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Towards characterisation of the Australian national tidal power resource

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Abstract—**Australia is home to some of the largest tidal resources in the world, but have been poorly quantified in the context of available tidal energy resources. A national tidal model, configured on an unstructured mesh with resolutions down to 500m in high resource areas, is under construction with this as the primary objective. Whilst the model is still undergoing calibration, we present here preliminary results from an early version of the model. Comparison to observed tidal elevations, and results from two regional models – one on a structured mesh of similar resolution to the national model, and a higher resolution regional model, shows the current skill of the model. Preliminary tidal stream resource estimates are determined for nine prospective sites, using a flux method. Several sites display sizable resources (up to 1300 MW), despite the national model displaying a negative bias in resource estimates relative to the regional models.**

Keywords—**Tidal Energy; Hydrodynamic Modelling; Australia.**

I. Introduction

THE tidal resources of Australia have long been recognised as a prospective renewable resource that could contribute to Australia's future energy mix. At the time of development of the La Rance Tidal Energy Plant in France (opened in 1966), serious consideration was given to development of a follow-on project in the Kimberley region on Australia's north-west shelf. In preparation, [1] provided preliminary resource assessments for 25 tidal inlets along the Kimberley coast suitable for potential tidal range technology development, on the basis of the limited data available at that time. Development never proceeded. However, on the basis of Lewis' assessments, a Select Committee of Energy and the Processing of Resources made recommendations to the Legislative Assembly of Western Australian in 1991 saying '*Long term plans should be made to harness Kimberley tidal power as one of the available renewable energy resources that Australia will need to employ in order to achieve sustainable development and reduce greenhouse gas emissions*' [2]. Furthermore, an Australian National Committee on Electric Energy wrote in 1994 '*Tidal power will undoubtedly play a role in future power systems, but significant development is unlikely to be economic for several decades and will need to deal with a range of environmental and heritage issues*' [3]. Despite these acknowledgments to the significant tidal resources available in Australia, the current level of understanding of distribution and magnitude of the resource is inadequate to meet the needs of prospective tidal energy developers – both Australian and International - seeking to make informed decisions and de-risk potential investment in Australian tidal energy projects.

The most relevant prior study seeking to quantify Australia's national tidal energy resource is the CSIRO 2012 Ocean Energy Report [4], which provided a preliminary view of the distribution of prospective sites for tidal energy development in Australia. However, the numerical model on which this assessment was derived has too coarse resolution (~10km) to resolve many features of accelerated tidal flow of interest to tidal stream energy developers, and as a result potentially overlooks prospective development locations.

To improve understanding of Australia's national tidal energy resource is the objective of the first component (of 3) of the three-year (2018-2020) Australian Renewable Energy Agency supported 'Tidal Energy in Australia' project, being led by University of Tasmania, in partnership with CSIRO, the University of Queensland and several industry partners (e.g., MAKO Tidal Technologies Ltd and Simec Atlantis Ltd), with International partners from Acadia University, Canada and Bangor University, Wales [5]. Component 1 –

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Quantifying the national Australian tidal energy resource – is led by CSIRO Oceans and Atmosphere, and is the focus of this manuscript.

Our objectives are to identify nationally attractive tidal energy resource sites, and to deliver pre-competitive information on these tidal energy resources via Australia's renewable energy atlas [6]. The project is still underway, and here we present initial results on the development of a national depth-averaged hydrodynamic tidal model seeking to meet requirements of a Stage 2a resource assessment (resolution of ~500m in regions of interest). Preliminary results from calibration simulations are presented, however it should be recognised that calibration simulations are ongoing.

II. The Numerical Model

The model used is a national Australian implementation of the *Coastal Ocean Model Predication Across Scales (COMPAS)* hydrodynamic model, developed at CSIRO Oceans and Atmosphere. COMPAS is a finite-volume hydrodynamic model for unstructured grids, following the MPAS-O framework as described by [7] and [8]. Whereas MPAS-O is a global model suitable for coupling with atmospheric and sea-ice models to investigate climate processes, COMPAS is aimed at coastal or regional sea scale applications. COMPAS is an unstructured development of the CSIRO *Sparse Hydrodynamic Ocean Code* (SHOC; [9]), based on the three-dimensional equations of momentum, continuity and conservation of heat and salt, employing the hydrostatic and Boussinesq assumptions. The framework is grid agnostic, provided it is an orthogonal mesh. COMPAS source code and documentation is made openly available via the CSIRO Coastal Environmental Modelling team's Environmental Modelling Suite GitHub distribution (https://github.com/csiro-coasts/EMS).

