

J12.5 OVERHAUL OF MDL'S EXTRATROPICAL STORM SURGE POST-PROCESSING AND WEB DISSEMINATION

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1. BACKGROUND AND MOTIVATION

The National Weather Service's (NWS) Meteorological Development Lab (MDL), in furtherance of its mission to help protect life and property, developed the Extra-Tropical Storm Surge (ETSS) model in 1995 to predict storm surge caused by mid-latitude cyclones (Kim et al. 1996). MDL enhanced its ETSS guidance in 2000 by developing a post-processed methodology which combined model surge output with tide predictions and used observations to statistically account for components such as sea level rise, waves, model error, and flooding from rain. That process results in a bias-corrected total water level product. Developers also created an ETSS website in 2000 to visualize post-processing output and provide raw data in text format. Users of the post-processing and website include forecasters, emergency managers, and the general public.

Recently, MDL updated the website to improve communication and interpretation of ETSS products and overhauled the model post-processing to provide River Forecast Centers (RFCs) operational access to bias-corrected total water level guidance. NOAAWatch reports that "Depending on the storm event, in the upper reaches of some tidal rivers, flooding from storm surge may be followed by river flooding from rain in the upland watershed. This increases the flood severity" (NOAA, 2014). Therefore, RFC models need bias-corrected total water level guidance to create downstream boundary conditions and achieve accurate river flooding forecasts.

MDL developers transferred ETSS post-processing code to National Center for Environmental Prediction's (NCEP) Weather and Climate Operational Supercomputing System (WCOSS) to meet operational

requirements. RFCs use a data retrieval and visualization environment called the Advanced Hydrologic Prediction Service (AHPS) which parses and displays incoming data written in Standard Hydrometeorological Exchange Format (SHEF). Data must be SHEF-encoded and placed on WCOSS before AHPS can access them. Therefore, developers SHEF-encoded bias-corrected total water level guidance for RFCs to use within the context of AHPS.

2. METHODOLOGY

ETSS post-processing utilizes three inputs:

1. Storm surge guidance from the ETSS model
2. Water level observations from Center for Operational Oceanographic Products and Services (COOPS) tide gauges
3. Tidal constituents from COOPS

ETSS outputs storm surge guidance in tenths of a foot (0.03 m). Guidance corresponds with physical locations (primarily COOPS tide gauges) for easy cross referencing with observations and tide predictions. Tide predictions and, in some cases, observations are unavailable at some locations corresponding with United States Geological Survey (USGS) river gauges, however ETSS still provides storm surge guidance at those gauges to assist forecasters. ETSS post-processing utilizes previous and current surge guidance: The first six hours of each previous surge forecast for the past five days are stitched together to create a hindcast for bias-adjustment. Next, the latest surge guidance, consisting of 96 hourly predictions, is used to calculate total water level guidance. New ETSS model output is available on WCOSS every six hours after each Global Forecast System (GFS) model run. ETSS uses GFS pressure and surface wind fields as input, so it must wait for GFS to output its first 96 hours of predictions approximately four hours after the forecast cycle begins due to model run time and associated pre- and post-processing.

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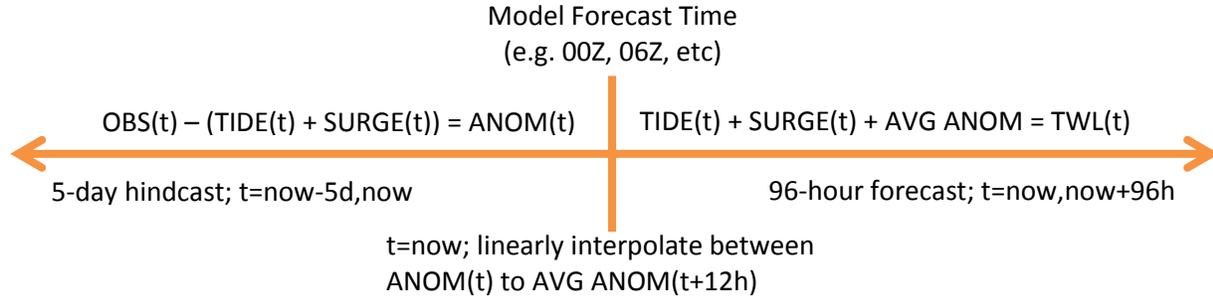


Fig. 1. Total Water Level Forecast Timeline: The surge + tide forecast is adjusted by adding a linear interpolation, for the first 12-h, of the current anomaly and 5-d average anomaly and then just the 5-d average anomaly after that.

