A comparison of near-surface current measurement methods

Eric Siegel
NortekUSA
222 Severn Avenue
Annapolis, MD 21403 USA

Dennis Mayer
&
Robert Weisberg
College of Marine Science
University of South Florida
140 Seventh Avenue South
St. Petersburg, FL 33701 USA

A solution to measuring near-surface currents via a single-cell acoustic Doppler current meter with horizontally oriented acoustic beams positioned very close to the sea surface is presented. The current meter was deployed on a surface buoy on the 25 m isobath of the west Florida continental shelf. Near-surface velocity observations from the current meter (1.1 m depth) are compared to estimates from a surface mounted acoustic Doppler velocimeter (0.8 m depth) and the first several cells of a downward looking acoustic Doppler current profiler (4.0 m to 13.0 m depth). Rotary auto spectra and cross spectra analyses are used to examine the velocity gain and veering angle at different frequencies as a function of water depth. Results indicate that velocity measurements at 1.1 m were 7% higher in the M2 tidal band and 18% higher in the synoptic band than measurements at 7.0 m. There was negligible near-surface velocity rotation in both the tidal band and the synoptic band compared with measurements at 7.0 m.

I. INTRODUCTION

Accurate measurements of near-surface currents are required for studying the dynamics of surface features such as freshwater plumes, harmful algal blooms, and surface contaminants, and may be used to corroborate HF radar maps of current velocity. Fresh water layers, thermoclines, and wind friction can cause the near-surface layer to have substantially different velocity properties compared to the underlying layer. However, near-surface current velocity is intrinsically difficult to measure.

Downward looking acoustic Doppler current profilers miss the top portion of the water column because of the required mounting depth and blanking distance. In deep water locations, long range current profilers must have large velocity cells and necessitate a large blanking distance to the first valid velocity cell; it is common for the first measurement to be as deep as 10 m below the surface. Reference [1] suggests that velocity measurements from buoy-mounted downward looking current profilers may exhibit small, but significant, reduction in rms speed values due to the existence of bubbles created during increased surface wave activity.

Upward looking profilers cannot measure accurate velocities in the top ~10% of the water column because of side-lobe errors. As directional wave measurements from bottom mounted current profilers become more widely used, there is an increased need for direct near-surface current measurements.

In 2005, Nortek modified the Aquadopp single-point current meter to achieve the purpose-built Aquadopp surface current meter (ASCM). The ASCM measures two-dimensional (u, v) current velocity near the surface by employing three horizontally oriented acoustic beams arranged on one hemisphere, with 60 degree spacing between the acoustic beams (Fig. 1). This design allows the ASCM to be mounted on one side of a surface buoy with the acoustic beams pointing out and away from the buoy. The measurement path length of the ASCM is 1.5 m and the blanking distance to the measurement volume can be adjusted with the software to be up to 5 m away from the transducers. The redundant use of three horizontal beams to measure two components of velocity allows for an "error velocity" calculation that helps describe the environmental variability at the study site.
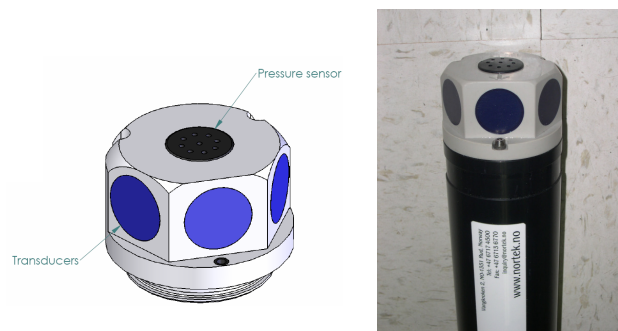

Figure 1. Configuration of the Nortek Aquadopp Surface Current Meter (ASCM) transducer head.

The ASCM has internal memory, batteries, and compass and tilt (pitch & roll) sensors. The compass and tilt sensors are capable of sampling at 1 Hz, which can resolve, and correct, for buoy motion during the current averaging period. The ASCM can be configured to log data to the internal memory or output current velocity measurements in binary and/or ASCII format for real-time observing systems.

