# NOTICE

CERTAIN DATA CONTAINED IN THIS DOCUMENT MAY BE DIFFICULT TO READ IN MICROFICHE PRODUCTS.

DOE/ER/60285--4

DE91 006262

Comprehensive report of

"Simulation analysis of moored fluorometer time series

from the Mid-Atlantic Bight" during 1987-1990

under Grant DE-FG05-85ER60285



John J. Walsh
Department of Marine Science
University of South Florida
140 Seventh Avenue South
St. Petersburg, Florida 33701

The goal of the previous research during 1987-1990 within the DOE Shelf Edge Exchange Processes (SEEP) program in the Mid-Atlantic Bight was to understand the physical and biogeochemical processes effecting the diffusive exchange of the proxies of energy-related, by-products associated with particulate matter between estuarine, shelf, and slope waters on this continental margin (Walsh et al., 1988a). The study sites of the SEEP-I and SEEP-II experiments were located north of Cape Hatteras, away from direct influence of western boundary currents of the Gulf Stream system. Prior DOE studies focused on the continental shelf of the South Atlantic Bight as well, rather than on processes within the Florida Current and its teleconnections via the Gulf Stream to the North Atlantic basin. As originally envisioned in the SEEP program plan, SEEP-III would take place at Cape Hatteras to study the advective exchange of materials by a major boundary current.

One problem of continuing interest is the determination of the local assimilative capacity of slope waters and sediments off the eastern seaboard of the United States to lengthen the pathway between potentially harmful energy by-products and man. At basin scales, realistic specification of the lateral transport by western boundary currents of particulate matter is a necessary input to global models of carbon/nitrogen cycling. Finally, at these global scales, the generic role of continental margins in cycling greenhouse gases, e.g. $CO_2$, $CH_4$, and $N_2O$, is now of equal interest. My continuing research of model construction and evaluation within the SEEP program focuses on all three questions at local (Fig. 4), regional (Fig. 11), and basin (Fig. 13) scales.

Over the last decade, a series of 16 sediment traps moored on the continental margins, ranging from depths of 450 to 3791 m within ~250 km of the coast, yielded a mean particulate organic carbon flux of 6.89 g C $m^{-2}$ $yr^{-1}$ at an average depth of 2265 m (Table 1). The SEEP-I traps were moored between 38° and 40°N (Table 1) and constitute 50% of these long-term sediment trap data. Another 16 sediment traps moored at depths of 635 to 3800 m in the deep sea indicated a mean particulate flux of only 0.84 g C $m^{-2}$ $yr^{-1}$ at the same average depth of 2257 m (Table 1). Since the area of the continental slopes is tenfold less than that of the deep sea, the total organic carbon loading at ∿2260 m above the margins and within the deep sea may be equivalent (Walsh, 1989).

The subsequent fate of organic carbon may be different in the two regions, however, with biogenic particles falling and decomposing over another 3000 m in the deep sea, before arrival on the sea bottom. Half of the degradable organic carbon within the surface mixed layer of ocean sediments, for example, is located on the continental margins, while 50% of the deep benthic oxygen consumption may occur within 500 km of the coast. Figures 1-3 show the respective organic carbon contents of surficial sediments in the Mid-Atlantic Bight, the South Atlantic Bight, and the Gulf of Mexico, depicting >1% dw maxima within slope depocenters. The higher contents of particulate matter on the continental margins is attributed both to greater primary production of the overlying water column, and lateral import of detritus from the adjacent shelves (Walsn, 1988), since the total mass flux increases with depth in the water column.

During the last 3 years at USF, Dwight Dieterle, myself, and a number of students have constructed a series of coupled physical-biological models, with the dedicated ECOS modeling facility (Table 2), to explore the nature of exchange of dissolved and particulate matter between the continental shelves

Table 1. Organic carbon fluxes (g C $m^{-2}$ $yr^{-1}$) at long-term (2-12 months) and short-term* (<1 month) moorings on the continental margin and in the deep sea (after Walsh et al., 1990a).

**Continental Margin**

| Region | Trap Depth | Flux | Source |
|---|---|---|---|
| 76°N | 1700 | 2.9 | Wefer (1989) |
| 38-40°N | 450 | 11.3 | Biscaye et al. (1988) |
| " | 975 | 15.5 | " |
| " | 1200 | 5.1 | " |
| " | 2250 | 2.2 | " |
| " | 2700 | 2.2 | " |
| " | 2160 | 6.5* | Rowe & Gardner (1979) |
| " | 2800 | 3.5* | " |
| " | 3500 | 5.4* | " |
| " | 3520 | 3.8* | Hinga et al. (1979) |
| 34°N | 1350 | 10.8* | " |
| 36°N | 1500 | 25.9* | Knauer & Martin (1981) |
| 13°N | 3200 | 0.7-2.1[1] | Deuser et al. (1988) |
| 5°N | 3560 | 4.9 | Honjo (1982) |
| " | 3791 | 3.8 | " |
| 62°S | 1588 | 4.3 | Wefer (1989) |
| Mean: N = 16 | 2265 | 6.89 | |

**Deep Sea**

| Region | Trap Depth | Flux | Source |
|---|---|---|---|
| 65-78°N | 2442 | 0.4 | Wefer (1989) |
| " | 2823 | 0.4 | " |
| " | 2749 | 0.5 | " |
| " | 2761 | 1.4 | " |
| " | 2630 | 0.6 | " |
| 50°N | 3800 | 1.1 | Honjo (1984) |
| 32°N | 3200 | 0.7 | Deuser (1986) |
| 31°N | 976 | 0.9 | Honjo (1978) |
| " | 3694 | 0.3 | " |
| 14-36°N | 1500 | 1.8* | Martin et al. (1987) |
| 15°N | 2778 | 0.4 | Honjo (1980) |
| 13°N | 988 | 1.4 | " |
| 11°N | 635 | 0.9 | Fischer (1984) |
| " | 1565 | 1.3 | " |
| " | 2700 | 1.3 | " |
| 62°S | 863 | 0.03 | Wefer (1989) |
| N = 16 | 2257 | 0.84 | |

[1] Assuming organic carbon is 4.5% of total particle flux.

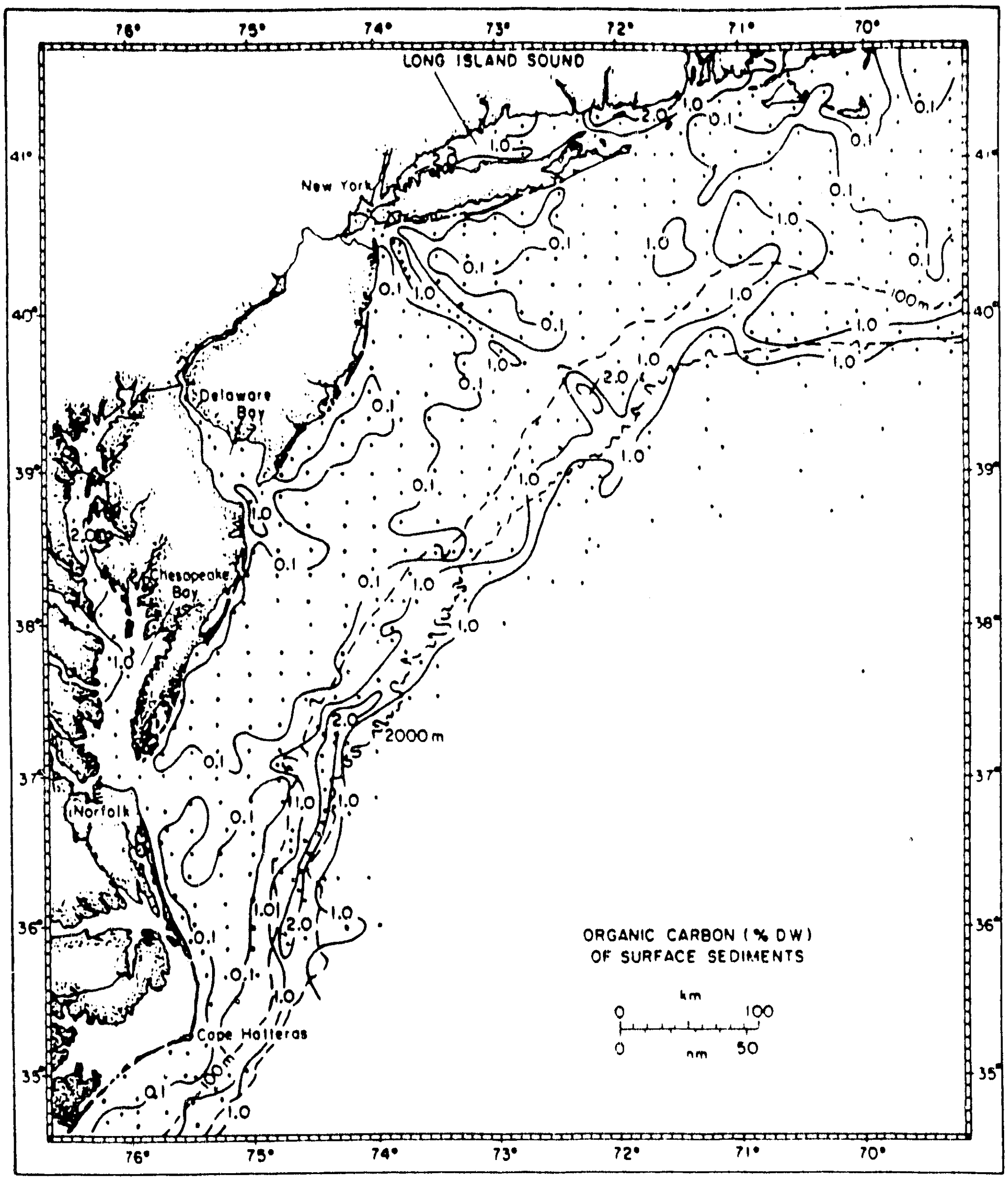


Fig. 1. The organic carbon content (% dw) of surficial sediments in the Mid-Atlantic Bight.

