The Use of Lagrangian Drifters to Measure Biogeochemical Processes and to Analyze Satellite Data Sets

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Extended Abstract:

Lagrangian drifters, which have historically been used for tracking upper ocean water circulation and sea surface temperature, are increasingly being used to measure biogeochemical parameters within the ocean. Here we present an overview of the current uses of these drifters as well as planned future modifications.

Use of WOCE SVP Drifters to study biogeochemical processes:

Our initial efforts with using Lagrangian drifters to measure biogeochemical processes has focused on using the existing WOCE SVP Surface Lagrangian drifters to track individual water parcels through time (Niiler, et al., 1987). The individual drifter tracks are being used to generate multivariate time series by interpolating/extracting the biological and physical data fields retrieved by remote sensors (ocean color, SST, wind speed and direction, wind stress curl, and sea level topography). The individual time series of the physical data (AVHRR, TOPEX, NCEP) are being analyzed against the ocean color (SeaWiFS) time-series to determine the time scale of biological response to the physical forcing. The results from this research will provide the necessary time series data needed to investigate the interactions between the ocean

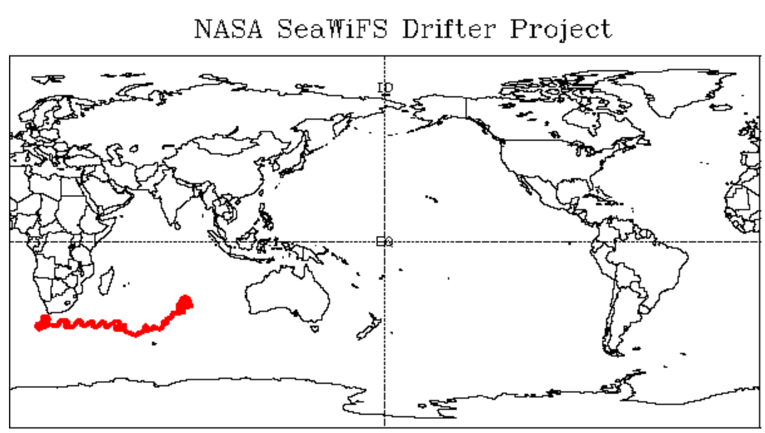

Figure 1: Trajectory of an individual Surface Velocity Program Lagrangian Drifter.

mesoscale features, wind, and the biogeochemical processes. We presently have over 1000 individual time series which span over the past four years and have global coverage. An example of one such time series is presented in Figures 1-2. This specific drifter was released into the retroflection region of the Agulhas Current off the Southern tip of South Africa. The drifter was then advected eastward within the eddy field of the Agulhas Current and into the Indian Ocean. At present, we are able to interpolate SeaWiFS estimated surface integrated chlorophyll, day and night MCSST surface temperature, NCEP wind speeds, sea surface height anomaly (not shown), and atmospheric pressure (Figure 2). We are also able to derive several additional fields such as Ustar[3] and Ekman pumping. We are currently developing the time series analysis methods to determine the effect of physical forcing scale on the time evolution of the chlorophyll fields.

