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Decision Support Systems for Coastal Resilience: The Role of Early Warning Systems and Validation

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Abstract

This study presents an advanced Integrated Ocean Forecast Decision Support System (DSS) crafted to elevate ocean forecasting capabilities and enable well-informed decision-making, with a specific focus on the Indian Ocean region. The DSS has a visualization module for scientific inference and spatial analysis. It also has a validation component where each weather model is checked against observations from coastal buoys, open ocean buoys, and ASCAT and SCATSAT satellite data. The system integrates the operational forecasts and observation data and automatically informs the users of the best-correlated model. In cases of extreme conditions like cyclones, the system automatically pulls information from some of the meteorological agencies in real-time for further assessment and refining the models. With the forecasts and observations at its disposal, the DSS suggests the most accurate model to be taken into consideration when issuing alerts. Metrics like the scatter index, correlation coefficient, and root mean square error are displayed on a web interface to generate recommendations. This system facilitated decision-makers in issuing alerts for high winds, elevated waves, and other conditions, particularly during various cyclones in the Arabian Sea and Bay of Bengal, including notable events such as Tauktae and Gulab. The implementation details, the handling of extreme events, and the process of informed decision-making are thoroughly discussed in detail.

Keywords*:* Decision Support System, Coastal Warning System, Hazard mitigation, Ocean State Forecast validation.

1. Introduction

Coastal regions are dynamic and complex environments where the interaction between the ocean and land poses significant challenges. The increasing frequency and intensity of coastal hazards, including storms, cyclones, and high waves, underscore the urgent need for effective decision support systems (DSS) to mitigate risks and enhance coastal resilience. This paper introduces a comprehensive and integrated DSS tailored for coastal hazard management in the Indian Ocean region. While there has been considerable progress in the development of decision support systems, particularly in non-lifecritical domains, there is a notable gap in research addressing life-critical applications, especially in the context of forecast validation using real-time data. The need for robust decision support systems is evident, and efforts towards their development continue to advance.

Forecasting ocean conditions in the Indian context is marked by several intricate challenges explained by Venkatesan et al. (2013); Hermes et al. (2019). The region's susceptibility to monsoonal variability introduces complexities in predicting long-term trends due to seasonal shifts in wind patterns and precipitation. The occurrence of tropical cyclones during the monsoon season adds a layer of unpredictability, demanding accurate forecasts for their formation, intensity, and trajectory. The Indian Ocean Dipole (IOD) (Ashok et al. (2001)), a climate phenomenon, further influences the monsoon and regional weather patterns, necessitating nuanced consideration. Diverse coastal geographies, encompassing varied ecosystems and bathymetric features, present a challenge in creating precise models tailored to each region. Limited observational data, particularly in remote or deep-sea areas, impedes the development and validation of forecasting models. Integrating sparse observational data into models, known as data assimilation, is challenging, affecting the accuracy of initial conditions. Coastal areas experience sediment transport, erosion, and deposition, demanding intricate modeling. Multi-nation collaboration, essential for effective forecasting, is complicated by diverse requirements and capabilities. Climate change impacts, such as sea-level rise and ocean warming, add further intricacies to forecasting models. In addressing these challenges, a comprehensive approach involving international collaboration, technological advancements, and adaptive modeling is imperative for accurate and reliable ocean forecasting in the Indian Ocean region. Extensive efforts have been undertaken to enhance the prediction of ocean conditions in the Indian Ocean region by Nair et al. (2013); Balakrishnan Nair et al. (2022), with a focus on utilizing ocean general circulation models such as Mike 21 Spectral Wave by Sirisha et al. (2017), WaveWatch III by Remya et al. (2022); Meena et al. (2023), and SWAN by Sandhya et al. (2014, 2018). Sridevy et al. (2023) highlights the urgency of addressing agricultural

