NEAR-SURFACE CURRENT PROFILE MEASUREMENTS

OVER THE

MIDDLE SECTION OF NAZARE CANYON (W PORTUGAL)

July 2012 – February 2013

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1. INTRODUCTION

Near surface current profile measurements were collected by Instituto Hidrografico at one location over the middle section of Nazare Canyon, from 26 July 2012 to 07 February 2013. The current profile measurements were collected using an ADCP installed in the multi-parametric buoy MONICAN 1, used by Instituto Hidrografico to provide real-time monitoring of the near surface oceanographic conditions in that region of the western Portuguese continental margin. This report describes the main aspects of the processing of this ADCP data.

2. BACKGROUND

A multi-parametric WAVESCAN (FUGRO-OCEANOR) buoy is maintained in permanence by Instituto Hidrográfico in a position over the middle-section of Nazare Canyon, offshore the Nazare coast. This buoy is part of the real-time monitoring system that was implemented by Instituto Hidrográfico in the framework of project MONItoring the Nazare CANyon (MONICAN, 2009-2011), financed by the EEA Grants 2004-2009 program (Figure 1). The MONICAN system integrates two real-time multi-parametric WAVESCAN buoys, the one located over the middle-section of Nazare Canyon (MONICAN 1, water depth about 1900m) and a second one located over the mid-shelf south of Nazare (MONICAN 2 water depth about 90m depth). It also integrates two coastal tidal stations (Nazare and Peniche ports) and one coastal meteorological station (Ferrel).

Presently the MONICAN system is integrated in a global system for the monitoring of the coastal ocean waters offshore Portugal – the MONIZEE system – that integrates the different monitoring networks operated by Instituto Hidrográfico, including a third multi-parametric buoy located in the deep oceanic area offshore Leixões (Porto).

The multi-parametric buoys are maintained in permanence in the chosen areas, being recovered only for short periods of maintenance at IH facilities (typically one or two annual periods of one or two weeks) or in case of accident or major malfunction of the system.

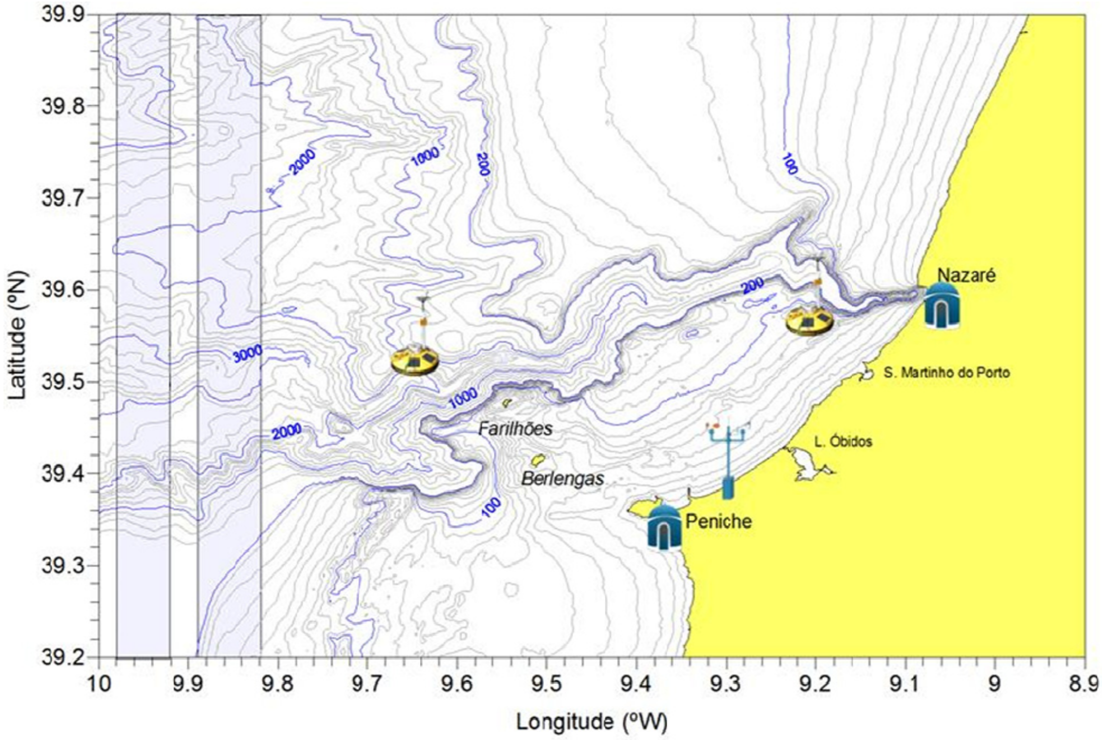


Figure 1. Bathymetric map with the location of the different monitoring systems that integrate the MONICAN network.

3. THE PERIOD OF MEASUREMENTS JULY 2012-FEBRUARY 2013

The deployment operation was conducted during the 26 July 2012, by a team of Instituto Hidrografico onboard NRP "Andromeda". The MONICAN 1 buoy was towed from the port of Peniche to the deployment area. The deployment operation started at 12:30 UT, at about 3 nautical miles from the planned mooring location and was finished at 14:11 UT with the deployment of the anchors. The buoy was deployed in the position 39º 30.945'N, 009º 38.248'W (WGS84), by a bottom depth of about 1900m.

The recovery of the MONICAN 1 buoy was conducted during the 01 and 02 March 2013 by a team of Instituto Hidrografico onboard NRP "Almirante Gago Coutinho". At 18:20 UT 01 March 2013 the MONICAN 1 buoy and ADCP were disconnected from the mooring cable and installed onboard the ship. The recovery of the rest of the mooring line needed to be delayed to the following day. At 06:52 UT 02 March 2013, the release command was sent to the acoustic release and the mooring line start to made surface. At 10:30 UT all the mooring line and equipments was recovered aboard NRP " Almirante Gago Coutinho".

