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A PRELIMINARY DESCRIPTION OF THE CODE-1 FIELD PROGRAM

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ABSTRACT

A Coastal Ocean Dynamics Experiment (CODE) has been undertaken to identify and study the important dynamical processes which govern the wind-driven motion of coastal water over the continental shelf. The initial effort in this four-year research program is to obtain high-quality data sets of all the relevant physical variables needed to construct accurate kinematic and dynamic descriptions of the response of shelf water to strong wind forcing in the 2 to 10-day band. A series of two small-scale, densely-instrumented field experiments of four-month duration (CODE-1 and CODE-2) is designed to explore and to determine the kinematics and momentum and heat balances of the local wind-driven flow over a region of the northern California shelf which is characterized by both relatively simple bottom topography and large wind stress events in both winter and summer. A more lightly-instrumented, long-term, large-scale component has been designed to help separate the local wind-driven response in the region of the small-scale experiments from motions generated either offshore by the California Current system or in some distant region along the coast, and also to help determine the seasonal cycles of the atmospheric forcing, water structure, and coastal currents over the northern California shelf.

This report presents an overview of the CODE program and a preliminary description of the observational programs conducted during CODE-1. The various logical components of CODE are identified and described, and their relationship to the entire effort is discussed. The report itself represents a minor revision of the original cover proposal submitted to NSF in late 1979 by the principal investigators and is not a comprehensive guide nor does it contain any descriptions of the initial results from CODE-1. Scientific and engineering results will be presented elsewhere in individual technical and scientific reports. CODE has been jointly conceived by the following principal investigators (who collectively make up the CODE group): J. Allen, R. Beardsley, W. Brown, D. Cacchione, R. Davis, D. Drake, C. Friehe, W. Grant, A. Huyer, J. Irish, M. Janopaul, A. Williams and C. Winant.

1. INTRODUCTION

At a given coastal location on the continental shelf, the basic mechanisms which can force low frequency motion are, (a) the local alongshore component of the wind stress, (b) the wind stress acting at other locations alongshore, where disturbances propagate to the region of interest in the form of coastal trapped waves, (c) large-scale currents, eddies, or wave motions from offshore flow regimes which may impinge on the continental margin, and (d) river runoff. Although the characteristics of shelf flow fields vary considerably from region to region, the results of recent field experiments show that the primary forcing mechanism for subtidal motion on most continental shelves is the wind stress. The wind stress may act either locally or non-locally, with the 2 to 10-day synoptic-scale wind events typically producing the most energetic fluctuation in the shelf velocity field. On longer time scales, the monthly and seasonal variability of the alongshore wind stress may also drive a strong seasonal variation in the shelf flow. Huyer, Pillsbury, and Smith (1975) have found that, off Oregon, the alongshore components of wind stress and shelf currents exhibit a similar seasonal cycle, with northward stress and flow in winter and southward (upwelling - favorable) stress and flow in summer.

The fundamental importance of wind-driven coastal currents in the entire ecology of the shelf and the conceptual simplicity of a primary energy source in the wind stress and energy sinks in friction and radiation provide a strong motivation for establishing reliable models for these motions. The theoretical problem is complicated, however, by the interaction of the effects of the Earth's rotation, density stratification, variable bottom topography, the possible importance of non-linearities in the governing equations, and poorly understood turbulent mixing and frictional processes. Several models have been developed by Allen and Kundu (1978), Csanady (1978), Hsueh and Peng (1978), and Clarke (1977) using different assumptions about the principal dynamical balances. In

most of these cases, however, it is difficult to critically assess the applicability of the different models on the basis of existing data sets. For example, the extent to which the alongshore pressure gradient and bottom stress components enter the alongshore momentum balance is still largely unknown. The vertical structure of horizontal currents, the nature of the surface and bottom boundary layers, and the mechanism(s) of stress transfer through the water column are also unclear, primarily because many coastal moored array experiments have been conducted with relatively sparse vertical sampling, especially in the surface and bottom boundary layers.

In order to answer some of these important questions concerning the dynamics of shelf circulation, the following group of principal investigators (J. Allen, R. Beardsley, W. Brown, D. Cacchione, R. Davis, D. Drake, C. Friehe, W. Grant, A. Huyer, J. Irish, M. Janopaul, A. Williams, C. Winant) began in 1980 a four-year research program (called CODE for Coastal Ocean Dynamics Experiment) to determine the important dynamical processes which govern the wind-driven motion over the continental shelf off northern California. It was our feeling then that (a) such a research program was clearly required to test existing ideas, provide new insight into important physical phenomena, and to develop new models, and (b) the technology and methodology needed to successfully conduct such a research program was either in existence or rapidly becoming available. The initial effort in this four-year program has been to obtain high quality data sets of all the relevant physical variables needed to construct accurate kinematic and dynamic descriptions of the response of shelf water to strong wind forcing in the synoptic 2 to 10-day band. A series of two densely-instrumented small-scale field experiments of four-month duration (called CODE-1 and CODE-2) has been designed to explore and determine the kinematics and momentum and heat balances of the local wind-driven flow over a region of the northern California shelf which is characterized by both relatively simple bottom topography and large wind stress fluctuations in both winter and summer. A more lightly instru-

mented long-term large-scale component has been designed to (a) help separate the "local" wind-driven response in the region of the small-scale experiments from motions generated either offshore by the California current system or in some distant region along the coast, and (b) help determine the seasonal cycles of atmospheric forcing, water structure, and shelf circulation over the northern California shelf.

We present in this report a brief overview of the CODE program and a preliminary description of the observational programs conducted during CODE-1. An overview of CODE as the program was originally conceived and some of the initial scientific questions which helped motivate CODE are summarized in Section 2, followed in Section 3 by a more complete description of the field program for the first small-scale experiment, CODE-1, conducted during April-August, 1981. The sequence of field activities in CODE-1 and information concerning when and where data was collected are presented in Figure 6. Program management is outlined in Section 4. This report is intended to serve as a brief introduction to the CODE research program and the specific observational programs conducted in CODE-1. The report itself represents a minor revision of the original cover proposal submitted to NSF by the principal investigators in late 1979 and is not a comprehensive guide nor does it contain any descriptions of the initial results from CODE-1. Scientific and engineering results for CODE-1 will be presented elsewhere in individual technical and scientific reports.

2. OVERVIEW OF ORIGINAL CODE PROGRAM

2.1 Initial Scientific Questions and Program Objectives

The general objective of CODE as initially proposed is to study the response of coastal water to wind stress in a simple geomorphological setting. Starting in 1980, the four-year program will conduct two intensive small-scale experiments, each of about four months duration, supplemented by long-term observations at the same site which span the time duration of the two small-scale experiments. The first intensive small-scale ex-

periment (CODE-1) conducted between April-August, 1981 was a pilot study in which primary emphasis was placed on characterizing the wind-driven "signal" and the "noise" from which this "signal" must be extracted. In particular, CODE-1 was designed to identify the key features of the circulation and its variability over the northern California shelf and to determine the important time and spatial scales of the wind-driven response. Results from CODE-1 and other programs were used to design the second small-scale experiment (CODE-2), conducted between April-August, 1982. The major observational elements in CODE are: (a) moored arrays instrumented to measure wind, solar radiation, currents, temperature, conductivity, bottom pressure, and bottom stress, (b) shipboard observations of temperature, conductivity, currents, wind and surface fluxes; and (c) aircraft observations of wind, wind stress, sea surface temperature, surface drifter motion, and atmospheric parameters. In addition, satellite-derived sea surface temperature data will be collected and measurements made by other agencies of wind, atmospheric pressure, and sea level at appropriate coastal stations and environmental buoys will be utilized.

