

***National Report for India (1963-1966)***

**PHYSICAL OCEANOGRAPHY**

**For  
International Union of  
Geodesy and Geophysics  
Association of Physical  
Oceanography**

**FOURTEENTH GENERAL ASSEMBLY, 1967**

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NATIONAL REPORT FOR INDIA  
ON  
PHYSICAL OCEANOGRAPHY, 1963-1966

by

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# **NATIONAL REPORT**

## **ON**

### **PHYSICAL OCEANOGRAPHY 1963-1966**

#### **I INTRODUCTION**

Physical Oceanographic studies in India during the years following 1962 may be broadly classified under three heads:—

- (i) Scientific work carried out as part of the Indian Programme of the International Indian Ocean Expedition.
- (ii) Investigations carried out by other institutions/university departments as part of a regular programme of studies.
- (iii) Coastal and nearshore investigations with application to coastal engineering problems.

#### **2 THE INTERNATIONAL INDIAN OCEAN EXPEDITION - INDIAN PROGRAMME, 1962-65**

The years following 1962 are to be considered as a period of great and sustained activity in Indian Oceanography. India's participation in the multi-disciplinary and the multi-national venture—the IIOE marked the beginning of an integrated and a well co-ordinated programme of oceanographic researches in the country. The Indian Programme of IIOE helped to place oceanography in the “scientific map” of the country.

The IIOE was first discussed in 1958 by a group of scientists constituting the Special Committee on Oceanic Research, now renamed as the Scientific Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions (ICSU). The project was then given definite shape under the co-sponsorship of UNESCO through its Intergovernmental Oceanographic Commission. Nineteen countries participated in this Expedition with well equipped research ships and a large contingent of scientific personnel with the single objective of knowing all about the Indian Ocean—the least-explored among all the world oceans. When the expedition concluded in 1965 it became one of the best explored oceans. The co-ordination of this great venture was effected by IOC through the National Co-ordinators and the National Committees on Oceanic Research.

The Indian Programme of IIOE (1962-65) was executed by the Council of Scientific and Industrial Research through its Directorate of Indian Ocean Expedition headed by Dr. N. K. Panikkar, the Director. The Indian Navy actively co-operated in this effort by providing the essential ship facility. The scientific programme for India's participation was drawn up by the Indian National Committee on Oceanic Research under the Chairmanship of Dr. D. N. Wadia, FRS, with Dr. Panikkar as Member-Secretary. Among the working groups con-

stituted by the INCOR for the drawing up of scientific programmes under the various disciplines, the one on Physical Oceanography and Meteorology worked out a comprehensive programme in Physical Oceanography while some aspects of work in Chemical Oceanography which have a direct bearing on Physical Problems were worked out by the working group on Chemical Oceanography.

The details of work outlined in the programme with reference to Physical Oceanography (including some aspects of Chemical Oceanography) are:

- (i) Distribution of properties and parameters such as temperature, salinity, density, dissolved gases and inorganic nutrient salts.
- (ii) Location and characterization of different water masses.
- (iii) Study of water movements and pattern of oceanic circulation, including dynamic computations.
- (iv) Upwelling along Indian coasts.
- (v) Wave observation and analysis.
- (vi) Internal waves.
- (vii) Seasonal and spatial variations of thermocline.
- (viii) Study of the Scattering layers.
- (ix) Instrumentation for wave studies, current measurements, measurements of temperature and transparency, Calibration and checking of bathythermographs.
- (x) Studies on Light penetration in the sea.

The area of study included the whole of the Arabian Sea up to 60°E, Bay of Bengal from the Indian coast up to 95°E and part of the Indian Ocean from southern tip of Indian Peninsula to Equator and between longitudes, 60°E and 90°E. Small extensions beyond these limits such as down to 1°30'S, westward up to the Island of Socotra, and eastwards up to straits of Malacca and Singapore were also made in the cruises.

The main cruising in the Indian Programme was done by INS KISTNA (the Indian Navy's Frigate converted for Oceanographic work and made available for the period of the IIOE). A total number of twenty-eight cruises was made by this ship during the period 1962-65, and a total number of 765 stations were occupied in the areas proposed for study. Several scientists belonging to various governmental and non-governmental institutions participated in this field programme. The Defence scientists were entrusted with the responsibility for the processing of the physical oceanographic data.

The second vessel, R.V. VARUNA, the Fishery Research Vessel belonging to the Indo-Norwegian Project participated in the Indian programme and carried out Physical Oceanographic studies along the west coast of India up to 70°E and also made two cruises to the northern equatorial Indian Ocean.

With the conclusion of the Indian Programme of IIOE in December, 1965 all the activities of the Indian Ocean Expedition Directorate were

taken over by the newly established National Institute of Oceanography (CSIR). The new Institute came into existence from 1 January, 1966.

The main physical oceanographic studies are now being continued at the Physical Oceanography Division of the National Institute of Oceanography at Ernakulam. The quality checking, processing and storage of all the Physical, Chemical Oceanographic Data and the work of dissemination of these data have been taken over by the Data Division of the Institute which has begun functioning as the National Oceanographic Data Centre for India. This Centre has also begun storing quantitative biological data such as Biomass of Zooplankton processed by the Indian Ocean Biological Centre, Ernakulam. The Indian National Oceanographic Data Centre (INODAC) is at present located at New Delhi along with the temporary headquarters of the NIO.

In addition to the general Physical Oceanographic studies, the Division of the Institute at Ernakulam handles a rather comprehensive programme of researches in the field of coastal and nearshore oceanography. The main problems are:—

- (i) Nearshore water movements and Tidal studies in harbours, estuaries, coastal lagoons and backwaters.
- (ii) Beach cycles, coastal erosion and accretion as governed by physical phenomena such as wave refraction and coastal currents.
- (iii) Storm surges and sea level variations.