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challenges such as climate change and water scarcity. Leveraging Decision Support Systems (DSS) with ICT, the work reviews their role in empowering farmers with timely, informed decisions for maximizing productivity amidst resource constraints. With the ongoing advancements in the scientific community aimed at improving prediction systems, there is a need for a decision support system that can address the requirements of forecasters. This system should enable decision-making based not on a single model output but on a spectrum of models whose physics are tuned to meet specific needs. some of the implementations from Araujo et al. (2023); Govardhan et al. (2023); Reljic et al. (2023); Na-Yemeh et al. (2023). Several efforts have been made to collect atmospheric and ocean observations, with notable advancements in the development of wave rider buoys (Mankayarkarasi et al. (2023); Kumar and Anusree (2023); Reddy et al. (2023)). These buoys, strategically placed along coastlines or in open oceans, are equipped with powerful batteries, ensuring a minimum one-year lifespan. They communicate reliably with ground stations through fail-proof INSAT communication Ahmed et al. (2023). While satellites remain a dominant source of observations, their limitations include constraints in swath, pass, and frequency of observations Soisuvarn et al. (2023); Sinha et al. (2023). Building on these advancements, there is a pressing need to merge forecasts and real-time observations to enhance predictions and identify localized events such as Kallakadal, remote swell events, and cyclonic occurrences. This imperative integration of forecasts and observations in real-time holds the key to achieving superior predictive accuracy and bolstering our ability to respond effectively to critical events along coastal regions. Proper planning, facilitated by early warning systems, is crucial for mitigating the effects of natural disasters. The significance of coastal warnings has been emphasized by various researchers POATE et al. (2023); Pal et al. (2023). Numerous measures have been implemented to enhance communication with the coastal community, utilizing methods such as SMS, email, outbound calls, mobile apps, TV, radio, village information systems, and electronic display boards, among others. As mentioned in the research conducted by Patriarca et al. (2023); Fang et al. (2023), the primary concern now lies in the accuracy of the alerts issued to the community. Building effective decision support systems capable of processing spatial data and providing meaningful inferences is the need of the hour Uccellini and Ten Hoeve (2019). The spectrum of decision-making considerations encompasses various elements such as evaluating multiple forecast models, assessing the reliability and accuracy of predictions, considering the potential impact on different sectors, and determining appropriate courses of action Dolif et al. (2013). The goal is to create a well-rounded and effective decision-making framework that takes into account the dynamic and complex nature of weather patterns, ensuring that alerts issued are accurate, timely, and tailored to specific needs and potential risks as noted by Argyle et al. (2017).

The primary objective of this paper is to present the architecture, functionality, and outcomes of an innovative DSS designed to address the specific challenges of coastal hazard management. By amalgamating data from diverse sources such as meteorological models, oceanographic measurements, and satellite observations, the DSS aims to provide decision-makers with a holistic understanding of impending hazards, enabling them to formulate and implement timely and effective response strategies.

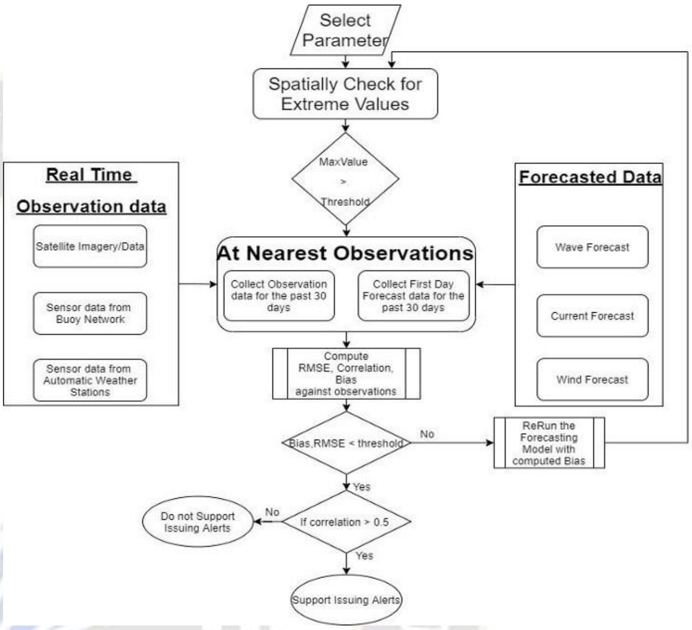

Figure 1: The graphical representation outlining the process of the Decision Support System.

2. Proposed Decision Support System

Ocean forecasting is indispensable for coastal communities to anticipate and mitigate the impact of natural events. The following section introduces a state-of-the-art Integrated Ocean Forecast Decision Support System (DSS) designed to enhance ocean forecasting capabilities, with a primary emphasis on the Indian Ocean region.

2.1. Approach

The approach taken in developing the Integrated Ocean Forecast Decision Support System (DSS) is designed to seamlessly integrate operational forecasting with real-time observational data for enhanced accuracy and reliability. Foremost, forecasters play a pivotal role in the system's functionality by updating it with operational model outputs. These outputs, spanning various parameters, are systematically indexed and stored in threedimensional data cubes, forming a comprehensive repository for swift and efficient data retrieval. Simultaneously, real-time

