

TRIAXYS™ Acoustic Doppler Current Profiler Comparison Study

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Figure 1. Nortek ACP mounted in TRIAXYS™ Directional Wave Buoy Hull

Abstract:

A field trial was conducted during the summer months of 2004, off the West Coast of Vancouver Island comparing ADCP measurements from a buoy-based platform and two bottom based installations in about 45m depth. The buoy-based instrument was a Nortek 600KHz Aquadopp™ Acoustic Current Profiler (ACP) downward looking unit, integrated into the hull of a 1m diameter TRIAXYS™ Directional Wave Buoy. The two bottom mounted units were a Nortek 600KHz ADCP and an RDI 300KHz ADCP™. Post recovery data analysis compared both bin averaged depths (10-15m and 20-25m) with no tidal correction and a set of corrected bin alignments for tidal height effects from which direct comparison of data was completed. The TRIAXYS™ mounted ACP data agreed with the bottom mounted units typically to within 4-5 cm/s for velocity and to within 3-5 degrees for direction for depths down to 30m. For the trial period, maximum wave heights to 2.5m were measured, with no significant effect on ACP measurements.

Introduction:

A TRIAXYS™ Directional Wave Buoy was fitted with a Nortek Aquadopp™ 600 KHz Current Profiler in a downward looking configuration as shown in Figure 1. From July 14 to August 16, 2004 the TRIAXYS™ Buoy was deployed in the Pacific Ocean off the west coast of Vancouver Island near Ucluelet, B.C., Canada at 48° 55.50' North Latitude by 125° 34.13 ' West Longitude. Nearby at 48° 55.52' North Latitude by 125° 34.17 ' West Longitude a bottom mooring, consisting of an upward looking Nortek Aquadopp™ 600KHz Current Profiler and an upward looking RDI Workhorse Sentinel 300KHz ADCP™ was deployed. The Nortek and RDI Instruments were spaced 100m from each other, with the instruments moored at 45m depths. The location of the trial was selected to determine if there was any detectable difference in measuring vertical profile currents with an Acoustic Current Profiler integrated into a moored surface buoy (slack line mooring) versus a static bottom mounted mooring, under a range of wave climate regimes. The location was on the western margin of the Pacific Ocean and provided both swell and chop conditions during the trial period.

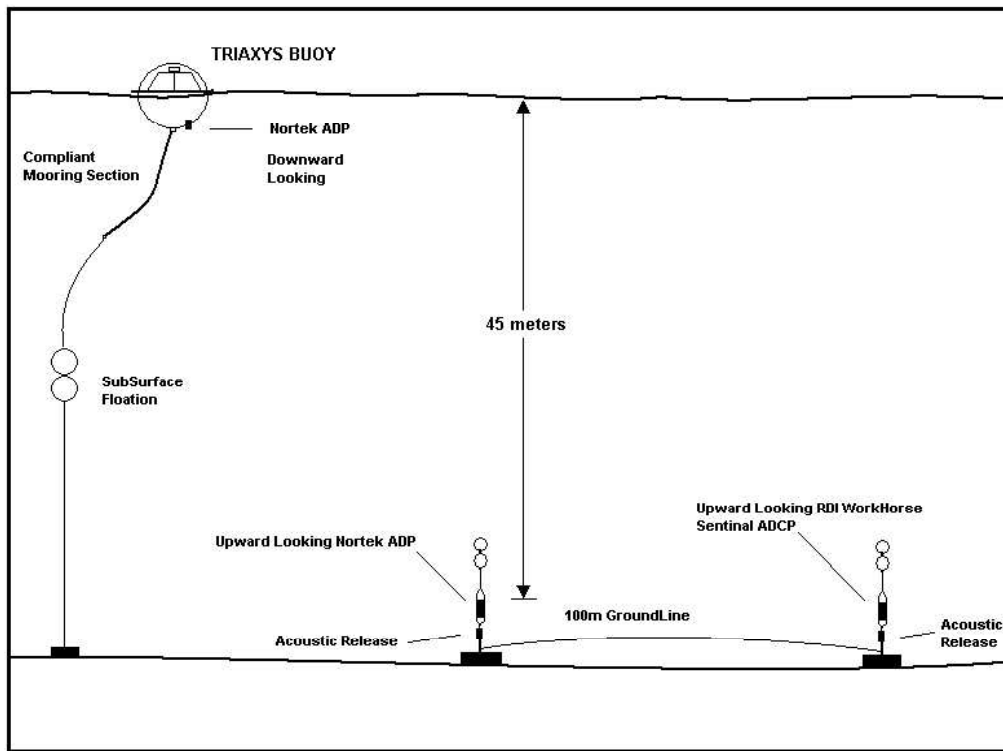


Figure 2. Mooring Configuration

The systems for the trial were configured as follows:

Instrument	Ping Ensemble (seconds)	Sampling Interval (minutes)	Orientation
TRIAXYS™ Nortek 600 KHz ACP	300	30 (15/45 of hour)	Surface-downward
Nortek 600 KHz Aquadopp	300	60 (bottom of hour)	Bottom-upward
RDI 300 KHz ADCP™	600	60 (top of hour)	Bottom-upward

The sampling times of the bottom mounted Nortek and RDI Current Profilers were offset to eliminate the possibility of signal interference between the two instruments. The data from both the bottom-mounted units was logged to internal RAM and downloaded at the end of the trial.



Observations:

Since the TRIAXYS™ Buoy is floating and rising up and down with the tidal fluctuation (range of about 4 metres), average of currents within a 5 meter depth bin (Figure 14), for two specific depth ranges were selected. Specifically, 20 to 25 m depth and 10 to 15m depths. The 20 to 25m bins was mid-water range since the depth of the study site was at about 45 metres. Readers of this report should be aware that references are made for depth (m) from the surface and for depth from the bottom, depending on whether the surface unit or bottom units are the reference datum.

A secondary examination was completed by correcting the TRIAXYS™ Nortek data for tidal elevations, into the corresponding bin depths of the Nortek Bottom upward looking ACP.

Examination of the average Standard Deviations (n=>350 RDI/350Nortek records) of current velocity profile measurements showed the following trends as supported by Figures 3,4,5, where corresponding data sets for time alignment to the TRIAXYS™ Nortek were compared:

- Current Profiles measured from the TRIAXYS™ Buoy were typically anomalous below ~42m depth, with a peak anomaly at the 30m depth.
- Reliability of the measurements for the bottom mounted current metres were similarly anomalous for the depths from 5 or 6 metres depth to the surface.

This is consistent with near surface or near bottom signal contamination due to overwhelming of the side lobe suppression of the ACP transducer. From this phenomenon, the maximum range of valid data can be calculated by:

$$R_{max} = D \times \text{Cos}(\theta) \quad (RD \text{ instruments, } 1996)$$

where:

Rmax is the maximum range for acceptable data.

D is the distance from the ACP to the surface or bottom (whichever is appropriate)

Theta is angle of the beam relative to the vertical.

Given that the 300 KHz RDI ADCP™ beam angle is 20 degrees and the surface ranged from 43 to 46 metres with the tide, therefore the theoretical maximum range would be in the order of 40 to 43 metres.

Given that the 600 KHz Nortek Aquadopp™ Profiler beam angle is 25 degrees and the surface ranged from 43 to 46 metres with the tide, therefore the maximum range would be in the order of 39 to 42 metres.

The above calculation is consistent with the observed profile of Standard Deviations.

The TRIAXYS™ Buoy Nortek ACP standard deviations and differences with the bottom ACP's increase and vary at depths below 30 metres.

Results 10-15m and 20-25m depth average bin comparisons.

Figures 6 and 7 show the concurrent time series of the 3 profilers' current speeds for the 20 to 25 meter depth bins and 10 to 15 meter depth bins. Figure 8 shows the concurrent time series of the 3 profilers' current directions for the 20 to 25 meter depth bins. These time series show that the 3 profilers track each other closely.

Figures 9, 10,11 and 12 show how closely the 3 current metres track each other. These figures show the difference between the average to the 2 bottom Acoustic Current profilers and the TRIAXYS™ ACP profiler. It can be seen that the differences between the Surface and Bottom profilers is in the range of +/- 0.05 m/s (+/- 5 cm/s). These figures are overlaid with the

concurrent Significant Wave Height (Figures 9 and 10), Wave Steepness (Figure 11) and Wave Direction (Figure 12), which demonstrate quite clearly that the wave climate was not a factor causing the observed differences between the surface and bottom profilers.

Figures 13 and 14 show the cumulative percent occurrence of differences within the time series. They show that about 95 percent of the differences were less than 0.1 m/s (10 cm/s) and 70 to 80 percent of the differences were less than 0.05 m/s (5 cm/s).

Comparison of Depth Corrected and Time Aligned Data

In order to examine the TRIAXYS™ downward looking Nortek with the upward looking bottom Nortek, in a bin depth to bin depth correspondence, it was necessary to align the depths according to the observed tidal elevation changes at each sample time. (See Figure 15). This was done by using the bottom Nortek pressure sensor readings to adjust the surface current meter bins to match those of the bottom. Secondly, because the TRIAXYS Nortek sampled every one half hour (at 15 and 45 minutes past the hour) we averaged the half to half hour velocities to obtain an hourly average at the top of the hour. The bottom Nortek sampled on the half hour, from which successive readings were averaged to obtain an average velocity corresponding to the top of the hour.

Figures 17 to 21 show a comparison between concurrent TRIAXYS™ Nortek and the bottom Nortek velocity and direction profiles for a few representative times during this study. Figure 22 to 24 show a similar comparison between the Nortek and RDI concurrent velocity and direction profiles. For these profiles, the depths of side lobe contamination for the surface layer measurements and the TRIAXYS™ Nortek contaminated data from below 30 metres depth (15m from bottom) were not plotted. The plots show that the TRIAXYS™ Nortek profiles and bottom Nortek profiles and RDI profiles appear to match each other closely, especially during times of peak flood and ebb currents. As expected, during times of tidal current changes, the velocities become weak and directions are more variable (see Figures 20 and 22).

