The Human Impact on Climate

by Thomas R. Karl and
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How much of a disruption do we cause? The much-awaited answer could be ours by 2050, but only if nations of the world commit to long-term climate monitoring now

The balance of evidence suggests a discernible human influence on global climate.” With these carefully chosen words, the Intergovernmental Panel on Climate Change (jointly supported by the World Meteorological Organization and the United Nations Environmental Program) recognized in 1995 that human beings are far from inconsequential when it comes to the health of the planet. What the panel did not spell out—and what scientists and politicians dispute fiercely—is exactly when, where and how much that influence has and will be felt.

So far the climate changes thought to relate to human endeavors have been relatively modest. But various projections suggest that the degree of change will become dramatic by the middle of the 21st century, exceeding anything seen in nature during the past 10,000 years. Although some regions may benefit for a time, overall the alterations are expected to be disruptive or even severe. If researchers could clarify the extent to which specific activities influence climate, they would be in a much better position to suggest strategies for ameliorating the worst disturbances. Is such quantification possible? We think it is and that it can be achieved by the year 2050—but only if that goal remains an international priority.

Despite uncertainties about details of climate change, our activities clearly affect the atmosphere in several troubling ways. Burning of fossil fuels in power plants and automobiles ejects particles and gases that alter the composition of the atmosphere. Visible pollution from sulfur-rich fuels includes micron-size particles called aerosols, which often cast a milky haze in the sky.

A New York City pedestrian fights heavy rains from Hurricane Floyd, which hit the area this past September. Downpours associated with tropical storms are just one type of severe weather that worsens with global warming.

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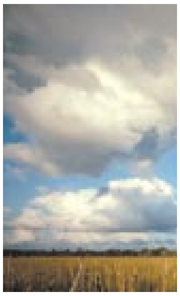

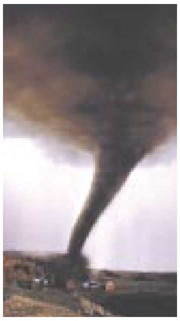

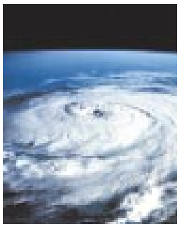

CORBIS (*hurricane*); JIM ZUCKERMAN *Corbis* (*tornado*); DAVID MUENCH *Corbis* (*clouds*); ROBERT PICKETT *Corbis* (*snowflake*)

These aerosols temporarily cool the atmosphere because they reflect some of the sun's rays back to space, but they stay in the air for only a few days before rain sweeps them to the planet's surface.

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Certain invisible gases deliver a more lasting impact. Carbon dioxide remains in the atmosphere for a century or more. Worse yet, such greenhouse gases trap some of the solar radiation that the planet would otherwise radiate back to space, creating a "blanket" that insulates and warms the lower atmosphere.

Indisputably, fossil-fuel emissions alone have increased carbon dioxide concentrations in the atmosphere by about 30 percent since the start of the Industrial Revolution in the late 1700s. Oceans and plants help to offset this flux by scrubbing some of the gas out of the air over time, yet carbon dioxide concentrations continue to grow. The inevitable result of pumping the sky full of greenhouse gases is global warming. Indeed, most scientists agree that the earth's mean temperature has risen at least 0.6 degree Celsius (more than one degree Fahrenheit) over the past 120 years, much of it caused by the burning of fossil fuels.

The global warming that results from the greenhouse effect dries the planet by evaporating moisture from oceans, soils and plants. Additional moisture in the atmosphere provides a swollen reservoir of water that is tapped by all precipitating weather systems, be they tropical storms, thundershowers, snowstorms or frontal systems. This enhanced water cycle brings on more severe droughts in dry areas and leads to strikingly heavy rain or snowfall in wet regions, which heightens the risk of flooding. Such weather patterns have burdened many parts of the world in recent decades.

Human activities aside from burning fossil fuels can also wreak havoc on the climate system. For instance, the conversion of forests to farmland eliminates trees that would otherwise absorb carbon from the atmosphere and reduce the greenhouse effect. Fewer trees also mean greater rainfall runoff, thereby increasing the risk of floods.

