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JULY 18, 2013

CLIMATE CHANGE: IT'S HAPPENING NOW

U.S. SENATE COMMITTEE ON ENVIRONMENT & PUBLIC WORKS

ONE HUNDRED THIRTEENTH CONGRESS, FIRST SESSION

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Senior Fellow
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Hearings

Statement of Barbara Boxer
Hearing: Full Committee hearing entitled, “Climate Change: It’s Happening Now.”
Thursday, July 18, 2013

Statement of Barbara Boxer
Full Committee Hearing: "Climate Change: It's Happening Now"
July 18, 2013
(Remarks as prepared for delivery)

Today's hearing will focus on climate change and the serious threat it poses to our nation. The body of evidence is overwhelming, the world's leading scientists agree, and predictions of the impact of climate change are coming true before our eyes.

This issue has been a priority for me since I became Chairman of this Committee, because climate change puts our environment and public health at great risk.

Scientists and other experts have testified before this Committee in the past, and they spoke many times about the severe impact of climate change.

Let me share just a few of these experts' predictions with you:

"It is very likely that hot extremes [and] heat waves . . . will continue to become more frequent." (Dr. Kevin E. Trenberth in 2008)

"It is likely that tropical storms and hurricanes will become more intense and with much heavier rainfalls, and thus risk of flooding." (Dr. Kevin E. Trenberth in 2008)

"With climate change, an increase in the severity, duration, and frequency of extreme heat waves is expected in the United States." (Dr. Howard Frumkin in 2009)

"On the most basic level, climate change has the potential to create sustained natural and humanitarian disasters on a scale and at a frequency far beyond those we see today." (Vice Admiral Dennis McGinn in 2009)

In just a few short years since these predictions were made, we can look out the window and see the evidence of climate change mounting around us.

In 2012, Superstorm Sandy resulted in the loss of life, wiped out entire communities, and caused approximately $65 billion of damage.

And the impacts of climate change are being felt throughout our nation. The Arctic has lost more than a third of total sea ice volume over the last decade -- making Alaskan native villages increasingly vulnerable to erosion and storms.

We have seen large wildfires break out earlier in the season in California, and recently 19 brave firefighters in Arizona tragically lost their lives. In 2012, New Mexico experienced the largest wildfire in state history, Colorado suffered the second largest wildfire in state history, and Oregon had its largest wildfire since the 1860s.

According to the National Oceanic Atmospheric Administration (NOAA), over the past two years there have been 25 weather and climate disasters - each one costing more than $1 billion.

Climate change is real, human activities are the primary cause, and the warming planet poses a significant risk to people and the environment.

Today we will hear from scientists and other experts who will tell us about the growing impacts associated with climate change. On our first panel today we welcome:

• Dr. Heidi Cullen, Chief Climatologist at Climate Central, who is an expert in the links between climate change and extreme weather.

• Mr. Frank Nutter, President of the Reinsurance Association of America, who can describe some of the mounting costs related to some of the extreme events we have experienced.

• Ms. Diana Furchtgott-Roth, Senior Fellow at the Manhattan Institute for Policy Research and Dr. Robert P. Murphy, Senior Economist at the Institute for Energy Research.

• And we will end the first panel with Mr. KC Golden, who is the Policy Director at Climate Solutions and winner of 2012 Heinz Award in Public Policy. He will describe the urgent need to tackle this dangerous threat.

Scientists tell us that the damage caused by climate change continues to worsen, and we cannot afford to ignore these warnings. We must heed these alarms and take action.

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Extreme Weather Within the Context of Our Changing Climate

Heidi Cullen, PhD
Chief Climatologist, Climate Central
Senior Research Fellow, Wharton Risk Management and Decision Processes Center, University of Pennsylvania
Visiting Lecturer, Princeton University

Briefing to the United States Senate Committee on Environment and Public Works
July 18, 2013

Introduction

Chairman Boxer, Ranking Member Vitter and distinguished members of the Senate Environment and Public Works Committee – thank you for the opportunity to present today. It is a privilege and an honor to testify on this important topic.

I am Heidi Cullen and I currently serve as Chief Climatologist at Climate Central. Climate Central is an independent organization of scientists and journalists who research and report on climate and energy. Climate Central surveys and conducts scientific research on climate change and informs the public of key findings. Our scientists publish in peer-reviewed literature and our journalists report on climate science, energy, sea level rise, wildfires, drought, and related topics. Climate Central does not lobby, or support any specific legislation, policy or bill. I am also a Senior Research Fellow at the Wharton Risk Management and Decision Processes Center at the University of Pennsylvania. Assessing and communicating the risks of climate change is something I care deeply about.

Climate change was for a long time thought to be an issue for the distant future. But I am here today to testify that it has, in many respects, moved into the present. The impacts of human-caused climate change are being observed right here and right now in our own backyards and neighborhoods.

My testimony today draws from peer-reviewed literature and is an attempt to concisely review the following:

1. The science of extreme weather and climate change.
2. The so-called global warming hiatus of the early 2000s.
3. The important role of oceans in our climate system.

1. The Big Picture

When it comes to climate change, scientists focus on carbon dioxide (CO_2) because it is the most important long-lived global warming gas. CO_2 is emitted via human activities including fossil fuel burning, cement production and deforestation. Once emitted, a molecule of CO_2 can remain in the atmosphere for hundreds of years. Global CO_2 emissions reached a record high of 35.6 billion tons in 2012 (Peters et al., 2012). Carbon dioxide and other greenhouse gases warm the planet by absorbing the sun's energy and preventing heat from escaping back into space. The latest carbon dioxide emissions continue to track the high end of emission scenarios (Figure 1). Without significant emissions reductions, the world's average temperature could climb as much as 7 to 11°F by 2100 (Peters et al., 2013).

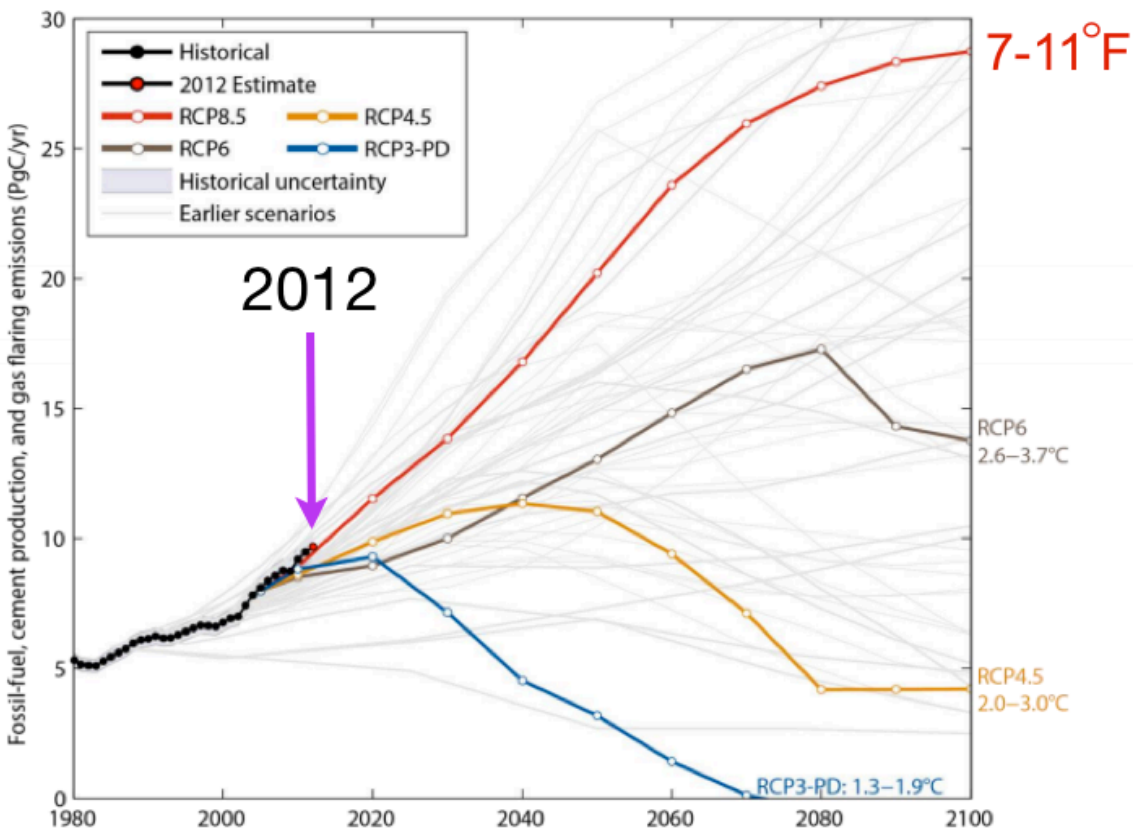

Figure 1: Observed emissions (black dots) and emissions scenarios (colored lines). Source: Peters et al., 2013, Global Carbon Project[1].

This past May, the amount of carbon dioxide in the air exceeded 400 parts per million (ppm) for the first time in at least 800,000 years (Figure 2). The news marks a troubling milestone, showcasing the steady increase of human-caused CO_2 emissions over the past century. Additional lines of evidence including ice cores and ocean sediments, suggest this may be the highest atmospheric CO_2 concentration as far back as 15 million years (Tripati et al., 2009).

[1] http://www.globalcarbonproject.org/carbonbudget/index.htm

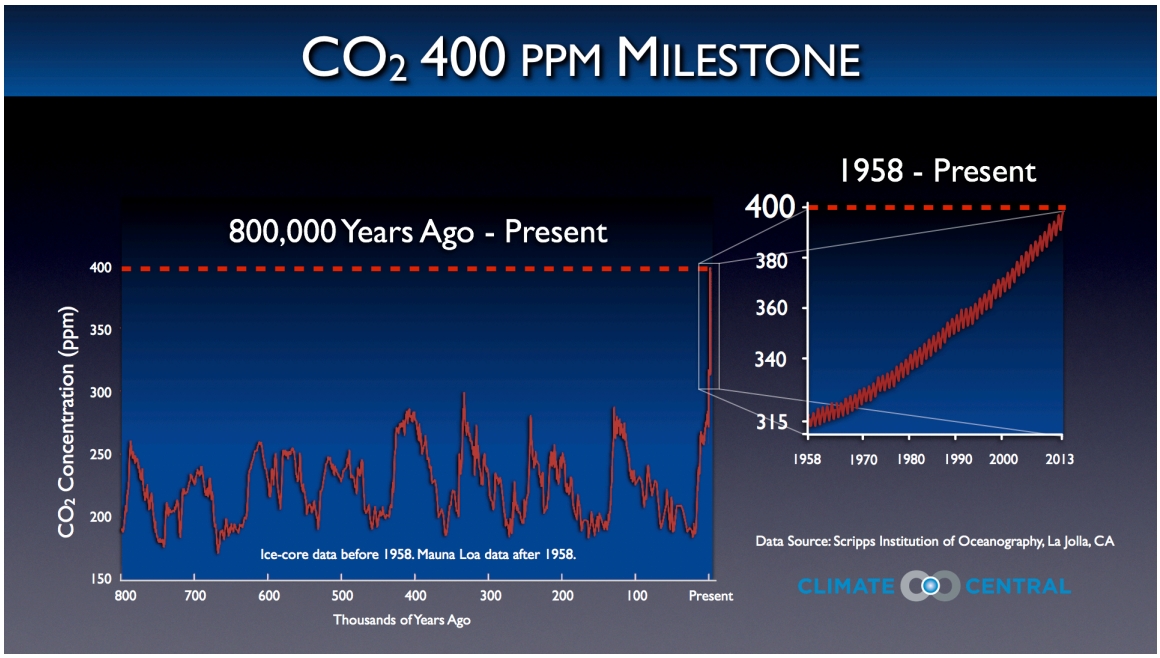

Figure 2: Carbon dioxide in the air exceeded 400 parts per million (ppm) for the first time in at least 800,000 years.

Across the globe, we are observing things we would not expect to observe in a climate controlled purely by natural variability. According to the National Oceanic and Atmospheric Administration (NOAA), 2012 was the 10th warmest year since records began in 1880. The annual global combined land and ocean surface temperature was 1.03°F above the 20th century average of 57.0°F. This marks the 36th consecutive year (since 1976 – during the presidency of Gerald R. Ford) that the yearly global temperature was above average. Currently, the warmest year on record is 2010, which was 1.19°F above average. Including 2012, all 12 years to date in the 21st century (2001–2012) rank among the 14 warmest in the 133-year period of record. Only one year during the 20th century—1998—was warmer than 2012.[2]

Despite this remarkable string of warmer-than-average temperatures, it is important to note that human-induced warming is superimposed on a backdrop of natural climate variations, meaning that the rise in temperature has not been, and will not be, smooth over space or time. There will still be cold spells, cool days, etc. for places just as we saw this past winter along the U.S. East Coast.

Here in the United States average temperatures have increased by roughly 1.5°F since record keeping began in 1895. More than 80 percent of this temperature increase has occurred since 1980. The most recent decade was the nation's warmest on record. Looking back, 2012 was an impressive year in terms of extreme weather and climate events. It was the warmest year on record in the lower 48 states. According to NOAA, the average temperature in the United States for 2012 was 3.2°F above the 20th-century average, and 1°F above 1998, the previous warmest year (Figure 3). The year also featured a massive drought, deadly heat waves that broke thousands of temperature records, and a

[2] http://www.ncdc.noaa.gov/sotc/global/2012/13

powerful Hurricane Sandy that devastated parts of the Mid-Atlantic and Northeast. The National Snow and Ice Data Center announced that Arctic sea ice had reached a new minimum extent that was drastically lower than the previous record, set in 2007, by an area about the size of Texas. Sea ice in the Arctic has also decreased dramatically since the late 1970s, particularly in summer and autumn. Since the satellite record began in 1978, minimum Arctic sea ice extent (which occurs in early to mid September) has decreased by more than 40 percent (NSIDC, 2012). This decline is unprecedented in the historical record and is consistent with human-induced climate change (Min et al., 2008; Kay et al., 2011).

There were 11 extreme weather and climate disasters in 2012 *each* costing upwards of $1 billion. According to NOAA's National Climatic Data Center in Asheville, N.C., these billion-dollar events cost the United States a total of $110 billion, which puts 2012 behind only 2005 on the list of costliest years since 1980 (Smith and Katz, 2013).

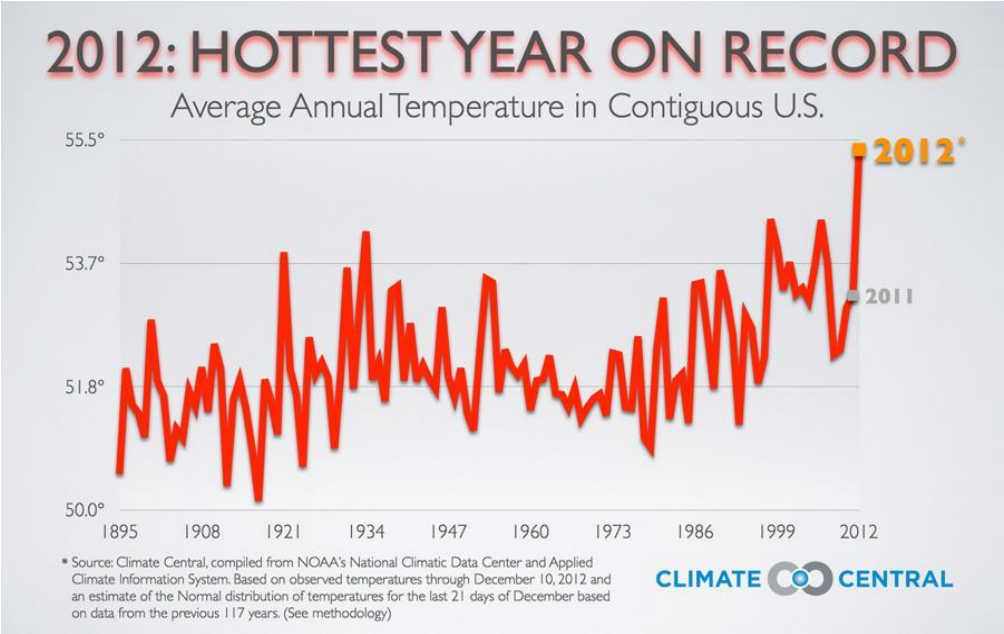

Figure 3: Average annual temperature in the contiguous United States.

Records continue to fall in 2013, with the continuation of drought conditions throughout the West. One of the greatest heat waves in North American history came in late June and peaked in early July, smothering states from Arizona to Washington state under a persistent "heat dome" of high pressure. It was during this heat wave that 19 firefighters lost their lives battling the Yarnell Hill fire in Arizona. The extraordinary heat wave, caused by an unusually extreme standing wave pattern in the jet stream, brought Earth's highest June temperature ever recorded on Sunday, June 30, when the mercury hit 129.2°F in Death Valley, Calif.

The seemingly endless string of extreme events has left many wondering if the weather here in the United States has fundamentally changed. Are we moving in the direction of ever more dangerous and costly extremes? The losses associated with these extreme events have raised questions about the overall vulnerability of our communities and the need to focus on pre-disaster resilience planning. The short answer to this first scientific question is yes.

We can already see the impacts of warming in certain types of extremes. The second question is a matter of policy. According to the Federal Emergency Management Agency (FEMA), every dollar spent on enhancing communities' ability to withstand extreme events reduces the cost of damage from such events by about $4.[3]

1a. Extreme weather

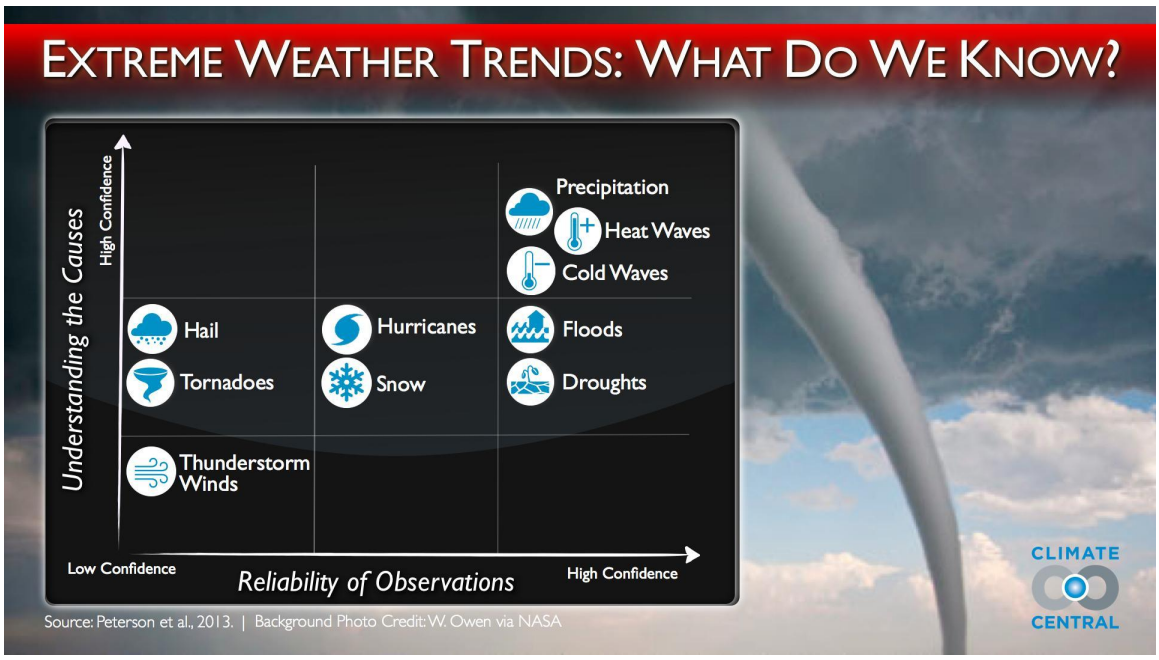

Figure 4: Our understanding of extreme weather events within the context of climate change is a function of the reliability of our observations coupled with our understanding of the causes of the extreme weather phenomenon. Source: Peterson et al., 2013.

The current state of the science on extreme weather trends is summarized in Figure 4. Our understanding of extreme weather events and trends within the context of climate change is a function of the reliability of our observations (e.g., how much data do we have about droughts?) coupled with our physical understanding of the causes of the specific extreme weather phenomenon (e.g., what causes a tornado or a heat wave?). There are certain types of extremes that we understand better than others and there are certain types of extremes for which we have better (wider coverage in space, longer records in time, and more accurate measurements) observational data than others. What follows is a summary of our understanding broken down by the type of extreme event.

- Heat Waves/Cold Waves

Periods of extreme heat and extreme cold can have profound societal, agricultural, economic impacts. Extreme heat ranks as the No. 1 weather-related killer in the United States (National Weather Service 2012; Borden and Cutter, 2008.) The scientific community has a solid physical understanding of heat waves and cold waves. Because our climate is warming, heat waves are expected to occur more often, while cold waves are expected to

[3] http://www.climatecentral.org/news/campaign-for-climate-resilience-spreads-at-local-level-16135

decrease. In fact, recent decades tend to show an increase in the number of heat waves and a decrease in the number of cold waves, but over the long term, the drought years of the 1930s stand out as having the most heat waves (Figure 5). The chances of record-breaking high temperature extremes will continue to increase as the climate continues to warm. These results parallel the results of Meehl et al. (2009), who found that the current observed ratio of record high maximum temperatures to record low minimum temperatures averaged across the United States is about 2 to 1.

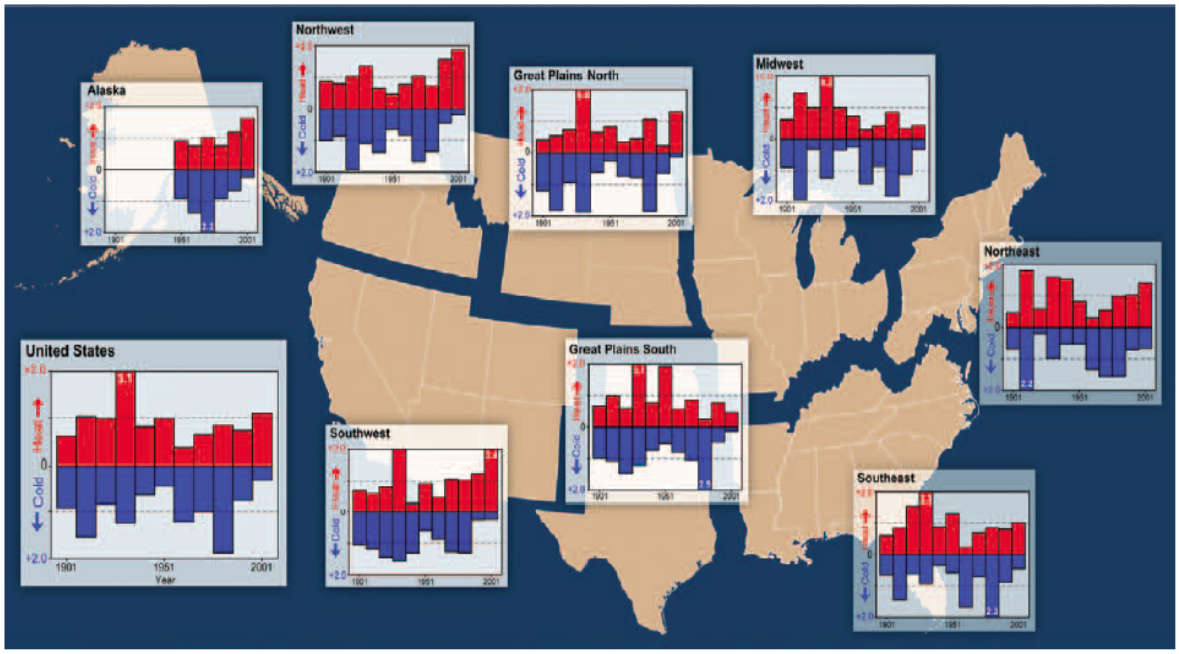

Figure 5: Time series of decadal-average values of heat wave (red bars) and cold wave (blue bars) indices from Peterson et al., 2013. Recent decades tend to show an increase in the number of heat waves and a decrease in the number of cold waves but, over the long term, the drought years of the 1930s stand out as having the most heat waves.

There has also been an increasing trend in persistently high nighttime temperatures. High overnight temperatures have broad negative impacts because they deprive people and animals from getting a reprieve from the heat, increasing the chances of heat-related illness. For a more specific example, the *State of the Climate in 2011* report, published by NOAA and the American Meteorological Society (AMS), looks at how human-induced global warming is influencing recent extreme weather and climate events. The report notes that global warming has already been playing a role in shifting the odds for several extreme events, including the 2011 Texas drought - the worst one-year drought in Texas history, costing nearly $8 billion in agricultural losses[4] - including the closing of a beef-processing plant in Plainview, Texas that employed 2,300 people[5]. The study concluded that human-induced climate change made the 2011 Texas heat wave and drought 20 times more likely than it would have been 50 years ago.[6]

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[4] http://www.statesman.com/news/news/state-regional/drought-cost-texas-close-to-8-billion-in-agricultu/nRmNt/

[5] http://www.nytimes.com/2013/02/28/us/drought-fells-a-texas-towns-biggest-employer.html?pagewanted=all&_r=0

[6] http://www.ncdc.noaa.gov/bams-state-of-the-climate/2011.php

- Wildfires

The deadly Yarnell Hill fire that killed 19 elite firefighters in June played out, like other wildfires in the West this summer, in the midst of one of the most extreme heat waves on record, in combination with a prolonged drought. While the factors contributing to specific fires are varied and include natural weather and climate variability as well as human factors, such as arson, the National Climate Assessment found that human-induced climate change has already increased the overall risk of wildfires in the Southwest.

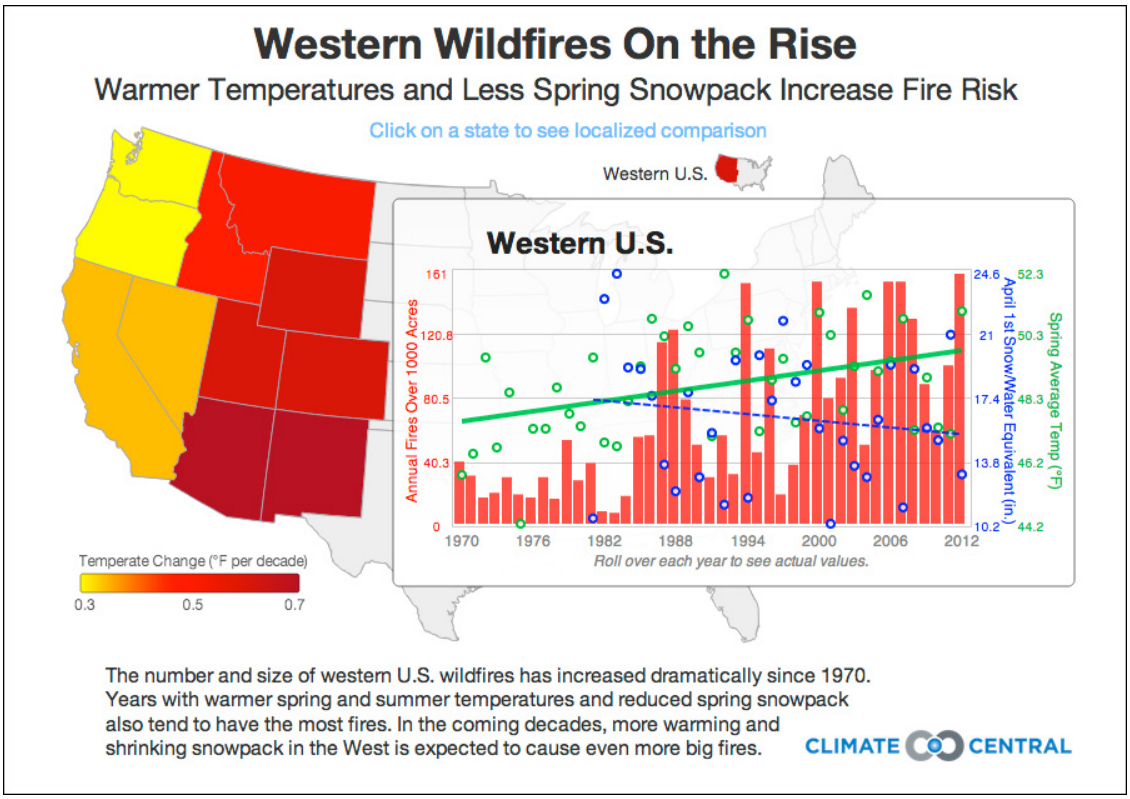

Figure 6: The number and size of western U.S. wildfires has increased since 1970.[7]

According to Climate Central research[8], average spring and summer temperatures across 11 Western states have increased by more than 1.5°F since the 1970s (Figure 6). Spring temperatures in Arizona have warmed faster than any other state, rising nearly 1°F per decade since 1970, which has likely played a key role in Arizona's rapid increase in fires over the past two decades. The number of large fires burning each year in states like Arizona and Idaho have tripled or even quadrupled over that time. And in other states, including California, Colorado, New Mexico, Nevada, and Wyoming, the number of large fires has doubled. During the past decade there were seven times more fires greater than 10,000 acres each year in 11 Western states and nearly five times more fires larger than 25,000 acres each year, when compared to an average year during the 1970s. Years with

[7] http://www.climatecentral.org/news/rising-temps-shrinking-snowpack-fuel-western-wildfires-16222

[8] http://www.climatecentral.org/news/report-the-age-of-western-wildfires-14873

abnormally warm spring and summer temperatures tend to be years with more and bigger fires. Years with low spring snowpack (measured as the amount of water in snowpack on the ground as of April 1) also tend to be years with more fires. When there is a relatively thin snowpack come spring, it can melt quickly as the weather warms, leaving the forest drier earlier and much more likely to burn. Across the Southwest in particular, several recent years of below-average spring snowpack has extended the region's drought and fueled more big fires.

Overall, hotter and drier weather and earlier snow melt, coupled with land use changes and other trends, mean that wildfires in the West start earlier in the year, last later into the fall, threaten more homes, cause more evacuations, and burn more acreage. The growing season also starts earlier, so there is more to burn. According to Craig D. Allen, a research ecologist at the United States Geological Survey station at Bandelier National Monument in New Mexico, the fire season has lengthened substantially, by two months, over the past 30 years.[9] Other factors contributing to the increase in wildfire trends include long-standing fire-suppression policies that have left many forests with substantial amounts of vegetation to serve as fuel, population growth, and more specifically, development in areas that have a history of wildfires, known as the "wildland-urban interface."

In 2009, The Quadrennial Fire Review projected that the effects of global warming would lead to "greater probability of longer and bigger fire seasons, in more regions in the nation." Specifically, climate change would result in shorter, wetter winters coupled with warmer, drier summers.[10] Climate models used to predict future fire risks show an alarming increase in large wildfires in the West in coming years, as spring snowpack melts earlier, summer temperatures rise, and droughts occur more frequently and with greater intensity.

- Heavy Downpours/Floods/Drought

Heavy downpours are increasing nationally (Figure 7), especially over the past three to five decades. According to the National Climate Assessment (currently available in draft form[11]) those events in the top 1 percentile of intensity have increased in every region of the contiguous United States since 1958 - with the largest increases occurring in the Midwest and Northeast and smallest increase occurring in the Northwest. The reason for these heavier rain events is relatively simple: in a world warmed by heat-trapping greenhouse gases, there's more evaporation, the atmosphere can hold more water vapor, and when that water vapor condenses as rain or snow, there's more of it available to fall. As a result, many flood management/storm water systems are not designed for 21st century rainstorms.

It is important to note that while the trend in intensity has been upward, it has not been steady. The record contains ups and downs from one decade to the next. This provides another example of the fact that human-caused climate change hasn't replaced natural climate variability: it appears on top of it. The frequency and intensity of extreme precipitation events are projected to increase throughout much of the country in the future.

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[9] http://www.nytimes.com/2013/07/02/us/experts-see-a-hotter-drier-west-with-more-huge-fires.html
[10] http://www.iafc.org/files/wild_QFR2009Report.pdf
[11] http://ncadac.globalchange.gov/

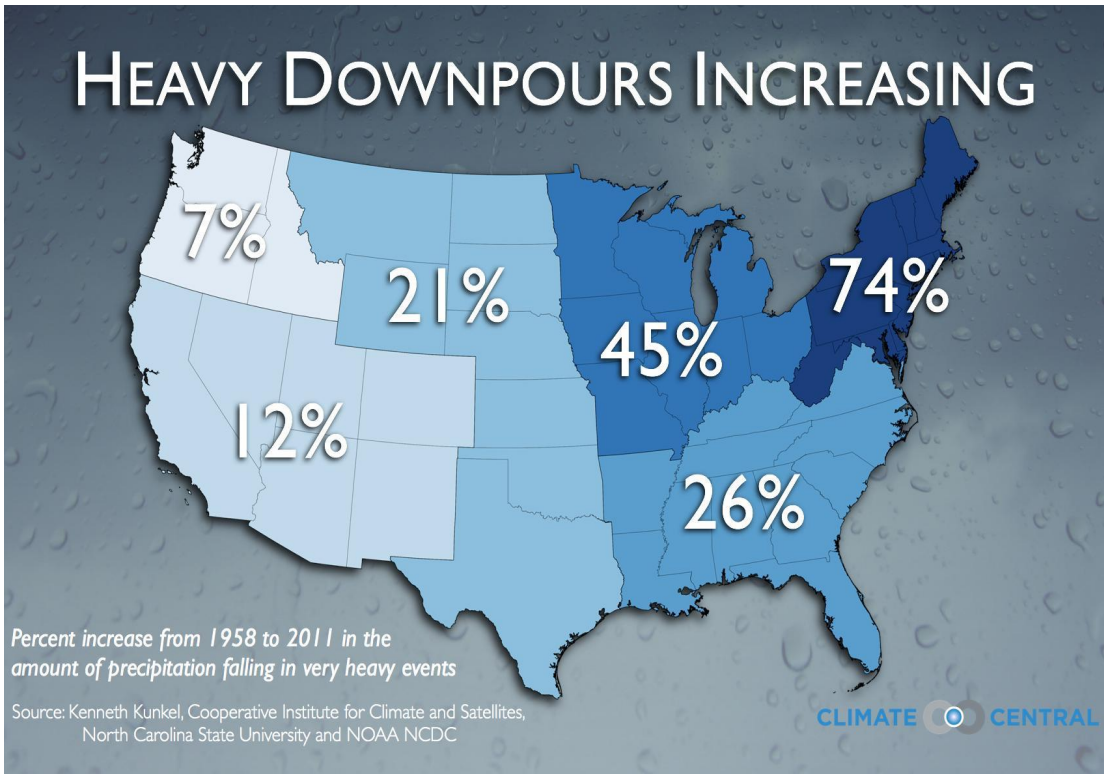

Figure 7: Percent increase from 1958 to 2011 in the amount of precipitation falling in very heavy events.

When it comes to understanding the causes of changes in floods and droughts, we don't know quite as much - even though we have good data. Overall, because of the way large-scale warming will affect the atmosphere, we expect to see dry regions become drier and wet regions become wetter. In general, the northern parts of the United States (especially the Northeast and Alaska) are projected to see more precipitation, while the southern parts (especially the Southwest) are projected to see less.

