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Mesoscale Eddies in the Gulf of Aden and Their Impact on the Spreading of Red Sea Outflow Water

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The Gulf of Aden (GOA) in the northwestern Indian Ocean is the receiving basin for Red Sea Outflow Water (RSOW), one of the World's few high-salinity dense overflows, but relatively little is known about spreading pathways and transformation of RSOW through the gulf. Here we combine historical data, satellite altimetry, new synoptic hydrographic surveys and the first in situ direct observations of subsurface currents in the GOA to identify the most important processes in the spreading of RSOW. The new in situ data sets were collected in 2001-2003 as part of the Red Sea Outflow Experiment (REDSOX) and consist of two CTD/LADCP Surveys and 49 one-year trajectories from acoustically tracked floats released at the depth of RSOW.

The results indicate that the prominent positive and negative sea level anomalies frequently observed in the GOA with satellite altimetry are associated with anticyclonic and cyclonic eddies that often reach to at least 1000 m depth, i.e. through the depth range of equilibrated RSOW. The eddies dominate RSOW spreading pathways in the gulf and help to rapidly mix the outflow water with the background. Eddies in the central and eastern gulf are basin-scale ($\sim$250-km diameter) and have maximum azimuthal speeds of about 30 cm/s at the RSOW level. In the western gulf, smaller eddies not detectable with satellite altimetry appear to form as the larger westward-propagating eddies impale themselves on the high ridges flanking the Tadjura Rift. Both the hydrographic and Lagrangian observations show that eddies originating outside the gulf often transport a core of much cooler, fresher water from the Arabian Sea all the way to the western end of the GOA, where the highest-salinity outflow water is found. This generates large vertical and horizontal gradients of temperature and salinity, setting up favorable conditions for salt fingering and diffusive convection. Both of these mixing processes were observed to be active in the gulf.

Two new annually appearing anticyclonic eddies are added to the previously identified Gulf of Aden Eddy (GAE and Somali Current Ring (SCR). These are the Summer Eddy (SE) and the Lee Eddy (LE), both of which form at the beginning of the summer monsoon when strong southwest winds blowing through Socotra Passage effectively split the GAE into two smaller eddies. The SE strengthens as it propagates westward deeper into the GOA, while the Lee Eddy remains stationary in the lee of Socotra Island. Both eddies are strengthened or sustained by Ekman convergence associated with negative wind stress curl patches caused by wind jets through or around high orography. The annual cycle in the appearance, propagation and demise of these new eddies and those described in earlier work is documented to provide a comprehensive view of the most energetic circulation features in the GOA.

The observations contain little evidence of features that have been shown previously to be important in the spreading of Mediterranean Outflow Water (MOW) in the North Atlantic, namely a wall-bounded subsurface jet (the Mediterranean Undercurrent) and submesoscale coherent lenses containing a core of MOW ('meddies'). This is attributed to the fact that the RSOW enters the open ocean on a western boundary. High background eddy kinetic energy typical of western boundary regimes will tend to shear apart submesoscale eddies and boundary undercurrents. Even if a submesoscale lens of RSOW did form in the GOA, westward self-propagation would transport the eddy and its cargo of outflow water back toward, rather than away from, its source.