Advances in Drifting Buoy Technology

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The WOCE/TOGA/CLIVAR Surface Velocity Program (SVP) has facilitated development and deployment of Lagrangian drifting buoys to sample the global upper ocean circulation on time scales of days to years. This initiative, now known as the Global Drifter Program (GDP) of the Data Buoy Cooperation Panel of the WMO and IOC, constitutes a major component of the effort to operationally monitor ocean currents. Over 17 countries and 41 principal investigators have contributed data and resources to the GDP. As of the beginning of 1997, over 750 SVP drifters that routinely measure sea surface temperature (SST) were being tracked globally. Of these, subsets have been successfully equipped with additional instrumentation to measure mixed layer temperature and salinity, barometric pressure, winds, and ocean colour. In this note we present a brief overview of the evolution of the SVP drifter and its state-of-the-art upper ocean measurements.

Drifter design

The basic SVP drifter design consists of a surface float for satellite telemetry of data and a subsurface drogue for approximating water parcel motion at depth. The drogue and float designs have evolved from the ancestral window shade drogue drifter with a spar buoy, to the TRISTAR drogue with surface and subsurface floats, into the present day holey sock drogue (Fig. 1). The present design combines desired water following characteristics with affordability, durability, and ease of deployment.

Hydrodynamics

Since winds cause drifters to slip through the water, it is desirable to have subsurface drogues to follow the motion representative of near surface circulation. However, a surface float, which is inevitably subject to the extremes of wind stress, seas, and swell, is required so that the drifter can telemeter its observations. Furthermore, vertical shear of the near surface currents and wave forces induce variable slip along the length of the drogue (Niiler et al., 1987). Consequently, upper ocean drifters are not perfect Lagrangian parcels.

The SVP design minimises the direct effects of wind and waves at the surface with partially submerged floats (Fig. 2, see page 24). In addition, wave effects on the drogue have been addressed with a subsurface float; low tension in the tether connecting the surface and subsurface floats allows the former to move in three dimensions with the sea surface while the latter is relatively unaffected by wind waves (Niiler et al., 1987; Niiler et al., 1995).

Meanwhile, the vector slip (U_s) of drifters may be successfully modelled as a linear function of wind speed at 10 m (W), vertical shear of horizontal currents across the length of the drogue (ΔU), drag area ratio (R), and the angles relative to the wind and shear directions (α and β), respectively:

$$U_s = (a e^{i\alpha} W + b e^{i\beta} \delta U) / R \qquad (1)$$

where R is the ratio of the drogue drag area to the sum of the drag areas of the floats and tethers (drag area is the product of the drag coefficient and area). The slip and vertical shear have been measured by vector measuring current meters (VMCMs) at the top and bottom of drogues. Over 84% of the variance in the slip of both drogue types can be accounted for by linear fits to the four coefficients (a, b, α, and β), giving the result that R must be greater than 40 to achieve less than 1 cm/s slip in 10 m/s winds (performance in stronger winds is unknown) (Niiler et al., 1995). At the same time, it follows that knowledge of the winds can be used to correct drifter motions for slip.

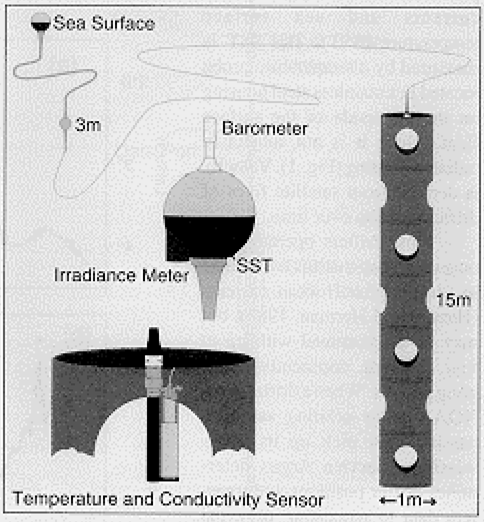

Figure 1. Schematic of the SVP drifter and various instrument configurations: the basic layout of surface buoy, tether, and holey sock drogue; barometer, submergence sensors, SST probe, and irradiance meter, mounted on the surface float; and SeaCat at the joining of the tether and drogue.

