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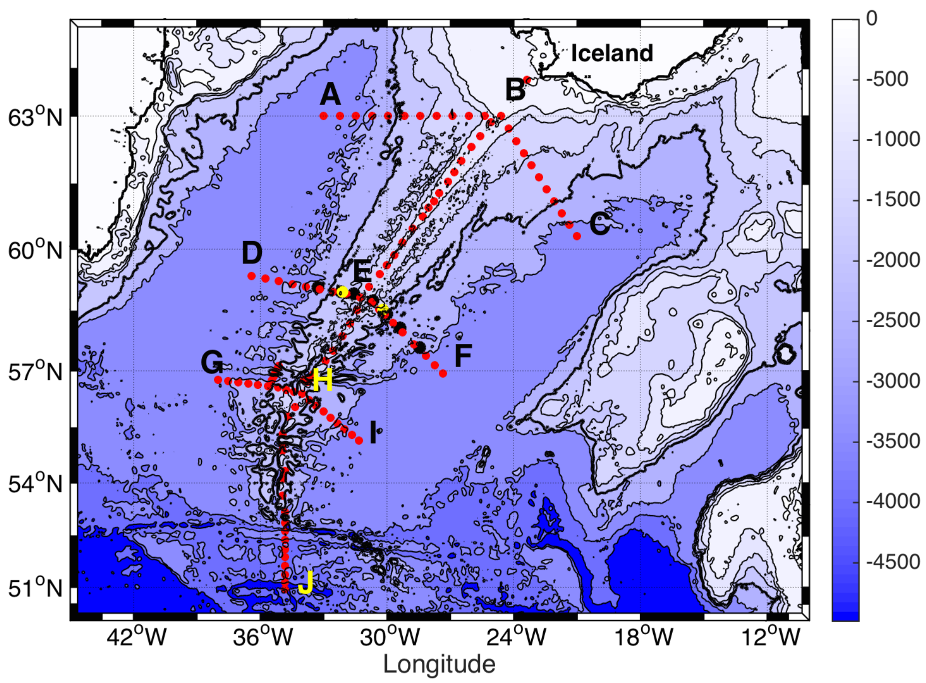
RREX 2015

S-ADCP data processing report

Auteurs : T. Petit, V. Thierry, H. Mercier



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LOPS - Campus Ifremer – ZI de la Pointe du Diable – CS10070 – 29280 Plouzané
Tél 33 (0)2 98 22 48 50 – Fax 33 (0)2 98 22 44 96
IUEM, Rue Dumont d'Urville, 29280 Plouzané

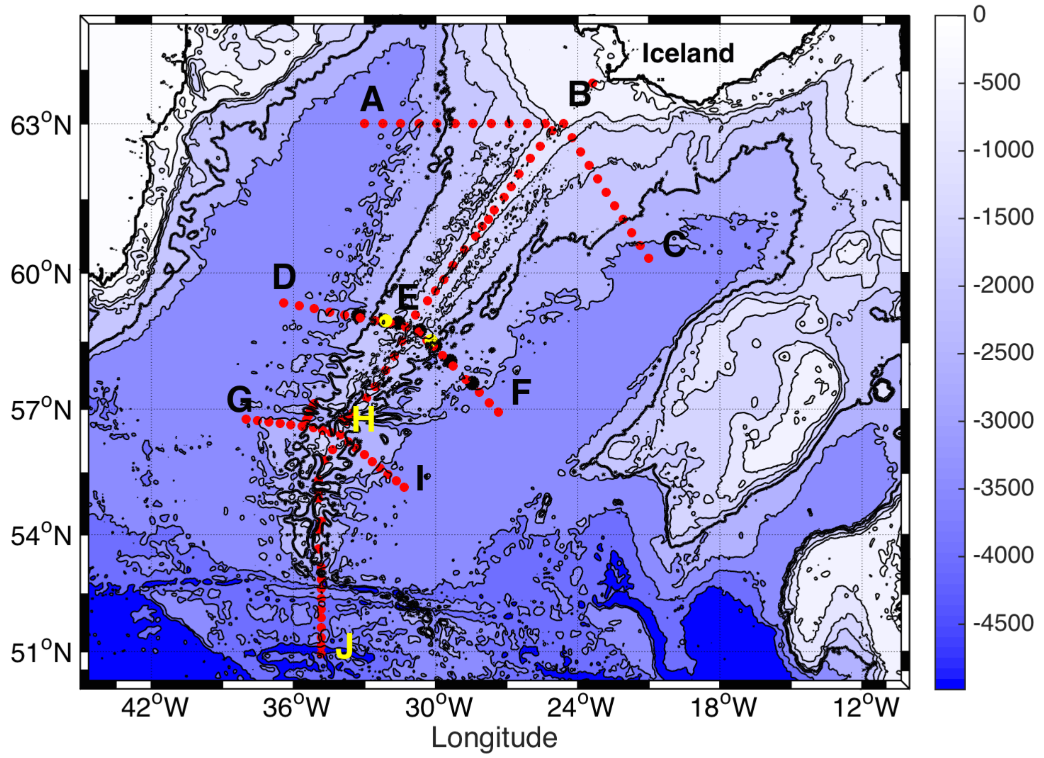
RREX 2015

S-ADCP data processing report

05/06/2015 to 10/07/2015

On board N/O Thalassa

Brest (France) - Brest (France)



ABSTRACT

The Reykjanes Ridge is a major topographic feature of the North-Atlantic Ocean. It lies in a central position along the main paths followed by the upper and lower limbs of the Meridional Overturning Cell (MOC), which contributes at moderating the European climate by transporting heat northward. The objective of the RREX project was to conduct a process study in order to better understand the role of the Reykjanes Ridge on the dynamics and water mass transformation in the subpolar gyre and ultimately on the MOC. The RREX2015 cruise, carried out from 5 June to 10 July 2015 on the R/V Thalassa, was the first of the two cruises carried by the RREX project. During this cruise, we realized 133 surface-bottom CTDO2-LADCP stations along 4 sections. Current measurements were continuously acquired by two Shipboard ADCPs (RD Instrument) operating at 38 kHz (OS38) and at 150 kHz (OS150). This report details the processing of those two S-ADCPs datasets using the software Cascade. The processing consisted in validating, correcting, filling gaps in, filtering, and selecting final S-ADCP data. Considering the mean vertical velocity averaged over the cruise, we estimated an attitude corrections of 0.3° for OS38 and 0.1° for OS150. We also estimated the misalignment (α) and amplitude (a) corrections in comparing the ship velocity, determined by GPS, to the ship velocity estimated from the S-ADCP bottom ping in shallow water. Minimizing the bias between OS38 and OS150 further refined the misalignement correction. For the OS38, we found α = 0.05° and a = 1.0067 cm s^{-1}. For the OS150, we found α = -0.04° and a = 1.0027 cm s^{-1}. We also estimated the total instrumental error on the absolute ocean velocity calculated from errors on the flow velocity relative to the ship velocity estimated by the ADCP data, and errors on the ship velocity relative to the bottom measured by GPS. For OS38 in Narrow Band mode, the total instrumental error on absolute ocean velocity during the cruise is 4.39 cm s^{-1}. For OS150 in Broad Band mode, the total instrumental error during the cruise is 2.40 cm s^{-1}.

