Regional Challenges of Future Climate Change: Endless Summer or Business as Usual?

THE 2006 COLORADO COLLEGE STATE OF THE ROCKIES REPORT CARD

By Matthew Reuer, guest contributor

Are humans truly warming the planet? If so, what are the consequences for the Rockies, a region dependent on adequate winter precipitation and temperate summers? Since the 19th century scientists have postulated that rising carbon dioxide concentrations from fossil fuels could increase global surface temperatures, as heat reflected from the Earth's surface is trapped by atmospheric greenhouse gasses.[1] The implications for the Rockies region are significant, ranging from the availability of water for an increased population to the economic impact of diminished snowpack to the tourism industry. In the following chapter, Gregory Zimmerman, Caitlin O'Brady, and Bryan Hurlbutt present state-of-the-art estimates of future temperature, precipitation, and snowpack and address key impacts of these model scenarios. Here a brief introduction to the climate change issue is presented, explaining how we arrived at this challenge.

First, the atmospheric signature of our carbon emissions is best demonstrated by atmospheric carbon dioxide measurements from remote locations and prehistoric air trapped in polar ice cores (Figure 1). These records show increased carbon dioxide concentrations throughout the 20th century, which accounts for most of the global warming potential relative to other greenhouse gases, such as methane, nitrous oxide, and halocarbons. The 2004 atmospheric carbon dioxide concentration of 377 parts per million (ppm) greatly exceeds the average prehistoric carbon dioxide concentration of 278 ppm.[2] Because the rise in carbon dioxide concentrations is unprecedented throughout the geological past and coincides with 20th century industrialization, the human impact on the Earth's atmosphere is well-established.

How much will rising carbon dioxide concentrations affect the Earth's surface temperature and future global climate? A global perspective on past temperature variability is shown in Figure 2, but future estimates rely on a variety of complex models that mimic some or all of the Earth's climate system at different resolutions. Scientists often refer to the "climate sensitivity" of a particular model as how much global temperature responds to twice the amount of atmospheric carbon dioxide (i.e., 278 ppm to 456 ppm). Energy Balance Models (EBMs), which calculate global surface temperature from a balance of heat inputs and outputs, were first utilized to calculate this temperature change. Using these models, a U.S. National Research Council report in 1979 suggested a 1.5ºC to 4.5ºC temperature increase, and this range represents a key baseline for future warming estimates.[3] General Circulation Models (GCMs), which approximate the circulation of the Earth's atmosphere and oceans, have also been employed to estimate the climate system's sensitivity to atmospheric carbon dioxide. GCM temperature estimates are quite variable, and some models now predict a 6ºC temperature increase with doubled carbon dioxide concentrations. For example, Morgan and Keith[4] surveyed 16 climate experts for their best estimate of climate sensitivity. The results ranged from 0 to 5ºC, with a mean value and uncertainty of 3±1ºC. The wide range described here reflects the complexity of these circulation models and their different approximations of complex physical processes, akin to the challenges of accurate weather forecasting in the Rockies. However, a 2 to 3ºC increase in global surface temperature would be a reasonable future expectation.

For the Rockies region, a partial answer might be obtained from historical climate records. In the following chapter Zimmerman et al. consider historical temperature records from the U.S. Historical Climatology Network. The mean temperature change for the time period 1989 to 1996 equals +0.60ºC (calculated as the temperature difference relative to the 1940 to 1996 mean). The mean atmospheric carbon dioxide concentration for 1989 to 1996 equals 357 ppm, just 28 percent above the prehistoric background. If one assumes a constant carbon emission rate, the estimated climate sensitivity from the historical record equals 2.1ºC. However,

