Signature 55 Long Range Current Profiler Data from a Short Deployment

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This report presents and evaluates data collected by a Nortek Signature 55 AD2CP Current Profiler in the Gulf of Mexico. The instrument was deployed only for a few days, but it was deployed at 1000 m depth. The data look to be of consistently high quality out to 900 m from the Signature 55. Above that, the last 8% of the distance to the surface is contaminated by echoes from the surface.

The Signature 55 has three acoustic beams that transmitted at 55 kHz with beams tilted 20° from vertical, and with beam widths of around 4°. It implements broadband signal processing with modes that use 6% and 25% bandwidths. The narrower bandwidth produces a longer range, while the wider band produces better detail. The Signature 55 can switch transmit frequencies, alternating between 55 kHz and 75 kHz. 55 kHz also produces longer range, while 75 kHz produces better detail. In this test, the Signature 55 was optimized for range and used only 55 kHz and a bandwidth of 6%.

The Signature 55 collected data in 64 20 m range cells. It collected data in bursts of 30 pings, each ping separated by 6 s and each burst by 30 minutes. The instrument recorded the data from every ping. The ambiguity velocity was 2 m/s. In post processing, four data points exceeding the ambiguity velocity were set to zero.

The Signature 55's single ping data provides the opportunity to clean the data by removing transients, and its magnetometer data provide the opportunity to calibrate the heading data and apply the calibration to the velocity data in post processing.

Raw data

Single ping data were processed by converting to Signature 55 coordinates, correcting for heading, pitch, and roll, then by averaging the bursts into 30 ping ensemble averages.

Figure 1 shows profiles of signal strength. This plot locates the surface at 980 m above the Signature 55. Figures 2-4 show east, north and up velocities versus depth and time. The east and north velocities exhibit patterns typical of near-inertial internal waves, which are observed commonly in places like this. Horizontal currents reached 20 cm/s. The vertical currents were considerably smaller, and the average vertical velocity was only 0.2 mm/s.

The vertical velocity shows patterns of velocity that are almost certainly diurnal migration of zooplankton. The animals go down, then swim back up again, repeating the pattern every day.

Figure 5 shows time series of current around 230 m above the Signature 55.

Figure 6 shows vertical velocity standard deviation. Aside from some glitches in the profile, the vertical velocity standard deviation near the Signature 55 is around 4 mm/s. The standard deviation near the surface increases mainly because of the diurnal migration. Outside of the migration events, the vertical velocity does not appear to be much more variable in the top 300 meters than it does below, so it appears that the data quality in the top third of the range is comparable in quality with data in the ranges closer to the Signature 55.

Bin 45, at 902 m above the Signature 55, a local minimum in the standard deviation, is also the top bin where we find good quality data.

Cleaning up single ping data

Doppler profilers mostly measure the velocity of small animals that float with the water, but both fish and ambiguity errors can introduce large isolated transients. Figure 7 plots time series of beam data in bins 1-45, i.e. where the good data are. Transients are obvious in this plot, but they account for only about 0.05% of the data. However, because of their magnitude, the transients have an outsized effect on averages.

Figure 8 plots the beam velocities as distributions, comparing the distributions to normal distributions with zero mean and 4 cm/s standard deviation. The red curves represent normal distributions out to about 5 standard deviations, so the transients are clearly far outside the normal distribution.

Figure 9 shows beam data after transients were removed and data interpolated into the gaps. A transient was defined as any beam velocity more than four standard deviations (16 cm/s) from zero velocity. Interpolating the data, as opposed to simply setting values to zero, has the advantage that it does not introduce bias toward zero velocity.

When data are processed into ensemble averages and recorded internally, transients are harder to see and impossible to remove.

Correlation data

Broadband Doppler processing involves transmitting a sequence of repeated acoustic signals, then comparing the echoes from these repeated signals against one another. The echo correlates with itself at delays corresponding to the delays between the repeated signals in the transmission. The magnitude of the correlation is a measure of the quality of the velocity data. The recorded correlation therefore provides another means for cleaning up data. As with the transient processing, above, the correlation data are useful only if the instrument records single ping data.

The Signature 55 records correlation data for each range cell for every ping. Velocity errors are small for correlations above 0.3, and the errors increase as correlation falls below 0.3. Correlation correction selects velocity data having correlations below a threshold, and replaces the data with interpolated data. Correlation correction added little to this data set because the velocity correction cleaned up most of the data affected by low correlation. Correlation correction could be more useful when mean velocities are high relative to typical velocity transients.

Correlation data will also be useful to identify the extent of the Signature 55's profiling range. In this data set, the correlation remained high all the way to the surface, which suggests the instrument could have profiled further had it been deeper.

***In-situ* Compass Calibration**

The Signature 55 measures and records all three components of the earth's magnetic field, **M**, along with the single-ping beam data. As long as the Signature 55 rotates in its mooring, it is possible to used the in-situ data to calibrate the compass and correct measured velocities in post processing. If there are no magnetic materials around, the Signature 55 measures the same field **M** independently of its orientation. The components of **M** vary, but |**M**| is always the same. The small Signature 55 pitch and roll allow us to ignore the vertical component of M and to focus in the following on the horizontal components, $\mathbf{M}_h$.

Figure 11 plots $\mathbf{M}_h$ and compares it to a circle centered on the origin. While the Signature 55 did not rotate a full circle, the partial circle formed by $\mathbf{M}_h$ is clearly offset from the center. This offset is caused by nearby "hard iron" that rotates with the Signature 55. Nearby "soft iron" squeezes the circle into an ellipse instead.

The compass heading is computed from angle($\mathbf{M}_h$), where $\mathbf{M}_h$ is the horizontal component of the magnetic field. With 0° pointing to the top of Figure 11, the magnitude $|\mathbf{M}_h|$ is less at 180° than at 90°. Figure 12 plots $|\mathbf{M}_h|$ vs. this angle and compares it to a constant magnitude of 286.6 counts. The largest offset is about 5.6 counts at 184°, or $\mathbf{M}_o = (-.4, -5.6)$, where $\mathbf{M}_o$ is the offset vector. The data are corrected using:

$$\mathbf{M}_c = \mathbf{M} + \mathbf{M}_o$$

where $\mathbf{M}_c$ is the corrected data. The largest heading error is

$$\sin^{-1}(|\mathbf{M}_o|/\langle|\mathbf{M}_h|\rangle) \cong 1.1°$$

Figure 13 plots $\mathbf{M}_c$ and shows that it lies on top of a circle centered on zero. Figure 14 shows that the magnitude $|\mathbf{M}_c|$ is independent of heading.

Figure 15 shows how the heading error depends on direction. The 1.1° maximum correction is hard to see in data, but mounting frames can introduce considerably larger errors. While most current profiles have compass calibration routines, it is not always possible to calibrate compasses in mooring frames. Calibrating compasses on a boat is usually impossible. While bottom mounted instruments do not rotate, one option is to devise frames that rotate on the trip to and from the bottom. *In-situ* calibration makes it possible to turn a system around at sea without worrying about the calibration.

