UNITED STATES DEPARTMENT OF COMMERCE
The Under Secretary of Commerce
for Oceans and Atmosphere
Washington, D.C. 20230

JUL - 8 2011

The Honorable Edward J. Markey
Ranking Member
Committee on Natural Resources
U.S. House of Representatives
Washington, DC 20515

Dear Representative Markey:

Thank you for your letter to the National Oceanic and Atmospheric Administration (NOAA) regarding extreme weather events. We share your concern over the historic number of severe weather fatalities despite early NOAA National Weather Service (NWS) warnings. In 2011, there have been eight disasters that each inflicted more than a billion dollars in damages – just one shy of the annual record of nine. It has already been the 6th deadliest tornado year in U.S. history with over 536 fatalities. The flooding along the Red, Mississippi, and Missouri Rivers has caused billions of dollars in economic losses and destroyed lives. Wildfires have burned at least four times the acreage this year as in the first 6 months of 2010. NOAA is committed to continuing to improve severe weather warning services to the Nation and better understand links between climate change and these extreme events

While the NWS modernized about 20 years ago, we know that demographic trends and population growth, and an increased reliance on technology, have made our society more vulnerable to extreme weather. There is more that can and must be done, which is why NWS has started a national conversation with the Nation's top experts in broadcast meteorology, emergency management, and the weather industry to take a look at what is happening and what can be done in the short and long term to improve the Nation's severe weather warnings and community preparedness. Infusing social and behavioral sciences, exploiting communications technologies, integrating water resource prediction and management efforts, and researching methods to improve tornado warnings are just a few areas of focus needed to improve services.

Likewise, continuing to improve long-range forecasts of extreme weather events and advance our scientific understanding of links between climate change and extreme weather is a high priority for NOAA. Doing so will require significant improvements in our high-resolution climate models that can be achieved through greater integration of our climate science and service capabilities. NOAA's proposed reorganization to establish a Climate Service Line Office would consolidate the management of our climate capabilities, which are currently dispersed across the agency. This will allow more efficient and effective integration of the increased observations, improved understanding of key natural processes, and advanced computing capability that are key to providing better long-range forecasts Americans can use to prepare for extreme weather hazards.

Enclosed please find detailed answers to your questions. We thank you for your leadership as we all strive to build a Weather-Ready Nation. If you have any further questions, please contact Mr. John Gray, Director of NOAA's Office of Legislative and Intergovernmental Affairs, at (202)482-0809.

Sincerely,

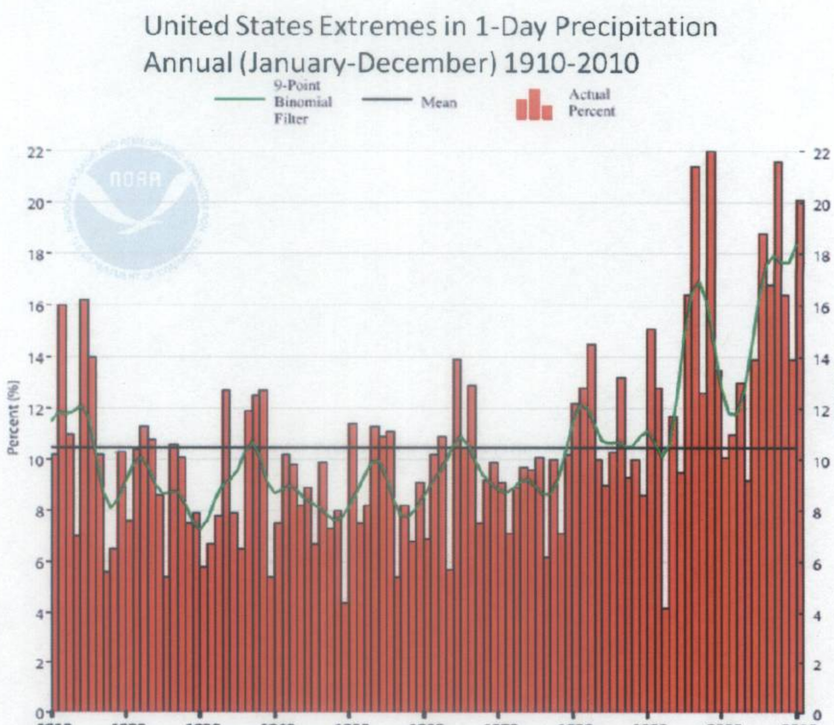
Jane Lubchenco, Ph.D.
Under Secretary of Commerce
for Oceans and Atmosphere

