In 1861, the natural philosopher John Tyndall made the prediction, little noted at the time, that anthropogenic emissions of carbon dioxide would trap the radiative energy of the sun within the earth’s atmosphere and raise surface temperatures. An early investigation of this “greenhouse effect” concluded that a “large-scale geophysical experiment” began ever since the Industrial Revolution, wed civilization to fossil fuels. The recent data of several international consortia show that global warming is accelerating at a rate far greater than that predicted a century ago and is due in large part to combustion of fossil fuels.

This issue of MSJAMA brings together several lines of published evidence that global warming has emerged as a public health challenge requiring serious, concerted action. Jonathan Patz and Mahmooda Khaliq survey the immediate threats posed by climate change as well as some of the more insidious ones. Kent Bransford and Janet Lai find grounds for a common approach to both climate change and air pollution. Stephen Liang and colleagues describe technologies that can help track the spread of climate-sensitive infectious disease vectors. Finally, William Burns discusses public policy tools to respond and adapt to these challenges.

Unfounded alarmism has no place either in clinical practice or in the legislative process. On the other hand, we cannot simply ignore extensive, peer-reviewed data on the causes and impacts of climate change. Lending a sense of urgency to this seemingly distant and abstract threat may well require us to link its consequences to our quality of life. In the absence of domestic leadership on global warming, one way to accomplish this goal might be to summon health care professionals to nontraditional advocacy roles. A similar approach helped give birth to the Montreal Protocol of 1987. Parties to the convention that produced the treaty identified depletion of the UV-absorbing ozone layer by chlorofluorocarbons (CFCs) as a public health threat of potentially catastrophic proportions requiring immediate action, namely, the phasing out of CFCs and related compounds.

A role for health care professionals in global environmental policy is a natural extension of a growing ethos of preventive medicine, the sort that has, for instance, reduced the prevalence of smoking in the United States and led to improvements in food, highway, and gun safety. Similarly, it is not too late and none too soon for the health care community to advocate policies that wean us from fossil fuels and ultimately mitigate the extent of human-induced climate change.

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Global Climate Change and Health: Challenges for Future Practitioners

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OVERVIEW
Global climate change is expected to have broad health impacts.1 If current warming trends continue, heat waves, floods, and droughts and their attendant physical effects are likely to become more frequent and severe. Warmer air temperatures can influence the concentration of regional air pollutants and aeroallergens. Less direct health impacts may result from the disruption of ecosystems and of water and food supplies, which in turn could affect infectious disease incidence and nutritional status. Finally, sea-level rise could lead to major population displacement and economic disruption.

Climate Change Science
Human activities related primarily to the burning of fossil fuels and changes in land cover such as deforestation are changing the concentration of atmospheric constituents or properties of the earth’s surface that help to absorb or scatter radiant energy.2 Since the preindustrial mid-1800s, increases in concentrations of three major greenhouse gases, carbon dioxide, methane, and nitrous oxide, have exceeded past changes that occurred over the last 10,000 years; carbon dioxide alone has increased by 30% since the late 1800s.3 Warmer air, such as that resulting from the greenhouse effect, can hold more moisture and more quickly evaporate surface water, thereby increasing the frequency of severe storms, floods, and droughts.1

According to the United Nations Intergovernmental Panel on Climate Change (IPCC), “An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.” During the 20th century, global average surface temperature increased about 0.6°C, global average sea level rose 10 cm to 20 cm, and snow and ice cover decreased.2 The latest IPCC report predicts that if current trends continue, sea level rise will rise 45 cm and global temperatures will increase by 3°C by the year 2100.3

Temperature-Related Morbidity and Mortality
Small changes in global mean temperatures can produce relatively large changes in the frequency of extreme temperatures.2 Mortality rates increase at both hot and cold extremes of temperature.4 Increases in temperature have a direct and substantial impact on excess mortality for elderly individuals and individuals with pre-existing illnesses. Much of the mortality attributable to heat waves is a result of cardiovascular, cerebrovascular, and respiratory disease.5 A 1995 heat wave in Chicago that caused 514 heat-related deaths (12 per 100,000 population)5 may be part of a recent trend of longer, more frequent heat waves and record-setting temperatures.7 Long-term global warming trends are further exacerbated by the “heat island” effect, whereby high concentrations of heat-retaining surfaces such as asphalt and tar roofs sustain higher temperatures through the night. Heat waves also have the secondary effect of worsening urban air pollution. Ozone, which forms chemically from precursor pollutants, is the most temperature-dependent air pollutant and may contribute to the development of asthma in children.8

