Work Package IV

Integrated Margin-Exchange Product

Executive Summary of Scientific Achievements

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Introduction

The principal co-ordinated integrating activities have been physics and modelling workshops in November 1998, and six scientific theme sessions at the OMEX workshop in Plymouth, April 1999. These sessions were arranged to cover the carbon cycle elements in the **Task IV.2** description. Thus:

Task IV.2 carbon cycle element	*Workshop session; task IV.n*	*theme title*
Inputs	1; 2	distribution, inputs and exports …
Lateral advection and exchange, filament transport	4; 1	horizontal and vertical transport
Air-sea exchange	6; 2,6	
Production, phytoplankton, pigments, DOC	2; 3	phytoplankton production: new,…
Bacteria, zooplankton	3; 2	heterotrophic losses, respiration, …
Particulates, vertical flux	4; 4	
Modelling pelagic cycling, pelagic-benthic coupling	6; 6	modelling requirements, integration..
Near-bed turbulence, benthic cycling and burial	5; 4	benthic fluxes and burial of C and N

Reports of these integrating activities are embodied in the following where the tasks of Work Package IV are discussed in turn, as indicated in the table (excepting task IV.5, not yet due to start).

Task IV.1 Water budget and circulation

Water masses

A historic hydrographic data set has been assembled by NIOZ-b for the north-eastern Atlantic Ocean, with emphasis on the European ocean margin including the Galician margin. These data have been used for the evaluation of the large scale and local hydrography, and analysed in order to define source regions for deep, intermediate and upper ocean water types as found near the north-west Iberian margin. The existing multi-parameter water mass description of the Eastern North Atlantic has been revised; alternatives for linear combination models for the water mass description have been explored.

Historical nutrient and oxygen data (to be used in the estimate of boundary fluxes) 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.

A first analysis and description of the water mass structure and geostrophic flow in the OMEX II research area has been set up for the summer of 1997 and the winter of 1997/98. The descriptions cover deep, intermediate, and central water masses. However, at mid-level there are too many water types for definitive analysis. It is concluded that cruises should measure nutrient profiles (silicate, nitrate, phosphate) as well as temperature, salinity, dissolved oxygen.

The lower layers are occupied by Labrador Sea Water moving south through the region. Above this at 1000 m, particularly near the coast, is northward moving Mediterranean Water embedding Meddies which show up in the low frequency variance of the current meter observations (variance is considerably less above and below this level). Near-surface waters are more seasonal as described below for summer and winter conditions.

Currents
UCG have analysed available current meter data for mean currents and variance (generally decreasing downward but maximum at Mediterranean Water levels; ellipses "fat" but aligned along-slope).

IH moorings in March to May 1998 showed some upwelling events. Current spectra showed M_2 and higher tidal harmonics but changes of tidal form on a 30-day period. Salinity maxima in 100-200 m (upper slope) were found associated with poleward flows.

Internal tides and solitons
It has been suggested that these waves' momentum could generate longshore drift and rip current as do surface waves. As well as the 30-day modulation of tidal current forms (including internal tides), IH data show strong non-linearity (rectification might be the source of the modulation).

IH have studied the Nazaré and Setubal canyons in the vicinity of Lisbon. In the Nazaré canyon the internal tide appears to be a propagating wave, whilst in the Setubal canyon it seems to be standing. Possibly as a result, pCO_2 levels in this canyon (which leads to an industrialised estuary) were higher in the canyon than on the sides, suggesting that water was being drawn into it from the shelf.

The internal wave regime and associated turbulence dissipation on the shelf near Vigo have been studied by UWB-b. Unlike the shelf edge in MORENA at 41°N, where packets of very large non-linear internal waves are phase-locked to the barotropic tide, there were many 5 to 10 m internal waves spread throughout the tidal period. Measurements in August 1998 showed solitons at 15-20 min intervals most of the time. The overturning length scale was about 5 m. In the band between 13.5°C and 15.5°C, the vertical diffusion coefficient was measured to be about $3.7\ 10^{-4}\ m^2\ s^{-1}$.

POL have examples of 3-D numerical models including internal tides at the shelf edge. For the Malin Shelf west of Scotland the model shows enhanced mixing from internal waves at the head of the slope, at the sea bed and in the thermocline. Upwelling can affect the amount of internal tide generated; this response is sensitive to the steepness of the topography and is probably less varied off Vigo.

*US-French programme ARCANE*
This extends from Biscay to 40°N and 25°W with observations in 1996-1999. It includes: 90 acoustically tracked floats (450, 1000, 1500 m), 40 buoys drogued at 150 m, hydrography, current moorings - two just off Vigo and three at 9.5°W, 44°-45°N. Off Vigo, strong tides were seen at 700 m, near-bed mixing in 1700 m, and semi-diurnal wave energy spreading up and down from near 1000 m. Eddying had been tracked, especially near Galicia Bank and near filaments.

*Remote-sensed features*
NSS analysis of remote sensed features (filaments etc.) includes boundary definition, composite locations and dynamic visualisation, using sea-surface temperature and colour (effective depth order 10 m).

Conditions in summer and winter regimes have been discussed.

