European Research Conference

Mediterranean Forecasting

Grand Challenges for European cooperation in forecasting the behaviour and characteristics of the Oceans

La Londe Le Maures, France
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Conference Proceedings

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Contents

Foreword

This book of proceedings collects the scientific presentations given at the Mediterranean Forecasting EuroConference held in La Londe Le Maures (21-26 October 1995). The Conference discussed the scientific basis for operational waves and current forecast in the Mediterranean Sea. The scientific issues, related to the structure of the general circulation variability, the data requirements and the development of models to represent the general circulation and the ecosystem evolution, were examined. It was found that seasonal and interannual variability is large, partly connected to atmospheric forcing and that predictability studies of the ocean currents should be started in order to understand practical ranges of forecasting in the Mediterranean basin.

I would like to thank all speakers and participants for their contribution in making the scientific discussions at the meeting fresh and stimulating and for providing advanced and constructive scientific criticism.

I would like also to thank the European Commission for its support in the organisation of the meeting. This report was prepared by N. Pinardi with the editorial help of EMaPS, Dr. L. Amato of IMGA-CNR, and the support of MAS2-CT93-0055 Contract (Mediterranean Targeted Project-MERMAIDS).

This conference was funded by the EUROCONFERENCE activity of the European Commission.

N. Pinardi
Conference chairperson

Scientific summary of the meeting

The Conference lasted four full days, from Sunday 22 October until Wednesday 25 October 1995. There were 23 invited lectures plus 5 short unsolicited presentations. A round table discussion was organized on Tuesday 24 October to discuss the future of pre-operational Mediterranean ocean forecasting systems.

The scientific presentations at the meeting were of the highest scientific standards and usually prompted long discussions at the end of each lecture. Highlights of the presentations consisted both in observational and modelling studies that showed a realm of new scientific discoveries about the variability of the Mediterranean general circulation.

Firstly, the Conference discussed the growing observational needs for Mediterranean monitoring and the success in analysis of both historical in situ data and altimetry from Topex/Poseidon and ERS-1. Recently, the banking of a relevant data set for climatological studies allowed a definitive representation of seasonal climatologies in the overall basin. On the other hand, the altimetric data set was shown to give already reliable estimates of the mean sea level excursions and the surface circulation variabilities. New in situ data sets brought evidence of large interannual variability in the strength of the general circulation. Interannual variations in the ocean are connected to large scale atmospheric circulation patterns over the Asian and African tropical areas, where atmospheric anomalies can correlate with the Eastern Mediterranean Sea surface temperatures.

Secondly, the modelling and predictions of oceanic anomalies in the world ocean were overviewed together with the predictability studies carried out in the atmosphere. The surface wind wave predictions in the Mediterranean area were then presented together with the simulations of the Mediterranean Sea general circulation. The need for accurate atmospheric data sets for both wind and current predictions was stressed. The results of global Mediterranean GCM's and regional primitive equation models were reported which pointed out some of the outstanding problems still to be solved, such as the climate drift and the accurate representation of circulation structures. The real time forecasting of the mesoscale variability was also shown for different areas of the world ocean and for the Mediterranean. The need for preoperational and operational systems in the world was also presented and discussed in the light of possible user communities, exploitation of marine resources and sustainable development of coastal areas.

Thirdly, the impressive work on the development of data assimilation methods in ocean sciences was presented, and its application to the large scale ocean circulation in the Mediterranean was introduced. The promising aspects of assimilation of altimetric data to correct for model deficiencies and initialization purposes were shown and the degree of generality and operationality of these techniques was assessed. New techniques for melding data and models were presented for a large range of applications.

Fourthly, the meeting concentrated upon the various aspects of ecological modelling of the Mediterranean basin, from the lower to higher trophic levels, in particular the pelagic nutrient dynamics and the coupling of the biochemistry with the physical environment. The issues involved the prediction of the primary production of the basin which is connected to the success in modelling the processes occurring in the physical environment, at different scales in the space-time, from the Northern nutrient-rich areas of the Mediterranean basin to the southern oligotrophic areas .

This Conference has given an important contribution to the discussion on future applied and theoretical research in the Mediterranean. The need for a study in order to define possible scientific forecasting systems in the Mediterranean has been put forward and discussed. Several methodological/practical steps have been outlined that are possible and that will make Mediterranean Forecasting possible for several parameters of interest. Scientists should meet and start the design of recommendations for a Mediterranean Forecasting activity. This action is timely in order to assess the scientific feasibility of ocean predictions in the Mediterranean area.

Report of the round table discussion:

Operational forecasting in the Mediterranean?

Discussion Leaders: L. Cavaleri, N. Flemming, G. Mellor and N. Pinardi

The focus of the discussion was:

1) Establish the need for ocean forecasting in the Mediterranean area;
2) The possible methodology of approach;
3) The data and model requirements.

The discussion was introduced by Dr. Flemming who analyzed the need for a Mediterranean forecasting system. It was then suggested that only the scientific community can establish priorities on the basis of a sound analysis of the potential of predictions and the assessment of the predictability time scales for the different components of the Mediterranean marine system, from the large to the coastal scale. The impact of such predictions in a heavily-populated area of the world ocean such as the Mediterranean are starting to be understood but the reality of a Mediterranean-based operational forecasting system for waves and currents could give far more benefits than the ones foreseen up to now.

Dr. Cavaleri exposed the strategy that the ocean wave's community started 15 years ago in order to put together a preoperational forecasting activity for wind ocean waves. Again, it was emphasised that the scientific community realized the potential of the application of the numerical models developed and converged toward the common aim of trying predictions. The latter were a formidable tool in evaluating model performance, needs for model improvements and data requirements that could satisfy the needs of a forecasting activity.

Prof. G.Mellor described the experience of numerical ocean forecasting for the United States coastal and North Atlantic area that started about a year ago at the National Meteorological Center (NMC), Washington, DC. The lesson to be learned is that there are many steps to be taken before a fully operational activity can be set. However, from the very beginning, the interaction between the ocean and the meteorological forecasting communities has defined the standards for the coupling, assessed the required precision for the atmospheric data to drive an ocean model and produced nowcasting of sea surface temperatures which were, in certain circumstances, more accurate than statistical analyses of ocean direct measurements.

Dr. Pinardi introduced the problem of Mediterranean forecasting activities, pointing out the great necessity of starting a monitoring program of important physical and biochemical parameters in the basin. It is then likely that general circulation models would be run with such data sets assimilated and satellite altimetry. The need for interfacing the GCM with atmospheric high resolution data sets was stated, as well as the need for development of nested regional or subbasin scale models.

The recommendations from this group are as follows:
1) the Mediterranean is an important region for preoperational ocean forecasting activities due to the potential benefit of predictions in such heavily-populated European coastal areas;
2) it is timely to start a "scientific feasibility" study for Mediterranean forecasting that will try to address the scientific problems which remain between the present state of knowledge and the procedures to run an operational system;
3) there is an urgent need for basin-scale accurate in situ data sets for data assimilation;
4) such a scientific study should consider large-scale numerical modelling work and several high resolutions nested model to capture coastal area dynamics;
5) the usage of coupled ecological models should be tried at the very start as a purely scientific exercise but keeping in mind important applications that such models may have.

The round table discussion ended with the auspices that a scientific working group will be set up to define the conceptual and technical work for future Mediterranean forecasting activities.

Scientific abstracts

Mesoscale and seasonal variabilities of the circulation in the Western Mediterranean Sea

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The Mediterranean Sea is a machine which transforms Atlantic waters into Mediterranean waters. This results from the atmospheric forcing occurring all year long and all over the sea, especially in winter and in some specific areas, when dry and cold air masses are swept along by strong northerly winds. The Mediterranean waters are saltier, colder and thus denser than the Atlantic waters. All these waters circulate from the zone where they enter the sea or are formed to the zone where they leave the sea or are transformed. As driven strongly by the Coriolis force, the general circulation of these waters, at all depths and all year long, is expected to be cyclonic along the continental slope in most of the sea. Nevertheless, depending on the vicinity of the dense waters formation zones, the various straits and channels, or some marked topographic features, the relative importance of the mesoscale and seasonal variabilities in the whole sea can be very different. As an example in the Western Mediterranean Sea, the Algerian basin in the south and the Liguro-Provencal basin in the north display very specific characteristics. As soon as it leaves the Alboran Sea, the flow of Atlantic water tends to follow the Algerian slope and is thus named the Algerian Current. Relatively long and numerous current time series now available off Algeria show no evident seasonal variability, while the Algerian Current is markedly unstable and can generate mesoscale meanders and coastal anticyclonic eddies. These features (size of 50-100 km at least, downstream translation speed of a few km/day, lifetime of up to several months per year) can induce currents of several tens of cm/s sometimes perpendicular to the mean alongslope direction for weeks to months. It is definitively demonstrated that the whole Algerian Current can interact with larger (diameter up to 200 km) eddies encountered in the interior of the Algerian basin, and flow at right angles with the slope for months, but it is not yet clear whether these eddies are older stages of the coastal ones or not. Another hypothesis concerning the origin of the larger mesoscale eddies arises from our recent data sets. It considers that the vein of

"LIW" (the water formed in the Eastern Mediterranean Sea) which flows along the Sardinian slope (at least according to us, as the "LIW" route is still in debate) could be unstable and generate Leddies, more or less in the way Meddies are generated off the Iberian peninsula.

Anyway, it is clear that a tremendous variability at scales ranging from seasonal to annual, but having nothing to do with the atmospheric forcing, can be induced in the south by mesoscale phenomena.

The part of the Atlantic water which has spread across the Algerian basin and the part which has crossed the Sardinian channel but not the Sicilian one join in the Ligurian Sea to form a current, transporting roughly as much water as the Algerian Current, due to recirculation in the interior of the Algero-Provençal basin. This current, clearly evidenced all year long along the continental slope up to the Catalan Sea, and thus formerly named Liguro-Provençal-Catalan Current, is in fact a Northern Current, i.e. a characteristic feature of the circulation in the northern part of all mid-latitudes Mediterranean Seas. Whether it is forced mainly by the wind stress, by the spatial variability of the thermohaline forcing, or as an adjustment to the dense water formation process is still in debate. In any cases, it displays a marked seasonal variability which manifests itself as a variability of the current flux (not easily quantified) and shape and, more obviously, as a variability of the mesoscale activity. In winter, the current is relatively narrow and deep, its flux is relatively large, and it is markedly unstable, generating mesoscale meanders especially steep (amplitude and wavelength of a few tens of kms), propagating downstream at 10-20 km/day and having a baroclinic structure. It thus generates a mesoscale turbulence which will slowly spread seaward for months, across the zone where dense water is formed, while clearly getting a more barotropic structure with currents of several tens of cm/s over most of the depth.

Therefore, and whatever the forcing mechanisms of the Northern Current are, the most perceptible variability of the circulation in the north is not the dense water formation per se (which is obviously the basic phenomenon for the functioning of such a Mediterranean sea), but the seasonal variability of the mesoscale activity.

Monitoring of the mean sea level and oceanic circulation of the Mediterranean Sea by satellite altimetry

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Thanks to the high accuracy of Topex/Poseidon, the mean sea level and the oceanic circulation of the Mediterranean can be observed for the first time with satellite altimetry. Results of the analysis of three years of Topex/Poseidon data will be presented. The mean sea level has variations of up to 25 cm. It has an annual cycle with a fast drop during winter. Steric effects account for about half of the observed variations. The remaining signal is thought to be driven by evaporation minus precipitation (E-P) forcing and internal hydraulic control in the straits of Gibraltar. There are also important variations related to atmospheric pressure which have been analyzed. Topex/Poseidon data have also clearly shown the seasonal variations of the surface circulation. The large scale cyclonic circulation appears thus to be more intense in winter, and principally driven by wind stress curl variation. Strong anticyclonic mesoscale signals such as Alboran gyres or Ierapetra gyre were shown to have a clear seasonal variability, with a maximum in summer. Topex/ Poseidon data can also be combined with data from ERS-1 and now ERS-2 to provide a better resolution of the surface circulation This will be illustrated with results from the combination of ERS-1 and Topex/ Poseidon.

