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Assimilation of Blended Sea Surface winds for simulating Tropical cyclones over the Indian Ocean




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Abstract

Sea surface wind assimilation plays a pivotal role in the simulation of cyclone features. Global Numerical Weather Prediction (NWP) centres assimilate space-based sea surface winds from various active instruments. Currently there are three scatterometer instruments, Advanced Scatterometers (ASCAT) onboard MetOp-B and MetOp-C, and Oceansat-3. Coverage of these Scatterometer over the Indian Ocean region is limited during the 0600 and 1800 UTC assimilation cycles. National Oceanic and Atmospheric Administration (NOAA) has released a 6-hourly interval blended sea surface wind product with global coverage. The NOAA National Centers for Environmental Information (NCEI) Blended Sea Winds (NBS) product has been generated by blending data from multiple sources. The NBS winds are not available in real time, and hence limit its operational usage. In this study, these blended winds are used in the NCMRWF Unified Model (NCUM) system to simulate the characteristics of two back-to-back cyclones Mocha and Fabien formed over the Indian Ocean during May 2023. This study has been carried out particularly to address the requirement of sea surface Scatterometer winds during all the six hourly intermittent assimilation cycles.

1. Introduction

Space-borne scatterometers winds are essential for improving the Numerical Weather Prediction (NWP) initial conditions. National Centre for Medium Range Weather Forecasting (NCMRWF) has demonstrated the requirement and impact of space-based sea surface Scatterometer winds through various research and operational analysis (Rani et al., 2014, Prasad et al., 2013, Johny et al., 2019). The latest addition to the list of Indian Scatterometer mission is Oceansat-3 after Oceansat-2 and Scatsat-1. Apart from the Scatterometer winds from Indian mission, NCMRWF receives the sea surface winds from Advanced Scatterometer (ASCAT) onboard the European satellites MetOp-B and MetOp-C. However, the three existing space-based Scatterometer instruments (Oceansat-3, ASCAT onboard MetOp-B and MetOp-C) have coverage over the Indian Ocean region during 0600 and 1800 UTC assimilation cycles, and lacks coverage over the Indian Ocean region during 0000 and 1200 UTC.

National Oceanic and Atmospheric Administration (NOAA) and National Centre for Environmental Information (NCEI) released blended global sea winds covering all six hourly intermittent assimilation cycles (Saha et al., 2022) in lagged mode. Present study analyzes the impact of NBS winds for the simulation of tropical cyclones (TCs) and hence to put forth the requirement of real-time sea surface winds during all assimilation cycles. NBS winds are used to simulate the characteristics of two back to back cyclones, Mocha and Fabien which emerged over northern and southern Indian Ocean during May 2023. Four Dimensional Variational (4D-VAR) assimilation method is used for the assimilation of NBS winds in the NCMRWF's global unified model (NCUM-G). The data and methodology is described in section 2, the main findings from this study are briefed in section 3 and followed by the summary and way forward in section 4.

2. Data and Methodology

The NBS winds produced by NOAA-NCEI is assimilated for simulating the Mocha and Fabien cyclone characteristics using the NCUM-G model with 4D-VAR assimilation method. The NBS winds are produced by merging multi satellite data including scatterometers, microwave radiometers/imagers and L-band radiometers and blended with the global NWP equivalents from ERA5/NCEP GFS. The global NBS winds are available at 0.25° grid box throughout all the four six hourly intermittent assimilation cycles. Detailed description of NOAA-NCEI blended sea surface winds is available in Saha et al. (2022). NBS data can be downloaded from the following link:https://coastwatch.noaa.gov/cwn/products/noaa-ncei-blended-seawinds-nbs-v2.html

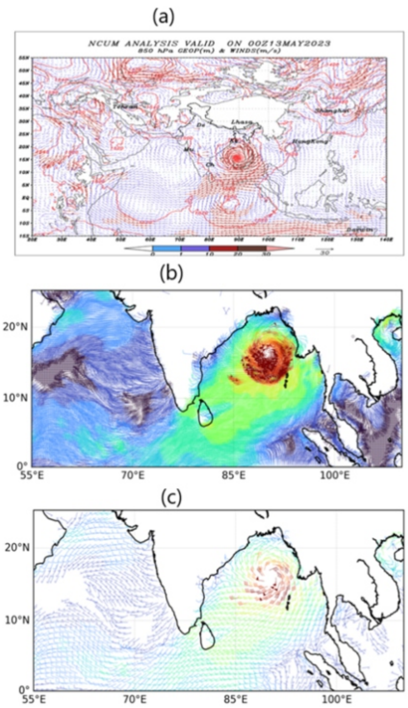

Figure 1. (a) NCUM-G analysis of 850 hPa winds and geopotential height (b) NBS wind vectors with wind magnitude in shading and (c) quality controlled NBS winds available for assimilation valid for 0000 UTC of 13 May 2023.

