PERSPECTIVES: MEDICINE

Climate and Health

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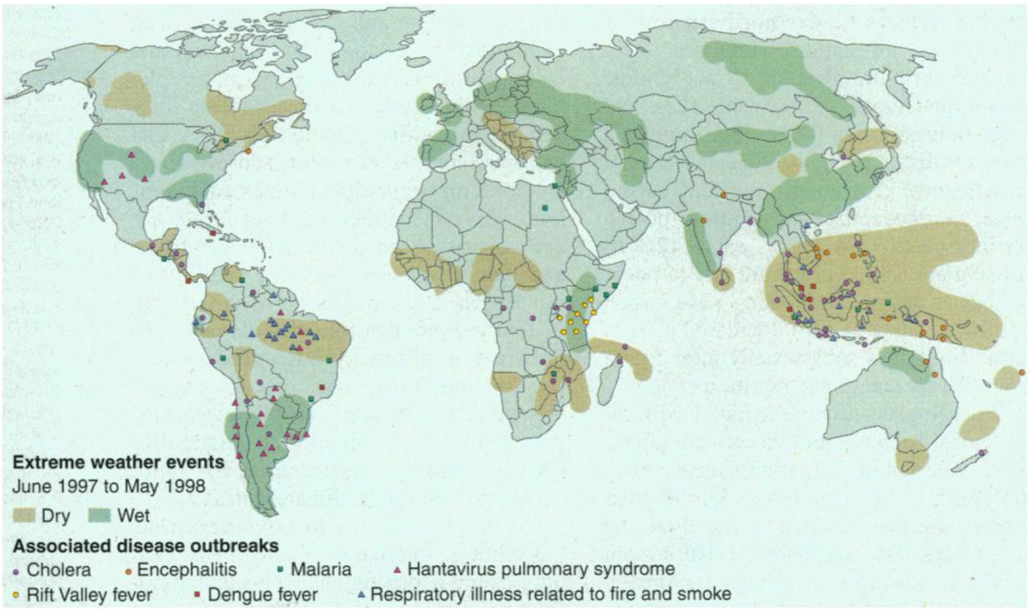
Extreme weather events—unusually heavy rainfall or long periods of drought—have a profound impact on public health, particularly in developing countries, and the aftershocks are rippling through economies worldwide (*1*). For example, Hurricane Mitch—nourished by a warmed Caribbean—hit Central America in November 1998, killing more than 11,000 people and causing damage exceeding $5 billion. The intense precipitation and flooding associated with the hurricane spawned a cluster of disease outbreaks, including cholera, a waterborne disease (>30,000 cases), and malaria and dengue fever, transmitted by mosquitoes that flourish under these conditions (>30,000 and >1000 cases, respectively). If more frequent and intense extreme weather events continue to be a primary manifestation of climate change (*2*), then harnessing climate data to better forecast future disease outbreaks should enable preventive action to be taken.

In a report on page 396 of this issue, Linthicum *et al.* (*3*) examine links between periods of heavy rainfall in East Africa between 1950 and 1998 and outbreaks of Rift Valley fever, a mosquito-borne viral disease that infects both domestic animals and humans (see the figure). In the Horn of Africa, records since 1950 indicate that Rift Valley fever outbreaks follow periods of intense precipitation. During the 1997–98 El Niño event, the Horn received up to 40 times the average rainfall, isolating villages, obliterating roads, and precipitating a cluster of diseases: tens of thousands of new cases of cholera and malaria and 89,000 cases (with nearly 1000 deaths) of Rift Valley fever (*4*). Linthicum and colleagues show that by tracking sea surface temperature anomalies of the Pacific and Indian oceans and combining these data with vegetation changes detected by remote sensing satellites (*3*), they were able to forecast Rift Valley fever epidemics 5 months in advance of outbreaks. Such early warnings would give sufficient time for interventions, such as vaccination of livestock and treatment of mosquito breeding sites. Using climate data to project conditions that are conducive to disease outbreaks will be invaluable in combating the burden of extreme weather events on public health.

Connections between climate and disease are not new (*5*). Climate constrains the range of many infectious diseases, and weather affects the timing and intensity of outbreaks (*6*). Reappraisal of these associations is aided by increased understanding of the Earth's climate system, in particular how land and sea surface temperatures and pressure gradients drive winds and weather. The atmosphere holds 6% more water vapor with each 1°C rise in temperature. The resulting increase in evaporation and greater residence time for water vapor in the atmosphere (*7*) boosts humidity and heat indices, fuels storms, and reinforces the greenhouse effect (the trapping of heat by atmospheric gases such as carbon dioxide). An increase in the cloud cover blocks outgoing heat, contributing to disproportionate warming at night and during the winter (*8*)—conditions that are unhealthy for humans but advantageous for insects that transmit infectious diseases. A moisture-laden atmosphere also generates more tropical-like downpours that create breeding grounds for mosquitoes, propel rodents from burrows, and flush nutrients, chemicals, and microorganisms into waterways.

Sudden weather changes and sequential extremes can also yield surprises. Droughts suppress predators, whereas heavy rains boost food supplies—a synergy that can spark rodent population "explosions." A large increase in the deer mouse population in the southwestern United States in 1993 resulted in the emergence of Hantavirus Pulmonary Syndrome (*9*). In Honduras, drought-sustained wildfires consumed 11,000 km^2 of forest during the summer preceding Mitch (*4*), widening the deforestation that magnified the flooding and devastation from the hurricane (*1, 10*).

