Spatio-temporal wave climate using nested numerical wave modeling in the northern Indian Ocean

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INTRODUCTION

In order to simulate the wave climate in a specific region for different purposes such as climate change impact assessment, wave energy assessment, etc., it is important to consider the long-term variations (Shimura et al., 2015). Due to the scarcity of the wave measurements, numerically modeled wave data are an appropriate alternative to provide the wave characteristics in desired spatial and temporal coverage. There are limited studies which investigated the wave climate in the northern Indian Ocean. Amrutha et al. (2016) studied the wave climate in the eastern Arabian Sea at the west of India by comparison of the results of a nested numerical modeling with buoy data. Kamranzad et al. (2016) also assessed the temporal-spatial variation of wave energy and nearshore hotspots in northern Gulf of Oman based on the locally generated wind waves.

In this study, wave modeling performance is investigated in the northern Indian Ocean (NIO) considering long distance swells. A nested wave modeling was utilized in the NIO to discuss the accuracy of wave simulation both temporally (by comparing to buoy dataset) and spatially (by comparing to the satellite altimeter records in the domain). High temporal resolution is important to consider the peak events for extreme value analysis, while the accurate estimation of spatial distribution is important for long-term variation of average wave climate in a domain.

METHODOLOGY

Since the NIO is affected by the seasonal monsoon, and wave propagation is influenced by both seas and swells (from the Equator or the Antarctic), spatio-temporal assessment of the wave field is necessary there. For this purpose, SWAN (Simulating WAves Nearshore) (Booij et al., 1999) was utilized to generate the wave characteristics in the region, using the wind field obtained from JRA-55 and with and without boundary condition produced by WAWEWATCH III (WW3) (Tolman, 2014) covering the whole Indian Ocean to consider the swells, as well. Wind data obtained from Japanese 55-year Reanalysis Project (JRA-55), developed by the Japan Meteorological Agency (Mori et al., 2015; Kobayashi et al., 2015) was used as model forcing. The temporal resolution of JRA-55 wind field is 6 hrs, while the spatial resolution is around 0.56 degree. The WW3 domain is global while the SWAN domain covers parts of NIO and Arabian Sea (Fig.1).

The modeled hindcasts were validated in a near-shore location in Gulf of Oman, where the measured data were available by buoy measurements provided by Iran Meteorological Organization (IRIMO). The location of the buoy is 60.65°E and 25.26°N. The satellite altimeter dataset (AVISO) were also used for spatially validation of the modeling results in a relatively long-term period.

Fig.1 Study area and location of computational grid for nested local model

RESULTS AND DISCUSSION

The model outputs were compared to the buoy measurements (Fig.2) and error indices were calculated (Table 1), and the results show that the modeled wave parameters represent the reliable values comparing to the buoy measurements. ERA-Interim wave characteristics were also compared to the measurements in the study area, and the results illustrated that the accuracy of modeled waves is higher than ERA-Interim waves.

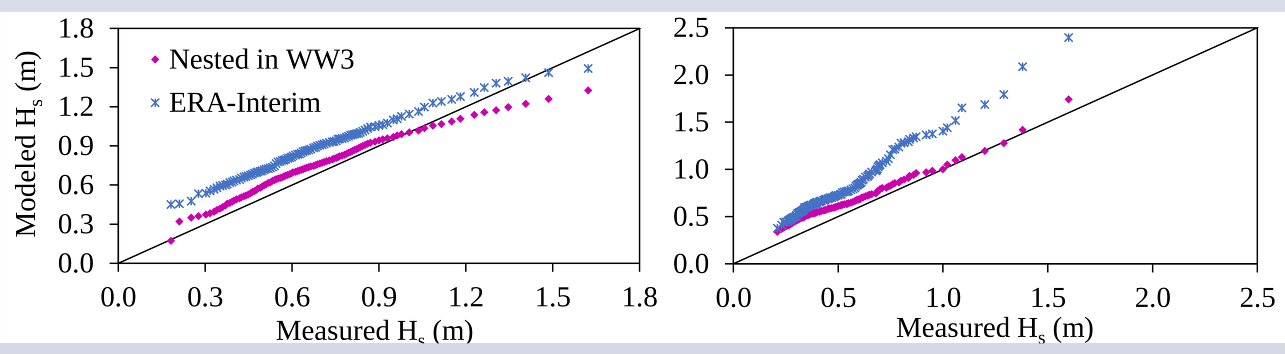

Fig.2 Quantile plots for comparison of modeled wave height results and ERA-Interim data compared to buoy data for two different validation periods

Table 1. Error indices for significant wave height in comparison with buoy data for two different validation periods

	Validation 1		Validation 2	
Error Index	Nested model	ERA-Interim	Nested model	ERA-Interim
Bias (m)	0.05	0.18	0.11	0.29
R	0.53	0.48	0.65	0.77
RMSE (m)	0.26	0.29	0.24	0.35
SI (%)	0.37	0.42	0.42	0.62

Then, the spatial distribution of the simulated waves was compared to the satellite altimeter records in the NIO during a relatively long-term (8 years) (Fig.3). The results indicate that the nested model outperforms both in high temporal resolution and spatial distribution, and is able to simulate the monthly variation of the wave parameters in the domain, accurately, to demonstrate the effect of monsoons during the summer time.

