Two or 12 degrees warmer? Greenhouse gas emission scenarios that drive future climate outlooks

By Zack Guido

It's 2100. Thousands of power plants incinerate coal to help feed a bustling world economy. People from Bangladesh to the United States generally are more affluent than they are today, and many of the planet's 8.7 billion inhabitants can afford cars, air conditioning, and other comforts that make life easier but more resource intensive.

This combination of population growth and a burgeoning energy appetite come at a climate cost. Carbon dioxide (CO_2) spews from tailpipes and smokestacks at nearly four times the present rate, congesting the atmosphere with CO_2 concentrations that approach 1,000 parts per million (ppm)—nearly 350 percent more than the amount before the Industrial Revolution began in earnest in the late 1800s. The build-up of greenhouse gases has sent the global average temperature soaring up to 12 degrees Fahrenheit warmer than it is now.

Scientists have called the 1,000 ppm point and its impact on temperature the worst-case scenario, citing increased chances that about half of the known endangered species will go extinct, most regions of the globe will feel economic shocks, ocean acidification will eat away at coral reefs, and millions of people will be displaced as sea levels rise from melting polar and mountain ice. Many scientists have stated CO_2 should not exceed 450 ppm for a long period, if at all, to avoid dangerous warming of the planet.

The good news is that this future world picture represents only one of 40 scenarios that each project different climate futures; some include increases in temperature as low as 2 degrees F. The bad news is that between 2000 and 2008, global greenhouse gas emissions outpaced scientists' worst-case scenario. So, what is the story with these scenarios, and how do scientists arrive at them?

Emission scenarios and temperatures projections

Future outlooks uniformly predict warmer temperatures but differ by up to 10 degrees. Whether temperatures in 2100 will be closer to 2 or 12 degrees hotter than present depends on two factors: realistically describing human actions that influence emissions of greenhouse gases, including economic development and population growth, and accurately modeling physical processes, such as air and water movement. While emission scenarios describe the atmospheric fallout of human actions, climate models use that information to simulate the response of physical processes that alter temperature and other climate variables.

Ultimately, greenhouse gases like CO_2 cause changes in temperature. However, scientists cannot estimate the extent of change without knowing the amount of

continued on page 4

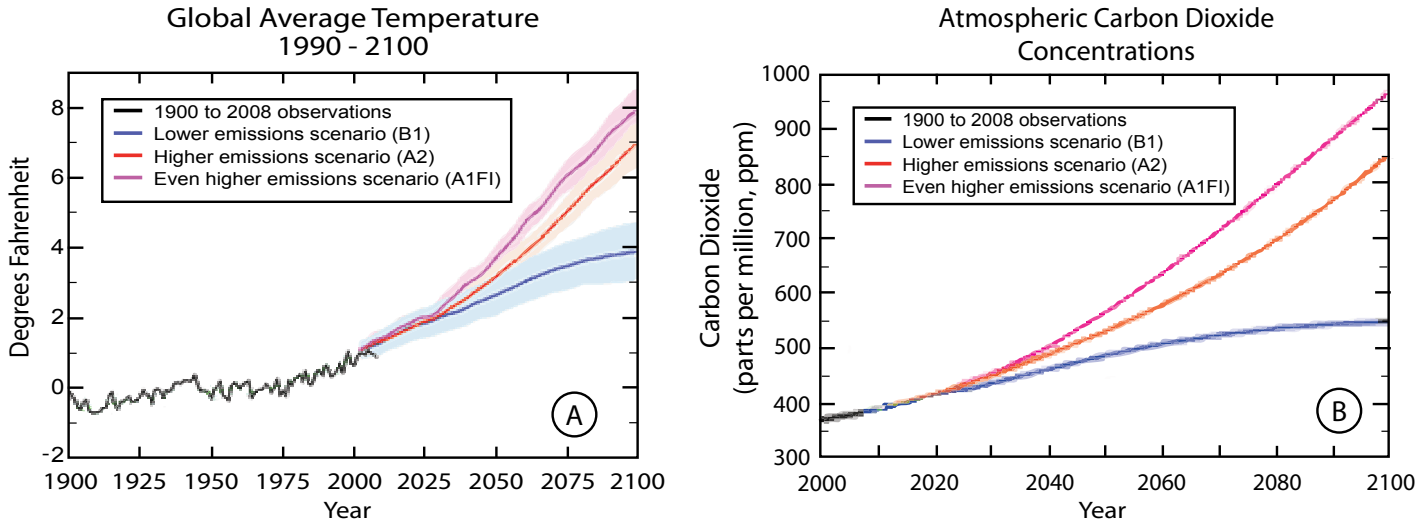

Figure 1a. Observed and projected changes in the global average temperature under three IPCC emissions scenarios. The shaded areas show the likely ranges, while the lines show the central projections from a set of climate models. A wider range of model types shows outcomes from 2 to 11.5 degrees F. Changes are relative to the 1960–1979 average.