There is, however, evidence of a detectable human influence in the timing and magnitude of snowmelt and resulting streamflow in some western states (Barnett et al. 2008; Andersen and Shepherd, 2013). Changes in the magnitude of peak annual river floods are shown in Figure 8. Flooding in the northern half of the eastern Great Plains and much of the Midwest has been increasing, especially over the past several decades. Flooding has decreased in the Southwest, although there have been small increases in other western states. In the areas of increased flooding, increases in both total precipitation and extreme precipitation events are contributing to the flooding increases. In general, heavier rains lead to a larger fraction of rainfall running off and, depending on the situation, more potential for flooding. Floods are projected to intensify in most regions of the United States, even in areas where average annual precipitation is projected to decline, but especially in areas that are expected to become wetter, such as the Midwest and the Northeast.

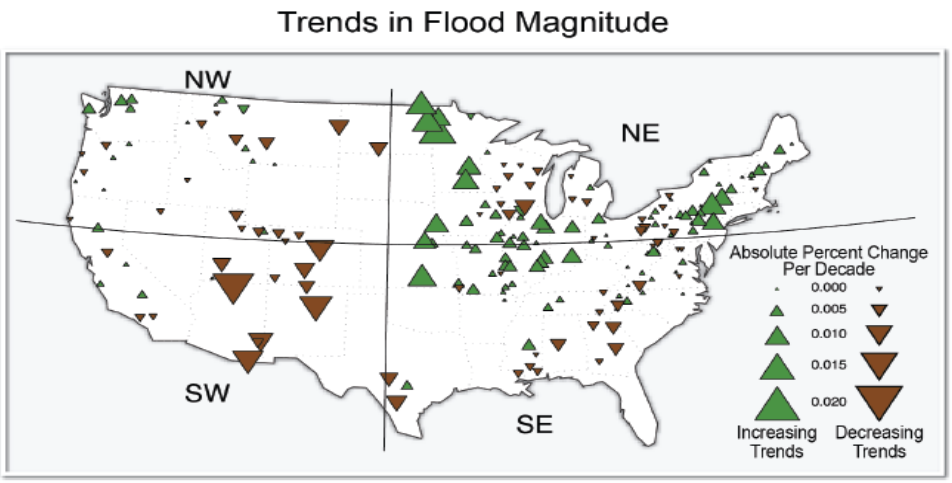

Figure 8: Trends in flood magnitude. Source: Hirsch and Ryberg, 2012.

Overall, precipitation has increased on average since 1900, with the largest increases the Midwest, southern Great Plains, and Northeast. Portions of the Southeast, the Southwest, and the Rocky Mountain states have experienced decreases. More winter and spring precipitation is projected for the northern United States, and less for the Southwest, during this century.

Examination of trends and variability of hydroclimatic conditions in the lower 48 states during the past century indicates that there has been a general drying across the western United States during recent decades (Figure 9). Precipitation has already declined in some areas within the Southwest and the Rocky Mountain states, and decreases in precipitation are projected to intensify in those areas and spread northward and eastward in summer. However, even in areas where precipitation does not decrease, projected higher air temperatures will cause increases in surface evaporation and loss of water from plants, leading to drier soils. As soil dries out, a larger proportion of the incoming heat from the sun goes into heating the soil and adjacent air rather than evaporating its moisture, resulting in hotter summers under drier climatic conditions.

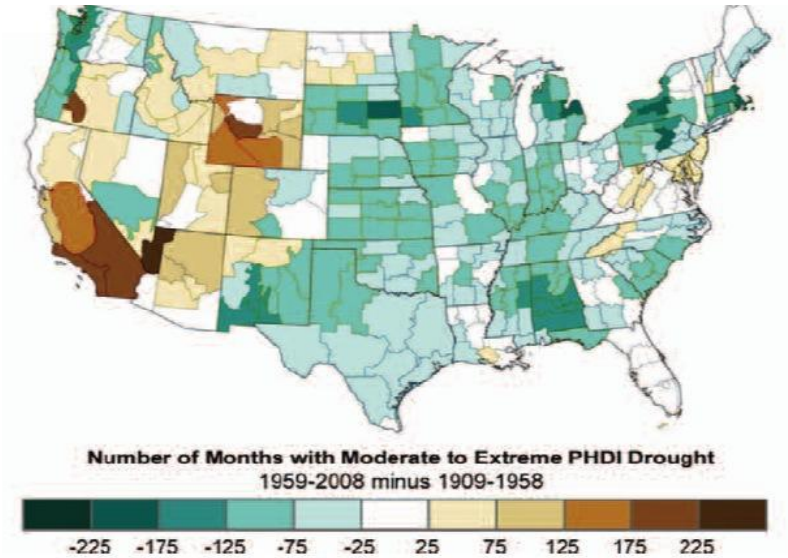

Figure 9: Geographic distribution of century-scale changes in droughts from Peterson et al., 2013.

- Sea Level Rise

Sea level rise is among the most serious potential consequences of global warming. Since 1880, sea level has risen approximately 8 inches around the world, on average, as a result of global warming. According to projections included as part of the draft National Climate Assessment, sea level could be as little as another 8 inches or as much as 6 feet 7 inches above 1992 levels by the end of the century. This high-end projection would put the homes of 7.8 million Americans today at risk of being flooded (Figure 10).

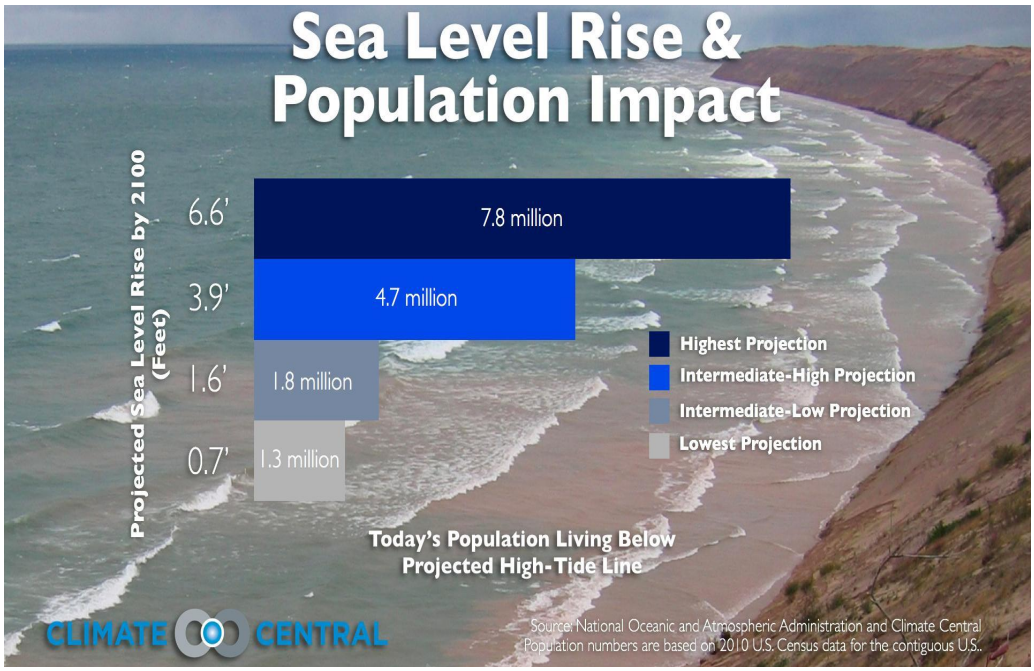

Figure 10: Potential population impacted (based on number of people currently living below the projected high-tide line) based on four sea level rise projections.

In the near term, sea level rise will be experienced as more coastal floods reach higher. Sea level rise due to global warming has already doubled the annual risk of extreme coastal flooding across widespread areas of the nation (Strauss et al., 2012). In some areas, especially for Louisiana, Texas, and mid-Atlantic states, sinking land will add to the rise and further exacerbate problems. All along the Pacific, from Seattle to the Oregon coast to San Francisco to Los Angeles, the component of past and mid-range projections of sea level rise from global warming more than triple the odds of "century" floods by 2030. The same is true inside the Chesapeake and Delaware Bays, and many sites to the north.

Sea level rise occurs for two reasons. First, water expands as it warms. As a result the ocean swells and rises. Second, more water is emptying into the ocean with each passing year as ice on mountaintops and ice sheets in Greenland and Antarctica continue to melt. It is still not known exactly how fast sea level will rise because 1) it is difficult to predict the dynamics of ice sheets collapsing and sliding into the sea and 2) it is not known exactly how much warmer the Earth's temperatures will be in the future.

Sea level rise is already contributing to increased storm surge. A recent example of this was during Hurricane Sandy. At 13.88 feet, the storm tide (relative to Mean Lower Low Water) associated with Sandy set a record for Battery Park and inundation was widespread. A

recent estimate looked at the sea level rise component of Hurricane Sandy's storm surge and concluded that sea level rise caused Sandy to flood an area roughly 25 square miles greater than it would have in 1880 - increasing the number of people living on land lower than the storm tide by about 38,000 in New Jersey and about 45,000 in New York City (Strauss et al, 2012; Miller et al., in press).

- Hurricanes

By some measures, there has been a small increase in the overall strength of hurricanes and in the number of strong (Category 4 and 5) hurricanes in the North Atlantic since the early 1980s and a decrease in the eastern North Pacific (Figure 11). A recent paper (Emanuel, 2013) suggests that, contrary to previous findings, tropical cyclones are likely to become both stronger and more frequent in the years to come. The study found this is especially likely in the western North Pacific but also in the North Atlantic, where about 12 percent of the world's tropical cyclones occur each year.

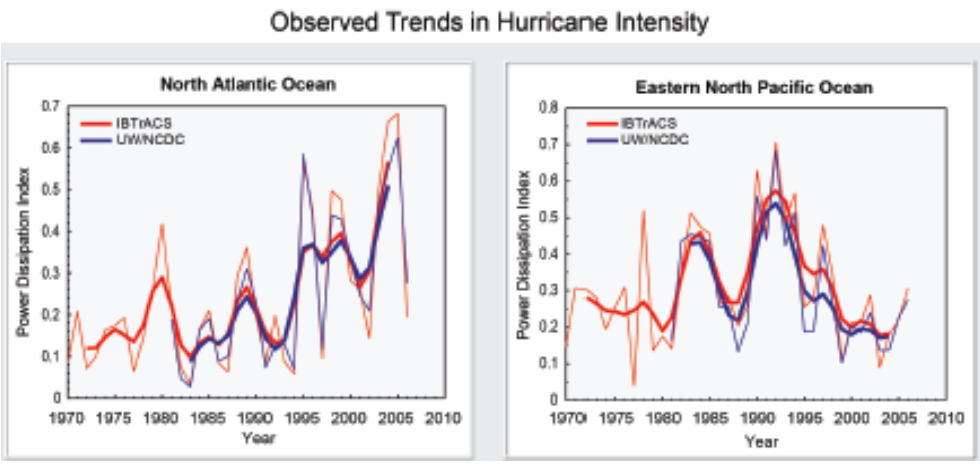

Figure 11: Observed trends in hurricane intensity. Source: National Climate Assessment draft report. Updated from Kossin et al., 2007).

However, a number of previous studies suggest that warming will cause tropical storms to be fewer in number globally, but stronger in force, with more category 4 and 5 storms (Knutson 22 et al. 2010), which is worrisome since major hurricanes (Category 3 or greater) are responsible for the most damage. This consensus view was expressed most recently in a 2012 report from the U.N. Intergovernmental Panel on Climate Change (IPCC, 2012).

With regard to other types of storms that affect this country, winter storms have increased slightly in frequency and intensity, and their tracks have shifted northward over the United States.

It is not surprising that Superstorm Sandy raised questions about links to global warming. Sandy was the largest (diameter of tropical storm force winds extending out 1000 miles[12]) and second most destructive Atlantic hurricane on record. According to Dr. Jeff Masters at Weather Underground, New York City experienced its worst hurricane since the city's

[12] http://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf

founding in 1624[13]. Sandy's 9-foot storm surge rode in on top of a high tide to bring water levels to 13.88 feet at The Battery (Figure 12), smashing the record 11.2 feet water level recorded during the great hurricane of 1821.

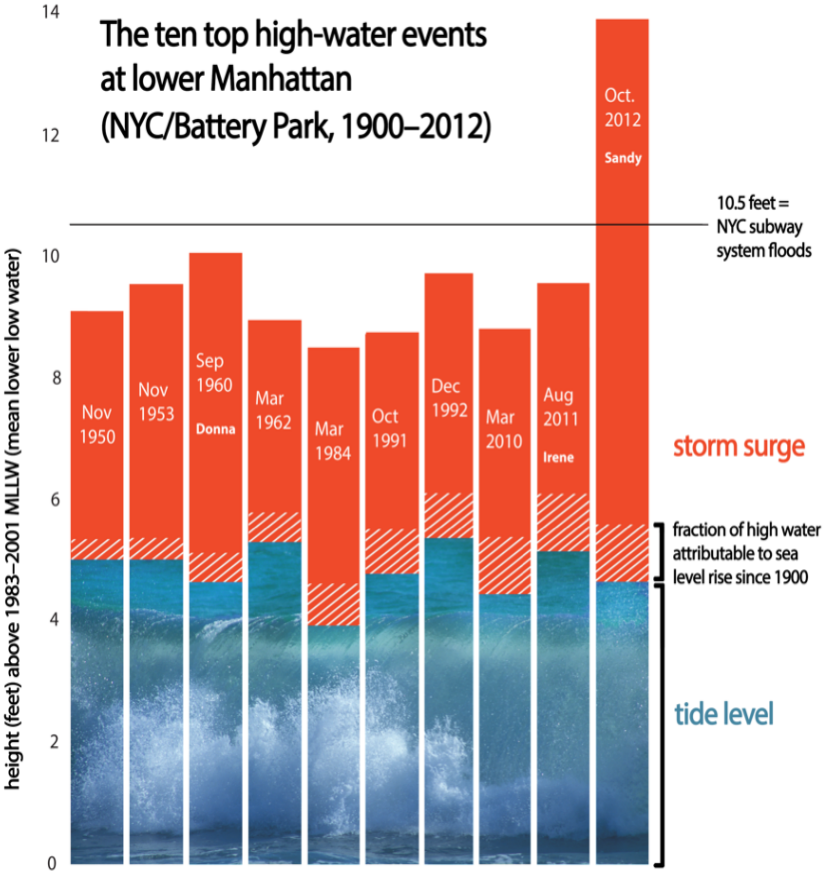

Figure 12: Top 10 high water events in lower Manhattan and fraction of high water attributable to sea level rise since 1900. Source: C. Calvin and B. Henson, UCAR.

There were three climate factors that helped shape Hurricane Sandy's unusual track and strength:

1. Ocean surface temperatures off the East Coast were running about 5°F above average during the summer of 2012. Global warming is contributing to warmer ocean temperatures.

2. Sea level rise gave the surge a higher launching pad than it would have had a century ago, making it more damaging than it otherwise would have been.

3. Upper-air flow over the Atlantic Ocean was temporarily jammed by a powerful area of high pressure near Greenland. It's possible that more frequent blocking events may be related to the loss of Arctic sea ice (Francis and Vavrus, 2012). This blocking affected Sandy's track.

[13] http://www.wunderground.com/blog/JeffMasters/article.html?entrynum=2282

Sandy was indeed a very unusual storm. A recent study (Hall and Sobel, 2013) calculated that the occurrence rate of a Sandy-style storm is 0.0014 per year, meaning that if future hurricane activity matches the recent past we should expect a storm like Sandy on average about once every 700 years. The fact that this calculation shows Hurricane Sandy's track to be so rare under long-term average climate conditions implies either the New York–New Jersey area was simply unlucky or that a climate-change influence increased the probability of its occurrence.

- Tornadoes

Tornadoes are currently the least understood extreme weather event when examined within the context of global warming. Tornado data do not reveal any obvious trends in tornado occurrence or deaths that would suggest a clear link to global warming (Figure 13). A recent paper (Kunkel et al., 2013), found that the occurrence of EF-1 and stronger tornadoes on the Enhanced Fujita Scale has shown no trend since 1954. Similarly, there is no evidence to indicate that EF-4 and EF-5 tornadoes — like the one that devastated a large swath of Moore, Oklahoma in May — are becoming more frequent or severe. In general, it's hard to identify meaningful trends in historical tornado data due to changing reporting practices (e.g., the advent of advanced radar technology).

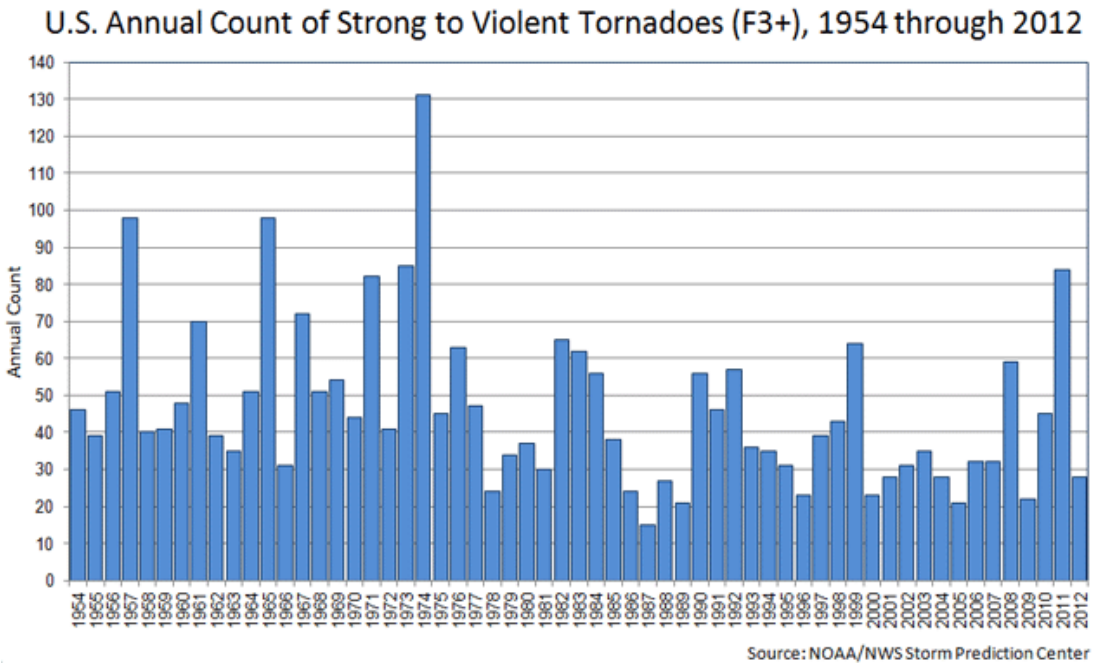

Figure 13: Number of annual EF-3 or greater tornadoes from 1954 to 2012. Credit: Storm Prediction Center.

Because historical tornado data is not considered very reliable or consistent, scientists have focused on how a warming climate might alter two of the basic ingredients that go into producing a tornado. First, you need warm, humid air beneath a layer of cool, dry air. Second, you need those layers to be traveling at different speeds or in different directions, a phenomenon called wind shear. These two conditions are common in the Plains states during the spring and early summer.

The jet stream pushes cool, dry air from the Rockies over slower-moving humid air from the Gulf of Mexico. When a disturbance like a cold front or a low-pressure system causes the two layers to interact, the hot layer tries to rise, and you get a rotating column of air that can turn into the sort of violent thunderstorm that sometimes spawns tornadoes.

Climate change will likely affect these two ingredients in opposite ways. On one hand, warmer air can hold more moisture than cool air can, so moisture content will increase with global temperatures. More moisture, plus higher temperatures may lead to more atmospheric instability and hence more thunderstorm activity.

On the other hand, wind shear is expected to decline as the Arctic warms. Most recent models point to higher moisture content resulting in more strong thunderstorms, but the lower wind shear means a smaller fraction of them will spawn tornadoes. Whether there will be so many more thunderstorms that they end up creating more net tornadoes, despite the lower wind shear, is unclear.

1b. What is causing the trend toward more extreme weather?

Ongoing research (Francis and Vavrus, 2012; Petoukhov et al., 2013) suggests a possible mechanism for the increasing extremes we are beginning to see. Specifically, by changing the temperature balance between the Arctic and mid-latitudes, rapid Arctic warming is altering the course of the jet stream, which is responsible for steering weather systems from west to east around the globe. The Arctic has been warming about twice as fast as the rest of the Northern Hemisphere, due to a combination of human emissions of greenhouse gases and unique feedbacks built into the Arctic climate system. According to this new research, the jet stream is becoming "wavier," with steeper troughs and ridges. Weather systems are moving more slowly, increasing the chances for long-duration extreme events, like droughts, floods, and heat waves. The tendency for weather to get stuck in one pattern is going to favor extreme weather conditions.

2. Global Warming Has Not Stopped

Global warming has not stopped. It is important that we distinguish between global mean *temperature* and global *warming*. While the temperature rise in the atmosphere may have temporarily slowed, the warming continues to penetrate into every component of our climate system.

The human impact on our climate system is significant. Current greenhouse gas concentrations are trapping enormous amounts of heat into our climate system every day. Despite, a record warm year in 2012, a steady rise in atmospheric greenhouse gas concentrations and a continued uptick in extreme weather events, some have begun to question whether global warming has stopped. Despite the fact that all 12 years of the 21st century (2001-2012) rank among the 14 warmest in the 133-year period of record, it is true that the rise in global surface temperature has been slower over the past 15 years when compared with the rate of increase during the 1970s, 80s and 90s (Figure 14).

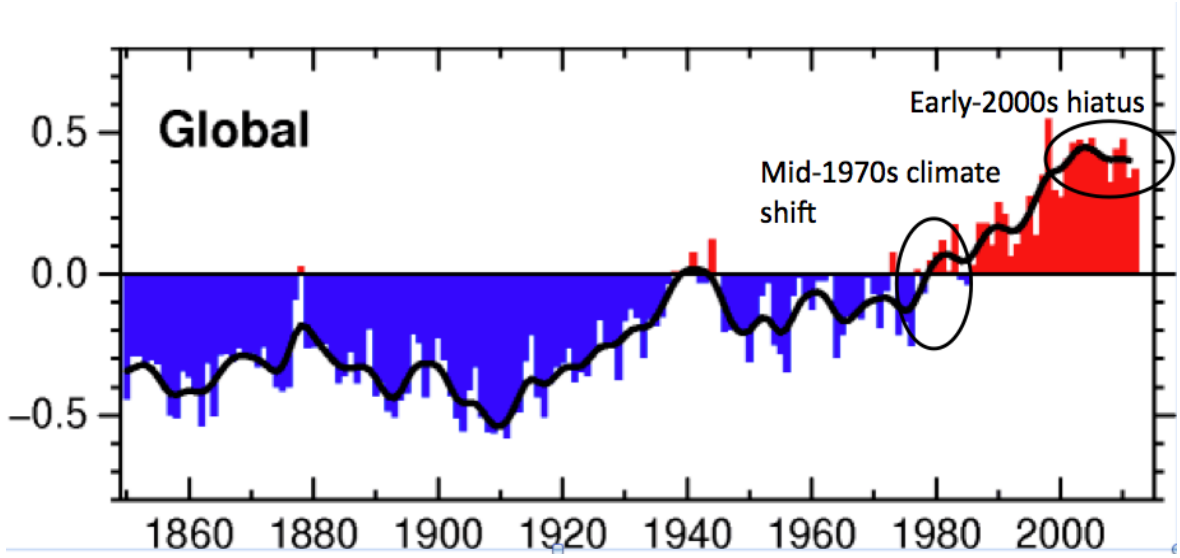

Figure 14: Global temperature anomaly from HADCRUT3. Courtesy: J. Meehl, NCAR.

First, this claim depends on the strategic selection of start and end points. The starting point for this so-called warming hiatus is almost always 1997-1998, a particularly warm period because of a strong El Niño. It is also important to note that the period contains several moderate-to-strong La Niña events, which tend to cool the planet slightly – including in 1999-2000, 2007-2008 and 2010-2011. The "early-2000s hiatus" is an area of active research that scientists are treating with extreme interest, as it is important to our understanding of the interplay between natural variability and human-induced warming, and also serves as a case study for improving the performance of our climate models. The active research question is focused on finding where the warming went and what possible sources of natural variations, resulting in a cooling effect, may have masked the warming.

A recent analysis of global ocean heat content measurements seem to have located the missing warming - in the deep ocean. Whereas upper ocean waters, from the surface to 2,300 feet depth, show no warming from 2004 to 2008, the waters from 2,300 to 6,500 feet show warming at an unprecedented rate. During the past decade, about 30% of the excess heat has been dumped into the deep ocean below 2,300 feet (Meehl et al., 2011; Balmaseda et al., 2013; Meehl et al., 2013). Ongoing research suggests that aerosols from a series of volcanic eruptions in the 2000s may also be playing a contributing role (Santer et al., in review).

3. The Important Role of the Oceans

It is important to keep in mind that there is much more to our climate system than our atmosphere. The oceans take up about a quarter of the CO_2 that we are putting into the atmosphere by fossil fuel burning and deforestation. The land surface takes up another quarter (Canadell et al., 2007).

Even more dramatic is the fact that the ocean absorbs more than 90 percent of the excess heat trapped by rising carbon dioxide levels (Church et al., 2011; Figure 15). This will continue until the surface ocean warms enough to balance the radiative forcing. This moderating effect of the ocean explains why there is 1°F of warming still in the pipeline

even if we stop adding CO_2 today. This is because water is both slower to warm and slower to release its heat than air. The process is no different than a cup of coffee. The coffee cools because it's releasing heat into the air above it, but the extra heat takes time to escape. Understandably, the process takes even longer if the coffee (ocean) continues being warmed as it is releasing heat. This is exactly what we see playing out in our climate system today. Therefore, it will take several decades for the climate to catch up to the warming expected for a given level of atmospheric carbon dioxide.

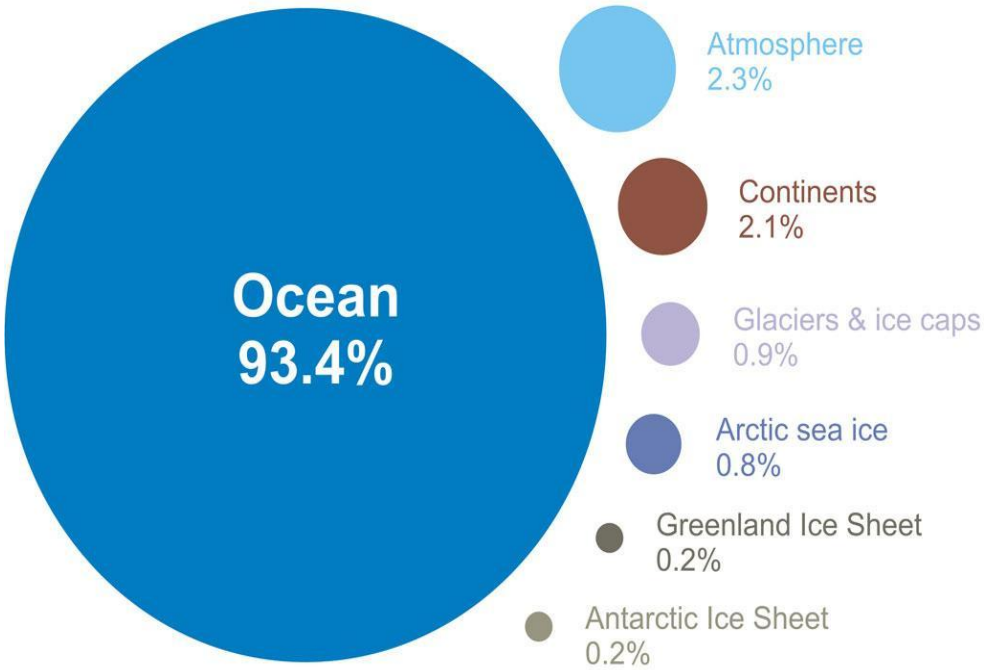

Figure 15: A breakdown of where the warming is going - components of global warming for the period 1993 to 2003 calculated from IPCC AR4 5.2.2.3.

3a. It's Largely Irreversible

Up until recently, most scientists were working under the assumption that if we went cold turkey and brought CO_2 emissions to zero, CO_2 concentrations (measured in parts per million or ppm) in the atmosphere would peak and then be most of the way back down toward pre-industrial levels in about 100 to 200 years, with the warming decreasing along with them. A recent study, using a climate model known as an Earth-system model of intermediate complexity, or an *EMIC*, looked at how long it would take for the concentration and climate to head back down (Solomon et al., 2009). Because EMIC's are not as sophisticated as general circulation models, they have the advantage of being fast allowing researchers to run very long simulations of the Earth's climate. The goal of the experiment being to see what the atmosphere remembered of current human activities 1,000 years from now, in the year 3000. The experiment tested what would happen if CO_2 emissions suddenly stopped after peaking at different concentrations, ranging from 450 to 1,200 parts per million. In the model, CO_2 levels dropped so slowly that by the year 3000 the atmospheric concentration was still substantially above pre-industrial levels. Global temperatures also stayed high, which means that downstream impacts such as irreversible dry-season rainfall reductions in several regions comparable to those of the "Dust Bowl" era and inexorable sea level rise are also irreversible. This irreversibility is just one of the

reasons why the United States National Academy of Sciences recently highlighted the need for an effective national response, including "enacting policies and programs that reduce risk by limiting the cause of climate change and reducing vulnerability to its impacts" (NRC, 2011).

In conclusion, climate change is, in many respects, the ultimate procrastination problem. The longer we wait, the greater the risks we will face and the greater the costs will be to respond.

Summary

The four primary points of my testimony today are as follows:

1. Global warming is occurring and it continues to influence all facets of our climate system – the atmosphere, oceans, land surface and ice sheets. This is a well-established fact despite recent claims of a so-called global warming hiatus.
2. There is very high confidence that the climate change of the past 50 years is primarily due to human activities (Stott et al., 2010).
3. There is strong evidence that certain types of extreme weather events in the United States have become more frequent and/or intense - including heat waves and heavy downpours, and in some regions floods, wildfires and droughts. For other types of extremes, such as tornadoes, evidence is much more limited.
4. Weather extremes that can be physically linked to human-induced climate change will likely worsen if emissions globally are not reduced. Because of the long timescales of the ocean – the warming is largely irreversible.

Thank you.

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RAA

REINSURANCE ASSOCIATION OF AMERICA

STATEMENT

TESTIMONY

OF

FRANKLIN W. NUTTER
PRESIDENT
REINSURANCE ASSOCIATION OF AMERICA

CLIMATE CHANGE: IT'S HAPPENING NOW

BEFORE

UNITED STATES SENATE
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

JULY 18, 2013

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My name is Frank Nutter and I am President of the Reinsurance Association of America (RAA). The RAA is a national trade association representing reinsurance companies doing business in the United States. RAA membership includes reinsurance underwriters and intermediaries licensed in the U.S. and those that conduct business on a cross border basis.

Thank you for the opportunity to testify before the committee to address the RAA's perspective on weather and climate-related weather impacts in the United States.

Reinsurance is essentially insurance for insurance companies. It is a risk management tool for insurance companies to reduce the volatility in their portfolios and improve their financial performance and security. It is widely recognized that reinsurance performs at least four primary functions—(1) helps insurance companies manage their risks; (2) stabilizes loss experience; (3) provides transfer for insurers of major natural and man-made catastrophe risk; and (4) increases insurance capacity.

Reinsurers have assisted in the recovery from every major natural and man-made catastrophe over the past century. 60% of the insured losses related to the events

of September 11, 2001 were absorbed by the global reinsurance industry. In 2005, 45% of the insured losses from Hurricanes Katrina, Rita and Wilma were paid by reinsurers; in 2011, insured losses for the New Zealand earthquakes totalled $17 billion, with reinsurers paying 73% of that total. In 2012, "Superstorm" Sandy caused an estimated $18 billion in insured losses. Reinsurers are expected to pay up to 40% of the insured losses.

Property casualty insurers are more dependent on the vagaries of climate and weather than any other financial services sector. Within the insurance sector, reinsurers have the greatest financial stake in appropriate risk assessment. The industry is at great financial peril if it does not understand global and regional climate impacts, variability and developing scientific assessment of a changing climate. Integrating this information into the insurance system is an essential function.

Insurance is a critical component for economic and social recovery from the effects of extreme weather and climate driven events. Through its pricing structure it is also a mechanism for conveying the consequences of decisions about where and how we build and where people chose to live. In this regard, it must be proactive and forward-looking in a changing climate/weather environment.

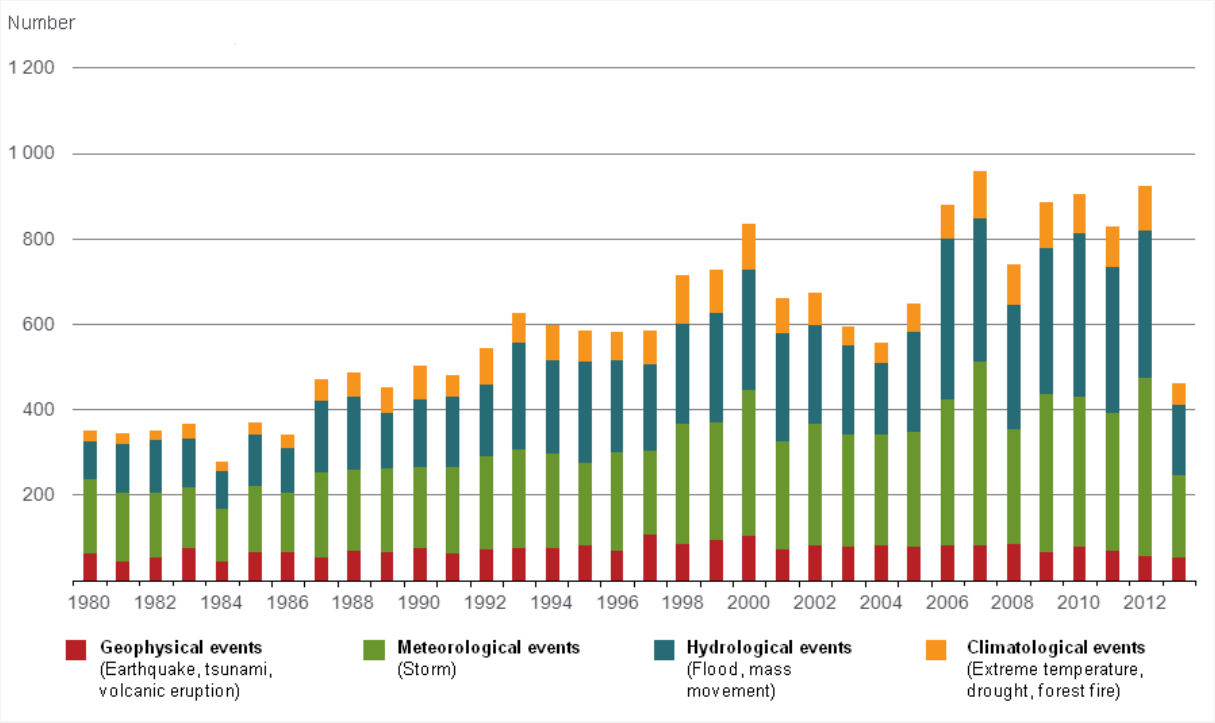
Our industry is science based. Blending the actuarial sciences with the natural sciences is critical in order to provide the public with resources to recover from natural events. As the scientific community's knowledge of changes in our climate and the resulting weather continue to develop, it is important for our communities to incorporate that information into the exposure and risk assessment process, and that it be conveyed to stakeholders, policyholders, the public and public officials that can, or should, address adaptation and mitigation alternatives. Developing an understanding about climate and its impact on droughts, heat waves, the frequency and intensity of tropical hurricanes, thunderstorms and convective events, rising sea levels and storm surge, more extreme precipitation events and flooding is critical to our role in translating the interdependencies of weather, climate risk assessment and pricing.

