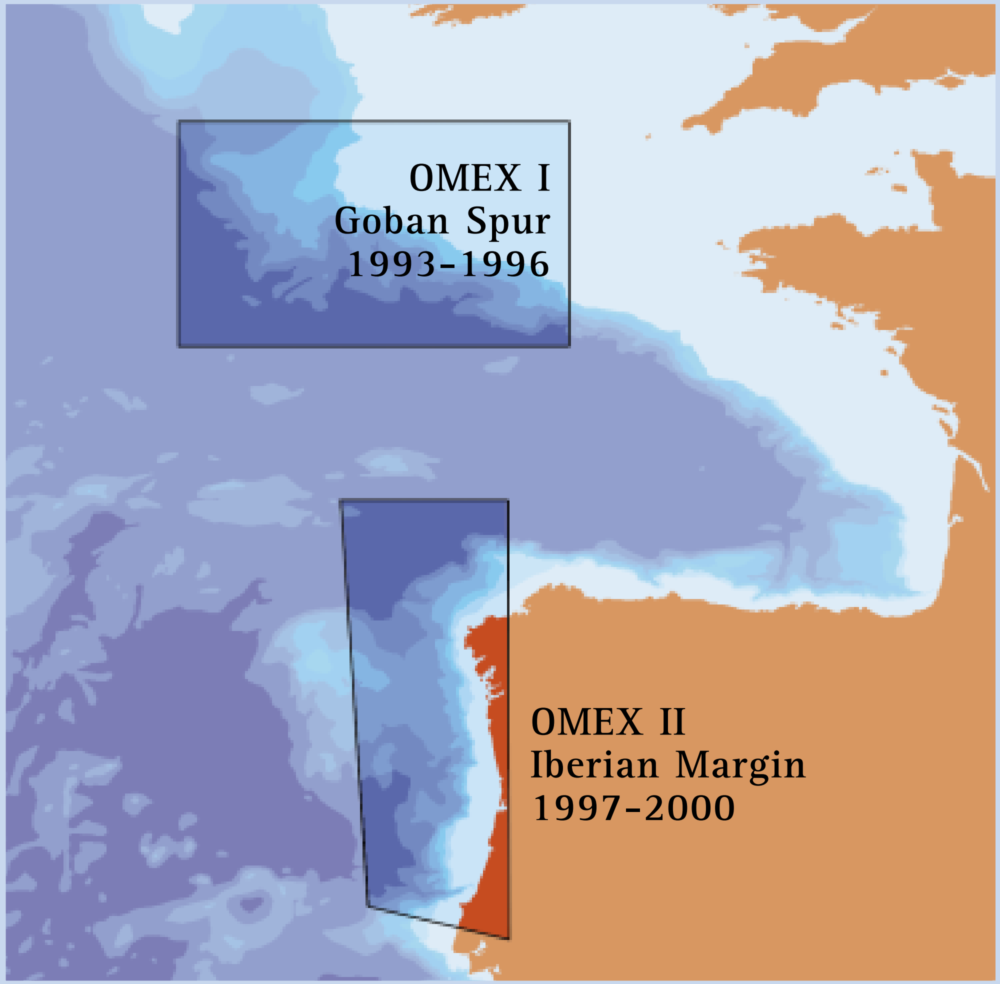
EXIT

OMEX PHASE II 1997-2000

Ocean Margin EXchange



EUROPEAN COMMISSION DG RESEARCH

MAST

OBJECTIVES

OMEX PHASE II 1997-2000

The ocean margin represents the interface between continental shelf and open ocean. It is potentially an area of strong exchange of energy and matter, and also of enhanced productivity, sustained by nutrients transferred from deep waters either by intense vertical mixing induced by bathymetric discontinuity or by coastal upwelling.

The exchange processes occurring at the ocean margin are still poorly understood. However, their evaluation is critical for the biogeochemical cycles of carbon and associated elements, between the continents, coastal zone and open ocean. Ultimately, a better understanding of these processes is a prerequisite to predict the consequences of global climatic change and other local anthropogenic perturbations.

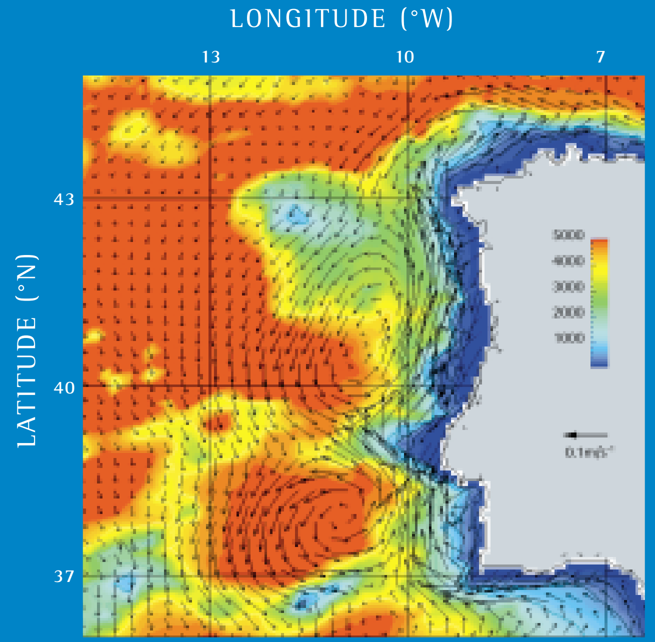
The Ocean Margin EXchange (OMEX) project is designed to meet the priority goals of the International Geosphere-Biosphere Programme (IGBP). It also takes into account the specific features of the European marine environments and benefits from the expertise of the EU oceanographic community.

OMEX aims at studying, measuring and modelling the processes and fluxes occurring along and across the European shelf break facing the North Atlantic Ocean. It serves as a basis for the development of predictive models of the global environmental change.

The first phase of OMEX (OMEX I, 1993-1997) focused mainly on the northwestern Bay of Biscay (Goban Spur) and its wide continental margin.

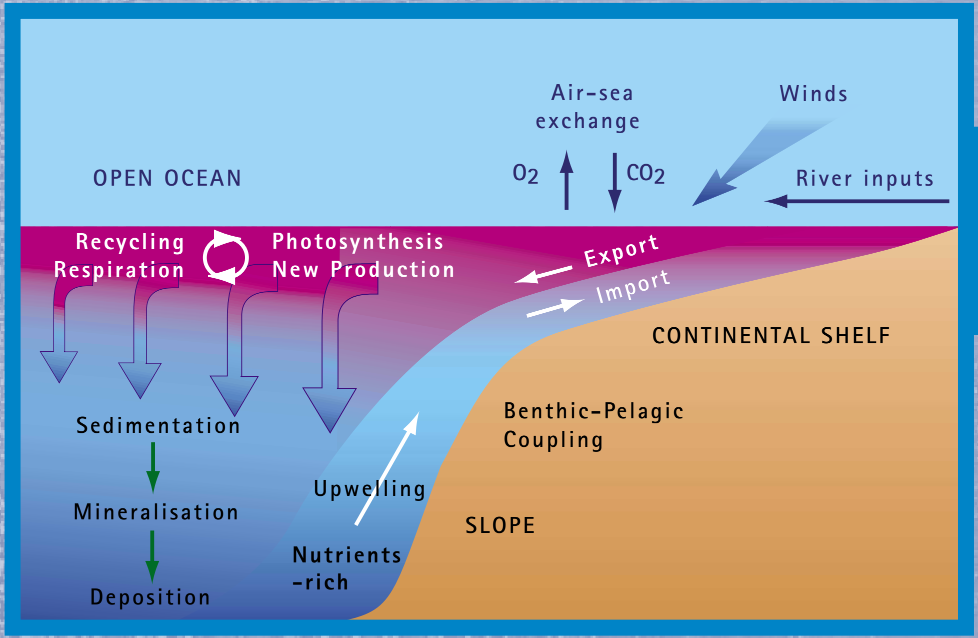
The second phase of OMEX (OMEX II, 1997-2000) concentrates on the upwelling region of the narrow Iberian margin.

Some highlights and major findings of OMEX II are presented hereafter.



5-m avearged velocity in July 1994, showing the equatorward upwelling jet over the shelf and the poleward slope current offshore. Contours represent isobaths and are for 200, 500, 1000, 2000 and 4000 m.

