Wave energy projections in Western Indian Ocean; a regional assessment for southeast Africa

Bahareh Kamranzad, Nobuhito Mori

Abstract— **Wave energy is a promising alternative to exhaustible fossil fuels to mitigate the negative impacts of climate change in the areas with absorption potential. However, the available resources are subject to alter due to climate change. The Indian Ocean as a high potential area for wave energy harvesting has been considered for downscaling of wave climate in regional and local scales to provide high resolution dataset. In this study, the wave energy has been evaluated in southeast Africa and the impact of climate change has been assessed to investigate the sustainability of available resources. For this purpose, dynamical downscaling of wave climate has been performed using the boundary condition obtained from an Indian Ocean-scale parent model. Spatial distribution of wave power in the study area indicates higher values in Reunion and Mauritius as well as southern Madagascar. In addition, these areas indicate higher stability in wave energy value in both short and long term. This study shows that despite the fewer investigations done in the southern Indian Ocean due to the scarcity of high resolution and reliable wave data, this area is a potential spot for wave energy extraction due to its high value resources and stability in short-term fluctuations and long-term changes.**

Keywords—**wave energy, climate change, Indian Ocean, southeast Africa**

I. INTRODUCTION

MARINE renewable energies and especially the wave energy as an alternative to fossil fuels are sensitive to changing climate. Uncertainties in the estimation of these resources due to unknown phenomena will result in increase of costs of any planning and under/over-design of wave energy converters (WECs).

To reduce the risk associated with uncertainties, different approaches can be considered such as the use of higher-resolution data set to achieve a higher accuracy estimate of the wave characteristics. In addition, taking into account both short-term variations and long-term changes in the available resources can reduce the uncertainties in the future prediction and provide reliable information for selecting the appropriate spots to extract the wave energy. Recent studies have also shown that the areas with lower potential of energy, but higher stability in available resources are more appropriate for wave energy exploitation (e.g., [1], [2]).

The stability of wave energy resources in the short-term can be discussed in terms of intra-annual, i.e., monthly and seasonal variations, as well as inter-annual variation. The long-term variations can be assessed in terms of decadal changes and even longer-term time spans referring to climate change impacts. This study focuses on the estimation of wave energy resources in the southeast (SE) Africa as derived from the previous studies conducted in the Indian Ocean, to be a potential spot for providing part of the electricity demand in this area.

Kamranzad and Mori [3] used super-high-resolution wind field MRI-AGCM3.2S as forcing to the numerical modelling of wave characteristics of the Indian Ocean and used satellite data to validate the model. They used the validated model to generate the wave climate in two 25 year periods (historical and future projections) and discussed the future change of wave climate in Northern and Southern Indian Ocean, separately. Then, Kamranzad and Mori [4] also investigated the climate change impact on wave energy resources in the Indian Ocean based on the dataset produced in [3] and showed that southern Indian Ocean contains higher wave power potential and lower monthly variation and relative future change. Hence, further assessment and downscaling in order to investigate the optimum locations for wave energy extractions in this region is required.

Until now, there has been no comprehensive study on evaluation of wave energy resources in SE Africa due to the lack of the high resolution wave dataset. Hence, the

1491 02-08 WRC

"Part of this research was supported by the Hakubi center for advanced research at Kyoto University, the framework of the Integrated Research Program for Advancing Climate Models (TOUGOU Program), and JSPS Grants-in-Aid for Scientific Research –KAKENHI- supported by the Ministry of Education, Culture, Sports, Science, and Technology-Japan (MEXT)."

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aim of this study is to provide the reliable information on wave energy resources in SE Africa and climate change impacts using a super-high-resolution dataset. More details on the used dataset and regional wave modelling will be represented in Section 2 and the results will be presented and discussed in Section 3 with a summary in Section 4.

II. DATA RESOURCES AND WAVE MODELING

In order to generate high resolution wave dataset in SE Africa, super-high-resolution 20 km wind field of MRI-AGCM3.2S [5] model with temporal and spatial resolutions of 1 hour and 20 km, respectively was used. This wind field was used to generate the historical and future projections for two 25-year periods (i.e., 1979-2003 and 2075-2099, respectively) according to Representative Concentration Pathway (RCP) 8.5 scenario [6], [7]. SWAN (Simulating WAves Nearshore) numerical model [8] was used for wave modelling for both historical and future projections.

Bathymetry dataset of GEBCO was used with spatial resolution of (1/120)° covering the whole domain. Fig. 1 shows the computational domain of the regional SE Africa model. This model was performed with a computational resolution of (1/6)° in the spatial domain and temporal resolution of 30 mins. Boundary conditions were obtained from the parent model developed for the whole Indian Ocean and performed with (1/2)° spatial resolution of the computational domain [3].