RESUME

La dorsale de Reykjanes est une structure topographique majeure de l'océan Atlantique Nord. Elle est située au cœur de la gyre subpolaire le long des chemins suivis par les branches hautes et basses de la cellule méridienne de retournement (MOC, Meridional Overturning Cell). Cette dernière transporte de la chaleur vers le nord de l'Atlantique Nord et contribue à modérer le climat européen. L'objectif du projet RREX est de réaliser une étude de processus afin de mieux comprendre le rôle de la dorsale de Reykjanes sur la dynamique et la transformation des masses d'eau dans le gyre subpolaire et, *in fine*, sur la MOC. La campagne RREX2015 réalisée du 5 juin au 10 juillet 2015 est la première des 2 campagnes prévues du projet RREX. Au cours de cette campagne, nous avons réalisé 133 stations CTDO2-LADCP le long de 4 radiales. Des données de courant ont été continuellement acquises par deux ADCPs: un S-ADCP opérant à 38 kHz appelé OS38 et un S-ADCP opérant à 150 kHz appelé OS150 (RD Instrument). Ce rapport détaille le traitement des données des ces deux S-ADCPs à l'aide du logiciel Cascade. Le traitement consistait à valider, corriger, interpoler, filtrer et sélectionner les données S-ADCP finales. Considérant la vitesse verticale moyennée sur toute la campagne, nous avons estimé une correction d'attitude de 0,3 ° pour l'OS38 et de 0,1 ° pour l'OS150. Nous avons également estimé les corrections de désalignement (α) et d'amplitude (a) en comparant la vitesse du navire, déterminée par GPS, à la vitesse du navire estimée à partir des données S-ADCP acquises en eaux peu profondes et en minimisant le biais entre l'OS38 et l'OS150. Pour l'OS38, nous avons trouvé α = 0,05 ° et a = 1,0067 cm s^{-1}. Pour l'OS150, nous avons trouvé α = -0,04 ° et a = 1,0027 cm s^{-1}. Nous avons également estimé l'erreur instrumentale totale sur la vitesse océanique absolue calculée à partir des erreurs sur la vitesse de l'écoulement relative à la vitesse du bateau estimée par les données ADCP, et sur la vitesse du navire par rapport au fond mesurée par GPS. Pour l'OS38 en mode Narrow Band, l'erreur instrumentale totale sur la vitesse absolue pendant la campagne est de 4,39 cm s^{-1}. Pour l'OS150 en mode Broad Band, l'erreur instrumentale totale pendant la campagne est de 2,40 cm s^{-1}.

SOMMAIRE

1. Introduction

1.1. The RREX 2015 Program

The Reykjanes Ridge is a major topographic feature of the North-Atlantic Ocean. It lies in a central position along the main paths followed by the upper and lower limbs of the Meridional Overturning Cell (MOC), which contributes at moderating the European climate by transporting heat toward the northern Europe. Our hypothesis is that the Reykjanes Ridge influences the main components of the upper and lower limbs of the MOC because it is a strong constraint on the horizontal and vertical circulation, it affects the water mass distribution and evolution and it is a region of intense turbulent mixing. The objective of this project was to conduct a process study in order to better understand the role of the Reykjanes Ridge on the dynamics and water mass transformation in the subpolar gyre and ultimately on the MOC. This project relied on two cruises to acquire the adequate datasets for: (1) providing a synoptic high-resolution and full depth survey to monitor the flow along and across the Ridge; (2) quantifying the variability of the vertical and horizontal structure of currents parallel to the Ridge at daily to seasonal time-scales; (3) providing sufficient turbulence observations to monitor the heterogeneous and intermittent mixing processes.

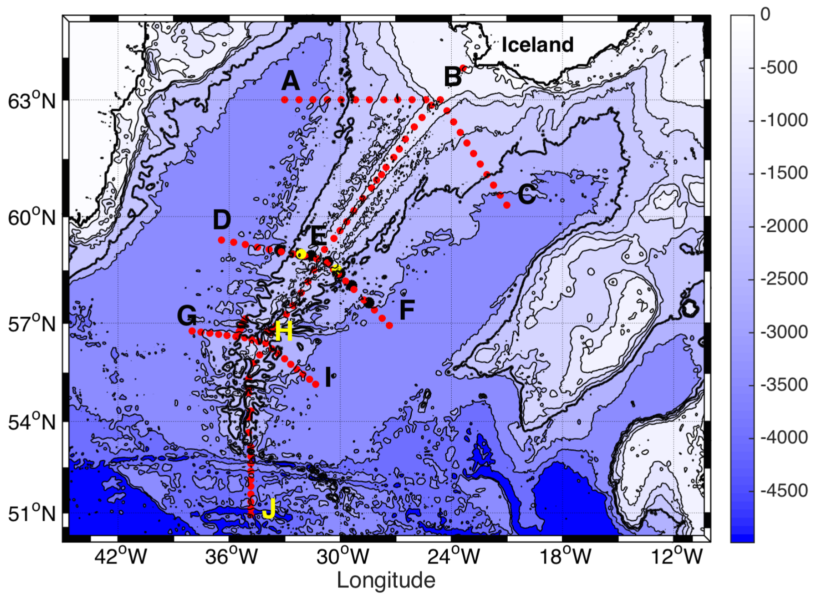


Figure 1: (Red dots) Stations realized during the RREX2015 cruise. (Contours) Bathymetry of the North-Atlantic Ocean.

The RREX2015 cruise, carried out from the 5 June to 10 July 2015 on the R/V Thalassa, was the first of the two cruises of the RREX project. During this cruise, we realized 133 surface-bottom CTDO2-LADCP stations along 4 sections (Figure 1). Current measurements were continuously acquired by two Shipboard

ADCPs (RD Instrument) operating at 38 kHz (OS38) and at 150 kHz (OS150). This report details the processing of those two S-ADCPs datasets using the software Cascade to get the best estimates of the absolute flow velocity.

1.2. Estimation of the absolute flow velocity from Shipboard-Acoustic Doppler Curent Profiler (S-ADCP)

We first recall ADCP measurement principle. An ADCP emits pulses of acoustic energy, called pings, in four directions from 4 beams positioned at 90° of each other. As those emitted pulses travel, they are reflected back to the ADCP by suspended particles moving with the flow (Figure 2). Due to the Doppler effect, the reflected acoustic pulses are shifted in frequency. This shift depends on the flow velocity and allows measurements of the velocity amplitude. By combining the shifts measured by the 4 beams, the ADCP provides three-dimensional velocities and a measurement error.

The Shipboard ADCP (S-ADCP) does not measure the absolute flow velocity, but the flow velocity in the ocean with respect to the ship velocity. The latter is in general larger than the absolute flow velocity. To estimate the absolute flow velocity (V_{flow}), the ship velocity relative to the bottom (V_{ship}) must be estimated and subtracted from the relative flow velocity estimated from the S-ADCP data (V_{ADCP}):

$$V_{flow} = V_{ADCP} - V_{ship} \quad (1.1)$$

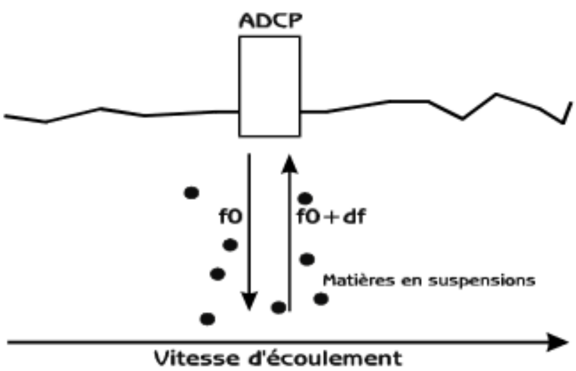


Figure 2: S-ADCP system (www.eaufrance.fr/IMG/pdf/Charte-fr.pdf).

Three different errors affect the S-ADCP measurements. Firstly, the S-ADCP axis may be misaligned with the ship axis as shown in Figure 3. This mounting angle can be known by the users, but may be uncertain. To this misalignment error adds the GPS accuracy (*Osinski*, 2000). Indeed, the GPS is used to estimate V_{ship}. To minimize these 2 sources of error, which will be referred to hereinafter as the misalignment error, a calibration procedure needs to be applied to determine the misalignement angle α. Secondly, an error can affect the amplitude of the velocity measured by the S-ADCP. Indeed in addition to calibration issues, the plastic window separating the S-ADCP from seawater can cause a modification of acoustic signal and an error in the estimation of velocity amplitude. Finally, the attitude of the ship during the cruise has to be corrected because it affects both measuring depth and vertical velocities.

