Operational Storm Surge Modeling

HFIP Annual Meeting
November 17th, 2020
NHC Storm Surge Unit

Laura Alaka  
laura.alaka@noaa.gov

Andrew Penny  
andrew.penny@noaa.gov
Hurricane Laura

How Might Storm Surge Inundation Have Been Different Had Hurricane Laura Made Landfall 20 Miles Farther West?

- 3 to 5 feet lower
- 1 to 3 feet lower
- No Significant Difference
- 1 to 3 feet higher
- 3 to 5 feet higher
- 5 to 10 feet higher
- 10 to 15 feet higher
- Inundation not mapped for levee area

Sources: Earl, HURR, Garmin, NOAA, USGS; © OpenStreetMap contribution, and the SS User Community

hurricanes.gov/surge
Introduction to Probabilistic Storm Surge

- **P-Surge** is based on an ensemble of Sea, Lake, and Overland Surge from Hurricane (SLOSH) model runs
  - SLOSH: numerical-dynamic tropical storm surge model
  - SLOSH requires bathymetry and is applied to a ‘basin’
  - SLOSH requires meteorological driving forces: “Wind model is just as important– if not more so– as a surge model” (Jelesnianski et al. 1992)

- **P-Surge** ensemble incorporates uncertainty using a statistical method based on NHC historical errors of:
  - Cross track (landfall location, # members varies) attempts to encompass 90% of cross track uncertainty
  - Along track (forward speed, 7 members)
  - Intensity (3 members)
  - Storm size (RMW, 3 members)

2017090900 P-Surge Tracks

@NHC_Surge
P-Surge Upgrade v2.8
Improvements to initial storm structure

- v2.7: RMW derived from SLOSH parametric wind profile often resulted in P-Surge ensemble failing to encompass observed storm size

- v2.8: improvement when 3-member P-Surge storm size ensemble (small, medium, and large storms) initialized from Best track RMW
P-Surge Retrospective Runs

- 13 storms between 2008-2018: Spans the period of USGS pressure sensors
- Evaluation Methodology:
  - Determine landfall advisory
  - Determine advisory when the 12-, 24-, 36-, 48-, 60-, 72-hr forecast points first came closest to the landfall point (the 60-hr was approximated)
- Evaluated the >3, >6, >9 ft NAVD88 probability fields from P-Surge
Which Thresholds to Evaluate?

>3 ft NAVD88: Common flooding, can extend beyond hurricane impact area (862/981)

>6 ft NAVD88: Significant flooding, greater than watch/warning threshold (450/981)

>9 ft NAVD88: Extreme flooding, confined to a small area (125/981)

USGS Stormtide Sensors: all available deployed sensors

NOAA tide station data: subjectively chosen relative to hurricane impact area, and must reference NAVD88
Forecast/Observation Pairing
Cumulative Probability > 9ft NAVD88
36 hours prior to Hurricane Sandy’s landfall

Battery NOAA tide station,
Observation: 11.28 ft NAVD88
Forecast: 24%, 53%

P-Surge v2.7
P-Surge v2.8
P-Surge advisories 36-hours prior to landfall

- v2.8 more frequently forecasts higher probabilities of >9ft NAVD88, especially for Sandy and Ike, and is more reliable
- v2.7 is overforecasting during Irma

Interpreting Reliability Diagrams:
How well do the forecast probabilities of an event (e.g. >9ft of Storm Surge) correspond to their observed frequencies?
Irma: 12-hours prior to landfall

Initial RMW: 28 n mi
Initial Intensity: 115 kts

v2.7

Initial RMW: 10 n mi
Initial Intensity: 115 kts

v2.8
v2.8 increases the detection without increasing the false alarms for a given forecast probability.

Interpreting ROC Curve:
Is the forecast able to discriminate between events and non-events?
P-Surge advisories 72-hours prior to landfall

- Improvement still needed with respect to 72-hour P-Surge advisories
- Relatively low probability of detection

Interpreting ROC Curve:
Is the forecast able to discriminate between events and non-events?

P-Surge 2.8  AUC=0.69
P-Surge 2.7  AUC=0.65
RMW Forecasts from current P-Surge Ensemble

- RMW forecast is ONLY a function of the initial RMW
- leads to inconsistencies in storm size when initial RMW is close to “bin” boundaries
RMW Forecasts

- consensus and corrected consensus forecasts based on global/hurricane models are skillful at longer lead times, but are too noisy
- RMW forecasts based on NHC OFCL forecast parameters have highest skill and are more consistent

RMW Regression Forecasts:

- $R_{34}$
- $R_{50}$
- $R_{64}$
RMW Climatology
BEST track times within +/- 120 minutes of aircraft reconnaissance from 2001-2019

- large amount of variability in the relationship between intensity and RMW from case to case

RMW vs intensity

Hurricane Matthew (2016)

Hurricane Jose (2017)
RMW Forecast Verification (2015-2019)

- **P-Surge v2.8**: improvement in storm structure when using BEST track RMW to initialize P-Surge

- **RMW forecasts** have lower MAE beyond 24 h and less negative bias

- Improvement in skill for RMW forecasts will help efforts to extend lead time of reliable/skillful P-Surge forecasts
Plans for future improvements
Extend reliability of storm surge forecasts to 72 h lead time

- evaluate skill/reliability of retrospective P-Surge forecasts that use RMW regression forecasts to generate storm size ensemble
- couple SLOSH + waves and integrate into P-Surge with code optimization
- add the capability to account for storms with an asymmetric wind structure
- incorporate dynamic uncertainty information when generating P-Surge ensemble
- extend operational storm surge modeling to Pacific regions (Southern California, Guam, and American Samoa)
Questions?
Extra Slides
Updated error characteristics for P-Surge

Average (5-yr) NHC OFCL track and intensity errors are used to create the P-Surge ensemble (2014-2019)

Previously, separate errors used for TDs, TSs, and HUs
- limited sample size for TDs
- error characteristics for H1 different from H5!

Errors now separated by initial intensity:
< 50 kt, 50-95 kt, > 95 kt
RMW Regression Forecasts

- although RMW corrected consensus forecasts based on GFS/COAMPS-TC/HMON/HWRF are skillful at longer lead times, large fluctuations in forecast RMW are not ideal for operational forecasting
Initial RMW: P-Surge vs. BEST track

2014-2018

RMW vs. Intensity

Minimum Pressure vs. Intensity

BEST RMW method

P-Surge RMW method
Example RMW Forecasts
Hurricane Jerry (2019) AL102019

P-Surge v2.8

- RMW forecast is ONLY a function of the initial RMW

RMW Regression Forecast
RMW₀, Intensity, latitude, R₃₄, R₅₀, R₆₄
P-Surge RMW Ensemble Verification

- using RMW regression forecasts to generate P-Surge storm size ensemble better encapsulates true RMW