THE ROLE OF ECOLOGICAL & CLIMATE FORECASTING

Developing Adaptive Strategies in a Changing Environment

BY JOHN ADAMS HODGE

The current discussion regarding climate policy often appears to be dominated by the catastrophists who liken future climate scenarios to the plagues in the Book of Revelation or those blind skeptics whose scientific reasoning is more appropriate in a discussion within the Flat Earth Society. While a political debate ensues in the United States, a debate often fueled by the opinions of radio talk show hosts and former politicians as opposed to scientists, the future well-being of humankind may depend on how willing governments are to adopt adaptive strategies to mitigate, based on the consensus of scientific research, the effects of climate change.

Typically, many broad generalizations are invoked to describe the effects of climate change. For example, the chairpersons of the ABA Climate Change, Sustainable Development, and Ecosystems Committee and International Environmental Law Committee stated in July 2009, "Greenhouse gases will have the same effect wherever emitted." The aforementioned statement is both incorrect and misleading, as climate forecasting has shown that some parts of the globe will warm at greater rates, and some may actually cool. In addition, the residents of small, low-lying Pacific atolls will see much greater effects than will inland residents in temperate climates. Similarly, in a discussion at a climate change symposium, a senior US official responsible for developing energy policy made the statement, "There will always be big waves . . . ," as if to imply that, irrespective of climate change, big waves would always exist. While big waves always will exist, their location will likely change, and thus the placement of energy-harnessing technologies will greatly be affected by our knowledge of the changing wave climate. The challenge for climate scientists in the future is to predict with reasonable certainty when, where, and how big such waves will be. In addition, prediction of the expected effects of climate change must be scaled down to a degree that is useful for environmental and resource agencies, policy makers, and resource managers.

Consider the Source

To date, most predictions of climate change have been gross generalizations that are not useful for the development of policy and management strategies. We hear about more desertification, stronger storms, northward (or southward) migration of species, hotter summers, longer growing seasons, more precipitation, less precipitation, etc. When they seek to understand the effects of climate change, responsible people should stick to the scientific method, relying on peer-reviewed research and the findings of scientifically accredited institutions such as the National Academy of Sciences. In contrast, the work and findings of think tanks and quasi-official sounding bodies that are funded by special interests such as industry groups, political parties, or wealthy individuals should be largely ignored. Uncertainty is a normal part of the scientific method; however, skeptics commonly latch onto uncertainty as a means of discrediting scientists.

In evaluating claims about climate change, it would be helpful to use analysis derived from *Daubert v. Merrell Dow*.[1] Are the claims or conclusions supported by the *Daubert* standard of analysis? Have conclusions regarding climate change been subjected to a scientific analysis? Although Rule 702 of the Federal Rules of Evidence is applicable only when scientific evidence is offered in federal court, it provides guidance for evaluating the veracity of climate science outside of the courtroom. In reviewing the scientific or technical sufficiency of climate research, the most important consideration is whether the work resulted from peer-reviewed research whose methods, principles, and conclusions are accepted by mainstream, scientifically accredited institutions.

The US Supreme Court in *Daubert* outlined the factors to be considered when a court looks to accept scientific testimony:

1. Has the technique been tested in actual field conditions?

2. Has a technique been subject to peer review and publication?
3. What is the known potential rate of error?
4. What standard exists for the control of the technique's operation?
5. Has the technique generally been accepted within the relevant scientific community?

Although the Supreme Court did not view these factors as a "checklist," they are a good guide when evaluating scientific evidence related to climate change.

Meet the Evidence

An article in *Science* in 2004 surveyed all 928 peer-reviewed scientific articles published from the period 1993 to 2003 in the ISI database with the keywords "climate change."[2] All of the articles agreed that the general consensus of the scientific community is that climate change is occurring and that humans are partly responsible for increasing greenhouse gases (GHGs).

The UN Environmental Programme (UNEP), the Inter-Governmental Panel on Climate Change (IPCC), and the British Meteorological Office all have websites that provide a great deal of information on climate science in a readable format.[3] Data derived from ice cores in Greenland and elsewhere document a direct relationship between the CO_2 content of the atmosphere and temperature over the last 400,000 years. In addition, direct measurements of carbon dioxide concentration in the atmosphere and from ice cores have shown a steady increase from approximately 275 parts per million (ppm) in 1750 to 310 ppm in 1950 and to 370 ppm in 2000.

