Perspectives on Contemporary Extreme Weather Within the Context of Changing Climate

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Key Takeaway Points

This topic is about impact to people--your constituents, my fellow citizens, my two kids--not just polar bears.

1) Most of the warming of the past 50 years is due to human activity, and extensive evidence supports this conclusion

2) Climate change is increasing the probability of extreme events, and in some cases may be strengthening their intensity or increasing their frequency (i.e. we are loading the dice towards more Sandy or blizzard type storms)

3) There is strong evidence that increases in some types of extremes are linked to human-induced climate change, notably extreme heat, coastal flooding, and heavy downpours. For other types of extremes, such as tornadoes, current evidence is much more limited

Introduction

I would like to thank Chairman Boxer and other senators for the opportunity to present before the Senate Environment and Public Works Committee. It is a great honor to have this opportunity to brief you. I view my presence here today as service to our Nation and a privilege. Last month, I took office as the President of the American Meteorological Society (AMS, www.ametsoc.org). Since 1919, AMS has been a leading authority promoting the development and dissemination of information and education on the atmospheric and related oceanic and hydrologic sciences and the advancement of their professional applications.

Our 14,000-person membership spans the private, public, and academic sector and includes operational meteorologists, broadcasters, research scientists, stakeholders, and practitioners. Our members are key leaders in the National Climate Assessment,

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[1] Dr. Shepherd is the president of the American Meteorological Society. He also serves on the NOAA Science Advisory Board, Earth Science Subcomittee of the NASA Advisory Council, and National Academy of Science studies, including one related to climate change and national security. President George W. Bush honored him with a Presidential Early Career Award in 2004.

Intergovernmental Panel on Climate Change (IPCC), National Academy of Science Climate Choices activity and almost every other major weather or climate initiative. AMS science journals, scientific meetings, and other services are gold standards for dissemination of climate change science. The *Bulletin of the American Meteorological Society* is the top rated journal in Atmospheric Sciences and *our Journal of Climate* is typically in the top 5. AMS also issues objective, science-based information statements and informs policy makers via our Policy Program. Aspects of my testimony today will be based on our 2012 Information Statement on Climate Change[2]

Context

In 2012, the United States had its warmest year on record, economy-altering droughts, major wildfires, and Superstorm Sandy. The National Oceanic and Atmospheric Administration (NOAA) characterized 2012 as the second most extreme weather year, on record, in the contiguous United States. Extreme weather influences citizens more than scientific graphs and charts. In my household, they meet the "spouse" threshold, meaning that my wife, an educated but otherwise non-science-expert citizen, understands the impact on our kids and "dinner table" topics like our budget, health, and well-being.

The fingerprint of events like the drought, Superstorm Sandy, or urban floods is traceable to increases in food prices, higher insurance rates, and changing property values. Global insurance company Munich Re noted that "*USA accounted for a higher proportion of global natural catastrophe losses than usual in 2012 ... natural catastrophes caused $160 billion in overall losses and $65 billion in insured losses worldwide*." Economists estimate that infrastructure, insurance claims, and other costs will likely be in the $50-100 billion range from Sandy alone. Studies published in the *Bulletin of the American Meteorological Society*[3], noted that weather impacts about 3.4 percent of the entire U.S. Gross Domestic Product (GDP), based on estimates through 2008 — roughly an economic cost of $485 billion. Given the impact of Sandy, the Northeast Blizzard, and other weather disasters from 2008 to 2013, this number is likely an underestimate.

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[2] http://www.ametsoc.org/policy/2012climatechange.html

