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Rapid Tidal Reconstruction for the Coastal Hazards System and StormSim Part I: Coastal Texas and Louisiana

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes the efforts towards incorporating a rapid tidal time series reconstruction and prediction subroutine within the Coastal Hazards System (CHS) framework. The CHS (<https://chs.erdcdren.mil>) is a national database and web tool that provides probabilistic coastal hazard analysis (PCHA) products developed from regional studies such as the North Atlantic Coast Comprehensive Study (Nadal-Caraballo et al. 2015; Cialone et al. 2015). PCHA considers hazards due to both tropical and extra-tropical cyclones, depending on the storm climatology of the region of interest.

The CHS supports feasibility studies, probabilistic design of coastal structures, flood risk management for coastal communities, and critical infrastructure. In the case of tropical cyclones (TCs) or hurricanes, both the timing of landfall and the level of the astronomical tide at the landfall location are critical in determining the magnitude of the still water level (i.e., storm surge + wave setup + astronomical tide). Therefore, a robust and accurate tide prediction methodology is needed to provide reliable reconstruction of tidal time series for historical, synthetic, and forecasted hurricane scenarios. This CHETN also discusses the quantification and validation of the Advanced Circulation (ADCIRC) tidal constituent database in the coastal Texas and Louisiana region as well as the implementation of the tidal reconstruction program Unified Tidal analysis (UTide) in the CHS framework.

BACKGROUND: Advances in numerical and surrogate modeling have expedited the ability to provide robust solutions to complex physical problems. Within the CHS framework, the Stochastic Storm Simulation System (StormSim) software tools are used to compute flood frequency and coastal storm hazards (e.g., hazard curves) including storm surge and waves at various locations of interest. The StormSim-CHRPS (Coastal Hazards Rapid Prediction System) allows for fast and efficient estimation of coastal hazards. Employing Gaussian process metamodels (GPM) trained on CHS data, StormSim-CHRPS can predict storm surge, flooding, and concurrent wave climate in real time for forecasting applications. The GPM methodology is made possible by a TC parameterization scheme that can be used to represent both historical and synthetic hurricanes (Taflandis et al. 2017; Zhang et al. 2018).

Two coastal ocean tidal databases have been developed for the Western North Atlantic Tidal (WNAT) (Szpilka 2016) and Eastern Pacific (Szpilka 2018) basins using the ADCIRC hydrodynamic model (Luettich et al. 1992; Westerink et al. 1993a, 1993b). These databases allow for surface-water elevation and tidal currents to be quickly defined in both coastal and open ocean environments. Tidal harmonic constituent information is available from southwestern Alaska through southern California, northern Maine through the Gulf of Mexico (GOM), and Puerto Rico and US Virgin Islands. The harmonic amplitude and phase can be processed through a tidal reconstruction software to generate reliable tidal time series.

An example of a recent tidal analysis software is the UTide program (Codiga 2011), which is a more robust and versatile version of the Foreman et al. (2009) method. Tidal time series can be reconstructed through their harmonic constituents. These constituents represent individual tide-producing forces (e.g., gravitational pull from the moon) and contribute to the determination of the national tidal datum based on observations from the previous tidal epoch. While the present national tidal datum is 1983–2001, the tidal datum for some regions is revised every 5 years (e.g., areas in the GOM and Alaska). The fundamentals of tidal analysis can be found in Godin (1972) and Parker (2007). There are two primary functions within the self-contained program: (1) a solver that decomposes an observed tidal time series into its harmonic components and (2) a predictor that reconstructs the time series using information from step (1) over a user-specified period. For details about the UTide capability and foundation of tidal prediction methods, see Codiga (2011) and Foreman et al. (2009), respectively.

Study Area and Data. The Coastal Texas Comprehensive Study (CTXCS) provides a database of storm surge and wave climate responses from 660 synthetic TCs along the Texas and Louisiana coastlines in the GOM. Hydrodynamic storm surge and wave simulation results are preserved at more than 18,000 save points within the study domain (USACE 2018).

Tidal data were gathered from the network of tidal gages managed by the National Oceanic and Atmospheric Administration (NOAA). Three tidal time-series products are available at most NOAA gages in the network: predicted, preliminary, and verified. The predicted tide is the expected water elevation as determined by the NOAA in-house tidal prediction program; the preliminary tide is the real-time water elevation, and the verified tide is the final observed tidal signal after quality assurance post-processing from the National Ocean Service. The observed signal, both preliminary and verified, is subjected to atmospheric and hydrologic forcings, which tidal prediction programs are unable to incorporate. Therefore, it is ideal to compare the predicted tidal time series from NOAA with the reconstructed series from UTide to eliminate other environmental influences on the signal.

In this study, tidal predictions from 45 NOAA gages within the Texas-Louisiana region (31 gages in Texas, and gages 14 in Louisiana) (Figure 1) were obtained and compared to tidal time series as reconstructed by UTide; see Table 1 in the Appendix for the full list of station names and locations. The dominant harmonic constituents in the study area are diurnal in nature (i.e., high/low tide occurs once daily) with relatively low amplitudes and variable phases.

The ADCIRC WNAT harmonic constituent database offers the potential to predict tidal time series in nearshore regions where NOAA tidal gages are sparse. The database was developed on an unstructured mesh that contains 2,066,216 nodes overall and has a spatial resolution of approximately 300 m* along the coastline and as fine as 50 m near coastal inlets in the GOM.