The site selected for CODE is a region of the continental shelf north of San Francisco extending from Point Reyes north to Point Arena. As shown in Figure 1, this particular location is characterized by both simple bottom topography (relative to the rest of the California shelf) and large wind stress fluctuations during both winter and summer. The monthly mean wind stresses in the selected region are the largest on the west coast (Bakun, 1973; Nelson, 1977). More importantly, the fluctuating wind stress exhibits large variability on time scales of several days, superposed on a strong annual cycle which consists of general southward (upwelling - favorable) winds in the spring and summer and northward (downwelling - favorable) winds in the winter. The mid- and outer shelf in this region has a mud/silty-sand bottom and is generally characterized by an absence of large-scale bedforms (D. Cacchione, personal communication), hence relatively well-behaved near-bottom flow was expected and found in CODE-1 (W. Grant, personal communication). Finally, the proximity of

adequate port and laboratory facilities in San Francisco, Bodega Bay and Newport (Oregon) simplifies logistics.

One initial objective of CODE is to acquire data from which we can estimate terms in the mass, momentum, and thermal energy balances. The relative magnitudes and cross-correlations of these terms during an experiment and their time evolution during wind events will provide insight into the specific physical processes which determine the response on the shelf. Several possible balances are conveniently discussed in terms of approximate depth-integrated mass, momentum, and energy conservation equations,

$$\begin{matrix} \eta_t & + & (U_x + V_y) & = & 0, & (2.1) \\ (1) \end{matrix}$$

$$\begin{matrix} U_t & + & \nabla \cdot \langle \vec{u}u \rangle & - & fV & = & - & \langle \frac{p}{\rho} \rangle & + & \frac{1}{\rho} (\tau_s^x - \tau_b^x), & (2.2) \\ (2) & & (3) & & & & & & & (4) \end{matrix}$$

$$\begin{matrix} V_t & + & \nabla \cdot \langle \vec{v}v \rangle & + & fU & = & - & \langle \frac{p}{\rho} \rangle & + & \frac{1}{\rho} (\tau_s^y - \tau_b^y), & (2.3) \\ (5) & & (6) & & & & & & & \end{matrix}$$

$$\langle T \rangle_t + \nabla \cdot \langle \vec{u}T \rangle = \frac{1}{\rho c_p} (Q_s - Q_b), \quad (2.4)$$

where a right-handed Cartesian coordinate system (x,y,z) is utilized with x positive onshore and z positive upwards from mean sea level and where t is time, $\vec{u}$ the horizontal velocity vector with components (u,v), p the pressure, T the temperature, η the sea surface elevation, ρ the density, c_p the specific heat, $\tau_s^{x,y}$ and $\tau_b^{x,y}$ the surface and bottom stress components in the x or y direction, and Q_s and Q_b the surface and bottom heat fluxes. The subscripts (x,y,t) denote partial differentiation and the bracket $\langle q \rangle$ represents the vertical integral of q from $z = -H$ to $z = \eta$,

where $H(x,y)$ is the bottom depth. The onshore and alongshore transports are $U = \langle u \rangle$ and $V = \langle v \rangle$, respectively.

A start towards verifying approximate forms of the continuity and momentum equations (2.1), (2.2), and (2.3), with terms (1), (2), (3), and (4) neglected was made by Allen and Kundu (1978) using Oregon data, and we intend to explore this further with a much improved data set. The dynamics involved in the alongshelf momentum equation are perhaps more interesting since different models of coastal circulation have made different assumptions concerning the size of individual terms in (2.3). For example, the arrested topographic wave solution presented by Csanady (1978) is based on equations where terms (1) through (6) are dropped. This time-independent solution may describe the quasi-steady behavior during wind events if the frictional adjustment time scale is sufficiently short. In some of the wave propagation models, effects of the nonlinear and bottom friction terms are ignored, whereas, in models of very shallow coastal circulation, the Coriolis term is sometimes omitted. Thus, one of the more important questions is to determine and understand which terms in (2.3) represent the critical dynamical balance at different shelf locations at different times.

Observed shelf circulation does not generally have the simple structure treated in theory [e.g., Smith (1981)]. Rather, we anticipate finding in the CODE area various mesoscale phenomena such as meandering fronts, upwelling plumes, eddies both on- and off-shelf, and intrusions. We will use the term mesoscale to describe phenomena which have significant (i.e., measurable) variations over alongshelf spatial scales of order 10 km and larger. Because the aggregated effects of mesoscale phenomena can strongly influence the general circulation on the shelf, we seek to observe examples of them with sufficient precision to achieve at least a first order dynamical description. We believe that the various terms in (2.1) through (2.4) can be estimated either directly or indirectly, with sufficient accuracy on the mesoscale to observe the evolution of the mass, momentum and

heat balances. This requires both adequate observational resources and sufficient knowledge of the dominant energetic scales so that our instrumentation can be efficiently situated. CODE-1 was designed to provide data both for an initial dynamical investigation and for a refinement of the CODE-2 array design.

Examination of mesoscale dynamics is expected to proceed primarily through deterministic analysis in the time domain. Clearly, mesoscale phenomena can only be examined at a few representative places and/or times in the CODE region. A few of the basic mesoscale questions to be explored are as follows. Is eddy variability baroclinic or barotropic? Are fronts persistent features, or do they wax and wane with wind forcing and eddy forcing? Do eddies sweeping onto the shelf represent the primary cross-shelf transport mechanism? To what extent are the surface temperature features observed by satellite representative of lateral eddy heat advection? What special flow disturbances are associated with topographic features such as Point Arena and Point Reyes?

Much of the shelf general circulation is believed to be the result of direct wind forcing. This view has been developed through statistical analyses of observations which show how the ocean changes during wind events. The large scale of wind forcing suggests that this response is most observable in the alongshore averaged "general circulation" to which mesoscale phenomena contribute through their aggregated effect. On this larger scale, certain terms in the balance equations are small almost by definition; for example, cross-shelf variations of the fluxes, uu , uv , and $\bar{u}T$ are larger than the alongshelf variations. At the same time, individual observation sites yield noisy, but hopefully representative, samplings of this large-scale component. We plan to examine the large scale wind response primarily through statistical analyses of the observations obtained with the small scale, large scale, and long term arrays. We want to determine the relative importance of pressure gradient, wind stress and bottom stress on shelf circulation during wind events. What

is the magnitude of the cross-shelf surface Ekman layer transport and where does the return flow occur? What role do propagating coastally-trapped phenomena play in the local shelf circulation? We also want to determine the cross-shelf heat budget and assess the relative importance of large scale advection and eddy fluxes in establishing it.

