Simultaneous seismic reflection and physical oceanographic observations of oceanic fine structure in the Kuroshio extension front

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[1] New simultaneous seismic reflection and physical oceanographic observations east of Japan demonstrate the utility of the seismic reflection method in mapping oceanic fine structure. Synthetic seismograms calculated from temperature and salinity data confirm that seismic reflections correlate with physical oceanographic structures. Seismic reflections at the boundary between the warm Kuroshio and the cold Oyashio water masses correspond to well developed, ~10 m scale, temperature fine structure. Vertical current profiles suggest that this fine structure is caused by interleaving of these two water masses. We compare our seismic images with acoustic Doppler current profiler (ADCP) intensity maps and discuss similarities and the differences between seismic images and the ADCP maps. Our study demonstrates that even relatively low-energy seismic sources, in this case a 3.4 l (210 in^3) generator-injector (GI) airgun, can be used to image upper oceanic fine structure. **Citation:** Nakamura, Y., T. Noguchi, T. Tsuji, S. Itoh, H. Niino, and T. Matsuoka (2006), Simultaneous seismic reflection and physical oceanographic observations of oceanic fine structure in the Kuroshio extension front, *Geophys. Res. Lett.*, *33*, L23605, doi:10.1029/2006GL027437.

1. Introduction

[2] Oceanic fine structure commonly develops at boundaries between different water masses. Understanding fine structure is critical to studies of large-scale thermohaline circulation, which is widely recognized to play a crucial role in global climate change and therefore the Earth system [e.g., *Thorpe*, 2005]. Physical oceanographers typically investigate fine structure using vertical profiles of temperature and salinity [e.g., *Moum*, 1998]. Because most physical oceanographic measurements are made at discrete locations, the horizontal scale and continuity of fine structure are not well understood. Therefore, 2D and 3D mapping of fine structure is of great interest to the physical oceanographic community and beyond [e.g., *Stommel and Fedorov*, 1967].

[3] Recently *Holbrook et al.* [2003] demonstrated that the seismic reflection method can image thermohaline fine structure as reflection events within the water column, following previous pioneering studies on such events in seismic data [*Gonella and Michon*, 1988; *Phillips and Dean*, 1991]. *Nandi et al.* [2004] conducted the first simultaneous seismic reflection and physical oceanographic observations, in the Norwegian Sea, to confirm the utility of the seismic reflection method in studying oceanic fine structure, and showed that the method has a temperature sensitivity of ~0.03°C. In the same region, *Holbrook and Fer* [2005] analyzed seismic reflections to reveal oceanic internal wave spectra, and *Páramo and Holbrook* [2005] undertook amplitude versus offset (AVO) analysis to quantify temperature contrasts remotely from seismic reflection data. South of Japan, *Tsuji et al.* [2005] imaged fine structure related to the Kuroshio current, using data from a 3D seismic volume. They showed that coherent fine structure can persist for at least 20 days. Overall, multidisciplinary "Seismic Oceanography" [*Holbrook et al.*, 2005] should greatly advance our understanding of oceanic fine structure.

[4] Herein, we report results of simultaneous seismic reflection and physical oceanographic (temperature, salinity, and current speed profile) investigations conducted in the boreal summer of 2005. Our survey area encompassed the Kuroshio extension front east of Japan (Figure 1a), where the warm Kuroshio current flowing generally northeastward meets cold Oyashio water. The front is the boundary between the two water masses characterized by different temperature and salinity profiles. At the front, the two water masses mix, and fine structure is likely to be well developed (Figure 1b) in the vicinity. We analyze the new seismic reflection data for fine structure, and use simultaneous oceanographic measurements for "ground truth."

2. Data and Analysis

[5] All data used in this study were obtained during the 2005 R/V *Tansei Maru* cruise KT05-21, the first-ever expedition devoted exclusively to joint seismic reflection and physical oceanographic observations for the purpose of studying oceanic fine structure. Within the Kuroshio extension front area east of Japan (Figure 1a), our two-line transect runs N-S, or perpendicular to the axis of the Kuroshio current. The surface current is too fast (~3.5–4kt) at the Kuroshio's axis to conduct a seismic reflection survey, so we acquired two separate survey lines, one north (Line 1: 111 km long) and one south (Line 2: 83 km long) of the main Kuroshio current axis.

[6] We acquired multi-channel seismic (MCS) data using a 48-channel, 1200 m streamer. The data were recorded at a 2 ms sampling interval. We employed three different single airgun configurations as seismic sources: a 20 l (1220 inch^3) airgun, a 9 l (550 inch^3) airgun, and a 3.4 l (210 inch^3) generator-injector (GI) airgun. We shot Line 1 three times, once each with the three different seismic sources. At R/V *Tansei Maru*'s shooting speed of ~7.5 km/hr, shot intervals of 75 s for the 20 l airgun, 40 or 50 s for the 9 l airgun, and

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