RV SINDHU SADHANA

(23 June – 24 July 2016)

BoBBLE Cruise

Chief Scientist: P. N. Vinayachandran

(vinay@caos.iisc.ernet.in)

Centre for Atmospheric and Oceanic Sciences

Indian Institute of Science

Bangalore 560 012

REPORT ON CRUISE 24 of RV Sindhu Sadhana

Contents

1.0 SUMMARY

SSD-024 is the cruise conducted as a part of the Bay of Bengal Boundary Layer Experiment (BoBBLE), a collaborative project between India and UK funded jointly Ministry of Earth Sciences (MoES), Govt, of India and Natural Environmental Research Council, UK. The major objective of this project is to understand the east-west contrast in the upper layer characteristics of the southern Bay of Bengal and its interaction with the summer monsoon. The major observational objectives of SSD-024 are to profile the hydrography along 8N in the international waters and to carry out a 10-day time series at 8N, 89E. 14 Scientists from India and 8 Scientists from UK made up the scientific contingent of SSD-024.

The vessel, RV *Sindhu Sadhana*, sailed from Chennai on 24 June 2016 and returned to Chennai on 23 July 2016. This period covers the first quarter of the summer monsoon. During this period the vessel sail upto 85.3E, 8N and then upto 89E along 8N. The western part of this track had sunny weather and east was interspersed with cloudy and sunny days. Winds (25-25kts) and currents (1-3kts) were strong during the cruise. The sea state ranged between 1-4 with moderate swells.

The data collected during SSD-024 can essentially be divided into two types: one during which observations were made at every one degree latitude along 8N and the other in which measurements were made at a fixed location (a time series giving temporal coverage), for a period of 10 days. The section was chosen to cover the east-west reach of the Bay of Bengal falling within the EEZ. The time series location (TSE; 89E, 8N) was chosen to fall within the rainy region of the Bay of Bengal with relatively warmer SST. Both oceanic and atmospheric parameters were measured during the cruise. Temperature, salinity, oxygen and currents were the primary targeted measurement parameters and chlorophyll, nutrients and underwater light were secondary targeted parameters. A CTD, 5 gliders, a Vertical Microstructure Profiler (VMP), an underway CTD, an IOP, a radiometer, 8 Argo floats and 8 drifting buoys were deployed during SSD-024. Upper air observations were made using radiosondes, automatic weather stations and fast response sensors for air-sea flux estimates.

The vessel reached the location AR (85.3E, 10N) on 27 June 2016. The FAAM aircraft flew over the vessel during the noon. Along 8N, gliders were deployed successfully at 86E, 87E, 88E and 89E. CTD and VMP profiles were measured at these location as well as samples for chemical and biological analysis were collected. 2 uCTD grids having a dimension of 6nm X 6nm were made during the cruise, one at Z2 and the other at TSE. The time series observations began at TSE (89E, 8N) on 04 July 2016 and continued till 14 July. At TSE, CTD profiles were measured at intervals of 2-3 hours. 5 VMP profiles, two IOP profiles and one radiometer profiles were measured daily during the time series. One uCTD section towards south of TSE and another to the west were mere made during the night. Each of this sections covered a distance of 6nm. Radiosonde balloons were launched twice daily during the entire cruise period. The AWS, ADCPs and thermosalinograph was set to record data throughout the cruise. Two ADCP squares were run on the continental shelf between 100 - 200m to correct its misalignment angle.

148 CTD profiles, 930 uCTD profiles and 915 glider profiles were measured during the cruise. SSD-024 also witnessed its first uCTD, VMP and gliders deployments and radiosonde balloon launch, .

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2.0 CRUISE TRACK

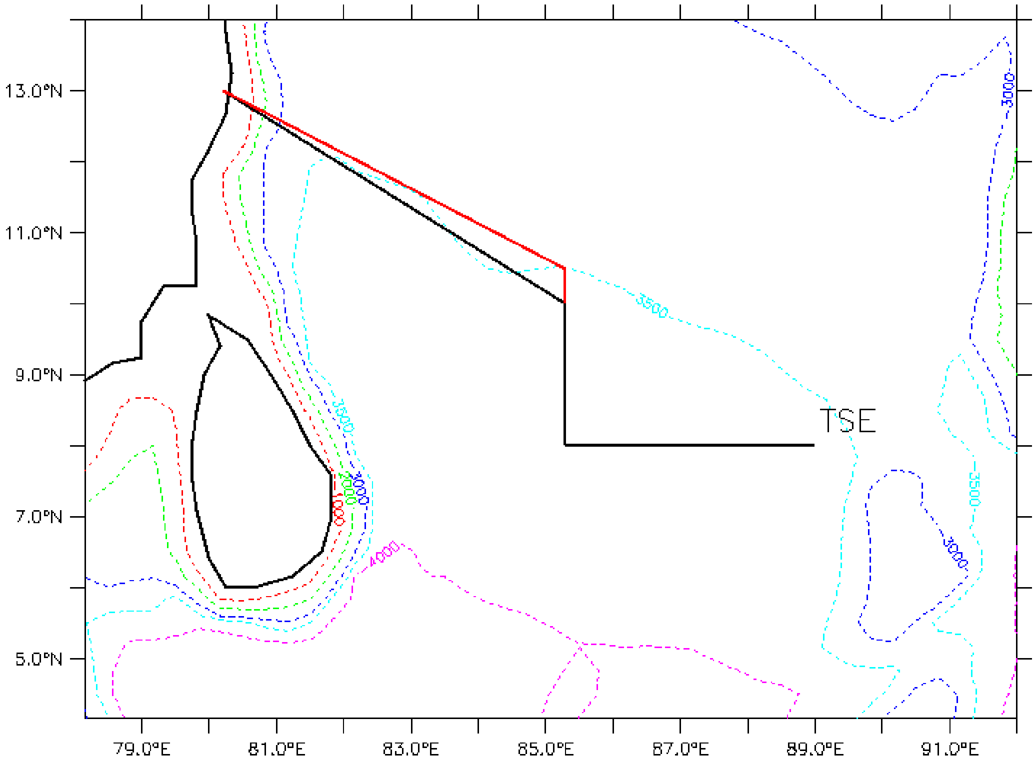


Figure 1. The cruise track of SSD-024. The cruise started at Chennai, India on 24 July 2016 and ended at Chennai on 23 July 2016. Stations were occupied along 8N latitude between 85.3 and 89 E, and along 85.3 from 8N to 10,5 N. Return track is shown in red and the time series location (8N, 89 E) is marked as TSE.

3.0 ITINERARY

Departure: Chennai India, 24 June 2016
Arrival: Chennai India, 23 July 2016

4.0 PARTICIPANTS

4.1 Scientific component

	Name	Institution
1	P. N. VINAYACHANDRAN Chief Scientist)	IISc, Bangalore
2	VIJITH V.NAIR	IISc, Bangalore
3	JENSON GEORGE	IISc, Bangalore
4	THUSHARA VENUGOPAL	IISc, Bangalore
5	ANOOP ASHOK NAYAK	IISc, Bangalore
6	SHRIKANT MUKUNDRAO PARGAONKAR	IISc, Bangalore
7	AMIT SARKAR	NCAOR, Goa
8	RAJDEEP ROY	NRSC, Hyderabad
9	DESMOND GASPAR GRACIAS	NIO, GOA
10	ASHOK KANKONKAR	NIO, GOA
11	SIDDHARTH VERNEKAR	NIO, GOA
12	ANTHONY COSMA D’SOUZA	NIO, GOA
13	VIJAYKUMAR	NIO, GOA
14	CHANDANLAL PARIDA	BHUBANESWAR UNI.
15	GOWTHAMAN VALLUVAN	NIOT, CHENNAI
16	DINESH KOTHANDARAMAN	INCOIS, HYDERABAD
17	ADRIAN JOHN MATHEWS	UEA, UK
18	ROBERT ALAN HALL	UEA, UK
19	BASTIEN YVES QUESTE	UEA, UK
20	RYAN GHILCRIST	UEA, UK
21	MARINA AZANEU	UEA, UK
22	MARCOS COBAS GARCIA	UEA, UK
23	ALEJANDRA SANCHEZ FRANKS	NOC, UK
24	DARIUZ BARANOWSKI	UEA, UK

4.2 Ship's complement

1.	DHIRENDRA KUMAR	MASTER
2.	AMARJEET SINGH	Ch. Off
3.	RAJESH JEYAKUMAR	2/OFF
4.	RAJKUMAR KUMARADOSS	3/OFF
5	MANAS RANJAN BEHURA	C/ENG
5.	RONALD MANUEL RAJ	2/ENG
6.	SATHAPPADI ARVINTH	3/ENG
7.	MARUDHUPANDIAN MUTHAIAH	EL.OFF
8.	DHILIPANBOSE ILANGOVAN	TR. ETO
9.	BIKRAMJIT NATH	TR.ELO
10.	DILIPKUMARCHAUHAN	DK/FTR
11.	JAIKESH KUMAR	AB(A)
12.	ISHWARBHAI TANDEL	AB(B)
13.	SOBHAN PATTANAIK	AB(C)
14.	GOKULNATH PUGAZHENTHI	O/S(A)
15.	GURU KANNAPIRAN	O/S(B)
16.	TRIPATHI CHANDRA	ENG/FTR
17.	SANTOSH	OLR(A)
18.	RAJEEV KUMAR	OLR(B)
19.	BIJENDRA KUMAR	OLR(C)
20.	DILSET ROSARIYO	CH.COOK
22.	MUTHU PALANI	CH.COOK
22.	SUDHIR KUMAR	GS
22.	SHIBIN CHALIL	GS
24.	ROBIN RENALD	GS
25.	RAJARAM NARESH	GS3
27	KARTHIKEYAN PICHAI	
28	MAHESHKUMAR MEENAKSHISUNDARAM	

5.0 INTRODUCTION

Under the border topic of “Drivers of east asian monsoon variability” Ministry of Earth Sciences, Gov. of India and Natural Environmental Research Council, UK approved three projects to study different aspects of the Indian summer monsoon. One among them is the Bay of Bengal Boundary Layer Experiment (BOBBLE) aimed understanding the air sea interaction over Bay of Bengal and its influence on monsoons. A major component of the BOBBLE project is to collect high quality atmospheric and oceanic data sets from across the southern the Bay of Bengal, during June - July 2016.

The BoB is characterised by large meridional and zonal gradients in both the properties of atmosphere and the ocean. A pronounced zone of low rainfall exists over the southwestern BB), in contrast to the southeastern and northern BoB, where precipitation increases to over 10 mm/day. The low rainfall region is located above relatively cool SST (< 28.6ºC) and saline (sea surface salinity, (SSS) > 34.0 psu) ocean. In contrast, warmer waters (SST > 29.0ºC) exist to the east and north where rainfall is higher. The role of the the east-west gradient in the ocean on defining the precipitation pattern and its variability is unknown. The goal of SSD-024 was to generate the much needed high quality data sets to address this issue.

Dr. M. Rajeevan, Secretary, MoES and Dr. S. S. C. Shenoi, Director, ESSO-INCOIS, visited RV Sindhu Sadhana on 24 July 2016. In a brief function held on board the secretary wished all the success to the cruise.

6.0 OBJECTIVES

The primary objective of the cruise is (a) to understand the relative roles of stratification, mixing, entrainment, vertical and horizontal advection, and surface fluxes in maintaining the SST, (b) map SST regeneration after the passage of a weather system and (c) to study the role of mixed layer processes and SST evolution on air-sea fluxes

Specific cruise objectives of SSD-024 are :

1. Measurements of CTD profiles, water samples, radiometer, IOP and microstructure profiles at every one degree longitude from 85.3E to 89E, along 8N upto a minimum depth of 100m.
2. Deployment of underwater gliders at 85.3E, 86E, 87E, 88E and 89E.
3. Continuous monitoring using ADCP, AWS and thermosalinograph during the cruise period.
4. Measurements of T and S along the track using a uCTD.
5. A 10 day time series of observations at 89E, 8N (TSE) of the items listed in (1).
6. Deployment of Argo floats and drifting buoys along the 8N latitude.
7. Upper air observations using radiosondes along the cruise track
8. Joint observation along with the FAAM aircraft at 85.3E, 8N(AR) on 27 June 2016.

7.0 WORK ACCOMPLISHED

The vessel sailed from Chennai on 24 June 2016. Along the continental shelf, between 150-25m, two ADCP squares were done, in order to correct its mis-alignment angle. These were done for a time period of 20minutes at a speed of 4kts. Then the vessel sailed towards the location AR (10N, 85.3E) where the FAMM aircraft flew sorties above the ship on 27 July. The vessel sailed towards south to TSW (85.3E, 8N) where the first glider was deployed. This glider, however, was retrieved the next day owing to a problem with its communication module. Then the vessel sailed along 8N, stopping at every one degree longitude till it reached TSE (89E, 8N). A glider was deployed at each of these stations. CTD, radiometer, VMP and IOP profiles were also measured and water samples collected for biological and chemical analysis. Two gliders were deployed at TSE and the time series observations began at TSE after the deployment of gliders in the evening of 4 July. The CTD observations during the time series were spaced between 2-3 hours. Five VMP profiles, one radiometer profile and two IOP profiles were also measured daily during the time series. During the night, one uCTD section was run for a distance of 6nm towards south and another towards west. Radiosonde balloons were launched twice daily during the entire cruise period.

ADCP was switched on throughout the cruise. The size of the sampling bin was set at 4m permitting sampling upto 400m and the shallowest possible sampling depth was set at 13m. The thermosalinograph, AWS and echo sounder was also switched on throughout the cruise.