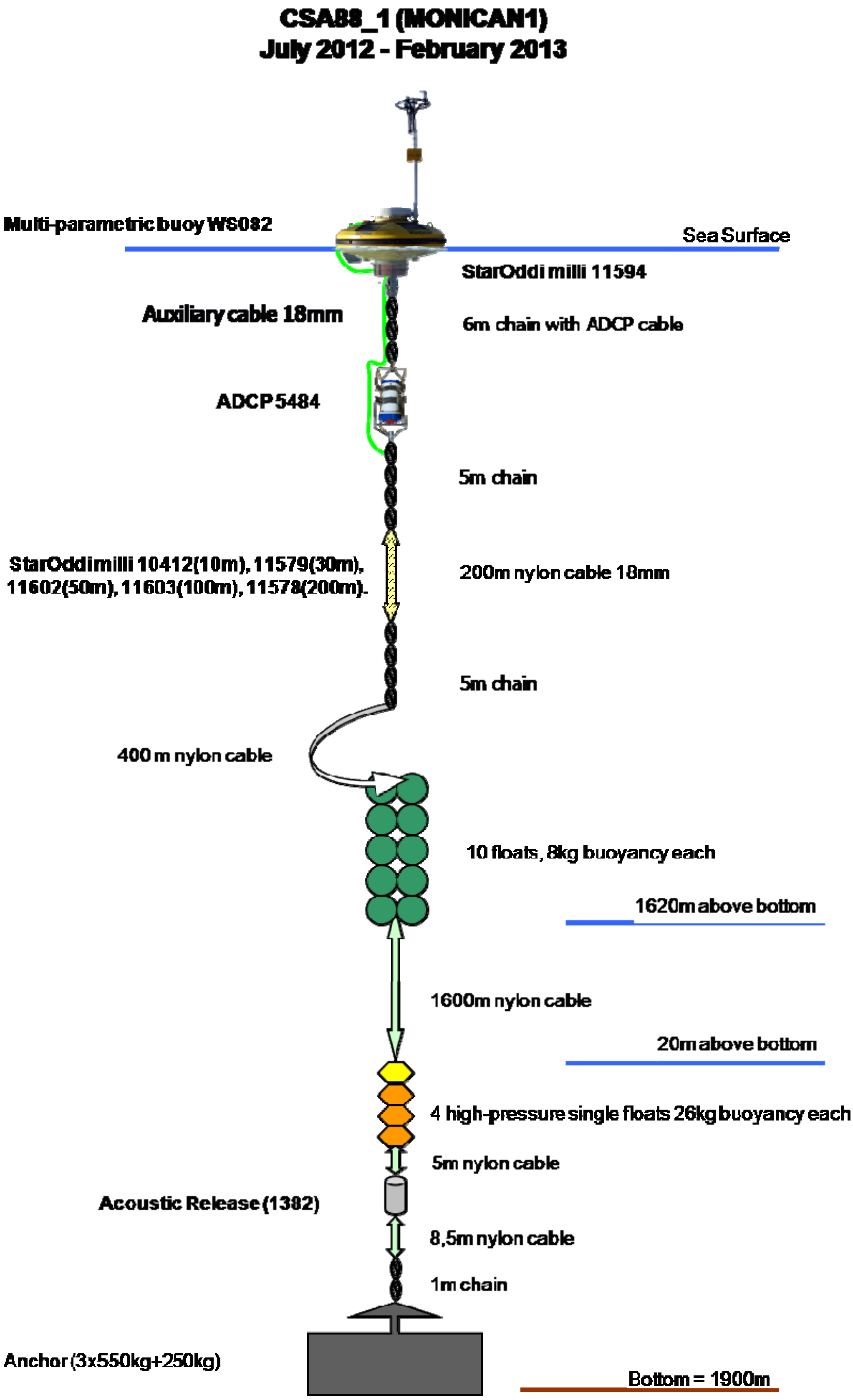


Figure 2. Scheme of the MONICAN 1 buoys in operation from June 2012 to February 2013.

Figure 2 depicts the mooring scheme and sensor locations adopted for this deployment. The MONICAN 1 WAVESCAN buoys was equipped with a 3m height meteorological mast that included sensors providing wind speed and direction, air temperature, relative humidity and atmospheric pressure. The buoy also included a wave sensor that measures wave spectra and provides the main wave parameters. Below the surface, the MONICAN 1 buoy was equipped with dissolved oxygen sensor and a chlorophyl sensor (fluorometer), both installed in the buoy hull, and with an ADCP installed 7m below the surface (detailed description in the following section). An oil-spill sensor, aimed to trigger an alert in case of the presence of an surface oil slick, was also installed in the buoy hull.

In its standard configuration the MONICAN1 buoys is equipped with a sea surface AADI thermistor installed in the buoy hull and with a set of 4 sub-surface Sea Bird thermistors coupled to an inductive cable. These sensors allow the real-time monitoring of water temperature at several depths, up to 200m data. During the present deployment, however, these sensors were not available as a consequence a previous accident. It was then decided to install 6 Star-Oddi milli temperature and pressure sensors, at the depths indicated in the table below.

Thermistor S/N	Depth	Sampling Interval
11594	1m – installed in buoy hull	30 min
10412	10m	30 min
11579	30m	30 min
11602	50m	30 min
11603	100m	30 min
11578	200m	30 min

A set of selected data from the different sensors installed in the MONICAN 1 buoy was transmitted in real-time to Instituto Hidrográfico using INMARSAT satellite transmission. The global data set collected by the different installed as part of the buoy and by the ADCP were saved, each hour, in the internal memory pack of the buoy and downloaded after the recovery of the buoy. The data collected by the ADCP was also saved in the internal memory pack of the ADCP (at its own time sampling interval) and downloaded after recovery. The data collected by each Star-Oddi thermistor was saved in the internal memory of each sensor, at its own time sampling interval, and downloaded after the buoy recovery.

4 ADCP CONFIGURATION AND DATA COLLECTION OPTIONS.

Current profiles were collected using an RDI Broadband Workhorse Sentinel 300 kHz Acoustical Doppler Current Profiler (ADCP). The specific ADCP used is S/N 5484, which uses a system frequency 307.2 kHz. The ADCP was installed in a frame connected to the buoy mooring line, about 7m below the surface (Figure 2), and used in downward looking profiling. The ADCP was equipped with a pressure sensor and a temperature sensor (thermistor) and the data collected by these sensors was used to calculate the sound speed at the transducer head, from which Doppler calculations are derivedt.

Each ADCP measurement corresponds to the mean value of an ensemble of individual pings transmitted during a chosen time interval. The standard deviation of the ADCP velocity measurement is inversely proportional to the square of the number of pings (RD Instruments, 1996). For the present deployment the ADCP was configured to provide one ensemble each hour, using 120 individual pings distributed uniformly in each interval of one hour to build the mean value. With this configuration, RDI software estimates the standard deviation of velocity measurements to be 0.36 cm/s. The first ensemble was saved at 17:20 UT of 25 Jun 2012. All the ADCP ensembles were then saved 20 minutes after the hour. The ADCP worked continuously until 04:20 UT of 07 February 2013 (last ensemble), when it stopped work due to battery failure.

In what regards the vertical range and resolution, the ADCP data was configured to operate with 32 bins (vertical cells) of 3 m thickness each. The ADCP measurements are provided for the center of each bin. The requirement that the cycle of acoustical signal transmission be completed before the start of the cycle of (retro-diffused) acoustical signal reception imposes a minimal distance from the transducer head for signal reception and estimates of current. This blanking distance is, in the present case, of 1.76 m. For the characteristics of the system used, speed of sound at transducer head, blanking distance and length of the bins, the center of the first bin was located at 5.18m from the transducer head.

The RDI BB WH uses 4 acoustical transducers installed in the ADCP head in a Janus configuration, each one with an angle of 20 degrees to the vertical. The ADCP was equipped with pitch, rolling and heading sensors and the information from these sensors was used in the bin mapping procedure implemented by RDI. This procedure allows to correctly calculate the current components using the 4 beam data, by using slightly different time windows of echo reception in each beam to compensate for the tilt of the acoustical transducers. The bin mapping procedure, however, is valid for angles not exceeding 20 degrees. For larger tilts the current components are no longer correctly calculated.

Current components were calculated in Earth Coordinates, using a value of magnetic declination of 4˚ to West (-4˚). With this option, the 3D current vector obtained from the ADCP measurements was decomposed in an eastward directed component (U component, positive to East), a northward directed component (V component, positive to north) and an upward directed component (W component, positive upwards).

The 4 beam configuration used by RDI in the BB WH ADCPs allows a redundant determination of the vertical velocity, from the estimation of 3D currents using two combinations of 3 beams. Differences in the two estimates of vertical velocities provide an estimation of the degree of consistency of the assumption of spatial uniformity of the current field in the area covered by the 4 beams. This difference is expressed, by RDI acquisition software, by a parameter with the dimensions of speed, the error velocity, which is included in the ADCP data set for each ensemble. In case one of the beams is clearly affected, the ADCP was configured to still provide a current measurement using only a 3 beam solution.

During the acquisition, the RDI WH ADCP uses a number a criteria to evaluate the quality of the data. One of such criteria regards the "fish rejection algorithm" for identification of false target, associated with the interference of fishes in one beam. RDI acquisition software allows to inter-compare the echo intensity from each beam, and to define if one beam differs from the others above a certain value. If so, this can indicate the presence of fishes or other obstacles to that acoustical beam, which act are strong reflectors leading to high echo intensities. The critical echo intensity difference assumed in the false target detection algorithm was 50 counts.

