Using Multi-frequency Radar Data for Sediment Classification in Dry-fallen Tidal Flats

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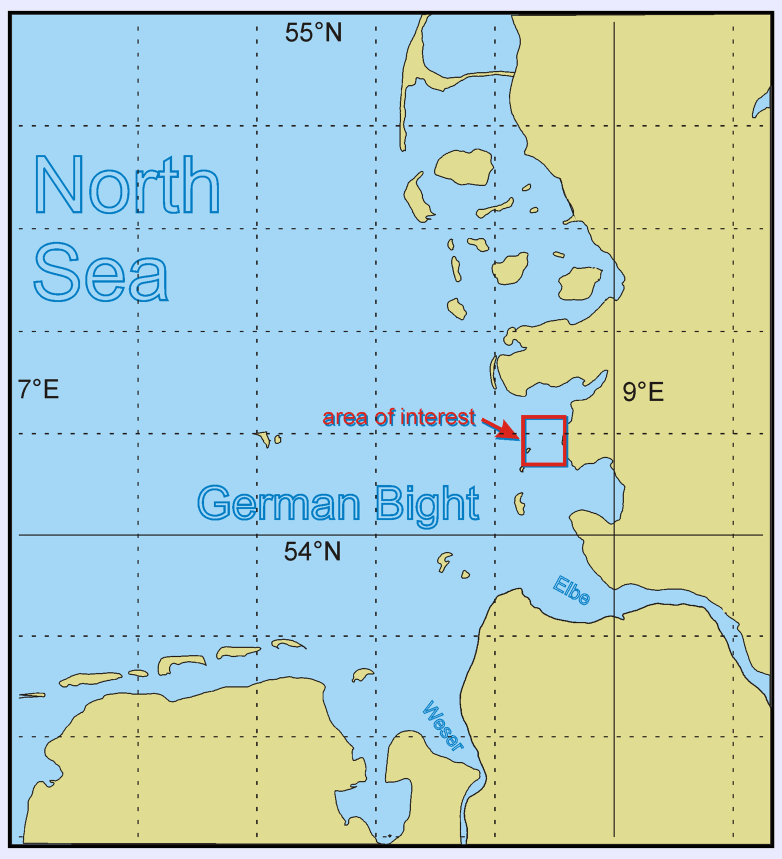
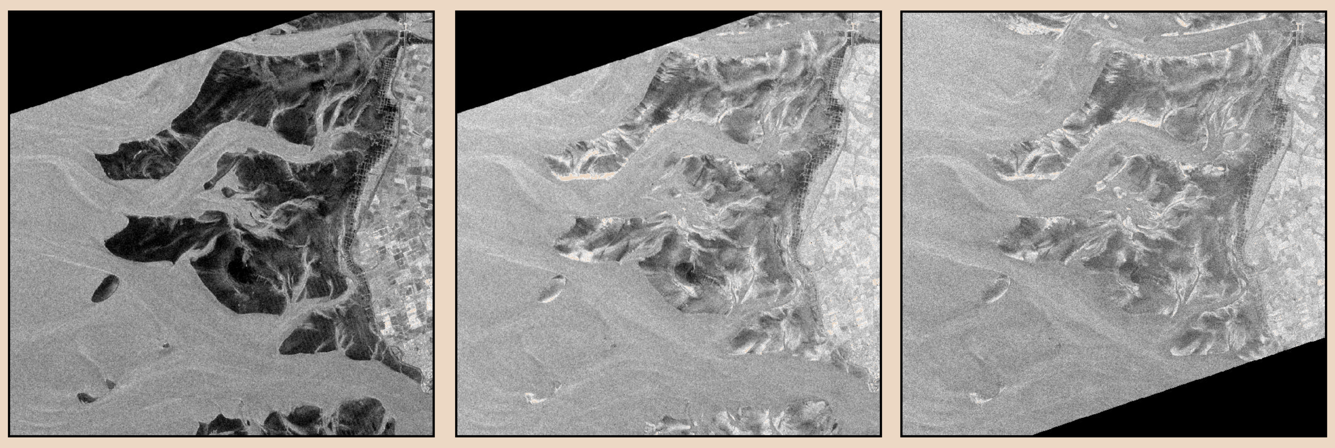
Abstract. A new method is presented for the extraction of roughness parameters of sand ripples on dry-fallen tidal flats from multi-frequency synthetic aperture radar (SAR) data. The SAR images used for this analysis were acquired over dry-fallen tidal flats in the German Bight of the North Sea by the Spaceborne Imaging Radar-C/X-Band SAR (SIR-C/X-SAR) during two missions in 1994. In addition, in-situ data were available from a field campaign performed in 1998, in parallel to an overpass of the ERS-2 satellite. Applying the single-scattering Integral Equation Model (IEM) we have calculated isolines of the normalized radar cross section (NRCS) at the three frequency bands deployed by SIR-C/X-SAR (L, C, and X band) as a function of the rms height and the correlation length of the sand ripples. These two roughness parameters could then be determined from the intersections of the NRCS isolines at different radar bands and they were used for a crude sediment classification for a test area at the German North Sea coast. This paper summarizes the results of a diploma thesis [1] and a technical report [2].