The goals of this study were to evaluate the performance and effectiveness of a new near-surface current meter. First, it was important to determine if the data quality from a near-surface current meter was adequate for scientific and engineering requirements. Second, it was important to determine if the new data obtained from the near-surface zone added any new information compared to velocity measurements available from the traditional upward- or downward-looking acoustic Doppler current meter.

Initial results from an ASCM, deployed on a large NOMAD buoy in the Chesapeake Bay, indicated that the data quality compared well with a bottom mounted upward-looking current profiler [2]. However, the NOMAD buoy caused substantial near-surface flow disturbance, so the blanking distance was required to be at least 3 m in order to measure acceptable velocities outside of the disturbed region. Also, the large, stable NOMAD buoy was acknowledged as an idyllic platform for the near-surface current measurements in the relatively calm conditions of the Chesapeake Bay. A true evaluation of the ASCM performance from a smaller buoy in an open ocean environment was necessary.

II. EXPERIMENT

The surface current measurement experiment was a collaboration between the Ocean Circulation Group (OCG) at the University of South Florida and NortekUSA. A Nortek ASCM and Nortek Vector Velocimeter were deployed on the "C10" buoy located 35 km offshore of Sarasota, Florida, on the West Florida Shelf (WFS) at the 25 m isobath [27° 10.152' N, 82° 55.552' W] (Fig. 2). The C10 buoy has a 2.5 m diameter and displacement of 6000 pounds. The C10 buoy also measured current profiles with a downward-looking 600 kHz ADCP (Fig. 3). The regional depth contours define an along-shelf direction rotated 28° anti-clockwise from North. The surface current meters were deployed on the buoy for 1.5 months (28 June 2006 to 17 August 2006).

Figure 2. The ASCM was deployed on the C10 buoy (red box) located on the 25 m isobath of the West Florida Shelf.
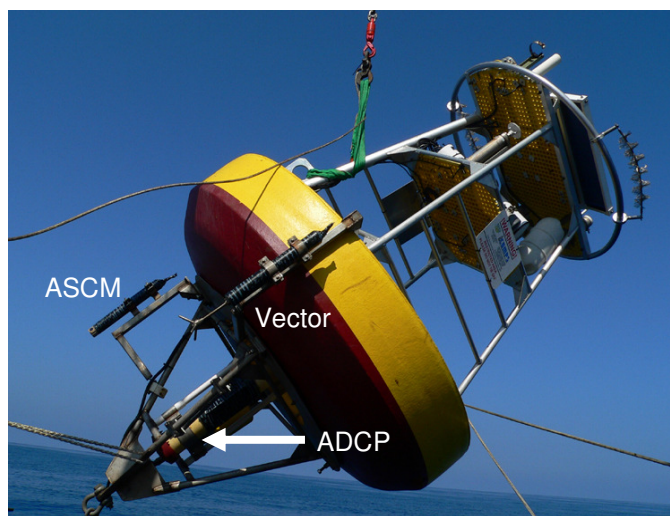

Figure 3. Photo of C10 buoy being deployed in Gulf of Mexico. The locations of the ASCM, Vector and ADCP are indicated.

The Nortek ASCM was mounted on an underwater bracket on the bridal of the buoy. It was positioned with the transducer head (and measurement volume) 1.1 m below the surface. The ASCM was configured to measure mean current velocities every 20 minutes with a 60 second averaging interval. The internal ping rate was set to 6 Hz, so a total of 360 pings were averaged to log a single current velocity measurement. The blanking distance to the start of the measurement volume was set to 3 m, allowing current measurements to be made away from any flow disturbance caused by the buoy. A separate "diagnostics" mode was

enabled to sample a 2 minute burst of 120 measurements sampled at 1 Hz, every 3 hours. The diagnostic data provides high temporal resolution of instrument and buoy performance by logging such data at pitch, roll, heading, signal strength and current velocity. These data were used to determine buoy motion and appropriate averaging intervals.

