NOAA Pacific Marine Environmental Laboratory
OCS / Saildrone

TECHNICAL NOTE 1-1

PMEL Science Requirements for ADCP on Saildrone

Prepared by: Meghan Cronin (NOAA PMEL), Dongxiao Zhang (JISAO), Jennifer Keene (JISAO)
With input from: Calvin Mordy, Ned Cokelet, Billy Kessler, Greg Johnson, Jessica Cross, Phyllis Stabeno, Chris Meinig

www.pmel.noaa.gov/ocs June 2016

PMEL Science Requirements for ADCP on Saildrone

Introduction

The purpose of this report is to identify the type of applications in which the ADCP might be used, and the type of upper ocean current structures that we hope to observe with the Saildrone. Our sources are from studies published in various scientific journals. Our goal is to determine what depth range is needed (including the desired top bin depth), the minimum and maximum bin sizes necessary to resolve the currents and its shear, the required temporal resolution, and the desired accuracy of the measurement. These requirements will then guide decisions for sensor choice and configuration.

Potential Applications for Saildrone

In the present Global Ocean Observing Systems, the ability to measure currents is limited. Estimates of the mean equatorial circulation are based on extrapolated data, as ship based and moored ADCPs cannot measure the currents in the upper 20m. The shallow keel of the Saildrone makes it a platform uniquely capable of measuring currents near the surface.

It is expected that the Saildrone will sometimes be used in combinations with other platforms (e.g., underwater gliders), and sometimes as the sole platform for a given mission.

Application 1: Saildrone as a sole platform for an air-sea interaction survey mission
As a sole platform on a survey mission, it will be important to observe the currents directly involved in air-sea interaction, and currents that may affect the performance of the Saildrone platform. For examples of the types of currents we are interested in observing, see Section 3.

Application 2: Saildrone used in combination with underwater gliders
Using the geostrophic thermal wind shear equation, it may be possible to use data from density transects made by underwater gliders to compute the vertical shear in the geostrophic currents, in the direction perpendicular to the transect. These shear profiles can then be converted into absolute current profiles, if used in combination with data from a Saildrone. The Saildrone would provide information about the near-surface ageostrophic wind-forced currents, and a reference for the geostrophic currents.

Required: To provide a reference for the glider currents, the depth range of the Saildrone currents must be deeper than the ageostrophic Ekman layer. Ekman depth, D, is the e-folding scale of the ageostrophic wind response and is computed as $D = \sqrt{2\nu/f}$, where ν is the eddy viscosity and f is the Coriolis parameter, which depends upon latitude. Assuming a viscosity of 16×10^{-3} m^2/s, at a latitude of 2° N, D = 80m, while at 30° N, the Ekman depth is 21m. For this purpose, it would be good for the ADCP range to be 2-3 times deeper than the Ekman Depth. To resolve the ageostrophic Ekman spiral in the layer D, the ADCP bins should be 4m or smaller. If the primary goal is to provide a reference for the geostrophic shears, a larger ADCP bin size could be used.

Types of currents structures expected to be observed by Saildrone

With the ADCP on the Saildrone, we will be able to observe the total (geostrophic + ageostrophic) upper ocean currents. Geostrophic currents are generally large-scale quasi-steady currents, and can be computed based upon density gradients, if a reference current is available. Thus for broad scales, away from the equator, these geostrophic currents can often be computed through the Argo array.

Ageostrophic currents are the portion of the total currents that are not in geostrophic balance. The ageostrophic portion of the current allows the geostrophic currents to vary with time. Currents that are directly wind-forced, or are rapidly varying, or are associated with a vertical velocity are ageostrophic. Ageostrophic currents can be large near the surface and in strong frontal regions associated with eddies and jets.

The following are examples of ageostrophic currents that occur on a variety of time scales. These types of currents must generally be measured by current meters and/or current profilers.

Tropical overturning cell

Over the long-term mean, the Trade Wind forcing results in poleward near-surface Ekman (ageostrophic) flow and upwelling along the equator. The zonal tilt in the thermocline gives rise to a return (equator-ward) geostrophic flow below this. Using shipboard ADCP data, Johnson, Firing and McPhaden (JPO 2001) show that the pole-ward Ekman flow extends to a depth of 50-80 m (Figure 1).

