Resource estimates in Lombok Straits, Indonesia

Ahmad M. Firdaus, Guy T. Houlsby, Thomas A.A. Adcock

Abstract—**Bali Island and Lombok Island are amongst the most famous tourist locations in Indonesia. The straits in this area have high velocity tidal streams and are already being considered by major turbine manufacturers as potential sites for tidal stream turbines. Three islands (Nusa Penida, Nusa Lembongan and Nusa Ceningan) separate the Lombok straits into three straits: Badung, Toyopakeh Strait and Lombok Strait. All of these sites have the potential for tidal energy extraction. As for other location, resource assessment at individual sites also requires consideration of interaction with other locations. This paper aims to establish and validate a robust numerical model for tides in this region using DG ADCIRC. Methods of incorporating the Indonesian Throughflow in the model and the selection of input data are described. We also present a preliminary estimate of tidal resources in the three straits using linear momentum actuator disc theory incorporated in the DG-ADCIRC model.**

Keywords—**Indonesia Tidal Resources, Bali Tidal Resources, Site-site interaction, Lombok Strait Resources.**

I. Introduction

ATLANTIS Resources Ltd. (Atlantis) and DCNS Energies, two UK-based energy development companies, have announced an agreement to develop tidal stream energy in the Bali and Lombok Straits. The total cost of this development has been estimated at $750 million for a quoted capacity of 150 MW, although it is unclear whether this the peak or average power. As announced by Atlantis, this project is supported by a 25-year power purchase agreement with the state-owned electricity company, Perusahaan Listrik Negara (PLN) [1].

Various authors have addressed the resource potential in Badung and Lombok Straits. For example, [2] investigated the potential tidal energy using Delft3D at eleven straits between the inner Indonesian seas and the Indian Ocean, including the Lombok and Badung Straits. They concluded that the maximum kinetic power densities are 2.36 kW/m^2 at Bali Strait and 1.52 kW/m^2 at Badung (Nusa Penida) Strait. However, there are three significant limitations to their approach. Firstly, the assessment was only based on power density instead of extracted power. Secondly, the simulation did not consider the effects of turbine array interaction with the flow. Finally, their model domain is not large enough to minimise the interaction of the turbine and the boundaries. Furthermore, a large domain is necessary to take the Indonesian Throughflow (ITF) into account.

II. Tidal Stream Numerical Modelling

Indonesia is arguably one of the most complex regions for modelling ocean hydrodynamics due to its geographic complexity with myriads of islands. Rugged bottom bathymetry next to wide shelves of shallow water complicates the currents in the water column. The presence of strong diurnal tidal components along with semidiurnal components sometimes leads to asymmetric tidal phenomena, which demands long computational time for accurate representation. The presence of a net throughflow current makes complicates the problem further. Relatively few studies of tidal resources have been carried out for this region. Furthermore, reliable data for calibration of the models are sparse in this region. While some data gathered by Indonesian government agencies exists, little data is available in the open literature.

A. *DG-ADCIRC Model*

Following [3], [4] and [5], the Discontinuous Galerkin version of the ADvanced CIRCulation Model (DG-ADCIRC) [6] is used to solve the Shallow Water Equations (SWEs) to model the tidal hydrodynamics. Tidal turbines

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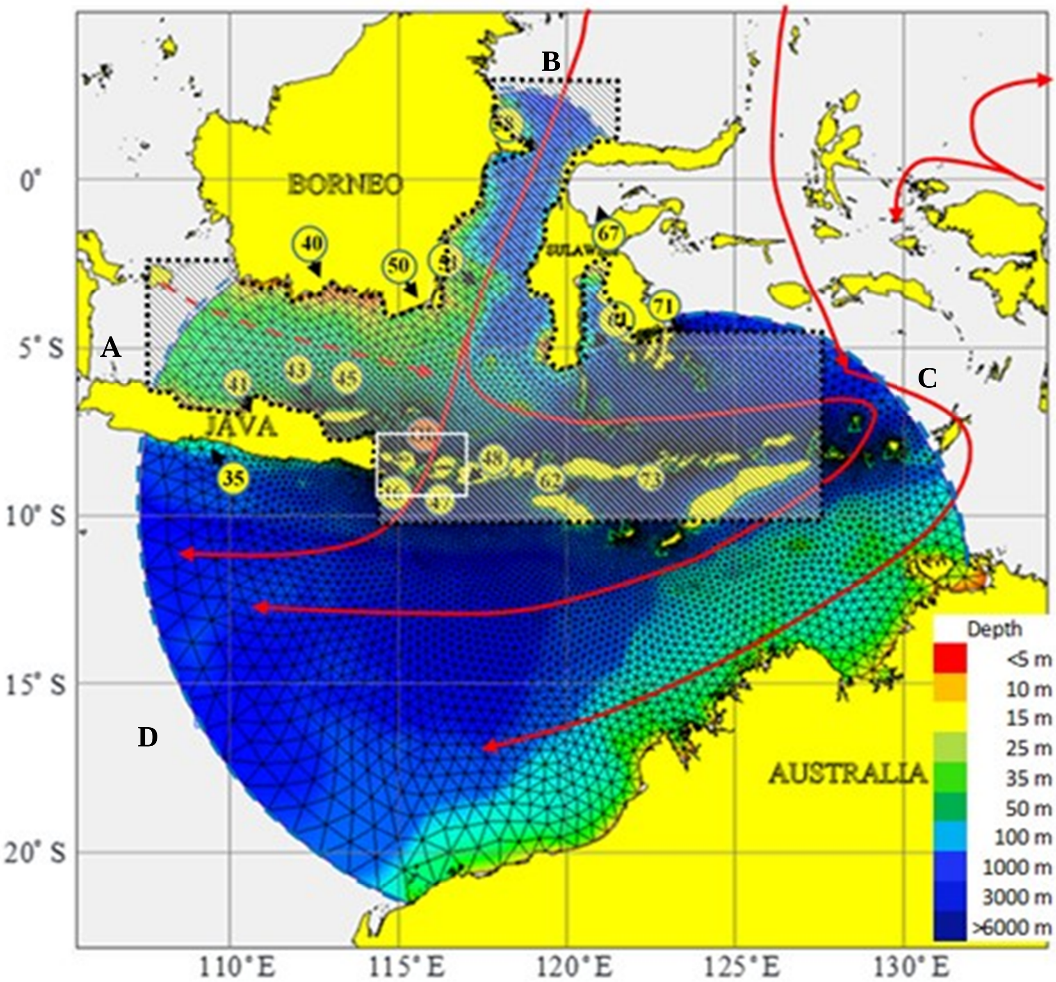