To obtain good estimates of the radial velocity along each one of the ADCP beams it is required that echoes arising from each bin be well correlated. The degree of correlation in the echoes arising from each bin, in a particular beam, is then a fundamental parameter for the assessment of the quality of ADCP data measured by that beam. A threshold value of 64 counts was used in the present deployment as the limited above which echo from a particular bin were judged not enough correlated to provide a good estimate of the radial velocity. For each ping of the ADCP, if one of the beams presents a correlation lower than that threshold value in a specific bin, then there is still possible to estimate the a 3 beam solution is enabled for that ping. In this case no error velocity can be calculated for that ping. The error velocity calculated for the ensemble is then only obtained from set of pings that have 4 beams solutions. In case 2 or more beams show a correlation below 64 counts then no solution is available for that ping and bin.

Other data quality criteria were set to be as much permissive as possible. Minimum error threshold was set to 200 cm/s, in practice not restricting any of the ADCP ensembles for the expected range of current velocities in this area.

5 PROCESSING OF ADCP DATA.

In this section we summarize the basic aspects of the processing of ADCP data for the period of measurement July 2012 – February 2013. The final goal of the processing procedure is to obtain good ADCP current velocities (and associated parameters such as error velocity and echo intensity) at fixed depths below the sea surface.

5.1 Extraction of ADCP data and selection of working period

After recovering of the equipment, the ADCP data file was downloaded using the RDI software. The raw data file is a binary file that contains the complete information for all ensembles, all bins and all variables collected by the ADCP. Using RDI software WinADCP, several ASCII files for specific variables were extracted from the raw data file. The procedure produce files for (a) ADCP depth and temperature at the transducer head, for all ensembles; (b) ADCP pitch, roll and heading for all ensembles; (c) individual files for U,V,W, Average Beam Correlation, Error Velocity, Percent Good for a 4 beams solution (PG4) and Average Echo Intensity, for all ensembles and all bins. Missing data (data that has not passed the data quality criteria set during the configuration) was set to the default value of 9999.

The ADCP data was truncate for the valid period of measurements. The combined analysis of the configuration and deployment/recovery reports as well as of the ADCP data (and other complimentary data such as thermistors and buoy position) it was established that the first good ensemble, with the ADCP already at the working depth and the buoy stable, was the ensemble that corresponds to 16:20 UT of 26 July 2012 (ensemble 24). Since the ADCP file stopped due to battery problems, prior from the buoy recovery, the last good ensemble was assumed to be the last ensemble saved by the ADCP, which corresponds to 03:20 UT 07 February 2013 (ensemble 4715).

5.2 Preliminary Data Quality analysis of data

The first step in the processing of ADCP data was the evaluation of data quality using additional quality criteria. One of such criteria corresponds to the identification of ensembles for which the ADCP tilt (pitch and roll) exceeded the maximum value above which the bin mapping procedure fails. The evolution of the ADCP pitch and roll for the complete period of measurements (Figure 3) shows a very good behavior of the ADCP, with only a few occasional ensembles for which the tilt exceeded the maximum value allowed (20˚). A total of 53 ensembles were identified to be in these conditions and the correspondent data (for all bins) was replaced by the default value of 9999.

Additional data quality criteria have also be used to identify bad data in a particular bin and ensemble. This included the indication as bad of the data of a particular bin in a given ensemble that shows an average correlation (averaged of the 4 beams) below 64 counts and an averaged echo intensity averaged 4 beams) below 64 counts. These criteria were only implemented in the files for U,V,W and Error Velocity. This is because this is a quality evaluation of the capacity of the ADCP to estimate currents from the propagation delay. This does not affect the real mean echo measured by each beam.

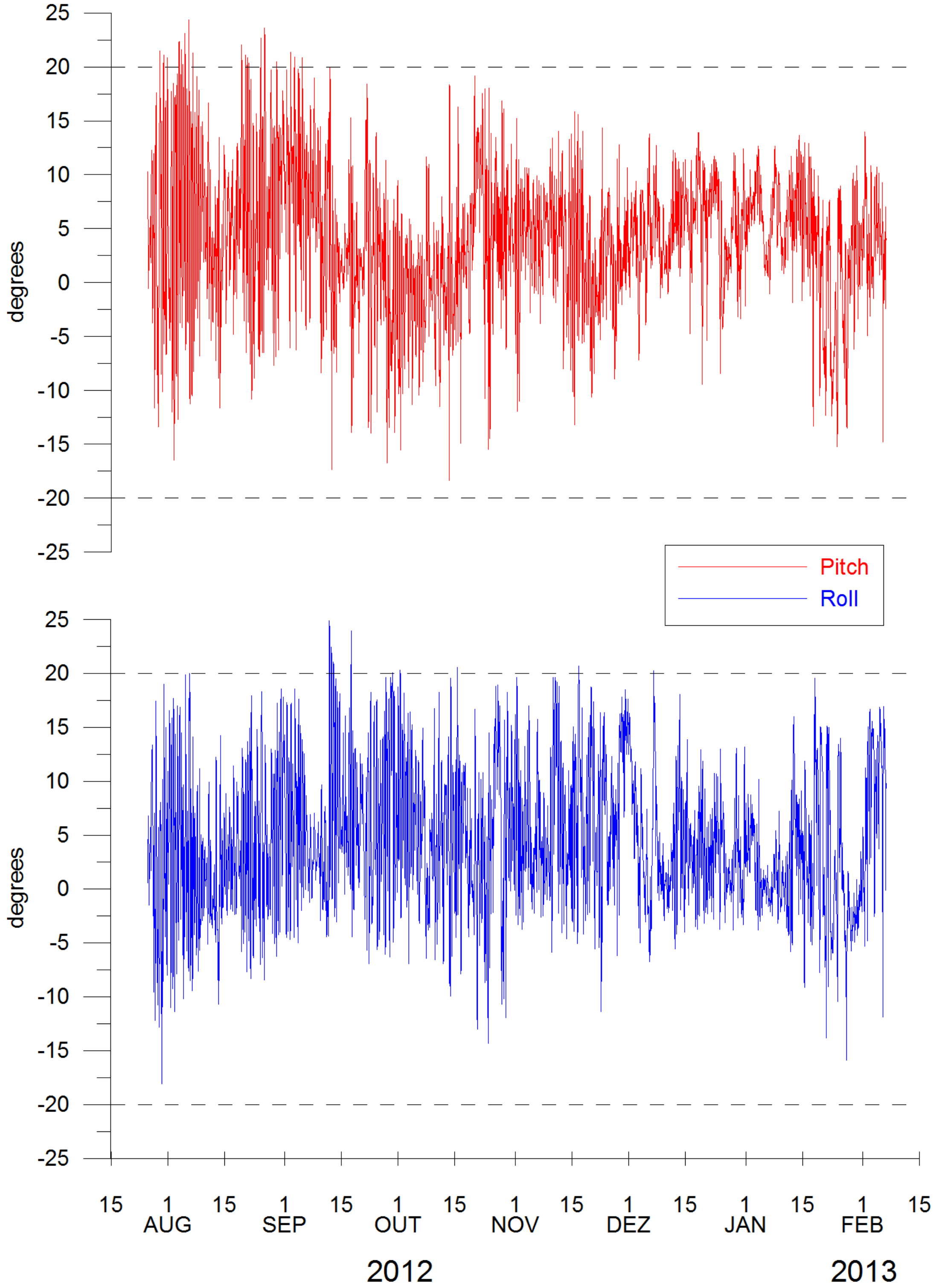


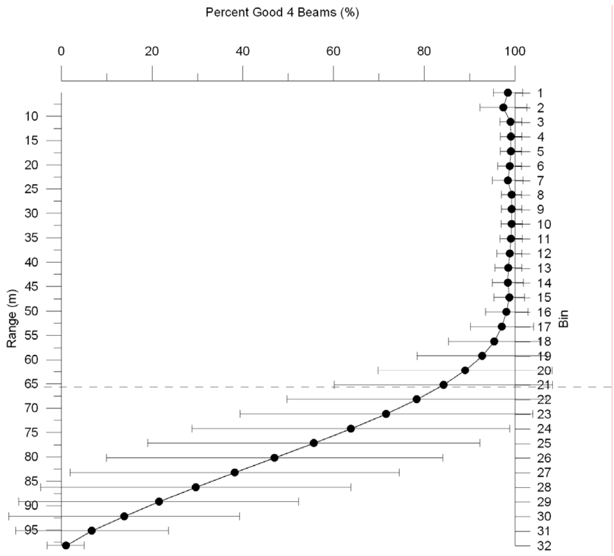
Figure 3. Evolution of ADCP pitch and roll during the measurement period.