Enclosure

NOAA Response to
Edward J. Markey
Ranking Member
Committee on Natural Resources
June 21, 2011

1. One of the prerequisites for tornado formation is a severe thunderstorm. Have the frequency and intensity of severe thunderstorms and heavy rainfall storms increased in the United States in recent decades? Is this attributable to the rising temperatures from the increasing amount of carbon pollution in the atmosphere?

One of the clearest precipitation trends in the United States is the increasing frequency and intensity of heavy downpours. Heavy downpours were responsible for most of the observed increase in overall precipitation during the last 50 years. On average, all regions have seen an increase in the percent of rainfall that is delivered in the heaviest doses. This trend is especially evident in the Northeast and Midwest United States (Global Climate Change Impacts in the United States [GCCI] 2009). The number of, and area affected by, extreme single-day precipitation events is also increasing. These changes are associated with the fact that warmer air conveys more water vapor. Global temperatures have risen and are projected to continue to rise over this century. The resulting increase in atmospheric water vapor has been observed by satellites, by surface stations over land, and by ships and buoys over the oceans. (GCCI 2009; Willett et al. 2008).



The relationship between the changing climate and severe local storms is more complex. The number of reports of severe weather, including thunderstorms and tornadoes, has increased in recent decades. However, this increase is believed to be due to improved ability for detection and confirmation, especially for less intense severe tornadoes that may have previously gone unreported. Severe weather is the result of a combination of ingredients, each having its own relationship with a changing climate. The moistening of the atmosphere in recent decades has generally increased, on average, the amount of potential energy available for developing storms (Marsh et al. 2007). This contributes to more powerful thunderstorm updrafts. However, the type of thunderstorms that produce the vast majority of tornadoes also requires strong vertical wind shear. The relationship between climate change and patterns of wind shear is unclear; some scientists expect that wind shear may decrease, on average, across much of the United States as the poles warm more quickly than the equator (Trapp et al. 2007). Additional research is needed to better understand the impacts of climate change on small-scale weather phenomena (like tornadoes).

2a. The sea surface temperature of the Gulf of Mexico is also warmer than average this spring. How does the surface temperature of the Gulf influence the potential for tornadoes?

It is difficult to single out one factor as responsible for increased tornado potential. Warmer sea-surface temperatures evaporate moisture more readily than colder ones, contributing to moister conditions in the lower atmosphere, cloud development, and additional rainfall downwind. Prevailing southerly winds during the spring transport moisture laden air from the Gulf of Mexico into the Great Plains and Southeast, providing an essential ingredient for thunderstorm development. However, this alone is not sufficient. Other essential ingredients include a southward displacement of the mid-latitude jet stream and pockets of cold air aloft, which are typically associated with a trough of low pressure in the western United States. During the spring, warm and moist air masses from the Gulf of Mexico meet cool and dry continental air masses from Canada over the central and eastern United States. The temperature and moisture contrast between these air masses and accompanying vertical turning of the wind with height provide a complete set of ingredients for the development of tornadic thunderstorms. During April 2011, the Gulf of Mexico was unusually warm (temperatures in the northern Gulf of Mexico were 1.5-2.0°F (0.9-1.1°C) above their historical average for April) and there were an unusually large number of upper level disturbances associated with a western trough, consistent with the explanation above.

2b. How have sea surface temperatures corresponded to increasing global temperatures?

Globally, ocean surface temperatures are strongly correlated with increasing global surface temperatures. According to NOAA data, compiled from ship and buoy reports, the global ocean surface temperature has increased by 1.24°F in the last 100 years, and 0.66°F in the last 30 years. Moreover, observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been absorbing more than 80 percent of the heat added to the climate system (IPCC 2007).