*Summer regime*
Above 600 m *poleward flow* is a minimum in spring and summer, and a maximum in the autumn. Overlying this is a general southward flow, which is linked to wind stress. Confined to the slope is a northward flow, which can be overcome by wind stress. External pressure gradients are believed to favour northward flow, especially along the upper slope but also nearshore at the Algarve, except where countered by the wind. The meridional gradient in sea surface height is weaker off Iberia than to the north or south, but still has to be overcome by the southward wind stress for upwelling to occur. Moroccan influence past Gibraltar is an open question.

Satellite images in summer show strong evidence of *upwelling* along the Iberian shelf, with associated offshore filaments stretching westward. In August 1998 coastal upwelling occurred consistently, with surface temperature <15°C near the coast compared with ~20°C offshore. Upwelling was more intense at the northern section, 43°N. The cold water of a filament near 42°N was seeded near the shelf break with surface drifters in August 1998 by UWB-a on *CD114* during a period when the filament was relaxing (this was the period of the biological experiment). Initially the conditions were calm and the drifters hardly moved, but when the northerly wind increased most drifters were advected in a large cyclonic loop that eventually brought them back to the slope after about 25 days. Speeds were typically 5 to 25 cm s^{-1} on the northern edge of the filament. The centre of the filament corresponded to upwelled oceanic water, which was moving slowly towards the coast (and not, as might be inferred from AVHRR images, away from it). It is suggested that the filament is essentially a surface phenomenon (in which case satellite images and surface drifters may be giving an indication of the flow in a superficial layer). There are no measurements of flows (or exchange) at depths between 20 m and 200 m at the shelf edge. CTDs included sections across filaments, where current maxima (also from the ship's ADCP) were 20-30 cm s^{-1}. From MORENA, one CTD section at 10.2°W showed (filament?) salinity maxima at 41°N and 41.8°N near 100 m.

The vertical upwelling flux is $\tau/\rho f$ but lateral exchange in filaments may be more. Different phases of upwelling should be distinguished: initial thermocline displacement, later surfacing, moving offshore, establishment at the shelf break, filament formation. Secondary upwelling fronts can form inshore of the established front. Stronger seasonal stratification (larger deformation radius) may imply more work to raise the thermocline to the surface - also affected by thermocline depth and friction. A shallower thermocline implies strong current response. Along-shelf flow to the south will tend to intensify until energy and momentum are lost (to filaments, eddies or friction). Persistence of upwelling is thought to be related primarily to the wind forcing; there may be a criterion - the time-integral of (signed) wind stress - for upwelling to be established; this should be investigated. Upwelling breakdown is poorly observed but may be rapid, related to change of wind regime and perhaps seasonal deepening of the thermocline. Remote sensing shows that upwelling at Finisterre is enhanced (starts earlier and more persistent). Cape St. Vincent is a particular location for filaments and distinctive regarding whether flows can pass around it.

Winter regime

From an analysis of oxygen uptake in the East Atlantic Central Water, NIOZ-b propose that upper layers of the water column are fed from the north. Potential vorticity calculations suggest that there is enhanced diapycnal mixing (across density contours) in this region. However, other data from IH indicate the presence of an east-west front down to about 300 m at latitude 39° to 40°N, which implies a convergence between, waters to the south and to the north. This front bends to the north near the shelf edge, which suggests that there is a tongue of northward moving water near the shelf edge. Current meter observations east of about 10°W between 300 m and 600 m confirm this flow.

There is generally a warm flow along the upper slope, 15 cm s^{-1} or more; UWB-a has observed its establishment with a "nose" going north at this speed. The external pressure field is possible forcing with maximum gradient in the sea surface slope close to the latitude of Cabo Roca. There may be a branch around Galicia Bank. The surface temperature field often shows a much broader (100s km) northwards extension of warm water, probably affected by winds; the seasonal thermocline from the previous summer persists through January at least.

Surface drifters released near the shelf edge tend to remain trapped in this region in winter. On the shelf, for most of the time (in early 1998), the wind was from the south driving a relatively small northward current. However, when the wind reversed, there was a strong southward flow with speeds of order 30 cm s^{-1} and upwelling flow towards the shore at the bottom and offshore in the surface waters. Pulsing of the slope current has been observed at mid-slope depths in the IH data.

There is varied evidence of some eddy motion around Cape Finisterre and Cape Ortegal at both surface and deeper levels (MEDDIES).

IH data around a canyon (February 1998) suggested flow onto the shelf at the head but flow of denser shelf water into the canyon around the sides.

Coastal waters show cooler river runoff.

Wind events can give sediment resuspension on the shelf. IH has wave data off Porto and evidence for resuspension during a winter survey cruise, and associated off shelf flows.

Good progress is being made in describing the advective processes of the OMEX II-II region. There is a question of the upwelling versus non-upwelling total nutrient supply.

Flux estimation
Owing to the distribution of most measurements, combination of fluxes to a budget probably means a "box" 42°-43°N, and from the coast to about 10°W, divided at the shelf break. Vertically, partitioning might be by the mixed layer and water mass bodies (density surfaces) as determined by NIOZ-b. In order to determine input and output fluxes across such a box, results obtained with the IST 3-D ocean circulation model were used. The box (42ºN to 43ºN; 10ºW to coast) was divided in four smaller boxes:
* BOX 1 - Coast to 9º30'W; 42ºN to 43ºN; surface to 110 m.
* BOX 2 - 9º30'W to 10ºW; 42ºN to 43ºN; surface to 110 m.
* BOX 3 - Coast to 9º30'W; 42ºN to 43ºN; 110 m to bottom.
* BOX 4 - 9º30'W to 10ºW; 42ºN to 43ºN; 110 m to bottom.

