Variations and Changes in Weather and Climate Extremes

Thomas R. Karl, L.H.D.
Director, National Climatic Data Center
Chair, U.S. Global Change Research Program

December 2012
Outline

• Climate-related activities
  – FY13 President’s Budget

• Motivation
  – Billion-dollar Disasters

• State of the Science
  – Climate Fundamentals
  – Heat and Cold Waves
  – Precipitation/flooding and drought
  – Snowstorms
  – Tornadoes

• Implications
NOAA’s National Climatic Data Center (NCDC):
Where are we? Who are we? What do we do?

- 160 Federal Employees
  - Alaska, Colorado, Hawaii, Maryland, Missouri, New York, North Carolina, Texas, Utah, Wisconsin
- 153 NCDC Headquarter Contractors
- 6 Regional Climate Centers
- 2 Cooperative Institutes
## Fiscal Year 2013 NOAA Climate-Related President’s Budget Request

<table>
<thead>
<tr>
<th>Activity</th>
<th>$ Millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitive Research Program</td>
<td>146.3</td>
</tr>
<tr>
<td>Climate Data and Information</td>
<td>13.0</td>
</tr>
<tr>
<td>Marine Ecosystems Climate Regimes and Ecosystem Productivity</td>
<td>1.8</td>
</tr>
<tr>
<td>Program Support</td>
<td>3.1</td>
</tr>
<tr>
<td>Laboratories and Cooperative Institutes</td>
<td>53.35</td>
</tr>
<tr>
<td>- Atlantic Oceanographic &amp; Meteorological Laboratory</td>
<td></td>
</tr>
<tr>
<td>- Air Resources Laboratory</td>
<td></td>
</tr>
<tr>
<td>- Chemical Sciences Division</td>
<td></td>
</tr>
<tr>
<td>- Global Monitoring Division</td>
<td></td>
</tr>
<tr>
<td>- Physical Sciences Division</td>
<td></td>
</tr>
<tr>
<td>- Geophysical Fluid Dynamics Laboratory</td>
<td></td>
</tr>
<tr>
<td>- Pacific Marine Environmental Laboratory</td>
<td></td>
</tr>
<tr>
<td>- Technology Transfer (Office of Research and Technology Applications)</td>
<td></td>
</tr>
</tbody>
</table>
## Fiscal Year 2013 NOAA Climate-Related President’s Budget Request

<table>
<thead>
<tr>
<th>Activity</th>
<th>$ Millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Climate Programs</td>
<td>135.5</td>
</tr>
<tr>
<td>- National Climatic Data Center</td>
<td></td>
</tr>
<tr>
<td>- Climate Data Records</td>
<td></td>
</tr>
<tr>
<td>- Climate Data Modernization Program</td>
<td></td>
</tr>
<tr>
<td>- Regional Climate Service</td>
<td></td>
</tr>
<tr>
<td>- Environmental Data Systems Modernization</td>
<td></td>
</tr>
<tr>
<td>- Earth Observing System (EOS)</td>
<td></td>
</tr>
<tr>
<td>- Cooperative Observer Network – Modernization (HCN-M)</td>
<td></td>
</tr>
<tr>
<td>- Local Warnings and Forecasts – Tropical Atmosphere Ocean (TAO)</td>
<td></td>
</tr>
<tr>
<td>- Climate Prediction Center</td>
<td></td>
</tr>
<tr>
<td>- National Weather Service’s Climate Services</td>
<td></td>
</tr>
<tr>
<td>- Comprehensive Large Array Data Stewardship System (CLASS)</td>
<td></td>
</tr>
<tr>
<td>- Jason-3</td>
<td></td>
</tr>
<tr>
<td>- Joint Polar Satellite System (JPSS) Climate Sensors</td>
<td></td>
</tr>
<tr>
<td>- High Performance Computing</td>
<td></td>
</tr>
</tbody>
</table>
The Nation Is Climate-Conscious... for Good Reason


Drought and Heatwaves

Hurricanes and Tropical Storms

Winter Storms and Crop Freezes

Flooding

Wildfires

Severe Local Storms

NOAA’s National Climatic Data Center
Example: Post-tropical Storm Sandy

- Over 100 lives
- Upwards of $40 billion
- What to expect in future?
- No one storm is "caused" by climate change, but all storms now happen in a changed context

U.S. Drought Spring-Summer 2011-12

- Spring-summer 2012 Heat & Drought
  - Early green-up
  - Followed by rapid deterioration of vegetation
  - Impacted primary corn & soybean regions
- Feedbacks between heat and drought likely to amplify extremes of both in U.S.

