The NEW ENGLAND JOURNAL of MEDICINE

Perspective

OCTOBER 6, 2005

Climate Change and Human Health

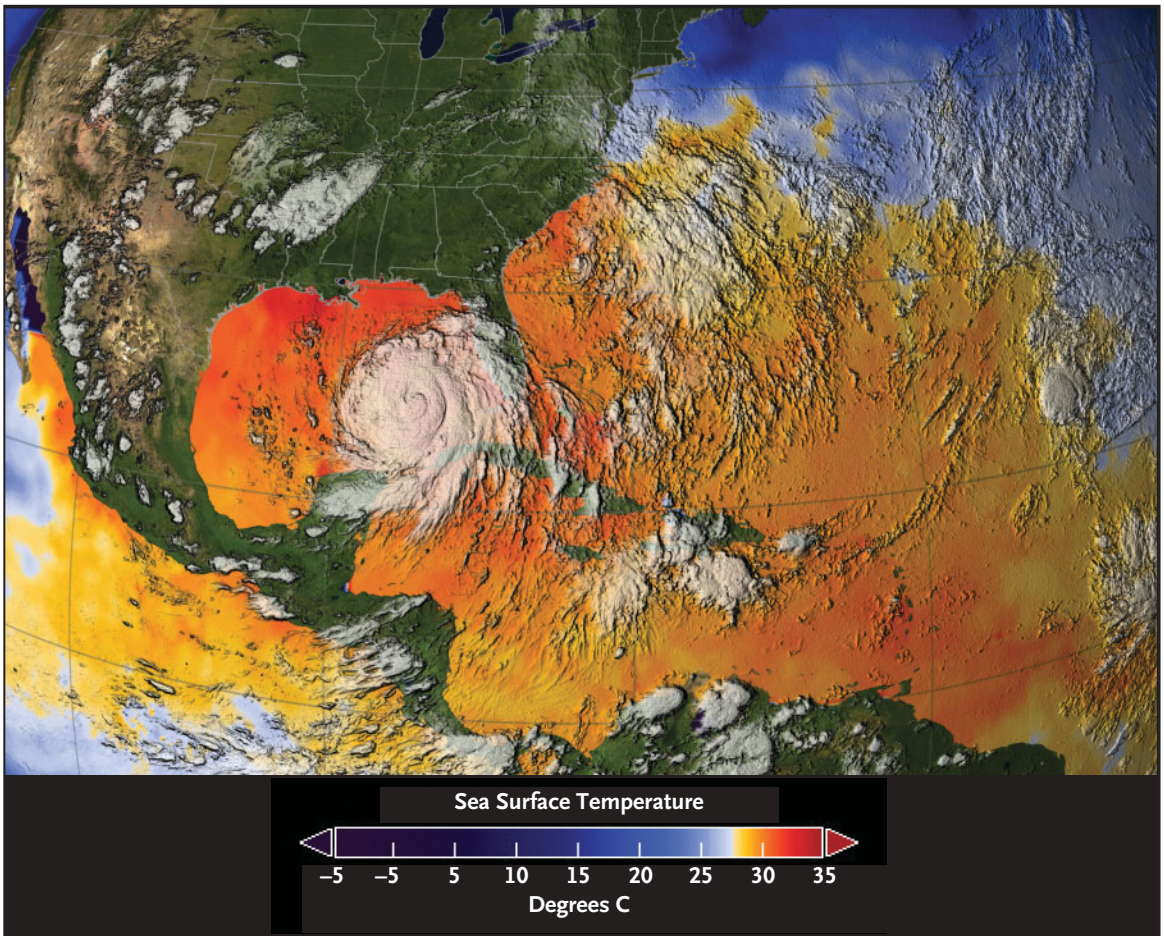
Paul R. Epstein, M.D., M.P.H.

