Testimony of

Kristie L. Ebi

ESS, LLC

Mailing Address:
5249 Tancreti Lane
Alexandria, VA 22034

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Weather and climate are among the factors that determine the geographic range and incidence of several major causes of ill health, including undernutrition, which affects 17% of the world's population in developing countries [FAO 2005]; diarrheal diseases and other conditions due to unsafe water and lack of basic sanitation, which cause 2 million deaths annually, mostly in young children [Kosek et al. 2003]; and malaria, which causes more than a million childhood deaths annually [WHO 2004]. The Human Health chapter in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, for which I was a Lead Author, concluded that climate change has begun to negatively affect human health, and that projected climate change will increase the risks of climate-sensitive health outcomes, particularly in lower-income populations, predominantly within tropical/subtropical countries [IPCC WGII SPM 2007].

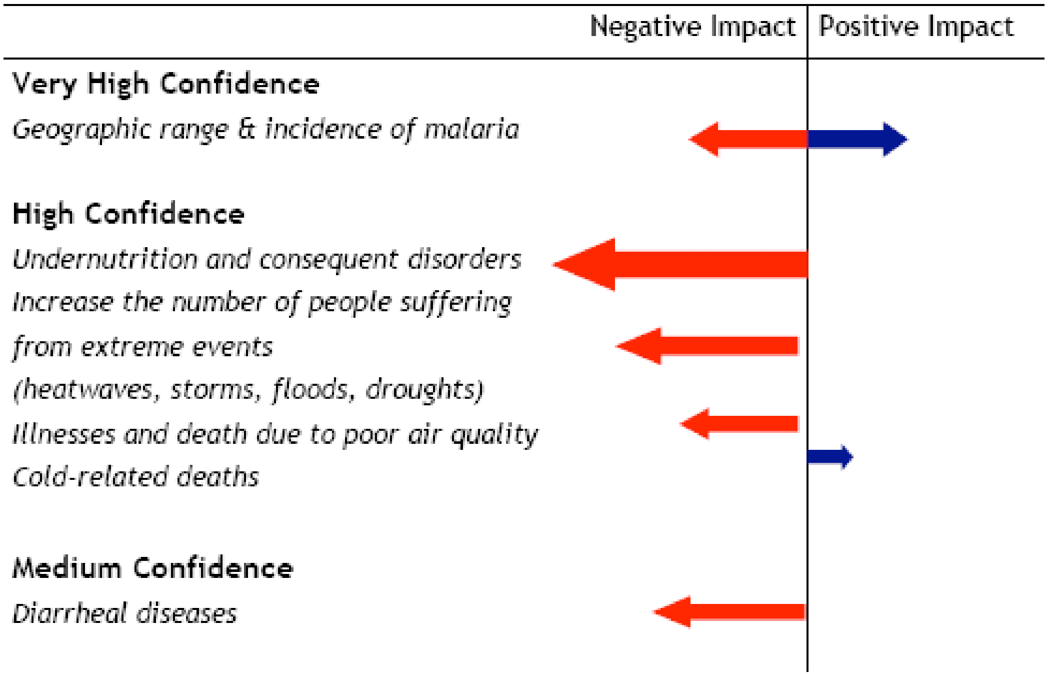
Weather, climate variability, and climate change can affect health directly and indirectly. Directly, heatwaves, floods, droughts, windstorms and fires annually affect millions of people and cause billions of dollars of damage. In 2003 in Europe, Canada, and the United States, floods and storms resulted in 101 people dead or missing and caused $9.73 billion in insured damages [Swiss Re 2004]. More than 35,000 excess deaths were attributed to the extended heatwave in Europe the same year [Kostasky 2005]. The health impacts of extreme events in developing countries are substantially larger. There is a growing body of scientific research projecting that the frequency and intensity of extreme weather events will likely increase over the coming decades as a consequence of climate change [Easterling et al. 2000; Meehl and Trebaldi 2004], suggesting that the associated health impacts also could increase.

Indirectly, climate can affect health through alterations in the geographic range and intensity of transmission of vector-, tick-, and rodent-borne diseases and food- and waterborne diseases, as well as through changes in the prevalence of diseases associated with air pollutants and aeroallergens. Climate change could alter or disrupt natural systems, making it possible for diseases to spread or emerge in areas where they had been limited or had not existed, or for diseases to disappear by making areas less hospitable to the vector or the pathogen [NRC 2001]. Climate-induced economic dislocation and environmental decline also can affect population health.

