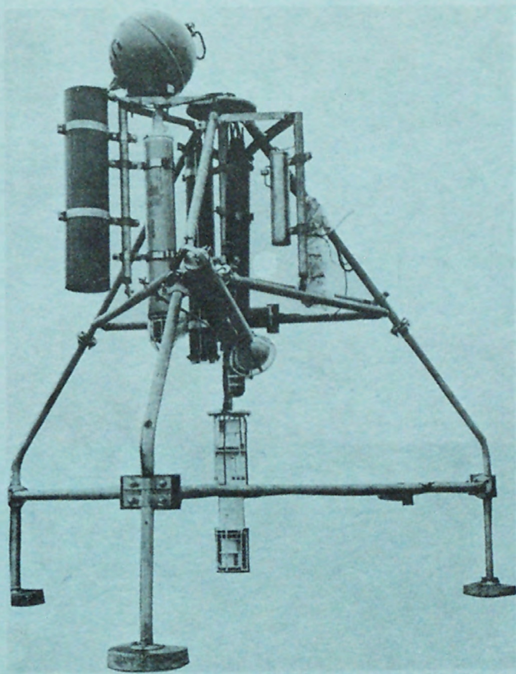
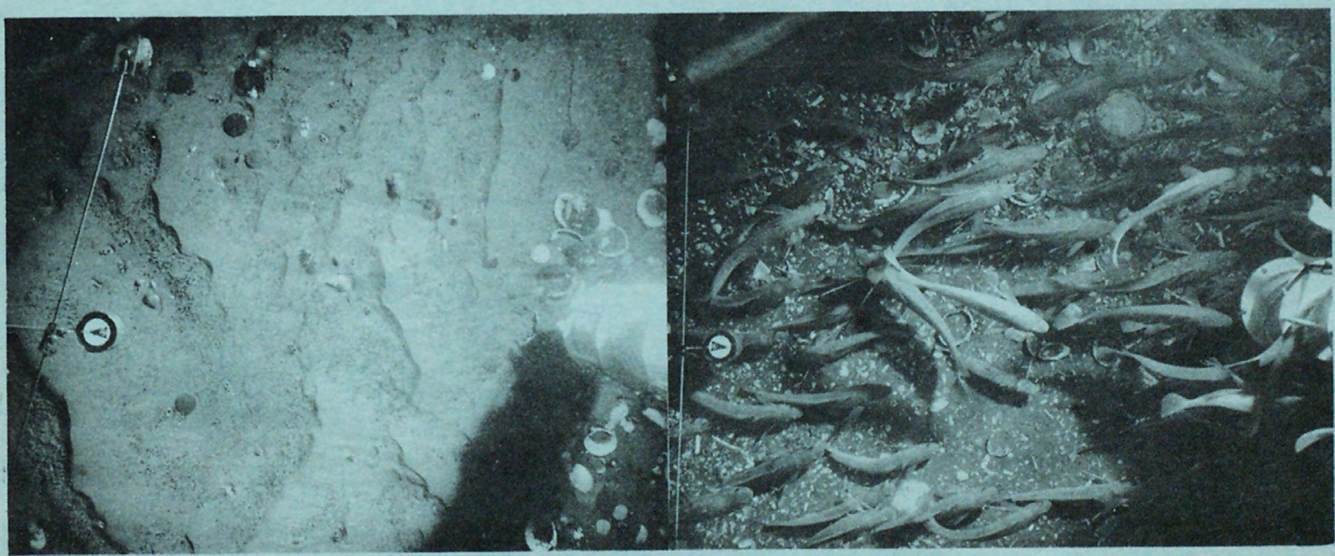
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

AN INSTRUMENT SYSTEM FOR LONG TERM SEDIMENT TRANSPORT STUDIES ON THE CONTINENTAL SHELF





BRADFORD BUTMAN AND DAVID W. FOLGER

OPEN FILE REPORT 78-1019
WOODS HOLE, MASS.
1978

AN INSTRUMENT SYSTEM FOR LONG-TERM SEDIMENT
TRANSPORT STUDIES ON THE CONTINENTAL SHELF.

by

Bradford Butman and David W. Folger

U. S. Geological Survey
Office of Marine Geology
Atlantic-Gulf of Mexico Branch

Woods Hole, Mass.
November 1978

Open File # 78-1019

TABLE OF CONTENTS

Page

Abstract 1

Introduction 1

The Bottom Tripod Instrument System 3

Sensors. 3

Current Speed and Direction. 3
Pressure 3
Turbidity. 3
Temperature. 6
Camera 7

Data Sampling Scheme 7

Electronics. 12

Tripod Frame: Deployment and Recovery 12

Data Variables and Accuracy. 14

U. S. Geological Survey Sediment Transport Studies 17

Examples of Observations 17

Discussion 22

Acknowledgments. 23

Literature Cited 23

AN INSTRUMENT SYSTEM FOR LONG-TERM SEDIMENT TRANSPORT STUDIES ON THE CONTINENTAL SHELF

Bradford Butman and David W. Folger

ABSTRACT

A bottom-mounted instrument system has been designed and built to monitor processes of bottom-sediment movement on the Continental Shelf. The system measures bottom current speed and direction, pressure, temperature, and light transmission, and photographs the bottom. The instrument operates in a burst sample mode. The system can be deployed for periods of 2-6 months to monitor intermittent processes of sediment movement such as storms, and to assess seasonal variability. Deployments of the system on the U.S. East Coast Continental Shelf show sediment resuspension and changes in bottom microtopography due to surface waves, tidal currents, and storms.

INTRODUCTION

We have designed and built an instrument system to investigate processes of bottom sediment movement on the Continental Shelf. The system is intended for use in regional studies of sediment transport to determine the physical processes responsible for bottom movement and to estimate the frequency, direction, and extent of sediment transport. The system measures bottom current speed and direction, pressure, temperature, and light transmission and photographs the bottom. It consists of three major components: (1) sensors for current, pressure, temperature, light transmission, and bottom photography; (2) a data recording unit; and (3) a tripod frame to which the sensors and data recording unit are mounted for deployment.

