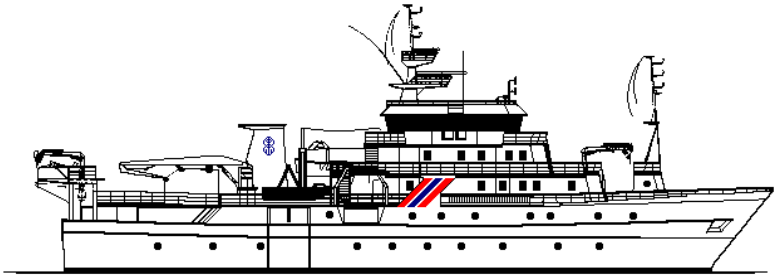

2008 ASCLME SURVEY NO 4

Preliminary cruise report No 8/2008

28 November – 17 December 2008

By

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Durban, South Africa 2008

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1 Introduction

Most of our understanding of the Agulhas Current system is based on research from south of the African coast. Far less is known about its highly complex region of origin in the Mozambique Channel. A number of recent exploratory cruises, satellite tracking and remote sensing studies have shown the Mozambique Channel to be a generally oligotrophic environment that nonetheless supports a large number of fisheries, a high biodiversity and high densities of ecologically important top predators. To date, the processes that sustain the biomass and diversity of this ecosystem are not well understood. It has been acknowledged, however, that the region at a global scale, is physically unusually dynamic and it has been suggested that the observed spatial and temporal variability of the physical environment may well play an important role in enhancing both pelagic and coastal production.

Physical anomalies such as southward migrating eddies along the Mozambique coast and northward moving eddies along the south-west coast of Madagascar have been suggested to interact with the coastal shelves and to result in enhanced production that may subsidize the energy and nutrient requirements of pelagic consumers and producers. Likewise, it has been hypothesised that physical anomalies in the pelagic environment may affect coastal regions by transporting allochthonous nutrients as well as by acting as larval dispersal agents.

Unlike other ASCLME / EAF Nansen cruises to the east of Madagascar, Voyage 2008409 in the Mozambique Channel is not purely exploratory in nature, as preliminary regional investigations into biodiversity, faunal standing stocks, and the physical environment have previously been undertaken. Instead, the motivation for this cruise is to carry out a full multi-disciplinary study, which will investigate the role and importance of Mozambique Channel Eddies in supporting regional biological production and diversity.

1.1 Aims & Objectives

1. To carry out a multi-disciplinary cruise that investigates the physico-chemical processes that result in Eddies subsidising the regional “Life-support System”.
2. To establish the distribution and composition of organisms at a number of trophic levels relative to Eddie positions.
3. To establish, as far as possible, the productivity, diversity and biomass of the pelagic ecosystem.
4. To establish the role of Eddies in linking coastal and pelagic biomes (coupling).
5. To define the physical and chemical nature of mesoscale anomalies.
6. To investigate the role of eddies as dispersal agents.
7. To investigate mesopelagic fish species diversity and abundance.
8. To link various sources of energy and nutrition to different food-web compartments.
9. Capacity building of ASCLME and SWIOPF trainees & young scientists.
10. To fulfil the data management agreement contained in Appendix A.

1.2 Key Questions

1. What are the processes that drive production in the region?
2. What is the relative importance of Eddies in producing and/or relocating biomass?
3. Do Eddies act as dispersal agents for fish larvae?
4. How are the main biological components of the Mozambique Channel affected by Eddies?
5. What is the phytoplankton, zooplankton, ichthyoplankton diversity of the pelagic ecosystem and the main mesopelagic fish fauna?
6. What is the distribution and abundance of the marine flora and fauna and the avifauna relative to mesoscale anomalies?
7. What are the main energy and nutrient sources that subsidise the pelagic food-web?
8. How important is coastal-pelagic coupling in supporting fish biomass?

Participation

Field	Names	Affiliation & nationality	Gender
Cruise Leader	Tor Gammelsrød	UB, Norwegian	Male
Cruise Leader (Local)	Sven Kaehler	RU, German	Male
Oceanography / long-liner	Jean-Francois Ternon	IRD, French	Male
Oceanography, communications	Tamryn Morris	BCRE, South African	Female
Ocean Modeling	Bjorn Backeberg	UCT, German	Male
Zooplankton	Jenny Huggett	MCM, South African	Female
Zooplankton	Andre Miggel	MCM, South African	Male
Isotopes / Genetics	Jaclyn Hill	RU, Canadian	Female
Phytoplankton / Chlorophyll	Bevin O'Reilly	NMMU, South African	Male
Primary Production /Phytoplankton	Keshnee Pillay	MCM, South African	Female
Fisheries Accoustics	Pascal Cotel	IRD, French	Male
Fisheries / pelagic trawls	Michel Potier	IRD, French	Male
Bird, mammal observations	Bruce Dyer	MCM, South African	Male
ASCLME trainee / mesopelagic fish	Doris Benivary	IHSM, Malagasy	Male
ASCLME trainee	Avelino Langa	ASCLME, Mozambican	Male
Oceanography	Bernadino Malaune	IIP, Mozambican	Male
Quality control of data	Magne Olsen	IMR, Norwegian	Male
Instrument Chief	Tore Mørk	IMR, Norwegian	Male
Instrument Operator	Jarle Kristiansen	IMR, Norwegian	Male
Total			18

List of abbreviations

ASCLME: Agulhas Somali Current Large Marine Ecosystem
MCM: Marine and Coastal Management
RU: Rhodes University
UCT: University of Cape Town
IMR: Institute of Marine Research, Norway
SAIAB: South African Institute for Aquatic Biodiversity
UB: Universitetet i Bergen, Norway
IHSM: Institut Halieutique et des Sciences Marines
IIP: Instituto de Investigacao Pesqueira
BCRE: Bayworld Center for Research and Education
IRD: Institut de recherche pour le développement, France
NMMU: Nelson Mandela Metropolitan University, SA

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MCM Scientific Advisor: Mike Roberts (squid@metroweb.co.za)
Ocean Modeling: C Reason, P Penven
Phytoplankton: R Barlow, T Bornman, M Kyewelanga
Remote Sensing: H Demarcq
Zooplankton: J Mwaluma, N Strydom
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Fisheries : F Marsac, F Menard, N Bodin, E Romanov, T Filippi
Nansen-EAF Project Research Coordinator: Dr Tore Strømme (Tore.Stromme@fao.org)
ASCLME Coordinator: Tommy Bornman (t.bornman@ru.ac.za)

1.3 Overview of the cruise and study area

The principal task of the cruise was to carry out a station grid that would investigate the physical nature of cyclonic and anti-cyclonic eddies, to investigate frontal zones between the eddies and to describe and study how the physical anomalies affect the biology of the Mozambique Channel. The location of transects and stations was guided by satellite altimetry (SSH), ocean colour (Chl) and sea surface temperature (SST) data provided by on-shore teams.
Before the cruise commenced, the area of study was restricted to the northern Mozambique Channel, as a number of promising positive and negative anomalies had been identified in this region. Several

transects and grids were then planned to disect areas of interest. The cruise then commenced to focus on five main study areas (see Fig. 1.3.1): 1) a north-south transect through two cyclones (**A**, **C**) and one anti-cyclone (**B**), 2) a frontal zone across the Mozambique Channel between eddies A and B, 3) a coastal convergence zone south of Angoche (**D**), 4) the central anti-cyclone (**B**) and 5) the south-western cyclone (**E**). The physical nature of these features will be discussed in more detail below.

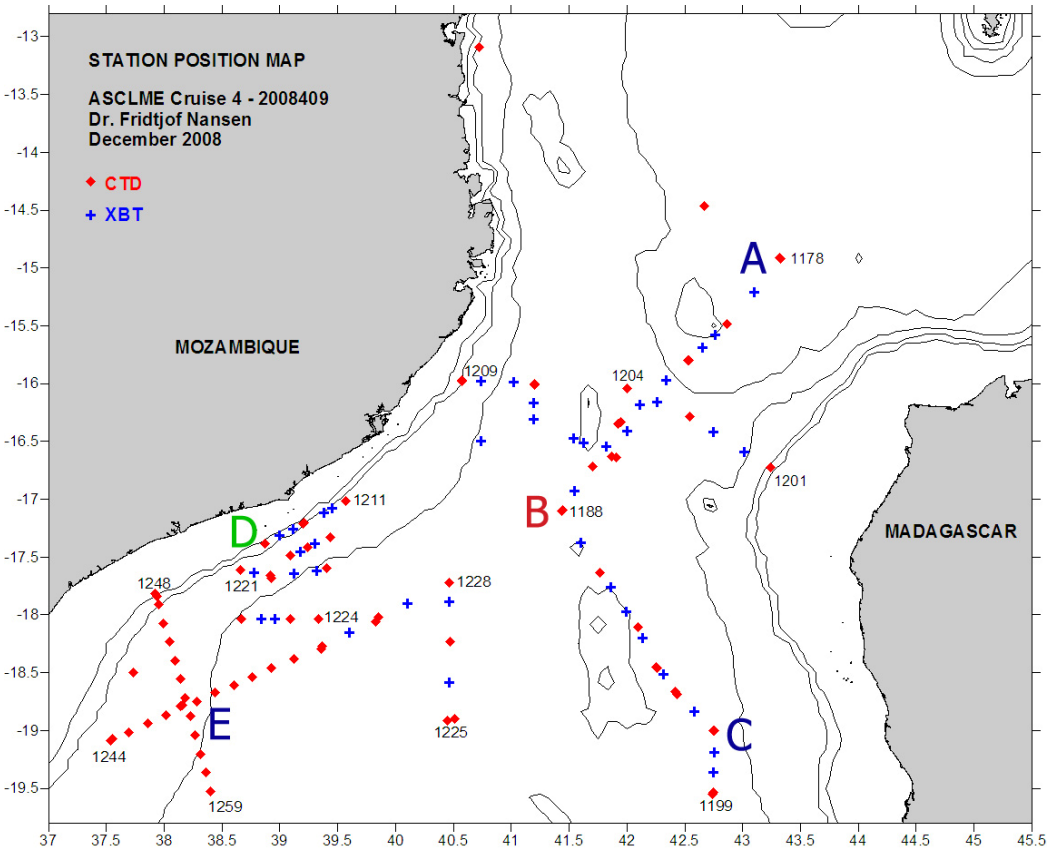

Fig. 1.3.1: CTD and XBT Sampling stations in the northern Mozambique Channel. Areas A, C and E are proximate positions of cyclones. B = anticyclone and D = coastal convergence area.

In each of the study areas, a number of physical or full environmental stations were completed (Fig. 1.3.1). These varied in composition depending on requirements of the survey. Full environmental stations typically included CTD, multinet, bongo, WP2 net as well as water samples for size-fractionated chlorophyll, phyto-pigments, particulate organic matter (POM), primary production, nutrients and nitrate isotope analysis. A detailed summary of samples taken at each station are provided in Table 1.3.1. Additionally, surface and meso-pelagic trawls were conducted in areas of interests, hydro-accoustics were used to identify areas of high zooplankton and fish biomass and bird and marine mammal observations were carried out during daylight hours.

Table 1.3.1: Stations and samples collected (grey)

Station #	Instrument	Date	Time	Lat	Long	DO	Salinity	Nutrients	Tot Chl	Pigm	Abs	Fract Chl	Prod	Isonitr	POM	Micro-zoo	WP2	Bongo	Multi-net
1176	CTD	28/11/2008	11:36	-13.093	40.719														
1177	CTD	29/11/2008	6:52	-14.467	42.670														
1178	CTD	29/11/2008	14:20	-14.916	43.329														
1179	CTD	29/11/2008	15:44	-14.913	43.323														
XBT1	XBT	29/11/2008	18:57	-15.211	43.097														
1180	CTD	29/11/2008	20:43	-15.480	42.866														
1181	CTD	29/11/2008	22:36	-15.487	42.868														
XBT2	XBT	30/11/2008	0:10	-15.58	42.762														
XBT3	XBT	30/11/2008	1:02	-15.685	42.655														
1182	CTD	30/11/2008	2:04	-15.800	42.531														
1183	CTD	30/11/2008	3:52	-15.799	42.531														
XBT4	XBT	30/11/2008	5:57	-15.969	42.342														
XBT5	XBT	30/11/2008	7:35	-16.181	42.113														
1184	CTD	30/11/2008	8:58	-16.332	41.948														
1185	CTD	30/11/2008	11:05	-16.349	41.920														
XBT6	XBT	30/11/2008	13:40	-16.544	41.822														
1186	CTD	30/11/2008	15:23	-16.716	41.700														
XBT7	XBT	30/11/2008	17:34	-16.927	41.549														
1187	CTD	30/11/2008	18:52	-17.099	41.432														
1188	CTD	30/11/2008	20:38	-17.094	41.443														
XBT8	XBT	30/11/2008	23:53	-17.378	41.605														
1189	CTD	01/12/2008	1:47	-17.633	41.77														
1190	CTD	01/12/2008	3:44	-17.633	41.768														
XBT9	XBT	01/12/2008	5:25	-17.759	41.858														
XBT10	XBT	01/12/2008	6:40	-17.971	41.991														
1191	CTD	01/12/2008	7:58	-18.107	42.093														

1192	CTD	01/12/2008	10:03	-18.107	42.095														
XBT12	XBT	01/12/2008	11:40	-18.2	42.133														
XBT11	XBT	01/12/2008	11:42	-18.204	42.136														
1193	CTD	01/12/2008	13:28	-18.453	42.25														
1194	CTD	01/12/2008	15:12	-18.462	42.259														
XBT13	XBT	01/12/2008	16:41	-18.516	42.316														
1195	CTD	01/12/2008	19:04	-18.664	42.414														
1196	CTD	01/12/2008	20:47	-18.683	42.434														
XBT14	XBT	01/12/2008	22:40	-18.833	42.583														
1197	CTD	02/12/2008	0:15	-19.002	42.746														
1198	CTD	02/12/2008	2:01	-19.003	42.752														
XBT15	XBT	02/12/2008	4:00	-19.186	42.753														
XBT16	XBT	02/12/2008	5:33	-19.363	42.748														
1199	CTD	02/12/2008	6:56	-19.533	42.745														
1200	CTD	02/12/2008	11:56	-19.547	42.736														
1201	CTD	03/12/2008	14:15	-16.722	43.241														
XBT17	XBT	03/12/2008	17:37	-16.590	43.014														
XBT18	XBT	03/12/2008	19:39	-16.417	42.746														
1202	CTD	03/12/2008	21:13	-16.284	42.540														
1203	CTD	03/12/2008	22:53	-16.285	42.572														
XBT19	XBT	04/12/2008	1:20	-16.158	42.258														
1204	CTD	04/12/2008	3:04	-16.043	42.005														
XBT20	XBT	04/12/2008	5:57	-16.410	41.998														
1205	CTD	04/12/2008	8:15	-16.638	41.908														
1206	CTD	04/12/2008	9:57	-16.632	41.870														
XBT21	XBT	04/12/2008	12:10	-16.514	41.624														
XBT22	XBT	04/12/2008	12:59	-16.471	41.542														
XBT23	XBT	04/12/2008	16:02	-16.312	41.192														
XBT24	XBT	04/12/2008	16:56	-16.167	41.195														
1207	CTD	04/12/2008	18:05	-16.003	41.199														
1208	CTD	04/12/2008	19:48	-16.013	41.200														

XBT25	XBT	04/12/2008	21:55	-15.989	41.024														
XBT26	XBT	04/12/2008	23:36	-15.979	40.739														
1209	CTD	05/12/2008	0:42	-15.968	40.572														
1210	CTD	05/12/2008	2:27	-15.983	40.574														
XBT27	XBT	05/12/2008	6:41	-16.500	40.739														
1211	CTD	05/12/2008	12:48	-17.014	39.569														
XBT28	XBT	05/12/2008	14:36	-17.079	39.449														
XBT29	XBT	05/12/2008	15:00	-17.114	39.382														
1212	CTD	05/12/2008	17:21	-17.208	39.198														
1213	CTD	05/12/2008	18:51	-17.200	39.208														
XBT30	XBT	05/12/2008	20:13	-17.255	39.112														
XBT31	XBT	05/12/2008	21:04	-17.317	38.999														
1214	CTD	05/12/2008	22:11	-17.385	38.867														
1215	CTD	06/12/2008	0:43	-17.484	39.093														
XBT32	XBT	06/12/2008	2:05	-17.452	39.175														
1216	CTD	06/12/2008	2:28	-17.419	39.236														
XBT33	XBT	06/12/2008	4:25	-17.385	39.305														
1217	CTD	06/12/2008	5:31	-17.327	39.433														
1218	CTD	06/12/2008	7:43	-17.594	39.401														
XBT34	XBT	06/12/2008	8:47	-17.616	39.317														
XBT35	XBT	06/12/2008	9:43	-17.644	39.118														
1219	CTD	06/12/2008	10:47	-17.678	38.923														
1220	CTD	06/12/2008	12:36	-17.655	38.917														
XBT36	XBT	06/12/2008	14:10	-17.635	38.776														
1221	CTD	06/12/2008	14:53	-17.609	38.660														
1222	CTD	06/12/2008	19:16	-18.036	38.667														
XBT37	XBT	06/12/2008	21:00	-18.032	38.837														
XBT38	XBT	06/12/2008	21:42	-18.032	38.956														
1223	CTD	06/12/2008	22:33	-18.037	39.09														
1224	CTD	07/12/2008	1:05	-18.035	39.332														
1225	CTD	07/12/2008	10:16	-18.915	40.450														

1226	CTD	07/12/2008	11:57	-18.900	40.508														
XBT39	XBT	07/12/2008	14:26	-18.587	40.466														
1227	CTD	07/12/2008	17:13	-18.233	40.468														
XBT40	XBT	07/12/2008	21:16	-17.888	40.864														
1228	CTD	07/12/2008	22:22	-17.724	40.464														
XBT41	XBT	08/12/2008	3:26	-17.904	40.103														
1229	CTD	08/12/2008	4:58	-18.021	39.849														
1230	CTD	08/12/2008	6:52	-18.058	39.828														
XBT42	XBT	08/12/2008	9:49	-18.150	39.597														
1231	CTD	08/12/2008	10:23	-18.269	39.366														
1232	CTD	08/12/2008	11:51	-18.297	39.355														
1233	CTD	08/12/2008	14:10	-18.38	39.120														
1234	CTD	08/12/2008	18:54	-18.459	38.925														
1235	CTD	08/12/2008	20:45	-18.537	38.763														
1236	CTD	09/12/2008	0:18	-18.608	38.604														
1237	CTD	09/12/2008	2:07	-18.675	38.442														
1238	CTD	09/12/2008	5:26	-18.749	38.282														
1239	CTD	09/12/2008	7:58	-18.788	38.143														
1240	CTD	09/12/2008	9:38	-18.783	38.155														
1241	CTD	09/12/2008	13:27	-18.869	38.014														
1242	CTD	09/12/2008	15:12	-18.941	37.855														
1243	CTD	09/12/2008	19:05	-19.014	37.695														
1244	CTD	09/12/2008	20:45	-19.086	37.535														
1245	CTD	09/12/2008	22:23	-19.073	37.555														
1246	CTD	10/12/2008	2:47	-18.498	37.733														
1247	CTD	10/12/2008	9:23	-17.818	37.92														
1248	CTD	10/12/2008	9:56	-17.839	37.933														
1249	CTD	10/12/2008	11:08	-17.913	37.952														
1251	CTD	10/12/2008	14:42	-18.072	37.994														
1252	CTD	10/12/2008	16:27	-18.232	38.043														
1253	CTD	10/12/2008	19:47	-18.394	38.091														

1254	CTD	10/12/2008	21:27	-18.555	38.137														
1255	CTD	11/12/2008	0:51	-18.718	38.183														
1256	CTD	11/12/2008	2:32	-18.879	38.224														
1257	CTD	11/12/2008	5:59	-19.042	38.267														
1258	CTD	11/12/2008	7:42	-19.203	38.313														
1259	CTD	11/12/2008	11:07	-19.365	38.357														
1260	CTD	11/12/2008	12:59	-19.525	38.402														
XBT43	XBT	11/12/2008	17:55	-19.891	38.305														
1261	CTD	11/12/2008	20:28	-20.285	38.330														
XBT44	XBT	11/12/2008	23:00	-20.587	38.301														
1262	CTD	12/12/2008	1:39	-21	38.252														
XBT45	XBT	12/12/2008	5:11	-21.385	38.063														
1263	CTD	12/12/2008	7:51	-21.753	37.877														
XBT46	XBT	12/12/2008	11:13	-22.136	37.675														
1264	CTD	12/12/2008	18:45	-22.498	37.499														
1265	CTD	12/12/2008	23:51	-23.168	37.217														
1266	CTD	13/12/2008	3:33	-23.169	36.651														
1267	CTD	13/12/2008	6:27	-23.176	36.284														
1268	CTD	13/12/2008	7:58	-23.179	36.138														
1269	CTD	13/12/2008	9:52	-23.180	35.92														
1270	CTD	13/12/2008	11:08	-23.204	35.769														
1271	CTD	13/12/2008	11:55	-23.238	35.678														
1272	CTD	13/12/2008	13:50	-23.242	35.531														

2 Methods, Instruments, Calibrations:

2.1 Conductivity, Temperature and Depth Instrument (CTD):

A Seabird 911 plus CTD was used to obtain vertical profiles of temperature, salinity, pressure and oxygen. Real time plotting and logging was carried out using the Seabird Seasave software installed on a PC.

2.1.1 CTD sensor calibrations:

Three calibrations were completed for this survey:

a) Dissolved Oxygen:

The dissolved oxygen calibration shows a very stable sensor with little to no correction needed to the raw data (Fig. 2.1.1a). Calibrations were done using the Winkler Titration on a manual 725 Dosimat system.