Map of the German Bight of the North Sea indicating the area where radar signatures of dry-fallen tidal flats have been investigated.

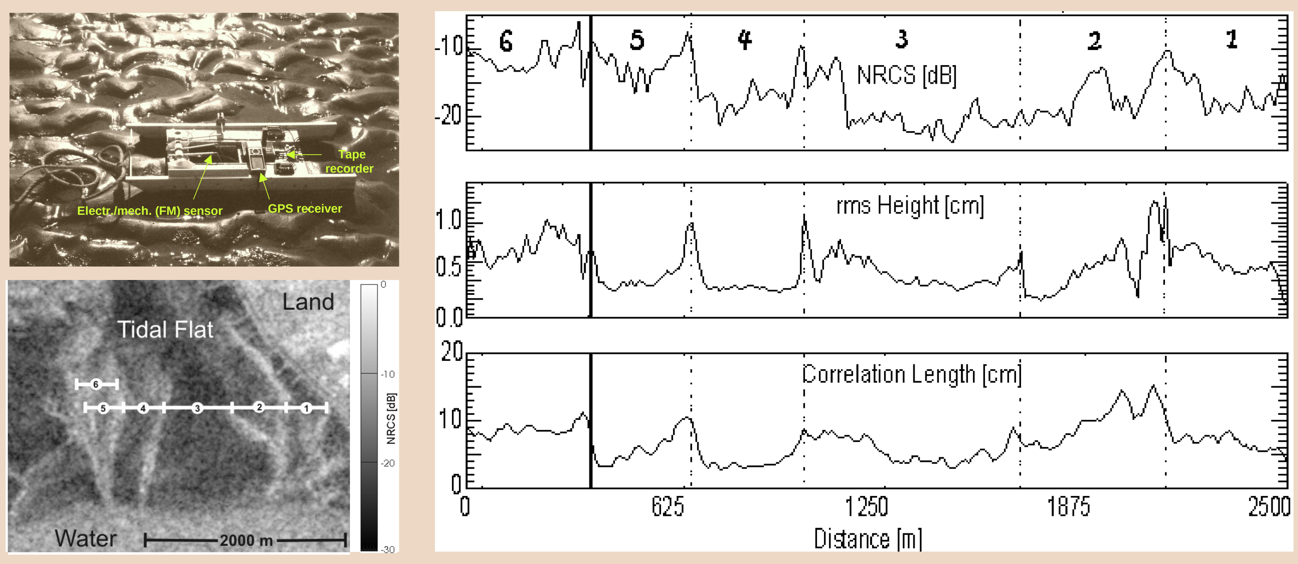
SIR-C/X-SAR Images



SIR-C/X-SAR images of the area of interest: L band (left), C band (middle), X band (right), VV polarization.
The images were acquired on April 10, 1994, at 0805 UTC, 2 h 45 min after low tide. Image dimensions are 12 km × 12 km.

The SIR-C/X-SAR was flown during two missions in April and October, 1994, onboard the space shuttle "Endeavour" and operated at three microwave frequencies: 1.25 GHz (L band), 5.3 GHz (C band), and 9.6 GHz (X Band). The data used for this analysis were acquired on April 10, 1994, at 0805 UTC (2:45 hours after low tide). Shown above are SIR-C/X-SAR images of the area of interest (cf. the top right map). Note that at L band (left image) dry fallen tidal flats appear much darker than the open water and the land, whereas at C and X band (middle and right image, respectively) tidal flats can appear both darker and brighter than the open water and the land.