The Nortek Vector Velocimeter was included in the experiment to evaluate a different type of surface current measurement. The Vector measures current velocity from a very small water parcel (~3 cm^3) located 15 cm below the probe. The mounting location of the Vector positioned the measurement volume 0.8 m below the surface. The Vector was configured to log 120 samples at 2 Hz (i.e. 1 minute duration) every 20 minutes. In post-processing each 120 sample burst was averaged together to obtain a representative 1 minute sample to provide comparable data with the ASCM and ADCP.

A 600 kHz ADCP was deployed in the bridal of the buoy pointing downwards. The ADCP was configured to measure current profiles in 1 m bins every 1 hour with 6 minute averages (360 pings at 1 Hz). After the 1 m blanking distance, the first valid velocity bin was located 4 m below the surface. However, due to bias issues described Ref. [1], the authors believe the first bin of quality data was located 7 m below the surface.

III. DATA

Pitch and roll data collected at 1 Hz with the diagnostic mode of the ASCM provided an estimate of buoy motion (Fig. 4). The mean pitch and roll of the ASCM was about -2°, indicating that either it was mounted slightly crooked, or the buoy had a mean list. The pitch & roll were nearly equal, showing the circular buoy had a symmetric response to waves and wind. During any given 2 minute measurement interval, the buoy would typically pitch and roll ±2°-5° about the mean position. The maximum excursion from the mean position was about 10°. The position of the measurement volume and the geometry of the buoy dictate that, presuming a flat sea surface, the buoy would need to tilt more than 15° before the far end of the measurement volume would touch the surface. An analysis of data quality suggests that the ASCM velocity measurements were not adversely affected by excessive tilt, and acoustic returns from the surface were rare and did not bias the velocity data.

The pattern of the raw 1 Hz (ASCM) and 2 Hz (Vector) velocity data indicate 60 sec averaging was not sufficient to remove buoy motion from all data; particularly during times with larger tilt variability (presumably larger waves). There is evidence of some lower frequency velocity signals with periods of 30 sec to over 60 sec that are not properly averaged out with a 60 sec averaging interval. These motions may be due to the excursions and compliance of the surface buoy and

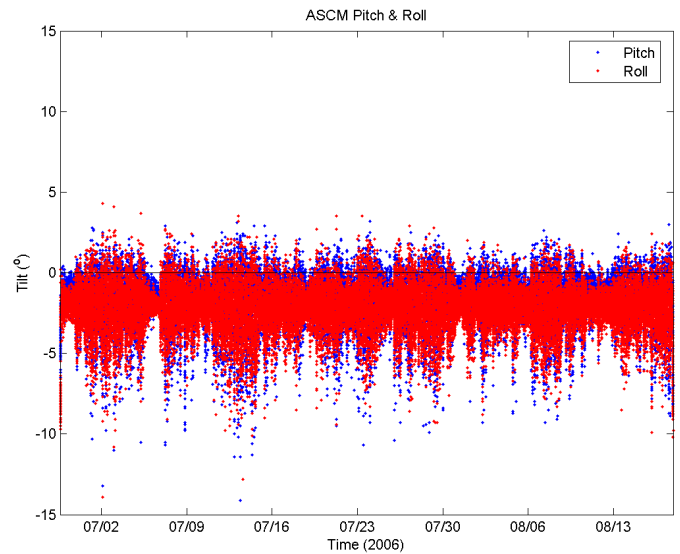mooring line. Further examination in future analysis is suggested.

Figure 4. Pitch and roll measurements collected by the ASCM at 1 Hz.

