



Global Climate Change and Children's Health

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abstract

Rising global temperature is causing major physical, chemical, and ecological changes across the planet. There is wide consensus among scientific organizations and climatologists that these broad effects, known as climate change, are the result of contemporary human activity. Climate change poses threats to human health, safety, and security. Children are uniquely vulnerable to these threats. The effects of climate change on child health include physical and psychological sequelae of weather disasters, increased heat stress, decreased air quality, altered disease patterns of some climate-sensitive infections, and food, water, and nutrient insecurity in vulnerable regions. Prompt implementation of mitigation and adaptation strategies will protect children against worsening of the problem and its associated health effects. This technical report reviews the nature of climate change and its associated child health effects and supports the recommendations in the accompanying policy statement on climate change and children's health.

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Global climate change is a leading public health threat to all current and future children. Rising global temperature, known as “global warming,” is causing major physical, chemical, and ecological changes in the planet. The term “climate change” is used in this report to include these broader effects. There is now broad consensus among the world's leading scientific organizations and approximately 97% of climate scientists¹⁻⁴ that these changes are the result of human-generated greenhouse gas emissions.

Rising greenhouse gas concentrations and climate change are part of a larger constellation of change resulting from contemporary human activity. Exponential increases in human population, habitat transformation, energy production and consumption, and climate change⁵ are putting unprecedented pressure on the earth, resulting in physical, chemical, and ecological changes that are fundamentally altering the planet.⁶ These accelerating changes threaten the biological systems on which the life, health, and prosperity of all children depend.

There is wide recognition of climate change among scientific bodies,⁷ international agencies,⁸⁻¹⁰ and world religions,¹¹ and it is important for pediatricians to be aware of the effects of climate change on the health and security of individuals, families, and communities. Children are a uniquely

vulnerable group that suffers disproportionately from these effects.^{12,13} Children also have a fundamental right to justice in a matter as essential as the condition of the planet on which they will live and raise their own children. Although uncertainties remain regarding risks and policy response, given the overwhelming scientific consensus on the cause and potentially irreversible harm associated with climate change, failure to take prompt, substantive action would be an act of injustice to all children.¹⁴

Pediatric health care professionals should increase their understanding of the health consequences of climate change so they are able to recognize and anticipate climate-associated effects and serve as advocates for children in the development of mitigation and adaptation strategies to address this global challenge. The purpose of this technical report is to educate pediatricians on the current knowledge of climate change and its effects on children's health. Specific recommendations for pediatricians and governments are included in the accompanying policy statement from the American Academy of Pediatrics on global climate change and children's health.¹⁵

CAUSES OF CLIMATE CHANGE

Climate is typically defined as "average weather" over a period of time, classically 30 years. Our climate system is a highly complex system of interactive components that evolves under the influence of variations in the earth's orbit, internal dynamics, and external drivers such as volcanic eruptions and human-induced changes in land use and the concentration of atmospheric gases.¹⁶ The climate has changed naturally throughout Earth's history. The last ice age ended only about 14 000 years ago. At that time, the global surface temperature was 5°C lower than it is today. The temperature

gradually warmed over about 5000 years and then remained stable until about 100 years ago. At that time, human activities caused a rapid increase in CO₂ and other greenhouse gas concentrations in the atmosphere, and global temperature began to rapidly increase.¹⁷

Atmospheric CO₂ has increased from approximately 280 ppm before the industrial revolution to 400 ppm in April 2013, a level last reached approximately 3 million years ago.¹⁸ This increase is primarily a result of fossil fuel emissions, although deforestation also affects the earth's atmosphere by reducing carbon storage in vegetation and changing land surface reflectivity.¹⁹ Approximately half of the total CO₂ increase has occurred in the last 40 years.²⁰ The heat-trapping nature of CO₂ and other gases has been recognized since the 1800s²¹ and can be demonstrated by simple experiments. Leading scientific

organizations agree that increasing greenhouse gases are the major driver of current climate change rather than natural factors that caused changes in Earth's past (see Figures 1 and 2).⁴

NATURE OF THE GLOBAL PROBLEM

Rising temperatures are causing observed changes across a range of climatic indicators (see Figure 3).²² These include worsening heat waves, shrinking ice sheets, rising sea level, increased humidity, worsening of some storms, and more frequent and severe wildfires.

Warming of the planet is unequivocal. Each of the last 3 decades has been successively warmer than any preceding decade since 1850. The global average temperature (combined land and ocean surface) increased 0.85°C (0.65–1.06°C) between 1850 and 2012 (see Figure 4). Much of this increased heat

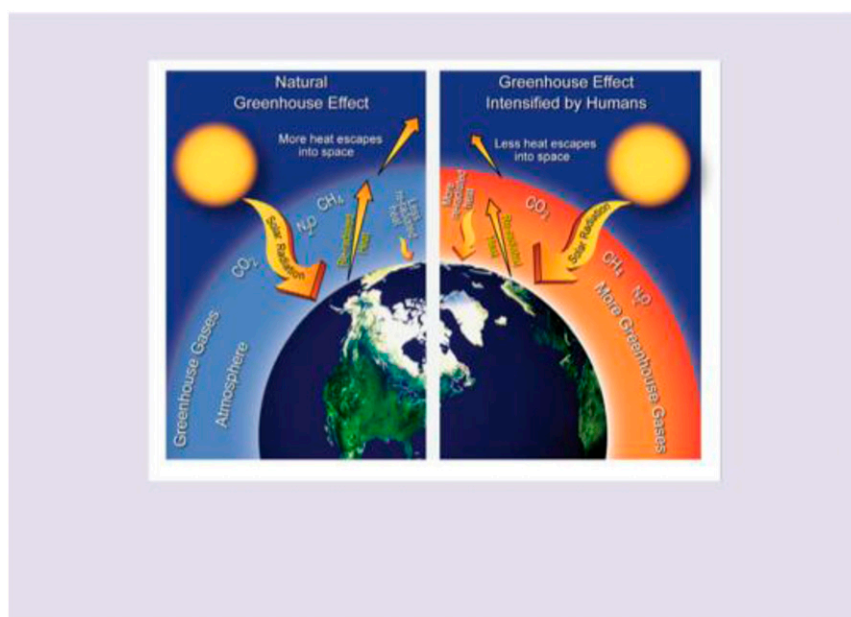


FIGURE 1

Left, A stylized representation of the natural greenhouse effect. Most of the sun's radiation reaches the earth's surface. Naturally occurring heat-trapping gases, including water vapor, carbon dioxide, methane, and nitrous oxide, do not absorb the short-wave energy from the sun but do absorb the long-wave energy reradiated from the earth, keeping the planet much warmer than it would be otherwise. Right, In this stylized representation of the human-intensified greenhouse effect, human activities, predominantly the burning of fossil fuels (coal, oil, and gas), are increasing levels of CO₂ and other heat-trapping gases, increasing the natural greenhouse effect and thus Earth's temperature. Figure and legend source: National Climate Assessment (NCA).²⁵