[3] http://journals.ametsoc.org/doi/abs/10.1175/2011BAMS2928.1

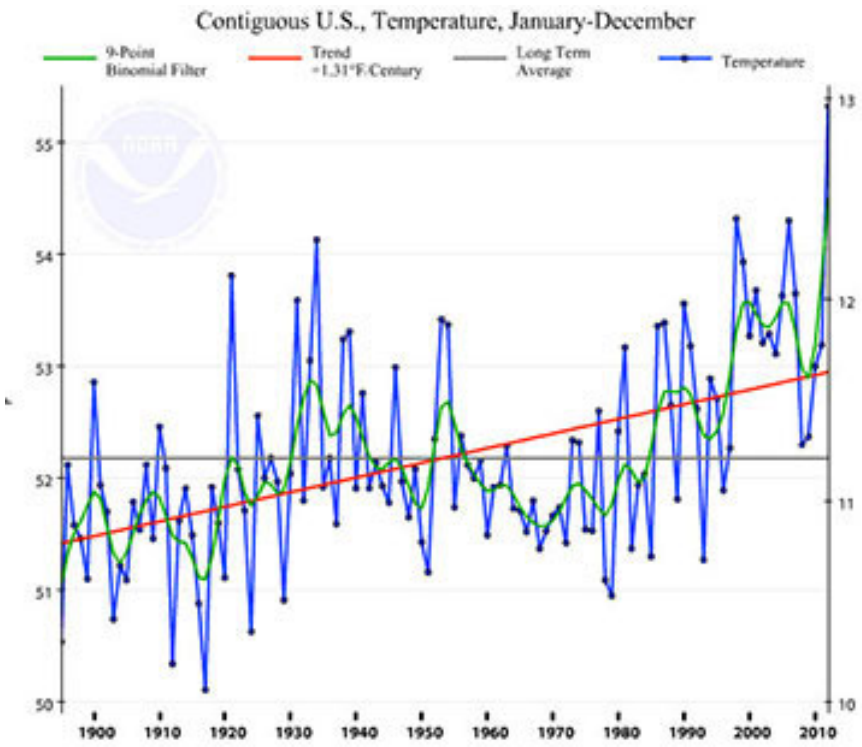


Figure 1: Contiguous U.S. temperatures from 1895 to 2012 (NOAA).

We are warming and human activities are contributing

NOAA confirms that "*average temperature in the United States for 2012 was ... 3.2 degrees Fahrenheit above the 20th-century average, and 1.0 degree above 1998, the previous warmest year*" in the United States (Figure 1). Studies have documented that over the last several decades, we have experienced far more record-high temperatures than record-low temperatures. This is a clear signal of human influence. In climate varying by natural processes but not changing over time, the number of record highs and lows should be roughly equal (Figure 2), but the figure clearly indicated that the past several years has been overwhelmingly skewed towards record high temperatures[4].

