On the Joint Use of Microwave and Optical Remote Sensing Sensors for the Observation of Dry-Fallen Intertidal Flats in the German Bight

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Abstract – We have used data from different spaceborne SAR sensors to investigate the sensitivity of the radar backscattering to surface roughness variations on dry-fallen intertidal flats in the German Bight of the North Sea. We demonstrate that the radar backscattering from dry-fallen intertidal flats depends on their surface roughness properties, which vary due to, e.g., current-induced ripple formation, which in turn depends on the grainsize composition of the sediment. Further, benthic fauna such as blue mussels or oysters cause an increase in surface roughness. The combination of optical and SAR sensors allows for gaining information about the optical properties and surface roughness properties of the different surface types quasi-simultaneously. This information, together with in-situ observations and time series of habitat maps, will yield an improved classification of different sediment types, as well as of mussel beds and seagrass.

Keywords: intertidal flats, synergistic sediment classification, multi-sensor remote sensing, multi-frequent SAR images, German Bight

1. INTRODUCTION

The increasing requirements of coastal monitoring, to some extend, can be met deploying remote sensing techniques that allow for relatively cheap surveillance of large coastal areas. Optical sensors are already being used for sediment classification purposes on intertidal flats, and promising results have been achieved through the classification of different sediment types, vegetation, and mussel beds. However, because of the strong dependence on daylight and cloud conditions, useful optical data (acquired at low tide) from the German North Sea coast are rare. A classification system based on spaceborne remote sensing data would therefore strongly benefit from the utilization of synthetic aperture radar (SAR) data.

The radar backscattering from wet sediments is dependent on their surface roughness properties. Fung et al. (1992) introduced the single-scattering Integral Equation Model (IEM), which predicts the radar backscattering from bare soil as a function of its dielectric constant and surface roughness. Gade et al. (2008) presented a method to provide estimates of two surface roughness parameters, the rms height and the correlation length of the sand ripple profiles, through an inversion of the IEM. For their crude sediment classification in dry-fallen intertidal flats in the German Bight of the North Sea they used a pair of dual-frequency, co-polarized SAR images that were simultaneously acquired during the Spaceborne Imaging Radar-C/X-Band SAR (SIR-C/X-SAR) Missions in 1994. The comparison of their results with an existing sediment map showed that the proposed method works fairly well if the surface of the exposed tidal flats is dominated by sand ripples.

In contrast to SIR-C/X-SAR, which was a multi-polarization L-, C-, and X-band SAR system deployed during two space shuttle missions in April and October, 1994, actual spaceborne SAR sensors operate at single frequencies. As a consequence, SAR data from different satellites have to be used for multi-frequency SAR classification purposes, which cannot easily be combined if they were acquired with a considerable time lag in between. Thus, a much deeper knowledge of the radar backscatter properties of the sediment types, and their dependence on weather conditions, tidal cycle, and imaging geometry is needed, which can only be gained from a joint analysis of those multi-satellite SAR data and optical remote sensing data, together with simultaneous in-situ campaigns. The sub-project 4 of the German national project DeMarine-Environment is particularly devoted to this synergistic approach. Apart from Brockmann Consult and the University of Hamburg, providing expertise in Wadden Sea classification techniques using optical sensors and SAR image analysis, respectively, the national park agencies of the two major national parks on the German North Sea coast are participating in this sub-project, thus ensuring a deep knowledge of the local conditions in the two test sites (see Figure 1).

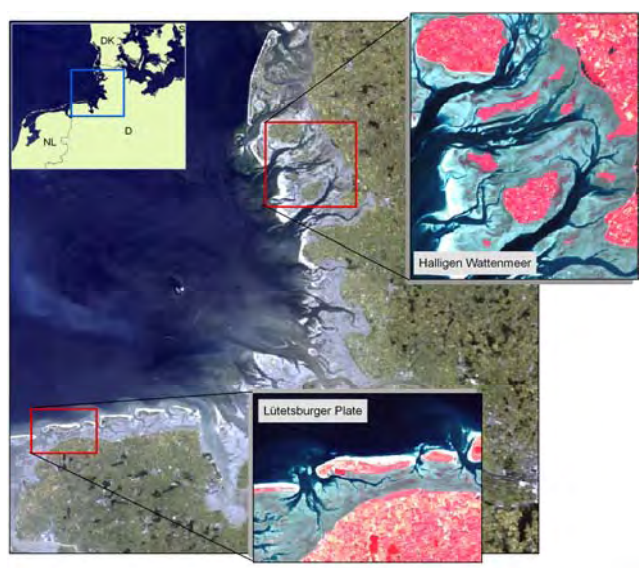

Figure 1. The two test sites of DeMarine-Environment's sub-project 4 on the German North Sea coast. "Lütetsburger Plate" is located south of the island of Norderney, "Halligwatt" is located between the Northern Frisian islands Langeness and Pellworm.

