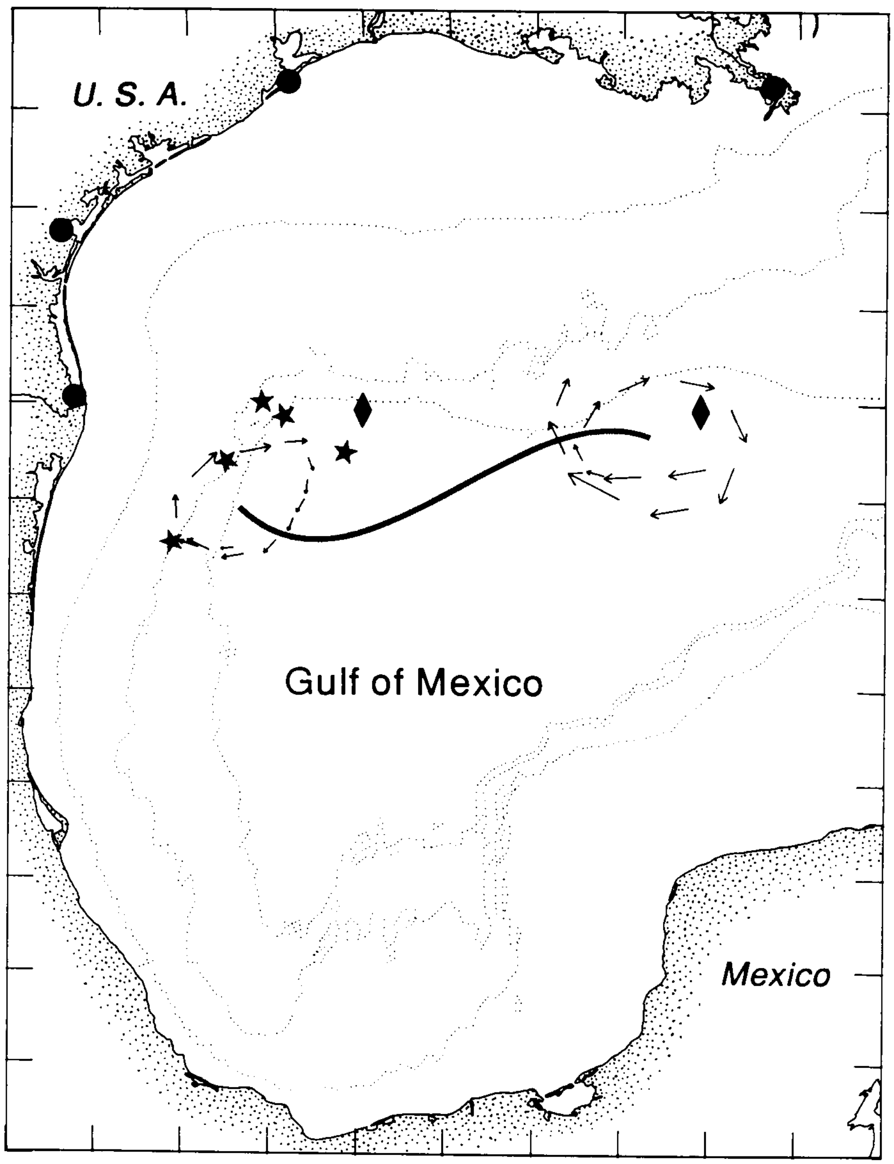
OCS Study
MMS 88-0045

Gulf of Mexico Physical Oceanography Program Final Report: Year 3

Volume I: Executive Summary



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Gulf of Mexico Physical Oceanography Program Final Report: Year 3

Volume I: Executive Summary

Author

Science Applications International Corporation

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by
Science Applications International Corporation
Raleigh, North Carolina 27606

Program Manager:
Evans Waddell, Ph.D.
Science Applications International Corporation
Raleigh, North Carolina 27606

Project Officer:
Murray L. Brown, Ph.D.
Minerals Management Service
Gulf of Mexico OCS Regional Office

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Gulf of Mexico OCS Regional Office
1201 Elmwood Park Boulevard
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I. INTRODUCTION

In 1982, Minerals Management Service (MMS) initiated a multi-year program under contract with Science Applications International Corporation (SAIC) to study the physical oceanography of the Gulf of Mexico as part of its outer continental shelf environmental studies program. This particular program, called the Gulf of Mexico Physical Oceanography Program (GMPOP), has two primary goals:

- Develop a better understanding and description of conditions and processes governing Gulf circulation, and
- Establish a data base which could be used as initial and boundary conditions by a companion MMS-funded numerical circulation modeling program.

The area studied emphasizes the deep Gulf and shallow regions where conditions may be directly or indirectly affected by patterns associated with or originating in the deep Gulf. This phased, multi-year program investigates the eastern and western Gulf separately (Figure 1.1-1), with this particular report presenting the results of Program Year 3 in the western Gulf.

1.1 Program Participants

Science Applications International Corporation, the prime contractor for the GMPOP, is working with a team of scientists from SAIC, universities and institutes to study the physical oceanographic processes in the Gulf. Presented alphabetically below are the participating scientists and their primary areas of focus.

- Dr. D. Brooks (TAMU) - Subsurface Currents and Hydrography
- Mr. F. Kelly (TAMU) - Subsurface Currents and Hydrography
- Dr. J. Lewis (SAIC) - Lagrangian Drifters
- Dr. F. Vukovich (RTI) - Satellite Imagery

Note that all PI's had access to and used relevant portions of the program's overall data base; however, each tended to approach from a differing primary data set.

Loop Current (LC) eddies affect circulation patterns throughout the western Gulf. As a result many of the processes and features of interest were in both U.S. and Mexican waters. MMS-funded efforts were closely coordinated with and supported by the Mexican Navy. For those scheduled cruises going into the Mexican exclusive economic zone (EEZ), Mexican Navy vessels were used. Without mutual support for this undertaking, the available data base and associated synthesis would have been much more limited. Of particular importance was Captain A. Vazquez of the Mexican Navy. His continued involvement was essential to the program's success.

