ADDRESSING THE NEED OF MARINE OBSERVATIONS FOR FISHERIES

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1. Introduction

The quest to gain knowledge and understand the workings of the oceans has been a constant undertaking by mankind since the dawn of history. Information on the sea has served navigators to exploit ocean winds and currents, ancient explorers to reach new continents and merchants to reach distant harbours, fishermen and whalers to ascertain their catches, and navies to master ocean space. The need and practical use of ocean knowledge has become even more important today with our increasing dependence on the sea, and an evolving conscience confessing its commitment to the sustained management of ocean resources and obligation towards ocean governance.

The practical study of the sea has in the last two decades leaped forward along with the advancement in science and technology, improved sensors to observe the sea by direct measurements as well as remotely from space, and in particular with the progress in information technology. It goes today under the name of 'Operational Oceanography' which can be defined as the activity of systematic and long-term routine measurements of the seas, oceans and atmosphere, and their rapid interpretation and dissemination [1,2]. Important products derived from operational oceanography are:

- nowcasts: providing the most usefully accurate description of the present state of the sea including living resources;

- forecasts: providing continuous forecasts of the future condition of the sea for as far ahead as possible; and

- hindcasts: assembling long term data sets which provide data for description of past states, and time series showing trends and changes.

Operational Oceanography proceeds usually, but not always, by the rapid transmission of observational data to data assimilation centres. There, powerful computers use processing software and numerical forecasting models to extract added-value information from the data. The outputs are used to generate data products, applications and services often through intermediary value-adding organisations. Examples of final products include warnings (of coastal floods, storm impacts, harmful algal blooms and contaminants, etc.), electronic charts, optimum routes for ships, prediction of seasonal or annual primary productivity, ocean currents, ocean climate variability, etc. The final products and forecasts are targeted for rapid distribution to industrial users, government agencies and regulatory authorities. Operational oceanography thus fulfils the demands of the many marine activities, providing support to recurrent and emerging needs such as for safer and more efficient navigation, improved and new marine services, effective assessments on the state of health of the ocean, mitigation of marine hazards, forecasting climate variability, and furthering in general the mastering of the oceans as a resource of food, materials, energy and space.

2. Implications for fisheries

The physical environment is a key influencing factor on the behaviour and distribution of fish. Marine organisms live in a very dynamic and changing medium with water movements carrying with them fish larvae from one place to another, sea current streams and favourable water temperatures being exploited by migrating pelagic species, upwelling water providing nutrients at the surface from the deeper parts of the ocean, and the general conditions of the marine environment dictating the overall behaviour of fish and creatures in the sea.

Ocean weather - Indeed we are all accustomed to the rapidly changing patterns of atmospheric phenomena that we follow from daily forecasts, with high and low pressure systems evolving and interacting, producing severe winds, and fronts with associated rain. It is however hardly realised by the general public that even the ocean is populated by similar ever-changing systems. The continuously evolving oceanic systems are the equivalent of atmospheric highs and lows, and are often termed the ocean ‘weather’. They occur in the form of gyres and eddies, revolving and moving, transferring heat and momentum, and causing water masses to mix. The oceanic physical patterns constitute

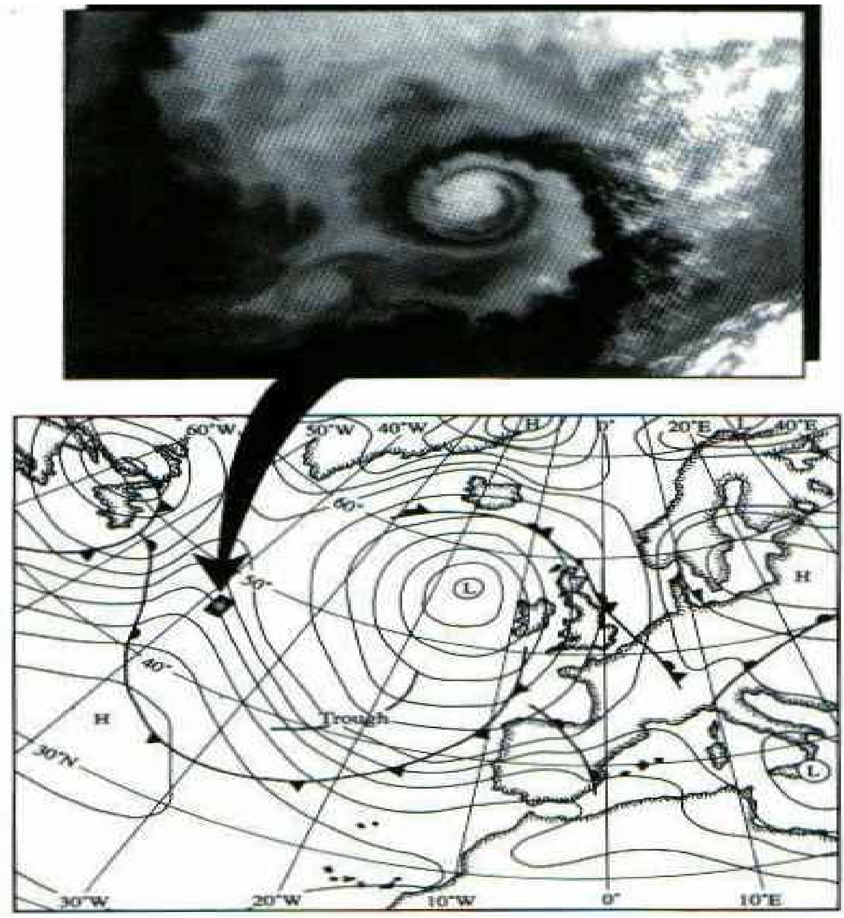

Fig. 1 Comparison of spatial scales between oceanic and atmospheric synoptic variability - from Chapter 4 in Oceanography, An Illustrated Guide by Summerhayes & Thorpe [3].

what is better known as the ocean mesoscale variability. As in the atmosphere, they can trigger intense activity producing strong currents, shaping the temperature and salinity fields, and giving rise to frontal areas separating warm and cold water masses.

The wind field plays a major role in the evolution of the upper ocean phenomenology and thus drives what is known as the barotropic (depth-averaged) component of the ocean currents. The gyres that characterise the surface circulation of the basin are mainly forced by the wind.

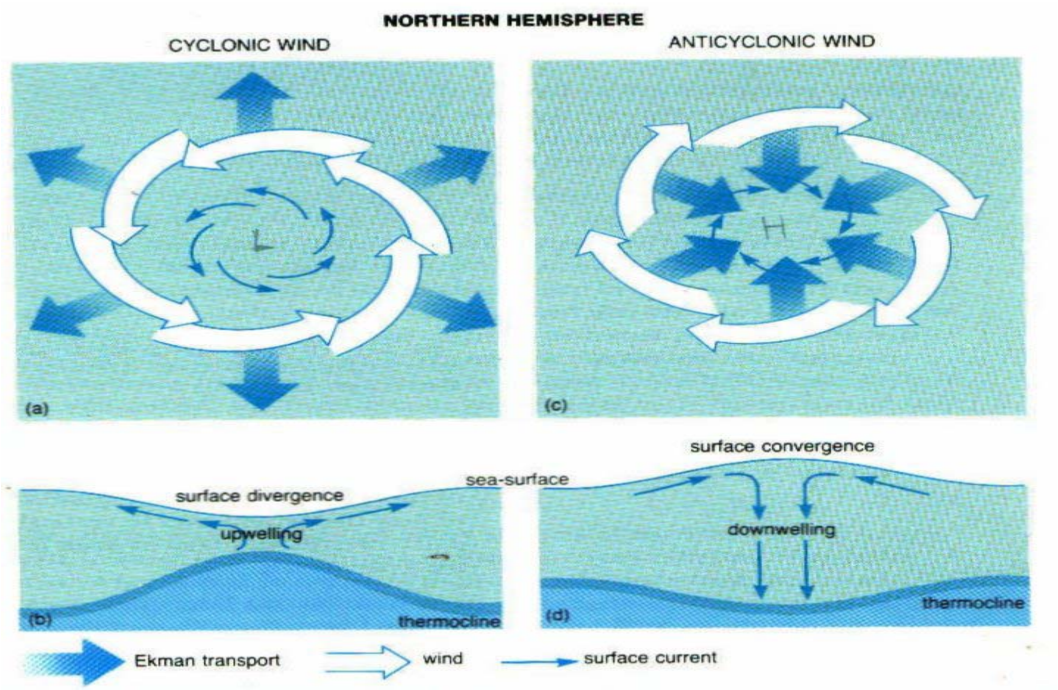

Fig. 2 Examples of divergence and convergence zones forced by the wind in the Northern Hemisphere (Adapted from Ocean Circulation, Open University Course Team, [4])

The action of the wind does not however only cause horizontal motion, but also triggers vertical movements that feed the deeper water masses. The effect of a cyclonic (anticlockwise) wind in the northern hemisphere causes a divergence of surface water away from the centre of action, and there results a lowering of sea level and a vertical rise of the thermocline (see Fig. 2). The associated upward movement (upwelling) of water is termed Ekman Pumping. The opposite effect occurs in the case of an anticyclonic (clockwise) wind which creates a convergence of surface water, with a consequent rise in water at the centre, a lowering of the thermocline and a downward movement (downwelling) of water.

