HEAT, FIRE, WATER:

HOW CLIMATE CHANGE HAS CREATED A PUBLIC HEALTH EMERGENCY

By Alan H. Lockwood, MD, FAAN, FANA

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1985 NOBEL PEACE PRIZE
PHYSICIANS FOR SOCIAL RESPONSIBILITY

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How Climate Change Has Created a Public Health Emergency

Second Edition

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How Climate Change Has Created a Public Health Emergency

PHYSICIANS FOR SOCIAL RESPONSIBILITY

U.S. affiliate of International Physicians for the Prevention of Nuclear War,
Recipient of the 1985 Nobel Peace Prize

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About Physicians for Social Responsibility (PSR) and climate change: PSR is a non-profit 501(c)(3) scientific and educational organization. It was founded in 1961 when a small group of physicians determined there could be no medical response to a nuclear war and that such a war could lead to the end of civilization as it was known. Articles published in the New England Journal of Medicine were followed by symposia in major cities and countless presentations to medical audiences, civic organizations, churches, and many others. The presenters maintained a sharp focus - there was no effective treatment for nuclear war and therefore it must be prevented. As the Cold War faded, PSR expanded its mission to include other threats to global survival. The subsequent climate change campaign "Death by Degrees" was carried to many states. Health effects of environmental degradation and climate change were conveyed by numerous reports including Coal's Assault on Human Health, Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking , Saving Energy, Saving Lives, Too Dirty, Too Dangerous: Why Health Professionals Reject Natural Gas, The Clean Air Act: a Proven Tool for Healthy Air, and others. This report is a part of PSR's health leadership on climate change. PSR is committed to the fundamental precept of public health: prevention is always superior to treatment.

PSR 1985 NOBEL PEACE PRIZE PHYSICIANS FOR SOCIAL RESPONSIBILITY

U.S. AFFILIATE OF INTERNATIONAL PHYSICIANS FOR THE PREVENTION OF NUCLEAR WAR

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CONTENTS

HEAT, FIRE, WATER: How Climate Change Has Created a Public Health Emergency

Summary

Climate change affects the health of all Americans - right now. There are no exceptions. Although needed adaptation will reduce risks for all, only prompt, significant reductions in greenhouse gas emissions will stave off a crescendoing public health emergency. Children, the elderly, and those with pre-existing conditions or who are socially the most vulnerable will be the most susceptible to the ravages of climate change.

HEAT: The earth is hotter now than at any time since the beginning of the industrial revolution. Records fall each year. There is no clear end to the warming that is under way. Adaptation is a needed and proven lifesaver.

- Heat illnesses were the leading cause of weather-related deaths between 1988 and 2017.
- The 1995 Chicago heat wave killed around 740 and 70,000 died in the 2003 European heat wave.
- More numerous and more severe heat waves are inevitable.
- By 2100 there will be between 2 and 3 times as many days when temperatures are over 95°F.
- Parts of the earth will become uninhabitable.
- Heat-related yields of corn and other crops may fall 80 percent by 2100. Rocketing prices, famine, food riots, civil unrest, and large refugee populations are likely. Things will be worse in El Niño years.

FIRE: Over 73,000 wildfires occur in the U.S. annually, a number that has been relatively constant for 30 years. But since 2000 about 6.9 million acres have burned annually, double the area consumed in the 1990s.

- 85 percent of wildfires are caused by human activity exacerbated by climate-related drought and pests.
- Immediate fire effects include deaths, injuries, and property damage. Paradise, California, was obliterated.
- Wildfire locations become hazardous waste sites.
- Downwind air pollution triggers asthma, worsening of COPD, acute heart attacks, and strokes, and increases long-term cancer risks. Emergency room visits and hospitalizations rise.
- West-coast fires led to increases in ozone on the East Coast that exceeded EPA standards.
- Worldwide wildfires cause over 300,000 annual deaths, a toll highest during El Niño years.

WATER: Sea levels are rising faster than expected, storms are more violent, floods and droughts affect millions, as warm moist weather fosters the spread of vectors of tropical diseases.

- Hurricane Harvey dumped 50 inches of rain on Houston, TX, Maria ravaged Puerto Rico, worse is ahead.
- High sea levels and storms combined to yield storm surges that flooded NY City during Superstorm Sandy.
- After Sandy FEMA paid $1.4 billion 179,016 individuals and households in New Jersey and New York.
- A 0.9 m sea level rise will displace 4.2 million Americans, 13 million if oceans rises twice as much.
- Some island nations will disappear completely.

REGIONAL EFFECTS: U.S. regions will experience toxins from algal blooms, more ragweed pollen, Zika, West Nile Fever, dengue, severe thunderstorms with tornadoes, "king tides," flooding of low-lying coastal areas, intra-state and interstate climate refugees, mud and landslides, saltwater intrusions on water supplies, the loss of water for irrigation and/or drinking as glaciers, rivers, and aquifers dry up, and much more.

1.5°C IS CRUCIAL: The Intergovernmental Panel on Climate Change wrote that limiting global warming to 1.5°C "is projected to lower the impacts on terrestrial, freshwater, and coastal ecosystems and retain more of their services to humans" including health. "Rapid and far-reaching transitions ... unprecedented in terms of scale ..." are required.

PREVENTION IS IMPERATIVE Prevention is a fundamental precept of medicine. We must mitigate climate change by curtailing greenhouse gas emissions and adapt to change by strengthening the public health infrastructure. This requires political leadership from the top down at federal, state, and local levels and bottom-up activism that demands change. Surveys indicate that this is what the public wants, but so far knowledge has not been an adequate stimulus to act. This must change. There are no alternative facts. Healthcare providers have a professional responsibility to use our medical knowledge to deal with this growing healthcare emergency. We may not get another chance.

FOREWORD

The adoption of the 2015 Paris Agreement by virtually every nation on earth was hailed widely as a critical first step toward mitigation and adaptation to climate change. However the initial sense of optimism has not been matched by a sense of urgency and deeds. Carbon dioxide emissions are still increasing. Time is not our friend. The increased need to combat climate change is reflected in two landmark studies. Four years ago the authors of the *Lancet* Commission on Health and Climate Change wrote that "tackling climate change ***could be*** the greatest global health opportunity of the 21st century (emphasis added)."[1] The more recent *Lancet* Countdown concludes that "trends in climate change impacts, exposures, and vulnerabilities show an ***unacceptably high level of risk*** for the current and future health of populations across the world (emphasis added)."[2]

While the scientific community responded to climate change with an outpouring of research, the health community has remained largely silent. The authors of the *Lancet* Countdown tallied around 43,000 articles in the general area of climate change that were published in 2017.[2] But only four percent of that number linked health and climate change and of that small number only one percent (256 papers) focused primarily on climate change and health. In the decade between 2007 and 2017 the *Lancet* authors found about 2,500 reports that address climate change and health. Slightly fewer than half of those papers conveyed the results of new research. Of the remainder, review articles were the most common (55 percent) with editorials, commentaries, and viewpoints making up the rest. Articles about climate change in the Americas and Europe were the most common.

There is a similar lack of focus on the relationship between health and climate change by what the *Lancet* authors refer to as the "elite media" (The New York Times = NYT, Le Monde = LM, and the Frankfurter Allegemeine Zeitung = FAZ).[2] Between 2009 and 2017 climate coverage increased by 133 percent in the NYT, 18 percent in LM, and 200 percent in the FAZ. As with the scientific journals, the link between climate change and health received scant attention (two percent in FAZ and NYT, and eight percent in LM). One of the four major conclusions of the *Lancet* Countdown placed a responsibility on the health and media sectors to ensure "a widespread understanding of climate change as a central public health issue [that] will be vital in delivering an accelerated response [to climate change] ... the health sector [is] beginning to rise to this challenge."

Physicians for Social Responsibility (PSR) moves to fulfill the charge of the *Lancet* Countdown with this report. We believe that healthcare providers have a professional responsibility to be advocates for the mitigation and adaptation to climate change as put forth by two of our earlier leaders in the *Annals of Internal Medicine* and reiterated by others more recently in the *AMA Journal of Ethics.* [3, 4] This responsibility is derived from our special knowledge of medicine and the public health effects of climate change. Our profession compels us to be advocates for health for our patients as well as our families, communities, nation, and all of the people of the world. Acting on behalf of those who are the most vulnerable exemplifies the best tradition of medicine.

"If we don't take action, the collapse of our civilizations and the extinction of much of the natural world is on the horizon."
David Attenborough[5]

CLIMATE CHANGE IS A PUBLIC HEALTH EMERGENCY

In 1896 Savante Arrhenius expressed the hope that his treatise "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground" would prove "useful in explaining some points in geological climatology."[6] Skip ahead to the formation of the Intergovernmental Panel on Climate Change (IPCC) which, along with its reports warning of global warming and Vice President Al Gore's documentary film "An Inconvenient Truth," led to the award of the Nobel Peace Prize in 2007. Global warming temperature targets have been falling. In 2012 the World Bank report "Turn Down the Heat" warned of the consequences of exceeding a 4°C temperature rise. The Paris Agreement's goal of keeping the global temperature increase to 2°C has been superseded by the most recent IPCC report that predicts worldwide calamities if temperatures exceed 1.5°C.[7] As goals move toward lower temperatures the atmospheric concentration of carbon dioxide and other greenhouse gases (GHGs) has increased. Knowledge has not proven to be power. PSR concludes climate change is a public health emergency that threatens our future survival.

Unless prompt, effective efforts at mitigation by massive curtailment of GHG emissions does not begin very, very soon, there will be serious irreversible effects. This is the inescapable conclusion drawn from three transformative reports: The 2018 *Lancet* Countdown on Health and Climate Change (*Lancet* Countdown), the IPCC special report Global Warming of 1.5°C, and the Fourth National Climate Assessment: Impacts, Risks, and Adaptation in the United States (NCA4).[2, 7, 8]

The NCA4 is unique among these three because of its focus on ten regions of the U.S. and its territories, as shown in figure 1 and the fact that it is mandated by U.S. law, the Global Change Research Act of 1990. This act requires the U.S. Global Change Research Program to deliver a report to the President and Congress no less often than every four years. These reports, known as National Climate Assessments, must contain information that "1) integrates, evaluates, and interprets the findings of the Program ....; 2) analyzes the effects of global change on the natural environment, agriculture, land and water resources, human health and welfare, human social systems ...; and 3) analyzes current trends ... both human-induced and natural, and projects major trends for the subsequent 25 to 100 years."[9] The second part of the fourth such assessment (NCA4) was issued in October, 2018.[8]

To slow, stop, and reverse the effects of climate change it is necessary to make sharp reductions in the emission of GHGs and to make health-conserving adaptations to the realities of the changing climate. The same intense focus that PSR's founders brought to nuclear war prevention is

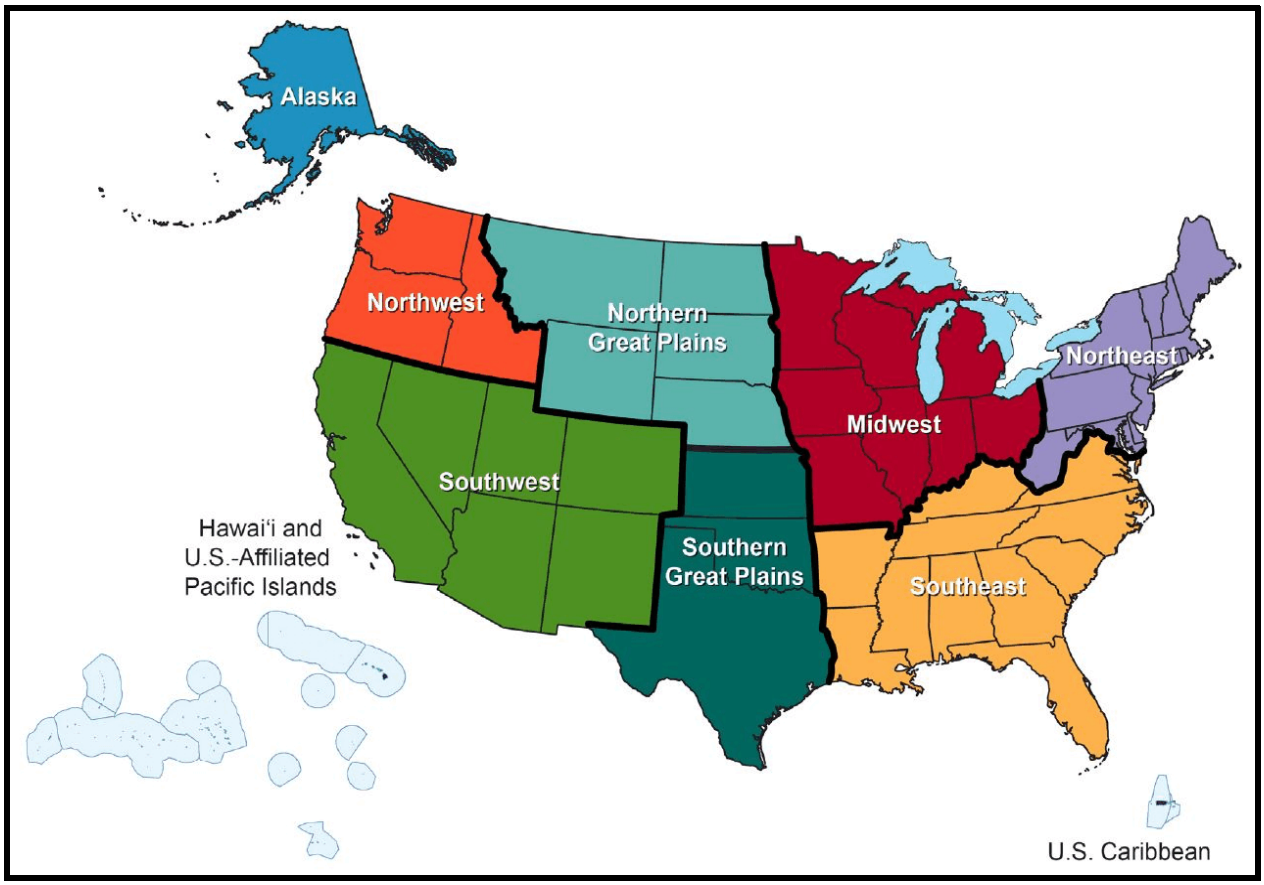

Figure 1. NCA4 regions, Source: NCA4[5]

needed to confront the public health emergency created by climate change.

The Paris Agreement, signed by virtually every nation on earth was an encouraging step. However backsliding from these limited goals seems increasingly likely. In the short interval between the signing of the Agreement and the present the efforts to mitigate and adapt to climate change have been largely aspirational and insufficient. In the U.S., President Trump has referred to climate change as a hoax, has stated his intent to withdraw from the Paris Agreement, and has proposed the climate change denier William Happer as the head a new climate change panel. In Brazil, the election of Jair Bolsonaro as President poses similar threats. He cancelled Brazil's plan to host a 2019 U.N. meeting on climate change and threatens even more development and deforestation of the Amazon Basin. At the beginning of the 2018 Conference of the Parties to the United Nations Framework Convention on Climate Change (COP-24) in Katowice, Poland, the US, Russia, Kuwait, and Saudi Arabia joined together to not "welcome" the IPCC's special report that increasing global temperatures above 1.5°C would have serious consequences.

Carbon dioxide (CO_2) emissions by the energy and transportation sector are the principle

drivers of climate change. This gas accounts for approximately two-thirds of all GHG emissions.[10] Methane accounts for around 20 percent of GHG emissions. In addition to producing the largest amount of CO_2 per unit of heat, burning coal also produces other pollutants that damage health. These include small particles, oxides of sulfur and nitrogen, and heavy metals such as mercury. Toxic ash is left behind. China leads the world in coal production and supports the construction of coal plants in other countries. India, the U.S., Australia, and Indonesia round out the top 5 CO_2 producers.

Each year the atmospheric concentrations of carbon dioxide and methane continue to increase with no end in sight.[11, 12] After three consecutive years of almost no increase in the atmospheric concentration of CO_2, the Global Carbon Project estimates that the 2018 emissions of this GHG will reach a new record high of approximately 41 billion tons of CO_2 (or 10.1±0.5 GtC, or 37.1 $GtCO_2$, where one gigatonne, Gt, is equal to one billion tonnes, and one tonne equals 2,200 lb). Even if the impossible were to occur and the emission of these two greenhouse gases reached net zero levels instantaneously, global mean temperatures and the temperature of the oceans would continue to rise.

