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MODELING THE RESPONSE OF THE CALIFORNIA CURRENT SYSTEM TO GLOBAL GREENHOUSE WARMING

FINAL REPORT

to the National Institute for Global

Environmental Change (August 1993)

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This is the final report for the project "Modeling the Response of the California Current System to Global Greenhouse Warming," supported in 1990 and 1991 by NIGEC. The scientists involved are Dr. Richard C.J. Somerville and Alejandro Pares-Sierra of Scripps Institution of Oceanography, UCSD. A copy of papers submitted to the *Journal of Physical Oceanography*, and *Geofisica Internacional* that were supported in part or whole by WESTGEC, as well as a summary of a talk delivered at the XX General Assembly of the IUGG, Vienna (1991) are appended to this report.

Objective of the research: The objective of the research was to improve our understanding of the response of the California Current system to the large-scale anomalous forcing thought to be associated with greenhouse warming. We viewed this as a necessary initial step in the study of the California climate response to global change.

Results: The project had three main thrusts: 1) upgrading and fine tuning our ocean circulation model to tackle the scales (in time and space) that were needed for this research, 2) carrying out numerical experiments to assess the capability of our models, and 3) analyzing the long-term, high-density sea-surface temperature data from satellite to be used eventually in the thermal constraining/forcing of the circulation model. Results were accomplished on each of these thrusts:

1) We implemented a mixed-layer model to augment our adiabatic multilayer primitive equation model. This upgrading was essential in order to predict real sea-surface temperatures (instead of the SST proxy we had been using, i.e., upper-layer-thickness) and, more importantly, to be able to eventually couple our ocean model to an atmospheric model. The formulation of the mixed-layer model is based on the one presented by McCreary and Kundu (1988), which in turn is based on the Kraus-Turner one-dimensional formulation. The depth and thickness of the mixed layer are controlled by entrainment and detrainment in the mixed layer, which are determined by wind stirring and cooling at the ocean surface.

The rate of entrainment is controlled by two mechanisms: the shear instability that occurs at the base of the layer whenever the bulk Richardson number of the dynamical layer is less than unity (i.e. when $Ri = \alpha g(T - T_d)h/(u^2 + v^2) < 1$, where T,h and (u, v), are the temperature, depth and velocity of the layer, respectively, and α, T_d are the coefficient of thermal expansion and temperature of the deep ocean, respectively), and the classical Kraus-Turner balance between the opposing contributions of the wind stirring and the surface cooling (i.e. whether the net rate of generation of turbulent kinetic energy $P = mu_*^3 - (\epsilon + \frac{1}{2}\alpha g Q)$ is positive or negative, with mu_*^3 and $-\alpha g Q h/2$ being the contributions due to wind stirring and surface cooling, respectively, and $-\epsilon h$ the rate of viscous dissipation [McCreary and Kundu, 1989]). The mixed-layer formulation has been implemented in one version of our model.

2) Two indirect mechanisms exist whereby global warming could alter the regional climate in the California Current region: first, through an enhancement of the coastal upwelling/downwelling regimes by the intensification of the local winds; and, second, through the effects of remotely generated (of equatorial origin, for example) warm and cold events propagating into the region in the form of coastal waves. We have performed numerical experiments to assess the relative importance of local (atmospheric) versus remote (oceanic) forcing on the local oceanic response to global warming. The experiments have clearly shown that, although the enhancement of coastal upwelling and downwelling regions by the intensification of the local winds is an extremely important mechanism in determining the regional climate, its effectiveness critically depends on the long-term modulation of the equatorial contribution.

Figure 1 shows one of the results of such experiment: the hindcast of the major 1982 El Niño event of 1982 along the coast of North America. The experiment consisted in forcing the model from 1980 to December of 1981 with observed winds (COADS) and, through its southern boundary, with the equatorial variability obtained from an equatorial model. Starting in January 1982, we stopped the "normal" forcing and used different forcings as shown in Fig. 1. The figure represents a 3-year time series for the model at $40°N$ near the coast. The lines correspond to relative sea-level with the model forced by "real" winds (COADS) and equatorial forcing (line A, the control run), climatology winds and equatorial forcing (line B), equatorial forcing only (line C), no forcing (line D), and forcing with the climatology wind only (line E). Figure 1 shows very clearly that the anomalous character of the 1982 event is due mostly to the equatorial contribution. Figure 1 shows for example that most of the anomalous signal in the California current region in this year was produced by the contribution of the equatorial forcing and that the enhanced upwelling driven by the more intense winds produced only a relatively minor contribution. Experiments like this have shown that the local and remote contributions can interact in such a way as to reinforce (or cancel) each other to produce an enhanced (or suppressed) response in the coastal North Pacific. A manuscript is being prepared on this subject, i.e. the influence of the two mechanisms in determining the overall response of the California Current to anomalous (e.g. global-change type) forcing.