EXIT



Schematic diagram representing the main processes that control the carbon cycle at the ocean margin. (ULB, BE)

PROJECT CONTENT

Coastal upwelling, largely wind-driven, is complex in both space and time, making it difficult to understand how this physically driven biogeochemical system functions. Such understanding can only be achieved through an interdisciplinary approach. Accordingly, the OMEX II project is organised in multidisciplinary Work Packages that involve the integration of physical, biological, chemical and sedimentological aspects:

- Work Package I:
Temporal Evolution of Surface Production and Fate of Organic Matter
- Work Package II:
Spatial and Seasonal Fluxes and Biogeochemical Processes in the Water Column
- Work Package III:
Fluxes and Processes in the Nepheloid Layers and Surface Sediments
- Work Package IV:
Integrated Margin-Exchange Product
- Work Package V:
Project Management and Coordination

THE UPWELLING PHENOMENON

The sources and circulation of various water masses along the NW Iberian Margin are seasonally variable, because of their coupling with the large-scale climatology of the northeastern Atlantic.

During summer months, trade winds along the coast induce along-shore flow and upwelling of deep nutrient-rich water at the shelf-edge. Major headlands and flow instabilities in the slope current may generate several eddies and filaments extending into the open ocean. Filaments are potential exporters of coastal water, including organic matter produced on the shelf, to the open ocean.

The variable wind pattern may stop the upwelling and cause relaxation periods or downwelling to occur, especially in winter, when current directions are reversed and the riverine fluxes of nutrients and terrestrial matter are at a maximum.

EXIT

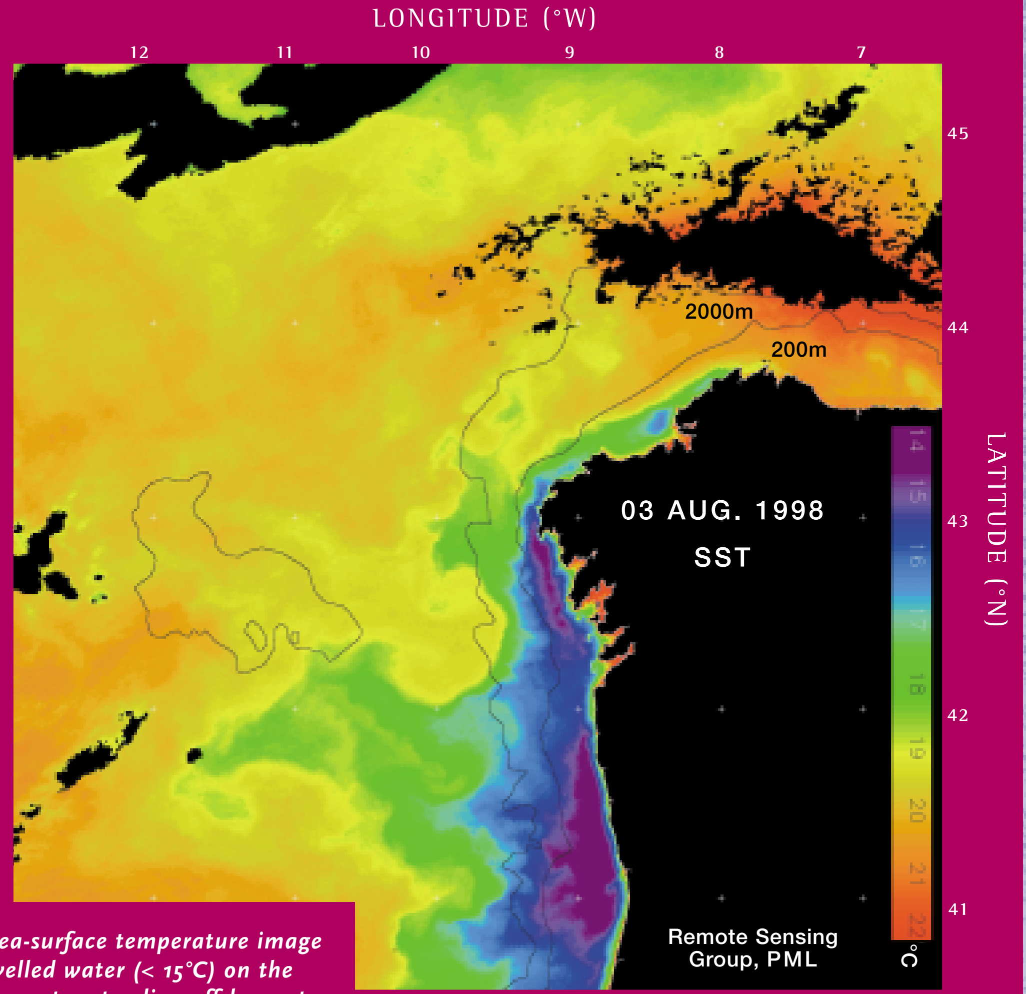
Remote Sensing

Satellite remote sensing provides large-scale, high-resolution, high-frequency observations not available from research vessels. In addition, real-time remote sensing information helps to improve the strategy of ship-borne samplings and deployments during research cruises.

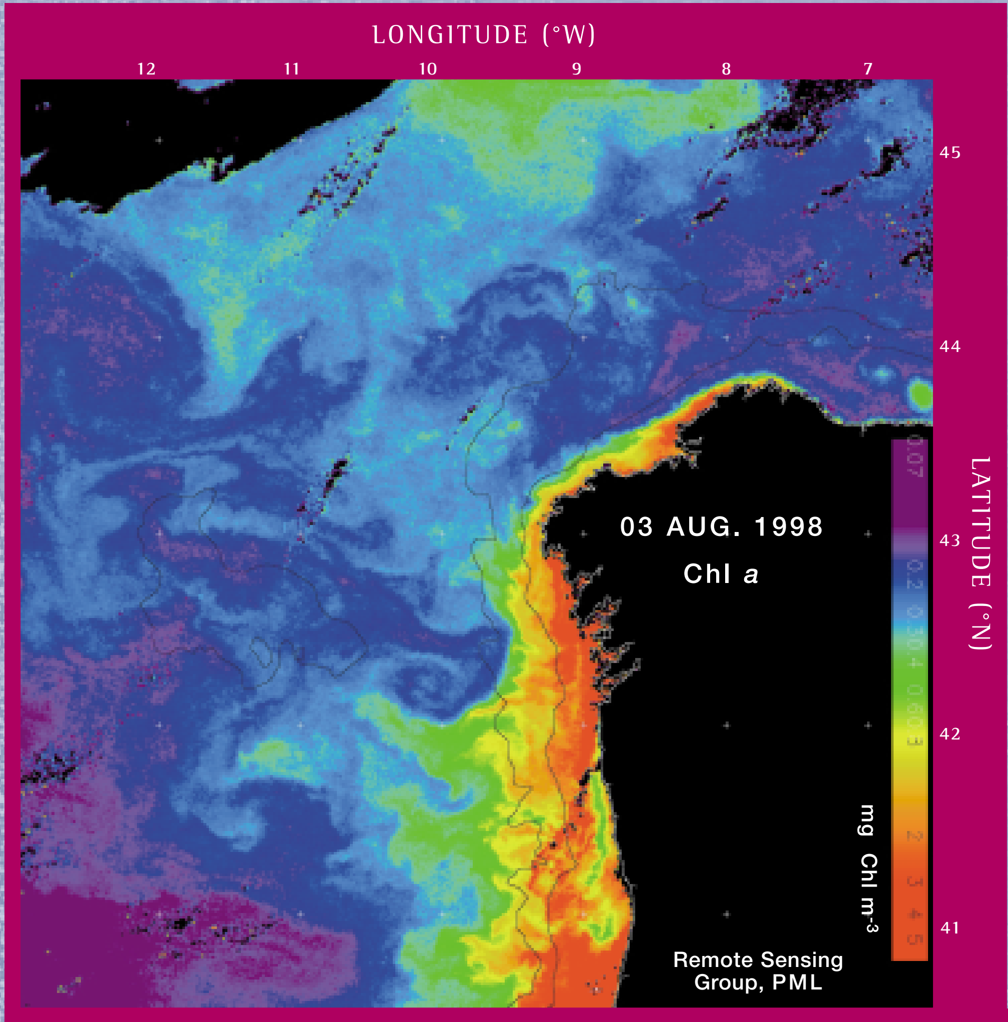
The Iberian margin region exhibits wide ranges in sea surface temperature and chlorophyll concentration, in a complex environment with upwelling, filaments, eddies and river-generated plumes. It is thus an ideal location to test and improve remote sensing tools for ocean biogeochemistry.

Depending on the source of the limiting nutrients for phytoplankton growth in surface waters, the trophic status of the ecosystem could be considered as a combination of new production (based on nitrate) and regenerated production (based on ammonium and organic nitrogen).

The new production is particularly relevant in the context of the global increase of atmospheric carbon dioxide (CO_2) concentration. It represents the main way to increase an oceanic sink for this CO_2, via enhanced phytoplankton photosynthesis and stronger export of organic matter to deeper waters.



AVHRR-derived sea-surface temperature image shows colder upwelled water (< 15°C) on the shelf and two filaments extending offshore at 42 and 43°N.



