)]**.

NOAA's National Climatic Data Center (NCDC) reported that the 2012 combined global land and ocean surface temperature was the 10th warmest year since records began in 1880. The 2012 annual global combined land and ocean surface temperature was 0.57 Co (1.03 Fo) above the 20th century average of 13.9 °C (57.0 °F). All 12 years to date in the 21st century rank among the 14 warmest in the 133-year period of record. The only year during the 20th century warmer than 2012 was 1998.

In **Figure 2**, average surface temperatures from 2008 to 2012 are compared to the average of the 1951-1980 time period used as a reference. Warm colors (e.g., yellows, reds) denote positive anomalies, or higher than average temperatures, and cool colors (e.g., blues) identify negative anomalies, or lower than average temperatures. White denotes no departure from the 1951-1980 average. For reference, draw a horizontal straight line across the figure to represent the equator (0o latitude).

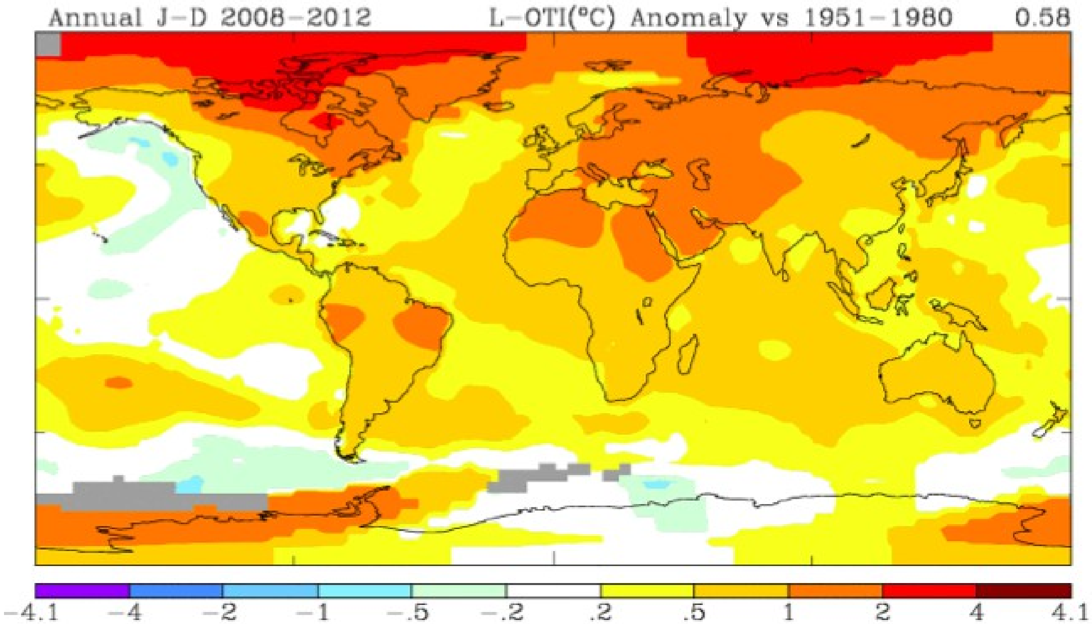


Figure 2.

Global temperature anomalies averaged from 2008 through 2012 compared to averages temperatures from 1951 to 1980. [NASA GISS]

2. Figure 2 shows that **[(*only warming)*(*only warming and no temperature change*) (*warming, no temperature change, and cooling*)]** occurred in the 2008-2012 time period in various locations worldwide relative to the 1951-1980 time period.

3. Figure 2 shows the Northern Hemisphere's **[(*higher*)(*middle*)(*equatorial*)]** latitudes experienced the greatest warming when the averages of the 2008 - 2012 time period are compared to the 1951-1980 average.

   [Optional: To explore global temperature change based on Global Historical Climatology Network data, go to http://data.giss.nasa.gov/gistemp/maps/. There, you can interactively produce graphics. To start, select "Anomalies" for Map Type, "Annual (Jan-Dec)" as Mean Period, key in 2008 and 2012 as Time Interval and 1951 and 1980 as Base Period, select "1200 km" for Smoothing Radius, select "regular" for Projection type, and click on "Make Map" button. Compare with Figure 2.]

4. By 2012, the last year reported in Figure 3, the contiguous U.S. had experienced 16 years in a row with annual temperatures above the 1951-1980 mean. Comparison of Figure 3 with Figure 1 shows that from 2010 to 2012, the mean annual contiguous U.S. temperature generally changed in the **[(*same*)(*opposite*)]** direction compared to the mean annual global land-ocean temperature. Comparison the graphs shows that the variability of temperature from year to year is normally greater for the smaller geographical area.

