Work Package II

Spatial and seasonal fluxes and biogeochemical processes in the water column

Executive Summary of Scientific Achievements

Elaine Fileman *on behalf of* Peter Burkill

CCMS, Plymouth Marine Laboratory
Prospect Place, The Hoe, Plymouth PL1 3DH, United Kingdom

Introduction
Significant progress has been made within WP II over the past 12 months. As well as 3 successful WP II cruises this year, a number of WP II partners participated in WP I cruise *CD114* in August '98 and WP III *M43/2* in Dec/Jan '99. A physics workshop was held in Bangor 24-25 Nov to review progress and synthesise results for Tasks 1,2, 3 and 12. Following this, a modelling workshop was held in Galway 28-29 Nov, to ensure integration across WP II tasks. At the OMEX II-II Annual Workshop in Plymouth 25-28 April 1999, WP II partners presented 28 posters and a large number of informal presentations of recent results were given during parallel sessions. Two of the parallel themes, "Phytoplankton Production" and "Heterotrophic losses" were chaired by F. Figueiras (20 IIM) and P. Burkill (04b PML-b) respectively.

Cruise	Dates	Science
Belgica BG9815B	25/06 - 26/06/98	Underway measurements between Lisbon and Vigo
Belgica BG9815C	27/06 - 07/07/98	Biogeochemical study of area 42-43° 30'N, 9-9° 30'W
Belgica BG9815D	10/07 - 15/07/98	Underway measurements along English Channel to Zeebrugge
Prof. Shtokman ST0898	01/08 - 11/08/98	Summer slope survey of physical, chemical and biological properties within the study area located between Cape Finisterre (43° 00'N) and Ría de Vigo (42° 09'N).
Charles Darwin CD114A	29/07 - 11/08/98	WP I: Study of biological activity and response to upwelling of nutrient-rich waters from deep ocean onto shelf. Emphasis on phytoplankton processes.
CD114B	11/08 - 24/08/98	Filament experiment with emphasis on mesozoo. grazing.
Meteor M43/2	28/12/98 - 14/01/99	Cycling of C, nutrients and trace elements, their deposition, lateral and vertical transport OMEX box and Nazaré Canyon; recovery of main OMEX trap moorings. Short bathymetric/seismic profiling section worked off Faro to provide supporting data for the INDIA project.
Almeida Carvalho	03/03 - 30/03/99	Northern Portuguese coast between 41º and 42º from the coast out to 11ºW.

The Work Package II Second Annual Report follows the format set in year 1. Part 1 concerns the Executive Management in which the responsibilities of partners (given as partner numbers and acronyms) are reported on a Task-by-Task basis. Part 2 is a series of syntheses covering Physics (Tasks 1-3), Nutrients and Particulates (Tasks 4-6), Primary production and Remote Sensing (Tasks 7, 8 and 12) and Fate of Production (Tasks 9-11) in which WP II scientific achievements are integrated into short papers.

Task II.1 Moorings, currents, circulation and flow fields

II.1.1 Review Historic Current Meter and Hydrographic Data
The number of data sets acquired for the historical analysis were increased with the delivery of the MORENA data sets for that project's northern line near 42°N. The southern line has still yet to be obtained from the relevant MORENA participants. Data sets essentially comprise BORDEST, OMEX I, SEFOS, MORENA and OMEX II-II. The seasonal picture for mean flows in the upper layer indicates that

strong (up to 10 cm s^{-1}) poleward flows are apparent in winter months (Nov-Jan) along the whole of the Iberian margin region. Weakening and reverse of the flow field is present between May-Aug. Historical analysis will be used for the calibration and validation of the hydrodynamical models in OMEX II-II. A comparison will be made for the year 1994 of measured and model data, based on statistical analysis of the low frequency motions and seasonally varying currents. This is underway and initial results were presented at the Plymouth workshop. However, those comparisons were thought not to be appropriate and a new approach is in progress (07 UCG). Data from historical hydrographic measurements from the large scale northeastern Atlantic as well as from the Galician margin has been collected. In the first year of the OMEX II-II project these data have been used to establish the large-scale water mass structure at deep and intermediate levels. In the second year the water mass analysis was shifted to the study of the Central Water in the permanent thermocline. Special attention was given to the inter-annual variability in the OMEX II-II area. (05b NIOZ-b). Following continual problems with obtaining MORENA data from the University of Lisbon data bank, it was decided to apply to the originators. Nearly all the useful data have now been acquired and made available to interested OMEX partners by UWB; they are now also stored at BODC. Only one line of current meter data from about 41°N is still outstanding and, as this is held at Lisbon, it is deemed unobtainable (06b UWB-b).

II.1.2 Deploy Current Meters and Traps on Moorings
The current meter mooring at 700 m depth on the slope has yet to be recovered. No time on any OMEX cruise was obtained to drag for the mooring. It has been arranged to hire a local vessel out of Vigo to complete this task and an attempt to recover the mooring will be made in July (07 UCG). Current meters and sediment traps were deployed and recovered twice on Pelagia, Poseidon and Meteor cruises on two moorings (IM 2 and IM 3) as planned. Deliverables completed according to schedule (17 IfM). A workshop for all the physics partners was held in November 1998, convened by POL and UCG and held at UWB. Summaries of work were given by the participants: NIOZ-b, POL, NSS, UCG, IH-a, IST, UWB-a, -b, and a representative (University of Brest) of the US-French programme ARCANE in the region. Conclusions from this workshop are given in science report (02 POL). One mooring has been maintained over the mid-shelf off Porto (41ºN) from January - May '98. This mooring was redeployed mid-July '98 but only the uppermost current meter (20 m) was recovered. During March '99 one mooring with 4 current meters was deployed over 2000 m on the Porto Canyon and will be maintained for several months. Two days of observations were conducted over the mid-shelf, off Porto, using one mooring with 4 current meters (1 RMC-7 and 3 RCM-9), one thermistor chain, one moored ADCP, one WAVEC wave buoy and repeated CTD casts (08a IH-a).

II.1.3 Current Meter Data Analyses
As for **II.1.2** the current meter mooring at 700 m depth on the slope has yet to be recovered (07 UCG).

II.1.4 Shipborne ADCP for Upper Ocean Currents
During the second year of the project UWB-a has participated in two cruises, one in summer (*CD114*) and one in winter (*M43-2*). Contacts with BODC have furthered the inventory and processing of previous Acoustic Doppler Current Profiler (ADCP) data sets and discussions with other partners have been established to arrive to estimates of fluxes and budgets of scalar properties within the OMEX II-II box. Data collection has consisted in along track ADCP data during both cruises and deployment and tracking of 8 Argos drifters 4 in summer and 4 in winter, plus one short term drifter which was recovered at the end of the summer cruise, together with standard hydrographic measurements (06a UWB-a).

II.1.5 Sourcing Currents
Assembled historical CTD-data have been analysed in order to define source regions for deep, intermediate and upper ocean water types as found near the Northwest Iberian margin (05b NIOZ-b). The opportunity arose on cruise *CD114* in August 1998 to tow a CPR and thus compare its instrumentation with that collected by the ship's underway sensors. Despite a problem with fouling of the ship's sensors during Leg b, and some small differences in the absolute values of the parameters, the patterns of change are virtually identical. At the end of the sampling period there will be a 30-month record of these variables, which will provide valuable supplementary information for understanding plankton distributions (12 SAHFOS). Historical currents processed by UCG were compared with virtual time

series of currents produced by the model in the same locations and for the same period. Locations and periods to do the comparisons were chosen bearing in mind available atmospheric data to drive the 3D-ocean circulation model. Virtual time series were analysed as if they are real (computation of mean, standard deviation, etc.) and comparison was made in that way (11 IST).

II.1.6 Detection, Typology and Statistics of Sea Surface Temperature and Colour
This year the Remote Sensing Group has processed 2000 SST and 350 ocean colour scenes for the OMEX II-II region of interest. A time-series of upwelling indices for the Vigo region during OMEX I and II-II has been obtained. Data showing the average monthly Ekman offshore transport relate well to the conditions experienced during the OMEX II-II cruises, such as the low upwelling experienced during *CD105*, and the sustained upwelling of summer 1998 sampled on *CD114*. Further examples are shown in Science report (09 NSS).