GHGs include water vapor, carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons. All GHGs are not created equal. The relative impact of different greenhouse gases differs over time expressed in terms of CO_2 equivalents as the "global warming potential" (GWP). If CO_2 has a GWP of one, methane has a GWP of 12; nitrous oxide, 114; and so forth (Table 1).

While CO_2 accounts for approximately 72 percent of the total greenhouse gases, its emissions are primarily from power stations, industrial processes, and transportation fuels. By contrast, methane comprises 18 percent of total GHG emissions; nitrous oxide, only 9 percent. However, both methane and nitrous oxide come predominantly from agriculture and methane, to a lesser extent, from fossil fuel retrieval, processing, and distribution. IPCC projections of temperature change over the next hundred years show a rise of 2°C to 4.5°C based upon most climate models. The earth's atmosphere retains heat, which allows our home planet to support life. Geological studies have demonstrated that the global climate has fluctuated throughout time as the result of astronomical, geophysical, and chemical processes. A review of the history of climate science demonstrates a belief until the 1970s that the earth's climate operated in a cyclical fashion about a "norm." With the growth of supercomputing and findings from space missions to Venus, Mars, and elsewhere, evidence began to build that global climate change could occur and that the Earth's climate did not simply swing like a pendulum between two different end points to maintain an average.

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Counting and Sequestering GHG Is Not Enough

To date, the major emphasis has been auditing, reducing, and sequestring GHG emissions. While these efforts have met mixed success, less effort has been made to adapt to the current and future anticipated effects of climate change. Even if significant reductions in GHG emissions are made in the next decade, climate change will continue to occur for at least 100 years. An article in *Science* indicated that, even if concentrations of GHGs in the atmosphere had been stabilized in the year 2000, the earth is still committed to further warming of approximately a half a degree Celsius, with an additional 320 percent rise in sea level by the end of the twenty-first century from the thermal expansion of the oceans.[4] In addition, trends in global surface temperature from 1976 through 2000 show that global temperature change differs locally, with the highest increases in the Arctic and Subarctic regions. However, in some parts of the world, the global temperatures have actually decreased. Thus discussions of climate change should avoid simplistic notions such as GHGs will have the same effect wherever emitted (Figure 1).

In understanding the effects of climate change, one of the underlying principles must be that "all climate change is local." Although climate change is a worldwide phenomenon, organisms experience such change only in a localized environment, particularly those organisms that cannot migrate in response to changes in habitat. For invertebrates and plants, their world is localized to a spot, and their response to climate change cannot be to migrate elsewhere.

Climate and Ecological Forecasting Are Necessary to Develop Adaptive Strategies

In predicting the effects of climate change, the science of ecological forecasting has the potential to predict climate effects at the level of the organism and, in the future, at the scale of the ecosystem.

Ecological forecasting seeks to predict changes in organisms, and ultimately ecosystems, as a result of factors such as physiological stress.[5] The goal of ecological forecasting is to produce models that can generate forecasts and nowcasts at scales relevant to resource managers, land managers, policy makers, environmental regulators, and the public. These models can be tested by nowcasting and hindcasting with actual field data.

For example, researchers from the Ecological Forecasting Laboratory at the University of South Carolina have teamed up with other institutions to install biomimetic sensors in the intertidal zone on rocky coasts around the world. These sensors measure temperature and pressure, from which one can deduce wave period, wave height, tidal range, and the aerial and submerged temperatures of intertidal animals. These sensors are affixed to a rocky substrate, typically in a bed of mussels, and they collect data to infer mussel temperatures. From the sensors, a heat budget model can be developed. Mussel temperature measurements at one marine station on the west coast of the United States showed that the maximum yearly mussel temperatures had increased from 2000 to 2007. Data demonstrated that one species of mussel does not survive if the temperature is above 38°C for only two hours. These shellfish die from warm temperatures during a portion of the tidal cycle, when they are exposed at low tide to solar radiation. High mussel temperatures often occur when air and water temperatures are highest, but at other locations, high mussel temperatures occur out of phase with temperature extremes.