In-situ Measurements



Top left: photograph of the self-constructed sledge that was used for the in-situ measurements. *Bottom left*: subset (3.45 km × 2.67 km) of an ERS-2 SAR image acquired on April 4, 1998, at 1045 UTC (23 min before low tide). Simultaneous in-situ measurements were performed with the sledge along the white track. *Right*: Comparison of the normalized radar cross section (NRCS) derived from the ERS-2 SAR image and the simultaneously measured soil roughness parameters. The numbering corresponds to the subsections marked in the SAR image.

On April 4, 1998, in-situ measurements were conducted in the area of interest: soil samples taken at 18 different locations revealed an average volumetric soil moisture of 43%. For the measurement of surface roughness profiles we used a self-constructed sledge equipped with an electrical-mechanical sensor that was following the ground contour while the sledge was towed along a certain track. Deploying this sensor several surface profiles of a total length of about 2500 m were collected (see above figure).
We found that the ripple troughs are still about half-filled when the tidal flats fall dry. This water effectively reduces the surface roughness experienced by the incident microwave (because they are backscattered from the water surface), but it was not measured by the sensor mounted on the sledge. This effect had to be considered later when measured roughness data were compared to those inferred from the model inversion.

References:

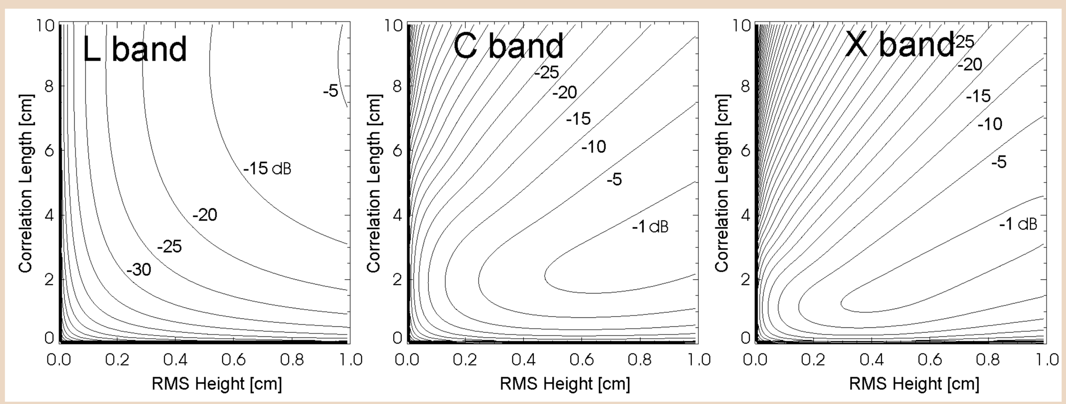
(1) Tanck, G. (1998), "Untersuchungen der Radarrückstreueigenschaften unterschiedlicher Wattypen des schleswig-holsteinischen Wattenmeeres mit Hilfe eines Multi-frequenz/Multipolarisations-SAR", Diplomarbeit, Fachbereich Physik, Universität Hamburg, Hamburg, Germany, 101 pp.

(2) Alpers, W. (1999), "XEP, Klassifizierung von Wattgebieten unter Verwendung von X-SAR/SIR-C-Daten", Abschlussbericht, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Bonn, Germany, 23 pp.

(3) Fung, A. K. , Li, Z., and Chen, K. S. (1992), "Backscattering from a randomly rough dielectic Surface", *IEEE Trans. Geosci. Remote Sens., 30,* 356-369.

