VALUE OF A WEATHER-READY NATION

LAST REVISED 9/13/2011

NOAA activities support science, service, and stewardship that protect life, health, and property and create economic value, income, and jobs. Across the agency, we have begun collecting data on the economic importance of the sectors we support, the costs of natural environmental hazards, and the value of NOAA activities that help society and commerce prepare for a constantly changing environment. Below you will find our current knowledge of the economic value of the sectors we serve, societal risks we face, and our emerging understanding of the economic and societal value of our work as it relates to the National Weather Service (NWS). Here we provide data on: What is at Risk and the Value of NOAA's NWS Products. They are organized by sources of economic costs and by product or service type. If you find data about weather that may be useful in your work, but are not in this document, please feel free to contact Hillary Huffer (Hillary.Huffer@noaa.gov) or me, Dr. Linwood Pendleton (Linwood.pendleton@noaa.gov). The document will be updated frequently, please check back frequently for updates or email Hillary.Huffer@noaa.gov to receive update announcements.

NOAA's National Weather Service (NWS) is the nation's first line of defense against severe weather. NWS provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters, and ocean areas for the protection of life and property and the enhancement of the national economy. NWS data and products form a national information database and infrastructure that is used by other government agencies, the private sector, the public, and the global community.

More and more sectors of the U.S. economy recognize and plan for changing weather, water, and climate conditions. The renewable energy industry is one such sector. Renewable energy firms use NOAA weather and climate forecasts to make more accurate predictions of power production, thereby improving the economic viability of renewable energy.

To meet the growing demand for information and to improve the timeliness and accuracy of weather-related data – especially hazard data – the NWS continues:

- to enhance observing capabilities;
- improve data assimilation to effectively use all the relevant data NWS and others collect;
- improve collaboration with the research community;
- make NWS information available quickly, efficiently, and in a useful form (e.g., the National Digital Forecast Database); and

- include information on forecast uncertainty to help customers make fully informed decisions.

With about 4,600 employees in 122 Weather Forecast Offices, 13 River Forecast Centers, 8 national centers, and other support offices around the country, NWS provides a national infrastructure to gather and process data worldwide from the land, sea, and air. This infrastructure enables data collection using technologies such as NEXRAD Doppler weather radars; satellites operated by NOAA's National Environmental Satellite, Data and Information Service (NESDIS); data buoys for marine observations; surface observing systems, such as weather balloons, automated surface stations (ASOS), cooperative observer sites and reconnaissance aircraft; and instruments for monitoring space weather and air quality. The data collected inform sophisticated environmental prediction models running on high-speed supercomputers. Our highly trained and skilled workforce uses powerful workstations to analyze all of these data to issue public, aviation, marine, fire weather, air quality, space weather, river and flood forecasts and warnings around the clock. A high-speed communications hub allows for the efficient exchange of these data and products between NWS components, partners, and customers. NWS forecasts and warnings are rapidly distributed via a diverse dissemination infrastructure, including 1010 NOAA Weather Radio All Hazards transmitters, which provide emergency information coverage to an estimated 97 percent of the U.S. population. Finally, customer outreach, education, and feedback are critical elements to effective public response and improvements to NWS services.

> *Source:* Office of Management and Budget. (2011). *President's Budget Request for Fiscal Year 2012 Budget: National Weather Service*. Washington, DC.

What is at Risk: The Economic Costs of Severe Weather

Our understanding of the impacts of weather on businesses and economic activity is still developing. Below are examples of the economic consequences of weather events and the importance of the economic sectors most affected by weather events and changing weather conditions.

Weather and Storms in General

Routine weather events in the U.S., such as rain and cooler-than-average days, can add up to an annual economic impact of as much as $485 billon (in 2008 dollars), or about 3.4 percent of the 2008 gross domestic product.

> *Source:* Lazo, J.K., Lawson, M., Larsen, P.H., and D.M. Waldman. (2011, June). U.S. Economic Sensitivity to Weather Variability. *Bulletin of the American Meteorological Society*, 92(6).
> Available at: http://journals.ametsoc.org/doi/pdf/10.1175/2011BAMS2928.1

As predicted when El Niño oceanic conditions grew to record proportions in the tropical Pacific during the Summer of 1997, California was assaulted by a series of coastal storms and heavy rains that caused floods, numerous landslides, and damage to the state's valuable agriculture, with losses totaling over $1.4 billion (in 2010 dollars) statewide. Overall, the 1997-1998 El Niño is estimated to have caused over $5.4 billion (in 2010 dollars) in damages nationwide.

> *Source:* Changnon, S.A. (ed.). (2000). *El Niño 1997-1998: The Climate Event of the Century.* New York, NY: Oxford University Press, 15, 151.
> Available at:
> http://books.google.com/books?id=aMHwVy3ZPpwC&printsec=frontcover#v=onepage&q&f=false

Tornadoes and Severe Thunderstorms

Spring 2011 was one of the deadliest and costliest tornado seasons on record. As of mid-June, the NWS had preliminarily recorded approximately 1,482 tornadoes so far in 2011. The 10-year annual average number of tornadoes is 1,274. According to ***preliminary*** estimates, from early April through June 1, tornadic storm systems – that also produced dangerous hail, straight-line winds and flooding – killed at least 585 people, and led to at least 2 million structure insurance claims, at least $21 billion in economic damages, and at least $15 billion in insured losses.

The largest tornado outbreak in recorded history occurred throughout the eastern U.S. from April 25-28, 2011. At least 334 tornadoes (perhaps more than 430) touched down during this period, causing at least 322 deaths. Straight-line winds and flooding resulting from the outbreak killed an additional 22 people. An estimated 190 tornadoes touched down between the early afternoon hours on April 27 into the early morning hours on April 28, setting the world record for most tornadoes in a 24-hour period. Several major metropolitan areas were directly impacted by strong tornadoes including Tuscaloosa, Birmingham, and Huntsville in Alabama and Chattanooga, Tennessee. This outbreak produced tornadoes in states as far south as Texas and as far north as New York.

According to ***preliminary*** reports, this outbreak, combined with the tornadic storm systems that hit the same regions from April 22-24, accumulated over $7 billion in economic damages. At the time of this writing, insurers had received more than 650,000 claims from dozens of states and anticipated payouts were expected to be in excess of $5 billion.

One of the most active and deadliest stretches of severe weather in U.S. history occurred from May 21-27, 2011. Over the course of these seven days, an area from southern Texas to New England sustained major damage due to the severe weather. At least 180 tornadoes (and perhaps as many as 325) touched-down in this period, resulting in at least 179 deaths.

The tornado outbreak that began on May 22 produced an EF-5 tornado that struck the city of Joplin, Missouri. It resulted in at least 154 deaths and injured more than 1,150 others, making it the deadliest single tornado to strike the U.S. since modern tornado record keeping began in 1950. Local officials estimate that the tornado completely destroyed up to 25 percent of the city, while causing significant damage to an additional 50 percent of the city. Catastrophic damage occurred to more than 8,000 homes, 500 commercial properties, 18,000 vehicles, and hundreds of additional businesses, schools and other structures.. Other tornadoes and severe storms over the course of those seven days destroyed or damaged at least 1,000 homes and businesses across the nation.

