RESEARCH LETTER:

Improved wave predictions with ST6 Physics and ADCIRC+SWAN

By

Carter Day[1] and J.C. Dietrich[1]

1) Department of Civil, Construction, and Environmental Engineering, North Carolina State University,
915 Partners Way, Raleigh, North Carolina 27695; jcdietrich@ncsu.edu

Manuscript submitted 17 December 2021; revised & accepted 2 February 2022.

The Simulating WAves Nearshore (SWAN, Booij *et al.* 1999) model is used widely for predictions of waves in coastal regions. Like other spectral wave models, SWAN uses parameterizations to represent wave evolution due to sources (e.g. wind), sinks (e.g. whitecapping, bottom friction, depth-limited breaking), and resonance (e.g. quadruplet and triad wave-wave interactions). Each parameterization is based typically on observational data to represent the transfer of energy to, from, and between waves. It is necessary for each term to represent its physical process, but it is also necessary for the terms to be calibrated collectively to represent their combined effects on wave evolution. The calibrated wave predictions can then be coupled with models for circulation and coastal flooding, e.g. ADvanced CIRCulation (ADCIRC, Luettich *et al.* 1992)

SWAN release version 41.20 included a new "package" of wave physics (referred to as ST6 physics). This package has new parameterizations of wind input, whitecapping, swell dissipation, wind speed scaling, and other processes (Rogers *et al.* 2012). The ST6 physics have been adopted by other wave models (e.g. NOAA's WaveWatch III, Liu *et al.* 2019), and it may become the preferred physics package for SWAN. However, because the ST6 physics package has changes to so many parameterizations, it is necessary to quantify its effects on wave predictions. Recent studies (e.g. Aydogan and Ayat 2021) have demonstrated the benefits of using the ST6 physics in the standalone version of SWAN, but its effects have not been quantified for the coupled ADCIRC+SWAN (Dietrich *et al.* 2011a), which is used for real-time forecasts during impending storms. Do the ST6 physics improve the ADCIRC+SWAN wave predictions?

For simulations of Hurricane Gustav (2008), we compared SWAN predictions using the ST6 physics with similar predictions using the "default" physics in two recent SWAN release versions. These three simulations are summarized in Table 1. These simulations used the EC2015 mesh, which was designed for tide predictions with relatively high resolution of nearshore and offshore regions, but which does not include floodplains. Details of the EC2015 mesh are given in Szpilka *et al.* (2016); the only changes for this study were the use of spatially variable parameters for Manning's n (with three classes of 0.02, 0.03, 0.04) and for the primitive weighting term in ADCIRC's generalized wave continuity equation (with three classes of 0.005, 0.02, 0.03). The storm simulations were driven by surface wind and pressure fields developed by OceanWeather Inc., with fields at 900-s intervals during the storm, and with an outer domain with coverage of the Gulf of Mexico at 0.05° resolution and an inner domain near the storm's landfall location at 0.015° resolution. Details of the atmospheric forcing are given in Dietrich *et al.* (2011b). The time steps for ADCIRC and SWAN were 1 s and 600 s, respectively, and the coupling interval was 600 s. SWAN was run with its default criteria for convergence of its significant wave heights, with a requirement that these criteria be met at 95 percent of the computational points, and convergence was achieved during each SWAN time step typically within about 5 iterations.

We quantify performance via comparisons to observations of significant wave heights, as collected by the National Data Buoy Center (NDBC). For each observation location, performance is quantified via root-mean-square errors (E_{RMS}):

$$ERMS = \sqrt{\Sigma^{N}_{t=1} (H_{p.i} - H_{o,1})^2/N}$$

in which H_p are the predicted significant wave heights at that buoy location in a model simulation, H_o are the observed significant wave heights as observed at a buoy location by the NDBC, and N is the total number of values in the time series. Values of E_{RMS} closer to zero indicate predicted values that were closer to the observed values, meaning more accurate simulation results. We focus specifically on predictions of significant wave heights in the following analyses. Analyses of other wave parameters are left for future work.

Gustav formed on 25 August 2008 and strengthened rapidly as it moved across the Gulf of Mexico. The storm created

Table 1.
Summary of SWAN release versions (41.10 and 41.31), physics parameterizations (Default and ST6), and associated input commands for the three tests considered herein.