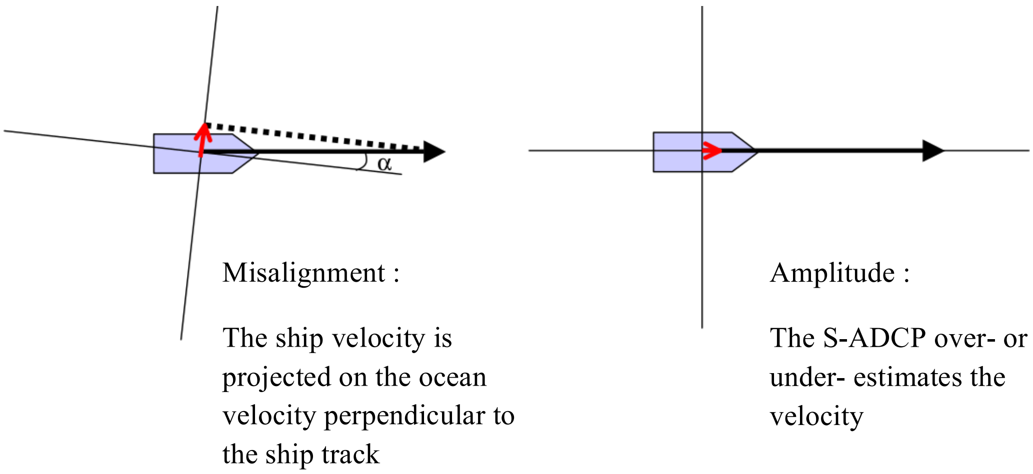


Figure 3: Scheme of the misalignment and amplitude errors.

Configurations of the two S-ADCPs used during the RREX15 cruise are described in Section 2. Section 3 describes the S-ADCP data processing done with CASCADE software to provide the best estimate of V_{flow}. It presents in particular the attitude, amplitude and misalignement corrections applied to the S-ADCP data to take into account errors due to the S-ADCP installation on the ship. Errors associated with V_{ADCP} and V_{ship} are discussed in section 4. Conclusion is provided in Section 5.

2. S-ADCPs configuration during RREX15 cruise

V_{ADCP} were measured during the RREX2015 cruise from two Shipboard-ADCPs operating at 38 kHz (OS38) and at 150 kHz (OS150). As shown in Figure 4, the maximum depth reached by the pulses was 1300-1400m for the OS38 and 200-250m for the OS150.

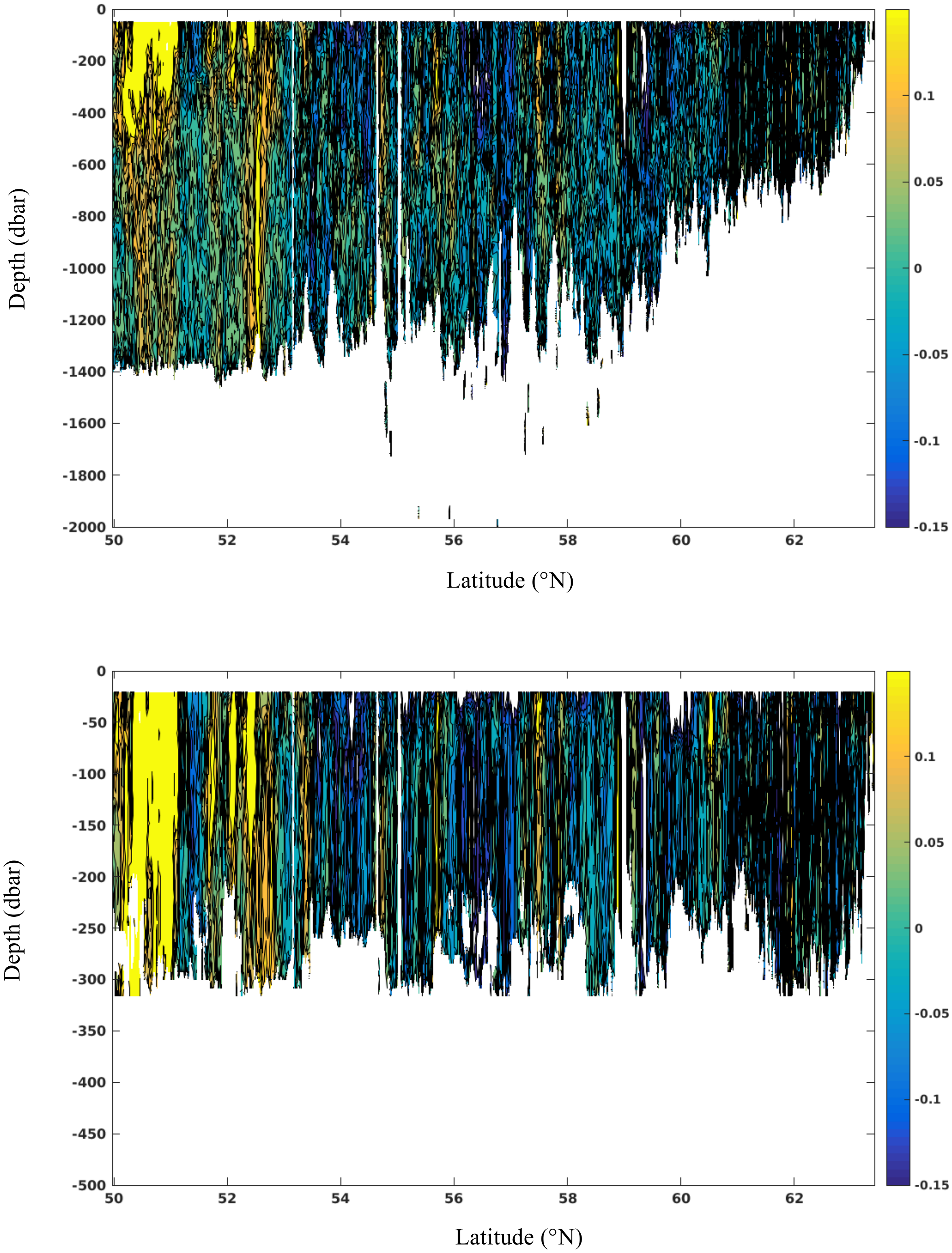


Figure 4 : Velocity profile along the Reykjanes Ridge section estimated by the two S-ADCPs mounted on the French R/V Thalassa. Amplitude in cm s^{-1} of the component perpendicular to the section is shown for OS38 (top panel) and OS150 (bottom panel). Note the different vertical scales.

Data Acquisition System VMDAS is used to configure S-ADCP data. The configuration parameters are specified in Table 1. The number of vertical cells (called bins) was set to 85 for OS38 and 38 for OS150. The vertical sizes of bins were 24 m for OS38 with the middle of the first bin at 47.06 m, and 8 m for OS150 with the middle of the first bin at 20.28 m. No data is available in the first 35 m for OS38 and the first 16 m for OS150 because of the delay between emission and reception. To avoid interferences, the two S-ADCP emissions were synchronized. The resulting ping rate was 4.27 seconds for both instruments. Pings were averaged by VMDAS over 2-minute periods referred hereinafter as 2-minute ensembles.

The two instruments can operate in unmodulated Narrow Band mode (NB) or in modulated Broad Band mode (BB). The NB mode allows long-range emission while BB mode allows higher precision velocity measurement at the expense of the range. For a given accuracy, the vertical resolution in BB is better than in NB mode. A drawback of BB mode is its strong sensitivity to ambient acoustic noise and interference with other sonars (*Firing and Hummon*, 2010), but this was dealt with on board by synchronizing acoustic emissions. As seen in Table 1, OS38 was used in NB mode for maximal range. Because OS150 only reaches 200-300m, high precision was preferred over depth range and the BB mode was used. The BB mode was also used for OS38 during Bottom-Tracking (BT) because this mode is used in shallow waters. In BT, one ping over two is used to measure the ship velocity with respect to ocean bottom, which, as discussed in section 3.3, allows estimation of S-ADCP misalignement.