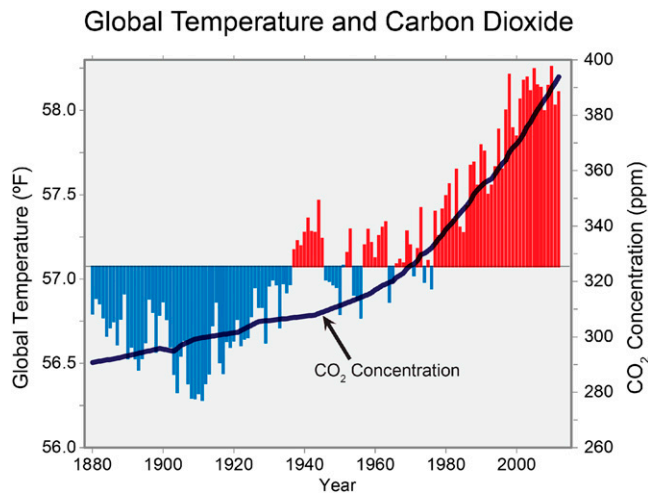


FIGURE 2

Global annual average temperature (as measured over both land and oceans) has increased by $>1.5^{\circ}\text{F}$ (0.8°C) since 1880 (through 2012). Red bars show temperatures above the long-term average, and blue bars indicate temperatures below the long-term average. The black line shows atmospheric CO_2 concentration in parts per million. Although there is a clear long-term global warming trend, some years do not show a temperature increase relative to the previous year, and some years show greater changes than others. These year-to-year fluctuations in temperature are due to natural processes, such as the effects of El Niños, La Niñas, and volcanic eruptions. Figure and legend source: NCA.²³

has been absorbed by the ocean.¹⁹ In the United States, average temperature has increased by approximately 0.83°C since record keeping began in 1895, most of which has occurred since approximately 1970.²³ Limiting temperature rise to 2°C above preindustrial times has been envisioned by the Intergovernmental Panel and Climate Change as a goal to prevent the most damaging consequences on humans, food systems, and ecosystems.¹⁷

Associated with this global warming is a worldwide shrinkage of glaciers, decreasing mass of the Greenland and Antarctic ice sheets, and diminished spring snow cover in the Northern Hemisphere. According to the Third National Climate Assessment, the frost-free season has increased in every region of the United States, with increases ranging from 6 to 19 days (see Figure 5).

Global sea level has risen by approximately 8 inches since reliable record keeping began in 1880. The rate of rise of the global sea level has also accelerated, and it is projected to rise another 1 to 4 feet by 2100.²³

Relative sea level rise in different regions varies because of local changes in land movement or coastal circulation patterns.²² Glacier mass loss and ocean thermal expansion attributable to warming explain approximately 75% of the observed global mean sea level rise.¹⁹

Warmer air has greater capacity for water vapor than cooler air. Increased water vapor in the atmosphere has contributed to an increase in heavy precipitation events in most regions, including the United States, where increases have been greatest in the Midwest and Northeast (see Figure 6). In some areas, prolonged record high temperatures have been associated with droughts, particularly in the southwestern United States.²³

Heat waves have become more frequent and prolonged in many regions, and the number of extreme cold waves in the United States is the lowest since record keeping began.²³ Other forms of severe weather, such as hurricanes in the North Atlantic, have increased in intensity since 1970, although causality remains uncertain.¹⁹ There has also been an

increase in wildfire frequency, duration, and severity in North American forests.²⁴

Climate change is already occurring, and past and present emissions make some continued changes inevitable. However, projected levels of global warming, sea ice shrinkage, and sea level rise by the mid-21st century vary greatly for different greenhouse gas emission scenarios. Higher future emission levels will result in more warming and thus more severe effects on the natural world and human society and health (see Figure 7).²³

EFFECTS OF CLIMATE CHANGE ON CHILDREN'S HEALTH

Observed changes in temperature, precipitation patterns, sea level, and extreme weather events are bringing instability to the major determinants of human health. Children are uniquely vulnerable to these changes. Their immature physiology and metabolism; incomplete development; higher exposure to air, food, and water per unit body weight; unique behavior patterns; and dependence on caregivers place children at much higher risk of climate-related health burdens than adults.²⁵ It is estimated that 88% of the existing global burden of disease attributable to climate change occurs in children younger than 5 years old in both industrialized and developing countries.²⁶ Children in the world's poorest countries, where the disease burden is already disproportionately high, are most affected by climate change.²⁷ Climate change is currently affecting child health through increased heat stress, decreased air quality, altered disease patterns of some climate-sensitive infections, physical and mental health effects of extreme weather events, and food insecurity in vulnerable regions (see Figure 8). At present, the global health burden attributable to climate change is poorly quantified compared with other health stressors.²⁴ Over