Dr. Brian Helmuth of the University of South Carolina compared mussel temperatures from Santa Barbara, California, to Puget Sound, and determined that the yearly peak average temperatures and yearly maximum occurred in Puget Sound at the northernmost stations, as opposed to those in southern California.[6] What do these data suggest? First, they confirm that animal temperature does not fall in a linear fashion from the equator heading toward the poles. They also suggest that the effects of climate change are local, influenced by factors such as solar radiation, coastal geomorphology, wave, climate, tidal regime, tectonic forces, and so forth. In addition, short-term extreme temperature stresses may be responsible for the mortality of intertidal shellfish (and other organisms). Acute and temporary climate stresses may have permanent effects on the survivability of the organisms. The University of South Carolina group has developed models that forecast mussel temperatures around the world, and their forecasts have been correlated to known field conditions. Field surveys indicated that a particular species of barnacle moved northward from southern Portugal to Denmark between 1984 and 2005. This shift correlates with changes in the winter sea surface temperature, which also warmed and moved northward during the same period.[7]

In reviewing ecological forecasting models, one should consider the purpose of a forecast or trend analysis. The model's accuracy is a function of the level of detail in space and time. Furthermore, models that have been tested to reflect field conditions, are independently verifiable, and are based upon peer-reviewed literature are more likely to be accepted. However, modeling is not a substitute for field surveys and study.

In addition to ecological forecasts, other investigations seek to predict local climate change. The US Geological Survey (USGS) has forecast the effects of sea level rise on saltwater intrusion in coastal regions. The work has attempted to forecast, over a 100-year period, the potential for a rise in sea level to cause saltwater intrusion into specific coastal aquifers that the public relies on for drinking water. These salinity changes may make the water nonpotable. Such studies are important for communities to plan for, protect, and adapt to forecasted changes brought about as a result of climate change.

Global sea level rise is predicted to occur over the next 100 years and beyond as a result of density changes in seawater caused by thermal expansion and from contributions of melting ice sheets, including those covering Greenland, Antarc-

	LIFETIME	GWP TIME HORIZON		
	(Years)	20 Years	100 Years	500 Years
CARBON DIOXIDE	(Variable)	1	1	1
METHANE	12	72	25	7.6
NITROUS OXIDE	114	289	298	153
HFC-23 (HYDROFLUOROCARBON)	270	12,000	14,800	12,200
HFC-134A (HYDROFLUOROCARBON)	14	3,830	1,430	435
SULFUR HEXAFLUORIDE	3,200	16,300	22,800	32,600

TABLE 1 GLOBAL WARMING POTENTIAL (GWP) OF SELECTED GREENHOUSE GASES AND CALCULATED LIFETIMES
The complete list compares 62 chemical substances to carbon dioxide. CO_2 has a GWP of 1 and a GWP time horizon of 1 for each period compared to other substances listed. From the Intergovernmental Panel on Climate Change, Fourth Assessment Report (AR4), 2007. **www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf**.

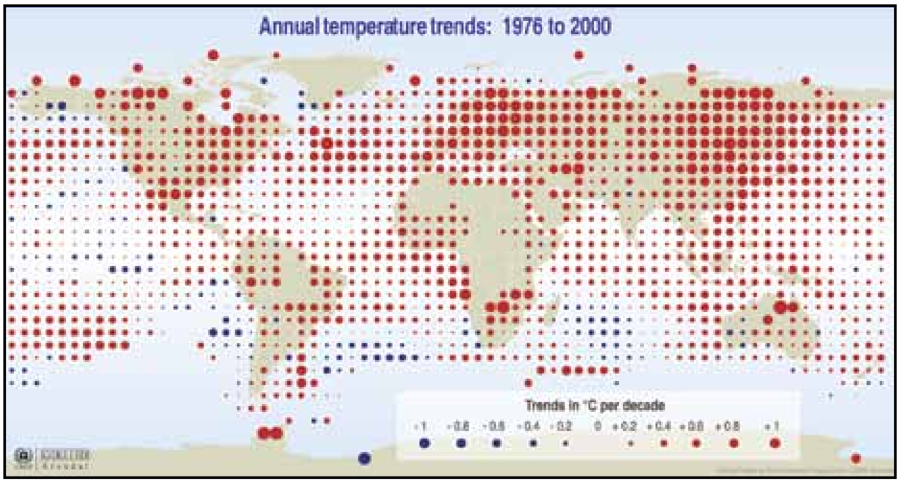

FIGURE 1 TEMPERATURE TRENDS (1976–2000)

