Supplemental On Line Materials for: Robotic Observations of Dust Storm Enhancement of Carbon Biomass in the North Pacific.

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CARBON COMPONENTS

In the presence of light, marine plants fix nutrients and dissolved inorganic carbon (DIC) species into particulate organic carbon (POC, biomass), particulate inorganic carbon (PIC, as calcium carbonate shells, or liths), and dissolved organic carbon (DOC) pools. The DIC pool (or ΣCO_2), is comprised of aqueous CO_2, H_2CO_3, HCO_3^-, CO_3^{-2} components. In surface waters, DIC dominates all forms of carbon in seawater and is present at concentrations of ~2000 μM. Next in importance is the DOC pool at ~70-100 μM. The POC and PIC ($CaCO_3$: as calcite and aragonite minerals) pools rarely add up to more 10 and 1 μM, respectively. In surface waters, the dynamic range of these parameters is in opposite order: 10% (DIC), ~30% (DOC), and factors of 10-100 for both POC and PIC. This is why diurnal variability in particulate matter concentrations is easily detected even in oligotrophic waters (S1)., whereas diurnal variability of DIC or DOC are smaller than measurement error.

CARBON EXPLORER

The core of the Carbon Explorer is the Sounding Oceanographic Lagrangian Observer (SOLO, S2). The SOLO is nearly neutrally buoyant relative to seawater. It adjusts it's relative buoyancy by pumping hydraulic fluid between a reservoir within its pressure case and an external inflatable bladder. Typical profiling speeds are 10 m min^{-1}.

SOLO's telemetry and operational capabilities have been greatly enhanced. We replaced SOLO's slow, unidirectional System Argos satellite communication system with much faster and bidirectional ORBCOMM telemetry. ORBCOMM transmits data at a rate of 2400 bits per second, 20 times faster than the comminications system it replaced. This enables substantially more data to be relayed, has the effect of reducing biofouling problems by cutting the time spent at the surface (tens of minutes instead of days), increases operational life by reducing energy for communication (often 40% of a System Argos SOLO's energy) and permits missions which adapt to measurements taken. Improved interfaces for sensors, on board computer, and new data compression and telemetry logic schemes were also implemented.

Each Carbon Explorer was preprogrammed to operate on a repeating 2 day cycle to quantify the magnitude of net daily production of POC and to provide surface layer observations at the time of overpass of the SeaWiFS ocean color satellite. The programming was: day 1 - profile up from 1000 m to surface at 0600 local time (near dawn), return to 200 m and sleep, profile up from 200 m to surface at 1800 hrs (near dusk), return to 200 m and sleep; day 2- profile up from 200 m to surface at 1200 (mid-day), return to 1000 m. The Carbon Explorers were remotely reprogrammed from shore, for example, the day 2 surfacing time was shifted one hour earlier to coincide better with overpass times of SeaWiFS. After the first 20 days, profiling depths were adjusted from 200 to 300 m to minimize the tendency for biofouling. After 100 days, SOLO1175, was commanded to sleep for an additional 2 days between the three step profiling cycle as a strategy for prolonged observations.

At each surfacing, SOLO obtains a GPS fix and transmits to ORBCOMM satellites for 80 minutes. In good conditions, position and profile data transmission was usually completed within minutes; any previously unsent data are transmitted in the remaining time. Over the first 50 days, average time at the surface after profiling was 30 minutes for both floats. Prior to transmission, data are averaged in 5 m intervals to 250 m, in 10 m intervals from 250 to 500 m, and in 20 m intervals from 500 to 1000 m..

Our early projections suggested sufficient battery power for between 200 and 300 profiles. SOLO1175 completed 258 profiles and SOLO1128 completed 387 profiles before ending operations. The two observers have returned nearly identical and uninterrupted data streams. Only ~0.02% of the profile data and ~6% of GPS positions were lost in the first 5 months of operation. The POC sensors on both floats ceased to operate (and began to flood) after 5.5 months yet the SOLO’s continued to operate and transmit the other data for another 3 months. Flooding of one sensor likely sank SOLO1175 early. The POC sensor problem has been identified and since fixed.

SENSORS

SOLO's Seabird CTD was augmented with a new stabilized WETLabs transmissometer for the measurement of particulate organic carbon (POC). A SeaPoint light scattering sensor was added to cross-check transmissometer data and to permit investigation of the relationship between transmissometer and scattering signals.

