Probabilistic Storm Surge (P-Surge) in 2015 and Beyond

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NWS/OSTI/MDL

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Background

As part of its mission to save lives and protect property, the National Weather Service (NWS) issues tropical storm surge forecasts within the National Hurricane Center's (NHC) advisory package. To provide guidance for those forecasts, NWS' Meteorological Development Laboratory (MDL) created the Sea Lake and Overland Surges from Hurricanes (SLOSH) model in the 1980s (Jelesnianski et al. 1992).

The SLOSH model was designed to be computationally efficient so it could be used operationally and tied to NHC's forecast. Thus its input parameters:

- the position of the storm,
- the radius of maximum winds and
- the difference between the atmospheric pressure at the center of the storm and the ambient (or peripheral) atmospheric pressure can be derived directly from NHC's advisory package.

While SLOSH has been used to generate deterministic storm surge guidance, the value of such guidance is hindered by the fact that slight errors in the advisory can result in considerable variations in storm surge model results. Thus deterministic storm surge guidance is not very useful until landfall (Figure 1)

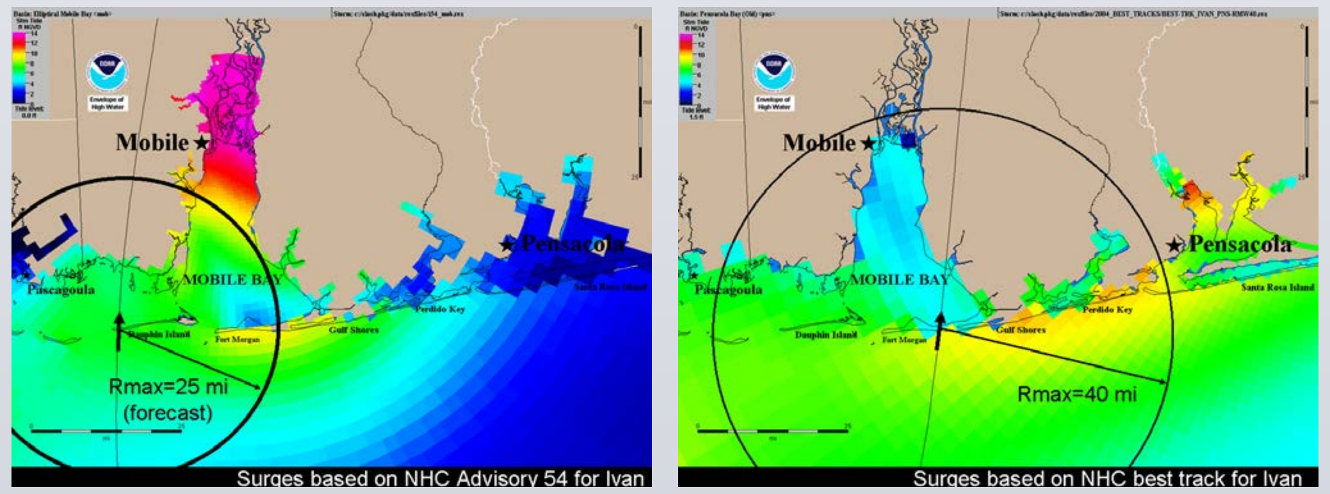


Figure 1. (left) SLOSH storm surge forecast for Hurricane Ivan (2004) made 12 hours before landfall. (right) SLOSH storm surge hindcast created with the best available information for Hurricane Ivan (2004). The color bar in the upper left indicates surge height in feet. In 2004 the mean Cross track error at landfall was 19 nmi for the 12-hour and in 2014 was 14 nmi.

Due to the limitations of deterministic storm surge guidance, MDL originally developed the probabilistic tropical cyclone storm surge (P-Surge) model between 2003 and 2008 to produce probabilistic guidance. In 2014, MDL overhauled the system by introducing gridded tide predictions amongst other improvements. MDL continues to enhance P-Surge in support of NWS' mission to produce storm surge forecasts.

Methodology

The P-Surge model is an ensemble of SLOSH model runs, where each ensemble member's input is derived from the current NHC hurricane forecast along with the associated 5 year average errors. Specifically the cross track, along track and intensity error distributions are derived by assuming a normal error distribution and assigning the 5 year mean absolute error to 0.7979 sigma.

Once the error distributions are established, ensemble members are created. This could be done by a Monte Carlo method, but to avoid missing key permutations, a prohibitively large number of storm surge model runs would be needed. Instead P-Surge samples the various error spaces an d assigns appropriate weights.