Task II.2 Water mass analysis by conservative and transient tracers

II.2.1 Classical Hydrography and Water Masses
Hydrographic data collected on board RV Pelagia have been processed. With BODC, quality control of hydrographic data (CTD, oxygen, nutrients) from OMEX II-II cruises has been carried out. Some problems have arisen regarding the calibration of salinity and nutrient analyses. Questions regarding calibrations have been sent to the data originators. Comparison with historical data indicates that the OMEX II-II data are within the expected ranges and hydrographic structure. The historical and OMEX II-II data revealed an inter-annual variability of the thermohaline structure of the Eastern North Atlantic Central Water (ENACW). The existing multi-parameter water mass description of the Eastern North Atlantic has been revised. A first analysis and description of the water mass structure in the OMEX II-II research area has been set up for the summer of 1997 and the winter of 1997/98 (05b NIOZ-b). CTD data from *ST0898* cruise have been processed and submitted to BODC. This is a voluntary contribution from IEO to this Task within the OMEX II-II project (20 IEO). A cruise took place between 3 and 30 March 1999, onboard the NRP Almeida Carvalho. The sampling area included the northern Portuguese coast between 41º and 42º from the coast to 11ºW. 154 CTD stations were sampled, moorings were deployed and water samples were collected for calibration, nutrients, O_2 and SPM. Bottom sediment samples were collected and a seismic and side-scan sonar study of the area was carried out (08a IH-a).

II.2.2 Tracers and Mixing End Members
Water mass advice is given on request and has been supplied at the OMEX II-II workshop in Plymouth. Alternatives for linear combination models for the water mass description have been explored (05b NIOZ-b). Water samples for analysis of the $\delta^{13}C$ of dissolved CO_2 and $\delta^{18}O$ have been collected on *BG9815* and *M43/2*. Carbon isotope analysis from *BG9714*, Poseidon *P211*, and *M43/2* has been successfully completed at the Leibniz Laboratory, University of Kiel. Samples from *BG9815* will be analysed during the next couple of months. The oxygen isotopes will be analysed in autumn, 1999. Analysis of methane along OMEX Line S and some additional stations have been performed during *M43/2*. Collection of radiocarbon samples took place on the same cruise. All targets are being met (24a GEOMAR-a).

Task II.3 Spatial distribution of turbulence and mixing

II.3.1 Deploy Free-Falling YOYO
See **WP I Task I.1**.

II.3.2 Map 3-D Distribution of Turbulent Kinetic Energy and K_z.
SAR data have been processed and delivered before and during *CD114* cruise (09 NSS).

II.3.3 Provide Parameters for Comparison with Turbulence in Closure Models
A 1-D vertical model developed during OMEX I has been applied for the OMEX II-II region. A technique for correction of heat fluxes has been developed using observed SST producing more accurate results for temperatures and for turbulence parameters such as turbulent kinetic energy, turbulent

viscosity and turbulent diffusivities. The model has been coupled to an ecological model and run for several years. In order to validate the turbulence closure, UCW-b provide profiles of temperature, kinetic energy and turbulent viscosity as well as atmospheric forcing for comparison with 1-D and 3-D correspondent profiles (11 IST). The facility to impose a forcing function as a time series of (vertical) profiles has been added to the NIOO model. This will enable the profile of vertical diffusion coefficients, as measured by UWB-b, to be imposed on the 1-D model of the Lagrangian experiment that we will model next year (15 NIOO a). UWB-b has estimated a lower bound of vertical diffusivity of 4-13 10^{-4} m^2 s^{-1}, which will be imposed on the turbulence-closure formulation (15 NIOO-a).

Task II.4 Nutrient distribution, speciation, upwelling and fluxes

II.4.1 Nutrient Oceanography

Nutrient concentrations were measured throughout *CD114* in August 1998. Nitrate, nitrite, phosphate, silicate and ammonium were measured by standard autoanalyser methods during both Lagrangian experiments. In addition, in the offshore filament, the concentrations of nitrate and ammonium were measured by sensitive chemiluminescent and fluorescent methods. In these oligotrophic waters, nitrate concentrations were *ca* 10 nmol kg^{-1} and ammonium *ca* 30 nmol kg^{-1}; these concentrations are close to the limits of detection of even these sensitive methods and emphasise that phytoplankton are extremely efficient at taking up nutrient at very low concentrations (04c PML-c). Nutrient concentrations have also been measured during a summer upwelling cruise, *BG9815C*. Surface nutrients over the shelf increased from south (off the Ría de Vigo) to north (off Cape Finisterre), where 7 µmol kg^{-1} nitrate, 0.5 phosphate and 3 silicate were recorded after strong upwelling. Nutrient distributions along the OMEX line P showed nutrient enrichment of upwelled ENAW by mineralisation on the shelf. Mineralisation increased from north to south and mainly affected SiO_4H_4 (13 IIM). Dissolved inorganic nutrients (nitrate, nitrite, ammonium, phosphate and silicate) were collected during *ST0898*, frozen on board, and analysed by IEO-La Coruña. Analytical procedures used at IEO-La Coruña were tested regularly in QUASIMEME inter-comparisons. Parallel samples were collected and distributed to IIM for inter-calibration (Task IV. 3) (20 IEO). Nutrient samples have been analysed from cruise *CD114* (August 1998) (04c PML-c). Nutrient samples have been collected during *BG9815C*. Dissolved phosphate has been analysed on board and data have been banked at BODC. Duplicate samples were taken and kept frozen for later analysis of other nutrients (01b ULB-b). Nutrient samples (NH_4, Urea) have also been collected along vertical profiles on *BG9815C*. The samples have been analysed (23 VUB). Total dissolved nitrogen (TDN) samples have been collected during *ST0898* and *M43/2* cruises, data are currently being processed and quality controlled and should be submitted to BODC in summer 1999 (04a PML-a).

II.4.2 Conserved Nutrient Tracers

Historical nutrient and oxygen data have been assembled and quality controlled. Alternative methods to construct quasi-conservative nutrient tracers have been studied. Nutrient data from OMEX II-II cruises are becoming available and have allowed a first analysis of the effect of production/regeneration on the water mass structure for the cruises carried out in the summer of 1997 and winter of 1997/98 (05b NIOZ-b).

II.4.3 Nutrient Boundary Fluxes

In order to determine input and output fluxes across the OMEX box, results obtained from a 3D-ocean circulation model were used. The OMEX box (42ºN to 43ºN, 10ºW to coastline) was divided in four smaller boxes. Water fluxes were integrated at monthly intervals across these box boundaries. Results are shown in science report and will be the subject of further investigation. Once the model is calibrated net fluxes across box boundaries will be computed (11 IST). The nutrient and oxygen data to be used in the estimate of boundary fluxes have been assembled and quality controlled (05b NIOZ-b). Assembly of the nutrient database has been postponed until the final year, when more data will be in the BODC database (15 NIOO-a).

II.4.4 Nitrate Remote Sensing Algorithms

One major objective of OMEX II-II is to develop algorithms which will allow satellite remote sensing to estimate parameters over large spatial scales. Although the region sampled during *CD114* was very heterogeneous, it has been possible to develop algorithms to estimate nitrate concentration from sea surface temperature (04c PML-c) with a view to being able to remotely sense the new (or nitrate-driven) production (09 NSS).

Task II.5 Source markers of particulate matter

II.5.1 Biomineral and Lithogenic Composition
Sampling with Stand Alone Pumps (SAP) in moorings could not be performed as planned due to technical problems with two SAP´s and loss of the third one at sea (for details see Management Report Task 11.1)(17 IfM). Suspended matter, collected by centrifugation during *BG9714* and *BG9815*, has been analysed for major, minor and trace elements. Analyses of SAP samples collected during the *CD110* have been completed. SAPs were also used to sample particulate material during *BG9815*, the analyses of which are well in progress and close to completion (01b ULB-b).

II.5.2 Stable Isotopic Signatures
The ^{15}N signature of surface suspended matter displayed considerable variability in samples collected during the *BG9714* cruise. This was ascribed to nitrate exhaustion in surface waters and to the fact that regenerated production was predominant during the investigated period. Most probably, varying isotope fractionation factors were associated with these uptake and remineralisation processes. As a consequence, ^{15}N results were difficult to interpret and to relate to new production, which was our primary objective. In July 1998, the situation evolved towards an extension to the south of the upwelling area starting at Cape Finisterre. A few samples were collected in this area and analyses are in progress (23 VUB).

