1. Print this file (and associated linked images if any). Also answer the "Concept of the Week" questions in the Weekly Climate News File. (Check for additional News updates during the week.)

2. Complete the Investigation by responding to the Chapter Progress Questions (Study Guide binder) and the Investigations 5A and 5B from the Climate Studies Investigations Manual, and this Current Climate Study.

**Notice:** A course requirement is to develop a Plan of Action for your climate science resource teacher activities following the course completion. (Link to Plan of Action Guidelines.) Consult your LIT leader or mentor if you have questions.

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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 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 CO₂ 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 \([\text{increases, decreases, remains the same}]\) 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 \([\text{increases, decreases}]\). 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 390 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](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 baseline will increase about $[(1.4)(2.3)(3.3)(4.8)]$ 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 $[(\text{decrease})(\text{remain the same})(\text{increase})]$. 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.

Instructions for Communications with Mentor:

Transmit this week’s work to your LIT mentor by Monday, 25 February 2013, or as coordinated with your mentor. Include:

- **Chapter Progress Response Form** from the *Study Guide* or the course website.
- **Investigations Answer Form** for 5A and 5B from the *Study Guide* or course website.
- **Current Climate Studies Answer Form** from course website.

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