Global deployment

While both the TRISTAR and holey sock drogues minimise slip induced by vertical shear in the currents, the holey sock has been used because it is lightweight and durable, making it inexpensive to manufacture and easy to deploy. Over the past decade the cost of the standard SVP has dropped from $3,200 to $2,200, while the mean half life has more than doubled to 500 days. These improvements are direct consequences of the three way collaboration between academia, industry, and government in the development and deployment of the SVP drifter.

Drifter deployment may take place from ships or even aircraft; once in the water, the drifter packaging dissolves and the drogue unfolds itself under the influence of gravity. The drifters telemeter their identifiers and measured parameters to polar orbiting satellites from which Service Argos produces a raw data set of buoy fixes. These data are then routinely processed, archived, and distributed by the Global Drifter Data Center at NOAA Atlantic Oceanography and Meteorology Laboratory (AOML), which also aids in the global deployment of drifters. Over 17 countries and 41 principal investigators have contributed data and resources to the GDP.

Instrumentation

Velocity and SST

SVP drifters routinely provide in-situ data on mixed layer currents and sea surface temperature (SST). The SST is measured by a temperature probe located in a stainless steel housing on the underside of the surface float, where it is not subject to radiative heating (Fig. 1). Velocity is derived from satellite fixes of drifter position over time.

Most drifters operate for 1 out every 3 days, as this is adequate to sample global ocean currents (Hansen and Herman, 1989), but may be programmed with up to four different, consecutive sampling periods. When a drifter is on, NOAA polar orbiting satellites passing over pick up its transmissions. Service Argos determines drifter positions and transfers data to requesting principal investigators and the Drifter Data Center at NOAA AOML, which in turn provides raw (Argos), edited (bad data removed), and krigged (interpolated) data sets.

The krigging interpolation assumes a temporal covariance structure for the sampled fields and provides data at 6 hour intervals. As can be seen in Fig. 3a, the 3 day burst sampling is adequate for obtaining smooth positions as a function of time – the decorrelation time scale for velocity in the subtropics and tropics is approximately 6 days (Hansen and Herman, 1989). Interpolation of SST is also performed, but the diurnal cycle portion of the SST structure function is not resolved by drifters on the 1 day on, 2 days off cycle (Fig. 3b).

Drogue loss

Also standard for all SVP drifters are submergence sensors on the surface float. A properly drogued drifter spends a significant fraction of time completely submerged as surface waves break and swell pass by. Thus, a marked decrease in submergence is a robust indicator of drogue loss. This information is used to quality control drifter data by AOML. Knowledge of when drogue loss occurs is also being used to study the behaviour of free drifting surface floats. This will provide additional information on wind forcing and increase the total useful data base beyond that of only drogued drifters (Pazan, 1996).

Salinity

Thermistors and conductivity cells have been attached to SVP drifters at 11 metres depth to determine mixed layer temperature and salinity (Fig. 1). SeaCats were purchased from and calibrated by SeaBird and modified for a neutrally