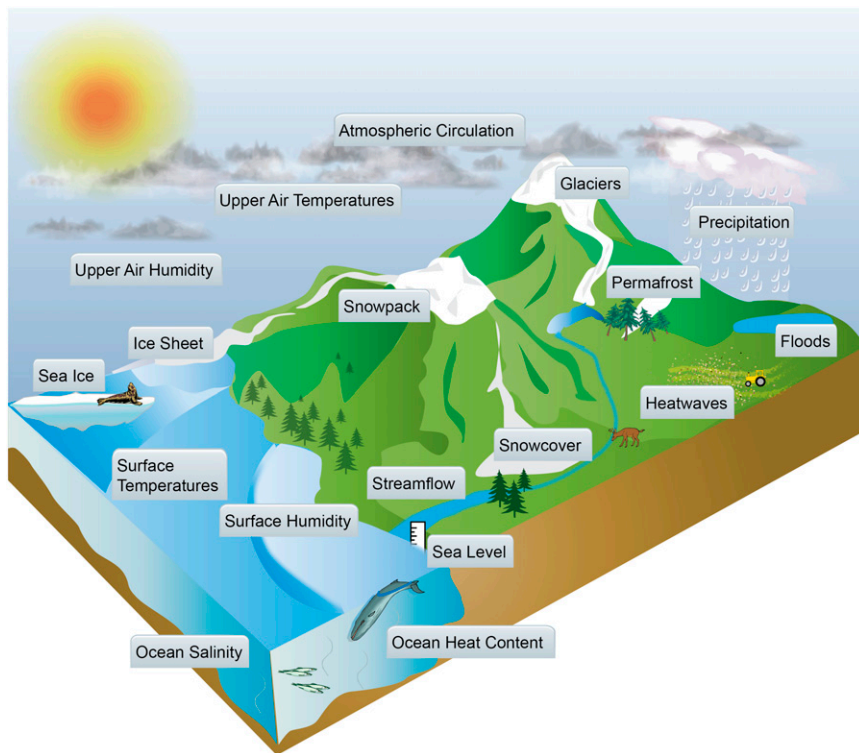


FIGURE 3

Examples of the many aspects of the climate system in which changes have been formally attributed to human emissions of heat-trapping gases and particles by studies published in peer-reviewed science literature. For example, observed changes in surface air temperature at both the global and continental levels, particularly over the past 50 years, cannot be explained without including the effects of human activities. Although many natural factors have affected climate in the past and continue to do so today, human activities are the dominant contributor to recently observed climate changes. Figure and legend source: NCA.²³

the 21st century, however, the negative health effects are expected to increase.

Heat-Related Illness

Extreme heat is the leading cause of environmental deaths in the United States, killing more people than hurricanes, lightning, tornadoes, and floods.²⁸ The body's heat regulation system is able to cope effectively with thermal stress within certain limits. However, extreme temperatures exceed the body's coping capacity, resulting in heat exhaustion and heat stroke, and potentially death. Excess morbidity and mortality attributable to extreme heat have been well documented.^{29–31} As temperatures increase and heat waves become more frequent, longer, and more severe, illness and death from heat exposure are expected to increase.³²

The health effects of extreme heat have been shown to outweigh the benefits of milder winters.^{33–35}

Research on the relationship between temperature and morbidity and mortality in children is limited. However, studies have shown a unique vulnerability of children younger than 1 year old to heat-related mortality.^{36–38} One study from the Massachusetts Institute of Technology found that by the end of the 21st century, under a business-as-usual scenario, infant mortality rate may increase by 5.5% in girls and 7.8% in boys because of heat-related deaths.³⁹ This vulnerability is consistent with the immaturity of infants' thermoregulatory systems.⁴⁰ Several studies have shown increased pediatric hospitalizations and emergency department (ED) visits during extreme heat events,³⁶

primarily because of renal and electrolyte disturbances^{41–43} and lower respiratory disease.⁴⁴ Rising ambient temperatures may also increase adverse birth outcomes, including preterm birth^{45–47} and stillbirth.⁴⁸

US student athletes are a high-risk group for exertional heat injury. Of the estimated 5946 people treated for exertional heat illness each year in EDs in the United States from 2001 to 2009, more than one-third were teenage male athletes, most commonly football players.⁴⁹ The Centers for Disease Control and Prevention report heat illness as a leading cause of death and disability in high school athletes, with a national estimate of 9237 illnesses annually, with football players at highest risk.⁵⁰ This risk appears to be increasing. ED visits for heat illness increased 133.5% between 1997 and 2006, according to 1 study.⁵¹ The number of deaths from heat stroke in American high school and college football players has doubled in the past decade.⁵² Another subpopulation of children in the United States at risk for extreme heat are child farm laborers, of which there are more than approximately 120 000.⁵³ Children may also be indirectly affected by heat illness in family members. The 1995 Chicago heat wave resulted in more than 650 deaths,³² and the record-breaking 2003 European heat wave resulted in an estimated 30 000 premature deaths.⁵⁴ There is a >90% chance that by the end of the 21st century, average summer temperatures will exceed the most extreme temperatures recorded in many regions across the world.⁵⁵ Increasing heat exposure is likely to reduce work capacity and economic and social development in heat-exposed jobs in vulnerable countries.⁵⁶ Global lost labor capacity in peak months is projected to double by 2050 because of heat stress.⁵⁷ Thus, excess heat may influence children indirectly

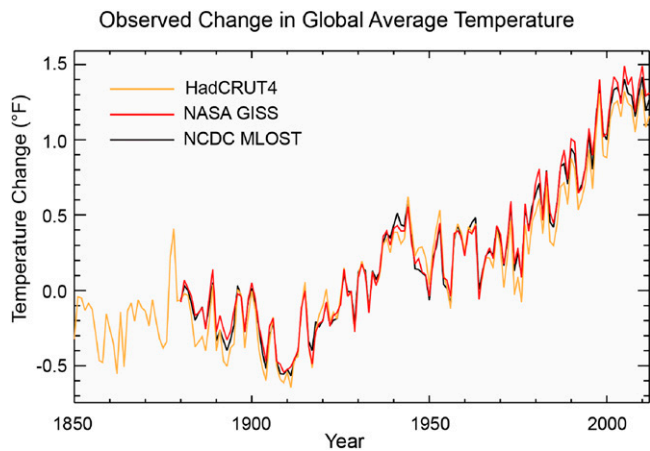


FIGURE 4

Three different global surface temperature records show increasing trends over the last century. The lines show annual differences in temperature relative to the 1901 to 1960 average. Differences between data sets, reflecting choices in data selection, analysis, and averaging techniques, do not affect the conclusion that global surface temperatures are increasing. GISS, Goddard Institute for Space Studies; HADCrut, Hadley Centre and the Climatic Research Unit at the University of East Anglia; MLOST, Merged Land–Ocean Surface Temperature; NCDC, National Climatic Data Center. Figure and legend source: NCA.²³

through effects on family health and financial security.