Details of the measurements are given in the Apendices

8.0 PERFORMANCE OF THE SHIP AND EQUIPMENTS

Most of the sailing along the cruise track was done at a speed of 6 knots. The ship was able to maintain the steady course and speed as preferred by the uCTD system. The vessel was able to attain high speed of 10-11 knots on occasions. The DP was used for most of the CTD stations. The DP, however, did not stand when the wind speed was high (> 25knots).

An oil leakage from the tube prevented the CTD operation for one day. A pipe on the gamma frame burst once and it was replaced in 2 hours.

The auto-analyser on board is not functional.

Operations of VMP and uCTD required waiting at these instruments for long period of time. It would be useful to have some all-weather chairs to be taken to the deck.

The ambiance of Sindhu Sadhana is pleasant and performance of the air conditioners in the laboratories and the accommodation was satisfactory.

9.0 CONCLUSIONS

Most of the planned operations have been successfully carried out during the cruise SSD024. An unprecedented number of temperature and salinity profiles have been obtained during SSD024.148 CTD profiles were measured, The uCTD measured 930 profiles and the gliders measured 915 profiles. SSD-024 also witnessed several firsts in its history. The radiosonde balloons, uCTD, VMP and gliders were all deployed from Sindhu Sadhana, for the first time, during this cruise. Clearly this BOBBLE cruise on board RV Sindhu Sadhana has been a memorable one.

11.0 ACKNOWLEDGEMENTS

The chief scientist and participants of cruise SSD-024 express their deep sense of appreciation and gratitude to the Caption, officers, engineers and crew for their wholehearted supported to the scientific operations. We thank National Institute of Oceanography for sanctioning RV Sindhu Sadhana for the BOBBLE project. Dr. P. S. Rao, Mr. G. P. Naik and their team at ship cell, NIO, for their support and assistance in organizing and conducting this cruise. We thank Dr. Venkatesan, NIOT and their team for their help and support. We thank NCAOR and NRSC for their support to this program. The BOBBLE cruise is funded by MoES, Govt. India.

Appendix 1: CTD casts

The SBE 9/11+ CTD was used for profiling along the section as well as along the time series location. Time series stations were profiled upto 500m at 2-3 hourly interval. Daily one 1000m cast was also done. Deep casts upto 3500m were done at 5 stations. A total number of 148 CTD profiles were measured. The details of measurements are given in the table below.

Stn. No.	**Latitude**	**Longitude**	**Date**	**Time IN**	**Time OUT**	**Stn. Depth(m)**	**Cast Depth(m)**	**Bucket SST(0C)**
SSD024_AR	9 59.812'N	85 17.959'E	27-06-2016	0707hrs	1050hrs	3542	3500	29.6
SSD024_TSW_01	7 59.995'N	85 18.04'E	28-06-2016	1200hrs		3762	1000	29.4
SSD024_TSW_02	8N	85 18'E	28-06-2016	1605hrs	1653hrs	3758	1000	29.1
SSD024_TSW_03	7 52.88'N	85 18.144'E	29-06-2016	0830hrs		3767	1000	29
SSD024_z1_01	7 59.96'N	86 01.1'E	30-06-2016	0700hrs	0810hrs	3727	1000	28.5
SSD024_z1_02	8 0.941'N	86 01.368'E	30-06-2016	1110hrs		3727	1000	28.4
SSD024_z1_03	8 0.641'N	86 0.452'E	30-06-2016	1530hrs	1840hrs	3726	3600	28.6
SSD024_z2_01	8 0.829'N	87 0.427'E	01-07--2016	0548hrs		3673	1000	28.6
SSD024_z2_02	8 0.24'N	87 0.37'E	01-07--2016	1738hrs	1920hrs	3674	1000	28.4
SSD024_z3_01	8 0.46'N	88 0.11'E	02-07--2016	0640hrs	0805hrs	3654	1000	28.3
SSD024_z3_02	8 0.096'N	88 0.043'E	02-07--2016	0905hrs	0935hrs	3655	500	28.3
SSD024_z3_03	8 0.08'N	88 0.04'E	02-07--2016	1100hrs	1128hrs	3654	500	28.4
SSD024_z3_04	7 59.992'N	87 59.995'E	02-07--2016	1300hrs	1327hrs	3655	500	28.5
SSD024_z3_05	8 0.02'N	88 0.022'E	02-07--2016	1610hrs	hrs	3654	3500	28.5
SSD024_TSE_01	8 0.473'N	89 0.029'E	03-07—2016	0630hrs	0720hrs	3604	1000	28.2
SSD024_TSE_02	8 0.45'N	89 0.041'E	03-07—2016	0943hrs	-	3595	3500	28.5
TSE_D01_01	7 59.99'N	88 59.99'E	04-07-2016	0600hrs	0635hrs	3602	500	28.2 (at 0600)
TSE_D01_02	7 59.99'N	88 59.99'E	04-07-2016	0802hrs	0855hrs	3602	1000	28.5
TSE_D01_03	7 59.99'N	88 59.99'E	04-07-2016	1053hrs	1121hrs	3602	500	28.5
TSE_D01_04	8 N	89 E	04-07-2016	1255hrs	1328hrs	3593	500	28.9
TSE_D01_08	8 0.134'N	89 0.042'E	04-07-2016	2157hrs	2232hrs	3602	500	29.5
TSE_D01_09	8 0.96'N	89 0.00'E	05-07-2016	0000hrs	0026hrs	3602	500	29

TSE_D01_10	8 0.238'N	89 0.170'E	05-07-2016	0320hrs	0345hrs	3596	500	28.9	
TSE_D01_11	8 0.238'N	89 0.173'E	05-07-2016	0430hrs	0456hrs	3595	500	28.9	
TSE_D02_01	8 2.308'N	89 1.057'E	05-07-2016	0625hrs	0700hrs	3578	500	28.9 (at 0600)	
TSE_D02_02	8 0.06'N	89 0.001'E	05-07-2016	0843hrs	0933hrs	3603	1000	28.9	
TSE_D02_03	8 0.030'N	89 0.004'E	05-07-2016	1112hrs	1140hrs	3602	500	28.8	
TSE_D02_04	8 0.575'N	89 0.426'E	05-07-2016	1325hrs	1352hrs	3586	500	29	
TSE_D02_05	8 0.047'N	89 0.047'N	05-07-2016	1515hrs	1545hrs	3610	500	29.1	
TSE_D02_06	8 0.095'N	89 0.106'E	05-07-2016	1730hrs	1755hrs	3598	500	29.1	
TSE_D02_07	8 0.050'N	89 0.127'E	05-07-2016	1925hrs	1950hrs	3601	500	28.8	
TSE_D02_08	8 0.002'N	89 0.006'E	05-07-2016	2235hrs	2305hrs	3599	500	28.9	
TSE_D02_09	7 59.964'N	89 0.046'E	06-07-2016	0100hrs	0125hrs	3602	500	28.8	
TSE_D02_11	8 0.054'N	89 0.140'E	06-07-2016	0415hrs	0445hrs	3601	500	28.8	
TSE_D03_01	8 1.000'N	89 1.296'E	06-07-2016	0611hrs	0642hrs	3532	500	28.7	
TSE_D03_02	8 0.107'N	89 0.138'E	06-07-2016	0819hrs	0905hrs	3599	1000	28.5	
TSE_D03_03	8 0.024'N	89 0.052'E	06-07-2016	1100hrs	1127hrs	3603	500	28.7	
TSE_D03_04	8 0.043'N	89 0.016'E	06-07-2016	1320hrs	1342hrs	3603	500	28.8	
TSE_D03_05	8 0.077'N	88 59.998'E	06-07-2016	1500hrs	1525hrs	3602	500	28.9	
TSE_D03_06	8 0.188'N	89 0.082'E	06-07-2016	1655hrs	1720hrs	3600	500	28.9	
TSE_D03_07	8 000149'N	89 000557'E	06-07-2016	1915hrs	1945hrs	3602	500	28.6	
TSE_D03_08	8 0.068'N	89 0.061'E	06-07-2016	2225hrs	2300hrs	3602	500	28.6	
TSE_D03_09	7 59.904'N	89 0.152'E	07-07-2016	0100hrs	0130hrs	3601	500	28.6	
TSE_D03_11	8 0.072'N	88 59.980'E	07-07-2016	0405hrs	0435hrs	3603	500	28.6	
TSE_D04_01	8 1.231'N	89 1.337'E	07-07-2016	0607hrs	0637hrs	3526	500	28.2 (at 0600)	
TSE_D04_02	8 0.062'N	89 0.014'E	07-07-2016	0825hrs	0911hrs	3602	1000	28.6	
TSE_D04_03	7 59.996'N	89 0.174'E	07-07-2016	1115hrs	1145hrs	3600	500	28.6	
TSE_D04_04	8 0.029'N	89 0.890'E	07-07-2016	1300hrs	1325hrs	3586	500	28.6	
TSE_D04_05	7 59.988'N	89 0.205'E	07-07-2016	1535hrs	1558hrs	3599	500	28.6	
TSE_D04_06	7 59.988'N	89 0.206'E	07-07-2016	1705hrs	1730hrs	3599	500	28.6	
TSE_D04_07	7.999723 N	89.002281 E	07-07-2016	1905hrs	1935hrs	3601	500	28.6	

TSE_D04_08	8 0.000'N	89 0.088'E	07-07-2016	2215hrs	2245hrs	3597	500	28.8
TSE_D04_09	8 0.028'N	89 0.204'E	08-07-2016	0055hrs	0120hrs	3600	500	28.6
TSE_D04_11	7 59.963'N	88 59.999'E	08-07-2016	0400hrs	0425hrs	3600	500	28.6
TSE_D05_01	8 0.100'N	89 1.518'E	08-07-2016	0610hrs	0640hrs	3578	500	28.8
TSE_D05_06	8 0.149'N	89 0.216'E	08-07-2016	1735hrs	1800hrs	3597	500	28.7
TSE_D05_07	8 0.140'N	89 0.120'E	08-07-2016	1945hrs	2015hrs	3599	500	28.9
TSE_D05_08	7 59.977'N	89 0.143'E	08-07-2016	2250hrs	2320hrs	3601	500	28.9
TSE_D05_09	8 0.082'N	89 0.032'E	09-07-2016	0120hrs	0148hrs	3603	500	28.7
TSE_D05_11	7 59.838'N	89 0.233'E	09-07-2016	0415hrs	0445hrs	3600	500	28.7
TSE_D06_01	7 59.827'N	89 0.234'E	09-07-2016	0600hrs	0625hrs	3600	500	28.5
TSE_D06_02	7 59.972'N	89 0.006'E	09-07-2016	0805hrs	0853hrs	3599	1000	28.4
TSE_D06_03	8 0.028'N	89 0.047'E	09-07-2016	1122hrs	1150hrs	3600	500	28.5
TSE_D06_04	7 59.978'N	89 0.059'E	09-07-2016	1310hrs	1410hrs	3602	362	28.6
TSE_D06_05	7 59.971'N	89 0.966'E	09-07-2016	1605hrs	1655hrs	3593	500	28.8
TSE_D06_06	8 0.241'N	89 2.320'E	09-07-2016	1700hrs	1735hrs	3560	500	28.8
TSE_D06_07	7 59.848'N	89 0.460'E	09-07-2016	1948hrs	1954hrs	3594	500	28.9
TSE_D06_07	7 59.824'N	89 0.865'E	09-07-2016	2000hrs	2036hrs	3588	500	28.9
TSE_D06_08	7 59.916'N	89 0.365'E	09-07-2016	2340hrs	0010hrs	3601	500	28.9
TSE_D06_09	7 59.806'N	89 0.676'E	10-07-2016	0120hrs	0145hrs	3591	500	28.9
TSE_D06_11	7 59.857'N	89 0.332'E	10-07-2016	0435hrs	0500hrs	3601	500	28.8
TSE_D07_01	7.997821 N	89.055634 E	10-07-2016	0619hrs	0651hrs	3573	500	29.1
TSE_D07_02	7.999967 N	89.000748 E	10-07-2016	0900hrs	0934hrs	3600	750	28.7
TSE_D07_03	7 59.987'n	89 0.052'e	10-07-2016	1110hrs	1137hrs	3602	500	28.7
TSE_D07_04	7 59.934'N	89 0.023'E	10-07-2016	1305hrs	1340hrs	3600	500	29.1
TSE_D07_05	7 59.986'N	89 0.049'E	10-07-2016	1525hrs	1550hrs	3601	500	29.1
TSE_D07_06	7 59.998'N	89 0.244'E	10-07-2016	1705hrs	1735hrs	3598	500	29.1
TSE_D07_07	7 59.974'N	89 0.055'E	10-07-2016	1915hrs	1944hrs	3602	500	28.7
TSE_D07_08	8 0.013'N	89 0.145'E	10-07-2016	2215hrs	2242hrs	3600	500	28.7
TSE_D07_09	8 0.114'N	89 0,062'E	11-07-2016	0100hrs	0125hrs	3601	500	29

