

An Experiment in Two-Way Communication with a Multivariable Moored System in Coastal Waters

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ABSTRACT

An experimental data acquisition system (telepack) was interfaced with a multivariable moored system in order to transmit physical and biooptical data from a coastal mooring site to a shore-based work station. The study site was located off the coast of Los Angeles, California, and the telepack provided two-way communication via the Los Angeles cellular telephone system with a work station at the University of Southern California, approximately 20 km away. Data were obtained from the system on a call-up basis at intervals of approximately 8 h. The present work demonstrates the utility of a relatively inexpensive communications system for near-real time data acquisition in coastal waters. In addition, this study represents an initial step toward development of a worldwide environmental data collection and distribution system that could exploit existing and planned communication resources, including satellites, to provide near-real time two-way, high data rate communications between researchers' work stations and remote, unattended sensor platforms such as buoys and drifters.

1. Introduction

One of the advantages of automated sampling is that data collected from such systems can be transmitted, in principle, in near-real time (e.g., within hours) to shore-based laboratories. The development of the two-way (digital duplex) communication system described in the present report has several motivations. For example, interdisciplinary data from coastal moorings (e.g., Whitley and Wirick 1983, 1986; Dickey and Manov 1991) and drifters (e.g., Abbott et al. 1990) are commonly recorded internally on tape or hard disk drives. Data recorded in this manner are thus inaccessible to investigators until instrument recovery and sampling strategies cannot be modified. In addition, losses of instruments or disk drive failures can result in substantial if not total loss of data. Present satellite-based telemetry systems, such as Argos, have inade-

quate data transfer capacity (e.g., bandwidth) for many interdisciplinary data collection applications (e.g., Dickey et al. 1993a). In particular, the data accumulated by four multivariable moored systems (MVMS; described later) exceed 650 kbyte daily, while the present Argos system can transmit less than 3 kbyte daily. Also desired is the capability to send commands to platforms to modify collection routines in response to detected dynamics in phenomena of interest, to manage onboard power resources, or to check on system status. Although coastal problems are the focus of the present report, the study described here is seen as a step toward application to open ocean data transmission systems using satellite platforms (e.g., see reviews by Briscoe and Frye 1987; Brooks and Briscoe 1991; Frye et al. 1991; Walker 1991; Dickey et al. 1993a). Finally, the present study involves telemetry from a near-surface (10-m depth) instrument package; however, the technology for telemetering deeper moored, drifting, or in the future, autonomous underwater vehicle (AUV; e.g., Blidberg 1991) systems is evident. Several promising subsurface-to-surface data transmission approaches (e.g., electrical induction, acoustics, etc.) have been

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described by Frye et al. (1991). Based on increasing telemetry capabilities, it should be possible to adequately transmit a high percentage of interdisciplinary data collected from moorings and drifters in support of programs such as the Joint Global Ocean Flux Study (JGOFS), Global Ocean Ecosystems Dynamics (GLOBEC), and the planned global ocean observing system within the next few years.

2. Background for study

The specific problems addressed by the present study concern the evolution of particulate distributions in the vicinity of the Los Angeles County outfall as forced by physical and biological processes (Jones et al. 1990; Dickey and Manov 1991; Jones et al. 1991; Wu et al. 1991; Washburn et al. 1992). Another important aspect relates to the effects of effluent discharge and sediment resuspension on primary production in the vicinity of the outfall. A potential practical application based on our study could entail the near-real time monitoring of waters in the vicinity of outfalls. For example, chlorination could be increased or decreased based on data telemetered from a mooring (or moorings) to a plant manager.