II.5.3 Particle Residence Times
Large seawater volumes for ^{234}Th and ^{228}Th measurements were collected on *M43/2* and *PE138*. ^{234}Th data from *CD105* have been interpreted in collaboration with partner 26. See also report of Partner 26 (I. Hall *et al.*, UCamb) for the discussion of the influence of particles on ^{234}Th scavenging and of POC - PON export flux derived from ^{234}Th. Scavenging constant rates and particle residence times have been estimated from ^{234}Th. During *CD110* the average residence time for particle, derived from ^{234}Th, was around 40 days, significantly longer than the summer situation on *CD105* when the average residence time was 26 days. Most of nepheloid layer samples have been collected during *PE138*, May 1999; these are currently being treated. (27 CFR).

II.5.4 Pigment Biomarkers
Pigments detected in the OMEX grid included chlorophylls *a*, *b*, c_1, c_2, c_3 and a wide range of chemotaxonomic carotenoids. Of these, biomarkers namely carotenoids, peridinin (PER), 19'-butanoyloxyfucoxanthin (BUT), fucoxanthin (FUC), 19'-hexanoyloxyfucoxanthin (HEX), alloxanthin (ALLO), zeaxanthin (ZEA) and chlorophyll *b* (CHLb) were used to indicate the presence and abundances of dinoflagellates, chrysophytes, diatoms, prymnesiophytes, cryptophytes, cyanobacteria and chlorophytes respectively. Levels of CHL*a* in Iberian Shelf waters contrasted sharply with those measured across the shelf break during summer and winter. Patterns appear to be primarily related to nutrient abundance. During summer a clear transition in the dominant classes of phytoplankton was observed across the shelf. On shelf (station P100) diatoms were calculated to contribute ~ 40% of measured CHL*a* while offshore (P2000) prokaryotes were calculated to contribute >50% of total CHL*a*. Certain classes appeared to be most important in intermediate regions *e.g.*, prymnesiophytes contributed 42 and 32% of the CHL*a* at P200 and P1000 stations respectively. During winter, no clear transition in biomass composition was observed. Prymnesiophytes (10-32% CHL*a*) chlorophytes (19-31%), cryptophytes (19-34%) and diatoms (11-21%) were the most important classes (04a PML-a). Chlorophyll concentrations of different size fractions of phytoplankton were measured during *CD114* as part of this task (04c PML-c). Results from chlorophyll *a* analyses of samples taken during *BG9815* along the P line indicate a maximum concentration at the surface near the coast and exhibit a sub-surface maximum at offshore stations (01b ULB-b).

II.5.5 Biomass Carbon
Microzooplankton data are being generated from 5 cruises (04b PML-b). Integration of this data together with bacteria, phytoplankton and mesozooplankton data sets from relevant partners has been initiated

(04b PML-b). Mesozooplankton carbon measurements are dependent on the CPR data collected under 10.1 and 10.2. (12 SAHFOS). Bacterial biomass estimates are available from 4 WP II cruises in 1998 (14 UAL-a). Bacterial biomass data has been generated from 4 cruises in 1998 (14 UAL-a). Measurements of zooplankton body lengths using light microscopy have now been completed for the 24 WP2 net samples collected on cruises *CD105b*, *CD110b* and *BG9815*; these will be later converted to carbon biomass using length-weight equations, many of these having already been compiled (16 SOC). Phytoplankton counts from *ST0898* have been sent to PML-b for conversion to C biomass (IEO). Zooplankton carbon has been determined for *ST0898* and data has been sent to PML-b for integration (UOV).

Task II.6 Dissolved organic carbon

II.6.1 Seasonal and Spatial Distribution of DOC

Shipboard HTCO-DOC/TDN measurements made during *ST0898* show that background DOC concentrations inshore were 54-58 µM-C, with a large increase (~24 µM-C) observed at 60 m. It has been suggested that nutrient-rich upwelled waters are stimulating primary production, as indicated by the high Chl *a* concentration at ~30 m. The increased productivity may be producing higher DOC concentrations through phytoplankton activity (*i.e.*, exudation, cell lysis), or zooplankton grazing on phytoplankton. DOC concentrations below 500 m at station N2300 were generally characteristic of the water masses present. At the MOW maximum (~1000 m) DOC was lowest (42±2 µM-C), reflecting the oligotrophic character of this water mass. In the upper 200 m, DOC and Chl *a* concentrations were strongly correlated. Surface samples were collected during the Meteor cruise to provide accurate DOC measurements for algorithm development of SeaWiFS remotely sensed data to enable basin scale mapping of DOC distributions to be undertaken in collaboration with NSS (04a PML-a). An algorithm has been implemented to derive DOM from SeaWiFS data, and compared with historical *in situ* data provided by IIM (09 NSS).

II.6.2 Planktonic production of DOC

Experiments for the determination of DOC production rates were carried out during *ST0898*. Data will be delivered to BODC before the end of July 99. In upwelling stations, rates of DOC production ranged from 0.10 to 2.81 mg C m^{-3} h^{-1}, representing from 4% to 46% of total primary production (TPP). Relatively high percentages of DOC production with respect to total primary production (35% and 46%) were found at deeper samples where TPP was significantly lower. Unfortunately, reliable measurements of DOC production at off-shore oligotrophic stations were not obtained. One experiment was carried out in collaboration with UOV to assess the effect of mesozooplankton grazing upon DOC production rates (21 UVI).

II.6.3 Bacterial Utilisation of DOC

DOC uptake by bacteria in surface waters ranged from 0.23 to 0.46 µM C h^{-1} at stations P100 and S1000 (*ST0898*), respectively. These values corresponded to bacterial growth efficiencies of 19.3 and 20.3%, respectively. Although these estimates are in agreement with those reported in the literature, more variation should be expected further onshore and offshore. Additional experiments will be performed during Belgica 09/99 and, possibly, Thalassa 10/99 to provide a better assessment of spatial and temporal variability (14 UAL-a).

Task II.7 CO_2 drawdown and ventilation

II.7.1 CO_2 Partial Pressures and Upper Ocean Biogeochemistry

During the two first years of the OMEX II-II project, the University of Liège has carried out three summer cruises and two winter cruises (*BG9714*, *BG9815*, *CD114A* and *B*, *CD110B* and *M43-2*) during which underway measurements of pCO_2 and vertical profiles of pH, Total alkalinity and dissolved oxygen were carried out. These data have been processed and banked at BODC. The order of magnitude of the variation of pCO_2 on a daily scale (~10 µatm) was smaller than on a seasonal scale (~200 µatm). The dynamics of subsurface pCO_2 were related to the daily cycle of biological activity (photosynthesis and respiration) when the phytoplanktonic biomass was located close to the sea surface. This depends on nutrient availability in the mixed layer so directly depends on upwelling. Distribution patterns of

subsurface pCO_2 in the OMEX box during summer were complex but reproducible from one cruise to another: oversaturation at Cape Finisterre, undersaturation off the Rías Baixas area and values close to saturation offshore. During winter, undersaturation of pCO_2 was observed in relation to cooling of surface seawater. (22 ULg).
PML-c is a minor partner in this task and activities have been limited to providing primary production estimates to the partners involved in pCO_2 measurements (04c PML-c).
ULB-b has supplied to ULg chlorophyll *a* and primary production data for the *BG9714* and *BG9815* cruises to help interpret their pCO_2 results (01b ULB-b).

II.7.2 Air-Sea Exchange of CO_2
Within the second year of OMEXII, the modelling work, summarised in section 2, was concluded as a Ph.D. project (followed by a post-doc continuation). The project report has been defended and accepted at University of Odense, Denmark (Kjeld, 1999). Field data from the first OMEXII cruises on pCO_2, as obtained by ULg (partner 22) and the transformation of these data to surface fluxes has been initiated. These initial results show very indicate small deviations from the transfer-coefficient predictions only (10 RISØ).

II.7.3 Marine versus Anthropogenic CO_2
Water samples for analysis of the $\delta^{13}C$ of dissolved CO_2 have been collected on cruises *BG9815* and *M43-2*. Carbon isotope analyses from *BG9714*, Poseidon *P211*, and *M43/2* at the Leibniz Laboratory, University Kiel, are successfully finished. Samples from *BG9815* will be analysed during the next couple of months. Collection of radiocarbon samples took place on *M43/2*. The inter-calibration of continuous underway pCO2 measurements with ULg was performed during *M43/2* (24 GEOMAR).

