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Wave hindcast for the Indian Ocean region covering the period of ARMEX-I (June-August 2002)

J. SWAIN, M. K. SINGH*, CHANCHAL DE, D. VIJAYAKUMAR*

and

N.R. VENKITACHALAM

Naval Physical and Oceanographic Laboratory, Kochi, India

**Naval Operational Data Processing and Analysis Centre, Indian Navy, Kochi – 682 021, India*

e mail : tsonpol@vsnl.com

सार – आरमेक्स के प्रथम चरण प्रेक्षणात्मक कार्यक्रम (जून–अगस्त 2002) के अंतर्गत हिंद महासागर के क्षेत्र (30°–120° पू., 30° द., – 30° उ.) के लिए तरंग हिंडकास्ट किया गया है। राष्ट्रीय मध्यम अवधि मौसम पूर्वानुमान केन्द्र, नई दिल्ली द्वारा उपलब्ध कराए गए छः घंटों के अंतराल के बाद विश्लेषित पवन क्षेत्रों का उपयोग तीसरी अवस्था के तरंग निदर्श "डब्ल्यू. ए. एम." (1.5° × 1.5° विभेदन) को संचालित करने के लिए किया गया। इस हिंड कास्ट के प्रमुख उद्देश्य आरमेक्स की अवधि के दौरान समुद्र की स्थिति की सूचनाएँ उपलब्ध कराना है जो भविष्य की अनेक आवश्यकताओं को पूरा करने के लिए अनुसंधान अनुप्रयोगों और हिंद महासागर में डब्ल्यू. ए. एम. को प्रचालनात्मक रूप से कार्यान्वित करने में सहायक सिद्ध होंगे। इस मॉडल को आई. एन. एस. सागरध्वनि पर एकत्रित किए गए शिप बॉर्न तरंग रिकार्डर (एस. बी. डब्ल्यू. आर.) आँकड़ों का उपयोग करते हुए प्रमाणित किया गया और दृश्य आकलनों की सूचना भारत मौसम विज्ञान विभाग (आई. एम. डी.) द्वारा प्रकाशित भारतीय दैनिक मौसम रिपोर्ट (आई. डी. डब्ल्यू. आर.) और राष्ट्रीय महासागर प्रौद्योगिकी संस्थान के समय श्रृंखला प्लव मापों में दी गई है। बताए गए दृश्य आकलनों और निदर्श के आउटपुट की तुलना एन. आई. ओ. टी. के उपलब्ध प्लव आँकड़ों के साथ की गई हैं। हिंडकास्ट तरंग प्राचलों और मापों के बीच की गई तुलना से यह पता चलता है कि ±12 प्रतिशत से. ±20 प्रतिशत की त्रुटियों सहित तरंग ऊँचाइयों से मॉडल पूर्वानुमान कर सकता है।

ABSTRACT. Wave hindcast has been carried out for the Indian Ocean (30°-120° E, 30° S - 30° N) region covering ARMEX, PHASE-I observational programme (June-August 2002). The analysed wind fields at six hourly intervals provided by National Centre for Medium Range Weather Forecast (NCMRWF), New Delhi is used to drive the third generation wave model "WAM" (1.5° × 1.5° resolution). The primary objectives of this hindcast, is to provide the sea-state information for the period of ARMEX which would help in research applications and to implement WAM operationally for the Indian Ocean to meet various requirements in future. The model was earlier validated using the Ship Borne Wave Recorder (SBWR) data collected onboard INS Sagardhwani, the visual estimates reported in the Indian Daily Weather Report (IDWR) published by the India Meteorological Department (IMD) and time-series buoy measurements of National Institute of Ocean Technology (NIOT). The model outputs are compared with the available buoy data of NIOT. The comparisons between the hindcast wave parameters and measurements reveal that the model could predict wave heights with errors ranging from ±12% to ±20%.

Key words – ARMEX, WAM validation, Wave hindcast, Sea-state prediction.