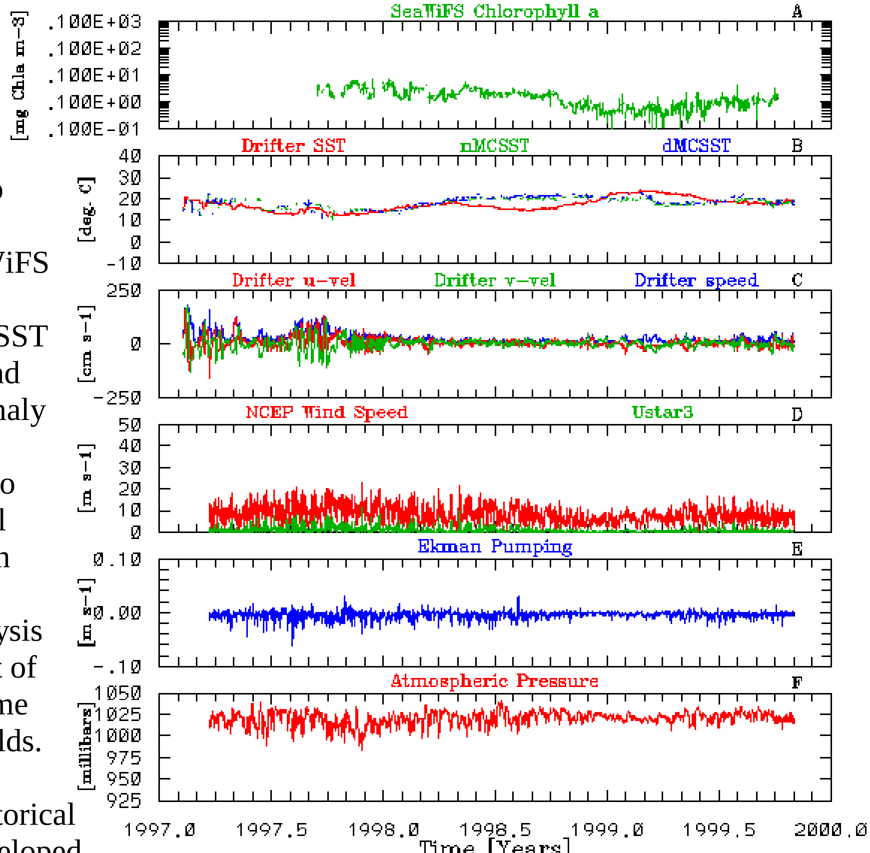

Figure 2: Time series of observed or calculated variables observed along the time/space track of the individual Lagrangian drifter shown in Figure 1.

In addition to analyzing the historical drifter tracks, we have also developed a new bio-optical drifter which was designed to obtain real time physical forcing data (wind, solar radiation) in conjunction with bio-optical data to obtain direct measurements of physical forcing effects on chlorophyll time series. Below, we present an overview of this sensor.

Autonomous Drifting Ocean Station (ADOS):

The Autonomous Drifting Ocean Station (ADOS) is a state-of-the-art ocean data collection platform that has been developed and continuously enhanced at Scripps Institution of Oceanography. The instrument was initially designed as a tool to measure the surface circulation and temperature of the world ocean in support of the WRCP Surface Drifter Program. These drifters are drogued at a depth of 15 meters and the historical data dates back to 1985. Changes in the drifter positions are used to estimate the drifter velocity and the horizontal drift of particles in the upper layer. The data from the drifters is maintained at the Drifter Data Assembly Center at AOML/NOAA in Miami.

The ADOS bio-optical sensors incorporate a bio-optical sensor package similar to that used by Abbott et al. (1991). The sensors will be obtained pre-calibrated from Satlantic, Ltd, Canada. The ADOS units have an irradiance sensor mounted to the top of an open port that measures the downwelling irradiance at 490 nm over a 20 nm waveband and 3 sets of upwelling radiance sensor pods positioned on the bottom of the surface float. Each sensor pod will determine the upwelling light radiance at 3 carefully chosen wavebands within the biologically active portion of the light spectrum. The number of active pods can vary between 1 and 3 which gives the option of maintaining between 3 to 9 different wavebands. All of these sensors are off-the-shelf technology which has been previously tested on Lagrangian drifter (Abbott and Letelier, 1997; Letelier et al., 1997). The planned configuration for 24 units will be to have two pods open at the time of release. Two of the pods will have upward radiance sensors for the wavebands 443, 490, and 555. One of these pods will be closed upon deployment. A third pod will have upward radiance sensors for 490, 670, and 683. We plan to use the ratio between the Lu(683):Lu(555) as an estimate for bio-fouling of the sensors. The ADOS unit will pop off the closed pod with the redundant 443, 490, 555 Lu sensors once this ratio exceeds 0.2, an idea that was obtained from Abbott and Letelier (1998) where they suggest this as evidence of bio-fouling.

