# MSM 08/1

(18.04.2008 – 03.05.2008)

Short Cruise Report

SFB 754

## MINDELO-MINDELO

by Prof Dr. Martin Visbeck, Chief Scientist
Leibniz-Institut für Meereswissenschaften (IFM-GEOMAR)
an der Universität Kiel

**In memory of Prof. Dr. F. Schott who passed away in Kiel during our cruise**

| | | | |
|---|---|---|---|
| 1. | Prof. Dr. Martin Visbeck | Fahrtleiter / *Chief Scientist* | IFM-GEOMAR |
| 2. | Dr. Toste Tanhua | Tracer Release (OTIS) | IFM-GEOMAR |
| 3. | Andreas Pinck | OTIS / CTD | IFM-GEOMAR |
| 4. | Mario Müller | OTIS / CTD / Mikrostrukturs. | IFM-GEOMAR |
| 5. | Dr. Johannes Karstensen | CTD / Salinometer | IFM-GEOMAR |
| 6. | Martin Vogt | ADCP | IFM-GEOMAR |
| 7. | Rebecca Hummels | Mikrostruktursonde | IFM-GEOMAR |
| 8. | Jens Brandt | CTD / Mikrostrukturs. | IFM-GEOMAR |
| 9. | Johanna Zocher | O2 | IFM-GEOMAR |
| 10. | Christian Schlosser | Spurenstoffe/trace elements | IFM-GEOMAR |
| 11. | Dr. Philip Raab | Nährstoffe/Nutrients | IFM-GEOMAR |
| 12. | Tim Kalvelage | Nährstoffe/Nutrients | MPI-Bremen |
| 13. | Judith Klatt | Nährstoffe/Nutrients | MPI-Bremen |
| 14. | Abdul Rahiman Sheik | Nährstoffe/Nutrients | MPI-Bremen |
| 15. | Gordana Ivcic | Nährstoffe/Nutrients | MPI-Bremen |
| 16. | Tom Visbeck | Schüler/Pupil | G. Heikendorf |
| 17. | Tamy Jacobsen-Biallas | Schüler/Pupil | G. Heikendorf |
| 18. | Teresa Kerl | Schüler/Pupil | G. Heikendorf |
| 19. | Manuel Monteiro | Lehrer/School teacher | Mindelo CV |
| 20. | Manuel Monteiro | Schüler/Pupil | Mindelo CV |
| 21. | Denise Lopes | Schüler/Pupil | Mindelo CV |
| 22. | Klaus Scheurich | Film Journalist | MarcoPolo Film |

## *Participating Institutions*

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## Scientific Background

Major changes to marine sources and sinks of important nutrient elements such as nitrogen, phosphorus and iron occur when oceanic oxygen concentrations decrease below threshold levels. Paleo-records give evidence for periods of dramatically reduced oceanic oxygen that had major consequences for marine ecosystems. Oxygen levels can therefore be viewed as a “switch” or “tipping point” for nutrient cycling.

Oceanic oxygen levels are, themselves, controlled by an interplay of physics and biology that is not fully understood. The Oxygen Minimum Zones (OMZs) of the tropics are the key regions of low oxygen in today’s ocean. These spatially limited OMZs impact nutrient budgets, biological productivity and CO2-fixation of the global ocean. Recent modeling results suggest that oxygen levels will decrease significantly over the next decades in response to climate change, and altered ocean circulation. Hence the future ocean may experience major shifts in nutrient cycling triggered by expansion and intensification of tropical OMZs.

There are numerous feedbacks between oxygen, nutrient cycling and biological productivity; however existing knowledge is insufficient to understand past interactions or to adequately assess the potential for future change. The overall goal of the Collaborative Research Project (SFB) is to improve understanding of the coupling of tropical climate variability and circulation with the ocean’s oxygen and nutrient balance, to quantitatively evaluate the nature of oxygen-sensitive tipping points, as well as to assess consequences for the Ocean’s future. SFB research focuses on the following questions: How does subsurface dissolved oxygen in the tropical ocean respond to changes in ocean circulation and ventilation? What are the sensitivities and feedbacks linking low oxygen levels and key nutrient source and sink mechanisms? What are the magnitudes, timescales and controlling factors of past, present and likely future variations in oceanic oxygen and nutrient levels?

*Circulation, Mixing and dissolved Oxygen*

This second SFB754 expedition focuses on key processes responsible for the structure of the oxygen minimum zone in the tropical North Atlantic region. Of special interest are the diapycnal mixing processes and their associated vertical transport of oxygen, as well as the several lateral oxygen supply routes into the OMZ. The focus during this cruise was on a purposeful tracer release, where about 100kg of a chemically inert and nontoxic substance (SF5CF5) was to be injected and 6, 12, and 24 months later sampled. This method allows a very accurate estimation of the mixing, which can be used to improve and calibrate mixing parameterizations in numerical ocean models. The diapycnal mixing can also be locally estimated using a microstructure profiling device, that can observe the turbulence spectra of the upper 400m of the water column. A regional survey of the oxygen minimum zone in the vicinity of the tracer release site preferentially in an east-west direction were planned.

*Nitrogen fixation*

Open ocean waters are often limited by nutrients that are essential for microbial growth. Nitrogen, in the form of Nitrate and Ammonia, is supposed to be the major limiting factor in these oligotrophic areas. There is increasing biogeochemical evidence that nitrogen fixation by marine diazotrophs contributes significantly to new production.

Nitrogen fixation is a highly energy consuming process, in which microorganisms, so called nitrogen fixers, assimilate atmospheric nitrogen and incorporate it into bioavailable forms. This process is of interest as it is the major source for nitrogen input into oceans.

Dispite recent progress in mapping the diversity of diazotrophs in the tropical North Atlantic only a small portion of these microorganisms are assumed to be identified. So far every new effort to investigate the diversity of marine diazotrophs usually presents new phylotypes of the nifH gene. Such molecular studies have led to the discovery of multiple novel unicellular organisms capable of fixing nitrogen in addition to the globally important Trichodesmium sp.

*Trace Metals*

While it is established now that Fe can be a (co)limiting nutrient for phytoplankton in High Nutrient Low Chlorophyll (HNLC) regions of the world  we still know little about the processes by which Fe and other trace metals are supplied to the ocean (Saharan dust, resuspension of continental shelf sediments, etc.) and how processes in the ocean scavenge/uptake, solubility or remineralize dissolved trace metals. By examining trace metal chemistry in the Tropical Atlantic we can try to complete the overview of the key processes controlling biogeochemistry of trace metals in seawater. From this basis we can start to quantify the fluxes involved in each individual process.

## Research Program

In order accomplish the various research objectives a cruise plan was developed that consisted of four parts. After a test CTD station north of Mindelo near the location of a moored time series site the first transect was along the 23°W Meridian with underway SADCP measurements and the first nutrient sampling stations on the way to the planned tracer release site at 8°N 23°W. A small CTD section between 9°N and 7° 30'N was performed to ensure that the planned location shows indeed a well developed vertical oxygen gradient over a well developed OMZ.

