Climate Change and Extreme Events: What we know and what we can do

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Is it hot in here or is it just me?

Theoretically, records will always be broken, but the time between record events should increase.

Climate change is causing just the opposite:

• 15 of the last 17 years have each been the “warmest year on record”.
• April 2016 became the warmest April on record across the planet.
• April 2016 crushed the April 2015 record by 0.5 °F

→ July 2016 was the warmest month on record...EVER!
→ 2016 was the warmest year on record, by a large margin.
  → NASA: 0.99 °C (1.8°F) above 1951-80 average
  → NOAA: 0.94 °C (1.69°F) above 1901-2000 average

https://youtu.be/s3RWTTtPg8E
But isn’t this all just part of natural climate variability on planet Earth?

Source: https://www.britannica.com/science/Little-Ice-Age
But isn’t this all just part of natural climate variability on planet Earth?

→ We are already at a level not seen in ~ 1 million years!

Source: USGCRP, Karl et al, 2008
But isn’t this all just part of natural climate variability on planet Earth?

➔ And it will only get worse…

Source: USGCRP, Karl et al, 2008
Climate change is happening and humans are the predominant cause.

The Intergovernmental Panel on Climate Change (IPCC AR5, 9/27/13):

- it is “unequivocal” that Earth’s climate is warming.
- Since the 1950’s, it is “extremely likely” that human emission have been the dominant cause of the rise in global temperature.

But how do they know that?


Upsetting the natural Carbon balance.
Things don’t appear to be getting better

Fossil fuel emission (GtC per year)

Small changes in an average value can result in larger changes in the extremes.

A changing climate leads to changes in:

- Frequency
- Intensity
- Spatial extent
- Duration
- Timing

of extreme weather and climate events, and can result in unprecedented extreme weather and climate events. (IPCC SREX, 2011)
Presidentially declared disasters

Event frequency (US) vs. Event Frequency (NE)

Legend:
- Blue diamonds: US
- Red squares: New England
### Billion dollar disasters in the US: Type, frequency and cost

<table>
<thead>
<tr>
<th>Disaster Type</th>
<th>Number of Events</th>
<th>Percent Frequency</th>
<th>CPI-adjusted Losses ($ billions)</th>
<th>Percent of Total Loss</th>
<th>Average Event Cost ($ billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>21</td>
<td>12.4</td>
<td>199</td>
<td>19.1</td>
<td>9.5</td>
</tr>
<tr>
<td>Flooding</td>
<td>19</td>
<td>11.2</td>
<td>86</td>
<td>8.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Freeze</td>
<td>7</td>
<td>4.1</td>
<td>25</td>
<td>2.4</td>
<td>3.6</td>
</tr>
<tr>
<td>Severe Storm</td>
<td>65</td>
<td>38.2</td>
<td>143</td>
<td>13.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Tropical Cyclone</td>
<td>34</td>
<td>20.0</td>
<td>530</td>
<td>50.9</td>
<td>15.6</td>
</tr>
<tr>
<td>Wildfire</td>
<td>12</td>
<td>7.1</td>
<td>26</td>
<td>2.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Winter Storm</td>
<td>12</td>
<td>7.1</td>
<td>35</td>
<td>3.4</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Table 1: Damage cost statistics from U.S. Billion-dollar disaster events (1980-2013) reflecting number of events, event frequency, CPI-adjusted loss (present year), percent of total losses and average event cost

**Source:** Smith, A.B., and J. L. Matthews, 2015. Quantifying uncertainty and variable sensitivity within the US billion-dollar weather and climate disaster cost estimates, Nat Hazards (2015) 77:1829–1851
Many circumstances must come together for a hurricane to form:

- Sea surface temperature (SST) at least 26.5°C (80°F) → warm SST most expansive in September
- Atmospheric temperature profile that supports thunderstorm development (T-storms are the “seeds” of most hurricanes)
- High humidity in the troposphere
- At least 300 miles from the equator for Coriolis effect to cause spin
- Low vertical wind shear (surface winds vs upper winds)

Source: http://www.hurricanescience.org/science/science/hurricanegenesis/
Hurricane impacts now & in the future

So why are these hurricane-based disasters becoming more costly?
Well…. It’s complicated!

One the one hand, models have gotten much better at forecasting hurricane tracks ...

….but forecasting hurricane intensification (strengthening) has not improved much since 1990 (Emanuel, 2017)

On the other hand, more of us are living in more vulnerable places and we have more stuff!

→ global population exposed to hurricanes has gone up 3X between 1970 and 2010 (Peduzzi et al., 2012)

→ Accounting for inflation and population change, per capita wealth has increased by 1.5X between 1979 and 2005 (Pielke et al., 2008)
Dramatic increases in population of US coastal counties

No trend in normalized damage 1900-2005

The future could look quite different

Figure 3 | Estimated storm surge level as a function of return period for Tampa in the climate of 1980–2005 (based on 2,100 events), 2006–2036 (3,100 events), 2037–2067 (3,100 events), and 2068–2098 (3,100 events) projected using each of the six climate models for the IPCC AR5 RCP8.5 emission scenario. The annual frequency (f) is noted for each case. The thin dash curves show the 90% statistical confidence interval. (The data points and goodness of fit for the upper tail are shown in Supplementary Fig. 1.)