The heat and water budgets of the Mediterranean basin are also key forcing agents dictating the general circulation. They mainly alter the vertical density structures of the ocean water masses. These density anomalies can produce gravitational adjustments leading to what are called baroclinic flows, that is currents triggered by the 3D density structure of the seawater column, and which usually vary with depth. The slow Mediterranean thermohaline basin scale circulation maintains the two-layer flow consisting of a fresh Modified Atlantic Water (MAW) eastward surface flow and a deeper saltier westward Levantine water flow.

Recent observational data and numerical studies have furnished a new picture of the Mediterranean surface circulation that departs somewhat from that advocated in the early 80s [5]. It is mainly characterised by the westward flow of the Atlantic Water vein which divides the basin in two regimes, with anticyclonic gyre systems to the south, and predominantly cyclonic flows to the north. In the western basin the Atlantic Water enters through the Strait of Gibraltar and feeds what is known as the Algerian Current that is characterised by large meanders along the African coast. Beyond Sardinia this current bifurcates into two branches, with one flow moving north into the Tyrrhenian Sea and the other proceeding towards east across the Sicilian Channel where it drives the Atlantic Ionian Stream. This swift current moves into the Ionian Basin and further leads to the Mediterranean Mid-Oceanic Current, that starting from South of Crete leads to a system of gyres in the Eastern basin.

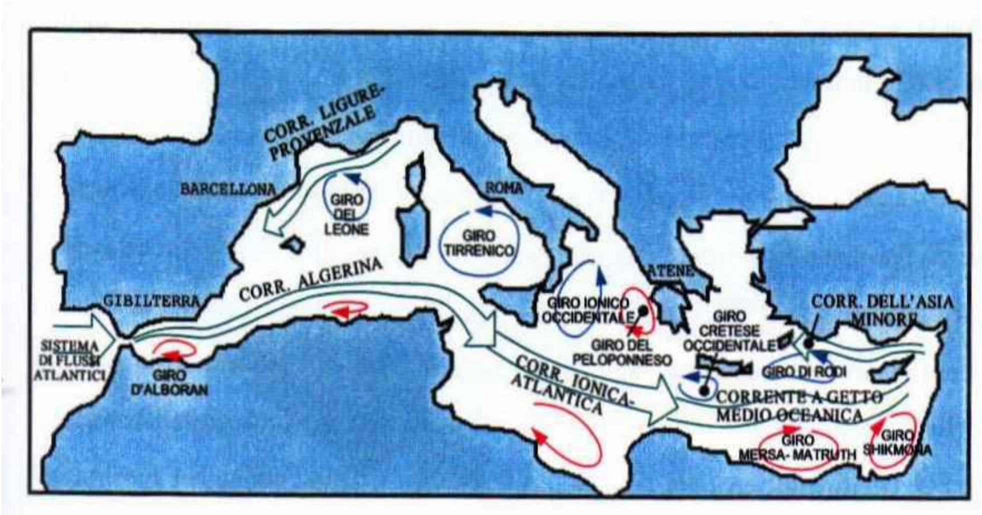

Fig. 3 General pattern of the surface circulation in the Mediterranean Sea

The eddy field (mesoscale) patterns triggered by the synoptic scale atmospheric forcing (wind field vorticity) are in addition superimposed upon the general background larger scale circulation [6]. The mesoscale field structures give rise to eddies, coastal upwelling, jets and frontal zones, such as are depicted in the satellite image in Fig. 4. They evolve on time scales of the order of 1-10 days; which is much slower than that of atmospheric movements, but the spatial scale (10-100 Km) is much shorter with respect to atmospheric systems. This means that a much greater resolution of observations is necessary to map oceanic movements, rendering the effort even more demanding both on technology and resources with respect to atmospheric mapping and forecasting. In this context satellite imagery in the infra-red, visible and very high frequency ranges of the spectrum become very useful tools to acquire synoptic maps of the ocean surface circulation [7,8]. Remote sensing has opened the way to sample the richness in structure of the oceanic eddy field, and we have only just started to assess the importance of these oceanic eddies in shaping the large-scale ocean circulations and their impact on climate and the biology of the oceans [3].

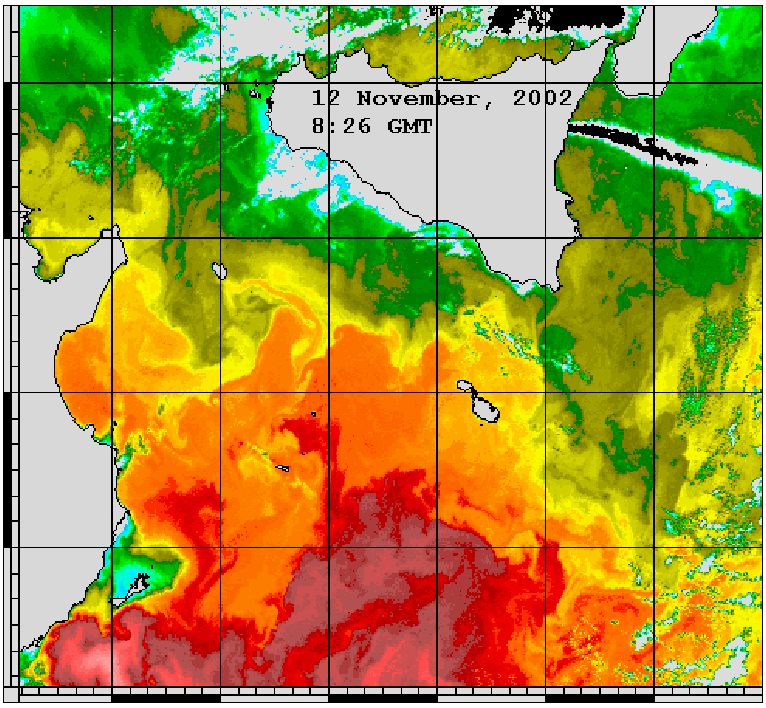

Fig. 4 Satellite picture showing the complex surface circulation structures in the Central Mediterranean on 12/11/2002. (Picture by courtesy of Sergey Stanichny, Hydrophysical Institute, Ukraine)

Impact of the physical conditions on fisheries - Mesoscale phenomena play a significant role in the exchange, mixing, distribution and redistribution of the main physical, chemical and biological parameters of the marine ecosystem. They carry biogenic material and shape the phythoplankton biomass distributions that constitute the most rudimentary levels of the marine food web, and thus bear important links to biological processes. Particular fish stocks are known to favour certain types of eddy and their associated fronts. It is also well known that important commercial fishing grounds are found in zones of temperature fronts, borders of flows, in zones of divergence and convergence. The convergence of flows produces a "mechanical" congestion of fodder organisms and small-sized fishes. In divergence zones and upwelling areas the high concentration of biogenic elements and supply of nutrients in the upper layer favours the provision of food for fish through the proliferation of phythoplankton and zooplankton organisms [9]. The Maltese Islands are situated in one of the most important upwelling areas of the Mediterranean (refer section 3 for details). The current boundaries associated with these zones keep changing positions with the seasons and with varying meteorological conditions. Predictions of their movements and future positions is an important subject of synoptic oceanography. Under certain conditions there is an accumulation of species near the current or water type boundaries. A water type boundary might be considered as a limit of the normal distribution of a given species. Greater insight on the relationships and dependencies of bio-productivity and physico-chemical conditions thus offers a possibility to use spatial ocean patterns as fish indicators such as for (i) quantifying stress on fish stocks, (ii) identifying threats on stocks and biodiversity, and (iii) controlling factors affecting the occurrence of fish. The relationships between environmental conditions and fish occurrence thus offers new means for the conservation and sustainable use of marine resources, as well as to improve confidence on fish stock assessments and fisheries management methodology.

