RIGHT HERE, RIGHT NOW

How Climate Change Impacts Us Today

climatenexus

Climate change is no longer a distant threat. We are living with the reality of it, right here and right now. The impacts of climate disruption in the United States and around the world are clear, costly and widespread. Human action can reduce the toll of climate change, but every year of delay means higher costs and impacts. Some of the impacts include:

- Intense wildfires
- flooded coastlines
- extreme heat waves
- growing threats to human health

The Cost of Climate Change

Weather catastrophes in the United States have incurred a cost of over $1 trillion in damages over the past 30 years. [1] Climate disruption has driven up food prices[2] increased the risk of West Nile outbreaks across the U.S., and helped fuel wildfires that caused over $1 billion in damages in 2013.

Our seas are now 30 percent more acidic[3] due to the carbon pollution taken up by the oceans. Global warming drives up sea levels, increasing the reach of storm surges and amplifying disasters such as Typhoon Haiyan, which devastated parts of the Philippines in the fall of 2013. Arctic sea ice is retreating[4], a change that may be altering global weather patterns and bringing harsh winter storms south[5] to the United States. Permafrost is melting[6] due to warming, which could trigger climate feedbacks that further worsen warming.

As our understanding of specific impacts improves, we are better equipped to “connect the dots” and recognize that we are living in a rapidly changing climate.

Climate Change Overview

As science has long predicted, climate change is bringing damage and disruption to ecosystems, infrastructure and society across the United States and the world:

- **Ice**: Dramatic changes are occurring in the mass and extent of Arctic sea ice, Greenland and Antarctic ice sheets, glaciers, permafrost, and snow cover worldwide. The melting of snow and ice contribute to sea level rise, affect global weather formation, influence water supply and crop production, and introduce issues for infrastructure and international relations. They also serve as useful scientific indicators of the ongoing reality of warming.

- **SLR:** Sea level rise is accelerating, posing risks to coastal cities. Storm surges boosted by higher seas are causing unprecedented damages, and seawater is now found in the drinking water in some cities. Melting ice sheets and glaciers contribute to sea level rise, as well as thermal expansion caused by warming oceans.

- **Ocean Acidification**: Oceans are becoming more acidic as they absorb excess carbon dioxide from the atmosphere. In more acidic waters, it is difficult for hard-shelled organisms like corals, oysters, and other shellfish to construct their shells. The impacts of this change have already been felt by the oyster industry, and are projected to become much more severe. This puts entire marine ecosystems at risk.

- **Seasons**: The timing of seasonal events is shifting in response to warming temperatures. Spring arrives earlier, and winter comes later. Plant and animal activities like flowering and migrations are changing as well, in some cases being thrown out of sync with one another. One vivid example of how season creep can create “threshold effects” is how bark beetle infestations across the West that have decimated old-growth forests, Other examples, such as a ski industry threatened by shorter winters, illustrate how climate change threatens the businesses and activities that anchor the U.S. economy.

- **Extreme Weather**: Many types of extreme weather are increasing in frequency and severity due to climate change. Different types of extreme weather are connected to warming temperatures through different pathways. Worsened by climate change, extreme weather has the power to produce cascading impacts through human society, including impacts to food security, health, and the economy.

- **Food**: Droughts, heat waves, and extreme precipitation are influencing crop production, leading to spikes in food prices and disruptions in food supply. Damage to transportation systems and spikes in fuel prices also impact food prices and availability. As climate change continues, it is projected to reduce crop yields and shift the regions in which crops can be grown.

- **Health**: Climate change is already impacting human illness patterns and exposure risks. Outbreaks of West Nile virus correlate with higher temperatures, for instance, and heat waves are the number one weather-related cause of death. Warmer temperatures can also increase the incidences of food and water-borne illnesses.

- **Infrastructure**: Climate change is disrupting the physical foundations of modern society. Heat waves cripple utilities' cooling systems, droughts reduce essential hydroelectric generating capacity, and storm surges devastate public transportation systems and road networks. The range of systems threatened by climate disruption encompasses transit and transportation, the electric grid, the public health network, emergency response, and water and sewage systems.

- **Military and Security:** Top officials are increasingly recognizing climate change as a national security issue. Newly opened Arctic seas have caused international tension over shipping and drilling rights. In addition, food and water insecurity can exacerbate political unrest in vulnerable nations. In high-warming future scenarios, mass migrations are projected to occur as some regions become uninhabitable.

Ice Sheets, Glaciers, and the Cryosphere

Arctic Sea Ice

Research shows that before the 20th century's influx of greenhouse gases, the Arctic was in a 2,000-year cooling trend (Kaufman et al. 2009), but that trend has reversed. In fact, due to interactions between global warming and feedback unique to the Arctic, the region has been warming at double the rate of the rest of the globe, and its ice is disappearing (Blunden et al. 2013).

Ice thickness in the Arctic has declined 50 percent since 1980, and September minimum ice extent has plummeted as well, at a rate of 14 percent per decade relative to the 1981-2010 average (Perovich et al. 2013). In fact, the rate of ice retreat is accelerating at a pace that exceeds most models' forecasts (Stroeve et al. 2007).

In 2012, the ice extent reached an all-time record low, at 50 percent of the historic average. The area of missing ice was equivalent in size to 43 percent of the contiguous United States (Perovich et al. 2012). While sea ice recovered a bit in 2013 (leading to spurious claims of global cooling), NASA's Walt Meier explains how this small recovery is normal and expected. "In our satellite data, the Arctic sea ice has never set record low minimums in consecutive years." 2013's Arctic sea ice extent was still the sixth lowest on record (Perovich et al. 2013).