2c. How are they anticipated to correspond in the future?

Ocean surface temperatures will continue to correlate to global air temperatures in the future.

During the past 30 years, annual sea surface temperatures in the main Atlantic hurricane development region, for example, increased nearly 2°F. Projections are that sea surface temperatures in this region will increase at even faster rates during the second half of this century under higher emissions scenarios. All climate models project that human-caused emissions of heat-trapping gases will cause further warming in the future.

Model-based estimates of global average surface air warming by the end of the 21st century (2090-2099) range from 1.8°C (low scenario) to 4.0°C (high scenario) (IPCC 2007). These increases have been linked to human activities, primarily through increases in atmospheric greenhouse gases (IPCC, 2007; Global Climate Change Impacts in the United States, 2009).

3a. What are the trends in tornado frequency and intensity in the United States in recent decades?

Reports of tornadoes have increased during the past 50 years while reported intensity has decreased (see also answer to question 1 and 5a). The increase in the number of reports is believed to be due to improvements in monitoring technologies, such as Doppler radars, combined with changes in population and increasing public awareness. Decrease in intensity appears to be an artifact resulting from changes in damage estimation practices. When adjusted to account for these factors, there is no clear trend in the frequency or strength of tornadoes since the 1950s for the United States as a whole (Brooks and Doswell 2001; Verbout et al. 2006; Doswell et al. 2009).

3b. How do they relate to the global temperature trend?

We have not detected a trend in tornado frequency and intensity with global temperatures in recent decades.

3c. How are they predicted to respond to increasing temperatures in the future?

Climate models project future increases in the frequency of environmental conditions favorable to severe thunderstorms. The inability to adequately model the small-scale conditions involved in thunderstorm development remains a limiting factor in projecting the future character of severe thunderstorms and other small-scale weather phenomena (like tornadoes).

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4a. Yesterday was the start of the hurricane season, one that NOAA scientists have predicted will see an above average number of storms in the Atlantic. Sea surface temperatures are also critical to hurricane formation and intensity. What have been the trends in Atlantic hurricane intensity in the recent decades?

The intensities of the strongest hurricanes in the Atlantic basin have been increasing since around 1980. However, reliable basin-wide records of intensities are probably too short (only about 30 years) to determine confidently whether or not there is any trend in intensity over a 100 year period. Because of the strong multi-decadal variability present in the Atlantic basin, records on the order of a century are needed for confident assessment of this issue.

The high frequency of Atlantic hurricanes of recent years is similar to that seen during other high frequency eras, which occurred during 1880-1900 and 1935-1960. Separating these eras were decades-long periods (1900-1920 and 1971-1994) with a notably lower frequency of hurricanes.

4b. How do recent trends in Atlantic hurricane activity correspond to increasing sea surface temperatures from global warming?

Tropical Atlantic sea surface temperatures (SSTs) have warmed over the past century. However, no such upward trend is seen in U.S landfalling Atlantic hurricane frequency, or in basin-wide hurricane frequency after adjusting for estimated missing storms.

The causes of strong multi-decadal modulation of Atlantic hurricane frequency observed in the climate record remain under investigation. One proposed mechanism is a natural climate variation called the Atlantic Multi-decadal Oscillation (AMO), which appears to strongly modulate Atlantic SSTs on time scales of decades. The influence of greenhouse warming on natural modes of variation such as the AMO or El Niño/Southern Oscillation remains uncertain.

In addition to the AMO, other types of natural or anthropogenic forcing may have also contributed to the multi-decadal variability of Atlantic SSTs and hurricanes, including aerosols, dust, volcanic activity, ozone changes, and so forth. The relative contributions from these different mechanisms to the multi-decadal variations in hurricane activity remain under investigation at this time.

Computer model simulations suggest that while global warming leads to increased Atlantic SSTs, it may also create wind patterns that are less conducive to hurricane formation. There is some indication that the differences in the rate of ocean warming between ocean basins may contribute to a decrease in the frequency of Atlantic hurricanes, with global warming, but with the most intense hurricanes (category 4-5) becoming stronger.

