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Projected changes of the southwest Australian wave climate under two atmospheric greenhouse gas concentration pathways

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ABSTRACT

Incident wave energy flux is responsible for sediment transport and coastal erosion in wave-dominated regions such as the southwestern Australian (SWA) coastal zone. To evaluate future wave climates under increased greenhouse gas concentration scenarios, past studies have forced global wave simulations with wind data sourced from global climate model (GCM) simulations. However, due to the generally coarse spatial resolution of global climate and wave simulations, the effects of changing offshore wave conditions and sea level rise on the nearshore wave climate are still relatively unknown. To address this gap of knowledge, we investigated the projected SWA offshore, shelf, and nearshore wave climate under two potential future greenhouse gas concentration trajectories (representative concentration pathways RCP4.5 and RCP8.5). This was achieved by downscaling an ensemble of global wave simulations, forced with winds from GCMs participating in the Coupled Model Inter-comparison Project (CMIP5), into two regional domains, using the Simulating WAves Nearshore (SWAN) wave model. The wave climate is modeled for a historical 20-year time slice (1986–2005) and a projected future 20-year time-slice (2081–2100) for both scenarios. Furthermore, we compare these scenarios to the effects of considering sea-level rise (SLR) alone (stationary wave climate), and to the effects of combined SLR and projected wind-wave change. Results indicated that the SWA shelf and nearshore wave climate is more sensitive to changes in offshore mean wave direction than offshore wave heights. Nearshore, wave energy flux was projected to increase by ~10% in exposed areas and decrease by ~10% in sheltered areas under both climate scenarios due to a change in wave directions, compared to an overall increase of 2–4% in offshore wave heights. With SLR, the annual mean wave energy flux was projected to increase by up to 20% in shallow water (< 30 m) as a result of decreased wave dissipation. In winter months, the longshore wave energy flux, which is responsible for littoral drift, is expected to increase by up to 39% (62%) under the RCP4.5 (RCP8.5) greenhouse gas concentration pathway with SLR. The study highlights the importance of using high-resolution wave simulations to evaluate future regional wave climates, since the coastal wave climate is more responsive to changes in wave direction and sea level than offshore wave heights.

1. Introduction

To efficiently manage and operate coastal and offshore industries over the next century, a thorough understanding of waves and expected changes in wave climate are essential. Wave-driven currents are the primary mechanism for sediment transport and contribute to coastal mixing, and erosion along wave-dominated coastlines. The strength and direction of these currents depend on the incident wave energy flux (Hemer et al., 2010; Masselink and Pattiaratchi, 2001).

The Southern Indian Ocean features one of the most energetic wave climates in the world (Bosserelle et al., 2012; Hemer et al., 2008; Sterl and Caires, 2005; Young, 1999; Young et al., 2011) and is therefore an ideal study site to investigate how future changes in offshore wave climates may affect the incident waves nearshore. Waves impacting the southwest Australian (SWA; Fig. 1) coast are typically generated by storms in the Southern Indian Ocean (gener-

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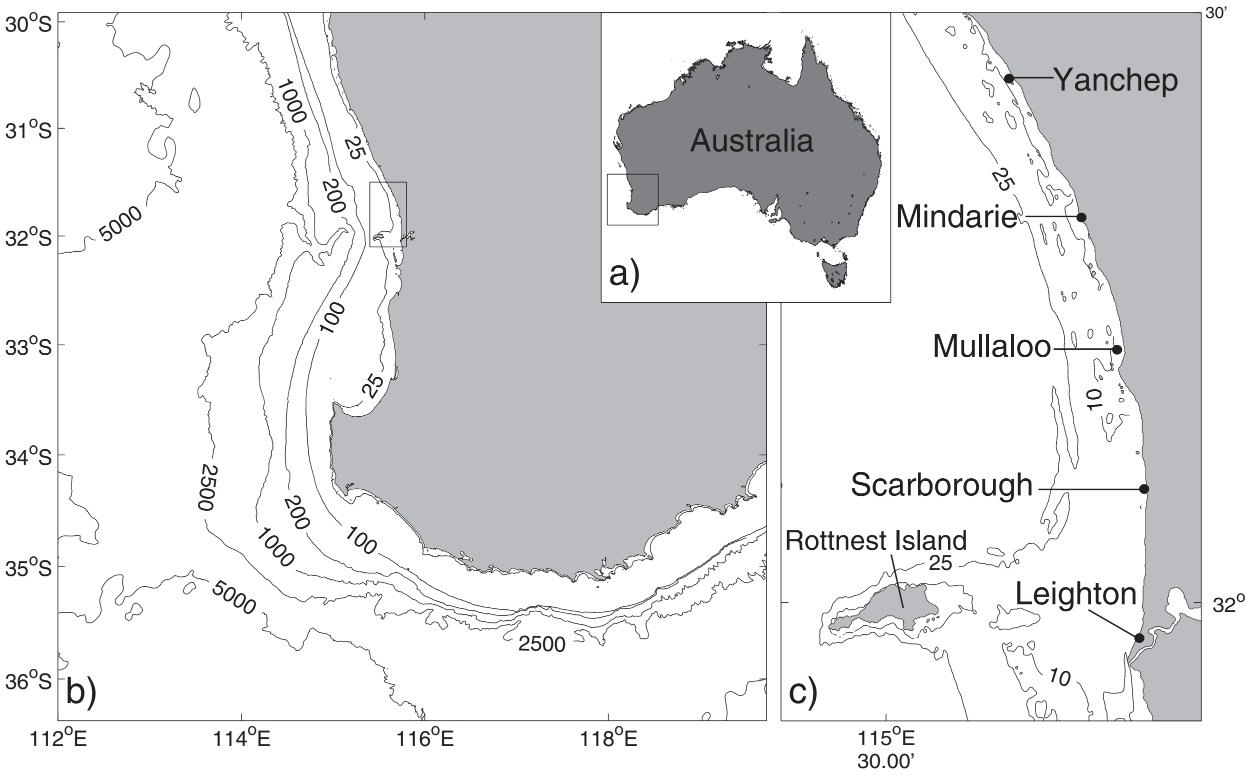