The second part of the cruise was devoted to the tracer injection and simultaneous microstructure measurements. This work was done within 15nm to the north-east of 8°N 23°W.

The third part of the cruise was dedicated to an east-west oxygen section between 21°W and 26°W with a station every 30nm.

Finally on the northward transit towards Mindelo SADCP data were taken and a final surface nutrient/DNA sample was taken. The last station located between the Cap Verde Islands was dedicated towards trace metal sampling of the upper 250m.

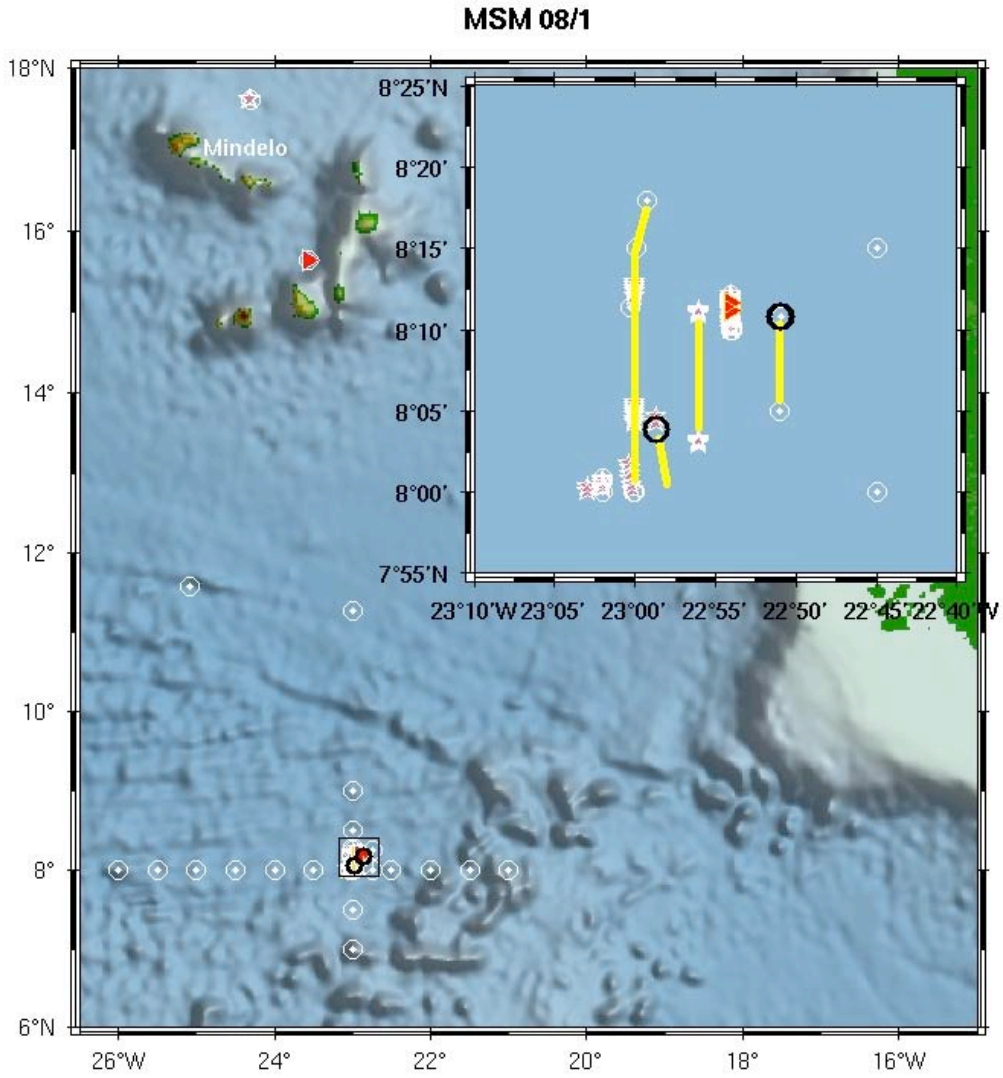


*Figure 1: Station map of MSM08-01 cruise. White dots with circle are locations of CTD positions. Yellow lines are the positions where the tracer was released. Red stars denote microstructure profiles*

## Narrative of the cruise

**April 18:** All scientists went on Board MERIAN in the afternoon.

**April 19:** The containers were unpacked and the work places were set up. We received the container and a large number of boxes from INDP. During the day the newly installed automatic winch control system was tested. The glider “deepy” was unleashed, cleaned and properly stowed in his box.

**April 20:** MERIAN sails in the morning. It steams northward towards the Cap Verde Moored Time Series Station at 17°N 36’ 24°W 19’ against the trade wind of 5 bft and some choppy seas. Near the mooring a deep CTD cast and two microstructure profiles were performed. All systems were working well and we began steaming towards Praia.

**April 21:** Early in the Morning at 4:30 we took the first shallow water sample for the biogeochemical incubation experiments. After that the newly developed trace metal sampler MITESS that will replace the GOFLOW system in the future was successfully tested. At 10:00 in the morning we received at rolls in Praia the SF5 tracer gas and two Argo floats, that both could not be shipped to Mindelo in time. An hour later we were steaming south. After lunch we stopped briefly for a buoyancy test of OTIS (Ocean Tracer Injection System) and then continued towards 23°W along which we measured upper ocean velocities with the SADCP system.

**April 22:** After the early morning water collection station we reached 9°N 23°W in the afternoon and began a short CTD section with 1000m deep stations every 30nm. The weather conditions have improved quite a bit with only a light breeze from Northern directions. All systems work well.

**April 23:** Early in the morning after the last CTD station at 7° 30’N 23°W we steamed back to the planned tracer release site and began the injection work after breakfast. Between 10:20 and 21:05 23kg of the tracer were successfully injected on the target density of $Sig_0$ = 26.85 kg $m^{-3}$. For the first time an automatic winch control was used on MERIAN and from the first minute it worked flawlessly. During the night microstructure and CTD casts we performed while OTIS was reloaded.

**April 24:** During the next OTIS tow between 09:29 and 12:19 14kg of tracer were injected. The tow had to be stopped early because one of the two pumps failed. Microstructure profiles and CTD work marked the afternoon’s activity including the release of one Argo float using the fast rescue boat to mark the tracer. The repair work of OTIS lasted until late at night but just before midnight it went back into the water again.

**April 25:** Unfortunately the second pump failed right away again but we continued the tow. Between 23:21 and 10:35 22kg of tracer were released using only one of the pumps. After recharging the accumulators with tracer and switching the batteries a second tow began at 17:08 and by 23:34 16kg of tracer were injected. As always microstructure and CTD casts were performed during the night.

**April 26:** OTIS went back on its final tow at 06:14. By 11:09 all remaining 18kg of tracer were perfectly injected. After the tracer release two more Argo floats were deployed (one APEX one PROVOR) followed by a well deserved grill party. At 22:00 science started again with a 48 hour long mircostructure profiling program.