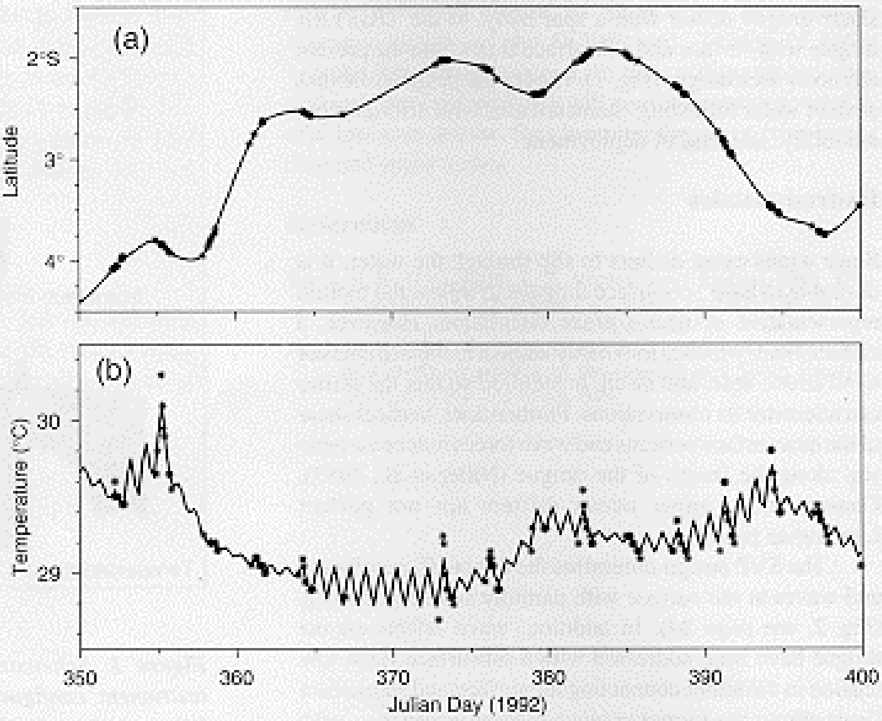

Figure 3. Comparisons of raw (asterisks) and interpolated (lines) drifter data as a function of time for (a) latitude and (b) sea surface temperature for drifter 15390.

buoyant, streamlined housing.

Seventy-two SVP SeaCat drifters were deployed in the western equatorial Pacific Ocean in 1992 and 1993. Several of these passed within 6 nautical miles of TOGA COARE moorings equipped with SeaCats in the mixed layer, allowing a comparison of the sensors. An example is shown in Fig. 4, which depicts drifter fixes as large bullets on top of a SeaCat mooring time series from 2°N, 156°E. In other instances where similar comparisons could be made, the drifters usually agreed with the moorings, or showed large gradients in salinity nearby to the moorings. The results not only confirm the stability of the SeaCat sensors on the drifters, but also the veracity of large temporal salinity gradients, associated with spatially patchy convection in the region.

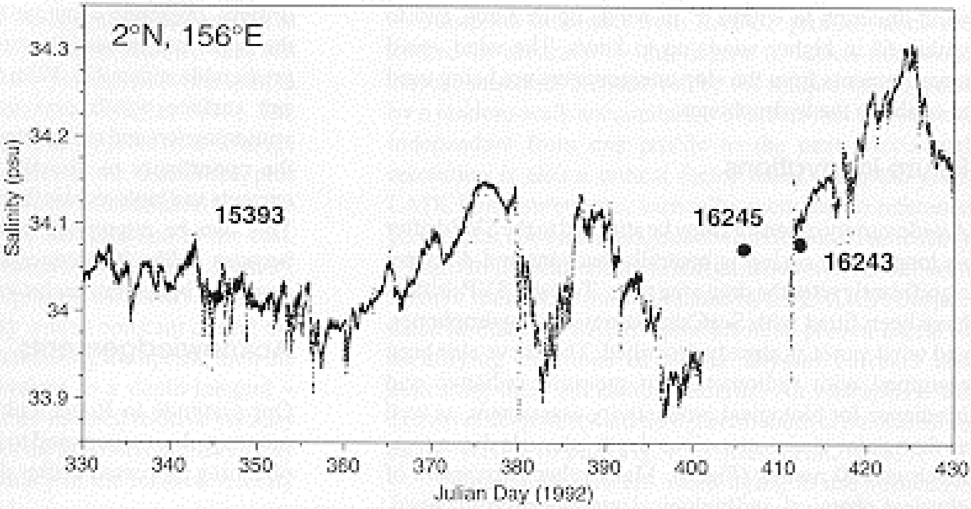

Figure 4. Comparison of salinity at 15 m depth as measured by a SeaCat moored at 2°N, 156°E and drifters (dots) that passed within 6 nautical miles. (Mooring data courtesy of R. Lukas).

Atmospheric Pressure

Barometers have been placed on the surface float of SVP drifters to measure the atmospheric pressure at the sea surface (Fig. 1). The barometer port extends vertically out of the top of the float with a pressure sensor located inside with the electronics and battery pack. The barometers are calibrated prior to drifter assembly, and have a half life of about a half year. The major obstacle to accurate SVPB drifters results from submergence of the barometer port in seas, giving erroneously high pressures. Thus, the data are quality controlled by taking the median of only the lowest 1/16 measurements. SVPB drifters cost approximately $3,400.

Winds

While the SVPB drifter augments global ship monitoring of atmospheric pressure at sea level, the Minimet represents a conceptual leap in Lagrangian ocean measurements by providing the wind stress condition following water parcels. The Minimet is a SVPB drifter, modified to carry a wind vane on the top of the surface float and a WOTAN hydrophone at 11 metres depth (Fig. 5). A compass composed of a 3-axis magnetometer and a 2-axis tilt sensor are housed within the surface float, which is rotationally decoupled from the subsurface motions via a swivel in the tether.