Water temperature, oxygen content, pH (alkalinity), nutrients, water stratification, proximity to land and seabed morphology and type, constitute a strong bearing on where fish reside in the sea. Understanding how these factors affect fish is essential in defining habitats of marine creatures and in forecasting the abundance, transit pathways and locations of migrating pelagic fish.

Temperature is perhaps the most important parameter influencing fish distribution and abundance. Although short-term changes such as weather conditions may impact a fish for a day or two, temperature has more predictable and seasonal effects. The vertical temperature gradients in the sea are also several orders of magnitudes sharper than horizontal temperature gradients such as those at the surface. Temperature tells a fish when to spawn, when to feed, as well as where to be located.

Homoiothermic species maintain a constant body temperature. But most fish are ectothermic tending to take on the temperature of the surrounding water. Like cold-blooded animals their metabolic rate thus varies greatly with temperature, meaning that fish in colder water operate at a slower rate than fish in warm water. It also means that a cold fish is less active, digests food items at a slower rate, feeds less frequently and requires less energy than a warmer fish. Growth and lifespan are also largely attributed to water temperature. Fish in warmer environments have a longer growing season and a faster growth rate than do fish in cooler waters. This fast growth comes at the price that fish in warmer waters tend to have a shorter lifespan than do fish in cooler waters. Every fish species is different and each species has a preferred temperature range at which it is most active. Each species also has a temperature range related to spawning. Water temperature also affects the immune system and wound healing capacity of fish. The immune response can be severly inhibited when water temperatures go below a certain threshold. On resumption of normal temperatures there is furthermore a time lag that can be as long as a week before the immune system starts to function normally again. Unfortunately fish parasites and bacteria tend to become active a lot quicker as temperature starts to rise again, and often take advantage of sluggish fish.

The thermal structure of the water column with depth is also an important factor. Water temperature profiles are usually measured with CTD (conductivity, temperature, and depth) sondes and/or XBTs (Bathythermographs), but may also be measured with a temperature sensor in a netsonde attached to a trawl. There are pelagic fish which are found above the thermocline or close to the thermocline, while others are found mainly in deeper water. The information on the depth of the thermocline can thus be useful for setting the depth of the long lines and of drift nets (e.g. in herring and salmon fisheries), to determine the optimal depth of midwater trawling, as well as to decide whether a purse seine cast is advisable (e.g. in case of a deep mixed layer depth (MLD) shoals might dive below the pursing depth). Many species have diurnal vertical migrations, which are limited either upwards or downwards by the existence of the sharp thermocline that acts as an environmental barrier. Other species tend to aggregate in the thermocline regions and especially in areas where the thermocline would intersect the bottom off a coast. A knowledge of the thermocline depth thus provides a means for the tracking and study of these fish. Furthermore most species prefer certain optimum temperatures and their normal distribution is limited between a minimum and a maximum temperature.

Dissolved oxygen in the sea is another key requirement by all submerged plants and animals, including algae and fish. These organisms are constantly removing dissolved oxygen from the water and excreting carbon dioxide during their normal respiration process. In fish the extraction of oxygen from the water and transfer to the bloodstream is done by gills, lungs, specialized chambers, or skin, any of which must be richly supplied with blood vessels in order to act as a respiratory organ. Extracting oxygen from water is more difficult and requires a greater expenditure of energy than does extracting oxygen from air. Water is a thousand times more dense than air, and at 20 ^oC it contains only about 3% as much oxygen as an equal volume of air. Fish, therefore, have necessarily evolved very efficient systems for extracting oxygen from water; some fish are able to extract as much as 80% of the oxygen contained in the water passing over the gills, whereas humans can extract only about 25% of the oxygen from the air taken into the lungs.

Oxygen intake in the sea occurs at the air-sea interface, and is subsequently carried by vertical currents to aerate the deeper parts of the oceans. The solubility of oxygen in water reduces as temperatures increase. Conversely, due to the increased metabolic rate, the oxygen requirement by fish increases as water temperatures increase. With warmer water the gap between the level of dissolved oxygen and the minimum oxygen demand of the fish becomes even more close. Clearly, if the total oxygen demand of the system, which includes fish, bacteria and submerged plants, exceeds the dissolved oxygen levels, the fish, especially the larger species, are likely to suffer.

The release of carbon dioxide during respiration has an acidifying effect (reduced pH) on the sea water. In addition to respiration, all plants, including all algal forms, photosynthesise actively during daylight hours. In this process carbon dioxide is absorbed from the water and the sun's energy used to convert it to simple organic carbon compounds. Contrary to respiration, this process has an alkalising affect (increased pH). These two processes, respiration and photosynthesis, carry on alongside each other, with photosynthesis being the dominant during the day while removal of oxygen from the water and excretion of carbon dioxide by respiration takes on again during the night when plants stop to photosynthesise. This leads to variations in pH even in reasonably well circulated waters. In poorly buffered water this can cause significant diurnal fluctuations in pH - being more alkaline in the evening and less so during daytime.

Each species of fish has its own very narrow range of pH preference, and levels outside of this range will cause health problems. Changes in pH, even though they may still be within the preferred range, are likely to be stressful and damaging to the fish health. High acidity or alkalinity can cause direct physical damage to skin, gills and eyes. Prolonged exposure to sub-lethal pH levels can cause stress, increase mucus production and encourage the thickening of the skin or gill epithelia with sometimes-fatal consequences. Fish also have to maintain their own constant internal pH. Even small fluctuations of blood pH can prove fatal. Extreme external or water pH can influence and affect blood pH, resulting in either acidosis or alkalosis of the blood. Furthermore changes in pH will affect the toxicity of many dissolved compounds, such as for example ammonia which becomes more toxic as pH increases.

Effect of bathymetry - Bathymetry is a term used to describe the topography, or bottom contours of the seabed. There are deep valleys and rifts, trenches, steep mountains and hills, and flat plains and shelves - all beneath the ocean's surface. The bathymetry of an ocean, sea, or bay influences the flow of water in that area as the moving water interacts with the ocean floor. This has then direct implications on the bottom substrate characterisation (including bottom sediments, geological features underlying the waters, and associated biological communities and submerged aquatic vegetation) and hence on aquatic habitats and fish type. Changes in sea depth lead to variations in temperature, salinity and nutrient concentrations, and finally dictate which animals live there. In areas where bottom sea currents hit a shallow shelf on the ocean floor, colder deep water is forced upwards as it makes its way over the shelf. This action brings high concentrations of nutrients from the ocean floor to the surface waters, which power marine food webs and create an abundance of food for fish, seabirds, and marine mammals.

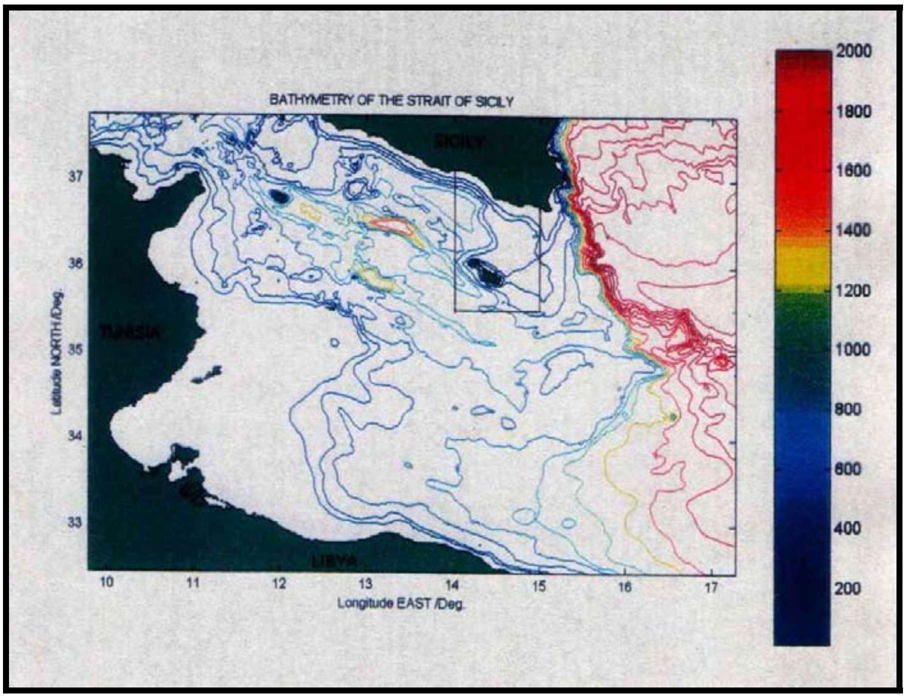

Fig. 5 The Maltese Islands lie on a ridge separating the two main Mediterranean basins, with its southern perimeter close to the shelf break, and in an area exposed to complex hydrodynamical phenomena.

