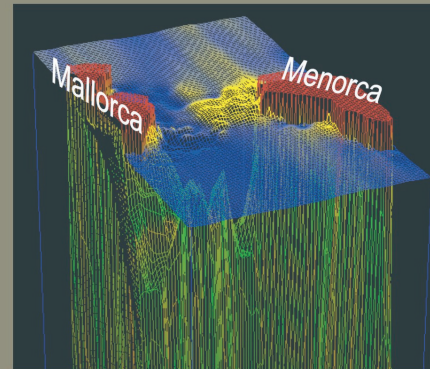
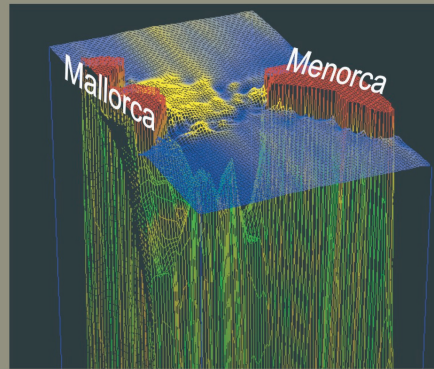


NUMERICAL SIMULATIONS

3D Modelling long waves generation by atmospheric pressure

A 3D primitive equation model (Wang, 1982) is used to simulate the generation of long waves by atmospheric pressure disturbances. The model uses a semi-implicit scheme in the horizontal dimension and a mode-splitting technique in the vertical dimension. Primitive equations are written in staggered grid centered-difference form and are solved with a leapfrog scheme in time.

The model is applied to the region between Mallorca and Menorca under different atmospheric conditions. The forcing introduced are non-dispersive atmospheric waves travelling from SW, with different frequencies and velocities. The main objective is to test the response of the shelf flow and to find out the eigenfrequencies of the shelf.



Surface elevations obtained from the model for two different times using an atmospheric forcing of 12 frequencies, with values between 5 and 100 min^{-1} , traveling from Mallorca to Menorca with $v=30 \text{ m/s}$.

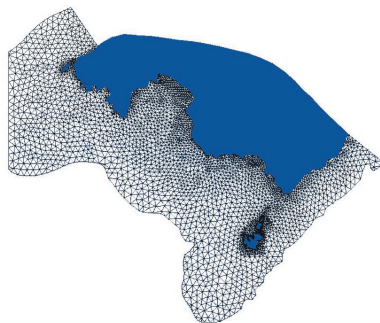
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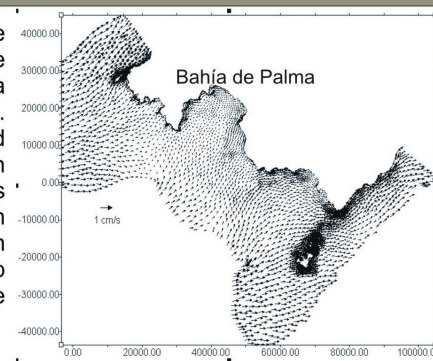
3D Modelling for shallow waters

We present here a three-dimensional finite element model for shallow waters. We use numerical and insitu studies of shelf circulation and interaction with nearshore processes for the study of beach erosion, marine outfalls and all the coastal processes related to a sustainable management.

The mesh is formed by 3798 in the horizontal 6825 elements and 11 nodes in the vertical (41778 nodes in (x,y,z)) and covers the domain of the southern coast of the Mallorca Island. This model solves the linearized 3-D shallow water equations with conventional Hydrostatic and Boussinesq approximations.



This figure shows the response of the surface layer under a realistic sea breeze forcing. Horizontally flows around capes, headlands and in nearshore show features associated with topography and bottom stress. Vertically the top and bottom flows oppose each other.



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SUMMARY

IMEDEA, Institut Mediterrani d'Estudis Avançats (Mediterranean Institute for Advanced Studies) is a joint centre between the University of the Balearic Islands (UIB) and the Spanish Council for Scientific Research (CSIC). Within IMEDEA, the Balearic Islands Physical Oceanography Group (BIPOG) is carrying out research on different topics from open ocean mesoscale dynamics to coastal processes, and from climatic time scales to short-period shelf waves. In terms of methodology, BIPOG research involves from the acquisition of in-situ data in oceanographic cruises to satellite altimetry, and from the temporal and spatial objective analysis of data to forecasting using both numerical modelling and evolutionary computation.



