MODELLING COASTAL UPWELLING

by

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1.   Introduction

Upwelling in the ocean is concentrated in regions along the coast where winds are favourable, along the edges of the continental shelf, in equatorial regions, near the edge of ice sheets and in frontal zones. Models have to be adapted to the dynamics and physics of each region. However, modelling techniques for each region have much in common and provide useful methods for use in other regions.

Near the equator, the upwelling is associated with the propagation of Kelvin waves along the equator from west to east and with equatorial currents and undercurrents. It has been described by McCreary (1985), and is driven by a combination of local winds through Ekman divergence away from the equator and of distant winds through the action of Kelvin waves.

Upwelling near the edges of ice sheets is associated with the change in the effect of the surface wind stress on the open ocean and on the ice covered ocean. The abrupt change in Ekman transport in the surface layers produces upwelling along the edge of the ice, and is mainly a product of local winds. Røed and O'Brien (1983) describe a model of upwelling in the marginal ice zone.

Modelling of upwelling in frontal zones is not very advanced. The difficult geometry caused by a moving front and the effects of non-linear advection make modelling difficult. An outline of the dynamics has been given by Mooers et al. (1976) and a contrary view using an unsteady model of a coastal upwelling front is presented by Chen and Wang (1990).

2. Coastal Upwelling

In the eastern North Atlantic, important coastal upwelling occurs along the North West African coast near the Canary Islands and along the Iberian shelf when the favourable Trade winds are present with a component towards the equator. Mittelstaedt (1983) has described the North West African upwelling and Frouin et al. (1990) discuss the seasonal reversal of the ocean circulation off Portugal with upwelling in summer, but not in winter. Shelf break upwelling is observed along the edge of the shelf as shown by satellite images.

Models of coastal upwelling need to allow (i) for the variability of the wind stress producing upwelling events after less than a day of favourable winds, (ii) for the stratification of the ocean, and (iii) for various aspects of the bottom topography. The stratification is particularly important in determining the cross-shelf flow and the density field, and causes most problems for modellers due to the non-linear advection. The bottom topography has to include the shelf break and major features such as canyons, ridges and headlands. A review of U.S. modelling studies of coastal-offshore processes is presented by Wroblewski and Hofmann (1989).

3. Stratification

The inclusion of stratification has been attempted in various ways including normal modes (Gill and Clarke, (1974), spectral methods (Davies (1986)), separate barotropic and baroclinic time scales (Johnson (1982)) to overcome the intractability of the non-linear equations. None of these methods is entirely satisfactory, and numerical models have to be used to get realistic distributions.

Secondary upwelling may be generated at the shelf break where the deep water, which flows with long (greater than monthly) time scales and large length scales, meets the shelf currents with their short (almost daily) time scales and small length scales. In many circumstances a sharp shelf break can act as an effective barrier between the deep ocean circulation and the shelf circulation, as demonstrated by Johnson and Nurser (1984). The shelf break upwelling is strongest above sharp shelf breaks.

4. Shelf Waves

Unsteady models allow propagation of Kelvin waves and continental shelf waves that have important effects on the part of the upwelling signal that is not caused by local winds. Along an eastern boundary of the ocean, Kelvin waves propagate away from the Equator, but the direction of continental shelf waves depends on the wave length and may change due to reflection or scattering by irregularities in coastline and topography. The scattering of coastal trapped waves is modelled by Wilkin and Chapman (1990). A stochastic model of the wave field generated by a distribution of wind at different frequencies is described by Brink et al. (1987). Grimshaw et al. (1993) discuss the generation of edge waves by radiation stress caused by surface waves.

5. Jets and Eddies

Associated with upwelling off the Iberian coast, there are jets and eddies in which upwelled water is often carried offshore beyond the shelf break. Similar features are observed in the eastern Pacific off the California coast in which 20-50 km wide filaments of upwelled colder water extend 200-300 km offshore, as surveyed by Kosro and Huyer (1986). Models of these jets, eddies and filaments are not yet very wide spread. An attempt to model this phenomenon has been made by McCreary et al. (1991) using a three layer model with two active upper layers. Instabilities occur in the coastal currents that resemble filaments but the generation time (greater than 60 days) is too long.

6. The MORENA Programme

The MORENA project that is funded by the EC MAST II programme aims to measure, understand and model the shelf - open sea exchange in the coastal upwelling region off Iberia. A multidisciplinary approach is used with an observational programme along specific sections that is combined with remote sensing methods and new numerical and laboratory models.