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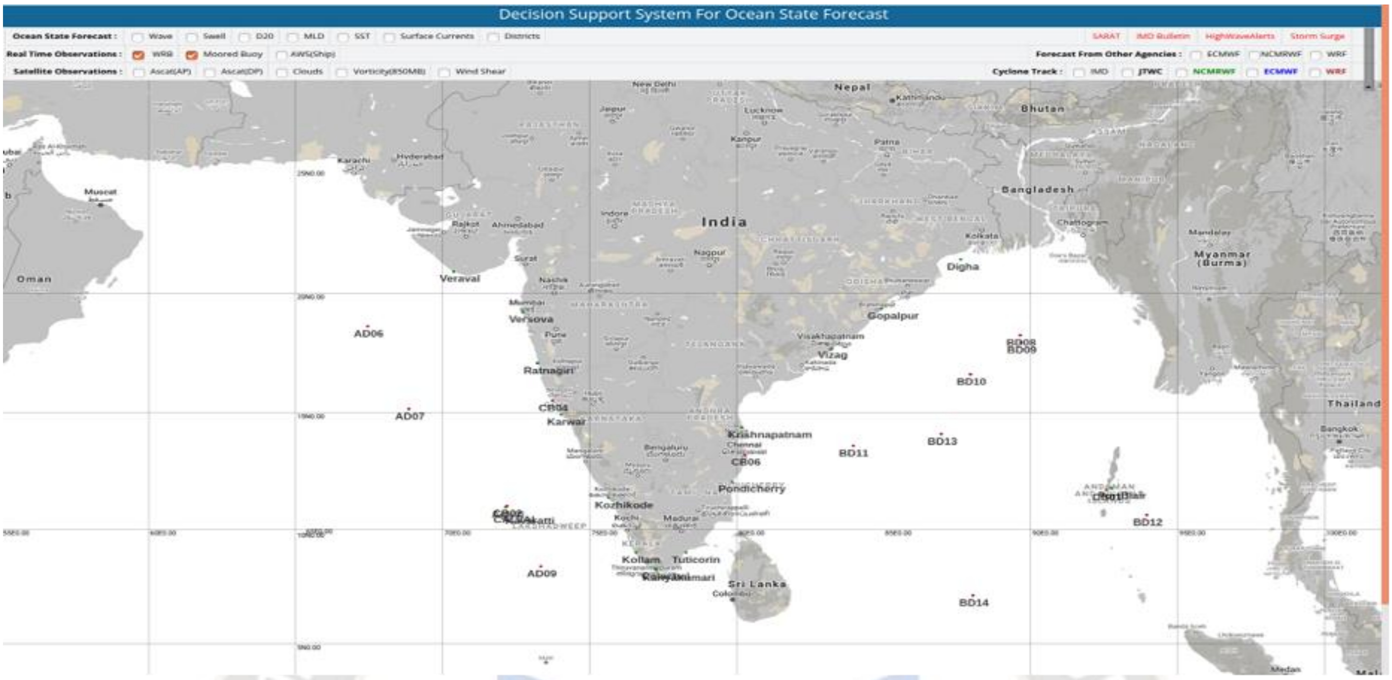

Figure 2: Home screen interface of the Decision Support System (DSS), offering forecasters intuitive options to select overlays from diverse datasets, facilitating real-time comparisons and analyses for informed decision-making in ocean forecasting

observational data from both in-situ measurements and satellite sources is continually fed into the system, residing in a dedicated database. This real-time observational data is instrumental in validating the operational forecasts and ensuring that the system remains responsive to dynamic oceanic conditions. The validation results serve as the basis for constructing alerts, enabling timely and informed decision-making. To illustrate the flow of this approach, a flowchart is provided below:

This visual representation represented in figure 1 encapsulates the iterative and interconnected nature of the system, showcasing the continuous loop of forecast updates, data indexing, real-time validation, and alert generation. At the core of the proposed system lies a robust technological architecture that incorporates advanced tools including Python, Ferret, Generic Mapping Tools (GMT), and Climate Data Operator (CDO) on the backend.

2.2. Ocean Forecasting Models

In the existing decision support system, ECMWF and NCMRWF contribute wind predictions, while models such as WW3, SWAN, and MIKE are utilized for forecasting variables such as waves, currents, and sea surface temperature. The forecasting of waves or currents in ocean general circulation models involves complex mathematical formulations. Although the specific equations can vary between models, a generalized representation can be expressed as follows:

Hs = f(Wind, Ocean Currents, Atmospheric Pressure, Bathymetry, Coriolis Effect, etc.)

In this case, Hs stands for the significant wave height, and the function f shows how wind, ocean currents, atmospheric pressure, bathymetry, the Coriolis effect, and other important factors interact with each other.

$$F.v = - 1/p \; dp/ dx$$

Where f is the Coriolis parameter, v is the geostrophic current, p is the water density, p is the pressure, and x is the horizontal distance. This equation essentially states that the Coriolis force acting on the ocean current is in balance with the pressure gradient force. It’s important to keep in mind that this equation only gives a simplified representation of the influences on ocean currents, which also include tides, atmospheric forcing, and Earth’s rotation.

