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2aAO3. Seismic oceanography imaging of thermal intrusions in strong frontal regions

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The Naval Research Laboratory and collaborating partners carried out two dedicated seismic oceanography field experiments in two very different strong frontal regions. ADRIASEISMIC took seismic oceanography measurements at the confluence of North Adriatic Dense Water advected along the Western Adriatic Current and Modified Levantine Intermediate Water advected around the topographic rim of the Southern Adriatic basin. ARC12 took seismic oceanography measurements in and around the Agulhas Return Current as it curved northwards past the Agulhas Plateau and interacted with a large anticyclone that had collided with the current. Despite one study focused on coastal boundary currents and the other focused on a major Western Boundary Current extension, the complex horizontal structures seen through seismic imaging are tied to the processes of thermal intrusions and interleaving in both systems. Seismic Oceanography provides a unique capability of tracking the fine-scale horizontal extent of these intrusions.

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The Naval Research Laboratory and collaborating partners carried out two dedicated seismic oceanography field experiments in two very different strong frontal regions. ADRIASEISMIC took seismic oceanography measurements at the confluence of North Adriatic Dense Water (NAdDW) advected along the Western Adriatic Current and Modified Levantine Intermediate Water (MLIW) advected around the topographic rim of the Southern Adriatic basin. ARC12 took seismic oceanography measurements in and around the Agulhas Return Current as it curved northwards past the Agulhas Plateau and interacted with a large anticyclone that had collided with the current.

Seismic oceanography data is obtained from a ship moving at ~4 knots towing a controlled sound source and a linear array of hydrophones both at a depth of a few meters. Air-guns, devices that explosively release compressed air creating a sound pulse in the ocean with a duration of 5–10 ms, are used as the sound source. A small fraction of the sound pulse reflects off of near-horizontal interfaces of sound-speed impedance changes in the ocean. The reflected energy is then recorded at the hydrophone array also towed by the ship. The backscattered sound, seismically measured by the array, is a convolution between the acoustic wavelet of the sound source and the water column reflectivity, which is created by changes in the acoustic impedance. The latter is defined as the product of the in situ water density and the sound speed, both of which are functions of temperature, salinity, and pressure. After processing, a seismogram is produced which gives a very high horizontal resolution (~10 m) image of the reflectivity depth structure over long sectional extents (10's-100's of km). Further details on the seismic oceanography method can be found in Ruddick et al. (2009).

Due to the convolution with the wavelet, singular features of water column reflectivity will generally produce multiple bands of alternating positive and negative values in the seismograms. The seismic images shown in this paper use the convention such that a strong black band over a strong white band generally represents a cold over warm temperature feature and a strong white band over a strong black band generally represents a warm over cold feature in the water column.

Despite the one study focused on coastal boundary currents and the other focused on a major Western Boundary Current extension, both systems are alike in that the complex horizontal structures seen in the seismic imaging are tied to the processes of thermal intrusions and interleaving. Figure 1 shows one example of seismic oceanography data taken in March 2009 offshore of the Bari Canyon in the Adriatic Sea. The blue line is the temperature profile that was measured by an expendable bathy-thermograph (XBT) cast acquired simultaneous to the seismic acquisition, and this establishes that the main water column feature seen in this portion of the seismogram (only a small subset of the section is shown) is due to a 0.5°C thermal "intrusion" of cold water in the depth range of 200-250 m. Both the upper and lower boundaries of this water mass can be spatially traced in the seismogram. Other data measured during ADRIASEISMIC establish that this tongue of cold intermediate waters is of NAdDW origin (Carniel et al., 2012).

