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Joint use of multiple Synthetic Aperture Radar imagery for the detection of bivalve beds and morphological changes on intertidal flats

Martin Gade*, Sabrina Melchionna

Universität Hamburg, Institut für Meereskunde, Bundesstr. 53, 20146 Hamburg, Germany

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ABSTRACT

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.

1. Introduction

Intertidal flats are coastal areas that fall dry once during each tidal cycle. Large intertidal flats can be found in Europe, e.g. on the Dutch, German, and Danish North Sea coasts, on the U.K. east and west coasts, and along the French Atlantic coast, and at other places worldwide, e.g. in South Korea and northwest Africa. 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 (European Commission, 1992, 2000, 2008) a frequent surveillance of the entire area is mandatory.

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 ongoing research. van der Wal et al. (2005) showed that the surface roughness decreases with the amount of mud and increases with the sediment's median grain size. Consequently, van der Wal and Herman (2007), who analyzed SAR images of intertidal flats on the Westerschelde, The Netherlands, found that the radar backscatter from sandy sediments exceeds that from muddy sediments, though water puddles with spatial coverages exceeding 50% may decrease the effective surface roughness and, thereby, the radar backscattering (Kim et al., 2011).

Multiple SAR imagery, or SAR imagery combined with data from other sensors, have been used to extract surface characteristics of dry-fallen intertidal flats. Waterlines, i.e. the boundaries between water-covered and dry-fallen areas, imaged at different phases of the tidal cycle were used by Niedermeier et al. (2000) and Heygster et al. (2010) to generate topography maps of the Elbe estuary using ERS SAR imagery. Waterlines on tidal flats on the South Korean coast were extracted from TerraSAR-X imagery by Won (2009). van der Wal and Herman (2007) were the first to combine optical and SAR data of dry-fallen intertidal flats on the Westerschelde. More recently, Dehouck et al. (2011) used TerraSAR-X data and optical imagery of the Arcachon Bay, France, to detect mussels, salt marshes, and sandy sediments. Similar to Gade et al. (2014), they showed that radar has great potential to complement optical sensors for the routine monitoring of intertidal flats.

* Corresponding author.
E-mail address: martin.gade@uni-hamburg.de (M. Gade).

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Slatton et al. (2008) analyzed several L-band SAR images with respect to temporal changes in multi-polarization signatures of coastal wetlands. The use of polarimetric SAR data was also supported by Won (2009) and Lee et al. (2012), who both analyzed TerraSAR-X imagery of salt marshes on the South Korean coast. Won (2009) compared polarimetric SAR signatures of salt-marsh plants with ground-based radar measurements, and Lee et al. (2012) found that the radar backscatter from wetlands is stronger at horizontal (HH) than at vertical (VV) polarization. In addition, Choe et al. (2012), demonstrated that polarimetric SAR data can also be used to detect mussel beds. Those bivalves, sticking out of the sediments, increase the surface roughness locally, and this is why they are visible on SAR imagery (Dehouck et al., 2011; Choe et al., 2012; Gade et al., 2014). Pacific oysters, rapidly spreading over large parts of the German Wadden Sea, can thus be monitored using spaceborne SAR sensors working at different radar bands.

Within the German national project SAMOWatt ('Satellite Monitoring of the Wadden Sea'), we analyzed 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, which were built solely upon optical data (Brockmann and Stelzer, 2008). Gade et al. (2008) demonstrated that multi-frequency SAR imagery may be used to extract surface roughness parameters of dry-fallen intertidal flats. However, their inversion scheme requires L-band SAR imagery, which was no longer available after the sudden end of the ALOS-1 mission in 2011. Nonetheless, Gade et al. (2014) showed that single-frequency, multi-temporal SAR imagery can be used for the detection of bivalve (oyster) beds. In the present paper we proceed along those lines and summarize some further results obtained through the analysis of a great deal of SAR images acquired close to low tide.

The following section introduces those four test sites on the German North Sea coast, of which SAR imagery was used for the present studies. A number of coefficients, each calculated using pairs of SAR images, are introduced thereafter, along with statistical parameters that are used for the identification of oyster and mussel beds. The obtained results are then discussed, and finally, we draw some conclusions with respect to the use of our results within existing classification schemes.