2.3. In-situ observation stations and Satellite data

To ensure a comprehensive and timely assessment of atmospheric and oceanic conditions along the Indian coastline, an extensive network of strategically positioned wave rider buoys, equipped with atmospheric and ocean sensors, has been implemented. Each coastal state in India is equipped with a dedicated buoy, strategically situated to capture localized conditions accurately. Additionally, buoys have been strategically deployed in the open waters of the Arabian Sea and Bay of Bengal to detect and characterize disturbances in the ocean. The geographical distribution of buoys is illustrated in Figure 1. These buoys operate as pivotal in-situ observation stations, continuously relaying real-time data on parameters

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such as sea surface temperature, salinity, wave height and direction, along with atmospheric conditions like wind speed and direction, pressure, air temperature, etc.

In synchronization with in-situ observations, wind data is continuously acquired from satellite-based instruments, namely the Advanced Scatterometer (ASCAT) and the Scatterometer Satellite (SCATSAT-1). This satellite-derived data is received at regular intervals of every 6 hours, offering a broad-scale perspective of wind patterns over the open ocean.

The coastal wave rider buoys employ a robust communication strategy, transmitting data every half hour through a combination of INSAT and HF transmission. On the other hand, the open ocean buoys utilize a slightly less frequent transmission schedule, sending data every hour through INSAT. This meticulous data transmission protocol ensures real-time monitoring and analysis.

2.4. Model Validation Process

Every day, operational models are checked by doing root mean square error (RMSE) analyses, scatter index calculations, and spatial and point-wise correlation calculations. These metrics collectively provide a comprehensive evaluation of the models' predictive capabilities.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (1)$$

The Pearson Correlation Coefficient (PCC) as mentioned in equation 1 measures the linear correlation between observed (Xi)and predicted (Yi) values, with a range of -1 to 1, where 1 indicates a perfect positive correlation.

$$RMSE = \sqrt{\frac{1}{n}\Sigma_{i=1}^{n}\left(\frac{d_i - f_i}{\sigma_i}\right)^2} \quad (2)$$

The Root Mean Square Error (RMSE) in equation 2 quantifies the average magnitude of the differences between observed (Xi) and predicted (Yi) values, providing a measure of overall accuracy.

$$SI = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})}}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})}} \quad (3)$$

The Scatter Index represented in equation 2, represents the ratio of the standard deviation of the residuals (Yi Yj) to the standard deviation of the observed values (Xi), offering insights into the dispersion of model predictions.

2.5. Decision Making Inerfaces

The forecasters serve as the end users of the system, equipped with options to select overlays from four distinct buckets: model forecasts, real-time in-situ and satellite observations, validation statistics, and extreme event information sourced from other meteorological forecasting entities. Additionally, the system tracks information about the cyclone from the Indian Meteorological Department (IMD), Joint Typhoon Warning Center (JTWC), the European Center for Medium Weather Forecast (ECMWF), and the National Center for Medium Range Weather Forecast (NCMRWF).