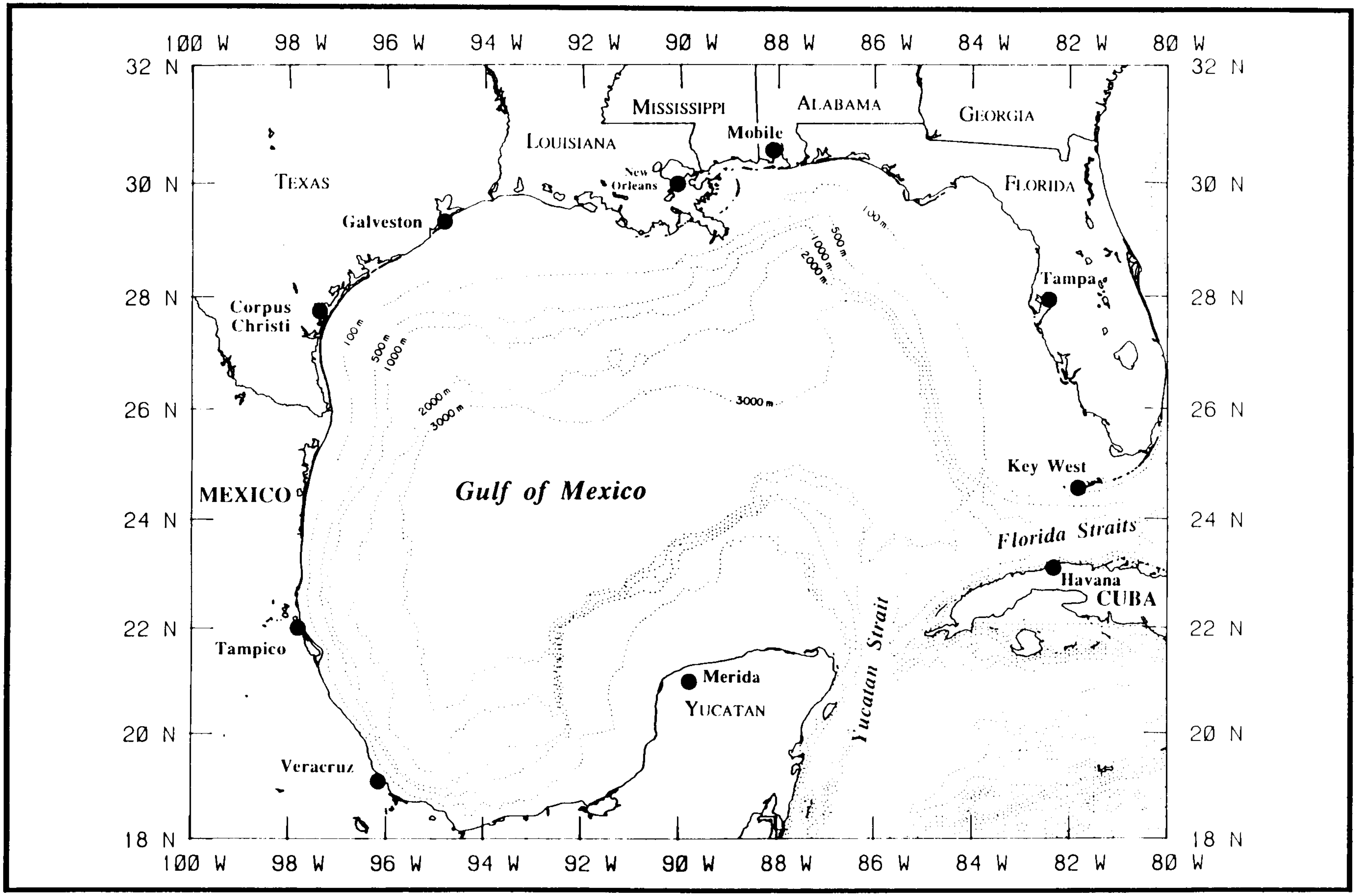

Figure 1.1-1. Study area for the Gulf of Mexico Physical Oceanography Program. This Year 3 Report focuses on Loop Current eddies in the central and western Gulf.

The scientific principals were supported by an experienced SAIC team. Dr. E. Waddell is Program Manager, Mr. R. Wayland is Data Manager and Mr. J. Singer is responsible for logistics and the ship-of-opportunity (SOOP) activities. The SAIC personnel planned and conducted the cruises, managed the data and provided most of the data analysis and associated graphics used in this study.

1.2 Report Organization

An exceptional multivariate data base was taken during Program Year 3. An evaluation of these data from the perspective of the stated program objectives resulted in organizing the synthesis into sequential phases, each of which tend to result from differing processes or substantially different relative influences of similar processes. These identified segments are an effort to subdivide on a rational basis what is a continuous, evolutionary sequence.

The process-based eddy stages include the following:

- Eddy Separation and Initial Movement
- Western Gulf Eddy/Slope Interaction and Associated Cyclone Intensification
- Eddy Reflection and Dissipation
- Eddy-Eddy Interaction

As is apparent from the discussion in Volume II of this report, conditions surrounding an eddy have a major effect on its evolution. As a consequence, the relative influence of various processes may differ for other eddies. Of particular importance is the presence and "vigor" of other eddies.

II. TECHNICAL DISCUSSION

2.1 Introduction

The following material summarizes important elements and insights developed during Year 3 of the MMS-sponsored Gulf of Mexico Physical Oceanography Program. The multivariate data set is rich in its characterization of kinematics and dynamics associated with the evolution of a LC eddy. Much of the coordinated data set allows a previously unavailable documentation of processes and conditions associated with LC eddies which are a major influence on the physical oceanography of the central and western Gulf (Figure 1.1-1).

2.2 Experimental Design and Program Objectives

The program objective of obtaining and using data to develop an improved understanding of Loop Current eddies interacting with the western slope of the Gulf required an experimental design which was flexible and which could be adjusted to accommodate the differing paths that an eddy might take. The primary data taken and used were as follows:

- Subsurface currents/temperatures
- Ship- and plane-base hydrographic and expendable bathythermograph (XBT) surveys
- Lagrangian (ARGOS) drifters
- Satellite thermal imagery
- Ship-of-opportunity (SOOP) XBT surveys.

Of these, all but the current/temperature moorings could be adjusted to accommodate a given trajectory. Fortunately, however, an eddy moved directly over the general mooring array, resulting in a comprehensive and coordinated multivariate data base.

The mooring placement is shown in Figure 2.2-1. Many surveys were conducted during the life cycle of the studied eddy. Two ship-based surveys included detailed hydrography, and the SOOP- and plane-based surveys relied on XBT's. MMS-funded ARGOS drifters were also placed in Eddy B as well as other features of interest. In addition, trajectory data from five drifters funded in part or wholly by Shell Oil were made available to the program. During cool months (November through May), satellite-derived sea-surface temperatures provided important support information for real-time operations and for historical and independent reconstruction of the size and location of key features in the study area.

