Climate Studies

GLOBAL CLIMATE CHANGE: A PLANETARY PERSPECTIVE / CLIMATE MODELS: LARGE SCALE AND PREDICTABLE / U.S. NATIONAL CLIMATE CHANGE: AN OVERVIEW

GLOBAL CLIMATE CHANGE: A PLANETARY PERSPECTIVE

Enduring ideas are statements summarizing important concepts, principles and core processes that are central to a discipline. Among enduring ideas we know about climate and climate change are the following:

- Fundamentally, climate is the story of how the solar energy intercepted by Earth is absorbed, scattered, reflected, stored, transformed, put to work, and eventually emitted back to space as infrared radiation.
- Earth's climate evolves through changes in external agents that affect the climate system and the climate system's internal dynamics.
- Earth's climate is undergoing change, as it always has and always will. The climate record shows change can be gradual or abrupt.

With these enduring ideas in mind, we will explore global climate change and impacts based on the observational record. Our goal is to gain an overview of climate change from a planetary perspective.

Evidence of a Warming World:

As was seen in *Current Climate Studies 3*, the instrument-based observational record from 1880 through 2012 reveals a generally rising global mean surface temperature that unequivocally confirms change in the state of Earth's climate system. Simply stated, it verifies that we live in a warming world.

This global warming results from the addition of extra heat to Earth's climate system, primarily arising from the build-up of heat-trapping gases in the atmosphere. As you also recall from *Current Climate Studies 3*, the impact of such a build-up was explored via the AMS Conceptual Energy Model's (AMS CEM) comparison of the impacts of an imaginary planet with one and two atmospheres. When making the comparison, we indicated that the double atmosphere was analogous to the doubling of heat-trapping carbon dioxide in the atmosphere.

Numerous research studies, based exclusively on the observational record and fundamental principles of physics and chemistry, have quantified how much heat has been and is being added to Earth's climate system and where it is located. **Figure 1** summarizes where the additional heat responsible for global warming resides in Earth’s climate system in recent years.

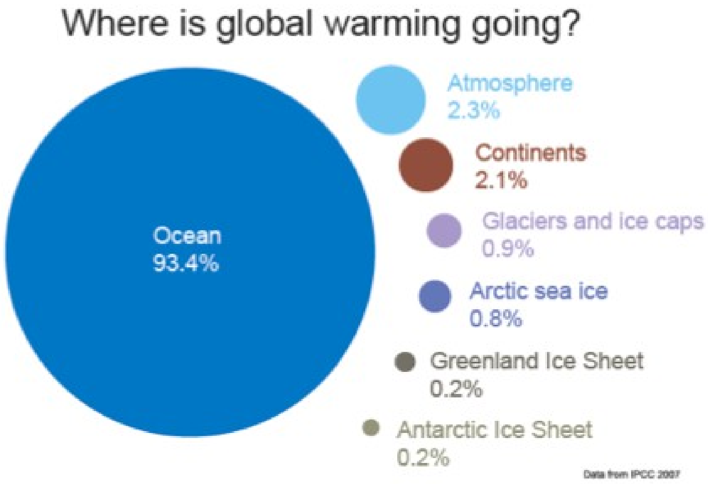


Figure 1.

Reservoirs for heat added to Earth’s climate system responsible for global warming. [2009 State of the Climate Highlights, NOAA]

1. Figure 1 shows that most of the heat responsible for global warming that has been added to Earth’s climate system resides in the **[(*glaciers, ice caps, and ice sheets*)(*atmosphere*) (*continents*)(*ocean*)]**.

About 71% of Earth’s surface is covered by ocean, which contains 97% of the planet’s water. Because of factors including its fluid motions and ecosystems, the global ocean plays a major role in shaping Earth’s climate, its variability and change. Because of water’s high heat capacity, the ocean holds the heat it accumulates while warming and cooling far more slowly than air. This sluggishness extends the impacts of human activity on the state of the climate for decades, centuries, and millennia into the future. **This is one example that demonstrates what we do today to perturb Earth’s climate system will have far greater consequences on future generations than on us.**

Figure 2 displays the yearly heat content of the top 700 m (2300 ft) of the global ocean from 1955 through 20121 based on departures from the 1971-2000 average as calculated independently by three agencies: NOAA in red, Australia’s Commonwealth Scientific and Industrial Research Organization (CSIRO) in green, and the Japan Meteorological Agency’s Meteorological Research Institute (MRI/JMA) in blue. While showing different variabilities, the trends of all the curves are generally consistent.