The cause-and-effect chain from climate change to changing patterns of health determinants and outcomes is often complex and includes factors such as wealth, distribution of income, status of the public health infrastructure, provision of medical care, and access to adequate nutrition, safe water, and sanitation [Woodward et al. 1998]. Therefore, the severity of future impacts will be determined by changes in climate as well as by concurrent changes in nonclimatic factors and by the adaptation measures implemented to reduce negative impacts. It is important to note that even if future trends decrease burdens of some climate-sensitive health outcomes, the attributable burden due to climate change could increase.

Figure 1 summarizes the relative direction, magnitude, and certainty of climate change-related health impacts as concluded by the Human Health chapter of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Figure 1: Summary of the Relative Direction, Magnitude, and Certainty of Climate Change-Related Health Impacts



Source: Confalonieri, Menne, et al. IPCC 2007.

Heatwaves, Floods, and Droughts

The impact of an extreme weather event is determined by the physical characteristics of the event, attributes of the location affected, and interactions of these with human actions and social, economic, institutional, and other systems. The health and social burden of extreme weather events can be quite large, causing loss of life and livelihood, infrastructure damage, population displacement, and economic disruption (such as in Honduras and Nicaragua following hurricane Mitch in 1998, and hurricane Katrina). Climate change is projected to increase the intensity and frequency of extreme weather events in many regions [IPCC SPM WGI 2007].

Heatwaves affect human health via heat stress, heatstroke, and death [Kilbourne 1997], as well as exacerbations of underlying conditions that can lead to an increase in all-cause mortality [Kovats and Koppe 2005]. The frequency and intensity of heatwaves [Meehl and Tebaldi 2004] and heat-related deaths are projected to increase with climate change [Keatinge et al. 2002; Dessai 2003; McMichael et al. 2003; Hayhoe et al. 2004]. For example, the annual number of heatwave days, the length of the heatwave season, and heat-related mortality were projected for four cities in California [Hayhoe et al. 2004]. By the 2080s, under two climate scenarios, the number of heatwave days in Los Angeles were projected to increase from 4-fold to 6-8 fold over the 1961-90 baseline. Annual heat-related deaths in Los Angeles were projected to increase from about 165 in the 1990s to 319 to 1,182 under different scenarios. The length of the heatwave season in California was projected to increase from 5-13 weeks. Projections have not considered changes in the frequency or intensity of severe heatwaves, such as occurred in 2003 in

Europe, nor have they estimated impacts in developing countries where increasing temperatures could affect human and agricultural productivity.

The adverse health consequences of flooding and windstorms can be complex and far-reaching [Ahern et al. 2005; Hajat et al. 2003]. Adverse health impacts include the physical health effects experienced during the event or clean-up process, or from effects brought about by damage to infrastructure, including population displacement. The physical effects largely manifest themselves within weeks or months following the event, and can be direct (such as injuries) and indirect (such as water and food shortages and increased rates of vector-borne and other diseases). Extreme weather events are also associated with mental health effects resulting from the experience of the event or from the recovery process. These psychological effects tend to be much longer lasting and can be worse than the direct physical effects [Ahern et al. 2005; Hajat et al. 2003].

The effects of drought on health include malnutrition (protein-energy malnutrition and/or micronutrient deficiencies), infectious diseases, and respiratory diseases [Menne and Bertollini 2000]. In addition, malnutrition increases the risk of dying from an infectious disease. The loss of livelihoods due to drought is a major trigger for population movements, which can cause additional disease burdens.

Parry et al. [2004] projected that the world will have sufficient food to feed everyone up to the end of the 21st century; however, this assumed that people in low-income countries, where climate change impacts are predominantly negative, would have access to food produced in temperate countries.

Attribution of the some portion of the burden of injuries, illnesses, and deaths due to floods, windstorms, and droughts to climate change is complex because of the multiple determinants of disease. Although data are limited, malnutrition associated with drought and flooding may be one of the most important consequences of climate change due to the large number of people that may be affected. For example, one study projected that climate change could increase the percentage of the Malian population at risk of hunger from 34% to 64 - 72% by the 2050s, although this could be reduced by implementation of a range of adaptive strategies [Butt et al. 2005].