4c. How is Atlantic hurricane activity expected to be impacted by global warming in the future?

An expert team that included four NOAA researchers was recently commissioned by the World Meteorological Organization (WMO) [1] to review climate model projections of potential future changes in global hurricane activity due to greenhouse warming.

The authors of this review paper concluded the following regarding global tropical cyclone projections for the late 21[st] century:

- "It is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged owing to greenhouse warming….Current models project changes ranging from -6 to -34 percent globally, and up to +/-50 percent or more in individual basins [including the Atlantic]…."
- "Some increase in the mean maximum wind speed of tropical cyclones is likely (+2 to +11 percent globally) with projected twenty-first century warming, although increases may not occur in all tropical regions."
- "Rainfall rates are likely to increase. The projected magnitude is on the order of +20 percent within 100 km (60 mi) of the tropical cyclone center."
- "We have low confidence in projected changes in tropical cyclone genesis-location, tracks, duration and areas of impact."
- "…a recent downscaling study [from NOAA] using an operational (9-km grid) hurricane prediction model shows a tendency towards increased frequency of Atlantic Category 4 and 5 hurricanes over the twenty-first century. We judge that a substantial increase in the frequency of the most intense storms may also occur globally, although this may not occur in all tropical regions."

5a. What is NOAA doing to further our understanding of the relationship between extreme weather and climate change?

NOAA scientists have been at the forefront of weather and climate science for decades, and our science helps save lives and protect property. One of NOAA's longest and proudest legacies is that of being a leader in the field of climate science and service delivery, including maintaining the longest continuous data record of carbon dioxide measurements and producing operational seasonal forecasts that include drought and flood outlooks.

Work is urgently needed to identify causes and effects of changes such as extreme weather, to produce accurate predictions, to identify risks and vulnerabilities, and to inform decision making. NOAA envisions an informed society anticipating and responding to climate change and its impacts. To achieve this vision, NOAA is committed to advancing our strong scientific foundation and decades of engagement with interagency, academic, and private sector partners.

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[1] "Tropical Cyclones and Climate", *Nature Geoscience*, vol. 3, 157-163 (2010).

In focusing specifically on the relationship between extreme weather and climate change, the National Weather Service (NWS) forecast offices conduct local climate studies nationwide to determine the impacts of climate on extremes in weather and water events such as tornadoes, floods, drought, severe storms, wild fire weather, and others. These studies integrate the latest science and technology into tools available to forecasters to respond to user needs for their decision support.

NOAA is also taking a lead role in organizing, and participating in, a series of workshops specifically focused on the following aspects of changes in weather and climate extremes as input to the National Climate Assessment, conducted as part of the U.S. Global Change Research program:

- Trends of severe local storms including tornadoes and extreme precipitation.
- The attribution of changes in climate extremes.
- Trends of extreme waves, winds and extra-tropical storms along the coasts.
- Trends and causes of observed changes in heat and cold waves as well as drought.
- Climate Model Inter-comparison (CMIP) Results for IPCC 5

In addition to studies that focus on the relationship between extreme weather and climate change, it is also essential to continue our detailed research on severe storms and extreme events. NOAA's National Severe Storms Laboratory (NSSL) serves the Nation by working to improve the lead time and accuracy of severe weather warnings and forecasts in order to save lives and reduce property damage. Significant research is required to improve our scientific understanding of links between large-scale climate change and changes in the properties of tornadoes, including:

- *Better data*. Develop improved observed records of the true changes in tornado frequency and intensity. This will require better ways of removing non-meteorological effects from these records, and better use of other, newer sources of data (like Doppler radar measurements).
- *High-resolution simulations*. Perform and analyze simulations with very high-resolution climate models. This gives us useful information on detailed physical processes affecting the formation and statistical properties of tornadoes.
- *Exploiting large multi-model archives.* Existing and new archives of climate model simulation output[2] can help us determine how the large-scale environmental conditions that affect tornadoes respond to natural and human-caused changes in greenhouse gases.

5b. What additional resources are necessary to help NOAA with this work?