1.1. Test sites and data

Four test areas on the German North Sea coast were identified (Fig. 1), which represent areas of typical sediment distributions on intertidal flats and which also include vegetated areas and mussel and oyster beds. Three of them, namely the test areas 'Amrum', 'Pellworm' and 'Wesselburen' (denoted as 'A', 'P', and 'W', respectively, in Fig. 1) are located in the northern part of the German North Sea coast, in the German National Park 'Schleswig–Holstein Wadden Sea'. The other test area, 'Jadebusen' ('J' in Fig. 1), is located further south and is part of the German National Park 'Lower Saxonian Wadden Sea'. Most of those test areas were already subject to previous studies (Gade et al., 2008, 2014), 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.

The test site 'Amrum' is the northernmost test site, between the islands of Amrum and Föhr (Fig. 1), and contains sandy and muddy sediments, bivalve beds (mainly Pacific oysters [*Crassostrea gigas*] and cockles [*Cerastoderma edule*], but also blue mussels [*Mytilus edulis*]), and seagrass meadows (of *Zostera noltii* and *Zostera marina*). Oysters have been invading into that area only recently: first observations of this species were made about twenty years ago (Troost, 2010), and a structurally relevant expansion started only in the first decade of the 21st century (Diederich et al., 2005). Meanwhile most bivalve beds are dominated by oysters, whose size of 5 cm–30 cm is larger than that of blue mussels (up to 7 cm).

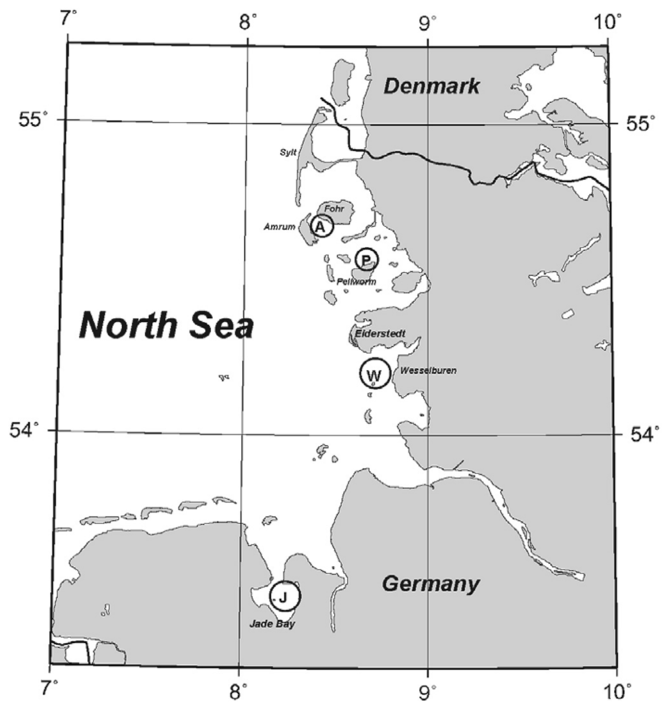

Fig. 1. Four test sites on the German North Sea coast. A: 'Amrum', P: 'Pellworm', W: 'Wesselburen', and J: 'Jadebusen'.

Together with the 'Amrum' test site, 'Pellworm' is part of an area called 'Halligen Wadden Sea' including several small and undiked islands, called 'Hallig', which are frequently flooded during storm surges. The 'Pellworm' site lies north of the island of Pellworm (Fig. 1) and has already been subject to previous studies focusing on the SAR imaging of remnants of historical land use (Gade and Kohlus, 2011). Here, the sediments are mainly sandy, though partly consisting of morphologically harder clay and peat. Muddy sediments are mainly found along the coast and mark calm hydrologic conditions.

The test area 'Wesselburen' was chosen, because it can be considered as mostly unvegetated, except for narrow elongated areas along the coast, which are covered by sea grass during the vegetation period. 'Wesselburen' covers the intertidal range south of the Eiderstedt peninsula on the Schleswig Holsteinean North Sea coast, and it was already subject to earlier SAR imaging by the multi-frequency SIR-C/X-SAR in 1994 (Gade et al., 2008). 'Wesselburen' covers a wide range of tidal channels and creeks, whose very form and location may undergo strong interannual changes after heavy storms and storm surges in fall and winter. The sediments are mainly sandy, and muddy areas with a high percentage of fine grain are only found along the narrow arms of the tidal creeks and along the coast.

The 'Jadebusen' test site has been recently included into our studies, because the Jade Bight is a semi-enclosed bay at the mouth of the (small) river Jade, consisting of sandy and muddy sediments and extended bivalve beds being exposed to strong tidal currents. A deep tidal channel in the bay's center allows inflow and outflow of sea water from/to the open sea, while its arms reach into shallow areas along the coast covered by sea grass during the vegetation period.