Malaria and Other Infectious Diseases

Climate is a primary determinant of whether a particular location has environmental conditions suitable for the transmission of several vector-, rodent-, and tick-borne diseases, including malaria, dengue, cholera, meningitis, Japanese encephalitis, St. Louis encephalitis, West Nile virus, tick-borne encephalitis, Rift Valley Fever, schistosomiasis, and leishmaniasis. A change in temperature may hinder or enhance vector and parasite development and survival, thus lengthening or shortening the season during which vectors and parasites can survive. Small changes in temperature or precipitation may cause previously inhospitable altitudes or ecosystems to become conducive to disease transmission (or cause currently hospitable conditions to become inhospitable).

While climate is an important driver of malaria and other diseases, it is not the only one. The many determinants of infectious diseases often form an interconnected web with feedbacks between transmission dynamics and other factors [Chan et al. 1999]. For example, the socioeconomic and biological drivers of malaria include drug and pesticide resistance, deterioration of health care, deterioration of public health infrastructure (including vector control efforts), demographic change, and changes in land use.

Malaria is a complex disease to model, and current models have not completely parameterized the key factors that influence transmission. Given this limitation, models suggest that, in Africa, climate change may be associated with both expansions and contractions of the geographic area suitable for transmission of stable *Plasmodium falciparum* malaria, with expansion projected to be larger than contraction [Ebi et al. 2005; Tanser et al. 2003; Thomas et al. 2004; van Leishout et al. 2004]. These projections are consistent with experiences with malaria control officers in the field. Some projections suggest that the season of transmission may be extended, which may be as important as geographical expansion.

Several food- and waterborne diseases are climate sensitive, suggesting that climate change could affect their incidence and distribution. For example, studies report an approximately linear association between temperature and salmonellosis, a common form of food-poisoning [e.g. D'Souza et al. 2004; Kovats et al. 2004; Fleury et al. 2006].

Water and foodborne diseases continue to cause significant morbidity in the U.S. Annually, there are approximately 1,330 food-related disease outbreaks [Lynch et al. 2006], 34 outbreaks from recreational water (2004), and 30 outbreaks from drinking water (2004) [Dziuban et al. 2006, Liang et al. 2006]. For outbreaks of foodborne disease with known causes, *Salmonella* accounted for 55% and viruses accounted for 33% [Lynch et al. 2006]. Water- and foodborne disease are highly underreported; using a combination of underreporting estimates, passive and active surveillance data, and hospital discharge data, Mead et al. (1999) estimated that over 210 million cases of gastroenteritis annually in the U.S., including over 900,000 hospitalizations and over 6,000 deaths. Approximately 39 million of the cases can be attributed to a specific pathogen and about 14 million are transmitted by food. The causes differ somewhat from those reported for outbreaks, with the highest frequency of illness caused by viruses (67%; primarily noroviruses), followed by bacteria (30%; primarily *Campylobacter* and *Salmonella*) and parasites (3%; primarily *Giardia* and *Cryptosporidium*). Children ages 1-4 and older adults (>80 years) each make up more than 25% of hospitalizations involving gastroenteritis, but older adults contributed to 85% of the associated deaths [Gangarosa et al. 1992]. Clearly, as the U.S. population ages, the economic and public health burden of diarrheal disease will increase proportionally without appropriate interventions.

Air Pollutants

There is extensive literature documenting the adverse health impacts of exposure to elevated concentrations of air pollution, especially particulates with aerodynamic diameters under 10 and 2.5 μm, ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide, and lead. In 2000, there were 0.8 million deaths from respiratory problems, lung disease, and cancer that were attributed to urban air pollution, with the largest burden in developing countries in the Western Pacific region and South East Asia [WHO 2002]. In addition, there were 1.6 million deaths attributed to indoor air pollution caused by burning biomass fuels.

Air pollution concentrations are the result of interactions among local weather patterns, atmospheric circulation features, wind, topography, human responses to weather changes (i.e. the onset of cold or warm spells may increase heating and cooling needs, and, therefore, an increase in electricity generation), and other factors. Climate change could affect local to regional air quality directly through changes in chemical reaction rates, boundary layer heights that affect vertical mixing of pollutants, and changes in synoptic airflow patterns that govern pollutant transport. Indirect effects could result from increasing or decreasing anthropogenic emissions via changes in human behavior, or from altering the levels of biogenic emissions because of higher temperatures and land cover change. Establishing the scale (local, regional, global) and direction of change (improvements or deterioration) of air quality is challenging [Bernard et al. 2001].