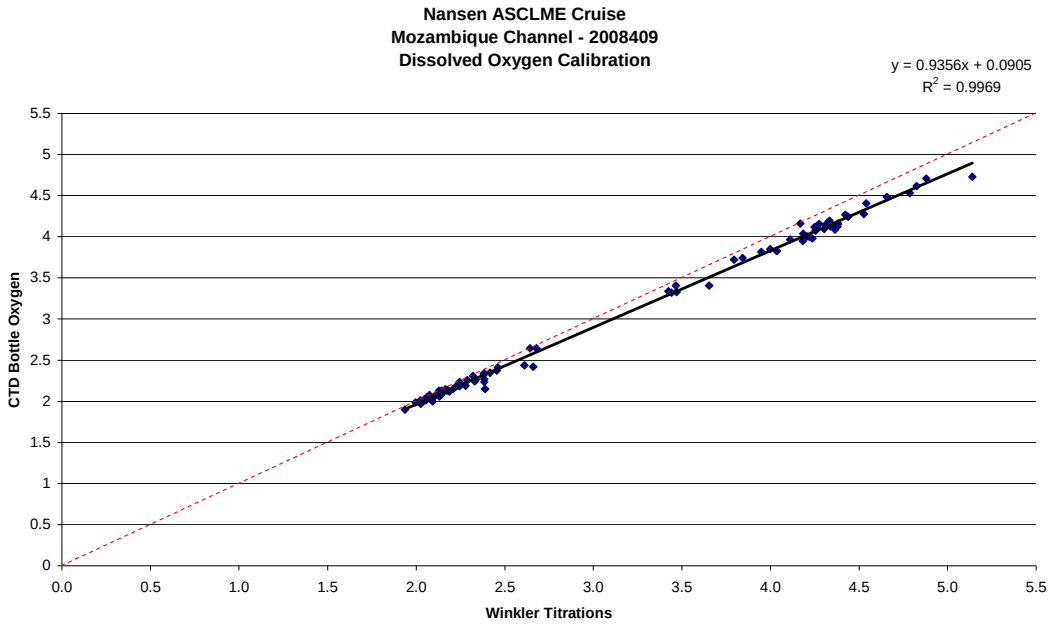

Figure 2.1.1a. Dissolved oxygen linear regression plot – CTD bottle oxygen vs. Winkler Titrations.

b) Derived Salinity:

The calibration of the conductivity cell using derived salinity from the CTD compared to samples analyzed on a Guildline Portasal system proved to be a bit tricky. The Guildline Autosal gave numerous problems and was eventually dismantled to fix leaking capillary tubes and service the pump motor. However, a calibration was made with the samples that remained stable enough (Fig. 2.1.1b). It is recommended that the Guildline Autosal onboard the vessel be sent back to the manufacturer for a factory calibration and a general service.

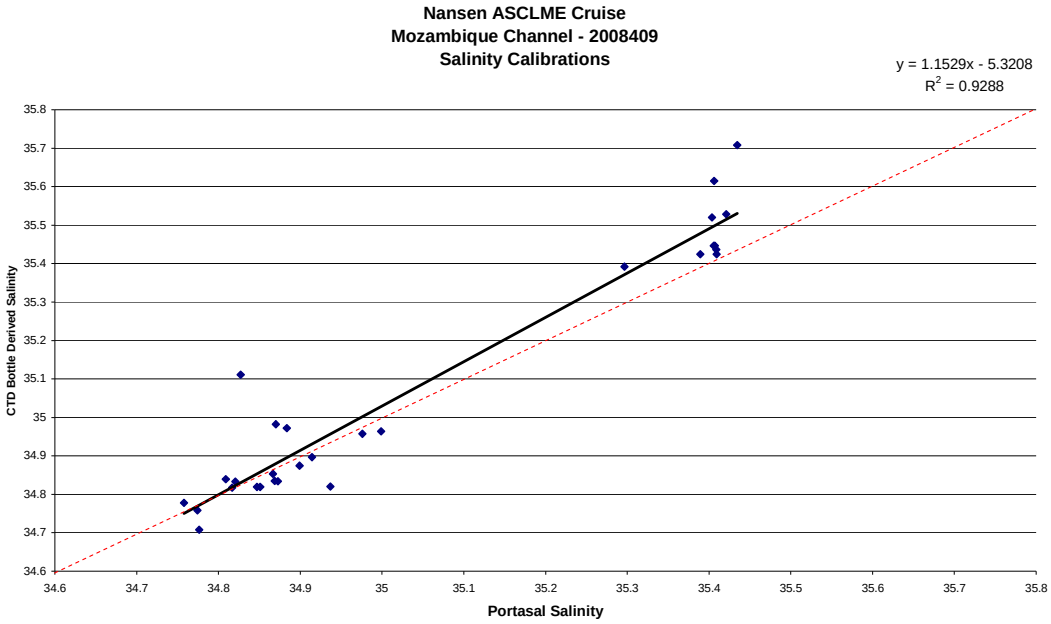

Figure 2.1.1b. Derived salinity regression plot – CTD bottle salinity vs. Portsal Salinity readings.

c) Fluorescence:

Total extracted chlorophyll was calculated from size fractionated chlorophyll samples analyzed onboard the vessel on a Turner Designs Fluorometer. The linear regression against the derived fluorescence (equivalent chlorophyll *a*) from the Chelsea UV Aquatracka is considered fairly good given the sensitivity of the fluorometer instruments in general (Fig. 2.4). Samples where dilutions were needed were excluded due to particular high values being recorded from the extracted values and further analysis is required to resolve these data anomalies.

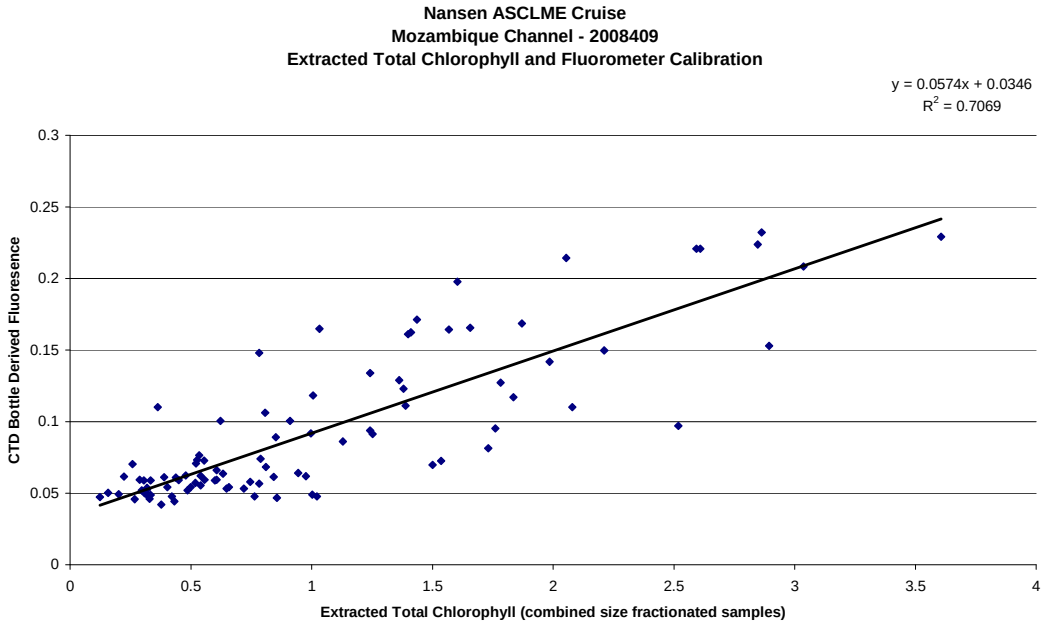

Figure 2.1.1c: Extracted total chlorophylls from size fractionated chlorophyll analysis vs. the Chelsea UV Aquatracka on the CTD – linear regression.

2.2. Methods for water samples:

2.2.1 Dissolved Oxygen

Two dissolved oxygen samples were taken at all full hydrographic stations, usually at the bottom and from an oxygen minima bottle sample. Seawater was tapped from the Niskin bottle using a PVC pipe that fits over the tap. Water was allowed to flow for 20 seconds before the pipe was removed, without entrapping any bubbles within the glass container. Two reagents were then added to the bottle, Manganous chloride and Potassium Iodide with Sodium Hydroxide (1 ml each). The lid was replaced onto the bottle and shaken to capture all the dissolved oxygen out of the seawater. This precipitate was titrated against Sodium thiosulphate, after mixing in 2 ml of concentrated hydrochloric acid. The titrated volume was then used to calculate dissolved oxygen..

2.2.2 Salinity

Two salinity samples were taken at most full stations for calibration purposes. This was eventually stopped to allow for the servicing of the Guildline Portasal. Sample bottles were washed out three times with seawater from the Niskin bottle, before being filled to the bottle neck. These samples were stored alongside the Portasal and analyzed once they reached room temperature.

2.2.3 Total Chlorophyll

Five samples were taken for total chlorophyll *a*. One sample was taken at the fluorescence maximum, two samples above and two samples below, in order to get a description of the fluorometric profile. Due to the oligotrophic nature of the Mozambique Channel, 500 ml of seawater was filtered for each depth, onto 25 mm glass fiber GF/F filters. These filters were frozen and await analysis in Cape Town.

2.2.4 Size fractionated Chlorophyll

Five samples were collected at the same depths described in 2.2.3. For each depth collected, 500ml of seawater was filtered through a serial filtration tower set. The tower set consisted of a 20 µm Nylon Net Millipore filter situated at the top, a 2 µm Macherey-Nagel filter at the middle and a 0.7 µm GF/F Whatman filter at the bottom. Once 500ml of seawater had passed through the entire tower, filters were removed using tweezers and placed in plastic tubes with 10ml of acetone. Trays with plastic tubes were covered with aluminium foil to prevent exposure to light. Samples were cooled in a fridge for 24 hours before determining chl using a Turner Designs fluorometer. Acidification with HCL was used to determine phaeopigment concentrations.

2.2.5 Phytoplankton samples

500 ml phytoplankton samples were collected at the surface and Fmax. Storage was in plastic bottles and 5% formalin.

2.2.6 Nutrients

Samples were collected at all water depths where Niskin bottles were triggered. The test tubes were rinsed three times and filled ¾ to allow space for freezing. Test tubes were cleaned in the laboratory in Cape Town prior to them being packed and loaded onto the vessel. Test tubes were marked with a pencil (station # and depth), and trays of samples were stored in plastic bags in the freezer once the samples had frozen properly.

Duplicate samples were taken (in the same manner as above), for inter-laboratory comparison between MCM in Cape Town and UKZN in Durban. Five consecutive stations through the anti-cyclone were used for this comparison.

Four of the above five duplicate stations were also sampled using the pasteurization method of nutrient preservation. These samples were collected in specialized plastic containers, marked with the relevant station information and placed in the oven at 80° C for 2 and a half hours. The samples were then stored in a dry, dark area before being packed for analysis in Durban.

Additionally, two stations were dedicated to inter-bottle comparison of nutrients during the survey, one at the beginning and one towards the end. At the first station, only seven of the bottles closed at 1000 m, so only a partial inter-bottle comparison will be possible. On the second cast, all twelve bottles were closed providing a full inter-bottle comparison.

2.2.7 Pigments and Absorption

Two litres of water was taken from the surface and at the fluorescence maximum and was filtered through 25 mm glass fiber GF/F filters. Pigment samples were stored within cryo-vials and frozen in a -27° C freezer (not optimal) for analysis in Cape Town. Absorption samples were stored horizontally in embedding cases, also in a -27° C freezer.

2.2.8 Nitrate isotopes

Nitrates for isotope analysis were collected at all productivity stations. One litre double capped bottles were acid washed and rinsed before use. Approx. 900 ml of water was collected at the surface, Fmax, 450m and 800m. Salinity, temperature and pH were determined immediately. Bottles were then sealed and immediately frozen for transport to the laboratory.

2.2.9 POM

Particulate organic matter was collected at the surface (10 l) and from Fmax (5 l) at all full environmental stations and certain other CTD stations. POM was collected on precombusted GFF filters and will be analysed for stable isotopes on return to South Africa.

2.2.10 Microzooplankton

Water samples were collected from the surface and depth of maximum fluorescence (f-max) at each station to sample the microzooplankton community. Surface samples were collected using a bucket, and the F-max samples were obtained from the CTD. At each depth, 2000 ml of water was passed through a 200 µm mesh and collected on a 20 µm mesh to provide the 20-200 µm size fraction. Organisms were washed into dark plastic bottles using <20 µm filtered seawater (FSW), preserved with Lugol's solution and strontium sulphate, following JGOFS protocols, and stored in the dark.

2.3 Other physical methods

2.3.1 Expendable Bathythermographs (XBT)

A total of 46 XBT's were deployed for this survey. They were placed in between CTD stations to enhance the resolution of the CTD data, and in particular, the temperature data. The model of XBT used was a Lockheed Martin Sippican Deep Blue, rated to 760 m.

2.3.2 Underway Acoustic Doppler Current Profiler

(see below section 3.2. for description)

2.3.3 Satellite Tracked Drifters

This particular version of a satellite tracked drifter was developed and manufactured within South Africa. The drifter casts are made up to be light weight and aerodynamic to avoid unnecessary wind drag on the surface float, with the "sock" sunk down to below the surface to capture the surface currents. Drifters were deployed using two people as the vessel was leaving station to avoid getting caught up in overside operations. The drifters were tracked using satellite technology and the raw data was transmitted to the base station in Cape Town. Thereafter the cleaned data was sent to the vessel for processing.

2.3.4 Satellite data collection

As already mentioned in the report, identifying eddie locations from satellite imagery played a crucial role in achieving the cruise goals. Satellite information complemented the real time survey of currents achieved onboard by S-ADCP. However, a regular update of the satellite data base was necessary.

This was achieved onboard the ship for altimetry data, by downloading data from the AVISO Web Site (CNES, France) that delivers near real time (NRT) files of sea level anomaly and geostrophic current. Data are available after 7 days, which was reasonable for our purpose as the dynamics of the eddies in the area are generally slow to change. Products distributed by CCAR (Colorado Center for Astrodynamics Research) are available on a daily basis, without any delay. It was shown, however, that CCAR data was not accurate in terms of structure location, at least in closed area such as the Mozambique Channel. Main reason could be linked to the poor satellite coverage available for a real time delivery.

In contrast, AVISO[1] data (sea level anomaly and geostrophic currents) proved to be in good agreement with structures observed at sea (from ADCP current measurements). The main reason for this is thought to be the use of a more complete averaged data set to construct the product deliver after one week (fig. 2.3.4).

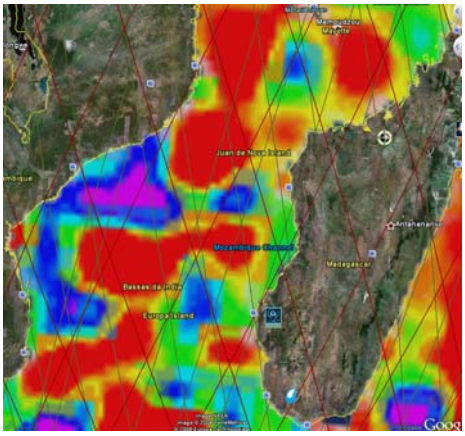

Figure 2.3.4 Track of the satellites used to construct the AVISO SLA picture for the 28/11/2008 (red tracks = Jason ; blue tracks : Envisat – source: CLS, France)

Sea surface colour (related to chlorophyll *a* concentration, hereafter chl_a) and sea surface temperature (SST) are two other satellite products used to locate the actual eddy shape and boundary. In contrast to altimetry, chl_a and SST are real rather than interpolated data products that avoid the interpolation bias observed in altimetry products. However, SST and chl_a have their own constraints mainly linked to cloud coverage (MODIS[2] infrared SST and visible length wave for chl_a). When cloudy weather is encountered, work can be conducted on composite images (pictures averaged over 3 or 4 days). In the case of a slowly moving system such as the eddie field in the Mozambique Channel, this process may be useful to deal with limitation of sea surface visibility. However, as averaging commences, the near-real time aspect of the data is lost. SST data may also be downloaded from a combination of several satellite inputs. Among the available products, TMI[3] (a micro-wave sensor less sensitive to water content of the atmosphere) offers an opportunity to get SST data even in cloudy conditions. The spatial resolution of this product, is however low.

An additional difficulty with remotely sensed data is with its interpretation. For instance, does a chl_a front observed on a particular MODIS image correspond to the inside or outside border of an eddy (i.e. is chl_a production associated with the eddies inside border or caused by advected cholorophyll outside the eddie border)? Recent processes allow getting pictures of dynamical fronts from SST products. Some of these were made available during the last days of the cruise, but did not seem to add significantly to eddie mapping (at least for the present study).

It is the combination of all of the above products that made the use of satellite imagery useful for identifying and mapping eddies during our cruise. The use of all the different products was made possible by colleagues at the IRD (Hervé Demarq, UMR EME, Sète, and Dominique Dagorne, US 191 IMAGO, Brest) who made available the latest processed imagery on a daily basis. Many thanks for their important contribution to the success of this cruise!

The large amount of data collected during the cruise – remotely sensed as well as *in situ* data – and the steep learning curve associated with identifying their uses and limitations – is likely to lead to additional methodological studies in the next few months, at a minimum, in order to help improve our interpretation of the various products for upcoming cruises planned in the next two years.

2.4 Biological sampling methods

2.4.1 Multinet sampling

Oblique multinets (200 µm) were conducted at 39 stations. The multinet was lowered while steaming at 0.3-0.5 $m.s^{-1}$ to 200 m depth. The five nets were opened sequentially at the surface (0-20m), above Fmax (20-50m), through the Fmax,

[1] AVISO: distributed by CNES/CLS; www.aviso.oceanobs.com
[2] Data produced by the Ocean Biology Processing Group at the Goddard Space Flight Center, Greenbelt, MD 20771, USA. Data available at http://oceancolor.gsfc.nasa.gov
[3] TMI = TRMM Microwave Imager ; TRMM = Tropical Rainfall Measurements Mission. Produced by RSS Remote Sensing Systems; sponsored by NASA Earth Science REASoN DISCOVER Project. Data available at www.remss.com

below the Fmax and in the deepest layer (120m to 200m). Between 50 – 60 cum of water were filtered per stratum. After the dip, the nets were rinsed into 500 ml jars and fixed in formalin. Multinet and CTD chits for each station were collected with the samples.

2.4.2 Bongo sampling

Oblique bongos were deployed to a depth of 200m with 300 & 500 µm nets. Flowmeter readings on both nets were noted before and after each dip and allowed for the determination of water volume filtered. Between stations, the flow-meters were washed in distilled water. The bongo was lowered to 200 m while steaming at 2 to 3 knots. Thereafter it was retrieved at a rate of 10m per minute. From each Bongo, the 500 µm sample was washed into 50 ml plastic jars and fixed in formalin. These samples will be used to work on fish larval abundance and distribution patterns. The 300 µm samples were size-fractionated by washing through serial 4mm, 2mm, 1mm, 500 µm and 250 µm sieves. Each size fraction was touch dried on a paper towel and then weighed to the nearest 0.1 g. Each size fraction was then sorted into major taxonomic groups under a dissecting microscope and representative samples were collected for isotope analysis. Samples were stored in Eppendorf vials, labelled on the outside and then dried for 24 hrs at 50^{o}C.

2.4.3 WP2 net sampling

A 100 µm WP2 net was lowered to 200m depth at each Bongo station. Flowmeter readings were taken before and after each deployment. After retrieval, nets were washed into 500 ml jars and fixed in formalin for later analysis.

2.4.4 Acoustics

A SIMRAD ER 60 Echo sounder connected to four transducers of 18, 38, 120 and 200 kHz recorded data throughout the survey. Data was stored on .raw data files.
Acoustic surveys were carried out along all the transects. The survey targeted firstly micronekton aggregates that occurred around dynamic features linked to the eddies. Secondly, the dynamics of the migrating scattering layer and the pelagic layer communities was studied using acoustic results. A permanent watch of the sounder output was organized in order to capture (and note) acoustic events. This will help with future analysis of acoustic records. The acoustic surveys were pursued at a cruising speed of 10 knots or less. Additional information can be found in the acoustics result section (3.7.4).

2.4.5 Surface and mesopelagic trawls

Midwater trawls were conducted to identify acoustic registrations and, approximately once a day, to investigate the pelagic fish fauna. 17 trawls were performed at different depths and during day and night time (more details in the results). A standard haul was 30 minutes long, at 3-5 knots. The exact time for start and stop of the trawl operation was determined by SCANMAR sensors. The output from the SCANMAR system was also recorded on files to facilitate future analysis of opening and depth of the haul set.
Specimen from the trawls were collected for size and weight determination, stable isotope and genetic analysis (more information in the relevant sections).

2.4.6 Trophodynamic approach working with the longliner.

In order the complete the tropho-dynamic approach developed during the Mozambique Channel cruise, a companion cruise funded by SWIOFP was achieved onboard a longliner (Manohal) of La Réunion. The Manohal and R/V Nansen were intended to work in the same area, at dates and positions as close as possible. In terms of Programs, this common work was part of the SWIOFP and ASCLME collaboration (the other point being the presence of three SWIOFP scientists onboard the R/V Nansen for the acoustic / trawl part of the cruise).

The scientific objective of this coupled cruise was to analyse different trophic levels of the pelagic food chain including marine top predators (tunas, swordfish, …) caught by the longliner. The study of the intermediate trophic levels, including mesopelagic fishes and top predator forage fauna through acoustics and trawling, were part of the Nansen cruise objectives. The link between the two operations carried out on board the Manohal and R/V Nansen will consist in the comparison of the stomach contents of top predators to the results of the acoustics and trawlings. On the other hand, environmental data (hydrological structure of the water column) collected by the Nansen team were used by the Manohal to better define its fishing strategy (depth of the thermocline, strength and vertical structure of the currents).