[4] Meehl et al. (2009) Geophysical Research Letters

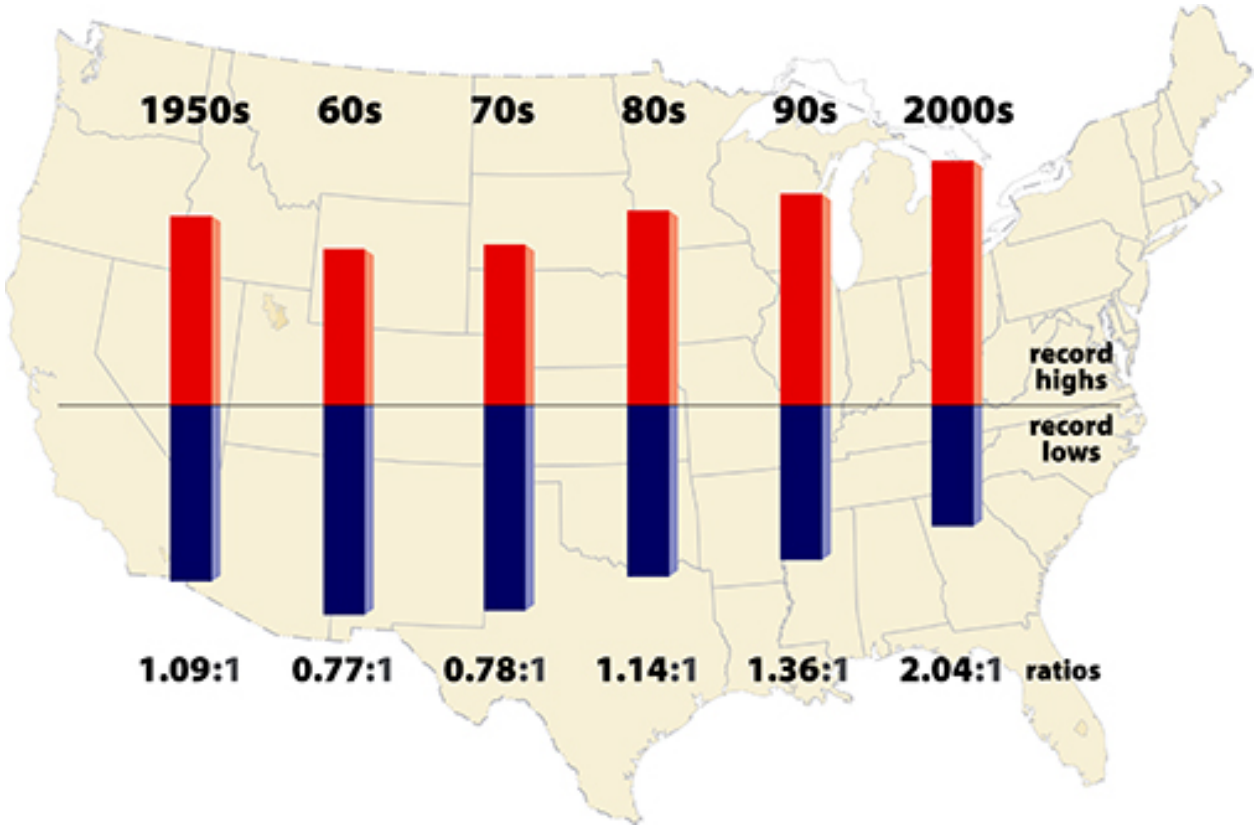


Figure 2: Trends in record highs vs record lows (National Center for Atmospheric Research -NCAR).

According to NOAA, "*the globally-averaged annual combined land and ocean surface temperature in 2012 was 1.03 degrees above the 20th-century average.*" Temperature changes of 1 degree or so may not seem like much (tomorrow may be several degrees different than today). But to put this global number in perspective, globally averaged temperatures of the last ice age were 9° F degrees cooler than today and occurred over the range of 1000's of years, rendering the planet basically unrecognizable by today's standards. This value is of similar magnitude to the upper end of the range projected for the end of this century due to our greenhouse gas emissions. It is also worth a reminder that changes we are observing now happen over periods 10-100 years. Future changes are projected to be unprecedented in terms of both magnitude and rate for human civilization. The current rate of change is another indicator of human influence.

NOAA further notes "*all 12 years of the 21st century (2001-2012) rank among the 14 warmest in the 133-year period of record.*" This is very consistent with statements in the AMS Climate Change Statement, which also states "*warming of the climate system now is unequivocal, according to many different kinds of evidence*." All major global temperature datasets, including those developed out of concern about the validity of accepted climatological records, show warming over the last century.

Contemporary Extreme Weather and Climate Change

Adding heat-trapping gases to the atmosphere through the burning of coal, oil and gas is like putting Earth's climate system on steroids. In sports, you can't say any individual home run or fast bike race time was "caused" by steroids, but it is clear that the drugs increased the odds of those events and changed the overall pattern of performance of the athlete. By the same token, the forthcoming National Climate Assessment[5] report cites "strong evidence" that adding greenhouse gases to the atmosphere increases the odds of some types of severe weather, such as extreme heat (e.g., 2011 in Oklahoma and Texas) and heavy downpours. For example, the literature is increasingly clear that, on average, the intensity of rainstorms (i.e. how hard it rains) is greater than 50 years ago. This leads to increased urban flooding and landslide risk because engineered structures assumed storm intensities would remain constant but they have not.[6] Further, the same report emphasizes data consistent with findings I have independently corroborated in an NSF funded study in the Southeast, namely rainfall variability is increasing and "extremes" like drought or flooding are becoming more extreme. The report shows that the Southeast, Southwest, Rocky Mountain are seeing less precipitation, which worsens water supply issues, causes drought, and increases wildfire risks.

Will 80% Chance of Rain Convince You to Get an Umbrella?

Studies are now being conducted that can probe specific extreme weather events to determine how much climate change might have changed the odds of a particular event. Their conclusions are presented in probabilistic terms, such as: human-induced climate change made the 2011 Texas heat wave and drought 20 times more likely as it would have been in its absence. As a reminder, the public consumes probabilistic information every day. If I tell you there is an 80% chance of rain, I am guessing that most of you will grab an umbrella.