Details of the 4D-VAR assimilation method and NCUM-G model are available at Kumar et al., (2021). The NCUM system comprises of observation pre-processing, observation processing system, variational assimilation, surface analysis module and the forecast model. The NCUM-G has a grid resolution of 12 km, while the data assimilation has been carried out at a coarse resolution of ~40 km. Table 1 lists the best observed characteristics (location and intensity in terms of MSLP) of Mocha from the India Meteorological Department (IMD) and Fabien from the Joint Typhoon Warning Centre (JTWC).Figure 1a shows the NCUM-G analysis of 850 hPa winds (m/s) and geopotential height (m) valid for 0000 UTC of 13 May 2023 which represents both the systems. Coverage of NBS winds and the winds available for assimilation after quality control valid for the 0000 UTC of 13 May 2023 are shown respectively in Figures 1b and c. The data assimilation has been carried out four times daily during period 4 – 23 May 2023. In addition to the NBS winds, conventional observations and satellite observations are also assimilated in this study. Two experiments are designed, one in which the NBS winds are denied in the assimilation (Control) and the other in which NBS winds are assimilated (NBS experiment) along with other observations. In this study we have evaluated the analysis and six hour short forecasts based on different assimilation cycles.

Table 1. The best observed characteristics of cyclones, the location, mean sea level pressure (MSLP) and the various stages of Mocha from the IMD and Fabien from JTWC.

Mocha (8-15 May)		**Fabien (15-21 May)**	
(Location)	MSLP (hPa)	(Location)	MSLP (hPa)
(9.10 N,88.70 E)	999 (DD)	(5.20 S,79.40 E)	969 (DD)
(11.20 N,88.10 E)	997 (CS)	(7.30 S, 75.10 E)	969 (CS)
(13.20 N,880 E)	982 (SCS)	(8.80 S, 73.80 E)	962 (SCS)
(15.40 N,89.10 E)	952 (VSCS)	(9.40 S 71.40 E)	989 (CS)

3. Results and Discussion

Figure 2 shows the comparison of the estimated tracks of cyclone Mocha and Fabien from control and NBS experiments with the observed best track available from IMD and JTWC. The NBS experiment estimated accurate position of cyclone Mocha during the initial development stage than the control experiment when compared against the observed track. The track of Mocha cyclone estimated from the NBS experiments remains closer to the observed track till the storm attained the maximum intensity before making the landfall. The track position estimated from the control experiment was closer to the observed track duringthe VSCS stage of Mocha. This can also be seen from Figure 3a, which shows the track errors in the control and NBS experiment against the observed track during the period of Mocha cyclone. The track errors in the NBS experiment are higher during the intensification stage of cyclone Mocha and thereafter the errors are reduced in both the experiments. In the case of cyclone Fabien, both the experiments simulated more or less similar track. The time series of track errors during the life cycle of Fabien is shown in Figure 3b. The track error for cyclone Fabien shows higher error with NBS winds before attaining the maximum intensity, while weakening, it has provided significant reduction in track error as compared to the control experiment.

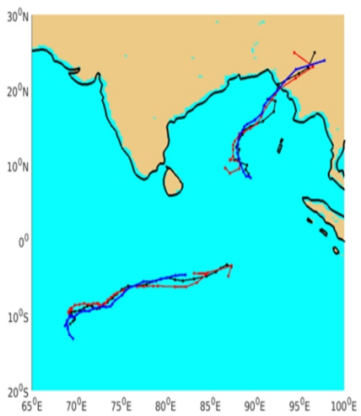

Figure 2. Comparison of the estimated tracks of Mocha and Fabien from the NBS experiment (black), and Control (red) with the observed best track (blue).