The SOOP program has provided essential and virtually continuous temperature data on a transect from Yucatan to New Orleans. All LC eddies must cross this line during westward migration. In addition, "opportunistic" cruises allowed documentation of specific features of interest.

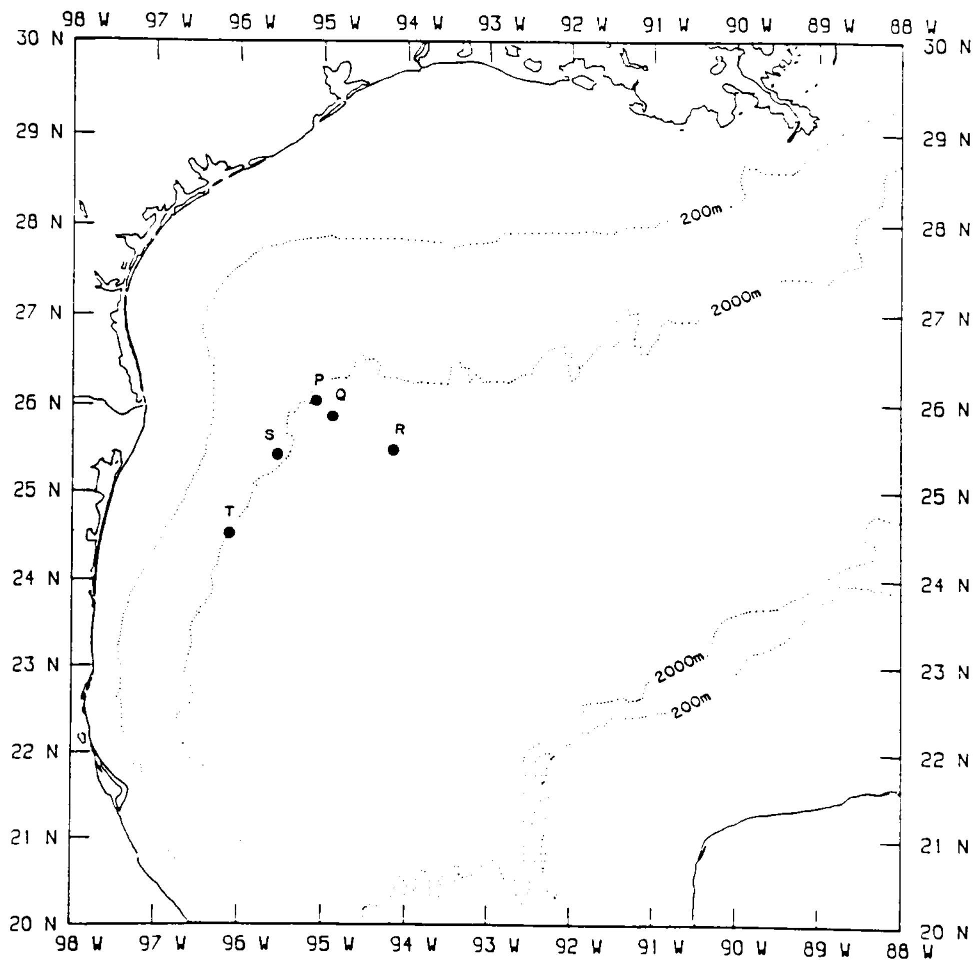

Figure 2.2-1. Mooring locations in the western Gulf of Mexico for Year 3 of the MMS-sponsored Gulf of Mexico Physical Oceanography Program.

2.3 Eddy Separation and Initial Movement

Eddy B which separated from the Loop Current in July 1985 was documented by one or more methods as it moved westward at approximately 5 km day^{-1} (Buoy 3378, Figure 2.3-1a). The separation sequence involved the vertical doming of cold water until the LC lobe and main current field separated (Figure 2.3-2). During the initial stages following separation, the eddy maintained kinematic and dynamic properties quite similar to the unseparated Loop Current.

During the first three months of westward movement there was little change in the vertical structure of Eddy B. As expected, water mass characteristics in the eddy, away from boundaries especially at or near the surface, were essentially like the water masses seen in the Loop Current.

The swirl or tangential velocity within the eddy was estimated at different times during this initial interval by three different means: drifters, current meters and geostrophic calculations. Surface drifter velocities were of the order of 60-80 cm sec^{-1}. Geostrophic calculations relative to 950m had a maximum surface current of 80-90 cm sec^{-1}. Filtered current time series from 100m were 40 cm sec^{-1} vs. a corresponding geostrophic estimate of 62 cm sec^{-1}. At greater depths (1000m and deeper), the measured currents were strongly barotropic; that is, they had little vertical shear. In contrast, at shallower depths in the eddies, large horizontal density gradients produced strongly sheared (baroclinic) current profiles.

2.4 Westward Translation

While moving to the west, Eddy B seems to have been influenced by the presence of the northern slope and by the presence and location of an eddy (Eddy A) in front of it and to the west. A qualitative consideration of relevant dynamics suggests that non-linearities and vorticity adjustment were active while the eddy impinged on the northern slope. In addition, an apparent change in the volume within closed isotherms suggests entrainment of water, possibly from the northern slope and outer shelf.

Prior to the arrival of Eddy B, other rotational features may have been active adjacent to the western slope. Subsurface currents and limited XBT data show a rich current field. Again, the probable presence of features such as eddies with a strong density signal contributes to the observed velocity field, especially above 1000m. Below this where horizontal density gradients are weak or absent, current speed varied little with depth. Current speeds of 25 cm sec^{-1} and greater were observed at depth during episodic events (Figure 2.4-1).

Quite energetic, non-tidal currents having a period of about one day (local inertial period) were measured (Figure 2.4-2). These occur throughout the water column and have short horizontal and vertical coherence lengths. It should be noted that the clockwise-rotating inertial currents are a major component of the local kinetic energy field measured at the moorings.