The consequences of unchecked GHG emissions are clear. In 2017 NASA reported that 2016 as the warmest year ever observed since modern temperature recordings began in 1880.[13] The global average temperature that year was 1.78°F (0.99°C) higher than the mid-century mean. NASA's report went on to reveal that not only was 2016 the hottest year on record, but it was the third record-breaking year in a row. Most of this warming has taken place in the last 35 years with 16 of the 17 warmest years occurring after 2001.

The three seminal reports that form the impetus for this report are wide-ranging but linked by three elements that have profound effects on health; heat, fire, and water.

A Broad View of Climate Change and Health

The section devoted to health in the NCA4 identified four key messages and acknowledged the impact of climate change on vulnerable populations as shown in figure 2.[8]

1. Climate change affects the health of all Americans.
2. Exposure and resilience vary across populations and communities.
3. Adaptation reduces risks and improves health.
4. Reducing greenhouse gas emissions results in health and economic benefits.

This fourth key message is fundamental to the success of all other efforts to adapt to the challenges posed by climate change. All efforts to respond to climate change fail or become more difficult if GHG emissions are not curtailed sharply or brought to net zero.

The World Health Association (WHO) grappled with a definition of health when it adopted its constitution on July 22, 1946. The WHO preamble states that "Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity."[14] The WHO went on to emphasize its position that health was a fundamental right of every human being, that governments have a responsibility for the health of their people, and that peace and security were essential to the provision of health. They placed a special emphasis on the need to assure the healthy development of children. The Centers for Disease Control and Prevention has adopted an identical

definition of health.

Climate change impacts many of the complex factors that combine to determine a person's state of health. These factors may be biological, socioeconomic, psychosocial, behavioral, or social in nature. The WHO expanded on its definition of health with a health impact assessment (HIA). This emphasizes the complexity and inter-relatedness of multiple factors that determine health.[15] Some are relatively easy to quantify and others are more difficult. A partial list of the WHO's determinants of health or, in their words, "things that make people healthy or not" includes the following:

- Biological: age, gender, and genetic makeup
- The social and economic environment
- The physical environment
- Social support networks
- Access to health services
- Availability of food: a robust food supply, food safety including hazards of naturally occurring toxins, and the nutritional content of commodities
- Water: safe drinking water, flooding, drought, and the availability for irrigation
- Housing: tenure and homelessness, relocation and refugees
- Breeding of disease vectors
- Energy: the use of fossil fuels, pollution, global warming

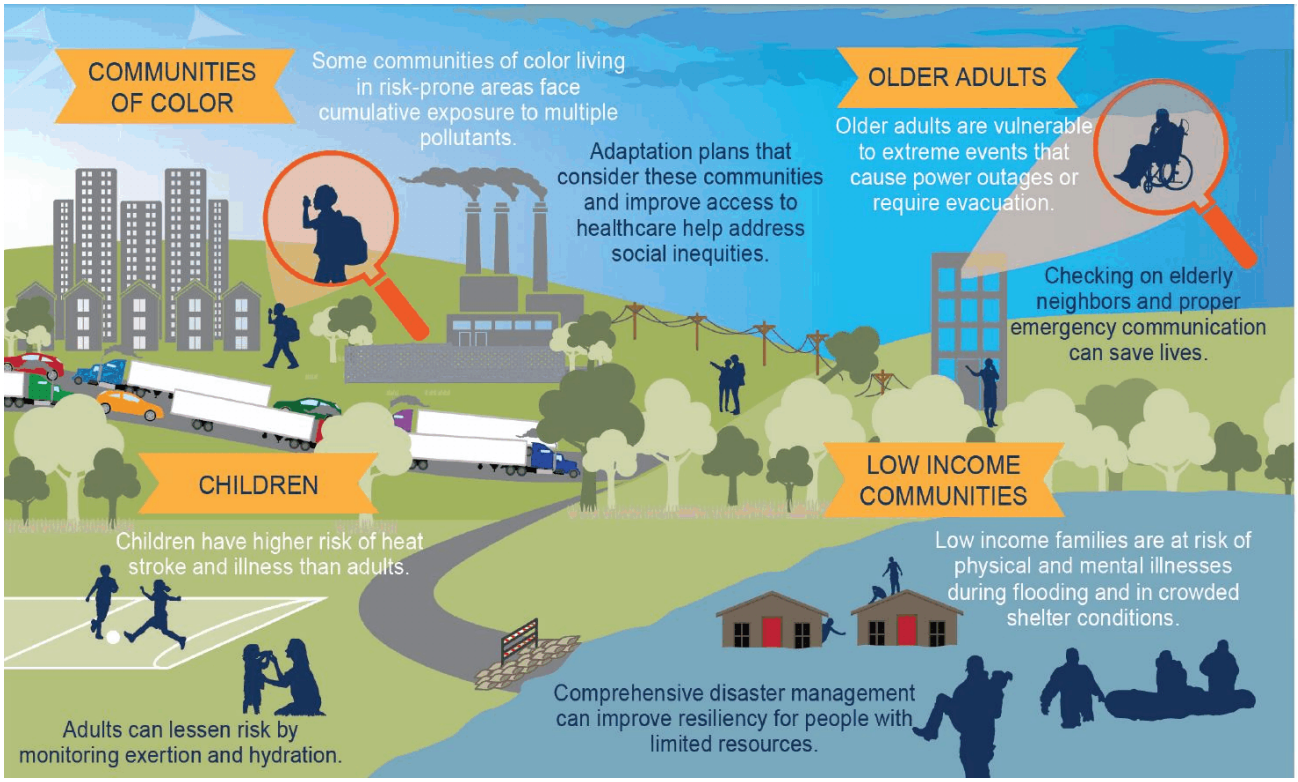

Figure 2. Populations at high risk for adverse climate-related health threats are shown with the adaptation measures that can help address disproportionate impacts. These groups are among the most exposed, most sensitive, and have the fewest individual and community resources to prepare for and respond to health threats. White text indicates risks faced by those communities while dark text indicates actions that can be taken to reduce risks. From NCA4.[8]

Each of these factors is already affected by climate change. The following have been brought into sharp focus by recent events and are emphasized by the IPCC, the Lancet report, and the NCA4:

- Heat: heat waves
- Fire: proximate and downwind effects of wildfires
- Water: sea level rise and storm surge, drought, and severe weather

It takes a broad brush to paint a complete picture of health.

Linking Specific Weather Events to Climate Change

Virtually all climate scientists and organized high-level scientific organizations such as the U.S. National Academies of Sciences, Engineering, and Medicine, agree that climate change is real and caused by human activity. A recent survey of registered voters found that 74 percent of Americans believe that global warming is happening and 62 percent think that it is caused mainly by human activities.[16]

There are few data that allow one to attribute a specific event to climate change. However, progress in the field of attribution has been rapid and was summarized in a special supplement to the Bulletin of the American Meteorological Society in 2018.[17] Climate scientists have borrowed from the fields of public health and epidemiology using a statistical technique referred to broadly as event attribution. In this approach researchers calculate the fraction of attributable risk (FAR) for an event. To compute the FAR the observed data (e.g. temperature, rainfall, etc.) are compared to modeled behavior in which changes in the atmospheric composition are ignored. In other words FAR compares the observed *versus* the expected behaviors. When FAR equals 1, an event is judged to be impossible in a world without anthropogenic greenhouse gas emissions. Examples of FAR greater than one include: record global warmth, record heat over Asia, and the large persistent area of anomalously warm ocean water off the coast of Alaska, commonly referred to as "The Blob." Twenty-one of the 27 papers in the supplement identified climate change as a significant driver of the event studied while six did not. Over the past six years of analyzing climate data, presented in 131 papers published in similar supplements, the editors state that approximately 65 percent of the papers identified a significant role for climate change.

Extreme value analysis, one of the statistical techniques used to link climate change to specific weather events, has been used to study hurricanes Harvey and Maria. Both of these hurricanes had reached category 4 on the 5-step Saffir-Simpson scale when they struck the Houston, TX, area and Puerto Rico, respectively. Harvey made landfall on August 26, 2017. Thereafter it stalled. According to data from the NOAA Advanced Hydrologic Prediction Service, 829.3 mm or 32.6 inches of rain fell over an elliptical area that included Houston, Galveston, Beaumont, and Port Arthur, TX and a small portion of western LA. In places the total reached 50 inches. The authors of the Harvey report concluded that 37.7 percent of the rainfall was due to human-induced activity.[18] Hurricane Maria struck Puerto Rico on September 20, 2017. An analysis of the data from that storm yielded complementary results. Maria produced the largest maximum rainfall event since 1956 and the highest total averaged precipitation of the 129 storms that had impacted the island since that year. The authors calculated that climate change had increased the best estimate for the probability of

precipitation of Maria's magnitude by a factor of 4.85.[19] These observations of storm data and subsequent analyses are entirely consistent with the predictions that climate change will produce more severe storms. As the climate warms, sea-surface temperatures rise and the atmosphere will hold more water. More intense storms will follow. The worst is surely yet to come.

HEAT

Heat is the leading cause of weather-related deaths in the U.S.[20] The Weather Service reports that the average annual death toll from heat was 134 in the interval between 1988 and 2017. This may be a substantial underestimate according to the Centers for Disease Control and Prevention (CDC).[21] The CDC data document 7,233 heat-related deaths between 1999 and 2009 for a rate of 658 per year. The CDC data do not include deaths due to the 1995 Chicago heat wave, discussed below. Another approach toward defining heat as a risk factor for death was taken by a group that examined temperature and mortality data for approximately 250,000 deaths.[22] They reported a 2.3 percent increase in mortality for each 10°F increase in the temperature. These studies illustrate some of the problems associated with defining "heat" as a contributing factor or cause of death. Many heat-related deaths are likely to list an underlying chronic disease as the proximate cause. This leads to an underestimation of the impact of heat on mortality.

Heat is an equal opportunity killer. One might think that Kory Stringer was unlikely to be a victim of heat stroke.[23] He was a highly conditioned all-star offensive tackle for the Minnesota Vikings. On the day before he died he complained of post-practice fatigue. On the fatal day he took to the practice field in a full uniform. It was 90°F. During practice he vomited three times and left the field for an air conditioned space. When he complained of dizziness he was taken to a hospital where his temperature was 110°F. He lapsed into a coma and died shortly thereafter.

Moving from the famous to the unknown, a group from the University of Houston examined deaths among migrants attempting to cross into the U.S. from Mexico in 2001.[24] We see images of suffering among these desperate individuals on the news but they remain largely faceless. The Houston team found that deaths among migrants rose sharply in the last half of the 1990s. A more contemporary account of migrant deaths was filed by Reuters in June, 2018. Even though the hottest time of the year had not yet arrived, deaths due to extreme heat had risen by 55 percent in the 9 months before their report. Forty-eight had died compared to 31 over the same period in 2017.

Medical ethics requires healthcare providers to tend to the needs of all, regardless of who they are or the circumstances involved. In the face of the rising toll along the border with Mexico, the U.S. government appears to be cracking down on those who would aid migrants, particularly on volunteers from the group No More Deaths - No Más Muertes.[25] The Guardian newspaper reported that 8 humanitarian volunteers were arrested and faced jail time for offenses including "driving in a wilderness area, entering a wildlife refuge without a permit and abandoning property—the latter an apparent reference to leaving water, food and blankets on migrant trails." The article referenced claims by No More Deaths that suggest that border patrol agents deliberately sabotaged water containers left to aid migrants. In December, 2018, 32 protesters from the American Friends Service Committee were also arrested. In its "defense" of the border with Mexico the U.S. government appears to be taking steps to criminalize advocacy or aid for those who wish to claim refugee status.

Heat Waves

Global warming means that more severe and more numerous heat waves are an inevitable part of our future. Unfortunately, there is no agreed-upon definition for heat waves. NCA4 defines a heat wave as "a period of abnormally hot weather lasting days to weeks."[26] Since the definition is quite subjective and lacks precision, statistical treatment of the term is problematic. Another more precise definition, also referred to as a heat wave duration index, occurs "when the daily maximum temperature on five or more consecutive days exceeds the average by 5°C, compared to the period between 1961 and 1990."[27] This too has limitations, as do all attempts to define heat waves because of the regional variations in climate and temperature that must be taken into account.

The thorough examination of approximately 740 deaths from Chicago heat wave of 1995 has provided valuable insights into adapting to increasing heat. Although the National Weather Service issued warnings about the impending high temperatures, the weather was not the "front page news" that it is today. Warnings were largely ignored as sustained high pressure in the upper atmosphere combined with high humidity. Most date the beginning of the heat wave to July 12 when the temperature at both Chicago O'Hare and Midway airports reached 97° F. It ended on the July 16 when temperatures finally fell to 93°F at both sites, temperatures that were more typical for that time of the year.[28] Healthcare in Chicago was strained by the heat. During the height of the heat wave hospital admissions were 11 percent higher than expected, based on comparisons to similar dates with more typical temperatures.[29] Among those over 65, hospital admissions were up by 35 percent. The diagnoses that accounted for most of the extra admissions included dehydration, heat stroke, and heat exhaustion. Admissions due to exacerbations of chronic medical conditions also contributed to the increase in morbidity and mortality. These included cardiovascular disease (up 23 percent) diabetes (up 30 percent) renal disease (up 52 percent), and nervous system disorders (up 20 percent).

It is not a simple task to make an accurate assessment of the toll exacted by this heat wave. An example of the approach to this problem is exemplified by a study that compared deaths during the heat wave with deaths during 50 day intervals centered in the day of the Chicago temperature peak.[30] The investigators in this study found that deaths peaked on July 15, two days after the peak temperature. There was a total of 692 excess deaths between June 21 and August 10. An average of 241 people died each day during the peak effect: only 4.7 percent were reported to be due to heat alone; 28.1 percent had heat as a contributing factor, while some form of cardiovascular disease was present in just over ninety percent. Only a quarter of the deaths were considered to be premature. Many of those who died were expected to die soon anyway. Technically this is known a mortality displacement, or, more morbidly, as a harvesting effect of the heat wave. Although mortality displacement was lowest amongst African-Americans, this group had the highest overall risk.

To better understand heat-death risk factors, face-to-face interviews were conducted amongst a cohort of 339 friends or relatives of those who succumbed. The study population included individuals older than 24 if the death certificate specified heat or cardiovascular disease with or without heat as a contributing cause of death.[31] The control population consisted of the same number of individuals with the same age who lived in the same neighborhood. Individuals with known medical problems were at the highest risk for death. The highest death rate occurred among those who had been visited by a nurse. They were followed, in order, by those confined to bed and by

patients who had mental problems. Next came those with a heart or a lung condition. The death risk was reduced if an individual had been contacted by a city worker during the heat wave. The most important risk factors for death were being bed-bound or living alone. Living on the top floor of a building also increased the risk for death. Access to air-conditioning and transportation were protective as were social contacts, access to group activities, and having friends in the area.

The Chicago heat wave was not the most severe in recent history nor was it the first to have a stealthy beginning. The 2003 European heat wave began with often humorous anecdotes in the local media.[32] A Danish taxi driver wore a skirt to work because his employer would not permit shorts. An Italian chocolate seller suspended shipments because the product was melting in delivery trucks. A much more morbid report came from a French nursing home where 5 people died during a single weekend. The serious nature of the heat wave emerged when the largest group of undertakers in France, Les Pompes Funebres Generales, reported taking care of 50 percent more bodies in a week. They were forced to rent refrigerated trucks to take care of the large number of bodies. In what became a colossal understatement, a representative from the French health ministry was quoted as saying "Things are not as simple as they seem." The final death toll throughout Europe may have reached 70,000.[33] In 2010 temperatures in the Moscow area exceeded 30°C for 27 days in a row.[34] The extreme heat combined with wildfire-related air pollution levels that were 2 to 3 times "maximum safe levels" and carbon monoxide levels that soared to 6.5 times above the so-called "safe level." The deadly combination led to around 15,000 deaths. After a year of numerous wildfires in the U.S. this sounds like a familiar scenario as described in the fire section.