**Figure 3** displays the annual and 5-year running mean surface air temperatures in the contiguous United States (1.6% of Earth's surface) relative to the 1951-1980 mean. Draw a horizontal line on the graph at the 0 value representing the 1951-1980 mean.

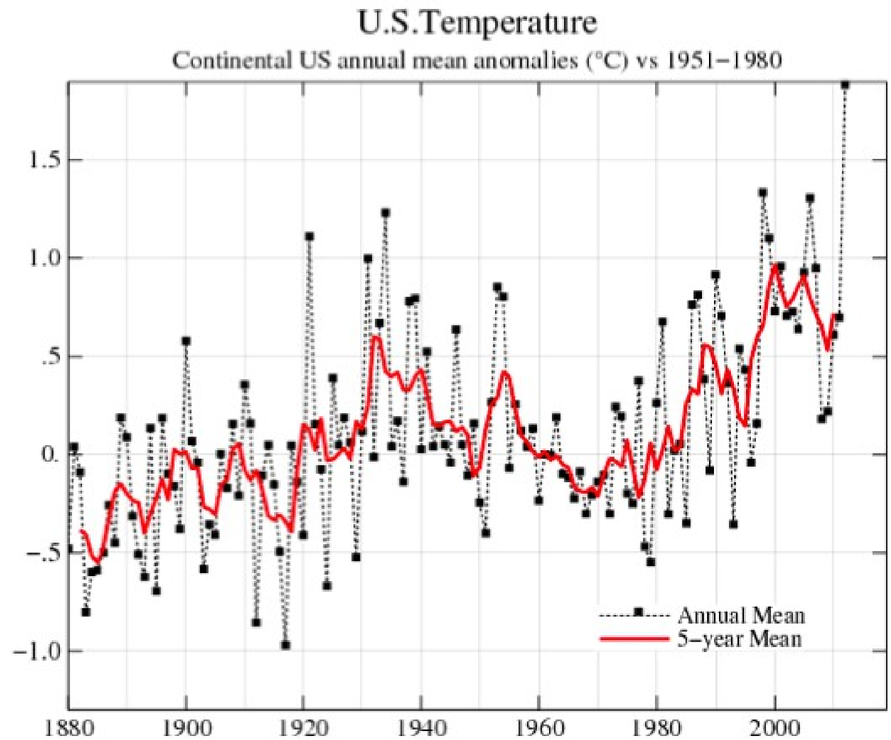


Figure 3.

U.S. annual mean temperature departures (anomalies) from the 1951-1980 mean. Anomaly values in Celsius degrees. [NASA GISS]

Among other measures employed as climate indicators is the global mean sea level. **Figure 4** presents sea level changes derived from measurements acquired with the TOPEX and Jason series of satellite radar altimeters, released on 4 September 2013. Calibrated against a network of tide gauges to subtract seasonal and other variations, these determinations allow for an estimate of the global mean sea level change rate. Figure 4 covers the period from 1993 to mid-2013.