IV. RESULTS

A. Time Domain & Frequency Domain

Current velocity data from the ASCM and Vector were rotated 28° anti-clockwise from North to define an along-shelf and across-shelf direction. The raw data (20 minute measurement intervals) are plotted in Fig. 5 and the 40 hour low-pass filtered data are plotted in Fig. 6. Both near-surface velocity measurements show similar patterns of tidal and lower frequency energy. The tidal currents are nominally 20 cm/s and the lower frequency events can have larger amplitudes. The lower frequency events are primarily directed in the along-shelf direction.
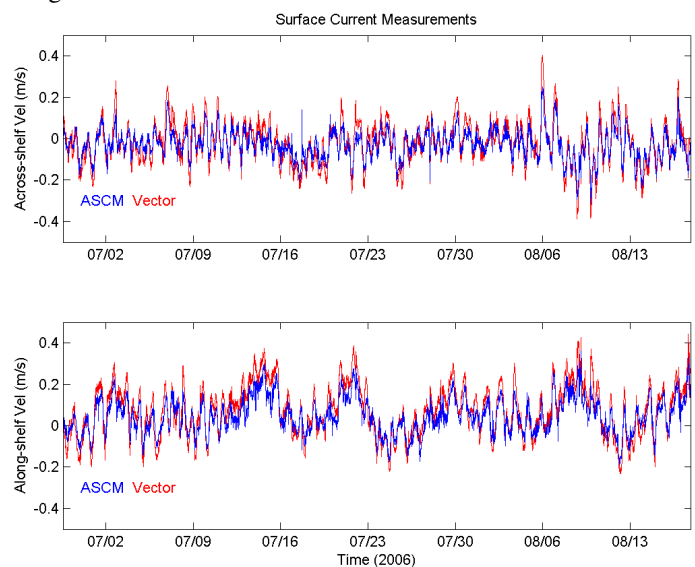

Figure 5. Unfiltered across-shelf and along-shelf velocity components from the Vector (0.8 m) and the ASCM (1.1 m).
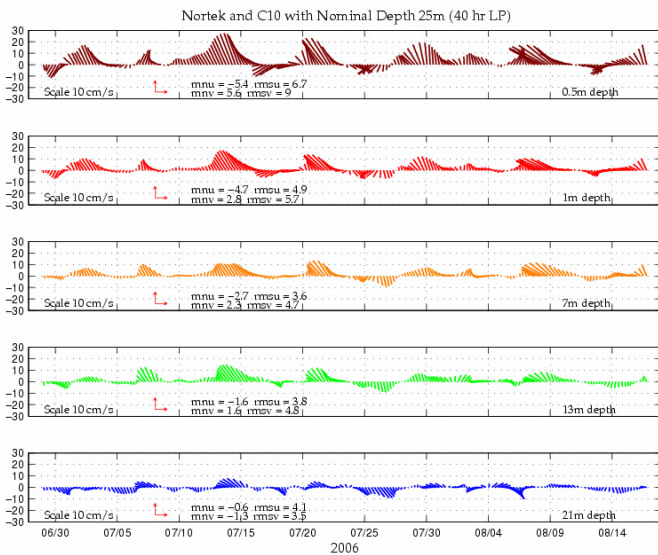
Figure 6. Vector stick plot of 40 hour low pass filtered from the Vector (0.8 m), ASCM (1.1 m), and ADCP (7, 13, 21 m).

Auto-spectra are presented for the ASCM, Vector, and ADCP (at the 4 m depth cell) for both the along-shelf and across-shelf directions (Fig. 7). The auto-spectra show peak along-shelf energy in the low frequency synoptic band and peak across-shelf energy in the M2 tidal band. Overall, it is clear from the raw time series and auto-spectra that the Vector measures more energy across all frequency bands compared to the ASCM and ADCP. The ASCM measures more energy than the ADCP across most frequency bands. Finally, the noise floor of the ASCM and Vector is much lower than the ADCP measurements, indicating data quality is excellent.