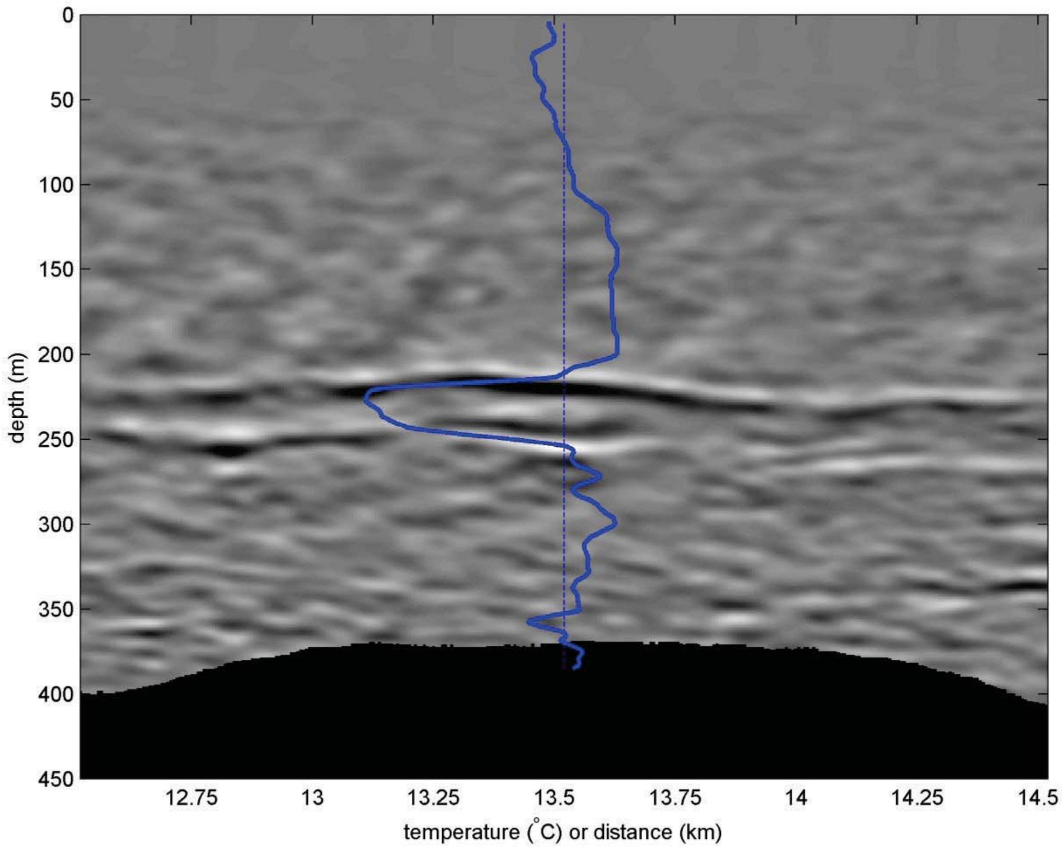

FIGURE 1. Seismogram from the Bari Canyon region of the Adriatic and simultaneous XBT temperature measurements. The seismogram data is shown at the depth where the first trough of the wavelet interacts with the water column reflectivity. The bottom interference zone is blanked in black. The blue dashed line gives the position of the XBT measurement and the solid blue line shows the XBT temperatures. The x-axis is a temperature scale for the XBT and a distance scale for the seismogram with 1°C scaled as 1 km.

Figure 2 shows a second example from the major anticyclonic eddy that collided with the Agulhas Return Current during January 2012. Due to the strong swirl velocity of this eddy (maximum velocity exceeded 1.4 m/s), the temperature profile here has a strong gradient from the 50 m surface mixed layer down to deep depths. The relative linear change in temperature is interrupted in three places by 0.5°C cold anomalies near 150 m and in the 200-250 m range. The seismogram reflects these intrusions with several alternating bands at these depth levels, although the second and third feature cannot be easily separated in the seismogram due to the finite duration of the seismic wavelet.