The BIPOG was created as a group in 1993, although some of its members had been working in oceanography since 1985. During the last three years, the BIPOG has participated in several regional, national and european projects that produced more than 30 papers in international journals. In the following we present the guidelines of the main research topics, altogether with most relevant results.



IMEDEA

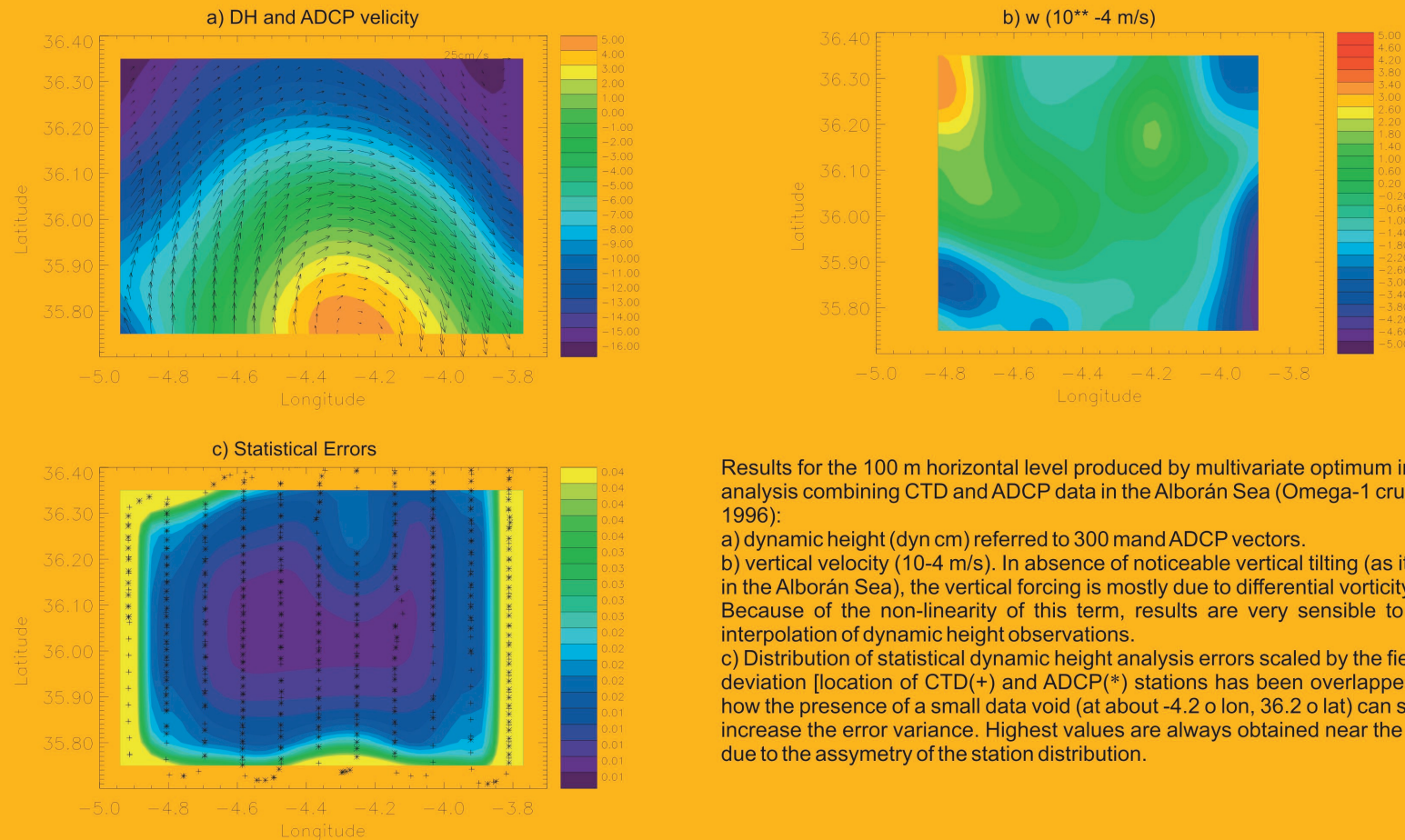


FROM THE INTERPOLATION OF OBSERVED VARIABLES TO THE ESTIMATION OF VERTICAL VELOCITIES

In the last years several works have addressed the computation of vertical velocity from oceanographic cruise data. In our case, we have obtained estimates of vertical displacements in frontal regions, mainly in the Alborán Sea (Tintoré et al., 1991), but also in Antarctic fronts. Recently, we have shown that the sampling strategy and the spatial objective analysis of observed variables can be extremely critical in the estimation of the vertical velocity.

