New ensemble-based products for tropical cyclones

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Why uncertainty products?

Paraphrasing Vice President Joe Biden:

“Barack, if you lived in this city, then knowing the uncertainty would be a big *&^%ing deal.”
There are existing NHC uncertainty products, but they are primarily based on average statistics of past forecast errors.

### Intensity (Maximum Wind Speed) Probability Table

**Hurricane Ike Advisory Number 31**  
5:00 PM EDT Sep 8 2008

<table>
<thead>
<tr>
<th>Wind Range (mph)</th>
<th>12 hour for 2 AM Tue</th>
<th>24 hour for 2 PM Tue</th>
<th>36 hour for 2 AM Wed</th>
<th>48 hour for 2 PM Wed</th>
<th>72 hour for 2 PM Thu</th>
<th>96 hour for 2 PM Fri</th>
<th>120 hour for 2 PM Sat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissipated &lt;1%</td>
<td>&lt;1%</td>
<td>1%</td>
<td>1%</td>
<td>2%</td>
<td>11%</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>Tropical Depression (&lt;39)</td>
<td>1%</td>
<td>&lt;1%</td>
<td>3%</td>
<td>2%</td>
<td>9%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Tropical Storm (39-73)</td>
<td>22%</td>
<td>15%</td>
<td>32%</td>
<td>19%</td>
<td>16%</td>
<td>17%</td>
<td>26%</td>
</tr>
<tr>
<td>Hurricane (all categories)</td>
<td>76%</td>
<td>84%</td>
<td>65%</td>
<td>79%</td>
<td>79%</td>
<td>63%</td>
<td>46%</td>
</tr>
<tr>
<td>-- Category 1 (74-95)</td>
<td>59%</td>
<td>59%</td>
<td>46%</td>
<td>40%</td>
<td>28%</td>
<td>19%</td>
<td>19%</td>
</tr>
<tr>
<td>-- Category 2 (96-110)</td>
<td>14%</td>
<td>19%</td>
<td>14%</td>
<td>23%</td>
<td>22%</td>
<td>16%</td>
<td>11%</td>
</tr>
<tr>
<td>-- Category 3 (111-130)</td>
<td>2%</td>
<td>5%</td>
<td>4%</td>
<td>13%</td>
<td>21%</td>
<td>18%</td>
<td>10%</td>
</tr>
<tr>
<td>-- Category 4 (131-155)</td>
<td>&lt;1%</td>
<td>1%</td>
<td>1%</td>
<td>3%</td>
<td>7%</td>
<td>8%</td>
<td>5%</td>
</tr>
<tr>
<td>-- Category 5 (&gt;155)</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Forecast Maximum Wind</td>
<td>90 mph</td>
<td>90 mph</td>
<td>85 mph</td>
<td>100 mph</td>
<td>110 mph</td>
<td>115 mph</td>
<td>110 mph</td>
</tr>
</tbody>
</table>
“Cone of uncertainty”
Are we ready for ensemble-based products?

• Ensembles still exhibit systematic errors
  – Global models under-forecast hurricane intensity
  – Ensemble spreads often too small – direct use may result in overconfidence in forecasts.

• Still...
  – There are methods such as statistical post-processing to ameliorate the errors.
  – Forecasters, media, emergency users want the products, even if imperfect.
  – It makes sense to start planning for a future with ensemble-based products.
And we are getting better.

As models and ensemble techniques improve, ensemble predictions will increasingly be used to improve hurricane forecasts.

Still, there are not that many tropical cyclone forecast products that leverage the uncertainty estimates produced by ensembles.
The remainder of the presentation will summarize recommendations from this workshop.
Recommendations for products oriented toward forecasters

- Intensity and intensity change
- Cyclogenesis
- Structure
- Track
- Associated phenomena (storm surge, winds, rainfall, tornadoes).
- Locations for supplemental adaptive observations.

Non forecasters may be interested in the same products, but given early stage with these products, may be wise to put “experimental” disclaimer statement if made widely available.
Augment track products with intensity-related information

Analyzed ocean tropical cyclone heat potential (TCHP), forecast central pressure (mb-900) and vertical wind shear are shown.

Permits visualization of co-variations, e.g., central pressure’s relation to TCHP, shear.
Time series of variables that may be related to intensity, displaying mean, 20\textsuperscript{th} & 80\textsuperscript{th} percentiles (white lines) and min/max from ensemble (blue).