The coherent structure of the velocity field is difficult to isolate and reconstruct. The features moved so that the fixed position arrays changed locations within the organized features. Thus the association between currents at different sites changed with time. Typical coherence calculations which assume stability of statistics and stationarity of the process would

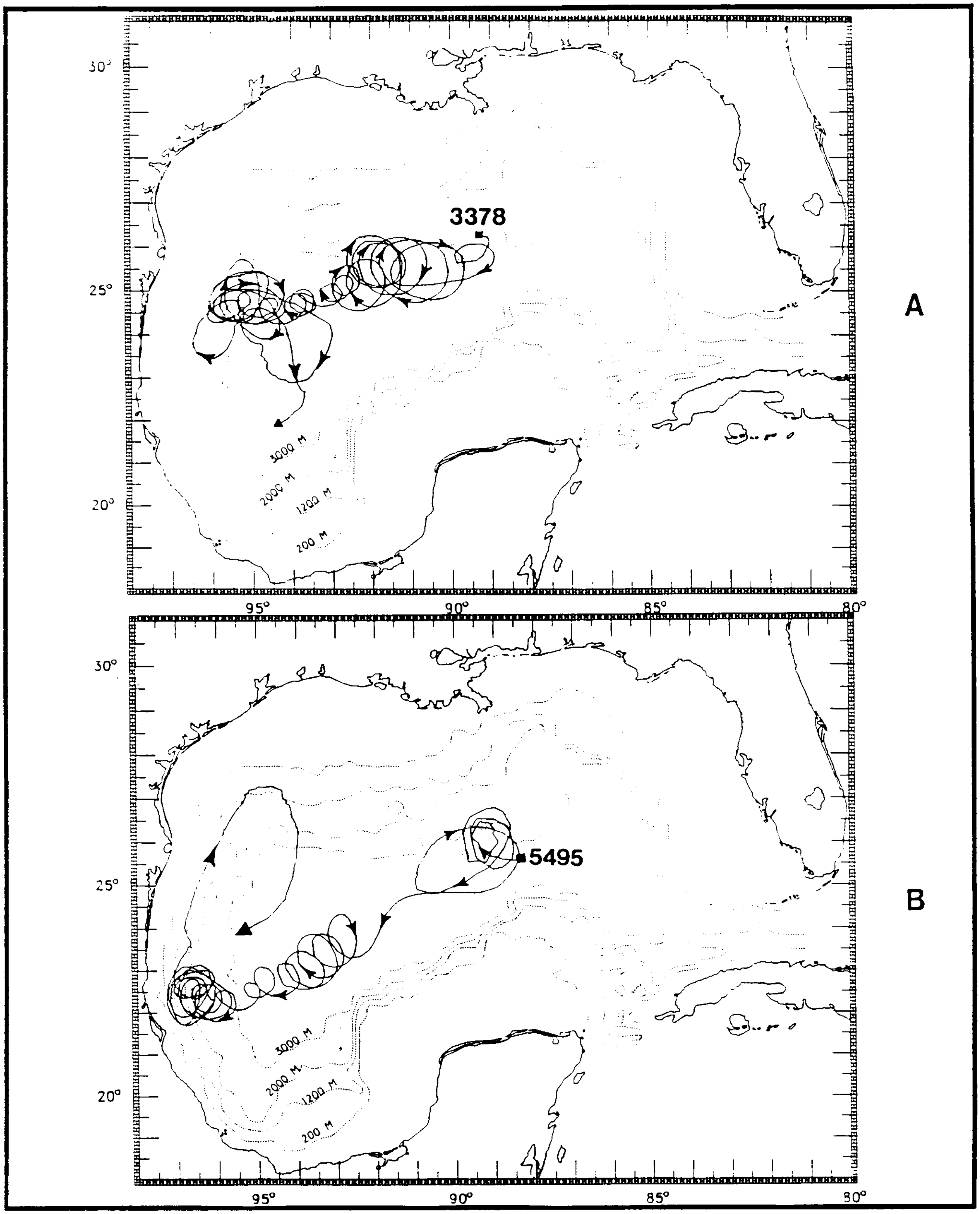

Figure 2.3-1. Trajectory for: (a) Drifter 3378 and (b) Drifter 5495. The presence of Eddy A was detected at ~93°W when Drifter 5495 began making anticyclonic loops. Depth contours are in meters. Squares denote the beginning positions of the drifter trajectories and triangles denote the end positions.