The correction here used only the horizontal component of the magnetic field. Corrections could be improved by including the vertical component of the magnetic field and/or the pitch and roll, particularly when instruments tilt more, or in near-surface deployments where instruments move about more.

Corrected Data

Figures 16-18 plot velocity components versus depth and time. Compared to Figures 2-4, the velocity data are obviously cleaner. Figure 19 shows the same time series as Figure 5, and comparison of the two shows that some transients were removed. Figure 20 shows the vertical velocity standard deviation.

Is correction really necessary?

In this data set, the uncorrected and corrected data are not very different. This is because the data were high quality to begin with. Data correction is nevertheless worth some effort because it provides confidence in the data and it quantifies the measurement uncertainty.

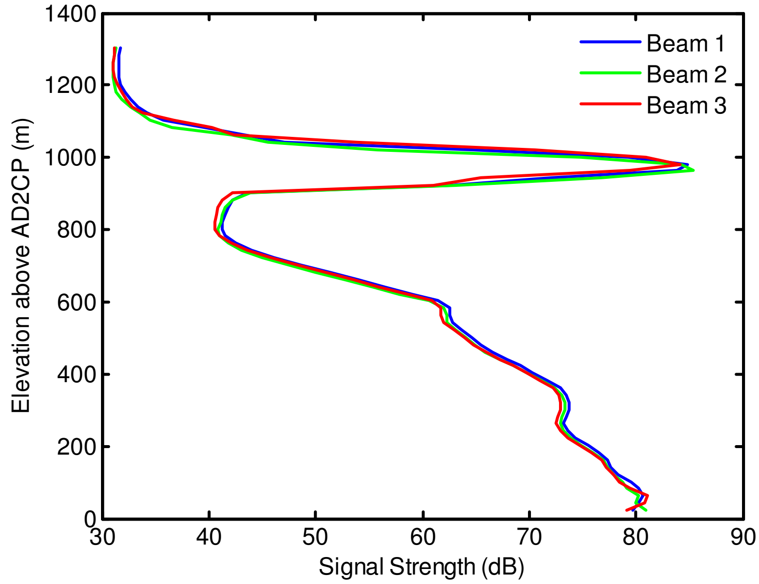

Figure 1. Signal strength showing the location of the surface at about 980 m above the Signature 55. Starting at around 200 m below the surface (800 m above the Signature 55), the signal strength ceases to decrease. Elevated signal strength near the surface is normal in the ocean.

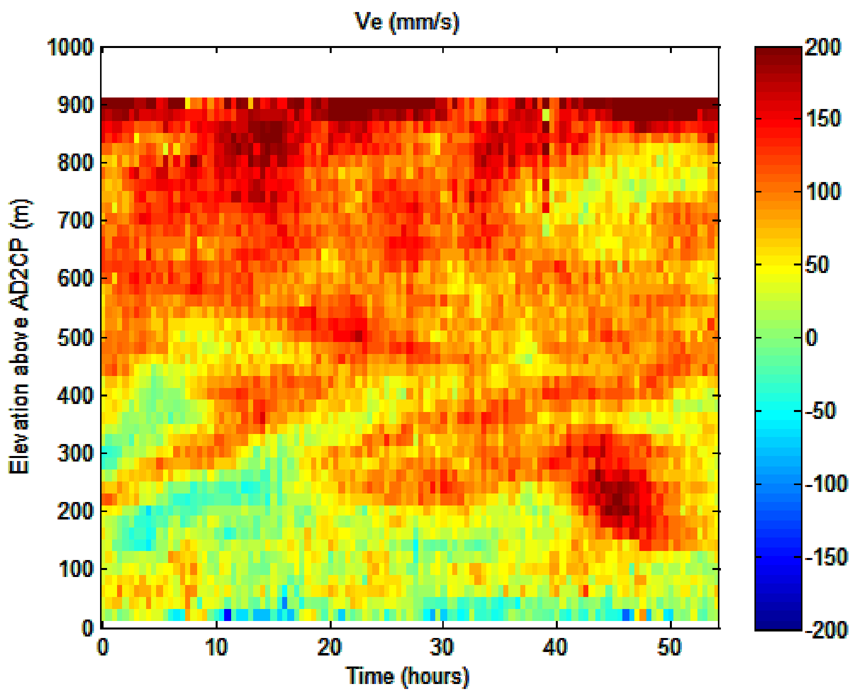

Figure 2. East velocity vs. elevation above the Signature 55. The patterns are characteristic of ocean currents. The rising streaks in the data suggest internal waves.

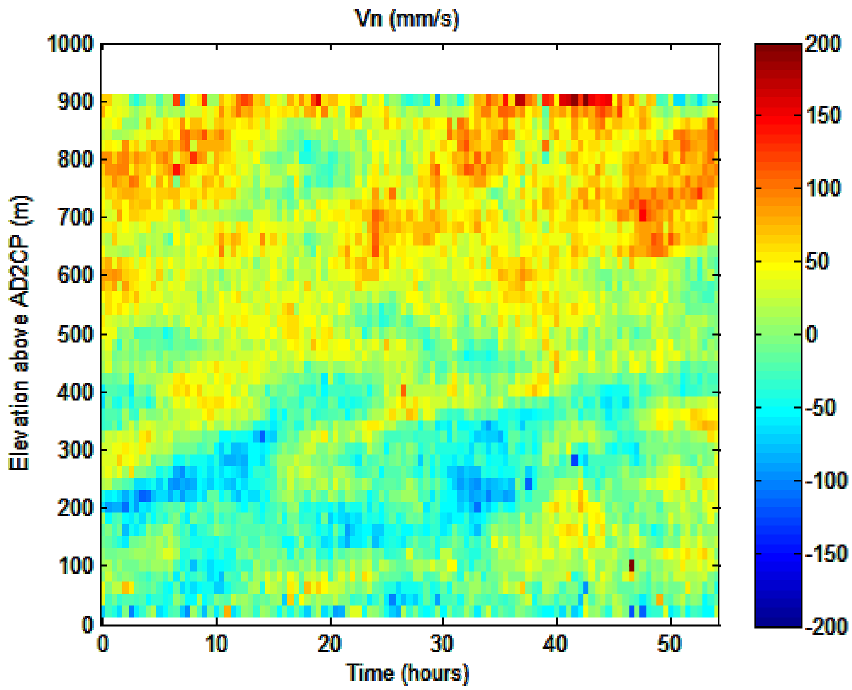

Figure 3. North velocity.