TSE_D07_11	8 0.053'N	89 59.945'E	11-07-2016	0400hrs	0430hrs	3603	500	29
TSE_D08_01	7 59.790'N	89 1.780'E	11-07-2016	0601hrs	0630hrs	3583	500	28.6
TSE_D08_02	7.999609 N	89.001350 E	11-07-2016	0800hrs	0846hrs	3601	1000	27.5
TSE_D08_03	8 0.020'N	89 0.104'E	11-07-2016	1124hrs	1150hrs	3602	500	28.7
TSE_D08_04	7 59.988'N	88 59.923'E	11-07-2016	1305hrs	1335hrs	3603	500	29.1
TSE_D08_05	8 0.025'N	89 0.004'E	11-07-2016	1510hrs	1538hrs	3611	500	29.1
TSE_D08_06	7 59.923'N	89 0.006'E	11-07-2016	1700hrs	1725hrs	3602	500	29.1
TSE_D08_07	8.000301 N	89.001251 E	11-07-2016	1900hrs	1924hrs	3610	500	28.7
TSE_D08_08	8 0.032'N	89 0.028'E	11-07-2016	2202hrs	2230hrs	3602	500	28.7
TSE_D08_09	8 0.038'N	89 0.031'E	12-07-2016	0055hrs	0120hrs	3600	500	29
TSE_D08_11	8 0.010'N	89 0.242'E	12-07-2016	0400hrs	0425hrs	3598	500	29
TSE_D09_01	8 0.668'N	89 1.259'E	12-07-2016	0558hrs	0650hrs	3551	500	28.8
TSE_D09_02	8 0.032'N	89 0.058'E`	12-07-2016	0828hrs	0912hrs	3602	1000	28.9
TSE_D09_03	8 0.016'N	89 0.050'E	12-07-2016	1120hrs	1145hrs	3602	500	29
TSE_D09_04	8 0.032'N	88 59.993'E	12-07-2016	1300hrs	1330hrs	3599	500	29.1
TSE_D09_05	8 0.020'N	89 0.053'E	12-07-2016	1500hrs	1525hrs	3602	500	29.2
TSE_D09_06	8 0.054'N	89 0.050'E	12-07-2016	1705hrs	1735hrs	3602	500	29.2
TSE_D09_07	8 0.018'N	89 0.028'E	12-07-2016	1905hrs	1932hrs	3602	500	28.7
TSE_D09_08	7 59.998'N	89 0.043'E	12-07-2016	2206hrs	2234hrs	3601	500	28.7
TSE_D09_09	8 0.017'N	89 0.029'E	13-07-2016	0100hrs	0130hrs	3602	500	28.9
TSE_D09_11	8 0.028'N	89 0.065'E	13-07-2016	0400hrs	0425hrs	3610	500	28.9
TSE_D10_01	8 0.462'N	89 1.636'E	13-07-2016	0600hrs	0629hrs	3459	500	28.9
TSE_D10_02	7 59.940'N	89 0.064'E	13-07-2016	0805hrs	0850hrs	3608	1000	28.8
TSE_D10_03	7 59.998'N	89 0.053'E	13-07-2016	1109hrs	1136hrs	3600	500	28.9
TSE_D10_04	7 59.988'N	89 0.020'E	13-07-2016	1255hrs	1330hrs	3610	500	29
TSE_D10_05	7 59.965'N	89 0.016'E	13-07-2016	1500hrs	1530hrs	3602	500	29.2
TSE_D10_06	7 59.930'N	89 0.094'E	13-07-2016	1700hrs	1725hrs	3609	500	29.2
TSE_D10_07	8.000463 N	89.001175 E	13-07-2016	1905hrs	1932hrs	3602	500	29.1
TSE_D10_08	8 0.024'N	89 0.004'E	13-07-2016	2210hrs	2242hrs	3608	500	29.1

TSE_D10_09	8 0.048'N	88 59.989'E	14-07-2016	0100hrs	0130hrs	3602	500	29.1
TSE_D10_11	7 59.947'N	89 0.325'E	14-07-2016	0400hrs	0425hrs	3596	500	29.1
TSE_D11_01	8 0.224'N	89 1.153'E	14-07-2016	0604hrs	0632hrs	3579	500	28.9
TSE_D11_02	7 59.980'N	89 0.043'E	14-07-2016	0805hrs	0851hrs	3602	1000	28.8
TSE_D11_03	8 0.058'N	89 0.000'E	14-07-2016	1055hrs	-	3602	500	28.9
TSE_D11_04	8 0.040'N	88 59.988'E	14-07-2016	1300hrs	1335hrs	3599	500	29.1
TSE_D11_05	7 54.062'N	88 54.248'E	14-07-2016	1500hrs	1555hrs	3578	1000	29.2
TSE_D11_11	8 0.041'N	89 0.064'E	15-07-2016	0400hrs	0430hrs	3602	500	29.1
TSE_D12_01	8 0.038'N	89 0.070'E	15-07-2016	0555hrs	0620hrs	3602	500	29.1
TSE_D12_02	8.000662 N	89.001091 E	15-07-2016	0803hrs	0828hrs	3602	500	28.9
TSE_D12_03	7 53.338'N	89 5.584'E	15-07-2016	0955hrs	1039hrs	3598	1000	29.1
TSE_D12_04	8 0.074'N	89 0.067'E	15-07-2016	1810hrs	1845hrs	3609	500	29.1
TSE-2-Z3-1	08 0.059'N	88 45.116'E	15-07-2016	2132hrs	2201hrs	3614	500	29.3
TSE-2-Z3-2	8 0.031'N	88 29.978'E	16-07-2016	0050hrs	0117hrs	3631	500	29
TSE-2-Z3-3	8 0.072'N	88 14.999'E	16-07-2016	0415hrs	0445hrs	3645	500	29.1
Z3R-01	7 59.986'N	88 0.007'E	16-07-2016	0800hrs	0900hrs	3656	1000	29.1
Z3R-02	7 59.946'N	88 0.125'E	16-07-2016	1230hrs	1300hrs	3655	500	29.1
Z3toZ2-01	7 59.999'N	87 45.191'E	16-07-2016	1610hrs	1640hrs	3645	500	29.1
Z3toZ2-02	8 0.000'N	87 30.150'E	16-07-2016	1953hrs	2016hrs	3666	500	28.9
Z3toZ2-03	8 0.050'N	87 15.365'E	16-07-2016	2304hrs	2330hrs	3676	500	29.1
Z2R-01	8 0.107'N	87 0.665'E	17-07-2016	0250hrs	0555hrs	3673	3600	29
Z2toZ1-01	8 0.103'N	86 45.010'E	19-07-2016	0933hrs	1005hrs	3686	500	29.5
Z2toZ1-02	8 0.056'N	86 30.185'E	19-07-2016	1445hrs	1520hrs	3712	500	29.4
Z2toZ1-03	8 0.074'N	86 15.132'E	19-07-2016	1907hrs	1938hrs	3732	500	29.4
Z2toZ1-04(Z1R)	8.000936 N	86.003922 E	19-07-2016	2330hrs	0000hrs	3724	500	29.2
Z1toTSW-01	8 0.065'N	85 45.299'E	20-07-2016	0405hrs	0432hrs	3735	500	29.4
Z1toTSW-02	8 0.02'N	85 30.094'E	20-07-2016	0842hrs	0914hrs	3757	500	29.4
TSWR-01	8 9.17199'N	85 22.45953'E	20-07-2016	1150hrs	1238hrs	3744	1000	29.5
TSWR-02	8 0.020'N	85 18.014'E	20-07-2016	1957hrs	2025hrs	3755	500	29.5

TSWtoAR-01	8 15.042'N	85 18.001'E	20-07-2016	2205hrs	2235hrs	3733	500	29.5
TSWtoAR-02	8 30.0092'N	85 18.00346'E	21-07-2016	0015hrs	0044hrs	3715	500	29.4
TSWtoAR-03	8 44.988'N	85 17.959'E	21-07-2016	0240hrs	0305hrs	3674	500	29.4
TSWtoAR-04	9 0.066'N	85 18.010'E	21-07-2016	0500hrs	0530hrs	3644	500	29.4
TSWtoAR-05	9 15.040'N	85 18.034'E	21-07-2016	0735hrs	0759hrs	3636	500	29.2
TSWtoAR-06	9 29.988'N	85 17.982'E	21-07-2016	0942hrs	1010hrs	3599	500	29.4
TSWtoAR-07	9 46.310'N	85 17.998'E	21-07-2016	1210hrs	1240hrs	3570	500	29.3
AR-R-01	10 0.103'N	85 17.902'E	21-07-2016	1430hrs	1500hrs	3540	500	29.3
TSWtoAR-09	10 14.978'N	85 18.023'E	21-07-2016	1700hrs	1725hrs	3511	500	29.2
TSWtoAR-10	10 29.936'N	85 18.07'E	21-07-2016	1935hrs	2010hrs	3480	500	29.1

Appendix 2: Glider measurements

Overview:

Seven Seagliders were deployed in the southern Bay of Bengal from ORV Sindhu Sadhana during the BoBBLE cruise. These autonomous underwater vehicles fly in a continuous repeating sawtooth pattern from the surface down to a maximum depth of 1000 m. They are all equipped with conductivity-temperature-depth (CTD) sensors. Additional sensors include dissolved oxygen, chlorophyll fluorescence and backscatter, photosynthetically active radiation (PAR), and microstructure sensors (see table for list of gliders and sensors). Four Seagliders (including two microstructure enabled gliders) are from the University of East Anglia (UEA), UK glider facility. The remaining three Seagliders are from the Marine Autonomous Robotics Systems (MARS) national UK facility. All seven Seagliders were deployed and piloted by UEA and associated personnel.

Over the course of the deployment and after initial trimming, the Seagliders were set to run 3 hour dive cycles to maximise temporal sampling. This short dive cycle limited the dive depth to 700 m. Hence, once a day each glider was sent on a longer dive to 1000 m, so that the full depth was sampled once daily.

The first glider was deployed on 28 June 2016, and the final glider was recovered on 20 July 2016, giving a total deployment time of 22 days. The gliders were deployed along the west-east section at 8°N, from TSW at 85°18'E to TSE at 89°E. Beginning from the western end of the section, one glider was deployed at each waypoint, spaced approximately 1 degree (60 nautical miles) apart. However, at the eastern end of the section (waypoint TSE), three gliders were deployed in a configuration designed to calculate horizontal advection explicitly, when combined with ship CTD and ADCP data.
Actual successful glider deployments

Table 1. Glider deployments. CT = conductivity and temperature sensor. dO2 = dissolved oxygen sensor. Wetlabs = electromagnetic radiation sensor (proxy for chlorophyll concentration and others). PAR = photosynthetically active radiation sensor

ID	Waypoint	Deployed	Recovered	# day	Specification
579	G2 (7°59’N 86°01’E, next to Z1), then G1 (7°59’N 85°19’E, next to TSW)	0410 UTC, 30 June	0820 UTC, 20 July	20	Standard fairing. CT. dO2. Wetlabs. PAR
534	G3 (7°59’N 87°01’E , next to Z2)	0400 UTC, 1 July	0330 UTC, 17 July	16	Standard fairing. CT. dO2. Wetlabs.
532	G4 (7°59’N 88°01’E , next toZ3)	0440 UTC, 2 July	0630 UTC, 16 July	14	Standard fairing. CT. dO2. Wetlabs.
620	G5NEW (7°54’N 88°54’E , upstream of TSE)	0245 UTC, 3 July	1200 UTC, 14 July	11	Standard fairing. CT. dO2. Wetlabs.
613	G6NEWSE (7°54’N 89°06’E , cross-stream of TSE)	1200 UTC, 4 July	1230 UTC, 15 July	11	Ogive fairing. CT. Microstructure shear and temperature.

Deployments

SG533

Seaglider SG533 was deployed at 0900 UTC (1430 local time, LT) on 28 June 2016 at waypoint TSW. The glider was deployed using the gamma frame (main CTD frame) midships on the starboard side. The wind was 12 kts from the SW, and the current was 1 kt from the SW. The sea state was 3 with a 3 m swell. The ship was controlled by its dynamic positioning system (DPS) and held station, with its port side to the wind. The standard operating procedure (SOP) was used for deployment. The Seaglider was suspended nose down from the gamma frame using a rope looped around the rudder, in the specially designed notches at the base of the rudder. The rope was stiffened by two lengths of polythene tubing that prevent it wrapping around and damaging the delicate antenna.

First, a buoyancy test was carried out to test the overall buoyancy of the glider in the ocean. This is necessary as the gliders are operating near the limit of their capacity in the strongly stratified tropical oceans. They need enough positive buoyancy at the surface to float (a minimum surface density of 1019 kg m-3 was budgeted for) and enough negative buoyancy at 1000 m (density of 1027.6 kg m-3) to generate thrust for flying. Theoretical calculations are first used to ballast the glider. This is then tested in a buoyancy tank in the UK. However, a final safety buoyancy test is needed in the ocean before deployment. During the final buoyancy test a cable tie secures the rope around the rudder so the glider cannot be accidentally release. The buoyancy test was carried out for SG533 by lowering it into the water and allowing the rope to be slack and the glider to float free. After approximately 3-4 minutes, the fairings fill with water and the glider was visually judged to be correctly ballasted.

The glider was then lifted out of the water and swung back to the ship, where the cable tie was cut. It was then lowered into the water for final deployment. The loop of rope eventually works its way free from the rudder and the glider was released. It drifted toward the bow on the starboard side. The ship was manoeuvred to port and the glider drifted free from the ship. Visual observations confirmed the glider was floating correctly, and the signal was sent for it to make its first dive. This was a short dive to 50 m which took 17 minutes. On surfacing, the glider had been instructed to go into “recovery mode” where it waits on the surface. It transmitted its data to the base station at UEA. Glider pilots on the ship were logged into the base station, to download the flight and science data to a local workstation on the ship for immediate analysis.