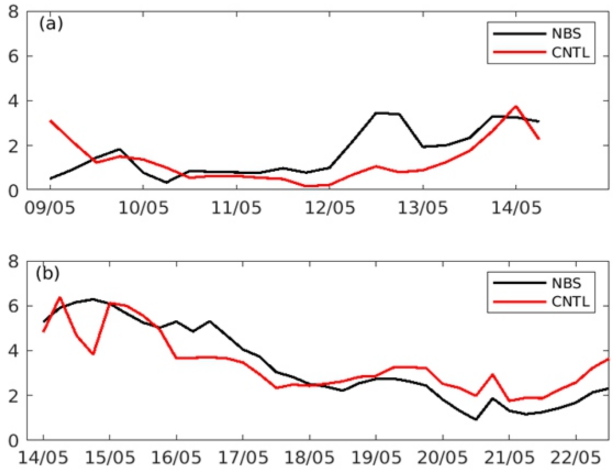

Figure 3. Time series of track errors for (a) Mocha and (b) Fabien from control and NBS experiments computed against the IMD/JTWC observed best track.

Figure 4 shows model estimated analysis fields of wind speed (shaded) and MSLP (contour) from NBS experiment (left column), control (middle column) and the differences between control and NBS experiment (right column). Various rows in Figure 4, marked as (a), (b), (c), and (d) correspond to the DD, CS, SCS, and VSCS stages of Mocha cyclone as reported by IMD. NBS experiments simulated the DD, CS and SCS stages of Mocha cyclone better than control, while the NBS experiment failed to simulate the VSCS stage that is evident from row (d) of Figure 4. Figure 5 is similar to Figure 4, but for cyclone Fabien. Unlike the case of Mocha, various rows in Figure 5 shows DD, CS, SCS and CS stages of Fabien as reported by JTWC. NBS experiment simulated a weaker circulation with slightly high MSLP compared to the control experiment.

Assimilation of NBS winds generated different results in the case of Mocha and Fabien. The characteristics of Mocha are simulated better till the SCS stage of the cyclone, while the assimilation of NBS winds did not produce any noticeable improvement in the VSCS stage of the cyclone Mocha. This suggests that once the storm has attained the required strength in SCS stage, assimilation of sea surface winds may not have any further impact in the analysis as the model background has been saturated with the storm information. The cyclone Fabien dissipated in the open ocean without attaining the VSCS stage, and the assimilation of NBS winds resulted in the better simulation.

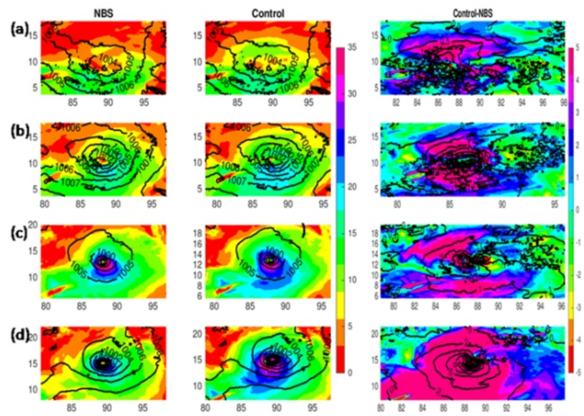

Figure 4. 10 m wind speed (in meters) (shading) and MSLP (in hPa; contours) from control experiment (left column), NBS experiment (middle column) and difference between Control and NBS experiment (right column) during a) Deep Depression (DD), b) Cyclonic Storm (CS), c) Severe Cyclonic Storm (SCS) and d) Very Severe Cyclonic Storrm (VSCS) phases of cyclone Mocha.

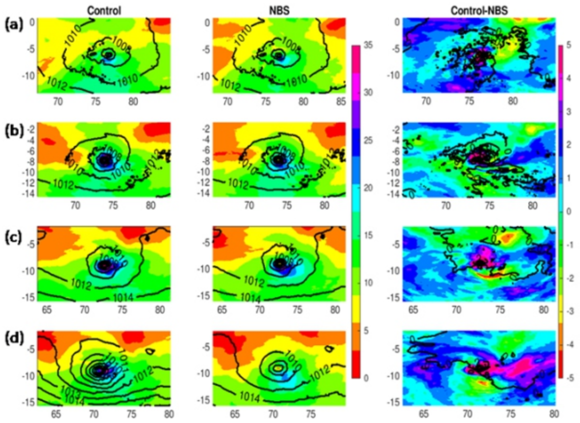

Figure 5. 10 m wind speed (in meters) (shading) and SLP (in hPa; contours) from control experiment (left), NBS experiment (middle) and Control-NBS difference for a) Deep Depression (DD), b) Cyclonic Storm (CS), c) Severe Cyclonic Storm (SCS) and d) CS phases of cyclone Fabien.