III. Model Configuration

The objective of the component is to identify prospective tidal locations surrounding Australia. Whilst it is known that the majority of tidal energy in Australia is located across Northern Australia, and in the Bass Strait, other tidal streams are known to exist in less energetic regions owing to the local geography (tidal passages and around headlands). The national scale tidal model aims to resolve locations of all potential sites. Furthermore, several secondary objectives, to support other Australian marine science objectives, warrant a complete national domain. The Australian mainland has a coastline length of over 35000 km (59000 km including islands), and thus any national scale hydrodynamic model able to resolve tidal streams at resolutions of 500m to 1km (as required of a phase 2a assessment) requires considerable model resources, with a large model domain.

COMPAS is an unstructured model, enabling high resolution in regions of requirement with lower resolution elsewhere. Of highest priority to our study are regions with high tidal energy. Thus, using JIGSAW (https://github.com/dengwirda/jigsaw [10]) mesh generation software, we generate an unstructured model mesh with high resolution nearer the coast (bathymetry dependence, with higher resolution in shallow regions) and in regions with greater tidal energy. A preliminary mesh was constructed, with resolution weighted on the basis of bathymetry and tidal range. This mesh contains 212686 2d cells, with a minimum horizontal resolution of 54km and a maximum resolution of ~450m. A prototype implementation of COMPAS (run1) was completed using this initial mesh (mesh 1) to produce an initial tidal simulation. Mesh 1, while having higher resolution in regions of high tidal range does not necessarily have high resolution in areas with high tidal stream energy (e.g., constrained flows). Thus, following meshes have been constructed weighting tidal energy on the basis of tidal stream energy determined from the initial simulation (run1).

Two following meshes have been constructed. Mesh 2 (Figure 1) has 183810 cells, with a minimum/maximum resolution of 58km/400m. Mesh 3 has 620574 cells, with a minimum/maximum resolution of 51km / 282m. Computations on both meshes are expensive, but particularly so for Mesh3. Presently, sensitivity and calibration simulations are being completed using Mesh 2, but ultimately Mesh3 will be used to define a national resource. Figure 1 displays the transition of resolution across scales for Mesh2, across the extent of the National domain. Figure 2 displays the mesh in two regions of interest: Banks Strait, NE Tasmania, and Port Phillip Heads, Victoria. Initial simulations presented here, being completed to identify the appropriate model configuration, have a duration of 16 days. This duration is the minimum required to allow for spinup and resolve the four main tidal constituents (Section IV). Once configuration is optimised, simulations will span at least 35 days to resolve a more complete set of constituents.

IV. National Model Validation

Aside from two site specific field campaigns targeted at high flow prospective tidal stream development sites, which are yet to be completed, calibration and verification of the national model is dependent on sparse opportune data. This data is predominantly elevation data from commissioned tide gauges (Figure 3), with an objective to complete further validation relative to existing current meter data in more energetic locations available from the Australian Ocean Data Network (http://www.aodn.net.au), noting these data are collected for other oceanographic applications.

Further to the observational data, existing high resolution sub-regional model simulations are used for comparison, to assess the model solution obtained using the newly developed model. For the purpose of this manuscript, we refer to two comparison models being implementations of SHOC on curvilinear model grids, which CSIRO has

