Coastal Engineering 131 (2018) 12–30

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

Comparison of a mid-shelf wave hindcast to ADCP-measured directional spectra and their transformation to shallow water

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ARTICLE INFO

Keywords:
Wave measurement
Wave hindcast
Bottom friction
WAM
SWAN
ADCP

ABSTRACT

In conducting a cross-shelf wave transformation experiment off the Atlantic coast of north Florida, a unique opportunity was exploited in which an Acoustic Doppler Current Profiler (ADCP) instrument was installed 30 km offshore at the exact location of one of the archive-nodes of a WAM-like wave hindcast model (OWI3G). A second ADCP was installed 550 m from shore. Approximately 53 days of directional wave spectra collected with the two ADCPs are used to (a) locally test the reliability of a subsequent update of the hindcast, (b) document the loss in energy as the waves crossed the broad, relatively shallow continental shelf between the two instruments, (c) test the ability of the SWAN (Gen2) nearshore wave transformation model to replicate the measurements taken in shallow water when driven by the offshore ADCP spectra, and (d) reassess the spectral transformation results when the offshore hindcast is used as input. In addition to direct comparison of the time series of frequency spectra and the directional distribution of energy, typical spectral parameters are each subjected to standard error tests. Results indicate that the offshore hindcast performs well in replicating significant wave height, fairly well for mean period, but not as reliably for peak period. Directional spreading in deeper water is generally well-represented, although vector mean direction is not, and is believed due to the proximity of the coast to the hindcast node. The nearshore model requires an order-of-magnitude reduction in bed roughness from its default value before agreement in wave energy at the nearshore ADCP can be achieved. Outcomes of the error tests for the hindcast-driven versus the ADCP-driven nearshore results (after roughness calibration) are quite similar, but nevertheless indicate that transformed wave period, wave direction, and directional spreading require improvement.

1. Introduction

It is common practice in coastal engineering to develop nearshore wave information by transforming deepwater hindcast results using one of the many available nearshore spectral wave transformation models (*e.g.* STWAVE, Smith et al., (2001), Smith (2007); SWAN, Booij et al. (1999), SWAN Team (2013)). However, one persistent issue in conducting wave hindcasting and forecasting in deep water is the inability to fully validate the results with reliable *in situ* measurements. Until now the most commonly used instrument has been the wave-following buoy. Since first proposed by Longuet-Higgins et al., (1963) development of wave surface buoys has progressed over the past several decades to the point where the frequency spectrum of a wave field can be measured with confidence under most environmental conditions (*e.g.* Matti et al. (1981); Sand (1984); Steele et al., (1992), O'Reilly et al., (1996)) generally to a limit in frequency of nominally 0.4 Hz. However, the ability to accurately measure the *directional distribution* of high frequency wave energy in deeper water is lacking, though such measurements are key to validating the physics of wave-wave interactions and the approximations thereof used in spectral wave generation models (Stopa et al., 2016). According to Strong et al., (2001) and Jeans et al., (2003) any direction-capable 'triplet-based' instrument can make only coarse estimates of wave direction and spreading, and cannot resolve multiple wave fields approaching from different directions. Also, O'Reilly et al., (1996) found biases in directional spread in measurements from buoys, as did Jeans et al., (2003). These issues obviate the use of many of the simpler systems. Work (2008) has shown that using a Maximum Entropy Method (Lygre and Krogstad, 1986; Miles, 1986; Nwogu, 1989), a Triaxys buoy, which uses six measurement elements, was able to resolve sea and swell components arriving from different directions. Other systems such as cloverleaf buoys (Mitsuyasu et al., 1975), slope arrays (*e.g.* Herbers and Guza (1989); Carvalho and Parente (2000)) and remote sensing with radar (*e.g.* Izquierdo et al., (2005)) have been developed and tested. Until recently the state-of-the-art in directional wave measurement has been

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https://doi.org/10.1016/j.coastaleng.2017.10.009
Received 14 December 2016; Received in revised form 31 July 2017; Accepted 22 October 2017

0378-3839/

the use of an array of bottom-mounted pressure transducers (Pawka, 1983). However if high frequency directional spectra are sought, the use of this technology is limited to relatively shallow water (~8 m). Invention and study continue.

1.1. The Acoustic Doppler Current Profiler (ADCP) wave gauge

The Acoustic Doppler Current Profiler (ADCP) is capable of measuring both current profiles and the vertical distribution of wave-induced water particle motions, and is routinely used in collecting directional wave information in coastal waters. During their advent, ADCP instruments were first tested against directional wave buoys (see, *e.g.* Herbers et al., (1991)) and such comparisons have continued (Jeans et al., (2003); Hoitink et al., (2007); Work (2008); Herbers and Lentz (2010)). The ability of the ADCP to measure wave spectra at much higher directional resolution than most buoys was established by comparisons to the '8-meter array' of pressure transducers operated by the U.S. Army Field Research Facility (Terray et al., 1997; Terray et al., 1999). However if the higher frequency directional wave data are sought, ADCP instruments are also limited to relatively shallow water. This is because the Nyquist frequency is determined by the beam spacing at the lowest layer in the water column utilized by the instrument, and not by the sampling rate (http://www.rdinstruments.com/waves.aspx). An attempt was made by Pedersen and Siegel (2008) to address this issue by attaching the acoustic instrument to a subsurface buoy, thereby bringing it closer to the surface. However the inability to effectively compensate for the motion of the buoy precluded use of the multi-layer advantage of the acoustic technology. Consequently there has not been a means to closely check the veracity of the directional information provided by hindcasts in deeper water, particularly at higher wave frequencies. As described below however, one occasion to compare an offshore hindcast to data from a bottom-mounted, fixed ADCP has presented itself. Although not perfectly contrived, the results of this undertaking are intriguing and encouraging.