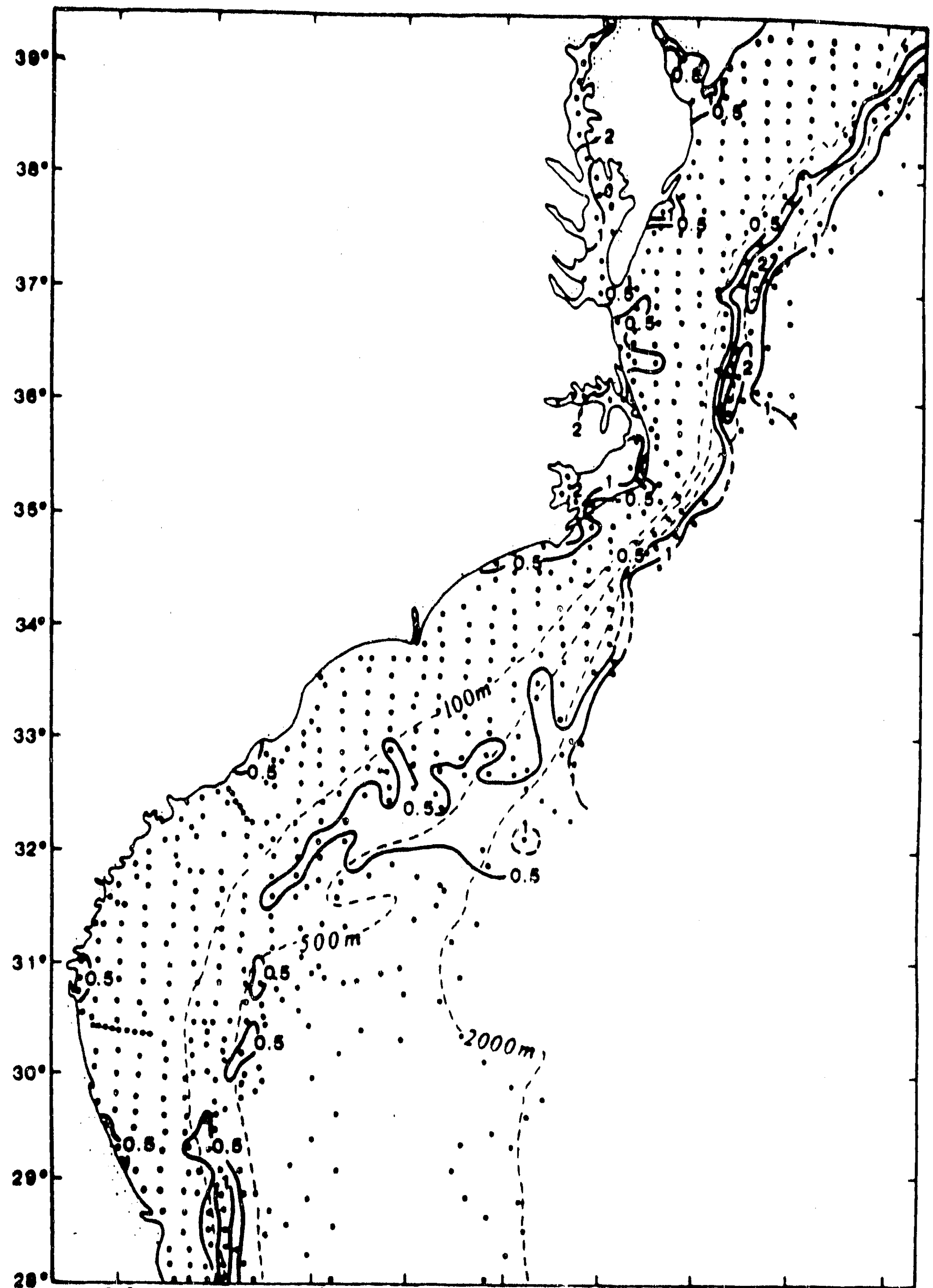


Fig. 2. The organic carbon content (% dw) of surficial sediments in the South Atlantic Bight.

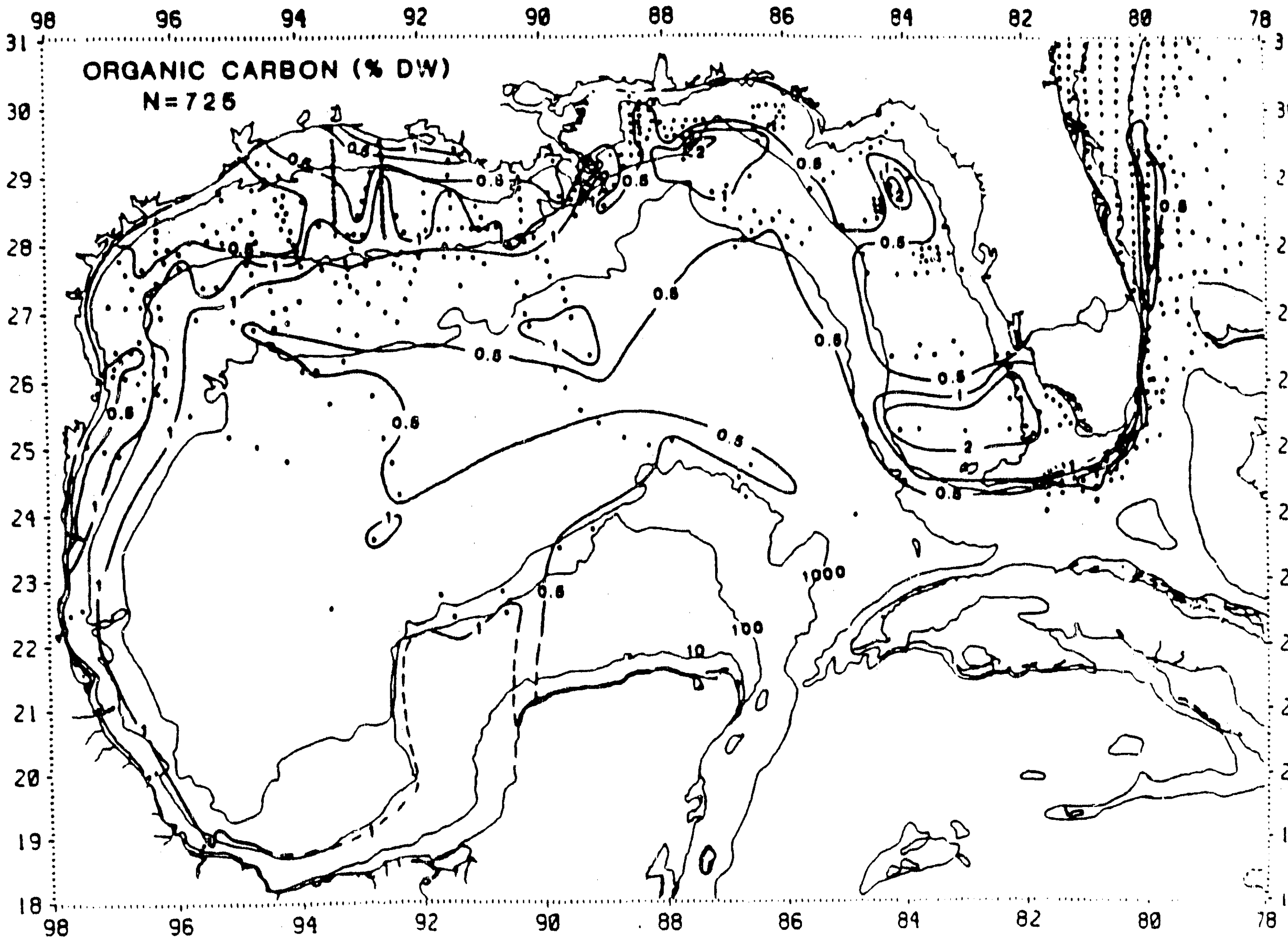


Fig. 3. The organic carbon content (% dw) of surficial sediments in the Gulf of Mexico.

Table 2. USF ECOS Modeling Facility

| |
|---|
| DEC MICRO-VAX III multi-user systems (2) with 4 graphics terminals |
| Systems Industries 9-track, 6250 bpi magnetic tape drive |
| Imagen printer |
| Hewlett Packard laser printer |
| Matrix camera (multiple image) |
| DEC 70 and 300 mbyte discs (2), for VMS operating systems and backup |
| DEC 500 mbyte discs (2) and 1 gigabyte discs (2) for storage of simulation output |
| HP large and small plotters |
| HP 404 mbyte disc (input data) |
| CSPI 6430 Array Processors (2), with 48 mbyte memory |
| SONY optical disc (WORM) system |
| UPS battery backup (15 minutes) |
| Adage display system |
| HP 19" color monitor |
| Evans and Sutherland PS 390 Graphics Workstations (2), with 16 mbyte local memory and data tablet |
| Ethernet and DOD standard software (TCP/IP) for linkage of HP, DEC, SONY, Adage, SI, CSPI, Matrix, Imagen and E/S components |