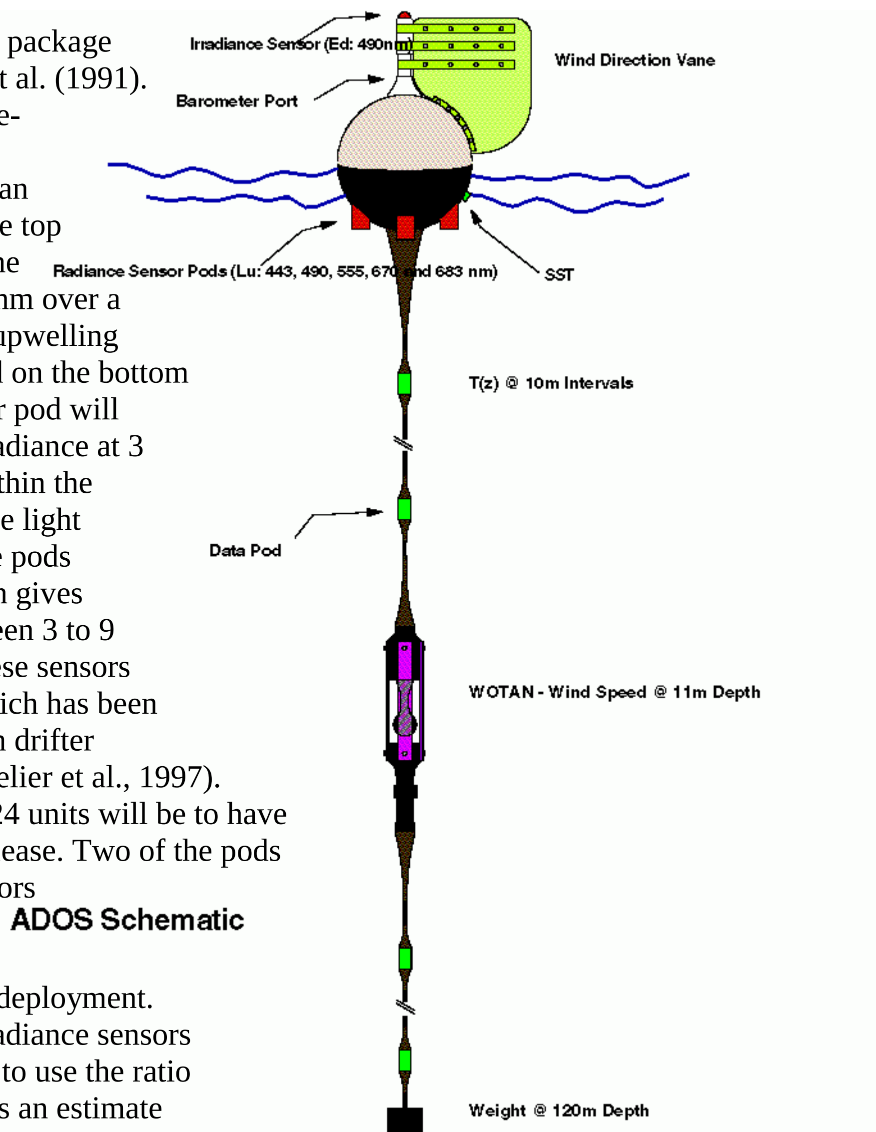

Figure 3: ADOS Schematic.

The ADOS will also measure the temperature of the ocean at 11 different depths, from the near surface to 110 m depth, at 10 m intervals. ADOS units with thermistor chains will not be drouged at 15 m because the thermistor chain imparts a significant drag to the ADOS unit. Sea surface temperature will be measured using a thermistor probe mounted to the bottom of the hull of the surface float. Sea surface temperature thermistors are already part of most deployed drifters and are currently being used in validation programs for AVHRR data. Below the surface, temperature will be measured by smart temperature sensors positioned on an electromechanical (E/M) cable hanging below the surface float.