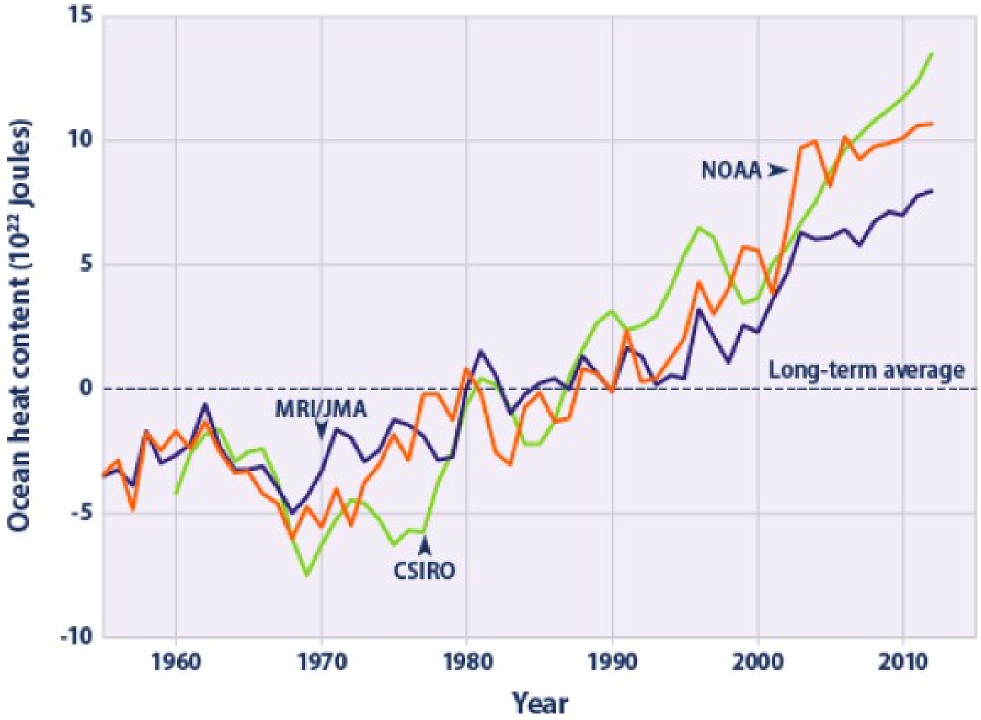


Figure 2.

Heat Content in the top 700 m of the Ocean, 1955-2012. Calculations by NOAA, Australia's CSIRO, and Japan's MRI/JMA. [EPA http://www.epa.gov/climatechange/science/indicators/oceans/ocean-heat.html]

2. Figure 2 confirms that from the late 1960s until 2012 the overall trend of 0-700 m global ocean heat content was **[(*downward*)(*no change*)(*upward*)]**.
3. In addition to revealing overall trends in the change of global ocean heat content, the Figure 2 heat-content curves suggest a variability pattern (from one crest to the next) often lasting **[(*two to several years*)(*one or two decades*)(*several decades*)]** in length. This implies the presence of internal processes at work in the Earth's climate system not directly related to the system's astronomically determined boundary conditions.

A Global-scale Climate Change Impact Example: Coral Bleaching

Many changes have been directly observed in the global climate over the past century or so, with more significant changes evident in recent decades. Of the many that could be cited, a striking example of a climate change impact is the increasing frequency that coral reefs around the world experience high enough water temperatures to produce ***coral bleaching***. Coral bleaching results from conditions that cause coral death, and the loss of vibrant ocean ecosystems and their fisheries that feed millions of people. As the world ocean continues to warm, an increase in the number and intensity of coral bleaching episodes is inevitable.

Corals are marine colonial organisms. Most reef-building corals contain brightly colored photosynthetic algae, called zooxanthellae, that live in their tissues. The corals and algae have a symbiotic relationship, each benefiting the other, and many are unable to survive unless together. When corals become physically stressed, they expel their algae and become stark white, appearing bleached. Without zooxanthellae, corals will starve to death.

Corals are vulnerable to bleaching when the sea-surface temperature (SST) exceeds what they would normally experience during the hottest month of the year. NOAA's ***Coral Bleaching HotSpots*** report, which is updated every 3 or 4 days, shows where temperatures exceed coral's limits. **Figure 3** describes the worldwide HotSpots on 12 September 2013, near the end of the Northern Hemisphere summer. The HotSpot value of 1.0 C° is a threshold for thermal stress leading to coral bleaching. To highlight this threshold, values of 1.0 C° or greater are displayed in yellow to red on the map.

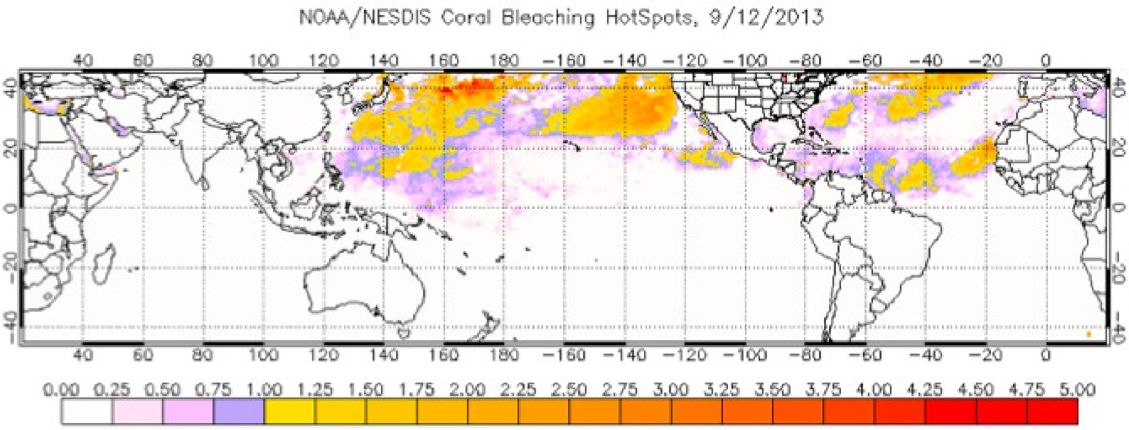


Figure 3.

NOAA Global Coral Bleaching HotSpots on 12 September 2013. The more red the color, the greater the coral bleaching threat.

4. Figure 3 shows extensive coral bleaching HotSpot in the **[(*Arabian Sea*) (*Gulf of Mexico*) (*Cape Verde islands off western Africa*)]** in mid-September 2013.
5. **Figure 4** is an experimental NOAA product that assigns alert level to places experiencing coral bleaching stress. The figure shows the general area identified in Item 4 above as having alert locations as high as **[(*Watch*)(*Warning*)(*Alert Level 1*)]**. This level indicates bleaching likely.