Since the shallowest ship based ADCP measurement was at 20m, the currents above 20m were extrapolated by assuming that shear was uniform above 25m. With this assumption, about half the transport of this poleward flow lies above 13m, all of which was extrapolated. Hopefully with the Saildrone ADCP, we will be able to directly measure this poleward flow.

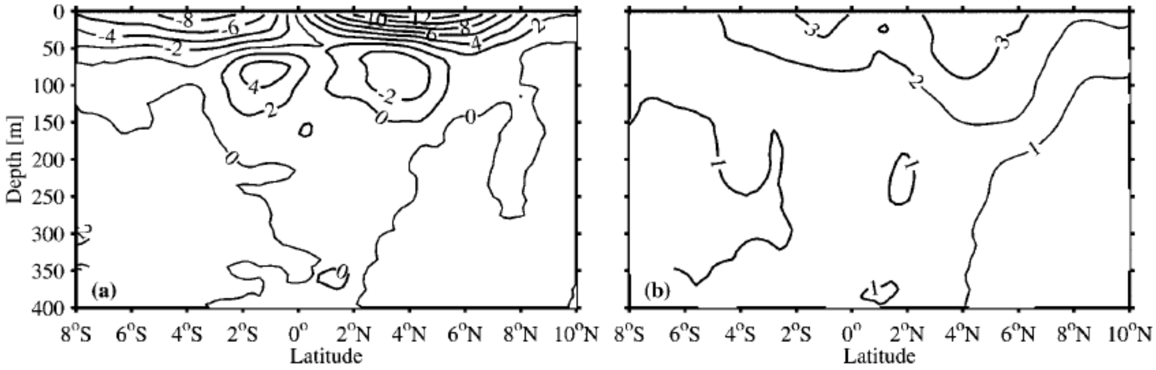

Figure 1: Vertical-meridional sections based on centered 2° latitude linear fits to data taken from 170° to 95°W, regardless of longitude. (a) Meridional velocity, *v* (10^{-2} m/s), CI 2, positive (northward) shaded. (b) Standard error of *v*, e_v (10^{-2} m/s), CI 1, $|v| > e_v$ shaded. (Figure from Johnson, *et al.*, 2001)

Requirement: Top bin at or above 5m. Bottom bin at or below ~80m. Bin size of at most 8-10m. Accuracy of 2 cm/s needed, but this may be achieved through repeat sections.

Diurnal variations in regions with sunny days and low winds

On sunny days with low winds, wind-forced currents can be trapped near the surface by the high near-surface afternoon stratification. This was shown by Cronin and Kessler (2009) at 2°N, 140°W. Currents relative to 25m were composited into a diurnal cycle and overlaid upon the temperature composite diurnal cycle, shown in Figure 2.

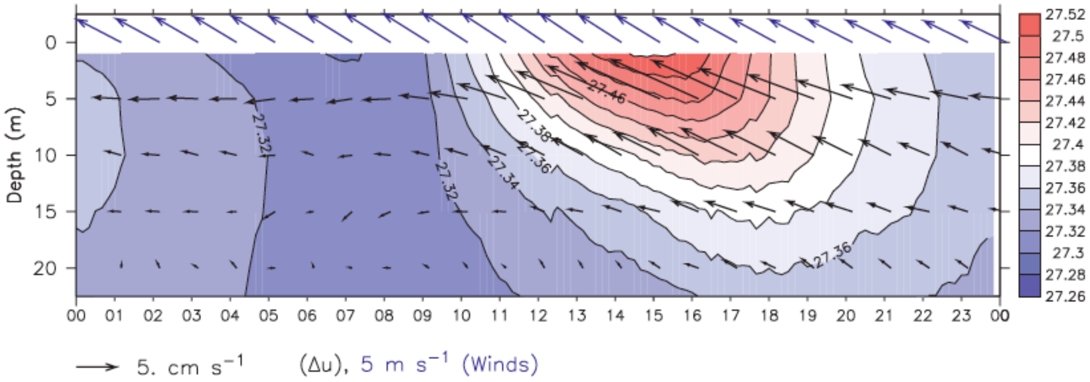

Figure 2: Mean diurnal composite (24 May 2004 - 7 Oct 2004) of wind (blue vectors), temperature (color shading), and currents relative to 25m (black vectors). (Figure from Cronin and Kessler, 2009)

