Tidal asymmetry and salt intrusion in the Ems estuary, North Sea

Wünsche A. [1], Becker M. [2], Fritzsch R. [1], Kelln J. [1], and Winter C. [2]

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Abstract

Tidal asymmetry in estuaries and other tidal regimes of coastal systems is commonly evaluated to assess (changes in) system states. It classifies local states as either flood or ebb dominant. The method for deriving the tidal asymmetry is often determined by the available data basis. As such, it can be estimated based on hydrodynamic parameters, sediment properties, or the geometry of the estuary. Due to the wide availability of monitoring data of water level, the derivation from these is one of the most common methods. In recent years the number of descriptors deriving tidal asymmetry increased noticeably. In this study, we compare and discuss their sensitivity to the quality of the input data.

Our study area is the Ems estuary, located southwest of the North Sea between the Netherlands and Germany. The estuary stretches about 100 km from the island Borkum landward until the tidal weir, which marks the inland boundary of the tidally influenced area. The shape of the estuary can be described by three features: the outer part adjacent to the North Sea is funnel-shaped and borders the central area, characterised by the Dollard, a tidal flat, and north of it, the main shipping channel. Further inland, the cross-section narrows into a channel-like course. Tides in the estuary are predominant semi-diurnal and described as asymmetric. The Ems estuary has been repeatedly studied (e.g. Talke et al. 2009, van Maren et al. 2015) to understand the mechanism that led to the observed increase of suspended sediment concentrations, coupled with the occurrence of fluid mud. The transition to its hyperturbid state is linked to a drastic change in the estuarine geometry (Winterwerp und Wang 2013), both vertically and horizontally. Repetitive interventions have amplified and deformed the tides, resulting in changes in current phases of M2 and M4, as well as in shifting tidal asymmetry to a stronger flood dominant state that favours sediment import (e.g. Dijkstra et al. 2019). Several studies, which vary in terms of analysis period, data set and type (e.g. field measurements in van Maren et al. 2023 or simulation results in Chernetsky et al. 2010), have occasionally revealed opposing directions of tidal asymmetry for similar sections of the Ems estuary. This provides another reason to investigate the extent to which the data basis can influence the outcome of tidal asymmetry.

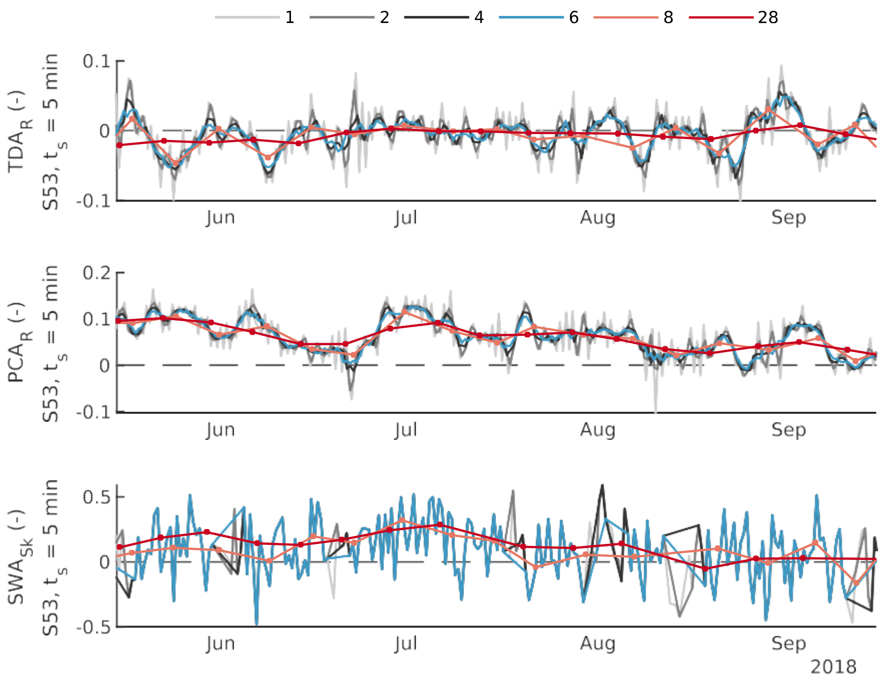

*Figure 1: Time series of scaled **a** tidal duration asymmetry (TDA) at km 53, **b** peak current asymmetry (PCA) at km 53 and **c** slack water asymmetry (SWA) at km 53 from May 15 to September 15, 2018. TDA and PCA are derived by using the ratio method (R) and SWA is derived by derivative skewness (Sk). Window length (tides) are displayed in different colors: 1 to 4 tides in grey tones, 6 tides in blue, 8 tides in orange and 28 tides in red. A dashed grey line represents zero. Positive values represent flood dominance, negative values represent ebb dominance. The sampling interval of the input data is 5 minutes*

[1] Federal Waterways Engineering and Research Institute, Hamburg, Germany, anna.wuensche@baw.de
[2] Institute of Geosciences, Coastal Geology and Sedimentology, Christian-Albrechts-Universität zu Kiel, Kiel, Germany

Based on one-year measurements of water level and near-surface current velocity along the Ems estuary, we computed tidal asymmetry from different descriptors: phase lag, tidal duration asymmetry, peak current asymmetry and slack water asymmetry. The descriptors are deduced from harmonic, ratio, and skewness methods. These methods yield values of tidal asymmetry in different ranges for the same interpretation of the dominant asymmetry direction. To compare the different methods, we scaled the descriptors to a new value range using conformal maps. We investigated the sensitivity of the descriptors by varying the sampling intervals of the input time series and the length of the computation window.