Because shelf circulation is a complex interaction of various dynamical regimes, no single uniformly valid simplified dynamics is apt to pertain in all regimes. Some of the particular regimes and processes which we intend to investigate during CODE are discussed below.

Surface Boundary Layer: In the deep ocean, the direct influence of atmospheric forcing is in a surface layer which rapidly redistributes mass and momentum internally by vertical mixing, transports mass laterally by an Ekman transport, and communicates with the interior ocean by mechanisms not fully understood. In sufficiently shallow water, this layer may include the entire water column, then wind stress is transmitted to the bottom, there is no veering of the flow under Coriolis acceleration, and there is no Ekman transport. In the deep ocean, entrainment of water into the layer is evidenced by mixed layer deepening and is modeled as the result of thermocline erosion by mixed layer turbulence and/or the result of shear instability at the base of the mixed layer. The essential elements of deep ocean mixed layers have been described in results from the recent MILE experiments (Davis et al., 1981a, 1981b).

In CODE we intend to apply the deep ocean mixed layer picture to the shelf setting and inquire about elements special to that situation. First order questions involve a determination of the depth of the momentum-mixed layer and the nature of the interaction of this layer with the near-coast bottom boundary layer. An understanding of the near-coast interaction may determine where the Ekman flux divergence occurs.

Entrainment and Mixing: A knowledge of the rate at which, and the location where, the surface layer advects water laterally and entrains

water from below is crucial to understanding up/downwelling. Ekman transport divergence induces vertical velocities which range from 0.1 cm s^{-1} on the Oregon and West African shelves to 0.5 cm s^{-1} on the narrow southern California shelf. If these persist for a day or more, advection completely alters the shelf water mass. For example, under persistent upwelling-favorable alongshore winds, an offshore surface Ekman flux removes low density water from the shelf which must be replaced by higher density deep water. There must be an additional buoyancy flux if a quasi-steady state is to occur. The work of Bryden, Halpern, and Pillsbury (1980) plus examination of the complex surface temperature patterns observed by satellite suggest that most of the required buoyancy flux can be supplied by an onshore near-surface eddy heat transport.

Entrainment into the surface layer appears essential if there is to be a net transport of deep water properties and nutrients into the surface layer in upwelling regions. Halpern (1976) has shown that mean properties (temperature and currents) can be observed during mixing events with sufficient accuracy to make meaningful estimates of parameters (such as the Richardson number) which characterize the entrainment process. Briscoe (personal communication) reports that in JASIN-78, the evolution of the Richardson number can be used as an indicator of mixing events. We plan to extend these studies by estimating velocity shears (a) over relatively large vertical scales using differences between moored current measurements, and (b) over smaller vertical scales by observing the advection of the base of the mixed layer (where possible) past our sensors. Winant (1980) has used an assumption similar to Taylor's hypothesis to estimate vertical velocity gradients of 20 cm/sec in 2 m and vertical temperature gradients of 5°C in 1 m in the southern California Bight. Such observations suggest active entrainment even during downwelling events.

Bottom Boundary Layer: The bottom boundary layer, like the surface layer, is characterized by intense mixing of thermal energy, mass and momentum, and by the lateral transport of these quantities through pro-

cesses governed by turbulent, rotating boundary layer dynamics. In the CODE study region, we expect the flow in the bottom Ekman layer to be composed of low frequency fluctuations associated with, for example, wind forcing or coastally-trapped waves, and high frequency fluctuations associated with internal and surface gravity waves. The bottom shear stress and turbulent generation at the boundary is the direct consequence of complex non-linear interactions between the fluid motions in these discrete frequency bands. The thickness of the bottom boundary layer depends on the magnitude of the bottom stress and the degree of stratification in the water column.

The bottom mixed layer at the study site is produced by the turbulence generated in the boundary layer and modified by downwelling and upwelling. Such a description suggests the presence or absence of the bottom mixed layer is due, in part, to a balance between advective processes and mixing caused by turbulence production at the boundary. A complete description requires knowledge of mixed layer formation and growth during upwelling events and the extent of restratification of the mixed layer during upwelling events in regions subject to large boundary shear stresses.

In CODE, velocity and density measurements will be made simultaneously over the entire boundary layer to provide knowledge of mixed layer behavior. Estimates of the local boundary shear stress will be made from detailed measurements of the vertical variability in the near-bottom flow. The spatially-averaged stress field, which must be known to determine dynamical balances of momentum on the shelf, will be determined from simultaneous estimates of the local stress. Boundary layer thickness and mixing time scales will be estimated from these measurements.

Interior: Coastal models generally employ inviscid, quasi-geostrophic interiors in which the return flow for the surface Ekman layer can occur. It seems of the highest priority to find the extent of this interior. In CODE the observations of both the barotropic and baroclinic pressure

fields combined with the current meter observations will be used in an attempt to determine to what extent the interior is governed by inviscid dynamics and on which time scales. The existence of coastal fronts in the CODE area suggests that identifying an interior region may be a difficult measurement problem which, at least, requires a high vertical resolution of observations. In fact, we may find out that the simple notion of a distinct interior region separating surface and bottom boundary layers is inadequate over much of the shelf.

2.2 CODE Program

To achieve the above general objectives, we designed two intensive small-scale field experiments (CODE-1 and CODE-2), each of approximately four months duration, conducted in 1981 and 1982. The relative timing of these experiments is shown schematically in Figure 2. Several lightly instrumented moorings were deployed in the CODE region in 1980 in an engineering test experiment called CODE-0 and the results (see Winant, 1980) used in the design of CODE-1. CODE-1, the first highly instrumented small-scale experiment was conducted from 1 April 1981 to 31 July, 1981 and covered a period when the winds were southward and upwelling-favorable. The specific objectives of CODE-1 included (a) acquisition of new scientific information at this site regarding the intensity and the time and space scales of the current, pressure, density, surface wind, and bottom stress fields, (b) gaining field experience with new instruments and measurement methodologies, and (c) gaining experience using new analysis techniques which pertain to these data sets. These objectives permitted us to (a) refine our list of scientific questions and experimental strategy, (b) modify our blend of measurement methodologies, and (c) identify the most useful analysis techniques in preparation for the second small-scale experiment, CODE-2, which took place from April through July, 1982.

Three long-term site moorings with current meters and bottom pressure gauges will supplement the small-scale intensive experiments. These meas-

urements will be made from 1 April 1981 to at least 1 April 1982 so that they span the time periods of the intensive experiments. One mooring in the center of the CODE area will be maintained for two years. These measurements should give valuable information about the lower frequency along- and cross-shelf flow fluctuations. In addition, sea level and wind measurements from existing NOAA (or other agency) stations along the Pacific coast and calculated winds from the National Weather Service (NWS) or Fleet Numerical Weather Central (FNWC) will be collected for the period of the long-term measurements in order to study the response of coastal sea level and alongshelf currents to the large-scale wind field. These studies taken with other direct current data collected along the California coast in the Super-CODE* program will provide important information about alongshelf scales of wind forcing, shelf response, and forced coastal wave propagation along the California shelf.