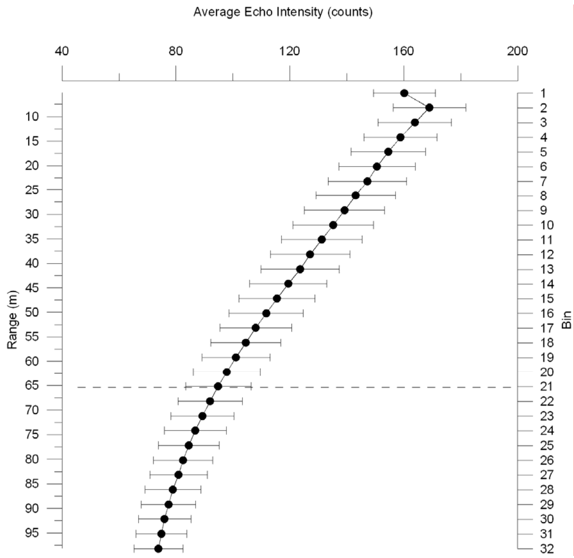
5.3 Statistics of ADCP parameters

Basic statistics were calculated from the quality controlled files produced by the previous step. These statistics, presented in figures 4a and 4b, were used to evaluate the global behavior of the ADCP and to estimate the maximum range of good data. Quality control parameters, presented in figure 4a, indicate that data quality is, in global terms, rather good in the first 18 bins, corresponding to a nominal range of 55m from the transducers. These bins show a percentage of 4 beams solutions in each ensemble that is consistently higher than 90% and an average correlation close to 120 counts, up to bins 12-13 close to the optimal value of 128 counts. Below bin 18, both the mean values of PG4 and average correlation decrease very rapidly and the range of variability of these parameters increases substantially. The echo intensity shows, from bin 2, a gradual decrease with range towards a value close to the background echo intensity of 70 counts (circa 30-40 dB). Echo intensity below bin 27 (range 82m) is lower than 80 counts (about 35-45 dB).

The overall mean error velocity is virtually zero for all the bins. With the exception of the first two bins, where the standard error velocity is somewhat higher (of about 2cm/s), the values up to bin 21 are small, of about +/- 1 cm/s. This values rapidly increases for the bins below, reaching +/- 10 cm/s at bin 32.

Based on the analysis of the basic statistics for the ADCP parameters, we assumed ADCP data with good quality to be limited to bin 21, with a nominal range of 65m from the ADCP head. This bin shows a PG4 consistently above 60% with a mean PG4 over 80%, an average correlation above 90 counts with a mean value above 105 counts and an echo intensity above 80 counts, with a mean value about 95 counts.





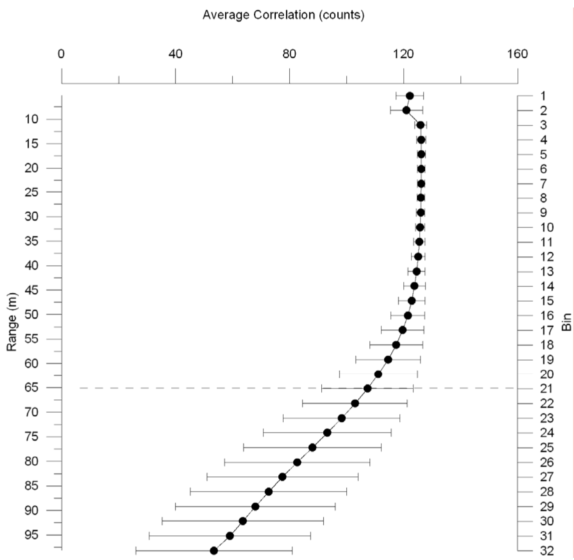


Figure 4a. Mean values (dots) and mean ± standard deviation (intervals) for (top left) percent of good data for 4 beam solutions, (top right) average echo intensity and (bottom) average correlation. The interrupted line marks the assumed maximum range of good ADCP data.

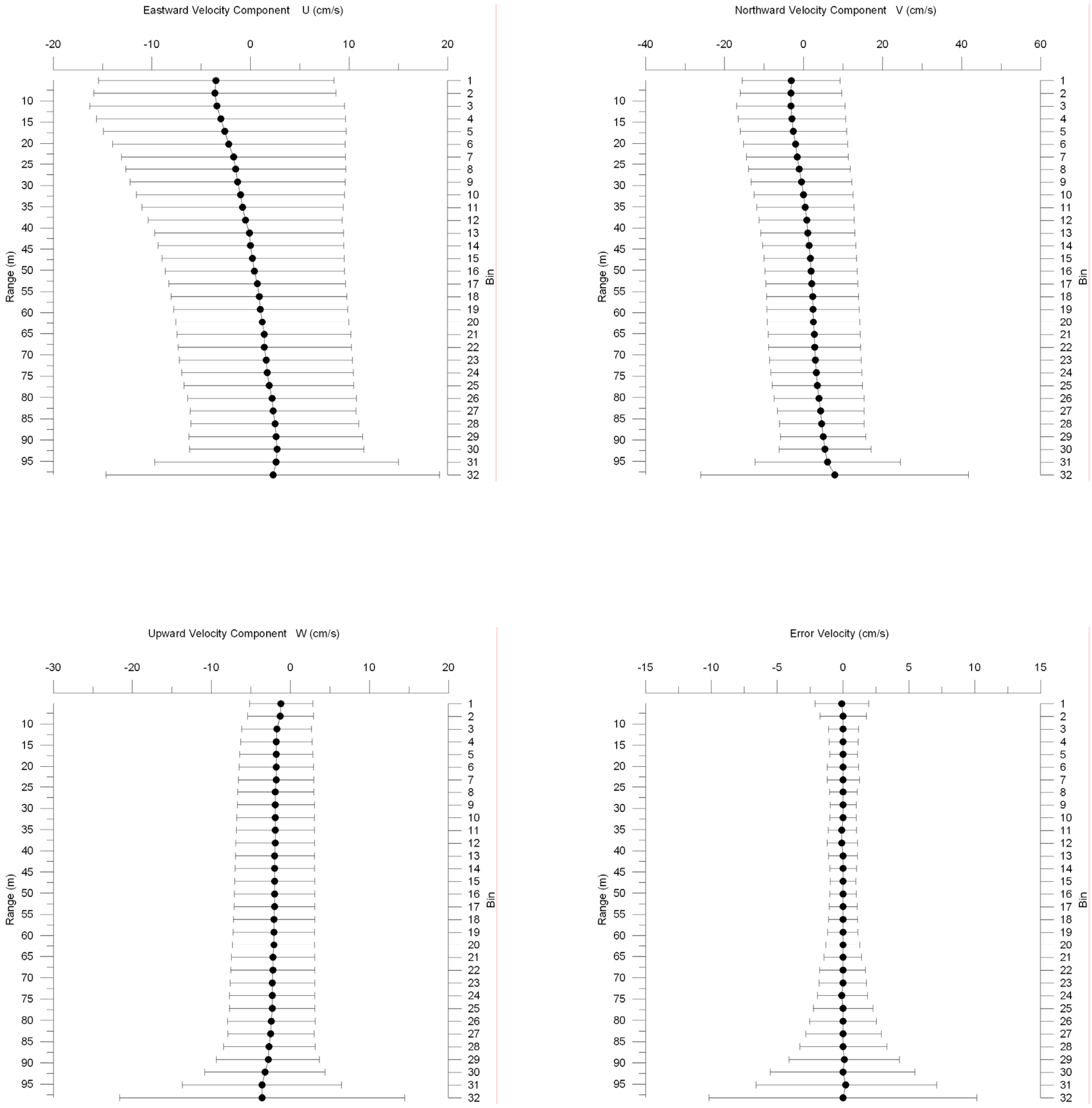


Figure 4b. Mean values (dots) and mean ± standard deviation (intervals) for (top left) eastward velocity component (U), (top right) northward velocity component (V), (bottom left) upward velocity component (W) and (bottom right) error velocity.

