

*Review Article***Physical Sciences of the Ocean: A report to IAPSO/IUGG**S PRERNA¹, B PAUL¹, P A FRANCIS¹ and S S C SHENOI^{1,*}¹Indian National Centre for Ocean Information Services, Hyderabad 590 090, India

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A brief sketch of the advances in the oceanographic research in India that deals with physical, chemical and biological processes in the ocean during the period 2000-2018 are highlighted in this report. It is found that there have been significant progress in the research activities in this field with more than 2300 research papers published during the past 18 years. About 4827 Indian researchers were involved in authoring/co-authoring these papers and many publications were co-authored with foreign researchers spread across 44 countries. Notable achievements in the field of ocean sciences in the recent past are (a) a revolutionary understanding on the coupled processes over the tropical ocean and atmosphere, (b) enhanced capability in the numerical ocean modeling and data assimilation, (c) advancements in remote sensing techniques, algorithms and applications, (d) progress in our knowledge on coastal processes, and (e) marine bio-geochemistry.

Keywords: Ocean; IAPSO/IUGG; Physical, Chemical and Biological Sciences; Publications

Introduction

There has been significant advancement in research and development activities in the field of Physical Sciences of the Oceans in India in the 21st century. Since January 2000 to February 2018, 2345 research papers were published in this field. About 4827 Indian researchers were involved in authoring/co-authoring these papers in collaboration with 44 foreign countries. The steady growth in the number of papers published in different areas of physical sciences of oceans can be seen in Fig. 1 which depicts the number of papers published each year. The number of publications steadily rose from about 30 in 2000 to more than hundred in 2006-2007 and then increased rapidly to 240 papers per year in 2015. The same number continued in the later years also. Research areas within the broad category of physical sciences of the oceans, in which significant research have been carried out in India can be further classified as follows (number of publications in each category are given in brackets).

1. Air sea interaction (95)
2. Bio-geochemistry (104)

3. Climate change (85)
4. Coastal studies (94)
5. Estuaries and nearshore waters (260)
6. Marine ecosystem (38)
7. Ocean acoustics (15)
8. Ocean circulation (227)
9. Ocean modeling and data assimilation (205)
10. Ocean optics (75)
11. Physical processes (97)
12. Potential fishing zones (44)
13. Remote sensing (205)
14. Sediment transport (68)
15. Tides, Storm-surges and Sea-level (261)
16. Tsunami (142)
17. Waves (308)

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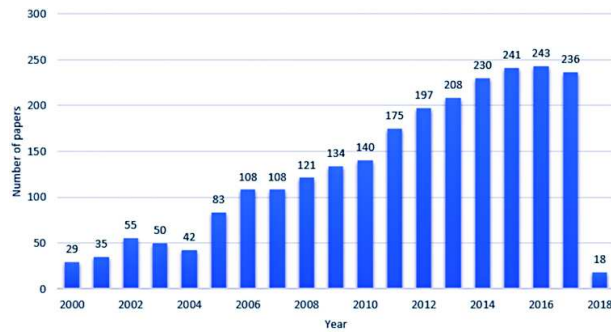


Fig. 1: Year-wise number of publications in the field of Oceanography for the period 2000 to present

Topic wise distribution of publication is shown in Fig. 2. It is interesting to note that maximum number of papers were published in the field of tides, storm surge and sea-level changes (261) and this is closely followed by research in estuaries and nearshore waters (260) and ocean modeling and data assimilation (205). Ocean remote sensing (205), Tsunami (142) and ocean biogeochemistry (104) are the other areas which witnessed significant amount of research in the branches of physical sciences of the oceans.

Discussion

A large number of papers were published on the physical processes in the Indian Ocean, which mainly described the large-scale oceanic circulation including that in the coastal waters of India, equatorial Indian Ocean and Southern Indian Ocean. These studies reported the basic mechanisms involved in the observed variability in physical parameters in the Indian Ocean. The deployment of Acoustic Doppler Current Profilers (ADCPs) in the shelf and slope regions in the coastal waters around the country has been providing continuous high-frequency data of coastal currents for the past 10 years and that has enhanced our insights in the variability of coastal circulation. Similarly, the data from Ocean Data Buoys deployed in the deep and shallow waters in the Indian Ocean also helped in improving the understanding of Indian Ocean variability and air-sea interaction processes. Research publications based on the data from observational campaigns in the Indian Ocean, the Arabian Sea Monsoon Experiment (ARMEX), Continental Tropical Convergence Zone (CTCZ), Bay of Bengal Boundary Layer Experiment (BoBBLE), Ocean Mixing and Monsoon (OMM), International Indian Ocean Expedition-II (IIOE-II), etc., have also

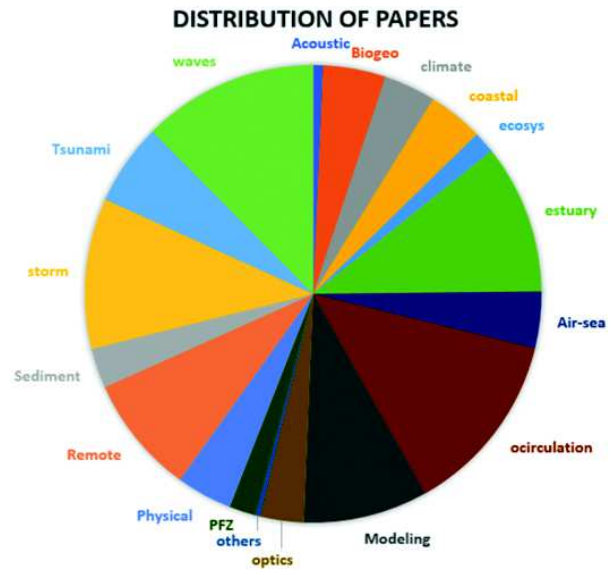


Fig. 2: Distribution of research papers published after 2000 in different sub-categories in the broad field of Oceanography

contributed significantly to the increased number of publications in this category.