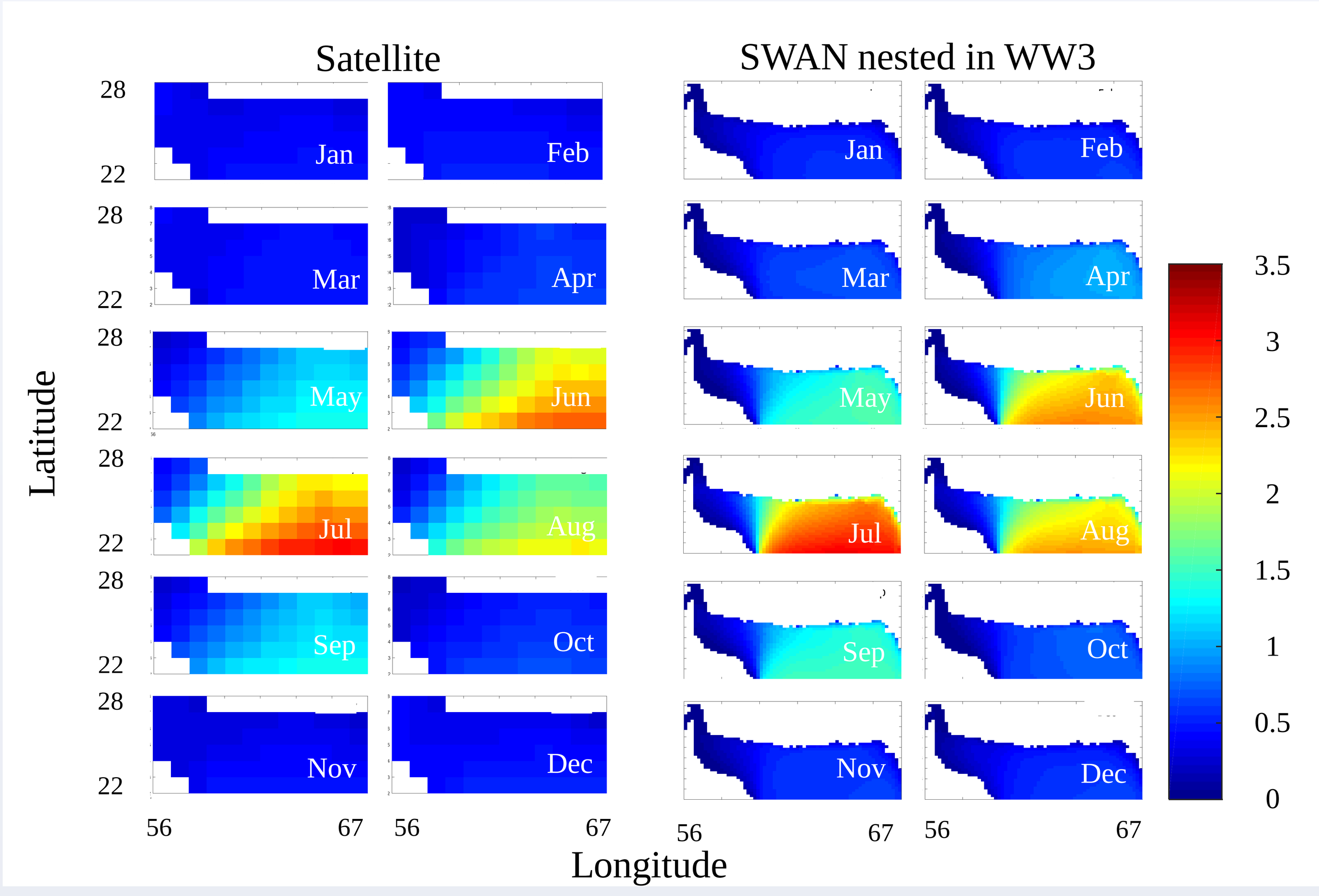

Fig.3 Monthly distribution of significant wave height (m) in domain obtain from satellite measurements and wave modeling

Percentages of swells were also investigated in this region and plotted in Fig. 4 showing that the swells dominance increases during the summer monsoon season, i.e., Jan-Aug. According to this figure, the percentage of swell waves does not exceed around 40% the rest of the year.