Fig. 1. Model domain with and mesh and bathymetry. The area within the dotted line uses the DISHIDROS bathymetry. Yellow numbered circles indicate the locations of tidal observation stations. The orange circle indicates the ADCP measurement point. Solid red lines represent the Indonesian Throughflow (ITF) and the red dash line the China Sea Throughflow. The box with a white outline is the area enclosing the analysed tidal stream turbine arrays.

are modelled using actuator disc theory [7], [8] and included in the model as line discontinuities at element boundaries. Using several values of wake factor and blockage ratio, we estimate the resources that could be harvested by particular configurations of turbine arrays. By comparing different array configurations, the interactions between deployments in the various straits are analysed.

B. *Model Domain*

In modelling the hydrodynamics of a tidal stream turbine arrays, Adcock *et al*. [5] suggest that the location of the boundaries have to be far enough away to avoid resonances due to the turbine implementation. Fig. 1 shows the area of modelling.

C. *Bathymetric Data*

This model uses the GEBCO bathymetric data. However, Koropitan and Ikeda [9] have shown this dataset to be inaccurate in the central and coastal regions in the Java Sea, and we also found this is to be the case. Hence, bathymetric chart data from DISHIDROS TNI-AL, a hydro-oceanographic Division of the Indonesian Navy, is also incorporated. Several bathymetric maps from DISHIDROS in the Java Sea, Banda Sea and Makassar Sea are combined as shown in Fig. 1 in the region enclosed by the dotted line.

Since these data are referred to Lowest Water Spring (LWS) while GEBCO and Le Provost's model [10] is referred to mean sea level (MSL), it is necessary to adjust the datum for the data. Bathymetric data also need to be refined in the area of the narrow straits in the island chain from Bali Islands to Eastern Nusatenggara. For example, this model uses some detailed bathymetric surveys by Marine Geology Research and Development Centre (P3GL) [11], a research agency under the Indonesian ministry of energy and mineral resources, as shown in Fig. 2.

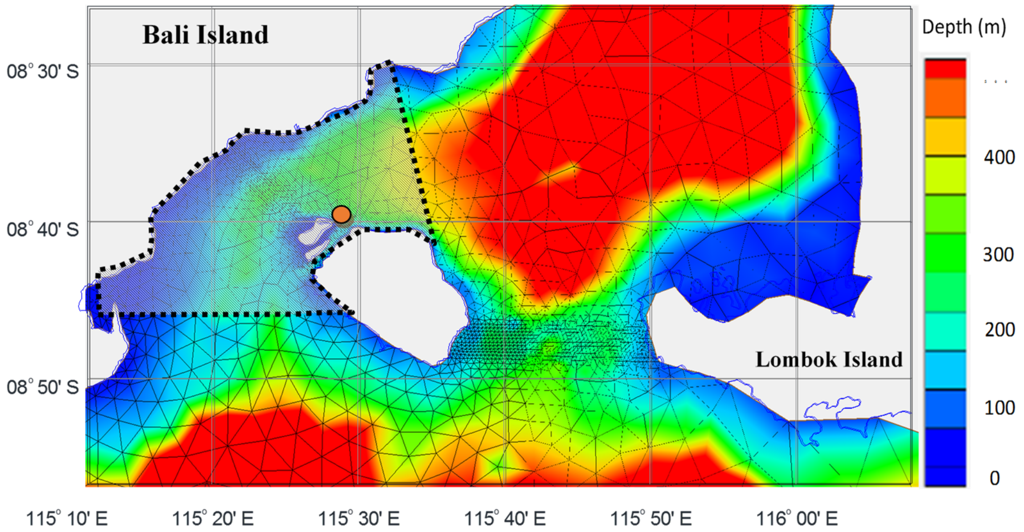

Fig. 2. Mesh for DG-ADCIRC in the area of the turbine. Colours indicate bathymetry. The area within the black dotted line is the area of the bathymetric survey. The orange circle marks the ADCP measurement point in the P3GL survey [11].

D. *Tidal forcing*

The simulation was forced with thirteen tidal components applied at the boundaries, using data from the Le Provost model [10].

E. *Representing Residual Flow in the Model*

Located between the Pacific and the Indian Oceans, this area is passed through by a thermohaline circulation [12, 13]. To mimic the Indonesian Throughflow (ITF) as shown in Fig.1, we apply a small differential head at each boundary: the mean elevations on the open ocean boundaries are set as 0.0075 m, 0.01 m, 0.005 m and 0.000 m on boundaries ABCD respectively, see Fig. 1. For example, these head differences between the northern and southern boundaries, creates a flow in the area of Badung with a velocity ranging from 0.25-0.35 m/s. Because of the inclusion of the ITF as a residual current, the model is spun up for 2 days before the results from the following 60 days are recorded and harmonically analysed for comparison with data.

