Sediment Flux at Selected Coastal Sites: Proposed Time Series Measurement by Particle Traps

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ABSTRACT: Particle flux in the ocean reflects ongoing biological and geological processes operating under the influence of the local environment. Estimation of this particle flux through sediment trap deployment is constrained by sampler accuracy, particle preservation, and swimmer distortion. Interpretation of specific particle flux is further constrained by indeterminate particle dispersion and the absence of a clear understanding of the sedimentary consequences of ecosystem activity. Nevertheless, the continuous and integrative properties of the particle trap measure, along with the logistic advantage of a long-term moored sampler, provide a set of strategic advantages that appear analogous to those underlying conventional oceanographic survey programs. Emboldened by this perception, several stations along the coast of Southern California and Mexico have been targeted as coastal ocean flux sites (COFS).

INTRODUCTION

Over the past few years PACLIM discussion has included natural time series that, among other things, can serve as a proxy for pre-instrumental climate (PACLIM Workshop Reports, 1985-1988; Baumgartner et al., 1989). In the case of time series derived from marine sediment, emphasis has been on high resolution varve sequences such as those found in the Santa Barbara Basin and the Gulf of California. However, as with all proxy records, the series are fixed and have only limited potential for expansion; furthermore, appreciation of how such records form and their significance is constrained by availability of meaningful environmental and ecological information.

Two limitations of "high resolution" sediment records are their geographic rarity and their inherent resolution of one year. These limitations may, in part, be circumvented through use of sediment trap devices configured to intercept particles within the water column. While there is continuing community discussion as to the effectiveness of such devices for specific purposes (e.g., measuring carbon flux in surface waters), it is clear that sediment traps do provide insight into the ocean process that is otherwise unavailable (Deusser et al., 1981; Knaur et al., in prep).

PERCEPTIONS

An operational framework and justification for deployment of sediment traps in coastal waters can be derived from the following perceptions.

- **Under certain circumstances, sediment traps provide a reasonably accurate measure of inorganic and biogenic particle flux in the ocean.**

  It is perhaps self evident that most upwardly concave structures placed in a still water environment (or carried along with no relative motion) will reliably intercept settling particles. One of the simplest shapes is an open mouth cylinder, and work continues in flues and field to understand the hydromechanics of particle collection in the more common case of water movement past a moored collector (Hawley, 1988; Butman, 1968; Gardner, 1980; Lau, 1979). An alternative collection mechanism utilizing a grid surface to intercept particles essentially suspended in horizontal flow has been suggested (Soutar et al., 1977; Dymond et al., 1981).

  Ideally sediment trap devices should be evaluated in natural sedimentation regimes that are essentially deterministic. That is to say: synoptic, independent, and reliable measures of particle flux should be available for comparison to sediment trap catch. Placing sediment traps near the bottom in regions of annually layered sediments provides one reasonable approach to the ideal. Indeed, regions of varved sedimentation can be considered as unusually large sediment traps that sequence twice a year and have fairly good sample preservation.

  A 2-year deployment of grid-surface collectors configured as paired cones (see Figure 1) in the Santa Monica Basin indicates a collection efficiency of 96% relative to contemporary bottom accumulation adjusted for silica dissolution and organic matter decomposition (R. Janke, pers comm; see Table 1). This result, coming after a number of intermittent attempts (Soutar et al., 1977; Bruland et al., 1981), provides a relatively clear operational pathway for interpretation of trap samples collected in the deep Santa Monica basin and environments having similar current and particle characteristics.

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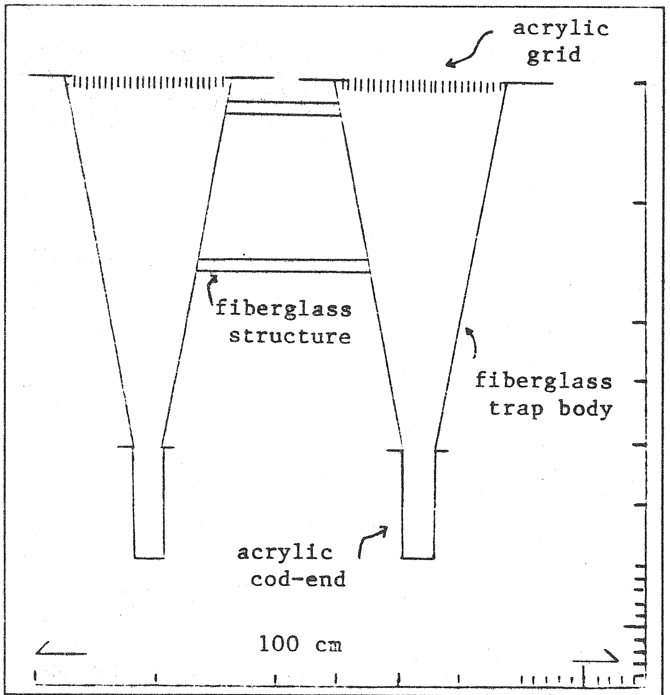