As a consequence, our present efforts focus on producing a general formulation aimed to quantify the reliability of all these results, something which is lacking in the scientific literature. Namely, we intend to evaluate the effect that different error sources have on derived variables involved in the computation of vertical velocity, such as geostrophic velocity, relative vorticity or vorticity advection, in addition to the vertical velocity itself. Namely, we aim at quantifying the influence of instrumental errors, the sampling strategy and the interpolation procedure. Preliminary results (Gomis et al., 1999) show that instrumental errors are always a small contribution to total errors. Instead, the sampling strategy or boundary effects (even in cases with an apparently optimal sampling) are the most relevant contribution to the total error variance. The later is shown to be typically of the order of a few tens percent of the field variance, but it can easily be higher than 100% in certain cases, then preventing from any reliable estimate of vertical displacements.

EXAMPLE OF VERTICAL VELOCITY DIAGNOSTIC FROM OCEANOGRAPHIC CRUISE DATA



Results for the 100 m horizontal level produced by multivariate optimum interpolation analysis combining CTD and ADCP data in the Alborán Sea (Omega-1 cruise, october 1996):

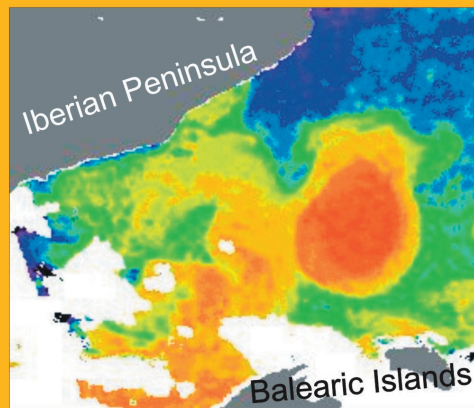
- a) dynamic height (dyn cm) referred to 300 mand ADCP vectors.
- b) vertical velocity (10^{-4} m/s). In absence of noticeable vertical tilting (as it is the case in the Alborán Sea), the vertical forcing is mostly due to differential vorticity advection. Because of the non-linearity of this term, results are very sensible to the spatial interpolation of dynamic height observations.
- c) Distribution of statistical dynamic height analysis errors scaled by the field standard deviation [location of CTD(+) and ADCP(*) stations has been overlapped]. It shows how the presence of a small data void (at about -4.2 o lon, 36.2 o lat) can substantially increase the error variance. Highest values are always obtained near the boundaries due to the assymetry of the station distribution.

ALTIMETRY AND HYDROGRAPHY

A case of intense anticyclonic blocking in the Balearic Sea

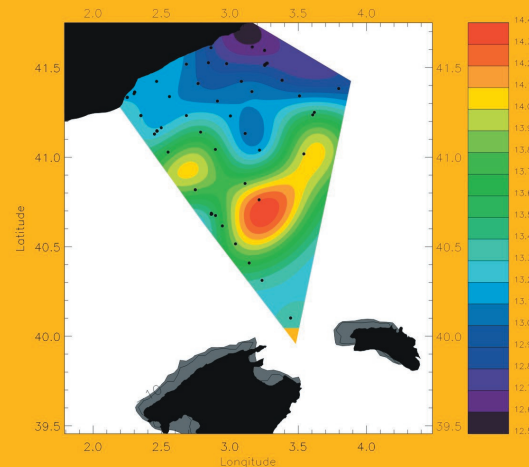
TOPEX/POSEIDON and ERS-2 satellite data have revealed the presence of an intense mesoscale anticyclonic eddy at the northern boundary of the Balearic Sea, which appeared in July 1998 and remained almost stationary until March 1999. The combination of Sea Surface Temperature (SST) images and Sea Level Anomalies (SLA) maps has allowed to investigate the path followed by the eddy, which was apparently originated as an instability of the Algerian Current. Additional data from an oceanographic cruise in February 1999 ("Hivern-99") confirmed the signature of Atlantic Water in the region.