Health Effects of Extreme Weather Events
Higher average ambient air temperatures are likely to induce more vigorous cycles of evaporation and precipitation. Indeed, a trend of increasing climate variability and extreme precipitation events has been observed over the past century, and recent models strongly correlate this trend with anthropogenic production of greenhouse gases.9,10 Human health impacts are most likely to occur where extreme weather and population vulnerability converge. At highest risk are communities that are most exposed (eg, in floodplains and coastal zones) and that have the fewest technical and social resources.11 The health impacts of extreme weather events include physical injury; poorer nutritional status, especially in children; increases in respiratory and diarrheal diseases due to overcrowding of flood survivors and limited access to potable water; increased risk of water-related diseases due to disruption of water supply or sewage systems; and release of dangerous chemicals from storage sites and waste disposal sites into flood waters.11,12

El Niño. An El Niño occurs approximately every 3 to 7 years when warm equatorial water shifts from the western to eastern Pacific Ocean.13 The 1997-1998 El Niño event was one of the two strongest of the past century. It was associated with extremely dry conditions and devastating fires in many areas of the world and with extensive flooding in others.14

Some infectious diseases that are typically seasonal have shown marked interannual variability. Many epidemics of malaria are associated with El Niño–driven climate extremes.15 The 1997-1998 El Niño resulted in torrential rain in parts of East Africa and a subsequent malaria epidemic in the highlands of southwestern Uganda.16

Floods. Climate change may increase the risk of both river and coastal flooding, whose immediate effects include drowning and physical trauma.17 Longer-term effects include increases in communicable diseases such as those caused by ingestion of contaminated water (eg, cholera and hepatitis A) or contact with contaminated water (eg, leptospirosis). Respiratory infections may result from overcrowding of settlements or from overgrowth of molds in flooded homes.17

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Droughts. Droughts have their largest impact on population health by threatening food supplies. In addition, diarrheal diseases, scabies, conjunctivitis, and trachoma are associated with poor hygiene and may result from inadequate sanitation as water resources become depleted.14 Drought-induced wildfires can cause direct injury and have the potential to affect air quality. During the 1997-1998 El Niño, biomass smoke from drought-exacerbated fires in Indonesia affected large population centers in southeast Asia. In some areas, smoke concentrations were more than six times higher than the ambient air quality standards outlined by the US Environmental Protection Agency.15

Water-Related Infectious Diseases

Waterborne diseases in marine or coastal zones are especially sensitive to climate. During the 1997-1998 El Niño, the number of daily hospital admissions in Lima, Peru, for childhood diarrhea increased more than two fold over the averaged rate for the preceding four years.19 The increase in ambient temperature in excess of regular seasonal variability was found to be the main environmental variable affecting admissions: for each 1°C increase in mean ambient temperature, the number of admissions increased by 8%. Cholera outbreaks occur seasonally in Bangladesh, with consistent patterns associated with monsoon seasons, surface temperatures, rainfall, and zooplankton populations.20 In the marine environment, warm water and nitrogenous waste favor blooms of dinoflagellates. The resulting "red tides" can cause paralytic, diarrheic, and amnesiac shellfish poisoning.14 Finally, certain vector-borne pathogens, such as those that spend a part of their life cycle in arthropod vectors, are sensitive to ambient temperatures.21

Sea-Level Rise

Global mean sea level is predicted to continue to increase primarily by the loss of mass from glaciers and thermal expansion of water. Sea-level rise would especially affect coastal communities and, in some cases, may force population migration.22 Thirteen of the world’s 20 major metropolises are situated at sea level. Nicholls and Leatherman showed that a 1-meter rise in sea level would inundate low-lying areas, affecting 18.6 million people in China, 13 million in Bangladesh, 3.5 million in Egypt, and 3.3 million in Indonesia.22 Furthermore, rising seas may salinate coastal freshwater aquifers and disrupt stormwater drainage and sewage disposal.23 Considering the health burden experienced by refugees and populations subjected to overcrowding, lack of shelter, and competition for resources, the response to displaced populations may well become the largest public health challenge posed by global climate change.

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Climate change and air pollution are linked to one another by our increasing use of fossil fuels, including coal, petroleum, and natural gas. In the United States fossil fuel combustion accounts for 98% of anthropogenic emissions of carbon dioxide, the predominant greenhouse gas by volume. Although increasing levels of ambient carbon dioxide have no known direct adverse health effects, other by-products of fossil fuel combustion have known impacts on respiratory health.