B. Rotary Auto Spectral Analysis

Rotary auto spectral analysis is a quantitative examination of the current velocity geometry as a function of frequency [1]. Decomposing a velocity vector sequence using Fourier transforms results in an ellipse that pertains to the average geometry of the motion. The Fourier transform has negative and positive frequencies corresponding to clockwise (CW) and anti-clockwise (ACW) components of the ellipse, respectively. The auto spectra describes the elliptical structure for each mooring via the CW and ACW spectral density, the stability (γ^2), the axis ratio, the principal axis orientation (α), and the semi-major axis. The stability is a measure of the geometric coherence of the ellipse, and the axis ratio and semi-major axis are geometric properties of the ellipse. An axis ratio close to zero indicates rectilinear motion on the shelf; values near unity indicate circular motion, with the sign indicating the direction of rotation.

Rotary auto spectral quantities for the ASCM and ADCP (at 7 m) are shown in Fig. 8 (low frequency) and Fig. 9 (high frequency). The low frequency plot shows the highest stability at the synoptic band of 8.3 days (0.005 cph). The axis ratio is near zero, indicating rectilinear motion consistent with other findings of low frequency motion on the WFS [3]. The principle axis orientation is +30 degrees (anti-clockwise from North), which is consistent with flow in the along-shelf direction.

The high frequency plot shows the highest stability at the M2 tidal band (0.081 cph). The axis ratio is near 0.5, indicating elliptical motion consistent with offshore tidal motions. The principle axis orientation is -60 degrees (clockwise from North) which is consistent with flow in the across-shelf direction.
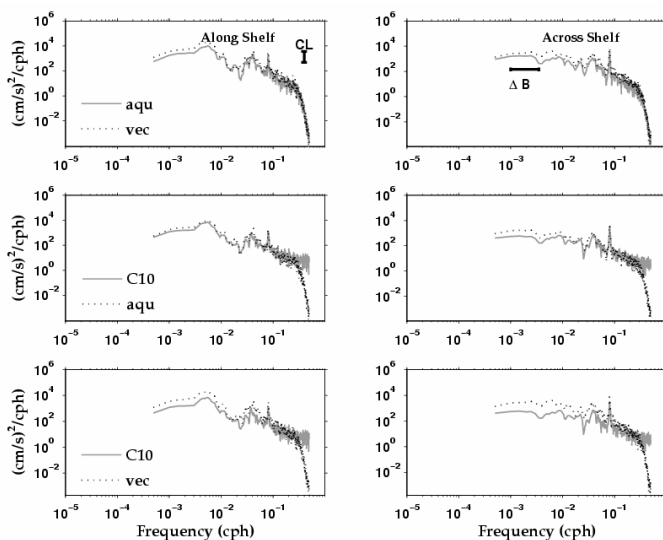

Figure 7. Auto spectra estimates of the along-shelf and across-shelf velocity components from the Vector (vec, 0.8 m), ASCM (aqu, 1.1 m), and ADCP (C10, 4 m).
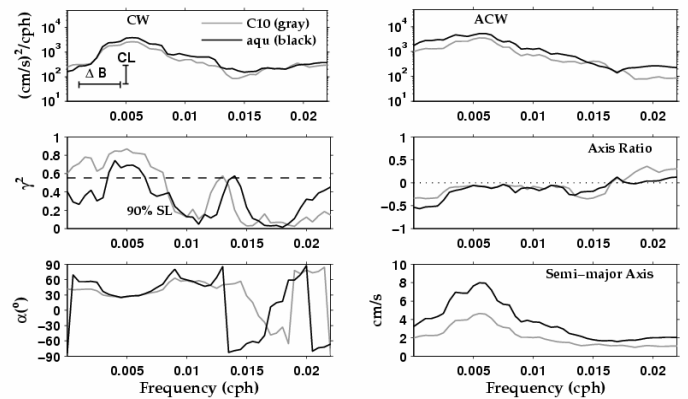

Figure 8. Low frequency band rotary auto spectra of the ASCM (aqu, 1.1 m) and ADCP (C10, 7 m). Top row: clockwise (CW) and anticlockwise (ACW) auto spectra. Second row: (left) stability (γ^2) and (right) axis ratio (minor/major, negative values denote ACW rotation). Third row: (left) orientation angles (+ ACW with respect to North) and (right) amplitude of semi-major axis.