All of the climate models predict that it will be hotter in the future. The 2014 American Climate Prospectus predicts that there will be between 2 and 3 times as many days when the temperature exceeds 95˚F by the end of the century, assuming a "business as usual" emissions scenario (RCP8.5, see Text Box 1 for explanation). When these data are combined with the modeling predictions from the Third National Climate Assessment, the American Climate Prospectus authors predict that residents of the Southeastern part of the U.S. are likely to experience temperatures in excess of 95˚F for almost one third of the year (between 56 and 123 days).[35,36] Between 1981 and 2010 these residents experienced an average of 9 days per year when temperatures exceed this threshold.

Text Box 1:
Representative Concentration Pathway (RCP) A series of possible climate scenarios developed for the IPCC Fifth Assessment Report. They refer to radiative forcing, the difference between energy gain by the earth and energy radiated back into space and are measured in Watts/meter^2. They are driven mainly by greenhouse gas emissions and are consistent with certain socio-economic assumptions including land cover, all greenhouse gases, and pollutants. The RCP2.6 scenario presumes a possible peak of forcing at around 3 W/m^2 (about 490 ppm CO_2 equivalents) with a decline to 2.6 W/m^2 by 2100. RPC4.5 and RPC8.5 lead to 4.5 W/m^2 at stabilization after 2100 (about 750 ppm CO_2 eq) and 8.5 W/m^2 (about 1370 ppm CO_2 eq) at 2100 with continued fossil fuel burning. RPC8.5 is a business as usual scenario with no mitigation of climate change.[37]

Adaptation to Heat

The Chicago experience provided extremely useful information that can be used to

prevent heat-related morbidity and mortality.[31] An action plan should be developed to identify and protect at-risk citizens. These include those who are bed-bound and socially isolated as well as those who are chronically ill with heart disease, diabetes mellitus, renal, or neurological conditions. It may be necessary to move these people to cooling shelters. Socially-determined factors also contribute to heat-related medical risk. These factors include absence of air conditioning particularly for those who live on top floors of buildings with a black roof, as opposed to a roof that is white or reflective. These individuals may also require evacuation to a cooling shelter.

Text Box 2

Humans must be able to dissipate the heat produced by metabolic activity to maintain a normal temperature of 98.6˚F, or 37˚C and prevent overheating. Excess body heat is dissipated by four mechanisms; convection, conduction, radiation, and evaporation. Evaporative heat loss is normally the most important of these. It is also possible to dissipate heat by immersion into water, a more efficient but often impractical alternative to the usual process of sweating. The ambient temperature and humidity limit the ability to lose heat by evaporation. Above a critical temperature, the body gains heat, no matter what. That limit is defined by what is known as the wet bulb temperature (T_w), the temperature registered by a well-ventilated ordinary thermometer covered by a wet cloth. The T_w limit for humans is around 35˚C with a relative humidity of 100 percent. Above a T_w of 35°C the body temperature must rise. A T_w of 35°C can be maintained at higher temperatures if the relative humidity falls. For example, the T_w remains at 35°C if the relative humidity drops to 50 percent and the temperature rises to 46°C (115°F) and the individual is not generating heat by working. A 2015 study concluded that climate change and the T_w barrier could make parts of the earth uninhabitable.[39]

As a response to the heat wave, Chicago officials developed a comprehensive climate action plan.[38] They began by creating an inventory of CO_2 emissions to better control and reduce them. They found that 70 percent of the city's greenhouse gas emissions were attributed to buildings and 21 percent to the various forms of transportation, mostly from cars, trucks, and busses. This led to a five-pronged approach to climate change adaptation: 1) improve the energy efficiency of buildings; 2) use clean renewable sources of energy; 3) improve transportation options making public transportation more accessible, switching to hybrid or electric vehicles, and making both walking and bicycling safer and easier; 4) reduce waste and industrial pollution and improve overall energy efficiency; and 5) adapt to higher temperatures throughout the city by creating more green spaces, planting more trees, and other measures. The task force emphasized the fact that everyone can do something, such as switching to LED lighting, improving insulation, purchasing energy-efficient appliances, and using energy-efficient modes for personal transportation.

This example of a city working to reduce carbon dioxide emissions, save energy (and money!), and improve health represents one of many possible strategies for moving forward toward a more sustainable energy future and a future that holds the promise of better health for its citizens. There are other paths forward, but they require a recognition of the need and the will to act (see final

section for discussion of governmental responses to climate change).

Several groups have advocated for changes in the set-point at which a heat emergency is declared. Typically this is based on the heat index (HI).[40, 41] These authors suggest lowering the trigger criterion from 100° F to 95°F. The HI is a measure of how hot it really feels when the relative humidity is factored in with the actual air temperature. It can be determined with an on-line calculator published by the National Weather Service.[42] For example, a temperature of 90°F with a relative humidity of 60 percent, conditions encountered frequently, results in a calculated HI of 100°F. If the temperature remains the same, but the humidity rises to 90 percent, the HI soars to 122°F. See text box 2 for information concerning the ability of normal healthy adults to maintain a normal body temperature.

The number of people living in urban areas across the world is rising due to a number of factors, including climate change. This trend toward urbanization increases the number of people susceptible to the effects of heat. Urban areas become heat islands, that is areas that are hotter than surrounding more rural areas. The EPA heat island web site states that this temperature differential in cities with a million or more inhabitants may be between one and three degrees C (1.8 to 5.4°F) and can be as high as 12° (22°F) at night.[43] This increases the demand for energy to run air conditioners, the concentration of air pollutants, and GHG emissions. Naturally, heat-related illness increase. Mitigation efforts include increasing urban vegetation, creating green roofs, smart urban design, and others.

A 2019 study evaluated the effects of climate change mitigation on urban morality in major U.S. cities.[44] The investigators compared the expected annual mortality due to heat if temperatures rise by 3°C, the increase expected if nations adhere to the goals set by the Paris Agreement, to annual mortality expected if temperature increases are limited to 2.0°C and 1.5°C. The reductions are significant. They conclude that achieving a 2.0°C threshold would prevent between 70 and 1980 deaths each year per city. A 1.5°C threshold would avoid between 110 and 2720 heat related deaths per year per city. They did not account for changes in population or the fact that the population is aging, i.e., number of elderly individuals, who are more susceptible to the effects of heat is increasing. They conclude that their results "provide compelling evidence for the heat-related health benefits of limiting global warming to 1.5°C in the United States."

FIRE

Valerie Evans was a 75 year old woman. She died trying to save her dogs from the Tubbs Fire.[45] Christina Hanson, who used a wheelchair, was only 27 when she died in the same fire. They were among the 22 individuals who were killed by the next-to-the-worst wildfire in California history. Barely a year later, in November, 2018, the Camp Fire formed an urban firestorm in the city of Paradise, Califonia.[46] David Hawks, the Fire Chief in Paradise, said that "I got into my firefighting gear and immediately responded to Pentz Road, which was where the fire was first reported in Paradise." He compared it to a snow blizzard saying, " ... it's just an ember blizzard and all those embers were pelting homes and pelting the ground." His efforts were not enough. His home burned to the ground along with almost all of the others in the town.[47] At least 86 people died. The Camp Fire covered 153,336 acres before it was contained. The best estimate concludes that 18,804 structures were incinerated. The damage estimate of $16.5 billion made it the costliest disaster in the world for the year 2018.[48]

The Congressional Research Service defines wildfires as "unplanned, unwanted fires including lightning-caused fires, human-caused fires, and escaped prescribed fire projects."[49] Their report, based on data from the National Interagency Fire Center, indicate that there was an average of 73,200 wildfires per year in the U.S., a figure that showed little change over the past 30 years. However since 2000, an average of 6.9 million acres burned each year, nearly double the number that burned in the 1990s.

Dramatic and terrifying scenes of wildfires raging out of control, and stories like those above, dominated the news in the fall of 2018. The U.S. Forestry Service data attributes 85 percent of wildfires to human activity, such as unattended fires, discarded smoking material, arson, and poorly maintained infrastructure, particularly sparking from power lines. This problem is thought to have caused the Camp Fire that forced Pacific Gas & Electric into bankruptcy, potentially extending fire-related financial loss to share-holders. As the result of climate change, fires that would have been contained easily and extinguished now rage out of control. Regardless of the cause, climate change makes wildfires more dangerous to health and more damaging to property.

It is likely that climate change contributed to the increase in burned acreage. Warmer temperatures, reductions in rainfall, the proliferation of pests, such as the bark beetle, and changing patterns of land use combine to make small wildfires grow uncontrollably.[8] The role of the bark beetle and its spread due to climate change is somewhat controversial. However, most agree that pine trees infested by bark beetles go through several stages during which they dry out, have a lower ignition temperature, a shorter time to ignition, and higher heat yields.[50] This makes affected forests into a disaster waiting to happen, particularly those where prescribed burns have not taken place.

Deaths and injuries are the most immediate and tangible evidence for health effects of wildfires. However, they represent only a fraction of their public health impact. The chief public health officer for Napa County, California, Dr. Karen Relucio, declared a public emergency when

she heard that former residents in the Tubbs Fire area were scouring their burned-out homes looking for personal effects without taking precautions to protect themselves.[51] She was quoted in the New York Times as saying "Just think of all the hazardous materials in your house. Your chemicals, your pesticides, propane, gasoline, plastic, and paint - it all burns down into the ash. It concentrates in the ash and it's toxic." Images of the burned-out town of Paradise, California, show the extent of the

Figure 3. EPA Household Waste Removal Team cleaning up debris after Camp Fire. Source: EPA

damage and the health hazard that had been created. When the EPA Household Hazardous Waste Team searched the debris from the Camp Fire they wore disposable suits, hard hats, gloves and boots, and breathed through filters as shown in figure 3.

When the New York Times interviewed me about the post-fire hazards I drew a comparison between working in the burned-out areas and working in the debris left after the World Trade Center attacks.[51]

Large wildfires create smoke plumes that travel enormous distances. Figure 4 shows the plume from the Camp Fire moving south to blanket San Francisco, the Central Valley of California, and a great deal of the Western U.S. Before it moved out over the Atlantic Ocean it traveled across the Southern Great Plains, the Midwest, and the Northeast.

Wildfire smoke is a complex mixture of gases and aerosols. The exact composition may vary. It usually contains water vapor, carbon dioxide, carbon monoxide, non-methane volatile organic compounds (VOCs), oxides of nitrogen, trace minerals and elements (including mercury), particulate

matter, and "several thousand other compounds."[52]

Particulate matter, especially that which is less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$), is perhaps the greatest threat to health (for details see Lockwood[53]). The inhalation of particulate matter has been linked to a large number of adverse health effects, including heart disease, cancer, diseases of the respiratory system including chronic obstructive pulmonary disease and asthma, stroke, and possibly type II diabetes mellitus and Alzheimer's Disease.[53] Thus, it follows that wildfire downwinders will have smoke-related adverse health effects.

The health impact data after the 2003 California wildfires show what can be expected in the future.[54] The investigators in this study combined satellite-derived measurements of the $PM_{2.5}$ concentrations with hospital records. The increases in the two-day average $PM_{2.5}$ concentrations were substantial. In Orange County, the pre-fire concentration of 23.3 micrograms per cubic meter ($\mu g/m^3$) rose to 64.3 $\mu g/m^3$ and in San Diego County the pre-fire concentration of 18.5 $\mu g/m^3$ rose to 76.1 $\mu g/m^3$. (The National Ambient Air Quality Standard for $PM_{2.5}$ is 15 $\mu g/m^3$.[55]) During heavy smoke conditions, asthma hospital admissions rose by 34 percent. The elderly were at the highest risk. For those over 65, there was a 10.1 percent increase in hospitalization risk for an increase in the $PM_{2.5}$ concentration of 10 $\mu g/m^3$. There were also increases in the admissions for other respiratory diseases including pneumonia, chronic obstructive pulmonary disease, and acute bronchitis. There was limited evidence for a small impact on cardiovascular disease. The downwind spread of particulate matter after the wildfires of 2018 is shown in figure 4.

The 2004 wildfires in Alaska and Canada emitted huge amounts of carbon monoxide into the atmosphere. Using various air monitoring techniques as much as 30 percent of this gas over the Northeastern U.S. could be traced to these fires.[56] In a communication with colleagues, the authors of the report learned that this pollution plume was detected in Europe. Carbon monoxide participates in photochemical reactions that produce ozone.

The National Ambient Air Quality Standard for ozone was lowered to 70 ppb in 2015.[55] Multiple instances when the standard was exceeded in Maryland were attributed to distant Canadian wildfires.[57] These authors also found increases in the atmospheric concentrations of $PM_{2.5}$ due to black carbon and organic carbon particles along with other ozone precursors such as VOCs, carbon monoxide, and oxides of nitrogen.

Anthropogenic and natural sources of mercury deposit this toxic metal in forests. Wildfires cause a re-emission of these deposits.[53] Mercury is highly toxic, bioaccumulates, and damages the developing nervous system and other organs. This source is becoming more important as the acreage of wildfires increases. In the post-industrial age burning coal has been a leading anthropogenic source of this metal.

A joint conference sponsored by EPA and the University of Washington had very specific and useful advice for minimizing the risk associated with the inhalation of wildfire smoke.[52] They urged members of the general public to pay attention to public service announcements, to be prepared to change plans for outdoor events, etc., and to consult a healthcare professional if early

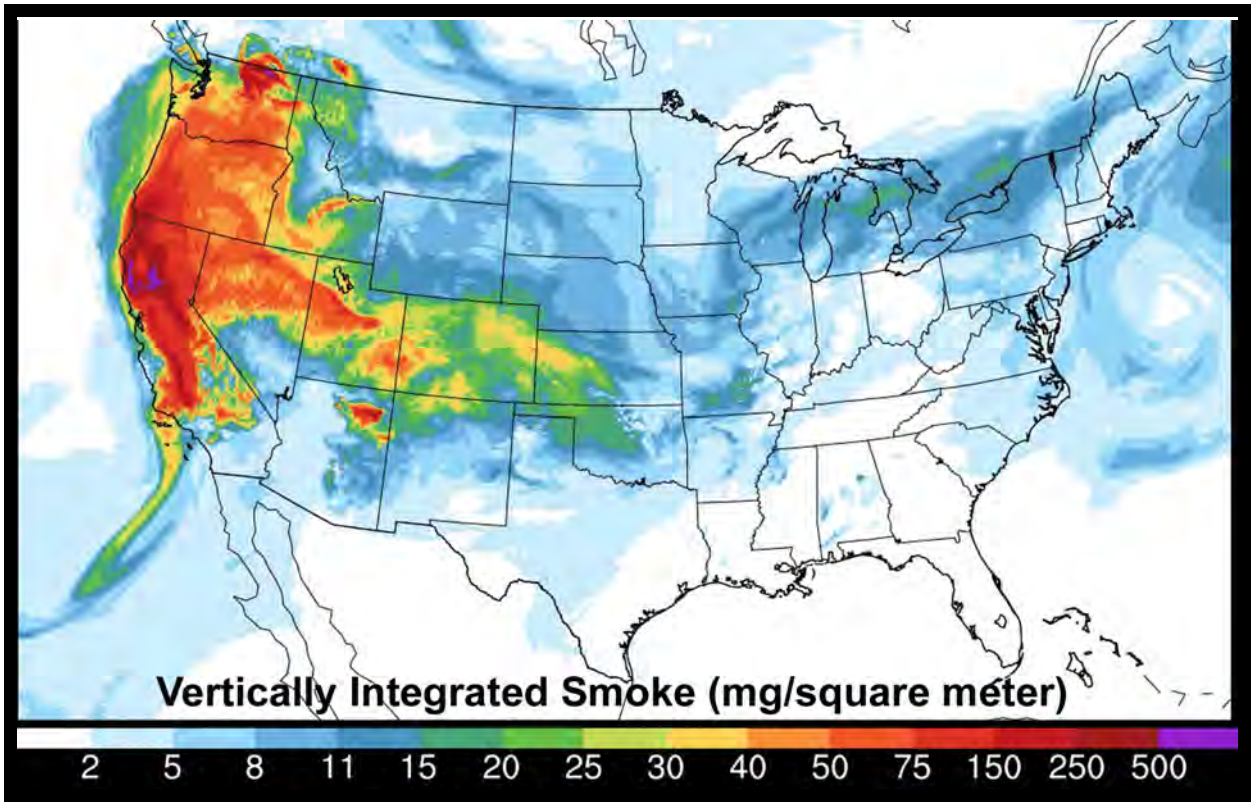

Figure 4. Smoke from Camp, Hill, and Woolsey Fires spreads across the country. Image courtesy National Aeronautics and Space Administration and the U.S. Weather Service.

signs of a respiratory condition develop. For those at higher risk, particularly those with asthma, additional explicit advice was offered. This included having a specific, written plan for action. The plan should include stockpiling an adequate supply of medications and a commitment to contact a healthcare provider if there is a worsening of asthma. The plan should also include making preparations to keep smoke levels as low as possible indoors including use of a high-efficiency particulate air (HEPA) air filter and masks marked R95, N95 or P95. These masks filter out 95 percent of particles 0.3 microns in diameter. Masks with higher ratings with marks R, N, or P99 or P100 are even more effective, but more expensive. They warn about leaks around masks, including those induced by facial hair, that make them much less effective. Additional public health measures include the establishment of clean air shelters, analogous to those that protect vulnerable populations from extreme heat or cold, and closure or curtailment of some businesses, schools, or outdoor activities. Although most evacuations are designed to protect the public from being engulfed by the fire itself, evacuations of some vulnerable individuals may be prudent to avoid wildfire smoke.

