Using Physics to Help Assess Tropical Cyclone Risk

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Program

- Limitations of the actuarial approach
- A physics-based approach
- Coupling to ADCIRC to assess surge risk
Hurricane Risks:

- Wind
- Rain
- Storm Surge

- Drowning (F): Fresh Water
- Drowning (S): Salt Water
- Wind
- Tornado
- Other: Aircraft accidents, hypothermia, electrocution, ...

Total = 589

Limitations of the Actuarial Approach

From Pielke and Landsea

<table>
<thead>
<tr>
<th>Category</th>
<th>Total Damage (in $10^{11} 2004 U.S. Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>4.0</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Total Number of Landfall Events, by Category, 1870-2004

The bar chart shows the total number of landfall events by category from 1870 to 2004. Category 1 has the highest number of events, followed by Category 2, with a significant decrease in the number of events for higher categories.
Limitations of a strictly statistical approach to hurricane risk assessment

- >50% of all normalized U.S. hurricane damage caused by **top 8 events**, all category 3, 4 and 5
- >90% of all damage caused by storms of category 3 and greater
- Category 3, 4 and 5 events are only 13% of total landfalling events; only 30 since 1870
- ∴ **Landfalling storm statistics are inadequate for assessing hurricane risk**
Risk Assessment by Direct Numerical Simulation of Hurricanes: The Problem

- 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.
Numerical convergence in an axisymmetric, nonhydrostatic model (Rotunno and Emanuel, 1987)
How to deal with this?

Embed high-resolution, fast coupled ocean-atmosphere hurricane model in GCM or reanalysis data
Time-dependent, axisymmetric model phrased in R space

\[ M = rV + \frac{1}{2} fr^2 \quad \frac{1}{2} fR^2 \equiv M \quad f \equiv 2\Omega \sin \theta \]

- Hydrostatic and gradient balance above PBL
- Moist adiabatic lapse rates on M surfaces above PBL
- Boundary layer quasi-equilibrium convection
- Deformation-based radial diffusion
- Coupled to simple 1-D ocean model
- Environmental wind shear effects parameterized
Angular Momentum Distribution

Altitude (km)

z (km)

Radius (km)

Storm Center
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 the earth’s rotation and sphericity.

- **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. Can easily generate 100,000 events.

Comparison of Random Seeding Genesis Locations with Observations
Cumulative Distribution of Storm Lifetime Peak Wind Speed, with Sample of 1755 Synthetic Tracks

Annual Exceedence Frequency

Maximum Wind Speed (knots)

211 Best tracks, 1990 to 2005
1755 Synthetic tracks

90% confidence bounds
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)
Sandy: ~400 years
Taking Climate Change Into Account
Captures effects of regional climate phenomena (e.g. ENSO, AMM)
GCM flood height return level, Battery, Manhattan
(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)
A Black Swan: Dubai

Max Surge (NCEP track237; Dubai: 3.45 m)
Black Swan Affecting Tampa
cnrma1b2081_2100tampasurgeal
Track number 261, August 16, 08:00 GMT
Peak Surge at each point along Florida west coast
History is too short and imperfect to estimate hurricane risk

Better estimates can be made from downscaling hurricane activity from climatological or global model output

Hurricanes clearly vary with climate and there is a risk that hurricane threats will increase over this century