Air Quality

Asthma is the most common pediatric chronic disease,⁵⁸ affecting 6.8 million, or 9.3% of American children in 2012.⁵⁹ Climate change has been projected to increase childhood asthma via an associated rise in air pollutants, including ground-level ozone. Ozone is a potent lung irritant that increases asthma morbidity and mortality. It is formed in the lower atmosphere in the presence of heat and light from precursor molecules (oxides of nitrogen and volatile organic compounds) that are emitted during fossil fuel combustion. Higher surface temperatures promote the formation of ground-level ozone,⁶⁰ even in the absence of increased precursor molecules.⁶¹

Because of their higher minute ventilation and time spent outdoors during the summer, children are the group most vulnerable to ozone.⁶² Exposure has been associated with asthma exacerbations,⁶³ increased ED visits⁶⁴ and pediatric ICU admissions for asthma, and increased risk of developing asthma.^{65,66} Ozone

concentrations in the United States have been projected to increase by 5% to 10% between now and the 2050s because of climate change alone.⁶⁷ Climate change–associated ozone elevations have already been associated with a significant health burden and related cost,⁶⁸ and this burden is expected to increase with additional temperature rise.⁶⁹ Climate change–associated increase in ground-level ozone may increase child asthma ED visits, with 1 study projecting an increase of 5% to 10% in New York City by 2020.⁵⁸

Wildfires produce smoke that contains hundreds of chemicals, many of which are harmful to human health. These include particulate matter, carbon monoxide, and ozone precursors. Wildfire smoke travels for thousands of miles and can affect far-away regions. For example, forest fires in Canada in July 2002 resulted in a 30-fold increase in airborne fine particles in Baltimore, nearly 1000 miles downwind. Exposure to wildfire smoke has been estimated to cause 260 000 to 600 000 global deaths annually.⁷⁰ Exposed children, both asthmatic and nonasthmatic, have been shown to suffer substantial eye

symptoms and upper and lower respiratory symptoms.⁷¹ The 2003 wildfire in southern California resulted in a 25% higher rate of asthma admissions in 5- to 19-year-olds during the fire and a 56% higher rate after the fires.⁷² These data are consistent with other studies showing increasing numbers of respiratory ED visits and hospital admissions with exposure to wildfire smoke.⁷³ Wildfire smoke also elevates harmful ground-level ozone concentrations.⁷⁴

In 2012, 9% of American children suffered from hay fever.⁵⁹ The ragweed pollen season in North America has lengthened by 13 to 27 days since 1995 because of delayed first frost and lengthening of the frost-free period, with greater increases in higher latitudes.⁷⁵ In addition, ragweed allergen production increases in response to increased levels of CO₂ and increased temperature.⁷⁶ Pollen counts from ragweed grown in today's approximate CO₂ level are twice the level as for plants grown at CO₂ levels of the previous century.⁷⁷ Elevated pollen counts place a greater number of children at risk for allergy-associated asthma attacks.⁷⁸

Infectious Diseases

Climate influences the behavior, development, and mortality of a wide range of living organisms,^{79–81} some of which have the potential to influence child health. Determining the effects of climate change on infectious diseases is complex because of the confounding contributions of economic development and land use, changing ecosystems, international travel, and commerce.⁸² Although many uncertainties remain, there is evidence of a climatic contribution to range shifts of some climate-sensitive infections, emergence of novel diseases, and projected increases in diarrheal illness in vulnerable regions.

Diarrheal illness is a leading cause of child mortality across the world, with approximately 1.6 million deaths

Observed Increase in Frost-Free Season Length

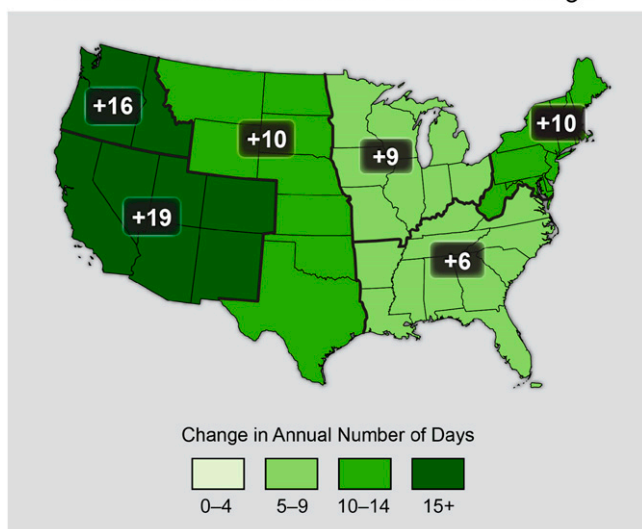


FIGURE 5

The frost-free season length, defined as the period between the last occurrence of 32°F in the spring and the first occurrence of 32°F in the fall, has increased in each US region during 1991 to 2012 relative to 1901 to 1960. Increases in frost-free season length correspond to similar increases in growing season length. Figure and legend source: NCA.²³

annually in children younger than 5 years old.⁸³ It is also a major cause of morbidity in the United States. There are an estimated 2 to 19 million cases of gastrointestinal illness attributable

to drinking water in the United States yearly,⁸⁴ and more than 19 000 cases of foodborne illness were reported in 2013, the highest incidence occurring in children younger than 5 years