3) We implemented a new version of the California Current model based on work by McCreary *et al* (JGR, 1991). We conducted experiments on the response of this new model to different wind forcings associated with possible greenhouse scenarios. In particular, we have investigated the seasonality of the upwelling frontal instability near the coast of California. Marked seasonal changes have been found. These changes are associated with annual variations of the wind strength at the coast. Figure 2 shows the results of one of the experiments in which the frontal upweling zone became unstable. The figure shows a sequence of snap shots of the model forced by realistic wind. The development of an instability, evidenced in the figure, appears first as a small disturbance of the mean current and front. Then, intensification of the disturbance produces the breaking of the front and the generation of eddies and jets. The generalization of these results to the global-change scales is speculative, but a qualitative connection can be expected between enhanced winds near the coastal regions (the most common global-change scenario) and more instability in the frontal region, for examples number of eddies. A manuscript on this subject is being prepared.

4) In preparation for the assimilation phase of the project, a study of the large scale characteristics of the sea surface temperature in the California Current area was conducted. The data analyzed were derived from weekly composites of SST derived from TIROS-N/NOAA series of AVHRR by Dr. Otis Brown at the University of Miami and distributed by the Jet Propulsion Laboratory. Using standard statistical techniques (i.e. EOF, extended EOF, B-D spectrum, etc.) we were able to extract from the SST data several features and modes of variability that have not been observed, although they have been predicted by theory or have been suggested by much less dense data (e.g., either a few snap shots or latitudinal transects). The presence of a critical latitude, for example, which delimits a region of propagation, south of it, from a region of strong dissipation north of it, is an important feature that we were able to isolate from the data. The theoretical explanation for the existence of this latitude is well understood but, as far as we know, it has never been seen in real observations. A paper was submitted to *Geofísica Internacional* and another is being written on the results of the analysis of these data sets, which emphasizes the large-scale, low-frequency character of the data.

Enclosures:

1 Pares-Sierra A., W. White, C.K. Tai, 1992; Wind-driven coastal generation of annual mesoscale eddy activity in the California Current. *Journal of Physical Oceanography*, **23**, 1111-1121.

2 Auad,G., A. Pares-Sierra, and G. Vallis, 1991; Circulation and energetics of a model of the California Current system. *Journal of Physical Oceanography*, **21**, 1534-1552.

3 Pares-Sierra, A., 1991; Remote and local forcing of Rossby wave variability in the mid-latitude Pacific Ocean. *Geofisica Internacional*, **30**, 121-134.

4 Pares-Sierra, A., and R. Somerville, 1991; Modeling the response of the California Current system to global greenhouse warming. Abstract of presentation to the XX General Assembly of the IUGG, Viena, Austria.

5 Herrera, H., and Pares-Sierra, A., 1992; Propagación de señales de baja frecuencia en la temperatura superficial del mar analizadas a partir de datos de satélite en el Pacifico Nor-Oriental. (In review: *Geofísica Internacional*)