Figure 25 shows a depth profile of the average of absolute differences of velocities between the TRIAXYS™ Nortek and the bottom Nortek ACP's for the entire study. Similarly, Figure 26 shows a depth profile for the average of Absolute Differences of velocities between the bottom Nortek ACP and the RDI ADCP™ for the entire study. The increase in differences at the surface can be attributed to side lobe contamination in the bottom ACP's. The increase in the differences at the bottom is not so clear. It appears that for the downward looking TRIAXYS™ Nortek ACP there is something causing an increase in differences at about 30 metres depth (15 metres from the bottom). There are also some anomalous data in the first RDI ADCP bin that is causing a difference between the bottom Nortek and RDI. These profiles show the average difference between the RDI and Nortek was about 3-5 cm/s. The difference between the downward looking TRIAXYS™ Nortek and the bottom Nortek in the depths from 5 to 30 metres (15 to 37 metres from the bottom) was on the order of 4-5 cm/s. For these depths it would appear that the differences between the downward looking TRIAXYS™ Nortek ACP is only slightly more than the difference between the two bottom ACPs. It is likely the slight difference could be explained by the physically spatial differences of the deployment positions and perhaps the primary difference is due to the relative accuracies of the ACPs themselves. That is to say, if the quoted accuracies for each ACP velocities is +/- 1 cm/s (i.e. a range of 2 cm/s), then we could expect average differences to be in the order of 2 cm/s. Which is very close to what we have observed.



Acoustic Signal Interference in TRIAXYS™ Nortek ADP Data :

There was a significant increase in differences below 30 to 40 metres depth (or 5 to 15 metres above the bottom) between the TRIAXYS™ Nortek and the bottom mounted ACP units, for both velocity and direction data. This poorer correlation could be attributed to a number of factors including:

- Site specific (temporal-spatial) differences (differences in flow due to location and time)
- Differences observed near the surface and bottom are expected, and likely caused by acoustic side lobe contamination.
- Reduced effective range due to acoustic contamination.
- Acoustic beams hitting the TRIAXYS™ mooring components.
- low velocity drift of the surface buoy around its mooring (from wind, Ekman currents or wave orbital velocities (Stokes)).

The effective range due to acoustic contamination is stated as a function of the beam angle of the ADP. Our data has shown that the TRIAXYS™ ACP had a maximum range (Rmax) of about 30 metres, in a water depth (D) of 45 metres.

i.e.

$R_{max} = D * \cos(\theta)$. Therefore, $\cos(\theta) = R_{max}/D$

As a result,

$\cos(\theta) = 30m/45m$

Then,

$(\theta) = \arccos(.75)$

and finally,

$(\theta) = 47^\circ$

The observations for the system deployed in 45 metres depth, with an Rmax of 30 metres, results in a apparent acoustic beam angle θ of 47° . The fixed beam angle of the Nortek 600 KHz ADP is 25° , with a difference of 22° between the apparent and the fixed beam angles.(i.e. $47^\circ - 25^\circ = 22^\circ$) This may be due to the TRIAXYS™ ACP pitching and rolling at the surface possibly causing an increase in the effective acoustic beam angle. The 22° difference indicates that the TRIAXYS buoy may have an average pitch and roll on the order of $\pm 11^\circ$. Examination of the raw TRIAXYS™ sensor data, shows the maximum instantaneous pitch and roll displacements are in the order of 9 to 11° . Figure 30 is an example of the instantaneous pitch and roll data recorded July 17 at 00:00:00Z. Figure 31 shows a time series of the Rmax range data as determined by taking the depth at the maximum velocity difference between adjacent bins occurs. The depth maximum difference is a indicator of how the maximum range of the TRIAXYS™ ACP varies with time. The depth of Rmax difference oscillates in an essentially random manor. No correlation was found when comparing Rmax with wave heights, periods and directions. The randomness of pitch and roll of the TRIAXYS™ buoy is due to the nonlinear combination of sea state parameters and there interaction with the buoy and mooring.

Figures 27 and 28 are plots of average differences between adjacent bin depth pairs from the bottom to the surface. Figure 27 shows the TRIAXYS™ Nortek with an anomaly occurring at 10 to 15 metres from the bottom (30-35m depth). This does not appear with the bottom Nortek ACP. The bottom Nortek ACP does clearly show the effects of surface side lobe contamination in Figure 28. The specificity of the difference at 10 to 15 metres from the bottom (30-35m depth) for the TRIAXYS™ Nortek ACP is further evidence of some sort of contamination of ACP signals at these depths.

Figure 29 is a profile of average differences in current directions between the surface TRIAXYS™ Nortek ACP and the bottom Nortek ACP. The effects both the surface and bottom acoustic contamination is observed. The data suggest that for the depths not contaminated, agreement of directions is on the average better than 5 degrees between the surface and bottom Acoustic Current Profilers.

This study has identified a number of areas for further examination including:

- Ensure that all instruments are set to identical averaging intervals;
- Need to collect raw ping data on the TRIAXYS™ Nortek ACP for future studies;
- Program should expand to include measurements in higher sea states.

Conclusions:

- The TRIAXYS™ Nortek Aquadopp™ velocity magnitudes agreed with the bottom mounted ADCP™/ACP profilers within 4-5 cm/s, with the average difference of about 4 cm/s.
- The TRIAXYS™ Nortek ACP direction measurements agree with the bottom mounted profilers to within 5 degrees, with the average difference being less than within 3 degrees.
- The wave heights (to 2.4 m Hs) experienced during the trial did not affect the current velocity or direction data between the TRIAXYS™ Nortek ACP and the bottom-mounted units.
- The downward looking TRIAXYS™ Nortek had a maximum range on the order of 20 to 30 metres,
- The differences identified in this study may be due to:
 - Differences observed near the surface and bottom are expected, and are caused by acoustic side lobe contamination,
 - Site specific (temporal-spatial) differences,
 - Instrument errors,
 - TRIAXYS™ buoy and mooring induced velocities.

Acknowledgements:

We would like to thank Nortek AS for providing the Nortek Aquadopp Profiler for testing in the TRIAXYS™ Directional Wave Buoy. Also thanks to Paul Devine of RD Instruments for the extended loan one of their 300Khz ADCP™ Workhorse Sentinels. Many thanks to Dave Fissel of ASL Environmental Sciences Inc. for the loan of there 600 KHz Nortek Aquadopp Acoustic Current Profiler and with Keith Borg of ASL for reviewing some of the data for this report.

References:

RD Instruments. 1996. Acoustic Doppler Profiler. Principles of Operation. A Practical Primer. 2nd Edition. RD Instruments. rdi@rdiinstruments.com

Figure 3.

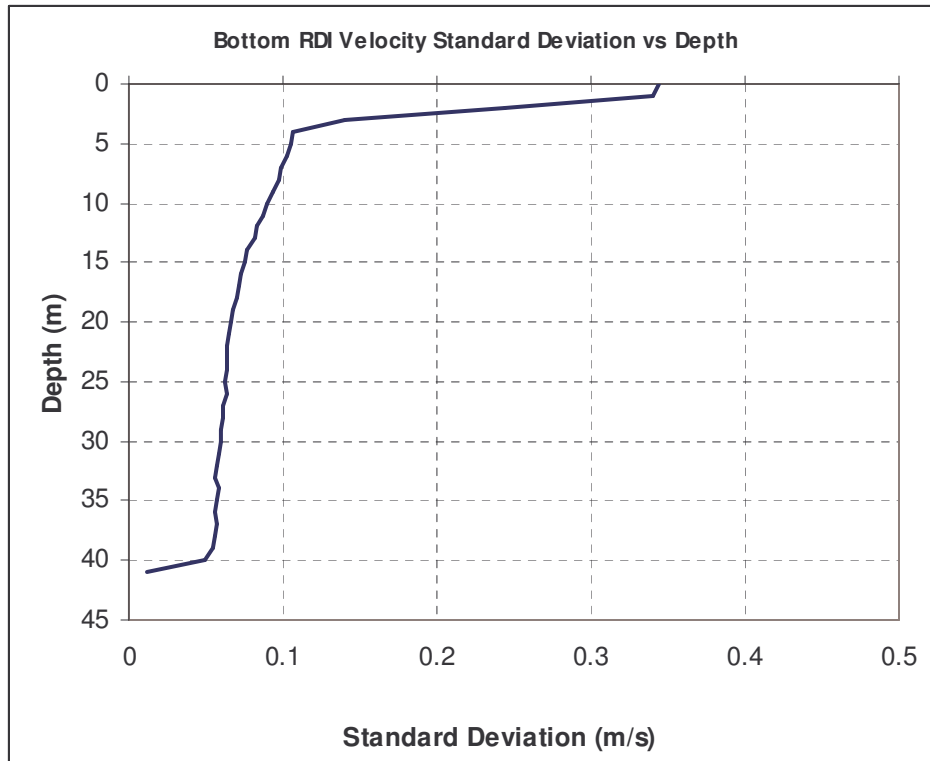


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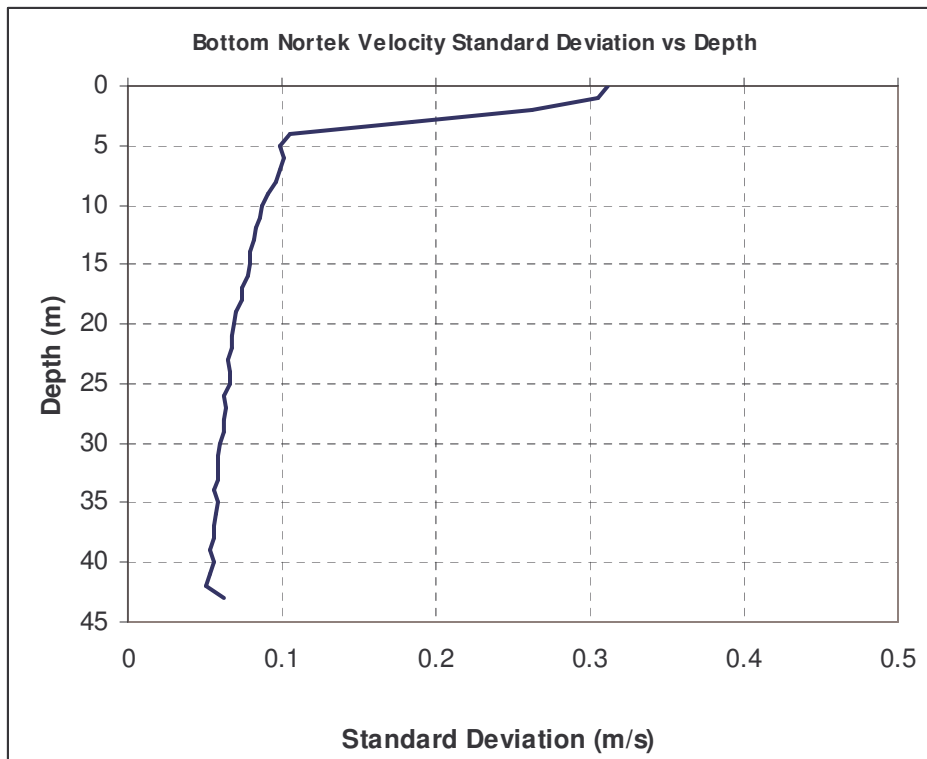