The average age of Arctic ice has been falling as well. In 1988, 26 percent of ice was four years old or older, compared to just 7 percent in 2013 (Perovich et al. 2013). And the Arctic melt season has lengthened at a rate of five days per decade from 1979 to 2013 (Stroeve et al. 2014).

Ice melt has impaired many important functions the Arctic performs in our climate. Arctic sea ice serves as the planet's air conditioner, moderating solar heating by increasing the reflectivity of Earth's surface and decreasing the amount of heat that would otherwise be absorbed by ice-free Arctic seas. The loss of the air-conditioner effect, as sea ice disappears, creates a feedback loop that accelerates global warming (Bintanja and Linden 2012; NCA Chpt 22, p. 763).

Changes in the Arctic, especially sea ice loss, may also be affecting weather patterns in the United States. The loss of Arctic summer sea ice and the rapid warming of the area alter the jet stream, which changes the movement of weather patterns over North America, Europe and Russia. These changes may increase the likelihood of extreme weather in mid-latitudes and drive winter storms south (Francis and Vavrus 2012; Lui et al. 2012).

Through this jet stream alteration, Arctic sea ice melt was found to increase the likelihood of cold winter extremes in the northern hemisphere (Tang et al. 2013). It may also have influenced Superstorm Sandy's path, keeping it where it could do the most damage.

If heat-trapping pollution continues, summer sea ice will be lost entirely. The climate models that most accurately simulate past sea ice trends suggest this will probably happen within 22 years, possibly as soon as eight years (Kerr 2012; NCA Chpt 22, p. 762).

Greenland Ice Sheet

The ice sheet that covers Greenland is one of the largest bodies of fresh water on the planet.

The surface of the Greenland ice sheet has experienced summer melting over increasingly large areas during the past several decades. Research shows that decrease in surface albedo, an indicator of melting, is accelerating (He et al. 2013). During the 2000s, the normal daily melt area was double the typical melt area during the 1970s (Mernild et al. 2011), and in 2012 a new daily record of 98.6 percent melt area was set (Nghiem et al. 2012).

Melt season has lengthened as well. The melting period now lasts 70 days longer than in 1972, according to simulated temperature reconstructions (Mernild et al. 2011).

All of these factors increase Greenland's contribution to sea level rise. Between 1992 and 2011, the Greenland ice sheet lost 142 gigatons of mass per year. This melt, combined with Antarctica's contribution, has raised global sea levels about half an inch since 1992 (Shepherd et al. 2012).

One additional way we know that Greenland is losing ice mass comes from the island's elevation. The massive weight of Greenland's ice sheet physically pushes the island down into the ocean. As the ice sheet melts and the weight decreases, the island rises in response. In recent years, so much ice has melted so quickly that the rate of Greenland's rising has accelerated since the 1990s (Jiang et al. 2010).

Projections of future sea level rise show significant uncertainty, and part of this is due to lack of knowledge about the ice sheets and their behavior. Some scientists posit that ice sheets may exhibit "tipping points" where enough melt triggers an irreversible collapse (Ridley et al. 2010). This critical threshold may be as low as 1.6ºC over preindustrial temperatures (Robinson et al. 2012), and collapse could be quite sudden based on reconstructions of past ice sheet response to temperature change (Deschamps et al. 2012). If the entire Greenland ice sheet melted, global sea levels would rise by more than 20 feet.

Antarctica Ice Sheet

In the face of climate change, Antarctica presents a more complex picture than its counterpart in the Arctic.

Continent-wide, Antarctica has shown a positive warming trend over the last 50 years (Steig et al. 2009). The Antarctic Peninsula on the west side of the continent is one of the most rapidly warming areas on the planet, with over 2ºC of temperature increase between 1958 and 2010 (Bromwich et al. 2013). New research shows that melting from below is causing the continent's ice shelves to grow thinner, some at a rate of up to seven meters per year (Pritchard 2012). This can lead to ice sheet collapse, and the acceleration of land ice loss.

The summer melting of the Antarctic Peninsula is currently greater than at any time over at least the last 1,000 years (Abram et al. 2013), and the net mass balance of the continent as a whole is negative. Antarctica is losing ice at an accelerating rate of over 246 billion tons per year (Velicogn 2009). This means Antarctica is contributing to sea level rise (Allison et al. 2009; Shephard et al. 2012). Melting of the Antarctic and Greenland ice sheets alone was responsible for about a half inch of sea level rise since 1992 (Shephard et al. 2012).

However, not every region has responded in the same way. East Antarctica and the continental interior have at times shown cooling trends (Steig et al. 2009). To explain these trends, researchers note that ocean currents deliver heat to the Antarctic Peninsula and coastal regions, implicating warm waters for the Antarctic Peninsula's warming (Li et al. 2014). In the interior and eastern regions, on the other hand, reduced ozone coverage alters air currents, increases winds, and thereby diverts warm air

(Shindell and Schmidt 2004; Thompson and Solomon 2002).

When it comes to sea ice, the story is similarly complicated. In spite of warming temperatures, sea ice extent in some areas of Antarctica has increased (Zhang 2007). Research suggests this is due to reduced mixing between warm and cool layers in the ocean that ordinarily speeds the melting of ice (Zhang 2007). The previously mentioned wind patterns induced by ozone depletion may also play a role. And paradoxically, warmer temperatures may be contributing to the increase in snowfall in East Antarctica (Winkelmann et al. 2012).

