SAR Indicators for Morphological Changes and Bivalve Beds on Intertidal Flats

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We analyzed a large amount of high-resolution Synthetic Aperture Radar (SAR) data of dry-fallen intertidal flats on the German North Sea coast with respect to the imaging of sediments, macrophytes, and mussels. TerraSAR-X and Radarsat-2 images of four test areas acquired from 2008 to 2013 form the basis for the present investigation and are used to demonstrate that pairs of SAR images, if combined through basic algebraic operations, can already provide indicators for morphological changes and for bivalve (oyster and mussel) beds. Multi-temporal analyses of series of SAR images allow detecting bivalve beds, since the radar backscattering from those beds is generally high, whereas that from sediments may vary with imaging geometry and environmental conditions. Our results further show evidence that also single-acquisition, dual-polarization SAR imagery can be used in this respect. The polarization coefficient (i.e., the ratio of the difference and the sum of both co-polarizations) can be used to infer indicators for oyster and blue-mussel beds.

Background and Areas of Interest

Oyster beds on the German North Sea coast. Photograph: M. Gade

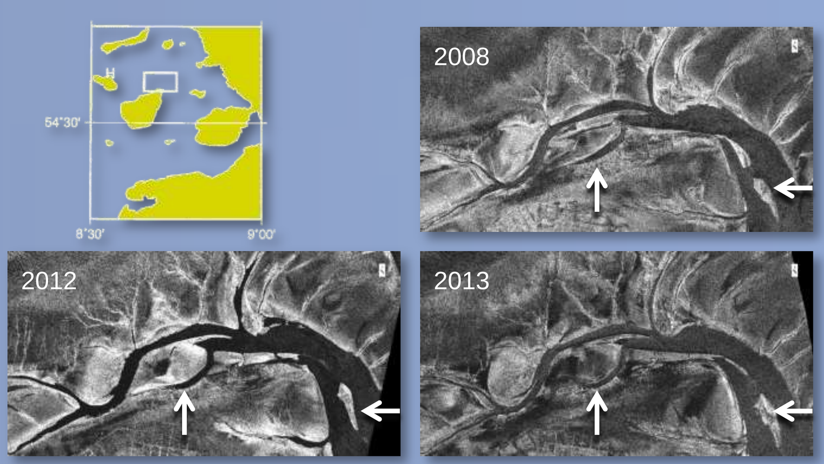
Intertidal flats are coastal areas that fall dry once during each tidal cycle. Adopting the Dutch name those areas are often referred to as Wadden Seas. Since 2009 the German Wadden Sea is a UNESCO World Natural Heritage, and according to national and international laws and regulations a frequent surveillance of the entire area is mandatory. Remote sensing techniques are ideally suited in this respect, and SAR sensors, because of their all-weather capabilities and their independence of daylight, may be the first choice.

Within the German project SAMOWatt ('Satellite Monitoring of the Wadden Sea') we analysed SAR images of dry-fallen intertidal flats on the German North Sea coast to gain further insight into mechanisms of the radar backscattering from those flats, and to provide a basis for the inclusion of SAR data into existing classification systems. Multi-frequency SAR imagery may be used to extract surface roughness parameters [1], and single-frequency, multi-temporal and dual-polarization SAR imagery can be used for the detection of bivalve (oyster) beds [2,3].

Four test areas on the German North Sea coast were identified (left), which represent areas of typical sediment distributions on intertidal flats and which also include vegetated areas and mussel and oyster beds. Three of them, 'Amrum', 'Pellworm', and 'Wesselburen', are located in the German National Park 'Schleswig-Holstein Wadden Sea'. The other test area, 'Jadebusen' (J), is part of the German National Park 'Lower Saxonian Wadden Sea'. Most of those test areas were already subject to previous studies [1,2], and they were complemented by the test area 'Jadebusen', because this bay is characterized by a high spatial variability in surface types, along with strong tidal currents.

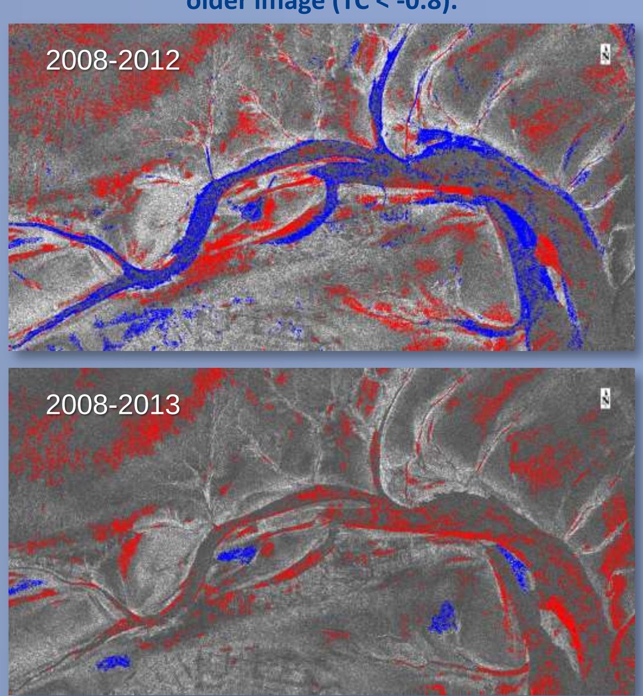
Four Areas of interest on the German North Sea coast: Amrum (A), Pellworm (P), Wesselburen (W), and Jadebusen (J)