More is known about the potential impact of climate change on ground-level ozone than on other air pollutants. Changes in concentrations of ground-level ozone driven by scenarios of future emissions and /or weather patterns have been projected for Europe and North America [Stevenson et al. 2000; Derwent et al. 2001; Johnson et al. 2001; Taha 2001; Hogrefe et al. 2004]. Future emissions are, of course, uncertain, and depend on assumptions of population growth, economic development, and energy use [Syri et al. 2002; Webster et al. 2002]. Based on projections of county-level pollutant concentrations, summer ozone-related mortality was projected to increase by 4% in the New York area by the 2050s based on climatic changes alone [Knowlton et al. 2004]. Increases in background ozone levels could affect the ability of regions to achieve air quality targets.

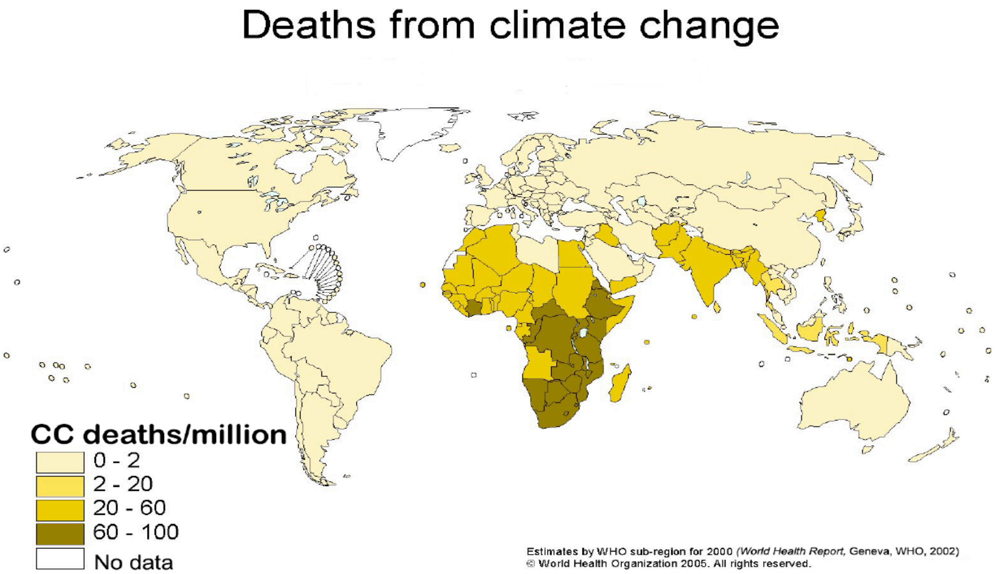
Global Assessments of the Health Impacts of Climate Change

Hitz and Smith [2004] reviewed the literature on the projected health impacts of climate change and concluded that health risks are more likely to increase than decrease with increasing global mean surface temperature, particularly in low latitude countries. In addition to greater vulnerability to climate, these countries have some of the highest populations, tend to be less developed, and generally have poorer public health infrastructure, likely leading to greater damages.

In the most comprehensive evaluation of the burden of disease due to climate change, McMichael et al. [2004] used a comparative risk assessment approach as part of the Global Burden of Disease study to project the total health burden attributed to climate change between 2000 and 2030 and to project how much of this burden could be avoided by stabilizing greenhouse gas emissions. Health outcomes were analyzed by region to better understand where current and projected future disease burdens are highest and to identify the outcomes that contribute to the largest share of the total burden. Limitations of the approach include the limited number of quantitative models that estimate the likely impacts of climate change on health and the limited geographic range of many of the models.

The health outcomes included in the analysis were chosen based on sensitivity to climate variation, predicted future importance, and availability of quantitative global models (or feasibility of constructing them) [McMichael et al., 2004]. Specific health outcomes included were episodes of diarrheal disease, cases of *Plasmodium falciparum* malaria, fatal unintentional injuries in coastal floods and inland floods/landslides, and nonavailability of recommended daily calorie intake (as an indicator for the prevalence of malnutrition). Inclusion of a limited number of health outcomes suggests that the estimated impacts are likely to be an underestimate of the true health impacts. In the year 2000, climate change was estimated to have caused the loss of more than 150,000 lives (0.3% of worldwide deaths) and 5,500,000 Disability Adjusted Life Years (DALYs) (0.4% worldwide), with malnutrition accounting for approximately 50% of these deaths and DALYs [Ezzati et al. 2002; McMichael et al. 2004; Patz et al. 2005]; see Figure 2. These estimates relate to a period when limited climate change had occurred, suggesting that future studies are likely to estimate larger health burdens due to climate change.

