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Climate Change and Children

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The increasing temperatures, changing precipitation patterns, and more extreme weather events that are occurring because of climate change [1] have begun to increase morbidity and mortality from climate-sensitive health determinants and outcomes [2,3]. Children are particularly vulnerable to many of these health outcomes because of their potentially greater exposures (resulting, in part, from behavioral patterns), greater sensitivity to certain exposures, and dependence on caregivers for appropriate preparedness and response. These factors can interact with poverty, race, and class to increase risk further. Because vulnerability to some climate-sensitive health outcomes changes with age, education programs could prepare children for future risks. Consideration of the health impacts of climate change raises issues of intergenerational equity.

Although it should be obvious that children are particularly vulnerable to the changes brought by climate change, little has been written that focuses on the special risks posed to children [4,5]. This article first reviews the key issues related to climate change, then reviews climate-sensitive health determinants and outcomes in the context of children's health, considers intergenerational equity issues, and finishes with a discussion of opportunities for reducing current and projected vulnerabilities to climate change.

Climate change

The earth's climate is determined by complex interactions that involve the sun, oceans, atmosphere, cryosphere (which includes sea ice, freshwater ice,

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snow, glaciers, frozen ground, and permafrost), land surface, and biosphere. These interactions are based on physical laws: conservation of mass, conservation of energy, and Newton's second law of motion. The principal driving force for weather and climate is the uneven warming of the earth's surface because of the tilt in the axis of rotation. In addition to complex and changing atmospheric and oceanic patterns redistributing solar energy from the equator to the poles, some absorbed solar radiation is reradiated as long-wave (infrared) radiation. Some of this infrared radiation is absorbed by the atmospheric greenhouse gases (including water vapor, carbon dioxide [CO_2], methane, nitrous oxide, halocarbons, and ozone) and is reradiated back to the earth, thereby warming the surface more than would be achieved by incoming solar radiation alone and raising the global average surface temperature to its current 15°C (59°F) [6]. Without this warming, the earth's diurnal temperature range would increase dramatically, and the global average surface temperature would be about 33°C (91°F) colder. Although atmospheric concentrations of greenhouse gases have varied over geologic history, they have not been higher than current concentrations for hundreds of thousands, perhaps millions, of years. Based on the physical laws governing climate, increasing concentrations of greenhouse gases will increase the amount of heat in the atmosphere, which will warm the earth further. Fig. 1 illustrates the greenhouse effect.

CO_2 is the most important anthropogenic greenhouse gas. CO_2 is not destroyed chemically; its removal from the atmosphere occurs through multiple processes that store the carbon transiently in land and ocean reservoirs and ultimately in mineral deposits [1]. Natural processes currently remove about half the incremental anthropogenic CO_2 added to the atmosphere annually; the balance is removed over 100 to 200 years [7]. Atmospheric concentrations of CO_2 have increased by 31% since 1750 to about 370 ppm by volume [1]. This concentration has not been exceeded during the past 420,000 years and probably not during the past 20 million years. About 75% of the anthropogenic CO_2 emissions to the atmosphere during the past 20 years resulted from fossil fuel burning; most of the rest resulted from changes in land use, especially deforestation [1].

Instrumental records of temperature, precipitation, and other weather elements began in the 1860s. In its Third Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) evaluated this record and concluded that during the twentieth century, the global average surface temperature increased about 0.6°C ± 0.2°C (1.1°F ± 0.4°F), with the 1990s being the warmest decade [1]. Global surface temperatures increased by about 0.2°C (0.4°F) per decade in the past 30 years [8]. The warmth of the 1990s was outside the 95% confidence interval of temperature uncertainty, defined by historical variation, during even the warmest periods of the last millennium [1]. Further, the IPCC concluded that most of the warming observed during the past 50 years is attributable to human activities, and that human influences will continue to change atmospheric composition throughout the

