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REFERENCING GEOSTROPHIC VELOCITIES USING ADCP DATA AT 24.5 °N

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Referencing geostrophic velocities using ADCP data at 24.5 ºN

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Abstract

Acoustic Doppler Current Profilers (ADCPs) have proven to be a useful oceanographic tool in the study of ocean dynamics. D279 hydrographic cruise transatlantic section along 24.5 ºN data carried out in Spring 2004, is processed and lowered ADCP (LADCP) bottom track data is used to inform the choice of reference velocity for the geostrophic calculations. To build this offset to each geostrophic profile, a previous statistics analysis is carried out to distinguish the better performing instrument during the measurements. The tidal barotropic component is subtracted, providing a final reference velocity obtained from LADCP data. Results of the velocity fields are also shown with satisfactory results in future applications of using direct velocity measurements in referencing velocity sections. Further studies involving inverse solutions will include the reference velocity here calculated.

1. Introduction

Velocity observations from Acoustic Doppler Current Profilers (ADCPs) have provided a new oceanographic tool, allowing the further study of many aspects of ocean dynamics. Ship-mounted ADCPs (SADCPs) have allowed detailed insights into the upper-ocean dynamics, however limited to a maximum depth of approximately 800 metres. On the other hand, lowered ADCP (LADCP) profiling provides the chance of measuring deep velocity profiles during standard hydrographic casts.

The use of direct velocity measurements has already been applied in the understanding of the oceanic circulation. The sampling of the complete dynamical structure of the Agulhas Current using LADCP data revealed a very different vertical structure than the imposed by the traditional assumption of a zero velocity surface in a deep and horizontal layer. The total volume transport of the Agulhas Current was re-estimated, and the presence of a north-eastward undercurrent was unveiled (Beal and Bryden, 1997). The use of LADCP data to inform the initial geostrophic calculations has also been applied in different oceanographic regions (Joyce *et al.*, 2001; McDonagh *et al.*, 2008). In both cases, the velocity observations were used to correct the choice of reference velocity for the initial geostrophic field as initialization of an inverse model.

The main scientific objective during cruise 279 carried out in Spring 2004 onboard the RRS Discovery (D279) was to estimate the circulation across the zonal section at 24.5 ºN. This section has been previously carried out in 1957 (Fuglister, 1960), 1981 (Roemmich and Wunsch, 1985), 1992 (Parrilla *et al.*, 1994) and 1998 (Baringer and Molinari, 1999). Nevertheless, cruise D279 in 2004 comprised for the first time the use of LADCP profiles at each station as constraints in an inverse study.

Circulation across 24.5 ºN and its variability has already been studied throughout cruise D279 data (Bryden *et al.*, 2005). Our study aims to apply LADCP profiles in a better quantification of the North Atlantic circulation. These estimates have been limited by the uncertainty in knowing the reference velocities, usually estimated as zero. The use of LADCP data will provide a reference velocity from the bottom track measurements. This will be used to inform the geostrophic calculations, once obtained an estimate of the depth-averaged offset to each geostrophic profile.

The reference velocity will be used in other study in obtaining an inverse solution referenced to ADCP data in comparison to the inverse initialised by a reference zero velocity. The circulation at 24.5ºN and the transatlantic distribution of temperature, salinity and other properties will also provide heat, freshwater and property fluxes. The size and structure of the Atlantic Meridional Overturning Circulation (AMOC) will be defined and compared to results using the transatlantic mooring array deployed in the framework of the rapid climate change/meridional overturning circulation and heat flux array (RAPID/MOCHA) experiment (Kanzow *et al.*, 2007; Cunningham *et al.*, 2007).

2. Data

The cruise D279 onboard the RSS Discovery comprised a transatlantic section at a nominal latitude of 24.5 ºN (Fig. 1). It took place in Spring 2004 (4 April to 10 May), carrying out hydrographic, velocity, chemistry and other measurements in the whole water column from shallow waters on the eastern seaboard of the USA to shallow waters near Africa. During the cruise, 125 full depth CTD (Seabird 911+) stations were carried out with dual sensors. CTD conductivities were calibrated by comparing them to bottle conductivities derived from salinity samples obtained during the CTD upcast. Therefore a slope correction was applied to account for sensor drifts.