5.4 Correction of ADCP estimates.

Corrections in horizontal components of current due to bad sound speed estimates.

During the present period of measurements, the ADCP used the data collected by its own pressure and temperature sensors to calculate the sound velocity at the transducers head, assuming a salinity of 35. A bad estimate of the sound velocity at the transducer head, due to malfunction of one or both of these sensors, would lead to a bad estimate of the current velocities, which can be corrected *a posteriori* if a better estimated of sound speed is available (RD Instruments, 1996). It was then important to evaluate the behavior of the ADCP pressure and temperature sensors.

Since the ADCP is suspended at a fixed distance, relatively close to the WAVESCAN buoy hull, it is easy to confirm the good performance of the ADCP pressure sensor for the present measuring period. Figure 5a shows that the data collected by the ADCP pressure sensor (saved as ADCP depth) is consistent with the ADCP position in the MONICAN1 mooring. The measurements indicate an ADCP position at about 7m depth during the complete period of measurements, showing also depth fluctuations associated with the buoy movements around the central deployment position. These depth fluctuations were generally of a few tens of centimeters, but in some occasions the ADCP moved up by about 1m (see mid January 2013), during periods when the buoy was farther away from the central mooring position and the mooring line was more under tension, originating a combination of large pitch and roll angles in the ADCP.

The performance of the ADCP temperature sensor was evaluated by comparing the corresponding time series with the time series of temperature measured by the two Star-Oddi milli TD sensors placed above (1m below the sea surface) and below (10m depth) the ADCP. The inter-comparison was excellent (figure 5b), all the 3 thermistors show a consistent behavior, depicting the stratified surface layer conditions found in the offshore oceanic waters of western Portugal during the summer, the erosion of seasonal thermocline by October and November and the development of deep mixed layer during the winter, marked by cold surface waters. Only on the very last month of measurements does the inter-comparison show some mismatch between the ADCP thermistor and the two Star-Oddi thermistors, but differences are at most of 0.1 ºC and negligible for the purposes here considered.

The good performance of the ADCP temperature sensor precluded the need for correction of ADCP horizontal velocity components due to sound speed.

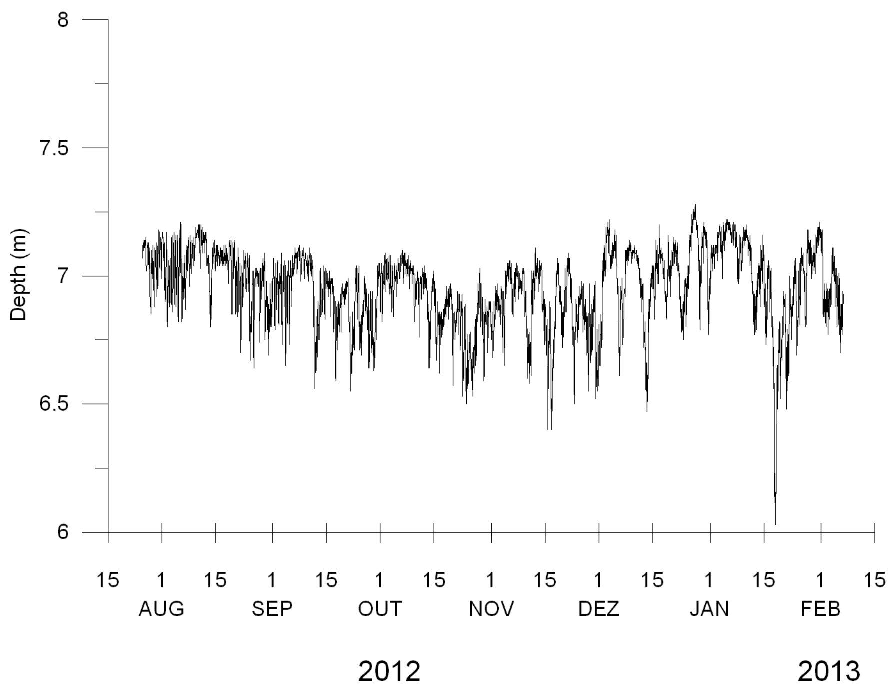


Figure 5a. Time series of ADCP depth.

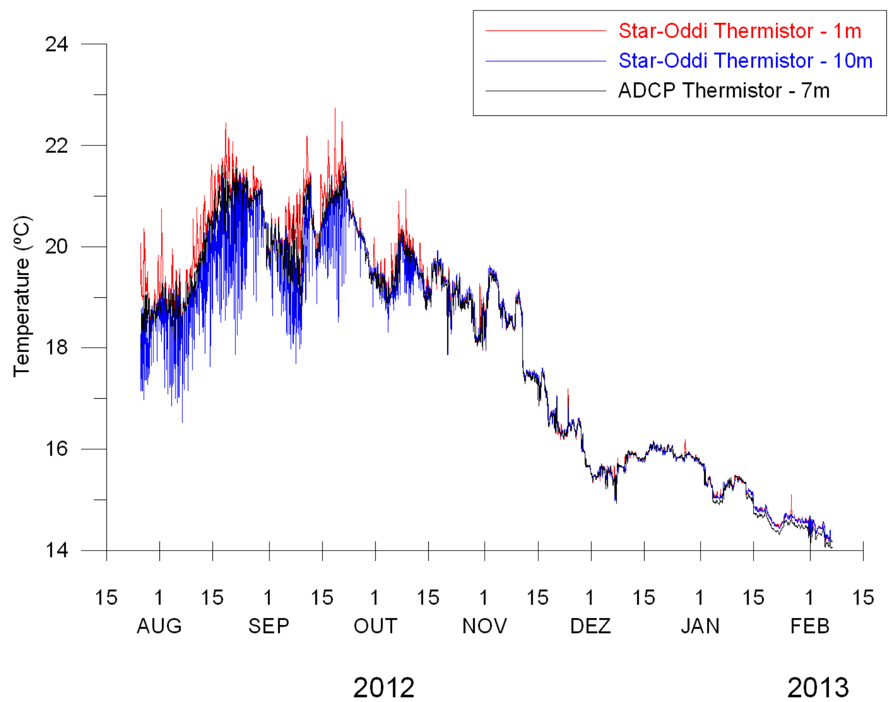


Figure 5b. Time series of temperature measured by the ADCP and the Star Oddi sensors installed above and below the ADCP.

Determination of corrected bin depths and bin sizes

To reach the final objective of calculating ADCP current velocities at fixed depths below the sea surface, it is of fundamental importance to correctly locate the vertical position of ADCP bins, for each ensemble.

The ADCP uses a time gate procedure to receive echoes from successive bins of a chosen size, which are located at increasing distances from the transducers. During the period of measurements analyzed here, the ADCP used the sound speed at the transducer head to define the time windows that correspond to the reception of echoes from a particular bin with the chosen size, which is located at the correspondent distance from the ADCP head. If the sound speed at the transducer head was, in fact, the sound speed in the water column, then the vertical position of each bin was to be obtained from the distance between the ADCP head and the center of that bin measured along the ADCP axis (which is obtained from the bin number, the chosen bin size and the know location of the center of first bin), projected in the vertical axis by using the pitch and roll data for the ensemble.

However, sound speed changes in the water column, due to changes in pressure, temperature and salinity. For measurements in the upper layers of the ocean, during periods sufficiently longs, the sound speed profile can also change considerable along the period due to changes is the stratification conditions. This was the case for the period of measurements discussed here. Vertical profiles of temperature for the start and end of this period are represented in figure 6a. These profiles were constructed by combining the data collected by the Star-Oddi and ADCP thermistor and show the important changes that occurred in the stratification conditions of the upper 200m water column, during the period of interest. The correspondent changes in the vertical profile of the sound speed can be depicted in figure 6b, were the sound speed is presented at the depth of the ADCP bins.

