Ocean Power for Australia– Waves, Tides and Ocean Currents

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Abstract- **A preliminary resource assessment is made for three forms of Ocean Renewable Energy in Australia. The wave energy incident on the south coast of Australia constitutes Australia's principal resource of ocean renewable energy. Integrating the total energy flux crossing the 25m isobath between Geraldton WA and the southern tip of Tasmania, we estimate the total size of this resource to be 1329TWh/yr. Noting that this estimate may exceed the true value by perhaps 20%, it nevertheless greatly exceeds the amount of electricity (254TWh) generated in Australia in 2005/6, suggesting that wave energy does have the potential of becoming a major contributor to Australia's energy, if an economic way of exploiting the resource can be developed. The economic viability of exploiting the wave energy resource is not assessed but a new fine-resolution atlas characterizing the spatial and temporal variability of this resource is discussed. Strong tidal currents (ie, median speed in the vicinity of 1m/s) occur in a much more restricted set of locations, including straits near Flinders Island, Tasmania, King Sound, WA, Darwin, NT, and Cape York, Qld. Instrument measurements of the unexploited current speeds, and model estimates of the impact of energy extraction on those speeds, do not exist, so the potential yield can not yet be estimated with any confidence. The region where non-tidal ocean currents are most likely to be worth exploiting is the upper continental slope between Fraser Island and Byron Bay. The median current speed there is about 1m/s according to the Bluelink ocean model, translating to an upper-limit estimate of the resource at 44TWh/yr, probably more than from the tides, but much less than the waves. Concerns about the environmental and navigational impact of very large numbers of very large turbines deserve careful consideration.**

I. Wave Power

The southern ocean is well known for its large waves and this fact is recognized in global atlases of the wave energy resource, eg [1].

The height and period of these southern ocean waves have been measured by wave buoys for many years at a few Australian locations. Off Cape Sorell on Tasmania's west coast, the long-term average wave height, period and energy flux are 3m, 12.3s and 51kW/m respectively, at a site in 100m of water [2]. This observed energy flux average is significantly less than the values shown south of Australia by [1], but are nevertheless indicative of a very significant resource. The west coast of Tasmania is about 300km long and the waves are incident nearly normal to the coastline, so the total energy incident on the west coast over a year is therefore about 134TWh, or 12.2 times Tasmania's present consumption (11TWh/yr [3]) of electrical energy.

A global map like the one in [1] is potentially misleading if used as an indicator of the resource available to a near-shore wave farm somewhere in southern Australia, unless attenuation of the deep ocean waves as they cross the continental shelf is taken into account. Estimates of the near-shore wave height are available from the radar altimeters embarked on ESA and NASA/CNES missions (ENVISAT, TOPEX/Poseidon, Jason-1, OSTM, etc) but these measurements are only indirect estimates, along discrete track lines. As a first step towards serving the needs of the wave energy sector, and to reconcile these various model and observed data sets, [4] have recently produced a wave energy atlas for southern Australia with fine (0.01º×0.01º, ie about 1km) spatial resolution, by running the SWAN wave model with offshore boundary conditions specified by three percentile levels of the NOAA WaveWatchIII operational model, after [5] showed that this was the most accurate data set presently available to describe the offshore wave climate. To reduce the computational cost of this task, [4] ran the fine resolution models for just a small (3×13) number of representative wave states, defined by 3 (the 10^{th}, 50^{th} and 90^{th}) percentile levels of the wave energy during *i)* all of 1997-2006, and *ii*) each of the 12 months in that period. The resulting atlas, comprising maps of wave height, period, direction and energy is to be included in the Australian Government's Atlas of Renewable Energy [6]. The domain of the wave energy atlas is restricted to the stretch of coast (Geraldton WA to the southern tip of Tasmania) where the offshore wave climate is fairly uni-modal, and therefore adequately described by the NOAA WaveWatchIII archive of integrated wave parameters.

The purpose of mapping the three percentile levels is to facilitate the basic engineering calculations that need to be done to assess the feasibility of exploiting the wave energy resource. Performing those calculations, however, is beyond the scope of the present paper, as it was for [4], principally because the frequency- and amplitude-response functions of devices to be used need to be specified. The design of the devices, of course, cannot be optimized until the characteristics of the wave field are known, hence the need to do the resource characterization work first.

