

SAR Imaging of Archeological Sites on Dry-Fallen Intertidal Flats in the German Wadden Sea

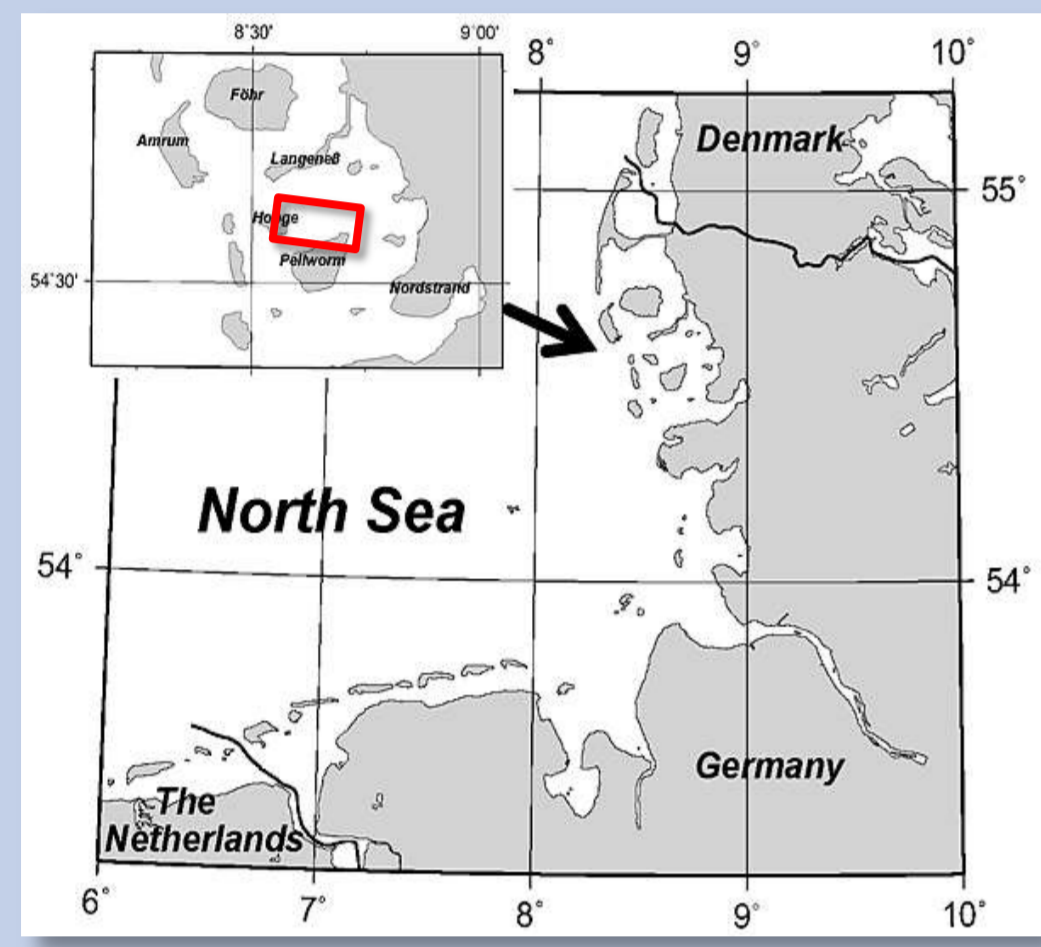
Martin Gade¹ and Jörn Kohlus²

¹Universität Hamburg, Institut für Meereskunde, Hamburg, Germany

²LKN, Nationalparkverwaltung, Tönning, Germany

After major storm surges in the 14th and 17th centuries, vast areas on the German North Sea coast were lost to the sea. However, remnants of former settlements and of historical landuse, which were buried by sediments for several centuries, can still be found in the German Wadden Sea, if the surface layer is driven away under the permanent action of wind, currents, and waves. We show that high-resolution SAR imagery with pixel sizes well below 1 m² can be used to complement archeological surveys and that TerraSAR/ TanDEM-X images clearly show remnants of farmhouse foundations and of former systems of ditches, dating back to the 14th century and to the 16th/17th century. In particular, the new high-resolution TerraSAR-X acquisition mode ('staring spotlight') allows for the detection of various kinds of residuals of historical landuse, some of which have been unknown so far.