The vertical change in the speed of sound does not affect the measurement of the horizontal components of the current (for which only the sound speed at the ADCP transducer head is required) but do change the range and size of the ADCP bins as well as the estimates of the vertical component of current (RD Instruments, 1996).

The procedure to correct the bin range and bin size for the vertical profile of the sound speed started with the interpolation, for the times of ADCP ensembles, of the temperature/depth measurements collected by the Star-Oddi sensors that were located below the ADCP. Then, for each ensemble, the set of ADCP and interpolated Star-Oddi temperature data was vertically interpolate to the mid-point between the ADCP head and the center of the first bin and between the centers of consecutive bins. The sound speed at those depths was calculated from Urick (1983) equation, using the interpolated temperatures and assuming a constant salinity of 35 in the water column. From these sound speed estimates, the correct bin sizes and the corrected range from the ADCP of each bin was estimated using RDI correction procedure (RD Instruments, 1998). The depth of each bin was calculated from the depth of the ADCP measured in each ensemble, followed by the projection in the vertical axis of the range of the bin center to the ADCP project, using the pitch and roll data.

Correction of vertical velocities

The vertical component of current that is measured in each ensemble and in each bin, was also corrected for the effect of using a constant sound velocity profile instead of the true sound velocity profile. This uses the sound velocity estimations at the mid-point between the center of each bin (or between the ADCP head and the center of the first bin) profile obtained from the interpolated temperatures measured by thermistors as decribed above. The corrected procedure follows RD Instruments (1998).

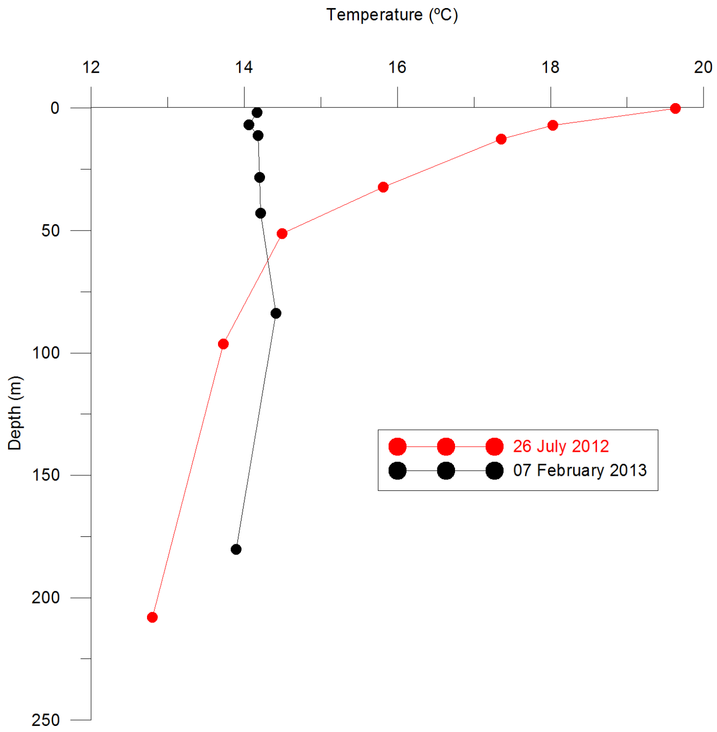


Figure 6a. Temperature profiles at the start and end of the measuring period. Dots mark the position of Star-Oddi and ADCP thermistors.

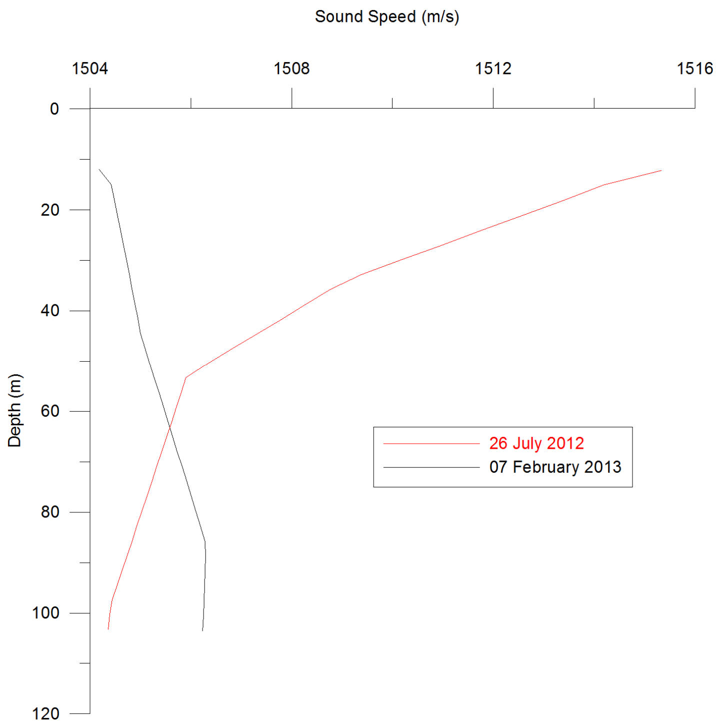


Figure6b. Sound speed profiles estimated at the depths of ADCP bins, at the start and end of the measuring period.

5.5 Interpolation to fixed depth levels.

All along the measurements period the depths of the ADCP bin change as consequence of tilts and depth changes of the ADCP or the changes in the stratification of the upper layers of the ocean that changes the vertical sound speed profile. Once the correct bin depths were calculated, for each ensemble, the ADCP data is then interpolated to fixed depth levels. In this case, a total of 19 fixed depth levels with 5m depth resolution were chosen, starting at 15m depth. The last fixed depth level is then 105m. However, from the discussion of section, good data is only expected to be available until bin 21, located roughly about 72m below the sea surface.

5.6 Correction of platform movement

The currents measured by the ADCP installed on the MONICAN 1 buoy are contaminated by the movement of the platform itself. Important and rapid vertical movements of the platform are due to the movement of the surface under surface gravity waves. The characteristics of the ADCP sampling, however, greatly filter these effects by averaging pings over one hour interval, so we assume that the contamination due to the averaged vertical movement of the platform is negligible. Horizontal movement of the MONICAN buoy, under the action of waves, currents and eventually also wind (although the buoy design is aimed to minimize wind drag effects), must however be corrected in the ADCP horizontal velocities.

During the present measurements period, the MONICAN 1 buoy was equipped with two Global Position System (GPS) sensors, which provided the position of the buoys each hour. One of these sensors is incorporated in the INMARSAT satellite communication system, installed in the buoy mast and used to transmit the buoy data in real-time to Instituto Hidrografico. Inter-comparisons between the data collected by this type of GPS sensors and high resolution differential GPS sensors, conducted with a similar buoy during a prior deployment, revealed the occurrence of shifts in position affecting the INMARSAT GPS data but also showed that the shifts were could be identified an corrected in the time series of buoy velocity and corrected. In this inter-comparisons, the corrected buoy velocities estimated suing the INMARSAT GPS were in good agreement to the ones obtained with high resolution DGPS. Here we use this same procedure to identify and correct the bad buoy velocity data calculated from the INMARSAT. Each INMARSAT velocity estimates calculated from two hourly positions, then correspond to the mean displacement velocity of the buoy during that one hour interval and is centered at the midpoint of this interval (each half an hour).

The second sensor installed in the MONICAN 1 buoy to provide position data was an UBLOX sensor, which is a high performance GPS sensor. During the measuring period, however, the sensor was affected by several problems, in part associated with uncorrected reading of the GPS data by the buoy logger and, in part promoted by the spodradic occurrence of humidity in the sensor connections. These problems are easily identified in the UBLOX data by the presence of default values. Buoy velocity estimates were then calculated for the UBLOX data from the difference between consecutive position data points, using only the correct data. As before, each UBLOX velocity estimate also corresponds to the mean buoy velocity in the one hour interval and is centered at the midpoint of this interval.