In this case, the min in central pressure at 51 h appears to be related to a decrease in vertical shear.
Incorporate ensemble information into LGEM (Logistic Growth Eqn. Model)

\[ \frac{dV}{dt} = \kappa V - \beta V \left( \frac{V}{V_{mpi}} \right)^n \]

\[ \kappa = a_1 \cdot S + a_2 \cdot C + a_3 \cdot SC + b \]

V = forecast velocity
V_{mpi} = maximum potential intensity (a function of SST at forecast position)
S = 850-200 shear (normalized)
C = 0-15 km average vertical velocity from plume model using SST, temperatures and humidity in a 200 to 800 km ring around storm.
Red are parameters of the model, fit using reanalysis data, an adjoint algorithm, and steepest descent algorithm.

Ref: DeMaria, MWR, January 2009
LGEM intensity “forecast” (fit with dependent reanalysis data and observed track info)

When trained after the fact on environmental analysis data from Frances, the reconstructed intensity is very accurate.

(But of course less accurate when trained on data across many storms and feeding real-time forecast information, with its biases).

Ref: ibid
Possible ensemble improvements to LGEM

• Provide ensemble of tracks and environmental forecasts to LGEM, resulting in ensemble of intensity forecasts.

• If large data set of past forecasts (reforecasts) are available from same model run operationally:
  – Statistically adjust forecasts for systematic errors (in position, in thermodynamic profiles, etc.)
  – Possibly train LGEM on forecast data as opposed to analysis data (i.e., MOS instead of perfect-prog).
Tropical cyclogenesis

Uses TCgenesis from reforecasts to provide some calibration for possible biases.

Ref: D. Richardson, personal communication, ECMWF.
Other recommendations for new ensemble products for cyclogenesis, storm structure, storm surge, winds, rainfall, tornadoes in slides after conclusions.
Innovations here:

(1) Cone of uncertainty estimated directly from ensemble (contains 90% of probability).

(2) Lagged forecast track data shown in lighter grey colors, provides sense of trends in track.
Recommendations for/from media, emergency managers, end users.

- Keep it simple! Perhaps red/yellow/green confidence levels on deterministic forecasts.
- Desire some products similar to but simpler than those for forecasters.
- Associated explanatory web pages to accompany new graphics.
- Train product recipients, possibly by COMET.
Conclusions

• Several possible new ensemble-based graphics shown here.
• We welcome your input concerning other possible new graphics that will be useful to the community.
• BAMS draft article at tinyurl.com/4t6onm4
Other cyclogenesis recs.

• Include tracker output of model-generated storms and genesis probabilities estimated from the ensemble in geographical areas, especially at the 48-hour and 120-hour lead times.

• Examine whether a statistical model of genesis (Schumacher et al. 2009) incorporating ensemble genesis information might provide skillful guidance.
Storm structure products

• Ensemble averages of the radius of the outermost closed isobar (OCI), which provides one possible measure of overall storm size.

• Ensemble-mean predictions of 34, 50, and 64-kt (15.4, 25.7, and 32.9 ms\(^{-1}\)) wind radii in different quadrants, where the ensemble of storms is relocated to a common position.

• Probability distributions of the OCI and wind radii might also be useful.
Targeted observations

- Ensemble-based techniques may be useful for determining the most useful locations for supplemental observations.
- Typically, an ensemble-based targeting algorithm considers how much the forecast uncertainty (usually measured in this case as some function of the ensemble spread, i.e., the standard deviation about the mean) would be reduced as a result of the reduction in analysis-error variance in an ensemble due to the assimilation of extra data.
- Techniques are promising but are limited in their utility by the lack of calibration of the ensemble and the assumption of linear error growth (Majumdar et al. 2006; Reynolds et al. 2010).
Storm surge, winds, rainfall, tornadoes

- Storm surge probabilities might be generated by driving surge models like SLOSH (Sea, Lake, and Overland Surges from Hurricanes; Houston et al. 1999) with ensemble guidance.
- Post-processed ensemble guidance may provide improved estimates of precipitation from land-falling TCs.
- Statistical models may also make it possible to estimate tornado likelihood based on the environmental characteristics.
- Additional probabilistic forecasts could be generated for winds above critical thresholds such as tropical-storm or hurricane-strength and could provide information on the timing (onset, duration).