

Final version

Ocean Observing System:

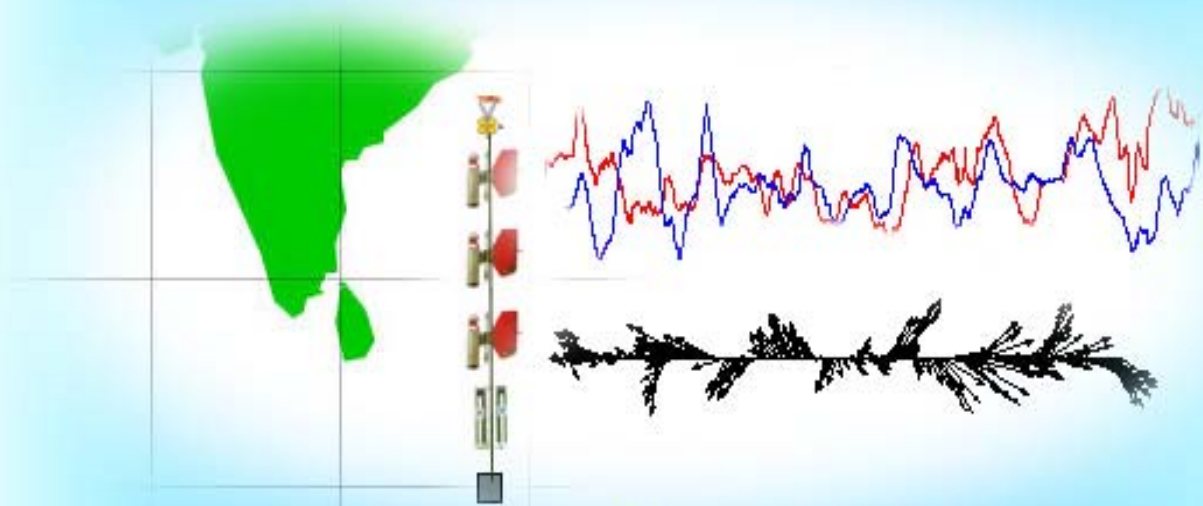
***Long-term Measurements of Currents in the Equatorial Indian Ocean
through deep-sea Moorings.***

A Project Proposal submitted to

Indian National Center for Ocean Information Services (INCOIS)

Ministry of Earth Sciences (MoES)

Government of India, New Delhi



by



*Physical Oceanography Division
National Institute of Oceanography
Dona Paula, Goa-403004*

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1. Title of Scheme (also give name of the Umbrella programme under which it is included)

Title: Long-term measurements of currents in the Equatorial Indian Ocean through deep-sea moorings.

Umbrella programme: Ocean Observing System (OOS), Indian National Center for Ocean Information System (INCOIS), Ministry of Earth Sciences, New Delhi

2.0 Description of the scheme and its objectives:

Background

The annual variation of currents in the equatorial Indian Ocean under the semi-annual reversal of monsoon forcing draws the attention of the Physical Oceanographers and the modelers alike. In the recent years, the Ministry of Earth Sciences (MoES) (formerly the Department of Ocean Development, New Delhi) launched the Ocean Observing System (OOS) program in 1997 and one component of the program is the sustained time-series current measurements along the equator. The initiation of the OOS program, has given an opportunity for the generation of long-term current data from the eastern equatorial Indian Ocean (EEIO) from 2000 to 2007. The project on “*Long-term measurements of currents in the equatorial Indian Ocean through current meter moorings along the equator*” has been executed successfully at the National Institute of Oceanography (NIO), Goa since February 2000. Under this project, an array of 3 deep-sea current meter moorings was deployed at 77°E, 83°E and 93°E sites along the equator. Current data were generated using Recording Current Meters (RCMs) placed at 6 depths (100 m to 4000 m) at each mooring site. Besides RCMs, Acoustic Doppler Current Profilers (ADCPs) were also used to obtain the currents data in the upper 100 m depth during the deployments in 2003 and 2004.

Besides India, the Japan Agency for Marine-Earth Sciences and Technology (JAMSTEC) and the Pacific Marine Environmental Laboratory/National Oceanic and Atmospheric Administration (PMEL/NOAA) also initiated time-series measurements in the upper ocean in the EEIO region. In fact, the PMEL/NOAA deployed their first moorings in the equatorial Indian Ocean in collaboration with NIO and the National Center for Antarctic and Ocean Research (NCAOR)/MEOS (McPhaden et al., 2006).