Task II.8 Primary, new and size-fractionated primary production

II.8.1 Spatial and Temporal Distribution of Phytoplankton Biomass. Species, Pigments and their Remote Sensing
Pigments samples have been collected from four WP II cruises (*CD105*, *CD110*, Poseidon *P237*, and *BG9815*) and from one WP I cruise (*CD114*). The generated data has been used in calibration of *in situ* optical and fluorometric sensors and development of ocean colour remote sensing algorithms (04a PML-a). The phytoplankton biomass during *BG9714c* showed higher diatom standing stock near to the coast and higher flagellate and dinoflagellate biomass at the shelf break and oceanic stations. Flagellates were the most abundant phytoplankton group, accounting for 64% of the total phytoplankton biomass. Cyanobacteria constituted 29% of the total biomass and were more abundant at coastal stations, and significantly lower along the shelf. Diatoms and dinoflagellates accounted for only 0.4 and 6% of the total biomass. Diatom biomass was higher at the coast and successively lower towards the ocean. During the winter poleward conditions of *CD110b*, flagellates accounted for 60% of total biomass and were slightly higher in outwelled water from the coast than in the poleward current. Cyanobacteria accounted for 35% of the phytoplankton biomass and were more abundant in the poleward current than at the coast. Both the diatoms and the dinoflagellates were in low abundance and accounted for only 2% of the phytoplantkon biomass (13 IIM). Size-fractionated chlorophyll *a* concentrations were determined at 15 stations during *ST0898*. Clear differences in size-fractionated chlorophyll *a* were found between upwelled and off-shelf stations. Large-sized phytoplankton (>5 µm) accounted for more than 80% of total chlorophyll *a* at coastal upwelled stations. The contribution of >5-µm cells was also relevant (>40%) at the deep chlorophyll *a* maximum of transect N. This percentage decreased from coastal to open oceanic waters as well as with depth. An opposite pattern was found for the small phytoplankton size fractions, being the <2 µm fraction the dominant at oceanic stations (21 UVI). CPR samples collected during OMEX II-II are also being analysed for large phytoplankton abundance. All samples collected in 1997 and 1998 have been analysed and will be used to determine spatial and temporal distribution. Historic data are also available for comparison. This work will be carried out in year three. The most common taxonomic groups have been identified (12 SAHFOS).

II.8.2 Intercalibration of Primary and New Production

During the first Lagrangian experiment on *CD114*, two independent groups measured primary production. PML-c made measurements by *in situ* incubations for 24 hr and IIM estimated primary production from the photosynthetic parameters determined from short-term incubations within an artificial light gradient. This was a major intercalibration since simultaneous measurements were done over the whole of the first Lagrangian experiment. Results were compared at the OMEX Annual meeting in Plymouth and it is clear that there is a large discrepancy between the methods. Another intercalibration experiment will be carried out in Plymouth on 19-21 July 1999 to resolve this discrepancy (04c PML-c). The intercalibration exercise will involve PML-c, ULB-b, VUB and IIM.

II.8.3 Parameterisation of Primary Production

Completion of the parameterisation is not possible until the problem outline above is resolved (04 PML-c). Production *vs*. light intensity experiments conducted during *BG9815C* have allowed the characterisation of the photosynthetic properties of the phytoplankton and the identification of surface species in deeper waters of the euphotic zone (01b ULB-b). During *BG9714C*, the range in Primary Production ($PP_{(PUR)}$) was 773 to 1989 mgC m^{-2} d^{-1}, with lower values at southerly stations and higher values at northerly coastal stations. This coincided with the start of upwelling at 43.0°N. There were no significant differences in PP between coastal and oceanic stations. The range in $PP_{(PUR)}$ during cruise *CD110b* was 251 to 923 mg m^{-3}. Within the winter poleward current (stations P200 and P1000) PP was the lowest of all hydrographic conditions surveyed. PP was higher at station V110 in outwelled coastal water. Photosynthetic parameters for these two cruises have already been given in the first scientific report (13 IIM). The more complex phytoplankton model implemented during the first year will be tested to the depth-variation of P *versus* I curves. If these are caused by the variable physiological condition of the algae, this model should be able to reproduce the trends (15 NIOO-a).

II.8.4 New Production

Another algorithm developed during OMEX I linked f-ratio with nitrate concentration. A relationship exists between f-ratio and nitrate concentration in the upper 10 m of the water column obtained during *CD114*. The nitrate concentrations were much lower than those measured in OMEX I and so these data help to better define the shape of this curve. This has led to a robust understanding of the relationship between *f*-ratio and ambient nitrate concentration and this algorithm can be applied to the OMEX region to obtain estimates of new production from satellite remote sensing (04c PML-c).

II.8.5 Assimilation of Phosphorus

Phosphorus uptake by phytoplankton and bacteria was measured during cruise *CD114*. Most of the uptake was by cells smaller than 2 µm and there was significant uptake in the dark. These data indicate that a significant proportion of the uptake may have been by bacteria (04c PML-c). Results on the incorporation of phosphorus under constant light conditions during *BG9815*, indicate a higher assimilation rate in the upwelling zone than in open ocean. Phosphate uptake was dominated by the 0.2-2 µm fraction except for stations near Cape Finisterre where there was stronger upwelling. Michaelis-Menten kinetics for phosphorus assimilation were established at 3 stations offshore. They showed higher specific uptake rates where higher production was observed but similar half-saturation constants (01b ULB-b).

II.8.6 Spatial and Seasonal Distribution of Primary and New Production

Primary production has now been measured by *in situ* incubations on 3 cruises, *CD105* in June 1997, Poseidon 237 in February/March 1998 and *CD114* in August 1998. This is a substantial data set, which describes the activities of different size fractions of phytoplankton throughout the year. The data from all three cruises emphasise the importance of the picophytoplankton to the productivity of this region. Even in winter, picoplankton can account for more than 50% of the production at certain stations (04c PML-c).
Results from ^{14}C incubation experiments, conducted under constant light conditions during *BG9815C*, confirm the existence of high values of primary production dominated by the >2-µm size fraction where upwelling prevailed. The reverse trend was observed for offshore stations (01b ULB-b).

Size-fractionated primary production rates were measured at 7 stations during cruise *ST0898*. In addition, the rates of microbial O_2 production and respiration were quantified at 4 stations. Rates of primary production were higher in coastal upwelled stations with a maximum value exceeding 20 mgC m^{-3} h^{-1}. This maximum rate was coincident with the maximum concentration of chlorophyll *a*. The lowest rates of primary production were measured in transect S, where upwelling conditions were less intense. The data set will be delivered to BODC before the end of July 1999 (21 UVI).

Task II.9 Microbial populations as pelagic sinks

II.9.1 Distribution of Bacteria and Microzooplankton

Microzooplankton samples have been collected from N, P and S lines on a further 2 WP II cruises this year (*BG9815*, 16 stations and *ST0898*, 15 stations). Sample analysis by inverted microscopy has begun, initially concentrating on the P-transect. Not surprisingly, lowest biomass levels of <2 mg C m^{-3} have been recorded in January (*CD110*) and highest biomass of almost 15 mg C m^{-3} in August (*ST0898*). During March (*P237*) and August microzooplankton biomass was highest on the shelf, but this trend is not so evident during July (*BG9815*), further analysis will be carried out to address this (04b PML-b). Vertical profiles observed during summer upwelling (*ST0898*) in N, P and S reference transects showed a sub-surface (5 to 50 m) maximum in bacterial abundance (and biomass) of 3-4.5 x 10^6 cells ml^{-1}. Values decreased rapidly with depth reaching a minimum of ca. 0.5 x 10^6 cells ml^{-1} below 250 m. During winter downwelling (*CD110b*), bacterial abundance was generally much lower (< 0.6 x 10^6 cells ml^{-1}). Very low frequency of dividing cells (<0.8%) were associated with downwelling conditions. Vertical structure in bacterioplankton distribution was much more apparent during upwelling than downwelling situations (14 UAL-a).