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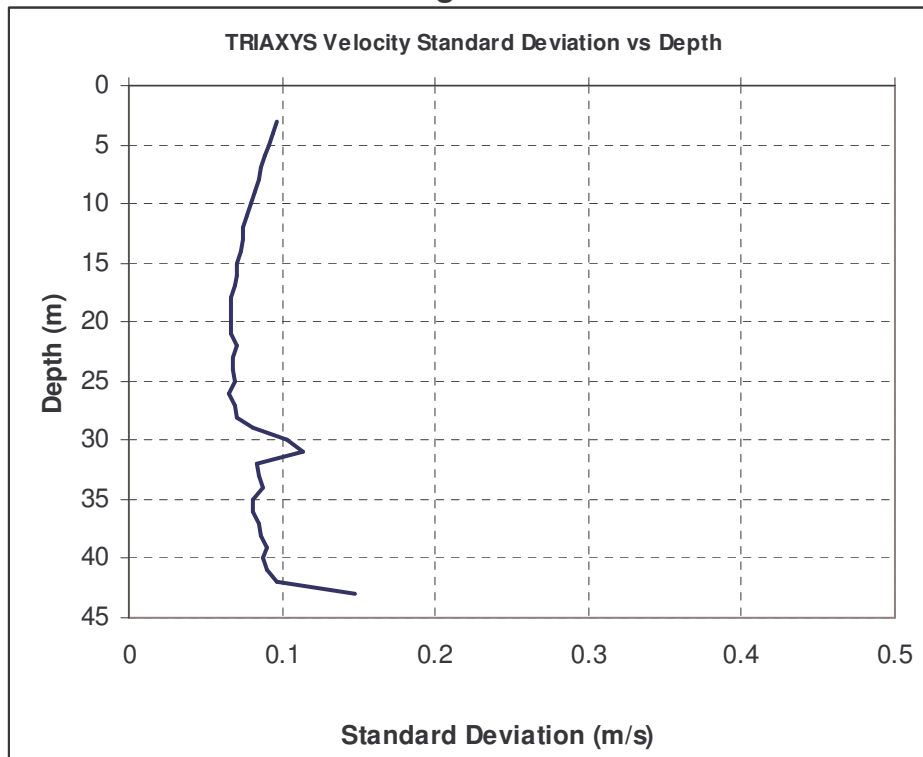


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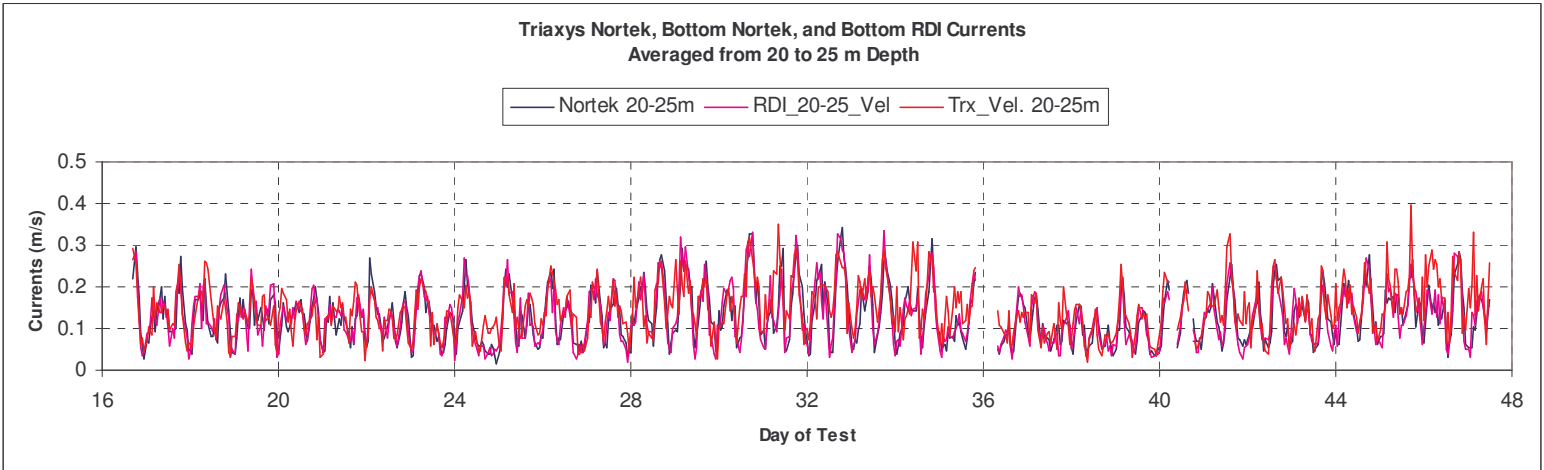


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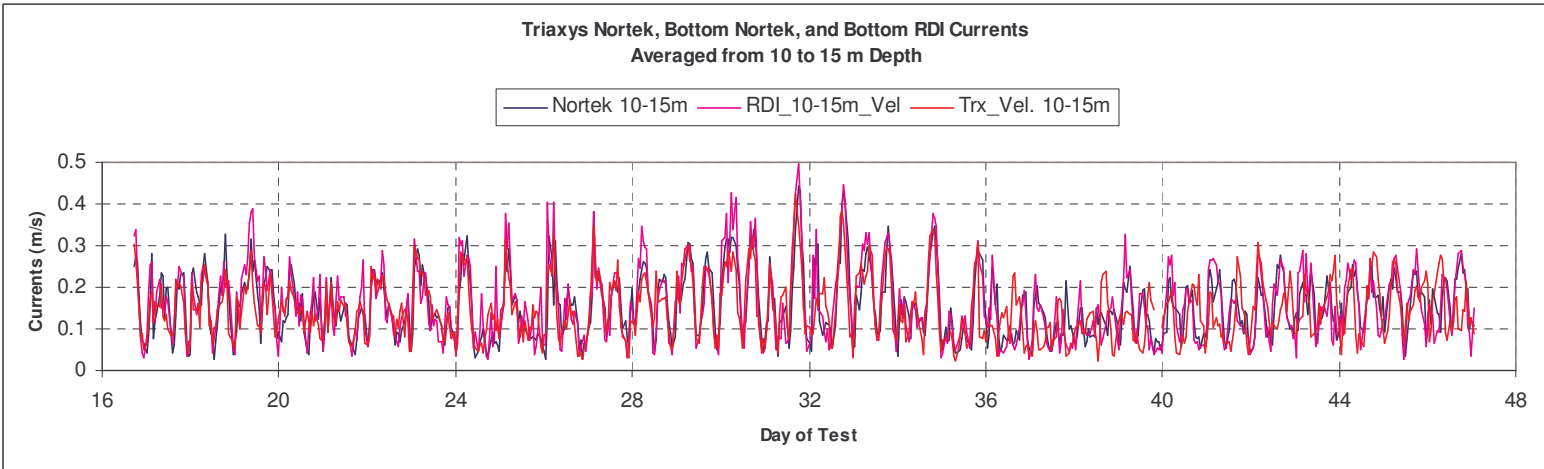


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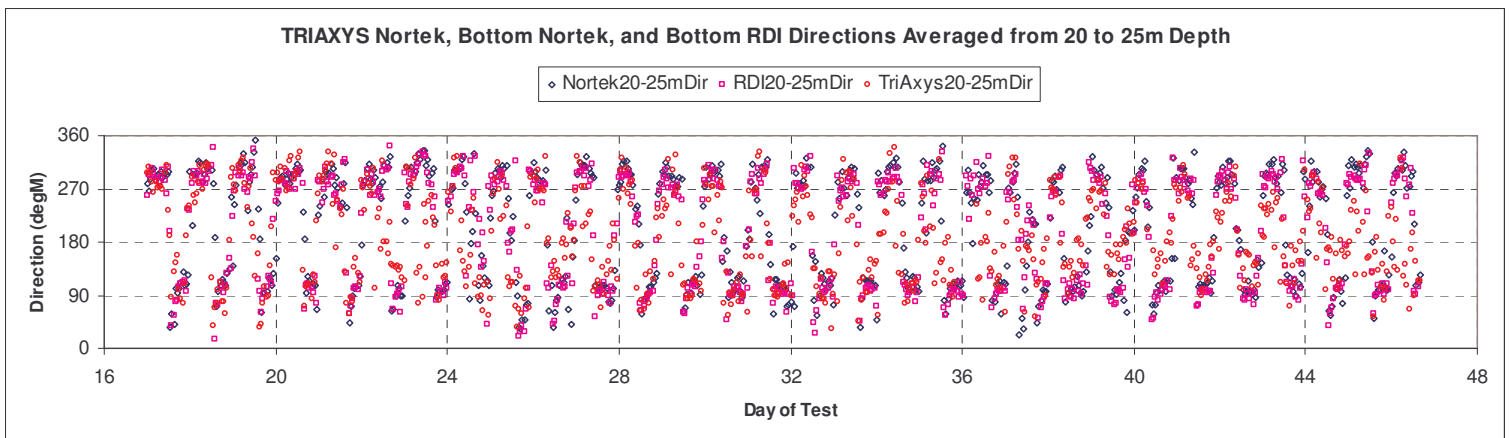