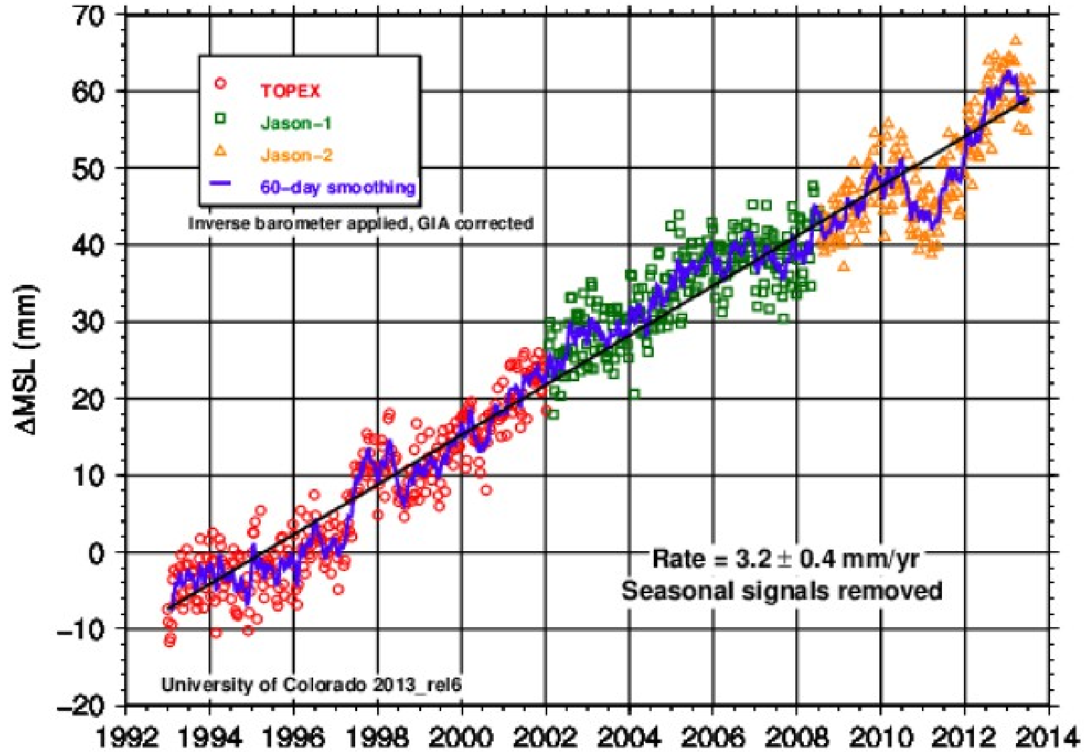


Figure 4.

Global Mean Sea Level with seasonal signals removed, released 4 September 2013. [University of Colorado Sea Level Research Group]

5. According to Figure 4, the straight black trend line ("line of best fit") shows that in the years of satellite data from 1993 through late 2012, the rate of change in mean sea level (MSL) averaged approximately **[(*–3.2*)(*0*)(*+3.2*)]** mm/yr.
6. The data plots and the blue 60-day smoothing (running average) curve in Figure 4 show that beginning in 2010 until mid-2011 the global mean sea level **[(*dropped*) (*remained steady*) (*rose*)]**.

This short-term change in global mean sea level from 2010 until mid-2011, shown best by the blue 60-day smoothing curve, is contrary to the long-term trend. (Note the general rise in sea level from mid-2011 to mid-2013.) NASA scientists have concluded that the temporary drop in sea level was due to strong La Niña conditions that occurred in the Tropical Pacific Ocean in much of 2010 and into 2011. La Niña produces abnormally high rainfall over land, which temporarily transfers large volumes of water from the ocean to land surfaces and results in a measureable change in sea level. After the water drained back to the ocean, the mean sea level returned to its long-term trend. A lesson learned from this dip in sea level is that marked changes in climate indicators might simply be part of natural climate variability.

## The Implications of Climate Change and Urgency for Action:

The ***AMS Climate Paradigm*** includes a description of why there is growing concern about climate change:

*Climate is inherently variable and now appears to be changing at rates unprecedented in recent Earth history. Human activities, especially those that alter the composition of the atmosphere or characteristics of Earth's surface, play an increasingly important role in the climate system. Rapid climate changes, natural or human-caused, heighten the vulnerabilities of societies and ecosystems through impacts such as those on water resources, food supply, energy demand, human health, biological systems on which we depend, and national security. These vulnerabilities are global to local in scale and call for increased understanding and surveillance of the climate system and its sensitivity to imposed changes. Scientific research focusing on key climate processes, expanded monitoring, and improved modeling capabilities are already increasing our ability to predict the future climate. Although incomplete, our current understanding of the climate system and the far-reaching risks associated with climate change call for the immediate preparation and implementation of strategies for sustainable development and long-term stewardship of Earth.*

7. The *Paradigm* points out that rapid climate change, whether natural or human-caused, places stress on **[(*societies*)(*ecosystems*)(*both of these*)]**.
8. The *Paradigm* implies that the current knowledge about the workings of Earth's climate system and the far-reaching risks associated with climate change is substantial, although not complete. At the same time, it calls for **[(*immediate initiation of*)(*prudent delay in*)]** the preparation and implementation of strategies for sustainable development (meeting the needs of the present without compromising the ability of future generations to meet their own needs) and long-term stewardship of Earth.

The U.S. Global Change Research Program (USGCRP) provides a comprehensive state of knowledge report as part of the nation's effort to provide sound and thorough science-based information for policy formulation and the setting of climate change research priorities. On the course website, go to the Societal Interactions and Climate Policy section and click on "US Global Change Impacts Report".