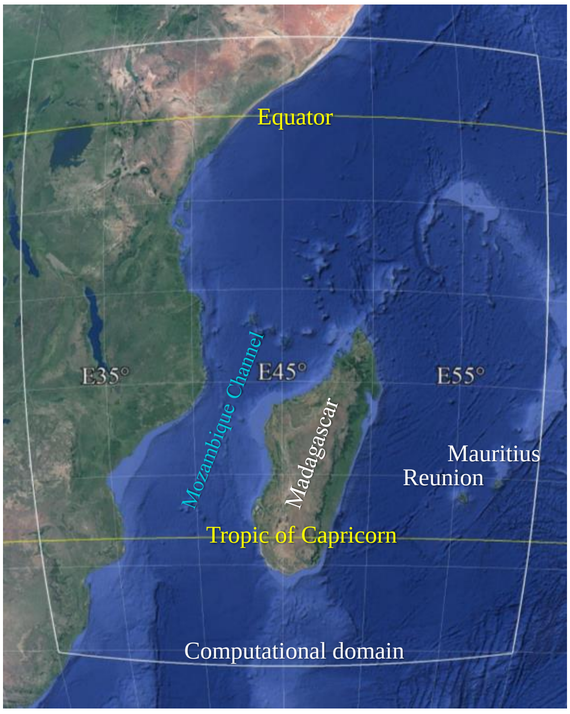

Fig. 1. Computational domain in SE Africa

III. RESULTS AND DISCUSSION

The regional SE Africa model was performed for two 25-year periods (historical and future projections) and time series of wave characteristics were extracted in domain with the same spatial resolution as computational grid.

The wave power (P) values were calculated at each output grid for each period (i.e., historical and future projections) using the wave characteristics, including significant wave height (H_s) and energy period ($T_e = m_{-1}/m_0$) [9] as $P = 0.49 \times H_s^2 \times T_e$ for deep water condition and annual and monthly mean wave power values were calculated.

Fig. 2 shows the mean annual H_s in domain for historical and future projections and the absolute and relative change of it due to climate change. The dominant wave direction in both historical and future projections is from south and southeast propagating toward the Islands and SE Africa. Mean annual H_s reaches from around 2.5 m in south of Madagascar to less than 1 m in the north west of the island (reduction of about 60%). Low values of H_s in the African side of Madagascar illustrate that most of the wave energy is damped due to the sheltering effect of Madagascar, which functions like a natural barrier protecting part of the SE Africa from the Southern Ocean waves.

Moreover, Fig. 2 depicts that, however, the highest waves propagate in the south of Madagascar and around Reunion and Mauritius Islands in both historical and future periods, these areas experience lower change in the future due to climate change, compared to the northern parts of Madagascar (were lower waves propagate). The future change of H_s in this area varies between around 3 cm increase in the north of Madagascar to 10 cm decrease in the Mozambique Channel.

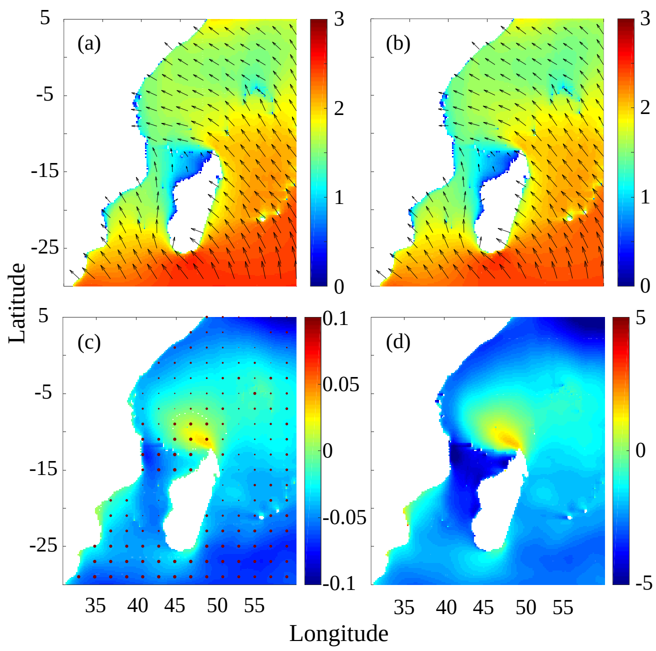

Fig. 2. (a) Historical mean annual H_s (m), (b) Future mean annual H_s (m), (c) Absolute change (m) and (d) Relative change (%)

Fig. 3 indicates the mean annual wave power in historical and future projections and its absolute and relative change. As this figure depicts, the spatial distribution of wave power corresponds that of H_s and presence of Madagascar causes the decrease of wave power from around 30 kW/m in the south of Madagascar, Reunion and Mauritius islands to around 3 kW/m in the northwest of Madagascar and Mozambique Channel (reduction of about 90%). In SE Africa coasts, the wave power varies from around 10 kW/m in northern parts to around 6 kW/m in Mozambique Channel and to around 20 kW/m in southern parts.