WATER

Water - it's essential for life yet is possibly the cause for greatest concern as climate change grips the globe. Contrast the euphoria associated with the discovery of water on Mars as a sign of possible life, with the despair of those affected by the floods associated with Hurricanes Katrina, Harvey, and Superstorm Sandy. Drought has gripped much of the Sahel where it contributes to starvation. Images of emaciated children dying of drought-associated starvation are wrenching. In Ethiopia UNICEF estimates that 8 million lives are at risk due to drought. Of these, 1.4 million are children.[58] Rising sea level threatens to obliterate some island nations. Everything that affects water affects health.

Floods and Sea Level Rise

Too much water applies to many conditions ranging from severe storms with flooding to rising sea level. For healthcare professionals, the nightmare of too much water may have been best captured by Sheri Fink, MD, in Five Days at Memorial: Life and Death in a Storm-Ravaged Hospital, a book-length expansion of her Pulitzer Prize winning essay published in the New York Times Magazine.[59] The hapless patients and providers in Memorial Hospital were cut off from the rest of New Orleans by the rising flood waters in the aftermath of Hurricane Katrina. Faced with impossible choices, staff members allegedly euthanized very ill patients who could not survive a move when emergency plans proved inadequate after the hospital lost power and back-up generators failed. The hospital, staff, and patients were left without lights, air conditioning, sewer systems, and essential medical equipment such as ventilators. Two ICU nurses and one physician allegedly administered fatal doses of morphine to critically ill patients who were judged to be too ill to survive. Although they were charged with second-degree murder, none were prosecuted after charges were dropped or grand juries failed to indict them.

On August 23, 2017, almost exactly 12 years after Katrina, the ordeal of Wayne Daily and his wife was just beginning, according to Dr. Fink's description of another health catastrophe caused by a hurricane.[60] While Daily's wife was in the operating room undergoing the removal of an adrenal gland tumor that had caused Cushing's Syndrome, he consulted weather apps on his phone and watched Hurricane Harvey gain strength. The next day he went to Memorial Hermann Hospital to bring her home to their trailer park on Enchanted Path Drive. She was not given a prescription for the steroids that she would need to protect her from the sudden loss of the tumor-produced hormone. Fifty inches and a trillion gallons of rain fell when Harvey stalled over the Texas Gulf Coast. Houston officials delayed actions because they did not wish to risk another disaster such as the one caused earlier by the poorly-planned exodus associated with Hurricane Rita. Houston's 911 system and the rest of the county's emergency response systems were poorly organized in spite of the earlier flooding of the Texas Medical Center. Damages from that earlier flood were caused by Tropical Storm Alison and totaled $2 billion dollars. When it became evident that they were being overwhelmed by Harvey's flood, Houston city officials sent out a plea to boat owners to help evacuate stranded individuals. Wayne Daily saw boats that he hoped were there to help. But they, like a helicopter that rescued neighbors, passed them by. His wife died one day, 2 hours, and 15

minutes after the first of increasingly urgent emergency calls for help. Dr. Fink quotes Francisco Sánchez, who was the Harris County emergency management coordinator as saying "As catastrophic as Harvey was it had the potential to be much worse." Unfortunately, his comment is completely in line with the predictions made in NCA4.[8]

Storm surges, particularly those associated with hurricanes, will produce flooding that is above and beyond that due to sea level rise. The low atmospheric pressures associated with hurricanes create a "dome" of sea water. The dome's height is increased further by the force of wind working on the water. As the surge approaches a shoreline, additional intensification of the height of the surge occurs. If the shoreline is V-shaped further amplification of these effects takes place. This worst-case-scenario occurred in 1970 when Cyclone Bhola headed up the Bay of Bengal. Wind speeds that may have reached 150 mph and a storm surge of 25 feet led to the deaths of as many as 500,000 people in what was then East Pakistan, now Bangladesh.[61] The storm surge and secondary flooding were major factors that caused the damage and deaths produced by Hurricane Sandy.

Hurricane Sandy, unofficially known as Superstorm Sandy, made its U.S. landfall on October 29, 2012. Although it was only a category 2 storm when it came ashore, the storm surge of 8.9 feet, recorded at Battery Park in New York City, was nearly twice as great as its nearest competitor.[62] The peak storm surge was around 13.5 feet above the mean lower low water level (MLLW, the average of the lower low water height of each tidal day). To put this in another perspective, the New York City subway system floods at a MLLW of 10.5 feet. Flooding caused extensive damage to the subways and other electrical systems. The magnitude of the surge was due to the shape of the shoreline, the immense size of the hurricane, and the last-minute turn toward the west. Property damage from Sandy totaled approximately $65 billion, about half of the total associated with Hurricanes Katrina and Harvey, and was responsible for 157 deaths in the U.S. and total of 233 along its path.[63]

These death toll and property damage estimates fail to describe the complete impact of the hurricaines on health. Traumatic stress, anxiety, and depression are difficult to capture and are not included in the final tallies. The Federal Emergency Management Agency's (FEMA) five year Sandy retrospective summarized many other disruptions due to the storm.[64] The agency reported that 23,000 people required evacuation, a number that is likely to be an underestimate. Ninety-seven percent of the Long Island Power Authority's customers were without electricity. The New York University Langone Medical Center was evacuated without the chaos and deaths associated with the Memorial Hospital events described by Sheri Fink. After Sandy FEMA paid out $1.4 billion to 179,016 individuals and households in New Jersey and New York.

Maria was the second category 5 hurricane of the very active 2017 season. It devastated many of islands in the Caribbean. The Puerto Rican government's estimate of the death toll was 64. Many scoffed at this and eventually more refined methodology revised the total to an estimate of 2,975.[65] This number only begins to tell the story of the destruction caused by this hurricane documented by numerous reports seen on TV newscasts, print, and electronic media. As of this writing, not all damage has been repaired on this unincorporated territory of the U.S. where the inhabitants are

American citizens. In addition, huge amounts of damage was inflicted on other islands, particularly Dominica, the Dominican Republic, and the U.S. Virgin Islands.

Substantial progress has been made toward accurate predictions of future hurricane activity. Converging results predict that there will be an increase in the number of the most intense storms (category 4 and 5 on the Saffir-Simpson wind intensity scale). One study predicts that the number of these high intensity storms will double by the end of the 21st century.[66] The largest increase is expected to take place in the Western Atlantic Ocean north of the line at 20 degrees north latitude. The authors of another review came to similar but somewhat more specific conclusions in their analysis.[67] They predicted that anthropogenic increases in greenhouse gases will lead to a shift toward more intense storms of between 2 percent and 11 percent by the end of this century. They forecast that precipitation rates within 100 km of the storm's center will increase by about 20 percent. Finally, the good news is that multiple models predict that there will be a reduction in the frequency of tropical storms of between 6 percent and 34 percent by 2100.

The NCA4 predicts that there will be significant increases in annual precipitation in the winter and spring over the Northern Great Plains, Upper Midwest, and the Northeast.[12] These increases may be 40 percent higher than the historical amounts in the last three decades of this century in the Midwest and Northeast.

Sea Level Rise

Katrina, Harvey, and Maria were terrible but transient events with long-lasting consequences. In contrast, low-lying islands face permanent consequences of climate change. In 2012 Anote Tong, President of Kiribati, engaged officials from Fiji about the need to move his entire nation to a new site. He was reported as saying "Our people will have to move as the tides have reached our homes and villages."[68] Their situation required a new word, overwash, which occurs when the combination of a higher sea level and waves result in the flow of water over coastal dunes or beaches.

Two mechanisms make the most important contribution to rising sea level. They are thermal expansion of warming oceans and melting ice. There are two widely-used measures of sea level: global mean sea level (GMSL) and regional sea level (RSL). See the glossary for precise definitions. RSL measurements are critically important at the site of the measurement but may not be a valid measure of changes in the GMSL. RSL measurements become better measures of GMSL when the land-based reference point is geologically stable i.e., where the land is not rising or sinking.

Satellites capable of measuring sea level have been in place since January, 1993. More than thirty years of satellite data is a sufficient period of time to identify trends in GMSL with a high level of confidence. The data show that GMSL has risen by 88 mm since January, 1993, and that the rate of sea level rise is increasing, reaching a rate of 3.2 mm per year in September, 2018.[69] The reasons? Ice is melting faster than in the past. Melting of the Greenland ice cap has accelerated four-fold since 2003.[70, 71] Similarly, measurements of the Antarctic ice sheet have shown a three-fold acceleration in the rate of melting in the interval between 1992 and 2017.[72] During this interval planetary warming, including warming of the oceans, has led to accelerating thermal expansion of oceanic water.

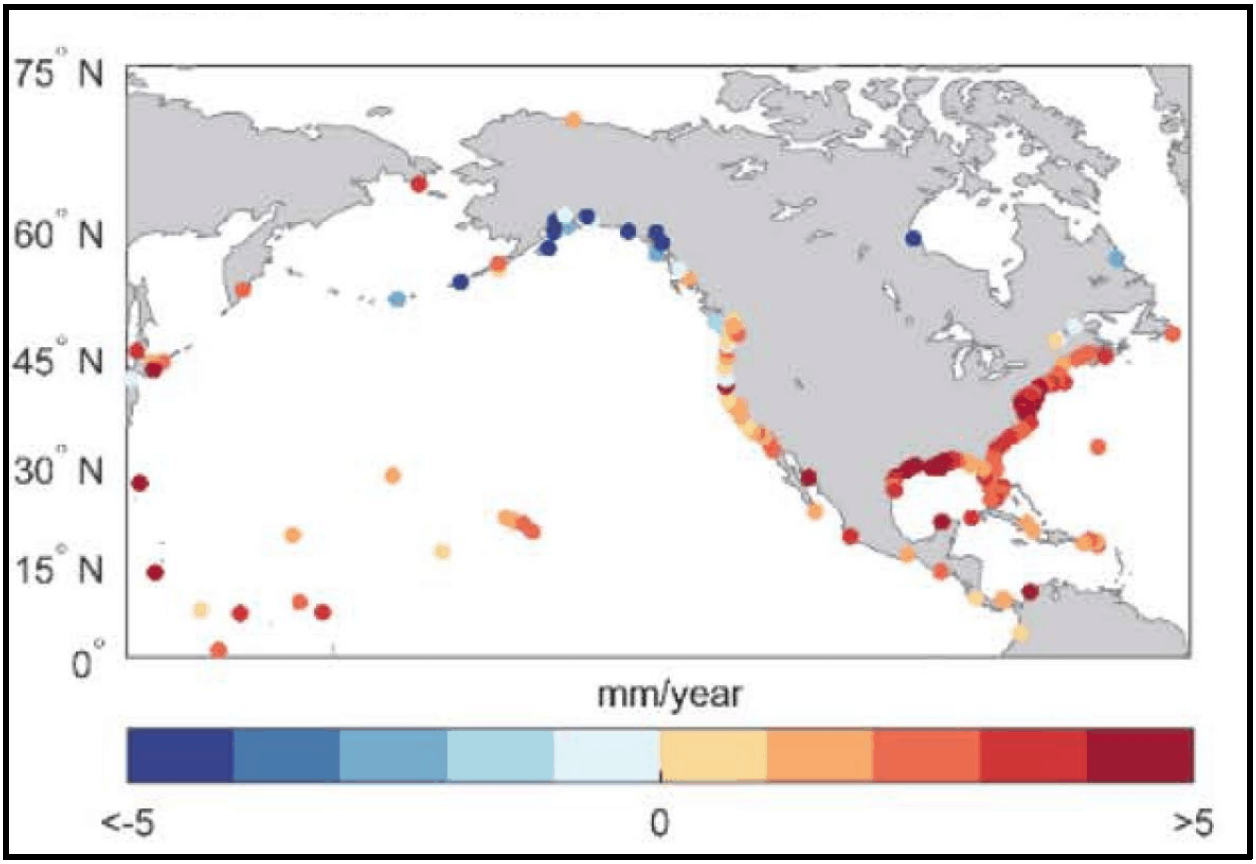

Figure 5. Relative sea level trends based on more than 30 years of measurements made with NOAA tide gauges made through 2015. From NOAA publication, Sweet, et al.[73]

As a result of all of the above forces acting on sea level, there are portions of the U.S. where RSL is falling and others where it is rising. These latter areas are of the greatest concern because they are sites where flooding, with or without storms, and inland intrusion of salt water are of the greatest concern. This is illustrated in figure 5 which portrays the effects of these variables on RSL.[73]

The impact of sea level rise for the U.S. varies substantially. Low-lying coastal areas, such as Miami and Miami Beach, are among those that will be the most susceptible to flooding. This is shown in figure 6, depicting the areas of these two cities that would be inundated by an increase in sea level of 5 feet.[74] Virtually all of Miami Beach would be flooded along with the causeways that connect this island city to the mainland. Major portions of Miami would also be inundated, particularly those along the Miami River. Healthcare facilities in the Miami area and more generally are often located in regions that are prone to flooding as was shown after Katrina and Sandy.

In addition to flooding, increases in sea level threaten fresh water supplies. Higher sea levels cause salt water to intrude into underground water sources that produce drinking water and water for irrigation. Again, South Florida is at high risk because the bedrock is composed of highly porous

coral-based limestone. This sponge-like stone allows water to move freely within it. Barrier defenses, such as sea walls, will not protect these underground water resources or people who live behind them.

As a part of the preparations for NCA4, an interagency task force updated prior efforts toward making regional predictions that are anticipated to affect the entire U.S. coastline. They developed several scenarios to predict future GMSL. New data indicate that prior estimates were too low and found that GMSL may increase by as much as 2.5 meters by 2100 with a lower estimate of 0.3 meters. They then developed 6 scenarios predicting effects between these extremes in 0.5 meter increments. They reached the following conclusions:[73]

Figure 6. Five feet of sea level rise inundates parts of Miami, most of Miami Beach, and the causeways that connect them. Source: NOAA Sea Level Rise Viewer, https://coast.noaa.gov/slr

- Along the Virginia coast northward and along the western Gulf of Mexico, RSL will be higher than the global average for almost all scenarios.
- Along much of the Pacific Northwest and Alaska coastlines, RSL is expected to be less than the global average under many scenarios.
- Under the highest scenarios RSL will be higher than the global average along almost all of the U.S. coastline with the exception of Alaska.
- Perhaps most importantly, for 90 cities along the U.S. coastline, Alaska excepted, a RSL rise of 0.35 m (14 in) will be associated with a 25-fold increase in the annual frequency of disruptive, damaging flooding with the possibility of serious loss of life and or property by 2080 for the low GMSL rise scenario of 0.3 meters and by 2030 for the intermediate high GMSL rise scenario of 1.5 meters.

Large increases in the RSL become more probable for each year that unabated discharges of greenhouse gases into the atmosphere continue.