Exposure Assessment

Insurers see climate primarily through the prism of extreme natural events. Research by Munich Re reflects a rising number of natural catastrophes globally and in the U.S.

Natural Catastrophes Worldwide 1980 – 2013

Number of Events (Annual Totals 1980 – 2012 vs. First Six Months 2013)



Source: MR NatCatSERVICE

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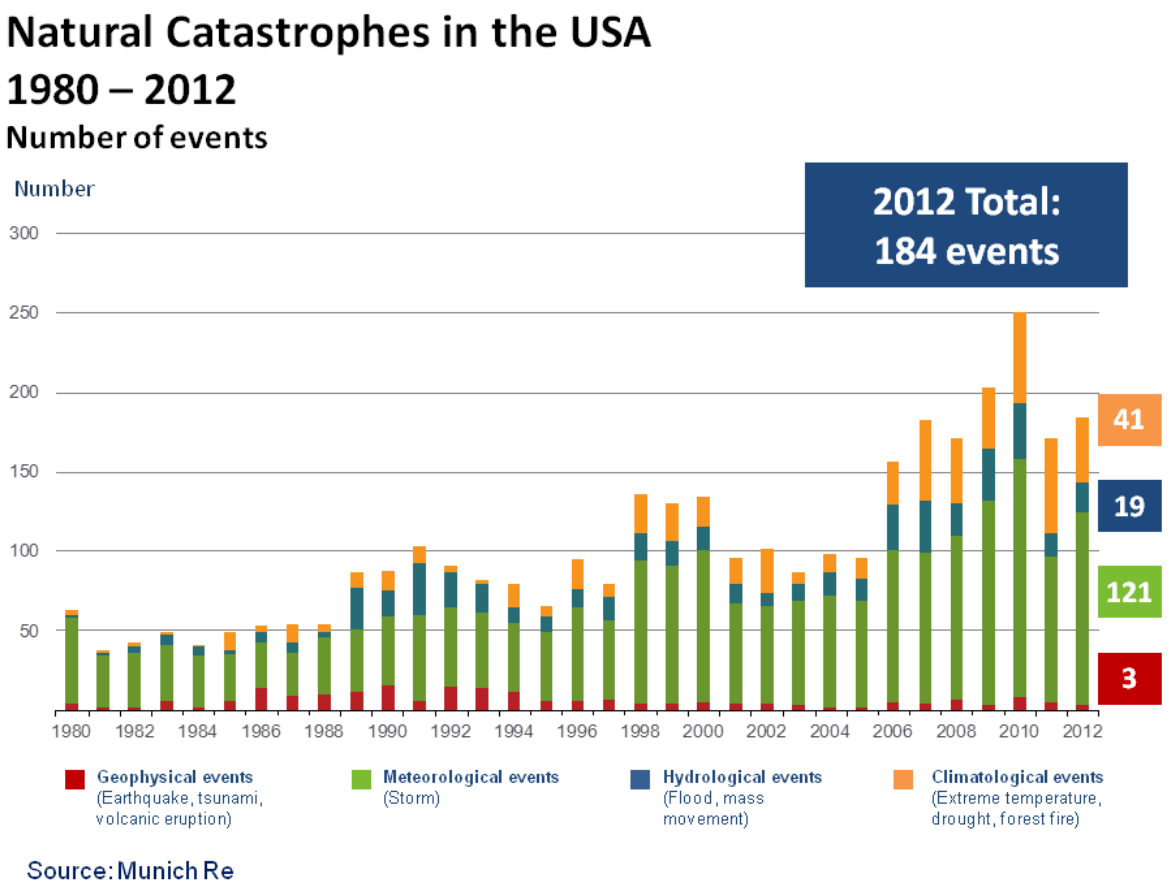
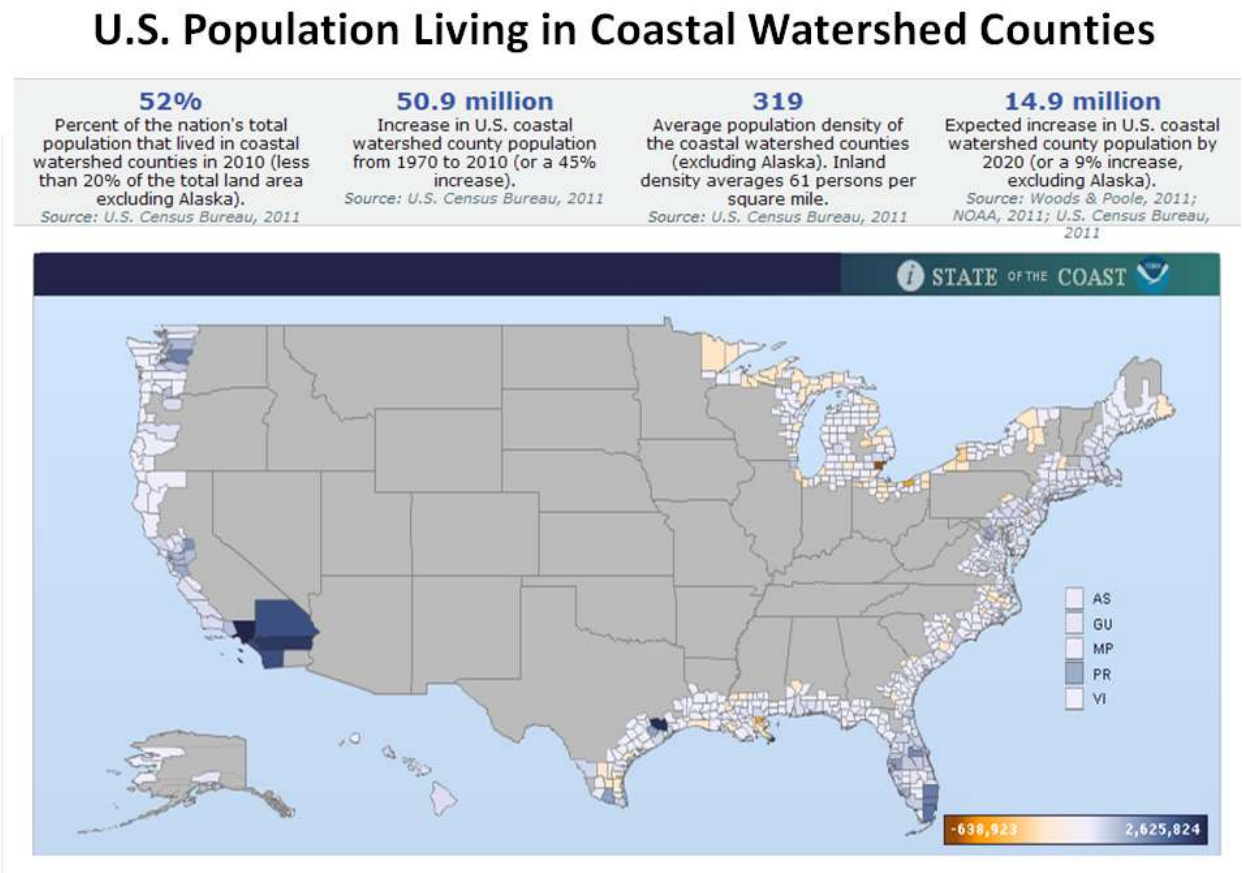


In the 1980's, the average number of natural catastrophes globally was 400 events per year. In recent years, the average is 1000. Munich Re's analysis suggests the increase is driven almost entirely by weather-related events. North America has seen a fivefold increase in the number of such events since 1980. In comparison, Europe has seen a twofold increase.

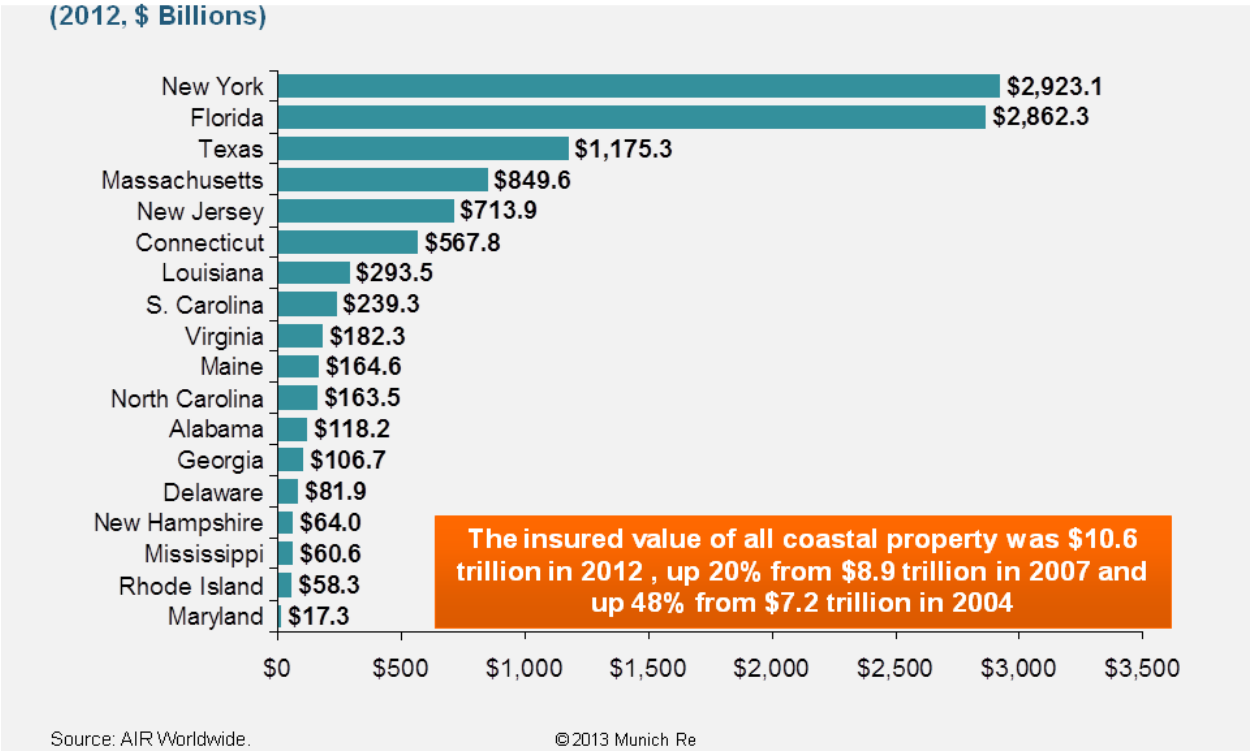
In this regard, it is indisputable that the recent rise in damages, insured, economic and uninsured, is heavily influenced by the concentration of people and property in geographically vulnerable areas. Urbanization, increased development and

population shifts have placed more people with destructible assets in areas most impacted by extreme weather. NOAA's recent State of the Coast report observes that in a U.S. population of 313 million (based on the 2010 census), coastal shoreline counties comprise 39% or 123 million people; watershed counties comprise 52% of the U.S. population. In coastal shoreline counties, NOAA reports there are 49 million housing units with an expected increase in population of 10 million people before the next census in 2020. The NOAA report notes that an average of 1355 building permits are issued per day in these shoreline counties.

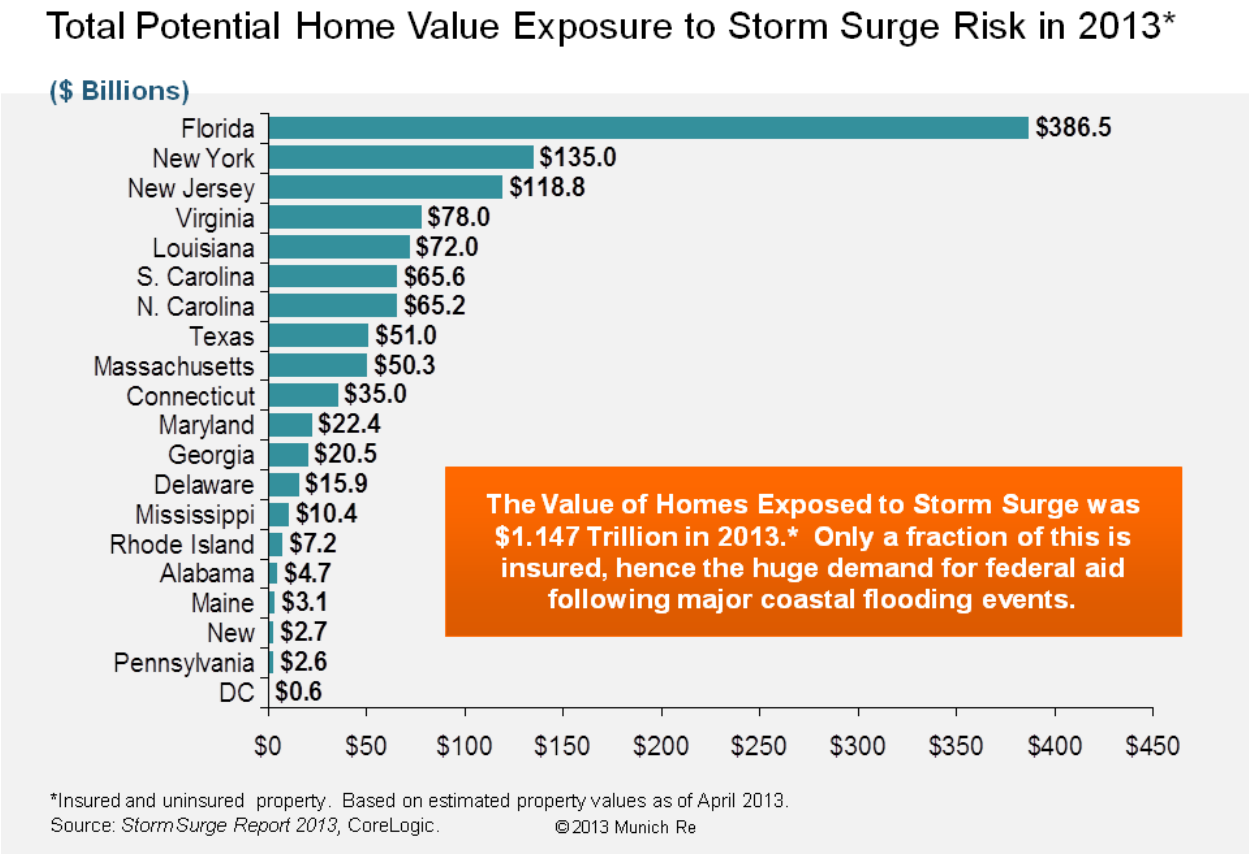


The Insurance Information Institute and Munich Re report that insured coastal property values on the East and Gulf coasts total nearly $10 trillion. Florida and New York each have nearly $3 trillion of insured coastal values.

Total Value of Insured Coastal Exposure in 2012



Research and consulting firm Core Logic reports there are 4.2 million homes along the Gulf and Atlantic coast exposed to storm surge–the most significant factor in damages associated with Superstorm Sandy. Most of these storm surge affected properties are in 10 metropolitan areas. One million of these are in the category of extreme risk to storm surge and another 839,000 in the high risk category. Core Logic notes that 23 of the 25 most populous U.S. counties are ocean-facing.



Catastrophe modeling firm AIR estimates the insured value of coastal properties (defined as replacement cost not market value) is expected to increase at a rate of 7% per year which means that values would double every decade.

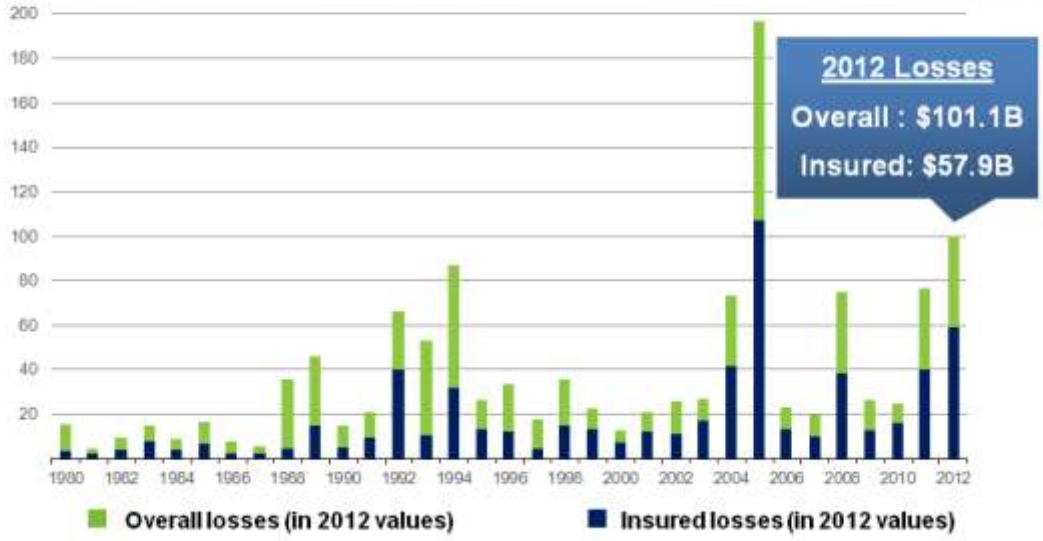
Together with changes in weather patterns, intensity, and number of events, the result, of course, is an inevitable rise in insured and uninsured damages globally and in the U.S.

Natural Catastrophes in the USA

1980 – 2012

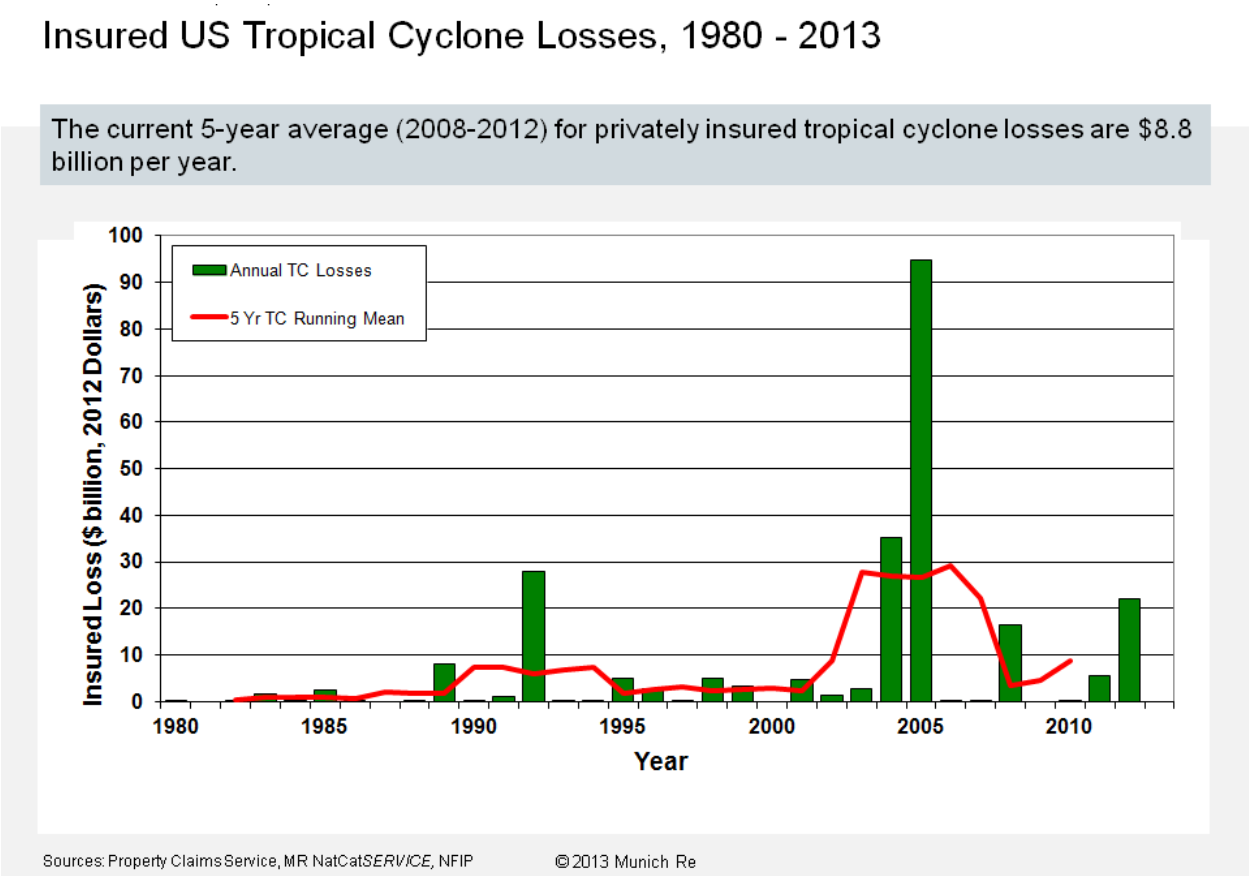
Overall and insured losses

Insured losses in the U.S. In 2012 were the second highest on record.

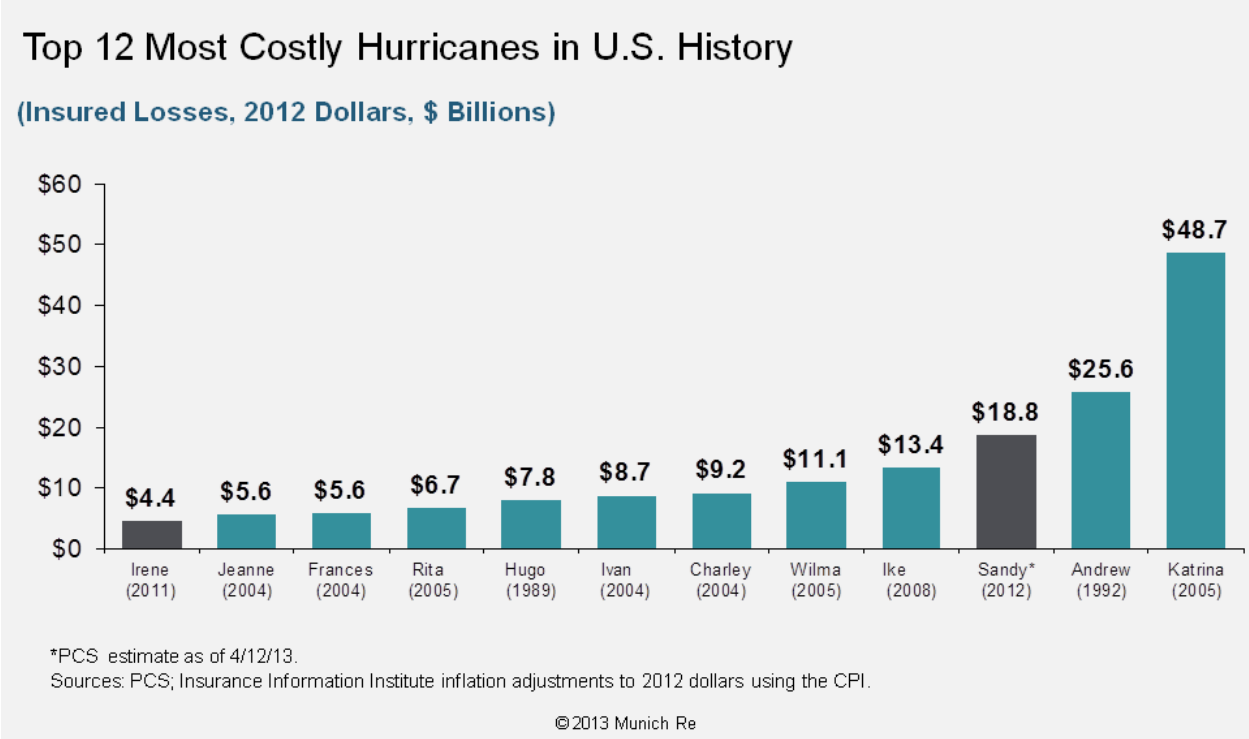


Source: Munich Re

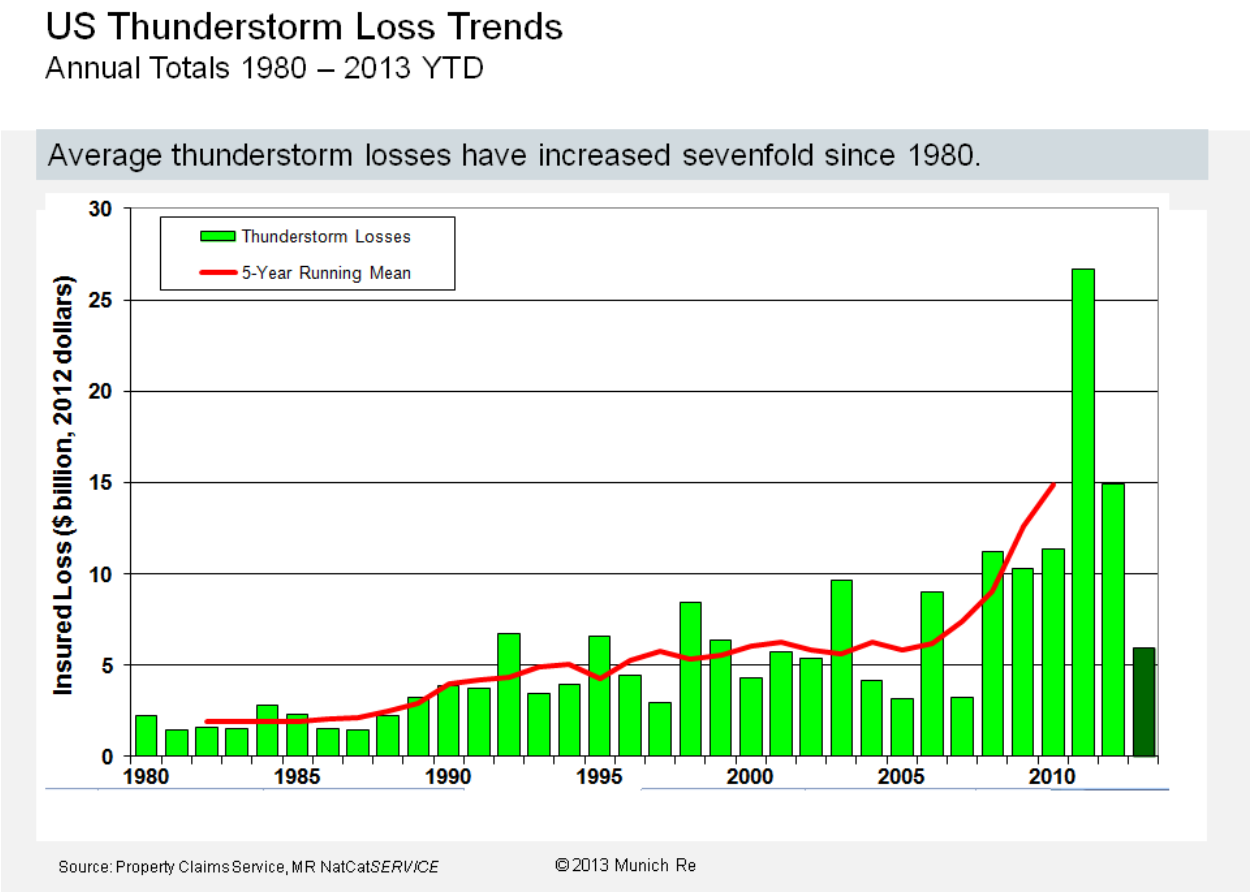
Hurricane related losses tend to dominate the pattern of large losses.



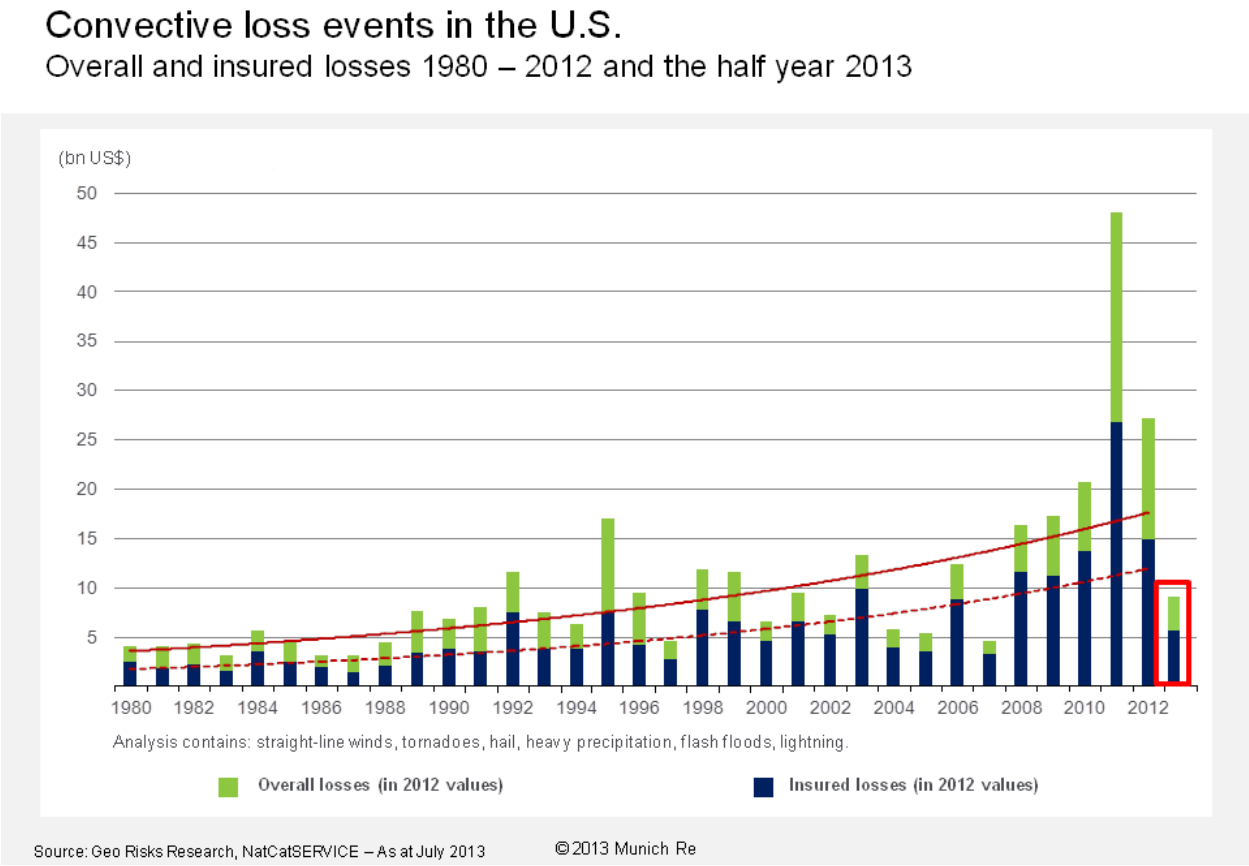
The pattern is recent. Ten of the 12 most costly hurricanes have occurred in the last nine years.



However, other climate/weather related perils also cause major damage.

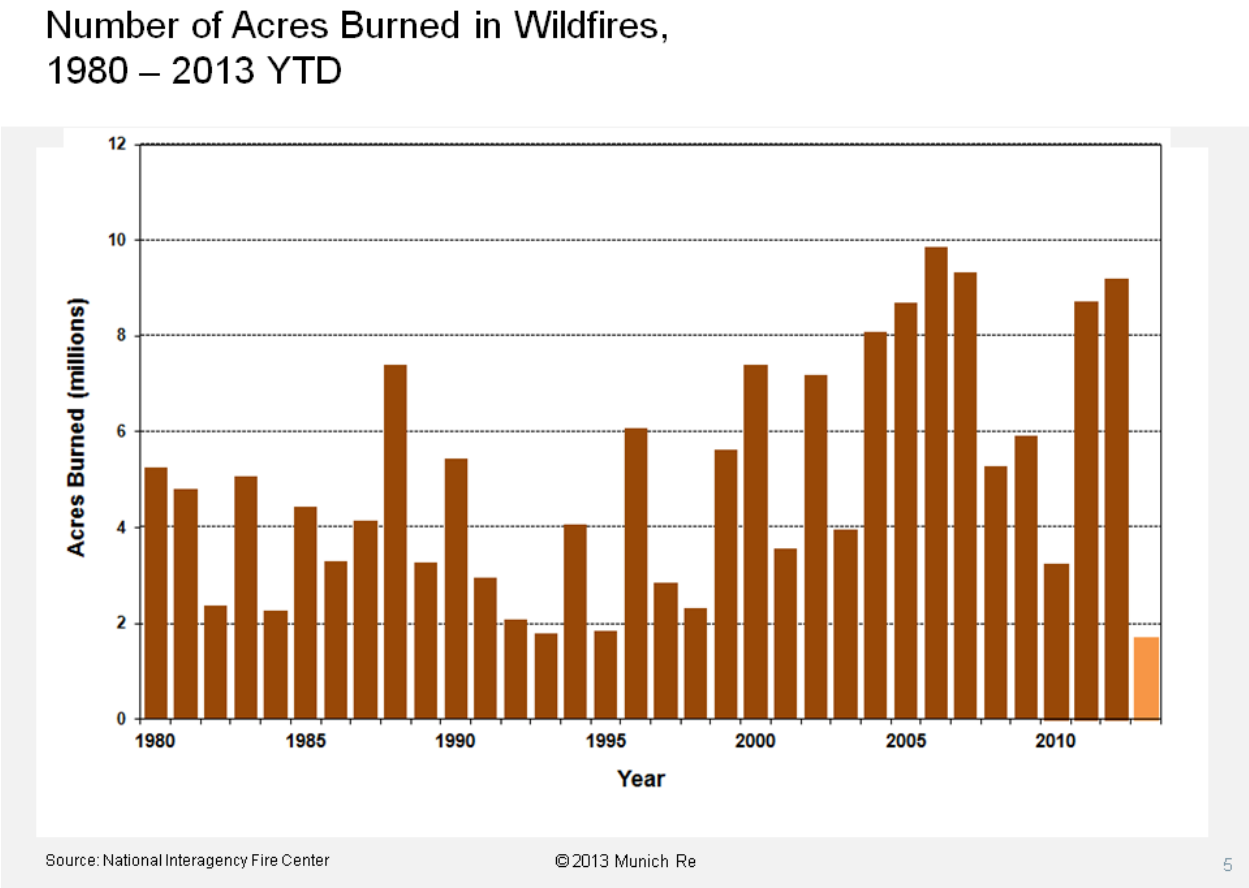


Tornado losses in the U.S. exceeded $1 billion only once prior to 1998. Since then, there have been 29 such events.