Figure 1b. The graph displays atmospheric concentrations on the right under four emissions scenarios, including a "stabilization scenario" designed to stabilize atmospheric carbon dioxide concentration at 450 ppm. The figure was modified from the U.S. Global Climate Research Program (2008).

Two or 12 degrees, continued

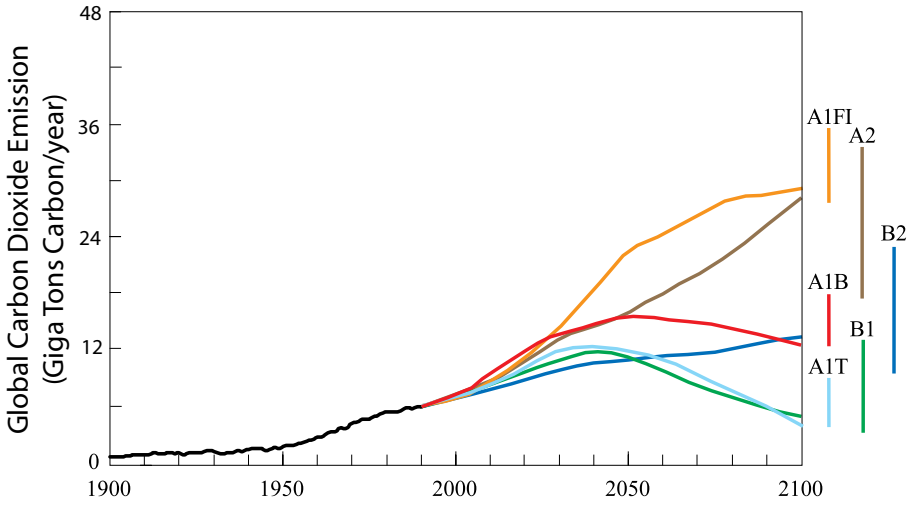

Figure 2. Global CO_2 emissions produced by energy generation and industry from 1900 to 2100. Each path depicts how future CO_2 emissions may change in response to different societal evolutions. The vertical bars indicate the range of emissions in 2100, which was generated by creating slightly different variations of each narrative. The figure was modified from the U.S. Global Climate Research Program (2008).

gases injected into the atmosphere. To do this, the Intergovernmental Panel on Climate Change (IPCC) created six emission narratives to explore the evolution of and relationship among economic, social, and environmental factors that influence greenhouse gas emissions, and hence climate.

These story lines, published in 2000 in the Special Report on Emissions Scenarios (SRES), are conceptual outlines that guide quantitative assessments of the key factors that influence greenhouse gas emissions, including gross domestic product, income disparity, energy intensity, fossil fuel and clean energy use, and CO_2 consumption by the land. Six modeling groups used these guidelines to create different evolutions for the key indictors and generated 40 unique greenhouse gas scenarios, about seven for each narrative.

The groups did not cobble together haphazard assessments of these indicators. They were informed by more than 800 emission scenarios published in academic journals as well as sophisticated studies from institutions like the International Institute for Applied Systems Analysis, which projects population trends and highlights the strains that a more crowded planet place on resources and society.

The narratives, described in more detail in the "IPCC Emission Scenarios" textbox, unfold something like this: The A1T and B1 scenarios dump the least amount of greenhouse gases into the atmosphere. A1B and B2 have moderate emissions, and A1F1 and A2 spew the highest amount of gases. An outline of B1, for example, would describe a world in which solar and wind farms dot the landscape in many countries, population growth is low, and CO_2 emissions are slightly less than they were in 1990. On the other hand, in an A1FI world—"FI" stands for Fossil Fuel Intensive—thousands of coal-fired power plants would belch CO_2 and other greenhouse gases into the atmosphere at four times the present rate to fuel the economy.

Emission scenarios by themselves say little more about future climate than higher concentrations of greenhouse gases will elevate temperatures. To quantify gas concentrations in ppm, which allows for more precise estimates of temperature changes,

continued on page 5

The IPCC Emission Scenarios

The Intergovernmental Panel on Climate Change (IPCC) developed six story lines to guide quantitative assessments of key indicators that influence greenhouse gas emissions, thus leading to a broad assessment of climate change (Figure 2). Although the IPCC states each scenario has the same probability of occurrence, current emissions are outpacing the highest emission scenario, A1FI. This suggests that if society continues burning fossil fuels at current levels, the global average temperature may be around 12 degrees F warmer by 2100.

A1 narratives: A1FI, A1B, A1T

Throughout this century, the global economy expands rapidly and becomes tightly integrated. As a result, wealth increases and regional differences in per capita income nearly vanish by 2100. Population growth is low, peaking in 2050 at 8.7 billion and declining thereafter.