The water fluxes were integrated monthly across these boxes' boundaries. In August 1994, larger transports are associated with the slope current at levels deeper than 200 m, reaching about 12 Sv at the southern boundary of BOX 4. Part of this transport is then topographically deflected offshore (7 Sv) while the rest passes across the northern boundary of BOX 4 (5 Sv). It is possible that most of the 7 Sv deflected offshore still flows northward around Vigo seamount but west of the western limit of OMEX box (Mazé *et al.*, 1996). According to comparisons of the model with current meter data (IV.6) these transports are probably exaggerated and are the subject of future investigation.

A process-based approach to fluxes may be preferred.

Reference
Mazé, J.P., Arhan, M., Mercier, H., 1997. Volume budget of the eastern boundary layer off the Iberian Peninsula. Deep-Sea Research I, 44, 1543-1574.

Task IV.2 Carbon sources, cycling and fates

Distributions, inputs and exports, and terrestrial sources of carbon and nutrients
Distributions, inputs and exports are primarily seen as a function of physical forcing, and modified by the biota.

NSS find distributions of sea-surface temperature and chlorophyll *a* from *remote sensing*. Images suggest that terrestrial riverine input can be seen from satellite ocean colour imagery. Contemporary data from *Charles Darwin CD110* (December 1997 – January 1998) provided evidence that the observed signal was caused by a shallow low-salinity surface-layer of terrestrial origin. The techniques developed are most useful for a spatial scaling of the coastal zone and the results should be compared with the sea-surface representations of temperature and chlorophyll by the numerical model.

NIOZ-b have analysed spatially and seasonally varying distributions of *oxygen*, and *nutrient* distributions due to regeneration of organic matter, for the first OMEX year. IIM have data from a winter (downwelling) cruise *Charles Darwin CD110b*, and two upwelling cruises *Belgica BG9815* and *CD114*.

Transect P (42°40′N) during *CD110b* showed the warmer more saline poleward flow of the Navidad at P200, P1000 and P2800 with nitrate levels ~1.4 µM and low phosphate and silicate, contrasting with P100 which showed continental waters overlying the poleward flow with high nitrate, silicate and phosphate. During the summer (along transect P) nitrate values are high on the shelf and undetectable off the shelf.

PML use an HPLC method for *pigments*. Data from transects from *Poseidon P237* and *CD114* show different seasonal distributions under winter and summer conditions respectively. Coccolithophore blooms (prymnesiophytes and a source of $CaCO_3$) may be present. Blooms of the coccolithophore *Emiliania huxleyi* are not seen on satellite imagery (as in the Celtic Sea) but populations of coccolithophores are found offshore west of Spain.

UAL have seasonal distributions of *bacterial* biomass and production from *CD110b* and Stockman *ST0898* (August 1998). Biomass exhibits seasonal variability (high in summer low in winter) but with no on/offshore variability. By contrast, production is higher nearshore and lower offshore, the former possibly related to high terrestrial DOC near to the coast. There was little vertical structure in winter but in summer there is high production near the surface with a maximum at ~50 m.

IEO have data on temporal *microplankton* offshore of La Coruña; seasonal and inter-annual variability is significant. Care must be taken to interpret distributions in light of this potentially significant variability.

Underway measurements of *pCO_2* were carried out three summer cruises and two winter cruises (*Belgica BG9714*, *Belgica BG9815*, *Charles Darwin CD114 A* and *B*, *Charles Darwin CD110B* and *Meteor M43/2*) along with vertical profiles of pH, total alkalinity and dissolved oxygen.

The order of magnitude of the variation of pCO_2 at daily scales (~10 µatm) is smaller than at seasonal scales (~200 µatm). The dynamics of subsurface pCO_2 are related to the daily cycle of biological activity (photosynthesis and respiration) when the phytoplanktonic biomass is located close to the sea surface. This depends on nutrient availability in the mixed layer and so directly on upwelling. The temperature variation in surface water, related to heat exchange, also has a strong effect on the variation of subsurface pCO_2.

The pattern of the distribution of subsurface pCO_2 in the OMEX box during summer is complex but reproducible from one cruise to another: over-saturation at Cape Finisterre, under-saturation off the Rías Baixas area and values close to saturation offshore. This pattern is imposed by the input of over-saturated water by upwelling, primary production, outwelling from the rías and seawater temperature variation. The variability from one cruise to another is imposed by the intensity of upwelling. The variability is in the intensity of the pCO_2 gradients, the extent of spatial features, the presence of upwelling filaments and the outwelling from the rías either of over-saturated or under-saturated water. During strong upwelling (20 August 98), pCO_2 is higher in the ría than on the shelf in spite of the fact that water is warmer. This is related to the enrichment of upwelled water in pCO_2 by input from the sediment as described for nutrients in literature (Álvarez-Salgado *et al.,* 1993). In other hydrographic conditions pCO_2 is lower in the ría than on the adjacent shelf in relation to primary production as shown by the distribution of oxygen saturation and pCO_2 (17°C).