According to ***preliminary*** reports, total economic losses resulting from the May 21-27 storms were approximately $6.5 billion. At the time of this writing, insurers had received at least 550,000 claims, with anticipated payouts expected to exceed $4.5 billion. Nearly half of these losses were caused by the Joplin tornado. The total rebuilding cost of Joplin may approach $3 billion, and the total combined insured losses caused by the tornado are expected to be in excess of $2 billion.

> *Source:* AON Benfield. (2011, June 26). *United States April and May 2011 Severe Weather Outbreaks.* Chicago, IL.
> Available at:
> http://www.aon.com/attachments/reinsurance/201106_us_april_may_severe_weather_outbreaks_recap.pdf

Since the early 1980s, average annual insured losses caused by thunderstorms have increased by 500 percent.

> *Source:* Munich Re. (2011). *TOPICS GEO: Natural Catastrophes 2010 (U.S. Version).* Munchen, Germany: Munchener Ruckversicherungs-Gesellschaft, 43.
> Available at: http://www.munichre.com/publications/302-06742_en.pdf

In 2010, lightning strikes caused more than $1 billion (in 2010 dollars) in insured losses. These losses ranged from damage to expensive electronic equipment to structural fires that destroyed entire homes. There were more than 213,000 lightning claims in 2010, with an average cost per lightning claim of $4,846 (in 2010 dollars). The average cost per lightning claim rose more than 80 percent from 2004 to 2010, even as the actual number of lightning claims fell by a little over 23 percent in the six-year period. The total amount of insured losses caused by lightning strikes also rose 40 percent during that time.

> *Source:* Insurance Information Institute. (2011, June 21). Claim Costs From Lightning Continue to Rise; the Culprit Is Often Expensive Electronics. Press Release.
> Available at: http://www.iii.org/press_releases/claim-costs-from-lightning-continue-to-rise-the-culprit-is-often-expensive-electronics.html

Hurricanes

A helpful metric in analyzing the economic impact of hurricanes is normalization, which provides an estimate of the damage that would occur if storms from the past made landfall under another year's societal conditions. Normalization methods use changes in inflation and wealth at the national level and changes in population and housing units at the coastal county level.

If the Great Miami Hurricane of 1926 (a Category 4 storm) were to have made landfall in the same spot in 2005, it would be the costliest hurricane on record, amounting $140-157 billion (in

2005 dollars) in damages. It would be nearly twice as destructive as Hurricane Katrina. If the Galveston Hurricanes of 1900 and 1915 (both Category 4) were to have made landfall in 2005, they would be the third and fourth most destructive hurricanes, resulting in damages of $72-78 billion and $57-62 billion (in 2005 dollars), respectively. The fifth costliest hurricane under 2005 normalization would be Andrew, creating $54-58 billion (in 2005 dollars) in damages.

Coastal populations in the U.S. continue to grow, thereby increasing the amount of personal wealth that is vulnerable to hurricane damage. This migration has already led to a doubling of losses every 10 years. This suggests that a storm like the Great Miami Hurricane of 1926 could result in $500 billion (in 2005 dollars) in damages as soon as the 2020s.

Average annual normalized hurricane damage from 1900-2005 was $10 billion. The annual likelihood of a $10 billion hurricane event (with $5 billion in insured losses) during that period was approximately 25 percent, while the annual likelihood of a hurricane event exceeding $50 billion (with $25 billion in insured losses) was approximately 5 percent (all values in 2005 dollars).

> *Source:* Pielke, Jr., R. A., Gratz, J., Landsea, C. W., Collins, D., Saunders, M. A., and R. Musulin. (2008, February). Normalized Hurricane Damages in the United States: 1900-2005. *Natural Hazards Review, 9(1).*
> Available at: http://sciencepolicy.colorado.edu/admin/publication_files/resource-2476-2008.02.pdf

Hurricane Katrina destroyed 350,000 homes, which was more than 12 times the number destroyed by any previous natural disaster in the nation's history.

> *Source:* National Association of Home Builders. (2005). Rebuilding Katrina-Destroyed Homes at Least a Year Away. *Nation's Building News.*
> Available at: http://www.nbnnews.com/NBN/issues/2005-10-10/Front+Page/index.html

Winter Weather

From 1990-2009, winter storms in the U.S. resulted in about $25 billion in insured losses (in 2009 dollars).

> *Source:* Insurance Information Institute. (2010). Winter Storms.
> Available at: http://www.iii.org/facts_statistics/winter-storms.html

Insured losses due to winter storm events in the U.S. in 2010 totaled nearly $ 2.8 billion (in 2010 dollars), the largest loss total in eight years and one of the top five largest annual winter storm losses in the nation's history. In February 2010, a series of three severe snowstorms impacted the mid-Atlantic region in rapid succession, shattering snowfall records across the region. Aside from breaking records, the three events also cumulatively caused 41 deaths and over $1 billion (in 2010 dollars) in insured property damage. Primary causes of loss from the events were damage to buildings due to high winds, ice damming on roofs, or roof collapse due to excessive snow loads. Power outages and disruptions in ground and air transportation generated some business interruption losses, and icy road conditions caused numerous automobile accidents.

The 5-year running average for insured winter storm losses from 2006-2010 was almost $1.7 billion per year (in 2010 dollars). The medium-term average has been relatively stable over the past decade, but is about $800 million (in 2010 dollars) or 200 percent higher over the average in the early 1980s (after adjusting for inflation).

> *Source:* Munich Re. (2011). *TOPICS GEO: Natural Catastrophes 2010 (U.S. Version).* Munchen, Germany: Munchener Ruckversicherungs-Gesellschaft, 40-43.
> Available at: http://www.munichre.com/publications/302-06742_en.pdf

Floods

From 1955-2008, floods in the U.S. caused over $252 billion (in 2008 dollars) in damages. Adjusted for changes in weather in addition to inflation, the total U.S. flood damage during that time increases to $397 billion (in 2008 dollars).

> *Source:* National Center for Atmospheric Research. (2011). Extreme Weather Sourcebook: Economic and Other Societal Impacts Related to Hurricanes, Floods, Tornadoes, Lightning, and Other U.S. Weather Phenomena.
> Available at: http://www.sip.ucar.edu/sourcebook/floods.jsp

In the spring of 1927, the most catastrophic river flood to impact the U.S. occurred along the Mississippi River, inundating parts of Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee. In all, approximately 27,000 square miles were left underwater, ruining crops, damaging or destroying 137,000 buildings, causing 700,000 people to be displaced from their homes, and killing 250 individuals across the seven impacted states. In the aftermath, direct economic losses along the lower Mississippi River were estimated by the American Red Cross and the then-U.S. Weather Bureau to be between $250-350 million (or $3.1-4.4 billion in 2007 dollars). Using a normalization model that accounts for changes in inflation, wealth and population in the same 100 counties affected in 1927, researchers estimate that if the exact same flood were to have occurred in 2007, it would have cause between $130-160 billion (in 2007 dollars) in economic damages. Despite the development of flood insurance programs since 1927, 84 percent of these damages would not be insured. The resulting uninsured losses would be greater than the total amount of uninsured losses experienced after Hurricane Katrina.

