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Tidal straining induced upwelling in the Rhine ROFI

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SST imagery and a 3D numerical model of a river plume are employed to detect tidal straining in the Rhine ROFI (Region of Fresh Water Influence). Previous studies (starting with Simpson et al., 1993, Oceanologica Acta, 16 (1), 23-32), have shown that the Rhine ROFI in the North Sea exhibits strong cross shore density gradients that compete with tidal and wind mixing to establish stratification. During neap periods with low mixing energy an area measuring 30 km offshore by 100 km alongshore becomes stratified. During stratification strong cross shore currents with surface velocities rotating anti-cyclonically, and bottom current cyclonically are observed. In contrast, during well-mixed situations the currents are rectilinear alongshore. The cross shore currents interact with the cross shore density gradients to alternately induce and destroy stratification with a semi-diurnal frequency. Due to continuity requirements imposed by the proximity of the coast the opposed cross shore currents in the surface and bottom layer should lead to coastal upwelling. In May 1990 6-day series of unclouded SST-imagery was found. The series shows that that the Rhine ROFI is much warmer than the surrounding water, exhibits a distinct diurnal solar heating response and is delineated by large spatial temperature gradients at the edges. This indicates that the whole ROFI area is stratified. On three consecutive noons a marked 10 km wide and 100 km alongshore band of cold upwelling is visible along the coastline, while in the morning and afternoon this upwelling band is not present. Comparison of the timing of the upwelling with measured water levels shows that it is caused by tidal straining. A simulation with a 3D numerical model of an idealized river plume confirmed this conclusion. It exhibits the same cold upwelling band returning every 12 hours. We believe these are the first SST images to show upwelling induced by tidal straining, as well as the large spatial scale of tidal straining in the Rhine ROFI.