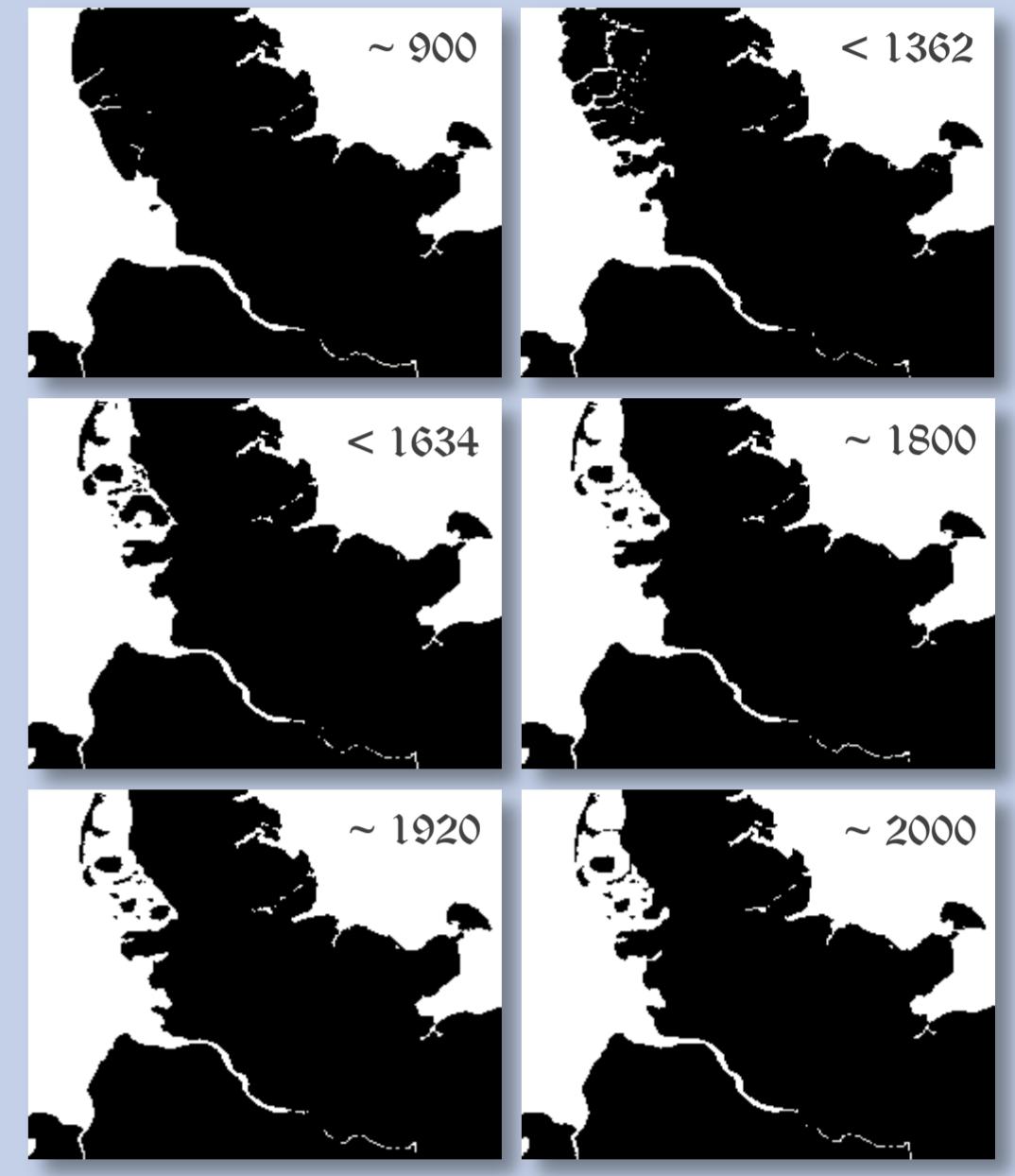
History and Area of Interest. In the Middle Ages, the German North Sea coast was looking very different from how it looks today (right figure) [2]. Vast areas along the coast were dominated by swamps, marshes, and swamp forests, which often made any settlements difficult or impossible. In the sparse settlements on the German North Sea coast, houses were sometimes built on dwelling mounds, protected by small dikes. Systems of ditches were built to remove the water from the farmlands, thereby allowing for any kind of agriculture.