Salinity

The Salinity sensor on SOLO1175 drifted upwards by +0.2 salinity units (to better agreement with historical T/S) with most drift occurring during the first 50 days. Salinity data from this SOLO were normallized to the deep water T-S relationship found during CJGOFS cruises.

At times the resolution of salinity measurement in the upper 100 m was degraded by a very low surface salinity reading due to surfacing of the float prior to shut down of the CTD. This is an artifact of the data compression scheme. This problem affected SOLO1128 significantly.

Transmissometer

The stabilized 25 cm path-length WETLabs transmissometer operates at 660 nm (red) and has a precision of better than 0.001 m^{-1}. The two transmissometers deployed the Carbon Explorers have been compared with the measures of beam attenuation coefficient, c, obtained by the same 1 m path-length Sea Tech transmissometer that has beeb used by our group since 1981. c_p and c_w are the components of beam attenuation coefficient due to particles and water, respectively. The water component, c_w is invariant and is subtracted or is removed instrumentally; absorption of light by dissolved matter is negligible at 660 nm. Comparison of c_p data computed from our ‘reference’ 1-m instrument shows that the two new transmissometers were ~10% less sensitive to particles. All

c_p data were corrected upwards by 10% and then corrected for minor biofouling effects. This sensitivity difference is believed to be a function of acceptance angle of the transmissometer detector.

Assessment and correction of biofouling effects were possible because beam attenuation coefficient (***c***) at 1000 m near PAPA is known to vary by less than 0.003 m^{-1} on an annual basis .) Biofouling effects were small (transmission was reduced by <0.6% over 30 profiles and 20 days; <1% over 75 profiles and 50 days; <2% after 200+ profiles and 160+ days). The corresponding drift in $\boldsymbol{c_p}$ for transmissometers on SOLO1175 and SOLO1128 was +0.04 and +0.05 m^{-1} after 50 days and +0.08 and +0.11 m^{-1} after 160 days, respectively. All results here are adjusted to compensate for biofouling by referenceing to 1000 m ***c*** values. The major improvement of optical performance of our untreated sensors over moored optical systems is due to the combined effects of much shortened exposure of the sensors to the euphotic zone (due to ORBCOMM telemetry) and the varying profiling depths.

POC calculation

The optical detection of particulate organic carbon (POC) is based on a robust linear relationship found between beam attenuation coefficient, ***c***, measured at 660 nm by transmissometer and POC measured in concurrently collected size-fractionated particulate matter samples obtained using the Multiple Unit Large Volume in-situ Filtration System (MULVFS). The relationship is: POC = 16.1 ($\boldsymbol{c_p}$) µM, The conversion factor 16.1 was shown to be invariant (differences <5%) for data collected during two 2600 km US JGOFS transects of the equatorial Pacific during warm and normal phases of ENSO in 1992, and from the the multi-season revisits to subarctic north Pacific waters during the Canadian JGOFS program in 1996 and 1997. Results closely agreed with similar observations in the NW Atlantic. (S4). Readers are referrend to the last two references below (S3 and S4) for details of these observations and a review of other recent literature on the use of transmissometers for studies of particulate matter variability.

Scattering

Scattering was measured using a Seapoint sensor. Scattering / transmissometer relationships will be described separately. POC / scattering ratios varied by more than a factor of two in surface waters at PAPA. During the first 50 days the ratio of POC to scattering (µM/FTU) in the mixed layer ranged between 10 and 18. Values rose from ~10 on day 102 to ~14.5 by day 115, ratios decreased to ~11 by day 125 and rose to ~14 by day 135. Around day 145, both SOLOs recorded a sudden increase in POC to scattering ratio to values of ~16-18. The jump corresponded to a downward shift in mixed layer salinity.

References.

S1 D.A. Siegel, T.D. Dickey, L. Washburn, M.K. Hamilton, B.K. Mitchell, *Deep-Sea Res.* **36**, 211 (1989).

S2 R.E. Davis, J.T. Sherman, J. Dufour, *J. Atm. Oceanic Tech.*, **18**, 982 (2001)

S3 J.K.B. Bishop, S.E. Calvert, M. Y.-S. Soon, *Deep-Sea Res. II* **46**, 2699 (1999)

S4 J.K.B. Bishop, *Deep-Sea Res. I.* **46**, 355 (1999).

POSSIBLE COVER

The original of this was done professionally, it may appear dark in this document. SOLO Carbon Explorer in foreground, R/V New Horizon in the background. SeaWIFS chlorophyll fields in next page might be added. .

Some SeaWiFS observations from the PAPA area