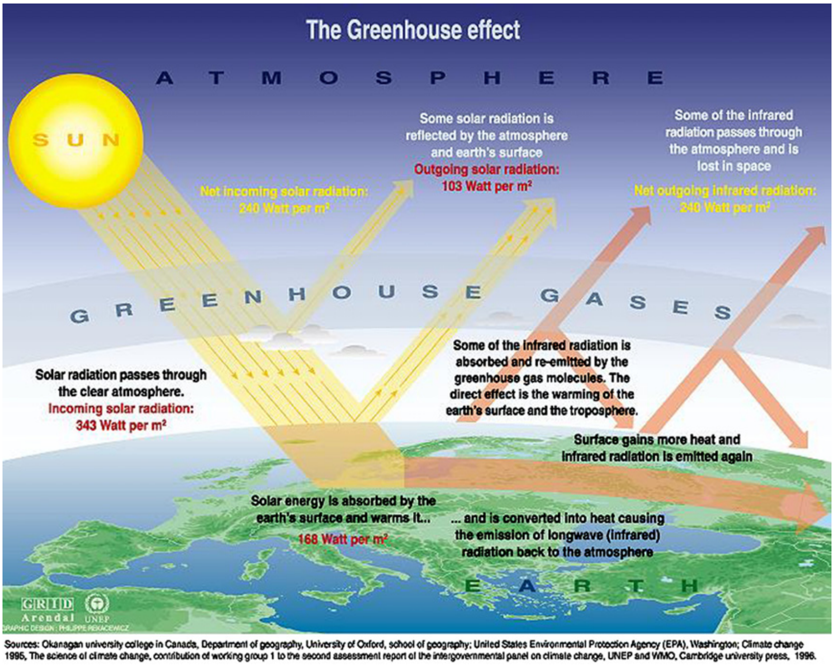

Fig. 1. Greenhouse effect. (*From:* United Nations Environment Programme GRID-Adrenal. Available at: http://www.grida.no/climate/vital/03.htm, Accessed December 20, 2006; with permission).

twenty-first century. The earth is now within about 1°C (1.8°F) of the maximum temperature of the past million years [8].

By 2100, atmospheric concentrations of CO_2 are projected to be between 490 and 1260 ppm (75%–350% above the concentration of 280 ppm in the year 1750) [1]. As a consequence, the global mean surface temperature is projected to increase by between 1.4°C and 5.8°C (2.5°F and 10.4°F) during the same period (Fig. 2). The projected rate of warming is much larger than the observed changes during the twentieth century and is likely to be without precedent during at least the last 10,000 years. The half-life of CO_2 and other greenhouse gases means that the earth is committed to decades of climate change; only beyond mid-century could mitigation efforts begin to reduce projected increases in global mean temperatures [1].

Temperature increases will not be spatially uniform. Average temperature increases are projected to be greatest in the northern regions of North America, Europe, and in northern and central Asia. Precipitation is projected to increase over the northern mid to high latitudes. Climate change also will be characterized by changes in global precipitation patterns, rising sea levels, and increases in the frequency and intensity of some extreme

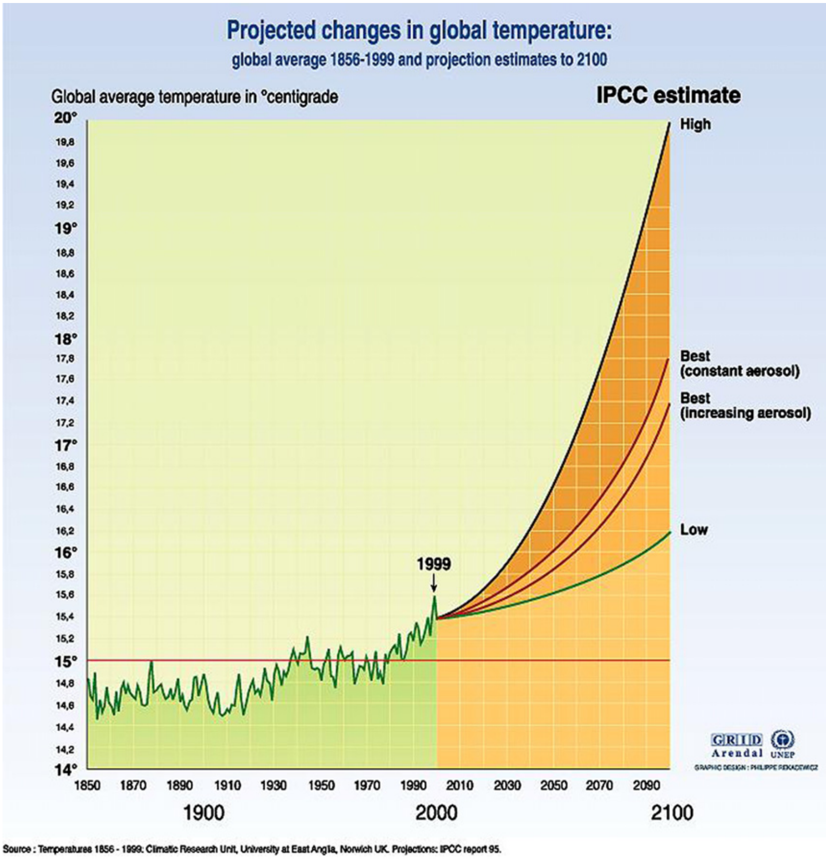

Fig. 2. Projected changes in global average surface temperatures. IPCC, Intergovernmental Panel on Climate Change. (*From:* United Nations Environment Programme GRID-Adrenal. Available at: http://www.grida.no/climate/vital/36.htm, Accessed December 20, 2006; with permission).