4. Summary and conclusion

The present study analyses the impact of NOAA-NCEI blended Sea Surface winds on the evolution and progressions of tropical cyclones Mocha and Fabien in the North Indian Ocean. Assimilation of NBS winds showed distinct results in the case of two cyclones selected in this study. The NBS assimilation produced better results till the SCS stage of Mocha. The better simulation of cyclone characteristics till the SCS stage in the NBS experiment can be attributed to the continuous assimilation of sea surface winds in all the six hourly intermittent assimilation cycles. Assimilation of sea surface winds during the VSCS stage did not produce any noticeable impact. This can be due to the fact that after attaining the SCS stage, the model background might be contented with the required information for the further development of cyclone. In the case of cyclone Fabien, the NBS wind assimilation produced better results. The geographical location of the cyclones might also have played an important role in the simulation. NBS winds assimilation produced beneficial impact during various stages of the cyclones Mocha and Fabien; however we cannot make a generalized comment on the impact of these winds in the assimilation system. Assimilation experiments are planned for more selected cyclones over different basins to establish a concrete conclusion on the impact of NBS winds.

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Wave energy in the coastal waters of Indian mainland



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Social and economic development, improvement of human welfare, and health demands energy. Renewable Energy (RE) assures energy independence and contributes to sustainable growth by decoupling the correlation between economic development and energy use with a large amount of greenhouse gas emissions. The ocean's renewable sources are tides, currents, waves, salinity gradient, and temperature gradient. Among the ocean RE sources, ocean waves contain the highest energy density and have the potential to become a commercially viable energy source. The annual average wave power increases progressively from the equator to the poles and varies from 1 to 50 kW/m (Cornett, 2008). The energy associated with waves can be harnessed through Wave Energy Converters (WEC). Wave energy assessment at the regional scale is required to plan and install WEC and progress from full-scale testing to commercialization. For more than two centuries, researchers and inventors have proposed different devices to make use of this wave energy.

WECs are categorized either by their interaction with waves, such as Point absorbers (e.g., AquaBuOy), terminators (e.g., Salter's duck), and attenuators (e.g., WaveStar), or by their operational principle, including oscillating water columns (e.g., Backward Bent Duct Buoy), wave-activated bodies (e.g., Pelamis, WaveRoller, etc.), and overtopping devices (e.g., Wave Dragon). (Babarit, 2017). The overtopping system uses the wave to fill a reservoir and the potential energy available to drive the turbine. A moored buoy uses the rise and fall of the wave to drive the hydraulic pumps, and an Oscillating Water Columndevice uses the compressed air within the chamber to drive a turbine to generate electricity. In addition to the updated design of the PTO system and its control mechanism, there is considerable interest in improving the WEC's performance through geometric design modifications. To achieve this,

