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Examining coastal upwellings from a Lagrangian perspective in the Gulf of Finland, Baltic Sea

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This study examines from a Lagrangian perspective the impact that an upwelling event may have on mixing and the Lagrangian transport of surrounding surface waters. To accomplish this we employ in-situ surface drifters (that follow the currents in the uppermost layer with a thickness of 2 m), satellite derived sea surface temperature data (obtained from the MODIS Aqua satellite), and high-quality open sea wind time series. The study area is located near the southern coast of the Gulf of Finland where easterly winds are known to trigger intense coastal upwellings. The properties of mixing were evaluated using the daily rate of temperature change along several transects.

Results show that unlike classical upwelling events that normally show cooler water hugging the coastline in a longitudinal direction, this upwelling event instead took the form of transverse jets that protruded as much as 40–45 km from the coastline at distinct locations. Interestingly, the surface drifters show that the presence of the upwelling event superseded classic Ekman-type drift of the surface layer and in effect slowed down the average speed of surface currents in the surrounding waters.

It was discovered that intense and long-lasting upwelling events may contain three distinct stages, which was clearly influenced by the wind intensity: During the first stage (strong winds) the cooler water is brought to the surface. The second stage (strong winds) is characterized by the presence of coherent cooler water transverse jets that protrude some distance from the coast at two distinct locations and that lasted $\sim$ 5 days, during this stage very little mixing took place it was mainly the advection of colder water to the open sea. Whilst the third stage encompasses the presence of filaments/squirts and eventually the disintegration of these structures and intense mixing of upwelled and surrounding waters under weaker winds. Thus the upwelled cooler water largely kept its identity during almost the entire duration of the upwelling event (identified as stage 2 above) and these jets were shown to influence the Lagrangian currents dynamics of the surrounding waters. Therefore from a Lagrangian perspective it is shown that the dynamics that occur during stage 2 and stage 3 are quite different.

The two main areas of the discussed upwelling transverse jets may serve as frequent starting domains of intense cross-gulf net transport of various items and substances in the surface layer of the sea. Further analysis shows that the two main areas of transverse jets were influenced by the bathymetry of the area along with other oceanographic factors. To our knowledge, this is the first detailed co-examination of dynamics of an upwelling using satellite SST information together with high-resolution information from in-situ drifters in the Gulf of Finland.