A Lowered Acoustic Doppler Current Profiler (LADCP) array was deployed, and continuous underway observations were made in the upper 1000 metres using a ship mounted 75kHz ADCP (SADCP) installed on the research vessel’s hull. The LADCP array consisted of three instruments and two battery packs, fitted to the CTD frame. One Broadband (BB) 150 kHz running free in downward looking mode, with its own battery pack, while two 300 kHz Workhorse (WH) narrow band units were run in master/slave mode, one upward looking (slave) and one downward looking (master) with a shared battery pack.

3. Methodology

a. LADCP data processing

LADCP data are processed through the Visbeck software, developed in the Columbia University (Fischer and Visbeck, 1993). The procedure is carried out considering instruments separately in order to distinguish which full depth profiler is performing a better measurement during the cruise. Therefore, BB and WH master are processed individually, as the pair of WH configured in master/slave mode. Only GPS reference is applied, not taking the chance developed in the software of referencing to the bottom-track data nor the SADCP data (Visbeck, 2002).

Fig. 2 shows the processed data and the differences between the measurements taken by each instrument at station #23 (26.5ºN, 75.9ºW). Bottom track data are also computed for comparison in the range of depth near the sea bottom, as well as SADCP data but in the upper 1000 metres. Particularly, some discrepancies are shown between the bottom track profiles and the LADCP measurements near the bottom. Therefore, a statistical study is needed in order to differentiate the instrument that performed better during the cruise, in the sense that the differences between the BB and the downlooking WH bottom track measurements at each station are closer to zero (Fig. 3a).

Each full depth profile is compared to its instrument bottom-track, considering separately the downcast, upcast and the mean obtained from both. BB, WH master and the WH master/slave package are processed independently. The measurements near the bottom are compared to the bottom-track data in the matching range of depth (Fig. 3b). SADCP data are also compared to the profile values near the surface in the coincident depths (Fig. 3c). Means and standard deviations to each offset are obtained, providing conclusions through the similarities deduced from the values near zero. The instrument providing a better performance is the one which mean differences and deviation are the closest to null. Averaging each instrument's performance during the cruise, the difference obtained between the BB and WH master bottom track measurements is 1.7 ± 1.8 cm s^{-1} (Fig. 3a). On the other hand, the mean differences between each instrument and its bottom track are -1.1 ± 1.6 cm s^{-1} for the BB, -0.3 ± 1.1 cm s^{-1} for the WH master processed free running and 0.6 ± 1.0 cm s^{-1} for both WH in master/slave mode (Fig. 3b). Finally, the mean differences calculated for each LADCP in comparison to the SADCP data are 0.9 ± 3.0 cm s^{-1} for the BB, 0.0 ± 2.8 cm s^{-1} for the WH master processed free running and 0.5 ± 2.6 cm s^{-1} for both WH in master/slave mode (Fig. 3c).

Therefore, the instrument chosen for the correction of the geostrophic velocities is the WH master, processed free from its slave. Unfortunately, a study using both WH in master/slave mode is not able to be done due to the fact that the uplooking WH (slave) suffered some data reception errors during the whole cruise and finally stopped to be deployed after station #81 (24.5ºN, 44.9ºW) to the end of the survey.

Only the velocity component that is perpendicular to the section is further considered. Thus, a velocity rotation is applied in the slanting part of the section, at the eastern and western boundaries.

b. Tidal barotropic component correction

The tidal barotropic component is subtracted from the LADCP and SADCP velocity measurements. It is calculated using the OSU (Oregon State University) TPXO model (Egbert *et al.*, 1994; Egbert and Erofeeva, 2002). This global model of ocean tides best-fits, in a least-squares sense, the Laplace Tidal Equations and along track averaged data from TOPEX/Poseidon and Jason (on TOPEX/POSEIDON tracks since 2002) obtained with OTIS. The time considered for the tidal prediction is the bottom track time, which is half of the time spent on station.