Topex/Poseidon and ERS-1 results have thus shown that the monitoring of the Mediterranean sea mean sea level and circulation is feasible. In the next decade, the Mediterranean sea will be observed by several satellites (Topex/Poseidon, ERS-2, Geosat Follow on, ENVISAT, Topex Follow on). This should allow us to set up an operational monitoring of the Mediterranean sea.

The observational evidence of the general circulation in the Mediterranean from historical data sets

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Significant numbers of hydrographic data have been collected in the Mediterranean during this century, providing the basic ingredients needed to construct a climatological picture of the general circulation. This background picture is an important element for developing operational models and prediction tools of the circulation at various time scales. In this talk, recent climatological studies will be reviewed with the aim of exhibiting the main features of the general circulation shown by observations. To conduct such climatological studies, it was first needed to have access to the widest possible inventory of observations made at sea. Several historical data sets gathered in various institutions have been identified and merged together after elimination of duplicated profiles and careful check of the data quality. This work was conducted within the framework of the MODB (Mediterranean Oceanic Data Base) initiative of the MAST programme. The pooled hydrographic, which is freely accessible through Internet (http://mob.oce.ulg.ac.be), currently contains over 100,000 station profiles (CTD, Nansen bottle, XBT and MBT) taken in the Eastern and Western Mediterranean Sea between 1900 and 1993. Climatological analyses of temperature and salinity data have been performed at the seasonal and monthly scales, using a variational method and a finite element numerical technique. The variational formulation is demonstrated to be equivalent to objective analysis, and a hydrid combination of the statistical and variational methods allows computation of error fields associated to the climatology. The free parameters of the scheme have been determined using a cross-validation algorithm to extract the 'best' seasonal statistics from the data sets. Various versions of the gridded climatological fields have been prepared at a resolution of 1/4 degree on the horizontal and 19 levels on the vertical, and are freely accessible on Internet. Compared to earlier climatologies (e.g., Levitus 1982), these analyses show significant improvements with respect to the regional scales of the general circulation gyres. In addition, several features of the general circulation are described with better accuracy, such as the eastward transport of Atlantic

Water in the Western basin, the Mid- Mediterranean current in the Ionian sea, the Rhodes and Cretan Gyres, and the westward propagation and progressive transformation of Levantine Intermediate Water. Finally, the barotropic equations (external mode) of a free-surface, primitive equation model have been integrated in time to diagnostically adjust the sea-surface elevation to the thermohaline structures. Geostrophic velocities are then computed, integrating the thermal-wind equations with the sea-surface pressure as a reference. The derived velocity fields essentially reflect the information contained in the observations, the task of showing and explaining the features unresolved by currently available data sets being entrusted to fully dynamical, prognostic, primitive-equation models.

Local and remote climate variability associated with East Mediterranean sea-surface temperature anomalies

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1. Introduction

Walker and Bliss (1932) implicated the eastern Mediterranean (E Med) as a participant in large-scale climate anomalies through their inclusion of Cairo surface pressure in the original Southern Oscillation Index for boreal summer-time. Support for their suggestion is found in Ward (1992, 1994) where air-sea variables in the E Med repeatedly show significant correlations with indices of rainfall for the Sahel and India through the current century. Furthermore, it was noted that in an extensive set of GCM experiments (Rowell et al., 1995) strong teleconnections between Sahel, India and the Mediterranean existed (Ward, 1994), while a group at Reading University have also proposed connections between Indian rainfall and Mediterranean dynamics using GCM integrations. This paper looks in more detail at the nature of these associations, which offer the prospect of improved understanding of Mediterranean variability and for seasonal prediction of summers in the Mediterranean region.

2. Data and methods

Sea-surface temperature (SST) data are taken from MOHSST4 (Bottomley et al., 1990). Sea level pressure (SLP) and near-surface vector wind (zonal, u and meridional, v) are taken from COADS (Woodruff et al., 1987). All data are formed into seasonal mean 10lat x 10long anomalies, as described in Ward (1992, 1994). Near-surface vector wind has been corrected for trends seemingly introduced by change in observation method (Ward and Hoskins, 1996). The period analysed here is 1949-88. Most analysis is reported for high-pass filtered values, effectively removing timescales greater than 11.25 years. These series have near-zero serial correlation, so assessment of statistical significance is much simplified, since an effective sample size of 40 can be assumed. The rainfall indices for Sahel (N Africa, 12.5-17.5N), Soudan (N Africa, 10-12.5N) and India are constructed from standardised grid-box rainfall anomalies taken from the CRU gridded precipitation dataset (Hulme, 1994).

SST, SLP, u and v anomaly indices for July-September (JAS) were calculated for the E Med, defined to be 30-40N, 20-40E. This region showed most consistent correlations with rainfall indices in the studies of Ward (1992, 1994). A regional index of meridional wind further west is also calculated (10-20E, 30-50N). Finally, JAS values of the Southern Oscillation Index of Allen (personal communication) are used. Some of the indices are plotted in Figure 1, and the intercorrelation of all indices is shown in Table 1. The rest of this paper analyses this correlation matrix in some detail.

	Shl	Sdn	Ind	SST	SLP	U	V	Vc	SOI
Shl	1.00								
Sdn	0.74	1.00							
Ind	0.54	0.49	1.00						
SST	0.30	0.41	-0.13	1.00					
SLP	-0.53	-0.52	-0.32	-0.48	1.00				
U	-0.12	-0.19	-0.04	-0.41	0.09	1.00			
V	-0.09	-0.12	-0.53	0.37	-0.17	0.12	1.00		
Vc	-0.59	-0.51	-0.37	-0.20	0.49	-0.15	0.05	1.00	
SOI	0.48	0.52	0.55	0.10	-0.41	-0.05	-0.30	-0.51	1.00

Table 1. Inter-correlation of local Mediterranean and remote climatic variables in JAS. Rainfall indices (Sahel, Soudan, all India), Eastem Mediterranean Indices (SST, SLP, u-wind and v-wind), v-wind in the central Mediterranean (Vc) and Southern Oscillation Index (SOI). All indices are high pass filtered (50% cut-off frequency set to 11.25 years). Correlations statistically significant at the 5% level are underlined.

3. Local interaction of near-surface wind and SST in the Eastern Mediterranean

The climatological E Med near-surface winds in JAS are from the North-north-west. The winds are known as the Etesian winds. It was hypothesised that a strengthening of these winds would lead to enhanced evaporation and, other things being equal, a reduction in SST. To test whether the data were consistent with this, the following regression model was fitted to the high frequency (HF) components of the series:

$$SST = -0.0 + 0.55*v - 0.56*u \qquad \textbf{(Model 1)}$$

Multiple Correlation: $r=0.59$
Significance: (i) v, $p=0.001$ (ii) u, $p=0.003$

The SST predicted by the model is shown in Figure 2. The statistical significance probability gives the likelihood that the true regression coefficient is not greater than zero. Statistical significance is clearly <1% for both coefficients i.e. the coefficients are highly statistically significant. The sign of the coefficients confirms that a stronger northerly and westerly component in the wind vector accompanies cooler SST. In addition to the stronger winds leading to enhanced evaporation and latent cooling, the winds may also be bringing colder air over the ocean, and creating cooler SST in this way as well.

4. Sahel/Soudan Rainfall and the Eastern Mediterranean

It was shown in Ward (1994) that Sahel and Soudan rainfall both have a statistically significant positive HF correlation with the E Med SST in both 1904-48 and 1949-88 (though for the SST index used here, the correlation with Sahel does not quite reach significance at the 5% level in Table 1). However, the strong low frequency rainfall fluctuation in 1949-88 also showed a strong positive correlation with low frequency JAS SST (visible in Figs. 1a and 1b). The existence of the relationship is difficult to refute.

An initial hypothesis was that circulation anomalies associated with Sahel rainfall lead to changed wind forcing of the E Med ocean which in turn modifies the SST, as shown in section 3. However, the data do not support this. The SST predicted by Model 1 shows no correlation with either Sahel ($r=0.03$) or Soudan ($r=0.06$) rainfall.

Sahel Rainfall (Top) and East Med Air-Sea Variables in JAS

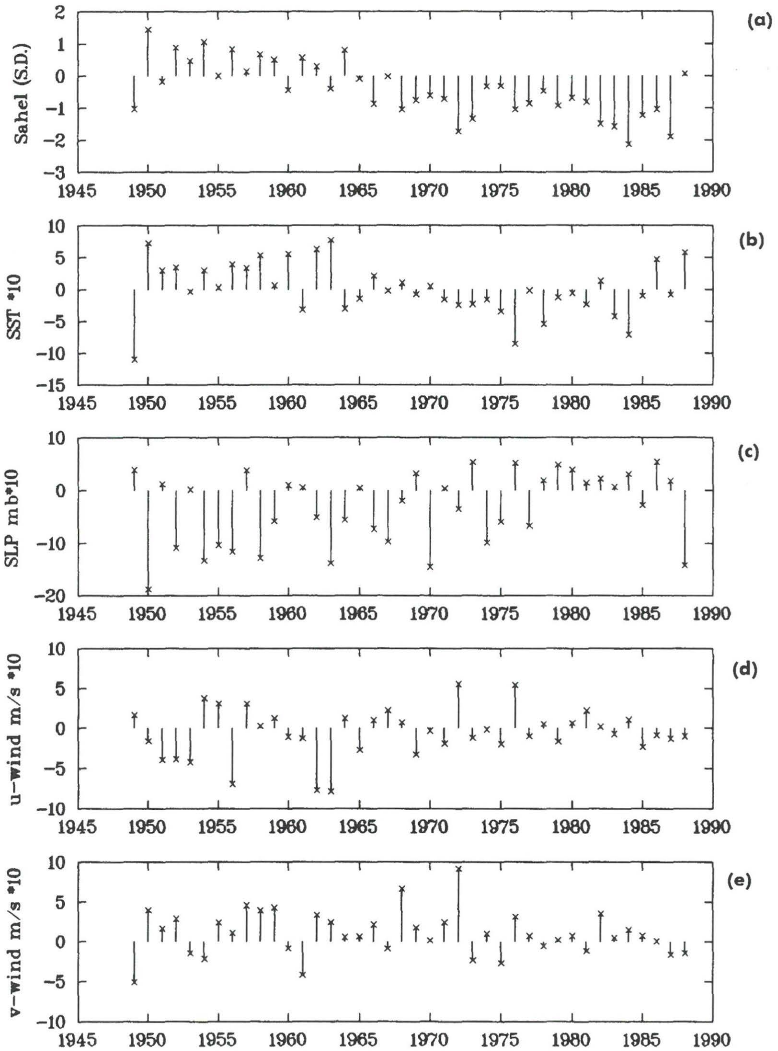

Fig. 1: July-September anomaly time-series 1949-88 (a) Sahel rainfall, (b) Eastern Mediterranean SST, (c) SLP, (d) Near-surface zonal wind, (e) Near-surface meridional wind. The series are unfiltered.

