High-resolution structure of the upper Western Boundary Undercurrent core shaping the Eirik Drift

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***Abstract**: For the first time the method of seismic oceanography was applied to identify fine structure of a water mass in greater depths (> 1500 m) close to the seafloor. The pathway of the upper high-velocity Western Boundary Undercurrent (WBUC) branch was tracked over the Eirik Drift, 200 km south of Greenland at seafloor depths between ~2200 and 3000 m. It appears as an upward convex structure attached to the slope with a transparent, i.e. well mixed, core surrounded by higher amplitude reflections. These reflect gradients and fine structure. Fine structure is a result of enhanced mixing processes, presumably due to entrainment of surrounding water of less momentum by the intensified deep current core. We show that this new information about structure and pathways of the WBUC could not have been gained by conventional oceanographic measurements alone.*

***Key words:** Western Boundary Undercurrent (WBUC), seismic oceanography, Eirik Drift, Thermohaline Circulation, Labrador Sea.*

INTRODUCTION/BACKGROUND

The North Atlantic Western Boundary Undercurrent (WBUC; also referred to as Deep Western Boundary Current (DWBC)) is a deep (~1900-3000 m), equator ward contour current along the western continental slope. It represents the main component of the deep branch of the North Atlantic Thermohaline Circulation (THC) (e.g., Dickson and Brown, 1994; Stanford et al., 2011). The WBUC (location, intensity) is believed to be an important indicator for climate changes, and since the Eirik Drift is located closely downstream of the WBUC formation region it appears as a well-suited location to detect changes in the complex WBUC system.

We analyzed high-resolution seismic reflection data along with discrete CTD stations aiming for the first seismic oceanography study of deep-water circulation in water depths > 1500 m. This study will show that tracking the high-velocity core of the WBUC at the Eirik Drift and imaging its pathway, morphology and structure in a high lateral resolution by using seismic data represents an important supplement for the conventional, discrete oceanographic measurements.

DATA AND RESULTS

During RV Maria S. Merian cruise MSM12/2 in 2009, ~2000 km of high-resolution multichannel seismic reflection data were collected at the Eirik Drift. Eight CTD casts were conducted during MSM12/2 cruise and we used a CTD cross-section at the entrance of the Labrador Sea of the following cruise MSM12/3 (CTDs 8-12; by courtesy of Rhein (2011)), which lies east of our study area (Fig. 1).

The temperature-depth profiles of the CTDs in the pathway of the upper WBUC core (MSM12/2 #4, #5, #7; Fig. 1) show a similar pattern: A homogenous bottom layer (T ~2° C) of different thickness is observed. Above the gradient a section of fine structure is observed, which extends up to ~2000 m, where pronounced intrusions mark the top of the section of enhanced T variability. The T profiles then continue upward to 1500 m depth with an almost linear increase. The sections of strong T gradients and fine structure of the CTD casts are reflected in the synthetic seismograms as sections of enhanced reflectivity.

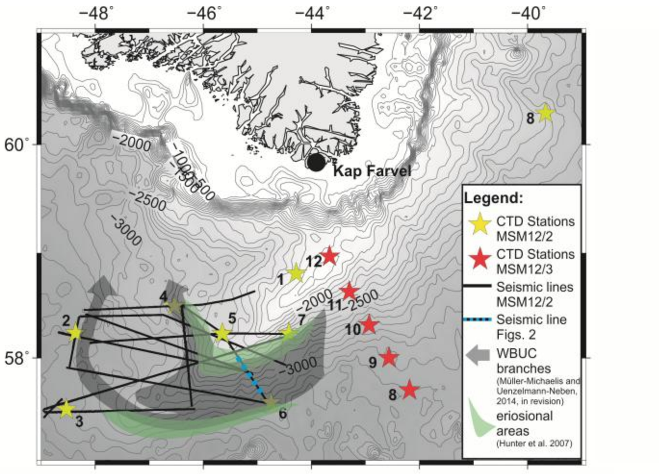

FIGURE 1. Satellite bathymetric map including the locations of the seismic lines and CTD stations. The seismic section shown in FIGURE 2 is indicated by the blue dotted line.

In our seismic data we observe an upward convex band of higher reflectivity attached to the slope of the Eirik Drift. The higher reflectivity band domes up from the seafloor and the reflections diverge at the center of the structure (Fig. 2). The area enclosed by this reflections and the seafloor appears rather transparent (Fig. 2). The transparent interior of the structure correlates with the non-reflective mixed layer of the synthetic seismograms of the CTD stations (Fig. 2). The high reflections of the synthetic seismograms resulting from thermohaline fine structure correlate with the high reflection band in the seismic profile (Fig. 2). Thus, we assume that this structure is the upper core of the WBUC with its mixed interior surrounded by higher reflections representing fine structure due to mixing processes as suggested by the CTD data.