> *Source:* Risk Management Solutions. (2007). *The 1927 Great Mississippi Flood: 80-Year Retrospective.* Hoboken, NJ.
> Available at: http://www.rms.com/Publications/1927_MississippiFlood.pdf

Wildfires
Between FY 1996 and FY 2007, both the average acreage burned annually and federal appropriations for wildland fire management activities more than doubled. In FY 1996, Congress appropriated $984 million (in FY 2007 dollars) for wildfire management. In FY 2007, over $3 billion (in FY 2007 dollars) was appropriated. During FY 2001 through FY 2007, the average annual appropriation for wildfire management was $2.9 billion.

> *Source:* U.S. Government Accountability Office. (2009, July 21). *Wildland Fire Management: Federal Agencies Have Taken Important Steps Forward, but Additional Action Is Needed to Address Remaining Challenges* (Publication no. GAO-09-906T). Washington, DC.
> Available at: http://www.gao.gov/new.items/d09906t.pdf

Tsunamis
Since 1900, tsunami events have caused more than 700 deaths and over $200 million (in 2008 dollars) in damages to American coastal states and territories. More than 50 percent of the U.S. population now lives in coastal communities and may be at risk for impacts from a destructive tsunami.

> *Source:* Dunbar, P.K. and C.S. Weaver. (2008, August). *U.S. States and Territories National Tsunami Hazard Assessment: Historical Record and Sources for Waves.* Report prepared for the National Tsunami Hazard Mitigation Program. Boulder, CO and Seattle, WA. 1-1.
> Available at:
> http://nthmp.tsunami.gov/documents/Tsunami_Assessment_Final.pdf

On March 11, 2011, a magnitude 9.0 earthquake occurred off the Pacific coast of Japan. The earthquake generated a devastating tsunami that swept through communities along Japan's eastern coast, leaving close to 23,000 people dead or missing. According to ***preliminary*** estimates, direct material damage caused by the earthquake and tsunami is expected to be at least ¥16.9 trillion ($217 billion in 2011 U.S. dollars). This figure does not include economic losses related to the tsunami-induced meltdown of the Fukushima nuclear power plant.

> *Source:* Reconstruction Design Council in Response to the Great East Japan Earthquake. (2011, June 25). *Towards Reconstruction: Hope beyond the Disaster*. A report presented to the Prime Minister of Japan. Tokyo, Japan: Government of Japan.
> Available at: http://www.cas.go.jp/jp/fukkou/english/pdf/report20110625.pdf

The most devastating tsunami in history was generated by a magnitude 9.0 earthquake on December 26, 2004, in the Indian Ocean west of Sumatra. It killed more than 228,000 people across 14 countries bordering the Indian Ocean. In addition, the tsunami displaced 1.7 million people and caused approximately $10 billion in economic losses (verification of monetary base year still pending).

Source: Cosgrave, J. (2007, January). *Synthesis Report: Expanded Summary, Joint evaluation of the international response to the Indian Ocean tsunami.* London, United Kingdon: Tsunami Evaluation Coalition.
Available at: http://www.alnap.org/pool/files/Syn_Report_Sum.pdf

On September 29, 2009, a magnitude 8.1 earthquake in the Samoa Islands region spawned tsunamis that mainly hit Samoa, American Samoa and Tonga. In American Samoa alone, the tsunamis killed 32 people, injured an additional 129, and caused $81 million in damages (in 2009 dollars).

Source: NWS Office of Climate, Water and Weather Services. (2011, March 11). *Summary of Natural Hazard Statistics for 2009 in the United States.* Silver Spring, MD.
Available at: http://www.nws.noaa.gov/om/hazstats/sum09.pdf

False tsunami warnings result in additional significant economic impact. In 1986, a seismic event led to a tsunami warning in Hawaii. Without deep ocean data (i.e., detection buoy instrumentation) the warning was not cancelled until after an evacuation had taken place. The Hawaii Department of Business, Economic Development and Tourism estimated the cost to Hawaii in lost productivity was $70 million (in 2003 dollars).

Source: National Science and Technology Council. (2005, December). *Tsunami Risk Reduction: A Framework for Action.* Washington, DC.
Available at:
http://www.sdr.gov/Tsunami%20Risk%20Reduction%20for%20the%20US%20-%20A%20Framework%20for%20Action%202005-12-22.pdf

<u>Space Weather</u>

Strong geomagnetic storms with the potential to impact critical elements of our nation's infrastructure can occur over 100 times during an 11-year solar cycle.

Source: Office of Management and Budget. (2011). *President's Budget Request for Fiscal Year 2012 Budget: National Weather Service*. Washington, DC. 717.

In the fall of 2003, with little warning, three of the largest and most intense sunspot clusters witnessed in the prior 10 years emerged on the surface of the sun. Over a three week period, the NWS Space Environment Center issued over 250 solar energetic event watches, warnings, and alerts. The storms caused blackouts in Sweden and forced airlines to divert flights away from the North Pole at a cost of $10,000 to $100,000 each. The storms also destroyed ADEOS-2 – a $640 million Japanese science satellite that carried the $150 million NASA SeaWinds instrument (all values in 2003 dollars).

Source: NWS. (2004, April). *Service Assessment: Intense Space Weather Storms October 19–November 7, 2003*. Silver Spring, MD.
Available at:
http://www.weather.gov/os/assessments/pdfs/SWstorms_assessment.pdf

In January 1997, a geomagnetic storm severely damaged the U.S. Telstar 401 communication satellite, which was valued at $270 million (in 2010 dollars), and left it inoperable.

Source: Sawyer, K. (1997, January 23). Earth Takes a 'One-Two Punch' From a Solar Magnetic Cloud. *Washington Post*, p. A01.

In 1989, a geomagnetic storm caused a major power outage for nine hours for the majority of the Quebec region and for parts of the northeastern U.S. The total cost of the Hydro-Quebec incidents is estimated to be $6 billion (in 2002 U.S. dollars).

Source: CENTRA Technology, Inc. (2011, January 14). Geomagnetic Storms. A report prepared on behalf of the U.S. Department of Homeland Security as a contribution to the Organization for Economic and Community Development's "Future Global Shocks" project. Burlington, MA and Arlington, VA.
Available at: http://www.oecd.org/dataoecd/57/25/46891645.pdf

The most severe space weather event recorded in history is the Carrington-Hodgson Event of 1859, in which Earth was hit by two solar superstorms within the matter of a week. The intensity of this event is estimated to be approximately 150,000 pfu (proton flux units). Auroral displays, often called the northern or southern lights, spanned several continents and were observed around the world. Across the world, telegraph networks experienced disruptions and outages as a result of the currents generated by the geomagnetic storms.