Direct observations, acquired *in situ*, are necessary to determine the character, extent, and causes of sediment dispersal over different regions of the Continental Shelf. Measurements must resolve motions with broad time scales ranging from a few seconds for wave frequency processes to weeks and months for processes associated with meteorological and oceanic forcing. Observations must be made to assess seasonal variability and to document catastrophic events. The tripod mounted instrument package, referred to hereafter as a bottom tripod system, was designed to measure the physical parameters necessary to understand regional processes of sediment transport for periods of 2-6 months. Similar systems, previously developed and used on the continental shelf, influenced our design (Sternberg et al., 1973; Smith and McLean, 1977). Photographs are taken periodically to document the bottom response to physical forcing and assess the effects of biological organisms on sediment movement. The photographs remove the need to rely exclusively on empirical competency curves to determine sediment movement (for instance, Miller et al., 1977).

The measurement of bottom stress is of prime interest in studies of sediment transport to determine movement threshold. However, the accurate measurement and parameterization of bottom stress requires the use of sophisticated instrumentation (Smith and McLean, 1977; Williams and Tochko, 1977; and Cacchione and Drake, 1978), which is not yet routine in oceanography, especially for long time periods. Measurement of the stress profile in the bottom boundary layer is required to accurately determine the stress on a sediment particle. We designed the tripod system for use in regional studies of shelf sediment transport and chose to measure current at a single fixed height from the bottom to monitor and define processes of sediment movement and transport; the system does not measure stress. Determination of bottom stress and sediment movement thresholds can probably best be made in short term detailed experiments using other specialized instrument systems.

THE BOTTOM TRIPOD INSTRUMENT SYSTEM

The tripod system (Figure 1) measures current speed and direction, pressure, temperature, and light transmission and photographs the bottom. A data recording package samples, formats, and records the data and distributes power to all sensors. The sensors are deployed and recovered on a rigid tripod frame. All major tripod components and manufacturers of the components are listed in Table 1.

Sensors

Current Speed and Direction

Bottom current speed is measured by means of a savonius rotor sensor located approximately 1 m from the sea floor. A small vane directly below the rotor senses current direction. The savonius rotor was considered adequate for use in a fixed frame mounting in water depths greater than 40 m where high frequency surface waves seldom reach the bottom. The pressure measurements indicate periods of large waves when the rotor-vane system may overestimate the current speed.

Pressure

Pressure is measured by means of a quartz-crystal pressure sensor mounted approximately 1.5 m from the sea floor. Bottom pressure is sampled to measure both wave frequency variations and lower frequency changes in sea level due to tides and storms.

Turbidity

A transmissometer mounted approximately 2 m from the sea floor is used to monitor changes in the suspended matter concentration of bottom water. It uses a wide-spectrum incandescent light source regulated by a

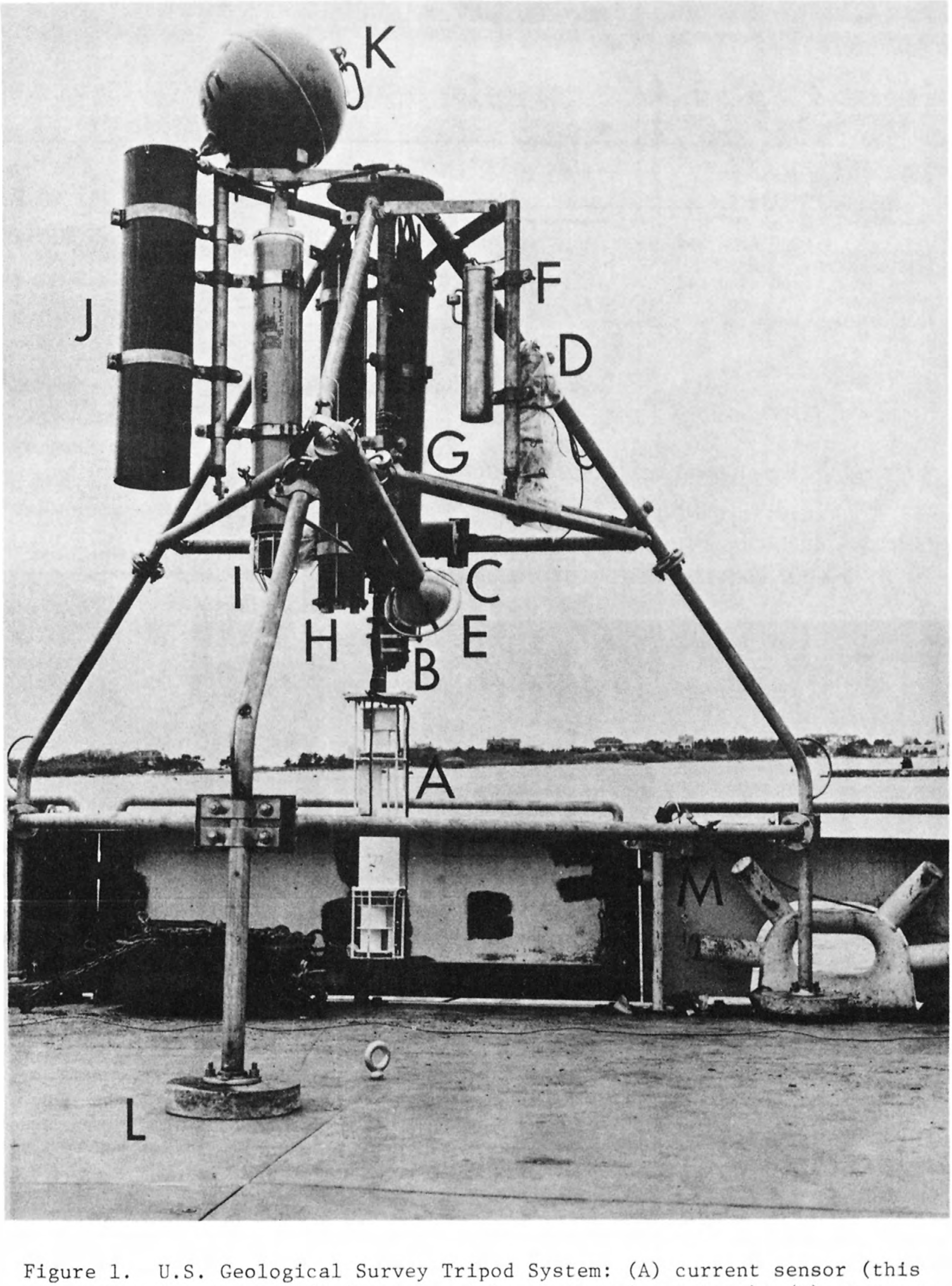


Figure 1. U.S. Geological Survey Tripod System: (A) current sensor (this photograph is of a modified system with two savonius rotors); (B) pressure sensor; (C) transmissometer; (D) camera (wrapped in protective plastic bag to enclose anti-fouling ring); (E) strobe light; (F) camera battery pack; (G) Sea Data electronics; (H) battery pressure housing; (I) acoustic release transponder; (J) rope cannister; (K) recovery float; and (L) lead anchor feet.