SeaWiFS-derived chlorophyll concentration image shows high phytoplankton abundance (> 1 mg Chl. m^{-3}) on shelf, and moderate abundance within the filaments, compared with the surrounding offshore waters.

The remote sensing data are available via the World Wide Web on:

http://www.npm.ac.uk/rsdas/omex/

NASA registration required for SeaWiFS data

The ratio of new-to-total production could be mapped using regional correlations between ship-derived nitrate concentration and remotely sensed sea surface temperature, and between nitrate and new production obtained from nitrogen incubations on-board ship.

Ultimately it is possible to map and to extrapolate spatially and temporally a wide range of processes including primary production, export, CO_2 exchange fluxes and nutrient inputs at the ocean margin.

As an example, the two pictures chosen herein are satellite images showing strong upwelling along the Galician coast on 3 August 1998. These were transmitted in real-time to an OMEX Phase II research cruise to better guide the Lagrangian experiments taking place to study the short-term evolution of the physical and biological characteristics of upwelling and filaments. (RSG-PML, UK. Raw satellite data courtesy of Dundee Satellite Receiving Station, UK; NASA SeaWiFS project, USA and Orbital Sciences Corporation, USA.)

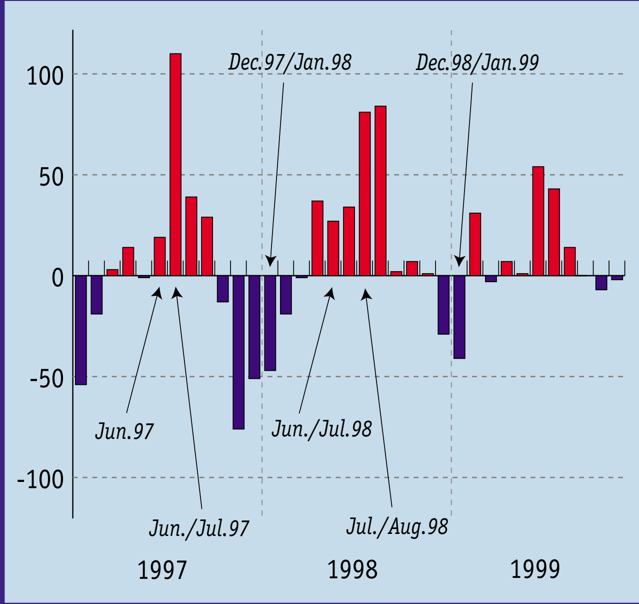
Physics

During summer, the Azores high-pressure cell in the central north Atlantic drives trade winds with southerly components along the western Iberian coast. This induces an equatorward surface current and upwelling of nutrient-rich East-North Atlantic Central Water.

The monthly upwelling index at the Vigo region for the entire OMEX period, derived from synoptic pressure analyses, exhibits a large seasonal variability. Upwelling predominates only from June to September.

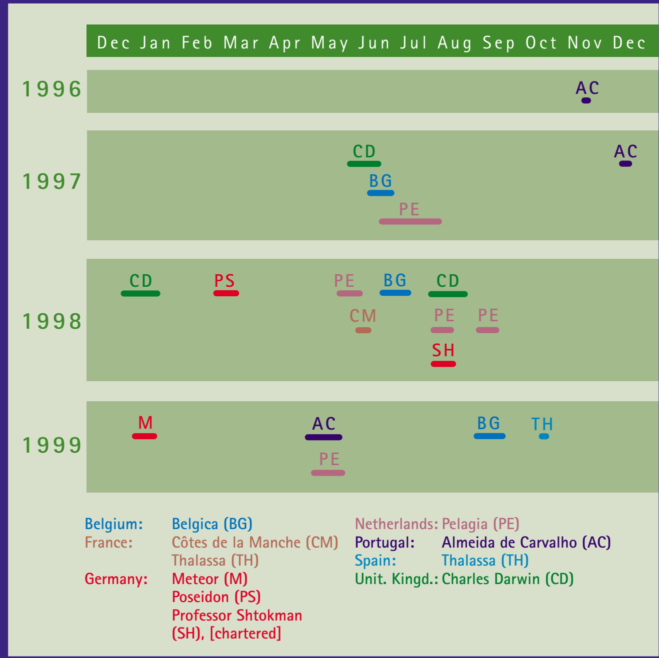
By late June or July, the upwelling intensity has increased to the point that instabilities in the equatorward current generate eddies and filaments, which occur principally from late July to extend 200-250 km offshore into the open Atlantic Ocean, during September. They have potential importance as exporters to the ocean of coastal water and its contents (including large quantities of organic matter produced on the shelf), supporting a seasonally intense cross-slope flux.

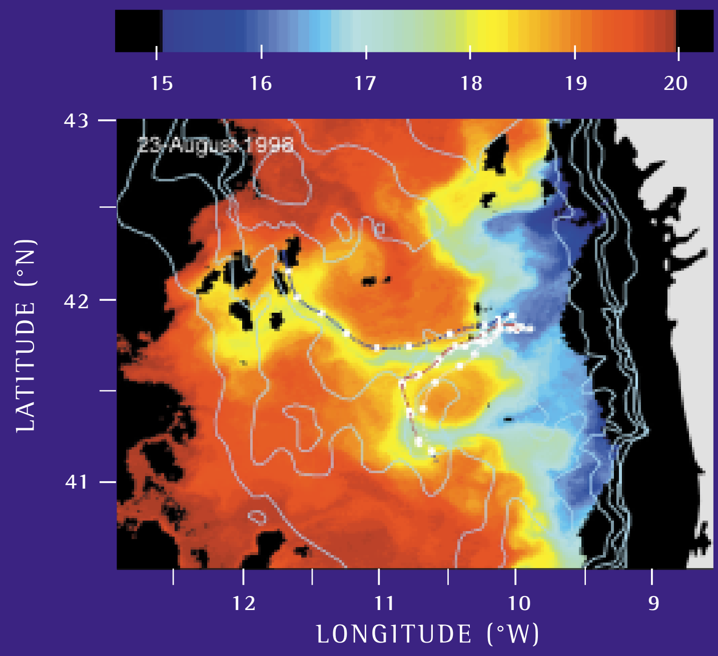
The stable forcing of the upwelling system during spring and summer may be stopped by atmospheric low-pressure passages, which alter the wind pattern and may cause periods of relaxation or even downwelling.



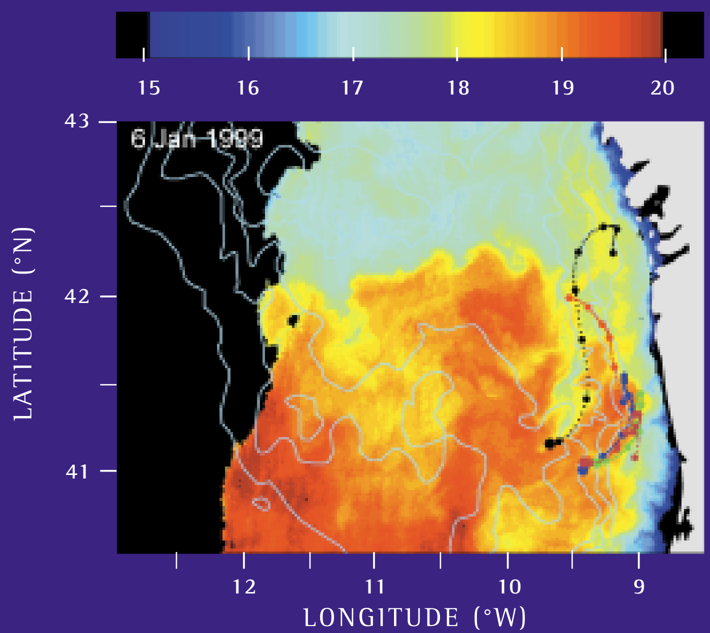
Monthly upwelling index for the Vigo region for the OMEX Phase II period. A large variability exists in all months, and a net upwelling can only be expected from June to September, whereas all other months include the possibility of a net up- or downwelling. Dates correspond to cruise periods. (RSG-PML, UK after FNMOC, USA)

Cruises of the OMEX Phase II project (ULB, BE)





Trajectories of drifters launched in August 1998 superimposed on the satellite sea surface temperature image. Each solid dot represents the drifter position after one day. Deployed during a relaxation event, the drifters slowly converged towards the filament's southern boundary. During the next upwelling period, one drifter followed the offshore extent of the filament while two others returned shorewards. (UWB, UK)



Drifter tracks in January 1999 overlaid on the satellite sea surface temperature image. The drifters moved northward following the bathymetry in a warm tongue, but there was a net southward transport both near the coast and in the open ocean, related to exceptional weather conditions and northerly winds. There was a clear inhibition of the shelf-ocean exchange seen during the summer deployment. (UWB, UK)

During the non-upwelling period in winter, current directions are reversed and the riverine fluxes of nutrients and terrestrial matter are at their maximum. Therefore, land sources, via freshwater from river-flushing events and plumes in the coastal zone, have direct effects on the Iberian shelf, especially in the North. A general northward water flow extends, along the Iberian coast from the surface down to the range 800-1200-m depth), characterised by the poleward flow of Mediterranean Outflow Water along the Iberian slope.