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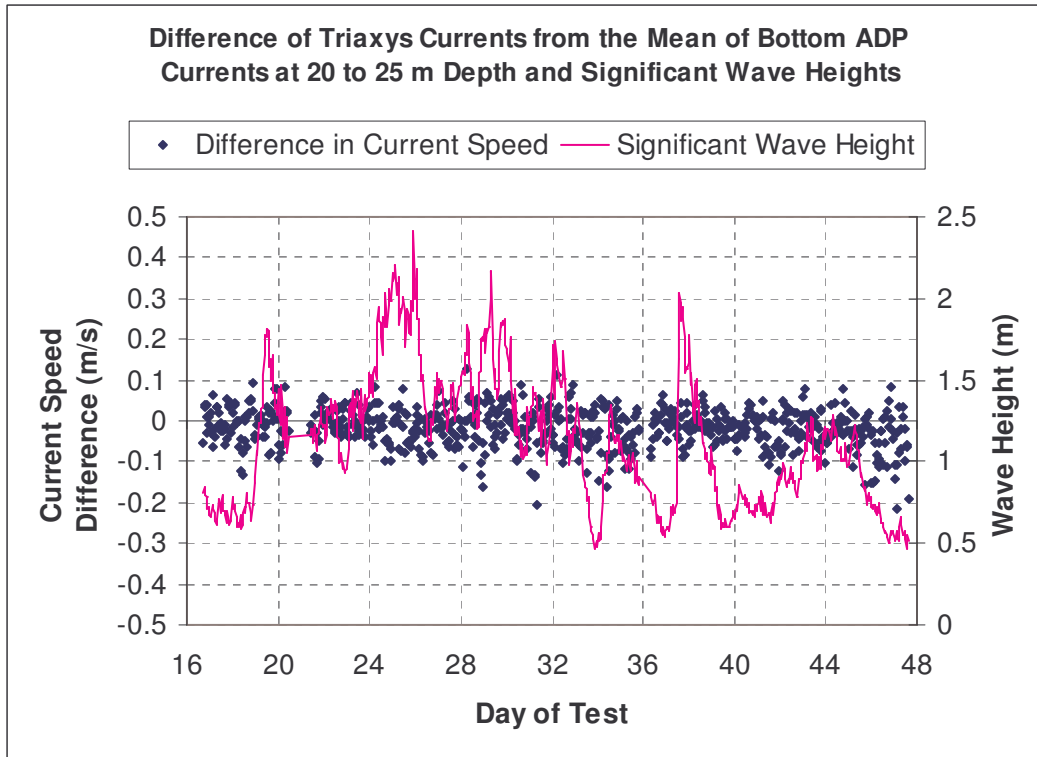


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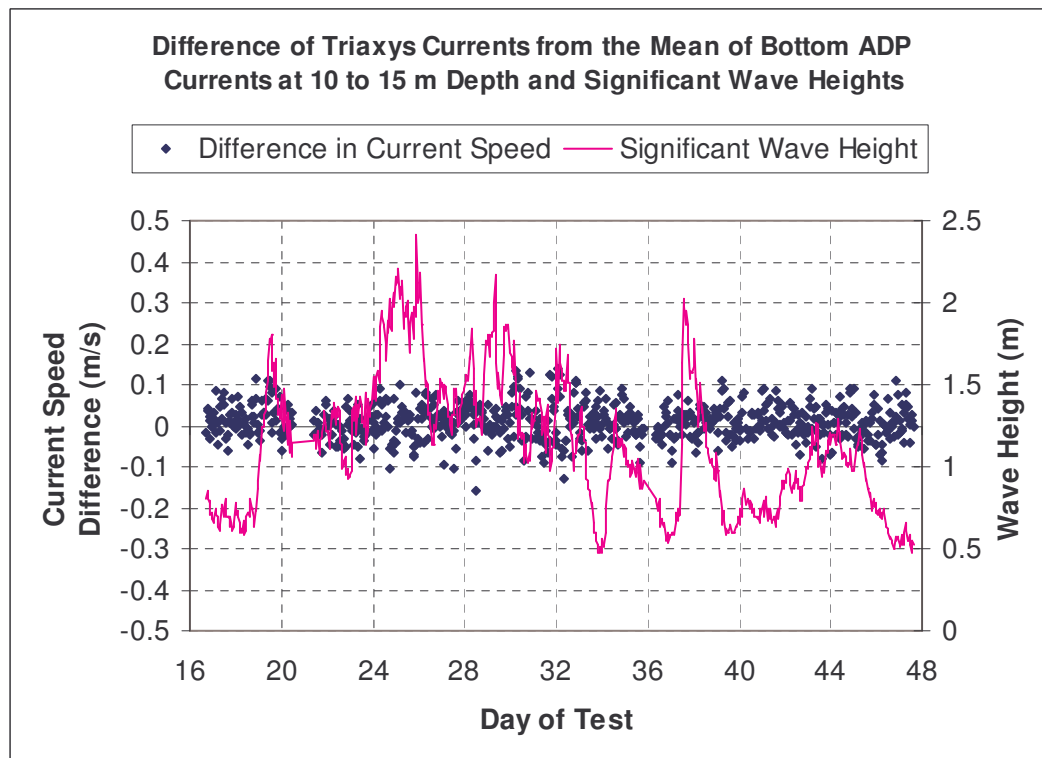


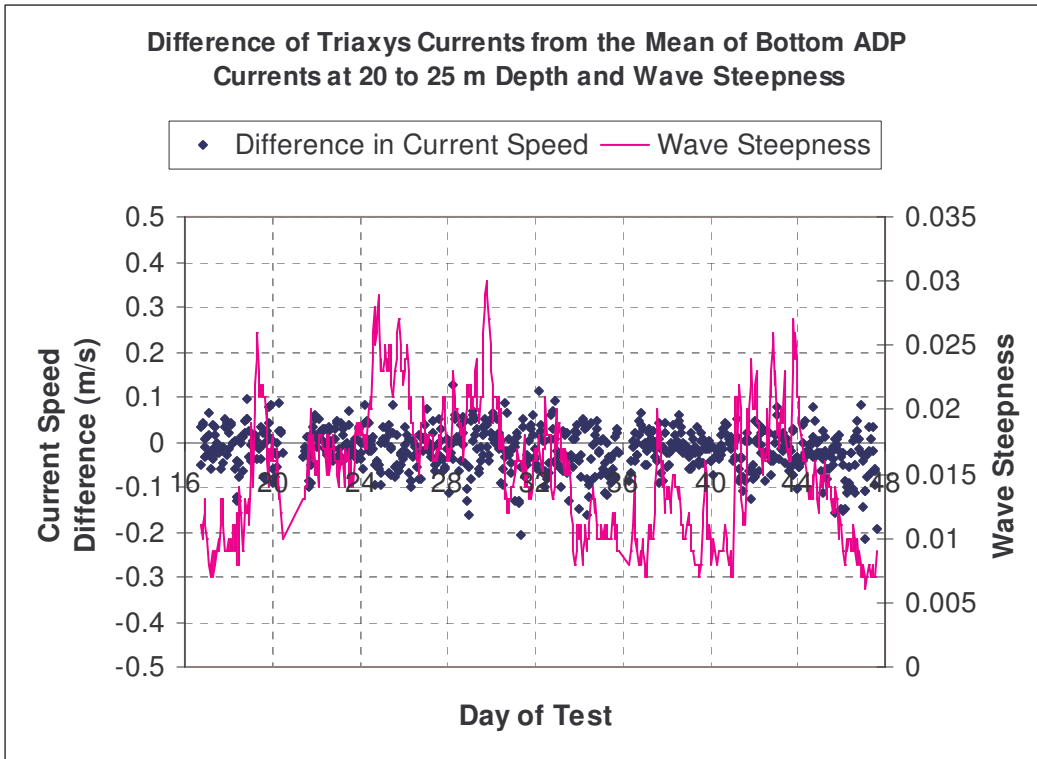
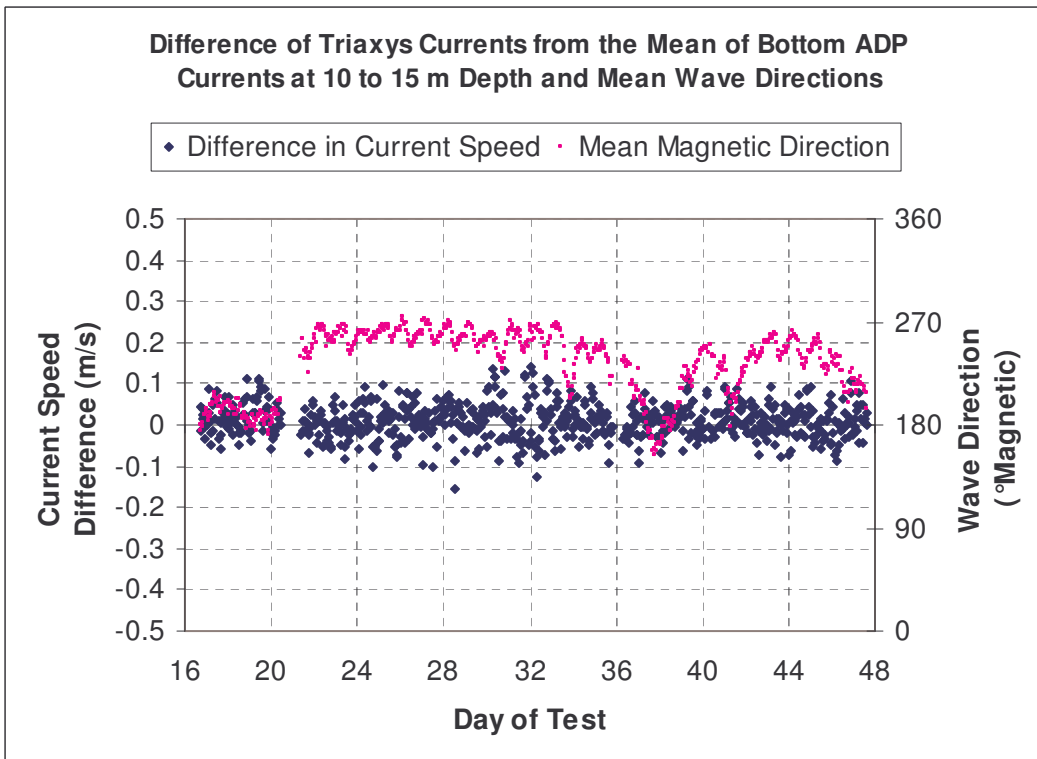
Figure 11.

Figure 12.


Figure 13.