II.9.2 Nitrogen and CO_2 Regeneration by Bacteria, Micro- and Mesozooplankton

Experimental incubations of microplankton with ^{15}N have been made during *ST0898* cruise at 7 stations to determine DON production rates. Samples are being processed in the laboratory at IEO-La Coruña and results are expected to be available to OMEX-II-II partners by the end of summer 1999 (20 IEO). Bacterial respiration rates have been determined for 3 1998 cruises (*BG9815*, *CD114* and *ST0898*). In general, the fraction of respired ^{14}C-leucine varied from 11 to 68% in surface waters with an increasing offshore trend. Bottom waters always exhibited higher values reaching a maximum of 100% at an offshore station (14 UAL-a). As for task 9.1, further microzooplankton samples have been collected and once analysed the respiratory role of microzooplankton will be determined using methods adopted in OMEX I.

Task II.10 Mesozooplankton distribution and production processes

II.10.1 Zooplankton Distribution and Seasonality

CPR samples have been collected off the Spanish and Portuguese coast between 1958 and 1990, although most intensively between 1978 and 1986. Over 1500 samples have been analysed between latitudes 40°N and 44°N. Between 100 and 150 samples per month have been collected in the area making it possible to calculate an average seasonal cycle of abundance. Monthly mean copepod abundance in the WP II area were much lower in the late summer/autumn of 97 and spring/summer of 98 than is historically recorded in the northern most boxes (12 SAHFOS). Taxonomic identification of WP II samples collected on *CD105b*, *CD110b* and *BG9815* is now complete, allowing good seasonal resolution of community evolution, in conjunction with the measured size distributions. The Tromsø group has taxonomically sorted samples collected with UITØ on *CD110b*. There was a marked decrease in overall zooplankton abundance between *CD105b*, (average abundance 964 ind.m^{-3}) and the 1998 cruises, *CD110b* and *BG9815* (216 and 324 ind.m^{-3} respectively). However preliminary analyses do not show marked differences in taxonomic composition (16 SOC). During August, (*ST0898*) maximum biomass of small mesozooplankton (200-500 µm) was associated with the shelf-break along northern transects. Medium and large size fractions showed a gradient of biomass from coastal to oceanic stations. High values of mesozooplankton biomass were measured on coastal stations, reaching more than 2.80 mg C / m^2. Total mesozooplankton biomass was dominated by the large fraction (19 UOV).

II.10.2 Zooplankton Grazing, Exudation and Faecal Export

Grazing experiments were carried out in collaboration with UITØ on *CD114b*. Analysis of this data is now close to completion, and much that remains concerns the integration of these data with other biological parameters measured on the cruise (16 SOC). Length and dry weight measurements have been made on individuals of key species collected on cruises in the area according to the methodology described in OMEX 1. CPR abundance data collected during the project will be converted to biomass and from this, estimates will be made of mesozooplankton rate processes to compare with the experimentally derived grazing and respiration rates. This work will be completed in year 3 (12 SAHFOS). An experiment to determine the role of copepods in the rate of DON production was conducted in collaboration with UOV and UVI during *ST0898*. Samples from this experiment are being processed and results are expected to be available to OMEX-II-II partners by the end of summer 1999 (20 IEO). Copepods ingestion rates and their impact on phytoplankton was estimated on 20 stations during *ST0898*. Results indicate that highest values of gut contents were observed at coastal stations. The copepod gut contents ranged from 0.10 to 2.19 ng Chl *a*-eq ind^{-1} for the small fraction, from 0.23 to 3.04 ng Chl *a*-eq ind^{-1} for the medium fraction, and from 0.71 to 3.14 ng Chl *a*-eq ind^{-1} for the large fraction. The average percentage of phytoplankton biomass grazed daily by copepods was 5.5%. A method to determine gut passage time in *Appendicularia* has been developed, and accepted for publication in *Marine Ecology Progress Series* ("Gut throughput dynamics in the appendicularian *Oikopleura dioica*") (19 UOV). Microscopic analyses of trap samples for fecal pellets of various planktonic origins are being carried out and are well on schedule (17 IfM).

Task II.11 Suspended and sedimenting marine and terrestrial matter

II.11.1 Sediment Trap Moorings: Speciation, Deployment and Sampling

Instrument deployments in two moorings IM 2 and IM 3 were carried out according to schedule. The mooring work is considered an overall success as, together with current meter and transmissiometer data, a time-series of altogether 140 sediment trap samples was obtained, each integrating over a period of 10 to 14 days. The sampled period covers the period July 1997 – January 1999, with an intermediate recovery/ redeployment in March 1998 and a final retrieval, both under challenging weather and sea conditions (17 IfM).

II.11.2 Seasonal Vertical Fluxes from Biogeochemical and Morphometric Analyses of Suspended and Sediment Trap Material

On a seasonal scale, fluxes of all variables were elevated during August at both sites and at both sampled depth horizons. Sea surface temperature distribution in the upper water column off the northern Iberian Margin, as investigated by the OMEX Remote Sensing Group, clearly showed upwelling conditions prevailing at both mooring positions. Results of ongoing microscopic analyses indicated numerous diatoms, pennate and centric species, in trap samples from July/August. Elevated exports from summer upwelling were followed by a period of reduced fluxes until December during which, however, sporadic flux events were recorded. Small dinoflagellates and abundant tintinnid *loricae* from a variety of species indicate that a more regenerated type of production prevailed during this period. A second major seasonal increase in fluxes was recorded during winter (January). Mass fluxes at IM 3 and IM 2, of 193 and 269 mg m^{-2} d^{-1} respectively, exceeded those at the Goban Spur by a factor of 2 – 10.The percentage contributions of POC and Opal to the biogenic flux were strikingly similar at both OMEX sites. Contributions of carbonate appeared elevated by 10% or so at the Iberian Margin (17 IfM).

Trap samples (IM2 and IM3, at 600 m and 1100 m) were received by ULB-b from IfM for the period from June 97 to February 98 and have been analysed for major, minor and trace elements. These elements include Si, Al, Fe, K, Ca, Mg, Na, Pb, Cd, Co, Cr and Cu. No flux calculations could be made because the mass flux of individual samples has not yet made available by IfM (01b ULB-b).

Hard-shelled plankton retained in sediment trap material will be compared with the CPR contemporary samples as one aspect of the integration of water column and mooring data. This work will begin once the trap material has been analysed, however, contemporary CPR data are currently being processed. Data show that the tintinnids, a group of hard-shelled ciliates, are one of the most frequently recorded taxa on Iberian CPR samples, occurring every month and in >36% of all the samples (12 SAHFOS). Radionuclide measurements onto trap samples are on course. Particle samples from the IM3 mooring at 600 m have been measured. ^{210}Pb specific activities varied from 30 to 100 dpm g^{-1} with the highest values associated with the lowest mass fluxes. As expected from production ratio in the ocean, ^{228}Th specific activities were lower, from 4 to 10 dpm g^{-1} (27 CFR).

Task II.12 Remote sensing and biogeochemical algorithms

II.12.1 Archived and Real-Time Remote Sensed Data
Individual AVHRR SST and thermal infrared images and SeaWiFS ocean colour images, are being continuously processed in near-real time and made available to OMEX scientists *via* the web site and Inmarsat transmissions. Five cruises have been supported with near-real time data this year (09 NSS).

II.12.2 Algorithm Development and Validation
This year has seen research, development and validation of SeaWiFS algorithms, SST-nitrate relationships and front detection. The optical measurements taken aboard the *BG9815* cruise, from which water leaving radiances were derived, show excellent agreement with the global NASA database, implying that the SeaWiFS atmospheric correction procedure is working correctly. However, the HPLC-derived chlorophyll *a* comparison shows a departure from the current operational SeaWiFS algorithm when it is applied to the *in situ* optical measurements. The operational SeaWiFS algorithm requires improvement in such regions with moderate to high values of chlorophyll *a*. The SST-Nitrate algorithms were derived from *CD114* data with a view to being able to remotely sense the new (or nitrate-driven) production (09 NSS). Primary production data have been supplied to NSS and collaboration is continuing to produce algorithms for remote sensing of primary production (04c PML-c). Surface water samples from throughout the *OMEX Grid* have been analysed for the *CD110b* and *M43/2* cruises. Quality controlled data will be made available for the potential development of remotely sensed *Gelbstoff* algorithms (NSS) through BODC (04a PML-a). One of the objectives within this Task is to calculate nitrogen flux rates and *f*-ratio with uncertainties from the results of ^{15}N tracer experiments obtained during *BG9714* and *BG9815*. This has been achieved through numerical modelling and focused on the statistical propagation of errors (systematic and random errors). The numerical model describes nitrogen cycling during ^{15}N tracer experiments through aggregated chemical (nitrogen pools) and biological compartments (plankton). It includes the Monte-Carlo simulation technique, which is more accurate than linearisation methods especially when the distribution function of the response variable is too complicated to be analytically calculated. The output of this model provides confidence limits for N-flux rates and *f*-ratio at a specified level of significance and is used to refine empirical relationships between *f*-ratio and nutrient concentrations. These empirical relationships are based on non-linear regression models for which the search for good parameterisation has a purposeful basis. The goal of re-parametrisation is to obtain close-to-linear model since the latter has many advantages, *i.e.*, it provides almost unbiased, normally distributed and minimum variance estimators, and the confidence intervals for each parameter are close to being exact. Results of the uptake and inhibition kinetics (Task 8) are currently being used to refine empirical models for the Iberian margin zone (23 VUB).