NOAA's continuation of priority activities to understand extreme weather and the climate are supported by NOAA's FY 12 Budget Request.

2 An example of an existing archive of climate model simulation output is the Coupled Model Intercomparison Project, phase 3 (CMIP-3). Phase 5 of this project (CMIP-5) is now underway, and will provide simulation results from computer models developed at all of the world's major climate modeling centers.

6. NOAA also provides important weather and climate products that help businesses and all levels of government prepare for the next day and the next decade. As the climate changes, the past is no longer prologue and additional information is needed as policymakers and business leaders make long-term decisions. As part of its FY 2012 budget submission, NOAA proposed a budget-neutral re-organization to create a NOAA Climate Service. How would a climate service help NOAA meet the needs of decision makers for climate information?

The FY 2012 proposed reorganization will consolidate NOAA's existing, widely dispersed, climate capabilities under a single Line Office management structure, called the Climate Service, to better organize NOAA to respond to the rapidly increasing demand for climate information and services. This strategic alignment of climate assets will allow NOAA to better provide the reliable and authoritative climate data, information, and decision-support services that Americans seek through a centralized structure that will better facilitate coordination with other Federal, State, local, and tribal partners. NOAA has long recognized that no one Federal agency, nor the Federal Government alone, can meet the Nation's need for climate science and services. The proposed Climate Service would better organize NOAA such that the agency can be a more accessible, transparent, and collaborative partner. NOAA will continue to rely on governmental, academic, and private sector partnerships to achieve the agency's climate goals and to ensure that America's need for climate information is met.

NOAA's climate services are supporting the growth of a new category of economic, scientific, and technology innovation: entrepreneurs and businesses that specialize in the provision of tailored climate services and products that support specific users. This emerging commercial climate service industry is adopting a business model similar to the existing commercial weather services industry. A goal of the proposed Climate Service is sustained engagement with the private sector to ensure that all of NOAA's climate data and products are easily accessible and support the development of this emerging market with tremendous growth potential. A roughly billion-dollar commercial weather industry has grown up around NOAA's weather services. It is expected that a similar commercial climate industry will emerge in coordination with NOAA's climate services. Climate information helps existing businesses to maximize opportunities and minimize exposure to risks in a changing environment – safeguarding lives, property and economic investments.

The proposed Climate Service will:

- Develop a sustained capacity to provide regional and sectoral climate vulnerability and risk assessments to meet the requirements of the U.S. Global Change Research Act;
- Clearly establish a regional focus coordinating and providing climate services - deliver locally relevant climate information that will help existing businesses and local communities maximize opportunities and minimize their exposure to risks in a changing environment to safeguard lives, property and economic investments;
- Better align climate observing and modeling assets with strategic needs;

- Improve integration and coordination of climate communications and outreach efforts throughout the agency, and function as a one-stop trusted source for information from the public, the private sector, and other government agencies;
- Create a visible and easy to find, single point of entry for people to access NOAA's climate science service assets;
- Enable improved information sharing and more productive partnerships with Federal agencies, local governments, private industry and other users and stakeholders; and
- Establish an improved budget structure that provides considerable transparency into the funding levels for the underlying climate programs, thereby allowing Congress and the public to ensure climate science is not diminished.

Please refer to the NOAA testimony provided by Dr. Jane Lubchenco at a hearing entitled *"Examining NOAA's Climate Service Proposal"* before the House Committee on Science, Space, and Technology on June 22, 2011, for additional information regarding NOAA's Climate Service.

7a. Finally, it takes a large infrastructure on the land and sea and in space to make the observations and forecasts that allow NOAA to issue life-saving weather warnings. Over the last decades, our investment in this infrastructure has led to improved forecasts and increased warning times for tornadoes, floods, and hurricanes and thus saved lives. I am concerned that budget cuts are jeopardizing this critical national infrastructure. For example, you testified before the Senate in April that the final FY 2011 budget agreement would mean that the launch of the Joint Polar Satellite System (JPSS) would be delayed and could lead to an 18-month gap in crucial weather satellite data. What are some of the potential impacts of the delay in launching the JPSS?