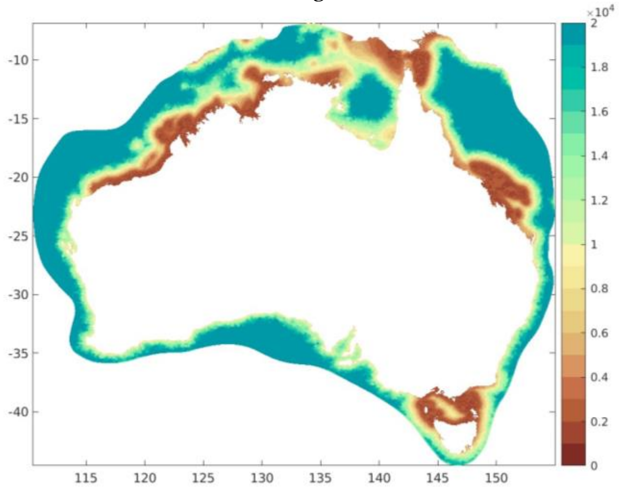

Fig. 1. Run 2 Australian national domain and cell resolution (m).

previously developed for regions with known energetic tidal streams. These regions being Banks Strait (Figure 2a) and Port Phillip Heads (Figure 3). The models – TASC, encompassing Banks Strait at a resolution similar to the national model (of ~1.5km) on a structured curvilinear mesh, and VIC3, encompassing Port Phillip Heads at a higher resolution of ~500m – were developed for other purposes (environmental management decision support systems), without emphasis on high flow regions of predominant interest here.

Figure 4 displays how the 3 models compare in their representation of tidal elevation relative to observations in this region. At many locations – the current National model compares well to observations, with similar skill to

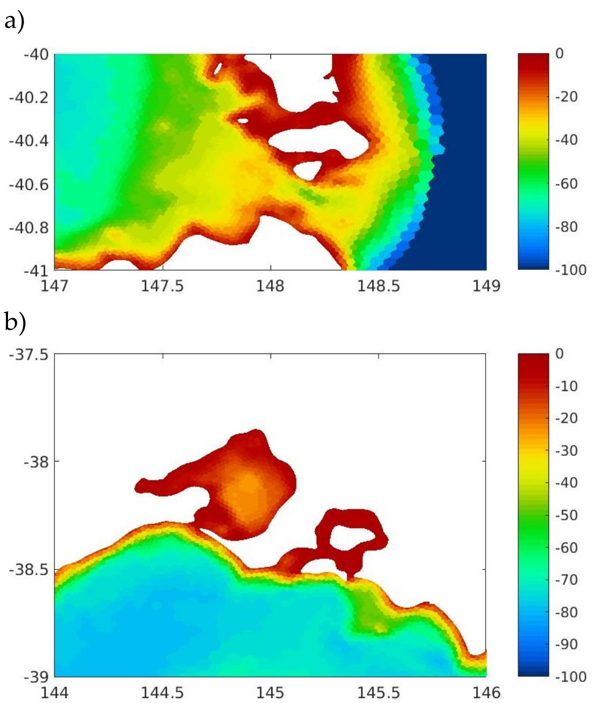

Fig. 2. Model bathymetry (m), displaying cell resolution for prospective tidal energy sites. a) Banks Strait, NE Tasmania, and b) Port Phillip Heads, Victoria.

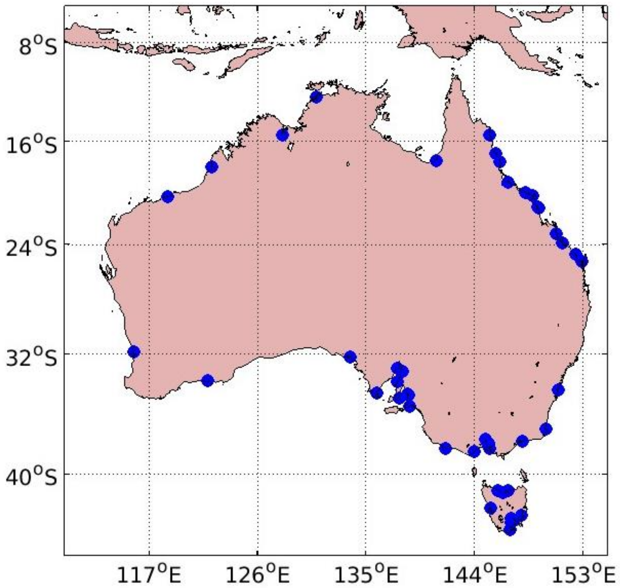

Fig. 3. Location of Tide gauges being used for ongoing model calibration and preliminary validation.