Observed Change in Very Heavy Precipitation

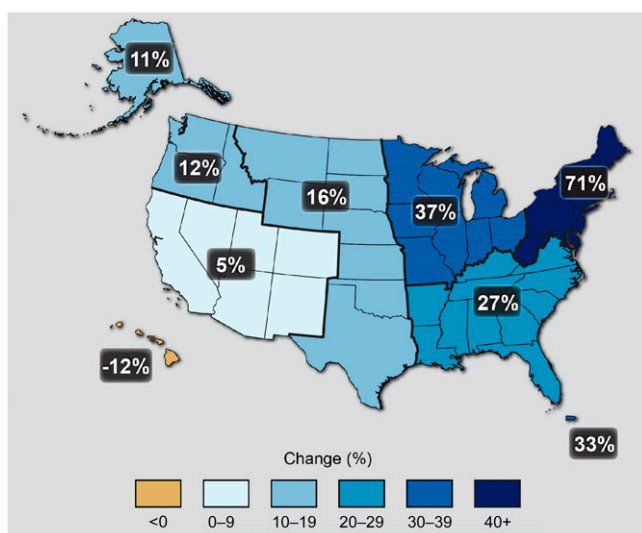


FIGURE 6

The map shows percentage increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. These trends are larger than natural variations for the Northeast, the Midwest, Puerto Rico, the Southeast, the Great Plains, and Alaska. The trends are not larger than natural variations for the Southwest, Hawaii, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012. Figure and legend source: NCA.²³

old.⁸⁵ In general, cases of bacterial gastroenteritis, including *Salmonella*, *Campylobacter*, *Escherichia coli*, *Cryptosporidium*, and *Shigella*, increase when temperatures are higher,⁸⁶⁻⁹² although patterns vary by organism and location. There is reason to be concerned that these infections may increase because of rising global temperatures. An increased incidence of community gastroenteritis with higher temperature has been documented.^{93,94} By contrast, higher temperature and humidity during cooler months have been associated with lower rates of diarrheal illness and hospitalization attributable to confirmed or suspected viral pathogens.^{95,96}

Heavy precipitation and drought events have also been associated with increased gastrointestinal illness resulting from disruption and contamination of water systems.⁹⁷⁻¹⁰¹ In North America, most documented waterborne disease outbreaks occur after extreme precipitation events.⁸⁴ Heavy downpours are increasing in the United States, and additional increases in frequency and intensity are projected,²³ thus raising the concern of increased associated gastrointestinal illness.

The risk of *Vibrio* infection is strongly influenced by climate. Cholera remains a major global public health threat, with an estimated 3 to 5 million cases and 100 000 to 120 000 deaths attributable to cholera yearly.¹⁰² Although any age group can suffer, young children in areas with endemic disease are most affected.¹⁰³ High temperature plays an important role in the transmission dynamics of cholera.^{104,105}

Because of these effects, climate change has been projected to increase the burden of diarrheal illness,¹⁰⁶ particularly in low-income regions already experiencing a large burden of disease.^{106,107} Climate change is projected to cause an additional 48 000 deaths attributable to diarrheal

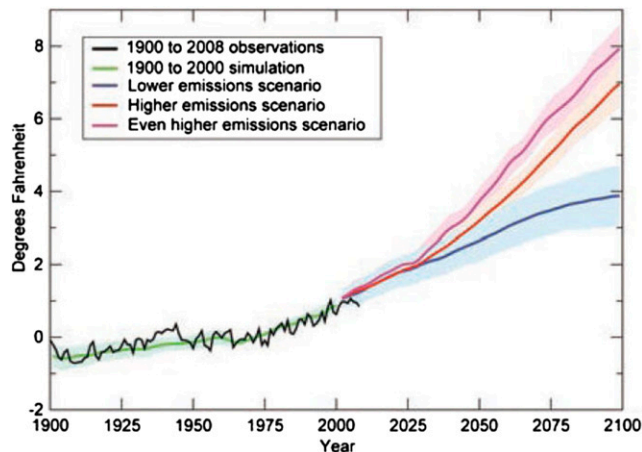


FIGURE 7

Scientists have modeled future temperature changes based on a variety of greenhouse gas emissions scenarios. Each scenario is based on a set of assumptions about population trends, economic development, and technology, all of which affect the amount of greenhouse gases emitted over time. The figure shows the best estimate (solid line) and likely range (shaded area) of how much temperature will have changed at different points in time relative to the 1960 to 1979 average for emission scenarios cited in various graphics throughout the original publication. Figure and legend source: Centers for Disease Control and Prevention.³²

disease in children younger than 15 years old in 2030, primarily in Asia and sub-Saharan Africa.¹⁰⁸ In these regions, climate change has been projected to increase the burden of diarrheal diseases by approximately 2% to 5% in 2020.¹⁰⁹

Climate influences a number of vectorborne diseases that affect children across the world. These include malaria, dengue fever, West Nile virus, Chikungunya, Lyme disease, Rocky Mountain spotted fever, plague, hantavirus pulmonary syndrome, and Chagas disease.

Malaria is a significant cause of child mortality globally, with an estimated 482 000 deaths in children younger than 5 years old in 2012.¹¹⁰ The effect of climate change on human malarial disease is uncertain because of multiple confounding variables. Current research indicates that climate change effects will probably be limited to increased malaria suitability over the African highlands, where the population at risk is large.¹¹¹

Dengue fever is similarly a major global health concern. It is the most rapidly spreading mosquito-borne

viral disease in the world. The World Health Organization estimates there are 50 to 100 million infections yearly, including 22 000 deaths, mostly among children.¹¹² Climate, including temperature and humidity, has a strong direct and indirect influence on the dengue virus and vector, although many other variables also influence disease occurrence.^{113–116} Although dengue is primarily a disease of tropical and subtropical regions, outbreaks have occurred in the United States, including Texas, Florida, and Hawaii.¹¹⁷ How climate change will influence disease patterns remains incompletely understood.

In the United States, West Nile virus has been a growing threat since it first appeared in 1999. Although predominantly affecting adults, it is an important cause of central nervous infections in children¹¹⁸ and is probably underdiagnosed in the pediatric population.¹¹⁹ Temperature influences both vector abundance and rates of virus replication and thus disease transmission.^{120,121} A review of disease cases in the central and western United States between 2002

and 2004 revealed that disease always entered new areas during years with above-normal temperatures.¹²⁰ Precipitation has also been shown to affect mosquito populations and prevalence of West Nile infections, although results have been conflicting.^{121–124} Additional research on West Nile ecology in the setting of climate change is needed.

According to the Centers for Disease Control and Prevention, Lyme disease affects approximately 300 000 Americans each year, with boys 5 to 9 years of age at greatest risk.