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2. FIRST RESULTS

Typical surface classes in the German Wadden Sea are dominated by different sediments, mussel beds, sea grass beds, and macro algae. Therefore, during the first phase of the project, a thorough analysis is undertaken of remote sensing data from those areas where the above surface classes can be encountered at close quarters.

In order to investigate if a short time lag of 30 minutes between two SAR image acquisitions results in a significant variation in the radar signatures, we generated a false-color composite (Figure 2) of an ENVISAT ASAR image acquired on July 27, 2008 at 1001 UTC (purple) and an ERS SAR image acquired on the same day, at 1031 UTC (green). Both SAR images were acquired at C-band, VV-polarization and show the estuary of the river Ems, at the border between The Netherlands and Germany. At the time of image acquisitions low winds (2-3 m/s) blowing from easterly directions were encountered.

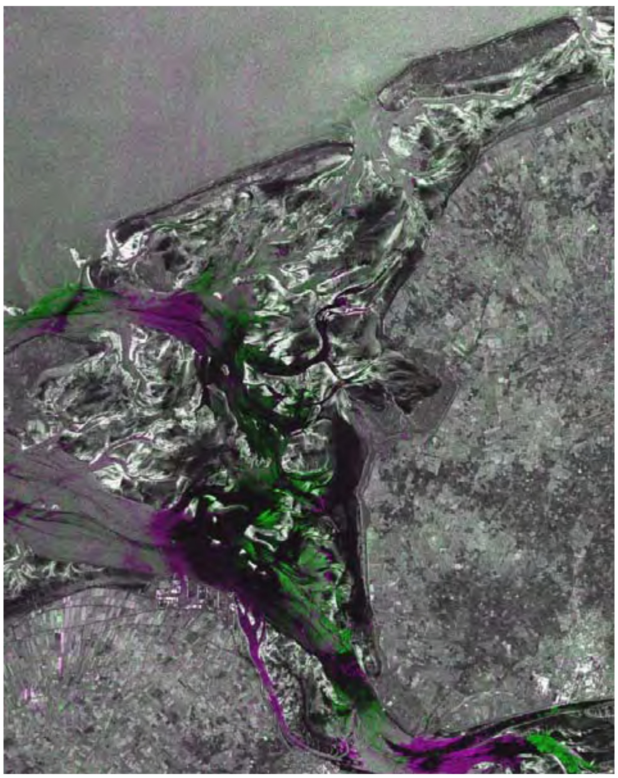

Figure 2. False-color composite of two SAR images (40 km × 50 km) acquired on July 27, 2008 over the river Ems estuary separating The Netherlands in the south-west and Germany in the north-east. Purple: ENVISAT SAR image acquired at 1001 UTC; green: ERS SAR image acquired at 1031 UTC. The bright patches in the image center are due to exposed intertidal flats south of the islands of Borkum (left), Juist (center), and Norderney (right).

Purple and green colors denote differences in the two SAR images, which are observed only in the mouth of the river Ems and in areas of major current variations within the river estuary. In contrast, shades of grey denote similarities of both SAR images, which are particularly observed in the exposed intertidal flats, off the main river stream. These results clearly demonstrate that SAR image signatures of dry-fallen intertidal flats are not subject to strong temporal changes, particularly closely after low tide and at low wind conditions.

2.1 Test Site "Lütetsburger Plate"

The test site "Lütetsburger Plate" is dominated by a strong spatial variation of different sediment types (sandy, muddy, and mixed), along with a high coverage by mussels (Pacific oysters and blue mussels) and, during summer season, some regions are covered by sea grass and green algae. Thus, a simple classification method that assumes bare sediments cannot be applied in this area. Figure 3 demonstrates how the test site is imaged by SAR sensors working at different radar bands: the upper panel shows a ALOS PALSAR (L-band) image acquired on April 12, 2008, at 2143 UTC, 23 minutes after low tide, and the lower panel shows a TerraSAR-X (X-band) image acquired on August 30, 2008, at 1710 UTC, 34 minutes after low tide. In both SAR images, the islands of Norderney (upper left) and Baltrum (upper right), and the main land (bottom) can be delineated.