AVHRR image
25/02/1999



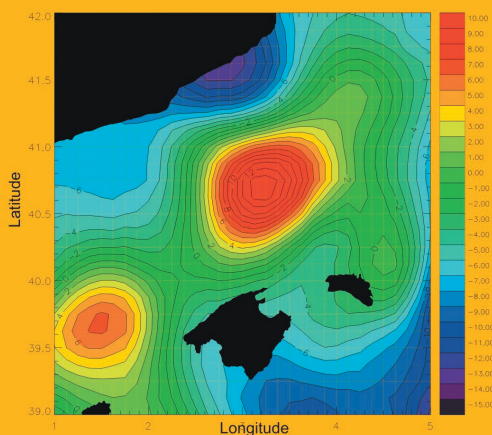
Red indicates warm areas and blue cold areas.

Oceanographic cruise
24/02/99 - 28/02/99

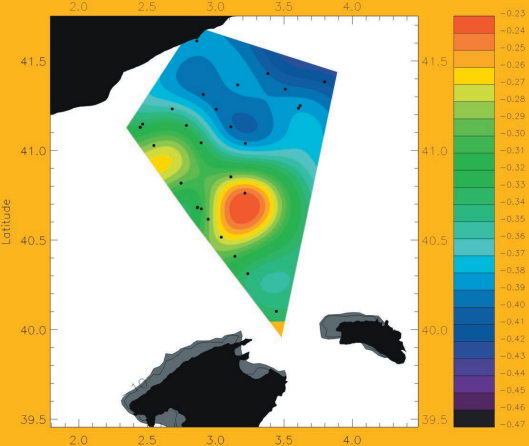


Temperature at 10 dbar. Units in °C

Altimetry
24/02/99



SLA map obtained from TOPEX/POSEIDON and ERS-2 satellite data. Units in cm.



Dynamic height at 10 dbar referred to 500 dbar. Units in dyn cm.

Methods for inferring the deep structure of the ocean from upper level observations

An extension of the use of altimetric data (alone or complemented by surface density data) is explored to infer the vertical structure of the velocity field (and therefore to computing transports). In a first step, the dominant vertical modes (Empirical Orthogonal Functions) of the mass field are computed from regional historical hydrographic data. We then contemplate two different scenarios: i) only altimetric data are available, in which case only the amplitude of the first leading EOF can be determined; ii) along-track surface density is also available, in which case also the amplitude of the second leading EOF can be determined.

Only altimetric data (Φ)



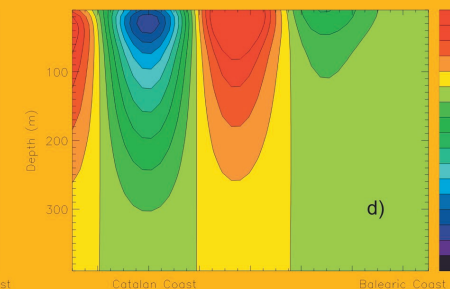
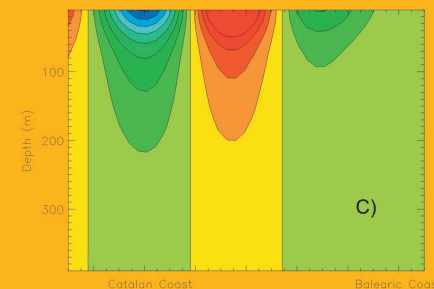
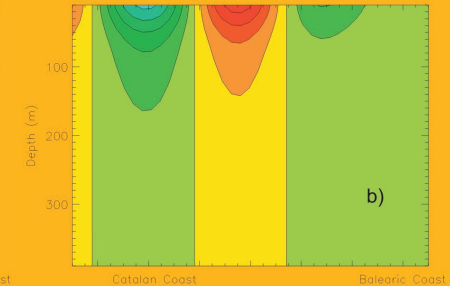
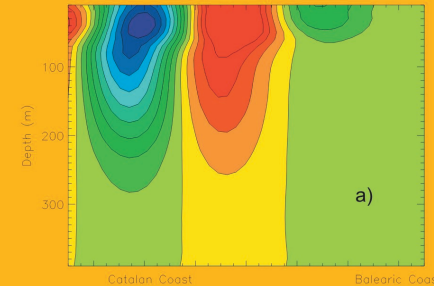
1 EOF

$$\Phi(x, y, p = \text{surface}) = A_1(x, y)PC_1(p = \text{surface})$$

Altimetric data (Φ) + surface specific volume (α)

2 EOFs

$$\alpha(x, y, p) = -\frac{\partial \Phi(x, y, p)}{\partial p} = -\sum_i A_i(x, y) \frac{\partial PC_i(p)}{\partial p}$$



Results of the different methods of extrapolation in the Balearic Sea. Panel a) shows the real geostrophic velocity field. In b) a previous method based in Carnes et al., 1990. In c) and d) the results of 1 EOF DH and 2 EOFs DH, respectively. Units are in cm/s.