One such pollutant is ground-level ozone, the major component of smog. Ozone is formed from the reaction of nitrogen oxides and volatile organic compounds, as from power plant emissions and automobile exhaust, in the presence of light and heat. This reaction occurs more rapidly at higher temperatures, explaining, in part, why smog is more marked during the summer months. Global warming would be expected to worsen this form of air pollution.

Ozone has been linked to decreased pulmonary function in healthy adults, an effect that depends on exposure concentration and duration. At low levels (0.3 ppm-0.5 ppm), ozone irritates mucous membranes of the eyes and throat and induces chest tightness. High-level exposure (5.0 ppm-10.0 ppm) for more than one hour can lead to pulmonary edema and death. Long-term exposure (4 or more years in areas with summer ozone levels of 80 ppb or more for at least 1 h daily) has been associated with adult-onset asthma in otherwise healthy, nonsmoking individuals.

More generally, elevated ozone levels have been found to lead to more frequent asthma attacks, emergency department visits, and hospitalizations; increased use of asthma medications; and greater morbidity and mortality in patients with pre-existing pulmonary or cardiovascular disease. Children are at even greater risk because their respiratory systems are still developing, they spend significantly more time outdoors, and they breathe more air per pound body weight than adults. One study found that the relative risk of asthma developing in active children (three or more outdoor sports) living in high ozone environments is 3.3 times greater than those who did not play those sports.

The burning of fossil fuels produces other major air pollutants including airborne particulates, nitrogen oxides, and sulfur oxides. Fine particulate matter (less than 2.5 μm in diameter) is easily inhaled deeply into the lungs where it can be absorbed into the bloodstream or remain embedded in the lung parenchyma. Oxides of nitrogen (NOx) are formed during high-temperature combustion processes, such as those that power automobiles and power plants. Oxides of sulfur (SOx) are formed when fuel containing sulfur (mainly coal and oil) is burned, as during metal smelting and other industrial processes.

One study of never-smoking cohorts grouped by age (7-59 years old) compared areas in southern California with moderate levels of SOx, NOx and particulate matter (mean values: 0.01 ppm, 0.03 ppm, and 85 μg/m3, respectively) to those with higher levels (mean values: 0.04 ppm, 0.11 ppm, and 101 μg/m3, respectively). Chronic exposure to higher levels of these pollutants adversely affected the small and large airways of the lungs, as determined by spirometric parameters, in females older than 7 years and males older than 15 years. A larger, more recent study concluded that fine particulate and sulfur oxide-related pollution is associated with all-cause, lung cancer, and cardiopulmonary mortality, after controlling for cigarette smoking, occupational exposure, and other risk factors.

Because the burning of fossil fuels is linked to both human-induced climate change and air pollution, there is a common solution: reducing the use of fossil fuels as an energy source. Clearly, this can be accomplished in part by using and developing technologies that increase energy efficiency and by jump-starting the transition from fossil fuels to renewable energy resources.

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GLOBAL WARMING IS LIKELY RESHAPING THE ECOLOGY OF MANY medically important arthropod vectors. Warmer temperatures have been shown to directly increase mosquito and tick vector reproduction, biting, and pathogen transmission despite shortening mean daily survivorship. Related changes in rainfall, humidity, and the El Nino/Southern Oscillation (ENSO) may alter the quality and availability of some vector breeding sites. In the face of these changes, remote sensing (RS) and geographic information systems (GIS) have become powerful tools to study vector populations that transmit diseases such as Rift Valley fever, malaria, and Lyme disease.

Satellite RS, which involves acquisition of environmental data by orbital sensors, has tracked climatic variables affecting important disease-propagating vectors. These instruments measure the intensity of ambient solar energy reflected or radiated from the Earth’s surface or atmosphere, and yield quantitative indices of land surface temperature, vegetation, atmospheric moisture and rainfall that can be referenced to a precise location and time. While selected climatic data have been collected and recorded for more than a century, computer-based software tools collectively known as GIS have led to an unprecedented capability to consolidate environmental data. An increasing number of medical scientists are turning to these tools to study the effects of climate on global patterns of vector-borne disease.