Ensambling - Methodology

Cross Track Error Sampling:

- Cross track sample cover 90% of the area (± 1.64 sigma) under the normal distribution.
- To be dense enough, the storms were chosen to be one radius of maximum winds (Rmax) apart from each other at the 48 hour forecast projection. (See Figure 2).

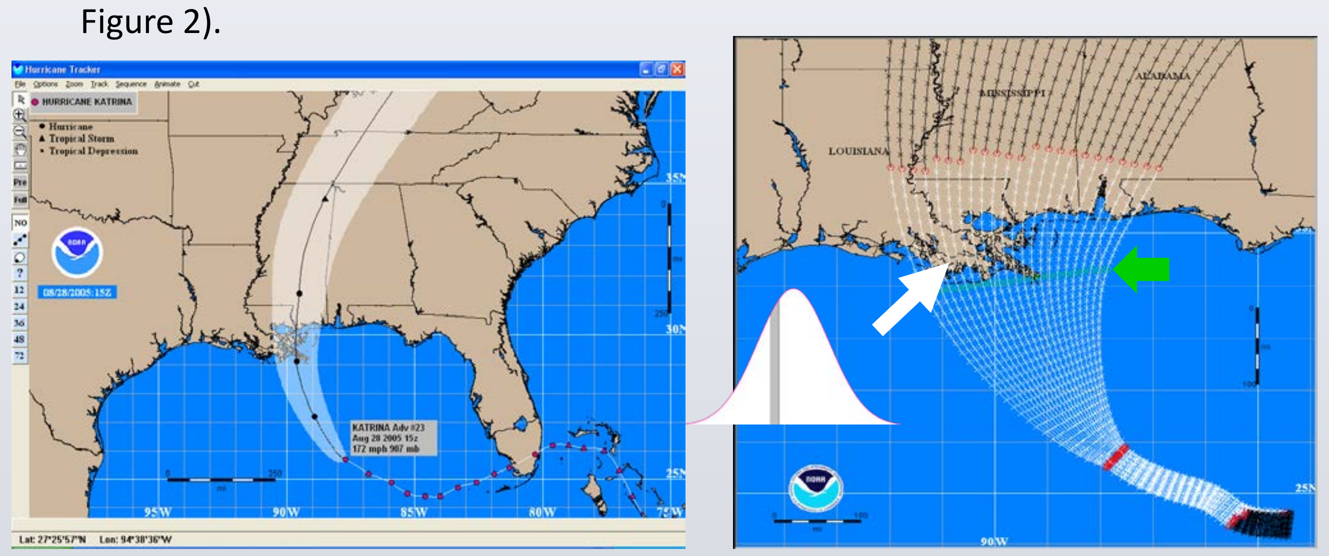


Figure 2. (left) Katrina Advisory 23. (right) Example hypothetical storm tracks for Hurricane Katrina (2005) advisory 23. The tracks cover 90% of the normal distribution, and are sampled in such a way that the distance between storms at the 48-h forecast projection is the same as the 48-h Rmax forecast. The green arrow is the 48-h forecast locations.

Along Track and Intensity Error Sampling:

- Along Track (aka Speed) errors and Intensity errors are each sampled three times. One at the average (40%) and one each at + 1.0 sigma (30%.). (Figure 3)

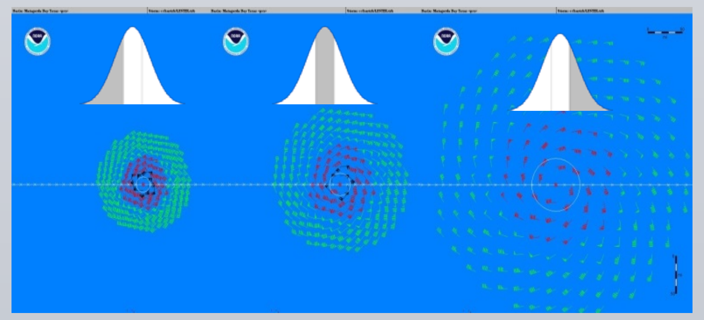
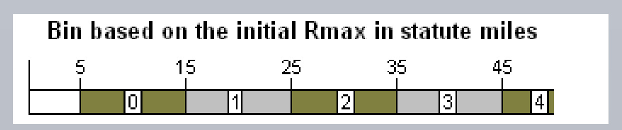


Figure 3. (left to right) Size: Small (30%), Medium (40%), Large (30%); Forward Speed: Fast (30%), Medium (40%), Slow (30%); Intensity: Strong (30%), Medium (40%), Weak (30%)

Size Error:

The size error is bounded, so can't assume a normal distribution. Instead error distributions were established for five initial size conditions. Those errors were then sampled three times similar to the Along Track and Intensity manner.

