Estimated Global Mortality from Present to 2100 from Climate Change

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Abstract

Introduction. Climate change mortality emanates from increased heat, air pollution, extreme weather/damage to coastal cities, coral death and loss of fisheries, and food insecurity/population growth and migration.

Methods. The purpose of this paper is to propose estimates of mortality 2018-2100 with the objective to increase observations in order to develop methodology to accurately predict climate change mortality.

Results. The past three years have broken records for global warming due to continued release of greenhouse gases. CO_2 is the primary driver, and is a long-lived greenhouse gas with one-third remaining in the atmosphere after a century of its original release. The Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway 2.6 estimated mortality is 13.5 million versus 106.5 million for RCP 8.5.

Conclusion. Business-as-usual with continued release of 40 billion tons of CO_2 may increase global mean temperature by 4.8±4 °C increasing mortality to 2 million deaths/year for the period 2050-2100 from the WHO estimate of 250,000/year 2030-2050.

Introduction.

Global warming became a term to describe the global greenhouse effect following Dr. James Hansen's testimony June 23, 1988, before the U.S. Senate; he raised such alarm that "Climate Change" was subsequently used which also broadened the scope of ecological concern (Hansen 2013). The concepts of a greenhouse effect from anthropogenic CO_2 release were recognized by Svante Arrhenius in 1896. Measurements of CO_2 and global temperature from many sources led to substantiation of the theory, and by the end of the 1990s, climate change gained traction because every year reached record highs for mean global temperature (Rom 2014). The last three years 2014, 2015, and 2016 broke the global temperature record each year (Karl 2015). With an increase of global mean temperature of 1 °C from the first 500-600 gigatons of CO_2 released, there is a carbon budget of 150-1050 Gt remaining to keep from exceeding the 1.5° C target global temperature increase agreed to by the 195 nations signing the Paris Climate Agreement in 2015. The World Health Organization has estimated global mortality from climate change to be 150,000 deaths/year increasing to 250,000 deaths/year by 2030 (Hales 2014). The purpose of this Commentary is to estimate global mortality due to climate change from the present to 2100 using the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP) of 2.6 Watts/cm^2 versus Business-as Usual RCP of 8.5 Watts/cm^2(Brown 2014, Hansen 2016). There currently is no methodology for accurately projecting mortality, and this Commentary hopefully will encourage development of biostatistical and computational methods. Currently estimates vary widely, e.g. Hurricane Maria officially caused 64 deaths in Puerto Rico although news reports estimate 1,052 deaths.

Moreover, dengue, spread by *Aedes aegypti* mosquitoes whose range is expected to increase dramatically 2050-2100 due to a warmer and wetter mid-latitudes, has been estimated to cause 12,500 deaths annually (Liu-Helmersson 2014). In forecasting the future, attribution of health effects due to climate change will increase as temperature and humidity also increase.

The Physical Science of Global Warming.

The amount of CO_2 in Earth's atmosphere has been chronicled by the Keeling curve representing data collected from the summit of Mauna Loa in Hawaii since 1959, the International Geophysical Year (Rom 2014). In 1959 the level was approximately 310 ppm; this level was higher compared to the 250 ppm measured in bubbles in ice cores from Greenland or Antarctica, and going back 400,000 to 800,000 years (Luthi 2008). From 1959 to 2016 the atmospheric CO_2 has increased from 310 to 400 ppm (~43%). Importantly, the annual rise or rate of increase has jumped from less than 2 ppm to more than 3 ppm (over the past two years) (Zeebe 2016). CO_2 forms a greenhouse gas layer around the earth that allows sunlight to pass through, and then reflects infrared radiation back to the surface of the earth causing surface heating. Methane, CH_4, is approximately 22 times more potent as a greenhouse gas than CO_2, and may be 80 times more potent over a 20-year time frame (Montzka 2011). CH_4 in parts per billion is emitted from landfills, fracking, conventional natural gas, and oil wells, leaks in pipelines, wetlands, emissions from livestock, and melting permafrost. Additionally, there are other strong greenhouse gases, e.g. nitrous oxide emitted from rice fields and fertilizers. Carbon black is emitted by diesel engines and biomass cooking in developing countries. Several gases used as refrigerants and in air conditioners such as hydrofluorocarbons, have a global warming potential up to 2000 times that of CO_2 (Molina 2009). The source of carbon pollution is anthropogenic: oil used in industry and transportation, natural gas and coal used in electricity generation and steel manufacture, cement production, and buildings in cities (IPPC 2014). The increase in the anthropogenic greenhouse gas releases primarily occurred over the past 50 years, and parallels the increase in CO_2 measurements, i.e. the Earth is out of energy balance (Karl 2009, USGCRP 2014). Importantly, CO_2 pollution is different from other air pollutants while particulate matter or ozone varies by hour or day or season, CO_2 is persistent and cumulative (Driscoll 2015). After 100 years, 33% remains in the atmosphere, and after a millennia, 20% remains (Solomon 2009). CO_2 is part of the carbon cycle with major sinks in the oceans and soil. The world's forests remove CO_2 from the atmosphere in the process of photosynthesis and the Earth's energy balance is further upset by deforestation (Levinson 2014).