*For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

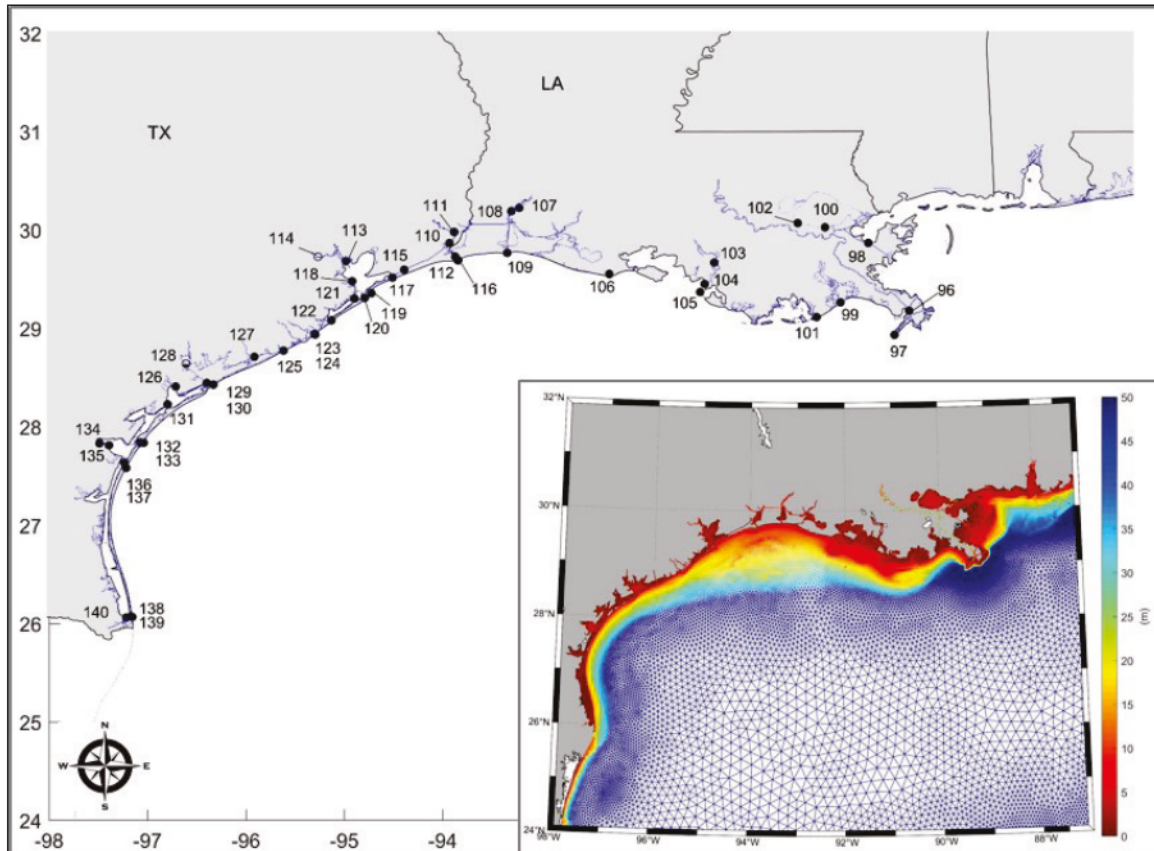


Figure 1. Geographic location of NOAA tidal gages in TX and LA coastal areas; (inset) spatial resolution and bathymetry of the ADCIRC WNAT grid in the study region.

Initial Conditions. Before applying the ADCIRC WNAT harmonic constituent data to the tidal reconstruction program, its constituent information was compared to the NOAA data, and baseline tidal conditions were defined in the region. Each NOAA tidal gage has an online table containing a description of the 36–37 tidal harmonic constituents observed at that location. The harmonic amplitude and phase were extracted from this table and compared to those extracted from the ADCIRC tidal database for each station.

The GOM is primarily dominated by the diurnal harmonic constituents and the overall tidal range is small (0.11–1.0 m) compared to the Atlantic and Pacific basin areas (0.3–8 m). These characteristics leave room for large scatter of the harmonic amplitude and phases in the GOM, shown in Figure 2, in both of the NOAA and ADCIRC datasets. There is general agreement between NOAA and ADCIRC in this region, where ADCIRC slightly overestimates the O1 and K1 harmonic constituent amplitudes and underestimates the M2 amplitude relative to the NOAA observations.

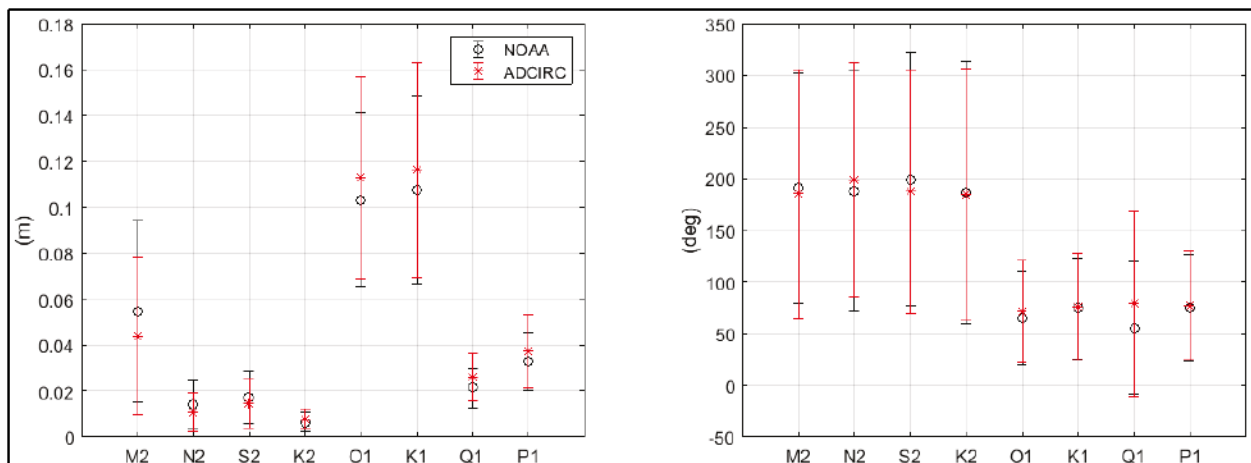


Figure 2. Mean amplitude in meters (left) and phase in degrees (right) of eight harmonic constituents (M2, N2, S2, K2, O1, K1, Q1, P1) for the 45 gages located within the CTXCS region, as reported by NOAA (black) and ADCIRC (red), respectively; the error bars represent one standard deviation from the mean for all the data.

Figure 3 shows the relationship between NOAA and ADCIRC harmonic amplitude and phase in the CTXCS region. There is more variability among the larger amplitude, diurnal constituents (O1, K1) than among the smaller amplitude constituents. Further, there is more agreement of harmonic phase for all constituents at most all stations. Szpilka (2016) made similar observations in the validation of the updated ADCIRC WNAT tidal database (v2015).