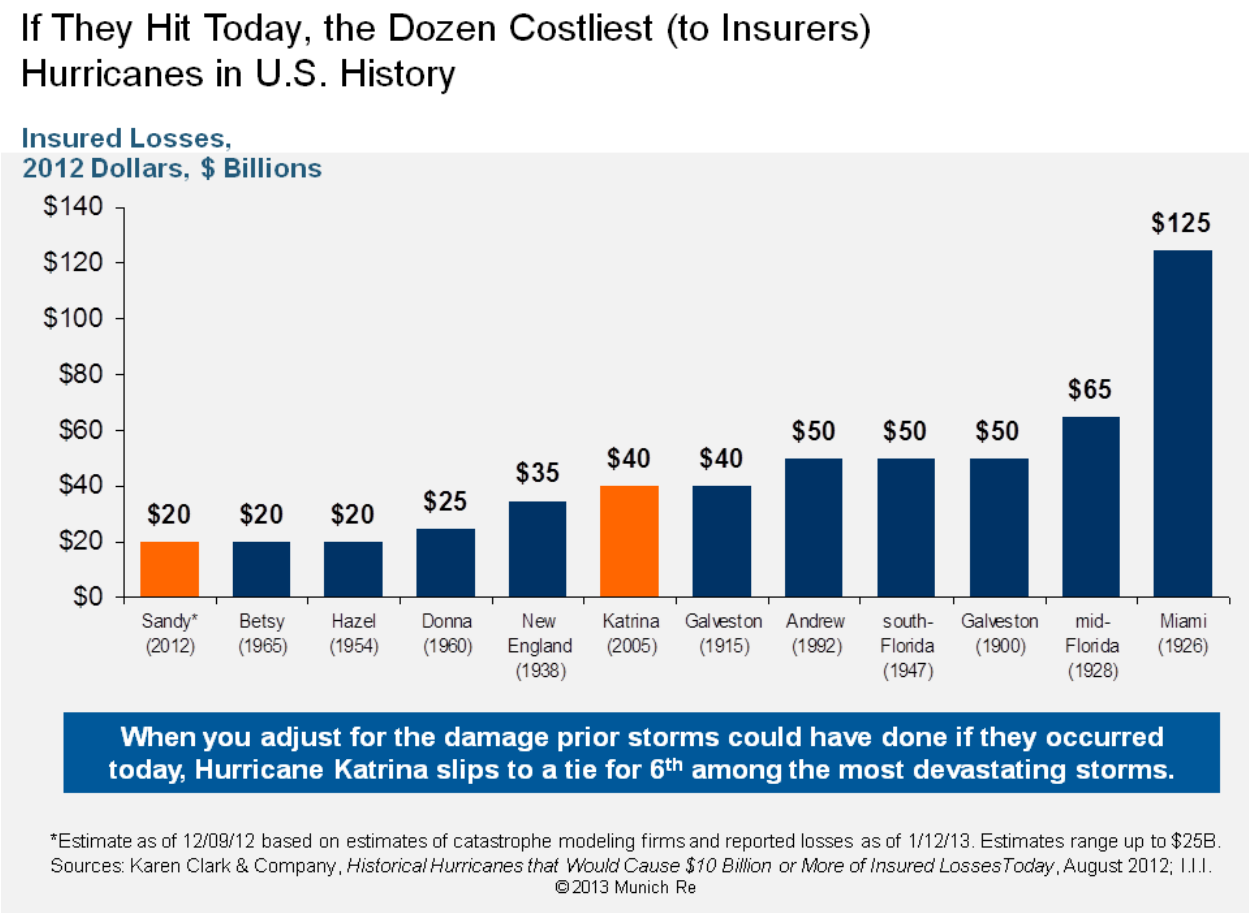
Severe wind is not the only peril reflecting this pattern. Goldman Sachs Global Economics reports the 2012 U.S. drought alone cut crop yields, reducing 3rd quarter 2012 GDP by .4%—the equivalent of another Supertsorm Sandy. Droughts are now the third most costly category of natural catastrophe loss with crop losses dominant.

Recent wildfire major events have destroyed homes and threatened communities.



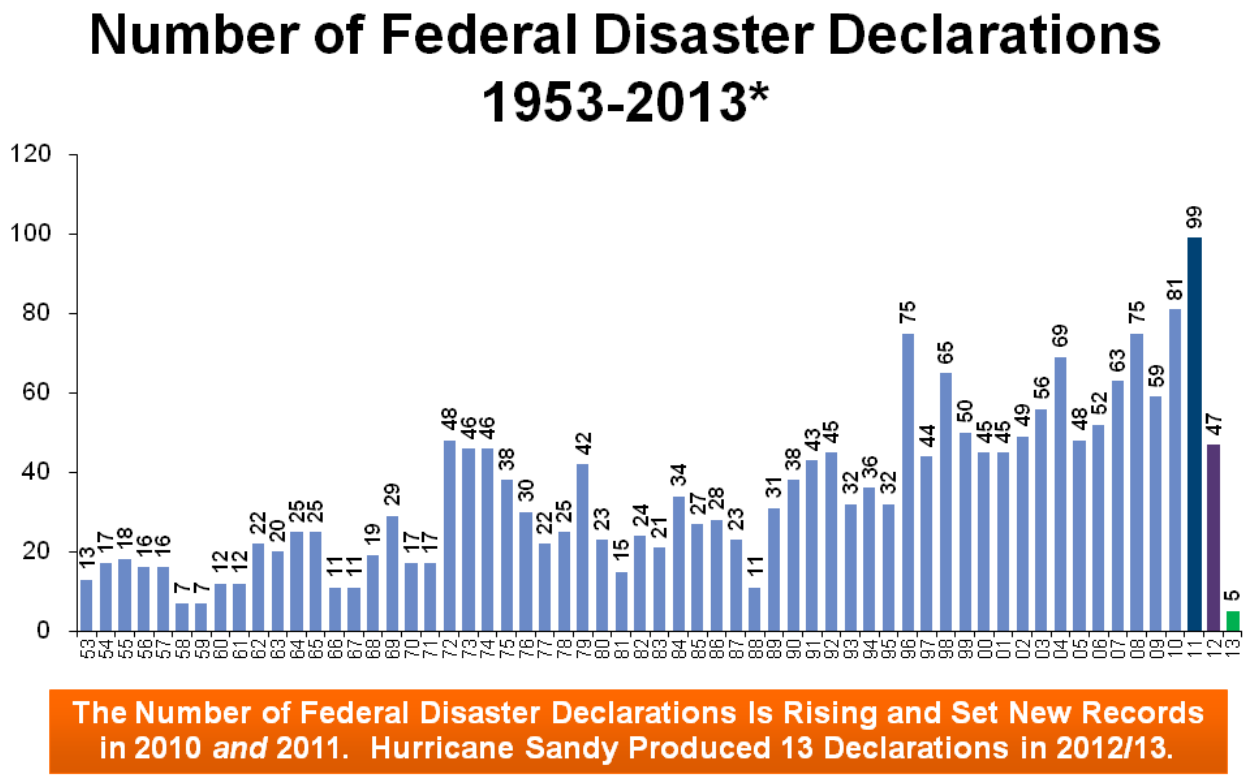
Future Assessment

But what if the past is not prologue and, in a changing climate, weather, economic and social trends exacerbate the impact. The Insurance Information Institute projected future losses from past events that reflect rising exposures in areas proven to be at high risk to major climate/weather events.



In a study on Climate Change Impacts conducted for FEMA by AECOM, the firm concluded that the typical 100 year floodplain nationally would grow by 45% and by 55% in coastal areas (with significant regional variations and assuming a fixed shoreline). Notably the report attributed 70 percent of the projected growth in 100 year floodplains to climate change and 30 percent to expected population growth (the analysis assumes 4 feet of sea level rise by the year 2100). The study recommends immediate attention to the implications for the Federal government's National Flood Insurance Program, which is already $26 billion in debt.

Disaster assistance is already a major expense to the Federal government and has set records in recent years.



Dr. David Cummins of Temple University's School of Risk Management estimates the subsidization of disaster-prone areas embedded in Federal disaster assistance practices has encouraged development and increased Federal exposure. He estimates the expected average annual bill for Federal disaster assistance related to natural catastrophes at $20 billion. Current funding for FEMA's Disaster Relief Fund is $1 billion. Dr. Cummins estimates this unfunded liability over the next 75

years at $1.2 to $5.7 trillion, at the high end, essentially the unfunded obligations for Social Security.

Adaptation and Mitigation Strategies

Swiss Re has been a leader in addressing climate change for many years.

"Today, global warming is a fact. Since the beginning of industrialization and the rapid growth of world population, man's activities – along with natural variability – have contributed to a change of climate manifesting itself as a considerable increase in global temperature. Climate change has the potential to develop into our planet's greatest environmental challenge of the 21st century.

As an enabler of change, the financial services industry can help guide society towards an effective response. However, the industry can only be effective in this role if the regulatory and legislative framework establishes the right incentives for emissions reduction and adaptation on a global scale."

Munich Re shares this view:

"Anthropogenic climate change is believed to contribute to this trend (a jump in catastrophe losses) though it influences various perils in different ways.

In order to realize a sustainable model of insurance, it is crucially important for us as risk managers to learn about this risk of change and find improved solutions for adaptation and mitigation." (Peter Roeder)

"Globally, climate change alone will increase worldwide losses by 100% by the end of the 21st century. The overall increase in losses in the United States due to climate change alone will be more than 70% by the end of the century according to a wind-based model."

The Geneva Association (International Association for the Study of Insurance Economics) states the need for action as follows:

"The economic and social impacts of climate change could be immense; there is therefore a need for urgent and concerted *mitigation* action to reduce GHG emissions, supported by strong incentives from policy-makers. But regardless of the action taken to mitigate climate change, we can expect many decades of changing climate risks due to inertia within the climate system. We therefore also need concerted *adaptation* to avoid the predicted impacts of climate change and especially to protect the most vulnerable populations."

Congressional Action

As Congress considers the impact of climate change, the RAA suggests the following legislative principles or actions to consider:

- Provide tax credits to individuals for specified mitigation and resiliency actions associated with extreme weather and climate change.
- Incent communities to develop and implement mitigation and resiliency initiatives.
- Reform the National Flood Insurance Program to reflect extreme weather and climate risk in its rates.
- Apply Federal standards to state/local building codes and incorporate climate and extreme weather risk into these standards.
- Purchase or relocate properties near coastal or river areas at repeat risk.
- Use nature to mitigate risk before and after extreme events.
- Transfer development rights from coastal and river properties to areas inland (Strengthen the Coastal Barrier Resources Act)
- Fund adequate remote sensing for NOAA and NASA.
- Require the Army Corps of Engineers to assess climate risk for all projects.
- The Federal government should lead by example: GSA should assess its buildings and critical facilities in light of climate and extreme weather information.

- Fund climate and weather research through the National Science Foundation, NOAA and other Federal agencies at priority levels.
- Use disaster assistance as an incentive for local communities for climate and extreme weather sensitive, forward looking recovery.

Conclusion

The Reinsurance Association and its member companies welcome the attention of Congress to the critical issues of extreme weather and climate. We are committed to work with you to address the exposure of citizens and their property to extreme weather risk and to seek ways to improve the resilience of our communities.

Resources

- Core Logic: Storm Surge Report: Residential Storm Surge Exposure Estimate for the US Coastal Areas (2012)
- Federal Financial Exposure to Natural Catastrophe Risk, David Cummins, Michael Suher and George Zanjani (2010)
- Goldman Sachs, Global Economics, Commodities and Strategy Research
- ClimateWise, Summary of the IPCC Special Report on Managing the Risks of Extreme Events and Disasters
- Applied Insurance Research Coastline at Risk: Update to the Estimated Insured Value of US Coastal Property (2013)
- NOAA State of the Coast National Coastal Population Report (March 2013)
- Geneva Association (International Association for the Study of Insurance Economics): The Insurance Industry and Climate Change (July 2009)
- Munich Reinsurance, Climate Variability and Climate Change
- AECOM: The Impact of Climate Change and Population Growth on the national Flood Insurance Program through 2100 (June 2013)

Testimony of KC Golden
Senior Policy Advisor, Climate Solutions
before the

Committee on Environment and Public Works
United States Senate
"Climate Change: It's Happening Now"

July 18, 2013

Madame Chair, Ranking Minority Vitter, members of the committee, thank you for the opportunity to tesify today. My name is K.C. Golden, and I serve as Senior Policy Advisor to Climate Solutions, a Northwest regional organization promoting practical and profitable solutions to climate disruption.

My testimony will affirm that climate solutions are feasible, practical, and economically sound. Americans are stepping forward to develop and deploy these solutions now. Our commitment to deliver clean energy, energy efficiency, and better transportation choices is helping us build stronger local economies and healthier communities. But we cannot implement these solutions at scale without the active engagement and partnership of our federal government, including the United States Congress. And so it is with tremendous hope and determination that I welcome this opportunity to speak with you and invite that partnership.

My knowledge of these issues and the examples I will use are based primarily on my experience implementing solutions in the Pacific Northwest, but there are similar examples of Americans delivering promising solutions throughout the nation. My testimony will focus on three points:

- **We have the tools – the technologies, the resources, the economic models – to deliver cost-effective climate solutions at scale.**

- **Key Federal actions needed to accelerate deployment of climate solutions are straightforward: responsible limits on climate pollution; a fair price for dumping carbon into the atmosphere; and an end to federal support for major new capital investments that make the problem intractably worse.**

- **The absence of these federal actions is taking a high toll on Americans now, including the rising cost of climate damages, costly misallocation of our energy dollars, and undermining Americans' efforts to develop and deploy solutions.**

After reviewing some of the testimony you will hear today about the dimensions of the climate crisis and the human costs it imposes, one can't help but wonder why the United States of America has been so slow and timid in rising to this challenge. If there were viable solutions that spared us these astronomical costs, wouldn't the world's most powerful nation, with the world's greatest technical and economic resources, already be implementing those solutions?

To make sense of this apparent contradiction between the dimensions of the crisis and the weakness of our national response, we might be tempted to conclude that we *have* no viable solutions. We might infer that the technology doesn't exist; that the economics of switching from fossil fuels to clean energy are prohibitive; that we lack the knowledge, the policy tools, the technical capacity, the economic models or some other critical resource for implementing solutions at scale.

The purpose of my testimony here today is to affirm that none of these insurmountable obstacles exist. We can do this. In the Northwest, we *are* doing it. But no city, no state, no region can do it at the scale and pace that the climate crisis demands without the power and will of the United States Congress. We are prepared to play our part and then some, but nothing short of a firm national commitment and international leadership for solutions will do the job.

1. **We have the tools – the technologies, the resources, the economic models – to deliver cost-effective climate solutions at scale.**

Climate disruption is a *big* challenge, but at its core, it is not overwhelmingly complicated. The primary solution is the transition from inefficient use of fossil fuels to efficient use of clean energy forms that do not add to the concentration of heat-trapping gases in the atmosphere. (Terrestrial carbon storage – in healthy forests, soils, and wetlands – will also play an important role in stabilizing greenhouse gas concentrations[1].)

Non-fossil energy forms are abundant and reliable. The sun delivers thousands of times more energy to the Earth than humans use, and has been doing so, without an outage, for over 4 billion years. The amount of solar energy that hits in the Earth in an hour is more than humans use in a year[2]. The fossil fuels we use today are, of course, one form of this energy – solar energy harvested by plants and stored in the Earth's crust. But this is hardly the only way to harvest, store, and use solar energy. Wind, waves, biomass, and hydropower are all solar-derived energy sources. Technology for converting these resources to usable heat and electricity is widely available now, at costs that are already competitive with fossil fuels in many applications. The climate challenge in a nutshell is the challenge of meeting our energy needs with fresh energy instead of "canned" fossil fuels, while squeezing far more work out of

[1] See Northwest Biocarbon Initiative: http://climatesolutions.org/programs/NBI/nbi_onepager
[2] "Spotlight on Solar Energy," *Nature Education* http://www.nature.com/scitable/spotlight/solar-energy-8731061

the energy we use by using it more efficiently. (I include brief observations about the prospective roles of two non-fossil, non-solar-derived resources – geothermal and nuclear – in footnotes 3 and 4 below[3][4].)

The availability and feasibility of climate solutions at scale is thoroughly documented. Some of the more comprehensive treatments include:

- McKinsey and Company's "Pathways to a Low-Carbon Economy"[5], which develops a global greenhouse gas abatement cost curve, combining a range of technologies, many of which carry a negative price tag. They find that known climate solutions can be deployed at a pace and scale sufficient to avert catastrophic climate changes, at a cost of less than 1% of global GDP.
- In its "Renewable Electricity Futures Study,"[6] The National Renewable Energy Laboratory finds, "Renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the country."
- The Princeton Carbon Mitigation Initiative has developed a widely used tool for comparing and analyzing climate solutions called "Stabilization Wedges"[7] Their analysis confirms: "We already have the technology we need to take the world off the path toward dramatic climate change."

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[3] Geothermal energy – in both direct application and for power production – holds tremendous potential. See, e.g., http://thinkprogress.org/climate/2011/11/06/359699/google-geothermal-supply-chu/ and http://www.nrel.gov/gis/geothermal.html.

[4] Nuclear power remains plagued by cost, safety, waste, and weapons proliferation problems. (http://pbadupws.nrc.gov/docs/ML1129/ML112940552.pdf) For those who see promise in new nuclear designs, the climate policy recommendations below should be attractive as a fair way to level the playing field with fossil fuels and offer new nuclear "A Fair Shot, not a Free Ride": http://grist.org/article/2009-11-09-new-nukes-a-fair-shot-not-a-free-ride/

[5] "Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve," McKinsey and Company, http://www.epa.gov/statelocalclimate/documents/pdf/mckinsey_summary_11-19-09.pdf

[6] National Renewable Energy Laboratory http://www.nrel.gov/analysis/re_futures/

[7] Princeton Carbon Mitigation Initiative: http://cmi.princeton.edu/wedges/intro.php An accelerated application of the basic wedges approach is necessary to develop solutions at the required pace and scale, as former Acting

In the Pacific Northwest, we are ground-truthing these estimates of clean energy potential. Renewable energy isn't "alternative" energy in Washington and Oregon. It's the backbone of our existing power system. We have honed our "renewable edge" with decades of investment in energy efficiency, maximizing the value and productivity of our hydroelectric supplies while improving the comfort of our buildings and the competitiveness of our industries. Our air is cleaner, our economy is stronger, and we enjoy some of the lowest cost power in the nation because of our long-term commitment to clean energy.

In recent years, we have begun to add substantial amounts of new renewable resources to our energy portfolios. And we have adopted climate plans[8] that commit our jurisdictions to responsible limits on climate pollution and accelerated deployment of clean energy systems. Climate disruption and ocean acidification represent clear and present dangers[9] to Northwest communities and economies – threatening our water, power, and food production systems, undermining the health and productivity of our forests, eroding our shorelines, and increasing the loss of lives and property from extreme weather and fires. We cannot solve this problem alone, but we are committed to do our part, and we believe that doing so helps us build a healthier future and a stronger, more durable economy.

These historic and new clean energy commitments are vital to the region's economy. They support our existing manufacturing and industrial base, including global leaders in aviation, wood products, and materials. They are accelerating the development of dynamic new, job-creating industries including renewable energy, energy efficiency, advanced transportation, software, and smart grid technology.

Assistant Secretary of Energy Joe Romm describes at: http://thinkprogress.org/climate/2011/01/10/207320/the-full-global-warming-solution-how-the-world-can-stabilize-at-350-to-450-ppm/

[8] Washington State Executive Order 09-05, "Washington's Leadership on Climate Change," at http://www.ecy.wa.gov/climatechange/2009EO.htm ; Oregon Global Warming Commission Interim Roadmap to 2020 at http://www.keeporegoncool.org/sites/default/files/Integrated_OGWC_Interim_Roadmap_to_2020_Oct29_11-19Additions.pdf

[9] See, e.g., Washington State impact assessment at: http://www.ecy.wa.gov/climatechange/

And our clean energy edge is an important part of the overall quality of life that attracts investment, innovation, and an excellent workforce to our region. Clean energy leadership is part and parcel of our regional identity and our economic profile.

As a result of this leadership, we are phasing coal out of our regional energy supplies. Seattle City Light sold off its share in a coal plant in 2000, and completely eliminated net carbon emissions from the City's power supply in 2005, while providing some of the cheapest power in urban America. In 2011, we reached a consensus agreement[10] to phase out that same coal plant – the only coal-burning commercial power plant in Washington, and the source of roughly 10% of the state's total emissions of climate pollution. That agreement enjoyed unanimous support from the plant's owner, the local community, conservation groups, and the workers at the plant. Our successful experience with clean energy created a widely-shared sense of confidence in our ability to power our future with cleaner energy sources.

The Northwest Power and Conservation Council, created by an act of Congress in 1980, develops long-range electric power plans for the 4-state region served by the Bonneville Power Administration. In its sixth and most recent plan, the Council concludes that the most cost-effective plan for the region would meet 85% of the region's projected growth with energy efficiency, and most or all of the remaining 15% with new renewable resources. At the Council's meeting earlier this month, Washington Governor Jay Inslee charged the Council with developing a plan to meet all of the region's electricity needs (including load growth and existing demand) with clean, carbon-free resources.

We take pride in our clean energy achievements and our commitment to climate solutions. Our communities are healthier, our economy is stronger, and our future is more secure as a result of these investments. But we know full well that no city or state can successfully address the climate challenge unilaterally. And so our climate strategies are designed to pioneer and prove out the technologies,

[10] "Transalta Agreement Shows the Power of Compromise," *Olympian,* March 11, 2011 at http://www.theolympian.com/2011/03/11/1574719/transalta-agreement-shows-the.html

energy systems, and transportation strategies that can power a healthy future, in our region or anywhere else. Rising to the climate challenge means not just reducing our own carbon footprint, but opening up energy pathways to economic security – pathways that work for the long haul, not just for us, but for the billions of people worldwide who yearn for economic opportunity. We call this "sustainable prosperity," and we believe it's our best future.

"Global warming" accurately describes the trajectory of the global average temperature, but no one lives in the global average temperature. No one works or plays or gets anything done in the global average temperature. When we think concretely about the impacts, the causes, and the solutions, the action is primarily local. Communities can do most of the practical work of implementing solutions. But we know we can't build this future on an island. We need federal action to create the larger policy context in which local actions can succeed and drive national and global solutions at scale. Next, I'll address some of the most important features of that policy context.

2. **Key Federal actions needed to accelerate deployment of climate solutions are straightforward: responsible limits on climate pollution; a fair price for dumping carbon into the atmosphere; and an end to major new capital investments that make the problem intractably worse.**

The federal government has many vital roles to play in rising to the climate challenge, some of which it is already playing. My testimony will not comprehensively address these roles and actions, but rather focus on three that are foundational for driving solutions at scale.

In focusing on these three, I do not mean to understate the importance of other critical federal actions, including but not limited to expanding America's commitment to energy innovation[11], clean

[11] See, e.g., the recommendations of the American Energy Innovation Council http://americanenergyinnovation.org/the-business-plan-summary/

energy deployment in federal operations (particularly the military and the federal Power Marketing Administrations), low-income weatherization, energy codes and standards, clean transportation infrastructure, tax credits for clean energy production and manufacturing, and international leadership in climate solutions. But all of the federal government's existing and prospective clean energy and climate initiatives would be made more effective, efficient, and productive if the United States had the basic infrastructure of a responsible climate policy, as described below.

Responsible limits on climate pollution:

There is of course no single policy that will effectuate all the necessary solutions. But there is a policy choice that calls the essential question — a single decision that will signify a genuine commitment to reduce fossil fuel dependence and deliver climate solutions at scale, with real accountability for results: *firm, science-based limits on climate pollution*.

The United Nations Framework Convention on Climate Change[12] (which the first President Bush signed in 1992) commits the world to implement actions that avoid dangerous climate disruption. The Copenhagen Accord[13] further refined that commitment, calling for emission reductions designed to prevent global average temperatures from increasing by more than 2 degrees Celsius, the scientific standard for dangerous climate change.

Limits on climate pollution that meet these scientific requirements are the simplest, strongest climate policy. Some states and cities, and the rest of the world's advanced economies, have adopted such limits in various forms. The absence of such a policy in the United States remains the most conspicuous missing piece of a viable global strategy for solutions.

[12] http://unfccc.int/2860.php
[13] http://unfccc.int/meetings/copenhagen_dec_2009/items/5262.php

A limit on climate pollution is not a complete policy blueprint, by any means. But it is a foundation — a serious public policy commitment to do the whole job. It is the clearest possible signal — to energy markets, to the international community, to ourselves — that we are stepping up to the climate crisis and the unprecedented opportunity for economic renewal in solving it. It will unleash investment and innovation to implement existing solutions and develop new ones. It leaves many questions unanswered, but it answers the first and most important threshold climate policy question: "Do we have the will to do what is right and necessary?"

A fair price for dumping carbon pollution in the atmosphere:

"The problem of climate change involves a fundamental failure of markets: those who damage others by emitting greenhouse gases generally do not pay,"[14] according to Sir Nicholas Stern, Chair of the British Academy and author of Stern Review[15], a comprehensive assessment of the economic costs of climate disruption and climate solutions. Economists refer to this market failure as an "externality" – a circumstance in which real costs are not properly accounted for in economic transactions because they remain external to the prices paid by buyers in the marketplace.

As other testimony today will show, these costs are real and present. Americans are paying them now, in the form of more extreme weather events, more destructive fires, drought, and a variety of other climate impacts. Were these costs more accurately reflected in the economic choices we make in energy markets, we could *avoid* many of them. We could choose non-fossil energy sources that would be *cheaper* if these climate-related costs were properly accounted for and included in prices.

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[14] "Stern: Climate change a market failure," *Guardian,* http://www.guardian.co.uk/environment/2007/nov/29/climatechange.carbonemissions

[15] *Stern Review on the Economics of Climate Change* http://webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/sternreview_index.htm

This market failure amounts to a massive subsidy. Americans are forced to pay the costs of climate disruption -- a huge, involuntary transfer of private costs onto the public. Internalizing this cost by pricing carbon would spare of us many of these impacts and damages, as energy markets began to more efficiently allocate capital toward solutions. When prices tell the truth about costs, markets function will more effectively, and climate solutions will accelerate. Experience in British Columbia, which relies on a revenue-neutral carbon tax, confirms that the policy has been effective in reducing emissions while BC's economic growth outpaces the rest of Canada's[16].

Prices for carbon pollution are the natural corollary to limits. In a market economy, scarcity generally drives value, so when the right to pollute becomes more limited, it also becomes more valuable (insofar as it can, like other goods and services in a market economy, be bought and sold). Carbon prices can either be set directly by governments, through a carbon tax, or set by markets, by issuing a limited quantity of pollution allowances and allowing them to be traded. The difference between a system of tradable allowances and a carbon tax is largely a matter of whether government sets the allowable *quantity* of carbon pollution (and allows private markets to arrive at the corresponding price) or government sets the *price* (and allows markets to arrive at the corresponding quantity.) Both limits and prices are necessary in order to drive innovation, investment, and deployment of climate solutions at scale. The Climate Protection and Sustainable Energy Acts introduced by Senators Boxer and Sanders would set a predictable, price, escalating over time, while returning most of the revenues directly to citizens as dividends. Clean energy investments funded by this policy would help to ensure that consumers have a growing array of cost-effective alternatives to fossil fuel dependence.

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[16] "British Columbia's Carbon Tax Shift: The First Four Years" *Sustainable Prosperity,* http://www.sustainableprosperity.ca/dl872&display

Fair carbon pricing is simply sound economic policy. It would allow energy markets to function more efficiently, reduce total energy costs, and more equitably assign accountability for the true costs of climate pollution. The absence of these prices imposes real and growing economic burdens on Americans and makes all other emission reductions efforts less efficient and productive than they should be, as I will describe in the final section.

Opponents of carbon pricing sometimes characterize it as a penalty for fossil fuel consumption. As the growing number of victims of climate-related disasters can attest, the cost "penalty" associated with fossil fuels *already exists*; pricing carbon simply asks those who cause the costs to incur them, rather than foisting them on to everyone else. And it is important to note that the purpose of such a policy in this context is not to pay the cost at all. By correctly and fairly aligning prices with costs, carbon pricing empowers consumers, producers, investors, and other economic actors to make more rational decisions to *avoid* the cost of carbon by reducing emissions. When we square up to the true costs of climate disruption, we will find that we have better, less costly ways to meet our energy needs.

An end to major new capital investments that make the problem intractably worse:

In its 2011 World Energy Outlook[17], the International Energy Agency warned that the global pattern of energy infrastructure investment must shift, decisively and immediately, away from fossil fuels or we will "lose forever" the chance to avert catastrophic climate disruption. This does not mean that we need to cease fossil fuel consumption immediately. It does, however, mean that we must *stop making the situation worse* with large and irreversible *new* investments that "lock-in" emission trajectories which guarantee dangerous climate disruption. Once these long-term investments are

[17] "The world is locking itself into an unsustainable energy future which would have far-reaching consequences, IEA warns in its latest World Energy Outlook", *International Energy Agency,* http://www.iea.org/newsroomandevents/pressreleases/2011/november/name,20318,en.html

made, their emissions are locked in not for months or years, but for decades. And the impacts of those emissions will persist for centuries.

In his recent speech announcing his climate plan[18], President Obama indicated that the State Department would not approve the Keystone Pipeline if it significantly increased emissions of climate pollution. Leaving aside the subtleties of the factual determination, the principle is vital for federal climate policy: *Specifically and categorically, we must cease making large, long-term capital investments in new fossil fuel infrastructure that "locks in" dangerous emission levels for many decades and makes avoiding catastrophic climate disruption impossible.*

This core principle emerges from multiple lines of scientific and economic research, most notably the International Energy Agency's 2011 World Energy Outlook. As a guide to policy development, it makes simple common sense. A comprehensive strategy for global climate solutions called "Design to Win"[19] put the point succinctly: "First, don't lose."

It will take decades to decarbonize our transportation and energy systems. We can do it over time, patiently and incrementally, building stronger economies and healthier communities as we go, and without precipitous economic disruption. But we cannot make big new capital investments now that irrevocably commit us to catastrophic climate failure. Federal actions that facilitate such investment are inconsistent with a genuine commitment to climate solutions.

Now that the era of climate consequences is upon us, the application of this principle is vital in order to ensure the integrity of the federal government's commitment to climate solutions. Federal climate policy must be a way to answer to the victims of climate-related disasters – and to our kids, the

[18] "Remarks by President on Climate Change" http://www.whitehouse.gov/the-press-office/2013/06/25/remarks-president-climate-change
[19] "Design to Win," California Environmental Associates http://www.climateactionproject.com/docs/Design_to_Win_8_01_07.pdf

prospective victims of still-preventable climate disasters. Our policy must affirm that we will do what it takes to protect them, to make it better. But they won't believe us until we stop making it worse.

3. The absence of these federal actions is taking a high toll on Americans now, including the rising cost of climate damages and economically costly misallocation of our energy dollars.

It would be impossible to comprehensively catalogue all of the economic, physical, and human damage that is occurring now as a result of our national failure to adopt a responsible climate policy. The most troubling impacts are, of course, the unprecedented loss of life and property due to increasingly extreme weather-related disasters and other climate impacts. But the lack of a national policy is also having other near-term, practical impacts on consumers, policy makers, businesses, and energy investments – impacts that weaken our economy, raise our energy bills, and make the climate crisis more intractable. Below, I offer a few examples from recent experience.

Critical policy, permitting, and programming decisions are more difficult and less effective without rational climate policy.

Last month, I testified to the Committee on Energy and Commerce Subcommittee on Energy and Power on the issue of exporting Powder River Basin coal from proposed terminals in the Pacific Northwest. A witness representing the National Association of Manufacturers objected to the notion that federal environmental analysis of proposed coal export facilities might include consideration of the climate impacts of burning the coal. He worried that such an evaluation would create a slippery slope, necessitating evaluation of the climate consequences of other products, including corn and toys.

Common sense should prevail here. The export of corn and toys is not one of the leading preventable causes of catastrophic global climate disruption. The introduction of large amounts of

cheap, subsidized, American coal into the world's fastest growing economies is, because it would trigger economic "lock-in" to dangerous climate disruption, described above.

However, the concern raised by the witness is, in at least one respect, legitimate. Because we have no meaningful national climate policy, we are left to ask and answer these kinds of questions on ad hoc basis, leading to outcomes that are surely less efficient and effective than we could achieve with a thoughtful, comprehensive policy. The issue of where and how to ensure accountability for the costs of climate pollution is indeed a very important climate policy design consideration[20]. But in June of 2013, 25 years after our foremost climate scientist first confirmed to Congress[21] that climate change was a real threat requiring decisive and immediate action, we were not having a hearing on climate policy design in the House of Representatives. We were grappling with one of the many adverse consequences of failing to design and adopt a climate policy.

In the absence of federal policy on climate, we are left to consider the climate implications of coal export outside the context of any structured, systematic approach to solving the problem. State and county officials reviewing permits for coal docks are faced with questions about the dynamics of Asian energy markets and how they influence the climate impact of exporting Powder River Basin coal. The alternative to considering these impacts – simply ignoring them as the climate crisis escalates, and permitting facilities that will significantly exacerbate the problem – is not a responsible course of action. But almost anyone could devise a better way to fairly and fully evaluate this issue than the way we will have to do it now, in the absence of a responsible federal climate policy.

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[20] The Climate Protection Act introduced by Senators Boxer and Sanders would assign accountability "upstream" (at the coal mine, oil refinery, natural gas processing point, or at the point of importation), thereby minimizing complexity and administrative costs.

[21] "Global Warming Has Begun, Expert Tells Senate," *New York Times,* June 24, 1988 http://www.nytimes.com/1988/06/24/us/global-warming-has-begun-expert-tells-senate.html

Ironically, on the same day last month when the Army Corp of Engineers announced that it would not consider the climate impacts of coal export in its environmental review of proposed coal export terminals, the commander of the Corps called for new, stronger standards for levee design and flood protection to cope with climate disruption[22]. Taxpayers can count on the Corps to request larger budgets for responding to climate impacts but not, apparently, to analyze those impacts in the context of decisions which might *prevent* them. We are gearing up for pounds of cure at public expense, because we lack the responsible federal climate policies that would provide an ounce of prevention.

The failure to adopt a responsible national energy policy results in misallocation of energy investment and waste of consumers' energy dollars.

Consumers' energy dollars generally flow to their utilities, which make energy investments on their behalf, in order to serve current and foreseeable energy needs. For investor-owned utilities, state public utility commissions set rates, allowing utilities to recover the costs of these investments, plus a reasonable return. In evaluating which costs utilities will be allowed to recover, utility commissions aim to minimize the costs of reliable energy service to consumers, encouraging utilities to choose the least-cost mix of resources to serve their customers.

With no national climate policy, the large and growing costs of carbon pollution are generally not included in the price that utilities pay for energy to serve their customers. And yet those costs are being paid by customers, and all Americans, every day. We pay for the cost of controlling the fires and floods that are becoming more frequent and intense as climate disruption accelerates. We pay to raise seawalls and levees. We pay higher food prices when crops and ranches fail due to drought. Growing numbers of Americans are paying with their lives. But none of these costs are paid by utilities when they buy the energy that creates this climate pollution on our behalf.

