THE USE OF HIGH-RESOLUTION RADARSAT-2 AND TERRASAR-X IMAGERY TO MONITOR DRY-FALLEN INTERTIDAL FLATS

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ABSTRACT

High-resolution Synthetic Aperture Radar (SAR) data of dry-fallen intertidal flats in the German Wadden Sea have been analyzed with respect to the imaging of sediments, macrophytes, and mussels. A large number of high-resolution TerraSAR-X and Radarsat-2 images of five test areas along the German North Sea coast were acquired in 2012 and 2013 and form the basis for the present investigation. Depending on the type of sediment, but also on the water level and on environmental conditions (wind speed) exposed sediments may show up on SAR imagery as areas of enhanced, or reduced, radar backscattering. The (multi-temporal) analysis of series of such images allows for the detection of mussel beds, and our results show evidence that also single-acquisition, multi-polarization SAR imagery can be used for that purpose.

Index Terms— SAR, coastal remote sensing, intertidal flats, sediments, mussel beds

1. INTRODUCTION

Intertidal flats are coastal areas that fall dry once during each tidal cycle. Large intertidal flats can be found on the Dutch, German, and Danish North Sea coasts, as well as at other places worldwide, e.g. in South Korea and the United Kingdom. Adopting the Dutch name those areas are often referred to as Wadden areas. 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 [3].

Remote sensing techniques are ideally suited for the surveillance of areas that are difficult to access. In this respect, Synthetic Aperture Radar (SAR) sensors, because of their all-weather capabilities and their independence of daylight, may be the first choice; however, the radar imaging of bare soils is rather complex, and the very processes responsible for the backscattering of microwaves from exposed intertidal flats are still subject to research. Within the German national project SAMOWatt ("Satellite Monitoring of the Wadden Sea") SAR images of dry-fallen intertidal flats on the German North Sea coast are being analyzed to gain insight into those scattering mechanisms and to provide a basis for the inclusion of SAR data into existing classification systems of intertidal flats, which are based on optical data [1]. In this paper we present results obtained through the analysis of a great deal of TerraSAR-X and Radarsat-2 SAR images showing the German Wadden Sea close to low tide.

2. TEST SITES AND DATA

Five test areas on the German North Sea coast were identified (Figure 1), which represent areas of typical sediment distributions on intertidal flats, but also include vegetated areas and mussel and oyster beds. Three of them, the test areas "Amrum", "Pellworm" and "Wesselburen" (denoted as "A", "P" and "W", respectively, in Figure 1) are located in the northern part of the German North Sea coast, in the German National Park "Schleswig-Holstein Wadden Sea". The other two test areas, "Norderney" and "Jadebusen" ("N" and "J", respectively, in Figure 1), are located further south, in the German National Park "Lower Saxonean Wadden Sea". Most of those test areas were

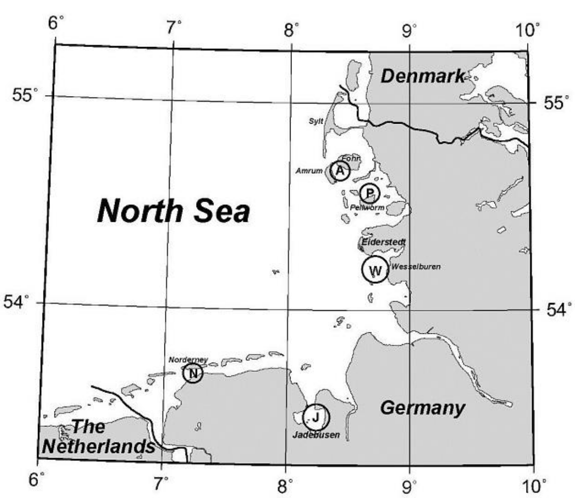

Figure 1. Five SAMOWatt test sites on the German North Sea coast. A: Amrum, P: Pellworm, W: Wesselburen, J: Jadebusen and N: Norderney.

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already subject to previous studies [6][7][8], and they are now complemented by the test area "Jadebusen", because this bay is characterized by a high variability of surface types.

A total of 20 Radarsat-2 (RS2) and 55 TerraSAR-X (TSX) SAR images of the SAMOWatt test areas were acquired between June 2012 and December 2013 and form the basis of the analyses presented herein. Depending on the acquisition mode, both SAR systems may provide imagery with pixel sizes of 1 m², or even below, which allowed us to study the radar backscattering from exposed intertidal flats in great detail.

3. RESULTS

Two RS2 and TSX SAR images of the test site "Wesselburen", acquired on September 14, 2012, between 1h and 2h after low tide, are shown in Figure 2. At the time of the image acquisitions a south-westerly (225°) wind of 7 m/s was reported, which was high enough to cause a stronger radar backscatter from the sea than from the exposed flats. In general the radar signatures in both SAR images are very similar, and slight differences may be due to a change in the waterline and/or in the tidal currents.