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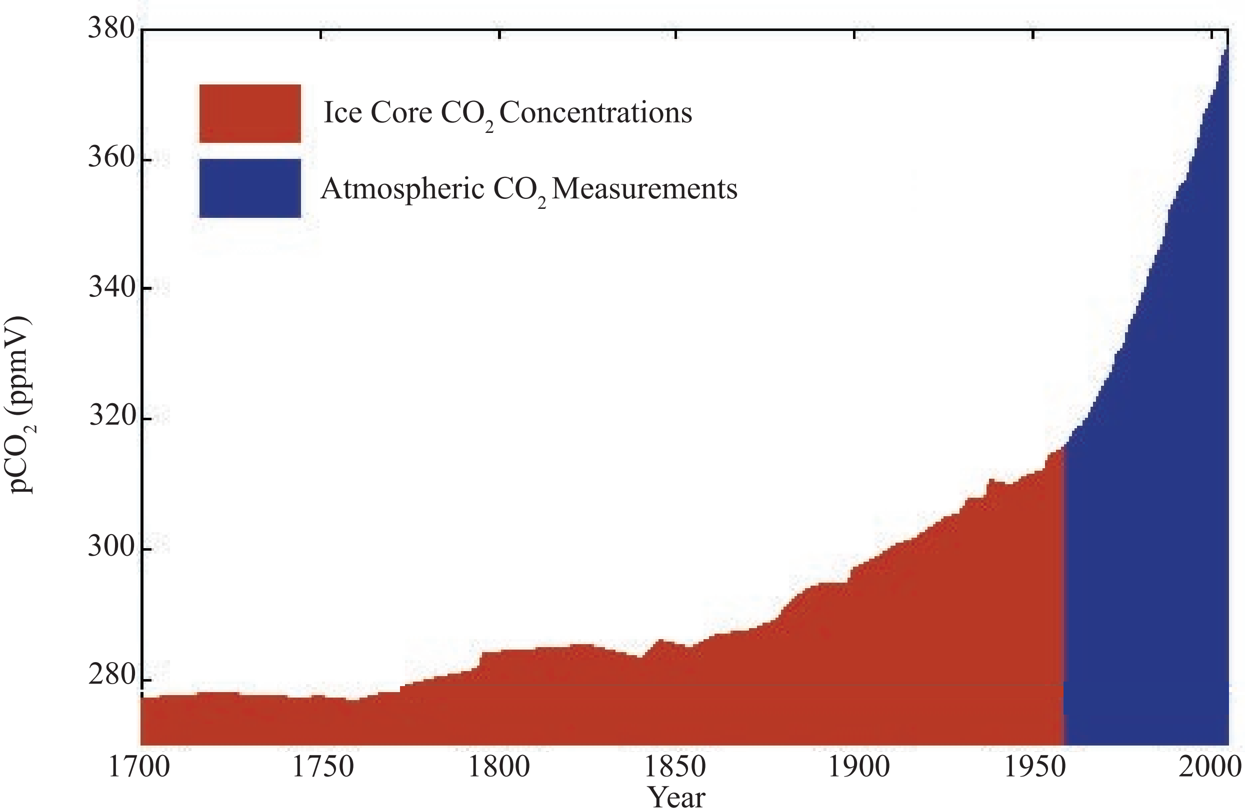
this estimate is likely a lower limit as it does not include anomalously warm years in the meteorological record (1998 and 2005), and constant carbon emission rates are unlikely considering future development rates.

Although model and observational uncertainties are often amplified in public debates, the future behavior of modern societies remains a key unknown. Annual atmospheric carbon emissions from transportation, heating, and electricity equal 6.98 gigatons[5] in 2002.[6] These emissions are ultimately tied to a nation's population, industrialization, and affluence. Second, the nations responsible for global carbon emissions are highly variable due to economic growth and the associated energy requirements. For example, economic development in China increased carbon emissions from 21.5 to 761.6 million metric tons between 1950 and 2000, second only to the United States in 2000 (1528.8 million metric tons).[7] Finally, the availability of future fossil fuel might be limited given inadequate discovery or development of new oil, natural gas, and coal reserves.

Within this context of uncertainty, scientists and policymakers have developed new agreements to mitigate future warming. The multi-national Kyoto Protocol was negotiated in Kyoto, Japan, in 1997, representing an amendment to the United Nations Framework Convention on Climate Change (UNFCCC) developed in 1992. This amendment requires participating countries to reduce their greenhouse gas emissions by at least 5.2 percent below 1990 levels between 2008 to 2012. The nations may also engage in emissions trading if they maintain or increase their emissions. As of fall 2005, 156 countries have ratified the agreement, representing 61 percent of global greenhouse gas emissions. The United States and Australia have signed but not ratified the Kyoto Protocol, leaving the policy non-binding in those countries. Objections to the protocol in the United States include the potential harmful effects on the U.S. economy (supported by economic analyses of the Congressional Budget Office and the Energy Information Administration), the lack of restrictions on developing signatory nations (notably China and India), and the potential transfer of wealth to third-world countries.