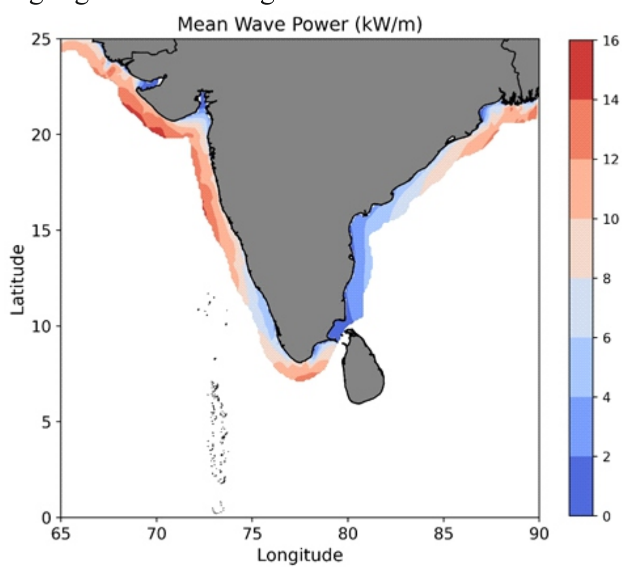

Figure 1. Annual mean wave power in the coastal waters of India

various approaches are being explored, such as implementing a stepped sea bottom effect, incorporating a reflecting wall, and integrating diverse types of WEC devices with current breakwaters. Around 600 MW wave power plants are installed worldwide, and ~ 4 MW are fully operating, but most of them are test facilities working intermittently. Indian Institute of Technology, Madras in Chennai, has conducted early studies on wave energy resources and a nearshore oscillating water column wave energy plant was installed on the southwest coast of India at Vizhinjam (Raju, and Ravindran, 1997) and presently this plant is decommissioned. With the advancement in technology, ocean waves will become an economically viable renewable energy source. Since the global population is heavily concentrated in coastal areas, the demand for electricity is also higher in coastal areas.

Several studies have been carried out to evaluate wave power in Indian shelf waters, and these studies are listed in the references. Figure 1 shows the annual mean wave energy in the coastal waters of India estimated from the wave parameters obtained from the WAVEWATCH-III (WWIII) numerical model. A large domain (75S-35N & 20E-112E) with a resolution of 0.5° covering the Indian Ocean and part of the Southern Ocean and a small domain (5N-25N & 60E-90E) with a resolution of 0.1° covering the Indian shelf seas are used and the simulations are carried out from 2005 to 2015. Hourly ERA5 wind data at 0.5° resolution in space is used to force the model, and depth data is obtained from ETOPO1 bathymetry data.

The annual mean values of wave power in the Indian shelf seas vary up to 15 kw/m off Diu. Most of the low mean wave power (<2 kW/m) points are at the northeast and northwest (the Bay of Gulf of Kambath and Gulf of Kachchh) coastal waters and also at the southeastern Bay of Bengal (the area between Rameswaram and Palk Strait) coastal points. There are large seasonal variations in the wave power in a year. Off the west coast, southernmost peninsular, and northwest BoB locations, the wave power available during summer (SW) monsoon is 40-83% of the annual wave power. During the non-monsoon period, the maximum values of wave power are found at the southernmost location.

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Blue Economy Perspectives for India: Mapping Possibilities for Sustainable Development

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Abstract

India has actively engaged in international dialogues through platforms like the G20 and the Global Maritime India Summit, and plays a proactive role in shaping the global discourse on the Blue Economy. The article delves into the measures adopted by nations across the globe to manage their marine resources, emphasising the global significance of the Blue Economy in fostering economic growth. It explores the significant potential of India's extensive coastline and abundant marine resources in advancing the Blue Economy. Furthermore, the article identifies traditional (or established) and emerging maritime sectors in India, elucidating their connections with the United Nations' Sustainable Development Goals. It endeavours to spark interest among researchers and practitioners in the coastal and marine domains, aiming to guide research and initiatives related to Blue Economy towards the principles of sustainable development.

Keywords: Blue Economy, Sustainable Development Goals, maritime sectors, oceans, economic growth

1. Introduction

India, with its vast coastline and extensive marine space, holds significant potential for unlocking the benefits of the Blue Economy. The World Bank defines the Blue Economy as the "sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of the ocean ecosystem." India's Blue Economy - A Draft Policy Framework describes Blue Economy as "A subset of the national economy comprising the entire system of ocean resources and man-made economic infrastructure in marine, maritime and the onshore coastal zones within India's legal jurisdiction, which aid in the production of goods and services and have clear linkages with economic growth, environmental sustainability and national security." Belgian economist Gunter Pauli introduced the term blue economy and published a book titled "The Blue Economy: 10 Years, 100 Innovations, 100 Million Jobs."

The objective of the Blue Economy is to make the appropriate use of marine assets containing all economic activities related with seas, ports, coastal zones and other ocean-based exercises to entirely reduce ecological hazard and enhance human prosperity (Bir et al., 2020).Bari (2017) emphasises that mechanisms of optimising benefits which may be derived from marine resources can be looked into, and a possibility of sustainably using ocean resources.

India actively participates in global and regional discussions on the Blue Economy, contributing to forums such as the G20 and the Global Maritime India Summit. These engagements seek to cultivate a Blue Economy emphasising elements like green ports, sustainable infrastructure, cruise tourism, and attracting international investments.