**April 27:** The whole day was filled with a series of microstructure profiles every three hours and CTD casts interspersed. We swapped one sensor pair from the OTIS CTD to the normal CTD for calibration. We also calibrated two Aanderaa $O_2$ sensors by

adding them to the CTD rosette. The sensors were used for glider deployments and are now post-calibrated.

**April 28:** The 48 hour microstructure time series station continued until 20:00 when we finally left the tracer release site after four days to perform a CTD survey. The first few CTD stations boxed the tracer release site.

**April 29:** During the morning two CTD stations extended the 23°W section south to 7°N and then we steamed towards 8°N 21°W to begin an east to west transect with CTD stations every half degree.

**April 30:** The whole day was occupied by CTD stations along 8°N. In the afternoon we got word, that at noon time Prof. Dr. Schott, a recently retired professor of physical oceanography and the chief scientist's PhD Advisor from IFM-GEOMAR had passed away. This was a sad moment for all of us who knew him well.

**May 01:** At 07:30 a final CTD station concluded the transect at 8°N and 26°W. From there we began steaming towards the Cape Verde Island with one last bioassay shallow station at 23:30 after the party that marked a double holiday in Germany and the close end of this cruise.

**May 02:** The scientists are busy packing the equipment that will not be needed anymore, making long lists, and producing final plots. Various reports get written and the mandatory group picture taken. The highlight of the day are the school kids presentations about their work and the 'kicker' finale.

**May 03:** The ship

**Summary of cruise:**

The research cruise MSM08-1 was extremely successful. Despite the two-day delay we manage to accomplish all our planned research goals. We are particularly grateful to the previous group, who picked up our glider for us on their way to Mindelo.

The main objective of the cruise was to inject a tracer into the ocean using the new OTIS (Ocean Tracer Injection System) for an experiment that we call GUTRE (Guinea Upwelling region Tracer Release Experiment). The target density for the tracer injection was chosen to 26.85 σΘ, which corresponded to depths of 330 – 390 meters during the injection. 92 kg of SF5 ($CF_3SF_5$) was injected during 5 different tows in 5 streaks. The OTIS was towed at a speed of 1 +/- 0.1 knots, mostly in a northward direction, i.e. into the wind (Figure 2). Table 2 summarizes the injection parameters. During the injection we experienced a few problems with the injection pumps on the OTIS that forced us to, at times, operate at a lower injection rate. But in general the system worked well and the combination of perfect ship motion controlled by the DP system together with the new automatic winch control allowed for a smooth and precise tows.

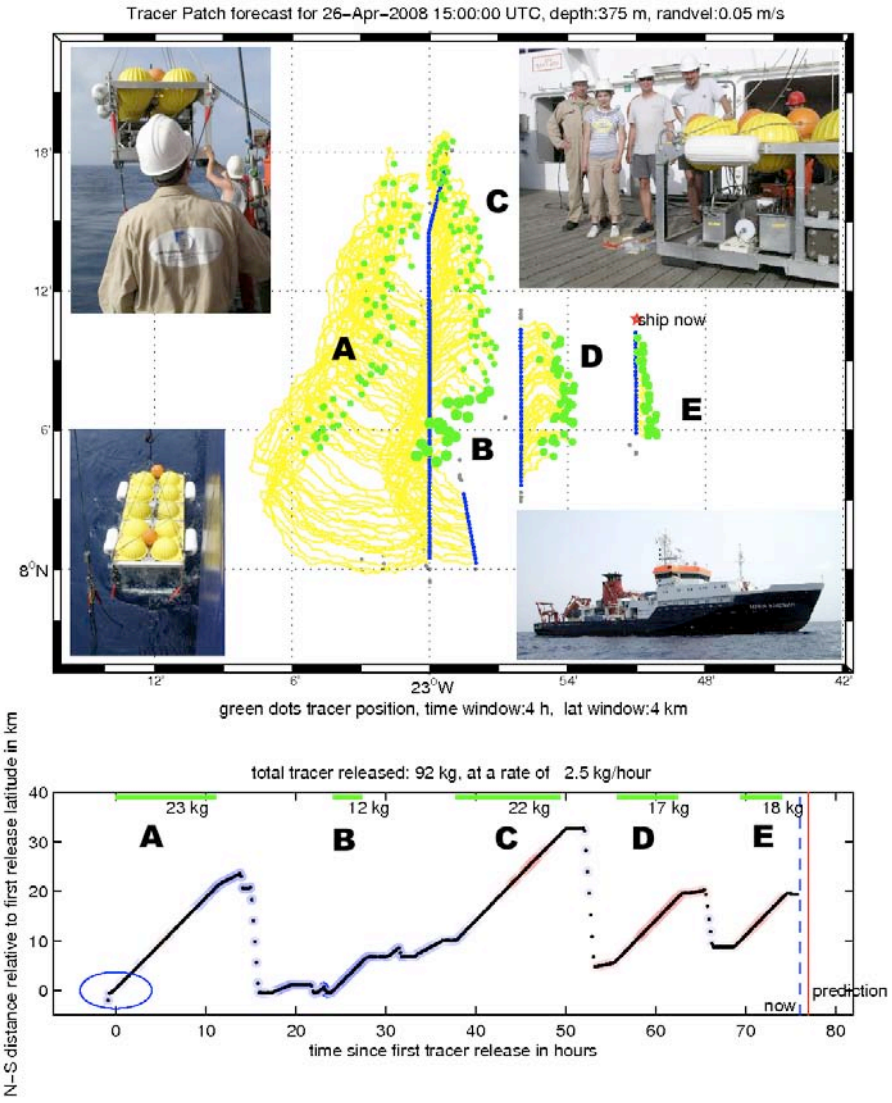


*Figure 2: Tracer Injection. The green dots are the estimated tracer position after propagating their release position with the SADCP velocity data for that layer. Lower panel displays the latitude of the ship during the injection. Blue color marks westward flow, red color eastward flow.*

The second objective was to map the OMZ in the vicinity of the tracer release site. We therefore repeated a short segment of the 23°W section that was fully occupied six weeks earlier during an ATALANTE cruise (Fig. 3). In addition we surveyed the OMZ in the east west direction along 8°N almost reoccupying a 15 year old ATALANTE section along 7° 30'N (Fig. 4). The electric oxygen measurements were constantly checked by bottle samples and Winkler titration.