One intrinsic problem with wave power is that it is intermittent, like many natural energy resources. The ratio of the 10^{th} and 90^{th} percentile levels to the median or average levels is a succinct way of characterizing the extent of that

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intermittency. At the wave buoy site off Cape Sorell, the three percentile levels of buoy-measured wave height (1985-2006) are 1.6, 2.7 and 4.5m [4]. The model estimates (1992-2006) are slightly higher, at 2.1, 3.2 and 4.9m, a difference we attribute to the NOAA WWIII estimates being slightly high offshore, as indicated by comparisons with altimetry. Comparing model and buoy estimates of wave energy flux suggests that the model is high by perhaps 20%, averaged over all sites and percentile levels.

An important figure to note is that the (buoy-measured) peak wave period at Cape Sorell corresponding to the 10th, 50th and 90th percentiles of the energy flux are 11.5, 12.4 and 13.5s, respectively. The present version of Pelamis, for example, is not tuned for high efficiency at these long periods; it generates just 149kW in 3m, 12.5s waves (compared with 340kW from 3m, 7.5s waves) and just 266kW in 4.5m, 13s (compared with 648kW from 4.5m, 7.5s waves) [7].

Analysing data for September only, [4]'s model estimate of the 90th percentile wave height on Tasmania's west coast is 5.5m, a figure not matched anywhere else along Australia's south coast (Fig. 1). In January this falls to 4.1m, showing that there is a definite seasonality, but with amplitude not so strong as to have a severe impact on the economics of exploitation. Buoy estimates of the three (all-month) percentiles of the energy flux are 13, 41 and 123kW/m. For 10% of the year (mostly from November to March) therefore, the incident energy is only 13/51=25% of the average value.

As mentioned above, the total wave energy incident on Tasmania's west coast far exceeds the state's energy requirements. Reference [4] made a more careful model-based calculation of the total amount of energy crossing the 25m isobath between Geraldton, WA and the southern tip of Tasmania. This came to 1329TWh/yr (without attempting to correct for the possibility that the model slightly over-estimates the energy flux), about 5 times the energy requirements of the whole nation. Turning just 10% of that into electricity would be a massive investment but it would provide half the country's electricity. Clearly, it is the economics of energy extraction that will decide the future of wave energy, not the extent of the resource.

Advantages of wave power that may offset some of the high maintenance costs inherent to marine engineering include 1) a tractable degree of competition with other uses of potential wave farm sites, 2) negligible visual impact of submerged or offshore devices, and 3) relatively little risk of significant ecosystem impact.

II. TIDAL POWER

Initial interest in tidal power focused on impoundment systems, where natural bays are turned into reservoirs by the construction of a dam. More recently, attention is switching to free-stream turbines, which are more like wind turbines than hydro-electric schemes. In the Australian context, there exist just a few regions where tidal power is possibly feasible. One of the best of these is the region between Flinders Island and the rest of Tasmania (Fig. 2). The major passage here is Banks Strait, where tidal current speeds reach 2.6m/s (according to an unverified CSIRO computer model – the true value is possibly higher). The speed of the currents is not as high as some sites overseas but since Flinders Island uses diesel generation, tidal power is relatively attractive.

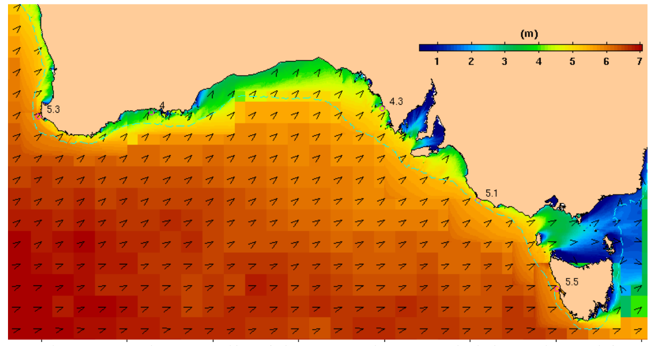

Figure 1. 90th percentile of the September wave height, estimated from archives of the NOAA WaveWatch III operational model for the deep ocean, and nested high resolution runs of the SWAN model for the continental shelf, reproduced from [4]. Arrow heads show the direction of the dominant wave.

An upper limit on the power that could be generated in a year by an array of turbines (eg 30 dual-16m-diameter SeaGen turbines each generating an average of 200kW) across Banks Strait is probably in the vicinity of 50GWh. This upper-limit value is much less than Tasmania's total power usage, so in contrast to the situation with wave power, it is clear that tidal power can only possibly have a niche role, regardless of the economics of extraction. Fig. 2 shows that other places where strong tidal currents exist are near King Sound (discussed by [8]), Darwin and Torres Strait.