Still another possible wild card in Antarctic trends is errors in processing data from satellites. One study found that the apparent expansion of East Antarctica sea ice might simply be an error in the data rather than a real trend (Eisenman et al. 2014).

In summary, Antarctica is both warming in temperature and contributing significantly to sea level rise. Some localized areas may be cooling or gaining ice, but they are outliers.

Glaciers, Snow Cover, Lake-ice and Permafrost

As temperatures continue to rise, glaciers are increasingly at risk of melting away. Glaciers in every region have been losing mass at an accelerating rate. According to the IPCC, several hundred glaciers have completely disappeared over the last 30 years (IPCC AR5 WGI Chpt 4). In the period of 2003-2009, there was a global loss of glacier mass amounting to 259 gigatons a year. This melting was responsible for around a third of the observed sea level rise in that period (Gardner et al. 2013).

In the Canadian Arctic Archipelago, ice melt seems to be accelerating, with one study finding that the rate of mass loss tripled in 2007-2009 compared to 2004-2006 (Gardner et al. 2011).

The snow cover extent of the Northern Hemisphere (where the measurement record is most reliable) has decreased over the last 90 years, particularly since the 1970s (Brown and Robinson 2011). The duration of Northern Hemisphere snow season has declined by 5 days per decade between the winters of 1972-73 and 2007-08 (Choi et al. 2010).

Northern Hemisphere lakes have frozen later and ice has broken up earlier over the last 150 years, with the most rapid changes occurring in the past 30 years (Benson et al. 2012).

Permafrost, the layer of ground that stays frozen year-round, has warmed up by an average of 3ºC over the past 30 years as air temperatures have risen and snow cover has decreased (although this is not consistent in all regions). Some regions have seen a complete thaw since 1975, and the southern limit of permafrost has moved north by 80 kilometers (IPCC AR5 WGI Chpt 4, p.320). Permafrost thawing has implications for infrastructure, causing potholes, collapsed hillsides and "drunken trees." It can also accelerate warming through the release of trapped greenhouse gases.

Sea Level Rise

Sea levels have risen by eight to ten inches since they began increasing in the middle of the 19th century. The rise has accelerated, with its rate doubling since 1992 (NCA). These changes stand in stark contrast to the prior 2,000 years, when there was little change (Titus et al. 2009). If emissions go unchecked, we are likely to see a meter of sea level rise by 2100, according to a survey of experts (Horton et al. 2014).

Sea level rise is already impacting coastal communities in the United States. These impacts are occurring through changes in storm surge, tidal flooding and saltwater intrusion into fresh water aquifers. Sea level rise will put more homes and infrastructure at risk from hurricanes, as much as a 230 percent increase in houses at risk by 2100 (Maloney and Preston 2014). During Hurricane Sandy, sea level rise enabled the storm surge to reach an additional 80,000 homes.

While sea level rise may be modest relative to the total height of storm surge or high tides, it can be the straw that breaks the camel's back. Human infrastructure and natural systems have developed to cope with a range of historical extremes, such as 100-year events. New, more intense extremes can overwhelm and collapse existing human systems and structures, crossing thresholds that represent tipping points for greater damages (Peterson et al. 2008). Coastal infrastructure including roads, rail lines, energy infrastructure, and port facilities including naval bases, are at risk from storm surge that is exacerbated by rising sea levels (Steig 2009).

Higher sea levels also destroy the marshes and wetlands that provide coastal areas with an essential buffer from storms and flooding.

Climate change drives sea level rise in two major ways. First. warming expands the volume of water in the oceans, which pushes up sea levels. Second, warming also melts glaciers and ice sheets on land, with the run-off adding to sea levels. Melting sea ice is *not* a significant factor. For instance, consider how ice cubes melting in a glass of water don't raise the water level.

Regional sea levels vary based on regional and local changes in land movement and long-term changes in coastal circulation patterns. Looking forward, the science consensus suggests an upper limit of 6.6 feet of global rise by 2100 should be used for risk analysis (NCA Chpt 2, p.63).

Ocean Acidification

Ocean acidification is driven directly by rising carbon dioxide levels in the atmosphere. It is progressing steadily and measurably, and is already taking a toll on sea life (NCA Chpt 24, p.839). Ocean acidification is like an "evil twin" to global warming in that both stem from carbon pollution. The production of CO_2 emissions from power plants, factories, cars and buildings has already tipped the balance in the oceans around the world.

Acidification poses risks to food resources, related industries and the broad web of relationships between ecosystems. Acidification primarily threatens sea life by making it harder for animals with shells and skeletons (such as corals) to access material to build shells (Pandolfi et al. 2011). Weaker and thinner shells make sea life more vulnerable to predators, disease and death (Kroeker et al. 2010). Scientists believe acidification may worsen the corrosion of marine animal shells and skeletons in the future.

The increase in ocean acidity is indisputable, and the rate and magnitude of the change is unprecedented. Acidification has seen a 30 percent jump since the beginning of the industrial revolution, as reported by the National Academy of Sciences. The rate of change is one of the main reasons scientists are concerned that marine life may not be able to adapt quickly enough to acidification.