BALEARIC SEA:OBSERVATIONS

The Balearic channels are key places to monitor the circulation variability in the Western Mediterranean (WM), in particular the variability of the meridional fluxes between the (thermo) dynamically well contrasted northern and southern regions. It seems that this variability is determined by the presence or not of a Winter Intermediate Water (WIW) mass to the north of the Ibiza channel, characterising two flow regimes in the area. To study this time variability we have used different data:

- Experimental data from CTD, obtained between 1996 and 1998 (Fig. 1a, Fig. 2a).
- Satellite data in the Balearic Sea region (Fig. 1b, Fig. 2b).

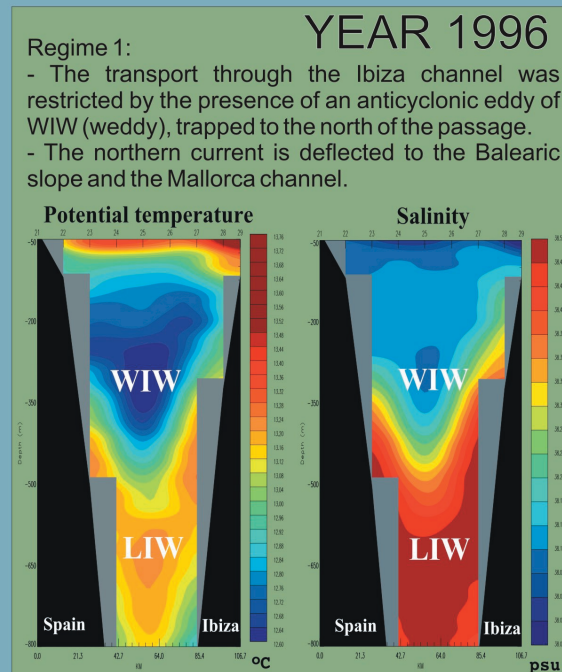


Figure 2a: CTD section to the north of Ibiza the Channel

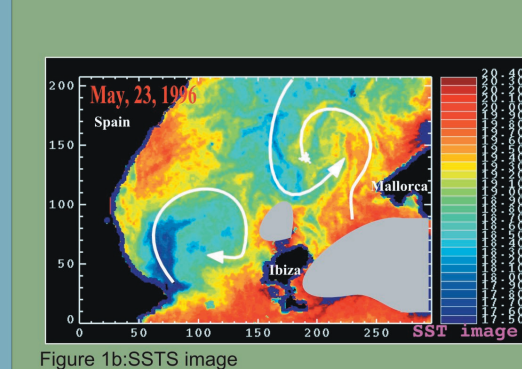


Figure 1b: SST image

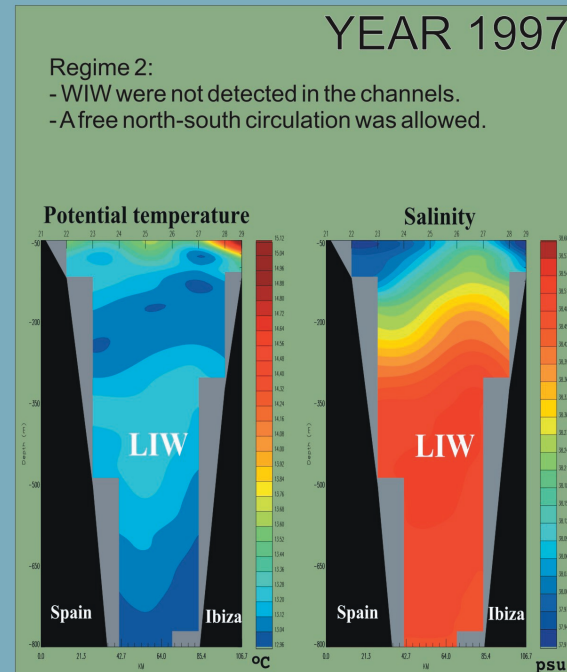


Figure 2b: CTD section to the north of Ibiza the Channel

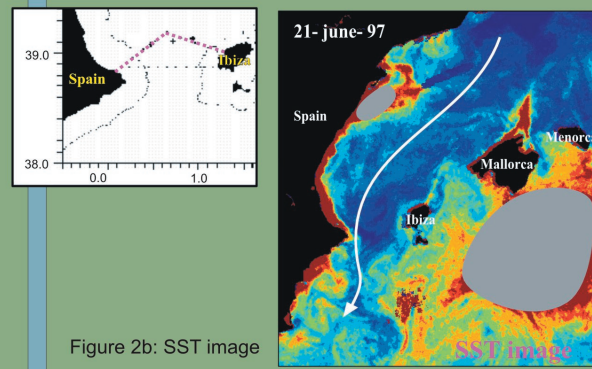


Figure 2b: SST image

MEDITERRANEAN SEA: MODELLING

The objective is to study, using a numerical model, the interannual variability of the Mediterranean circulation due to external forcing in contrast with the internal modes of variability of the system. Here, a 3D primitive equation model (MOM) is used to investigate the effects on the Western Mediterranean circulation of increased ocean-atmosphere fluxes associated with severe winter conditions in the northern Mediterranean (figure 1). The anomalous winter is set up as increased heat loss and higher evaporation in the northern area.