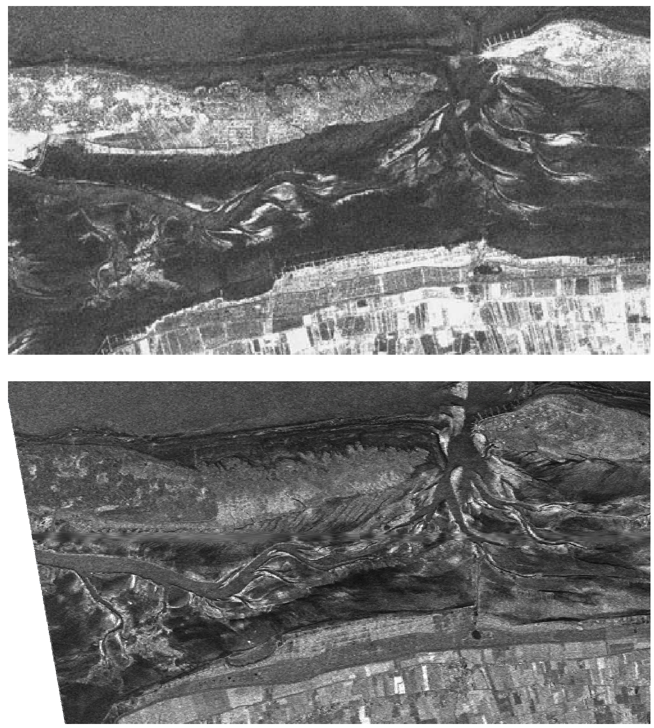

Figure 3. Two SAR images of the test site "Lütetsburger Plate", south of the German island of Norderney (upper left part of the images), acquired shortly after low tide. Image dimensions are 25.7 km × 13.4 km. Top: ALOS PALSAR image (© JAXA 2008) acquired on April 12, 2008, at 2143 UTC; bottom: TerraSAR-X image (© DLR 2008) acquired on August 30, 2008, at 1710 UTC.

The location of the tidal creeks can be delineated through an enhanced radar backscattering (and, thus, image brightness) of the sediments on their edges. This local enhancement of the radar backscatter was already found by Gade et al. (2008) who attributed it to an enhanced current-induced surface roughness of the sediments (i.e. sand ripple height). However, some irregular bright patches in the left part of both SAR images are not due to sand ripples, but due to mussel beds. The respective image sections are shown in Figure 4.

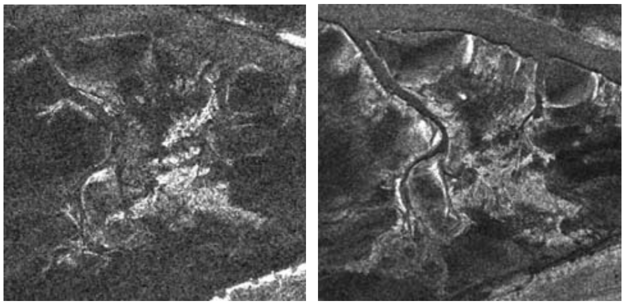

Figure 4. Subsections of the two SAR images shown in Figure 2. Left: ALOS PALSAR, right: Terra-SAR-X.

Note the pronounced irregular bright patches in the image center of both SAR image subsections, which are due to large mussel beds composed of a mixture of Pacific oysters and blue mussels. The mussel beds result in an enhanced radar backscattering not only at X-band, whose wavelength (3 cm) is similar to the size of the mussel shells, but also at L-band, whose wavelength (30 cm) is considerably larger than the mussel shell size. For the first time, these mussel beds were detected by a spaceborne L-band SAR sensor.

Figure 5 shows a false-color composite generated from the ALOS PALSAR image (Figure 2) and an ENVISAT ASAR image acquired on April 13, 2008, at 1001 UTC, 26 minutes after low tide. For the generation of the composite the PALSAR image was resampled to the lower pixel size of ASAR (12.5 m).

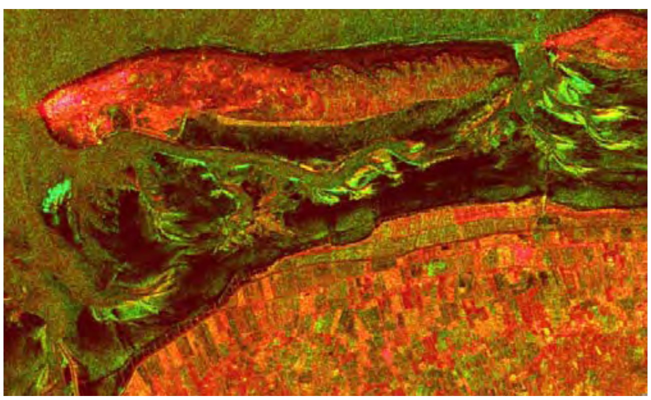

Figure 5. False-color composite of an ALOS PALSAR image acquired on April 12, 2008, at 2143 UTC (red), an ENVISAT ASAR image acquired on April 13, 2008, at 1001 UTC (green), and their difference (blue).