The result is the number of ensemble members is X*3*3*3 where X depends on the density of the cross track sampling. The weight of each member is the product of the weight of each error sample (e.g. 0.1 * 0.3 * 0.4 * 0.3 = 0.0036).



P-Surge 2014

Improvements to P-Surge:

- New SLOSH basins: from NGVD-29 to NAVD-88, Utilizes latest bathymetrc and topographic data (Figure 6)
- Include tide component in each ensemble member, as a result gives a more accurate overland inundation (Figure 4)
- Increases the number of samples of the forward speed error (from 3 to 7)
- Needs to make 100-h "tideOnly" runs in each basin for hours -20 to +80
- Above Ground Level (AGL) products in addition to datum products (Figure 6).

Include time component for AGL products at 6 hour time steps (0 to 78 hour) :

Datum products: Maintain dissemination of cumulative (0-80 hours) probabilities

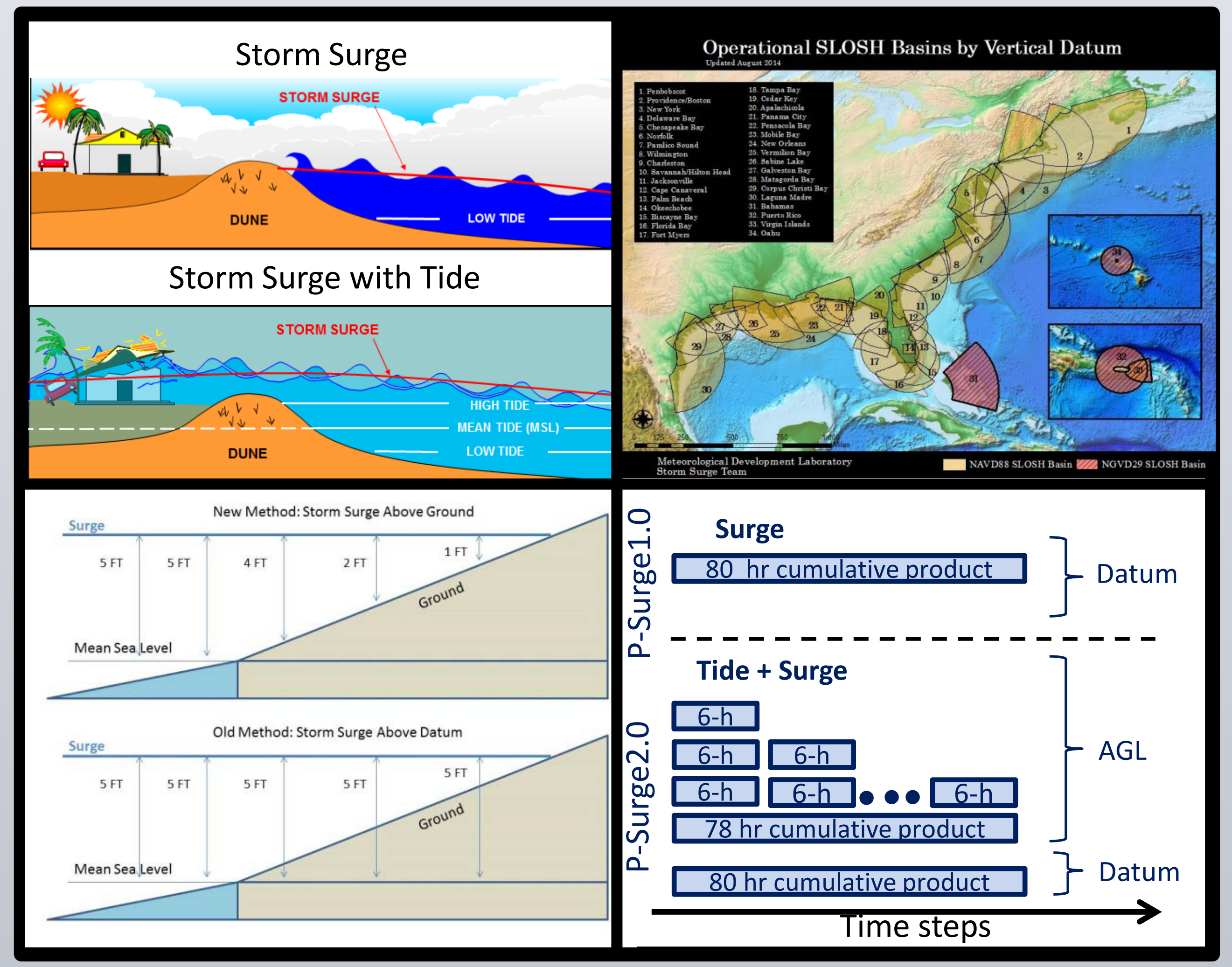


Figure 6. P-Surge 2.0 enhancements

P-Surge 2015

The Enhancements for 2.5 :