### **3. PHYSICAL OCEANOGRAPHIC PROGRAMMES IN OTHER INSTITUTIONS IN THE COUNTRY**

In addition to the programmes of research carried out at the various divisions of the National Institute of Oceanography which has the major role in the oceanographic researches and programmes, a few institutions and university departments have been carrying out studies on certain aspects of physical oceanography. These are listed below:—

- I. *Andhra University, Waltair (Department of Meteorology & Oceanography)*:
  - (i) Some aspects of the Physics of the Atmosphere and the sea.
  - (ii) Meteorological and Oceanographic studies in the coastal waters off Waltair in relation to upwelling and sinking.
  - (iii) Limnological studies of the Chilka Lake and wave refraction in relation to shore-line development.
  - (iv) Hydrography and Hydrology of the estuaries—(a) Krishna, (b) Godavari—Vasishtha Branch.
- II. *Annamalai University (Marine Biological Research Station) Porto-Novo*:

Investigations on the hydrological features of the Vellar river estuary and coastal waters off Porto-Novo.

III. *Atomic Energy Department, Bhabha Atomic Research Centre (Health Physics Division) Bombay:*

- (i) Studies on water movements in the Bombay Harbour Bay with special reference to dispersal of pollutants.
- (ii) Current Measurements off Mormugao Bay.
- (iii) Hydrographical and Current Measurement studies in the Angria Bank region of the Arabian Sea—in collaboration with the fisheries department of the Government of Maharashtra.
- (iv) Application of radiotracers to study sediment movements in the Sethusamudram Project area, Palk Bay.

IV. *Central Marine Fisheries Research Institute, Mandapam and its Sub-station at Ernakulam:*

Physical Oceanographic studies along the east and west coasts of India with special reference to conditions on the fishing banks.

V. *Indian Naval Physical Laboratory (Defence Research and Development Organization) Cochin:*

- (i) Processing of BT data.
- (ii) Instrumentation for calibration of BT's, design of wave recorders, current meters etc.
- (iii) Problems relating to sound transmission in the sea with reference to naval operation problems.
- (iv) Currents and waves.
- (v) Estuarine studies.
- (vi) Seismic and topographic surveys of selected areas.

VI. *Oceanographic Laboratory, (University of Kerala), Ernakulam:*

Mainly devoted to Marine Biological studies. Teaching and some research problems in physical oceanography relating to waters near Cochin have been taken up recently.

VII. *Survey of India, Geodetic and Research Branch:*

Work on compilation and analysis of Tidal data and preparation of Tide Tables.

VIII. *Hydrographic Department, Indian Navy:*

Mainly engaged in surveys with the help of Survey Vessels with a view to preparation of Charts.

IX. *International Meteorological Centre (India Met. Deptt.), Bombay:*

Mainly researches into weather processes in the Indian Ocean region for understanding the origin and progress of the monsoons and tropical cyclones.

Some aspects of ocean-atmosphere interactions were also undertaken at the Centre.

Three Symposia were held in this period to bring together the scientists working at these various institutions to a common forum to discuss their various research problems and exchange notes:

- (i) Symposium on Meteorological Results of the International Indian Ocean Expedition—jointly sponsored by the Indian National Committee on Oceanic Research and the India Meteorological Department; co-sponsored by UNESCO and the World Meteorological organization—July 1965;
- (ii) Symposium on Coastal and Nearshore Oceanography—Organized by the Indian National Committee on Oceanic Research jointly with the National Institute of Oceanography in November 1966 at Cochin;
- (iii) Symposium on Indian Ocean—organized by the Indian National Committee on Oceanic Research, jointly with the National Institute of Sciences of India, in March 1967 at New Delhi.

In all these symposia a large number of papers on various aspects of physical oceanography and maritime meteorology were presented and discussed.

#### **4. DETAILS OF THE STUDIES CARRIED OUT AND THE RESULTS OBTAINED**

In the following paragraphs, the details of work and some results are presented. The first part deals mainly with the results of the work carried out during the IIOE, while the second part summarises the work and results from other institutions.

During the IIOE a good coverage of Arabian Sea and Bay of Bengal has been achieved not only by the occupation of a large number of stations, but also working these during both the monsoons as well as in the inter-monsoon periods. The northern Indian Ocean between equator and the southern tip of India was worked both during the northeast monsoon and the southwest monsoon. The main observations in Arabian Sea, Bay of Bengal and the northern Indian Ocean are recorded here.

##### **ARABIAN SEA:**

During the period September to December 1962 four cruises were made covering 12 Sections and occupying 101 stations. This period covers the transition between the two monsoons and also the early part of North east monsoon. From the vertical distribution of parameters in the upper 500 meters, the following features have been inferred.

In general the surface temperature increases towards east. In the mid Arabian Sea east of 65°E a homogeneous layer of relatively warm water (temperature 28°C) is present in the surface. It extends gradually towards west in the southern part of the Arabian Sea. The mixed layer is well developed in the eastern part, its thickness increasing towards east as well as south. Strong surface heating as well as wind mixing are the likely causative factors.