In deeper waters, there are overall trends of decreasing temperature and salinity from south to north, and below 2500 m, Lower Deep Water is transported northwards on the deep eastern boundary.

At small scales, turbulent contributes to cross-shelf, tidal and wind-driven mixing and to sediment resuspension. Despite the difficulty to accurately parameterise mixing, the numerical models of circulation and exchange in OMEX II take into account successfully these complex and non-linear processes.

Phytoplankton, Zooplankton and Bacteria

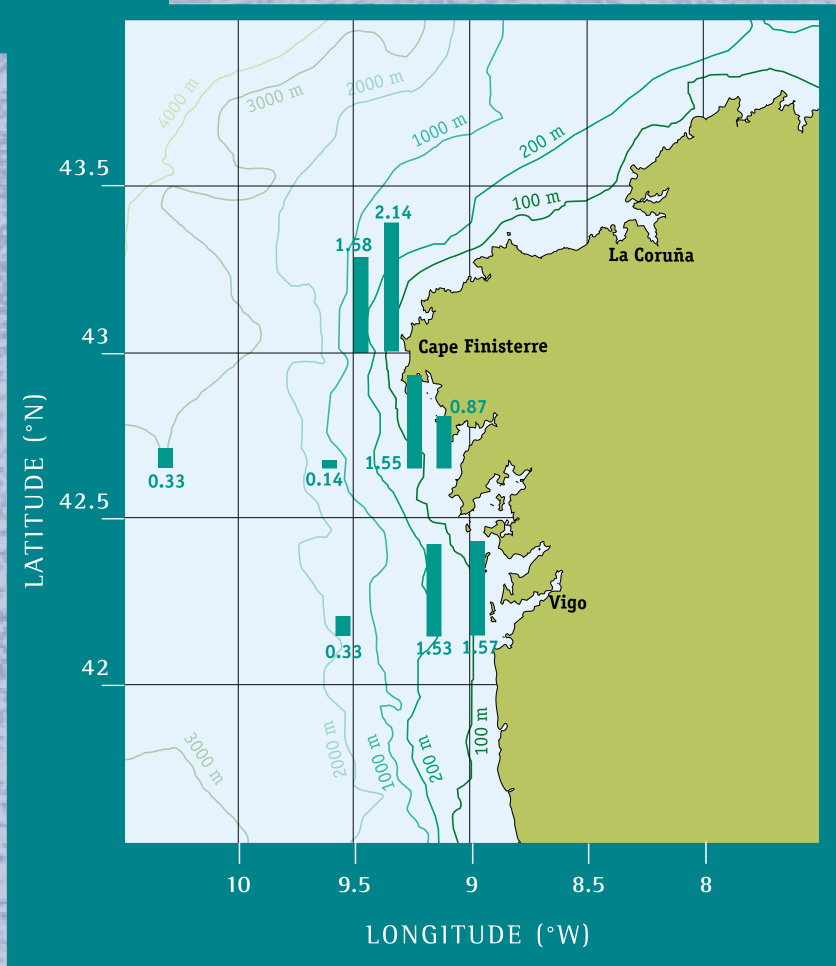
Phytoplankton and Primary Production

In order to evaluate the total and new primary production of the various size classes of phytoplankton, the rates of carbon fixation and utilisation of nutrients (mainly nitrate and ammonium) are measured during incubation experiments using labelled C, N and P. Estimates of the primary production obtained from remotely sensed chlorophyll data show good agreement with in situ determinations in both the upwelling region and the off-shelf filaments. This approach allows us to determine carbon and nitrogen fluxes through the phytoplankton compartment for the entire area over a 1-year period.

The annual primary production reaches 360 gC m^{-2} a^{-1} on the shelf and decreases to 270 gC m^{-2} a^{-1} on the slope. The export of organic carbon produced on the shelf to subsurface slope waters contributes significantly to a total production of about 200 gC m^{-2} a^{-1}, as recycled production.

Under upwelling conditions, a clear transition in the dominant classes of phytoplankton is observed across the margin. On the shelf, large cells (diatoms) are the major chlorophyll contributors and are responsible for most of the nitrate uptake (new-to-total production ratio ~0.7), while small cells (prokaryotes) are dominant in off-shelf waters. During winter, the recycled nitrogen source (mainly, ammonium and organic nitrogen) becomes more important.

The new-to-total production ratio decreases to 0.5 and the recycled production is dominated by small phytoplanktonic cells. During a Lagrangian experiment in the upwelling region, the maxima of chlorophyll concentration and primary production are initially observed in the surface layer, where nitrate concentration declines rapidly. Later, a general deepening of maximum chlorophyll concentration and primary production is observed off-shelf, with well-established vertical gradients in nitrate.

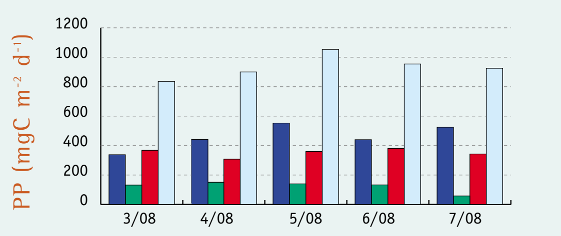


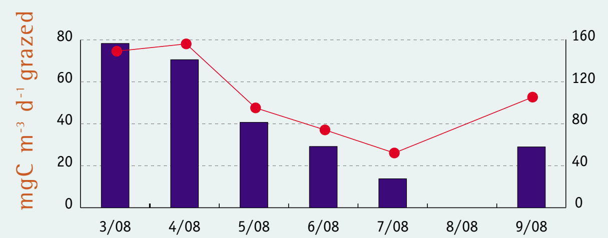
Distribution of integrated daily primary production (gC m^{-2} d^{-1}) in early September 1999, during an upwelling event at Cape Finisterre. The coastal upwelling is responsible for the high values observed on the shelf while the primary production decreases rapidly towards the slope and the open ocean (ULB, BE)

ZOOPLANKTON DISTRIBUTION AND GRAZING

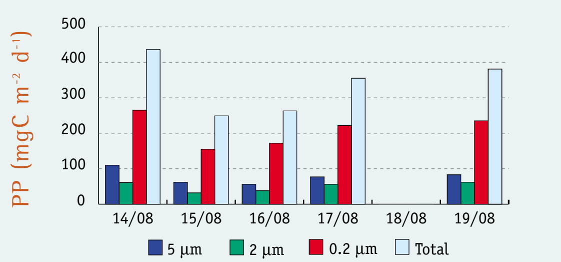
Total zooplankton distribution is closely related to the chlorophyll concentration, with higher values on the shelf, in summer. Large zooplanktonic organisms (copepods) are important in term of biomass, as observed using the Continuous Plankton Recorder (CPR), with seasonal abundance peaks in April and September, and a minimum in December. Micro-zooplankton exhibit a maximum along the shelf break and may constitute, there, particular constraints for the fate of phytoplankton. On an annual average, the total copepod community ingests only about 6% of the total chlorophyll stock per day, and rarely exceeds 20% per day off-shelf during summer. However, on a daily basis, the Lagrangian experiment shows that the impact of zooplankton herbivory on primary production may reach about 80% per day on the shelf, while within the off-shelf filament, it was about 40% per day.