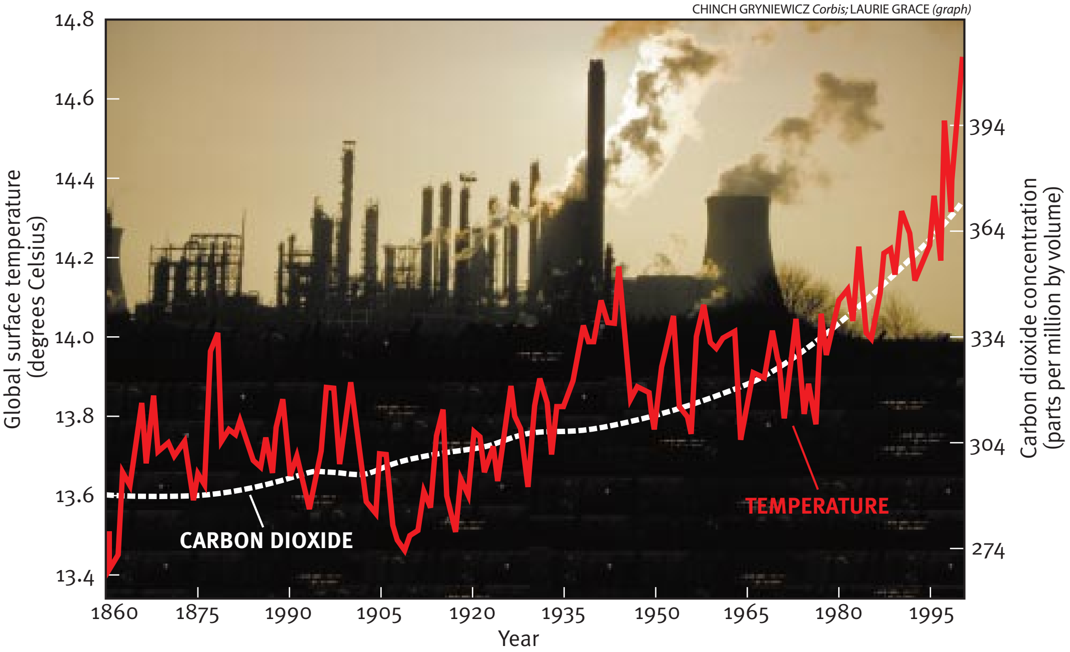
It is one thing to have a sense of the factors that can bring about climate change. It is another to know how the human activity in any given place will affect the local and global climate. To achieve that aim, those of us who are concerned about the human influence on climate will have to be able to construct more accurate climate models than have ever been designed before. We will therefore require the technological muscle of supercomputers a million times faster than those in use today. We will also have to continue to disentangle the myriad interactions among the oceans, atmosphere and biosphere to know exactly what variables to feed into the computer models.

Most important, we must be able to demonstrate that our models accurately simulate past and present climate change before we can rely on models to predict the future. To do that, we need long-term records. Climate simulation and prediction will come of age only with an ongoing record of changes as they happen.

Computers and Climate Interactions

For scientists who model climate patterns, everything from the waxing and waning of ice ages to the desertification of central Africa plays out inside the models run on supercomputers. Interactions among the components of the climate system—the atmosphere, oceans, land, sea ice, freshwater and biosphere—behave according to

CHINCH GRYNIEWICZ *Corbis;* LAURIE GRACE (*graph*)



Burning fossil fuels (*photograph*) has increased atmospheric concentrations of carbon dioxide (*white dashes*) and has contributed to a rise in global surface temperatures during the past 140 years (*red line*).

physical laws represented by dozens of mathematical equations. Modelers instruct the computers to solve these equations for each box in a three-dimensional grid that covers the globe. Because nature is not constrained by boxes, the chore is not only to incorporate the correct mathematics within each box but also to describe appropriately the transfer of energy and mass into and out of the boxes.

The computers at the world's preeminent climate-modeling facilities can perform between 10 and 50 billion operations per second, but with so many evolving variables, the simulation of a single century can take months. The time it takes to run a simulation, then, limits the resolution (or number of boxes) that can be included within climate models. For typical models designed to mimic the detailed evolution of weather systems, boxes in the three-dimensional grid measure about 250 kilometers (156 miles) square in the horizontal direction and one kilometer in the vertical. Tracking patterns within smaller areas thus proves especially difficult.