The Los Angeles County outfall is used to discharge treated effluent at a rate on order of 350 million gallons

per day (or 1.4 million cubic meters per day). Submerged multiport diffusers (approximating line sources) are located on the 60-m isobath about 2 km offshore of White's Point (Fig. 1). The diffusers were designed to maximize diffusion with the initial dilution ratio being about 100:1 (Fischer et al. 1979). The effluent rises as a buoyant plume with continuing dilution through mixing with ambient ocean waters. The diluted wastewaters continue to disperse through mixing and advective processes, which are highly dependent on both the characteristics of the plume (e.g., buoyancy, etc.) and the prevailing physical oceanographic conditions (e.g., currents, stratification, etc.). The spatial extent of the concentrations of substances and particulates associated with the wastewater plume have also been described. The attenuation of light in the water column is affected by 1) pure seawater, 2) living particulate matter (phytoplankton), 3) nonliving detrital matter associated with marine organisms, 4) dissolved organic matter, 5) effluent particulate matter, and 6) resuspended sediments. The particulate fields associated with the outfall effluent are significant and have been mapped using beam transmissometer measurements. In situ fluorometer data have also been obtained and have been used to distinguish the phytoplankton component from other components (effluent and sedimentary particulates).

DUPLEX COMMUNICATIONS EXPERIMENT

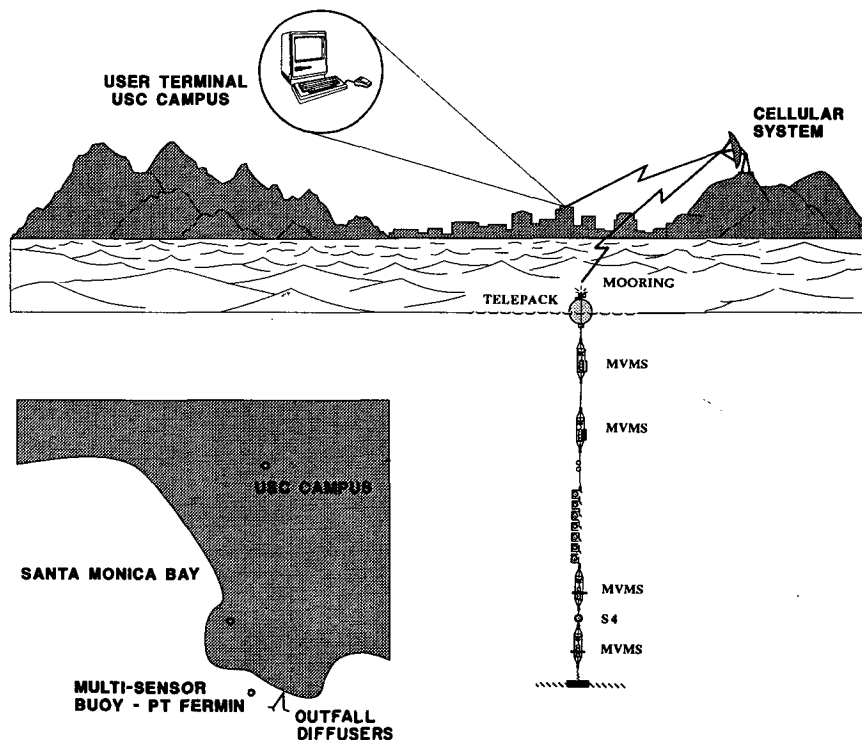


FIG. 1. Geographic map of study region and conceptual drawing of duplex communications experiment. Drawings are not to scale.

3. Field experiment

The present field study entailed MVMS time series measurements of physical and biooptical variables (Fig. 2). The MVMS was developed within the past few years (e.g., Dickey et al. 1991; Dickey 1991; Dickey and Manov 1991; Dickey et al. 1993a,b). These systems have been successfully utilized to collect physical and biooptical time series data in the Sargasso Sea, south of Iceland, off the coast of Los Angeles, and in the equatorial Pacific. The MVMS mooring data are complemented with spatial mapping data analogous to the mooring data, benthic flux data, viral data, benthic sediment core data, and aircraft ocean color data (e.g., Jones et al. 1991).