that of the higher resolution regional models. Battery Point (top subplot) is representative of model performance for most locations. However, the national model has difficulty in Bass Strait and sheltered water ways, as represented by the Burnie and Whalers Point sites (Figure 4: middle and bottom subplots), which are represented reasonably well by the regional models. The national model has been investigated for sensitivity to altered minimum bathymetry at the coast (2m, 4m and 10m); maximum bathymetry capped at 3000m; constant bottom drag coefficients; smoothing options 1 vs 2 smoothing passes, 0.06 vs 0.07 maximum bathymetry gradient; inclusion of atmospheric pressure and not; horizontal viscosity, range from zero, constant (7200 m^2/s), Smagorinsky (0.1), Smagorinsky with base rate, Bi-Harmonic viscosity; no nonlinear terms (advection or horizontal mixing); open boundary flux adjustment timescales. The tidal solution in Bass Strait (and sheltered bays) has been found to be highly sensitive to friction parameters only. Currently the model is being tuned through variation of the bottom friction parameterisation, to optimise the fit against all tidal elevation observations (time-series RMSE and constituent fit of the four main constituents).

As a measure of model skill, we extract simulated sea-level time-series at the grid points closest to the tide gauges displayed in Figure 2. We then extract the amplitude and phase of the four main tidal constituents (M2, S2, K1 and O1), using the T_TIDE package, from the observed time-series, the national model time-series, and for those gauge sites within their domains, the TASC and VIC3 model time-series. Figure 5 displays a comparison of the amplitude (left) and phase (right) between the observed and simulated records across all sites.

The current national model displays scatter amongst the model constituent fits which is comparable to the more highly tuned regional models. Model tuning is ongoing to improve these comparisons. Once the model is finalised, a more thorough validation is intended, comparing model to observed tidal streams at both (limited) purposely collected and opportune data sites.

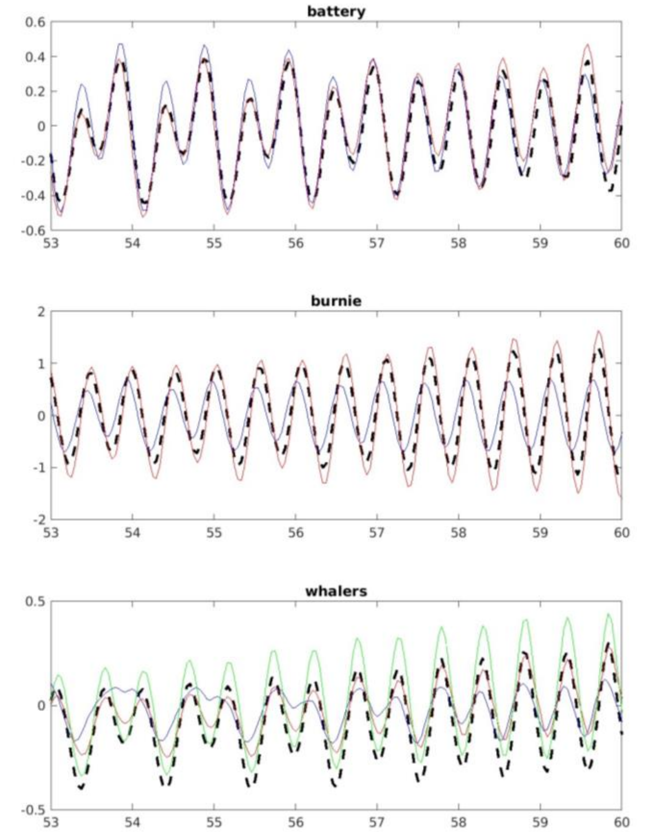

Fig. 4. Tidal elevation (m) time-series (days) at Battery Point, SE Tasmania (Top), Burnie, N Tasmania (Middle), and Whalers Point, Port Phillip Bay (Bottom). Observations are represented by dashed black line, the national model by the blue line, the TASC model in red, and the high resolution VIC3 model in green.