The current data generated so far since February 2000 under the OOS program yielded new findings and the modelling community used these data sets to validate the Ocean General Circulation Models (OGCMs). The current data analysis yielded the existence of high-frequency intraseasonal variability (at 10-20 day and 30-60 day periods) besides the dominant semi-annual variability in the zonal and meridional currents in the EEIO region (Murty et al., 2002). Sengupta et al. (2004) used this observational data and validated the regional OGCM simulated currents and this study documented the existence of biweekly (10-20 day) intraseasonal mode through observations and model simulations. This study was well appreciated by the international modelling community, and has been followed by a series of studies on the biweekly mode in the Indian Ocean (for example, Miyama et al., 2006). Murty et al. (2006) provided details of the OOS-program, data generated and preliminary

results on the variability of currents together with the semi-annual variation of zonal currents in the equatorial Indian Ocean. The OOS deep-sea current moorings generated ADCP currents were also compared with the simulations of the JAMSTEC's OGCM for the Earth Simulator (OFES). This study revealed the presence of intraseasonal bands within the equatorial jets and a large scale meandering of the spring equatorial jet. Another study using the OOS-current data at 2000 m and 4000 m depths and the OFES simulations confirmed the theoretical study on the existence of 'Equatorial beams' in the equatorial Indian Ocean (McCreary, 1984; Miyama et al., 2006). This study points out that the surface wind forcing in the western equatorial Indian Ocean is responsible to the intraseasonal variability of currents at 4000 m depth in the EEIO (Ogata et al., 2007). During October 2004 deployment period, the ADCPs placed at 120 m depth generated 21-month long upper ocean currents at the existing 3 mooring sites at 77°E, 83°E and 93°E. This is in addition to the RCMs placed at deeper depths. The data analysis reveals the upper ocean response to the Indian Ocean Dipole (IOD), which is recognized as the climatic event of the tropical Indian Ocean (Saji et al., 1999; Webster et al., 1999). This data provided a unique vertical structure of zonal and meridional currents along the equator, when the IOD was developing in the EEIO off Sumatra coast in 2006. Many studies are initiated using the observations and model simulations to understand the dynamics and biogeochemistry of the equatorial Indian Ocean (for example, Suryanarayana et al., 2007; Murty et al., 2007, Prasanna Kumar et al., 2005, 2007 and Sarma et al., 2007). Lakshmi et al. (2007) studied the semi-annual variability of zonal currents in the equatorial Indian Ocean, using the ADCP data. In this study, the observed zonal currents suggest the reflection of equatorially trapped Kelvin Waves at the Sumatra coast into the westward propagating Rossby waves along the equator from the Sumatra coast. These observed zonal currents are also compared with the OGCM simulations carried out for the Indo-Pacific region (Murtugudde et al., 2000), and results are being compiled into a scientific publication.

The data generated from the project have been made available to research community through the websites of NIO [http://www.nio.org/data_info/deep-sea_moorings/oos-deep-sea-currentmeter-moorings.htm] and INCOIS [<http://www.incois.gov.org>]

During the X Five year plan, time-series current data were generated along the equator. While comparing with the model simulations, it was noticed that the equatorial jets meander about the equator in the model simulations and the jets were shifted up to 2°N. Whether the meander and the shift of the jet are an artifact in the model simulation or a real variability in the jets is to be ascertained with more observations across the equator. It is not known whether the zonal wind stress variability across the equator, closer to the equator, is responsible for the shift in the jet away from the equator. The meridional vertical structure of zonal currents is another aspect to be studied. The information on the instability waves in the EEIO is also not known, though its presence is suggested in the EEIO region during the 1997-98 IOD/ENSO. The variability in the north-south extent and the transport associated with the equatorial jets in the central equatorial basin and the eastern basin are not known on intraseasonal to interannual time scales. In order to address these scientific investigations and the details of equatorial dynamics both from observations and model simulations and to refine the models, additional observations on time-series of currents are essential both across and along the equator in the EEIO.

Therefore, this project proposal envisages continuation of time-series current measurements for another 5 years in the equatorial Indian Ocean at the existing 3 mooring sites (77°E, 83°E and 93°E) along the equator and also at 4 proposed additional mooring sites across the equator (at 1.5°N, 77°E; 1.5°S, 77°E; 1.5°N, 93°E; 1.5°S, 93°E) during the XI Five Year Plan (2007-2012).