Example Results



Upper: TerraSAR-X images (4.2 km × 2.3 km) of the 'Pellworm' test site : 1 July 2008, 17:01 UTC; 28 October 2012, 05:50 UTC; 7 May 2013, 17:01 UTC.

Lower: temporal coefficients derived from the above SAR data. Red colours denote much higher radar backscatter in the newer image (TC > 0.8); blue colours denote much higher radar backscatter in the older image (TC < -0.8).



Morphological Changes.

The test site 'Pellworm' was imaged by TerraSAR-X in 2008, 2012, and 2013 (left figure). Wind speeds were low (3.0 m/s - 4.5 m/s) during all acquisitions; the water level (measured at Hooge, 'H') was lowest in 2008 and 37 cm and 14 cm higher in 2012 and 2013, respectively. Strong differences can be seen in the image centres: a narrow tidal creek had changed its form (vertical arrows); and in the right image parts: the location and size of sandbanks inside the tidal channel had changed (horizontal arrows).

We define the temporal coefficient, TC, as the normalized difference temporal index of two SAR images acquired by the same sensor, but at different times:

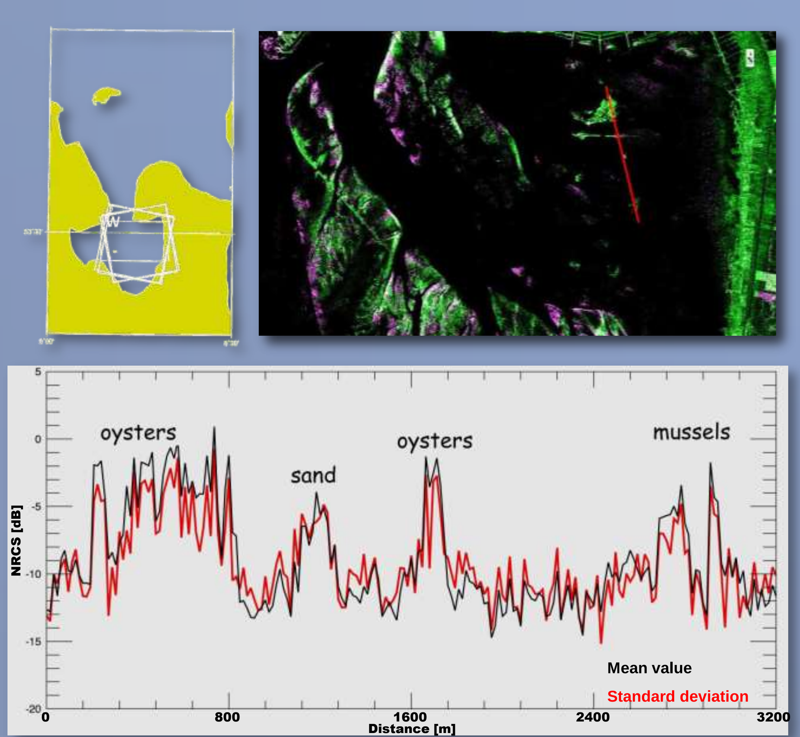
$$TC(SAR_{new}, SAR_{old}) = \frac{SAR_{new} - SAR_{old}}{SAR_{new} + SAR_{old}}$$

with SAR_{new} and SAR_{old} as the respective younger and older SAR images. Strong changes (large temporal coefficients in the middle ledt figure) were detected from 2008 to 2012 along the edges of the tidal channels (different water levels during the image acquisitions, and wind shadowing in 2012). The narrow tidal creek in the image center and the sand banks on the right also caused blue and red patches. In contrast, changes in the radar backscatter from the open flats, in some distance from the tidal creeks and channels, are likely to be due to other factors such as different amounts of remnant water or different soil moisture.

Bivalve Beds.

We used five TerraSAR-X images of the 'Jadebusen' test site acquired in 2012 to calculate the temporal mean and standard deviation of the NRCS. The lower left figure shows a false-colour composite of the central 4.40 km × 2.35 km part (green: mean; magenta: standard deviation). The lower panel shows the respective values along the red scan line. Highlighted are areas of oyster and mussel beds and of sandy flats, which were identified during a field campaign in 2013.