Figure1. Cross section of paired cone configuration of open grid-surface sediment trap. Collection area of each trap is 0.06 m^2, grid cells are 1x1x4 cm deep, and the angle of funnel wall is 7° off vertical.

Table 1. Santa Monica central basin deployment (50 m above 890 m bottom, 734 days between February 1986 and February 1988 [76% of time]; 1986 average current speed, 2 cm/sec, max. < 10 cm/sec [Hickey, 1986]).

Bottom (net) mass flux (a)	*440 mg/m^2/day
Measurement inferred mass out-flux of recycled opal and organic matter (b)	*210 mg/m^2/day
Gross bottom sediment mass flux (a+b)	650 mg/m^2/day
Gross sediment trap mass flux	625 mg/m^2/day

*R. Janke, pers comm

- **The passive particle flux gathered by sediment traps in coastal regions is a continuous and integral measure on predominantly local spatial and temporal scales and, thus, serves as a selective index to geological, chemical, and biologic activity and may serve as an indirect index to environmental and climatic change.**

Certainly, a reasonably accurate collection of mass particle flux implies a capability of assessing geologic and geochemical processes within the water column. Furthermore, extrapolation to time scales shorter than one year and to regions distant from the bottom may be contemplated. Limitations of time scale resolution involve realistic assessment of particle formation, particle interaction and particle descent rate factored into water movement at depth. In terms of biological processes, Takahashi (1986), working with sequential trap samples collection at separate depths, was able to estimate an aggregate diatom sinking speed of 175 m/day. Similar settling in 900-meter coastal waters would imply a 5-day response time, with perhaps a 10 km to maximum 60 km dispersion after particle injection (Table 2). However, surface water advection (e.g., coastal Davidson current) of live and temporarily buoyant particles (such as diatoms and radiolarians having lifespans of days to weeks) could lead to occasional dispersions on the order of 100 to 500 km. Taken at face value, these conjectures would suggest that material from month or longer sampling intervals would tend to be drawn from a wide, though only generally determinate, area.

Table 2. Horizontal dispersion of surface injected particles in a sea with a very simple hypothetical current structure and a particle fall velocity of 175 m/day.

Depth *(meters)*	Current Velocity *(cm/sec)*	Dispersion (Uniform) *(km)*	Dispersion (Alternate) *(km)*
0-100	50	24.6	24.6
100-200	25	12.3	–12.3
200-400	10	9.8	9.6
400-900	5	12.4	–12.4
Total		59.1	9.7

Local interpretation of biogenic sediment trap flux in terms of productivity can be equivocal. Takahashi (1986; 1987) considers diatom, radiolarian and foraminiferal fluxes at depth direct indicators of productivity in the overlying North Pacific waters. Baumgartner (1988) indicates an increase in measured primary productivity during the 1982-1983 ENSO event and increased diatom flux to the sediments during previous such events. Lang et al. (1988) indicate an increase in radiolarian deposition in the sediments during the 1982-1983 ENSO period that is in opposition to the ENSO related general decline of zooplankton stock and productivity in the Southern California bight emphasized by McGowan (1985). This productivity index reversal is not limited to the recent event, but consistently extends back through past ENSO events (Weinheimer, 1987) and also includes planktonic forms (Dunbar, 1981).

- **Active particle flux (swimmer organisms) can occur during sediment trap deployment.**

Placement of sediment traps in near-surface waters not only increases exposure to much higher current regimes but also exacerbates the problem of swimmer entry into collectors (Lee et al., 1988). This action may routinely interfere with accurate estimation of organic carbon and nutrient flux in such waters; however, there is the potential of continuously monitoring and indexing the standing crop of "problem" organisms.