In the pursuit of sustainable development, understanding the diverse facets of maritime sectors is crucial. This article endeavours to list both traditional and emerging maritime sectors in India, shedding light on their intricate interlinkages with various United Nations' Sustainable Development Goals (SDGs). By delving into the dynamic relationships between marine activities and SDGs, this study aims to provide valuable insights that can inform strategic policymaking and foster a holistic approach to harnessing the potential of marine resources for comprehensive and sustainable societal progress.

2. Global and national scenario

The Blue Economy plays a pivotal role in contributing to a nation's GDP and fostering economic growth. By harnessing the vast potential of oceans and maritime resources, the maritime industries not only generate substantial revenue but also create employment opportunities, stimulate innovation, and enhance trade. The sustainable utilisation of marine resources bolsters economic diversification and aligns with environmental conservation goals, making the Blue Economy a key driver for long-term economic prosperity.

America's marine economy contributed about $361 billion (1.7%) of the nation's gross domestic product in 2020 (National Oceanic and Atmospheric Administration, U.S. Department of Commerce). The Blue Economy of China employs more than nine million people; contribution of the Chinese marine economy to the national economy increased from 6.46% to 13.83% in 2000–2011 (Alharthi and Hanif, 2020). A rough computation indicates that the Blue Economy in South Asia is contributing between 3–5% to global GDP (Patil et al., 2016). The fisheries in the South Asia region augment livelihoods by 5–8%; the coastal travel industry in the area has grown by 8% annually (Alharthi and Hanif, 2020). The 'Draft Blue Economy Policy of India' indicates that the Blue Economy contributes 4% to India's GDP.

In 2017, a pivotal milestone was marked with the announcement of the Decade of Ocean Science for Sustainable Development (2021–2030), coinciding with The Ocean Conference held in New York, United States. This was followed by the Sustainable Blue Economy Conference in 2018 convened in Nairobi, Kenya. The year 2019 saw the unique designation of COP 25 as the 'Blue COP' in Madrid, Spain, emphasising a heightened focus on ocean-related issues within the broader climate change discourse. In 2020, the rallying cry 'RISE UP – a blue call to action' was officially launched in February during the preparatory meeting for the UN Ocean Conference. These sequential events reflect a growing global commitment to advancing the agenda of sustainable ocean governance and responsible Blue Economy practices.

Countries such as Australia, Brazil, the UK, the US, and Russia have established dedicated national ocean policies, complete with defined objectives and allocated budgets. In alignment with the European Green Deal, the European Union launched its Blue Economy plan in 2021, focusing on climate change mitigation, circular economy principles, and biodiversity preservation. Concurrently, Scandinavian nations like Norway and Denmark have implemented policies targeting the reduction of greenhouse gas emissions in the shipping industry. Australia's Blue Economy is predominantly characterised by offshore aquaculture and renewable energy production, aligning with its commitment to sustainably manage 100 percent of its national waters by 2025, as pledged at the High-Level Panel for a Sustainable Ocean Economy.

As a nation, India has embarked on a journey to tap into coastal and marine resources to drive economic growth. This commitment is evident in various governmental initiatives, such as the draft Blue Economy Policy formulated by the Ministry of Earth Sciences, the integration of the Blue Economy into Vision 2030 as one of its ten dimensions, the establishment of a committee by Niti Aayog to draft a National Maritime Policy, Deep Ocean Mission, and the Sagarmala Programme, among others.

3. Methodology

This article explores the intricate linkages between India's traditional and emerging maritime sectors and the SDGs. It outlines a provisional inventory of various maritime sectors, considering each sector's alignment with SDGs, taking into account their environmental implications, societal impact, and economic contributions.