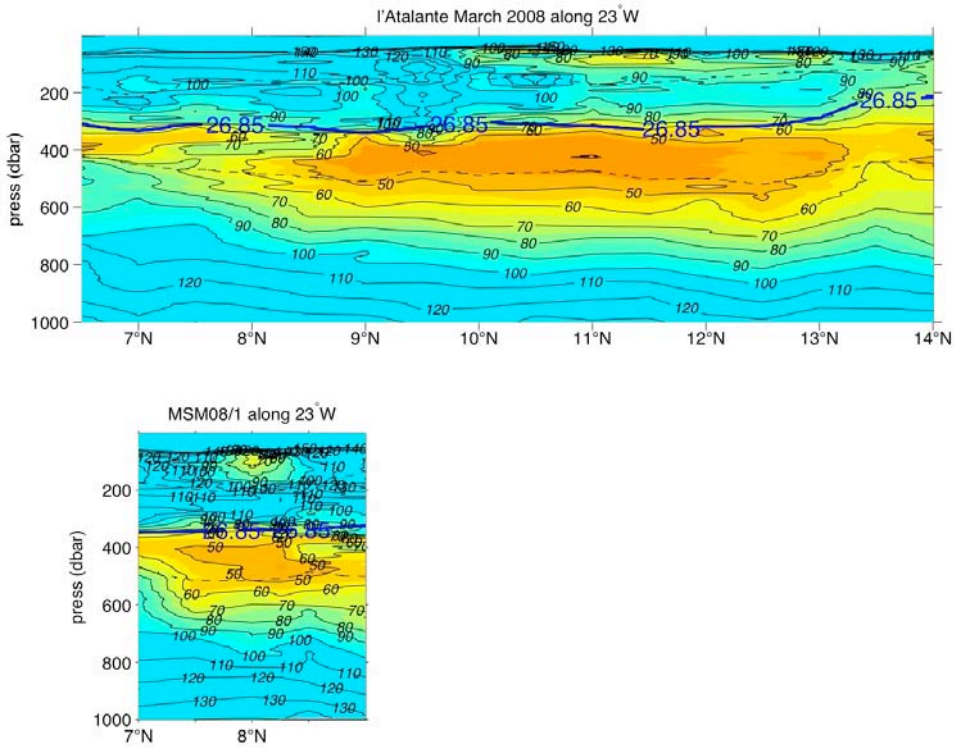


*Figure 3: Dissolved oxygen section along 23°W. Top panel ATALANTE March 2008 cruise, bottom panel our data.*

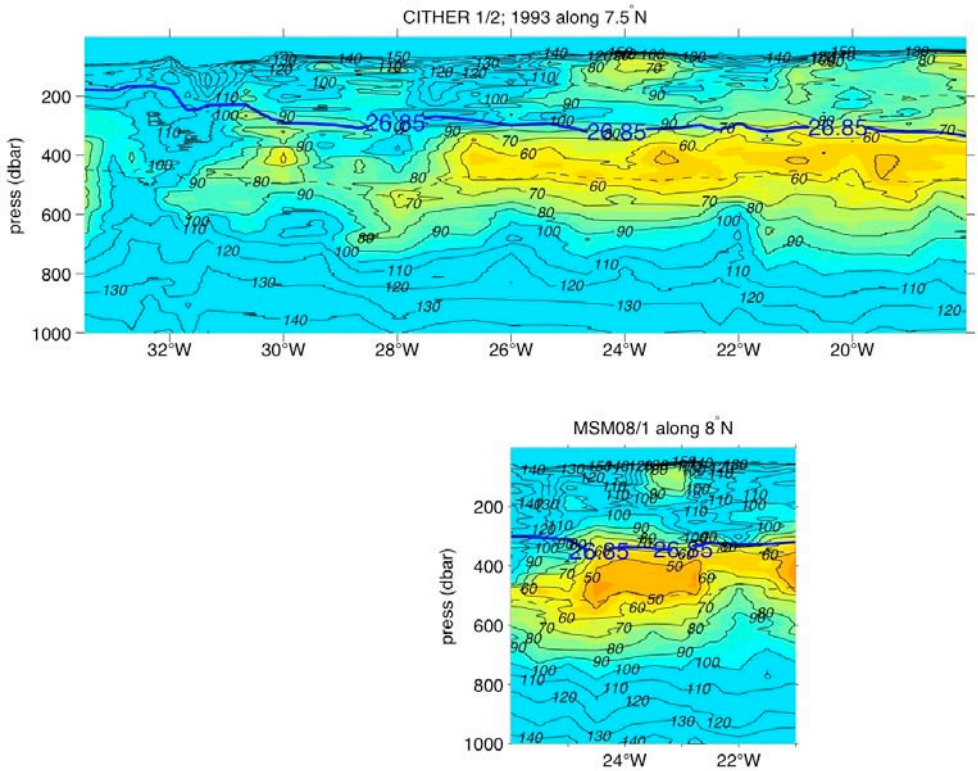


*Figure 4: Dissolved oxygen section along 7°39'N and 8°N. Top panel ATALANTE March 1993 cruise, bottom panel our data.*

Throughout the cruise ship board ADCP data were collected and processed in real time. They were used to make short-term forecasts of the tracer patch to optimize the OTIS injections (Fig. 2). Figure 5 shows a comparison between the ATALANTE cruise six weeks ago and our observations.