COOPS measures water level observations in six-minute intervals, SHEF-encodes them, and transmits them to WCOSS (Todd Ehret 2014, personal communication). Once on WCOSS, the observations are re-encoded in Binary Universal Format for the Representation of meteorological data (BUFR) and placed in date-based data storage directories (a.k.a. “data tanks”). Developers customized NCEP’s BUFRLib v10.2.3 (NCEP 2013), a collection of C and FORTRAN routines for parsing BUFR files, to search specifically for water level observations and ignore all other metadata apart from observation location and time. That customization allows for faster retrieval and more specific results.

New ETSS post-processing calculates tides using COOPS tidal constituents and outputs them in six-minute intervals, as opposed to the original method’s hourly intervals. The higher resolution data matches COOPS observation times and may allow for higher resolution total water level guidance in future implementations.

COOPS calculates tidal constituents from its long-term observation records. Each set of constituents represents diurnal and semi-diurnal tide components, which COOPS combines with yearly tide constants in the following equation (Schureman 1958):

$$h(t) = H_o + \sum_{i=1}^{37} f_i H_i \cos[(V_o + U)_i - K_i + a_i t] \quad (1)$$

where $h(t)$ is the predicted height relative to datum at time t , H_o is mean height of water at datum, f_i is the yearly nodal constant, H_i is constituent amplitude, $(V_o+U)_i$ is the yearly equilibrium argument constant, K_i is constituent phase, and a_i is constituent angular speed. $(V_o+U)_i$ and f_i change yearly but are the same

for all sets of tide constituents; a_i is the same for all constituent sets every year.

COOPS lacks long term water level records in some locations, so tidal constituents are not available everywhere. For instance, the Alaskan Bering Sea coast - which is at high risk from extra-tropical surge - has a shortage of tide gauges and, by extension, updated constituents. In such areas, ETSS post-processing uses older constituents in lieu of acceptable replacements.

Additionally, ETSS post-processing does not calculate all tides by utilizing the method of Schureman (1958). Using observed height and time offsets between similar locations, tides can be calculated in places with no long-term observation record. Tides at these “subordinate” stations can reasonably be derived from those at nearby “reference” stations due to proximity and similar bathymetry (COOPS 2013). COOPS provides adjustments for high and low tide at subordinate stations in Table 3 of its tide tables, however users are responsible for calculating values in between. MDL developers adapted an interpolation algorithm developed by Jean-Pierre Lapointe of Collège Notre-Dame du Sacré-Cœur in Montreal, Canada and used within the XTide software program (FlaterCo 1996) to calculate subordinate tides for this particular project.

ETSS post-processing adds tide and surge at hourly intervals and compares them to water level observations to derive a five-day anomaly hindcast (Fig. 1). Once the system derives the anomalies, it averages them and combines them with tide and surge to create a corrected total water level prediction for the next 96 hours. This average anomaly, or bias-adjustment, accounts for phenomena not included in the model such as wave action, sea level rise, and

flooding from rain upriver. To avoid discontinuities, the system linearly interpolates the adjustment for the first 12 hours from the current anomaly to the five-day average anomaly. MDL previously explored various hindcast durations (3, 5, 7 and 30 days) with little statistical difference between choices, however more study is needed (Rios-Berrios 2010).

2.1 WCOSS Load Sharing Facility

MDL moved ETSS post-processing, originally completed on a local machine with one CPU, to WCOSS to meet standards for operationalization, allowing output data to be distributed nationally. Thousands of computational scripts run on WCOSS every day, a process which requires prioritization of jobs and distribution of computational load. WCOSS's Load

Sharing Facility (LSF) accomplishes that and allows users to select the amount of memory and run time needed for a script, among other options. The system also creates efficient workflow by allowing some jobs to wait on others to finish. ETSS post-processing now utilizes LSF to parse several days' worth of BUFR data in parallel and to kick off jobs at the right time. WCOSS's CPUs are integral in processing data quickly, allowing for a run time of approximately eight minutes. Additionally, WCOSS provides NOAA-wide data dissemination, organization, security, and reliability. If the production machine fails, a backup machine is waiting to take its place. Staff are tasked with implementing and maintaining operational products. Strict protocols ensure no access to unauthorized users harboring nefarious intentions.