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[22] "Army Corps Chief Suggests US Needs Stronger Levees as Climate Changes" from *Climate Wire* http://www.nwra.org/content/articles/army-corps-chief-suggests-us-needs-stronger-levees/

Public utility commissions are thus faced with a difficult challenge: either ignore these costs, which essentially guarantees that total energy costs to consumers (including climate damages) will be unnecessarily high; or try to assess these costs in utility ratemaking and regulatory decisions, in the absence of a meaningful national plan or policy to reduce climate pollution to safe levels. Understandably, public utility commissions often consider such evaluations to be outside of their realm of expertise or responsibility.

This is, of course, an almost universal problem for climate action; relevant decision-makers often consider it to be outside the scope of their jurisdiction or effectiveness. And so as a practical matter, they too often ignore the costs of climate pollution. That doesn't make the costs go away; on the contrary, failure to consider these costs generally increases them. But one can understand the plight and frustration of decision-makers with smaller jurisdictions than yours, when they are asked to consider climate consequences that could have been evaluated and managed so much better and more comprehensively by the United States Congress.

Public and private clean energy initiatives would work better, accomplish more, and cost less if we had a rational climate policy.

Many clean energy policies and programs exist now at the federal, state, and local levels. But all of these policies and programs are swimming against the tide of a vast economic distortion – the disincentive created by failure to internalize the real costs of climate pollution. Notwithstanding this economically perverse incentive structure, many of these programs are quite successful. Energy codes have saved an enormous amount of energy and emissions, and put billions of energy dollars back in consumers' pockets[23]. Renewable energy standards have accelerated investment, reduced emissions,

[23] Building Codes Fact Sheet, USEPA
http://www.epa.gov/cleanenergy/documents/suca/buildingcodesfactsheet.pdf

and delivered a new driver for good jobs and prosperity in many states[24]. Production tax incentives have helped to reduce the competitive handicap that American clean energy businesses face in the absence of a national climate policy. Energy efficiency codes and programs have been a boon to the economy. In the Northwest, energy efficiency gains have been the biggest, cheapest, and most successful part of our energy strategy for the last 30 years[25].

However, virtually all of these programs and policies could work better, accomplish more, and cost less if we had a sound national climate policy. For example, suppose a tax incentive were designed to bridge the gap between a fossil energy resource costing $60 per megawatt-hour and a renewable resource costing $70 per megawatt-hour. Much of the gap is due to the fact that the fossil resource externalizes the cost of carbon pollution; the public in effect subsidizes that resource by picking up the tab for the climate impacts. If the cost of that pollution were internalized with a fair carbon price, the gap would be smaller. Under those circumstances, a given amount of public expenditure (or foregone revenue) would go further, delivering more clean energy for the same cost.

In a market economy, public policy should be aligned with private incentives wherever possible. Our prevailing national climate policy is free and unlimited carbon dumping, a policy that is directly at odds with other policies like energy codes and clean energy incentives. A climate policy with responsible limits and fair prices for climate pollution would align private incentives with public policy goals, and get America working much more efficiently and effectively for solutions.

The lack of a federal climate policy undermines individuals, communities, states, and businesses in their efforts to be part of the solution.

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[24] "Renewable Energy Standards, State Success Stories" Governors' Wind Energy Coalition http://www.governorswindenergycoalition.org/wp-content/uploads/2013/03/RES-White-Paper-March-2013.pdf

[25] Northwest Power and Conservation Council http://www.nwcouncil.org/media/30092/2012_06.pdf

A less quantifiable but critically important impact of the failure to adopt a national climate policy is the confusing and counterproductive effect of that failure on the many Americans who want to be part of effective solutions.

A participant in a focus group on climate once said, "I don't think it's a big issue, because nobody's doing anything about it." This is a remarkable insight. Surely, she deduced, if it were as bad as all that, the responsible authorities would be addressing the problem with urgency and resolve. That would be a much more reliable barometer of the risk than all the claims and counterclaims on cable news.

We *should* be able to expect that public institutions and elected officials respond to grave threats, guided by objective facts, in order to prevent mass-scale human tragedies. Americans *should* have confidence that when America faces a big problem, when we need to mobilize our national resources and will for big solutions, the United States Congress will act.

Millions of Americans are implementing climate solutions – driving cleaner cars, installing more efficient lights, improving the efficiency of their offices and factories, etc.. But they understandably wonder whether their efforts make much difference in the absence of a serious national policy commitment. Mayors and governors who have adopted climate plans face cynicism, since their jurisdictions represent such a small fraction of the total global emissions that drive climate disruption. The rest of the world desperately waits for the America they know – the proud, powerful, solution-oriented America – to step forward and step up to the climate challenge. Individuals and mayors and governors and businesses and other nations CAN make a difference; they CAN do their part. But they know it's only part of something hopeful and realistic if and when the United States of America steps up to the kind of leadership and commitment of which it is uniquely capable.

Only a serious national climate policy can unleash America's greatness for climate solutions. Given the dimensions of the challenge and the lateness of the hour, we'll need every bit of that greatness.

Thank you. I look forward to any questions you may have.

If Climate Change Is Happening Now, What Do We Do?

Diana Furchtgott-Roth
Senior Fellow, Manhattan Institute

Testimony before the Senate Environment and Public Works Committee

July 18, 2013

If Climate Change Is Happening Now, What Do We Do?

Chairman Boxer, Ranking Member Vitter, members of the Committee, I am honored to be invited to testify before you today on climate change.

I am a senior fellow at the Manhattan Institute. From 2003 until April 2005 I was chief economist at the U.S. Department of Labor. From 2001 until 2002 I served at the Council of Economic Advisers as chief of staff. I have served as Deputy Executive Secretary of the Domestic Policy Council under President George H.W. Bush and as an economist on the staff of President Reagan's Council of Economic Advisers.

Is climate change happening now? Since 2003 global temperatures appear to have reached a plateau.[1] With rising greenhouse gas emissions from Asia and other emerging economies, many predicted that temperatures would continue to rise. Why they have not done so is a puzzle.

With an apparent stall in global warming, the focus has switched to "climate change." For instance, on July 11, 2013, the Department of Energy issued a report entitled *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather*. The report projects increases in storm and flood frequency.

However, a review of the data over the past 100 years does not show a steady increase in major storms such as hurricanes, nor a steady increase in the number of floods, even though greenhouse gas emissions increased**.** The National Oceanic and Atmospheric Administration shows the number of hurricanes over the past 100 years has been volatile, with no clear trend, see Figure 1. There were seven floods reported by the NOAA's Mid-Atlantic River Forecast Center in 2012, the precise number reported in 1912. In between, some years have shown higher numbers, others have shown lower numbers. The data have been sporadic at best, as shown in Figure 2.

Despite Congress's decision not to pass cap-and-trade legislation, on June 25, in a speech at Georgetown University, President Obama called for similar regulatory measures to reduce greenhouse gases. He announced that he will use his executive powers to reduce greenhouse emissions from existing power plants, as well as future plants. He also plans to increase efficiency standards for appliances and authorize the placement of wind farms and solar power plants on federal lands. He asked the Department of Defense to install 3 gigawatts of renewable power on bases. He

[1] National Aeronautics and Space Administration, *Global Land-Ocean Temperature Index*, http://data.giss.nasa.gov/gistemp/graphs_v3/Fig.A2.txt

announced that over the next 7 years, 20 percent of the energy the federal government will consume will come from renewable sources. He mentioned plans for federal tax dollars to fund building infrastructure, such as seawalls for communities.

The 111th Congress failed to pass legislation to regulate emissions in 2009-2010, when Democrats had majorities in the House and Senate. The cost of the legislation is a major reason for the failure of the Waxman-Markey and Kerry-Lieberman "cap-and-trade" bills, which would have capped emissions and encouraged firms to buy and sell rights to pollute.

The bill would have required EPA to shrink greenhouse gas allowances steadily to 2050. When any year's emissions would have exceeded a firm's cap, the firm would have to purchase allowances from the government or other companies. That is a tax under another name, driving up costs that would be passed on to consumers.

The costs of the Kerry-Lieberman and Waxman-Markey bills were too large for a Democratic Congress to support, even with Obama's backing. The revenues from the bills, about $646 billion over 8 years, would have at that time been the largest tax increase in history.

Even if rising greenhouse gas emissions are affecting the climate, actions by the United States will not be helpful in the absence of changes by China and India. The U.S. global share of greenhouse gases is 17 percent.

Other countries are increasing emissions. China, India, and Germany are expanding coal consumption, according to the International Energy Agency. Global coal use will rise by 1.2 billion tons in five years. "By 2017," according to a December 2012 IEA report, "coal will come close to surpassing oil as the world's top energy source."[2] Mr. Obama's reductions in U.S. emissions, with their associated costs, will just be a drop in the global bucket.

Polls show that many believe protecting the environment is less important to Americans than economic growth.[3] With the slowdown in many measures of global warming over the past decade, climate change is playing second fiddle to jobs. Americans know that no reduction in global warming will occur if America reduces greenhouse gases without similar action by China and India, and these countries have not agreed to comparable steps.

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[2] International Energy Agency, *Medium-Term Coal Market Report,* December 2012, http://www.iea.org/publications/medium-termreports/#coal.
[3] Gallup Poll, April 2013, http://www.gallup.com/poll/161594/americans-prioritize-economy-environment.aspx.

U.S. greenhouse gas emissions have been declining since 2007, and fell by 1.6 percent between 2010 and 2011, the Environmental Protection Agency announced earlier this year.[4] Required use of alternative energy technology might reduce greenhouse gas emissions further, but the new technologies make fuel and electricity more expensive, reducing economic growth and adversely affecting employment.

The message that government can create more total jobs by requiring more costly technology is seductive but empty. Yes, some Americans might be employed building the technology, but others lose jobs due to more expensive energy.

Although President Obama advocates green jobs, the Labor Department's green jobs survey for 2011, released in March 2013, found only 3.4 million such jobs, despite $500 million in the stimulus bill for green jobs training. By the end of 2011, combined expenditures of the Energy Training Partnership, Pathways out of Poverty, and State Energy Sector Partnership green jobs stimulus programs totaled $257.3 million. However, only 5,400 new jobs through the programs were retained at least 6 months, yielding a cost of $47,754 per job. The Bureau of Labor Statistics has announced that it will discontinue its green jobs survey due to the sequester.

However, the White House website writes in its 4th report on the stimulus "A central piece of the ARRA is more than $90 billion in government investment and tax incentives to lay the foundation for the clean energy economy of the future" and references "$3 billion for Green Innovation and Job Training to invest in the science, technology, and workforce needed for a clean energy economy."[5] The most recent quarterly report does not mention the Green Innovation and Job Training funding.[6]

The $90 billion includes items like the loan guarantee money (some of which will be recovered), and other items like grants for weatherizing and retrofitting.

The president's climate change measures will reduce economic growth by raising energy prices. As well as reducing jobs in the mining industry—over 100 coal-fired power plants have closed since the beginning of 2010—it will also discourage energy-intensive manufacturing.

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[4] Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011*, April 12, 2013, http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2013-Main-Text.pdf, p. 26.

[5] Council of Economic Advisors, *Recovery Act Fourth Quarterly Report - The Public Investment Provisions of the Recovery Act*, 2010, http://www.whitehouse.gov/administration/eop/cea/factsheets-reports/economic-impact-arra-4th-quarterly-report/section-4#14.

[6] Council of Economic Advisors, *The Economic Impact of the American Recovery And Reinvestment Act of 2009: Ninth Quarterly Report*, February 1, 2013, http://www.whitehouse.gov/sites/default/files/docs/cea_9th_arra_report_final_pdf.pdf

Manufacturers are returning to America due to low-cost energy, and the president's proposals will drive them away and discourage others. The new French Vallourec Star pipe mill in eastern Ohio is making tubes for the electric pipe industry. Other companies making similar investments are Luxembourg's Tenaris and China's Tanjin Pipe. Royal Dutch Shell is building a $4 billion ethane cracker plant in Pennsylvania, and is planning on hiring 5,000 construction workers.

Since 2009, the German chemical company BASF has invested more than $5.7 billion into North America, including a formic acid plant under construction in Louisiana. BASF officials say that energy prices in America are lower than in Europe, where fracking is discouraged.

Other European countries planning to invest in America due to low energy prices include Austrian steelmaker Voestalpine (an iron-ore processing plant in Texas), and South Africa-bases Sasol (a natural gas to diesel conversion plant in Louisiana).

If these companies run into difficulties, their investors and shareholders will bear the losses. But when the government picks investments in risky new technology, as the president recommends, taxpayers and the federal budget lose if the projects fail. Of the 33 energy loan guarantees made since 2009 under the Energy Department's programs, 30, or over 90 percent, have shown signs of trouble, ranging from missed production goals to bankruptcy filings.

Companies which received loans or grants from the Energy Department during the Obama administration then filed for bankruptcy include Solyndra, Abound Solar, A123, Ener1, Evergreen Solar, Solar Trust of America, Energy Conversion Devices, and Beacon Power. Grant recipients Ecototality, SunPower, and Smith Electric have reported losses.

The Inspector General of the Energy Department, Gregory Friedman, found that employees of LG Chem, a battery manufacturer in Holland, Michigan, "spent time volunteering at local non-profit organizations, playing games and watching movies during regular working hours." LG Chem, meanwhile, sold batteries made in South Korea to U.S. firms rather than producing the batteries in Michigan.

Raising the cost of energy at any time is poor economic policy, but especially when economic growth is slow. After four years of economic "recovery," U.S. annualized GDP growth was 1.8 percent in the first quarter of 2013. America has 2.1 million fewer nonfarm payroll jobs than in December, 2007, the start of the recession. Now is not the time for Obama to overrule Congress and slow the economy further.

Electricity from natural gas, of which America has a 200-year supply, is less expensive than electricity produced from alternative fuels. The U.S. Energy Information Administration has estimated that the average levelized cost for natural gas-fired plants entering service in 2018 is $67 per megawatt hour, compared to $144 per megawatt hour

for solar-powered plants, $87 per megawatt hour for wind power, and $111 per megawatt hour for biomass. [7]

The bottom line: households have far higher electricity bills using alternative energy than natural gas.

This disproportionately affects low-income Americans, who spend a higher share of their income on energy, as shown in Table 1 and Figure 3. Data from the Labor Department released September 2012 show those in the lowest fifth of the income distribution spend an average of 24 percent of income on energy, compared to 10 percent of income for those in the middle fifth, and 4 percent of income for those in the top fifth.

A CBO report shows that emissions reduction programs would cause job losses in coal mining, oil and gas extraction, gas utilities, and petroleum refining. In addition, workers' wages adjusted for inflation would be lower than otherwise because of the increase in prices due to a cap and trade program. CBO concludes that some workers, therefore, would leave the labor market, because at the new lower wages they would prefer to stay home.[8]

Any reader of the CBO report would realize that it is not in the interests of American workers to embark on an emissions reduction program with our current high unemployment rate. According to CBO, "While the economy was adjusting to the emission-reduction program, a number of people would lose their jobs, and some of those people would face prolonged hardship." Workers laid off in declining industries would find it hard to get new jobs.

The CBO report points out that "In cases in which a shrinking industry was the primary employer in a community, the entire community could suffer." The tax base would dwindle and real estate would lose its value as unemployed workers moved elsewhere. The community's personal income would diminish and real estate values would fall as the jobless moved away.

That is why a carbon tax would harm the U.S. economy.

A $15 tax per metric ton of CO_2 would result in an increase in gasoline prices of 15 cents per gallon, 75 cents per thousand cubic feet of natural gas, $6.45 per barrel of oil, and $28.50 per ton of coal. A $50 CO_2 tax rate would raise the price of gasoline by 50 cents

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[7] U.S. Energy Information Administration, *Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013*, January 28, 2013, http://www.eia.gov/forecasts/aeo/electricity_generation.cfm.
[8] Congressional Budget Office, *How Policies to Reduce Greenhouse Gas Emissions Could Affect Employment*, May 5, 2010, http://www.cbo.gov/sites/default/files/cbofiles/ftpdocs/105xx/doc10564/05-05-capandtrade_brief.pdf.

per gallon, natural gas by $2.50 per thousand cubic feet, oil by $21.50 per barrel, and coal by $95 per ton.[9]

The carbon tax is a favorite of many academic economists for restructuring the tax system.[10] Proponents suggest that the tax be used to replace other taxes, such as the individual income tax, the corporate income tax, or a Kerry-Lieberman-style cap-and-trade system.

However, as tax practitioners know, a carbon tax is complex to set up. It requires adjustments to make sure that the tax is not unduly regressive and does not encourage consumption of imports relative to domestic production. A carbon tax without such offsets would be another add-on levy, with exemptions for friends and punishments for enemies.

A carbon tax raises the price of energy and so discourages consumption and production, as manufacturers choose to locate elsewhere.

One major problem with the carbon tax is that it is regressive. Since low-income people use more energy as a percent of their income than high-income people, a switch to a carbon tax would have to be accompanied by transfers to low-income groups.

Academics suggest that offsets be returned to taxpayers through lower income taxes, perhaps with the proceeds going chiefly to low-income households (individuals and families), which are disproportionately hurt by what is in essence an energy consumption tax. This could be done by adjustments of the income tax.

However, low-income earners are not required to file returns, and they would have to do so in order to be identified and compensated. That means extra work for them, and for the Internal Revenue Service.[11] And, as recent events have shown, the IRS is not prepared to take on more responsibilities with its current level of funding.

Another problem is that carbon-intensive sectors, such as coal, would be the biggest losers under the new tax. Politicians from coal-producing regions are influential in Congress and they would demand a share of revenues.

Finally, a carbon tax would raise the prices of energy-intensive goods relative to imports from countries without carbon taxes. So Americans would prefer to buy imports, and American firms would lose business. Proponents of the tax suggest

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[9] Ramseur, Jonathan L., Jane A. Leggett, and Molly F. Sherlock, Carbon Tax: Deficit Reduction and Other Considerations, Congressional Research Service, September 17, 2012, p. 11, http://www.fas.org/sgp/crs/misc/R42731.pdf.

[10] Carbon Tax Center, "Supporters," March 24, 2012, http://www.carbontax.org/who-supports/.

[11] Dinan, Terry, *Offsetting a Carbon Tax's Costs on Low-Income Households*, Congressional Budget Office Working Paper Series, November 2012, http://www.cbo.gov/sites/default/files/cbofiles/attachments/11-13LowIncomeOptions.pdf.

putting tariffs on imports in proportion to their carbon content so that American companies will not be at a disadvantage. But the precise quantities are complex to calculate, and such tariffs might be illegal under World Trade Organization regulations.

So for a carbon tax to make our tax system more efficient, its revenues would have to be used to offset other taxes in the economy. Its negative effects on low-income Americans and on energy-intensive regions would have to be ameliorated. Some border adjustment would have to be made so that domestic goods were not disfavored.

But the legislative process makes it difficult to craft a carbon tax with these attributes. It is more likely that any tax on carbon would be an additional tax. It would hurt the poor and raise domestic prices relative to prices of imports.

To reduce global greenhouse gas emissions in a less costly manner, America could assist China and India develop shale gas from hydrofracturing and build natural-gas fired plants to reduce their reliance on coal. Or, America could ship coal to China, because U.S. coal burns cleaner than Chinese coal. The majority of China's coal (54 percent) is bituminous, which has a carbon content ranging from 45 to 86 percent.[12] On the other hand, 47 percent of the U.S.'s coal, a plurality, is subbituminous, which contains a carbon content of only 35 to 45 percent.[13]

Congress could fund research into geoengineering measures. More needs to be done to study solar radiation management, which potentially diminishes the warmth caused by the sun's rays. This could be done by injecting fine sulfur particles or other reflective aerosols into the upper atmosphere to reflect incoming radiation, or spraying clouds with salt water to increase their reflectance.

Clouds seeded with salt water would be thicker, and would reflect more heat back toward the sun, away from Earth. Cooling effects — as well as other, adverse consequences — have been observed after volcanic eruptions.

Another avenue of research is to explore making the surface of the planet more reflective, by brightening structures and painting roofs white, as well as increasing the reflectivity of deserts and oceans.

Such measures would cost a fraction of what cap-and-trade regulations and therefore do less damage to the economy.

Thank you for allowing me to testify today. I would be glad to answer any questions.

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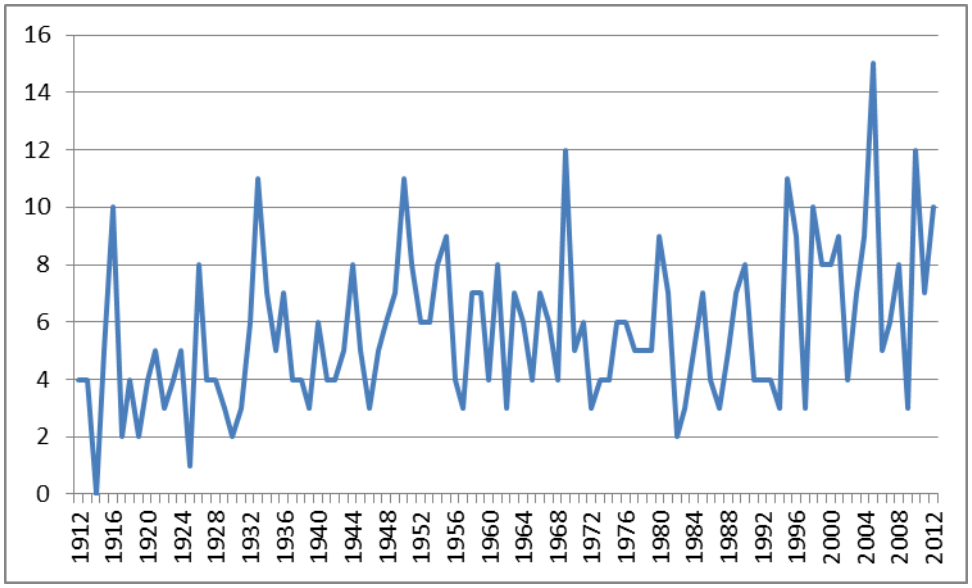
[12] U.S Energy Information Administration, *International Energy Outlook 2011*, Table 10, http://www.eia.gov/forecasts/ieo/table10.cfm.

[13] U.S. Energy Information Administration, *Subbituminous and bituminous coal dominate U.S. coal production*, 2011, http://www.eia.gov/todayinenergy/detail.cfm?id=2670/.

Figure 1: Atlantic Basin hurricanes by year, 1851-2012

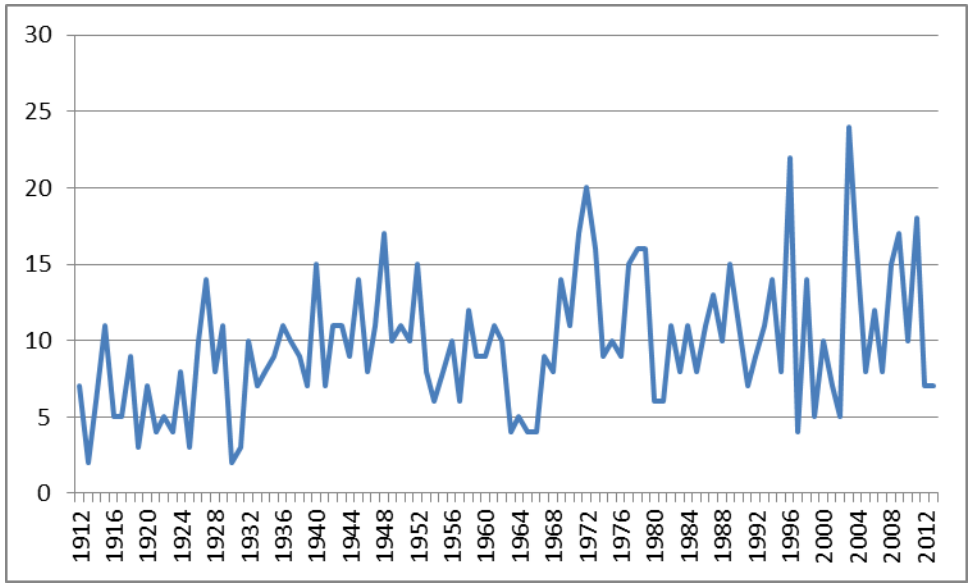
(number)



Note: Hurricanes using Saffir-Simpson Hurricane Scale 1 to 5.

Source: National Oceanic & Atmospheric Administration, Atlantic Oceanographic & Meteorological Laboratory, Hurricane Research Division, July 2, 2013, http://www.aoml.noaa.gov/hrd/tcfaq/E11.html.

Figure 2: Number of floods per year, 1912-2012



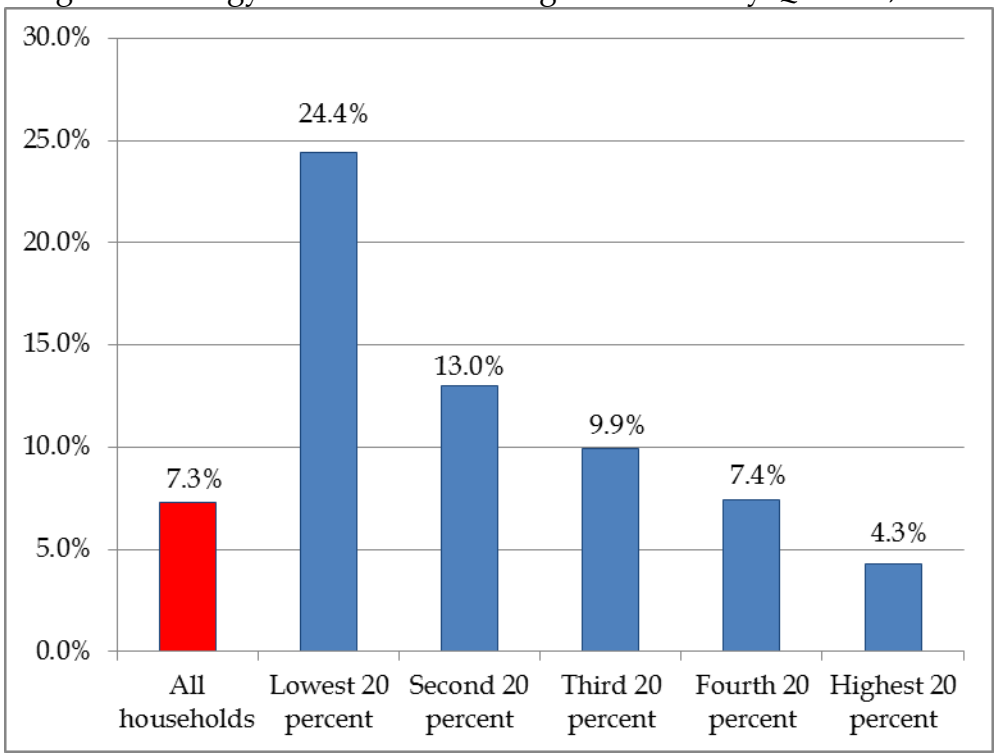
Source: National Oceanic and Atmospheric Administration, *MARFC Flood Events Yearly Summary 1687-2013*, 2013, http://www.erh.noaa.gov/marfc/Rivers/FloodClimo/1687-2013FloodSummaries/1687-2013-Year-Decade-Total-Table.pdf.

Table 1: Energy Costs as a Share of Income by Income Quintile, 2011

	All households	**Lowest 20 percent**	**Second 20 percent**	**Third 20 percent**	**Fourth 20 percent**	**Highest 20 percent**
Income after taxes	$61,673	$10,074	$27,230	$45,563	$72,169	$153,326
Natural gas	$420	$243	$338	$386	$472	$659
Share of income	0.7%	2.4%	1.2%	0.8%	0.7%	0.4%
Electricity	$1,423	$985	$1,234	$1,429	$1,603	$1,863
Share of income	2.3%	9.8%	4.5%	3.1%	2.2%	1.2%
Gasoline and motor oil	$2,655	$1,227	$1,981	$2,694	$3,295	$4,073
Share of income	4.3%	12.2%	7.3%	5.9%	4.6%	2.7%
Sum of natural gas, electricity, and gasoline and motor oil	$4,498	$2,455	$3,553	$4,509	$5,370	$6,595
Share of income	7.3%	24.4%	13.0%	9.9%	7.4%	4.3%

Note: Not all percentages sum because of rounding.
Source: Department of Labor, Bureau of Labor Statistics, *Consumer Expenditure Survey*, *2011*, September 25, 2012, and Manhattan Institute calculations.

Figure 3: Energy Costs as a Percentage of Income by Quintile, 2011



Source: Department of Labor, Bureau of Labor Statistics, *Consumer Expenditure Survey*, *2011*, September 25, 2012, and Manhattan Institute calculations.

Written Testimony of
Robert P. Murphy, Senior Economist,
Institute for Energy Research
Before the
Senate Committee on Environment and Public Works
On the Matter of
"The 'Social Cost of Carbon': Some Surprising Facts"
July 18, 2013

1. About IER

The Institute for Energy Research (IER) is a not-for-profit organization that conducts intensive research and analysis on the functions, operations, and government regulation of global energy markets. IER maintains that freely-functioning energy markets provide the most efficient and effective solutions to today's energy and environmental challenges and, as such, are critical to the well-being of individuals and society.

Founded in 1989 from a predecessor nonprofit organization, IER is a public foundation under Section 501(c)(3) of the Internal Revenue Code and is funded entirely by contributions from individuals, foundations, and corporations. Headquartered in Washington, D.C., IER supports public policies that simultaneously promote the welfare of energy consumers, energy entrepreneurs, and taxpayers.

2. Robert P. Murphy Resumé

Robert Murphy earned his Ph.D. in economics from New York University in 2003. From 2003 – 2006 he taught economics at Hillsdale College. After three years teaching, Murphy left academia for the private sector, taking a job with Laffer Investments. In this capacity, Murphy maintained and improved stock selection models, and also helped write research papers for clients.

In the summer of 2007 Murphy joined IER as an economist. His academic research has focused on climate change economics, specifically the proper discount rate to use when evaluating mitigation policies. He has published an academic paper analyzing the assumptions of William Nordhaus' "DICE" integrated assessment model of the global climate and economic system,[1] and has prepared a study for IER on carbon "tax swap" proposals.[2]

3. The "Social Cost of Carbon": Definition and Importance

According to the White House Interagency Working Group assigned to the project, the social cost of carbon is defined as

> an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change. [Working Group May 2013, p. 2][3]

The quantitative estimates of the social cost of carbon (SCC) are extremely significant. The Working Group document itself states that the purpose of the SCC estimates "is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions." Some obvious examples of the application of the SCC estimates are fuel economy standards, EPA greenhouse gas regulations, efficiency standards for household appliances, and programs to subsidize so-called "alternative"

energy sources and transportation technologies. Critics of the Keystone XL pipeline have recently called for a second look into the environmental impact of the project, citing the SCC as one of the justifications for a revised assessment.

Through its role in justifying regulations and other policy actions that will restrict carbon dioxide emissions, the estimate of the SCC could have profound impacts on both industry and consumers.

4. The "Social Cost of Carbon" Is Not an "Objective" Measurement But Instead a Malleable Concept Dependent on Modeling Assumptions

Because of the significant impact it could have on energy prices and other economic conditions, it is crucial that citizens and policymakers alike realize that the SCC is a very malleable figure. It is *not* analogous to a physical constant such as the charge on an electron or the boiling point of water, with scientists coming up with ever more precise estimates of a feature of nature that is "out there" to be measured. Instead, the estimation of the SCC relies on computer simulations of the economy and climate system for hundreds of years into the future, and furthermore depends on many subjective modeling assumptions. As I will demonstrate, these assumptions can have an enormous impact on the final number, meaning that an analyst can generate just about any SCC he or she wishes by adjusting certain parameters.

Perhaps more significant, when reporting various estimates of the SCC, the White House Working group explicitly disregarded two default guidelines provided by the Office of Management and Budget (OMB) for cost/benefit analysis. Had the Working Group heeded both guidelines, the officially reported SCC would be virtually $0 if not negative, meaning that there would be no justification for government restriction of carbon dioxide emissions.

A. Choice of Discount Rate

When estimating the social cost of carbon (SCC), the choice of discount rate is crucial, because the computer simulations of large climate change damages occur decades

and even centuries in the future, and also because some models show net *benefits* from global warming through the year 2050. Indeed, the patterns in the output of the Working Group's own computer runs suggest that their approach shows net external *benefits* from global warming in the early years. Therefore, the rate at which we discount future impacts (both positive and negative) into present monetary terms will have an enormous impact on the estimated SCC. For example, in the May 2013 Working Group update, the SCC in the year 2010 was reported as $11/ton at a 5% discount rate, but $52/ton at a 2.5% discount rate. In other words, cutting the discount rate in half caused the reported SCC to more than quadruple. Policymakers and citizens should realize just how influential the choice of discount rate is, when it comes to the SCC.

The Office of Management and Budget writes instructions for federal agencies in regulatory analysis. These are called "OMB Circulars." OMB Circular A-4[4] (relying in turn on Circular A-94) states that "a real discount rate of 7 percent should be used as a base-case for regulatory analysis," as this is the average before-tax rate of return to private capital investment. However, Circular A-4 acknowledges that in some cases, the displacement of consumption is more relevant, in which case a real discount rate of 3 percent should be used. Thus it states: "For regulatory analysis, you should provide estimates of net benefits using both 3 percent and 7 percent." Note that Circular A-4 does *not* say that a discount rate should be chosen based on the impacts; instead it says quite clearly that estimates should be made using both rates.

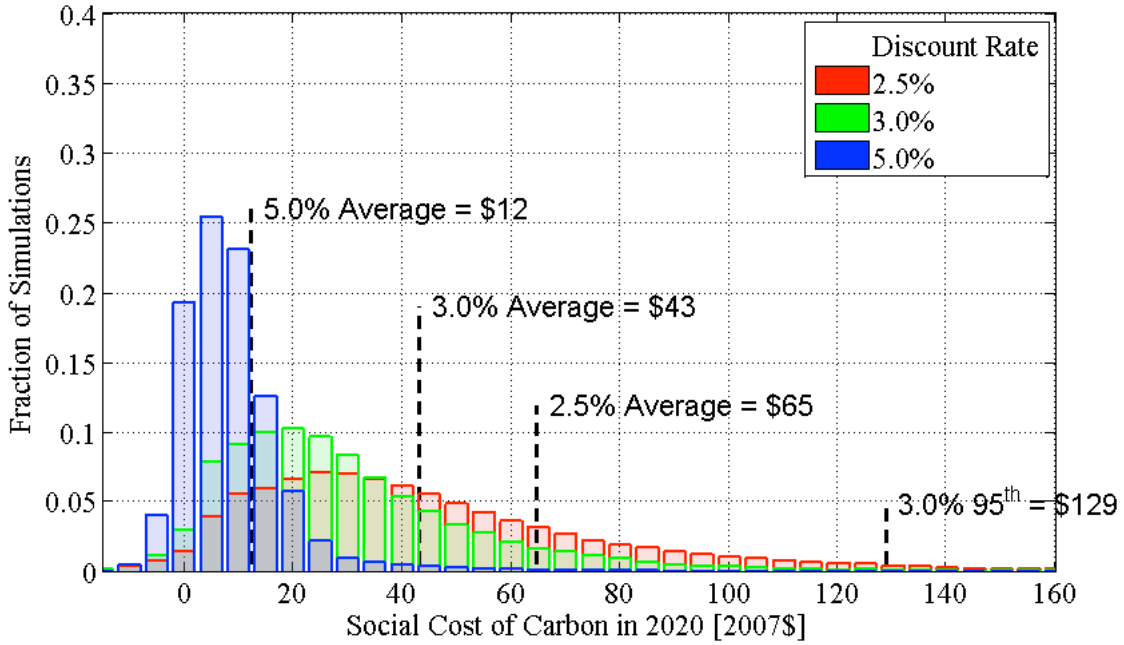
In the economics of climate change academic literature, there are disputes over the proper discount rate, with some economists arguing that very low rates should be used in order to place future generations on a nearly equal footing with the present generation in policy analysis. Circular A-4 and the White House's primer on Circular A-4,[5] explicitly cited the work of Martin Weitzman, one of the leading scholars in the field on this issue, who argues for a low discount rate in climate change analysis.[6] Nonetheless, after this discussion the 2011 primer still concluded:

> If the regulatory action will have important intergenerational benefits or costs, the agency might consider a sensitivity analysis using a lower but positive discount rate, ranging from 1 to 3 percent, **in addition to calculating net benefits using discount rates of 3 percent and 7 percent.** ["Regulatory Impact Analysis: A Primer," p. 12, bold added.]