Table 1: Configuration of S-ADCP OS38/OS150. Bin size is in meters.

Section	**Parameterization**	**Number of bin**	**Bin size**	**BT mode on**
1 to 2	BB/BB	85/38	24/8	1/1
3 to 21	NB/BB	85/38	24/8	0/0
22 to 24	BB/BB	85/38	24/8	1/1
25 to 37	NB/BB	85/38	24/8	0/0
38 to 39	BB/BB	85/38	24/8	1/1

3. S-ADCP data processing

S-ADCP data acquired during the RREX2015 cruise were processed with Cascade Version 7.0 software (« Chaine Automatisée de Suivi des Courantomètres Acoustiques Doppler Embarqués », http://www.umr-lops.fr/en/Technology/Software/Cascade-V7.1-a-matlab-software-to-process-Vessel-Mounted-ADCP-data) developed by LOPS (Laboratoire d'Océanographie Physique et Spatiale, Brest, France) since 1998. This software is designed to qualify, correct, fill gaps in, filter, and select final S-ADCP data acquired by VMDAS (file.STA).

The S-ADCP data processing was done in two stages summarized in Table 2 (*Le Bot et al.,* 2011). The processing is done on the absolute flow velocity, that is on 2-minute ensemble data points to which the ship velocity was removed (Section 1.2). In first stage, ETOPO1 bathymetry (*Amante, C. and B. W. Eakins*, 2009) was used with statistical tests to detect doubtful or bad data (Section 3.1). Then barotropic tides were removed based on tidal currents generated by the OSU tidal prediction software tpxo8.0 (*Egbert and Erofeeva*, 2002). The model resolution is 1/6° for the open ocean and it resolves the tidal components M2, S2, N2, K2, K1, O1, P1, Q1, M4, MS4, MN4, MM and MF. Finally, attitude, amplitude and misalignment corrections were estimated (see Sections 3.2 and 3.3). The same steps were followed in a second stage except that the latter corrections were applied before data qualification and removal of the barotropic tides. At the end, filters were applied to the data and the gaps were filled in.

Table 2: Treatment steps of Cascade.

Step 1: New file ➔ Remove ship velocity ➔ Add bathymetry ➔ Quality control ➔ Compute the barotropic tides➔ Determination of the corrections to apply (attitude, amplitude, misalignment)
Step 2: New file ➔ Remove ship velocity ➔ Add bathymetry ➔ Correction applied ➔ Quality control ➔ Compute the barotropic tides➔ Filtering and gap filling

3.1. Quality control of the data

The objective of the quality control of data was to detect doubtful or bad data. First, bins below ocean bottom were removed by Cascade using ETOPO1 bathymetry. Then, series of tests were applied based on parameters defined in Table 4. Those parameters were default values proposed by Cascade, and we verified that they were appropriate for our study. The parameters were the same for OS38 and OS150. The data were rejected if (see also Table 4):

- The horizontal velocity (U,V) was greater than 200 cm s^{-1}
- The correlation between emitted and received pings averaged on 2 minutes was less than 0.60.
- The velocity error, which was computed as the difference between the two estimates of the vertical

velocity, was greater than 20 cm s^{-1}.

- The percentage of good pings for a given 2-minute ensemble (PGOOD) is smaller than 10%.
- The vertical shear of the horizontal velocities was larger than 0.2 s^{-1}.
- The value is larger than ±2.7 times the standard deviation computed over 30 2-minute ensembles

Depending on the test that was failed by the data point, a specific flag is attributed to this rejected data (Table 3).

Table 3: Definition of the flags.

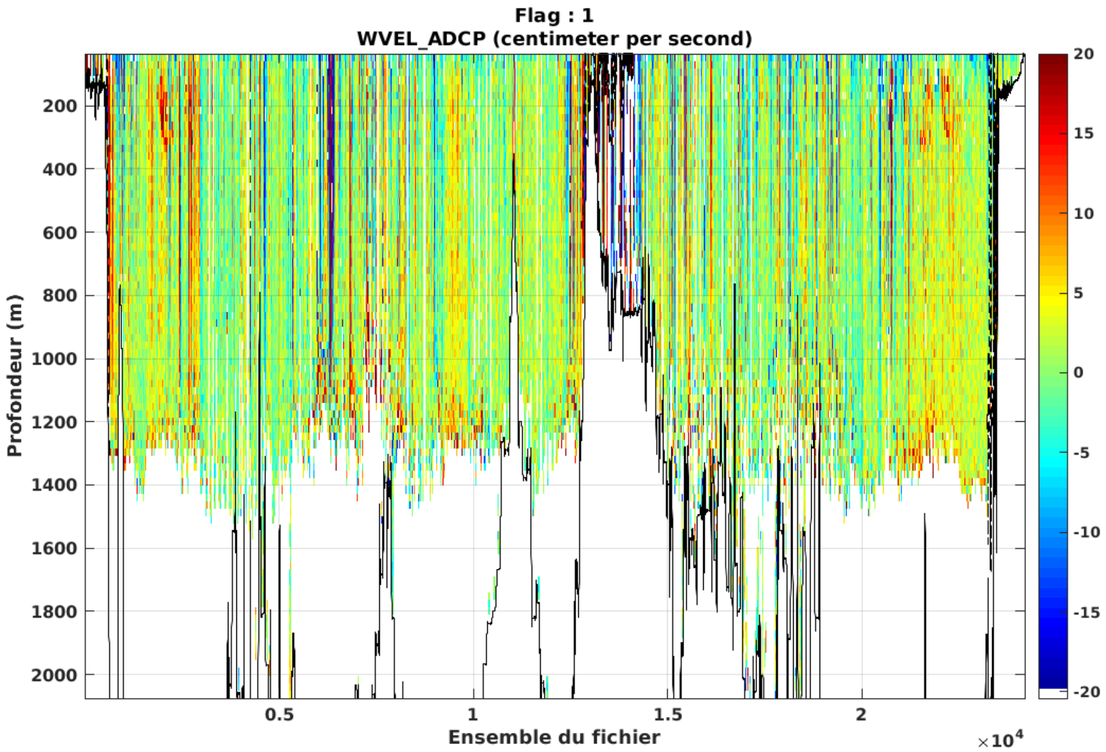
Flag 2: suspicious data	
Flag 3: bad data	Moving median test
Flag 4: bad data	Vertical shear > 0.2 s^{-1}
Flag 5: bad data	Error velocity > 20 cm s^{-1} & correlation < 60 & PGOOD < 10%
Flag 6: bad data	Horizontal velocity > 2 m s^{-1}
Flag 7: no data	
Flag 8: below the bottom	
Flag 9: manual invalidation	

Table 4: Statistical test parameters used to quality control S-ADCP data in Cascade. Data that were rejected by statistical tests are flagged as bad.