However, communications from the glider were very poor. On each communication attempt, the glider will first send its GPS coordinates, downloads the latest command files, and then uploads the flight and science data from the previous dive(s). The glider was able to send its GPS position but was not able to maintain a communication session for long enough to receive its command file or upload its data. During the initial first dive a $QUIT command was placed in the command file but the glider was not able to download this, hence it continued on another (two) short dives. It eventually picked up the $QUIT command at the end of dive 3. A decision was taken to recover the glider as soon as practicable at this point, because of its poor communications. However, it was now dusk and too dark to effect a safe recovery. The glider was sent on a 400 m dive and then a 1000 m dive overnight, with a $QUIT command entered during dive 5, such that the glider would go into recovery in the early morning of 29 June, for a retrieval. The glider was sent on dives overnight rather than allowed to remain on the surface, to minimise its surface drift and vulnerability on the surface. Also the Sri Lankan EEZ was close by and in the drift direction. Recovery from within the Sri Lankan EEZ would present additional bureaucratic difficulties.

Overnight, reliable GPS fixes were obtained on each surfacing, but by dawn, the only flight and science files were recovered were a single engineering file, for dive 3 (6 dives had been completed by this time). The emergency recovery was initiated soon after dawn on 29 June. Successive GPS positions and timings were used to calculate the gliders drift and predict its position over time. This was used to direct the ship to within 200 m of the glider, where it was spotted visually. The ship manoeuvred under DPS to place the glider on the starboard side, where it was lassoed using a recovery pole and brought back onto the ship. Communications for SG533 were tested over the next few days on the aft deck, but were always poor, and the decision was taken not to deploy SG533 again.

SG579

Seaglider SG579 was successfully deployed at 0410 UTC (0940 LT) on 30 June, at waypoint Z1. The deployment method was as for SG533. The recovered SG533 had a PAR sensor. Hence SG579 (the only other glider with a PAR sensor) was chosen for the second deployment, to give PAR measurements at the western end of the section. Glider communications were good. Dives 1 and 2 were to 50 m, dives 3 and 4 to 400 m, and dive 5 onward to 1000 m. The glider flight parameters were adjusted (trimmed) after each dive. After several successful dives, at 0500 on 2 July (dive 14), SG579 was redirected from waypoint G2 to G1 (at TSW) to occupy the vacant position at the western end of the section, left by SG533. Because of the strong north/northeastward currents, SG579 was not able to occupy G1 within its watch circle. Instead it was able to hold station at approximately 8°04’N and then later in the mission at 8°08’N.

SG534

Seaglider SG534 was deployed at 0400 UTC (0930 LT) on 1 July, at waypoint Z2. The deployment method was as for SG533, midships off the starboard side, with wind and current on the port side and the ship holding station with DPS. SG534 drifted to stern, and the ship moved away to port under DPS. As for SG579, SG534 communications were good, and the glider was soon moved to 1000 m dives after trimming. SG534 held station well during its entire deployment.

SG532

Seaglider SG532 was deployed at 0440 UTC (1010 LT) on 2 July, at waypoint Z3. The deployment was as for SG534, with the glider drifting to stern on the starboard sign and the ship moving away to port after release. SG532 held station well during its entire deployment.

SG620

Seaglider SG620 was deployed at 0245 UTC (0815 LT) on 3 July, at waypoint TSE. Because of strong currents and winds, the ship was bow into the wind (20 kts from SW), with a 1.6 kt current from the S. On release, the glider drifted to stern and the ship moved away forward and to port using DPS. SG620 held station well during its entire deployment.

SG619

Seaglider SG619 was deployed at 0815 UTC (1345 LT) on 3 July, also at waypoint TSE. Deployment conditions were very similar to those during the successful deployment of SG619 earlier the same day. The same deployment procedure was used. However, as the ship moved away to port immediately after release, the glider was swept under the ship by a wave. It emerged at the surface to stern and was severely damaged. An immediate emergency recovery procedure was put into practice, using visual, Argos goniometer, and acoustic transponder techniques. However, the glider was not able to be recovered and was declared lost. A detailed account of the SG619 deployment is given in the SG619 loss report.

SG613

Seaglider SG613 was deployed at 1200 UTC (1730 LT) on 4 July, at waypoint TSE. Sea state conditions (sea state 1-2) had dropped sufficiently to use the aft cranes for deployment. SG613 was deployed using the port aft crane, with the ship drifting port beam to the wind, with the current from the port stern quarter. After release, the wind pushed the ship to starboard faster than the glider, with the result that the glider drifted to port relative to the ship, and therefore immediately clear of the ship. SG613 was difficult to trim because of the heavy microstructure pods and sensor in the ogive fairing. It did not maintain station well during its deployment. During the mission, SG613 was redirected westwards with the intention of it quickly traversing to waypoint G5NEW (location of SG620) and then to a new waypoing G6NEWNW (in an equivalent cross stream relative position to TSE, but to the NW rather than SE). The purpose was two-fold: to test the sensitivity of the advection calculations to the spacing between SG620 and SG613, and to resolve the E-W and N-S difference in internal tides across the region. However, because of the poor trimming of SG613, it was not able to successfully make the transit, and was returned back to its original waypoint at G6NEWSE.

Recoveries

SG620

Seaglider SG620 was recovered at 1200 UTC (1730 LT) on 14 July 2016. Wind was 15 kts from the SW with a 0.2 kt current toward ESE. A 1000 m final dive was carried out simultaneously with a 1000 m ship CTD for calibration. A drift method was used for recovery. The glider was to be recovered on the starboard side. Under the assumption that both the glider and the ship are approximately equally affected by the current, but that only the ship is significantly affected by the wind, the ship was positioned upwind from the glider and port beam on to the wind using DP. The DP and all propellors and thrusters were then switched off and the ship was allowed to drift down on to the glider. The glider was lassoed successfully once at the side of the ship, then winched back on board using the starboard gamma frame.

SG613

Seaglider SG613 was recovered at 1230 UTC on 15 July. The same method was used as for SG620. Recovery began at 0615 UTC (1145 LT). However, on the first three attempts the glider was not lassoed successfully. On one occasion, the glider went under the stern and on another under the bow. All thrusters had been switched off well in advance, for this eventuality, and the glider eventually emerged complete on the port side. The recovery was then postponed due to worsening weather conditions from a atmospheric convective system, with winds at 38 kts and heavy rain. Once the weather system had passed after 1 hour, recovery was attempted again, and the glider was successfully recovered at 1230 UTC (1500 LT).

SG532

Seaglider SG532 was recovered on 16 July. Recovery began at 0330 UTC (0900 LT), but was postponed due to an atmospheric convective system. Successful recovery (using the same method as for SG620) was at 0630 UTC (1200 LT), at the first attempt.

SG534

Seaglider SG534 was successfully recovered on 17 July at 0330 UTC (0900 LT), on the first attempt.

SG579

Seaglider SG579 was successfully recovered on 20 July at 0820 UTC (1350 LT), on the first attempt. However, when the glider was being winched in, the winch cable snapped. The glider struck the ship with a glancing bow on the edge of the deck and dropped into the sea, snapping the antenna. The rope remained looped around the rudder and the glider was hauled in manually.

Glider training

A glider training programme was run for the benefit of scientists on board who were new to operating gliders. This consisted of:

- “Introduction to Seagliders” lecture, by Dr Rob Hall, with a question and answer session

- “Mission planning” lecture, by Dr Bastien Queste, with a question and answer session
- Glider piloting: a series of study groups on glider piloting, where small groups of 2-4 students were led by a trainer through an actual BoBBLE glider deployment (SG579), using the glider log of all piloting changes made, in conjunction with the glider dive plots that were available in real time to the real pilots. Each study group had 3 1-1.5 hour sessions, following SG579 from initial deployment through to dive 15, by which time the glider had been successfully trimmed. Groups were led by Prof. Adrian Matthews, Dr Alejandra Sanchez Franks, Dr Rob Hall, Dr Dariusz Baranowski, Ms Marina Azaneu.
- “Post processing” lecture on the matlab toolbox for processing raw glider data, led by Dr Bastien Queste, with a question and answer session, and 3 break-out groups to do practical work with the toolbox.

Appendix 3: uCTD measurements

This report includes a brief description of the Underway Conductivity Temperature Depth (uCTD) profiler operation during the first expedition of the BoBBLE cruise, on board 24th cruise of Sindhu Sadhana (SSD 24) during 24 June – 23 July 2016. The uCTD was manufactured by the Ocean Sciences-Teledyne. The temperature sensor and conductivity cell in the uCTD were manufactured by SeaBird Electronics (SBE).

The uCTD was used extensively during the cruise to measure vertical profiles of temperature and salinity, while the ship was in transit. The total number of profiles measured equals to 930. (Figure shows the locations observations). These measurements were made from the aft of the ship while the ship was transiting at a steady speed of 6 knots. Most of the time, the probe was operated in profiling mode. This method consisted of repeatedly sending down the probe for 2 minutes and retrieving it back near to the ship. The drop rate achieved in this technique is about 1.5 – 2.5 m/s. In this mode the probes went to about 225 – 250 m. Bringing the probe back to the ship took about 4 – 5 minutes. Rarely, we followed tail-spooling method for taking few deep cast, with about 400 m of wire spooled on to the uCTD tail. With this technique the uCTD probes went to about 700 m in 3 minutes. The drop rate of the probe with this technique was between 3 – 4 m/s. The battery lasted for more than 6 hours. Probe was retrieved back to the deck before the ship was going to stop or take turns. The retrieval operation was carried out at a ship speed of 2 – 3 knots. We used a bumper and pole to safely retrieve the probe. The probe was then replaced with another one during the next schedule. Three teams consisting of two persons each worked for schedules of typically 2 – 3 hours duration.

The data were processed using SBE data processing software. The processing consisted of the following steps suggested by the manufacturer: align parameters in time to ensure that all the parameters are measured from same water parcel; removal of wild spikes; and loop edit. Approximate vertical resolution of the processed data is about 25 cm.

The major measurements consist of the following. We measured a section from TSW to TSE, twice. Two grids at TSW and TSE of approximate size 6' x 6' were occupied with more than 50 profiles. A north-south section and an east-west section were occupied at TSE everyday for continuously 10 days. The data will now be used to investigate the advection of temperature and salinity, mesoscale and sub-mesoscale distribution of temperature and salinity, and structure of summer monsoon current.

All the participant are now well trained in the operation of the uCTD. Few lessons learned during the operation are summarised below. First, the health of the wire, winch and probes needs to be monitored regularly. Second, although the manufactures recommend that the probes can be used at ship speeds as high as 13 knots, it is wise to operate it at a maximum speed of 6 knots, as higher speeds tend to damage the conductivity cell. Also, at higher ship speeds conductivity data showed wiggles.

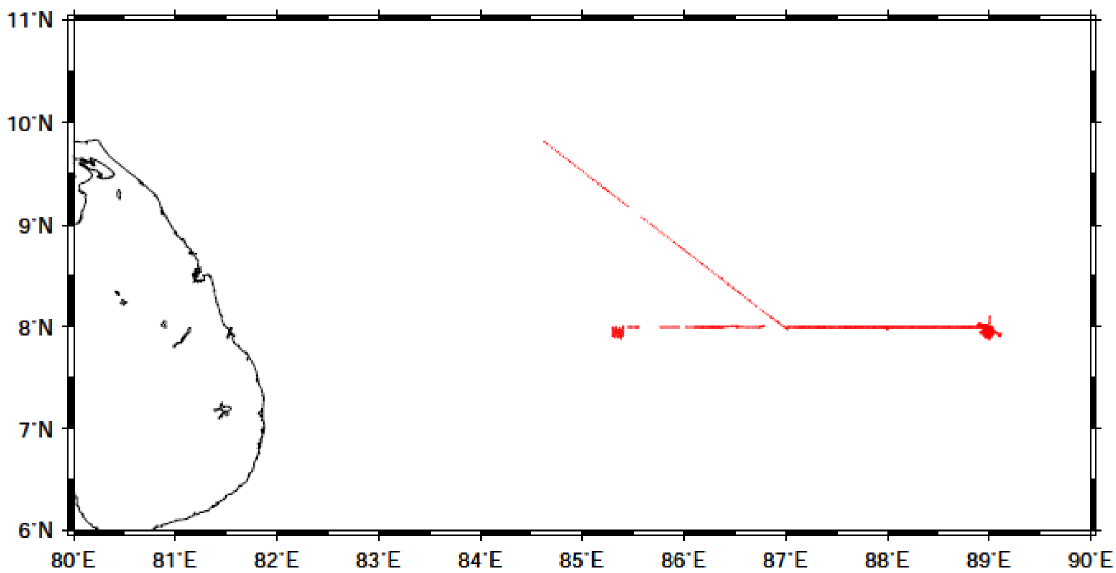


Figure. Locations sampled using uCTD.

Appendix 4: Turbulence profiler measurements

The microstructure profiler used in the first BOBBLE cruise onboard Sindhu Sadhana is VMP250 microstructure profiler Rockland Scientific (Canada). It is a loosely tethered system, comprising of two shear probes, one high resolution micro temperature (FP07) and a conductivity sensor and one set of standard CTD sensor. As the profiler sinks through the water column, cross force acting on the shear sensor tip will bend the ceramic beam of shear sensor and proportionate current will be generated (Figure 1). The generated current is a measure of the microstructure velocity shear. The turbulent kinetic energy dissipation rate (ε in isotropic turbulence, is given by $\varepsilon = 75 \nu \frac{\partial u'}{\partial z}$ Where, ν is the kinematic viscosity, as a function of temperature and salinity, $\frac{\partial u'}{\partial z}$ is the turbulence velocity shear (the over bar represents the ensemble average). The measured turbulent kinetic energy dissipation rate is further used to infer the vertical eddy diffusivity (K_ρ) following the equation $K_\rho = \Gamma \frac{\varepsilon}{N^2}$, where Γ is the mixing efficiency and N^2 is the Brunt Vaisala frequency. The details of the station location and number of profiles carried out are given in the Table1.