The sensitivity of the descriptors is strongly site-specific, particularly in response to variations in sampling intervals. That variability may lead to changes in the asymmetry direction in tidal duration asymmetry and phase lag. This sensitivity is most pronounced at locations where the initial difference between flood and ebb duration is minimal. The highest sensitivity is encountered calculating slack water asymmetry, which is likely related to the short duration of slack water compared to the duration of a full tide. Increasing the window length acts as a low-pass filter, reducing the variability of the tidal asymmetry, especially when computed over a small number of tides (Figure 1). Moreover, the relevance of the window length and the analysis period becomes apparent in the differences in the direction of tidal asymmetry resulting from spring or neap tides.

Overall, we find that data quality and analysis period play a crucial role in the assessment of tidal asymmetry in the Ems estuary. Consistent with other studies (e.g. Gong et al. 2016), the river discharge has a pronounced and downstream decreasing impact on the tidal asymmetry. This influence is particularly prominent in descriptors derived from current data during (high) discharge events. Wünsche et al. (under review) discuss the critical nature of interpreting (residual) sediment transport based solely on tidal asymmetry and point to the need for more comprehensive datasets.

Outlook

In addition to our sensitivity study (Wünsche et al., under review), we present preliminary findings regarding the long-term development of tidal asymmetry in the Ems estuary by extending the analysis period to 20 years. We are interested in the connection between spatially variations of tidal asymmetry, observed shifts in dominant asymmetry directions combined with the long-term alterations in near-surface salinity. Furthermore, the transformation of seasonal patterns in tidal asymmetry and salinity. That includes to investigate the extent to which possible long-term changes can be attributed to the recent progression in river discharge, leading to an increasing number of years with low discharge conditions. Moreover, we illustrate the impact of high and low discharge seasons on the research parameters of tidal asymmetry and salinity.

References

Chernetsky, A. S.; Schuttelaars, H. M.; Talke, S. A. (2010): The Effect of Tidal Asymmetry and Temporal Settling Lag on Sediment Trapping in Tidal Estuaries. In: Ocean Dynamics 60 (5), S. 1219–1241. DOI: 10.1007/s10236-010-0329-8.

Dijkstra, Yoeri M.; Schuttelaars, Henk M.; Schramkowski, George P.; Brouwer, Ronald L. (2019): Modeling the transition to high sediment concentrations as a response to channel deepening in the Ems River Estuary. In: Journal of Geophysical Research: Oceans (124:1-17). DOI: 10.1029/2018JC014367.

Gong, Wenping; Schuttelaars, Henk; Zhang, Heng (2016): Tidal asymmetry in a funnel-shaped estuary with mixed semidiurnal tides. In: Ocean Dynamics 66 (5), S. 637–658. DOI: 10.1007/s10236-016-0943-1

Talke, S. A.; Swart, H. E. de; Schuttelaars, H. M. (2009): Feedback between residual circulations and sediment distribution in highly turbid estuaries: An analytical model. In: Continental Shelf Research 29 (1), S. 119–135. DOI: 10.1016/j.csr.2007.09.002.

van Maren, D. S.; Colina Alonso, A.; Engels, A.; Vandenbruwaene, W.; Vet, P. L. M. de; Vroom, J.; Wang, Z. B. (2023): Adaptation timescales of estuarine systems to human interventions. In: Front. Earth Sci. 11, Artikel 1111530. DOI: 10.3389/feart.2023.1111530.

van Maren, Dirk S.; Winterwerp, Johan C.; Vroom, Julia (2015): Fine sediment transport into the hyper-turbid lower Ems River: the role of channel deepening and sediment-induced drag reduction. In: Ocean Dynamics 65 (4), S. 589–605. DOI: 10.1007/s10236- 015-0821-2.

Winterwerp, Johan C.; Wang, Zheng Bing (2013): Man-induced regime shifts in small estuaries—I. Theory. In: Ocean Dynamics 63 (11-12), S. 1279–1292. DOI: 10.1007/s10236-013-0662-9.

Wünsche, Anna; Becker, Marius; Fritzsch, Ralf; Kelln, Jessica; Winter, Christian: The sensitivity of tidal asymmetry descriptors in the Ems estuary. [under review]. In: Ocean Dynamics.