During winter in the OMEX box, under-saturation of pCO_2 is observed in relation to cooling of surface seawater. The presence of different water masses related to the poleward slope current also induces variability; the saltier and warmer ENAW tropical end member is characterised by lower pCO_2 values than the polar end member of ENAW. The variability from one cruise to another depends on the intensity of the poleward slope current related to general meteorological conditions.

IfM have noted that the vertical distribution of *suspended particulates* along the slope shows no consistent patterns, possibly the effect of canyons. Particles' influence on spatial variability in sediments or vertical export remains unquantified but probably important.

To conclude, there do not appear to be any gaps in the *in situ* observational campaigns regarding the inputs required for the numerical models.

Heterotrophic Processes
There is still scope to give feedback to modellers regarding structure, compartments and relationships. (Models have to balance complexity with manageability).

PML microzooplankton grazing data from *Poseidon P237/1* and *CD114* show higher grazing in upwelling regions on the shelf than offshore. Discussions concluded that to determine the amount of carbon grazed requires good Chl:C ratios (the same is true for the mesozooplankton herbivorous grazing work). Mesozooplankton abundance, species composition and their herbivorous grazing rates from *CD114b* show that small copepods dominate in terms of abundance and grazing, with no strong diel patterns in grazing.

For grazing estimates, *CD114* (August 1998) provides comprehensive biological data for heterotrophy, etc. Microzooplankton grazing amounts to 40-120% of primary production. The copepod community present during *CD114b* may have obtained at most 12% of their carbon requirement from microzooplankton. Between 2% and 10% of the microzooplankton standing stock may have been consumed per day by the copepods.

An annual budget of nitrogen fluxes for a shelf station at La Coruña suggests that, even though at certain times (*e.g.*, upwelling pulses) the ecosystem has an excess of primary production, at annual scales most of the shelf displays a net heterotrophy: consumption exceeds production.

Some zooplankton relationship (preliminary) to phytoplankton has been found; there are CPR and cruise data to study this. There is a decreasing trend in phytoplankton biomass from coastal to oceanic stations. Higher values of chlorophyll near the shore are associated with an upwelling of cool nutrient-rich waters. Mesozooplankton biomass follows in general the same pattern: there is a gradient from coastal to oceanic stations, although high values were observed on the shelf-break area for the smaller size-class (200-500 µm). The highest densities of both mesozooplankton and phytoplankton occurred in front of the rías, with largest zooplankton classes in shelf waters coinciding with the largest phytoplankton cells.

For DOC and DON, there are spatial and temporal data. There is a major reservoir of DOC in the ocean. A budget approach to DOC is being developed in the OMEX II-II Area, and bacterial control of DOC is being investigated. In the Lagrangian experiment conducted during cruise *CD114*, the upwelling filament appeared to tranport labile DOM from the shelf to the ocean.

It is not yet known whether the OMEX II-II area is a net source or sink of CO_2, but the data exist and an answer is expected during the year.

Benthic fluxes and burial of C/N
Shelf studies carried out with high spatial and temporal resolution indicate: intensive remobilisation and mixing; organic carbon concentrations >1.5% in the south decreasing northwards; mineral composition and high C/N ratios indicative of terrestrial (riverine) contributions.

Cross-slope transport is restricted on the evidence of current regimes, transmissometer and optical backscatter data. Along-slope transport routes dominate.

Sediment trap results indicate: low organic carbon fluxes; high mass fluxes; pulsed signals (winter maxima).

Distributions of chlorophyll *a* / Phaeoph.*b* suggest pulses of fresh material input at the foot of the slope.

^{234}Th disequilibria measurements indicate (organic) particle residence times of 10 days (coastal) to 30 days (offshore), and organic carbon export from the productivity zone of 25%.

Early diagenetic studies (porewater profiles) indicate organic carbon mineralisation rates to be roughly similar to those at Goban Spur (>6 - <1 mmol C m^{-2} d^{-1}). Variability (also in methods) hampers detection of seasonal signals as yet.

Porewater results and carbon mineralisation will be further constrained by coupled diagenetic model application.

Organic carbon burial rates are higher than at Goban Spur.

3-D hydrodynamic model application is especially of interest for comparison of modelled and measured seasonal variation in signals (fluxes).

Deliverables
To month 24 these are intercalibrations (month 6) and conclusions about practical applications of techniques (month 12). These are subsumed in the intercalibrations listed in task IV.3.

Reference
Álvarez-Salgado, X.A., Rosón, G., Pérez, F.F., Pazos, Y., 1993. Hydrographic variability off the Rías Baixas (NW Spain) during the upwelling season. Journal of Geophysical Research, 98, 14447-14455.

Task IV.3 Nutrients, trophodynamics and fertility

Intercalibrations
For nutrients, these have shown satisfactory results apart from ammonium. The number of nutrient determinations now completed gives confidence in the methods being used by the different partners. In addition, PML-c is part of the QUASIMEME Quality Control Programme and fully achieves the standards set in that programme. On *CD114*, nitrate, nitrite, ammonium, silicate and phosphate concentrations were measured by standard colorimetric techniques. In addition, sensitive fluorometric methods were used to measure nitrate and ammonium at very low concentrations (limit of sensitivity *ca* 5 nmol l^{-1}). These data give the best information to date on the availability of nutrients both in upwelling waters and in the oligotrophic waters offshore.