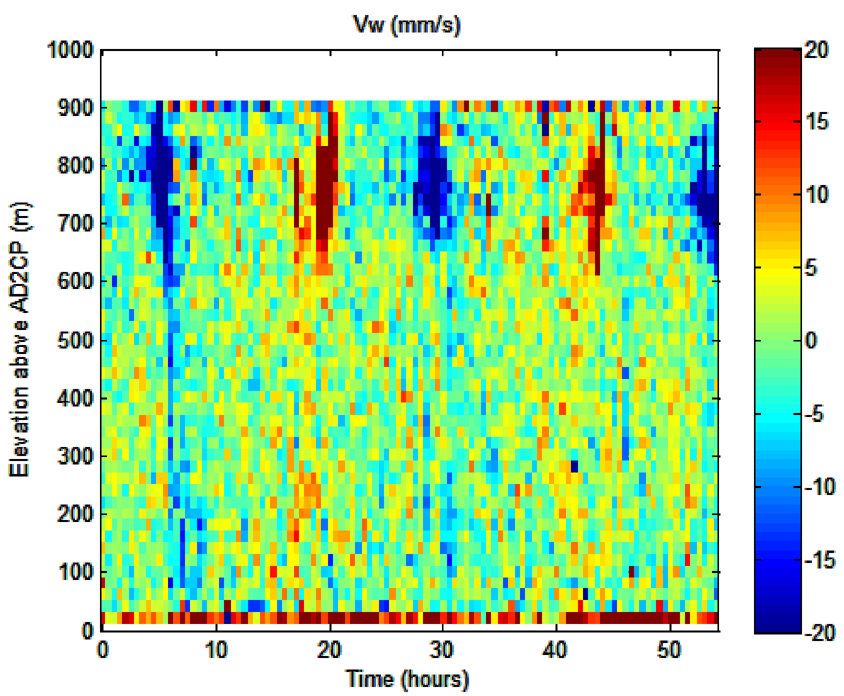

Figure 4. Vertical velocity. The blue and red patches around 800 m above the Signature 55 are probably caused by diurnal migration of zooplankton. Note the change in velocity scale relative to Figs. 2 and 3.

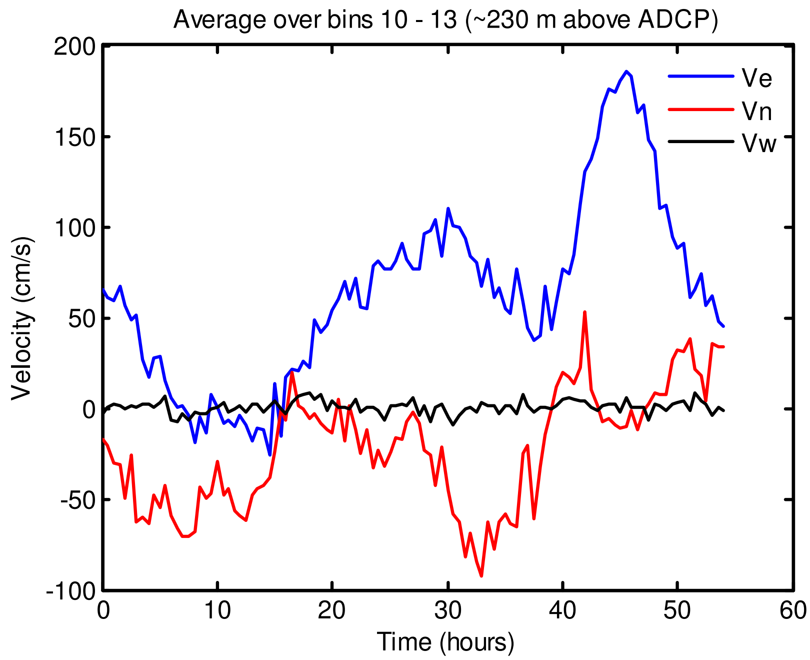

Figure 5. An example time series at around 230 m depth.

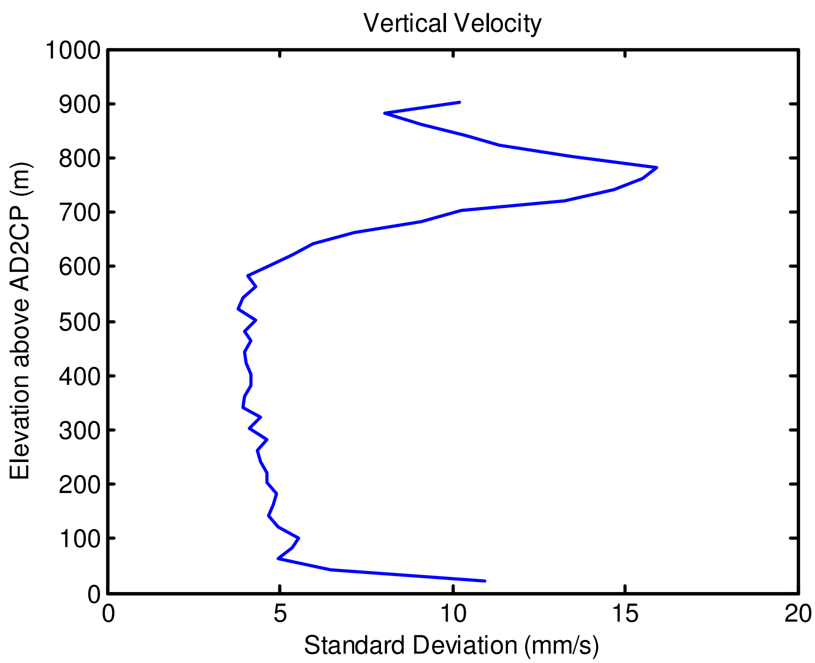

Figure 6. Standard deviation of vertical velocity. The increase in standard deviation around 800 m is the result of diurnal migration, not an increase in the Signature 55 measurement uncertainty.