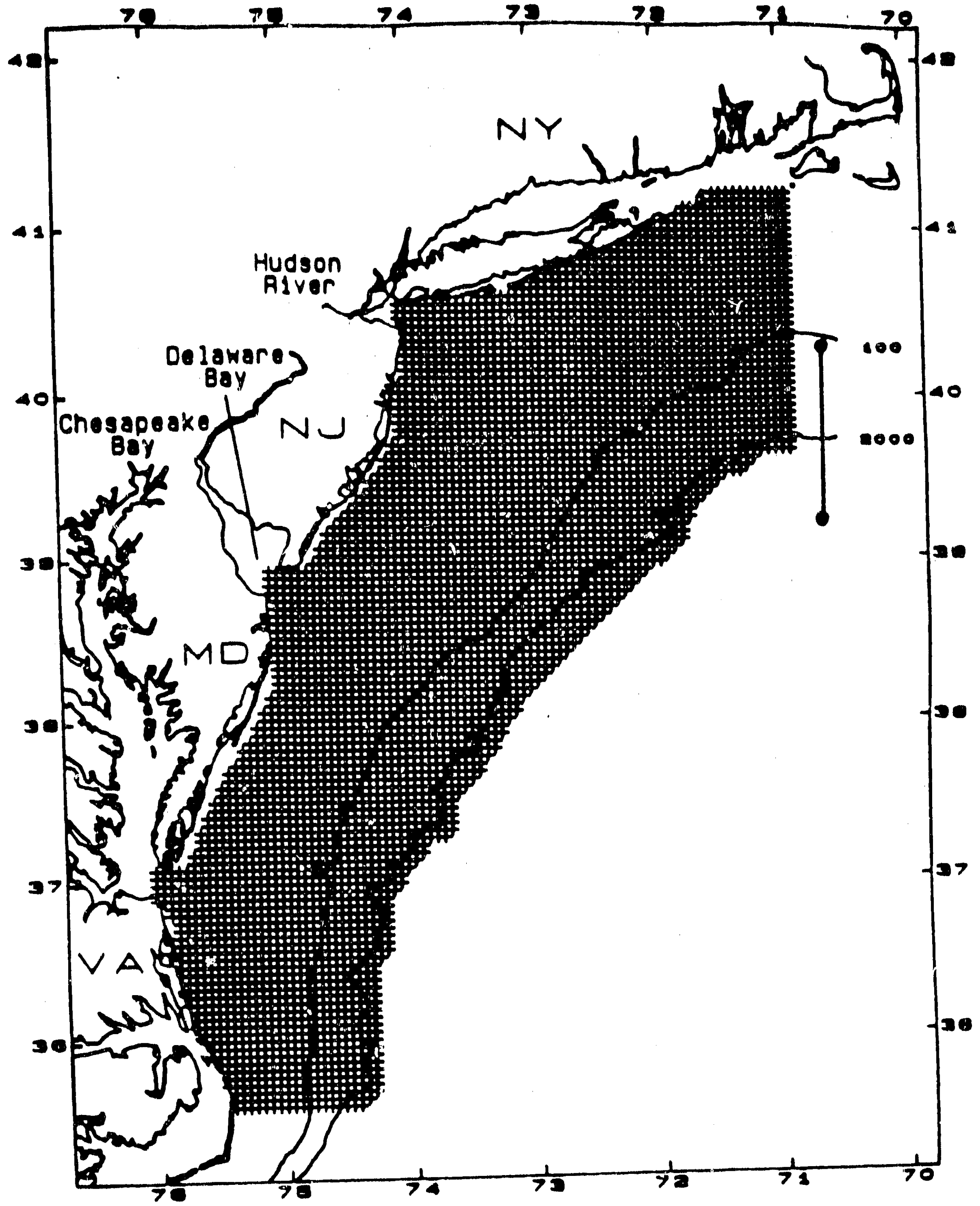


Figure 4. The spatial grids of simulated carbon cycling within a 3-dimensional model of the euphotic zone, and of a 2-dimensional model of the aphotic zone, in the Mid-Atlantic Bight (after Gregg and Walsh, 1990; Walsh et al., 1990a).

and the deep sea (Walsh, 1988). As part of the SEEP-I synthesis effort and of the SEEP-II experimental design, for example, we constructed a time-dependent, 3-dimensional model of the spring bloom over 3 depth layers at ∿14 km spatial resolution on the Mid-Atlantic shelf (Walsh et al., 1988b). The wind-forced model replicated fairly well both moored fluorometer data (Walsh et al., 1988c) and satellite color data (Walsh et al., 1987), predicting a threefold increase of the seaward flux of organic matter at the shelf-break as one moved southwest, from Martha's Vineyard to Cape Hatteras. A significant fraction (33%) of the simulated export of particulate carbon exited the Mid-Atlantic Bight at the downstream shelf boundary of the model domain near Cape Hatteras, however, while the fate of both shelf-derived and allocthonous detritus in the slope water column and sediments was not addressed.

We thus focused our resources during SEEP-II on two areas of research: 1) species succession at the base of the food webs in shelf and slope waters of the Mid-Atlantic Bight to allow estimates of primary production and sinking losses from the euphotic zone, for comparison with time series of particulate fallout caught in the aphotic zone by moored sediment traps; and 2) the relative contributions from the South Atlantic and Mid-Atlantic Bights to the total particulate fluxes measured in the Gulf Stream, after it separates from Cape Hatteras. For example, the net eastward transport of suspended matter by the Gulf Stream is ∿1.5 tons $sec^{-1}$ (J. Bishop and T. Joyce, personal communication), or $7.5 \times 10^9$ g C $day^{-1}$, assuming that 5% of the particulate flux is organic carbon. A mean carbon fixation of 0.5 g C $m^{-2}$ $day^{-1}$ over a shelf area of $2 \times 10^5$ $km^2$ between Miami and Georges Bank implies that such an export by the western boundary currents may be ∿10% of shelf photosynthesis, ignoring _in situ_ production of slope waters.

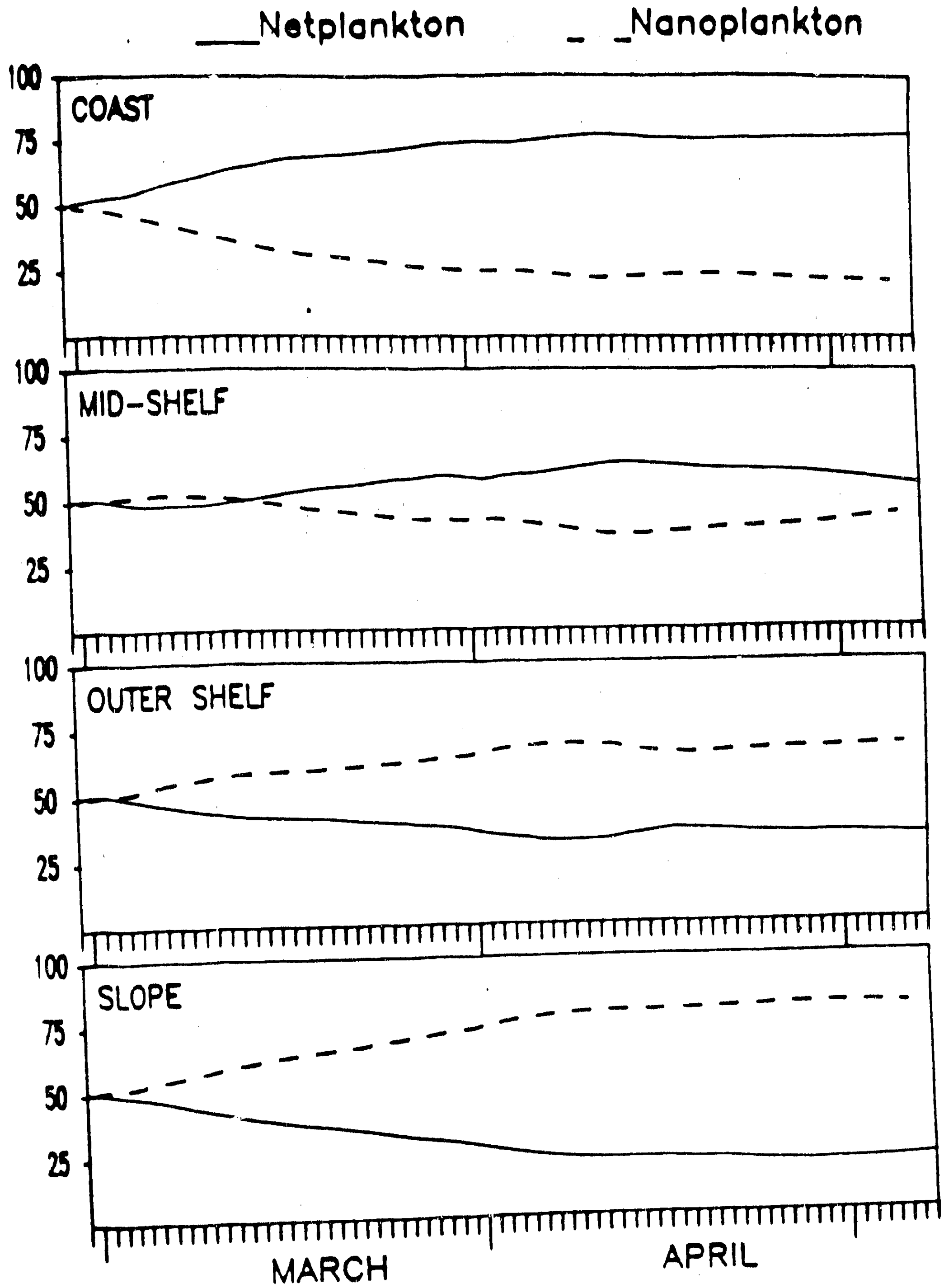


Figure 5. The relative abundance (%) of netplankton, with a sinking rate of 10 m day$^{-1}$, and of nanoplankton, with a rate of 0.5 m day$^{-1}$, after 70 days of spring blooms in the coastal (<30 m isobath), mid-shelf (30-60 m), outer shelf (60-200 m), and slope (200-2000 m) regions of the Mid-Atlantic Bight (after Gregg and Walsh, 1990).