However, during this particular cruise, only part of the planned objectives were achieved. It was not possible for the two ships to meet up for work in one location. One of the main reasons probably stands in the starting point of the Nansen cruise. The Sailing Order of the Nansen cruise mentioned two to three days of sailing before reaching the study area. According to this provision, the Manohal intended to reach the Mozambique Channel steaming South of Madagascar. The Manohal had already left La Reunion Island via a southern route, when the scientific team on the R/V Nansen

decided that work had to be conducted on stronger and better defined eddies in the northern part of the Mozambique Channel. This resulted in the Manohal requiring a longer steaming time to meet up with the R/V Nansen and the possible loss of several working "long-lining"days. The Manohal therefore decided to start with its activities in the southern part of the Channel and work its way north to a new meeting point. In parallel, the R/V Nansen changed its scientific plan and started to complete its northern most objectives in order to be free to meet up further south. A new meeting position and date was established between the two vessels (5am, 11th of December, 18°30'S/41°30'E). On the evening of the 10th of December, the Manohal reconsidered its position and its sailing and working capabilities and decided that logistics did not allow for the planned meeting. Instead, it preceded east-ward to sample the area previously investigated by the R/V Nansen.

With a meeting now unlikely, the two ships pursued their own working plans, the Manohal reaching the north east of the study area while the R/V Nansen started to work on the western side of the basin according to the eddy field distribution. The Manohal left the Mozambique Channel by the north (Cap d'Ambre) on the 14th of December. Nine long-line sets were conducted within the Mozambique Channel, mostly at locations sampled some days before by the R/V Nansen.

The two ships did not perform the combined work, in the same location, as had been expected. However, an improvement of our knowledge of the food chains occurring in the Mozambique Channel should nonetheless result from the work achieved by the two vessels as similar areas were sampled within a short period of time (few days). Conclusions will have to be drawn for future projects including similar collaborations. One of the main points is that the two ships have to start the cruise together (time and location) and have to follow a strategy established in collaboration between the scientific teams of the two vessels.

2.4.7 Productivity

Primary production incubations were only carried out at selected stations. Prior to each station a daytime light profile was determined using a hand-held PAR sensor. 100%, 50%, 25%, 12.5% and 1.25% light depths were determined. Three 2 litre bottles of water were collected at each of the predetermined depths. Bottles were Acid wash and rinsed in distilled water before use. Temperature, salinity and pH from each depth were determined. All bottles were kept in the dark until and after incubation and one of the samples was incubated in the dark (wrapped in aluminium foil). Bottles were carried to incubation chambers and spike with 4ml of tracer ($NaH^{13}CO_3$). Incubation in the respective light chambers occurred for 24 hrs. Bottles were continually cooled with surface water. After incubation bottles were immediately transferred into black bags and filtered onto pre-combusted GFF filters. After filtration, filters were dried for 24 hrs at 50^{o}C. The filtration apparatus and all vessels and bottles were acid washed immediately after use. Filters will be analysed upon return to South Africa.

3 Results

3.1 Water masses

Scatter plots shown in Figure 3.1.1 represent all the stations sampled for the entire cruise. Stations were confined to the northern extremity of the Mozambique Channel, due to the placement of the eddies present in the channel at the outset of the survey. Water masses identified on the temperature-salinity plot include:

Subtropical South Indian Ocean Water (Subt. SIOW)
Equatorial Indian Ocean Water (Eq. IOW)
Antarctic Intermediate Water (AIW)
North Indian Deep Water (NIDW)
North Atlantic Deep Water (NADW)

Red Sea Water was not recorded during the survey. Further analysis of the CTD data will determine whether specific water masses are associated with anti-cyclonic or cyclonic eddies.

The temperature-fluorescence scatter plot illustrates the fluorescence maximum to occur between 20 and 25° C for the entire survey. For this reason, hydrographic surface sections were plotted using the depth at the 22° C isotherm as the thermocline depth (see fig 3.3.1 and 3.4.1 for the anti-cyclone and cyclone descriptions in particular).

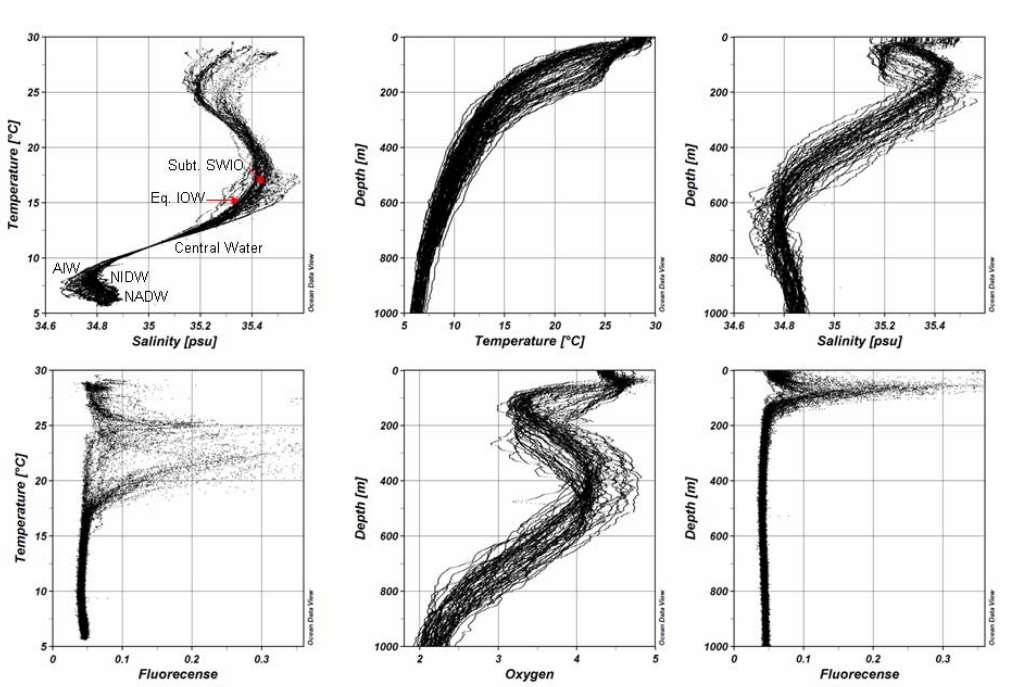

Figure 3.1.1 Stations showing TS- and TF diagrams upper and lower left.
Figure 3.1.2 Stations showing temperature, salinity, oxygen and fluorescence profiles upper and lower right side.

3.2 Mapping eddies (N-S Transect)

Contrary to traditional thought, the flow in the Mozambique Channel is characterised by the frequent southward passage of large anticyclonic eddies, rather than a well-defined current. Historically satellite altimetry observations have played an integral role in describing the ocean dynamics of the region, and in the case for this leg of the ASCLME cruise, have played an important role in determining the position of the eddies.

The main aim of this survey was to collect in-situ measurements of eddies in the Mozambique Channel, mapping their horizontal as well as their vertical extent.

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3.2.1 Current Structure

Altimetry satellites measure the distance from the satellite to the ocean surface by recording the time a radar pulse takes to travel from the satellite to the target surface and back again. From this measurement a lot of other information can be extracted. For the purposes here, we are interested in the sea surface height (SSH) measurement, from which geostrophic flows may be derived (source: www.aviso.oceanobs.com).

Sea level data from multiple altimeter missions, namely TOPEX/Poseidon, Jason-1, ERS-1/2, GFO and ENVISAT, are merged to provide a gridded map. These data were obtained from the SSALTO/DUACS near-real time mode multimission altimeter data processing system at Centre National d'Etudes Spatiales (CNES; www.aviso.oceanobs.com). The gridded data has a horizontal resolution of 1/3º on a Mercator grid, which therefore provides grid-resolution of 24km to 37km in the greater Agulhas region, including the Mozambique Channel.

The geostrophic currents derived from the gridded SSH data are shown in Figure 3.2.1. During the period of our survey there was a large anticyclonic eddy which had formed in the narrows of the Mozambique Channel, between 16 º E and 18.5 º S. It was approximately 350 km in diameter, and strong current velocities were found at its edges.

To the northeast and south of the anticyclone two cyclonic features could be found. The northeast cyclonic feature is fairly uniformly circular, suggesting that it is indeed an eddy. To the south, the cyclonic feature is elongated, spreading across most of the channel.

During the survey the ship continuously collected current data measured from an Acoustic Doppler Current Profiler (ADCP). This instrument transmits high frequency acoustic signals which are backscattered from plankton, suspended sediment, and bubbles, all of which are assumed to be travelling with the mean speed of the water. The ADCP estimates horizontal and vertical velocity as a function of depth by using the Doppler Effect to measure the radial relative velocity between the instrument and scatterers in the ocean.

The data from bin 2 (approximately 16 m deep) are plotted together with the geostrophic currents from altimetry on Figure 3.2.1. Generally, the altimetry derived geostrophic currents are in remarkably good agreement with the observations from the ADCP. This is impressive considering the geographically sparse sampling by the satellite, and the fact that data has to be averaged and interpolated to provide the gridded field. The slight disagreements evident arise from the fact that this north-south section was surveyed over a period of 3 days (29 November – 2 December), while the comparative geostrophic velocities are averaged for all available satellite measurements leading up to 1 December.

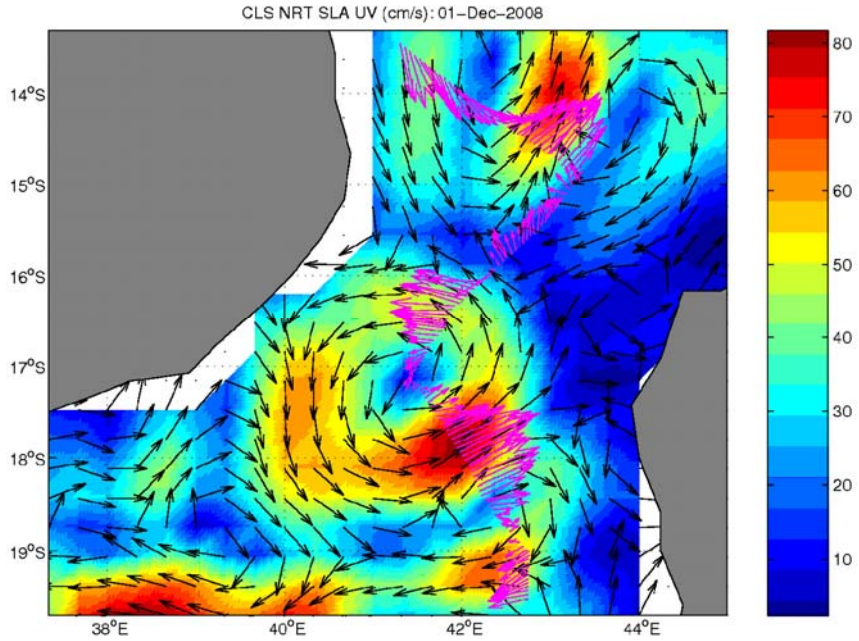


Figure 3.2.1: Geostrophic Currents derived from satellite altimeter sea level measurements. The near real-time (NRT) gridded data is available from AVISO. The vectors (magenta) represent the onboard ADCP data collected during the first, north-south transect of our study area.

The maximum magnitude of geostrophic currents observed from altimetry is approximately 80 cm/s, while the maximum current velocity measured by the ADCP is 172 cm/s. The altimetry underestimate the in-situ observed current velocities significantly, which is to be expected considering the mapping technique relies on averaging and interpolating relatively few observations. The respective maxima are found at the edges of the anticyclonic feature.

It remains that the altimeter data were instrumental in providing the information required for identifying the eddies and planning the survey, thus optimising the ship time available for this leg of the cruise.

In order to provide additional information on the current structure, in particular with regards to the ageostrophic component, surface drifters were deployed at key locations along the north-south transect.

A total of ten satellite tracked drifters were deployed for this survey. These were deployed during the North-South hydrographic transect in order to define the three eddies being sampled – the northern cyclone, central anti-cyclone and the southern cyclone (see Figure 3.2.1 for the satellite imagery of these three mesoscale features). Unfortunately only seven of these transmitted data back to the satellites for tracking purposes. Of those that transmitted, the very first has since stopped transmitting and it is suspected that the drifter has been picked up by fishermen off the Comoros Islands. The drifters reported data as follows:

 # 52:
The drifter was deployed on the edge of the northern cyclone in the hope that it would travel in a clockwise direction southwards around the eddy. However, as stated above, the drifter moved northwards and stopped reporting south of the Comoros Islands.
 # 53 and # 54:
These two drifters were deployed within the northern cyclone and the frontal region between the northern cyclone and the anti-cyclone respectively, but never transmitted.
 # 55:
This drifter was deployed within the anti-cyclone and can be seen rotating anti-clockwise and propagating southwards over time.
#56:
The objective here was to understand what happens over time to the centre of the anti-cyclonic eddy. The drifter remains within the centre for only a short period of time before it becomes entrapped with the outer edges of the anti-cyclone and eventual rotates along with drifter # 55.
 # 57 and # 58:
These two drifters were deployed within the frontal zone between the anti-cyclone and the southern cyclone. It was hoped that the two would diverge apart and follow the anti-cyclone and the southern cyclone respectively. The divergence aspect of the experiment did indeed take place, however the entrainment into the edges of the eddies did not occur, potentially owing to the proximity of the Madagascan shelf. Drifter # 57 eventually traveled northwards and # 58 has moved onto the shelf proper.
 # 59:
A similar objective to drifter # 56, with this drifter being deployed within the centre of the southern cyclone instead. The drifter remained entrapped within the centre for a longer period of time before moving into the "body" of the cyclone at a later stage.
 # 60:
This drifter was deployed on the outer edge of the southern cyclone and has followed in quite a large circle the assumed perimeter of this particular cyclone.
 # 61:
This last drifter was kept in reserve to sample in affect the third cyclone in large scale intensity. However it never transmitted data.
The drifters provide additional information regarding the current structure in the Mozambique Channel, as not all of the dynamics can be observed from the relatively coarse altimetry measurements.

From these data it is clear, that there is no well-defined western boundary current in the Mozambique Channel, as previously thought. Rather, the data indicates that the current field is much more dynamic and turbulent, and seems to be eddy driven.

3.2.2 Hydrographic structure

The aim of the first north-south transect was to identify, from hydrographic measurements, the extent of the eddies we observed from altimetry. Starting in the north, we began our survey in the cyclonic feature, moving southwards through the anticyclonic eddy, finishing this transect in the east part of the channel, in another cyclonic feature.

Temperatures along this section range from 15-18ºC at 250 m to more than 28ºC near the surface. The isotherms become shallower in the cyclonic features, where colder water is upwelled in the centre due to surface divergence. Conversely in the anticyclone, the isotherms are deeper due to downwelling resulting from surface convergence. This "doming" is clearly evident from the 22ºC isotherm which has a minimum depth in the cyclonic features of ~100 m, while it lies at ~200 m in the anticyclonic feature. Similar patterns are also evident in the salinity, oxygen and fluorescence data (Fig 3.2.2).

In addition to the doming, the salinity data shows a subsurface minimum within the anticyclonic eddy. High oxygen levels are found closer to the surface, and these extend to greater depths in the anticyclone compared to the cyclones.

Furthermore, the depth of the maximum fluorescence (Fmax) is also dependent on the position within the feature, lying deeper towards the centre of the anticyclone and shallower towards the centre of the cyclonic features. Overall, higher phytoplankton biomass (as determined by chlorophyll analysis), indicates that there seems to be more primary production occurring within the cyclonic features, as nutrient rich waters are pushed upward into the euphotic zone.

In general, the doming evident in all hydrographic variables along this section confirmed, that during this first north-south transect, two cyclonic eddies and one anticyclonic eddie were sampled.

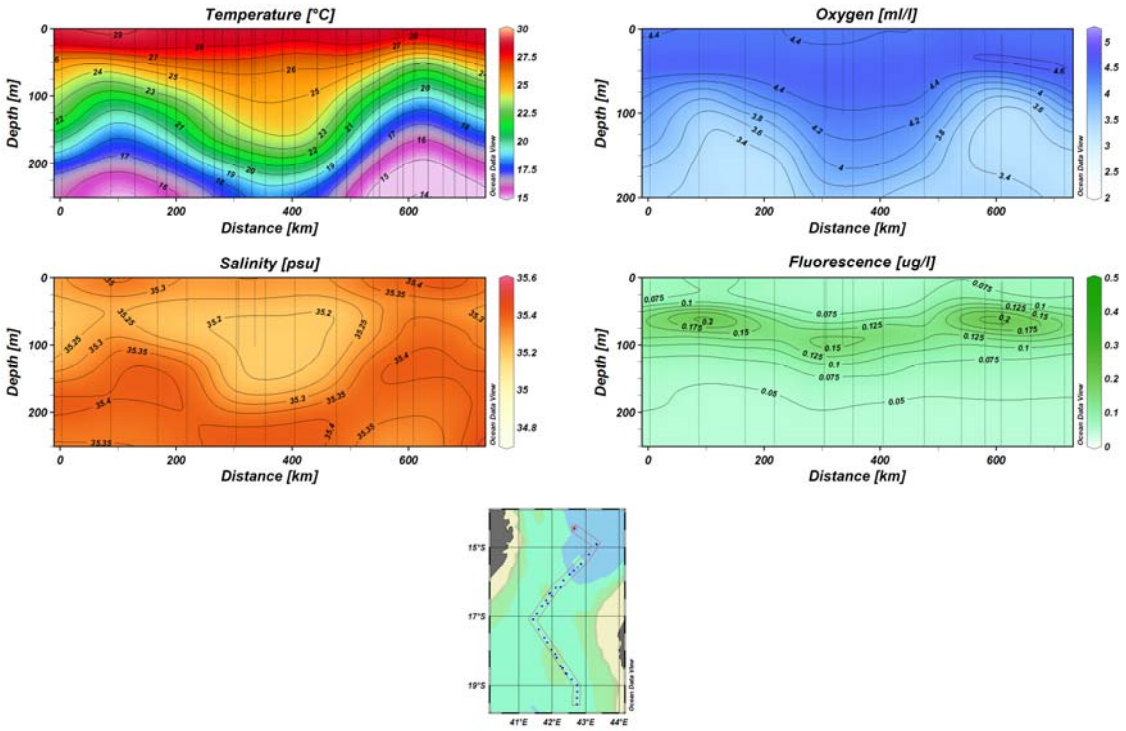


Figure 3.2.2: Vertical cross section of temperature (top left), salinity (bottom left), oxygen (top right) and fluorescence (bottom right) for the upper 250 m of the north-south transect.

3.3 Anticyclone mapping

The section shown in Fig. 3.2.2 demonstrates that the isolines are deeper in the centre of the anticyclone. The 22˚C isotherm is found at 200m in the anticyclone, but only at 100m in the neighbouring cyclones. A similar behaviour is observed for the 35.35 isohaline and the 3.6 ml/l oxygen contour. But the amplitude is much smaller for the fluorescence because of the low production in the centre of the anticyclone.
The horizontal fields shown in Fig.3.3.1 also demonstrate that high fluorescence levels are shallower in the anticyclone compared to the 22˚C isotherm. These horizontal fields also indicate an elongated structure of the anticyclone, oriented SW-NE. This is likely due to the propagation of the anticyclone south-west ward during the sampling period.

