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Coastal-Shelf Transport and Diffusion
Annual Progress Report, 1981

MASTER

G.T. Csanady
Principal Investigator

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

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Introduction

The fundamental objective of much DoE supported research is to explore the coastal flow environment and to develop an intellectual framework for its understanding to the point where the effects of energy-related perturbations (e.g. the release of waste heat or of radionuclides) may be confidently assessed. The Woods Hole project "Coastal-Shelf Transport and Diffusion" aims to contribute to this common goal through theoretical and observational studies of the physics of continental shelf circulation, the mechanics of the coastal boundary layer, and the pathways of mass exchange between the coastal waters and the deep sea. In addition, attempts are also in hand to develop the engineering science of pollution prediction under the complex circumstances prevailing in the coastal ocean.

The present progress report summarizes work carried out on this project during fiscal year 1981 (i.e. beginning 1 Oct. 1980), extended by four months to 31 Jan. 1982. It is organized into five sections, outlining recent accomplishments in five different subject areas.

Dynamics of Shelf Circulation

In earlier years of this project a "boundary layer" theory of continental shelf circulation has been developed (Csanady 1978b, 1979b, 1980a). A recent further contribution to this theory is the paper entitled "Shelf Circulation Cells", (Csanady 1981a), first presented at a meeting of the Royal Society in

London (Feb. 1981). This paper focusses on the predictions of the boundary layer theory as they affect especially the nearshore circulation (within 30 km or so of the coast) and relates the theory to a considerable body of observational evidence available on coastal sea levels. A key conclusion of the study is that semi-open circulation cells exist in many shelf regions and contribute to cross-shelf mass exchange in an important way.

Applications and extensions of the boundary layer theory of shelf circulation are contained in two Ph.D. theses completed during the 16 months' period covered by this report. The thesis of N.R. Pettigrew (1981) relates shelf circulation cells to observations along the south shore of Long Island, obtained in the course of the COBOLT experiment, a joint study of the coastal boundary layer by Brookhaven National Laboratory and W.H.O.I. In particular, substantial and persistent offshore transport in the COBOLT area is interpreted as one leg of a shelf circulation cell, with the onshore transport leg postulated to be present on the north shore of Long Island. Pettigrew also presents a detailed analysis of the influence of nearshore topography on shelf circulation cells, removing some of the restrictions of the early models, which supposed a plane inclined beach.

The thesis of P.T. Shaw (1981) is mainly theoretical and carries the development of the boundary layer theory considerably further, addressing in particular the question of deep ocean influence over realistic topography. Another important contribution of this work is the demonstration that density driven flow, induced partly by nearshore freshening of shelfwater through

runoff from land, partly by the production of cold, dense water in fall and winter, accounts for most, if not all, of the observed southwestward mean circulation over the east coast North American shelf.

Among its other conclusions Shaw's work shows that the continental slope acts as an insulator between the circulations on the shelf and in the deep ocean. Specifically, owing to this insulating effect on circulation on both sides of the slope, near-bottom flow over the middle continental slope should be particularly weak. This appears to explain geochemical evidence showing a low transfer rate of radon and other elements from the sediments to the water column (Biscaye, personal communication) over the middle slope. Also, it provides dynamical backing for the underlying hypothesis of the proposed joint experiment of northeast DoE contractors (1983-1984), which is that the middle slope is a principal sink for land-derived substances in the water column, especially particulates. In the absence of a significant flow (and turbulence) fine suspended particles should be able to settle out of suspension more readily and more permanently than elsewhere, presumably leading to the incorporation into sediment of heavy metals and other harmful substances. These results are to be presented to the geophysical community in an invited lecture at the San Francisco AGU meeting, December 1981.

The last yearly progress report described extensive efforts at the synthesis of knowledge on the circulation of the coastal ocean. The two publications resulting from this effort appeared recently (Csanady 1981 b, c).

Coastal Boundary Layer

The mechanics of the coastal boundary layer was identified early in this project as a prime target of investigation, because this region of the coastal ocean—typically 0 - 10 km from the coast—constitutes a particularly important link in the chain of cross-shelf transfer processes. Prior to the joint Brookhaven-Woods Hole "COBOLT" experiment off Long Island (1977-78) there was little systematic evidence on coastal boundary layer behavior.

The thesis of Pettigrew (1981), already mentioned above, is primarily aimed at the analysis of the COBOLT observations. It describes statistical properties of coastal currents such as spectra, empirical orthogonal functions, time series of currents with tides filtered out, and relates these to forcing by wind stress. Also the hydrographic structure of the coastal boundary layer is described, its variability characterized and advection and mixing processes of importance identified. The many and varied physical processes revealed by this study (and by the earlier analysis of tidal motions in the thesis of May, 1979) are particularly important in the oceanic dispersal of substances originating from land. They serve as the background for the development of engineering transport and diffusion models (see below).