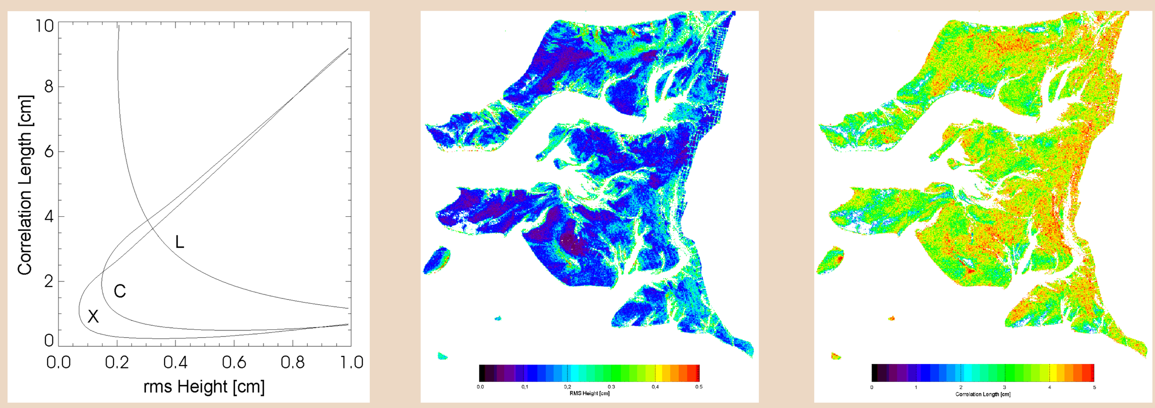
IEM-based Sediment Classification

The single-scattering Integral Equation Model (IEM [3]) predicts the normalized radar cross section (NRCS) of a bare soil in dependence of its dielectric constant and surface roughness. The latter is generally described by an autocorrelation function and standard deviation of the roughness height (rms height). The sensitivity of the predicted NRCS to changes of the soil moisture is generally very low at volumetric water contents greater then 30% and, hence, it is predominantly the surface roughness rather than the soil moisture that determines the strength of the backscattered radar signal from dry-fallen tidal flats.



Isolines of the NRCS (in dB) predicted by the IEM for L band, VV polarization (left), C band, VV polarization (middle), and X band, VV polarization (right) for a Gaussian soil surface.

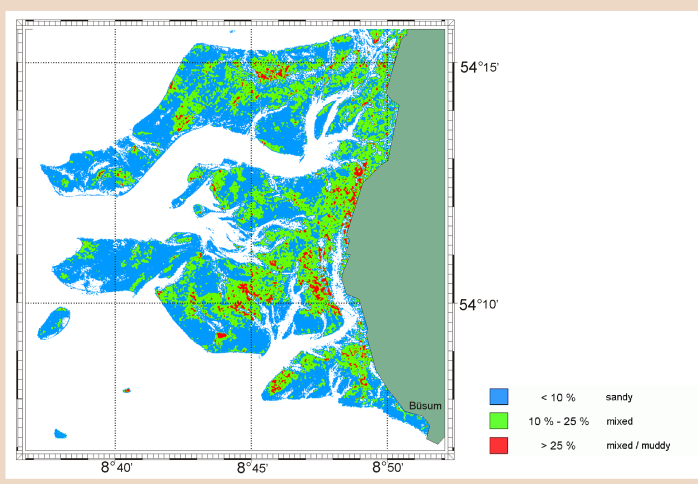
Applying the IEM we calculated the three isolines that correspond to NRCS values derived from collocated pixels in SIR-C/X-SAR images of a selected location on the tidal flats (cf. the left panel in the figure below). The roughness parameters could then be inferred from the intersection point of the three curves. Because the isolines for C band and X band are quite similar compared to those for L band, we suggest to generally use L band images in combination with either C band or X band images for the derivation of the soil-surface roughness parameters applying the IEM inversion approach.



Left: Three isolines corresponding to measured NRCS values at a selected location in the area of interest: –18 dB, -9 dB, and –11 dB at L, C, and X band, respectively. *Middle*: map of the rms heights of the tidal flats as a result of the inversion process. *Right*: map of the correlation length obtained by inversion of the IEM. In both panels open water has been masked using a supervised maximum likelihood classifier.

By applying this inversion procedure we have obtained maps of the rms height and correlation length for the area of interest (middle and right panel, respectively, of the above figure). Note that larger rms heights above 0.4 cm are especially found near the tidal creeks and the open water where the current velocity and wave action is increased, while the rms height on the plane flats away from the creeks is low. Larger correlation lengths are mainly found in areas of reduced hydrodynamic forces, near the coastline and in the center of the flats, away from the creeks.

Sediment classification as a result of the inversion process based on the IEM and on the SAR data shown on the left. The three classes correspond to different percentages of micro particles (i.e., of particles with diameters d ≤ 63 µm).



Finally, this figure shows a crude sediment classification based on a simple relationship between sediment types and the derived correlation lengths. In general, the open tidal flats are dominated by mixed / muddy soil (micro-sediment content between 10% and 25%), whereas the vicinities of the tidal creeks are dominated by sandy soil (micro-sediment content less than 10%). These results show good agreement with sediment maps provided by local authorities (National Park Office), that are based on samples taken during former campaigns.

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