- **The uncertainty of sediment trap flux interpretation due to lack of sufficient information on water movement, particle interaction and particle settling velocity does not intuitively appear greater than:**

- **The uncertainty associated with either continuous but surface limited or continuous but widely spaced point measures (temperature, salinity, current) associated with physical oceanography and**
- **The uncertainty associated with the occasional point measures (nutrients, productivity, standing crop) associated with chemical and biological oceanography.**

In this regard, it is interesting to note that the present CalCOFI program conducts quarterly cruises to the Southern California bight and utilizes about 65 unreplicated standard stations to characterize the physical and biological condition of the region. In terms of area, this amounts to one station for every 3700 square kilometers. Characterization of the biological character is made more difficult by strong day-night differences and patchiness in near-surface waters. Allowing a sampling to remain representative for 0.5 day might suggest an uncontestable description for 2 days out of the year. It is perhaps a tribute to the persistence of both the system and the investigators that identifiable bio-oceanographic patterns emerge.

- **The number and scope of parameter measurement that should be carried out as part of a comprehensive program to understand a regional ecosystem and its sedimentary consequences greatly exceed most combinations of physical-economic restraint and technical capability.**

If one sits down with an interdisciplinary group of people to plan an ecosystem dynamics program, it is not long before the chalkboard overflows with a *wish list* of field and analytical items. Probably quite a few such programs have been planned, and at least one approximation has been attempted. The CUE *(Coastal Upwelling Experiment)* program of the 1970s comes to mind. Such a program can run into the tens of millions of dollars, can only be sustained for a few years, and can only be carried out occasionally in a very few deserving regions.

- **Some measurement is better than no measurement in that:**

- **Predictive efforts in complex natural systems appear, for the foreseeable future, to be limited at best to elegant descriptions of eventlike processes; therefore, it will be necessary to carry out measurements to maintain a realistic image of such systems;**
- **Substantial environmental measures (atmospheric pressure, temperature, rainfall, sea level, satellite overview) and occasional oceanographic measures (nutrients, productivity, standing crop) will continue to be available. These provide an opportunity base for continuous study of coastal marine ecosystems;**
- **Sediment trap sampling in definable circumstances can, at the least, provide a broad range of indices that are equivalent to otherwise unobtainable measures of ocean activity.**

We live in a world where persistence and surprise are the rule. The seasons progress and return with mathematical certainty; however, the seasonal excursions of weather and climate are often sufficient to cause discomfort and disaster. A substantial arrangement of resources in the form of the weather service provides perhaps a 2-week warning of either. The oceans have a familiar pattern of flow. In coastal regions of high latitude, the sign of the new year is the return of sunlight, keying phytoplankton production. No one can say how intense the resultant blooms will be. Nevertheless, just as hurricanes are tracked and the possibilities for landfall broadcast, so now in the ocean is the development of an ENSO condition dutifully followed. We know more hurricanes and El Niños will come. We would like to think an historical perspective could lead someone to guess just how many to expect. We are quite sure that no one knows when they will occur or how substantial they will be.

If the predictive grasp on highly visible events such as hurricanes and El Niño is marginal, then certainly the situation for most regional seas should be tenuous. CalCOFI (a fundamental fisheries program) has been operating at varying levels off California for 40 years. This has resulted in a considerable body of information on the physical and biological makeup of the California current. Aside from the dominating effect of local ENSO development (Bernal, 1981; Chelton, 1981), nothing has appeared to suggest how the system will develop from year to year. Rather, there are suggestions that even this substantial effort is programmatically wanting. Smith and Moser (1988), commenting on the CalCOFI fish-related time series, note that the extensive egg surveys carried out in conjunction with the physical and biological measurements, though a good measure to spawning population, are not sufficient to predict the success of a fish year class. In coastal fishery regions having no tradition of time series, the verdict on year class success must, in parallel fashion, await catch landings.

PROGRAM

An informal cooperative project designed to provide time series of particle flux in regional coastal waters is advocated *(acronym: COFS, Coastal Ocean Flux Sites)*. Presently, some institutional and individual resources have been diverted to a local program.

A southern California and central Mexico group (composed of at least the authors) is targeting a few sites (three off southern California, one off southern Baja California, and one off Guaymas, the Gulf of California) for development of sediment flux time series (see Figure 2). The group will attempt to deploy sediment traps more or less continuously at two of the sites (San Diego basin and Guaymas slope). With the exception of the San Diego Basin, all sites have laminated deposition that could provide, in retrospect, a hard confirmation of findings.