Table 1. U.S. Geological Survey tripod components

Component	Type and Model	Manufacturer/ Supplier*
Electronics	Digital, CMOS (651-4)	Sea Data Corp.
Tape Transport	Stepping Digital Cassette (610)	Sea Data Corp.
Sensors		
Current	Savonius Rotor and Small Vane (Q-9)	Bendix, Inc.
Pressure	Quartz Crystal (4130,4270,4600)	Paroscientific, Inc.
Temperature	Thermistor	Sea Data Corp.
Transmissometer-Nephelometer	Incandescent Lamp. Transmission and 90° Scatter (TMU-1b)	Montedoro-Whitney
Camera	35mm (372,382,391)	Benthos, Inc.
Release	Acoustic Release - Transponder (325)	AMF Sea-Link
Frame	Tripod. Type 316 Stainless Steel	USGS/WHOI
Pressure Cases	Aluminum, hard anodized	Oceanic Industries
Penetrators, Connectors		Electro-Oceanics
Anti-Fouling	Porous bronze, impregnated with CeCAP (tri-butyl tin oxide and fluoride)	Miami Marine Research, Inc.

*Specification of manufacturer does not imply endorsement by U. S. Geological Survey.

photocell. The light beam travels a folded path of 1 m length; a 180° prism is at one end of the path. To obtain a percent transmission measurement, the sensor output is normalized by the lamp output in filtered distilled water. We have calibrated similar sensors in the field to determine the relationship between percent transmission and naturally occurring suspended matter. However, particle size and composition affect light transmission, and any absolute calibration of the transmissometer is qualitative. Also, many major near-bottom changes in transmission are due to resuspension of bottom material which may have different transmission characteristics than samples obtained in the field in calm weather. Biological growth on the transmissometer prism and windows also limits the long term stability of the sensor calibration. Growth is retarded by using porous bronze plates impregnated with tri-butyl tin oxide; the plates fit closely around the exposed surfaces and gradually release the tin oxide into the water during deployment, inhibiting growth. Despite calibration difficulties and problems with biological fouling, the transmissometer provides a useful qualitative indication of the relative changes in bottom sediment concentration as a function of time.

The transmissometer sensor also incorporates a 90° scattering nephelometer, which shares the regulated incandescent light source. The nephelometer is not sensitive to the low concentrations (generally less than 2 mg l^{-1}) of suspended sediment typical of the U. S. east coast mid-Continental Shelf.

Temperature

Water temperature is measured by a thermistor mounted inside the aluminum electronics pressure housing on the lower end cap. The time constant of the temperature measurement is several minutes.

Camera

Bottom photographs are obtained by means of a 35 mm deep-sea camera system. Quantitative estimates of changes in bottom microtopography (ripple size, ripple migration rates, etc.) associated with various forcing mechanisms such as storms and waves, and the effects of biological activity on the sediments can be determined from the photographs. Qualitative estimates of changes in the suspended matter concentration can also be made from the photographs to verify the transmissometer observations. In addition, the photographs provide information on benthic biological populations, variability in populations, and behavior patterns.

Data identification, date, and time are recorded directly on each 35 mm frame for reference in data analysis. A total of 750 frames are available for each deployment. The camera is mounted approximately 2 m from the sea floor; the 42° x 54° lens opening gives a 1.5 x 2 m viewing area on the bottom. A magnetic compass and current vane is fixed in the camera field of view to provide frame orientation and a simple current direction measurement. Biological growth is inhibited by means of a porous bronze ring impregnated with tri-butyl tin oxide fitted around the camera window.

Data Sampling Scheme

The tripod system samples the output from the sensors in two modes: interval mode and burst mode (Figure 2). The sampling scheme resolves high frequency processes without storing excessive data (Webster 1967). In the interval mode, pressure and rotor speed are averaged for a time period called the basic sampling interval, typically several minutes in length (in the present system 3.75, 7.5, 15.0, or 30.0 min can easily be selected). In the center of the basic sampling interval, a single

Figure 2. U. S. Geological Survey Tripod System Data Sampling Scheme (see text for further discussion): a. Interval and burst sampling scheme. The time at which data is written on the tape transport is indicated by I (record interval) or B (record burst).

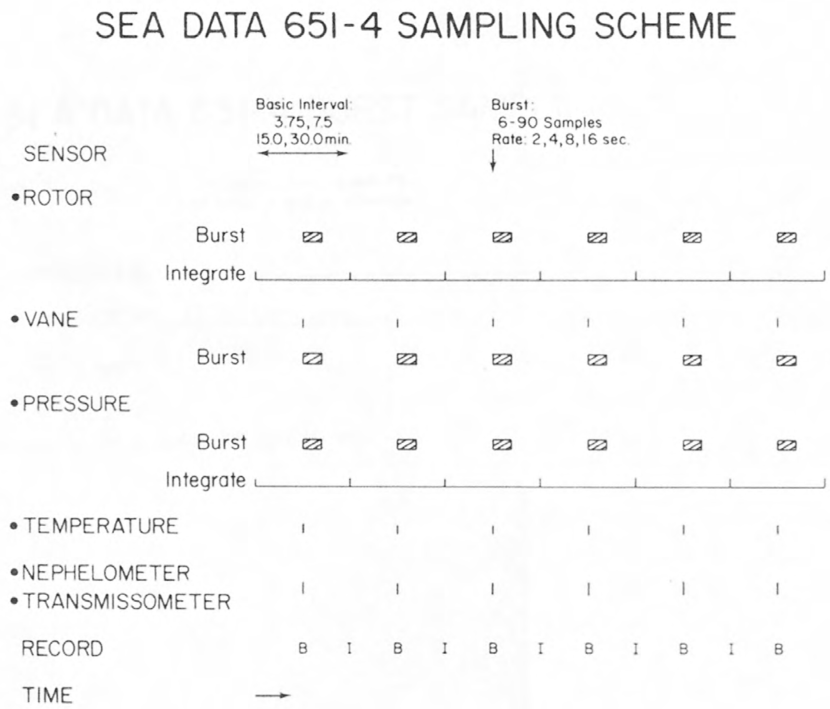
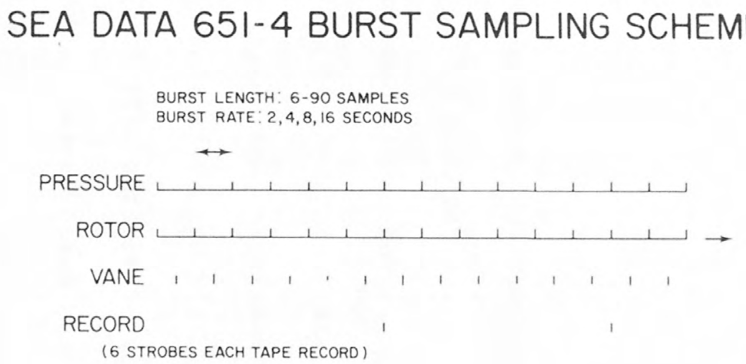