Even the most sophisticated of our current global models cannot directly simulate conditions such as cloud cover and the formation of rain. Powerful thunderstorm clouds that can unleash sudden downpours often operate on scales of less than 10 kilometers, and raindrops condense at submillimeter scales. Because each of these events happens in a region smaller than the volume of the smallest grid unit, their characteristics must be inferred by elaborate statistical techniques.

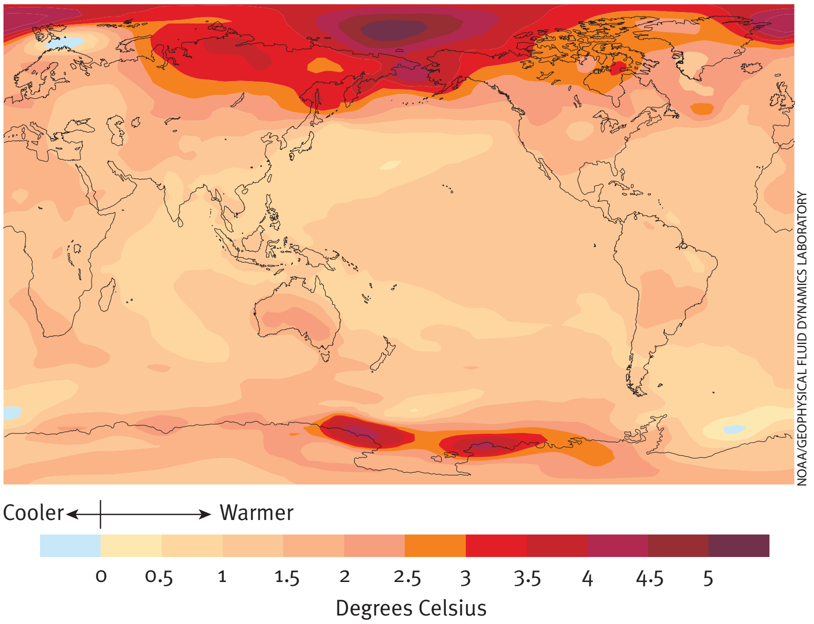
Such small-scale weather phenomena develop randomly. The frequency of these random events can differ extensively from place to place, but most agents that alter climate, such as rising levels of greenhouse gases, affect all areas of the planet much more uniformly. The variability of weather will increasingly mask large-scale climate activity as smaller regions are considered. Lifting that mask thus drains computer time, because it requires running several simulations, each with slightly different starting conditions. The climate features that occur in every simulation constitute the climate "signal," whereas those that are not reproducible are considered weather-related climate "noise."

Conservative estimates indicate that computer-processing speed will have increased by well over a million times by 2050. With that computational power, climate modelers could perform many simulations with different starting conditions and better distinguish climate signals from climate noise. We could also routinely run longer simulations of hundreds of years with less than one-kilometer horizontal resolution and an average of 100-meter vertical resolution over the oceans and atmosphere.

Faster computers help to predict climate change only if the mathematical equations fed into them perfectly describe what happens in nature. For example, if a model atmosphere is simulated to be too cold by four degrees C (not uncommon a decade ago), the simulation will indicate that the atmosphere can hold about 20 percent less water than its actual capacity—a significant error that renders meaningless any subsequent estimates of evaporation and precipitation. Another problem is that we do not yet know how to replicate adequately all the processes that influence climate, such as hiccups in the carbon cycle and modifications in land use. What is more, these changes can initiate feedback cycles that, if ignored, can lead the model astray. Raising temperature, for example, sometimes enhances another variable, such as moisture content of the atmosphere, which in turn amplifies the original perturbation. (In this case, more moisture in the air causes in-