Source: Grey swan tropical cyclones, Ning Lin and Kerry Emanuel, 2016. Nature Climate Change, 6: 107-112. DOI: 10.1038/NCLIMATE2777
So what does this all mean for us here in coastal Massachusetts?
CLIMATE READY BOSTON

Results from Boston Research Advisory Group (BRAG)

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Robyn Hannigan, PhD
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www.climateready.boston.gov
CLIMATE RISK FACTORS

Sea Level Rise
Coastal Storms
Extreme Precipitation
Extreme Temperatures
COASTAL STORMS

Hurricanes…not frequent in New England
• Intensification is complex and not perfectly understood
• No scientific consensus yet on how climate change will affect hurricanes in the future…a fascinating debate!
• But, according to Emanuel (2005; 2007):
  → there has been strong increase in the destructive power of hurricanes (PDI)
  → PDI related to increase in sea surface temperatures (SST).

Nor’easters…much bigger influence in New England (2-3 per year)
• Not as easy to classify and study as hurricanes, hence much less research
• An area of active research now.
  → From what has been done, there is as yet no evidence of significant changes in magnitude or frequency
  → Some evidence of northward migration of storm tracks
  → Some evidence expansion of extratropical storm season.
Thermal expansion of ocean water was the biggest contributor to 20th century sea level rise.

20th Century Global Mean Sea Level Rise (GMSLR)

- Thermal expansion of ocean water
- glaciers: 0.9 ± 0.4 mm/yr
- Antarctica: 0.3 ± 0.1 mm/yr
- Greenland: 0.3 ± 0.1 mm/yr
- Impoundment & groundwater: 0.4 ± 0.1 mm/yr
- Relative sea level rise: 1.1 ± 0.3 mm/yr

→ Thermal expansion of ocean water was the biggest contributor to 20th century sea level rise.
Future potential contributions to GMSL rise

- Ice sheet dynamics and mass loss will be biggest factor later in century

SEA LEVEL RISE

21st Century GMSLR

- Greenland: 7m
- West Antarctic Ice Sheet: 5m
- East Antarctic Ice Sheet: 52m

→ Ice sheet dynamics and mass loss will be biggest factor later in century

IPCC AR5 2013
Ice Sheet "fingerprints"

- The effects of melting Ice Sheets is more than just added water volume.
Greenland: 36% less SLR at Boston

E Antarctica: 5% more at Boston

W Antarctica: 24% more at Boston!
SEA LEVEL RISE

GREENHOUSE GAS EMISSIONS REDUCTIONS IMPACT FUTURE SEA LEVELS IN BOSTON

LOW EMISSIONS SCENARIO (MAJOR EMISSIONS REDUCTION)

RELATIVE SEA LEVEL RISE* IN FEET (ABOVE 2000)

MEDIUM EMISSIONS SCENARIO (MODERATE EMISSIONS REDUCTION)

HIGH EMISSIONS SCENARIO (BUSINESS AS USUAL)

* Relative sea level rise is the change in sea level resulting from a combination of increases in ocean height and decreases in land surface elevation ("subsidence").

Data Source: BRAG Report
Now for some good news!

The US has learned some lessons from previous disasters (NYTimes, Sept 12, 2017)

• 9/11/2001 forced government agencies to coordinate disaster response
• Hurricane Katrina highlighted the threat of major flooding events
• Building codes greatly improved in FL after Hurricane Andrew in 1992
• Medical centers upgraded in Houston after Hurricane Allison in 1978
• Loss of life in US disasters has been greatly reduced
The United States Climate Alliance: States united for climate action (https://www.usclimatealliance.org/)

In response to the U.S. federal government’s decision to withdraw the United States from the Paris Agreement on climate change, Governors Andrew Cuomo, Jay Inslee, and Jerry Brown created The United States Climate Alliance. This bi-partisan coalition of states is committed to the goal of reducing greenhouse gas emissions consistent with the goals of the Paris Agreement. Smart, coordinated state action can ensure that the United States continues to contribute to the global
Boston and the Commonwealth lead the nation in climate change initiatives

Massachusetts Global Warming Solutions Act of 2008

- Reduce GHG to 25% below 1990 emissions by 2020 (at 21% reduction now)
- Reduce GHG by at least 80% by 2050 (on Tues, Gov. Baker pledged carbon neutrality by 2050)
- 205 MA communities have adopted the Board of Building Regulations and Standards (BBRS) Stretch Code, as of June 19, 2017
- Market transition to renewable energy as dominate fuel by 2050
  - 800+ solar hot water systems installed since 2011 (1200 MTCO\textsubscript{2} saved)
  - anticipate an economy-wide GHG reductions in 2020 of 1.0 MMTCO\textsubscript{2} (1.1% of 1990 levels)
Speaking of electricity consumption