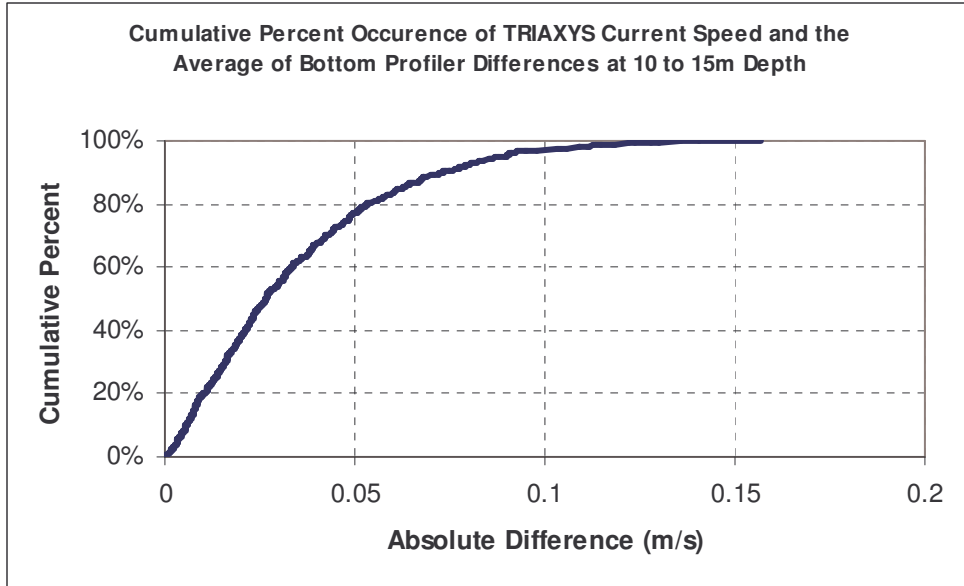


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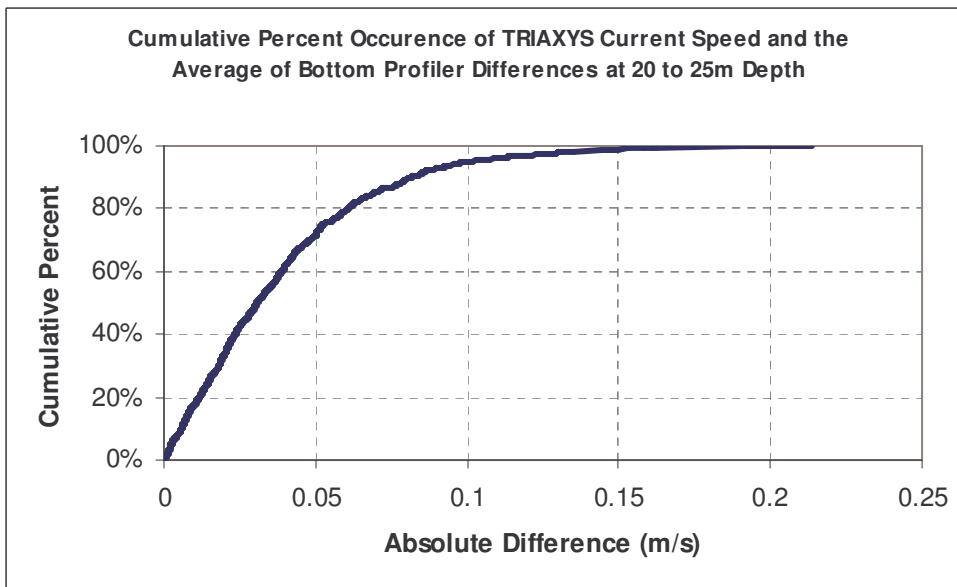


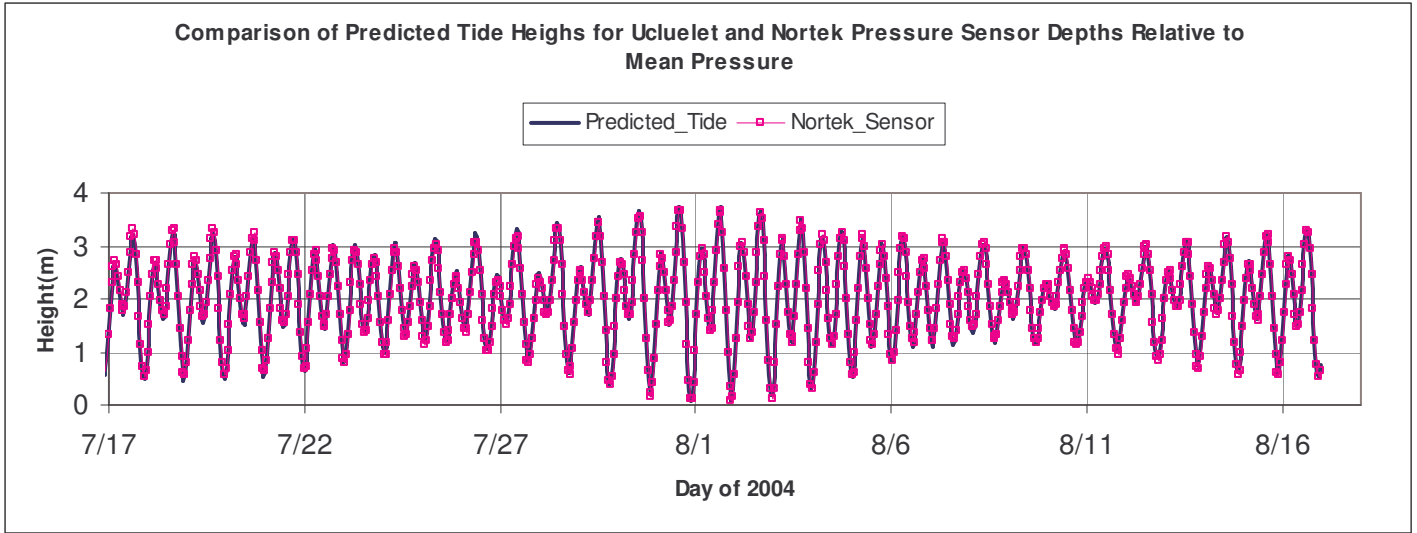
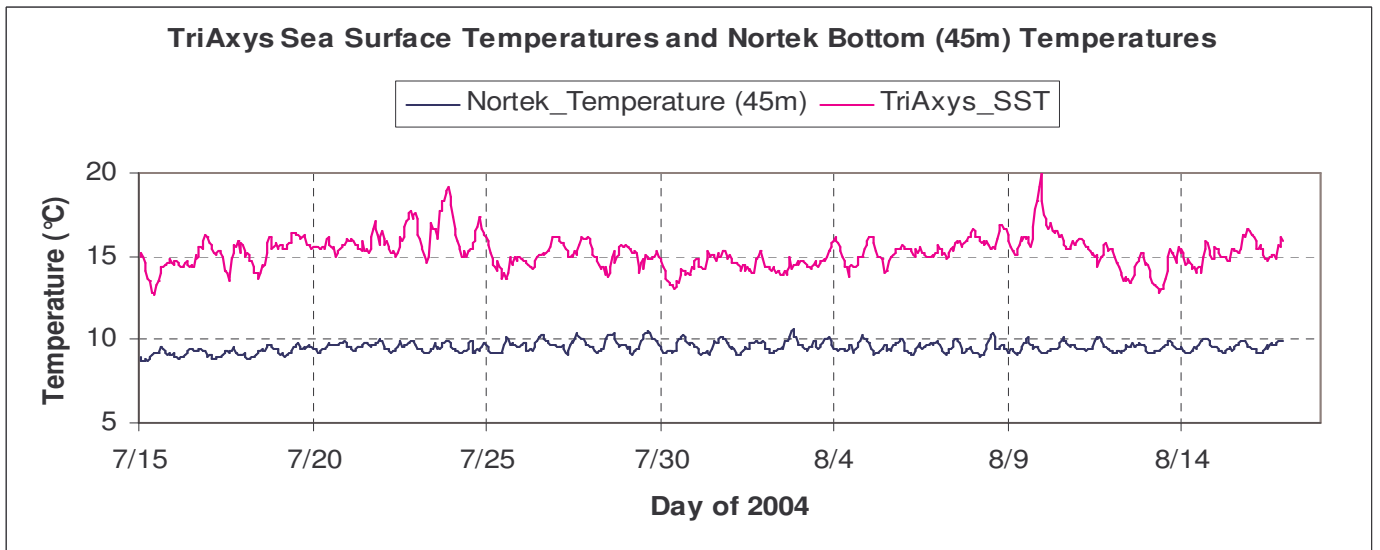
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Figure 16.


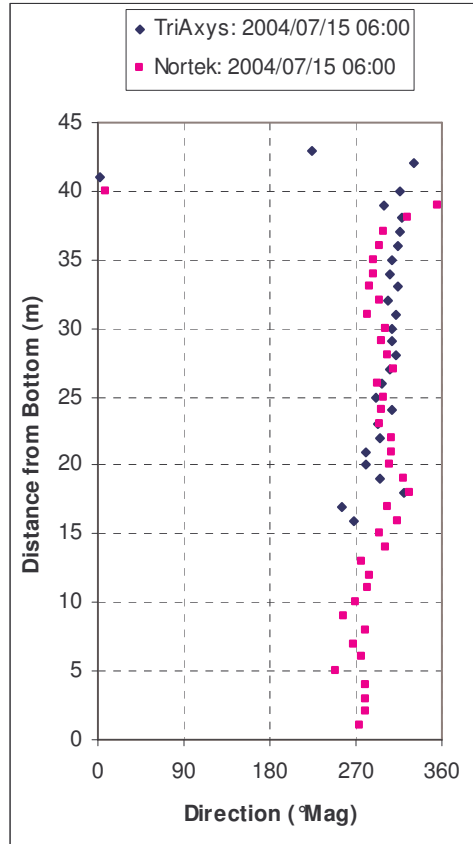
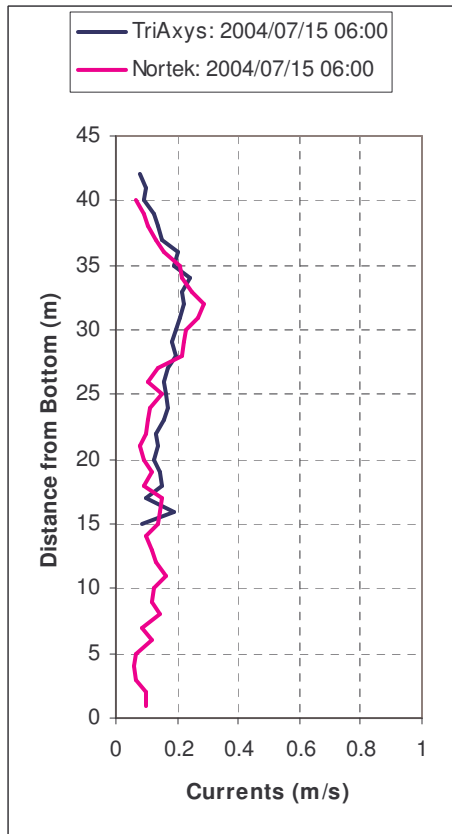
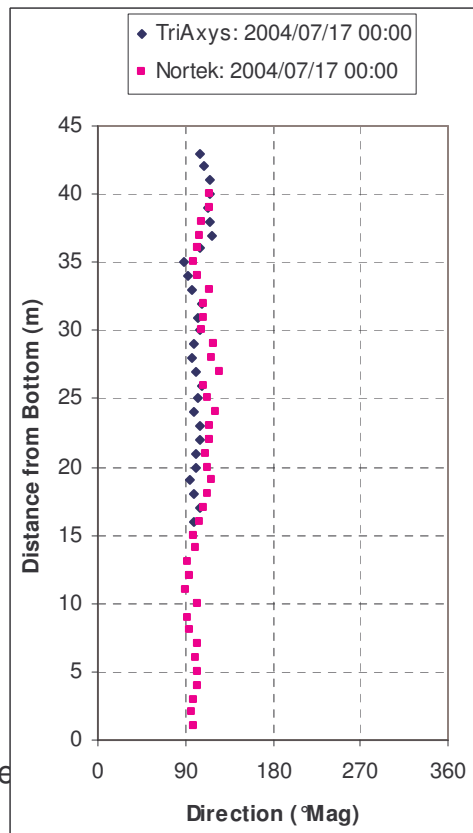
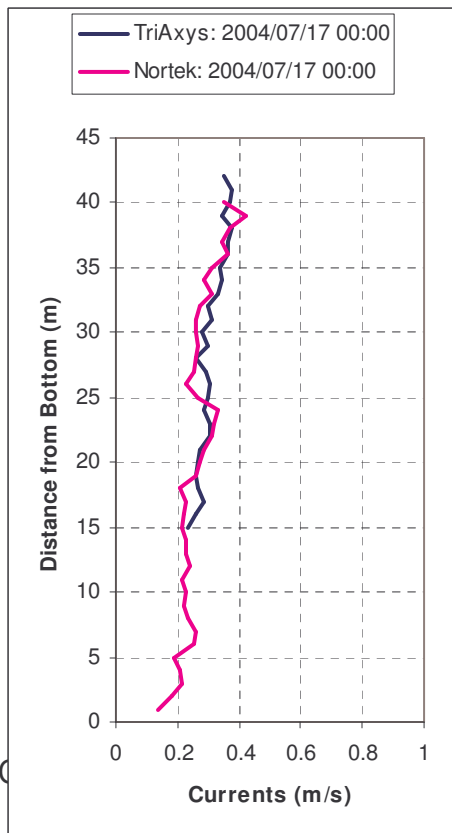
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Figure 18.