The Maltese Islands lie at the edge of the southeastern continental shelf of Sicily. As shown in Fig. 5, the region presents a rather complex bathymetry in the form of a large roughly square bank with the Maltese Islands residing on its southernmost extremity. The shelf is interrupted from its extension towards west by the relatively deep Gela Sicilian basin separating it from Adventure Bank. On its eastern extremity it deepens abruptly into the deep Ionian Sea with a very sharp escarpment (known as the Malta Escarpment). The Malta Graben to the southwest of Malta forms part of a cluster of flat bottomed depressions reaching a depth of around 1650m. In its shallower parts the shelf is characterised by a plateau in the middle part, with an average depth of 150m. The shelf is flanked by a submarine ridge protruding in the form of a submerged extension of Cape Passero and embracing the shelf area along the eastern and southern perimeter. The Maltese Islands represent the emerged part of this ridge while the Hurds Bank to the northeast of Malta shallows to a depth of just over 50m. The islands are very close to the shelf break and flanked by a very steep bathymetry in the south.

Except for rather narrow pathways, the continental shelf of Malta is thus disconnected from the adjacent shallow sea areas and groundfish species are believed to be somewhat isolated. From the fisheries point of view, this means that fish populations over the Malta platform area should be considered as an independent management unit stock especially for shelf demersal resources [10]. The limited extent of this area accentuates the vulnerability of the ecosystem and calls for precautionary measures against unsustainable fishing efforts and bad fishing practices.

Improving fisheries management - Fish stock assessments usually adopt population dynamics methods involving the regular collection of catch, fishing effort and biological data pertaining to given stocks at a number of ports in the region of interest. The dynamics of fish is however complicated in its interaction with the natural system, and mortalities by predation and/or by fishing for different life stages, are not easy to measure. Fish stock assessments, especially for highly mobile pelagic species such as tunas, can be greatly misleading if changes in abundance are not evaluated with a consideration that capture potential is strongly dependent on the natural variability of oceanographic conditions. Yet there is today still a great lack of knowledge on the relationships between species density and environmental conditions. Additionally, missing data, limitations inherent in catch per unit effort (CPUE) indices, and the enormous difficulty of producing integrative models, render pelagic fish population assessment issues and resource allotment questions devoid of sufficient confidence. The truth is that the overall management of fish stocks today, and limits on fish catch established by regulations and guidelines set by the Fisheries Commission, are not based on a sufficiently robust scientific background. The scientific community is thus asked to furnish some answers and intervene to put fisheries management on a more solid foundation.

This is by no means an easy endeavour and requires a leap forward in our understanding of the complex bio-geochemical oceanic processes and of the interactions and functioning of ecosystem components. The challenge is to develop the basis for an eco-system based approach to the management of fish resources, in which forecasts of the ocean’s physical behaviour can lead to forecasts of the distributions of productivity, and, eventually to forecasts of the ecosystem and the associated fish development. Knowledge of how different species interact with environmental variables, especially temperature, salinity, density, stratification, and other biological variables such as zooplankton distributions, is necessary. This is not yet achieved because, while progressively more accurate 3D fields of environmental variables are beginning to be available daily as model forecast output, there are still very limited (spatially and/or temporally) information about geographical distributions of fish and their daily variations.

Operational oceanography and marine observations conducted over various temporal and spatial time scales through a collaborative undertaking between countries is the unique key towards an improved capacity in providing essential indicators for the conservation and sustainable use of marine living resources. Modern satellite sensors view the spatial distributions and resolve the temporal variability of the physical and biological parameters of the waters in near real time with a delay ranging from a few hours to a few days. Near-real-time multi-spectral data (thermal and optical satellite images) can be used for the routine mapping of relevant processes in the oceanic ecosystem, and offer a unique possibility for the complex investigation of the biological and physical processes by establishing correlations of 3D environmental fields to pelagic fish abundance. The integration of fisheries data for a joint analysis using remote sensed, meteo and model data to develop algorithms for the tracking of fish stocks through the elaboration of fields of sea surface temperature and chlorophyll, position and displacement of frontal zones and mesoscale structures (eddies, jets, upwellings, etc.), offers the solution towards the adoption of an operational fisheries management tool.

The overall objective is to develop a short term forecast system for fish abundance, applicable to different pelagic species and adaptable to different marine regions. Fisheries nowcasting/forecasting is one of the current MFSTEP (Mediterranean Forecasting System - Towards Environmental Predictions) research tasks with a pilot application to anchovies in the Adriatic Sea. The concept relies on the creation of a Fishery Observing System targeting to obtain detailed data in near real time on spatial and temporal deployment of fishing effort and commercial catches, including depth and in situ temperature during hauls, obtaining series of geographic referenced data, relating statistically the fishery data to environmental variables from observations and models, and subsequently leading to the release of operational nowcasts/forecasts of anchovy abundance, distributions and movements.

3. Studies of the marine physical environment in Malta

The PO-Unit - The main contributions to the study of the physical characteristics of our coastal seas are those conducted by the Physical Oceanography Unit. The PO-Unit was established under the Malta Council for S&T in the early nineties. It now constitutes the research arm of the IOI-Malta Operational Centre at the University of Malta. The Unit undertakes fundamental research in coastal meteorology, hydrography and physical oceanography with a main emphasis on the experimental study of the hydrodynamics of the sea in the vicinity of the Maltese Islands. It offers facilities for the gathering, processing, analysis and management of high quality physical oceanographic observations both for long term and baseline studies as well as for general applications in marine environmental research and assessments. The Unit endeavours to enhance its activity on an operational scale by the installation and maintenance of permanent monitoring systems to provide data for ocean forecasting, and by applying numerical modelling techniques in the study of physical marine systems. It operates in collaboration with international organisations with which it has expanded its activities through a number of funded research projects. The Unit also provides services and technical support to local entities including government departments and private agencies. It organises conferences, seminars, workshops and specialised training programs in order to promote oceanography in Malta and in the Mediterranean.

Ocean Data Management - Furthermore the PO-Unit provides support to local entities involved in marine research and monitoring to collect and maintain oceanographic data according to international standards. The PO-Unit plays the role of keeping track of ocean observations made in the vicinity of the Maltese Islands. Data collected by individual scientists, local agencies and governmental departments is primarily kept under the respective sources, and under different, often incompatible formats. The PO-Unit aims to identify these data holdings and bring the data under one database with standardized formats.

The PO-Unit has followed and promoted the IOC/IODE (International Committee for Oceanographic Data & Information Exchange) activities in the past years through the organisation of regional meetings and training courses. Contact is kept with local entities involved in marine research and monitoring in order to disseminate IODE products and updates on IODE activities. The involvement in several projects has further enhanced the expertise of the PO-Unit in ocean data quality control, transcoding and management to international standards. It has also consolidated the role of the Unit to locally promote the IOC/IODE products and activities in Malta. The most important contributions in ocean data management concern the Global Oceanographic Data Archaeology Rescue Project (GODAR) [11] with a regional workshop held in Malta, and the participation in MEDAR/MEDATLAS [12,13]. These two initiatives have enabled the location and collation of a large number of marine data in the Mediterranean. During the period 2001/2 the PO-Unit has supported the establishment of the MeDir directory which consists of an online searchable database of marine scientists and professionals working in the Mediterranean region (http://ioc.unesco.org/medir). The PO-Unit is currently involved in another project related directly to oceanographic data and information management - SEA-SEARCH (http://www.sea-search.net). This project targets the extension and enhancement of the current online European database on ocean metadata by including other European states and some Mediterranean Partner countries. On a national scale this project will provide a framework to enhance and update the national database of oceanographic data sets, holdings and research projects.