Kevin Trenberth of NCAR argues that asking if a specific event is affected by climate change is the wrong question.[7] He further explains that it is a more appropriate assumption that climate change is affecting all weather now, because the background conditions are so changed - more heat in the system and more water vapor in the air. Statements by several climate experts also confirm this notion[8]:

Michael F. Wehner, staff scientist at the Lawrence Berkeley National Laboratory: "Whenever an extreme weather event occurs, it is natural for the public to ask, "Is this event a result of global warming?" This is not the quite the correct question to ask, as to date, all individual weather events observed could have happened prior to the human intervention in the climate system, however unlikely that may have been. The more relevant question to ask is "How has

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[5] http://ncadac.globalchange.gov/
[6] http://www.earthzine.org/2011/04/29/floods-and-droughts-in-a-changing-climate-–-now-and-the-future/
[7] http://link.springer.com/article/10.1007%2Fs10584-012-0441-5?LI=true
[8] http://www.guardian.co.uk/environment/blog/2012/jul/03/weather-extreme-blame-global-warming

the risk of this event changed because of climate change?.....For instance, the chances of the 2003 European summer heat wave, responsible for as many as 70000 additional deaths, at least doubled and likely increased by a factor of 4 to 10. The chances of the 2010 Russian and 2011 Texas events also undoubtedly increased. While these events could have occurred without the human changes to the climate, it is important to know that the amount of climate change that we have experienced so far is very small to what is projected to occur by the middle and end of this century. By 2100, today's most extreme weather events will seem relatively normal."

Michael Oppenheimer, professor of geosciences and international affairs at Princeton University's Woodrow Wilson School and Department of Geosciences: "*The link between extreme events which have occurred recently and the build-up of the greenhouse gases is best represented by the "loading the dice" analogy – as the world warms, the likelihood of occurrence (frequency), intensity, and/or geographic extent of many types of extreme events is increasing. The events are individual data points in a broader pattern, akin to pixels on a computer screen. You can't say much from any one pixel, but a picture emerges when you step back and look at the pattern. That said, for a few types of extreme events, particularly heat waves, it is sometimes possible to connect the pixel to the bigger picture more directly. The best case is the European heat wave of 2003"*

Context on Sandy, Blizzards, and Drought

A recent IPCC report[9] on extreme events and peer-reviewed science summarized [i]in the Bulletin of the American Meteorological Society[10] present compelling evidence that the magnitude of heat waves, extreme coastal water levels, extreme precipitation events, and drought have increasing links to human-caused climate change. The scientific literature is less clear on linkages to increased hurricane frequency and tornadic activity.

The AMS Climate Change Statement clearly articulates that "*weather patterns will continue to vary from day to day and from season to season, but the frequency of particular patterns and extreme weather and climate events may change as a result of global warming*. " I often use the following analogy: "weather is your mood and climate is your personality." You cannot know my personality simply based on my mood today. In a similar vein, the weekend blizzard does not refute climate warming nor does a hot day support it. Our mood can reflect aspects of our personality as weather can reflect the background climate. As noted earlier, every weather system forms within a warmer and moister atmosphere than a similar weather system just 30 years ago.

The AMS statement goes on to say: "*Model simulations project an increased proportion of global hurricanes that are in the strongest categories, namely 4 and 5 on the Saffir-Simpson scale, although the total counts of hurricanes may not change or may even decrease*." This is very consistent with a recent paper by a group of hurricane experts that has expressed divergent views within the group at times.

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[9] http://ipcc-wg2.gov/SREX/report/

[10] http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-12-00021.1

It is not surprising that Superstorm Sandy raised questions about linkages to climate change. My colleague John Knox and I noted that "*our atmosphere and oceans are, indeed, warming, with substantial residual heat stored in the ocean, to be released at some future time……It is quite certain that sea levels have risen over the last century, and continue to rise, in response to changing climate. And storm surges now ride on these elevated sea levels, amplifying flooding losses where they strike*."[11] Clearly, the most damaging facet of Sandy was surge inundation (Figure 3), which affected very populous areas. In a related note, I recently served on National Academy of Science study commissioned by the Navy that evaluated the impacts of climate change on naval operations/national security and that report echoes such concerns about inundation among others.[12]

Our discussion also noted that "*sea surface temperatures along the U.S. northeast coast were about five degrees Fahrenheit above average, which may have helped to intensify Sandy just prior to landfall. At this point, it is premature to link the storm's severity to warmer sea-surface temperatures, because regional variability is known to occur. But the link certainly is plausible*."

