RRS DISCOVERY
Cruise 241
Report

Dimethyl Sulphide Biogeochemistry within a Coccolithophore Bloom

DISCO

5th June – 1st July 1999

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UK MOD Defence Evaluation Research Agency

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Executive Summary

DISCO is an integrated, multidisciplinary Lagrangian study of the routes, rates and controls on the biogeochemical cycling of dimethyl sulphide (DMS) within a bloom of the coccolithophorid alga, *Emiliania huxleyi*. The cruise took place between 5th June and 1st July 1999 in the northern North Sea. The biogeochemical process study was preceded by ~ 52,000 km^2 survey of the region to locate an *E. huxleyi* bloom suitable for study. Although not originally planned, the 8-day survey was necessary because heavy cloud cover precluded use of remote sensing to locate blooms. *E. huxleyi* blooms, typically common in the region during mid summer, were unusually sparse during the cruise period. The bloom chosen for the process study was initially centred at ~58° 56'N 02° 52'E, and a 40 km^2 patch labelled for study with 30g SF_6 was marked on 16th June. The original patch labelling was re-labelled with further SF_6 on 24th June. During the process study, the patch drifted in a SE direction and was eventually sub-ducted under Norwegian coastal water at the end of our process studies on 26th June.

The process study comprised analyses of the time-varying physical and optical properties of the patch as well as studies of DMS, DMSP, DMSO, nutrients, halocarbons, methylamines, CO, DOC and TDN. The role of viruses, bacteria, phytoplankton, micro- and mesozooplankton and the dynamics of primary, new and bacterial production, plankton respoiration, zooplankton grazing, and sedimentation, were studied in relation to DMS biogeochemical cycling.

This research involved 28 scientists and technicians from 8 separate institutions. The study forms part of CCMS' Core Strategic Research Programmes of the *Dynamics of Marine Ecosystems* (DYME) and *Oceans, Climate and Consequences for the Coastal Zone* (OC4Z,) and addresses NERC's Strategic Issues including that of *Global Change*. DISCO was funded principally by NERC through Core Strategic and Responsive Mode Funds and by MOD DERA JGS Grant (TD/10/3/5).

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1. BACKGROUND

Dimethyl sulphide (DMS), a climatically active gas, is the main natural source of sulphur in the Earth's atmosphere. It is derived from dimethylsulphoniopropionate (DMSP), which is used by certain marine phytoplankton taxa, such as *Emiliania huxleyi,* for osmoregulation. Although the broad patterns of DMS distribution are now becoming understood, the mechanisms by which it is produced are not. In particular, the rates and controls on the conversion of DMSP to DMS and associated compounds (DMSO, demethylation and demethiolation transformations) are poorly understood in marine waters, and it is these processes that are generally recognised as the next critical step towards understanding DMS production. Current understanding of the mechanisms involved in the sources and cycling of DMS in surface waters is summarised in Figure 1.1.

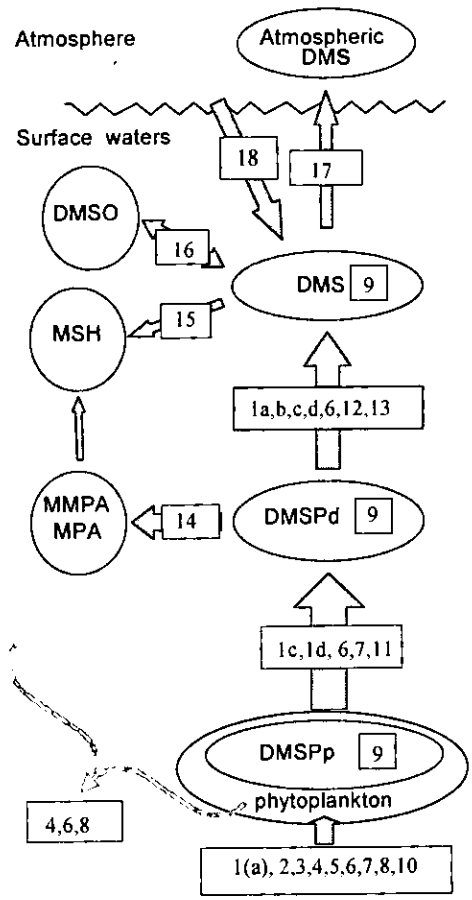


Figure 1.1: Biogeochemical cycling of DMS in marine surface waters and the processes and measurements addressed during this cruise. 1: Plankton community taxonomic composition: a) phytoplankton, b) bacteria, c) viruses, d) zooplankton; 2: Physics; 3: Optics; 4: Chemistry – nutrients & DOM; 5: Plankton productivity; 6: Zooplankton grazing; 7: Viral lysis; 8: Vertical export; 9: DMSP, DMSPd, DMS measurements; 10: Ammonia, MAs and Qas; 11: Algal release; 12: Algal DMSP cleavage; 13: Bacterial DMSP cleavage; 14: Bacterial DMSP demethylation; 15: Bacterial DMS demethiolation; 16: DMSO production and reduction; 17: Sea-air gas exchange; 18: Photochemistry. DMSP: dimethylsulphoniopropionate; DMSO: dimethylsulphoxide; MMPA: methylmercaptopropionate; MPA: mercaptopropionate; MSH: methanethiol.

2. AIM, OBJECTIVES, *MODUS OPERANDI* AND ACHIEVEMENTS

Our aim was to quantify the pools and processes, shown in Figure 1.1, that influence the biogeochemical cycling of DMS in surface waters during the progression of a bloom of *E. huxleyi.*

The following objectives were addressed on the cruise:

a) characterisation of the plankton communities (algae, bacteria, virus, microzooplankton, mesozooplanton) associated with the developing bloom and addressing the role of individual components in the biogeochemical synthesis of DMS and related compounds.

b) determination of the temporal changes in physical, optical, chemical and biological parameters that affect the progression of the coccolithophore bloom.

c) quantification of DMSPp, DMSPd, DMS, and DMSO and their production, consumption and transformation processes during the bloom.

d) generation of data for testing DMS biogeochemistry models and the models of microzooplankton trophodynamics in DMS generation within the bloom.

The approach adopted centred on a Lagrangian drift study of a coherent water patch tagged with SF_6. Within this patch, a JGOFS type process study was carried out. This involved a series of observations and experiments carried out on a daily basis in order to build a time-series of the evolution of DMS biogeochemical cycling.

Before beginning the process study, a suitable patch of water was required. The cruise was planned to allow access to blooms of *E huxleyi*, using previous satellite data. The satellite archives revealed good blooms of *E huxleyi* in the northern North Sea during June. However 1999 seemed to be an anomolous year and few blooms were present. Bloom location was also hampered because of extensive cloud cover particularly during early June.

The cruise track, shown in Figure 2.1, identifies the region surveyed as well as the Lagrangian drift study area. The region survey comprised an approximately rectilinear box of 180 by 80 km size situated between ca 57° 50'N to 61° 00'N and from 00° 35'W to 02° 00'E. Preliminary analysis of the hydrography of the surface waters of the region is shown in Figure 2.2. While the thermal structure is rather homogenious, there are clear pools of cold water situated to the south-east of Shetland Isles (60°N) and to the east of the Orkneys (59°N). In contrast the salinity filed shows a gradient from the SE to NW of the region depicting the oceanic influence. Chlorophyll, inferred from *in-vivo* fluoresence, had a pattern similar to salinity with higher values found in association with higher salinity waters of the NW of the region.

Preliminary analysis of the Lagrangian drift study waters (Figure 2.3) shows little change in the basic pattern, as would be expected. However the ingression of surface low salinity water on day 5 of the experiment is noteworthy.

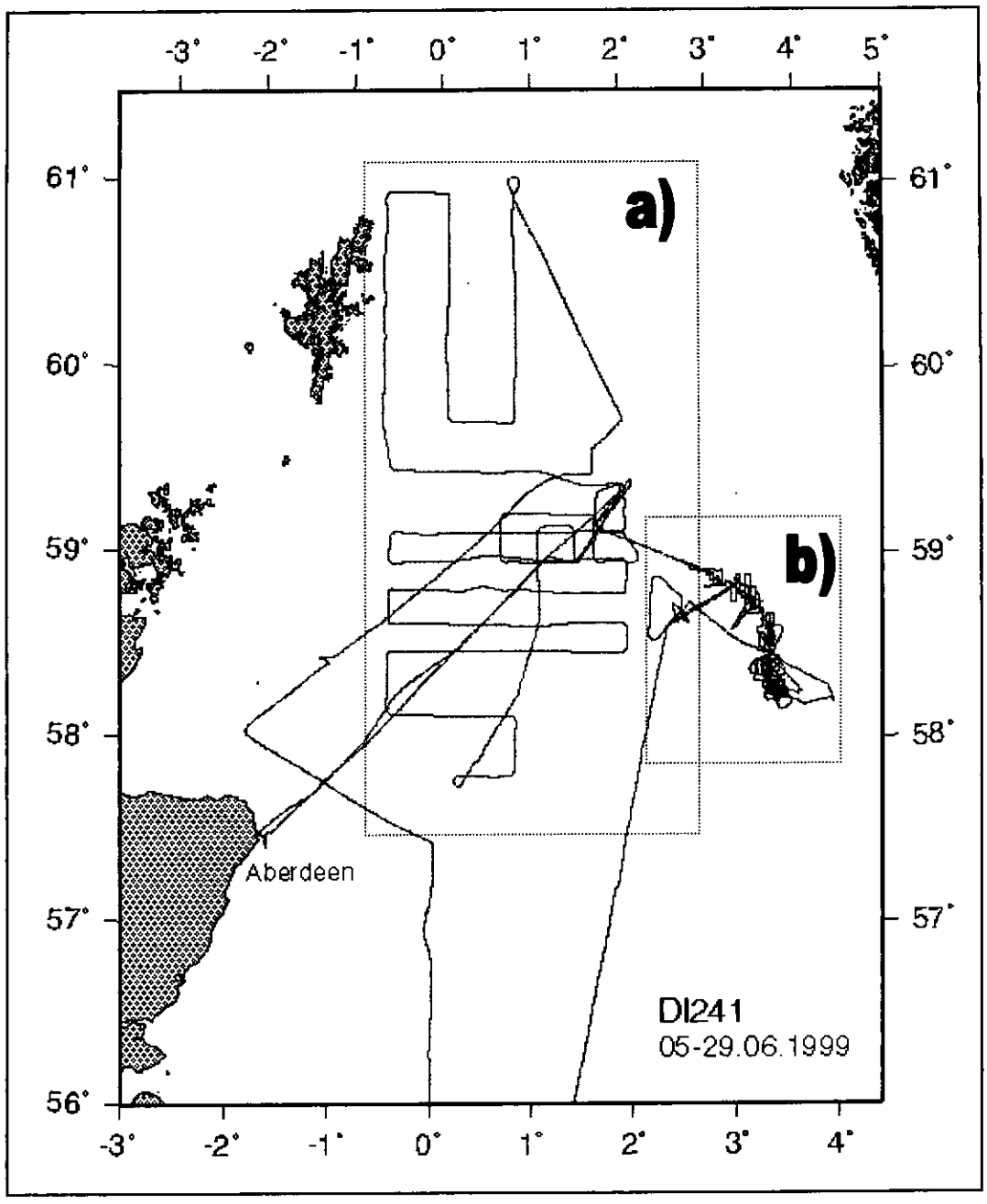
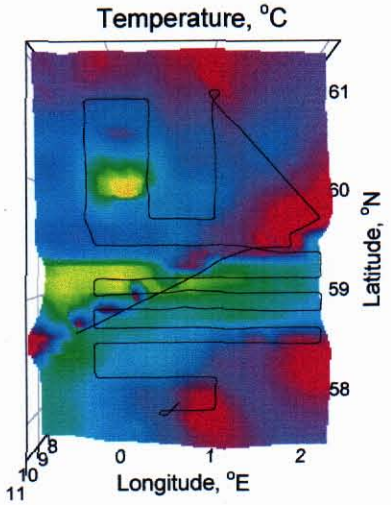


Figure 2.1: DISCO cruise track showing a) a 52,000 km^2 survey carried out between ~57°30' and 61°00' N and b) the location of the Lagrangian process study.

i)



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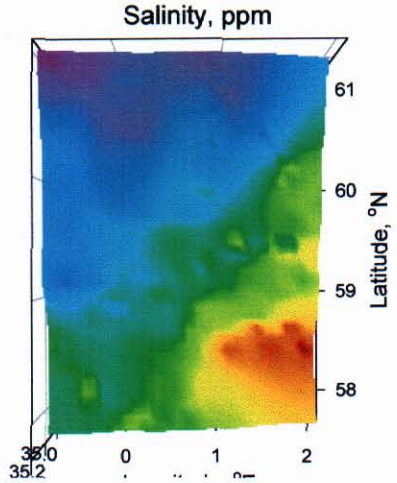

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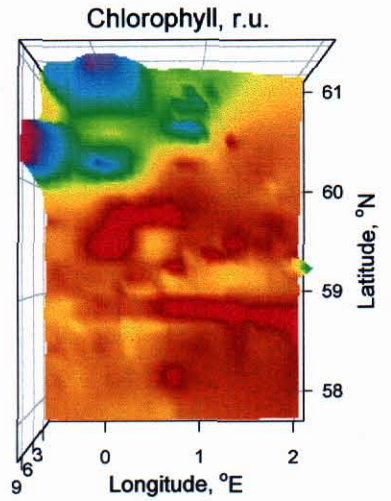

Figure 2.2: Spatial distributions of surface i) temperature, ii) salinity and iii) chlorophyll fluorescence fields on the survey shown in i) and in Figure 2.1 (a). In all plots, the scale red through blue represents low through high values (Figure prepared by M Zubkov).

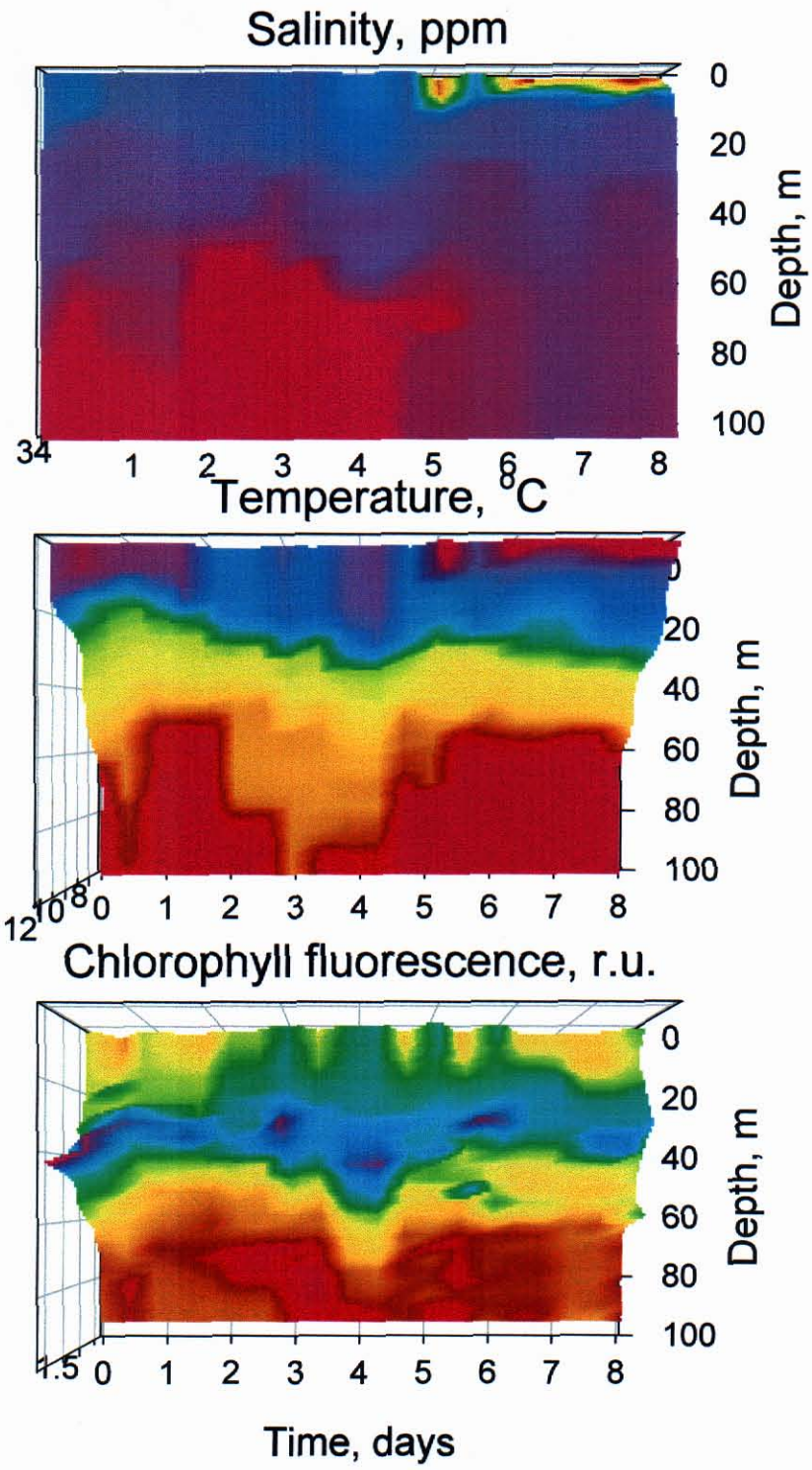

Figure 2.3: Temporal evolution of salinity, temperature and chlorophyll fluorescence fields during the Lagaragian process study. Note - the SF_6 patch we were following was based on subsurface measurements and so sub-thermocline water has no temporal continuity (Figure prepared by M Zubkov).

The broad scale temporal evolution of the Lagrangian drift patch is shown clearly in Figure 2.4. The *E huxleyi* bloom which can be discerned from both backscatter and true colour images as a discrete patch on 15th June becomes slowly eroded with time. While the western end of the patch moves little, it is clear that the eastern end accelerates to the SE as it is influence by currents associated with the Norwegian coast waters to the east.

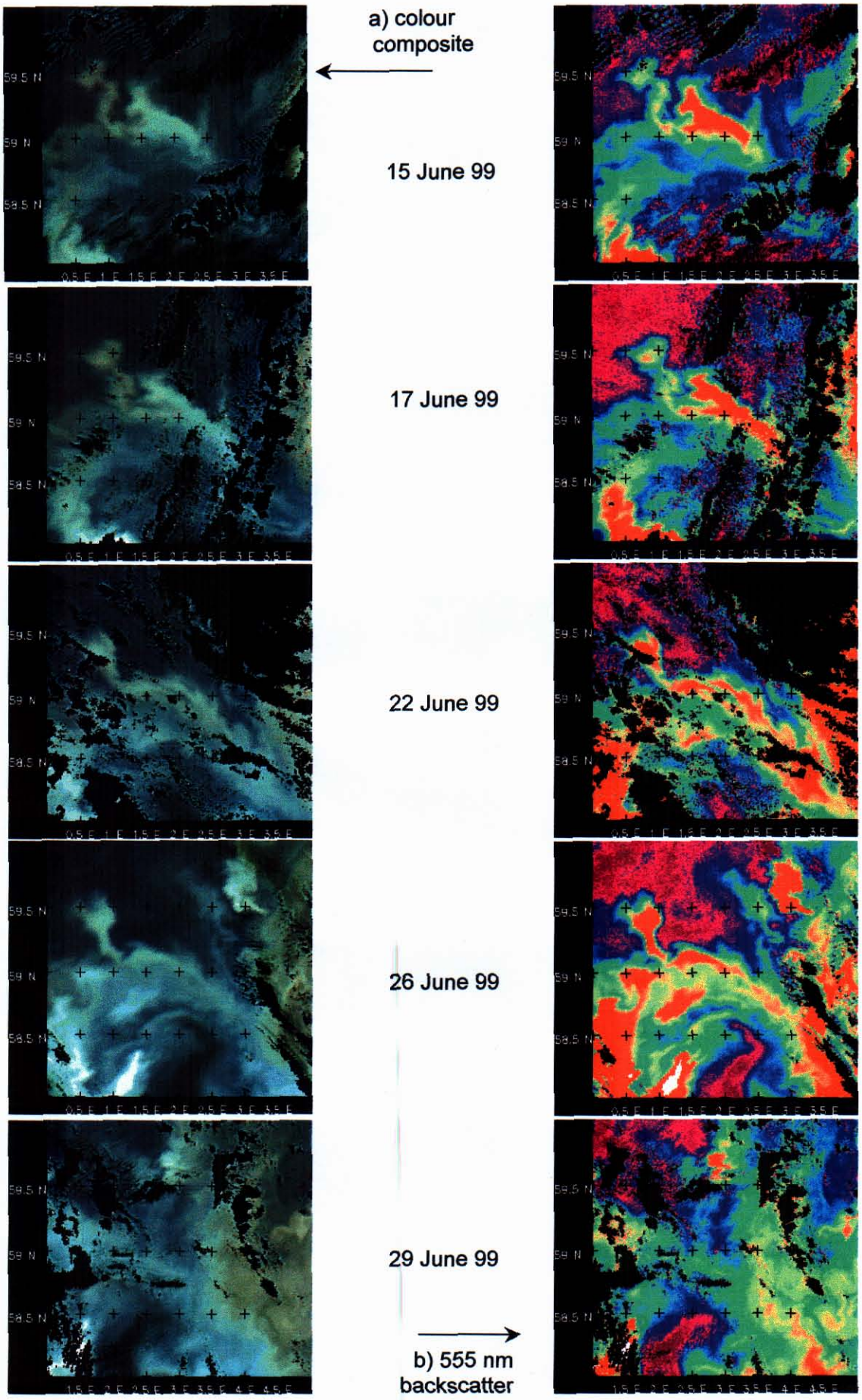

Figure 2.4: Remote sensing images show the temporal & spatial evolution of the study patch.

The main achievements of DISCO included:

1. an 8 day survey of 52,000 km^2 of the northern North Sea for salinity, temperature, fluorescence, nutrients;
2. successful laying of a 40 km^2 patch of SF_6 at 58° 56'N 02° 52'E to allow an 8 day Langrangian drift process study to be carried out;
3. time-varying physical and optical properties of the patch were measured, as were:
4. concentrations of dissolved components: DMS, DMSP, DMSO, nutrients, halocarbons, methylamines, CO, DOC and TDN;
5. concentrations of particulate components: viruses, bacteria, phytoplankton, micro- and mesozooplankton and POC in the patch;
6. the dynamics of components including - primary, new and bacterial production, plankton respiration, zooplankton grazing, and sedimentation (by traps and by radiogeochemistry);
7. all measurements made were related to DMS biogeochemical cycling.

Further detailed achievement of DISCO are presented in the Section 5 of this report .