Instead, the rainfall - SST correlation results from years in which SLP and SST vary in tandem, independent of local wind anomalies over the E Med. To show this, regression models were first formed using just SLP:

Sahel = 0.01 - 0.05*SLP **(Model 2)**
significance, p=0.00
correlation, r=0.53

Soudan = 0.01 - 0.05*SLP **(Model 3)**
significance, p=0.00
correlation, r=0.52

When E Med SST is used as a second explanatory variable in these models, the models explain no further variance of Sahel or Soudan rainfall (multiple correlation values stay essentially the same as for Models 2 and 3). Therefore, synchronous SLP and SST anomalies are associated with the same rainfall anomaly events.

What is causing the SST and SLP variations that are associated with Sahel/Soudan rainfall? It is possible that more than one chain of processes is involved. We can speculate that in anomalously wet Sahel years, there is a stronger Northern Hadley circulation leading to enhanced descent in the E Med. This would lead to enhanced solar radiation and a generally warmer atmosphere (both tending to heat the SST). Support for this hypothesis is offered by the association between enhanced Sahel rainfall and a general reduction in precipitation through the Mediterranean (Figure 2). The low SLP in wet Sahel years may in part be a hydrostatic response to the higher SST.

These hypotheses require more detailed physical examination, but the robustness of the teleconnection is supported by the Sahel and Soudan correlation with northerly wind in the central Mediterranean (Table 1), which is geostrophically consistent with the correlation with lower SLP in the E Med. Note that the local northerly wind in the E Med neither correlates with the northerly wind in the central Mediterranean nor the rainfall in the Sahel and Soudan (Table 1).

Correlation between Sahel rainfall and rainfall (HF) 1949-1988

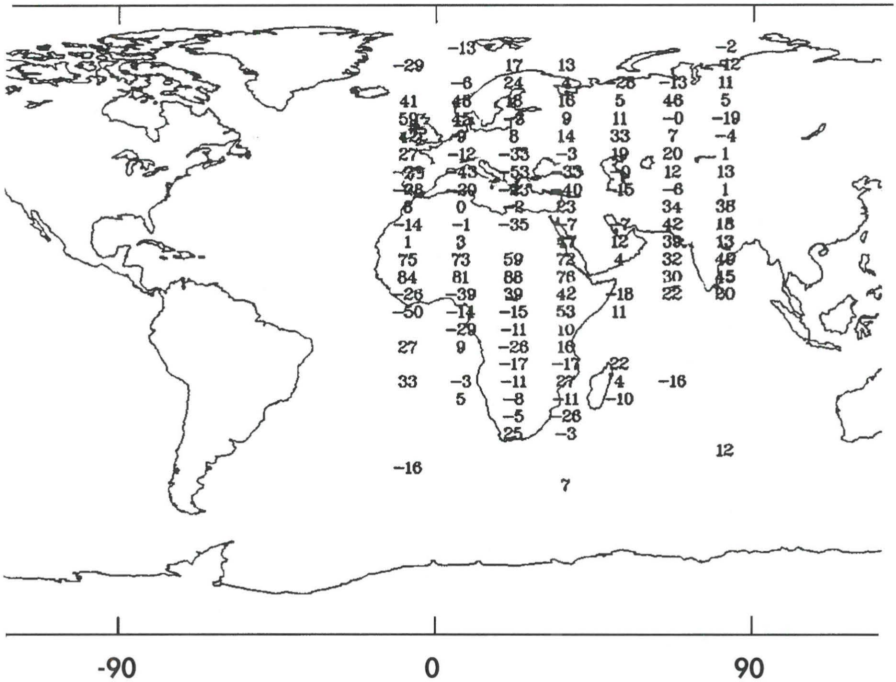

Fig. 2: Correlation (*100) between the JAS Sahel rainfall index and JAS rainfall in each 5° lat x 15° long grid-box. All series were high-pass filtered prior to analysis, removing timescales > 11.25 years.

5. Indian Rainfall and the Eastern Mediterranean

Indian rainfall is strongly correlated with enhanced northerly wind in the local E Med (Table 1). If the northerly Etesian winds are viewed as part of the enlarged monsoon circulation, this teleconnection is natural, and consistent with the proposal of the Reading group. The northerly winds are associated with a portion of Indian rainfall variability that is independent of ENSO, as can be seen from the extremely high statistical significance of meridional wind and SOI in a regression model predicting Indian rainfall:

India = 0.01 - 0.14*v + 0.04*SOI **(Model 4)**
Multiple Correlation, r=0.67
Significance: (i) v, p=0.00 (ii) SOI, p=0.00

Enhanced northerly wind is associated with cooling of the E Med SST (Table 1, and section 3). Thus, a puzzle concerns the absence of any correlation between Indian rainfall and E Med SST (Table 1). This can be reconciled if one considers a second chain by which India connects to E Med SST. The second chain results because Indian and Sahel rainfall are positively correlated, and Sahel rainfall and E Med SST are positively correlated (Table 1). This second chain therefore favours a positive correlation between India and E Med SST, whereas the first chain favoured a negative correlation. It is suggested that the two effects cancel to give no correlation between Indian rainfall and E Med JAS SST.

6. Conclusions

A triangle of effects is proposed:
(i) Enhanced Indian monsoon rainfall leads to a stronger northerly surface wind over the E Med - In the absence of other effects, these winds lead to cooler SST.
(ii) Enhanced Sahel rainfall leads to (and may in part be created by) high SST and low SLP in the E Med.
(iii) Sahel rainfall and Indian rainfall correlate positively; this was first proposed by Kraus (1958) and placed in the context of a tropic-wide oscillation in Ward et al. (1994).

From the viewpoint of links between remote rainfall and E Med SST, the India-E Med correlation results from (i) a weak negative forcing via India - E Med wind - E Med SST and (ii) a weak positive forcing via the India - Sahel - E Med SST/SLP chain. The two weak forcings cancel out to give no correlation between India and E Med SST.

In contrast, the Sahel - E Med SST correlation is made up of a strong positive forcing via Sahel -E Med SST/SLP connection, and a weak negative forcing via Sahel - India - northerly wind connection. The strong positive forcing dominates to give a positive correlation between Sahel and E Med SST.

The cancellation that leads to no correlation between E Med SST and India is also the probable explanation for the absence of a correlation between SOI and E Med SST (Table 1), since SOI correlates with both Sahel and Indian rainfall. The two ways to connect to the E Med do not lead to cancellation of the SLP associations, so E Med SLP shows the strongest and most statistically significant correlations with Sahel rainfall, Indian rainfall and SOI (Table 1), in support of Walker and Bliss (1932).

Clearly uncertainties in the relationships still exist. Further analysis of the mechanisms is needed, and caution is needed concerning the large size of the boxes used here for studying Mediterranean variability. Nonetheless, the analysis here suggests that the relationships are internally consistent and physically plausible. The recurrence of the statistically significant associations in all variables analysed (SST, SLP, surface vector wind) strongly supports coherent air-sea interaction in the Mediterranean that participates in large-scale climatic anomalies over tropical North Africa and India, and through them, to tropics-wide and

Eastern Med in JAS 30-40N. 20-40E

Simulation of High Frequency SST from High Frequency u and v

.... simulated ______ observed

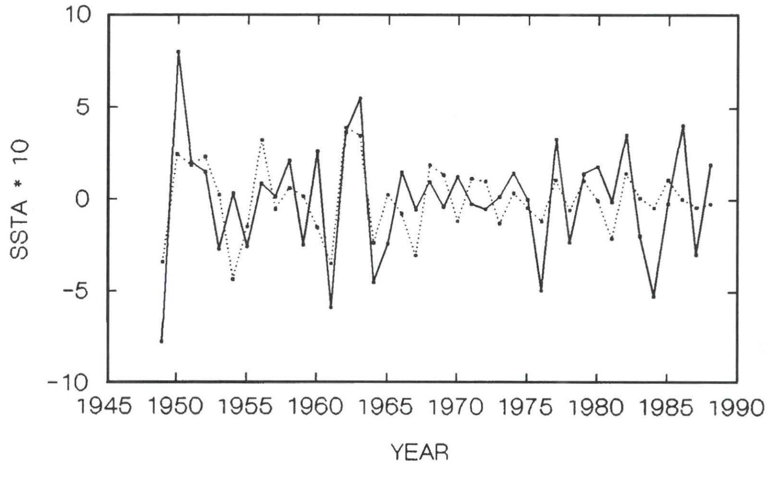

Fig. 3: Simulation of July-September Eastern Mediterranean SST anomaly from a multiple regression model with JAS values of near-surface zonal wind and near-surface meridional wind. The correlation of the simulated (dashed line) and observed (solid line) is 0.59. All series were high-pass filtered prior to analysis, removing timescales > 11.25 years.

ENSO variability. The Mediterranean anomalies are probably in large part a response to variations in African and Indian rainfall and circulation anomalies, but a feedback on or a smaller primary causative influence into the tropics is possible.

For understanding extratropical circulation anomalies, the next stage is to assess whether these E Med associations are a route to understanding better the correlation between Sahel rainfall and summer precipitation and circulation over Europe as a whole (Fig. 3, and see Folland et al., 1988 and Ward, 1992). For understanding Mediterranean air-sea variability, work is underway to look at the three-dimensional variability of salinity and temperature during JAS in the Mediterranean (Fabio Raicich, personal communication).

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Climate variability processes in the Eastern Mediterranean

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It is important to understand the natural climatic variability in ocean regions in order to establish their sensitivity to change. The Mediterranean region is one of the areas of the world where interannual climatic variability seems to be the strongest. Since the entire Mediterranean Sea is efficiently ventilated, with a relatively short memory of ~ 100 years, the basin is very sensitive to climate variability, and possibly to climatic changes; similarly the Mediterranean can have an impact on local climate, perhaps more significantly than suggested by its size. Recent evidence of long term warming and increasing nutrients in the deep waters of the Western Mediterranean, point to the importance of understanding individual processes contributing to changes on interannual and interdecadal scales. We describe such variability in the Eastern Mediterranean, and suggest synchronism with events in the surrounding seas, in order to establish a record of the events.

Buoyancy fluxes from the sea into the atmosphere during cold outbreaks in winter lead to the formation of Levantine Intermediate Water (LIW) in the northern Levantine Sea. Various hypotheses have been advanced to date to explain the formation of LIW: isopycnal sinking of dense water from cyclonic regions, convection at continental shelf/slope regions, convection in anticyclonic eddies, Ekman flux convergence near the coasts, and wide-area convective overturning. The heterogeneous distribution of LIW in the Levantine Sea is maintained by these various source mechanisms and complex dynamics. Consequently, there is a wide range of interrannual variations in the pattern of LIW formation.

Compared to LIW, the origin of the deep waters in the Eastern Mediterranean is less clear: While it is generally accepted that the Bottom Water is formed by waters cooled in the shallow Adriatic Sea, it is recognised that the more heterogeneous overlying Deep Water seems to have multiple sources. The possibility of Deep Water formation in the cyclonic Rhodes Gyre region has been confirmed by recent observations.

In contrast to the analogous deep convection events in the west, pre-conditioning is not essential for deep convection in the Rhodes Gyre region, a permanent cyclonic region of the Eastern Mediterranean. During severe winters, LIW and DW are simultaneously formed in the northern Levantine region.

Qualitative changes in the northern Levantine circulation are often associated with the recurrence of deep convection events in the Rhodes Gyre. After the 1986/87 event, drastic changes in the circulation resulted in the flooding of the northern Levantine by low salinity Atlantic Water (AW) from the south.

Similar events of deep convection leading to changes in the basin-scale circulation have been demonstrated in the Western Mediterranean. These changes in the modality of circulation could, in turn, lead to short term (interannual) climatic variations via ocean-atmosphere interaction.

In the case of the 1992 deep mixing event, an atmospheric anomaly of global scale, with substantial influence in the Black Sea region seems to have played an important role. The average air temperature for the year 1992 in Turkey was cooler by 1-2 C in comparison to the averages of the previous year.