III. MODEL VALIDATION

The model is calibrated using several data sources. In addition to comparing with the tidal elevations, as is commonly used for validation, the model is validated with a co-tidal chart and with time series of tidal observations and an ADCP current measurement survey.

A. *Tidal Constituents Data Validation*

There are at least sixteen tidal elevation measurement stations in the model domain (yellow numbered circles in Fig.1). These are located in the area of ports or navigation channels. As for bathymetric data, the tidal components from each station are obtained from DISHIDROS TNI-AL.

Table I compares amplitudes from the model results and tidal components from the DISHIDROS tide table [14], while the phase is shown in Table II. Although the amplitude of the principal diurnal and semidiurnal components (K_1, O_1, S_2 and M_2) is imperfectly modelled at particular locations, in general the model shows good agreement with data.

Poor agreement (categorized as >20% log ratio of data/model) between the data and the model results is highlighted in red. The observation stations used here are mainly located ports. Some of the stations at ports are located in river channels (*e.g.* stations 35, 40, 43 and 50) where the tidal characteristics may differ significantly from those in the adjacent open sea, which is modelled in the analysis. The precise location for station 45 is unknown, since the eastern navigation channel of Surabaya is 70 miles long. Station 41 is close to an amphidromic point [15] and the model is rather unsatisfactory in this area.

Comparing to the tidal data, the model shows disagreement in the K_1 phase, see Table II. The model results are categorized as having a poor agreement with the tidal data when $|\phi_{model} - \phi_{data}| \geq 45^0$ where ϕ_{model} is phase from the model and ϕ_{data} is phase from tide tables. This category is highlighted in red on Table II.

Most of the stations show the unsatisfactory phase validation. However, this problem may be due to the different time reference points. To clarify this issue, we compare the results with the co-tidal chart from [15]. As seen in Fig. 3, the model has a good agreement with satellite data.

B. *Field Survey Data Validation*

The model is also validated against tidal observations and ADCP measurements conducted by Yuningsih *et al.* [11]. The observations and ADCP measurements are

TABLE I
DATA VALIDATION OF AMPLITUDE AT TIDAL OBSERVATION STATIONS

Station	M_2				S_2				K_1				O_1			
	Data (m)	Model (m)	Diff (m)	Log Ratio (m)	Data (m)	Model (m)	Diff (m)	Log Ratio (m)	Data (m)	Model (m)	Diff (m)	Log Ratio (m)	Data (m)	Model (m)	Diff (m)	Log Ratio (m)
35. Cilacap	0.5	0.17	0.33	47%	0.25	0.12	0.51	32%	0.19	0.39	-0.2	-31%	0.12	0.35	-0.23	-46%
40. Kota Waringin	0.22	0.27	-0.05	-9%	0.06	0.65	-0.59	-103%	0.36	0.26	0.1	14%	0.16	0.19	-0.03	-7%
41. Semarang	0.1	0.67	-0.57	-83%	0.08	0.24	-0.16	-48%	0.22	0.47	-0.25	-33%	0.08	0.48	-0.4	-78%
43. Kali Anget	0.39	0.72	-0.33	-27%	0.19	0.29	-0.1	-18%	0.42	0.34	0.08	9%	0.24	0.23	0.01	2%
45. Surabaya Eastern Navigation Channel	0.59	0.17	0.42	54%	0.29	0.12	0.17	38%	0.45	0.39	0.06	6%	0.27	0.35	-0.08	-11%
46. Meneng	0.54	0.41	0.13	12%	0.29	0.23	0.06	10%	0.32	0.26	0.06	9%	0.13	0.19	-0.06	-16%
47. Benoa (Bali)	0.71	0.61	0.1	7%	0.33	0.35	-0.02	-3%	0.25	0.21	0.04	8%	0.12	0.15	-0.03	-10%
48. Lembar (Labuhan Tring)	0.27	0.38	-0.11	-15%	0.16	0.19	-0.03	-7%	0.36	0.25	0.11	16%	0.24	0.17	0.07	15%
50. Sungai Barito (Ambang Luar)	0.34	0.67	-0.33	-29%	0.05	0.24	-0.19	-68%	0.64	0.47	0.17	13%	0.33	0.48	-0.15	-16%
51. Tarjun	0.47	0.27	0.2	24%	0.48	0.65	-0.17	-13%	0.34	0.26	0.08	12%	0.2	0.19	0.01	2%
58. Teluk Sangkulirang (miang besar)	0.52	0.49	0.03	3%	0.34	0.45	-0.11	-12%	0.19	0.18	0.01	2%	0.19	0.15	0.04	10%
61. Makassar	0.1	0.13	-0.03	-11%	0.13	0.19	-0.06	-16%	0.3	0.25	0.05	8%	0.25	0.17	0.08	17%
62. Bima	0.35	0.42	-0.07	-8%	0.1	0.06	0.04	22%	0.3	0.28	0.02	3%	0.1	0.16	-0.06	-20%
67. Pantoloan	0.54	0.48	0.06	5%	0.47	0.45	0.02	2%	0.22	0.18	0.04	9%	0.08	0.15	-0.07	-27%
71. Baubau	0.54	0.48	0.06	5%	0.18	0.16	0.02	5%	0.34	0.28	0.06	8%	0.21	0.15	0.06	15%
73. Maumere	0.53	0.47	0.06	5%	0.17	0.14	0.03	8%	0.24	0.28	-0.04	-7%	0.2	0.15	0.05	12%