3. PERSONNEL

Scientists

Name	*Role*	*Institution*
Peter Burkill	Chief Scientist	CCMS/PML[1]
Steve Archer	Deputy CS; DMS & Microzooplankton	CCMS/PML[1]
Denise Cummings	New Production / Nutrients	CCMS/PML[1]
Louise Darroch	DMS experimental	UEA[7]
Jane Foster	Radiogeochemistry	CCMS/DML[4]
Stuart Gibb	Chemotaxonomy & MAs	CCMS/PML[1]
Angela Hatton	DMSO, DMS	SAMS[3]
Xavier Irigoien	Mesozooplankton	CCMS/PML[1]
Mal Liddicoat	SF_6	CCMS/PML[1]
Roger Ling	CO / N_2O / CH_4 / SF_6	CCMS/PML[1]
Axel Miller	DOC, DN	UHI[2]
Phil Nightingale	Halocarbons / SF_6	CCMS/PML[1]
Mat Pinkerton	Optics / UOR	CCMS/PML[1]
Andy Rees	Production/Nutrients	CCMS/PML[1]
Carol Robinson	Respiration O_2/CO_2	CCMS/PML[1]
Bablu Sinha	Physical Oceanography / SF_6	CCMS/PML[1]
Geoff Smith	DMS	DERA[6]
Mike Steinke	DMSPlyase / DMS experimental	UEA[7]
Claire Stelfox	Phyto & Microzooplankton	CCMS/PML[1]
Glen Tarran	Flow Cytometry	CCMS/PML[1]
Willie Wilson	Viruses	MBA[5]
Mal Woodward	Nutrients & Logistics Officer	CCMS/PML[1]
Mike Zubkov	Bacteria & DMS	CCMS/PML[1]
Jeff Benson	Senior Technical Officer & CTD Engineer	RVS[8]
Dave Jolly	CTD Engineer	RVS[8]
Kevin Smith	Mechanical Engineer	RVS[8]
Alan Sherring	Mechanical Engineer	RVS[8]
Rob Lloyd	Computing Engineer	RVS[8]

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8. Research Vessel Services, Southampton Oceanography Centre, Southampton, Hants

Ship's Officers and Crew

Name	*Rank*	*Institution*
Robin Plumley	Master	RVS – Marine, UK
Derek Noden	Mate	RVS – Marine, UK
Syd Sykes	Second Mate	RVS – Marine, UK
Titus Owoso	Third Mate	RVS – Marine, UK
Martin Holt	Chief Engineer	RVS – Marine, UK
Jet Jethwa	Second Engineer	RVS – Marine, UK
Ray Perriam	Third Engineer	RVS – Marine, UK
AN Other	Third Engineer	RVS – Marine, UK
Dave Stewart	ETO	RVS – Marine, UK
Mick Drayton	Bosun	RVS – Marine, UK
Kevin Luckhurst	Deck PO	RVS – Marine, UK
Robert Johnson	AB	RVS – Marine, UK
Steve Day	AB	RVS – Marine, UK
Jim Dale	AB	RVS – Marine, UK
Timmy Edwards	AB	RVS – Marine, UK
Greg Cooper	AB	RVS – Marine, UK
Keith Pringle	Motorman	RVS – Marine, UK
Eddie Staite	Catering Manager	RVS – Marine, UK
John Haughton	Chef	RVS – Marine, UK
Andy Duncan	Mess Steward	RVS – Marine, UK
Wally Link	Steward	RVS – Marine, UK
Sheila Link	Stewardess	RVS – Marine, UK

4. SCIENTIFIC LOG

Time (LT)	Event
Friday 28 May (Julian Day 121)	
1045	Commence de-mobilisation of D240 equipment and mobilisation of RVS D241 equipment. Commence repairs to aft port scientific crane.
1330-1545	Marconi Marine commence Radio Survey.
Tuesday 1 June (Julian Day 125)	
	Continue mobilisation for D241.
Wednesday 2 June (Julian Day 126)	
	MCA complete assessment audit for issue of ISM Code Safety Management Certificate.
	Scientific party join vessel. Resume mobilisation for D241.
Thursday 3 June (Julian Day 127)	
	Continue mobilisation for D241. Marconi Marine complete Radio Survey.
900-940	Basic Safety Familiarisation briefing completed for non-RVSM personnel joining in Southampton. Problem with forward hangar top crane.
Friday 4 June (Julian Day 128)	
	Continue mobilisation.
	Late arrival of scientific equipment (gas cylinders). Re-assessment of time required for remedial action on crane and stowing/securing of scientific equipment determines decision to postpone sailing until morning LW of 5/6/99.
Saturday 5 June (Julian Day 129)	
0810	Pilot aboard.
0839	Clear of berth.
0853	Clear of Empress Dock.
1034	Pilot away.
1130	Clear of Nab entrance. Proceed towards Sandown Bay.
1230	Hove to in Sandown Bay.
1247-1324	Complete test of CTD system in Sandown Bay off IOW. Proceed towards work area.
Sunday 6 June (Julian Day 130)	
0145-0209	Cross Dover Strait TSS.
0900-1000	Cruise planning meeting.
1030-1100	Emergency Drill and Boat Muster.
1845	UOR deployed in 54-09.2N 000-23.9E
2126	UOR recovered in 54-35.5N 000-24.2E
Monday 7 June (Julian Day 131)	
0613	UOR deployed in 56-06.1N 000-00.1W
1120	UOR recovered in 56-57.5N 000-04.0W
1345	UOR deployed in 57-23.3N 000-00.6E

Tuesday 8 June (Julian Day 132)

0000	UOR recovered in 58-26.1N 001-07.7W
0106-0148	CTD at 58-28.4N 001-11.2W
0228	UOR deployed in 58-28.8N 001-03.2W.
1502	UOR recovered in 59-50.0N 001-56.6E
1612	UOR deployed in 59-53.3N 001-53.3E

Wednesday 9 June (Julian Day 133)

0026	UOR recovered in 61-00.0N 000-51.0E
0030-0426	Underway sampling only due to restricted visibility.
0426	UOR deployed 60-31.7N 000-50.4E
1100	Reduce scope of UOR cable to 200 mtrs due to sea conditions and reduced visibility.
1641	UOR recovered in 60-34.3N 000-05.9E

Thursday 10 June (Julian Day 134)

0635	UOR recovered in 59-29.8N 00-14.8W
0748	UOR deployed in 59-29.8N 00-06.6E
2020	UOR recovered in 59-09.7N 00-06.4E
2145	UOR deployed in 59-08.9N 00-04.7E

Friday 11 June (Julian Day 135)

900	Contact made with BRAE production field guard ship on intentions to pass through field. Not impressed with lack of warning so promise to chase up NAVTEX warning.
950	Order to recover UOR due to developing close quarter / risk of collision situation in restricted visibility.
1030	Training drill for SCBA work in for=d hold for deck ratings & officers.
1004	UOR recovered in 58-50.0N 01-36.0E
1008	Resume course through BRAE filed at reduced speed in poor visibility.
1140	UOR deployed 58-50.5N 01-14.6E. Continue at reduced speed in restricted visibility.
2320	UOR recovered in 58-39.7N 00-46.9E

Saturday 12 June (Julian Day 136)

0050	UOR deployed in 58-39.2N 01-03.4E
1310	UOR recovered in 58-13.1N 00-30.0W
1325-1458	CTD at 58-12.4N 00-29.2W
1515-1532	Plankton nets at 58-12.2N 00-29.1W
1548	UOR deployed in 58-12.2N 00-29.1W

Sunday 13 June (Julian Day 137)

35	Order to recover UOR due to developing close quarter / risk of collision.
0050	Commence hauling UOR.
0105	UOR recovered in 57-55.oN 00-26.0E
0222	UOR deployed in 57-50.4N 00-30.9E
1312	UOR recovered in 59-00.0N 00-55.0E
1430	UOR deployed in 59-00.5N 00-52.3E

Monday 14 June (Julian Day 138)

0412	UOR recovered in 59-02.6N 01-32.5E. End of grid survey.
0602	Commence CTD grid survey.
0613-0643	CTD at 59-00.1N 01-30.1E
0840-0910	CTD at 59-51.0N 01-37.2E
1040-1108	CTD at 59-08.6N 01-41.6E

1225-1255	CTD at 59-10.8N 01-45.5E
1344-1415	CTD at 59-15.0N 01-48.9E
1515-1547	CTD at 59-19.3N 01-54.4E
1646-1718	CTD at 59-23.9N 02-00.3E
1736-1758	Plankton nets at 59-23.8N 02-00.3E
1806	All secure, proceed towards Peterhead.

Tuesday 15 June (Julian Day 139)

0930	Stopped off Peterhead Bay.
0954-1030	Starboard lifeboat lowered to water and released from falls, taken away under power for familiarisation training and planned maintenance.
1132	Engineer and laser spares on board.
1919	Engineer away.
1930	All secure, proceed to work area.
2000-2040	Meeting with PS to discuss intentions for SF6 and ARGOS drifter buoy deployments.

Wednesday 16 June (Julian Day 140)

0548	UOR deployed in 58-53.0N 00-53.7E
1043	UOR recovered in 59-26.7N 02-03.8E
1100-1215	Meeting to discuss results and confirm intentions.
1418	UOR deployed in 59-12.0N 01-42.4E
1816	UOR recovered in 58-55.1M 02-55.6E. V/l hove to while processing data.
2230-2320	Meeting to discuss results and confirm intentions. Decision made to commence investigation and lay SF6 in 58-56N 002-52E (C1). Reposition v/l. Commence preparations for laying SF6 and drifting buoys.

Thursday 17 June (Julian Day 141)

0107	Drifting buoy B1 deployed in 58-56.0N 02-52.1E
0110	Commence deploy SF6.
0114	Problem with flow. Stop and v/l re-position.
0151	Resume deploying SF6 in 58-56.1N 02-52.1E following pre-determined grid.
0204	Drifting buoy B2 deployed in 58-56.5N 02-52.0E
0216	Drifting buoy B3 deployed in 58-56.5N 02-53.2E
0232	Drifting buoy deployed in 58-56.0N 02-53.0E. Continue deployment of SF6.
0845	Complete SF6 deployment in 58-53.3N 02-56.7E
0920-1652	CTD survey of SF6 patch.
1912-2008	Recovered Buoys B2 & B4.
2110	Deployed Buoy B2/4 in 58-53.0N 003-01.0E
2110-2355	Hove to in vicinity of revised centre (C2) 58-52.1N 03-03.6E

Friday 18 June (Julian Day 142)

0000-0332	CTD sampling in vicinity of C2.
0332-1007	Hove to in vicinity of C2.
1012	Deploy ADCP mooring in 58-52.46N 3-11.63E
1229-1503	CTD sampling in vicinity of C2.
1503-2359	Underway survey of SF6 patch.

Saturday 19 June (Julian Day 143)

0015-0312	CTD sampling in vicinity of revised centre (C3). 58-49.3N 3-12.7E
0312-0700	V/l hove to in vicinity of C3.
0700-0716	Recover Buoy B1. Reposition to C3.

0902	New centre revised (C4). 58-47.4N 3-16.2E
1000-1454	CTD sampling in vicinity of C4.
1120	Bottom moored Sediment Trap deployed in 48-47.2N 3-17.9E
1523	Buoy B1 redeployed in 58-45.4N 3-17.9E
1523-2330	Underway survey of SF6 patch.
2205	New centre revised (C5). 58-44.3N 3-20.5E
2330-	

Sunday 20 June (Julian Day 144)

0840	V/l hove to for weather at PS request.
0920-0945	Sediment Trap recovered.
1005	New centre revised (C6). 58-43.3N 3-25.7E
1220	New centre revised (C7). 58-42.7N 3-24.3E
1249-1543	CTD sampling in vicinity of C7.
1650-2325	Underway survey of SF6 patch.
	New centre revised (C8). 58-36.5N 03-31.4E
2330-	

Monday 21 June (Julian Day 145)

0247	CTD sampling at C8.
0840-0928	CTD at C8.
1020-1037	Trial deployment of DERA sensor.
1105	Deploy Sediment Trap in 58-36.5N 3-29.89E
1115-1352	Underway survey of SF6 patch.
1255-1617	CTD sampling vicinity of 58-33N 03-27E
1649-2359	Underway survey of SF6 patch.

Tuesday 22 June (Julian Day 146)

0027-0324	CTD sampling in vicinity of 58-33.0N 3-29.8E
0415-0912	UOR survey of SF6 patch.
1040	Recover Sediment Trap.
1102-1247	Underway survey of SF6 patch.
1258-1528	CTD sampling in vicinity of 58-25.7N 3-30.1E
1615-1700	Emergency drill and boat/raft muster.
1705-2345	Underway survey of SF6 patch.
2348-	

Wednesday 23 June (Julian Day 147)

0246	CTD sampling in vicinity of 58-26.0N 3-29.0E
0816	Buoy B1 recovered for re-positioning.
0816-1135	Underway survey of SF6 patch.
1139	Buoy B1 deployed in 58-24.6N 3-25.4E
1146-1417	CTD sampling in vicinity of 58-25.0N 3-25.0E
1506	Deploy Sediment Trap in 58-24.4N 3-24.1E
1542-2355	Underway survey of SF6 patch.

Thursday 24 June (Julian Day 148)

0020-0250	CTD sampling in vicinity of 58-20.7N 3-28.4E
0343-0718	UOR survey of SF6 patch.
0820-1125	Deploying SF6 tracer in vicinity of 58-18.4N 3-30.5E
1147-1435	CTD sampling in vicinity of 58-17.0N 3-30.0E
1611	Recover Sediment Trap
1718-2343	Underway survey of SF6 patch.
2345-	

Friday 25 June (Julian Day 149)

0015	CTD in vicinity of 58-15.9N 3-31.0E
0015-0300	CTD not working. V/l hove to.
0934-1519	CTD sampling in vicinity of 58-15.9N 3-31.0E
1032-1250	RIB work-boat away for remote sampling.
1059	Deploy Sediment Trap in 58-15.66N 3-29.78E

1522-2253	UOR survey of SF6 patch.
1653-1722	Investigate pollution matter on surface in vicinity of 58-16.9N 003-37.6E
2330	

Saturday 26 June (Julian Day 150)

0232	CTD sampling in vicinity of 58-15.7N 3-33.0E
0250-0300	Pollution samples transferred to NOCGV Alesund.
0347-0720	UOR survey in vicinity of 58-15.2N 3-33.7E
0828	Recover Sediment Trap.
0945-1143	Underway sampling.
1143-1417	CTD sampling in vicinity of 58-17.2N 3-33.1E
1609	Recover Buoy B1 in 58-11.7N 3-49.1E
1734	Recover Buoy B2/B4 in 58-12.7N 4-07.7E
1831	Recover Buoy B3 in 58-17.7N 4-04.5E
1843-2340	UOR survey.
2351-	

Sunday 27 June (Julian Day 151)

0300	CTD sampling in vicinity of 58-46.8N 2-40.0E
0305-0828	UOR survey.
0858-0933	CTD in vicinity of 58-43.4N 2-35.0E
1015	Deploy Sediment Trap in 58-43.5N 2-36.0E
1015-1403	CTD sampling in vicinity of 58-42.7N 2-36.6E
2330-	

Monday 28 June (Julian Day 152)

0228	CTD sampling in vicinity of 58-41.8N 2-30.8E
0230-0800	Activities suspended due to adverse conditions and poor visibility.
0925	Recover Sediment Trap.
1105-1412	CTD sampling in vicinity of 58-40.1N 2-27.8E
1647-0006	Attempts to release ADCP unsuccessful.
2130-	

Tuesday 29 June (Julian Day 153)

0006	Attempts to drag for ADCP unsuccessful.
0316-0436	CTD sampling in vicinity of 58-38.3N 2-24.9E
0436	Proceed towards Southampton.

Wednesday 30 June (Julian Day 154)

0900-1005	Cruise De-brief meeting.
2223-	

Thursday 1 July (Julian Day 155)

0233	Transit Dover TSS.
1200	Entering East Solent by Nab Tower.
1301	Pilot on board at N. Sturbridge buoy.
1454	All secure stbd side to No.26 Berth, Empress Dock, Southampton.

5. SCIENTIFIC AND TECHNICAL LOGS

5.1: Physical Oceanography

Bablu Sinha (CCMS, Plymouth Marine Laboratory, UK)

OBJECTIVES

To characterise the hydrographic and velocity structure in the Northern North Sea, to relate physical, remote sensing and biological measurements.

METHODS

Analysis of ADCP, CTD, XBT and surface properties data.

a) Acoustic Doppler Current Profiler

The ship's hull-mounted ADCP was successfully utilised during the cruise and recorded data continuously. As it was anticipated that we would be working on the continental shelf (depth < 150m) for the duration of the cruise, the bottom tracking option was selected on the PC-based ADCP Data Acquisition Software. This enabled accurate measurement of absolute current velocities without the need for calculation of the ship's velocity from navigation data. Ensembles were averaged over 2 minute intervals by the PC and logged directly by the level A of the RVS ship's computer system. Software was version 2.48 and firmware version 17.07. Good underway data was typically achieved to a depth of about 75m in the survey area with around 45 pings per ensemble. The ADCP clock on the PC ran fast by about 30 seconds in a 24 hour period and was reset once per day. The timing error accrued between clock resets was eliminated in subsequent processing. Comparison of the ADCP (ship's) gyro and heading data from the GPS Ashtech system indicated a consistent bias of about 3° in the gyro (thanks to Rob Lloyd, RVS for calculating this). The offset has not been applied to the archived data. All processing was on the PSTAR system , the data being dealt with in roughly 24 hour sections. Post processing consisted of reading the raw data into the PSTAR processing system, correcting timing errors, merging with navigation data (bestnav) averaging into 20minute intervals and archiving. Contour plots (with time and depth) of east and north velocities, vertical velocity, %good and amplitude were routinely plotted in 12 hour sections. In addition current vectors were plotted at regular intervals and progressive vector diagrams indicating water movement were prepared regularly, these being of use in estimating the position of the SF_6 patch during the Lagrangian experiment.

b) CTD Processing

Each of the 71 CTD's performed during the cruise was converted into ASCII format (data recorded at 24hz) using the DATCNV program of the Seasoft PC-based processing package. The variables recorded where Time, Temperature, Conductivity, Pressure, Oxygen, Fluorescence, Upwelling and

downwelling (PAR) irradiances, light transmission and Seatech sensor. The ASCII format data was archived, before reading into the PSTAR processing system. Post processing consisted of calculation of derived variables (e.g. salinity and density), separation into up- and down- casts and plotting of profiles. Spikes in the data have been identified and will be removed during post-cruise processing. Table 1 summarises the CTD deployments.

c) Expendable bathythermographs

A total of 94 XBT's were launched during DY241 (see Table 2). The UK hydrographic office kindly provided the probes, all of the T7 variety (maximum depth capability 760m). The launch system was PC based, using SEAS software, with facilities to plot and list data, and performed well during the cruise. Failure rate of the probes was under 10%. Data from all successful launches were transmitted direct to the hydrographic office via the GOES satellite. The profiles were found to indicate a spurious high temperature in the top 5m and this data was disregarded. The XBT's were used to provide real-time hydrographic information, during the initial survey and during the Lagrangian experiment. The data will complement the UOR measurements as they provide information deeper down the water column and were also used in situations when the UOR was not deployed or did not carry it's CTD (e.g. during SF6 survey periods).

d) Underway data processing

The surface properties (Temperature, Salinity, fluorescence and transmission) were periodically plotted in near real time as an aid to detection of the bloom and to determine suitable sites for release of the SF_6 tracer.

Table 5.1.1: D241 XBT Station List

Seq.	Day	Time	Stn.	Latitude			Longitude			Depth (m)
001	157	1431	06/02	53	34.9	N	000	56.0	E	25
002	158	1405	07/03	57	31.8	N	000	14.1	W	90
003	158	1606	07/04	57	42.0	N	000	53.3	E	119
004	158	1758	07/05	57	52.8	N	001	24.9	E	111
005	158	2001	07/06	58	04.7	N	001	56.0	E	72
006	159	0228	08/03	58	33.8	N	000	50.3	W	123
007	159	0341	08/04	58	41.8	N	000	29.9	W	118
008	159	0351	08/05	58	43.7	N	000	25.9	W	127
009	159	0430	08/06	58	48.1	N	000	14.3	W	121
010	159	0511	08/07	58	52.8	N	000	05.8	W	116
011	159	0607	08/08	58	58.9	N	000	08.9	E	146
012	159	0716	08/09	59	06.5	N	000	26.2	E	131
013	159	0813	08/10	59	13.4	N	000	40.5	E	132
014	159	0919	-	59	22.2	N	000	56.5	E	119
015	159	0930	08/11	59	22.9	N	000	58.2	E	116
016	159	1014	08/12	59	27.3	N	001	12.1	E	104
017	159	1116	08/13	59	28.7	N	001	32.7	E	114
018	159	1223	08/14	59	37.4	N	001	40.1	E	124
019	159	1320	08/15	59	44.4	N	001	55.9	E	116
020	159	1617	08/18	60	02.4	N	001	44.4	E	109
021	159	1725	08/19	60	13.4	N	001	33.8	E	123
022	159	1814	08/20	60	21.7	N	001	26.0	E	138
023	159	2017	08/21	60	41.4	N	001	07.5	E	147
024	159	2215	08/22	60	59.4	N	000	48.5	E	150