- Provides NHC outputs to 2.5 km CONUS grid to enable AWIPS to quickly load the national grid and to assist with storm surge watch/warning.
- Provides NWPS and RFC's with better temporal resolution (1-hr vs 6-hr)
- Provides 10, 20, 30, 40, 50% exceedance above datum in 1-hourly (vs 6-hourly) increments through 78 hours .
  - 1 hour data adequately resolve the tidal and peak surge water levels

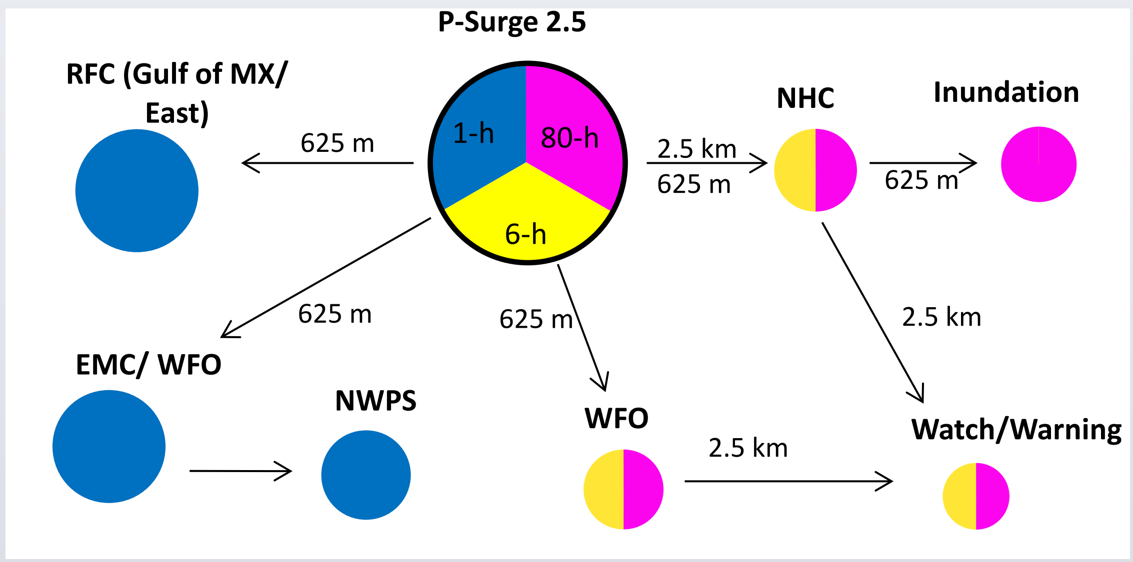


Figure 8. P-Surge 2.5 users, 1-hour, 6-hour, 80 hour resolution

Future Plans (P-Surge 2016 and Beyond)

P-Surge 2.6 (for 2016 hurricane season):

- Extend forecast to 102-hr (vs 78-hr) and use 24-hr (vs 20-hr) hind-cast (2.6)
  - Add one smaller probability product (5% exceedance level) (2.6)
- Handle weaker tropical storms

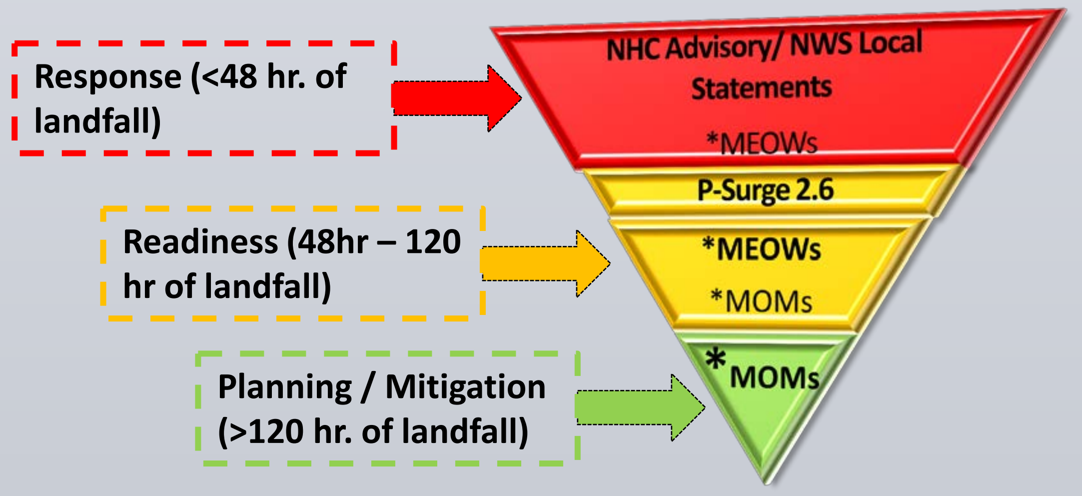


Figure 9. Surge Guidance 120 hour to landfall Timeframe.