The amount of carbon dioxide emissions we can emit while still having a likely chance of limiting global temperature to 2° C above pre-industrial levels after 565 Gigatons (Gt) already released is 150-790 Gt more (McKibben 2012). At global annual emissions of ~40 Gt CO_2 we will exhaust the carbon budget in 3-22 years for stabilization at 2° C. In the IPCC Representative Concentration Pathway (RCP) 8.5 (Business-as-Usual) CO_2 emissions approximately double by 2050 and increase by three-fold by 2100 with corresponding increases in CO_2 beyond 900 ppm and global temperature increase of as much as 4.8±4° C (Brown 2017). Unknown in this scenario would be release of CO_2 and methane from permafrost thawing across the tundra regions of Canada, Russia, and Alaska, and de-stabilization of Antarctic and Greenland glaciers.

The purpose of this paper is to encourage methodologies to accurately forecast future mortality from various scenarios of global heating and the five topics contributing to mortality outlined below. The temperatures at the end of this period (2080-2100) will be outside the range most living species have ever experienced (Moritz 2013). Mortality under RCP 8.5 is predicted to increase after 2050 to 2 million deaths/year (an 8-fold increase) and persist at least at that level through 2100 (cumulative 106.5 million deaths) due to global heating compared to 13.5 million (250,000 deaths/year) under RCP 2.6 (Watts 2015, 2017). The five topical areas that will feature climate-related mortality are discussed below (Watts 2015, Watts 2017, Whitmee 2015).

Heat waves may contribute approximately 10% to the 2050-2100 RCP 8.5 mortality (Gasparini 2015). Heat waves will increase in frequency from once per 500 years to annual events with wide regional differences. In 2003 there was a heat wave in France where temperatures exceeded the norm by 11-12° C for 9 consecutive days. There were 15,000 deaths in France; 32,000 in western Europe, and 70,000 across Europe during this period (Fouillet 2006). These increases illustrate how climate change mortality will impact large geographic areas. Mortality was age-related and was 45% higher in women than in men >45 years. Mortality was increased in widowed, single and divorced people, and lack of air conditioning was a major cause.

A significant increase in deaths was related to heatstroke, hyperthermia, and dehydration; heart failure, chronic respiratory diseases and stroke were markedly increased, and psychiatric disorders, especially depression increased (Hales 2014). More recently heat waves have been recorded in Moscow (associated with wild fires) and New Delhi (Mazdiyasni 2017). Using a probabilistic model, an increase of mean temperatures over India of 0.5 °C corresponded to a 146% increase in the probability of heat-related mortality events of more than 100 people (Mazdiyasni 2017). There are heat islands surrounding urban areas from the black asphalt pavement, buildings, and lack of green space (Greene 2011). During heat waves, there is a lack of cooling at night since the heat does not dissipate. Heat waves are accompanied by dry periods leading to a lack of moisture in neighboring forests and bushlands. These can easily catch fire from humans or lightning strikes causing extensive smoke. In the United States, the western fire season has been extended 78 days since 1970, and the average duration of fires has increased five-fold. Epidemiological studies have shown that an increase of 10 $\mu g/m^3$ in PM_{10} from wildfires results in approximately 1% increase in non-accidental mortality (Whitmee 2015). During Australian brushfires overall mortality rose 5%, and hospital admissions for respiratory illnesses increased from 3-5% (Johnston 2011). New South Wales in Australia had a brutal heat wave in the summer of 2017 with temperatures reaching 113° F; World Weather Attribution found these maximum temperatures were 10 times more likely compared to a century ago before anthropogenic global heating (Whitmee 2015). In addition to heat waves, global heating will increase mortality for certain diseases including arthropod-borne diseases as the mosquito range increases for dengue, malaria, zika, yellow fever, and chikungunya; water-borne illnesses due to vibrio, cryptosporidia; and rodent–borne diseases including lyme disease (Rom 2014). In addition, heat has an adverse effect on pregnancy outcomes (Watts 2017). More recently, heat related mortality occurs apart from heat waves due to lack of adaptation to increasing temperatures (O'Neill 2005, Watts 2017). An estimated 125 million additional vulnerable adults were exposed to heat waves between 2000 and 2016 (Watts 2017).