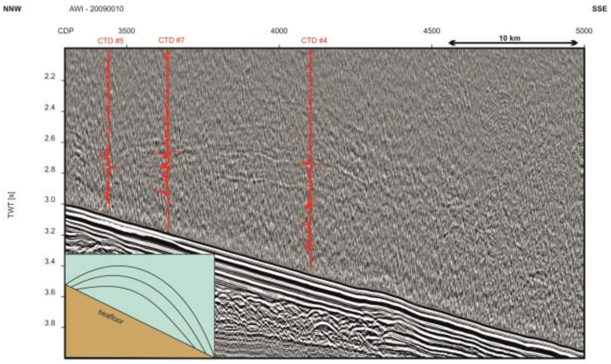

FIGURE 2. Seismic line AWI-20090010. The synthetic seismograms calculated out of CTD MSM12/2 #4, #5, and #7 are inserted according to their water depths of each CTD cast. Please note that these are not the true but projected locations of the MSM 12/2 CTD casts. The box in the lower left corner depicts a schematic sketch of the structure observed in the seismic data at the SE flank of the Eirik Drift.

DISCUSSION

The WBUC core described above is attached to the slopes of the main Eirik Drift at seafloor depths between 3.0 and 3.8 s TWT at the SE flank of the Eirik Drift (Fig. 2) and at seafloor depths between 3.1 and 4.15 s TWT at the NW flank. The observed downslope shift of the WBUC core from the SE to the NW flank of ~200 m may result from an increased sediment load carried by the WBUC core at the NW flank due to enhanced erosion at the SE flank. Also the bathymetric structure may be responsible for this shift. The thickness of the WBUC core is about ~800 m at the SE flank and ~600 m at the NW flank and its domed structure is found flattened at the NW flank. Also the lateral extent of the structure changes from ~35 km at the SE flank of the Eirik Drift to 70-90 km at the NW flank. The observed structural changes at the downstream and upstream flanks of the drift go along with a strong change in the slope of the flanks. The SE flank of the Eirik Drift shows an almost homogenous dip of ~1.3° from 2000 to 3500 m depth. The NE flank, however, has a steep upper part (slope ~1.3-1.5°) and continues almost horizontally to the west (slope < 0.3°). We can therefore conclude that the change in topography over the drift influences the shape of the WBUC core. It appears concentrated and domed at the homogenous, steep slope at the SE flank and broadens, flattens and maybe also deepens at the NW flank due to the influence of an almost horizontal part of the slope.

The observed pathway of the upper WBUC core over the drift is in good agreement with that suggested by Müller-Michaelis and Uenzelmann-Neben (2014) for the time period < 800000 years based on a subsurface seismic study. The structure of a concentrated WBUC core attached to the slope of the flank as observed in the seismic data cannot be observed in the MSM12/3 CTD section at the entrance of the Labrador Sea (Fig. 1). We can state that discrete CTD stations alone are not sufficient to resolve the structure of the upper WBUC core.

CONCLUSIONS

We were able to identify and track the upper core of the WBUC via the combination of CTD and seismic reflection data. It appears as a concentrated transparent seismic feature with a high reflectivity surrounding attached to the slope of the Eirik Drift at seafloor depths between 2200 and 3000 m. Its lateral and vertical extent changes with the dip of the seafloor slope from a concentrated domed core (35 km broad and 800 m thick) at the steep, homogenous SE drift flank to the flattened, broader core (70-90 km broad and 600 m thick) at the NW drift flank, where the slope changed significantly and provides an almost horizontal part (< 3° steep). The pathway of the upper WBUC core suggested by Müller-Michaelis and Uenzelmann-Neben (2014) for the period < 800000 years was confirmed by our observations. For the first time the seismic oceanography method was successfully applied to depths > 1500 m, but seems restricted in depths > 3000 m. This study revealed that seismic oceanography provides an important supplement to conventional oceanographic measurements, as the small-scale structures of the deep-water masses cannot always be resolved properly by discrete CTD measurements due to their large distance.

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REFERENCES

Dickson, R.R., Brown, J., 1994. The production of North Atlantic Deep Water: Sources, rates, and pathways. Journal of Geophysical Research 99(C6), 12319-12341.

Müller-Michaelis, A., Uenzelmann-Neben, G., 2014. Development of the Western Boundary Undercurrent at Eirik Drift related to changing climate since the early Miocene. Deep-Sea research I, in revision.

Rhein, M., 1994. The Deep Western Boundary Current: tracers and velocities. Deep-Sea research I 41(2), 263-281.

Rhein, M., 2011. Strength of the Subpolar Gyre and the Formation of Deep Water. Report 24, Institut für Meereskunde, Hamburg, Germany.

Stanford, J.D., Rohling, E.J., Bacon, S., Holliday, N.P., 2011. A review of the deep and surface currents around Eirik Drift, south of Greenland: Comparison of the past with the present. Global and Planetary Change 79(3–4), 244-254.