One such disease is Rift Valley fever (RVF), a viral disease of humans and livestock in much of sub-Saharan Africa. Hemorrhagic fever syndrome from RVF is seen in about 1% of human cases with a case fatality rate of about 50%. Outbreaks of RVF in East Africa have been associated with unusually heavy rainfall thought to result from local ENSO effects. These events likely foster an ideal environment for mosquito eggs harboring the virus and increase the population of the major vector, Culex mosquitoes. One indicator of the relative availability of water, which is important for vector propagation, is the extent of actively photosynthetic vegetation, which can be spectrally differentiated from senescent vegetation. Remotely sensed anomalies in both vegetation density and sea surface temperatures could have predicted excessive rainfall and, in turn, each of the 3 RVF outbreaks in East Africa from 1982 to 1998. Malaria is a tropical vector-borne disease that kills more than 1 million people each year. In Chiapas, Mexico, Beck et al used RS data to associate transitional wetlands and unmanaged pasture with a greater abundance of an important malaria vector—the adult Anopheles albimanus mosquito—in nearby villages. Models based on these findings were used to predict malaria risk for 40 randomly selected villages in a neighboring region, with an overall accuracy of 70%. Tick development and survival are highly sensitive to temperature and humidity, with decreased survival resulting during dry periods. As in the case of mosquito vectors, remotely sensed indicators of moisture availability have reliably predicted the distribution of ticks. Lyme disease, transmitted to humans through Ixodes ticks, is the most common vector-borne disease in the United States, where some 12,500 cases were reported from 1993 to 1997. Using remotely sensed land cover data, Dister et al showed that suburban residential properties in New York state with a high moisture and density of green vegetation had greater tick abundance and a higher theorized risk for exposure to Lyme disease.

Environmental data gathered by RS and analyzed using GIS may provide a cost-efficient way to identify regions at high risk for exposure to vector-borne diseases. Because these technologies can monitor environmental variables across wide regions, they may be particularly useful in countries unable to carry out routine field surveys of vector populations. The ability to predict outbreaks months in advance based upon climate change indicators may make it possible to implement early vaccination initiatives or aggressive vector control programs and guide the relocation of human populations away from trouble spots. In short, RS and GIS will likely enhance our understanding of the relationship between climate and vector-borne disease and prepare health professionals for changes in the distribution of important infectious pathogens.

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Climate Change and Human Health: The Critical Policy Agenda


Climate change during the next century and beyond may exacerbate many of the health threats faced by human populations, especially in resource-poor countries. These threats include disruption of water and food supplies by extreme weather events and the enhanced spread of vector-borne diseases by increasing air and water temperatures. Even under the most optimistic scenarios for reducing greenhouse gas emissions, average global temperatures will likely rise at least 2.5°C to 3.0°C over the next few centuries. This is well above the threshold for substantially increasing climate-related health threats. Thus, an effective strategy must provide long-term policies to reduce emissions, decrease vulnerabilities, and ameliorate negative impacts.

The primary international response to global climate change is the 1992 United Nations Framework Convention on Climate Change (UNFCCC), which has been ratified by 186 nations. The objective of the UNFCCC is to “stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system,” although this level is not specified. Because of resistance by the United States and other nations to binding targets, the UNFCCC called upon parties merely to “aim” to return their emissions to 1990 levels at an unspecified point in the future.

In the face of mounting evidence that parties to the UNFCCC were failing to voluntarily reduce their emissions and projections that emissions might increase by 40% from 1990 levels by 2010, the third conference of the UNFCCC parties drafted the Kyoto Protocol in 1997. The Protocol calls for industrialized nations to reduce their emissions by at least 5% below 1990 levels by the period 2008-2012.

The Bush Administration has stated that it will not submit the Protocol for ratification by the Senate. This decision effectively excludes the United States, responsible for approximately a quarter of the world’s greenhouse gas emissions, from a major multilateral effort to confront global warming. President Bush recently announced a series of initiatives to address climate change, including additional funding for research and largely voluntary efforts to reduce the ratio of greenhouse gas emissions to economic output. The World Resources Institute predicted, however, that US emissions under the Bush plan will grow by an additional 14% or more over the next decade.

Even if the Kyoto Protocol itself is fully implemented, it represents a small down payment on what the world must ultimately do to mitigate climate change. To stabilize greenhouse gas concentrations at twice preindustrial levels (a critical threshold according to many researchers), greenhouse gas emissions must be reduced by 60% to 70% below 1990 levels. This would demand immense political will on the part of both industrialized and developing countries to fundamentally restructure many sectors of their societies.

Given the likely inevitability of substantial climate change over the next few centuries, strategies to adapt to its potential impacts on human health are critical. Indeed the seventh conference of the UNFCCC parties recognized this need, and the European Union together with other developed countries agreed to collectively contribute $410 million annually by 2005 to a preliminary fund for adaptation initiatives. These measures include establishing stations to monitor sea-level rise and extreme weather risks, improving geographic information systems and other tools to track the spread of disease vectors, and promoting public awareness on climate change issues.