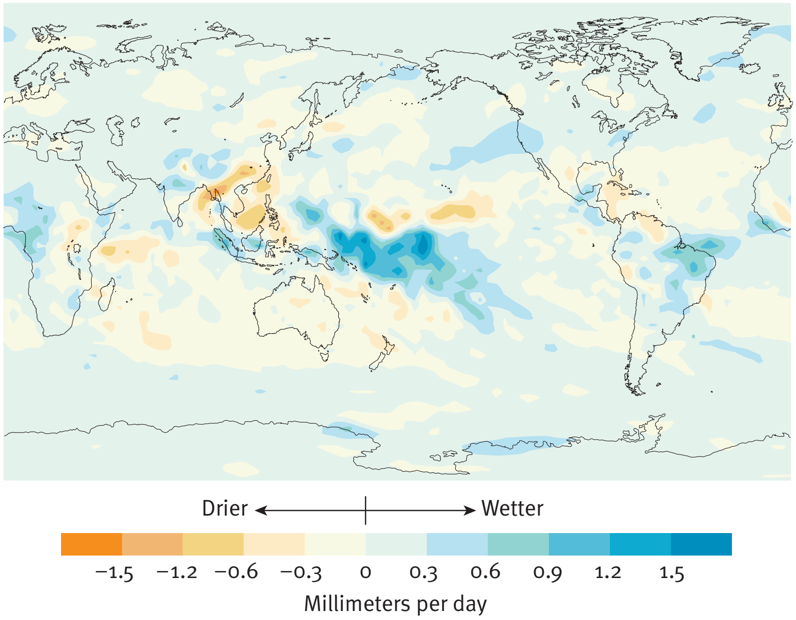
CLIMATE CHANGE BY 2050

TEMPERATURE



NOAA/GEOPHYSICAL FLUID DYNAMICS LABORATORY

PRECIPITATION



Global warming of up to five degrees Celsius (*top*) could enhance precipitation (*bottom*) in much of the world by the middle of the 21st century. These simulations use 1992 estimates by the Intergovernmental Panel on Climate Change for emissions of greenhouse gases and sulfate aerosols between the years 2000 and 2050.

NEIL RABINOWITZ *Corbis*

Deforestation changes climate in more than one way: Cutting down trees makes the forest less able to scrub carbon dioxide out of the air. Dark-colored forests also absorb more solar energy and keep the region warmer and more moist than do the light-colored areas left when the trees are gone.

creased warming because water vapor is a powerful greenhouse gas.)

Researchers are only beginning to realize how much some of these positive feedbacks influence the planet's life-giving carbon cycle. The 1991 eruption of Mount Pinatubo in the Philippines, for instance, belched out enough ash and sulfur dioxide to cause a temporary global cooling as those compounds interacted with water droplets in the air to block some of the sun's incoming radiation. This depleted energy can inhibit carbon dioxide uptake in plants.

Using land in a different way can perturb continental and regional climate systems in ways that are difficult to translate into equations. Clearing forests for farming and ranching brightens the land surface. Croplands are lighter-colored than dark forest and thus reflect more solar radiation, which tends to cool the atmosphere, especially in autumn and summer.

Dearth of Data

Climate simulations can never move out of the realm of good guesses without accurate observations to validate them and to show that the models do indeed reflect reality. In other words, to reduce our uncertainty about the sensitivity of the climate system to human activity, we need to know how the climate has changed in the past. We must be capable of adequately simulating conditions before the Industrial Revolution and especially since that time, when humans have altered irrevocably the composition of the atmosphere.

To understand climate from times prior to the development of weather-tracking satellites and other instruments, we rely on indicators such as air and chemicals trapped in ice cores, the width of tree rings, coral growth, and sediment deposits on the bottoms of oceans and lakes. These snapshots provide us with information that aids in piecing together past conditions. To truly understand the present climate, however, we require more than snapshots of physical, chemical and biological quantities; we also need the equivalent of long-running videotape records of the currently evolving climate. Ongoing measurements of sea ice, snow cover, soil moisture, vegetative cover, and ocean temperature and salinity are just some of the variables involved.

But the present outlook is grim: no U.S. or international institution has the mandate or resources to monitor long-term climate. Scientists currently compile their interpretations of climate change from large networks of satellites and surface sensors such as buoys, ships, observatories, weather stations and airplanes that are being operated for other purposes, such as short-term weather forecasting. As a result, depictions of past climate variability are often equivocal or missing.

