Hurricane Variability

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Program

- Natural variability of Atlantic Hurricanes
- Hurricanes and global warming
Global Tropical Cyclone Frequency, 1980-2013

Data Sources: NOAA/TPC and NAVY/JTWC
Number of Atlantic Tropical Cyclones

Year

Number of Named Storms

10-year running average
3% chance of run of 7 or more years with no major U.S. landfalls, if process is random (Poisson)
Hurricanes and Climate Change
Atlantic Storm Maximum Tropical Cyclone Power Dissipation during an era of high quality measurements, 1970-2011 (smoothed with 1-3-4-3-1 filter)
Atlantic Storm Maximum Tropical Cyclone Power Dissipation and Sea Surface Temperature during an era of high quality measurements, 1970-2011 (smoothed with 1-3-4-3-1 filter)

Aug-Oct Atlantic SST vs Power Dissipation

$r^2 = 0.87$
Use Linear Regression to Predict Power Dissipation back to 1870 based on SST:
Now Compare to Observed Storm Maximum Power Dissipation

Predicted vs Observed Atlantic Power Dissipation

$r^2 = 0.60$
Analysis of satellite-derived tropical cyclone lifetime-maximum wind speeds

Box plots by year. Trend lines are shown for the median, 0.75 quantile, and 1.5 times the interquartile range.

Trends in global satellite-derived tropical cyclone maximum wind speeds by quantile, from 0.1 to 0.9 in increments of 0.1.

Paleotempestology

Source: Jeff Donnelly, WHOI
The hurricane eyewall is a front, attaining scales of ~ 1 km or less.

At the same time, the storm’s circulation extends to ~1000 km and is embedded in much larger scale flows.

The computational nodes of global models are typically spaced 100 km apart.
Histograms of Tropical Cyclone Intensity as Simulated by a Global Model with 50 km grid point spacing. (Courtesy Isaac Held, GFDL)

Global models do not simulate the storms that cause destruction
Solution:
Embed a very simple hurricane model, coupled to the ocean, inside climate models

- Coupled Hurricane Intensity Prediction System (CHIPS) developed at MIT during 1990s
- Has been used to make real-time forecasts of tropical cyclone intensity globally since late 1990s
Disclaimer: The tropical cyclone objective aids displayed on this website are collected from multiple forecast centers and may or may not be the most current data available to the operational forecast centers. The MIT tropical meteorology group obtains these forecasts for research purposes and assumes no responsibility for their use in the forecasting of tropical cyclones. Concerned individuals or organizations should confirm these forecasts with official sources.

http://wind.mit.edu/~emanuel/storm.html
How Can We Use This Model to Help Assess Hurricane Risk in Current and Future Climates?
Risk Assessment Approach:

- **Step 1**: Seed each ocean basin with a very large number of weak, randomly located cyclones.

- **Step 2**: Cyclones are assumed to move with the large scale atmospheric flow in which they are embedded, plus a correction for beta drift.

- **Step 3**: Run the CHIPS model for each cyclone, and note how many achieve at least tropical storm strength.

- **Step 4**: Using the small fraction of surviving events, determine storm statistics.

Synthetic Track Generation:
Generation of Synthetic Wind Time Series

- Extract winds from climatological or global climate model output

- Postulate that TCs move with vertically averaged environmental flow plus a “beta drift” correction

- Approximate “vertically averaged” by weighted mean of 850 and 250 hPa flow
Comparison of Random Seeding Genesis Locations with Observations

Random Seeding

Observations
Calibration

- Absolute genesis frequency calibrated to globe during the period 1980-2005
Cumulative Distribution of Storm Lifetime Peak Wind Speed, with Sample of 1755 Synthetic Tracks
Captures effects of regional climate phenomena (e.g. ENSO, AMM)
Sample Storm Wind Swath

Track number 7940, September
Return Periods

New England

Wind Speed (knots)

Return Period (years)

- Theory
- Synthetic events
- 59 Best tracks, 1900 - 2007
Storm Surge Simulation

SLOSH mesh
~ $10^3$ m

ADCIRC mesh
~ $10^2$ m

Battery

ADCIRC model
(Luettich et al. 1992)

SLOSH model
(Jelesnianski et al. 1992)

ADCIRC mesh
~ 10 m

(Colle et al. 2008)
5000 synthetic storm tracks under current climate. (Red portion of each track is used in surge analysis.)
Taking Climate Change Into Account
Downscaling of AR5 GCMs

- GFDL-CM3
- HadGEM2-ES
- MPI-ESM-MR
- MIROC-5
- MRI-CGCM3

**Historical:** 1950-2005, **RCP8.5** 2006-2100
Global annual frequency of tropical cyclones averaged in 10-year blocks for the period 1950-2100, using historical simulations for the period 1950-2005 and the RCP 8.5 scenario for the period 2006-2100. In each box, the red line represents the median among the 5 models, and the bottom and tops of the boxes represent the 25\textsuperscript{th} and 75\textsuperscript{th} percentiles, respectively. The whiskers extent to the most extreme points not considered outliers, which are represented by the red + signs. Points are considered outliers if they lie more than 1.5 times the box height above or below the box.
Change in track density, measured in number of events per $4^\circ \times 4^\circ$ square per year, averaged over the five models. The change is simply the average over the period 2006-2100 minus the average over 1950-2005. The white regions are where fewer than 4 of the 5 models agree on the sign of the change.
Global Tropical Cyclone Power Dissipation

![Box plot showing the distribution of power dissipation index over time from 1955 to 2095. The x-axis represents the year, and the y-axis represents the power dissipation index. The box plots indicate the interquartile range and the median, with the error bars showing the range of data.](image-url)
Change in Power Dissipation
Return Periods based on GFDL Model

Peak Wind within 100 km of New Haven, CT

- **Historical**
- **RCP8.5**

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<th>Peak Wind Speed (Knots)</th>
<th>Return Period (Years)</th>
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<tr>
<td>120</td>
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Return Periods of Storm Total Rainfall at New Haven
GFDL Model

![Graph showing return periods of storm total rainfall at New Haven using GFDL Model.](image)
GCM flood height return level
(assuming SLR of 1 m for the future climate)

Blue: A1B future climate (2081-2100)
Red: A1B future climate (2081-2100) with $R_0$ increased by 10% and $R_m$ increased by 21%

Lin et al. (2012)
Projections of U.S. Insured Damage

GFDL CM2.0

Global hurricane frequency is stable, and not well understood

Most destruction in U.S. done by major hurricanes at landfall

Low numbers: no possibility of seeing climate signal; no possibility of seasonal forecasting

Consensus that global warming will increase incidence of high intensity hurricanes, and cause more hurricane-related flooding