Figure 2. U. S. Geological Survey Tripod System Data Sampling Scheme (see text for further discussion): b. Burst sampling scheme. Six measurement sets of rotor speed, pressure, and vane orientation are recorded in each burst record. The spacing between the burst samples is 2, 4, 8 or 16 sec. and 1-15 records (6-90 sample sets) comprise a burst.



sample of temperature, light transmission, and turbidity is made. A sample of transmissometer and nephelometer sensor output with lamp off is made to assure no contamination from the ambient light.

In the burst sampling mode, a sequence of rotor speed, vane direction, and pressure measurements are taken at relatively short intervals (a "burst" of samples). The beginning of the burst sequence is centered in the basic sampling interval and is repeated at the basic interval (Figure 2b). The time between samples in the burst (burst rate) is typically several seconds (adjustable to 2, 4, 8, or 16 seconds). The number of sample cycles within a burst (number of strobes in a burst) is adjustable from 6 to 90 strobes. Vector averaging electronics is not used for the current measurements.

For a typical four month deployment in 60-80 m of water, the basic sampling interval is 7.5 min, the burst rate is 4 seconds, and 12 samples (strobes) are made in a burst. The selection of the number of samples in a burst and of the burst rate for a deployment are primarily determined by water depth and experiment duration. Data record length for typical sampling selections are listed in Table 2. A larger number of data strobes and a faster burst rate are used in shallow water where higher frequency water waves reach the bottom. The basic sampling interval is selected to resolve the physical processes of interest; because the current meter is not vector averaging, the sampling interval must be rapid enough to prevent serious aliasing from motions that have time scales less than twice the basic sampling interval. Generally 7.5 minutes is adequate in winter when the water column is well mixed and the Brunt Väisälä period is long. In summer, when the Brunt frequency may be 10-15 minutes, a basic sampling interval of 3.75 minutes is selected.

Table 2. Data Capacity of Sea Data 651-4 Data Logger (with double tape transport) for a Basic Sampling Interval of 3.75 min and Typical Burst Lengths.

Strobes in Burst	Capacity (days)
6	208
12	138
18	104
24	82
30	68
36	58
etc.	

The camera is programmed to photograph the bottom at a fixed time interval, typically 2 or 4 hours for a 2 or 4 month deployment. In addition, logic circuitry has been developed to trigger the camera according to current speed, mainly to document bottom changes associated with high speed current events. In the present configuration, this conditional photographic sampling allows bursts of pictures. The photographic threshold (current speed above which a sequence of pictures is initiated), the number of pictures in a burst sequence, and the picture rate are adjustable within wide limits. The camera logic contains two provisions to avoid repetitious conditional picture taking and to insure that sufficient camera shots will be available for the evenly spaced time series; the total number of pictures triggered conditionally in a deployment may be specified, and the frequency at which the conditional logic is activated to examine current threshold may be fixed at a multiple of the basic instrument sampling interval.

Electronics

The data recording package utilizes low-power digital circuitry. The circular electronics rack fits inside a 15.5 cm (inner diameter) pressure housing; penetrators in the upper end-cap connect the data logger to the various sensors mounted on the tripod frame. Power is provided from stacks of alkaline batteries, arranged to give a 21 v 100 amp-hr supply. The incremental stepping digital cassette recorder writes four bits across the tape at a longitudinal density of 800 bits per inch. Two cassette tape drives are used with a total data capacity of 3.6×10^7 bits.

Tripod Frame: Deployment and Recovery

The tripod components are deployed and recovered attached to a rigid tripod frame (Figure 1) designed to cause minimum disturbance to the current flow and still be durable enough to withstand repeated deployments and harsh treatment at sea. The frame is 3.4 m high, 3.4 m on a base, and is constructed entirely of type 316 stainless steel; the major structural members are 6.03 cm (outer diameter) schedule 40 or 80 pipe. All components are bolted together; thus the frame can be dismantled and shipped easily. Instruments are mounted by means of clamshell-like brackets so that placement can be easily changed and adjusted, and so that additional instruments for specific studies can be attached and removed as required. All dissimilar metals are completely insulated from the frame, and sacrificial zinc anodes are mounted at several places on the frame as well as on the instruments to minimize corrosion. A tripod with anchor pads and all instruments weighs approximately 950 kg (2100 lbs.) in air, and 600 kg (1300 lbs.) in water. Each lead anchor pad weighs 91 kg (200 lbs.) in air. On the basis of static calculations, the tripod is probably stable in steady currents as fast as 150 cm sec^{-1} (3 knots).

For deployment, the tripod is lowered to the bottom on a braided polypropylene slip line. The acoustic-release transponder in the system is fitted with a tilt switch which, when interrogated from the surface, modifies a reply code if the unit is tipped at an angle greater than 30^{o} from the vertical. The release is interrogated immediately after deployment and before recovery to determine that the tripod is upright.

For recovery, a coded acoustic command from the surface actuates the release; a float pulls one end of a 100 m long, 1.6 cm (5/8") diameter nylon line from a rope cannister on the tripod to the surface. A radio transmitter and strobe light are mounted on the float to enable it to be located on the surface. The entire tripod frame is recovered with the nylon line. The deployment and recovery scheme is limited to depths less than 100 m.