If the ADCP bin size is 8m, then basically all of the area of interest will reside in the first bin. This is probably one of the strongest arguments for wanting a bin size of 4m. In order to resolve the currents in a single section, the accuracy must be near 2 cm/s.

Near-inertial oscillation shears at the mixed layer base at a mid-latitude site

Wind forcing of currents that occurs extremely rapidly (~1 day), or forcing associated with a moving storm (rotating locally clockwise in the northern hemisphere, or anticlockwise in southern hemisphere near the local inertial period), can generate very large inertial oscillations at the surface that propagate into the deeper ocean through near inertial internal gravity waves.

Figure 3, from Cronin *et al*. 2013, is based on mixed layer depth observations from the PMEL KEO mooring, KEO near-surface current meter observations from June-Nov 2005, and observations from an upward-looking ADCP on a nearby KESS mooring. At the base of the mixed layer, large shears can develop on inertial timescales (right) as well as on longer time scales (left). Within a mixed layer where the surface is turbulent, shears are generally minimal.

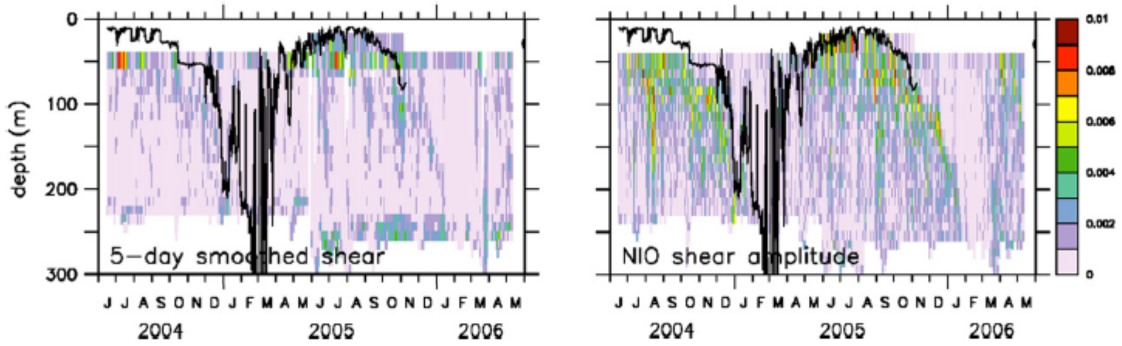

Figure 3: (Left) 5-day smoothed shear. (Right) Amplitude of the shear near the inertial oscillation frequency, estimated from a complex demodulation. Shear has units of s^{-1}, and daily mixed layer depth is shown as a black line. (Figure from Cronin, *et al*., 2013)

At the KEO site, the mixed layer depth can become very deep (~300m) during winter. This is because the site is in a Subtropical mode water formation (ventilating) region. These regions are generally found on the equator side of the western boundary current extensions into the interior ocean. Away from ventilating or deep convection sites, wintertime mixed layers are generally no deeper than ~100m. Summertime mixed layers can be less than 10m deep on sunny days with low winds, but are generally around 20m deep.

Shears are calculated from derivatives of the current velocity. Since the error in a derivative quantity will increase as the separation distance between measurement points decreases, measurements from an ADCP with a larger bin size will produce a shear value with a lower error. This provides reasoning for a larger bin size. However, a larger bin may miss small-scale vertical shears. The KESS ADCP used for the plots in Figure 3 had 10m bins.