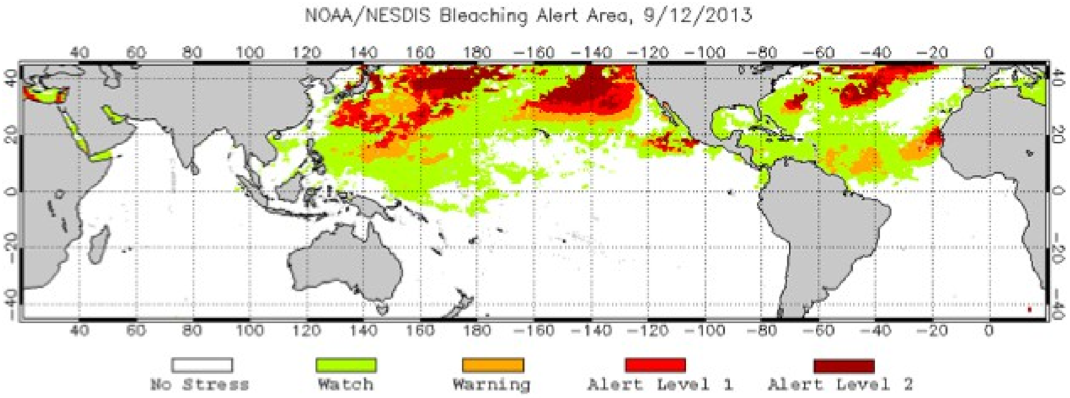


Figure 4.

NOAA Coral Reef Watch (CRW) Bleaching Alerts, 12 September 2013

You can track current conditions or impacts of coral bleaching and possible relationships to global warming by going to: http://coralreefwatch.noaa.gov/satellite/index.html.

What Has Been Happening to Earth's Climate System?

Among most recent comprehensive studies on climate change, the U.S. National Academies' *Climate Change: Evidence, Impacts, and Choices* 2012 report, introduced in *Current Climate Studies 2*, strongly confirms the major findings of earlier IPCC and USGCRP studies.

Because its contents have been consistently validated by research findings reported in more recent publications such as the National Academies' report, the highly detailed USGCRP's *Global Climate Change Impacts in the United States* will be the *Current Climate Studies* primary reference. To access the USGCRP report, go to the course website, scroll down to the Societal Interactions and Climate Policy section, and click on "US Global Change Impacts Report". Or, you can go directly to the report at: http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.

6. Read the *Executive Summary* starting on page 9. Key Findings presented on page 12 indicate that over the past 50 years or more, increases have occurred in all of the following except **[(*heat-trapping gases*)(*global average sea level*) (*rate of solar radiation intercepted by Earth*) (*global average temperature*)]**.
7. The Key Findings listing ends with the projection that global climate change, including rising temperatures, will continue into the future. How great the change and rise will be is **[(*known to a high level of certainty*)(*dependent on a number of factors*) (*totally unrelated to any mitigating actions that might be taken by humans*)]**.
8. The Key Messages reflect the IPCC finding that the increases identified in Item 6 above are due primarily to human activity, including increases in heat-trapping gases in the atmosphere, especially carbon dioxide. The USGCRP report (p. 14) indicates that over the past several decades about **[(*20%*)(*50%*)(*80%*)]** of the carbon dioxide associated with human activities is due to the burning of fossil fuels.
9. The USGCRP report states that all of the following are significant heat-trapping (greenhouse) gases in Earth's atmosphere except **[(*water vapor*)(*carbon dioxide*) (*methane*)(*nitrogen*) (*nitrous oxide*)(*halocarbons*)]**.
10. The report (page 15, right column) also points out that when the gas primarily responsible for the global-scale climate warming over the past 50 years enters the atmosphere, its concentration will remain elevated for **[(*decades*)(*centuries*)(*thousands of years*)]**. Even if its production were immediately reduced to pre-industrial age levels, it would be decades or more before its impact on global temperatures would even begin to be evident.
11. In addition to the global warming of the past 50 years, the USGCRP report (page 19) indicates that human "fingerprints" **[(*have*)(*have not*)]** been identified with many aspects

of the climate system, including changes in heat-trapping atmospheric gases, ocean heat content, precipitation, atmospheric moisture, and Arctic sea ice.

12. In the figure in the left column on page 20 of the USGCRP report, climate model simulations which include or remove human influences from model experiments are compared with observed global average temperatures (black curve) over the last century. The pink band in the figure shows model projections of the effects of natural and human forces combined while the blue band shows natural forces only. The figure and its caption indicate that, in the absence of human influence, the global average temperature in recent decades (since about 1950) would have **[(*increased slightly*)(*remained steady*) (*decreased slightly*)]**.

13. As described beginning on page 22, the IPCC developed a set of emissions scenarios to explore the potential for future climate change. None of the scenarios include implementation of explicit climate policies to reduce concentrations of atmospheric heat- trapping gases. The expected impact of the different IPCC emissions scenarios (lower, higher, even higher) on global average temperature from 1900 to 2100 is displayed on page 25 in the upper graph. The graph shows that even in the lower emissions scenario (blue line on graph), it is projected that from 2000 to 2100 the global average temperature will rise about **[(*1*)(*3*)(*5*)(*7*)]** Fahrenheit degrees.
14. The USGCRP report points out on page 26 that not all changes in climate are gradual. The long-term record of climate reveals shifts in climate patterns from one stable state to another within a period as short as a decade. An abrupt climate change could be initiated in a number of ways, including rapid ice sheet collapse with related sea-level rise, sudden release of methane into the atmosphere, and shifts in ocean currents. Also included are abrupt shifts related to drought episodes. Ancient climate records indicate that in the United States, the **[(*Southwest*)(*Northwest*)(*Northeast*)(*Southeast*)]** may be at greatest risk for abrupt shifts in drought frequency and duration.

Summary:

Thus far, we have focused on climate change from a global perspective. The observational record and scientific analysis verify that we are living in a warming world, with most of the extra heat added to the Earth system residing in the ocean. Coral bleaching is an example of the impacts of rising temperatures. Widely recognized science-based sources of information on what has been happening to Earth's climate system referred to or mentioned in this *Climate Studies* are available via the Internet.