Area of interest on the German North Sea coast. Inserted into the small map is the location of the SAR image below.

On January 16, 1362, after more than 24 hours of severe storm, the small dikes broke at many places, thus causing the death of a great number of cattle and men. As a result of that storm surge, huge land areas were lost to the sea, and they haven't been diked ever since. Thereafter, it took a long time until new dikes were built to protect the (remaining) marsh land. New farmland was characterized by a dense system of ditches, the dikes enclosed larger polders than in the centuries before, and farmhouses on terps were connected by narrow lanes. Another major storm surge occurred on October 11, 1634, again destroying farmland, farms, and whole villages, and killing cattle and men. The big (second) "Mandränke" is still the most-known storm surge in history in the area of the North Frisian Wadden Sea.

Over the following centuries, great parts of this former agricultural area have been buried by muddy and sandy sediments, which nowadays form the German Wadden Sea. However, under the permanent action of the tidal forces the muddy and sandy marine sediments may be driven away, and traces of former peat digging, drainage systems, and settlements appear again on the surface [1]. Since those areas are difficult to reach, and thus to observe from ground, airborne sensors have proven to be advantageous for a systematic observation of the residuals of those historical places [3]. Their use, however, is cost-intensive, which makes high-resolution spaceborne sensors an alternative source of data that can be used by archeologists for their frequent surveillance of the area [4].



Changes in the German North Sea coastline during the past 1100 years, after [2]. The middle row shows dramatic changes after major storm surges in the 14th (left) and 17th (right) centuries.

Example SAR Data

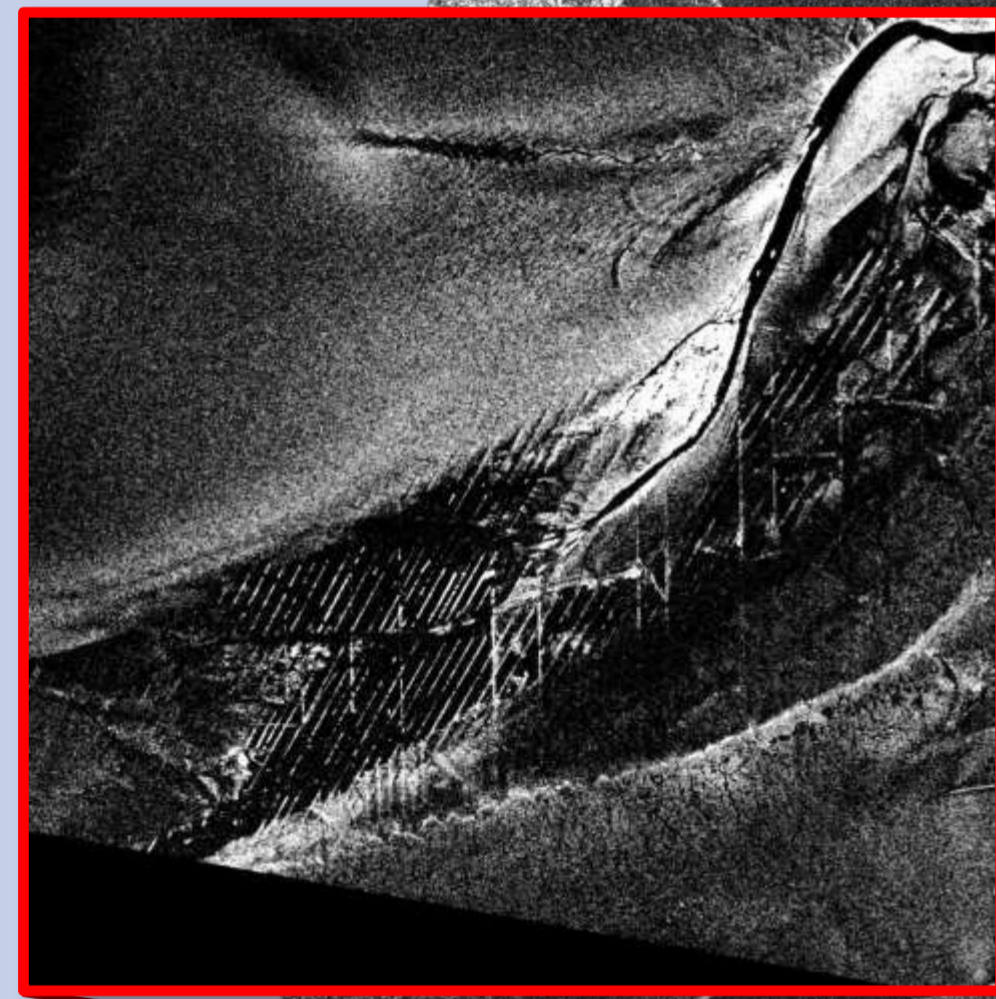
TerraSAR-X image of the area of interest (north of Pellworm, east of Hooge, see the map above), acquired December 12, 2012. Red squares denote the locations of the SAR image details. © DLR 2012.