Yet even though the guidance from OMB was quite explicit on this point, both the initial White House Working Group report from 2010, as well as the recent update in May, did *not* report the SCC using a 7 percent discount rate; they only used discount rates of 2.5, 3, and 5 percent.

This omission of a 7 percent figure masks just how dependent the SCC is on discount rates. As indicated in Figure 1 from the May 2013 update, when the Working Group used a discount rate of 5 percent, more than a fifth of the computer simulations reported a SCC that was near-zero or even *negative*, and that was for the year 2020. (See the three left-most blue bars in Figure 1 below.) If the Working Group ran the computer models again, this time using a 7 percent discount rate and an earlier reference year such as 2015, presumably a larger fraction of simulations would register zero or negative values for the SCC, so that the mean result would itself be closer to zero—or conceivably even negative, meaning that carbon dioxide emissions conferred extra *benefits* on humanity.

FIGURE 1. SOCIAL COST OF CARBON AT VARIOUS DISCOUNT RATES.



SOURCE: Figure 1 in May 2013 White House Working Group on Social Cost of Carbon.

My point in this discussion is not to argue for or against a particular discount rate. Rather, I am demonstrating how crucial this apparently innocuous modeling choice is. Further, in neglecting the clear guidance from OMB on reporting costs and benefits using a 7 percent discount rate, the Working Group on Social Cost of Carbon has misled policymakers, most of whom probably had no idea of the significance of this parameter. If the choice of discount rate means the difference between a SCC of $50/ton versus zero, this is clearly a matter that should not be left to a handful of regulators to decide. It underscores my claim that the "social cost of carbon" is not an objective empirical feature of the world, but is rather a very malleable figure dependent on subjective modeling assumptions, and can be made large, small, or even negative depending on parameter choices.

B. Domestic versus Global Social Cost of Carbon

Related to its decision regarding discount rates, the Working Group has also neglected clear OMB guidance to report costs and benefits from a *domestic* perspective. As the original 2010 Working Group report admits: "Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional" (p. 10). Nonetheless, the Working Group goes on to explain why it will instead use a global perspective in reporting its estimates of the SCC.

Were the Working Group to present its main findings from the domestic perspective, the impact would be striking. Using two different approaches, the Working Group in 2010 "determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range" (p. 11).

When the May 2013 update came out, the headline media reports typically focused on the SCC figure for the year 2010 at a 3 percent discount rate, which was $33/ton; this value was often reported as "the" social cost of carbon. Yet this was a *global* estimate of the SCC. If instead the default reports were expressed from the

domestic perspective, then the same 2010 figure at a 3 percent discount rate would only have been in the range of $2 to $8 per ton.

To see the significance of this decision by the Working Group, consider the following scenario: Suppose the EPA issues a new regulation that causes private industry to restrict carbon emissions, and that the compliance costs (in terms of forfeited economic output in the U.S. because of the new regulation) work out to $25/ton. Using the Working Group's recent headline SCC estimate of $33/ton, this regulation would apparently pass a cost/benefit test, because the $25 cost to American industry for every ton of restricted emissions would be counterbalanced by $33 in avoided future climate change damage. However, *Americans* would still on net be hurt by the regulation, as they would only receive $2 to $8 of the stipulated benefits (i.e. avoiding the *domestic* social cost of carbon on each ton no longer emitted), while suffering the full $25 in compliance costs.

To be sure, as with the discount rate, here too the Working Group gave a justification for its decision to report only the global SCC, rather than following OMB guidelines. I am bringing up this issue merely to show the huge impact their decision has, so that policymakers understand this decision will allow regulations to appear to pass cost/benefit tests when they actually do not confer net benefits on Americans.

5. Conclusion

The American public and policymakers alike have been led to believe that the social cost of carbon is an objective scientific concept akin to the mass of the moon or the radius of the sun. However, although there are inputs from the physical sciences into the calculation, estimates of the social cost of carbon are heavily dependent on modeling assumptions. In particular, if the White House Working Group had followed OMB guidance on *either* the choice of discount rate *or* reporting from a domestic perspective, then the official estimates of the current SCC would probably be close to zero, or possibly even negative—a situation meaning that (within this context) the federal government should be subsidizing coal-fired power plants because their activities confer external benefits on humanity.

The reason for this outcome is that some computer models show significant benefits of global warming through mid-century, and moreover the United States is poised to reap a larger share of the global benefits than the stipulated global damages from climate change. This is why following standard OMB guidelines—by at least providing an estimate of the SCC that uses a 7 percent discount rate and looks at only domestic impacts—would paint a completely different picture from the one that Americans have thus far seen.

Clearly, the public and policymakers have not been fully informed on what the economics profession actually has to say about climate change. Before justifying economically damaging regulations by reference to "the" social cost of carbon, policymakers must realize the dubious nature of this concept.

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[2] Murphy, Robert P. (2012) "Carbon 'Tax Swap' Deals: A Review and Critique." Institute for Energy Research, November 2012. Available at: http://www.instituteforenergyresearch.org/wp-content/uploads/2012/11/IER-Murphy-Carbon-Tax-Swap-Deals-A-Review-and-Critique.pdf.

[3] Interagency Working Group on Social Cost of Carbon. (2013) "Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866." May 2013.

[4] OMB Circular A-4 available at: http://www.whitehouse.gov/omb/circulars_a004_a-4.

[5] "Regulatory Impact Analysis: A Primer," available at: http://www.whitehouse.gov/sites/default/files/omb/inforeg/regpol/circular-a-4_regulatory-impact-analysis-a-primer.pdf.

[6] See: http://www.whitehouse.gov/sites/default/files/omb/inforeg/regpol/circular-a-4_regulatory-impact-analysis-a-primer.pdf.

Testimony for a Hearing of the Senate Environment and Public Works Committee

by **Dr. Jennifer Francis**, Research Professor, Institute of Marine and Coastal Sciences, Rutgers University, *francis@imcs.rutgers.edu*

The Warming Oceans: Present and Future Impacts

It seems as though the weather gods have gone berserk in recent years, as nearly every day the headlines report unusual droughts, floods, prolonged cold and snow, heat waves, or unusual weather events happening somewhere around the globe. Sea level is rising ever faster, and its contribution to damage from coastal storms is already being felt. Nearly three-quarters of the sea ice floating on the Arctic Ocean has disintegrated…in only 30 years. How and why are these changes happening, and what can we expect in decades to come?

Atmospheric changes drive ocean changes

In the past year, the human/Earth system reached three important milestones.

- In 2012 more carbon dioxide was emitted into the atmosphere than ever before.
- The amount of carbon dioxide in the atmosphere reached 400 parts per million, a 40% increase since the beginning of the industrial revolution. The last time the atmosphere contained this much carbon dioxide (about 2 million years ago), the Earth was several degrees warmer and the seas were tens of feet higher.
- Arctic sea ice melted to its lowest summer extent in at least 5000 years.

Greenhouse gases, of which carbon dioxide is one, trap heat emitted by the Earth's surface. This fact has been known for over a century. As human activities augment CO_2 concentrations in the atmosphere through fossil fuel burning, we are effectively putting a thicker blanket on the planet. The oceans absorb the vast majority of this excess energy, and because of water's huge heat capacity, the warming process takes a long time. This is why the Earth's temperature is not as warm as it was 2 million years ago: we've added the CO_2 so fast that the warming hasn't been able to catch

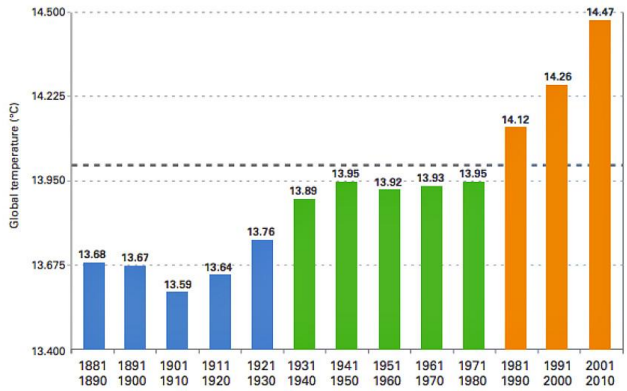

Figure 1: Global average temperature by decade. From http://library.wmo.int/pmb_ged/wmo_1119_en.pdf

up. But it's starting to.

This month the U.N. released a report stating that the past decade was the warmest in at least 160 years (**Figure 1**). Counter to claims by those who choose to ignore peer-reviewed scientific research, the heating of the Earth is not slowing down. Because of surface cooling over much of the Pacific Ocean in recent years owing to natural fluctuations in ocean circulation patterns, global-average *air* temperatures have not risen as fast as during the previous decade. Instead, the additional heat trapped by greenhouse gases has warmed deeper layers of the ocean, as evident in **Figure 2**.

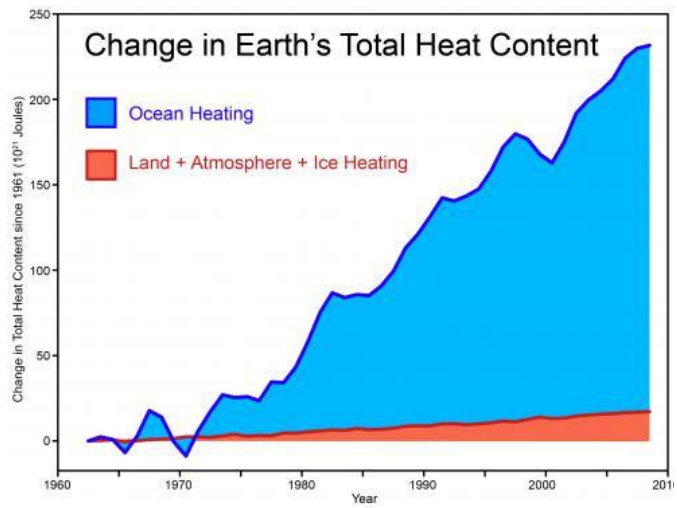

Figure 2: Changes in Earth's heat content, from Church et al (2011).

The Earth's Surface is Not Warming Uniformly

Owing to the effects of ocean currents, weather patterns, and variations in surface characteristics, temperature changes around the globe are far from uniform. This is abundantly clear in **Figure 3**, which illustrates the temperature differences from normal during the past decade. While nearly everywhere warmed, the changes were larger over land than over the oceans, and warming was especially pronounced over the Arctic. Differences in temperature are the drivers of weather patterns, so these spatial differences in warming must disrupt what we consider to be normal weather conditions.

Surface temperature changes are also affected by natural fluctuations in ocean conditions, such as El Niño/La Niña, the Pacific Decadal Oscillation, and the Atlantic Multi-decadal Oscillation, but as shown in **Figure 2**, the overall trend is for global ocean heating.

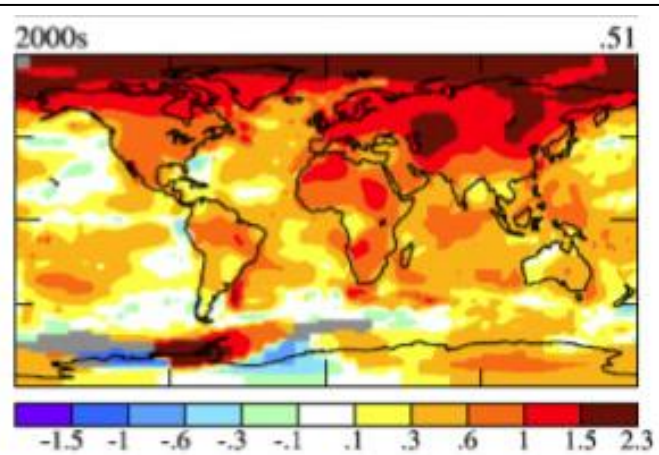

Figure 3: Annual surface temperature differences from normal during 2000-2010. From NASA/GISS.

Warming Oceans Contribute Directly to Sea Level Rise

A basic fact of physics is that when a gas or liquid warms, it expands. Warmer oceans have contributed about half of the observed global-average sea level rise (~1 foot since 1900). The pace of warming has increased, and so has the rate of sea level rise. By the end of the 21st century, sea levels are expected to be about 3 feet higher, which will have devastating impacts on low-lying coastal cities and communities around the world. Approximately 600 million people will be affected. Even if storms do not increase in frequency or intensity (which is *not* the expectation), they will ride on a higher ocean, increasing the destruction by storm surges and wind-driven waves.

Just as temperatures are not changing uniformly, neither will sea-level rise. Some land areas have been sinking and others rising since the last ice age, which either exacerbates or lessens the impact of rising seas. Changes in ocean currents also redistribute heat, and thus affect the amount of water expansion in a particular area. The loss of Greenland's ice sheet and other large masses of land ice also influence sea levels by imposing gravitational changes. The sum of these influences result in the low-lying and densely populated mid-Atlantic coast of the U.S. experiencing some of the largest increases in sea level (http://tidesandcurrents.noaa.gov/sltrends/index.shtml).

Warming Oceans Cause Increased Evaporation of Moisture into the Atmosphere

As the oceans and atmosphere warm, evaporation from the ocean surface increases, which adds water vapor to the air. This extra water vapor plays several important roles in exacerbating climate change. First, water vapor is a potent greenhouse gas, and as its concentration increases, additional heat is trapped, amplifying the original surface warming – a classic example of a positive feedback in the system. The second effect is to provide additional fuel for storms, because when water vapor condenses into cloud droplets, heat is released into the atmosphere. This energy is the primary power source for hurricanes in particular, as well as for other types of storms. Third, the additional water vapor enables storms to produce more rain and snow, increasing

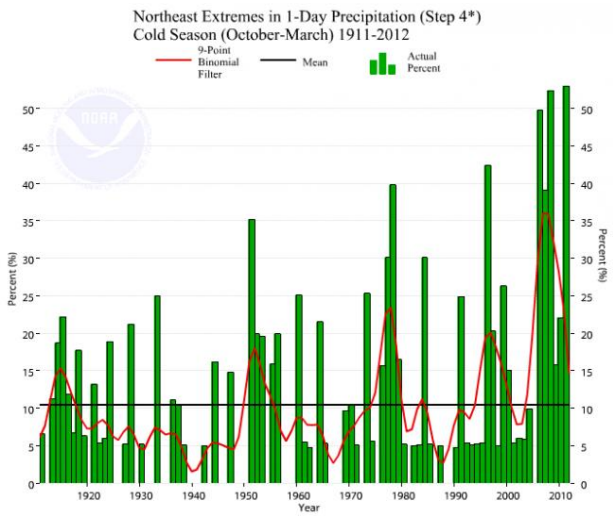

Figure 4: Heavy precipitation events are increasing in the northeastern U.S. From NOAA Climate Extreme Index.

the likelihood of severe rain events, flooding, and heavy snow falls. Heavier precipitation events have already been documented in the northeastern U.S. (**Figure 4**). Fourth, it is one of the main factors contributing to the disproportionate warming occurring in the Arctic, especially in winter and spring. The ramifications of this are discussed later.

Warmer Oceans May Affect Tropical Storms

Very warm ocean temperature is one of the essential ingredients for the development of tropical storms, primarily because it drives large evaporation rates, which supply copious amounts of water vapor that fuel the storms. As the oceans continue to warm, hurricane seasons are expected to lengthen, and the regions where tropical storms can develop and survive will expand. The situation that existed during Superstorm Sandy's lifespan may offer a glimpse of what we can expect to see occur more often in the future.

When Sandy moved out of the Caribbean in late October, it encountered ocean temperatures much above normal for late October all along the east coast of the U.S., which may have allowed the storm to survive intact longer and travel farther north than would be typical for that time of year (**Figure 5**). Meanwhile, the ingredients for an autumn nor'easter were gathering along the eastern seaboard. Because Sandy endured so far north, the two systems – that normally occur in distinct seasons – were able to coalesce into the powerful hybrid storm that wreaked havoc from Delaware to Nova Scotia, along with record blizzard conditions in West Virginia.

Figure 5: Superstorm Sandy survived farther north than usual for a late-October tropical storm, where it merged with a developing nor'easter. From ClimateCentral.org.

Warming Oceans Contribute to Sea Ice Loss in Both Hemispheres

A number of factors contribute to the recent and ongoing rapid decline of the Arctic sea ice cover (**Figure 6**). These include rising air temperatures, increasing water vapor and clouds, changing wind patterns, and warming oceans. As sea ice retreats, less of the sun's energy is reflected back to space by the diminished ice surface and more of it is absorbed into the ocean. In 2012 alone, the extra energy absorbed into the Arctic Ocean where there used to be ice is roughly the amount used to power the entire United States for 25 years! As this energy warms

the ice-free areas, more melting ensues, establishing another powerful positive feedback in the system. Additional ocean heat is also entering the Arctic from lower latitudes via currents flowing in from the North Atlantic and North Pacific Oceans. This source of heat has been shown to be particularly important for reducing the ice extent in the Arctic north of Norway during winter and north of Alaska during summer. Rising ocean temperatures have also been implicated in thinning ice shelves along the Antarctic Peninsula and in warming the air in that region.

Figure 6: Summer Arctic sea ice has declined in extent by HALF and in volume by THREE-QUARTERS in only 30 years. Image from LiveScience.org.

A Rapidly Warming Arctic Disrupts Weather Patterns in the Northern Hemisphere

Recent research has revealed some less intuitive links between climate change and the escalation of extreme weather. The Arctic is warming two to three times faster than the rest of the northern hemisphere owing primarily to sea-ice loss, earlier snow melt on Arctic land in spring, and increasing water vapor. This so-called "Arctic amplification" means that the temperature difference between the Arctic and mid-latitudes is lessening. This is important because the west-to-east winds of the jet stream are driven by that temperature difference. The jet stream is a fast river of wind high in the atmosphere that takes on a wavy path as it encircles the northern hemisphere, forming the boundary between warm air to the south and cold air to the north. As its westerly flow weakens owing to the reduced Arctic/mid-latitude temperature difference, the waves in its trajectory tend to take larger north-south swings (**Figure 7**). These waves control weather systems on the surface: conditions tend to be clear and dry in the part of the wave where winds blow from the northwest, and it's generally stormy where winds come from the southwest. As the waves increase in size owing to Arctic amplification, they are expected to progress eastward more slowly, which means that the weather associated with those waves lasts longer in any particular location (Francis and Vavrus, 2012). Larger waves are also more likely to form "blocks," which are like back-eddies in a stream that tend to prevent the jet-stream waves on either side—and the weather associated with them—from moving at all.

Large excursions of the jet stream caused many of the recent extreme weather events, such as the unusually cold, snowy winters experienced recently in Alaska and Europe, the unprecedented flooding in Alberta and the Mississippi Valley, and the ongoing drought and heat waves in western North America. The rapidly warming Arctic appears to be increasing the likelihood of blocking over the North Atlantic, and may have contributed to the unusual wind conditions that steered Sandy on its unprecedented westward path toward New Jersey.

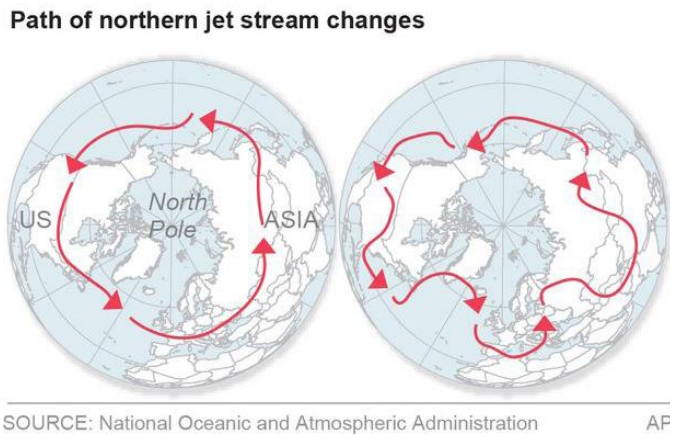

Figure 7: The jet stream, 3 miles above the surface, usually moves fast and relatively straight. Lately it has meandered north and south, causing unusual weather around the northern hemisphere. From NOAA/AP.

The Bottom Line

As the oceans continue to absorb additional heat trapped by ever-accumulating greenhouse gases, as sea ice continues to disappear, and as the Arctic continues to warm faster than the rest of the globe, we can only expect to see more weather-related adverse impacts. The details of those impacts are still emerging from ongoing research, but the overall picture of the future is clear.

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WRITTEN TESTIMONY OF
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WOODS HOLE OCEANOGRAPHIC INSTITUTION[1]

HEARING ON
Climate Change: It's Happening Now

BEFORE THE
COMMITTEE ON ENVIRONMENT & PUBLIC WORKS
UNITED STATES SENATE

JULY 18, 2013

Introduction

Good morning Chairman Boxer, Ranking Member Vitter and members of the Committee. Thank you for giving me the opportunity to speak with you today on climate change, the ocean carbon cycle and ocean acidification.

My name is Scott Doney, and I am a Senior Scientist at the Woods Hole Oceanographic Institution in Woods Hole MA. My research focuses on interactions among climate, the ocean and global carbon cycles, and marine ecosystems, and I have published more than 200 peer-reviewed scientific journal articles and book chapters on these and related subjects. I have served on the U.S. Carbon Cycle Science Program Scientific Steering Group and the U.S. Community Climate System Model Scientific Steering Committee. I was the inaugural chair of the U.S. Ocean Carbon and Biogeochemistry (OCB) Program and am currently on the steering committees for the Ocean Carbon and Biogeochemistry Program and the U.S. CLIVAR/CO2 Repeat Hydrography Program. I am also a convening lead author for the Oceans and Marine Resources chapter of the U.S. 2013 National Climate Assessment.

For today's hearing, you asked me to discuss how rising atmospheric carbon dioxide levels alter seawater chemistry, put at risk a wide range of marine life, and affect coastal communities and economies. My comments are based on my own extensive research and on a broad scientific consensus as represented in the current scientific literature and scientific assessments such as the 2013 National Climate Assessment, which was released this past winter in draft form for public comment (Doney et al., 2013; Walsh et al., 2013).

Over the past two centuries, human activities have resulted in dramatic and well-documented increases in atmospheric carbon dioxide and acidification of the upper ocean. Today the surface ocean is almost 30% more acidic than it was in pre-industrial times, and over the next few decades, the level of acidity of the surface ocean will continue to rise without deliberate action to reduce carbon dioxide emissions and stabilize

[1] The views expressed here do not necessarily represent those of the Woods Hole Oceanographic Institution

atmospheric carbon dioxide levels. Increasingly this will cause major problems for many marine organisms like shellfish and corals.

The ocean takes up roughly one quarter of human emissions to the atmosphere of carbon dioxide from fossil fuel burning and deforestation. Additional carbon dioxide uptake causes direct changes in seawater acid-base and inorganic carbon chemistry in a process termed ocean acidification. Acidification is independent of warming of the atmosphere but the two are linked through the underlying cause of elevated atmospheric carbon dioxide. Growing evidence suggests that ocean acidification will strongly impact many types of marine organisms, from microscopic plankton to shellfish and corals. Acidification and climate change will put further pressure on living marine resources, such as fisheries and coral reefs that we depend upon for food, tourism and other economic and aesthetic benefits.

Scientific observations show that ocean acidification is already occurring around the globe and is amplified in some coastal regions by changing ocean circulation, pollution, and land management practices. Recent near collapses of the oyster fishery in the Pacific Northwest, directly attributed to changing seawater chemistry, had substantial negative impacts on local jobs and economies.

In addition to ocean acidification, marine ecosystems are also already experiencing other large-scale trends linked to global change. Documented trends relevant to marine biota include increasing sea surface temperature, upper-ocean warming, rising sea-level, retreating Arctic sea-ice, and declining subsurface oxygen. Ocean warming is linked to poleward migration of commercial fish stocks and higher intensity and increased spatial ranges of marine diseases that attack corals, abalones, oysters, fishes, and marine mammals.

We have an opportunity now to limit the negative impact of ocean acidification in the future. Key elements include curbing human carbon dioxide emissions to the atmosphere, improved control of local pollution sources, reducing coastal habitat destruction, and better preparing coastal human communities to withstand the amount of ocean acidification and climate change that is unavoidable. At the State and local level, adaptation and mitigation strategies are being developed for ocean acidification. This topic is discussed more in the Adaptation and Mitigation section of the written testimony.

Social and Economic Impacts of Ocean Acidification

Acidification and climate change will likely affect many of the benefits people derive from the ocean–supply of seafood, recreation and tourism, protection from coastal flooding–as well as the jobs and livelihoods that depend on healthy marine ecosystems (Cooley et al., 2009; Halpern et al., 2012; Ruckleshaus et al., 2013).

Many economically and culturally important mollusk species are harvested in the United States, and a number of these species have been show to respond poorly to ocean acidification (Table 1). These include, for example, larval hard clams, oysters, and bay scallops (Talmage and Gobler, 2011), softshell clams (Green et al., 2009), and blue

mussels (Gazeau et al., 2010). Declines in these populations or delays in time to maturity could cost fishers, and dependent industries, millions of dollars (Cooley and Doney, 2009). Moreover, some additional impacts may still be identified; studies have not examined yet whether ocean acidification affects economically relevant harvest qualities of mollusks such as meat weight, appearance, and flavor. The commercial revenue numbers in Table 1 reflect what fishermen are paid at the dock for their catch and does not reflect the larger regional total economic impact of fishing, which can be several times larger.

Table 1: Commercial U.S. harvests in 2011 of mollusks with demonstrated negative responses to ocean acidification (Data: NOAA National Marine Fisheries Service, 2012).

Common name	**Scientific Name**	**Commercial revenue, dockside (millions)**
Hard clam, (Northern) quahog	*Mercenaria mercenaria*	$32
Eastern oyster	*Crassostrea virginica*	$91
Bay scallop	*Argopecten irradians*	$2
Softshell clam	*Mya arenaria*	$21
Blue mussel	*Mytilus edulis*	$7
Pacific oyster	*Crassostrea gigas*	$45
Olympia oyster	*Ostrea lurida*	$12
Sea urchins	several	$14

As atmospheric carbon dioxide levels continue to grow, ocean acidification may negatively impact the revenue derived from the commercial harvest of clams, scallops, oysters, mussels, and other calcifiers (like urchins). In 2011, harvests of calcifiers accounted for 19% of the $5.3 billion U.S. ex-vessel commercial fishery revenue. The biological responses to ocean acidification have not yet been determined for particularly valuable mollusk species such as sea scallop (*Placopecten magellanicus*), with national ex-vessel revenues for 2011 of $585 million, and Pacific geoduck (*Panopea generosa*), with revenues of $72 million. Similarly, early results suggesting red king (*Paralithodes camtschaticus*) and Tanner crab juveniles (*Chionoecetes bairdi and C. opilio*) fare poorly under ocean acidification are worrisome, given that the ex-vessel revenues from king crab (including red, blue, brown king crab) in 2011 were $111 million, and for Tanner crabs they were $15 million. "Snow crab," referring to anything in the *Chionoecetes* genus, had revenues of $116 million in 2011.

Elevated seawater carbon dioxide levels appear to be the cause of repeated failures at Pacific Northwest oyster hatcheries from 2005-2009 (Barton et al., 2012). The source of the acidified, low pH water varies regionally; along the coast resulting from enhanced upwelling of carbon dioxide rich ocean waters (Feely et al., 2008) with additional contributions from local pollution sources (nutrients, soil erosion) in estuaries and Puget Sound (Feely et al., 2010). The oyster hatchery failures are especially of concern given that:

> "Washington is the country's top provider of farmed oysters, clams, and mussels. Annual sales of farmed shellfish from Washington account for [more

than $107 million, which is] almost 85 percent of U.S. West Coast sales (including Alaska) [2]. The estimated total annual economic impact of shellfish aquaculture is $270 million, with shellfish growers directly and indirectly employing more than 3,200 people [3]. Shellfish are also an integral part of Washington's commercial wild fisheries, generating over two-thirds of the harvest value of these fisheries [4]. Licensing for recreational shellfish harvesting generates $3 million annually in state revenue and recreational oyster and clam harvesters contribute more than $27 million annually to coastal economies [5]. Overall, Washington's seafood industry generates over 42,000 jobs in Washington and contributes at least $1.7 billion to gross state product through profits and employment at neighborhood seafood restaurants, distributors, and retailers [6]."

(Quotation from Washington State Blue Ribbon Panel on Ocean Acidification, 2012 and citations therein)

Washington State's story is the best-known story of economic losses due to ocean acidification so far. However, low pH levels in Maine sediments are increasing clam mortality and decreasing harvests, and harvest areas, to levels that are alarming Maine shellfish managers. The Maine shellfish industry is estimated to be worth $60 million a year (Koenig, 2011), and is particularly important in areas of the state where there may be fewer alternative economic opportunities. Potential economic and social impacts extend beyond domestic commercial fishing. Recreational shellfishing, which is typically managed at the local or state levels, supports important sources of seafood, recreational opportunities, and a substantial number of local jobs and coastal economies. Much of the seafood consumed in the United States is imported from abroad, and ocean acidification and climate change put at risk some aspects of global wild-harvest fisheries and aquaculture. Domestic processing, wholesaling and retailing of both domestic and imported seafood supports an important economic sector.

Coral reefs are important for human societies, often supporting locally essential artisanal reef fisheries, and reefs are some of the most valuable marine ecosystems because of tourism and recreation income and coastal protection (Cooley et al., 2009). Ocean warming, coral bleaching, and ocean acidification are highlighted as major risks for the Hawai'i and U.S. Affiliated Pacific Islands region in the draft 2013 National Climate Assessment (Leong et al., 2013). Ocean warming and acidification could threaten the estimated $385 million Hawaiian coral reefs provide in goods and services annually (Cesar and van Beukering 2004) as well as put at risk subsistence fisheries in Pacific island communities (Maclellan 2009). Over the past decade, the Northwestern Hawai'ian Islands experienced several mass coral bleaching events, the result of higher sea surface temperatures (Jokiel and Brown 2004; Kenyon and Brainard 2006), and acidification may make corals more susceptible to bleaching. Under business as usual scenarios, the continued loss of coral reefs will likely result in extensive losses in both numbers and species of reef fish; even with a substantial reduction in emissions, reefs could be expected to lose as much as 40% of their reef-associated fish by the end of this century (Pratchett et al. 2011).

Ocean and Global Carbon Cycle

Over the last two centuries, global average atmospheric carbon dioxide has increased by more than 40% from preindustrial levels, from 280 to 395 ppm (parts per million) by mid-2013 (www.esrl.noaa.gov/gmd/ccgg/trends/ Ed Dlugokencky & Pieter Tans, NOAA/ESRL). Temporary excursions to 400 ppm have already been recorded at the Mauna Loa Observatory in Hawai'i. The excess carbon dioxide can be definitively attributed to human activities using carbon isotopes and ice-core carbon dioxide measurements. Many economic and "business as usual" scenarios project atmospheric carbon dioxide values as high as 700 to 1000 ppm by the end of the twenty-first century, levels not experienced on Earth for the past several million years. Excess carbon dioxide persists in the atmosphere for decades to centuries, and the impact of carbon dioxide emissions are global in extent.

Detailed assessments are now available for the global carbon budget (Le Quéré et al., 2013; Global Carbon Project, www.globalcarbonproject.org/). The main source of excess atmospheric carbon dioxide is fossil fuel combustion with contributions from cement production, agriculture and deforestation. For the last decade for which data are available (2002–2011), fossil fuel emissions averaged 8.3 ± 0.4 billion metric tons of carbon per year and grew with time at a rate of 3.1% per year since the year 2000. Deforestation and land-use change accounted for an additional source of 1.0 ± 0.5 billion metric tons of carbon per year.

The ocean plays a critical service by removing excess carbon dioxide emitted to the atmosphere (Sabine & Tanhua, 2010). The global inventory and distribution of excess carbon dioxide in the ocean was first mapped using measurements from an intensive, international survey in the late-1980s and early 1990s. Ongoing observational programs and numerical models continue to document further ocean uptake of carbon dioxide over time. Over the same time period cited above (2002–2011) ocean carbon uptake is estimated at 2.5 ± 0.5 billion metric tons of carbon per year, 27% of global emissions (Le Quéré et al., 2013). Cumulatively since the beginning of the industrial age the ocean is estimated to have removed about 25-30% of total human carbon dioxide emissions. The physical mechanism for the dissolution of excess carbon dioxide into the ocean is well understood. The global ocean uptake rate is governed primarily by the atmospheric carbon dioxide excess and trend, and by the rate of ocean circulation that exchanges surface waters equilibrated with elevated atmospheric carbon dioxide levels with subsurface waters that have not yet been exposed to atmosphere since preindustrial times.

Climate warming is projected to reduce ocean uptake of excess carbon dioxide due to decreased solubility, increased vertical stratification, and slowing of cold deep-water formation (Arora et al., 2013). There is some evidence that climate change is already slowing ocean carbon dioxide uptake (Le Quéré et al., 2010).

Several other factors, including ocean acidification, may either increase or decrease the ocean uptake of carbon dioxide as the ocean warms and acidifies (Denman et al., 2007). The net effect of these other processes is not well known at this time but is thought

to be relatively small compared to overall ocean carbon dioxide uptake over this century (Gehlen et al., 2011). The concern is that the ocean's capacity to absorb excess carbon dioxide may decrease, resulting in an increased growth rates in the atmosphere.