The Water Side of the Air-Sea Interface

Beginning with some current meter studies off Long Island in 1975, one continuous strand of work under this contract has been an effort to observe and understand transport and mixing processes at the top of the water column, adjacent to the water

side of the air-sea interface, on which very little observational evidence was previously available. During the 16 months Oct. 1980 - Jan. 1982 observations carried out in prior years on the top two meters of the water column with the aid of large contact surface ("horsehair") drogues have been compiled, analyzed and a series of data reports prepared (Churchill, Pade and Peal, 1981; Churchill, 1981; Churchill and Pade, 1981). A paper for presentation at an international meeting on air-sea interaction in The Hague, May 1982, is in an advanced stage of preparation.

The principal conclusion of this work is that, contrary to a widely accepted hypothesis, no highly sheared region analogous to a "wall layer" is present near the free surface. The relative velocity of the surface, referred to the velocity 1.8 m below the surface, is directed downwind, and is of significant magnitude. However, it differs little (if at all) from the second-order (Lagrangian) wave-related velocity sometimes described as Stokes drift. It may be inferred that momentum transport in the top meter or two of the water column is not viscous fluid-like, nor is it conventional turbulent transfer, with a length scale proportional to distance from the boundary (which is what characterizes a turbulent wall layer).

The results pose a challenging theoretical problem for the explanation of momentum transfer within the water column. From the point of view of horizontal transport processes they are important in that no very large shear near the free surface needs to be allowed for in calculating the "shear diffusion" of substances.

Cross-Shelf Mass Exchange

As already pointed out most work under this contract relates directly or indirectly to cross-shelf mass exchange processes. Some of the effort was directly aimed at parameterizing and modelling cross-shelf mass exchange, especially mass exchange across the coastal boundary layer and the shelf-edge front.

Pettigrew's thesis (1981) contains a model of horizontal exchange in the coastal boundary layer, including estimates of horizontal and vertical transfer coefficients. The results do not differ from values given in the literature as typical of mid-shelf (K_h a few times $10^2 \text{ m}^2 \text{ sec}^{-1}$, K_v of order $10^{-4} \text{ m}^2 \text{ sec}^{-1}$). The horizontal coefficient parameterizes what is known as "shear diffusion".

An important nearshore transfer mechanism in a stratified fluid is associated with the large isopycnal excursions in upwelling and downwelling events. A three layer model constructed to simulate this process (Csanady 1982), allowing large vertical movements of the isopycnals, revealed a "bellows" mechanism of mass transfer affecting the intermediate density fluid: in an upwelling event the middle layer expands nearshore, drawing intermediate density fluid shoreward, in a downwelling the layer contracts at the coast, squeezing intermediate density fluid offshore. The model was presented at the ASLO meeting in Milwaukee, June 1981, and will appear shortly in the J. Phys. Oceanogr.

A major new initiative during this past contract year was taken in preparation for the joint DoE contractors' experiment on cross-shelf transport processes (1983-84). All available

property transects (temperature, salinity, density) between Cape Hatteras and Cape Cod were located and constant property contours drawn to 350 m depth and to the 4000 m isobath all on the same scale, unlike the few transects now scattered around the literature. Those sections with a good resolution of the frontal zone, including especially a significant portion of the slopewater, were retained to form a collection characterizing the seasonal progression of frontal structure and near-surface processes on both sides of the front. This collection will contain some 100 sections (each of temperature, salinity and density) in a shelf-edge front Atlas, expected to appear some time in 1982. It will form a basis for efforts at constructing conceptual models of cross-frontal transfer processes.

One of the key mixing processes across the shelf-edge front is the "bolus" separation phenomenon, discussed previously by several authors. The effect of this process on the salinity distribution in the frontal region was considered in a recent study (Csanady, 1981d). It was shown that valuable information on the mixing rate of boluses may be extracted from the distribution of mean square salinity fluctuation in this highly heterogeneous region. The typical bolus was shown to have a lifetime of the order of 5 months.

Dispersal of Contaminants

A major handicap facing the utility industry today is the lack of accepted models for assessing the dispersal of contaminants,

on the basis of which environmental issues arising in power plant location could be rationally settled. The available "effluent plume" models developed for sewage outfalls only address short-term effects and postulate steady, uniform flow. During the past year a major effort was begun under this contract to develop engineering models of contaminant dispersal appropriate for use in a field of irregularly varying nonuniform currents, addressing short and long term effects.

A theoretical study ("Dispersal by randomly varying currents" by the principal investigator) is well advanced and some of its results have been presented at the Univ. of Cambridge, U.K. in Feb. 1981. This study makes use of the concept of escape probability (i.e. the probability that a puff of tracer escapes from a finite domain) and attempts to calculate the probability of "fumigation", i.e. of the presence of a puff near a target point. A visiting investigator has also been invited to Woods Hole (B. Henderson-Sellers) and is currently working on a proposed Markov chain simulation model of contaminant dispersal. The analogy with atmospheric diffusion is being exploited and the California experience on coastal sewage disposal studied in the course of this work.

A survey of problems in modelling oceanic dispersal was prepared recently for a symposium of the Marine Board, Nat. Acad. of Engineering, at Lewes, Del., June 1981 (Csanady 1981e). This survey emphasizes the importance of determining the oceanic sinks for man-made substances, and points out the weaknesses of existing dispersal models.

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