I should also note that a weather pattern known as a "block," a persistent area of high pressure linked with record melting in Greenland, was most likely what caused Sandy to make a hard "left" rather than a "right" as hurricanes normally do at that latitude. At this point, the science is emerging on whether this is weather variability, short-term climate variation, or climate change.[13]

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[11] http://www.project-syndicate.org/commentary/hurricane-sandy-and-climate-change-by-j--m--shepherd-and-john-knox

[12] http://www.nap.edu/catalog.php?record_id=12914

[13] http://onlinelibrary.wiley.com/doi/10.1029/2012GL053611/abstract

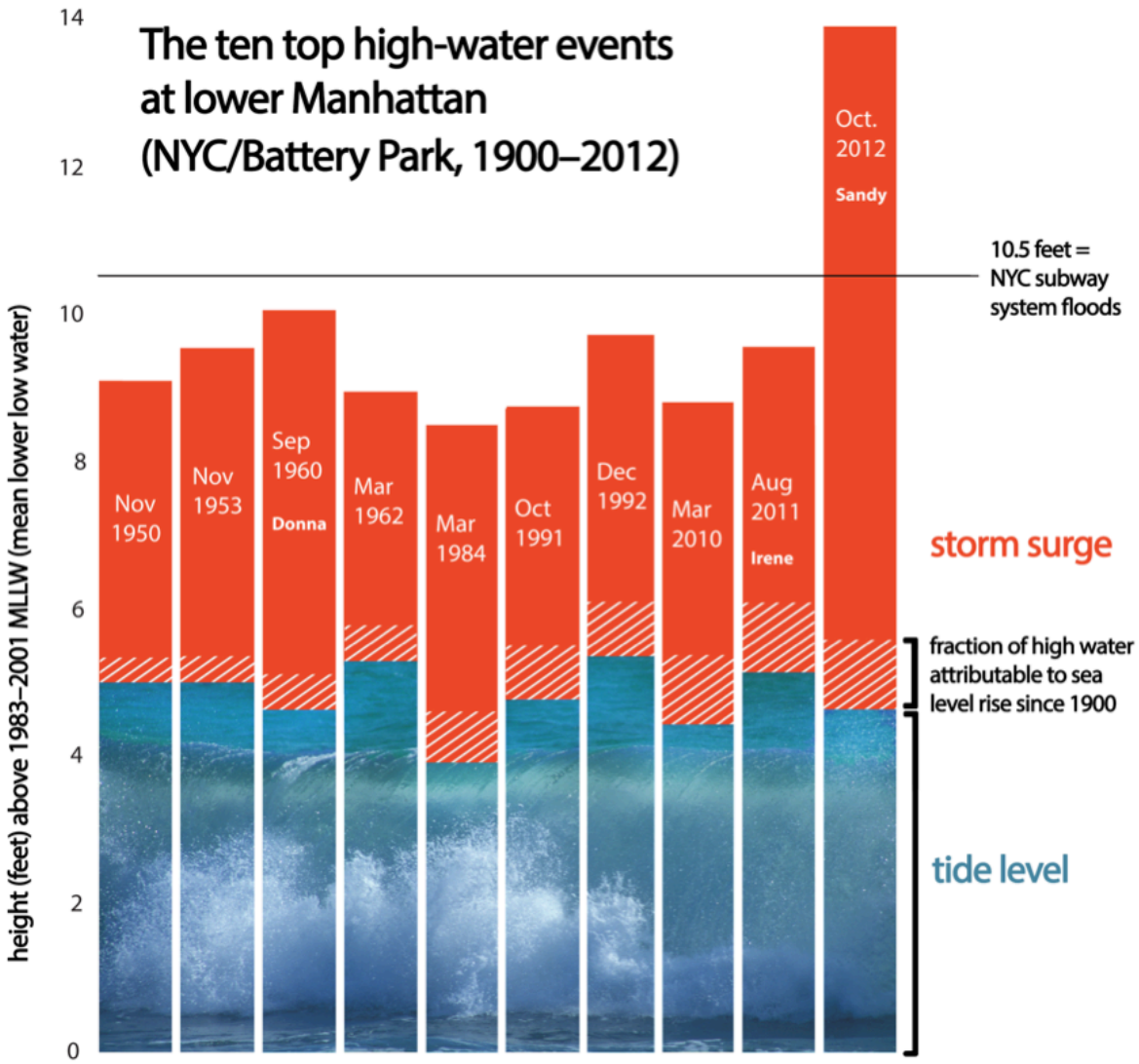


Figure 3: Top 10 high water events in lower Manhattan and sea level contributions.[14]