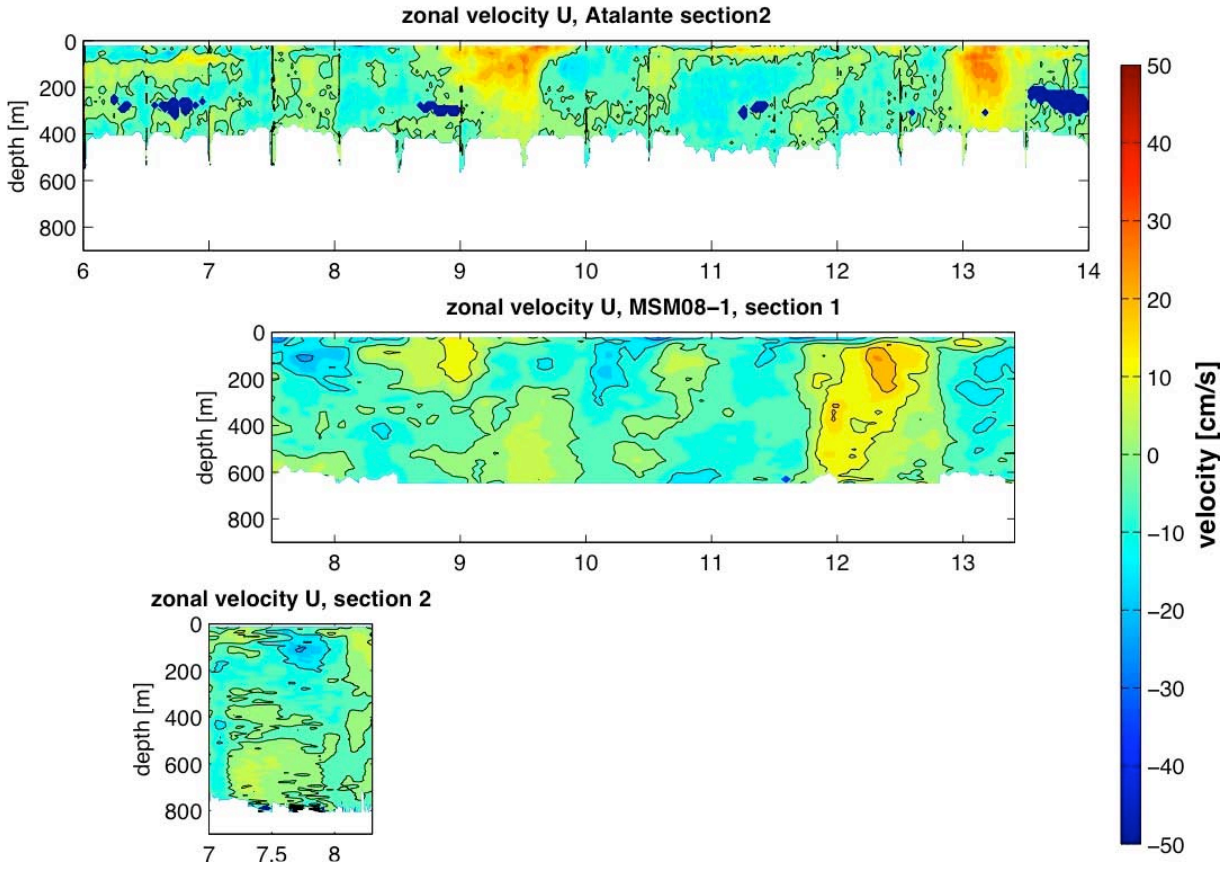


*Figure 5: Zonal velocity along the 23°W section. Top panel ATALANTE March 1993 cruise, lower two panel our data.*

Microstructure measurements were done before and after the tracer release when the OTIS system was on deck for maintenance. Once all tracer was injected a dedicated 48h long experiment was done to investigate the variability of the vertical mixing as a function of time of the day and tidal flow. Between the ‘normal’ microstructure profiles CTD casts with a WH300 ADCP in high-resolution mode were taken and sometimes additional microstructure profile measurements with a slower fall rate.

The profiler used on this cruise was manufactured by ISW-Messtechnik in collaboration with SEA and Sun Technology (Trappenkamp, Germany). The profiler is operated with a special winch connecting the free-falling profiler via a data cable to the computer deck unit on board. Optimum measurements are achieved if the sinking rate of the profiler is adjusted to about 0.6 m/s. Ballasting had only to be changed during the “Heat flux experiments”, which were performed within the 48 hour station, where the profiler was made to drop at 0.1 m/s. This gives the opportunity to take out the electrical amplification of the fast thermistor sensor and test another type of parameterisation for the eddy coefficients, which will be interesting to compare with the standard procedures.

In total, four shear probes (s/n 6089, 6061, 6054, 003) were used, as some lost its sensitivity and another one had water inside. Once the cable had to be reterminated because of a water leak.
To get a first impression of our measurements, we calculated profiles of the dissipation rate from the raw data, smoothed and averaged them for every station. It must be kept in mind that this is only a preliminary section and further processing is needed.

Almost every day water samples were taken to investigate diazotrophs with molecular approaches and the determination of nitrogen fixation rates by heterotrophic and autotrophic microorganisms. At several stations seawater from different depths (surface, upper and lower oxygen minimum zone and chlorophyll maximum) was filtered (200L per sample) for further metagenomic analysis in Kiel on the diazotrophic and bacterial diversity. In addition, chlorophyll and flow cytometry samples were collected.

To distinguish between heterotrophic and autotrophic nitrogen fixation, waters were labelled with the stable isotope 15N2 and a 13C-labelled carbon source (acetate, bicarbonate or glucose depending upon the experimental setup). Samples were incubated simulating either daylight or night to track the conditions of highest nitrogen fixation rates. Experiments were terminated by filtration. Furthermore, water samples were taken to determine the nutrient concentrations before and after incubations. The future investigation of the 15N/13C filters will be conducted at the Max Planck Institute for Marine Microbiology, Bremen. They will be analysed to determine isotopic composition and nitrogen fixation rates by isotope ratio mass spectrometry. To identify nitrogen-fixing bacterial groups FISH and NanoSIMS will be applied.

At two stations (Station I: 8° 11'N, 22° 54'W; Station II: 15° 50'N, 24° 35'W), seawater for trace metal analysis was sampled by a new computable *in-situ* trace element sampler (MITESS, Figure X). The sampler was deployed at the ship's own Kevlar wire (Standard winch, Serienwinde) and collected seawater samples in 20, 40, 80, 140 and 200 m water depth (euphotic zone). The collected seawater was filtered through a 0.2 µm filter and acidified with $HNO_3$, below pH 2 to prevent wall sorption effects of the sample bottle. The treatment of seawater samples were performed under a clean hood working bench. The collected trace metal seawater samples (10 samples) will be shipped to the IFM-GEOMAR, Kiel and there analyzed by GFAAS (graphite furnace AAS) under clean air conditions.

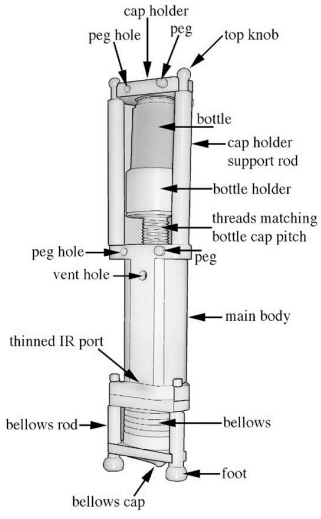


*Figure X: MITESS sampler*

Throughout the cruise we held a lecture series entitled "Introduction to Physical Oceanography" for the five school children and other students on board. Three of them came from a high school near Kiel (Heikendorf) and are part of the IFM-GEOMAR organized NAT-working program. The other two came from a high school in Mindelo and were accompanied by their Mathematics and Physics teacher. During most evenings we also had science presentations from the participating scientist who reported about their scientific interest and the work they are performing on board.