025	-	-	-	60	41.7	N	000	49.3	E		153
026	160	0223	09/01	60	40.9	N	000	49.4	E		154
027	160	0419	09/03	60	23.3	N	000	50.6	E		149
028	160	0631	09/04	59	58.9	N	000	50.2	E		133
029	160	0831	09/05	59	46.0	N	000	30.7	E		137
030	160	1029	09/06	59	52.6	N	000	05.9	E		125
031	160	1235	09/07	60	10.0	N	000	04.4	E	-	
032	160	1432	09/08	60	25.0	N	000	06.0	E	-	
033	160	1736	09/10	60	45.0	N	000	06.1	W		115
034	161	2356	10/01	60	30.1	N	000	36.3	W		142
035	161	0458	10/02	59	30.1	N	000	26.7	W		127
036	161	0731	10/04	59	29.9	N	000	18.3	E		129
037	161	1033	10/05	59	27.9	N	001	17.0	E		108
038	161	1330	10/06	59	15.8	N	002	00.0	E		121
039	161	1638	10/07	59	10.0	N	001	03.4	E		116
040	161	2111	10/09	59	09.3	N	000	15.2	W		146
041	162	0015	11/01	59	00.4	N	000	00.7	E		132
042	162	0514	11/02	59	00.9	N	001	37.2	E		119
043	162	1250	11/04	58	51.4	N	000	38.0	E		148
044	162	1837	11/05	58	39.9	N	000	23.4	W		131
045	162	2130	11/06	58	40.0	N	000	30.5	E		139
046	163	0109	12/02	58	40.1	N	001	25.3	E		115
047	163	0411	12/03	58	30.5	N	001	46.8	E		109
048	163	9717	12/04	58	31.0	N	000	39.4	E		152
049	163	1032	12/05	58	29.9	N	000	30.1	W		133
050	163	1909	12/10	58	08.5	N	000	50.9	E		156
051	164	0245	13/02	58	08.8	N	000	42.6	E		156
052	164	1007	13/03	59	03.6	N	001	28.3	E		123
053	164	1103	13/04	58	59.9	N	001	15.2	E		134
054	164	1224	13/05	59	00.0	N	000	54.1	E		137
055	164	1522	13/07	59	13.4	N	000	41.4	E		131
056	164	1623	13/08	59	16.0	N	000	59.2	E		113
057	164	1755	13/09	59	15.6	N	001	31.9	E		114
058	164	1852	13/10	59	08.9	N	001	40.7	E		117
059	164	2144	13/11	59	07.4	N	002	01.7	E		120
060	164	2344	13/12	59	19.1	N	001	51.8	E		122
061	165	0114	14/01	59	21.2	N	001	42.3	E		120
062	165	0155	14/02	59	13.9	N	001	42.0	E		117
063	167	1340	16/02	59	10.1	N	001	47.8	E		120
064	167	1411	16/03	59	08.2	N	001	56.9	E		121
065	167	1443	16/04	59	06.3	N	002	06.4	E		122
066	167	1510	16/05	59	04.0	N	002	16.4	E		118
067	167	1543	16/07	59	01.8	N	002	26.1	E		123
068	167	1613	16/08	58	59.4	N	002	36.7	E		125
069	167	1641	16/09	58	57.5	N	002	45.5	E		129
070	168	0936	17/07	58	56.0	N	002	53.0	E		129
071	168	1128	17/09	58	56.5	N	002	56.0	E		129
072	168	1254	17/11	58	55.3	N	003	01.0	E		130
073	171	1617	20/06	58	39.5	N	003	25.9	E		105
074	171	1756	20/07	58	40.2	N	003	30.1	E		116
075	171	1930	20/08	58	41.1	N	003	32.3	E		127
076	171	2116	20/09	58	38.3	N	003	31.5	E		120
077	173	0349	22/06	58	34.5	N	003	23.9	E		111
078	173	0422	22/07	58	57.9	N	003	31.5	E		122
079	173	0508	22/08	58	33.7	N	003	35.7	E		126
080	173	0543	22/09	58	27.7	N	003	29.9	E		118
081	173	0628	22/10	58	21.2	N	003	29.6	E		117
082	173	0724	22/11	58	26.7	N	003	34.2	E		113
083	175	0311	24/05	58	21.9	N	003	21.4	E		115
084	175	0420	24/06	58	25.3	N	003	27.6	E		117
085	175	0509	24/07	58	16.5	N	003	25.8	E		104
086	175	0557	24/08	58	17.9	N	003	36.9	E		117
087	175	0800	24/09	58	18.7	N	003	31.8	E		126

088	177	0317	26/04	58	17.6	N	003	33.5	E		123
089	177	0410	26/05	58	18.1	N	003	24.5	E		115
090	177	0445	26/06	58	15.3	N	003	35.3	E		113
091	177	0547	26/07	58	11.7	N	003	32.9	E		85
092	178	1532	27/05	58	36.9	N	002	23.3	E		101
093	178	0455	27/06	58	44.3	N	002	15.3	E		105
094	178	0632	27/07	58	51.6	N	002	28.0	E		115

Table 5.1.2: D241 CTD Station List

Day	Time	Stn.	Seq.	Latitude			Longitude			Depth (m)	Max.P	#Recs
159	00:23:55	08/01	001	58	28.3	N	001	11.3	W	105	104	24975
163	12:27:47	12/06	002	58	12.9	N	000	29.6	W	116	107	20507
163	13:30:27	12/07	003	58	12.3	N	000	29.2	W	116	110	36333
165	05:17:31	14/04	004	59	00.1	N	001	30.1	E	125	115	34390
165	07:45:20	14/05	005	59	06.0	N	001	37.6	E	119	101	33261
165	09:43:54	14/06	006	59	09.0	N	001	41.5	E	118	101	33103
165	11:30:21	14/07	007	59	11.0	N	001	45.0	E	118	104	32606
165	12:48:49	14/08	008	59	15.0	N	001	48.6	E	120	106	34392
165	14:20:33	14/09	009	59	19.4	N	001	54.4	E	121	111	34650
165	15:52:02	14/10	010	59	23.9	N	002	00.3	E	126	111	36269
168	10:24:54	17/08	011	58	56.6	N	002	50.5	E	127	117	45349
168	12:06:25	17/10	012	58	56.4	N	003	00.5	E	130	121	34946
168	13:29:31	17/12	013	58	51.4	N	003	00.6	E	121	112	39660
168	15:00:29	17/13	014	58	51.4	N	002	50.5	E	123	111	34305
168	23:02:19	17/1716	015	58	52.1	N	003	02.6	E	120	111	26946
168	23:55:21	17/17	016	58	52.6	N	003	03.0	E	121	111	53698
169	01:58:48	18/03	017	58	52.5	N	003	04.3	E	121	111	46086
169	11:34:13	18/06	018	58	51.0	N	003	14.5	E	108	104	53408
169	13:49:35	18/09	019	58	50.9	N	003	16.8	E	116	50	17314
169	23:16:48	19/01	020	58	49.0	N	003	10.8	E	116	100	17976
169	23:58:54	19/02	021	58	49.5	N	003	12.8	E	106	95	40049
170	01:41:51	19/04	022	58	49.5	N	003	12.6	E	106	95	40421
170	09:08:30	19/05	023	58	46.8	N	003	17.0	E	110	32	15361
170	11:43:23	19/08	024	58	46.6	N	003	17.9	E	113	104	47675
170	13:28:56	19/10	025	58	45.9	N	003	18.0	E	106	76	30198
171	11:52:11	20/01	026	58	42.6	N	003	24.6	E	113	100	39583
171	13:41:59	20/03	027	58	42.4	N	003	24.0	E	112	94	31414
171	22:36:39	20/10	028	58	36.6	N	003	31.2	E	122	106	30778
171	23:32:30	20/11	029	58	36.8	N	003	30.9	E	123	105	49964
172	01:18:36	21/02	030	58	37.1	N	003	30.8	E	122	104	39304
172	09:23:24	21/05	031	58	36.2	N	003	29.9	E	122	40	15690
172	12:58:48	21/07	032	58	33.0	N	003	27.2	E	112	102	42844
172	14:31:48	21/09	033	58	33.1	N	003	27.9	E	113	46	16954
172	23:31:51	22/01	034	58	31.0	N	003	30.9	E	114	102	23507
173	00:09:39	22/02	035	58	30.8	N	003	30.4	E	114	100	54215
173	01:52:15	22/04	036	58	31.2	N	003	30.3	E	115	75	42457
173	12:02:25	22/12	037	58	25.8	N	003	30.0	E	120	108	39057
173	13:34:39	22/14	038	58	25.6	N	003	29.7	E	118	75	25704
173	22:52:36	22/15	039	58	25.5	N	003	29.8	E	117	100	21860
173	23:30:50	23/01	040	58	25.7	N	003	29.5	E	119	100	50892
174	01:15:36	23/03	041	58	26.0	N	003	28.9	E	118	101	42201
174	11:25:57	23/06	042	58	24.6	N	003	24.8	E	114	101	39129
174	13:00:08	23/08	043	58	24.2	N	003	24.6	E	114	40	20279
174	23:01:07	23/10	044	58	20.4	N	003	28.2	E	119	109	23411
174	23:38:46	24/01	045	58	20.5	N	003	28.4	E	119	110	55463
175	01:19:21	24/03	046	58	20.7	N	003	28.1	E	119	106	42803
175	11:32:44	24/11	047	58	17.2	N	003	31.1	E	113	100	40459
175	13:10:18	24/13	048	58	16.9	N	003	30.2	E	113	101	33291
175	22:50:02	24/14	049	58	15.9	N	003	30.9	E	112	100	31551
175	23:44:27	25/01	050	58	16.2	N	003	29.6	E	115	99	7322
176	08:37:26	25/03	051	58	15.9	N	003	31.0	E	112	42	17971

176	11:24:23	25/06	052	58	15.7	N	003	29.4	E	112	103	49012
176	13:17:40	25/08	053	58	16.2	N	003	28.8	E	113	62	27457
176	22:33:10	25/10	054	58	16.4	N	003	34.1	E	111	101	19843
176	23:16:07	26/01	055	58	15.7	N	003	34.0	E	108	99	47543
177	00:57:46	26/03	056	58	14.8	N	003	33.7	E	110	101	47411
177	11:20:27	26/09	057	58	17.5	N	003	33.2	E	123	113	42143
177	12:51:20	26/11	058	58	16.9	N	003	32.5	E	122	102	33658
177	22:55:11	26/12	059	58	46.8	N	002	39.7	E	116	102	19553
177	23:40:29	27/01	060	58	46.8	N	002	40.1	E	116	102	39912
178	01:09:41	27/03	061	58	46.8	N	002	40.4	E	116	102	38340
178	08:14:25	27/08	062	58	43.6	N	002	35.0	E	110	101	23642
178	11:11:22	27/11	063	58	42.5	N	002	36.2	E	110	101	48417
178	12:41:30	27/13	064	58	41.7	N	002	37.2	E	110	77	27781
178	22:45:50	27/14	065	58	42.2	N	002	31.0	E	108	103	19607
178	23:30:18	28/01	066	58	42.0	N	002	30.6	E	108	100	47119
179	00:56:53	28/03	067	58	41.6	N	002	31.2	E	107	102	42270
179	11:24:42	28/05	068	58	40.3	N	002	27.6	E	106	96	36652
179	12:52:26	28/07	069	58	39.8	N	002	27.9	E	105	91	25935
180	02:20:04	29/01	070	58	38.4	N	002	25.1	E	103	81	17883
180	03:00:27	29/02	071	58	38.3	N	002	24.9	E	103	91	49560

5.2: Optical Oceanography

M.H. Pinkerton (CCMS Plymouth Marine Laboratory, UK)

SUMMARY

The purpose of work was to measure the bio-optical structure of the upper water column. This used three combinations of instruments:

1. CTD with single-flash fluorometer (CTDF). A beam transmissometer at 660nm is also used when the CTDF package is deployed in the UOR. This measures beam attenuation (c660) arising from a combination of absorption and scattering.
2. Seven-band precision spectral radiometers for measuring irradiance and radiance across the visible part of the spectrum, 412 – 665 nm.
3. Fast Repetition Rate Fluorometry (FRRF) to characterise the photosynthetic state of the phytoplankton population in near-real time. The Chelsea Instruments FastTracka (serial number 182027) was used throughout.

The three instrument combinations were deployed in four ways during the cruise:

1. The FRRF measured continuously from the ship's non-toxic supply situated at a depth of about 5 m.
2. Undulating Oceanographic Recorder (UOR). This is towed 200 m behind the ship and undulates between the near surface (approximately 7 m) to about 50 m. A complete undulation is completed every 15 minutes.

3. Attached to the main CTD of the ship. The FRRF and CTDF were piggy-backed on the CTD system provided and operated by Research Vessel Services (RVS). The assistance of the RVS CTD personnel in this work is acknowledged and much appreciated.

4. The radiometers were profiled through the water column to 80 m on a stand-alone optical profiling rig which minimises instrument and ship shading. Downwelling irradiance (Ed) and upwelling radiance (Lu) were measured, together with depth and instrument attitude from the vertical. A third sensor mounted on the monkey-island of the ship (above the bridge) was used to measure incident irradiance (Es) during the optical profiling. The wavelengths measured are centred on 412, 443, 490, 510, 555, 620 and 665 nm, with a 10 nm bandwidth.

Table 5.2.1: FRRF Underway Sampling

File	Start		End	
	Date	Time GMT	Time GMT	Date
0506_01	05/06/99	13:53	19:30	05/06/99
0506_02	05/06/99	19:43	07:52	06/06/99
0606_01	06/06/99	08:09	08:17	06/06/99
0606_02	06/06/99	08:30	15:42	06/06/99
0606_03	06/06/99	15:50	05:56	07/06/99
0706_01	07/06/99	06:08	06:13	07/06/99
0706_02	07/06/99	06:16	07:27	07/06/99
0706_03	07/06/99	07:35	13:43	07/06/99
0706_04	07/06/99	14:20	02:00	08/06/99
0806_01	08/06/99	03:27	15:30	08/06/99
0806_02	08/06/99	16:00	02:34	09/06/99
0906_01	09/06/99	02:54	03:11	09/06/99
0906_02	09/06/99	03:20	17:54	09/06/99
0906_03	09/06/99	18:10	07:00	10/06/99
1006_01	10/06/99	07:45	18:22	10/06/99
1006_02	10/06/99	18:45	00:30	11/06/99
1106_01	11/06/99	00:42	10:45	11/06/99
1106_02	11/06/99	11:19	00:36	12/06/99
1206_01	12/06/99	00:55	16:21	12/06/99
1206_02	12/06/99	16:49	02:35	13/06/99
1306_01	13/06/99	02:55	14:29	13/06/99
1306_02	13/06/99	14:42	04:36	14/06/99
1606_01	16/06/99	12:10	18:31	16/06/99

Table 5.2.2: UOR Tows

File	Start		End				
	Date	Time GMT	Time GMT	Date	Periods	Instruments	FRRF file
d069901	06/06/99	18:10	20:05	06/06/99	1	CTDF, Ed#02, Lu#02, c660	
d069902	07/06/99	05:00	10:00	07/06/99	1.5	CTDF, Ed#02, Lu#02, c660	
d069903	07/06/99	12:38	23:05	07/06/99	2	Ed#02, Lu#02	
d069904	08/06/99	01:15	14:00	08/06/99	2	CTDF, Ed#02, Lu#02, c660	
d069905	08/06/99	15:05	23:35	08/06/99	2	CTDF, Ed#02, Lu#02, c660	
d069906	09/06/99	03:20	15:50	09/06/99	2	CTDF, Ed#02, Lu#02, c660	
d069907	09/06/99	16:55	05:50	10/06/99	2	CTDF, Ed#02, Lu#02, c660	
d069908	10/06/99	06:30	19:30	10/06/99	2	CTDF, Ed#02, Lu#02, c660	
d069909	10/06/99	20:15	09:15	11/06/99	2	CTDF, Ed#02, Lu#02, c660	

d069910	11/06/99	10:15	22:30	11/06/99	2	CTDF, Ed#02, Lu#02, c660	
d069911	11/06/99	23:30	12:20	12/06/99	2	CTDF, Ed#02, Lu#02, c660	
d069912	12/06/99	14:30	01:15	13/06/99	2	CTDF, Ed#02, Lu#02, c660	
d069913	13/06/99	01:00	12:25	13/06/99	2	CTDF, Ed#02, Lu#02, c660	
d069914	13/06/99	13:00	03:20	14/06/99	2	CTDF, Ed#02, Lu#02, c660	
d069915	16/06/99	04:25	09:55	16/06/99	0.8	CTDF, Ed#02, Lu#02, c660	
d069916	16/06/99	13:05	17:30	16/06/99	0.5	CTDF, Ed#02, Lu#02, c660	
d069917	22/06/99	03:00	08:15	22/06/99	1	FRRF, PAR, Ed#02, Lu#02	d0699f35
d069918	24/06/99	02:45	06:20	24/06/99	1	CTDF, Ed#02, Lu#02, c660	
d069919	26/06/99	02:45	06:30	26/06/99	1	FRRF, PAR, Ed#02, Lu#02	d0699f55
d069920	26/06/99	17:30	22:50	26/06/99	1	CTDF, Ed#02, Lu#02, c660	
d069921	27/06/99	02:00	06:20	27/06/99	1	CTDF, Ed#02, Lu#02, c660	

Table 5.2.3: CTD Piggy-backs

Date	Start time GMT	CTDF file	FRRF file
05/06/99	11:44	d0699p01	
14/06/99	05:15	d0699p02	d0699f01
14/06/99	07:42	d0699p03	d0699f02
14/06/99	09:40	d0699p04	d0699f03
14/06/99	11:15	d0699p05	d0699f04
14/06/99	12:40	d0699p06	d0699f05
14/06/99	13:13	d0699p07	d0699f06
14/06/99	15:45	d0699p08	d0699f07
17/06/99	08:20	d0699p09	d0699f08
17/06/99	10:10	d0699p10	d0699f09
17/06/99	12:00	d0699p11	d0699f10
17/06/99	13:25	d0699p12	d0699f11
17/06/99	14:50	d0699p13	d0699f12
17/06/99	22:55		d0699f13
17/06/99	23:49		d0699f14
18/06/99	13:43		d0699f17
18/06/99	23:17		d0699f19
18/06/99	23:59		d0699f20
19/06/99	11:40		d0699f22
20/06/99	11:46	d0699p18	d0699f24
20/06/99	13:34		d0699f25
20/06/99	22:32		d0699f26
20/06/99	23:27		d0699f27
21/06/99	01:13		d0699f28
21/06/99	12:53	d0699p20	d0699f30
21/06/99	23:26		d0699f32
22/06/99	00:04		d0699f33
22/06/99	01:47		d0699f34
22/06/99	03:14		d0699f35
22/06/99	11:57	d0699p22	d0699f36
22/06/99	13:30		d0699f37
22/06/99	22:46		d0699f38
22/06/99	23:26		d0699f39
23/06/99	00:10		d0699f40
23/06/99	11:18	d0699p25	d0699f41
23/06/99	12:55		d0699f42
23/06/99	22:55		d0699f43
23/06/99	23:31		d0699f44
24/06/99	01:13		d0699f45
24/06/99	11:27	d0699p27	d0699f46

24/06/99	13:01		d0699f47
24/06/99	22:44		d0699f48
24/06/99	23:40		d0699f49
25/06/99	11:15	d0699p28	d0699f50
25/06/99	13:10		d0699f51
25/06/99	22:26		d0699f52
25/06/99	23:11		d0699f53
26/06/99	00:51		d0699f54
26/06/99	02:52		d0699f55
26/06/99	11:17	d0699p31	d0699f56
26/06/99	12:45		d0699f57
26/06/99	22:49		d0699f58
26/06/99	23:35		d0699f59
27/06/99	01:03		d0699f60
27/06/99	08:08		d0699f61
27/06/99	11:04	d0699p33	d0699f62
27/06/99	12:35		d0699f63
27/06/99	22:39		d0699f64
27/06/99	23:24		d0699f65
28/06/99	00:51		d0699f66
28/06/99	11:17	d0699p35	d0699f67
28/06/99	12:45		d0699f68
29/06/99	02:14		d0699f69
29/06/99	02:54		d0699f70

Table 5.2.4: Optical Profiling

File	Date	Start time GMT	End time GMT	Ed sensor	Lu sensor	Es sensor	Freq Hz
D0699s01	18/06/99	12:18:10	12:50	02	02	85	3
D0699s02	19/06/99	10:36:10	11:15	02	02	fail	3
D0699s03	20/06/99	14:22:30	14:55	02	02	85	3
D0699s04	21/06/99	14:58:30	15:37	02	02	85	3
D0699s05	22/06/99	14:07:30	15:33	02	02	85	3
D0699s06	23/06/99	10:47:15	11:22	02	02	85	3
D0699s07	24/06/99	10:45:10	11:05	02	02	85	3
D0699s08	25/06/99	13:59:00	14:25	02	02	85	3
D0699s09	26/06/99	10:44:05	11:10	02	02	85	3
D0699s10	27/06/99	10:25:40	10:55	02	02	85	6
D0699s11	28/06/99	10:06:10	10:30	02	02	85	6

5.3: MICRO- and NANO- NUTRIENT ANALYSIS

Malcolm Woodward, Denise Cummings, and Andy Rees (CCMS Plymouth Marine Laboratory)

OBJECTIVES:

To study the spatial and temporal variations of the micro nutrients Nitrate, Nitrite, Phosphate, Silicate, and Ammonia, and nanomolar concentrations of Nitrate and Ammonia during an investigation of a coccolithophore bloom from its early growth phase through to senescence. Nutrients distributions were studied during an extensive surface water box survey (1500 square

miles) of the northern North Sea from the Murray Firth, through to the east of the Shetlands and then further transects south and east in order to attempt to identify an area suitable for a later detailed lagrangian study of a suitable plankton bloom. Once located there was an initial CTD survey to study in detail the nutrient regime of the chosen area, then the final lagrangian study was effected by the release of an SF6 gas tracer into the water column. The lagrangian experiment was to study over the final 12 days the spatial variation of the nutrient concentrations in the marked water in relation to the growth of the coccolithophores in that water. Studies were to be also carried out in collaboration with the other members of the 'nutrient team' for nitrogen uptake experiments.

A number of photo degredation experiments and on-deck incubations were to be attempted also during the cruise.

METHODS

The nutrient analyser was a 5 channel Technicon AAII, segmented flow autoanalyser. The chemical methodologies used were nitrate (Brewer and Riley, 1965), nitrite (Grasshoff, 1976), phosphate (Kirkwood, 1989), silicate (Kirkwood, 1989) and ammonia (Mantoura and Woodward, 1983). Nanomolar nitrate and nitrite detection was from Garside (1982), and the nanomolar ammonia system adapted from Jones (1991).

Sampling from the CTD was sub sampled into clean Nalgene bottles and analysis for the samples was in every case complete within 2 hours of sampling. No samples were stored.

Underway continuous surface sampling was from the non-toxic water system, and the water flow was in-line filtered (Morris *et al*, 1978), before analysis. Data output was stored on the ships mainframe computer for all 5 channels with a data point every 30 seconds during the surface transects.

EQUIPMENT PERFORMANCE

All CTD samples were analysed successfully with a very low sample loss rate.

The main 'Technicon' nutrient analyser system showed good reliability and good reproducability of data output, despite the ageing nature of the equipment and non computerisation of the data output. However, certain key components are beginning to break down on a more regular basis and the time will soon be here when this main analytical tool will begin to fail and compromise scientific knowledge during these cruises.

The nanomolar ammonia and nitrate system caused no problems during the cruise. However again the ageing nitrate system was at the limits of its detection limits and at the low levels encountered during the majority was not as reproducible as would be desired. Equipment replacement here again is urgently required to enable this facility to continue.

A lack of any type of reliable portable computer severely curtailed any data analysis whilst on board the ship.

Table 5.3.1: CTD Samples Analysed.