For the present work, a mooring was placed on the 55-m isobath approximately 2 km upcoast of the Los Angeles County outfall diffusers. MVMS units were placed on the mooring at depths of 10, 30, 48, and 52 m (Fig. 2). The MVMS units located at 10 and 30 m were used to measure horizontal currents, temperature, conductivity (for salinity at 30 m only), beam

attenuation (for water clarity/turbidity), strobe-stimulated and natural (upwelled radiance at 683 nm) chlorophyll fluorescence, photosynthetic available radiation (PAR), and dissolved oxygen (Fig. 2). Temperature, conductivity, and current data are used to characterize the physical environment. The beam transmissometer data are used for particulate concentration and particle production determinations. The PAR, natural fluorescence, chlorophyll fluorescence, and dissolved oxygen data along with the beam transmissometer data are used for production determinations (e.g., Dickey 1991). The salinity (from conductivity and temperature data) and beam transmission data are also used to distinguish effluent water masses from resuspended bottom particulate-laden water masses.

The 10-m instrument of interest here resides in the mixed layer and is particularly important for studying biooptical processes (e.g., primary production). The 10-m MVMS data can be used in combination with the 30-m MVMS data to determine near-surface stratification, shears, advection, etc. Data collected from

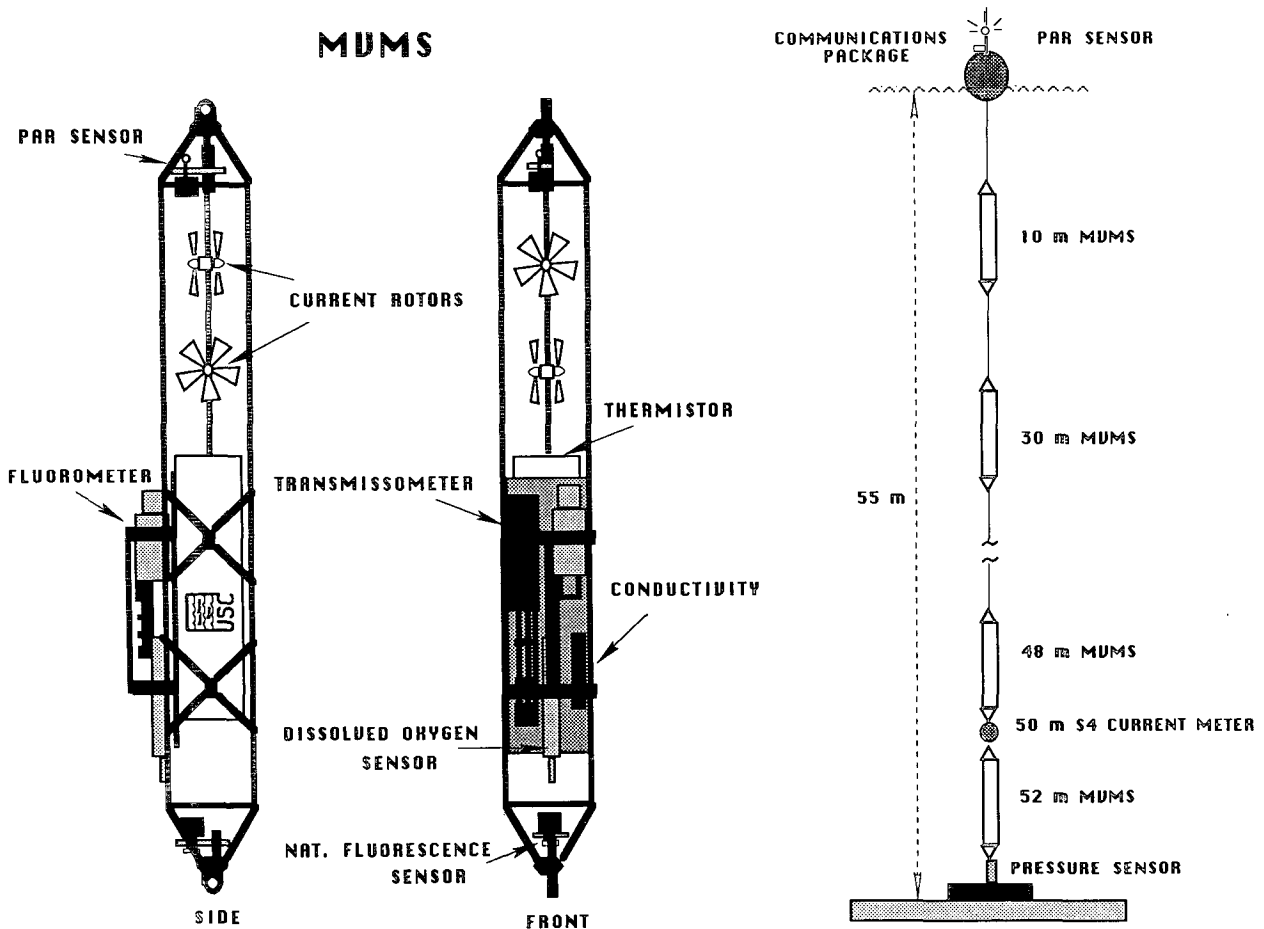