Figure 9. High frequency band rotary auto spectra of the ASCM (aqu, 1.1 m) and ADCP (C10, 7 m). Top row: clockwise (CW) and anticlockwise (ACW) auto spectra. Second row: (left) stability (γ^2) and (right) axis ratio (minor/major, negative values denote ACW rotation). Third row: (left) orientation angles (+ ACW with respect to North) and (right) amplitude of semi-major axis.
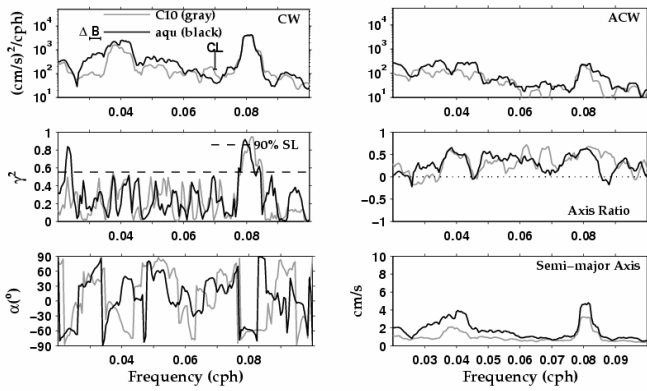
C. Rotary Cross Spectral Analysis:

Rotary cross spectra adds more information by describing the frequency dependence of the velocity field between the ASCM and ADCP measurements at different positions in the water column. The quantities computed include the vector correlation squared (ρ^2), the vector phase lag (θ), the veering angle (α), the relative ellipse orientation (φ), and the transfer function (gain).

As the auto-spectra suggests, there are basically two modes of motion at this site on the WFS: across-shelf motion in the tidal band and along-shelf motion in the synoptic band. The visual coherence of velocities in Figs. 5 and 6 (raw & low pass filtered) can be quantified by examining the vector correlation amplitudes for the velocity between the ASCM and ADCP (7 m) (Fig. 10).

The correlation square between the ASCM and ADCP are greater than 0.95 in the synoptic and tidal band. It is also above 0.80 at a band consistent with inertial oscillations at this latitude on the WFS. The subsequent analysis will focus on the synoptic and tidal bands of high correlation.
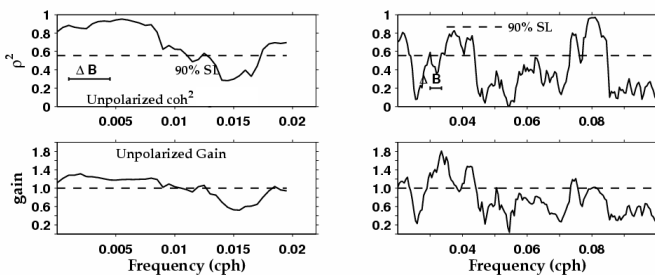

Figure 10. Rotary cross spectra estimates of correlation squared (ρ^2) and transfer function (gain) between the ASCM (1.1 m) and ADCP (7 m) for the low frequency band (left) and high frequency band (right).

Assuming the relationships between the current measurements are linear, we can use the transfer function (gain) and the observation from one depth level to provide a prediction of observations at the other depth levels. Table 1 summarizes the gain between the ASCM and the Vector (not plotted) compared to velocity measurements from the ADCP at 7 m depth.

	Synoptic Band (0.005 cph)		M2 Tidal Band (0.081cph)	
Observation	Amplitude	Gain	Amplitude	Gain
Vector (0.8 m)	13.3 cm/s	1.73	6.4 cm/s	1.39
ASCM (1.1 m)	9.1 cm/s	1.18	4.9 cm/s	1.07
ADCP (4.0 m)	7.5 cm/s	0.97	4.3 cm/s	0.95
ADCP (7.0 m)	7.7 cm/s	1.00	4.6 cm/s	1.00

Table 1. Current amplitude (semi-major axis) and gain (relative to ADCP at 7 m) for peak correlation (>0.95) at tidal and synoptic bands.