Together with the islands and the mainland, the mussel beds in the left image center show up in reddish colors, which reflect the fact that the image contrast in those areas with respect to the surrounding areas is stronger at L-band than at X-band. These first results show evidence that a detection, and probably a classification, of mussel beds on exposed tidal flats is possible through an analysis of multi-frequency SAR imagery.

3.2 Test Site “Halligwatt”

Similar to the southern test site in Lower Saxony the spatial variations of different sediment types, along with the occurrence of mussel beds, see grass, and macro algae, is typical for the test site “Halligwatt” in Schleswig-Holstein. Figure 6 shows two SAR images of the test site that were acquired from different satellites on the same day, during, or shortly after, low tide. The ENVISAT ASAR image in the upper panel was acquired on October 18, 2007, at 0955 UTC (during low tide), and the ALOS PALSAR image in the lower panel was acquired on October 18, 2007, at 1023 UTC (28 minutes after low tide).

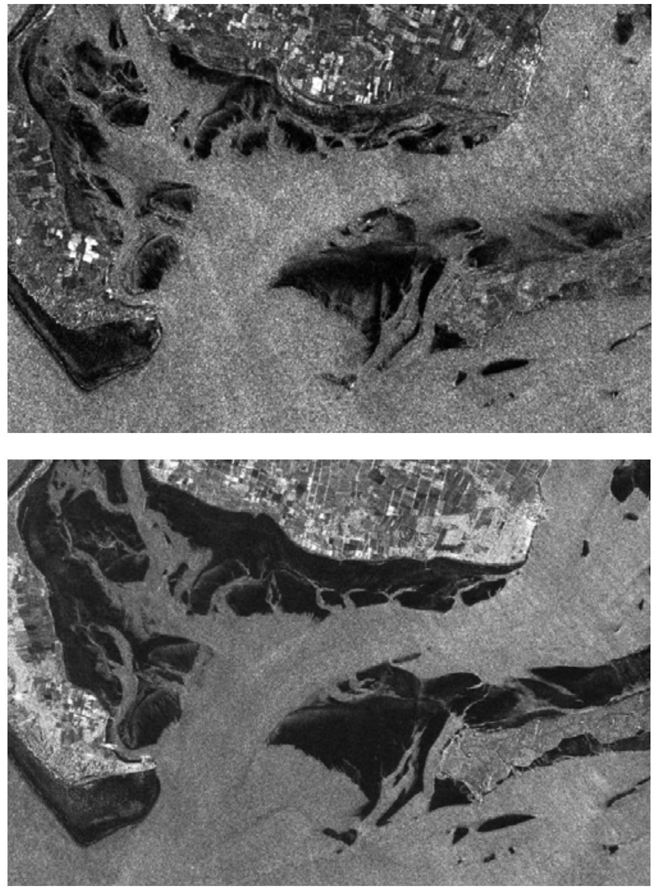

Figure 6. Two SAR images of the test site “Halligwatt”, between the islands of Amrum (left), Föhr (top), and Langeness (right), acquired during, or shortly after, low tide. Image dimensions are 37.5 km × 25.0 km. Top: ENVISAT ASAR image (© ESA 2007) acquired on October 18, 2007, at 0955 UTC; bottom: ALOS PALSAR image (© JAXA 2007) acquired on October 18, 2007, at 1023 UTC.

At the time of both image acquisitions, a strong wind (12-13 m/s) blowing from north-westerly directions was encountered. This explains why the exposed tidal flats result in dark patches on the SAR images, i.e. their radar backscattering, is much lower than that from the wind-roughed sea surface.

Figure 7 shows a false-color composite generated from the two SAR images of October 18, 2007. Similar to Figure 5, reddish colors appear in land areas, where the image contrast in the PALSAR image is stronger than that in the ASAR image. However, no reddish areas can be found on the exposed intertidal flats, even though there are mussel beds east of the island of Amrum. The reason for this may be the different season, in which the images were acquired: in early spring, the mussels are usually bare, whereas they become covered by brown algae in the course of the year. This coverage may result in a reduced surface roughness of the mussel bed, which in turn results in a lower contrast at L-band and, thus, in an absence of reddish patches in the false-color composite.