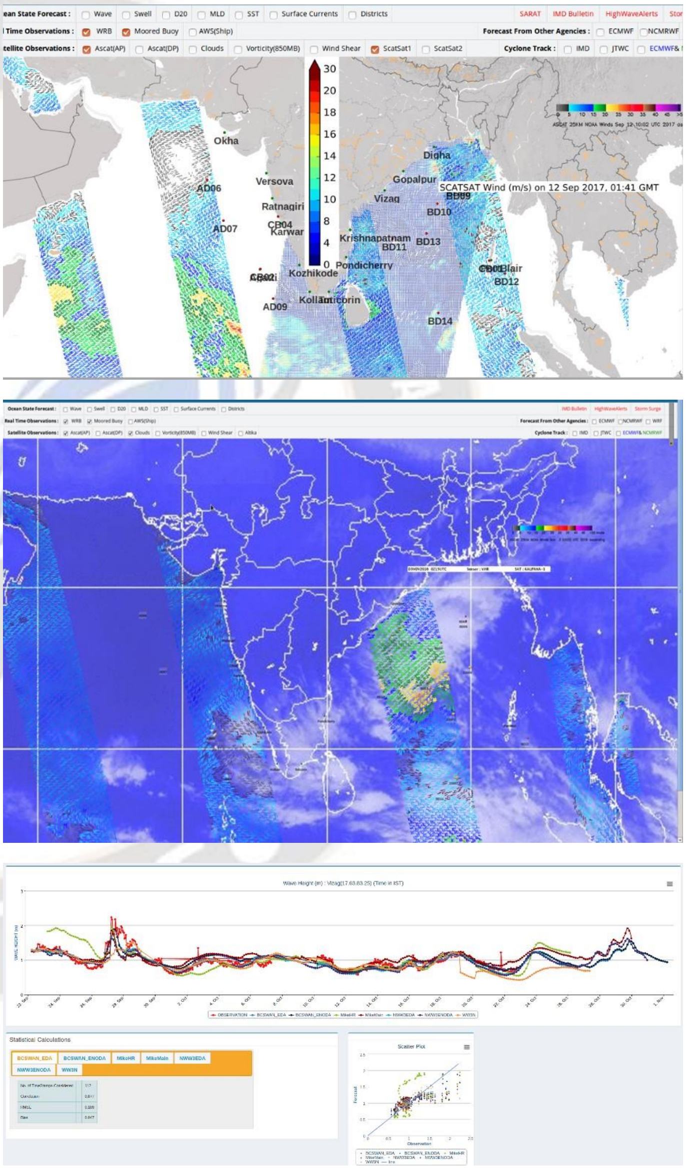

Figure 3: (a) Assessment of the Ascat and ScatSat-1 winds over the Indian Ocean region; (b) Monitoring the real-time satellite imagery for any disturbances in the ocean; (c) Example of wave height validation process at Visakhapatnam, India.

They exercise the flexibility to compare and contrast each model output against the observations by overlaying model outputs and station data on an interactive map.

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3. Results and Discussion

The Decision Support System (DSS) has played a crucial role in validating ocean forecasting models and deriving insights for the issuance of alerts to coastal communities. The system has been actively utilized during recent extreme events, serving both for alert generation and daily operations. It has proven instrumental in providing timely alerts during critical events and is routinely employed on a daily basis for continuous model validation, refinement, and accuracy improvement. Several instances highlight the system's efficacy in aiding forecasters to issue alerts.

3.1. SWELL Surge Events

The Decision Support System (DSS) has demonstrated remarkable utility during SWELL surge events, particularly in alerting forecasted high-period swells originating from the southern Indian Ocean and traversing northward, posing potential threats to coastal regions. The data gathered from the wave rider buoy at the Seychelles serves as an example of when the system detected the beginning of a swell event on October 4, 2020. Subsequently, a consolidated warning was promptly issued to the west coast of India, specifically targeting the Lakshadweep Islands, Gujarat, Maharashtra, Kerala, Karnataka, south Tamil Nadu, Andaman, and Nicobar Islands. The forecast issued for October 8 and 9, 2020, proved accurate, and timely actions taken by the corresponding states resulted in the preservation of lives and properties. The accurate validation of swell propagation at various locations, including Seychelles buoy, AD07, AD09, BD14, Karwar, Kavaratti, and Tuticorin, was promptly communicated to the coastal community. This early and precise intimation played a crucial role in containing potential damage and ensuring timely preparedness.

3.2. Cyclone Events

The Decision Support System (DSS) played a pivotal role in providing validation and decision-making support during cyclone events. The system facilitated the visualization of crucial information, including cyclone intensity, forecasted tracks with a cone of uncertainty, and observed tracks from authoritative sources such as the Indian Meteorological Department (IMD) and the Joint Typhoon Warning Center (JTWC). Additionally, the real-time location of the cyclonic system was captured through ASCAT and SCATSAT imagery overlays. A systematic approach was adopted during cyclone events to issue high wave alerts, swell surge warnings, strong wind alerts, etc., through INCOIS-IMD joint bulletins. The following sequential steps were executed: Validated wind forecasts from ECMWF and NCMRWF against moored buoy observations and satellite data from ASCAT and SCATSAT. Computed biases, if any, and applied bias correction techniques to wind data, enhancing the accuracy of ocean forecasts. Utilized corrected wind fields as forcing inputs for ocean forecasting models to generate wave and current forecasts. Validated wave and current forecasts using real-time observations from moored buoys and wave rider buoys, computing statistical measures such as correlation, RMSE, and bias. Finalized the most accurate forecasting model and issued INCOIS-IMD joint bulletins based on the selected model.

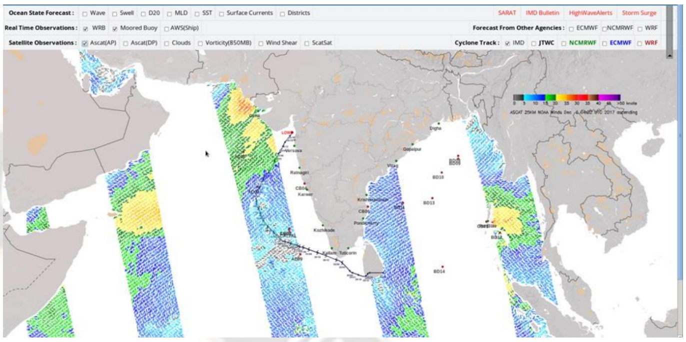

Figure 4: During Cyclone Ockhi, evaluating the trajectory from IMD and validating wind data against ASCAT pass.

Efficient and accurate alerts were transmitted well in advance before the cyclone made landfall, ensuring timely preparedness and response measures were undertaken. The early warning system successfully facilitated proactive actions, minimizing potential risks and enhancing community safety. As demonstrated in figure 7, during the Ockhi cyclone, the system played a crucial role in validating and issuing joint bulletins. the track of the cyclone Kyant in figure 5 is being assessed using the DSS.