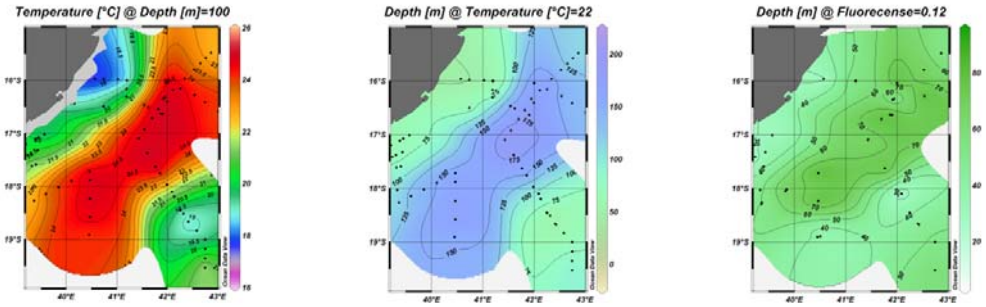


Fig.3.3.1. Horizontal fields in the anticyclone of a) Temperature at 100 depth, b) Depth of the 22 ˚C isotherm c) Depth of 0.12 ug/l fluorescence

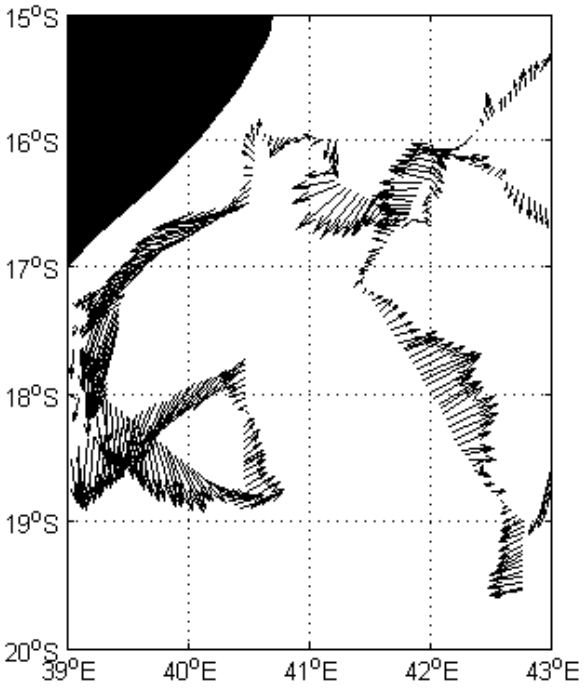


Fig.3.3.2. Velocities obtained with the ship ADCP upper bin (23m) in the position of the anticyclone

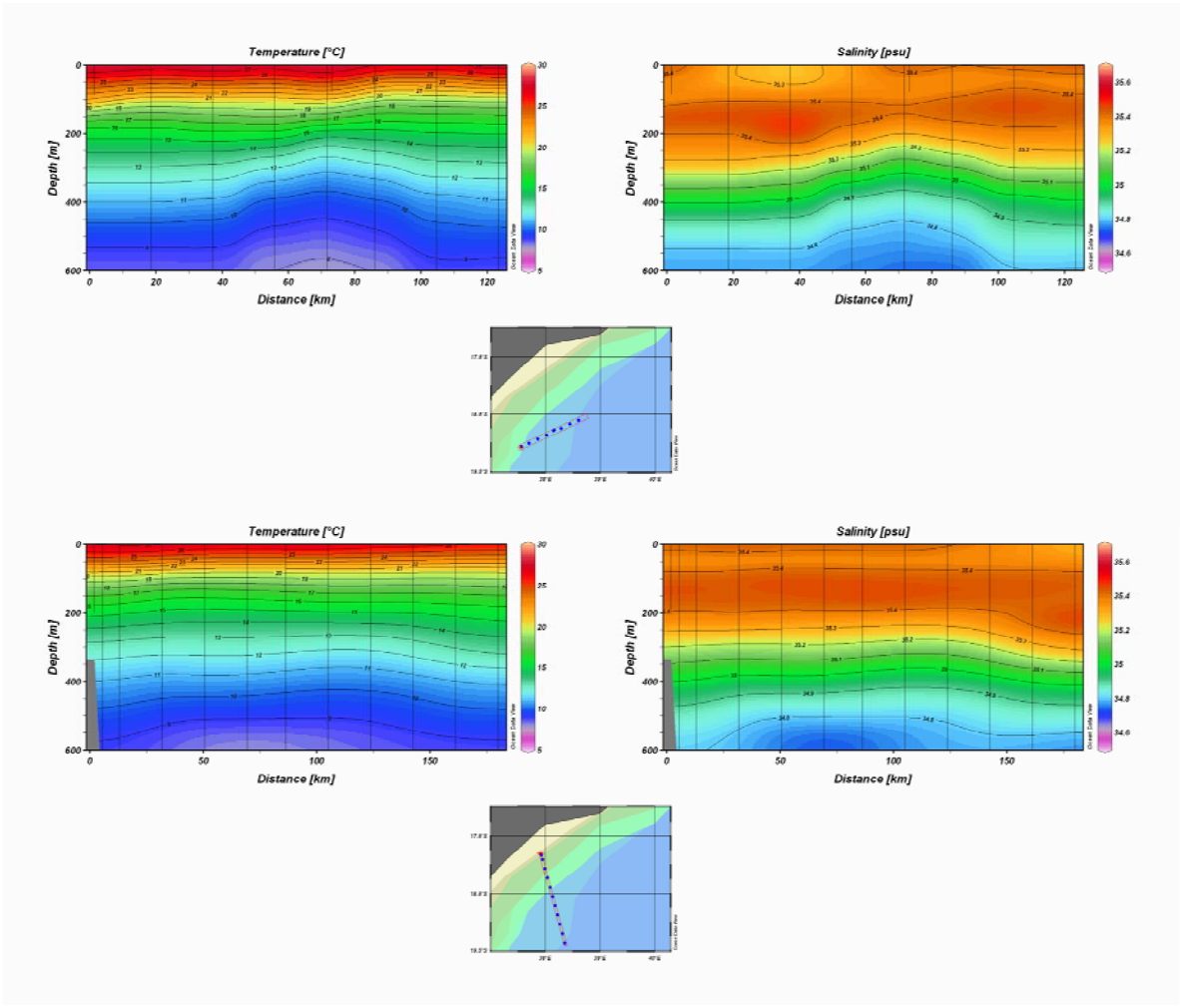
3.4 Cyclone Mapping

3.4.1 South west cyclone

The cyclone centred around 39°E / 18°30'S could be identified from time-averaged altimetry data collected since the 23rd of November. During the sampling period, however, data suggested that the cyclone was decreasing in strength and perhaps disintegrating.

In situ information concerning this cyclone:

- ADCP measurements indicate a strong eastward flow on its north-east edge, where it is close to the anticyclone. Otherwise, the flow is very weak all over the structure, especially in its south (and south-west) part.
- Biological samples are in favour of a cyclonic signature: relatively high zooplankton biomass as well as significantly high catches in the midwater trawl (while lower than the catches within the eastern cyclone, a few days earlier). Even though the cyclone was decreasing in strength, the biological signature remained strongly that of a cyclonic feature. This is not surprising as there is typically a time-lag between physical upwellings and biological production and consumption.
- The physical signature (hydrology) doesn't give clear evidence of doming, at least in the 200m top layer. When looking at the temperature and salinity distribution in deeper layers (around 500-600m), however, doming is still apparent in the middle of the section, but it doesn't reach the surface (1st SE-NW section). This again indicates a decreasing structure.
- The NW-SE section, achieved one day later, shows even less evidence of doming (see temperature and salinity sections), which again argue for a decreasing phase of this cyclone.



Figur 3.4.1 Vertical sections of Temperature and Salinity for the SW-NE transect (top) and NW-SE transect (bottom) through the south-west cyclone.

3.5 Frontal Structure

The section shown in Fig.3.5.1 was taken to sample the front between the Anticyclone centred at 17˚S and the cyclone at 15˚30'S, see Fig 3.2.1. At 41.5˚E we obviously traversed the front into the cyclone, with corresponding very steep gradients as the isolines are shallowing towards the coast. High fluorescence values were found near the Mozambique coast in this area in the upper 60m with a fluorescence maximum above 0.75 ug/l at 50m depth. Note, however, that the maximum fluorescence found at 100m in the east does not seem to be related to the shallow maximum in the west, indicting that there are different sources for these two maxima. High fluorescence values were also seen near the Mozambique coast in the satellite imagery, see Fig.3.5.2

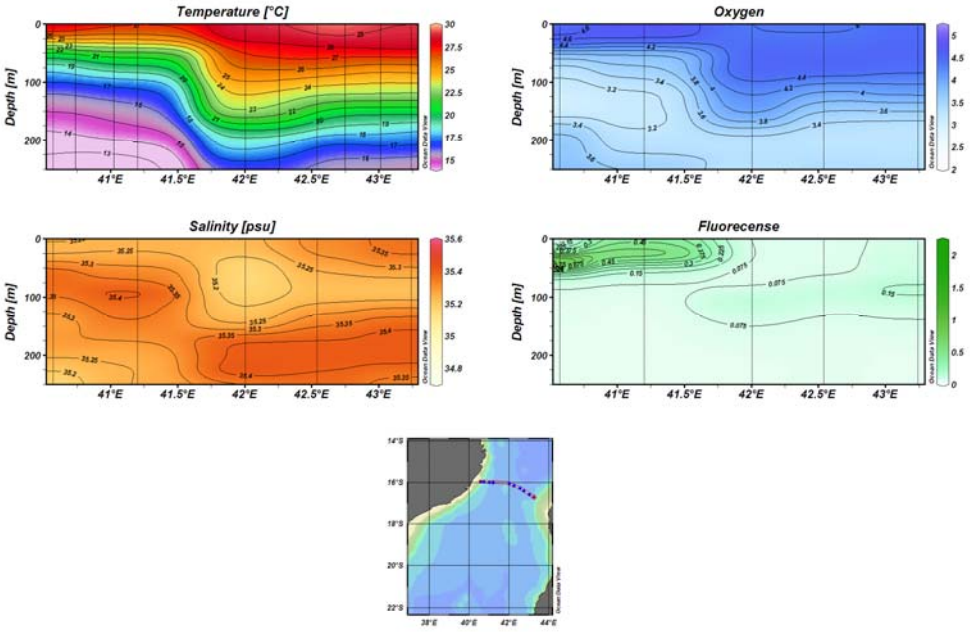


Fig.3.5.1 Vertical section in the frontal zone of a) Temperature, b) Salinity, c Oxygen and d) Fluorescence

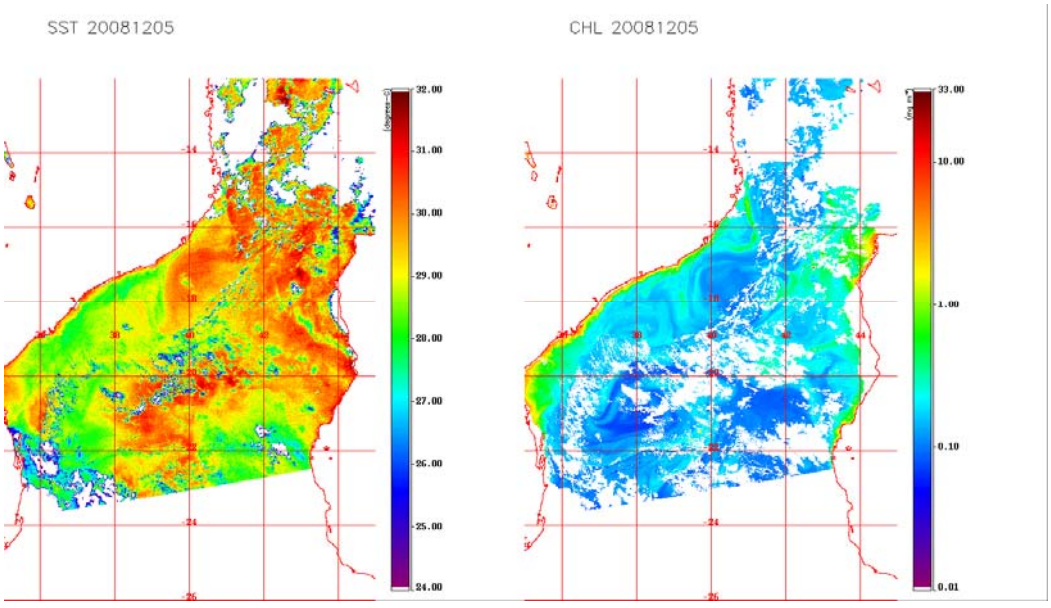


Fig.3.5.2 Sea surface temperature and chlorophyll mapping from satellite imagery obtained December 5th 2008

3.6 Convergence Zone

3.6.1 Convergence area

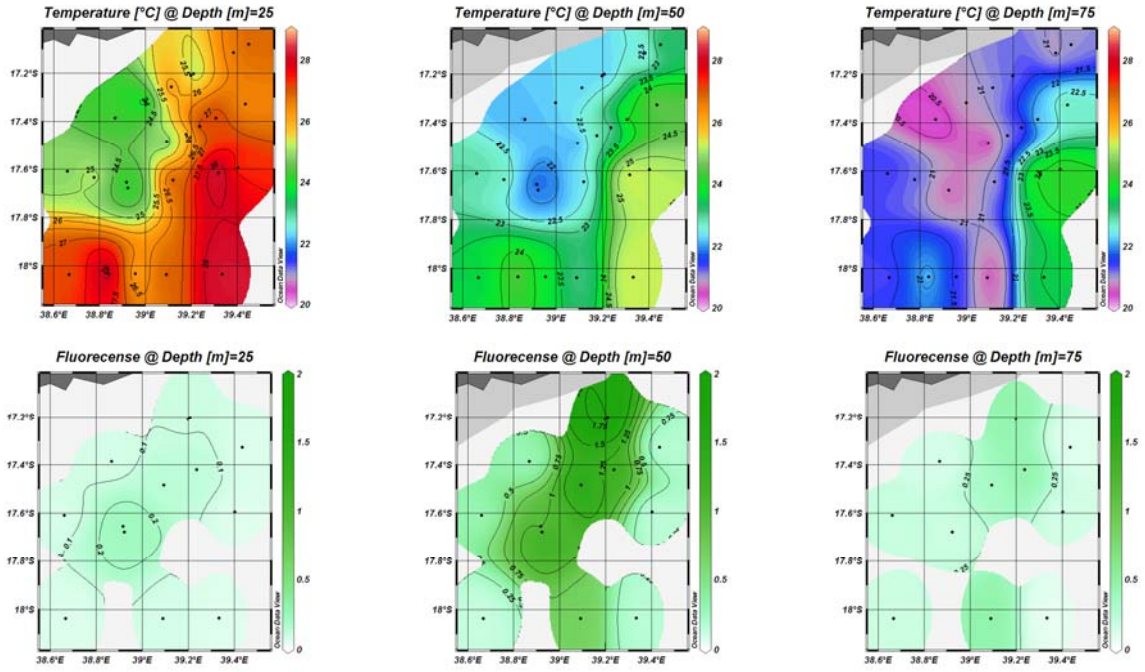
A convergence area south of Angoche was studied in more detail to improve our understanding of the sources of chlorophyll entrainment from the coast. The convergence area was located west of the boundary between the previously sampled anticyclone in the north and a cyclone on the south. This area was evident on Modis and SST satellite imagery as a "triangle" of high chlorophyll and low temperature. It was also characterised by ADCP measurements that indicated very strong south-eastward currents on the edge of the anticyclonic cell bordering the convergence area. On the western side of the area, the convergent cyclonic flow was considerably lower.

The horizontal distribution of chlorophyll and temperature (at depths 25m, 50m and 75m), indicated an area of high phytoplankton biomass and lowered temperature in the supposed convergence zone between the two eddies (Fig. 3.6.1). The cold water expanded from the coast southeast-ward into deeper water. Chlorophyll values appeared high primarily along the margin of the anti-cyclonic cell, with phytoplankton being washed off-shore (south-ward) from the coast along the eastern margin of the convergence cell.

There are at least two possible explanations for the observed decrease in temperature and increase in chlorophyll biomass.

a) The convergence cell produces an upwelling of colder, nutrient rich water which may result in increased primary production and chlorophyll standing stocks.
b) The convergence cell entrains colder water from the south-west (cyclone) and coastal chlorophyll from the north-east (anticyclone).

The question of the origin of the chlorophyll (coastal phytoplankton vs new production related to upwelling) cannot currently be resolved with available data. Information from nutrients, stable isotopes and primary production estimates will help us further interpret the processes involved.



Figur 3.6.1 Horizontal distribution of temperature and fluorescence in convergence zone at 25m depth, 50m depth and 75m depth, respectively.

3.7 Biology

Only partial and preliminary results will be presented here as more detailed data and laboratory analyses are required for most studies and additional background information needs to be acquired.

3.7.1 Size fractionated Chlorophyll

Size-fractionated chlorophyll was determined at a total of 58 stations. Only stations along the north-south transect will be reported here.

Size fractionated chlorophyll was highly variable in surface waters along the north-south transect. Generally, surface chlorophyll concentrations were higher in the frontal regions (e.g. 1182, 1191, 1193) between the eddies than within the eddies. Furthermore, chlorophyll in all size-fractions increased to its highest levels in the vicinity of the Malagasy shelf (e.g. 1197, 1199). All of these observations indicate that surface chlorophyll concentrations might be driven by coastal entrainment of phytoplankton.

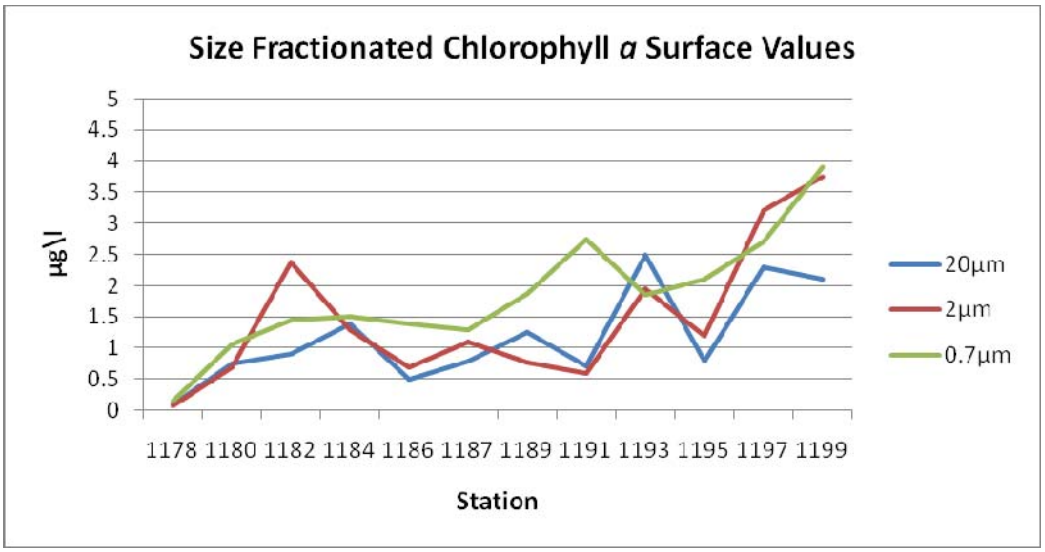


Fig. 3.7.1a: Surface size fractionated chlorophyll a concentrations along the north – south transect.

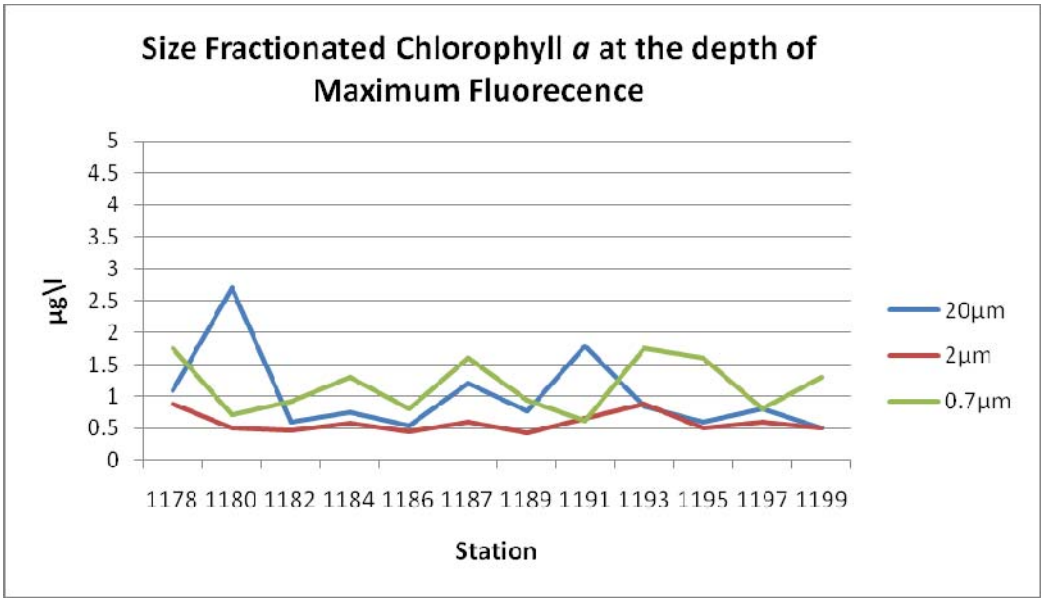


Fig. 3.7.1b: Fmax size fractionated chlorophyll a concentrations along the north – south transect

In contrast to the surface chlorophyll, phytoplankton biomass at F*max* is far less variable. Below the surface, phytoplankton growth is limited by light penetration from the surface and nutrient availability from deeper waters. At this depths, chlorophyll concentrations are likely to be reduced unless additional nutrients become available. While not clearly defined, slightly elevated chl *a* values are exhibited at stations 1180, 1193 and 1195 which correspond to stations within cyclonic eddies that are shown to have upwellings in their centres (see section 3.2.2). Further analysis is required to determine general patterns in chlorophyll distributions.

3.7.2 Productivity

A total of 14 productivity incubation stations were performed, each at 5 light depths of 100%, 50%, 25%, 12.5% and 1.25% PAR. No results can be described here as samples require laboratory analysis before carbon incorporation rates can be determined.

3.7.3 Zooplankton

Zooplankton results as presented here comprise data from both Bongo and Multinet sampling.

a) Bongo

The main aims of the Bongo sampling were to:

a) provide samples for stable isotope analysis and investigation of trophic links
b) provide samples for fish-larval identification and abundance estimates
c) provide an estimate of size-fractionated biomass distribution

Of the three aims, only the biomass estimates can be discussed at this stage as the other samples require further lab-based analysis.

During the Mozambique Channel survey, at total of 35 Bongo trawls were conducted and 271 stable isotope samples were collected from 5 size-fractions (from the 300 µm net). Zooplankton from one net (500µm) from each bongo was furthermore preserved for fish larval work (n=35).

b) Bongo biomass:

Only partial and preliminary biomass estimated will be provided in this section as additional work is required to separate abundance estimates at the taxonomic group level (i.e. copepods, euphausids, decapods etc). Furthermore, any interpretation of zooplankton distributions must at this stage be tentative as mesoscale anomalies cannot yet be positioned with certainty. Additional required datasets will become available over the next few weeks.

Total zooplankton wet biomass in the top 200m of the water column (as sampled by the Bongo) ranged from 23 to 512 mg m^{-3}. The predominant taxa in the smaller size fractions from most stations were:

280µm – 500µm: copepods (also some gastropods, ostracods and amphipods)
500µm – 1mm: copepods (also some amphipods, ostracods and euphausiid nauplii)
1mm – 2mm: small euphausiids and chaetognaths (also some large copepods, amphipods)

The larger size fractions were more variable in composition, with euphausids, decapods, fish larvae and gelatinous zooplankton making up the bulk of the biomass. These larger size fractions of the zooplankton tended to make up a large proportion of the total biomass only during night-time stations (see below) and / or in the anti-cyclonic eddie where gelatinous zooplankton was abundant. Particularly obvious in their temporal variability were the larger euphausids and decapods which exhibited a strong vertical migration to the surface during dusk and retreated back to depth at dawn. These migrations could be picked up as an increase in the contribution of the larger size-fractions to total biomass (Fig. 3.7.3a) as well as in the acoustic record of the deep-scattering layer (DSL, see acoustics section).