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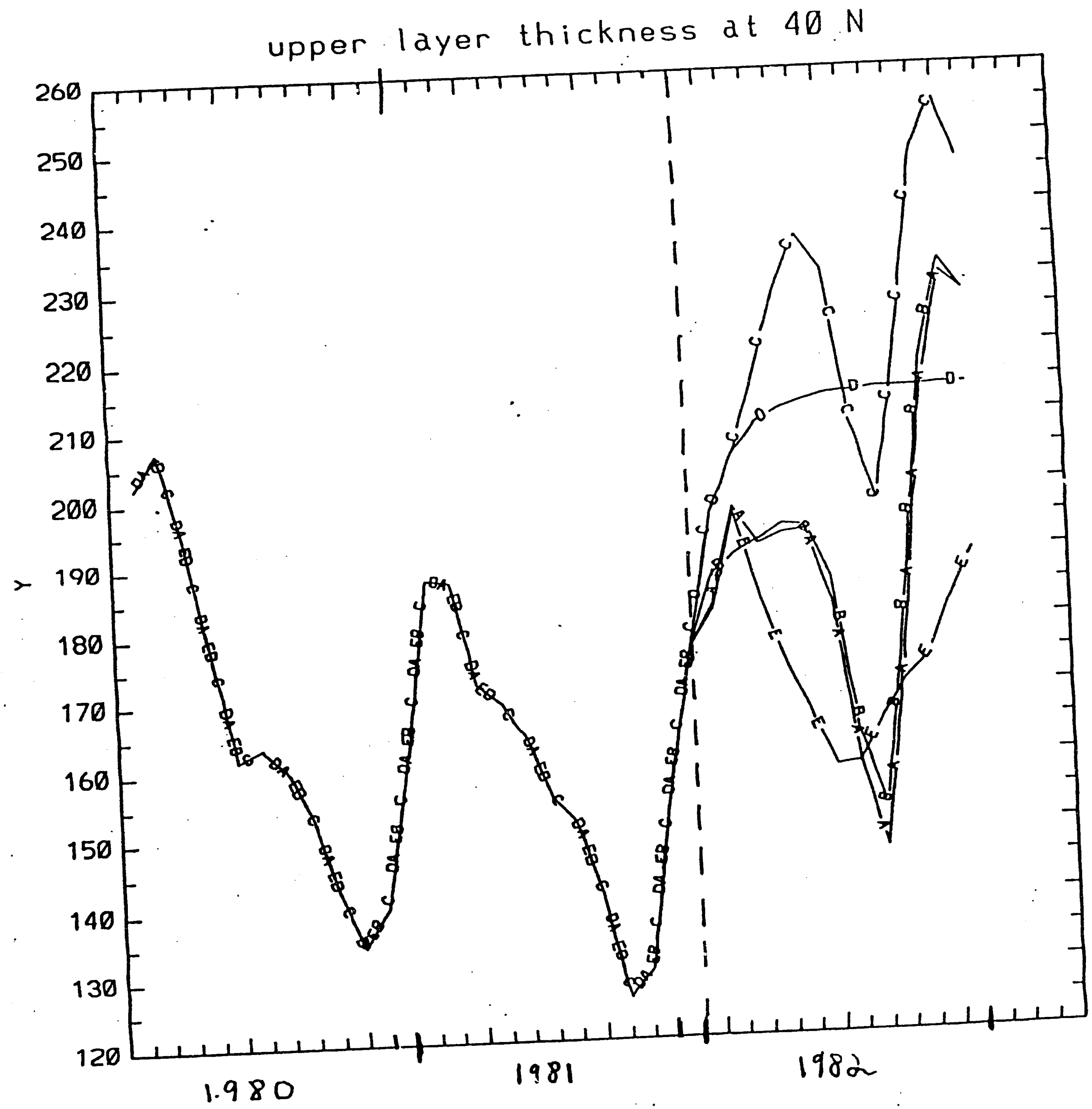