Figure. Vertical microstructure profiler retrieval during BOBBLE cruise.

The VMP was operated from the starboard side of the ship as the ship drifted towards the port side. The winch was kept close to the edge of the ship and wire was send manually by pulling keeping the gear of the winch in free mode. During the microstructure profiler operation, the vessel was on drifting mode and extreme care was taken to keep the slack in the microstructure profiler cable. 2-3 casts were made at each station. The winch was used to bring the VMP back after each cast. Finally, the instrument was recovered back to the deck using a specially designed davit. VMP was then washed using fresh water. Immediate quality check of the data was then carried out using the ODAS 4.0 Matlab library supplied by the manufacturer.

Table1. VMP operation details

Sl_No	Date (UTC)	Time_in (UTC)	Latitide (N)	Longitude (E)	No. of casts
1	29-06-2016	08:00	7.882	85.325	3
2	30-06-2016	07:48	8.023	86.028	3
3	01-07-2016	07:49	8.001	87.002	3
4	02-07-2016	08:30	8.000	88.000	3
5	04-07-2016	08:06	8.008	89.001	3
6	04-07-2016	12:13	8.032	89.007	3
7	04-07-2016	17:12	8.002	89.001	2
8	04-07-2016	23:30	8.004	89.003	3
9	05-07-2016	04:13	8.001	89.000	3
10	05-07-2016	08:30	8.010	89.007	2
11	05-07-2016	12:18	8.002	89.002	2
12	05-07-2016	17:47	8.000	89.000	2
13	05-07-2016	23:26	8.002	89.004	2
14	06-07-2016	03:54	8.002	89.002	2
15	06-07-2016	08:18	8.001	89.000	2
16	06-07-2016	23:58	8.003	89.001	2
17	06-07-2016	17:40	8.001	89.001	2
18	06-07-2016	23:26	8.001	89.000	2
19	07-07-2016	04:01	8.001	89.001	2
20	07-07-2016	08:11	8.000	89.015	2
21	07-07-2016	12:00	8.000	89.003	2
22	07-07-2016	17:22	8.000	89.001	2
23	07-07-2016	23:40	7.999	89.000	2
24	08-07-2016	03:52	7.999	89.001	2
25	08-07-2016	08:40	8.000	89.004	2
26	08-07-2016	12:53	8.002	89.004	2
27	08-07-2016	18:04	8.002	89.002	1
28	09-07-2016	03:57	8.001	89.010	3
29	09-07-2016	08:44	7.999	89.023	2
30	09-07-2016	12:53	8.009	89.050	2
31	09-07-2016	18:46	7.995	89.020	1
32	10-07-2016	23:50	8.001	89.017	2
33	10-07-2016	16:15	7.999	89.002	2
34	10-07-2016	08:07	7.999	89.000	2
35	10-07-2016	12:14	8.000	89.004	2
36	10-07-2016	17:20	8.000	89.002	2
37	11-07-2016	23:17	8.001	89.000	2
38	11-07-2016	03:51	8.001	89.007	2
39	11-07-2016	08:15	8.000	88.999	2
40	11-07-2016	12:03	7.999	89.001	2
41	11-07-2016	17:15	8.500	89.003	2
42	12-07-2016	23:16	8.001	89.005	2
43	12-07-2016	04:00	8.001	89.001	2
44	12-07-2016	08:05	8.001	89.000	2
45	12-07-2016	12:18	8.001	89.001	2

46	12-07-2016	17:11	8.000	89.001	2
47	13-07-2016	23:15	8.000	89.001	2
48	13-07-2016	03:49	8.000	89.002	2
49	13-07-2016	08:11	8.000	89.002	2
50	13-07-2016	12:01	7.999	89.002	2
51	13-07-2016	17:26	8.001	89.002	2
52	14-07-2016	12:22	8.000	89.008	2
53	14-07-2016	04:05	8.000	89.001	2
54	15-07-2016	05:21	7.904	89.102	2
55	15-07-2016	08:12	7.923	89.108	2
56	15-07-2016	11:10	7.994	89.009	2
57	16-07-2016	05:08	8.001	88.012	2
58	19-07-2016	04:41	8.013	86.794	2
59	19-07-2016	09:58	8.001	86.503	2
60	19-07-2016	14:22	8.001	86.011	2
61	19-07-2016	18:43	8.000	86.000	2
62	20-07-2016	23:15	8.002	85.759	2
63	20-07-2016	03:56	8.000	85.500	2
64	20-07-2016	11:00	8.001	85.300	2

Appendix 5: Atmospheric Observations (Radiosonde, AWS, Fluxes)

Measurement of surface meteorological variables, air-sea fluxes, and vertical profile of temperature, humidity, and wind speed and direction over the southern Bay of Bengal

Seas that surround subcontinent are sources of moisture and cloud systems for the Indian monsoon. The propagation of weather disturbances/cloud systems generated over the Bay of Bengal (BoB) influences the rainfall over India. Hence it is important to understand the conditions over the BoB during the monsoon season and the interactions between the atmosphere and the sea. There is an area in the Southern Bay of Bengal off Sri Lanka where it rains little during June to September months. During the BoBBLE cruise (SSD-024) the needed atmospheric observations were made to understand the dynamics of this so called rain shadow area, which extends into Tamil Nadu and southern Andhra Pradesh. The observational components include Autonomous Weather Station (AWS), air-sea flux observing system, and radio sonde. These are described briefly below.

Autonomous Weather Station (AWS)

An Autonomous Weather Station (NIO-AWS) for measuring meteorological weather parameters and Sea Surface Temperature (SST) was fitted on board the CSIR-NIO’s research vessel RV Sindhu Sadhana, The NIO-AWS is a state-of-the-art fully in-house designed, and developed system (however sensors imported) has ability to relay the weather information on ship board local area network (LAN), whichcan be viewed from various nodes over the ship LAN configuration. It makes use of a personal computer (Met-PC) for data acquisition, on-line display, and data storage. The data collected by the AWS are true wind speed & direction, atmospheric pressure, air temperature, relative humidity, sea surface temperature (SST), GPS speed, GPS course, water depth and ship heading along with latitude and longitude of the ship’s position. Each data string is stamped with date and time (in UTC). The wind gust (i.e., the high wind speed amongst an ensemble of 6 samples that are measured during the 1-minute sampling span) is also recorded. All data are stored in the internal hard disk of the Met-PC. The AWS is powered from a 12-Volt rechargeable battery kept in the physics lab. To account for ship's motion, ship GPS and Log/Gyro (both from ATLAS Hydrographic GmbH, Bremen, Germany) are used. The GPS is mounted on top of the bridge from where data is fetched through a shipboard cable. An independent SST sensor (Make: Sea Bird Electronics, USA) is installed in the engine room, very close to the sea-chest valve. A manufacturer-supplied cable is used for reading the SST strings. The distance between engine room and Met-PC is < 60-m. The distance between intake sea water (sea-chest) valve and SST sensor is less than a meter so as to avoid contamination arises due to ambient temperature or heat loss through a pipe. The NIO-AWS sensors are sampled at 10-sec intervals. Temperature, humidity and pressure are measured instantaneously at start of every 10-sec. The sampled values of wind are vector averaged over 1-minute and are stored in the Met-PC with corresponding date & time stamps along with ship’s geographical position. SST is configured to provide data every 1-sec however; data is read instantaneously every 1-min along with AWS data strings.

Table 1: Specifications of NIO-AWS

Parameter	Range	Mean accuracy	Resolution
Wind speed (RM Young**)**	0.7-50 ms^{-1}	0.2 ms^{-1} or 2%	0.1 ms^{-1}
Wind direction (RM Young)	0-360^0	3°	1°
Air Temperature (YSI)	0 to +45°C	0.2°C	0.05°C
Relative Humidity **(**Rotronic)	0-100 %	2%	0.5 %
Atmospheric Pressure (Honeywell)	850-1050 hPa	0.1 hPa	0.01 hPa
Optical rain gauge (Optical Scientific)	0-50 mm hr^{-1}	0.4 mm hr^{-1}	0.25 mm
Radiation (SW in) (Licor)	0-300 $mWcm^{-2}$	5 %	---
Sea surface Temperature (Sea Bird)	0 to +35 °C	0.1°C	0.05°C

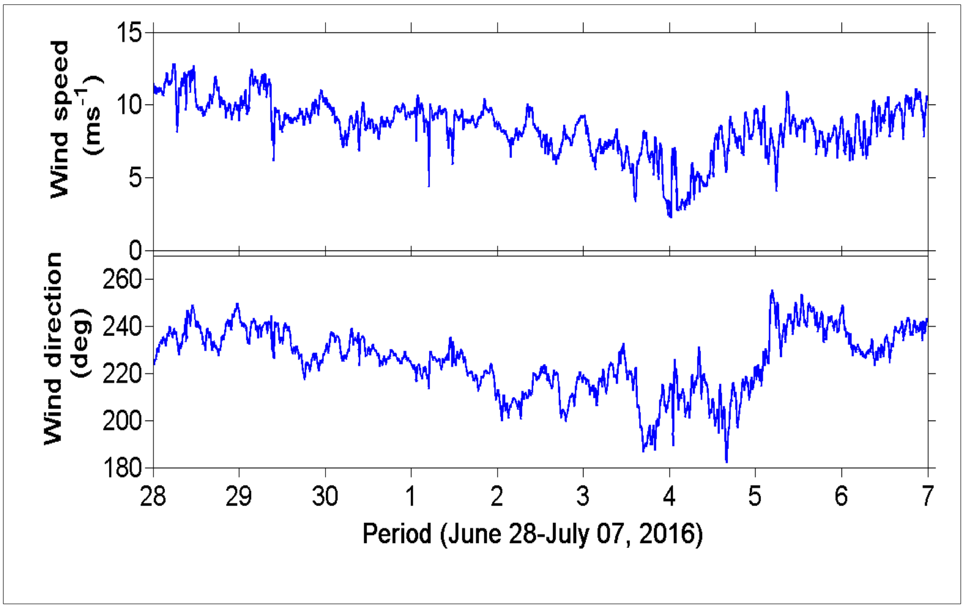


Fig.1 Variation of typical wind speed and wind direction during the BoBBLE cruise

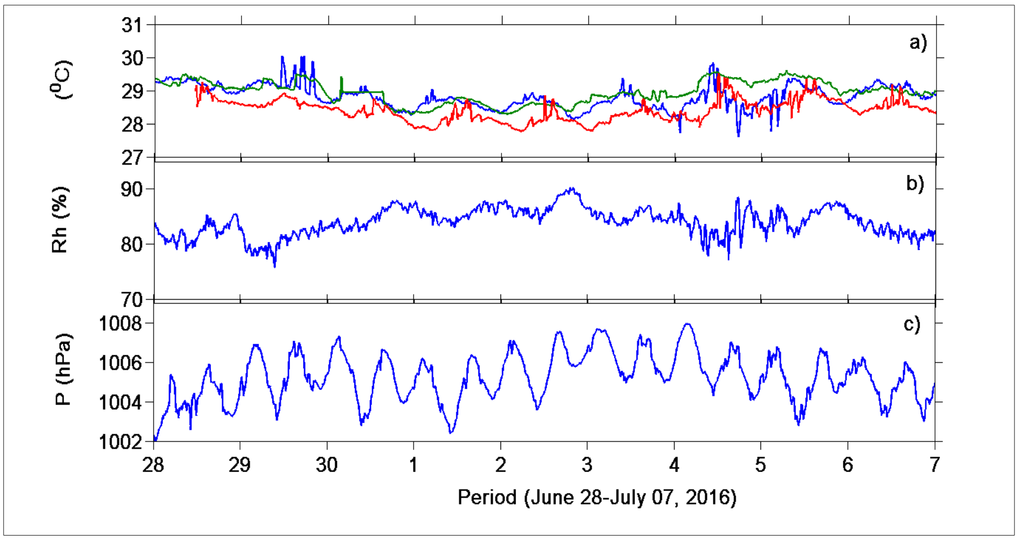


Fig.2 Variation of air temperature, SST relative humidity, and air pressure during the BoBBLE cruise. a) temperature (blue line air, green line bulk SST, and red line skin) ; b) relative humidity ; c) surface atmospheric pressure

Air-sea flux observing system

The fluxes of latent and sensible heats and momentum at the air-sea interface cannot be directly measured and are computed from wind velocity, water vapour concentration, and air temperature data. In the Reynolds average equations, these fluxes are related to the covariance terms, and the method is called ECM (eddy covariance method). For computing these terms, the variables are to be measured with sufficient temporal resolution (at least at 10 Hz), and hence these are called fast response sensors or fast sensors. The CSIR-NIO flux system consists of five components. (1) A fast response sonic anemometer, (2) A fast response ship motion sensor, (3) A fast response Licore Infrared Gas Analyzer (IRGA) Hygrometer. These sensors are mounted on the flux tower at the bow, approximately at 15m above the sea surface, (4) A four component (Kipp & Zonen) net radiometer (an upward facing short wave for incoming (↓) and downward facing short wave for outgoing (↑) and pyrgeometers upward facing for incoming (↓) long wave and downward facing (↓) for outgoing long wave) mounted on the horizontal boom at the bow in the close vicinity of flux tower, (5) A narrow-band IR thermal radiometers, is used to measure the interfacial sea surface temperature. These systems are logged in the data logger and archived for later processing. They are running continuously throughout the cruise. The best situation for obtaining flux data is with the ship going slow ahead (<2 knot) and the wind within 45 degrees of the bow.