FIG. 2. Multivariable moored system (MVMS) and the White's Point mooring array including a surface buoy, surface PAR sensor, MVMS's, an S4 current meter, and a bottom pressure sensor. The telepack communications package is mounted on the buoy. Schematic is not to scale.

the MVMS's at 48 and 52 m are relevant to bottom boundary-layer and benthic processes. Other sampling from the mooring included currents (S4 current meter) at 50 m and bottom pressure to describe the surface wave and tidal variability with relevance to sediment resuspension. The sampling rates for the observational period are as follows: MVMS—1 per min, S4 current meter—1 per 10 min, and bottom pressure—1 per 2 s. All data were recorded on hard disk drives. Only the 10-m MVMS data were transmitted for the present study.

4. Duplex communications system

The telepack and antenna communications package were mounted on the mooring's flotation buoy as shown in Figs. 1, 2, and 3. The telepack provided duplex communication via the Los Angeles cellular telephone system with a personal computer workstation located at the University of Southern California (USC). The telepack could also have been used to communicate with other users in the United States provided they had IBM-compatible personal computers plus the cellular telephone number, access code, and appropriate modem parameters.

A microprocessor in the telepack periodically sampled and stored data generated by sensors of the 10-m depth MVMS. The communications cable connecting the 10-m MVMS and the telepack is illustrated in Fig.

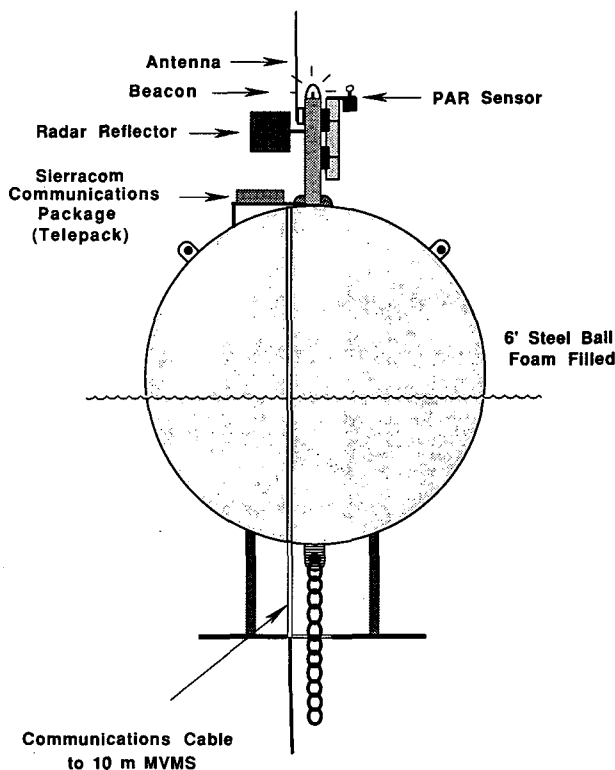


FIG. 3. Schematic illustrating the surface buoy, PAR sensor, telepack, and communications cable link to 10-m MVMS.

