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# Tidal bedforms dynamics, Weser River, Germany

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The distribution, morphology and dynamics of tidal bedforms in the Weser estuary, Germany, between the tidal limit (river-km 0 at the tidal weir in Bremen) and the open North Sea (river-km 111 in the Outer Weser) has been analysed for a five-year period based on monthly bathymetric surveys carried out along the main waterway. For the years 2009 to 2014, bedforms were detected from gridded bathymetry data (2x2 m) and their geometric properties described. In particular, the presence and position of a slip face, here defined as the portion of the lee side steeper than 15°, was traced. This was shown to be a practical criterion for the presence of permanent flow separation and turbulent wake in the lee of bedforms. Here it is used as a simplified indicator of bedform roughness: if a bedform does feature a slip face, it is assumed to be an active roughness element. The results were related to river discharge, water levels, and flow velocities.

Bedforms were present along most of the river channel, apart from a large section between river-km 55 and 75. There, muddy cohesive sediment in the estuarine turbidity maximum zone hindered the formation of bedforms. Along the channel and throughout the years, bedform lengths varied between 20 and 60 m and heights between 0.3 and 1.6 m.

During times of high fluvial discharge, in winter and spring, ebb velocities were stronger than flood velocities. The bedforms then were small, long and ebb-oriented (i.e. the ebb lee side was shorter than the flood lee side) and many bedforms featured an ebb slip face but no flood slip face. This suggests that throughout the survey area, bedforms were active roughness elements during the ebb phase only.

In summer and autumn, when the discharge was low, bedforms in the upper reach (ca. river-km 15 to 30) gradually became flood-oriented and many bedforms there developed a flood slip face, implying that these bedforms were active roughness elements during the flood. Between km 30 and 55, bedforms were predominantly ebb-oriented, and many bedforms had an ebb slip face but only few had a flood slip face, so most bedforms were only active during the ebb phase.

The annual variations of bedform dimensions and shapes reveal an intricate feedback between river and tidal flows, channel morphology, sediment dynamics and bedforms. The results have implications for bedform research, river management and numerical modelling.