CLIMATE MODELS: LARGE SCALE AND PREDICTABLE

Essential to modern climate science and climate change research is **climate modeling**. A **model** is an approximate representation or simulation of a real system, incorporating only the essential features (or variables) of a system while omitting details considered neither needed nor predictable. **Figure 1** displays the features of climate models, which are essentially systems of mathematical equations representing the basic laws of physics, fluid motion, and chemistry. Computer-based numerical climate models are either empirical or

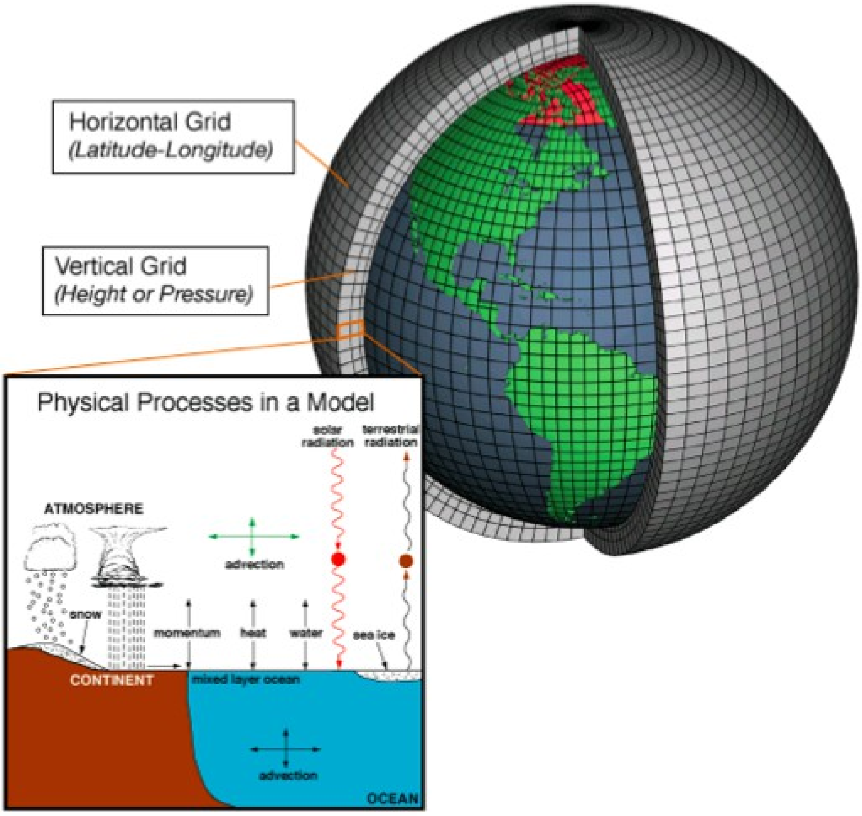


Figure 1.

Features of three-dimensional climate models that are systems of mathematical equations. [NOAA]

dynamic. Empirical climate models, based on actual observational data, are especially useful in predicting and interpreting climate variability. Dynamic climate models, based on interacting forcing mechanisms both internal and external to the climate system, are employed to predict climate change.

In recent decades, dynamic computer models of Earth's climate system have increasingly demonstrated their potential to realistically model past and simulate future climate. The USGCRP *Global Climate Change Impacts in the United States* report (page 22) points out that climate models are extremely important, because:

- Current climate models accurately portray many important aspects of today's weather and climate.
- Models capture not only the present-day climate, but also key features of the observed climate changes over the past century.
- Many large-scale observed climate changes are driven by very basic physics, which is well-represented in models.
- Climate models can be used to predict changes in climate that can be verified in the real world.
- Models are the only tools that exist for trying to understand the climate changes likely to be experienced during the course of this century (and beyond).

1. A climate model that projects temperature changes resulting from increases in atmospheric heat-trapping gases would be a(n) **[(*empirical*)(*dynamic*)]** model.

You have already been introduced to a simple dynamic climate model, the **AMS Conceptual Energy Model (AMS CEM)**. Dynamic climate models use mathematical expressions of physical processes and known initial conditions which can lead to model calculations of responses to forcings. Such forcings result from changes in 1) the rate of incoming solar radiation, 2) the fraction of solar radiation that is reflected (albedo) back to space, and 3) the rate of radiation emitted by the climate system to space. The AMS CEM is a one- dimensional model that varies only in the vertical and assumes everything else is uniform or homogeneous, thereby focusing on how these changes would impact the flow of energy to and from an imaginary planet's climate system. AMS CEM is conceptual in that it presents interactions (determined by a set of rules) among components of a system, and these interactions can be considered analogous to what happens in the real world (e.g., an energy unit absorbed by an atmospheric molecule has an equal chance of radiating upward or downward). While the AMS CEM is rudimentary, it presents fundamental understandings concerning energy flow that are integral to even the most sophisticated dynamic climate models.

2. So far, you have compared energy budgets of the AMS CEM when an imaginary planet has zero, one, and two atmospheres. When comparing the planet with no atmosphere to that with one atmosphere, it can be seen that the addition of an atmosphere which absorbs outgoing infrared (heat) radiation **[(*increases*)(*decreases*)]** the amount of energy retained in the planetary climate system. This would be expected to have a similar effect on the climate system's temperature.
3. When comparing the energy budgets of the AMS CEM with one and two atmospheres, a two-atmosphere (or two-layer atmosphere) planet acts analogously to the doubling of the concentration of heat-trapping atmospheric CO_2 and **[(*increases*)(*decreases*)]** the amount of energy retained in a planetary climate system. It, too, has a similar effect on the climate system's temperature.
4. The change from a no-atmosphere planet to a planet with an atmosphere produces feedback in terms of energy flow. As described in Investigation 1B, a ***feedback*** occurs when part of an output returns to serve as an input again, so that the net response of the system is altered. The feedback may amplify (positive feedback) or dampen (negative feedback) the output. Adding an atmosphere that returns infrared radiation to the planet's surface is an example of **[(*negative*)(*positive*)]** feedback.

