ISSUES : DATA SET

Global Temperature Change in the 21st Century
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THE ECOLOGICAL QUESTION:
How might global temperatures change during the 21st century? How might these changes vary geographically, seasonally, and depending upon future human activities?

ECOLOGICAL CONTENT:
Abiotic environment, global change, global warming, climate change, greenhouse gases, latitudinal gradients, seasonality

ACKNOWLEDGEMENTS:
We thank the Canadian Centre for Climate Modeling and Analysis for making available the data from their climate models. Dr. Gregory M. Flato provided help in obtaining permission to use this data, and suggested useful approaches for using climate model output. Students in various editions of DRT’s Global Change Biology class provided valuable feedback on these exercises. The editor and two anonymous reviewers provided numerous helpful suggestions. Canadian Centre for Climate Modelling and Analysis. Online data repository, http://www.cccma.ec.gc.ca/data/data.shtml

OVERVIEW OF THE ECOLOGICAL BACKGROUND
Human industrial activity, use of fossil fuels, and land use changes have been leading to increasing emissions and atmospheric concentrations of carbon dioxide and other greenhouse gases (Figure 1). Greenhouse gases are ones that allow electromagnetic radiation (light) at the wavelengths emitted by the sun to pass through to the Earth’s surface, but absorb the radiation that is emitted by the Earth out toward space. In this fashion, they act to heat the atmosphere near the Earth’s surface. Recent increases in the concentrations of these gases, along with increases in temperature, have been the basis for concerns about “global warming.”

Major changes in climate that might result from such increased concentrations of greenhouse gases could of course have profound implications for agriculture, human health, natural resources, and a host of other areas of ecological and social importance. To anticipate these effects, we must first anticipate the details of projected changes in climate. For example, how much warming can be expected to occur over the next
century? How would different social, economic, and technological developments affect greenhouse gas emissions and climate change? Would warming be truly global, or vary from location to location? Would warming occur mostly in summer (affecting the prevalence of heat wave, heat damage to crops, etc.), mostly in winter (potentially decreasing the severity of winters, affecting sea ice formation, etc.) or equally in both?

Since these questions concern the future, they cannot be answered directly by empirical observation—unless we are willing to wait decades for the answers. We have only one Earth, so we cannot directly perform experiments with the climate system (other than the one we are inadvertently performing). To make detailed predictions about the future, researchers therefore must rely on perturbing simulated Earths rather than the actual Earth. It would be impossible in a physical simulation (such as a giant globe) to capture the processes in the Earth’s complex systems in a realistic and meaningful way.

![Figure 1. Atmospheric concentrations of greenhouse gases have been rising rapidly in recent years.](image)

Figure 1. Atmospheric concentrations of greenhouse gases have been rising rapidly in recent years. Reprinted from Faq 2.1, Figure 1 of Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Used with permission.
Researchers therefore rely on computer simulations that mathematically represent the chemical, physical and biological complexities of global climate systems and how they inter-react and respond to changes in external conditions (such as increasing emissions of CO₂ from the burning of fossil fuels).

In practice, there are two major steps to predictions of the effects of future human activities on climate. The first is to predict the quantities of greenhouse gases, particulate matter, and other substances that will be emitted into the atmosphere. The second is to use these estimates of emissions as inputs into models that simulate global climate.


<table>
<thead>
<tr>
<th>ScENARIO CHARACTERISTICS</th>
<th>A1B</th>
<th>A2</th>
<th>B1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Population growth</td>
<td>Low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Globalization, economic convergence among regions of the world</td>
<td>High</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Increases in social and political emphasis on environmental sustainability</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Economic growth</td>
<td>very high</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td>Land-use changes</td>
<td>Low</td>
<td>medium/high</td>
<td>high</td>
</tr>
<tr>
<td>Pace of technological changes in energy use</td>
<td>Rapid</td>
<td>slow</td>
<td>medium</td>
</tr>
<tr>
<td>Changes in energy use and production</td>
<td>rapid: changes in both energy production and use</td>
<td>slow: vary by region</td>
<td>medium: emphasis on efficiency of use and shift to lowered use of materials</td>
</tr>
<tr>
<td>Energy use</td>
<td>very high</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>
Climate simulation models then are used to predict future climates under these different emissions scenarios. Typically, these models divide the surface of the Earth, the ocean and the atmosphere into large spatial cells (Figure 3). Each cell has specified physical properties; for example, a cell in the atmosphere will have a specified temperature, pressure, humidity, etc. In the model, time is simulated in steps; for each step the chemical and physical properties of each cell are updated as the cell receives radiation from the sun and Earth, exchanges energy and materials with adjacent cells, etc. One can use such models to predict changes in any of these physical and chemical parameters, in any location within the Earth-atmosphere system.

In these exercises, students work with output from simulations of future climates performed using models developed by the Canadian Centre for Climate Modeling and Analysis (CCCma), focusing on near-surface air temperature, a concept familiar through daily weather reports. In doing so, students develop increased understanding of how predictions of future climate are derived, as well as practicing skills in analysis and interpretation of large data sets.

**STUDENT INSTRUCTIONS**

**Background on the data**

In these exercises, you will work with output from one set of climate models, created by the Canadian Centre for Climate Modeling and Analysis (CCCma), who have kindly made the results of a number of runs of their models available online. Information on the models can be found on the Models section of the CCCma website ([http://www.cccma.ec.gc.ca](http://www.cccma.ec.gc.ca)). We will be using data from their third-generation (CGCM3) model. This is the latest model for which they have made available extensive climate predictions over nearly the entirety of the Earth’s surface. We will focus on one
parameter, temperature above surface, defined as the air temperature 2 m above the Earth’s surface. This corresponds to the familiar air temperature reported in the daily weather report in newspapers and on TV.

The data you will examine is the mean temperature (°K) for each month over the 100 years (2001-2100), giving a total of 1200 values for the 1200 consecutive months. You are provided these data for the three scenarios described in Table 1 (A1B, A2, and B1) and for a fourth set of conditions representing “Committed” climate change. The “Committed” set of conditions assumes that the composition of the atmosphere remains unchanged at year 2001 values. Therefore, the only climate changes that will occur are those to which the climate system is already committed due to past changes in atmospheric concentrations. The Committed scenario is not intended as a realistic scenario. Instead, it serves as a control for comparison with the other scenarios. By comparing the results of a given scenario with the results under the Committed scenario, one can see how much additional climate change a scenario produces compared to what would be produced if alterations in climate forcing agents were to immediately stop.

For each scenario, we provide data for 19 grid cells in a continuous North-South transect through North America (Figure 4). Your instructor will assign you or your group a latitude or latitudes to work with.

Answer these two questions to help you consider how you will organize and analyze your data. We will discuss these answers in class, bring them as a hardcopy.

1. What would be the best graphical format for presenting the data to illustrate changes (if any) in temperature across the century?
2. How should you organize and analyze the data to determine: 1) whether or not a meaningful trend exists, and 2) how much the temperature has changed (if at all) over the course of the century?