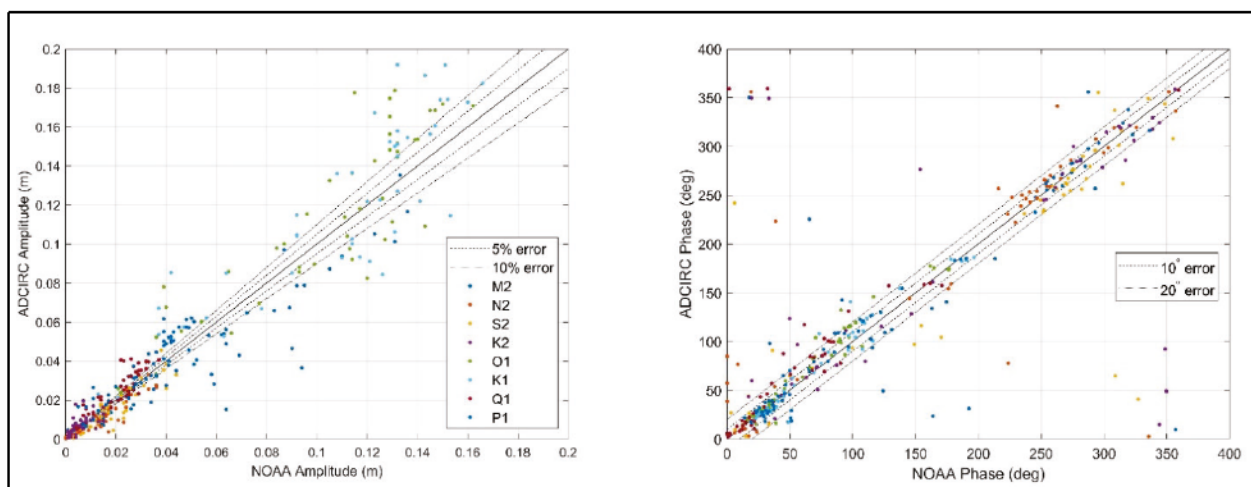


Figure 3. NOAA versus ADCIRC harmonic amplitude (left) and phase (right) for eight primary harmonic constituents in CTXCS region.

SKILL ASSESSMENT: The objective of integrating an accurate tidal reconstruction program into the CHS framework requires an understanding of the tidal signal produced by the program, including the corresponding uncertainty. The initial step in the tidal reconstruction process is to conduct a basic skill assessment of how well the characteristics of the predicted tides are captured in the reconstructed signal. These characteristics include seasonal variability, magnitude and timing of maximum and minimum water level, spatial variability, and other features of interest. Standard statistical and time-series analysis techniques were used to assess the accuracy of the

reconstructed signal compared to the tidal time series as predicted by NOAA, including root-mean-square error (RMSE) and mean bias error (MBE) normalized by the range of the tide, and the Pearson correlation coefficient (CC). The normalized RMSE (nRMSE) and normalized MBE (nMBE) are given by:

$$nRMSE = \frac{\sqrt{\frac{\sum_{i=1}^k (\eta_i^U - \eta_i^N)^2}{k}}}{range(\eta_i^N)} \quad (1)$$

$$nMBE = \frac{\frac{\sum_{i=1}^k (\eta_i^U - \eta_i^N)}{k}}{range(\eta_i^N)} \quad (2)$$

where η_i^N is the NOAA prediction at the i^{th} observation and η_i^U is the UTide reconstruction at the i^{th} observation.

Methodology. To reconstruct a tidal time series, the harmonic amplitude and phase of specified tidal constituents are captured in a coefficient structure. This structure is initially generated by the UTide solver function that decomposes water level observations (e.g., NOAA) into the respective harmonic tidal components. At this step, tidal constituents can either be specified or inferred by the internal program. For the purpose of the initial skill assessment, eight primary constituents (M2, N2, S2, K2, O2, K1, Q1, and P1) were specified. This analysis was completed using a 365-day record of tide from each NOAA tidal station in the CTXCS region beginning 1 January 2018 00:00 and ending 31 December 2018 23:00 at a 6 min interval. The reconstructed tides were generated over this period. UTide was executed with default input parameters for the initial assessment; see the Table 2 in the appendix for the list of default parameters.

Ultimately, the goal is to be able to rely on harmonic constituent information from the ADCIRC tidal database alone. The increased spatial resolution of the WNAT mesh as it approaches the coastline in the GOM is ideal in order to provide more accurate tidal harmonics in locations without a nearby NOAA gage. Once the coefficient structure is developed using pre-existing tidal time series as input (e.g., NOAA), the harmonic amplitudes and phases listed in the structure can be replaced using the ADCIRC database. From here, the tidal time series can be reconstructed.

To separate the uncertainties generated within UTide and the uncertainties carried over from the differences between NOAA and ADCIRC harmonic constituents, the tides were reconstructed and compared with NOAA-predicted tides twice: first, using NOAA constituents, referred to as UTide(N) in this CHETN, and second, using ADCIRC constituents, referred to as UTide(A). The residual errors of nRMSE between the two forcing cases were assessed in the statistical analysis.

Storm surge prediction is contingent upon a number of geospatial and hydrodynamic considerations leading up to the landfall of a TC. These considerations include geological features in the regional area (e.g., a continental shelf), and other factors such as phase of the surge relative to astronomical tide (i.e., high versus low tide). In this analysis, the timing of daily high and low tide is explicitly evaluated. Daily maximum and minimum water levels were isolated in the tidal time series, and the error statistics (i.e., nRMSE and CC) were evaluated for the UTide forcing cases against the NOAA time series. In the following, an assessment of (1) the overall time series and (2) the local maxima

(daily high tide) and minima (daily low tide) is presented to quantify the overall accuracy and/or uncertainty in the modeled tidal time series.

The matching local maxima and minima were identified between the NOAA and the two UTide forcing cases for the entire time series. The nRMSE and CC were computed to determine the accuracy of the magnitude and phasing between UTide and NOAA. The nRMSE represents how well UTide reconstructed the magnitude of the high and low tide on a scale similar to the total nRMSE. The CC represents how well the high and low tide signal align in phase on a scale from 0 (not aligned) to 1 (very well aligned). In the event that both the nRMSE and CC are larger values, the reconstructed signal in phase, but the magnitude of the signal is less accurate. The opposite is true for small values of nRMSE and CC. Ideally, a well-matching signal has a low nRMSE and high CC.

Results and Discussion. The mean water level in the Coastal Texas region for the simulated period was approximately 2.84 cm, as predicted by NOAA, with a minimum value or elevation of -3.1 cm and a high of 32.3 cm for the year (2018). When assessing the entire time series, the modeled time series generally underestimated the mean water level by 2.0 cm for both forcing cases. The average nRMSE was 8% and 9% for the UTide(N) and UTide(A) cases, respectively. Of the 45 station locations, 24 (N) and 18 (A) show errors higher than the respective mean. In Figure 4, the nRMSE is broken down by station (left), and the residual errors between UTide(N) and UTide(A) are compared spatially (right). The spatial comparison shows that a few stations in northern Texas and Louisiana (i.e., no. 96, 108, and 115) have residual error near 6% (towards UTide(A)). Concerning nMBE of the entire time series, errors were very low (within 1%) and positive (biased high) at all locations in the region and did not differ much between the two forcing cases.