Globally, 1992 was the coolest year since 1986 in the north hemisphere, in the period following the June 1991 eruption of the Mt. Pinatubo volcano, which resulted in a significant decrease in solar energy input especially in the northern hemisphere, lasting for more than a year. The surface air temperature anomaly pattern for the first three months of 1992 showed a significant deviation from climatic means, of up to -4 C in the Eastern Mediterranean and the Middle East, and +5 C in the northern part of Europe. The anomaly in the Middle East persisted, while it dissipated over Europe, in the remaining nine months of the year.

A great degree of synchronism is suggested with the adjacent seas. For example, during the 1987 and 1992 deep water formation events in the Rhodes Gyre region, extreme cooling effects were also noted in the surrounding seas, e.g., dense water intrusion into the Marmara Sea from the Aegean, and convective erosion of the pycnocline in the Black Sea. An extraordinary productivity event during 1986-1988 is reported in the Black Sea, based on radioactive dating of fresh bottom sediments.

Persisting a number of years since the 1992 event, an intrusion of saline, warm and well oxygenated waters have been consistently detected entering the Levantine Sea from the Aegean Straits. Since a similar event was not observed in the preceding years of intensive surveys, it is suggested that the severe winters of 1991 and 1992 have resulted in dense water formation in the Aegean Sea, filling the deep Cretan Sea basin of the Aegean, and cascading into the Levantine Basin through the Straits.

Satellite data indicate persistent patterns of some eddies in the Levantine Basin. However, interannual variability, and its effects on the productivity pattern are strongly felt in the Mediterranean.

Predictability of surface changes from Mediterranean deep water signatures of physical and biogeochemical trends

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There are several signatures of past and present evolutions in the Mediterranean Sea and in its environment. Apart from geodynamical evolutions which are on very large time scales (million years), in the sediment there are signatures of past changes in climate, hydrology, fauna, oxygen, biological production (e.g. the peculiar example of the sapropel layers over the last half million years, Bethoux, 1993). Interpretation of past records allows elaboration of forecast scripts. During the last three decades, changes have occurred in the temperature and salinity characteristics of the Western Mediterranean deep-waters. They are signatures of evolutions of climate and/or environment which are neither truly perceptible at a local scale of terrestrial or coastal measurements, nor anticipated. Trace metals together with nutrients also give examples of non-steady state concentrations in sea-water, according to the environmental evolution. Concerning the biological ecosystem, Lessepsian migrators (Galil, 1993), opportunist fauna or flora, red tides, etc. are signatures of quite fast changes induced by human activities (the Suez Canal, the High Dam, the import of Japanese spawn, aquariology, coastal eutrophication, etc.) and by possible climatic change. Today, most of these biological changes concern fishes and tides of specific plankton with socio-economic consequences (fishery and tourism); they were foreseeable but not forecast. These marine signatures prove that the Mediterranean Sea offers the opportunity of a unique challenge to describe, understand and monitor, in quite real time, the evolution of a deep-sea submitted to climatic and environmental changes. But evolution scenery is necessary in order to describe, model and forecast the environmental consequences.

1. Temperature and salinity changes

In the Algero-Provencal basin (Western Mediterranean), analysis of measurements made since the early sixties has shown that temperature and salinity in the deep water (from about 1000m depth to the bottom at

2700m) were increasing with time. Between 1959 and 1995, the deep water warming reaches O.13=B0C and the salinity increase is about 0.04 psu. In the intermediate water (at a depth of 300 and 400m) of the Ligurian sea, at about 30 miles off Nice, temperature and salinity increasing trends are about twice the deep water trends. Temperature and salinity changes occurring in the deep and intermediate waters of the Western basin are signatures of changes in heat and/or water budgets occurring at the surface of the Western and/or Eastern basin (Bethoux and Gentili 1995). In Bethoux et al.(1990), the warming trend in Western deep-water (WDW) was assumed as a first piece of evidence of the green-house effect, concomitant with a change of the water budget linked to an increase of evaporation as well as to a decrease of rainfall, as shown from meteorological data around the north-western Mediterranean sea. In later studies (e.g. Rholing and Bryden,1992), the warming trend was also anticipated as a response to a salinity increase, imported from the Eastern basin and linked to changes in the freshwater budget (e.g. damming of the Nile river in 1964 and of rivers of the Black Sea since the early fifties). The use of marine changes towards a monitoring of climatic or environmental evolutions needs to know marine circulation but also the changes of surface driving forces, precipitations, river runoff, air-sea exchanges, etc, on a basin or whole sea scale. At present, calculated surface evolutions (e.g. temperature) do not agree with surface mean trends from meteorological data, probably according to differences in time and space scales.

2. Nutrient evolution signatures

Analysis of historical data together with recent data acquired in the Western Mediterranean proved increasing concentrations of phosphate and nitrate in the deep water, about 0.5% a year (Bethoux, et al. 1992). Via marine circulation, this marine increase was calculated to correspond to a 3% yearly increase of atmospheric and/or terrestrial discharges around the whole Sea since the early sixties. From ground enquiries, there is no corresponding estimate available, but this result is in agreement with the global scenario proposed by Meybeck (1982) where total dissolved phosphorus in land surface water globally increases proportionally to the watershed population and to its energy consumption. Effectively, in the Mediterranean countries, socio-economic data show inhabitant increase of 1.6% a year, standard of living of +4.5% a year and energy consumption +6% a year, over the 1960-1985 period (Unep 1988). But since the end of the eighties, the slack times for socio-economic activities, the change in agricultural methods and the beginning of implementation of waste-water treatment, we have no more evaluations of the real anthropogenic pressure on a basin scale. Terrestrial input of phosphorus occurs in the coastal area; their increasing trends may be seen by frequent eutrophications in some hot points. But, more diffusely, they mean increasing biological production in surface layer, increasing consumption of oxygen in deep water for the remineralization of organic matter settling from the surface and a probable partial anoxia in a few decades. Knowledge of terrestrial input of nutrients and thermohaline circulation may allow the behaviour of biological production and its effects on oxygen and carboncycles to be estimated.

3. Trace metal concentration changes

Trace metal profiles in the Mediterranean sea are quite different from those in the open oceans, i.e. rather high concentration in the surface layer and more or less constant vertical profile (Ruiz-Pino, et al. 1990; 1991). These differences were explained by the non-steady-state of the Mediterranean concentrations and allowed the calculation of dissolved atmospheric and terrestrial input and their probable evolution between 1960-1985: +6% a year for zinc and lead and +2% a year for copper and cadmium (Bethoux et al. 1990). These data give a new evaluation, at a basin scale, of the changing environment of the Mediterranean Sea. Another example of the rapidly evolving Mediterranean environment was given in the study of decreasing lead concentration in the surface layer occurring since 1988 in the north-western basin (Nicolas et al. 1994). A halving of the surface concentration followed the application of the European policy concerning the decrease of lead additives in gasoline and the increasing use of unleaded fuel. This study needed data from the petroleum industry. Moreover, using economic scenarios for the evolution of population, energy consumption and vehicle numbers over the 1950-2025 period, a prediction of the marine lead concentration evolution was proposed (Tian and Ruiz-Pino, 1995).

Conclusion

From the previous examples, one may consider that the monitoring of a Mediterranean ecosystem evolution is on the right track. This monitoring may also have a chance of producing a better understanding of the whole Mediterranean environment (sea, watershed population and activities, climate) as far as marine signatures at basin scale can be compared to climatic and socio-economic studies and may be used in evolution scenario. This is an opportunity for forecasting. But anthropogenic changes are difficult to define and quantify at the Mediterranean basin scale, insofar as differences are great between bordering countries (demography, standard of living, mean gross national product, industrial and agricultural activities, etc.). According to the strong space and time variabilities of the local climate, detection of a climatic trend (heat and/ or water budget) over the whole sea is also difficult to investigate from some ground observatories. Nevertheless, quite isolated from the oceanic advection, the Mediterranean Sea may be an opportunity to detect, monitor and forecast probable consequences from climatic and environmental changes.

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10-year series of ocean data assimilation

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A system of ocean data assimilation (DA) is applied to global oceanographic analysis, using XBT and sea surface data. The DA scheme is that of Derber and Rosati (1989), and ocean datasets are: the COADS, MOODS, TOGA, and FOCAL, the time span being 10 years, 1979 - 1989. These data are injected into an oceanic GCM of Rosati and Miyakoda (1988), i.e., a subset of MOM (Modular Ocean Model).

The DA scheme is based on the variational principle, in which ocean model solutions are used as the first guess. In reality, only temperature observations were injected through the spatial statistical analysis technique of Gandin (1966).

The resulting DA product was compared with independent analysis, and observations. For example, using the mean of the 10-yr period as a climatology, the DA results are compared with the Levitus climatological atlas, and with the Reynolds sea surface temperature maps. The agreement is good.

These oceanic DA are utilized as initial conditions, together with the NMC atmospheric DA, for one-year ENSO forecasts, and successful results have been obtained, using a coupled ocean-atmosphere GCM. Another achievement is that deficiencies of the oceanic GCM have been identified by comparing model's simulation with the DA results. For example, tropical thermocline structure. However, a number of drawbacks of this particular DA have also been noticed. First, comparing the current results of DA with the TAO observation over the equatorial Pacific, the agreement is not satisfactory. Secondly, the salinity data are not injected in this 10-yr DA.

This 10-yr series of oceanic DA is the first attempt at reconstructing a synoptic oceanographic dataset. In meteorology, a first long term DA was conducted in FGGE (First Global GARP Experiment). Two meteorological centers participated in producing synoptic series of DA, i.e., the GFDL and the ECMWF. Noticing deficiencies in these DA results, re-analysis of FGGE data was carried out in the late 1980's. But the time span of DA in these experiments was short, i.e., one year. Recently the value and the necessity of long continuous synoptic DA have been recognized; CDAS in NMC and the similar analysis in ECMWF, for example, are being conducted, which cover at least 10 years, 1985 ~ 1995. The period may be expanded even further. It is quite essential and indispensable to obtain such a long-term series of DA, in order to explore interannual variation of the atmosphere-ocean system (see Bengtsson and Shukla 1992).

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MonteCarlo techniques in simulations of geophysical flows

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It has been known for a long time that hydrodynamic instabilities play a key role in the maintenance and evolution of the atmospheric circulation. Since the pioneering works of Charney and Eady, baroclinic and barotropic normal mode instabilities have been shown to provide the basic framework to understand the energetic and the life-cycle on atmospheric disturbances. The concept has been made sharper by the work of Lorenz and many others that have shown the chaotic nature of the atmospheric circulation. The atmosphere is a classical system and therefore it would be more correct to describe it as a pseudo-chaotic system. In this case the random element stems from the extreme sensitivity to small differences in the initial conditions, rather than from a real random nature of the physical system, as in microscopic quantum systems.

