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14. ABSTRACT
Interleaving in the Agulhas Return Current (ARC) frontal region is commonly manifested in the form of thermohaline intrusions, as subtropical and sub-polar water masses of similar density meet. In Jan/Feb 2012, the Naval Research Laboratory and collaborators carried out a field experiment in which seismic and traditional hydrographic observations were acquired to examine frontal zone mixing processes. The high lateral resolution (10 m) of the seismic observations allowed fine-scale lateral tracking of thermal intrusions, which were corroborated with simultaneous XBT casts. Between seismic deployments both salinity and temperature data were acquired via CTD, Underway-CTD and microstructure profiles. This study focuses on analyzing seismic reflection data in a particular E-W transect where the northward flowing ARC interacted with the southward flowing portion of a large anticyclonic eddy. Strong reflectors were most prominent at the edge of a hyperbolic zone formed between the eddy and ARC, where sub-polar waters interacted with waters of sub-tropical origin on either side. Reflectors were shallow within the hyperbolic zone and extended to 1200 m below the ARC. The nature of the observed reflectors will be determined from comparison of seismic reflection and derived $\partial T/\partial z$ fields, and XBT and TS profiles from the available hydrographic data.

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seismic oceanography, Agulhas return current, eddy, thermohaline instrusions, water mass tracking

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Interleaving in the Agulhas Return Current (ARC) frontal region is commonly manifested in the form of thermohaline intrusions, as sub-tropical and sub-polar water masses of similar density meet. In Jan/Feb 2012, the Naval Research Laboratory and collaborators carried out a field experiment in which seismic and traditional hydrographic observations were acquired to examine frontal zone mixing processes. The high lateral resolution (10 m) of the seismic observations allowed fine-scale lateral tracking of thermal intrusions, which were corroborated with simultaneous XBT casts. Between seismic deployments both salinity and temperature data were acquired via CTD, Underway-CTD and microstructure profiles. This study focuses on analyzing seismic reflection data in a particular E-W transect where the northward flowing ARC interacted with the southward flowing portion of a large anticyclonic eddy. Strong reflectors were most prominent at the edge of a hyperbolic zone formed between the eddy and ARC, where sub-polar waters interacted with waters of sub-tropical origin on either side. Reflectors were shallow within the hyperbolic zone and extended to 1200 m below the ARC. The nature of the observed reflectors will be determined from comparison of seismic reflection and derived $\partial T/\partial z$ fields, and XBT and TS profiles from the available hydrographic data.

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The Agulhas Return Current (ARC) is an intense eastward flowing current that begins downstream of the Agulhas Current retroflection in the southeast Atlantic Ocean. The close contact between sub-polar water (at the southern boundary of the sub-tropical gyre), and sub-tropical water (transported to the south by the Agulhas Current) produces a strong frontal zone in this region characterized by the presence of a strong temperature front. In addition, the frontal zone features high levels of mesoscale variability, abundant eddy events and a quasi-permanent northward meander of the return current in the vicinity of the Agulhas Plateau.

In January and February 2012 the Naval Research Laboratory and collaborators conducted the ARC12 research cruise aboard the R/V Melville to assess the mixing of the subtropical and subpolar water masses in the ARC region. The main objective of the field effort was to investigate mesoscale stirring and diapycnal mixing mechanisms in the study area with a focus on the interaction of temperature fine structure with mesoscale features of the ARC system. The experiment was conducted at the first meander of the return current at around the 2000 m isobath of the Agulhas Plateau.

To examine frontal zone mixing processes, the field experiment collected seismic reflection data from the relatively new seismic oceanography technique. This method employs low-frequency (10-200 Hz) sound waves in the ocean to generate direct reflections off temperature contrasts in the water column. The reflections are then used to identify water mass boundaries from eddies, fronts and oceanic fine structure on scales of meters to tens of meters (Ruddick et al., 2009). With a horizontal and vertical resolution approaching 10 m and data spanning from about 50 m depth to the seafloor, the technique produces banded images of $\partial T/\partial z$ and allows the structure of this field to be traced over multiple kilometers. Large reflectors in seismic reflectivity images are evidenced by alternating positive and negative bands, and indicate areas of strong vertical temperature gradients. For a more detailed explanation of the seismic oceanography technique the reader is referred to Ruddick et al. (2009).

Overall, the experiment acquired reflectivity data from eight seismic sections across the ARC which were combined with traditional hydrographic observations of temperature salinity and current velocity. The seismic transects were corroborated with 204 expandable bathy-thermograph (XBT) casts. Between seismic deployments, salinity and temperature data were acquired via 18 CTD, 39 Underway CTD (UCTD), and 37 microstructure profiles. Velocity data were collected throughout the cruise via a 75 KHz vessel-mounted ADCP.

This study focuses on analyzing seismic reflection data and available hydrographic data in a particular east-west transect (S5) collected on February 1, 2012. In this section the northward flowing ARC in the vicinity of the Agulhas Plateau interacted with the southward flowing portion of a large warm-core anticyclonic eddy. This event formed a hyperbolic flow point in the intersection region of the eddy and ARC as the southern portion of the stream was detrained into the eddy and a northwest portion of the eddy was entrained back into the ARC.