Figure 19.

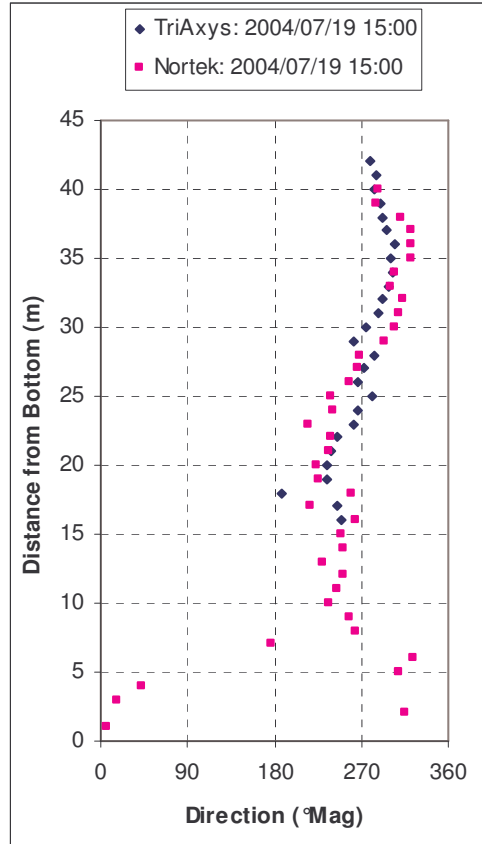
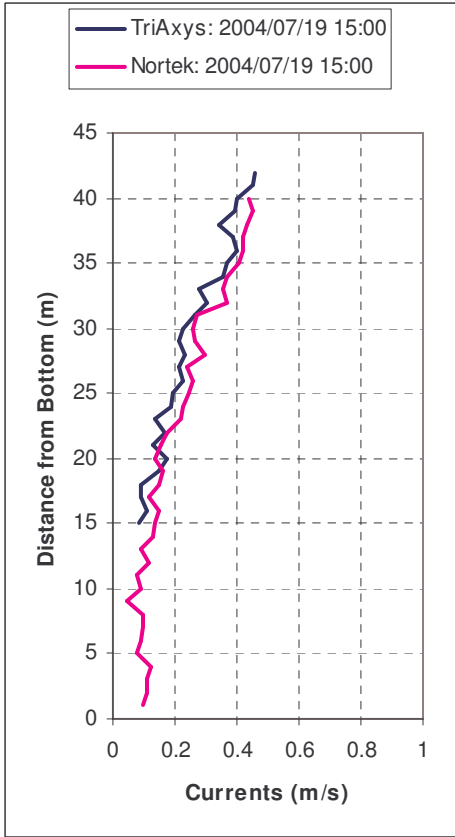


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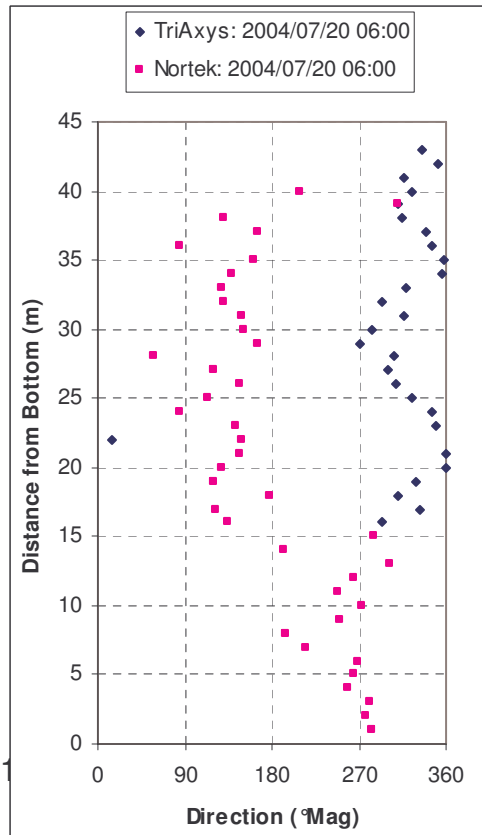
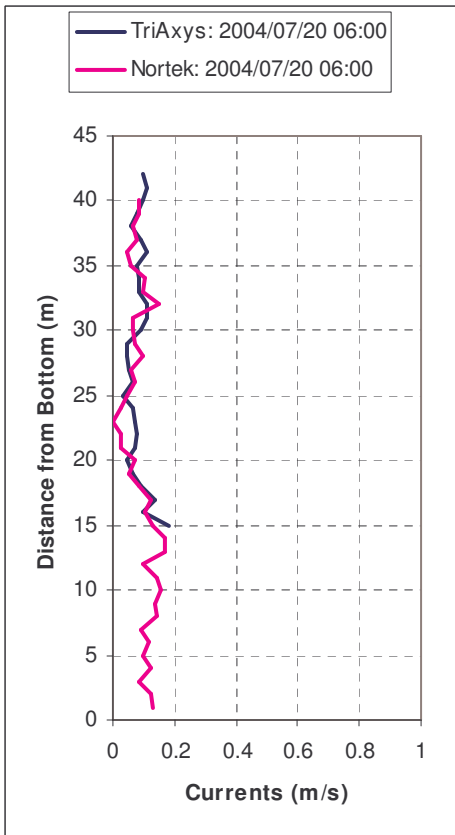


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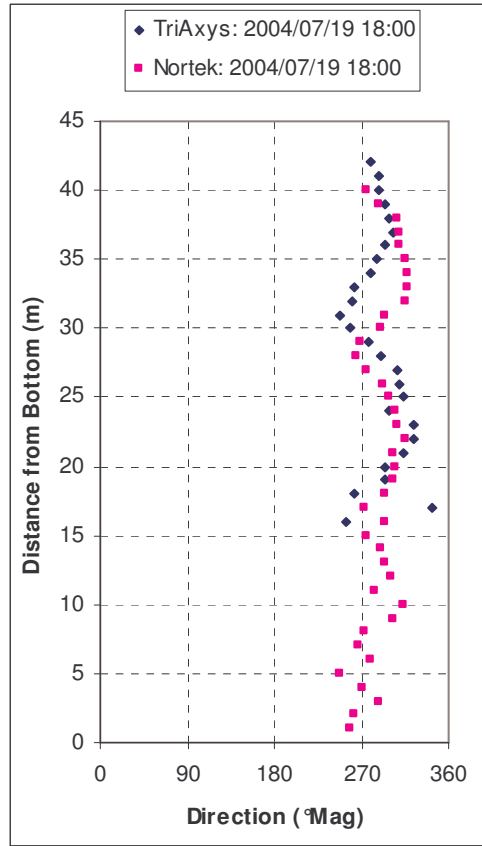
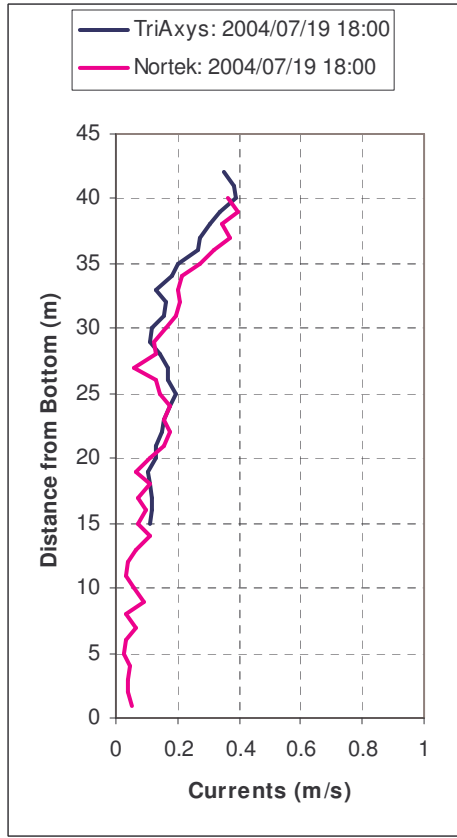