1. Introduction

The sea-state or wind-induced surface gravity wave information is an essential requirement for various applications such as design of coastal and offshore structures, protection of coastal zone, optimum tracking of ships, assessment and exploitation of wave power potential, towing of underwater bodies, detection of underwater objects and rescue operations. Sea surface waves also play a dominant role in the air-sea interaction process of the coupled ocean atmosphere system while predicting the future weather sufficiently in advance. Therefore, wave prediction for the region of interest becomes unavoidable, as it is not possible/feasible to completely monitor the ocean in space and time either through direct measurements using state-of-the-art

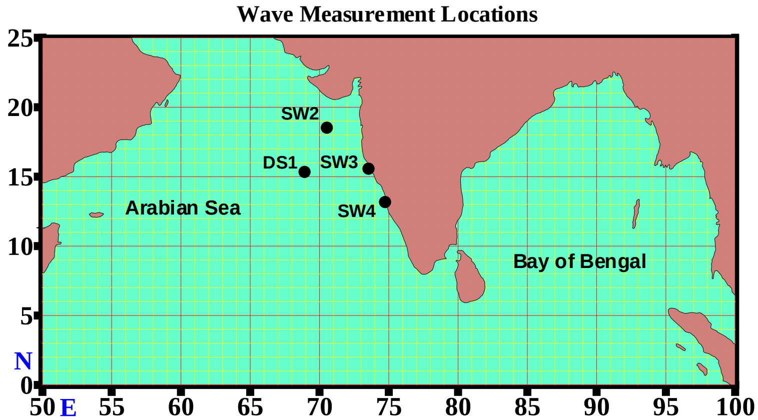


Fig. 1. Map showing NIOT buoy measurement locations

equipment/buoys or from satellite. Hence, the present study is one of the attempts to simulate the wave field over the region of interest through hindcasting (prediction using past winds). Here, the third generation wave model "3g-WAM" developed by the WAMDI Group (1988) is used for the regional grid system (1.5° × 1.5° resolution) for wave hindcast and to compare with sea-truth for evaluation of the model performance using the analysed winds obtained from National Centre for Medium Range Weather Forecast (NCMRWF), New Delhi for the period of ARMEX-I (June-August 2002). The model outputs have been compared with the available buoy measurements from NIOT (National Institute of Ocean Technology, Chennai) at four different locations (Fig. 1). The primary objective of this study is to provide sea-state information for research application for the ARMEX-I observational period and to implement WAM in the Indian Ocean to meet various user requirements in near future. The model was earlier validated (Swain *et al.*, 2001; Panigrahi *et al.*, 2001) for July-August 1999 using NIOT buoy data, measurements onboard INS Sagardhwani during BOBMEX-99 and the visual estimates reported in the Indian Daily Weather Report (IDWR) published by the India Meteorological Department (IMD), New Delhi. Similar results on 3g-WAM model validation using buoy data were also published (Swain *et al*., 2002; Swain *et al*. 2003) subsequently and the comparisons between the model outputs and the observations were encouraging.

2. The wave model

Third generation wave model 3g-WAM (Cycle-4) incorporates latest physics and integrates the basic transport equation without any prior assumption on the shape of the wave spectrum (Gunther *et al.*, 1992). It is being used for global and regional wave forecasting purposes by several institutions in the world. The model requires the wind input at the prescribed model grids and computes the evolution of two dimensional wave spectrums for the full set of degrees of freedom (Komen *et al*., 1996). The source terms and the basic transport equations are integrated for the prescribed time steps, which includes both depth and current refraction. Model outputs are the significant wave height, peak and mean wave periods; mean wave and wind-wave directions; the swell wave height, frequency and direction; frictional wind velocity, wave-induced stress, and the two-dimensional wave spectrum at selected locations and output time steps. The model is being updated with new advances and continually validated with long-term measurements of moored buoys and satellite data.

3. Wave hindcast and post-processing

The wave model 3g-WAM is executed using the six hourly analysed wind inputs without depth (deep water run) and current refraction. The source integration and the propagation time steps have been set to 10 minutes and 1 hour respectively. The model output parameters at all the grid points are stored at three hourly intervals. However, the 2d-spectral outputs are stored only for selected grid points. The outputs such as the significant wave height (Hs), significant period (Ts), mean wave period (Tc), mean wave direction, sea-state dependent drag-coefficient (Cd), wave stress and spectra have been processed for analysis and comparison with buoy measurements.