In general, the depth of occurrence of thermocline increases towards the east. North of 15°N between 59°E and 64°E, the thermocline starts

at depths less than 40 m. East of 64°E the depth of occurrence of thermocline increases from about 40 m. at 20°N to 75–100 m. at 12°N. Along the southern boundary of the Arabian Sea (i.e. 8°N), the thermocline is developed well with greater temperature gradients. Regions of upwelling are:—

- (a) Moderate upwelling is present in the top 50 m. at 24° 18'N; 64° 00'E.
- (b) Upwelling is present in the top 50 m. at 20° 00'N; 64° 00'E associated with the diverging surface currents in this region.
- (c) Strong upwelling is observed in the vicinity of the Minicoy Island and just south of it, in the upper 150 m. This upwelling is associated with the divergence between the northerly flow of monsoon current and the north equatorial current in the vicinity of Minicoy (L.V.G. Rao and R. Jayaraman, 1966).

#### *Water Movements:*

- (a) At the head of the Arabian Sea, the Persian Gulf waters flow east-wards upto about 63°E and sink there to sub-surface levels.
- (b) South-east of the Island of Socotra, a strong southward flow is present across 12°N in the top 300 m. with its eastern boundary situated between 57°E and 58°E.
- (c) At 20°N between 63° 55'E and 65°00'E moderately strong sub-surface flow exists at depths below 20 m.
- (d) Sub-surface water movements of moderate intensity are indicated at 15° 30'N between 63° 00'E and 66° 00'E.
- (e) Movement of sub-surface waters are seen at depths greater than 50 m. along 12° parallel between 59°E and 62° E.

Sub-surface movement of water associated with slow sinking to greater depths is observed along 8°N parallel between 61°E and 63°E.

Features (a), (d), (e) and (f) are possibly related to the southward subsurface movement of high salinity water from the northern part of the Arabian Sea.

Based on the data collected by INS KISTNA during the monsoon season of 1963 and 1964, the distribution of temperature and oxygen at selected levels have been investigated.

In the surface layers upto 20 m. depth, a tongue of warm water off the west coast of India shows a tendency to spread southwards from the Gulf of Cambay and this spreading occurs almost parallel to the coast. Temperatures less than 26°C were observed around the south-western coast south of 9°N.

At depths of 50 m. and more low temperature water off the south western coast has shown a movement northwards along the coast and further offshore.



A detailed study of T. S. Relationships in the Upper 500 meters of the Arabian Sea has shown the existence of several well-defined water masses. Red Sea, Arabian Sea, Persian Gulf and Gulf of Oman waters have been identified. Arabian Sea water whose source region is located around  $65^{\circ}\text{E}$  and  $21^{\circ}\text{N}$  occurs as salinity maximum associated with thermocline throughout the eastern Arabian Sea and spreads southwards upto  $8^{\circ}\text{N}$ . Arabian Sea monsoon water characterized by low salinity has been traced in the surface layers all along the Malabar Coast. Thompson's Intermediate water is identified around Minicoy Island.

Study of dynamic topographies in the upper 500 meters of the Eastern Arabian Sea shows the existence of some zonal currents. The south westerly drift present in the Eastern Arabian Sea during the southwest monsoon is considerably modified by the presence of Laccadives—Maldives group of islands, resulting in establishment of a circulation pattern round this island group.

Detailed studies have been made on oceanographical conditions of the Arabian Sea with special reference to the upwelling along the south-west coast of India in an attempt to explain the complex nature of the sardine—mackerel fisheries along that coast. The upwelling is shown to be present during the south-west monsoon period, when the shelf is pervaded by cold, dense and low oxygen waters. The processes are found to be very complex and somewhat different from those of the classical upwelling regions of the world, particularly in regard to the causative factors (Panikkar & Jayaraman 1966).

#### *Northern Equatorial Indian Ocean:*

The region of the north equatorial current in the Indian Ocean has been studied in great detail during the IIOE—by R/V VARUNA in September-October 1962, by INS KISTNA in January-February 1963 and August 1963. The distribution of the various parameters show the following interesting features.

The surface temperature increases towards the equator. Its value generally varies between  $28.0^{\circ}$  and  $29^{\circ}\text{C}$ , the extreme cases being  $27.3^{\circ}\text{C}$  at  $6^{\circ}\text{N}$  and  $29.7^{\circ}\text{C}$  at  $1^{\circ}30'\text{S}$ . Latitudes.

The mixed layer is well developed in the region east of  $68^{\circ}\text{E}$  meridian (with thickness of 75-100 m) compared to the region to the west of it. Along the equator, the thickness decreases from about 100 m. in the eastern part to less than 50 meters in the western part.

The depth of occurrence of thermocline decreases towards the equator in general, particularly in the western part of the region. In the eastern part, especially along  $83^{\circ}\text{E}$  meridian, the depth of thermocline shows a tendency to increase as we approach towards the equator. From a depth of 50 m. off Ceylon, the thermocline deepens to 100 m. near the equator.

Internal waves are observed south of  $6^{\circ}\text{N}$ . This feature associated with a well-defined thermocline with steep thermal gradient particularly in the eastern and middle portions is indicative of a stable stratification.

The surface salinity varies, in general, between 35.0 and 35.6‰. Subsurface salinity maximum is generally found in the entire region at the top of the thermocline.

Two water masses—the low salinity water of the Bay of Bengal (salinity less than 34.0‰ and  $\sigma\text{-t}$  22.0) and the high salinity water associated with the typical subsurface salinity maximum of the Equatorial Indian Ocean, are identified in the upper 150 meters. The Persian Gulf water (S: 35.2‰) is seen to be present at about 200 meters and the Red Sea water (35.3‰) at depths greater than 450 meters with limited extents.

The presence of Equatorial under current with an approximately East-North-easterly direction has been detected (during the northeast monsoon period of 1963) at 50 to 150 meters, with spreading of thermocline and a high salinity core between 61° and 63°E and within 2° south of the equator.