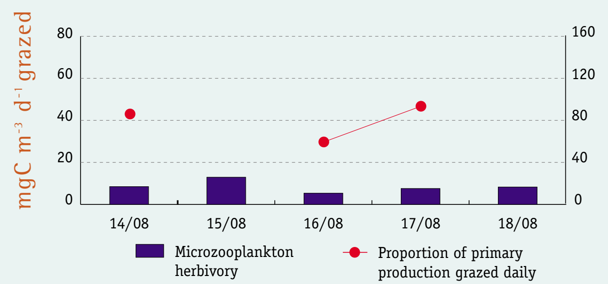
ON-SHELF, UPWELLING





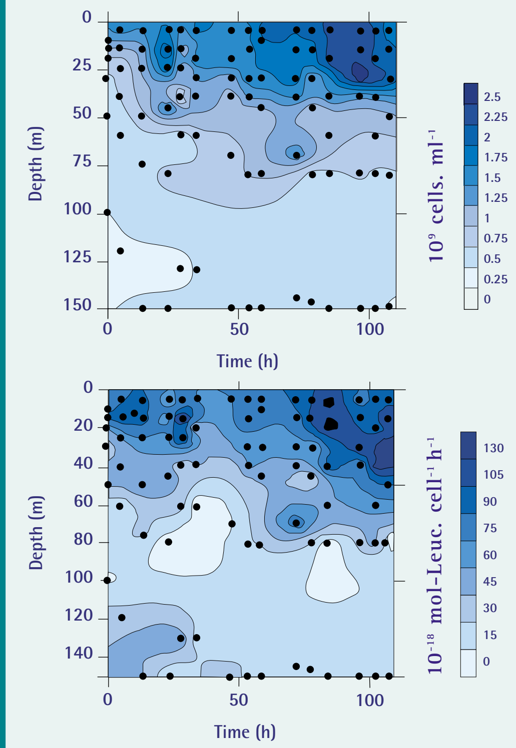
OFF-SHELF, FILAMENT





Size-fractionated primary production during two Lagrangian experiments. As upwelling developed, the large-sized phytoplankton became dominant. In the off-shelf filament, production was much lower than during the upwelling experiment, and the small-sized fraction was always the most productive one. (PML, UK)

The impact of microzooplankton on primary production during the upwelling Lagrangian experiment decreased from 80% to less than 40%. Microzooplankton herbivory was much lower within the off-shelf filament but the proportion of primary production consumed still represents about 40% daily. (PML, UK)



Short-term variation of bacterial abundance and specific bacterial production in the upper 150 m during Lagrangian drift experiments along the shelf-edge and in the upwelling filament. (UAlg, PT)

BACTERIAL LOOP

Biomass and activity patterns of bacteria also exhibit seasonal variations, related to the upwelling cycle. During summer upwelling, the bacterial biomass is maximal (30 mgC m^{-3}) and an off-shelf deepening is observed from surface down to 50 m. During a Lagrangian experiment along the shelf-edge, both bacterial abundance and production were closely related to primary production, with marked gradients across the shelf-break.

Particle Fluxes

The fate of primary production in the Iberian margin area is controlled by several key processes with different time-scales, which include mineralisation and respiration by bacteria and zooplankton, particle transformation and aggregation, removal from surface waters by gravity sinking. The food web structure is critical for the composition and amount of biogenic matter exported from the surface water.

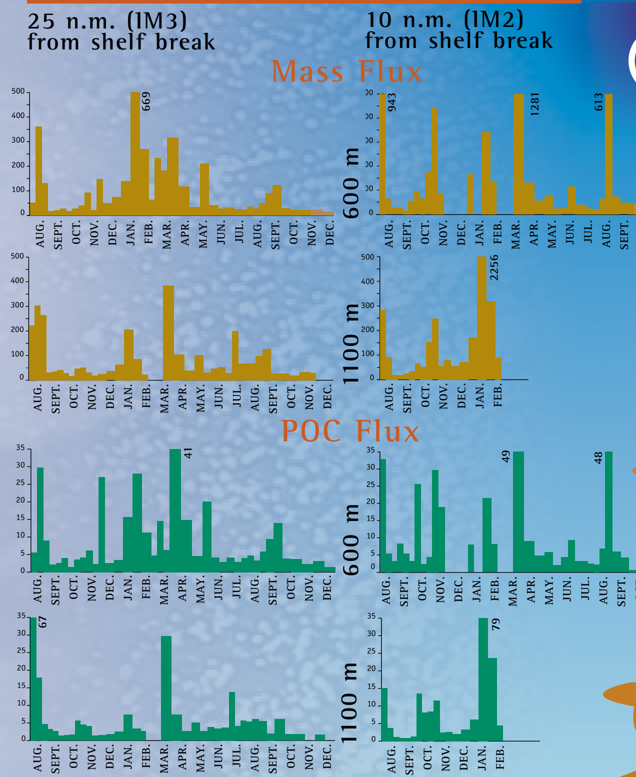
These processes are reflected in the time-series recordings obtained with sediment traps moored at two locations, 10 n.m. (IM2) and 25 n.m. (IM3) from the shelf break. Both moorings are under the influence of upwelling and, hence, experience vertical particle fluxes from seasonally varying export regimes, but encounter different lateral inputs of particles originating from the shelf.

Intermediate nepheloid layers are commonly observed at about 200 to 300-m depth, within a limited distance of the shelf break only. The poleward current limits high particle loads to areas close to the shelf break.

Annually integrated carbon fluxes at 600-m depth are 5 and 4 gC m^{-2} a^{-1}, at IM2 and IM3, respectively. At 1100-m depth they decrease from about 4.7 gC m^{-2} a^{-1} near the shelf (IM2) to 2.9 gC m^{-2} a^{-1} further offshore (IM3). A strong seasonality and also short-term variability are observed in carbon fluxes, which range from <2 to 50 mgC m^{-2} d^{-1} at 600-m depth.

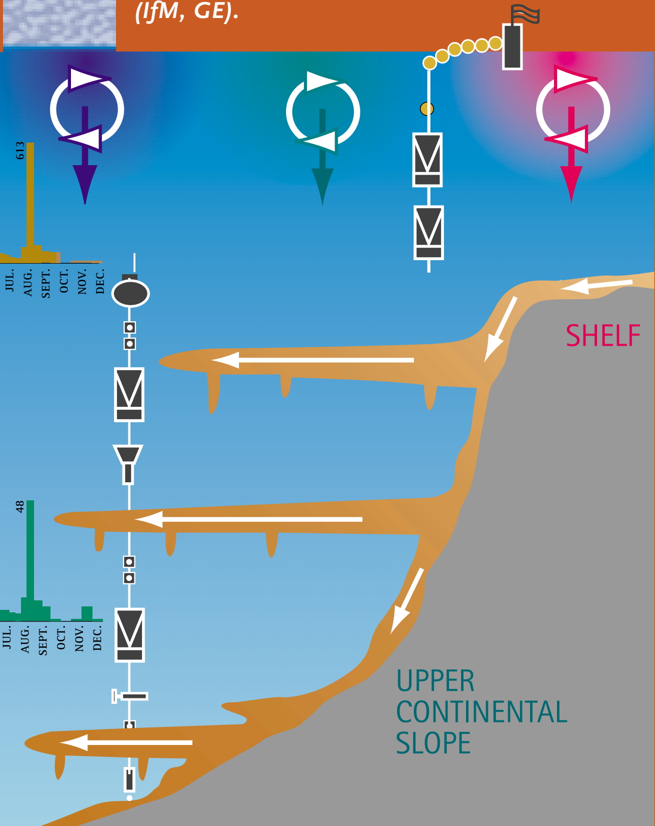
This holds true for the export of plankton species, with a marked diatom signal in winter and during summer upwelling events. Most of phytogenic particles are recycled within the seasonal mixed layer.

Mass and POC fluxes as measured with traps at 600 m and 1100 m at two moorings between July 1997 and December 1998. (IfM, GE)



