Ocean Modelling 100 (2016) 78–95

Contents lists available at ScienceDirect

Ocean Modelling

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

Thirty-four years of Hawaii wave hindcast from downscaling of climate forecast system reanalysis

Ning Li[a], Kwok Fai Cheung[a,*], Justin E. Stopa[b], Feng Hsiao[c], Yi-Leng Chen[c], Luis Vega[d], Patrick Cross[d]

[a] Department of Ocean and Resources Engineering, University of Hawaii, Honolulu, HI 96822, USA
[b] Laboratory of Ocean Physics and Satellite Oceanography, University of Brest, Plouzane, France
[c] Department of Atmospheric Sciences, University of Hawaii, Honolulu, HI 96822, USA
[d] Hawaii Natural Energy Institute, University of Hawaii, Honolulu, HI 96822, USA

ARTICLE INFO

Article history:
Received 15 September 2015
Revised 5 January 2016
Accepted 1 February 2016
Available online 10 February 2016

Keywords:
Swells
Wind waves
Wave hindcast
Island sheltering
Spectral wave models
Weather Research and Forecasting model

ABSTRACT

The complex wave climate of Hawaii includes a mix of seasonal swells and wind waves from all directions across the Pacific. Numerical hindcasting from surface winds provides essential space-time information to complement buoy and satellite observations for studies of the marine environment. We utilize WAVEWATCH III and SWAN (Simulating WAves Nearshore) in a nested grid system to model basin-wide processes as well as high-resolution wave conditions around the Hawaiian Islands from 1979 to 2013. The wind forcing includes the Climate Forecast System Reanalysis (CFSR) for the globe and downscaled regional winds from the Weather Research and Forecasting (WRF) model. Long-term in-situ buoy measurements and remotely-sensed wind speeds and wave heights allow thorough assessment of the modeling approach and data products for practical application. The high-resolution WRF winds, which include orographic and land-surface effects, are validated with QuickSCAT observations from 2000 to 2009. The wave hindcast reproduces the spatial patterns of swell and wind wave events detected by altimeters on multiple platforms between 1991 and 2009 as well as the seasonal variations recorded at 16 offshore and nearshore buoys around the Hawaiian Islands from 1979 to 2013. The hindcast captures heightened seas in interisland channels and around prominent headlands, but tends to overestimate the heights of approaching northwest swells and give lower estimates in sheltered areas. The validated high-resolution hindcast sets a baseline for future improvement of spectral wave models.

1. Introduction

Hawaii has unique wave climate associated with its North Central Pacific location and massive archipelago. Fig. 1 provides a location map to illustrate the prominent wave regimes and geographical features. Extratropical storms near the Kuril and Aleutian Islands generate swells toward Hawaii from the northwest to north during the boreal winter. The south facing shores experience moderate swells from the year-round Southern Hemisphere Westerlies that are augmented by mid-latitude cyclones in the boreal summer. The persistent trade winds generate waves from the northeast to east throughout the year, while subtropical cyclones during the winter and passing cold fronts can generate waves from all directions. The steep volcanic mountains speed up the wind flows in the channels and create prominent wakes leeward of the Hawaiian Islands (Yang et al., 2005; Nguyen et al., 2010; Hitzl et al, 2014). These localized wind flows together with island sheltering create regional wave patterns with large spatial and temporal variations (Aucan, 2006; Caldwell et al., 2009; Stopa et al., 2011).