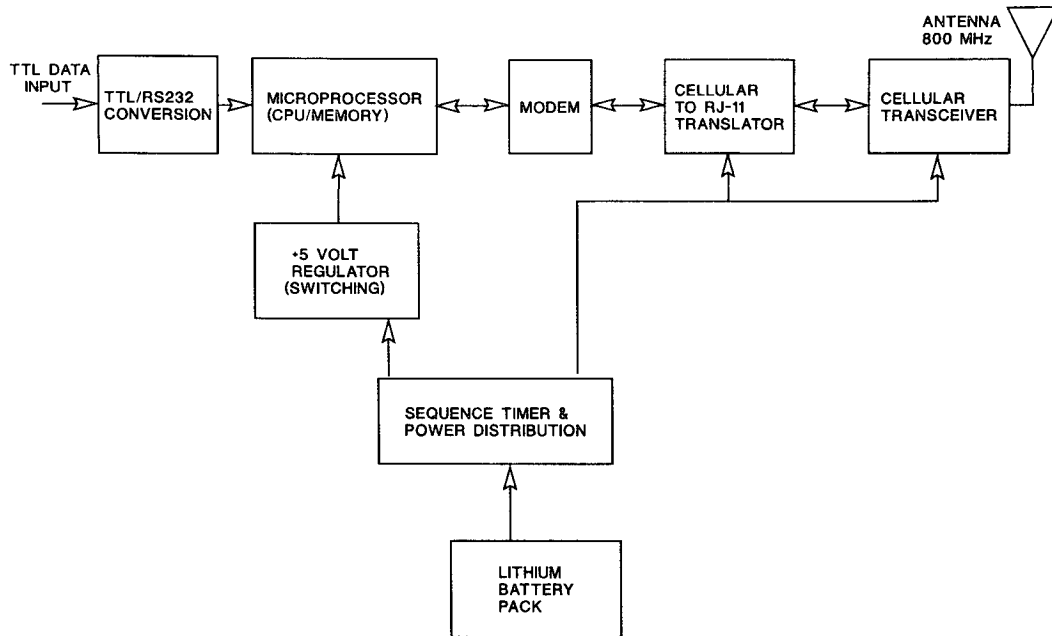
3. The data were subsequently read by command via the cellular link at a data rate of 2400 baud. The cellular telephone was turned on for three preset 20-min intervals per day to conserve primary battery power. Also to conserve power, stored data were restricted to five 69-byte samples taken at 1-min intervals each hour. Longer missions could use a rechargeable battery and a solar-powered charger to alleviate these power-driven data-throughput constraints.

A block diagram of the telepack is shown in Fig. 4. Off-the-shelf components were used for the transceiver, processor and memory units, format converters, modem, antenna, and battery pack, as well as the communications and operating system software. Custom-designed and -built components included the programmer-timer, power management hardware, waterproof enclosure, and data handling software.

The telepack was developed by Sierracom, Inc. Cost of the off-the-shelf components was approximately \$3200 excluding the custom hardware, software, assembly, and test costs. A complete unit is available from Sierracom for \$8100 excluding software modifications and power source.

To maximize compatibility with existing user resources, the processing was designed for data retrieval by an IBM-compatible personal computer using the MS-DOS operating system and Hayes modem-compatible communication software. The onboard processor operated in two modes: 1) data acquisition and 2) data retrieval. The data acquisition process consisted of receiving 69-byte bursts of $19.2 \text{ kbyte s}^{-1}$ formatted logic level data once per minute from the MVMS, converting it to an RS-232 format and inputting it into the INTEL 80286-based onboard microprocessor. A data acquisition window was opened once per hour by a timer to accept five consecutive iterations of the MVMS data record. A 5-byte time tag was added to each 69-byte burst. These were stored in a static random access memory (SRAM) with a battery backup to save processor power during the nonsampling intervals.