TABLE II
DATA VALIDATION OF PHASE (IN DEGREES) AT TIDAL OBSERVATION STATIONS

Station	M_2			S_2			K_1			O_1		
	Data (? º)	Model (? º)	Diff (º)	Data (? º)	Model (? º)	Diff (º)	Data (? º)	Model (? º)	Diff (º)	Data (? º)	Model (? º)	Diff (º)
35. Cilacap	157	120	37	57	83	-26	85	206	-121	103	126	-23
40. Kota Waringin	182	213	-31	244	295	-51	34	155	-121	131	105	26
41. Semarang	102	188	-86	203	117	86	7	219	148	128	141	-13
43. Kali Anget	46	58	-12	32	47	-15	61	170	-109	96	116	-20
45. Surabaya Eastern Navigation Channel	41	120	-79	30	83	-53	64	206	-142	100	126	-26
46. Meneng	91	20	71	35	37	-2	117	161	-44	117	116	1
47. Benoa (Bali)	73	348	-275	5	45	-40	59	140	-81	84	109	-25
48. Lembar (Labuhan Tring)	52	24	28	43	36	7	76	162	-86	96	116	-20
50. Sungai Barito (Ambang Luar)	209	188	21	279	117	162	20	219	161	79	141	-62
51. Tarjun	234	213	21	140	295	-155	54	155	-101	97	105	-8
58. Teluk Sangkulirang (miang besar)	211	236	-25	154	281	-127	69	126	-57	103	80	23
61. Makassar	279	78	180	145	284	-139	62	157	-95	95	109	-14
62. Bima	357	61	180	305	128	177	56	166	-110	104	120	-16
67. Pantoloan	167	236	-69	162	281	-119	135	126	9	58	81	-23
71. Baubau	358	70	180	295	148	147	60	169	-109	86	126	-40
73. Maumere	355	67	180	301	147	154	55	168	-113	77	124	-47

conducted on the North East side of Nusa Lembongan Island as indicated by the orange circle in Fig.2.The measurement were carried out from 4th-14th April 2008. The data are not ideal, due to the relatively short period of observation. However, they may show qualitatively how well the model fits the tidal pattern. The validation against ADCP data for a longer duration (say 15 days) would be desirable, but such data are not available

The comparison of ADCP current measurements and the model results is presented in Fig. 4. Despite the fact that the model gives smaller velocity magnitudes, this comparison shows that model matches the velocity pattern quite well. Fig. 5 shows that the tidal elevations match better than the velocity.

Modelling flows in Indonesian waters is certainly challenging. Many authors that have done modelling in this area have found difficulty matching with validation data. For example, Robertson and Ffields [18], successfully replicated tidal elevation fields as determined from TOPEX/POSEIDON with 4-6 cm differences for semidiurnal constituents (S_2 - M_2) and 7-10 cm for diurnal constituents (K_1 - O_1). However these results are for the Root Mean Square (RMS) error for all points. There are some points with significantly higher discrepancies. For example, M_2 at the coordinate 9°46'S, 133°130'E is higher by 47.7 cm than the data.