## Tabels:

*Table 1: Station parameter*

| Station | P# | Date | Time | Latitude | Longitude | Gear | Comment |
|---|---|---|---|---|---|---|---|
| MSS 1 | 1 | 20/04/08 | 15:27:00 | 17° 36.05' N | 24° 18.95' W | MSS | |
| 1 | 1 | 20/04/08 | 17:15:00 | 17° 36.30' N | 24° 18.66' W | CTD/RO/lADCP | |
| MSS 1 | 1 | 20/04/08 | 18:56:00 | 17° 36.48' N | 24° 18.50' W | MSS | |
| 2 | 2 | 21/04/08 | 05:40:00 | 15° 38.80' N | 23° 33.76' W | CTD/RO/lADCP | |
| | | 21/04/08 | 06:11:00 | 15° 38.80' N | 23° 33.76' W | MITESS | |
| 3 | 3 | 22/04/08 | 05:38:00 | 11° 16.12' N | 23° 0.17' W | CTD/RO/lADCP | Incubation experiment 10m, Chl-a filter |
| 3 | 4 | 22/04/08 | 06:13:00 | 11° 16.12' N | 23° 0.17' W | CTD/RO/lADCP | |
| 4 | 5 | 22/04/08 | 16:56:00 | 8° 59.96' N | 22° 59.87' W | CTD/RO/lADCP | |
| 5 | 6 | 22/04/08 | 20:14:00 | 8° 29.98' N | 23° 0.01' W | CTD/RO/lADCP | |
| 6 | 7 | 22/04/08 | 23:29:00 | 8° 0.03' N | 23° 0.08' W | CTD/RO/lADCP | Metagenomics 10m, Chl-a filter |
| MSS 2 | 1 | 23/04/08 | 00:17:00 | 8° 0.12' N | 23° 0.13' W | MSS | |
| MSS 2 | 2 | 23/04/08 | 00:39:00 | 8° 0.44' N | 23° 0.22' W | MSS | |
| MSS 2 | 3 | 23/04/08 | 01:07:00 | 8° 0.75' N | 23° 0.26' W | MSS | |
| MSS 2 | 4 | 23/04/08 | 01:30:00 | 8° 1.04' N | 23° 0.30' W | MSS | |
| MSS 2 | 5 | 23/04/08 | 01:56:00 | 8° 1.44' N | 23° 0.35' W | MSS | |
| MSS 2 | 6 | 23/04/08 | 02:21:00 | 8° 1.75' N | 23° 0.39' W | MSS | |
| 7 | 8 | 23/04/08 | 05:14:00 | 7° 29.99' N | 23° 0.03' W | CTD/RO/lADCP | Incubation experiment 10m, Chl-a filter |
| 7 | 9 | 23/04/08 | 06:14:00 | 7° 29.99' N | 23° 0.03' W | CTD/RO/lADCP | Metagenomics 10m, Chl-a filter |
| OTIS 1 | | 23/04/08 | 10:21:00 | 8° 0.78' N | 23° 0.01' W | OTIS | |
| MSS 3 | 1 | 23/04/08 | 21:57:00 | 8° 12.06' N | 23° 0.01' W | MSS | |
| MSS 3 | 2 | 23/04/08 | 22:22:00 | 8° 12.27' N | 23° 0.01' W | MSS | |
| MSS 3 | 3 | 23/04/08 | 22:45:00 | 8° 12.46' N | 23° 0.01' W | MSS | |
| MSS 3 | 4 | 23/04/08 | 23:10:00 | 8° 12.66' N | 23° 0.01' W | MSS | |
| MSS 3 | 5 | 23/04/08 | 23:36:00 | 8° 12.87' N | 23° 0.01' W | MSS | |
| 8 | 10 | 24/04/08 | 00:33:00 | 8° 11.40' N | 23° 0.34' W | CTD/RO/lADCP | |
| 9 | 11 | 24/04/08 | 02:42:00 | 8° 0.00' N | 23° 2.00' W | CTD/RO/lADCP | |
| MSS 4 | 1 | 24/04/08 | 03:44:00 | 8° 0.16' N | 23° 2.00' W | MSS | |
| MSS 4 | 2 | 24/04/08 | 04:09:00 | 8° 0.33' N | 23° 2.00' W | MSS | |
| MSS 4 | 3 | 24/04/08 | 04:33:00 | 8° 0.49' N | 23° 2.00' W | MSS | |
| MSS 4 | 4 | 24/04/08 | 04:56:00 | 8° 0.65' N | 23° 2.00' W | MSS | |
| MSS 4 | 5 | 24/04/08 | 05:21:00 | 8° 0.81' N | 23° 2.00' W | MSS | |
| 10 | 12 | 24/04/08 | 05:49:00 | 8° 0.88' N | 23° 2.00' W | CTD/RO/lADCP | Incubation experiment 10m, Chl-a filter |
| 10 | 13 | 24/04/08 | 06:54:00 | 8° 0.89' N | 23° 2.00' W | CTD/RO/lADCP | |
| 10 | 14 | 24/04/08 | 07:39:00 | 8° 0.88' N | 23° 2.00' W | CTD/RO/lADCP | Metagenomics 10m, Chl-a filter |
| MSS 5 | 1 | 24/04/08 | 08:26:00 | 8° 0.06' N | 23° 2.97' W | MSS | |
| MSS 5 | 2 | 24/04/08 | 08:48:00 | 8° 0.29' N | 23° 2.97' W | MSS | |
| OTIS 2 | | 24/04/08 | 10:29:00 | 8° 0.50' N | 22° 58.02' W | OTIS | |
| MSS 6 | 1 | 24/04/08 | 16:40:00 | 8° 4.25' N | 22° 58.70' W | MSS | |
| MSS 6 | 2 | 24/04/08 | 17:08:00 | 8° 4.62' N | 22° 58.70' W | MSS | |
| MSS 7 | 1 | 24/04/08 | 19:35:00 | 8° 4.24' N | 23° 0.00' W | MSS | |
| MSS 7 | 2 | 24/04/08 | 20:00:00 | 8° 4.46' N | 23° 0.00' W | MSS | |
| MSS 7 | 3 | 24/04/08 | 20:25:00 | 8° 4.67' N | 23° 0.01' W | MSS | |
| MSS 7 | 4 | 24/04/08 | 20:50:00 | 8° 4.88' N | 23° 0.01' W | MSS | |
| MSS 7 | 5 | 24/04/08 | 21:17:00 | 8° 5.10' N | 23° 0.01' W | MSS | |
| MSS 7 | 6 | 24/04/08 | 21:40:00 | 8° 5.29' N | 23° 0.01' W | MSS | |
| MSS 7 | 7 | 24/04/08 | 22:03:00 | 8° 5.50' N | 23° 0.01' W | MSS | |
| OTIS 3 | | 25/04/08 | 00:17:00 | 8° 6.11' N | 23° 0.01' W | OTIS | |
| 11 | 15 | 25/04/08 | 13:02:00 | 8° 17.95' N | 22° 59.28' W | CTD/RO/lADCP | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| MSS 8 | 1 | 25/04/08 | 15:46:00 | 8° 2.94' N | 22° 56.04' W | MSS | |
| MSS 8 | 2 | 25/04/08 | 16:08:00 | 8° 3.01' N | 22° 56.03' W | MSS | |
| MSS 8 | 3 | 25/04/08 | 16:31:00 | 8° 3.08' N | 22° 56.03' W | MSS | |
| MSS 8 | 4 | 25/04/08 | 16:55:00 | 8° 3.17' N | 22° 56.04' W | MSS | |
| MSS 8 | 5 | 25/04/08 | 17:16:00 | 8° 3.23' N | 22° 56.03' W | MSS | |
| OTIS 4 | | 25/04/08 | 18:06:00 | 8° 3.92' N | 22° 56.03' W | OTIS | |
| MSS 9 | 1 | 26/04/08 | 01:35:00 | 8° 10.88' N | 22° 56.04' W | MSS | |