Scientists have documented damage from acidification to oyster larvae in the Pacific Northwest (Barton et al. 2012). Acidification is also responsible for poor shell development in sea snails that many whales depend on as a food source (Bednaršek et al. 2012). Both observations confirm scientific expectations of threats from acidification. Coral reefs are not only critical parts of many ocean ecosystems; they are also hotspots for the tourism industry. The scuba diving and snorkeling around the coral reefs of the Florida Keys alone generate more than $1.6 billion annually, an important part of the local economy.

Season Creep

As climate change continues to advance, spring is arriving much sooner, while winters are becoming shorter and milder. This phenomenon has been documented around the world and informally dubbed "season creep."

In the United States, the growing season has lengthened by 10 days in the past 30 years (Barichivich et al. 2013). Many migratory bird species show up earlier. For example, northeastern birds that winter in the southern United States now return to the Northeast an average of 13 days earlier (NCA Chpt 16, p.561). Spring snowmelts have shifted so that peak melt flow now arrives 1-4 weeks earlier. Flowers are blooming earlier, including a week earlier on average for Washington D.C's famous cherry blossoms. Hardwood forests in the Northern Hemisphere are holding their green leaves for over a week longer than normal (Jeong et al. 2011).

Global warming drives season creep (NCA Chpt 2, p.39). Natural variability can, at best, explain only one-third of the rate of "creep" in the arrival of spring (Ault et al. 2011).

Season creep is an example of how small changes can have a big impact. Climate change disrupts the critically important timing of events, such as snow melt and spring bloom, upon which ecosystems and agricultural industries depend (Cleland et al. 2006). For example, warmer winters can lead to early bud-burst or bloom of some perennial plants, resulting in frost damage when cold conditions occur in late spring. This was the case with Michigan cherries in 2012 (NCA Chpt 6, p.235). Maple syrup production requires cold temperatures for strong sap flow and good flavor, and the brevity of recent winters has cost producers.

Finally, season creep impacts biodiversity, with cascading effects on agriculture, tourism, hunting, and fishing. All species do not respond to the change of seasonal cues in the same way. This can lead to mismatches between the availability of flowers and their pollinators or predators and their prey (Kudo et al. 2013). For example, the pied flycatcher now migrates at the wrong time relative to its prey and has experienced a 90 percent population decline (Both et al. 2006). In some cases, these disruptions can enable takeover by invasive species, as witnessed at Thoreau's Walden Pond.

Extreme Weather

Heat Waves

Climate change amplifies the intensity, duration and frequency of heat wave events. Even a small change in average global temperature can lead to a dramatic change in the frequency of extreme events such as heat waves.

Since 1950, the number and duration of heat waves worldwide have increased, as have the frequency of hot days and nights (IPCC AR5 WGI, Table SPM.1) and the level of humidity in the air (Willett et al. 2007). The geographic area hit by extreme summer temperatures has grown by well over ten times in the past 30 years (Hansen et al. 2012).

The influence of human-caused global warming has been firmly identified in all of these trends (IPCC AR5 WGI, Table SPM.1; Willett et al. 2007; Hansen et al. 2012).

Extreme temperatures have an element of probability. Climate change provides baseline warming that raises the bar on what natural variation can produce. For example, one study found that greenhouse gas pollution caused "over half" of the anomalous U.S. warming of 2006 (Hoerling et al. 2007), and another found that Russia's devastating 2010 heat wave was made over five times more likely by climate change (Watanbe et al. 2013). In recent years, new record-breaking high temperatures have outnumbered new record lows in the U.S. by a ratio of about 2:1 (NCA Chpt 2 Fig 2.18, p.53).

Cold Spells

Average global temperatures are rising with global warming. Natural variation means that we will still sometimes see cold spells, but they are becoming less frequent. In some cases, cold spells might be connected to warming if they are associated with weather patterns such as increased "waviness" in the jet stream. Warming of the Arctic may be slowing the jet stream, which enables larger waves to form and allows cold air to move farther south than usual. These large jet stream waves were thought to be involved in the cold weather that covered the Eastern U.S. in early 2014.

Rain and Snow

For rain and snowfall, the trends driven by climate change differ by region. Global warming has changed the geographic pattern of precipitation; some areas are getting drier while others are getting wetter (Fyfe et al. 2012). Mid-latitude areas, such as the U.S. Midwest and Northeast, have experienced an increase in total precipitation. Sub-tropical areas, such as the U.S. Southeast and Southwest, on the other hand, have experienced a sharp decrease. As a result, the risk of both drought and flooding in differing regions of the U.S is increasing (NCA Chpt 2, p.26). Some sub-tropical areas, such as Texas, have not witnessed clear changes in long-term precipitation trends.

Climate change has also increased the intensity of heavy precipitation events (Min et al. 2011; Zhang et al. 2013). Even areas that see less precipitation overall, like the Southwest, have experienced this trend of concentrated (NCA Chpt 2 Fig 2.16, p.50).

Since 1958, every region of the United States has witnessed an increase in the amount of precipitation falling in the heaviest downpours. The increase is highest in the Northeast and Midwest, which have respectively seen a 74 percent and 45 percent rise (NCA Chpt 2 Fig 2.16, p.50). The trend is made possible by the ability of a warmer atmosphere to hold more moisture (Trenberth 2011).

Heavier snowfalls are also consistent with climate change. Many people hear the words "more snow" and instinctively think of colder temperatures, but the two are not necessarily connected. Relatively warm, just-below-freezing winter temperatures are favorable for heavy snowfalls. The U.S. actually tends to get more snow in warmer years, and the Northeast has experienced a dramatic increase in one-day precipitation extremes during the October to March cold season.