One of the principal objectives of CODE is to refine our ideas about the important dynamic balances. Thus, the planned observational program consists of five main components: moored measurements of current, pressure, and boundary (surface and bottom) stresses, and moored and ship-board measurements of water structure. The following briefly relates each of the individual components to the specific objectives of CODE.

The moored current and temperature program is designed to provide descriptions of the scales of the horizontal velocity and temperature fields, as well as to obtain time series of these fields for use in analyses of specific flow regions, the mesoscale and wind-scale dynamical balances, and the Reynolds stresses and heat fluxes which determine the general circulation. The instruments were deployed in dense vertical arrays during CODE-1 and CODE-2 in order to provide the resolution required to resolve boundary and shear layers. In addition, the current

*Super-CODE is the informal name given a separate NSF-funded program entitled "A Large-Scale West Coast Shelf Experiment" organized by J. S. Allen, A. Huyer and R. L. Smith of Oregon State University.

and temperature results will be used to make estimates of the vertical mixing which occurs during upwelling or downwelling. Small radio-tracked surface drifters were used to investigate the mesoscale surface Lagrangian currents, especially near the headlands. The densely instrumented CODE-1 and CODE-2 current meter arrays are supplemented by long-term site moorings which will extend the coverage of the current array during CODE-1 and CODE-2 and provide a long-term description of the current field. The long-term results will help us to interpret the data from the intensive experiment in a seasonal context and will provide important statistical information about very low frequency current variability at the CODE site.

The pressure program in CODE is designed to provide information about the pressure and pressure gradient fluctuation field. The depth-integrated component was observed using pressure sensors anchored to the bottom. During CODE-1, the sensors were deployed on two scales. Widely spaced elements of the array were used to observe the fluctuations in the pressure field on alongshore scales corresponding to the wind forcing. Since the latter has variability on length scales of order several hundred km, bottom pressure sensors were deployed offshore of existing sea level stations along the California coast. On a smaller scale, an array of bottom pressure sensors was deployed offshore in the CODE area during CODE-1 to attempt to estimate pressure gradients over horizontal scales similar to those resolved by the current observations. The baroclinic pressure field in the CODE area will be estimated from observations made using density chains, which consist of vertical arrays of temperature and conductivity sensors moored above the bottom pressure instruments, and shipboard hydrographic measurements.

A shipboard hydrography program was used to determine the structure of water properties and the density field in the CODE region, and to determine their temporal and spatial variability. Repeated hydrographic sections along the central mooring line extending well beyond the shelf

break and down to at least 600 db were used to determine to what extent, and at what depths, fluctuations in the wind stress and coastal sea level are reflected in the density field. Higher frequency density fluctuations, due for example to internal tides, were measured primarily by the moored temperature and conductivity sensors, which will be supported by adjacent CTD profiles repeated over a tidal cycle. Repeated synoptic surveys of the shelf and slope region from north of Point Arena to Bodega Bay were made to attempt to determine the influence of the isobath curvature off Point Arena and the isobath divergence between Point Arena and Bodega Bay on the structure of the density field. Occasional surveys farther offshore were made to try to determine whether offshore currents and eddies affect the motions over the continental shelf and vice versa. During most hydrographic sections and surveys, the Doppler acoustic log provided information on the instantaneous current field; this information will be combined with the temperature and salinity data to make estimates of instantaneous fluxes of heat and salt into the CODE region and in doing so determine what scales contribute to these fluxes.

A surface stress program, designed to describe the variability of the local wind field in the CODE area, consists of surface meteorological buoys and coastal meteorological stations. The picture developed by these fixed instruments is complemented by shipboard observations as well as low-level aircraft observations provided by NCAR aircraft. These combined observations will help in the determination of the important temporal and spatial variability in the coastal wind and wind-stress fields.

The bottom stress program is designed to determine bottom stress variability over various portions of the shelf and its contribution to bottom boundary layer behavior and dynamical balances over the shelf. Long term time series of bottom stress were generated from one to three-month deployments of bottom tripods employing a burst sampling format. Information on high frequency variability in bottom stress from a two-week intensive experiment will be used to generalize the lower frequency

discrete stress samples. These intensive experiments will provide a description of the near-bottom turbulent flow structure, and by deploying an array of bottom tripods, also will help relate point estimates of stress to spatially-averaged values.

In summary, the CODE program has the following major objectives; (a) to deploy sufficient instrumentation in CODE-1 and CODE-2 to describe the temporal variability of the current, wind stress, bottom pressure, bottom stress, and density fields on the wind event time scale of 2-10 days, and to describe the spatial structure on cross-shelf scales of a few kilometers, alongshelf scales of tens of kilometers, and vertical scales of a few meters, (b) to determine from the small-scale measurements the important dynamic balances present in the shelf flow field and to determine the time evolution of the various terms in the momentum and thermal energy equations in response to wind events, (c) to attempt to distinguish the local wind-driven flow from variability due to other local or distant forcing, using observations of the large-scale wind field, coastal sea level, offshore bottom pressure, and currents over the continental slope, (d) to obtain information on the annual cycle in which the small-scale experiments are embedded, and (e) to obtain oceanographic measurements from a major shelf region off the west coast of the United States where very little data presently exist.

3. A DESCRIPTION OF THE PILOT SMALL-SCALE EXPERIMENT, CODE-1

The design and rationale of the pilot small-scale experiment CODE-1 will be described next. A location map of the CODE-1 mooring sites is shown in Figure 3, and schematics showing the details of the instrumentation at each site are shown in Figures 4 and 5. Figure 6 depicts what instrumentation is deployed when. This array represents a compromise designed to determine the dominant time and length scales of the various variable fields while examining both the dynamics of wind-driven and mesoscale components and assessing the feasibility of using different method-

ologies in these dynamical analyses. The following is a component discussion of the CODE-1 experiment.

3.1 Moored Current Array

One objective of CODE-1 is to determine the vertical spacing of current meters required to resolve the wind-driven velocity field over the shelf. Previous results from CUEA show that the vertical structure is likely to vary most strongly in the cross-shelf direction. Therefore, the SIO current meter resources were concentrated in the cross-shelf array while the smaller number of WHOI current meters were deployed in an alongshelf array and further offshore.

The vertical structure of the velocity field was explored with the three mooring SIO array which consists of elements at C1, C3, and C4, at depths 30, 90, and 130 m, respectively, along the central cross-shelf transect. Experience obtained in other shelf experiments (Winant and Beardsley, 1979) suggests that the 30 m site will be strongly influenced by bottom friction while the 130 m site will be characteristic of outer shelf dynamics.

Although little was known about the density structure in this region, the one hydrographic section made near the site in May, 1977 by Halpern and Freitag (personal communication) suggests an internal Rossby radius of order 10 km which is greater than the cross-shelf mooring spacings. We expect that the alongshelf and cross-shelf current observations will be coherent over the extent of the CODE-1 array.