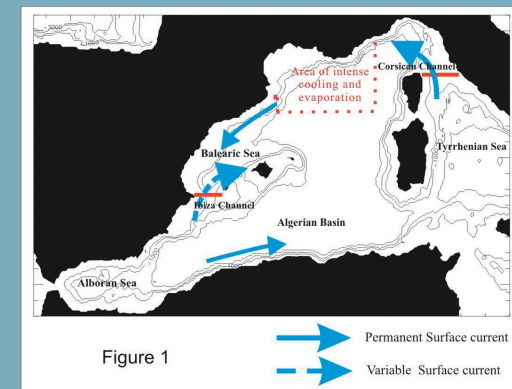


Figure 1

The transports through some key channels and sections are quite modified as a result of a dynamic adjustment of the global Mediterranean dynamics to a local modification of the atmospheric forcings. The qualitative changes in the Ibiza and Corsican passages are shown here in figures 4 and 5 where the transport in the climatological situation (according to MEDMEX conditions) are compared to the transports when the fluxes are modified in the north.

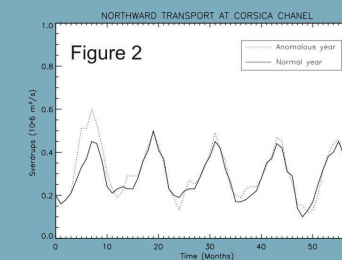


Figure 2

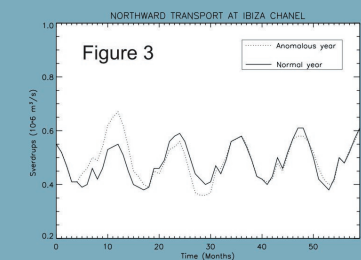


Figure 3

LARGE-AMPLITUDE HARBOUR OSCILLATION INDUCED BY SHELF WAVES

Very large seiche oscillations related to meteorological forcing are regularly observed in several regions around the world. Ciutadella Harbour (Menorca Island, Spain) is one of such places. Harbour oscillations, locally known as "Rissaga", with heights of up to 3-4 m, have been observed in Ciutadella several times, causing severe damage to the harbour structures and ships. Seven years of monitoring seiche oscillations, open-ocean long waves and atmospheric pressure fluctuations, and several theoretical studies undertaken by the BIPOG, allowed to suggest that the abnormal oscillations in Ciutadella inlet were induced by open sea long waves generated by the atmosphere on the outer shelf of Menorca and Mallorca islands (see Monserrat et al., 1991; Gomis et al., 1993; Garcies et al., 1996).