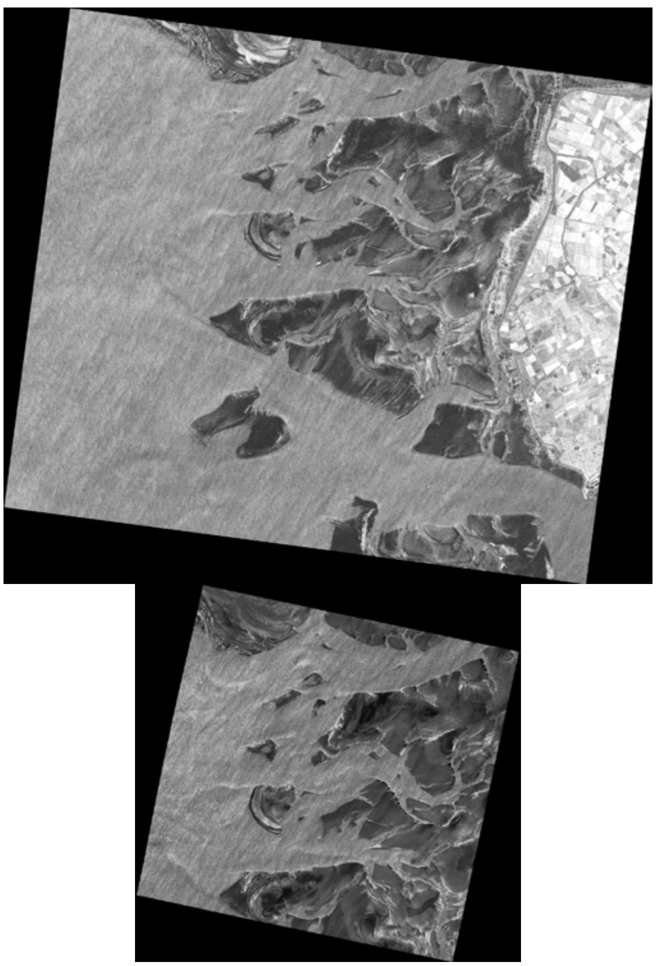

Figure 2. Two SAR images (VV polarization) of the test area "Wesselburen" acquired on September 14, 2012. Upper: RS2 image (22.0 km × 18.9 km) of 05:27 UTC; lower: TSX image (12.3 km × 12.0 km) of 05:50 UTC. Low tide was at 04:09 UTC, wind conditions were 7 m/s / 225°. © CSA, DLR

However, some differences in the radar backscattering also appear on the open flats and cause a change in the band coefficient, *BC*, which we define as the normalized difference band ratio of two SAR images acquired at different radar bands:

$$BC(SAR_1, SAR_2) = \frac{SAR_1 - SAR_2}{SAR_1 + SAR_2} \quad (1)$$

where SAR_1 and SAR_2 are the respective collocated (and calibrated) SAR image data. Figure 3 shows a map of band coefficients, *BC*(*TSX*, *RS*2), derived from the pair of SAR data shown in Figure 2: red colors denote a stronger radar backscatter at X band (TSX), mainly due to a change in the water level, blue colors denote a stronger radar backscatter at C band (RS2), which may be due to different sediments and/or remnant water on the open flats. We also note that the mean incidence angles were quite different, 28.7° (TSX) and 48.1° (RS2), which may have resulted in the observed differences. Further research is needed here.

In a similar way, the polarization coefficient, *PC*, can be defined as the normalized difference polarization ratio:

$$PC(SAR_{HH}, SAR_{VV}) = \frac{SAR_{HH} - SAR_{VV}}{SAR_{HH} + SAR_{VV}} \quad (2)$$

where SAR_{HH} and SAR_{VV} are the respective collocated (and calibrated) SAR image data acquired at horizontal

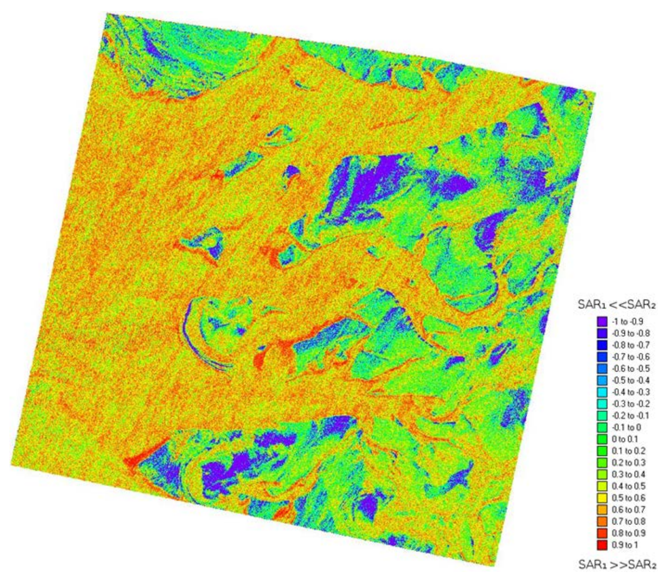

Figure 3. Band coefficient (normalized difference band ratio) calculated from the calibrated TSX and RS2 SAR images shown in Figure 2. Red colors denote a higher radar cross section at X band (TSX), blue and purple colors denote a higher radar cross section at C band (RS2).