Fig. 1. Maps of the model domains. The black box within the map of Australia (a) indicates the area of the regional SWA domain. (b) Bathymetry of the SWA domain. The black box indicates the location of the high-resolution Perth domain. (c) Bathymetry map of the high-resolution Perth domain.

ally between 40° and 60°S), resulting in gradually decreasing wave heights from south to north (Bosserelle et al., 2012; Hemer and Griffin, 2010). The wave energy resource along Australia's south coast has been estimated around 30–50 kW/m along the 25 m isobath (Hemer and Griffin, 2010). The annual mean significant wave height (H_s) offshore of Perth is 2 m, with a mean wave period (T_m) of 8.8 s (Lemm et al., 1999). The wave climate varies seasonally, with smallest wave heights between December and February, during austral summer ($H_s = 1$–2 m; $T_m < 8$ s) and largest wave heights between June and August, during austral winter ($H_s = 1.5$–2.5 m; $T_m > 8$ s) (Bosserelle et al., 2012; Lemm et al., 1999). In contrast, the inter-annual variability in the Southern Indian Ocean wave climate is relatively small ($< 6\%$) (Bosserelle et al., 2012).

The seasonal and inter-annual variability of the SWA climate can be explained by the fluctuation of atmospheric pressure systems in the Southern Indian Ocean (Bosserelle et al., 2012; Hemer et al., 2010; Li et al., 2011; Wandres et al., 2017). The Southern Annular Mode (SAM) describes the variability of the zonal pressure gradient between 45° and 65°S. It describes the north-south fluctuation of the extra tropical cyclones (Southern Ocean storm belt) that circle Antarctica (Marshall, 2003). During a negative phase of the SAM index, the swell-generating storm belt shifts northward, resulting in increased wave heights in SWA, whereas a positive SAM indicates a southward shift of the storm track (Bosserelle et al., 2012). The SAM is therefore strongly correlated to Southern Indian Ocean wave climate (Bosserelle et al., 2012; Hemer et al., 2010). Furthermore, the latitudinal position of the subtropical high-pressure ridge (STRP), a band of eastward traveling anti-cyclones in the Southern Hemisphere mid-latitudes, is closely connected to the SAM and, like the SAM, can be linked to the wave climate around Australia (Mortlock and Goodwin, 2015; O' Grady et al., 2015; Wandres et al., 2017). A northward shift of the STRP results in increased SWA wave heights, as the Southern Ocean storms pass closer to the Australian continent, and a southward shift of the STRP resulted in decreased wave heights. Over recent decades, an overall intensification and southward shift of the Southern Ocean storm belt has been observed, which resulted in an increase in mean wave heights in the Southern Indian Ocean (Bosserelle et al., 2012; Young et al., 2011).

With increasing atmospheric greenhouse gas concentration, the global climate, and atmospheric circulation patterns are likely to continue changing over the next century. Global climate models (GCMs) simulate climate variables such as temperature, precipitation, and wind, under different greenhouse gas concentration scenarios. Commonly studied greenhouse gas concentration scenarios are the Representative Concentration Pathways (RCPs): RCP4.5 describes an intermediate concentration scenario with radiative forcing stabilized at $\sim 4.5\,\mathrm{W/m^2}$, and RCP8.5 describes a high concentration scenario under which the radiative forcing exceeds $8.5\,\mathrm{W/m^2}$ by the end of the year 2100 (Moss et al., 2008). Harvey et al. (2012) used an ensemble of GCMs participating in the World Climate Research Program's Coupled Model Intercomparison Project phases 3 (CMIP3) and 5 (CMIP5) (Taylor et al., 2012), to investigate the projected changes in winter storm tracks. The authors predicted increased storm activity over the Southern Ocean, particularly in higher latitudes towards the end of the 21st century.

Surface winds and pressure fields can be used to statistically determine wave climate predictions. A statistical approach to estimate future wave heights by Wang et al. (2014) used mean sea level pressure (MSLP) predictions from 20 CMIP5 GCMs. The study showed a significant increase in Southern Ocean wave heights south of 45°S, as well as an increase of the present-day one in ten year extreme wave events until the end of the 21st century under RCP8.5. The wind output from GCMs can also be used to force wave models in order to dynamically assess future changes in wave climates. Dobrynin et al. (2012) used a global wave model forced with winds from a GCM to study historical and future wave climates under RCP4.5 and RCP8.5. The GCM and wave simulations