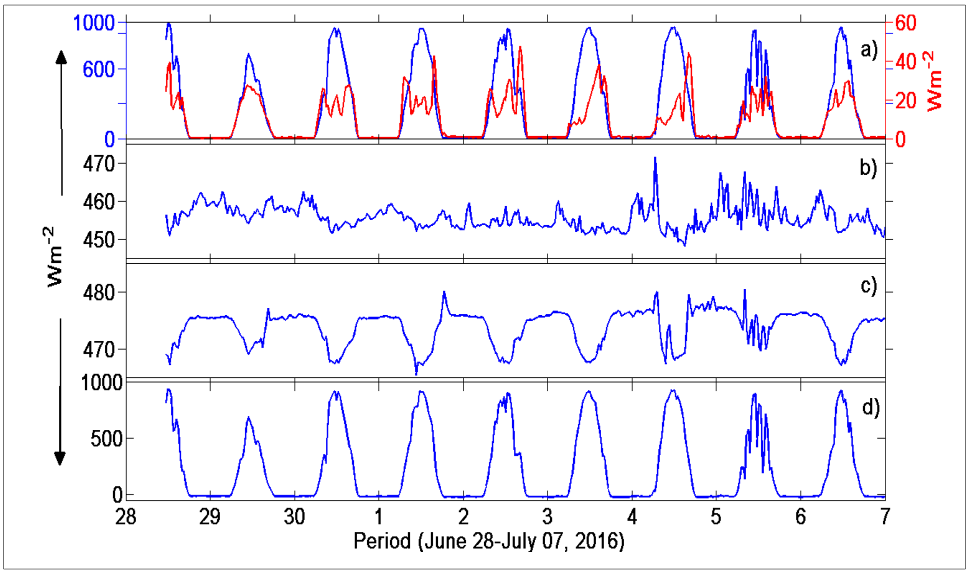
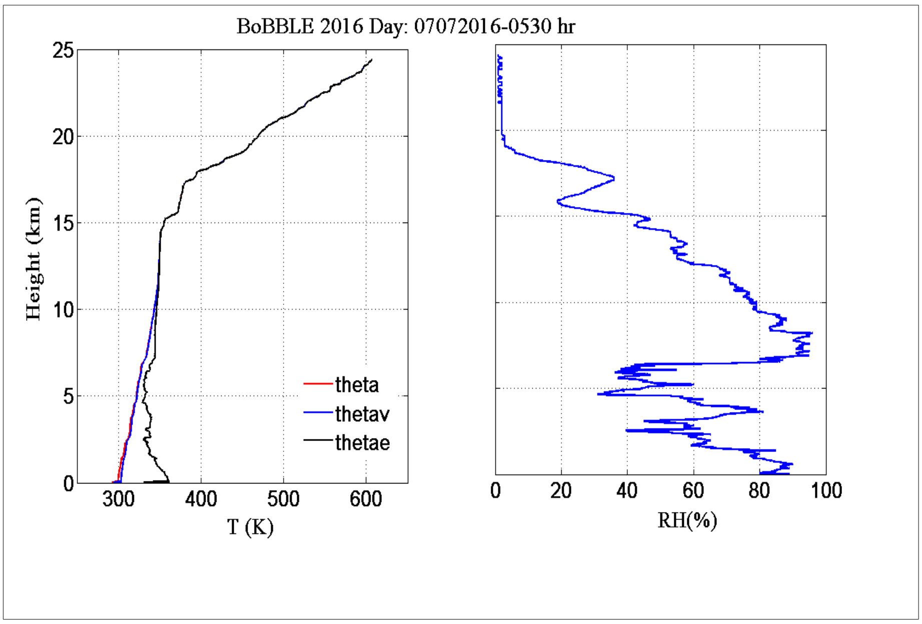


Fig.3 Variation of SW and LW radiations during the BoBBLE cruise: a) incoming SW radiation and outgoing SW radiation; b) down welling LW radiation; c) upwelling LW radiation; d) net radiation

Radio Sonde (weather balloons)

Data on the vertical profiles of temperature, water vapour, wind speed and wind direction along with oceanic conditions are needed as a part of observational components during BoBBLE cruise. Vertical profiles of temperature, humidity, and wind are measured by radio sondes which are attached to a gas filled balloon and released in the atmosphere. Radio sondes are launched nominally at 0000 UTC and 1200 UTC every day from the ship's B deck aft during the cruise period. Additional launches were also made on 27 June at 0600 UTC and 0900 UTC in order to complement the pre- and post arrival of the aircraft observation. Observation of 0600 UTC and 0900 UTC were resumed on daily basis at later part of the cruise. The sounding procedure include measurement of surface humidity and temperature from Rotronics humidity probe and atmospheric pressure from Vaisala pressure transmitter kept on ground check unit table in proximity to the launch area for reference. In order to minimize the possibility of the upper-air sounding becoming fouled on the ship's Superstructure, the ship was maneuvered prior to balloon launch such that the relative wind on deck will safely blow the balloon away from the ship. Normally the relative wind was required to be at the starboard side.



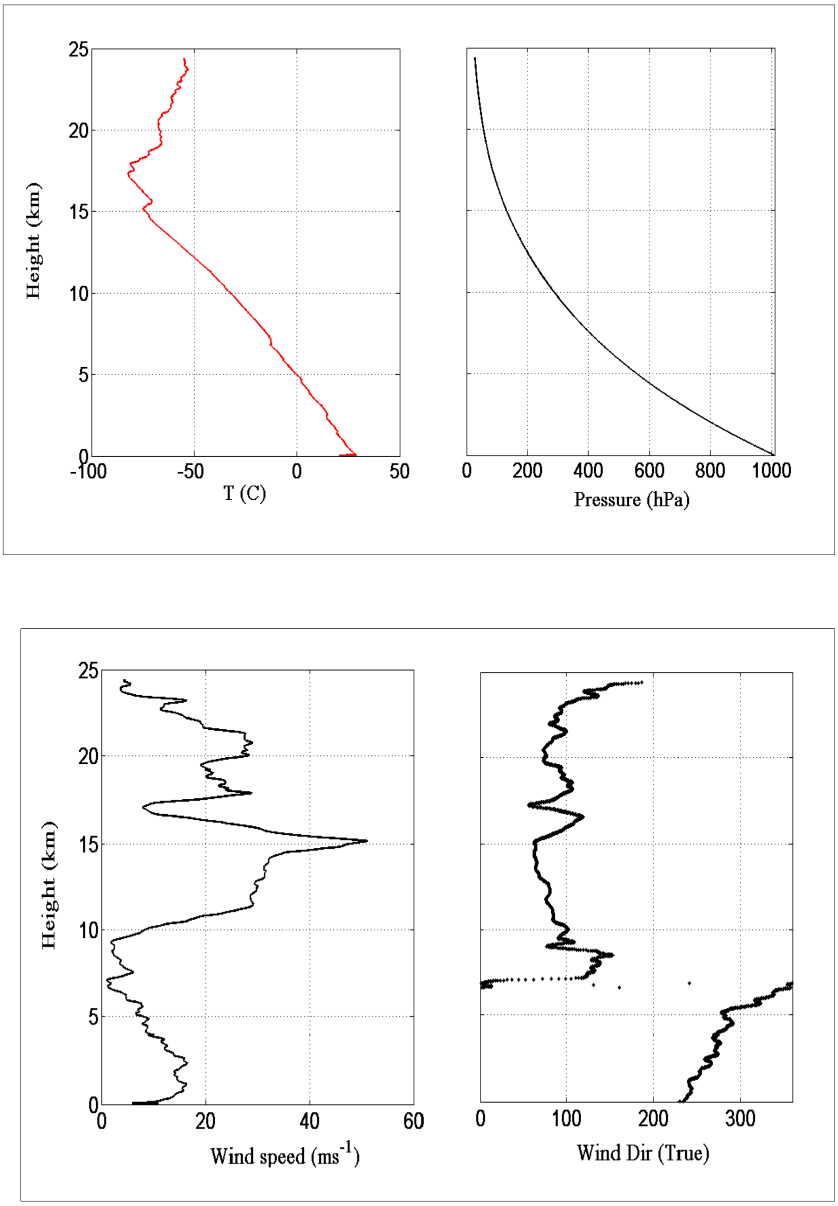


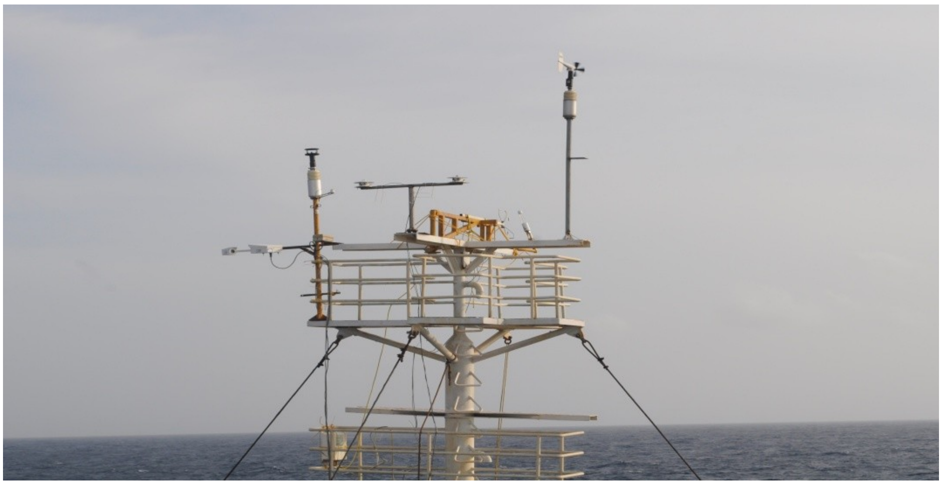
Fig.4 Vertical profiles of derived theta temperature (top left), relative humidity (top right), temperature middle (left) atmospheric pressure (middle right) wind speed (bottom left) and wind direction (bottom right) on July 7 over the southern Bay of Bengal during the BoBBLE cruise.

Few photos

Radiosonde ground check and data receiver setup

Balloon inflating

Inaugural balloon launch by the chief scientist



Flux observation system setup

Radiation measurement

Appendix 6: Chemical and BiogeochemIcal measurements

Objectives:

1. To investigate the inorganic carbon components in the Southern Bay of Bengal waters during summer monsoon.
2. To understand the oxygen minimum condition and nutrient dynamics – processes governing its distribution.

3. Halocarbon and Iodine recycling in Southern Bay of Bengal (Brigit Quake, GEOMER and Rosy Chance, University of York) and production and fluxes of N_2O.

SURFACE SAMPLING

Sea -surface samples were collected from underway and Niskin bottles using as detailed in table 1.Samples collected will be analysed for nutrients, pigments and iodine.

Table 1: The locations of the surface samples taken during BOBBLE

Date	Stns	Time IST	Lat [N]_decimal	Long [E]_decimal	Depth (m)
26-06-2016	Underway_1	09:00	10.889	83.885	3
26-06-2016	Underway_2	12:00	10.609	84.334	3
26-06-2016	Underway_3	16:00	10.374	84.703	3
26-06-2016	Underway_4	19:00	10.170	85.031	3
Date	**Stns**	**Time IST**	**Lat [N]_deg**	**Long [E]_deg**	**Depth (m)**
15-07-2016	TSE2Z3_01	21:32	8.000	88.450	3
16-07-2016	TSE2Z3_02	01:00	8.000	88.300	3
16-07-2016	Z32Z2_01	17:00	8.000	87.450	3
16-07-2016	Z32Z2_02	20:00	8.000	87.300	3
16-07-2016	Z32Z2_01	23:00	8.000	87.150	3

STATIONS

Sampling details

Seawater samples were collected at several predetermined depths upto 3500m in Niskin bottles of 10 L capacity mounted on a rosette sampler along with CTD, for various chemical parameters like dissolved oxygen, nutrients, dissolved inorganic carbon (DIC), pH and Alkalinity, Nitrous oxide (N_2O), Pigments, halocarbon, iodine etc.

Table 2: multidisciplinary station location.

Sr No.	Station ID	Latitude	Longitude	Date	Time (IST)	Sampling depth	Parameter collected
1	STN#1 AR	9.9976	85.2992	27.06.2016	0707	0, 10, 30, 50, 75, 100, 150, 200, 300, 500, 750, 1000, 1500, 2000, 3000 and 3500 m	pH, DIC, Alkalinity, Dissolved oxygen, N_2O, Macro Nutrients, Pigments, Dissolved Iodine and Halocarbon
2	STN#2 TSW	7.9999	85.3013	28.06.2016	1200		
3	STN#3 TSW	7.8808	85.3394	29.06.2016	0843		
4	STN#4 Z1	7.9993	86.0183	30.06.2016	0700		
5	STN#5 Z2	8.0138	87.0071	01.07.2016	0815		
6	STN#6 Z3	8.007	88.0018	02.07.2016	0640		
7	STN#7 TSE	8.0075	89.00068	03.07.2016	0943		
8	STN#8	8.0075	86.5183	19.07.2016	1445		
9	STN#9	8.0003	85.30023	20.07.2016	1957		

TIME SERIES

Seawater sampling was done as mentioned above at 8°N and 89°0068E (TSE), at a 8-12hrs interval for dissolved oxygen, nutrients, pH, alkalinity, dissolved inorganic carbon (DIC) and pigments for 11days along with atmospheric CO2 by LICOR-840A. Details of sampling is given in table 3.