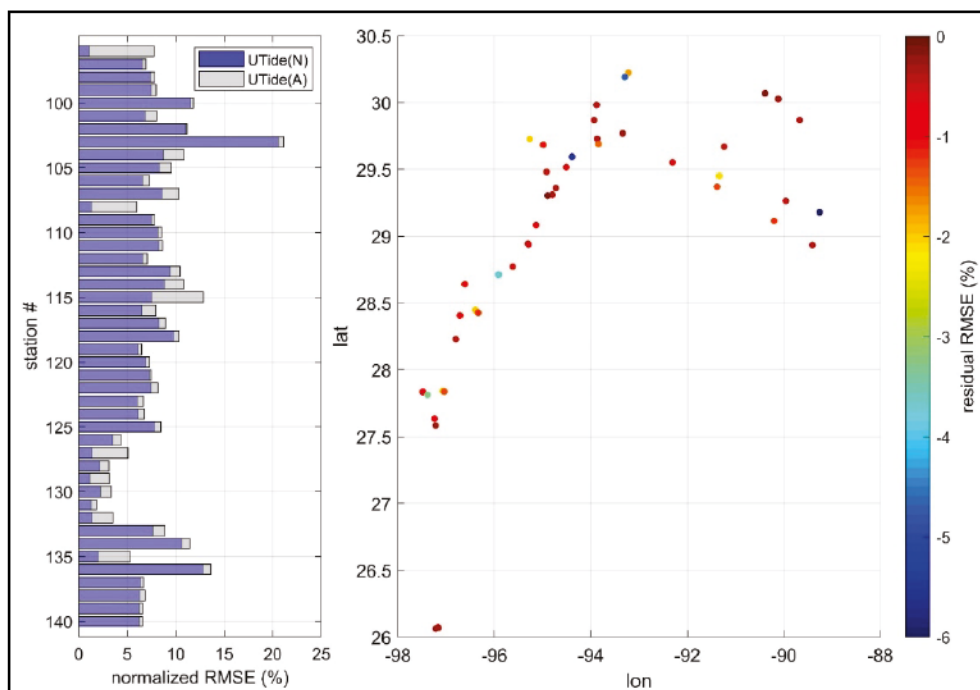


Figure 4. Breakdown by station of nRMSE (%) between NOAA and UTide time series (left), and spatial comparison of nRMSE residuals between UTide(N) and UTide(A) in the CTXCS region (right); see Figure 1 for station locations and numbering.

Objectively, an nRMSE of 8%–9% is an acceptable amount of error when considering water elevation over a long period. Nevertheless, the magnitude and timing of the daily (high-low tide) variability in the tidal signal is investigated to ensure the modeled time series is accurately estimating these characteristics. The nRMSE and CC of the maxima (top) and minima (bottom) are shown in Figure 5. The UTide(N) case is represented by the “x” symbol, and the UTide(A) case is represented as “o”. In both cases, there were mixed results. Generally, there was low nRMSE (8%) and high CC (0.74–0.88) in the UTide(N) signal for both maxima and minima points, suggesting that the magnitude was in agreement and the timing was accurate. In the UTide(A) signal, the nRMSE was higher (10%) and CC was lower (0.70–0.86), suggesting that both the magnitude and timing were less accurate.

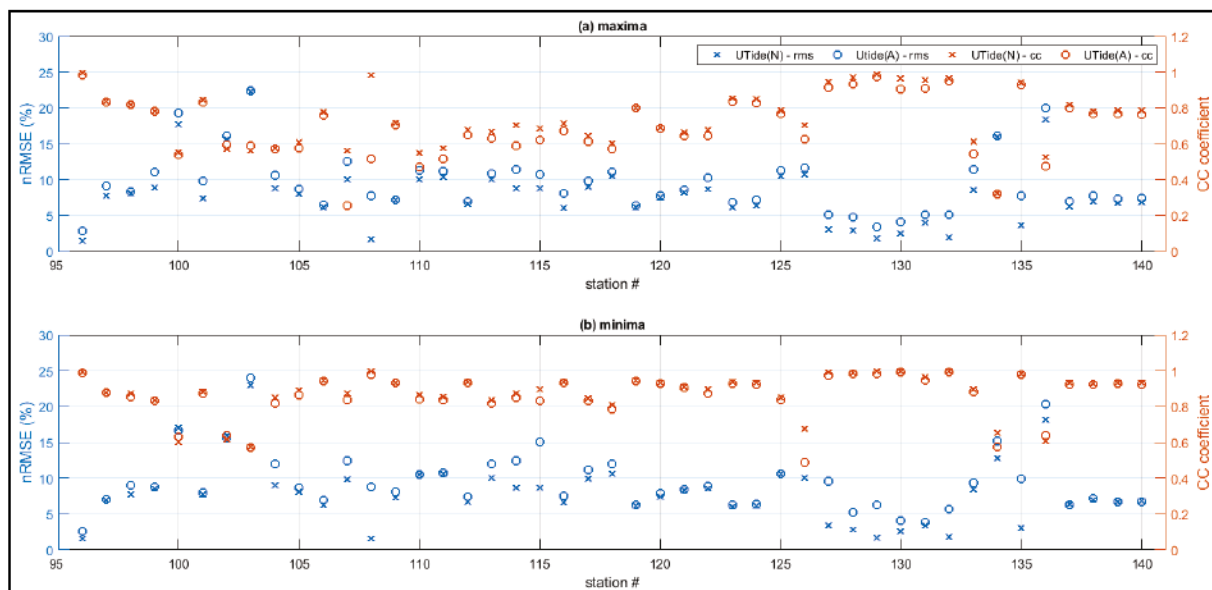


Figure 5. Performance of UTide(N) (x) and UTide(A) (o) compared to NOAA predicted tidal time series for daily (a) maxima or high tide and (b) minima or low tide in terms of nRMSE (blue) and CC (orange); See Figure 1 for station locations.