Arbitrary small deviations in the initial conditions will amplify very rapidly in large deviations in finite times. Numerical experiments and the forecasting experience have demonstrated very effectively this property of the atmosphere, documenting the severe limitation of the useful forecasting range implied. Current estimates range around two-three weeks limit for an instantaneous forecast in the atmosphere. In an atmospheric forecasting context the presence of the random component will be dominated by the insufficient specification of the initial condition (model deficiencies are neglected). In practice, it is impossible to estimate an initial condition accurate enough to eliminate the random component, and the small errors, i.e. deviations from the "true" state of the atmosphere, will quickly grow in full-size features. In order to minimize the impact of the initial errors, it is necessary to perform multiple forecasts for the same nominal initial date, each slightly perturbed, so that the actual forecasts can be obtained from the whole ensemble through statistical methods. Ensemble mean is the most commonly used in the hope that the random components will compensate each other. The choice of the initial perturbations is of course a crucial one and much effort has been devoted to the development of strategies and techniques to choose optimal perturbations that will sample around the initial condition. The basic requirement is that perturbations should be fast-growing, to maximize the development of errors, and they should have some connection to the error of the initial condition as estimated from the data assimilation procedure. Two main methods have been devised; the first is based on the concept of non-normal-mode instabilities and it is currently under development at the ECMWF, whereas the second, currently under development at NMC, selects the perturbations by breeding them from the analysis process. The evolution of the ocean circulation seems to be dominated by strong nonlinear instabilities in the same way as the atmosphere and therefore it is reasonable to expect that MonteCarlo techniques will be needed. The relevance of these efforts to ocean forecasting will be discussed.

El Niño-Southern oscillation prediction experiments

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1. Introduction

The El Niño-Southern Oscillation phenomenon (ENSO) is an interannual perturbation of the climate system. It is characterized by a weakening of the trade winds and a warming of the sea surface temperature in the equatorial Pacific. ENSO occurs every 4-7 years and its impacts are felt world-wide. Recently, coupled ocean-atmosphere models have been used to describe ENSO and to predict it at lead times of up to one to two years. The predictability of ENSO is determined by the oceanic part of the coupled system. The accuracy of the initial state from which a prediction is started is crucial. Hence, data assimilation into ocean models should be a powerful tool to improve ENSO forecasts. The two different types of observational data most relevant for ENSO predictions are oceanic temperature measurements down to a depth of several hundred meters and sea level observations. In general, the accuracy of temperature measurements is satisfactory and they contain the required information to initialize a coupled ocean atmosphere forecast system. However, these data are mainly taken from ships or buoys which may lead to poor spatial and temporal data coverage in certain areas. In contrast, sea level data are available almost continuously in space and time since they can be measured with reasonable accuracy from satellites. In principle, they both contain the ENSO signal, and it is an interesting question whether the impact on ENSO forecasts is comparable for both types of data.
In this study we present an intercomparison of the impact of sea level and temperature data on ENSO predictions. The two different types of data are assimilated one by one into a primitive equation model of the tropical Pacific. ENSO forecasts with a hybrid coupled ocean-atmosphere model are performed, and their impact on the predictive skill is investigated. Another problem that occurred during our investigations was the validation of ENSO predictions. An alternative skill measure is

presented which shows more clearly the positive impact of data assimilation on ENSO forecasts.

Furthermore, a case study of the 1986/87 ENSO event with a coupled general circulation model is presented.

2. Data

To initialize the hybrid coupled model (HCM), FSU pseudo wind stress fields were used [FSU product, Goldenberg and O'Brien 1981, Legler, O'Brien 1984], and a relaxation of the temperatures in the uppermost layer of the ocean model towards observed climatological sea surface temperatures was applied. Reynolds SST anomalies were used for validation purposes [Reynolds 1988, Reynolds and Smith 1994]. For the case study, ECHAM-3-AMIP wind forcing fields were employed.

The data that were assimilated to initialize the HCM, were obtained from the NMC (National Meteorological Center) reanalysis data set. This is the output of an oceanic analysis system in which surface and subsurface temperature observations are assimilated [Ji et al. 1995]. In the case study of the 1986/87 event, analyzed XBT data provided by the BMRC were assimilated.

3. Experiments

3.1 Experiments with the hybrid coupled model

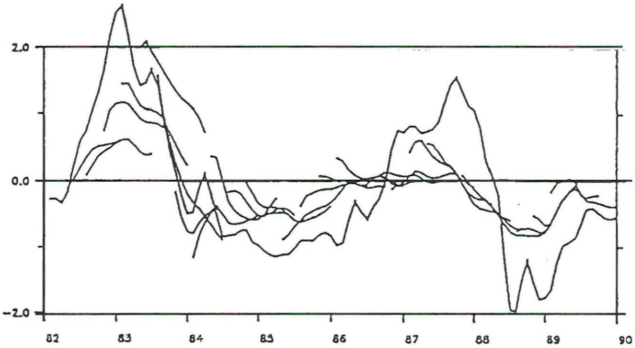
The experiments presented in this section were performed with a hybrid coupled ocean model. It consists of a primitive equation model of the tropical Pacific which is coupled to a simplified statistical atmospheric feedback model [Latif 1987, Barnett et al. 1993]. The ocean model has a relatively coarse resolution and simplified parameterizations. The assimilation system is a continuous insertion scheme which is based on the successive correction method.

Three sets of experiments are presented. Each set consists of an initialization run in which the ocean model is forced with observed wind stress data and an ensemble of forecast experiments in which the model is integrated in a coupled mode. In a control experiment, no oceanic observations were assimilated. In the second and third set, 3-dimensional NMC temperatures and sea levels were assimilated respectively during the initialization.

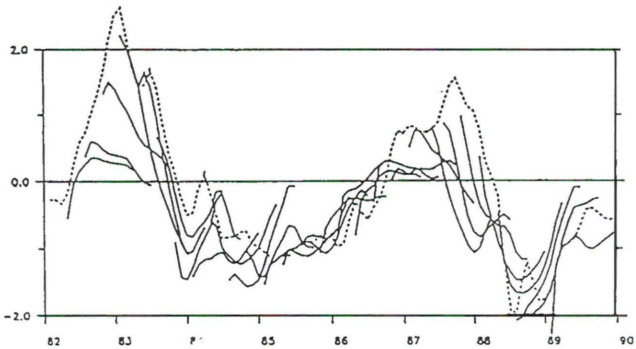
In recent studies [Miyakoda et al. 1994, Ji et al. 1994], it has been shown that the assimilation of subsurface temperatures may improve ENSO predictions significantly; this was confirmed by our studies. From the third experiment, assimilating levels, we found that the impact of 3-dimensional temperatures and sea levels on ENSO forecasts is comparable for both types of data. This result was also indicated by preliminary investigations in which GEOSAT altimetry data were assimilated [Fischer et al. 1994]. In Fig. 1, the individual forecasts are compared to observed SST anomalies averaged over NINO-3 for the three experiments. These results indicate that the assimilation of sea levels substantially improved the forecasts relative to the control ensemble. However, this positive impression was not confirmed, using the traditional skill measure which is based on the correlation between predicted and observed temperature anomalies. This was shown more clearly when the predicted temperature differences, rather than the temperature anomalies themselves, were compared with observations. This indicates that the question of forecast validation has to be addressed in more detail [Fischer et al. 1995].

3.2 Case study for the 1986/87 El Niño event using a CGCM

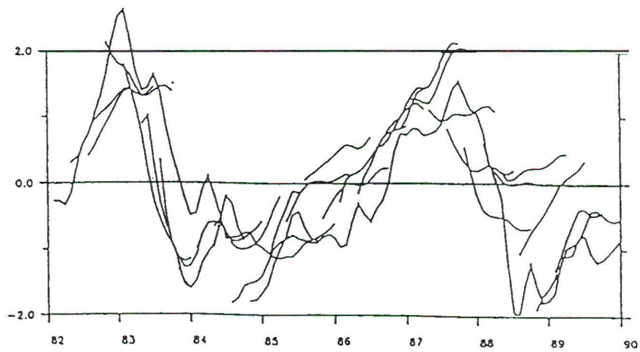
This case study was carried out with a full coupled general circulation model (CGCM). It consists of a global high resolution ocean model [...] based on the primitive equations which is coupled to an atmospheric general circulation model with a T-42 resolution [...]. To initialize this model, the oceanic part was forced with wind fields obtained from an AMIP integration of the ECHAM-3 model. Two experiments were performed. In a control run, no additional data were assimilated. In a second run, XBT observations from the tropical Pacific were assimilated into the ocean model during the initialization. A rather strong impact on the forecast was observed. In the control experiment, the model failed to predict the 1986/87 event, whereas in the assimilation experiment it was clearly predicted at lead times of one year. Again the validation of the forecast turned out to be a considerable problem. The positive impact of data assimilation became much more obvious when the predicted SST anomalies were projected on EOFs of observed SST anomalies.



a: control experiment



b: temperature experiment



c: sea level experiment

Fig. 1: Observed and predicted SST anomalies averaged over NINO-3 for the period to 1989. Each individual forecast was carried out over one year.

The problem of large scale ocean predictions in the Mediterranean Sea

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The Mediterranean Sea is found to have large scale variabilities at seasonal and interannual time scales from observational data and modelling results. The latter point out that the atmospherically induced variability can be as large as the "internal variability". Many puzzles about the character of the general circulation were solved after the eighties, when the major data sets were collected and evidence for a new picture of the general circulation emerged. On the basis of these observational sets, it is clear that time resolution is an important parameter to consider if an efficient system of monitoring the space-time variability has to be set for the entire basin. There is a need for ship of opportunity data which give the subsurface thermal structure of the ocean, continuing activity on the combination of satellite altimeter and infrared imagery with the subsurface in situ data and the necessity of development of new systems to monitor the salinity variations on an almost operational basis.

From the numerical modelling point of view, much progress has been made in recent years to simulate the large scale ocean circulation of the major subbasins and the overall basin. The general circulation models applied to the region are already capable of simulating the upper thermocline large scale structure of currents, the water mass formation processes and the dispersal of waters throughout the basin. However, the critical assessment of the state of the art simulations suggests that improvements on the air-sea interaction physics, the vertical mixing parametrizations and the representation of dense waters downslope motion are needed. Numerical forecasting is also the activity which will set the standard of the numerical simulations and the future needs for the improvement of the model physics and data assimilation tools.

The critical assessment of observations and models has also pointed out that the knowledge of atmospheric forcing is essential to any ocean forecasting activity in the Mediterranean. The critical assessment of the sensitivity to different space-time resolution on the atmospheric forcing has to be carried out in the very near future. It is also evident by now that the Mediterranean is part of a complex atmospheric circulation which includes the North African continent and the Monsoon regime. Direct coupling between the ocean and the atmosphere on the Mediterranean and neighbouring land areas should also be reconsidered in the light of practical usage of ocean forecasting activities.

Advanced data assimilation in non-linear ocean models

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An overview is given of the current status of inverse methods and data assimilation for non-linear ocean models with particular focus on so-called advanced methods, i.e., methods which use proper error statistics.

The general formulation of a variational inverse problem for time dependent dynamical models is discussed and the most promising solution methods are illustrated using simple examples. The representer method is discussed in an application with the Ekman flow model in a parameter estimation problem and a gradient descent method is used to solve the inverse of the Lorenz equations. It is shown that strong constraint variational formulations can only be solved for short time intervals compared to the predictability limit of the model, while a weak constraint formulation removes the constraint on the time interval and eliminates the strong sensitivity of the penalty function with respect to the initial condition. Further, a weak constraint variational formulation can be solved as easily as a strong constraint formulation using, for example, a gradient descent method with the full state in space and time as control variables or by calculating representers.

Advanced sequential methods have traditionally been based on the Kalman Filter with various approximations for computational feasibility. However, the Kalman filter has proven to be rather impractical in realistic applications with non-linear dynamics. In addition to the computational aspect there is also a closure problem for the error covariance evolution for non-linear dynamics.

A new sequential method which is based on ensemble integrations, i.e. the Ensemble Kalman Filter, was recently proposed and has been examined with a non-linear QG model. The method will be discussed and illustrated with examples from a data assimilation experiment in the Agulhas current. The ensemble Kalman Filter provides a mathematically consistent sequential method where no closure assumption is applied. The only approximations are due to a limited ensemble size and the numerical load is the integration of the ensemble of ocean states.