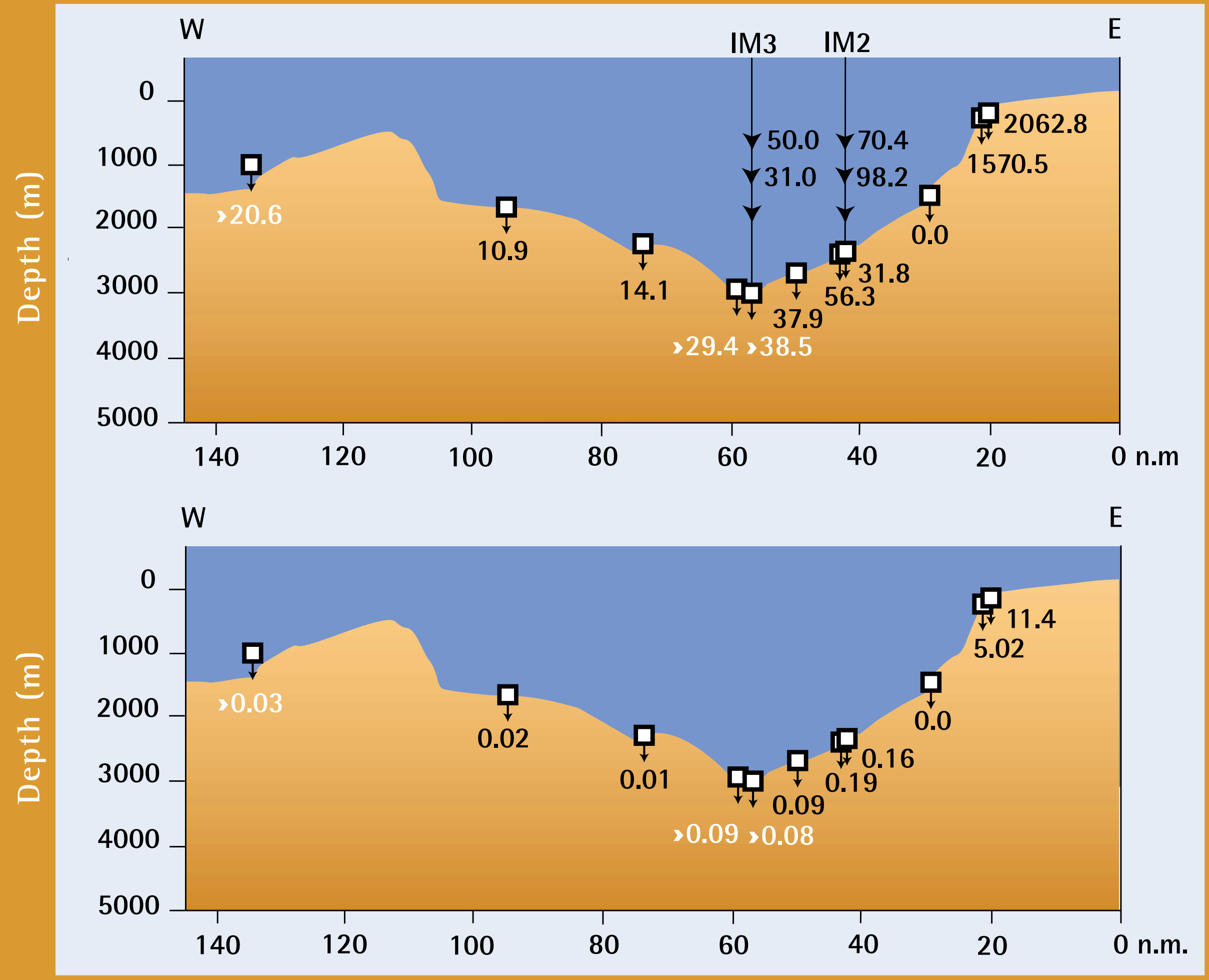
Lateral advection takes place primarily close to the shelf break. Traps moored at 1100-m depth intercepted on the average three times more material at the near-shelf mooring than at the off-shore mooring, with a higher lithogenic (continental) component.

Conceptual scheme of primary particle flux (from surface production regimes) and secondary flux (laterally advected from the shelf by intermediate and bottom-near nepheloid layers), as determined using the automated sediment traps, in situ pumps and current meters in deep-sea moorings (IfM, GE).



SEDIMENTATION AND BURIAL

Total sediment (above) and organic carbon burial (below) fluxes along a transect sampled at about 42.6°N during 1997-1998. Organic carbon content strongly decreased with ncreasing distance to shore. On the steep upper slope, recent sedimentation is almost negligible. Organic carbon burial fluxes are strongly correlated with mass accumulation rate. (NIOZ, NL)



Major particles sources and fluxes in the Iberian Margin area are identified and quantified, based on particle and sediment distributions, and on transport mechanisms, as determined by studies of short-lived isotope activities and near-bottom hydrodynamics.

Sedimentation is very intense on the shelf (from about 400 to 3400 g m^{-2} a^{-1}), whereas considerably lower values are measured on the middle- and lower-slopes (from about 30 to 110 g m^{-2} a^{-1}). This appears to be strongly related to the presence of canyons, potential pathways for episodic and fast transport of particles and organic matter from the shelf edge to the abyssal plain.

Benthic faunal respiration decreases with increasing water depths from ~6.4 gC m^{-2} a^{-1} on the shelf, to ~0.5 gC m^{-2} a^{-1} at the deepest station.

In the canyon sediments, rapid transfer of high quality organic matter leads to a contrasting benthic community structure compared with margin sediments at similar depth.
Organic carbon burial fluxes strongly decrease from the shelf break (2-19 gC m^{-2} a^{-1}) to the deeper stations (0.2-0.7 gC m^{-2} a^{-1}).

Assessment of long-term change in the Iberian Margin shows consistent patterns of slower flows during glacial conditions.

EXIT

Air-Sea Exchange of CO_2

The distribution of the carbon dioxide partial pressure (pCO_2) and the net budget of CO_2 exchange across the air-sea interface are key issues for identifying and quantifying oceanic and coastal sources and sinks for atmospheric CO_2.

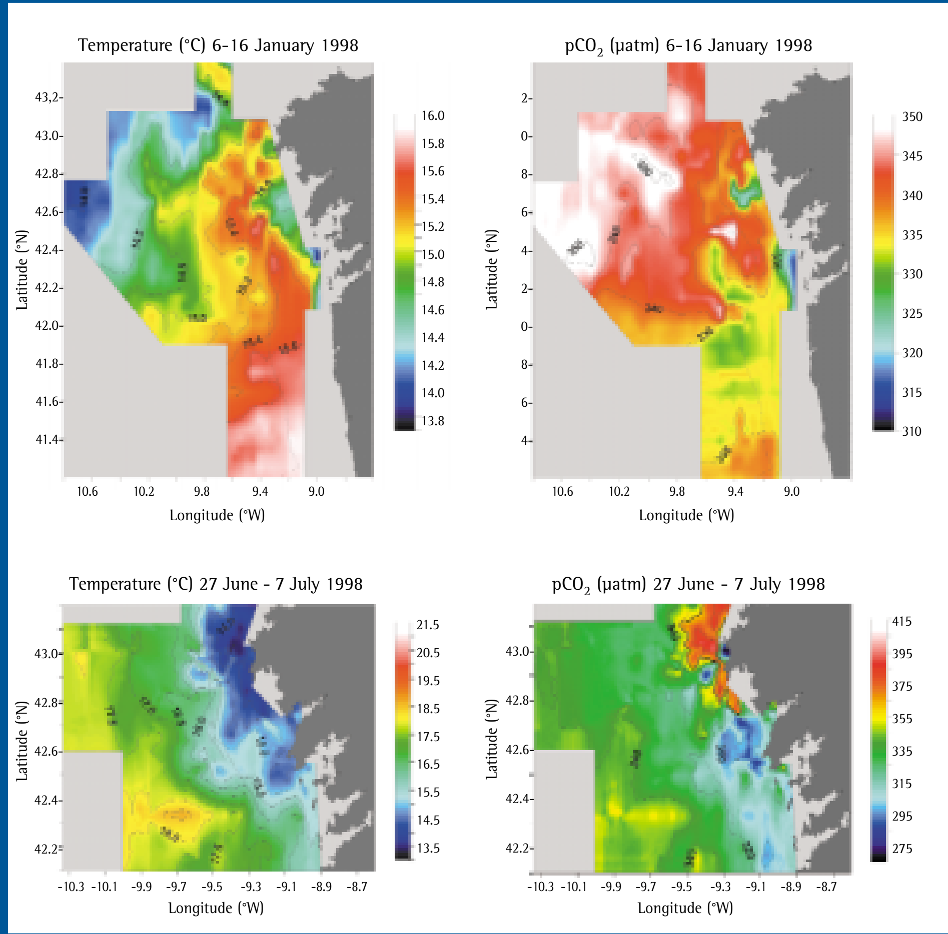
The Iberian margin is characterised by intense biological activity and coastal-related processes (e.g. upwelling, river input, slope current) that can induce high CO_2 fluxes across the air-sea interface. However, their role and impact on the net inorganic carbon budget remains controversial because coastal zones are sites of processes that have opposing effects on the CO_2 flux across the air-sea interface.

Upwelling brings to the shelf, CO_2-rich, deep waters that induce over-saturation in CO_2 while primary production fuelled by the input of nutrients lowers the pCO_2 values and cause a net air-sea flux of CO_2. In addition, river inputs and changes in seawater temperature are important seasonal factors.

The distribution of subsurface pCO_2 in the Iberian Margin thus exhibits a contrasted pattern with strong seasonal and spatial variations (~200 µatm). Summer is characterised by over-saturation at Cape Finisterre, under-saturation off the Rías Baixas area and values close to saturation in the open ocean. During winter, CO_2 under-saturation is observed in the entire Iberian Margin area in relation to cooling of surface waters.