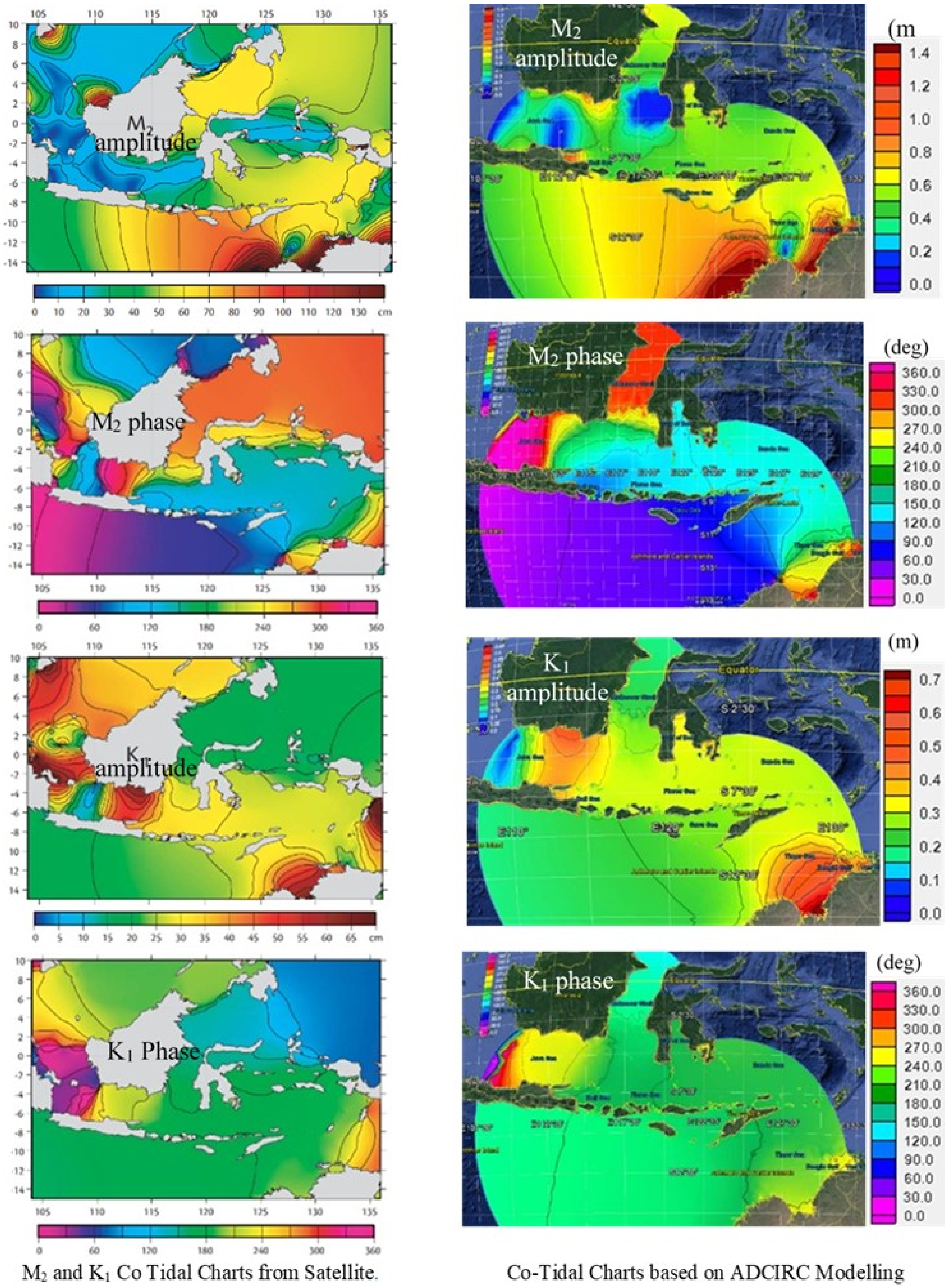

Fig. 3. Comparison of co-tidal charts from (left) satellite altimeter [15] data and (right) model

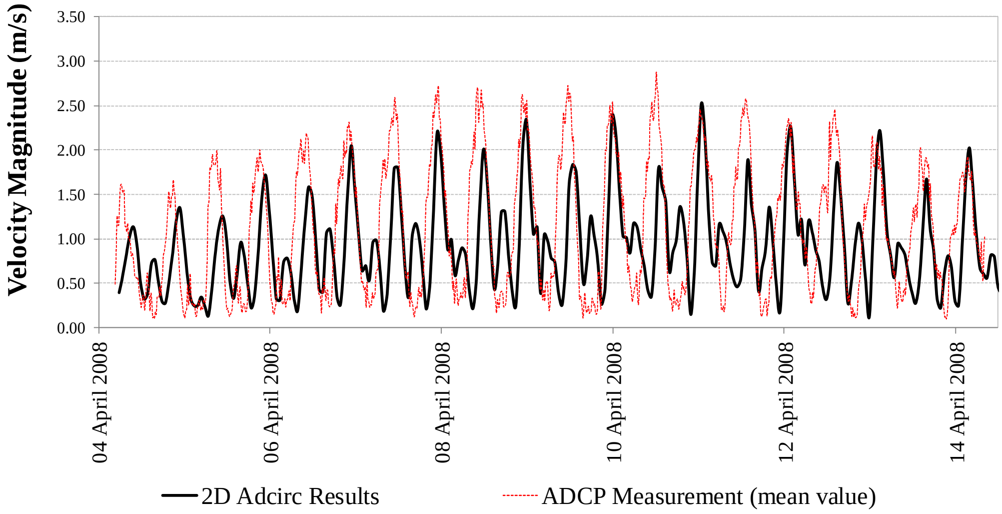

Fig. 4. Comparison of current velocity from model and measurement using ADCP (mean from in several water depths) [12].

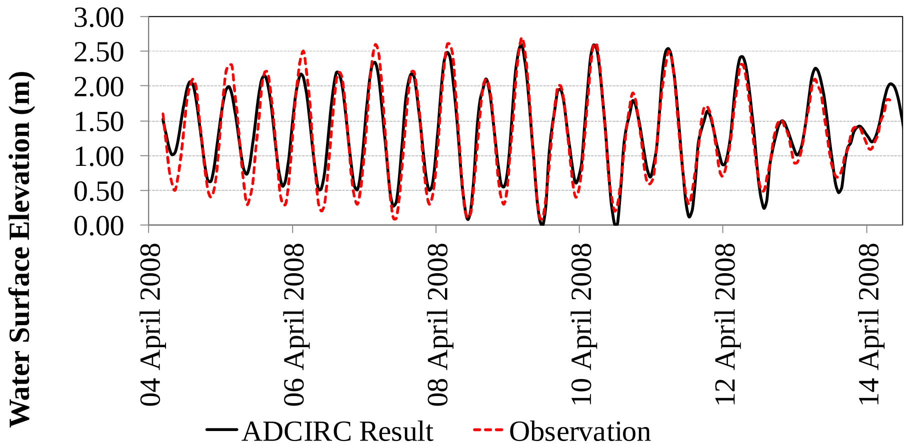

Fig. 5. Comparison of model and tidal elevation observations [12].

IV. Resource Assessment and Analysis

Tidal energy resources are assessed here by Linear Momentum Actuator Disc Theory (LMADT) [7, 8]. The Power (P) removed from the flow in an open channel is calculated by:

$$P = \frac{1}{2}\rho u^3 B A_c C_p \quad (1)$$

where u is velocity of the tidal stream, B is blockage ratio, A_c the cross sectional area of the channel and C_p is a dimensionless power coefficient which is a function of the upstream Froude Number, the blockage ratio and the wake induction factor α_4. For further detail see [7, 8].

There is no publicly accessible report on the exact site in Bali that has been awarded to a developer for tidal turbine arrays. The potential sites around Bali Island are therefore determined from the kinetic power density as calculated by Eq. (2):

$$E = \frac{1}{2}\rho v^3 \quad (2)$$

where E is kinetic power (W/m^2), ρ is seawater density (1025 kg/m^3) and v is the average velocity (m/s).

The flow calculated by DG-ADCIRC is used to calculate the kinetic power density and the power density in Bali waters is shown in Fig. 6. Based on this figure, there are three potential sites for turbine arrays, Badung (A), Toyopakeh (B) and Lombok (C).