Increased Lyme disease transmission risk in the northeastern United States in recent decades is probably related to multiple factors, including disease reporting, reforestation, and increased deer populations.¹²⁵ Rising global temperatures may have co-driven the emergence of Lyme disease in northeastern North America and expanded its range to higher latitudes and altitudes in Europe. Higher temperature also increases tick development rates and may drive an increase in the risk of tickborne infections where they are already endemic.^{81,126–128} Temperature has similarly strong influence on the development of the Chikungunya virus and its vector mosquito. Shifting distribution of the vector and disease transmission from southern to northern Europe because of climate change has been projected.^{129,130}

As ecosystems change because of the climate, newly emerging infections may occur or increase. Coccidioidomycosis, or valley fever, is caused by the *Coccidioides* fungus, which resides in soil from the southwestern United States to South America. In regions of the United States where coccidioidomycosis is endemic, incidence of reported cases has increased substantially, from 2265 cases in 1998 to 22 401 in 2011. Of the cases in 2011, 2166 were in children younger than 19 years old. Although the reasons for

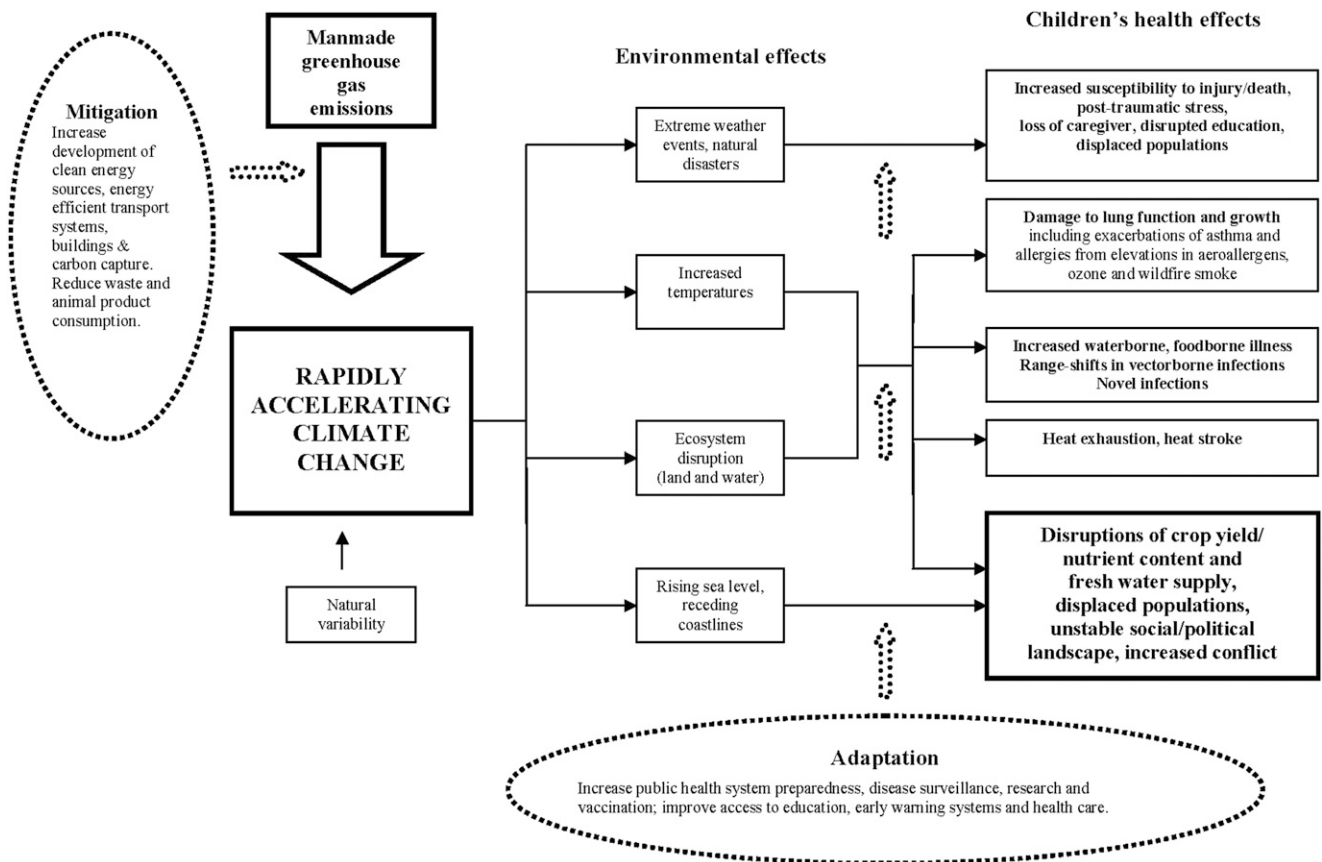


FIGURE 8 Potential effects of global climate change on child health. Adapted from American Academy of Pediatrics policy statement “Global Climate Change and Children’s Health” (2007).¹⁹³

this increase are uncertain, environmental changes, including drought, rainfall, and temperature, as well as soil disruption by human activity, may be contributing factors.¹³¹ Similar concern for climatic influence on disease incidence exists for amebic meningoencephalitis caused by *Naegleria fowleri*, an amoeba commonly found in warm freshwater lakes and rivers. Minnesota reported its first case in August 2010, the third warmest for August in that region since 1891. This fatal case occurred 550 miles north of the previous northernmost reported case.¹³²

Extreme Weather Events

The unique health, behavioral, and psychosocial needs of children place them at unique risk from extreme weather events.^{25,133,134} The

frequency of reported natural disasters has increased in recent decades.¹³⁵ Three times as many extreme weather events occurred between 2000 and 2009 as did between 1980 and 1989. The scale of natural disasters has also increased because of deforestation, environmental degradation, urbanization, and intensified climate variables.¹³⁶ Increased extreme events are predicted to increase the number of children affected by disasters from an estimated 66.5 million yearly in the 1990s to as many as 175 million per year in the upcoming decade. The greatest burden of these disasters will be borne by the world’s poorest children, who are up to 10 times more likely to be affected by climate change-associated disasters than children in higher-income families.¹³⁷

Direct Effects

Extreme weather events directly harm children through injury and death. The most common injuries after hurricanes include lacerations, puncture wounds, and blunt trauma. In the 24 hours after Hurricane Ike, there were more than 500 emergency cases presented to the Children’s Hospital in Camaguey, Cuba. Ninety-six of these patients needed admission, and 4 needed surgery.¹³⁸

