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Wave energy resource assessment along the Southeast coast of Australia on the basis of a 31-year hindcast

Joao Morim [a,*], Nick Cartwright [a], Amir Etemad-Shahidi [a], Darrell Strauss [a], Mark Hemer [b]

[a] Griffith School of Engineering, Griffith University, Gold Coast, Southport, Queensland 4222, Australia
[b] The Commonwealth Scientific and Industrial Research Organisation (CSIRO), Hobart, Tasmania 7001, Australia

HIGHLIGHTS

- High-resolution wave hindcast is performed and extensively validated over 31-years
- The highest resolution wave energy resource atlas of Southeast Australia is developed
- The spatial distributions of wave power are analyzed on a seasonal and annual basis.
- Wave power roses and combined scatter and energy diagrams are presented at locations.
- Annual electrical power outputs are determined for different wave energy converters.

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ABSTRACT

In this study, a long-term assessment of the wave energy resource potential for the Australian southeast shelf is performed from deep to shallow water, based on a 31-year wave hindcast. The hindcast, covering the period from 1979 to 2010, has been performed at high spatio-temporal resolution with the wave energy transformation model SWAN using calibrated source-term parameters. The model has been applied with a variable spatial resolution of up to approximately 500 m and at 1 h temporal resolution and driven with high-resolution, non-stationary CFSR wind fields and full 2D spectral boundary conditions from WaveWatch III model. Model validation was conducted against wave measurements from multiple buoy sites covering 10–31 years and showed a relatively high correlation between hindcast and measured significant wave height (H_s) and mean wave direction (θ_m).

Maps of wave power resource distribution for annual and seasonal mean potential were generated along with the maps of resource reliability and variability. The high resolution allowed us to perform in-depth analysis of wave power characteristics, providing resource knowledge on seasonal and longer-term variability necessary for reliable and optimal design of wave technology. The most promising area for wave power exploitation was found to be the central coast of New South Wales, where various high-energy hotspots were selected for a further analysis. For each of the considered hotspots, the wave power magnitude, variability and consistency were carefully assessed and characterized by means of sea state parameters and mean wave directions. Finally, estimates of electric power outputs from different types of pre-commercial wave energy converter devices were drawn for each hotspot based on the wave data hindcast and discussed.

1. Introduction

Approximately 87% of the world's total anthropogenic carbon dioxide emissions come from burning fossil fuels for production of electricity and heat [1]. Although Australia only accounts for 1% of global emissions, it has the highest carbon dioxide emissions per capita among western countries [2], owing to its heavy dependence on coal-fired power plants for energy production. In 2013–2014, coal and gas accounted for approximately 61.2% (151 TW h) and 21.9% (54 TW h) of Australia's total electricity production, respectively [3]. In contrast, renewable energy sources only accounted for a mere 14.9% (37 TW h) [3], but could potentially supply up to 100% (248 TW h) of the Australian

* Corresponding author.
E-mail addresses: joao.morimnascimento@griffithuni.edu.au (J. Morim), n.cartwright@griffith.edu.au (N. Cartwright), a.etemadshahidi@griffith.edu.au (A. Etemad-Shahidi), d.strauss@griffith.edu.au (D. Strauss), mark.hemer@csiro.au (M. Hemer).

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national electricity demands [4]. In response to the need to reduce carbon dioxide emissions, the Australian Government legislated a renewable energy target (RET) scheme to ensure that at least 23.5% of Australia's electricity generation by 2020 will come from renewable energy sources [5]. This policy is part of the government's international commitment to reduce Australia's greenhouse gas emissions by 80% below 2000 levels till 2050 [6]. In order to reach the national RET, Australia will necessarily need to generate approximately 20 TW h of additional renewable energy per year by 2020.

Among the potential renewable energy sources, wave energy is one of the most powerful, consistent and promising [7]. Australia's southeastern coast is the most densely populated margin of the continent and has been suggested to be potentially suitable for electricity generation from wave energy [8]. This region experiences a moderate wave power resource characterized by time-averaged levels of 10–20 kW/m on the continental shelf [8–10]. In addition, the resource is fairly sustained throughout the year over much of the shelf, exhibiting a low seasonal variability compared to the more energetic southern margin of the continent but with a relatively similar reliability in resource delivery [8,11]. Furthermore, this region experiences a relatively small number of extreme events relative to its modal wave climate compared to the southern margin of the continent [10,11]. These resource characteristics are extremely advantageous under a technical and economical perspective [12], because WECs are typically tuned to sustained wave power resource levels of ca. 5–10 to 30 kW/m and excessive amounts of energy cause significant downtime, poor performance and equipment damage (e.g. [8,13]).