We deploy one to four large lighted buoys (5 ft. diameter steel spheres with 6 ft. light towers) around the tripod site so that fishermen can identify the instrument location and avoid fouling their nets (Figure 3).

Data Variables and Accuracy

Once a tripod is recovered, the data are decoded, reviewed, and edited prior to scientific analysis and display. Typically 50 points in $2x10^5$ (.02%) require editing.

Variables computed from the burst and interval measurements and the resolution and estimated accuracy of these tripod measurements are listed in Table 3. Average vector current direction and current speed are computed from the burst measurement pairs of current speed and direction. The ratio of burst vector current speed to average burst rotor speed (called burst normalized unit vector, BNUV) is computed as a measure of the current variability within a burst. The ratio of average burst rotor speed to interval rotor speed (called BROTOR/IROTOR) is also computed as a measure of the variability of current flow between burst and interval measurement periods. The standard deviation of the burst pressure measurements is computed as a first order indicator of wave induced pressure fluctuations. Spectra of the burst pressure measurements can be calculated to resolve frequency and amplitude of the high frequency pressure field. Finally, the difference between average burst pressure and interval pressure is computed as a crude measure of the pressure variability between burst and interval time scales and as an instrumental check.

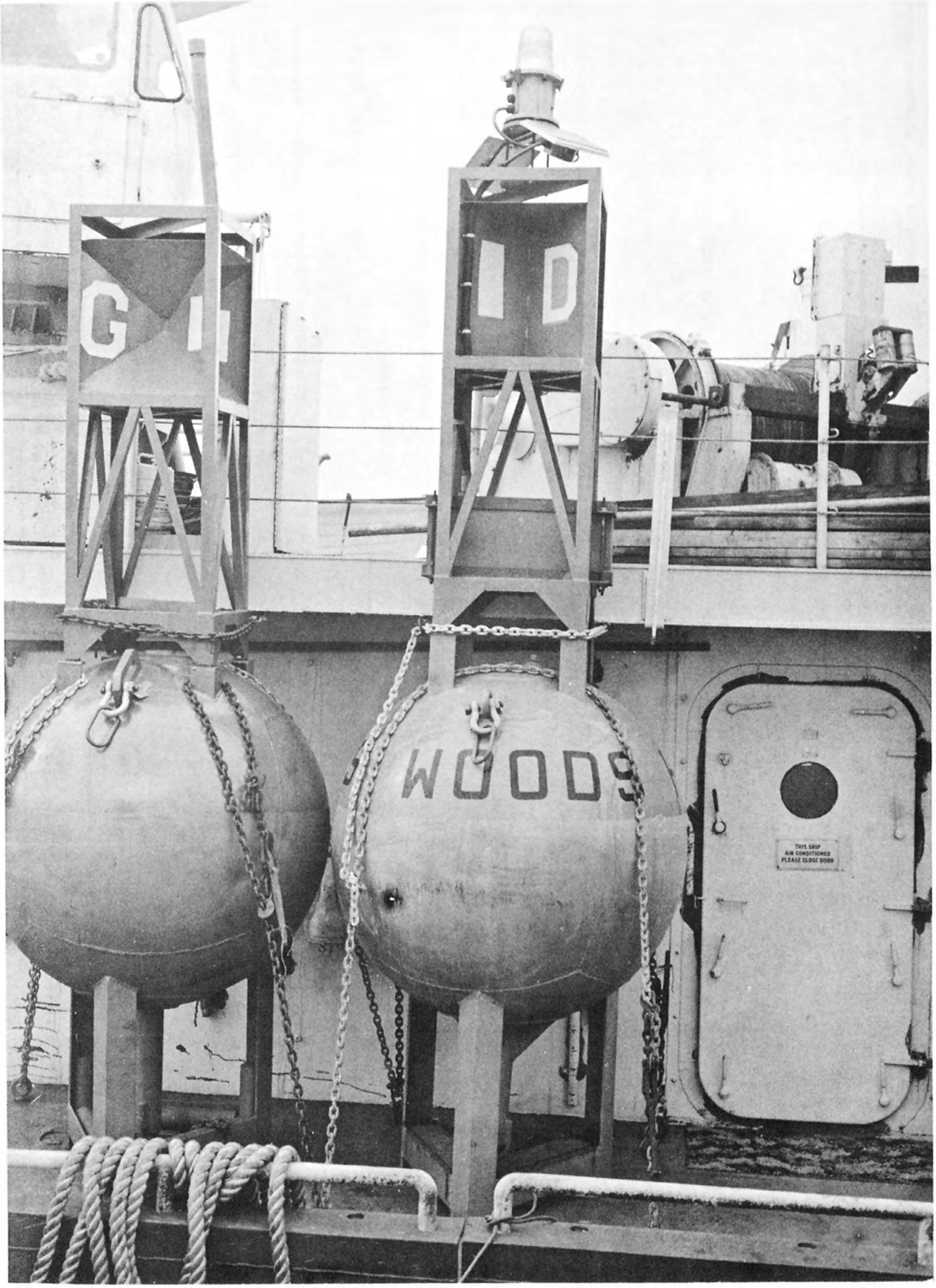


Figure 3. Surface bouys used to mark tripod locations.

Table 3. Variables Measured by U. S. Geological Survey Tripod System. Resolution and Estimated Accuracy.

Variable	Units	Resolution	Accuracy*	Definition
1. Current Speed	cm sec^{-1}	.1	±2.5	computed from burst speed and direction pairs
2. Current Direction	degrees	1.41	±5.0	same as variable 1
3. Interval Rotor	cm sec^{-1}	.02	±2.5	average rotor speed over basic interval
4. Temperature	degrees centigrade	.02	.1	temperature inside instrument pressure case endcap
5. Interval Pressure	millibars	$\sim$ .04	±3.0	average bottom pressure during basic interval
6. Burst Pressure	millibars	$\sim$ 1.0	±3.0	average burst pressure
7. Burst Pressure Standard Deviation	(millibars)^2			standard deviation of burst pressure
8. Burst Rotor Speed/ Interval Rotor Speed	non-dimensional (ratio)			average rotor speed in burst ÷ variable 3
9. Burst Normalized Unit Vector	non-dimensional (ratio)			vector current speed ÷ scalor current speed
10. Transmission	relative (% full scale)	.05	$\sim$ 5.0	transmissometer output
11. Nephelometer	relative (% full scale)	.05	$\sim$ 5.0	nephelometer output
12. Time	seconds	56.25	1 in 10^5	internal digital quartz clock
13. Bottom Topography (photographs)	cm	.1 to 150		

*Accuracies are from manufacturer's specifications. Accuracy of the transmissometer was estimated from laboratory experiments. The current sensor accuracy assumes steady conditions. The accuracy will be less under dynamic conditions (for instance, waves) (McCullough, 1975).