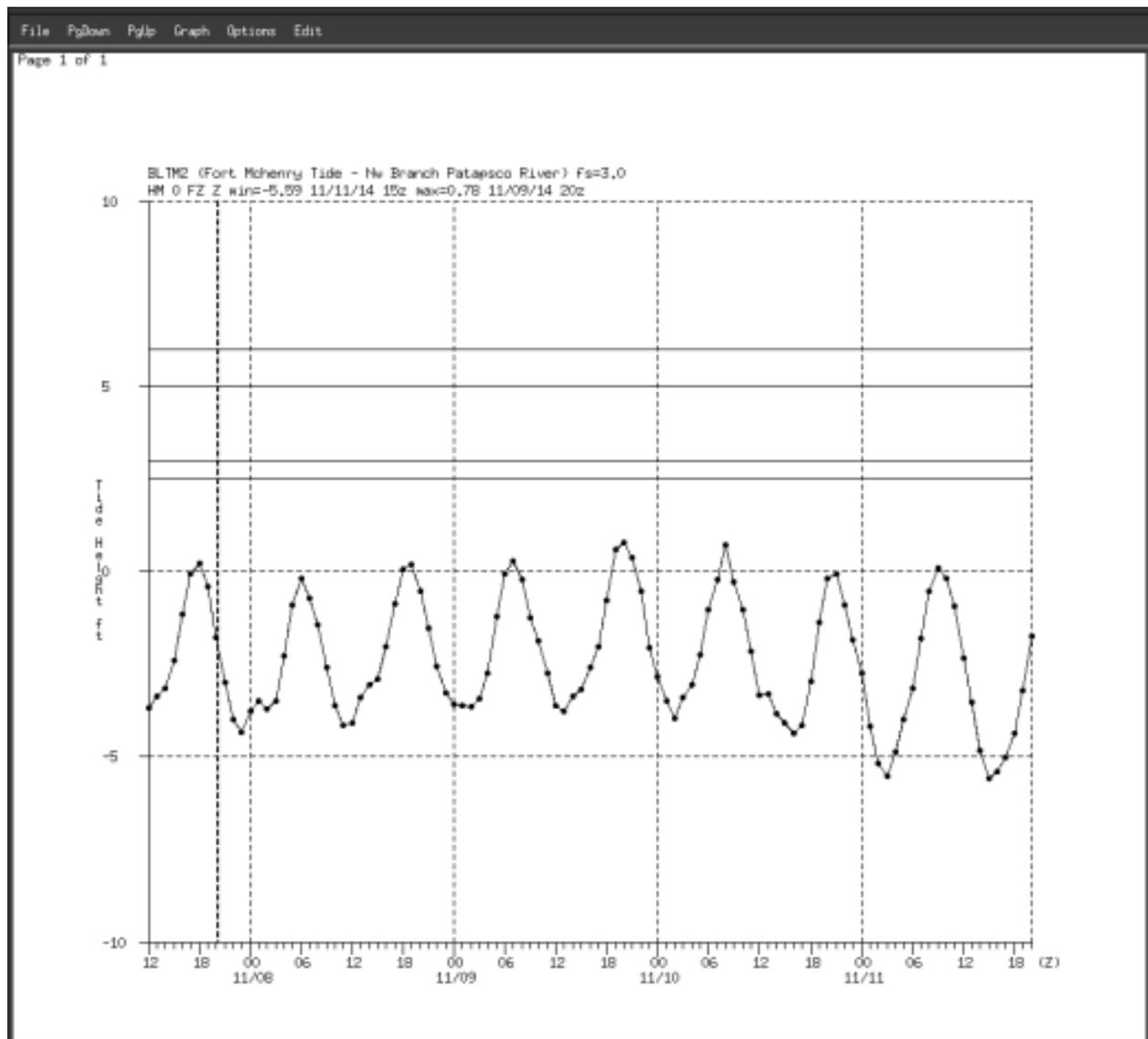


Fig. 2. Example of ETSS post-processed SHEF-encoded total water level guidance on AHPS.