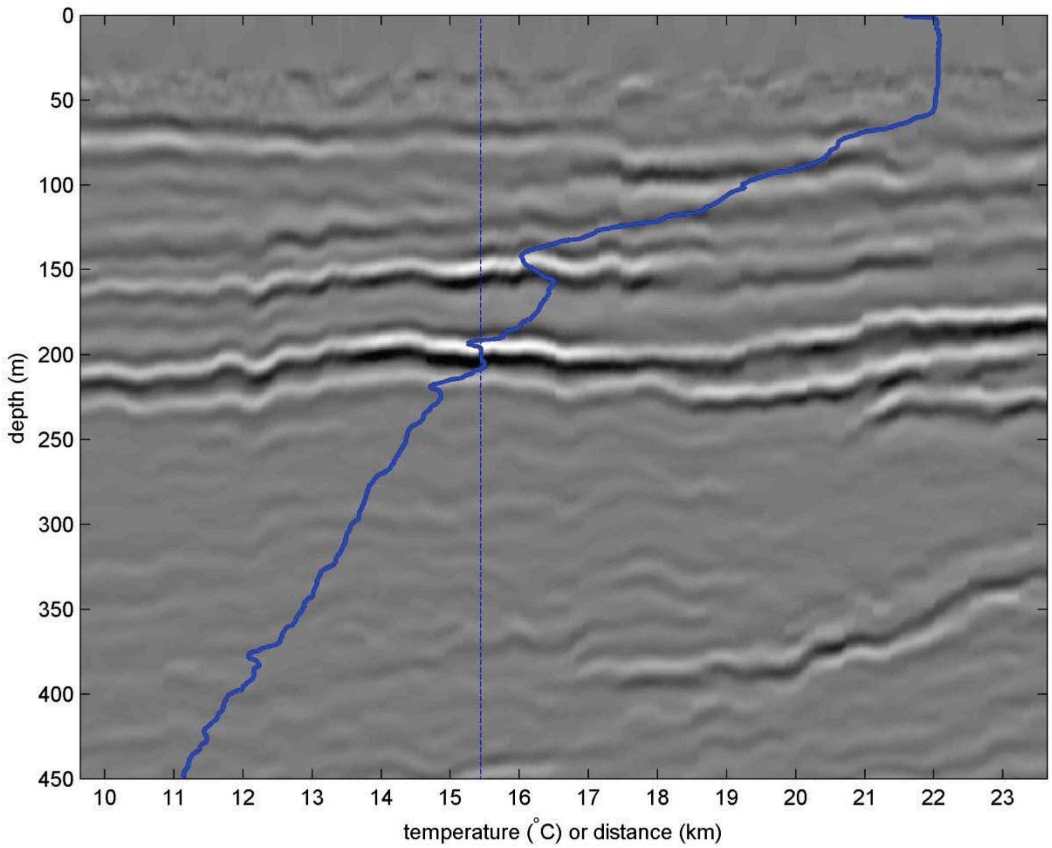

FIGURE 2. As in Figure 1, but the seismogram and XBT measurements are from an anticyclonic eddy over the Agulhas Plateau that was colliding with the Agulhas Return Current in January 2012.

The seismic images can be used to find possible origins and mixing pathways for the intrusions that are producing these bands in the seismograms. In the case of the Adriatic image, this thin extension of NAdDW can be directly traced in the longer seismic section (not shown) to a larger cold water mass trapped on the Adriatic outer shelf and slope. So these temperature anomalies seen offshore can be explained by the process of dense water detachment from the shelf and slope region, interleaving with saltier and warmer MLIW located further offshore. In the case of the Agulhas Return Current eddy, the cold anomalies can be traced in the longer seismic image (not shown) to the colder and fresher sub-polar waters located in-between the eddy and the main current, suggesting that these waters are being subducted under the eddy core and interleaving with the warmer and saltier South Indian sub-tropical water that make up the core. In both cases the seismic oceanography technique provides a new capability of tracking the horizontal extent at high resolution (6-25 m) of such intrusions over long distances (25-130 km), and thus provides a new technique for locating regions of thermal intrusion origin.

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