Ideas and perspectives: Ushering Indian Ocean into the UN Decade of Ocean Science for Sustainable Development (UNDOSSD) through Marine Ecosystem Research and Operational Services – An early-career's take

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Abstract.

The Indian Ocean-rim hosts many of the world's underdeveloped and emerging economies that depend on the ocean resources for the livelihoods of the populations of millions residing in. Operational ocean information services cater to the requirements of managers and end-users to efficiently harness those resources, and to ensure safety. Fishery information is not the only operational services that will be needed to empower such communities in the coming decades. Coral bleaching alerts, SCUBA-assist advisories, conservation or ecotourism assist services (e.g. Turtle-watch/Whale-watch), poaching/bycatch reduction support, jellyfish/microplastic/oil-spill watch are to name a few, but not an exhaustive list of the services that are needed operationally. This paper outlines existing tools, and explores the ongoing research that has potential to convert the findings into operational services in near-to-mid term.

1. Introduction

About a third of the world population reside in the Indian Ocean -rim (IOR) countries. This is projected to increase and may reach to 50% of the global populations by the year 2050 (Doyle, 2018); whose lives and livelihoods are inherently intertwined with the Indian Ocean and its dynamics. These countries have very diverse cultures and philosophies. Their financial capabilities vary widely and so do their aspirations and world-views. The IOR countries thus present a confluence of ideologies to a manager, with their vivid and vibrant demographics that have very different challenges and opportunities. Majority of the IOR countries have either expansive or stationary population pyramid profile, with limited land resources. Their nutritional and employment needs will have more reliance on the Indian Ocean in coming decades. Marine ecosystems are a promising source for the nourishment of populations and at the same time, are under more serious threats than ever before. As more people are brought up from the poverty, consumerism is poised to extend to larger parts of the population, which will create concerns for the health of the adjoining ocean ecosystems.

The International Indian Ocean Expedition (IIOE) conducted during 1962-1965, was the first major attempt to study the Indian Ocean, its processes and diversity. It resulted into many multidisciplinary collaborations and gave birth to institutions such as National Institute of Oceanography (NIO) in India. The second IIOE (IIOE-2) was observed during 2015-20 commemorating five decades of the first IIOE, and witnessed even greater participation globally. It has been underlined on the onset IIOE-2 that, the Indian Ocean is one of the relatively poorly studied oceans of the world (Hood et al., 2016). It is thus important to ensure that the resources from this unique (land-locked from the north) ocean are harnessed in harmony with sustainability, and with the equal opportunities. For the successful planning and execution, it is imperative for the resource managers to have community participation (Martini et al., 2017). Hence, it is especially important for the IOR countries to chart the right path at the eve of the United Nations Decade of Ocean Science for Sustainable Development (UNDOSSD, 2021-2030).

Advancement of geosciences in last century has provided us many tools to cope with the changing environment and associated challenges. The role of providing such insights in the twenty first century is shifting to operational oceanography (OSOS, 2019). Operational oceanography is defined as systematic and sustained ocean observations which are converted into outputs as per the stakeholder/user requirements; using the scientific research done in the development of those outputs. Operational ocean services are the mechanism through which these outputs are disseminated effectively (often, in real-time or near real-time) and feedbacks are collected on users' experience and needs (Fig.01). Robust combination of observations and modelling, artificial intelligence, effective tools of interpretation and user-friendly dissemination of information can change millions of lives dependent on the oceans. This paper hypothesizes that the best possible approach to win the community attention (and to invoke the responsible ownership of the resources) is to engage the communities with the operational ecosystem related services. Further, this paper explores the regional needs and solutions based on presently available data and technologies.

2. Marine Ecosystem Research and operational Services (MERS)

The marine ecosystem related operational ocean information and forecasts services (or products as a service) can be grouped into three major categories based on their prime objectives. The first type of services is related to resource management, conservation and support to livelihood. The second type comprises of services that deal with threats to the ecosystem. The third group is of the solutions for community engagement and dissemination.