Numerical Ocean Modeling has been one of the key research areas among the Indian researchers. 217 papers were published in this area. Access to high performance computational facilities, availability of ocean observations and exposure to state-of-art numerical ocean models have contributed significantly to this achievement. Supported by the ocean modeling activities, Indian National Centre for Ocean Information Services (INCOIS) has setup India's first Operational Ocean Forecast System (INDian Ocean Forecast System, INDOFOS) in 2010, which comprises a suit of numerical ocean models and that has now evolved into one of the leading ocean forecast system in the world. INCOIS is now providing real-time ocean analysis for the global oceans and short-term ocean forecasts for the Indian Ocean. Very high-resolution coastal forecasts are also being provided now by INCOIS for the waters around India. Publications in the field of ocean modeling describe the results of the studies on how the ocean models could be improved by incorporating various physical processes and by using improved atmospheric forcings. Ocean models were also used to study the specific oceanographic features and the processes responsible for the genesis of the ocean features. Ocean data assimilation has also been a focus of

research in the last two decades. Fifty seven papers were published on data assimilation, including the studies that described the methodologies of data assimilation and how the data assimilation improved the ocean analysis and forecasts. One of the significant studies in this field described how the ocean analysis in the pre-Argo era are contaminated due to the assimilation of data from the bounded observational network like Tropical Atmosphere Ocean (TAO) moorings in the Pacific.

Publications on air-sea interactions, including those focused on the response of oceans on tropical cyclones and monsoon have also contributed significantly to the growth of research publications in the recent years. Many papers in the field of air-sea interaction also discussed the influence of oceans on tropical cyclones and Indian and South Asian monsoon. The increase in the number of publications on air-sea interaction processes in the Indian Ocean could be largely attributed to the discovery of Indian Ocean Dipole (IOD) in late 1990's and Equatorial Indian Ocean Oscillation (EQUINOO) in early 2000's. These discoveries have revived the research interests in the field of tropical coupled air-sea interaction processes and their influence on the Indian summer monsoon. Several papers were published on the potential impacts of Indian Ocean Dipole, EQUINOO, El Niño and Southern Oscillation (ENSO) on Indian monsoon. Several other studies focused on the processes involved in the initiation and evolution of IOD. Some of the papers revisited the relationship between sea surface temperature and convection.

Studies on Marine Bio-geochemistry also have shown considerable growth in the past two decades. 109 papers were published during this period on Bio-geochemistry which dealt with geochemical and biological processes mostly focusing on studies of Carbon, Nitrogen and Oxygen elements. Several papers were also published focusing the sources, sinks and internal cycles of the trace elements as they have important applications in chronology, paleo-oceanography and ocean mixing. Substantial number of studies on zooplanktons and phytoplanktons described their spatial and temporal distributions. The role of mesoscale dynamics in regulating the phytoplankton biomass by modulating the nutrient input to the surface layer and the mixed layer depth were the focus of some of the publications in this area.

Several papers were published on the marine ecosystems. Some publications brought out the need for the conservation of Mangroves and Seagrass Ecosystems. Group level classification of zooplankton and phytoplankton, study of plankton taxonomy, their behavior and adoption to the anthropogenic effects were also studied. Around forty publications came from Indian authors on marine ecosystem during this period. Some of them dealt on how to improve the Potential Fishing Zones (PFZ) identified based on the satellite remote sensed sea surface temperature and Chlorophyll concentrations in the sea water. The additional information on ocean circulation and marine ecosystem parameters are shown to improve the identification of PFZ.

Considerable number of research papers were published on climate change by Indian authors since 2000. They included Indian Ocean warming, sea level changes, changes in primary productivity related to global change, sea surface salinity and hydrographic changes owing to climate change. Some papers reported the Climate Change and Sea-Level Rise and impact on agriculture. Studies using ocean observations and global coupled ocean-atmosphere model simulations have shown that besides the direct contributions from greenhouse warming, the long-term warming trend of the western Indian Ocean during summer depends on the asymmetry in El Niño-Southern Oscillation (ENSO) teleconnection, and the positive SST skewness associated with ENSO during the recent decades.

There are several publications on the changes taking place on the shoreline of India. Most of them focused on mapping and monitoring of coastline changes associated with the Indian Ocean tsunami and tropical cyclones. Few papers reported on coastal pollution and erosion and their implications. The papers on estuaries and nearshore waters of Indian coast described some of the physical and biogeochemical processes with the help of observations and models. Few publications dealt on the mangroves and sea grass. Some papers discussed on the influence of hydrological and anthropogenic factors controlling the abundance and variability of enteropathogens in the estuaries.

Ocean remote sensing is another major area of research during the past few years as remote sensing has established with wide ranging applications in the

field of coastal engineering, estimation of sea surface temperature, chlorophyll content, suspended sediment concentration, algal blooms, wave characteristics, identification of Potential Fishing Zones (PFZ), etc. Many papers reported the use of remote sensing and GIS in the mapping and monitoring of coastal resources, detecting shoreline changes, studying coastal landforms etc. The advancement in technology and the availability of high resolution data has attracted many researchers in this field which is highlighted by the increased number of publications in the last decade. Several papers were also published on the algorithms used for the retrieval of various parameters using remote sensing data. Studies on bio-optics also witnessed remarkable growth in the recent years. Papers describing the superiority of regional algorithms for the retrieval of oceanographic parameters using remote sensing methods were also published. Some of the studies described the effective use of statistical and computer aided tools like Wavelet Analysis, Neural Network, etc. for the accurate retrieval of geophysical parameters.

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