This story line produces a wide range in carbon dioxide (CO_2) emissions due primarily to different strategies for supplying energy. To explore the effect of energy choices, this narrative is divided into three categories. A1FI encompasses the fossil fuel-intensive scenarios, which produce only modest increases in non-carbon energy such as wind and solar. The A1B story line has a more balanced energy portfolio, with a mixture of both clean and fossil-fuel energies. A1T is the green technology story line, which continually expands non-carbon energy production to 85 percent by 2100.

A2 narrative

This story line generates medium to high CO_2 emissions. Economic growth is slower than it is in A1 and geographically different. Although

continued on page 5

Two or 12 degrees, continued

scenarios are fed into state-of-the-art climate models. When the 40 emission scenarios are each filtered through climate models—which can capture thousands of dynamic natural processes that influence temperature, among other climate variables—the highest and lowest temperatures create bookends that provide a range in which global average temperature likely will fall.

The recently published Global Climate Change Impacts in the United States report conducted by the U.S. Global Change Research Program (GCRP) presents results from state-of-the-art climate models—the same ones used in the latest IPCC assessment report—driven by low (B1), high (A2), and higher (A1FI) emissions scenarios (Figure 1a).

For the B1 scenario, concentrations of CO_2 hover around 550 ppm by 2100, causing temperature increases of about 4 degrees F, according to the report. Concentrations of CO_2 and temperature in the A2 scenario climb even higher, reaching 850 ppm and about 7 degrees F. The A1FI scenario suggests CO_2 will approach 1,000 ppm, driving temperatures upwards of 8 degrees F (Figure 1b).

These results collectively suggest that if emissions are within the ranges specified by the narratives, a 66–90 percent chance exists that temperatures will be 3 to 8.5 degree F warmer than the 1960–1979 average. Lower probabilities, however, indicate a larger temperature range, between 2 and 12 degrees F. The results also show that temperatures for all of the story lines are similar until 2030, regardless of how society evolves.

Future Policy

The current scenarios should be viewed cautiously. They are not predictions, and the IPCC does not assign probabilities to their occurrences due to uncertainty. The genius of the scenarios is that they span a wide range of greenhouse gas emissions. With the help of climate models, this enables the exploration of the climate implications of each scenario for society and the planet.

The IPCC emissions scenarios also do not explicitly evaluate the effect of policy changes on emissions. For example, no scenario evaluates the impact of a worldwide adoption of the Kyoto Protocol, which puts enforceable limits on many greenhouse gases but was not ratified by some countries, including the United States. Also, the scenarios do not encompass the full range of possible emissions. The IPCC avoided "disaster" or "surprise" scenarios that describe economic collapse or crises that hurl society back to primitive times, or futures where emissions outpace the A1FI scenario.

New emission scenarios are in the works. They will include up-to-date data and a wider range of emissions. They also will likely include scenarios that analyze the impact of global climate treaties on greenhouse gas concentrations. Some will seek answers to the emission reductions needed to stabilize CO_2 concentrations at 450 ppm, 550 ppm, and other levels. The results will help test and devise new policy actions.

Many nations are debating legislation that curbs greenhouse gas emissions, and a world treaty which will update the Kyoto Protocol is set to be negotiated in December in Denmark. An important question is, to what degree will these new laws minimize temperature change? The U.S., for example, proposes reducing greenhouse gas emissions 17 percent below 2005 levels by 2020 and 83 percent by 2050. The European Union, which has the most aggressive targets, proposes a 30 percent cut below 1990 levels by 2020 and up to 80 percent by 2050.

Scenarios, continued

wealth increases and the income disparity narrows between rich and poor nations, inequality is still widespread. Fertility remains high in some regions, resulting in high population growth—15.1 billion people by 2100. Technological change is also regionally disparate, and adoption of clean energy production is lower than in all other story lines. Greenhouse gas emissions rise unabated and are nearly five times more than they were in 1990.

B1 narrative

This story line, along with A1T, produces the lowest CO_2 emissions. Widespread economic growth increases wealth and reduces the income disparity between rich and poor nations. Society rapidly transforms from a manufacturing-based economy to one that provides services and information, reducing material consumption and the burden on some natural resources. Energy is increasingly produced by clean and efficient technologies. By 2100, 53 percent of the energy produced emits zero greenhouse gases. Global population peaks in 2050 at 8.7 billion and then declines, similar to A1. The evolution of these characteristics cause greenhouse gas emissions to peak in mid-century and decline below 1990 levels by 2100.

B2 narrative

CO_2 emissions fall in the medium range. Economic development is moderate and clean technologies are slowly integrated into society. By 2100, clean energy supplies nearly 50 percent of the total energy consumed. Population growth continues to increase but slows in the second half of the 21st century. Greenhouse gas emissions also persistently rise, but their growth is progressively slower so that by 2100 emissions are double what there were in 1990.