The mean monthly wind and Hs for June to August are shown in Fig. 2. The contours show the distribution of parameters considered and the arrows show the mean monthly directions. The mean Hs, Ts, mean wave direction, drag coefficient and wave stress for the hindcast period (June to August 2002) are plotted in Fig. 3. The time-series of all these parameters and evolution of wave spectral estimates (model outputs) for one of the buoy location DS1 (69.19° E, 15.58° N) are shown in Fig. 4 and Fig. 5 respectively.

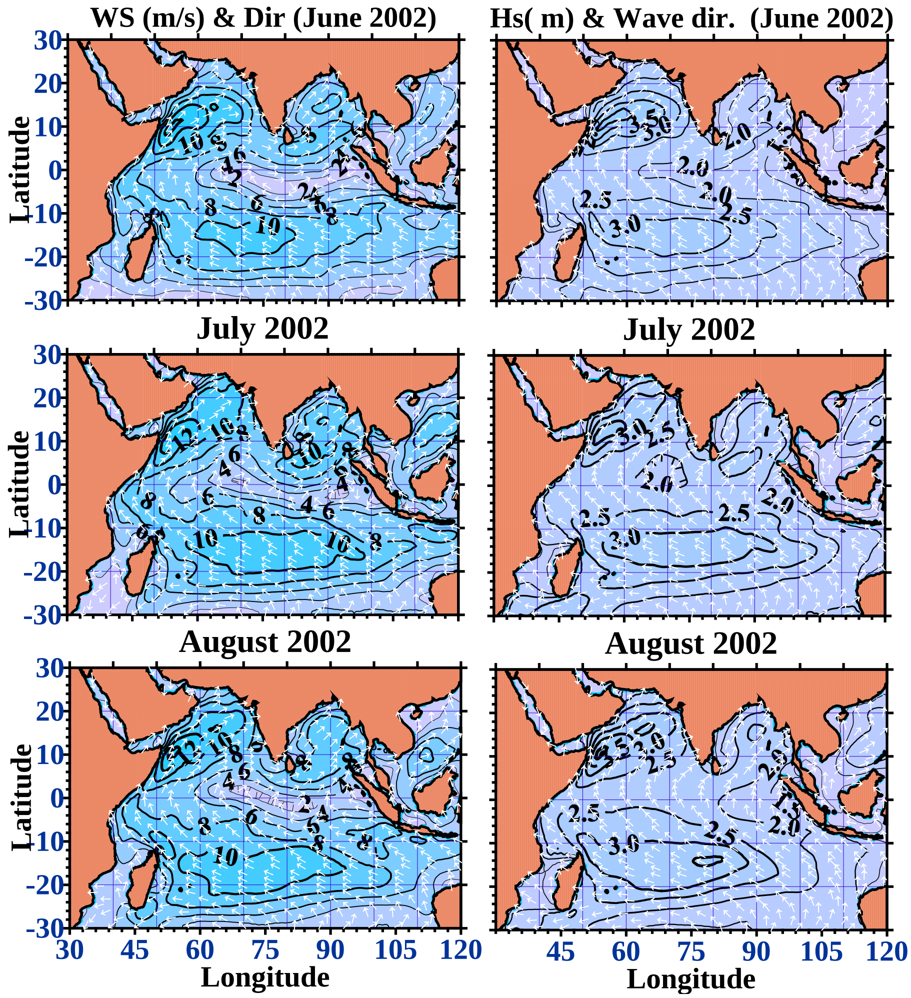


Fig. 2. Mean monthly fields of wind speed (WS), wind direction (Dir), significant wave height (Hs) and mean wave direction for the June, July and August 2002

4. Comparisons with buoy data

Three hourly time-series measurements of waves from four selected locations/buoys were obtained from NIOT. The data available from these locations were for limited periods excepting SW4 (74.73° E, 12.94° N). SW4 data, although available throughout the hindcast period from June to August 2002, was purely the shallow water data (Mangalore Port, depth 18m) whereas the model can only cater for waves up to a depth of 30m. The measurements of DS1 and SW2 (Off Ratnagiri, 71.04° E & 18.58° N) were purely at deep locations but SW3 (73.76° E, 15.41° N) data was from a shallow water (near 30m depth contour) coastal location Off Goa.

The observed data and model out puts of Hs for all the four buoy locations are plotted in Fig. 6, where the thick line represents the buoy measurements and the thin line indicate the model predictions. The mean deviation (MD), standard deviation (SD) and prediction error (PE) in percentage are shown in the respective plots. Similarly, the comparisons for Tc are plotted in Fig. 7 except for SW4.