A second NOAA group produced detailed model-based flooding “tipping point” projections

for 26 U.S. coastal cities.[75] They defined their tipping point as the probability that sea level would rise at least 0.5 m above the average of the mean higher high water (MHHW) mark for each day 30 or more times per year (there are usually two high tides each day). They performed this analysis for three emissions scenarios (RCPs 2.6, 4.5, and 8.5, the latter being the business as usual scenario). The results of these analyses are shown in figure 7.[75]

Populations are becoming progressively more urbanized and urban centers are commonly

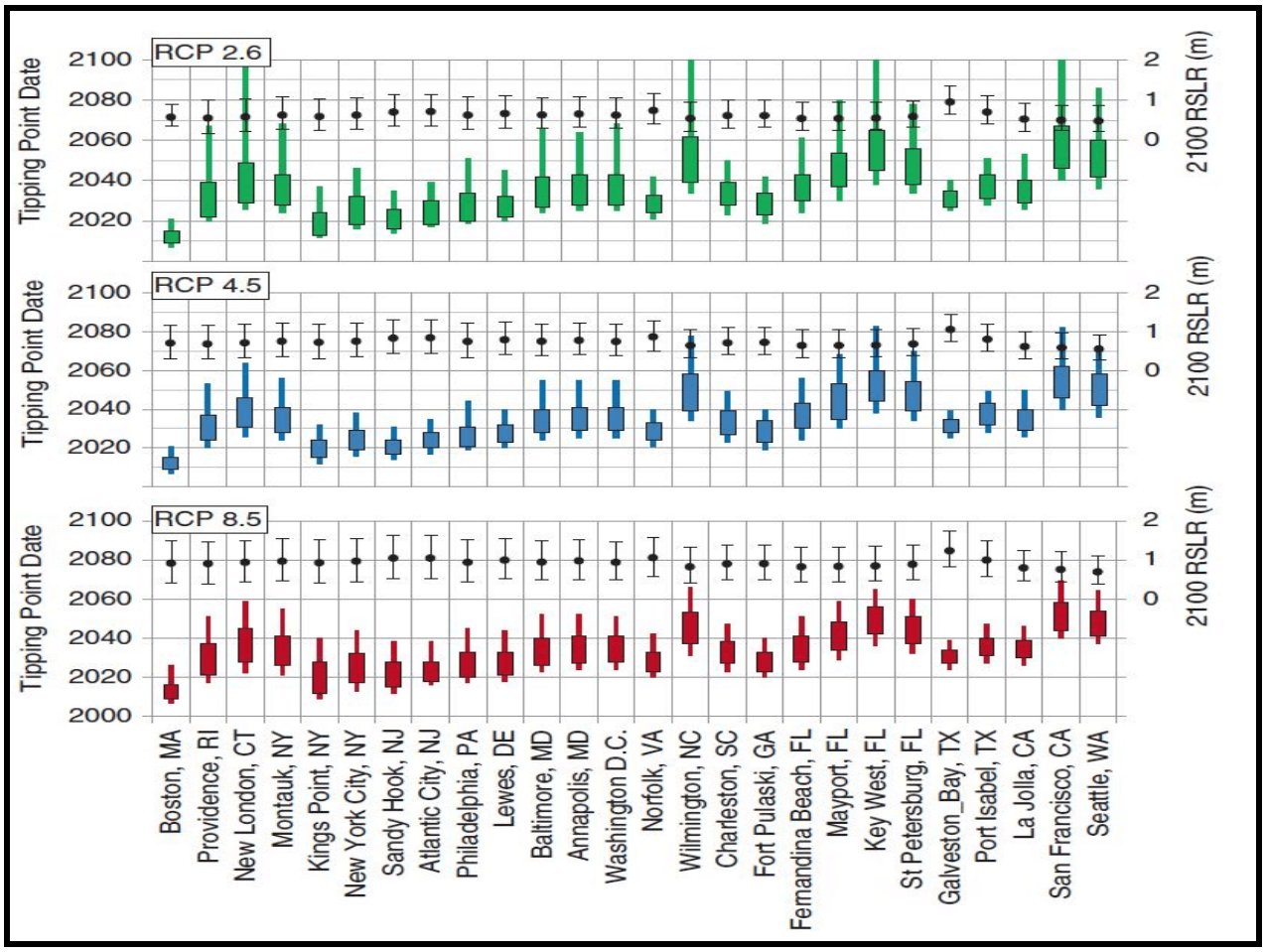

Figure 7. Tipping point data (left vertical axes) when a location is projected to experience 30 days per year of flooding above 0.5 m MHHW in response to RSL projections at a specified RCP. Boxes represent dates associated with the 20 percent and 80 percent projection probabilities and the whiskers represent 5 percent and 95 percent probabilities. Local RSL amounts are shown on the right y axes with dots representing the 50 percent and the error bars the 5 percent and 95 probabilities. Reproduced with permission from Sweet and Park.[75]

located on coastal sites that are susceptible to flooding. Too often these communities lack the

capacity to respond quickly and effectively to a flooding disaster. The strategies for dealing with coastal flooding are limited: 1) armor the coastline with sea walls, etc., an approach taken in the Netherlands where huge public works projects were created, 2) nourish coastal areas by restoring natural coastal systems such as salt marshes, mangroves, beaches, dunes, etc. and 3) abandoning property that is too vulnerable or not valuable enough to warrant protecting.[32] A comprehensive study of coastal locations in the contiguous U.S. showed that as social vulnerability (based on a multifactorial scale including poverty) increased, the population living in structures likely to be abandoned also increased, while those who had low vulnerability scores lived where shorelines were ikely to be protected by armoring.[76] These data address one of the key findings of NCA4: the impacts of climate change will be disproportionately severe for those in the lower social and economic classes, people of color, and vulnerable individuals such as children and the elderly.

Rising sea level is creating a new class of American migrants: those who are or will become environmental refugees. These are people who are likely to be in the lower social and economic groups, who may live in government-supported housing, and therefore may have few, if any, resources to pay for relocation. Forced migration creates substantial levels of anxiety, stress, and depression. With a sea level rise of 0.9 meters, the number displaced is estimated to be 4.2 million.[78] If sea level rises by twice that amount, the number displaced more than triples to an estimated 13.1 million. The impact of rising sea level for coastal counties in the continental U.S. is shown in figure 8.

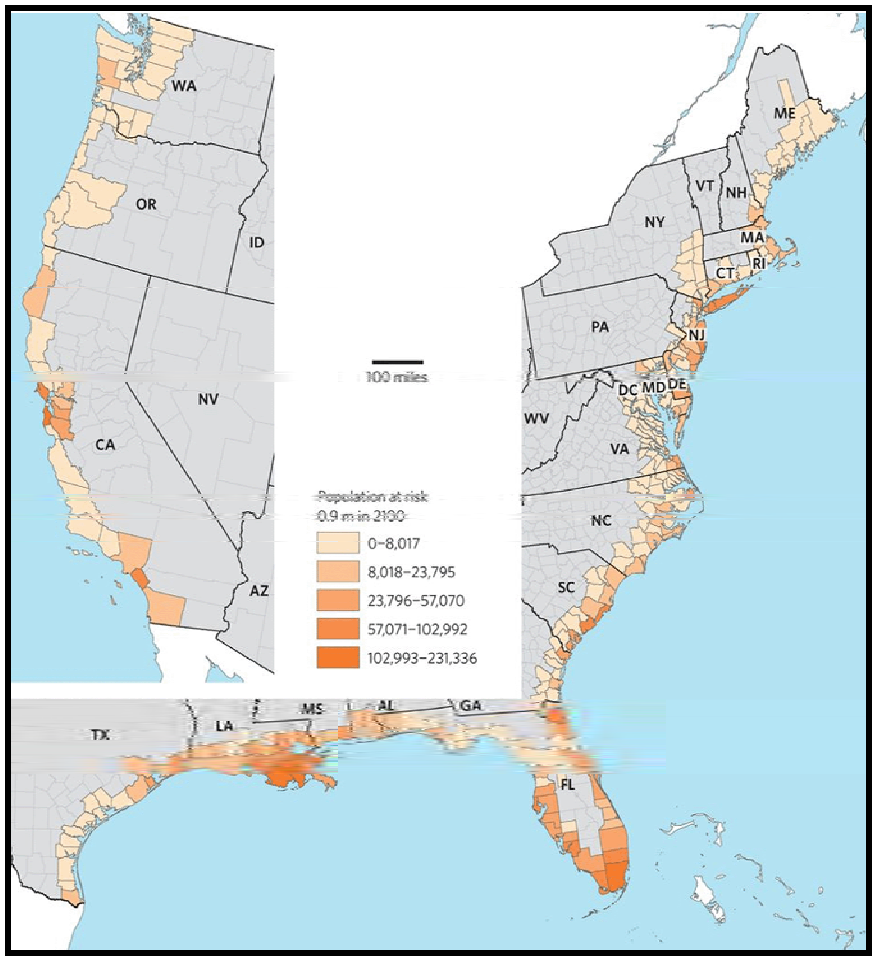

Figure 8. Cumulative projected populations at risk of SLR under the0.9 m scenario by 2100 for U.S. counties. Counties not included in the study are colored in grey. Reproduced with permission from Hauer, Evans, and Mishra, Nature Climate Change.[77]

Florida will bear the brunt of the disruption as one might expect from figures 6 and 8. If the present population of Florida were to remain constant, an unlikely assumption, and sea level rose by 0.9 meters by 2100, state and local officials should expect to evacuate around 600,000 individuals, a number that rises to 2.7 million if the oceans rise 1.8 meters. It is more likely that the population of Florida will not remain stable and will continue to rise.

Displaced people will need to go somewhere. The author of a complementary study compares this migration to the population displacement during The Great Migration, in which huge numbers of African-Americans fled the South to escape the effects of segregation.[78] Some people will stay in the affected state but others will move elsewhere - many to inland states.[79] Again, Florida will face a huge population loss of 2.7 million citizens. Texas is forecast to receive the largest number of these migrants, with an increase that is estimated to be just under 1.5 million. It seems unlikely that responsible agencies will be able to adapt to these changes.

Refugees carry more than their personal belongings. There will be stories behind the statistics that describe these numbers. Refugees will carry fear, anxiety, depression, traumatic stress disorders and more along with their physical injuries and needs.

Drought, Threats to Food Production, and Starvation

As of the middle of 2018, much of the contiguous U.S. was affected by drought. Data from the National Weather Service, indicated that drought had reached "exceptional" levels in parts Arizona, New Mexico, Oklahoma, and Texas.[80] Exceptional drought "corresponds to an area experiencing exceptional and widespread crop and pasture losses, fire risk, and water shortages that result in water emergencies."[81] These data are depicted in figure 9.

The NCA4 notes that ensuring an adequate supply of water "is the foundation of human and ecological health."[82] While the report notes that major metropolitan utilities, the Army Corps of Engineers, and others have taken steps to adapt to diminishing water supplies, the pressure on underground water supplies is increasing. This is particularly true for aquifers over North Texas, Oklahoma, Louisiana, Arkansas, and small portions of Alabama, Tennessee, Kentucky, Illinois, and Missouri where the groundwater depletion rate was in excess of 7 cubic kilometers per year in the years between 2001 and 2008. This represents a 2 to 7-fold increase compared to the interval between 1990 and 2000.

Climate change manifestations such as altered rainfall, increases in temperature, and increases in the atmospheric concentration of carbon dioxide are virtually certain to have major effects on agriculture. Some of these are already apparent. An analysis of climate trends from 1980 to 2008 found that global production of corn (maize) and wheat declined by 3.8 percent and 5.5 percent respectively.[83] Looking ahead to the future, predictions are dire. While temperature increases may have transient positive effects on yields, temperature changes are frequently accompanied by changes in rainfall making it difficult to separate these two variables. There is a tipping point for yields for soybeans and corn, the two most important agricultural commodities grown in the U.S. and

leading crops in drought-affected regions shown in figure 9.[84] Temperatures in excess of 25°C that occur when pollination takes place trigger a dramatic reduction in yield. The tipping point for soybeans is similar. When climate models are viewed along with these responses the authors of that paper predict that the yields of these two critical crops will decline by as much as 80 percent by the end of the century in a business-as-usual scenario. Changes in rainfall may alter those predictions.

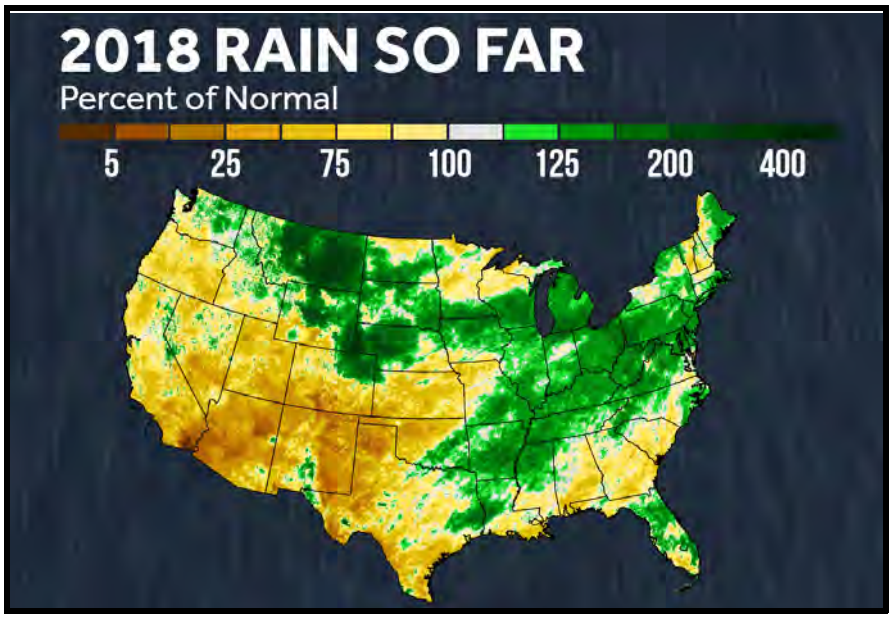

Figure 9. Rainfall data for 2018 from January 1 to May 21. Data from NOAA and the National Weather Service compiled by Climate Central. Reproduced per Climate Central policy: climatecentral.org.

The impacts of drought are amplified when the effects of the increase in the atmospheric concentration of CO_2 are included. Climate change deniers tout the fertilizer-like effects of CO_2 that promote the growth of plants. While this effect exists, it comes at a price in terms of the nutritional value of crops. When legumes and certain grains such as wheat, rice, peas, soybeans, and corn are grown in plots where the CO_2 concentration is increased to levels expected by mid-century, the content of zinc and iron is reduced.[85] The protein content is reduced in wheat, rice, and peas. Dietary deficiencies of zinc and iron are major threats to health worldwide. Estimates place this disease burden at around 60 million life-years.[86] Unless there is success in the breeding programs designed to make these crops resistant to this effect, the impacts of drought and CO_2 on health will be substantial.

Droughts have major effects on food prices and civil unrest.[32] Drought and, paradoxically, even small increases in rainfall are correlated with increases in civil strife in Africa.[87] Increases in food prices are associated with food riots.[88] In response to rising food prices a vegetable vendor in Tunisia protested with the extreme act of self-immolation. This marked the beginning of the Arab Spring, the precursor to much of the current violence in the Middle East.

Perhaps the ultimate threat to water for drinking, agriculture, and cultural identity lies in the Himalayas. A new report by the Hindu Kush Himalayan Monitoring and Assessment Programme projects a dire future for nations that depend on water from the melting glaciers in the Himalayas.[89]

The report's authors write that even if the stated goals for controlling climate change are met, as much as one-third of these glaciers will be gone by the end of the century. This would have a major impact on the countries that depend on this source. If greenhouse gas emission goals are not met, the authors predict that additional glacial melting will occur. This would result in water supply reductions that are twice as great. After the 2019 resumption of border hostilities between India and Pakistan, the thought of a dry and thirsty India that is armed with nuclear weapons is unsettling at best.

REGIONAL IMPACTS

The NCA4 divided the continental US into 7 regions, listing Alaska, the US Carribean and Hawai'i plus the US affiliated islands separately as shown in figure 1. These regions have aspects in common along with many differences. This section of the report summarizes some of the effects that climate change is having in each of these regions and what to expect in the future.