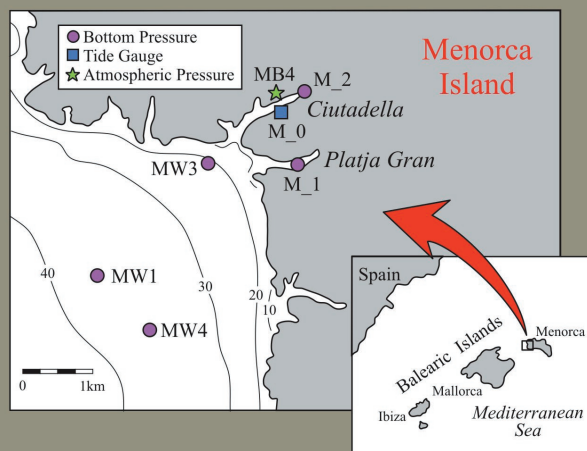
Photo a



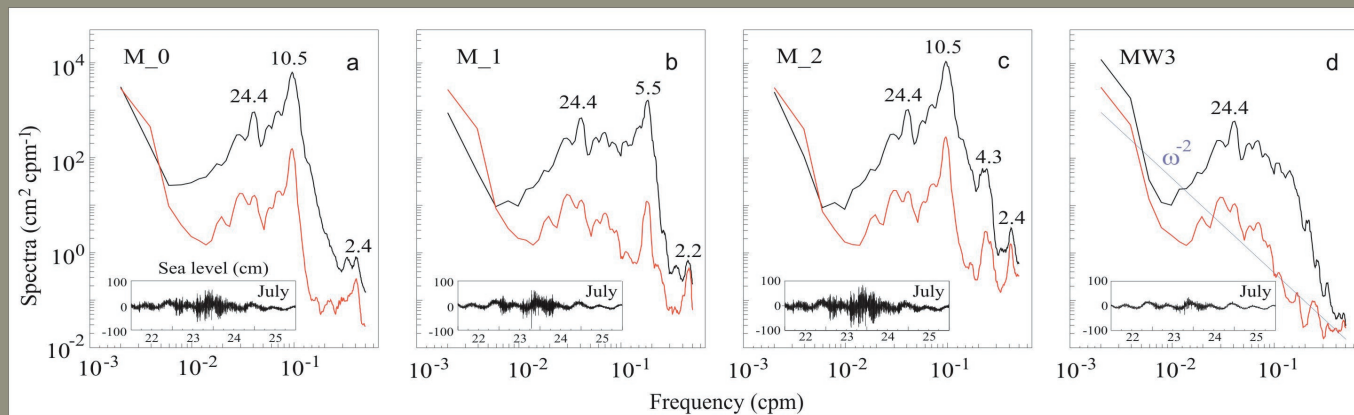
Photo b

Ciutadella harbour view during a rissaga event on July 1997 (a) as a comparison with a normal situation at the same location (b).

An extensive field experiment (LAST-97) was developed in collaboration with the University of Cantabria in summer 1997, to examine in detail the generation mechanism of Rissaga waves. All recorded events are well correlated with significant disturbances of atmospheric pressure observed simultaneously. However, the detailed character of this correlation is not simple. The relative increase of atmospheric energy at the resonance bay frequencies is a favourable factor for seiche excitation, but, this energy is far too small to assume a direct resonance generation mechanism. We have also found that in most significant cases, atmospheric waves have always a phase speed of about 30 m/s, i.e. very close to the phase speed of long waves on the shelf of Mallorca, and propagate over the Balearic Islands from the Southwest. Numerical simulations suggest that these atmospheric wave properties are optimal for the generation of large standing waves on the shelf between Mallorca and Menorca. Moreover, one of the shelf modes is close to the fundamental mode of Ciutadella inlet, which suggests that a double resonance mechanism is the most likely explanation of the strong oscillations observed at Ciutadella.



Location of the instruments deployed during LAST'97 experiment



Sea level spectra for the Rissaga event registered on July 1997 (red) and for background oscillations (black) for the instruments; M_0 at the middle of Ciutadella inlet (a), M_1 at Platja Gran (b), M_2 at the end of Ciutadella inlet (c) and MW3 on the shelf. The straight line in (d) corresponds to the log-log linear fit with a slope equal to -2. The actual data associated with the selected four days for Rissaga event are shown in insets.

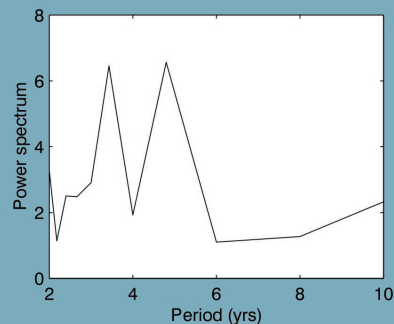
WESTERN MEDITERRANEAN: TELECONNECTIONS

Since some years ago there has been a great interest in ENSO and NAO events and its related teleconnections. Some authors found connections between ENSO and NAO events in some Eastern Atlantic areas but there has been few evidences of ENSO/NAO impacts in the Mediterranean area.