CTD	DATE	DEPTHS (m)
CTD 12/06	12.6.99	106m
CTD 12/07	12.6.99	2, 5
CTD 14/04	14.6.99	4,8,12,16,20,24
CTD 14/05	14.6.99	1,10,20,30,50,75
CTD 14/06	14.6.99	1,10,20,30,50,75
CTD 14/07	14.6.99	1,10,20,30,50,75
CTD 14/08	14.6.99	1,10,20,30,50,75
CTD 14/09	14.6.99	1,10,20,30,50,75
CTD 14/10	14.6.99	1,10,20,30,50,75
CTD 17/06	17.6.99	1,10,20,30,50,75
CTD 17/07	17.6.99	1,10,20,30,50,75
CTD 17/08	17.6.99	1,10,20,30,50,75
CTD 17/09	17.6.99	1,10,20,30,50,75
CTD 17/10	17.6.99	1,10,20,30,50,75
CTD 17/17	17.6.99	5,10,15,18,20,22,25, 30,40,50,75,100
CTD 18/03	18.6.99	5,10,15,20,30,36,50, 75,100
CTD 18/06	18.6.99	5,10,15,17,20,25,30, 35,40,55,75,99
CTD 19/02	19.6.99	1,6,10,12,15,19,28 35,45,49,75,93
CTD 19/04	19.6.99	5,10,20,25,35,46 60,75,100
CTD 19/08	19.6.99	1,5,10,15,20,30,35 40,50,60,75,100
CTD 20/01	20.6.99	1,5,10,20,25,30,35,40,50,5 0,75,97
CTD 20/11	20.6.99	1,5,10,15,18,20,25,29,35,5 0,75,100
CTD 21/03	21.6.99	5,10,15,20,25,33,50, 75,100
CTD 21/07	21.6.99	1,5,10,15,20,25,30,40,75,1 00
CTD 22/02	22.6.99	1,5,10,15,20,25,30,40,50,6 0,75,99
CTD 22/04	22.6.99	5,10,15,20,30,40
CTD 22/12	22.6.99	1,5,10,15,20,25,30,40,50,6 0,75,107
CTD 23/01	23.6.99	1,5,10,15,20,25,30,40,50,6 0,75,99
CTD 23/03	23.6.99	5,10,15,20,27,35
CTD 23/06	23.6.99	1,5,10,15,22,25,28,35,46,6 0,75,100
CTD 24/01	24.6.99	1,5,8,15,22,24,26,30, 40,50,75,100
CTD 24/03	24.6.99	3,10,15,18,25,34
CTD 24/11	24.6.99	1,5,10,15,20,30,34,45,55,6 5,75,100
CTD 25/06	25.6.99	1,5,10,15,20,30,36,50,54,6 5,75,100
CTD 26/01	26.6.99	1,3,8,15,20,27,31,36, 40,58,75,100
CTD 26/03	26.6.99	3,10,15,20,27,33
CTD 26/09	26.6.99	1,5,10,15,20,25,30,40,50,6 0,75,100
CTD 27/01	27.6.99	1,5,10,15,20,24,26,30,40,5 0,75,100
CTD 26/09	26.6.99	1,5,10,15,20,25,30,40,50,6 0,75,100
CTD 27/01	27.6.99	1,5,10,15,20,24,26,30,40,5 0,75,100
CTD 28/01	28.6.99	1,5,10,15,20,25,30,35,38,5 0,75,100
CTD 28/03	28.6.99	5,10,15,23,30,37
CTD 28/05	28.6.99	1,5,10,15,20,25,30,38,50,6 0,75,100

ON-LINE SAMPLING SURVEY.

Continuous surface nutrient analyses was performed from 7.6.99 at 03:25 to12.6.99 at 22:00.

PRELIMINARY RESULTS

Surface nitrate distributions during the spatial survey phase of the cruise identified areas with concentrations greater than 6 µmoles l^{-1}, at the northern extremes of the box survey to the east of the Shetlands. Elevated concentrations (~3.6 µmoles l^{-1}) were observed just offshore from the Murray Firth. However, once the area off the Shetlands was traversed and the transect survey continued southwards the surface nitrate, and indeed all the other nutrient became undectectable (<0.08 µmoles l^{-1}) by the colorimetric autoanalyser, and were in nanomolar concentrations at the surface.

The results from the CTD profiles during the remainder of the cruise showed that the nitrate concentrations in the surface mixed layer, that is depths to about 30/35 metres were always in the range of between 5 and 15 nanomoles l^{-1}. Below the nutricline the deep water concentrations for nitrate were about 8 µmoles l^{-1}. Due to unavaialability of water samples because of other scientific priorities, information from around the nutricline region is poor in detail and a secondary objective of the cruise to investigate nutrient fluxes across this region will be poorly served with the information acquired on this cruise. Nanomolar concentrations in the surface waters were typically around 45-60 nanomoles l^{-1} during the lagrangian phase of this cruise. There was a similar structure in the concentration depth profile to the nitrate in that the ammonia increased in concentration below the nutricline to about 2-2.4 µmoles l^{-1}. This concentration was maintained to a greater or lesser extent to the bottom water sampled at 100m.

Effects of a secondary water mass (low salinity water) that encroached upon our survey 'patch' were noted later in the cruise both at depth and as a surface wedge, this water was characterised by a higher nitrate concentrations and very low ammonia concentration.

5.4: USE OF SULPHUR HEXAFLUORIDE AS A LAGRANGIAN TRACER.

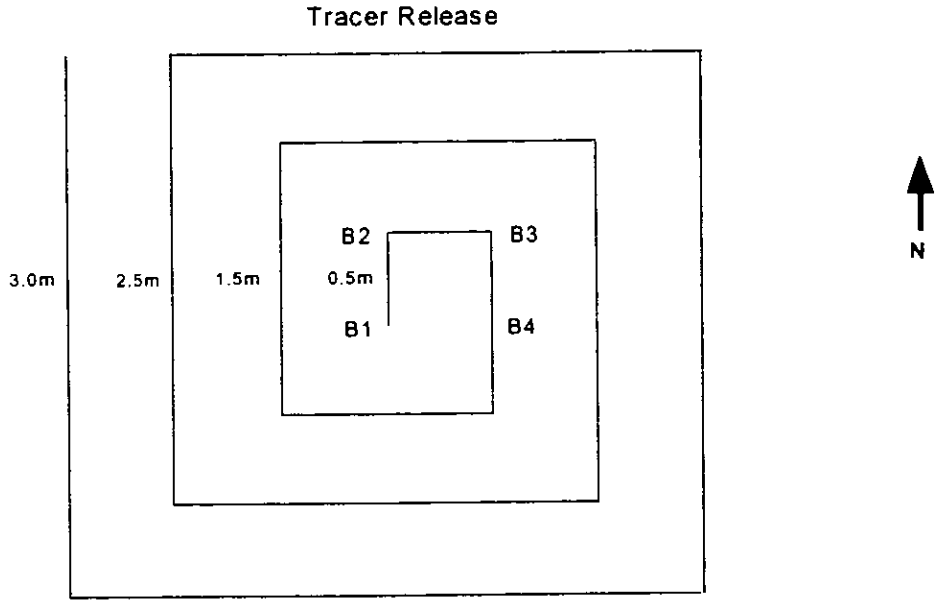
Phil Nightingale, Malcolm Liddicoat and Roger Ling (CCMS Plymouth Marine Laboratory)

DEPLOYMENT OF TRACER

Release 1: Approximately 30 grams of sulphur hexafluoride (SF_6) was dissolved into 2200 litres of seawater contained in an air-tight tank over a 36 hour period during the transit of the ship towards the initial survey site. The concentration of SF_6 in the tank immediately prior to deployment was approximately 0.25 % by volume. Coincident analysis of air inside the ship showed that background levels were only twice ambient and that we had been successful in avoiding contamination of the laboratories.

Initial CTD casts in the release area indicated a that the water column was well mixed to about 15 m. The tracer was released from 18:45 GMT on 16/6 through to 07:45 GMT 17/6 via gravity feed at a target depth of 8 metres using a 50 kg depressor. In order to limit the potential loss of tracer into the tank headspace as the tracer-tagged water was deployed, a header tank and balloon were utilised so that no air was entrained into the tank. Subsequent analysis of temperature and pressure data from a sensor located immediately adjacent to the tank outlet showed that the mean depth of release was 7.5 m and that more than 90% of the tracer was released between 6.5 and 9.5 m. The temperature varied between 11.33 and 11.39 °C during the release period, indicating that all of the tracer was released in the mixed layer and within the same water mass. Some variability in depth was unavoidable given the movement of the stern of the vessel in the inclement weather encountered.

The initial intention had been to release the tracer as the ship steamed an expanding box shown below in order to create a patch with dimensions of 3 by 3 miles. Unfortunately the direction and magnitude of the surface current was considerably greater than expected. An approximation of the initial release grid relative to a fixed point in the water was therefore made using a combination of output from the Livenav display and regularly updated information from B1, the mother buoy. The size of the patch was therefore probably nearer 3 miles by 4 miles.



B1 Central 'mother' buoy, drogue depth 35m (GPS to ship)

B2 pCO2 buoy, drogue depth to 35m

B3 DML buoy, surface temperature sensor, drogue depth 10m

B4 Thermistor chain, drogue depth 65m

Figure 5.4.1: Tracer release scheme

Release 2.: The remnants of the original patch were re-seeded with tracer from 08:00 GMT through to 12-00 GMT on 24/6. Approximately 2200 litres of seawater containing 0.025% by volume of SF6 was deployed in a 1 by 1 mile box. Previous CTDs indicated that the surface water was well mixed to a depth of only 4 m. The tracer was therefore released between 2 and 3m, difficult to achieve given the vertical motion of the stern of the ship. The repositioned B1 buoy served as a central reference point for the re-infusion.

UNDERWAY SF_6 MEASUREMENTS.

Semi-continuous measurements of SF_6 were made from the ship's non-toxic supply every 3.5 minutes for the whole period of the tracer experiment. The data was interfaced to a GPS in order to obtain in near-real time a visual representation of the patch and this used as an aid to survey the patch and identify the patch centre in time for the midnight CTD casts. The movement of the

tracer can be clearly seen in the figure below. Unfortunately one of the traps proved to be of qualitative use only and data from it have not been used subsequently.

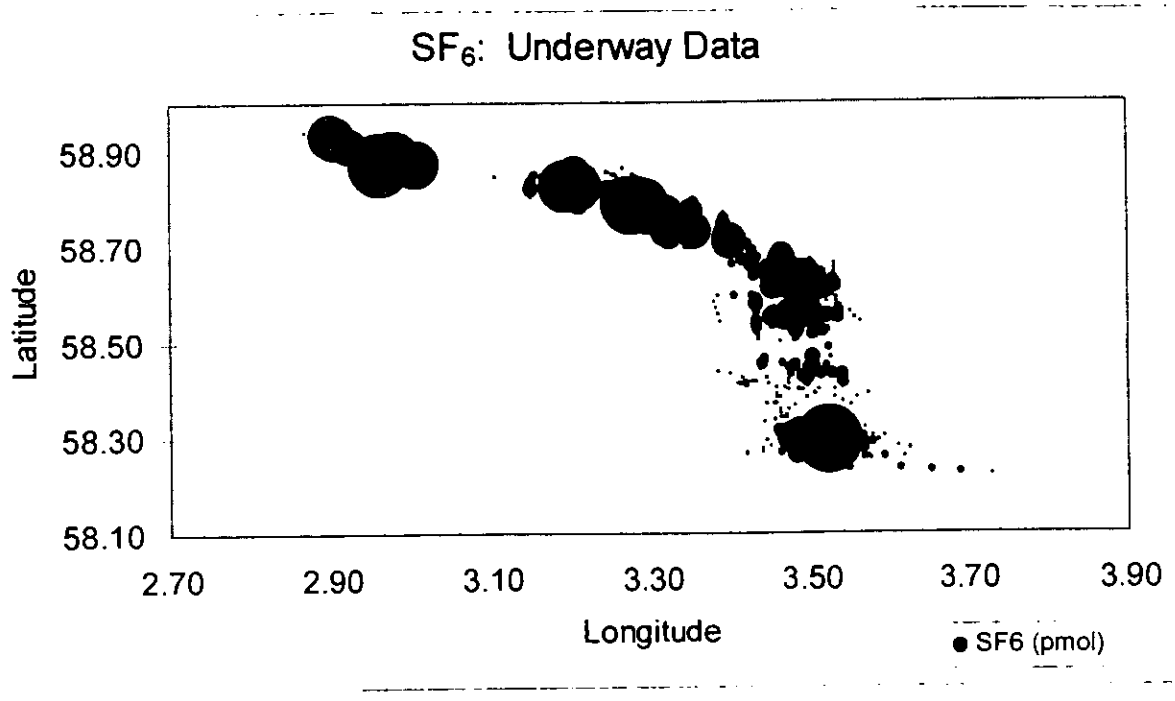


Figure 5.4.2: Concentrations of SF_6 tracer

This work had two main aims. The first was to track the movement of the tracer in the surface of the water column for the duration of the experiment and identify the patch centre for subsequent vertical profiling. This was successfully achieved. The second was to obtain sufficient coverage of the patch on a regular basis in order to be able to estimate horizontal diffusion rates (K_y). Unfortunately the length of time agreed to achieve this (12 hours) was routinely reduced to typically 5-6 hours steaming due to time overruns associated with the midday station and sediment trap deployments. The data generated are unlikely to be sufficient to obtain estimates of K_y.

DISCRETE SF_6 MEASUREMENTS.

Highly accurate measurements of vertical SF_6 profiles were made on 18 CTD casts inside the tracer patch and on 8 background casts. Measurements were routinely made from typically 12 depths varying from 1 m to 75 m. These data will be used to obtain estimates of vertical diffusion (K_z). A preliminary examination of the data shows that within 24 hours of the release the tracer had mixed uniformly to 10 m and penetrated to 15 m. By 21/6 the SF_6 was uniformly mixed to 25 m and had penetrated to 30 m. Subsequently the tracer was rapidly depleted (due to mixing) in the surface and no depth of uniform mixing could be identified from the tracer in vertical profiles. Contact with the deeper SF_6 enriched water was maintained until the 24/6, after which the patch was reseeded. After re-infusion the SF_6 penetrated to a maximum of 5 m but was well mixed to only a depth of 2 m (as observed in near-surface profiles obtained from a RIB.

Further to the vertical profiles, measurements were made of background SF_6 in marine air on three different days, and from a floating flux chamber in order to try to directly estimate the air-sea transfer velocity of SF_6.

We gratefully acknowledge the help of the ship's crew in deploying the tracer and the ship's officers in accommodating our requests when surveying the tracer patch.

5.5: DMS AND HALOCARBON DETERMINATIONS

Geoff Smith (Environmental Sciences, DERA Haslar)

OBJECTIVES

1. To collect DMS, DMSP(d), DMSP(p) data from diurnal level 1 CTD casts.
2. To collect DMS and DMSP data from the various surveys of 'the patch.'
3. To collect part of the underway DMS determinations when locating the area for the Lagrangian study.
4. To perform opportunistic intercalibration for DMS and DMSP during the homeward journey to check the 5 independent analysis systems on board.
5. To determine background variability of various biogenic halocarbons in seawater.

METHODS

DMS analyses of all samples will be completed during the trial using Purge and trap preconcentration with GC mass spectrometry using deuterated internal standards (ie d6DMS, D_3CSCD_3). All DMSP analyses use the internal standard d6DMSP. Analysis for DMSP(d) will be completed after the cruise by cold hydrolysis of the prepurged sea water with analysis of the resulting DMS in the method outline above. DMSP(p) will be calculated from the determination for Total DMSP.

A range of 21 halocarbons were analysed by purge and trap GC/MS using a method with selective single ion monitoring and a detection limit of typically <0.2pptw (parts per trillion by weight, ng/l). Halocarbon analyses were completed for certain depths (ie 5,10,30,50,100m) of certain level 1 CTD casts. Halocarbon photodegradation experiments were also set up.

Table 5.5.1: Samples Analysed

Event	Date and Time (GMT)	DMS and DMSP	Halocarbons
Underway	7/6/99 14:00 to 22:00	Every ½ - 1 hr	not determined
Underway	8/6/99 13:30 to 20:00	Every 1 hour	not determined
Underway	9/6/99 12:00 to 21:00	Every 1 hour	not determined

Underway	10/6/99 12:00 to 19:00	Every ½ - 1 hr	not determined
Underway	11/6/99 15:00 to 19:00	Every ½ - 1 hr	not determined
Underway	12/6/99 14:00 to 20:00	Every 1 hour	not determined
CTD 14/04 (survey)	14/6/99 06:00	All depths	not determined
CTD 14/05 (survey)	14/6/99 09:30	All depths	not determined
CTD 14/06 (survey)	14/6/99 11:30	All depths	not determined
CTD 14/07 (survey)	14/6/99 13:00	All depths	not determined
CTD 14/08 (survey)	14/6/99 14:00 †	All depths	not determined
CTD 14/09 (survey)	14/6/99 15:00 †	All depths	not determined
CTD 14/10 (survey)	14/6/99 16:30 †	All depths	not determined
Underway	16/6/99 15:30 to 16:30	Replicate smpls	1 analysis
CTD 17/06 (survey)	17/6/99 08:40	All depths	10m depth
CTD 17/08 (survey)	17/6/99 11:00	All depths	10m depth
CTD 17/10 (survey)	17/6/99 12:30	All depths	10m depth
CTD 17/12 (survey)	17/6/99 14:00	All depths	10m depth
CTD 17/13 (survey)	17/6/99 15:15	All depths	10m depth
CTD 17/17 (level 1)	18/6/99 00:30	All depths	10m depth
CTD 18/06 (level 1)	18/6/99 11:30	All depth	10m depth
CTD 19/02 (level 1)	19/6/99 00:02	All depths	5,10,28,49,93m
CTD 19/08 (level 1)	19/6/99 11:40	All depths	5,10,35,50,100m
CTD 20/01 (level 1)	20/6/99 11:49	All depths	5,10,35,50,97m
CTD 20/11 (level 1)	20/6/99 23:32	All depths	5,10,25,50,100m
CTD 21/05	21/6/99 09:20	Not determined	40m depth replcts
CTD 21/07 (level 1)	21/6/99 12:55	All depths	5,10,30,50,100m
CTD 22/02 (level 1)	22/6/99 00:08	All depths	5,10,30,50,99m
CTD 22/12 (level 1)	22/6/99 11:59	All depths	5,10,30,50,107m
CTD 23/01 (level 1)	23/6/99 00:00	All depths	30m depth
CTD 23/06 (level 1)	23/6/99 11:22	All depths	5,10,28,46,100m
CTD 24/01 (level 1)	23/6/99 23:37	All depths	5,8,26,50,109m
CTD 24/11 (level 1)	24/6/99 11:29	All depths	5,10,34,55,99m
CTD 25/06 (level 1)	25/6/99 11:19	All depths	8 depths total
Zodiac surface smpls	25/6/99 12:00	All depths	not determined
CTD 26/01 (level 1)	25/6/99 23:15	All depths	not determined
CTD 26/09 (level 1)	26/9/99 11:17	All depths	not determined
CTD 27/01 (level 1)	26/6/99 23:40	All depths	not determined
CTD 27/11 (level 1)	27/6/99 11:08	All depths	not determined
CTD 28/01 (level 1)	27/6/99 23:29	All depths	not determined
CTD 28/05 (level 1)	28/6/99 11:19	All depths	5,10,20,30,,-75m
CTD 29/02 (level 1)	29/6/99	All depths	1-10,20,24,32-80
Intercalibration exercise between 4/5 of the field analytical systems on board for DMS, DMSP (p+d). Planned for 30/6/99			

† GC/MS maintenance required after two power failures. Low confidence of DMS results for this CTD deployment.

COMMENTS: The mass spectrometer had to be repaired over 36 hours following two power cuts prior to the level 1 CTD casts.

5.6: INCUBATION EXPERIMENTS TO INVESTIGATE THE TURNOVER OF DMS, DMSO AND DMSP.

Louise Darroch (School of Environmental Sciences, University of East Anglia)

OBJECTIVES

1. To carry out incubation experiments to investigate the turnover of DMS, DMSP and DMSO along a Lagrangian time series.
2. To carry out incubation experiments to determine the half-saturation constants for DMS and DMSP consumption.

METHODS

Seawater from CTD bottles were filtered through a 200µm mesh and collected in a 40L keg. From this, replicates were set up in either 4L – 1L polycarbonate bottles. Inhibitors such as dimethyldisulphide (DMDS) and glycine betaine (GBT) and substrates such as dimethylsulphoniopropionate (DMSP) were added to some bottles during several experiments. Bottles were incubated in the dark at the rear in situ temperatures in an on-deck incubation tank, filled with running seawater. Concentrations of dimethyl sulphide (DMS) and dimethylsulphoxide (DMSO) were monitored over 12 to 18 hour time courses using a Varian gas chromatograph with flame photometric detector. DMS was preconcentrated prior to GC analysis using a cryogenic purge-and-trap method. DMSO analyses were done using a novel enzyme-linked method developed at our laboratory (Hatton *et al* 1994). This technique involves using DMSO reductase isolated from the photosynthetic bacterium. Rhodobacter capsulatus to reduce DMSO to DMS which can then be analysed by GC. A total of 6 incubation experiments were carried out.

SUMMARY OF WORK

Lagrangian Time series

6 incubation experiments to estimate the turnover of DMS, DMSP and DMSO.

Non – Lagrangian waters

Incubation experiments to determine half-saturation constraints for DMS consumption.

INITIAL RESULTS

The addition of DMDS as a competitive inhibitor of DMS consumption had little effect on DMS concentrations from surface water collection from the pre-dawn casts on the 18,21 and 23 June. However, the addition of DMDS did cause a small increase in DMS concentrations (~1nM after 14hrs incubation) from water collected on the 26 June (CTD 26-03). In contrast GBT caused a small decrease in DMS concentrations during this experiment (~1nM after 14hrs incubation), DMS consumption was estimated at 2.53nM/d, while DMS production was 6.97nM per day.

During the Lagrangian time series, DMS concentrations ranged from 2 – 4 nM.

Refs:

Hatton, A.D., Malin, G., McEwan, A.G. and Liss, P.S. 1994. Determination of dimethyl sulphoxide in aqueous solution by an enzyme-linked method. *Analytical Chemistry* 66:4093-4096.

