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Spectral wave conditions in the Colombian Pacific Ocean

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ABSTRACT

A comprehensive characterization of the wave conditions in the Colombian Pacific based on wave spectra is presented. The spectral approach offers a detailed description of the different wave regimes, their associated meteorological conditions and their variation in time and geographical space. To this end, two complementary data sources are used, the first is representative for the near-shore zone and comes from observations of the local monitoring network. The second comes from numerical wave model results that cover the open ocean. The measured data used are the first systematically collected spectral wave data in the Eastern Equatorial Pacific. Modelled spectra correspond to the ERA-Interim database of the European Centre for Medium-Range Weather Forecasts that spans 35 years. An indicator for statistical analysis of the wave spectra has been introduced which basically consists of the occurrence probability of spectral partitions. This indicator has proved to be skilful for the task of defining spectral wave systems of both model and, the more challenging, measured spectra. Following the spectral approach and using this new indicator, six main wave regimes are found in the study area. Two of these systems have well defined swell characteristics that are originated outside the study area in the northern and southern hemispheres. Other three wave systems are to a certain extent associated to the local winds, and in general may be classified as old wind-seas. These are found to flow northeastwards, westwards, and southwards. The sixth system is composed of locally generated wind waves of relatively low magnitude that propagate in several directions. The time variability of these wave systems is highly dependent on the boreal and austral winter storms and on the tropical conditions, in such a way that the wave energy propagation to the region is rather constant along the year, but their origin and characteristics vary significantly.

1. Introduction

The focus of the present study is the characterization of the wave conditions in the Colombian Pacific Zone using spectral wave data from both *in-situ* measurements and numerical model results. The spectral approach needs to be emphasized because wave conditions in the study area are rather complex due to the presence of swells arriving from different parts of the Pacific Ocean. Under these conditions, integral wave parameters like significant wave height, mean wave period, and mean wave direction (H_{m0}, $T_{m\text{-}1,0}$, θ_m, see Appendix A for definitions) poorly describe the complexity of the wave field because they correspond to vectorial means. On the contrary for many applications like climate assessment, navigation, structural design, among others, it is more important to know which (two or more) wave systems are involved, and what are their specific characteristics, rather than having an averaged value (e.g., WMO, 1998). The wave spectrum is the most standard approach to statistically describe the wave conditions, and that is typically derived from the measured data of modern instrumentation and directly from numerical spectral models (e.g., Holthuijsen, 2007). In the spectral approach, the complexity of the sea surface is represented as the superposition of a finite number of harmonic components of different frequencies and directions (i.e., Fourier representation). This representation gives a complete description of the sea surface in a stochastic sense (Barber and Ursell, 1948; Deacon, 1949; Ochi, 2005).

The Colombian Pacific area is under the influence of the InterTropical Convergence Zone (ITCZ), a global scale phenomenon that encircles the Earth along the tropics. The ITCZ is where the northerly and southerly trade winds converge (with respectively southwesterly and northwesterly predominant flow directions). Because of this,

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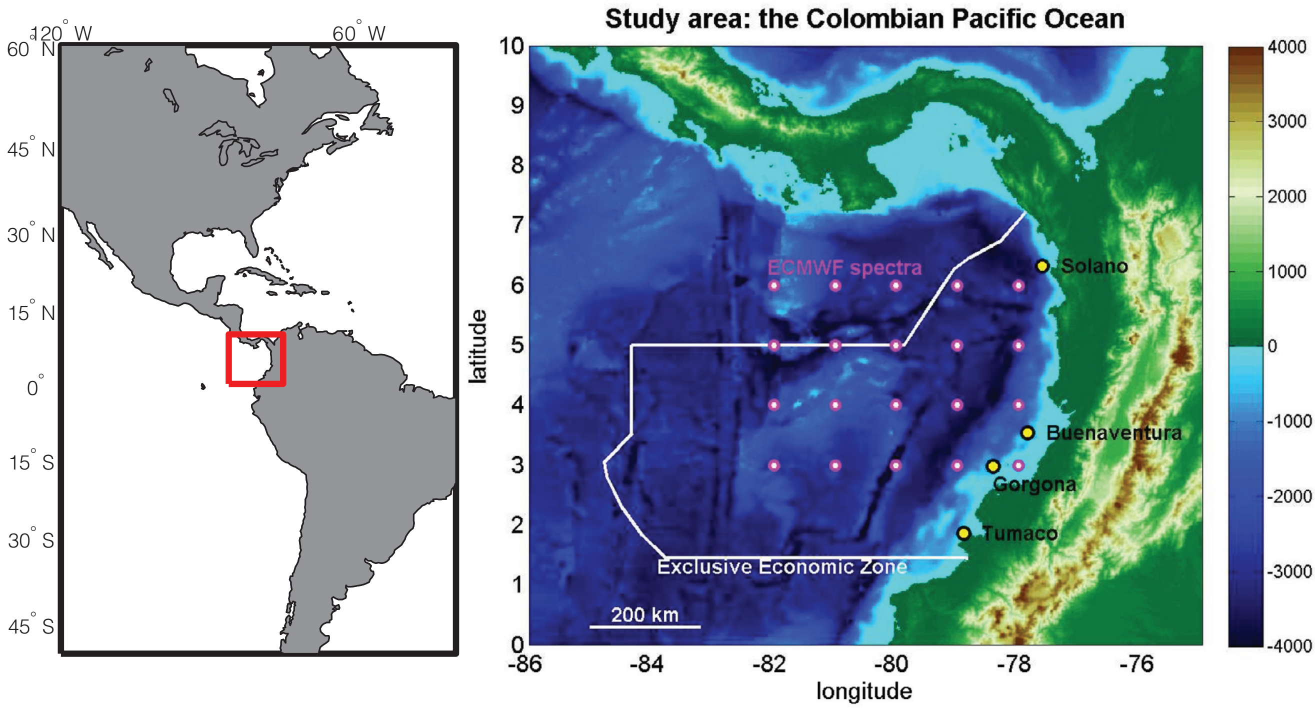