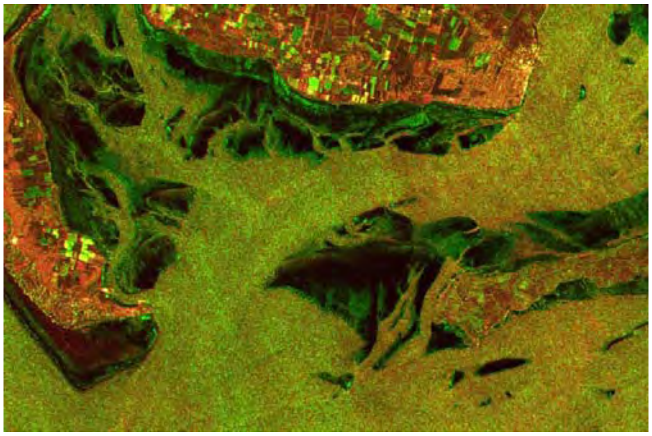

Figure 7. False-color composite of the two SAR images shown in Figure 6: ALOS PALSAR (red), ENVISAT ASAR (green), and their difference (blue).

Some of the exposed intertidal flats show greenish patches in their center, which reflect an increase in C-band radar backscattering. This effect may be due to remaining water, which stays in the sand ripple troughs and whose surface is roughened by the strong wind. The map in Figure 8 shows the frequency of water coverage on exposed tidal flats in the test site “Halligwatt”, as derived from two SPOT-4 and five Landsat images. Although only a small population of seven images was used to generate this map (through linear spectral unmixing), the results show evidence that remaining water contributes to the radar backscattering at C-band, particularly under high wind conditions.

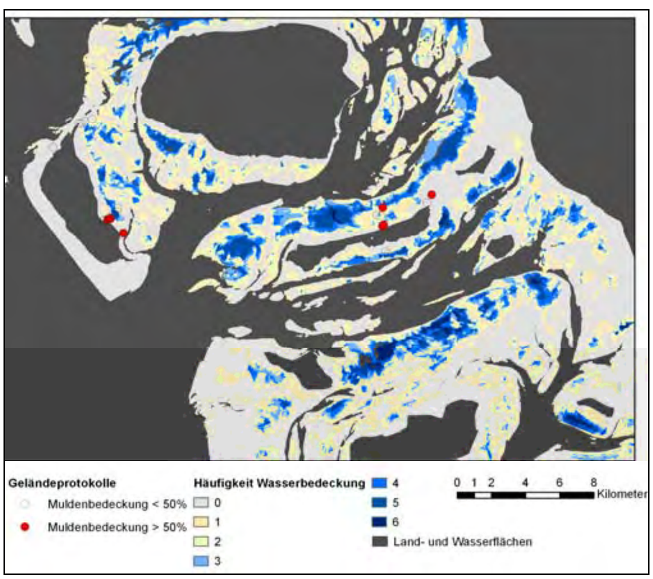

Figure 8. Map showing the frequency of water coverage on exposed tidal flats in the test site “Halligwatt”, as derived from two SPOT-4 and five Landsat images. The open sea, islands, and the mainland are colored in dark grey. The red spots denote locations where the mean spatial water coverage was above 50%.

3. SUMMARY AND CONCLUSIONS

Within subproject 4 of the national German project DeMarine-Environment multi-satellite SAR images are analyzed with respect to SAR signatures of exposed intertidal flats. While optical data are being used to help interpreting the observed radar signatures, the ultimate goal of these studies is to improve existing classification systems including SAR data.

Our first results show that SAR signatures of dry-fallen intertidal flats are not subject to strong temporal changes, particularly when they were acquired close to low tide and at low wind conditions. For the first time, extensive mussel beds (composed of a mixture of Pacific oysters and blue mussels) have been observed in multi-frequency SAR imagery. However, the strength of their signatures, and thus the capability of SAR sensors to detect and to classify them, may depend on the seasonal change in coverage by brown algae.

Further research performed during later stages of the project will comprise the inclusion of results from in-situ campaigns, along with classification results derived using optical remote sensing data. Of particular interest will be to investigate how the observed SAR signatures depend not only on radar frequency and polarization, but also on the season, on weather conditions, and on the tidal phase. Although a profound knowledge of all main factors contributing to the observed SAR signatures is essential for any improvement of existing classification systems, our results are insofar promising as they show evidence that multi-satellite SAR data can be used for sediment classification on exposed intertidal flats.

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