2.1 Services to cater resource management, conservation and livelihood

Under the decadal initiative, the UN Sustainable Development Goal (SDG)-14 (Life below water) will receive significant attention, which heavily relies on remote sensing data in general and in particular, on Ocean Color (OC) observations. In the late 90's, the OC science achieved operational status (after a decade long hiatus post-CZCS era) due to adequate satellite coverage. Since then researchers have made extensive use of these data despite often encountering spatial (clouds and sun-glint), temporal (daily once, daytime only coverage) or spectral (fixed, limited bands) limitations. The applications range wide from fisheries and aquaculture to Harmful Algal Bloom monitoring to estimating productivity and carbon budgeting (Wilson, C., 2011). However, there are limitations with regard to predictability of the base of the food pyramid itself. There are global products for primary production such as Vertically Generalized Productivity Model that are developed with relatively low observations of the Photosynthesis-Irradiance parameters from the Indian Ocean. It is thus very important for the IOR countries to have regional Primary Productivity models for operational applications. This could be taken up as a priority during the UNDOSSD.

This decade is chiefly important due to the planned launch of an operational hyperspectral mission named PACE (Plankton, Aerosol, Cloud, ocean Ecosystem), by NASA (National Aeronautics and Space Administration, USA) in the early 2020's. A hyperspectral sensor scans oceans with high-resolution of as much as 1nm wavelength for the entire visible spectrum, that enables the researchers to begin a new era in the OC sciences due to its potential of developing a plethora of applications. This includes but is not limited to better resolving phytoplankton functional types, fishery resource management and ecosystem health monitoring. The latter is more important especially for the second type of services and is discussed in detail in a subsequent section.

At the same time, the temporal limitations seem to be mitigated through various approaches such as using the Day-Night Band data or OC data from the geostationary orbit such as Geostationary Ocean Color Imager (Miller et al., 2013; Ruddick et al., 2014). When OC science follows the footsteps of other satellite types, we may also have a "swarm" of nano-satellites or cubesats – further improving temporal and up to some extent, spatial coverage as well. This however needs to be rightly balanced with the concerns of overcrowding the orbits and associated complexities (Bruinsma et al., 2021). Studies are required to shed light on the fate of ocean observations platforms (chiefly, drifting platforms) and setting up best-practices, to minimize their contribution to marine debris. Placement of HICO (Hyperspectral Imager for Coastal Ocean) on International Space Station (ISS) reminds us that the OC science may not be limited to satellite remote sensing in coming decades (Huemmrich et al., 2017). Validations, sampling protocols, inter-comparison exercises and training for all of

97   these will be needed. Modelers are putting efforts to assimilate data products into numerical models or, making

98   use of surface information for better resolving subsurface characteristics. Others strive for carbon, or heat-

99   budgeting. With more than two decades of uninterrupted observations, (applying the rule of thumb of minimum

100   30 years' time-series) we are a few years away of making use of OC data for climate applications.

101   There are some proven (e.g. telemetry) and emerging (e.g. eDNA) tools that can help researchers for the

102   services related to higher trophic levels (Costa et al., 2010; Stat et al., 2017). These tools are very useful in

103   providing vital information habitat utilization, migration, environmental preferences and presence-absence

104   analysis. The research can then support the operational services that cater to sustainable resource management,

105   prevention of bycatch or help reduce accidental mortality. TurtleWatch advisory by NOAA (National Oceanic

106   and Atmospheric Administration, USA), is the best suited example for the majority of the Indian Ocean

107   countries (Howell et al., 2015). Other species for which such products are very much needed in the operational

108   mode are Cetaceans, Sharks and marine mammals.

109   The operational services that can predict the movement and presence of these animals are required for

110   conservation authorities who can then effectively design protected areas, do better marine spatial planning or

111   monitor potential hotspots for poaching or IUU (Illegal, Unreported and Unregulated) fishing. Additionally

112   these can also support the ecotourism (e.g. WhaleWatch) as an alternate livelihood for the fishermen that face

113   capture fishery as a less lucrative occupation. Ecotourism needs support from operational services monitoring of

114   mangroves and corals as well. Innovative ideas that put together existing observations and forecasts (e.g. water

115   clarity from OC satellite data, currents and wave-height forecasts from numerical model simulations, and coral

116   health i.e., no-bleaching/stress alert with the help of satellite-based SST), and generate novel products (e.g.,

117   SCUBA-buddy advisories), will support dive operators in many of the IOR-countries, especially the SIDS

118   (Small Island Developing States). Mariculture (open ocean cage culture) is emerging as another area of

119   livelihood as an alternate to the capture fishery and is poised to be more feasible at wider areas with newer

120   designs of submerged cages (Korsøen et al., 2012).