If a superstorm of the same intensity as the Carrington-Hodgson Event were to occur in the current solar cycle (2007-2018), the damage caused to the existing geosynchronous Earth-orbiting satellite population would lead to an estimated $30 billion (in 2006 dollars) in lost revenue. Satellite revenue is generated by leasing the services of the satellite transponders to clients, who will pay a rental fee for these services.

Source: Odenwald, S. F., and J. L. Green. (2007, June 12). Forecasting the impact of an 1859-calibre superstorm on geosynchronous Earth-orbiting satellites: Transponder resources. *Space Weather*, 5.

A severe geomagnetic storm could severely damage the nation's electric power grid and result in estimated economic costs of $1-2 trillion (verification of monetary base year still pending). Full recovery could take 4-10 Years.

Source: National Research Council. (2008). *Severe Space Weather Events — Understanding Societal and Economic Impacts: A Workshop Report.* Washington, DC: The National Academies Press.
Available at: http://www.nap.edu/catalog.php?record_id=12507

Weather and Energy

High temperatures often lead to peak power demand by consumers, creating many power transmission reliability problems. Real-time environmental information is used in energy transmission and distribution companies' site-specific adaptive control strategies to maintain reliability, since the amount of power that can be transmitted through power lines is directly related to the temperature-based rating of the line.

Strategic plans for the San Diego region's energy infrastructure were examined under different climate scenarios, one of which indicated a much higher incidence of summer temperature extremes for Southern California that would stress major infrastructure assets. A one-degree change in temperature during the summer months of May-October creates an additional 50-258MW of demand, taking into account price, customer growth, and average use factors. Using a 20-year value of this demand at $1,300/MW cost would mean an additional $65 million-325 million in additional generating capacity would be required to meet climate-related demand increases (verification of monetary base year still pending).

> *Source:* Altalo, M., and M. Hale. (2004, May). Turning Weather Forecasts Into Business Forecasts. *Environmental Finance*. 20-21.
> Available at:
> http://www2.lse.ac.uk/CATS/publications/papersPDFs/AltaloAndHale_forecasts2BusinessForecasts_2004.pdf

The former U.S. Minerals Management Service (now the Bureau of Ocean Energy Management, Regulation and Enforcement) estimated that 3,050 of the 4,000 platforms in the Gulf of Mexico and 22,000 of the 33,000 miles of Gulf pipelines were in the direct path of either Hurricanes Katrina or Rita.

Because of the large amount of infrastructure in the path of hurricane-force winds and waves, the amount of damage was substantial. In comparison with Hurricane Ivan in 2004, Katrina and Rita accounted for considerably more damage because of the paths taken by these two devastating storms. Collectively, Katrina and Rita destroyed 135 platforms and seriously damaged over 50 platforms. However, there was no loss of life or significant oil spills from wells on the outer continental shelf attributed to either storm.

One hundred percent of Gulf oil production (approximately 1.5 million barrels per day) was secured and taken out of production during Katrina and Rita, and 94 percent of gas production (10 billion cubic feet of gas per day) was out of production during Katrina. More than 90 percent of the manned platforms and 85 percent of working rigs were evacuated at one time.

> *Source:* U.S. Mineral Management Service. (2006, January 19). Impact Assessment of Offshore Facilities from Hurricanes Katrina and Rita. Press Release.
> Available at: http://www.boemre.gov/ooc/press/2006/press0119.htm

The catastrophic EF-5 tornado that struck Joplin, Missouri, on May 22, 2011, caused upwards of $30 million in damages to the infrastructure of Empire Electric District Company, which serves about 150,000 people in the southwestern part of the state. The company expects that the tornado wiped-out as much as 15 percent of customer demand for electricity.

> *Source:* AON Benfield. (2011, June 26). *United States April and May 2011 Severe Weather Outbreaks.* Chicago, IL.
> Available at:
> http://www.aon.com/attachments/reinsurance/201106_us_april_may_severe_weather_outbreaks_recap.pdf

Global positioning systems (GPS) are particularly vulnerable to space weather interruptions. In the oil-drilling industry, GPS is critical for positioning. Marking the location of prospective oil strikes requires near-pinpoint accuracy. If GPS is disrupted, it can cost approximately $1 million per day to delay operations of oil drilling in the Gulf of Mexico (verification of monetary base year still pending).

> *Source:* National Research Council. (2008). *Severe Space Weather Events — Understanding Societal and Economic Impacts: A Workshop Report.* Washington, DC: The National Academies Press.
> Available at: http://www.nap.edu/catalog.php?record_id=12507

Weather and Agriculture

The agriculture industry has long relied on NOAA weather and climate information to improve planning and decision-making for improving crop yields. Environmental factors, such as seasonal precipitation, drought vulnerability, mean and extreme temperatures, and the length of the growing season (i.e. the last spring and first fall freezes), help to determine the type of crop that can be profitably grown in a region. However, over the course of a season, a farmer must make crop planning and management decisions at different time scales.

During the 1997-1998 El Niño and 1998-1999 La Niña, the U.S. agricultural sector experienced damages of $2.4-2.8 billion and $3.6-10.7 billion (in 2010 dollars), respectively.

> *Source:* Adams, R.M., Chen, C.C., McCarl, B.A., and R.W. Weiher. (1999, December 10). The economic consequences of ENSO events for agriculture. *Climate Research,* 13.
> Available at: http://www.int-res.com/articles/cr/13/c013p165.pdf

Weather and Transportation

In 2010, more than 37 percent of flight delays were attributable to weather, accounting for 24.7 million delayed minutes.

> *Source:* Bureau of Transportation Statistics. (2011). Airline On-Time Statistics and Delay Causes: Weather's Share of Delayed Flights.

Available at:
http://www.transtats.bts.gov/OT_Delay/ot_delaycause1.asp?display=data&pn=1

The total cost of domestic air traffic delays to the U.S. economy in 2007 was as much as $41 billion (in 2007 dollars), including $19 billion in raised airline operating costs and $12 billion worth of passengers' time. Delayed flights cost the airlines and customers an additional $1.6 billion in fuel (740 million additional gallons of jet fuel at an assumed wholesale price of $2.15 per gallon in 2007). In addition, an estimated $10 billion was lost by industries that rely on air traffic for supplies or customers, such as food services, lodging, general retail and ground transportation.