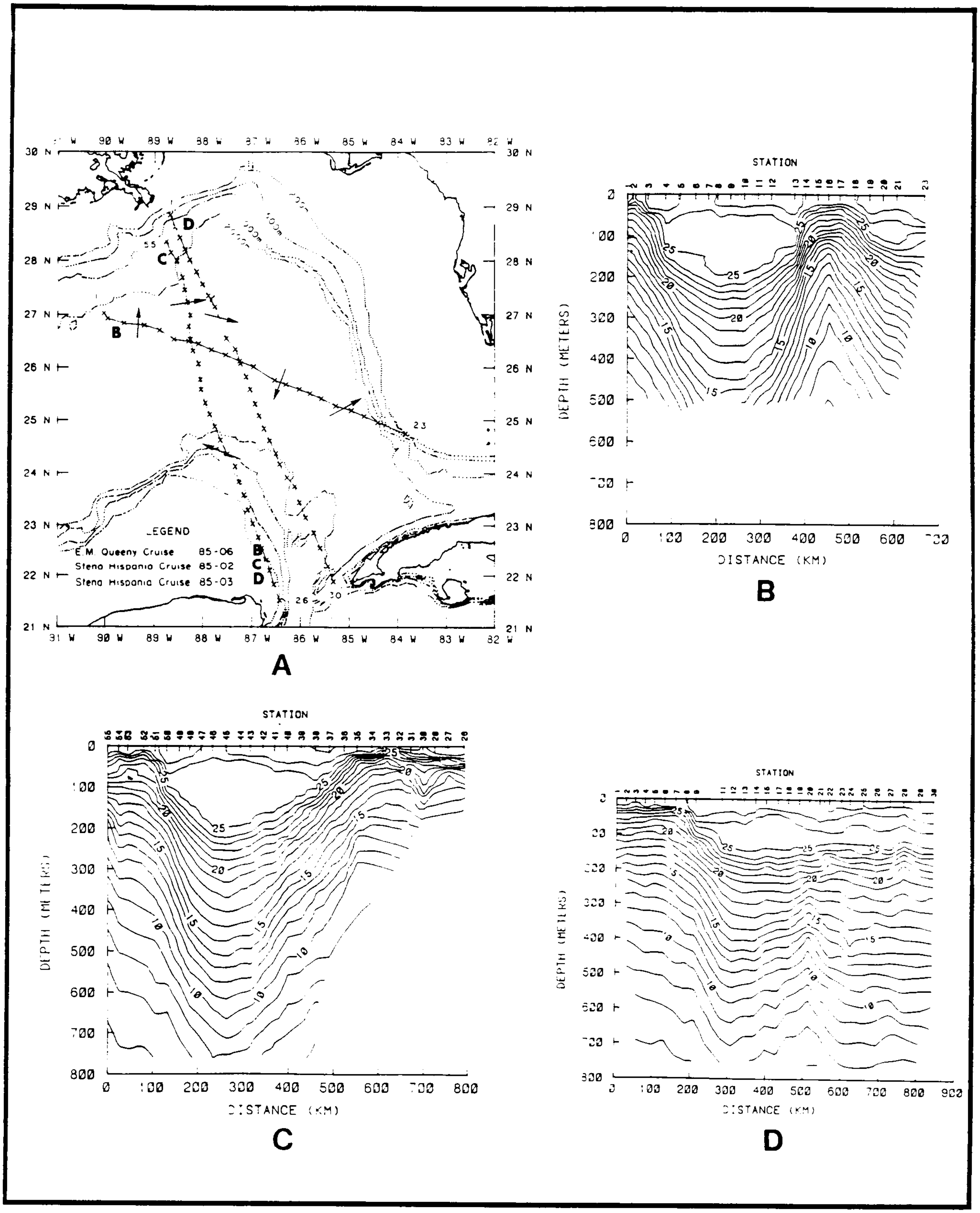

Figure 2.3-2. (a) Cruise tracks for SOOP XBT data collected during May 26-31, 1985. The arrows denote the flow at the edges of the Loop Current based on the vertical temperature structure shown in temperature data from: (b) the E. M. QUEENY cruise, May 26-27, 1985, (c) the STENA HISPANIA cruise, May 27-28, 1985 and (d) the STENA HISPANIA cruise, May 30-31, 1985.

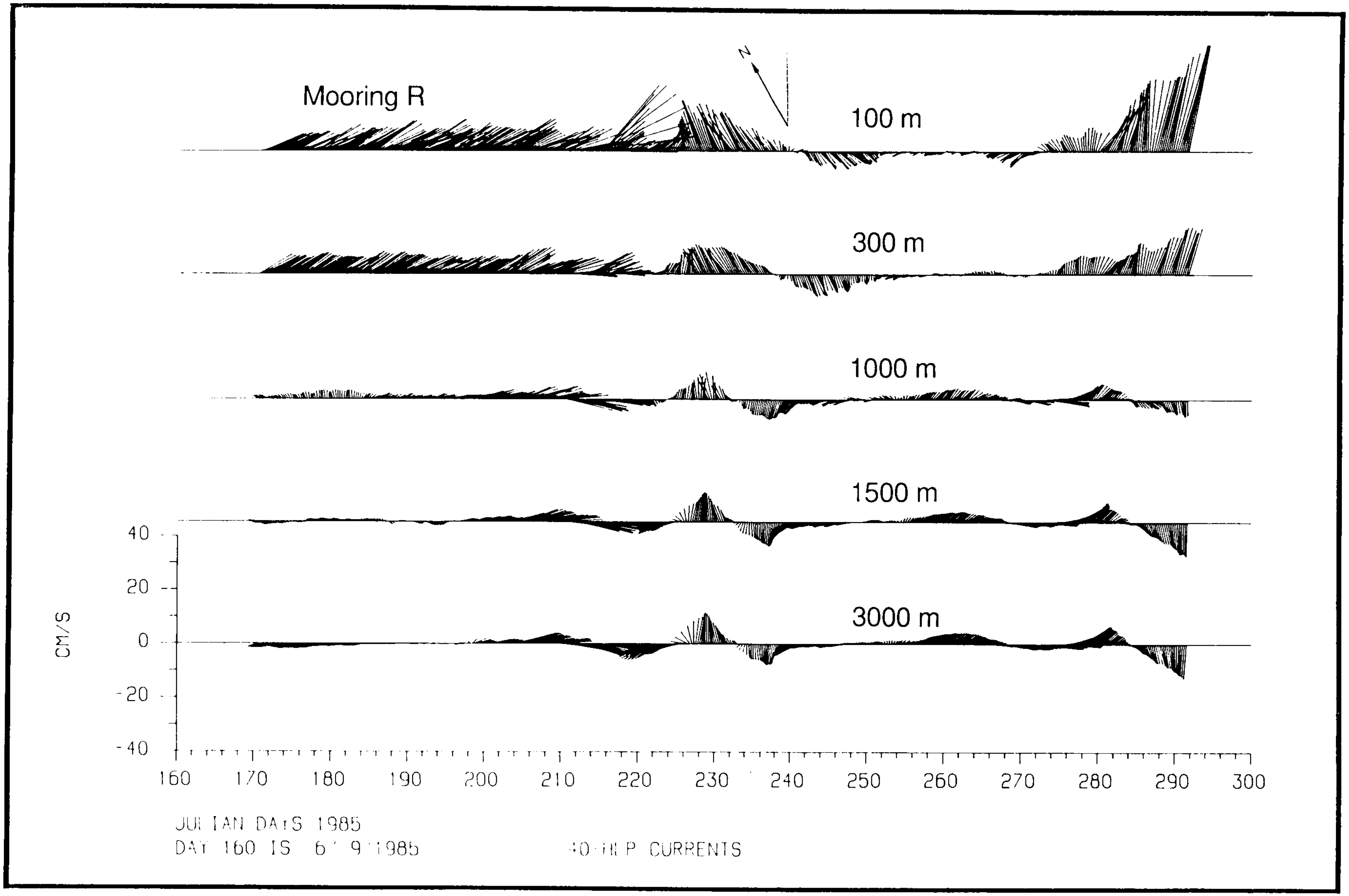

Figure 2.4-1. Velocity vector time series of 40-hour, low-passed currents recorded at Mooring R.