Understanding the evolution of such weather anomalies will require integrating data from the El Niño–Southern Oscillation (ENSO; the anomalous warming or cooling of the eastern Pacific) with local sea surface temperatures (*3*) and, eventually, with decadal-to-centennial cycles in climate variability and human influences. Changes in atmospheric chemistry may



Predicting disease outbreaks. The map shows regions of heavy rainfall and drought during 1997–98 and the associated clustering of outbreaks of emerging infectious diseases. Extreme weather events have resulted in a surge in epidemics, particularly in tropical regions. Using climate data to predict the arrival of conditions that are likely to favor disease outbreaks can facilitate public health interventions, such as vaccination and preparations at treatment facilities.

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have so altered Earth's heat budget that natural climate modes such as ENSO have been modified. Studies suggest that the ocean is becoming warmer at intermediate depths and around both poles (*11*). If the world's oceans are a long-term heat sink for this century's global warming, then this has profound implications for marine life and terrestrial weather patterns.

Historically, periods of accelerated social transition have often been accompanied by the reemergence of infectious diseases (*12*). The current resurgence (*13*) can be attributed to changes at three levels—social (economic disparities and untoward practices such as excessive use of antibiotics and pesticides), ecological (habitat loss and simplification), and global (alterations in climate and stratospheric ozone). Ecological integrity is central to health. Habitat mosaics (for example, wetlands and forests) absorb floodwaters and support the genetic, species, and functional group diversity that ensures resilience to stress and resistance to pests and pathogens (*14*).

Extended droughts and thawing during warmer winters render northern forests vulnerable to infestations with insect pests. Parched agricultural lands attract aphids, locusts, and virus-bearing white flies, and fungi flourish after floods. Warming and "CO_2 fertilization" causing enhanced plant growth may also encourage leaf-eating pests, favor weeds, and promote pollen production (*15*). Already, 35 to 42% of growing and stored crops are lost to pests, pathogens, and weeds, costing $244 billion worldwide annually (*16*). Increased climate variability could substantially alter future food security and global nutrition (*17*).

Emerging diseases associated with algal toxins, bacteria, and viruses are affecting a wide range of marine species: fish, shorebirds, and mammals (*18*). Of great concern are diseases that attack coral and sea grasses, essential habitats that sustain mobile aquatic species. Corals are already endangered: High sea surface temperatures in the 1990s have resulted in widespread bleaching, perhaps the most disturbing biological sign of global warming.

With disproportionate warming in the winter, at higher latitudes and high elevations (*19*), most summit glaciers are in retreat. Polar researchers suspect that melting at the base of the Greenland ice sheet may be sculpting fault lines that could diminish its stability (*20*). Shrinking of Earth's ice cover (cryosphere) has implications for water (agriculture, hydropower, and health) and for climate stability. The impacts of warming and changing weather patterns on forests, agriculture, marine life, and water may hold the most profound consequences for global health.

The cost of extreme weather events and associated emerging infectious diseases is mounting. Trade, travel, and tourism can be affected. In 1998, livestock exports were blocked from East Africa because of Rift Valley fever, and Europe refused seafood imports because of cholera outbreaks in the same region. Indonesian forest fires (the extended drought compounding hazardous land-clearing practices) resulted in widespread acute and chronic respiratory illnesses and plummeting rice yields (*1*). The 1998 summer floods in China killed 3700 individuals, displaced 223 million people, and cost $30 billion. All told, weather-related losses—combining growth of coastal settlements, ecological vulnerabilities, and extreme weather—grew exponentially from the 1980s to the 1990s; losses of $89 billion in 1998 (11 months) eclipsed the losses of $55 billion for the entire decade of the 1980s (*21*).

There are several solutions to combating the increased burden of emerging infectious diseases. Greater surveillance of and response to outbreaks is essential (*22*). Health early-warning systems (*23*) based on climate forecasting and remote sensing, such as the system developed by Linthicum and colleagues for Rift Valley fever, can complement famine early-warning systems. Prevention is possible if the underlying social and environmental causes are addressed.

Contemporaneous changes in greenhouse gas concentrations, ozone levels, the cryosphere, ocean temperature, land use, and land cover challenge the stability of our epoch, the Holocene—a remarkable 10,000-year era that followed the retreat of the great ice sheets from temperate zones. High-resolution ice core records suggest that greater variance from climate norms may indicate greater climate instability (*24*), increasing the potential for rapid shifts between stable climate states (*25*).

In the 1980s, health considerations helped forge international agreements banning ozone-depleting chemicals and atmospheric nuclear testing. Today, concerns for our health in the face of global change necessitate ecological restoration and development of nonpolluting energy sources.

Clean energy helps to stabilize the climate and also can be used to power health facilities, pump water for irrigation, and purify it for consumption. Renewable and energy-efficient technologies may become the new engine of economic growth, driving improvements in public health. Ultimately, we must shed inherited economic burdens and adopt new financial mechanisms—incentives, subsidies, and funds—to reverse environmental assaults on public health, preserve the global commons, and achieve healthy, clean, and equitable development in the coming century.

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