CONTINENTAL SHELF PROCESSES AFFECTING THE
OCEANOGRAPHY OF THE SOUTH ATLANTIC BIGHT

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INTRODUCTION

This completes the second year of the ERDA funded South Atlantic Bight study, activities are out of the equipment acquisition and planning phase and into field experiment, data analysis and hypothesis formulation and testing.

The summer 1975 and 1976 field experiments yielded valuable data sets that are now in different stages of analysis. Our concept of the role of intrusions in shelf oceanography is developed to the stage of hypothesis testing and these ideas are presented here. Preliminary studies in the nearshore have identified several functional zones and these data will lead to future studies.

The CTD/Rosette systems are fully operational and have been used extensively. The systems' software is also operational and being improved. The field and technical accomplishments are shown in the following table.

TABLE 1

SCHEDULE OF FIELD AND TECHNICAL ACCOMPLISHMENT 1976-1977

	June	July	August	September	October	November	December	January	February
Onslow Bay Experiment		Onslow Bay Intrusion Study							Onslow Bay Data Finalized
Georgia Bight Studies							ISELIN G. Bight Cruise		
Nearshore Studies				Thermograph Replacement	5 "front hunt" cruises; preliminary nearshore studies				Thermograph Replacement
Technical	System Tests	CTD Operational						Arrival of HP System	

SCIENTIFIC RESULTS

The general results of our research are described in the following sections. These are brief accounts of our general results, the full accounting of which is made in the open scientific literature. The data discussed here are available as technical reports, two of which are attached.

Influence of Gulf Stream on Onslow Bay

We believe that we now have a much better understanding of how Onslow Bay operates in a physical sense. The long-term current meter moorings deployed, maintained and analyzed by Dr. Pietrafesa (North Carolina State University) combined with the hydrographic measurements made by our group have allowed us to plan a combined data synthesis that seldom occurs in studies of this size. The primary data base for the analysis are the Onslow Bay Intrusion Studies of September 1975 and again in July and August 1976. At present much of the analysis is in the formative stages but from our initial analysis, we have formulated a conceptual model of Onslow Bay circulation during the summer. The complete plans for the data analysis are given in the research proposal.

Current spectra at a mid-shelf location in Onslow Bay are assumed to partially reflect Gulf Stream oscillations (Figure 1). This assumption will be verified with 1976 data. Notable in Fig. 1 is the fact that the alongshore spectra show no frequencies greater than about five days, an indication that the Gulf Stream flows northward with considerable constancy. However, the onshore/offshore component has a dominant 5-day period. This 5-day period also shows in the adjusted sea level data described by Mysak and Hamon (1968). Our hypothesis begin at this point.

These on/offshore oscillations of the Gulf Stream are the key process by which nutrient-rich Gulf Stream waters are forced on the shelf. Offshore motion, probably resulting from a meander eastward, causes a compensatory upward flow at the shelf break thus elevating cold, nutrient-rich water above the level of the shelf break. Onshore motion would depress the nutrient-rich water below the shelf break. An important aspect of our model is that wind is not required to send the elevated Gulf Stream water across

Figure 1. Spectral analysis of onshore/offshore and alongshore current.

the shelf break. Internal pressure gradients force the water shoreward independent of the wind, but the magnitude of penetration across the shelf would be influenced by the alongshelf wind component, among other things. Southwesterly winds would accelerate nutrient-rich waters across isobaths (uphill) only if this water had been elevated by Gulf Stream oscillations. Thus our model of intrusion can be described as a fine-tuned process between Gulf Stream oscillations with an approximate 5-day period and the local wind. With offshore oscillations and southwest winds in phase, a maximum penetration of Gulf Stream waters across the shelf may be expected. With these factors out of phase, minimum penetration is expected.

