Tropical Cyclone Intensity Forecasting: Still a Challenging Proposition

Daniel Brown
National Hurricane Center
April 20, 2017
What do we mean by Intensity?

Maximum sustained winds:

*Strongest* wind speed *averaged during a 1-minute period* at an altitude of *10 m (33 ft)*, associated with the circulation of the tropical cyclone at a given point in time.

- Central pressure is correlated with intensity, but pressure-wind relationship has variability.
- Max wind speed usually estimated, rarely directly measured.
More Data for Land-Threatening TCs

No Threat to Land
Mostly Satellite Data

Threat to Land
More Data

Hurricane Irene
21-28 August 2011
120 mph

Hurricane Irene
21-28 August 2011
120 mph

Hurricane Michael
3-11 September 2012

Wind Speed (kt)

Date (Month/Day)
Determine the Official Intensity

- Subjective Dvorak: \[115 / 102\] kt
- Objective ADT: \[130\] kt
- SFMR surface wind: \[103\] kt
- Recon sfc-adjusted flight-level wind: \[119\] kt
- Dropsonde surface value: \[111\] kt
- Drop sfc-adjusted WL150: \[118\] kt
- Drop sfc-adjusted MBL: \[111\] kt

- OFCL at 0600 UTC: \[110\] kt

We can only sample a part of the TC
Each observation has strengths and weaknesses
We want a value that is representative of the TC’s circulation
Typical Intensity & Size Uncertainty

Since there are insufficient observations of surface wind in tropical cyclones:

- Intensity estimates are believed to be good to within 10%
- Tropical storm wind radii (size estimate) are believed to be good to within 25% and hurricane wind radii to within 40%

A 100 mph hurricane could have maximum winds of 90 mph or 110 mph.
Intensity Forecast Considerations

• Much more complex forecast problem than track
  – Involves interactions between thunderstorms in the core, the environment, and atmosphere-ocean interactions

• Important factors
  – Track
  – Wind, temperature, and moisture patterns in the core and the near environment
  – Internal processes, such as eyewall replacement cycles, that are poorly understood
Factors Affecting Tropical Cyclone Intensity

• Upper Ocean Temperatures
  More heat favors a stronger storm

• Interaction with Land/Topography
  More land increases weakening

• Vertical Wind Shear
  Shear limits strengthening

• Moisture in Storm Environment
  Dry air can limit strengthening

• Structural Changes, Eyewall Replacement
  Difficult to forecast and not straightforward

• Interactions with other weather systems
Tropical Cyclone Intensity Statistical Models

• Decay SHIFOR
  – **Statistical Hurricane Intensity FOREcast** with inland decay.
    • Based on historical information - climatology and persistence (uses CLIPER track).
    • Baseline for skill of intensity forecasts
Tropical Cyclone Intensity Statistical-Dynamical Models

• SHIPS and DSHIPS:
  – Statistical Hurricane Intensity Prediction Scheme:
    • Based on climatology, persistence, and statistical relationships to current and forecast environmental conditions (with inland decay applied in DSHIPS)

• LGEM
  – Logistic Growth Equation Model:
    • Uses same inputs as SHIPS, but environmental conditions are variable over the length of the forecast (SHIPS averages over the entire forecast)
    • More sensitive to environmental changes at the end of the forecast, but also more sensitive to track forecast errors.

Example of SHIPS Model Output

Hurricane Geogette 2016 (EPAC)

SHIPS forecasts often miss peak intensity during rapid intensification periods
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FORECAST TRACK FROM OFCI
INITIAL HEADING/SPEED (DEG/KT): 25/8
T-12 MAX WIND: 40
GOES IR BRIGHTNESS TEMP. STD DEV. 50-200 KM RAD: 23.8 (MEAN=14.5)
% GOES IR PIXELS WITH T < -20 C 50-200 KM RAD: 67.0 (MEAN=65.0)
PRELIM RI PROB (DV .GE. 30 KT IN 24 HR): 14.8
Dynamical Models:

