Abstract for the 18th Physics of Estuaries and Coastal Seas Conference, 2016

# Lag-Driven Sediment Transport in Tidal Basins: an Eulerian Perspective

V.M. Gatto[1]*, B.C. van Prooijen[1], Z.B. Wang[1,2]

*Keywords: lag effects, settling lag, tidal asymmetry, Wadden Sea*

**Abstract**

Tidal basins host valuable and often threatened ecosystems on and within their tidal flats. The rich biodiversity of our study site, the Wadden Sea (fig. 1a), has made it a UNESCO World Heritage. As the tidal flats have to keep pace with sea-level rise and withstand human interferences, it is crucial to quantify the transport mechanisms underlying sediment dynamics. The *lag effects* (LEF - e.g. *settling and scour lag*, Van Straaten and Kuenen, 1957) are barotropic mechanisms of suspended transport related to tidal propagation and regarded to be among the main drivers of landward SPM accumulation. Their classic descriptions are in a Lagrangian frame and do not account for wind waves. These restrictions need to be overcome, as: i) diffusive processes and other barotropic mechanisms (*tidal asymmetry* - TAS, *Stokes' drift compensation* - SDC) are defined in an Eulerian frame and therefore cannot be compared with LEF; ii) waves dominate resuspension in the intertidal zone (Green and Coco, 2014). The study aims at quantifying the relative contributions of LEF, TAS and SDC on the residual fluxes of non-cohesive fine sediment, by means of a fully Eulerian framework comprising short wind waves. We consider the Vlie basin (fig. 1a) as test case.

From the continuum viewpoint, decomposing the individual LEF is far from trivial and their definitions based on particle trajectory have to be adapted to the concentration field. The approach aggregates LEF into 2 main categories, according to their origin: *temporal* (local) *lag* stemming from the delayed response of sediment concentrations to changing hydrodynamics (Groen, 1967); *spatial lag* from unbalanced, alternate advection among areas at different levels of energy acting on the bed (Friedrichs, 2012). The Eulerian LEF are defined from the same underlying assumptions of the Lagrangian ones and result in equivalent dynamics. Their magnitudes are computed by the differences between fluxes based on: i) full advection-diffusion equation and time-relaxed equilibrium concentration (spatial lag); ii) time-relaxed and instantaneous equilibrium concentrations (temporal lag). The magnitude of TAS+SDC is based on the instantaneous equilibrium concentration. All mechanisms depend on tidal hydrodynamics, which is in turn controlled by the basin's morphology. In order to keep advantages of both idealized and process-based models, a hybrid 1DH model (Van Prooijen and Wang, 2013) is developed. The code derives a schematized but irregular geometry by combining observations and results from existing process-based simulations (fig. 1b). By outputting (depth-averaged) flow velocities and water elevations which are realistically distributed with respect to the bed level, the model constitutes an improvement from some assumptions commonly found in previous idealized studies (e.g. over-simplified geometry, *rigid lid*).

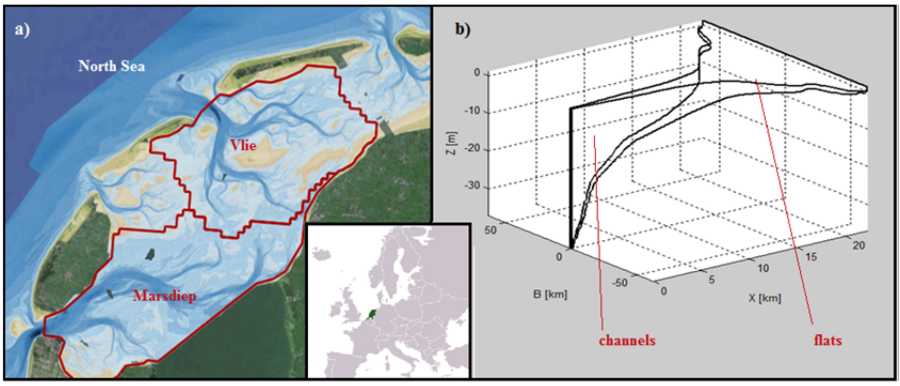


Fig. 1: a) The western Dutch Wadden Sea (in red, the watersheds contouring the sub-basins). B) Schematized Vlie basin: a deep, narrow part resembles the channel network and a wide, shallow part the tidal flats. Inlay – position of the Netherlands in Europe.

The results show *temporal lag* is negligible (note this may not apply to cohesive fractions), while the other mechanisms have a distinct spatial difference. In the deeper region (fig. 2a), waves are ineffective and *spatial lag* is dominant, overturning the small export caused by TAS and SDC into a consistent import. Onto the tidal flats, the overall fluxes decrease by two orders of magnitude and TAS becomes dominant. Here, wave-induced bed-shear stresses highly impact sediment dynamics. In absence of waves (fig. 2b), import is caused by a pronounced inequality in peak flood/ebb velocities. Mild-weather waves amplify the effect up to a factor 10 (fig. 3a), but they also result in a transition towards export of the same magnitude seaward to the intertidal edge (tidal amplitude is ~1 m). Stormy waves further enhance the import slightly, while export increases fourfold. Being wave resuspension more effective during low water,

[1] Department of Hydraulic Engineering, Delft University of Technology
[2] Marine and Coastal Systems, Deltares
*Corresponding author, v.m.gatto@tudelft.nl

sediment is carried away by the residual seaward velocity compensating tidal Stokes' drift and the much longer duration of ebb compensating a skewed, faster-rising tidal curve (due to relatively consistent *M4* and *M6* overtides).

