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Wind driven setup in east central Florida's Indian River Lagoon: Forcings and parameterizations

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ABSTRACT

High resolution hydrodynamic models are computationally expensive to run – especially if ensemble forecasts are desired. This can be problematic within coastal estuaries which are not well resolved by today's operational meteorological forecast models. As an alternative, this paper evaluates the wind forcing for three setup parameterizations (based on the Zuiderzee, modified Zuiderzee, and long wave equations) using a combination of observed setup from in-situ water level gauges and local wind observations. In addition, three methods are explored for developing hourly time series of wind forcing from 5-min observations: top of the hour, hourly mean, and wind run approach. The wind forcings, which are weighted by the length of two lagoon-oriented axes, are used to drive the setup parameterizations. The observed setup is used to tune each of the parameterizations via a least squares approach. The observation spread, linear model residuals, coefficient of determination (R^2), and root mean squared error (RMSE) indicate that the wind run out performs the other two methods. In terms of the three parameterizations, the modified Zuiderzee had consistently higher R^2 values, lower RMSE, and narrower 95% confidence intervals than the two other methods. This optimized parameterization is currently being used operationally to generate ensemble setup forecasts for the Indian River Lagoon, a restricted estuary on Florida's east-central coast. These simple ensemble forecasts are designed to guide the National Weather Service (NWS) in identifying potentially significant setup events that warrant high resolution hydrodynamic simulations.

1. Introduction

The National Weather Service (NWS) Nearshore Wave Prediction System (NWPS, van der Westhuysen et al., 2013), is designed to provide high resolution nearshore model guidance to coastal weather forecast offices. As a result, the NWPS does not include a hydrodynamic component and does not extend beyond the shoreline into coastal estuaries. Given the complex land-water mask and coastal geometry, hydrodynamic models require high spatial resolution (Weaver et al., 2016b), making them computationally expensive to run, particularly for ensemble forecasting. For example, the National Centers for Environmental Prediction (NCEP) has two operational atmospheric ensemble forecast systems including the Short Range Ensemble Forecast (SREF, Du and Tracton, 2001) and the Global Ensemble Forecast System (GEFS, Toth and Kalnay, 1993), both of which have more than 20 members. While it is not practical to run the full suite of hydrodynamic simulations on a high-resolution grid using wind forcing from each of the atmospheric ensemble members, a probabilistic approach that captures the magnitude and uncertainty associated with high impact wind events remains attractive. An inexpensive setup parameterization can serve as a proxy to generate probabilities for setup and wave height inside the coastal zone. Use of parameterizations because of their computational efficiency is not uncommon (e.g., Apotsos et al. (2008) tested and calibrated several widely used wave parameterizations for coastal management). The objective here is to develop and tune a system that can be forced by ensemble wind forecasts. In addition, the probabilistic product can be used to determine whether resources for a high resolution hydrodynamic model run are warranted and in the subsequent selection of the relevant wind forcing (i.e., a particular ensemble member) for a deterministic water level forecast. The goal is not to replace hydrodynamic models but rather to facilitate their use.

For the most part, setup parameterizations are used for engineering design (structural) purposes with a focus on threshold exceedance, i.e., what magnitude of wind speed, fetch and depth produce critical setup (Mostertman, 1963). The approach here is somewhat different since the focus is geared towards ensemble forecasting and model guidance. As a result, effort is spent in the development and evaluation of representative wind forcing that accounts for the local geometry, i.e., the lagoon orientation. Three different averaging methods are applied to surface wind observations and then used to force three setup parameterizations.

The Indian River Lagoon (IRL), located in east-central Florida (Fig. 1), is long (195 km), shallow (1–3 m), narrow (2–4 km), and has five inlets that connect it with the ocean, making it a restricted lagoon system (Kjerfve, 1986). In general, water movement in estuaries is influenced by atmospheric forcing, tidal action, and freshwater runoff