One of three possible events accompany the movement of the deeper cold water onto the shelf. If, as occurs during the summer, the shelf waters are warm and relatively low in density, the dense intruding water moves along the bottom displacing the existing bottom waters. However, during the cooler months the shelf water may be of high enough density to result in the intruding Gulf Stream water riding over the shelf waters. A third case is that the intruding waters are of a density such that they interleave between a denser bottom water mass and a less dense surface water mass.

This hypothesis of a "5 day presentation schedule" has been partially confirmed by our Onslow Bay studies. In addition the data has clearly shown how Onslow Bay circulates in a general way. The conceptual model resulting from these analyses are shown schematically in Fig. 2. On day 0 the Gulf Stream is positioned such that cold, nutrient-rich water is at the shelf break. If southwest winds are occurring, the lobe of water moves into the Bay and on about day 1-2 it is isolated because the Gulf Stream moves back offshore. This we call "stranding". With time the intruded water mass moves to the northeast and leaves the Bay by day 5-10.

Gulf Stream Meander

Stranding

New Cycle

Movement out of Area

Movement to N & E

Figure 2. Conceptual intrusion model for Onslow Bay.

There are two important aspects of the intrusion model. First, nitrate-rich water is advected onto the shelf causing large "perturbations" to the phytoplankton and zooplankton populations. Secondly, the intruding water masses displace large amounts of ambient shelf water causing a rapid flushing action. Figure 3 shows a typical temperature-nitrate relationship. The line is the regression of all the deep water points. Note that below 21°C the water contains significant amounts of nitrate. The data points below the line showing low amounts of nitrate represent formerly nutrient-rich waters that have a nitrate deficit due to phytoplankton growth.

In August 1975 we observed a spectacular intrusion across the mid shelf and these data offer further validity to our tentative hypothesis. Forty-two day current meter records during this time period have revealed that Gulf Stream water intrudes in the southwest corner of Onslow Bay and exits in the upper layer near the northeast corner. Nine such events occurred over the 42-day period yielding about one event per five days. The magnitude of such events are not very consistent. One such event, a spectacular one, has been shaded in Fig. 4. Clearly water was intruding through the area almost 5 days before a wind stress greater than 0.2 dynes/cm² was obtained. The favorable southwest wind undoubtedly caused the event to last much longer than is "typical". We can use the above model for a calculation of replacement rate using current meter data. The following parameters are used:

- 1. Intrusions occur over southern half of shelf break, $L = 50 \times 10^5 \text{ cm}$
- 1. Average intrusion thickness in mid-shelf, $T = 10 \times 10^2 \text{ cm}$
- 1. Average cross-isobath speed $S = 10 \text{ cm/sec}$
- 1. Average duration, 3 days
- 1. Intrusion volume over 3-day period $V = 1.3 \times 10^{16} \text{ cm}^3$
- 1. Onslow Bay total volume (100 km x 50 km x 30 m) = $1.5 \times 10^{17} \text{ cm}^3$
- 1. Number of intrusions required to displace total volume: 12

Figure 3. Temperature-nitrate relationship.

Figure 4. Current meter record for August 1975.

If intrusions occur each 5 days, a replacement rate = $12 \times 5 \text{ days} = 60 \text{ days} = 2 \text{ months}$.

Results of the Analysis of Georgia Bight Data

In 1973 and 1974 we made four cruises into the Georgia Bight as part of an internally funded effort to gather preliminary data. These data are now being analyzed as part of the process of planning for large scale experiments in the Georgia-North Florida area and the results are proving to be of interest. The following are some interpretations of that data.

Freshwater Flushing Rates. We have synthesized 1973-74 hydrographic data from the South Atlantic Bight between Charleston, South Carolina and Jacksonville in order to calculate freshwater flushing rates in this region (Atkinson and Blanton, in preparation). Our results are summarized as follows:

FRESHWATER VOLUMES AND FLUSHING RATES

Date	Cruise	Freshwater Volume (km ³)			Flushing Rate (months)
		0-20 m	20-offshore	Total	
September 1973	E-13-73	5.9(75%)	2.0(25%)	7.9	2.9
December 1973	E-19-73	5.6(80%)	1.4(20%)	7.0	2.8
April 1974	E-3-74	9.1(77%)	2.7(23%)	11.8	2.6
July 1974	E-12-74	3.8(73%)	1.4(27%)	5.2	2.7

The flushing rate is about three months and is surprisingly consistent. A comparison with other regions using similar methods is shown below.