Regional Greenhouse Gas Initiative (RGGI): the nation’s first mandatory multi-state program to reduce power sector CO₂ emissions (began 2009)

• Reduce CO₂ cap by 2.5% per year, thereby reducing overall emissions over time
• Invest savings into energy efficiency and reduced bills
• 2014 comprehensive over report states:
  → $1.37 billion in RGGI proceeds have been invested in energy efficiency, clean and renewable energy, greenhouse gas abatement, and direct bill assistance.
  → RGGI investments are projected to return $4.67 billion in lifetime energy bill savings to 4.6 million participating households and 21,400 businesses.
  → Energy efficiency and clean energy have made up the largest shares of RGGI investments. Efficiency has been widely proven to be one of the most cost-effective ways to reduce pollution while encouraging growth.

Boston Climate Action Plan

Boston’s Resilience Challenge

Boston has prioritized improving water management while fostering social cohesion and equality.

Source: http://www.100resilientcities.org/cities/boston/
Some of the things we’re doing in the School for the Environment at UMass Boston

Track 1: Investigate social and institutional vulnerability (TBHA, East Boston)

Track 2: Investigate infrastructure vulnerability (MassDOT, BWSC, Massport)
Track 1...
Coastal Flooding and Environmental Justice:
Identifying Vulnerable Communities and Feasible Adaptation Strategies for the Boston Metro Area
Legend

- 2100 100-Year Flood 14.5 feet MSL

Sources: ESRI, MassGIS

Figure 5 - 100-Year Flood Inundation in 2100
Lower Emissions Scenario
East Boston, Massachusetts

Coastal Flooding and Environmental Justice: Developing Strategies for Adapting to Climate Change
Expectation
Hate
Greed
Species Migration
Death of Species
Economy
Extinction of
End of Human Nation
Wor
East Boston Adaptation

- **Protection:** “hard” (sea walls) or “soft” (beach/dune) measures
  - combination of the two most likely. Lots of constraints (ie., DPA, densely urbanized).

- **Accommodation:** “floodproofing” of homes and buildings
  - residents can’t afford this on their own; many are residents are rentors, not property owners.

- **Temporary evacuation:**
  - Current plan inadequate, facilities flooded, tunnel access, no place to go.

- **Retreat:**
  - Absolutely not an option for East Bostonians
Preparedness Planning in East Boston
Workshops to work out values and options
ClimateCARE
Climate: Community Action for Resilience through Engagement in East Boston, Massachusetts

Proposal for Implementation Phase Funding

submitted by
NOAH
Neighborhood of Affordable Housing Inc.
East Boston, Massachusetts

to the
Kresge Foundation
Climate Resilience and Urban Opportunity Initiative

September 28, 2015
Track 2...
MassDOT-FHWA Pilot Project: Climate Change and Extreme Weather Vulnerability Assessment and Adaptation Options for the Central Artery/Tunnel System Boston, Massachusetts
MHHW + 7.5 ft.
Vent Building 1
Causes of flooding

Tropical Storms
- Data set provided by Kerry Emanuel, MIT
- Select storms based on storm surge index
- Increased storm intensities for 21st century based on climate models

Extra-Tropical Storms
- Data set developed by examining Boston tidal residual water levels
- Re-analysis data used to feed a balanced wind model

- A Large Statistically robust set of storms.
- No need to determine joint probabilities.
Hydrodynamic modeling
Flood exceedance probabilities
Flood exceedance probabilities
1% Flood depths
Good News and Bad News

The good news:

- Extent of flooding under current conditions is fairly limited with low exceedance probabilities. This allows MassDOT to focus their efforts on reducing the vulnerability of individual Structures and on local adaptation strategies.
- Regional adaptation can prevent flooding in some areas

The bad news:

- Vulnerable Structures under current conditions include some Tunnel Portals; the number of vulnerable Portals triples by 2070.

The plan:

- Currently field verifying results and recommendations.
- Developing strategies for prioritizing and implementing adaptation approaches over short and long term.
In Conclusion…
Things we know about climate change

- Human greenhouse gas (GHG) emissions are the main cause of the warming that we’ve observed since 1880.
- Even small changes in the average of a climate process (ie., temp, rain) means bigger changes at the extremes.
- Reducing GHG emissions now will reduce impacts later in the century, so accelerate mitigation.
- Our emissions history has embedded change into the climate system, so we need to adapt.
- If we ignore the changing climate, our future plans and designs will be wrong.
What is the role of climate change in disasters?

Extreme events will always happen, but more frequently and more powerfully as the climate changes.

For those we’ve experienced, climate change is pouring salt into a deep wound we have created for ourselves.

- Floodplain and coastal development
- Social and economic inequities
- Sane and sustainable development
- Energy use and policy

Making progress on “low hanging fruit” but the hard decisions await.
Thank You!