Objectives:

- To deploy and service the existing 3 deep-sea moorings at 93°E, 83°E, 77°E along the equator and 4 additional current meter moorings across the equator at 1.5°N, 77°E; 1.5°S, 77°E, 1.5°N, 93°E; 1.5°S, 93°E).
- To describe the intraseasonal, interannual and long-term variability of currents in the equatorial Indian Ocean.
- To decipher the ocean processes and dynamics those impact the surface and subsurface variability by employing various model simulations to understand climate variability of the region.
- To study the meridional vertical circulation in the equatorial Indian Ocean.
- To study the deep-sea circulation from observations and model simulations in the equatorial Indian Ocean.

This proposed project forms one of the major links to the Indian Ocean Global Ocean Observing System (IOGOOS) program as a contribution from India to probe the Indian Ocean. In the sidelines of the IOGOOS program, participation of scientists/technicians is envisaged from the developed or developing Indian Ocean rim countries in the proposed cruises as well as for joint data analysis.

By the nature of 1 year-long deployment of the moorings, the time-series currents are obtained only in non-real time. This observational plan was successful since February 2000 and long-term current data are generated from the equatorial Indian Ocean, without any loss of moorings. The international community has also appreciated this plan of subsurface moorings, as there was no vandalism problem, which was often encountered in the case of surface moorings of PMEL/NOAA in the equatorial Indian Ocean. The uninterrupted year-long time-series current data is an asset and useful to the modeling community, particularly the INDOMOD (Indian Ocean Modeling). The long-term current data at various mooring sites across and along the equator at different levels at each mooring site generated under this project will be very useful to the INDOMOD as well as other international Modeling community (those interested in the Indian Ocean) for validating the model results generated from the INDOMOD program. The long-term data will also help greatly in understanding the meridional vertical circulation in the Indian Ocean, besides understanding the equatorial dynamics. This data together with the Argo profiles data would be beneficial to develop and fine-tune the existing OGCMs and air-sea coupled models for the tropical Indian Ocean.

This proposed project involves cruises onboard a research vessel for the annual servicing of the deep-sea moorings at 7 sites in the equatorial Indian Ocean.

The total outlay of the project is about Rs. 1077.14 lakhs.

3. Description of the manner in which the scheme is proposed to be implemented and institutional arrangement:

The deep-sea moorings program has been established at NIO since February 2000 and the mooring engineers from the institute achieved considerable expertise. During X Five year plan, the moorings were successfully serviced without any loss of equipment. We propose to continue with the same I-type deep-sea moorings design, with a change in the instrumentation during 2007-12. At all the moorings, one uplooking ADCP (75/150 kHz) will be placed at 400 m depth. One downlooking ADCP (300 kHz) will be placed at around 400 m depth on the moorings along the equator. On each mooring, one high precision Temperature/depth probe will be placed on the ADCP buoy frame to obtain the depth data closer to the ADCP pressure sensor. The rotor type RCMs will be replaced with the Acoustic Doppler Current meters (Aanderaa Instruments, RCM9/11). Three RCMs will be placed at 500 m, 2000 m and 4000 m and one MicroCAT CTD at 500 m on the moorings along the equator and two RCMs will be placed at 500 m and 4000 m on the moorings across the equator. Two Acoustic Releases in parallel will be hooked close to the bottom current meter at each mooring site.

Figure 1 shows the mooring locations planned in the eastern equatorial Indian Ocean during 2007-2012. The existing mooring locations are along the equator and the 4 additional are shown across the equator at 77°E and 93°E.

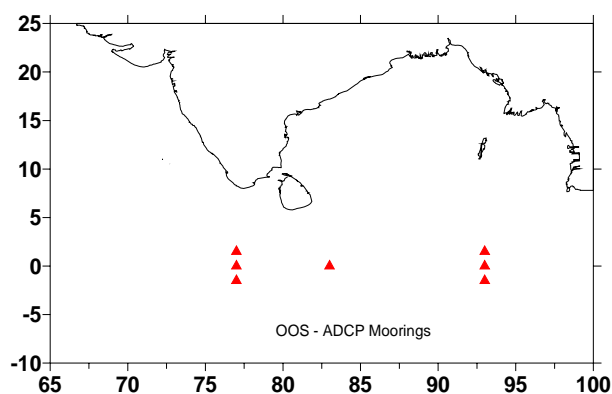


Fig. 1 Proposed ADCP moorings in the equatorial Indian Ocean during XI Five year plan period (2007-2012).