Region	Reference	Flushing Rate (months)
Mid-Atlantic Bight	Ketchum and Keen, 1955	15 to 20
North Carolina Shelf	Stefansson, Atkinson & Bumpus, 1971	<1
Georgia Shelf	Paper in preparation	<3

The rate for the North Carolina shelf using freshwater (<1 mon) compares with a rate of 2 months using current meter data. This is surprisingly close considering that different parameters, freshwater versus momentum, were used for each estimate.

It seems clear that the intruding Gulf Stream south of Cape Hatteras can efficiently remove freshwater before it can accumulate there in large quantities. We are currently assessing whether the shelf off Georgia is sufficiently wide to diminish this process in the nearshore zone where freshwater enters the shelf via the several large rivers on the South Carolina and Georgia coasts. We wish to eventually compare the degree of flushing off North Carolina with that off Georgia and Florida.

Drift Studies. We now have drift bottle returns from four cruises in the Georgia Bight (Table 1). The results can be summarized as follows:

Deployment	Observed Drift	Geostrophic Current Direction	Wind Induced Drift
September 1973	SW	S	NE/E
December 1973	--	NE	SE/E
April 1974	NE	S	SE/E
July 1974			
Northern area	NE	S	NE/E
Southern area	SW	S(weak)	NE/E

We are currently assessing these findings by summarizing monthly values of wind stress during the time from August 1973 until August 1974. The hypothesis is that wind stress variations between Jacksonville, Florida and Charleston, South Carolina may explain our drift bottle returns and account for differing return rates from the four cruises. Drift bottles are no longer being deployed.

Nearshore Studies

Four short cruises were conducted in October and November, 1976 in order to define the frontal zone that separates the saline shelf waters from the fresher, more turbid water originating from the inlets and marshes. The processes that transfer material across this zone control the transport and dilution of energy-related contaminants. Offshore oil spills must cross this zone before they can impact the vulnerable coastal zone if they are injected on the ocean side of the front.

We have developed a schematic picture of this complicated zone based on our four cruises (Fig. 5). A primary front at the surface separates vertically homogeneous shelf water from stratified turbid water. This front extends underwater and shoreward, thus the turbid waters actually overrun the shelf waters. The position of the front is severely modulated by tidal currents which guarantees that the quantitative measurement of the mixing processes across the front will be an equally severe challenge. Our proposal outlines some analyses we will complete in our 1976 data before future experiments would be designed.

Fig. 5 Schematic salinity structure ($S^{\circ}/\text{‰}$) characterizing the zonation of nearshore waters off Georgia. Zone A may be very small at locations away from the inlets.

TECHNICAL ACCOMPLISHMENTS

Data Acquisition

The Plessey CTD/Rosette system has now been operational for a year. The equipment arrived with scarcely enough time to prepare for the summer Onslow Bay Experiment but through the hard work of our electronics technician, Carroll Baker, all systems were in running order one week into the Onslow Bay cruise. We had considerable problems with both the CTD and Rosette in the initial tests, most of which were caused by poor quality control and below specification parts. The problems did force us to quickly learn the intricacies of the CTD/Rosette.

The shipboard use of the system was straightforward and standard operating procedures were soon established. The advantages of the CTD/Rosette over hanging bottles were in both the improved quality of data and the greatly decreased station time. These items are especially important in this study since the goal of synopticity is more closely achieved with faster station time. Also the fine detail of vertical temperature and salinity structure enhance our understanding of the physical processes and permit more accurate volumetric analyses.