5.7: MICROZOOPLANKTON HERBIVORY AND PREY SELECTIVITY AND ITS RELATIONSHIP TO DMS(P) DYNAMICS

Stephen Archer, Claire Stelfox & Glen Tarran (CCMS Plymouth Marine Laboratory, UK)

INTRODUCTION AND OBJECTIVES

Microzooplankton are considered to be an important control of phytoplankton production in the sea and estimates of their grazing impact indicate that 20 to >100 % of daily primary production is consumed. In addition, microzooplankton grazing has been identified as one of the key processes that control the production of dissolved DMSP and DMS in marine surface waters. In the context of a coccolithophore bloom we had the following objectives:

1. to determine the rates of microzooplankton grazing on phytoplankton during the progression of a bloom / lagrangian patch
2. to determine prey selectivity by microzooplankton in order to link rates of herbivory to the fate of DMSP-rich phytoplankton and DMS/DMSPd production.
3. to quantify DMS/DMSPd production due to herbivory by microzooplankton

METHOD

The dilution approach (Landry & Hassett 1982) was chosen as a means to alter microzooplankton grazing pressure on phytoplankton with minimal manipulation of the community. An increase in the proportion of filtered to unfiltered water in incubations reduces the probability of encounter between predator and prey and thereby, reduces grazing pressure on the phytoplankton. From these experiments we hoped to determine the impact of microzooplankton grazing on :

1. the total phytoplankton community, through changes in chlorophyll *a* concentration
2. specific taxa of the phytoplankton, in particular coccolithophores, through flow cytometry and chemotaxonomy
3. DMSP-rich phytoplankton, through changes in DMSPp concentration associated with altered grazing pressure
4. the production of DMS/DMSPd

Table 5.7.1: EXPERIMENTAL DATES AND THE MEASUREMENTS CARRIED OUT:

Dates	Chlorophyll a	AFC	Pigments	DMSP	Bacteria	DMS Production

18/06/99	Y	Y	Y	Y	Y	Y
19/06/99	Y	Y	Y	Y	Y	Y
21/06/99	Y	Y	Y	Y	Y	Y
22/06/99	Y	Y	Y	Y	Y	?
24/06/99	Y	Y	Y	Y	Y	N
26/06/99	Y	Y	Y	Y	Y	deep water
27/06/99	Y	Y	Y	Y	Y	deep water
28/06/99	Y	Y	Y	Y	Y	deep water

COMMENTS

There was certainly a fairly significant grazing impact on the bloom. Further analyses and interpretation of the data will hopefully give us some interesting incites into the role microzooplankton play in controlling primary production during such blooms and in the fate of the large pool of phytoplankton DMSP produced in these waters. We modified the set up of our dilution experiments on this cruise as a result of some complicated results from previous studies in waters containing abundant coccolithophores. It seems to have worked well. Disturbing the relative concentrations of dissolved DMSPd and DMS in setting up the experiments, hampers detection of DMS/DMSPd production rates. We tried several different approaches to prevent this but are unclear whether they worked yet.

5.8: STUDIES TO INVESTIGATE THE ROLE OF DIMETHYLSULPHOXIDE IN THE BIOGEOCHEMICAL CYCLE OF DIMETHYLSULPHIDE

Angela Hatton (Scottish Association for Marine Science, DML, UK)

The transfer of any trace gas from seawater to the atmosphere is essentially a physical process. However, the quantity of any volatile biogenic compound available for sea-to-air gas exchange is a balance of the production, transformation and utilisation processes occuring in the water column. For dimethylsulphide (DMS) a network of pathways have been proposed and some of these are reasonably well established, but the role of dimethylsulphoxide (DMSO) remains poorly quantified. DMSO has been suggested to be both a sink (*via* photooxidation and bacterial oxidation) and a source (*via* direct production from phytoplankton and bacterial reduction) of oceanic DMS. However, little work has been conducted on this subject, due to analysis of DMSO being problematic, until recently. The aims of my research during DISCO were to carry out routine CTD analysis for DMSO, to conduct light/dark studies in order to assess the significance of photooxidation, and to conduct sediment trap studies to investigate the turnover of DMS, DMSP and DMSO in sedimenting material.

A total of twenty-one CTD's (DMSO only), five photooxidation experiments and five trap deployments were carried out (Table 1). Concentrations of DMSO, DMS and DMSP (dissolved and particulate) were analysed using a Varian gas chromatograph fitted with pulse flame photometric detectors. DMS was preconcentrated prior to GC analysis using a cryogenic purge-and-trap method. DMSO analyses were done using a novel enzyme-linked method. This

technique involves using DMSO reductase isolated from the photosynthetic bacterium *Rhodobacter capsulatus* to reduce DMSO to DMS, which can then be analysed by GC. DMSP analyses were performed after addition of10 M soduim hydroxide had broken down any DMSP to DMS, which could then be analysed as above.

A number of samples will be taken back to the laboratory for analysis over the next few months and the data needs to be fully checked and interpreted before any conclusions can be drawn. However, initial results look very exciting. The light/dark studies appear to show that photolysis, and not photooxidation, is the dominant process involved in the removal of DMS (Figure 1), and trap samples showed relatively high concentrations of DMSP were removed from surface waters due to sedimentation.

Figure 5.8.1: Removal of a) DMS and b) DMSO by different treatments.

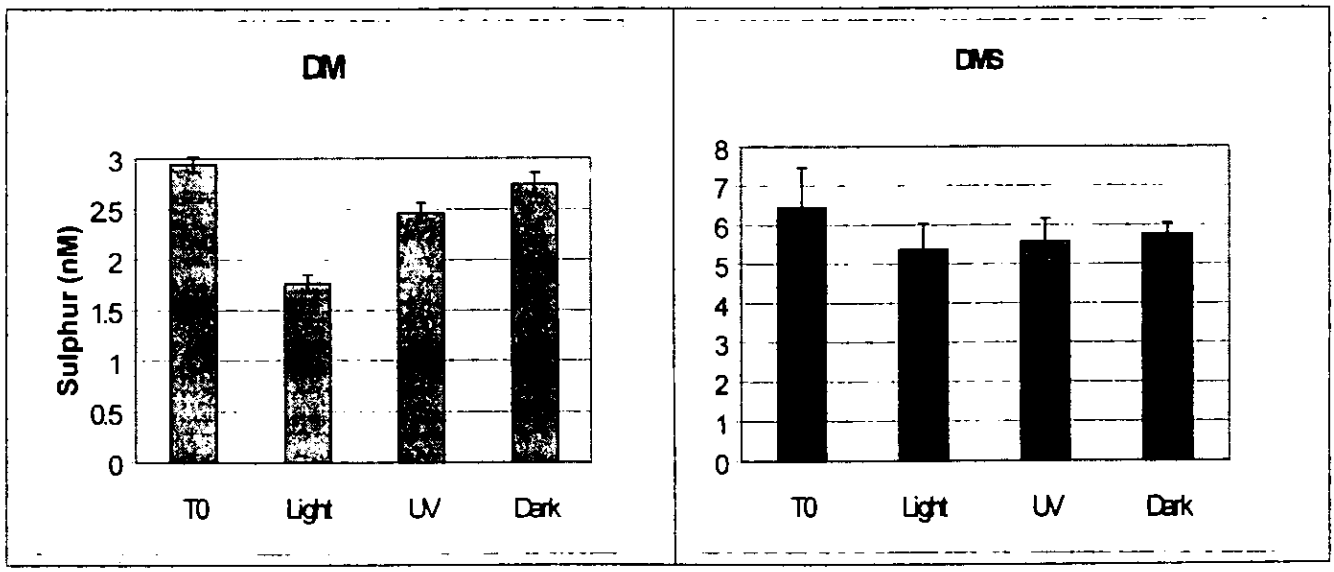


Table 5.8.1: Samples analysed and experiments carried out.

Date	Study	Event number	Depth range	Number of depth	Samples
10/6/99	Light/dark	Exp A	N/A	N/A	DMS, DMSO, DMSPd
14/6/99	CTD	14/04	1-75 m	6	DMSO
14/6/99	CTD	14/06	1-75 m	6	DMSO
14/6/99	CTD	14/08	1-75 m	6	DMSO
14/6/99	CTD	14/10	1-75 m	6	DMSO
17/6/99	CTD	17/06	1-75 m	6	DMSO
17/6/99	CTD	17/08	1-75 m	6	DMSO
17/6/99	CTD	17/10	1-75 m	6	DMSO
17/6/99	CTD	17/12	1-75 m	6	DMSO
17/6/99	CTD	17/13	1-75 m	6	DMSO
17/6/99	CTD	17/17	1-100 m	11	DMSO
19/6/99	CTD	19/02	1-95 m	11	DMSO
19/6/99	Light/dark	Exp B	N/A	N/A	DMS, DMSO, DMSPd
19/6/99	CTD (trap)	19/05	1-40 m	2	DMS, DMSO, DMSPp, DMSPd.

19/6/99	Trap A	19/06	40 m	1	DMS, DMSO, DMSPp, DMSPd
20/6/99		20/11	1-75 m	11	DMSO
21/6/99	CTD (trap)	21/05	1-40 m	2	DMS, DMSO, DMSPp, DMSPd
21/6/99	Trap B	21/06	40 m	1	DMS, DMSO, DMSPp, DMSPd
21/6/99	Light/dark	Exp C	N/A	N/A	DMS, DMSO, DMSPd
23/6/99	CTD	23/01	1-100 m	11	DMSO
23/6/99	CTD (trap)	23/08	1-40 m	2	DMS, DMSO, DMSPp, DMSPd
23/6/99	Trap C	23/09	40 m	1	DMS, DMSO, DMSPp, DMSPd
23/6/99	Light/dark	Exp D	N/A	N/A	DMS, DMSO, DMSPd
24/6/99	CTD	24/01	1-108 m	11	DMSO
25/6/99	CTD (trap)	25/03	1-40 m	2	DMS, DMSO, DMSPp, DMSPd
25/6/99	Trap D	25/05	40 m	1	DMS, DMSO, DMSPp, DMSPd
26/6/99	CTD	26/01	1-100 m	12	DMSO
27/6/99	CTD	27/01	1-75 m	10	DMSO
27/6/99	CTD (trap)	27/08	1-100	3	DMS, DMSO, DMSPp, DMSPd
27/6/99	Trap E	27/09	40 m & 100 m	2	DMS, DMSO, DMSPp, DMSPd
28/6/99	Light/dark	Exp E	N/A	N/A	DMS, DMSO, DMSPd
8/6/99 to 12/6/99	Underway	N/A	Surface (Non-Toxic)	N/A	DMS

5.9: METHYLATED AMINES: THE NITROGENOUS ANALOGUES OF DMS

Stuart W. Gibb (CCMS Plymouth Marine Laboratory)

BACKGROUND

In the biogeochemical cycle of nitrogen, the enzymatic production of methylamines (MAs, methylamine, MMA; dimethylamine, DMA; trimethylamine, TMA) from precursors such as trimethylamine oxide (TMAO)and glycine betaine is analogous to the conversion of DMS to DMSP. MAs, like ammonia (NH_3), are dynamic constituents of the reduced nitrogen cycle, widely distributed in the marine environment and intimately involved in marine nitrogen fertility. However, in contrast to studies which have suggested prymnesiophytes and dinoflagelletes to be major producers of DMS, recent evidence suggests a link between the concentrations of MAs and the abundance of diatoms .

In seawater, MAs and NH_3 partition between their dissolved gaseous forms (e.g. $NH_{3(s)}$) and solvated cations (e.g. $NH_4^+{}_{(s)}$) which account for > 90 % of the their total dissolved concentrations. However, the gaseous species may participate in air-sea gas exchange, and in doing so introduce basic, reduced nitrogen into the atmosphere. Atmospheric MAs and NH_3 are implicated several key

aspects of tropospheric chemistry including the regulation of aerosol, rain and cloud water acidity and the nucleation of new particles which may act as CCN to influence CCN mass concentration and thus cloud albedo in an analogous manner to DMS.

OBJECTIVES

1. To characterise the spatial distribution and temporal variability of the methylamines (MAs) and TMAO in surface waters and vertical profiles within a Lagrangian perspective.
2. To relate distributions to *a.* observed nutrient conditions, *b.* phytoplankton biomass and composition *c.* bacterial abundance and *d.* DMS / DMSP distribution and fturnover
3. To investigate the spatial relationship between MAs and TMAO and their sulphur cycle analogues DMS and DMSP with reference to phytoplankton taxonomic data to elucidate taxa-specific nitrogen - sulphur osmolytic preference.

METHODOLOGY

Methylamines (MAs) were analysed using Flow Injection Gas Diffusion coupled to Ion Chromatography (FIGD-IC). MAs were resolved using ion-exchange chromatography and quantified using suppressed conductimetric detection. TMAO was first enzymically converted to TMA which was then determined by FIGD-IC.

Underway surveys: Samples were collected from the ships non-toxic supply at regular intervals during transect and passage legs and analysed for MAs and TMAO to determine the spatial variability of the distribution of these compounds in surface waters. This study constituted the first of MAs in the North Sea and the first shipboard study of TMAO.

CTD profiles: Samples were collected from selected depths from mid-night and mid-day CTD profiles and analysed for MAs and TMAO.

Incubation studies (with Xabier Irigoen and Angela Hatton): A series of incubation studies were conducted to examine the microbial and photochemical turnover of these labile compounds.

Sediment trap studies (with Angela Hatton): Sediment trap samples and corresponding water column samples were analysed for both MAs and TMAO to investigate the significance of these compounds in sedimentation and turnover of nitrogen in the water column.

5.10: CARBON MONOXIDE ANALYSIS

Roger Ling (CCMS Plymouth Marine Laboratory)

Carbon monoxide is produced in the surface layers of seawater by photo-oxidation of dissolved organic material by solar radiation.

The analysis of carbon monoxide (CO) in seawater is performed by equilibration of the water sample with a headspace created in the sample bottle. The headspace gas is zero grade air that is

further purified and is introduced through a septum in the bottle cap as the surplus water is simultaneously expelled. After a period of mixing the equilibrated headspace is introduced into the gas chromatograph and detected by a mercury based reducing gas detector.

Seawater samples from the following CTD casts were analyzed for carbon monoxide. In addition CO was analyzed in water taken from the ships non-toxic seawater supply and in atmospheric samples.

Table 5.10.1: Samples analysed

DATE	CAST NO.
12 June	1207
14 June	1404,1405,1406,1407,1408,1409,1410
17 June	1706,1707,1708,1709,1710
18 June	1717,1806
19 June	1902,1908
20 June	2001
22 June	2212
23 June	2306
24 June	2411
27 June	2701, 2711
28 June	2801, 2805

On the 17,21, 24 and 28 June photo incubations were set up and analyzed to compare the production of CO in filtered and unfiltered seawater under natural sunlight and under a Mylar optical filter.

On 25 June the ships inflatable boat was used to gather water and air samples from a shallow depth range and to measure CO production from the sea surface. Samples for other analyses were also taken.

Over the period 25 and 26 June samples of ships non-toxic seawater and atmospheric air were taken at two hourly intervals for a period exceeding 24 hours. During this period solar irradiance spectra were also recorded.

5.11: DISSOLVED ORGANIC CARBON & TOTAL DISSOLVED NITROGEN ANALYSIS USING HIGH TEMPERATURE CATALYTIC OXIDATION

Axel E J Miller (Scottish Association for Marine Science, University of the Highlands and Islands)

INTRODUCTION

The total oceanic dissolved organic matter (DOM) pool holds between 200-800Gt carbon; equivalent to the amount held as atmospheric CO_2. The DISCO project aims to establish a link between the marine carbon and sulphur cycles; following the dynamics of a *Coccolithophore* sp. bloom and its influence on marine biogeochemistry. Overall, *in situ* biological activity appears to be the dominant source of oceanic DOM, and one which can be variously subdivided into phytoplankton exudation, virally mediated cell damage or lysis; "sloppy feeding" and excretion by zoobenthos, zooplankton and higher pelagic organisms. The principal input of DOM to the ocean is phytoplanktonic release, leading to significant accumulation of dissolved organic carbon (DOC) in oceanic waters following algal blooms. Approximately 7% ($1.8x10^{15}$g $C.yr^{-1}$) of global annual primary production accumulates as DOM in surface waters; where it is available for recycling *via* the "microbial loop"; resulting in bacterial turnover of between 21-30% of total primary production. Another significant mechanism for removal of DOM from surface waters is photochemical oxidation - photolysis. The general magnitude and influence of this process are still poorly known.

METHODOLOGY

Relatively rapid and precise techniques are available for the determination of DOC and total dissolved nitrogen (TDN). Most commonly used for this purpose is high temperature catalytic oxidation (HTCO). Such techniques involve the direct injection of acidified and decarbonated sea water onto a platinised alumina catalyst, at high temperatures (680 - 900°C), under an atmosphere of oxygen or high purity air. Quantitative production of CO2 gas allows DOC concentrations to be determined using a CO2-specific infrared gas analyser (IRGA). In this work these measurements are made using a *Shimadzu TOC 5000* analyser. Incorporation of a *Licor 6252*, solid-state IRGA, and a PC-based integration system (ATi Unicam, *4880*) allows high precision measurements to be made. Addition of a nitrogen-specific chemiluminescence detector (Antek 705D), in series with the IRGA, provides a method for simultaneous measurement of TDN. Combustion of nitrogenous compounds under an oxygen atmosphere at 680°C (in the *TOC 5000* furnace) leads to quantitative production of the nitric oxide (NO) radical. Subsequent reaction with ozone produces excited nitrogen dioxide (NO_2) species, which emit quantifiable light energy upon decay to their ground state. When finalised N-based nutrient data are available, the TDN concentrations can be corrected, giving a measure of DON, complementary to HTCO-DOC measurements.

SPECIFIC OBJECTIVES

1. Characterise the ship-board precision (reproducibility and repeatability) of the analytical methodology and techniques.

2. Determination of HTCO-DOC/TDN from water column profiles during a lagrangian study - tracking a *Coccolithophore* bloom through its various stages of development; to map the temporal dynamics of the vertical distributions of bulk dissolved organic matter.

3. Investigation of the dissolution of organic matter in sediment traps, as a potential mechanism for amelioration of the sinking carbon flux below the photic zone. Sample collection will come from moored rigs, after hours-scale deployments (in collaboration with Angela Hatton, SAMS).

Collaborative temporal incubation experiments to investigate dynamics of DOC and DON reservoirs: (i) relative to carbon monoxide production under varying light conditions (Roger Ling, CCMS-PML); (ii) through assessment of DOC consumption in parallel with net community respiration (Carol Robinson, CCMS-PML); and (iii) by participating in micro-zooplankton grazing experiments, looking at release of DOC through 'sloppy feeding'.

RESULTS

Preliminary data for TDN analysis showed that, where inorganic nutrients were detectable only at nano-molar concentrations, organic material was the dominant form of dissolved nitrogen. For example, data are presented from the initial survey (Figure) showing relatively high TDN concentrations compared to inorganic nitrogen (see Woodward *et al.*, this report) along the sampling transect.

Figure 5.11.1: Total dissolved nitrogen concentrations at 3 depths.

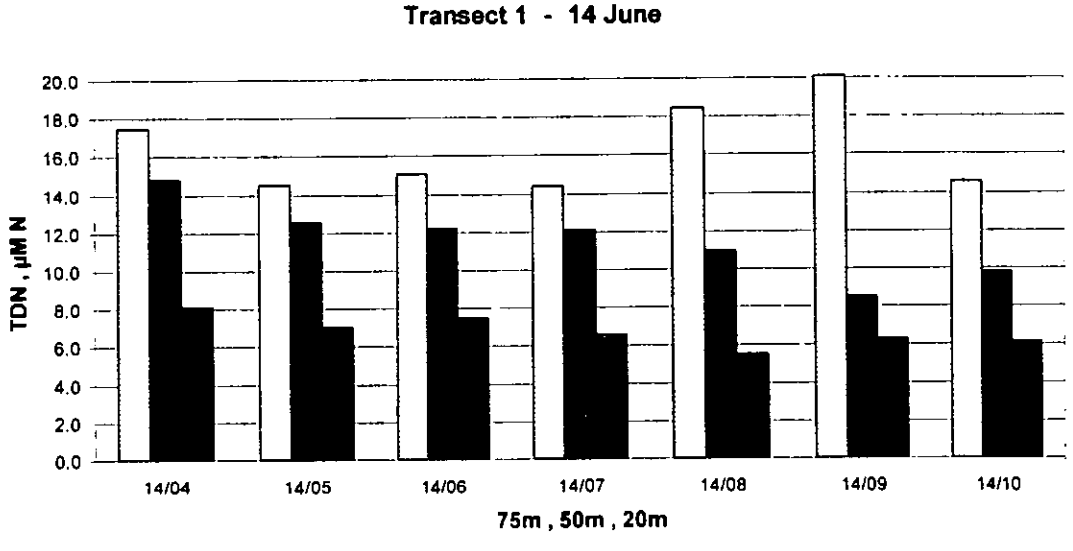


Table 5.11.1: Participation in experiments.

Experiment	Collaboration	Dates (June)
Dark community respiration	Robinson, Zubkov, Woodward	12 - 20
Photo-irradiation studies	Hatton, Ling, Woodward	16, 19
Zooplankton grazing dilution	Archer, Stelfox	18, 21
Sediment trap collection	Hatton	19, 21, 23, 27

Table 5.11.2: Samples collected from CTDs.

Sampling	Date in June) / Station Numbers	Depths (m)
Survey 1	14/04 – 14/10	20, 50 , 75
Survey 2	17/06	1 , 10 , 20 , 30 , 50 , 75
	17/08 , 17/10	10 , 50 , 75
	17/12 , 17/13	10 , 50 , 75
Midnight (SF_6)	17/17 , 19/02	Surface – 100
	21/01 , 22/02	
	23/01 , 24/01	
	26/01	
Midday (SF_6)	24/11	Surface – 100
	25/06 + "SLAPPER"	+ 0 , 0.1 , 0.5 , 1.0 , 2.0
Midnight (no SF_6)	27/01 , 28/01	Surface - 100
	29/01	

5.12: ACTIVITY OF DIMETHYLSULPHONIOPROPIONATE (DMSP) LYASE IN SIZE-FRACTIONATED PARTICLE SAMPLES

Michael Steinke (School of Environmental Sciences, University of East Anglia)

OBJECTIVES

Measurements of DMSP lyase activity to:

1. track changes in activity along a Lagrangian time series,
2. study the relative contribution of size-fractionated particles to total DMSP lyase activity,
3. compare *in-vivo* vs. *in-vitro*, and extracellular vs. total DMSP lyase activities.

Additionally, the phylogenetic diversity of *E. huxleyi* populations will be studied using a microsatellite DNA technique (in co-operation with Debora Iglesias-Rodriguez, Bristol University).

OUTLINE OF METHODS

Seawater samples (about 2 litres per enzyme test) were taken from profile and productivity CTD casts (6 depths; Table 1) and immediately filtered through a 200 µm mesh to remove macrozooplankton. Particles were then collected on polycarbonate filters (2 µm poresize). Filters were snap-frozen in liquid nitrogen then further stored at -80°C until analysis commences at the University of East Anglia.

An on board measurement was carried out within 3 hours after sampling to highlight activity changes during the time series and to later correlate these immediate measurements with activity measurements from the stored samples. A filter from a surface water sample (1, 5 or 10 m depth) was therefore suspended in a buffer (300 mM Bis-tris propane in 500 mM NaCl, pH 8.2) before particles were homogenised with an ultrasonic probe. The resulting crude extract was analysed for enzymatic production of dimethyl sulphide (DMS) from exogenous dimethylsulphoniopropionate (DMSP) in an *in-vitro* enzyme assay.

Gravity size-fractionations of particles were used to investigate relative enzyme activities, sources of particulate DMSP and chlorophyll *a* in four size-classes (20-200 µm, 5-20 µm, 2-5 µm and 0.2-2 µm).