The modelling tasks include a primitive equation numerical model extending from the Gulf of Cadiz to the Celtic Sea and from the Iberian and French coasts out beyond the shelf break. This model is forced by seasonal wind stress and surface heat and salt fluxes and includes run off from rivers and the outflow from the Mediterranean. The topography of the first model is shown in the

figure with a well defined shelf break and various canyons and ridges. The fine scale of the model permits offshore jets and filaments to be resolved.

Other modelling projects include the use of reduced gravity models with single and double active layers, and laboratory models of rotating stratified channel flows. The models are to be validated against both in-situ and satellite observations collected as part of the observational programme.

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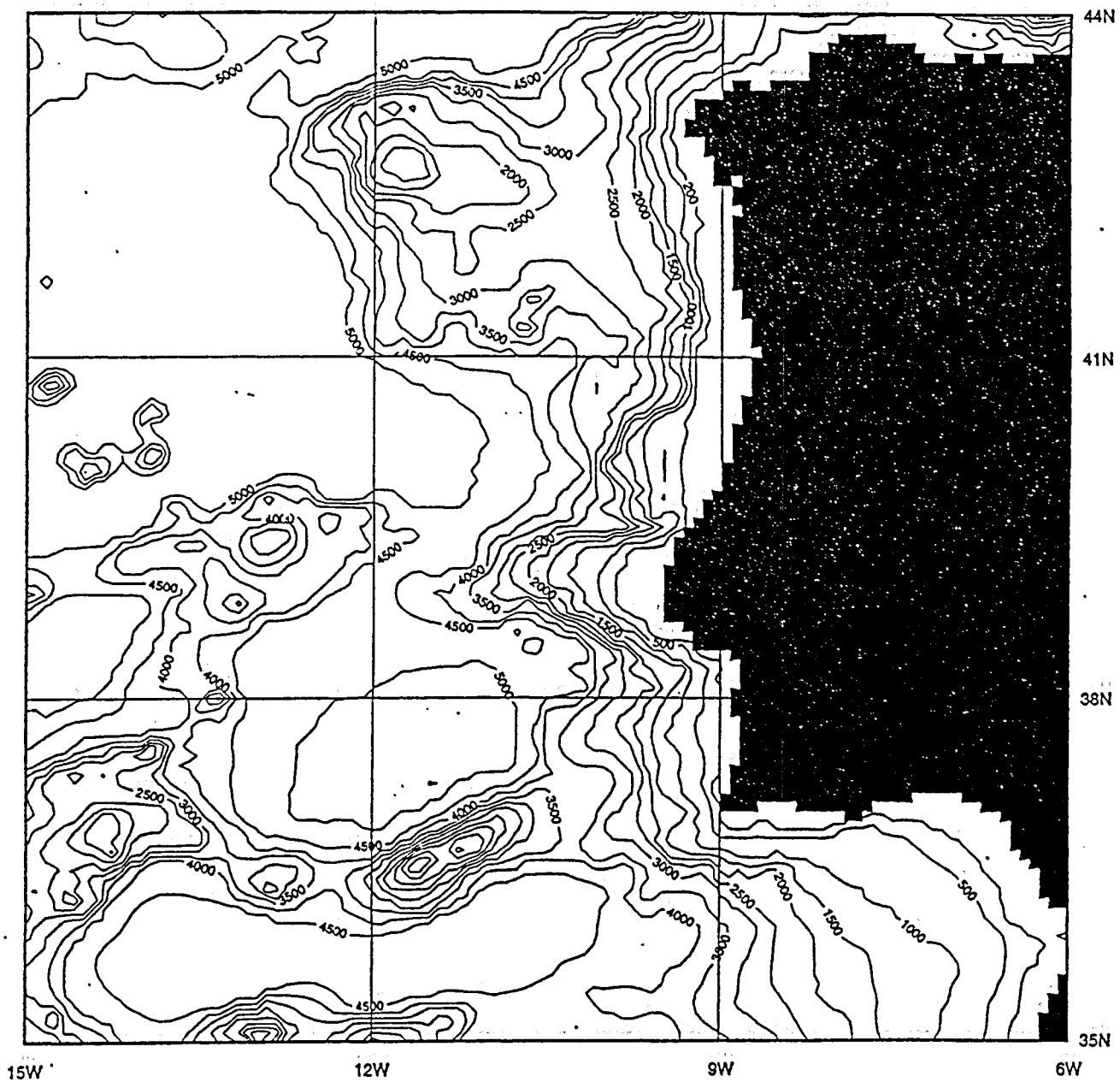
Bottom topography for MORENA model over the Iberian shelf and shelf-break.