The distribution of various parameters including the inorganic phosphates, nitrates and silicates, show that the north equatorial Indian Ocean has properties somewhat different from the same regions of Atlantic and Pacific oceans. The equatorial divergences are somewhat weaker near and along the equator. Vertical distribution of nutrients show low concentrations at the surface layers upto 50 or even to 75 m. Sudden increase in the concentrations is seen below this level and values continue down to 200 m.

#### *Bay of Bengal:*

A study of the conditions in the southern and central Bay of Bengal during the transition between the summer and winter monsoons based on the data collected during the year 1963 shows the following features:-

The surface temperature varies, in general, between 27.0°C and 28.0°C except along the southern boundary of the Bay (8°N) where the temperature goes as high as 28.5°C.

The mixed layer is well developed and has a thickness of 75-100 m. in the western part of the Bay nearer the Indian east coast as compared with the waters east of 90°E. meridian. In the eastern Bay and the Andaman Sea, the range is 50–100 m. with a tendency more towards shallowing of the mixed layer.

The thermocline is well developed in the middle part of the Central and southern Bay. Maximum thermal gradients were of the order of 0.20°C/m.—0.25°C/m. The thermocline layer—i.e. the layer of steep gradient of temperature—was found to have a maximum thickness of about 80 meters.

The surface salinity has shown increases towards west and south. It generally varies between 32‰ and 34.5‰, except in the eastern part of the Central Bay and the Andaman Sea where its value lies between 30.0‰ and 32.5‰. The subsurface salinity maximum, which is usually present at the top of the thermocline, within the equatorial waters of the Indian Ocean is not, in general, found in the Bay of Bengal

Two water masses have been located in the upper 100 meters. The first mass is found in the upper 50 meters in the eastern Bay and the Andaman Sea with salinity less than 33.0‰ and sigma-t less than 21.0. This water appears to have been formed by the admixture of the run-off from the Burmese Coast with the waters of Pacific origin entering the south-eastern Bay through the straits of Malacca. The name, Eastern Dilute water of Indo-Pacific origin, has been tentatively given to this water mass. The second water mass has been identified in the upper 100 meters of the southern Bay and the western and middle parts of the central Bay with a salinity range between 33.0 and 34.0‰ and sigma-t 21.0–22.0. Throughout the region under study the Indian Ocean Equatorial water (or the Indian Equatorial water) with temperature ranging between 4°C and 16°C and salinity between 34.8 and 35.2‰ is encountered as the major subsurface water mass. Traces of high salinity water which can be related to Persian Gulf water are found with limited extent in a specific region in the central part of the Bay of Bengal below 300 meters.

A zone of divergence is found in the upper 150 meters lying between the southern boundary of the anticyclonic circulation of the Bay and the northern boundary of the north equatorial current. Another zone of sub-surface divergence is found with considerable spreading of thermocline between 75 and 100 meters in the eastern part of the southern Bay.

Convergence zones have been located with sinking of waters to considerable depths, in the middle part of the southern Bay and the central Bay.

#### *Upwelling along the East Coast of India:*

An examination of the physical characteristics of the shelf waters off Karaikal in the premonsoon period and off Madras and Waltair in the premonsoon and monsoon periods shows the presence of upwelling along the east coast of India but with the following differences:

1. Off Madras and Karaikal upwelling seems to be weak. Waters from shallow depths reach the surface nearshore and there is no marked lowering of the surface temperature near the coast.
2. Upwelling is prominent off Waltair during the premonsoon and monsoon periods. Waters from the deeper layers of the shelf appear to reach the surface causing considerable fall of surface temperature near the coast particularly during the latter period.

#### *Vertical distribution of oxygen in the Bay of Bengal and Andaman Sea during February–March, 1963:*

An analysis of the vertical distribution of oxygen in the upper 500 meters of the Bay of Bengal and the Andaman Sea during February–March 1963 has indicated that in general, the thickness of the upper oxygen rich layer is greater in the Andaman Sea than in the Bay of Bengal wherein it decreased towards north. The thickness of the oxygen poor layer in the Bay of Bengal appeared to be increasing towards north. The concentration in the oxygen poor layer was greater in the Andaman Sea than in the Bay of Bengal where it decreased towards north.

*Observations on internal waves in the Bay of Bengal:*

Vertical sections of temperature and sigma-t at different latitudes in the south-western Bay of Bengal during the south-west monsoon season reveal the probable existence of internal waves of long periods and wave lengths, in the thermocline region. The wave lengths vary from about 150km to 500km but the waves of any particular latitude have the same length roughly. The exact nature of these waves could not clearly be established but it is felt that they are probably standing oscillations. Internal waves of short periods were also observed. These waves were noticed in association with slicks in certain areas of the Bay. Studies show that these are of progressive type.

*On the level of least motion and the circulation in the upper layers of the Bay of Bengal:*

The circulation pattern in the upper 500 meters of the western Bay of Bengal between 9°N and 16°N during the south-west monsoon period, based on the geopotential anomalies computed from the hydrographic data were studied. The circulation is characterised by two anticyclonic cells centred at 11°N 83°E and 16°N 85°E and with a strong shear zone between at 11°N 83°E and 16°N-85°E decreasing with depth and becoming feeble below a depth of 400 metres. The level of least motion is situated around 500 meters depth.