Additionally, water samples were taken for the isolation of various plankton organisms, which will later be tested for species- and strain-specific DMSP lyase measurements. Also, zooplankton samples (various copepods and cladocerans), zooplankton detritus (including faecal pellets) and particles from a moored sediment trap were analysed for DMSP lyase activity.

Table 5.12.1: Samples taken for DMSP lyase activity measurements and phylogenetic characterisation during DISCO '99 (R.R.S. "*Discovery*" cruise D241, 5 June - 2 July 1999).

Station	Sampling depth [m]	Experiment
12/06	106	Check for contamination
12/07	5	Comparison: CTD, bucket, non-toxic supply
14/04	1, 10, 20, 30, 50, 75	Depth profile
14/05	1, 10, 20, 30, 50, 75	Depth profile
14/06	1, 10, 20, 30, 50, 75	Depth profile
14/07	1, 10, 20, 30, 50, 75	Depth profile
14/08	1, 10, 20, 30, 50, 75	Depth profile
14/09	1, 10, 20, 30, 50, 75	Depth profile
14/10	1, 10, 20, 30, 50, 75	Depth profile
17/06	1	Comparison 0.2 vs. 2 µm poresize
17/08	1	Comparison: 2 µm duplicates
17/10	0.8	Size-fractionation #1
17/12	0.6	Comparison: 2 µm triplicates
17/13	0.6	Comparison 0.2 vs. 2 µm poresize
17/17	5, 10, 20, 30, 50, 75	Depth profile
18/03	5	Size-fractionation #2
19/02	5, 10, 20, 28, 50, 75	Depth profile
19/04	5	Storage comparison "*In-vivo*" experiment #1
19/10	5, 10, 20, 35, 50, 75	Phylogenetic characterisation
20/01	1, 5, 10, 20, 35, 50	Depth profile Size-fractionation #3
20/03	5, 10, 20, 30, 40, 50	Phylogenetic characterisation
21/01	1, 5, 10, 15, 25, 50	Depth profile
21/07	5, 10, 20, 30, 40, 50	Phylogenetic characterisation
22/02	5, 10, 20, 30, 40, 50	Depth profile
22/04	5	Size-fractionation #4 "*In-vivo*" experiment #2 Comparison of storage methods

		Comparison of gravity vs. vacuum filtration
22/12	5, 10, 20, 30	Phylogenetic characterisation
23/01	5, 10, 20, 30, 40, 50	Depth profile
23/03	15	Comparison with CTD 23/01
23/06	5, 10, 22, 35, 46	Phylogenetic characterisation
24/01	5, 15, 32, 40, 50, 75	Depth profile
24/03	10	"*In-vivo*" experiment #3 Photochemical loss of DMS
25/06	1, 5, 10, 20, 36, 50	Depth profile Phylogenetic characterisation
26/01	1, 8, 20, 36, 58, 75	Depth profile "*In-vivo*" experiment #4
26/09	1, 5, 10, 25, 40, 50	Phylogenetic characterisation
27/01	1, 5, 10, 20, 26, 40	Depth profile
27/03	5	Size-fractionation #5 DMSP saturation experiment
28/01	1, 5, 10, 20, 38, 50	Depth profile
27/09	90 (sediment trap E)	*In-vitro* and "*in-vivo*" measurements
28/07	5	Size-fractionation #6

PRELIMINARY RESULTS

DMSP lyase activity in particles 2-200 µm was low during the Lagrangian time series (18-23 June 1999: average = 36.4 nM DMS h^{-1}, range = 26.3 - 49.5 nM DMS h^{-1}, Figure 5.12.1). Activities also remained low during the influence of low salinity water at the surface. Higher DMSP lyase activities were associated with other parts of the coccolithophorid bloom towards the north-west of the initial patch marked with SF_6: At stations 27/01 and 27/03 activities increased to 93 and 118 nM DMS h^{-1}, respectively. Highest activities were found at station 28/01 showing an in vitro activity of 1791 nM DMS h-1, about 8 times higher than activities previously measured in a coccolithophorid bloom south of Iceland in 1998.

***Calibration error*: Please double all activity rates presented in text !**

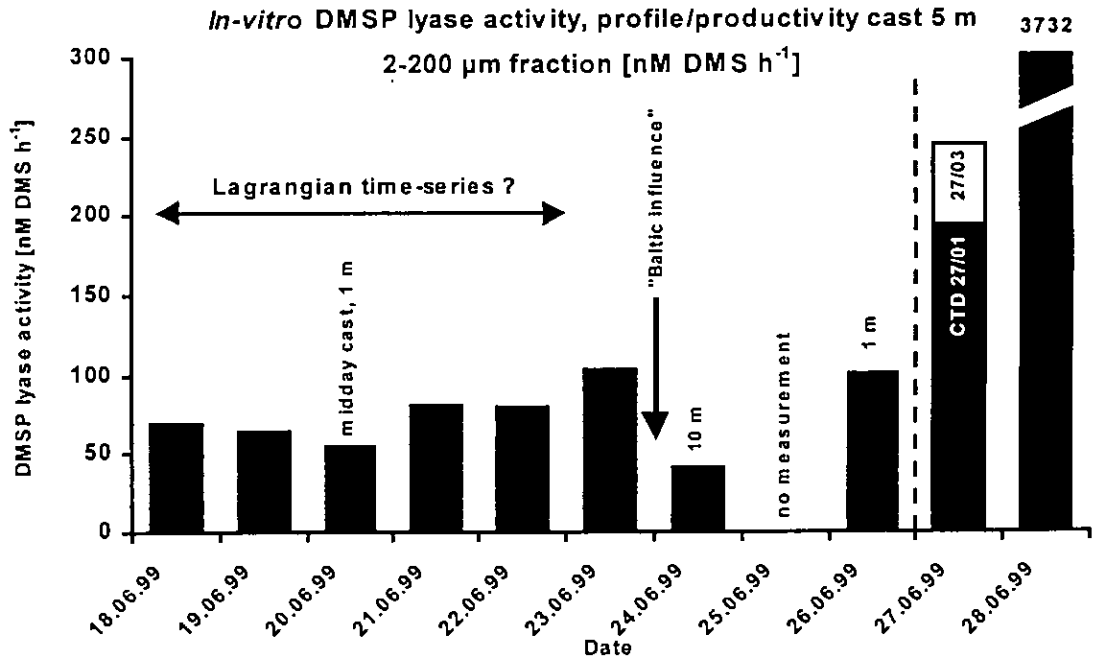


Figure 5.12.1: *In-vitro* DMSP lyase activities in surface water during DISCO '99.

5.13: CHEMOTAXONOMIC ASSESSMENT OF PHYTOPLANKTON DISTRIBUTION AND DYNAMICS

Stuart W. Gibb & Denise Cummings (CCMS Plymouth Marine Laboratory)

BACKGROUND

The photosynthetic pigments, particularly chlorophyll *a* (Chl *a*) have long been recognised as unique molecular markers of phytoplankton biomass. Whilst the distribution of Chl *a* has typically been studied by spectrophotometry or fluorimetry, these methods suffer from inaccuracies associated with spectral interferences from chlorohyll *b* (Chl *b*), carotenoids and Chl *a*-degradation products (e.g. chlorophyllides, phaeophytins and phaeophorbides) which may occur during senescence, grazing, sedimentation, and re-suspension of phytoplankton. The use of high performance liquid chromatography (HPLC) allows a more accurate estimate of Chl *a* to be obtained and also the rapid separation and quantification of up to 50 additional chloropigments and carotenoids in extracts of marine plankton.

Many of these pigments exhibit strong chemotaxonomic associations which may be used characterise the distribution and composition of phytoplankton assemblages. For example, 19'-hexanoyloxyfucoxanthin (HEX) has been found to be a biomarker of prymnesiophytes including coccolithophores and *Phaeocystis* spp. while fucoxanthin has been used as a biomarker for diatoms.

The analysis of phytoplankton pigments HPLC and the exploitation of their chemotaxonomic relationships provides us with incisive information on the composition of the phytoplankton community as well as the biomass abundance. In addition, pigment degradation products can be used as indicators of transformation processes such as grazing and bacterial degradation that contribute significantly to the turnover of phytoplankton carbon and subsequent sedimentation processes. There is also growing evidence that individual classes of phytoplankton exhibit a unique impact on ocean chemistry and this has important implications for biogeochemical cycling. Since various pigments are biomarkers for specific groups, there is often a correlation between pigments and biogeochemical features e.g. HEX with DMS.

METHODOLOGY

Samples were collected on-board by vacuum filtering of seawater (1.0 - 2.15 L) though GF/F filters. Filters were preserved in liquid nitrogen; a technique which has been demonstrated to be effective in maintaining pigment integrity for periods of up to one year. Upon return to the PML, pigments will be extracted from samples at the PML using methanol and analysed using reverse phase high performance liquid chromatography with diode array detection. Pigment will be identified through

co-elution with authnetic standards and confirmed using spectral evaluation. Concentrations will be calculated using an internal standard methodology.

OBJECTIVES

Pigment data will be used towards the following objectives:

1. To chemotaxonomically track the spatial and temporal evolution of the phytoplankton community.
2. To estimate the contribution of the major taxonomic groups to the total phytoplankton biomass from measured concentrations of phytoplankton pigments.
3. To evaluate taxon specific production of biogases and hence the use of pigments as potential surrogate markers of biogas production e.g. HEX as a surrogate for DMS.
4. To integrate microscopy, flow cytometry and HPLC data to fully characterise algal bloom characteristics
5. To evaluate the validity of derived pigment algorithms in the determination of primary productivity

Table 5.13.1: Summary of samples collected for chemotaxonomic pigments

Date	CTD (no of depth)
12-6-99	CTD02 (7)
14-6-99	14.04(6), 14.05 (6), 14.06 (6),14.07 (6), 14.08 (6), 14.09(6), 4.10 (10)
17-6-99	17.06(6), 17.08(6), 17.10 (6),17.12 (6), 17.13 (6), 17.17 (10)
18-6-99	18.06 (10), 19.02 (12)
19-6-99	19.02 (12), 19.08 (12)
20-6-99	20.01 (12), 20.11 (11)
21-6-99	21.07 (12)
22-6-99	22.02 (12), 22.12 (12)
23-6-99	23.01 (12), 23.06(12)
24-6-99	24.01 (12), 24.11 (12)
25-6-99	25.06 (12)
26-6-99	26.01 (12), 26.09 (12)
27-6-99	27.01 (12), 27.11(12)
28-6-99	28.01 (11), 28.05(11)
29-6-99	29.02 (12)
10-6-99 - 12-6-99	34 underway samples (non-toxic supply)

Acknowledgements: Thanks to those who helped with the collection of samples !!

5.14: PHYTOPLANKTON CARBON FIXATION AND NITROGEN UPTAKE.

Andrew Rees and Denise Cummings (CCMS Plymouth Marine Laboratory)

AIMS

During a Lagrangian study of a developing coccolithophore bloom:

1. To determine the rates and relative proportions of nitrate, ammonium and urea assimilation by size fractionated marine phytoplankton.
2. To determine rates of carbon incorporation into the organic and calcite fractions of coccolithophorids and associated phytoplankton.
3. To collect samples for laboratory analysis of chlorophyll and dissolved urea concentration.
4. To estimate the potential for ammonium regeneration and nitrification rates within and immediately below the nutrient deplete surface waters.

METHODOLOGY

Primary production/calcification: At eight depths within the euphotic zone 8 x 60ml polycarbonate bottles were filled with sea water and innoculated with 10μCi $NaH^{14}CO_3$ Two of each set were incubated in the dark, the remainder were transferred to an on-deck incubator, which consisted of a series of 8 tanks with spectrally corrected light screens, which permitted transmission of ambient irradiance in the range 97 – 1% and was maintained at surface seawater temperature. Incubations were terminated after 24 hours by filtration. The phytoplankton population was size-fractionated into > and < 5.0μm. At each depth, four bottles (3 light, 1 dark) were treated with fuming hydrochloric acid to remove inorganic carbon, the remaining bottles were simply filtered and dried over silica gel prior to onboard counting of ^{14}C activity by liquid scintillation counter.

Relative rates of carbon fixation were determined during several surface surveys to aid in choosing the optimum position for the Lagrangian study: Following innoculation with 10μCi $NaH^{14}CO_3$ 60ml samples were incubated at fixed light (~50μE m^{-2} s^{-1}) at surface temperature for between 2 – 6 hours.

Nitrogen uptake: Assimilation rates for nitrate, ammonium and urea were determined following the incorporation of the stable isotope ^{15}N. Duplicate samples of water from each depth were distributed into 620 ml clear polycarbonate bottles and ^{15}N-NO_3, ^{15}N-NH_4 and ^{15}N-$CO(NH_2)_2$ were added at a final concentration of 10% ambient nitrate or ammonium concentration. Incubations were in the on-deck incubator. Incubations were performed for both 24 hours and for shorter time periods of approximately 4 hours to determine mean daily and linear uptake rates respectively. Incubations were then terminated by size fractionated (<5μm and total community) filtration (< 40 cm Hg vacuum) onto ashed Whatman GF/F filters, which were frozen until return to the laboratory, where they will be analysed by continuous flow nitrogen analysis-mass spectrometry.

Ammonium regeneration: Following inoculation with ^{15}N-NH_4 and 24 hour incubation as described above, the filtrate from a number of samples throughout the euphotic zone were stored in ashed, acid cleaned pyrex bottles with mercuric chloride. Ammonium regeneration will be estimated according to an isotope dilution technique following the extraction of dissolved ammonium in the laboratory.

Nitrification: The bacterial oxidation of ammonium to nitrite and nitrate was estimated by two methods from a number of depths throughout the water column.

(i) The first involved the incorporation of ^{14}C in the dark with and without the prescence of a nitrification inhibitor – allylthiourea (ATU). 6 x 100ml polycarbonate bottles were filled from a number of depths, 10µCi of ^{14}C bicarbonate was added to each, then to three of the bottles ATU was added to a final concentration of $10mgl^{-1}$. Incubations were in the dark at ambient temperature for approximately 6 hours and were terminated by filtration onto 0.2µm polycarbonate filters, which were then dried over silica gel dessicant prior to analysis by liquid scintillation counter onboard ship.

(ii) On samples collected for determination of ammonium regeneration; following extraction of dissolved ammonium, samples will be further treated with Devarda's alloy to allow extraction of dissolved nitrate, and following isotopic ratio analysis of $^{15}N/^{14}N$ an estimate will be made of ammonium oxidation based on the isotope dilution theory.

Dissolved Organic Carbon production: At each station, at the depth approximating to the subsurface fluorescence maximum, a single sample plus blank (0.2µm filtered seawater) was incubated with 10µCi $NaH^{14}CO_3$ for 24 hours. 14C incorporation into the dissolved organic fraction will be estimated by liquid scintillation counting in the laboratory. On 10ml subsamples which were treated with 10µl conc. HCl.

Table 5.14.1: Summary of experiments carried out.

DATE	POSITION	No. DEPTHS	DEPTH RANGE (m)	VARIABLE
18/6	58°53'N	8	0 – 36	^{15}N uptake – 24h
	03°4'E	1	10	^{15}N uptake – 4h
		6	0 – 36	Urea concentration
		6	0 – 36	Size fractionated chlorophyll
		8	0 – 36	14C - Primary production
		4	0 - 100	ATU sensitive 14C - nitrification
19/6	58°50'N	8	0 – 46	^{15}N uptake – 24h, size fractionated
	03°13'E	2	5, 28	^{15}N – NH4 regeneration/oxidation
		1	10	^{15}N uptake – 4h
		6	0 – 46	Urea concentration
		6	0 – 46	Size fractionated chlorophyll
		8	0 – 46	14C - Primary production
		1	46	DOC prodn.
21/6	58°37'N	8	0 – 36	^{15}N uptake – 24h, size fractionated
	03°31'E	2	5, 36	^{15}N – NH4 regeneration/oxidation
		1	10	^{15}N uptake – 4h
		6	0 – 36	Urea concentration
		6	0 – 36	Size fractionated chlorophyll
		8	0 – 36	14C - Primary production
		5	0 – 100	nitrification
		1	36	DOC prodn.
22/6	58°31'N	8	0 – 40	^{15}N uptake – 24h, size fractionated
	03°30'E	2	5, 30	^{15}N – NH4 regeneration/oxidation
		1	10	^{15}N uptake – 4h
		6	0 – 40	Urea concentration
		6	0 – 40	Size fractionated chlorophyll
		8	0 – 40	14C - Primary production
		4	0 – 75	nitrification

		1	40	DOC prodn.
23/6	58°26'N	8	0 – 35	^{15}N uptake – 24h, size fractionated
	03°29'E	2	5, 27	^{15}N – NH4 regeneration/oxidation
		1	10	^{15}N uptake – 4h
		6	0 – 35	Urea concentration
		6	0 – 35	Size fractionated chlorophyll
		8	0 – 35	14C - Primary production
		1	35	DOC prodn.
24/6	58°21'N	8	0 – 34	^{15}N uptake – 24h, size fractionated
	03°28'E	2	3, 34	^{15}N – NH4 regeneration/oxidation
		1	10	^{15}N uptake – 4h
		6	0 – 34	Urea concentration
		6	0 – 34	Size fractionated chlorophyll
		8	0 – 34	14C - Primary production
		5	0 – 60	nitrification
		1	34	DOC prodn.
26/6	58°15'N	8	0 – 33	^{15}N uptake – 24h, size fractionated
	03°34'E	2	3, 33	^{15}N – NH4 regeneration/oxidation
		6	0 – 33	Urea concentration
		6	0 – 33	Size fractionated chlorophyll
		8	0 – 33	14C - Primary production
		1	33	DOC prodn.
27/6	58°47'N	8	0 – 30	^{15}N uptake – 24h, size fractionated
	02°40'E	2	5, 30	^{15}N – NH4 regeneration/oxidation
		1	10	^{15}N uptake – 4h
		12	0 – 100	Urea concentration + Intercalibration
		6	0 – 30	Size fractionated chlorophyll
		8	0 – 30	14C - Primary production
		5	0 – 75	nitrification
		1	30	DOC prodn.
28/6	58°41'N	8	0 – 38	^{15}N uptake – 24h, size fractionated
	02°31'E	2	5, 30	^{15}N – NH4 regeneration/oxidation
		1	10	^{15}N uptake – 4h
		6	0 – 38	Urea concentration + Intercalibration
		6	0 – 38	Size fractionated chlorophyll
		8	0 – 38	14C - Primary production
		5	0 – 80	nitrification
		1	38	DOC prodn.

5.15 MICROZOOPLANKTON COMMUNITY STRUCTURE AND GRAZING

Claire Stelfox (CCMS Plymouth Marine Laboratory)

Microzooplankton and nanozooplankton (phagotrophs <200µm) are important mediators of energy transfer in marine systems where they are able to remineralise organic matter and nutrients, control phytoplankton biomass and provide a link to higher trophic levels. Therefore the objective of this study was to quantify the microzooplankton, in-terms of species composition and herbivorous impact, during the progression of a coccolithophore-dominated phytoplankton bloom.

METHODS

1. Samples were preserved in acid lugol's iodine, glutaraldehyde and both formaldehyde and lugol's for the enumeration of the microzooplankton, heterotrophic nanoflagellates (HNAN) and phytoplankton communities respectively. Samples (Table 1) will be analysed by

inverted light and epifluorescence microscopy in the laboratory. POC samples were also collected, by Bablu Sinha, from each level 1 CTD profile cast and will be analysed in the laboratory.

2. The dilution technique was used for quantifying phytoplankton growth and mortality through microzooplankton grazing in surface waters (see Steve Archer's cruise report). Fluorometry (for total phytoplankton herbivory) and HPLC pigments (for growth of and selective grazing on coccolithophores and specific phytoplankton groups) were used as indices of phytoplankton growth and microzooplankton grazing.

RESULTS

Fluorometric analyses of the dilution experiments show that higher phytoplankton growth rates were measured at the beginning of the Lagrangian study and were equivalent to 1.5 doublings d^{-1}. Grazing pressure by the microzooplankton accounted for a turnover of between 35% and 63% of the daily chlorophyll standing stock, which represents a flux of between 0.1 and 0.6 µgchla l^{-1} d^{-1}.

Table 5.15.1: List of state measurements collected

Date	Event	Depth range (m)	No. of depths	Sample
12/6/99	12/07	1-106	7	Phytoplankton
14/6/99	14/04	1-50	5	Phytoplankton
		1-50	5	POC
	14/05	1-50	5	Phytoplankton
		1-50	5	POC
	14/06	1-50	5	Phytoplankton
		1-50	5	POC
	14/07	1-50	5	Phytoplankton
		1-50	5	POC
	14/08	1-50	5	Phytoplankton
		1-50	5	POC
	14/09	1-50	5	Phytoplankton
		1-50	5	POC
	14/10	1-50	5	Phytoplankton
		1-50	5	POC
16/6/99		non-toxic	1	Phytoplankton
		non-toxic	1	POC
17/6/99	17/06	1-75	6	Phytoplankton
			6	POC
	17/08	1-50	5	Phytoplankton
			5	POC
	17/10	1-50	5	Phytoplankton
			5	POC
	17/12	1-50	5	Phytoplankton
			5	POC
	17/14	1-50	5	Phytoplankton
			5	POC
18/6/99	17/17	5-100	8	Phytoplankton
			10	POC
			8	Microzooplankton
			7	HNAN
	18/06	5-99	8	Phytoplankton
			10	POC

19/6/99	19/02	1-95	8	Phytoplankton
			10	POC
			8	Microzooplankton
			7	HNAN
	19/08	1-100	8	Phytoplankton
			9	POC
20/6/99	20/01	1-98	8	Phytoplankton
			10	POC
21/6/99	21/01	5-100	8	Phytoplankton
			10	POC
			8	Microzooplankton
			6	HNAN
	21/07	1-100	8	Phytoplankton
			10	POC
22/6/99	22/02	1-100	8	Phytoplankton
			10	POC
			8	Microzooplankton
			6	HNAN
	22/12	1-107	8	Phytoplankton
			10	POC
23/6/99	23/01	1-100	8	Phytoplankton
			10	POC
			8	Microzooplankton
			8	HNAN
	23/06	1-100	8	Phytoplankton
			10	POC
24/6/99	24/01	1-108	8	Phytoplankton
			10	POC
			8	Microzooplankton
			8	HNAN
	24/11	1-100	8	Phytoplankton
			10	POC
25/6/99	25/06	1-100	8	Phytoplankton
			10	POC
26/6/99	26/01	3-100	8	Phytoplankton
			10	POC
			8	Microzooplankton
			8	HNAN
	26/11	1-100	8	Phytoplankton
27/6/99	27/01	5-100	8	Phytoplankton
			10	POC
			8	Microzooplankton
			8	HNAN
	27/03	54	1	Phytoplankton
	27/11	1-100	8	Phytoplankton
			10	POC
			8	Microzooplankton
			5	HNAN
28/6/99	28/01	5-100	8	Phytoplankton
			10	POC
			8	Microzooplankton
			7	HNAN
	28/05	5-90	8	Phytoplankton
			10	POC
			8	Microzooplankton
			8	HNAN
29/6/99	29/02	1-90	8	Phytoplankton
			10	POC
			8	Microzooplankton
			8	HNAN

5.16: MICROBIAL COMMUNITY STRUCTURE AND FUNCTION BY FLOW CYTOMETRY

Glen Tarran (CCMS Plymouth Marine Laboratory)

OBJECTIVES & COLLABORATIONS

No.	ACTIVITY	COLLABORATION/ LINK
1	Quantification of phytoplankton (<1µm - ~50µm) – including coccolithophores and other DMSP producing phytoplankton. Spatial, Vertical and Temporal studies from Level 1 CTD's and underway	
2	Quantification of phytoplankton (<1µm - ~50µm) – including coccolithophores and other DMSP producing phytoplankton from Productivity CTD's.	All involved with productivity CTD's
3	Determination of group-specific grazing of phytoplankton by microzooplankton.	Steve Archer, Claire Stelfox
4	Dermination of size structure of nano and pico-phytoplankton communities, DMSP analysis of filters and fixation of filtrates for phytoplankton analysis	Steve Archer
5	Cell sorting of microbial populations (Grazing selectivity, DMSP producers, molecular analysis)	Steve Archer Willie Wilson
6	Quantification of heterotrophic bacteria. Spatial, Vertical and Temporal studies	Mike Zubkov
7	Quantification of viruses	Willie Wilson
8	Provision of flow cytometry support	

METHODS

Two flow cytometers were used during the cruise: a Becton Dickinson FACSort from PML and a Becton Dickinson FACScan which was loaned by Becton Dickinson, UK Ltd. Both flow cytometers were modified to analyse cells at a maximum flow rate of approx. 103µl min^{-1} and the FACSort was additionally modified to measure depolarised light scatter for enhanced analysis of coccolithophores. Quantification of eucaryotic phytoplankton (approx. 1-50µm) whilst underway, from the non-toxic supply, midnight Level 1 and Productivity CTD's was made by collecting samples in 125ml polycarbonate bottles which were then kept in the dark at 4°C until analysed (< 1h). 12 depths were sampled from the Level 1 CTD's and 9 depths from the Productivity CTD's. Samples were analysed for 3 minutes on the FACSort flow cytometer to determine total phytoplankton abundance within the analysis range, coccolithophores, dinoflagellates, picoeucaryotes and other phytoplankton. Measurements of light scatter and autofluorescence were also collected and stored on disk as listmode data for subsequent analysis. The same sampling strategy was used for the noon Level 1 CTD's but additional analyses were performed to determine cyanobacteria (*Synechococcus* sp.) abundance. A similar analysis protocol as for the CTD's was used for group- specific grazing studies except that analysis times were increased to obtain statistically significant cell counts and both FACSort and FACScan flow cytometers were used simultaneously to decrease the overall sampling time required.