Changes in the rate of incoming solar radiation can also bring about climate change. Show this with the AMS CEM (course website, Extras section, click on "AMS Conceptual Energy Model", then click on "Run the AMS CEM"). First, set the AMS CEM to **One Atmosphere**, **Energy: 100%**, **100 cycles**, and **Introductory mode**, click on "Run". After the run is completed, verify that it is reported directly under the animation that the mean (average) quantity of energy in the climate system under these settings was 4.4 units.

5. Change the Energy setting to **50%** while keeping the other settings the same. With the CEM at the 50% energy setting, a unit of energy arrives with every other cycle rather than every cycle, thereby depicting a lower rate of incoming solar radiation. Click on "Run". As the model runs, hit "Pause" and "Resume" several times to better track flows of energy units into, through, and out of the climate system. After the run is completed, the CEM reports that the mean quantity of energy in the climate system over the 100- cycle run was **[(*1.4*)(*2.2*)(*4.4*)]**.
6. Next, run the AMS CEM after changing the Energy setting to 33% while keeping the other

settings the same. At this setting, one solar energy unit enters the climate system every third cycle. After the run is completed at this setting, the CEM reports that the mean quantity of energy in the system over the 100-cycle run was **[(*1.4*)(*2.2*)(*4.4*)]**.

7. Compare the mean quantities of energy in the climate system after 100-cycle runs were made at 100%, 50% and 33% energy settings. It can be deduced from the model runs that the amount of energy residing in the climate system **[(*increases*)(*decreases*) (*remains the same*)]** as the rate of incoming solar radiation decreases. It can be expected the opposite would happen if the rate of incoming solar radiation increases.

Changes in the amount of incoming solar radiation that is reflected back to space is another way the state of the planetary climate system is changed. This reflectivity, called **albedo**, is the percentage of the solar radiation striking the planetary system that is reflected away. The greater the proportion of the incoming solar energy absorbed in the system, the lower the albedo.

8. The AMS CEM can also be used to demonstrate the impact of a change in the planet's albedo. This can be done by **redefining** the CEM's Energy setting as the percentage of the incoming solar radiation that is absorbed in the planetary system as the actual incoming solar radiation rate is kept constant. When the "Sun's Energy" setting is selected as 33%, it now means 33% of the incoming sunlight is being absorbed in the planetary system and 67% is being reflected, that is, the albedo is 67%. When the "Sun's Energy" setting is 100%, all of the incoming sunlight is absorbed and the albedo is 0%. Therefore, running the AMS CEM with different settings of the Energy amount of solar radiation that is absorbed in the system can demonstrate that as the planet's albedo increases, the amount of energy in the system**[(*increases*)(*decreases*)]**. This would have a similar effect on the planetary system's temperature.

The AMS CEM is a useful tool to learn the basic concepts of climate modeling. An understanding of Earth's climate system can provide a broad quantitative estimate of a globally averaged variable but with very little detail. The simulation of Earth's climate system and its changes require a much more sophisticated and detailed approach. Such computer-based numerical models are greatly needed as they are the only tools that can provide quantitative estimates of future climate changes.

State-of-the-Art Climate Models:

State-of-the-art climate models include interactive representations of the atmosphere, ocean, land, hydrologic and cryospheric processes, land and ocean carbon cycles, and atmospheric chemistry. The comprehensive models employed by climate scientists are highly complex systems of mathematical equations that are solved by using a three-dimensional grid over the globe. To simulate climate, the major components of the climate system are represented in sub-models, along with the processes that go on within and between them.

These models have demonstrated simulations in close alignment with recent climate and past climate change. As reported by the IPCC, there is considerable confidence that Atmosphere- Ocean General Circulation Models (AOGCMs) provide credible quantitative estimates of future climate change, particularly at continental and larger scales. In its 2007 Fourth Assessment Report, the IPCC detailed 23 major AOGCMs from around the world. We will look at products from the National Center for Atmospheric Research Community Climate System Model (NCAR CCSM), a recognized U.S. climate model.

View an animation of NCAR CCSM products:
http://www.vets.ucar.edu/vg/IPCC_CCSM3/index.shtml. At that site, click on the image or elect one of the modes listed at the lower right for delivering the animation.

9. Play the animation and view the changes that occur as the NCAR CCSM depicts simulated global surface warming from 1870 to 2100. Simulated and observed temperature change values to the Year 2000 show close agreement. In the lower panel, note the several curves generated after 2000 that show warming based on different atmospheric CO_2 concentration scenarios. [Note: The current CO_2 concentration is about 393 ppm.] Also, note in the lower panel the impact of major volcanic eruptions that lowered the average global surface temperature. The eruption impacts typically last only for a couple of years. **[(*Krakatau*)(*Pinatubo*)(*Agung*)]** was the most recent major eruption evidenced in the temperature curve.

10. Replay the animation. Using the control bar, stop the animation at the Year 2000 (when 2000 appears to the lower right on the global map). The value appearing to the right of the year notation indicates the global surface temperature change relative to the 1870- 1899 baseline. It is **[(*0*)(+*1.0*)(+*1.5*)(+*3.3*)]** C degree(s).

11. Continue the animation. As the year appearing on the global map advances, follow the **green** curve depicting temperature change under the IPCC A1B mid-level emissions scenario (in which the atmospheric CO_2 concentration is programmed to stabilize at 720 ppm). Under this scenario, at Year 2050 the temperature change is projected to be **[(+*1.0*)(+*1.5*)(+*2.5*)(+*3.3*)]** C degrees.

