GLOBAL WARMING SPECIAL

Climate Science 101

BY BRUCE STUTZ

Global warming is a reality. The year 2004 was the fourth-hottest on record; NASA predicts that 2005 will be even worse. But how rapidly is the climate changing? And what does the future look like? To answer those questions, scientists need information about long periods of time over widely spread geographic regions. They use a range of tools to gather the data they need. Here are six:

1 The Ring Cycle

MOST OF US KNOW THAT BY COUNTING THE RINGS ON a cross-section of a tree trunk we can tell its age. But tree rings can tell much more. Each year's growth is made up of two rings: the first, a ring of a lighter shade of wood composed of large cells that develop during the spring growing season; the second, a dark ring of smaller cells that develop throughout the rest of the year, when the tree receives fewer nutrients. Since scientists know that a tree's growth is limited by the resource that is in shortest supply—the growth of desert trees, for instance, depends most on the availability of water—they can tell by comparing the widths of the tree rings what the climate was like during each spring growing season.

Scientists called dendrochronologists (*dendron* is Greek for tree, and *chronos* means time) use hollow drills the diameter of a soda straw to extract cores from tree trunks throughout a forest. By comparing the ring widths they can develop a forest's climatic history. And by lining up the rings of dead trees with those of living ones scientists can extend that history back to the forest's beginnings, thereby learning what the climate was like when the forest began to grow and seeing the patterns of drought and temperature change. Climate scientists now have tree-ring data going back as far as 9,000 years.

2 Hot Air

CARBON DIOXIDE, WATER VAPOR, METHANE, NITROUS oxide, and chlorofluorocarbons in the earth's lower atmosphere prevent much of the warmth from each day's sunlight from radiating back into space, thus stabilizing the earth's temperature. Without them there would be a 60-degree Fahrenheit temperature difference between day and night. But by pumping more of these greenhouse gases into the atmosphere, we're preventing too much heat from escaping, throwing the earth's energy balance out of whack.

Until the 1950s, nobody knew where the CO_2 generated by human activity was stored after it left our smokestacks and tailpipes: atmosphere, oceans, plants? But then Charles Keeling of the California Institute of Technology began measuring atmospheric CO_2 in locations that were remote from sources of industrial emissions, such as Antarctica and the Mauna Loa volcano in Hawaii. Within two years Keeling's data showed that even in these pristine environments, CO_2 concentrations were rising each year to levels that could not be explained by natural variability, revealing for the first time that our industrial emissions were being stored, in part, in the atmosphere.

Readings from Mauna Loa indicate that the annual rise in CO_2 levels has accelerated over the past 50 years. Today CO_2 concentrations are higher than at any time in the past 400,000 years. The U.N. Intergovernmental Panel on Climate Change projects that without new controls on emissions, CO_2 levels may more than double by 2100, raising global temperatures by as much as 10.8 degrees Fahrenheit from their 1990 levels.

3 Bustin' Out All Over

AS ANY GARDENER KNOWS, IN THE NATURAL WORLD timing is everything. The study of the timing of recurring biological events is known as phenology. By systematizing the evidence, a phenologist hopes to see trends and relationships between, say, the time a tree's leaves appear, the time the moth that feeds on the leaves hatches, and the time the bird that feeds on the moth makes its migration. For animals as well as for plants, accurate timing is key to survival.

In the late eighteenth century, European scientists began taking phenological data seriously. Later, as concerns rose that the world's climate was changing, scientists began to look at their records of animal and plant phenology and wondered whether these had been changing relative to rising global temperatures. While the studies are fairly new, the results all show that global warming has been resetting many biological clocks.

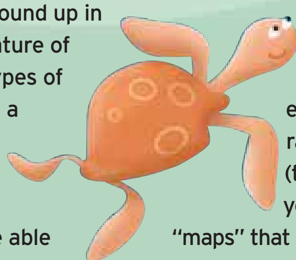
Mark D. Schwartz of the University of Wisconsin has found that between 1959 and 1993, the first-leaf date for lilacs had advanced 5.4 days and that the first bloom appeared 4.2 days sooner. The cherry trees in Washington, D.C. now bloom as much as a week earlier than they did 30 years ago. These don't appear to be isolated deviations. Studies of more than 1,500 species worldwide show that on average frogs mate, birds nest, and trees bud more than a week earlier than they did 50 years ago.