The potential resources are assessed by installing a ~13.8 km long turbine array at Badung (A), ~980 m long array at Toyopakeh (B) Strait and 25km long array at Lombok (C) Strait. In the analysis a fence of turbines occupies whole channel width in each strait.

A. Resource Assessment at Individual Sites

In the assessment, three different wake coefficients (α_4) are applied to each array. An example of power extraction time series is presented in Fig. 7. Average power extraction is calculated for each case and plotted against α_4, see for example Fig. 8. The optimum α_4 at

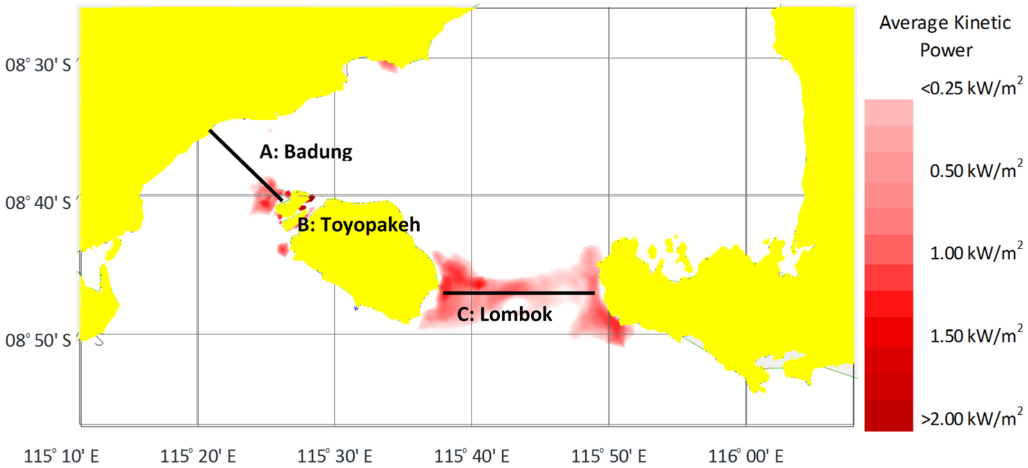

Fig. 6. Potential areas for turbine arrays and kinetic power density from DG-ADCIRC simulation.

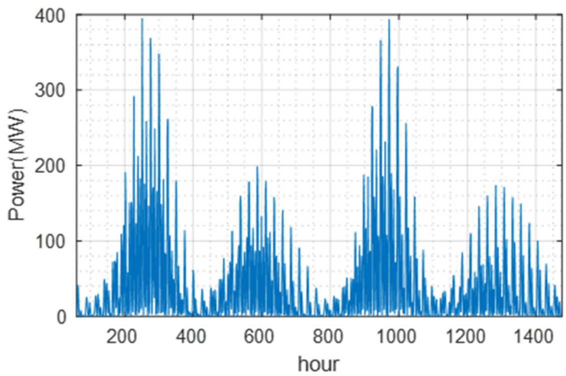

Fig. 7. Power Extraction of Individual Fences at Badung Strait (A)

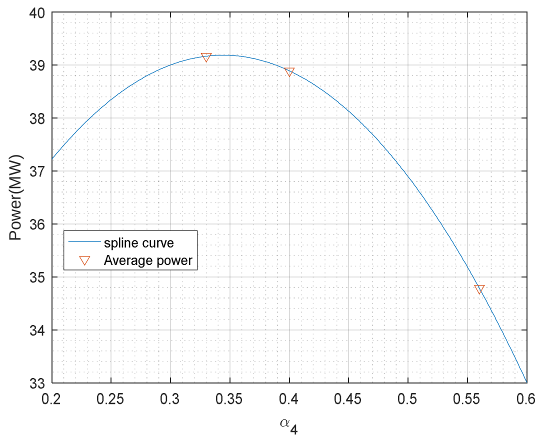

Fig. 8. Average Extraction of Individual Fences at Badung Strait (A)

which maximum power extraction is achieved is obtained by fitting a cubic spline through the data points. The entire assessment is carried out for two blockage ratios: $B = 0.1$ (low blockage) and $B = 0.4$ (high blockage).

The average resource at Badung is approximately ~39 MW while Toyopakeh is ~4.4 MW and Lombok is ~273 MW at low blockage ratio. Atlantis Resources Ltd. (Atlantis) and DCNS Energies promised to deliver 150 MW electricity from this site. It seems this can be achieved at low blockage from Lombok Strait. At high blockage, the resources increase significantly, and is about five to six times higher than for the low blockage case. In detail the resource in Badung is ~232 MW or almost six times higher, Toyopakeh is ~22 MW or about five times higher and Lombok is ~1.8 GW, more than six times higher than the resources at $B = 0.1$. These results show that the given sites are promising for tidal turbine implementation.

B. Site-Site Interactions

Regarding site-site interaction, Draper *et al.* [4] have analysed the case of the Pentland Firth, and Coles *et al.* [17] did a similar study on the Channel Islands. Both studies show that when the turbine arrays are installed in a parallel manner, the power harnessed by the turbine will increase. This implies that parallel sites give advantages for turbine competition.

Since there are three straits parallel to each other, the schemes modelled in this study are ABC, AB, AC and BC. The letters of scheme represent the channel used for tidal energy generation. For example, the ABC scheme means all channels are harnessed simultaneously and AB means that turbines are deployed at Badung (A) and Toyopakeh (B).

Table III shows the average power obtained for optimum wake coefficient for different schemes and the two blockage ratio. The Table also shows the resources from each array in any given scheme. The final column shows the optimum wake coefficient for the model.