Oyster/mussel beds and the sandy rim cause high values of both the mean and standard deviation. However, inside the bivalve beds the mean is exceeding the standard deviation. Bivalves increase the surface roughness, causing a high NRCS, independent of the imaging geometry and environmental conditions. In contrast, the NRCS from exposed sediments may depend on the incidence angle, on remnant water, and on environmental (weather) conditions [2], thereby leading to high standard deviations. Similar results are already being used to improve an existing monitoring system based on optical data [2].



Temporal statistics for the test site 'Jadebusen'. Upper right: false color composite of the mean value (green) and the standard deviation (magenta); lower: downward transect along the red line.

More Bivalve Beds.

We define the polarization coefficient, PC, as the normalized difference polarization ratio:

$$PC(SAR_{HH}, SAR_{VV}) = \frac{SAR_{HH} - SAR_{VV}}{SAR_{HH} + SAR_{VV}}$$

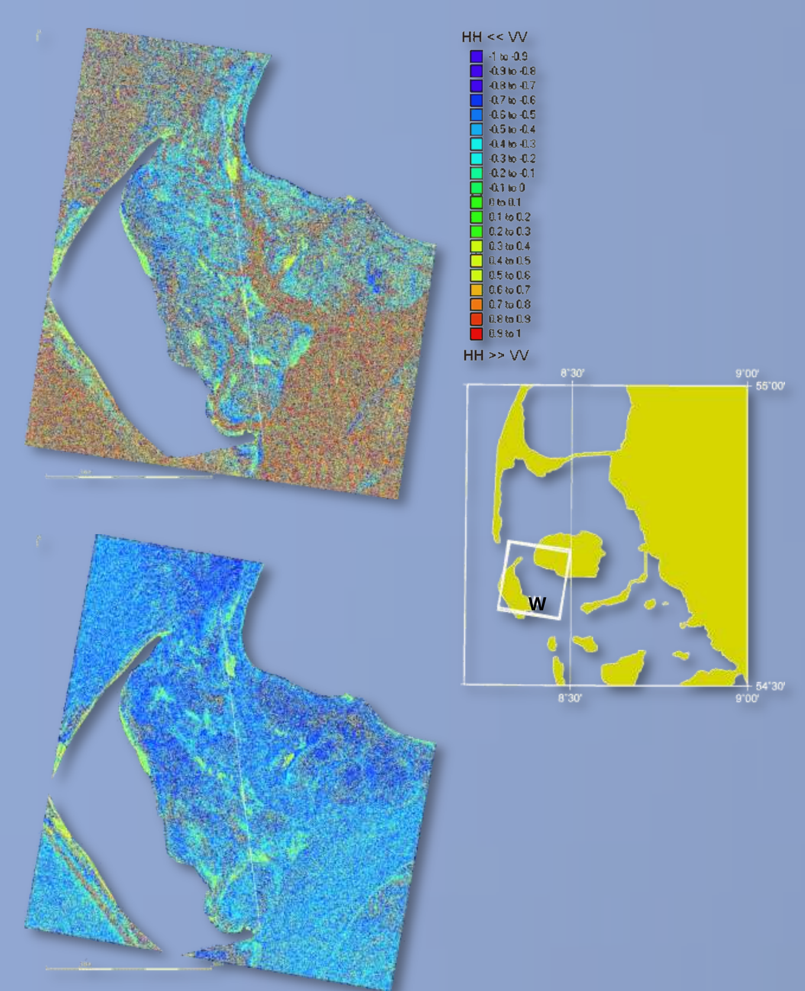
where SAR_{HH} and SAR_{VV} are the respective SAR data acquired by the same sensor and at the same time, but at horizontal (HH) and vertical (VV) polarizations. Two examples are shown on the upper right, both derived from pairs of HH and VV polarization TSX images of the test site 'Amrum' (11.2 km × 13.3 km).

Bare soil on the open flats always appears in cyan to dark blue colours, indicating higher backscatter at vertical polarization. In addition, several green patches between the two islands, with sharp edges, coincide with oyster beds monitored during field campaigns. The oysters, arranged irregularly and with no dominant orientation, cause similar radar backscatter at both polarizations (polarization coefficient close to zero), independent of the imaging geometry. The contrast to their vicinity is much stronger when the images were acquired at high incidence angles (> 40°).