A more detailed ordination analysis of zooplankton will be carried out at a later stage, when compositions have been quantified and exact positions of mesoscale anomalies have been identified.

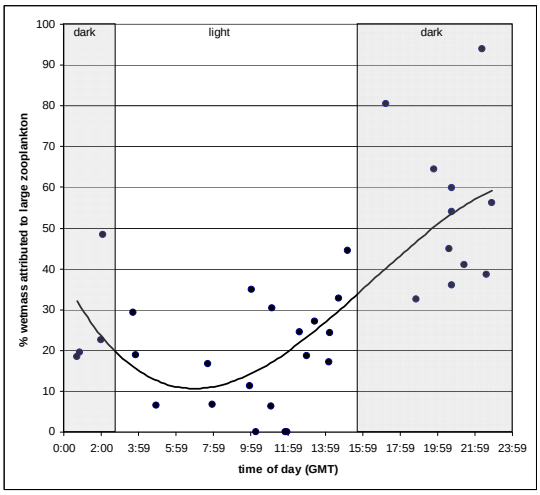


Fig. 3.7.3a: Percentage of total wet-mass attributed to large zooplankton (>2mm). Larger zooplankton is relatively more abundant during night stations, indicating an upward migration of larger size-classes into the top 200m during dark hours and a downward migration during day-time hours.

Preliminary results suggest that the smaller size fractions of the zooplankton do not exhibit distinct migrations and that these size-classes may, therefore, be more readily used for determining overall abundance patterns where both night and daytime samples are collected.

The horizontal (geographical) distribution of small zooplankton taxa (Fig. 3.7.3 b,c) suggests that warm-core eddies contain overall very little zooplankton when compared to cold-core eddies and frontal boundary regions. While this result needs to be reinvestigated once updated altimetry data is available, current data suggest that biomass increases on average two-fold outside of the warm-core eddies (Fig 3.7.3 d).

Similar investigations of biomass will also be carried out against SHH slope, current speed and proximity to land.

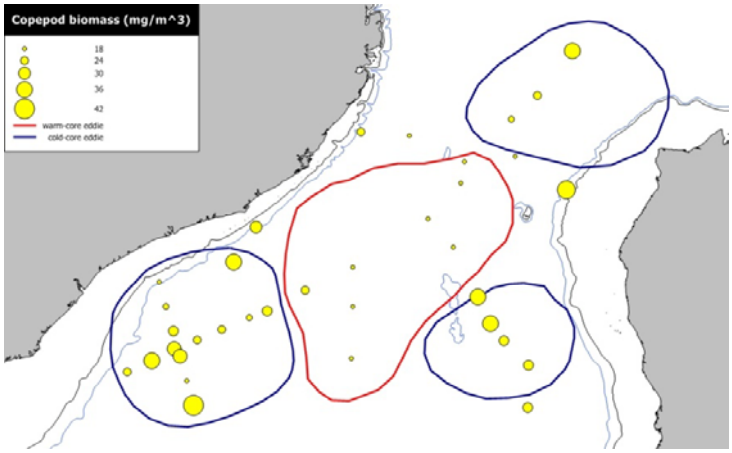


Fig. 3.7.3b: small copepod (<1mm) biomass distribution

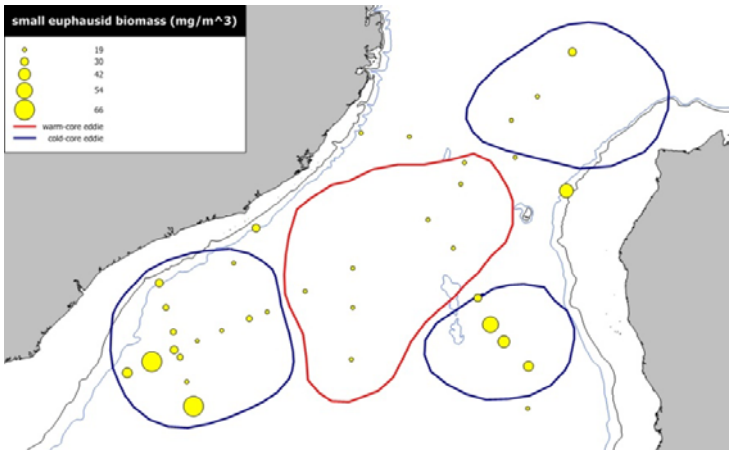


Fig 3.7.3c: small euphausid (<2mm) biomass distribution

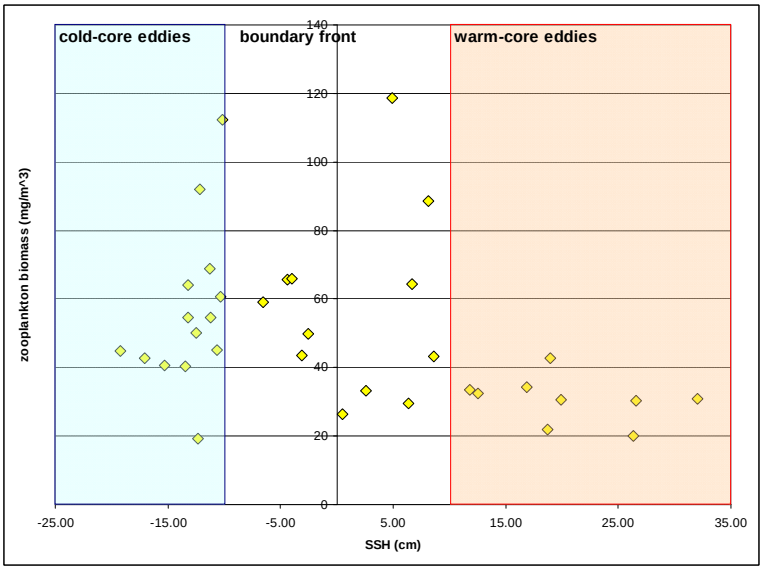


Fig.3.7.3 d: Biomass distribution of small zooplankton (< 2mm) in relation to physical anomalies (SSH = Sea Surface Height, AVISO data).

c) Multinet & Bongo biovolume

A rough index of zooplankton biovolume in the upper 200 m was obtained by recording the settled volumes in each sample jar and calculating the biovolume per square meter (using volume filtered and depth sampled). Mean mesozooplankton biovolume sampled by the Multinet during Cruise 4 was 105.2 $ml.m^{-2}$, and mean macrozooplankton biovolume sampled by the Oblique Bongo (500-µm fraction) was 74.1 $ml.m^{-2}$. A contour plot of mesozooplankton biovolume with depth (Figure 3.7.3 d) shows that most of the plankton was concentrated in the upper 100 m of the water column. The average weighted mean depth (WMD) of the biovolume was 54.7 m, and ranged between 29.7 and 85.1 m. There was no significant difference between day and night-time WMDs, suggesting that diel vertical migration was not important for this component of the zooplankton. High patches of biovolume from stations 1209-1223 were associated with the Mozambican coast and the convergence zone between the anti-cyclonic and cyclonic eddies.

A map of integrated zooplankton biomass superimposed on a plot of near-real time sea level anomaly (Figure 3.7.3 e) shows moderate to high zooplankton biomass associated with the cyclonic features in the south-west (off Mozambique) and south-east (off Madagascar), and relatively low zooplankton biomass associated with the large, central anticyclonic eddy. Biomass was high near the coast and in the convergence zone between the SW cyclone and the anticyclone. The map of macrozooplankton biovolume in Figure 3.7.3f shows a similar distribution to the mesozooplankton, although biomass was lower near the Mozambican coast. Biomass was higher off the edge of the Madagascar shelf, at station 1201.

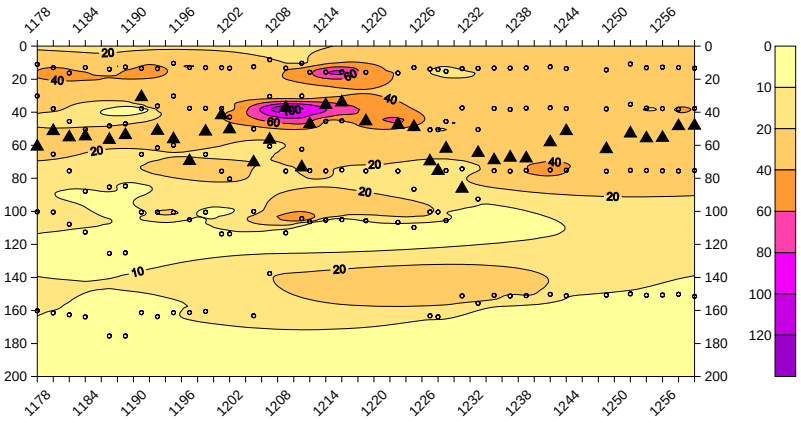


***Figure 3.7.3 d**: Contour plot representing the vertical distribution of mesozooplankton biovolume (ml.m^{-2}) from the Multinet during the eddy study. Each data point represents the integrated biovolume from the depth stratum sampled; small circles indicate the mid-point of each depth stratum. Large triangles indicate the weighted mean depth (WMD, m) of plankton biovolume at each station. Station numbers are shown on both upper and lower X-axes.*

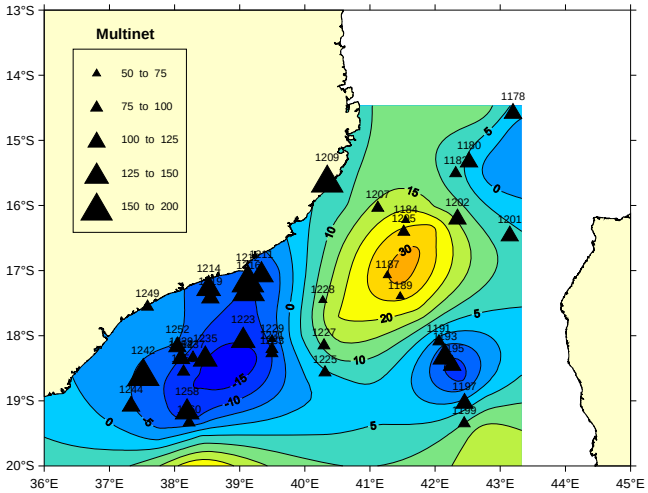


***Figure 3.7.3 e**: Map of integrated mesozooplankton biovolume (ml.m^{-2}) in the upper 200 m at each station superimposed on a contour plot of real time sea level anomaly (SLA, cm).*

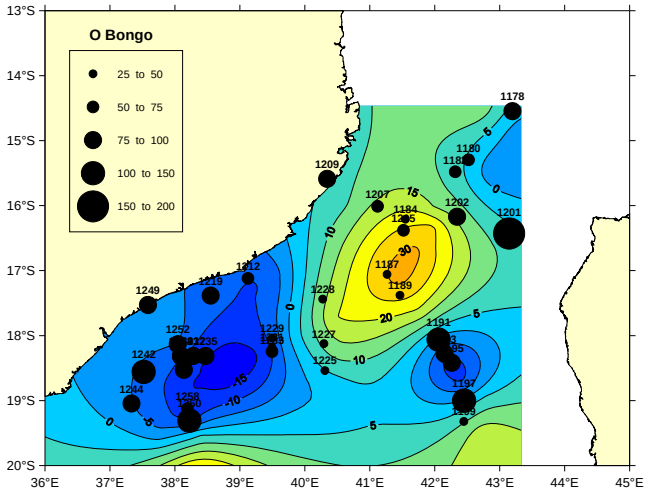


***Figure 3.7.3 f**: Map of integrated macrozooplankton biovolume (ml.m^{-2}) from the oblique bongo in the upper 200 m at each station superimposed on a contour plot of real time sea level anomaly (SLA, cm).*

There was a significant negative linear regression between Sea Level Anomaly (SLA, cm) and mesozooplankton biovolume collected by the Multinet (Figure 3.7.3 g), indicating high biomass associated with the cyclonic eddies (depressed sea level) and low biomass associated with the anticyclonic eddy (raised sea level). Interestingly, there was also a significant negative relationship between zooplankton biovolume and the sea surface anomaly gradient (Figure 3.7.3 h), with low biovolume in areas of high gradient and vice versa.

Attempts to measure rates of secondary production were hampered by the consistently high abundance of the cyanobacterium *Trichodesmium*, which dominated the small copepod size fractions, and the lack of sufficient female copepods for egg production incubations. Pelagic harpacticoid copepods are known to use colonies of *Trichodesmium* as both a substrate and a food source, and these small copepods were indeed observed to be very abundant. It is not clear, however, whether larger copepods feed on *Trichodesmium*, as some populations contain highly neurotoxic compounds, which the harpacticoids seem able to tolerate. At some stations high abundances of the large calanoid copepod *Rhincalanus rostifrons* (as well as other Eucalanidae) were noted, which appeared very healthy with bright red antennules and large amounts of lipid. It would be interesting to know whether they were able to feed on the *Trichodesmium*, and we hope that the isotope studies may provide some answers in this regard.

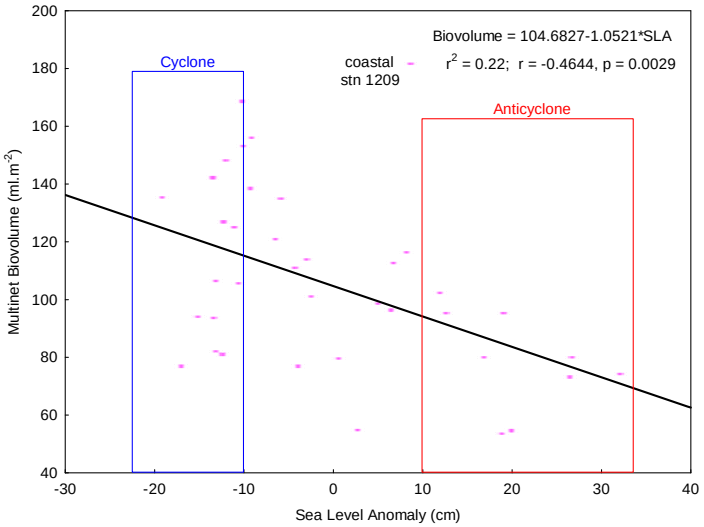


***Figure 3.7.3 g**: Linear regression of Sea Level Anomaly (cm) and Multinet Biovolume (ml.m^{-2}) showing significant negative relationship between these variables.*

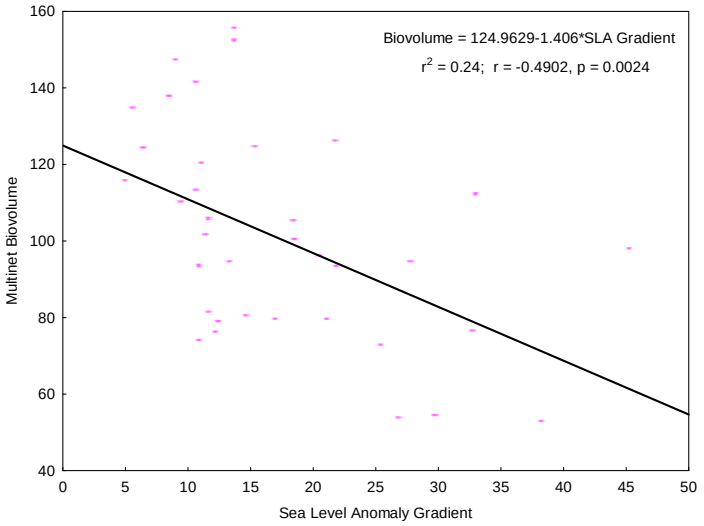


***Figure 3.7.3 h**: Linear regression of Sea Level Anomaly Gradient and Multinet Biovolume (ml.m^{-2}) showing significant negative relationship between these variables.*

3.7.4 Acoustics

The aim of the acoustic assessment was to study the spatial distribution of fish and zooplankton biomass continuously along our cruise track, on a regional scale. Firstly, the objective was to look for the signature of mesoscale cyclonic and anti cyclonic eddies on the total "acoustic population", including micro organisms and fish. A second step will consist in the discrimination of organisms from each other using multi-frequency acoustical records, and in the assessment of integration indexes in order to get localized quantitative information. Thirdly, fish and deep scattering layer behaviour will be analysed.
The overlap of environmental, biological and acoustic data will bring a new insight on the functioning of the ecosystems dynamics.

Oceanographic measurements and trawl fishing were carried out during the day as well as at night. Usually at least one trawl was performed every day in the morning/afternoon and/or at night. The cruise track was designed in order to conduct detailed description of different mesoscale features in the area. The strategy, for acoustic / fishery, consisted of conducting trawling according to the scattering structures observed during the acoustic survey.

Fish sampling strategy

Structures were almost the same all along the cruise:

- at day, a thin or thick surface layer. Small (scarce) fish aggregates or scattered fish have been observed below the surface layer. At depth (500 m) a deep and dense scattering layer (Fig 3.7.4 a) was observed.
- at night, the DSL ascended up to the surface; some less dense layers remained at depth (3.7.4 b).
- at dusk (upward) and dawn (downward), the DSL migrated rapidly between the surface and 500m depth (Fig 3.7.4 e).

Trawling was performed in all these different features

Design of the acoustic survey

Most of the acoustic data have been collected along straight transects designed to explore the mesoscale eddies field of the studied area. This strategy, linked to the "environmental" objectives of the cruise, differs from the classical shape of acoustic survey (gridding coverage of the prospected area) and results in limited goals in the acoustic survey, particularly in terms of fish aggregates prospecting.

Rectangular surveys called "magic squares" were performed twice during the cruise (2/12/08 on the eastern side of the Channel and 12/12/08 on the western side) in order to study the migration of the Deep scattering Layer (DSL) before and after dusk. "Magic squares" started before dusk and ended after night fall. They were respectively a 6x6 nautical miles square at a speed of 10 knots, and a 3x3 nautical miles square at a speed of 5 knots. The analysis of the Target Strength (see below) will inform us about the migration process

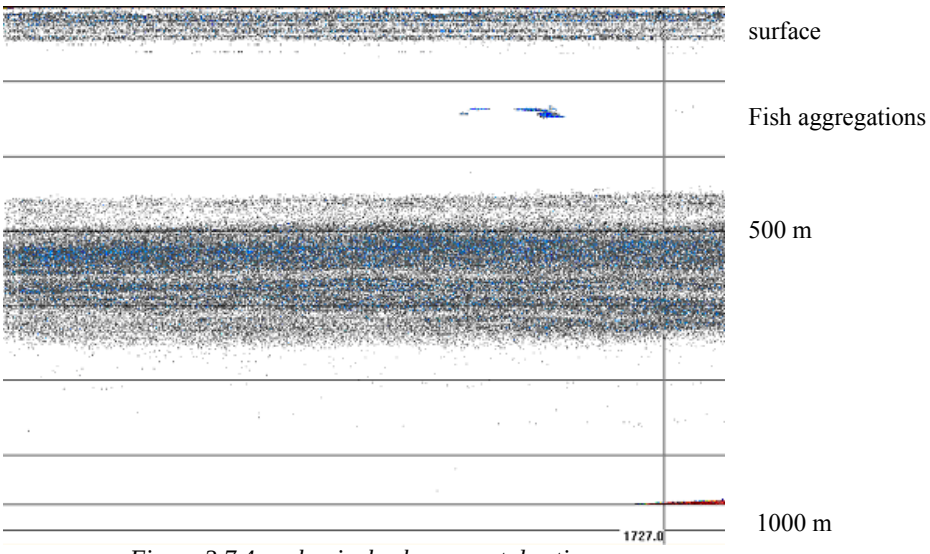


Figure 3.7.4 a classical echogram at day time

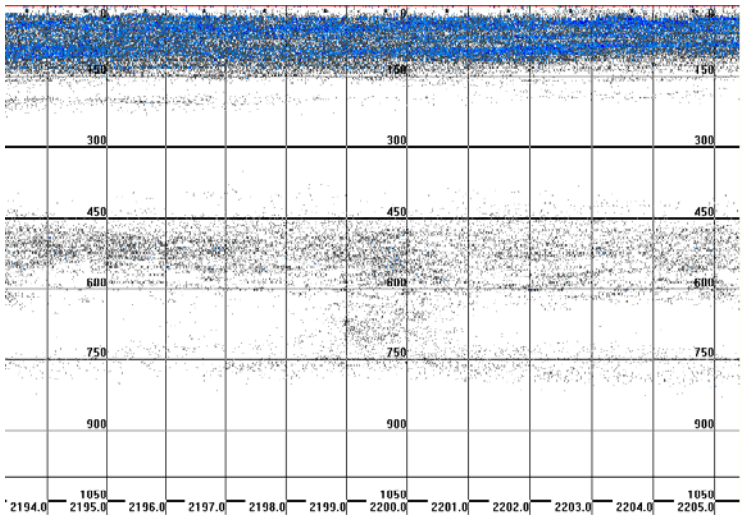


Figure 3.7.4 b classical echogram during the nigh

Data processing

Acoustic data were collected with 4 synchronized SIMRAD split-beam ER60 echo sounders with hull-mounted transducers. The frequencies used were 18, 38 (fig.3.7.4 d), 120 and 200 kHz; the pulse durations were all set at 1 ms. The water column was sampled down to a depth of 1000 m. Acoustic and navigation data were stored on a PC equipped with the Movies+ IFREMER software (which is usually used by the French acoustic team - fig. 3.7.4 c). It was not possible to perform the direct processing of the data with the IFREMER software (incorrect software settings). So, data were reprocessed one day after their acquisition through the Movies+ software. A –80 dB threshold was applied on data to reject noise and non-micronekton organisms.