1.2. The MSC hindcast

The development of the 'MSC' wave hindcast was performed by Oceanweather, Inc. (OWI), and is fully described in Swail et al., (2006). The wave model applied, OWI3G, is based on the third-generation spectral wave model WAM (WAMDI Group, 1988), but with several modifications as described in Swail et al. Being a 'third generation' model, nonlinear wave-wave interactions are computed explicitly using the Discrete Interaction Approximation (DIA), also described in WAMDI Group (1988). Germane to the examination and discussion of cross-shelf wave energy losses due to bottom friction to be presented in Section 4.1 below, it is noted that the OWI3G model utilizes the JONSWAP bottom friction formulation (Hasselmann et al., (1973)) but adopts a uniform value for the friction coefficient, $\Gamma = 0.076\ m^2\ s^{-3}$, which is twice that originally proposed for WAM based on pure swell attenuation in the North Sea JONSWAP experiment.

The results of the original MSC wave hindcast and each subsequent update have been compared to *in situ* measurements made by surface wave buoys throughout the North Atlantic and to remotely sensed satellite altimeter data. However only certain spectral parameters have been examined, *i.e.* energy-based significant wave height (H_s), peak and mean wave period (T_p, T_m), and vector mean direction ($\bar{\theta}$). It is also noted that because only a limited number of buoys are equipped to measure wave direction, there is roughly an order-of-magnitude fewer directional observations available for validation (Swail et al., (2006)). In the present effort in addition to bulk parameters provided by the MSC hindcast, the time series of the detailed distribution of wave energy with frequency, and particularly with wave direction, will be compared to that measured by a collocated ADCP.

2. Objectives and methods

A cross-shelf wave transformation experiment was conducted from November 8, 2008 until January 11, 2009, during which a pair of ADCP instruments was deployed in order to measure directional wave spectra simultaneously in both deep and shallow water. The data collected were to be used to (a) locally test the veracity of the subsequent MSC wave hindcast update, particularly in regard to the directional distribution of energy, (b) document the loss in energy as the waves crossed the broad continental shelf between the two instruments, (c) test the ability of the SWAN spectral wave transformation model to replicate the measurements taken in shallow water, and (d) assess the veracity of the results of the transformation model when the MSC is used as input as compared to using the data measured by the offshore ADCP.

2.1. Instrument deployment and data collection

The offshore ADCP ($ADCP_O$), a self-recording RD Instruments 1200 kHz Sentinel, was purposely deployed at the location of grid node #7332 of the MSC wave hindcast, nominally 30 km offshore of St. Johns County, Florida (Lat-Long 30.0011° N, 81.0012° W) as indicated in Fig. 1. This unique opportunity was afforded by the fact that this node was one of the shallowest of the MSC nodes archived along the Florida Atlantic coast (24 m depth), enabling the use of a diver-installed, jetted-pipe mooring that is not susceptible to burial or to movement caused by scour induced by currents or long-period waves. Although decommissioned in February of 2014, the National Data Buoy Center (NDBC) buoy 41012, which was located approximately 43 km farther offshore (38 m depth) as shown in Fig. 1 (Lat-Long 30.0400° N, 80.55000° W), had directional capability and provided measurements of H_s, T_p, T_m, and peak wave direction (θ_p) to contrast with the ADCP data, as well as providing a general check of the hindcasted wind information used in this study. The other adjacent MSC grid nodes are also shown in Fig. 1 for reference, with their spacing being equivalent to 0.5° in latitude (~55 km).

Although being a high-frequency instrument and deployed at a depth of 24 m (mounted approximately 1 m above the bed), $ADCP_O$ had sufficient signal-to-noise ratio so that frequency-direction wave spectra

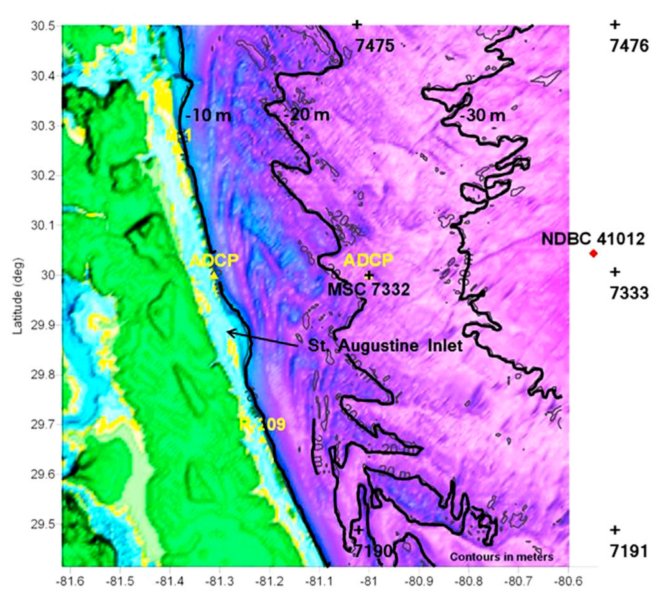

Fig. 1. Site map of the cross-shore wave transformation experiment off St. Johns County, Florida showing the locations of the offshore ADCP collocated with the MSC deepwater hindcast node #7332 (24 m depth), the nearshore ADCP (7.5 m depth) and the NDBC directional wave buoy 41012 (38 m depth). Adjacent MSC nodes shown for reference.