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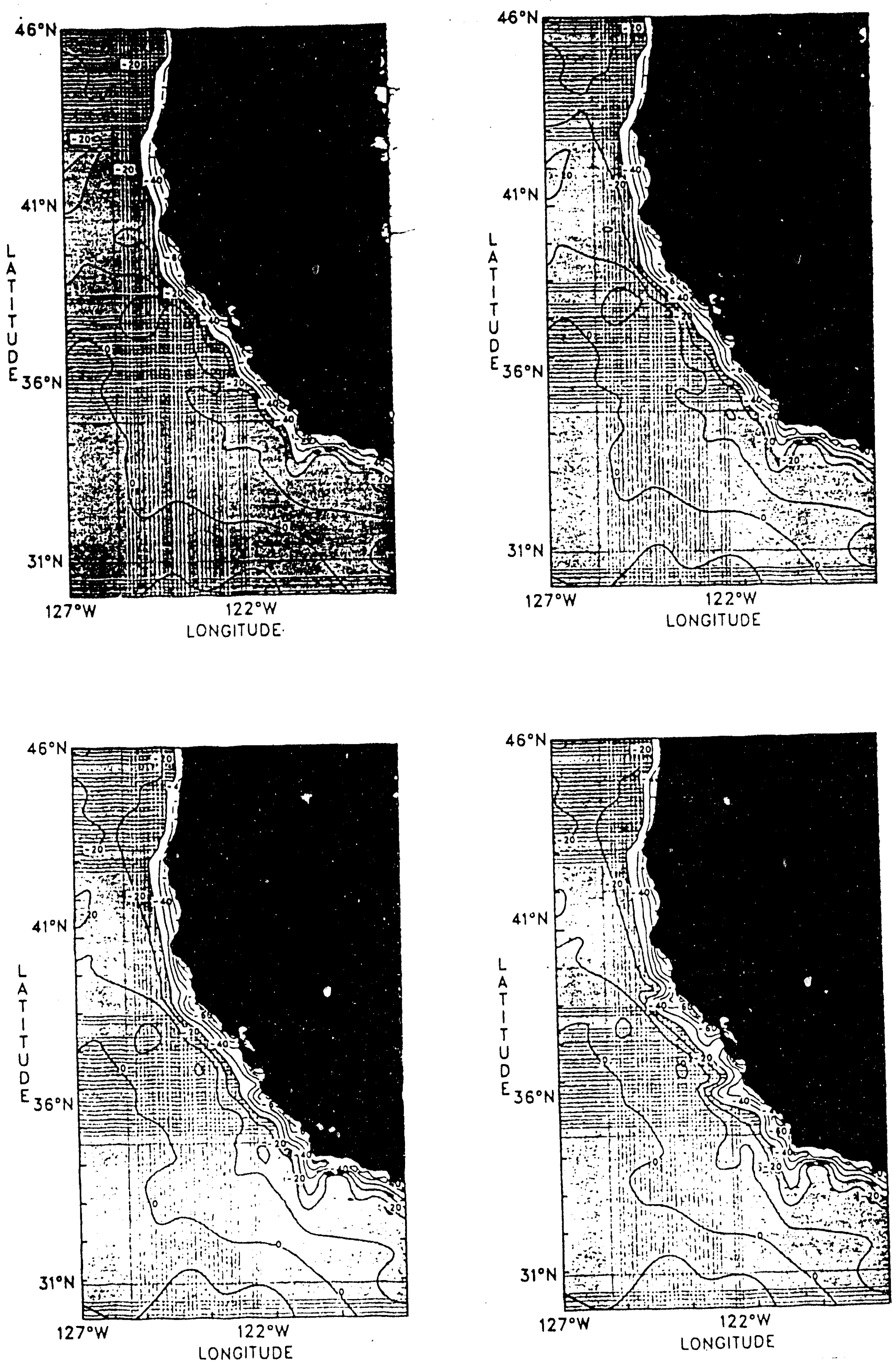
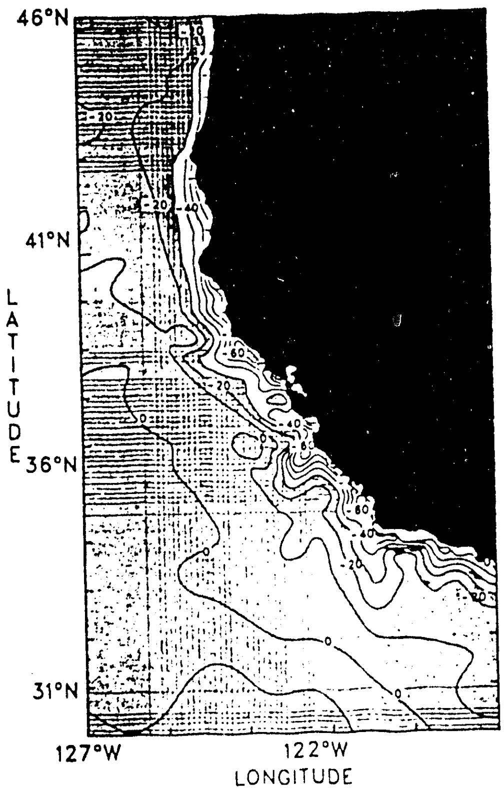