Version-Physics	Input command(s)
v41.10-Default	GEN3 KOMEN AGROW
v41.31-Default	GEN3 KOMEN AGROW
v41.31-ST6	GEN3 ST6 4.70E-7 6.6E-6 4 4 UP HWANG VECTAU U10PROXY 28 AGROW SSWELL ARDHUIN 1.2

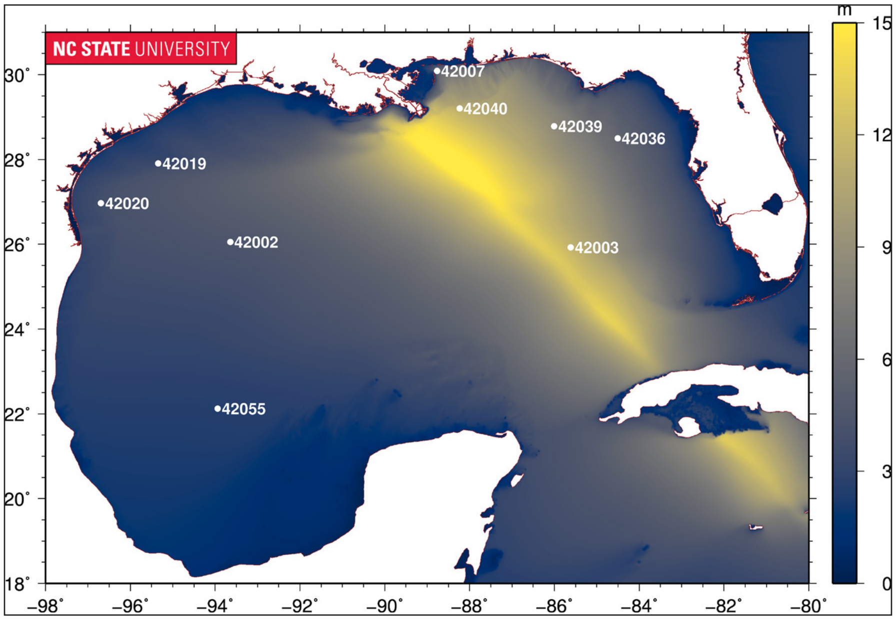

Figure 1. For Gustav (2008), contours of maximum significant wave heights (m) as computed by SWAN v41.10, and locations of NDBC buoys.

waves with significant heights as large as 12 m as observed at NDBC buoys, and it pushed storm surge into southeast Louisiana, causing the total water levels to be as large as 4 m at nearshore gauges (Dietrich *et al.* 2011b). Gustav made landfall on 1 September 2008 as a Category-2 hurricane, resulting in significant damages as well as seven casualties. Figure 1 shows the SWAN-predicted maximum significant wave heights along the storm track. Gustav was selected to test the new physics package because the storm's effects on the wave environment were well-documented in the Gulf of Mexico. Observations of significant wave heights were recorded for buoys near the storm track. As shown in Figure 1, nine buoys were selected for this analysis based on location relative to the storm track and availability of data for the duration of the storm. The observations at these buoys were used as a basis with which we could compare our simulation results to determine accuracy.

Figure 2 shows the time series of observed and predicted significant wave heights at the NDBC buoy locations. In most cases, the differences in the significant wave heights were small between the three simulations. The *v41.10-Default* and *v41.31-Default* results are very similar at almost all stations. However, in some cases (i.e. Buoys 42019, 42036, and 42039), the predicted wave heights were more accurate for the *v41.31-ST6* simulation. At these three buoy locations, the *v41.10-Default* results had peaks that were too high relative to the observations, including a peak of 5 m at Buoy 42019. However, the *v41.31-ST6* results were a better match to the peak significant wave heights including 3 m at Buoy 42019.