PML-c measured primary production by *in situ* incubations during *CD114* while IIM made estimates using short term incubations and determination of Photosynthesis / Irradiance (P/I) parameters. As they used same water samples daily for nine days, this offers a true intercalibration of these methodologies. However, overall four different methods for the determination of primary production have been used (3 x ^{14}C; 1 x δO_2), a main area of contention. For example, rates determined on the same cruise (*CD114*) during the upwelling by PML and IIM returned estimates differing by a factor 2 to 3. There is a need to resolve the uncertainty between the methods of primary production determination reported; the differences are most likely to be resolved in terms of gross versus net rates. For this purpose a ^{14}C intercalibration experiment will be done in Plymouth in July 1999 to resolve the different estimates which derive from the two methodologies in use. In addition, there will be an intercalibration of ^{15}N methods with VUB and of phosphate uptake determinations with ULB.

DOC Methods Intercalibration
A paper has been published (Álvarez-Salgado and Miller, 1999; partners IIM and PML). This details work carried out by the authors during the period of OMEX I; as a result, much valuable collaboration and common experience in the analytical methodologies is being employed during OMEX II-II.

Both PML-a and IIM are part of an on-going international DOC intercomparison programme, organised by Jonathan Sharp (Univ. Delaware) and Dennis Hansell (Bermuda BSR). This programme collects and circulates ampoules of deep Sargasso Sea water, of known DOC concentration, to all registered members of the international community, with formal analytical and reporting protocols. This is an extremely important move towards wide-scale analytical consistency, and will be included at all stages of the OMEX DOC measurement programmes.

IIM collected samples from two shallow profiles (a total of nine samples) in the Ría de Vigo, during September, 1997. Replicates of these samples have been analysed by PML-a (and passed to ULB for opportunistic participation in the intercalibration exercise). Results from this exercise are now available. As a continuation of the programme, PML-a has collected samples from two oceanographic profiles (a total of approximately 20 samples) on the Iberian Shelf, during August 1998 and January 1999. Replicates of these samples were analysed on-board (PML-a); preserved aliquots will be analysed in the laboratories of PML-a and IIM.

Collaborative shipboard experiments have been performed to investigate the phytoplanktonic production of DOC (PML-a, UVI) and the bacterial utilisation of DOC (UAL-a, PML-c; ^{3}H-leucine uptake at two stations).

The combined results from these activities will result in repeatedly intercalibrated methodologies, producing data sets from WP I and WP II.

Intercalibrations summary

Intercalibrations have been constrained by the ship-time available, but maximum opportunity has been taken. In particular, the August 1998 cruises enabled progress regarding pigments, primary / new production, nutrient uptake, grazing and bacterial activity.

Phytoplankton production: New, regenerated and nutrient fluxes

The majority of data describe conditions experienced from spring to autumn and contrast the coastal upwelling regime with relaxation or stratified periods onshelf and the offshore oligotrophic areas.

Nutrients

In August 1998, nutrient concentrations (as exemplified by nitrate) reached highest concentrations in subsurface and deep waters of section N (43°N). Phytoplankton biomass (indicated by chlorophyll *a* concentrations) increased near the surface in coastal stations, where maximum concentrations were found at <20-m depth. The layer of maximum chlorophyll concentration deepened towards oceanic stations, where it reached depths >75 m. The distributions of chlorophyll *a* concentrations of sections N and S (42°10′N) were similar, but section P had a patchy pattern, with maximum values up to 7 mg m^{-3} near the coast. Upwelling greatly affected most concentrations and biological rates measured.

Phytoplankton

Historically there is a wealth of data on the phytoplankton species experienced in this sea area. When considering all environments from the rías to the offshore areas, approximately 600 phytoplankton species have been observed between 1948 and the present. Diatoms and dinoflagellates are present in equal numbers; for the area of shelf and shelf break under consideration, their relative distributions can generally be summarised as diatoms characterising the nutrient-replete upwelling whereas flagellates dominate during the summertime stratification. HPLC-determined phytoplankton pigments give further evidence of the transition in species composition and biomass. This is especially noticeable during onshore to offshore transects of the margin, particularly in summer when there is a correlation between the pigment signature and the dissolved inorganic nitrogen concentration. Upwelling is characterised by relatively high fucoxanthin (the marker for diatoms). Offshore waters are dominated by smaller cells - cyanobacteria and prochlorophytes which are typical of the normal oligotrophic ocean and are found to contribute up to 40% of the phytoplankton biomass as determined by the ratio of divinyl-chlorophyll *a* : chlorophyll *a* concentrations.

Production

The distribution of phytoplankton biomass is reflected in the primary production. Rates offshore and in a filament were low and found to be dominated by the pico- and small nano-plankton whilst onshore rates were higher, at a maximum during upwelling and dominated by the >5-µm size fraction.