Northeast

It is likely that the residents of the NE will experience very large increases in heat-related morbidity and mortality as heat waves become more frequent and severe. Many people living in this region are clustered in major metropolitan areas and subject to heat-island effects that amplify the effects of higher temperatures. The NCA4 models predict that compared to the 1975 - 2005 interval the mean average temperature in this region is expected to increase by 4.0˚F (2.2˚C) by 2050 even if there are moderate reductions in emissions (RCP4.5) and by 5.1˚F (2.8˚C) under a business-as-usual scenario (RCP8.5). In 2017 an EPA report, produced as a precursor to the NCA4, indicated that by 2050 Northeasterners can expect about 650 more excess deaths per year caused by extreme heat regardless of the emission scenario. This is due to the fact that temperatures are not expected to diverge much by mid-century. But by 2090, when temperatures predicted by these scenarios do begin to diverge, the toll is likely to be approximately 960 per year under the RCP4.5 scenario soaring to 2,300 under the RCP8.5 scenario.[90]

The demand for electricity for air conditioning systems rises when temperatures rise. This places pressure on the electrical grid and may bring fossil fuel-burning electrical generating units (EGU) on line to meet the need for more electricity. This, in turn, will increase the use of water to cool these EGUs and to cool some air conditioning units. These demands will compete for requirements for water for human use and other needs including agriculture. Particulate emissions by coal-fired EGUs make air pollution and associated diseases worse and carbon dioxide emissions will hasten climate change.

Hot weather, ultraviolet radiation from the sun, and increases in the concentration of precursor agents that participate in the photochemical reactions that form ozone will lead to increases in the concentration of this pollutant. Ozone precursors of concern are carbon monoxide, oxides of nitrogen produced by EGUs and internal combustion engines, and volatile VOCs from natural and anthropogenic sources. Children, asthmatics, and adults with chronic pulmonary disease will be vulnerable. The impact of these effects will become even greater if proposed rollbacks in clean air regulations occur.

Carbon monoxide and VOCs from distant wildfires lead to increases in the ozone concentration downwind.[57] In 2015 the ozone concentration in Baltimore exceeded the new National Ambient Air Quality Standard of 70 parts per billion due to the smoke plume from Canadian fires that reached the city.[57] This problem is discussed in more detail in the Fire section.

Longer growing seasons and increased atmospheric CO_2 favor the growth of the deceptively named plant *Ambrosia artemisiifolia*, commonly known as ragweed.[91] Ragweed pollen poses risks for asthmatics and individuals with hay fever. There are multiple species in this genus and their range is expected to expand.[92] In the spring, tree pollens are important triggers for asthma and allergic rhinitis as shown by correlations with emergency room admissions, over-the-counter sales of medications, and pollen counts.[93] Maple, birch, beech, ash, oak, and sycamore appear to be the major offenders.

Ocean waters in the Northeast have warmed as a consequence of climate change. The warmer waters are more hospitable environments for certain bacteria and algae. This includes *Vibrio parahaemolyticus* (*Vp*), a naturally-occurring bacterium that is found in brackish water and thought to be the cause of approximately 35,000 cases of gastroenteritis each year.[94] Most of these infections are due to eating raw or undercooked shellfish. In the summer of 2013 there was an outbreak of *Vp* gastroenteritis along the Northeastern seaboard. Warmer waters were thought to be a contributing factor. Similarly, warming of the waters in the Gulf of Maine have lengthened the duration of algal blooms by 8 weeks in the interval between 1982 and 2016.[95] Two species, *Alexandrium fundyense* and *Dinophysis acuminata*, are particularly problematic as they are synthesizers of saxitoxin and okadaic acid. These toxins cause paralytic shellfish poisoning and a diarrheal syndrome respectively.

Low-lying portions of the Northeast are at risk from rising sea level, severe storms, and the storm surges that will accompany future hurricanes.

Southeast

Miami, Miami Beach, and other coastal urban areas will be susceptible to the effects of heat and rising sea levels. Many of these areas already experience regular flooding of roadways during perigean tides more commonly known as “king tides.” These usually occur twice a year when the moon’s orbit brings it closest to earth (astronomically known as perigee). Roadways have already been raised in parts of Miami Beach. Now shoppers must step down from streets to enter some stores.

Rising sea level, storm action, and other factors are causing a loss of coastal wetlands. This is a serious problem in Louisiana, where erosion is causing the loss of an area the size of a football field every 34 to 100 minutes.[96]

Vector-borne diseases are likely to increase. Dengue is of particular concern.[32] This disease, also known as dengue hemorrhagic fever or break-bone fever, is caused by one of four strains of dengue virus. Infection by any one of these strains makes the individual even more susceptible to the effects of infections by other serotypes. This has created problems in the production of an appropriate vaccine. Dengue is transmitted by the bite of *Aedes aegypti* mosquitoes. Although dengue has been rare in the continental US, this is likely to change. The interactive dengue map, maintained by the CDC, revealed four cases of the disease in November, 2018, two each in Texas and Florida. As an illustration of the fact that dengue is a world-wide problem, the CDC dengue map

on Earth Day, April 22, 2019, identified 1456 global alerts for the preceding 3 months. Many states have conditions that are favorable for the multiplication of the vector and have been recipients of dengue-infected Puerto Rican refugees who fled their island after Hurricane Maria. *Ae. aegypti* mosquitoes are already found in the Gulf Coast portions of the US.[97] Cool winter temperatures have kept this insect from posing a year-round threat. This could change as temperatures warm. By the end of the century, one projection estimates that half of the world's population will be at risk for contracting dengue if greenhouse gas emissions continue along the present trajectory.[98]

Zika virus, a flavivirus similar to dengue, is also carried by *Ae. aegypti* mosquitoes. It affected 1.3 million Brazilians and spread to the U.S.[99] The fetus of infected pregnant women may develop microcephaly due to infection of the fetal brain. This virus may persist in the environment for an indeterminate length of time.

Warming of the ocean's surface is likely to lead to more algal blooms.[100] Warnings of this problem appeared in the NCA3 and conditions favoring this threat have only worsened. Ciguatera fish poisoning is also a threat. This syndrome is characterized by diarrhea, vomiting, and dizziness that may combine with itching. It typically appears within hours to days of ingesting reef fish containing ciguatoxins, notably ciguatoxin and maitotoxin produced by *Gambierdiscus toxicus,* a marine organism that grows on and around coral reefs.[101]

Although wildfires have been most problematic in California, the combined effects of drought, increased temperatures, and proliferation of invasive species in Southeastern forests combined to make 2016 the worst wildfire season in the past century.[8]

Heat, smoke from wildfires, emissions from vehicles and power plants, ozone, $PM_{2.5}$, and air-borne allergens (particularly ragweed, discussed earlier) combine to threaten air quality and health. Again, vulnerable populations including asthmatics, patients with other chronic respiratory diseases, and the elderly will be at the highest risk.

Midwest

Heat will be a major threat to health throughout the Midwest. We have already seen what happened in Chicago during the 1995 heat wave. NCA4 reports that temperatures in Chicago rarely exceed 100°F.[8] Climate predictions indicate that this threshold will be crossed frequently as time passes, regardless of whether an RCP4.5 or RCP8.5 pathway is followed. The average maximum 5-day temperature in northern Minnesota between 1976 and 2005 was 88°F. This is expected to climb to 93°F in the 2036 to 2065 interval if the RCP4.5 scenario is followed and to 95°F if the emissions-as-usual RCP8.5 scenario is followed. Things are worse for southern Missouri where historical data show the maximum 5-day mean to be 97°F, climbing to 102°F and 103°F under the two emissions scenarios respectively.

Ozone levels track heat quite closely. Ground-level ozone levels are expected to rise across most of the region to levels above the new National Ambient Air Quality Standards of 70 parts per

billion and to result in an additional tens to thousands of ozone-related illnesses and premature deaths per year.[8, 102]

Extending the growing season for ragweed will affect those who suffer from asthma, chronic pulmonary disease, and seasonal allergies.

The warming that has already occurred has caused large changes in the distribution of a variety of pests, disease vectors, and mediators of pollination.[103] Many taxonomic groups are affected including bacteria, fungi, diptra (insects with two wings), hemiptera (a group of insects that may be called "true bugs" including grasshoppers, aphids, and others), hymenoptera (wasps, bees, and ants), and others. These species have moved northward at a rate of approximately three km/yr since 1960. Modification of agricultural practices and disease vector control may be required to adapt to this migration.

Much of the U.S. wheat, corn, and soybeans is grown in the Midwest. As discussed above, increases in the ambient temperature during critical phases of crop development, usually pollination, will have devastating impacts on yields and food prices. This will trigger additional problems as the consequences of a wave of crop failures moves across the globe.

The combined effects of fertilizer run-off and warming have increased the temperature of Lake Erie and its tributaries such as the Maumee River. This resulted in a record algal bloom in 2011 which was exceeded in 2014.[104] These algae produced microcystins, a class of at least 50 poisonous agents that may attack the liver or brain and cause diarrhea, vomiting, and liver damage. This is a major seasonal concern for communities that draw drinking water from the lake and has already caused a brief shutdown of the water supply of Toledo, Ohio.

The status of the Great Lakes is an important factor in the assessment of the impact of climate change on Midwestern biodiversity and ecosystems. This is the third key message in the NCA4 section on the Midwest.[8, 102] Here the authors point to the diversity of native species that provide services such as water purification, flood control, crop pollination, and the provision of resources. Climate change and changing patterns of use for the land are inter-related and amplify the impact of each on the other.

Tornadoes are among the most feared examples of severe weather and with good reason. They often strike with little or no warning and cause severe injuries and deaths along with substantial damage to property. They attract lots of media attention that tends to focus on property damage and ignore health. On May 3, 2018, ABC reported that 29 tornadoes had struck in the past 4 days with the possibility that more would follow.[105] Portions of the Midwest region lie in what is popularly known as Tornado Alley. The core of this media-designated region includes Texas, Oklahoma, Kansas, Nebraska, and South Dakota. However more Midwestern states such as Missouri, Iowa, Minnesota, Wisconsin, Illinois, Indiana, and western Ohio lie in the path of these storms. A more detailed discussion of tornadoes is included in the Northern Great Plains section.

Northern Great Plains

The NCA4 begins its section on this region by stating "Water is the lifeblood of the Northern Great Plains." The report continues noting that "even small changes in annual precipitation can have large effects."

Projected climate change effects in this region, like others, are scenario-dependent.[8] The RCP4.5 scenario concludes that there will be between 15 and 30 more days per year when the temperature exceeds 90°F. Under the higher emissions or business-as-usual scenario, RCP8.5, the number of days above 90°F will rise to between 25 and 40. Adverse effects on health and agriculture will follow. Large amounts of corn, wheat, barley, and dry beans are grown in this region. Reductions in yields pose threats to the U.S. and international food security.

The number of days when there is more than one inch of precipitation is also likely to increase under both of these scenarios. Increased rainfall is expected to be most prominent in the mountains and eastern parts of the region along the Mississippi and Missouri Rivers.

Parts of this region are in the core of Tornado Alley where severe thunderstorms and tornadoes are likely. An analysis of rainfall east of the Rocky Mountains has shown that as much as 70 percent of the warm-weather rainfall in this region can be attributed to complexes of severe thunderstorms. These are larger than an individual thunderstorm but smaller than the cyclones that form outside of tropical regions (see Feng et al for details[106]). Meteorologists refer to these as mesoscale convective systems (MCS). Relatively brief, intense periods of rainfall associated with squall lines, strong winds, and tornadoes are characteristic of MCSs. These events may be associated with injuries, deaths, along with flash flooding and property damage. Based on the observed increases in MCSs, this trend is likely to continue as climate change worsens.

Southern Great Plains

This region will be affected strongly by many of the climate stressors that have already been discussed, including extreme precipitation, tropical storms or hurricanes, rising temperatures, and sea level rise. Additional threats to health arise due to food- water-, and insect-borne diseases. Those who are socially the most vulnerable will be displaced.

Record-setting rainfall totals are characteristic of this region. The record for 24 hour total precipitation was set in Alvin, Texas, in July, 1979. Tropical Storm Claudette (not a hurricane) was the culprit. Other record-breaking storms occurred in 2015, 2016, and 2017. None of these matched the rainfall total from Hurricane Harvey, in late August, 2017, setting the record for rainfall on the continental US when Cedar Bayou, about 30 miles from Houston, recorded 51.88 inches of rain before the storm abated.

In addition to the disaster that befell the Daily family during Harvey (see Water section), numerous other patients with severe medical conditions were impacted.[8] The NCA4 report states that more than 30,000 people were evacuated. Evacuation cut many of these individuals off from the

healthcare that they depended upon. Texas has one of the lowest rates of health insurance in the nation in spite of a high level of need. Estimates indicate that 11 percent of Texans are diabetic. Seventeen percent of adult Texans have renal disease. About 1,500 people per million require hemodialysis. During Harvey, dialysis centers were overtaxed as were pharmacies that were cut off from suppliers of critical medications such as insulin and inhalers. At least 15 hospitals were forced to evacuate patients.

Encouraging signs of an increase in resilience followed in the aftermath of Harvey. The Rebuild Texas Fund has tried to bring numerous entities from government, non-profits, businesses, and others together to plan for the storms that are certain to come. The fund has four foci: health and housing, schools and childcare, transportation and workforce, and funds to assist in the rebuilding of small businesses.

As implied in figure 7 rising sea level will be particularly cruel to those who live in Galveston, Texas, and along the Texas Gulf Coast.[75] Since 1880 global sea level has risen by about 8 inches. Sea level rise along the Texas coastline has varied between 5 and 17 inches each 100 years resulting in a loss of around 180 acres of land per year.[107] The variance in sea level rise is due primarily to local factors, particularly the amount of water, gas, and oil pumped from underground sources. The more that is pumped, the more the land subsides. As a result of pumping the relative sea level rises. Rises displace people, particularly when coupled with storm surges.

Temperatures will rise throughout the region. The increases will be the most severe along the Rio Grande River where there may be as many as an additional 90-100 days per year where the temperature is above 100°F, depending on the emissions scenario.[8] Health and outdoor work productivity will suffer. Higher temperatures will be particularly harsh for those who may be attempting to cross the river from Mexico to seek asylum in the U.S.

Water supplies are already imperiled and are likely to worsen with time, increasing temperatures, and drought. The supply of water for drinking is tenuous and worse for the demands for irrigation and raising cattle. Rivers, lakes, underground aquifers, and around 50 energy-demanding desalination plants seek to meet the demand for water in this region. Droughts have already had severe impacts on agriculture with ripple effects on businesses that deal with farms, farm supplies, and industries that purchase livestock and crops. Growers of water-intense rice are at risk if water rationing becomes necessary.

Northwest

The theme of tree mortality propelled forward by drought, insect infestations, and fire permeates this section of NCA4.[8] In a morphing of a proverb one author writes “Where there’s smoke there’s fuel aridity.” Aridity is defined by the American Meteorological Society as “the degree to which a climate lacks effective, life-promoting moisture." Trees become tinder in the absence of adequate moisture and are ready to burn at the slightest provocation. In an analysis of the impact of climate change on wildfires in the Northwest the authors of the NCA4 are clear: “anthropogenic

climate change accounted for approximately 55 percent of observed increases in fuel aridity from 1979 to 2015". This translates into an estimate that anthropogenic effects on climate change contributed to more than 4.2 million hectares of burned forests in the interval between 1984 and 2015 (a hectare is an area measuring 10,000 m^2). This is more than double the area expected in the absence of climate change. The fires in the Northwest are associated with the health threats discussed elsewhere in this report.

Areas that have been burned are more likely to experience landslides, or more properly mudslides. Although not the result of a fire, the residents of Osa, Washington, experienced one of the most devastating mudslides after a period of heavy rain on March 22, 2014.[109, 110] The volume of the slide was sufficient to cover about 600 football fields to a depth of 100 feet. It caused 43 deaths and demolished 40 homes. Since then there have been numerous reports of smaller, fire-related mudslides, many of which blocked important highways and caused deaths, injuries, and property loss.

Southwest

This region may illustrate the nexus between heat, water and fire better than any other part of the U.S.