In the data relay mode, a cellular to RJ-11 translator converted a conventional cellular telephone output into a conventional telephone line equivalent. This permitted the use of an off-the-shelf Hayes-compatible telephone modem for the processor interface. At three programmed time intervals during each 24-h period, the cellular receiver was energized to await an experimenter's call for data. A call initiated by a shore-based computer and modem was routed by the cellular system to the buoy modem and microprocessor for password authentication. Once authenticated, the shore and buoy telemetry modems established a communication path for reading the buoy data files. Buoy memory was divided into two sections: a new file section and an old file section. Files were retained until both sections were full. Then the full new file data would displace the old file data. Depending on the file section cycle, a minimum of five and up to ten days of data were available for readout without overwrite. Data files were retained



BLOCK DIAGRAM - BUOY TELEMETRY PACK

FIG. 4. Block diagram of buoy telemetry pack (telepack).

after readout so multiple experimenters could access the data base.

Power was provided from a lithium battery pack at a nominal 13 V dc. A high-efficiency switching regulator provided +5 V dc to the processor. This configuration can easily be adapted for use with a rechargeable battery and solar-powered charger. The single battery voltage design allows for total utilization of battery energy and flexibility in establishing duty cycles for individual telepack elements (e.g., processor, modem, transceiver, etc.). To conserve battery power, a sequence timer was used to control the duty cycle of the microprocessor, cellular telephone, and modem. A ring detector was provided to prevent timer truncation of the data retrieval process before the complete file was transferred.

The onboard processor operates under MS-DOS 5.0 and with Hayes Smartcom II communication software. A custom software module controls operation in the data acquisition and relay modes and includes the functions of time synchronization, setting up data files, and date-time tagging. A second custom module resident in the shore-based computer eliminates any redundant data that may have been erroneously transferred and separates the data into individual files by date. The power management control timer operated the telepack in four different modes: standby, data collection, receiver on, and data transmit. Power consumption for each mode is given in Table 1.

The radio frequency data transmission parameters were set by the cellular system. The maximum data

rate was 2400 bit s⁻¹ and the nominal transmit energy was 0.33 mJ bit⁻¹ (0.8 W bit⁻¹). The cellular system automatically adjusts the transmitted energy to maintain link quality while minimizing channel interference. The maximum available transmit energy was 1.5 mJ (3.5 W) under noisy channel conditions. The modems used an error-free protocol so that if one or more errors were detected in a block, then the entire block was retransmitted. Unloading a complete daily file of approximately 9000 characters at 300 characters (2400 bits) per second only requires 30 s, so many retransmissions can be accommodated without adversely affecting dc power consumption or data throughput. As noted, the dc power consumption was based on a 5-min transmission time during which 90 000 error-free characters can be transmitted. This value can be

TABLE 1. Power consumption for each operational mode.

Mode	dc power (W)	Daily on time	Watt-hours per day
Standby	0.07	23 h day ⁻¹	1.6
Data collection	2.8	5 min h ⁻¹	5.6*
Receiver on	5.2	3 × 20 min day ⁻¹	5.2*
Data transmit	16.5	5 min day ⁻¹	1.4*

* These values are user specific. For example, if only one 20-min receiver access per day was required, then 3.5 W-h day⁻¹ could be saved or if one data sample per hour was acceptable, then 4.5 W-h day⁻¹ could be saved.

doubled by increasing the transmit time to 10 min for only 1.4 W-h day^{-1} . Data rates up to 9600 bit s^{-1} are planned for future cellular systems and this added capacity can be used to further increase throughput and/or reduce dc power consumption.

During the five-week experiment, the link encountered very few data dropouts. Link connection was always established at the Sierracom test site, although occasionally two or three automatic dial-up attempts were required by the test site modem. Initially, connection difficulties were encountered at Manhattan Beach and Santa Cruz, California, sites, apparently due to delays introduced by the cellular system. Modem parameters were adjusted and subsequent connections were achieved without any further problems.

The cost of using the cellular system was quite modest. Excluding an initial hookup charge of \$50, the charge was \$45 per month plus \$0.45 per minute. At 9000 character per day, the monthly charge was under \$60. This throughput would be impossible on Argos and prohibitively expensive using Inmarsat C.