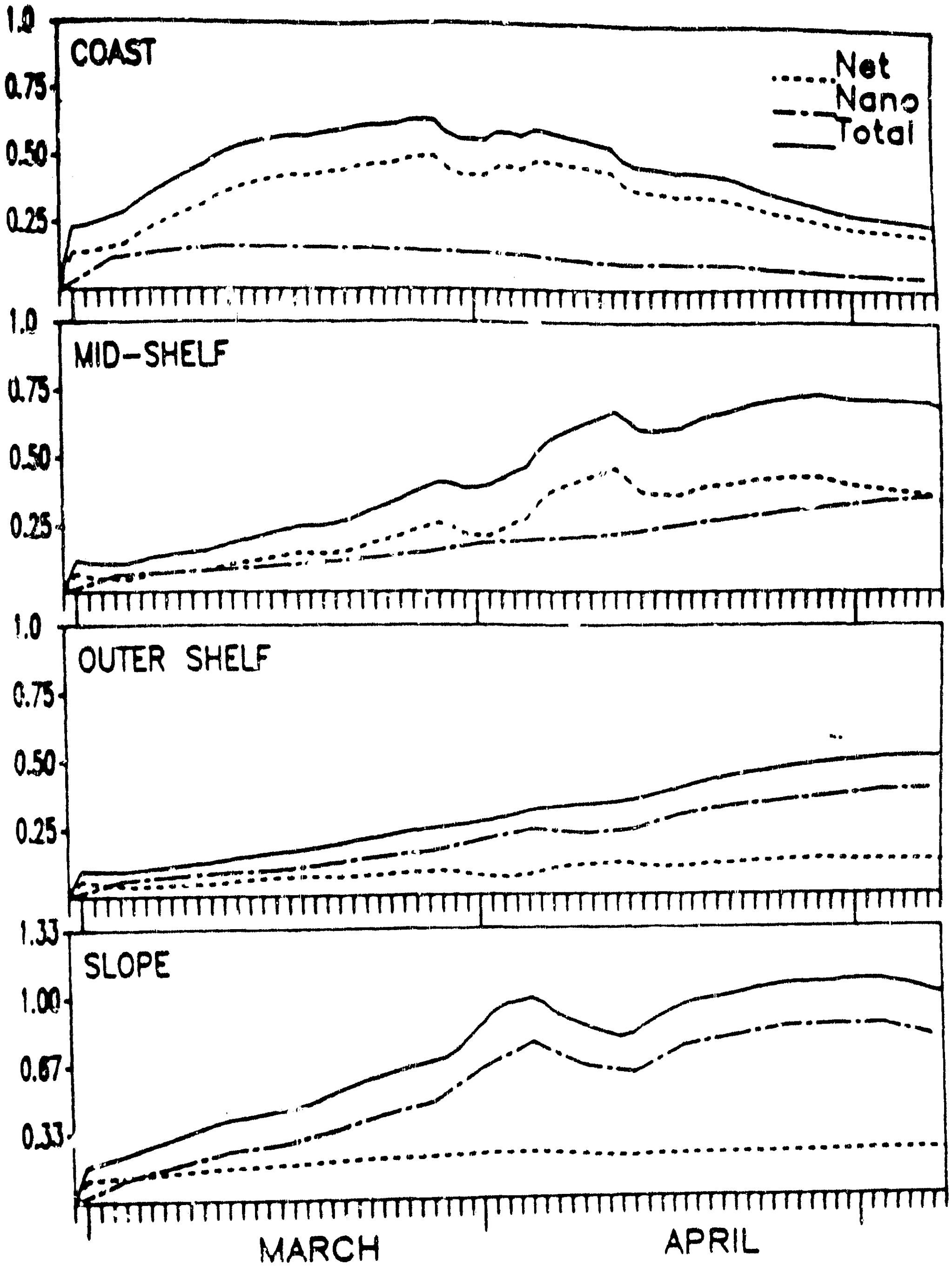


Fig 6. The size fractionation of primary production (g C $m^{-2}$ $day^{-1}$) during the spring bloom, averaged over the same 4 regions of the Mid-Atlantic Bight (after Gregg and Walsh, 1990).

Using a stream function version of the Walsh et al. (1988b) 3-dimensional, barotropic shelf model, the dissertation research of Mr. Watson Gregg involves an analysis of phytoplankton species succession within the February-April blooms of the Mid-Atlantic Bight. The model's domain extended over 10 depth layers at 5-km spatial resolution, from the 10-m to 2000-m isobaths (Fig. 4). Population growths of netplankton, with a mean sinking velocity of 10 m $day^{-1}$, and of nanoplankton, with a rate of 0.5 m $day^{-1}$, were functions of light, nutrients (nitrate and ammonium), temperature, and differential grazing stress (twice in slope waters).

At higher growth and sinking rates, netplankton dominate after 70 days (Fig. 5) in the coastal (78% of the biomass) and mid-shelf (55%) regions, where simulated wind events resuspend the diatoms back into the euphotic zone, similar to observations (Walsh, 1988). In contrast, nanoplankton dominate on the outer shelf (63%) and slope (80%), where <1% of the daily productivity of this size fraction (Fig. 6) sinks through the 200-m pycnocline of the model (Gregg and Walsh, 1990). If the simulation is extended for another 30 days of light May winds, i.e. fewer and weaker resuspension events, the nanoplankton even dominate (58%) on the mid-shelf (30- to 60-m isobaths), mimicking seasonal succession on the shelf as well.

The fate of organic matter in the aphotic zone (>150 m) of the Mid-Atlantic Bight was then examined (Walsh et al., 1990a) with a separate two-dimensional, fine-mesh model (0.5 km and 2.5 m grid spacing) of the SEEP-I line, ranging from depths of 150 m at the shelf-break to 2750 m on the continental rise along 71°W (Fig. 7). Slope detritus of picoplankton and zooplankton fecal pellet origin sinks at respective rates of 1 and 100 m $day^{-1}$ in this simulation, while shelf detritus had time-dependent sinking rates of

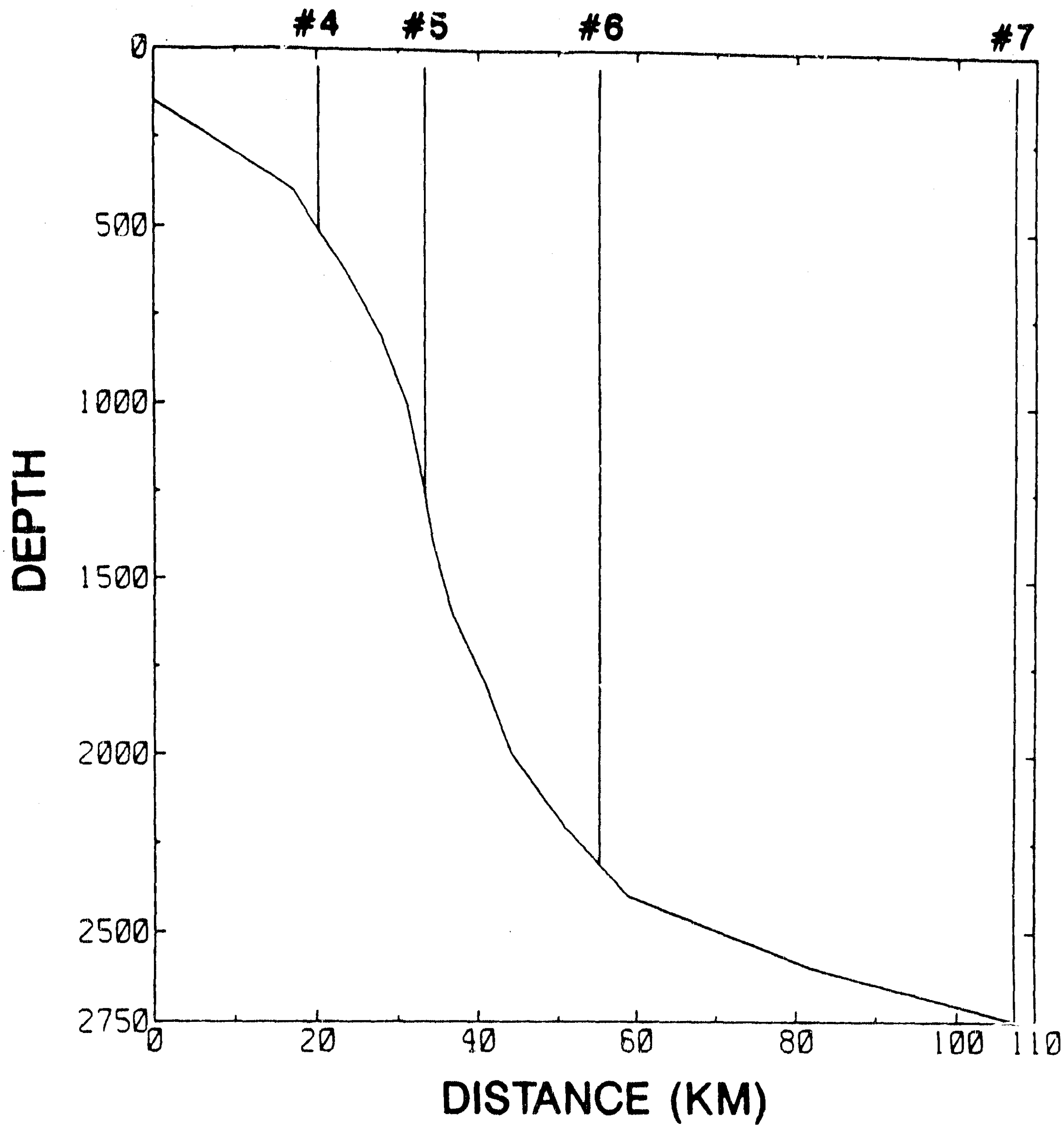


Fig. 7. Location of the SEEP-I sediment trap arrays (#4-7) in relation to a fine mesh model (0.5 km, 2.5 m) of the fates of shelf macroaggregates, diatoms, and nanoplankton, as well as of slope picoplankton and zooplankton fecal pellets, in the Mid-Atlantic Bight.