The observational gap resulting from a delay of the launch of the JPSS-1 satellite would cause an immediate degradation to National Weather Service (NWS) numerical weather prediction (NWP) global models that are run every 6 hours. This would substantially degrade our ability to predict the severity of many major weather events. For example, a recent NWS study showed that if data in the afternoon orbit had not been available for the 2010 East Coast "Snowmageddon" storm, the weather models would have under-forecasted snowfall accumulation in the Mid-Atlantic region by 10 inches, and the 5-7 day maximum snow forecast would have been displaced by 200-300 miles or not even predicted at all. The resulting precipitation prediction errors (up to 50 percent) would have had enormous consequences for the American public, businesses, local governments, and emergency managers.

In addition to the loss of sounding data to the models, the loss of polar-orbiting imagery data has critical operational impacts. This is especially true over the data-sparse areas such as oceans and Alaska. The loss of imagery could degrade forecasting the timing and accuracy of high-impact maritime weather events and endanger lives and property. Polar-orbiting high-resolution imagery is used to produce volcanic ash products. This imagery is a mission-critical tool for forecasters to detect and track airborne ash, providing forecasts that have a direct impact on flight safety and help minimize unnecessary disruption to the aviation industry. Polar-orbiting imagery is used to provide data to a wide range of seasonal forecasts. Imagery can be critical to the positioning of people and equipment to respond to summertime forest fires, as well as forecasting the wintertime sea ice extent so that indigenous Alaskan natives can travel on sea ice during the hunting and fishing trips necessary to sustain their families and villages.

The degradation in forecast accuracy would have a large impact on the U.S. economy. Although the benefit of public weather forecasts and warnings cannot be fully measured in economic terms alone, a recent survey has nevertheless estimated its annualized value at about $31.5 billion, compared to a $5.1 billion cost to generate the information (Lazo et al., 2009).[3]

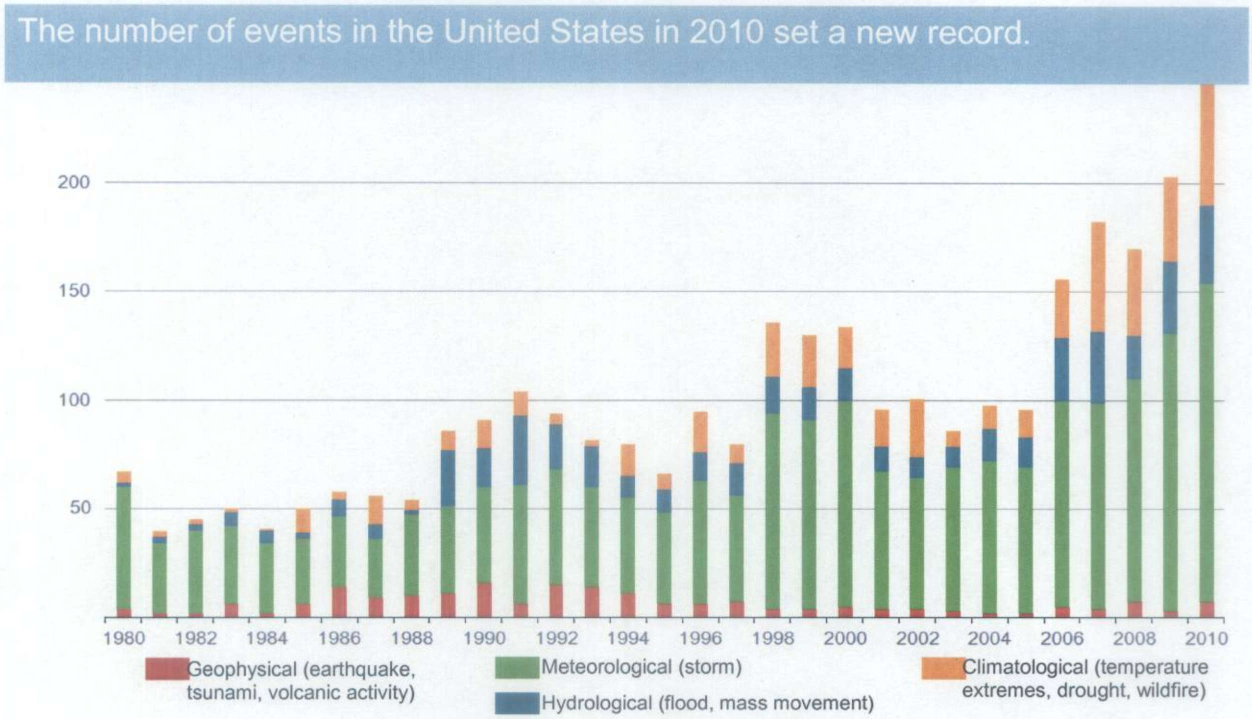
7b. Is other weather infrastructure in jeopardy due to budget cuts?