The purpose of developing the ADOS is to investigate the local response of the ecosystem (changes in chlorophyll *a* concentration and chlorophyll *a* fluorecense quantum yield) to physical forcing. Also, it is possible to compare the temporal and spatial variability registered by sensors mounted in the drifters to that registered by the sensors mounted in the satellites in order to assess the scales of variability that are not resolved by the ocean color satellite. These types of time series/data sets are required for investigating the interactions between the ocean mesoscale features, wind, and the biogeochemical processes. It is anticipated that we will be able to draw conclusions from this data set about the time and space scale of the response of the ocean ecosystem to physical forcing events over a large region of the ocean. Also, by sampling the ocean at scales smaller than those that can be observed from a satellite, the ocean bio-optical drifters can quantify the unresolved variability present in the satellite data sets. Such information is essential for optimal interpolation as well as for data assimilation models. We are presently planning deployment of 24 of these units within a variety of ocean regions. The present bio-optical fields from the sensor platform can be used to generate inherent optical properties such as reflectance spectra (Figure 5) or integrated chlorophyll fields (Figure 6). Additionally, the ADOS drifters will be useful for obtaining data sets useful for development and validation of mixed-layer models and heat budget calculations. In their present configuration they are capable of Cal/Val support for remotely-sensed sea surface temperature, ocean color, wind stress, mixed-layer depth, and heat flux. Additional long-term sensors for salinity are planned and a carbon dioxide sensor is presently being integrated (See Below).

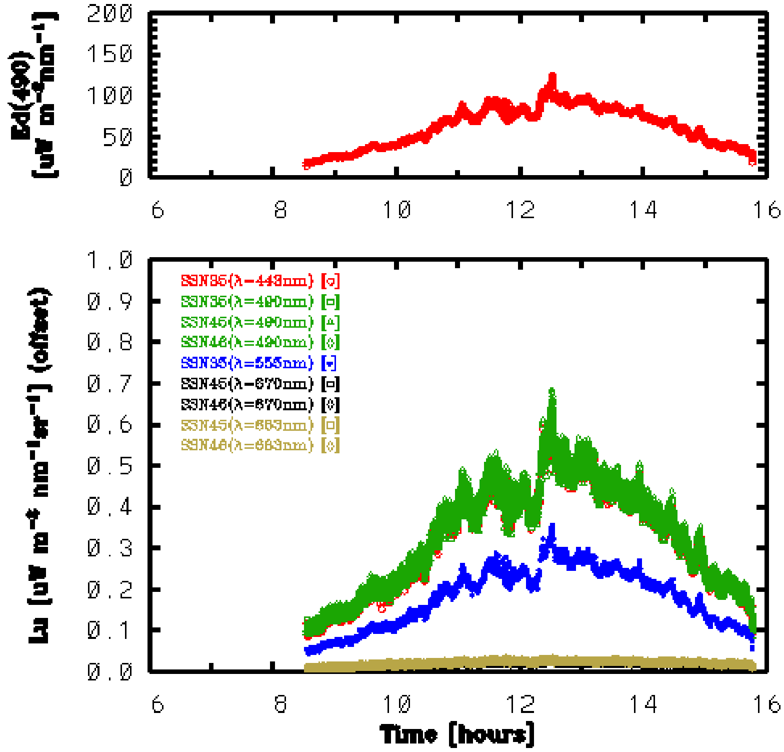

Figure 4: Time series of downwelling irradiance at 490nm (top panel) and upwelling radiance at 443, 490 555, 570, and 663nm (bottom panel) obtained over the course of one day during a test deployment of a bio-optical drifter.