The question of vertical resolution of the horizontal flow field will be examined in CODE-1 by concentrating the SIO current meters on the three moorings, C1, C3, and C4 (see Table 1). A spacing of 10 m was chosen for the "interior" region on the basis of error estimates made with current profile data from other shelves. More specifically, the current profile

Table 1: Instrumentation Summary for CODE-1

Station I.D.	Water Depth	Instruments		
		Source	Type	Depth (m)
A4	127	UNH	P/T Standard	Bottom
B4	125	UNH	P/T Standard	Bottom
S4	130	UNH	P/T Standard	Bottom
E4	131	UNH	P/T Standard	Bottom
N4	131	UNH	P/T Standard	Bottom
N2	57	UNH	P/T Micro	Bottom
N1	41	UNH	P/T Standard	Bottom
C1	30	SIO	VMCM/T	4,7,11,23,27
		USGS	Geoprobe Tripod	Bottom
		SIO	P/T	Bottom
S0	Coastal	SIO	P/T	Coastal
C4	133	SIO	VMCM/T	19,29,35,45,55,65,75,95, 105,115,123
		UNH	T/C Chain	23,43,53,73,192,122,131
		UNH	P/T Micro	Bottom
		WHOI	VMCM	4,11,14,37,47
C2	63	SIO	T Chain	10,13,17,21,25,29,33,37, 41,45,49,53,57,61,63
		SIO	P/T	Bottom
		SIO	T Chain	10,13,17,21,25,29,33,37, 41,45,49,53,57,61,63
S2	65	SIO	P/T	Bottom
		SIO	T Chain	10,13,17,21,25,29,33,37, 41,45,49,53,57,61,63
		SIO	P/T	Bottom
		WHOI	VMWR/VAWR/AT/WT/I	-3.5
C3	90	SIO	VMCM/T	4,9,14,24,29,35,39,55, 75,83
		WHOI	BASS Tripod	Bottom
		USGS	Geoprobe Tripod	Bottom
M3	90	WHOI	VACM/T	9,35,55,75
		WHOI	VMCM	10
R3	90	WHOI	VAWR/AT/WT/I	-3.5
		WHOI	VACM/T	9,35,55,75
C5	402	WHOI	VACM/T	9,77,152,252,352
Sea Ranch	Coastal	SIO	WR/AP	-10
Bodega Bay	Coastal	SIO	WR	-10

Where P = pressure; T = temperature; C = conductivity; VMCM = vector measuring current meter; VACM = vector averaging current meter; VMWR = vector measuring wind recorder; VAWR = vector averaging wind recorder; WR = wind recorder; AP = atmospheric pressure; AT = air temperature; I = insolation; WT = water temperature at 1 m.

data of Johnson, Van Leer, and Mooers (1976) and Johnson and Johnson (1979) have been used to determine the error expected in performing vertical integrals such as those required for heat, mass and momentum budgets. We find that the 10 m separation between current meters and Simpson's quadratic integration leads to errors of order 10% or less in the vertical integral of horizontal flow. A vertical spacing of 4 m between adjacent current meters was used in the surface and bottom boundary layers. The work of Halpern (1976), Weatherly (1977), Smith and Long (1976), and others suggests that this choice of spacing should provide reasonable vertical sampling of the outer region in both boundary layers.

The moored array measurements of current in CODE-1 will be made with two types of current meters, the VMCM and VACM. The VMCM (Vector Measuring Current Meter) was developed at Scripps by Weller and Davis (1980) for measuring currents in the presence of "noise" induced by large surface waves. The VMCM measures the projection of the horizontal current on two orthogonal axes using an arrangement of propellers, and because of its good cosine response, is relatively insensitive to vertical motion caused by wave-induced mooring motion. This key feature allows accurate current measurement with VMCMs deployed at depths up to 50 to 100 m beneath surface flotation. The VACM (Vector Averaging Current Meter) senses current speed and direction separately and is more sensitive to mooring motion contamination. For this reason, the VACMs were preliminarily deployed on subsurface moorings. Laboratory test results and field inter-comparisons with other current meters [see Weller and Davis (1980), Briscoe et al. (1979), Halpern et al. (1980), and Beardsley et al. (1981)] indicate that both instruments, the VMCM and VACM, should provide accurate estimates of mean velocity under conditions expected at the CODE site.

3.2 The Pressure Array

The main objective of the pressure program in CODE-1 is to estimate the pressure gradient field from measurements of bottom pressure, coastal

synthetic subsurface pressure (SSP - the sum of atmospheric and sea level equivalent pressure), and the density field. We intend to characterize the signal and noise of (a) the cross-shelf bottom pressure gradient, (b) the alongshelf bottom pressure gradient, and (c) the horizontal pressure gradients in the water column above the bottom.

Observations of cross-shelf pressure gradients by Hayes (1979) in Alaska, Huyer et al. (1975) and Osmer and Huyer (1978) on the Oregon shelf, and Brown et al. (1982) on the New England shelf indicate that the CODE-1 array should be able to resolve the curvature ($\partial^2 p / \partial x^2$) in the cross-shelf component. The alongshelf bottom pressure gradients are expected to be smaller and therefore the estimates to be more susceptible to contamination by both instrumental and geophysical noise. Typical instrumental noise levels suggest a minimum alongshelf separation of about 20-40 km. In order to address the geophysical noise question, a vertical six-element temperature-conductivity chain (hereafter referred to as a density chain) was deployed at C4 to obtain data for estimating the depth-averaged density fluctuations.

The small-scale CODE-1 pressure array consisted of nine bottom-mounted Paroscientific quartz pressure-temperature gauges deployed in a 3 x 3 array (see Figure 5). UNH deployed instruments located along both the 130 m isobath and the northern transect while SIO deployed the four shallower instruments located along the central and southern transect as indicated in Figure 5. An array of three additional UNH bottom pressure-temperature instruments were deployed along the 130 m isobath at A4, B4, E4 offshore of National Ocean Survey (NOS) coastal sea level stations in order to explore the large-scale alongshelf pressure field.

SIO also deployed 15 element thermistor chains at S2 and C2, and UNH deployed one six-element temperature-conductivity chain at C4. This constituted a feasibility study for making long-term conductivity measurements as well as determining the quality of measurements required to meet

overall program objectives. Because these are new measurements at a new site, these questions cannot be answered a priori.

In general, the CODE-1 pressure mooring sites were chosen to bracket the current meter mooring sites so that the locations of gradient estimates correspond to those of observed currents. In cases where that does not occur, interpolated values of the pressure field will be used for the gradient computations, a procedure justified in a highly coherent pressure field.

3.3 Boundary Stress Arrays

The shelf flow field responds to wind stress and bottom stress which therefore must be resolved on the scales of persistent variation, and sampled sufficiently so that representative spatial averages are obtained.

Wind Stress: The surface wind program is designed to describe the spatial and temporal variability of the wind and wind stress fields over the shelf and slope in the CODE region. The surface wind stress during CODE-1 will be calculated using the observed wind with the best empirical stress formulation based on sea state and atmospheric boundary layer stability (e.g., Ruggles (1970); Wu (1969); Garrett (1977); Large and Pond (1981)).

The CODE-1 wind measurement array (Figure 5) consisted of standard meteorological stations located on the beach at Sea Ranch and Bodega Bay, vector averaging wind recorders (VAWRs) mounted on toroid buoys, and two NOAA Data Buoy Office (NDBO) environmental buoys deployed near the 130 m isobath south of Bodega Bay and north of Point Arena. The NDBO buoys will be in place for least a three-year period and should provide local measurements of 10 m wind speed and direction, sea state, air and sea surface temperature, and atmospheric pressure throughout the CODE field program.