Within available FY 2011 funding, NWS has identified resources to address high priority needs for critical weather infrastructure. The NWS has also requested funding in the FY 2012 President's Budget to maintain key infrastructure.

Maintaining the NWS infrastructure has reached a level of extreme priority. In 2011, we have already seen eight disasters that each inflicted more than a billion dollars in damages – just one shy of the annual record of nine. It has already been the 6th deadliest tornado year in U.S. history with 536 fatalities. The flooding along the Red, Mississippi, and Missouri Rivers have caused billions of dollars in economic losses and destroyed lives. Wildfires have burned at least four times the acreage this year as in the first six months of 2010.

In 2010, the United States experienced a record number of disasters.

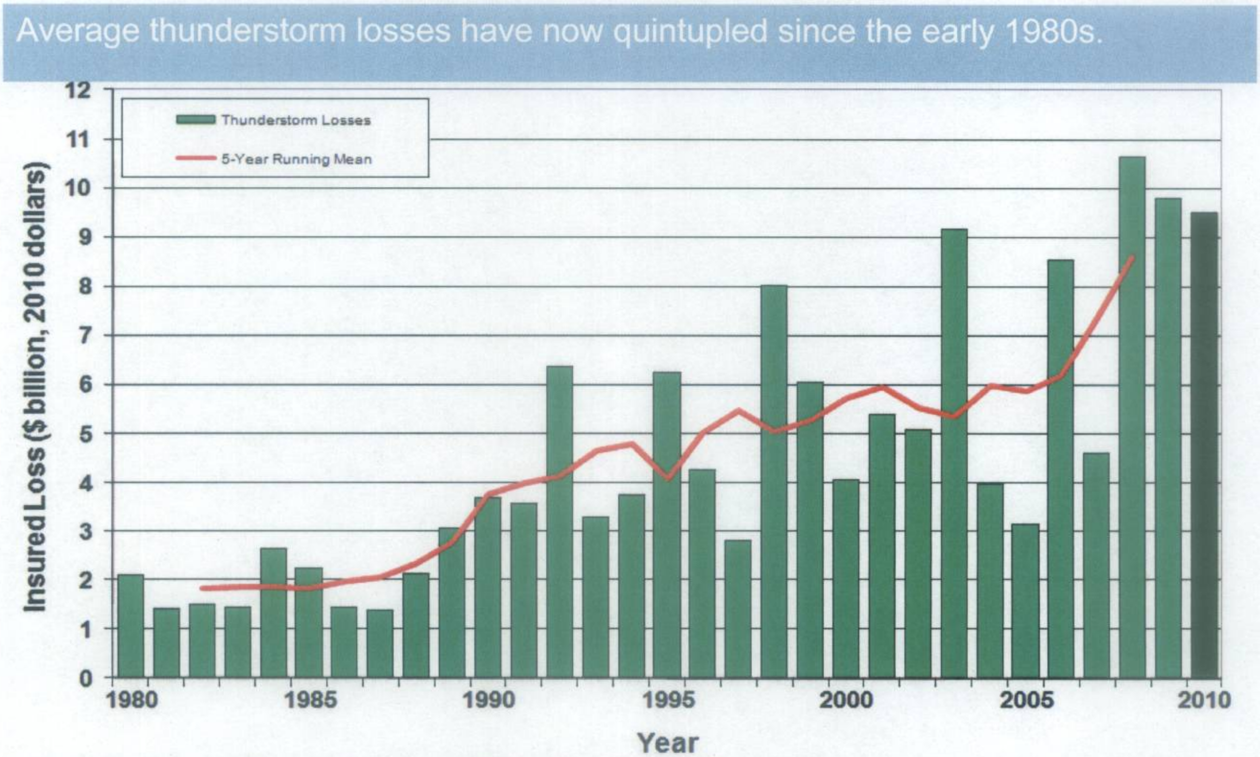
[3] from "When Weather Matters...Science and Services to Meet Critical Societal Needs", NRC national academies report, www.nap.edu, 2010.