Threshold of the vertical speed error (cm s^{-1})	20
Maximum of the vertical shear of horizontal velocity (s^{-1})	0.2
Number of ensembles to be considered before/after every profile	30
Number of std from the median	2.7
Bottom depth detection	Bathy ETOPO1
Maximal speed (cm s^{-1})	200
Correlation threshold	0.60
Minimum % of good ensemble	10

3.2. Attitude correction

The pitch and roll given by the ship navigation system were used by VMDAS for real time correction of S-ADCP measurements. We thus considered that the remaining attitude error, which depends on the position of the S-ADCP on the ship, was constant during the cruise. Cascade computed the remaining attitude angle between ship and S-ADCP from the mean vertical velocity averaged over the cruise. Indeed, vertical velocities should be of the order of 10^{-3}m s^{-1} and not affected by the ship motion. Without attitude correction, vertical velocities estimated from OS38 are positively biased (yellow zones in Figure 5), with a large value of mean vertical velocities averaged over the cruise (0.026 m s^{-1}) of 5.4 10^{-3} rms. Assuming that the mean vertical velocity was induced by a projection of ship horizontal velocity onto the vertical, the attitude correction was obtained by dividing S-ADCP vertical velocity by the ship horizontal velocity. Indeed for low angle values, the sinus of the angle can be considered as being a good approximation of the angle. The corrections are 0.3° for OS38 and 0.1° for OS150. The correction removes the bias of vertical velocities and was applied to our dataset. For instance, once the OS38 data were corrected, the mean vertical velocity averaged over the cruise was 10-fold lower (−0.0048 m s^{-1}) and the rms (4.5 10^{-3}) was barely changed (Figure 5).



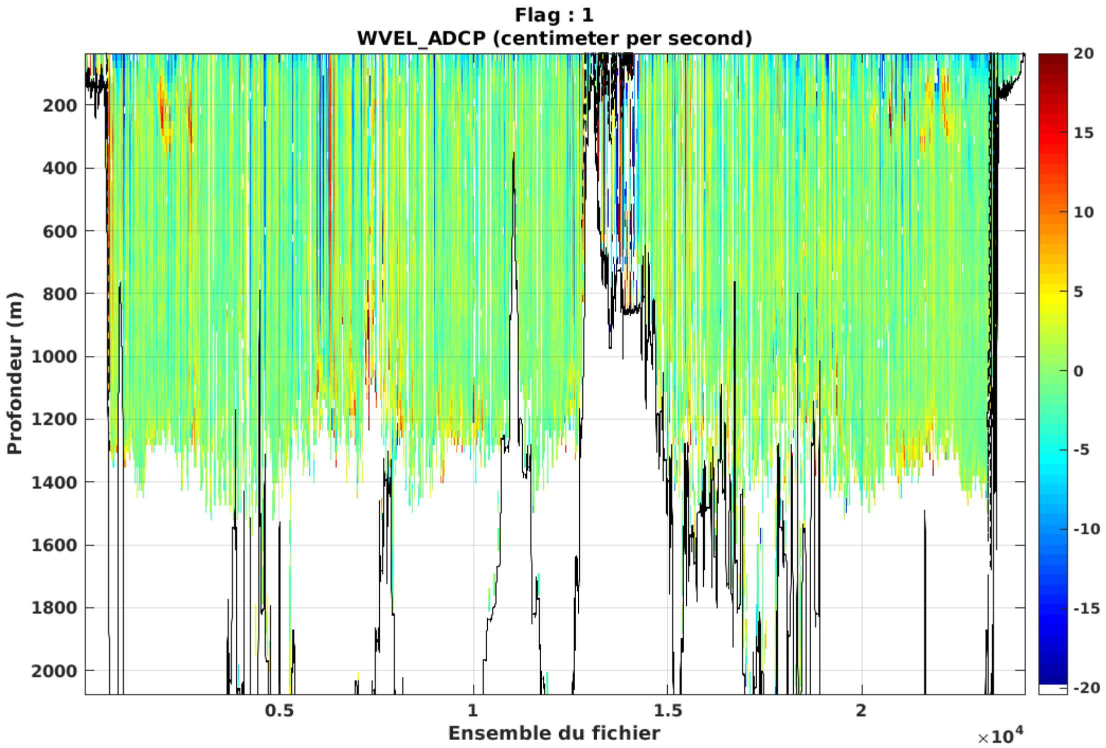


Figure 5: Vertical velocity of OS38 (cm s^{-1}) without attitude correction (top) and with attitude correction of 0.3° (bottom). Figures from Cascade.

3.3. Amplitude and misalignment correction

To correct misalignment and amplitude errors, S-ADCP data should be calibrated using a Water-Tracking (WT) method or a Bottom-Tracking (BT) method. The WT calibration minimizes the root-mean-square differences between ocean velocities estimated by S-ADCP and GPS during ship accelerations and decelerations, assuming a constant ocean current in a reference layer during acceleration and deceleration periods. The BT calibration compares the ship velocity, determined by GPS, to the ship velocity estimated from the S-ADCP bottom ping. The latter calibration is the most reliable even if it requires specific conditions. Indeed, the BT calibration must be realized in shallow water (the acoustic pulse has to reach the bottom), which was the case at the beginning and end of the cruise, as well as on the northern part of the Reykjanes Ridge.

An amplitude and misalignment correction was thus estimated using Bottom-Tracking (BT) data in Cascade. Coefficients of amplitude and misalignment correction are associated with the difference of amplitude (Figure 7) and direction (Figure 8) between GPS and BT ship velocities for rectilinear motion and uniform speed of the ship. Those computations should only take into account data recorded while the ship was moving (ship velocities > 2.5 m s^{-1}). Indeed, linear regression of BT versus GPS ship velocities used for the determination of amplitude correction in Figure 6 highlights the outliers at low ship speed. Statistical tests were implemented in Cascade to remove outliers. We considered data for which C_{ship}> 1 m s^{-1} and data for which the amplitude differences between BT and GPS ship velocities were less than 2.7 times the standard deviation. By following this procedure, we obtained a correlation coefficient of 0.99 between the BT and GPS ship velocity estimates (Figure 7). The amplitude correction was estimated as the slope of the linear regression between the two estimates (Figure 7, Table 5). Similar statistical tests were implemented for the misalignment computation (Figure 8, Table 5).

Table 5: Misalignment and amplitude corrections for OS38 and OS150.

OS38	*Misalignment α (°)*	*Amplitude a (cm s^{-1})*
Bottom Tracking	0.07 ± 0.03	1.0067 ± 0.0001

OS150	*Misalignment α (°)*	*Amplitude a (cm s^{-1})*
Bottom Tracking	-0.06 ± 0.03	1.0027 ± 0.0001