At low blockage, the power at C (Lombok Strait) decreases from ~273 MW to ~267 MW for scheme ABC, while A remains at ~39 MW and B remains at ~4.4 MW. The small decrease at C is also present in other schemes

TABLE III
AVERAGE POWER RESOURCE FOR EACH SCHEME

		A	B	C	Total	
Fence length (m)		13,893.73	994.48	25,008.72		
		Power (MW)	Power (MW)	Power (MW)	Power (MW)	α_4
B = 0.1	ABC	39.27	4.43	267.07	310.77	0.34
	AB	39.31	4.42	-	43.73	0.34
	BC	-	4.37	266.56	270.93	0.34
	AC	39.14	-	266.90	306.05	0.34
	A	39.18	-	-	39.18	0.34
	B	-	4.37	-	4.37	0.35
	C	-	-	292.83	292.83	0.34
B = 0.4	ABC	251.97	24.60	1,777.11	2,053.68	0.41
	AB	252.29	25.05	-	277.34	0.43
	BC	-	22.70	1,757.72	1,780.42	0.41
	AC	245.50	-	1,771.88	2,017.38	0.41
	A	231.56	-	-	231.56	0.44
	B	-	21.79	-	21.79	0.48
	C	-	-	1,834.72	1,834.72	0.41

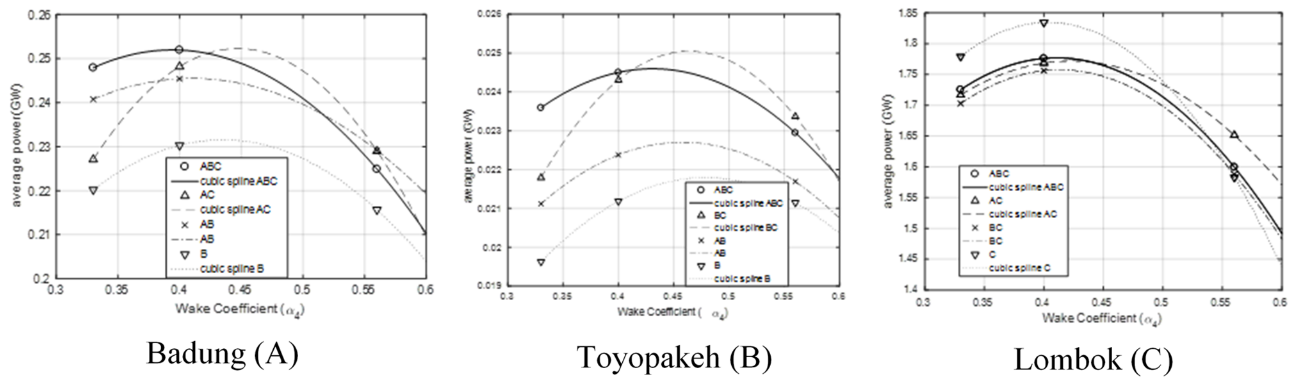

Fig. 9. Average power extraction for high blockage (B = 0.4)

such as BC and AC, the fence at C decreases while A and B remain at the same value as when it is exploited individually. Fences A and B have no diminishing effect on each other when the resources are harnessed simultaneously.

At high blockage, the trend at C is again observed. The average at C decreases from ~1.83 GW when the channel is harnessed individually to ~1.78 GW when the channel is exploited simultaneously with the other two channels (scheme ABC). The same trend is exhibited in other schemes, the resources at C tend to decrease when it exploited in parallel with other channels. These effects are small though and need to be confirmed by further analysis.

In contrast, the other two channels show a slight increase in power at the high blockage when exploited in parallel. The resource at Badung increases from ~232 MW to ~252 MW while Toyopakeh's resource rises from ~22 MW to ~25 MW when all channels are exploited simultaneously. This trend is consistent for other scenarios. Badung increases approximately ~13 MW to 20 MW and Toyopakeh increases by ~1 MW to ~4 MW at the high blockage.

The percentage resource changes due to site-site interaction are shown in Table IV, which shows the output of each array in different schemes in comparison to its output as an individual array. Lombok Strait consistently exhibits a decrease due to site-site interaction, with about 9% loss at low blockage and 4% loss at high blockage. The increasing at other sites is only apparent at high blockage.

Since the resources calculated here are based on the optimum wake coefficient, it is useful also to compare the results at each α_4. Fig. 10 shows the average resources plotted against wake coefficient for the different schemes at each of the three sites.

TABLE IV
RATIO OF RESOURCE IN COMBINED ARRAY TO THAT IN EACH INDIVIDUAL ARRAY

		A*/A	B*/B	C*/C	Total*/Total
B = 0.1	ABC	100.23%	101.40%	91.20%	92.39%
	AB	100.25%	101.25%		100.35%
	AC	99.89%		91.15%	92.18%
	BC		100.01%	91.03%	91.16%
	A	100.00%			
	B		100.00%		
	C			100.00%	
B = 0.4	ABC	108.72%	112.87%	96.86%	98.34%
	AB	108.79%	114.94%		109.32%
	AC	106.01%		96.57%	97.63%
	BC		104.18%	95.80%	95.90%
	A	100.00%			
	B		100.00%		
	C			100.00%	

*Power extraction from multiarray scheme

Based on the figures, the resources at Badung (Fig. 10, A) tend to be higher for parallel array schemes than for the individual array scheme. Consider scheme AC, where the turbines are installed at Badung (A) and Lombok strait (C), the average power extractions at all three different α_4 values and from the cubic spline maximum are higher than the scheme of the individual array (scheme C). At higher $\alpha_4$the average power extraction from scheme AC tends to decline rapidly. The same pattern is also observed at Toyopakeh (Fig.10, B). However, the average extractions are still higher for combined arrays than for the individual array.

