## Seasonal and interannual variability of the Black Sea circulation
## Numerical modelling

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Deep and intermediate waters in the Black Sea are strongly influenced by the variability in the Bosphorus an rivers inflow, buoyancy fluxes at the sea surface and the momentum flux. The analysis of meteorological data illustrates their seasonality and the strong interannual signals. The response of the sea to the forcing changes includes variations in the intensity of the general circulation, formation of quasi permanent sub basin gyres and changes in the total heat content in the cold intermediate layer. Major physical problems are the interplay between the large variety of forcing factors, the mechanisms of the formation of vertical stratification and the energetics. The lack of experimental data motivates us to try to understand how the Black Sea works using numerical models with improved forcing. So far the numerical models are forced with climatic annual mean or seasonally varying boundary conditions. Such forcing functions do not include enough variations in the atmospheric signal. Its amplitude is drastically reduced which could result in underestimation of the sea response to the atmospheric signal. In the present work we address the problem of the role of high frequency variability for the ocean circulation on the example of the Black Sea model.

The numerical model used in this study is the well known GFDL Princeton Ocean General Circulation Model (OGCM). Horizontal resolution is $\Delta\lambda = 1/3°$ $\Delta\varnothing = 1/4°$ . The vertical structure is approximated using 11 levels with vertical resolution varying from 2O m in the surface layer to 980m in the deepest part of the basin. Bottom relief and coastal line are specified from bathymetric map in the horizontal grid points.

The model is initialized with annual mean temperatures and salinity. Small area including the Strait of Bosphorus is relaxed to the climatology in order to maintain the exchange with the Mediterranean Sea. After the model fields adjust to the initial forcing and topography the integration continues with time variable forcing.

Forcing functions are calculated in the model from the NMC 12 hours atmospheric analysis including air temperature, humidity and winds at the sea surface. Sea surface salinity is relaxed to monthly mean data. All forcing functions are interpolated linearly at each time step. The model is run for 9 years and the analysis of the simulated results is presented in this paper. The emphasis is given to the processes which form the sea surface heat fluxes, intermediate water formation, variability of the circulation patterns and to the net role of the short period atmospheric variability for the general circulation. The comparison of the simulated results obtained for each year manifests the fundamental role of the interannual atmospheric variability for the Black Sea circulation.



## Eulerian and Lagrangian statistics of mesoscale motions in the Tyrrhenian Sea

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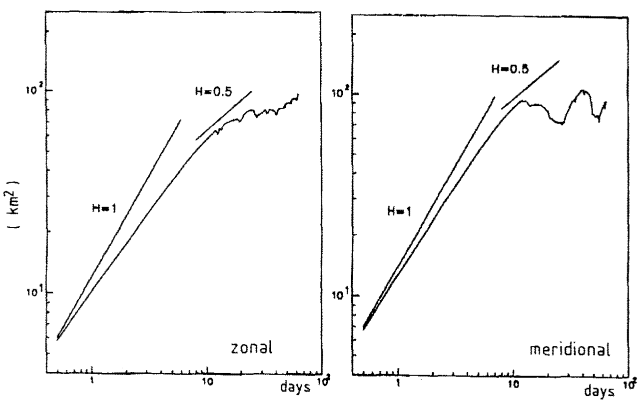
A data set from the three free satellite-tracked drifter buoys (drogued at a depth of ten meters) and the three current-meter moorings deployed in the central Tyrrhenian sea in autumn 1989 during the TEMPO experiment (TEMPO Group, 1990), was analyzed. The circulation in this area is dominated by large and coherent systems of vortex of an estimated scale of about 100-200 Km. Other than the surface dynamical and statistical properties of these vortices, the study focused on relating the Eulerian and Lagrangian description of the flow field on the basis of the drifter data and the data from a current-meter placed at depth of 8 meters.

Both the drifter and current-meter spectra indicate that the characteristic frequencies of the basin (around 20 and 10 days) exhibit a high anticlockwise polarization, which drastically decreases with depth. The autocorrelation functions reach the zero value after about 10 days for both the drifters and the surface current-meter with the relative integral time scales, $(T_{Lx}, T_{Ly}) = (2.0, 1.8)$ days and $(T_{Ex}, T_{Ey}) = (2.3, 0.9)$ days. The substantial equivalence between the Eulerian and the Lagrangian time scale infers weak non-linear (advective) effects for periods extending from 1 to 10 days.

The study of the structure function $S_i(t) = ([X_i(t+\tau) - X_i(\tau)]^2)^{1/2}$ (COLIN de VERDIERE, 1983) showed an anomalous behaviour ($S_i(t) \propto t^H$ with $1/2 < H < 1$) for $1 \leq t \leq 7\sim8$ days with a scaling exponent of $H \sim 0.8$. For $8 < t < \sim15$ days, a transition, especially on the zonal direction, towards a brownian like motion can be observed (Figure). For greater t the drifters are diffused less than required by a random walk and the motion is dominated by the strong wave like vortex circulation. The analysis of the behaviour of the coefficient of eddy diffusivity with time provided a numerical estimate of $(K_x, K_y) = (2.9, 3.5) \cdot 10^7$ cm$^2$/sec which was however valid only for $8 < t < 15$ days. For greater t our drifter records are too short to resolve the properties of diffusion of the vortex although a value of $O(10^6)$ cm$^2$/sec or less for K seems appropriate.

Moreover, the drifter trajectories display a homogeneous fractal behaviour with a dimension $D \sim 1.3$, for $1 < t < 7$ days and $10 < L < 80$ Km in the time-space scale of both the eddy dynamics and the anomalous diffusion. A fictitious trajectory obtained by integrating the velocity data of the surface current-meter displayed similar fractal and diffusion characteristics in the same space and time scale. A multifractal analysis of the velocity time series of the same current-meter using the generalized Reny's dimension showed homogeneous behaviour in the eddy time scale and evidence of multifractality or intermittency for $t \leq 4\sim5$ hours. The spectra of the surface current meter and the freely moving drifters demonstrated a similar shape with the same slope in the range of 1-10 days. The results of our analysis, thus seem to indicate that, in these time scales, the fractal and diffusion characteristics of the drifter trajectories are "driven" by the Eulerian field and are apparently less influenced by nonlinear phenomena like chaotic advection.

On the other hand, a significant difference between the root mean square velocities of the drifters and the surface current-meter (the drifter values were definitively larger) was observed suggesting the relevance of nonlinear effects in high frequency time scales.




**A log-log plot of the dispersion versus time**

**REFERENCES**

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