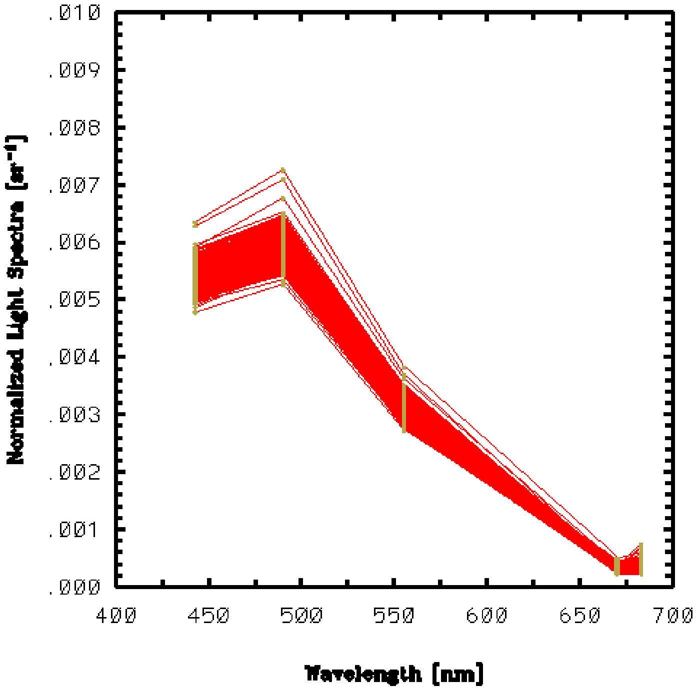

Figure 5: Upwelling radiance spectra normalized by the downwelling irradiance at 490 nm.

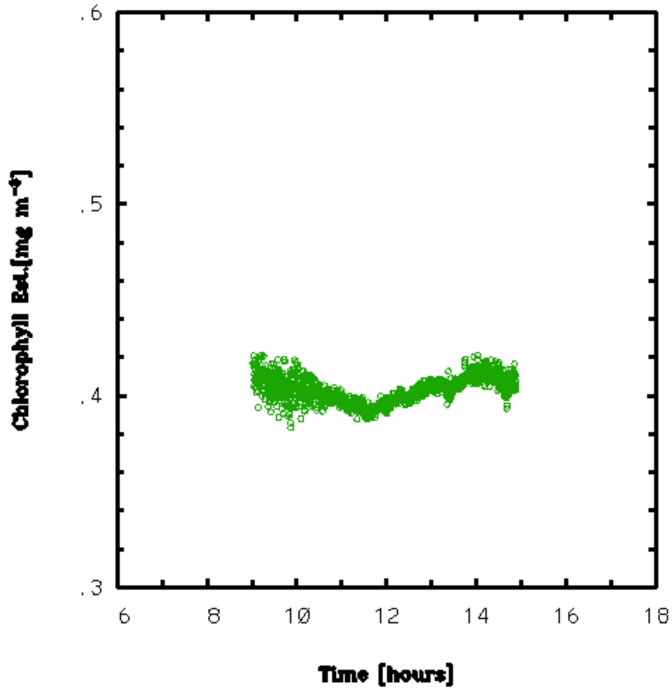

Figure 6: Integrated chlorphyll estimate derived from a two waveband algorithm that uses the ratio between Lu_{443} and Lu_{555}.

Direct Measurement of Carbon Dioxide and Heat Fluxes:

Present methods used to estimate the flux of carbon dioxide across the air-sea interface use the following formulation:

$$CO_2 \text{ Flux} = Vp \bullet \alpha_{CO2} \bullet (pCO_{2sw} - pCO_{2air}),$$

where Vp is the piston pumping velocity, α_{CO2} is the solubility of CO_2 in seawater, and pCO_{2sw} and pCO_{2sw} are the partial pressures for CO_2 in seawater and air, respectively. This difference in partial pressures is known as ΔpCO_2. We are presently modifying an ADOS unit by augmenting it with an eddy flux measurement system for the flux of CO_2 and heat. This system will include a surface-mounted open path CO_2 infrared gas analyzer, a sonic anemometer, a hot-wire temperature sensor, dual axis inclinomenters, and an accelerometer. The system will record each of these measurements at 10 Hz. Additionally, we will attach a sensor to measure the pCO_2 of the seawater just below the surface. All of the technology used in this modification is derived from off-the-shelf products. The challenge will be to develop an eddy-flux method capable of sensing a low flux of CO_2 in a constantly changing environment.