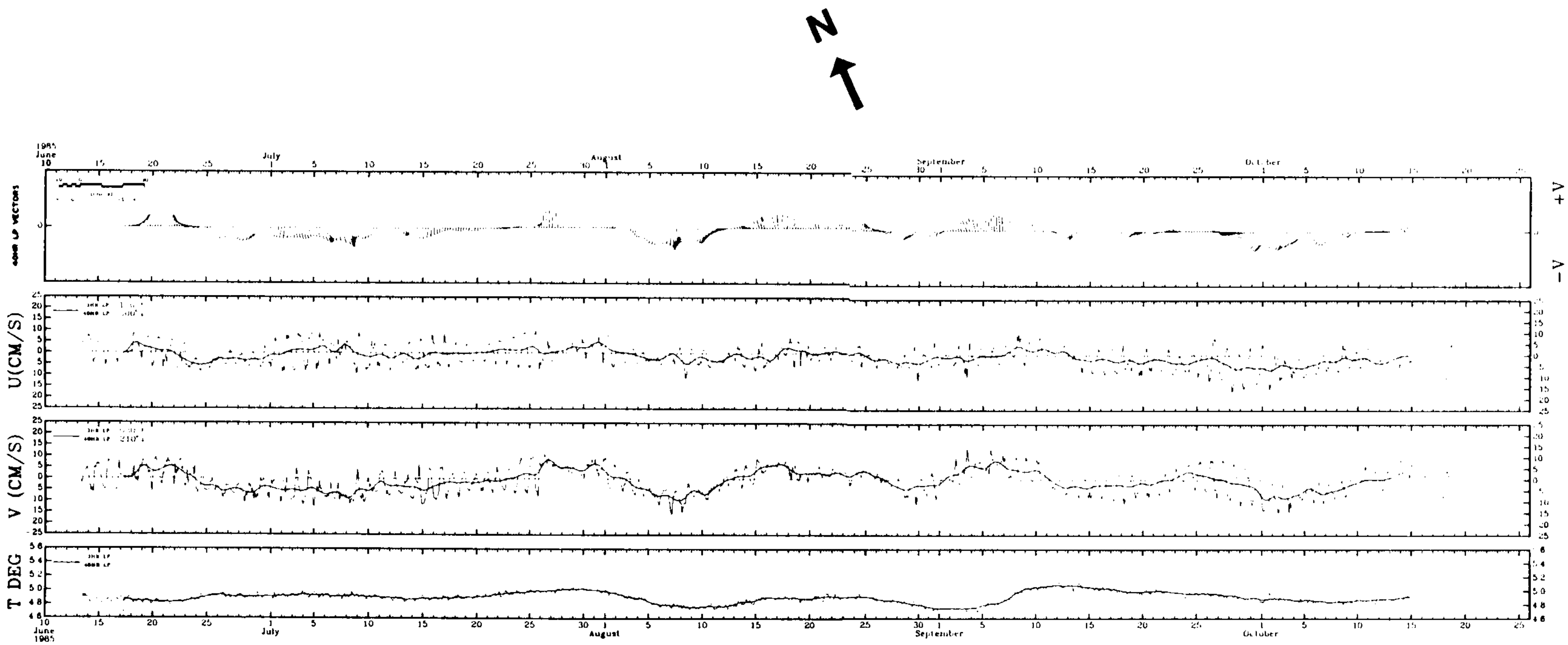

Figure 2.4-2 Time-series plots of 40-hour, low-passed stick vectors, and 3-hour (light line) and 40-hour (heavy line), low-passed U and V components and temperature for second deployment period at Mooring P at 1000m. Vertically up (+V) is toward 30°.

have reduced utility for defining the organization of the linear relation between such observations.

2.5 Eddy-Slope Interaction

Survey data showed the initial development and intensification of a cyclone paired to the anticyclone, Eddy B. Other station data and imagery suggest the presence of other possible cyclones proximate or linked to Eddy B, but one cyclone to the northwest grew substantially. Note, more recent drifter and imagery data have documented the presence of smaller cyclones on the periphery of an LC eddy. While having an internal counterclockwise sense of rotation, these cyclones may be moving as a unit in a clockwise sense around the anticyclone. The primary cyclone, Eddy Z, is represented by the doming of isotherms as initially seen in November 1985 (Figure 2.5-1). By the end of January 1986, the cyclone had intensified considerably (Figure 2.5-2). By April 1986 the cyclone had developed and was comparable to Eddy B to the south (Figure 2.5-3). This is the first time the development and evolution of this anticyclone-cyclone pair has been documented and is a major achievement for this project.

During this period of interaction with the western slope, there is some evidence that Eddy B may have continued to interact with Eddy A to the south. A result of this could have been incorporation of streamers of Eddy A water into the near-surface layers of Eddy B.

Using a density field as estimated from an AXBT survey, geostrophic velocities between 150 and 650m were estimated to be approximately 52 cm sec^{-1} while consideration of density to approximately 1500m only increased this estimate to 70 cm sec^{-1}. Clearly, the major portion of density effects on the velocity remained in the upper layers while strongly barotropic current profiles persisted at depth.

An examination of the location of maximum density and the apparent center of rotation showed the vertical axis of both the anticyclone and cyclone to be tilted downward to the east. This vertical structure adds to the difficulties in using fixed arrays to evaluate details of the event kinematics. Between Eddy B (anticyclone) and Eddy Z a "jet" can develop as both are moving offshore. This region of strong offshore motion can and did seem to draw water off the slope and shelf. This is shown as a region of less dense (lower salinity) water. At times when shelf waters are relatively cold compared to offshore waters, satellite thermal imagery shows these features.

Subsurface current observations show episodic and event influences on circulation. Linear analysis methods such as spectra and coherence reproduce these as broad spectral bands of relatively low frequency (red) variance. In addition, many time series are not stationary (statistically time invariant) or stable because lower frequency circulation is linked to evolving and moving self-similar patterns. As an example, currents can be vigorous or relatively quiescent depending on the small and non-periodic movement of eddies.

Subsurface (in-situ) temperatures also reflect the local vertical isotherm motion which can come from changes in temperature structure with time but are also from horizontal movement and associated vertical isotherm movement relative to fixed measurement positions.