Physics (Tasks 1, 2 and 3) Synthesis

Martin White (University College Galway, Ireland)

Analysis of hydrographic data, both archived and that measured in OMEX II-II has been ongoing during the second year, with all participants responsible contributing. Historical analysis of current meter data has been supplemented by the addition of the northern MORENA line, but efforts to obtain the southern line have failed. Analysis of historical data has shown the seasonal variability in the slope current from winter poleward flow to summer (upwelling dominated) southerly flow. This seasonality has also been measured along the OMEX II-II line maintained by IH. Sediment trap moorings have also been serviced during the second year. There is a reduction in the winter poleward slope current further north. CTD sections across the slope by IH indicate that a reduction in the north-south density forcing further north along the Iberian margin may be responsible. A reduction in across slope variability in the currents has been found from the historical analysis with a more polarised along slope current within the OMEX box region, and this characteristic has also been observed in distribution of Intermediate Nepheloid Layers (INL) in the region. CTD sections with transmissometer show INLs with minimal extension out from the slope region, indicating a dominance of along slope transport. There is also a suggestion of branching of the poleward flow around the Galicia Bank and eddy activity off NW Spain, observed both in historical buoy tracks and satellite imagery. Analysis of the climatological upwelling index for the OMEX II-II region indicates that, within the variability of one standard deviation of the mean index, conditions may be upwelling favourable in winter for restricted periods of time. This has been observed in current measurements by IH and also from buoy measurements in the winter of 1998/99. Buoys movement initially was to the north for approximately 10 days, associated with a tongue of warm water, but the onset of northerly winds produced a net southward flow for the remaining measurement period.

The summer situation is the well-known upwelling dominated regime. This hydrodynamic regime was studied principally for the WP I tasks in the summer of 1998, but results are applicable to WP II in terms of characterising the processes for flux estimates and validation of the models. Satellite imagery has indicated that the upwelling is enhanced at Cape Finisterre, starting earlier and is more persistent in nature. The frontal detection algorithms applied to SST and Ocean Colour imagery has also highlighted the progression of the upwelling front across the shelf to shelf break as northerly wind events occur. The filament studied within the WP I cruise has been characterised for WP II purposes. The filament, located just south of 42°N, went through relaxation and reactivation periods throughout the duration of measurements. Filament geometry changed with meteorological conditions, ranging from long (150 km) and narrow (17 km) to short (55 km) and wide (37 km). ADCP observations indicated an asymmetry in the currents, with strongest surface velocities at the filament boundaries, particularly the northern boundary where steeper isotherms were found. T-S measurements within the filament indicated surface waters of shelf origin but a T-S signature below the surface layer of more oceanic characteristics and associated onshore currents. The drifters initially converged towards the filament boundary. One drifter followed the filament signature offshore with a mean velocity 28 cm s^{-1}, while others left the filament and recirculated shoreward in a gyre with a period of 20 days.

NIOZ has continued the analysis of water masses from an extensive historical database of CTD profiles taken along the European Margin, as well as those made during OMEX II-II cruise. This analysis has provided a large-scale framework, within which to place the hydrographic work within OMEX II-II. Analysis has been completed for deeper levels but full interpretation at mid depth is harder because of the larger number of water masses to consider. As well as T-S properties, other tracers such as preformed nutrient, dissolved oxygen have been used. Increase in the Apparent Oxygen Utilisation (AOU) to the south within the isopycnals of the permanent thermocline indicates a broad southward flow in the deep oceanic region. This is not in conflict with the analysis of the current measurements and hydrography, which suggests northward flow, as this analysis is for the region immediately adjacent to the slope margin. Papers for analysis of the thermocline, intermediate and deep- water masses have been prepared.

Measurements of turbulence and dissipation from the FLY probe were concentrated within WP I, but again can be reported in terms of WP II objectives. A large number of FLY profiles were made in the region of the filament at 42°N. Temperature measurements on the probe have supplemented CTD work to map out the filament structure. Energy dissipation rates were found to be highest at the filament boundaries. A mean value for the vertical turbulent diffusivity of K_z 37 cm^2 s^{-2}, vertically averaged over the thermocline (and also tidally averaged) was found.

Modelling activities span all tasks within WP II. IST has run the hydrodynamic model to simulate flow features within the OMEX region. A poleward slope current is observed above the Mediterranean level up to 200 m during the summer upwelling season, but reaching the surface in winter when upwelling favourable winds relax. This poleward current decreases northwards as suggested by the historical analysis. The SINTEF model, which has a 10-km grid and 23 vertical levels, has also shown results which has a surface poleward current, even with a weak northward directed wind stress. The SINTEF model also shows branching of the current around the Galician Bank. IST has also coupled a Lagrangian particle-tracking model to the hydrodynamic model, in addition to an ecological model. Preliminary results for the coupled model, for August 1994, show the upwelling in the OMEX region, generation of a filament near 42°N and an associated increase in primary production and reduction in time of nutrient levels. Within the filament, increased phytoplankton levels suggest export of material from the shelf within the system. A nested model module has also been tested by IST.

Model validation in conjunction with the statistical analysis of current meter data sets has begun. At a meeting of physics participants in Bangor (November 1998) it was decided that one year (1994) should be chosen to test the model. In 1994, current meter data is available from the OMEX I, SEFOS and MORENA projects and statistics from these data sets are to be compared with that generated from the model, run under 1994 ECMWF winds and fluxes. Initial comparisons of monthly mean currents were made. These showed that whilst the model predicted current direction well, model currents were much stronger than that measured. Possible reasons for the poor agreement are the lack of vertical resolution in the model at Mediterranean Water (MW) depths and also the poor resolution in the Levitus density data set. IH have shown a decrease in density forcing for the slope current, not resolved in the Levitus data set. This type of comparison, however, is not the most meaningful, and a more rigorous validation is underway.

Results from all participants of the physics (Bangor) and modelling (Galway) meetings have been brought together to assess findings and potential problems and plan future synthesis work, including how to validate the hydrodynamical models. Results were discussed in terms of quantifying the physical processes that control shelf edge exchange and how these processes can be ‘captured’ within a defined OMEX box. Schematic representations of the summer and winter regimes along the Iberian margin were developed. Represented as a sketch, these have been put onto the OMEX web page. Discussion of the requirements for the OMEX box for flux estimates took place and it was decided that as there were too few observational data taken in the box, fluxes should be calculated from the model dynamics. For this to be accurate, model dynamics need to be validated and this is now an ongoing task. Initial comparisons, as stated above, have shown the influence of the vertical resolution in the model, particularly at the MW depths, model bathymetry and the density forcing used, in obtaining accurate model dynamics for use in flux estimates.