100, 10, and 1 m day$^{-1}$ for macroaggregates, diatoms, and nanoplankton, to mimic each month the seasonal decay of the spring bloom (March to August). A bottom boundary layer of ∿10 m thickness, with maximum velocities of ∿1 cm sec$^{-1}$ and vertical mixing of ∿15 cm$^2$ sec$^{-1}$, retarded settling of particles to the sediments. Outside the benthic boundary layer, horizontal and vertical mixing were parameterized by respective eddy coefficients of $2.5 \times 10^4$ cm$^2$ sec$^{-1}$ and 1 cm$^2$ sec$^{-1}$, while respiration losses were 1% day$^{-1}$ everywhere for all the size classes of detritus. A time series of carbon fluxes from the four SEEP-I sediment trap arrays (Table 3) provided validation data.

At 50 m above the bottom on the 500-m isobath, the model replicates the sediment trap fluxes of 85 and 73 mg C m$^{-2}$ day$^{-1}$ at the end of April and May, as well as that of 16 mg C m$^{-2}$ day$^{-1}$ at the end of August (Fig. 8a). Without sediment trap data at the end of March, the 30-day pulse of 10 m day$^{-1}$ phytodetritus from the shelf (Fig. 9a), as well as constant inputs of picoplankton debris (Fig. 9b) and zooplankton fecal pellets (Fig. 9c) from slope waters, account for most of the model's fidelity from April to August (Table 3). At 30-35 m above bottom on the 2300-m isobath, the model also mimics the observed fluxes at 2250 m (Table 3) of 14 and 11 mg C m$^{-2}$ day$^{-1}$ at the end of May and June, as well as 2-4 mg C m$^{-2}$ day$^{-1}$ for the next 3 months (Fig. 8b).

However, at this 2300-m isobath, the detrital signature of shelf diatoms, sinking at 10 m day$^{-1}$, is negligible (Fig. 10a), none of the slope picoplankton survive the longer descent, the flux of zooplankton fecal pellets here at 25 m above bottom (Fig. 10c) is half that at the 500-m isobath (Fig. 9c), and a pulse of macroaggregates, sinking at 100 m day$^{-1}$, instead provides the seasonal pulse of carbon loading (Fig. 10b). The actual duration

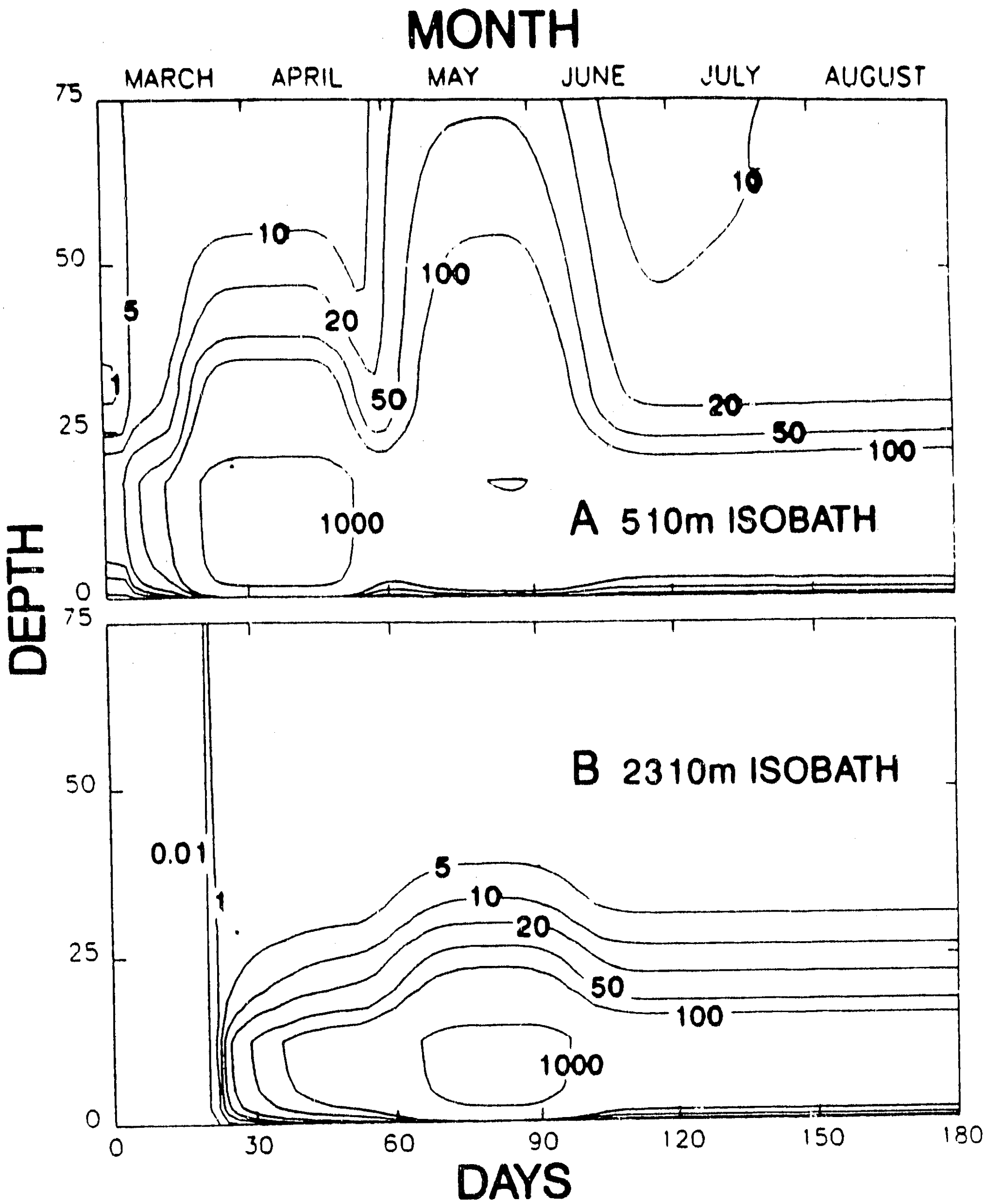


Fig. 8. The vertical structure of the total detrital flux (mg C $m^{-2}$ $day^{-1}$) of macroaggregates, diatoms, nanoplankton, picoplankton, and zooplankton fecal pellets over 180 days (March-August) within the lower 75 m of the water column at a) the 510-m isobath (array #4 of Table 3) and b) the 2310-m isobath (array #6).

Table 3. Organic carbon fluxes (mg C $m^{-2}$ $day^{-1}$) within slope waters of the Mid-Atlantic Bight during April-September 1984

| Station # | Isobath (m)/distance from shelf-break (km) | Sediment trap depth (m) | Month (1984) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | A | M | J | J | A | S | Mean |
| 4 | 500/20 | 150 | 20 | 32 | 11 | 25 | 9 | 6 | 17.2 |
| | | 450 | 85 | 73 | 34 | 42 | 16 | 22 | 45.3 |
| 5 | 1250/33 | 150 | 38 | 73 | 26 | 34 | 7 | 6 | 30.7 |
| | | 450 | 35 | 43 | 46 | 13 | 5 | - | 28.4 |
| | | 850 | 32 | 37 | 32 | 12 | 9 | 8 | 21.7 |
| | | 1200 | 30 | 36 | 20 | 10 | 12 | 8 | 19.3 |
| 6 | 2300/55 | 150 | 19 | 40 | 24 | 14 | 8 | 2 | 17.8 |
| | | 450 | 8 | 27 | 27 | 4 | 8 | 7 | 13.5 |
| | | 850 | 18 | 22 | 31 | 6 | 17 | 8 | 17.0 |
| | | 1750 | 17 | 21 | 15 | 2 | 6 | 6 | 11.2 |
| | | 2250 | 12 | 14 | 11 | 3 | 2 | 4 | 7.7 |
| 7 | 2750/107 | 150 | 21 | 37 | 15 | 13 | 11 | 3 | 16.7 |
| | | 450 | 4 | 5 | 10 | 6 | 4 | 3 | 5.3 |
| | | 850 | 7 | 8 | 14 | 2 | 6 | 4 | 6.8 |
| | | 1750 | 3 | 7 | 5 | 1 | 2 | 3 | 3.5 |
| | | 2250 | 9 | 11 | 7 | 3 | 3 | 4 | 6.3 |
| | | 2700 | 7 | 15 | 7 | 4 | 2 | 3 | 6.2 |