There are increasing demands for long-term wave data in support of ocean renewable energy planning, marine ecosystem assessment, shoreline management, and infrastructure development in Hawaii. Altimeters aboard polar orbiting satellites have the advantage of providing significant wave heights with global expanse. The observations are available along satellite tracks at time intervals between 10 and 35 days. The lack of wave direction and period in a multi-modal sea state as well as contamination of the signals by landmasses hamper their application in coastal regions. Offshore and nearshore buoys have provided in-situ wave measurements at strategic locations along the island chain as shown in Fig. 1. Some of the buoys recorded over 30 years of wave data and most of the recent measurements are directional. Despite their ability to fully record the sea state, they are limited to discrete

---

* Corresponding author. Tel.: +1 808 956 3485; fax: +1 808 956 3498.
E-mail addresses: ningli@hawaii.edu (N. Li), cheung@hawaii.edu (K.F. Cheung), Justin.Stopa@ifremer.fr (J.E. Stopa), hsiaof@hawaii.edu (F. Hsiao), yileng@hawaii.edu (Y.-L. Chen), luisvega@hawaii.edu (L. Vega), pscross@hawaii.edu (P. Cross).

http://dx.doi.org/10.1016/j.ocemod.2016.02.001

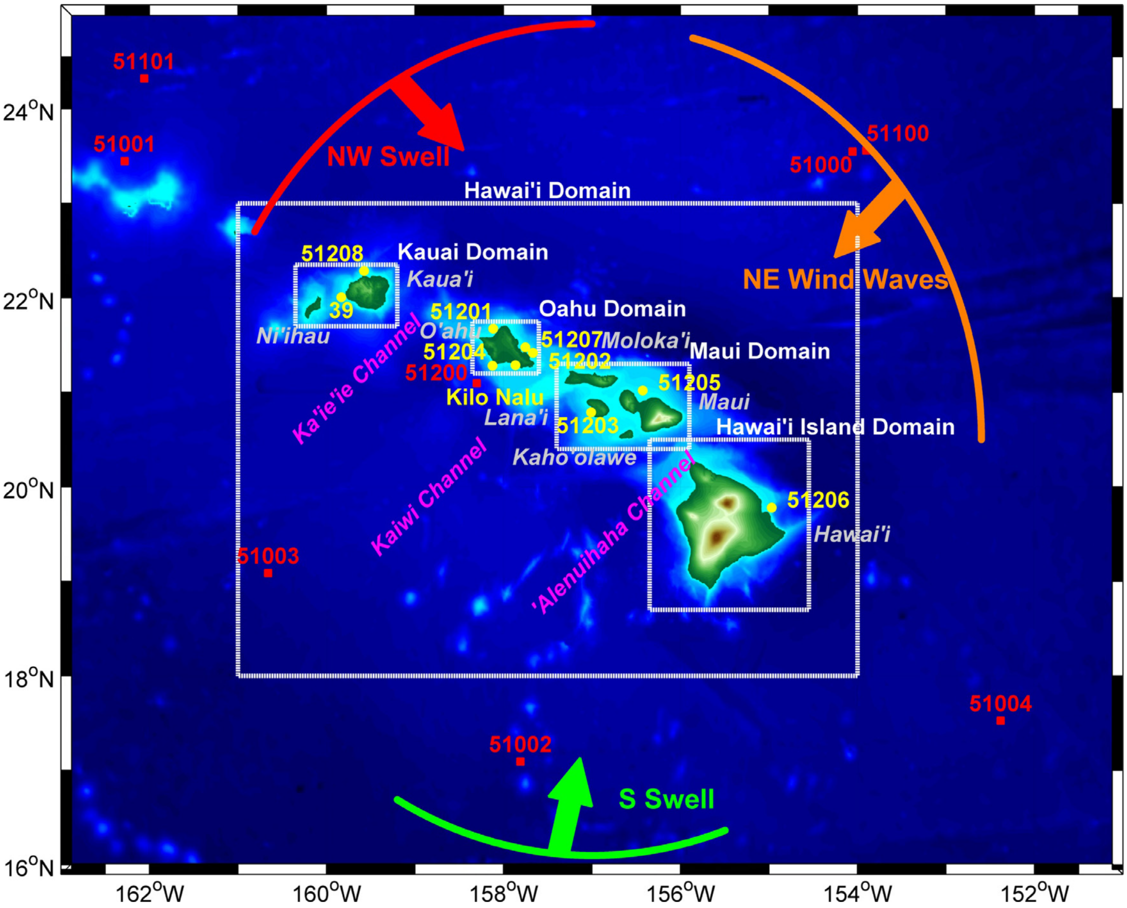

Fig. 1. Illustration of Hawaii wave climate, location map for buoys and geographical features, and layout of nested computational grids for WAVEWATCH III and SWAN.