In 1998, Hurricane Mitch dropped six feet of rain on Central America in three days. In its wake, the incidence of malaria, dengue fever, cholera, and leptospirosis soared. In 2000, rain and three cyclones inundated Mozambique for six weeks, and the incidence of malaria rose fivefold. In 2003, a summer heat wave in Europe killed tens of thousands of people, wilted crops, set forests ablaze, and melted 10 percent of the Alpine glacial mass.

This summer's blistering heat wave was unprecedented with regard to intensity, duration, and geographic extent. More than 200 U.S. cities registered new record high temperatures. In Phoenix, Arizona, sustained temperatures above 100°F (38°C) for 39 consecutive days, including a week above 110°F (43°C), took a harsh toll on the homeless. Then came Hurricane Katrina, gathering steam from the heated Gulf of Mexico and causing devastation in coastal communities.

These sorts of extreme weather events reflect massive and ongoing changes in our climate to which biologic systems on all continents are reacting. So concluded the United Nations Intergovernmental Panel on Climate Change,[1] a collaboration of more than 2000 scientists from 100 countries. In 2001, the panel concluded that humans are playing a major role in causing these changes, largely through deforestation and the combustion of fossil fuels that produce heat-trapping gases such as carbon dioxide.

Since 2001, we've learned substantially more. The pace of atmospheric warming and the accumulation of carbon dioxide are quickening; polar and alpine ice is melting at rates not thought possible several years ago[2]; the deep ocean is heating up, and circumpolar winds are accelerating; and warming in the lower atmosphere is retarding the repair of the protective "ozone shield" in the stratosphere. Moreover, ice cores that are drilled in Greenland indicate that the climate can change abruptly. Given the current rate of carbon dioxide buildup and the projected degree of



Hurricane Katrina Passing over the Gulf of Mexico

The map shows the three-day average of sea-surface temperatures from August 25, 2005, through August 27, 2005, and Hurricane Katrina growing in strength and breadth as it passes over the unusually warm Gulf of Mexico. Yellow, orange, and red areas are at or above 82° F (27.8° C, the temperature required for hurricanes to strengthen). Since the 1970s, the number of category 4 and 5 hurricanes has increased as sea temperatures have risen.

From the Scientific Visualization Studio of the National Aeronautics and Space Administration.

global warming, we are entering uncharted seas.

As we survey these seas, we can see some of the health effects that may lie ahead if the increase in very extreme weather events continues.[3] Heat waves like the one that hit Chicago in 1995, killing some 750 people and hospitalizing thousands, have become more common.[1] Hot, humid nights, which have become more frequent with global warming, magnify the effects. The 2003 European heat wave — involving temperatures that were 18°F (10°C) above the 30-year average, with no relief at night — killed 21,000 to 35,000 people in five countries.

But even more subtle, gradual climatic changes can damage human health. During the past two decades, the prevalence of asthma in the United States has quadrupled, in part because of climate-related factors. For Caribbean islanders, respiratory irritants come in dust clouds that emanate from Africa's expanding deserts and are then swept across the Atlantic by trade winds accelerated by the widening pressure gradients over warming oceans. Increased levels of plant pollen and soil fungi may also be involved. When ragweed is grown in conditions with twice the ambient level of carbon dioxide, the stalks sprout 10 percent taller than controls but produce 60 percent more pollen. Elevated carbon dioxide levels also promote the growth and sporulation of some soil fungi, and diesel particles help to deliver these aeroallergens deep into

our alveoli and present them to immune cells along the way.

The melting of the earth's ice cover has already become a source of physical trauma. In Alaska, Inuits report an increase in accidents caused by walking on thin ice.[2] Ocean warming and Arctic thawing are also spawning severe winter storms and hazardous travel conditions in the continental United States. Although tropical sea surfaces are warming and becoming saltier, parts of the North Atlantic are freshening from melting polar ice and increased amounts of rain falling at high latitudes. Contrasting barometric pressures over changing oceans increase winds and propel storms.