U.S. GEOLOGICAL SURVEY SEDIMENT TRANSPORT STUDIES

We have constructed nine bottom tripod systems for a cooperative program with the U.S. Bureau of Land Management (BLM); this program is designed to investigate processes of sediment mobility in the three major petroleum lease areas on the Continental Shelf of the United States East Coast. A total of 30 deployments of the instrument system have been made on Georges Bank, in the Middle Atlantic Bight, and in the South Atlantic Bight (Figure 4). In each area, one tripod is maintained continuously at a selected location to provide long-term observations of sediment movement. Shorter term measurements of the cross-shelf and alongshelf variability of the processes of sediment resuspension and transport are made by means of a second tripod system. At present, measurements have been made primarily in mid-shelf regions where the water depth is between 40 and 100 m.

EXAMPLES OF OBSERVATIONS

Observations made during the winter of 1976-1977 by means of a tripod system on the southern side of Georges Bank near the mean position of the shelf-slope water front showed frequent resuspension of the surficial bottom material (Figures 4, 5, and 6) and are typical of measurements made to date.

The transmissometer indicated changes in suspended sediment concentrations caused by several processes (Figure 5). The warm slope water is generally less turbid than shelf water (Milliman and Bothner, 1977). Gradual movement of slope water offshore at the tripod location and a corresponding decrease in transmission took place during the first month of the deployment. A rapid temperature decrease on 25 December 1976, indicating offshore movement of the front, was associated with a

USGS TRIPOD LOCATIONS

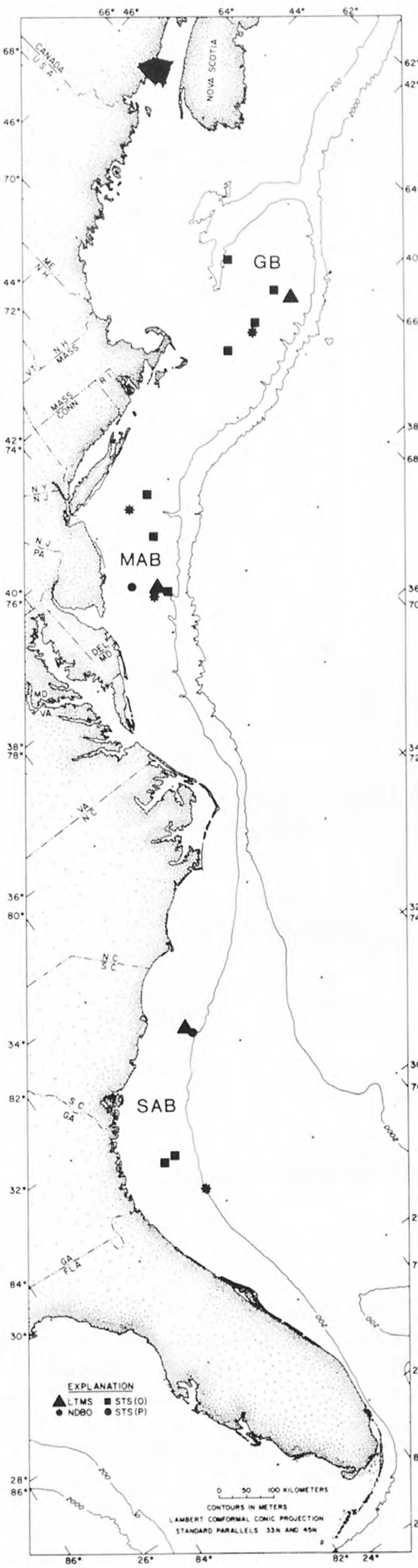


Figure 4. Locations of U. S. Geological Survey Tripod Deployments on U. S. East Coast Continental Shelf. (LTMS (▲) = long term monitoring station; STS (O) (■) = occupied short-term monitoring station; STS (P) (●) = proposed short-term monitoring station; NDBO (*) = environmental buoys). The three major petroleum lease areas on the East Coast shelf are located on Georges Bank (GB), in the Middle Atlantic Bight (MAB), and in the South Atlantic Bight (SAB).