The fixed position wind observations will be combined with shipboard wind observations and low level aircraft observations made with the NCAR Queen-Aire to produce a better description of the spatial variability of the wind field. Ship coverage during CODE-1 was substantial; aircraft coverage was less frequent in time, but provides a spatially intensive measurement of the wind field and the directly-measured stress field. Buoy measurements of insolation and air/sea temperature difference will be used to estimate the net shortwave and longwave radiative heat fluxes and the latent and sensible fluxes (Simpson and Paulson, 1979) for use in the heat budget.

Bottom Stress: The CODE bottom stress program seeks to determine the magnitude and spatial and temporal variability of the bottom shear stress and the structure of the near-bottom region and its relationship to the turbulent Ekman layer. In addition, the CODE-1 bottom stress experiments will address (a) the accuracy of the stress estimation techniques employed, (b) the relationship between point estimates of bottom stress and the spatially-averaged value over kilometer scales and (c) the influence of stratification and internal waves on the structure of the flow field at the CODE site. We expect variability in bottom stress on horizontal scales due to (1) bottom topography, (2) roughness changes, (3) stratification, and (4) the relatively different long wave climate across the shelf [Grant and Madsen (1979)].

The CODE-1 bottom stress experiments provide long term (1-3 months) time series of discrete stress estimates at a point and short term (2-5 days) time series of nearly continuous stress estimates at several points. The short term, more intensive experiments, were nested within the long term measurements, and provide high frequency information on the variability in bottom stress; during this time the long term time series represent discrete points within the continuous measurements. High sampling rates used in the short term experiments allow the examination of details of turbulent flow structure and high frequency flow variations (surface

and internal waves) contributing to the stress estimates and shape of the mean velocity profile. These details are necessary to determine the accuracy of the various techniques used in the study to estimate stress, as well as to investigate hypotheses on key processes contributing to the generation of bottom stress.

Long term stress estimates were made from velocity profiles measured by GEOPROBE (Cacchione and Drake, 1979), a bottom tripod with four 2-axis electromagnetic current meters stacked vertically in the lower meter. High frequency continuous, stress estimates were made from flow measurements using BASS-W tripods containing four, 3-axis acoustic travel time current meters stacked vertically. Stress estimates from the BASS-W measurements were made using profile techniques, inertial dissipation techniques and eddy correlation techniques. The BASS-W estimates of stress using the various techniques are intercompared with each other to establish the validity and error bias on the stress estimates made from the profiles. Both GEOPROBE and BASS-W are proven measurement systems and have undergone extensive calibration.

One GEOPROBE tripod was placed near the C3 mooring (Figure 4) for much of the CODE-1 experiment. A second GEOPROBE was deployed at C1 for the intensive, short term (two-week) experiment. BASS-W tripods were used in the intensive experiment to resolve the spatially variable bottom stress field by making short term deployments at both shallow and deep sites near C1 and C3. The change in the local stress field was explored using two BASS-W tripods, holding one tripod fixed and moving the other over short intervals up to 1 km.

An intensive program to gather the supporting data necessary to provide unambiguous interpretation of the bottom stress and near-bottom flow measurements was also undertaken in CODE-1. Detailed side scan sonar tracks made during the tripod deployment cruise and other geological cruises to the CODE area by the USGS investigators, were used to map the

topography at the CODE site and at tripod locations. Box cores were used to determine the bottom sediment distribution and to document the benthic biota responsible for bioturbating the bottom. Suspended sediment data was obtained from water samples and transmissometer data on the tripods. CTD profiles were taken to provide data on the mixed layer location. A three current meter VMCM mooring was deployed to match the tripod velocity measurements to the VMCM arrays higher in the boundary layer. In addition, the VMCMs located near the top of the mixed layer provided valuable information on internal waves influencing the near-bottom flow.

3.4 The Density Field

The objectives of the CODE-1 shipboard hydrographic program were to (a) determine the general structure of the stratification and water properties over the shelf and upper slope in spring and early summer in the CODE area; (b) to help test and evaluate the time-series density data from the moored temperature/conductivity sensors by making frequent CTD casts alongside the moorings; (c) to determine the time scales and the vertical-offshore distribution of density fluctuations associated with the day-to-day changes in the wind stress; (d) to determine the onshore and the alongshore spatial scales of the density field in the presence of significant isobath curvature (off Point Arena, probably upstream of the CODE-1 region in terms of the mean alongshore flow), and significant isobath divergence (the 100 m, 200 m, 500 m, and 1000 m isobaths are each twice as far from shore at Bodega Head as Point Arena); and (e) to determine whether offshore currents and eddies affect the density field over the shelf.

To meet these objectives, the shipboard hydrographic program undertook the following activities:

- (1) Repeated CTD sections were made along the CODE-1 central line, at intervals of several days to obtain data under a variety of wind con-

ditions. These sections extend well beyond the shelf edge, and include at least two stations down to 500 db or more so that we can compute the pressure field over the shelf relative to 500 db, and compare variations in dynamic height with sea level and bottom-pressure observations. These sections include stations adjacent to the moored temperature and conductivity sensors at C4, and therefore will provide in situ intercomparison data for these sensors.

(2) Repeated CTD surveys were made in the shelf-slope region from north of Point Arena to Bodega Head (Figure 7). Each survey was completed in less than three days, and therefore is quasi-synoptic, since the dominant time scale of wind and sea level fluctuations in this region is 3-5 days or longer. Sea level data will be used to determine whether each survey was synoptic, and hence to interpret the observed spatial variability. The mean surface currents during CODE-1 were southward, hence the CODE-1 region is downstream of the bend in the isobaths off Point Arena. The synoptic surveys should show to what extent and on what time scales the isopycnal topography follows the bottom topography.

(3) A reconnaissance survey was made beyond the slope off Point Arena to search for offshore eddies that might be advected onto the shelf and document their vertical structure.

(4) Repeated CTD stations were made over a tidal cycle adjacent to the moored density chain and the thermistor chains. These are being used partly for calibration, but also to determine whether the variability associated with the internal tides is concentrated at some depths, i.e., to determine whether the moored sensor spacing is optimal.

The CODE-1 hydrographic data have been summarized in a series of data reports (Gilbert et al., 1981, 1982a, 1982b; Fleischbein et al., 1982; Olivera et al., 1982).

During much of the hydrographic work, the instantaneous velocity field beneath the ship was measured with a Doppler acoustic log (described in Section 3.7 below). Together, the hydrographic and velocity observations can be used to compute instantaneous heat fluxes. The results will be compared to the heat transports calculated from the moored instruments. In addition, they may provide good estimates of the spatial scales of the onshore and alongshore heat fluxes.