Community size structure determinations were made using the same analysis protocol as for the CTD's. Samples were gravity filtered through polycarbonate filters ranging from 0.6-18µm. Filtrate sub-samples were analysed by flow cytometry to see how many cells had passed through the filter. Filter pore size was plotted against proportion of cells getting through the filter (with respect to unfiltered seawater). By reading the size at which 50% of the cells got through it was possible to get a median cell size. Remaining filtrate from each pore size was fixed with 0.5% glutaraldehyde for subsequent microscopic analysis. Filters were placed in glass vials with 1ml NaOH (5M) and topped up with Milli-Q water for subsequent DMSP analysis.

Cell sorting was carried out using samples concentrated by tangential flow filtration (approx. 60l seawater to 600ml concentrate). Phytoplankton groups were sorted for subsequent DNA analysis and determination of cellular DMSP content. Methods for bacterial and virus analysis are covered elsewhere.

SUMMARY OF RESEARCH

Table 5.16.1: Underway sampling and CTD's

Date	Time (BST)	Cast no./ Sample	Operation	Depth(s) (m)
7/6 – 12/6	08:00 – 23:00	UWAY1 – UWAY164	Underway coccolithophore surveying through northern North Sea	3
13/6 – 14/6	09:00 – 02:46	SVEY1 – SVEY48	Underway coccolithophore surveying, area of interest near the Shetland Isles	3
16/6	08:05 – 10:30	TSCT1 – TSCT11	Fine-scale, preSF_6 release transect approx. SW to NE	3
16/6	14:00 – 18:15	SESVEY1 – SESVEY18	Fine-scale, preSF_6 release transect approx. NW to SE	3
17/6	10:19 – 15:38	UWAY1 – UWAY11	Post-SF_6 deployment underway samples between CTD's	3
17/6	09:33	CTD17/06	Post-SF_6 deployment CTD	1-76
17/6	11:30	CTD17/08	Post-SF_6 deployment CTD	1-75
17/6	13:11	CTD17/10	Post-SF_6 deployment CTD	1-75
17/6	14:35	CTD17/12	Post-SF_6 deployment CTD	1-76
17/6	16:04	CTD17/13	Post-SF_6 deployment CTD	1-75
18/6	01:35	CTD17/17	Level 1	5-100
18/6	03:02	CTD18/03	Productivity	5-36
18/6	143:13	CTD18/06	Level 1	5-99
19/9		CTD19/02	Level 1	1-93
19/9	03:15	CTD19/04	Productivity	5-93
19/9	13:30	CTD19/08	Level 1	1-100
20/9		CTD20/01	Level 1	1-97
21/6	01:12	CTD21/01	Level 1	1-100
21/6	02:28	CTD21/03	Productivity	5-101
21/6	14:30	CTD21/07	Level 1	1-100
22/6	12:49	CTD22/02	Level 1	1-99
22/6	03:25	CTD22/04	Productivity	5-75
22/6	13:31	CTD22/12	Level 1	1-107
23/6	01:10	CTD23/01	Level 1	1-99
23/6	02:50	CTD23/03	Productivity	4-100
23/6		CTD23/06	Level 1	1-100
24/6	01:30	CTD24/01	Level 1	1-109
24/6	02:51	CTD24/03	Productivity	3-80

24/6	13:03	CTD24/11	Level 1	1-99
25/6	13:00	CTD25/06	Level 1	1-100
26/6	00:51	CTD26/01	Level 1	1-99
26/6	02:33	CTD26/03	*Productivity*	3-81
26/6		CTD26/09	Level 1	1-100
27/6	01:13	CTD27/01	Level 1	1-101
27/6	02:40	CTD27/03	Productivity	5-76
27/6	03:27 – 07:59	SVEY1 – SVEY10	Final survey in high reflectance water of main bloom	3
27/6	12:47	CTD21/11	Level 1	1-99
28/6	01:10	CTD28/01	Level 1	1-98
28/6	02:30	CTD28/03	Productivity	5-80
28/6	12:57	CTD28/05	Level 1	1-95
29/6	04:40	CTD29/01	Level 1	1-90

Table 5.16.2: Size fractionation experiments

Date	Experiment
19/6	Size determination of cluster at 45m
19/6	Size fractionation 1
20/6	Size fractionation 2
21/6	Size fractionation 3
23/6	Size fractionation 4
25/6	Size fractionation 5
28/6	Size fractionation 6

Microzooplankton grazing experiments: Eight grazing were carried out. Details can be found elsewhere in the cruise report.

COMMENTS

Flow cytometry work was jeopardised early in the cruise as the laser on the FACSort flow cytometer ceased to function on 7 June. Work continued using the FACScan but a week later the laser on this instrument was also seriously under-performing. Having ruled out the possibility of power supply problems to the laboratory container it was considered that one possible reason for the failure of two lasers in such a short time was vibration caused by the location of the container on the aft deck over the prop shaft. It was noted, however, that the FACSort had been in exactly the same position for 6 weeks during the PRiME Cruise in June/July 1996 and no such problems had occurred. Both flow cytometers were moved into the ship. The FACSort went into the photo. laboratory and the FACScan into the chemistry laboratory. Contact was made with the suppliers, Becton Dickinson (BD), UK Ltd who were able to source 2 replacement lasers and power supplies and we were able to arrange to rendevous with the spares and BD engineer Stuart Caffry by launch, just off Peterhead on 15 June. Stuart installed both lasers and one power supply during the day and got both flow cytometers fully operational again by 19:00 (BST). Both flow cytometers then functioned flawlessly for the remainder of the cruise.

5.17: ANALYSIS OF VIRUS COMMUNITIES.

Willie Wilson (Marine Biological Association, Plymouth)

OBJECTIVES

Viruses are ubiquitous components of the marine environment, with concentrations in excess of 10^8 mL^{-1} being reported. It is generally regarded that viruses play an active role in population dynamics and structure of microbial and plankton communities. A significant proportion of viruses in the marine environment are known to infect oceanic primary producers and it is thought that phytoplankton community succession dynamics may be influenced by viruses, however, the actual role of viruses remains largely unknown.

Laboratory-based experiments have demonstrated that there is a significant increase in DMS production following virus infection of *Phaeocystis* cultures. It was clear from these simple experiments that viral activity in DMS-producing phytoplankton should be considered as an additional process in the global flux of DMS to the atmosphere.

The main aim of the DISCO cruise was to determine the role of viruses in sulphur cycling throughout the progression of a coccolithophore bloom. To achieve this, the primary (technical) aim was to develop a flow cytometry method to count viruses and differentiate virus populations. In addition, samples would be taken for transmission electron microscopy (TEM) thin-section analysis of coccolithophores to calculate the proportion of cells which are infected by viruses at any one time.

METHODS

Samples for virus counts were fixed in 0.5% glutaraldehyde and stored at –20°C. When the sample had defrosted, 100µl was added to 900 µl of staining solution (made up in autoclaved 10 kDa-filtered MilliQ water) containing 0.025µm-filtered 0.1% Triton X-100 and 10,000x dilution of SYBR Green I (nucleic acid-specific green fluorescence stain) and heated at 60°C for 15 minutes. Samples were analysed by flow cytometry for 2 minutes at a delivery rate of 12µl min^{-1} using settings very close to the noise level. A blank was run using the same staining solution minus the sample.

Samples for TEM analysis were concentrated by tangential flow filtration using a 0.3µm filter. 100 l volumes were concentrated down to 500 ml, fixed in 3% glutaraldehyde and stored at 4°C. Fixed concentrates will be taken back to the lab and further concentrated by centrifugation prior to thin-sectioning and TEM.

Genetic diversity of coccolithophores.

It is generally regarded that coccolithophores form mono-specific blooms. This theory is primarily based on morphological and basic molecular characterisation, and has not been rigorously tested

using some of the more powerful molecular techniques currently available. Flow cytometry analysis of level-one CTD casts by Glen Tarran has revealed that there at least 2 different types of coccolithophores (based on back-scatter and fluorescence properties), it is likely that they will be separate genotypes.

The secondary aim of this cruise was to analyse the genetic structure of coccolithophores, throughout the progression of the bloom, using a technique called denaturing gradient gel electrophoresis (DGGE). Different banding patterns obtained by DGGE (using an oligonucleotide probe based on 18S rRNA) will be analysed and inferences made on the diversity of coccolithophore populations.

METHODS

Seawater (1l) was filtered onto 0.45μm supor™ filters and snap frozen in liquid nitrogen. DNA will be extracted from the filters and subsequent DGGE/sequencing analysis will be carried out back at the lab.

Other peripheral experiments included; analysis of viral communities in sediment traps (Angela Hatton); diel sampling to examine *Synechococcus* cell cycle and detection of infected *Synechococcus* cells by flow cytometry (involved fixing 4ml samples every hour over a 27 hour period with subsequent analysis back at the lab); collection of samples for RNA extraction to analyse the expression of light harvesting genes throughout the progression of the bloom (in collaboration with Dave Scanlan – University of Warwick).

Samples collected:

Virus counts will be calculated for all depths at every level one CTD cast.

DGGE analysis of coccolithophore diversity from all depths will be made from CTD casts (date in June/event#) 1717, 1806,1902, 2001, 2101, 2301, 2306, 2411, 2506, 2609, 2711, 2801, 2805, 2902.

Thin section TEM analysis (and RNA extraction) will be carried out on samples from monster cast numbers (sample depth in brackets) 1716 (35m), 1910 (35m), 2010 (30m), 2109 (45m), 2215 (10m), 2308 (10m), 2414 (20m), 2508 (20m), 2612 (10m), 2713 (10m), 2714 (10m), 2803 (35m), 2807 (40m).

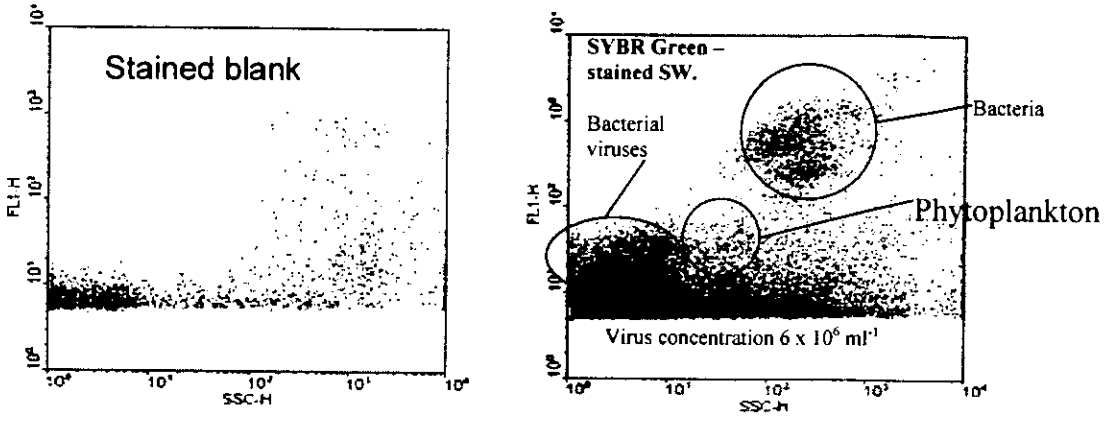
Analysis of virus communities in sediment traps will be determined from traps brought in on 24/6/99 and 28/6/99.

Diel incubation sampling started at 0100hrs on 26/6/99 and run for 27 hours. Samples taken from CTD# 2601 at depths of 1m, 8m and 20m, one additional incubation started using seawater from the on-board non-toxic supply.

Results

Most of the analysis will be carried out back at the laboratory. A significant amount of time was spent at the start of the cruise optimising flow cytometry for virus counts. Different virus communities can now be identified (see fig. 1) and virus concentrations seem to vary between 5 x 10^6 and 5 x 10^7 ml^{-1} which is similar to that previously reported using more time consuming techniques. There is still a minor problem with the staining procedure where stained samples are losing fluorescence over time. This results in an apparent drop in counts between the first and last samples analysed in a large batch. Consequently, no further analysis will be carried out until this problem is rectified (preparation of samples in the dark should solve the problem).

Fig. 5.17.1: Flow cytometry analysis of virus communities.



5.18: QUANTIFICATION OF BACTERIAL ROLE IN TURNOVER OF ORGANIC SULPHUR COMPOUNDS DMSP AND DMS IN MARINE SURFACE WATERS DURING COCCOLITHOPHORE ALGAL BLOOM.

M. Zubkov (CCMS Plymouth Marine Laboratory)

OBJECTIVE

The main objective of the work was to quantify the rates of bacterial turnover of DMSP and DMS dissolved in surface waters, at water density gradient (picnocline) and in a layer of deep chlorophyll maximum. The rates of bacterial total incorporation of DMSPd, incorporation of metabolised molecules into bacterial protein and other macromolecules, transformation of DMSPd into volatile derivatives; total uptake of DMS by bacteria and transformation of this molecule into nonvolatile derivatives were determined. These measurements were done in conjunction with estimates of bacterial production, abundance and biomass.

Radioactive tracer technique and analytical flow cytometry have been employed to estimate the rates of DMS, DMSP and general (uptake of leucine and thymidine) bacterial metabolism and bacterial numbers and biomass respectively. Throughout a survey in the northern part of the North Sea bacteria were enumerated in samples collected underway almost in real time (Fig. 5.18.1). During monitoring of the SF6 labelled surface waters the rates listed above were estimated generally at four depths in the surface mixed layer and at picnocline (Fig. 5.18.2). Corresponding estimates of bacterial production were done at the same depths and additionally at two more depths generally below picnocline. Samples for conducting these measurements were collected at 14 midnight CTD casts. Samples for determining bacterial concentration were collected from all 12 sampled depths both at midnight and midday casts. These collected samples will be analysed after the cruise. Preliminary radioassaying of tracers were done on board the ship and the analyses will be completed on return back.

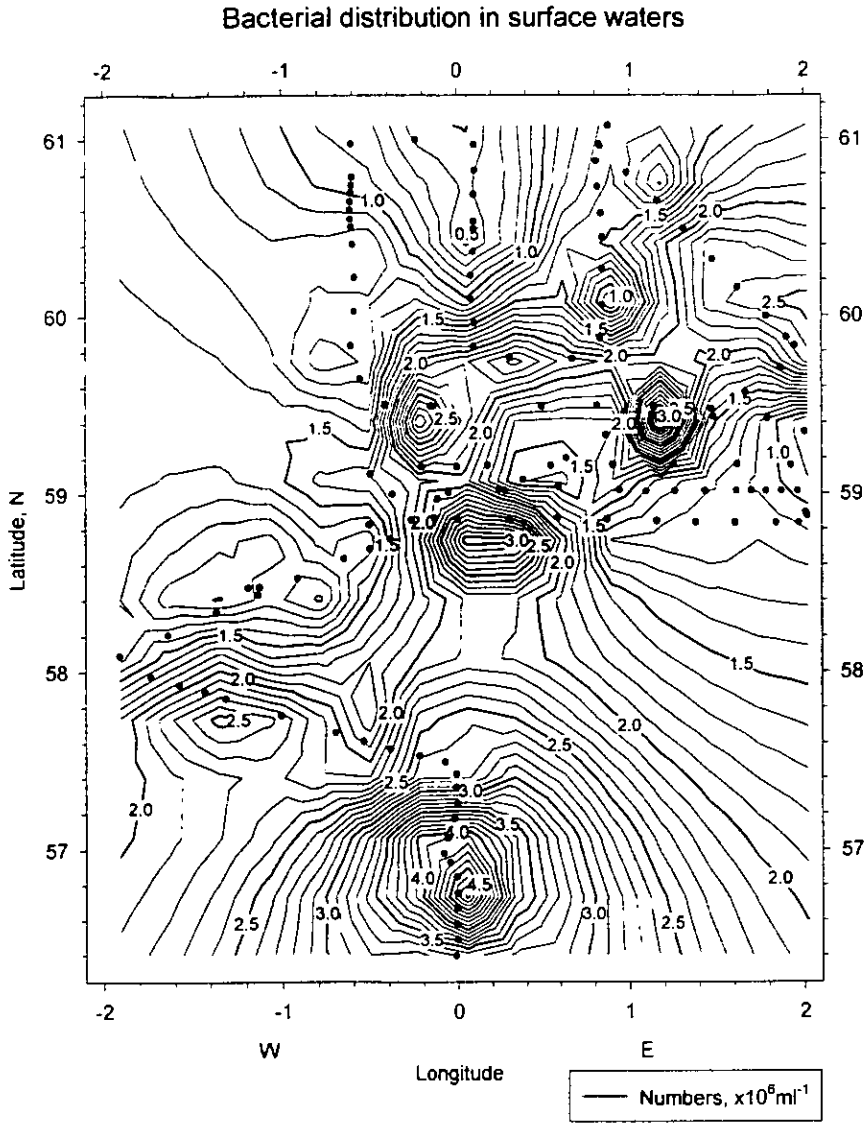
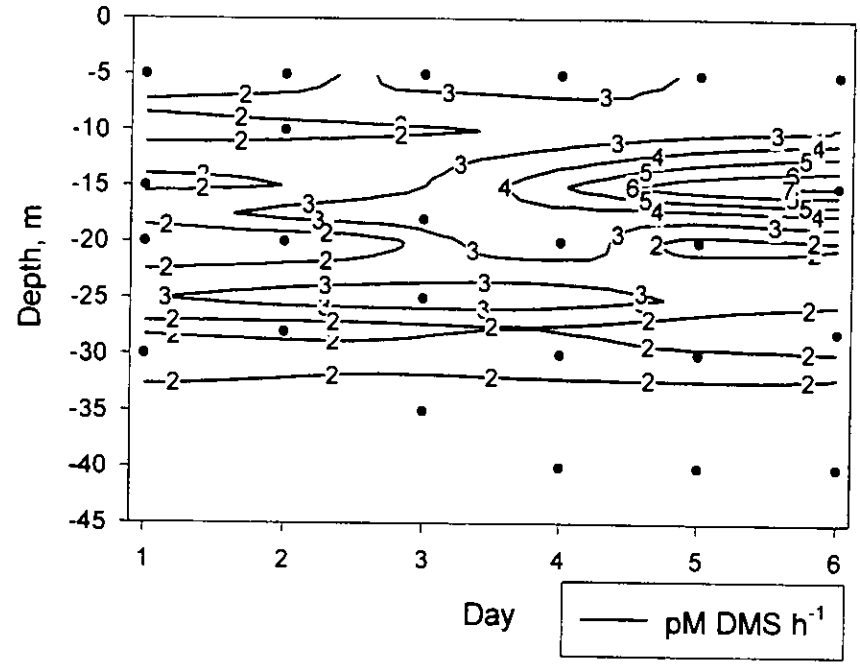


Figure 5.18.1. Bacterial concentrations in surface waters in the survey



Transformation of DMS into nonvolatile form

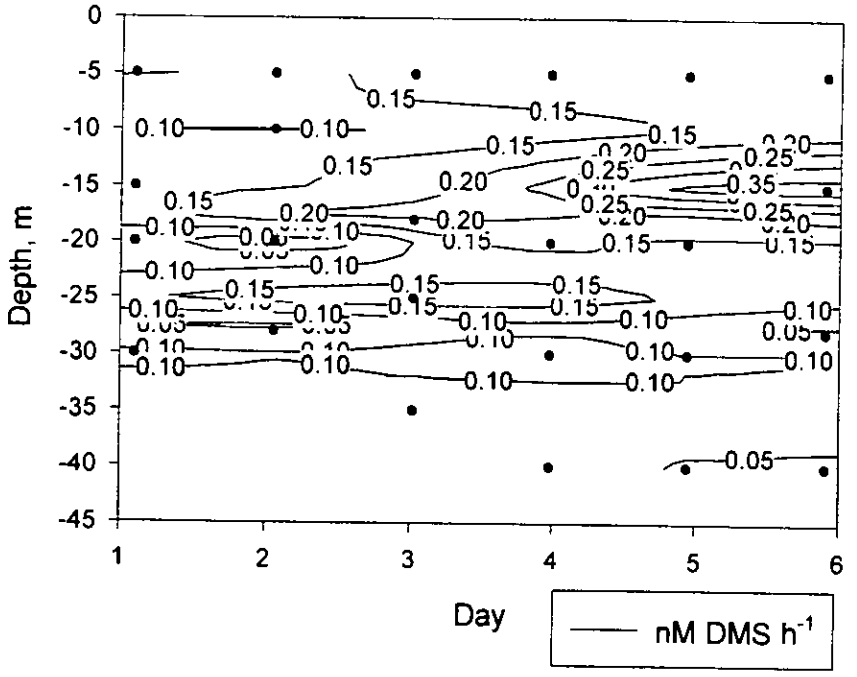


Fig 5.18.2. Assimilation and transformation of DMS by bacteria

5.19: PLANKTON DARK COMMUNITY RESPIRATION (DCR), GROSS PRODUCTION (GP) AND NET COMMUNITY PRODUCTION (NCP)

Carol Robinson (CCMS Plymouth Marine Laboratory)

OBJECTIVES

1. To compare the magnitude and time progression of autotrophic production and heterotrophic respiration during a bloom of coccolithophores
2. To determine the depth distribution of respiration above and below the euphotic zone
3. To relate the magnitude and variability of community respiration to bacterial, algal and microzooplankton respiration
4. To compare two methods of determining plankton respiration : an *in vitro* dissolved oxygen flux and an instantaneous measure of the electron transport activity (ETS)
5. To measure bacterial growth efficiencies from concomitant changes in DOC and DIC during large volume week long incubations
6. To measure changes in dissolved oxygen and dissolved inorganic carbon due to photo-oxidation processes

METHODS

Dark community respiration, net community production and gross production were determined from *in vitro* changes in dissolved oxygen and dissolved inorganic carbon (DIC). Dissolved oxygen was measured by automated Winkler titration, and DIC by an automated coulometric titration. Samples were collected, filtered and stored in liquid nitrogen for later analysis of plankton electron transport system activity (ETS). Water was collected from the productivity casts each morning from depths equivalent to 97%, 55%, 33%, 20%, 14%, 3% and 1% of surface irradiance plus three depths below the euphotic zone and incubated in 60 ml and 125 ml glass bottles in surface water cooled deck incubators for 24 hours. Normally four replicates were incubated in the light, four in the dark and four fixed for determination of zero time concentrations. Water was collected from the same CTD casts as that analysed for phytoplankton assimilation of ^{14}C (A.Rees) and ^{15}N (D.Cummings) and microzooplankton grazing (C.Stelfox) and bacterial enumeration (M.Zubkov). Light depths were calculated from PAR measurements made the previous day (M.Pinkerton). The vertical distribution of dissolved oxygen and dissolved inorganic carbon concentrations was determined from the midnight 'JGOFS Level I' CTD cast. Large volume incubations of 0.8 μm filtered seawater were undertaken in collaboration with A.Miller (DOC) and M.Zubkov (bacterial enumeration). On deck incubations of 0.2 μm filtered seawater were undertaken to measure changes in dissolved oxygen and dissolved inorganic carbon due to photo-oxidation. These photo-oxidation experiments were co-ordinated by A. Miller and involved concomitant measurements of DOC (A.Miller), DMS

(A.Hatton) and CO (R.Ling). Samples from moored sediment traps deployed for 24 hours were kindly obtained from A.Hatton and filtered and stored for later analysis of ETS activity.