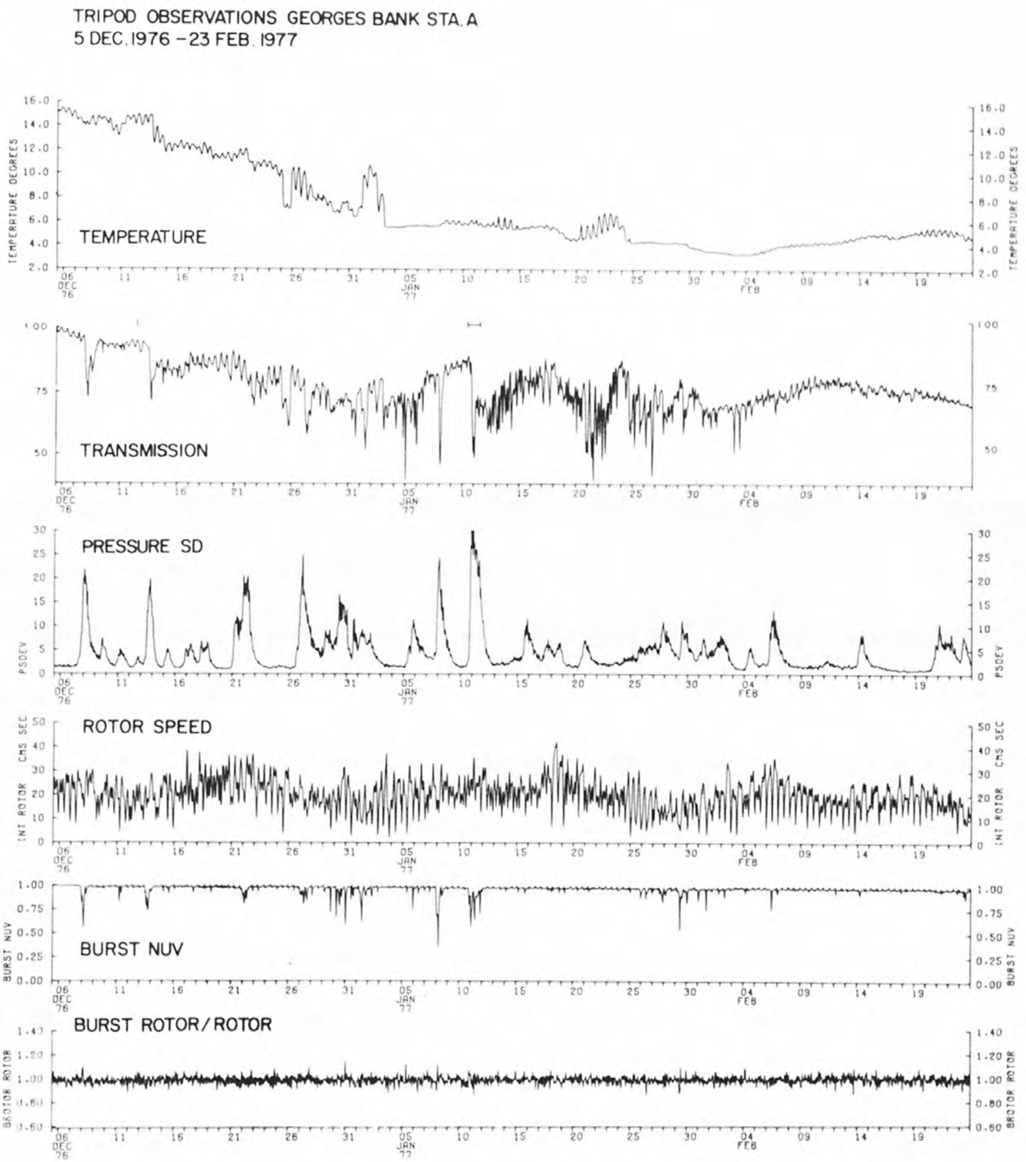


Figure 5. Tripod Observations from Southern Flank of Georges Bank, Winter 1976-1977: Temperature, relative light transmission (normalized by maximum observed value), pressure standard deviation, interval rotor speed, burst normalized unit vector, and burst rotor/interval rotor. Calibration from field observations made in calm weather suggest that a relative transmission of 1.0 = .5 mg l^{-1}, and .5 = 1.0 mg l^{-1}.

drop in relative transmission; conversely, a temperature increase on 1-2 January was associated with an increase in relative transmission, suggesting onshore movement of the front.

The peaks in burst pressure standard deviation (PSDEV) and decreases in burst normalized unit vector in December and January indicate periods when surface waves were large (Figure 5). The storm on 21-22 December in which the ARGO MERCHANT broke apart is clearly shown. Increases in PSDEV on 8, 13, 22, 27 December, 8, 11, 28, 29 January, and 7 February are correlated with a marked decrease in transmission. For scale, the amplitude of bottom pressure fluctuations associated with an 11-sec wave having a 2 m peak-to-trough amplitude in 85 m of water is 14 mb, and maximum bottom current speed is 8 cm sec^{-1}. Superimposed on the wave resuspension events and low frequency variations in transmission (attributed to movements of the shelf-slope water front) were variations in suspended concentration at the tidal period and at harmonics of the tidal period.

Bottom photographs taken on Georges Bank illustrate scour and other changes in bottom microtopography. They also show, qualitatively, changes in suspended sediment concentrations (Figures 6a-d). The clarity of photographs taken in the warm slope water at mooring site A early in December 1976 indicates a low level of suspended sediment (see photograph taken on 12 December, Figure 6a). Small mounds of fecal matter from burrowing clams, most likely ocean quahogs, covered the bottom. By 10 January most of this material had been eroded by winter storms (Figure 6b). A major storm on 11 January resuspended so much material that the bottom was entirely obscured from view (Figures 6c, d). This resuspension was associated with large surface waves and the formation of small asymmetrical ripples.