*The nutrients of the North-western Bay of Bengal:*

The distribution of phosphates, silicates and nitrates in relation to some hydrographical features of the north-western Bay between latitudes 16° and 19°N during the month of January showed marked regional variations. The distribution is found to be related to the prevailing currents. The chief feature of the region investigated is the commencement of coastal upwelling. The ascent of the sub-surface waters is weak and extends only up to 20 m. below the surface. From the disposition of the isolines it appears that the vertical motions of the waters extend down to 500 m. Phosphate maximum is found between 600 to 800 m. and the nitrate maximum between 300 and 800 m. The silicates, on the other hand, continue to increase with depth. The factors influencing the distribution of nutrients over the entire regions have been studied.

*Specific alkalinity in the northern Indian Ocean during the south-west monsoon:*

Titration alkalinity was measured for a total number of 500 water samples from the northern Indian Ocean during the south-west monsoon cruises of INS KISTNA in 1963 and the specific alkalinity were calculated from the chlorinity values. Results are represented along two sections in the Indian Ocean, two in the Arabian Sea and three in the Andaman Sea.

Observations were restricted to a depth of 200 meters in the Indian Ocean and to about 500 meters in the Arabian and the Andaman Seas.

In the Indian Ocean the values decreased between 25 and 50 meters

where the optimal conditions for the lime secreting organisms seem to exist. The values then increase to about 100 meters and then show a slight decrease to 200 meters. The higher values appear to be in the core of the equatorial under-current, which has been found to exist in the Indian Ocean as well. In the Arabian Sea the values vary little with depth and slightly higher values are found below 150 meters. These higher values may be due to the high salinity intermediate water in the Arabian Sea whose origin has been traced to the Persian Gulf. The values in the Andaman Sea are comparatively lower at the surface than at the depths slightly below it (between 20 and 40 meters). This may either be due to the 'Island effect' or this area being in a zone where precipitation exceeds evaporation, and the observations were taken at the time of almost the highest precipitation. The surface values at the eastern section is in general higher than those at the western part which may be due to the effect of the discharge from the River Irawaddy and its tributaries. The values gradually decreased towards the depth which may also be due to the fact that this is an area of intense southwest monsoon upwelling.

#### *Distribution of total phosphorus in the Bay of Bengal:*

The values obtained in the inshore waters of the Bay of Bengal off the coast of Waltair for a period of two years (1961 to 1962) and also from the different regions of the Bay of Bengal obtained during March April, 1963 in the International Indian Ocean Expedition are presented.

Surface average values of total phosphorus exhibit a seasonal variation from high values of  $3.4/\mu\text{g}$  at /l (July 1961) and  $3.02/\mu\text{g}$  at /l (June 1962) to low values of  $0.99/\mu\text{g}$  at /l (April 1961), and  $1.66/\mu\text{g}$  at /l (April 1962) and low values occur also in the October-December period.

Average values in the surface water of the different regions of the Bay of Bengal reveal only a slight variation during March-April 1963 and show a tendency to increase in a south to north direction from the Nicobar Sea towards the head of the Bay. The vertical distribution reveals that the total phosphorus content is generally low in surface water and increases with depth upto 500 meters after which the values decrease. Total phosphorus varies almost by a factor of 3 in the vertical distribution.

#### *Current measurements at Angria bank in the Arabian Sea:*

Current measurements were carried out at two stations (1)  $16^{\circ}34'N$ ,  $72^{\circ}01'E$ ; (2)  $16^{\circ}25.6'N$ ,  $72^{\circ}06'E$ , in the Angria Bank in the Arabian Sea.

An analysis of the data indicated steady currents with an average velocity of 0.23 knots at station I and 0.29 knots at Station II. The current directions were west southwest at Station I and west at Station II.

#### *Current measurements off Mormugao:*

Preliminary study of the current pattern was undertaken off Mormugao during January 1967. Currents were measured at three stations ( $15^{\circ} 23'-30''N$ ,  $73^{\circ}47'-18''E$ ;  $15^{\circ} 24'-33''N$ ,  $73^{\circ} 46'-44''E$ ;  $15^{\circ} 24'-40''N$ ;

73° 44'25"E), at hourly intervals for 26 hours, using an Ekman Current Meter. Measurements were made at three depths at each of the stations. Simultaneously tidal elevation studies were also made at hourly intervals for the same period at all the three stations.

The tidal elevations ranged from 0.5 m to 2.0 m. and currents were comparatively weak not exceeding 0.80 knots. The observed currents were mostly towards northwest, with practically no southerly component. The steady currents were also directed towards northwest and ranged from 0.04 to 0.60 knots in speed.

#### *Observations on the Scattering Layers over the Continental shelf off Konkan Coast (India):*

The echograms obtained by R/V VARUNA using asdic during the September 1963 cruise are analysed. Scattering layers observed over the shelf area, off Ratnagiri, are examined and studied in relation to the thermocline layer present. Comparison of the reflections from the layers in the thermocline region with similar observation in the North Sea has indicated that the layers are not directly due to the physical discontinuity.

#### *Water movement and Tidal studies in Bombay Harbour Bay:*

Theoretical evaluations of tidal water movement and water renewal rates in the Bombay Harbour Bay were made by the Health Physics Division from sounding data and informations of tidal timings and elevations, to assess the diluent availability of the Bay for Trombay effluents.

The land-locked mass of water in the Bay is connected with the Arabian Sea in the south and Ulhas river through Thana creek in the North.

During premonsoon period there was practically no net flow of river water into the Bay. In Monsoon the average net inflow was about 0.5% of tidal streams near the Trombay shore. Even under extremely favourable conditions of maximum low tide flow in the monsoon, the net inflow was only about 6% of tidal streams and even this flow did not reach the discharge area in a single tide cycle. It was observed that the overall contributions due to Ulhas river to the ultimate dilution of discharged effluents and water renewal rates in the Bay were not very significant.

