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ASAR imaging of the coastal upwelling in the Baltic Sea

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Analysis of Envisat ASAR and Aqua/Terra MODIS infrared (IR) imagery of coastal upwelling in the southeastern Baltic Sea is presented. It is shown that the observed dark anomalies in the SAR images are attributed to the manifestation of the cold upwelling waters. Unlike the SST fields derived from IR imagery, the ASAR data provides valuable information on the location of the thermal front under cloudy conditions. Moreover, under favorable low wind speed conditions the SAR also captures the finer structures of the upwelling front at the order of 2-5 km with the corresponding SST drops of just 1-2˚C.

A quantitative interpretation of the SAR image expressions was executed by model simulations of the MABL transformation over the SST front. The SST difference across the front leads to changes in the MABL stratification and, in turn, changes in the near surface wind speed and wind stress and hence the radar backscatter (calculated from the CMOD4 model). The model simulations of the radar backscatter patterns are in a good agreement with the SAR observations.

It is found that the SAR image contrasts (in dB) over the SST front can be related to the dimensionless stratification parameter $\mu_f = \kappa^2(g/T_K) \cdot \Delta\theta_s/fU_{10}$ based on the 10-m wind speed on the upwind side of the front and the SST difference across the front. This empirical relationship is consistent with the general finding of the MABL transformation over the abrupt change in the surface temperature. The maximum observed suppression of the SAR signal over the cold water was about -10 dB. However, the magnitude of the SAR backscatter anomalies over the SST front attenuates rapidly with the increase of the wind speed and the decrease of the SST difference across the front. Following the empirical relationship, a "reliable" SAR detection of the SST front with $\Delta\theta_s$ varying from 2˚C to 10˚C (assuming that the NRCS difference over a front should exceed $\Delta\sigma; \circ = -3$dB) is possible at low to moderate wind speeds.

It is moreover found that the suppression of the radar backscatter by the presence of surface films plays an important role in the SAR image manifestation of the upwelling zones. Dark narrow and elongated SAR backscatter features are associated with the suppression of the short waves by the surfactants accumulated in the zones of the surface current convergence. This was documented by the reconstruction of the surface current convergence field from the MODIS SST and SAR wind fields.

In summary the combined effect of the MABL stratification and the effect of the short wave damping by the surfactants accumulating in the surface current convergence produces rather complex SAR signatures of the upper ocean upwelling dynamics in the coastal zone. However, under favorable wind conditions the SAR data reveal promising capabilities to detect and monitor coastal upwelling zones with high spatial resolution regardless of the cloud conditions.

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