Comparisons at sea with anemometers mounted on a ship bow have shown that the Minimet vanes can measure

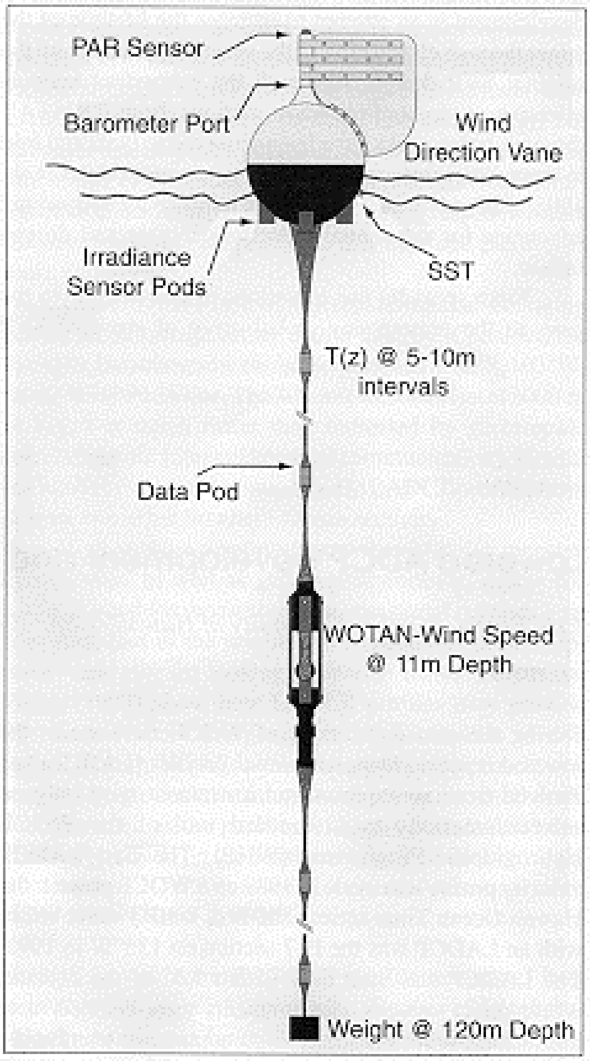

Figure 5. Schematic of a hybrid Minimet/ADOS drifter: a SVP drifter equipped with a wind vane, radiance (PAR) sensor, irradiance sensors, SST probe, thermistor chain, and WOTAN hydrophone.

wind direction to within 8° in winds up to 3 m/s, and to within 6° in higher winds up to 8 m/s. The wind speed measurements from the ship anemometers are being used to calibrate the hydrophones.

Future innovations

A wide variety of sensors may be attached to the SVP drifter so long as the casing is neutrally buoyant and does not significantly alter the drag area ratio. To date, SVP drifters have been fitted with SeaCats, barometers, hydrophones, and wind vanes as already described. They have also been equipped with radiometers to measure radiance and irradiance for biological productivity assessment, as well as thermistor chains at various depth intervals down to as much as 120 metres (Fig. 5). Many other parameters of physical, chemical, and biological interest can be imagined.

Currently, the SIO development laboratory is engaged in calibrating the wind speed measurements of the Minimet and improving confidence in quality control. Another recent development is an attempt to increase the lifetime of the tether through elimination of the subsurface buoy from the original SVP design. Although the subsurface buoy is effective at decoupling wave motions from TRISTAR drogues, holey socks have been observed to twist and fold in three dimensions regardless of its presence (Niiler et al., 1995). This advance will sacrifice minimal hydrodynamic advantage for substantial reductions in cost and drogue failure.

From sporadic use of various drifter designs in the past, to the present day global array of standard SVP drifters, obtaining accurate Lagrangian measurements in the upper ocean has become an affordable, reliable, and predictable endeavour. With the advent of globally inferred sea surface winds and ocean colour from satellite scatterometers and radiometers, SVP drifters further present the opportunity to directly test models of wind forced currents and biological influences in the Lagrangian frame. This can be attempted with unprecedented confidence because unlike its predecessors, the SVP exhibits easily modelled behaviour under various wind conditions.

Acknowledgements

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