- HWRF, HMON, CTCI, GFS, ECMWF, UKMET
- Based on the present and the future by solving the governing equations for the atmosphere (and ocean).
- These models are of limited use, because of...
  - Sparse observations
  - Inadequate resolution; the HWRF and HMON our highest-resolution operational hurricane models
  - Incomplete understanding and simulation of basic physics of intensity change
  - Problems with representation of shear
Tropical Cyclone Intensity
Dynamical Hurricane Models

• HWRF
  – Hurricane Weather Research and Forecast System
  – Moving nests of 18, 6, and 2 km
  – Coupled with the Princeton Ocean Model
  – Uses GSI 3D VAR data assimilation

• HMON - New for 2017 (Replaces GFDL)
  – Hurricanes in a Multi-scale Ocean coupled Non-hydrostatic model
  – Moving nests (same resolution as HWRF)
  – Will be coupled to other (ocean, waves, surge, inundation, etc.) models, but not in 2017
  – No data assimilation for 2017
Tropical Cyclone Intensity
Consensus and Ensemble Models

• **ICON**
  - Consensus by averaging Decay-SHIPS, LGEM, and HWRF – All must be available

• **IVCN**
  - Consensus that requires at least 2 of the following: Decay-SHIPS, LGEM, HWRF, and CTCI

• **Florida State Superensemble (FSSE)**
  - Consensus that uses dynamical models and the previous NHC forecast. FSSE learns from past performances of its members in a “training phase”, then accounts for the model biases.

• **HFIP Corrected Consensus Approach (HCCA)**
  - FSSE approach adapted to NHC operations using a slightly different set of input models than FSSE.
NHC Official Intensity Forecast

- Persistence is used quite a bit, especially for short-term forecasts.

- Obvious signs in the environment, i.e. cooler waters, increasing upper-level winds, are taken into account.

- Tends to be conservative; *extreme events are almost never forecast.*

- For forecasts 24 h and beyond, the average error is roughly 1 SSHWS Category (about 15 kt)
Intensity errors increase for the first 2-3 days and then level off.

Forecast Intensity Errors
NHC 5-Year Averages
Intensity errors increase for the first 2-3 days and then level off.

Forecast Intensity Errors
NHC 5-Year Averages
2016 Intensity Guidance

Among the consensus aids, IVCN was a little better than HCCA and FSSE.

DSHP and LGEM were skillful but not as good as consensus aids or HWFI, CTCI.

GFSI was competitive at 48 h and beyond.

GFNI, GHMI, and EMXI trailed.

Official forecasts skillful at all times, near or better than the top models.
NHC Intensity Error Distribution

Most of the errors are small.

NHC OFCL 48-h Intensity Forecasts
Atlantic Basin 2012-16

Number of Forecasts

Forecast Error (kt)

TOO LOW  TOO HIGH
Difficulty Predicting Rapid Changes in Intensity

The center of Matthew is exposed to the southwest of the deep convection due to moderate southwesterly shear. Given the current shear and structure of Matthew, only slight strengthening is predicted during the next 24 hours.

NHC Discussion 11 am Thursday, September 29, 2016

The center of Matthew is exposed to the southwest of the deep convection due to moderate southwesterly shear. Given the current shear and structure of Matthew, only slight strengthening is predicted during the next 24 hours.

Forecaster Brown

Tropical Storm Matthew – 70 mph
8:00 am September 29
Difficulty Predicting Rapid Changes in Intensity

36 hours later
Hurricane Matthew
Category 5 – 165 mph

Tropical Storm Matthew – 70 mph
8:00 am September 29
First NHC forecast and models predicted intensification but not to the rate that was observed.
Hermine’s Intensification

- NHC intensity forecasts were conservative during the first couple of days of the depression’s existence.
- Hurricane Watch issued a little more than 48 h before the arrival of TS-force winds along the coast.
  - System was a 35-mph tropical depression at the time
Hermine strengthened from a 35-mph tropical depression to a 80 mph hurricane in a little more than 48 hours.

SHIPS Rapid Intensification Index a helpful tool?