At Lombok strait (Fig. 9, C) the average power at low α_4 for the individual array scheme (scheme C) is higher than for the multi-array schemes. It is worth observing though that at higher α_4 the average power extraction is lower than for the multi-array schemes. Thus, this lower average power extraction for multi-array schemes is only applicable at low α_4.

C. *Flow field change*

To understand further the site-site interaction in this region, it is important to examine the flow field change when the turbine fences are installed. For example, Fig. 11 shows the flow changes for the ABC scheme and Fig. 12 for the AB scheme. As seen in the figures, the overall flows in the region decrease for the ABC scheme, while (apart from local near the turbines) they tend to increase for the AB scheme.

This implies that the flow is diverted to C when only A and B are occupied by turbines, while scheme ABC generally decreases the flow field in the entire region. The flow field change is not just in the area of the turbine arrays. As shown in Fig. 13, the flow field decreases in a significant the area of Indonesian Throughflow (ITF).

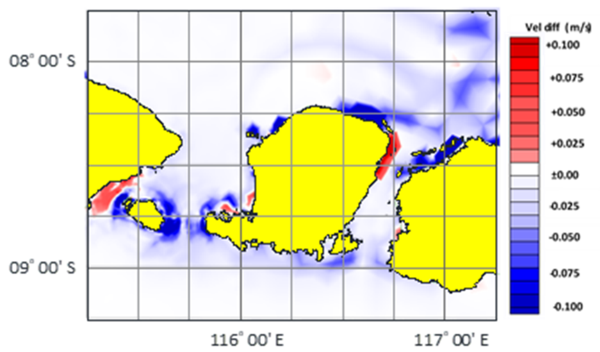

Fig. 10. Flow field changes for turbines installed in all straits, Nusa Penida (A), Toyopakeh (B) and Lombok (C).

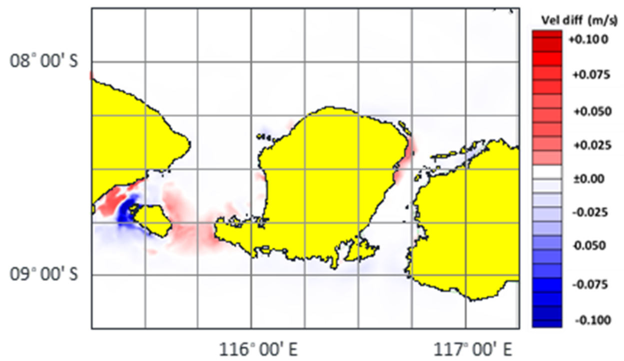

Fig. 11. Flow field changes for turbines installed only in sites A and B

The ~2.053 GW resource in Bali waters might be obtained by deploying turbines at all channels at high blockage. However, it is necessary to consider the effect on global currents. Since ITF is a part of the so called "Global Ocean Conveyor Belt", these small changes might have an impact to the global ocean system.

V. DISCUSSION AND CONCLUSION: THE TIDAL RESOURCE IN BALI WATERS

This study indicates that the total theoretical power potential of the Bali waters is approximately ~2.05 GW (from three sites exploited simultaneously at high blockage).

The simulations are run with 13 tidal constituents for a period of 62 days. However, it is possible that slightly different conclusions would be drawn if a longer period were to be simulated. Long period constituents such as Solar semi-annual (Ssa) and Solar annual (Sa) play an important role in this area, with seasonal changes in tides being important.

The estimates have been obtained using a 2D depth-averaged numerical model. This should represent be an improvement on previous assessments based on the undisturbed on kinetic flux. However, the limitations of 2D analysis employing the Shallow Water Equations should be noted. The discrepancies with measurements at some stations may be attributable to these limitations.

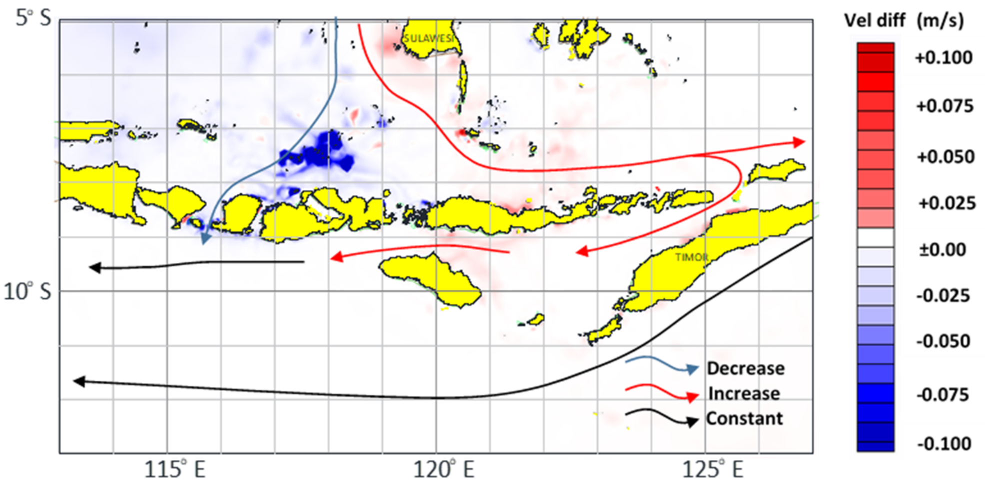

Fig. 12. The effect of turbine arrays on the global current (the turbines are installed in all straits (ABC) and using a simulation with 13 tidal constituents)

This investigation modelled arrays that span across each entire channel. Since this area is part of international shipping routes, this assumption is unrealistic. The deployment of arrays partially spanning the channel would reduce the net power available from the values given here. Furthermore, we have assumed a constant blockage ratio for each array, which is unlikely to be practicable. When more sophisticated analyses are conducted the conclusions about site-site interactions may change.

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