Source: MR NatCat*SERVICE*

While the NOAA National Weather Service modernized in the 1980s and 1990s, we know that demographic trends and population growth, as well as our increased reliance on technology, has made our society more vulnerable to extreme weather. In addition to lives lost, there is a staggering economic impact.

Thunderstorm losses alone have more than doubled in the last 20 years.



Source: Property Claims Service, MR Nat*CatSERVICE*

NOAA's National Weather Service is critical to mitigating the impacts from these hazards.

7c. Are there ways to increase warning times further if we were to increase funding for observations infrastructure?

Yes. NOAA is already working to increase warning times and will continue to do so through dedicated mission-driven research and transition of research to operations. Increasing warning times requires a "Warn-on-Forecast" (WoF) capability using operational computer-based forecast models to go beyond the current "Warn-on-Detection" (WoD) capability. A WoF capability could provide 30-60 minutes of tornado lead time while WoD is typically limited to 10-25 minutes. A WoF capability is possible by 2020, provided funding is increased for focused research over the 2012-2020 period, operational and backup/transition computing capabilities, and improved observing capabilities. Additional research is needed in order to bring this technology to the point where it can be transitioned to operations. Funding for this program began in FY 10. Additional operational computing capabilities are required for running the computer-based forecast models for WoF. A focused research effort covers model development and developing new observing system capabilities such as augmented data from aircraft, gathering surface observations from a large variety of networks across the country, new wind, temperature and moisture measurements in the lower atmosphere, and the next-generation of radar system that will allow for faster refresh rates and increased confidence - Multifunction Phased Array Radar (MPAR).

MPAR technology already exists within the military to track aircraft and missiles and is being adapted by NOAA from de-classified Navy technologies. A network of MPAR units could provide next-generation expansion of our current weather surveillance network, replace the Nation's aging air traffic surveillance radars, and meet homeland security and defense requirements for identifying and tracking non-cooperative craft operating over the U.S. homeland. The Nation's current radar technology is comprised of several independent mission-specific systems (separate systems for FAA, for weather, for defense, etc.) Combining the operational requirements of these various radar systems with a single technology solution would result in an estimated savings to the Nation of $4.8 billion in acquisition and maintenance costs. Services could improve dramatically despite being able to reduce the number of radars by 35 percent. In addition, MPAR features more flexible and faster sampling time (43 seconds versus 2-3 minutes) which would enable forecasters to issue tornado warnings more rapidly and with greater confidence. In FY 12, NOAA proposes to work with the FAA to engage in a Risk Reduction Program to determine if this technology will meet NOAA and FAA requirements.

We know that our National Weather Service community-based preparedness programs are also vital in saving lives. Whether a tornado warning is 24 minutes before impact, as we saw during the April 27 tornado outbreak in the south, or the conceptual 1 hour in advance, public preparedness and action remain the most critical link in the chain. A National Weather Service warning that is not received or heeded provides little benefit. A sustainable community presence where public preparedness and effective and accessible decision support services for emergency managers remains a top priority.

7d. What resources are needed to further improve warnings?

There is a need for research to determine where society's needs for weather warning and preparedness are not being met. Infusing social and behavioral sciences, exploiting communications technologies, integrating water resource prediction and management efforts, and researching methods to improve tornado warnings are just a few areas of focus needed to improve services. Improved services will require augmentation of operational high performance computer resources to generate next-generation model output. Historically, forecast improvements have followed improved models and model improvements are enabled by increased computing resources.

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