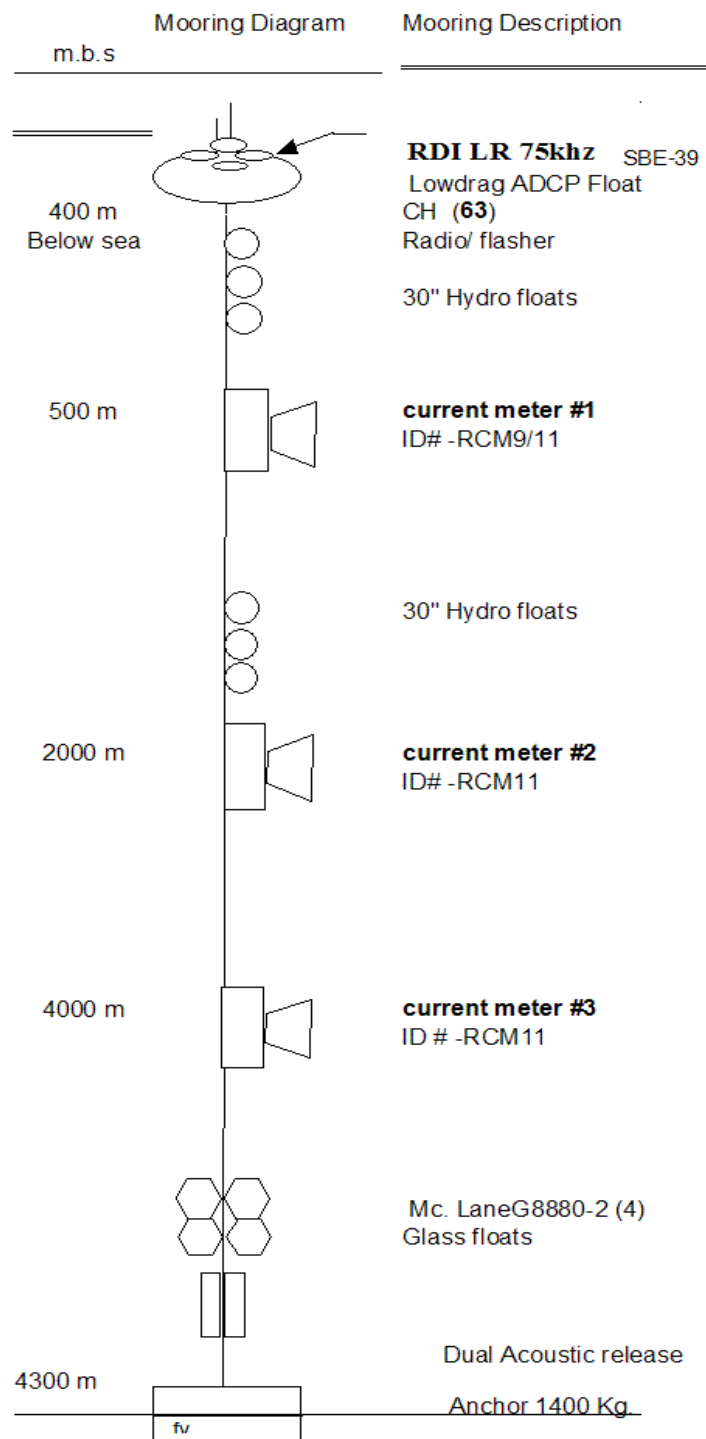


Fig. 2 A schematic of the design of the deep-sea mooring instrumented with the uplooking ADCP at 400 m and the RCMs deeper depths.

Table 1 describes the details of work plan shown for each quarter of the years.

Table 1. Proposed work plan in each quarter of the year. 1 – First quarter of the year (April, May, June); 2- Second quarter of the year (July, August, September); 3- Third quarter of the year (October, November, December); 4-Fourth quarter of the year (January, February, March). R & D – refers to the Recovery and re-deployment of the moorings.