Furthermore, the magnitude of the residuals was evaluated to quantify the differences in local maxima and minima between the predicted and modeled time series. On average, the local maxima (minima) are overestimated 45–50% (50–54%) of the time by 2.5–5% (2.5–5%), which is relatively even with respect to the tidal signal. In general, when the modeled time series overestimates the local maxima, it also underestimates the local minima, indicating a shift in the mean. In terms of phase lag, the modeled time series estimated the timing of the local maxima and minima slightly before the predicted time series by 13 minutes \pm 9 min and 5 min \pm 12 min on average, respectively. There were no timing differences between the UTide(N) and UTide(A) forcing cases because the time series was generated over the same period with a 6 min interval.

A sample time series from station 115 on High Island, TX, is shown in Figure 6. Here, the discrepancies in both daily and seasonal tidal magnitude are visualized between NOAA (black), UTide(N) (blue), and UTide(A) (red). There is a reduction in amplitude for both UTide cases, contributing to discrepancies at the local maximum and minima. The total nRMSE for the two modeled time series were 8% and 14.5%, respectively, at this station.

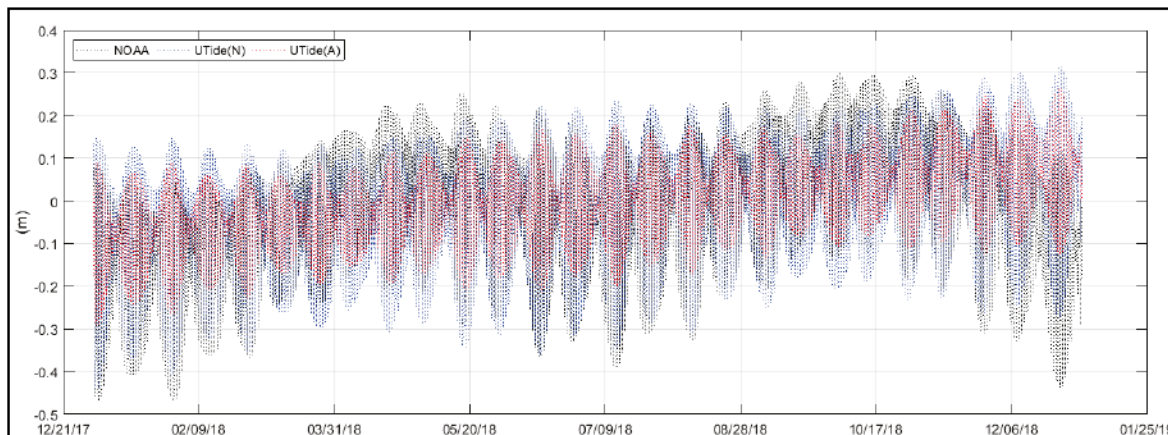


Figure 6. Time-series comparison from station 115 – High Island, TX (NOAA ID 8770808); NOAA predicted time series shown in black; UTide(N) reconstructed time series shown in blue; and UTide(A) shown in red; see Figure 1 for station location.

SENSITIVITY ANALYSIS. In an effort to improve the accuracy of the modeled time series, an informed selection of which tidal harmonic constituents to include in the analysis was considered. Recall that the GOM is dominated primarily by the diurnal constituents. In addition, seasonal variability is prevalent at many station locations, where baroclinic processes and radiational heating give rise to increased water levels during the warmer months (Westerink et al. 2008). Selecting the naturally dominant tidal harmonic constituents for the region should provide sufficient information to most accurately reconstruct the tidal signal.

The naturally dominant tidal constituents were selected from the respective NOAA harmonic constituent webpages. The constituents were sorted in descending order based on amplitude (m). The common top eight constituents among the stations in the region were identified as O1, K1, P1, M2, SSA, SA, S2, and Q1, where SA and SSA are the solar annual and semi-annual harmonic constituents, respectively. The UTide(N) and UTide(A) modeled time series were generated for the same 1-year period as the initial analysis.

Results. An initial assessment of the mean harmonic amplitude and phase differences between NOAA and ADCIRC was conducted (Figure 7). Upon review, the ADCIRC tidal database does not contain SSA and SA amplitude (i.e., values near zero). In addition, the phases of SSA do not overlap with the phases reported by NOAA for this region.

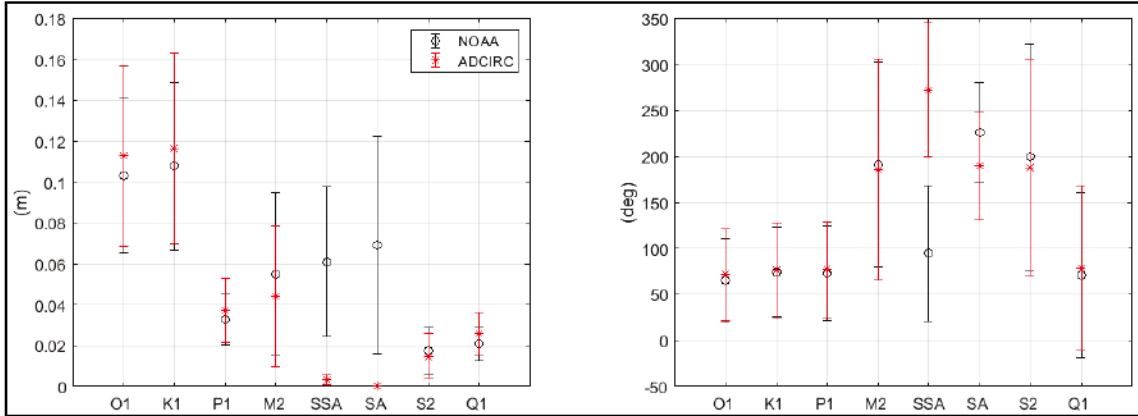


Figure 7. Mean amplitude in meters (left) and phase in degrees (right) of eight harmonic constituents (O1, K1, P1, M2, SSA, SA, S2, Q1) for the 45 CTXCS observation locations as reported by NOAA (black) and ADCIRC (red); the error bars represent one standard deviation from the mean for all the data.

The nRMSE of the total time series was evaluated for the selected constituent scenario (Figure 8). The UTide(N) modeled time series improved across a majority of stations using the selected constituents. The average nRMSE decreased from 8% to 2%, with a maximum reduction of 22% at station 103. For the UTide(A) case, the average nRMSE slightly increased from 9% to 11%. This outcome suggests that additional errors were introduced to the time series from the ADCIRC SSA and SA harmonic constituents.