Once calculated, the tidal barotropic component (Fig. 4) is subtracted from the velocity measurements taken by the LADCP and SADCP profiles.

c. Reference velocity field

The initial geostrophic velocity field is calculated with a zero-velocity reference layer at 1000 metres at stations #1-44 (79ºW to 69.5ºW) and 3000 metres at stations #45-125 (69.1ºW to 13.4ºW) following the study carried out by Bryden *et al.* (2005). As already mentioned, the reference velocity is obtained using WH master bottom-track data. Each station pair has a geostrophic velocity profile and two bottom track data profiles located on both stations surrounding it. Therefore, the correction is applied calculating differences between geostrophic and bottom-track profiles at the coinciding depth range. The differences obtained are averaged and a final mean between the contributions on both-sided stations is used (Fig. 5). On station pairs with LADCP data available just on one station, this is taken as the whole correction contribution.

4. Results

The initial geostrophic velocity profiles and those using the LADCP contribution are compared as shown in Fig. 5, corresponding to the station pair #22-23 (located at 26.5ºN, at 76.1ºW and 75.9ºW respectively). Individual plots, as shown in Fig. 5, are drawn to compare the initial velocity profile at each station pair with the ADCP-referenced, as well as the bottom track data taken into account for each correction, corresponding to the previous and following station's data. SADCP is also included in those plots, in order to check the resemblances between the available data with the corrections made.

SADCP data can be included in the study considering two ways. Firstly, taking the value for each station pair as the averaged measurements during each cast. Secondly, taking the values obtained while the ship navigated between stations and averaging it. Nevertheless this last option could register ageostrophic features located between stations, not shown at the computed geostrophic profile obtained from the CTD casts at the two neighbour stations. Therefore, only the first option is further considered.

The reference velocity is plotted throughout the section to appreciate the corrections made (Fig. 6a). As already mentioned, the initial reference velocity was considered zero in the geostrophic calculations (Bryden *et al.*, 2005). The velocity offset shown reflects the behaviour of some oceanographic features (Fig. 6a). On the western boundary, high positive (northward) velocities across the section represent the Florida Current contribution. Moving eastwards, negative (southward) velocities stand for a recirculation structure and the Deep Western Boundary Current (DWBC). Moving further eastwards, some minor structures can be appreciated, considering the offset contribution less than 5 cm s^{-1}. The positive and negative velocities switching between close stations stand for mesoscale contribution. In order to constitute the contribution from the reference level velocities, final velocity estimation at the sea bottom are plotted for the initial case considering null reference velocity and for the LADCP-referenced velocity field (Fig. 6b). The contribution of the LADCP data is clearly seen. Fig. 7 shows vertical sections to appreciate the main resemblances of the velocity field across the section before and after the correction. As expected, no qualitative changes are shown near the surface, where northward and southward flows remain behaving in a similar way. Nevertheless, the water column performance changes once introduced a new reference velocity where initially considered null. Almost barotropic currents are clearly seen along the section as well as northward/southward adjacent currents that represent the eddy oceanic field.

5. Summary and discussion

The obtaining of a reference velocity has been described as a depth-averaged offset to each geostrophic profile using bottom track LADCP data from cruise D279 along 24.5 ºN. Results indicate the useful application of this methodology to obtain absolute geostrophic estimations from direct velocity observations during the hydrographic measurements.

The most significant advance made to previous works concerning the D279 cruise data is the statistical analysis carried out in order to distinguish the better instrument performance. Final results are not masked by constraints during the LADCP data processing or the conditioning between the different devices performance.

The further use of these data will be carried out by Ocean Observation and Climate team at the National Oceanography Centre, Southampton (NOCS) in order to throw some light upon the Atlantic Meridional Overturning Circulation (AMOC) quantification and dynamics.

Concluding, the ADCP is nowadays a valuable tool to measure ocean deep velocity profiles. Currently it is being demonstrated its utility in the correction of standard hydrographic measurements and calculations. LADCP data processing can provide independent constraints in the study of the ocean dynamics through inverse methods. There still are some deficiencies in the resulting data but continuous improvements are being made in the instruments performing, as well as their processing and further applications.

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FIG. 2. Processed LADCP data through the Visbeck method at station # 23 (26.5ºN, 75.9ºW). a) eastwards velocity component, b) northwards velocity component. BB and WH master represent data processed free running, while WH master/slave correspond to the combined data of WH down and up-looking running in master/slave mode. Every subplot has a different y-scale.