Our aim is to understand the influence of climatic phenomena on the SST Mediterranean variability.

We have used pairs of oceanic/atmospheric time series for the search of teleconnections between the interannual variability in the Western Mediterranean and well known climate phenomena like ENSO and NAO.

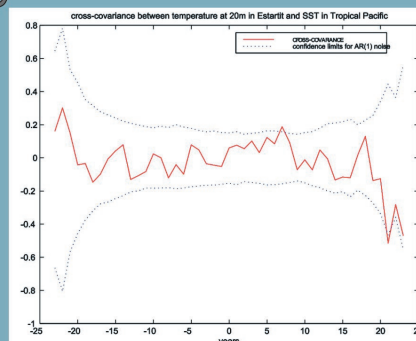
First evidences of teleconnections between sea temperature in the Western Mediterranean and ENSO



The interannual variability of the Western Mediterranean sea temperature is analysed using auto-correlation and spectral functions.

As an example the figure shows the periodogram of sea temperature at 20 m depth in Startit (Girona). The peaks found are quite coincident with the most representative NAO periodicities.

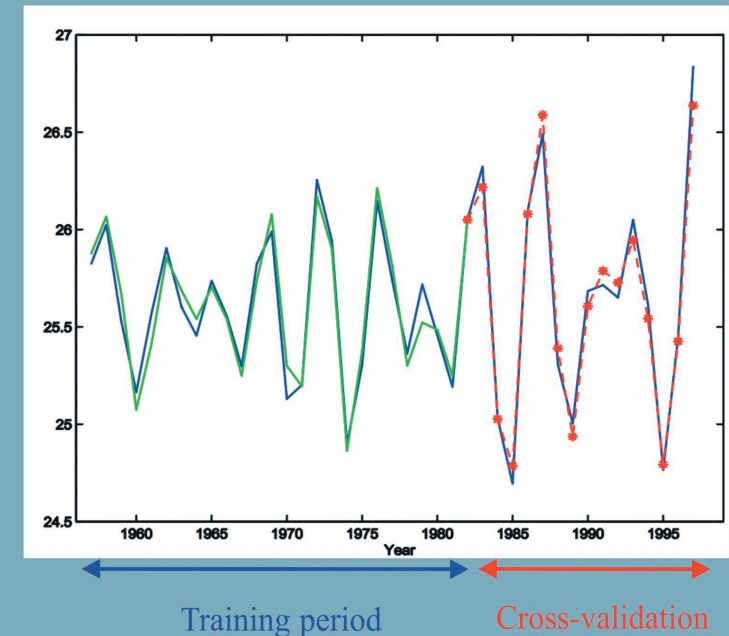
To find teleconnections we also analyse the crosscorrelation function between signals. We employ the Monte Carlo Singular Spectral Method that allows us to discriminate the noise from the data records. The blue dash dotted lines shows the 95% of probability that the process is generated by a first order autoregressive (AR) process and the red line is the crosscorrelation function between the sea temperature in Western Mediterranean and ENSO. This result suggest that the 7 years periodicities cannot be explained by a simple AR process but they can be an indication of some connection between the time series. More work is ongoing.



FORECASTING FROM TIME SERIES

We construct a dynamical model for the ENSO using observations of the annual average sea surface temperature (SST) in the Tropical Pacific Ocean (1950-1993). To do that, a state space reconstruction of ENSO dynamics is carried out. Then, we obtain a dynamical model that maps the current state of ENSO to a future state. This is accomplished with an evolutionary algorithm using 34 years (1950-1983) of a filtered SST record. The model is validated with the collected data for the next ten years of the filtered series (1984-1993). Finally, the forecast skill of the method is tested against five years (1994-1998) of unfiltered recorded SST.

- The blue line is a filtered (SSA method) time series taking account of the most relevant Principal Components of the original data.
- The green line is the prediction in the 32 years used to find the mapping function P (the training period).
- The red dashed line is the time series obtained in the cross-validation test.
- Explicitly, the cross-validation consists of a direct comparison between the prediction and the cleaned time series in the testing subset.



The major findings are:

- We have shown that some aspects of ENSO variability are predictable.
- We have established the chaotic nature of ENSO, from observations and using an evolutionary genetic analysis.
- We have found that a five years forecast (1997-2001) yields a strong cooling (La Niña) during 1999 and a significant El Niño in 2001.