The Unit also provides technical support to several activities of the 'Mediterranean network to Assess and upgrade Monitoring and forecasting Activity in the region' (MAMA) project (refer to Section 4), including the conduction of surveys and assessments on current routine ocean monitoring activities in the Mediterranean.

Research activities in physical oceanography - In the past the PO-Unit conducted several physical oceanographic surveys especially in the NW coastal area of the Maltese Islands. Subsurface sea currents were also studied at several stations. These measurements were aimed to study the phenomenology of the sea currents on the shelf, particularly in connection with the expression of coastally trapped waves in the form of strong diurnal signals. The Unit is also responsible for the collection of meteo and sea level data at two coastal stations in Ramla tal-Bir and Mellieha Bay respectively.

In February 2001 the installation of a sea level gauge in the Portomaso marina at the Malta Hilton in St. Julians was completed. It constitutes the first real-time monitoring station for oceanographic data in Malta and forms part of the MedGLOSS sea level network [14]. The instrument, donated by the International Commission for the Scientific Exploration of the Mediterranean Sea (CIESM), collects sea level data (every half-a-minute), seawater temperature, atmospheric pressure and waves in the marina. Data can be viewed online on the website of the PO-Unit (www.capemalta.net). Besides the importance of these measurements in relation to studies on global climate change and sea level rise, the use of this data is essential for studies on salt intrusion in the natural ground water acquifer, effect on the dispersion and flushing of pollution in the coastal areas, calculation of extreme sea levels in connection with the building of coastal structures, and other applications. Rises in sea level by only a few tens of centimeters can have serious consequences for many coastal areas; the most evident are coastal inundation and erosion.

The coastal seiching phenomenon - The long term sea level measurements have also permitted the scientific study of non-tidal short period sea level fluctuations which are the expression of a coastal seiche, known by local fishermen as the *'milghuba'* [15,16,17,18]. The seiche is a rapid sea level oscillation with typical periods of about 20 minutes, which can be easily followed by the naked eye. This phenomenon has now been observed to occur all along the northern coast of the Maltese archipelago and manifests itself with very short resonating periods in the adjacent coastal embayments. Weak seiching is present uninterrupted and appears like a background 'noise' on the tidal records. During random sporadic events the seiche oscillations can become greatly enhanced, reaching a vertical range of a few tens of centimetres, and thus completely masking the astronomical signal (Fig.6). The maximum seiche peak-to-peak amplitude measured in Mellieha Bay reached 1.1m. The seiche is accompanied by currents that are comparable in size to those generated in coastal areas characterised by tidal forcing. The detailed study of the 'milghuba' has involved the use of open sea bottom pressure gauges in conjunction with measurements from a land-based array of micro-barographs. Reference to similar sea level variations (known as the *'Marrubbio'*) on the southern coast of Sicily is found in the Italian 'Portolano' for ship navigation. Their occurrence is reported to be most frequent in May or June in association to south easterly winds, and their crest-to-trough amplitudes can reach as high as 1.5m. The phenomenon is attributed to the response of the coastal sea level to signals generated in the open sea, which are believed to be mainly triggered by the presence of atmospheric pressure disturbances travelling in the lower troposphere as trapped gravity waves. The periods of these seiche oscillations are similar to those of tsunami waves. Their transformation as they approach the coastal areas, and their amplification in bays and harbours can be equally disastrous. The associated strong currents can furthermore be a hazard to navigation.

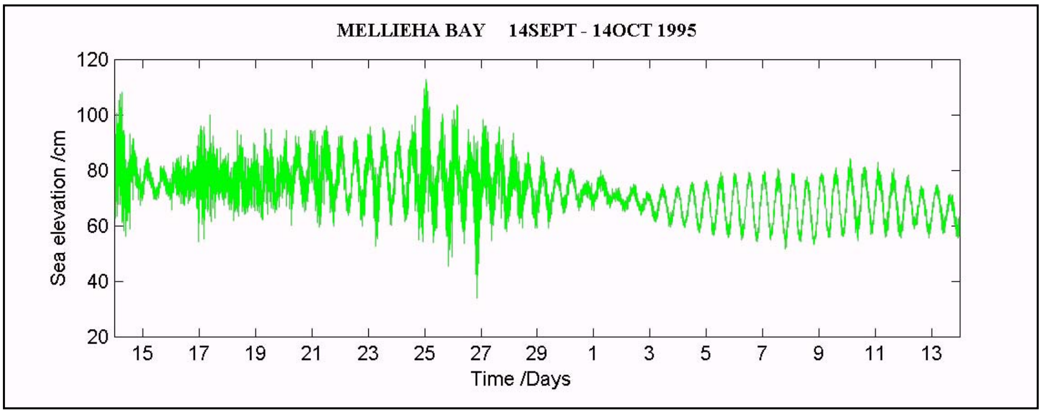

Fig.6 Time series of sea level measurements in Mellieha Bay showing seiching events

Hydrographic measurements - Several physical oceanographic surveys conducted mainly in the period 1992/4 have served to give a first understanding of the phenomenology of the coastal oceanography in the NW area of Malta. Analysis of these water column (CTD profiles) and subsurface current measurements indicate the presence of some intriguing unprecedented hydrodynamical aspects that are influenced by processes covering a wide spectrum of time scales.

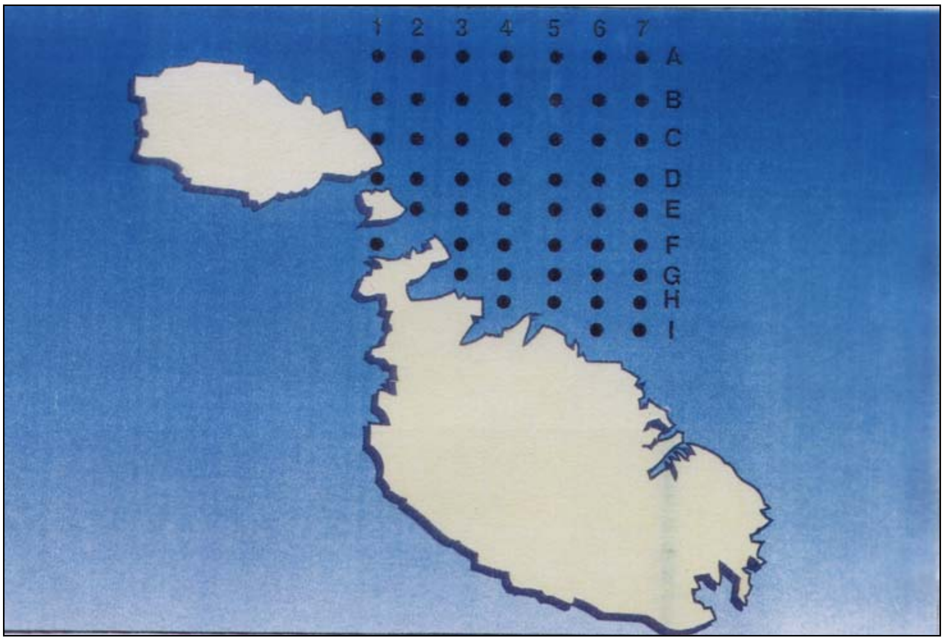

Fig. 7 Station positions visited during the Oceanographic survey during 1993

The most important phenomenon is the occurrence of intense diurnal and semi-diurnal baroclinic flows, that typify the current field with a rotary oscillating character similar to that of tidally dominated regimes [19,20,21]. This gives rise to unexpectedly strong subsurface currents, often with opposed directions of flow in the upper mixed layer close to the surface as compared to those in the deeper layer below the sharp thermocline. Very often the current sets downshore in an SSE direction for most of the day, and subsequently reverses with weaker magnitude for the rest of the day (Fig. 8). These currents are not related to the wind and cannot either be a signature of the barotropic tidal wave since tidal amplitudes in the vicinity of the Maltese Islands are all too small. These