Source: U.S. Congressional Joint Economic Committee. (2008, May). *Your Flight Has Been Delayed Again.* Washington, DC.
Available at: http://jec.senate.gov/public/?a=Files.Serve&File_id=47e8d8a7-661d-4e6b-ae72-0f1831dd1207

The use of cross-polar routes by airlines has been growing rapidly over the past decade, thanks to developments in global positioning system (GPS) technology and rising fuel costs. One of the more popular routes, which was designed by Canada's civil air navigation service (Nav Canada), has been across the Hudson Bay. The route is guided by a series of new GPS-based Automatic Dependent Surveillance-Broadcast (ADS-B) towers installed by Nav Canada. The organization estimates that by following the Hudson Bay route, airlines save $187 million (in U.S. dollars, verification of monetary base year still pending) annually in fuel costs and reduce emissions by 547,000 metric tons of carbon dioxide. One major concern, however, is that GPS is particularly vulnerable to space weather interruptions. Furthermore, cross-polar routes will be particularly hazardous for air travel during a severe geomagnetic storm.

Source: Schofield, Adrian. (2010, March 8). Northern Network. *Aviation Week and Space Technology*.
Available at:
http://www.navcanada.ca/ContentDefinitionFiles%5CNewsroom%5CInTheNews%5C2010%5Citn0323a_en.pdf

Each year trucking companies and other commercial vehicle operators lose an estimated 32.6 billion vehicle hours due to weather-related congestion in 281 of the nation's metropolitan areas. Nearly 12 percent of total estimated trucking delays are due to weather in the 20 cities with the greatest volume of truck traffic. Estimated cost of weather-related delay to trucking companies ranges from $2.2-3.5 billion annually (verification of monetary base year still pending).

Source: Federal Highway Administration. (2009, May 11). How Do Weather Events Impact Roads?
Available at: http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm

Adverse winter weather can increase operating and maintenance costs of government entities responsible for road maintenance, traffic management, emergency services and law enforcement.

In 2008, roadway snow and ice removal expenditures amounted to $1.67 billion (in 2010 dollars) for state-level transportation agencies and $1.97 billion (in 2009 dollars) for local governments.

> *Source:* Federal Highway Administration. (2011). Annual Highway Statistics for 2009 and 2008: Tables LGF-2 and SF-4.
> Available at: http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.cfm

Severe wind and wave conditions associated with extratropical storms in the North Pacific and North Atlantic impose costs on maritime commerce by delaying and sometimes damaging vessels that encounter these storms. Globally, some 10,000 containers are lost annually at sea, largely due to inclement weather. The cost of a lost shipping container ranges from $50,000 to $200,000. The loss of a single dry bulk ship is $100 million, factoring in loss of life, cargo and the vessel itself. The upper bound estimates of average expected annual losses to container shipping (lost containers and associated damage to vessels) in the absence of good information about extratropical storm conditions were calculated to be on the order of $250 million in the North Pacific and $120 million in the North Atlantic. The upper bound estimate of average annual losses to bulk shipping operations from extratropical storm exposure in these regions is $150 million (all values in 2007 dollars).

> *Source:* Kite-Powell, H. (2008, December). *Benefits to Maritime Commerce from Ocean Surface Vector Wind Observations and Forecasts.* Woods Hole, MA: Woods Hole Oceanographic Institution, Maritime Policy Center.
> Available at:
> http://manati.orbit.nesdis.noaa.gov/SVW_nextgen/QuikSCAT_maritime_report_final.pdf

Value of NOAA's NWS Products:

NOAA's NWS provides raw data, analysis, and forecasts regarding a wide variety of weather events. What follows are examples of NWS activities that have been formally valued.

Weather Forecasts

Weather forecasts may be the best known of the NWS activities. These forecasts are generated by local data collection, satellite monitoring, and supercomputer modeling. Most forecasts are issued by the 122 Weather Forecasting Offices, located throughout the nation.

A nationwide survey indicates that 96 percent of the U.S. public obtains, either actively or passively, 301 billion forecasts each year. Based on an average annual household value of $286 placed on weather information, the American public collectively receives $31.5 billion in benefits from forecasts each year. These benefits far exceed the $5.1 billion spent annually by both private and public weather bureaus on generating forecasts.

> *Source:* Lazo, J.K., Morss, R.E., and J.L. Demuth. (2009, June). 300 Billion Served: Sources, Perceptions, Uses, and Values of Weather Forecasts. *Bulletin of the American Meteorological Society, 90(6).*

Available at: http://journals.ametsoc.org/doi/pdf/10.1175/2008BAMS2604.1

A separate survey was conducted in states prone to hurricane damage to learn of the average taxpayer valuation of enhanced hurricane forecasts. Using current household tax obligation as the baseline value of current forecasts, researchers found that, on average, households in at-risk states were willing to pay an additional $14.34 per year to receive more precise hurricane predictions 48 hours in advance, thus enabling them to make better evacuation decisions (verification of monetary base year still pending). The survey described an "enhanced hurricane forecast" as one that offers more accurate predictions of landfall time and location, maximum wind speed and storm surge.

Source: Lazo, J.K., Waldman, D.M., Morrow, B.H., and J.A. Thacher. (2010, February). Assessment of Household Evacuation Decision Making and the Benefits of Improved Hurricane Forecasting. *Weather and Forecasting*, 25(1). Available at: http://journals.ametsoc.org/doi/pdf/10.1175/2009WAF2222310.1

U.S. electricity producers save $166 million annually using 24-hour temperature forecasts to improve the mix of generating units that are available to meet electricity demand. Incremental benefits are relevant in assessing the merits of investments that will improve forecast accuracy. The incremental benefit of an improvement in temperature forecast accuracy is estimated to be about $1.4 million per percentage point of improvement per year. For a 1°C improvement in accuracy, the benefit is about $59 million per year (or a $37 million benefit for a 1°F improvement). It is estimated that a perfect forecast would add $75 million to these savings (all values in 2002 dollars).

Source: Teisberg, T., Weiher, R., and A. Khotanzad. (2005, December). The Economic Value of Temperature Forecasts in Electricity Generation. *Bulletin of the American Meteorological Society*, 86(12).
Available at: http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-86-12-1765

Maritime Forecasts

The NWS Ocean Prediction Center (OPC) discharges domestic and international meteorological products to marine interests under the International Convention for Safety of Life at Sea, to which the U.S. is a signatory. The OPC issues warnings and forecasts in print (bulletins) and graphical formats, on a 24x7 basis up to five days in advance. Over 100 of these products are issued daily. They cover the North Atlantic Ocean from the west coast of Europe to the U.S. and Canadian east coast, as well as the North Pacific Ocean from the U.S. and Canadian west coast to the east coast of Asia. OPC weather forecasts and warnings for these areas primarily ensure the safety of ocean-crossing commercial ships and other vessels on the high seas. Imbedded in these high seas areas are smaller offshore zones off the Atlantic and Pacific coasts. These zones extend from near the coast seaward to just beyond the U.S. Exclusive Economic Zones, out to about 250 nautical miles. OPC services ensure the safety of the extensive commercial and recreational fishing, boating, and shipping activities in these offshore waters.