A sigma coordinate model of the Mediterranean Sea; deep water formation and climate drift

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Part of the abstract of a paper by Zavatarelli and Mellor (1995) reads as follows:

A primitive equation ocean model (the POM model) which makes use of a curvilinear orthogonal grid and a sigma- coordinate system was used to study the general circulation of the Mediterranean Sea. The model was forced with monthly climatological values of wind stress, heat and salinity flux. Fresh- water river discharges of small rivers and the Black Sea were included in the forcing. With the help of the curvilinear horizontal grid, the larger scales of the entire Mediterranean Sea are modelled and the topography around the narrow and shallow Strait of Gibraltar is also reasonably well represented. The resulting model inflow and outflow seems to mimic the real Mediterranean, often in considerable detail. Levantine Intermediate Water is formed in the Levantine Basin and exits through the Strait of Sicily and the Strait of Gibraltar. Deep-water formation processes are clearly represented by the model.

Since the paper was published two things have happened. The run time of the model has been extended from 10 years to 30 years and the model results of Roussenov et al (1995) have appeared using the z-level, MOM model, a derivative of the Bryan-Cox model; this model was integrated for 67 years.

The present talk will present the new results of the extended POM calculations and comparatively review the results from the POM and MOM models. There will be an attempt to answer the ever burning question: Where do we go from here? For example, one might conclude that numerical studies of the Mediterranean should intensify - addressing issues of model characteristics and surface forcing - as a precursor to numerical studies of the World Ocean.

Zavatarelli, M. and G.L. Mellor, 1995: A numerical study of the Mediterranean Sea Circulation. J. Phys. Oceanogr, 25, 1384-1414.

Roussenov, V., E. Stanev, V. Artale and N. Pinardi, 1995: A seasonal model of the Mediterranean Sea general circulation. J. Geophys. Res., 100, 13515-13538.

Operational objectives for ocean forecasting in the civilian sector: the Mediterranean case

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Rapid progress is being made by modelling groups and experts on data assimilation towards the goal of having sufficient knowledge and expertise to run operational marine forecasting models. Over limited areas and with limited number of parameters, many such models are already in existence. Studies are needed, in parallel with the science, in order to ensure that observational data are gathered which can be assimilated into models, that governments and industry will provide the necessary finance, that data transmission and data quality control systems are adequate to transmit the data to modelling centres, that potential user groups have identified their needs for forecasts, and that economists and politicians are conviced that investment in a marine forecasting system for the Mediterranean is justified. The investment in an operational marine forecasting service will be large, and this can only be justified if the economic, social and environmental benefits in the Mediterranean area exceed the cost by a substantial multiple. The oceanographic and economic conditions of the Mediterranean are unusual, if not unique, and thus calculations and lessons learnt from other areas cannot be adapted easily by analogy. This paper outlines tentatively the investigations needed to provide a fully argued case for investing in a marine forecasting service in the Mediterranean. Reference is made to studies carried out by OECD, and by EuroGOOS, although the results cannot be applied directly in the Mediterranean area.

Altimetric data assimilation conserving water properties

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A data assimilation method has been developed which seeks for an adiabatic and frictionless re-arrangement of water parcels as a means of introducing altimeter data into ocean circulation models. Thus a Lagrangian conservation law is introduced into the assimilation problem. The development of this method from a quasi-geostrophic technique to a use with an ocean general circulation model is described. Twin experiments are used to validate the results and it is shown that, at least for the cases examined, the deep sub-thermocline circulations can be recovered well using surface pressure data alone (results involve penetration through 16 model levels to recover the flow at 2800 m depth).

The application of this method to real data sets is still in its early stages but results will be shown from TOPEX/ERS data assimilated into the MOM GCM model in the Mediterranean region. ECMWF winds and SST from the Along-track scanning radiometer are also used. The assimilation is shown to modify the distribution of LIW in the model compared to a control run without altimetric assimilation. This is examined by studying the salinity distribution on isopycnal surfaces, which is not changed directly at assimilation time. Attempts to hindcast the observed surface pressure distributions with the model have been less successful although some cases which show promise will be discussed.

Optimal interpolation and adaptive filtering in the Mediterranean

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In this paper, satellite altimetry and data assimilation are used to study the seasonal and interannual variations of the topography and three-dimensional circulation of the Mediterranean, as well as the temporal changes of the mean sea-level. In addition a new assimilation method called "adaptive filtering" is introduced.

The analysis of TOPEX/POSEIDON data has shown for the first time the seasonal sea-level cycle in the Mediterranean. The largest components are the steric effect, due to the variations of the heat storage, and the E-P induced variations. Occasional fast variations might be due to the cooling effect of winds on the surface layer, as well as to the combined effect of atmospheric pressure forcing and hydrodynamic control at straits.

The mean sea-level variations are removed from the topographic observations to produce a dataset suitable for assimilation, i.e. containing an oceanographic signal that can be represented in the rigid-lid primitive-equation model. The ERS-1 observations are used to complement the TOPEX/POSEIDON dataset for the purpose of improving the coverage at the eddy scale. A special algorithm is applied to avoid contaminating the whole dataset with the poor ERS-1 orbit.

The assimilation method uses suboptimal interpolation on the horizontal, and a statical method in the vertical based on space-varying vertical orthogonal modes. An alternative method conserving potential vorticity is also tested on the vertical. The initial guess is a 65-year spinup reproducing the seasonal cycle. It is shown that the model is able to produce three-dimensional estimates of the circulation and thermohaline structure, and that if the resolution is high enough, the forecasting capabilities of the scheme are quite good.

A new assimilation method, the adaptive filter, is introduced. There is no longer any need for the model related and observational error statistics, and the algorithm is very economical. The method is based on the variational identification of the steady-state gain. It is applied to a channel model of the Mid-Mediterranean Jet (MMJ) in the Levantine basin, and to the assimilation of surface observations.

A neural network forecasting model of the Mauritania upwelling

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The SST (Sea Surface Temperatures) changes observed off Mauritania coast are modelled by using a neural network (NN). The ocean state (temperature, salinity, currents, ...) at a specific location can be considered as the output of a complex transfer function forced by specific input as the wind, solar radiation, thermohaline exchanges...... This complex transfer function can be modelled by NN (Thiria et al, 1993) if the ocean state mainly depends on local forcing. In the present case the input of the neural network are the components of the wind vector which are parallel and perpendicular to the cost observed during the M preceding days of the computed SST and the output is the SST. The wind vector is obtained from the meteorological forecasting model ECMWF. In a near future the wind could be provided by satellite scatterometers as ERS1 and NSCAT. During the calibration and test phases of the NN the SST was provided by the METEOSAT satellite infra-red radiometer. Attention was focused on the year 1988. The data set was the daily value of the SST observed by METEOSAT at the studied point and four offshore points and the ECMWF winds observed at four points. The first 250 days were devoted to the calibration of the NN and the remaining 97 days to the tests. The NN we deal with are a peculiar class of NN, the so-called IIR-NN (Infinite Impulse Response Neurone Networks) which are suitable for autoregressive time series prediction (Wan, 1992). In the present work we used a small NN with 8 neurones on the input layer. Several experiments have been conducted. The results are very sensitive to the filtering and the temporal window we used. The performances of the neural network are linked to the number M of lagging days and to the adequate filtering of the trend in temperature. The best performances are obtained when we deal with temperature differences between the actual temperature and a six-day moving average temperature. The optimum temporal window for the wind is a four-day window. The NN could be improved by

adding other parameters on the input layer such as vertical temperature gradients, thermocline depth, offshore and longshore gradients....

As soon as they are calibrated, NN require small computation efforts and can easily be implemented on small computers. They can be used to predict the SST and upwelling occurences. For many problems they are a low-cost alternative to primitive equation oceanic models dealing with sophisticated data assimilation schemes.

Numerical simulations of the circulation in the Eastern Levantine Basin

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1. Introduction

During the past 10-15 years, there has been renewed interest in studying various aspects of the circulation in the eastern Medterranean Sea. Several recent field studies have provided a wealth of new and interesting information for this region. Most of the hipboard measurements have focused mainly on the open sea. The Marine Climate (MC) study (1979-1984) was restricted to the southeastern Levatine Basin (Hecht et al., 1988) while the multinational program Physical Oceanography of the Eastern Mediterranean (POEM) (ongoing since 1985) has covered most of the Eastern Mediterranean with a series of quasi-synoptic hydrographic crusies (e.g., The POEM Group, 1992). Both of these studies have shown that the open sea circulation in the Levantine Basin consists of features covering a wide range of spatial and temporal scales, ranging from very persistent sub-basin scale gyres to transient, highly energetic, mesoscale eddies. Based on these data, it was also shown that the dominant direction of flow at the eastern end of the Levantine Basin was southward. In contrast to this, recent direct current measurements conducted on the continental shelf and slope of Israel have shown that the dominant direction of flow throughout the year is northward (Rosentraub, 1995). This northward flow extends westward from the coast out to a distance of at least 25 km. Furthermore, recent modelling studies of the Mediterranean have not been able to adequately explain the presence of these two contrasting flow regimes. The results obtained by Malanotte-Rizzoli and Bergamasco (1991), Pinardi and Navarra (1993), and Zavatarelli and Mellor (1995) all failed to properly reproduce the eastern shelf/slope circulation due to relatively coarse model resolutions of 25 km or more which exceed the typical shelf width of 10-20 km. In this study we will present results from some of these field measurements as well as results from simulations with a high resolution numerical model of the eastern Levantine Basin.

2. Open sea circulation

The structure and variablitiy of the circulation in the Levantine Basin has been well documented in recent years based on the new data that have become available as a result of the various field studies mentioned above. Here we will only briefly summarize some of the major features. For more than seventy years the traditional picture of the circulation in the Levantine Basin was described as a simple basin wide cyclonic gyre with the strongest currents closely following the coastline based on the description of Nielsen (1912) with minor modifications. The important process of intermediate water formation was also recognized (Wust, 1961). By the 1970's some of the data began to hint at the presence of mesoscale eddies (e.g. Ovchinnikov, 1984). The first real challange to the traditional picture of the circulation was found in the MC data in which the southeastern Levatine Basin was studied extensively through a series of 20 hydrographic crusies (Hecht et al., 1988). With these data it was possible to define the climatological seasonal cycle of the three major surface and upper thermocline water masses of this region (Levatine Surface Water, Atlantic Water, and Levantine Intermediate Water). Further analysis of these data conclusively demonstrated the presence of a highly energetic and variable mesoscale field consisting of eddies interconnected by meandering jets. Subsequently, the POEM data (e.g. Ozsoy et al., 1991; The POEM Group, 1992) showed that this was in fact true for the entire Levantine Basin. The observed circulation features cover a wide range of both spatial and temporal scales. Some of the most prominent features include the Mid-Mediterranean Jet which flows eastward from the Cretan Passage and extends far into the central basin where it meanders around sub-basin scale gyres and bifurcates. Of the sub-basin scale features, the two most prominent are the cyclone/anticylone pair called the Rhodes and Mersa Matruh gyres, respectively, which are located in the central part of the basin. Further east, a persistent or recurrent anticyclone called the Shikmona gyre complex (Ozsoy et al., 1993) appears to the south of Cyprus. This gyre is often manifested as multiple anticylonic eddies. One of these centers which is extemely persistent has been studied extensively over the past few years and has been found to be a potential site of Levantine Intermediate Water formation (e.g., Brenner, 1993). Recent data indicate that the appearance and disappearance of this eddy may be linked to interannual variability of the local atmospheric forcing (Brenner, unpublished data). The location of the Shikmona gyre near the eastern end of the basin imples a southward flow near the eastern edge of the basin which is in direct contrast to the recent direct current measurements presented in the next section. In addition to these very prominent features, the open sea is populated by a variety of mesoscale eddies.