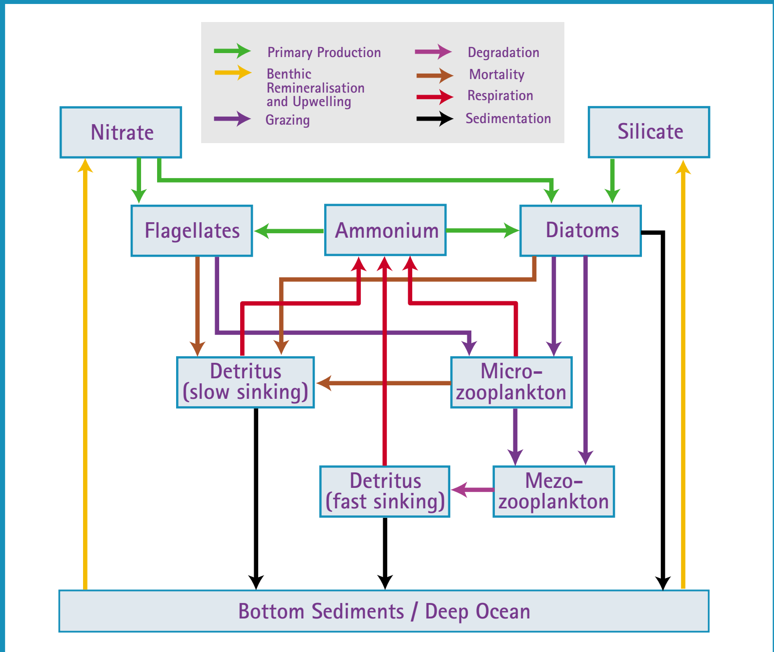
The values of pCO_2 over the continental shelf range from 265 to 415 µatm during the upwelling season and from 315 to 345 µatm during the downwelling season.

The computation of the air-sea CO_2 fluxes yields a net flux into the surface waters of about 22 gC m^{-2} a^{-1}.

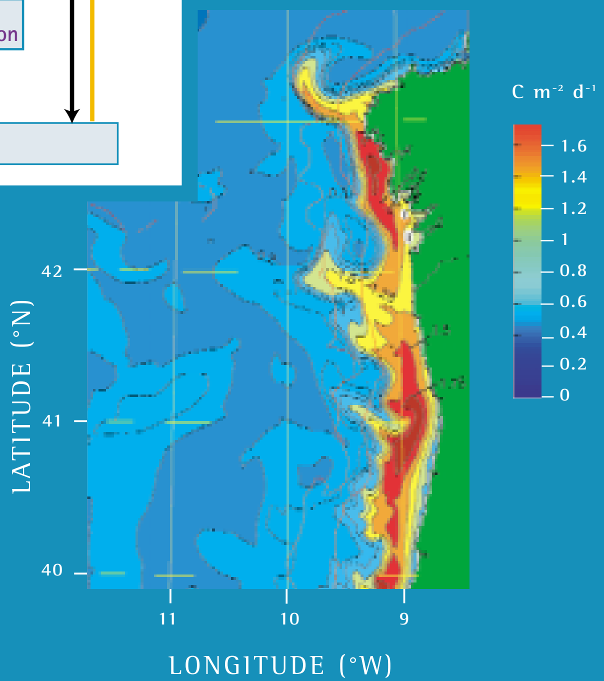


Surface water distributions of temperature (°C) and pCO_2 (µatm) in January 1998 and July 1998 off the Galician coast. The dotted line corresponds to the 200 m-isobath. The present value of atmospheric pCO_2 is about 365 µatm (ULg, BE).

Modelling



Biological components (boxes) and interactions (arrows) in the ecosystem model. It assumes nitrogen (nitrate and ammonium) and silicate are the potential limiting nutrients. The phytoplankton growth is a direct function of light, nutrients and temperature. The secondary producers are represented by micro- and mesozooplankton. Detritus is divided into slow- and fast-sinking components. (SINTEF, NO)



Model simulations show that primary production is most intense in the newly upwelled water near the coast. Three filaments are visible, exporting shelf water with high primary production and high content of organic matter. (SINTEF, NO)

Several models have been developed with different approaches and aims:

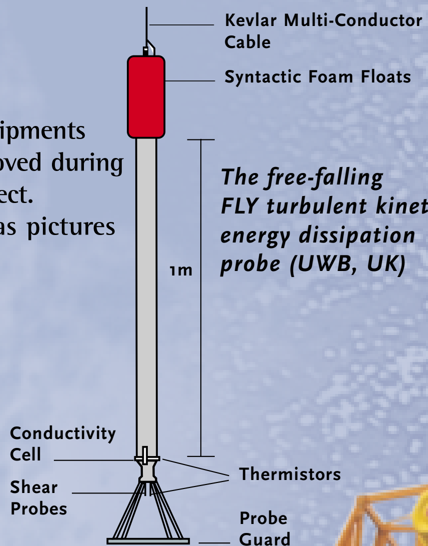
- A general circulation model takes into account the interactions between the NW Iberian area and the general circulation of the NE Atlantic.
- A nested hydrodynamic-ecological model for the water column is used to simulate upwelling events and Lagrangian experiments.
- A physical, benthic boundary layer model describes the physical factors controlling exchanges between the water column and the bottom sediments.
- Finally, a coupled hydrodynamic-ecological-diagenetic model is constructed to take into account the physical and biological factors controlling the carbon and nutrient cycles in the water column and sediment.

The nested hydrodynamic-ecological model, for instance, is used to simulate the response to wind events in the Iberian Margin area. The hydrodynamic model covering the North Atlantic basin produces the large-scale flow pattern and boundary conditions for a regional model. In order to resolve filament structures during the upwelling period, a sub-model, initialised with up-to-date density data and real atmospheric forcing, provides fine-resolution local flow. The ecological model includes several state variables (nitrate, silicate, diatoms, flagellates, micro- and mesozooplankton, slow- and fast-sinking detritus). Model results show upwelled nitrate (~2.5 mmol-N m^{-3}) at the surface near the coast, rapidly consumed by phytoplankton, leading to a primary production of 2.5 gC m^{-2} d^{-1} near the coast, and of less than 0.5 gC m^{-2} d^{-1} offshore. These results are coherent with the field observations.

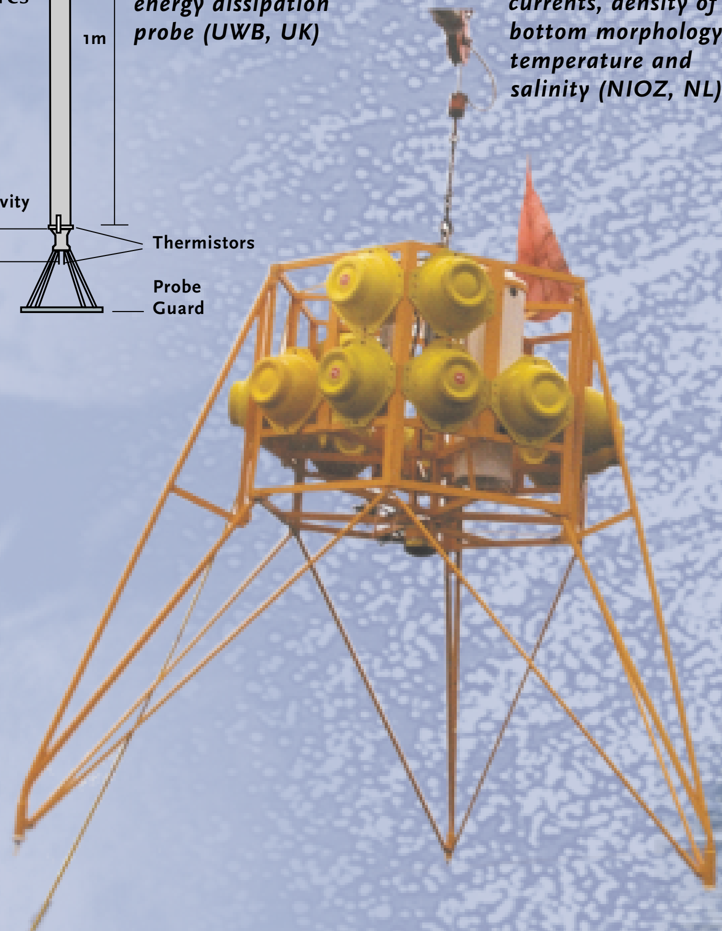
EXIT

Technological Applications

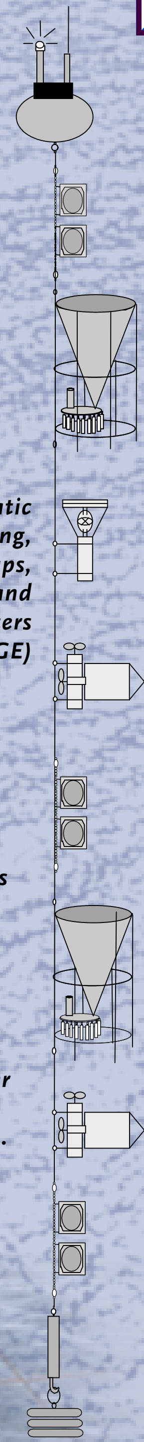
Submersible instruments and equipments were deployed, tested and improved during OMEX and were essential to the Project. Some examples are presented here as pictures or as schematic diagrams.