Source: NWS Ocean Prediction Center. (2009, May 12). Ocean Prediction Center Overview.
Available at: http://www.opc.ncep.noaa.gov/OPC_Overview_ESM.shtml

A significant fraction of risk to bulk shipping operations from extratropical storms in the North Pacific and North Atlantic can be avoided with ocean surface vector wind observations and forecasts. An upper bound estimate found that ocean surface vector wind information and associated forecasts provided with the help of the NASA Quick Scatterometer satellite (QuickSCAT) enables a 44 percent reduction in exposure of shipping to storms each year, producing an annual net savings of $135 million. The next generation of vector wind instruments (currently in the conceptual stages) is expected to provide an upper bound annual net benefit of $207 million. An upper bound estimate for expected annual benefits of a perfect forecast (not feasible with present technology) is $520 million from all shipping by allowing for the virtual elimination of exposure to storm conditions with no significant increase in operating costs (all values in 2007 dollars).

Source: Kite-Powell, H. (2008, December). *Benefits to Maritime Commerce from Ocean Surface Vector Wind Observations and Forecasts.* Woods Hole, MA: Woods Hole Oceanographic Institution, Maritime Policy Center.
Available at:
http://manati.orbit.nesdis.noaa.gov/SVW_nextgen/QuikSCAT_maritime_report_final.pdf

El Niño/La Niña Forecasts

The NWS Climate Prediction Center provides El Niño Southern Oscillation forecasts.

Annual benefits of El Niño Southern Oscillation forecasts to U.S. agriculture by altering planting decisions have been estimated to be in excess of $460 million (in 2010 dollars), throughout El Niño, normal, and La Niña years.

Source: Adams, R.M., Chen, C.C., McCarl, B.A., and R.W. Weiher. (1999, December 10). The economic consequences of ENSO events for agriculture. *Climate Research,* 13.
Available at: http://www.int-res.com/articles/cr/13/c013p165.pdf

Annual benefits of El Niño Southern Oscillation forecasts to U.S. corn farmers from optimizing inventory storage costs could approach $240 million (in 1996 dollars).

Source: McNew, K. (1997, September 15). *Valuing El Niño Weather Forecasts In Storable Commodity Markets: The Case of U.S. Corn.* A preliminary report presented to NOAA. College Park, MD: University of Maryland.
Available at: http://www.arec.umd.edu/libcomp/AREClib/Publications/Working-Papers-PDF-files/97-12.pdf

In the small northwest Coho salmon fishery, annual benefits of El Niño forecasts are estimated at $600,000 to $1.3 million (in 2010 dollars) from changing hatchery releases and harvest rates.

> *Source:* Costello, C.J., Adams, R., and S. Polasky. (1998, November). The Value of El Niño Forecasts in the Management of Salmon: A Stochastic Dynamic Assessment. *American Journal of Agricultural Economics*, 80(4), 774.
> Available at: http://www.jstor.org/stable/1244062?seq=1

Prior to the 1997-1998 El Niño, California's emergency management agencies and FEMA spent an estimated $219 million preparing for storms and heavy rain. Actual storm losses in the 1997-1998 El Niño were over $1.4 billion, compared to over $2.9 billion in damages as a result of the intense 1982-1983 El Niño. Although portions of the $1.5 billion difference are due to different intensities and durations of storminess during each El Niño, a significant portion of the savings came from heightened preparedness (all values in 2010 dollars).

> *Source:* Changnon, S.A. (ed.). (2000). *El Niño 1997-1998: The Climate Event of the Century*. New York, NY: Oxford University Press, 147-148.
> Available at:
> http://books.google.com/books?id=aMHwVy3ZPpwC&printsec=frontcover#v=onepage&q&f=false

A group of researchers estimated the value of improved stream flow forecasts for Columbia River hydropower, derived from improved forecasting of the El Niño Southern Oscillation and the Pacific Decadal Oscillation. Advances in climate forecasting have enabled forecasters to predict stream flows in the Columbia River basin – which covers portions of seven western states and British Columbia, and has a total drainage area about the size of Texas – six months earlier than forecasts that rely on actual snowpack measurements. This allows more spot market energy sales to be made in late summer and fall. Benefits from the improved forecasts were measured as the value of spot market energy sales that could result from improved stream flow estimates. It was estimated that these sales could increase annual revenue by approximately $161 million per year (in 2004 dollars).

> *Source:* Hamlet, A.F., D. Huppert, and D.P. Lettenmaier. (2002). Economic value of long-lead streamflow forecasts for Columbia River hydropower. *Journal of Water Resources Planning and Management*, 128(2).
> Available at:
> http://www.waterandclimateinformationcentre.org/resources/8022007_Hamlet2002_JWRPM.pdf

Enhanced decision-making capabilities, based on imperfect El Niño Southern Oscillation forecasts, yield annual benefits of $548 million-$1.03 billion for the U.S. agricultural sector. Perfect forecasts would provide the sector annual benefits of over $1.9 billion (all values in 2010 dollars).

> *Source:* Chen, C., McCarl, B., and H. Hill. (2002). Agricultural Value of ENSO Information Under Alternative Phase Definition. *Climate Change*, 54(3).

Available at: http://www.springerlink.com/content/eyernbu6y04h1t3h/fulltext.pdf

Drought and Climate Forecasts

In collaboration with other agencies and academic partners, the NWS Climate Prediction Center and NOAA's National Climatic Data Center (NCDC) administer the National Integrated Drought Information System (NIDIS) to monitor drought conditions and issue drought forecasts and warnings.

Source: National Integrated Drought Information System. (2011). U.S. Drought Portal.
Available at: www.drought.gov

For every $1 that railway companies spend in acquiring NOAA climate data, they receive a $13,140 savings in infrastructure costs that would be required to maintain their own climate database storage, archiving, and reporting system. After extrapolating these savings to the entire Class I freight railroad sector, the potential benefits are approximately $11.5 million (all values in 2003 dollars).

Source: Centrec Consulting Group, LLC. (2005, June). *Economic Value of Selected NOAA Products within the Railroad Sector*. Report prepared for NOAA's National Climatic Data Center. Savoy, IL.
Available at:
http://www.centrec.com/resources/pres/Economic%20Value%20of%20Selected%20NOAA%20Products%20within%20the%20Railroad%20Sector.pdf

In a 2002 study involving a large U.S.-based energy company that provides energy in multiple sectors of the energy industry, it was found that for every $1 that the company spent in acquiring NCDC products, the company received a potential savings of $495 in infrastructure costs that would be required to maintain its own climate database storage, archiving, and reporting system. Extrapolating the savings to the entire U.S. energy market (specifically electricity and natural gas providers) yields an annual potential benefit of $65 million. In FY 2002, it cost taxpayers $2.48 million to staff and maintain all NCDC divisions needed to provide the level of service and data products enjoyed by energy companies (all values in year-2000 dollars).