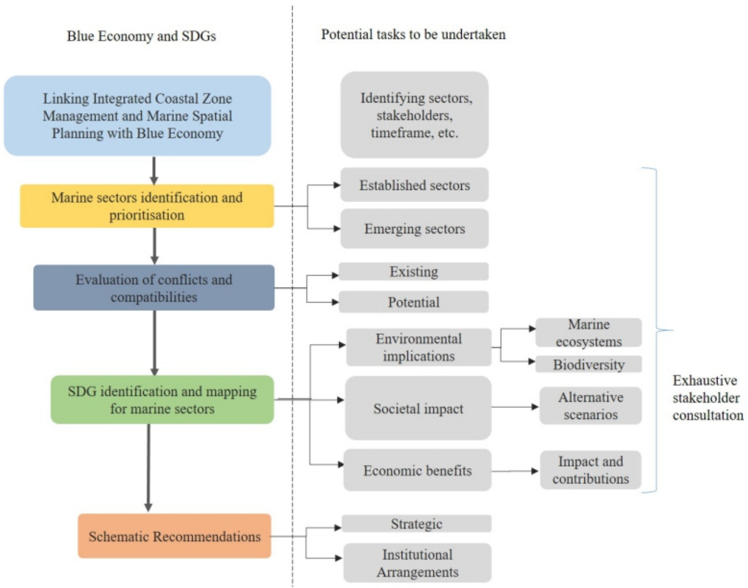

Figure 1 elucidates potential steps to be considered while undertaking a similar study. In essence, the study holds significant promise as a baseline for developing strategies that capitalise on India's marine wealth in a sustainable manner.

4. Maritime sectors

The Organisation for Economic Co-operation and Development (OECD) characterises the ocean as the forthcoming economic frontier, presenting opportunities for wealth, economic growth, employment, and innovation. In addition to traditional maritime economic sectors like fisheries, transport, aquaculture, and coastal tourism, nations are increasingly acknowledging the ocean's potential in emerging areas such as ocean-based renewable energy, marine biotechnology, and deep-sea exploration.

The fishing sector is a significant employer in India, with 15 million people engaged, ranking second globally (6.3% of theworld's fish production, valued at INR 10 billion in 2015–16). Additionally, coastal and maritime Tourism, contributing 5% to the world GDP, is anticipated to create job opportunities for approximately 8.5 million individuals by 2030 (compared to 7 million in 2010), playing a pivotal role in offering substantial employment and livelihoods in South Asia (Ghosh, 2023).

Within the spectrum of the ocean economy, several sectors distinguish themselves, including defence and (inter)national security, fishing and aquaculture, offshore energies, offshore mineral resources, transport, logistics, and maritime infrastructure, shipbuilding and repair, tourism, sport, and leisure, as well as environment and climate (Santos, 2019).

In India, shipping, fishing, marine security and coastal tourism are the leading maritime sectors, with significant policy actions and economic activities benefiting the society. Sectors such as offshore energy, marine biotechnology, deep sea mining, and oil and gas exploration are emerging and there is a thrust on mobilising these sectors.

5. Mapping maritime sectors with SDGs

There are interdisciplinary, transversal and interconnected perspectives of the Blue Economy. It encompasses diverse sectors and actors who need to interact, both nationally and internationally, to achieve the goals and targets proposed by the 2030 Agenda in an integrated and coherent manner. Lee et al.(2020), mention that identification of the scope and boundaries of the Blue Economy in line with the UN SDGs is vague and challenging, and the roles and interests of key stakeholders is also unclear.

The article encourages researchers to explore the integrative nature and trade-offs of the Blue Economy, trying to understand the interlinkages of environment, economy and society with different maritime sectors in India from the lens of SDGs. Literature review was undertaken to identify interconnectedness of different marine sectors with SDGs.

Although Blue Economy and coastal and ocean management is primarily associated with SDG 14 (Life below water), marine activities and resource use go far beyond SDG 14 in terms of impact and relations with varied sectors and actors. For instance, SDG 14 has direct and indirect interactions with other SDGs (Santos, T., 2023; Ntona and Morgera, 2018). Le Blanc (2015) stresses the close relationship between SDG 14 and SDG 8 (growth and employment) and SDG 12 (sustainable consumption and production). Lee et al, 2020 indicated that Blue Economy is highly associated with SDGs 14-17 based on a literature survey between 1998 and 2018.

SDG 14 is closely linked with SDG 13 and SDG 15, as biodiversity and ecosystems, including mangroves, wetlands, and other coastal habitats, play a crucial role in supporting and sustaining the Blue Economy. These coastal ecosystems act as natural buffers and enhance the resilience of coastal communities and infrastructure, reducing the impact of extreme weather events. These ecosystems also play a vital role in carbon sequestration by absorbing and storing large amounts of carbon dioxide, helping mitigate climate change impacts and contributing to global efforts to reduce greenhouse gas emissions.