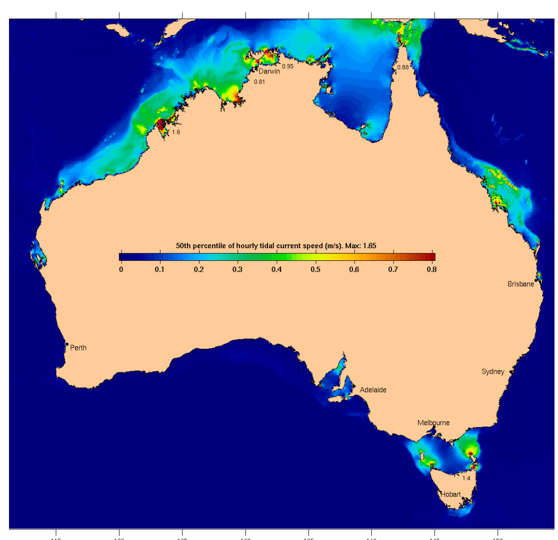

Figure 2. Median hourly tidal current speed estimated by the Bureau of Meteorology National Tidal Centre 0.08°×0.08° resolution tidal model.

In some places, the high tidal speeds are due to a local resonance which would be de-tuned by any attempt to exploit a large fraction of the kinetic energy of the unperturbed system. This is certainly not the case for Torres Strait, and probably not for Flinders Island, but probably is the case for the King Sound region.

III. NON-TIDAL CURRENTS

The East Australian Current flows southwards from Queensland into New South Wales, with a small fraction of its flow continuing past eastern Tasmania. While the current flows mostly as a fast narrow jet along the outer continental shelf between Fraser Island and northern NSW, from then onwards it is best characterised as a series of very large (100s of km), swirling eddies. Off Brisbane, the flow speed has been observed to exceed 2m/s but continuous measurements to document the frequency of this do not yet exist. Analysing the 15-year BRAN2.1 data archive generated by the Bluelink 0.1º×0.1º resolution ocean model (see [9] and [10]), we find that the median value of the current speed is about 0.9m/s (Fig. 3), making this stretch of coast the most promising location in Australian waters for extracting energy from non-tidal currents. The power density at this velocity is, however, quite low (500W/m^2 at 1m/s), so very large diameter devices are required in order to extract significant quantities of power. But even if a device extracts half the power of the upper 100m of the ocean, the power generation per horizontal meter is only 50kW/m. The total width of the fast region of the current is about 20km, giving an upper limit on the generated power of 1GW (8.8TWh/yr), as might be produced by a line of 200 100m-diameter turbines. Even if 5 such lines of turbines were installed at 100km intervals along-shore spanning the high-current region, the total production would be only 44TWh/yr. This is somewhat less than Australia's total present usage (254TWh/yr) and much less than the total wave resource

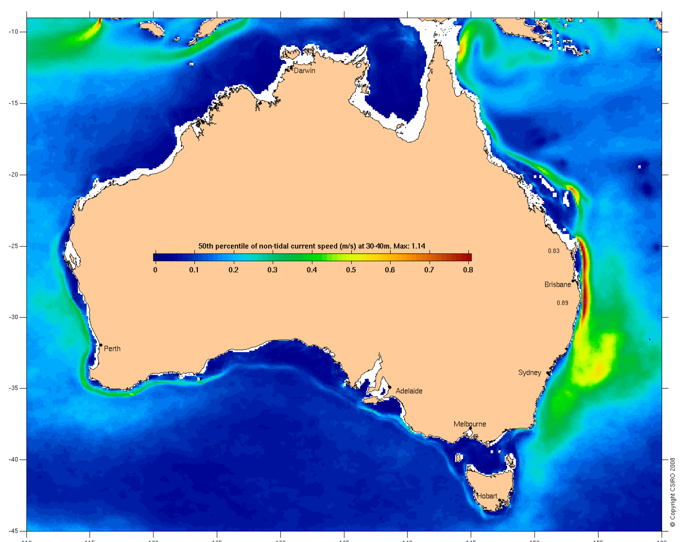

Figure 3. Median non-tidal current speed at 30-40 m.

(>1000TWh/yr), but worth further consideration, especially if measured speeds turn out to exceed the modeled current speeds, and/or if a low-cost, large-diameter (>30m) device can be developed. Any installation approaching this magnitude would, however, be likely to have a considerable effect on the physical properties of the East Australian Current, while also being a very significant hazard to navigation. For those reasons, we expect that exploitation of the wave energy resource of the southern coast is more likely, after closer inspection of both options, to appear feasible.

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