Ocean Acidification and Changing Seawater Chemistry

The ocean uptake of excess atmospheric carbon dioxide, the excess above preindustrial levels driven by human emissions, causes well-understood and substantial changes in seawater chemistry that can affect marine organisms and ecosystems (Doney et al., 2009; Gattuso & Hansson, 2011). Carbon dioxide (CO_2) acts as a weak acid when added to seawater leading to the release of hydrogen ions (H^+) and bicarbonate (HCO_3^-) ions:

$$CO_2 + H_2O \Rightarrow H^+ + HCO_3^-$$

The reaction increases seawater acidity and increases the hydrogen ion activity, thus lowering seawater pH. pH is defined as the negative logarithm of the hydrogen ion activity, so that a 1-unit change in pH is equivalent to a 10-fold change in H^+. Most of the extra hydrogen ions react with carbonate ions (CO_3^{2-}) and lower their ambient concentrations:

$$H^+ + CO_3^{2-} \Rightarrow HCO_3^-$$

This second reaction is important because reduced seawater carbonate ion concentrations decrease the saturation levels of calcium carbonate ($CaCO_3$), a hard mineral used by many marine microbes, plants and animals to form shells and skeletons. Many organisms require supersaturated conditions to form sufficient calcium carbonate shells or skeletons, and biological calcification rates tend to decrease in response to lower carbonate ion concentrations, even when the ambient seawater is still supersaturated.

Long-term ocean acidification trends are clearly evident over the past several decades in open-ocean time-series and hydrographic survey data, and the trends are consistent with the growth rate of atmospheric carbon dioxide (Dore et al., 2009). From preindustrial levels, contemporary surface ocean pH is estimated to have dropped on average from 8.2 to 8.1, or by about 0.1 pH units (a 26% increase in hydrogen ion concentration), and further decreases of 0.22 to 0.35 pH units are projected over this century unless carbon dioxide emissions are significantly reduced (Orr et al., 2005; Bopp et al., 2013).

Global upper-ocean chemistry trends driven by human carbon dioxide emissions are more rapid than variations in the geological past (Hönisch et al., 2012). For example, atmospheric carbon dioxide grew by approximately 30% during the transition from the most recent cold glacial period, about 20,000 years ago, to the current warm interglacial period; the corresponding rate of decrease in surface ocean pH, driven by geological processes, was approximately 50 times slower than the current rate driven largely by fossil fuel burning. Many marine organisms appear to be physiologically adapted to relatively constant local acid-base conditions and are sensitive to relatively small variations in pH and the saturation state of calcium carbonate.

Present-day ocean surface waters are supersaturated for the major carbonate mineral forms used by marine organisms, including the more soluble form aragonite (corals, many mollusks) and the less soluble form calcite (coccolithophores, foraminifera, and

some mollusks). However, calcium carbonate saturation states of both mineral forms are declining everywhere. Polar oceans are of particular concern because cold surface waters naturally hold more carbon dioxide and started off with lower calcium carbonate saturation states. Model simulations indicate that polar surface waters will become undersaturated for aragonite in the near future for the Arctic (atmospheric carbon dioxide of 400-450 ppm) and by mid-century for the southern ocean off the Antarctic (atmospheric carbon dioxide of 550-600 ppm) (Orr et al., 2005; Steinacher et al., 2009). This is expected to result in major changes in polar ecosystems.

Other ocean regions also may be more susceptible to aragonite undersaturation because of elevated background levels of carbon dioxide. These include eastern boundary current upwelling systems such as those off the U.S. west coast along coastal California, Oregon and Washington (Feely et al., 2008; Gruber et al., 2012), deep-sea and subsurface oxygen minimum zones (Brewer & Peltzer, 2009), and coastal waters that are already experiencing excess nutrient levels (eutrophication) and low dissolved oxygen (hypoxia) due to human-driven nutrient pollution from land-based activities (Feely et al., 2010; Cai et al., 2011). Nutrient overloading near shore encourages algal growth that is consumed by microbes, using up dissolved oxygen and releasing even more carbon dioxide locally. Coastal, estuarine, and coral reef systems also experience high levels of temporal variability on diurnal to weekly time-scales (Hofmann et al., 2011), challenging both observational efforts and interpretations of biological experiments.

In addition to ocean acidification, marine ecosystems are also already experiencing large-scale changes in physical climate and reduced subsurface oxygen (Doney, 2010; Gruber, 2011; Doney et al., 2012). Documented physical trends relevant to marine biota include rising sea surface temperature, upper-ocean warming, sea-level rise, altered precipitation patterns and river runoff rates, and sea-ice retreat in the Arctic and west Antarctic Peninsula (Bindoff et al., 2007).

Observations and numerical models show strong links between upper ocean temperature and the distributions of marine organisms. Based on satellite data, warming leads to declining tropical and subtropical productivity of phytoplankton at the base of the marine food web as well as expansion of the area of surface waters with very low plankton biomass (Behrenfeld et al. 2006; Polovina et al. 2008). Warming over the past few decades has resulted in the migration of commercial fish stocks poleward and in to deeper water (Nye et al. 2009), and productivity of fisheries is predicted to decline in the lower 48 states, while increasing in parts of Alaska (Cheung et al. 2009). Climate change also influences the spread and impact of marine diseases and parasites (Harvell et al., 2002). Marine disease appears to be on the rise with time, with warmer sea surface temperatures linked with higher intensity and increased spatial ranges of diseases that attack corals, abalones, oysters, fishes, and marine mammals (Ward & Lafferty, 2004).

Biological Impacts of Ocean Acidification

Ocean acidification and climate change effects arise both directly, via effects of warming, elevated carbon dioxide, and lower pH and carbonate ion concentrations on individual organisms, and indirectly via changes to the ecosystems on which they depend

for food and habitat (Doney et al., 2009; Doney et al., 2012). The potential biological consequences due to acidification are slowly becoming clearer at the level of individual species, but substantial uncertainties remain particularly at the ecosystem level (Gattuso et al., 2011). Ocean acidification and climate change acts as a stress on marine ecosystems will likely also exacerbate other human perturbations such as over-fishing, habitat destruction, pollution, excess nutrients, and invasive species.

Ocean acidification studies have been conducted for many economically and ecologically important species from both water-column (Riebesell & Tortell 2011) and seafloor or benthic (Andersson et al., 2011) environments. Most biological impacts are measured from short-term manipulation experiments in the laboratory where organisms are exposed to elevated carbon dioxide. In a recent meta-analysis of available scientific literature studies up until 2012, Kroeker et al. (2010; 2013a) found the following statistically significant effects:

calcifying algae	decreased abundance and photosynthesis
coral	decreased abundance and calcification
coccolithophores	decreased calcification
mollusks	decreased growth, calcification, and survival
echinoderms	decreased growth
fleshy algae	increased growth
diatoms	increased photosynthesis and growth

Recently published laboratory studies indicate additional potential negative ocean acidification effects for juveniles of valuable Alaskan crustacean species (Long et al., 2013a; 2013b).

red king crab	decreased growth and molting success
Tanner crab	decreased survival

Pteropods, a group of small planktonic marine mollusks, appear to be especially sensitive to ocean acidification (Orr et al., 2005). Pteropods are abundant in temperate and some subpolar waters and are important prey for juvenile fish. In shipboard incubations, elevated carbon dioxide levels causes dissolution of the shells of living pteropods, and in the present-day Southern Ocean there is evidence that pteropod dissolution is already occurring in some subsurface locations where seawater is undersaturated with respect to aragonite, the more soluble form of calcium carbonate (Bednaršek et al., 2012). A similar phenomenon may arise in the future in the North Pacific and off the U.S. West Coast as seawater conditions become more acidic.

A number of factors may influence the sensitivity of organisms to ocean acidification. Growing evidence indicates that warming amplifies sensitivity to ocean acidification (Kroeker et al., 2013a). Organism response also may vary with life-history stage; juvenile mollusks, for example, are often more susceptible than adults. Nutritional status may be important, and well-fed organisms may be better able to adjust to ocean acidification (Holcomb et al., 2012; Thomsen et al., 2013). In general, some species may be able to accommodate elevated carbon dioxide but at an additional energetic cost with negative consequences for development, reproduction and fitness. However, a recent

study looking across ocean regions with naturally low pH found that several species within a major group of stony coral (genus *Porites*) were not able to acclimate to ocean acidification at least with respect to skeletal growth and development (Crook et al., 2013)

Tropical corals appear to be particularly susceptible to the combination of ocean acidification and ocean warming, which would threaten the rich and biologically diverse coral reef habitats (Hoegh-Guldberg et al. 2007). Coral polyps are small animals that contain symbiotic algae. The coral-algal symbiosis is sensitive to minor increases in maximum seasonal temperature, and warming of as little as 1°C can cause coral bleaching, the expulsion of the colored algae that weakens the coral and can lead to coral death (Hoegh-Guldberg et al. 2007, Donner 2009). Acidification appears to make some corals more sensitive to thermal bleaching (Anthony et al., 2008) as well as making it more difficult for corals to secrete and maintain their skeletons (Salvat & Allemand 2009). Acidification is also a threat to other important reef calcifying organisms, such as crustose coralline algae that help build reef frameworks (Kuffner et al. 2008; Anthony et al., 2008; Johnson & Carpenter 2012).

Stony corals help build and maintain coral reefs, and decreases in growth can leave them less able to rebound from natural breakdown processes. In preindustrial times, nearly all coral reefs in or bordering the open ocean were located in water with sufficient carbonate ion concentrations to building hard skeletons (aragonite saturation state above 3.5) (Ricke et al., 2013). But by mid-century, model projections with even rather modest increases in atmospheric carbon dioxide (by 2050 about 475 ppm carbon dioxide) indicate that 50% or fewer of these coral reefs will still be surrounded by ocean waters with carbonate ion concentrations above this threshold to which they acclimated for thousands of years.

Coral and coralline algae losses decrease the structural complexity of the coral reef seascape and therefore the capacity of reefs to provide shelter and other resources for other reef-dependent species of fish and invertebrates (Alvarez-Filip et al. 2009). Because one-quarter of all marine species associate with coral reefs, the ecological impacts of changing climates and chemistry on overall marine biodiversity are potentially severe and widespread. About 75% of the world's coral reefs are threatened due to the interactive effects of climate change and local sources of stress, such as overfishing, nutrient pollution, and disease (Burke et al. 2011; Dudgeon et al. 2010; Hoegh-Guldberg et al. 2007; Hughes et al. 21 2010). In Florida, all reefs are rated as threatened, with significant impacts on the valuable ecosystem services they provide (Mumby and Steneck 2011). Caribbean coral cover has decreased from 50% to only 10% historic reef areas, an 80% reduction in less than three decades (Gardner et al., 2003).

Effects of ocean acidification on many natural populations and communities have been difficult to detect so far. An exception is studies of natural high-carbon dioxide environments, such as shallow volcanic vents, that generally support the conclusions found in laboratory studies (Hall-Spencer et al., 2008; Fabricius et al., 2011; Inoue et al., 2013). For example, Kroeker et al. (2013b) report on pH effects for benthic ecosystems surrounding seafloor carbon dioxide vents in the Mediterranean Sea. Ambient seawater in

the study region had a pH of 8.0 while acidified, low pH waters has a pH of about 7.7, roughly equivalent to surface ocean conditions expected at the end of this century under business as usual emission scenarios. In low pH waters, mollusks and crustaceans were less abundant, invertebrates with little or no calcification in their exoskeletons were more abundant, and the food web became simplified with more generalist species present. Kroeker et al. conclude that ocean acidification reduces the diversity, biomass, and food-web complexity of benthic marine communities. These high-carbon dioxide, low pH environments may be a window on the future under elevated atmospheric carbon dioxide conditions.

Adaptation and Mitigation Strategies

We have an opportunity now to limit negative ocean acidification impacts that are already underway and address future impacts that are expected to grow over the next several decades because of increasing atmospheric carbon dioxide levels. This will require a comprehensive strategy that balances adaptation to the amount of ocean acidification that is unavoidable and mitigation to reduce the further rise in atmospheric carbon dioxide. Decisions should incorporate precautionary considerations to account for the fact that potential carbon dioxide thresholds are presently unknown for many aspects of ocean acidification. Implementing adaptive management is also warranted because it can take advantage of new information as it becomes available. Further, it is important to recognize that many of the geoengineering strategies being proposed to mitigate future climate change, such as stratospheric aerosols to control solar albedo, will not reduce ocean acidification.

The Washington State Blue Ribbon Panel on Ocean Acidification (2012) outlined a series of recommended actions that could form the framework for action at the state, national and international levels. Critical tasks include:

- Reduce emissions of carbon dioxide to the atmosphere through a combination of increased energy efficiency, switching to renewable energy sources, and exploring the potential and challenges of carbon sequestration approaches;
- Reduce local land-based contributions to ocean acidification including excess nutrients from fertilizers and agriculture, organic matter from soil erosion, and local acidifcation from atmospheric deposition of pollutants;
- Increase our ability to adapt to and remediate the impacts of ocean acidification including approaches to sustain wild-harvest fisheries and aquaculture;
- Invest in our ability to monitor and investigate the causes and effects of ocean acidification;
- Inform, educate, and engage stakeholders, the public, and decision makers in responding to ocean acidification;
- Reduce other human disturbance factors such as overfishing and coastal habitat destruction to allow more time for ecosystems and social systems to adjust to ocean acidification and climate change.

Thank you for giving me this opportunity to address the Committee, and I look forward to answering your questions.

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WRITTEN TESTIMONY OF
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HEARING ON 'CLIMATE CHANGE: IT'S HAPPENING NOW'
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
U.S. SENATE
July 18, 2013

Introduction

Madame Chairwoman and Members of the Committee, thank you for the opportunity to speak with you this afternoon. My name is Margaret Leinen and I am the Executive Director of Harbor Branch Oceanographic Institute and Associate Provost of Florida Atlantic University. In addition I currently serve as the President-Elect of the American Geophysical Union. You have heard much today about the ways in which the climate is changing and physical evidence of those changes. I have been asked to concentrate on changes that we are observing in ecosystems or in systems that affect us directly. I will highlight three systems: US North Atlantic fisheries, Florida-Caribbean coral reefs, and South Florida sea level rise and its impact on shoreline communities.

Changes in the ranges of US East Coast Fisheries

US Fisheries are a major industry responsible for over $5.3T in 2011 (NMFS, Annual Commercial Landings Statistics, 2011). The east coast from North Carolina to Main accounts for $1.7T of that amount. I'm going to mention briefly how this area is being affected by climate change.

A 2009 study of fishing research vessel survey data collected every spring from 1968 through 2007 showed that about half of the 36 different fish species studied, many of them commercially important, have been shifting northward over the last four decades (Nye, et al. 2009). The study, led by Dr. Janet Nye, who is an Assistant Professor at the State University of New York at Stony Brook, focused on some of our most important commercial fish species: Atlantic cod, haddock, yellowtail and winter flounder, Atlantic herring, as well as several less well known species. It covered the entire region from North Carolina to the Canadian border.

Dr. Nye and her colleagues at the Northeast Fisheries Science Center also analyzed historic ocean temperature records and long-term processes like the Atlantic Multi-decadal Oscillation and the North Atlantic Oscillation dating back to

1850 so that they could put recent temperature increases into context. Ocean temperatures in the region increased during the 40 years of survey data.

In fact, a separate study by the Northeast Fisheries Science Center showed that sea surface temperature hit a 150 year high off the US east coast from Maine to North Carolina during 2012. They were high from the sea surface to the bottom, and east to the edge of the Gulf Stream. While sea surface temperatures in this area are generally less than 48°F, they exceeded 51°F during the first half of the year. And bottom temperatures were 1-2C (2 to 4°F) warmer in the Gulf of Maine. While these changes may seem small to us since we see large daily changes in temperature, they are statistically significant for the oceans, where temperatures are much more stable.

The 36 species that were studied were chosen because they were consistently caught in high numbers during the annual spring trawl survey. This is the longest time series of standardized fishery population data.

The researchers looked at where the fish were caught and their total population weight in each year of the survey. For each fish stock, the estimated the center of abundance as well as the average depth of the stock, the area that the stock occupied, and the average temperature at which the stock was found. They took into account natural cycles of ocean temperature and changes in fishing activity.

Nye and her colleagues found that 10 of the 36 stocks had significantly expanded their range while 12 had significantly reduced it. 17 of the stocks moved the increasingly greater depths with time, 3 moved shallower. But the temperature at which each stock was found did not change over time, suggesting that the fish are moving to remain within their preferred temperature range. Some of the stocks nearly disappeared from US waters as they moved further offshore. Studies completed last year (http://www.nefsc.noaa.gov/ecosys/advisory/current/advisory.html), show that the northward shift of the fish stocks has continued.

Changes in ocean temperatures and the timing and strength of spring and fall phytoplankton blooms that provide food for the fish stocks have the potential to affect the spawning success and/or the amount of food available. In fact parts of this regions were declared a fisheries disaster during the first six months of 2012 because stocks of cod, haddock and flounder are not rebuilding in spite of the fact that fishers have been adhering to tough quotas.

These changes have implications for our fisheries, as well as the fish themselves. The changes mean that fishers who have adapted their vessels and gear for one species or group of species, may have to travel further to catch those

fish – expending more fuel. Some stocks have moved out of US waters, meaning that our fishers will have to compete with fishers from other countries for the fish that they used to have exclusive access to. Remember that this is a $1.7T industry.

Increasing extent and number of Coral bleaching events on Florida and Caribbean reefs

Coral reefs comprise some of the most beautiful and diverse ecosystems on earth. They are also important economically. US Coral reefs spur near $17B in tourism spending with 45M tourist visits annually to US reefs. They are responsible for $247M in commercial fishing (NMFS, Annual Commercial Landing Statistics, 2011). And coral reefs provide coastal protection from strong ocean currents, waves, and hurricanes. I am going to focus my remarks on Florida and US Caribbean reefs, those closest to my home.

As you may know, small symbiotic algae live inside corals and provide food and energy for the corals through photosynthesis. When these symbiotic organisms are stressed by heat they often die and are expelled leaving the corals to starve. Because these algae are responsible for the color of the corals, the corals look white or 'bleached' and these events are called 'coral bleaching'. Both the intensity and duration of heat waves influence coral stress responses and bleaching. A weeklong spike in temperature at 4°C (7°F) above the average summer maximum temperature can lead to widespread coral bleaching. Likewise just a 1°C (2°F) increase that continues for 4 weeks can result in prolific coral bleaching. Bleaching events that persist for weeks or months usually lead to extensive coral mortality.

For the past 30 years detailed surveys of coral bleaching have been accompanied by discrete sea surface temperature data. Using satellite sea surface temperature data and in situ temperature data, NOAA tracks the sea surface conditions that could lead to coral bleaching. As compared to the previous 15 years, this heat stress in the Caribbean has nearly doubled in the last decade, accompanied by severe coral bleaching events (Eakin, 2007). The Caribbean/Florida region has shown sea surface temperature increases of about 1°C (2°F) per decade (Chollett, et al., 2012) concurrent with losses of viable coral reef area of between 5.5% and 9.2% per year (Cote et al, 2005; Gardner, et al., 2001). Western Atlantic reefs have the highest percentage area affected by bleaching of any reefs worldwide.

Numerous studies have documented increases in coral disease abundance and associated coral mortality during elevated summer temperatures (e.g. Voss and Richardson 2006, Jones et al. 2004). Like coral bleaching, the duration of high temperature anomalies can impact disease abundance and severity (Bruno et al. 2007, Ruiz-Morenol et al. 2012). Thermal stress is known to both compromise

coral immunity (Harvell et al. 2009, Mydlarz et al. 2010) and increase the growth rates of certain coral pathogens (Ward et al. 2007).

Superimposed on the increasing temperature of Florida/Caribbean region have been extreme events, like those of 1997-1998 (which was also an El Nino year) and 2005 (which was not an El Nino or La Nina year). 2005 had the warmest regionally averaged Caribbean sea-surface temperatures recorded in the last 150 years. 90% of the reefs in the US Virgin Islands experienced bleaching, and many of these coral experienced secondary disease infections. Overall, coral cover in the USVI was reduced by 60% due to bleaching and disease associated mortality (Miller et al. 2009).

Climate change and associated temperature stress are not the sole drivers of coral reef health. Excess nutrients, increased sedimentation, and other human influenced factors are known to impact coral reefs. Data suggests that the synergistic effects of local stressors can reduce corals thermal tolerance limits (Carilli et al. 2009), exacerbating the potential impacts of climate change on coral health.

Sea level rise

Humans are part of the ecosystem as well and my last example focuses on climate change impacts on coastal communities from sea level rise. Again, I'll focus on the area I know best, South Florida. While this is but one area that will be affected, economic analyses indicate that 40% of the economic impact of the first foot of sea level rise in the US will be in South Florida (Tebaldi, et al., 2012).

As you all know, Florida is very flat and very low. We have a large population, almost 19 million, and it is heavily concentrated with almost 14 million people living along our coast. In South Florida Miami, the 7th largest city in the country, the Florida Keys, coastal and inland portions of Broward Country, the Florida Everglades and Fort Lauderdale are all below 2 feet in elevation.

Florida has seen 5-8 inches of sea level rise in the past 50 years. Our civic infrastructure in South Florida -- roads, storm sewers, water supplies, and power grids – is already seeing the impact of sea level rise. Although sea level has only risen these few inches in 50 years, that rise has been sufficient to prevent drainage systems from working during lunar high tides and during storms. The streets of Miami Beach are now routinely flooded at peak high tide. The addition of storm surges to these higher sea levels means that drainage systems no longer work reliably causing seawater to move into storm sewer systems and force water inland. Several flood gates are unable to discharge storm water at their full capacity during high tides. Future sea level rise of only 6 more inches – forecast as early as 2030 – would cripple half of the areas flood control infrastructure.

But the sea level rise problem in Florida is not restricted to inundation. Very porous limestone underlies most of Florida. As sea level rises, salt water intrudes into the limestone and pushes freshwater up and out of the limestone. The Biscayne limestone aquifer provides much of the freshwater to the coastal region of the southern east coast of Florida. It has been affected by saltwater intrusion and will be subject to further intrusion. Many wells for south Florida communities are close to the current boundary of saltwater intrusion. The City of Hallandale Beach is already spending $16M to upgrade their storm water system and to move the city's entire drinking water supply westward. This will only be a temporary solution as sea level continues to rise.

This south Florida coastal ecosystem, of which people are so much a part, is already seeing the impact of climate change in the rate of sea level rise, as the thermal expansion of ocean waters with their warming is a major component of the sea level rise we are already seeing.

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STATEMENT OF DR. ROGER PIELKE, JR.
to the COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
of the UNITED STATES SENATE

HEARING on CLIMATE CHANGE: IT'S HAPPENING NOW
18 July 2013

Short Biographical Note

My academic degrees are in mathematics, public policy and political science. I began studying extreme weather and climate in 1993 at the National Center for Atmospheric Research in Boulder, CO. Over the past 20 years I have collaborated with researchers around the world to publish dozens of peer-reviewed papers on hurricanes, floods, tornadoes, Australian bushfires, earthquakes and other subjects related to extreme events. Since 2001, I have been a professor of environmental studies at the University of Colorado. A longer bio can be found as an appendix to this testimony. My views on climate policy and politics, not discussed in this testimony, can be found in my recent book, *The Climate Fix* (Basic Books, 2011).

Take-Home Points

- It is misleading, and just plain incorrect, to claim that disasters associated with hurricanes, tornadoes, floods or droughts have increased on climate timescales either in the United States or globally.[1] It is further incorrect to associate the increasing costs of disasters with the emission of greenhouse gases.
- Globally, weather-related losses ($) have not increased since 1990 as a proportion of GDP (they have actually decreased by about 25%) and insured catastrophe losses have not increased as a proportion of GDP since 1960.
- Hurricanes have not increased in the US in frequency, intensity or normalized damage since at least 1900. The same holds for tropical cyclones globally since at least 1970 (when data allows for a global perspective).
- Floods have not increased in the US in frequency or intensity since at least 1950. Flood losses as a percentage of US GDP have dropped by about 75% since 1940.
- Tornadoes have not increased in frequency, intensity or normalized damage since 1950, and there is some evidence to suggest that they have actually declined.
- Drought has "for the most part, become shorter, less frequent, and cover a smaller portion of the U. S. over the last century."[2] Globally, "there has been little change in drought over the past 60 years."[3]
- The absolute costs of disasters will increase significantly in coming years due to greater wealth and populations in locations exposed to extremes. Consequent, disasters will continue to be an important focus of policy, irrespective of the exact future course of climate change.

To avoid any confusion

Because the climate issue is so deeply politicized, it is necessary to include several statements beyond those reported above.

[1] The IPCC defines climate timescales to be 30-50 years and longer.
[2] This quote comes from the US Climate Change Science Program's 2008 report on extremes in North America.
[3] Sheffield et al. in Nature, http://www.nature.com/nature/journal/v491/n7424/full/nature11575.html

- Humans influence the climate system in profound ways, including through the emission of carbon dioxide via the combustion of fossil fuels.[4]
- Researchers have detected and (in some cases) attributed a human influence in other measures of climate extremes beyond those discussed in this testimony, including surface temperatures and precipitation.
- The inability to detect and attribute changes in hurricanes, floods, tornadoes and drought does not mean that human-caused climate change is not real or of concern.
- It does mean however that some activists, politicians, journalists, corporate and government agency representatives and even scientists who should know better have made claims that are unsupportable based on evidence and research.
- Such false claims could undermine the credibility of arguments for action on climate change, and to the extent that such false claims confuse those who make decisions related to extreme events, they could lead to poor decision making.
- A considerable body of research projects that various extremes may become more frequent and/or intense in the future as a direct consequence of the human emission of carbon dioxide.[5]
- Our research, and that of others, suggests that assuming that these projections are accurate, it will be many decades, perhaps longer, before the signal of human-caused climate change can be detected in the statistics of hurricanes (and to the extent that statistical properties are similar, in floods, tornadoes, drought).[6]

The remainder of this written testimony provides data and references to support the claims made in the "take-home points" above. The "take-home points" are broadly supported by peer-reviewed research, US governmental assessments of climate science and the recent report of the Intergovernmental Panel on Climate Change in its Special Report on Extreme Events (IPCC SREX 2012).[7]

Global Weather-Related Disaster Loss ($) Trends

What the IPCC SREX (2012) says:

- "There is high confidence, based on high agreement and medium evidence, that economic losses from weather- and climate-related disasters have increased"
- "There is medium evidence and high agreement that long-term trends in normalized losses have not been attributed to natural or anthropogenic climate change"

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[4] See, e.g., Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[5] There are exceptions, for instance, the IPCC SREX (2012) concludes of winter storms, "There is medium confidence that there will be a reduction in the number of extratropical cyclones averaged over each hemisphere."

[6] Crompton, RP, RA Pielke and KJ McAneney (2011), Emergence timescales for detection of anthropogenic climate change in US tropical cyclone loss data. *Environ. Res. Lett.* **6** (1) doi: 10.1088/1748-9326/6/1/014003

[7] IPCC SREX (2012) refers to IPCC, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (Eds.) Cambridge University Press.

- "The statement about the absence of trends in impacts attributable to natural or anthropogenic climate change holds for tropical and extratropical [winter] storms and tornadoes"
- "The absence of an attributable climate change signal in losses also holds for flood losses."

What the data says:

1. **Globally, weather-related losses have not increased since 1990 as a proportion of GDP (they have actually decreased by about 25%).**

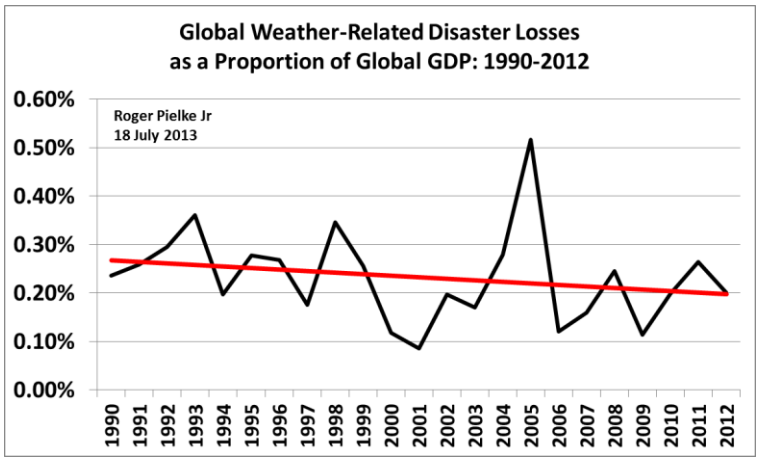

Figure 1. Global weather-related disasters as a proportion of global GDP, 1990-2012. Source of loss data: Munich Re.[8] Source of GDP data: United Nations.[9]

2. **Insured catastrophe losses have not increased as a proportion of GDP since 1960.**

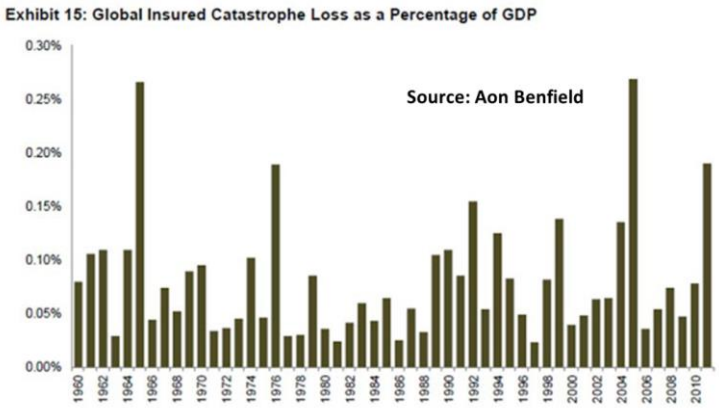

Figure 2. Global insured catastrophe loss as a percentage of global GDP. Source: Aon Benfield.[10]

[8] http://www.munichre.com/en/reinsurance/business/non-life/georisks/natcatservice/great_natural_catastrophes.aspx
[9] http://unstats.un.org/unsd/snaama/dnllist.asp
[10] http://thoughtleadership.aonbenfield.com/Documents/20130103_reinsurance_market_outlook_external.pdf

Note: The peer-reviewed literature on this subject is extensive and robust. Neumayer and Barthel (2011), in a study conducted at the London School of Economics and supported financially by Munich Reinsurance conclude:

> "[B]ased on historical data, there is no evidence so far that climate change has increased the normalized economic loss from natural disasters."[11]

Hurricanes

What the IPCC SREX (2102) says:

- "Low confidence in attribution of any detectable changes in tropical cyclone activity to anthropogenic influences."

What the data says:

3. **Hurricanes have not increased in the US in frequency, intensity or normalized damage since at least 1900.**

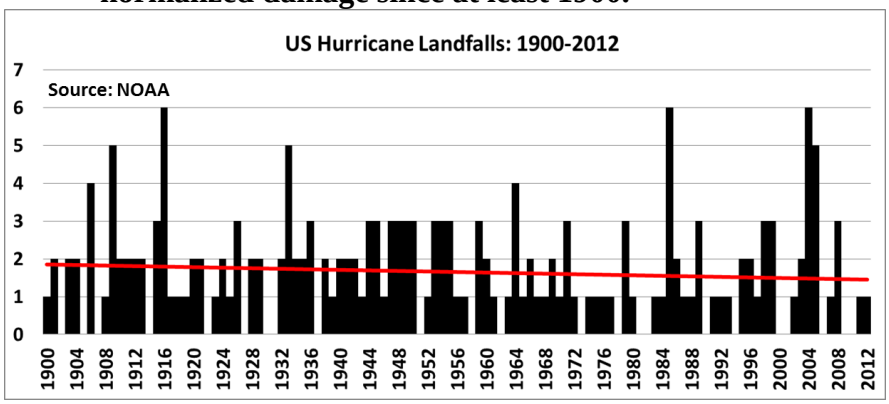

Figure 3a. Number of landfalling US hurricanes from 1900-2012. The red line shows the linear trend, exhibiting a decrease from about 2 to 1.5 landfalls per year since 1900. Source: NOAA.[12]

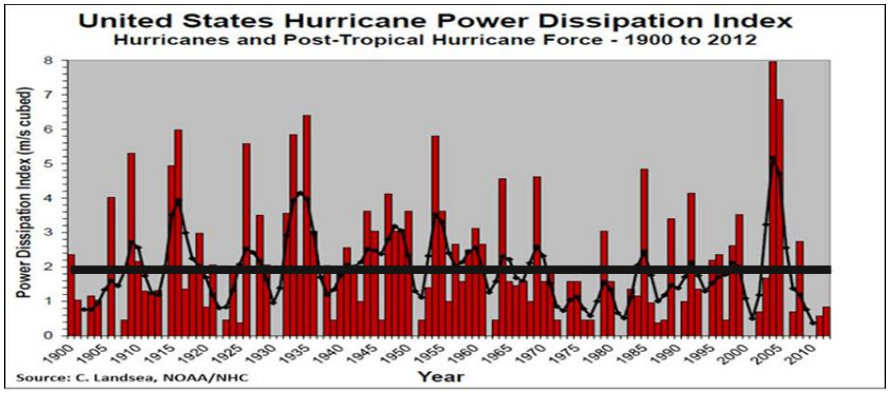

Figure 3b. Intensity of US hurricanes at landfall, 1900-2012 (measured as the summed power dissipation for each year). The heavy black line shows the linear trend. Source NOAA, figure courtesy Chris Landsea, NOAA/NHC.

[11] Neumayer, E. and F. Barthel. 2011. Normalizing Economic Loss from Natural Disasters: A Global Analysis, *Global Environmental Change*, **21**:13-24

[12] http://www.aoml.noaa.gov/hrd/hurdat/All_U.S._Hurricanes.html

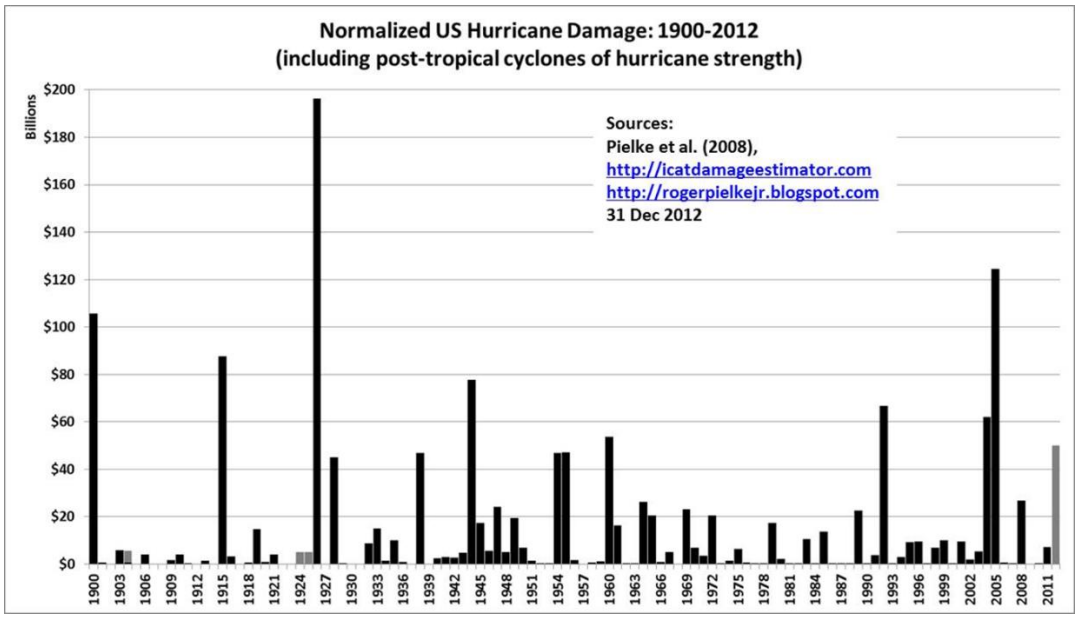

Figure 3c. Normalized US hurricane damage 1900-2012, estimated total damage if each past hurricane season occurred with 2012 levels of development. After Pielke et al. 2008.[13] Note that the figure includes Superstorm Sandy (2012) in gray and placeholders for the three other post-tropical cyclones of hurricanes which made landfall in 1904, 1924 and 1925.