	2007 – 08				2008 - 09				2004 - 10				2010 – 11				2011 - 12					
Activity	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4		
Procurement of equipment	←————→				←————→				←————→				←————→									
Cruises for the servicing of current meter moorings				↔				↔				↔				↔				↔		
				R & D				R & D				R & D				R & D				R		
Processing and analysis of time-series currents data		←————→																				

Institutional arrangement

At the institute level, the Principal Investigator will be responsible for the implementation of the project by meeting the objectives and the projected targets/ milestones. All equipment and accessories will be procured for the project by NIO. Data generated from the project and cruises will be processed and analyzed at NIO by the project members. The data generated under this project will be submitted to INCOIS. The team members of the project will be involved in the project activities including participation in the cruises, data analysis, and preparation of data reports and progress reports for submission to the INCOIS at regular intervals of time during the period of project. Following is the list of team members of the project.

<i>Principal Investigator:</i>	Dr. V.S.N. Murty, Scientist ‘F’
<i>Members:</i>	M.S.S. Sarma Sci. E-II
	A. Suryanarayana Sci. E-II
	Y.K. Somayajulu Sci. F
	R.J.K. Charyulu Sci. E-II
	G. Nampoothiri Sci. E-II
	Anselm M. Almeida TO-C
	Vijayan Fernando TO-C
	Sadashiv Khalap JTA
	Areef Sardar TO-B
	Desmond Gracias TO-C

While implementing this project, we need to organize a number of cruises for the annual servicing of current meter moorings (deploy/recovery/ redeployment) in the equatorial Indian Ocean. For organizing cruises and to fully implement the proposed scheme of work, the MoES/NCAOR will have to provide *ORV Sagar Kanya* ship-time for the mooring cruises, so that the moorings are serviced in time as per the mooring schedules.

Table 2 shows the plan of cruises for mooring operations (Recovery and Deployment) in the equatorial Indian Ocean during 2007-2012.

Table 2. Plan of cruises for moorings operations during 2007-12.

Year	Number of survey(s)	Survey area	Period	Operations
2008	1 (35 days)	Equatorial Indian Ocean – 7 mooring sites in the vicinity of 77°E, 83°E, 93°E	January/ February	Moorings (Rec. & Dep.)
2009	-- do --	-- do --	Feb. /March	-- do --
2010	-- do --	-- do --	March / April	-- do --
2011	- do--	-- do --	April / May	-- do --

4.0 Schedule of programmes, including physical targets and milestones, date of completion, Project monitoring and evaluation:

Physical Targets and milestones

Data Generation:

- Collection of long-term time-series currents data in the upper 400 m and at 3 deeper depths from 7 mooring sites in the vicinity of 77°E, 83°E and 93°E in the equatorial Indian Ocean.
- Collection of temperature and salinity profiles at the mooring locations before and after the deployment/recovery operations.

Data analyses / Deliverables

- Hourly/daily variation of measured currents data in the upper ocean as well as from deeper depths at the mooring sites in the equatorial Indian Ocean during the project period.
- Detailed description of the vertical structure of measured currents and their variability on intraseasonal, interannual and longer time scales in the equatorial Indian Ocean.
- Understanding the dynamics of the equatorial Indian Ocean from observations and various OGCM simulations.
- Understanding the variability of sea surface temperature (SST), sea surface salinity (SSS) and surface circulation in the equatorial Indian Ocean using the remote sensing satellites derived SST and sea surface height anomalies.
- Understanding the impact of near-surface temperature and salinity on the variability of atmospheric convection in the equatorial Indian Ocean.
- Understanding the nature of variability in the deep and bottom water circulation in the equatorial Indian Ocean.

- Data will be made available to the research community for validating the OGCMs and fine-tuning the models.
- The project personnel will present the results from the data analysis at various national and international conferences/workshops.
- Research publications in peer reviewed journals.

Date of completion of project: 5 years from the date of start of the project.

Project monitoring and evaluation:

NIO has an established mechanism of reviewing the projects towards the monitoring and evaluation of the project through both the internal and external committees with experts as its members. Further, we also participate and attend the project monitoring and review meetings as planned by the INCOIS in each year.