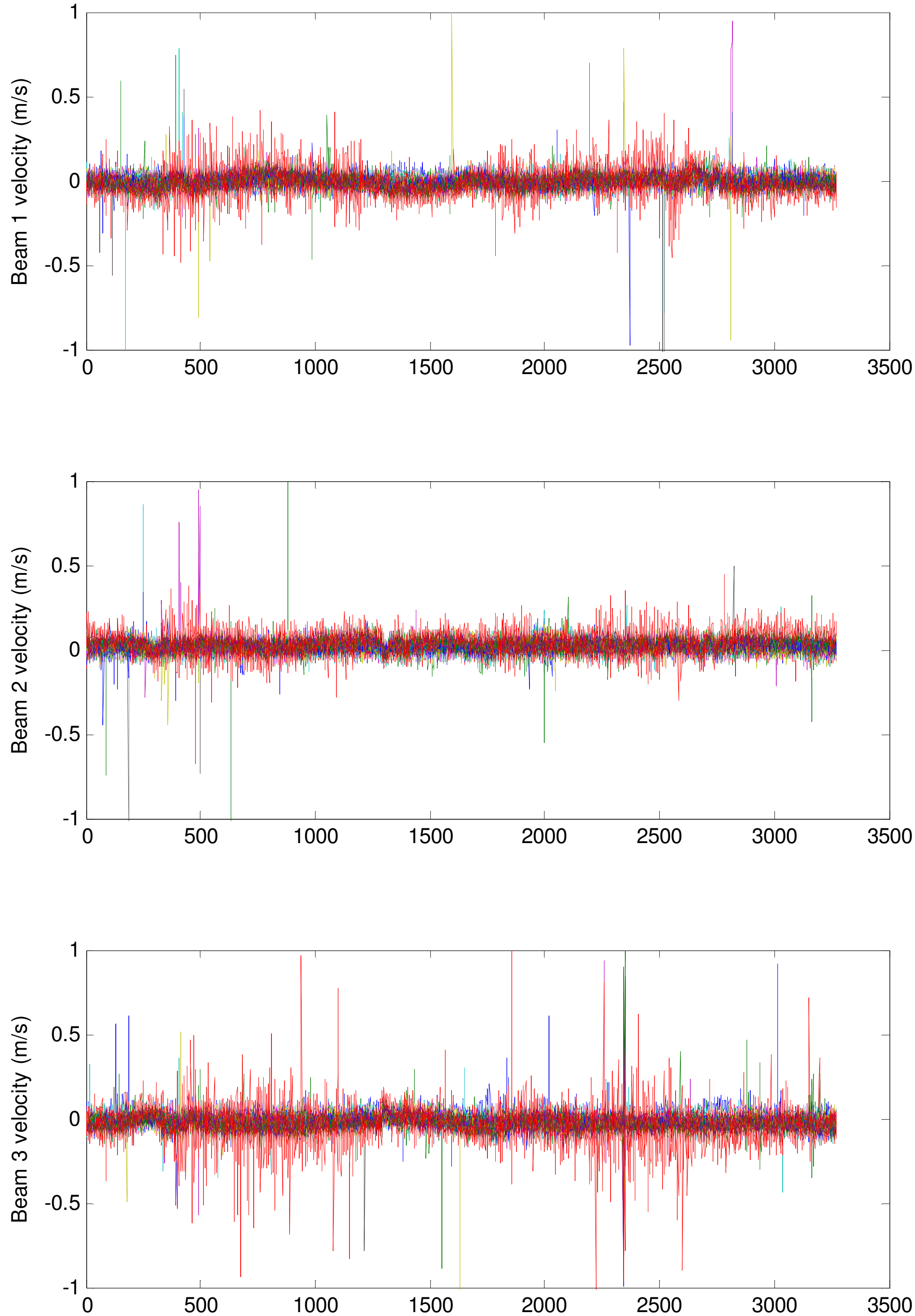

Figure 7. Single ping beam velocity from bins 1 to 45 in the range 0-900 m, where the data are good.

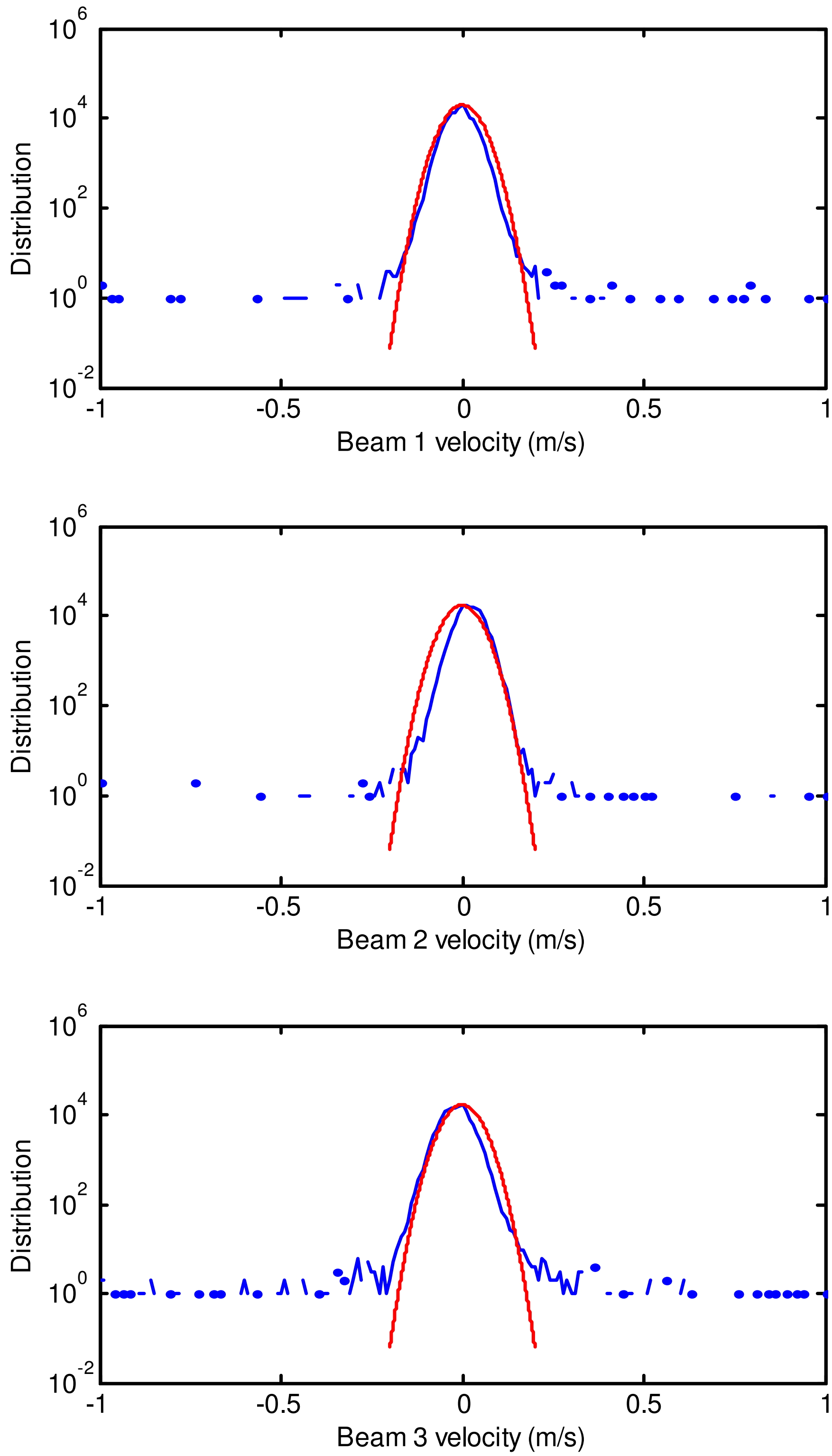

Figure 8. Beam velocity distributions compared with a normal distribution having a standard deviation of 4 cm/s.

