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GOW2: A global wave hindcast for coastal applications

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ABSTRACT

Global wave hindcasts provide wave climate information for long time periods which helps to improve our understanding of climate variability, long term trends and extremes. This information is extremely useful for coastal studies and can be used both directly or as boundary conditions for regional and local downscalings. This work presents the GOW2 database, a long-term wave hindcast covering the world coastline with improved resolution in coastal areas and along ocean islands.

For developing the GOW2 hindcast, WAVEWATCH III wave model is used in a multigrid two-way nesting configuration from 1979 onwards. The multigrid includes a global grid of half degree spatial resolution, specific grids configured for the Arctic and the Antarctic polar areas, and a grid of higher resolution (about 25 km) for all the coastal locations at a depth shallower than 200 m. Available outputs include hourly sea state parameters (e.g. significant wave height, peak period, mean wave direction) and series of 3-h spectra at more than 40000 locations in coastal areas.

Comparisons with instrumental data show a clear improvement with respect to existing global hindcasts, especially in semi-enclosed basins and areas with a complex bathymetry. The effect of tropical cyclones is also well-captured thanks to the high resolution of the forcings and the wave model setup. The new database shows a high potential for a variety of applications in coastal engineering.

1. Introduction

Many coastal applications require an accurate representation of the wave climate, especially in data sparse regions [55]. For example, the evaluation of wave power (e.g. [42,41,46]), the effect of wave energy on ecosystems (e.g. [39]) or the design of marine structures (e.g. [18]). Instrumental data are valuable for the analysis of the wave field although these data also have limitations. Buoys directly measure sea-state parameters in specific coastal locations, nevertheless buoys are not regularly distributed around the world and many coastal regions are missing in-situ records. Altimetry data from satellites (e.g. [25,58]) provide significant wave height sea-state parameter for more than 20 years, however satellite data are not available on the coastal and high latitude regions and altimeter products do not provide spectral and wave period information. An alternative for obtaining long-term and mostly homogeneous descriptions of global wave climate is using numerically generated wave hindcasts. Continuous improvements have been implemented in the third generation wave numerical models during the last years (e.g. [45,47,59]) and nowadays numerical simulations provide accurate information of the wave climate, greatly complementing observational data in terms of resolution and coverage.

In general, one of the key drivers limiting the quality of the global wave model results is the forcing used (i.e. winds and ice coverage). Forcing fields for global wave hindcasts can be obtained from reanalysis products. There are a variety of these products, with different resolution, assimilated data, and historical period covered. For example, NOAA-CIRES twentieth Century Reanalysis (20CR, [14]) starts in 1871 and only assimilates sea level pressure data, while NCEP-NCAR Reanalyisis I (NNRI, [27]) starts in 1948 and assimilates data from many different sources. ECMWF Interim Reanalysis (ERA-INTERIM, [15]) and NCEP Climate Forecast System Reanalysis (CFSR, [43]) start in 1979 when data from satellite became available for the assimilation system, which reduced errors over regions not well covered by in-situ observations, such as the ocean surface and the southern hemisphere.

The most appropriate reanalysis for a wave hindcast depends mainly on the period of interest. Long reconstructions of wave climate require long period reanalyses. For example, Reguero et al. [42] developed GOW, a $1.5° \times 1°$ global wave hindcast from 1948 to present based on NNRI, and Bertin et al. [6] developed a 1° wave hindcast from 1900 to 2008 in the North Atlantic based on 20CR. On the other hand, there are reanalyses covering a shorter period but with better physics and higher resolution. These reanalyses are more adequate for wave hindcasts aiming at representing wave climate as accurately as

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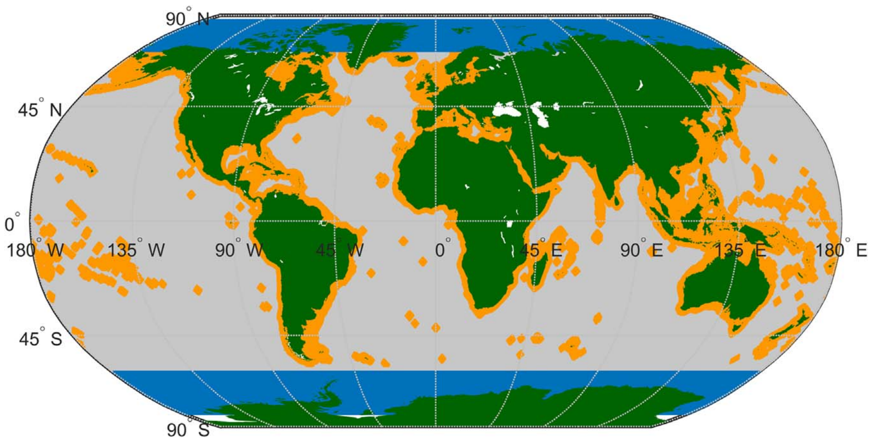

Fig. 1. Model domains. Global (0.5°×0.5°) in light gray, Arctic and Antarctic (0.25° latitude×0.5° longitude) in blue, and Coastal (0.25°×0.25°) in orange. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

possible. For example, Chawla et al. [12] developed a wave hindcast with a 0.5° global grid from 1979 to 2010 based on CFSR. Rascle and Ardhuin [40] developed two 0.5° global wave hindcasts; one from 1994 to 2012 based on CFSR and the other from 2005 to 2012 forced by ERA-INTERIM.