#### *Instrumentation for Coastal Oceanography:*

The instruments designed at the Indian Naval Physical Laboratory for oceanographic research are described. They are the shallow water wave recorder, thermistor thermometer, current meter and transparency meter.

The principle of capacitance variation between the sea level and a brass electrode is employed in the design of the shallow water wave recorder. Waves of any period can be recorded and is limited to about 12".

An F-type thermistor and Wheatstone bridge are employed in the Thermistor thermometer. The operable range of this instrument is 0°C to 30°C in three steps of 10°C each with an accuracy of 0.25°C.

The impeller type of current meter developed makes use of the photo-electric principle for indicating the speed and a freely suspended magnet and bridge circuit for indicating the direction of flow. The contact attached to the magnet closes the bridge circuit and the position of the shore potentiometer for null deflection in the meter gives the direction of the current.

Transparency meter has been developed using a light source whose intensity can be kept constant and the resulting photocurrent output from a photo cell placed at a distance of 50 cm gives a measure of the transparency of the water column.

#### *Wave Refraction and Beach Erosion Near Thottapally:*

Study of the refraction of the waves of different periods and deep water directions ranging from 200° to 320° was made as they enter the shallow waters near Thottapally area. The refraction and direction functions are obtained at various arbitrarily fixed locations along a stretch of 45 miles on the coast line between Thottapally and Manacad. From these parameters the possible regions of erosion and accretion are investigated and the direction of longshore currents evaluated.

#### *Studies on the currents and sediment transport near Cochin:*

The currents at the sea bed were measured by means of a "Pisa" current meter of Carruther's design, developed in this Laboratory. A self recording T.S.K. current meter was used to obtain the surface and sub-surface currents.

#### *Hydrography of Godavari Estuary:*

The results of the Hydrographic conditions of the Vasishta branch of the Godavari estuary upto distance of about 25 miles upstream from the confluence during four seasons have been studied. The salinities along the axis of the river during summer months indicate a decrease along the horizontal at all depths with the increase of distance from the confluence. Vertical sections at all stations show homogenous waters and slight variations at the extreme upstream regions which may be due to thorough mixing by the surface waves and tidal currents in the shallow waters. The salt water extends only through short distance of about 2 miles from the confluence at times of high tide during the flood season.

The diurnal variations of temperature at the surface follows the diurnal variations of air temperatures and in the sub-surface layers the range of variation decrease. The currents at the surface during summer show maximum upstream currents while the tide is passing from low to high and minimum while tide is passing from high to low. The current observations near the bottom observed by the drag do not indicate current magnitudes but the direction is opposite to the surface current. During flood season the river flow is modified by the tidal flow with low discharges at high tides and very high currents while the

tide reversed its direction. During summer, the circulation is cellular and forms homogeneous waters along the vertical.

#### *Studies on tides and their effect on Visakhapatnam Beach:*

Beach sections at Visakhapatnam opposite to Andhra University have been analysed for the year 1965. The annual variations of beach normal to the shore indicate that erosion takes place from March to September and deposition for the rest of the year. For the waves approaching the coast, this spot being neither strong zone of wave convergence nor wave divergence, the depletion and deposition of sediment from time to time is gradual. Steep waves from all directions erode the region and low waves build up the beach. The diurnal variations of beach relative to tide does not show any correlation, but typically the vertical extent of beach is more between low tide and high tide and less at half-way between high to low.

#### *Circulation in the Coastal Waters Off Waltair:*

The magnitude and direction of currents in the coastal waters off Waltair in the Lawson's Bay region have been evaluated from the observations of a float using a double theodolite. The circulation patterns of alternative months for the year 1964 have been explained on the basis of the existing wave characteristics from March to September; longshore currents are northerly and the magnitudes are relatively large during S.W. Monsoon. In the rest of the year, the currents are towards the coast in the same direction as wave normals with weak southerly longshore components.

Zones of rip currents have been also traced along the north of the Kailasahills. Weak offshore components of the currents from March to September may be due to the upwelling near the coast. Erosion and accumulation of sediment are associated with northerly longshore currents and southerly longshore currents respectively.

#### *On waves along Visakhapatnam coast:*

Data on waves during storms and normal weather conditions for the period 1963 to 1964 have been considered. The wave characteristics in different seasons depend upon the climatic and weather conditions. The waves are high and the sea is rough during southwest monsoon period and the sea is calm during N. E. monsoon. Exceptionally high waves have been reported during the cyclones in the Bay of Bengal.

#### *Solar Radiation, Light Penetration and Compensation Depth in Cochin Backwaters:*

On bright days the average solar radiation falling on the surface of Cochin backwater is approximately 500-700 kilolux hours each day. On cloudy days with intermittent sunshine the range is 300-500 kilolux hours and on very cloudy days with rain at times the range in the light intensity is 100-200 kilolux hours. Seasonal changes in the solar radiation showed that maximum light intensity reaches the water surface from December to March and minimum from June to September.

As light penetrates the water, it is partly absorbed by the water and suspended particles and partly it is scattered back. Measurement of the extinction coefficients with depths 25% of the surface light reaches



1 metre and at 4 metres it is reduced to about 1%. In the monsoon months, due to very high turbidity, the depth of penetration is reduced to 1% within 2 meters. Measurements of the scattering of light at different angles and at different depths showed the back-scattering from suspended matter is very high.

By Secchi disc measurements throughout the year, the average percentage transmission of surface light intensity, at Secchi disc depth was found to be 22.5%. The compensation depth (1% of the surface; light intensity) was maximum during January to March (5m) and minimum during the monsoon months, June to September (1.5m). The compensation depth varied from the Secchi disc readings by a factor 3-4.