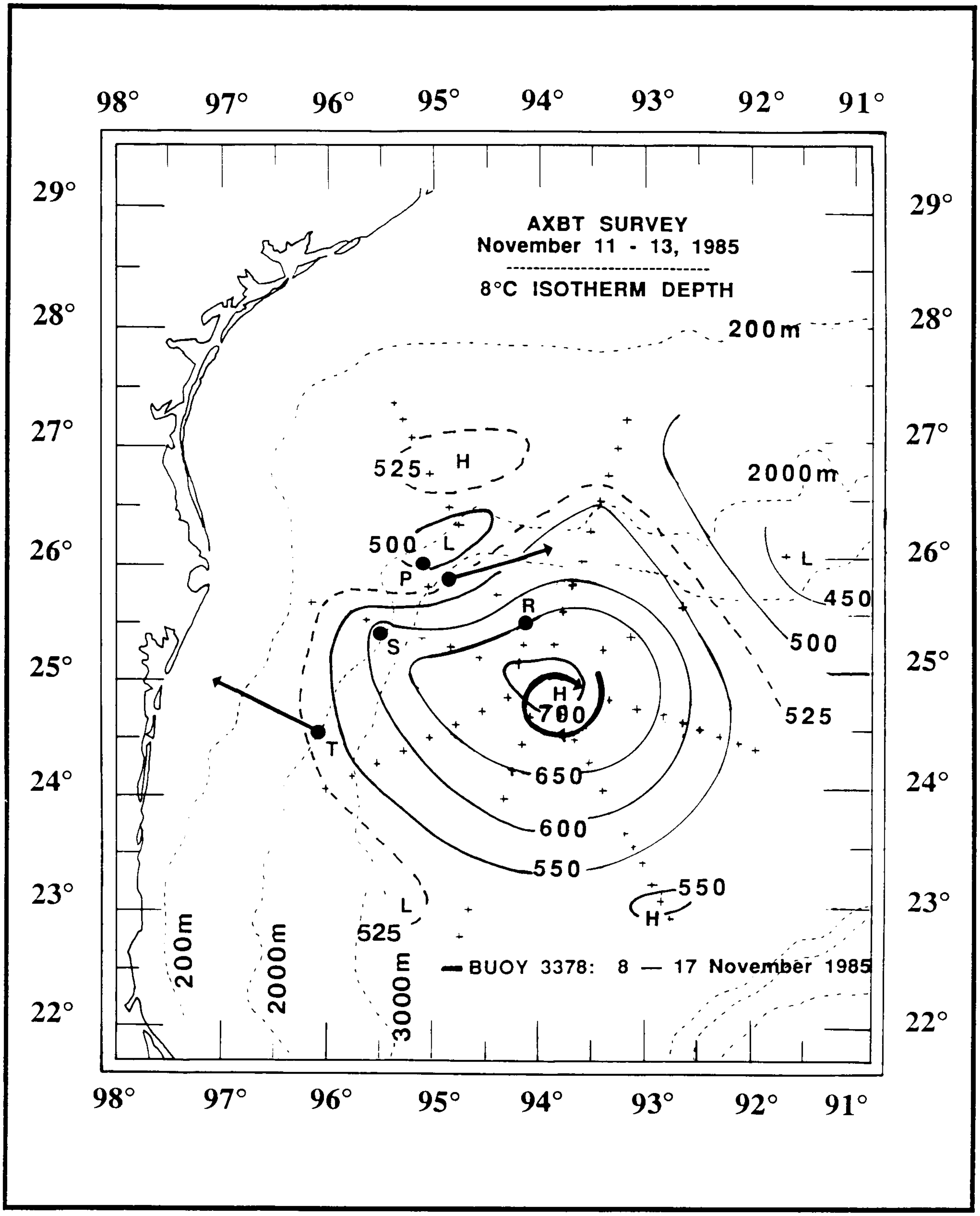

Figure 2.5-1. Topography of the 8°C temperature surface based on the AXBT survey.

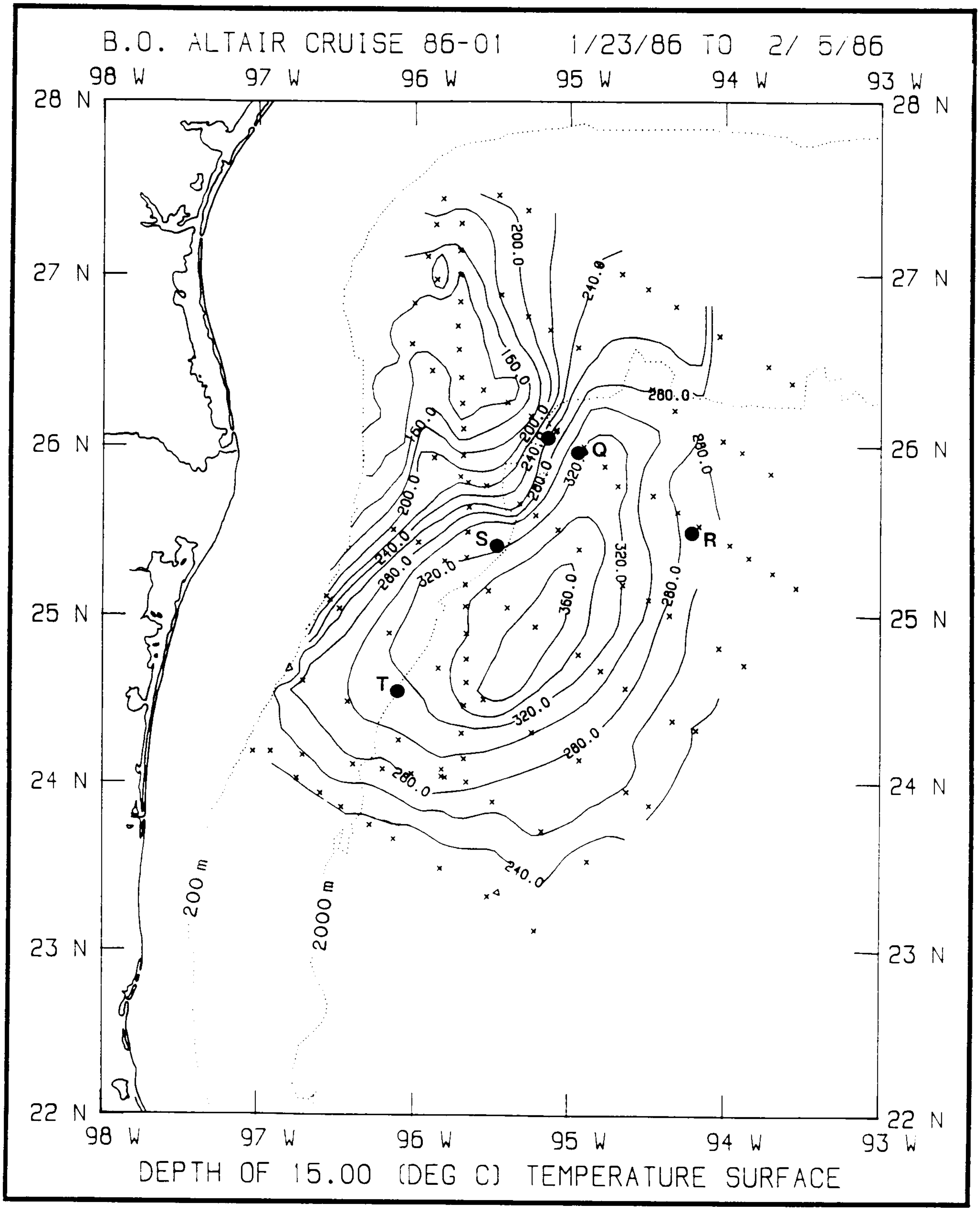

Figure 2.5-2. Topography of the 15°C temperature surface based on XBT data collected during the January 1986 B/O ALTAIR cruise.