weather events. Easterling and colleagues [9] evaluated modeling results of different types of climate extremes for the twenty-first century and concluded that the following changes are likely to occur (90%–99% probability):

Higher maximum temperatures, more hot summer days
An increase in the heat index
More heavy 1-day precipitation events
More heavy multiday precipitation events

It is very likely there will be more frequent and more intense heat waves, and it is possible (33%–66% probability) that there will be more intense mid-latitude storms and more intense El Niño events [9,10].

Climate-sensitive health determinants and outcomes

Weather, climate variability, and climate change can affect children directly and indirectly (Fig. 3). Directly, extreme weather events (such as floods, droughts, and windstorms) and heat events 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 [11]. More than 35,000 excess deaths were attributed to the extended heat wave in Europe during the same year [12,13]. Indirectly, climate can affect health through changes in the geographic range and intensity of transmission of vector-, tick-, and rodent-borne diseases and food- and waterborne diseases and 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 [7]. Children in the United States are most likely to be affected by air pollutants and aeroallergens, food- and waterborne diseases, vector-borne diseases, and extreme weather events.

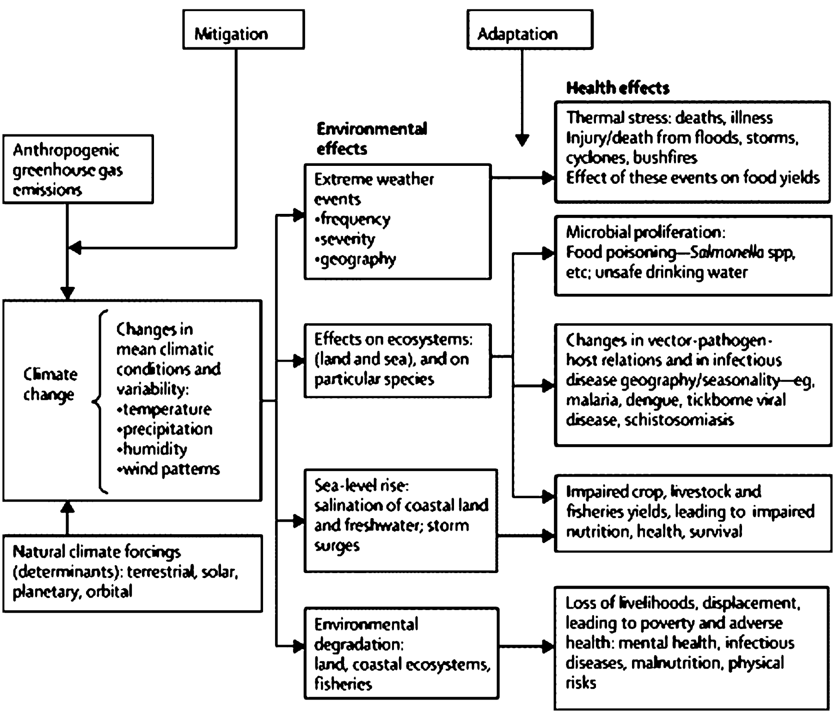

Fig. 3. Schematic summary of main pathways by which climate change affects population health. (*From*: McMichael AJ, Woodruff RE, Hales S. Climate change and human health: present and future risks. Lancet 2006;367:860; with permission.)

The cause-and-effect chain from climate change to changing patterns of health determinants and outcomes is often extremely 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 [14]. Therefore, the severity of future impacts will be determined by changes in climate and by concurrent changes in nonclimatic factors and by the adaptation measures implemented to reduce negative impacts.

The potential climate change–related health impacts of extreme weather and temperature events, infectious diseases, and air pollutants are summarized here, followed by a summary of global assessments of current and future disease burdens attributable to climate change.