Based on Karl, T.K. et al. (2012). U.S. Temperature and Drought: Anomalies of Spring and Summer 2011-12 and trends. EOS
Are Recent Extreme Events Related to Climate Change?

> $1B DISASTERS in 2011
What causes the climate to vary and change?

- Natural fluctuations in solar output
  - Output from the sun
  - Orbital mechanics
- Changes in atmospheric composition
  - Heat-trapping gasses
  - Heat-absorbing and reflecting particles
- Changes in Earth’s reflectivity (albedo)
  - Clouds, land (ice, snow, land use), sea ice
- Important gaps in knowledge
  - Clouds-particulate interaction, complex feedbacks
Is climate changing and how do we know?

- We have observed changes in the drivers of global climate
  - Solar radiation
  - Carbon dioxide and other greenhouse gases
  - Human-generated micron-size particulates: “aerosols”
Is climate changing and how do we know?

- How are changes in the drivers affecting the climate?
  - Paleoclimate records give a geological context

Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change
Has global warming stopped?

Records Set This Decade

In 132-year period of record:

• 2010
  – Warmest year on record globally (tied with 2005)

• 2011
  – 11th warmest globally (tied with 1997)

• 2012
  – Likely to be in top 10 warmest globally
  – In the U.S.:
    • 2012 virtually certain to be warmest on record
    • July was warmest month on record
Has global warming stopped?

- Short-term cooling is possible within long-term warming
- Separating signal from noise requires long-term monitoring
  - Natural internal variability overshadows trends at the decade scale

NOAA’s National Climatic Data Center
The Changing State of the Climate

Updated from Bulletin of the American Meteorological Society, 2010-12

- Specific Humidity: 3 Datasets
- Air Temperature Near Surface (Troposphere): 7 Datasets
- Glaciers (Glacier Mass Balance): 4 Datasets
- Temperature Over Oceans: 7 Datasets
- Snow Cover (March-April, Northern Hemisphere): 2 Datasets
- Sea-Surface Temperature: 7 Datasets
- Sea Level: 7 Datasets
- Sea-ice: 3 Datasets
- Ocean Heat Content: 7 Datasets
- Land Surface Air Temperature Over Land: 5 Datasets
The index is sensitive to climate extremes in:
- Monthly maximum and minimum temperature
- Daily precipitation and runs of dry days
- Monthly Palmer Drought Severity Index: indicates too little or too much soil water
- Landfalling tropical storm and hurricane wind velocity
What’s Driving the Increase Since the 1970s?

- Extremes in Maximum Temperature
- Extremes in Minimum Temperature
- Drought Severity and Water Surplus
- Extremes in 1-Day Heavy Precipitation

All graphs are year-to-date (Jan – Nov) 1910 to 2012

NOAA U.S. Climate Extremes Index
http://www.ncdc.noaa.gov/extremes/cei/
Intensified Water Cycle

Hotter/Drier Conditions (Interior West)
- Heat Trapped by the Atmosphere Causes More Evaporation and More Precipitation
- Decrease in Rainfall
- Decreases in Snowfall Due to Warming Lead to Proportional Increases in Rainfall
- Earlier Peak Streamflow
- Increased Water Usage
- Reduction in Runoff
- Increased Severe Droughts
- Decrease in Late-Summer Water Flow with Increased Water Temperature

Hotter/Wetter Conditions (NE and Coasts)
- A Warmer Atmosphere Holds More Water Vapor, Which is Also a Heat Trapping Gas
- Increase in Rainfall From Heavy Precipitation Events Leads to Increased Flooding and Sediments
- Increased Water Used by Plants
- Increased Evaporation
- Increase in Water Temperature Over Time
- Increase in Sediment and Runoff

Changes Common to Both Regions
- More Severe Droughts Between Rains
- Decrease in Lake Ice
- Increased Potential Evaporation and Water Temperature

Adapted from National Climate Assessment unpublished work
Percent of the U.S. with much above normal 1-day heavy precipitation (>50.8mm)