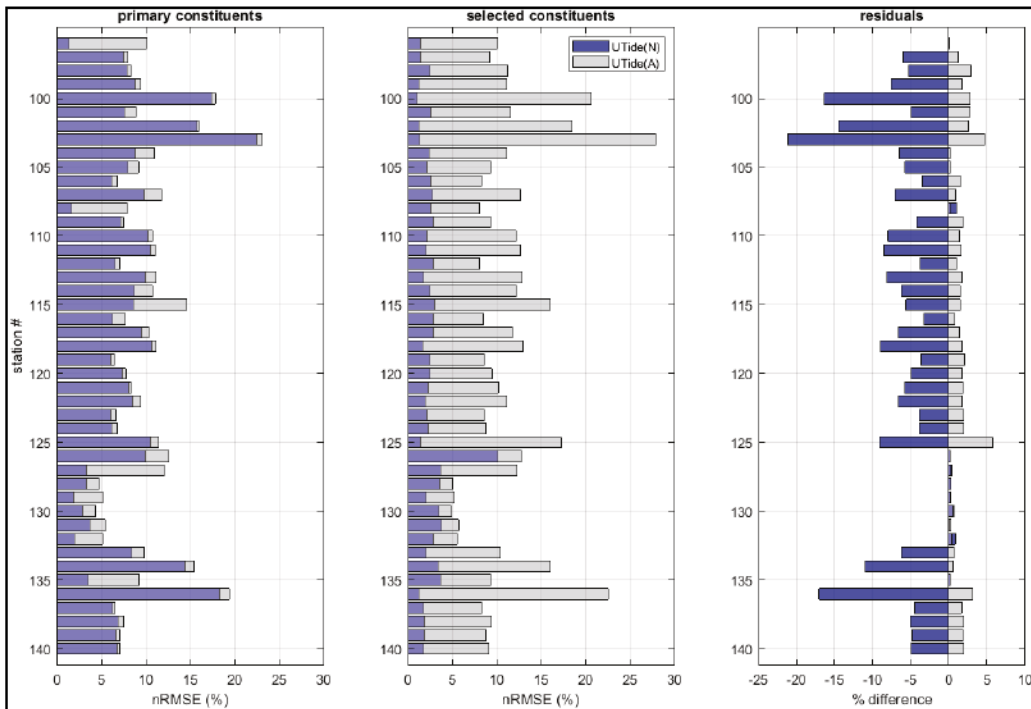


Figure 8. The nRMSE between NOAA-predicted and UTide-modeled time series for CTXCS stations using (left) primary constituents (M2, S2, N2, K2, O1, K1, P1, Q1) from original analysis and (middle) selected constituents (O1, K1, M2, P1, SSA, SA, S2, Q1) from sensitivity analysis; (right) represents residual change in nRMSE between primary and selected constituent cases.

In terms of the magnitude and timing of daily high and low tide, the selected constituents improved the accuracy of the UTide(N) time series (Figure 9). The nRMSE of the maxima and minima both reduced to 2%, which is a 6% decrease from the primary constituent scenario, and the CC further increased to 0.98. The opposite is true for the UTide(A) modeled time series, where the nRMSE increased to 11% when using the selected constituents. The CC coefficient remained the same (0.70–0.86) between the two constituent scenarios.

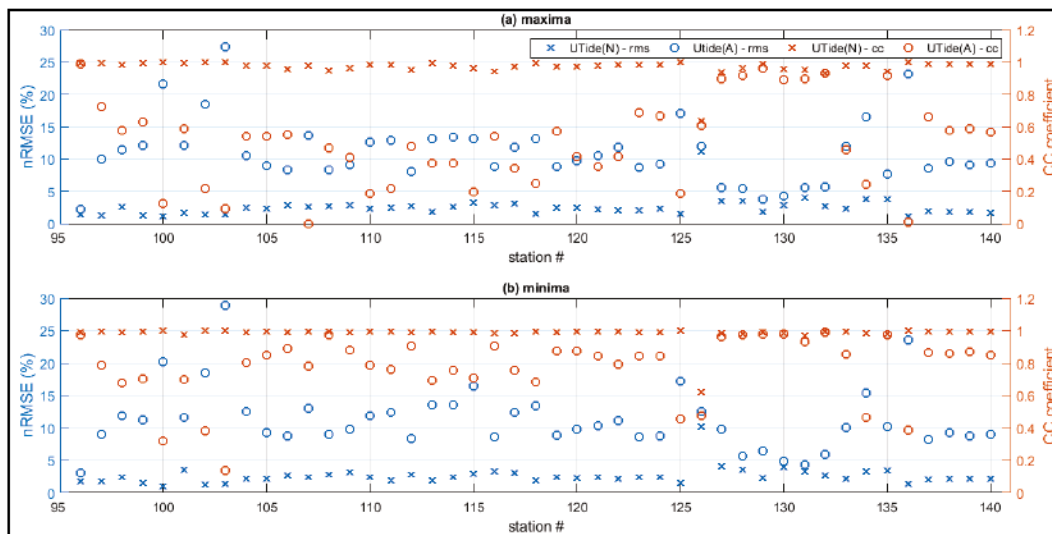


Figure 9. Performance of UTide(N) (x) and UTide(A) (o) for selected constituents (O1, K1, M2, P1, SSA, SA, S2, Q1) compared to NOAA predicted tidal time series for daily (a) maxima or high tide and (b) minima or low tide in terms of nRMSE (blue) and CC (orange); see Figure 1 for station locations.

The time series from station 115 on High Island, TX, was shown to improve the UTide(N) estimate of the daily and seasonal tidal magnitude when using the selected constituents (Figure 10). The total nRMSE for the UTide(N) time series reduced by 5% (8% to 3%) while the total nRMSE increased by 2% for the UTide(A) time series.