Table 3: Particulars of the time series station

Sr No.	Station ID	Date	Time (IST)	Sampling depth	Parameter collected
1	TSE-TS01	04-07-2016	0600	0, 10, 30, 50, 75, 100, 150, 200, 300 and 500m	pH, DIC, Alkalinity, Dissolved oxygen, Macro Nutrients and Pigments
2	TSE-TS02	04-07-2016	1330		
3	TSE-TS03	04-07-2016	2157		
4	TSE-TS04	05-07-2016	0625		
5	TSE-TS05	05-07-2016	2230		
6	TSE-TS06	06-07-2016	0611		
7	TSE-TS07	06-07-2016	2225		
8	TSE-TS08	07-07-2016	0607		
9	TSE-TS09	07-07-2016	2215		
10	TSE-TS10	08-07-2016	0610		
11	TSE-TS11	08-07-2016	2250		
12	TSE-TS12	09-07-2016	1309		
13	TSE-TS13	09-07-2016	2340		
14	TSE-TS14	10-07-2016	1305		
15	TSE-TS15	10-07-2016	2215		
16	TSE-TS16	11-07-2016	1124		
17	TSE-TS17	11-07-2016	2202		
18	TSE-TS18	12-07-2016	1300		
19	TSE-TS19	12-07-2016	2206		
20	TSE-TS20	13-07-2016	1255		
21	TSE-TS21	13-07-2016	2210		
22	TSE-TS22	14-07-2016	1300		

SAMPLE ANALYSIS

Dissolved oxygen was analyzed by winkler's method using Metrohmdossimat. Similarly alkalinity was measured using Metrohm potentiometer and pH was measured by both pH meter and potentiometer. DIC samples were fixed with mercuric chloride and were analysed using UIC coulometer. Nutrients samples were fixed with $HgCl_2$and will be analysed at NCAOR, Goa using SEALautoanalyser. Chlorophyll a and phytoplankton Pigment samples were preserved frozen and will be analysed at NRSC, ISRO. Hydrocarbon samples were fixed using 30% supra pure HCl and will be analysed by Dr Birgit group at IMF GEOMER, University of Kiel, Germany. Iodine samples are kept frozen and will be hand over to Dr Rosy Chance, University of York.

Appendix 7: Bio-optical Measurements

Introduction:
The main objective of the measurements is to know the surface and sub-surface light field.

Objectives:

- Measurement of surface and sub-surface light field using Hyperspectral Underwater Radiometer.
- Measurement of absorption and attenuation coefficient profiles using IOP profiler
- Collection of water samples for analysis of chl-*a*, Total suspended matter (TSM), phytoplankton absorption coefficient (a_{ph}), detritus absorption coefficient (a_{dg}) .

Instrument and Sampling details:

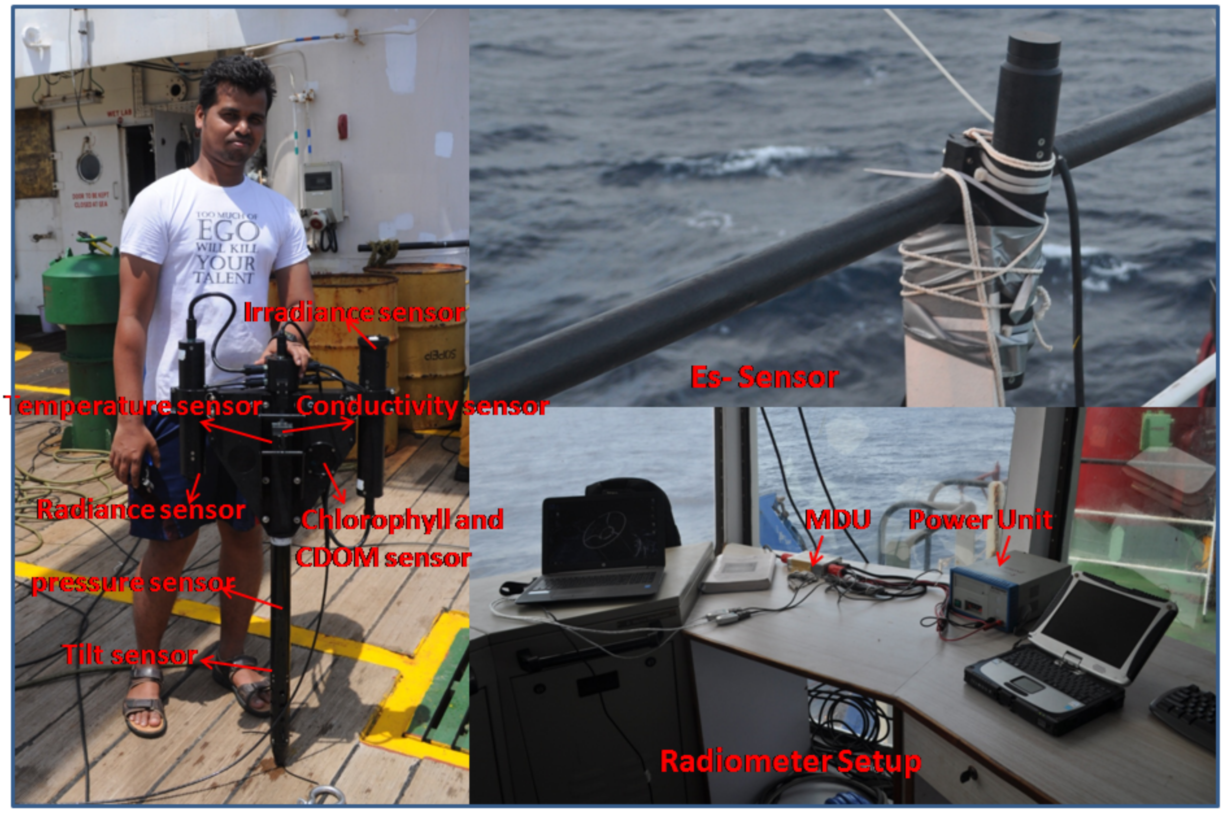
Hyperspectral Underwater Radiometer:
This instrument (Make: Satlantic; Model: HyperProII) measures underwater light field. The instrument has three sensors for light, ECO triplet for florescence and Color dissolved organic matter (CDOM), temperature conductivity and pressure sensors to measure the temperature salinity and depth. The light sensors for measurement of downwelling irradiance(E_d), upwelling radiance (L_u) and total solar irradiance (E_s). (Fig-1).

Hyperspectral underwater Radiometer was operated for 17 days with cloud free condition at 1130 to 1230 hrs at the time series location and along the way between 1100 to 1400 hrs. A total no of 37 profiles ware collected.

Figure 1: Radiometer configuration (left), E_s Sensor mounted on deck (Right upper) and Radiometer setup on deck (right lower).

Inherent Optical Property (IOP) Profiler:

This instrument measures the light absorption and scattering coefficients, backscattering coefficient; chlorophyll-a; coloured dissolved organic matter (CDOM); turbidity and PAR (Photosynthetically Available Radiation) with corresponding depth, salinity and temperature. All the optical sensors are from wetlabs with a Sea-bird CTD. The details of the sensors are given bellow.



PAR Sensor: The PARB model from WETLABS is used for measuring Photosynthetically

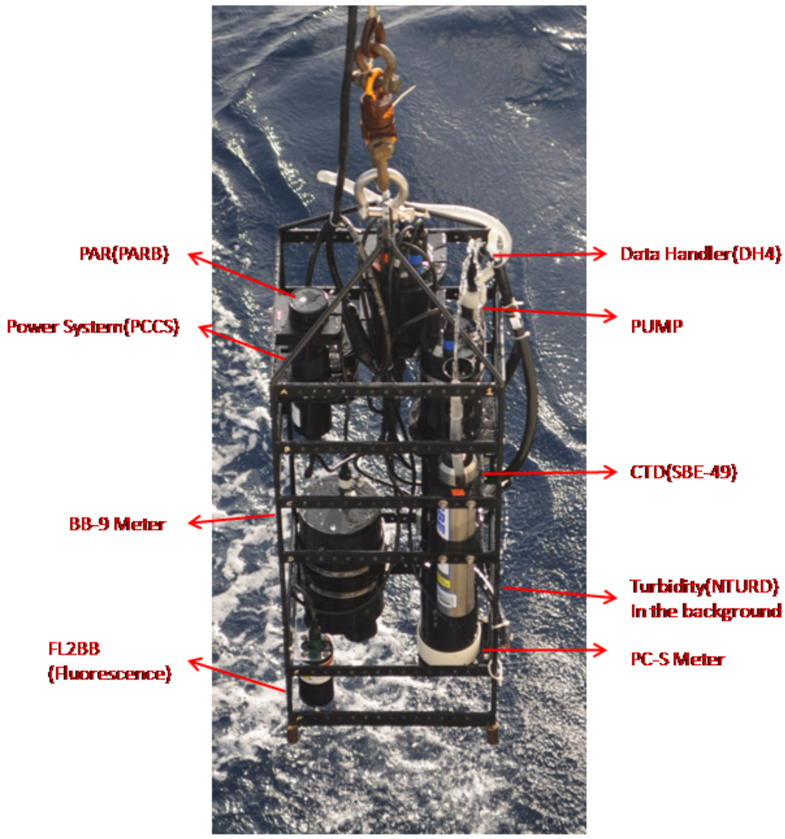
Active Radiation (PAR).

NTURT: The WETLABS NTURT measures the Turbidity in Nephelometric Turbidity Units(NTU). It has a range of 0–1000 and sensitivity of 0.123 NTU

BBFL2: The WETLABS BBFL2 measures the Chlorophyll fluorescence signal at 695 nm the Range is from 0 to 125 with a Sensitivity 0.016 µg/l. which can indicate the chlorophyll 35 concentration, CDOM fluorescence at 460nm the Range is from 0 to 500 with a Sensitivity 0.093 ppb and Volume scattering at 650nm the Range is from 0 to 3 with Sensitivity 0.002m-1.

IOP profiler was operated for 14 days on morning at 7000 to 0730 hrs and on afternoon 1400 to 1530 hrs. A total no of 34 profiles ware collected.

Figure 2: Configuration of IOP Profiler


PAR(PARB)
Power System(PCCS)
BB-9 Meter
FL2BB
(Fluorescence)
Data Handler(DH4)
PUMP
CTD(SBE-49)
Turbidity(NTURD)
In the background
PC-S Meter

Date	Time	Station Code	Lat	Lon	IOP	AOP	Sampling Depth	TSM	aPh
	HM		N	E	No of cast	No of Cast	m	Name	Name
27/06/2016	1337	S1(AR)	9.59'812"	85.17'959"			0	T1	A1
							50	T2	A2
							100	T3	A3
28/06/2016	800(W),1200 ®	S2(TSW)	7.59'995"	85.18'04"		3	0	T4	A4
							20	T5	A5
							36	T6	A6
							60	T7	A7
							100	T8	A8
29/06/2016	1345	S3(TSW)	7.88'196"	85.32'469"		2			
30/06/2016	1000(I),1200®	S4(Z1)	7.59'96"	86.01'1"	1	3	0	T9	A9
							25	T10	A10
							45	T11	A11
							100	T12	A12
1/7/2016	930	S5(Z2)	8.0'829"	87.0'427"		2	0	T13	A13
							25	T14	A14
							50	T15	A15
2/7/2016	1055	S6(Z3)	8.0'46"	88.0'11"	1	3	0	T16	A16
							27	T17	A17
							50	T18	A18
3/7/2016	1200	S7(TSE)	8.0'45"	89.0'00"			0	T19	A19
							40	T20	A20
							60	T21	A21
4/7/2016 (DAY-1)	600	S7(TSE)/D1/M	07.59'99"	88.59.99"	2	2	0	T22	A22
							20	T23	A23
							40	T24	A24
							60	T25	A25
	2330	S7(TSE)/D1/N	8.0'134"	89.0'042"			50	T26	A26
							70	T27	A27
5/7/2016 (DAY-2)	700	S7(TSE)/D2/M	8.2'308"	89.1'059"	2	2	0	T28	A28
							25	T29	A29
							50	T30	A30
							70	T31	A31
	1645	S7(TSE)/D2/E	8.0'047"	89.0'047"	2				
	2230	S7(TSE)/D2/N	8.0'002"	89.0'006"			0	T32	A32
							25	T33	A33
							54	T34	A34
6/7/2016 (DAY-3)	700	S7(TSE)/D3/M	8.1'00"	89.1'.296"	2	2	0	T35	A35
							25	T36	A36
							50	T37	A37
							70	T38	A38
	1530	S7(TSE)/D3/E	8.0'077"	88.59'998"	2				
	2230	S7(TSE)/D3/N	8.0'068"	89.0'061"			0	T39	A39