FIG. 3. Statistical analysis carried out for the three different instruments deployed during the survey. a) mean and standard deviation of the differences existing between the BB and WH master bottom tracks measurements. b) mean and standard deviation of the differences between each LADCP full depth profile and its bottom track record in the range of depth near the sea bottom. c) mean and standard deviation between the each LADCP full depth profile and the SADCP profile in a range of depth near the sea surface.

FIG. 4. Tidal barotropic component calculated from the OSU TPXO tide prediction model. This velocity is subtracted from the LADCP and SADCP profiles velocity measurements.

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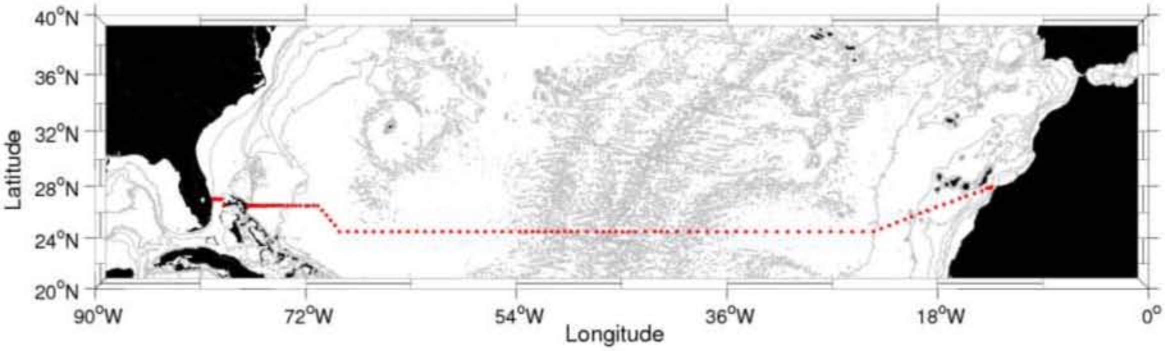
FIG. 7. Velocity fields (cm s^{-1}) contoured a) before, and b) after the correction applying the ADCP referencing.



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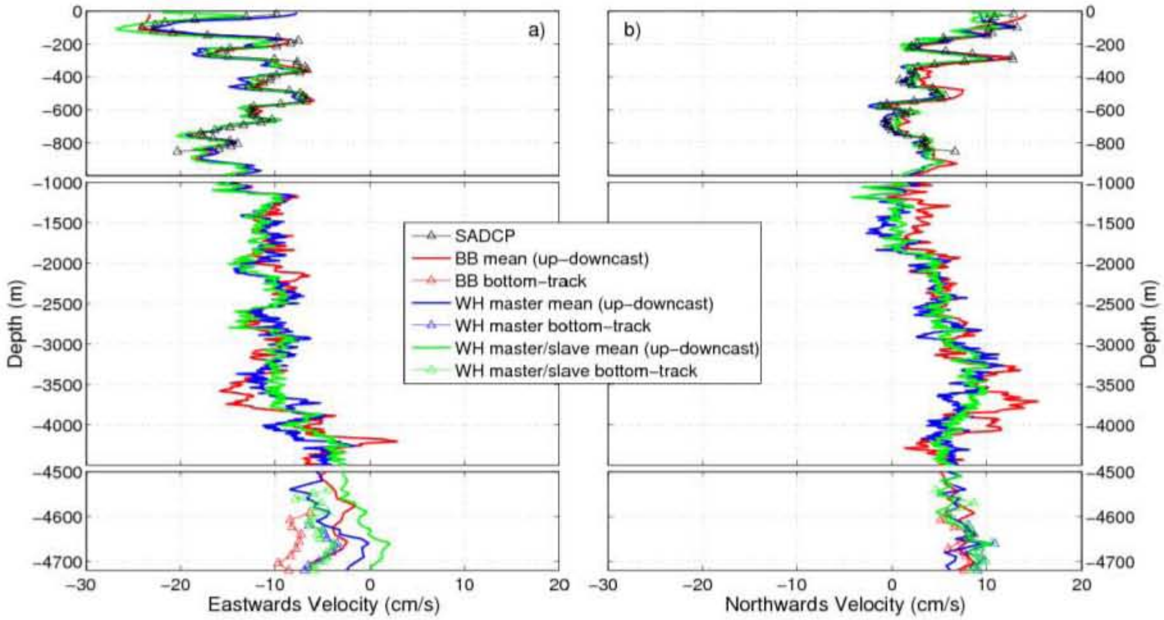