Mora and colleagues described in "Global risk of deadly heat," that one-third of the world's population is currently exposed to a deadly combination of surface temperature exceeding 95 °F and relative humidity for at least 20 days a year (Mora 2017). This will increase in 2100 to 74%, and even under RCP 2.6 will reach 48%. New York City could reach 50 days in the summer, but cities like Jakarta where their consistently warm temperatures would be near the deadly threshold year-around (Coffel 2017). Both ageing of the population and increasing urbanization could aggravate vulnerability to heat. Coffel and colleagues estimated that half of the world's population would be exposed to wet bulb temperatures that approach and exceed limits of human tolerability; under RCP 8.5 exposure to wet bulb temperatures above 35° C could exceed a million person-days per year by 2080 (Coffel 2017).

2). Air pollution may result in 20% of increased mortality although 7 million deaths/year are attributed from air pollution now (Doherty 2009, Balbus 2016). Currently the Global Burden of Disease estimates 3.5 million deaths/year from outdoor air pollution primarily due to cardiac and respiratory conditions and lung cancer (Hoek 2013, Lelieveld 2015). Another 3.5 million deaths/year occur from indoor air pollution due to biomass cooking (charcoal, dung, coal, wood) affecting primarily women (chronic obstructive pulmonary disease and lung cancer) and children (respiratory bronchiolitis and pneumonia) (Rice 2014). There is overlap between climate change health effects and air pollution health effects with co-benefits accruing from decreases in coal combustion and increased market penetration of renewable energy and electric vehicles (Berman 2012, West 2013, Garcia-Menendez 2015). Black carbon from diesel engines and biomass cooking is a short-lived global heating contributor. The Global Alliance for Clean Cookstoves has a target of 100 million clean cookstoves by 2020. Air pollution should decline 2050-2100 due to phase-out of coal combustion, introduction of electric vehicles, and clean cookstoves (Cromar 2016).

3). Droughts and heat effects on agriculture may cause 40% of the RCP 8.5 mortality 2050-2100 (Ebi 2016, Patz 2014, Egan 2016). The increased heat will cause severe droughts in certain areas, e.g. United States Southwest and California, whereas other areas will experience an increase in precipitation. Temperature has a variable effect on different crop species but higher temperatures will cause yield declines between 2.5% and 10% across a number of agronomic species; extreme high temperatures during the reproductive stage will affect pollen viability, fertilization, and grain or fruit formation (Hatfield 2015). Wheat, corn, and cotton yields have statistical declines between 63% to 70% for high CO_2 emission scenarios (before accounting for positive effects of rising atmospheric CO_2 on crop growth). The global population of 7.3 billion at present will grow to 9.3 billion by 2050 and 11.2 billion by 2100 with a corresponding demand for more food (McMichael 2013).

Higher minimum temperatures reduce grain yield of rice, and extreme maximum temperatures could also reduce rice yield (Hatfield 2015). Heat stress of 4 °C above optimum could lead to crop failure. Under global heating, perennial crops may not have enough hours of cooling to produce fruits, nuts, grapes, etc. requiring innovative strategies for genetic selection and tree and vine growth beyond 2050. Temperature effects interact with soil water status to increase the negative effects on grain production. The greatest risk for drought and food scarcity will be in Africa's Sahel, Ethiopia and Sudan, the Middle East, south and east Asia especially India, China, Russia and Central and South America (Park 2018). The Asian Development Bank estimates a 4.6°C rise in global temperature in 2100 with an 8.8% loss in annual domestic gross domestic product in 6 countries of South Asia including India.

4). Loss of coastal coral reefs due to global heating may result in a surprising 10% increase in mortality in coastal communities due to dependence on fish and marine life for sustenance that will dramatically decline (Anthony 2008). Global heating will also result in reductions of other fisheries such as cod off the Maine coast (Pershing 2015). Although 0.1% of the oceans are populated by coral reefs, these ecosystems are responsible for over one-third of fish reproduction. For example, 357 million people live in the Philippines and Indonesia, and 40% of them live in coastal communities that are dependent on the ocean for means of sustenance. Their coral reefs are all under heat stress with only 1% of Philippine reefs in pristine condition. The median return time between pairs of severe bleaching events has diminished steadily since 1980 globally, and is now only 6 years (Hughes 2018). Shortening the coral bleaching recovery time increases likelihood of coral death. 39% of the 40 million Filipinos living on the coasts live in poverty and 36% are reported to be food insecure. The Coral Triangle (Indonesia, Malaysia, East Timor, Philippines, Solomon Islands) encompasses 130 million people and their food, income, and livelihood depend on the coral reefs and fisheries (McIver 2016). They provide 11.3% of global fisheries' productivity and the Melanesian fisheries are worth $7 billion USD. The Food and Agriculture Organization of the United Nations estimates that climate-related natural disasters doubled over the period 2003-2013 compared to the 1980s causing an estimated $1.5 trillion USD in economic damages and leaving many vulnerable populations in developing countries exposed to >50% food insecurity.