Temperatures in the Southwest are already the highest in the nation. Heat is certain to be a continuing problem, particularly in large metropolitan areas such as Los Angeles and Phoenix, and in deserts. The aptly-named Death Valley holds the record for the highest temperature (134°F) ever observed in the U.S.[111] It also is the record-holder for the greatest number of consecutive days with a maximum temperature of 100°F or above (154 days in the summer of 2001). The records keep falling. In the summer of 1996 there were 40 days over 120°F, and 105 days over 110°F.[111]

There are already many extreme heat days in this region, defined as days when the temperature exceeds 90°F. It is likely that the number of these extreme heat days will increase by 60 per year if the business-as-usual emissions scenario (RCP8.5) persists. This is shown in figure 10. The adverse effects of extreme heat will be amplified by any increases in particulate or ozone pollution, both of which are likely.

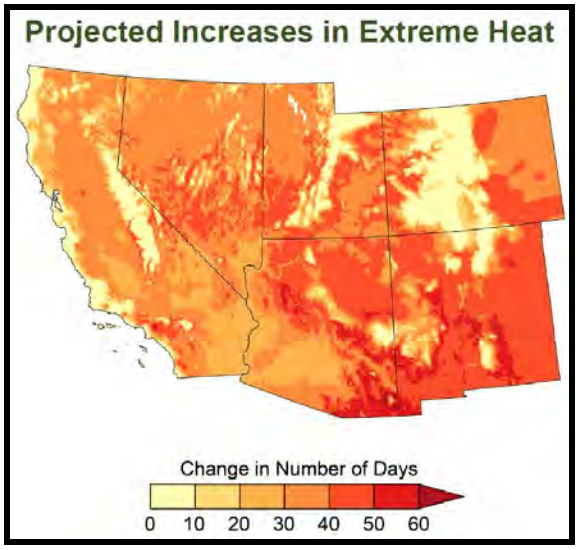

Figure 10. Projected increases in the number of extreme heat days by 2036-2065 compared to 1976-2005 under the RPC8.5 emission scenario. Extreme heat is defined as 90°F. Source, figure 25-10 in NCA4 adapted from NCA4 vol. 1.[8, 108]

Many of the residents of the Southwest live where temperatures are high during the day and low at night. This variability in temperatures

appears to be a risk factor for death among older individuals with chronic health problems.[112] A team of investigators evaluated Medicare records from 135 cities collected during the summer (June through August). They found that the temperature variance was a risk factor for mortality. Patients with chronic obstructive pulmonary disease, diabetes, congestive heart failure, and myocardial infarction were studied. They used the standard deviation (SD) about the mean or average temperature as their measure of variance (where one SD above and below the average includes 68.2 percent of all cases). Mortality rose among hospitalized patients aged 65 year or more when the SD exceeded 1°C. A high degree of temperature variance posed the greatest risk among diabetics, who experienced a 4 percent increase in mortality when the temperature variance exceeded 1°C. A lower, but still elevated, risk was found among persons with heart failure, who experienced a 2.8 percent increase if the temperature variance exceeded this criterion. Thus the amount of variability in temperatures may be a mortality risk factor that is independent of the temperature itself among patients with these disorders.

Many parts of the Southwest already face water shortages. Agriculture accounts for about 75 percent of the water used in the region, much of which comes from the Colorado River. Widespread water rationing has been required on occasion. The combined effects of rising temperatures that evaporate water in the Colorado River watershed and associated increases in the demand for water by plants have strained this water system. When Lakes Powell and Mead were full they contained around 50 million acre-feet of water. They now hold about half that amount. The Colorado River dries up before it reaches the Gulf of California.

Hydroelectric sources of power become increasingly important as the move toward the use of more renewable sources of energy and away from fossil fuels grows. Reports from the California Energy Commission reveal that hydropower accounts for about 20 percent of the in-state generation of electricity.[113] Drought and evaporative losses cut into this source by two-thirds between 2011 and 2015. California compensated for this, in part, by generating 50 percent more electricity from wind and 15 times more from solar. These two renewable sources account for about 30 percent of the electricity generated in the state.

Many of the most severe wildfires have occurred in this region. Images of the Camp Fire, which destroyed Paradise, California, persist. Many of the effects of wildfires have already been described. A somewhat unique approach to evaluating the effects of wildfires was reported in the Journal of Forest Economics using the Station Fire in Los Angeles County as an exemplar.[114] By the time the Station fire was contained on October, 16, 2009, it was the tenth largest in California history burning 160,577 acres, killing two firefighters, injuring 22, and destroying 209 structures including 89 homes. It threatened an additional 12,000 residents and forced the evacuation of thousands of people. The authors of this report found that the associated health costs were $9.24 per exposed person per day. The population of Los Angeles was approximately 3.8 million that year. By the use of surveys of this population they found that residents were willing to pay just over $84 per exposure day to avoid the symptoms of smoke exposure.

There are other hidden costs associated with wildfires. Another group evaluated the effects of 2012 High Park Wildfire in the Cache la Poudre River watershed in Colorado.[115] The Fort Collins, Colorado, water treatment facility had to change water sources as a result of contamination of this water supply. They were particularly concerned by unacceptable levels of a group of carcinogens known as trihalomethanes as well as other indicators of water pollution.

Alaska

Alaska evokes images of vast forests, and Denali covered in snow and ice. Although this is true for much of the state, Alaskans face many of the same problems faced by those who live in the contiguous states. Wildfires have been common and cause injuries, damage to the forests, and are the primary drivers of climate-induced air pollution. Smoke plumes, VOCs, carbon monoxide, and particulates travel long distances.

Since air conditioning is almost unheard of in Alaska very few citizens benefit from the pollution mitigation it affords.

Many communities are built along Alaska's very long shoreline where they are susceptible to storms and storm surges. Winter storms may damage above-ground water storage facilities and imperil both drinking water supplies and sewer systems. This increases risks for water-borne illnesses.

The oceans around Alaska are warming in a manner similar to the waters around New England. Warming raises the risk for harmful algal blooms that may result in paralytic shellfish poisoning. This condition is caused by saxitoxins produced by certain algae. These toxins bind to cell membrane sites near the sodium channel and can cause symptoms within minutes of ingesting contaminated shellfish. The Alaska Department of Environmental Conservation has developed guidelines to combat the threat from these toxins and gastrointestinal illness caused by *Vibrio parahaemolyticus*.[116]

The pervasiveness and extent of the tundra are unique features of Alaskan wilderness areas. The tundra permafrost and ocean beds around the state sequester large amounts of methane in the form of clathrates. Warming and the subsequent release of huge amounts of methane from clathrates do not appear to be factored into many climate change forecasts and could play a decisive role in determining the climate of the future.[116, 117]

Hawai'i and US Affiliated Pacific Islands

In 2016 the Hawai'i Department of Health declared a state of emergency because of an outbreak of dengue.[118] Although the disease was not endemic in the state, 263 cases had been identified. The disease was probably introduced by travelers, much as it was spread during the era of sailing ships. In late 2013 and early 2014 Fiji experienced around 27,000 known cases, with many more suspected.[119]

These two outbreaks exemplify the risk posed by the potential spread of vector-borne disease enhanced by climate change. The authors of a report that modeled the effects of population and climate change wrote that in 1990 1.5 billion people lived where the estimated risk for contracting dengue was 50 percent or more.[98] By 2085 they estimated climate change would place 5-6 billion people or between 50 percent and 60 percent of the projected world population in areas where the risk exceeded the 50 percent criterion. In the absence of climate change these numbers would fall to 3.5 billion people or about 35 percent of the population.

Water insecurity is central to the problems faced in this region. Rainfall patterns are changing and threaten flood or drought. Sea level rise threatens drinking water supplies as salt intrudes on already-fragile sources. In some cases entire islands will be engulfed and disappear. In the words of NCA4 these effects are expected to "catastrophically impact food and water security."[82]

This region is particularly sensitive to El Niño and the Southern Oscillation (ENSO). El Niño affects precipitation, the temperature of air and water, wave size, and trade winds. The frequency and intensity of ENSO and related effects on world-wide weather systems are expected to increase as the result of climate change. ENSO activity has been linked to periods of civil unrest in distant countries, a phenomenon referred to as teleconnection. [120, 121]

ENSO affects wave morphology in this region. Waves that are much larger than is typical may occur as a result.[122] When large waves break over reefs they may wash over the berm of sand above typical high tide lines causing overwash flooding of more inland areas. This adds to the hazards associated with rising sea level, contributes to property loss, and threatens habitability of islands with unfavorable reef morphology.

Puerto Rico and U.S. Caribbean

The official title of this section of NCA4 is just "U.S. Caribbean." This speaks to the frequent complaints made by Puerto Ricans after the devastation caused by Hurricane Maria. Residents still voice bitter resentments about being forgotten and the failure to recognize that residents of Puerto Rico are U.S. citizens.

Coasts are a central geographical feature of these islands. Rising sea level poses threats similar to that in other regions. Drinking water supplies may be tenuous in some locations. Salt water intrusion due to hydrostatic forces associated with higher ocean levels will become more problematic. Coastal communities are popular tourist areas and are threatened. Armoring shorelines and raising structures are considerations that must be contemplated to adapt to the new reality. These islands have many people who are vulnerable to this threat.

Severe weather events, most notably hurricanes and tropical storms, are a growing threat to this region, as described in the water section that dealt with some aspects of Maria. These extreme weather events threaten all aspects of the economies of these islands including agriculture, tourism, critical infrastructure, property of all types including public and private, and natural ecosystems that

provide essential services to other parts of the economy.

Surprisingly, vector-borne diseases, particularly dengue, receive little attention in this section of the NCA4. Dengue is endemic in Puerto Rico and most cases among Americans on the mainland are the result of infections acquired on the island.[123] The peak season for contracting the disease begins mid-year and lasts several months. In 2014 infection rates peaked at about 550 new cases per week. In 2007 there were 10,508 reported cases and in 2010 there were 26,766 cases. There is hope that a suitable vaccine for the disease may be forthcoming.[124, 125] During the post-approval period for the surveillance of the Dengvaxia vaccine for dengue it became evident that there may be a problem. Among some children who had no serological evidence for the disease prior to receiving the vaccine a subsequent infection appeared to result in an illness that was more severe than expected. This phenomenon is called antibody-dependent enhancement.[126] As a result the World Health Organization advised immunizing only those individuals with evidence of a prior infection. The manufacturers of the vaccine received FDA approval for the U.S. market after applying for and receiving an expedited review. The FDA website states that Dengvaxia is "indicated for the prevention of dengue disease caused by dengue virus serotypes 1, 2, 3 and 4. DENGVAXIA is approved for use in individuals 9 through 16 years of age with laboratory-confirmed previous dengue infection and living in endemic areas."[127]

Even though the vaccine has been approved it is important to protect against infection by vigorous measures designed to control the vector - *Aedes aegypti*. The vaccine is not completely effective and requires three separate injections of the vaccine separated by six months. This will be a formidable logistical task complicated by the fact that mosquito is capable of reproducing in small quantities of water, including rain gutters, discarded tires, and many other sites.

1.5°C *versus* 2°C: WHY IT MATTERS

The IPCC special report "Global Warming of 1.5°C" imparts a fresh perspective on the perils that await us if we fail to limit greenhouse gas emissions sharply and quickly. The authors make direct comparisons of the impacts under two scenarios: a temperature rise of 1.5°C rise *versus* a rise of 2.0°C.[128]

The IPCC has a high level of confidence that the 1.5°C temperature rise threshold will be reached between 2030 and 2052 if emissions continue unabated. In the least optimistic forecast we have 11 years to act. The IPCC concludes that the emissions to date will continue to impact the climate and health for "centuries to millennia." Existing emissions alone are not likely to cause warming beyond 1.5°C. More emissions will push us beyond that threshold. This bit of encouragement should help spur global societies to act more definitively. Here are some of the IPCC's conclusions with an emphasis on those that are related to health most directly.

- "Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2.0°C."
- Critical differences between the two temperatures include "increases in mean temperature in most land and ocean regions, hot extremes in most inhabited regions, heavy precipitation in several regions, and the probability of drought ... in some."
- Avoiding a 2°C temperature increase prevents a 0.1 meter rise in global mean sea level.
- Limiting global warming to 1.5°C "is projected to lower the impacts on terrestrial, freshwater, and coastal ecosystems and retain more of their services to humans." These services include health.
- Avoiding a global warming rise to 2.0°C preserves more of the services to humans provided by marine systems.
- "Climate-related risks to health, livelihoods, food security, water supply ... are projected to increase with global warming of 1.5°C and increase further with 2.0°C."

Heat

The IPCC reports that risks posed by heat-related morbidity and mortality due to global surface temperature increase to 1.5°C will be higher than risks in the pre-industrial climate. Further increases will occur if temperatures rise by 2°C. The risk difference between the two temperatures will be very high. Similar but more muted estimates for risk are associated with occupational activities. All regions of the earth will be affected.

More specifically, climate researchers have concluded that 13.8 percent of the world's population will be subjected to severe heatwaves at least once every 5 years if global mean temperatures rise to 1.5°C above pre-industrial levels. If global mean temperatures rise by 2.0°C the number triples to about 36.9 percent.[129] From another perspective, their data suggest that limiting the temperature increase to 1.5°C will prevent 420 million people from being exposed to extreme

heatwaves and 65 million from exceptional heatwaves. Inhabitants of huge cities with swelling populations will be at great risk. Those living in tropical regions where day-to-day variations in temperature are relatively small will be impacted the most. However, those in more northerly regions will experience a greater amount of variance in temperatures, a phenomenon that has adverse health effects as discussed above.[112]

Temperature and changes in rainfall combine to increase the risk for undernutrition if temperatures rise from 1.5°C to 2.0°C. Extreme undernutrition causes death - children are the most vulnerable. Less severe undernutrition causes stunting, or a failure to grow normally. Growth failure includes vital body organs such as the brain causing the undernourished child to fail to attain his or her intellectual potential. This impairs future earning ability for the individual and has serious negative effects on society. Undernourished children have an impaired ability to resist infections, such as malaria. They die at a higher rate than children who are well nourished. Undernourished pregnant women are likely to have affected babies and an inability to breast feed. As might be expected, low-income nations in Africa and Asia are the most vulnerable.

Fire

The IPCC report is relatively silent with regard to the effect of climate change on wildfires. However, the authors note that the wildfire risk increases if the global mean temperature rises to 2.0°C. The risks are projected to be "particularly high" in the U.S., Canada, and the Mediterranean. Mediterranean regions are projected to have a "particularly high" risk when transitioning from 1.5°C to 2.0°C. Some of this risk will be due to drought affecting these regions.

The IPCC authors cite a study that provides more data about climate-related fire activity.[130] They write that "substantial and rapid shifts are projected for future fire activity across vast portions of the globe." Increased fire activity is projected for regions that are already warm and that are located in mid- to high latitudes.

Water

Water and its relationship to health will be a central factor in the climate of the future. Some places on earth will have too much water, in the form of rising sea level, severe storms, storm surges associated with hurricanes and cyclones, and other forms of severe weather such as thunderstorms with associated mesoconvective storms that are likely to spawn tornadoes. Other areas will experience drought and will be subjected to water stress, defined as "the probability of extreme drought, precipitation deficits, and risks associated with water availability." With an increase of 1.5°C the authors estimate that between 3 and 3.5 billion people will be exposed to water stress. Of these almost 500 million are classified as exposed and vulnerable. At 2.0°C there is more uncertainty in the number, but between 3.1 and 4.0 billion people will be exposed to water stress with around 586 million both exposed and vulnerable.

Elsewhere in the IPCC report the authors make a different approach to the water stress theme with slightly different data and conclude that 8 percent of the world's population will at risk for

water stress at 2.0°C of warming, a doubling of the number expected at 1.5°C. Urban populations will not be immune to water shortages. The IPCC estimates that around 350 million urban dwellers will experience water risks from drought, a number that increases to around 411 million if the global temperatures increase from 1.5°C to 2.0°C. These effects will not be restricted to vulnerable countries in West Africa, Southeast, East, and West Asia, but will also include developed countries in central and southern Europe and the Mediterranean.