5. Results

The mooring was deployed on 8 January 1992 [Julian day (JD 8)] and was recovered on 18 February 1992 (JD 49). The observational period was unusual because of the occurrence of major rainfall and flooding in the Los Angeles Basin from JD 36 through JD 46. During this time, daily rainfall reached levels of 5 cm twice. Winds speeds of 10 m s^{-1} , and currents up to 40 cm s^{-1} were observed. Despite the heavy storm ac-

tivity, data reception was successfully achieved at USC; however, some difficulties were encountered at other locations due to processing delays inherent in the cellular acquisition process. These problems were resolved by extending the time delay on two modem interface parameters. The focus of the present data description is on the 10-m MVMS time series from JD 8 through JD 21, a period virtually devoid of biofouling effects on the optical sensors. Only telemetered data are presented here as the complete dataset will be described in a separate paper.

Time series of the 10-m MVMS data are shown in Fig. 5. Currents are generally greater in the along-shelf direction (u component), generally following the bottom bathymetry. During the period from JD 9 through JD 21, the currents tend to oscillate back and forth along the shelf (and to lesser extent across the shelf, v component) due to the semidiurnal and diurnal tides (also according to our spectral analysis). The along-shelf currents have a tidal amplitude of roughly twice those of the cross-shelf currents. Temperature exhibits a strong diurnal cycle (approximately $0.2^\circ\text{--}0.4^\circ\text{C}$ peak-to-peak). During several days, the diurnal cycle shows a temperature minimum near sunrise and a maximum near sunset, which is consistent with theory and past observations. It is likely that a diurnal mixed layer evolves similarly with deepest values before sunrise and shallowest values near sunset; however, there is inadequate vertical resolution to address this effect in detail. Both beam attenuation coefficient and chlorophyll fluorescence show significant semidiurnal and diurnal signals. Time series of coherence and phase at both the