Over the twentieth century there has been a consistent, large-scale warming of both the land and ocean surface, with largest increases in temperature over the mid and high latitudes of northern continents. This graphic shows the temperature changes from the years 1976 to 2000, as long-term deviations from the expected mean. The higher temperature increases over land surface–compared to ocean surface–are consistent with the observed changes in natural climate variations, such as the North Atlantic and Arctic Oscillations, and with the modeled pattern of greenhouse gas warming. Source: UN Environmental Programme, **http://maps.grida.no/go/graphic/temperature_trends_1976_2000**. Reprinted with permission.

tica, and various mountain glaciers. The IPCC has suggested that a rise between 0.2 and 0.7 meters is likely in the next hundred years. Some models have predicted a more rapid rise. Given such scenarios, the National Oceanographic and Atmosphere Administration, US Army Corps of Engineers, US Geological Survey, US Environmental Protection Agency, and others have sought to forecast the local or regional sea level rise on the coast of the United States and elsewhere. Local sea level rise is not uniform because of tectonic forces, including subsidence, uplift, glacial rebound, the slope of the continental shelf and nearshore slope, sediment supply, coastal geomorphology, wave height, and tide range.

A coastal vulnerability index has been developed by USGS to evaluate the potential for sea level rise to disrupt coastal communities. Localized forecasts of coastal erosion, flooding, salinity changes in estuaries, and other factors should be considered. For example, CERCLA sites in low-lying areas may be subject to inundation, which could result in changes in groundwater flow and chemistry as the result of a rising sea level. Site-specific forecasting of the impact of sea level rise on contaminant transport at such sites is vital, even where a record of decision (ROD) has been developed and a remedy is in place. Superfund cleanups should be subject to additional review as a result of forecasted changes in sea level or other effects of climate change.

The effect of pollution and runoff from development may provide subtle stresses that have the potential to interact with climate shifts, such as temperature, to adversely impact the health of biological systems. Water quality modelers should consider changes in temperature, precipitation, and chemistry suggested by high energy or extreme events. Traditionally, water quality modeling has focused on parameters such as 7Q10 flow; however, models should incorporate forecasts of temperature, rainfall, and runoff. In addition, forecasted changes in sedimentation, salinity, pH, and the relative energy of meteorological events should be considered when addressing pollutant loading. The physiological stress resulting from rapid climate change may interact with other stressors such as pollution, changes in land use, and competition with invasive species to result in mortality and the potential collapse of ecosystems. Climate change may force regulators to review water quality criteria necessary to protect aquatic life.

Because the range of species depends on many factors, of which climate variables are only one, it is insufficient to simply correlate species' range with environmental variables. One must also look to organisms as "filters" of their ambient environmental condition. The effects of change vary by species and by size. One approach may be to seek "indicator" species, that is, species that are representative of an ecosystem or ecozone and to study physiological changes as a result of environmental and climate variables. In choosing which organisms to model in ecological forecasts, organisms that provide structure to an ecosystem (such as trees, corals, kelp, and grasses in their respective ecosystems), should be considered as the structural species that set forth the climax of the respective ecosystem. In addition to these structural species, some of the more basic organisms at the lower portion of the ecosystem should also be considered, as well as other species (such as dominant predators) that shape ecosystems, as impacts to those organisms may precede structural failure of the larger ecosystem.

Ecological forecasting also can assist in predicting shifts in habitat for a range of economic species, such as fish, and non-economic species, including threatened and endangered plants and animals. Where habitat changes are forecast to occur, what decisions should a resource manager make to ensure the survival of such species? When the range or breeding area shifts beyond a preserve, state, or national jurisdiction, both national and international laws should anticipate how best to ensure the survival of a species. In addition, due to development, many preserves or large areas of habitat are biological islands that lack connectivity that would provide habitat as climate-induced shifts occur.

The Regulatory Response to Climate Change

As abrupt climate change occurs, are we willing to consider changes in our environmental management strategies, laws, and regulations in response to ecological forecasts? Are we willing to adopt environmental laws and policies to minimize the impact of climate change and to provide sufficient flexibility for adaptive strategies? Emphasis should be placed on providing forecasts that are produced at a useful scale in space and time. Forecasted impacts should be considered both short term and also out to at least 50 years. In environmental assessments (EAs) and environmental impact statements (EISs), pursuant to NEPA, an analysis of the impacts of a project should also be required using climate and ecological forecasts in the affected area. Detailed analysis should focus on the most likely climate scenarios where possible.

