



Seasonal variability of the Red Sea, from GRACE time-variable gravity and altimeter sea surface height measurements

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Seasonal variability of sea surface height and mass within the Red Sea, occurs mostly through the exchange of heat with the atmosphere and wind-driven inflow and outflow of water through the strait of Bab el Mandab that opens into the Gulf of Aden to the south. The seasonal effects of precipitation and evaporation, of water exchange through the Suez Canal to the north, and of runoff from the adjacent land, are all small. The flow through the Bab el Mandab involves a net mass transfer into the Red Sea during the winter and a net transfer out during the summer. But that flow has a multi-layer pattern, so that in the summer there is actually an influx of cool water at intermediate (~ 100 m) depths. Thus, summer water in the southern Red Sea is warmer near the surface due to higher air temperatures, but cooler at intermediate depths (especially in the far south). Summer water in the northern Red Sea experiences warming by air-sea exchange only. The temperature profile affects the water density, which impacts the sea surface height but has no effect on vertically integrated mass.

Here, we study this seasonal cycle by combining GRACE time-variable mass estimates, altimeter (Jason-1, Jason-2, and Envisat) measurements of sea surface height, and steric sea surface height contributions derived from depth-dependent, climatological values of temperature and salinity obtained from the World Ocean Atlas. We find good consistency, particularly in the northern Red Sea, between these three data types. Among the general characteristics of our results are: (1) the mass contributions to seasonal SSHT variations are much larger than the steric contributions; (2) the mass signal is largest in winter, consistent with winds pushing water into the Red Sea through the Strait of Bab el Mandab in winter, and out during the summer; and (3) the steric signal is largest in summer, consistent with summer sea surface warming.