Nutrients and Particulate Matter (Tasks 4, 5 and 6) Synthesis

Francisco G. Figueiras (Instituto de Investigaciones Marinas, Vigo, Spain)

Nutrient distributions were studied during cruises *BG9815C* and *ST0898* when upwelling occurred. During both cruises a narrow band of cold (<15 ºC) upwelled ENAW associated with dominant northerly winds was observed along the Galician shelf. In contrast, surface temperature of oceanic waters was >17 ºC. The contrast between cold upwelled waters over the shelf and warm stratified waters in the adjacent ocean affects surface nutrient distributions. Highest surface phosphate and nitrate concentrations were found at the coastal stations while they become rapidly depleted when moving westward from the upwelling zone. Silicate still maintained a relatively high concentration at the oceanic stations. Surface nutrients over the shelf increased from the south (off the Ría de Vigo) to the north (off Cape Finisterre), where 7 µmol kg^{-1} of nitrate, 0.5 of phosphate and 3 of silicate were recorded after strong upwelling. Nutrients supplied by the continental freshwater were negligible confirming that ENAW is the main source of nutrients for phytoplankton populations on the shelf. Upwelled waters showed a N/P ratio of 16-17, while N/Si = 3.5-5.2 was well below Redfield ratio, indicating potential silicon limitation for diatom populations in this zone. Nutrient distributions along the southernmost transect (OMEX line P) showed nutrient enrichment by mineralisation on the shelf of the upwelled ENAW. Mineralisation mainly affects silica and increased from north to south.

A SST-nitrate algorithm has been developed for the OMEX area. The relationship between temperature and nitrate concentration is linear and fairly good for temperatures below 16 ºC; beyond this temperature nitrate is essentially undetectable. This fact, together with the development of an automated front detection algorithm, which has been added to Panorama, will permit monitoring of nitrate concentration of recent upwelled water in the zone.

Particle residence times were studied during several WP II cruises by means of radionuclide technique. The results show that the average residence time for particle, derived from ^{234}Th, is significantly longest in winter, around 40 days, when compared to the summer situation (26 days) during stratified conditions. The results also show higher variability in shelf waters, probably caused by the higher dynamism of these waters. The resuspension of sediments in shelf waters during winter could be the reason of the higher ^{234}Th activity found on the shelf particles compared to that in summer. The particle residence times evaluated for the intermediate/bottom nepheloid layers indicate that these are relatively short and increase from 8-10 days in the deepest bottom nepheloid layer to 15-18 days in the clear water.

The analysis of phytoplankton pigments by HPLC and the application of the chemotaxonomy, based on phytoplankton classes-pigment specific relationships, allow mapping of phytoplankton and the inter-seasonal comparison. During summer a clear transition in the dominant classes of phytoplankton was observed across the shelf. On shelf diatoms contributed ~ 40% of measured chlorophyll *a*, while prokaryotes represented >50% of total chlorophyll *a* of offshore waters. Prymnesiophytes were special abundant in the intermediate regions where contributed ~ 40% of the chlorophyll *a*. During winter, no clear transition in phytoplankton biomass composition was observed. Prymnesiophytes, chlorophytes, cryptophytes and diatoms were equally represented (~20%) across the shelf. In contrast to summer, during winter prokaryotes contributed to a maximum of ~ 10% of measured chlorophyll *a*.

HPLC chlorophyll *a* concentration was used to validate the SeaWiFS chlorophyll *a* algorithm for the area (NSS). It was found that the algorithm consistently overestimates values of chlorophyll at low concentrations (<1 mg m^{-3}) and underestimates at high concentrations (>1 mg m^{-3}). Overall, the algorithm underestimates the chlorophyll *a* value. A comparison of *in situ* optical measurements and SeaWiFS retrieved radiances did not reveal biases, which suggests that the operational SeaWiFS algorithm requires improvement in regions with moderate to high values of chlorophyll. It is planned to reprocess the SeaWiFS images with a new algorithm constructed during the OMEX II-II project.

Carbon biomass of phytoplankton along the coast of Galicia was studied during summer and winter cruises. During summer there was a characteristic coastal-ocean transition, with higher diatom standing stock near the coast and higher flagellate and dinoflagellate biomass at the shelf break and oceanic stations. Flagellates were the most abundant phytoplankton group and accounted for 64% of the total phytoplankton biomass. Cyanobacteria constituted 29% of the total biomass and were almost uniformly distributed. Diatoms and dinoflagellates accounted for only 0.4 and 6% of total biomass respectively. Dinoflagellate biomass was low towards the coast and increased ocean-ward. The diatom biomass showed the opposite trend. During the winter poleward conditions, flagellates accounted for the highest biomass (60% of the total). Cyanobacteria accounted for 35% of the phytoplankton biomass and were more abundant in the poleward flow than in the coastal waters. Both diatoms and dinoflagellates accounted for only 2% of the phytoplankton biomass. These results compare fairly well with those derived from analysis of phytoplankton pigments by HPLC.

Dissolved organic carbon (DOC) distributions during summer upwelling period were determined. The background DOC concentrations inshore (54-58 µM C) increased (~ 24 µM C) at about 60 m depth, suggesting that the increased productivity in the photic layer due to upwelling may be producing higher DOC concentrations through phytoplankton activity (*i.e.*, exudation, cell lysis), or zooplankton grazing on phytoplankton. DOC concentrations in deep waters at oceanic stations were generally characteristic of the water masses present. At the Mediterranean water maximum DOC was the lowest (42±2 µM C), reflecting the oligotrophic character of the water mass. In the upper 200 m DOC and chlorophyll were strongly correlated (0.98).

During the same cruise DOC production by phytoplankton was determined. In the coastal (upwelling) stations, rates of DOC production were highly variable, representing from 4% to 46% of total primary production. Relatively high and stable percentages of DOC production compared with total primary production (35-46%) were observed at deeper samples, where total primary production was significantly lower.

Production and Remote Sensing (Tasks 7, 8 and 12) Synthesis

Ian Joint (CCMS, Plymouth Marine Laboratory, UK)

This report reviews progress for the reporting period in WP II **Tasks II.7** (*CO_2 Drawdown and Ventilation*), **II.8** (*Primary, New and Size-Fractionated Primary Production*) and **II.12** (*Remote Sensing and Biogeochemical Algorithms*). Refer to the individual annual reports for detailed descriptions of the activities of the OMEX II-II partners involved.

Good progress has been made in achieving the major objectives of this component of OMEX II-II – *viz* to quantify phytoplankton production and to determine how much of that production results from the utilisation of nitrate (new production) rather than ammonium or organic nitrogen compounds (regenerated production). The hypothesis driving the research is that the annual flux of nitrate into the euphotic zone is largely balanced by sedimentation of organic nitrogen into deep water and so new production (which is primary production which results from the utilisation of nitrate) also gives an indication of the quantity of carbon which may be transported from the euphotic layer into deeper water. The aims of the groups studying phytoplankton and new production (PML-c, ULB-b and VUB) are to quantify on a seasonal basis the rates of primary production and the utilisation of nitrate, ammonium, urea and phosphate. Hence, the amount of carbon which is fixed by phytoplankton will be known and will be compared with the carbon requirements of the heterotrophic community; in addition, the new production estimates will indicate how much of the carbon which is fixed by phytoplankton might sediment into deep water. These estimates of carbon and nitrogen flux through the phytoplankton are complemented with measurements made by ULg on seasonal and regional variations in the partial pressure of CO_2 and with estimates of flux of CO_2 across the air-sea interface made by GEOMAR-a. The use of satellite remote sensing by NSS allows all the measurements made at sea to be placed in larger spatial and temporal scales.

NSS have developed a time-series of upwelling indices for the period 1981 to 1999. The average seasonal upwelling distribution has been derived from these indices and shows considerable variability in all months. It is only in June and September that net upwelling can be expected; all other months have the possibility of net upwelling or net downwelling. NSS have also made considerable progress in developing algorithms to estimate primary production from satellite remote sensing of ocean colour. Very good agreement has been found between estimates of primary production from satellite data and from *in situ* determinations (r^2 =.86) in August 1998, when cruise *CD114* sampled both an upwelling region and an off-shore filament.

Primary and new productions have been measured on a number of cruises by different methods. Measurements were made in March 1998 on the Poseidon (PML-c), in June 1998 on the RV Belgica (ULB, VUB, ULg, and supported by satellite remote sensing by NSS) and in August 1998 on *RRS Charles Darwin CD114* (PML-c, IIM, ULg, NSS). Data have now been collected in most seasons of the year. The data from all three cruises emphasise the importance of the picophytoplankton to the productivity of this region. Even in winter, picoplankton can account for more than 50% of the production at certain stations (PML-c). In August, total phytoplankton biomass increased as a result of upwelling events. The biomass of picoplankton showed little change but there were substantial increases in the abundance of phytoplankton larger than 5 µm. IIM have shown that flagellates were the most abundant group and accounted for between 40 and 53% of the total phytoplankton biomass. At the beginning of the upwelling, diatoms accounted for 2% of the phytoplankton biomass but abundance increased 20 fold during a 5 day Lagrangian experiment to track a mass of upwelled water as it drifted south along the shelf edge.