121   Acoustics is another tool that can support development of operational services for various stakeholders.

122   Acoustic telemetry is useful for the species to which satellite telemetry isn't suitable due to various reasons

123   (Crossin et al., 2017), whereas the field of bioacoustics has been furthered into many sub-branches. The

124   estimation of zooplankton biomass with the help of acoustic backscatter isn't only limited to moored buoys and

125   these techniques have transcended to AUVs (Autonomous Underwater Vehicles), aptly called zooglider (Ohman

126   et al., 2019). Such surveys are vital for zooplankton and ichthyoplankton distribution monitoring, and for

127   ecosystem models that would connect the regional PP products to the higher trophic levels. Bioacoustics is also

128   used for monitoring the marine animals' movements by listening to the underwater sounds, often through

129   Passive Acoustic Monitoring (PAM), which would be one of the less intrusive ways of study (Brwoning et al.,

130   2017).

131   2.2 Services to mitigate threats to the ecosystem

132   Many of the human activities can be nuisance to the marine environment in different ways and anthropogenic

133   sound in the ocean is one such example (Williams et al., 2015). Future operational services will need to account

134   for and develop ways to monitor the oceanic soundscape.

135   Another common anthropogenic impact on the marine ecosystems is transport and introduction of alien (non-

136   native) species through the ballast water. These species when lack natural predators, are often turn out to be

137   invasive species and throw off the local ecological equilibrium (Bailey S.A., 2015). Oil spill is yet another

138   source of pollution from the ships. These can be addressed up to certain extent by monitoring vessel AIS

139   (Automatic Identification System) data and applying artificial intelligence-machine learning (AI-ML) tools to

140   identify the ship behavioural patterns prior to such discharges; and then use it as predictive model (Soares et al.,

141   2019).

142   Plastic adversely impacts the marine environment in multiple ways. The known pathways include ghost fishing

143   (entanglement), ingestion, bioaccumulation and allied effects, as well as transport of alien species and

144   pollutants. Among the top-20 countries globally with inadequately managed plastic as a source to the ocean, half

145   are the IOR countries. All of the Bay of Bengal peripheral countries face the issue of land-plastic management

146   (Jambeck et al., 2015). Thus, the Bay of Bengal needs to be a prime focus to monitor the oceanic and beach

147   debris in the mission mode, with the triad of *in-situ* surveys, dispersion models and latest remote sensing

148   techniques (Martínez-Vicente et al., 2019). Whether it is about addressing entry of the plastic from land to

149   ocean, or sustainable exploitation of shared fish stocks; progressive and tangible engagement among

150   stakeholders through forums such as SAARC (South Asian Association for Regional Cooperation), BIMSTEC

151   (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation), WIOMSA (Western Indian

152   Ocean Marine Science Association) or RIMES (Regional Integrated Multi-Hazard Early Warning System for

153   Africa and Asia), is a necessity.

154   On the other hand, mass sink of jellyfish swarming has been reported in the Arabian Sea (Billet et al., 2006).

155   Jellyfish swarms are known to be disruptive to fisheries and to the cooling water intake facilities of coastal

156   industries with causes little known, and thus the need for development of predictive capabilities. The Arabian

157   Sea also witnesses large scale blooms of *Noctiluca scintillans* and research in recent years may provide the

158   foundation for the bloom forecasting (Xiang et al., 2019). Crashing of jellyfish swarms or algal blooms have

159   implications to the deep sea ecology, particularly in regions such as the Arabian Sea, which has prominent

160   oxygen minimum zone (OMZ) (Rixen et al., 2020). .Stratified waters such as those of the northern Indian Ocean

161   basins have implications for large pelagic, which may face additional fishing pressure with the expansion of the

162   OMZs due to shrinkage of the habitat (Nimit et al., 2020).

163   2.3 Effective dissemination and user-engagement

164   While it is important to have robust observations and modelling capabilities in order to generate operational

165   services and products, it is equally important to have effective dissemination. Presently, the IOR countries rely

166   on information dissemination through conventional modes that are almost entirely land-based. Dissemination of

167   operational services onboard has its own benefits during fair weather as well in terms of fuel saving. However,

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168 due to limitation of cellular signal support at sea, it is imperative that a full-fledge dissemination system should
169 be supported through satellite communication (Singh et al., 2016). This results in episodes such as cyclone
170 Ockhi wherein lack of timely alerts costs many lives (Roshan M, 2018). Such dissemination systems are to be
171 provided along with feedback mechanism, to validate the services in real or near-real time. The feedbacks also
172 open new avenues of data collection. Crowdsourcing of data gathering could play an essential role in making
173 seafarers eyes and ears of the scientists (Kelly et al., 2020).