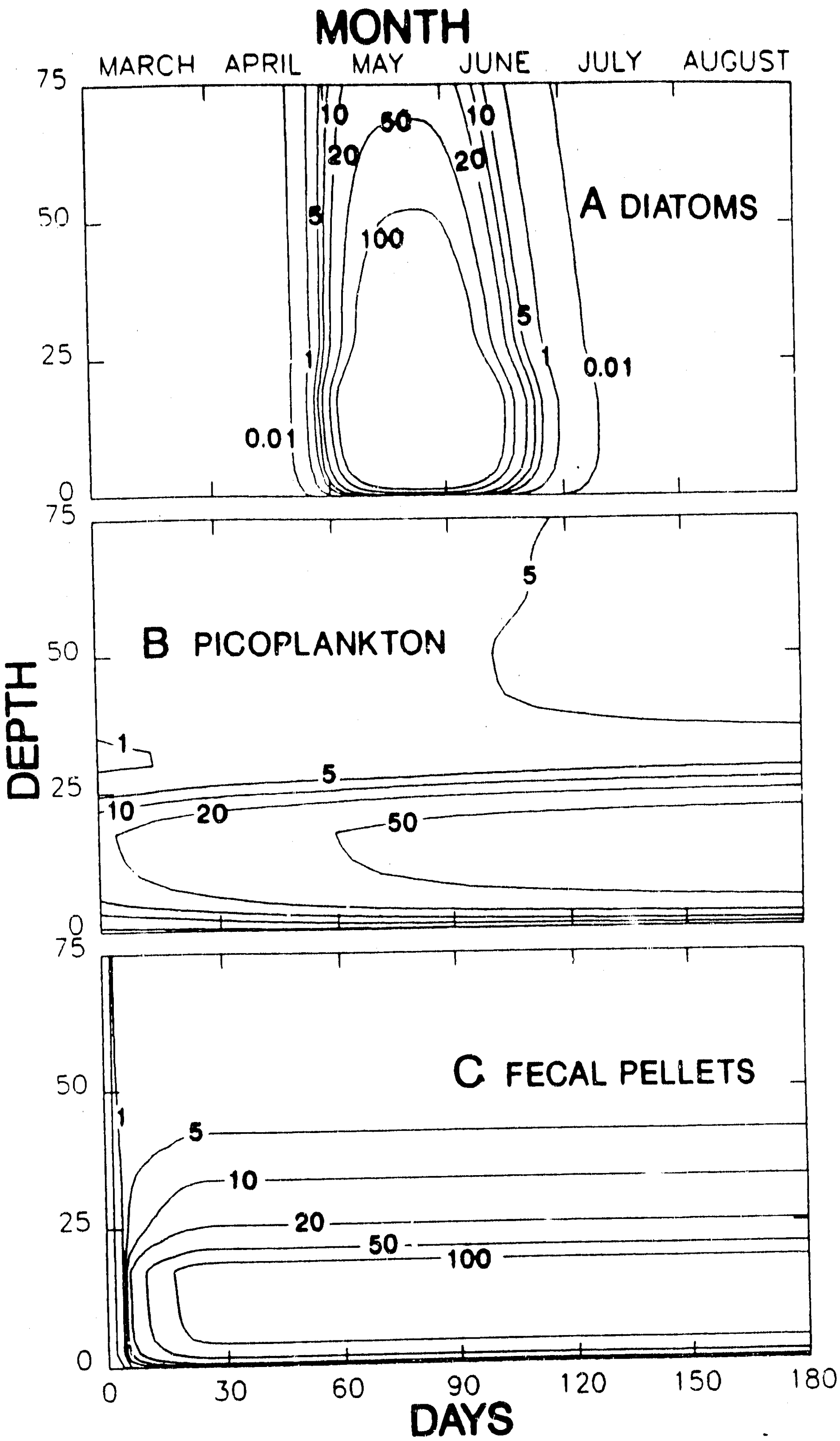


Fig. 9. The vertical structure of the detrital flux (mg C $m^{-2}$ $day^{-1}$) of a) diatoms, b) picoplankton, and c) zooplankton fecal pellets during March-August within the lower 75 m of the water column at the 510-m isobath.

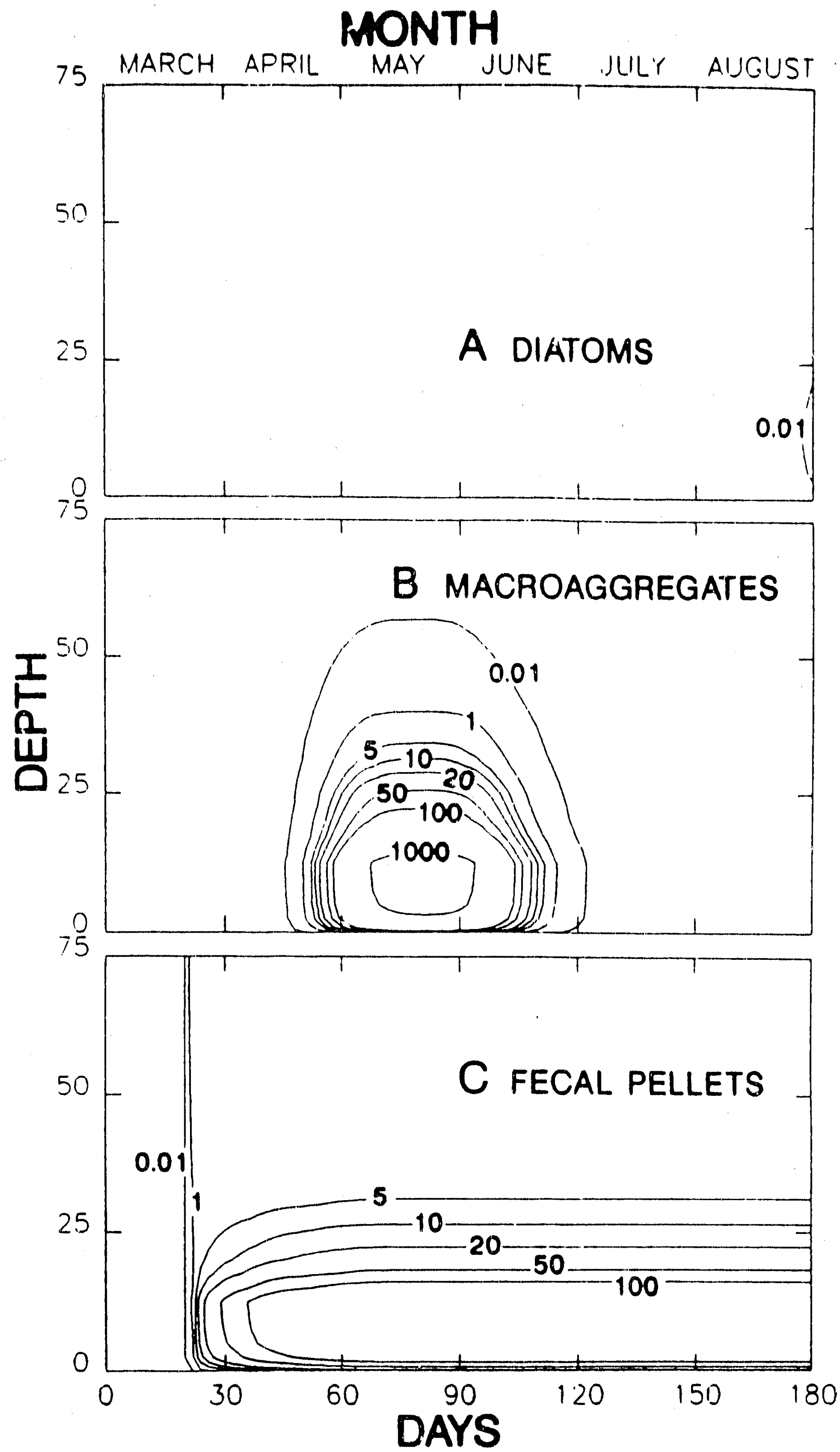


Fig. 10. The vertical structure of the detrital flux (mg C $m^{-2}$ $day^{-1}$) of a) diatoms, b) macroaggregates, and c) zooplankton fecal pellets during March-August within the lower 75 m of the water column at the 2310-m isobath.

of a macroaggregate pulse is unknown, but large particulate fluxes of ~1000 mg C $m^{-2}$ $day^{-1}$ at 10 m above bottom during April at 500 m, and in May at 2300 m, remain to be confirmed (Fig. 8); a seasonal pulse of fecal pellets, also sinking at 100 m $day^{-1}$, could instead yield the total response of Figure 8b at 30-35 m above bottom, with tenfold less organic carbon in the benthic boundary layer. When SEEP-II data reduction is completed, we will analyze these time series in a similar manner; this research constitutes part of the dissertation of Mr. Raymond Pribble.

Barotropic circulation models are of little utility, however, in describing either the seasonally stratified shelf habitat or the baroclinic instabilities of western boundary currents in slope waters. The simplest baroclinic circulation model is a two-layered "reduced gravity" model, with no flow in the lower layer, which has been used to formulate analytical descriptions of the Gulf Stream System. To avoid specification of open boundary conditions, we used a numerical version of a two-layered baroclinic model to explore at 25-km resolution, the biochemical consequences of nutrient injection by one of these western boundary currents, the Loop Current in the Gulf of Mexico (Walsh et al., 1990b), where only the transports through Yucatan and Florida Straits need to be specified.

With the time-dependent flow field, the vertical mixing and depth of a surface mixed layer as a function of seasonal wind stress, and a changing light field, the 4-dimensional (x, y, z, and t) structure of primary production, phytoplankton stocks (Fig. 11), and sinking fluxes was simulated by a 21-layered biological model over a one-year cycle of Loop Current penetration and eddy shedding in the Gulf of Mexico. Away from the continental margin, we were able to replicate the nutrient fluxes across the

Fig. 11. The simulated chlorophyll distribution at the surface of the Gulf of Mexico within a 21-layer model on day 170 of a penetration cycle of the Loop Current, with seasonal wind forcing and effluent from the Mississippi River.

pycnocline of this and other oligotrophic regions, the temporal and spatial structures of algal biomass (Fig. 12), and distribution patterns of organic matter in bottom sediments, e.g. Figure 3; this constitutes part of the dissertation of Mr. Mark Meyers. At the shelf-break, however, nutrient fluxes, algal biomass, and particle export were underestimated, because of the limitations of the physical model: 25-km grid spacing, flat 500-m deep shelves, and no wind forcing.

To improve the circulation model and specify the open boundary conditions of the Florida Current within the South Atlantic Bight, we initiated a collaborative research project with Dr. Wilton Sturges of Florida State University. He had adapted the GFDL/NCAR code of a primitive equation model to a 15-level description of the western boundary currents within the North Atlantic, from 8° to 36°N, and 50° to 100°W (Fig. 13), under realistic bottom topography, wind forcing, and specification of shear at the Mid-Atlantic Ridge. We recently obtained 140 hours of CRAY YMP time at the DOE-supported Super Computer Research Institute, FSU, to produce realistic flow fields for input to the biological models, now running on the ECOS modeling facility at USF (Table 2).