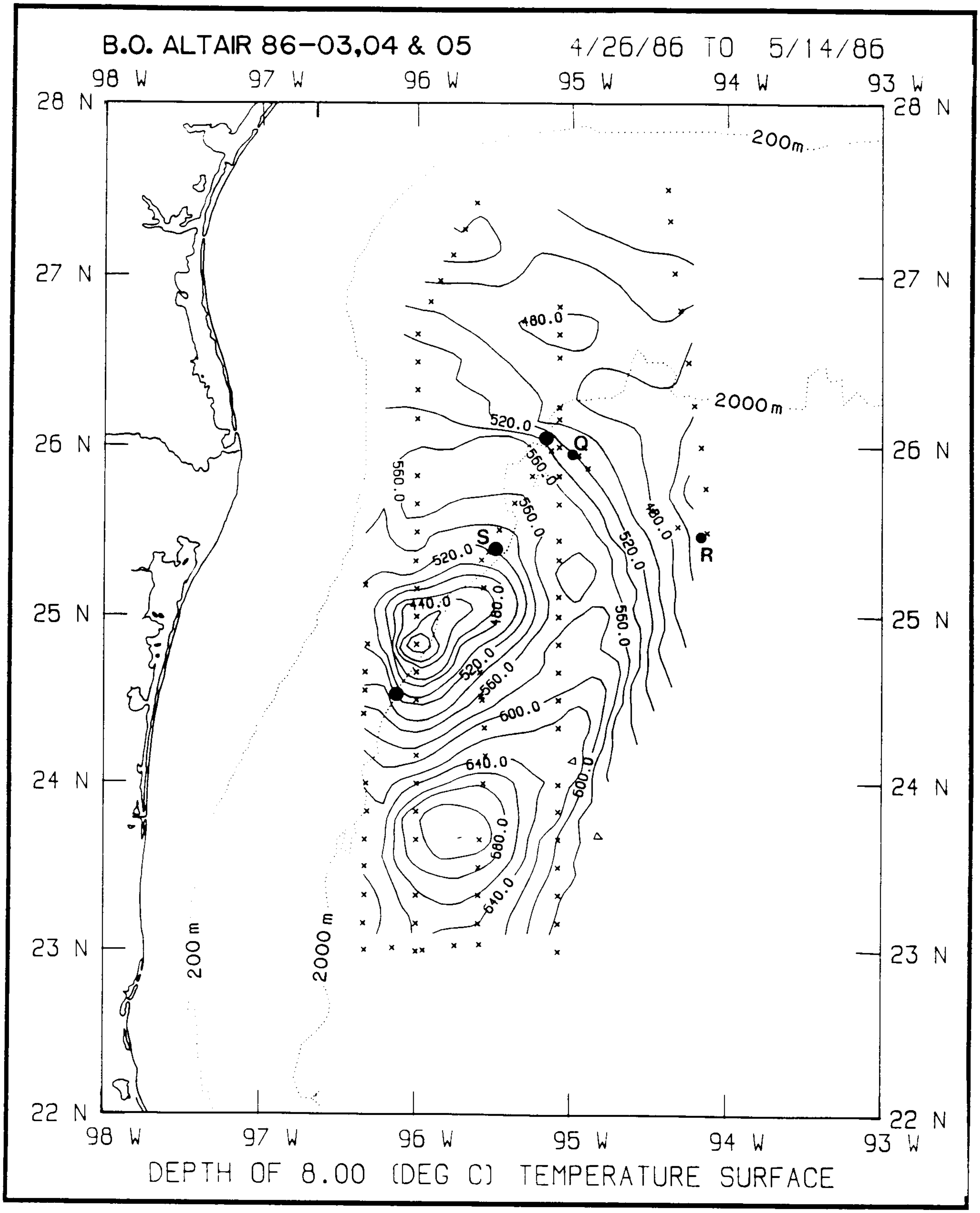

Figure 2.5-3. Topography of the 8°C temperature surface based on the April 26 to May 14, 1986 B/O ALTAIR XBT surveys.

2.6 Eddy-Eddy Interaction

During the spring of 1986, another major eddy (Eddy C) separated from the Loop Current and began to move westward. Eventually, Eddy C began to interact with the "decaying" Eddy B. Limited data suggest some coalescence of these two. There are insufficient data to describe with assurance what the sequence of events may be for the joining of the component mass and momentum fields. One possible mechanism is the joining of streamlines such that the pair of eddies reestablish a combined center of rotation.

An additional effort to examine data from two XBT surveys of the southwestern Gulf was made by Dr. V. Vidal of the Electrical Institute of Mexico with limited support provided by MMS. These surveys in 1987 documented another major LC eddy which took a more southerly course in moving into the western Gulf. Its features were comparable to Eddy B above. During a second cruise, approximately four months later, the eddy was against the slope and a cyclone was located on the northwest side.

2.7 Summary

The program data base provides excellent documentation of a series of specific episodes and conditions associated with eddies separating from the Loop Current and moving to the west. In addition to the patterns and processes described, several key points became clear:

- Unless an anomalous period was studied, eddy shedding is a fairly common occurrence, with several a year not being unusual. This rate of eddy formation has continued into 1987 and 1988.

- Based on this higher rate of eddy separation, the rate of westward movement and eddy persistence (or its converse, the decay time), the behavior of any given eddy should be directly affected by interaction with other anticyclonic eddies and/or coupled cyclones.

- A possible first-order eddy-eddy interaction is its influence on trajectories (e.g., a northern, central or southern path).

- Depending on the range of trajectories, eddies may interact first with the northern, western or possibly southern (Yucatan) slope and adjacent shelf.

- The frequency and size of LC eddies suggest that mass and velocity field in the western Gulf result from eddies that are evolving (decaying) and moving. This strongly suggests that basic circulation patterns are governed directly or indirectly by episodic events with changing locations, orientations and length scales.

These data show that eddies are dynamic and influence large portions of the Gulf. Any study of outer shelf and slope processes which does not document and consider the influence of eddies on circulation could miss a major factor affecting the circulation patterns of this area.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. The includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.