Figure 1 shows the reflection seismograms of the S5 transect, along with profiles of the vertical temperature derivative at each XBT location. The latter show the correlation between $\partial T/\partial z$ and the seismic response. Reflectors in the seismic field are evidenced by alternating negative (red) and positive (blue) bands. Strong reflectivity is indicated by yellow (negative) and black (positive) bands and denote areas of strong vertical temperature gradients. It is important to note that due to the nature of the seismic wavelet, each water column reflector likely produces multiple positive and negative bands. The seismic data reveal acoustic reflections that are most prominent at the edge of the hyperbolic zone between the edge of the eddy and ARC, where sub-polar waters interacted with waters of sub-tropical origin on either side. Reflectors within the hyperbolic zone were shallow, however below the ARC they occurred as deep as 1100-1200 m, extending for many tens of km away from the hyperbolic zone.

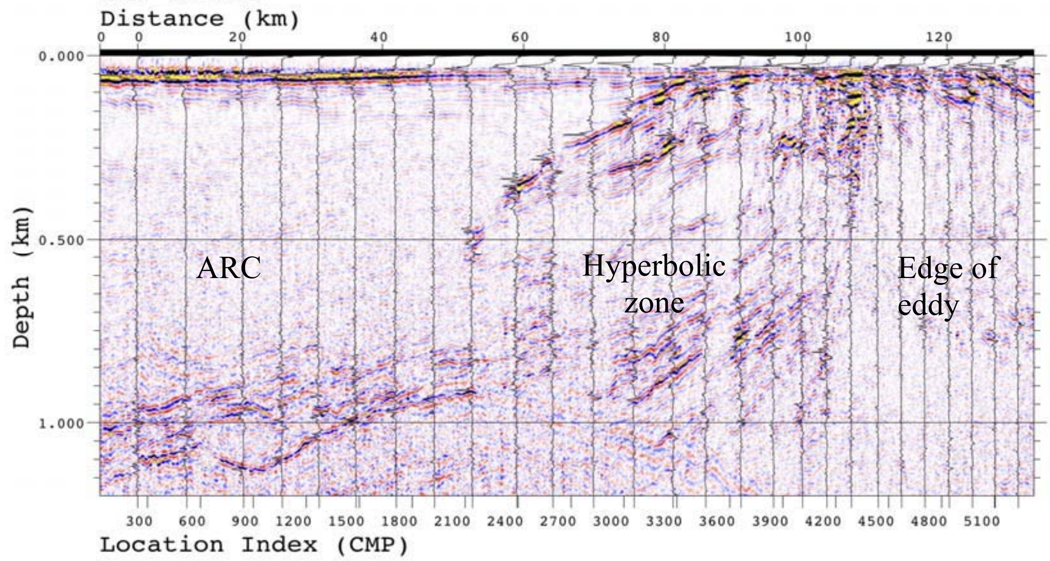

FIGURE 1. Reflection seismograms of ARC12 seismic line S5 overlaid with the derivative of the temperature field with respect to depth derived from the XBTs. The strong frontal region between the ARC and the warm core eddy is clearly evidenced by the strong reflectors at the edge of the hyperbolic zone between the edge of the eddy and the ARC.

To identify the nature of the water mass boundaries associated with the transect S5 reflectors, hydrographic data of temperature and salinity collected throughout the ARC12 cruise and within S5 were analyzed to produce the TS relationship in Figure 2a. As can be observed, the water types present in the ARC12 study area are distinctly different at the surface and at depth. Within the ARC, a core of Indian Subtropical Water characteristically exists at a depth of 200 m and is evidenced by its clear salinity maximum (Lutjerharms, 2006). At depth Antarctic Intermediate Water ranges from 2 to 10 ^{o} C and 34 to 34.8 psu and lies above North Atlantic Deep water. The mixture between surface and intermediate waters is called Central Water and in the vicinity of the ARC region is typically composed of South East Atlantic and South West Indian waters (Valentine et al., 1993).