Fig. 1. The Colombian Pacific. Orography and bathymetry data from Smith and Sandwell (1997). The vertical colour bar scale indicates metres. The Exclusive Economic Zone limits are indicated in white (data from marineregions.org, 2014). The ECMWF spectral output points, and the DIMAR moorings are shown in magenta and yellow respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

mean wind speeds in the ITCZ are typically low with the presence of seasonal and specific events of moderate magnitudes (e.g., Raymond et al., 2006). In addition, the boreal and austral winter activities influence the latitude of the ITCZ location, and these variations drive the meteorological conditions of the region (e.g., Barry and Chorley, 2009). Apart from the ITCZ, other interesting meteorological phenomena in the area are the wind jets flowing through the mountain passes of Central America. These derive from the large pressure gradients between the northern cooler atmospheric masses of North America and the Caribbean region and the warmer air masses of the Pacific. These are the so called Tehuantepec, Papagayo, and Panama wind jets (e.g., Chelton et al., 2000a, 2000b; Schultz et al., 1998). The dynamics of both the ITCZ and the wind jets of Central America generate to a large extent the local wind waves. However, the main source of wave energy is due to swells originated outside the area, especially in the extratropical storm belt of the southern hemisphere. These swell sources can be traced back to areas as remote as the Antarctic region (e.g., Alves, 2006; Collard et al., 2009; Portilla, 2012; Semedo et al., 2013).

Two main wave data sources constitute the basis to characterize the wave conditions in the Colombian Pacific. The first are observations from a local monitoring network owned by DIMAR (*Dirección General Marítima de Colombia*) composed of four directional Triaxys buoys arranged along the Colombian Pacific coast moored at depths of about 130 m. This network has been operational since 2009, with several gaps due to failure or maintenance (CIOH, 2014). The second data source corresponds to numerical results from the WAM wave model operated by the European Centre for Medium-Range Weather Forecasts (ECMWF, Reading, UK). This data source consists of time series of directional wave spectra from 1979 to 2013 (Dee et al., 2011). From the computational grid of WAM, twenty locations within the study area have been used (see Fig. 1). The purpose of combining these two data sources for the analysis is to provide an overall view of the wave characteristics using the best information available at present, quality controlled observations in the near-shore zone and validated model results in the open ocean. Other data consisting of model gridded integral parameters are also incorporated into the analysis. Details of the overall database are given in Section 2.

Naturally each data source has advantages and disadvantages. For instance, measuring buoys are specifically placed for serving coastal applications and therefore they are located rather close to the coast. Nevertheless the moorings are in sufficiently deep water in this case so that the swell characteristics are not significantly influenced by bathymetry and can be assessed rather neatly. However, depending on the specific location, buoys can be sheltered from certain incoming wave directions. This affects the long-term wave characteristics at the study site. Specifically the buoys located in the northern part of the considered area are partially sheltered from waves coming from the North Pacific (see Fig. 1), but are directly exposed to waves coming from the South Pacific. The reverse is true for the buoys located in the southern part. In addition, data discontinuity is almost impossible to avoid in observations and that is always an inconvenience. Other disadvantages of measured data are possible measurement errors, which are dealt with here using a dedicated quality control procedure. Finally, buoys are location specific, so they provide information at one point only, contrarily to the modelled data which provide detailed spatial and temporal information. The two data sources, modelled and measured ones, are thus to a large extent complementary. However, we stress that a comparison is not intended here, because the two data sources are not directly comparable. The main reason is that the model data from ECMWF correspond to a global grid implementation which is not designed to resolve near-shore processes. Therefore, any comparison can only be done qualitatively and the main purpose here is to use the two sources to provide on the whole the best comprehensive picture of the local wave climate presently possible.

Although at present the wave spectrum is the standard variable for wave representation, the methods for describing it statistically