							20	T40	A40
							40	T41	A41
							60	T42	A42
7/7/2016 (DAY-4)	700	S7(TSE)/D4/M	8.1'231"	89.1'337"	2	2	0	T43	A43
							25	T44	A44
							50	T45	A45
							81	T46	A46
	400	S7(TSE)/D4/E	7.59'963"	88.59'999"					
	2245	S7(TSE)/D4/N	8.00'000"	89.0'088"			0	T48	A48
							25	T49	A49
							50	T50	A50
8/7/2016 (DAY-5)	700	S7(TSE)/D5/M	8.0'100"	89.1'518"		2	0	T51	A51
							20	T52	A52
							62	T53	A53
							100	T54	A54
	430	S7(TSE)/D5/E	8.00'613"	89.03'422"	2				
	2320	S7(TSE)/D5/N	7.59'977"	89.0'143"			0	T55	A55
							20	T56	A56
							40	T57	A57
9/7/2016 (DAY-6)	630	S7(TSE)/D6/M	7.59'827"	89.0'234"	2	2			
	400	S7(TSE)/D6/E	7.59'963"	88.59'999"			0	T58	A58
							25	T59	A59
							50	T60	A60
							75	T61	A61
	10	S7(TSE)/D6/N	7.59'916"	89.0'365"			0	T62	A62
							25	T63	A63
							57	T64	A64
10/7/2016 (DAY-7)	730	S7(TSE)/D7/M	7.99'782"	89.0'55"	2	2			
	1330	S7(TSE)/D7/E	7.59'934"	89.0'023"	2		0	T65	A65
							20	T66	A66
							42	T67	A67
							62	T68	A68
	2242	S7(TSE)/D7/N	8.0'013"	89.0'145"			0	T69	A69
							20	T70	A70
							38	T71	A71
11/7/2016 (DAY-8)	630	S7(TSE)/D8/M	07.59'790"	89.1'780"		2			
	1150	S7(TSE)/D8/E	8.0'020"	89.0'104"	2		0	T72	A72
							20	T73	A73
							42	T74	A74
							62	T75	A75
	2230	S7(TSE)/D8/N	8.0'032"	89.0'028"			0	T76	A76
							20	T77	A77
							40	T78	A78
12/7/2016 (DAY-9)	650	S7(TSE)/D9/M	8.0'668"	89.1'259"	2	2			
	1330	S7(TSE)/D9/E	8.0'032"	88.59'993"	2		0	T79	A79
							41	T80	A80

							60	T81	A81
	2234	S7(TSE)/D9/N	7.59'998"	89.0'043"			0	T82	A82
							20	T83	A83
							36	T84	A84
13/7/2016 (DAY-10)	629	S7(TSE)/D10/M	8.0'462"	89.1'636"		2			
	1330	S7(TSE)/D10/E	7.59'988"	89.0'020"	2		0	T85	A85
							25	T86	A86
							54	T87	A87
							75	T88	A88
	2242	S7(TSE)/D10/N	8.0'024"	89.0'004"			0	T89	A89
							20	T90	A90
							40	T91	A91
							61	T92	A92
14/7/2016	632	S8(TSE)/D11/M	8.0'224"	89.1'153"	2				
	1130	S8(TSE)/D11/E	8.0'058"	89.0'000"		2			
15/7/2016	2201	RT-1	8.0'059"	88.45'116"			0	T93	A93
16/7/2016	117	RT-2	8.0'031"	88.29'978"			0	T94	A94
	915	RT-3	7.59'986"	88..0.007"	2				
	1640	RT-4	7.59'999"	87.45'191"			0	T95	A95
	2016	RT-5	8.0'000"	87.30'150"			0	T96	A96
	2330	RT-6	8.0'050"	87.15'365"			0	T97	A97
19/7/2018	1005	RT-7	8.0'103"	86.45'010"			0	T98	A98
							0	T99	A99
	1520	RT-8	8.0'056"	86.30'185"			36	T100	A100
							60	T101	A101
20/7/2018	1238	RT-9	8.9’171’’	85.22’45’’		2			

Appendix 8: Autosal measurements

Introduction:

Autosal is an instrument that measures the ratio of conductivity of the water sample under analysis with the conductivity of the Standard Sea Water. This conductivity ratio is then used to calculate the salinity of the water sample under analysis using the equation of state for seawater by the Joint Panel on Oceanographic Tables and Standards. The instrument contains a conductivity cell which measures the conductivity of seawater.

Objective:

During the BoBBLE Cruise, many measurements of salinity and temperature at various depths were taken using CTD. The objective of this exercise therefore, is to obtain measurements of salinity at various depths from water samples at those depths and validate the measurements obtained by CTD.

Methodology:

During CTD operation, water samples were collected in bottles attached to CTD rosette at predetermined depths. Those samples were transferred to smaller bottles once the CTD s on board. Care has been taken not to contaminate the bottles by rinsing it thrice before collecting samples. These samples were, then left for at least 3 hours to bring them to the room temperature. Before starting observations of the conductivity ratio by the instrument, the conductivity cell is rinsed thrice using the water sample under observation. Readings are noted down after they have stabilized. Three readings of the conductivity ratio have been taken, but the average of the three is used to calculate the salinity.

The formula given by Joint Panel on Oceanographic Tables and Standards, which is used in the calculation if salinity, is given below.

$$S = 0.0080 - 0.1692\, R_t^{\frac{1}{2}} + 25.3851\, R_t + 14.0941\, R_t^{\frac{3}{2}} - 7.0261\, R_t^{2} + 2.7081\, R_t^{\frac{5}{2}} + \Delta S$$

Where, $R_t = C(S, t, 0) / C(KCL, t, 0)$ and

$$\Delta S = [(t-15)/(1+0.0162(t-15))] \times \left[0.0005 - 0.0056 R_t^{\frac{1}{2}} - 0.0066 R_t - 0.0375 R_t^{\frac{3}{2}} - 0.0636 R_t^2 - 0.0144 R_t^{5/2}\right]$$

The details of the sample collection for the purpose of the Autosal analysis are given in the table below.

Sr. No.	Date	Station Name	Longitude	Latitude	Station Depth(m)	Time(hrs)	Cast Depth	Sampling Depths
1	27/06/2016	SSD024_AR	85 17.959'E	09 59.812'N	3542	0707-1050	3500	0 10 25 50 75 100 150 200 250 300 400 500 750 1000 1500 2000 3000 3500
2	28/06/2016	SSD024_TSW_01	85 18.19'E	08 0.269'N	3757	1300-1341	1000	0 10 20 40 60 100 150 200 300 500 750 1000
3	29/06/2016	SSD024_TSW_03	85.53E	07.88N	3771	1020	500	0 10 20 35 60 100 150 200 300 500
4	30/06/2016	SSD024_Z1-03	86 0.452'E	08 0.641'N	3726	1530	3600	0 10 25 50 69 75 100 116 150 171 200 222 250 300 400 500 750 1500 2000 3000 3500 3600
5	01/07/2016	SSD024_Z2_01	87 0.427'E	08 0.829'N	3673	548	1000	0 15 25 50 75 100 150 168 200 300 500 750 920
6	02/07/2016	SSD024_Z3-01	88 0.11'E	08 0.046'N	3654	0640-0805	3500	0 10 27 50 75 100 150 200 300 500 750 1000 1500 2000 3000 3500
7	05/07/2016	TSE_D02_08	89 0.006'E	08 0.002'N	3599	2235-2305	500	0 10 25 54 75 100 150 200 300 500
8	07/07/2016	TSE_D04_08	89 0.088'E	08 0.000'N	3597	2215-2245	500	0 10 25 50 81 100 150 200 300 500
9	09/07/2016	TSE_D06_08	89 0.365'E	07 59.916'N	3601	2340_0010	500	10 25 50 75 100 140 200 300 500
10	11/07/2016	TSE_D08_08	89 0.028'E	08 0.032'N	3602	2202-2230	500	0 10 20 40 60 100 150 200 400 500
11	13/07/2016	TSE_D10_08	89 0.004'E	08 0.024'N	3608	2210-2242	500	0 10 20 40 61 100 150 200 300 500
12	16/07/2016	Z3R_01	88 0.007'E	07 59.986'N	3656	0900-1000	1000	0 10 20 45 75 100 150 200 300 500 750 1000
13	20/07/2016	TSWR_02	85 18.014'E	08 0.020'N	3755	2025-2100	500	0 10 20 41 60 100 150 200 300 500

In conclusion, a total of 160 samples of seawater at various depths ranging from 0 (surface) meters to 3600 meters, were collected and analysed by Autosal instrument for the purpose of validating the data obtained by CTD probe.

Appendix 9: Argo float deployments

The original plan included deployment of 9 Argo floats with the following specifications:

- -2 TWR APEX floats configured with RBR CTD, composite hull, iridium, and lithium batteries
- -4 TWR APEX floats configured with a SBE 41 CTD, SBE STS sensor, composite hull, iridium, and lithium batteries
- -3 SBE Navis floats configured with a SBE 41N CTD, a Satlantic OCR-504 ICSW radiometer, tilt sensor, iridium, and lithium batteries

Among the above, 8 floats were deployed (see table). One float with RBR CTD did not function properly and therefore the other was not deployed.

Table 1. Argo float deployments.

No.	Argo Float ID	Date	Time (UTC)	Lon	Lat	Notes
1	Navis OCR 0629	28/06/2016	11:45	8N	85.3E	Daily profile surfacing at 1200
2	Apex RBR 7628	28/06/2016	11:45	8N	85.3E	Malfunctioned
3	Apex STS 7599	30/06/2016	09:10	8.04N	86.05E	Daily profile surfacing at 1500
4	Apex STS 7598	30/06/2016	09:10	8.04N	86.05E	Daily profile surfacing at 0300
5	Navis OCR 0631	01/07/2016	14:10	8.07N	87.04E	Daily profile surfacing at 1200
6	Apex STS 7597	01/07/2016	14:10	8.07N	87.04E	Daily profile surfacing at 1500
7	Apex STS 7596	02/07/2016	06:15	8N	88E	Daily profile surfacing at 1500
8	Navis OCR 0630	04/07/2016	13:23	8.06N	89.017E	Daily profile surfacing at 1200
9	Apex RBR 7629	-	-	-	-	Not deployed

Mission and sampling specifications per float type:.

APEX STS:

Initial mission: On the first 9 days, the float does 4 daily profiles down to 500 db (PnP 254), and on the 10th day it does a deep profile to 2000 db.

The surface cutoff pressure for the CTD on this float is 3 db. The STS sensor starts sampling 20 db from the surface, so the overlay sampling between the CTD and the STS sensor is from 20 to 3 db.

The APEX STS does continuous profiling down to 1000 db, so for the 500 db profiles everything is CP, and on the 10th day, the profile will be CP from surface to 1000 db, and the spot profiling from 1000 db to 2000 db. The spot profiling adheres to the following table: [2000.0, 1950.0, 1900.0, 1850.0, 1800.0, 1750.0, 1700.0, 1650.0, 1600.0, 1550.0, 1500.0, 1450.0, 1400.0, 1350.0, 1300.0, 1250.0, 1200.0, 1150.0, 1100.0, 1050.0, 1000.0]

The sampling for the SBE-41 (in continuous profiling mode):

	Lower depth (db)	Upper depth (db)	Bin size (db)	Sample/sec
Profile CTD	1000	3	2	1

STS samples are collected at the rate of one sample per 1.5 seconds while the SBE-41 CTD is in CP mode. Once the cutoff pressure is reached (3 db), the CTD pump turns off and the STS continues sampling at a rate of 1 Hz, which results in relatively high resolution of ~10 cm.

SBE NAVIS OCR:

Initial mission: daily 500 db profiles. This will likely change to 9 days of 500 db profiles, and 1 day of 2000 db profiles surfacing at 3 pm every day.
CTD surface cutoff pressure is 2 db.

The sampling for the SBE-41 (in continuous profiling mode):

	Lower depth (db)	Upper depth (db)	Bin size (db)	Sample/sec
Profile CTD	500	2	2	1

OCR (4-channel) radiometer samples the upper 500 db, and is programmed with the following wavelengths: PAR, 380, 490 and 555.

APEX RBR:

Initial mission: Daily profiles down to 500 db for the first 9 days, and down to 2000 db on the 10th day. Rinse and repeat.
The RBRs are set to continuously profile (CP) from depth to the surface since the additional continuous profiling does not pose any significant energy penalties (as opposed to the standard SBE-41 CTD).

The sampling is set as follows:

	Lower depth (db)	Upper depth (db)	Bin size (db)	Sample/sec
Profile CTD depth	2200	20	2	1
Profile CTD surface	20	0	0.1	6

So the float is doing 1 sample/sec, averaged into 2 db bins, from 2200 db to 20 db, and 6 samples/sec, 0.1 db binning, from 20 db to the surface.

Appendix 10: Drifting buoy deployments

A. Drifter Deployment by National Institute of Oceanography, Goa.

Drifter Sr. No.	Model No.	Date deployed	Latitude	Longitude
135779	MetOcean	27/06/2016	10.0275N	85.3774E
147132	MetOcean	29/06/2016	7.8997N	85.4348E
147134	MetOcean	01/07//2016	8.072N	87.044E
147133	MetOcean	14/07/2016	7.998N	88.998E

B. Drifter Deployment by National Institute of Ocean Technology, Chennai.

1.
Name of the item : Drifter Buoy

S.No : NIOT- DB12

Sensors interfaced : SST, Barometric sensor, DPS, Salinity Sensor & Thermistor string

Date of deployment : 19 - 7- 16

Location:

Latitude : 8.008136 Deg N ,

Longitude : 86.522736 Deg E

2.
Name of the item : Drifter Buoy

S.No : NIOT- DB15, (NIO - 147132)

Sensors interfaced : SST, Barometric sensor, DPS, Salinity sensor & Thermistor string

Date of deployment : 29 - 6 - 16

Location:

Latitude : 7.8997 Deg N ,

Longitude : 85.4348 Deg E

3.

Name of the item : Drifter Buoy

S.No : NIOT- DB18, (NIO - 135779)

Sensors Interfaced : SST, Barometric sensor, DPS & Salinity Sensor

Date of deployment : 27-6-2016

Location:

Latitude : 10.0275 Deg N ,

Longitude : 85.3774 Deg E