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Turbulence Observations in a Buoyant Hydrothermal Plume on the East Pacific Rise

BY ANDREAS M. THURNHERR AND LOUIS C. ST. LAURENT

Hot vent fluid enters the ocean at high-temperature hydrothermal vents, also known as black smokers. Because of the large temperature difference between the vent fluid and oceanic near-bottom waters, the hydrothermal effluent initially rises as a buoyant plume through the water column. During its rise, the plume engulfs and mixes with background ocean water. This process, called entrainment, gradually reduces the density of the rising plume until it reaches its level of neutral buoyancy, where the plume density equals that of the background water, and it begins to spread along a surface of constant density. (For a much more detailed discussion of buoyant hydrothermal plumes, see Di Iorio et al., 2012, in this issue.)

During a hydrographic survey carried out at the Ridge 2000 East Pacific Rise Integrated Study Site (ISS) in the context of the LArval Dispersal on the Deep East Pacific Rise (LADDER) project, 13 vertical profiles of hydrography (temperature and salinity, from which density can be calculated) and light scattering were collected with a conventional conductivity, temperature, depth (CTD) rosette in November 2007 directly above the ridge crest between 9°30'N and 9°50'N (Thurnherr et al., 2011). There are numerous hydrothermal sources on the ridge crest in this region (e.g., Jackson et al., 2010), and all ridge-crest CTD profiles in this data set show significant light-scattering anomalies associated with hydrothermal particles. The CTD data collected at station #3 (Figure 1a) stand out because they are associated with particularly strong light-scattering anomalies and, more importantly, because the corresponding density stratification contains layers of strong static instability where dense water overlies less-dense water (marked in red in the figure). Such layers of unstable stratification are sometimes interpreted as evidence that a buoyant plume has been sampled (e.g., Jackson et al., 2010). In our case, this interpretation is consistent with the observation that, below ~ 2,370 m, the density in profile #3 is consistently at least one standard deviation below the "background" density at the same depth calculated from the other 12 ridge-crest profiles, which do not contain similar layers of static instability.

At six out of the 13 ridge-crest stations, including buoyant plume station #3, additional profiles of turbulence intensity and light scattering were collected with an untethered turbulence measurement instrument, called a vertical microstructure profiler (VMP; Thurnherr and St. Laurent, 2011). The VMP and CTD casts were carried out simultaneously a few hundred meters apart. In addition to strong light-scattering anomalies, the VMP profile from station #3 is also associated with anomalously[1] high levels of kinetic energy dissipation (turbulence intensity; Figure 1b). To the best of our knowledge, our dissipation profile from station #3 is the first-ever direct measurement of turbulence associated with entrainment into a convective plume in the ocean.

Andreas M. Thurnherr *(ant@ldeo.columbia.edu) is Lamont Associate Research Professor, Division of Ocean and Climate Physics, Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, USA.* **Louis C. St. Laurent** *is Associate Scientist, Physical Oceanography Department, Woods Hole Oceanographic Institution, Woods Hole, MA, USA.*

[1] Anomalous compared to the other casts carried out on the ridge crest. Dissipation peaks of similar magnitude were observed during the same survey over the crests of several seamounts in this region (Thurnherr and St. Laurent, 2011).

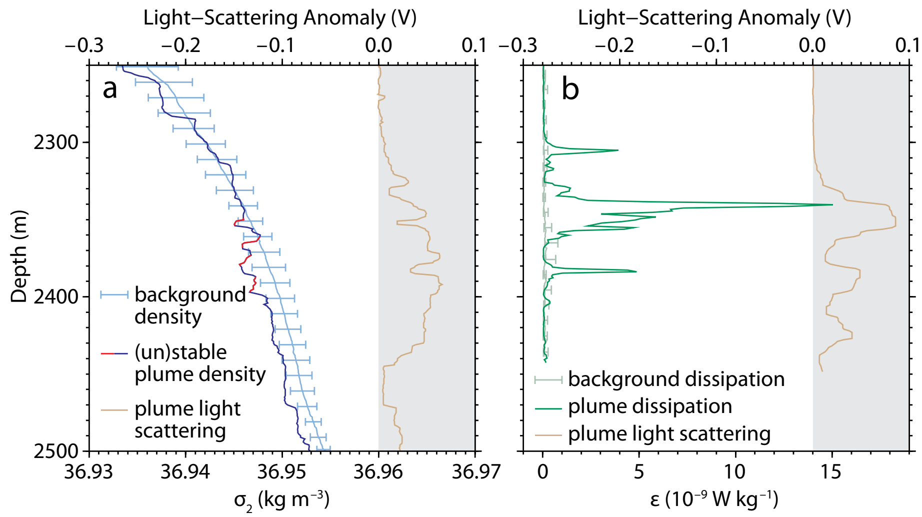

Figure 1. Vertical profiles of potential density (stratification), light scattering (particle concentration), and kinetic-energy dissipation (turbulence) intersecting a buoyant plume rising from a high-temperature hydrothermal source on the East Pacific Rise crest near 9°45'N. (a) Potential density (σ_2) and light-scattering profiles collected with a conventional conductivity, temperature, depth (CTD) rosette. Unstable regions of the buoyant plume density profile are marked in red; the background density profile was constructed from the remaining 12 ridge-crest CTD profiles without buoyant-plume signatures; error bars show standard deviations. (b) Kinetic energy dissipation (ε) and light-scattering profiles collected simultaneously less than 300 m from the CTD profile with an autonomous vertical microstructure profiler (VMP). The background dissipation profile was constructed in log space from the remaining five ridge-crest VMP profiles without buoyant-plume signatures; error bars show standard deviations. For clarity, error bars are only plotted every 10 m.

The data shown in Figure 1 imply a highly complex buoyant-plume structure characterized by small vertical, and short temporal, scales. In particular, there is no one-to-one association between maxima in light scattering, turbulence, and static instability. Furthermore, even the two light-scattering profiles that were collected within a horizontal distance of less than 300 m and not more than 20 minutes apart are strikingly dissimilar, which suggests that these light-scattering maxima should not be interpreted as plume layers with significant horizontal extent.

Although the turbulence levels observed in our buoyant plume profile are large, it is not possible to determine the representativeness of our measurements from a single profile and, therefore, to assess their significance on larger scales. However, results from a tracer-release experiment that was also carried out in the context of the LADDER project indicate that entrainment into buoyant plumes (i.e., buoyant plume turbulence) significantly increases vertical dispersal of material in the water column near the East Pacific Rise crest in this region (Jackson et al., 2010). This dispersion is particularly important in the context of the ecology of vent organisms, whose larvae are likely to disperse very differently in this region, depending on whether they are entrained into buoyant plumes or not (McGillicuddy et al., 2010). On even larger scales, the integrated neutrally buoyant plumes from all sources on the East Pacific Rise near 10°N can be traced across the entire width of the Pacific Ocean (i.e., over more than 13,000 km; Lupton, 1998; Thurnherr et al., 2011). Because it is the buoyant plumes turbulence that causes the mixing that produces the neutrally buoyant plume fluid, we infer that buoyant plume turbulence affects the ocean on a very large range of temporal and spatial scales.

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