Beyond:

- Nest tropical basins
- Incorporate newer SLOSH basins as they become operational
- Ability to run two storms
- Move to wave dominated areas (Adding waves to SLOSH)
- Investigate other parametric wind models
- Investigate other probabilistic ensemble methods

Product Generation

P-surge model products:

1. **Probability of Surge**: The probability of storm surge greater than X feet.
   Ex: Probability of > 4 ft is 60%
1. **Exceedance Height:** The surge value in feet which is exceeded by Y%.
   Ex: Height exceeded by 60% of storms = 4(.6 < .2 + .4 + .1)

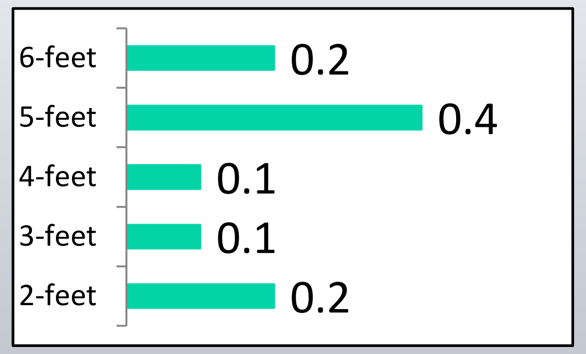


Figure 4. Example of storm values with surge (ft.) and respective weights

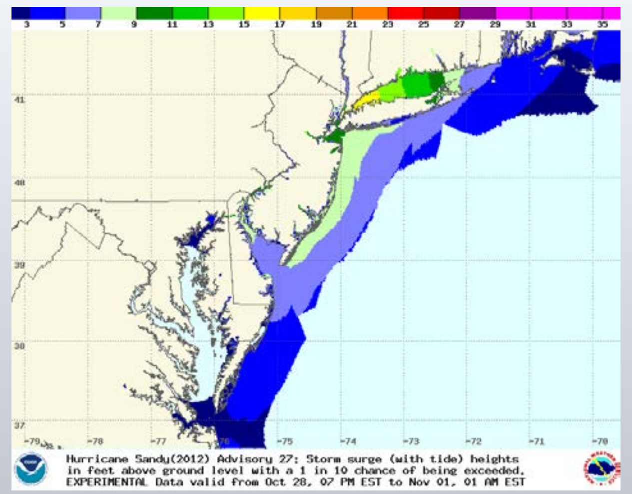


Figure 4. AGL Storm Surge with Tide exceeded by 10% of Ensemble Members for Sandy 2012 Advisory 27.

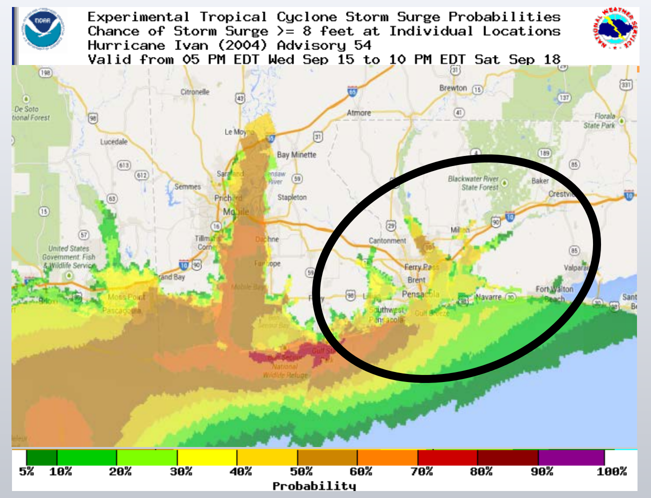


Figure 5. P-Surge product for Ivan (2004) based on NHC Advisory 54, shows considerable surge threat to Pensacola region.

References

Jelesnianski, J. Chen, and W. A. Shaffer, 1992: SLOSH: Sea, Lake, and Overland Surges from Hurricanes. NOAA Technical Report, NWS 48, U.S. Department of Commerce, 71 pp.

Taylor, A. Glahn, B., 2008: Probabilistic Guidance for hurricane storm surge. Extended Abstract for 19th Conference on Probability and Statistics.

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