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Application of the GHER 3D k -ε Model to the study of the general circulation and associated synoptic/mesoscale structures in the Western Mediterranean Sea

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The GHER model is a primitive equation, fully 3D (multi-level), time dependent, non-linear, baroclinic model with a k-ε turbulence closure. The state variables are the three components of the velocity vector, the buoyancy (or the temperature and salinity), the pressure (or the surface elevation), the turbulent kinetic energy, the energy dissipation rate (or the mixing length) and the concentrations of passive constituents.

The model has been described in earlier publications (e.g. Nihoul and Djenidi 1987, Nihoul et al 1989, Nihoul and Beckers 1989).

In the frame of the quasi-hydrostatic approximation, the vertical component of the momentum equation reduces to a simple balance between buoyancy and vertical grandient of $q = p/\rho o + gx_3$.

The mesoscale energy production rate is proportional to the 3/2 power of the wind stress. The coefficient of proportionality is a function of depth and of the flux Richardson number.

The computer code translation of the mathematical model is greatly facilitated by the introduction of new coordinates : the hat-coordinates (The hat-coordinates are quite similar to the so-called "σ-coordinates" used in Meteorology and are simply rechristened here to avoid confusion with isopycnal or "iso-σ" coordinates used in Oceanography).

The advantage of the new coordinates and associated variables is that horizontal and vertical length and velocity scales are then of the same order, the water column has everywhere the same height while the top and bottom boundary conditions reduce to zero vertical (hat) velocity.

Furthermore the comparison of the vertical velocities in real and hat coordinates provides a more complete understanding of vertical motions, separating what is due to the bathymetry of the basin (upsloping and downsloping) and what is due to Ekman circulation (upwelling and downwelling).

Considering the important variations of the Western Mediterranean's bathymetry, the three-dimensional model is applied conjointly to two superposed interconnected layers, the surface layer's depth following the shelf's bathymetry on the shelf and remaining at maximum shelf's depth in the deep-sea. The introduction of two different hat-coordinate systems has also the advantage of allowing a better representation of the vertical stratification. Indeed with a single hat-coordinate transformation for the whole basin, lines of equal $\hat{x}_3$ when retransformed to physical space cut the isopycnals and there is a risk that diffusion in hat-space destroys the vertical stratification.

The numerical model uses a mode-splitting technique based on the simultaneous resolution of a depth-integrated model to compute the surface elevation. The advection term is represented by either a centered-difference scheme, a Lax-Wendroff scheme or an upwind-difference scheme, according to the numerical requirements. The numerical method is implicit in the vertical but, to avoid numerical erosion of the pycnocline, the "implicity factors" of the advection and diffusion terms are modified at each mesh and at each iteration. Hydrostatic instabilities, as in cases of deep water formation, are taken into account using an original parameterization of the diffusion coefficients, generalized from Nihoul's formula for the stably stratified case (Beckers, 1988, 1990).

At the air-sea interface, all fluxes (momentum, heat, ...) are imposed and calculated from the available atmospheric data.

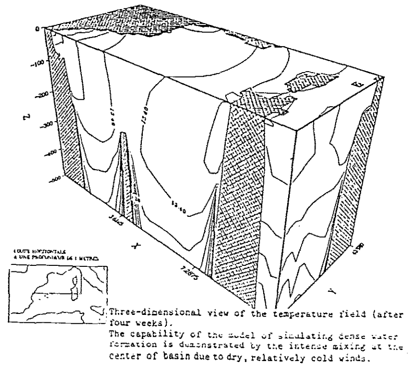
At the bottom, heat and salt fluxes are assumed to be zero but the flux of momentum (bottom stress) and the turbulent kinetic energy production rate are calculated using an analytical model of the bottom Ekman layer. (This solution gives the classical quadratic friction law for small bottom layer meshes but has the advantage on the logarithmic approximation to allow a veering of the velocity vector with height when the grid spacing near the bottom increases).

At the coasts, heat and salt fluxes are set to zero except at the mouths of main rivers like the Rhône. The velocity perpendicular to the coast is zero and a quadratic friction law is imposed for the tangential velocity.

At the straits, observed transports (integrated inflowing or outflowing velocities) are imposed. The boundary conditions for the other variables are basically of the Orlanski type but they are adapted to the numerical scheme and modified to make it possible to take a measured value into account when such a value is available.

RESULTS

the model can successfully reproduce the main trend of the general winter circulation and essential related large scale processes such as local secondary gyres, meandering of frontal currents, wind-induced upwellings and downwellings, dense water formation ...



Three-dimensional view of the temperature field (after four weeks).
The capability of the model of simulating dense water formation is demonstrated by the intense mixing at the center of basin due to dry, relatively cold winds.

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Development and applications of the coastal quasigeostrophic ocean model to the case of multiple coasts and multiply connected domains

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The Harvard quasigeostrophic ocean model has been generalized to be applicable to semi-enclosed or closed ocean domains bounded by multiple segments of coasts and/or multiply connected geometry. Inviscid coastal boundary conditions and consistency constraints are required and the Greens function methods are utilized in the solution algorithm. The performance of the model is guaranteed by comparison with analytical solutions of Flierl (1977) and cases derived from them. The methodology is applied to the quasigeostrophic dynamical modeling of the Levantine Basin. The robustness of the method is illustrated by the stable preliminary predictions and sensitivity runs.