12. Continue the animation to the Year 2100. **Figure 2** is the 2100 view at the end of the animation. The 2100 view shows the CCSM prediction of surface temperature changes relative to the 1870-1899 baseline. As seen on the graph, the Scenario A1B average global surface temperature change relative to the 1870-1899 baseline will increase about **[(*1.4*)(*3.3*)(*4.8*)]** C degrees by 2100.

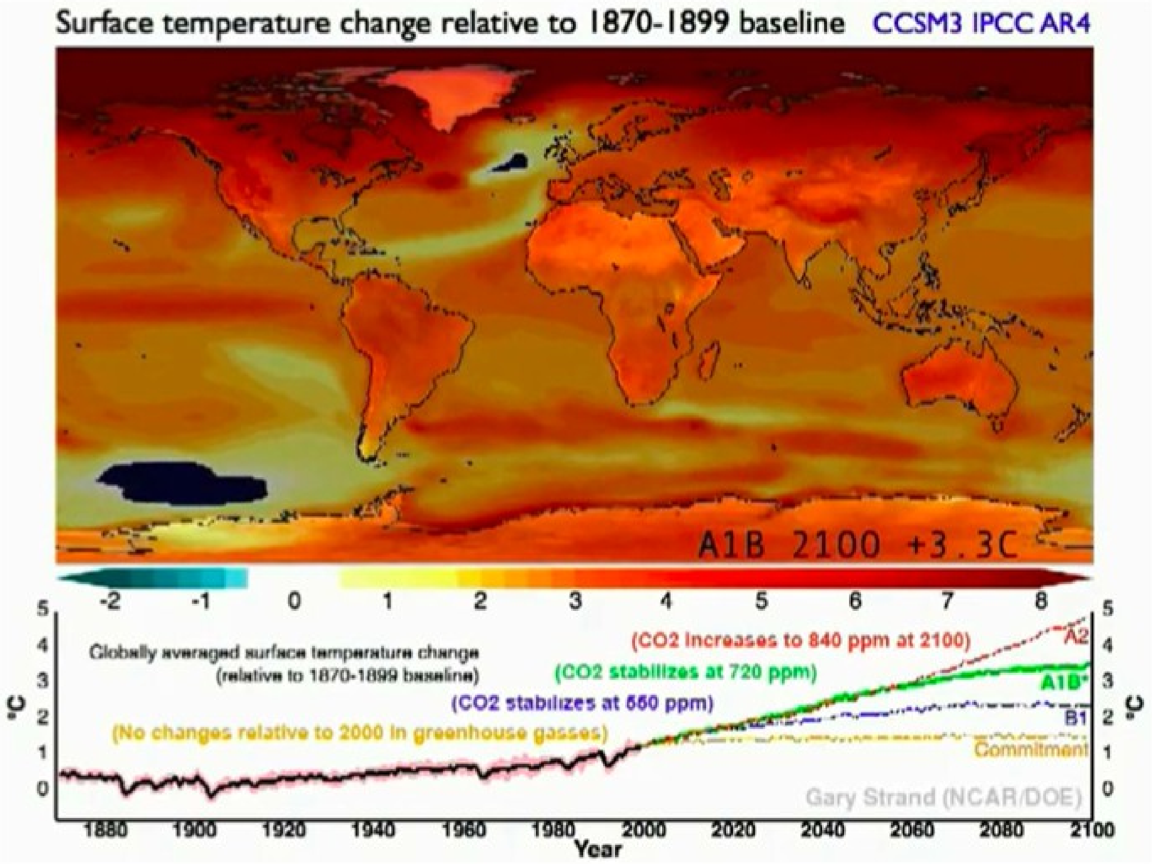


Figure 2.

NCAR CCSM prediction of global temperature change from 1870-1899 baseline following IPCC emissions scenarios with different CO_2 concentrations up to Year 2100. [NCAR]

13. Note the gold curve extending from Year 2000 onward. This shows the projected temperature change if atmospheric concentrations of CO_2 remained at 2000 levels. Referring back to Item 10 for the temperature change as of the Year 2000, the curve shows that without a change in the concentration of atmospheric CO_2, the average annual global temperature from 2000 to 2100 would **[(*decrease*)(*remain the same*)(*increase*)]**. This is referred to as a ***commitment*** because it would happen even if we could stabilize atmospheric CO_2 concentrations at 2000 levels. Unfortunately, such stabilization is not possible under current national and worldwide energy policies.

14. Figure 2 shows projected temperature changes under several scenarios. The blue Scenario B1 curve with atmospheric CO_2 concentrations stabilizing at 550 ppm, indicates the projected average global surface temperature change this century (since Year 2000) will be about **[(+*1.3*)(+*2.4*)(+*3.3*)(+*4.8*)]** C degrees by 2100. Comparing this temperature change with those of the other scenarios demonstrates the extent to which curbing CO_2 emissions can have major impact on future climate.

EdGCM Project:

Computer-driven global climate models (GCMs) are prime tools used in climate research. The Educational Global Climate Modeling Project provides a research-grade GCM, called **EdGCM**, with a user-friendly interface that can be run on a desktop computer. Educators and students can employ EdGCM to explore the subject of climate change the way research scientists do. The model at the core of the EdGCM is based on NASA's Goddard Institute for Space Studies GCMs. To learn more about EdGCM and its availability, go to: http://edgcm.columbia.edu/.