(HH) and vertical (VV) polarizations. Two examples are shown in Figure 4, which were both derived from pairs of HH and VV polarization TSX images of the test site "Amrum" (11.2 km × 13.3 km), acquired on June 6 (upper panel) and June 22 (lower panel), 2013.

At the time of the first image acquisition (June 6; upper panel) wind conditions were 4.3 m/s / 26° and during the second image acquisition (June 22; lower panel) they were 10.0 m/s / 228°. Both islands, Amrum on the left and Föhr on the upper right, appear in light green colors in both panels, indicating higher backscatter at horizontal polarization. On the opposite, open flats appear in bluish (cyan to dark blue) colors, indicating higher backscatter at vertical polarization. Several green patches with sharp edges can be found on the open flats, between the two islands, and coincide with oyster beds monitored during recent field campaigns. The oysters, being arranged irregularly within the beds, with no dominant orientation, cause similar radar backscatter at both polarizations and, in turn, a polarization coefficient close to zero. Those patches are more pronounced when the images were acquired at high incidence angles (> 40°).

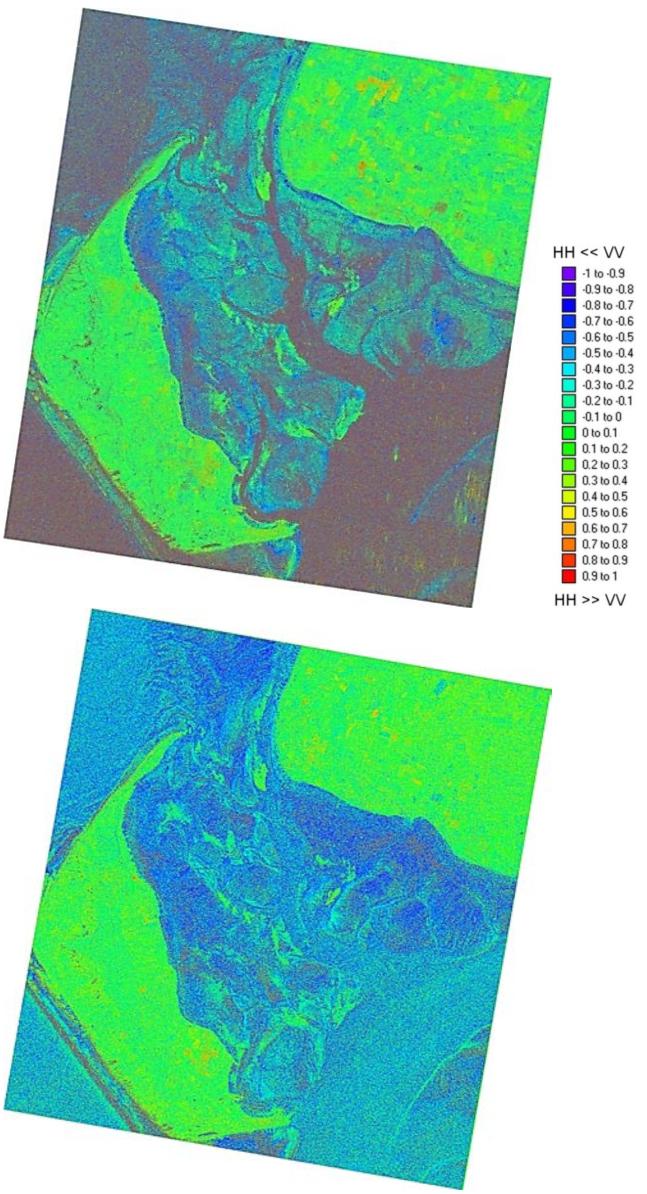

Figure 4. Polarization coefficient (normalized difference polarization ratio) calculated from dual-polarization TSX SAR images of the "Amrum" test site acquired (upper) on June 6, 2013 and (lower) on June 22, 2013.