To be relevant to decision makers, future US climate legislation should assess the current environment and encourage research to develop methods of predicting climate impacts on a small scale and over usable time frames, so as to be relevant to decision makers. These forecasts would not only be of assistance to land managers and environmental agencies, but they could also apply to the financial and insurance industry and to agriculture. The United States should also address mitigation and adaptation to climate change.

As future international agreements develop, mechanisms should be in place to plan for and mitigate ecosystem damage from climate change. The 1992 UN Framework Convention on Climate Change made several findings. In Article Three, the Convention found, "The parties should take precautionary measures to anticipate, prevent, or minimize the causes of climate change and mitigate its adverse effects. . . . [A] . . . lack of full scientific certainty should not be used as a reason for postponing such measures."

Existing regulatory programs should consider climate and ecological forecasting. Many of the tools are in place; however, additional work remains to perform periodic detailed assessment of subtle changes in physiological stress and to utilize biomarkers where changes may precede mortality events. As the Earth's climate changes, there will be winners and losers. Will the winners be robust, invasive species where the ecosystem is dominated by large numbers but low species diversity? Will the losers be sensitive, more specialized species and diverse ecosystems?

On October 5, 2010, the White House Council on Environmental Quality released a report entitled "Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of the National Climate Change Adaptation Strategy." While the report paints with a broad brush, it sets forth policy goals and recommended action for the federal government to:

1. Encourage and mainstream adaptation planning across the federal government.
2. Improve integrated scientific decision making. As part of this goal, actions should be prioritized to address science gaps important to adaptation and to build translation to improve communication and apply science to meet the needs of decision makers.
3. Address climate change impacts that cross jurisdictional missions of individual federal agencies. Measures include protecting human health by addressing climate change and public health activities and building resilience to climate change in communities. The policy seeks to incorporate climate change risks into insurance mechanisms and develop a strategic action plan to reduce the impacts of climate change on the nation's fish, wildlife, and plant resources and their habitats.
4. Enhance efforts to lead and support international adoption of multilateral and bilateral activities and US foreign assistance programs.
5. Coordinate capabilities of the federal government to support adaptation and establish performance criteria for evaluating federal efforts. The CEQ report states, "The United States must adapt to climate change in order to safeguard people, places, and natural resources, both domestically and abroad."

Incorporating Relevant Forecasts Into Federal Law

It is the consensus of the scientific community that climate change is occurring, and the anthropogenic sources of GHGs are a contributor. The emerging field of ecological forecasting seeks to analyze oceanographic, geomorphic, climatic, and biological data to predict physiological stress on species. Such tools may forecast ecosystem response to climate change. In addition, modeling and forecasting physical parameters such as sea level rise, coastal erosion, saltwater intrusion, and water quality changes should be an integral part of climate forecasting. These forecasts should be incorporated into NEPA requirements and into other federal law. Ecological forecasts may also cause governmental regulators to re-evaluate water quality criteria to protect aquatic life. International agreements and US legislation should provide for mechanisms to plan for and mitigate ecosystem damage as the result of climate change. Regardless of attempts to reduce or sequester GHGs, scientific consensus is that the climate is changing rapidly. Thus, climate and ecological forecasting offers the opportunity to develop adaptive strategies and mitigate dislocation and damage to human and environmental systems. ◆

Endnotes

1. *Daubert v. Merrell Dow Pharmaceutical, Inc.*, 509 U.S. 579 (1993).

2. Naomi Oreskes, *The Scientific Consensus on Climate Change*, 306 Science 1686 (2004).

3. www.unep.org/climatechange; www.ipcc.ch, www.metoffice.gov.uk/climatechange/science/explained.

4. Gerald A. Meehl et al., *How Much More Global Warming and Sea Level Rise?* 307 Science 5716 (2005).

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6. Brian Helmuth, Cristopher D.G. Harley, Patricia M. Halpin, Michael O'Donnell, Gretchen E. Hofmann, & Carol A. Blanchette, *Climate Change and Latitudinal Patterns of Intertidal Thermal Stress*, 298 Science 1015–17 (2002).

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