While the cost of developing adaptation programs will be substantial, it will likely pale in comparison to the cost of allowing climate change to proceed without intervention. The Kyoto Protocol goes far beyond the original UNFCCC by recognizing the immediacy of the problem and setting legally binding and verifiable emissions targets. It also establishes mechanisms to promote efficient and renewable energy technologies and to transfer them to developing countries willing to leapfrog the fossil-fuel route. Effective mitigation of climate change, however, will ultimately require the participation of the United States and its realization that the adoption of alternatives to fossil fuels is not only compatible with economic growth11 but is also a public health measure supported by a large body of peer-reviewed science.

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The Minotaur was a bullish, thickheaded creature. He had hands the size of racquetball racquets that crushed oil cans like fortune cookies but could dissect the finest tissues, handle the most friable serosas, and decipher the most intricate anastamoses. He barked orders, complained about incompetent residents, and grumbled about sleep deprivation. He was indigestion, reflux, and lactose intolerance incarnate.

He thought me an utter idiot—incompetent, lazy, and weak-spirited. He had the unique ability to stupefy me with a simple, answerable question, leaving me red-hot in the face. He spat at my ignorance. His glance was vinegar.

He regarded those around him as inferior, perhaps even indentured. In his eyes, no one was as diligent, dedicated, or determined as he. He trusted no one and respected only a few of his mentors. He was Hamlet—a solipsistic fellow reigning over his hospital, his castle, his kingdom.

Physically, he was a brick shithouse. Philosophically, a martyr. Socially, a tantrum-throwing tyrant. Yet, he was tired and tormented.

For this, I loved him fiercely.

During the day, the Minotaur stormed the halls, sussing out abnormalities of laboratory tests and equilibrating electrolyte imbalances. When fecund Petri dishes with multidrug resistant strains were reported, he would bellow for more thorough sensitivities. He juggled the minute details of cardiac-enhancing drips, diuretics, and colloid solutions, dazzling the whole team with his complex mental calisthenics. He would insist on careful attention to detail and scold us for incomplete patient reports. He did not praise. He did not nod his head in agreement. He reiterated that our “best” was not good enough by marching off to the next patient’s room.

I wondered if he knew pleasure. Perhaps being in itself was pleasurable to him. Perhaps he thrived by living life rapaciously. I could only imagine what drove him to perform, day-in and day-out. Was it a burdensome, magnetic force? Was it an opiate-like addiction? Was it a compulsion toward perfection with a take-no-prisoners mantra? I would never know.

The Minotaur burrowed deep into life. Not only did he suck the marrow out of it, he reconfigured and spliced its DNA.

But even Achilles had a heel. One night on call, I left my favorite note-writing pen down in little Rosa Garcia Marquez’s room. I journeyed down to the third floor in the wee hours of morning to retrieve it. As I tiptoed across the room, fumbling around the dirty laundry container and a wooden rocking chair, I tried my best to not wake Rosa or her tiny 9-month-old roommate, Sonya.

The curtains were pulled wide enough that the moon’s light flooded Rosa’s bedside. I could see my Bic 4000 with its luxurious gel grip. What I missed in the milky luminance was Thomas the Tank Engine. With a purposeful and salivating lurch, I grasped for my pen only to find Thomas under foot. I tumbled backwards and hit my head with a thwack.

Perhaps days went by. Maybe seasons. When I finally came to, I hoped I had Rip Van Winkled my way through medical school. But I still had a short white coat on and Sonya was howling. I heard a nurse say, “She’s at it again.” And then, a deep, husky voice replied that he would check in on her. A tearful Siren, Sonya had beckoned the Minotaur who whispered gently to her; “Sonya, my love. Sweet, sweet baby. I’m here, Sweetheart.” Although I recognized that I could indeed move my toes and feet, I remained paralyzed on the cool linoleum.

He reached out to the bandaged and splinted infant. Her voice suddenly softened. Sonya had been intentionally burned with hot grease by her now-incarcerated mother. Whether from pain from her wounds or from fear and anxiety, she was inconsolable. No nurse could calm her. She relented only to the soothing of sedatives.

The Minotaur, with his apeish hands, reached into the crib and pulled Sonya out. As he nestled her against his broad chest, he sank into the creaky wooden rocker and whispered sweet nothings. “Sonya, my love. My beautiful, beautiful girl. Don’t cry. Don’t cry, Honeybear.” And then, he paused. In a faltering, tearful voice, he asked, “How could anyone want to hurt you? How could someone be such a monster?”

And so he fathered the burned and scarred peanut into the early morning hours. One bottle of formula and a fresh pacifier later, the Minotaur and the Siren were inseparable in each other’s arms. Morpheus had escorted them both into a realm of peace and contentment.