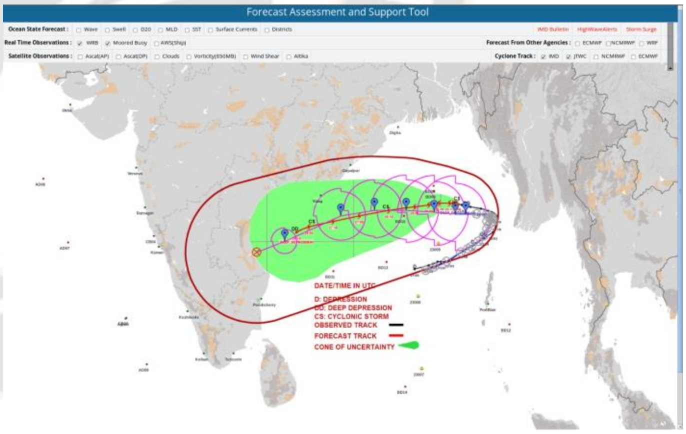

Figure 5: Evaluating the trajectory provided by JTWC during Cyclone Kyant.

3.3. High Wave Alerts

The Decision Support System (DSS) has proven instrumental in managing and issuing high wave alerts, contributing significantly to coastal safety. During high-wave events, the DSS operates within the Ocean State Forecast Division of INCOIS, where the validation of forcing fields and ocean model outputs is carried out in an operational capacity. The alerts are issued to the coastal communities in the local language and

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English for better reach and understanding. This multilingual approach ensures that the alerts are accessible to a broader audience, including those who may not be proficient in English. By providing information in the local language, the decision-makers aim to enhance the comprehension of the coastal community, allowing them to grasp the gravity of the situation and take necessary precautions effectively. Some of the alerts disseminated are given out in figure 6

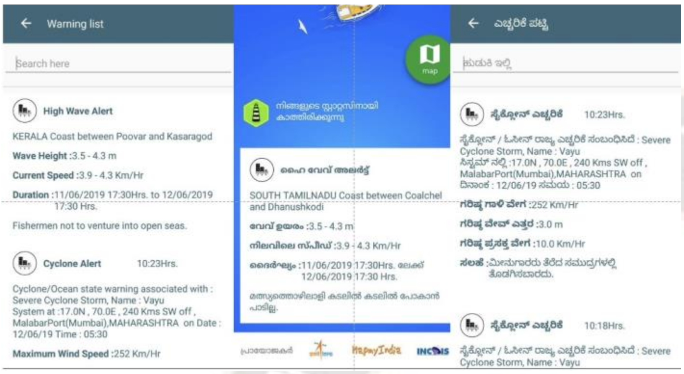

Figure 6: Snapshot of the alerts disseminated after validating the forecasts using the DSS.

As the decision-making process continues to yield positive results, the service of validating forecasts has been extended to encompass crucial maritime operations, including search and rescue missions Sahana et al. (2022), oil spill mitigation efforts, and advisory services Prasad et al. (2021).

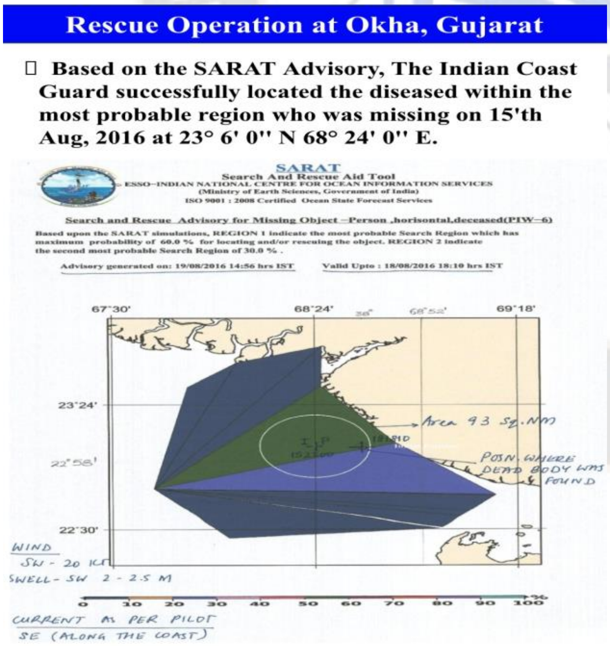

Figure 7: Indian Coast Guard effectively conducted maritime search and rescue operations with comprehensive details.

This expansion reflects the versatility and reliability of the validation services, contributing to enhanced safety and efficiency in various maritime activities.