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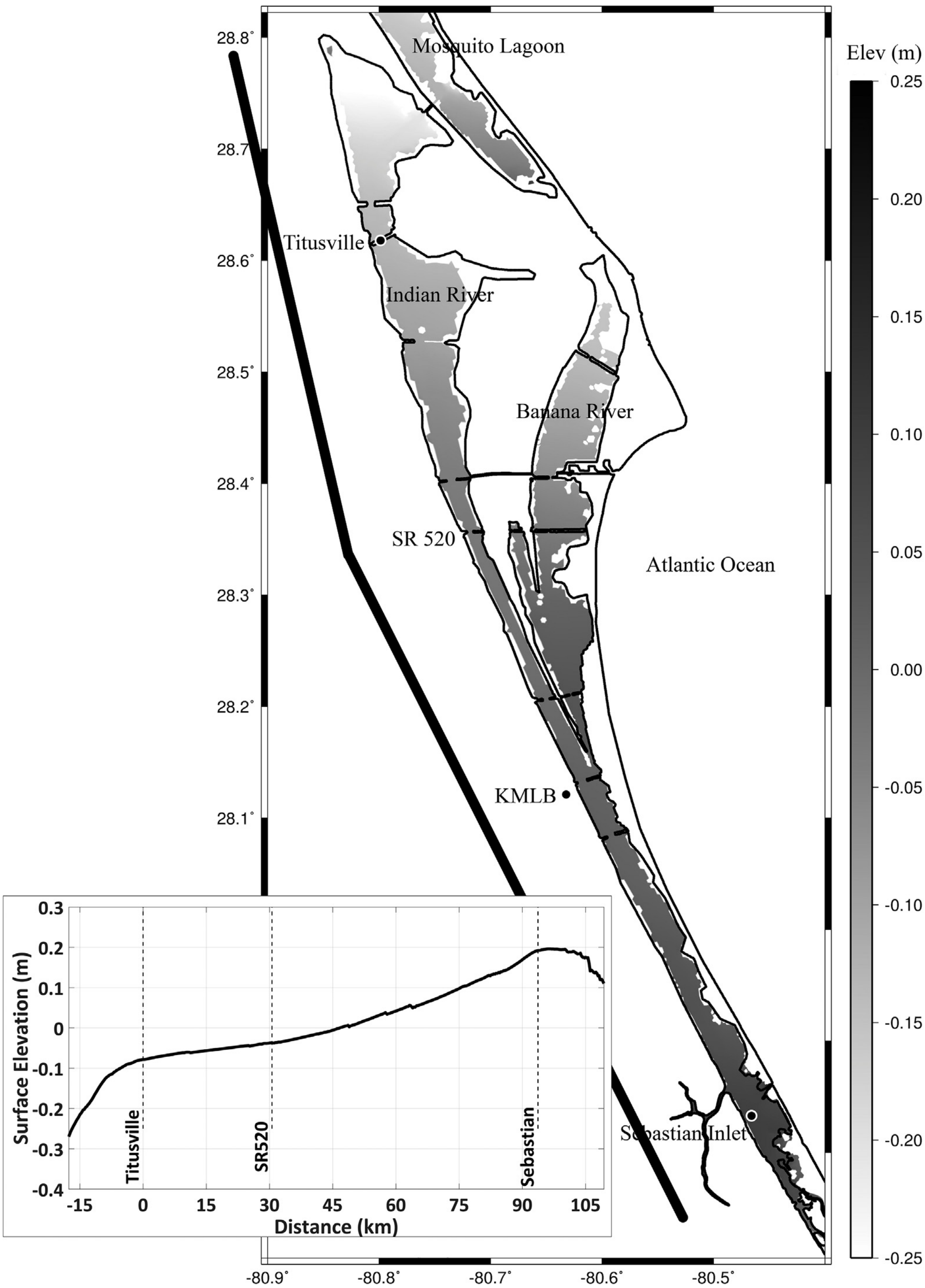

Fig. 1. The northern Indian River Lagoon (IRL) basin of study including: the sensor locations (Titusville and Sebastian Inlet), and the Melbourne National Weather Service Automated Surface Observing Station, KMLB. The bold black line approximates the orientation of the two lagoon axes (see text for details). Also shown are the water elevation anomalies (m, shaded) and a surface elevation transect (m, inset) from ADCIRC + SWAN during the peak setup on 7 March 2015.

(Reynolds-Fleming and Luettich, 2004). However, because of the restricted nature and orientation of the lagoon, the effects of tidal forcing are reduced and thus the IRL is primarily wind driven (Smith, 1990). Given its narrow geometry, the IRL is extremely fetch limited with its orientation providing setup favorable conditions only in the presence of persistent southeast (or northwest) winds. These events can cause local flooding along the IRL, property damage, erosion, and impact water quality as a result of enhanced nutrient loading, resuspension, and sediment transport. In terms of the latter, Csanady (1973) examined water motion forced by wind stress on long lakes (where the depth contours run parallel to the shores, similar to the IRL) and concluded that, in nearshore areas, the wind-forced component of the flow dominates. In fact, the wind-forced component was more important in transport than either seiching or oscillating movements, both of which are present in the IRL (Weaver et al., 2016a). Additionally, downwind-driven water level increases are able to support substantially higher wave heights given the depth-limited nature of the IRL. Our data show it is not uncommon to see water level increases on the order of 40–50 cm during frontal passages or approaching cyclones, yielding a near 50% increase in water levels in some locations along the IRL.

A brief overview of the setup parameterizations is presented, followed by a description of the observational datasets (water level and