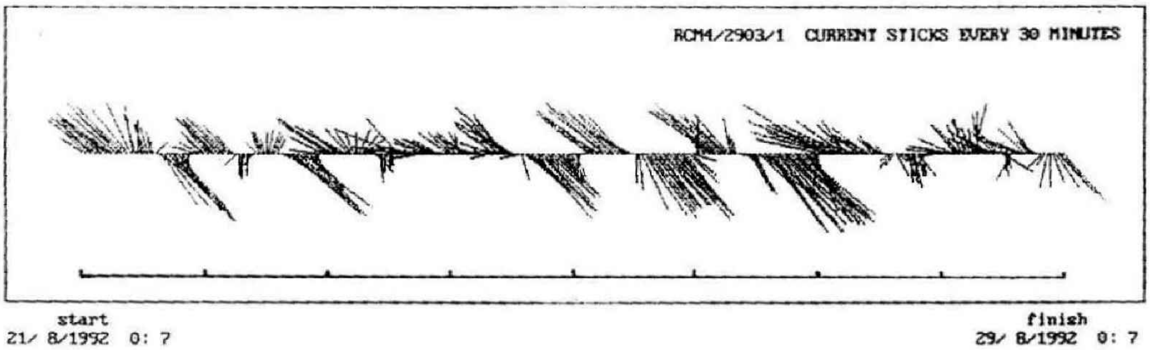

Fig. 8 Strong diurnal signature in the deep subsurface currents outside Mellieha Bay

signals are thus believed to ba an expression of the trapping of energy at the shelf break in the form of shelf wave modes. Grancini & Michelato [22] actually reported such a tidal component of the eddy kinetic energy in their sea current measurements over the Sicilian shelf, with an intensification close to our Islands. These currents are thus related to the close proximity of the Islands to the shelf break in the south, and are most probably an expression of a topographically trapped wave that takes the form of an internal Kelvin-like waveform in the deeper sea away from the shelf break, and is accompanied by shelf wave modes propagating over the continental platform and in the region of the Maltese Islands. A vertical oscillation of the thermocline in the form of an internal tide accompanies these flows. This results in vertical movements of the water column isotherms that have been quantified to reach crest-to-trough amplitudes of the order of 8m [23].

The implications of these phenomena on fisheries is still largely unexplored and will require multi-disciplinary studies with an opportunity to touch upon highly relevant current research themes.

Numerical modelling - The most significant numerical modelling effort of the PO-Unit is that conducted within the framework of the EU-funded Mediterranean Forecasting System Pilot Project (MFSPP) [24,25]. A high resolution (1.6Km horizontal grid on average, 15 vertical sigma layers) eddy resolving primitive equation numerical model is run over a domain covering the Malta shelf area, with climatological forcing, and including thermohaline dynamics with a turbulence scheme for the vertical mixing coefficients on the basis of the Princeton Ocean Model (POM). It is used to simulate the seasonal variability of the water masses and transport in the Malta Channel and proximity of the Maltese Islands. It is coupled by one-way nesting along three lateral boundaries (East, South and West) to an intermediate coarser resolution model (5Km) implemented over the Sicilian Channel area. The fields at the open boundaries and the atmospheric forcing at the air-sea interface are applied on a repeating 'perpetual' year climatological cycle [26].

The model is able to reproduce, with the right order of magnitude, the salient dynamical features in the area, providing in addition a detailed insight into their 3D phenomenology and their seasonal variability [27]. The model also reveals the water mass composition in the region, and the impact of the heat and momentum fluxes at the air-sea interface in mixing and altering the hydrophysical structure through the seasons. This modelling effort has now prepared the way for the future implementation of shelf-scale real-time ocean forecasting of physical parameters in the vicinity of the Maltese Islands. This is the endeavour of the PO-Unit under the framework of the current second phase of MFS, the Mediterranean Forecasting System – Towards Environmental Prediction (MFSTEP) [28], and will be done through the sequential coupling of a hierarchy of successively embedded model domains that will downscale the hydrodynamics from the coarse grid Ocean General Circulation Model of the whole Mediterranean Sea to the finer grid in the Malta shelf area.

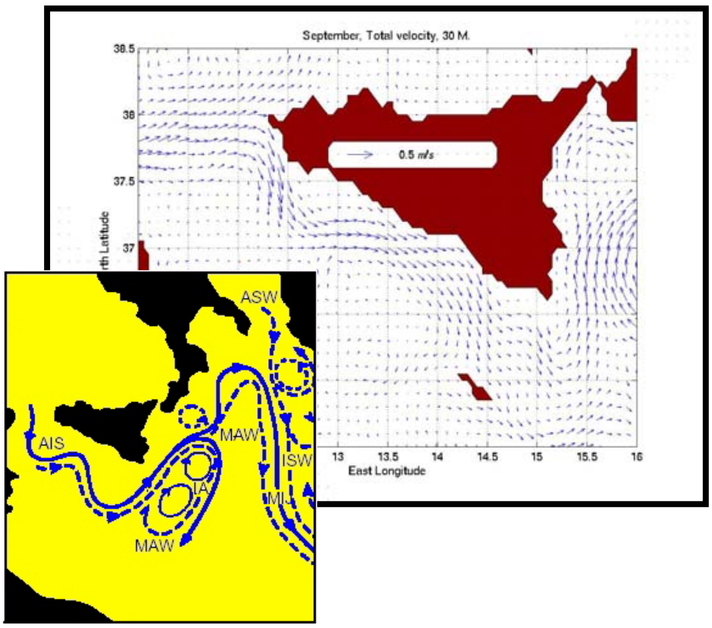

Fig. 9 Results from the Malta shelf model showing the simulated Atlantic Ionian Stream (AIS). The AIS characterises the surface circulation throughout the year. It is a swift topographically controlled current carrying fresh Modified Atlantic Water across the Malta Channel which starts its path as a meander to the South of Adventure Bank.

The main numerical model results include upwelling in summer and early autumn along the southern coasts of Sicily and Malta; a strong eastward shelf surface flow alongshore to Sicily forming part of the Atlantic Ionian Stream which is present throughout the year with significant seasonal modulation; and a westward winter intensified flow of LIW centered at a depth of around 280m under the shelf break to the south of Malta. The seasonal variability in the thermohaline structure of the domain and the associated large scale flow structures are shown to be significantly linked to changes in the surface momentum and heat fluxes.

The energetic and meandering Atlantic Ionian Stream (AIS) [29] is a swift topographically controlled current that normally starts its path as a meander to the south of Adventure Bank. It then proceeds southeastwards and loops back northward around Malta, forming the Maltese Channel Crest. As it reaches the sharp shelf break to the east of Malta, it abruptly gains positive vorticity and tends to deflect with an intense looping northward meander forming the characteristic Ionian Shelf Break Vortex. The progression of the AIS towards east carries with it the fresh modified Atlantic Water (MAW) across the Malta Channel. The contrast in temperature of the exiting MAW with the warmer Ionian Sea produces the Maltese Front which constitutes a conspicuous thermal filament on sea surface temperature AVHRR maps.