Information from global wave hindcasts is, generally, very accurate in the open ocean, but finer resolution is desirable in coastal and polar areas. Increased resolution in coastal areas is very advantageous since it produces a more precise representation of the coastline and the bathymetry over the continental shelf, which, in turn, results in improved calculation of bottom friction and depth induced breaking and a more accurate definition of the fetch length. Increased resolution near the poles is also important because it allows a better representation of the effect of ice coverage in wave propagation.

There are coastal wave hindcasts with high spatial resolution (i.e. regional downscalings) generated from outputs of global products (e.g. [8,31]). Regional downscalings are usually available in most developed countries but are scarcer in Africa, Asia and South America. Another limitation of the traditional one-way nesting approach is that local errors due to insufficiently fine resolution of the coarse grid (e.g. island blocking) can accumulate and affect vast portions of the domain [33], i.e. the quality of a downscaling depends on the quality of the boundary conditions. On the other hand, a comprehensive global wave hindcast is limited by the computational effort needed to reach high spatial resolution over all ocean basins. Although increased computational efficiency can be obtained by taking advantage of multigrid features, with higher resolution grids only in areas of interest [12], resolution of wave hindcasts is also very dependent on the resolution of the forcings available. Nowadays, CFSR is the global reanalysis which provides winds and ice coverage at highest resolution and has been reported to yield to better results than ERA-INTERIM for the most severe conditions [40]. CFSR surface wind and ice data are available on a grid at ~0.3° from 1979 to 2010 and are extended to present by CFSv2 [44] with a ~0.2° resolution.

Using recent improvements in numerical wave models and atmospheric reanalyses, this study presents the GOW2 dataset, a global wave hindcast focused on coastal engineering needs. GOW2 is generated using WAVEWATCH III version 4.18 numerical model [52], and provides homogeneous global wave data over the continental coastal areas and ocean islands from 1979 onwards, although only data from 1979 to 2015 is analyzed in this paper. This hindcast incorporates many improvements in forcings, parameterizations and grid configuration over the previous version of GOW [42]. GOW2 is forced by CFSR and CFSv2 reanalysis data, providing reliable wave climate information even for extreme analysis. A multigrid configuration is used and spatial resolution is increased, especially in coastal areas for reducing errors caused by morphological features smaller than the grid size. Wave parameters are validated against instrumental data to understand the database limitations. Among other data, spectral information is provided in more than 40000 coastal locations which helps understanding wave climate and facilitates boundary conditions for higher resolution models.

The paper is organized in five sections. Following the introduction, Section 2 presents the model set-up used in this study and Section 3 shows validation results against altimetry and buoys. In Section 4 the improvements obtained by increasing the resolution in coastal areas, and the accuracy for tropical cyclones and extremes are analyzed. The study is completed with some conclusions in Section 5.

2. Model setup

GOW2 is a wave hindcast, based on the numerical model WaveWatch III version 4.18 [52], hereinafter WW3. WW3 is a third-generation wave model which solves the spectral action density balance equation and is able to simulate global wave generation and propagation. One interesting feature of WW3 is that multiple grids can run simultaneously using a two-way nesting. In GOW2, the multigrid is composed of four regular grids. Fig. 1 shows the global parent grid (0.5°×0.5°), the two regional grids covering the Arctic and Antarctic areas (0.25° latitude×0.5° longitude) and the grid covering continental coastal areas and ocean islands globally (0.25°×0.25°). The polar grids are defined to increase efficiency by confining the smaller time steps required near the poles. In addition, since time steps are limited by longitudinal resolution, latitudinal resolution in those grids is halved. The coastal grid is defined to improve the representation of ocean islands and coastal features. It is designed to include all grid-points at depths below 200 m and the surrounding area within 1.5 degrees. WW3 requires the definition of four time steps for each grid (overall, CFL, refraction and minimum time steps). They are, respectively, 1200 s, 600 s, 600 s and 20 s for the global grid, and 600 s, 300 s, 300 s, and 20 s for the other grids. Wave spectra were defined by 24 direction bins and 32 frequencies ranging non-linearly from 0.0373 Hz to 0.7159 Hz with each frequency being 1.1 times the previous one.

Different formulations for simulating physical processes are available in the numerical model WW3. Since wave model outputs depend largely on the formulations chosen, they are summarized below.

- WW3 was implemented using the parameterization TEST451 [3]. Wave heights obtained with TEST451 (e.g. [40]) have smaller biases than those obtained with older parameterizations [45].
- Continuous ice treatment [50] was applied to sea-ice concentrations with increasing levels of blocking for concentrations from 0.25 (no effect) to 0.75 (total blocking).
- SHOWEX movable-bed bottom friction [2], based on field measure-