| MSS 9 | 2 | 26/04/08 | 01:57:00 | 8° 10.89' N | 22° 56.04' W | MSS | |
| MSS 9 | 3 | 26/04/08 | 02:18:00 | 8° 10.95' N | 22° 56.04' W | MSS | |
| MSS 9 | 4 | 26/04/08 | 02:40:00 | 8° 11.03' N | 22° 56.04' W | MSS | |
| MSS 9 | 5 | 26/04/08 | 03:00:00 | 8° 11.09' N | 22° 56.05' W | MSS | |
| MSS 9 | 6 | 26/04/08 | 03:22:00 | 8° 11.17' N | 22° 56.05' W | MSS | |
| 12 | 16 | 26/04/08 | 04:50:00 | 8° 5.00' N | 22° 51.01' W | CTD/RO/lADCP | Incubation experiment, Chl-a filter |
| 12 | 17 | 26/04/08 | 05:40:00 | 8° 5.00' N | 22° 51.01' W | CTD/RO/lADCP | |
| 14 | 18 | 26/04/08 | 06:35:00 | 8° 5.00' N | 22° 51.01' W | CTD/RO/lADCP | |
| OTIS 5 | | 26/04/08 | 07:21:00 | 8° 5.56' N | 22° 51.01' W | OTIS | |
| 15 | 19 | 26/04/08 | 14:18:00 | 8° 10.79' N | 22° 50.97' W | CTD/RO/lADCP | |
| MSS 10 | 1 | 26/04/08 | 23:17:00 | 8° 10.00' N | 22° 54.00' W | MSS | |
| MSS 10 | 2 | 26/04/08 | 23:42:00 | 8° 10.00' N | 22° 54.00' W | MSS | |
| MSS 10 | 3 | 27/04/08 | 00:05:00 | 8° 10.00' N | 22° 54.00' W | MSS | |
| 16 | 20 | 27/04/08 | 01:34:00 | 8° 10.00' N | 22° 54.01' W | CTD/RO/lADCP | |
| MSS 11 | 1 | 27/04/08 | 02:22:00 | 8° 10.00' N | 22° 54.00' W | MSS | |
| MSS 11 | 2 | 27/04/08 | 02:45:00 | 8° 10.00' N | 22° 54.00' W | MSS | |
| MSS 11 | 3 | 27/04/08 | 03:09:00 | 8° 10.00' N | 22° 54.00' W | MSS | |
| 17 | 21 | 27/04/08 | 04:25:00 | 8° 10.00' N | 22° 54.00' W | CTD/RO/lADCP | |
| MSS 12 | 1 | 27/04/08 | 05:21:00 | 8° 10.00' N | 22° 54.01' W | MSS | |
| MSS 12 | 2 | 27/04/08 | 05:48:00 | 8° 10.00' N | 22° 54.00' W | MSS | |
| MSS 12 | 3 | 27/04/08 | 06:11:00 | 8° 10.00' N | 22° 54.01' W | MSS | |
| | 22 | 27/04/08 | 06:57:00 | 8° 10.00' N | 22° 54.01' W | CTD/RO/lADCP | |
| MSS 13 | 1 | 27/04/08 | 08:06:00 | 8° 10.07' N | 22° 54.00' W | MSS | |
| MSS 13 | 2 | 27/04/08 | 08:26:00 | 8° 10.23' N | 22° 54.01' W | MSS | |
| MSS 13 | 3 | 27/04/08 | 08:48:00 | 8° 10.41' N | 22° 54.01' W | MSS | |
| | 23 | 27/04/08 | 10:07:00 | 8° 10.52' N | 22° 54.01' W | CTD/RO/lADCP | |
| MSS 14 | 1 | 27/04/08 | 11:09:00 | 8° 10.63' N | 22° 54.01' W | MSS | |
| MSS 14 | 2 | 27/04/08 | 11:33:00 | 8° 10.83' N | 22° 54.01' W | MSS | |
| MSS 14 | 3 | 27/04/08 | 12:00:00 | 8° 11.05' N | 22° 54.01' W | MSS | |
| | | 27/04/08 | 12:37:00 | 8° 11.16' N | 22° 54.01' W | MITESS | |
| | | 27/04/08 | 12:43:00 | 8° 11.16' N | 22° 54.01' W | MITESS | |
| MSS 15 | 1 | 27/04/08 | 14:32:00 | 8° 11.25' N | 22° 54.01' W | MSS | |
| MSS 15 | 2 | 27/04/08 | 14:59:00 | 8° 11.43' N | 22° 54.01' W | MSS | |
| MSS 15 | 3 | 27/04/08 | 15:25:00 | 8° 11.60' N | 22° 54.01' W | MSS | |
| | | 27/04/08 | 16:03:00 | 8° 11.69' N | 22° 54.01' W | MITESS | |
| | | 27/04/08 | 16:43:00 | 8° 11.69' N | 22° 54.01' W | MITESS | |
| MSS 16 | 1 | 27/04/08 | 17:38:00 | 8° 11.84' N | 22° 54.01' W | MSS | |
| MSS 16 | 2 | 27/04/08 | 17:57:00 | 8° 11.96' N | 22° 54.01' W | MSS | |
| MSS 16 | 3 | 27/04/08 | 18:17:00 | 8° 12.09' N | 22° 54.01' W | MSS | |
| 17 | 24 | 27/04/08 | 18:54:00 | 8° 12.16' N | 22° 54.01' W | CTD/RO/lADCP | Metagenomics 10m, Chl-a filter |
| MSS 17 | 1 | 27/04/08 | 20:32:00 | 8° 10.10' N | 22° 54.00' W | MSS | |
| MSS 17 | 2 | 27/04/08 | 20:52:00 | 8° 10.23' N | 22° 54.01' W | MSS | |
| MSS 18 | 1 | 27/04/08 | 23:19:00 | 8° 10.40' N | 22° 54.01' W | MSS | |
| MSS 18 | 2 | 27/04/08 | 23:48:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 18 | 3 | 28/04/08 | 00:15:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| 18 | 25 | 28/04/08 | 01:16:00 | 8° 10.42' N | 22° 54.01' W | CTD/RO/lADCP | Metagenomics 10m, Chl-a filter |
| MSS 19 | 1 | 28/04/08 | 02:19:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 19 | 2 | 28/04/08 | 02:44:00 | 8° 10.42' N | 22° 54.01' W | MSS | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| MSS 19 | 3 | 28/04/08 | 03:11:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 20 | 1 | 28/04/08 | 03:21:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 20 | 2 | 28/04/08 | 03:48:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 20 | 3 | 28/04/08 | 04:05:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 20 | 4 | 28/04/08 | 04:23:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 20 | 5 | 28/04/08 | 04:39:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 20 | 6 | 28/04/08 | 04:54:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 21 | 1 | 28/04/08 | 05:21:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 21 | 2 | 28/04/08 | 05:44:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| MSS 21 | 3 | 28/04/08 | 06:06:00 | 8° 10.42' N | 22° 54.01' W | MSS | |