V. Preliminary Resource Assessments

As stated above, the national model is still undergoing development and, at this time, it is premature to report a thorough assessment of the national tidal stream resource. Here however, we present some preliminary estimates of the size of the resource for some specific locations which are of emerging interest to the community. Where possible, we compare the resource estimate obtained from the national model relative to those from the regional TASC and VIC3 models. This comparison provides perspective of the relative uncertainty of the resource estimates from the National model.

Our preliminary estimates of the resource are focussed on the total power available in the cross sectional area of several channels that have been linked with potential tidal energy converter deployments. We determine the resource for 9 locations (Figure 6, Table 1) using the flux method, following [11]. Pflux is calculated across the full channel cross-sectional area by multiplying the average power density (APD) by the cross sectional area of the channel considered.

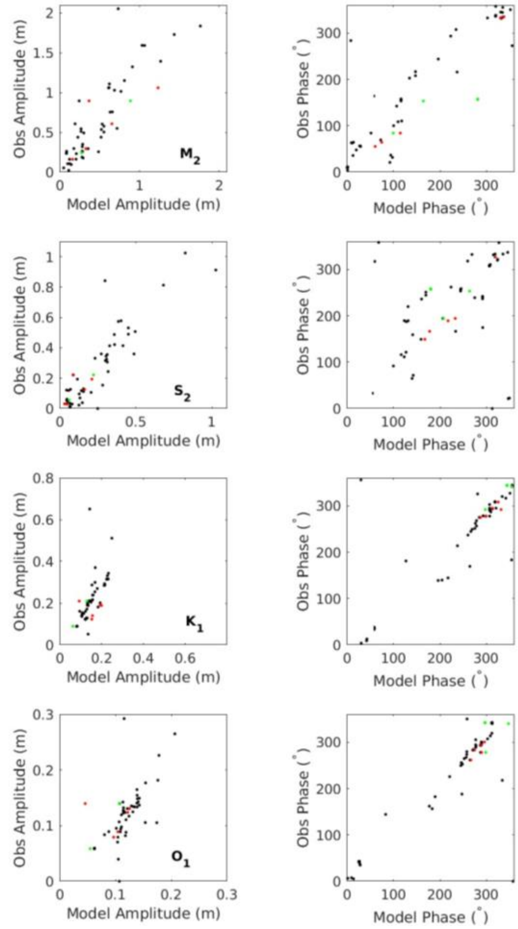

Fig. 5. Comparison of observed and simulated tidal amplitudes (left) and phases (right) for the M2 (top), S2 (second row), K1 (third row) and O1 (bottom) constituents at 47 tide gauge sites shown in Figure 2. The National/TASC/VIC3 model is represented by black/red/green dots.

$$P_{flux} = \sum_{i=1}^{N} APD_i d_i w_i \text{ (kW)}$$

Where

N = number of discrete cells across the channel

APD_i = average power density (kW/m^2) in a cell, as part of transect across channel, determined as:

$$APD_i = \frac{1}{2}\sum_{j=1}^{T}\frac{1}{2}\rho u_j^3$$

Where T is length of record, u_j is the velocity at time *j*, and ρ is the density of water (1025 kgm^{-3}).

D_i = depth of cell, as part of transect across channel (m)

w_i = width of cell, as part of transect across channel (m)

where the cross-sectional area of the channel, $A_{channel}$ is:

$$A_{channel} = \sum d_i w_i \text{ (m}^2\text{)}.$$

Table 1 summarises the preliminary resource estimates for each of the 9 locations. The largest identified resource is that at King Sound, WA, which has been long recognised as a large tidal resource [12], but has limited conventional electricity demand nearby. Other notable resources include Banks Strait (A site of focus of the AUSTEN project, [5], Clarence Strait (the location of a proposed tidal energy test centre, [13]), the nearby Dundas Strait, and