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****0000021076****CBOFS KWBC 061842
TIDNT
:SHEF ENCODED 30 MINUTE WATER LEVEL FORECAST GUIDANCE
:WATER LEVEL VALUES REFERENCED TO MLLW IN FEET (HMIFZ)
:TIME ZONE IS UTC
:WATER LEVEL FORECAST GUIDANCE IS FOR TOTAL WATER LEVELS
:PROVIDED BY DOC/NOAA/NOS/CO-OPS
:corms@noaa.gov 301-713-2540
.E SWPV2 20120906 Z DH1200/HMIFZ/DIN30/ 0.427 / 0.887 / 1.122 / 1.435 / 1.646 / 1.865
.E1 2.065/ 2.219 / 2.446 / 2.589 / 2.676 / 2.767 / 2.665 / 2.500 / 2.322 / 2.156 / 1.939 / 1.764
.E2 1.602/ 1.407 / 1.251 / 1.057 / 0.925 / 0.789 / 0.781 / 0.880 / 1.045 / 1.230 / 1.414 / 1.616
.E3 1.820/ 2.007 / 2.182 / 2.363 / 2.453 / 2.538 / 2.498 / 2.405 / 2.288 / 2.128 / 1.994 / 1.820
.E4 1.631/ 1.385 / 1.184 / 1.027 / 0.931 / 0.897 / 0.943 / 1.046 / 1.175 / 1.347 / 1.563 / 1.812
.E5 2.087/ 2.375 / 2.632 / 2.855 / 3.002 / 3.111 / 3.150 / 3.104 / 3.001 / 2.853 / 2.699 / 2.524
.E6 2.322/ 2.086 / 1.812 / 1.537 / 1.313 / 1.164 / 1.073 / 1.065 / 1.116 / 1.191 / 1.267 / 1.352
.E7 1.464/ 1.598 / 1.754 / 1.916 / 2.050 / 2.139 / 2.167 / 2.138 / 2.071 / 1.972 / 1.848 / 1.715
.E8 1.573/ 1.419 / 1.239 / 1.042 / 0.866 / 0.724 / 0.648

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Fig. 3. Example of ETSS post-processed SHEF-encoded total water level guidance.

3. SHEF-ENCODED OUTPUT

After ETSS post-processing calculates all five data types (surge, tides, observations, anomalies, and predictions), it uses them to create SHEF-encoded water level guidance for RFCs and specially formatted .csv files for the ETSS website. Each SHEF message represents an individual location, and post-processing sorts messages by geographical area into groups called SHEF bulletins. Each bulletin contains a unique World Meteorological Organization (WMO) header and Advanced Weather Interactive Processing System (AWIPS) ID for correct routing to forecast offices. Post-processing places final output files on WCOSS where they can reach NOAA's Satellite Broadcast Network (SBN) and, eventually, AHPS, or users can download them via FTP.

NWS designed SHEF and first documented it in 1983 (NWS 2012). The format's main feature is its readability: humans can easily identify the data being transmitted and machines can run software to decode and visualize messages (Fig. 2). Data type, interval time, observation time, and location are encoded in one header line, and data values follow. Standards and documentation exist detailing the many SHEF codes for data type and station identification. The format is flexible and allows for representation of new data categories. NWS systems such as AWIPS and AHPS rely on SHEF for real-time data transfer from a network of observational instrumentation across the world. For these reasons, MDL chose SHEF as the vehicle to

transfer bias-corrected total water level data to RFCs (Fig. 3).

4. VISUALIZING THE DATA: ET-SURGE 2.0 WEBSITE

In addition to SHEF-encoded output, ETSS post-processing now provides output .csv files containing all five data types (surge, tide, observations, anomalies, and total water levels) for the ET-Surge2.0 website: <http://nws.weather.gov/mdlsurge/etsurge2.0/>. The new ET-Surge website provides total water level guidance at more stations than the original site. Users can now select stations from a Google Map interface which allows them to scroll, zoom, and hover for more information. Two maps are available on ET-Surge2.0: the original status map with stations color coded by possible flood severity and a new maximum-values map where station colors represent the maximum level in feet (0.30 m) above mean higher high water in the next 96 hours (Fig. 4). On the maximum-values map, a number on each station tells how many hours will elapse before the maximum value occurs. Several features allow for further analysis, such as an archive page, bookmarking capability, and station search.