Source: Centrec Consulting Group, LLC. (2003, January). *Investigating the Economic Value of Selected NESDIS Products.* Report prepared for NOAA's National Environmental Satellite, Data and Information Service. Savoy, IL.
Available at: http://www.centrec.com/resources/pres/nesdis_report.pdf

Flood and Water Resource Forecasts

River and flood forecast services are provided in the form of daily river forecasts by the 13 NWS River Forecast Centers (RFCs). Some RFCs, especially those in mountainous regions, also provide water supply volume and peak flow forecasts based analysis of snow pack in high elevations. Each of these forecast services are used by a wide range of decision-makers, including those in agriculture, hydroelectric dam operation and electricity generation, and water resource. Information from the RFCs is also the basis for local flood and flash flood warnings, watches, and advisories issued by the NWS Weather Forecast Offices. These products communicate flooding impacts depending on geographic area, land use, time of the year, and other dynamic factors.

NWS also administers the Advanced Hydrologic Prediction Service (AHPS), which provides data to the public on the magnitude and certainty of occurrence of floods or droughts, hours, days and even months in advance of an event. Prior to AHPS, river forecasts were text products with 1-3 day lead times and were delivered via the weather wire. When full implementation of AHPS is complete in FY 2014, advanced river forecast information will be provided at 4,011 locations throughout the U.S. to assist emergency managers, water managers, and the general public in making decisions based on improved forecasts and the certainty of a hydrologic event.

> *Source:* Office of Management and Budget. (2011). *President's Budget Request for Fiscal Year 2012 Budget: National Weather Service*. Washington, DC. 691.

Some studies suggest that as little as one hour of lead-time can result in a 10 percent reduction in flood damages. The effects of improvements in long-range hydrologic forecasts are substantial, with an additional $243 million in annual benefits estimated to result from the full implementation of AHPS (which is expected by FY 2014). Factoring-in other water resources activities like hydropower, irrigation, navigation, and water supply conservatively adds another $523 million in benefits, bringing the total estimated annual benefits from improved long-range forecasting to $766 million. The average annual combined economic flood loss reduction benefit from NWS hydrologic forecasts to the U.S. resulting from the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation optimum reservoir operation is approximately $1 billion (all values in year-2000 dollars).

> *Source:* EASPE, Inc. (2002, May). *Use and Benefits of the NWS River and Flood Forecasts.* Report prepared for the National Hydrologic Warning Council. Available at: http://www.nws.noaa.gov/oh/ahps/AHPS%20Benefits.pdf

Weather Satellites

In collaboration with NOAA's National Environmental Satellite, Data and Information Service (NESDIS), the NWS uses satellite technology to improve its forecasting abilities.

One such technology, the Geostationary Operational Environmental Satellite (GOES) system, has contributed essential data in support of the NWS mission since 1975. In so doing, GOES has provided critically important information for the American economy and public. Circling the earth in a geosynchronous orbit, these satellites provide the continuous data streams necessary for intensive monitoring of weather and environmental conditions.

The next generation of GOES (titled GOES-R) is expected to be launched by 2015, and will become fully operational by 2017. This series of satellites will include upgraded technology, such as an improved Advanced Baseline Imager (ABI), which will provide faster image scans, with a higher resolution, covering a larger geographic area. Enhanced ABI capabilities will help decrease forecast error and expand the list of geostationary products offered by NOAA. One study provides estimates of the impact on selected sectors of the economy (see below). The impact of improved data from GOES-R on these selected sectors of the economy has a combined annual value for 2015 that exceeds $921 million (in 2010 dollars). The present value of the combined estimated benefits, for the selected sectors, for the 2015-2027 period approaches $5.1 billion (in 2010 dollars). Other benefits of GOES-R have not been estimated.[i]

The benefits for specific industries are as follows:

Coastal Emergency Management (in 2005 dollars): Geostationary satellites play an instrumental role in both the tropical cyclone monitoring and forecasting process. The GOES images are the foundation to the monitoring and diagnostic process. They are used for initialization in the numerical weather prediction models that provide guidance for NWS National Hurricane Center's official track, intensity, storm size and structure, and rainfall forecasts. GOES can gather measurements that buoys, weather balloons, reconnaissance aircraft and even polar-orbiting satellites cannot obtain. The GOES-R will further improve forecasts for tropical cyclones (hurricanes and tropical storms/depressions). Enhanced predictions will enable more effective action to protect property and individuals residing in the path of the storm. Tropical cyclone forecasts enhanced by improved ABI technology aboard GOES-R are expected to produce annual net economic benefits of $450 million in 2015 (an average of $130,000 per coastline mile from Maine to Texas). The present value of this benefit over the 2015-2027 period is estimated to be $2.4 billion (an average of $690,000 per coastline mile from Maine to Texas).

Recreational Boating (in 2005 dollars): The improved tropical forecasts are also expected to prevent annual losses to the recreational boating industry valued at $31 million in 2015. The present value of this benefit over the 2015-2027 period is estimated to be $141 million.

Aviation (in 2005 dollars): The new ABI technology will enhance the tracking of volcanic ash plumes. This will provide advance warning to pilots, who then can be routed around the damaging and deadly plumes. The annual net economic benefit to the airline industry from these enhancements is $58 million in 2015. The present value of this benefit over the 2015-2027 period is estimated to be $265 million.

Energy Providers (in 2005 dollars): One large cost of providing energy relates to the ability to forecast demand and then to supply the necessary energy on time. Energy providers rely on demand models to forecast electricity production and natural gas requirements. Demand forecasts for energy production are largely based on temperature forecasts. GOES-R data will allow for more accurate temperature forecasts, thereby enabling energy providers to better prepare for changes in demand. Annual savings for the energy sector is expected to be $256 million in 2015. The present value of this benefit over the 2015-2027 period is estimated to be $1.28 billion.

Agriculture (in 2005 dollars): Improved information from GOES-R will enable researchers and forecasters to produce more accurate forecasts, resulting in irrigation water being used more efficiently. More efficient use of irrigation water benefits irrigating farmers directly by reducing their production costs. Further efficiency gains can lead to surplus farm water being sold for other purposes (at a significant premium to cost for irrigation). The annual net economic benefit for agriculture is valued at $30 million in 2015. The present value of this benefit over the 2015-2027 period is estimated to be $545 million.

> *Source:* Centrec Consulting Group, LLC. (2007, February 27). *An Investigation of the Economic and Social Value of Selected NOAA Data and Products for Geostationary Operational Environmental Satellites (GOES).* Report to NOAA's National Climatic Data Center. Savoy, IL.
> Available at:
> http://www.centrec.com/resources/reports/GOES%20Economic%20Value%20Report.pdf

Tornado Warnings

Doppler radar plays a critical role in enabling NWS meteorologists to detect the formation of tornadoes before they touch down. The current generation of Doppler radars – the WSR-88D – were installed between 1992-1997, as part of the NWS modernization effort. All 120 radars now form a nationwide network called NEXRAD. The total base cost of NEXRAD installation was $1.8 billion (in 2007 dollars).