Figure 2: Current Health Burden due to Climate Change



Estimates by WHO sub-region for 2000 (*World Health Report*, Geneva, WHO, 2002)
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The projected relative risks attributable to climate change in 2030 vary by health outcome and region, and are largely negative, with the majority of the projected disease burden due to increases in diarrheal disease and malnutrition, primarily in low-income populations already experiencing a large burden of disease [McMichael et al. 2004]. Absolute disease burdens depend on assumptions of population growth, future baseline disease incidence, and the extent of adaptation.

Particularly Vulnerable Populations

Vulnerability to climate change will vary between and within populations. Vulnerability to the health impacts of climate change depends on the region of interest, the health outcome, and population characteristics, including human, institutional, social, and economic capacity, distribution of income, provision of medical care, and access to adequate nutrition, safe water, and sanitation. In general, the most vulnerable include slum dwellers and homeless people in large urban areas, particularly in low-income countries, those living in water-stressed regions, settlements in coastal and low-lying areas, and populations highly dependent on natural resources. However, as shown during the 2003 heat event in Europe, developed countries may not be prepared to cope with the projected increase in the intensity and frequency of extreme weather events.

Adaptation and Mitigation

Climate change will make more difficult the control of climate-sensitive health determinants and outcomes. Therefore, health policies need to explicitly incorporate climate-related risks in order to maintain current levels of control [Ebi et al. 2006]. In most cases, the primary response will be to enhance current health risk management activities. Nearly all of the health determinants and outcomes that are projected to increase with climate change are problems today. In some cases, programs will need to be implemented in new regions; in others, climate change may reduce current infectious disease burdens. The degree to which programs and measures will need to be augmented to address the additional pressures due to climate change will depend on factors such as the current burden of climate-sensitive diseases, the effectiveness of current interventions, projections of where, when, and how the burden of disease could change with changes in climate and climate variability, the feasibility of implementing additional cost-effective interventions, other stressors that could increase or decrease resilience to impacts, and the social, economic, and political context within which interventions are implemented [Ebi et al. 2006]. Although there are uncertainties about future climate change, failure to invest in adaptation may leave communities and nations poorly prepared and increase the probability of severe adverse consequences [Haines et al. 2006]. Adaptation policies and measures need to consider how to effectively reduce climate-related risks in the context of sustainable development, considering projected demographic, economic, institutional, technologic, and other changes.

Because fossil fuel combustion is a source of urban air pollutants and greenhouse gases, policies to reduce GHG emissions can have health benefits in the near- and long-term. There are potentially synergies in reducing GHG and improving population health via sustainable transport systems that make more use of public transport, walking, and cycling, especially in rapidly developing countries such as China and India [Haines et al. 2006]. For other energy sources, health impact assessments should be conducted to evaluate positive and negative health impacts.

The current burden of climate-sensitive diseases suggests that adaptation and mitigation policies and measures need to be implemented soon to reduce the projected risks due to climate change.

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Dr. Kristie L. Ebi is an epidemiologist and small business owner based in Alexandria, VA, who has been working on global climate change issues for more than 10 years. Her research focuses on the potential impacts of climate variability and change, including the impacts associated with extreme events, thermal stress, foodborne diseases, and vectorborne diseases. She is working with WHO, UNDP, USAID, and others on designing adaptation measures to reduce current and projected impacts in health and other sectors. She is a Lead Author for the Human Health chapter of the Intergovernmental Panel on Climate Change Fourth Assessment Report, and for the U.S. Climate Change Science Program Synthesis and Assessment Product 4.6 (Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems). She was a Convening Lead Author on the WHO publication: Methods of Assessing Human Health Vulnerability and Public Health Adaptation to Climate Change, and was a Lead Author in the Millennium Ecosystem Assessment and the U.S. National Assessment of the Potential Consequences of Climate Variability and Change. Dr. Ebi has more than 25 years of multidisciplinary experience in environmental issues. She has edited three books on climate change and health, and has more than 75 publications. Dr. Ebi's scientific training includes a M.S. in toxicology and a Ph.D. and MPH in epidemiology, and two years of postgraduate research in epidemiology at the London School of Hygiene and Tropical Medicine.