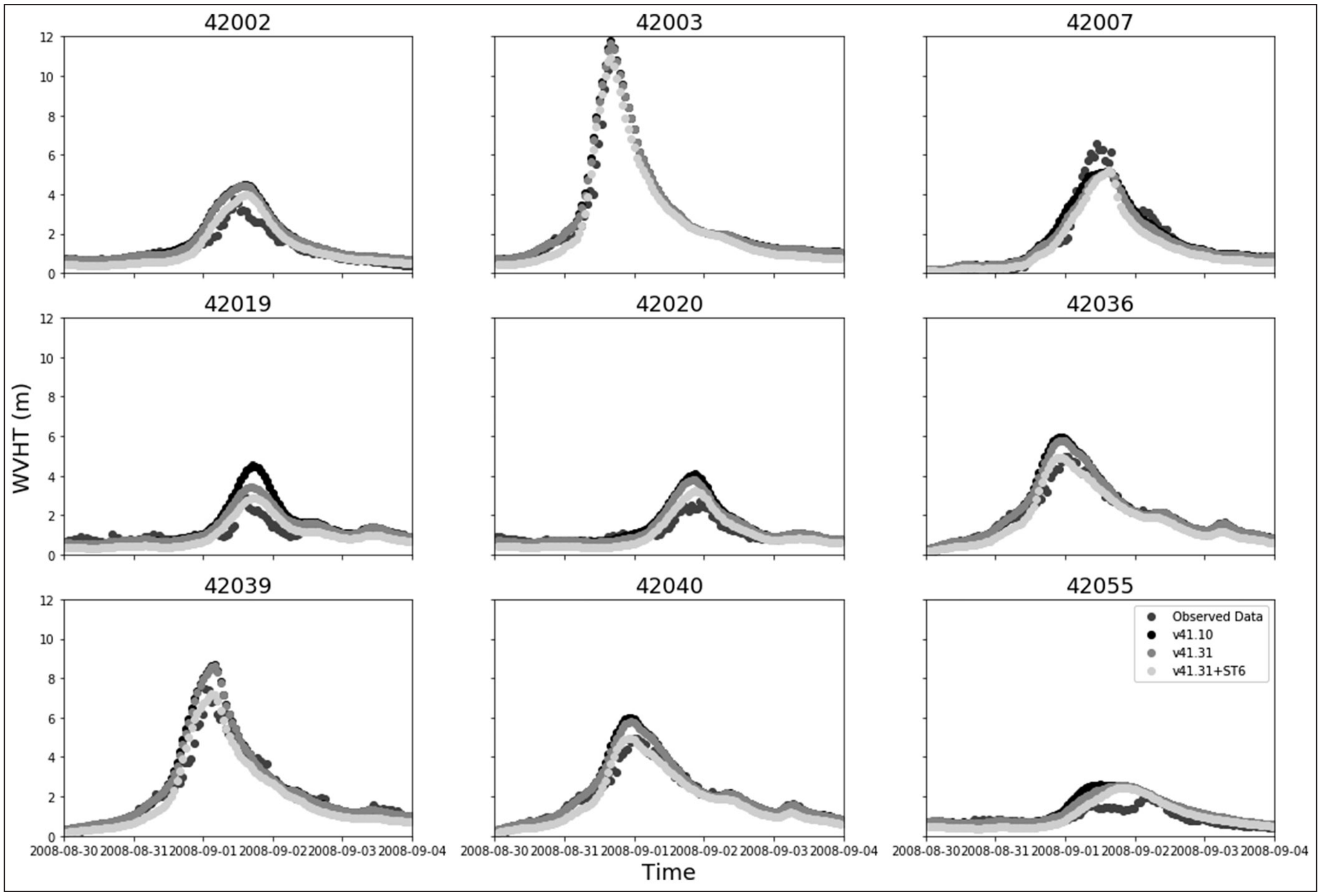

Figure 2. For Gustav (2008), time series of significant wave heights at nine NDBC buoys.

Figure 3 shows root-mean-square errors for the three combinations of release versions and physics parameterizations. For all nine buoy locations, *v41.31-ST6* produced the lowest E_{RMS}, meaning that the wave heights produced by this simulation were the most accurate.

For these simulations, from both the time series plots and the E_{RMS}, the *v41.31-ST6* simulation was consistently more accurate than simulations with the "default" physics parameterization. We recommend that SWAN users (and ADCIRC+SWAN users) should consider the ST6 physics in their storm simulations. Users will need to perform their own validations to feel confident in the performance of their models. But our results show that the ST6 physics can lead to more-accurate predictions of significant wave heights in storm simulations.