Meanwhile, in the past three decades, widening social inequities and changes in biodiversity — which alter the balance among predators, competitors, and prey that help keep pests and pathogens in check — have apparently contributed to the resurgence of infectious diseases. Global warming and wider fluctuations in weather help to spread these diseases: temperature constrains the range of microbes and vectors, and weather affects the timing and intensity of disease outbreaks.[4] Disease-bearing ticks in Sweden are moving northward as winters become warmer, and models project a similar shift in the United States and Canada. The encroachment of human housing on wilderness and reductions in the populations of predators of deer and competitors of mice are largely responsible for the current spread of Lyme disease.

Mosquitoes, which can carry many diseases, are very sensitive to temperature changes. Warming of their environment — within their viable range — boosts their rates of reproduction and the number of blood meals they take, prolongs their breeding season, and shortens the maturation period for the microbes they disperse. In highland regions, as permafrost thaws and glaciers retreat, mosquitoes and plant communities are migrating to higher ground.[5]

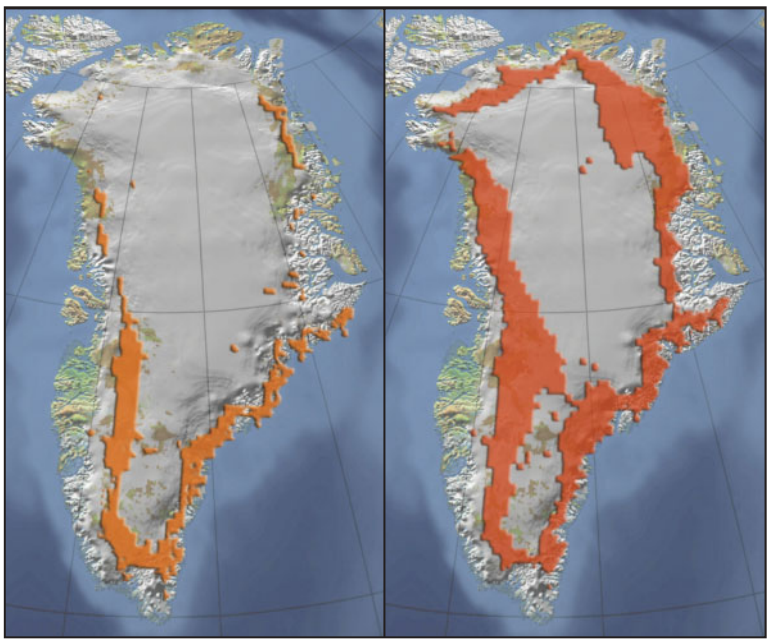
During the hot, arid summer, West Nile virus traveled across the country, infecting 230 species of animals.

The increased weather variability that accompanies climate instability contributed to the emergence of both the hantavirus pulmonary syndrome and West Nile virus in the United States. Six years of drought in the Southwest apparently reduced the populations of predators, and early heavy rainfall in 1993 produced a bounty of piñon nuts and grasshoppers for rodents to eat. The resulting legions of white-footed mice heralded the appearance of hantavirus in the Americas. The origin of the 1999 outbreak of West Nile virus in New York City remains a mystery, but city-dwelling, bird-biting *Culex pipiens* mosquitoes thrive in shallow pools of foul water that remain in drains during droughts. When dry springs yield to sweltering summers, viral development accelerates and, with it, the cycle of mosquito-to-bird transmission. During the hot, arid summer of 2002, West Nile virus traveled across the country, infecting 230 species of animals, including 138 species of birds, along the way. Many of the affected birds of prey normally help to rein in rodent populations that can spread hantaviruses, arenaviruses, and yersinia and leptospira bacteria, as well as ticks infected with *Borrelia burgdorferi*.

Extremely wet weather may bring its own share of ills. Floods are frequently followed by disease clusters: downpours can drive rodents from burrows, deposit mosquito-breeding sites, foster fungus growth in houses, and flush pathogens, nutrients, and chemicals into waterways. Milwaukee's cryptosporidium outbreak, for instance, accompanied the 1993 floods of the Mississippi River, and norovirus and toxins spread in Katrina's wake. Major coastal storms can also trigger harmful algal blooms ("red tides"), which can be toxic, help to create hypoxic "dead zones" in gulfs and bays, and harbor pathogens.