Given the marginal success of top-down regulation, local and state governments are addressing carbon emissions within the United States. For example, nine northeastern states are participating in the Regional Greenhouse Gas Initiative (RGGI), which seeks to stabilize carbon emissions by 2015 via a cap-and-trade program. Similarly, Mayor Greg Nickels of Seattle pioneered the U.S. Mayors Climate Protection Agreement, a policy where individual cities must exceed the Kyoto Protocol standards (the agreement calls for 7 percent reduction below 1990 levels,



The Human Impact on Atmospheric Carbon Dioxide Concentrations

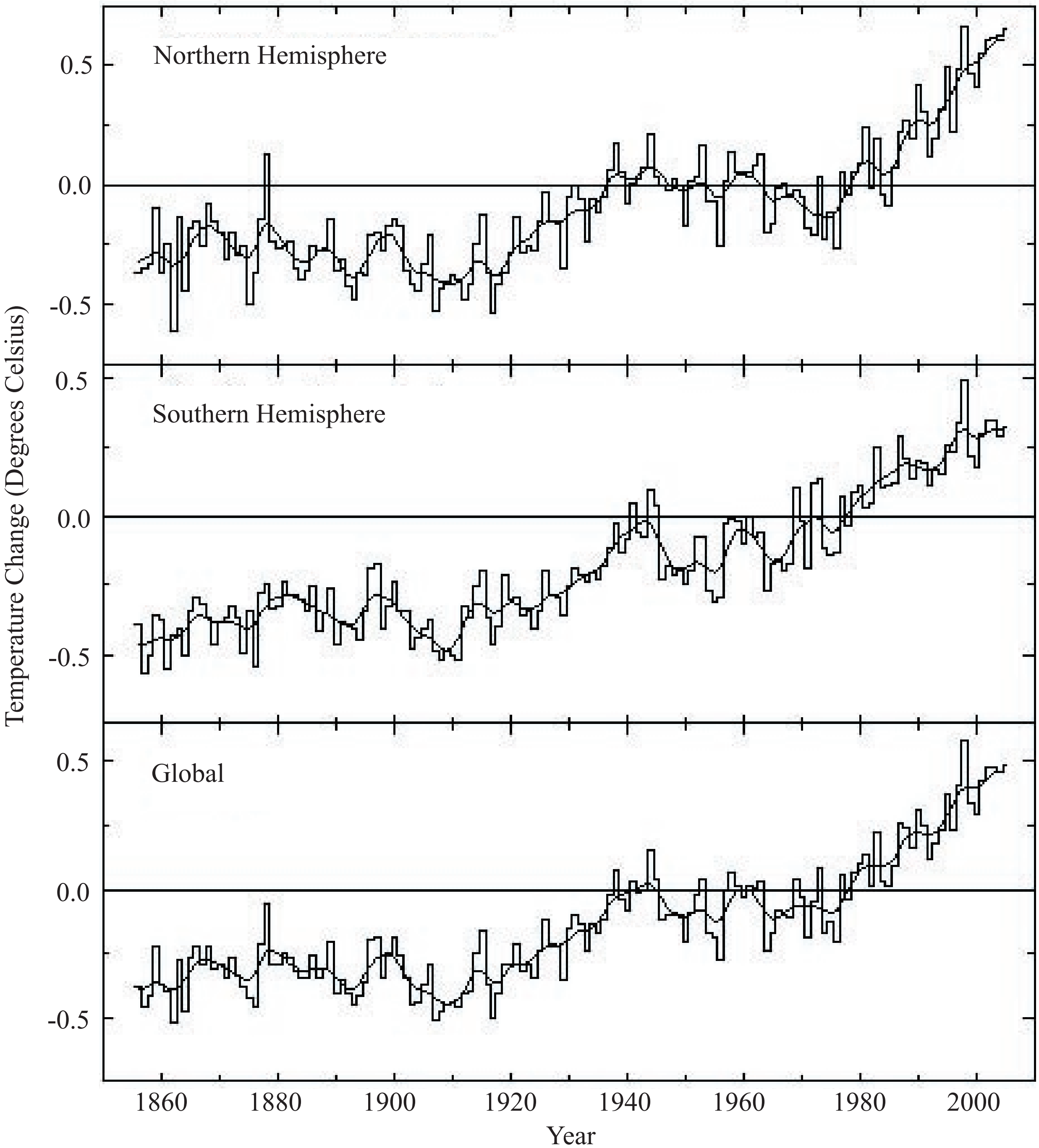
The red area corresponds to ice core measurements of past carbon dioxide concentrations, collected from Law Dome, Greenland.[8] The blue area reflects the mean annual carbon dioxide concentrations measured at Mauna Loa, Hawaii.[9] The white baseline is the pre-anthropogenic concentration of 278 ppm. Note that the 2004 mean (377 ppm) equals a 36 percent increase in atmospheric carbon dioxide concentrations from the 278 ppm baseline.