At this point, it is worth noting the Blizzard that impacted the Northeast this weekend will evoke discussions about climate change. A blizzard in the Northeast in February is winter, but having a 40-inch blizzard in Connecticut in February 2013 instead of a 30-incher or 35-incher may have been the result of human alteration of climate under Trenberth's premise. The blizzard, as does all current weather, formed in a warmer, moister climate than past decades. Figure 4 is a simple illustration of the basic physics

[14] https://www2.ucar.edu/atmosnews/opinion/8585/dissecting-sandys-surge

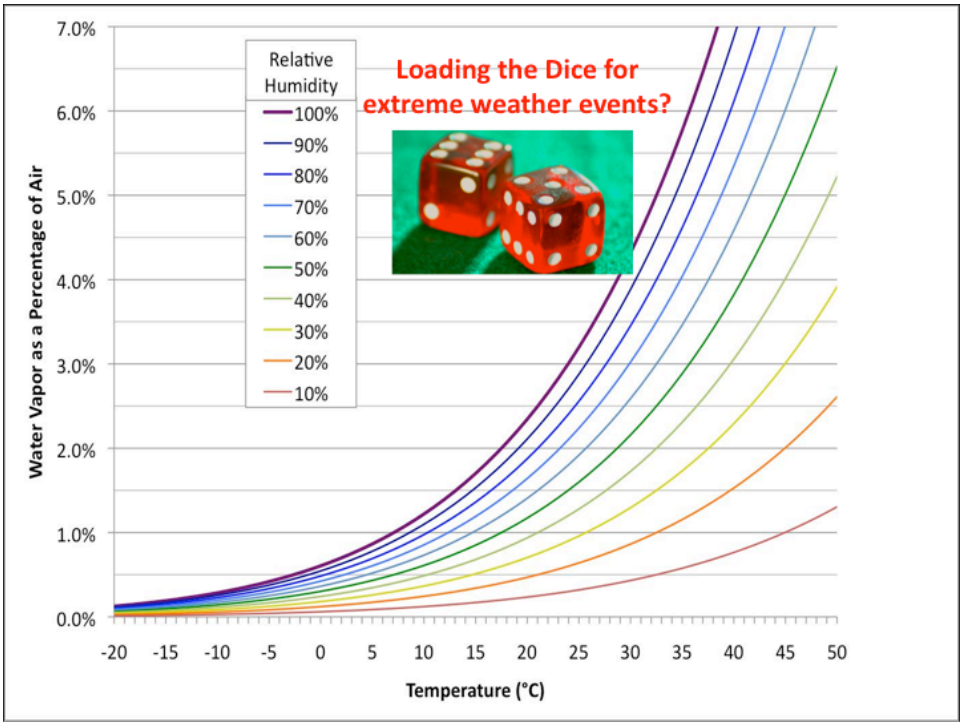


Figure 4: The relationship between temperature and moisture in the atmosphere. Is human-related warming, via this relationship, loading the dice for extreme events?

illustrating that warmer air holds more water vapor. If you spend a summer in Athens, Georgia, you know this too. NOAA also reports that the Northeast has seen a 74 percent increase in precipitation during the heaviest rain and snow events from 1958 to 2011. Figure 5 shows trends in 1-day Northeast precipitation extremes in the cold season from 1911 to 2012. The recent trend will certainly be increased by 2013 storm amounts. The trend is also related to increasing rain events in the late fall and early spring, another manifestation of the warming climate.