## **5. INDIAN NATIONAL OCEANOGRAPHIC DATA CENTRE :**

During the period of IIOE the Indian Ocean Data Centre was started in Delhi under the Indian Programme of the IIOE. The objective of the centre was to receive, compile, process and store all the physical and chemical data collected by the Indian participating ships. With the completion of the expedition this has been organized as the National Oceanographic Data Centre to be the repository of all the oceanographic data relating to the Indian Ocean.

The Data Centre receives and stores physical and chemical data in the standard proformae devised by the World Oceanographic Data Centre. These data are now being quality checked and processed and these will be then exchanged with the World Data Centres and other National Oceanographic Data Centres. This Centre is also functioning as the national facility for the exchange and dissemination of all kinds oceanographic data with particular reference to the Indian Ocean region and the seas round India.

The data that have been received and stored in the Data Centre are:—

1. a) INS KISTNA data for the cruise 1-28, Station Numbers 1-764; these data have been preliminarily processed by the Directorate of Scientific Research (Navy) and the Indian Naval Physical Laboratory Cochin.  
b) Data from R. V. Varuna for the year 1962 and 1963 (Processed by the Central Marine fisheries Research Institute).
2. Reduced Oceanographic Data from R. V. Anton Bruun (USA) Cruises A & 1-8 (Stations Numbers 1-421)
3. Meteorological, Physico-chemical and Biological Data of R. V. Koyo Maru, (Japan).
4. Physical, Chemical and Biological Data from Australia—HMAS Diamantina and HMAS Gascoyne.
5. Also received from World Data Centre A: Indian Ocean Data collected by RRS Discovery (U.K.), R. V. Vityaz (USSR), Commandant Robert Giraud (France), R. V. Pioneer (USA), R. V. Argo (USA)

The Centre has also carried out quality check of the data of INS KISTNA Cruises IV to VII (station Nos. 102-195).

The following requests for data were attended to:—

<i>Details</i>	<i>By whom</i>
1. XVI Cruise	Indian Naval Physical Laboratory, Cochin.
2. Corrected depths, temperatures and salinity data of 1963 monsoon cruise of INS KISTNA for 30 stations.	Shri R. Sen Gupta from Sweden.
3. Silicate data from Anton Bruun cruises.	Tata Institute of Fundamental Research.

**6. PHYSICAL OCEANOGRAPHIC STUDIES AT THE CENTRAL MARINE FISHERIES RESEARCH INSTITUTE OF THE MINISTRY OF FOOD AND AGRICULTURE, GOVT. OF INDIA.**

R. V. 'Varuna' has been commissioned for oceanographic research work in Indian waters during December 1961. A maiden cruise was then conducted to Laccadives. During 1962-63, the region between Cape-Comorin and Ratnagiri was intensively covered. The area of coverage was extended to Veraval in some of the cruises. The shelf region of the east-coast between Visakhapatnam and Mandapam was also covered during 1963. The equatorial region bounded by 8°N-1°S, 71°E-80°E and the area between Ratnagiri and Cape Comorin bounded by 70° and 76°E were covered under the International Indian Ocean Expedition Programme during 1962-63. Apart from regular observations on temperature salinity, dissolved oxygen from the standard depths at the stations, pH observations were also made in four sections (off Quilon, Cochin, Calicut and Karwar) during 1962 by R. V. 'Varuna'.

Regular monthly cruises of R. V. 'Varuna' have been implemented from 1964 onwards. Under this programme, the shelf region between Cape-Comorin and Mangalore and the shelf and off shelf regions between Cape Comorin and Cochin were covered by establishing regular stations in two separate cruises that were repeated every month. The areas are bounded by the coastline and the 100 fathom line and 7°30'N 10°40'N latitudes and 77°30'-74°30'E longitudes respectively. Observations on temperature, salinity, dissolved oxygen at International standard depths were taken. Surface meteorological observations were also made from each station. Water samples from selected stations and depths were also taken for nutrient analysis.

In addition to these two areas of monthly investigations, R. V. Varuna has covered the shelf area from Bombay to Karwar in one cruise during 1964 and the same area was repeated again during 1966.

From 1965-66 the area of oceanographic investigation was extended to Karwar with modification in the cruise tracks so that the off shelf region was covered with a combined programme of fishing and Oceanography.

During 1966-67 the investigations were extended to the region of Laccadives. The regions (1) Cochin-Cape Comorin (2) Laccadive North (3) Laccadive South and (4) Cochin-Karwar are paired so that each pair would be covered during alternate months. Under this pro-

gramme there are two cruises in each month. Under the same programme which is presently carried out, the region bounded by 10°N–14°50'N latitudes and 71°E–75°E in the south and 73°E in the north encircling the major islands of Laccadives is covered once in two months.

From the inception of R. V. Varuna's programme 3063 oceanographic stations have been established in 107 cruises upto April 18th 1967.

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## APPENDIX I

### *The Indian National Committee on Oceanic Research:*

The Indian National Committee on Oceanic Research—INCOR, for short—was set up by the Government of India in July 1960 under the Chairmanship of Dr. D.N. Wadia, F.R.S., Geological Adviser to the Department of Atomic Energy, with the following terms of reference:

- (a) To draw up a coordinated plan for India's participation in the International Indian Ocean Expedition.
- (b) To advise on the allocation of the programme between departments of Government, research organizations and University Laboratories.
- (c) To consider and approve detailed plans for research in the several scientific disciplines related to India's participation and to recommend financial grants.
- (d) To further and coordinate the research programme.
- (e) To advise the Government generally on all matters connected with India's participation in the Expedition.