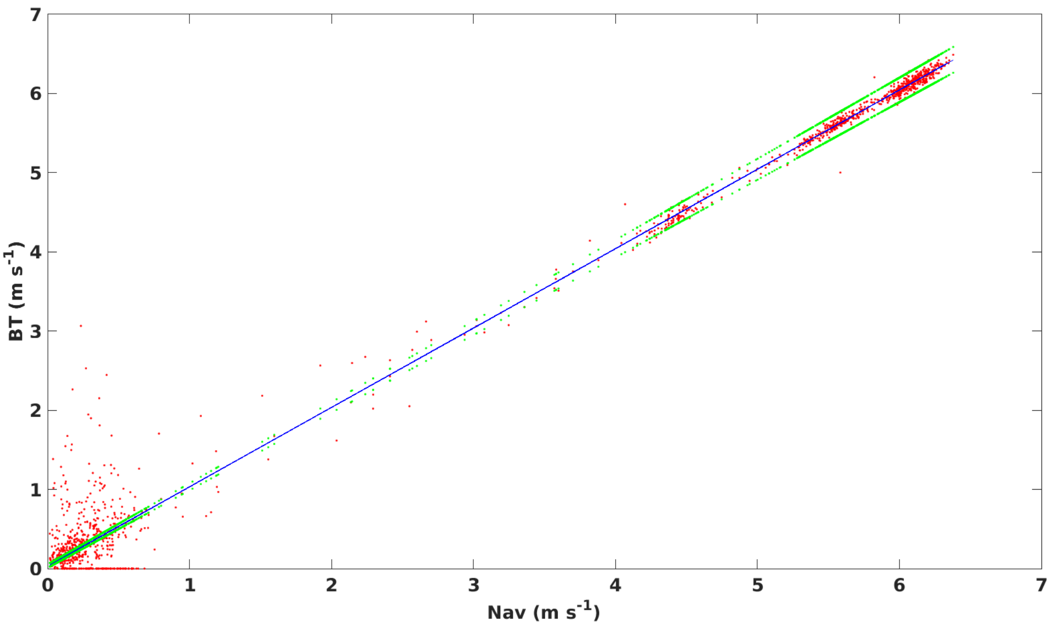
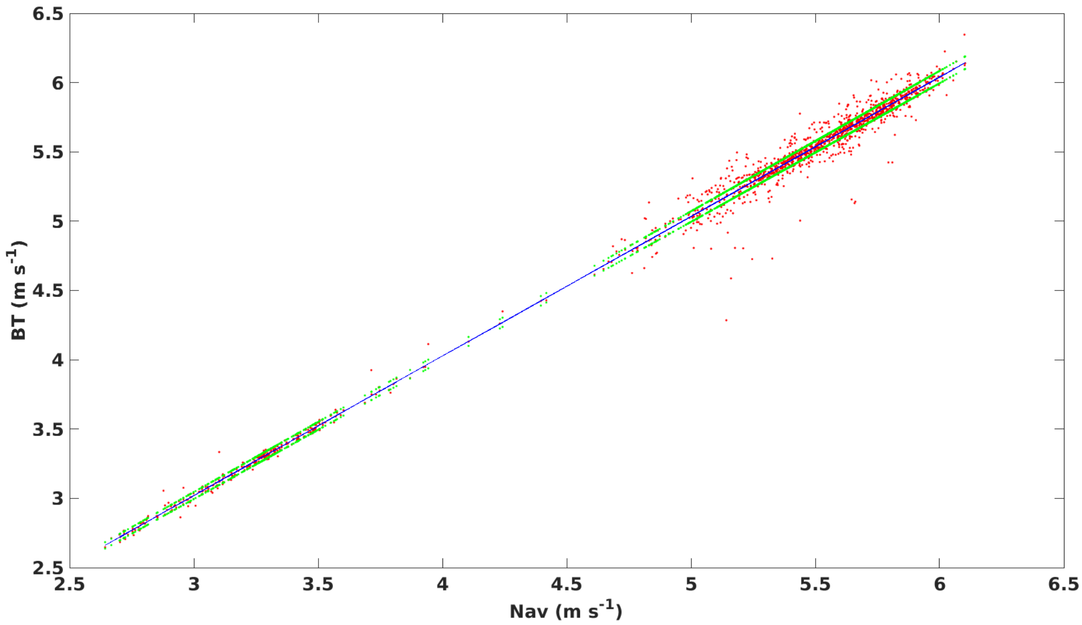


Figure 6: Linear regression (blue curve) of BT versus NAV (GPS) velocities above Reykjanes Ridge (red dots) with the 99% confidence interval (green curve) for OS38. All data acquired above Reykjanes Ridge were used for the determination of amplitude correction (R^2 = 0.98).



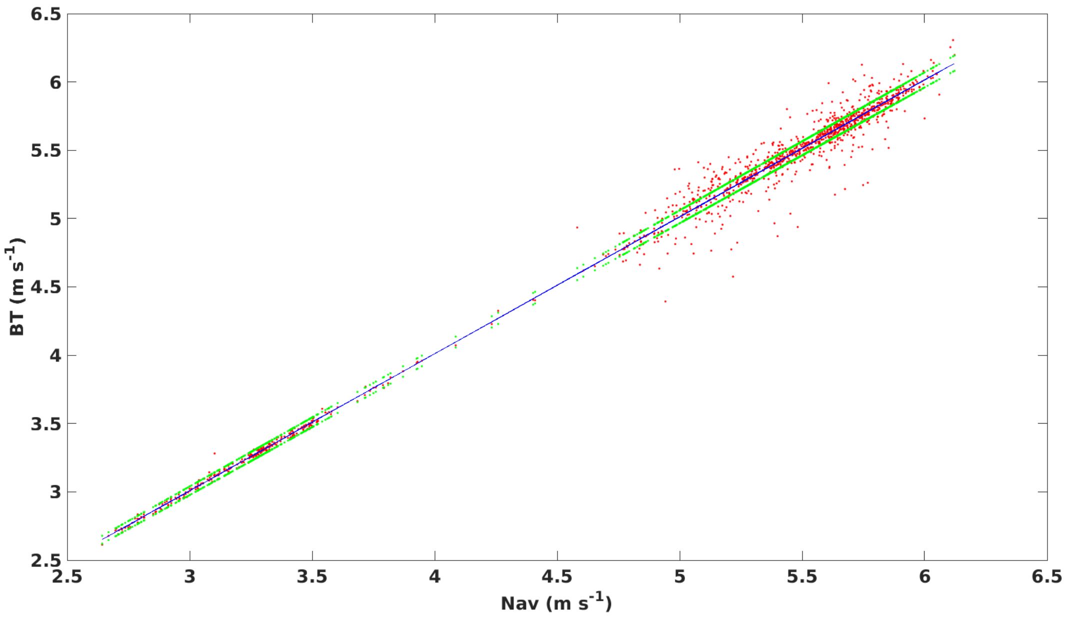


Figure 7: Linear regressions (blue curve) of BT versus NAV (GPS) velocities (red dots) with the 99% confidence interval (green curve) for OS38 (top) and OS150 (bottom). Data used for the determination of amplitude correction were taken at the beginning and end of the cruise (R^2 = 0.99). The correction factor applied was a = 1.0067 cm s^{-1} for OS38 and a = 1.0027 cm s^{-1} for OS150.

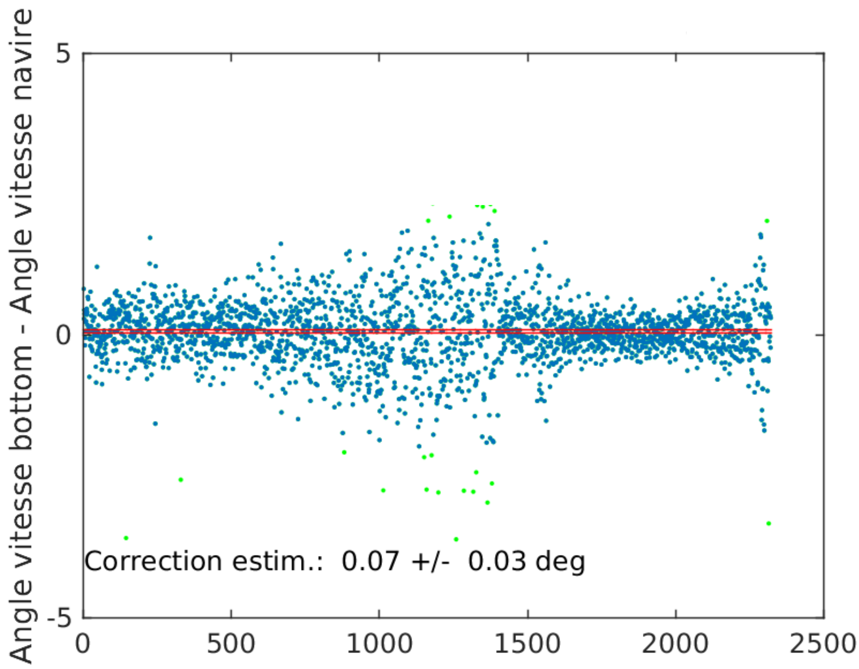


Figure 8: Difference of direction between Bottom-Tracking and GPS ship velocities for each 2- minute ensembles of OS38. The misalignment correction coefficient is the difference averaged on the whole dataset and was estimated by Cascade as 0.07 ± 0.03°. Blue dots are data taken into account for the computation while green dots were excluded by the statistical tests of Cascade. Red lines delimit the confidence interval of 95%

To refined misalignment corrections, OS38 data were compared with OS150 data for several corrections (Table 6). The aim was to determine whether those 2 datasets were compatible and if varying the misalignment correction within the confidence interval could minimize a possible bias between those two datasets.