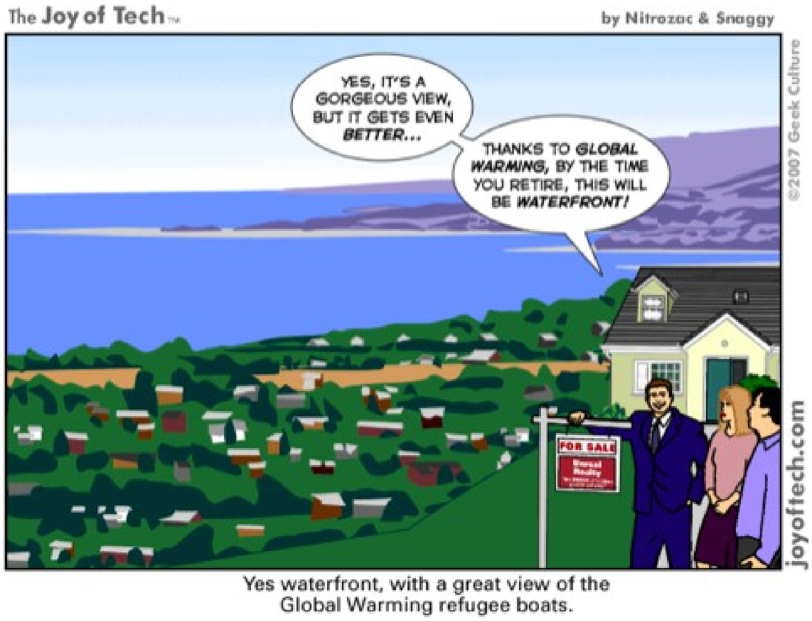
Summary:

Computer climate models are essential scientific tools for understanding and predicting natural and human-caused changes in Earth's climate. They are the only tools that exist for trying to understand and predict climate changes likely to be experienced in the future. Climate models are limited by our ability to understand and describe complicated atmospheric, oceanic, and chemical processes mathematically, as well as by computer capacity constraints. Numerous current climate models demonstrate considerable success in simulating past and current climate, thereby strengthening confidence in their predictions of future climate.

U.S. NATIONAL CLIMATE CHANGE: AN OVERVIEW

Introduction:

Assessing the social and environmental impacts of observed and anticipated climate change on global, regional, and local scales is a prerequisite to developing policies to respond to those impacts (as shown facetiously in **Figure 1**). Obtaining reliable forecasts of climate change is essential to this process. The international community recognized this and created the **Intergovernmental Panel on Climate Change** (**IPCC**) in 1989. The United States has participated in this worldwide effort as it concurrently addresses the science of climate change and the impacts of climate change in this country, now and in the future, at national, regional, and local levels. It does this through the funding of climate research and through the **U.S. Global Change Research Program** (**USGCRP**).



Yes waterfront, with a great view of the Global Warming refugee boats.

Figure 1.

Addressing the issue of projected climate change [With Permission: http://www.geekculture.com/joyoftech/joyarchives/989.html]

Simultaneously, the U.S. Congress has sought the independent assessment of Earth's climate system and climate change as it relates to the nation. In 2009, Congress asked the National Academy of Sciences' National Research Council (NRC), a private, nonprofit institution that provides expert advice on some of the most pressing challenges facing the nation and the world, to make such a study. The NRC issued its final report, ***America's Climate Choices***, in 2013 and firmly supports the fundamental conclusions of IPCC and USGCRP by stating that, "Climate change is occurring, is very likely caused primarily by the emission of greenhouse gases from human activities, and poses significant risks for a range of human and natural systems. Emissions continue to increase, which will result in further change and greater risks."

The NRC's *America's Climate Choices* goes beyond the IPCC and USGCRP findings by emphasizing the need to guide emissions reductions and adaptation efforts by an *iterative risk management approach*. This approach "emphasizes taking action to reduce risks while continuously incorporating new information and adjusting efforts accordingly." Iterative risk management is an ongoing process that must be durable enough to promote sustained progress while flexible enough to take advantage of improvements in knowledge, tools, and technologies as they emerge.

Go to the course website and under Societal Interactions & Climate Policy, click on "America's Climate Choices". Near the top of this website, under the heading Summaries & Booklets, click on "Climate Change: Evidence, Impacts, and Choices". Then click on "Click here to download a high-resolution PDF of the booklet". This NRC publication summarizes *America's Climate Choices* reports in a three-part presentation on 1) evidence for human- caused climate change, 2) warming, climate changes, and impacts in the 21st century and beyond, and 3) making climate choices.

1. On page 3 of the 2012 summary, it is confirmed by several research groups that Earth's average surface temperature has increased by more than **[(*0.5*)(*0.9*)(*1.4*)]** Fahrenheit degree over the past

100 years.

2. Starting on page 4, the summary describes the importance of greenhouse gases in the warming of Earth's climate system. In particular, it is stated on page 7 that atmospheric concentrations of heat-trapping carbon dioxide have increased so they are now nearly **[(*40%*)(*60%*)(*80%*)]** higher than preindustrial levels. In Box 2 on page 8, it is explained that the study of the radioisotopic composition of atmospheric carbon dioxide confirms that most of the added carbon dioxide comes from the burning of fossil fuels by human beings.

Challenges in Making Regional and Local Climate Change Projections:

Predicting impacts of climate change becomes increasingly difficult as the spatial scale decreases from global to regional to local. As suggested by the AMS CEM, global-scale modeling encompasses the Earth system that exchanges radiant energy with surrounding space, and is also regulated by large-scale forcing agents and mechanisms (e.g., flow of radiation from the Sun, concentration of heat-trapping atmospheric gases) that can be computed at fairly large grid spacings. However, regional and smaller-scale climate change derives more from the results of interactions of processes involving both energy and mass flows that operate across boundaries between scales or regions. As spatial scales decrease, grid spacing for model computations must also decrease.

Embedded within the global climate system, regional and local forcings (e.g., complex topography and coastlines, aerosols, snow cover) and wind circulations alter the spatial and temporal structure of the regional and local climate. Among the additional factors which must be considered include processes in a distant region (e.g., El Niño/Southern Oscillation) that can influence climate regimes in areas far from the source. Consequently, climate patterns at regional and local levels do not necessarily exhibit the same trends as the global- scale climate change.