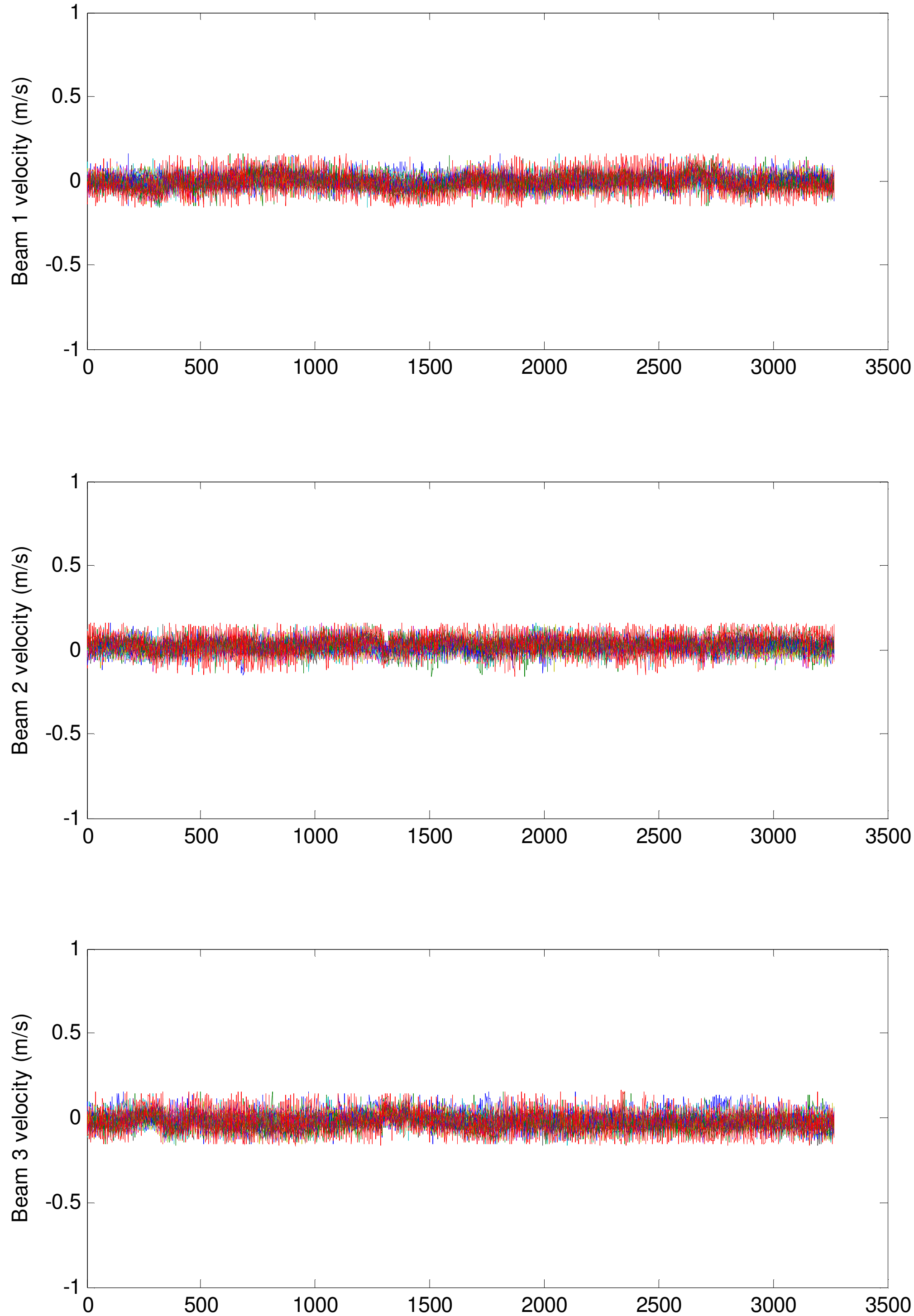

Figure 9. Beam velocities after removing velocities exceeding 4 standard deviations from zero.

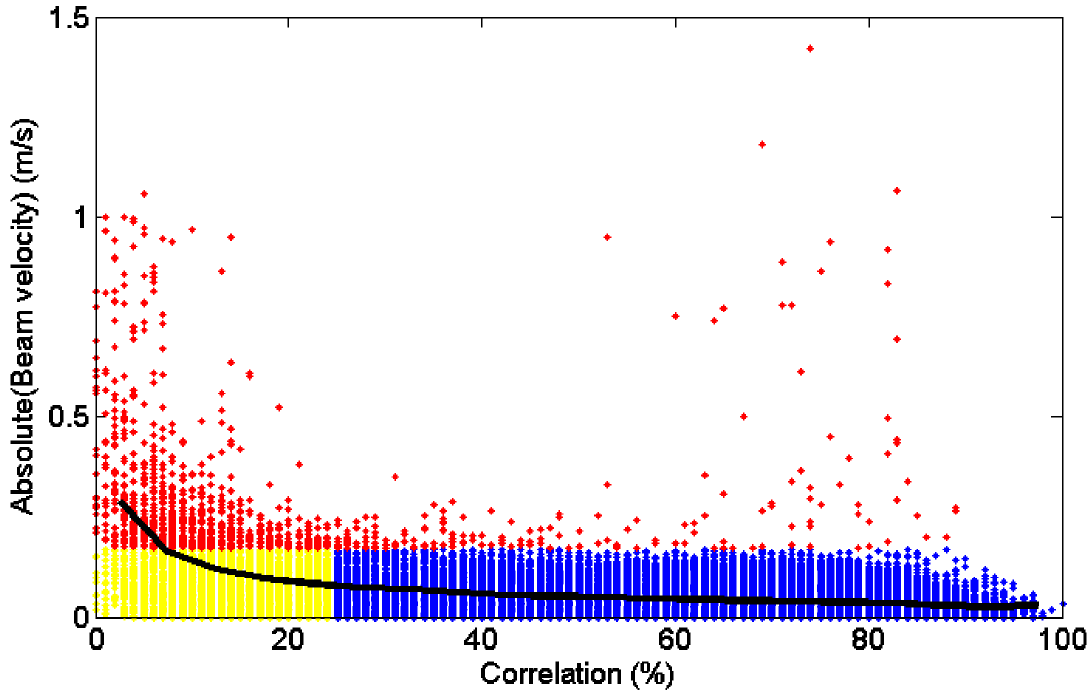

Figure 10. Beam velocity vs. correlation. Red dots are velocity that exceed the velocity standard deviation, 43 mm/s. This figure emphasizes the red dots, but they only account for 0.25% of all the velocities. The yellow dots, for correlation less than 25%, account for 1.4% of the data. 90% of the measurements exceed 60% correlation. The velocity standard deviation (black line) depends on correlation. At 25% correlation, the standard deviation roughly doubles.