Velocities in a western boundary current system

Strong western boundary currents can extend down to a depth of 1000m. Equatorward of their core, the relative vorticity of the jet is weak and the currents are generally in geostrophic balance. This portion of their vertical structure (Figure 4) can be faithfully estimated from temperature (T) and salinity (S) measurements by CTD and Argo float profiles, provided that reference velocities can be directly measured from other platforms, or from the inferred transit speed at the parking depth. Argo floats alone are likely unable to resolve the geostrophic portion of the jet, as there are generally too few Argo floats in these high current regions to properly measure the density gradient, and thus geostrophic currents.

With a transit speed much faster than most other unmanned vessels, the Saildrone equipped with an ADCP is the ideal platform

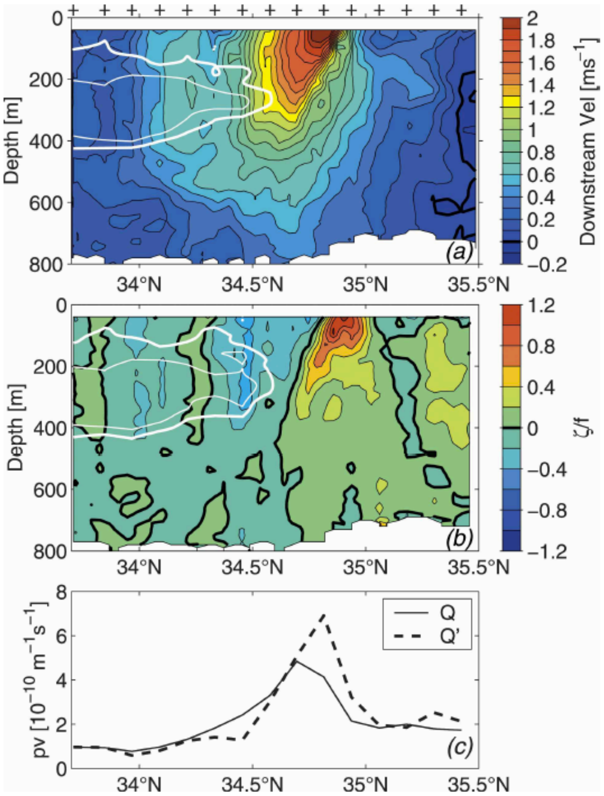

Figure 4: (Figure from Qiu *et al.,* 2006)
(a) Downstream velocity measured by a shipboard ADCP along a CTD section. Angle of downstream direction (138° from north) given by the maximum 50-250m depth-averaged velocity vector. Crosses at top indicate CTD stations. Thick (thin) white lines indicate PV = 2 (1) x 10^{-10} $m^{-1}s^{-1}$ isopleths associated with STMW.
(b) Ratio of the relative vorticity ζ over f. Thick (thin) white lines indicate PV = 2 (1) x 10^{-10} $m^{-1}s^{-1}$ isopleths that include the effect of ζ.
(c) PV values averaged in the depth range of 100-400m. Solid (dashed) line denotes the values without (with) the effect of ζ.

to survey western boundary current regions. For investigating the relation between the currents and subtropical mode water thickness (white contours in Figure 4), the range of the ADCP should extend several hundred meters, ideally to 400m.

Mesoscale and Submesoscale flows

Ocean currents, especially the western boundary currents, are dominated by mesoscale eddies and meanders on scales of tens to hundreds of kilometers. These eddies and meanders are important in advecting heat and lifting the thermocline, pycnocline and nutricline. However, the relatively small vertical velocity of their geostrophic currents limits their role in vertical exchange of heat and tracers.

On the poleward side of the western boundary currents, the flows become more ageostrophic, as indicated by the large ratio of relative vorticity to the planetary vorticity in the upper 200m ($\varsigma/f > 0.7$), shown in Figure 4b – 4c.

These ageostrophic currents are associated with submesoscale features (eddies, fronts, meanders and filaments) at horizontal scales of hundreds of meters to tens of kilometers. They are dynamically coupled with strong shears of larger scale currents and buoyancy fields, the mixed layer, and the overlying air-sea fluxes.

These submesoscale flows play an important role in biogeochemical processes, because of the large vertical velocity induced by strong divergence and convergence of the flows. Submesoscale eddies can occur in any part of the ocean, but are reenergized by air-sea fluxes and lateral buoyancy gradients.