At present the CTD data is analog plotted and recorded on a computer compatible tape. While this is a sophisticated system it significantly delays the data processing stage (the computer tape is processed via our interactive terminal). Last year we proposed and subsequently purchased a Hewlett Packard Data Acquisition System so that data could be processed in real time. This system has been in our laboratory about one month and is fully interfaced to the CTD system. The software is now being developed to acquire, reduce, plot and store the CTD on board using the HP system. Initial tests indicate the acquisition process will be more than adequate.

Software Development - Acquisition and Processing

A large effort has been spent in developing software to handle the computer tape stored data. The flowchart of this operation is shown in Table 2. Our development of the data reduction scheme was based to a large extent on the experience of others. We surveyed all the recent literature and contact many of the people now working with CTD data in order to develop a system appropriate to the problem. We feel the system is now "state of the art". One advantage we have over many systems is the use via terminal of the large direct access disc storage on the CYBER 70/74. Using this system we can merge the CTD data, nutrient and headers (time, position, weather) via direct access EDITING to form an NODC compatible file.

Software Development - Data Base Management

As part of our analysis and interpretation of the waters of the South Atlantic OCS we have ipso facto created a large data base of NODC available hydrographic data. Because of this we are slowly developing the file handling techniques to manage these large and growing data bases.

TABLE 2. CTD/DATA FLOW

CTD/DATA FLOW

SHIPBOARD ACQUISITION TO NODC SUBMISSION

PUBLISHED PAPERS, ABSTRACTS, WORKSHOPS AND
COORDINATION CONFERENCES

Papers in Reviewed Journals

Atkinson, L. P. and J. Hall. 1976. The distribution and production of methane in the Georgia salt marsh. *Estuarine and Coastal Marine Science*, 4:677-686. (Copy attached)

Dunstan, W. M. and L. P. Atkinson. 1976. Sources of new nitrogen for the South Atlantic Bight. *Proceedings of Third International Estuarine Research Conference, Galveston, Texas* (Martin Wiley, ed.), 1:69-78. (Copy attached)

Papers In Press

Windom, H. L., L. P. Atkinson and W. S. Gardner. 1975. Flux of materials from the ocean. In: *Oceans Handbook*.

Atkinson, L. P., W. M. Dunstan, J. Natoli. 1975. Analysis of techniques to determine the effect of volatile aromatics on phytoplankton. *Water, Air, Soil Pollution*. (A result of previous NSF grant)

Technical Reports Published

Atkinson, L. P., J. J. Singer and L. J. Pietrafesa. 1976. Onslow Bay Intrusion Study. Hydrographic observations during current meter servicing cruises in August, October and December 1975 (OBIS I, III, and IV). Georgia Marine Science Center Technical Report 76-4.

Atkinson, L. P. 1976. Oceanographic observations in the Georgia Bight. R/V EASTWARD Cruise E-3-74 and E-12-74. Georgia Marine Science Center Report 76-1.

Atkinson, L. P., J. J. Singer, W. M. Dunstan and L. J. Pietrafesa. 1976. Hydrography of Onslow Bay: September 1975 (OBIS II). Georgia Marine Science Center Technical Report 76-2.

Papers in Preparation

- Atkinson, L. P., G.-A. Paffenhofer and W. M. Dunstan. 1976. Observations of a Gulf Stream intrusion off St. Augustine, Florida.
- Atkinson, L. P., E. Haines, V. Burrell, D. Frankenberg, O. Pilkey and L. Pomeroy. 1976. The southeastern Atlantic Continental shelf. An AIBS Symposium on the Continental Shelf (R. Darnell, ed.).
- Atkinson, L. P. and J. O. Blanton. 1977. Chemistry and physics of the continental shelf. In: AIBS Symposium on the Continental Shelf (R. Darnell, ed.).
- Atkinson, L. P., J. O. Blanton, and L. Jaffe. 1977. Drift bottle observations in the Georgia Bight and the relationship to baroclinic and wind forcing.
- Atkinson, L. P., J. O. Blanton and E. Haines. 1977. Freshwater volumes and the flushing rate of the Georgia Bight.