A statistically significant increase in extremes

NOAA U.S. Climate Extremes Index
http://www.ncdc.noaa.gov/extremes/cei/
Precipitable Water Difference (Percent)


Adapted from Kunkel, K.E. et al., 2012 (In Review). Monitoring and Understanding Changes in Extreme Storm Statistics: State of Knowledge. BAMS.
Probable Max Precipitation

Theoretical Maximum Precipitation
(Washington, DC)

- TMP
  - Adjusted for Future Humidity Projections
- TMP
  - Adjusted for recent humidity trends
- TMP in currently used PMP

Inches vs. Duration (Hours)
Flooding and Precipitation

River-Flow Trends in Annual Maximum:
85-127 years ending 2008

Trends in Total Annual Precipitation:
1909-2008

Regional similarities between trends of annual precipitation, droughts, and extremes of river flooding

Drought

Widespread persistent drought

- 1930s (Central and Northern Great Plains, Northwest, Great Lakes)
- 1950s (Southern Plains, Southwest), 1980s (West, Southeast)
- First decade of the 21st century (West, Southeast)

Peterson, T. C. et al., 2012 (In Review).

Trends (% per century)

- 1900 to 2011: -0.1%
- 1930 to 2011: -10.0%
- 1971 to 2011: +31.6%
Projected Change (A2 Scenarios – “Higher Emissions”) in North American Precipitation (Late 21st Century)

15 Climate Models

Extreme Snowstorms

• Would changes in temperature and precipitation favor more or fewer extreme snowstorms?

• For the top 50 snowstorms during unusually warm, cool, dry and wet seasons, it varies:
  – E.g. Southern Plains much snowier when cool
  – Northern Plains much snowier when wet
- Although some ingredients that are favorable for severe thunderstorms have increased over the years, others have not
- Overall, changes in the frequency of environments favorable for severe convective storms have not been statistically significant
Tornadoes & Convective Storms
Wind Shear vs. Vertical Velocity–6km proximity values

Each cell is best viewed as a conditional probability

Kunkel, K.E., et al., 2012 (In Review). BAMS.
Assess the Earth’s Climate: International, National, Annual Assessments

International Assessments
- Fourth Assessment Report
- Fifth Assessment Report
- Special Report on Extremes

National Assessments
- Global Climate Change Impact in the United States 2009
- National Climate Assessment 2013
- Sustained Assessment Process

Annual Assessments
- State of the Climate
- Explaining Extremes
Are there tipping points or thresholds in the climate system we should be concerned about?

- **Tipping points**
  - Greenland ice melt, Arctic sea ice
  - Permafrost thaw, methane release

- **Thresholds**
  - Coral reefs – Ocean acidification & thermal stresses
  - Pine bark beetles – min temps
  - Invasive species
  - We know the thresholds for some species. E.g. 70-degree threshold for coldwater fish leading to decreasing habitat.

- **Potential areas of research**
  - Economic & ecosystems
    - Most systems, we don’t know threshold for disequilibrium

U.S. National Climate Assessment work in progress
DIGITAL COAST

Sea Level Rise Viewer

http://www.csc.noaa.gov/digitalcoast/tools/slrvviewer
Risk Modeling Framework

**RISK MODEL**
A tool that allows multiple risk-related modules to be used together to quantify known risks

**EVENT MODULES**
(e.g., frequency, intensity, track of extreme events)

- Datasets & Analysis
  - Obs & monitoring, e.g., CDRs, Normals, Trends
  - Historical/Predicted data

- Models
  - CFS, CMIP3,5, Ensemble Models, etc.
  - Heuristic Model Projections

**HAZARD MODULES**

- Temperature Extremes
- Storm Surge
- Precipitation Frequency & Amounts
- Wind Speeds

**VULNERABILITY MODULES**
(exposure of sectors)

- Public Health – Exposure to extreme heat
- Infrastructure – Exposure to storm surge
- Agriculture – Impact of water resources on crops
- Financial – Exposure of the insurance sector

**RISK MODULES**
(potential loss or gain)

- Ecosystem Services: Future impacts on fishing communities
- Financial: Return on investment to protect against storm surge
- Human Mortality and Morbidity: Loss of life and costs of extreme heat events

Open Source Platform: Ability to Combine Modules in a Common Format
Questions?