During the upwelling event studied on cruise *CD114*, nitrate was the dominant nitrogen source for phytoplankton. PML-c found that the >5-µm phytoplankton was responsible for more than 50% of the uptake. Most of the ammonium uptake (>65%) was by the small size-fraction and, although absolute rates also decreased each day, ammonium became increasingly more important as a nitrogen source and *f*-ratio decreased from 0.7 to 0.5. The phytoplankton assemblages show significant changes in nitrogen utilisation during upwelling and relaxation events. VUB have shown that nitrate concentrations were highest during upwelling events when new production dominated. Kinetic experiments to determine maximum uptake and half saturation constants showed that the phytoplankton has low affinity for nitrate during upwelling events. Affinity for ammonium and inhibition of nitrate uptake by ammonium were high in both upwelling and relaxation events.

Phosphate uptake by the microbial assemblage has been measured by ULB. Phosphate uptake in non-upwelling conditions was dominated by organisms smaller than 2 μm. In upwelling regions, higher phosphate assimilation was measured and a significant proportion of phosphate uptake was by bacteria. Phosphate concentration has also been used GEOMAR to interpret their data on $\delta^{13}C$. A plot of $\delta^{13}C$ against phosphate suggests that $\delta^{13}C$ has been shifted to lower values, probably as a result of penetration of isotopically light carbon into the upper 2000 m of the water column.

An investigation by IIM of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) has shown that these dissolved species are important in transport fluxes. In the offshore filament studied in *CD114*, the C:N ratio of the dissolved organic matter was 7, which suggests that the DOC was labile and recently formed. It appears that DOC is very important in the horizontal transport of carbon fixed by primary production but that carbon associated with particles will be much more important in vertical export flux.

ULg have a considerable body of data on pCO_2 distribution and have found a number of reproducible features. In the summer months, oversaturation is observed near Cape Finisterre as a result of input from upwelling water: undersaturation is observed on shelf in the region of the Rias Baixas as a result of enhanced phytoplankton production: values are generally close to saturation in the surface waters off-shelf waters. Superimposed on this general pattern, there is considerable variability, which results from variations in the intensity of upwelling and filament transport. In winter, undersaturation of pCO_2 was observed as a result of cooling of the sea surface.

In this reporting year, excellent progress continues to be made in all projects. Milestones and targets have been met and WP II is on target to achieve its objectives in the final year of the OMEX II-II Project.

Fate of Production (Tasks 9, 10 and 11) Synthesis

Rolf Peinert and Avan N. Antia (Institut für Meereskunde, Kiel, Germany)

Key processes that control the fate of pelagic primary production at the Iberian Margin are the same as in other parts of the ocean, namely heterotrophic mineralisation within the microbial food web, by mesozooplankton or larger gazers and, further, removal from the productive surface layers by gravity sinking of particles. Pelagic food web structure and the types of grazers dominating are decisive for the composition and the amounts of biogenic matter that is available for degradation and/or export from the epipelagial. Both aspects are being studied in the OMEX framework in conjunction with investigations of transports from the shelf to the adjacent deep-sea basin by advective processes. As a particular feature of the Iberian Margin compared to the Goban Spur environment, the role of upwelling in shaping the pelagic production and export fields is paid primary attention to. Merging all involved processes, active at different time and space scales, into a coherent picture of the fate of production is one of the challenging tasks of OMEX II-II. Progress at the time of this 24-Month Scientific Report is remarkable for the various relevant components.

Regarding the role of heterotrophic organisms as pelagic sinks, investigations of biomass distributions and activities on the OMEX transects highlight differences between seasons (also related to the upwelling cycle) and between the shelf and more oceanic environments, with an improving spatial and temporal data coverage. Bacterial biomass and activity patterns were found to change seasonally and related to upwelling, with lowest abundance and frequencies of dividing cells under winter downwelling conditions. This was associated with less vertical structuring than during summer upwelling when max bacterial biomass mounted up to >30 µg C l^{-1}. The 20 – 200 µm sized protozoan carbon biomass within the OMEX Box was lowest (<2.5 µg C l^{-1}) during winter as well, with no gradient between shelf and oceanic stations off the shelf break, and high values of almost 15 µg C l^{-1} were measured in summer. Microzooplankton community composition was dominated by ciliates throughout (including a 7-13% contribution by tintinnids) and had a significant 20 – 30% heterotrophic dinoflagellate component too. Heterotrophic nanoflagellates showed that this smaller-size fraction might comprise a high proportion of total microzooplankton biomass, in particular in the offshore oceanic realm. Results from microzooplankton grazing on primary production (serial dilution experiments during Lagrangian drift studies) are relevant here as results show differences between water bodies within the summer upwelling season as to the efficiency by which the primary product is utilized within the microbial food web or can be transferred to higher trophic levels or exported *via* sinking particles. Microheterotrophic herbivory during a summer Lagrangian experiment was shown to potentially consume all primary production on a daily basis, but pronounced changes were observed within single time–series and between stations within and outside of an upwelling filament. One important process may be located here for explaining spatial/temporal variabilities in the export field of primary produced particles which is indeed evidenced by short-term changes vertical fluxes recorded by sediment traps.

Towed Continuous Plankton Recorder (CPR) data provide information on the distributions of mesozooplankton on spatial and temporal scales not accessible by the comparatively few OMEX expeditions. Copepods are the major grazers in the OMEX region, and a review of 30 years historical CPR recordings show seasonal peaks for these organisms in September and April, and lowest numbers for December. Detailed analyses of the OMEX years 1997/98 show this basic pattern as well, but monthly averages were much lower for parts of the OMEX Box than the respective long-term means. Total zooplankton carbon distribution between 43° and 42°N in the OMEX Box exhibited the same overall spatial gradient as chlorophyll in August, with high values at coastal stations and lower ones off the shelf. Size fractionation, however, reveals that small copepods have a maximum at the very shelf-break, and particular constraints for the fate of primary produced matter may thus be expected to prevail on a band parallel to the shelf.

Copepod grazing activities were investigated for the summer period. As for the microheterotrophs as a food source, only an insignificant percentage of *e.g.*, the heterotrophic dinoflagellate stock was consumed by copepods per day. Using the gut-fluorescence method as a different approach, copepod herbivory was estimated for various stations on the N to S transects and compared to ambient food inventories in terms of chlorophyll. On average, the total copepod community ingested only about 6% d^{-1} of the chlorophyll stock. If the <5-µm chlorophyll fraction is not assumed to be efficiently grazed upon and, thus, excluded from calculations, this average increases to 14% d^{-1} (but rarely exceeds 20% d^{-1} at single stations). Significant progress as to our knowledge regarding the impact of mesozooplankton on the fate of production and its spatial distribution is expected from future conversions of CPR mesozooplankton abundance data into biomass data, and subsequent estimations of grazing and respiration rates for the key taxa based on experimentally derived relationships.

Continuous time-series of particle fluxes recorded with moored sediment trap at two positions with a different distance to the shelf break show the net result of ambient pelagic system properties regarding export from the epipelagial. The data depict the seasonality in the magnitude of fluxes, in elemental composition of intercepted particles and in plankton species exported. The magnitude of carbon fluxes, ranging from <5 to ~ 30 mg m^{-2} d^{-1} at 600 m depth, confirms that the lot of primary produced particles are recycled within the seasonally mixed layer. This holds true also for summer upwelling conditions which promote vertical export and during which seasonally high organic carbon fluxes are recorded together with elevated Opal fluxes (up to 30 mg m^{-2} d^{-1}, respectively). Trap samples from this season contain numerous diatom frustules, a selection of taxa found in surface water samples with the CPR. Comparisons between CPR and trap data will be carried out systematically for hard-shelled plankters (including microheterotrophy such as tintinnids once the respective data are complete in the coming months. Trap results in conjunction with shipboard mappings of bottom-near and intermediate nepheloid layers reveal that lateral advection takes place primarily close to the shelf break. Traps moored at 10 nautical miles off the 200-m isobath on average intercepted four times as much material at 1100-m depth, with a much higher lithogenic component, than those located at a distance of 25 n.m.