Figure 2. Development and breaking of an upwelling front in the circulation model. The intervale between figures is 5 days.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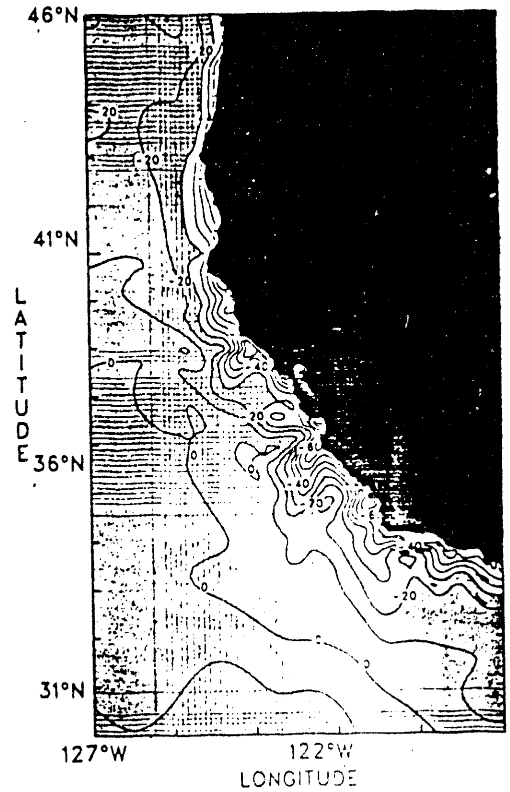
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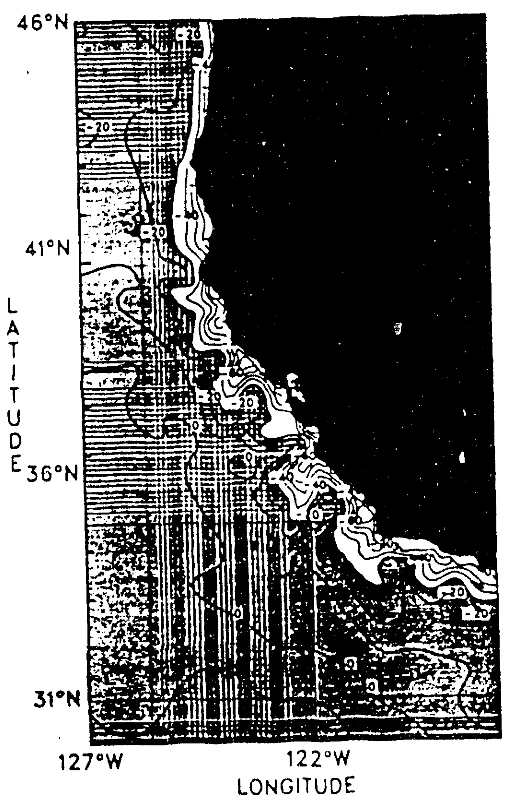
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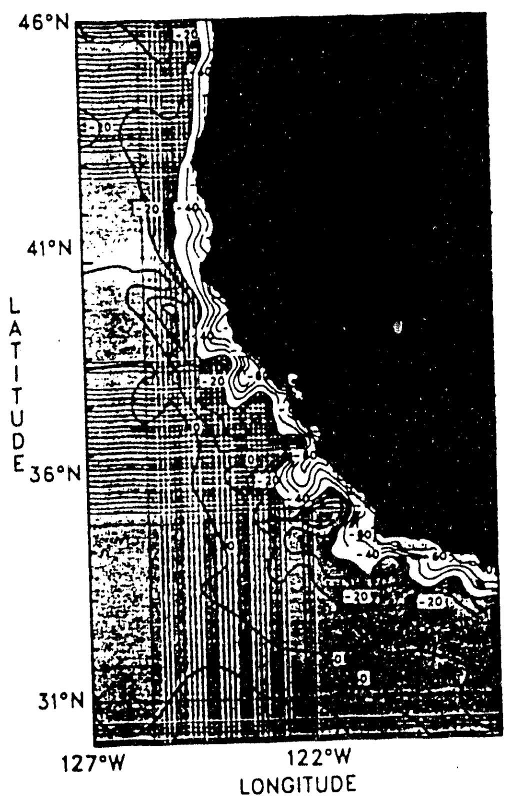
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