4. Conclusion

In conclusion, this study has presented an advanced Integrated Ocean Forecast Decision Support System (DSS) tailored to enhance ocean forecasting capabilities, with a specific emphasis on the Indian Ocean region. The DSS has a powerful validation module that validates the accuracy of weather models against real-time observations from different sources, as well as a visualization module for scientific inference and spatial analysis. The integration of operational forecasts and observation data, along with automated model selection based on correlation assessments, empowers the system to provide users with the most reliable forecasting model. Particularly during extreme events such as cyclones, the DSS dynamically incorporates real-time information from meteorological agencies, refining models for precise assessments. The DSS has proven instrumental in supporting decision-makers, enabling them to issue timely and accurate alerts for adverse conditions, including high winds and elevated waves, especially during significant cyclones like Tauktae and Gulab in the Arabian Sea and Bay of Bengal. The web interface displaying key metrics, such as correlation coefficients, root mean square error, and scatter index, facilitates a user-friendly environment for decision-makers to evaluate and select the most suitable forecasting model. This paper has provided a detailed exploration of the implementation details, highlighting the system's efficacy in handling extreme events and its pivotal role in fostering informed decisionmaking. The advancements and capabilities demonstrated by the Integrated Ocean Forecast DSS hold significant promise for enhancing preparedness and response strategies in the face of dynamic oceanic conditions, contributing to the broader field of ocean forecasting and disaster management. The work exhibits notable strengths in addressing ocean-originated threats. However, certain limitations should be acknowledged. Firstly, the system's current design confines its primary focus to threats originating from the ocean, potentially limiting its applicability to forecasting non-oceanic events. Secondly, the system exclusively processes atmospheric and ocean models, indicating a scope for improvement in forecasting accuracy. To get around this problem, future updates might include adding more advanced machine learning or neural computing engines, which would make it possible to predict how the environment will change in a more complex and accurate way. These limitations highlight valuable avenues for further research and development, emphasizing the need for a broader scope and the integration of cutting-edge technologies to enhance the system's overall forecasting capabilities.

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5. Data Availability

The data that supports the findings of this study is available on request from the corresponding author as per the data policy of INCOIS.

6. Funding and/or Conflicts of Interests/Competing Interests

No funding was received for conducting this study. The authors declare they have no financial interests. The authors have no conflicts of interest to declare that are relevant to the content of this article.

References

[1] Ahmed, T., Creedon, L., Gharbia, S.S., 2023. Low-cost sensors for monitoring coastal climate hazards: A systematic review and meta-analysis. Sensors 23, 1717.

[2] Araujo, S.O., Peres, R.S., Filipe, L., Manta-Costa, A., Lidon, F., Ramalho, J.C.,´ Barata, J., 2023. Intelligent data-driven decision support for agricultural systems-id3sas. IEEE Access.

[3] Argyle, E.M., Gourley, J.J., Flamig, Z.L., Hansen, T., Manross, K., 2017. Toward a user-centered design of a weather forecasting decision-support tool. Bulletin of the American Meteorological Society 98, 373–382.

[4] Ashok, K., Guan, Z., Yamagata, T., 2001. Impact of the indian ocean dipole on the relationship between the indian monsoon rainfall and enso. Geophysical research letters 28, 4499–4502.

[5] Balakrishnan Nair, T., Srinivas, K., Nagarajakumar, M., Harikumar, R., Nimit, K., Remya, P., Francis, P., Sandhya, K., 2022. Advances in ocean state forecasting and marine fishery advisory services for the indian ocean region, in: Social and Economic Impact of Earth Sciences. Springer, pp. 201–227.

[6] Dolif, G., Engelbrecht, A., Jatoba, A., da Silva, A.J.D., Gomes, J.O., Borges,´ M.R., Nobre, C.A., de Carvalho, P.V.R., 2013. Resilience and brittleness in the alerta rio system: a field study about the decision-making of forecasters. Natural hazards 65, 1831–1847.

[7] Fang, Z., Yue, P., Zhang, M., Xie, J., Wu, D., Jiang, L., 2023. A serviceoriented collaborative approach to disaster decision support by integrating geospatial resources and task chain. International Journal of Applied Earth Observation and Geoinformation 117, 103217.

[8] Govardhan, G., Ghude, S.D., Kumar, R., Sharma, S., Gunwani, P., Jena, C., Yadav, P., Ingle, S., Debnath, S., Pawar, P., et al., 2023. Decision support system version 1.0 (dss v1. 0) for air quality management in delhi, india. Geoscientific Model Development Discussions 2023, 1–30.

[9] Hermes, J.C., Masumoto, Y., Beal, L., Roxy, M.K., Vialard, J., Andres, M., Annamalai, H., Behera, S., D'Adamo, N., Feng, M., et al., 2019. A sustained ocean observing system in the indian ocean for climate related scientific knowledge and societal needs. Frontiers in Marine Science , 355.

[10] Kumar, V.S., Anusree, A., 2023. High waves measured during tropical cyclones in the coastal waters of india. Ocean Engineering 289, 116124.