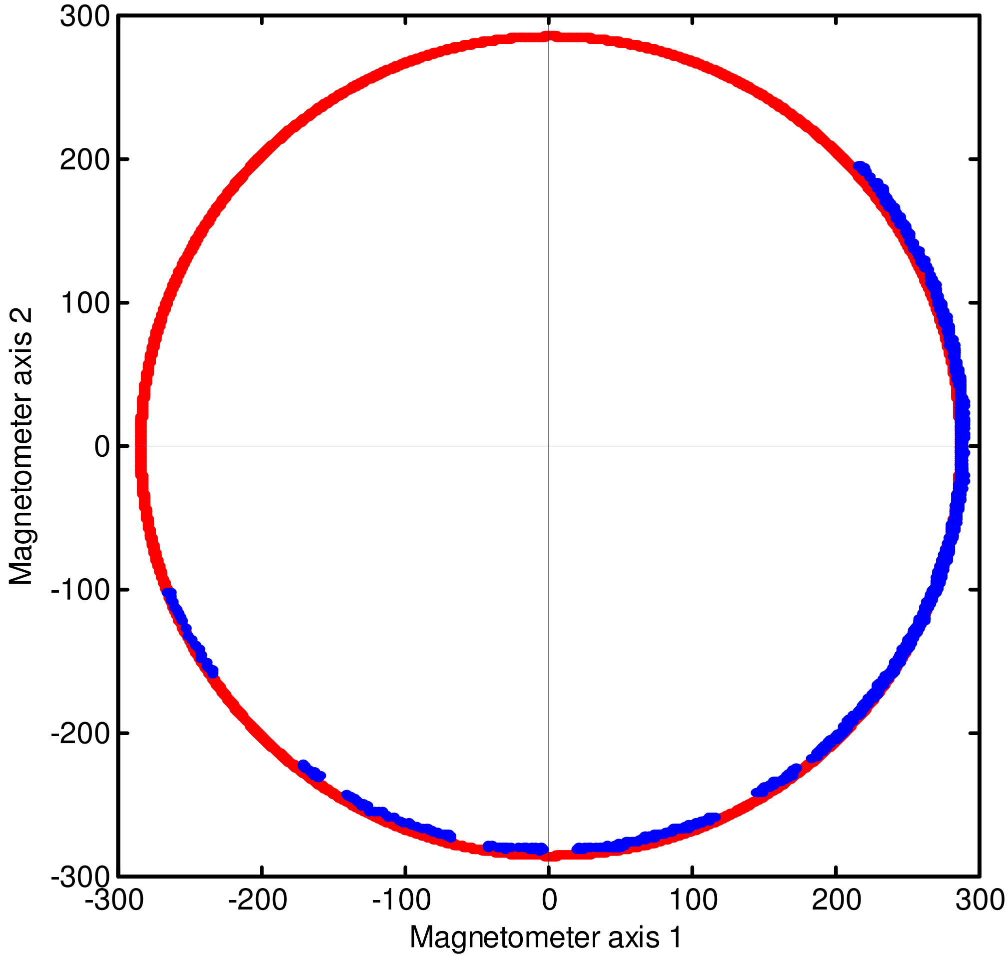

Figure 11. Magnetometer horizontal vector. Data from a perfect magnetometer will fall on a circle centered on the origin. The magnetometer data (blue dots) are offset slightly from the red circle.

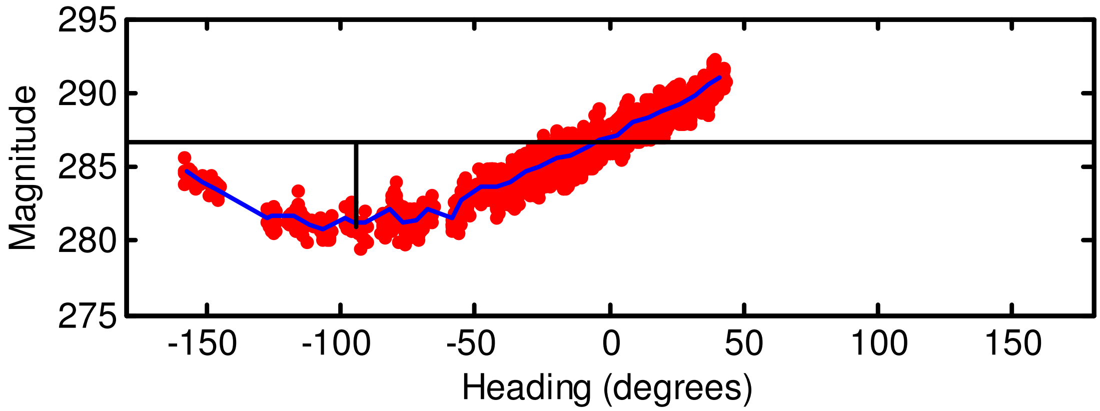

Figure 12. Magnetometer horizontal vector magnitude vs. heading. The vertical black line at -1.65 (-94.5°) shows the magnitude and direction of the offset in Fig. 10.

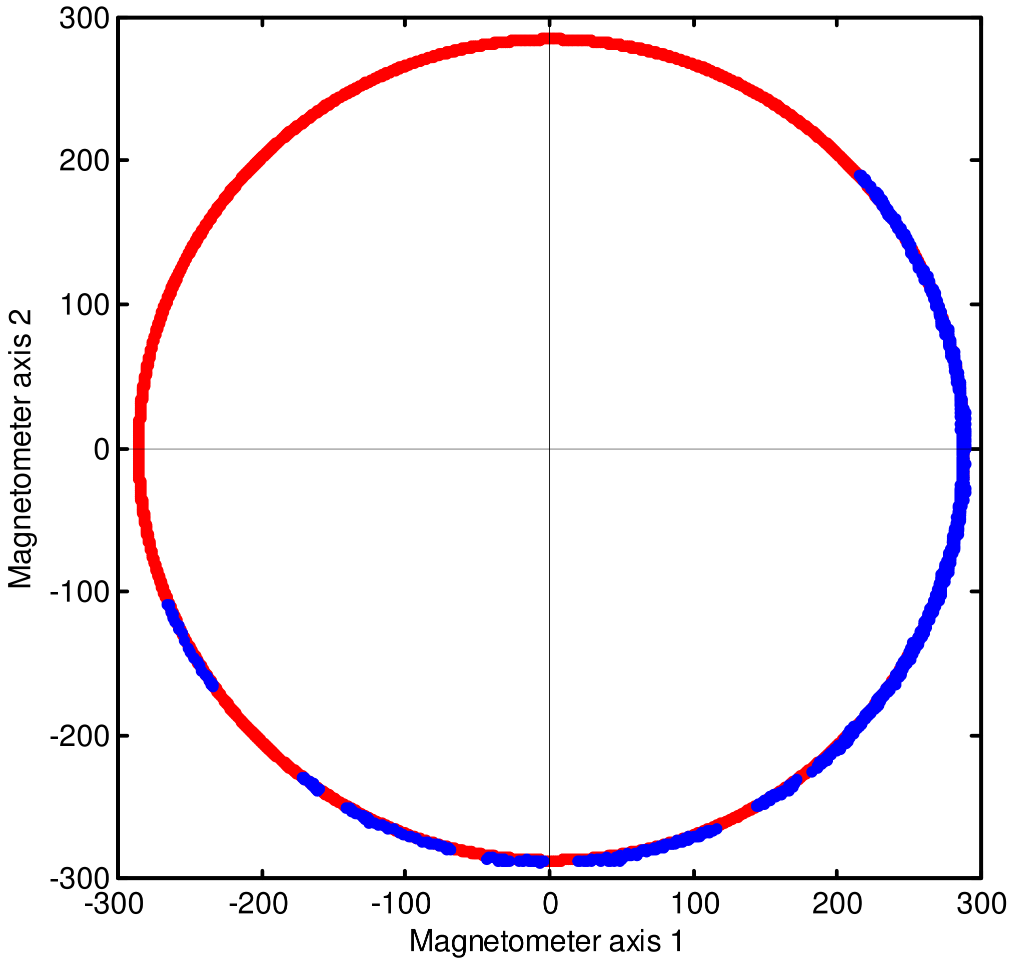

Figure 13. After offsetting the magnetometer horizontal vector data , the data (blue dots) now fall on top of a red circle centered on the origin.