Now and the Future

Cyclone Idai made landfall near Beira, Mozambique on March 15, 2019. It devastated portions of Mozambique, Zimbabwe, and Malawi. Tentative initial estimates projected a death toll of over 1,000 with the creation of 400,000 refugees among survivors. An attempt is under way to stave off an epidemic of cholera with a wide-spread vaccination effort. Some have called it the biggest weather-related disaster so far this century. Meanwhile, in the U.S., Midwest, record floods in spring of 2019 the have inflicted huge losses of property, devastated farmlands, and killed huge numbers of animals. Scientists are no doubt working to determine the role that climate change had in these weather-related disasters.

An account of the ultimate worst case scenario is portrayed in a publication with the grim title of "Combustion of Available Fossil Fuel Resources Sufficient to Eliminate the Antarctic Ice Sheet."[131] The authors of this study report that burning the entire known store of fossil fuels would be sufficient to melt virtually all of the Antarctic Ice Sheet, raise sea level by as much as 50 meters (about 160 feet), increase the atmospheric concentration of CO_2 by a factor of about 10 (to 4,000 parts per million), and raise temperatures by as much as 12.5°C (22.5°F). This report does not appear to include the probable release of the huge amounts of methane currently trapped in clathrates and the arctic permafrost. Methane releases would accelerate the rate of global warming and the rate of sea level rise. The earth would become uninhabitable as described in the new book by David Wallace-Wells *The Uninhabitable Earth: Life after Warming.*[132] No matter how hard we try, we could not burn these fuel reserves very quickly and the changes wrought by burning them would take place over hundreds of years. But, as the authors point out, the greatest effects would occur rather promptly.

The Bottom Line

The IPCC report concludes that the "pathways limiting global warming to 1.5°C ... require rapid and far-reaching transitions ... unprecedented in terms of scale but not necessarily in terms of speed and imply deep emissions reductions in all sectors." The panel further states that there is "a wide portfolio of mitigation options [that require] a significant upscaling of investments in those options." An increase of 1.5°C will be bad enough; 2.0°C would be intolerably worse. Burning all fossil fuels would be an unmitigated disaster.

CONCLUSIONS

"It's worse, much worse than you think.
The slowness of climate change is a fairy tale ..."
From *The Uninhabitable Earth: Life After Warming*
David Wallace-Wells[132]

The complexity and scale of the problems posed by the effects of climate change on health are so massive that preventing the "collapse of our civilization," as warned by Attenborough and the "unacceptably high level of risk" as described by the *Lancet* Countdown could elude our best efforts. Timothy Morton, a Professor of English at Rice University in Houston, TX, cites climate change as an example of a "hyperobject" a thing that is "so massively distributed in time and space as to transcend localization ..."[133] The effects of climate change are upon us and will continue to worsen unless prompt actions are taken. The literature warns us about tipping points, thresholds beyond which an event cannot be stopped or reversed. Indeed, an analysis using contemporary models revealed evidence for 37 tipping points in the ocean, sea ice, snow cover, permafrost, and terrestrial biosphere. [3, 134] Eighteen of these occur at 2°C or less. We must cope with the human tendency to prioritize short-term rewards over those that occur in the future that is exacerbated by a well-funded campaign to "obscure the truth on issues from tobacco smoke to global warming' as described by Oreskes and Conway in *Merchants of Doubt*.[135] Their more recent booklet *The Collapse of Western Civilization: a View from the Future* is an account in which the history of climate change blends imperceptibly and plausibly into a fictionalized account of the future as seen from the perspective of a survivor living in the Second Peoples Republic of China on the 300th anniversary of the "Great Collapse of 2093."[136] This was the year in which the Western Antarctic Ice Sheet disintegrated leading to a mass migration of climate refugees and a complete reordering of civilization. Oreskes, a well-known historian of science justifies this fictionalization by noting that thus far facts have not altered our behavior. Perhaps a dystopian view of the future will succeed where science and reason have failed. In a spring, 2019 lecture Oreskes noted that "Knowledge is not power."

Healthcare professionals have dealt with difficult problems in the past. We can do it again. It is our task to define climate change as a ***healthcare emergency*** that threatens the current and future health of populations in the U.S. and across the world. Greenhouse gas emissions must be reduced drastically. In parallel, the public health infrastructure must be strengthened so that the determinants of health described in the introduction can be maintained and enhanced.

The authors of a framework for approaching the climate change dilemma list the items below that must work together in order to mitigate and adapt to our changing climate:[137]

- Political leadership needed to instigate and support the process
- Institutional organizations that can execute policy
- Extensive stakeholder involvement

- Climate change information - a primary objective of this treatise
- Use of decision analysis and decision-making tools
- Explicit consideration of barriers
- Funding
- Development and spread of needed technology
- Research

Currently the political leadership at the national level that is needed to reduce GHG emissions is absent. Worse, the executive branch is working actively to withdraw from the Paris Agreement and disable the central provisions of the Clean Power Plan that are designed to reduce CO_2 emissions. International cooperative agreements are also at risk.

Although there is no effective national leadership to mitigate climate change, many state and local governments have made important steps in this direction. California is a leader in this area and has adopted major legislation, and the governor has issued executive orders designed to reduce GHG emissions to 1990 levels by 2020 with further reductions to 80 percent of 1990 levels by 2050.[138] The Oberlin Project, a joint effort by the City of Oberlin and The Oberlin College and Conservatory is one of 18 Clinton Foundation Climate Positive Development Program cities (one of only three in the United States). This commits the city and college to reducing Oberlin's greenhouse gas emissions to below zero. The success of this effort led the Obama administration to select Oberlin as a "Climate Action Champion."[139]

Institutional organizations, such as the EPA, the Department of Agriculture, and others, that can execute climate change policy are hampered by the absence of leadership that acts in the best interests of society. Too many administrators in critical agencies have unresolved conflicts of interest due to ties to the fossil fuel industries.

In spite of climate change leadership deficiencies, stakeholder involvement is substantial, growing, and becoming more vocal. Public opinion concerning climate change, its cause, and its remedies is evolving steadily as evidenced by support for the Green New Deal and the dawn of the Sunrise Movement.

A 2018 survey of registered voters revealed that 74 percent believe that global warming is happening. Of liberal Democrats 98 percent said yes and 85 percent of moderate-conservative Democrats said yes. Somewhat surprisingly similar numbers of self-identified moderate Republicans hold the same position. However, only 42 percent of conservative Republicans think global warming is happening. A majority of survey participants, 62 percent, think human activity is the cause and a similar number, 67 percent are worried about global warming. Thus far, the broadening recognition that climate change is real has not been translated into Congressional action.

Additional educational efforts must be made to encourage office-holders and candidates to embrace the fact that climate change is real as they promulgate laws and regulations to fulfill their responsibility to act in the best interests of all Americans, particularly children and other vulnerable

populations as outlined in NCA4, the IPCC, and peer-reviewed publications, such as the *Lancet* countdown.[2, 7, 8] Healthcare professionals must support proposals, laws, and regulations designed to mitigate and adapt to climate change. It is a part of our professional responsibility to use our medical knowledge to act on behalf of all to combat the numerous adverse health effects of climate change.[3, 4]

Several interactive online tools model the effects of adopting various measures designed to reduce CO_2 emissions. To see the effect on U.S. emissions created by a carbon tax modeled after British Columbia's, requiring all utilities to produce electricity from sources that emit no CO_2, adopting the European Union's legislation to abolish hydroflurocarbons, and other policies, visit the New York Times site (https://nyti.ms/2IeB7Qy, February 21, 2019). More complex modeling is possible at the Energy Innovation site (https://us.energypolicy.solutions/scenarios/home#, February 21, 2019). The models show that solving the climate change crisis will not be easy.

It is critical to support the research, development, and spread of the technology needed to mitigate climate change. Much of this technology is already available, but there is a desperate need for improvements in areas such better photovoltaic cells, mechanisms to remove carbon dioxide from the atmosphere, and others. The half-times for environmental CO_2 make the effects of present-day emissions persist for centuries or millennia.[140]

The fourth goal of *Lancet* Countdown authors is to ensure "a widespread understanding of climate change as a central public health issue [which will] be crucial in delivering an accelerated response ... to this challenge."[2] PSR is moving as rapidly as possible to meet the *Lancet* challenge as a part of our scientific and educational missions.

Healthcare professionals use the best tools possible to make informed decisions. We base our clinical practices on the principles of evidence-based medicine. We employ decision-making tools that recognize barriers. Toward those ends, the present report makes extensive use of peer-reviewed literature and data that are as free from bias as possible. We join the climate scientists and agree that climate change is real - there is no alternative fact. We just call it an emergency.

At the COP-24 conference in Katowice, Poland, David Attenborough, the renowned English broadcaster and naturalist, said "If we don't take action, the collapse of our civilizations and the extinction of much of the natural world is on the horizon."[5] Our professional responsibility demands that we must meet his challenge. Everything depends on it.

GLOSSARY AND ABBREVIATIONS

CDC: Centers for Disease Control and Prevention

Clathrates: water-based crystalline solids that resemble ice that trap non-polar molecules such as methane

COP-24: popular name for Conference of the Parties to the United Nations Framework Convention on Climate Change in Katowice

EGU: electrical generating units, often burning fossil fuels

ENSO: El Niño and the Southern Oscillation, a periodic fluctuation in the sea surface temperature and winds over the tropical eastern Pacific. The warming phase is known as El Niño and the cooling phase is known as La Niña. The Southern Oscillation is the atmospheric component that accompanies sea surface temperature changes. ENSO variations affect world-wide weather patterns and have been linked to civil conflict probabilities.

EPA: United States Environmental Protection Agency

FAR: fraction of attributable risk, a statistical technique used to attribute specific weather events to climate change

FEMA: Federal Emergency Management Agency, a branch of the US Department of Homeland Security

GHG: greenhouse gas, gases that trap solar heat, primarily carbon dioxide, methane, nitrous oxide, and chloroflurocarbons

GMSL: global mean sea level, the average height of all of the earth's oceans, now measured with satellites and operationally defined as a time series plots that are the area-weighted mean of all of the sea surface height anomalies measured by the satellite altimeter in a single, 10-day satellite track repeat cycle (time for the satellite to begin repeating the same surface track). It uses the center of the earth as the reference point.

HI: heat index, a measure of how hot it really feels when relative humidity is factored in with the actual air temperature.

IPCC: Intergovernmental Panel on Climate Change

LED: light emitting diode

MCS: mesoscale convective storms (basically a collection of thunderstorms bigger than an individual thunderstorm but smaller than tropical cyclone)

MHHW, defined by NOAA as the average of the higher high water height of each tidal day

NAAQS: National Ambient Air Quality Standards - set by the EPA for six criteria air pollutants, revised periodically

NCA4: Fourth National Climate Assessment, Volume II Impacts Risks, and Adaptation in the United States - NCA3 is the third National Climate Assessment

NOAA: National Oceanographic and Atmospheric Administration, a branch of the US Department of Commerce

$PM_{2.5}$: Particulate matter with an aerodynamic diameter of 2.5 microns

precipitation event - heavy: An episode of abnormally high rain or snow. The definition of "extreme" is a statistical concept that varies depending on location, season and length of the historical record.

RCP: Representative Concentration Pathway(s): A series of possible radiative forcing (the change in energy flux caused by a driver of climate change) scenarios relative to pre-industrial levels (measured in Watts/m^2), composed of numerous factors with emphasis on greenhouse gas emissions. RCP2.6 = severe prompt reductions in emissions, RCP4.5 = moderate reduction in emissions, RCP8.5 = business as usual [91] See also Text Box 1 in the Heat section.

RSL: regional sea level, the height of the ocean at a given point relative to an adjacent land mass. This is measured with a tide gauge and is highly dependant on whether the land mass is rising (e.g. due to relief of pressure from ice melting from prior glacier) or subsiding, due to extraction of gas, oil, water, etc.

Services, particularly ecosystem services: benefits received from ecosystems that function properly. These are grouped into four categories - *provisioning*, such as the production of food and water; *regulating*, such as the control of climate and disease; *supporting*, such as nutrient cycles and oxygen production; and *cultural*, such as spiritual and recreational benefits

VOC: volatile organic compounds are organic compounds with a high vapor pressure at room temperature. They may be produced by human activity, e.g. gasoline, paint thinner, and even emissions from office printers, or as the result of natural activity, such as the terpenes produced by trees or by a combination of both, such as wildfires.[19]

WHO: World Health Organization

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The next page was designed to be a handout for use at a meeting or other event.

PSR PHYSICIANS FOR SOCIAL RESPONSIBILITY

1985 NOBEL PEACE PRIZE

U.S. AFFILIATE OF INTERNATIONAL PHYSICIANS FOR THE PREVENTION OF NUCLEAR WAR

Climate change affects the health of all Americans - right now. There are no exceptions. Although adaptation will reduce risks for all, only prompt, significant reductions in greenhouse gas emissions will stave off a crescendoing public health emergency. Children, the elderly, and those with pre-existing conditions or who are socially the most vulnerable will be the most susceptible to the ravages of climate change. Our on-line report is our response:

HEAT, FIRE, WATER: How Climate Change Has Created a Public Health Emergency

HEAT The earth is hotter now than at any time since the beginning of the industrial revolution. Each year brings new records. There is no clear end to the warming that is under way. Adaptation is a needed and proven lifesaver.

- Heat illnesses were the leading cause of weather-related deaths between 1988 and 2017.
- The 1995 Chicago heat wave killed around 740 and 70,000 died in the 2003 European heat wave.
- More numerous and more severe heat waves are inevitable.
- By 2100 there will be between 2 and 3 times as many days when temperatures are over 95°F.
- Parts of the earth will become uninhabitable.
- Plants are damaged by heat - yields of corn and other crops may fall 80 percent by 2100. Soaring prices, famine, food riots, civil unrest, and large refugee populations are likely. Things will be worse in El Niño years.

FIRE Over 73,000 wildfires occur in the U.S. annually, a number that has been relatively constant for 30 years. But since 2000 about 6.9 million acres have burned annually, double the area consumed in the 1990s.

- 85% of wildfires are caused by human activity exacerbated by drought and pests - effects of climate change.
- Immediate fire effects include deaths, injuries, and property damage. Paradise, California, was obliterated.
- Wildfire locations become hazardous waste sites.
- Downwind air pollution triggers asthma, COPD, heart attacks, and strokes, and increases long-term cancer risks.
- West-coast fires led to increases in ozone on the East Coast that exceeded EPA standards.
- Worldwide wildfires cause over 300,000 annual deaths, a toll highest during El Niño years.

WATER Sea levels are rising faster than expected, storms are more violent, floods and droughts affect millions, as warm moist weather fosters the spread of vectors of tropical diseases.

- Hurricane Harvey dumped 50 inches of rain on Houston, Texas, Maria ravaged Puerto Rico, worse is ahead.
- High sea levels and storms combined to yield storm surges that flooded NY City during Superstorm Sandy.
- After Sandy FEMA paid $1.4 billion 179,016 individuals and households in New Jersey and New York.
- A 0.9 m sea level rise will displace 4.2 million Americans, 13 million if oceans rises twice as much.
- Some island nations will disappear completely.

REGIONAL EFFECTS U.S. regions will experience toxins from algal blooms, more ragweed pollen, Zika, West Nile Fever, dengue, severe thunderstorms with tornadoes, “king tides,” flooding of low-lying coastal areas, intra-state and interstate climate refugees, mud and landslides, saltwater intrusions on water supplies, the loss of water for irrigation and/or drinking as glaciers, rivers, and aquifers dry up, and much more.

1.5°C IS CRUCIAL The Intergovernmental Panel on Climate Change wrote that limiting global warming to 1.5°C “is projected to lower the impacts on terrestrial, freshwater, and coastal ecosystems and retain more of their services to humans” including health. “Rapid and far-reaching transitions ... unprecedented in terms of scale ...” are required.

PREVENTION IS IMPERATIVE Prevention is a fundamental precept of medicine. We must mitigate climate change by curtailing greenhouse gas emissions and adapt to change by strengthening the public health infrastructure. This requires political leadership from the top down at federal, state, and local levels and bottom-up activism that demands change. Surveys indicate that this is what the public wants, but so far knowledge has not been an adequate stimulus to act. This must change. Healthcare providers have a professional responsibility to use our medical knowledge to deal with this growing healthcare emergency. We may not get another chance.