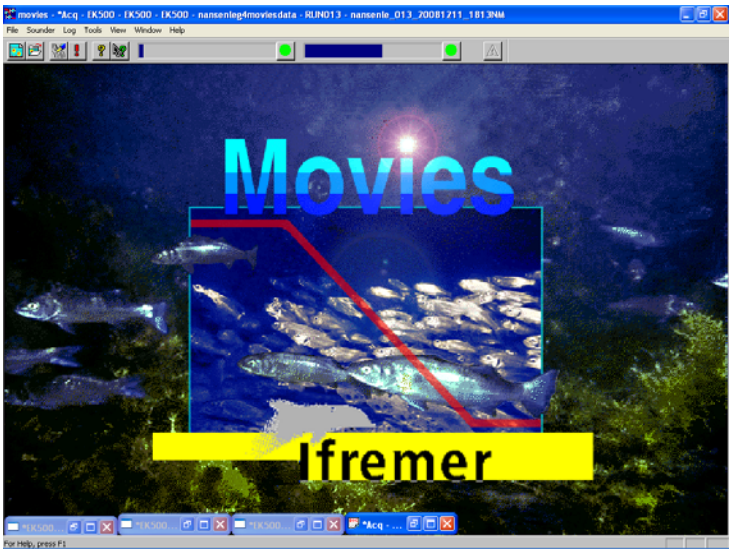


Figure 3.7.4 c the Movies software

Frequency:	38000 Hz	Beam Type:	Split
Gain:	25.82 dB	Two-way Beam Angle:	-20.60 dB
SaCorrection:	-0.53 dB	Absorption:	7.90 dB/km
Bandwidth:	2425 Hz	Sound Velocity:	1503 m/s
Sample Interval:	0.1924 m		

Angle Sensitivity,	Alongship:	21.90	Athwartship:	21.90
3dB Beam Width,	Alongship:	6.95°	Athwartship:	6.99°
Angle Offset,	Alongship:	0.11°	Athwartship:	0.04°

Figure 3.7.4d the 38 kHz transceiver settings

The 38 kHz echo-sounder is the best suited for general observation purposes (visual acoustic survey, biomass assessment). Other frequencies are more useful for discrimination purposes in the data analysis process (see below)

The total acoustic back-scattering energy per surface unit (s_A) values was calculated along the full survey track and for each trawl (fig. 3.7.4e). Target Strength measurements (individual acoustic response of organism or fish) were performed (fig. 3.7.4f) when the ship stopped for CTD stations. These indexes will be used later as conversion factors of the acoustic back-scattering energy per surface (s_A) into fish weight (biomass assessment).

The next step of the data processing will be the post processing of 3 of the 4 frequencies. Considering that organisms do not have the same acoustic response at different frequencies, the multi frequency analysis, performed using frequency masks (by overlapping and comparison between these frequencies), allow us to discriminate plankton and fish.

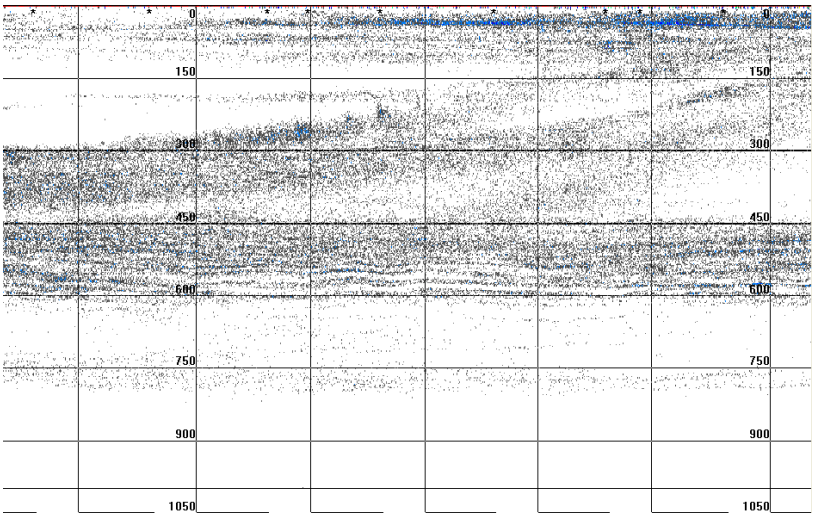


Figure 3.7.4 e the rising of the DSL at dusk

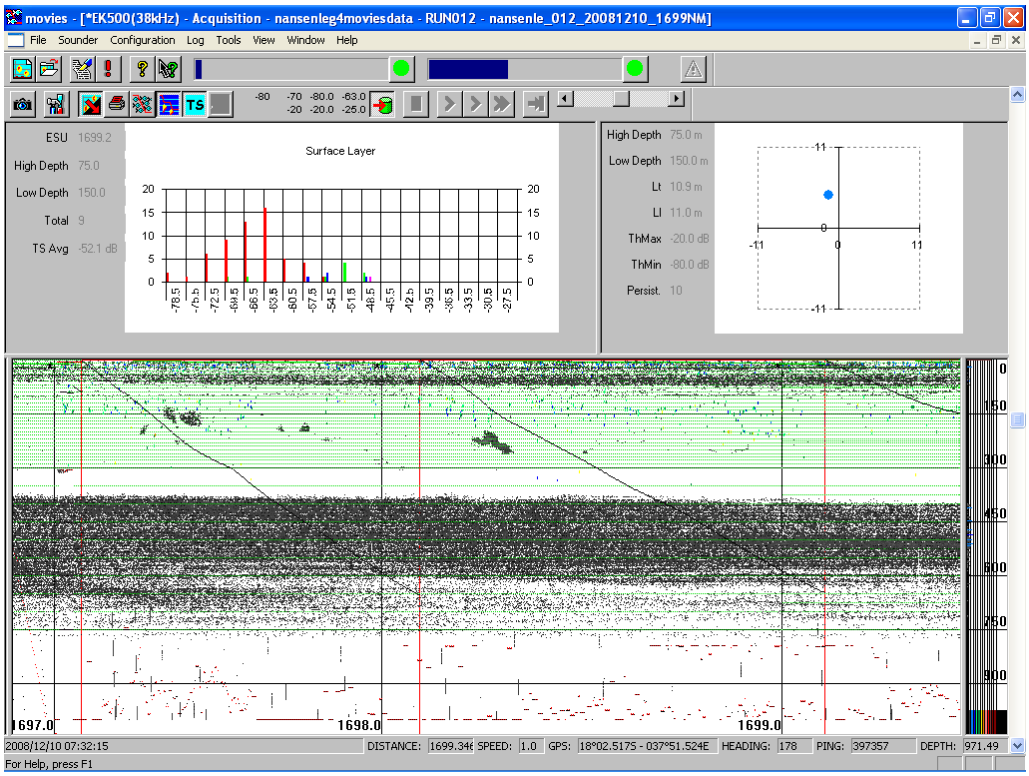


Figure 3.7.4 f TS measurements histogram on the top left hand side, echo tracking on the top right and the targets measured shown on the echogram.

First results

1- The global spatial distribution of the biomass

The total acoustic energy (acoustic density) have been measured along straight routes. Therefore, data collected cannot be processed by the usual gridding methods which requires a gridded horizontal survey of the area by means of radial transects geostatistically spaced. Hence, we only got vertical profiles which provide us with a rough idea of the biomass spatial distribution in the studied area.

The final product is an overlay of a large view of the sea level anomaly (SLA, in cm) and the acoustic densities (in m^2 nm^{-2}) collected along the route (*Figure 3.7.4 g*). For this preliminary presentation of the results, we chose to use the SLA map corresponding to the 08/12/2008. So, good correspondence between acoustic and SLA, on this figure, is mostly expected for the end of the survey (south of 19°S).

Three types of zoning could be differentiated (*Figure 3.7.4 g*):

- inside the anticyclones, where acoustic densities are below the mean average (zone a).
- zone where both (1) convergence or divergence occurs and (2) shallow water (less than 1000m depth) corresponding to coastal shelf or submerged bank in the north of the area – (zone b). Shelf-break upwelling (starting from 1000 up to shallow waters) together with trapped waters trapped at the eddies boundary could explain the richness of these areas.
- inside or at the boundary of offshore cyclones, where high acoustic densities have been detected (probably linked to cyclonic mesoscale dynamics) – (zone c). These areas seem to be located mostly at southern edge of the cyclones on figure 3.7.4 g, but we have to be aware of the non synchronicity of the two sources of information (i.e. acoustics vs SLA).

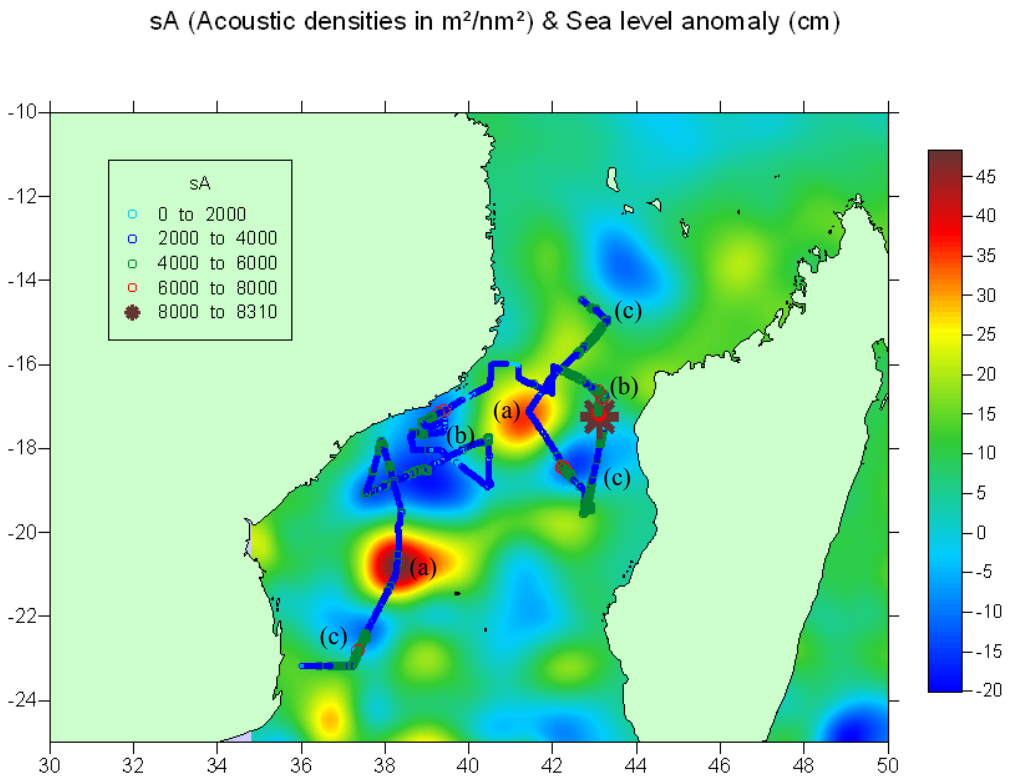


Figure 3.7.4 g Overlay of acoustic densities and sea level anomalies with the 3 types of zones (AVISO data for the 08/12/2008)

2- Target Strength (TS) analysis

Similar patterns are recurrent when looking at the TS spectrum. Typically, TS histograms show 2 distinct modes (fig.3.7.4h):

- first mode from -80 dB to -58 dB
- second mode from -58 dB to – 40 dB

Previous work has "calibrated" TS measurements by means of trawl samplings, and we can apply some of these TS results to our survey before starting more advanced analysis:

- Small Euphosiacee: from – 79 to -76 dB
- Large Euphosiacee: from -70 to -64 dB
- Squids: from -61 to -58 dB
- fish: from -55 to -44 dB (myctophids, cubiceps, and tuna-the highest TS)

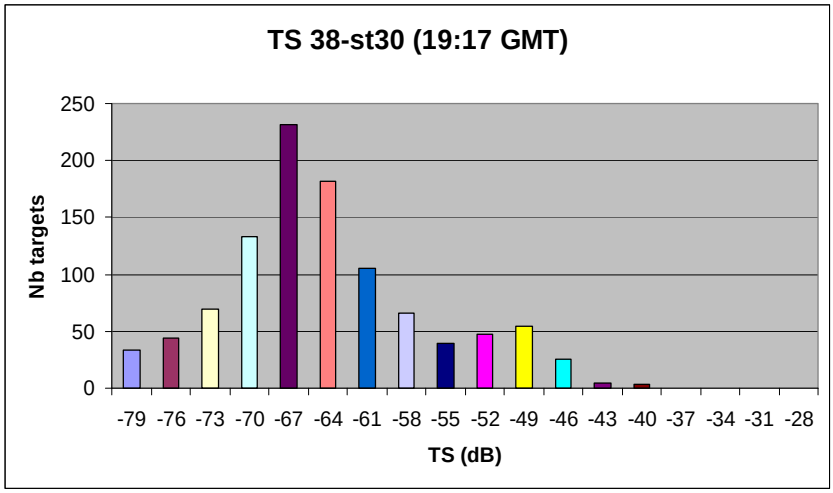


Figure 3.7.4 h TS histograms with the 2 modes showing different acoustic (TS) response for fish and micro organisms (colour is only for visual discrimination purpose).

3- Methodology for the discrimination between fish and micro organism (multi-frequency analysis)

This process will be carried out later. Indeed, several steps in the re-processing of the whole data set have to be achieved prior to the analysis, in order to work on a "clean" and coherent data sets for each of the 3 frequencies (38, 70 and 120 kHz). In this report, we only mention general information on the methods to be used for discrimination purposes.

The multi-frequency data analysis deals with the different reflection index of a same target according to the frequency of the transducer (fig.3.7.4 i, from previous study). It is therefore possible to discriminate plankton and fish by means of "acoustic masks" resulting from the combination of 2 or 3 frequencies (fig.3.7.4 j, from previous study).

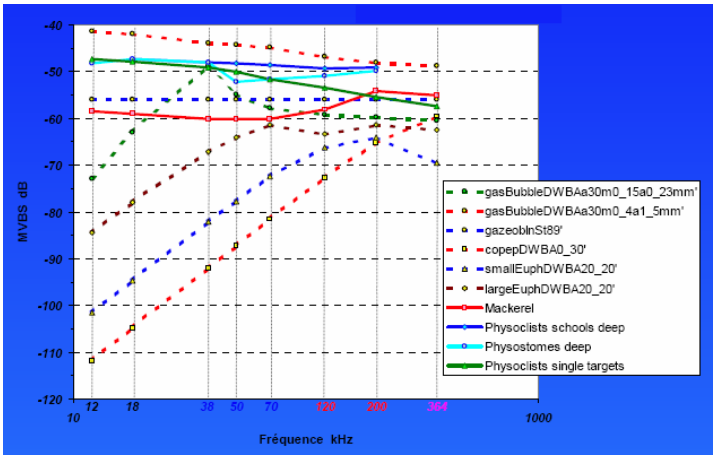


Figure 3.7.4 i Target acoustic response vs. frequencies.

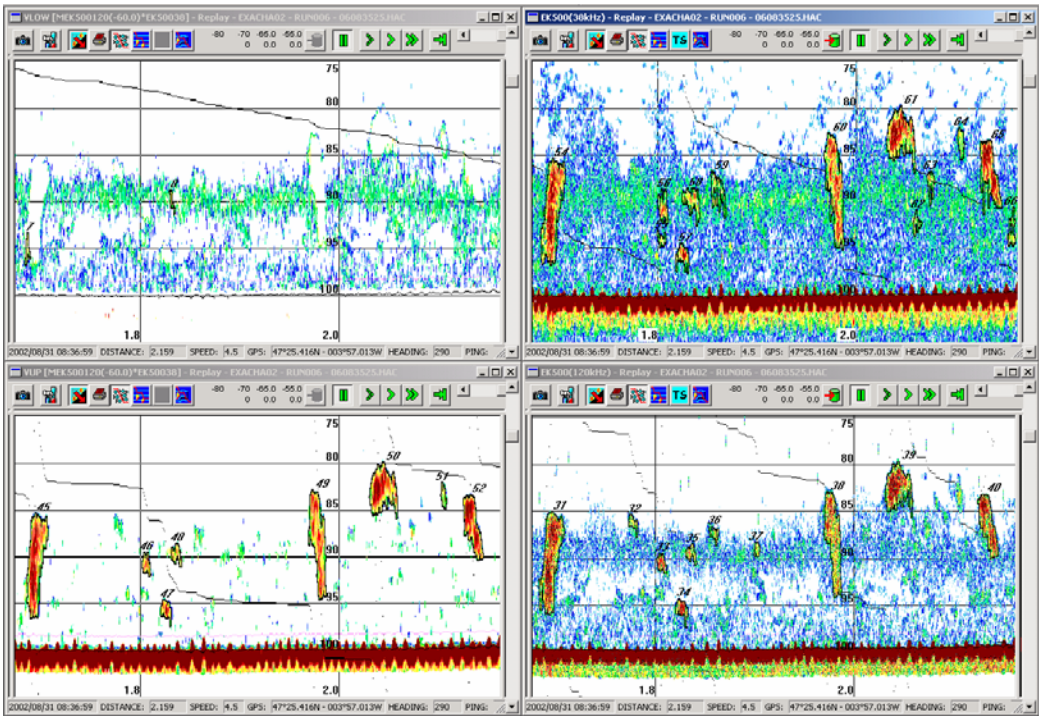


Figure3.7.4 j (upper left side): upper Mask of EK38 by EK120 with a threshold of –50dB, fish is then removed; (lower left side): lower Mask of EK38 by EK120 with a threshold of –50dB, plankton is then removed

Conclusion

The survey has been conducted very well thanks to the skill of the crew and the scientists on board. In terms of the acoustic survey and fishing trawl strategy, the general strategy of the cruise corresponding to a "physical oceanography

cruise" was not optimal. Better results would have been achieved with a "gridding oriented" approach. However, specific acoustic / fishing operations have been achieved during the cruise (so-called "carrés magiques"), and the whole cruise was an interesting experience especially in the view of future cruises with a similar multi disciplinary approach.

3.7.5 Fish trawls

Trawl sampling procedures

The standard pelagic trawl of R/V Dr Fridtjof Nansen, an akrahamn pelagic trawl, was used in the survey.

A standard haul was 30 minutes long, at 3-5 knots. The exact time for start and stop of the trawl operation was determined by SCANMAR sensors. The output from the SCANMAR system was also recorded on files to facilitate future analysis of opening and depth of the haul set.

The objective of the trawls was to analyse the fish assemblages encountered at day and night, in the different physical structures sampled during the cruise. The results of the trawls will be compared to the analysis of the stomach contents of large predators caught by longliner in the same structures a few days later.

Handling the catchability

In most cases, the whole trawl catch was sorted and all species were recorded with their weight and numbers. For big catches, the abundant species were sub-sampled while less abundant species were dealt with individually. Length measurements (Fork Length) were taken for target species. The length of each fish was recorded to the nearest 0,5 cm. The mantle length of squid was measured to the nearest 0,5 cm.

A manual measuring board and calipers were used for length measurement. Overall sample weights were recorded by Scanvaegt electronic balances and a Marle balance was used for single fish and small species measurements.

Biological samples

Biological samples were collected for the main prey species of tuna predators, mainly the longfin fatherhead (*Cubiceps pauciradiatus*), some myctophid species (*Myctophum asperum*, *Diaphus richardson*i, identification must be completed), and the ommastrephid *Sthenoteuthis oualaniensis*.

For the sampled individuals, lengths and weights were collected. On subsamples, pieces of white muscle tissues were removed for isotope and lipid analysis. For isotope analysis, samples were dried in an oven for 48h at 50°C and preserved in cryotubes. The lipid samples were preserved in Folch solution (Chloroform/methanol 2:1).

All remaining samples were then frozen to allow for future collection of additional samples for identification and isotopes.

Results

17 trawls (7 at daytime and 10 at night) were performed during the cruise (Table 3.7.5a, Fig. 3.7.5a). Night trawls were performed at the surface between 10 to 20 m depth were a DSL was detected (Fig. 3.7.5b). At daytime, 2 trawls targeted small aggregations detected at the surface under flocks of sooty terns (*Terna fuscata*) and schools of small tunas (*Katsuwonus pelamis*), two were done at 200 m depth on fish aggregations and three in the DSL present between 300 and 500 m depth.

Overall catch

Fish and cephalopod were the main components of the catch (70.5% and 22.4 % respectively). Gelatinous plankton represented 6.9% of the overall catch and crustaceans were a negligible part (0.3%).

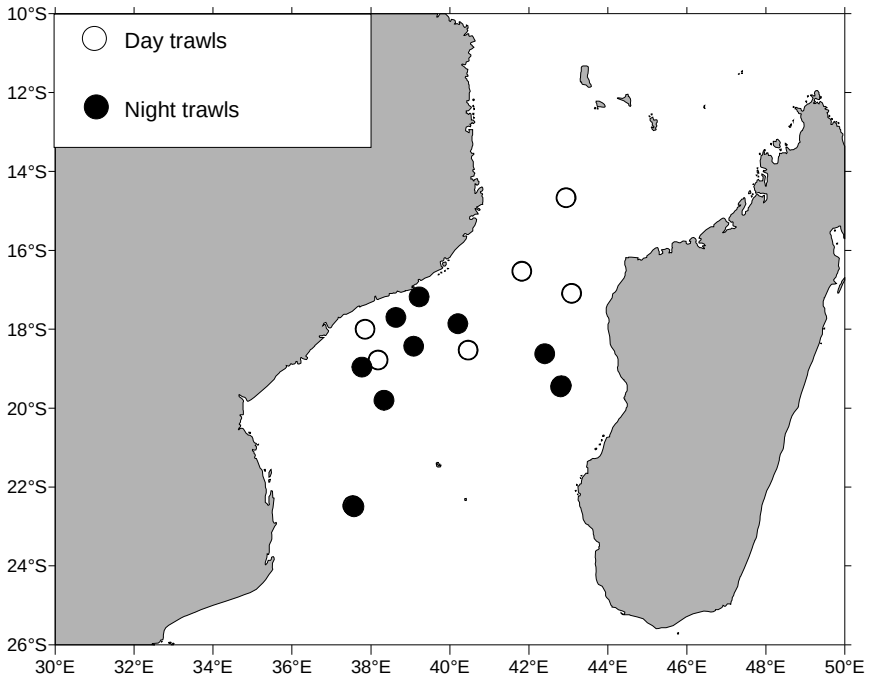


Figure 3.7. 5a. Location of the trawls performed during the Nansen cruise from 28 November to 17 December 2008.