### *The original membership of the Committee consisted of:*

- |                            |                    |
|----------------------------|--------------------|
| 1. Dr. D.N. Wadia          | — Chairman         |
| 2. Dr. K. R. Ramanathan    | — Member           |
| 3. Shri C. Ramaswamy       | — Member           |
| 4. Dr. J. N. Nanda         | — Member           |
| 5. Dr. D. Lal              | — Member           |
| 6. Capt. I. K. Puri, I. N. | — Member           |
| 7. Dr. N. K. Panikkar      | — Member-Secretary |

(The present composition of the Committee is given in the end.)

One of the first and most important tasks of the INCOR was to draw up a detailed scientific programme for India's participation in the IIOE and for this purpose a number of working groups under the various disciplines, were constituted. With the assistance of these working groups the Scientific programme was drawn up.

The next step was coordination and execution of the Indian Programme. On the recommendation of the INCOR the Indian Ocean Expedition Directorate was set up by the Council of Scientific and Industrial Research (CSIR) with Dr. N. K. Panikkar as Director and a few senior oceanographers to assist him. The INCOR provided the necessary guidance and supervision to the IOE Directorate during the various phases of the expedition. The link between the Indian Programme and the programme of other participating countries and also with the Intergovernmental Oceanographic Commission of UNESCO, was provided by the INCOR.

Apart from the general scientific advice and direction, the INCOR has also played a very important role in bringing about closer collaboration and contacts with the participating oceanographic ships from several countries, arranged exchange of scientific ideas among oceanographers and marine scientists from India and abroad. For this purpose a number of Hospitality Committees were set up by INCOR at

ports like Bombay, Cochin, Madras, Visakhapatnam and Calcutta, to accord hospitality to the scientists on board the ships, arrange for symposia, seminars and group discussions and also visits to Universities and scientific institutions in those places. Several special facilities were also extended by the Govt. of India to these ships on the initiative of the INCOR. These facilities included:

- (1) Duty-free import of scientific equipment and material by these ships in connection with the expedition work.
- (2) Exemption from Port and canal fees and pilotage charges.
- (3) Exemption from payment of Central Excise duty on the fuel oil. Among the various ships that visited the Indian Ports during the IIOE, mention is made of the following:—

ARGO, HORIZON,	}	U.S.A.	RRS DISCOVERY	}	U.K.
PIONEER, ATLANTIS II,		HMS OWEN			
ANTON BRUUN and TE VEGA		VITYAZ			USSR.

The U.S. Research Vessel *ANTON BRUUN* which was mainly under the U.S. Biology Programme of participation in the IIOE operated with its base in Bombay. The setting up of the office of the U.S. Biology Programme and facilities for the scientists of this programme to work in Bombay and Mandapam were made possible through the efforts of the National Committee on Oceanic Research. The INCOR has also been responsible for the establishment of two important centres of activity in the country during the IIOE—the Indian Ocean Biological Centre at Ernakulam (Cochin) for the handling of International collections of zooplankton from the Indian Ocean and the International Meteorological Centre at Bombay for the Meteorological Programme of the IIOE.

The National Committee also arranged for the award of several fellowships by UNESCO and through bilateral exchange agreements for the junior scientific workers in oceanography to undergo shipboard training in some of the modern oceanographic ships of the participating countries and to have institutional training in different disciplines of oceanography in some of the well-known oceanographic institutions in the World.

Both for participating in the Indian Programme and also for furthering oceanographic research in the country, INCOR had arranged with the Government of India for the creation of research fellowships—8 senior and 8 junior. These research fellows actively participated in the different cruises of *INS KISTNA* and have gained considerable shipboard and field research experience. The INCOR has played a very important role in the establishment of the National Institute of Oceanography. The detailed plan for the Institute and the various research projects to be carried out at the National Institute of Oceanography have been drawn up by the INCOR which was designated as the Planning Committee for the NIO.

Although with the completion of the IIOE some of the activities of the INCOR such as those connected with the provision of special facilities to visiting oceanographic ships from other countries, have been reduced, with the starting of the Institute of Oceanography and deve-

lopment of oceanographic programme in the country both in this Institute and also in some of the other institutions the National Committee has become the principal body for the coordination of the various oceanographic activities in the country in a wider perspective.

*The present composition of the Committee:*

1. Dr. D. N. Wadia	—	Chairman
2. Dr. K. R. Ramanathan	—	Member
3. Shri C. Ramaswamy	—	”
4. Dr. D. Lal	—	”
5. Capt. D. C. Kapoor, I. N.,	—	”
6. Capt. N. S. Tyabji, I. N. (Retd.)	—	”
7. Shri S. K. Ranganathan	—	”
8. Dr. Atma Ram, (DGSIR)	—	”
9. Shri M. S. Sundara (FA to CSIR)	—	”
10. Capt. L. N. C. Jesudason, I. N.	—	”
11. Dr. N. K. Panikkar	—	Member-Secretary

*Physical and Chemical Oceanography working groups:*  
*Physical Oceanography*

1. Dr. K. R. Ramanathan	—	Convener
2. Shri C. Ramaswamy	—	Member
3. Dr. S. S. Srivastava	—	”
4. Shri R. Jayaraman	—	”
5. Dr. V. V. R. Varadachari	—	”
6. Dr. C. B. Murthy	—	”

*Chemical Oceanography*

1. Dr. D. Lal	—	Convener
2. Dr. A. K. Ganguly	—	Member
3. Dr. J. N. Nanda	—	”
4. Dr. S. S. Srivastava	—	”
5. Shri R. Jayaraman	—	”
6. Shri N. M. Shah	—	”