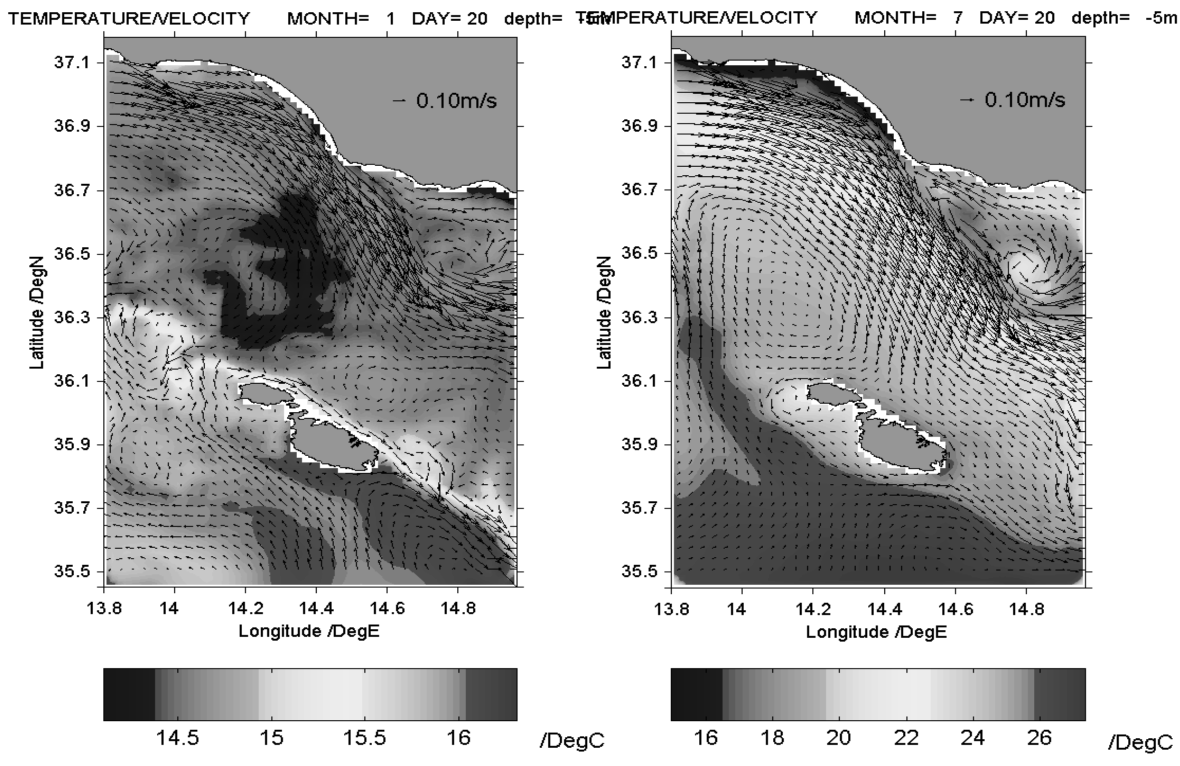

Fig. 10 Model velocity and temperature at 5m during (a) winter and (b) summer

Frequent coastal upwelling events bring to the surface cool water that is then swept along by the mesoscale eddy formations. The upwelling zone runs along the whole southern coast of Sicily and generally extends for a considerable distance (~100Km) offshore especially over Adventure Bank and on the Malta platform. The southeastward advection of these cold patches in the form of long plumes and filaments are a very characteristic feature in the thermal IR images of the region. The Sicilian upwelling thus produces a large influence on the upper layer dynamics in the region and has important implications on the biological productivity and fisheries activity. Although the upwelling events peak in summer and early autumn, they tend to be toward year round with a period of attenuation in spring. Thus the oceanic ecosystem in this zone is not limited to a single productivity event per year, and primary production is significantly greater on period and rate.

The model is also capable to resolve the mesoscale dynamics and produces a detailed spatial and temporal evolution of the rapidly changing flow patterns associated to fronts, eddies and jet meanders. The predominant characteristic of the mesoscale variability in the vicinity of the Maltese Islands consists in the evolution of eddies which form mainly as a result of the impact of the shallowing bathymetry and the proximity of land on the AIS flow. Besides trapping water and particulates, these eddies have associated vertical motions that influence phytoplankton biomass distributions and thus bear important links to biological processes, in particular to the location of fisheries. Moreover the proximity of the islands to the shelf break exposes the southern coast to upwelled water especially during summer.

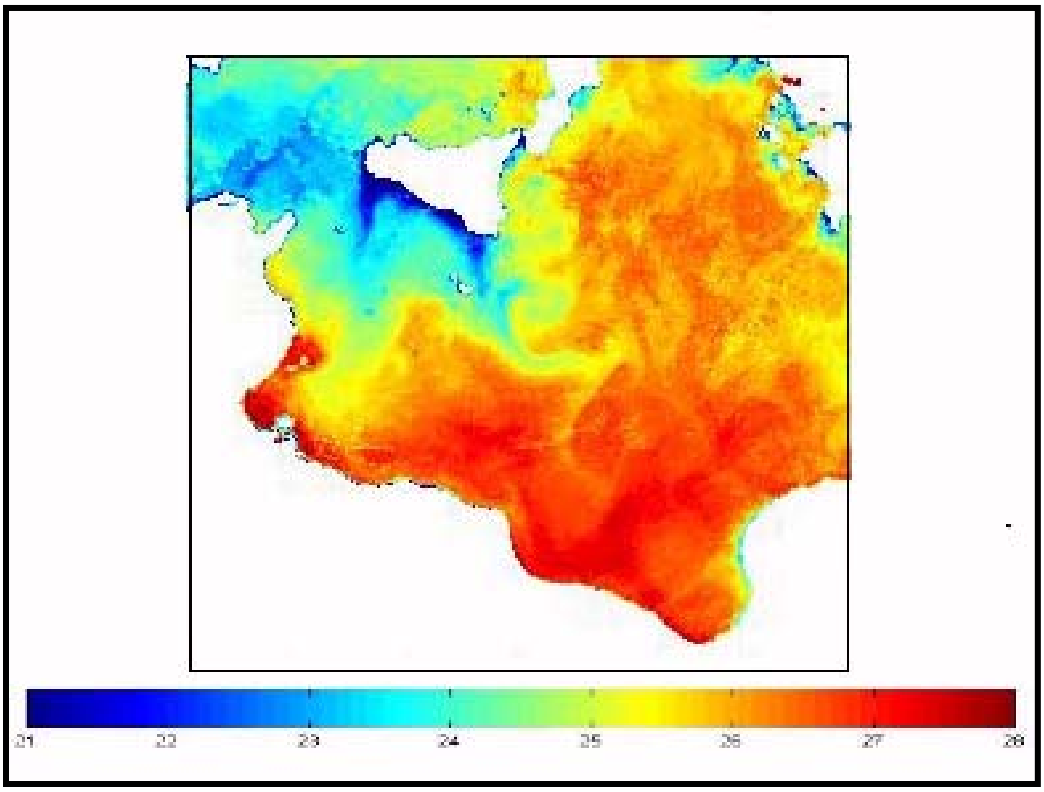

Fig. 11 A view from space showing upwelling along the southern coast of Sicily, very prominent mesoscale structures and sharp fronts in the proximity of the Maltese Islands.

The eastern approaches of Malta are controlled by the influence of the strong southward vein of MAW carried by the AIS that shifts and approaches close to the island especially during the period July to November. This flow triggers anticyclonic eddy formations as it brushes against the southeastern tip of Malta. The AIS vein is displaced away from the coast during winter when a prominent southeasterly meandering flow is established in the northern proximity of the Maltese Islands with a strong baroclinic nearshore current along the northern coast that continues as a prominent southeastward trail beyond Malta. The surface flow in the coastal areas of the islands is highly variable and is in some areas characterised by seasonal reversals of the currents such as to the south of Malta and along the northern coast of Gozo. During summer the AIS is displaced southwards and cuts across the islands with a swerving deflecting path against the northern coast of Gozo. The flow circles around the western tip of Gozo and proceeds with a southeastward current that follows closely the coastal southern perimeter of the area separating the two islands. The flow in this favourite area to local fishermen induces coastal upwelling during summer and early fall.

4. MedGOOS - A regional initiative for operational oceanography

What is MedGOOS? - The Mediterranean Global Ocean Observing System - MedGOOS - is an informal association founded under the auspices of the UNESCO Intergovernmental Oceanographic Commission (IOC) to provide a concerted approach to the development of an operational ocean observing and forecasting system at a regional and coastal scale to the benefit of a wide group of users in the region.

The key priorities targeted by the MedGOOS include the identification of the regional priorities for operational ocean forecasting and marine meteorology, an assessment of the related economic and social implications, and the guidance and assistance to the riparian states towards the harmonious implementation of the Mediterranean ocean observing and forecasting system built on existing elements and based on principles of co-development, co-ownership and sharing of benefits. The MedGOOS aims to build a system to the benefit of a vast spectrum of customers and marine industries, addressing the requirements of governments to enable sustainable development and lead to socio-economic goals. The MedGOOS will ensure the upgrading of national systems to the same level of expertise and infra-structure and will stimulate the necessary pre-operational R&D to ensure that GOOS is fully effective when it is eventually established, hopefully in ten to twenty years time.

Brief history of MedGOOS - Since the signing of the MedGOOS Memorandum of Understanding by the founding members in 1999, other marine institutes have joined. Membership already covers most of the riparian countries with a total of 19 members from 16 countries. The regional dimension of the Association is an enabling asset to the future projection of MedGOOS towards long term commitments at governmental level. The MedGOOS members play a leading role as a competent entity for the promotion of GOOS in their country and as a coherent team in the basin. Each member acts as a national focal point, establishing links with the scientific community and the public authorities, developing awareness activities to enable the implementation of MedGOOS and the future projection into long term commitments at governmental level.