3.5 Long-Term Component

The long-term component of CODE has been designed to obtain long-term current measurements at several sites over the mid-shelf and upper slope in the region of the small-scale CODE experiments. The long-term moored array consists of three current mooring sites C3, C5, R3, and four bottom pressure sites C1, C4, S4, and S0. A description of these moorings is given in Table 1 and the approximate mooring locations are shown in Figures 1, 3, 4, and 5. During CODE-1 and CODE-2, SIO mooring C2 will be placed at the site of WHOI mooring C3. Moorings C3 and R3 were deployed on the continental shelf along with the 90 m isobath while mooring C5 was deployed at the 400 m isobath.

The long-term array current moorings were deployed on the schedule shown in Figure 2. This schedule was designed to provide: (a) a two-year time series of current and temperature observations at the central shelf site C3, (b) a 16-month current and temperature time series at the cross-shelf sub-array defined by the central shelf (C3) and upper slope (C5) sites, and (c) a one-year time series of current and temperature data at the along-shelf sub-array formed by the two shelf sites C3 and R3. The two longer data sets (a) and (b) will be used to examine the seasonal changes in the structure of the wind-driven flow over the midshelf and upper slope and monitor the shelf response to the winter-spring transition from primarily northward to southward wind-stress and the fall-winter transition from primarily southward to northward wind stress. The one-year alongshelf data set will be used primarily to look for seasonal

changes in both the alongshelf coherence of the midshelf current and temperature fields and in the spatial and temporal structure of the cross-shelf eddy heat flux.

Each long-term shelf mooring supports VACMs at nominal depths of 9, 35, 55, and 75 m while the slope mooring supports VACMs at nominal depths of 11, 75, 150, 250, and 350 m. The 9 m VACMs were deployed beneath surface guard buoys while the deeper VACMs were deployed on standard subsurface moorings. The vertical instrument spacing for the shelf moorings was chosen to determine the seasonal variation in the vertical structure of both the alongshelf and (more crudely) the cross-shelf current components [based on the Oregon observations of Huyer, Smith and Sobey (1978)]. The vertical spacing for the slope moorings was chosen to monitor low frequency current transients associated with either near-surface eddies or waves in the California Current or deeper fluctuations in the California Undercurrent, which, based on the Oregon observations of Halpern, Smith and Reed (1978), is assumed to flow northward over the upper slope and perhaps outer shelf.

An additional objective of the long-term component is to obtain moored current and temperature data which can be used together with the midshelf wind observations obtained from the NDBO buoys and coastal sea level and bottom pressure observations to describe the seasonal circulation and low frequency variability over the shelf and upper slope in a region off northern California where no similar data presently exist. The long-term current and temperature data will also be used with other long-term current and temperature data collected in the Super-CODE program to examine the shelf response to transient forcing along the entire California coast north of Point Conception.

3.6 Large-Scale Component

Sea level and wind measurements from existing stations on the Pacific coast from southern California to Washington, together with NDBO buoy

winds and coastal winds for the same region obtained from National Weather Service (NWS) and Fleet Numerical Weather Central (FNWC) numerical weather analyses grids, will be collected by OSU and analyzed during the time period of the long-term array, i.e., April, 1981 through March, 1983. The primary objective is to investigate the response of coastal sea level, and hence of alongshore currents on the shelf, to the large-scale (200-2000 km) wind field. We will attempt to define the dynamically and energetically important alongshore scales of the wind stress and of coastal sea level, and to determine, with the aid of dynamical models, which components of the wind field are effective in driving currents on the California shelf and why.

Theoretical and observational studies (Gill and Schumann, 1974; Gill and Clarke, 1974; Huyer, Hickey, Smith, and Pillsbury, 1975; Kundu and Allen, 1976; Wang and Mooers, 1977; Clarke, 1977) indicate that the continental margin along the Pacific coast of the United States acts as a waveguide for subinertial frequency coastal trapped waves. As a result, the currents at one alongshore location may be strongly influenced by wind stress forcing at other points alongshore. The planned analyses should help in identifying the nature and source of nonlocally forced fluctuations in the velocity field at the site of the CODE small-scale experiments.

Sea level data is being obtained from NOS and SIO tide gauge stations listed in Table 2. Wind speed and direction and atmospheric pressure measured at regular time intervals at a large number of coastal, or near-coastal, stations along the Pacific coast of the United States (Table 3) will also be obtained. These will be supplemented by the CODE wind observations and those from appropriate NDBO buoys. Since wind measurements from coastal stations can be of poor quality because of local orographic effects, winds from numerical weather analyses grids will also be utilized. Wind and atmospheric pressure data will be obtained from the NWS Limited Fine Mesh (LFM) grid and from Bakun's calculations (Bakun, 1975) utilizing the FNWC pressure analysis. All wind observations will be used to produce the

Table 2: Sea Level Stations

Station	Latitude	Type
Neah Bay, WA	48 22	NOS
Astoria, OR	46 13	NOS
Garibaldi, OR	45 25	NOS
South Beach, OR	44 35	NOS
Charleston, OR	43 20	NOS
Crescent City, CA	41 45	NOS
Trinidad Head, CA	41 04	NOS
Shelter Cove, CA	40 01	SIO
Arena Cove, CA	38 54	NOS
Point Reyes, CA	38 00	NOS
S.F. (Ft. Pt. Presidio), CA	37 48	NOS
Monterey, CA	36 36	NOS
Port San Luis, CA	35 10	NOS
Point Arguello, CA	34 34	SIO
Santa Barbara, CA	34 24	NOS
Rincon Island, CA	34 21	NOS
Santa Monica, CA	34 00	NOS
Cabrillo Beach, CA	33 42	NOS
Los Angeles, CA	33 43	NOS
Long Beach Naval Station	33 45	NOS
Newport Bay, CA	33 36	NOS
La Jolla, CA	32 52	NOS
San Diego, CA	32 43	NOS

Table 3: Atmospheric Data Stations

Station	Latitude	Type
Quillayute, WA	47 57	WSO
Astoria, OR	46 09	WSO
Newport, OR	44 38	OSU
North Bend, OR	43 25	FAA
Chetco River, OR	42 02	MARS
St. George Reef Buoy, CA*	41 45	CG
Trinidad Head, CA	41 03	CG
Arcata, CA	40 59	FAA
Blunts Reef Buoy, CA*	40 26	CG
Point Arena, CA	38 57	CG
Bodega Bay, CA	38 19	CG
S.F. Pilot Station, CA	37 45	CG
Pillar Point, CA	37 30	CG
Pigeon Point, CA	37 11	CG
Point Pinos, CA	36 38	CG
Pt. Piedras Blancas, CA	35 40	CG
Point Arguello, CA	34 34	CG
Santa Barbara, CA	34 25	FAA
Ventura Harbor, CA	34 15	CG
Zuma Beach, CA	34 01	CG

*Wind Speed Only

NOS = National Ocean Survey
 OSU = Oregon State University
 FAA = Federal Aviation Agency

SIO = Scripps Institution of Oceanography
 CG = Coast Guard
 MARS = Marine Reporting Stations
 WSO = Weather Service Office

highest quality composite data set which resolves the large-scale along-shore structure and time variability of the wind stress.