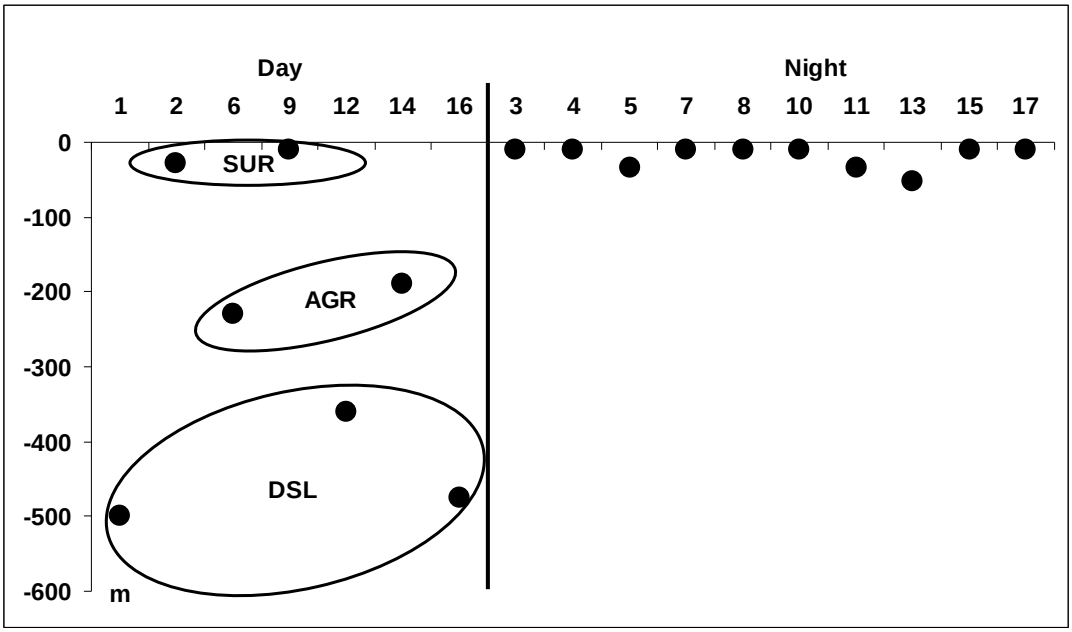


Figure 3.7.5 b Depth of the different trawls performed during the Nansen cruise from 28 November to 17 December 2008. (SUR: Surface, AGR: aggregations, DSL: Deep Scattering Layer).

Diel variations were observed in the composition of the main zoological groups. At night, the proportion of fish and cephalopod increases (Fig 3.7.5c), gelatinous plankton and crustaceans being negligible parts of the catch. At daytime, gelatinous plankton becomes the main component of the catch with fish, crustaceans and cephalopods representing only 2% of the catch (Fig 3.7.5d).

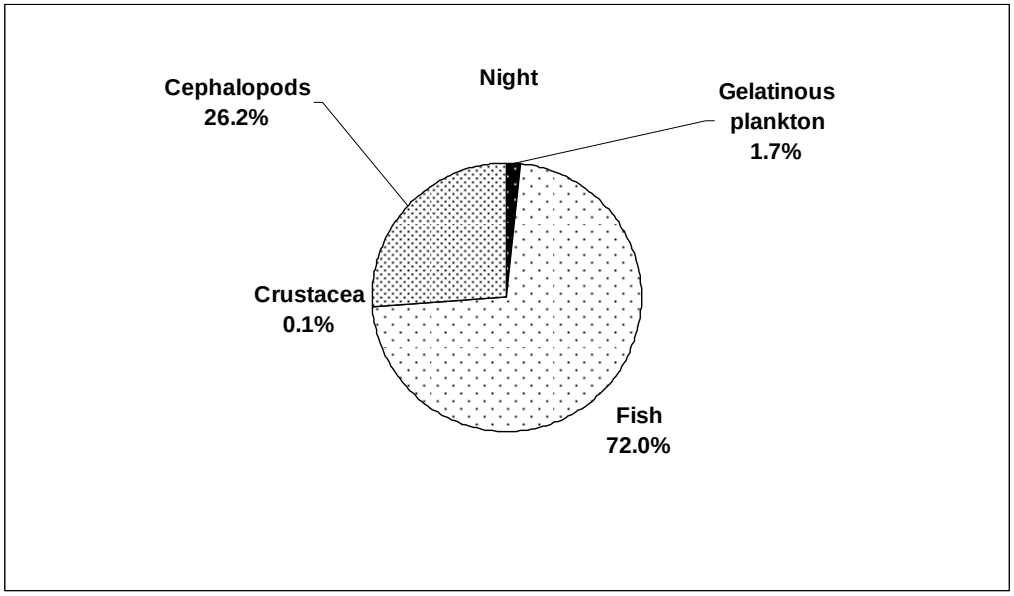


Figure 3.7.5c Composition of night catches according to the main zoological groups.

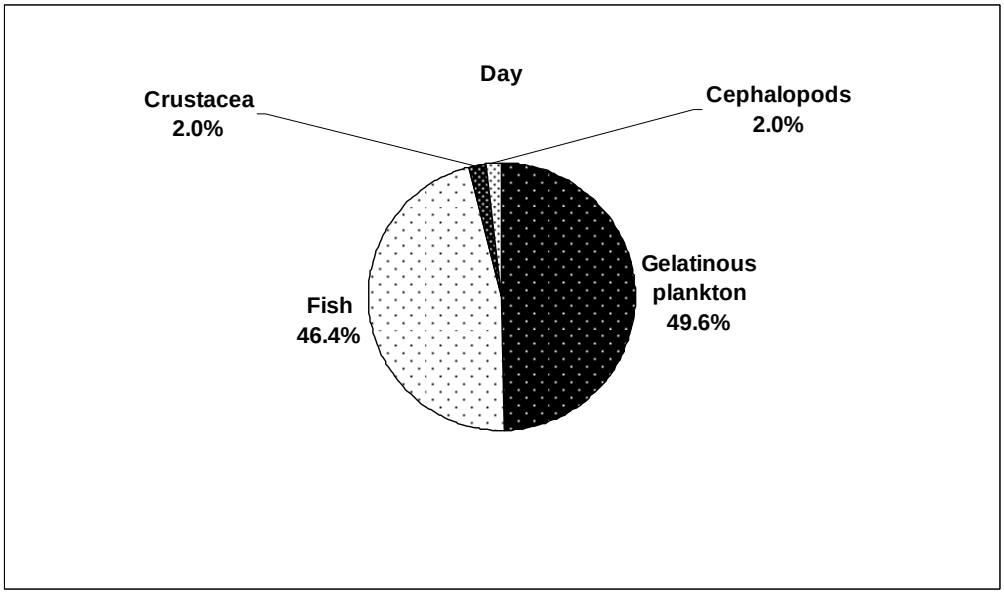


Figure 3.7.5d Composition of daytime catches according to the main zoological groups.

Catch composition by main zoological group.

Gelatinous plankton.

Different forms of gelatinous plankton were recovered. Salpidae, Siphonophorae and Heteropods (*Pteroderma palmatum*) were the most frequently observed. At night, gelatinous plankton was never abundant. During daytime, however, it could represent more than 60% of the catch when trawls were performed in the DSL (300-500m depth).

Crustacea

Whatever the period of the day, crustacean were rarely recovered from the trawls. 13 species of crustaceans were collected. Stomatopods, brachyourans and palinurids individuals collected were always larval forms. Shrimps were represented by two families; the peneidae (*Funchalia taaninggii*) and the oplophoridae (*Oplophorus typus, Oplophorus spinosus*). Amphipods group consisted of species from different families (*Platyscelus ovoides*, *Phronima sedentaria*, *Phrosina semilunata*).
In number, Stomatopod larvae dominated the crustacean catch at night and daytime (Fig 3.7.5e). In weight, at night, stomatopod larvae remained the dominant item. At night, occurrence of shrimps were rare (one occurrence on ten trawls for *Funchalia taaninggii,* absence of the oplophorids). At daytime, these species were recorded in the deep trawls

performed in the DSL. They were absent from the surface trawls. It seems that these species are deep living species which do not perform diel migrations to the surface of the ocean. At daytime they are the main crustaceans items in weight.

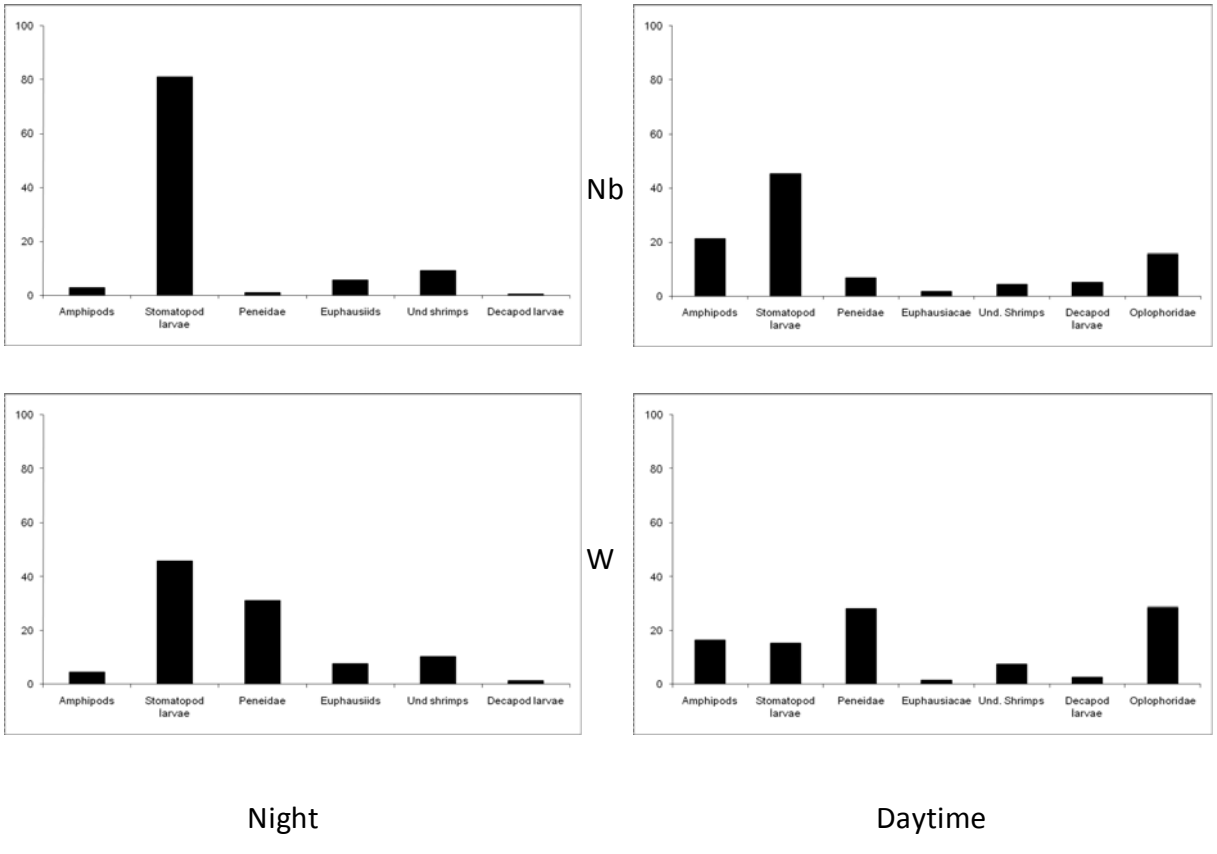


Figure 3.7.5e. Composition in number and weight (expressed in percent) of the crustacean catch during the Nansen cruise (28 November-17 December 2008).

Cephalopods

Five families of cephalopods have been collected. They were recovered in 3 daytime trawls (43% of occurrence) and 9 night trawls (90% of occurrence). Cephalopods were abundant in the night trawls for which they constitute the second item in number and weight. At daytime, two families (Enoploteuthidae, Cranchiidae) were recovered in the deep trawls. Pelagic octopoda and argonautids were recovered in the surface trawls. At night, most of the cephalopod catch consists in the flying squid species (*Sthenoteuthis oualaniensis*, *Ornithoteuthis volatilis*). *Sthenoteuthis oualaniensis* is the dominant species, *Ornithoteuthis volatilis* being represented by few individuals. At night, these species dominate the cephalopod catch in number and weight At daytime, the ommastrephids remain dominant in number, but pelagic octopods are dominant in weight.

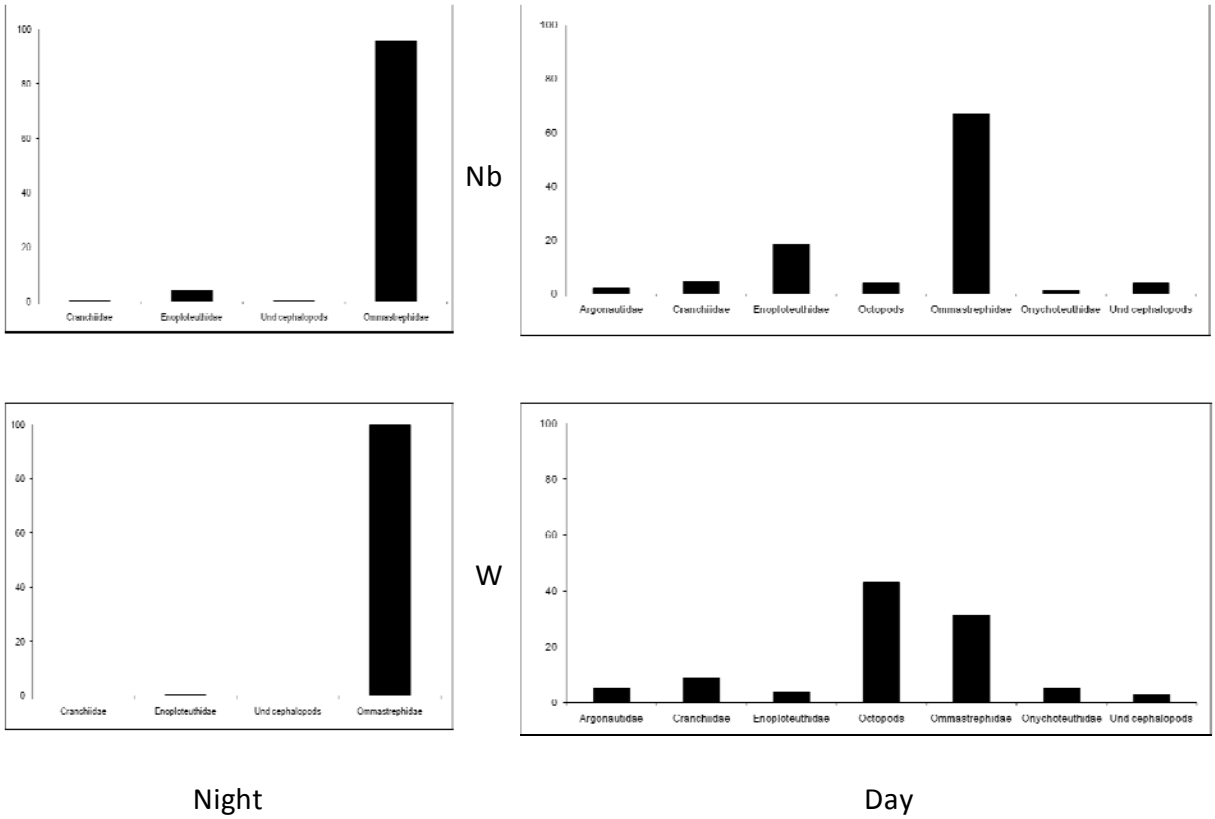


Figure 3.7.5f. Composition in number and weight (expressed in percent) of the cephalopod catch during the Nansen cruise (28 November-17 December 2008).

The overall size of the cephalopod catch was small (DML mean 8.5 ± 3.2 cm). Sizes (DML mean 3.2±0.8) observed were smaller at daytime than at night (DML mean 9.2±2.1). The size distribution of *Sthenoteuthis oualaniensis* shows a large mode at 8cm (Fig. 3.7.5g). Some large individuals (DML 36cm) were observed in the night trawls.

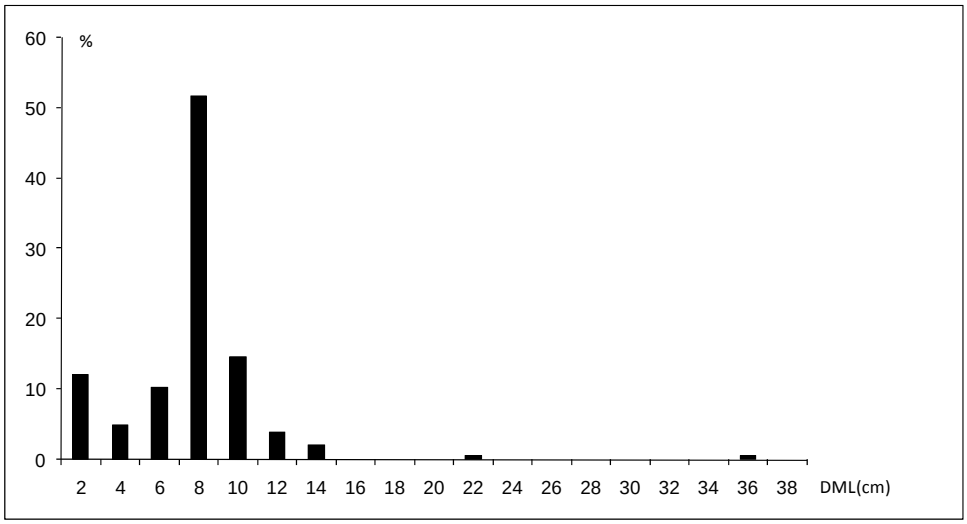


Figure 3.7.5g Size distribution of the flying squid Sthenoteuthis oualaniensis during the Nansen cruise from 28 November to 17 December 2008.

Fish

During the cruise, 12 families of fish were observed in the catches. Most of the epipelagic species were pooled in the Fish larvae category as they were juvenile forms of coral fishes (Monacanthids, Acanthuridae, Pomacentridae, Balistidae) and large pelagics (Scombridae, Carangidae). Adult forms were mesopelagic species of the myctophids,

diretmids, parelepidids, gempylids families, and meso-bathypelagic families (sternopthychidae, melanostomiidae, gonostomatidae, chauliodontidae). These deep-living forms were collected during deep daytime trawls and never during the night trawls. Fish larvae occurred during daytime and night surface trawls.

In number, the fish larvae and the myctophid family dominated the fish catch whatever the period of the day. A similar picture was observed during daytime for the composition by weight (Fig. 3.7.5h). This can be explained by the occurrence of 2 trawls performed on fish aggregations which were exclusively schools of the myctophid fish (*Diaphus richardsoni*).

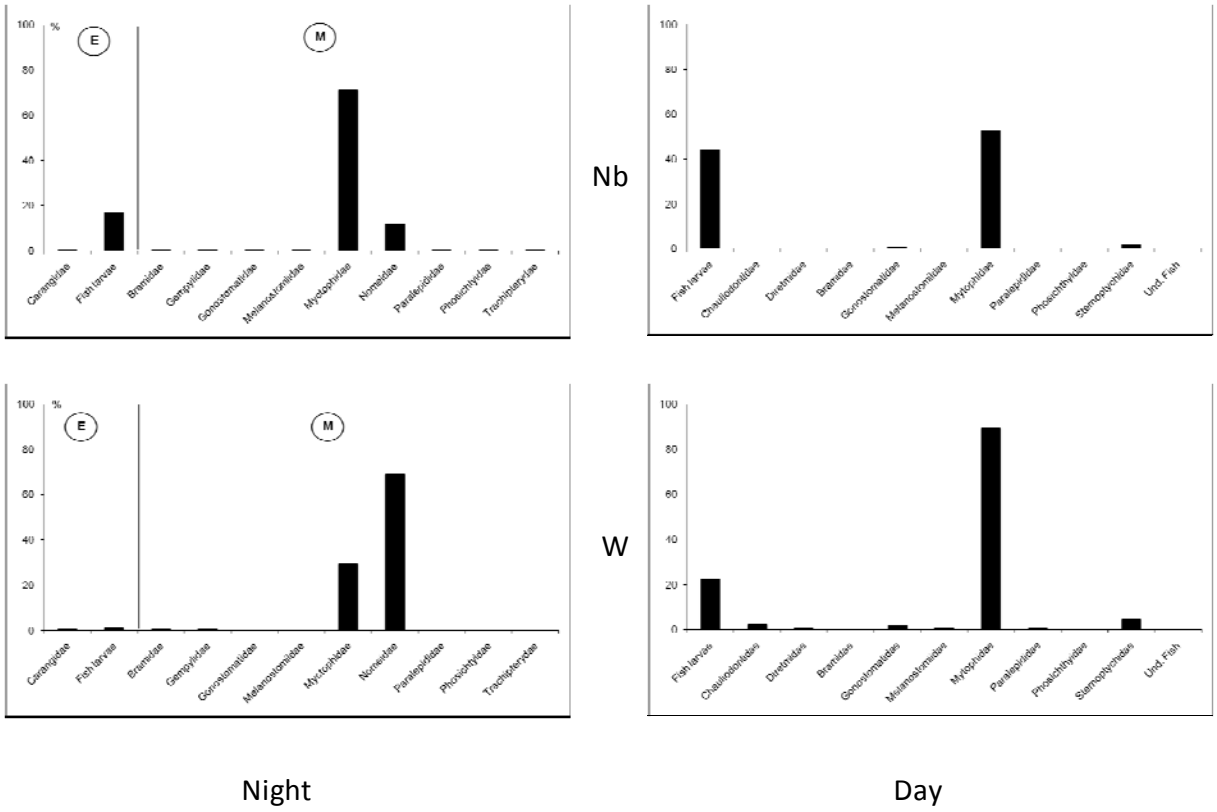


Figure 3.7.5h Composition in number and weight (expressed in percent) of the fish catch during the Nansen cruise (28 November-17 December 2008). E = epipelagic, M = mesopeagic

The two surface trawls were dominated by fish larvae. Sooty tern and small tunas were feeding on these aggregations.