Drought

Global warming exacerbates drought through changes in both precipitation and temperature, and these changes can vary greatly by region.

One precipitation-related driver of drought is the concentration of the year's precipitation into fewer but heavier downpours. This is occurring across the United States (NCA Chpt 2 Fig 2.16, p.50). Heavier downpours means that moisture is more likely to escape as runoff than be absorbed in the soil, a factor that contributes to drought.

Other precipitation trends that contribute to drought are dependent on latitude and current local conditions. In the very big picture, climate change is projected to cause dry areas to become drier, especially in the mid-latitudes and sub-tropics, while wet areas are projected to get wetter (IPCC AR5 WGI SPM, p.20). Consistent with this trend, the Western U.S., a historically dry area, is currently the driest in 800 years (Schwalm et al. 2012).

Global warming also raises local temperatures and drives more frequent and intense heat waves. This increases evaporation from the soil (Sherwood et al. 2014), and causes the early melt of snow pack in the spring. Melting snows typically slowly release water over the course of the spring and summer, providing a valuable water storage service (NCA Chpt 1, p.9). Early melt and high temperatures mean that by the hottest part of the summer, the water may be gone and drought conditions set in.

The different ways climate change drives drought can be observed across the United States. The Western U.S. has experienced drought worsened by loss of snow pack (NCA Chpt 1, p.9). In 2011, Texas experienced drought conditions worsened by record heat waves and overall high temperatures (Hansen et al. 2012; Rupp et al. 2012) that dry out soils. The extreme drought in California during 2013 was affected by all of these impacts: low precipitation, low snowpack, and high temperatures.

Flooding

Flooding is complicated in that it is impacted by both climatic and non-climatic factors. Flooding is worsened by regional climate trends such as increases in heavy rain and snow (see precipitation section), early snowmelt, and increased seasonal precipitation. Flooding is also affected by non-climatic factors such as land development, deforestation (Paix et al. 2011), levee placement and local topography, making it challenging to determine an overarching climate signal in flood trends.

Heavy precipitation is one of the most direct ways that climate change contributes to increased flooding around the world. Very heavy precipitation has increased over the past 50 years in the U.S (NCA Chpt 2 Fig 2.16, p.50). The extreme precipitation during both the Nashville flood of 2010 and Hurricane Irene provides an example of what we can expect to see more often in a warmer world. Climate change may also have provided the extra boost to precipitation totals that allowed flood levels to exceed the limits of drainage infrastructure and begin causing serious damage ($3 billion and $15.8 billion, respectively).

In contrast to flooding driven by short-term extreme precipitation, flooding in large river basins is caused by seasonal precipitation persisting for weeks or even months. The frequency of great floods (100-year floods in large basins) around the world has increased over the course of the 20th century (Milly 2002). Very heavy, sustained rains drove record-breaking Mississippi River flooding in 2011.

Overall, flooding in the Midwest and Northeast has been increasing (NCA Chpt 2, p.47). In the areas of greater flooding, increases in both total precipitation and extreme precipitation contribute to this troubling trend (NCA Chpt 2, p.55).

Storms

Climate change is increasing the amount of precipitation that falls in the heaviest storms (see precipitation section), but storms have other properties as well. Climate change loads storms with more warmth, moisture and energy, thus increasing intensity. General "storminess" as measured by winds speeds and ocean wave heights has increased in northern latitudes in recent years, particularly during winter months (Wang et al. 2009).

Hurricanes

Global warming worsens hurricanes by contributing to heavy rains, as well as higher storm surges through rising sea levels. The science is strongest on these links, and for many storms, the damages wrought by heavy rain and storm surge are often much worse than the damage from heavy winds. In a case study of Hurricanes Katrina and Ivan, human-induced warming was found to be responsible for six to eight percent of storm rainfall (Trenberth et al. 2007). Extreme rainfall also contributed to the catastrophic damage associated with Typhoon Haiyan in the Philippines. Climate change is projected to increase precipitation associated with intense cyclones by a further 20 percent by 2100 (Knutson et al. 2010).

At the same time, hurricane storm surge now rides on higher seas. About eight inches of global sea level rise since 1880 can be attributed to the effects of climate change: melting ice sheets and a warmer, expanding ocean. Rising sea levels can affect storm surge damages to an extent seemingly disproportionate to their rise. One simulation found that conservative sea level rise projections of around 5cm by 2030 resulted in an 8 percent increase in annual average U.S. property losses due to hurricanes, even assuming hurricane activity remains the same (Hoffman et al. 2010).

Hurricane frequency and intensity are more complicated climate impacts. The number of intense tropical cyclones, as well as the intensity of the strongest cyclones, has increased in the North Atlantic since the 1970s (IPCC AR5 WGI, Table SPM.1). These increases are connected to higher sea surface temperatures in the region that Atlantic hurricanes form in and move through (NCA Chpt 2, p.59), and supported by the finding that intense hurricanes are more likely in warm years than cold years (Grinstead et al. 2012). The rate of hurricane intensification has also increased, especially in the North Atlantic (Kishtawal et al. 2012), as well as the median size of hurricanes (Belanger et al. 2009).

In other regions of the ocean, existing trends in hurricane activity are less visible. Even in the North Atlantic, the observed trends hold for intense hurricanes, but not all hurricanes.