According to Behrens et al. [14], there is opportunity to generate up to ca. 40 TW h of total annual electricity across the full length of the 25-m isobath of the Southeast Australian Shelf (SEAS). Turning about 50% of this untapped energy into electricity with existing WECs would be sufficient to achieve the Australian binding RET. A fundamental step towards the successful exploitation of the wave energy is resolving the nearshore exploitable resource distribution and variability at sufficient resolution for power conversion project development [15]. Previous studies have shown that nearshore energy hot spots of concentrated energy are more suitable sites for wave farm facilities than offshore locations because the length of underwater transmission cables plays a critical role in determining the economic viability of power conversion projects [16–18]. Therefore, the mapping of the nearshore wave energy distribution is a prerequisite to optimize the benefits of prospective wave farm developments. In addition, the planning and tuning of the WECs require a reliable prediction of the available wave power at a range of timescales relevant to the energy production (e.g. [15]). Recently, several regions of the world have been investigated for the availability of wave power for energy conversion. Numerical wave models have been applied to assess the wave power resources along and in the coasts of Australia [8,11], Iran [19–21], Caspian Sea [22], Canary Islands [23–28], Spain [27–34], Madeira [35] and Azores Islands [36], Portugal [37,38], France [39,40], United Kingdom [41], Ireland [42,43], Balearic Sea [44], Italy [45,46], Mediterranean Sea [47–49], Morocco [50], Baltic Sea [51], Greece [52], Sweden [53], Scotland [54], Black Sea [55,56], Caribbean Sea [57], Canada [58,59], Hawaii Islands [13,60,61], Peru [62], Uruguay [63], Chile [64], Korea [65], China [66–71] and Malaysia [72].

To date, no study has yet been devoted or attempted to provide a detailed assessment of the coastal and nearshore distribution and variability of the wave power resource potential along the SEAS [73]. Existing energy resource estimates for this region have been solely derived from deep-water, ocean [74–76] and meso-scale [8] spectral wave models and therefore are not directly applicable to the nearshore [8,73]; where wave farms are typically positioned (e.g. [7,32,33]) and where shallow water wave physics become significant. In order to obtain more reliable predictions of the exploitable wave power resource in the nearshore, it is necessary to take into account the various shallow-water driven wave energy transformations such as refraction, shoaling and bottom friction, which can induce significant variations in the wave energy distribution across the inner-mid shelf (e.g. [25–31]). In addition to this limitation, the spatial resolution of the wave model grids used previously to assess the wave energy resource on the SEAS are of the order 10–125 km which is too coarse to resolve the smaller scale spatial variations in the complex nearshore bathymetry and hence wave energy (e.g. [45,47,77]). Also, given that such studies are preliminary resource investigations rather than detailed inshore assessments of a specific region, they lack in the elements needed for the estimation of energy production at any location of interest in a coastal region. For instance, the suitability of a certain location cannot be matched to any WEC, since no energy diagram or characterization matrices, representing the available energy and occurrence for the different wave height and period combinations, is provided (e.g. [78]).

Among the afore-referenced studies which include wave energy estimates for the SEAS, the national wave energy resource assessment developed by Hughes and Heap [8] has the highest spatial resolution with 10 km grid spacing. However, this study has further limitations due to the WAM model used being driven by spectrally derived wave parameters (H_s, T_p, θ_m) as wave boundary conditions (as opposed to full directional wave spectra) and no local wind forcing fields. Winds are a key driving force for wave energy generation along the SEAS, which experiences a multimodal wave climate with the coexistence of locally generated wind-seas and remotely generated swells from a wide latitudinal range (e.g. [10,11]). In addition, Hemer and Griffin [11] showed that spectrally integrated wave parameters cannot accurately describe the multi-modality in the spectral wave climate along the SEAS. Lastly, the WAM model was not calibrated nor was it validated against measured data and hence the epistemic uncertainty of the derived wave power predictions was not quantified.

In this context, this paper aims to provide the first comprehensive assessment of the wave energy potential along the SEAS, focusing on promising nearshore zones where full-scale farms could potentially be deployed. In doing so, it addresses the shortcomings of these previous studies in this region by conducting a fully validated 31-year wave model hindcast (1979–2010) which considers: (1) full directional wave spectra boundary conditions, (2) spatio-temporal varying wind forcing (3) shallow-water wave physics and (4) sufficiently high spatial resolution to resolve complex nearshore bathymetry. The model used is Simulating WAves Nearshore (SWAN) nearshore model [79,80], which includes the influence of water depth on the cross-shelf wave energy transformation. The model is forced with high-resolution winds derived from the National Center for Environmental Prediction (NCEP) over the domain and full directional wave spectra at the open ocean boundaries derived from the larger-scale model from the Collaboration for Australian Weather and Climate Research (CAWCR).

The paper is organized as follows. In Section 2, the study area is introduced (Section 2.1), the numerical wave model and its input data are described (Sections 2.2 and 2.3) and the methods used to characterize the wave energy resources are defined (Section 2.4), In Section 3, the wave energy resource is analyzed in-depth on a regional (Section 3.1) and local scale (Section 3.2) using several statistics. Finally, the conclusions are summarized in Section 4.