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Evaluation of an acoustic remote sensing method for frontal-zone studies using double-diffusive instability microstructure data and density interface data from intrusions

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HIGHLIGHTS

- Measurements of double-diffusive instability ocean microstructure spectra made with sensors towed nearly horizontally.
- Demonstration of vertically thin intrusions stacked one above another.
- Predictive calculations of broadband acoustic backscatter strength from the measured instability microstructure.
- Prediction of backscatter from frontal intrusion density interfaces.
- One example backscatter prediction from field-measured microstructure is shown.

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ABSTRACT

Understanding intrusive exchange at oceanic water mass fronts may depend on building data-constrained models of the processes, but obtaining the needed representative and comprehensive data is challenging. Acoustic imaging (remote sensing) is an attractive method for mapping the three-dimensional intrusion geometry to enable the required focused in situ sampling of the mixing processes in intrusions. The method depends on backscatter of sound from sharp interfaces and from microstructure resulting from double-diffusive instability (DDI), a probable occurrence at intrusions. The potential of the method is evaluated using data collected using established methods in a field of intrusions south of New England. Above and beneath warm and salty

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Echosounder
South New England shelf

intrusions may lie diffusive–convective DDI microstructure and salt-fingering microstructure, respectively, marking the intrusion boundaries, providing the backscattering features. The data show that both types of microstructure can occur in close proximity within intrusions, but the question of whether this is common or not is unanswered by the modest amount of data, as are questions about continuity of DDI-microstructure in intrusions (to facilitate intrusion acoustic imaging) and variability of DDI-driven heat, salt and buoyancy fluxes. Analysis here shows that detectable backscatter from DDI-microstructure will occur, and can be easily measured when plankton scattering is low enough. Interface scattering is also likely to be detectable. The DDI-linked microstructure data used here are inherently interesting in their own right and are presented in some detail.

1. Introduction

Intrusions are common features at ocean water mass boundaries and fronts. Efforts have been made to model intrusion dynamics and fluxes, for example by Walsh and Ruddick (1998) and May and Kelley (1997), but these require testing, and they also require input data because they rely on parameterized multi-modal diapycnal eddy diffusivities (salt-finger diffusivity, turbulence diffusivity, etc.) which require justification in the ocean and may depend on conditions surrounding the intrusion field. At this time, three-dimensional mapping and concurrent sampling of both finestructure and double-diffusive instability-triggered (DDI-triggered) microstructure within intrusions at lateral ocean water-mass boundaries (fronts), required for comprehensive validation of hypothesized intrusion-related fluxes, is a challenging measurement scenario. A particular challenge is the need to balance high resolution with broad coverage, a need that motivates a remote sensing strategy. Here, data from an intrusion are used to evaluate the strategy of using high-resolution broadband split-beam or multibeam echo sounders to map intrusions, allowing targeted in-situ sampling as well as a description of intrusion geometry.

To illustrate intrusive processes that might be investigated, data collected in a patch of dye tracer in an intentional injection experiment (Ledwell et al., 2004) shows that an intrusion can strain the patch (Fig. 1), intensifying diapycnal gradients faster than diapycnal mixing can destroy them. (This must be true over some time scale in some conditions, otherwise intrusions would not exist.) The figure shows structure in the y/ρ (north/density) plane on the eastern edge of a patch of dye in the third of five dye-dispersal experiments south of New England carried out in 1995–1997 (Ledwell et al., 2004). The depicted "boomerang" shape of the dye seen in the figure was unusual; virtually all transects showed dye areas of either oval shape or tilted oval shape (if shear was high), not the sideways-V deformation pattern that is suggestive of dye transport in an intrusion. Between the upper and lower edges of the patch was relatively fresh water apparently moving to the north. The 800-meter displacement to the north of the patch center, with respect to the upper and lower branches, is consistent with a steady advection speed of about 2.5 mm/s, impossible to instantaneously measure. (The actual flow may have been greater if the intrusive flow and the transect were not aligned.) Despite the challenges, definitive studies of frontal balances, diapycnal flux balances and processes, and advection in intrusions like this may be realizable with remote sensing mapping and informed in-situ sampling. In addition, extensive surveys could answer questions such as how variations of flow and stratification conditions at fronts can affect the intrusive processes.

The acoustic remote sensing strategy is examined here by calculating backscatter strength for DDI-triggered microstructure patches observed at the upper and lower boundaries of intrusions south of New England with a towed system. The work shows that the possibility of acoustic backscatter