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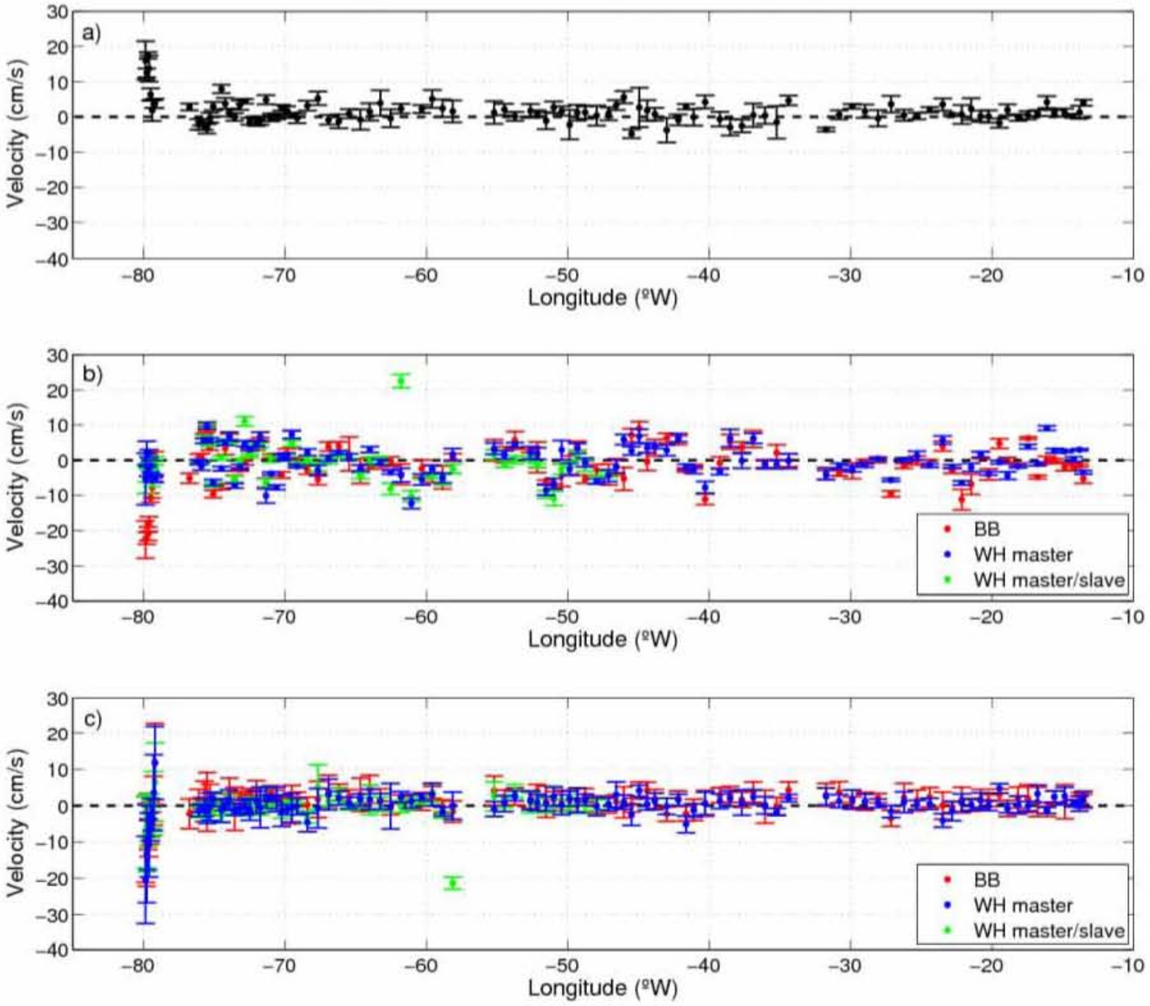