Without misalignment correction (0/0 in Table 6), there is a negative bias of −0.0099 cm s^{-1} between the two S-ADCP ocean velocity estimates averaged between the surface and 250m of depth. The OS38 alignment has then a positive trigonometric angle α with OS150, which means that OS38 orthogonal velocities are on the left side of OS150 orthogonal velocities.

Table 6: Statistical studies of the misalignment correction for the Ridge section. Among the coefficients proposed by Cascade, bias and standard deviation were computed between OS38 and OS150 orthogonal velocities (cm s^{-1}).

Misalignment corrections OS38/OS150 (degree)	*Bias (cm s^{-1})*	*Standard deviation (cm s^{-1})*
0/0	-0.0099	0.018
0.07/-0.06	0.0032	0.017
0.06/-0.05	0.0011	0.017
0.05/-0.04	-0.00081	0.017
0.04/-0.03	-0.0028	0.017
0.04/-0.04	-0.0018	0.017
0.06/-0.04	0.00020	0.017
0.07/-0.04	0.0012	0.017
0.05/-0.03	-0.0018	0.017
0.05/-0.05	0.00014	0.017
0.05/-0.06	0.0011	0.017

Applying the misalignment corrections provided by Cascade (0.07 for OS38 and -0.06 for OS150 in Table 6) divides the bias between OS38 and OS150 by three. Nevertheless, velocities perpendicular to the ship track still have a positive bias of 0.0032 m s^{-1}. By varying the misalignment corrections of OS38 and OS150 within their respective confidence intervals, we found that the smallest biases (10^{-3} m s^{-1}) were obtained with corrections 0.05/-0.04, 0.06/-0.04 and 0.05/-0.05. For those 3 pairs of corrections, bias values are very close. Figure 9 shows that the vertical average of cumulated differences is very similar whatever the choice. The maximum difference is 0.00073 m s^{-1} for the Ridge section, 0.00017m s^{-1} for the North section, 0.001m s^{-1} for the South section and 0.0001m s^{-1} for the Ovide section. Figure 9 shows the rapid convergence of these differences after averaging over ≈ 100 km. Because the misalignment correction 0.05° for OS38 and -0.04° for OS150 are among the best choices for the full cruise, we applied those corrections to our data set.

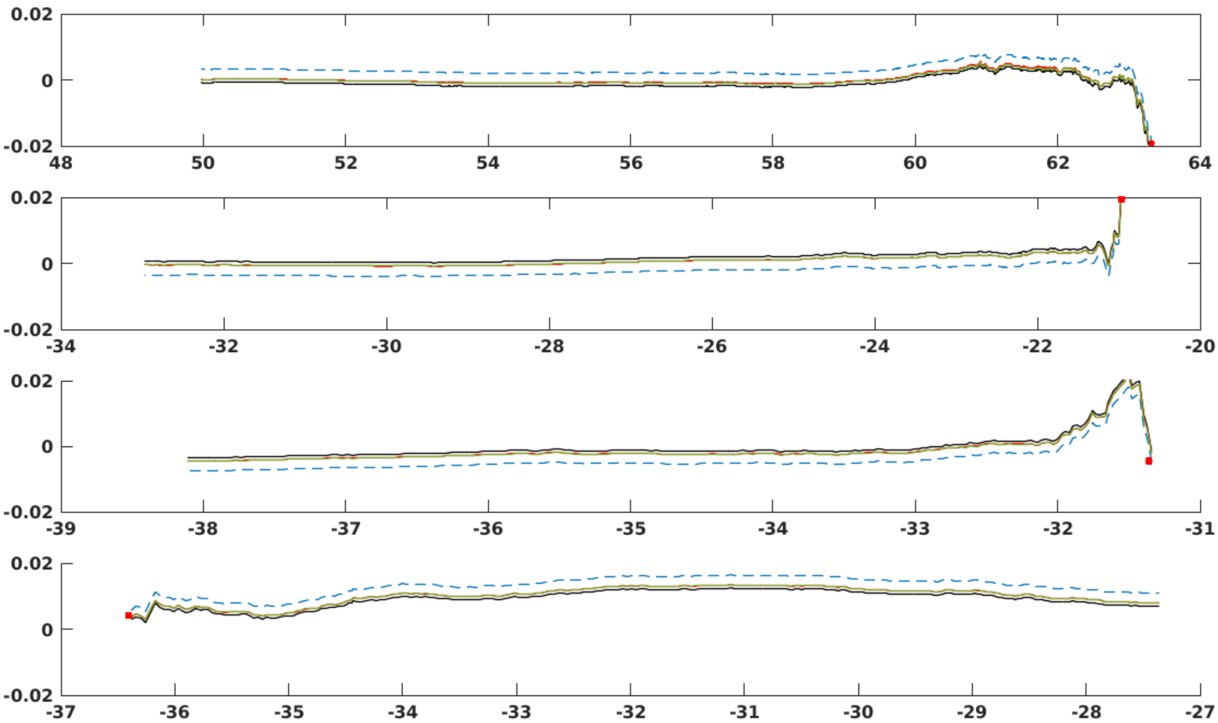
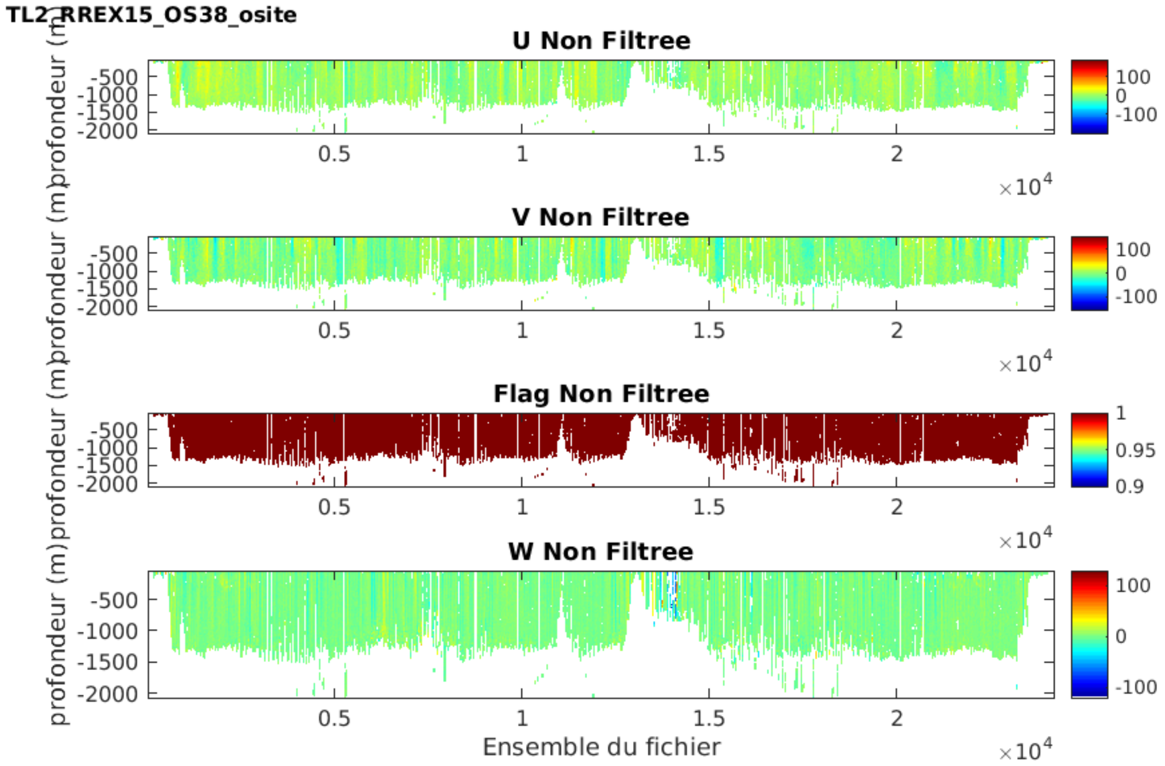


Figure 9: X-axis: Latitude/Longitude (°N/°W); Y-axis: Vertical top-to-bottom average of cumulated differences of orthogonal velocities (m s^{-1}) between OS38 and OS150 for various misalignment corrections along section Ridge (top), North (mid top), South (mid bottom) and Ovide (bottom). The blue dash curve is for the initial misalignment correction 0.07/-0.06; black curve for 0.05/-0.04; red curve for 0.06/-0.04; and green curve for 0.05/-0.05. Red point is the beginning of the accumulation.