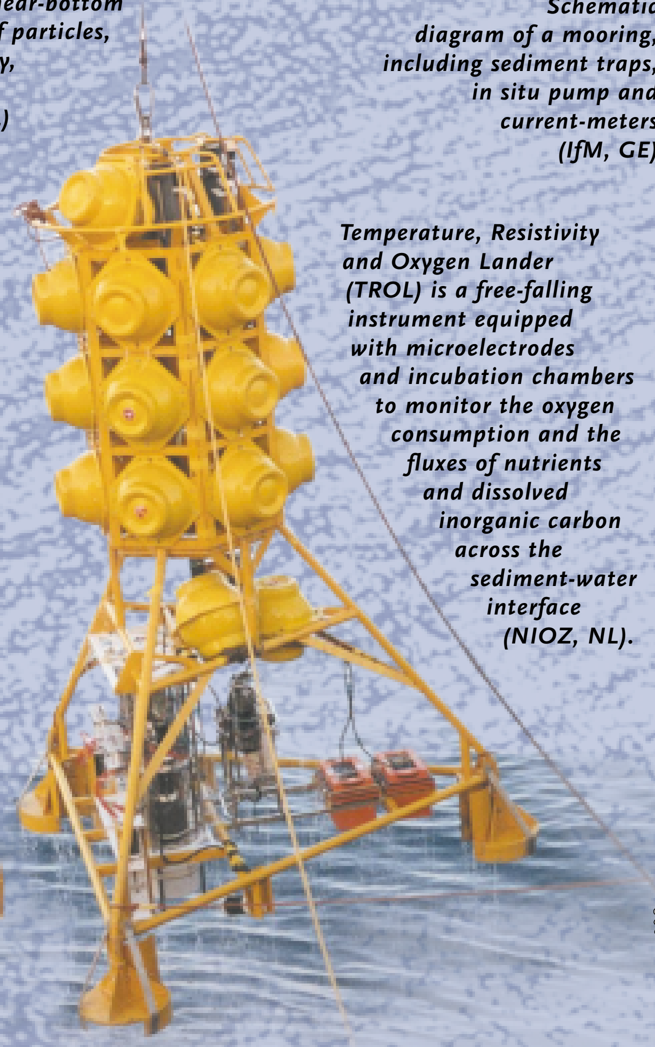
The free-falling FLY turbulent kinetic energy dissipation probe (UWB, UK)



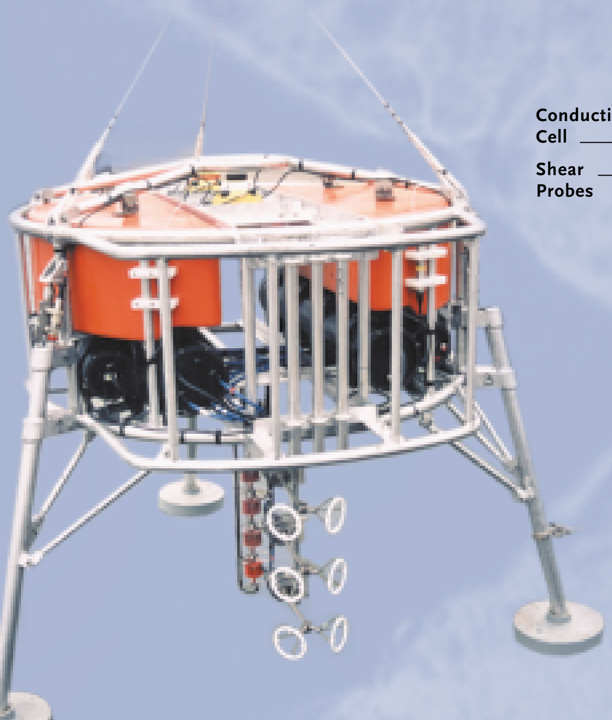
Bottom Boundary layer tripod (BOBO) lander records near-bottom currents, density of particles, bottom morphology, temperature and salinity (NIOZ, NL)



Schematic diagram of a mooring, including sediment traps, in situ pump and current-meters (IfM, GE)



Temperature, Resistivity and Oxygen Lander (TROL) is a free-falling instrument equipped with microelectrodes and incubation chambers to monitor the oxygen consumption and the fluxes of nutrients and dissolved inorganic carbon across the sediment-water interface (NIOZ, NL).



Sediment Transport And Boundary Layer Equipment (STABLE) records near-bottom 3D turbulent current data and suspended sediment profiles (POL, UK)

EXIT

Conclusions

The area of investigation of the OMEX Phase II Project is characterised by multiple physical forcings (especially, upwelling, filaments, eddies and river-generated plumes) that support and control the enhanced primary production and carbon export to the open ocean.

Compared to the results obtained during OMEX I in the Goban Spur area, the production and export of organic carbon in the Iberian Margin area are significantly higher: the annual primary production ranges from 360 gC m^{-2} a^{-1} on-shelf, to 200 gC m^{-2} a^{-1} towards the open ocean.

The air-sea CO_2 net annual flux into the surface waters ranges from 15 to 31 gC m^{-2} a^{-1}.
The Iberian Margin is thus a net sink for atmospheric CO_2.

Sedimentation and burial rates are very high on the shelf, and decrease rapidly downslope. In addition, nepheloid layers and canyons have been identified as important pathways for episodic and fast export of particles from the shelf edge to the abyssal plain.

Under upwelling conditions, the Iberian Margin is thus an area of high productivity with a large fraction of the organic matter exported to the slope and open ocean, but with only a small fraction preserved in sediments.

Coupled hydrodynamic-ecological modelling allows the integrated description of the main physical, chemical and biological processes.

The resulting synoptic evaluation of carbon fluxes is particularly important in the context of Global Change studies for the prediction of the potential effects of global warming on the upwelling processes.

List of OMEX Partners

Country	Institution	
Belgium	ULB	Université Libre de Bruxelles
	ULg	Université de Liège
	VUB	Vrije Universiteit Brussel
Denmark	RISØ	Forskningscenter Risø
France	LSCE	Laboratoire des Sciences du Climat et de l'Environnement
	UBord	Université Bordeaux 1
Germany	GEOMAR	Forschungszentrum für marine Geowissenschaften
	IfM	Institut für Meereskunde - Kiel
Ireland	NUIG	National University of Ireland at Galway
Netherlands	NIOO	Nederlands Instituut voor Oecologisch Onderzoek
	NIOZ	Nederlands Instituut voor Onderzoek der Zee
Norway	SINTEF	Stiftelsen for Industriell og Teknisk Forskning
	UiTø	Universitetet i Tromsø
Portugal	IH	Instituto Hidrográfico
	IPIMAR	Instituto de Investigação das Pescas e do Mar
	IST	Instituto Superior Técnico
	UAlg	Universidade do Algarve
Spain	IEO	Instituto Español de Oceanografía
	IIM	Instituto de Investigaciones Marinas
	UOvi	Universidad de Oviedo
	UVigo	Universidad de Vigo
United Kingdom	BODC	British Oceanographic Data Centre
	PML	Plymouth Marine Laboratory
	POL	Proudman Oceanographic Laboratory
	SAHFOS	Sir Alister Hardy Foundation for Ocean Science
	SOC	Southampton Oceanography Centre
	UCamb	University of Cambridge
	UWB	University of Wales Bangor

OMEX

Ocean Margin EXchange

Roland Wollast / Lei Chou / Bernard Avril
Laboratoire d'Océanographie Chimique et Géochimie des Eaux
Université Libre de Bruxelles
Campus de la Plaine - C.P. 208
Boulevard du Triomphe
B-1050 Brussels, BELGIUM
Tel.: +32-2-650-5213/5237
Fax: +32-2-646 34 92
E-mail: omex.management@ulb.ac.be

Klaus-Günther Barthel
European Commission
DG Research/D.1.3, SDME 7/83
200 rue de la Loi
B-1049 Brussels, BELGIUM
Tel.: +32-2-295 12 42
Fax: +32-2-296 30 24
E-mail: Klaus-Guenther.BARTHEL@dg12.eu.int

For the latest information
on the OMEX project,
visit our WWW site at:

http://www.pol.ac.uk/bodc/omex/omex.html

ACKNOWLEDGEMENTS
All OMEX II partners have contributed to the present work and are greatly acknowledged. The OMEX Phase II Coordination Office would like to express their special thanks to the Work Package leaders, Paul Wassmann (WP I), Peter Burkill (WP II), Tjeerd van Weering (WP III) and John Huthnance (WP IV) and to the BODC Data Management Team (Roy Lowry et al.). This study was partly supported by the EU-MAST contract number MAS3-CT97-0076.