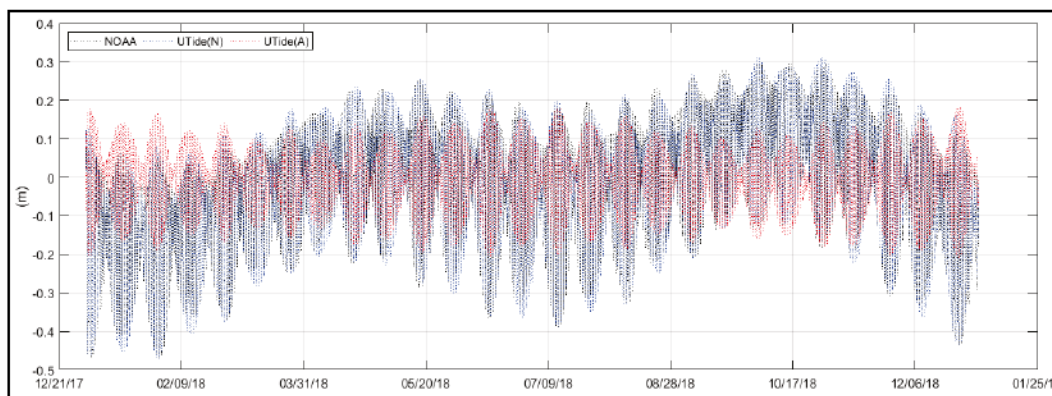


Figure 10. Improved time series comparison from station 115 – High Island, TX (NOAA ID 8770808) using selected constituents (O1, K1, M2, P1, SSA, SA, S2, Q1); NOAA-predicted time series shown in black; UTide(N)-reconstructed time series shown in blue; and UTide(A) shown in red; see Figure 1 for station location.

Discussion. The limitation of the ADCIRC WNAT database in the CTXCS region is the lack of SSA and SA harmonic constituent information. This limitation is typical in ADCIRC storm surge modeling applications. In these studies, a steric water level adjustment is applied to the initial and boundary conditions of ADCIRC to account for the seasonal variability (e.g., Westerink et al. 2008; Medeiros et al. 2013).

In an operational setting, such as for the CHS, it is not ideal to apply a water level adjustment in post-processing for multiple areas. As an alternative approach, it may be beneficial to supplement NOAA harmonic information as needed. SSA and SA harmonic amplitude and phase information can be interpolated onto the ADCIRC WNAT mesh for the GOM region and used in the tidal analysis automatically. This approach should be sufficient in capturing the seasonal variability of the tides along the GOM coast during hurricane season and improve model results.

IMPLEMENTATION: Once optimized to generate rapid and accurate tidal time series on a regional basis, the tidal reconstruction program will be incorporated as a subroutine into the CHS framework to precompute tidal time series for PCHA applications. The rapid tidal reconstruction subroutine will also be incorporated into the StormSim-CHRPS web tool. For CHRPS applications, the user can select a storm scenario, including hurricane parameters such as intensity, size, and translational speed, and StormSim will estimate the storm surge and wave time series at each save point in the study region. Figure 11 displays the spatial coverage and density of these save points (red dots) in the CTXCS region.

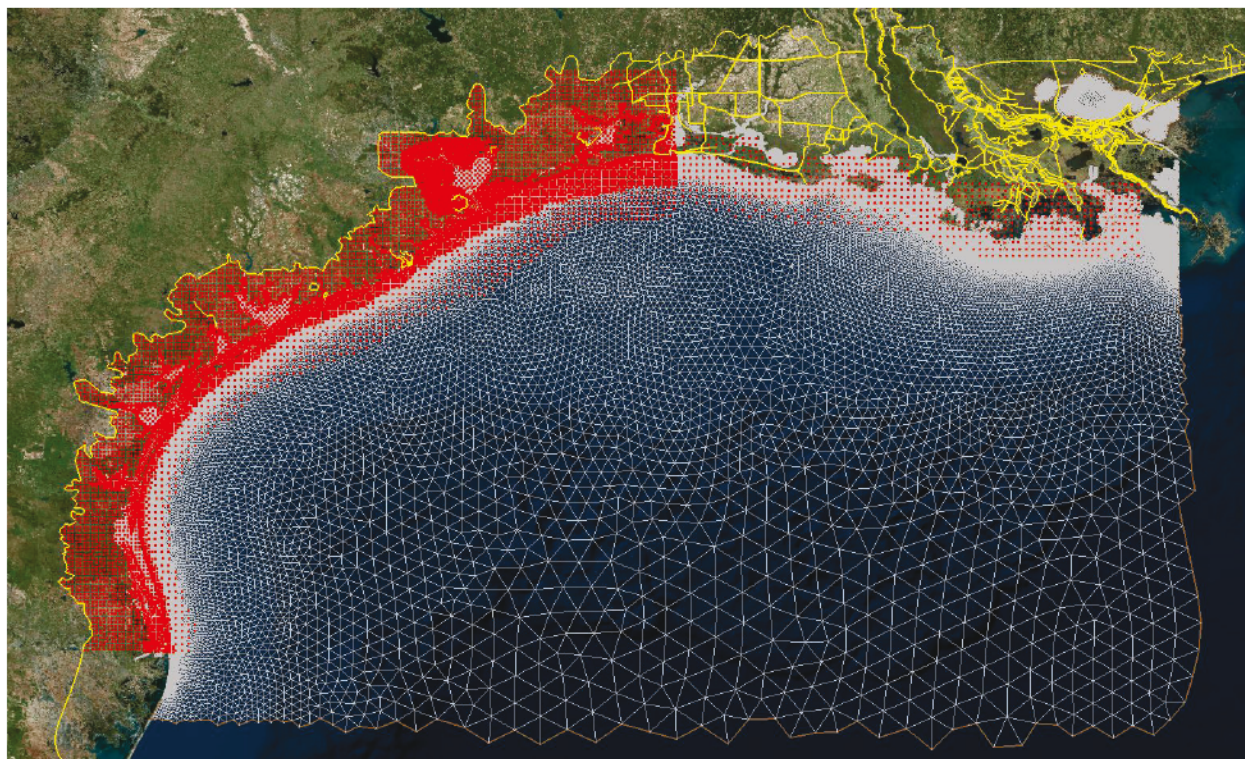


Figure 11. Visualization of the inland extent of the CTXCS mesh (p05; yellow) compared to the coverage and spatial resolution of the ADCIRC WNAT mesh in the area (white), with the coverage and density of CTXCS save points shown in red.

Parallel to StormSim-CHRPS, UTide will reconstruct the tidal time series for the user-specified date and duration of the storm. The tidal signal will be added as an option to view total still water level (surge + tide) in the web tool. The computational expense of the tide subroutine was estimated to be between 1.5 and 3 min for a 3–5 day storm case with a 1-hour time-step using eight tidal constituents. This estimate is expected to change if additional points are included in the program. Tidal harmonic information is expected to be assigned to all save points according to the nearest node from the ADCIRC WNAT mesh, including the inland save points. Exclusion of the inland locations did not significantly reduce the total computational burden.