Extreme weather and heat events

Children are particularly vulnerable in extreme events because of their dependence on adults to ensure their safety and well-being [15]. Because of their size and because of the differences in physiology and psychology, children need specialized medical care during and after man-made and natural disasters [16]. The health and social burden of extreme weather events can be complex, far-reaching, and difficult to attribute to the event itself [17,18]. Adverse health impacts of floods and windstorms include the physical health effects experienced during the event or clean-up process or brought about by damage to infrastructure, including population displacement. Extreme weather events also are associated with mental health effects resulting from the experience of the event or from the recovery process. These psychologic effects tend to be much longer lasting and can be worse than the direct physical effects [17,18].

Heat events affect human health through heat stress, heatstroke, and death [19] as well as exacerbating underlying conditions that can lead to an increase in all-cause mortality [20]. Although heat-related deaths could increase with climate change [21–24], incomplete understanding of how future populations might acclimate to warmer temperatures limits confidence in the size of projected impacts. Regular reports of infants dying when left unintended in vehicles suggest a generally low awareness of the dangers of heat events [25]. In the United States, most deaths associated with heat events have been in older adults [26].

Infectious diseases

Climate and anomalous weather events influence the geographic range and intensity of transmission of several vector-, rodent-, and tick-borne diseases by hindering or enhancing vector and parasite development and survival, including Lyme diseases, St. Louis encephalitis, and West Nile virus. Climate is a primary determinant of whether a particular location has environmental conditions suitable for disease transmission. A change in temperature may lengthen or shorten the season during which vectors or 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). Climate is not the only determinant of vector-borne diseases, however; the many determinants often form an interconnected web with positive feedbacks between transmission dynamics and other factors [27].

Studies have suggested that the changing weather patterns associated with climate change could increase tick populations and the incidence of Lyme disease [28,29]. Hjelle and Glass [30] reported an association between the increased climate variability associated with the El Niño events and rodent-borne outbreaks of Hantavirus. With natural reservoirs in animal populations, the emergence or re-emergence of diseases involves complex interactions [13,30]. Children may be at increased risk for vector-borne diseases because of more time spent outdoors with potentially greater exposure to vectors. For example, in two recent outbreaks, locally caught malaria affected two children in Virginia and one child in Florida [31,32].

A further risk to children (and adults) is the often limited experience of most physicians with emerging and re-emerging diseases. Vectors for dengue fever, malaria, and other diseases are present in many regions of the United States, so there are constant risks for reintroduction of these diseases, particularly with increased international travel. Further, vectors may alter their ranges with changes in temperature and precipitation (see, for example, [29]). After vector control, only prompt diagnosis and treatment can break chains of transmission, suggesting a need for a greater emphasis in medical schools on identification and treatment of these diseases.

Several food- and waterborne diseases are climate sensitive, suggesting the risk of diarrheal illnesses is likely to increase with higher ambient temperatures. An estimated 76 million cases of food-borne disease occur annually in the United States, with 325,000 hospitalizations and 5000 deaths [33]. Common forms of food poisoning such as salmonellosis have an approximately linear association with ambient temperature (see, for example, Refs. [34–36]). Curriero and colleagues [37] and Kistemann and colleagues [38] found that extreme precipitation events increase the loading of contaminants in waterways, and Casman and colleagues [39] concluded that climate change could increase the risk of illness associated with *Cryptosporidium parvum*.

Air pollutants and aeroallergens

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, and the air pollutants ozone, sulfur dioxide, nitrogen dioxide, and carbon monoxide. Air pollution concentrations are the result of interactions among local weather patterns, atmospheric circulation features, wind, topography, human responses to weather changes (ie, 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 and 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 [1]. Indirect effects could result from increased or decreased anthropogenic emissions brought about by changes in human behavior or from altered levels of biogenic emissions brought about by higher temperatures and land cover change. Establishing the scale (local, regional, global) and direction of change (improvement or deterioration) of air quality is challenging, however [40].

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 [41–45]. Future emissions are, of course, uncertain and depend on assumptions about population growth, economic development, and energy use [46,47]. In the United States a study of the projected increased adverse health impacts of ozone due to climate change concluded that summer ozone-related mortality could increase by 4% in the New York area by the 2050s based on climatic changes alone [48].

Recent studies examined the potential impact of climate variability and change on airborne allergen concentrations and reached conclusions similar to those of Bernard and colleagues [40]: that increased CO_2 and higher temperatures generally increase the growth rate of allergen-producing plants (eg, ragweed) and the production of pollen [49,50]. D'Amato and colleagues [51] also concluded that air pollution might facilitate the penetration and the depth of penetration of allergens into the lungs, thus increasing the risk of these allergens.