At night, the nomeid (Cubiceps pauciradiatus) was the main item in weight. This fish was absent from the daytime trawls. In the trawls, the remaining species are represented by few individuals. Among them, paralepidids were the most common catch, several individuals being caught regularly in the night trawls.

At depth, the species of the Sternopthychidae family (*Argyropelecus aculeatus, Argyropelecus sladeni, Argyroplelecus affinis*) were regularly present.

As observed for the cephalopod catch, the mean size of the fish catch is small. Again, the size of the fish being smaller at daytime (FL mean 3.8±2.2) than at night (FL mean 9.6±2.5cm). The size distribution of *Cubiceps pauciradiatus* is characterized by two modes, one at 9 cm which represents fish just acquiring maturity, and another one to 12cm corresponding to the adult fish (Fig. 3.7.5i).

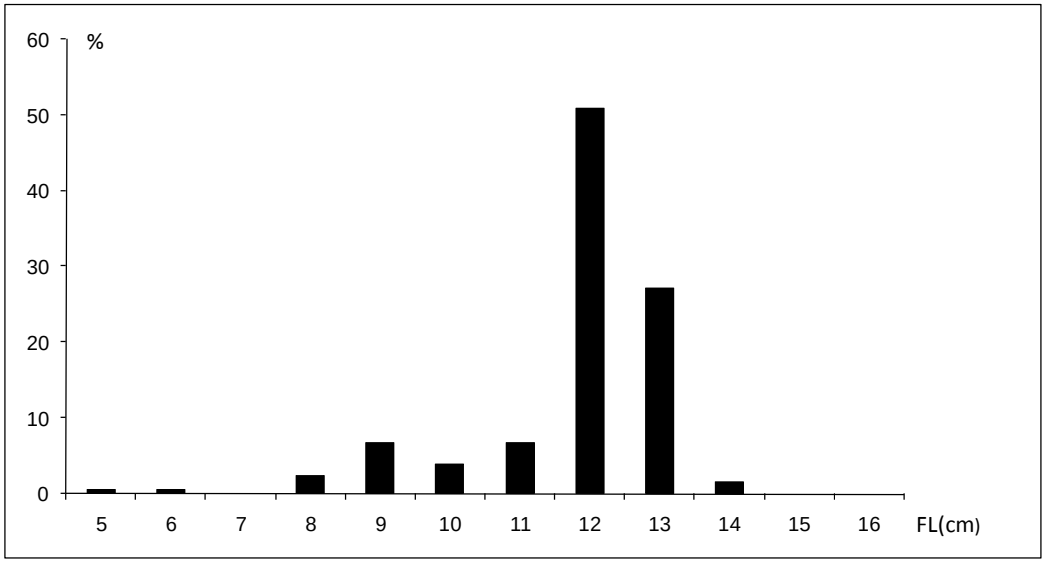


Figure 3.7.5i Size distribution of the nomeid fish Cubiceps pauciradiatus during the Nansen cruise from 27 November to 18 December 2008.

The size distribution of the myctophids covers a large spectrum, from 1 cm to 10cm lengths (Fig. 3.7.5j). Different species were identified, but identification must be verified by specialists. Possibly, then the different modes observed will refer to different species.

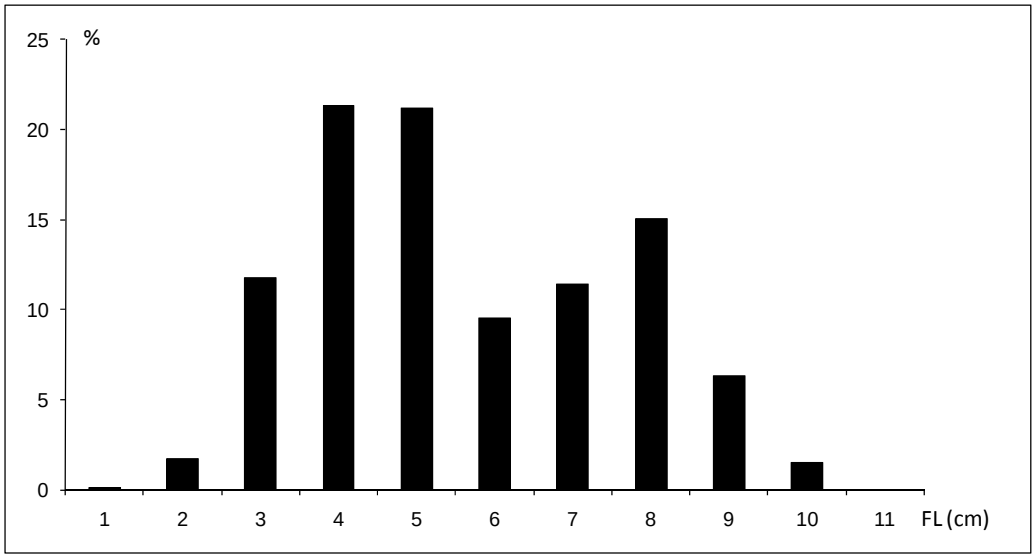


Figure 3.7.5j. Size distribution of the myctophids caught by trawl during the Nansen cruise from 27 November to 18 December 2008.

Table3.7.5a_Summary of the different pelagic trawls performed during the Nansen Cruise from the 28 november to the 17 december 2008.
D : Daytime, N: Night.
C : Cyclone eddy, AC : Anti cyclone eddy, I : Intermediary zone

Trawl	Physical Structure	Date	Latitude	Longitude	Gelatinous plankton (g)	Crustacea (g)	Cephalopods (g)	mean±std (cm)	Fish (g)	mean±std (cm)
1D	I	28.11.08	14°40'20	42°56'80	3999.34	20.5	0.1		510	5.4±2.1
2D	AC border	30.11.08	16°32'12S	41°49'53E	20	11.7	70	3.3±0.5	273.3	2.9±2.5
3N	C	01.12.08	18°37'55S	42°23'99E	34	10	1850	9.8±3.4	21556	6.8±3.1
4N	C border	02.12.08	19°27'66S	42°48'33E	270	0	4750	10.2±4.8	22130	9.8±2.7
5N	C border	02.12.08	19°26'30S	42°49'80E	30	10	1430	7.2±2.1	3480	7.0±3.7
6D	C border	03.12.08	17°05'75S	43°05'25E	82	18	8		2942	3.8±1.9
7N	I	05.12.08	17°11'97S	39°13'39E	25	4	1932	9.8±1.2	5929	8.6±6.0
8N	I	06.12.08	17°42'34S	38°38'81E	400	4	10530	9.7±1.7	6585	7.2±4.1
9D	AC border	07.12.08	18°32'85S	40°28'11E	149	2.2	25.8	3.0±1.0	609.4	2.9±1.1
10N	AC	08.12.08	17°52'25S	40°12'98E	168	4.9	16.3		197.7	2.8±2.1
11N	I	08.12.08	18°26'19S	39°05'57E	280	14	853	6.7±3.0	6020	6.3±3.9
12D	C	09.12.08	18°47'12S	38°11'92E	751	17	20	3.2±0.9	435	3.8±1.7
13N	C	09.12.08	18°58'48S	37°46'68E	60	24	335	8.5±1.0	11169	7.3±3.7
14D	C border	10.12.08	18°02'90S	37°51' 85E	163	89	123		63	2.8±1.3
15N	AC border	11.12.08	19°48'11S	38°20'26E	350	3	950	10.0±1.2	463	3.9±2.4
16D	AC	12.12.08	22°28'98S	37°31'95E	1285	97	15	4.5	1199	6.7±4.6
17N	AC	12.12.08	22°30'40S	37°33'44E	273	5	6070	9.8±1.5	1491	8.4±2.8

3.7.6 Predator observations

Observations of seabirds, cetaceans and flying fish were carried out daily from the upper front deck of the vessel or from within the bridge on days of inclement weather. A total of 157 observation hours was conducted. At all times every effort was made to identify the species of bird and cetacean. For flying fish, criteria used to separate "species" were common distinguishing features, most often e.g. pectoral fin colour.

Nineteen species of seabird were observed on Leg 4. Two vagrant species were also observed. The dominant seabird species on the cruise was the Sooty Tern *Sterna fuscata*, especially in the north and central regions surveyed. Sooty Terns were relatively sparse elsewhere. They were replaced by the Common Tern *Sterna hirundu* in the south-east on the last day of the survey. Red-footed Booby *Sula sula* attended the vessel on days when flying fishes were regularly encountered. The distribution of other seabirds in the survey region were a little haphazard, but much of the diversity seemed to mirror the north and east survey region. The sudden replacement of Sooty Tern by Common Terns on the 13th is of interest as both species were feeding in association with tuna.

Aggregations of Sooty Tern associated with feeding tuna were observed throughout the survey and these are shown in Table 3.7.6a. The information given on the 13th December are for Common Tern associated with tuna feeding.

Table 3.7.6a. Positions of feeding associations between terns and tuna

Date	Time	Number	Latitude	Longitude
29 November	05h05	14	14 03.661	42 05.082
	05h23	23	14 05.546	42 08.611
	06h48	81	14 16.364	42 27.757
	10h06	152	14 32.394	42 47.033
	10h58	183	14 38.254	42 54.887
	11h02	233	14 38.635	42 55.430
	15h11	59	14 55.803	43 18.520
30 November	06h20	126	15 48.242	47 30.856
	15h11	138	16 33.295	41 49.280
1 December	07h08	48	17 43.800	41 50.262
2 December	08h42	82	19 30.882	42 45.047
	08h45	64	19 32.164	42 44.860
	15h14	11	19 30.919	42 45.713
	16h27	93	19 25.378	42 24.087
	16h59	53	19 23.177	42 54.093
	17h15	33	19 21.721	42 52.895
3 December	06h31	38	17 51.257	43 08.203
	06h34	166	17 49.678	43 08.531
	09h50	356	17 22.148	43 09.420
	11h23	114	17 07.513	43 05.138
	11h55	63	17 04.900	43 05.440
4 December	07h00	54	16 15.221	42 00.204
4 December	13h31	87	16 36.676	41 47.945
	14h47	473	16 28.275	41 32.275
6 December	12h20	19	17 40.104	39 59.180
7 December	09h55	91	18 40.815	39 09.599
12 December	05h15	58	21 06.867	38 12.070
	06h15	29	21 24.990	38 03.437
	14h40	154	22 21.311	37 34.215
13 December	12h38	134	23 11.556	35 51.205
	13h00	98	23 12.158	35 47.148

Some Sooty Terns were seen to grab small slender silver fish. A bird aboard at night regurgitated several small Ommastraphid squid, *Stenotuethis ovalaniensis*, a species caught frequently in trawls conducted on the survey. On 13th, Common Terns (no Sooty Terns) were the dominant species feeding in association with feeding tuna.

One White-chinned Petrel *Procellaria aequinoctialis* and four Great-winged Petrel *Pterodroma macroptera* were seen for the first time after the survey was completed (15th).

SEABIRDS

Sooty Tern	*Sterna fuscata*	4494
Common Noddy	*Anous stolidus*	83
Crested Tern	*Sterna bergi*	4
Lesser Crested Tern	*Sterna bengalensis*	7
Common Tern	*Sterna hirundo*	360
Black-naped Tern	*Sterna sumatrana*	70
Little Tern	*Sterna albifrons*	2
Unid. Tern	*Sterna spp.*	2
Audobon's Shearwater	*Puffinus Iherminieri*	3
Wedge-tailed Shearwater	*Puffinis pacificus*	6
Jouanin's Petrel	*Bulwaria fallax*	5
Black-bellied Storm Petrel	*Fregetta tropica*	1
Wilson's Storm Petrel	*Oceanites oceanicus*	3
Great Frigatebird	*Fregata minor*	7
Red-footed Booby	*Sula sula*	16
White-tailed Tropicbird	*Phaethon lepturus*	2
Red-tailed Tropicbird	*Pheathon rubricuada*	2
Parasitic Jeager	*Stercorarius parasiticus*	3
Pomerine Jaeger	*Stercorcarius pomarinus*	2
Brown Skua	*Catharacta lonnbergi*	1
Madagascar Squacco Heron		1
Cattle Egret.		2

CETACEANS

Cetaceans were scarce, and when seen showed a tendency to avoid the vessel. This behaviour may be a consequence of acoustic equipment running continually to locate fish and uncharted topography. Only one feeding association between cetaceans, tuna and seabirds was observed. This was with False Killer Whales.

Sperm Whale	*Physeter macrocephalus*	5
Minke Whale	*Balaenoptera acutororostrata*	3
Bryde's Whale	*Balaenoptera edeni*	1
Cuvier's Beaked Whale	*Ziphius cavirostris*	5
Short-finned Pilot Whale	*Globicephala macrorhynchus*	2
False Killer Whale	*Pseudorca crassidens*	5
Bottle-nosed Dolphin	*Tursiops truncatus*	130
Common Dolphin	*Delphinus delphis*	50
Spinner Dolphin	*Stenella longirostris*	118
Pan-tropical Spotted Dolphin	*Stenella attenuata*	400
Unid. Dolphin		25
Unid. Whale		6

20 Risso's Dolphin *Grampus griseus*, 20 Melon-headed Whale *Peponocephela electra*, was seen together with 100 Spotted Dolphin and 10 Short-finned Pilot Whale, the morning after the survey was completed off Maputo.

FLYING FISH

257 unidentified Flying fish were observed. A further 196 were recognized as looking different. These were categorized into 12 different types of flying fish. Differences were based on, i) whether the fish

had one or two pectoral fins; ii) differing colour of pectoral fins, iii) differing lengths of pectoral fins or iv) distinctive body colour. All very small flying fish were categorized as unidentified. I would suspect that those I called "Type 1" which had a single transparent pair of pectoral fins would probably represent more than one species, as the detail on the pectoral fins was not always obvious. It cannot also be ruled out that the different colour pectorals fins of the other types may be males and females of a same species.

OTHER

No marine turtles or sharks were seen during the survey.

4 Summary and Conclusions

4.1 Summary of results

While much of the sample analysis remains to be done and data need to be put into context with the help of updated satellite imagery, preliminary results already suggest that the cruise as a whole was a success in terms of meeting its objectives.

A number of anti-cyclonic and cyclonic features were successfully transversed and their physico-chemical properties described. Cyclonic features were defined by strong central upwelling regions in terms of temperature, salinity and oxygen. The central portion of cyclonic eddies also exhibited elevated chlorophyll concentrations, presumably as a result of increased nutrient inputs and primary production. In contrast, anti-cyclonic features exhibited central downwelling and overall low biological biomass. Intermediate boundary zones between the eddies and areas close to the coast, at times also exhibited high chlorophyll biomass, but at this stage it is not possible to quantify the relative importance of new production vs coastal entrainment of "old" production in these systems. Preliminary data suggest that high surface chlorophyll values in the frontal regions are primarily a result of coastal entrainment. Further analysis of nutrients and stable isotopes should confirm this.

At higher trophic levels, animal biomass seemed to strongly reflect the availability of phytoplankton biomass at the base of the food-web and of prey species higher up the trophic chain. While more in depth analysis is required to confidently quantify these patterns, overall animal biomass (i.e. for zooplankton, fish, squid and birds) seemed to be highest in areas outside of the anti-cyclonic features. The one exception was that of gelatinous zooplankton, which tended to thrive in oligotrophic conditions and that was typically overestimated in wet-weight samples due to its high water content. It therefore appears, that mesoscale eddies are of prime importance to the pelagic life-support system of the Mozambique Channel by either producing and/or transporting nutrients and biomass into offshore environments.

Conversely, preliminary results also show that the offshore eddies may have far-reaching consequences for the coastal environment. Many of the birds, for example and the top-predator fish species such as tuna and swordfish (from acoustics) seem to aggregate and forage in areas of high eddy induced production. Through the foraging excursions of land-based birds and through fisheries landings for human-consumption, much of the captured offshore energy is transported to the coastline or land respectively. Furthermore, surface trawls undertaken during this cruise, have clearly shown that many coastal reef fish larvae are capable of surviving eddy induced dispersal for many 100's km and perhaps even across the Mozambique Channel. This observation is likely to have far-reaching consequences for our understanding of reef-fish dispersal, recovery and management.

Overall, the cruise was able to show that mesoscale features in the Mozambique Channel play a major role in producing and transporting energy in the pelagic realm and to thereby strongly support the Channel's life support system. More in depth analysis of samples and data will additionally answer questions on underlying physical, chemical and biological processes, energy-flow, overall productivity and the biology of individual species and assemblages.

4.2 Logistics

Overall, the cruise was successful in achieving most of its objectives and to a large extent, this was due to the professional handling of the logistics by both the crew and the scientists. For future purposes, however, a number of possible further improvements were discussed during a wash-up meeting on the last day of the cruise. The following should be regarded as an idealised wish-list.

1) **Top predator observations**: It was suggested that all weather day-time observations would be made possible if a permanent or temporary enclosure could be set up on the monkey-deck. This would facilitate continuous observations from the top of the ship in an area where radar and the satellite dome are otherwise considered dangerous.
2) **Bongos and multi-nets**: A request was made for more spare bongo and multi-nets of the right mesh-size to be carried on the Nansen. In several cases, mesh sizes and therefore sampling procedures had to be changed half way through a study, due to a lack of spares. It was also suggested that electronic flow-meters on the Bongo frames would facilitate more accurate data-acquisition as the existing mechanical meters were not very reliable.
3) **CTD**: Several of the Niskin bottles attached to the CTD rosette leaked and/or did not close/trigger at all times. Additional spare replacement bottles could forestall this becoming a problem in future. It was also suggested that a permanently fixed and depth rated PAR sensor would greatly facilitate additional biological information, especially in relation to phytoplankton work and productivity. The current PAR sensor, is rated to only 200m depth and cannot therefore be used during typical CTD casts that extend to 1000m or more. Additional and useful sensors (e.g. transmissometer / OBS / Turbidity sensors) could be provided by scientists. Would the Nansen consider installing these sensors for individual cruises that require them for biological surveys?
4) **Communications**: The installation of the OLEX system on the lab computer made a great difference to the scientists as it facilitated forward planning without visiting the bridge or acoustics. Would it be possible to additionally also slave acoustics and ADCP outputs to this computer? This is unlikely to be necessary for typical gridded fisheries surveys. On the other hand, during biological surveys, when searching for certain physical or biological features, it becomes necessary for the scientists to be immediately informed of any external changes that occur.
5) **Freezer storage**: Many types of biological samples require freezing at -80ºC or below. For future cruises, would it be possible to provide either a -80ºC freezer or allow for liquid nitrogen to be stored on board?
6) **Productivity**: During the past cruise, productivity incubations were performed with the stable ^{13}C isotope. This is a very sample-intensive and time-consuming methodology. A much higher resolution of productivity stations could have been achieved if it were possible to utilise radioactive ^{14}C isotopes. For future cruises, would it be possible to designate an area for radio-isotope work?
7) **Trawling and acoustics**: Trawling and acoustics were performed without any problems. However, the biological cruise strategy of sampling certain features of interest along straight lines, did not facilitate the ideal sampling grid as required for fisheries surveys. On future cruises this could be improved upon by: a) increasing the time available and then gridding the biological transects, b) reduce the number of hydrographic and biological stations to allow for more acoustic time, c) provide a second research vessel so that ideal acoustics grids and biological transects can be run in parallel. Realistically, slightly more time and an overall gridded sampling design would most likely optimise the situation as even for hydrographic measurements, a grid survey is preferable to simple straight lines. It was also suggested that a towed undulator (or similar) could be used to reduce the number of required hydrographic stations and thereby free up time for a more detailed gridded sampling strategy.
8) **Trainees**: The trainee's involvement in both the underway science and the analysis and interpretation of the data for this report was exemplary. Nonetheless, it was felt that in some cases our regional collaborators could have gained more out of the cruise had individual projects of interest been developed and made available to them. Due to time-constraints, this was not possible during this past cruise. For future purposes, however, this possibility should be investigated in more detail. Requests from two of the trainees were also made to remain part of the science team during the upcoming analysis and write-up of the research. Additional funding might have to be sought to facilitate their continual involvement.

4.3 Acknowledgements

Many thanks are due to the officers, scientists and crew of the RV Dr Fridtjof Nansen for their continuous support and for generally making this cruise a successful and enjoyable one. Specific thanks must go to the master Kjell O. Sandøy and chief instrument officer Tore Mørk for facilitating a very ambitious sampling strategy under often difficult circumstances.
Many thanks are also due to Hervé Demarcq and Dominique Dagorne (IRD, France) for making available daily updates of processed satellite imagery, which made the hunt for physical anomalies a successful one.
Last, but certainly not least a great many thanks to all those who made this cruise possible in first place. Specific thanks must go to the GEF/UNDP funded ASCLME programme and all of its regional representatives and the EAF Nansen project. Personally, I would like to thank David Vousden (ASCLME director), Tore Strømme (EAF Nansen research coordinator) and Tommy Bornman (ASCLME cruise coordinator) for their insights, financial and management support and generally for making this cruise possible.