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Mixing and entrainment in the Red Sea outflow plume

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The outflow of heavy, salty and warm water from the Red Sea through the Strait of Bab el Mandeb into the western Gulf of Aden differs from other marginal sea outflows in a pronounced seasonality with a winter maximum, in low latitude and hence small Coriolis parameter, and, most importantly, sea floor topography. Upon exiting from the Strait of Bab el Mandeb, the Red Sea outflow water (RSOW) continues downslope into the Gulf of Aden along two channels. The densest water is delivered to about 800 m depth through the 130 km long "Northern Channel" (NC), which is topographically confined and typically only 5 km wide. In it, the Red Sea plume shows unanticipated patterns of vertical structure, turbulent mixing and entrainment. Above the sea floor a 25-120 m thick weakly stratified layer shows little dilution along the channel. Hence this bottom layer undergoes only weak entrainment. In contrast, a 35-285 m thick interfacial layer shows stronger entrainment and undergoes vigorous turbulent mixing. It is thus the interface that exhibits the bulk of entrainment of the Red Sea plume in the NC. The interfacial layer also carries most of the overall plume transport, increasingly so with downstream distance. Compared to winter conditions, we encountered weaker outflow with shallower equilibration depths during the summer cruise. Bulk Froude numbers (*Fr*) computed for the whole plume vary within the range 0.2-1. Local maxima occur in relatively steep channel sections and coincide with locations of significant entrainment. Vigorous mixing in the interfacial layer is witnessed by overturns up to 30 m thick and extensive zones of gradient Richardson numbers below 1/4. Turbulent overturning scales, or Thorpe scales, served to quantify interfacial mixing, eddy diffusivities (K_ρ) typically being of the order of 10^{-2} m^2 s^{-1}. As the large K_ρ occur in strong stratification, vertical turbulent salt fluxes are also large. Relative maxima of, e.g., $K_{\rho \mathrm{s}}$ are correlated with maxima in *Fr*. Direct short-term, high-resolution

current measurements 4-40 m above the sea floor allow investigating the structure of the turbu-lence in the bottom layer and quantify the Reynolds stress.

In addition to the “near field” outflow addressed in the preceding, the 2000 *Red Sea Outflow Experiment* also explored the “far field” throughout the Gulf of Aden. In the far field, the RSOW plume is effectively stirred and eventually laterally homogenized by energetic mesoscale, cyclonic and anticyclonic eddies which span the width of the Gulf and have a large barotropic component.