Since UBLOX GPS provides a more accurate position data, the solution adopted to estimate the buoy displacement velocity was to use the estimate based on UBLOX GPS data when available and to replace the gaps of non-existent UBLOX estimates by the INMARSAT estimates. Figures 7a and 7b show the time series of buoy velocity components estimated both from the INMARSAT GPS sensor and the UBLOX GPS sensor and the final solution adopted. Overall there is a good agreement between the INMARSAT and UBLOX velocity estimates, with the differences ranging mostly 1 or 2 cm/s. During the peaks of buoy velocity, higher differences are observed, sometimes reaching 5 cm/s. The figures also show the existence of two broad time periods for which no UBLOX velocity estimates are available (due to frequent error in the position data collected by this sensor), were only the INMARSAT estimates are used. Figures 7a and 7b provide to the end-user of the processed ADCP data a basis for the assessment of how good was the procedure for correction of platform motion and where this procedure is expected to perform less well.

Once the buoy velocity components determined, the last step in the processing was the correction of buoy motion from the horizontal velocities calculated before at fixed depth levels. The corrected horizontal components of the currents, in each ensemble and at each fixed depth level, are then obtained as:

$$U(z) = U(z)_{uncorr} + U_{buoy} \quad ; \quad V(z) = V(z)_{uncorr} + V_{buoy}$$

More than focusing on the high frequency (inertial and super-inertial) variability of the upper ocean currents, the ADCP measurements provided by the MONICAN 1 buoy are aimed to monitor the low frequency, sub-inertial circulation that is driven by the wind forcing, interactions with deep ocean circulation and other forcing agents. To evaluate the magnitude of the errors that are expected to subsist in the low-frequency horizontal currents measured by the ADCP, after the platform motion is removed using the adopted solution, we present in figure 8 the time series of the differences between the low-pass buoy velocity components estimated from INMARSAT GPS and UBLOX GPS. The low pass filtering was achieved by a running mean in 24 hours, using the available pairs of INMARSAT and UBLOX estimates. Even with such a crude estimate, it is seen in figure 8 that the differences between the estimates of the low frequency movement of the MONICAN buoy differences are about 1-2 cm/s, only in some more severe cases reaching 4 cm/s. This gives confidence to use the INMARSAT estimates when no UBLOX estimates are available, indicating that the errors introduced in the low-frequency currents are low when compared with the typical magnitudes of upper ocean sub-inertial currents in this geographical area.

6 STRUCTURE OF THE PROCESSED ADCP FILES.

The ADCP data, processed with the strategy described in section 5 above, is provided in a set of files containing U, V, W, Error Velocity and Echo Intensity. Each file corresponds to one of the chosen fixed depth level, the name of the files including the information about which is the correspondent depth level.

Each file includes a 3 line header that specifies:

a) the characteristics of the ADCP used in this measurements period (type, frequency and serial number);

b) the central position of MONICAN buoy (and ADCP measurements) for this measurements period;

c) the parameters (an corresponding units) that are contained in the different file columns.

Below the header, each line corresponds to an ADCP ensemble and includes the following columns:

Julian Day Y M D H M U(cm/s) V(cm/s) W(cm/s) VErr(cm/s) Echo(count)

Column 1: Modified Julian day

Columns 2 to 6: Year, Month, Day, Hour and Minute

Colum 7: Eastward component of current (U) in cm/s

Colum 8: Northward component of current (V) in cm/s

Colum 9: Upward component of current (W) in cm/s

Colum 10: Error Velocity in cm/s

Colum 11: Echo intensity in counts (1 count ~0.5 dB)

7 REFERENCES.

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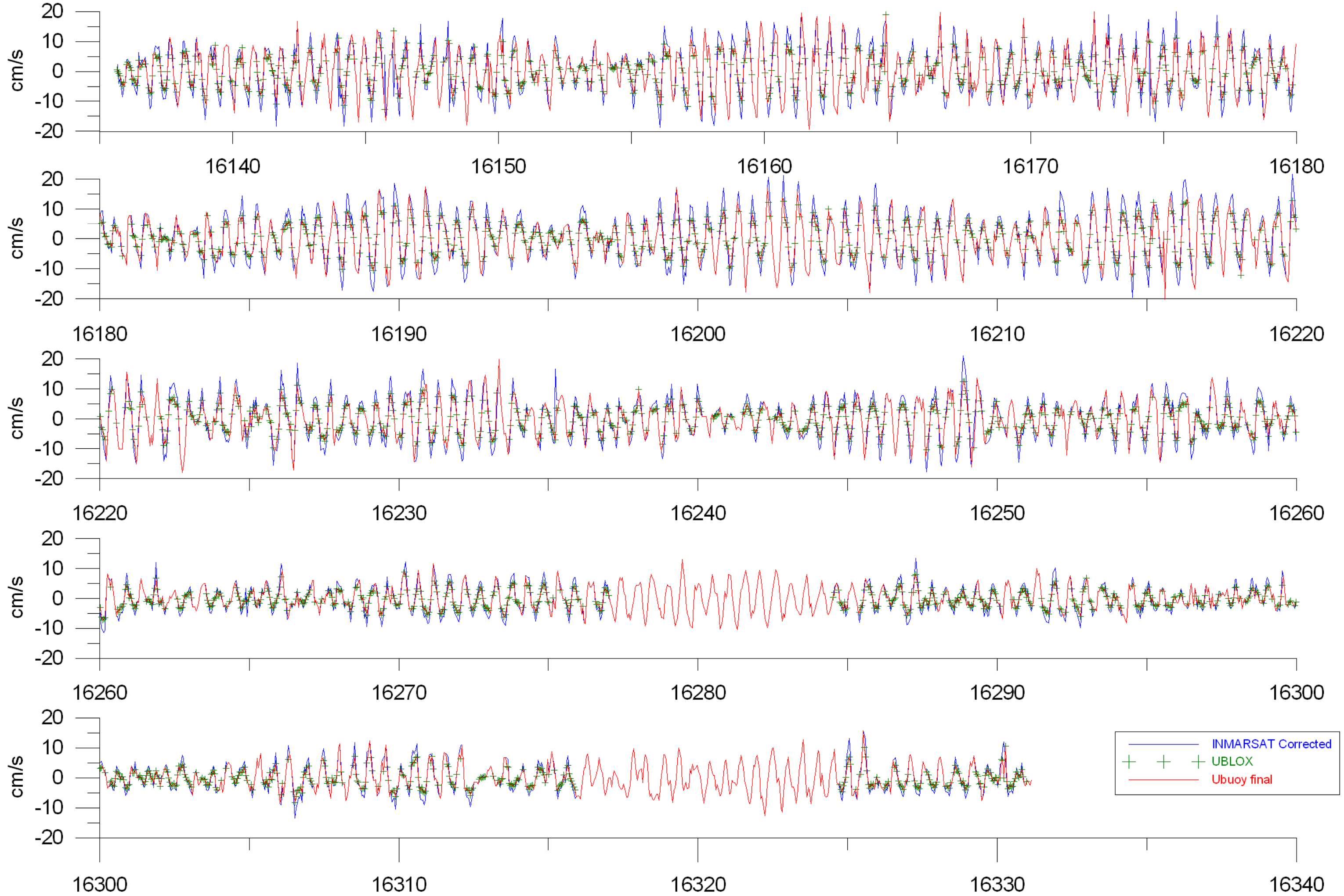

Figure 7a. Time series of eastward buoy velocity based on INMARSAT GPS data (corrected), UBLOX GPS data and adopted solution. X-axis labels correspond to modified Julian days.