locations and subject to downtime due to equipment failure and maintenance. A detailed description of the complex wave climate in Hawaii is best accomplished by numerical modeling, while measurements from altimeters and buoys are useful for validation of the model results and assessment of the model performance.

Third generation spectral wave models, such as WAVEWATCH III of Tolman (2008) and SWAN (Simulating WAves Nearshore) of Booij et al. (1999), are proven tools in describing the multi-modal sea states of Hawaii (Stopa et al, 2011). Despite being developed for open oceans and shelf seas, WAVEWATCH III is able to depict shadowing of the wave field by the Hawaiian Islands and heightened seas with small fetches in interisland channels and around headlands (Stopa et al., 2013; Foster et al., 2014). SWAN is better suited for near-shore environments due to its efficient implicit scheme to compute wave processes in fine resolution and ability to account for triad wave interactions in shallow water. Filipot and Cheung (2012) provided additional parameterizations for energy dissipation due to wave breaking and bottom friction in the fringing reef environment of Hawaii. The nesting of WAVEWATCH III and SWAN has proven its effectiveness in modeling wave generation and propagation from the open ocean to the shore.

High-quality global and regional wind forcing is critical for modeling of the multi-modal seas in Hawaii. Reanalysis datasets provide an opportunity to reproduce global wave conditions with high fidelity (Arinaga and Cheung, 2012; Caires et al., 2004; Chawla et al., 2013; Stopa et al., 2013). The Climate Forecast System Reanalysis (CFSR) of NOAA NCEP was generated from a suite of coupled ocean, land, ice, and atmospheric models with assimilation of observations in three space dimensions (Saha et al., 2010). Its products include hourly surface winds on a 0.5° grid from 1979 to 2010. The same model system produces the CFS version 2 reforecast data with 0.205° resolution from 2011 onward as an extension of CFSR (Saha et al., 2014). The ECMWF Reanalysis (ERA) Interim includes coupling to a spectral wave model and a 4-dimensional assimilation method (Dee et al., 2011). It has surface wind data every 3 h with a ∼0.7° grid spacing from 1979 to present. Stopa and Cheung (2014) inter-compared the wind speeds from CFSR and ERA-Interim with altimetry and buoy observations, and concluded that although both products have good spatial homogeneity and consistent levels of errors, CFSR provides better descriptions of the upper percentile winds for wave hindcasting.

The orographically induced airflow over Hawaii waters is not resolved by global reanalysis. The wind flow is significantly modified by steep volcanic mountains of up to 4000 m high and islands of up to 140 km across as well as the diurnal land–sea thermal contrast (Yang et al., 2005; Nguyen et al., 2010; Carlis et al., 2010). High-resolution wind data from locally calibrated atmospheric models is crucial for hindcasting the wave conditions around the Hawaiian Islands (Stopa et al., 2011, 2013). With proper descriptions of lower boundary conditions such as terrain, vegetation cover, and soil type, high-resolution models have considerable skills in simulating the island-scale airflow, weather climate, and ocean surface winds (e.g., Zhang et al., 2005; Yang et al., 2005; Carlis et al., 2010; Nguyen et al., 2010). The Weather Research and Forecasting (WRF) model of Skamarock and Klemp (2008) has become a standard tool for Hawaii regional climate studies (Hitzl et al., 2014). In addition, the high-resolution WRF model was employed for simulation of a heavy rainfall event over Oahu associated with a Kona storm and a winter cold front in the mid-Pacific by Tu and Chen (2011)