5). Storms, typhoons, hurricanes, flooding and weather-related events may result in the remaining 20% mortality (Grinsted 2013, Fisher 2015, Stott 2016). Hurricane Sandy in 2012 caused $60 billion USD in losses, 117 deaths (40 from drowning), and flooded much of lower Manhattan in New York City with a 14-foot storm surge (MMWR 2012, Rom 2013). Hurricanes may increase in intensity, and by 2050 will have increased in frequency, such that a Hurricane Katrina-like event could happen every two years. Hurricane Katrina caused over 1,800 deaths and over $100 billion USD in damage. Typhoon Haiyan was the deadliest Philippine typhoon on record, killing 6,340 people with 1,061 missing. Haiyan was also the strongest storm recorded at landfall in November 2013 with 1-minute sustained winds reaching 315 km/h (195 mph). Over 11 million people were left homeless in the Philippines (National Academy of Sciences, Engineering and Medicine 2016). Global heating will increase evaporation and cloud formation leading to heavy rainfall and rapid flooding in certain regions of the world (Taylor 2017). Mortality is difficult to estimate from hurricanes, e.g. Hurricane Maria's estimates ranging from 64 to 1,052 in Puerto Rico are still being investigated months later. Coastal flooding will increase due to ocean rise, and high tides will exacerbate coastal damage to homes, infrastructure and cities. Morabia and Benjamin described a new public health priority of rebuilding after climate change-related natural disasters, e.g. from three >$1 billion USD natural disasters in 1980 to seventeen in 2017 totaling $306 billion USD (Morabia 2018). The global mean sea level rise has increased from 2.2 mm/year in 1993 to 3.3 mm/year in 2014 as measured by satellite altimetry (Chen 2017). Sea level rise may exceed 2 meters in the RCP 8.5 scenario (DeConto 2016, Koppo 2014). Importantly, this is an issue of environmental justice since the mortality will fall disproportionately upon the poor, elderly, children, women, in low-income countries across Africa, South and East Asia, and South and Central America. Efforts at coastal and housing adaptation can mitigate storm-related mortality in the future as well.

Policy Implications of Climate Change Mortality.

Achieving an 80% reduction in CO_2 emissions by 2050 (RCP 2.6) would require three strategies:

1). *Transitioning to a low-carbon energy system*. This requires an increase in energy efficiency of buildings, appliances, more light-emitting diode (LEDs) in lighting, and conversion to electric vehicles. It is essential to decarbonize electricity by moving to ~55% wind and solar, 17% nuclear, 20% natural gas with carbon capture and storage, and 8% hydroelectric (The White House 2016). Electricity storage in large lithium battery facilities or other technologies, a demand response of the grid, and direct current high voltage transmission for renewable energy will be necessary.

2). *Sequestering carbon through forests and soils and CO_2 removal technologies*. There would be a need for at least a 50 million acres of forest expansion (U.S. alone and more elsewhere), and research to increase soil mass and depth of commodity crops (The White House 2016).

3). *There is a need for a policy to reduce non-CO_2 emissions which contribute ~20% of global heating, e.g. methane, nitrous oxide, and hydrofluorocarbons* (Pacala 2004).

An example was published by MacDonald and colleagues using a model of U.S. electricity generating capacity to achieve a 78% reduction of CO_2 emissions relative to 1990 and building renewable energy primarily wind and solar PV plants (MacDonald 2016). It included 523 gigawatts (GW) of wind (22 MW offshore), 371 GW of solar PV, 461 GW of nuclear, and 74 GW of hydroelectric with the remaining natural gas for a total of 1,529 GW of installed capacity. Their model focused on weather where wind blows on the U.S. Great Plains and the sun shines in the Southwest, with High Voltage Direct Current transmission lines transporting power to markets via 32 nodes. Their model predicted a growth of wind by a factor of eight and solar PV by a factor of 62. Although they did not discuss offshore wind, wind turbines there could be larger (6 MW) reducing the number needed by half, and can offer 33% more power due to more frequent and stronger wind over the sea. In addition, offshore wind is close to major coastal cities, and transport is less likely over private land (Jacobson 2016).

In summary, global heating is upon us, and an estimate of 106.5 million people may perish globally between 2018 and 2100 under the RCP 8.5 scenario compared to 13.5 million with the RCP 2.6 scenario (Markandya 2009). The period 2018-2050 is critical to advance towards a global clean energy revolution (Patz 2014, Rom 2008, Horton 2009, Millar 2017, Watts 2015, 2017).

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