5.0 Financial implications of the proposal:

Nature of scheme:

The project envisages the long-term measurements of currents at 7 mooring sites [At 93°E: 1.5°N, 0°, 1.5°S; at 83°E: 0°; at 77°E: 1.5°N, 0°, 1.5°S] in the equatorial Indian Ocean through regular annual servicing. The NIO-designed deep-sea mooring will be continued in the XI Five Year Plan also. Unlike the previous years during X Five year plan, it is proposed to place all the 7 moorings (3 existing and 4 additional) in the first year itself and attend annual servicing during the project duration. This is to ensure that synchronous time-series data from all the 7 sites is obtained. The entire mooring is of subsurface nature. The moorings on the equator will be instrumented with 1 uplooking ADCP (placed at 400 m depth), 1 down-looking ADCP at 400 m depth, 1 MicroCAT CTD at 400 m depth and 3 RCMs at 500 m, 2000 m and 4000 m depths. On the off-equator moorings, 1 uplooking ADCP at around 400 m depth and 2 RCMs at 500 m and 4000 m depth will be used. High precision Temperature and Pressure (T/P) sensor will be placed at the ADCP on all the moorings. Glass floatation modules will be placed at appropriate depths for the required buoyancy. Radio beacon and Recovery strobes will be placed at the top of the mooring line. 2 Acoustic Releases connected in parallel will be hooked up to each mooring.

The NIO equipment on the existing moorings - 75 kHz ADCPs (3 No.), 300 kHz ADCPs (3 Nos.), and OOS-equipment –MicroCAT CTDs (2 Nos.) and RCMs (17 Nos.) and Acoustic Releases (6 Nos.) will be reused. The additional instruments required, will be procured during the XI Five Year plan.

The estimated cost of the project is Rs. 1077.14 Lakhs

Foreign exchange component:

The mooring equipment such as RCMs, ADCPs, MicroCAT CTDs, Glass floatation, Wire rope, Acoustic Releases and RCM accessories will have to be procured from outside India and the total foreign exchange component amounts to **Rs. 841.4 lakhs.**

Target expenditure (recurring and non-recurring), yearwise phasing, budget provision available, expenditure already incurred etc.

Table 3. Year-wise budget estimates (recurring and non-recurring).

Amount in Rs. Lakhs								
SL No	Description	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	Grand Total	
1.	Mooring Equipment for 7 moorings (3+4 new) ADCP 75 /150 kHz – 4, RCMs – 14; Acoust. Releases – 8 Deck Unit – 2 SBE 39 (T/P) – 7 MicroCAT CTD – 1 Wire spooling winch - 1	118.50 219.00 112.00 15.60 10.20 4.00 25.00	----- ----- ----- ----- ----- ----- -----	----- ----- ----- ----- 15.60 ----- -----	----- ----- ----- ----- ----- ----- -----	----- ----- ----- ----- ----- ----- -----	----- ----- ----- ----- ----- ----- -----	519.90
2.	Consumables for the moorings and cruises Low drag floats – 4 Hydro float (1000m) – 12 Hydro float (3000m) – 12 Glass floats – 16 Mooring wire – 4000 m Data Storage Units - 7 Chains and shackles Flasher - 7 ADCP battery packs -7 RCM battery Anchor weights RCM accessories (zinc anodes + O-rings)	37.80 21.20 22.50 16.00 90.00 ----- 9.50 7.00 4.50 4.50 7.00 5.00	----- ----- ----- ----- ----- ----- ----- 4.00 4.50 4.50 ----- -----	----- ----- ----- ----- 40.00 5.50 ----- ----- 4.00 4.50 8.00 4.00	----- ----- ----- ----- ----- ----- ----- 4.00 4.50 4.50 ----- -----	----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----	----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----	321.50
3.	Contingency	6.00	6.00	6.00	4.00	4.00	26.00	
4.	Travel [domestic + International]	5.50	5.50	5.50	5.50	5.50	27.50	
5.	Manpower Proj. Asst. (3 Nos.) Res. Fell. (2 No.)	6.48	6.48	7.68	7.68	7.68	36.00	
6.	Hard duty allowance to the participants (10 Nos.)	0.75	0.75	0.75	0.75	0.75	3.75	
7.	Computing facility	-----	-----	2.00	-----	-----	2.00	
8.	Overheads (15%)	112.20	4.76	16.20	4.64	2.69	140.49	
	Total	860.23	36.49	124.23	35.57	20.62	1077.14	

Grand Total: Rs. 1077.14 Lakhs

The total budget does not include the cost of the ship time for the proposed cruises.