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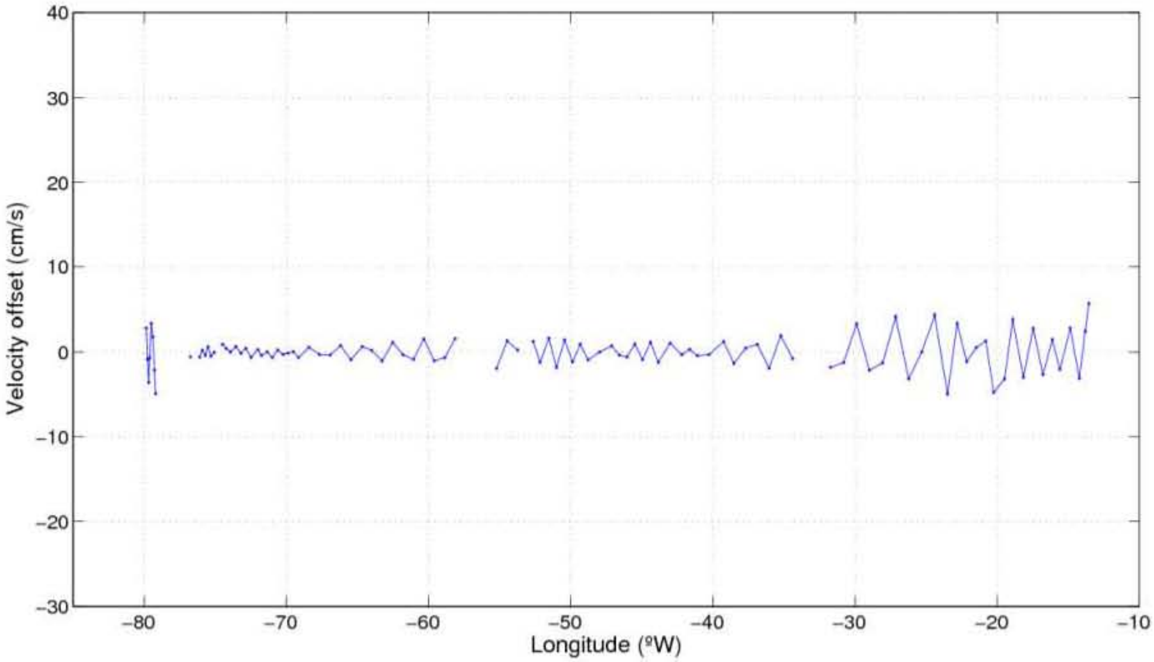

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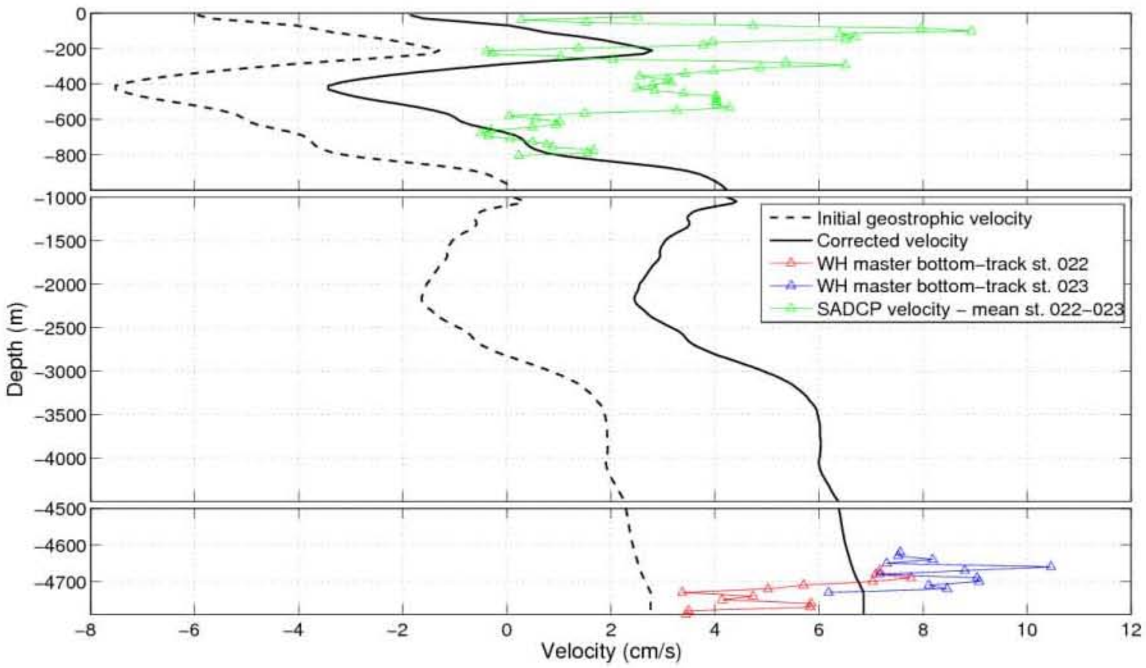