Global assessments of the health impacts of climate change

The most comprehensive evaluation of the burden of disease resulting from climate change 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 [2]. Health outcomes were analyzed by region to understand better where current and projected future disease burdens are highest and to identify the outcomes that contribute to the largest share of the total burden. The health outcomes included in the analysis were chosen based on sensitivity to climate variation, likely future importance, and availability of quantitative global models (or feasibility of constructing them) [2]. 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). 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 (0.4% worldwide), with malnutrition accounting for approximately 50% of these deaths and disability-adjusted life years [2,3]. These estimates relate to a period when limited climate change had occurred, suggesting that future studies may find larger health burdens caused by climate change.

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 resulting from increases in diarrheal disease and malnutrition, primarily in low-income populations already experiencing a large burden of disease [2]. Absolute disease burdens depend on assumptions of population growth, future baseline disease incidence, and the extent of adaptation.

Hitz and Smith [52] 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 largest populations, tend to be less developed, and generally have poorer public health infrastructure, likely leading to greater damages.

Exposure to UV radiation

Climate change has the potential to affect exposure to UV radiation either through its effects on the rate of healing of the stratospheric ozone hole or through its effect on clouds and smog [1]. Climate change is projected to slow the rate of healing of the stratospheric ozone hole, increasing exposure to UV. There are three segments of the UV spectrum, UVA (400–315 nm), UVB (315–280 nm), and UVC ($<$280 nm). UV exposure, particularly UVB, has potential beneficial and adverse health effects [53,54]. Vitamin D, which is produced by the skin as a result of UV exposure, increases calcium absorption and may protect against various cancers and myocardial infarction and reduce blood pressure. UV exposure also is associated with sunburn, photoaging, the development of cataracts, and the development of basal cell and squamous cell carcinomas and malignant melanoma. Adolescence seems to be a critical period for increased risk of development of subsequent squamous cell carcinoma and malignant melanoma. UV exposure also down-regulates the immune system in experimental animals; this phenomenon may be part of the causal chain leading to cancer development.

Intergenerational equity

The inherent inertia in the climate system means that the earth is committed to decades of climate change from the greenhouse gases currently in the atmosphere. Even if all greenhouse gas emissions stopped tomorrow, the earth probably will warm 0.5°C to 1.0°C during the next several decades; this warming will be in addition to the 0.6°C increase in global average surface temperature that occurred during the last century [1]. This probability raises intergenerational equity issues: the actions (or lack thereof) taken today will affect not only the climate for present adults' children and grandchildren, but also the costs of actions taken to adapt to and mitigate climate change [55]. Actions taken in the next 10 to 20 years will have only a limited effect on the climate over the next 40 to 50 years, but investing in mitigation now may avoid some of the severe consequences projected for later in the century. The longer serious reductions in greenhouse gas emissions are delayed, the higher will be the projected costs for both mitigation and adaptation, with these costs borne by future generations. Another intergenerational equity issue is that some impacts of climate change, such as the rise in sea level inundating low-lying coastal areas and some small island states, cannot be avoided. The unavoidable impacts will increase with increasing atmospheric concentrations of greenhouse gases.

Because fossil fuel combustion is a source of urban air pollutants and greenhouse gases, policies to reduce greenhouse gas emissions can have health benefits in the near and long term for children and adults. For example, there are potential synergies in reducing greenhouse gases and improving population health by creating sustainable transport systems that make more use of public transport, walking, and cycling [56]. For other energy sources, health-impact assessments should be conducted to evaluate positive and negative health impacts.

Opportunities for reducing current and future vulnerabilities to climate change

Climate change will make more difficult the control of climate-sensitive health determinants and outcomes. Therefore, health policies need explicitly to incorporate climate-related risks to maintain current levels of control [57]. In most cases, the primary response will be to enhance current health risk management activities. The health determinants and outcomes that are projected to increase with climate change are problems today (by definition, new risks are problematic to project). 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 caused by climate change will depend on factors such as [57]

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
The social, economic, and political context within which interventions are implemented

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 [56]. Adaptation policies and measures need to consider how effectively and efficiently to reduce climate-related risks within the context of projected demographic, economic, institutional, technologic, and other changes. The current burden of climate-sensitive diseases suggests that adaptation and mitigation policies and measures need to be implemented soon to avoid projected risks caused by climate change.

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