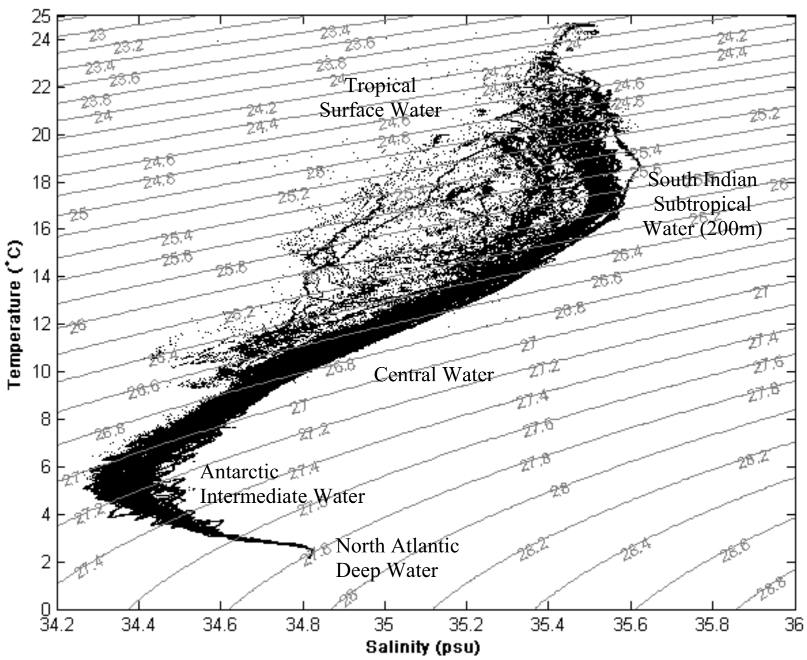

FIGURE 2A. Temperature-Salinity relationship of the CTD, UCTD and microstructure datasets collected during the ARC12 experiment January 25- February 6, 2012.

Figure 2b shows three individual T-S curves from three CTD casts acquired on January 31, 2012 along the S5 transect. The color scale indicates depth at each cast. The left panel displays the TS properties of CTD 12 collected within the northward flowing ARC. It features very warm (up to 25 ^{o} C) surface water above 200 m and the distinct subsurface salinity maximum at about 200 m associated with South Indian Subtropical Water. The middle panel shows the TS curve from CTD 10 acquired in the frontal zone generated by the interaction between the ARC and the warm-core eddy to the west. Interleaving between the ARC and eddy in this frontal region is evidenced by the strong temperature and salinity gradients throughout the water column and particularly between 200 and 800 m. The characteristic salinity maximum at 200 m no longer exists and the surface water within the front is colder and fresher than in the ARC due to the influence of Subantarctic Mode Water caught between the eddy and the ARC. Lastly, the right panel exhibits the TS curve from CTD 8 collected at the edge of the warm-core eddy. The TS characteristics there appear to be a combination of the TS curves representative of the ARC and frontal region. This observation attests to the notion that the eddy was likely spawned from the ARC at an earlier time before travelling to the west and interacting with newer ARC waters. In summary an analysis of seismic oceanography data combined with hydrographic data provides insight into the composition and location of water masses within the water column.

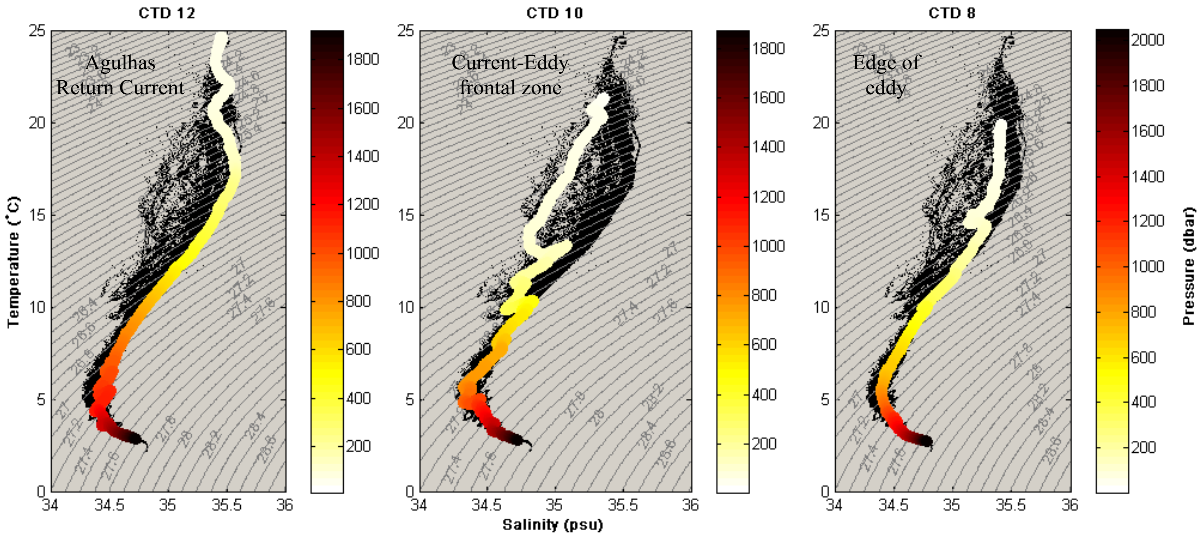

FIGURE 2B. Temperature-Salinity curves from three individual CTD casts collected during ARC12 on January 31, 2012. The left panel shows CTD cast 12, collected on the eastern edge of seismic line S5 (see Fig. 1) in the Agulhas Return Current; the middle panel CTD cast 10, collected in the current-eddy frontal zone, and the right panel CTD 8, collected at the edge of the warm core eddy. The color scale indicates the depth at each cast.

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