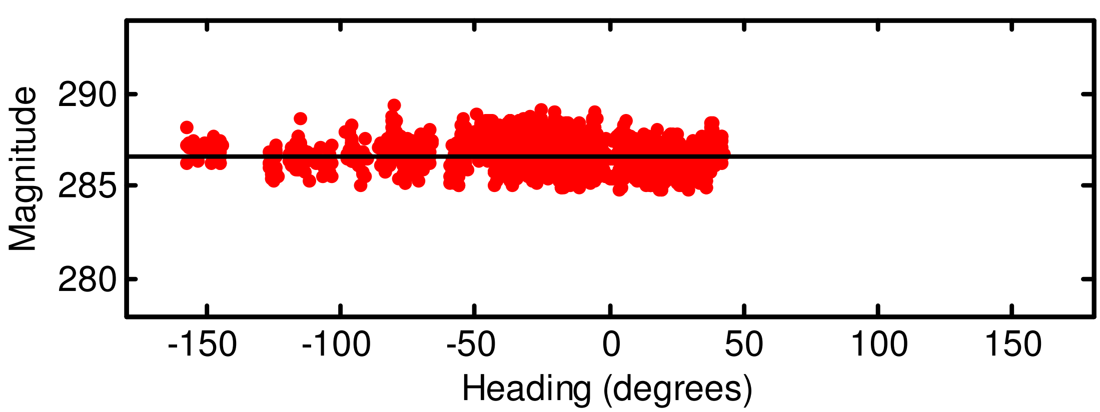

Figure 14. Magnetometer horizontal vector magnitude after correction.

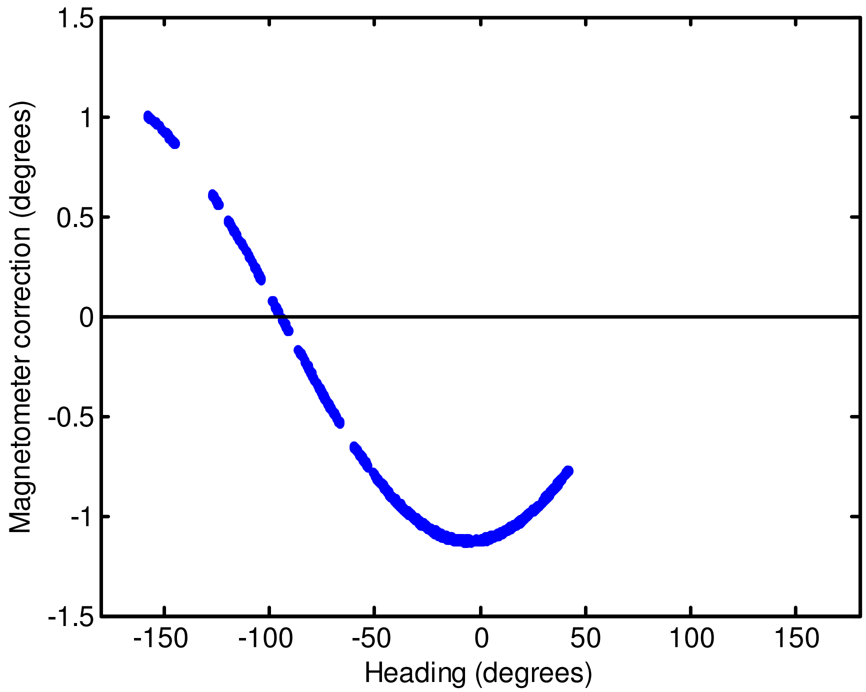

Figure 15. Heading correction; the value shown is added to the measured heading to get the corrected heading.

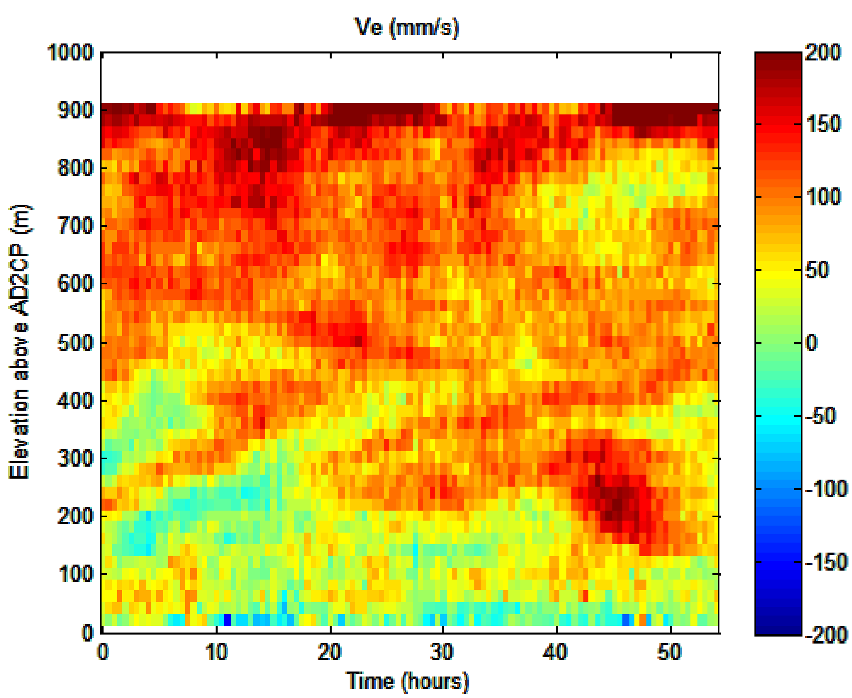

Figure 16. East velocity over the usable range of the ADCP, after cleaning up the data by removing transients and correcting for the magnetometer offset. Compare with Figure 2.