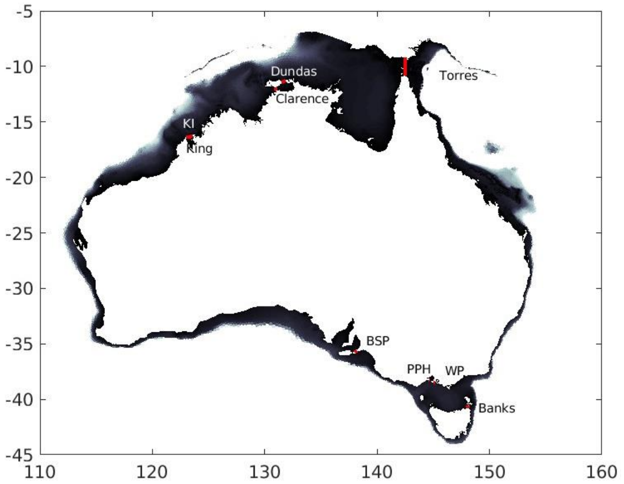

Figure 6. Map showing locations where preliminary resource estimates are shown. KI - Koolan Island; BSP – Backstairs Passage; PPH – Port Phillip Heads; WP – Western Port; King – King Sound.

Torres Strait. Of particular note is the comparison of the national model resource estimates, to the estimates of resource from the regional models. We are able to compare estimates between the National model and the TASC model at 3 locations, and between the National model and the VIC3 model at 2 locations. The National model estimates of resource range are up to 6.9 times less than the magnitude of resource determined from the TASC model (at Banks Strait), and up to 15.7 times less than magnitude of resource determined from the higher resolution VIC3 model (at Western Port). In each case, we see the national model underestimates the resource estimated by the higher resolution regional model. This suggests that the resource estimates from the National model at the other 6 sites may similarly underestimate potential resource. Figures 4 and 5 show that the VIC3 model has overestimated tidal amplitude, which may translate to overestimated velocity and power estimates. Thus, taking the more conservative estimate that the national model estimate of resource at King Sound of 1300 MW is underestimated by a factor of 6 suggests a resource comparable with some of the largest prospective tidal stream sites in the world.

VI. Discussion

There are several caveats to these preliminary estimates. First, we note that the regional models used here were not developed with the purpose of resolving flows in high energy sites, and are likely subject to large biases. We acknowledge the national model continues to be calibrated, with known biases relative to observed tidal elevations. Furthermore, we acknowledge that our estimates of resource using the undisturbed kinetic energy flux typically overestimate the average available power in a channel [14].

Once calibration against tidal elevations are completed, the national model will be set to complete a more careful

TABLE 1

SUMMARY OF PRELIMINARY ESTIMATES OF THE TOTAL AVAILABLE RESOURCE OF SEVERAL PROSPECTIVE TIDAL STREAM ENERGY SITES

Location:	Width (km)	Mean Depth (m)	Max Depth (m)	Power (MW)
Banks				
National	26	23	42	92
TASC	26	23	42	636
PPH				
National	7	5	7	18
TASC	5	11	25	35
VIC3	5	11	44	48
WP				
National	13	8	13	0.7
TASC	12	8	12	0.3
VIC3	12	13	21	11
Clarence				
National	30	14	30	375
Dundas				
National	24	33	60	685
Torres				
National	178	9	18	125
BSP				
National	23	19	23	57
King				
National	63	8	15	1300
Koolan				
National	3	3	4	1

and refined estimate of Australia's prospective tidal energy resources. Through the AUSTEN project, observations of tidal currents in high flow sites are being collected which will be available to validate the model in such regions. These observations will supplement already available tidal currents data collected and archived via the Australian Integrated Marine Observing System Australian Ocean Data Network, providing validation distributed across the national domain, albeit in less energetic sites.

VII. Summary

The development of a national Australian tidal model is underway with the primary purpose of resolving Australia's tidal energy resource. The model is a configuration of a new unstructured model code, COMPAS, with model resolution being a function of bathymetry and tidal energy on the shelf (higher resolution in high tidal energy / shallow sites). The model is currently being calibrated, with bed friction parameterisation being the most sensitive parameter by which to tune. Results of a preliminary model version are presented, displaying the fit of tidal elevation data relative to observations around the Australian coast. Despite the immature model status, we present estimates of the available tidal stream resource at several prospective tidal stream development sites, and in some instances compare these estimates to those determined from more mature regional models. In each instance, we see the estimates of the resource underestimate those from the regional models. With consideration of these resolution dependent biases, we speculate that the tidal resource in some locations may be somewhat larger than estimates presented here. A more thorough assessment of Australia's tidal resources are forthcoming, once the model status has matured.

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