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Several different projects have been completed during the course of the terminating grant. Both analytical and numerical models have been developed, and applied to the following 5 projects: (1) Summer cooling of the Arabian Sea; (2) Upwelling in the Gulf of Tehuantepec; (3) Dynamics of the Somali Current; (4) Dynamics of the Leeuwin Current; (5) Dynamics of the California Current System. Results of these studies compare very well with observations. (KR)

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Final Report

MODELLING OF THE CIRCULATION OF THE WESTERN INDIAN OCEAN

Contract N00014-85-K-0019

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1. SUMMARY OF WORK ACCOMPLISHED

The different projects carried out under this project are described below.

(i) Cooling of the Arabian Sea: *McCreary and Kundu (1989)* have just completed a modeling study of the variability in the Arabian Sea. The oceanic model used in the work is our latest version of a reduced gravity model that includes the most sophisticated thermodynamics. A novel feature of the model is the incorporation of a Kraus-Turner mixed layer embedded within the dynamic layer. It is forced by climatological wind, solar radiation and air-sea temperature fields. The flow fields are quite realistic; in particular, the model develops the strong gyre (the Great Whirl) off Somalia in July, and the intense upwelling at the coast of Somalia and Arabia. A major conclusion of the study is that this coastal upwelling is almost entirely responsible for the observed annual heat gained by the Arabian Sea.

(ii) The Gulf of Tehuantepec: *McCreary, Lee and Enfield (1989)* have completed a study of coastal response due to intense *offshore* winds. At three places in Mexico and Central America there are mountain passes that extend across land all the way from the Gulf of California to the Pacific Ocean. In winter, high pressure systems develop in the Gulf of California, and air rushes through the passes down the resulting pressure gradient, blowing offshore. These events typically last from 3-10 days, and wind speeds can approach hurricane strength. The observed upwelling cannot be classic Ekman drift, since the wind here blows offshore, not alongshore. Our study successfully simulates the observed flow pattern in a reduced-gravity model with entrainment thermodynamics. In particular, it models the development of a two-gyre system, elimination of the cyclonic gyre by entrainment, and the offshore propagation of the anticyclonic gyre. The study shows that the observed upwelling is due to an offshore ageostrophic current that is *not* Ekman drift.

(iii) Somali Current: *McCreary and Kundu (1988)* studied the Somali Current during the Southwest Monsoon using a non-linear, $2\frac{1}{2}$-layer numerical model which included entrainment thermodynamics. Our solutions forced by a local alongshore wind field were able to simulate the development and the coalescence of the observed two-gyre system. The solutions indicated that the coalescence is not due to the relaxation of the monsoon winds (a frequently suggested mechanism), but rather a non-linear response due to the fully developed Findlater Jet. Another conclusion is that remote winds over the interior Indian Ocean are not the dominant forcing mechanism of the Somali Current.

(iv) Leeuwin Current System: *McCreary, Shetye and Kundu (1986)* investigated the dynamics of the Leeuwin Current off the west coast of Australia using a continuously stratified model. This intriguing current, unlike other eastern boundary currents, flows poleward *against* the direction of the prevailing winds. Our model suggested that the major observed features of the current are forced by a thermohaline mechanism in the following way. Because tropical water is warmer than mid-latitude water, there is a poleward drop in the near-surface dynamic height field and a resulting eastward geostrophic current. This interior flow turns poleward along the west coast of Australia to form the Leeuwin Current.

Kundu and McCreary (1986) found that the Leeuwin Current could not be caused by southward bending of the throughflow from the Pacific into the Indian Ocean through the Indonesian archipelago. The throughflow, however, could contribute to the strength of the current.

(v) California Current System: *McCreary, Kundu and Chao (1987)* investigated the dynamics of the California Current System using a continuously stratified analytical model. The initial purpose of the study was to investigate the dynamics of the Davidson

Current, a wintertime poleward surface current adjoining the coast. Our solutions indicated that it was due to the positive wind curl near the coast, an idea first proposed by Munk. As the research progressed, however, it became obvious that a more interesting problem was to understand the dynamics of the more prevalent equatorward currents. Solutions indicated that near the coast they are driven by the alongshore component of the wind; farther offshore they are driven by *positive wind curl* in the presence of vertical mixing, a previously unexplored and surprising mechanism. The importance of having a sharp, near-surface pycnocline and remote forcing by winds off Baja California was also pointed out.

2. INDEX OF PUBLICATIONS

McCreary, J.P., S.R. Shetye and P.K. Kundu (1986) Thermohaline forcing of eastern boundary currents, with application to the circulation off the west coast of Australia. J. Mar. Res., 44, 71-92.

McCreary, J.P., P.K. Kundu and S. Y. Chao (1987) Dynamics of the California Current System. J. Mar. Res., 45, 1-32.

McCreary, J.P. and P.K. Kundu (1988) A numerical investigation of the Somali Current during the Southwest Monsoon. J. Mar. Res., 46, 25-58.

McCreary, J.P., H. Lee and D. Enfield (1989) The response of the coastal ocean to strong offshore winds: with application to circulations in the gulfs of Tehuantepec and Papagayo. J. Mar. Res., 47, 81-109.

McCreary, J.P. and P.K. Kundu (1989) A numerical investigation of the sea surface temperature variability in the Arabian Sea. J. Geophys. Res. (submitted).

Kundu, P.K. and J.P. McCreary (1986) On the dynamics of the throughflow from the Pacific into the Indian Ocean. J. Phys. Oceanogr., 16, 2191-2198.