3. As described in the paragraphs above, predicting impacts of climate change becomes more difficult as the scale decreases from global to regional to local. Climate models need to provide a better physical representation of process interactions across regions, more detailed specification of local boundary conditions, and **[(*finer*)(*coarser*)]** grid spacing for computations.

U.S. National Climate Change Overview:

Understanding U.S. climate change starts with the recognition that it varies more than the average global climate because regional and local climates respond to numerous local, regional and global factors. To access the USGCRP report, go to the course website and scroll down to the Societal Interactions and Climate Policy section. Click on "US Global Change Impacts Report". Or, you can go directly to the report at: http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.

Go to the *National Climate Change* chapter that begins on page 27. This chapter summarizes the science of climate change and the impacts of climate change on the United States, currently and in the future.

The following are from the key messages appearing at the beginning of the *National Climate Change* chapter (at top of page 27).

4. The U.S. average temperature has risen more than 2 Fahrenheit degrees in the past 50 years and is projected to continue rising. How much it rises depends primarily on **[(*the amount of heat-trapping gases emitted globally*)(*how sensitive the climate is to those emissions*)(*both of these factors*)]**.

5. During the past 50 years, annual precipitation over the U.S. **[(*decreased about 5%*) (*remained the same*)(*increased about 5%*)]**.
6. Projections of future precipitation generally indicate that some parts of the coterminous U.S. will become wetter and other parts drier. The driest area is projected to be in the **[(*Northeast*) (*Southeast*)(*Southwest*)(*Northwest*)]**.
7. Many types of extreme weather events, including heat waves and regional droughts, have become **[(*less frequent and more intense*)(*more frequent and less intense*) (*more frequent and more intense*)]** over the past 40 to 50 years.
8. Sea level has **[(*fallen*)(*risen*)]** along most of the U.S. coast over the last 50 years, and will continue to do so in the future.
9. Cold-season storm tracks are shifting to **[(*lower*)(*higher*)]** latitudes and the strongest storms are likely to become even stronger and more frequent.
10. Arctic sea ice is **[(*growing*)(*declining slowly*)(*declining rapidly*)]** and this trend is very likely to continue.

The USGCRP report relies heavily on IPCC scenarios for higher and lower heat-trapping gas emissions to project temperature changes during this century. These changes are displayed on maps presented on the report's page 29. The high emissions scenario impacts at mid- century (2040-2059) and at end-of-century (2080-2099) are shown on the upper maps. The lower emissions scenario impacts are displayed on the lower maps.

11. Generally, the projected temperature changes by mid-century for both the higher and lower emission scenarios will be greatest in **[(*the west coast*)(*the southeastern states*) (*the upper Great Lakes*)(*Alaska*)]**.

Page 31 of the USGCRP report shows projected future changes in North American seasonal precipitation relative to the recent past as simulated by 15 climate models under a higher emissions scenario.

12. By the end of this century, it is predicted that during summer most of the coterminous U.S. will experience **[(*less*)(*about the same*)(*more*)]** precipitation than in the recent past.
13. During winter and spring of the 2080-2099 time frame, the northern tier states of the coterminous U.S. are expected to have **[(*less*)(*about the same*)(*more*)]** precipitation than in the recent past.

The map at the top of page 33 displays changes in the observed dates of the onset of spring runoff pulses in the western U.S., marking the beginnings of snowpack melting.

14. Note that there are both earlier and later dates of the onset of the spring runoff pulse. However, the bulk of the reports show **[(*earlier*)(*about the same*)(*later*)]** beginning dates of snowmelt. Because snowpack runoff is critical to water resources in the western U.S., changes in timing and amount of runoff will heighten problems in regions already experiencing limited water supplies (e.g., allocating Colorado River water to the states and Mexico through which it flows).

As stated earlier in this investigation, predicting impacts of climate change generally becomes increasingly more difficult as the scale under study decreases from global to local. An essay in the *Bulletin of the American Meteorological Society* (*BAMS*)1 (http://journals.ametsoc.org/doi/pdf/10.1175/2009BAMS2769.1), describes the climate forcing by human influences due to extensive land use/land cover change (LULCC). It points out that human activities, exemplified by LULCCs, have modified the environment for thousands of years. Their impacts have been found in local, regional and global trends in modern atmospheric temperature records and other climatic indictors.

Summary:

Observations show that warming of the global climate over the past century is unequivocal and practically the entire community of climate scientists has reached consensus that the warming over the past 50 years is primarily due to human-induced emissions of heat-trapping gases. The USGCRP "National Climate Change" chapter ends on page 40 with a summation of U.S. emission and absorption of heat-trapping gases. It points out that until recently the U.S. has been the world's largest emitter of these gases. On a per capita basis though (with the exception of several smaller countries), the U.S remains by far the greatest emitter. With 4.5% of the world's population, the U.S. was responsible for about 28% of the human- induced heat-trapping gas emissions in the atmosphere in 2009. [According to the NRC's August 2012 publication, *Climate Change: Evidence, Impacts, and Choices*, the U.S. more recently emits roughly 20% of the total global emissions. While there has been a modest decrease in U.S. emissions in recent years, this percentage change is primarily due to the increased emissions by China and India.] The reality is that regional effects, such as these emissions, can have significant impacts on the global climate system.

15. According to the USGCRP report's page 40 summation, the country that has surpassed the U.S. in the total annual emission of heat-trapping gases is **[(*the United Kingdom*) (*India*)(*China*)]**.

1Mahmood, R., et al: Impacts of Land Use/Land Cover on Climate and Future Research Priorities. *Bull. Amer. Meteor. Soc.*, 91, 37-46.