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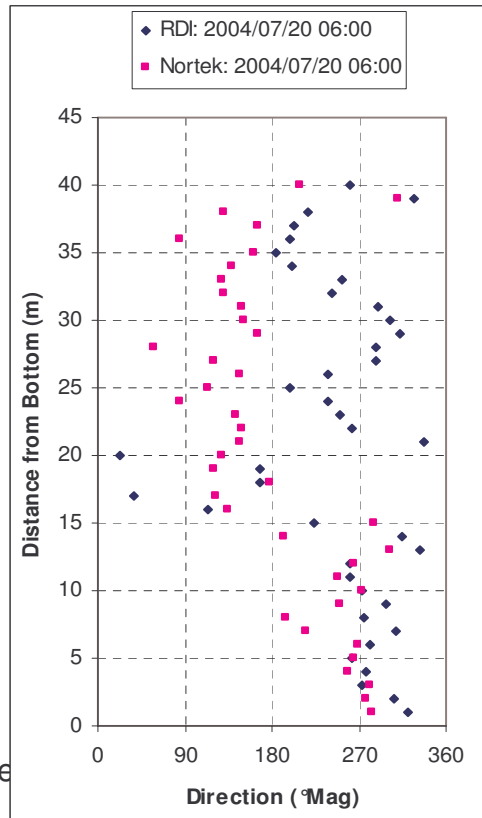
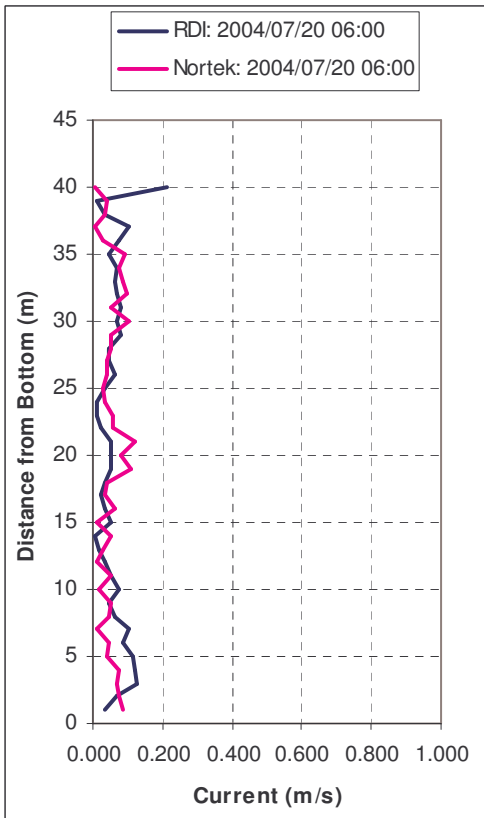




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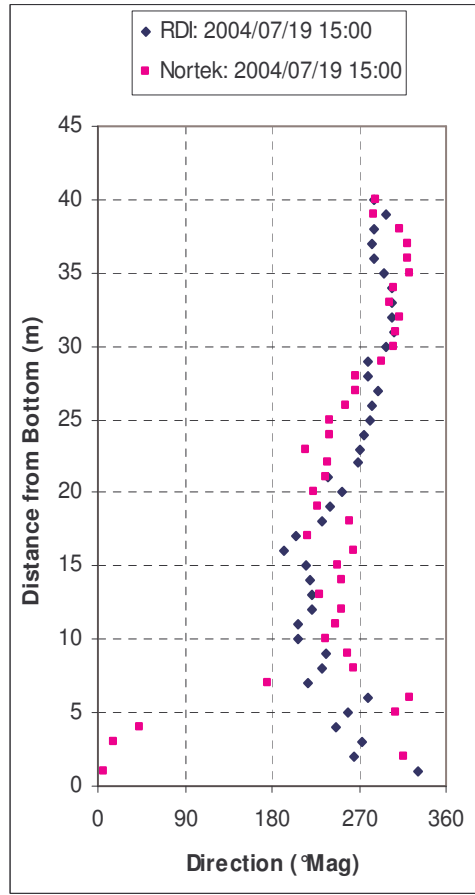
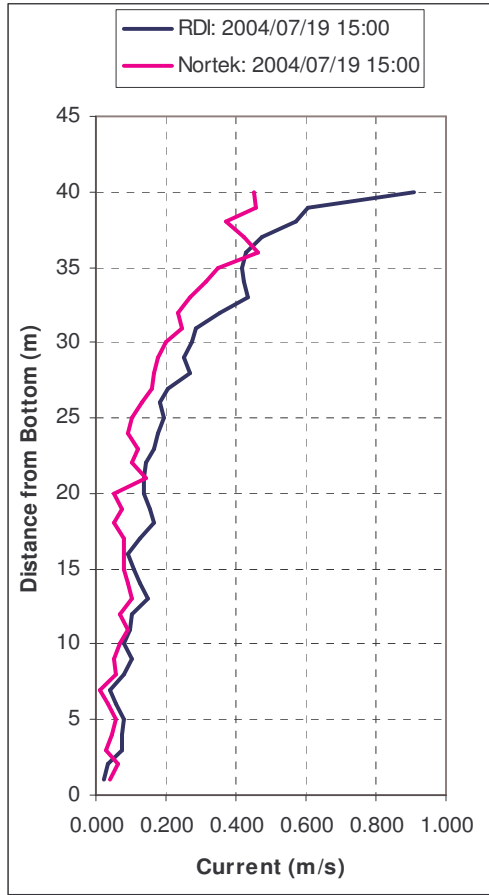


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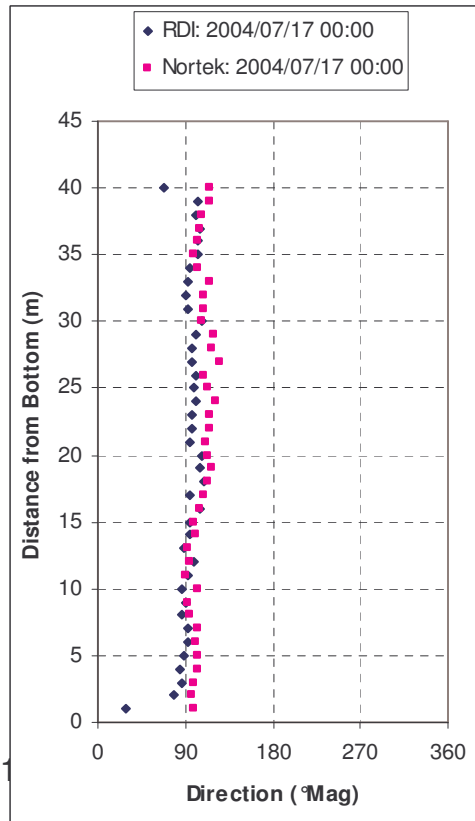
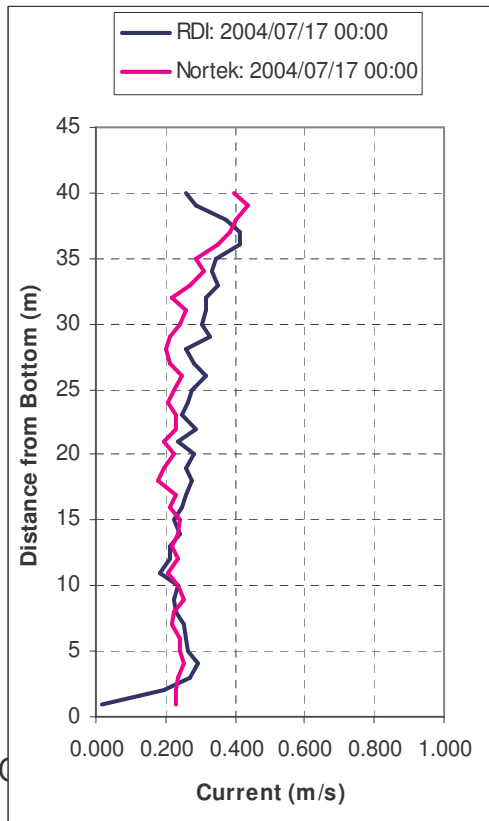


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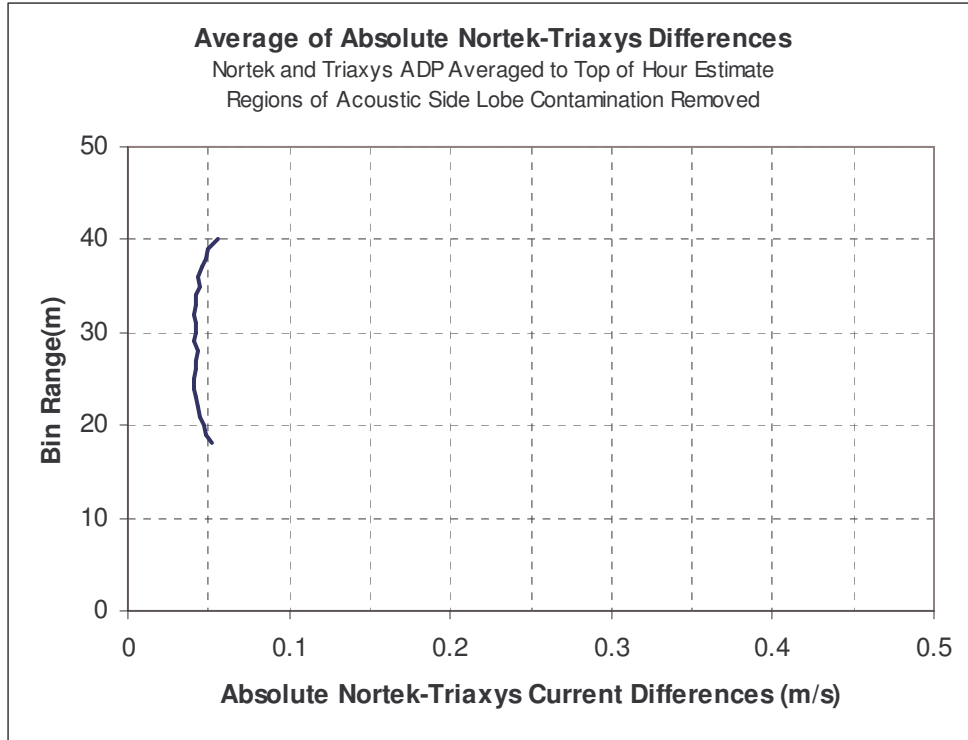