5. Results and discussions

The months from May to September are considered as the rough weather (south-west monsoon) period from wave climate point of view. Hence, the period of wave hindcast from June to August 2002 is the rough weather season during which one can expect higher wind and waves over the study area. July is considered as the peak of the south-west monsoon as the wind and wave activity during this month remain high compared to rest of the months (Hastenrath *et al.*, 1979; Young and Holland 1996). However, the mean monthly analysed fields as shown in Fig. 2 reveal higher wind and wave activity off west coast of India during June compared to July and

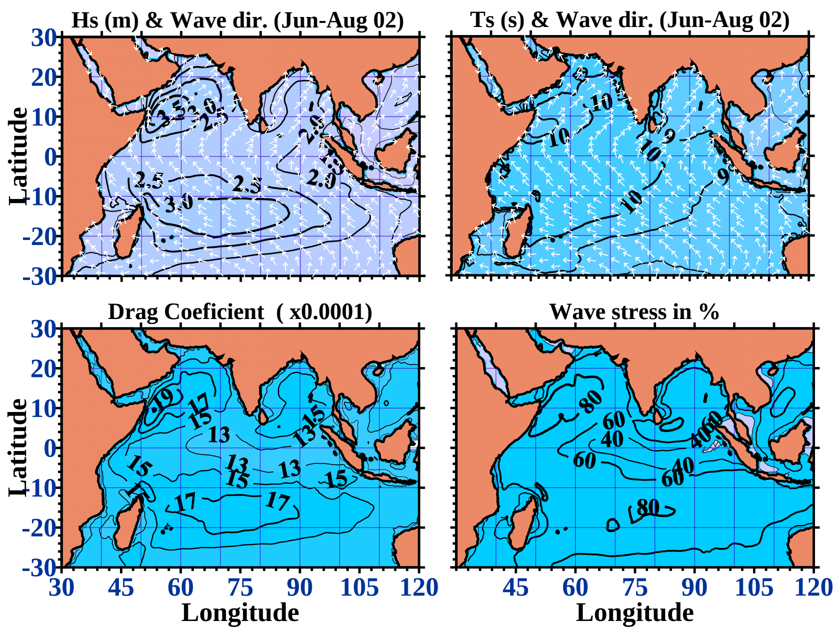
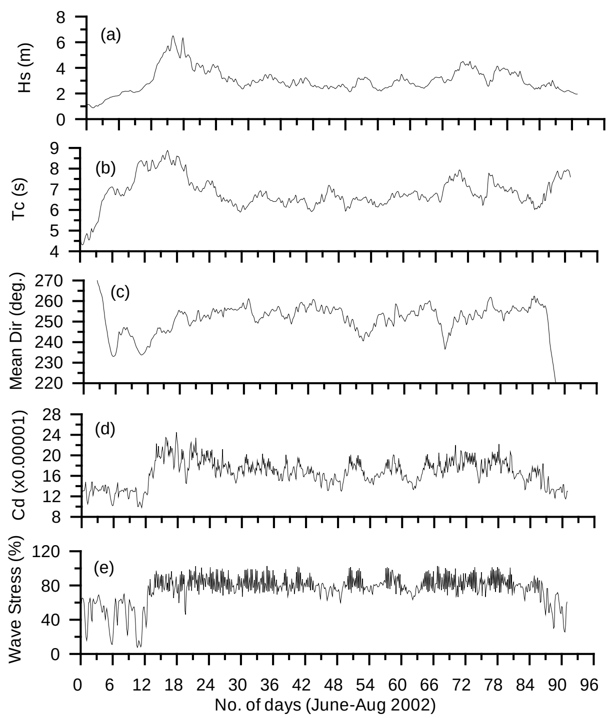


Fig. 3. Mean significant wave height (Hs), significant wave period (Ts), sea-state dependent drag-coefficient (Cd) and wave stress for June-August 2002

August. The mean monthly wind speed and Hs over the Arabian Sea range from 6 to 12 m/s and 2.5 to 4m respectively. Higher wind and wave conditions are noticed in the Bay of Bengal region during July.