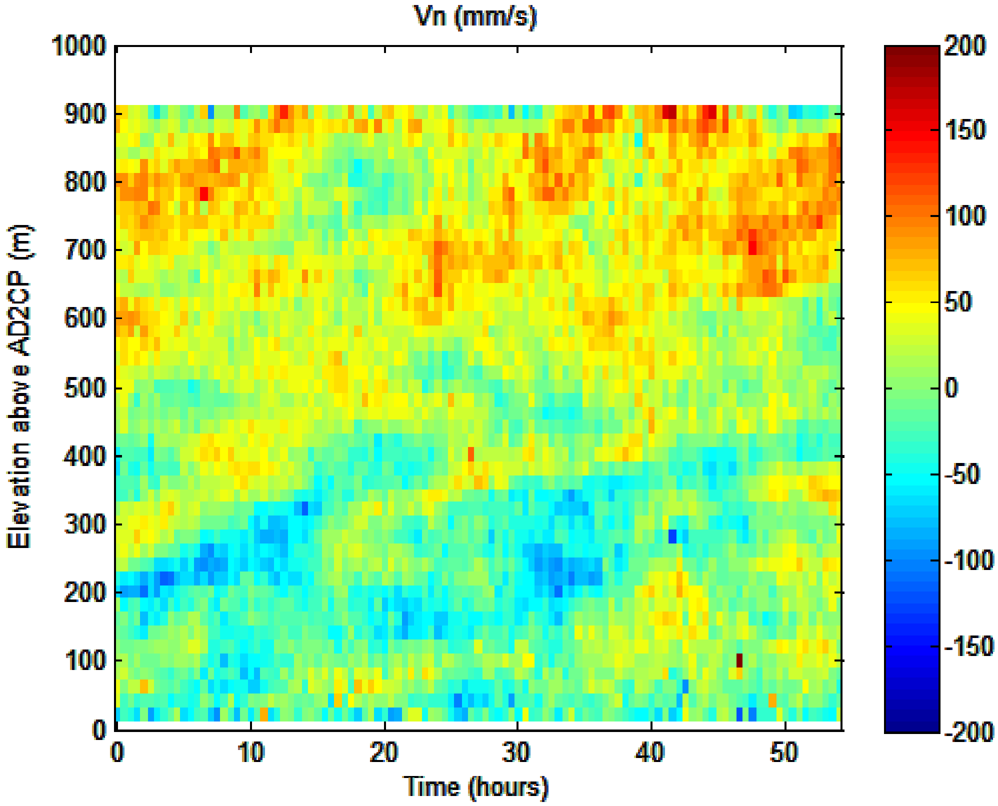

Figure 17. North velocity after cleaning. Compare with Figure 3.

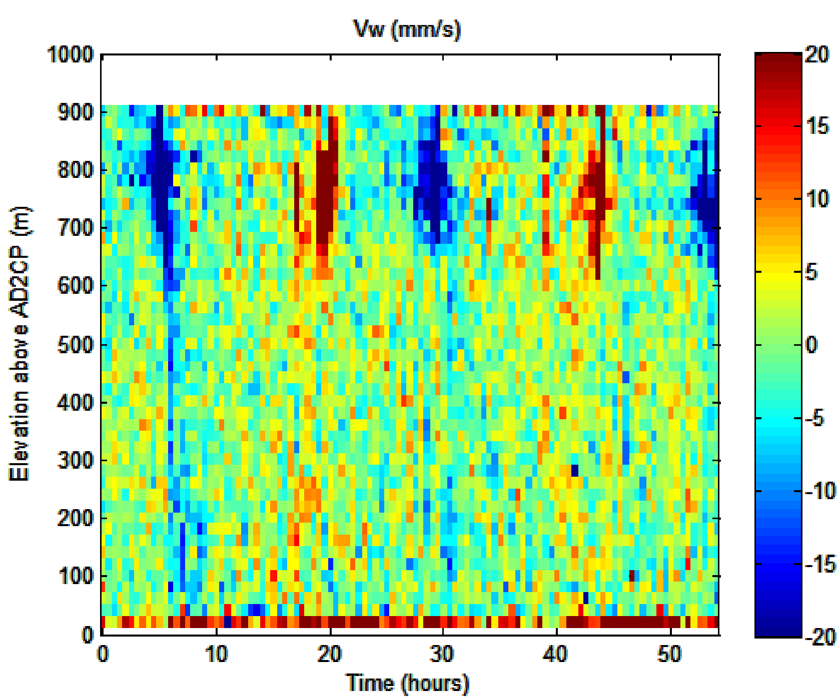

Figure 18. Vertical velocity after cleaning. Compare with Figure 4.

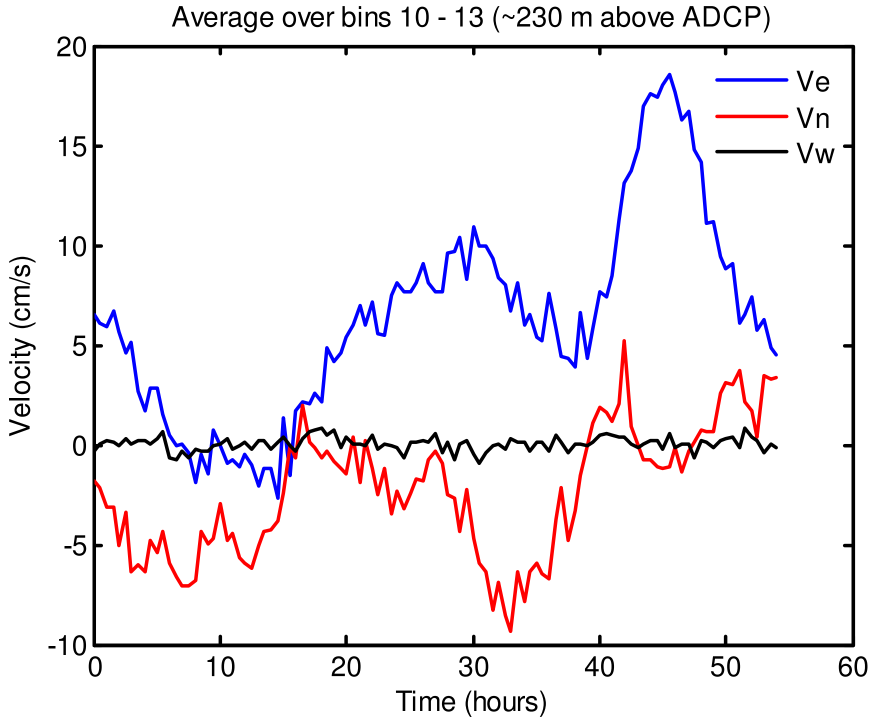

Figure 19. Time series around 230 m above the Signature 55, after cleaning the data. Compare with Figure 5.

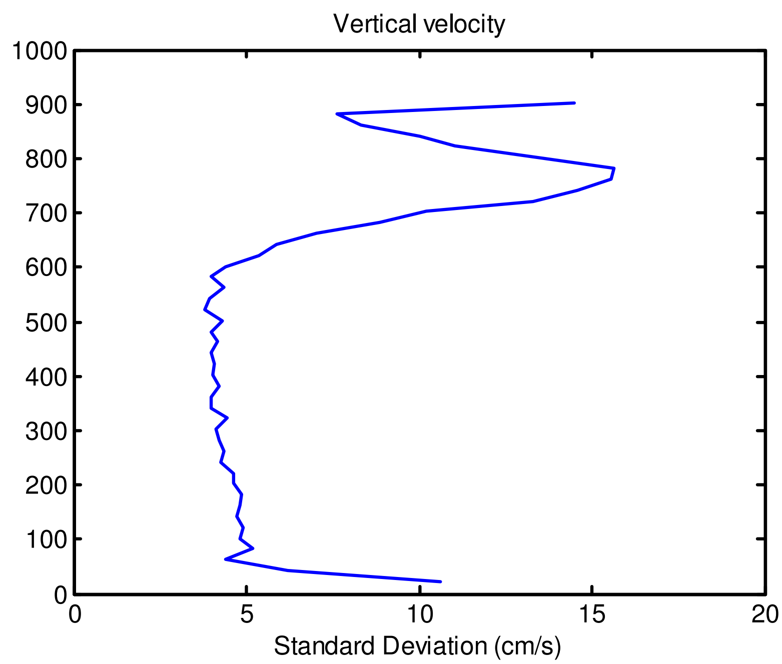

Figure 20. Vertical velocity standard deviation. Eliminating transients makes the vertical velocity nearly uniform up to 600 m above the Signature 55. Compare with Figure 6.