174 **3. Recommendations**

175 All of the seven themes of the UNDOSSD have major implications to the needs of the IOR countries, and has
176 stakeholders at its heart. Hence, operational services can be one of the most important approaches for the
177 community engagement in the fulfilment of theme's goals. The existing frameworks of IIOE-2 and others (e.g.
178 RIMES) may be utilized to ensure that the IOR countries can share their know-how (e.g. digital
179 gene/metabarcoding bank) and have access to the operational services, which will fulfil 'transparent ocean' and
180 'inspiring and engaging ocean' goals. Reliable maps of oil-spill and marine debris are essential for meeting the
181 goal of 'clean ocean'. In addition to the adverse physical sea-state, algal bloom and jellyfish swarming
182 predictions are required for achieving 'safe ocean' objective. Coral-bleaching and SCUBA-buddy advisories can
183 form important pillar to 'healthy and resilient ocean' by supporting ecotourism-based alternate livelihood.
184 Telemetry, acoustics and genomics aided by satellite data and model simulations will enable us in managing
185 responsible fisheries through the virtue of 'predictive ocean'. This can in turn ensure 'sustainable and productive
186 oceans' for the coming generations.

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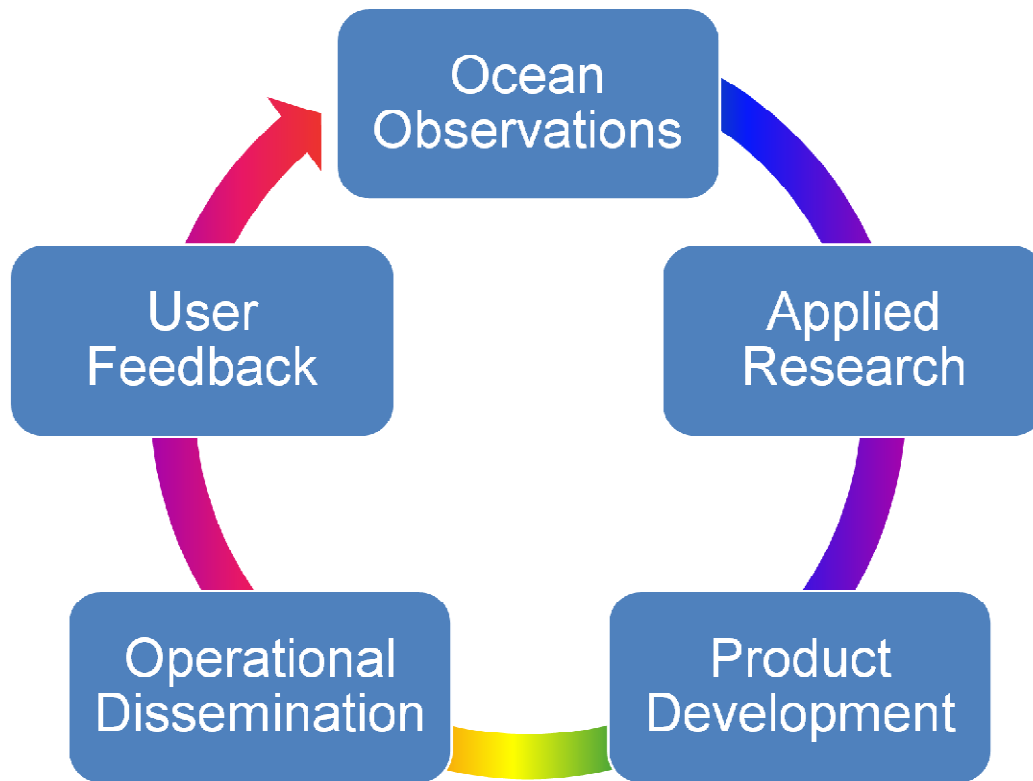
Fig.01. Evolution and life-cycle of an operational ocean service. After identification of user requirement and consultation with them, ocean observations are planned or retrieved (if already existing). The observations are then used for the research focused to the development of product customized for stakeholder requirement. The products are then disseminated as routine operations, and feedbacks from the users are collected for further improvement of the product. Due to the continuous advancement of the technology and change in the user requirements, this cycle repeats to find the best achievable solutions for the contemporary needs at the user-level.