The use of near-real time satellite imagery was critical in the planning of several of the cruises (*e.g., Belgica BG9815* and *Charles Darwin CD114*) and the excellent weather experienced provided the opportunity for calibration between SeaWiFS-derived chlorophyll and *in situ* HPLC chlorophyll. Derived algorithms were highlighted as powerful tools in the determination of primary production. Satellite-derived chlorophyll concentration was found to correlate well (r^2 = 0.88) with ^{14}C-derived primary productivity (PML), although these data are preliminary and will be further refined according to the results of the production intercalibration exercise and of the chlorophyll retrieval algorithm.

The major characteristic of upwelling is the supply of cool, nutrient-rich water to the surface layers of the ocean, resulting in elevated phytoplankton growth which is mainly supported in terms of nitrogen by nitrate *i.e.*, new production; f-ratios were estimated between 0.5 and 0.7; *i.e.*, nitrate provides up to 70% of phytoplankton nitrogen requirement. Conditions can be considered as autotrophic since respiration determined by the balance in oxygen concentration over 24 hours was equivalent to 37% of the primary production. In contrast, during stratified conditions, inshore and offshore production is supported by regenerated nitrogen (ammonium and urea), *f*-ratios 0.1 - 0.5; heterotrophic processes far exceed primary production (290%). The balance of autotrophy:heterotrophy is reflected in the contribution of bacterial activity; during upwelling bacteria were responsible for 32% of the phosphate uptake in contrast with 61% of the total in stratified waters offshore.

Export/losses

Loss terms described in terms of the total budget were limited to vertical export of organic matter and microzooplankton grazing on phytoplankton. In the steady state, new production is often equated to vertical export; therefore during the relatively dynamic condition of upwelling it is not surprising that the two are not equal; in fact vertical export is reported as very low, being equal to 2% of the biomass standing stock. The loss of 40 - 120% of the primary productivity is attributable to microzooplankton grazing. In an offshore filament the vertical export of organic matter was also low; 3% of the biomass was lost per day with <40% of the primary productivity accounted for by microzooplankton grazing.

An initial aim is to provide the rates necessary to complete a simple phytoplankton-based carbon-budget model. Although not completed, due to a small number of missing data (partly owing to the complexity of the area under consideration and the short time since the data were collected), the aim has been useful, directing Plymouth workshop presentations and providing the skeleton on which the discussion was based. Following the planned primary productivity intercalibration and consolidation of data on completion of all fieldwork, re-visiting this or a similar scheme is recommended.

A summary of processes at the NW Iberian Margin has been derived for the two extreme summer-time conditions.

	UPWELLING	OFFSHORE
Chlorophyll	1.5 - 8 µg l^{-1}	<1.0 µg l^{-1}
G.P.P.	3 gCm^{-2} d^{-1}	0.7 gCm^{-2} d^{-1}
N.P.P.	1.2 gCm^{-2} d^{-1}	0.4 gCm^{-2} d^{-1}
Size Fraction	>5-µm dominant	<2-µm dominant
f-ratio	0.7 - 0.5	0.1 - 0.5
DOC	13% of primary production	Higher??
Respiration	37% of primary production	290% primary production
PO_4 uptake	high	lower
Bacteria PO_4 uptake	32% of total	61% of total
Vertical export	2% of biomass	3% of biomass
Microzoo. Grazing	40-120% primary production	<40% primary production

Reference

Álvarez-Salgado, X.A. and Miller, A.E.J., 1999. Simultaneous determination of dissolved organic carbon and total dissolved nitrogen in sea water by high temperature catalytic oxidation: conditions for precise shipboard measurements. *Marine Chemistry*, 62, 325-333.

Task IV.4 Particle dynamics, scavenging and trapping

Particles and vertical particle movement
Evidence for the movement of particles over the slope has been presented. Combined backscatter and transmissometer measurements provide an indication of the variability in particle size, with the backscatter instrument more sensitive to smaller particles. In winter, both instruments gave similar results suggesting a uniform vertical distribution, but in summer there was a divergence with higher scattering at depth. Nepheloid layers were observed off the slope down to the upper part of the Mediterranean Water, which suggests that the nepheloids were derived from the slope above about 1000 m.

Thorium-234 levels increased from the slope into the ocean (they were very noisy on the shelf) which suggests that there was more scavenging near the slope than further offshore.

The sediment traps were deployed in the expected position of an offshore filament on the 1600 and 2200 m isobaths. Particle flux at the Iberian margin was greater than at the Goban Spur. The flux in terms of dry weight and other variables was greater in August and January than other months. A summer peak is attributed to upwelling, but the cause of the winter peak is unknown. One suggestion is that it may be due to an increase in productivity following an outflow of river water from the coast.

Task IV.6 Integrated margin exchange model

OMEX models
These include 3-D physics (IST, SINTEF) with coupled biology most relevant to WP I in describing some rate processes. NIOO are investigating parametrisations for various taxonomic groups, simplifications appropriate to longer-term integrations and (extensions to) benthic processes. An air-sea exchange model (Risø) enables flux estimates from CO_2 concentration measurements. IST are carrying out work to combine the various elements: (waves), hydrodynamics, advection-diffusion (Eulerian or Lagrangian), turbulence, air-sea exchange, sediment transport and water quality or ecosystem. Links are simplified by confining dimensionality to the hydrodynamics, advection and diffusion. POL is modelling near-bed turbulence and stresses suspending sediment.