The involvement of Malta in the development of MedGOOS has been instrumental. The founding meeting was held in November 1997 in Malta during the Workshop on GOOS Capacity Building for the Mediterranean Region [30] organised by the Malta Council for Science and Technology (MCST) and sponsored by the Government of Malta, IOC, a number of European agencies and the Bank of Valletta International Ltd. In 1998, the MedGOOS Executive Board decided to recognise this contribution by assigning to Malta the prestigious hosting of the MedGOOS Secretariat. The Secretariat currently operates under the IOI-Malta Operational Centre of the University of Malta. The presence of the MedGOOS Secretariat in Malta is certainly of great prestige. It is a benefit for MedGOOS itself, while it enhances the role of Malta in the quest to promote regional cooperation in the peaceful uses of the Mediterranean Sea.

RTD Projects Related to MedGOOS

Recent EU RTD projects are providing the science base for the implementation of the Mediterranean component of GOOS. The Mediterranean Data Archaeology and Rescue of Temperature, Salinity & Bio-chemical Parameters (MEDAR/MEDATLAS) [13,14] and the Mediterranean Forecasting System Pilot Project – MFSPP – [24,25] have already involved the participation of some non-EU Mediterranean countries contributing to co-operation in the region. The MFSPP has tested the feasibility of a Mediterranean pre-operational system to predict physical and biochemical parameters in the basin and coastal/shelf areas for time scales of weeks to months, by generating forecasts based on a nowcasting/ forecasting modelling system and data from a moored station and satellites. MFSPP has also developed interfaces to users to disseminate forecast results. The ongoing project MFSTEP (Mediterranean ocean Forecasting System: Towards Environmental Predictions) is a follow-up to MFSPP and will integrate and extend the observing system with biochemical components, trial forecasts in coastal areas and implementation of nested models.

These projects have started the initial design of an integrated and sustained monitoring/ forecasting system that addresses the needs of the region. They are proving that a long-term coastal/open sea monitoring/forecasting system must build on a strong collaboration among the neighbouring countries to share efforts, resources and provide a monitoring system with optimised temporal/spatial coverage.

The first MedGOOS project - In 2002, the 3-year thematic network project entitled "*Mediterranean network to Assess and upgrade Monitoring and forecasting Activity in the region"* (MAMA) [31] was launched. The project is funded by the Vth Framework Programme, *Energy, Environment and Sustainable Development* of the European Union. It brings together a consortium made up of major marine institutions from all the Mediterranean countries, and is staging a concerted effort between countries in the region to put in place the institutional and scientific linkages to establish the regional platform for the implementation of MedGOOS. MAMA focuses on the trans-national pooling of scientific and technological resources in the basin. The aim is to share experiences and transfer of expertise, to bring capacities in ocean monitoring and forecasting at comparable levels. The joint effort will contribute to the planning and design of the initial ocean observing and forecasting system in the Mediterranean. MAMA is interacting with stakeholders and relevant international organisations to trigger awareness on the benefits of ocean forecasting. Demonstration products and results are disseminated, national awareness campaigns are organised to build momentum towards long term commitments by governments. Within this effort MAMA is pioneering the implementation of GOOS by an unprecedented endeavour and novel approach that will put the region at the forefront of ocean monitoring and forecasting.

Fig. 12 Mama consortium compsed of leading marine institutes from all the Mediterranean countries, three international organisations and an Advisory Board with four members of international repute.

The strength of a regional partnership

An integrated and sustained ocean and coastal observing system needs an enduring collaboration among the neighbouring countries and a strong will to share efforts, resources and knowledge. The early dialogue and the involvement of all the Mediterranean countries in MedGOOS are crucial and vital for its long-term success. The regional dimension of the MedGOOS Association will ensure that this collaborative venture will bring benefits and opportunities equally to all the riparian coastal peoples.

The MedGOOS members play a leading role as a competent entity for the promotion of GOOS in their country and as a coherent team in the basin. The coordination role of each member as a national focal point, the establishment of links with the local scientific community and the public authorities, and the awareness activities are a main thrust for the implementation of MedGOOS and an enabling asset to the future projection into long term commitments at governmental level.

The scientific objectives of MAMA are to:
- Build the basin-wide network for ocean monitoring and forecasting, linking all the Mediterranean countries;
- Identify the gaps in the monitoring systems in the region and in the capability to measure, model and forecast the ecosystem;
- Integrate the knowledge base derived by relevant national and international RTD projects and programmes;
- Build capacities in ocean monitoring and forecasting;
- Design the initial observing and forecasting system, on the basis of a co-ordinated upgrading of capabilities in all Mediterranean countries;
- Raise awareness on the benefits of MedGOOS at local, regional and global scales;
- Bring together all stakeholders to harmonise strategies for operational oceanography at the service of sustainable development.

The expected long-term results are :

- the strengthening of the co-operation of all the Mediterranean countries towards the development of the Mediterranean operational forecasting system running at basin and local (regional to coastal) scales;
- the upgrading of the technical and scientific skills of human resources and the research infrastructure needed for the basin wide management of the coastal and shelf area;
- and the establishment of the platform for a Mediterranean virtual data and information centre as a basis for operational interagency exchange, merging data

and information, to produce added value oceanographic information, and the delivery of user-oriented products in an operational and interactive mode.

Furthermore MAMA will be contributing to the initial phase of the EC-ESA Global Monitoring for Environment and Security (GMES) initiative, with:
- an inventory on existing monitoring activities
- the design of an initial observing system for the coastal area
- reports on the present monitoring capabilities and on the limitation of data flow

MAMA will be implemented through the planned activities, divided into 8 workpackages, with a strong emphasis on assessing current capacities, cooperation, networking and awareness.

WP1 MAMA NOW – Inventorying and assessment of current national operational oceanographic activities, infrastructures and resources in the Mediterranean.

WP2 MAMA OBSERVING SYSTEM – Design of the real-time coastal data acquisition systems, fully integrated to the basin scale observing system.

WP3 MAMA CAPACITY BUILDING - Enhance in each country the basic technical and scientific expertise required to participate in MedGOOS.

WP4 MAMA MODEL – Transfer of know-how and modelling experiences to partners by dedicated model implementations in new shelf areas.

WP5 MAMA-NET – Design and test elements for inter-agency networking and for the exchange of data and information. Provide guidelines for a regional marine information system.

WP6 MAMA WWW - Establish the MAMA WWW as a reference point and showcase for operational oceanography in the Mediterranean.

WP7 MAMA AWARENESS – Undertake an awareness campaign on MedGOOS addressing governmental agencies and authorities, policy-makers, the marine scientific community, marine industries, the services sector, and the public at large.

WP8 MAMA DISSEMINATION & PRODUCTS – Promote the use and potential of added-value applications of routine data for the management of marine resources.

Benefits of MedGOOS - At its roots MedGOOS is conceived as an end-to-end user-driven system providing locally relevant, regional scale ocean data that is sustained, integrated, operational, and targeting multiple users and applications. The advent of multi-disciplinary, spatially widespread, long term data sets is expected to trigger an unprecedented leap in the economic value of ocean data. This will bring about a radical transformation in our perception of managing marine resources, and secure benefits to many sectors in industry and services such as public health and marine safety. The main perceivable profits will be in the:

- capability to make informed decisions based on the knowledge of the causes and consequences of change;

- effective and sustainable management of the marine environment in favour of fisheries, safe and efficient transportation, coastal recreation and other marine-related industries that contribute a large part of the total GNP for the bordering countries;

- support of economies and for improving standards of living on the basis of enhanced marine services;
- mitigation of marine hazards, with improved search and rescue operations, and in ensuring public health;
- detection and forecasting of the oceanic components of climate variability due to human activity;
- quest to preserve and restore healthy marine ecosystems.

More specific benefits apply to the Mediterranean fisheries. A regional scale ocean observing and forecasting system provides those supportive routine and synchronous observations with full basin scale coverage that constitute the backbone information for a better understanding of the ecosystem functioning, variability and response to perturbations. The capability to acquire, analyse and predict ocean phenomena on such an operational mode is a basic requisite to enable useful forecasts of biomass distributions, and will lead the way to develop fisheries modelling on a firm basis and as a reliable tool for assessment. This would imply a herculean stride towards achieving an effective ecosystem-based fisheries management.

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