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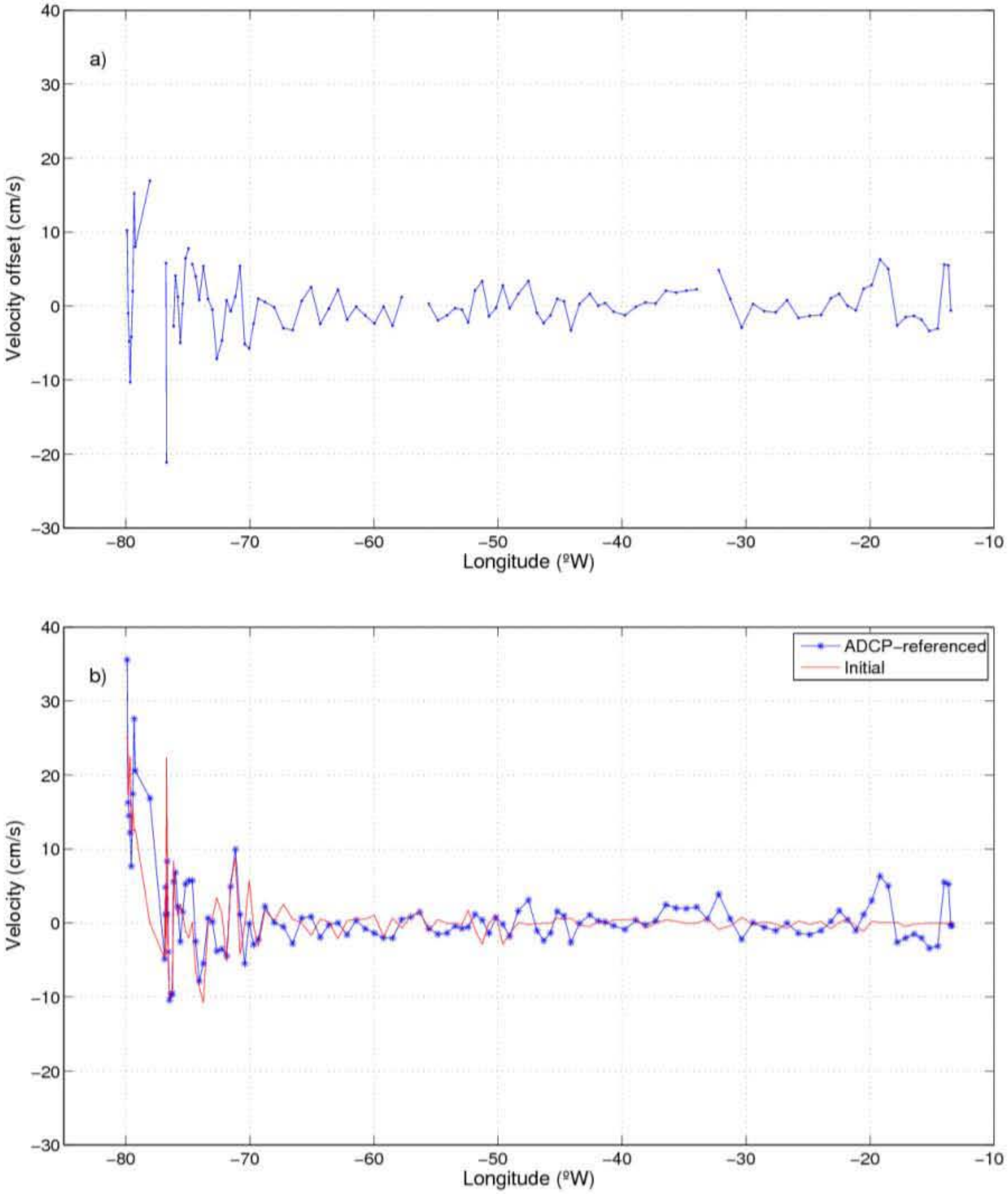