Looking forward, there is a consensus among experts that global warming will create stronger hurricanes (IPCC AR5 WGI, Table SPM.1). Although the global tropical cyclone count may decline slightly, the science projects an increase in the number of very strong hurricanes in the Atlantic.

Wildfires

Climate change has amplified the threat of wildfires; particularly in the western U.S. Higher average global temperatures are increasing the length of the fire season and the size of fires in places that have always had them (NCA Chpt 7, p.266; Chpt 13, p.479). New fires are expected to burn in regions where they have not been witnessed before (Moritz et al. 2012).

In the western U.S., both the frequency of large wildfires and the length of the fire season have increased substantially in recent decades. Earlier spring snowmelt and higher spring and summer temperatures drive this change (NCA Chpt 4, p.168). Due to a combination of warming temperatures, drought conditions (see drought section) and alterations of land management practices, there has been an increase in large fires unprecedented in their scale and impact, or "mega-fires." The intensity of these mega-fires has become a major concern for insurance companies that cover many homeowners in harm's way.

Warmer winter conditions also allow bark beetles (also called pine beetles, a pest that can kill large stands of pine trees) in the western U.S. to breed more frequently and successfully. In a warmer climate, these outbreaks are becoming more pervasive and sustained (Bentz et al. 2010). Dead trees left behind by bark beetles make crown fires more likely.

2013 was an average year for wildfires with about 4.3 millions acres burned. However, more than nine million acres burned in 2012, the third highest total on record (behind 2006 and 2007) with damages topping $1 billion dollars. More than 1.2 million homes in 13 western states— with an estimated total value of $189 billion — are located in areas the insurance industry has designated as high or very high risk for wildfire.

The wildfires during the summer of 2013 were extremely intense for some areas, especially the Rim Fire near Yosemite National Park that burned over a quarter of a million acres of forest. The Rim Fire was characteristic of the mega-fires that are becoming more common nowadays and now ranks among the top three largest wildfires in California history.

Food Price and Supply

Rising food prices are dependent on many factors, including population, income, and availability of supply (IFPRI 2010, p.2). This last factor is particularly affected by climate change. Climate disruption is already affecting prices for food and crops through impacts including changes in growing seasons, increasing extreme weather, rising sea levels, pest movement, and warming oceans.

The connections of U.S. agriculture and food security to global conditions are clearly illustrated by the recent food price spikes in 2008 and 2011 that highlighted the complex connections of climate, land use, demand, and markets. The doubling of the FAO food price index over just three months was caused partly by weather conditions in food-exporting countries such as Australia, Russia, and the U.S., but was also driven by increased demand for meat and dairy in Asia, increased energy costs and demand for biofuels, and commodity speculation in financial markets (NCA Chpt 6, p.244).

Many specific phenomena have been documented showing the impact of climate change on our food supply:

- Crop pests and pathogens have already been observed moving into new areas as our climate changes (Bebber et al. 2013).
- High nighttime temperatures affected corn yields in 2010 and 2012 across the Corn Belt (NCA Chpt 6, p.233).
- The 2012 drought, the United States' most extensive drought in 25 years, destroyed large areas of cropland and led to increased prices (USDA 2012).
- From 1980 to 2008, growing seasons changed in most parts of the world, with temperatures exceeding standard natural variability. These changes had a significant effect on global maize and wheat production, reducing yields by 3.8 and 5.5 percent respectively (Lobell 2011).
- Higher seas make flooding in rice fields in vulnerable areas more likely, reducing yields and leading to higher prices (Chen et al 2012).
- Climate change is also projected to change the distribution of marine species, affecting production from fisheries (Sumalia et al 2011).

Studies have found a link between conflict and climate, through the destabilizing mechanisms of food and water insecurity. One meta-review found a correlation between increases of violence and increases in temperatures and rainfall (Hsiang et al. 2013), while another found "a causal association between climatological changes and various conflict outcomes" (Hsaing and Burke 2013). A third study cited climate change as "arguably one of the greatest challenges to food security," particularly for "low-income individuals and communities" (Vermeulen et al. 2012), in addition to "exacerbating difficulties in obtaining sufficient food" for Inuit women (Beaumer et al. 2010).

In the future, the rising incidence of weather extremes will have increasingly negative impacts on crop and livestock productivity (NCA Chpt 6, p.241). One study comparing a number of difference models found that across the models agriculture would experience "strong negative effects from climate change" (Rosenweig et al. 2013). Climate disruptions are projected to lead to a 17 percent reduction in yield by 2050, relative to a scenario without climate change (Nelson et al. 2014). Adaptation may reduce losses somewhat, but will not be a substitute for mitigation.

Climate Change and Human Health

Climate disruption is already affecting human health and the prevalence of diseases transmitted by insects and rodents (NCA Chpt 9, p.333; Tabachnick 2010). The interaction between climate change and health is extremely complex. Scientific evidence increasingly points to ways that current health impacts that are consistent with known climate trends affecting the underlying risks and disease vectors. Some research has concluded that disease is sensitive enough to climate effects that it can serve as a "canary in the mine," warning of larger impacts to come (Randolph 2009).

Heat-Related Illness

Exposure to extreme heat is already the primary cause of weather-related mortality in the U.S. As climate change drives more frequent and longer-lasting heat waves (Duffy and Tebaldi 2012), associated illnesses and deaths are likely to multiply, especially in metropolitan areas (Medina-Ramón and Schwartz 2007). One study of 43 U.S. cities found that mortality did in fact increase during heat waves (Anderson and Bell 2011). There is also a marked difference in the rate of deaths resulting from hot and cold temperatures. Researchers have found that on average, cold snaps in U.S. cities increase death rates by 1.6 percent, whereas heat waves trigger a 5.7 percent increase in death rates (Medina-Ramón and Schwartz 2007).