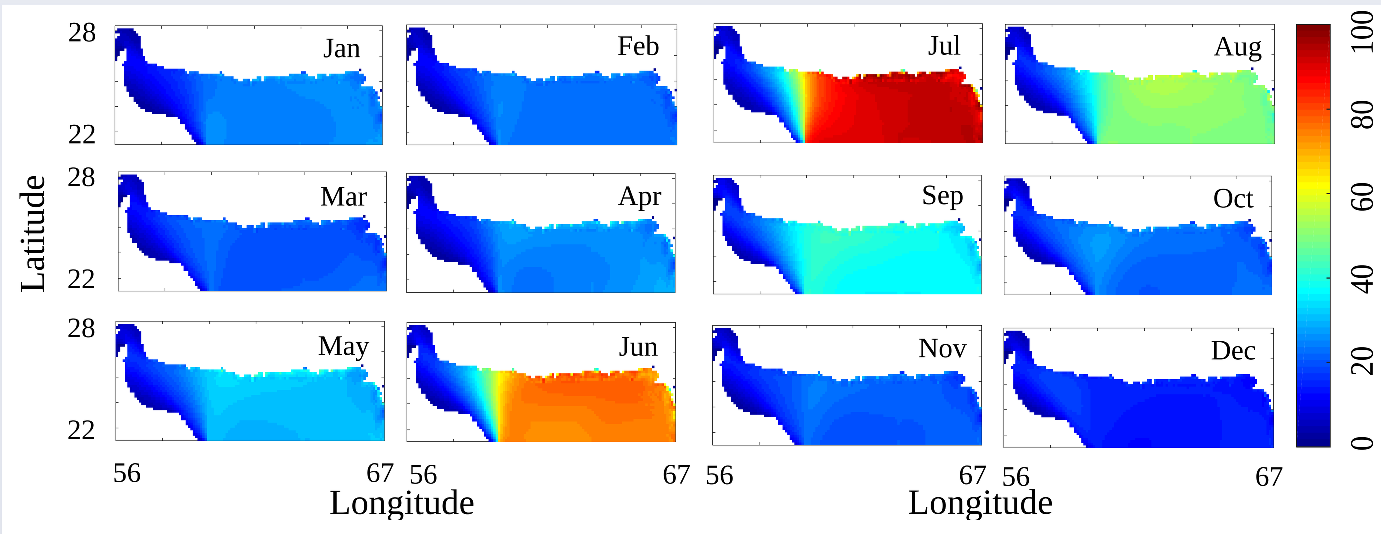

Fig.4 Percentage of swells to sea waves

CONCLUSION

Nested wave modeling approach including SWAN as a local high-resolution wave model nested in WW3 for providing the boundary condition was assessed. The results were compared to buoy measurement and represented a relative agreement in terms of error indices. The spatio-temporal variation of the wave climate generated by the nested numerical modeling was investigated in the domain and compared with the wave field obtained from satellite measurement for a longer period. The results indicate the proper performance of the model in terms of spatial distribution of the monthly significant wave height. Hence, according to the monthly distribution of the significant wave height, the model is able to simulate the monthly and seasonal variations related to the monsoon phenomena, well. In addition, the model results were used to estimate the percentage of swell waves distribution over the domain in different months representing the dominance of the swells during the monsoon season (June-Aug).

REFERENCES

Amrutha, M. M., Sanil Kumar, V., Sandhya, K. G., Ba-lakrishnan, Nair, T. M. and Rathod, J. L. : Wave hindcast studies using SWAN nested in WAVEWATCH III – comparison with measured nearshore buoy data off Karwar, eastern Arabian Sea, Ocean Engineering, Vol. 119, pp. 114-124, 2016.

Booij, N., Ris, R. C. and Holthuijsen, L. H. : A third-generation wave model for coastal regions. 1. Model Description and validation, Journal of Geophysical Re-search Vol. 104, pp. 7649-7666, 1999.

Kamranzad, B., Chegini, V. and Etemad-Shahidi, A. : Temporal-Spatial variation of wave energy and nearshore hotspots in the Gulf of Oman based on locally generated wind waves, *Renewable Energy*, Vol. 94, pp. 341-352, 2016.

Kobayashi, S., Ota, Y., Harada, Y., Ebita, A., Moriya, M., Onoda, H., Onogi, K., Kamahori, H., Kobayashi, C., Endo, H., Miyaoka, K. and Takahashi, K. : The JRA-55 Reanalysis: General specifications and basic characteristics. *Journal of Meteorological Society of Japan*, Vol. 93, pp. 5-48, 2015.

Mori, N., Shimura, T., Kamahori, H., Chawla, A., Yasuda, T., Mase, H. : Long-term wave hindcast and wave climate analysis by JRA-55, *Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering)*, Vol. 71, No. 2, pp. 103- 108, 2015.

Shimura, T., Mori, N., Mase, H. : Future projections of extreme ocean wave climates and the relation to tropical cyclones: ensemble experiments of MRI-AGCM3.2H, *Journal of Climate*, Vol. 28, pp. 9838-9856, 2015.

Tolman, H. L. : WAVEWATCH III Development Group, User manual and system documentation of AVEWATCH III version 4.18, National Oceanic and Atmospheric Ad-ministration, National Weather Service, National Centers for Environmental Prediction, College Park, MD 20740, pp. 311, 2014.

ACKNOWLEDGEMENT

B. Kamranzad was supported by the Japan Society for the Promotion of Science (JSPS) with Grant-in-Aid for JSPS Postdoctoral Fellowship for Overseas Researchers. The part of this research is supported by Integrated Re-search Program for Advancing Climate Models by MEXT, Japan.