Figure 1

Historical Global Temperature Records

Data compiled by Jones and Moberg,[10] including the combined global land and marine surface temperature record from 1856 to 2005. The results are separated by hemispheres. Note the temperature anomaly exceeds 0.5ºC by 2000 in the Northern Hemisphere, and the years 1998 and 2005 were the warmest on record. The temperature increase from 1970 to the present has been largely attributed to human-induced warming, not natural climate variability.

Figure 2



whereas Kyoto mandates a 5.2 percent reduction). Currently 196 mayors have signed the agreement, representing 40 million Americans. Such regional initiatives are a highly useful means to catalyze federal legislation and develop innovative new products.

Unfortunately, the regional scientific analysis has not kept pace with the policy advances, particularly in the Rockies. In the following chapter of the *2006 State of the Rockies Report Card*, Gregory Zimmerman and coworkers from Colorado College address this problem, presenting several future climate change scenarios for the Rocky Mountain West. The method used in this study is an innovative twist on General Circulation Model output developed and produced by Katherine Hayhoe at ATMOS Consulting. Starting with the coarse grid results generated by two GCMs (typically in dimensions of several hundred kilometers), Hayhoe and colleagues scaled the model output to a 12x12 kilometer grid by statistically comparing the model results with historical climate data. By statistically "training" the GCM output with many historical observations, a higher resolution look at future climate change is possible. With this approach Zimmerman et al. considered changes in temperature, precipitation, and snowpack through 2100, including two models with different sensitivities to atmospheric carbon dioxide forcing and two future carbon emission scenarios.

These high-resolution scenarios demonstrate the different spatial variability, where temperature shows variability on county-to-state scales whereas precipitation might vary on city-to-township scales. This spatial variability could reflect the different climate mechanisms affecting temperature and precipitation in this area (e.g., the impact of El Niño Southern Oscillation on the southwestern monsoonal precipitation) or how these variables are parameterized in General Circulation Models. Because climate forcing mechanisms are treated differently in each model and they respond differently to CO_2 variations, the socioeconomic implications strongly rely on the underlying assumptions and small details. Consider the importance of one inch of precipitation between Flagstaff and Phoenix, Arizona, which receive annual precipitation of 13 and 8 inches, respectively. The next question is what aspect of the models themselves are actually creating this spatial variability, and how can they be tested and improved?

The future climate of the Rockies will likely be dominated by human-induced warming under "business as usual" carbon emissions, so accurately characterizing the regional response is vital to the Rockies' future sustainability. These initial results suggest significant changes will be required in water management, agricultural land use, and tourism under all future climate scenarios, not just the worst-case estimate (model HadCM3, IPCC scenario A1fi). The report presented by Gregory Zimmerman and colleagues is a positive step in the right direction, stimulating an important conversation among the regional stakeholders and climate forecasters.

Endnotes

[1]Svante Arrhenius, the Swedish physical chemist well-known for his pioneering work on electrolytic solutions, first suggested the Earth's surface temperature might be altered by atmospheric carbon dioxide concentrations in 1896. Although the underlying spectroscopic data for carbon dioxide and water vapor has been revised, he qualitatively demonstrated how carbon dioxide concentrations could increase the Earth's surface temperatures.

[2]Keeling, C.D. and Whorf, T.P., 2005. "Atmospheric CO_2 records from sites in the SIO air sampling network, Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center," Oak Ridge National Laboratory, Oak Ridge, TN.

[3]Kerr, R.A., 2001. "Rising global temperature, rising uncertainty." *Science*, 292: pp. 192-194.

[4]Morgan, M.G. and Keith, D.W., 1995. "Subjective judgments by climate experts." *Environmental Science Technology*, 29(10): 467A-468A.

[5]This annual emission equals 6.98×10^9 metric tons, equivalent to 1.5×10^{13} pounds (15 terapounds).

[6]Marland, G., Boden, T.A. and Andres, R.J., 2005. "Global, regional, and national CO2 emissions, Trends: A Compendium of Data on Global Change. Oak Ridge National Laboratory," U.S. Department of Energy, Oak Ridge, TN.

[7]*Ibid*.

[8]Etheridge, D.M. et al., 1996. "Natural and anthropogenic changes in atmospheric CO2 over the last 1,000 years from air in Antarctic ice and firn." *J. Geophys. Res.*, 101: 4115-4128.

[9]Keeling, C.D. and Whorf, T.P., 2005. "Atmospheric CO_2 records from sites in the SIO air sampling network, Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center," Oak Ridge National Laboratory, Oak Ridge, TN.

[10]Jones, P.D. and Moberg, A., 2003. "Hemispheric and large-scale surface air temperature variations: an extensive revision and an update to 2001." *J. Climate*, 16: pp. 206-223.