To provide a larger context for the SEEP-I and SEEP-II results, as well as an experimental design for SEEP-III, we have begun simulation analyses of particle fluxes in the South Atlantic Bight. Previous studies employed 2-dimensional descriptions of carbon/nitrogen fluxes at a single depth, without a circulation model, such that the fates of particulate matter could not be examined outside a limited spatial domain of current meter arrays. Using the CRAY YMP, the SAB circulation model will employ a telescoped grid, with a minimum 1-km spacing at the shelf-break, extending 1400 km from the


Fig. 12. A monthly composite of the distribution of surface chlorophyll, detected by the Coastal Zone Color Scanner, during August 1979, using the same color bar as Figure 11.

**Florida Keys to Cape Hatteras, to generate cyclonic spin-off eddies, under eastward displacement of the Florida Current and boundary conditions of flow** at 25-km resolution (Fig. 13).

Since cyclonic eddies propagate northward at 25-50 km $day^{-1}$, ∿30-60 days residence time in the model domain, we will consider seasonal cases of nutrient injection by the Florida Current at 2-month scenarios of changing transport; during the summer of 1984, for example, a 22 Sv increment of the Florida Current occurred over 5 days, yielding a mean upwelling rate of 25 m $day^{-1}$ at the shelf-break. Nutrient injection within these spin-off eddies, phytoplankton species succession, sinking of various size classes of particulate matter, biogenic contributions to $CO_2$ storage beneath the thermocline, and downstream particulate fluxes at Cape Hatteras will be the next effort of our simulation modeling in the SEEP program. For example, increased "new" production is presumably the explanation for a downstream increment of particle flux within the Florida Current, from 5.3 g C $m^{-2}$ $yr^{-1}$ at 660 m off Florida to 10.8 g C $m^{-2}$ $yr^{-1}$ at 1350 m off North Carolina (Fig. 14).

Particle fluxes from the Mid-Atlantic Bight will then be added at the northern boundary of this model to explore which source (MAB or SAB) dominates the export at Cape Hatteras, a long-term goal of the U.S. JGOFS community. Assuming again that 5% of the total mass flux caught at 2340 m underneath the Gulf Stream (P. Biscaye, personal communication) is organic carbon, 27.4 g C $m^{-2}$ $yr^{-1}$ arrives at this depth off Cape Hatteras (Fig. 14). Such a flux is equivalent to the sum of 15.5 g C $m^{-2}$ $yr^{-1}$ measured at 975 m off New Jersey and 10.8 g C $m^{-2}$ $yr^{-1}$ extrapolated at 1350 m off North Carolina. Depending upon the settling velocities, rates of oxidation, and fluctuations of offshore

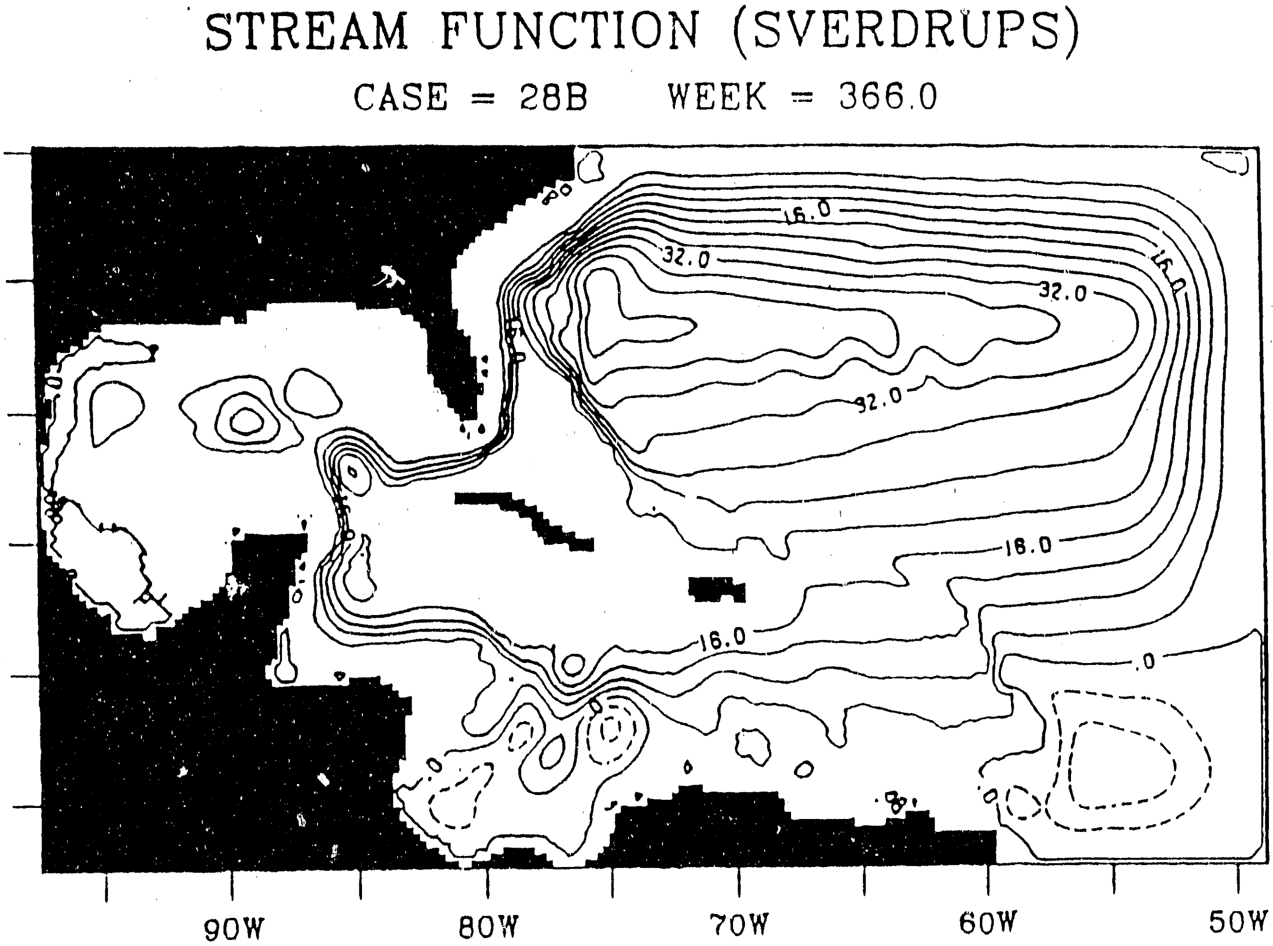


Figure 13. The transport (Sv) of water during week 366 within a 15-level, primitive equation model of the western boundary currents of the North Atlantic Ocean (after Sturges et al., 1989).

transport by the Gulf Stream, the entrained shelf particles may constitute most of the eastward particulate flux of 1.5 tons $sec^{-1}$ measured by J. Bishop and T. Joyce. Eventually such a lateral flux must rain out of the water column over some unknown area of the western North Atlantic Ocean.

For example, beneath the eastward path of the analogous Kuroshio Current, tongues of >10% biogenic siliceous sediments and high accumulation rates of organic carbon (M. Leinen, personal communication) extend across the North Pacific, from Japan to ∿160°W. Similarly, under the Gulf Stream at 71°30'W, organic carbon contents of 1.0% dw are found in surficial sediments at depths >4000 m, compared to <0.5% dw on most of the South Atlantic continental shelf, the Blake Plateau (Fig. 2), and the Hatteras Abyssal Plain. At 71°30'W, the mean carbon flux at a 4163 m sediment trap, moored underneath the Gulf Stream, was 7.2 g C $m^{-2}$ $yr^{-1}$ (Fig. 14), similar to that at ∿1000 m in SEEP-I (Table 1) and in contrast to 0.7 g C $m^{-2}$ $yr^{-1}$, measured either at 4000 m on the Cape Hatteras Abyssal Plain or at 3200 m off Bermuda. The residence times of organic carbon are estimated to be 35-85 yr within these surficial sediments under the Gulf Stream, and 1900-7000 yr farther south on the Abyssal Plain.

Additional recent studies of the poleward transport of dissolved nutrients and gases by the Gulf Stream suggest a possible longitudinal imbalance of at least nutrient fluxes in the North Atlantic at 36°N, with less nitrate transported equatorward. The lateral export at Cape Hatteras of nutrients, upwelled ∿700 m by the Gulf Stream, into the interior of the North Atlantic Ocean yields a net input of ∿120 kmol $NO_3$ $sec^{-1}$, which may fertilize the spring bloom of this region of the sea. A consequent regional sink of nutrients may occur here, in the form of either dissolved organic nitrogen or particulate matter, settling out of the water column to the bottom sediments (Fig. 14).