[11] Mankayarkarasi, B.V., Dhanalakshmi, A.S., Venkatachalam, J., 2023. Review on indian ocean buoys and its operations, in: AIP Conference Proceedings, AIP Publishing.

[12] Meena, S.P., Neetu, S., Adithyan, V., Imchen, I., 2023. Contribution of tropical cyclone induced waves to the mean and extreme wave climatology in the bay of bengal. Ocean Modelling 186, 102282.

[13] Na-Yemeh, D.Y., Legg, T.A., Lambert, L.H., 2023. Economic value of a weather decision support system for oklahoma public safety officials. Annals of the American Association of Geographers 113, 549–565.

[14] Nair, T.B., Sirisha, P., Sandhya, K., Srinivas, K., Kumar, V.S., Sabique, L., Nherakkol, A., Prasad, B.K., Kumari, R., Jeyakumar, C., et al., 2013. Performance of the ocean state forecast system at indian national centre for ocean information services. Current Science , 175–181.

[15] Pal, I., Ghosh, S., Dash, I., Mukhopadhyay, A., 2023. Review of tsunami early warning system and coastal resilience with a focus on indian ocean. International Journal of Disaster Resilience in the Built Environment 14, 593–610.

[16] Patriarca, R., Simone, F., Di Gravio, G., 2023. Supporting weather forecasting performance management at aerodromes through anomaly detection and hierarchical clustering. Expert Systems with Applications 213, 119210.

[17] POATE, T., STOKES, C., Masselink, G., BRODIE, L., GANDERTON, P., SYMONS, M., 2023. Development and validation of a remote bed-level sensor for improved operational coastal flood warnings, in: Coastal Sediments 2023: The Proceedings of the Coastal Sediments 2023. World Scientific, pp. 1006–1019.

[18] Prasad, S., Balakrishnan Nair, T., Vijayalakshmi, T., 2021. Oil spill trajectory prediction assessment using multi model ocean currents-case study of mt dawn oil spill 2017, in: International Oil Spill Conference, p. 684276.

[19] Reddy, J., Ganesan, L., Ramasubbu, B., Ramasamy, V., 2023. Shallow water wave spectral characteristics in southwest bay of bengal using measurements from a moored buoy. Arabian Journal of Geosciences 16, 357.

[20] Reljic, M., Romi´ c, M., Romi´ c, D., Gilja, G., Mornar, V., Ondrasek, G.,´ Bubalo Kovaciˇ c, M., Zovko, M., 2023. Advanced continuous monitoring´ system—tools for water resource management and decision support system in salt affected delta. Agriculture 13, 369.

[21] Remya, P., Rabi Ranjan, T., Sirisha, P., Harikumar, R., Balakrishnan Nair, T., 2022. Indian ocean wave forecasting system for wind waves: development and its validation. Journal of Operational Oceanography 15, 1–16.

[22] Sahana, M., Sengar, A., Dubey, A., Agrawal, U., 2022. Person detection in maritime search and rescue operations .

[23] Sandhya, K., Murty, P., Deshmukh, A.N., Nair, T.B., Shenoi, S., 2018. An operational wave forecasting system for the east coast of india. Estuarine, Coastal and Shelf Science 202, 114–124.

[24] Sandhya, K., Nair, T.B., Bhaskaran, P.K., Sabique, L., Arun, N., Jeykumar, K., 2014. Wave forecasting system for operational use and its validation at coastal puducherry, east coast of india. Ocean Engineering 80, 64–72.

[25] Sinha, M., Biswas, S., Banerjee, S., 2023. Genetic algorithm and deep learning models compared for swell wave height prediction. Dynamics of Atmospheres and Oceans 102, 101365.

[26] Sirisha, P., Sandhya, K., Balakrishnan Nair, T., Venkateswara Rao, B., 2017. Evaluation of wave forecast in the north indian ocean during extreme conditions and winter monsoon. Journal of Operational Oceanography 10, 79–92.

[27] Soisuvarn, S., Jelenak, Z., Chang, P.S., Zhu, Q., Shoup, C.G., 2023. Highresolution coastal winds from the noaa near real-time ascat processor. IEEE Transactions on Geoscience and Remote Sensing .

[28] Sridevy, S., Devi, M.N., Sankar, M., 2023. Decision support systems in agricultural industry perspective .

[29] Uccellini, L.W., Ten Hoeve, J.E., 2019. Evolving the national weather service to build a weather-ready nation: Connecting observations, forecasts, and warnings to decision-makers through impact-based decision support services. Bulletin of the American Meteorological Society 100, 1923–1942.

[30] Venkatesan, R., Arul Muthiah, M., Ramesh, K., Ramasundaram, S., Sundar, R., Atmanand, M., 2013. Satellite communication systems for ocean observational platforms: Societal importance and challenges. Journal of Ocean Technology 8.