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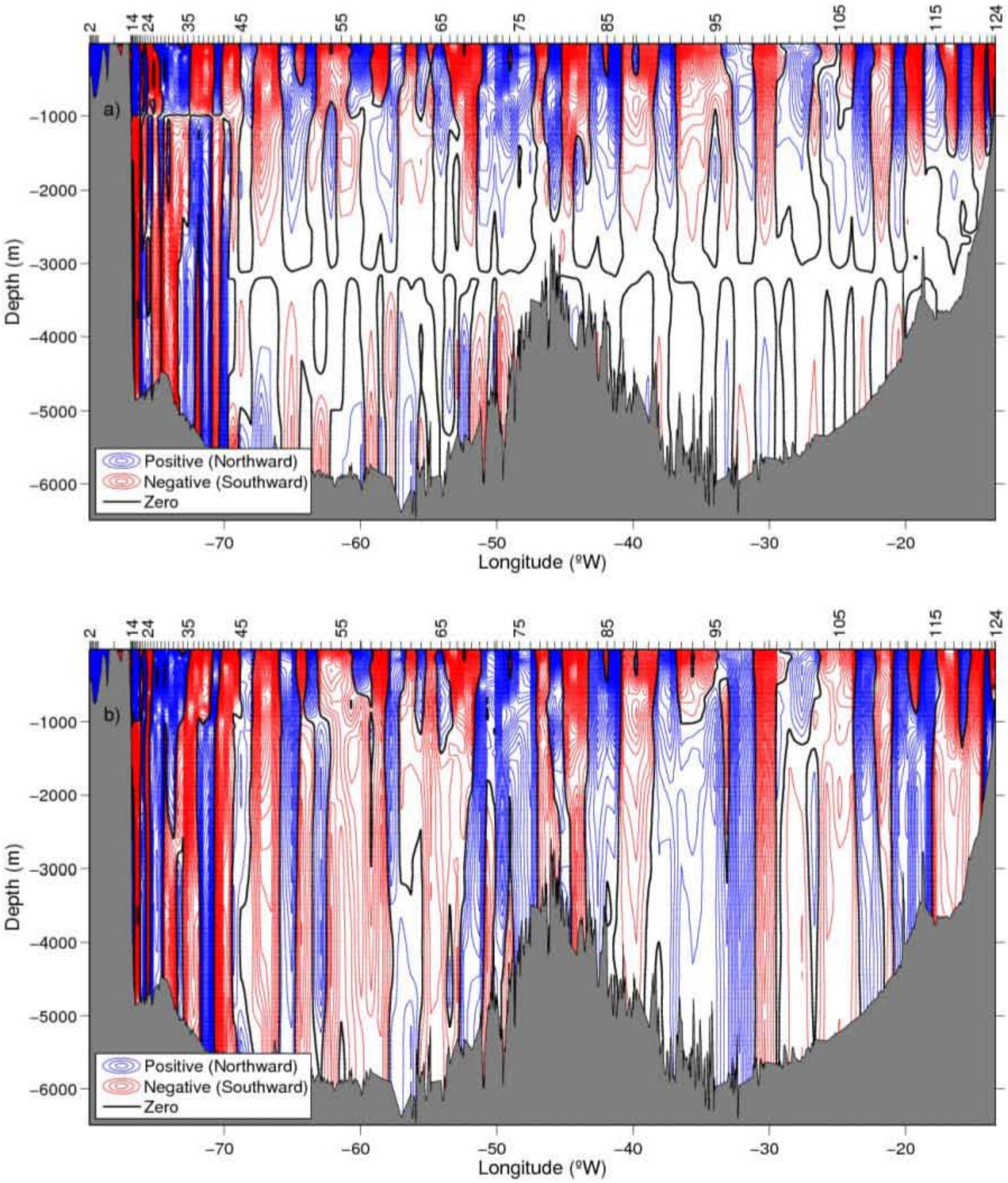

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