<table>
<thead>
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<th>Prob RI for 25kt/24hr RI threshold=</th>
<th>35% is 3.0 times sample mean (11.6%)</th>
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<tbody>
<tr>
<td>Prob RI for 30kt/24hr RI threshold=</td>
<td>21% is 3.0 times sample mean (7.2%)</td>
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<td>Prob RI for 35kt/24hr RI threshold=</td>
<td>12% is 2.9 times sample mean (4.2%)</td>
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<td>Prob RI for 40kt/24hr RI threshold=</td>
<td>9% is 3.3 times sample mean (2.8%)</td>
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# RI Guidance
## Hurricane Patricia (2015 - East Pacific)

* EAST PACIFIC SHIPS INTENSITY FORECAST *
* IR SAT DATA AVAILABLE, OHC AVAILABLE *
* PATRICIA EP202015 10/22/15 18 UTC *

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** 2013 E. Pacific RI INDEX EP202015 PATRICIA 10/22/15 18 UTC **
( 30 KT OR MORE MAX WIND INCREASE IN NEXT 24 HR )

- 12 HR PERSISTENCE (KT): 40.0 Range: -22.0 to 38.5 Scaled/Wgted Val: 1.0/ 2.2
- 850-200 MB SHEAR (KT): 6.4 Range: 18.7 to 1.4 Scaled/Wgted Val: 0.7/ 1.0
- POT = MPI-VMAX (KT): 54.3 Range: 40.3 to 141.7 Scaled/Wgted Val: 0.1/ 0.1
- STD DEV OF IR BR TEMP: 4.4 Range: 38.9 to 2.4 Scaled/Wgted Val: 0.9/ 1.0
- Heat content (KJ/cm2): 61.6 Range: 3.6 to 75.9 Scaled/Wgted Val: 0.8/ 0.7
- D200 (10**7s-1): 104.2 Range: -11.0 to 135.3 Scaled/Wgted Val: 0.8/ 0.6
- % area w/pixels <-30 C: 100.0 Range: 41.4 to 100.0 Scaled/Wgted Val: 1.0/ 0.5
- 850-700 MB REL HUM (%): 71.2 Range: 57.6 to 96.8 Scaled/Wgted Val: 0.3/ 0.0

Prob of RI for 25 kt RI threshold= 87% is 6.3 times the sample mean(13.1%)
Prob of RI for 30 kt RI threshold= 87% is 11.5 times the sample mean( 8.7%)
Prob of RI for 35 kt RI threshold= 87% is 16.7 times the sample mean( 6.0%)
Prob of RI for 40 kt RI threshold= 87% is 23.3 times the sample mean( 4.3%)
Rapid Intensification
Hurricane Patricia (2015 - East Pacific)

FORECAST POSITIONS AND MAX WINDS

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24 h

115 kt

180 kt
Intensity Guidance for Invests

- Nearly all of the guidance models (SHIPS, LGEM, HWRF) assume that the system already has the structure of a tropical cyclone, which often leads to a high bias in the intensity guidance.

- Guidance can have lots of run to run variability.

- SHIPS diagnostic information can be useful to determine large-scale environment, but forecast environmental conditions highly dependent on the forecast track which is often very uncertain before formation.
Intensity guidance for invests can also be unreliable!

HWRF intensity guidance for pre-Hermine invest (AL99)
18-28 August 2016
Intensity guidance for invests can also be unreliable!

SHIPS model intensity guidance for pre-Hermine invest (AL99)
18-28 August 2016
Concluding Remarks

- Intensity forecasting is not as advanced as track forecasting.
- There is less skill for intensity forecasting than there is for track forecasting.
- Current guidance is provided mainly by DSHIPS, LGEM, HWRF, IVCN and more recently, FSSE, HCCA, and in 2017 HMON
- We still have significant difficulty in forecasting rapidly intensifying and rapidly weakening storms.
- The main hope for the future lies in improved dynamical models, coupled with enhanced observations and understanding of the hurricane’s inner core. (HFIP)
- GOES-16 will provide new imagery and lightning data for dynamical and statistical-dynamical intensity models