The spatial distribution pattern of the predicted mean wave parameters for the hindcast period of three months (June-August), such as Hs, Ts, drag coefficient and wave stress (Fig. 3) have a general agreement with the input wind field variations. Hs varied from 1 to 2m over the Bay while in the Arabian Sea, it varied from 2 to 3.5m. The average Ts, drag coefficient and wave stress over whole of Indian Ocean region considered, ranged from 8.5 to 11s, 0.12×10^{-3} to 0.19×10^{-3} and 40 to 90% respectively.

Since DS1 belongs to one of the deep water buoy locations and wave measurements for a period of 16 days were available for comparison, the time-series of predicted wave parameters for the grid near to this buoy location has been plotted for analysis of temporal variability. Fig. 4 revealed high wave activity during June with a maximum wave height of 6m around middle of the month. Throughout July, Hs was around 3m, which increased during August (maximum Hs 4m) as shown by two peaks of 7 to 8 days period each. Tc varied from 6 to 9s and mean wave direction around west of south-west. Sea-state dependent Cd showed significant fluctuations, which is an important input for the other ocean environmental models. High frequency variations of wave stress around 80% indicated stronger but fluctuating coupling strength between the wind and the prevailing



Figs. 4(a-e). Time-series of hindcast significant wave height (Hs), average wave period (Tc), mean wave direction, sea-state dependent drag-coefficient (Cd) and wave stress for June-August 2002 at DS1 buoy location

waves (Fig. 4) for most part of the hindcast period. The wave spectral evolution at DS1 location revealed predominance of single peaked spectra (Fig. 5) perhaps

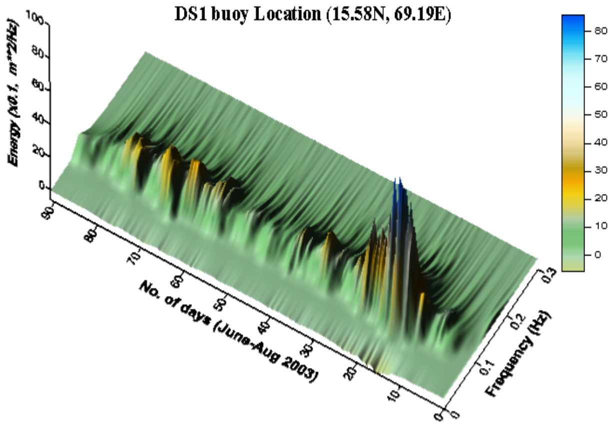
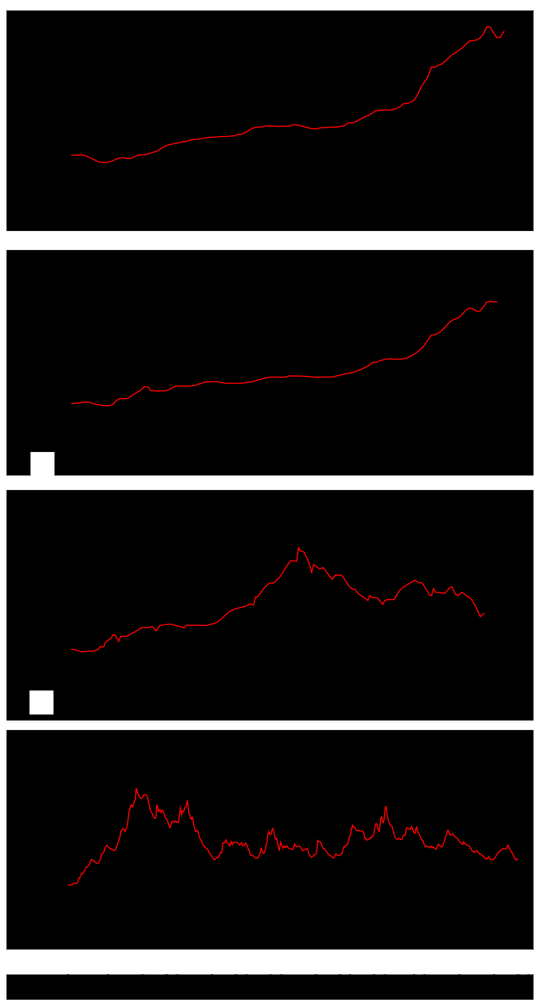
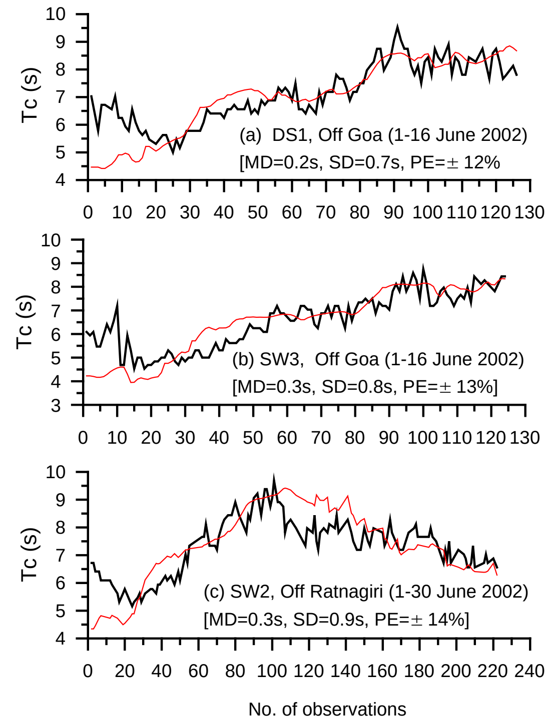