Much of our knowledge about submesoscale features is based on high-resolution numerical models. Direct observations of these features are challenging, due to their small size, and quick development. To effectively measure these submesoscale processes, the Saildrone ADCP will need to measure the upper 200-300m, with vertical bins of 4-8 m, and a horizontal resolution of 1km.

Coastal currents

For the PMEL EcoFOCI project, the most important application of the surface ADCP measurements will be in the Chukchi Sea. (The Gulf of Alaska and Bering Sea have very high tidal currents). We would like to better understand variability in flow patterns on the Chukchi Shelf. The shelf is ~40-50m deep, with current speeds of 20-25cm/s and weak tides.

On the US side of the Chukchi Sea, there are two very different water types that flow north through Bering Strait. Nutrient-poor water flows along the Alaskan coast, and nutrient-rich Bering Shelf Water flows up the central channel. We would like to conduct repeat cross-shelf transects to examine the variability in these flow patterns. Our preference would be a 300 kHz system, with bottom-tracking and 4m bins (2m bins are preferred, if possible).

Langmuir Circulations

Near the NOAA Station Papa surface mooring, our UW APL partners have a waverider surface mooring. The waverider is used to monitor wave properties, in order to better understand the influence of waves on the upper ocean mixed layer. In particular, they want to see how waves set up Langmuir circulations that can cause increased turbulence. For this purpose, an ADCP that can measure with high vertical and temporal resolution is most important.

Recommendations

The goal of this report is to determine the required parameters for an ADCP on a Saildrone. Ideally, the Saildrone ADCP will have the following capabilities:

Range: 300m
Top Bin Depth: 2m
Minimum Bin Size: 1m
Maximum Bin Size: 10m
Horizontal (Temporal) Resolution: 1km
Measurement Accuracy: 2cm/s

Since technology limitations may not allow full implementation of the ideal ADCP measurement capabilities on a Saildrone, some prioritization is required. Priorities may vary by project and mission, as detailed below.

Project Priorities

For Tropical Pacific Observing System (TPOS) applications, it is most important to resolve the near-surface currents, which can have strong near-surface shears. **An optimal bin size is 4m, with a minimum range of 80m.**

The TPOS bin size and range parameters would also be acceptable for the EcoFOCI group's work in the Chukchi Sea. The shelf there is ~40-50m deep, so optimizing bin size over instrument range is acceptable. **Bottom tracking along the shelf would be useful.**

University partners who are investigating surface processes, such as currents associated with waves, require **a small ADCP bin size as the highest priority**.

For work in western boundary current regions, optimizing the range at the cost of bin resolution is acceptable. **A range of 200-300m is desirable**, even if it is at the cost of increasing the bin size to 8-10m. We hope to organize a field program in the KEO region for 2018. This is not yet funded.

The accuracy of most ADCPs and current meters is marginal for resolving many of these current structures in a single profile. To achieve the necessary accuracy, some amount repeat sampling and averaging will be necessary.

Acknowledgement

All figures are reproduced with permission from the authors.

Bibliography

Cronin, M. F., N. A. Bond, J. T. Farrar, H. Ichikawa, S. R. Jayne, Y. Kawai, M. Konda, B. Qiu, L. Rainville, H. Tomita, 2013: Formation and erosion of the seasonal thermocline in the Kuroshio Extension recirculation gyre. *DSR II*, 85, 62-74, doi:10.1016/j.dsr2.2012.07.018

Cronin, M. F. and W. S. Kessler, 2009: Near-surface shear flow in the tropical Pacific cold tongue front. *J. Phys. Oceanogr.*, 39, 1200-1215.

Johnson, G. C., M. J. McPhaden, and E. Firing, 2001: Equatorial Pacific Ocean horizontal velocity, divergence, and upwelling. J. Phys. Oceanogr., 31, 839–849.

Qiu, B., P. Hacker, S. Chen, K.A. Donohue, D.R. Watts, H. Mitsudera, N.G. Hogg and S.R. Jayne, 2006: Observations of the Subtropical Mode Water evolution from the Kuroshio Extension System Study. *J. Phys. Oceanogr.*, **36**, 457-473.