Eventually developers will add an animated map of ETSS gridded products which will allow users to click and plot a surge forecast at any point on the output grid. A surge plus tide gridded water level field may be added as well. Unfortunately, a bias-corrected total water level grid will not materialize until a method is developed for providing gridded observational analysis.

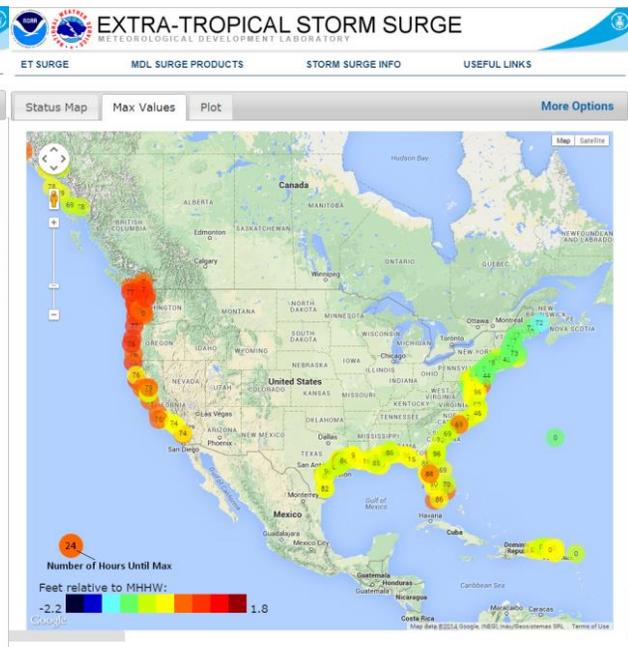
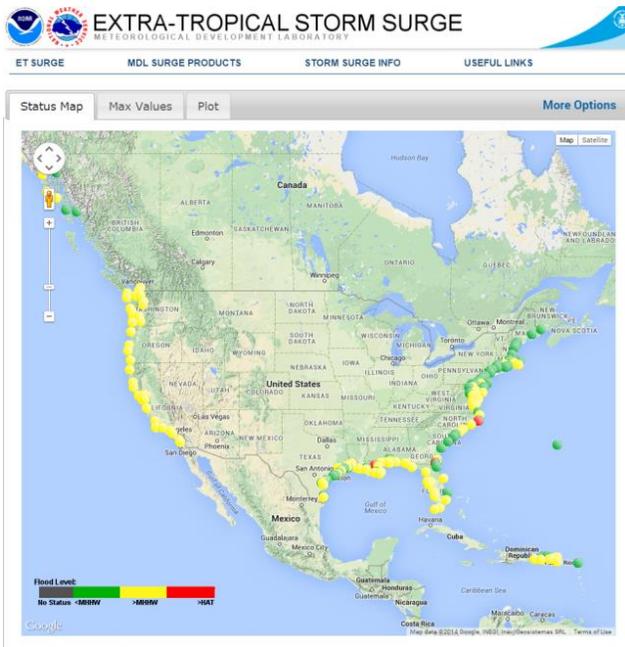


Fig. 4. ET-Surge2.0 website's flood status map (left) and "Max Values" map (right).

Free, open source libraries, plugins, and APIs provided the support necessary for the ET-Surge2.0 website's functionality. D3.js, a visualization library, dynamically plots the data in a way that users can zoom, pan, change datum, and hover to see values at a point (Bostock 2011). Google Maps API promotes data discovery by facilitating exploration of stations and flood statuses in the same vicinity (Google 2005). JQuery UI, a user interface plugin, provides utilities to promote site navigation and user input (González and Zaefferer 2007).

As internet usage and data literacy increase, more users will expect these tools in order to not just download model output but easily access it online. While data production is the aim of this particular project, the importance of dynamic web applications cannot be stressed enough. Open source tools are free and cut development time, boosting production while adding more features. They should be adopted whenever possible.

5. ACKNOWLEDGEMENTS

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