Prolonged droughts, for their part, can weaken trees' defenses against infestations and promote wildfires, which can cause injuries, burns, respiratory illness, and deaths. Shifting weather patterns are jeopardizing water quality and quantity in many countries, where groundwater systems are already being overdrawn and underfed. Most montane ice fields are predicted to disappear during this century — removing a primary source of water for humans, livestock, and agriculture in some parts of the world.

A still greater threat to human health comes from illnesses affecting wildlife, livestock, crops, forests, and marine organisms. The Millennium Ecosystem As-



Increase from 1992 (Left) to 2002 (Right) in the Amount of the Greenland Ice Sheet Melted in the Summer.

The extent of seasonal melting on the Greenland ice sheet has been observed by satellite since 1979. The melt zone (orange), where summer warmth turns snow and ice around the edges of the ice sheet into slush and water, has been expanding inland and to record-high elevations in recent years. When the meltwater seeps through cracks in the ice sheet, it may accelerate melting and allow ice to slide more easily over bedrock, speeding its movement to the sea. In addition to contributing to a rising sea level, this process adds freshwater to the ocean, with potential effects on ocean circulation and regional climate.

sessment of 2005 revealed that 60 percent of the resources and life-support systems examined — from fisheries to fresh water — are already in decline or are being used in unsustainable ways. The resulting biologic impoverishment may have important consequences for our air, food, and water.

Crops are being confronted with more volatile weather, vanishing pollinators, and the proliferation of pests and pathogens. One fungal disease, soybean rust, is thought to have been ushered into the United States by Hurricane Ivan last fall. Warmth and moisture will favor its propagation.

And many habitats are not faring well. Our coastal zones, for example, are in trouble: coral reefs are suffering from warming-induced "bleaching," excess waste, physical damage, overfishing, and fungal and bacterial diseases. Reefs provide a buffer against storms and groundwater salinization and offer protection for fish, the primary protein source for many inhabitants of island nations. One reef resident, the cone snail, produces a peptide that is 1000 times as potent as morphine and that is not addictive. We may never know what other potential treatments will be lost as reefs deteriorate.

All in all, it would appear that we may be underestimating the breadth of biologic responses to changes in climate. Treating climate-related ills will require preparation, and early-warning systems forecasting extreme weather can help to reduce casualties and curtail the spread of disease. But primary prevention would require halting the extraction, mining, transport, refining, and combustion of fossil fuels — a transformation that many experts believe would have innumerable health and environmental benefits and would help to stabilize the climate.

The good news is that we may also be underestimating the economic benefits of the clean-energy transition. When the financial incentives are adequate, renewable energy, energy-efficient and hybrid technologies, "green buildings," and expanded public transportation systems can constitute an engine of growth for the 21st century.

An interview with Dr. Epstein can be heard at www.nejm.org.

Dr. Epstein is the associate director of the Center for Health and the Global Environment, Harvard Medical School, Boston.

1. Houghton JT, Ding Y, Griggs DJ, et al., eds. Climate change 2001: the scientific basis: contribution of the Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge, England: Cambridge University Press, 2001.
2. Hassol SJ. ACIA, Impacts of a warming Arctic: arctic climate impact assessment. Cambridge, England: Cambridge University Press, 2004.
3. Leaf A. Potential health effects of global climatic and environmental changes. N Engl J Med 1989;321:1577-83.
4. McMichael AJ, Campbell-Lendrum DH, Corvalán CF, et al., eds. Climate change and human health: risks and responses. Geneva: World Health Organization, 2003:250.
5. Epstein PR, Diaz HF, Elias S, et al. Biological and physical signs of climate change: focus on mosquito-borne diseases. Bull Am Meteorol Soc 1998;78:409-17.

Map by Clifford Grabhorn, from the Arctic Climate Impact Assessment.