3. Shelf and slope circulation

Since 1987, we have been conducting a long-term program to investigate the circulation and the thermohaline structure on the continental shelf and slope of Israel. The data include currents, temperature, salinity, and bottom pressure at fixed subsurface moorings, a series of hydrographic cross sections, and wind measurements at coastal stations.

Over the shelf, the currents in all seasons are directed mainly northward and follow the bathymetry. In the turbulent bottom boundary layer the currents usually contain a seaward, cross-shelf component. Significant current fluctuations appear on both the daily (mainly sea breeze controlled) time scale and on the synoptic time scale (3-14 days). The synoptic time scale longshore fluctuations are highly coherent and in phase throughout the water column. In the stratified summer season, the mean velocity and the fluctuations are relatively strong (50 cm/s or more), confined to the upper layer, and increase towards the shelf edge. In the non-stratified winter season, the mean velocity and fluctuations are uniform throughout the water column with speeds reaching 80 cm/s or more.

The measurements at a station on the mid-slope (water depth of 500 m), which began in November 1993, indicate the presence of a strong northward flow in the upper layers throughout the year. Maximum seasonal speeds of 40 cm/s are reached in winter. The decrease of the current speed with increasing depth is in accordance with the horizontal density gradient across the slope.

Cross spectral analysis of the winds and the currents shows that the along-bathymetry components of the wind and currents on the shelf are significantly coherent on the synoptic time scale. They are especially coherent on the inner shelf but only marginally or non-significantly coherent near the shelf edge and over the mid-slope. Bottom pressure measurements show that during the non-stratified period the along-bathymetry, synoptic time scale velocity fluctuations are in geostrophic balance with the cross-shelf pressure gradient. The along-shelf bottom pressure measurements exhibit an along-shelf pressure gradient which is highly coherent and in phase with the along-shelf current. This forcing is stronger than the local wind forcing in driving the circulation on the inner and mid-shelf

4. Model simulations

In conjuction with the measurement programs described above we have also adapted a high resolution version of the Princeton Ocean Model (POM) (Blumberg and Mellor, 1987) to the eastern Levantine Basin. A coarse resolution version of POM has already been used by Zavatrelli and Mellor (1995) to simulate the entire Mediterranean. Briefly, POM is a three dimensional, primitive equations, free surface model with a terrain following sigma coordinate and an imbedded higher order turbulence closure scheme. We are presently using the high resolution version of POM to study various aspects of the coastal circulation, the open sea circulation, and the interaction between them. For the preliminary simulations, the model has been configured with a horizontal resolution of 5' corresponding to a longitude and latitude grid spacings of approximately 7.5 km and 9.25 km, respectively. The vertical resolution is 10 sigma layers with fine spacing near the surface.

For our preliminary simulation we have run the model for three years with surface heat fluxes and wind stress derived from monthly mean climatological fields. The required values at each model time step were obtained by linearly interpolating between the two adjacent monthly values. The model was initialized with the area mean January temperature and salinity profiles and zero velocity. Throughout the entire simulation the model properly simulates the persistent northward flow over the eastern shelf and slope region in all seasons. A jet develops over the shelf break and mid slope. It is driven by the cross shelf surface elevation gradient which develops as a result of higher elevations near the coast which are in turn maintained by the wind stress. Simulated speeds in the jet reach 40-50 cm/s. In the course of time, the jet meanders and forms rings that pinch off and drift out into the central part of the domain. The circulation in the open sea consists of a variety of large and small mesoscale features some of which are long-lived while others are transient. Additional simulations will include synoptically varying surface forcing fields as well as higher model resolution over the shelf and slope region.

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Coupled hydrodynamic/ecosystem models; what to include, what to leave out

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The requirement for ecological models of marine systems is to predict the spatial and temporal distribution of the marine biota, as well as the material fluxes through them. As these biota simplistically can be treated as living particulates consisting mainly of a mixture of C, N, P (and Si), as a minimum our models must resolve the cycling of these elements.

The three major processes involved in these cycles in terms of mass fluxes are:

1. The conversion of inorganic dissolved C ($CO2$ and $HCO3-$) to reduced organic particulate form with the simultaneous inclusion of dissolved inorganic nutrients (N, P (and Si))

2. The oxidation/mineralisation of these particulates by different routes
   - by trophic interactions (grazing)
   - mortality -> detritus formation -> microbial mineralisation in the water column

3. Sinking/sedimentation of particulates, which increases the time constants for recycling as a function of local depth and local hydrodynamics, with the mineralisation pathways in the benthic system a function of substrate supply, composition and local hydrodynamics (oxygen supply!).

As all three processes are highly nonlinear, interact strongly with each other and the hydrodynamics set the "environment" for these processes, the need is for coupled 3-D, mesoscale resolving GCM's/ecosystem models that are less of a caricature than the NPZD models at present are. It is quite clear that we now can begin to make qualitatively correct predictions of C, N, P, Si seasonal cycling in temperate seas, because of a few system properties which may not be valid for the whole world ocean.

These are:
The strong seasonality in the solar forcing "resets" the pelagic system annually, effectively making it start from scratch in the lower trophic levels (which are the only ones we can model halfway decently anyway). The other reason is that our approach to modelling the biological state variables as functional groups having size-dependent physiological rates with net growth being expressed as increased biomass of the functional group works well for unicellular groups where increased biomass is identical to higher numbers of same sized individuals with the same physiological rates. As the bulk of the production and mineralisation (80-90%) in the marine systems is mediated by unicellular organisms, this implies that we can be cautiously optimistic in expecting to get realistic results from our present models. However, to keep things simple, as we attempt to model higher trophic levels taking the same bulk functional group approach, we go disastrously wrong, because biomass increase in metazoan populations does not necessarily mean more organisms of the same size, but rather individual growth in size, with concomitant changes in physiological rates, susceptibility to predation, prey choice, mortality etc.

The usual response then is to take a stage - or size - structured modelling approach which in effect for crustacean zooplankton with exoskeletons and discrete moults solves this problem, but for groups with a continuous size distribution only cuts the problem into smaller pieces. However, even for crustacean zooplankton the real problem in modelling this group lies elsewhere: in the fact that they are not passive passengers, ruled absolutely by hydrodyna-mics: they have vertical migration, some to minimize predation, others to optimize grazing; they have overwintering strategies of a bewildering variety. In short, their distribution in time and space is less dependent on the history of the physical environment than it is on the history of the biotic interactions over their lifetime. If we, for the sake of computational simplicity, reduce the biological and chemical resolution in our models at the lower trophic levels, to increase it again at the higher trophic levels, we make another mistake: the higher trophic levels do not aselectively feed on "POC", but pick and choose and, at the very least, are size selective. Additionally they are usually food limited, so if our models do not get the "menu" right, we cannot hope to get realistic model results.

My suggestion thus would be to retain as much biological and chemical resolution in coupled GCM/ecosystem models at the lower trophic levels as possible, develop higher trophic level population models consisting of individual organisms, and then use the results from such models to parameterise "bulk" higher trophic level representations in the full model(s).

Modelling the nitrogen cycle in the Mediterranean Sea

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1. Introduction

Hydrodynamics plays a basic role in the ecosystem function because it provides an energy source to the populations transporting nutrients and heat (Margaleff, 1978). By forming fronts and eddies, the flow field may cause the separation of neighbouring populations and the development of spatial patches. This is particularly true at the mid-latitudes where high dynamical phenomena like seasonal thermocline formation, upwellings, transient and permanent gyres, strongly affect the biological dynamics. The modeling effort is therefore a combination of two highly interconnected parts: one describing the hydrodynamics and the other governing the ecosystem processes.

The gross phenomenology of a marine ecosystem can be described in terms of the dynamic of the limiting factors. These idealized processes can be modeled using a mathematical description which links and parametrizes the mutual interrelations among the different state variables of the ecosystem. The Mediterranean Sea is known to be an oligotrophic basin with some eutrophic regions near river outflows (the Rhone and Po rivers, for example) and in regions of strong upwelling (Gulf of Lions and southern Sicily coast). In this basin, the vertical structure of nutrients and phytoplankton distribution can be tentatively depicted. The dynamics of the productive zone (the zone above the compensation depth (i.e. the depth where photosynthesis balances the phytoplankton respiraton) is deeply influenced by the joint effect of the advective transport, the mixed layer dynamics and the compensation depth seasonal cycle. The convective mixing episodes and the Ekman suction highly contribute to regenerate a uniform distribution of nutrients and phytoplankton along the water column in the late winter. Owing to the oligotrophy of the basin, any input of nutrients is immediately taken up by the primary producers, whenever the light energy is sufficient. This is always true for the upper layer in the Mediterranean, while in depth a strong light limitation is obviously found. A two layer regime is thus induced, nutrient-driven at the surface, light-limited at depth. The convective mixing episodes and the Ekman suction highly contribute to regenerate a uniform distribution of nutrients along the water column in the late winter.

2. The numerical model

The model is composed of a three dimensional full hydrodynamic equation model tightly coupled with an ecological model of the lowest trophic level (Crise et al., 1992).

The ecological model represents the nitrogen cycle giving the space and time evolution of three large compartments: the Dissolved Inorganic Nitrogen (DIN) *N*, phytoplankton, *P* and the detritus *D*, all expressed in nitrogen equivalent units. The NPD equations are non linear diffusion - advection - reaction equations:

$$\frac{\partial N}{\partial t} = -(\vec{u}.\nabla)N + K_H \nabla_h^2 N + K_V \frac{\partial^2 N}{\partial z^2} - FP + rD; \qquad (1)$$

$$\frac{\partial P}{\partial t} = -(\vec{u}.\nabla)P + K_H \nabla_h^2 N + K_V \frac{\partial^2 P}{\partial z^2} - FP - dP; \qquad (2)$$

$$\frac{\partial D}{\partial t} = -(\vec{u}.\nabla)D + K_H \nabla_h^2 N + K_V \frac{\partial^2 D}{\partial z^2} - rD + dP \qquad (3)$$

F is the phytoplankton growth dependent on temperature, irradiance, and nitrogen concentration, *d* is the phytoplankton mortality and respiration rate, and *r* is the remineralization rate of the detritus. Basically, nitrates are utilized by phytoplankton which extrudes part of the assimilated nitrogen because of respiration and mortality rate creating the detritus which is remineralized in nitrates; this apparently simplistic scheme has the advantage of being conservative under the simplifying hypothesis that the non-conservative processes of the nitrogen cycle (nitrification, denitrification, riverine and atmospheric inputs, nitrogen biofixation) are in dynamic balance. This means that the integration of the whole organic and inorganic nitrogen gives a constant value in time, even there is an evident dynamics of each state variable. The hydrodynamical model was supplied by Nadia Pinardi and her group; this model is based on the MOM primitive equation GCM implemented for the Mediterranean as in Russenov et al. (1995) with some improvements such as the enhanced vertical resolution (31 levels) and the heat fluxes calibrated for the Mediterranean by Castellari et al (submitted to Oceanologica Acta).

By using this model we can investigate the response of the biogeochemical state variables to different forcings (nutrient advection, light, temperature, etc.) in a 'realistic' simulation. With the term 'realistic', we mean that all the physical and biological initial and boundary conditions, as well as the parameterization of the governing equations, rely upon known values coming from direct measurements or literature.

The limiting factor *F* for the algal growth depends on the temperature *T* on the irradiance L_f and on the Michaelis-Menten uptake formulation, through the expression

$$F = g_{\max}(T) L_f \frac{N}{C_N + N}, \qquad (4)$$

where C_N is the half-saturation constant for nitrogen.