Additional indicators for mussel beds were derived through statistical analyses of SAR image time series: we used five TerraSAR-X images of the "Jadebusen" test site acquired in 2012 to derive basic statistical parameters. For every (4 m × 4 m) pixel of the downscaled and collocated images we calculated the temporal mean value and standard deviation of the normalized radar cross section (NRCS). The upper panel of Figure 5 shows a false-color composite of the central 4400 m × 2350 m part of the test site, with the green and magenta channels representing the mean and standard deviation, respectively. Green areas correspond to a large mean NRCS exceeding the standard deviation, and in magenta areas the standard deviation exceeds the mean NRCS. The lower panel shows the respective values along the red scan line inserted in the upper panel, with the mean marked in black and the standard deviation marked in red. Highlighted are areas of oyster and mussel beds and of sandy flats, which were identified during field campaigns.

Both the oyster/mussel beds and the sandy rim (the latter resulting from a former track used for the transport of

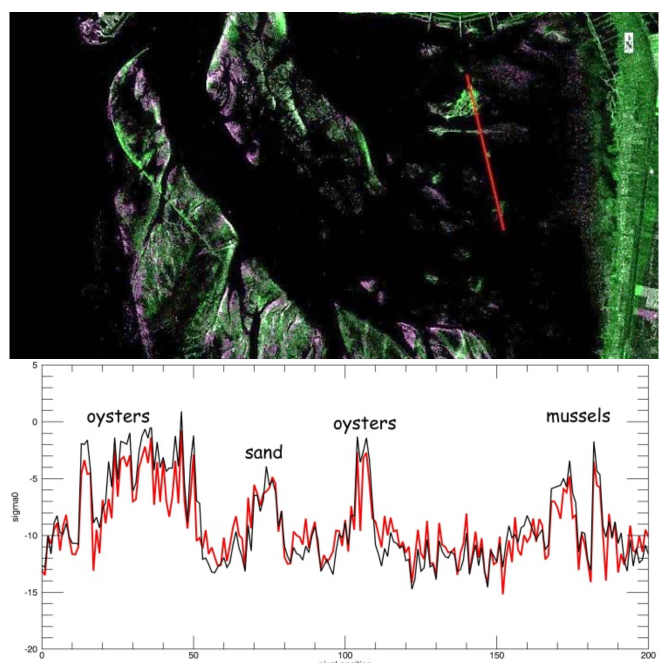

Figure 5. Temporal statistics for the test site "Jadebusen". Upper: false color composite of the mean value (green) and the standard deviation (magenta); lower: downward transect along the red scan line in the upper panel; black: mean; red: standard deviation.

cattle) cause high values of both the mean value and standard deviation, see the local maxima in the lower panel of Figure 5. Moreover, inside the bivalve (i.e. oyster and mussel) beds the mean is exceeding the standard deviation, which is generally not the case in all other areas (including those with small values of mean and standard deviation. i.e. the dark areas in the upper panel of Figure 5). Apparently, in addition to the polarization coefficient presented above, simple statistics can also be used to infer mussel indicators. Consequently, similar results are already being used to improve an existing monitoring system based on optical data.

4. CONCLUSIONS

Within the national German project SAMOWatt TerraSAR-X and Radarsat-2 SAR images of exposed intertidal flats are being analyzed to improve existing classification systems by including SAR data. We have demonstrated that a systematic analysis of SAR data from exposed intertidal flats, acquired close to low tide, provides valuable information to be used for the routine monitoring of the German Wadden Sea.

The combined analysis of TSX and RS2 imagery may help identifying small changes, both in the waterline and/or in the morphology, since exposed intertidal flats are imaged in a similar manner at both radar bands (X and C). However, care has to be taken when SAR images of both sensors are compared, since remnant water on the open flats and in water puddles may be imaged differently, particularly at different wind speeds [8].

Our results based on dual-polarization SAR images are very promising, since they allow for the detection of bivalve beds, particularly when the images were acquired at incidence angles exceeding 40°. Others [2][4][5] have already shown that the use of multi-polarization SAR imagery has some additional potential for the monitoring of intertidal flat surfaces using SAR sensors. In particular, the detection of mussel or oyster habitats seems easier when SAR data acquired at multiple polarization combinations are used [2].

The results of our statistical analyses, as presented herein, have already proven as valuable input for an existing classification system, since bivalve beds cause a strong and stable signal in the SAR imagery. We also note, however, that mussels may not be the only cause for a high mean NRCS exceeding the standard deviation. Vegetation on the mainland in the right part of the upper panel in Figure 5 also shows up as green areas, and so do extended seegrass meadows during the vegetation period (in the left part of the upper panel in Figure 5, and also, e.g., in the "Norderney" and "Pellworm" test sites; not shown herein). Therefore, only a combination of results based on SAR image analyses with those obtained from optical imagery and with a-priori knowledge can provide reliable classification results, as they are needed by the local agencies.

5. REFERENCES

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