Tracking and Nowcasting of Hurricanes

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Tropical Storm Ernesto Heading for Yucatan Peninsula

Landfall is expected as a hurricane CAT1

Source: Weather.com

Source: NOAA/NCDC (Lott and Ross, 2006)

<table>
<thead>
<tr>
<th>DISASTER TYPE</th>
<th>NUMBER OF EVENTS</th>
<th>PERCENT FREQUENCY</th>
<th>NORMALIZED DAMAGES (Billions of Dollars)</th>
<th>PERCENT DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical Storms/Hurricanes</td>
<td>16</td>
<td>28.0%</td>
<td>102</td>
<td>29.2%</td>
</tr>
<tr>
<td>Non-Tropical Floods</td>
<td>12</td>
<td>21.0%</td>
<td>55</td>
<td>19.8%</td>
</tr>
<tr>
<td>Heatwaves/Droughts</td>
<td>10</td>
<td>17.0%</td>
<td>144</td>
<td>41.2%</td>
</tr>
<tr>
<td>Severe Weather</td>
<td>7</td>
<td>12.0%</td>
<td>13</td>
<td>3.7%</td>
</tr>
<tr>
<td>Fires</td>
<td>6</td>
<td>10.0%</td>
<td>13</td>
<td>3.7%</td>
</tr>
<tr>
<td>Freezes</td>
<td>2</td>
<td>3.5%</td>
<td>6</td>
<td>1.7%</td>
</tr>
<tr>
<td>Blizzards</td>
<td>2</td>
<td>3.5%</td>
<td>9</td>
<td>2.6%</td>
</tr>
<tr>
<td>Ice Storms</td>
<td>2</td>
<td>3.5%</td>
<td>5</td>
<td>1.4%</td>
</tr>
<tr>
<td>Noreaster</td>
<td>1</td>
<td>1.5%</td>
<td>2</td>
<td>0.7%</td>
</tr>
</tbody>
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Source: NOAA/NCDC (Lott and Ross, 2006)
Dynamical, statistical and dynamical-statistical models used for hurricane track forecasting vary significantly in structure and level of complexity. Previous studies show that different modeling techniques have their own advantageous and disadvantageous (e.g., NHC, 2009).

In recent years, ensemble (consensus) models have become more popular. Ensemble models are obtained by combining the forecasts from a number of models or multiple simulations from a model with different parameterization, initial condition, etc.

Decision makers, however, may need to know which ensemble member is more likely to be true, particularly when the ensemble is spread out over a wider area.
Motivation: Hurricane Rita

For example, Nasrollahi et al., 2012 showed that differences of a 20-member ensemble of Hurricane Rita at landfall were nearly 3 degrees.

Hurricane Tracking Using Expert Advice Algorithm

Ensemble Response Using Expert Advice (EA) Algorithm

For $k=1$ to $K$ ensemble members:

$$\lambda(\omega, \gamma) = \sum_{o \in \Omega} (\gamma(\omega) - \delta_{\omega}(\gamma(\omega)))^2 \delta_{\omega} \in \{1, 0\}$$

\[ w_0^1, w_0^2, ..., w_0^K = 1 \]

\[ \phi_n(\omega) = -\ln \left( \sum_{k=1}^{K} w_{n-1}^k \times e^{-\lambda(\omega, \gamma_n^k)} \right) \]

Solve $\sum_{\omega \in \Omega} (s - \phi_n(\omega))^+ = 2$, $s \in \mathbb{R}$

Set $\gamma_n(\omega) = \frac{(s - \phi_n(\omega))^+}{2} \omega \in \Omega$

$\gamma_n \in \text{Pr}(\Omega)$

\[ w_n^k = w_{n-1}^k \times e^{-\lambda(\omega_n, \gamma_n^k)} \]

\[ E_0^1, E_0^2, ..., E_0^K = 0 \]

Ensemble Members $k$: $\gamma_n^k \in \Gamma$

Climate Response: $\gamma_n \in \Gamma$

Observation: $\omega_n \in \Omega$

$E_n = E_{n-1} + \lambda(\omega_n, \gamma_n)$

$E_n^k = E_{n-1}^k + \lambda(\omega_n, \gamma_n^k)$

$k = 1, 2, ..., K$
Hurricane Tracking: Emily 2005

Source: National Hurricane Center (NHC), NOAA
Acknowledgement: Hurricane track observations and model simulations are provided by James Francklin of the NOAA, National Hurricane Center (NHC)
Hurricane Tracking: Rita 2005

Source: National Hurricane Center (NHC), NOAA
Hurricane Tracking: Nate 2005

Source: Weather Underground
Hurricane Tracking: Nate 2005

- Observation
- Ensemble Mean
- Weighted Average
- EA Algorithm
- Ensembles

Latitude vs Longitude chart showing the progression and prediction of Hurricane Nate 2005.
Hurricane Tracking: Rita 2005

Error of Hurricane Track

Error (Distance in Degree)

Time Steps

- Error EA
- Error Mean
- Error Weight

Source: Hydroclimate Research Lab, Department of Civil & Environmental Engineering, University of California, Irvine
Predictability and Nowcasting

Predictability of EA Algorithm and Nowcasting
Emily 2005: Prediction after 10 steps

- Observation
- Ensemble Mean
- Weighted Average
- EA Algorithm
- Ensembles

Latitude vs. Longitude
Predictability and Nowcasting

Emily Error Plot

Error (Distance in Degree)

Time Step

EM Error
WA Error
EA Error
EA05 Error
EA10 Error
EA15 Error

Hydroclimate Research Lab, Department of Civil & Environmental Engineering, University of California, Irvine
Mean error of hurricane tracking using ensemble weighted average (WA) and expert advice (EA) algorithm methods in degree distance from observations

<table>
<thead>
<tr>
<th></th>
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<th>WA 10</th>
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<th>EA 10</th>
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<tbody>
<tr>
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A data fusion technique (Expert Advice Algorithm) is used to derive the response of ensemble hurricane simulations.

The results showed that merging simulations using the EA algorithm leads to less error compared to ensemble mean and weighted average in hurricane track analysis.

Overall, the EA algorithm was superior to the arithmetic mean and weighted average of ensemble simulations. This indicates that the EA algorithm can be used in real-time for nowcasting of hurricane tracks as simulations become available.