Moreover, the range of future change in available wave power varies between 0.5 kW/m of increase in the north of Madagascar to 2 kW/m of decrease in north of Reunion and Mauritius islands and south of the domain. There is almost no change in the future wave power in the northern parts of the domain as well as around Reunion and Mauritius. Although, in order to specify the areas with higher stability, assessment of short-term variations is necessary, as well.

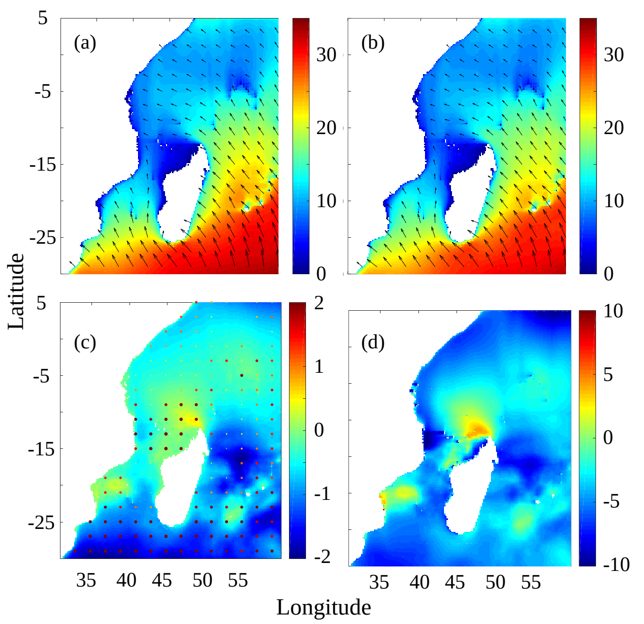

Fig. 3. (a) Historical mean annual wave power (P) (kW/m), (b) Future mean annual wave power (P) (kW/m), (c) Absolute change (kW/m) and (d) Relative change (%)

In order to quantify the monthly variability of available wave power in the region, Monthly Variability Index (MVI) was used. This factor is calculated as the ratio of difference between the highest and lowest monthly mean to the annual mean wave power and lower values imply higher stability of the wave power in monthly variability. Fig. 4 shows the spatial distribution of MVI in the domain. According to this figure, wave power has lower variability in monthly scale in SE Africa (below 15° S), south of Madagascar, Reunion and Mauritius. According to both Figs. 3 and 4, despite containing a higher potential of wave energy, the mentioned areas experience a relatively stable condition in wave climate in both short and long-term scales which makes them ideal for future planning of wave farm installation.

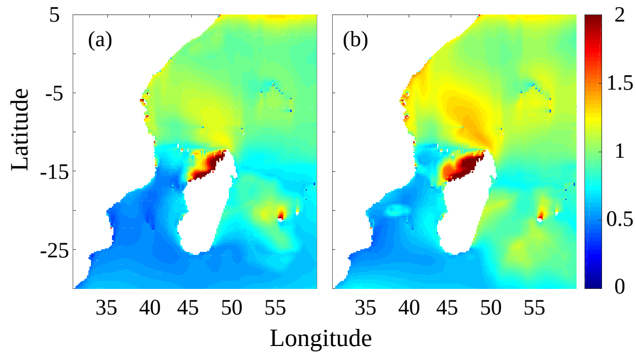

Fig. 4 (a) Historical and (b) Future MVI

IV. Summary and Conclusion

This study has provided super-high-resolution 20 km GCM output to reduce the uncertainties in the estimation of wave power in SE Africa and investigate the impact of climate change on available resources. A nested model was used to simulate the wave characteristics in domain using the boundary condition obtained from a previous study in the Indian Ocean (done by the authors) and generate the wave climate in two 25 year periods of historical and future projections.

The spatial distribution of H_s and wave power showed that considering the dominant direction of wave propagation in the domain which is from south and southeast, Madagascar plays an important role in damping the energy of the waves reaching SE African coasts by sheltering effect, which causes a reduction of about 60% in H_s, which leads to a reduction of 90% in wave power. The future change of H_s ranges between + 3 and -10 cm, whereas this range varies between +0.5 and -2 kW/m for wave power.

Based on the spatial distribution of the wave power in both historical and future projections as well as assessment of both short and long-term variations, south of Madagascar, Reunion and Mauritius were shown to be the most appropriate locations for wave energy extraction containing the highest potential for a future sustainable development due to the stability of the available resources.

Acknowledgement

We thank Meteorological Research Institute (MRI) of Japan for the MRI-AGCM3.2S dataset. We are also thankful to Delft University of Technology for making SWAN model freely available.

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