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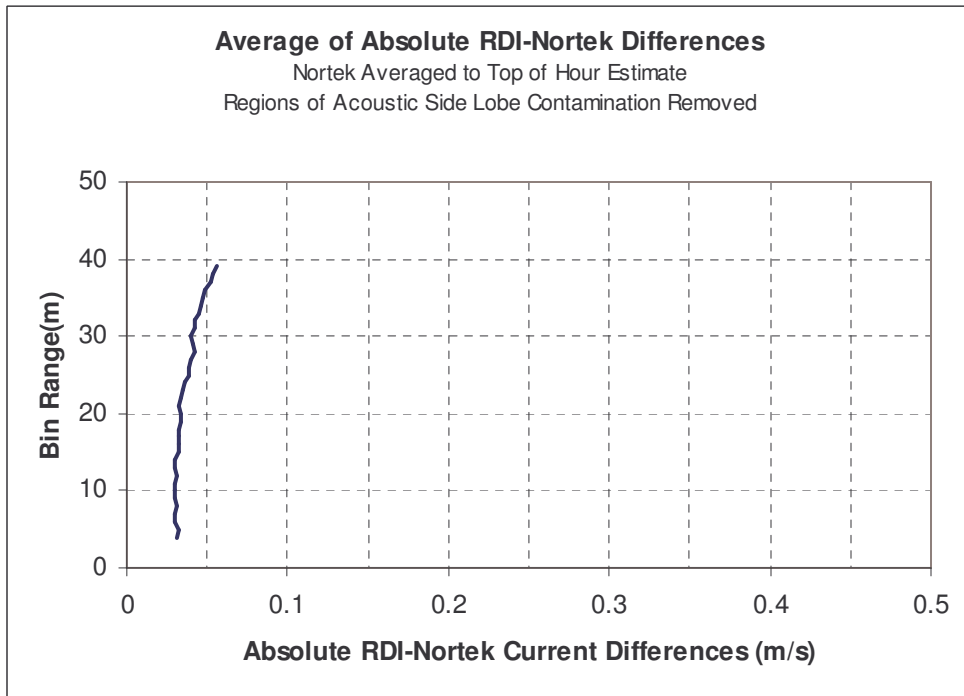




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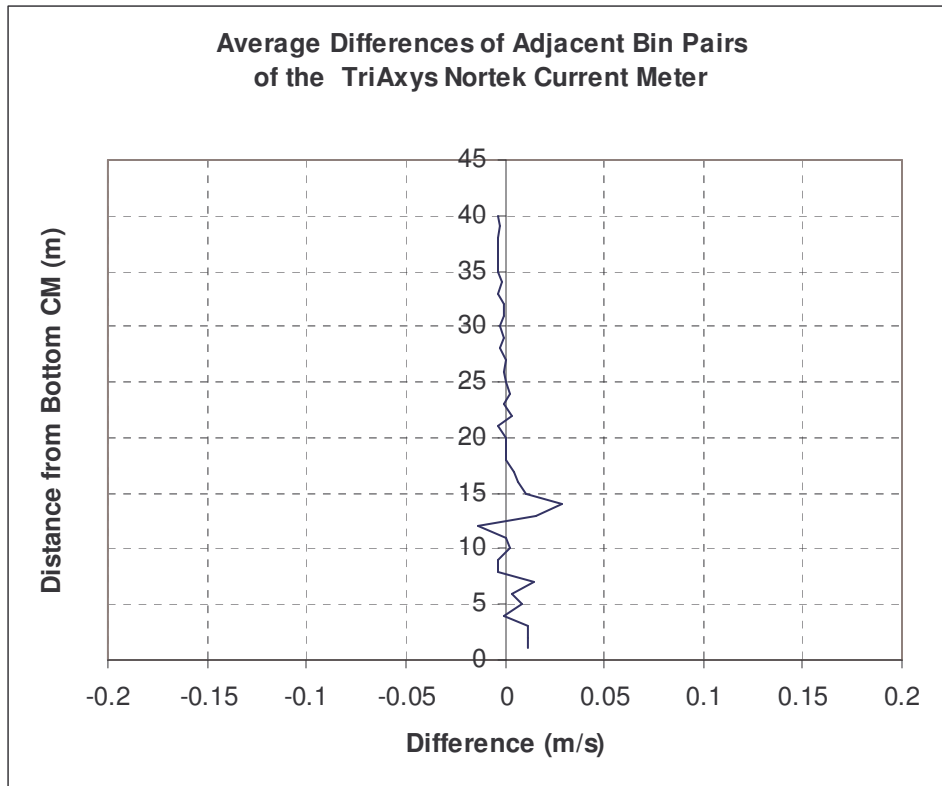


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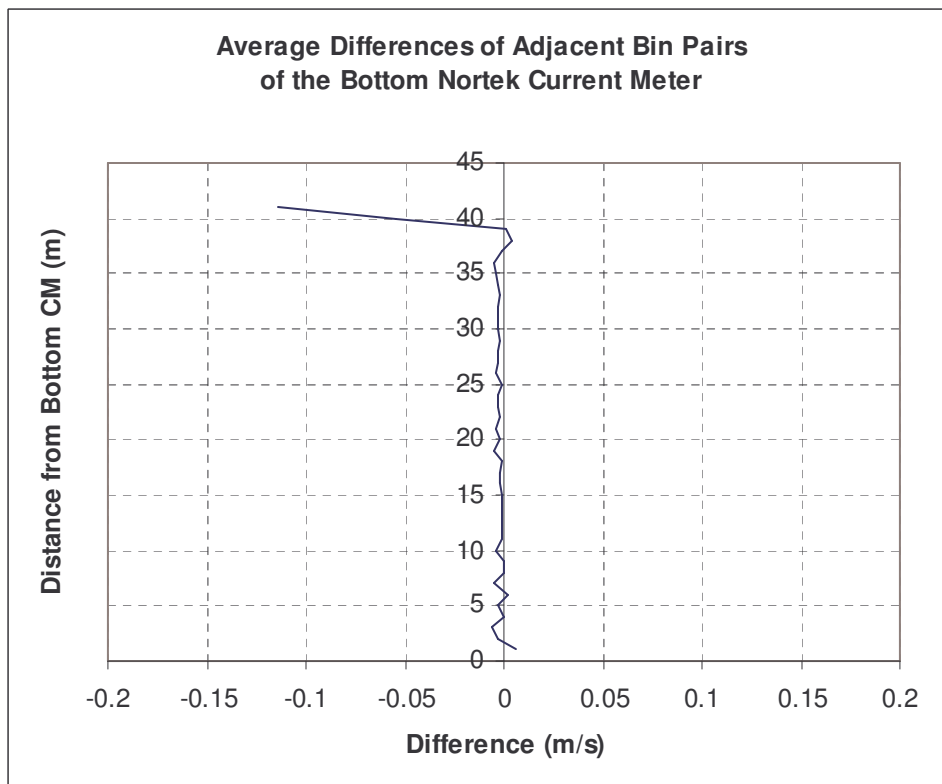


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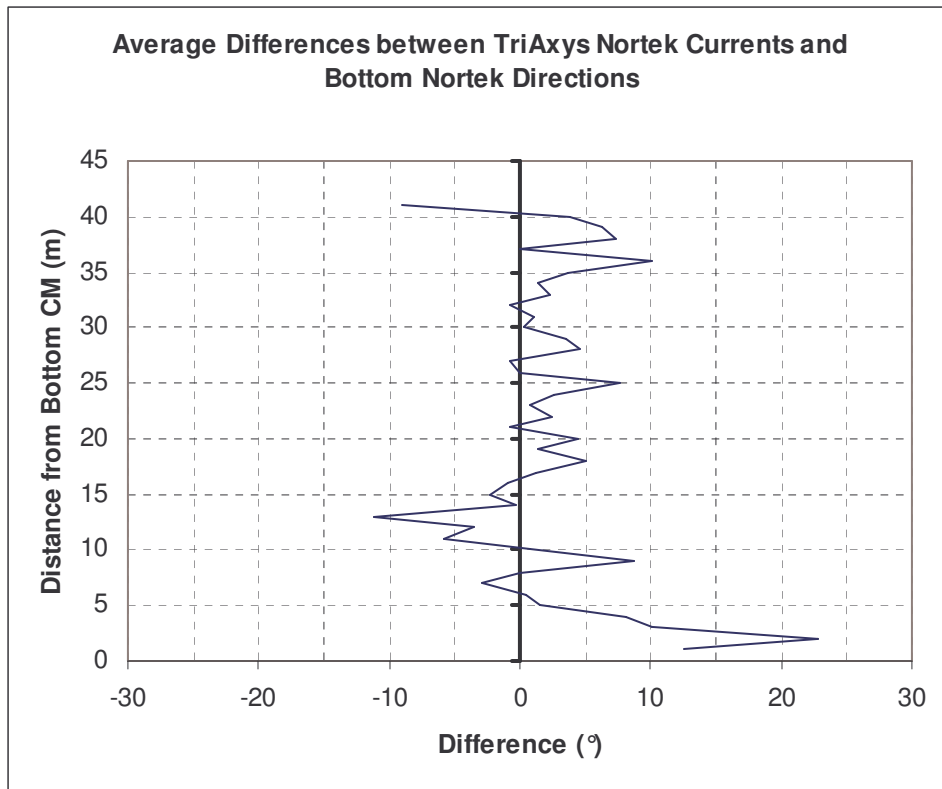


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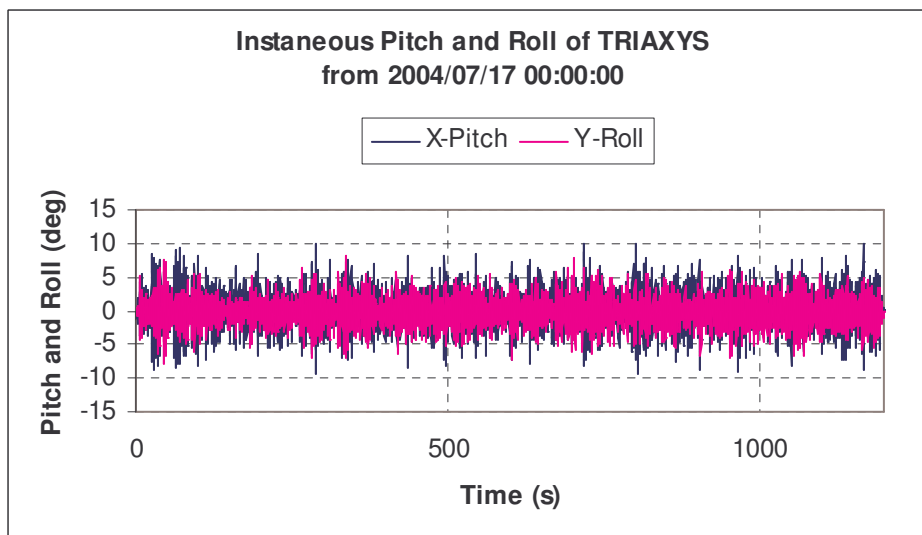




Figure 31.