From 1999-2009, the U.S. had an annual average of 658 heat-related deaths. In 2012, an extreme heat event in Maryland, Virginia, Ohio, and West Virginia lasting from June 30-July 13 resulted in 32 deaths from excessive heat exposure. During the same two-week period from 1999-2009, an average of only 8 deaths occurred in these four states (CDC 2013).

Asthma, Allergies and Lung Disease

Global warming has amplified some of the factors that drive asthma and lung disease (Bernstein and Rice 2013; Schmier and Ebi 2009). Hotter temperatures accelerate the processes that create surface ozone (Melkonyan and Wagner 2013), a key lung irritant that exacerbates lung diseases and can cause breathing difficulties even in healthy individuals (UCS 2011, p.2). Climate disruption has also prompted earlier onset for the spring pollen season in the United States (Ariano et al. 2010), and pollen allergies have shifted earlier in parallel (Bielory et al. 2012).

West Nile Virus

Climate change affects the life cycle and distribution of the mosquitoes that carry West Nile virus, which have thrived in higher temperatures (Johnson and Sukhdeo 2013; Morin and Comrie 2013). West Nile virus outbreaks have exploded across the U.S. since 1999, when the virus was first introduced to North America (Kilpatrick 2011). The risk of West Nile outbreak rises with more frequent heat waves, and the epicenters of recent outbreaks have been locations marked by drought or above-average temperatures (NCA 2009, p. 95). Warmer temperatures also facilitated the invasion of a new, more infectious viral strain (Kilpatrick et al. 2008). In 2012, Texas experienced a severe outbreak of West Nile Virus, with unprecedented virus transmission rates and 1,868 human cases (Murray et al. 2013). Across the U.S., more than 5,674 cases were recorded in 2012 (CDC 2013).

Lyme Disease

The incidence of Lyme disease in the U.S. has increased by about 80 percent between 1993 and 2007 (Tuite et al. 2013). Increases were especially identified in northern states, which suggests that warmer temperatures enabled the range increase (Tuite et al. 2013). Increases in tick density have also been correlated with temperature, and higher tick densities are associated with Lyme disease (Khatchikian et al. 2012).

Waterborne Diseases

Natural hazards such as hurricanes are known to be a risk factor in spills of hazardous materials, and these types of spills increased between 1990 and 2008, causing the evacuation of at least 5,000 people (Sengul et al. 2012).

Heavy rains can also trigger sewage overflows into water people use for drinking and swimming. Contaminated drinking water after a heavy rain has been linked to illness from organisms such as *Cryptosporidium* and *Giardia* (Edge et al. 2013; Frumkin 2008).

In agricultural areas, heavy rain and flooding can contaminate food crops with feces from nearby livestock or wild animals (Budu-Amoako et al. 2011). This increases the likelihood of food-borne disease associated with fresh produce (Wittman et al. 2013).

Shellfish Poisoning

Extreme rains can cause sewage to contaminate coastal waters, and water contamination has been linked to outbreaks of shellfish-borne food poisoning (Bellou et al. 2013).

Warmer temperatures also aid bacterial contaminants. The bacteria *Vibrio vulnificus*, which is the leading cause of death due to seafood consumption, thrives under warmer conditions and there is a close association between temperature, *Vibrio*, and clinical illness (Bross et al. 2007; Gilliss et al. 2013). *Vibrio* is one of the few foodborne illnesses with an increasing incidence. It accounts for 20 percent of illnesses and 95 percent of deaths associated with eating infected shellfish (Karl et al. 2009, p. 96). Concurrent with rising temperatures, the U.S. infection rate increased 43 percent in 2012 compared to 2006-2008 (Gilliss et al. 2013).

Infrastructure and Systems

The effects of sea level rise, more extreme storms, prolonged drought, and severe flooding threaten infrastructure systems that provide essential services for society — from drinking and wastewater systems to the transportation that drives our economy and the energy systems that power the national grid (NIPP 2013).

In the U.S., two of the most recent and prominent examples include the flooding of New York City subway stations during Sandy's storm surge, and the topping of the levee in New Orleans during Katrina. Although climate change may only partially contribute to the event underlying any particular disaster, it can be primarily responsible for most of the damages. This is because damages often exhibit a "threshold effect" associated with the limits of infrastructure. Once extremes top the threshold, damages mount dramatically (for example, no damage before a seawall is topped vs. dramatic damage after). Climate change can provide the boost necessary for overcoming infrastructure thresholds, thereby disproportionately contributing to damages.

Planners and engineers design infrastructure systems to cope with historical climate conditions and extremes in localized regions. By analyzing historical trends, planners anticipate how climate is likely to affect new infrastructure throughout its lifetime, which means they must consider future climate conditions 50 years or more into the future (NRC 2008, p.153). For example, bridges are often designed to withstand storms that have a probability of occurring only once or twice every 100 years (NRC 2008, p.30).