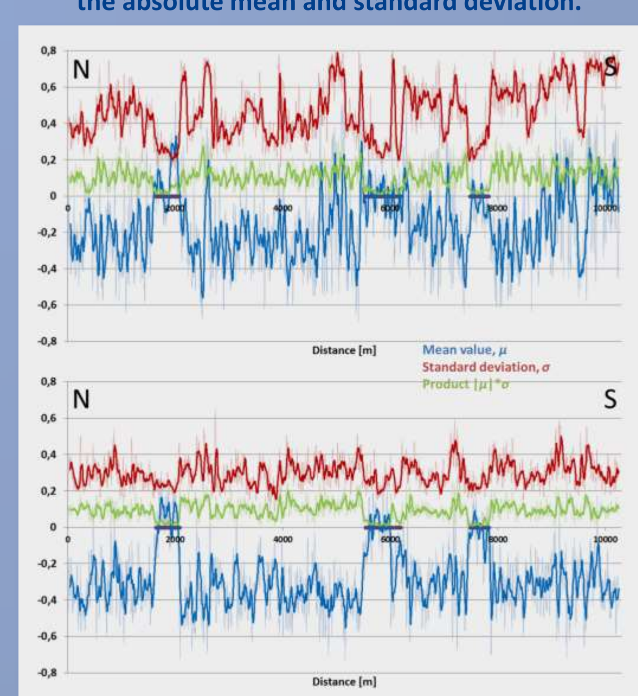
Transects along the white lines are shown on the middle right, with the locations of bivalve beds (recorded during the field campaigns) marked as thick horizontal bars on the abscissa. We note that bivalve beds appear to be the only areas where both the absolute mean and the standard deviation are always small, whereas exposed sediments may show mean values close to zero, but high standard deviations, and tidal channels may show the opposite. Therefore, a more robust bivalve indicator is the product of both, $P = |\mu_{PC}| \cdot \sigma_{PC}$.

We performed the same analysis for all TSX SAR imagery of the 'Amrum' test site acquired in 2013: five SAR image pairs (HH and VV) were used to calculated maps of the polarization coefficient. A moving 11 pixels × 11 pixels window was applied to derive the local product P, and the resulting maps were collocated and temporally averaged. The final result, therefore, contains the same, but two-dimensional, information as the green curves in the middle right figure. Lowest values (below 0.03) are marked in dark blue and coincide with bivalve beds.

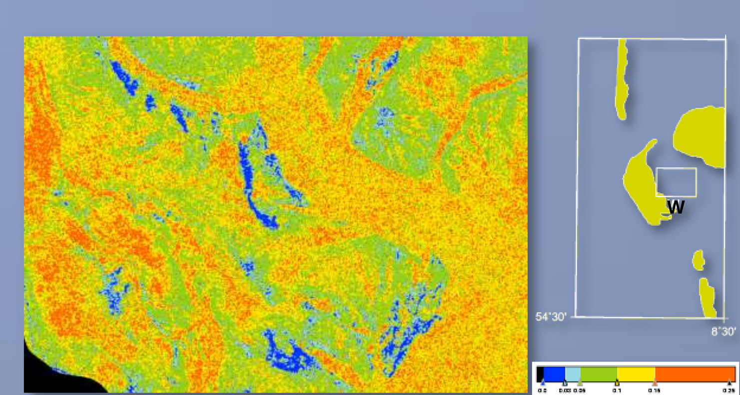
P provides another indicator for bivalve beds on exposed intertidal flats. Moreover, areas of frequent water coverage (i.e., mainly the tidal channels, but also parts of the open flats where remnant water can often be encountered) appear in yellow and orange colours, whereas the exposed flats appear in green.



Upper: polarization coefficient calculated from dual-polarization TSX SAR images of the 'Amrum' test site acquired (upper) on 6 June 2013 and (lower) on 22 June 2013.



Lower: Profiles along the white lines; blue: mean of a moving 11-pixel window, red: respective standard deviation, green: product of the absolute mean and standard deviation.



Product P of the absolute mean and standard deviation, each calculated for a moving window of size 11 px × 11 px. Shown is the mean value of five TSX dual-polarization acquisitions from 2013.

References

[1] Gade, M., Alpers, W., Melsheimer, C., Tanck, G., 2008. Classification of sediments on exposed tidal flats in the German Bight using multi-frequency radar data. *Remote Sens. Environ.*, 112: 1603-1613.

[2] Gade, M., Melchionna, S., Stelzer, K., Kohlus, J., 2014. Multi-Frequency SAR Data Help Improving the Monitoring of Intertidal Flats on the German North Sea Coast. *Estuar. Coast. Shelf Sci.*, 140, pp. 32-42.

[3] Gade, M., and S. Melchionna, 2016. Joint Use of Multiple Synthetic Aperture Rada.r Imagery for the Detection of Bivalve Beds and Morphological Changes on Intertidal Flats. *Estuar. Coast. Shelf Sci.*, *171*, pp. 1-10.