Combining models
Model components to be connected in order to model fluxes and the 'OMEX food web' include: hydrodynamics with atmospheric forcing, turbulence, grid, bathymetry, initial conditions and boundary conditions as sub-components; this can give velocity, elevation, water fluxes (and geometry) to a Lagrangian or an Eulerian transport module; ecological model. The issues in connecting these (interfaces, module substitution, ...) are almost exactly as in the MAST project COHERENS (although the latter has no seabed fluxes). (ERSEM was another MAST project linking modules to a “framework”.) The COHERENS framework is available as a possible scheme. IST has connected hydrodynamics to transport models and tracer 'particles' can evolve. Hydrodynamic developments continue.

It has been agreed that all partners should describe their modules, define needed inputs and outputs produced. Subroutines should exchange variables, defining the interfaces and using Fortran 90 with optional arguments. Each module wants its own initialisation, and optimised data input files with identifying keywords.

POL has since made its cross-section model available to NIOO; it is intended to continue the dialogue to establish parametrisations of bottom boundary-layer physics that are appropriate to the benthic biological model.

Hydrodynamic results are wanted on sub-domains for the ecological models.

Challenges

There are some technical challenges. Computational needs inhibit complex biology in 3-D. Processes should be included as not in equilibrium if their time-scale is as long as evolution times. More complex biology might be run for particular (short) periods within a longer run. Fine resolution is needed for filament flow structures (as distinct from location, which models already reproduce). Internal wave mixing (across the thermocline) should be represented, perhaps via shear input to turbulent energy.

Models have two-way relations with measurements. They need data for formulation, initialisation, forcing and validation (not guiding assimilation at this stage). Some comparisons with measurements have been made, with limited success for currents. More work is needed to compare "like with like": treat model output and observations similarly (*e.g.*, Principal Component Analysis); compare meteorology-model and meteorology-observation correlations; improve the "reality" of model forcing (actual meteorology; balanced oceanic pressure field derived from Levitus density field).

Progress with (individual) models

Historical currents processed by UCG have compared with virtual time series of currents produced by the *IST 3-D hydrodynamical model* in the same locations and for the same period. Locations and periods to do the comparisons were chosen having in mind available atmospheric data to drive the ocean model. Virtual time series were analysed as if they were real (computation of mean, standard deviation, etc.) and so comparison was made.

This kind of comparison has limited value, since the model is not able to reproduce many features that exist in nature. However, direction of the flow predicted by the model generally agrees with current meter data. The magnitude of the simulated mean currents is much larger than observed and this is very consistent in all the points considered. Reasons are now being investigated but two features must be pointed out. 1) Most of the variability found in current meter data is at the level of Mediterranean water and probably associated with MEDDIES. The model is not able to reproduce such variability in this simulation. In future the model domain will include the Strait of Gibraltar and the western Mediterranean Sea in order to simulate the outflow of Mediterranean Water. 2) From current meter analyses it is clear that the poleward slope current decreases to the North. This is unexpected; theory predicts an increase in slope current; all previous simulations by IST also predict an increase in slope current. Measurements made by IH have shown that meridional density gradient is concentrated further to the south and almost disappears north of Nazaré. This means that the forcing for slope current does not exist north of 41ºN.

ECMWF meteorological forcing previously caused long-term temperature and salinity divergence. IST developments have been to use monthly-mean density, a new flux algorithm relaxing to observations (with much better results including mixed layer depth in 1994) and a generalised vertical coordinate.

IST have coupled a *Lagrangian particle-tracking* model to the hydrodynamic model. Particles to be tracked can have a large number of properties (*e.g.*, volume, nitrate concentration, phytoplankton concentration, etc.). A non-dimensional biochemical model has been coupled to the particle-tracking model using a prototype interface developed during OMEX I.

IST have run their system of *coupled* models (hydrodynamic, particle tracking and ecological) for summer months. Some interesting features are reproduced. Upwelling near rías is identified by relatively high primary production (0.05 mgC l^{-1} after 15 days, 0.18 mgC l^{-1} after 30 days). In this area, where higher phytoplankton concentration is found, nitrate values are minimum and ammonia reaches maximum concentrations. It is also possible to identify a filament near 42ºN that seems to be topographically controlled. Inside that filament high phytoplankton values were found corresponding to export of material from the shelf to the open ocean.

A *nested* model module has been implemented by IST. The utility of this module is the ability to simulate small specific areas without reducing the spatial step in all the modelled area. The nesting is presently 1-way; information is passed only from the large-scale model to the small-scale model. Hence a run of the nested model can be done separately from the regional model. This represents a considerable reduction in

CPU and makes it possible for a different team to use the results of the regional model to run the nested model for their own purposes. In particular, the nested model is available for SINTEF to run it coupled with their biochemical model.

SINTEF models have unequal levels for the vertical coordinate and a 10-km grid over a wide area. For slope-current forcing using Levitus density, prognostic runs give sharper features than diagnostic runs. There is some anticyclonic flow around Galicia Bank, favoured by wind from the north. Varied conditions at the southern boundary make little difference to results in the Galicia area, even when the boundary was brought closer, to about 34°N. Nesting had also been carried out, with the Galicia area having 2-km resolution and 39°-45°N having 3.33-km resolution. Density forcing alone favours an anticyclonic eddy at the shelf edge near 42°N.