3.4. Filtering and gap filling

As described in Table 2, the corrections previously determined (attitude, misalignment and amplitude) are applied before filtering and gap filling the data.

To filter the data, a running average is used on 3 horizontal and vertical points following the [¼ ½ ¼] rule. Note that when the average includes more than 2 suspicious data (flag=2), the resulting data is flagged as suspicious (Table 3). Missing data (white areas of the raw data in figure 10, top panel) are replaced by the average of 2 surrounded good data and are flagged as suspicious (flag=2). The filtering and gap filling proposed by Cascade results in the bottom panel of Figure 10. Considering the surface-bottom accumulated transport along the Ridge (not shown), this interpolation does not impact the final result and was applied to our dataset (average velocity changed by 10^{-4}m s^{-1}).



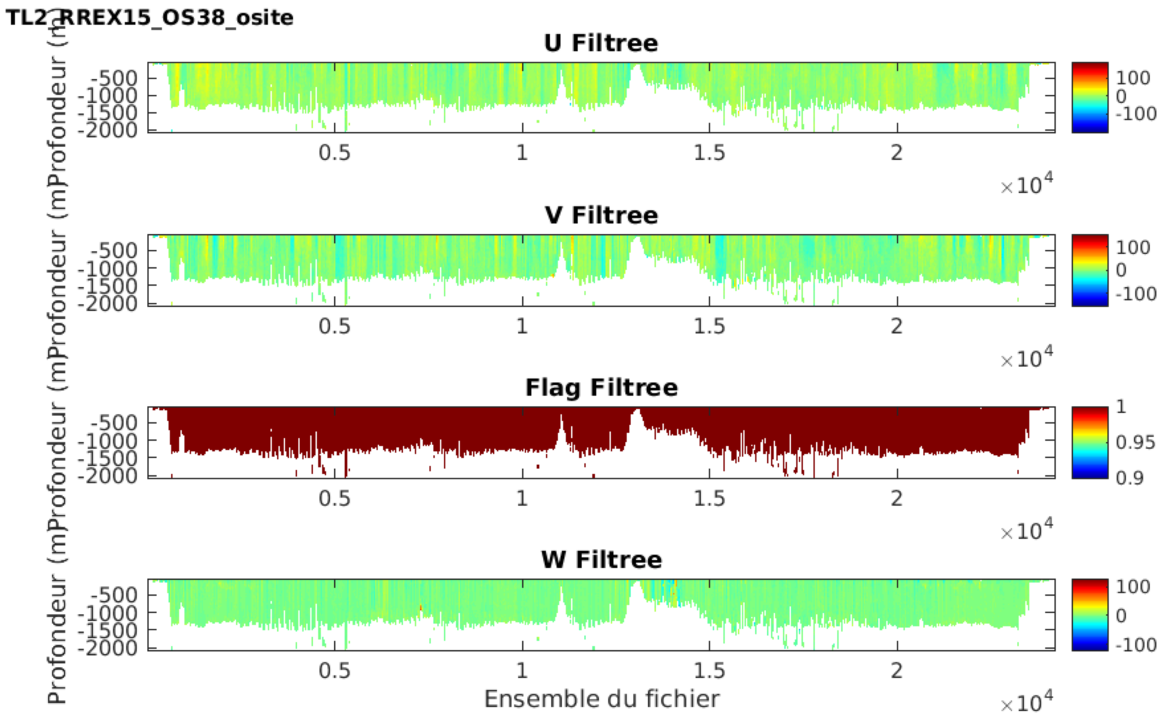


Figure 10: OS38 velocities and flag before (top) and after (bottom) fittering and gap filling. Figures from Cascade.

4. Instrumental errors

There are 2 instrumental error sources to be considered, coming from the S-ADCP and GPS, which respectively affect V_{ADCP} and V_{Ship}. Firstly, the S-ADCP error depends on the S-ADCP frequency, calibration, and configuration (such as the BT, bin size...) reported in Table 1. For OS38, profiles were mainly acquired in NB mode with a bin size of 24 m. As stated by the manufacturer, the measurement error on velocity is then 23 cm s^{-1} for a velocity obtained from a single ping. Averaging velocity profiles over a 2-minute ensemble of 29 pings, the velocity error decreases to $\varepsilon_{OS38} = 23/\sqrt{29} = 4.27$ cm s^{-1}. In BT, there were only 17 pings by 2-minute ensemble resulting in a larger velocity error of 5.58 cm s^{-1}. The OS150 was configured in BB mode with a bin size of 8 meters resulting in a velocity error of 9 cm s^{-1} per ping. For a 2-minute ensemble of 29 pings the velocity error decreases to $\varepsilon_{OS150} = 1.67$ cm s^{-1}. In BT, there were only 17 pings per 2-minute ensemble and the error becomes 2.18 cm s^{-1}.

The second main instrumental error comes from the GPS. As shown by *King and Cooper* (1993), a 0.5° error in the ship heading affects the ship velocity of the order of 1%. For a ship moving at 5 m s^{-1} the induced error is 5 cm s^{-1}. During the RREX mission, GPS HDS800 gave the geographical coordinates of the ship. Because the GPS system is the same as in *Chafik et al.* (2014), we could estimate its accuracy using the same calculation and obtained a magnitude for the 2-minute averaged GPS derived ship velocity standard error of $\varepsilon_{GPS} = 1$ cm s^{-1}.

In NB mode, the total instrumental error on absolute ocean velocity, caused by S-ADCP and GPS, is then $\sqrt{(4.27^2 + 1^2)} = 4.39$ cm s^{-1} for OS38. In BB mode, the total instrumental error is 2.40 cm s^{-1} for OS150. All those errors are random and decrease to zero for a large number of data.

5. Conclusion

We processed and qualified S-ADCP data acquired during the RREX 2015 cruise on the R/V Thalassa using the software Cascade. The processing consisted in validating, correcting, filling gaps in, filtering, and selecting final S-ADCP data. Considering the mean vertical velocity averaged over the cruise, we estimated an attitude corrections of 0.3° for OS38 and 0.1° for OS150. We also estimated the misalignment (α) and amplitude (a) corrections in comparing the ship velocity, determined by GPS, to the ship velocity estimated from the S-ADCP bottom ping in shallow water. Minimizing the bias between OS38 and OS150 further refined the misalignement correction. For the OS38, we found $\alpha = 0.05°$ and a = 1.0067 cm s^{-1}. For the OS150, we found $\alpha = -0.04°$ and a = 1.0027 cm s^{-1}. After correction, the agreement between OS38 and OS150 is remarkable and reveals the overall quality of those datasets (difference RMS of ≈ 0.0001m s^{-1}).

We also estimated the total instrumental error on the absolute ocean velocity calculated from errors on both V_{ADCP}, the flow velicity relative to the ship velocity estimated by the ADCP data, and V_{ship}, the ship velocity relative to the bottom measured by GPS. For OS38 in Narrow Band mode, the total instrumental error on absolute ocean velocity 4.39 cm s^{-1}. For OS150 in Broad Band mode, the total instrumental error is 2.40 cm s^{-1}.

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