Indirect Effects

The indirect effects of weather disasters on children are far reaching. Children’s biological and cognitive development occurs in the context of family, school, neighborhoods, and communities. Disasters can cause irrevocable harm to children through devastation of this broader social context.¹³⁹

Extreme weather events of the past decade have illustrated this potential for long-lasting harm to children through devastation of communities, institutions, and family stability. After hurricanes Katrina and Rita, more than 5000 children were separated from their families. More than 34 000 calls were made to a special hotline that the National Center for Missing and Exploited Children established after the storms, and the last missing child was reunited with her family after 6 months.¹³³ It is estimated that 400 children and adolescents were rescued from flooded homes and that 11 000 children were placed in the New Orleans Convention Center and Superdome at some time. Between 200 000 and 300 000 children were evacuated and relocated, temporarily or permanently.¹⁴⁰

Children displaced by Hurricane Katrina experienced an average of 3 moves per child. Some believe that a child needs 4 to 6 months for academic recovery after a move that results in a change in schools. In the year after Hurricane Katrina, displaced students in Louisiana public schools, on average, performed worse in all subjects and grades compared with other students. In addition, displaced students experienced a variety of problems related to attendance, academic performance, behavior, and mental health.¹³³

Hurricane Sandy, the largest storm ever recorded in the Atlantic Ocean, caused a record high storm surge, damaged or destroyed more than 375 000 housing units, and resulted in an estimated \$75 billion in damages. In New York City, 46.2 square miles had flooding, affecting more than 28 300 children younger than 5 years old.¹⁴¹ Mold growth in affected homes was a significant problem after the storm, placing inhabitants at risk for asthma exacerbations, cough, and wheeze.¹⁴²

Recent weather events outside the United States have exposed the

unique vulnerability of children, particularly in poor countries. In 2010, an unprecedented monsoon flood disaster in Pakistan affected more than 20% of the land area, killing more than 1700 and affecting more than 20 million people.¹⁴³ The flood left more than 10 million people homeless, caused massive disruption to crop systems and health care, and placed more than 100 000 children more than 5 years old at risk for death from malnutrition.¹⁴⁴

Children may be affected by infectious disease outbreaks that follow severe weather events. Measles, diarrheal illness, respiratory infections, and malaria can affect large numbers of survivors and displaced people.¹⁴⁵ After Hurricane Katrina, 20 clusters of diarrheal illness were reported in evacuation centers in Louisiana, and approximately 1000 cases of diarrhea and vomiting were reported in Mississippi and Texas. Norovirus, *Vibrio*, *Salmonella*, and other pathogens were identified. Skin infections were also a problem. A cluster of 30 pediatric and adult patients with methicillin-resistant *Staphylococcus aureus* was reported at a Texas evacuation facility after Hurricane Katrina, as well as 24 cases of hurricane-associated *Vibrio* wound infections, with 6 deaths.¹⁴⁶

Exposure to weather disasters, including hurricanes and flooding, has also been associated with adverse birth outcomes, including low birth weight and preterm delivery.^{147,148}

Food Security

Agriculture has always faced the challenge of weather variability. However, altered agricultural conditions attributable to climate change challenge farmers' ability to adapt. These include extreme heat and increased water demands; increased frequency of severe weather events, including drought and flood; sea level rise and flooding of coastal lands; beneficial impact of

CO₂ fertilization of crops; and changes in crop nutrient content.

Changes are also likely to occur in the number and type of pathogens and pests affecting plants and livestock, altered use of pesticides, damage to fisheries and aquaculture, and mycotoxin contamination.¹⁴⁹⁻¹⁵²

Elevated atmospheric CO₂ acts as a fertilizer and has been demonstrated to increase plant growth and water use efficiency in a wide range of crop species. However, these positive effects may not compensate for losses associated with heat stress, decreased water availability, weather extremes, increased tropospheric ozone, and changes in weed, insect, and disease dynamics.¹⁵³ Extreme temperatures and rising ozone have been demonstrated historically as well as experimentally to cause severe losses in a range of crops, including wheat, maize, soybean, rice, and fruit.¹⁵³⁻¹⁵⁶ Changes in the yield of these major crops have significant implications for food pricing and availability for families across the world, including in developed nations.¹⁵⁷

An emerging concern is the effect of increased atmospheric CO₂ on grain quality. Lowered protein content of the edible portions of wheat, rice, and barley has been demonstrated for plants grown under elevated CO₂ conditions. Decreases of 10% to 15% have been found in these grains when grown in CO₂ levels likely for year 2100 as compared with current levels.¹⁵⁸ Nitrogen fertilization compensates for some but not all of this decrease. CO₂ enrichment has also been shown to lower concentrations of zinc and iron in wheat, rice, soybeans, and field peas. Roughly 4 billion people live in countries where 60% to 70% of dietary zinc or iron comes from these crops.¹⁵⁹ Although understanding of these interactions remains limited, they carry serious implications for child growth and nutrition.^{151,160}

Seafood availability and safety are also at risk from climate change.

Marine ecosystems are changing rapidly, with warming of the ocean's upper layers, ocean acidification, and declining oxygen concentrations.¹⁶¹ Many coastal communities depend on seafood as a protein source and a vital part of the economy. Projected changes in seafood production, including declines in tropical regions and increases in high-latitude seas,¹⁶² have significant implications for communities that have depended on seafood availability for generations. As marine ecosystems change in response to climate change, emerging infections are also a threat. For example, a 2004 outbreak of *Vibrio parahaemolyticus* gastroenteritis was traced to Alaskan oysters, extending the northernmost documented source of this infection by 1000 km.¹⁶³

Climate also affects food safety. Mycotoxin-producing fungal contamination of legume and grain crops carries health risks for both humans and livestock.²⁵ Climate is the most important factor affecting food contamination by these fungi. Industrialized nations with temperate climates, including the United States

and Europe, may be at greatest risk from these toxins, because they will reach temperatures close to optimal for aflatoxin production. However, tropical countries may become too hot for fungal growth.¹⁶⁴ Exposure to aflatoxin is associated with hepatocellular carcinoma, growth stunting, and underweight.¹⁶⁵