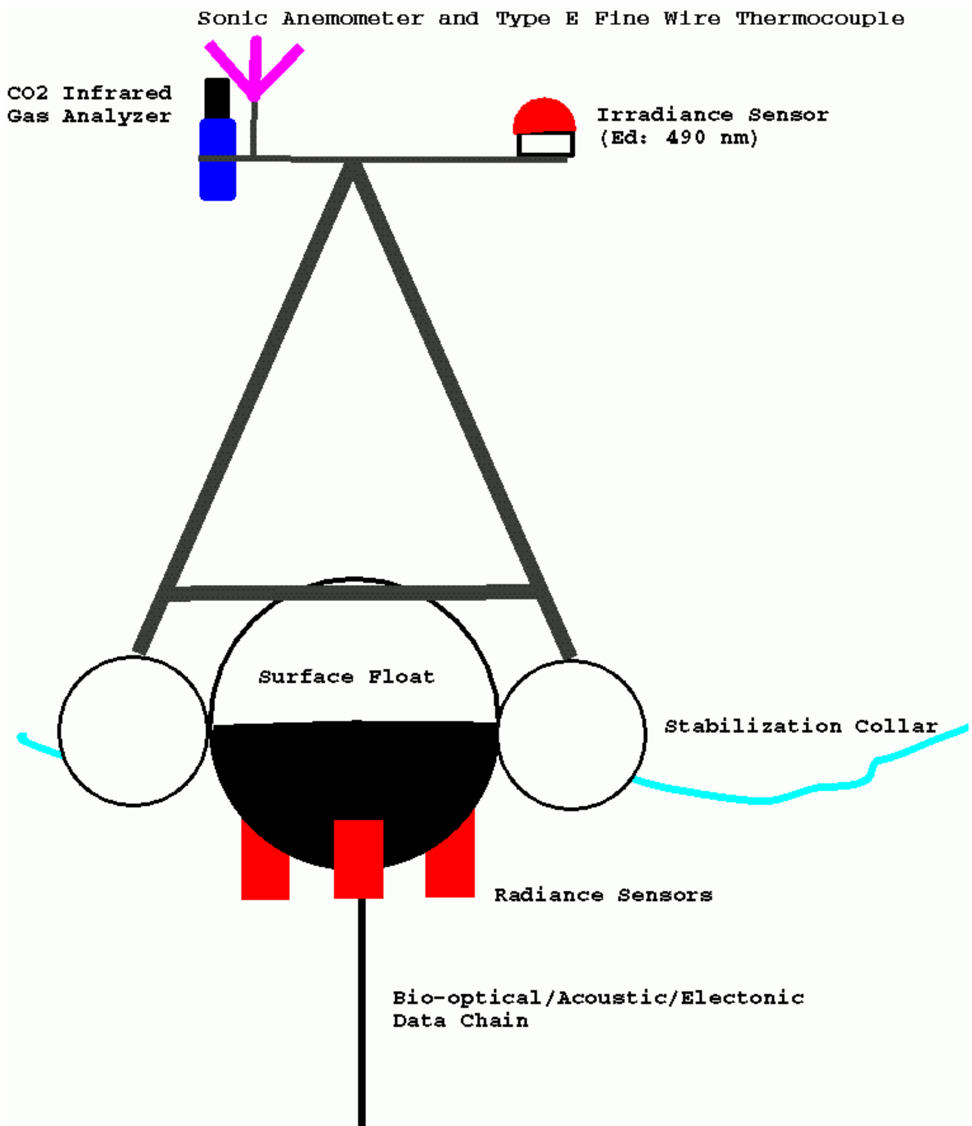

Figure 7: Schematic of modifications planned for developing a CO_2 flux sensor on the ADOS drifters.

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