Table 5.19.1: SAMPLES COLLECTED

Date	CTD / Non toxic	Measurements
7 June	Non-toxic	Oxygen 30 minutes from 08:30 BST to 15:30 BST
12 June	CTD 12/06	Oxygen from all Niskins
12 June	CTD 12/07	7 day respiration incubation
14 June	CTD 14/04	Oxygen and ETS at 6 depths
		Respiration time series
14 June	CTD 14/05	Oxygen and ETS at 6 depths
14 June	CTD 14/07	Oxygen and ETS at 6 depths
14 June	CTD 14/08	Oxygen and ETS at 6 depths
14 June	CTD 14/09	Oxygen and ETS at 6 depths
14 June	CTD 14/10	Oxygen and ETS at 6 depths
17 June	CTD 17/06	Oxygen and ETS at 6 depths
17 June	CTD 17/08	Oxygen and ETS at 6 depths
17 June	Non toxic	Photo-oxidation experiment
17 June	CTD 17/10	Oxygen and ETS at 6 depths
17 June	CTD 17/12	Oxygen and ETS at 6 depths
17 June	CTD 17/14	Oxygen and ETS at 6 depths
17 June	CTD 17/17	Oxygen and DIC at 12 depths
18 June	CTD 18/03	$GP(O_2)$ and $NCP(O_2)$ at 4 depths
		GP(DIC) and NCP(DIC) at 1 depth
		$DCR(O_2)$ at 6 depths
		DCR(DIC) at 1 depth
		ETS at 9 depths
19 June	CTD 19/02	Oxygen at 12 depths
19 June	CTD 19/04	$GP(O_2)$ and $NCP(O_2)$ at 4 depths
		GP(DIC) and NCP(DIC) at 1 depth
		$DCR(O_2)$ at 6 depths
		DCR(DIC) at 1 depth
		ETS at 9 depths
21 June	CTD 21/01	Oxygen and DIC at 12 depths
21 June	CTD 21/03	$GP(O_2)$ and $NCP(O_2)$ at 4 depths
		GP(DIC) and NCP(DIC) at 1 depth
		$DCR(O_2)$ at 6 depths
		DCR(DIC) at 1 depth
		ETS at 9 depths
21 June	CTD 21/05	Surface water for ETS
22 June	CTD 22/02	Oxygen at 12 depths
22 June	CTD 22/04	$GP(O_2)$ and $NCP(O_2)$ at 4 depths
		$DCR(O_2)$ at 6 depths
		ETS at 9 depths
22 June	Sediment trap 21/06	ETS from sample collected at 40m trap
23 June	CTD 23/03	$GP(O_2)$ and $NCP(O_2)$ at 4 depths
		$DCR(O_2)$ at 6 depths
		ETS at 9 depths
23 June	CTD 23/09	Surface water for ETS
24 June	CTD 24/01	Oxygen at 12 depths

24 June	CTD 24/03	$GP(O_2)$ and $NCP(O_2)$ at 4 depths $DCR(O_2)$ at 6 depths ETS at 9 depths
24 June	Sediment trap 23/10	ETS from sample collected at 40m trap
25 June	CTD 24/14	10m respiration time series ETS replication expt
25 June	CTD 25/03	Surface water for ETS
26 June	CTD 26/01	Oxygen at 12 depths
26 June	CTD 26/03	$GP(O_2)$ and $NCP(O_2)$ at 4 depths $DCR(O_2)$ at 6 depths ETS at 9 depths
27 June	CTD 27/01	Oxygen at 12 depths
27 June	CTD 27/03	$GP(O_2)$ and $NCP(O_2)$ at 4 depths $DCR(O_2)$ at 6 depths ETS at 9 depths
27 June	CTD 27/08	Surface water for ETS
27 June	CTD 27/11	Oxygen at 12 depths ETS at 9 depths
28 June	Sediment trap 27/09	ETS from traps at 40m and 90m
28 June	CTD 28/03	$GP(O_2)$ and $NCP(O_2)$ at 4 depths $DCR(O_2)$ at 6 depths ETS at 9 depths
28 June	CTD 28/05	Oxygen at 12 depths ETS at 9 depths
29 June	CTD 29/02	Oxygen at 12 depths ETS at 9 depths

5.20: MESOZOOPLANKTON

Xavier Irigoien (CCMS Plymouth Marine Laboratory)

OBJECTIVE

The main objective was to estimate the consumption rates of the mesozooplankton on the different phytoplanktonic and microzooplanktonic groups. On one hand this will provide data on the grazing pressure by the mesozooplankton on both coccolithophorids and microzooplankton and in the other hand it will feed the model with specific grazing rates for each phytoplankton group.

In order to accomplish those objectives two kinds of data are necessary:

- mesozooplankton biomass and

- mesozooplankton grazing rates on the different microplankton groups

Samples to estimate mesozooplankton abundance have been collected using WP2 in hauls from 100 m to the surface performed after the midnight level 1 CTD during the tracer release experiment. The samples were fixed with 1 % formaldehyde and will be counted back in the

laboratory. A total of eleven samples have been collected for abundance estimations. To estimate the biomass, samples collected at the same time that the abundance ones have been collected, frozen and will be analyzed for species specific carbon and nitrogen content.

Mesozooplankton grazing rates will be estimated from incubation experiments. Animals for the experiments were collected using WP2 nets during the midday sampling, sorted by species and stages under microscope and incubated on one liter bottles with filled with water obtained at different depths. The experiments were run for 24 hours and at the end samples were collected for HPLC analysis, microzooplankton counting and occasionally particulate DMSP analysis and flow citometry. A total of 157 samples have collected for HPLC analysis, 130 for microzooplankton counting, 44 for DMSP and 32 for flow citometry. Those samples will be analyzed in the laboratory.

Additional estimations on the total grazing pressure will be obtained from measurements of copepods gut fluorescence. Samples for this purpose were collected at the same time that abundance and biomass ones and frozen in liquid nitrogen until posterior analysis.

Detail of the sampling and experimental work is given in table 1.

In conclusion, an in attendance of the final the results, it can be said that the experiments and samples necessary to accomplish the objectives have been successfully collected.

Table 1: Detail of the sampling and experimental work.

Date	Abundance	Biomass	Gut fluo	Experiments
12/6/99				
14/6/99				
16/6/99				
17/6/99				
18/6/9				
19/6/99				
20/6/99				
21/6/99				
22/6/99				
23/6/99				
24/6/99				
25/6/99				
26/6/99				
27/6/99				
28/6/99				
29/6/99				

5.21: Radiogeochemistry

Jane Foster (CCMS Dunstaffnage Marine Laboratory)

INTRODUCTION.

Particle reactive radionuclides are useful in tracking particles through the water column. By measuring three nuclides with differing half lives, namely ^{234}Th (half life 24 days) ^{210}Po (half life 138 days) and ^{210}Pb (half life 22 years), processes on time scales of days to years can be measured.

OBJECTIVES

To sample vertical profiles of particulate (0.45□m) and dissolved (<0.45□m) matter and to carry out radiogeochemical measurements of the particle-reactive natural radionuclides ^{210}Po, ^{210}Pb and ^{234}Th on these fractions. Their activity will be measured in the laboratory to trace the fate of particles through the water column and quantify vertical export from and residence time in, surface waters.

METHODOLOGY

^{210}Po and ^{210}Pb analysis

Approximately twenty litre samples of seawater were collected from 30l Niskins at between six to eight depths (Table 1), from the surface to about 100m, and these were filtered through a 0.45□m polycarbonate filter to remove particulate material. After acidification with HCl, addition of a ^{208}Po spike and allowing around 24 hours for equilibration, the dissolved material (<0.45□m) was precipitated via APDC and cobalt (II) nitrate and collected on a 3□m polycarbonate filter.

In the lab these filters will be digested in a mixture of hydrofluoric, perchloric and nitric acids and the ^{210}Po and yield tracer,^{208}Po, plated onto silver discs and counted on an Ortec™ alpha spectrometer. The samples will be left for a period of 8 months to allow ingrowth of ^{210}Pb.

^{234}Th analysis

Approximately twenty litre samples of seawater were collected from 30l Niskins at six depths (Table 1), ranging from the surface to 75m, and these were filtered through a 0.45□m polycarbonate filter to remove particulate material. A 50ml aliquot of the filtrate was removed for subsequent U analysis.

The water was spiked with 50 dpm (disintegrations per minute) ^{230}Th and 10ml Fe (10mg Fe ml^{-1}) and allowed to equilibrate for 24 hours. After this time $Fe(OH)_3$ was precipitated with the addition of concentrated ammonia solution and collected on a 3□m polycarbonate filter. The precipitate was dissolved in 9M HCl and passed through an ion exchange column to remove Fe and U.

In the lab the samples will undergo further preparation and ultimately the ^{234}Th will be counted using a Packard Tri-Carb 2550TR/AB liquid scintillation spectrometer.

Table 5.21.1: Samples collected

Station	$^{210}Po + ^{210}Pb$	^{234}Th
	Number of samples	
1206	5	
1806	8	
1809	1	
1910		6
2003	8	
2214		6
2413	8	
2508		6
2611	8	
2713		6
2807	6	

5.22: Instrumentation systems

Jeff Benson & David Jolly (Research Vessel Services, Southampton)

CTD: A total of 73 CTD casts (consisting of 72 cruise files) were completed during this cruise, utilising two underwater unit configurations. The first cast was a preliminary check-out for the CTD and one cast was not recorded to the hard drive.

a) the first 51 cast files configuration were as follows:

24-way rosette frame
CTD underwater unit: RVS Sea-Bird 9+
Premium Fast Temperature Sensor 3P
Conductivity Sensor 4C
Digiquartz Temperature Compensated Pressure Sensor
Pylon: RVS Sea-Bird 32 Carousel/24-bottle position
Aux 0) Sea-Bird 13:Oxygen current
Aux 1) Sea-Bird 13:Oxygen temperature
Aux 3) Chelsea MKIII Fluorimeter
Aux 4) UWIRR 2pi PAR
Aux 5) DWIRR 2pi PAR
Aux 6) SeaTech Light Scattering Sensor
Aux 7) SeaTech 20 cm path Transmissometer
Sea-Bird Bottom contact switch

b) the next 21 cast files configuration were the same as above with the exception of the CTD underwater unit and temperature, conductivity and pressure sensors, which were replaced with the ETL leased Sea-Bird instruments. The reason for the change in the configuration was the loss of CTD real time data at the end of the downcast of cast 50. Subsequent investigation revealed a

short circuit in one of the bulkhead connectors on the "breakout" box leading to the UWIRR sensor. The "breakout" box was then replaced with a spare unit. The ETL instrument was left as the CTD so the RVS unit could be fully evaluated as to any internal damage caused by the short circuit. The bottom contact switch was also left off the frame as a further precaution.

During cast 47 the oxygen sensor began to show periodic large values on the downcast, typically at 55 to 65 metres. These shifts were subsequently determined to not be real features, and primarily occurred in the first cast of each station occupied. Different locations on the underwater unit body were tried to determine if the shift was caused by air bubbles trapped in the plumbing of the pumped system. As the remaining profiles and the rest of the symptomatic profiles were representational of the oxygen content the sensor was left in place.

CTD bottle configuration was 24 by 10 litre X-type Niskins for the first 2 casts, and then changed to 12 by 30 litre Niskins with internal Teflon coated stainless steel springs for the next 71 casts, alternating with 2 by 10 litre X-type Niskins/10 by 30 litre Niskins during the daylight stations.

A Chelsea FFRF was added to one bottle slot on the daylight casts, along with a PAR sensor and depth probe. In addition, an internally recording CTD was added to the frame for cross-calibration of the UOR towed vehicle. The Chelsea FFRF was placed in the bottom of the frame in lieu of the internally recording CTD for the night casts.

ADCP:

No problems experienced, with the exception of a "Beam 1, 2, 3 or 4 error: SIG, SGW, FREQ" message displayed periodically that did not affect the data collection or quality. Air trapped in the transducer housing is usually the cause of this problem in good seastate conditions, and the air was eventually eliminated.

Software used was DAS, in bottom tracking mode with navigation data added via the ABC logging system.

SURFMET:

1) The Surfmet system was installed for this cruise in the following configuration:

(a) TSG system: housing temperature, remote temperature, and conductivity sensors
(b) flow-through 20cm transmissometer and fluorometer
(c) Met system: air temperature, relative humidity, barometric pressure, PAR, TIR, wind speed and direction sensors

2) At the beginning of the cruise, the remote temperature sensor was observed to read 2 to 2.5 degrees C lower than the housing temperature sensor. Several days into the trip the remote sensor began to show markedly different readings, with the general trend to colder temperatures than the housing sensor. Upon inspecting the remote sensor, it was discovered that the probe had corroded severely; an earth fault in the 12v power supply is suspected as the cause. The remote sensor was

replaced, and the readings vs. the housing temperature are constantly within .25 to .27 degrees C. The data for the beginning of the cruise up to the replacement of the remote sensor will be corrected using the housing temperature sensor and the replacement remote sensor.

FIXED EQUIPMENT

1) Simrad EA-500 echo sounder had no working problems; the main lab forward monitor was replaced at the beginning of the cruise to attempt to solve the "shift" of the display that has occurred on previous cruises. (This display had "shifted" to the right side and disappeared from view if left powered on for a period of time.) The new monitor performed well with no observed problems.

2) PES fish was not deployed.

3) Chernikeef EM log functioned properly throughout the cruise.

4) Shipborne Wave Recorder was tested and operated throughout the cruise with no reported problems.

ARGOS DRIFTERS/MOORINGS

1) A total of 4 drifters were deployed on the cruise, in the following configuration:

B1: MetOcean OTD/GPS marker buoy, for SF6 "patch" location monitoring, ARGOS 10127
B2: Hydrosphere RVS/GPS buoy, with POL thermistor chain, ARGOS 01954
B3: Meldrum/GPS buoy marker buoy, for SF6 "patch" location monitoring, ARGOS 24295
B4: Hydrosphere RVS/GPS buoy, with pCO2 instrument, ARGOS 01953

Approximately 18 hours after deployment, the ship was notified via the base that B2 was not transmitting properly. The buoy was recovered along with B4 for the purpose of combining the two drifters into one functioning unit. B2/B4 with POL thermistor chain and pCO2 instrument, ARGOS 01953, was then deployed as a single buoy. Subsequent investigation revealed that ARGOS 01954 had leaked seawater through the top cover seal.

The MetOcean OTD buoy was recovered and redeployed two further times during the cruise, as it drifted more rapidly than the other buoys. An RVS drogue was lost from this buoy during the second stage of drifting and replaced with a drogue from DML. Also during one recovery the transmitting antennae was damaged and then replaced with the antennae from disused RVS Hydrosphere buoy ARGOS 01954.

The remaining three buoys were all recovered successfully at the end of the cruise.

2) The DML sediment trap mooring was deployed and recovered a total of five times during the cruise. The first four deployments consisted of a single trap configuration, whilst the last deployment consisted of two traps. During the fourth recovery the trap was discovered to be fouled in the mooring line. The trap was broken at two of the joints and the spindle was bent; the trap was then rewelded and the spindle replaced for the last deployment.

3) The POL bottom mounted SCADCP was deployed at the beginning of the cruise, but not subsequently recovered. The instrument was located and communicated with, but would not release its weight and float to the surface. The release codes were acknowledged by the unit, therefore damage to the SCADCP by fishing trawlers is suspected as the cause.

MISCELLANEOUS

1) A total of 98 CTD salinity samples were taken on this cruise, along with 75 TSG salinity samples, and all were analysed utilising the Autosal 8400A located in the stable lab. The Autosal experienced several periods of instability in the zero reference readings but was adequately stable to give quality analysis.

2) 94 XBT probes were launched during the cruise and transmitted to GOES; there were 4 probe failures bringing the total to 98 XBT launches.

5.23: R.V.S. - S.E.G. EQUIPMENT CRUISE REPORT

Alan Sherring & Kevin Smith (Research Vessel Services, Southampton)

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1) Aft Gantry

Used for the deployment of the U.O.R., the gantry worked without problems for the cruise duration.

2) 2.4 tonne Lebus GP winch

Mounted on the aft deck. Used extensively throughout the cruise for the deployment of the U.O.R., moored sediment traps, Argos buoy and SF6.

The winch operated without problems during the cruise.

3) 4.5 tonne Lebus GP winch

Mounted on the aft deck. Used only once during the cruise for the deployment of the bottom lander ADCP. No problems encountered during its operation.

4) Aft port side Acta HMC 30t crane

Used with a sheave block for the deployment of the U.O.R., moored sediment traps, Argos buoy, optic meter and SF6. The crane developed a minor hydraulic leak from a ram fitting but otherwise operated satisfactorily throughout the cruise.

5) Starboard gantry and Rexroth winch

The gantry was used for the deployment of CTD's and Plankton nets. The gantry operated without problems. A problem was encountered with the aft Rexroth winch which towards the end of the deployment of the plankton nets would sometimes cut out requiring the hydraulic pump motor to be

re-set after a short delay. The problem would appear to be caused by attempting to run the winch below three quarters speed. This fault is to be investigated during the refit.

6) 10 tonne Kley France winch and Seametrix monitoring system.

Used without problems for the deployment CTD's throughout the cruise.

5.24: SHIPBORNE DATA LOGGING SYSTEM

Rob Lloyd (Research Vessel Services, Southampton)

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1) Navigation data was collected without problem throughout the cruise in the following data files:-

gps_4000	Trimble Surveyor system using Marine Star differential corrections. This data formed the basis of all subsequent navigation processing
gps_glos	Trimble combined GPS and Glonass (USSR GPS equivalent) reciever.
gps_ash	Trimble 3D attitude sensing GPS
log_chf	Chernikeff electromagnetic log.
gyro	Sperry gyro compass. This read 3 degrees high

2) Surface data.

The RVS constructed 'Surfmet' system logged meteorlogical and sea surface data. The primary data file was:-

surfmet This data suffered the following interruptions:-

a. prior to day 161 13:20 the remote sea temperature data was U/S (see 'protsg' below).

b. between 165 14:300 and 165 15:10 data is unreliable due to a leak.

c. The system was off between 176 15:45 and 176 16:50 while the ship investigated a pollution incident.

Data files derived from raw 'surfmet' data were as follows:-

pro_wind	True wind vectors corrected for ship's motion. The heading offset is -90 degrees and the wind speed was adjusted to knots from m/sec.
protsg	Salinity was derived from temperature and conductivity. For the period when the remote temperature was suspect 0.24 degrees was subtracted from the housing temperature as a substitute. Therefore where temperature was changing rapidly the data cannot be relied upon to better than a quarter of a degree.

During the survey portion of the cruise data was logged into the data files:-

nutri	Nutrient data.
sf6	Sulphur hexafluoride concentration.

3) Other data sources.

proadcp	ADCP data.
ea500d1	Simrad EA500 echo sounder data.
winch	Winch system wire out, rate and tensions.

4) ARGOS buoy data was transmitted automatically from SOC by e-mail and stored in 3 buoy related files:-

a01953
a10127
a24295

5) CTD data was logged by the Seabird system and once translated to ASCII transferred for processing by the Pstar system (Bablu Sinha).

6. ACKNOWLEDGEMENTS

This work could not have been achieved without the considerable in put from many quarters. Our shipboard research was ably overseen by Captain Robin Plumley, his Officers and Crew who made sure that the scientists aims and aspirations were met to a very high degree. Theback at home base, we appreciated the input from PML's Remote Sensing Group particularly Sam Lavender whose daily beaming of satellite details were invaluable to us. We are also thankful to NERC, and Directors of CCSM and PML whose support both financially and professionally ensured that DISCO was a success. The Chief Scientist is particularly indebted to MOD DERA for their grant to him which covered a high proportion of the shipboard costs.