Food safety may be affected by an increased need for pesticide use. Pesticide needs may increase as pest populations expand and migrate to new habitats because of temperature and precipitation changes.¹⁶⁶ Additionally, the half-life of pesticides in soil has been shown to decrease with increased temperature.¹⁶⁷ Increased exposure to these products could negatively affect children's health.²⁵

The effects of these climate changes, and farmers' ability to adapt, will vary greatly by region. Moderate warming (1°C–3°C by 2050) may benefit crop and pasture yields in temperate regions, and even small local temperature rise could decrease yields in tropical and semiarid regions. However, warming greater than 2.5°C, as projected for after 2050, would decrease yields in all

regions.^{168–170} These effects on crops will occur simultaneously with an increased world population to 9.2 billion people by 2050 and the need to increase global food production by 50% to meet projected demand.¹⁷¹

Climate changes will cause substantial negative effects on childhood undernutrition and related child deaths in developing countries.²⁴ Currently, undernutrition underlies nearly 3.1 million deaths of children younger than 5 years old worldwide and is responsible for 45% of the disease burden in this age group.¹⁷² Studies have projected a 7% to 20% increase in the number of malnourished children globally because of climate change.^{157,173,174} The regions with the greatest risk of child malnutrition are also those most vulnerable to crop losses attributable to climate change.¹⁷⁵ Compared with a future with no climate change, an additional 95 000 child deaths attributable to malnutrition and an additional 7.5 million moderately or severely growth-stunted children have been projected for the year 2030.¹⁰⁸

It should be noted that the agriculture sector is itself responsible for approximately 22% of total global greenhouse gas emissions, 80% of which comes from livestock production.¹⁷⁶ It has been recommended that animal food consumption in industrialized countries decrease to cut emissions to the level necessary to limit global temperature increase to 2°C.¹⁷⁷ Animal food is a major source of vitamin D, calcium, iron, and protein intake for children in the United States. Recommendations regarding changes in intake to mitigate greenhouse gas emissions would need to account for child nutritional needs to prevent deficiencies.

Mental Health

To date, literature on the effects of climate change and children's mental health has focused on psychological

TABLE 1 Case Vignettes From 2007 Mental Health Patients

| |
|---|
| An 8-year-old boy was evacuated from floodwaters where he witnessed dead bodies floating by. He had persistent school problems while living in a Texas homeless shelter. After resettling in New Orleans, he was referred because of disruptive behavior in school. |
| A 4-year-old girl who had been evacuated from New Orleans before the storm was separated from her parents for several weeks, during which details of her situation were unclear. She was referred from her preschool as an alternative to expulsion after she was reunited with her homeless family. It emerged that she recently had been prevented from setting her doll on fire. |
| Mental health referrals from pediatricians included a 5-year-old with sleep disorder and panic attacks whose apartment and possessions were destroyed in the hurricane and a 4-year-old whose mother had died the year before the hurricane. After Katrina, she had nightmares and regressed functioning, and she was diagnosed with PTSD. |
| A 7-year-old girl was rescued from the floodwaters by boat and placed in a shelter apart from her family. She had multiple cigarette burns when reunited with her family. In the first 2 years after the storm, she attended 5 different schools. Her symptoms included enuresis, hyperventilation, and self-injurious behavior. She was diagnosed with PTSD. |
| A 7-year-old previously diagnosed with PTSD after an automobile accident spent 5 days after the hurricane in a hospital building without adequate food and water. He was evacuated to 2 different states. When he returned to New Orleans, he presented with nightmares and a depressive disorder. |
| Other features of this referred population included animal cruelty, multiple school expulsions, and fighting that necessitated police intervention. |

Source: Olteanu et al (2011).¹⁸⁷

trauma related to weather disasters. High rates of posttraumatic stress disorder (PTSD) symptoms in children have been described after a number of natural disasters that may or may not be climate related. These disasters include hurricanes,^{178–180} floods,¹⁸¹ earthquakes,¹⁸² and other disasters.^{183–185} Providing immediate psychological support and family reunion, as well as rapidly restoring safety and security, are probably effective means of preventing traumatic stress reactions.¹⁸⁶

Hurricane Katrina had a profound effect on the mental health of children in New Orleans. Stories of children referred for mental health services in 2007 illustrate what children endured in that event and the lasting psychological harm that resulted (see Table 1).¹⁸⁷

Although child posttraumatic mental health problems typically decrease substantially within 1 year after disasters, the high rates of forced relocation and prolonged community disruption years after Hurricane Katrina probably delayed the typical pattern of recovery. In 1 study, serious emotional disturbance persisted in 11.5% of children and adolescents 3 years after the hurricane, compared with an estimated 4.2% prehurricane prevalence.¹⁸⁸ Another study found PTSD symptoms in 46% of fourth through sixth graders 33 months after Hurricane Katrina.¹⁸⁰

In addition to PTSD, the indirect effects of climate change on children's mental health should be considered. Economic security, social inclusion, and freedom from violence and discrimination are all crucial to mental health and well-being.¹⁸⁹ These factors are uniquely important for children, whose lifelong health may be affected by early adverse social stressors.¹⁹⁰ Through effects on the economic viability of communities dependent on agriculture and tourism, population displacement attributable to sea level

rise and extreme weather, resource scarcity, and potentially increased violent conflict,¹⁹¹ the social foundations of children's mental and physical health and well-being are threatened by climate change. These effects will probably be greatest for communities already experiencing socioeconomic disadvantage.¹⁸⁶

SUMMARY

"Climate change is the biggest global health threat of the 21st century." This is the conclusion reached by *The Lancet* and University College London Commission on Climate Change in 2009.¹⁹² Climate change is not about a distant, unforeseeable future. It is about the world in which our children live today and the future in which they will raise their own children.¹³⁷

A new public health movement is needed to educate, advocate, and collaborate with local and national leaders regarding the risks climate change poses to children and the major health benefits associated with mitigation policy. In addition, ongoing research into the links between climate and health outcomes and the development of medical and public health interventions to protect individuals and communities from inevitable changes is needed. Pediatricians, as advocates for the population most vulnerable to climate change health effects, have a valuable role to play in this movement.

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ABBREVIATIONS

ED: emergency department
NCA: National Climate Assessment
PTSD: posttraumatic stress disorder

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