The National Oceanic and Atmospheric Administration operates many of these networks, but it does not have the resources to commit to a long-term climate-monitoring program. Even the National Aeronautics and Space Administration's upcoming Earth Observing System, which entails launching several sophisticated satellites to monitor various aspects of global systems, does not include the continuity of a long-term climate observation program in its mission statement.

Whatever the state of climate monitoring may be, another challenge in the next decade will be to ensure that the quantities we do measure actually represent real multidecadal changes in the environment. In other words, what happens if we use a new camera or point it in a different direction? For instance, a satellite typically lasts only four years or so before it is replaced with another in a different orbit. The replacement usually has new instruments and observes the earth at a different time of day. Over a period of years, then, we end up measuring not only climate variability but also the changes introduced by observing the climate in a different way. Unless precautions are taken to quantify the modifications in observing technology and sampling methods before the older technology is replaced, climate records could be rendered useless because it will be impossible to compare the new set of data with its older counterpart.

Future scientists must be able to evaluate their climate simulations with unequivocal data that are properly archived. Unfortunately, the data we have archived from satellites and critical surface sensors are in jeopardy of being lost forever. Long-term surface observations in the U.S. are still being recorded on outdated punched paper tapes or are stored on decaying paper or on old computer hardware. About half the data from our new Doppler radars are lost because the recording system relies on people to deal with the details of data preservation during severe weather events, when warnings and other critical functions are a more immediate concern.

Can We Realize the Vision?

Over the next 50 years we can broadly understand, if we choose to, how human beings are affecting the global, regional and even small-scale aspects of climate. But waiting until then to take action would be foolhardy. Long lifetimes of carbon dioxide and other greenhouse gases in the atmosphere, coupled with the climate's typically slow response to evolving conditions, mean that even if we cut back on harmful human activities today, the planet very likely will still undergo substantial change.

Glaciers melting in the Andes highlands and elsewhere are already confirming the reality of a warming planet. Rising sea level—and drowning coastlines—testify to the projected global warming of perhaps two degrees C or more by the end of the next century. Climate change will in all likelihood capture the most attention when its effects exacerbate other pressures on society. The spread of settlements into coastal regions and low-lying areas vulnerable to flooding is just one of the initial difficulties that we will most likely face. But as long as society can fall back on the uncertainty of human impact on climate, legislative mandates for changing standards of fossil-fuel emissions or forest clear-cutting will be hard fought.

The need to foretell how much we influence our world argues for doing everything we can to develop comprehensive observing and data-archiving systems now. The resulting information could feed models that help make skillful predictions of climate several years in advance. With the right planning we could be in a position to predict, for example, exactly how dams and reservoirs might be better designed to accommodate anticipated floods and to what extent greenhouse gas emissions from new power plants will warm the planet.

Climate change is happening now, and more change is certain. We can act to slow it down, and we can sensibly plan for it, but at present we are doing neither. To anticipate the true shape of future climate, scientists must overcome the obstacles we have outlined above. The need for greater computer power and for a more sophisticated understanding of the nuances of climate interactions should be relatively easy to overcome. The real stumbling block is the long-term commitment to global climate monitoring. How can we get governments to commit resources for decades of surveys, particularly when so many governments change hands with such frequency?

If we really want the power to predict the effects of human activity by 2050—and to begin addressing the disruption of our environment—we must pursue another path. We have a tool to clear such a path: the United Nations Framework Convention on Climate Change, signed by President George Bush in 1992. The convention binds together 179 governments with a commitment to remedy damaging human influence on global climate. The alliance took a step toward stabilizing greenhouse gas emissions by producing the Kyoto Protocol in 1997, but long-term global climate-monitoring systems remain unrealized. SA

FURTHER INFORMATION

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The United Nations Framework Convention on Climate Change and Kyoto Protocol updates are available at www.unfccc.org/ on the World Wide Web.

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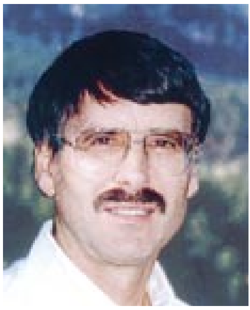

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