Papers Given

- May 1976: Chemical and physical processes on continental shelf, American Institute of Biological Sciences Symposium on the Continental Shelf, New Orleans, invited speaker.
- June 1976: Gulf Stream intrusions in the South Atlantic Bight, American Society of Limnology and Oceanography, Savannah.
- November 1976: Nearshore studies, Southeastern Estuarine Research Society, Brunswick, Georgia, L. P. Atkinson, J. J. Singer, et al.
- November 1976: Coastal currents, Southeastern Estuarine Research Society, Brunswick, Georgia, J. O. Blanton.
- January 1977: Chemical processes in the South Atlantic Bight, Gordon Conference on Chemical Oceanography, Santa Barbara, California, L. P. Atkinson, invited speaker.

Workshops Attended

October 1976: Workshop on Anoxia in the New York Bight, National Science Foundation, Washington, D. C., L. P. Atkinson.

ERDA Coordination and Workshop Meetings: June 1976, ERDA Coordination Meeting, Atlanta; September 1976, Data Management and Tracer Discussion, SRL, Augusta; September 1976, Data Management and Tracer Discussion, Skidaway; October 1976, Program Review, Atlanta; January 1976, Coordination Meeting, Raleigh.

PROGRAM COORDINATION

North Carolina State University - Skidaway Institute Onslow Bay Experiment

The cooperative field effort between North Carolina State University (Dr. Leonard Pietrafesa) and our group was a successful two years. The goal was to obtain a long series of current meter records combined with intensive hydrographic surveys during selected time periods. Our activities were centered around two intensive study periods in September 1975 and July-August 1976. The 1976 Onslow Bay experiment was, on preliminary analysis of the data, a very successful study.

The practical aspects of the cooperative study such as equipment sharing, data exchange and intercalibration have worked quite well. We are now in the data analysis stage which means even closer cooperation in the exchange of ideas and interpretation.

Rosenstiel School of Marine and Atmospheric Science - Skidaway Institute
Georgia Bight Experiments

The cooperative field effort between the University of Miami (Dr. Tom Lee) and our group is just beginning. Actually we did have a cooperative cruise in 1975 before Dr. Lee's funding began. These joint quarterly cruises began in December 1976. Our responsibility is the CTD/Rosette sampling and nutrient analysis. Preliminary exchange of CTD data has already occurred.

Internal

We have for several years coordinated very closely with Drs. Dunstan and Paffenhofer on the biological aspects of the study. We are now also coordinating our work and cruises with Dr. Windom's project. The planned activities are contained in the proposal.

Other

We had one cooperative cruise with Dr. Pomeroy's group. We were looking at the flux of material across the coastal front and they were studying the chlorophyll distribution. The analysis of these data is discussed in the proposal.

We also coordinate with Dr. Phil Richardson (WHOI) on a Gulf Stream Ring tracking program. He alerts us when a ring is about to merge into the Stream and we send him our data for that time.

APPLICATION OF RESULTS TO ENERGY RESEARCH AND DEVELOPMENT

We are now beginning to get a feeling for flushing rates for the South Atlantic Bight. South of Cape Hatteras, rates are typically 1-4 months. This is much more rapid than those found north of Cape Hatteras. It seems likely that accumulation of dissolved contaminants from energy related activity (if they remain dissolved) can be turned over within this time scale. Critical questions are:

- 1) What are the likely accumulations that can result over a one to four month period assuming now flushing; this would be an upper bound on which to assess an effort to living species in the shelf environment south of Cape Hatteras.

- 2) Do contaminants originating in rivers and along the shoreline actually mix outward thus becoming influenced by the flushing action of the Gulf Stream, or are they confined to the very nearshore zone?

These questions that should become a part of any assessment of an energy impact once the contaminant is identified and its chemical behavior in sea water is properly known. We are focusing an increasing amount of our attention on the second question as is evidenced in the proposal.

APPENDIX

Selected Papers and Technical Reports (Attached to Copy 1 only)