POL have 2-D and 3-D hydrodynamic models which have been used for *e.g.*, calculations of cross-slope circulation and bottom boundary-layer flow associated with along-slope flow, and of internal tides and consequent structure in SPM concentrations and transport.

NIOO have run a version of the IST physics in 3-D in an area extending 132 km along the shelf. A spurious response to upwelling winds, especially near the southern boundary, has the appearance of a shelf wave with zero group velocity from a boundary condition mismatch. It is to avoid this that it is proposed to run the biology model just on the sub-area of interest, with hydrodynamics done off-line (previously) on a larger area.

With regard to the *benthic* modelling, various formulations of benthic-pelagic coupling have been tested; a manuscript has been written and submitted. Meta-modelling of the results of the diagenetic model calibrated against field measurements will constitute the basis of the formulations that will be eventually used in the 3-D model. Diagenetic processes can be modelled using the OMEX I diagenetic model, extended during OMEX II-II. A newly added integration routine has increased computational speed for the dynamic mode by several orders of magnitude.

<u>*Validation*</u>
Proposals have been made for model validation. The year 1994 is being simulated and compared with archived data sets used in historical analysis. For this task, four mooring positions are available as well as possible MORENA/IEO data sets. (The IST physics model is already being compared with current meters and buoy data series processed by UCG, see above).

For model runs, and comparisons, there are Portuguese wave data from buoys, river runoff, meteorological data (IST contacts) which should include wind vectors, wind stress, heat fluxes, atmospheric temperature, humidity, cloud cover (problematic, from remote sensing?), rainfall. Spanish Meteorological Office data from June 1997 are available via BODC. (Atmospheric forcing and river inputs will be omitted initially, but information including any nutrient content should be checked). Data for comparison may also include: remote sensing including altimetry; UWB turbulence data with varied air-sea temperature difference, wind ... (data could give the Thorpe scale, a possible basis to convert turbulence energy to diffusivity); drogued buoys for lateral dispersion (ARCANE pairs; Haynes and Barton).

Validation via module inter-comparison is also proposed, involving definition of how results will be compared. Inter-comparisons should include
- turbulence and air-sea flux parametrisations; 1-D (vertical) calculations comparing mixed layer depths (IST and NIOO lead)
- grid (x,y; z), bathymetry, boundary conditions and location (SINTEF lead) to give agreed grids
- hydrodynamics; cases (applying equally to the grid comparisons) to include stratified tide under varied conditions, density forcing, density + wind, tide (internal relative to resolution). For contrasted upwelling cases, the MOMOP and MORENA examples should be used. Flow fields and kinetic energy can be compared

- initial conditions: there may be a 'window' after the solution settles down and before it drifts; what is the difference with more detailed initial temperature and salinity than Levitus?
- ecological model; experiment with different combinations of state variables in the 1994 Goban Spur context; for the Galicia area also there may be earlier data for comparison, from IIM, *Belgica BG9309* and other OMEX I, SEFOS; compare the bloom peak and time, total annual production.

Applications
Simulations to exploit the models should include
- the period observing the filament in 1998
- contrasting upwelling seasons: 1994, 1997, 1998, 1999(?) for which there are good cruise data. Interests are criteria/conditions for upwelling onset/establishment and ending, and the character of response. 1998 is a good year for looking at the biology (NIOO, SINTEF), possibly 1994 too.
- possibly water masses, which depend on initial and boundary conditions, flow and diffusion. This is only sensible for conservative behaviour, *i.e.*, below the depth of seasonal mixing. It is also only sensible if there are only three possible point end members (cf. the problem with middle waters), given that the analysis of Levitus data for the model input sources concerns only temperature and salinity. Another approach may be simply to simulate and compare the long-term evolution of temperature and salinity.
- attaching numbers to the summer and winter regime outlines (above). The models may be the best source of flux estimates, and automatically give closed budgets, but are good only if representing beliefs about processes occurring and agreeing with observations.

Continuing dialogue is needed regarding the desired model results and their form. Models should: represent filaments, vertical exchanges controlling profiles; distinguish DOM, POM, respiration as components of gross and hence "net" primary production for "export" (lateral and vertical). They should capture 1-day time-scales, upwelling (2-3 weeks) and aggregate winter and summer conditions for gross budgets, estimate lateral off-shelf flux and capture all (upwelling-) enhanced production by extending far enough off-shelf. All models are flexible regarding variable boundaries for an OMEX budget "box".

An OMEX 'box' for attempting (closed) budgets has been discussed. This ought to be away from a filament at its northern and southern boundaries (about 41.5°N and 43°N), enclosing the 1998 filament. Sub-partitions in depth may be at the base of the mixed layer and about 250 m, below seasonal mixing (to be checked with CTD profiles from *Poseidon*, Feb-Mar 1998). (The bottom would be the sea-bed surface - sub-bed divisions have not been discussed). Other sub-boundaries for fluxes may relate to flow features (*e.g.*, just inshore of the upwelled front) rather than be fixed a priori.