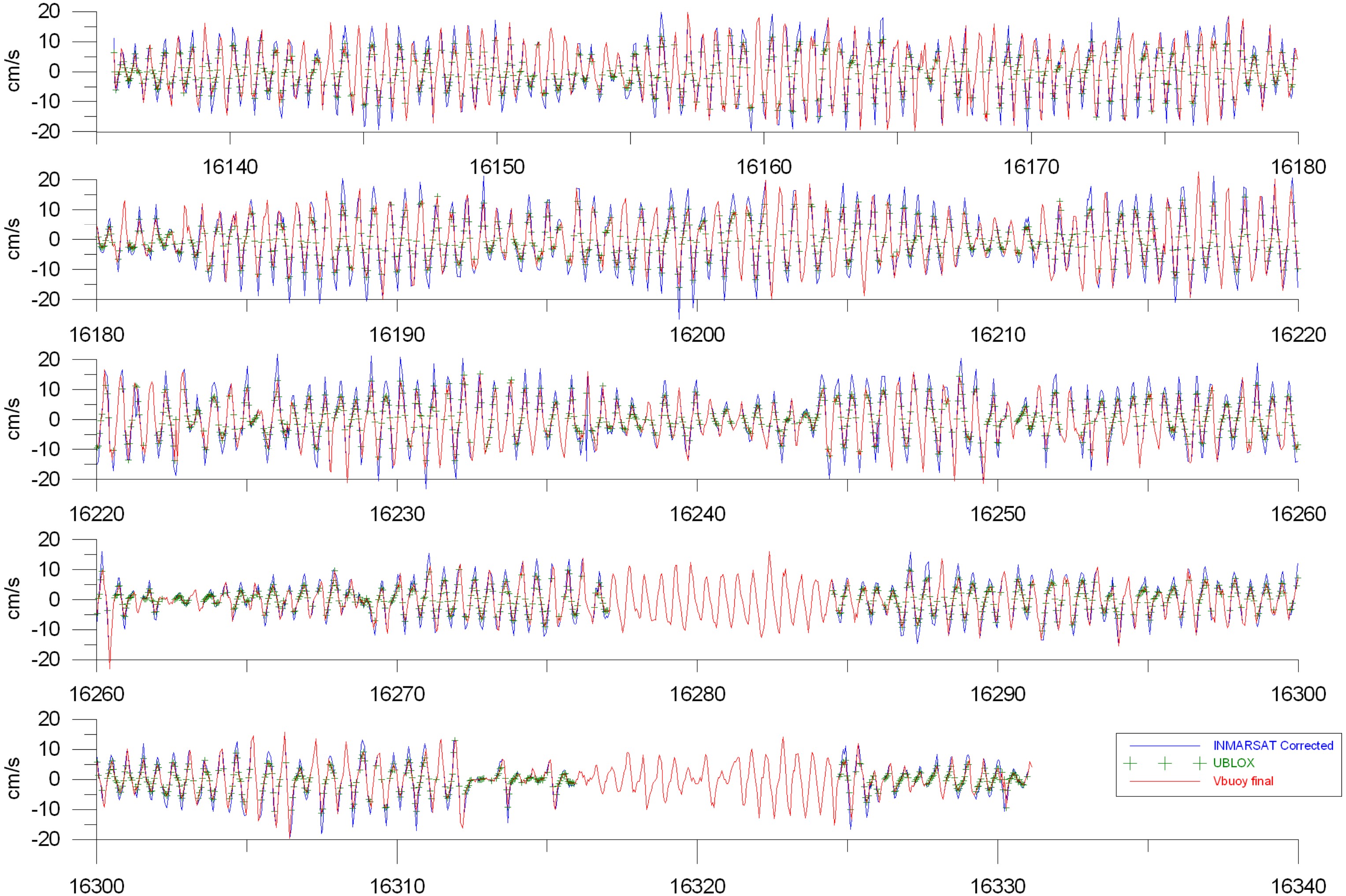

Figure 7b. Time series of northward buoy velocity based on INMARSAT GPS data (corrected), UBLOX GPS data and adopted solution. X-axis labels correspond to modified Julian days.

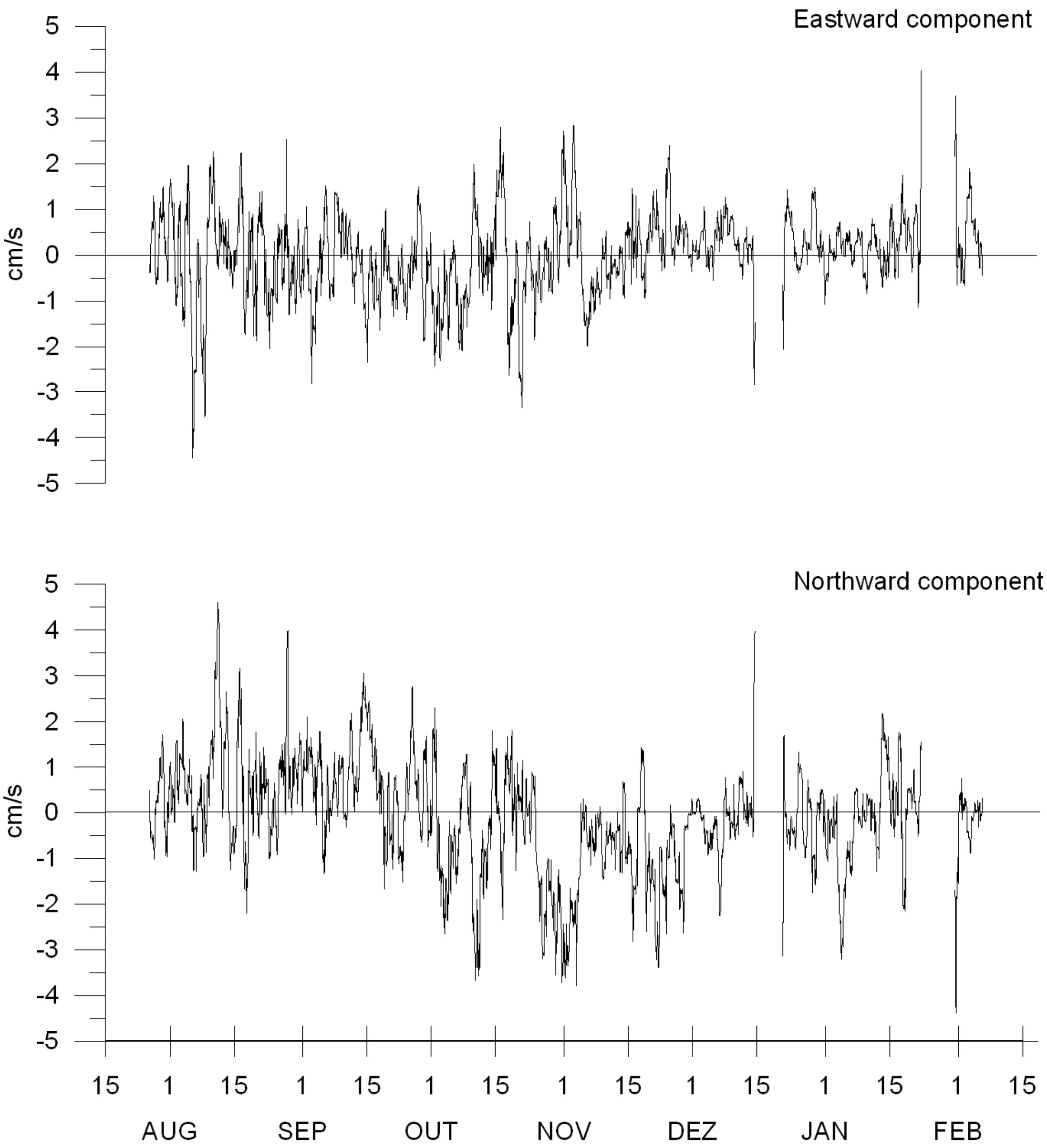

Figure 8. Difference between the estimates of low-pass filtered buoy velocity components obtained from INMARSAT GPS and UBLOX GPS.