Over the 10 years following NEXRAD's full implementation (1998-2008), tornadoes caused 668 fatalities and 10,252 injuries nationwide. When comparing these figures to those resulting from tornadoes on record that occurred prior to NEXRAD, and while holding constant several other factors that determine tornado casualties, NEXRAD has reduced deaths and injuries by 34 percent and 45 percent, respectively. When applying values of statistical life and injury ($7.6 million per life and $76,000 per injury), the value of tornado casualties avoided in the 10-year period was almost $3.2 billion. NEXRAD yielded net benefits of $1.4 billion based only on reduced tornado casualties (all values in 2007 dollars).

> *Source:* Simmons, K.M., and D. Sutter. (2011). *Economic and Societal Impacts of Tornadoes*. Boston, MA: American Meteorological Society.

NOAA Supercomputers

Improved supercomputing capabilities are considered essential to NOAA's mission. A new supercomputer would be used to:

- sustain geophysical research programs;
- development and testing of national-scale and global-scale observing systems;
- air quality, ocean, and climate modeling; and
- parallel processing research as applied to real-time numerical weather prediction.

The enhanced capabilities produced by upgraded NOAA supercomputing equipment are expected to contribute 4.95 percent to overall weather forecasting improvements. Using base-case assumptions and average total benefits from various sectors, the share of economic benefits from improved forecasting that is directly attributable to a new supercomputer is valued at $116 million (in 2002 dollars). The net present value of the investment in a new NOAA supercomputer is estimated at $105 million (in 2002 dollars). The specific estimated benefits by economic sector are as follows:

Households: Many household decisions, such as those regarding recreation, commuting and other travel, home improvement, and shopping, depend on weather forecasts. The share of economic benefits to the household sector resulting improved forecasting that is directly attributable to a new NOAA supercomputer is valued at $69 million (in 2002 dollars).

Agriculture: Agricultural activities are very sensitive to climate and weather conditions. Both short-term and long-term forecasts are essential in production decisions, such as those related to planting, irrigation, fertilization, pesticide application, harvesting, drying, land use, and breed selection. The share of economic benefits to the agricultural sector resulting improved forecasting that is directly attributable to a new NOAA supercomputer is valued at $26 million (in 2002 dollars).

Public Safety: Although not all weather-related fatalities and injuries are likely to be preventable with improved forecasts, some portion of the total number of casualties could be reduced with better predictions, warning systems, and changes in behavior on the part of people receiving this information. Using a value of statistical life of $6 million per life, the potential benefits to general public safety resulting from improved forecasting attributable to a new NOAA supercomputer, as estimated by the authors, is $21 million (all values in 2002 dollars).

> *Source:* Lazo, J.K., J. S. Rice, and M. L. Hagenstad. (2010, Feburary). Benefits of Investing in Weather Forecasting Research: An Application to Supercomputing. *Yuejiang Academic Journal*, 2(1), 18-39.

Tsunami Warnings

The two NWS Tsunami Warning Centers, in collaboration with the U.S. Geological Service, provide rapid response and monitoring of rapidly evolving conditions associated with tsunamis. NWS collects and analyzes observational data from an international network of seismological observatories and sea level observing stations that operate on a cooperative basis. Observational data is also collected from NOAA’s Deep Ocean Assessment and Reporting of Tsunamis (DART) Buoy Network. The DART Buoy Network consists of 39 deep-water buoys located throughout the Pacific Ocean, Atlantic Ocean, and Caribbean. The centers use these data to prepare watches and warnings covering all U.S. territories and states bordering on the Pacific and Atlantic Ocean Basins and disseminate them to NWS Weather Forecast Offices, federal and state emergency management agencies, military organizations, private broadcast media, and other facilities that can distribute warning information to the public.

> *Source:* Office of Management and Budget. (2011). *President’s Budget Request for Fiscal Year 2012 Budget: National Weather Service*. Washington, DC. 691.

Following a 7.5 magnitude earthquake near the Aleutian Islands in November 2003, the NWS Pacific Tsunami Warning Center issued a tsunami watch in Hawaii and Alaska. Data from DART buoys showed the wave was not significant, and no warning was issued, thus saving Hawaii greater than $68 million in evacuation costs.

> *Source:* Meinig, C., Stalin, S.E., Nakamura, A.I. and H.B. Milburn. (2005, June 4). *Real-Time Deep-Ocean Tsunami Measuring, Monitoring, and Reporting System: The NOAA DART II Description and Disclosure*. Seattle, WA: NOAA's Pacific Marine Environmental Laboratory.
> Available at:
> http://nctr.pmel.noaa.gov/Dart/Pdf/DART_II_Description_6_4_05.pdf

Thanks go to Jennifer Sprague and Michael Bilder of the National Weather Service and Charlie Morris and Hillary Huffer of PPI for their work in the compilation and verification of the data in this report.

For questions, comments, or to verify additional statistics, please contact:

Hillary Huffer
Hillary.Huffer@noaa.gov
(301) 713-1622 x192

---

[i] The $921 million and $5.1 billion figures were calculated by NWS staff and do not directly correspond with the values reported in CENTREC's main findings. CENTREC's findings were inflated, since its industry-specific estimates (excluding those for improved hurricane forecasts) were based on cost-benefit analyses on GOES-R issued by the Department of Commerce in 2002 and 2004. These analyses assumed that both the new ABI and a Hyperspectral Environmental Suite (HES) sounder were going to be included on the GOES-R platform. In 2006, shortly before CENTREC's report was published, the HES sounder was excluded from the GOES-R platform. The exclusion of the HES sounder significantly alters the projected benefits of GOES-R, since its output would have accounted for a large share of the improvements. Based on estimates from experts who were very familiar with the GOES-R project, CENTREC breaks-down the share of benefits between the two instruments on page 93 of its report (see Table 60). Using these percentages, NWS staff was able to calculate more realistic estimates for each sector based only on those values directly attributed to the ABI components. As reported in Table 60, the sum present value of ABI-related benefits for the aviation, agriculture, energy and recreational boating sectors for 2015-2027 is $2.232 billion (in 2005 dollars). The earlier Department of Commerce cost-benefit analyses did not include benefits associated with improved hurricane forecasts and therefore were excluded from Table 60. The improved hurricane forecasts can be solely attributed to the ABI. According to CENTREC's calculations, the present value of the benefits resulting from improved hurricane forecasts over the course of 2015-2027 is $2.4 billion (in 2005 dollars). Therefore, the realistic sum present value of the 2015-2027 benefits to all of the sectors analyzed is $4.632 billion (in 2005 dollars). Please note that the total combined annual benefit for 2015 of $825 million (in 2005 dollars) was calculated using the same methodology. These values were then adjusted to 2011 dollars to yield the $5.1 billion and $91 million figures respectively. Each set of values reported for each sector was also modified to reflect the exclusion of the HES sounder.