SUMMARY AND FUTURE DEVELOPMENT: The harmonic constituents in the ADCIRC WNAT database agree well with the recorded NOAA constituents with slight underestimation of the amplitude of the dominant harmonics in the coastal Texas and Louisiana region. When processed through UTide, the reconstructed tidal time series accurately estimates the timing of high and low tide. The solar semi-annual and solar annual tidal constituents are needed to optimize the tidal signal in this coastal region. Since ADCIRC does not fully represent these harmonic constituents in the tidal database, spatial interpolation techniques are being considered to supplement this information using NOAA harmonic constituent data in the GOM region. Once implemented in the CHS framework and in StormSim-CHRPS, the UTide subroutine will significantly contribute to the estimation of total still water level response in the event of a land-falling hurricane. This process will support probabilistic design, risk assessment, Specific, Measurable, Achievable, Realistic, and Timely (SMART) planning initiatives, and feasibility studies.

ADDITIONAL INFORMATION: The work reported in this CHETN was conducted as part of the *StormSim: Metamodeling of Coastal Storm Hazards for Probabilistic Applications* funded by USACE Flood and Coastal Systems Research and Development Program. This work was undertaken in response to the following Flood and Coastal Risk Management Statements of Need: 2017-F-17 Stochastic Coastal Forcing Data Used for Coastal Structure Design, 2017-F-33 Uncertainty in Design Flood Estimates, 2017-F-34 Model Uncertainty, 2017-F-43 Future Conditions, and 2014-F-29 Frequency Estimates for Extreme Flood Events. The CHETN was prepared by Marissa J. Torres, US Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory, and Dr. Norberto C. Nadal-Caraballo, ERDC, Coastal and Hydraulics Laboratory. Questions pertaining to this CHETN may be directed to Ms. Torres (Marissa.J.Torres@erdc.dren.mil) or to Dr. Nadal-Caraballo (Norberto.C.Nadal-Caraballo@erdc.dren.mil).

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APPENDIX

Table 1. List of NOAA tidal gages within CTXCS region.				
Station #	Lon	Lat	Station ID	Station Name
96	-89.258	29.17831	8760721	Pilottown
97	-89.4075	28.93222	8760922	Pilots Station East, S. W. Pass
98	-89.673	29.8683	8761305	Shell Beach
99	-89.9567	29.26333	8761724	Grand Isle
100	-90.1133	30.02722	8761927	New Canal Station
101	-90.1993	29.11425	8762075	Port Fourchon, Belle Pass
102	-90.39	30.06786	8762483	I-10 Bonnet Carre Floodway
103	-91.2376	29.6675	8764044	Berwick, Atchafalaya River
104	-91.3381	29.44961	8764227	LAWMA, Amerada Pass
105	-91.3839	29.3675	8764314	Eugene Island, North of, Gulf of Mexico
106	-92.3052	29.55169	8766072	Freshwater Canal Locks
107	-93.2217	30.22361	8767816	Lake Charles
108	-93.3008	30.19019	8767961	Bulk Terminal
109	-93.3429	29.76817	8768094	Calcasieu Pass
110	-93.931	29.86708	8770475	Port Arthur
111	-93.8817	29.98	8770520	Rainbow Bridge (TCOON)
112	-93.8701	29.7284	8770570	Sabine Pass North
113	-94.985	29.68169	8770613	Morgans Point, Barbours Cut
114	-95.2658	29.72622	8770777	Manchester
115	-94.3903	29.59472	8770808	High Island (TCOON)
116	-93.8419	29.68939	8770822	Texas Point, Sabine Pass
117	-94.5106	29.51556	8770971	Rollover Pass
118	-94.9183	29.48	8771013	Eagle Point, Galveston Bay
119	-94.7248	29.35733	8771341	Galveston Bay Entrance, North Jetty
120	-94.7933	29.31	8771450	Galveston Pier 21
121	-94.8971	29.30258	8771486	Galveston Railroad Bridge
122	-95.1313	29.08097	8771972	San Luis Pass
123	-95.3025	28.94331	8772447	Freeport
124	-95.2942	28.9357	8772471	Freeport SPIP, Freeport Harbor
125	-95.6172	28.77142	8772985	Sargent
126	-96.7124	28.4069	8773037	Seadrift
127	-95.914	28.71006	8773146	Matagorda City
128	-96.6098	28.6406	8773259	Port Lavaca
129	-96.3956	28.44586	8773701	Port O'Connor
130	-96.3301	28.4269	8773767	Matagorda Bay Entrance Channel, TX
131	-96.795	28.2283	8774230	Aransas Wildlife Refuge (TCOON)
132	-97.0725	27.8397	8775237	Port Aransas
133	-97.0391	27.8366	8775241	Aransas, Aransas Pass
134	-97.4859	27.83275	8775244	Nueces Bay
135	-97.39	27.81169	8775296	USS Lexington, Corpus Christi Bay
136	-97.2367	27.63331	8775792	Packery Channel
137	-97.2164	27.58083	8775870	Bob Hall Pier, Corpus Christi
138	-97.1669	26.07247	8779748	South Padre Island CG Station
139	-97.1547	26.0675	8779749	SPI Brazos Santiago
140	-97.2155	26.06117	8779770	Port Isabel

Table 2. List of input parameters for UTide solve function to execute harmonic analysis		
Variable	Description	Default
Time	Times of raw inputs (YYYYMMDD HH:MM:SS)	Required
Water level OR U velocity	Raw input values of water level (m) or U current velocity (m/s)	Required
Empty OR V velocity	Empty matrix ('[]') or raw input values of V current velocity (m/s)	Required
Latitude	Latitude correction (decimal degrees)	Required
Constituents	Cell array of constituent names or string 'auto' for solved constituents	Required
Linear trend	Linear/secular trend term	Included; no pre-filtering
Nodal/Satellite corrections	Use linearized times or omit corrections	Implemented at exact times
Greenwich phase lag	Use linearized times or report raw (not Greenwich-referenced) phase lags	Use astronomical argument at exact times
Infer	Include inference constituents	No constituents are inferred
Rmin (if 'auto')	Minimum conventional Rayleigh criterion for automated constituent selection	Value: 1
Method	Solution method with Cauchy weight function and tuning parameter	Iteratively re-weighted least squares (IRLS)
Confidence intervals	Determine confidence intervals of constituent harmonics solution	Monte Carlo, 200 realizations; spectra of actual residuals
Diagnostics	Constituent selection diagnostic table	Generated
Display	Runtime display of results	Results displayed: 'yyy'

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