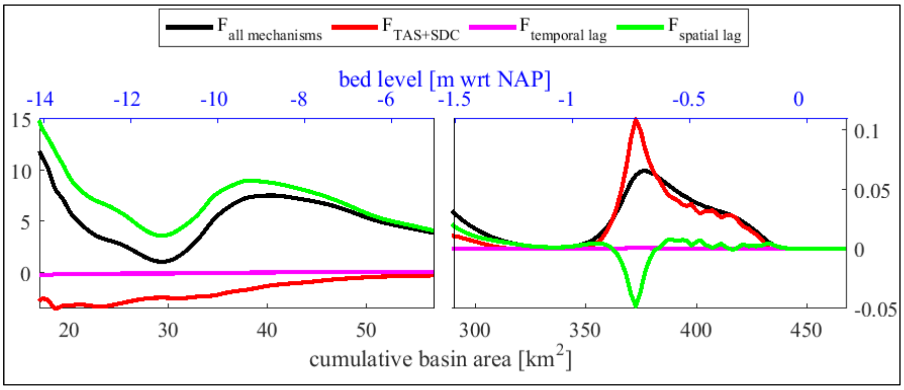


Fig. 2: Residual fluxes [kg/s] of suspended sediment in the Vlie basin for a) subtidal and b) intertidal transects, as a function of the hypsometry. No wind waves. Positive (negative) values mean net landward (seaward) transport.

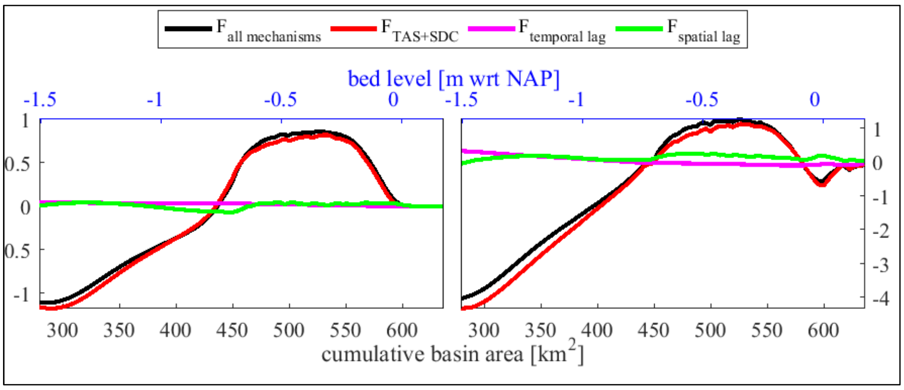


Fig. 3: Residual fluxes [kg/s] of suspended sediment in an intertidal transect of the Vlie basin, for a) mild-weather and b) stormy waves conditions, as a function of the hypsometry. Positive (negative) values mean net landward (seaward) transport.

Framework and methodology introduced in this study make *spatial lag* lose the exclusively-importing character of its Lagrangian equivalent, viz. *settling lag* (Pritchard, 2005). The mechanism can now be interpreted with an energy concept, whose proxy is the exceedance of the critical bed-shear stress, averaged over the tidal period. While in the channels this keeps reducing landward, a local maximum happens along the intertidal profile, and sediment is dispersed from that location. If we assume wave-current interaction and wind-driven flows on tidal flats can have the same magnitude of tidal circulation during low water stages, net transport could be in any direction in a 2D/3D model. In other words, *spatial lag* simply promotes advective displacement from high- to low-energy areas. While the magnitude of the overall fluxes is proportional to the energy *level*, that of spatial lag responds to the energy *gradient* in space. Without waves, the energy peak around the low-water line is due to the strong width divergence of the domain. The higher the waves, the longer the (shallow) subtidal transect experiencing frequent wave-induced resuspension and the flatter the energy gradient: LEF become comparably smaller with respect to the bulk of transport. Landward to the low-water mark, stormy waves accentuate the gradient instead, resulting in more lag-driven transport.

Concluding, a methodology to quantify the lag effects in state-of-the-art (Eulerian) process-based models is developed. Spatial lag is pinpointed as the dominant barotropic mechanism for import of fine, non-cohesive sediment in the channel network of the Vlie basin. Onto the tidal flats, tidal asymmetry is dominant but significant wave heights not exceeding 25 cm already alter the "classic" description of the investigated mechanisms. The outcome suggests the complex interactions between wind waves and tidal flow is a key to understand the channel/flat sediment exchange.

## References


Friedrichs, C. (2012) Tidal Flat Morphodynamics: A Synthesis. Treatise on Estuarine and Coastal Science, Volume 3 Estuarine and Coastal Geology and Geomorphology, Academic Press, 137-170.

Green, M., Coco, G. (2014) Review of wave-driven sediment resuspension and transport in estuaries. Reviews of Geophysics, 52, 1, 77–117.

Groen, P. (1967) On the residual transport of suspended matter by an alternating tidal current. Netherlands Journal of Sea Research, 4, 564-574.

Pritchard, D. (2005) Suspended sediment transport along an idealised tidal embayment: settling lag, residual transport and the interpretation of tidal signals. Ocean Dynamics, 55, 124-136.

Van Prooijen, B.C., Wang, Z.B. (2013) A 1D model for tides waves and fine sediment in short tidal basins - Application to the Wadden Sea. Ocean Dynamics, 63, 1233-1248.

Van Straaten, L., Kuenen, P. (1957) Accumulation of Fine Grained Sediments in the Dutch Wadden Sea. Geologie en Mijnbouw, 19, 329-354.