The temperature limitation is computed using the Arrhenius' formulation (Eppley, 1972):

$$g_{\max} = G_{\max} e^{k_T T} \qquad (5)$$

The formula for light limitation L_f is, following Steele (1962):

$$L_f = f \frac{\bar{I}}{I_{opt}} e^{1 - \frac{\bar{I}}{I_{opt}}} \qquad (6)$$

The optimum light I_{opt} is chosen to be

$$\frac{\bar{I}}{2}$$

in accord with Steele (1962).

The non-spectral formulation of the irradiance at depth *z* is given; according to the physical model, it has the following features:

1) light extinction in the water column dependent on the zonally variant extinction coefficient and on the phytoplankton concentration (selfshading):

$$\bar{I} = I_0^1 e^{-k_z z - k_{phyto} \int_0^z dz\, P} \quad (7)$$

k_z is the light extintion coefficient and k_{phyto} is selfshading factor;

$$I_0^1 = I_0 \,(1 - .62 clouds + .0019 sunsbeta) \quad (8)$$

where *sunbeta* is function of sun zenit angle 3) meridionally variant daylength

$$f = \text{daylength} / \pi = \arccos\left(-\text{tg}\left(\text{declination}\right)\text{tg}\left(\phi\right)\right) / \pi \quad (9)$$

where the sun declination is calculated as follows:

$$declination = -.406 \cos\left(2\pi\left(day + 10\right) / 360\right) \quad (10)$$

where ϕ is the latitude in radiants and k_z is the light extintion coefficient.

3. Results

The main results of the model using climatological forcings can be synthesized as follow:

- the general oligotrophy of the basin is induced by the estuarine inverse circulation, owing to the fact that the concentration of nutrients (and also the total nitrogen) is much higher in the deeper layers than at surface, \item the east-west gradient of DIN and phytoplankton concentation is reproduced together with a progressive shoaling of the nitracline, \item the seasonal cycle is basically driven by physical forcings: the combined effect of the mixed layer dynamics and the seasonal fluctuation of the irradiance determines different responses according with the trophic regime (basically nutrient limited at surface with the important exception of the winter period, and light limited in depth);

- a zonal gradient of the deep biomass maximum (with lower values in the Alboran Sea) is reproduced;

- the wind driven coastal upwelling seems to be an important nutrient source at least for the most oligotrophic areas; - the nitracline closely follows the compensation depth (i.e. the depth where the photosynthesis is balanced by phytoplankton respiration) dynamics in the summer and autumn seasons;
- the main influence of the general circulation on the Mediterranean ecosystem function is related to the nutrient horizontal and vertical transport.

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Influence of mesoscale dynamics on primary production: the spring bloom in the NW Mediterranean Sea

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As a first step, the issues of predicting primary production and its annual variation are addressed in a 1D modeling approach. The DyFAMed survey program provides relevant data to validate such a study in the area considered. The mixed layer (ML) dynamics is simulated using a 1D model based on a TKE closure scheme for vertical turbulent diffusion. It is forced with ECMWF heat fluxes and wind stress for 1991. The major processes involved in new, regenerated and exported production are represented by a 10-compartment geochemical model, coupled to the ML dynamical model. This nitrogen based geochemical model describes the interactions between nitrate, ammonium, phytoplankton, two sizes of zooplankton, two sizes of particulate organic matter, bacteria, labile and refractory dissolved organic matter. The model predictions are in good agreement with in situ measurements (1991) of nitrate and phytoplankton. Moreover, detrital sedimentation compares well with 200 m sediment trap data (1987-90) and simulated values of new/total production reproduce previous estimates (basin scale nutrient consumption/C14 measurements). The important Mediterranean DOC export (over four times the particulate export) is also simulated. The initial model is used to evaluate the predictive abilities of simplified model structures, as they are more tractable to 3D eddy resolving process studies. A NNPZDD (NH4-NO3-Phytoplankton-Zooplankton-Detritus-refractory DOM) model has been tested. It is shown that the major stocks and fluxes can be reproduced correctly with the simplified version, during the first part of the year, when regeneration is low. As a second step, this last model has been implemented in the LODYC primitive equation model. The dynamical conditions are the adjustment of a mesoscale chimney, characteristic of the winter situation in the Gulf of Lion. A pre-formed chimney of dense water is let free to evolve. The horizontal discretization (2.5 km) resolves the first three radii of deformation in the stratified zone. After the geostrophic adjustment phase, mixed barotropic-baroclinic instabilities induced by vertical and horizontal shears in the velocity field, result in the formation of 7 cyclonic eddies. These eddies eventually collapse towards greater scales, and a mixed layer is formed over the initial chimney, while dense waters spread at the bottom. Vertical velocities associated with these eddies reach up to 4 mm/s and bring nutrients to the surface. The signature of the 7 eddies is observed in the simulated surface phytoplankton field. CZCS data show such patches of chlorophyll during the bloom. The next step will be to diagnose total production and export fluxes and to quantify the role of the eddies on these fluxes.

Coupled physical-biological modelling of the Gulf of Lions: analysis of a one-year simulation

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In order to study the origin and fate of organic matter in the Gulf of Lions on an annual cycle, a biogeochemical conceptual model has been designed and coupled to a circulation model of the Gulf of Lions. Due to the scarcity of regular time series of data in the area, the biogeochemical model was first calibrated on a 1D basis, with data from the FRONTAL programme (year 1986). We present here the results of this calibration phase which has allowed us to understand better the functioning of the local ecosystem. The model considers 2 types of phytoplankton (diatoms and flagellates), 3 types of nutrients (NH4, NO3 and Si), dissolved organic matter and bacteria. It explicitly distinguishes the photosynthesis and the nutrient assimilation according to the AQUAPHY plankton model (Lancelot and Mathot, 86). In a second step, we implement this biogeochemical model on a 3D basis with a high resolution general circulation model of the Western Mediterranean (Herbaut & al., 1995; EUROMODEL Group, 1995). Based on the primitive equations and on the OPA code, both the actual resolution of the GCM and a higher resolution regional model of the Gulf of Lions embedded in the GCM are used (Laugier & al., 1995). The boundary conditions of the biogeochemical model at the Eastern and Southern entrance are provided by the annual simulation made in the Ligurian Sea. At the sediment/ water interface, we use a rough parameterization based on the tracers concentrations according to a climatological set of data issued from the EROS 2000 project.

We first present here the results of this work, which is still in progress. In particular, we show the importance of the boundary conditions, of the physical resolution of the processes, and of the software architecture.

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19) M. Fischer	D		
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30) L. Mortier	F		
31) G.L. Mellor	USA		
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33) C. Millot	F		
34) K. Miyakoda	I		
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Research Conference on

Mediterranean Forecasting

La Londe Les Maures, France, 21-26 October 1995

Chairman: N. Pinardi (Modena)
Vice-Chairman: L. Bengtsson (Hamburg)

Programme

Saturday 21 October

	Registration
19.00	Get Together
19.30	Supper

Sunday 22 October

Session chairman: N. Pinardi

08.30	Opening Remarks
08.40	J. Boissonnas (Bruxelles, Belgium), *The MTP Project in Mast II*
09.00	C. Millot (La Seyne-sur-Mer, France), *Mesoscale and seasonal variabilities of the circulation in the western Mediterranean Sea*
09.40	Discussion
10.00	P. Y. Le Traon (Toulouse, France), *Monitoring of the mean sea level and oceanic circulation of the Mediterranean Sea by satellite altimetry.*
10.40	Discussion
11.00	Coffee break
11.30	P. Brasseur (Liège, Belgium), *The observatioanl evidence of the general circulation from historical data sets*
12.10	Discussion
13.00	Lunch

Session chairman: N. Pinardi

15.30	N. Ward (Berkshire, U.K.), *Local and remote climate variability associated with Mediterranean Sea-surface temperature anomalies.*

16.10 Discussion
16.30 Coffee break
17.00 E. Ozsoy (Erdemli, TURKEY), *Climate Variability Processes in the Eastern Mediterranean and their Sea-surface temperature anomalies.*
17.40 Discussion
18.00 J. P. Bethoux (Villefranche sur Mer, France), *Predictability of surface changes from Mediterranean deep water signatures of physical and biogeochemical trends.*
18.40 Discussion
19.30 Dinner

Monday 23 October

Session chairman: P. De Mey

09.00 K. Miyakoda (Princeton, US), *Ten year series of ocean data assimilation*
09.40 Discussion
10.00 A. Navarra (Modena, Italy), *Montecarlo Techniques in simulations of Geophysical Flows.*
10.40 Discussion
11.00 Coffee break
11.30 M. Fisher (Hamburg, Germany), *El Nino/Southern Oscillation prediction experiments.*
12.10 Discussion
13.00 Lunch

Session chairman: K. Haines

15.30 L. Cavaleri (Venezia, Italy), *Wave forecast in the Mediterranean Sea and its implications for the forecast of the circulation*
16.10 Discussion
16.30 Coffee break
17.00 N. Pinardi (Modena, Italy), *The problem of large scale ocean predictions in the Mediterranean Sea.*
17.40 Discussion
19.30 Dinner

Tuesday 24 October

Session chairman: K. Miyakoda

09.00 G. Mellor (Princeton, US), *A sigma coordinate, numerical model of the Mediterranean; deep water formation and climate drift*

09.40 Discussion

10.00 A.R. Robinson (Cambridge, US), *Real-time forecasting of the synoptic-mesoscale variability in the Eastern Mediterranean*

10.40 Discussion

11.00 Coffee break

11.30 N. Flemming (Wormley, U.K), *Operational objectives for ocean modelling in the civilian sector. The Mediterranean case.*

12.10 Discussion

13.00 Lunch

Session chairman: G. Mellor

15:30 G. Evensen (Bergen, Norway), *Advanced Data Assimilation in Nonlinear Ocean Models*

16.10 Discussion

16.30 Coffee break

17.00 K. Haines (Edinburgh,U.K.), *Similation of ERS-1 altimetry data in the Mediterranean MOM using water property conservation.*

17.40 Discussion

18.00 P. De Mey (Toulouse, France), *Optimal Interpolation and Adaptive Filtering in the Mediterranean.*

18.40 Discussion

19.30 Dinner

21.00 Round Table Discussion: Operational Forecasting in the Mediterranean?
Moderators: N. Pinardi, G. Mellor, G. Cavaleri, N. Flemming

Programme

Wednesday 25 October

Session chairman: M. Crepon

09.00	J. Baretta (Horsholm, Denmark), *Coupled physical-biochemical models, what to include and what to leave out.*
09.40	Discussion
10.00	P. Nival (Villefranche sur mer, France), *Important processes and variables in the design of a biological-physical coupled model for the Mediterranean pelagic waters.*
10.40	Discussion
11.00	Coffee break
11.30	A. Crise (Trieste, Italy), *Modelling of the nitrogen cycle in the Mediterranean.*
12.10	Discussion
12.30	M. Levy (Paris, France), *Influence of mesoscale dynamics on primary production : the spring bloom in the NW Mediterranean Sea*
13.00	Lunch

Session chairman: N. Pinardi

15.00	M. Crepon (Paris, France), *A neural network forecasting model for ocean upwelling: an efficient low cost alternative with respect to OGCM.*
15.40	Discussion
16.00	Coffee break
16.30	S. Brenner (Haifa, Israel), *Numerical simulations of the circula tion in the Eastern Levantine basin*
17.10	Discussion
17.30	L. Mortier (Aix en Provence, France), *Coupled physical-biological modelling of the Gulf of Lions: Analysis of a one-year simulation.*
18.10	Discussion
19.30	Dinner

Thursday, 26 October

Morning: Departure

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