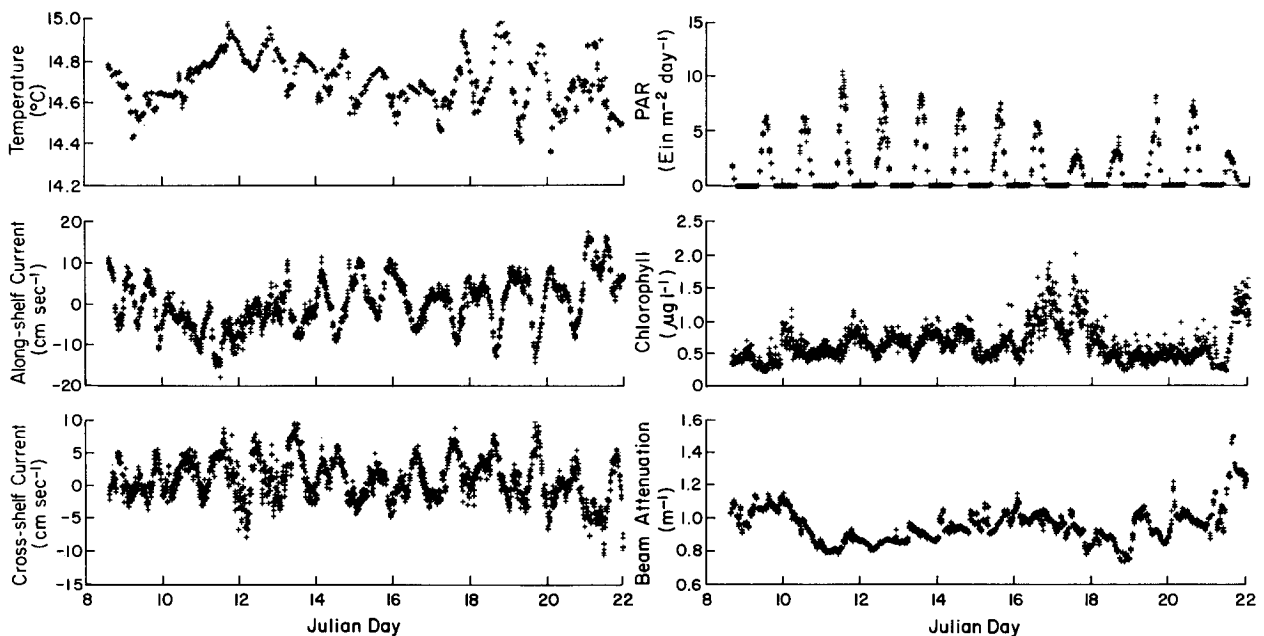


FIG. 5. Telemetered time series of physical and biooptical data collected with a multivariable moored system (MVMS) off the coast of Los Angeles in January 1992 at 10-m depth. Variables include: temperature, along-shelf and cross-shelf currents, photosynthetic available radiation (PAR), chlorophyll fluorescence, and beam attenuation coefficient.

semidiurnal and diurnal periods have been computed. The present dataset allows examination of questions concerning the nature of several physical and biological processes that may contribute to the observed relationships (e.g., Stramska and Dickey 1992a,b). In addition, inferences concerning local versus advective effects can be based on these data. A detailed analysis is beyond the scope of the present report and will be considered in a separate paper.

6. Conclusions

The present study has demonstrated the viability of telemetering data from coastal platforms such as moorings within 20 km of shore of Los Angeles. It is estimated that this range could be extended to 50–80 km of populated areas on the west coast of the United States because of the presence of coastal mountains (somewhat less on the east coast with lower terrain). It should be noted that the cellular coverage is increasing rapidly, thus ranges and capabilities (e.g., baud rates) will likely be enhanced in the near future. The telepack system described here could be used with minor modification for drifters by adding positioning instrumentation [e.g., unit for Global Positioning System (GPS) tracking]. Incorporation of a rechargeable battery and a solar-powered charging system can extend the deployment time significantly. The digital data processing hardware and software used in the experiment can be standardized and used with a wide variety of communication transceivers to recover data outside the cellular coverage areas. Although the present study concerned ocean pollution problems, applications of the telemetry system for other coastal research and monitoring activities are possible as well.

The methodology described here is too geographically restrictive for open ocean problems. As indicated earlier, the most commonly used data telemetry system, Argos, is presently incapable of satisfying data transmission needs for many interdisciplinary activities. Nonetheless, Argos remains the most viable source for data relay from platforms at latitudes greater than 70°. However, other potential relay systems are available where polar coverage is not required. For example, the NASA Tracking and Data Relay Satellite System (TDRSS) can provide high data throughput over a wide geographic area. A modest developmental effort would be required to produce a compatible platform-based transmitter. Another system, Inmarsat, covers a wide geographical area and is readily available; however, this system is relatively expensive for users.

It is likely that several more capable data communications systems will be available in the future. In particular, a number of companies have applied for licenses to deploy and operate communication systems using low earth orbit (LEO) satellites. These satellites are desirable for data relay because they reduce the required platform transmitter power for a given data rate by a factor of 100 or more. Also, a LEO satellite

in the proper orbit can provide coverage of the polar regions. One or more of the planned systems may be suitable for data recovery from instruments located throughout the world.

A data recovery concept could employ a data collection package and a satellite-to-satellite relay package on a polar-orbiting LEO satellite (Walker 1991). This system would collect data as the satellite passes over a platform and relay it through commercial geostationary communication satellites directly to users with conventional satellite receiver terminals. The advantage of this approach is that it can provide high total throughput from a single satellite whereas other LEO systems would require a large number of satellites with attendant high implementation and operating costs. The package could be easily installed on one of the planned earth observation satellites, in much the same way that the Argos package is flown on the NOAA TIROS weather satellites.

Finally, the experimental package tested on the USC mooring platform utilized a cellular telephone link for radio frequency communications. It can easily be configured to communicate through aircraft- or satellite-based links in evolving a wide-area, high data-rate system for command and data recovery. The package could be used with drifter as well as mooring platforms in the open ocean.

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