The orientation with respect to North of the semi-major axis was determined through standard harmonic analysis of tides for the M2 tidal constituent and through a principal axis analysis for the synoptic band (using 40 hour low pass filtered velocity time series). A vector correlation study [4], not presented, indicated nearly zero temporal phase difference between velocities at the various levels. Thus, a veering angle between any two time series can be computed by calculating the difference in orientation angles. The veering angle is negligible (<2°) between the ASCM and the ADCP (7 m) velocity at the M2 tidal band and the synoptic band.

In the M2 band, the orientation at 1.1 m, 7 m and 13 m is +32° (±1°). The orientation at 0.8 m (Vector) is +29°. The orientation at 21.0 m is +34°. This shows a steady ACW rotation from top to bottom in the water column which is consistent with effects of bottom friction. Interestingly, the orientation in the surface-most bin (4 m) of the ADCP is +35°, which is not consistent with the directional pattern in the rest of the water column.

In the synoptic band, the orientation at 1.1 m, 7 m and 13 m is -35° (±1°). The orientation at the 0.8 m (Vector) is - 23°. The orientation at 21.0 m is -52°. This shows a steady ACW rotation from top to bottom in the water column, consistent with bottom friction. Again, the orientation in the surface-most bin of the ADCP (4 m) is -30°, which is not consistent with the directional pattern in the rest of the water column.

Observation	Synoptic Band (40 hr low pass filtered)	M2 Tidal Band (0.081cph)
	Rotation	Rotation
Vector (0.8 m)	-23°	+29°
ASCM (1.1 m)	-35°	+33°
ADCP (4.0 m)	-30°	+35°
ADCP (7.0 m)	-34°	+31°
ADCP (13.0 m)	-35°	+32°

Table 2. Orientation of the semi-major axis of the M2 and synoptic band velocity time series. Rotation angle is degrees with respect to North; "+" indicates anti-clockwise rotation, "-" indicates clockwise rotation.

V. Conclusions

The purpose of this experiment was to evaluate the validity of using the Aquadopp Surface Current Meter to measure near-surface currents from a small buoy in an offshore location. First, we were interested in learning if the data quality would be adequate to provide research-quality velocity measurements in the near-surface region. Second, we wanted to know if there was anything to be gained by adding the near-surface measurement capability to an already complex buoy.

Analysis of the raw velocity data indicate not all of the buoy motion was averaged out during the 60 sec averaging interval, especially during times of increased wave energy. However, the time series and auto- and cross-spectral analyses indicate the ASCM provides robust near-surface velocity measurements that compare well with those of a downward-looking ADCP.

Reference [1] suggests low-biased velocity measurements from the near-surface bins of downward-looking ADCP's, so perhaps it is now more important to correctly characterize the near-surface currents in order to accurately measure shear for transport calculations and model validation. The ASCM observed near-surface currents (1.1 m) 7% higher (in the M2 tidal band) and 18% higher (in the synoptic band) than ADCP velocity measurements at 7 m. The small gain in the M2 band is consistent with barotropic flows which should have little vertical shear. The larger gain in the synoptic band is consistent with the lower frequency barotropic flow commonly found on the WFS.

The decrease in amplitude (gain<1) for both bands of the ADCP measurements at 4 m depth is consistent with the small reduction in rms speed values possibly linked to the existence of bubbles created during increased surface wave activity in downward looking ADCP measurements, as found in Ref. [1].

There was negligible near-surface velocity rotation in both the tidal and synoptic bands compared with measurements at 7 m from the ADCP.

Near-surface measurements from the Vector velocimeter (0.8 m) indicate correct signs for rotation, but the large rotation and shear suggests this is either a very strong surface Ekman layer,

or some type of rotation and acceleration caused by flow disturbance around the buoy. While the ASCM measures velocity from regions well away from the buoy, the Vector's measurement volume is directly below the buoy and may be more influenced by flow disturbance around the buoy and bridal.

References

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