| 19 | 26 | 28/04/08 | 06:41:00 | 8° 10.42' N | 22° 54.01' W | CTD/RO/lADCP | Metagenomics 10m, Chl-a filter |
| MSS 22 | 1 | 28/04/08 | 08:16:00 | 8° 10.49' N | 22° 54.01' W | MSS | |
| MSS 22 | 2 | 28/04/08 | 08:40:00 | 8° 10.65' N | 22° 54.01' W | MSS | |
| MSS 22 | 3 | 28/04/08 | 09:01:00 | 8° 10.79' N | 22° 54.01' W | MSS | |
| MSS 23 | 1 | 28/04/08 | 09:39:00 | 8° 11.04' N | 22° 54.01' W | MSS | |
| MSS 23 | 2 | 28/04/08 | 09:53:00 | 8° 11.13' N | 22° 54.01' W | MSS | |
| MSS 23 | 3 | 28/04/08 | 10:08:00 | 8° 11.25' N | 22° 54.01' W | MSS | |
| MSS 24 | 1 | 28/04/08 | 11:13:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| MSS 24 | 2 | 28/04/08 | 11:39:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| MSS 24 | 3 | 28/04/08 | 12:06:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| MSS 25 | 1 | 28/04/08 | 12:35:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| MSS 25 | 2 | 28/04/08 | 12:55:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| MSS 25 | 3 | 28/04/08 | 13:07:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| MSS 25 | 4 | 28/04/08 | 13:25:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| MSS 25 | 5 | 28/04/08 | 13:39:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| MSS 26 | 1 | 28/04/08 | 14:06:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| MSS 26 | 2 | 28/04/08 | 14:34:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| MSS 26 | 3 | 28/04/08 | 15:01:00 | 8° 11.29' N | 22° 54.01' W | MSS | |
| 20 | 27 | 28/04/08 | 16:06:00 | 8° 11.29' N | 22° 54.01' W | CTD/RO/lADCP | Metagenomics 10m, Chl-a filter |
| MSS 27 | 1 | 28/04/08 | 17:15:00 | 8° 11.34' N | 22° 54.02' W | MSS | |
| MSS 27 | 2 | 28/04/08 | 17:37:00 | 8° 11.41' N | 22° 54.02' W | MSS | |
| MSS 27 | 3 | 28/04/08 | 17:58:00 | 8° 11.48' N | 22° 54.03' W | MSS | |
| 21 | 28 | 28/04/08 | 18:38:00 | 8° 11.51' N | 22° 54.03' W | CTD/RO/lADCP | Metagenomics 336m, Chl-a filter |
| MSS 28 | 1 | 28/04/08 | 20:00:00 | 8° 11.56' N | 22° 54.04' W | MSS | |
| MSS 28 | 2 | 28/04/08 | 20:23:00 | 8° 11.63' N | 22° 54.04' W | MSS | |
| MSS 28 | 3 | 28/04/08 | 20:44:00 | 8° 11.70' N | 22° 54.05' W | MSS | |
| 22 | 29 | 28/04/08 | 22:17:00 | 8° 15.00' N | 22° 45.00' W | CTD/RO/lADCP | |
| 23 | 30 | 29/04/08 | 00:27:00 | 8° 15.00' N | 22° 59.94' W | CTD/RO/lADCP | |
| 24 | 31 | 29/04/08 | 04:51:00 | 7° 30.00' N | 22° 59.94' W | CTD/RO/lADCP | |
| 25 | 32 | 29/04/08 | 08:15:00 | 7° 0.00' N | 22° 59.99' W | CTD/RO/lADCP | |
| 26 | 33 | 29/04/08 | 19:17:00 | 8° 0.00' N | 21° 0.00' W | CTD/RO/lADCP | |
| 27 | 34 | 29/04/08 | 22:32:00 | 8° 0.00' N | 21° 30.00' W | CTD/RO/lADCP | |
| 27 | 35 | 29/04/08 | 23:27:00 | 8° 0.00' N | 21° 30.00' W | CTD/RO/lADCP | |
| 28 | 36 | 30/04/08 | 02:37:00 | 7° 59.97' N | 22° 0.01' W | CTD/RO/lADCP | |
| 29 | 37 | 30/04/08 | 05:58:00 | 8° 0.00' N | 22° 30.00' W | CTD/RO/lADCP | |
| 30 | 38 | 30/04/08 | 08:17:00 | 8° 0.00' N | 22° 45.00' W | CTD/RO/lADCP | |
| 31 | 39 | 30/04/08 | 10:30:00 | 8° 0.00' N | 23° 0.00' W | CTD/RO/lADCP | |
| 32 | 40 | 30/04/08 | 13:54:00 | 8° 0.00' N | 23° 30.00' W | CTD/RO/lADCP | |
| 33 | 41 | 30/04/08 | 17:17:00 | 8° 0.00' N | 24° 0.00' W | CTD/RO/lADCP | |
| 34 | 42 | 30/04/08 | 20:43:00 | 8° 0.00' N | 24° 30.00' W | CTD/RO/lADCP | |
| 35 | 43 | 01/05/08 | 00:05:00 | 8° 0.00' N | 25° 0.00' W | CTD/RO/lADCP | |
| 36 | 44 | 01/05/08 | 03:40:00 | 7° 59.97' N | 25° 30.02' W | CTD/RO/lADCP | |
| 37 | 45 | 01/05/08 | 06:49:00 | 8° 0.00' N | 26° 0.01' W | CTD/RO/lADCP | |
| 38 | 46 | 01/05/08 | 07:55:00 | 8° 0.00' N | 26° 0.00' W | CTD/RO/lADCP | |
| 39 | 47 | 02/05/08 | 01:33:00 | 11° 34.99' N | 25° 5.05' W | CTD/RO/lADCP | |

*Table 2: Summary table of the tracer release data*

| Tow # | Tracer | start time | end time | start pos. | end pos. | Pumps | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | 23 kg | 23/4 10:20 | 23/4 21:05 | N 8.013° W 23.000° | N 8.190° W 23.000° | Port #1 Stb. #3 | Pumped at 1500 psig |
| 2 | 14 kg | 24/4 10:29 | 24/4 13:19 | N 8.009° W 22.967° | N 8.055° W 22.975° | Port #1 Stb. #3 | Pump 1 failed 13:06, 2000+ psig |
| 3 | 22 kg | 25/4 00:21 | 25/4 11:35 | N 8.103° W 23.000° | N 8.290° W 22.988° | Port #2 Stb. #3 | Pump 2 failed from start |
| 4 | 16 kg | 25/4 18:08 | 26/4 00:34 | N 8.066° W 22.934° | N 8.174° W 22.934° | Port #2 Stb. #3 | Pump 2 failed at 20:35 |
| 5 | 18 kg | 26/4 7:14 | 26/4 12:09 | N 8.083° W 22.850° | N 8.173° W 22.850° | Port #1 Stb. #3 | |