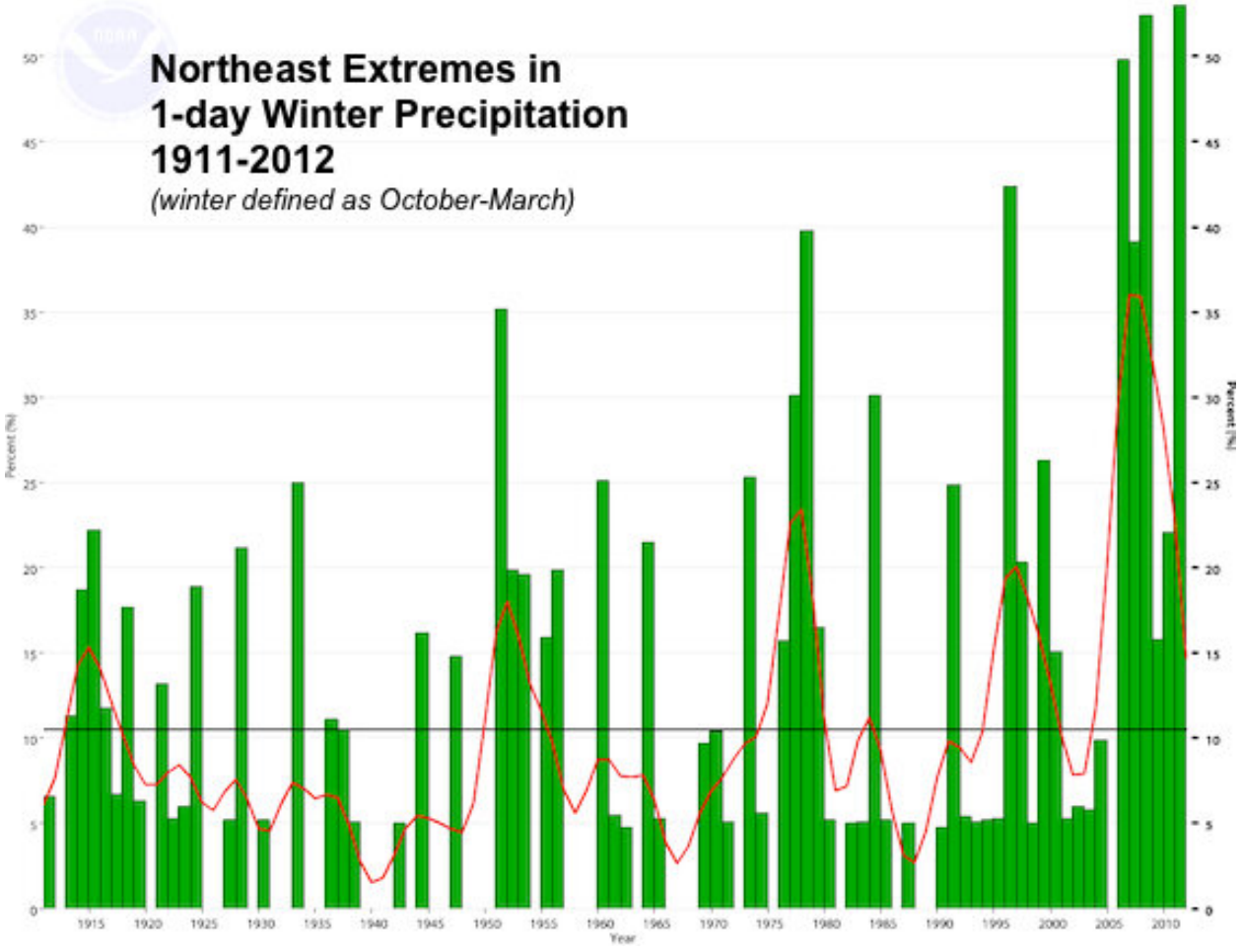
The combination of additional energy and moisture in the atmosphere could be seen as "steroids" for the atmosphere loading the dice towards greater probability of storms like Sandy or the blizzard. More certain, higher sea level from climate warming increases surge threats from Nor'easters or hurricanes like Sandy. The draft National Climate Assessment report notes that the chance of what is now a 1-in-10-year coastal flood event in the Northeast could triple by 2100. This would mean that such coastal flooding occurs once every 3 years, because of rising sea levels. With the weekend blizzard, coastal residents were vulnerable to snowfall and flooding. A post Sandy-report warned of increasing vulnerabilities in the Northeast to surge inundation.[15]

Recent studies even suggest that loss of polar ice due to amplified warming in the Arctic is modifying jet stream/weather patterns and creating greater weather extremes in all

[15] http://tbha.org/files/documents/preparing_for_the_rising_tide_executive_summary_final.pdf

seasons.[16] This is argued to happen in a similar way that El Nino (warm waters in the Pacific) affects weather patterns in the U.S. The research is still emerging on this topic.