4. **There are no significant trends (up or down) in global tropical cyclone landfalls since 1970 (when data allows for a comprehensive perspective), or in the overall number of tropical cyclones.**

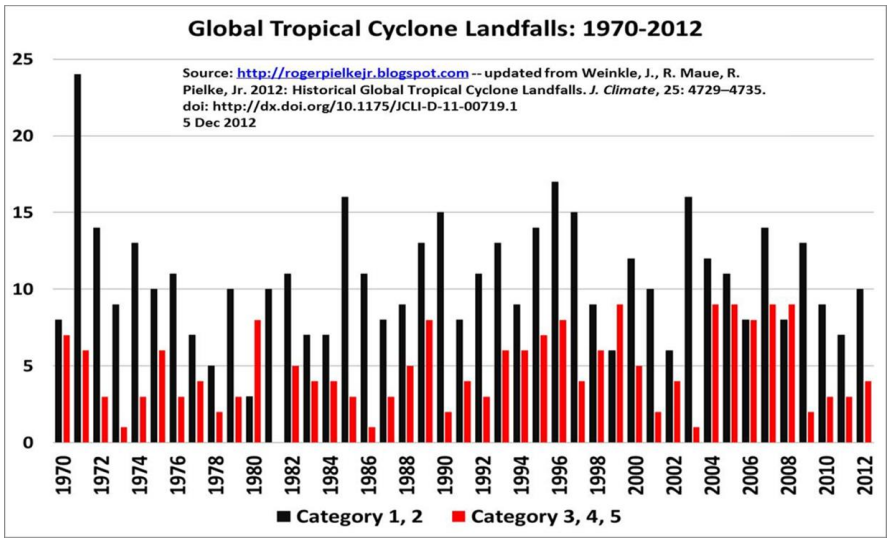

Figure 4a. Global tropical cyclone (called hurricanes in the North Atlantic) landfalls, 1970-2012, after Weinkle et al. 2012.[14]

[13] Pielke, Jr., R.A., J. Gratz, C.W. Landsea, D. Collins, M. Saunders, and R. Musulin (2008), Normalized Hurricane Damages in the United States: 1900-2005. *Natural Hazards Review* **9**:29-42. Data updated to 2012 values using the ICAT Damage Estimator: http://www.icatdamageestimator.com

[14] Weinkle, J, R Maue and R Pielke (2012), Historical Global Tropical Cyclone Landfalls. Journal of Climate, **25**:4729-4735

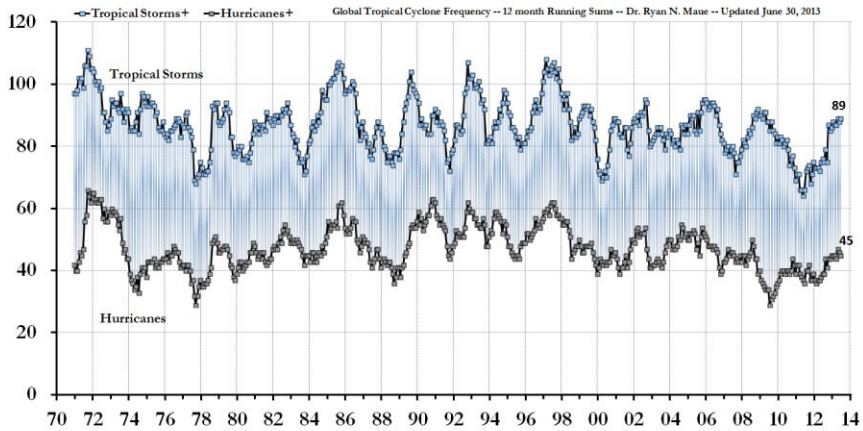

Figure 4b. Total count of tropical cyclones of tropical storm (top curve) and hurricane strength, 12-month running sums 1970 through June 30, 2013. Figure courtesy Ryan Maue.[15]

Floods

What the IPCC SREX (2012) says:

- "There is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scales"
- "there is low agreement in this evidence, and thus overall low confidence at the global scale regarding even the sign of these changes.."

What the data says:

5. **Floods have not increased in the US in frequency or intensity since at least 1950.**

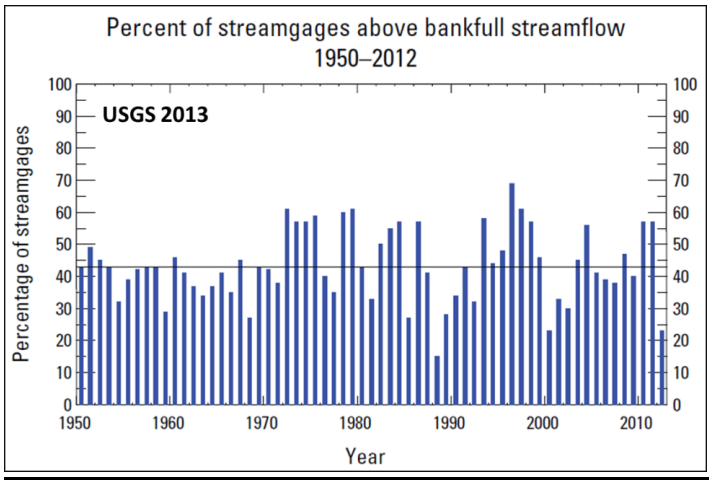

Figure 5. One measure of flood frequency from the USGS, percent of US streamguages above "bankfull streamflow." The USGS explains: "The bankfull streamflow is defined as the highest daily mean streamflow value expected to occur, on average, once in every 2.3 years."[16]

[15] After Maue, R. N. (2011), Recent historically low global tropical cyclone activity. , *Geophys. Res. Letts.* **38**:L14803, doi:10.1029/2011GL047711.

6. **Flood losses as a percentage of US GDP have dropped by about 75% since 1940.**

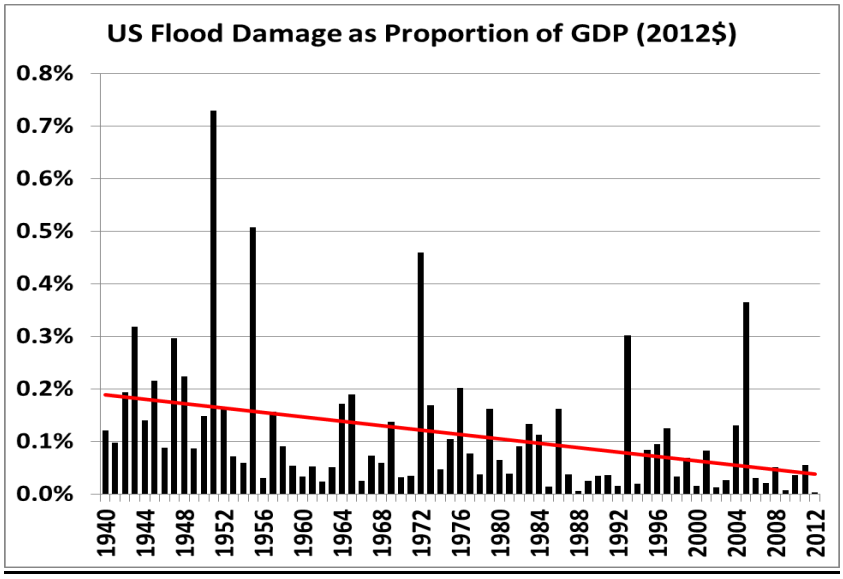

Figure 6. US flood losses as a percentage of US GDP. Annual flood losses have decreased from about 0.2% of US GDP to <0.05% since 1940. Flood loss data from NOAA HIC: http://www.nws.noaa.gov/hic/ GDP data from OMB: http://www.whitehouse.gov/sites/default/files/omb/budget/fy2014/assets/hist10z1.xls[17]

Note: A 2005 peer-reviewed paper examined flood trends around the world and concluded: "observations to date provide no conclusive and general proof as to how climate change affects flood behaviour."[18]

Tornadoes

What the IPCC SREX (2012) says:

- "There is low confidence in observed trends in small spatial-scale phenomena such as tornadoes and hail"

What the data says:

7. **Tornadoes have not increased in frequency, intensity or normalized damage since 1950, and there is some evidence to suggest that they have actually declined.**

[16] Xiaodong Jian, David M. Wolock, Harry F. Lins, and Steve Brady, Streamflow of 2012—Water Year Summary, U.S. Geological Survey, Reston, Virginia, May 2013.

[17] After Downton, M., J.Z.B. Miller, and R. A. Pielke, Jr. (2005), Reanalysis of the U.S. National Flood Loss Database. *Natural Hazards Review* **6**:13-22

[18] Kundzewicz, Z.W., D. Graczyk, T. Maurer, I. Przymusińska, M. Radziejewski, C. Svensson and M. Szwed, 2005(a):Trend detection in river flow time-series: 1. annual maximum flow. *Hydrol. Sci. J.*, **50**:797-810.

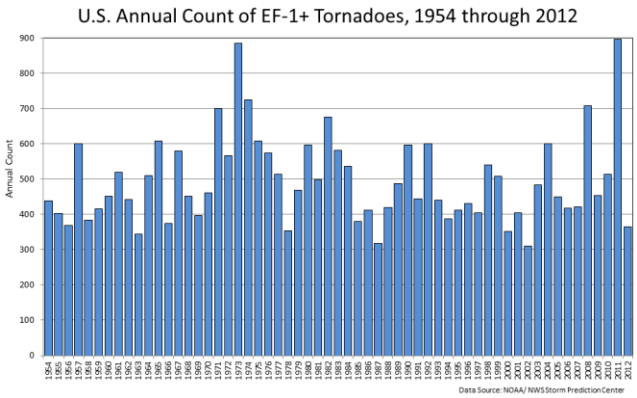

Figure 7a. Count of US tornadoes of at least EF1 strength, 1954-2012.
Source: NOAA, http://www.ncdc.noaa.gov/oa/climate/severeweather/tornadoes.html

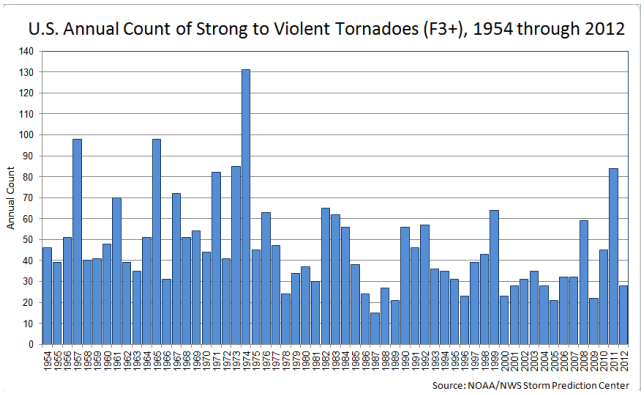

Figure 7b. Count of US tornadoes of at least EF3 strength, 1954-2012.
Source: NOAA, http://www.ncdc.noaa.gov/oa/climate/severeweather/tornadoes.html

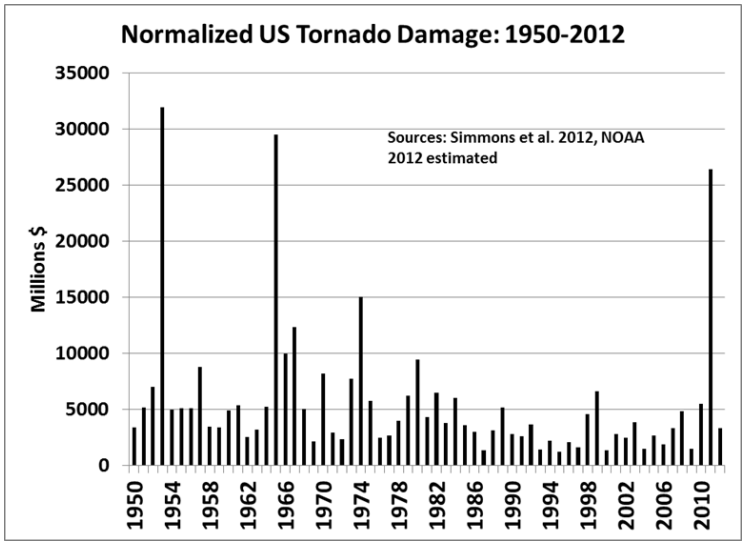

Figure 7c. Normalized US tornado damage, estimated total damage if tornadoes of past years occurred with 2012 levels of development. After Simmons et al. 2012. Note 2012 estimated.[19]

[19] Simmons, KM, D Sutter and R Pielke (2013), Normalized tornado damage in the United States: 1950-2011. *Environ. Hazards* **12**:132-14

Drought

What the IPCC SREX (2012) says:

- "There is medium confidence that since the 1950s some regions of the world have experienced a trend to more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions droughts have become less frequent, less intense, or shorter, for example, in central North America and northwestern Australia."
- For the US the CCSP (2008)[20] says: "droughts have, for the most part, become shorter, less frequent, and cover a smaller portion of the U. S. over the last century."[21]

What the data says:

8. **Drought has "for the most part, become shorter, less frequent, and cover a smaller portion of the U. S. over the last century."[22]**

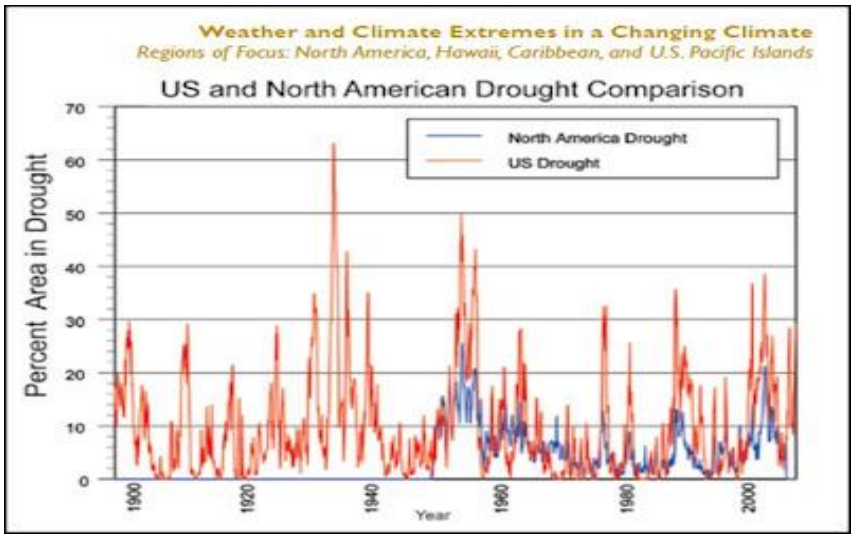

Figure 8. Figure 2.6 from CCSP (2008) has this caption: "The area (in percent) of area in severe to extreme drought as measured by the Palmer Drought Severity Index for the United States (red) from 1900 to present and for North America (blue) from 1950 to present."

Note: Writing in *Nature* Senevirnate (2012) argues with respect to global trends that, "there is no necessary correlation between temperature changes and long-term drought variations, which should warn us against using any simplifications regarding their relationship."[23]

[20] CCSP, 2008: Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Thomas R. Karl, Gerald A. Meehl, Christopher D. Miller, Susan J. Hassol, Anne M. Waple, and William L. Murray (eds.)]. Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA, 164 pp.

[21] CCSP (2008) notes that "the main exception is the Southwest and parts of the interior of the West, where increased temperature has led to rising drought trends."

[22] This quote comes from the US Climate Change Science Program's 2008 report on extremes in North America.

[23] http://www.nature.com/nature/journal/v491/n7424/full/491338a.html

Biography of Roger Pielke Jr.

Roger Pielke, Jr. has been on the faculty of the University of Colorado since 2001 and is a Professor in the Environmental Studies Program and a Fellow of the Cooperative Institute for Research in Environmental Sciences (CIRES). Roger's research focuses on science, innovation and politics and in 2011 began to write and research on the governance of sports organizations, including FIFA and the NCAA. Roger holds degrees in mathematics, public policy and political science, all from the University of Colorado. In 2012 Roger was awarded an honorary doctorate from Linköping University in Sweden and was also awarded the Public Service Award of the Geological Society of America. Roger also received the Eduard Brückner Prize in Munich, Germany in 2006 for outstanding achievement in interdisciplinary climate research. At CIRES, Roger served as the Director of the Center for Science and Technology Policy Research from 2001-2007. Before joining the faculty of the University of Colorado, from 1993-2001 Roger was a Scientist at the National Center for Atmospheric Research. Roger is a Senior Fellow of the Breakthrough Institute, and holds academic appointments at Macquarie University in Sydney, Australia and the London School of Economics. He is also author, co-author or co-editor of seven books, including **The Honest Broker: Making Sense of Science in Policy and Politics** published by Cambridge University Press (2007). His most recent book is **The Climate Fix: What Scientists and Politicians Won't Tell you About Global Warming** (2011, Basic Books). He is currently working on a book on technology, innovation and economic growth.

STATEMENT TO THE ENVIRONMENT AND PUBLIC WORKS COMMITTEE OF THE UNITED STATES SENATE

Roy W. Spencer, PhD
Earth System Science Center
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Huntsville, Alabama 35801

18 July 2013

1. Introduction

I would like to thank the Chairman and the Committee for the opportunity to provide my perspective on the subject of global warming and climate change.

I have been performing U.S. government-sponsored research for the last twenty-eight years, publishing peer reviewed papers on global temperature monitoring with satellites, on the amount of warming we might expect from greenhouse gas emissions, how to monitor hurricane strength from satellites, and quantitatively explaining ocean heat content changes.

Prior to my current position as a principal research scientist at the University of Alabama in Huntsville, I was Senior Scientist for Climate Studies at NASA's Marshall Space Flight Center. I am also the U.S. Science Team Leader for the Advanced Microwave Scanning Radiometer-E flying on NASA's Earth-observation satellite Aqua. I am a recipient of NASA's Medal for Exceptional Scientific Achievement.

In related endeavors I have authored a book on basic economics (*Fundanomics: The Free Market, Simplified*) now used in a college-level economics course; and have co-authored an Energy Law Journal article on the use of climate models under the *Daubert* standard for rules of evidence.

2. The State of Climate Science

My overall view of the influence of humans on climate is that we probably are having some influence, but it is impossible to know with any level of certainty how much influence. The difficulty in determining the human influence on climate arises from several sources: (1) weather and climate vary naturally, and by amounts that are not

currently being exceeded; (2) global warming theory is just that – based upon theory; and (3) there is no unique fingerprint of human caused global warming.

My belief that some portion of recent warming is due to humans is based upon my faith in at least some portion of the theory: that the human contribution to atmospheric greenhouse gas concentrations has resulted in an estimated 1% reduction in the Earth's ability to cool to outer space, and so some level of warming can be expected to occur from that change.

Exactly how much warming will occur, however, depends upon something we call "climate sensitivity" (Spencer & Braswell, 2010; 2011), and relatively few researchers in the world – probably not much more than a dozen – have researched how sensitive today's climate system is based upon actual measurements. This is why popular surveys of climate scientists and their beliefs regarding global warming have little meaning: very few of them have actually worked on the details involved in determining exactly how much warming might result from anthropogenic greenhouse gas emissions.

Our most recent peer-reviewed paper on this subject, Spencer & Braswell (2013), has arrived at a climate sensitivity of only 1.3 deg. C for a doubling of atmospheric carbon dioxide, based upon a variety of global measurements, including warming of the global oceans since the 1950s. This level of warming is below the lower limit of 1.5 deg. C minimum predicted in the last (AR4) IPCC report. It is also in line with (an admitted minority of) other estimates of low climate sensitivity published in the peer review literature.

It should also be noted that the fact that I believe at least some of recent warming is human-caused places me in the 97% of researchers recently claimed to support the global warming consensus (actually, it's 97% of the published papers, Cook et al., 2013). The 97% statement is therefore rather innocuous, since it probably includes all of the global warming "skeptics" I know of who are actively working in the field. Skeptics generally are skeptical of the view that recent warming is all human-caused, and/or that it is of a sufficient magnitude to warrant immediate action given the cost of energy policies to the poor. They do not claim humans have no impact on climate whatsoever.

3. Temperature Changes in the Atmosphere and Ocean

While 2012 was a record warm year in the U.S. (at least in the ~100 years for which we have thermometer records) this was not true of the global average, which has not experienced statistically significant warming since about 1998. This is not surprising since the contiguous U.S. covers only about 2% of the Earth, and persistent regional weather patterns – warm or cold – are responsible for most record weather events.

The only truly global temperature measurements, unaffected by artifacts such as urban heat island effects, are for the bulk atmosphere from Earth-orbiting satellites, the methodology for which John Christy and I developed almost 25 years ago; all other measurements are at points and so are geographically incomplete. Our monitoring of the lower troposphere since the satellite record began in 1979 is shown in Fig. 1,

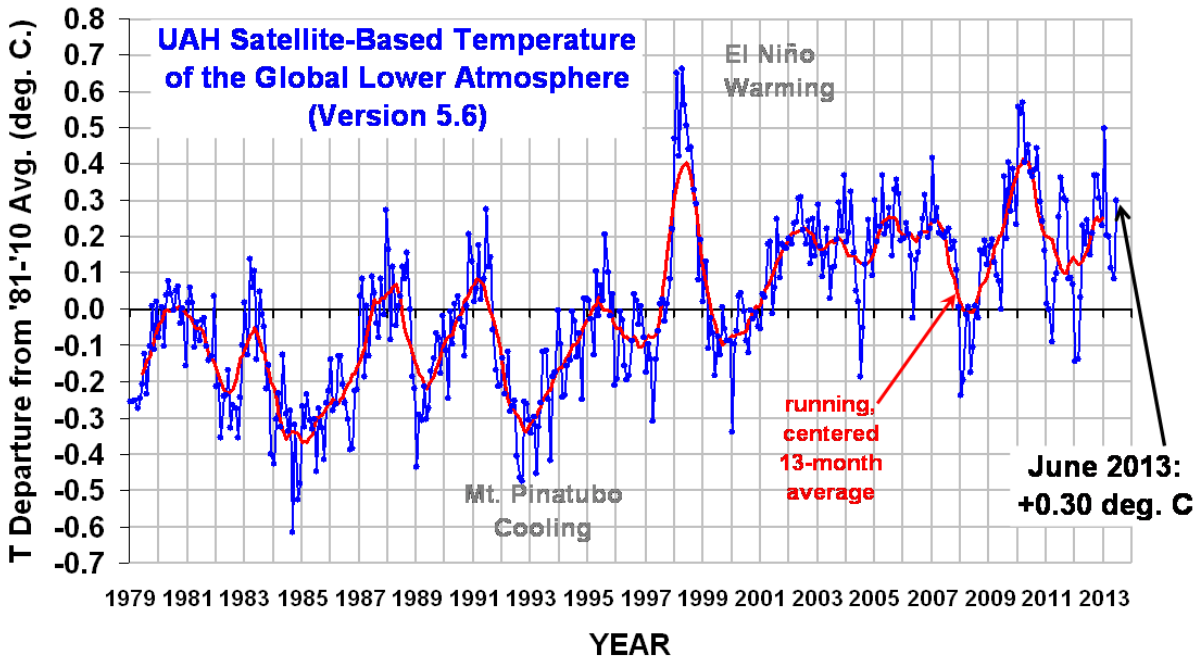

Fig. 1. UAH global lower tropospheric (LT) temperature variations between January 1979 and June 2013.

The satellite measurements reveal several significant features which are pertinent to our concern over human-induced climate change (all of the following points are also supported by the alternative version of the satellite-based temperatures from Remote Sensing Systems [RSS]):

1) The magnitude of global-average atmospheric warming between 1979 and 2012 is only about 50% that predicted by the climate models relied upon by the IPCC in their projections of global warming.
2) The level of warming in the most recent 15 year period is not significantly different from zero, despite this being the period of greatest greenhouse gas concentration. This is in stark contrast to claims that warming is "accelerating".
3) The level of observed tropical atmospheric warming since 1979 is dramatically different from that predicted by climate models; it is below all 73 models we have analyzed the output from (see Fig. 2).

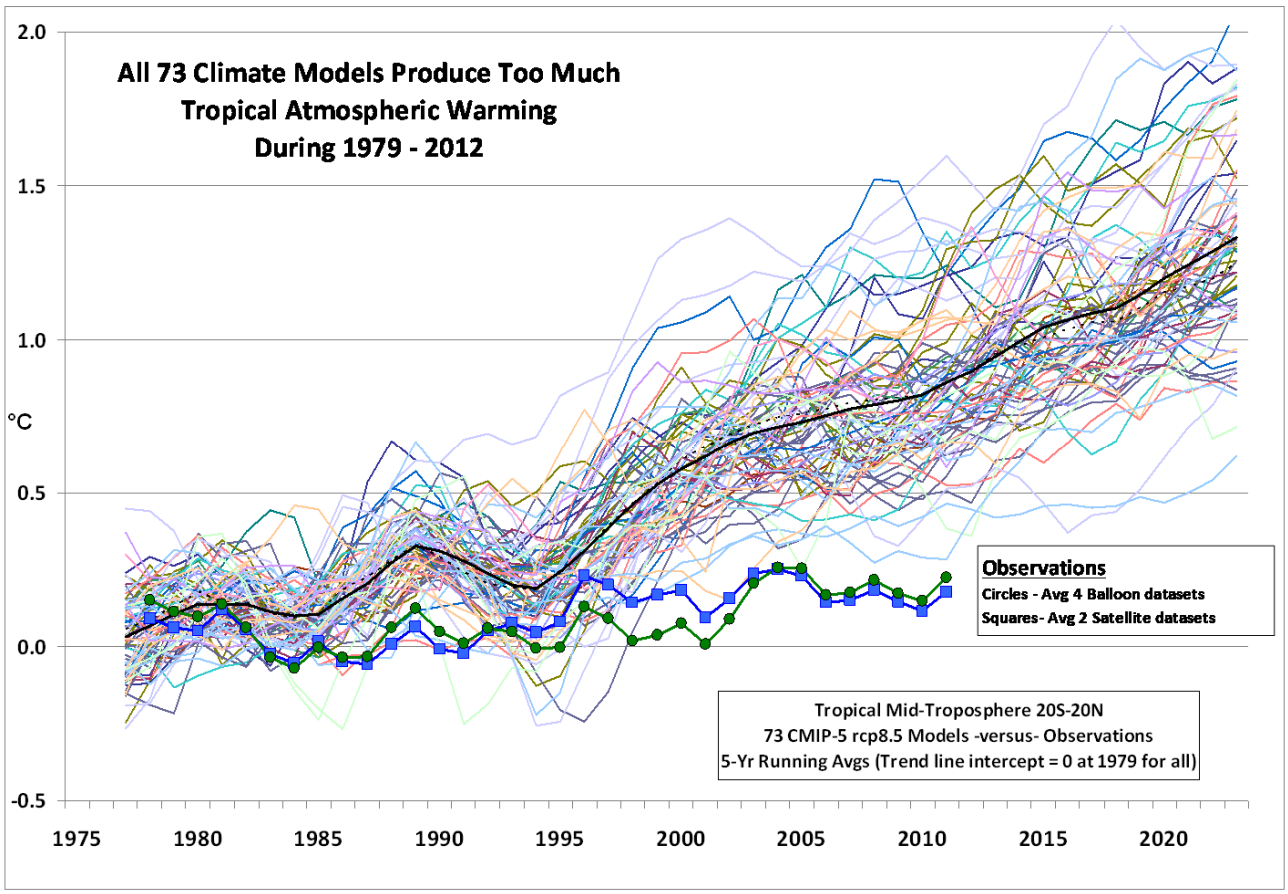

Fig.2. Mid-tropospheric (MT) temperature variations for the tropics (20°N to 20°S) in 73 current (CMIP5) climate models versus measurements from two satellite datasets and four weather balloon datasets.

On this last point, the level of disagreement between models and observations in Fig. 2 is quite striking. While one might argue that it is for a relatively restricted latitude band (20°N to 20°S), this is where almost 50% of the solar energy absorbed by the Earth enters the climate system. The discrepancy between models and observations is related to the lack of a middle- and upper-tropospheric "hotspot" in the observations, which the models produce in response to surface warming combined with positive water vapor feedback. The observations might be telling us that the global warming response to increasing CO2 (and any natural warming influence) is not being amplified by water vapor increases, which have their greatest temperature impact in the middle and upper troposphere (Spencer & Braswell, 1997).

The lack of statistically significant warming in the last 15 years (shown in Fig. 1 above, even more striking in the RSS dataset) is sometimes glossed over with the claim that the global temperature record has a number of examples of no warming (or even cooling) over fifteen year periods. But this claim is disingenuous, because *the IPCC-presumed radiative forcing of the climate system from increasing CO2 has been at its supposed maximum value only in the last 15 years*. In other words, when the climate "stove" has been turned up the most (the last 15 years) is also when you least expect a lack of warming.

It is time for scientists to entertain the possibility that there is something wrong with the assumptions built into their climate models. *The fact that all of the models have been peer reviewed does not mean that any of them have been deemed to have any skill for predicting future temperatures.* In the parlance of the *Daubert* standard for rules of scientific evidence, the models have not been successfully *field tested* for predicting climate change, and so far their *error rate* should preclude their use for predicting future climate change (Harlow & Spencer, 2011).

The claim has been made that the extra energy from global warming has mostly bypassed the atmosphere and has been sequestered in the deep ocean, and there is some observational evidence supporting this view (e.g. Levitus *et al.*, 2012). But when we examine the actual, rather weak level of warming (measured in hundredths of a degree C) at depths of many hundreds of meters, it implies relatively low climate sensitivity (Spencer

& Braswell, 2013). Part of the evidence for this result is satellite radiative budget measurements which suggest that more intense El Nino activity since the 1980s caused an apparent decrease in cloudiness, which allowed more sunlight into the climate system, which caused a natural component to recent global warming. Since the global energy imbalance leading to ocean warming since the 1950s is only about 1 part in 1,000 compared to the average rates of solar heating and infrared cooling of the Earth (Levitus *et al.*, 2012), it should not be surprising that natural climate cycles can cause such small changes in ocean temperature. Even if our ocean temperature measurements of deep warming of hundredths of a degree over the last 50 years are correct, and mostly due to human greenhouse gas emissions, they probably do not support the IPCC's pessimistic view of future warming.

4. Has Severe Weather Increased?

The most indefensible claim regarding climate change from an observational point of view is that severe weather has increased. Meteorologists like me have long known that public perception of weather is skewed by short memories and increasing media sensationalizing of weather disasters.

During globally cool conditions in 1970 a tropical cyclone (hurricane) killed 500,000 people in Bangladesh. Records of such storms killing hundreds of thousands of people extend back to 1582. In contrast, as of this writing, it has been a record 7+ years since a major (Cat 3 or stronger) hurricane has hit the U.S. mainland. New research from northwest Florida, based upon coastal sediments, suggest that the past 600 years has been a period of weaker hurricane activity compared to the 1,000 years before that (Brandon *et al.*, 2013). All of these facts indicate the huge amount of natural variability in tropical cyclones which exists and confounds attempts to determine whether tiny global energy imbalances caused by humans have any noticeable effect.

A Hurricane Sandy class of storm is not that unusual, but it hitting a densely populated area is. Sandy's transition to a strong extratropical cyclone is what happens to virtually all poleward-moving hurricanes. The fact that it happened to merge with a separate developing extratropical cyclone during landfall is somewhat less common, but

such events arguably happen every year somewhere in the world – just not where millions of people live.

There is little or no observational evidence that severe weather of any type has worsened over the last 30, 50, or 100 years, irrespective of whether any such changes could be blamed on human activities, anyway. Long-term measurements of droughts, floods, strong tornadoes, hurricanes, severe thunderstorms etc. all show no obvious trends, but do show large variability from one decade to the next, or even one year to the next. While the 2003 heat wave in France and the 2010 heat wave in Russia were exceptional, so were the heat waves of the 1930s in the U.S., which cannot be blamed on our greenhouse gas emissions.

While it is true that storm damage of manmade structures increases over time, this is due to socioeconomic reasons: there are simply more manmade targets for severe storms to hit.

5. Conclusions

The belief that global warming and associated climate change involve more severe weather cannot be supported observationally. And even if we were to observe a trend in severe weather, it would not be possible to determine with any level of confidence the extent to which the change was due to human activities versus natural variability.

While recent global warmth might well be the greatest in the last 150 years for which we have had thermometer records (WMO, 2013), proxy measurements (and even borehole temperatures from the Greenland ice sheet) suggest that global warmth could have been greater 1,000 years ago during the Medieval Warm Period, and 2,000 years ago during the Roman Warm Period (Loehle and McCulloch, 2008; Ljungqvist, 2010). Regarding severe weather, that same WMO report admits, "*the data do not demonstrate that the increase in observed losses is caused by an increase in the frequency and intensity of extreme events. Other factors come into play, notably the increased exposure of people and property to climate extremes and the improved and increased reporting of disasters*."

Thus, the evidence that humans are mostly responsible for either recent warmth or severe weather changes (if such changes exist at all) is equivocal, at best.

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Implications for global warming theory. *Bull. Amer. Meteor. Soc*., **78**, 1097-1106.

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U.S. Science Team Leader, Multichannel Microwave Imaging Radiometer Team, 1992-1996.

Member, TOVS Pathfinder Working Group, 1991-1994.

Member, NASA HQ Earth Science and Applications Advisory Subcommittee, 1990-1992.

Principal Investigator, High Resolution Microwave Spectrometer Sounder for the Polar Platform, 1988-1990.

Principal Investigator, an Advanced Microwave Precipitation Radiometer for rainfall monitoring. 1987-present.

Principal Investigator, Global Precipitation Studies with the Nimbus-7 SMMR and DMSP SSM/I, 1984-present.

Principal Investigator, Space Shuttle Microwave Precipitation Radiometer, 1985.

Member, Japanese Marine Observation Satellite (MOS-1) Validation Team, 1978-1990.

Chairman, Hydrology Subgroup, Earth System Science Geostationary Platform Committee, 1978-1990.

Executive Committee Member, WetNet - An Earth Science and Applications and Data System Prototype, 1987-1992.

Member, Science Steering Group for the Tropical Rain Measuring Mission (TRMM), 1986-1989

Member, TRMM Space Station Accommodations Analysis Study Team, 1987-1991.
Member, Earth System Science Committee (ESSC) Subcommittee on Precipitation and Winds, 1986.
Technical Advisor, World Meteorological Organization Global Precipitation Climatology Project, 1986-1992.

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1996: AMS Special Award "for developing a global, precise record of earth's temperature from operational polar-orbiting satellites, fundamentally advancing our ability to monitor climate."
1991: NASA Exceptional Scientific Achievement Medal
1990: Alabama House of Representatives Resolution #624
1989: MSFC Center Director's Commendation

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