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Uncertainty quantification for image-based motion estimation in bioirrigated marine sediments

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Benthic macrofauna flush their burrows and inject fluid into the sediment they inhabit, which has profound impacts on sediment biochemistry. The activity of burrowing organisms, commonly referred to as bioirrigation, oxygenated the commonly anoxic sediment. Knowledge of the flow field induced by bioirrigation is required to better understand the transport of dissolved chemicals in sediments and their exchange with the overlying water.
A $22\ cm \times 44.5\ cm \times 2.2\ cm$ aquarium was set up to quantify bioirrigation, containing $16\ cm$ of sediment inhabited by a Pacific lugworm and overlying water. A fluorescent tracer was added close to the lugworm's burrow, and images were taken over time to capture the spatial evolution of the tracer distribution.
So-called variational methods (such as the Horn-Schunck method), which relate flow fields to images by assuming that intensity is temporally conserved, have been used to estimate flow fields induced by bioirrigation. But since the true flow field is unknown, residual errors cannot be computed. A Kalman filter approach is used here: posterior variances act as a proxy for residual errors, making uncertainty quantification possible in the absence of the truth.
An advantage of the Kalman filter is that it is defined in terms of a general observation operator H. Unlike variational methods, this observation operator can be modified to account for factors such as diffusion or flows into and out of the plane (although an ensemble-based method would be required due to H becoming nonlinear). One can also include reaction terms, enabling analysis of images of non-conservative tracers obtained with planar optodes.