The atmospheric data will be used as a forcing function in approximate theoretical models (Gill and Schumann, 1974; Brooks, 1978) for the response of shelf waters. The results will then be compared with the statistical properties of the observed coastal and 130 m bottom pressure fluctuations and the alongshelf current fluctuations measured along the California coast in the CODE and Super-CODE program to test the applicability of the particular models and to give further insight into the physical properties of the observed response.

3.7 Other Measurement Components

The SIO Ametek-Straza Doppler acoustic log (DAL) mounted on the R/V WECOMA was used to examine the spatial variability in the horizontal velocity field during CODE-1. The inherent accuracy of this vertical profiling technique will be assessed through comparisons with data from the fixed-level moored current meters. The DAL measurements will be used with the synoptic measurements of temperature, salinity, and density to compute estimates of instantaneous heat, salt and buoyancy transports in the cross-shelf and alongshelf directions. Transport computations made from these data will permit comparisons with similar estimates made using the moored array measurements.

The CODE-1 moored and underway DAL velocity observations were supplemented with a modest program of surface drifter observations. The primary observational objectives of this component were determination of cross-shelf eddy dispersion as it relates to the heat budget, the spatial structure of eddy variability, and exploration of topographic steering of the surface flow, particularly at headlands such as Point Reyes and Point Arena. The drifters were developed at SIO by R. Davis to follow the flow over the top 1 m of water and are tracked using radio direction-finding

from either land or from aircraft. Both the SIO Cessna 337 aircraft and the NCAR Queen-Aire were used for drifter tracking. Eight deployments of clusters of drifters (a total of 90 buoys) were made during CODE-1, and each drifter was typically located once or twice a day for three to six days after initial deployment.

As a supplement to the CODE program, particularly the shipboard hydrographic and DAL components and the surface drifter experiments, satellite sea surface infrared imagery data was collected at the SIO remote sensing facility for the duration of CODE-1. Using a new multi-band analysis technique developed at SIO by K. Kelly, this data has been processed to produce high resolution rectified infrared images of the sea surface temperature field in the CODE region.

The surface current pattern was also mapped during CODE-1 using a shore-based high frequency radar system called CODAR operated by M. Janopaul of the NOAA Wave Propagation Laboratory. As described by Barrick et al. (1977) and Frisch and Weber (1980), this system employs two high frequency radar units positioned at the coast to estimate the two radial components of surface current (averaged over a depth of about 1 m) from the Doppler shift of the reflected radar waves. The two estimates of radial velocity are then combined into a map of surface current with a grid resolution of order 2-3 km. Maps of surface current were made for the region north of the central mooring line in CODE-1 for a 16-day period in May. One important objective will be to compare the CODAR velocity estimates with the near-surface current observations made at the different mooring sites.

4. PROGRAM MANAGEMENT

The different components of the CODE program have been described above. The individual principal investigators responsible for these components are listed in Table 4. The number of principal investigators

in CODE is sufficiently small that we have chosen not to erect a formal management structure per se. Each individual principal investigator has specific responsibilities within the context of both the field programs and preliminary data analysis. These responsibilities are also indicated in Table 4. Program management and scientific collaboration will be conducted by informal communication between investigators and by a more formal series of workshops. R. Beardsley is acting as the program coordinator and chief liaison between the different CODE program components and NSF and other agencies and research programs. Data and other technical reports from CODE-1 will be available from the respective investigators. A list of available technical reports can be obtained from R. Beardsley. Questions or requests for information can be directed either to him or to any of the other CODE investigators.

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TABLE 4

Principal Investigators and Initial Responsibilities

<u>Investigator</u>	<u>Affiliation</u>	<u>Responsibility</u>
Winant, C. D. Davis, R. E.	SIO	Small-scale currents and temperature, Lagrangian flow measurements, shipboard current measurements (DAL), and satellite data.
Huyer, A.	OSU	Hydrography, shipboard meteorology.
Allen, J. S.	OSU	Large-scale atmospheric pressure, winds, and coastal sea level.
Brown, W. S. Irish, J. D.	UNH UNH	Bottom pressure, density chain development.
Beardsley, R. C.	WHOI	Long-term currents and temperatures, small-scale buoy wind measurements, overall program coordination.
Grant, W. D. Williams, A. J., III Cacchione, D. Drake, D.	WHOI WHOI USGS USGS	Near-bottom flow, bottom stress; swell and wind-wave climate; bottom topography, and geology.
Friehe, C.	NCAR	Aircraft wind, wind stress, temperature and sea surface temperature measurements.
Janopaul, M.	NOAA/GRL	Radar measurements of surface currents (CODAR).

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Figure 1: The California coast and adjacent continental shelf. The elements of the large-scale pressure array and the long-term moorings are shown in relationship to the location of the CODE-1 small-scale array and coastal weather and tide stations. A set of 1968 coastal wind stress time series is shown at the appropriate latitudes.

Figure 2: The schedule of activities during CODE, including the time periods of the small-scale experiments CODE-1 and CODE-2, and the long-term arrays C3, R3, and C5. The timing of the ship schedule is also shown.

Figure 3: Locations of the principal CODE-1 mooring sites along north (N), and central (C), and south (S) cross-shelf transects. Bottom tripod locations are omitted for clarity. Schematics showing all instrumentation at each of these sites appear in Figures 4 and 5. Refer to Table 1 for additional details.

Figure 4: Schematic of CODE-1 small scale array. Current meter locations are identified by (●); wind buoys (⊗); temperature/conductivity (o); bottom stress (Δ, m) and pressure (■); CODAR stations (▲), meteorological stations (■). Thermistor chains are shown at C2, S2. Mooring designations are also indicated (see Table 1).

Figure 5: Schematic diagram of the CODE-1 moored array. The California coast is shown as a north-south boundary with the indicated isobaths (- - - -). Note the change of scale outside the region of the small scale array outlined by (-.-.-.-.). BP = bottom pressure; TC = thermistor chain; BS = bottom stress; CC = conductivity chain; VMCM = vector measuring current meter; VACM = vector averaging current meter; WR = wind recorder; MB = meteorological buoy; SL = sea level.

Figure 6: Schedule for deployment of CODE-1 instrumentation.

Figure 7: An example of the repeated quasi-synoptic hydrographic surveys conducted in CODE-1.

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16. Abstract (Limit: 200 words) The Coastal Ocean Dynamics Experiment (CODE) was undertaken to identify and study the important dynamical processes which govern the wind-driven motion of coastal water over the continental shelf. The initial effort in this four-year program was to obtain high-quality data sets of all the relevant physical variables needed to construct accurate kinematic and dynamic descriptions of the response of shelf water to strong wind forcing in the 2 to 10-day band. Two small-scale, densely-instrumented field experiments of four-month duration (CODE-1 and CODE-2) were designed to explore the kinematics and momentum and heat balances of the local wind-driven flow over a region of the northern California shelf characterized by relatively simple bottom topography and large wind stress events year-round. A more lightly-instrumented, long-term, large-scale component was designed to help separate the local wind-driven response in the region of the small-scale experiments from motions generated either offshore or in some distant region along the coast, and also to help determine the seasonal cycles of the atmospheric forcing, water structure, and coastal currents. This report presents an overview of the CODE program and a preliminary description of the observational programs conducted during CODE-1.					
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