Justification (Table 3):

Equipment and Consumables

- The proposed equipment is meant for the additional moorings across the equator. For the OOS moorings, we have been using the Aanderaa Instruments developed

rotor-type RCMs. Since they are out-off fabrication, we propose to procure the latest and sophisticated Acoustic Doppler Current meters and the Acoustic Doppler Current Profilers (ADCP). The latter have been in use on the OOS moorings since 2003 onwards. The Up-looking ADCPs will give information on currents in the upper ocean at each new mooring site. The existing NIO equipments (75 kHz and 300 kHz ADCPs) on the moorings will be reused. A self-recording MicroCAT provides higher accuracy time-series of temperature and salinity data. The wire spooling winch is required to spool the mooring wire rope while recovery and deployment operations and reduces the manual labor of handling the incoming and outgoing wire rope during the mooring operations.

- New spare sensors for temperature, conductivity and pressure for each RCM at each mooring site are essential for replacing the existing sensors for better accuracy in the respective data.
- The proposed consumables are essential for the deep-sea moorings.

Computing facility

- A Note book PC is essential to download and processing of the ADCP data and MicroCAT data using the specialized software and make presentations of the results at the meetings/conferences.

Hard duty allowance

- Hard duty allowance is proposed for the participants (engineers and scientists) in the cruise as they have to put up lot of hard work in extreme conditions onboard the ship (some times hostile weather) and very often onboard working hours stretch beyond 20 hours in a day. The longer-mooring cruises cover many land-holidays. Physical stress is another important aspect as they deal with sophisticated instruments and hard mooring material which need utmost care and caution during the mooring operations under the friendly/unfriendly environmental sea-conditions.

Hard duty allowance is estimated with an amount of Rs. 250/- per day per each participant for a total of 10 project personnel for the deep-sea mooring cruises of 30 days each.

Details of the budget for each item are given in Tables 4 to 6.

Table 4 Contingency (Amount in Rs. Lakhs)

SL No.		2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	Total
1.	Contingency	6.0	6.0	6.0	4.0	3.0	25.0
	Total	6.0	6.0	6.0	4.0	3.0	25.0

Justification (Table 4):

- Funding towards contingency is essential to meet the expenditure for organizing cruises for the deep-sea moorings, better computing facilities (PC upgradation, accessories and Annual Maintenance Contract).

Table 5. Travel (Amount in Rs. Lakhs)

SL No.		2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	Total
1.	Within India	3.0	3.0	3.0	3.0	3.0	15.0
2.	Outside India	2.5	2.5	2.5	2.5	2.5	12.5
	Total	5.5	5.5	5.5	5.5	5.5	27.5

Justification (Table 5):

- Funding towards travel is essential to meet the expenditure for the Project members for cruise participation and to attend the Project related meetings of the INCOIS/MoES. Funding for travel outside India is also essential for attending the International conferences/symposia for presenting the results of the data analysis for better interaction of scientists/engineers from international institutions.

Table 6 Manpower (Amount in Rs. Lakhs)

SL No.	Project Assistants / Engineers	Nos.	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	Total
1.	M.Sc. with Physical Oceanography /Physics/Maths @Rs. 10000/- p.m.	3	3.60	3.60	4.32	4.32	4.32	20.16
2.	Res. Fellow/ Res. Associate / Post-doc @Rs. 14000/- p.m.	2	2.88	2.88	3.36	3.36	3.36	15.84
	Total	5	6.48	6.48	7.68	7.68	7.68	36.00

Justification (Table 6)

- Apart from NIO's regular manpower devoted to this program, three Project Assistants will be recruited for assisting the engineers/scientists right from the procurement of equipment, cruise participation, data processing and analysis. From time to time, the DST/UGC/CSIR consider a hike in the monthly stipend of the Project Assistants. The same is envisaged from the 3rd year onwards and an amount of Rs. 2000/- hike is considered from the 3rd year onwards.
- Besides, it is proposed to recruit Research Scholars to analyze the data leading to publications in peer reviewed journals and Ph.D degrees. From time to time, the DST/UGC/CSIR consider a hike in the monthly stipend of the Research Scholars. The same is envisaged from the 3rd year onwards and an amount of Rs. 2000/- hike is considered from the 3rd year onwards.

The proposal is for a grant-in-aid project and the amount of funding envisaged is around Rs. 1077.14 lakhs.

Acknowledgements

We acknowledge the funding support received during the X Five Year plan (2002-07) from the Indian National Center for Ocean Information System (INCOIS), Ministry of Earth Sciences (MoES) [formerly the Department of Ocean Development], New Delhi, for the successful implementation of the project at NIO.

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