Further, there is a need to analyse the contributions, potential actions, and interrelations of each target of SDG 14 towards the Blue Economy prospects in India. Ocean targets comprise ecological and socioeconomic concerns, including reducing marine pollution (SDG 14.1); restoring marine habitat (SDG 14.2); reducing impacts of ocean acidification (SDG 14.3); eliminate overfishing as well as illegal, unreported and unregulated fishing (SDG 14.4); conserve marine areas (SDG 14.5); eliminate harmful fishing subsidies (SDG 14.6); and increase economic benefits to Small Island Developing States and least developed countries (SIDS, SDG 14.7).

6. Concluding remarks

The concept of the Blue Economy is gaining a growing international focus and increasingly becoming popular as a strategy for safeguarding the world's oceans. Research and policy interventions associated with the Blue Economy are emerging in India and hold great significance for driving our economic growth. Integrating decision-making related to resource allocation and use, spatial and temporal mapping mechanisms, research initiatives, efficient information flow and inter-agency coordination is crucial to implement Blue Economy strategies successfully. Key tools such as marine spatial planning and integrated coastal management can be leveraged to comprehend the complexities of coastal and marine areas and propel the nation into a higher growth trajectory.

The study can serve as a foundational reference, paving the way for the formulation of strategic and actionable recommendations, aimed at harnessing marine resources optimally while effectively addressing existing or potential threats. The course of action for attaining Blue Economy targets should be so planned that the economic benefits are balanced with social and environmental sustainability. As a nation, India can take suitable actions to jointly move ahead towards the path of Blue Economy, 2021-30 being proclaimed the Decade of Ocean Science for Sustainable Development by the United Nations.

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OSI Webinar Series (October-December, 2023)

November 2023

Topic: Projected Changes in Extreme Wave Height Indices over the Indian Ocean using COWCLIP2.0 Datasets

Speaker: Dr. Prashant Kumar, National Institute of Technology Delhi

Date & Time: 14 March, 2023 (Tuesday), 1600-1700 IST

About the Talk

The talk discusses on the extreme wave height indices described by the Expert Team on Climate Change Detection and Indices (ETCCDI) for the Indian Ocean (IO) region obtained from Coordinated Ocean Wave Climate Projections, Phase 2 (COWCLIP2.0) historical simulations and projected datasets. A multi-model ensemble (MME) approach is employed to study the projected changes under RCP4.5 and RCP8.5 emission scenarios. The projected changes in rough wave days, high wave days, and wave-spell-storm duration under both the scenarios are estimated.

Articles/research highlights of general interest to the oceanographic community are invited for the next issue of the Ocean Digest. Contributions may be emailed to osioceandigest@gmail.com

Cover Photo: Tide pool treasures: Discovering the beauty of sea fans and nudibranchs Image: Sea fan (unidentified Gorgonacea), Nudibranch : *Chromodoris sp.* found off Mumbai coast
Image credit: Dr.Sabyasachi Sautya, Senior Scientist, CSIR-National Institute of Oceanography, Regional Centre, Mumbai, India.

The cover page picture encapsulates a captivating exploration into the hidden world of rocky intertidal ecosystems, where a diverse array of marine life thrives amidst the turbulent rhythm of the tides. Among the inhabitants of these dynamic habitats, sea fans (Anthozoa: Gorgonacea) and nudibranchs (Gastropoda: Nudibranchia) stand out as prominent members, each contributing uniquely to the ecological dynamics of their environment. Sea fans, adorned with intricate branching structures, sway gracefully in the currents, providing shelter and habitat complexity within the rocky tide pools. Meanwhile, nudibranchs, with their vibrant hues and striking patterns, navigate the labyrinth of rocky crevices in search of food and refuge. At first glance, the relationship between these two organisms may seem enigmatic, yet upon closer inspection, a tapestry of ecological dynamics unfolds. Some nudibranch species form symbiotic associations with specific sea fan species, seeking refuge among their branches while potentially benefiting from the resources they provide. Others, however, become predators, delicately grazing on the tissues of sea fans, highlighting the intricate balance between symbiosis and predation within this microcosm of marine life. Beyond its scientific implications, the study of sea fans and nudibranchs in rocky tide pools holds broader significance for conservation and management efforts aimed at preserving coastal ecosystems. By unravelling the complexities of these interactions, we gain a deeper appreciation for the interconnectedness of marine life and the delicate balance that sustains coastal biodiversity.