9. The Executive Summary begins by stating that "warming of the climate is unequivocal" and that the global warming observed in the past five decades is due primarily to **[(*natural*)(*human-induced*)]** emissions of heat-trapping gases. [Note: The USGCRP uses the term *heat-trapping gases* to describe atmospheric gases that absorb and emit infrared radiation (e.g., water vapor, carbon dioxide, methane).]
10. After presenting projections of warming over this century, the Executive Summary states that future temperature increases are likely to be less severe if emissions of global heat- trapping gases are cut substantially. It further states that the **[(*earlier*)(*later*)]** the cuts in emission, the greater their effect in reducing climate change than comparable reductions made later.
11. The Executive Summary mentions two categories of actions society can take to respond to the climate challenge. **[(*Mitigation*)(*Adaptation*)]** refers to options for limiting climate change (e.g., reducing emissions of heat-trapping gases or enhancing their removal from the atmosphere) and the other term refers to adjustments in response to actual or expected climate change to reduce harm or exploit opportunities.
12. The Executive Summary ends with a listing of ten Key Findings, each of which is treated in detail later in the Report. One example of a key finding is that climate change will interact with many social and environmental stresses (e.g., pollution, population growth) causing larger impacts due to their effects being **[(*equal to any single factor*)**

**(*greater than from any of these factors alone*)]**.

The Key Findings that are listed at the end of the Executive Summary of the USGCRP report will be visited in detail as our investigation of global to regional and local climate change challenges are addressed as the course progresses.

## Impact of Atmospheric Heat-trapping Gases on Global Temperatures:

The USGCRP Report, along with the AMS/NOAA *State of the Climate 2012*, the findings of the IPCC, the conclusions of the U.S. National Academies' 2012 *Climate Change: Evidence, Impacts, and Choices* booklet, the 2012 *AMS Information Statement on Climate Change,* and the preponderance of climate change research have identified the increasing concentrations of heat-trapping gases in the atmosphere as the primary forcing agents of global climate change during the past century and into the future. We turn to the ***AMS Conceptual Energy Model*** (**AMS CEM**) to gain insight into how this happens.

Go to the climate studies website and in the Extras section, click on "AMS Conceptual Energy Model", scroll down and click on "Run the AMS CEM". In Investigation 1B you made runs of the AMS CEM when the imaginary planet had one atmosphere and when it had no atmosphere. In the computer simulation of a ***planet with no atmosphere***, you found that with settings of Sun's energy at 100%, 10 cycles of play, and Introductory mode, the number of energy units in the planet's climate system averaged 0.5 energy units per cycle. (Run the AMS CEM with these settings to verify the result.)

You also ran the AMS CEM as a ***planet with one atmosphere*** with settings of Sun's energy at 100% for 10 cycles of play in the Introductory mode. These settings resulted in the number of energy units in the planet's climate system averaging 3.9 energy units per cycle. (Verify this, too, by running the AMS CEM.)

13. The change you observed implies that the addition of an atmosphere changes the amount of energy in the planet's climate system and would result in the temperature of the climate system being **[(*lowered*)(*left unchanged*)(*raised*)]**.

**Imaginary Planet with a Double Atmosphere**: When set at two atmospheres, the AMS CEM graphic depicts two colored (aqua and blue) layers representing a doubling of the atmosphere. The visualization of two atmospheres can be considered analogous to doubling the concentration of heat-trapping carbon dioxide in the atmosphere. In this scenario, an energy unit rising from the planet's surface must stop in each atmospheric layer it enters, and any energy unit in an atmospheric layer has equal chances of moving upward or downward in the next cycle of play.

14. Set the AMS CEM to two atmospheres, Energy: 100%, 10 cycles, and Introductory mode. Run the model. These settings result in the number of energy units in the planet's climate system averaging **[(*2.8*)(*3.9*)(*4.7*)]** energy units per cycle. Compare this result with those when the AMS CEM ran in no atmosphere and one atmosphere settings as reviewed above.

15. The change you observed implies that a second atmospheric layer changes the amount of energy in the planet's climate system. Assuming that this double-atmosphere scenario is like the doubling of carbon dioxide, it suggests that increasing the concentration of heat- trapping gases in a planet's atmosphere results in **[(*lower*)(*no change in*)(*higher*)]** climate system energy and temperatures. [Note: The earliest climate models, developed in the 1960's at NOAA's Geophysical Fluid Dynamics Laboratory, evaluated the response of a model atmosphere to the doubling of the atmospheric concentration of carbon dioxide.]

## Summary:

The observational record definitively shows that global climate change is occurring with trends over the past several decades toward higher temperatures and rising sea level. The AMS CEM provides insight into the impact of heat-trapping gases as the primary forcing agent of climate change evidenced by the rising global mean temperature. The observational record shows that, while trending upward, these changes show considerable variability (ups and downs) and are not uniform around the planet.

The USGCRP *Global Climate Change Impacts in the United States* publication provides a comprehensive report of the climate-related changes that have already been observed globally and in the United States. The USGCRP report focuses on climate change and its impacts on the United States, particularly in terms of climate change by sector (water resources, energy supply and use, transportation, agriculture, ecosystems, human health and society) and by regional climate change impacts (e.g., northeast, southwest, coasts). The report is the prime reference employed in *Current Climate Studies* segments.