The start-up moorings will be at a single depth of 40 meters off the bottom, and recycling will be on a seasonal basis. Eventually, electromechanical sequences will be added to the collectors, and recovery intervals could extend to 6 months or greater, with a 1-month or less sampling resolution. On-site work (monthly at San

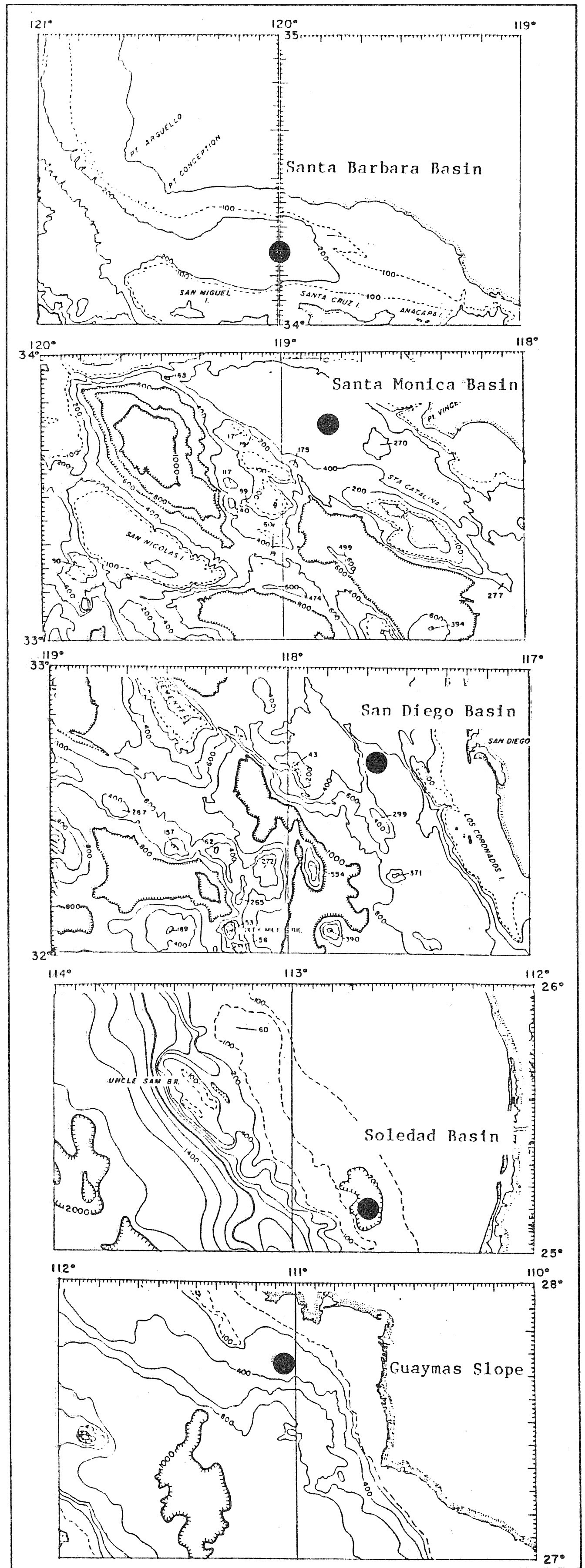

Figure 2. Location of targeted sediment trap sites.

Diego and seasonally at Guaymas) can include CTD/transmissometer cast and microplankton hauls. The San Diego site, at the southern end of the CalCOFI surveys, will benefit from their physical and nutrient/productivity information. Process and distributional studies in the central gulf could provide a similar, though less consistent, oceanographic context for the Guaymas deployment.

PRODUCT

We have attempted to convey the idea that the serial accumulation of sediment particles is, in effect, an index of the local state of the sea. Since a substantial portion of the index signal is composed of biological information and in view of the fact that frequent and comprehensive biological characterization of the sea is one of the more elusive of tasks, we will aim to assemble an ongoing view of local ocean activity placed within the framework of available environmental information.

This roughly translates as an ongoing presentation of seasonal flux rates of selected fish, zooplankton, and phytoplankton species-specific particles, along with mass fluxes and eventually (though analytical and sampling problems intrude), including something on organic carbon, carbonate, nitrogen, phosphorus, silica, and the trace elements. Given the systemic delay due to deployment/recovery and follow-on analysis, an eventual goal of a 6-month lag for key indicators is suggested.

We hope a number of important environmental parameters will be available through the auspices of PACLIM members and others for presentation in parallel form. We also hope the inauguration of camera-ready manuscripts for PACLIM might provide a continuing incentive and forum for reporting such efforts. In this regard, it seems that the ongoing patterns of climate in its broadest sense is of interest to an equally broad audience; and although our efforts in isolation might appear narrow, they are impacted by forces of hemispheric scope. A clear and well commented presentation of the ongoing Pacific climate picture would be of benefit to many.

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