Fig. 5. Evolution of predicted wave spectral estimates at DS1 buoy location during June-August 2002 at 3-hrly intervals



Figs. 6(a-d). Comparisons of measured (thick continuous line) and predicted (thin line) significant wave height (Hs) for all the four NIOT buoy locations



Figs. 7(a-c). Comparisons of measured (thick continuous line) and predicted (thin line) average wave period (Tc) for three NIOT buoy locations

due to six-hourly wind inputs used and the limited number of frequency bands considered in the model (25 frequencies). Secondly, the spectra are narrow banded during high wave activity and wide banded during low wave activity.

The comparisons between the measured and hindcast Hs, at two locations such as DS1 and SW3 for a period of 16 days at 3 hourly intervals reveal a good agreement with PE 16% and 12% respectively (Fig. 6). In case of DS1 and SW4, the estimated MD between the observed and predicted Hs are 0.3m and –0.2m respectively. In most cases, the deep water waves propagate through DS1 (deep water buoy) to SW3 (coastal buoy) location during the south-west monsoon. Therefore, a similar trend has been observed between the observed and measured wave parameters such as Hs and Tc for both the buoys. Please note that, although the data have been compared since from cold start of the model, the statistical estimates such as MD, SD and PE are computed from the fifth day onwards as the model results suggested a good agreement beyond fourth day. A comparatively higher departure between observed and measured Hs is noticed in case of SW2 buoy (PE = 20%) for the month of June 2002 especially for last 10 days period. It is evident that, the 3 hourly measurements shown by the thick line in Fig. 6 has more fluctuations compared to the model predictions in all the three cases discussed. This is primarily due to the input winds, which was supplied to the model were at coarser time intervals and it did not show much fluctuations. The increase or decrease of analysed winds used as input to the model was generally steady. The last buoy SW4 is a purely shallow water buoy in the Mangalore port. The model predicted data compared with the observations are from the neighboring grid representing deep water waves. Surprisingly, the observed variations of Hs for the complete period of hindcast (3 months) very well correlate with the deep water conditions. Hence, the comparison reveal that, it is possible to predict the shallow water waves at the port area using a shallow water model by using the WAM outputs as the boundary input.

Since SW4 is a shallow water buoy for which comparison was made for Hs, the observed and predicted Tc for rest of the three buoy locations only are shown in Fig. 7. Compared to Hs, large deviations have been noticed for Tc for the initial period after cold start. By and large, the subsequent agreement between the hindcast and observed Tc for all the three cases are quite encouraging with PE 12 to 14%.

6. Conclusions

This study was carried out to simulate the sea-state variations in the Indian Ocean (30° - 120° E, 30° S - 30° N) using the third generation wave model WAM for the ARMEX-I period (June-August 2002). The input winds (analysed fields) provided to the model were supplied by NCMRWF, New Delhi at six hourly intervals. The model results have been compared with the available buoy data (16 to 30 days period) received from NIOT at few selected locations in the Arabian Sea. The comparisons seen between the observed wave height and period parameters, appears to be very encouraging in spite of the limitations on model grid size considered and the interval of wind inputs provided to the model.

Acknowledgement

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