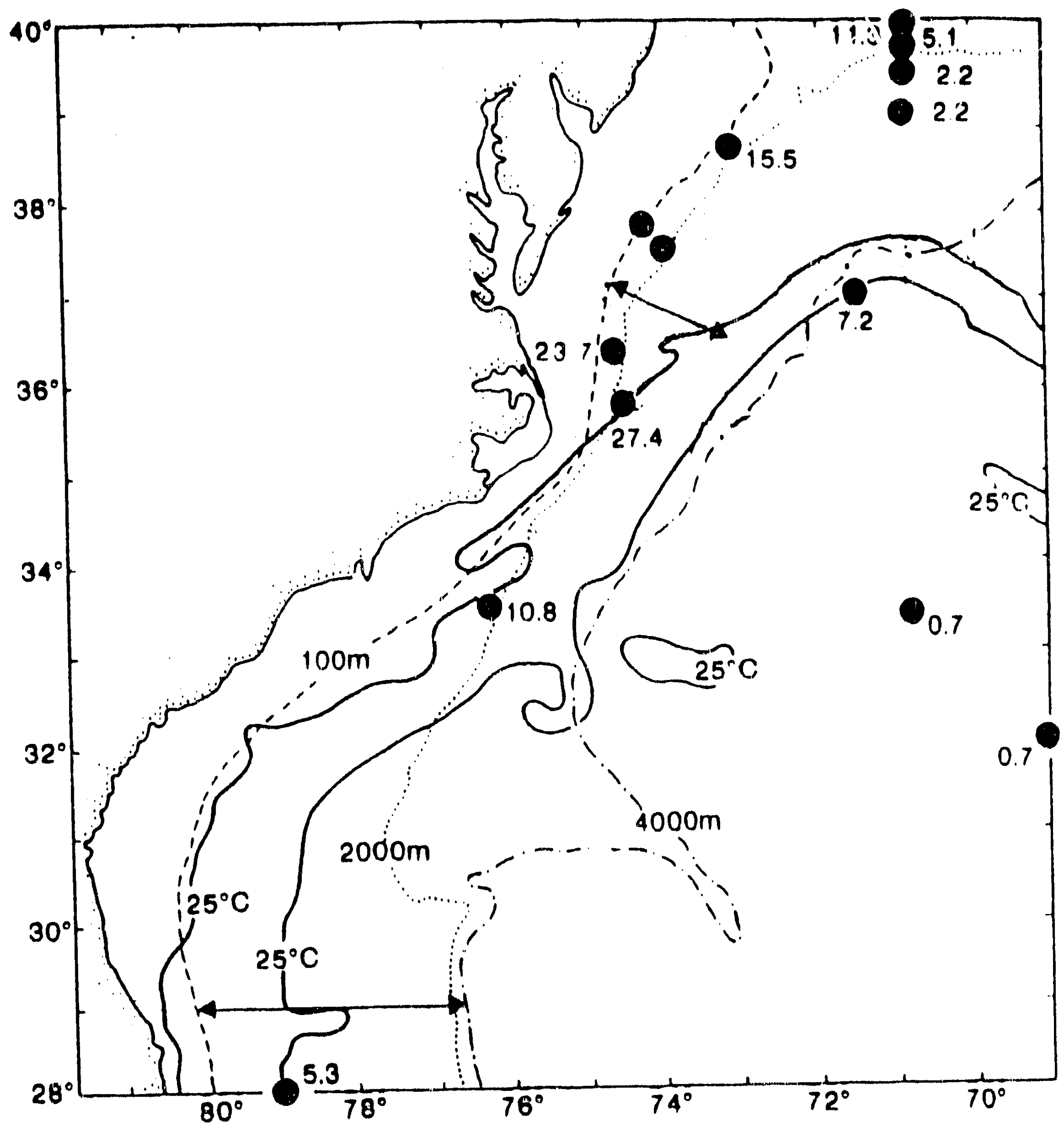


Fig. 14. The surface thermal envelope (25°C) of the Gulf Stream System during June 1984 in relation to annual, near-bottom carbon fluxes (g C $m^{-2}$ $yr^{-1}$) estimated from long-term moorings (except for the Florida Current observations) of sediment traps on the continental margin of the western North Atlantic Ocean.

Our continued simulation modeling within the SEEP program clearly addresses a number of pressing problems posed by the oceanographic community. Why should the Department of Energy continue to fund such research? The chemical processes of adsorption and desorption, through their role in the more general scavenging of reactive elements from the ocean water column, play an important role in the distribution, transport, and fate of reactive (insoluble) chemical species in the sea. Fundamentally, it is adsorption and desorption processes that link the transport and fate of heavy-metal-like elements, including pollutants, to the transport and fate of marine particulate matter. This, in turn, makes the biological and physical processes, which govern the production and transformation of particles, major factors influencing trace element behavior and the ultimate reservoirs of other energy-related by-products in the sea.

Scavenging of particle-reactive trace elements tends to be enhanced at ocean margins, compared to open-ocean regions. Consequently, there is usually a net lateral transport of pollutant-like elements from the open ocean to continental margins, with a resulting concentration, or enhanced deposition, of these elements in margin sediments. The overall process is termed boundary scavenging. If a recycling phase were added to this boundary scavenging process, then a potential pathway would exist for pollutant transport from the open ocean to man (who lives near, and extracts food from, ocean margin waters), particularly if the pollutants were not returned to the open sea by western boundary currents. Pollutants deliberately, or inadvertently, added to the coastal zone may similarly have a short pathway to man.

It is especially important to examine adsorption and desorption processes in SEEP-III off Cape Hatteras, because results from the SEEP-I experiment indicate that the Middle Atlantic Bight behaves very differently than all other ocean-margin regions, with respect to boundary scavenging. Boundary scavenging has been shown to occur in virtually every other ocean margin region studied to date. In contrast, early SEEP-I results indicated that there was little, if any, net transport of dissolved reactive chemical species from the open ocean to the margin of the Mid-Atlantic Bight.

These SEEP results of our LDGO colleagues indicate that, if anything, dissolved reactive elements are exported from the deep slope waters of the Mid-Atlantic Bight. This unusual behavior can be caused by one of two things: either the scavenging behavior (adsorption and desorption processes) of particulate matter in the MAB is fundamentally different from that of particulate matter in other ocean margin regions, or, the lateral exchange (physical transport) processes are somehow unusual. Either way, the mechanisms of scavenging in the South Atlantic and Mid-Atlantic Bights require further examination.

By relating the contrasting behavior of particle-reactive elements in different ocean-margin regions to the composition of particulate phases and to physical transport processes, we will greatly improve our understanding of trace element scavenging in the oceans. One specific possibility to examine in future DOE experiments is that the plume of particles, associated with the thermal track of the Gulf Stream as it heads offshore into the North Atlantic (Fig. 14), acts as a locus of scavenging, which is even more intense than that over the slope in the MAB. This would lead to the observed export of reactive elements from deep slope waters of the MAB (to the Gulf Stream). Whether the reactive elements are then dispersed over a much larger area of the North Atlantic, or concentrated in sediments underlying the Gulf Stream, depends on the fate of particulate matter carried offshore by the current -- the subject of continued simulation analyses within the SEEP program.

## Bibliography of DOE-supported publications during 1987-1990


Gregg, W. W. and J. J. Walsh. 1990. Simulation of the 1979 spring bloom in the Mid-Atlantic Bight: a coupled physical/biological/optical model designed for Coastal Zone Color Scanner data. J. Geophys. Res. (Submitted)

Stoddard, A. and J. J. Walsh. 1988. Modeling oxygen depletion in the New York Bight: the water quality impact of a potential increase of waste inputs. In "Oceanic Processes in Marine Pollution," Vol. 5, Urban Wastes in Coastal Marine Environments, D. A. Wolfe and T. P. O'Connor, eds., R. E. Krieger, Melbourne, pp. 91-102.

Walsh, J. J. 1988. On the Nature of Continental Shelves. Academic Press, New York, 520 pp.

Walsh, J. J. 1989. How much shelf production reaches the deep sea? In "Productivity of the ocean: past and present," W. Berger, G. Wefer and V. Smetacek, eds., John Wiley & Sons, Chichester, pp. 175-191.

Walsh, J. J. 1990a. Arctic carbon sinks: present and future. Global Biogeochem. Cycles (in press).

Walsh, J. J. 1990b. Global onwelling: "new" nitrogen constraints for carbon export at continental margins. Nature (submitted).

Walsh, J. J. and D. A. Dieterle. 1988. Use of satellite ocean colour observations to refine understanding of global geochemical cycles. In "Scales and Global Change. Spatial and Temporal Variability in Biospheric and Geospheric Processes. SCOPE 35," T. Rosswall, R. G. Woodmansee and P. G. Risser, eds., John Wiley & Sons, Ltd., Chichester, pp. 287-318.

Walsh, J. J., D. A. Dieterle and W. E. Esaias. 1987a. Satellite detection of phytoplankton export from the mid-Atlantic Bight during the 1979 spring bloom. Deep-Sea Res. 34: 675-703.

Walsh, J. J., T. E. Whitledge, J. E. O'Reilly, W. C. Phoel and A. F. Draxler. 1987b. Nitrogen cycling on Georges Bank and the New York shelf: a comparison between well-mixed and seasonally stratified waters. In "Georges Bank," R. H. Backus, ed., MIT Press, Cambridge, pp. 234-246.

Walsh, J. J., P. E. Biscaye and G. T. Csanady. 1988a. The 1983-84 Shelf Edge Exchange Processes (SEEP)-I experiment: hypotheses and highlights. Cont. Shelf Res. 8: 435-456.

Walsh, J. J., D. A. Dieterle and M. B. Meyers. 1988b. A simulation analysis of the fate of phytoplankton within the Mid-Atlantic Bight. Cont. Shelf Res. 8: 757-787.

Walsh, J. J., C. D. Wirick, L. J. Pietrafesa, T. E. Whitledge, F. E. Hoge and R. N. Swift. 1988c. High frequency sampling of the 1984 spring bloom within the Mid-Atlantic Bight: synoptic shipboard, aircraft, and *in situ* perspectives of the SEEP-I experiment. Cont. Shelf Res. 8: 529-563.

Walsh, J. J., D. A. Dieterle and J. R. Pribble. 1990a. Organic debris on the continental margins: a simulation analysis of source and fate. Deep-Sea Res. (submitted).

Walsh, J. J., D. A. Dieterle, M. B. Meyers and F. E. Müller-Karger. 1990b. Nitrogen exchange at the continental margin: a numerical study of the Gulf of Mexico. Prog. Oceanog. (in press).

Sources of present Federal support for research of J. J Walsh

| Agency | Title | Annual Support |
|---|---|---|
| Department of Energy | Simulation analysis of moored fluorometer time series from the Mid-Atlantic Bight | $150,000 |
| National Aeronautics and Space Administration | Analysis of CZCS time series from continental shelves (with O. Brown) | $260,000 |
| National Science Foundation | ISHTAR studies of the Bering/Chukchi Seas: Component B | $100,000 |
| Office of Naval Research | Four-dimensional analysis of particle dynamics at ocean margins | $ 80,000 |

# -END-

DATE FILMED

02 / 20 / 91