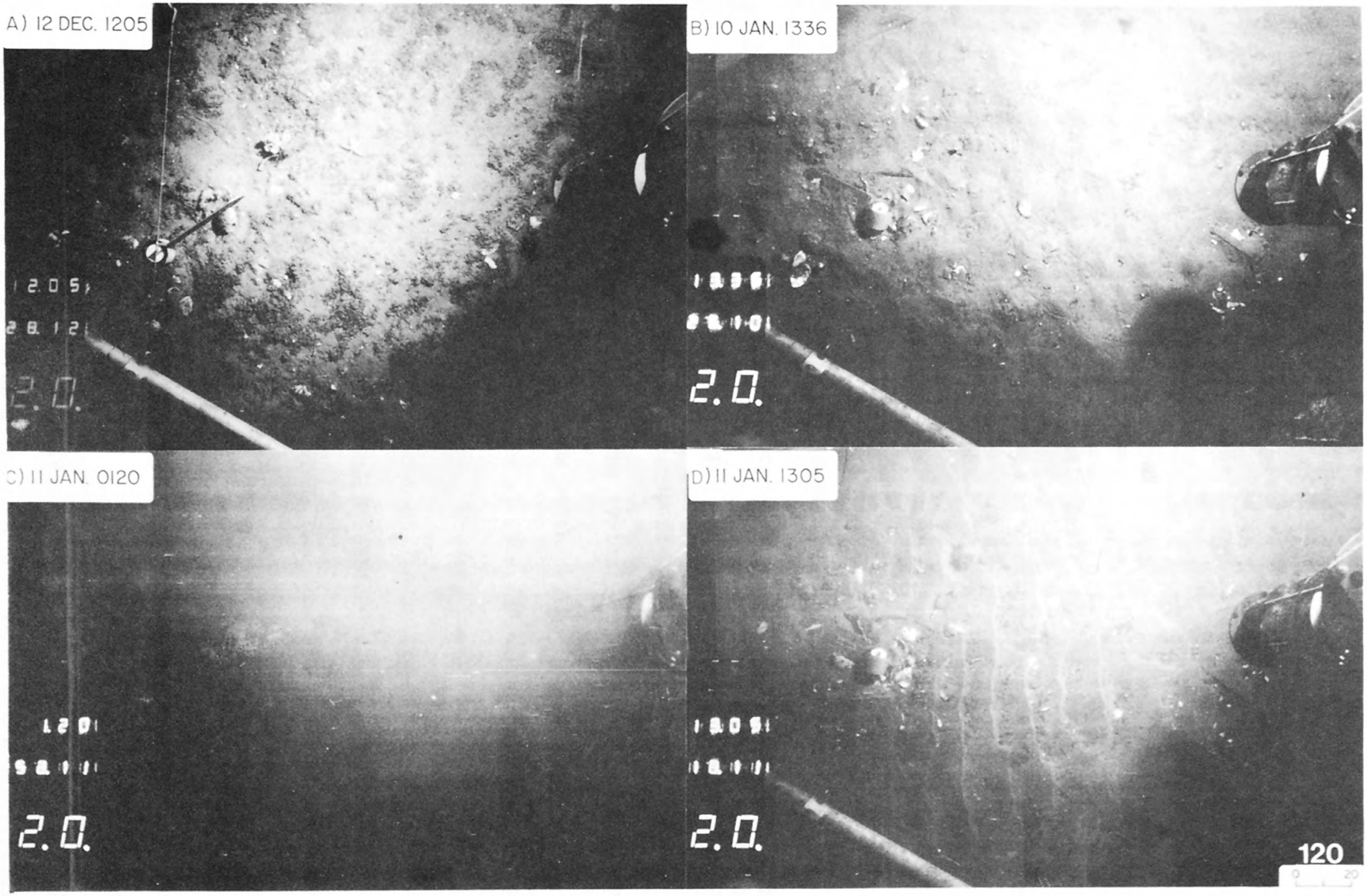


Figure 6. Typical Bottom Photographs from Georges Bank Tripod Deployment, December 1976-February 1977 (water depth = 85m): North is at 1 o'clock. The total viewing area is approximately 2.3 x 1.6m.

a. 1205 Dec. 12, 1976
b. 1336 Jan. 10, 1977
c. 0120 Jan. 11, 1977
d. 1305 Jan. 11, 1977

Date and time when bottom photographs were taken are indicated in upper left hand corner of photograph. Scale in lower right corner is 0-20cm.

DISCUSSION

Knowledge of the frequency, direction, and extent of bottom sediment movement on the sea floor of the Continental Shelf is important to assess the environmental consequences of many potential uses of the shelf area. Deployments of the bottom tripod systems on Georges Bank and on the New Jersey Continental Shelf have shown bottom sediment resuspension and transport caused by surface waves, tidal currents, and storms. The fine sediments can be transported 10-20 km alongshore in the mid-shelf region during one winter storm; thus fine material could be distributed over significant areas of the shelf in several years.

The intermittent and seasonal nature of sediment movement on the shelf indicates the absolute necessity of continuous long-term monitoring of bottom conditions to adequately define the frequency and processes of bottom sediment transport. Several months of observation appear adequate to determine the typical influence of surface waves, internal waves, tides and storms on the bottom at one location during a particular season. Several years of observation are probably required to assess seasonal variability, whereas many years of continuous observation (or different measurement techniques) may be necessary to determine the influence of catastrophic events. The diversity of transport mechanisms also indicates the need for multisensor instrument packages that measure the appropriate physical parameters. For example, interpretation of the transmission record presented in this paper would be difficult without simultaneous current, wave, temperature, and visual observations.

Future deployments of the type of instrument systems described here should continue to increase and refine our rather crude understanding of local bottom processes and of regional sediment transport on the Continental Shelf.

ACKNOWLEDGMENTS

The tripod system design, construction, and field observations were supported by the U.S. Bureau of Land Management (BLM) in cooperation with the U.S. Geological Survey. (BLM-U.S.G.S. MOU Nos. 08550-MU5-33, A550-MU7-31, and AA550-MU6-29).

Winfield Hill (Sea Data Corporation) designed and constructed the data recording package used on the tripod to U. S. Geological Survey specifications and provided invaluable assistance throughout the program. Marlene Noble and William Strahle (U.S.G.S.), and Dave Hosom and Val Wilson, of the Woods Hole Oceanographic Institution (WHOI), have made substantial contributions to the engineering design, and construction of the systems. John West, Charles Deadmon, Stephanie Pfirman, and Gary Prisby (all of U.S.G.S.) assisted in tripod deployment, maintenance, construction, and data processing. The use of the WHOI Buoy Group data processing program library is gratefully acknowledged. A similar tripod system has been constructed by USGS, Office of Marine Geology, Pacific Arctic Branch, which utilizes four electromagnetic current sensors to obtain a current profile in the bottom 2 m.

LITERATURE CITED

Cacchione, D.A. and D.E. Drake, 1978, A new instrument system to investigate sediment dynamics on continental shelves: Marine Geology (in press).

McCullough, J. R., 1975, Vector averaging current meter speed calibration and recording technique: Woods Hole Oceanographic

Institution, Ref. 75-44, 35 p. (unpublished manuscript).

Miller, M. L., I. N. McCave, and P. D. Komar, 1977, Threshold of sediment movement under unidirectional currents: Sedimentology, 24, p. 507-527.

Milliman, J., and M. Bothner, 1977, Suspended particulate matter along the shelf slope front, Northeastern U. S. (abs): Transactions of the American Geophysical Union, 58(9), p. 889.

Smith, J. D., and S. R. McLean, 1977, Spatially averaged flow over a wavy surface: Journal of Geophysical Research, 82, p. 1735-1746.

Sternberg, R. W., D. R. Morrison, and J. A. Trimble, 1973, An instrument system to measure near-bottom conditions on the continental shelf: Marine Geology, 15, p. 181-189.

Webster, F., 1967, A scheme for sampling deep-sea currents from moored buoys, in 2nd International Buoy Technology Symposium, Marine Technology Society.

Williams, A.J., III and J.S. Tochko, 1977, An acoustic sensor of velocity for benthic boundary layer studies, in, Bottom Turbulence, edited by J.C.L. Nihoul, Amsterdam: Elsevier, p. 83-87.