However, temperatures and corresponding climate impacts are increasing more rapidly than existing systems were designed to withstand. What's more, the interconnectivity of U.S. infrastructure raises the risk of "cascading system failures" that can have an even more profound impact on communities and the economy (Wilbanks and Fernandez 2012). Water, for example, relies upon energy infrastructure for extraction, transport, and treatment, but energy systems also rely upon water for resource extraction, fuel processing, thermal power plant cooling, and carbon capture and storage (DOE 2013, p. 5). Impacts to one system can have far reaching consequences, and already, the impacts of climate disruption on U.S. infrastructure are becoming increasingly apparent from both the growing number of climate-related disasters to the spectacular damage incurred in such disasters.

Insurance industry giant Aon reports that with 41 events, 2013 set a new record for billion-dollar weather disasters worldwide (Aon 2014). Another industry giant, Munich RE, reports that the number of weather catastrophes across the world has tripled since 1980 (Munich RE 2011), with the greatest increases in North America (Munich RE, 2012). Four out of five Americans live in counties where natural disasters have been declared since 2006 (Dutzik and Willcox 2012). Climate change is worsening these damages through sea level rise, as well as increases in extreme weather like heat waves and heavy precipitation.

The National Oceanic and Atmospheric Administration corroborates these findings, reporting an increase in billion-dollar weather disasters across the U.S. in recent years. There were seven such billion-dollar disasters in 2013, 11 in 2012, and 14 in 2011, compared to the average of six disasters per year over the previous ten years. Billion-dollar events are responsible for the majority of weather-related costs in the U.S. each year, estimated at roughly 80 percent (Smith and Katz 2013).

In 2014, the state of California faces record drought with widespread social consequences for the agricultural economy, farmers, and water infrastructure. In September 2013, record rainfall prompted historic flash flooding across the state of Colorado. Several major rivers and creeks crested at all-time levels (Aon 2013). The floods destroyed 20,000 homes and caused catastrophic damage to infrastructure costing the U.S. $2 billion (Aon 2013).

In 2012, the U.S. experienced mega-disasters costing many billions of dollars in infrastructure damages, including $65 billion in total damages due to Superstorm Sandy (Aon 2012). Storm surges from Sandy swamped New York City's subway system and disrupted the gasoline delivery system for the tri-state area.

Other examples of the myriad infrastructure impacts of climate disruption include Hurricane Irene, which washed out scores of roads and bridges across New England in 2011, including 300 bridges damaged or destroyed in Vermont alone (Marks et al. 2012, pg.12). In August 2012, a nuclear reactor in Connecticut shut down because the water in the Long Island Sound was, for the first time, too hot to effectively cool the equipment. A record-breaking heat wave in July 2012 melted the asphalt at Reagan National Airport in Washington DC, trapping a jet liner on the tarmac. Aquifers that supply drinking water to Hallendale Beach in Florida were contaminated with saltwater, prompting a $16 million upgrade to the water system. This issue continues to threaten water supplies along the heavily populated coast of south Florida (Berry 2012).

All of these examples represent individual instances of trends that are projected to increase as the climate warms. They represent a preview of the 'new normal.'

Security and the Military

Military officials and security experts in the U.S., U.K. and around the world continue to warn the public about the threats climate change poses to economic and political stability. Speaking recently in Indonesia, Secretary of State John Kerry called climate change "perhaps the world's most fearsome weapon of mass destruction," setting the stage for a series of speeches in 2014 emphasizing the national security risks of climate change.

Secretary Kerry's warning is not an overstatement. Some of the most dangerous impacts of climate change – coastal cities flooded by higher seas, global food supply disruption (NCA Chpt 6, p.243), drought and wildfires (NCA Chpt 7, p.266) – will indeed cause mass destruction if warming continues unchecked, and these changes will impact military action.

Military response to weather disasters have increased in recent years. The British Royal Navy, for instance, has been involved in providing relief to communities in the Thames Valley that were devastated by the historic floods of the winter of 2013-14. One study shows that natural disasters cost the world $192 billion in 2013 alone, with the highest total ever reaching $265 billion in 2011.

Climate change also puts stress on cropland and water delivery systems, and can increase food and water insecurity (Hanjra et al. 2010). The resulting instability can bring down weak governments. The World Food Program has established links between food insecurity and violent conflict, and military leaders are recognizing the connection as well. Former Army Chief of Staff General Gordon Sullivan has said plainly: "Climate change is a national security issue. We found that climate instability will lead to instability in geopolitics and impact American military operations around the world." For example, a drought that caused massive crop failures and livestock die-offs in Syria since at least 2006 helped instigate the civilian uprising that led to that country's ongoing civil war.

The impacts of global warming have the potential to displace large numbers of people, causing further political strife. Residents of the Pacific Island nation of Kiribati, for example, are being forced to resettle because of sea level rise, foreshadowing a problem set to increase on a massive scale. Alaskan communities such as Newtok, Kivalina, and Shishmaref are also facing the need to move. Such mass migration is creating a whole new class of climate refugees, and the latest IPCC report shows that this problem is likely to increase as more areas become uninhabitable. These factors caused Samuel J. Locklear, Commander of the U.S. Navy Pacific Command, to warn that significant upheaval related to a warming planet "is probably the most likely thing… that will cripple the security environment, probably more likely than the other scenarios we all often talk about."

Conclusion

Climate change is already upon us, right here right now. We see its fingerprints stretching from the Arctic circle to the plains of Texas, with significant impacts to communities all over the U.S. and across the world. From national security threats to human health impacts, a warming climate means a less stable environment for all. But solving it is not beyond us. We can make the switch from fossil fuels to clean energy sources, like wind and solar. And leaders must commit to action to reduce global emissions. Combating climate change is the greatest opportunity of our time.

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