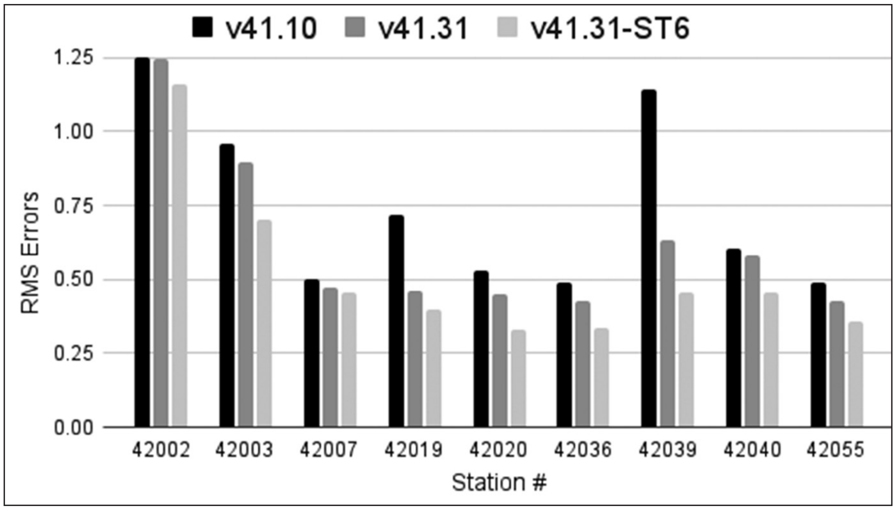

Figure 3. For Gustav (2008), root-mean-square errors for predictions of significant wave heights at nine NDBC buoys, with comparisons for SWAN versions and physics package.

REFERENCES

Aydogan, B., and B. Ayat, 2021. "Performance evaluation of SWAN ST6 physics forced by ERA5 wind fields for wave prediction in an enclosed basin." *Ocean Engineering*, 240, 109936.

Booij, N., Ris, R.C., and L.H. Holthuijsen, 1999. "A third-generation wave model for coastal regions, Part I, Model description and validation." *J. Geophysical Research*, 104, 7649-7666.

Dietrich, J.C., Zijlema, M., Westerink, J.J., Holthuijsen, L.H., Dawson, C.N., Luettich, R.A., Jensen, R.E., Smith, J.M., Stelling, G.S., and G.W. Stone, 2011a. "Modeling hurricane waves and storm surge using integrally-coupled, scalable computations." *Coastal Engineering*, 58, 45-65.

Dietrich, J.C., Westerink, J.J., Kennedy, A.B., Smith, J.M., Jensen, R.E., Zijlema, M., Holthuijsen, L.H., Dawson, C.N., Luettich, R.A., Powell, M.D., Cardone, V.J., Cox, A.T., Stone, G.W., Pourtaheri, H., Hope, M.E., Tanaka, S., Westerink, L.G., Westerink, H.J., and Z. Cobell, 2011b. "Hurricane Gustav (2008) waves and storm surge: Hindcast, validation and synoptic analysis in southern Louisiana." *Monthly Weather Review*, 139(8), 2488-2522.

Luettich, R.A., Westerink, J.J., and N.W. Scheffner, 1992. "ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts, and Estuaries, Report 1: Theory and Methodology of ADCIRC-2DDI and ADCIRC-3DL." United States Army Corps of Engineers.

Liu, Q., Rogers, W.E., Babanin, A.V., Young, I.R., Romero, L., Zieger, S., Qiao, F., and C. Guan, 2019. "Observation-based source terms in the third-generation wave model WAVEWATCH III: Updates and verification." *J. Physical Oceanography*, 49(2), 489-517.

Rogers, W.E., Babanin, A.V., and D.W. Wang, 2012. "Observation-consistent input and whitecapping dissipation in a model for wind-generated surface waves: description and simple calculations." *J. Atmospheric and Oceanic Technology*, 29(9), 1329-1346.

Szpilka, C., Dresback, K.M., Kolar, R.L., Feyen, J., and J.D. Wang, 2016. "Improvements for the Western North Atlantic, Caribbean and Gulf of Mexico ADCIRC Tidal Database (EC2015)." *J. Marine Science and Engineering*, 4(4), 72.