Studies captured in the AMS Statement also indicate "*that midlatitude storm tracks will shift poleward. Interannual variations of important large-scale climate conditions (such as El Niño and La Niña) will also continue to occur, but there may be changes in their intensity, frequency, and other characteristics, resulting in different responses by the atmosphere. Heat waves and cold snaps and their associated weather conditions will continue to occur, but proportionately more extreme warm periods and fewer cold periods are expected. Indeed, what many people traditionally consider a cold wave is already changing toward less severe conditions. Frost days (those with minimum temperature below freezing) will be fewer and growing seasons longer. Drier conditions in summer, such as those anticipated for the southern United States and southern Europe, are expected to contribute to more severe episodes of extreme heat. Critical thresholds of daily maximum temperature, above which ecosystems and crop systems (e.g., food crops such as rice, corn, and wheat) suffer increasingly severe damage, are likely to be exceeded more frequently.*"



[16] http://marine.rutgers.edu/~francis/pres/Francis_Vavrus_2012GL051000_pub.pdf

Figure 5: 1-day winter precipitation 1911-1912 (NOAA).[17]

Clearly, this provides context for why the recent drought (Figure 6) that has stressed crops and halted commerce on the Mississippi River can be plausibly linked to climate change. Even now, a majority of our country is in the grips of drought. The figure also shows how frequent and persistent drought has been the past decade.

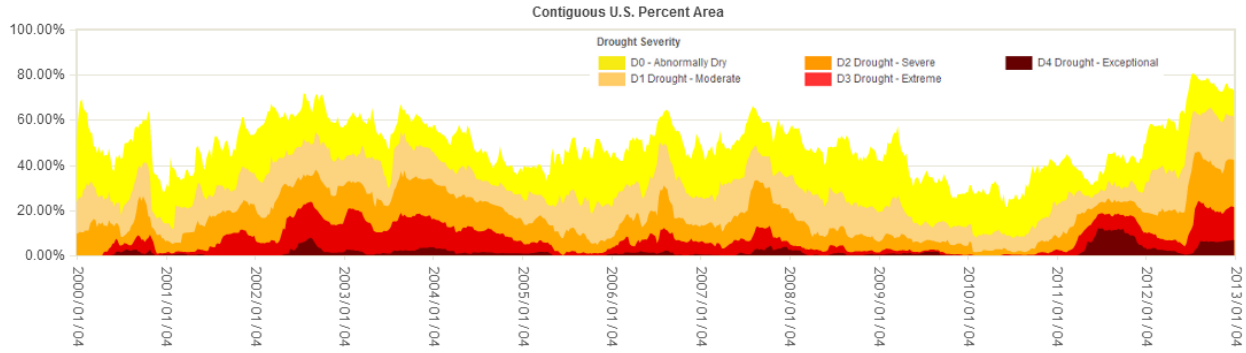


Figure 6: Percentage of U.S. in drought from 2000 to 2013.

Concluding Statements

In summary, this topic is about people, your constituents, not just polar bears. The key takeaway points that I would leave with you today are that:

1) Most of the warming of the past 50 years is due to human activity, and extensive evidence support this conclusion,

2) Climate change is increasing the probability of extreme events, and in some cases may be strengthening their intensity or increasing their frequency (i.e. we are loading the dice towards more Sandy or weekend blizzard type storms), and

3) There is strong evidence that increases in some types of extremes are linked to human-induced climate change, notably extreme heat, coastal flooding, and heavy downpours. For other types of extremes, such as tornadoes, current evidence is much more limited.

"Avoiding this future warming will require a large and rapid reduction global greenhouse emissions…….Technological, economic, and policy choices in the near future will determine the extent of future impacts of climate change. Science-based decisions are seldom made in context of absolute certainty. National and international policy discussions should include consideration of the best ways to both adapt and mitigate climate change" *(AMS Climate Change Statement, 2012).*

For me, being here is not just about the science, it's about a 5 and 9 year old back in Georgia.

Thank you.

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[17] http://www.ncdc.noaa.gov/extremes/cei/graph/ne/4/10-03