ILLUSTRATION BY BRUCIE ROSCH

4 Core Values

ABOUT 1.8 MILLION YEARS AGO, GREAT MOUNTAINS of ice began to form, blanketing the planet. In this grip of continuous cold, long periods of time passed when the annual snowfall didn't melt. As more snow fell, the deeper layers compacted into ice and the ice sheets grew thicker. The planet's climate began to warm 8,000 years ago, melting the ice at lower latitudes, but in the Arctic and in Antarctica, ancient ice still remains. In those places, scientists drill to depths of up to two miles to extract long cores of ice dating back 740,000 years.

By carefully analyzing the oxygen atoms bound up in the ice, scientists can determine the temperature of the air when those atoms fell as snow. Two types of oxygen atoms are common on earth; one has a heavier nucleus than the other. Water molecules containing light oxygen evaporate more readily than heavy ones. But as the air temperature rises, more heavy molecules are able to make the jump from ocean to atmosphere. When the water vapor falls as snow and accumulates on polar ice sheets, each year's snowfall serves as a built-in temperature gauge: Layers that are relatively abundant in heavy oxygen formed during warmer periods than those with very little. Scientists measure the ratio of light to heavy oxygen at regular intervals along an ice core, and from these data they can create a time line of climate change. Their findings reveal that climate varies over long periods, but at no point has the warming been as abrupt as it has been since the Industrial Revolution. Pockets of air trapped within the ice tell a similar story: CO_2 concentrations have risen most rapidly since we started burning fossil fuels.



5 Snow White

MORE THAN ANY OTHER PLACE ON EARTH, THE POLES are feeling the consequences of global warming. The increase in temperature has already altered the formation, thickness, and extent of ice on land and water. Snow reflects sunlight—which is why it's white. Researchers refer to this surface reflectivity as "albedo" (the term's Latin root, *albus*, means whiteness). A perfect albedo—that is, where all radiation from the sun is reflected—is 1, but as a whole the earth's albedo averages out to 0.31. Climate scientists spend a great deal of time measuring albedo because it's a key indicator of the earth's energy balance.

Since the advent of satellite technology scientists have been able to look down at the earth and take snapshots of the invisible energy radiated and reflected by the earth's surface (the technology is not so different from that of your digital camera). This data is used to create "maps" that show changes in the albedo in different areas.

The farther one travels toward the poles, the greater the consequences of changes in albedo. In the Arctic, for instance, summer is one six-month-long day, during which exposed surface areas are bombarded with sunlight around the clock. When huge masses of ice in the polar oceans break up, water is left exposed. Since the ocean has a lower albedo than the land (it absorbs more radiation), the warming is quicker, the melting more intense. Worse, winds stir the heat into the ocean, and the stored heat seeps beneath the floating ice shelves, attacking them from below. So summer lasts longer, spring comes sooner, and the winter between doesn't last long enough for ice and snow covers to re-form. In the winter of 2004 the Arctic ice pack extended over 15 percent less of the ocean than it did 30 years ago.

6 Poor Circulation

LIKE THE ORDERLY FLOW OF BLOOD THROUGH THE body, ocean and air currents distribute energy around the globe, regulating planetary temperature and climate. Two primary factors control the process: wind and water density. Winds direct surface water, while water density, which is controlled by temperature and salinity (the colder and saltier, the denser), dictates when and where currents descend to flow deep beneath the surface. The entire exchange operates like a giant conveyor belt. In the Atlantic Ocean, wind pushes warm, salty water north, where it cools—releasing heat to the atmosphere—and begins to sink and flow in the opposite direction, sucking more warm water northward. But as global warming melts the polar ice caps, the influx of freshwater may reduce the salinity of the North Atlantic, lowering its density enough to stop it from sinking. If that happens, the conveyor belt could shut down.

The idea of the oceans and atmosphere as a single, interconnected planetary thermostat is several decades old, and scientists have developed tools that allow them to watch the thermostat in action. Satellites detect infrared radiation from the oceans, allowing scientists to measure surface temperatures over large areas. Buoys tethered to the ocean floor have sensors that record the temperature, flow direction, and speed of deep water and surface currents. And free-floating devices rigged with a GPS system let scientists map the movement of a single ocean current; some even have salinity and temperature sensors. Together, these technologies help scientists understand exactly how earth regulates its body temperature, and will allow them to model more precisely what will happen as the earth warms.

Disturbingly, the oceans store four times more energy than the air, and satellite measurements over the past decade reveal that our seas are absorbing more heat than ever before. Scientists don't yet know for certain how long it will be before the oceans inevitably release this excess heat back into the atmosphere, but current models predict that we may have as few as 10 years before it happens. When it does, atmospheric temperatures are expected to jump by 1.1 degrees Fahrenheit, adding to the already quickening pace of global warming.