Former Settlements. The right example is a 1000 m × 1000 m detail of a TanDEM-X image (November 19, 2014, 17:01 UTC, low tide + 26 min, staring spotlight mode, pixel size 26 cm × 26 cm). The very fine pixel size allows for imaging residuals of historical landuse, which usually are too narrow to be identified on SAR imagery of conventional resolution. Note the linear and rectangular structures in the lower left image center, close to the tidal creek, along with groups of parallel vertical lines in the upper image center. The mean distance between those parallel lines is about 15 m, thus indicating that they are remnants of former ditches and drainage channels.

Below is an aerial photograph of the same area, taken on July 29, 2009, at low tide. The linear structures obviously origin from foundations of former settlements. Note the sandy sediment, by which those structures were buried for centuries, and which was driven apart by the action of currents and waves.

Also note that, during the five years between the two acquisitions, parts of the residuals were already lost, due to the permanent erosion and morphological changes (the tidal creek moved to the east).



Upper: subsection (1000m × 1000m) of a TanDEM-X staring spotlight scene acquired on November 19, 2014. © DLR 2014
Middle: photograph of the same area as above, taken from a dike on Pellworm island. Photo: M. Gade
Lower: reconstruction of a historical lane with ditches on either sides. Photo & sketch: J. Kohlus.

Former Landuse. The left example is a TanDEM-X scene (November 21, 2014, 05:41 UTC (low tide), staring spotlight mode, pixel size 22 cm × 22 cm) showing many bright and dark parallel lines with distances of 10 m to 20 m. They are remnants of a former mesh of ditches built for the drainage of the farmland. The ditch residuals are marked by denser sediment causing higher surface roughness, which, in turn, results in higher radar backscattering.

The middle panel is a photograph taken during low tide on May 14, 2009, from a dike on Pellworm island. The dark parallel structures in the image center correspond to those seen on the SAR image. Note the differences in sediment composition of the linear structures and the surrounding sandy flats.

The lower panel shows a reconstruction of a historical lane, with ditches on either sides, whose remnants can be found on the intertidal flats north of Pellworm. The sediments on the lost pastures are different from those in the linear structures of ditches, causing narrow ridges of only 10 cm to 20 cm width, which show up on SAR imagery, if its spatial resolution is high enough.



Upper: subsection (1000m × 1000m) of a TanDEM-X staring spotlight scene acquired on November 19, 2014. © DLR 2014.
Lower: aerial photograph of the same area as above, taken in July 2009. Photo: B. Hälterlein.

References

- [1] Bantelmann, A., Kuschert, R., Panten, A., Steensen T., 1995. Geschichte Nordfrieslands. Boyens, Heide, 472 pp.
[2] Behre, K.-H., 2009. Landschaftsgeschichte Norddeutschlands: Umwelt und Siedlung von der Steinzeit bis zur Gegenwart. Wachholtz, Neumünster, 308 pp.
[3] Gade, M., Kohlus, J., 2011. Archeological Sites on Intertidal Flats in the German Wadden Sea. Proceed. 4th TerraSAR-X Science Team Meeting, Oberpfaffenhofen, Germany, http://sss.terrasar-x.dlr.de/papers_sci_meet_4/poster/COA0118_gade.pdf.
[4] 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.