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Moment Approximations and Model Cascades for Shallow Mass Flows

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Rapid mass flows during transit are typically shallow, which motivates the use of a depth-averaged shallow flow model for their simulation. While the shallow flow formulation is advantageous in terms of computational efficiency, it comes at the price of losing vertical information such as the flow's velocity profile. In many situations this idealization of the physical process seems admissible, though a direct quantification of the arising model error is seldom done. Other situations even require a detailed depth-profile knowledge, e.g. when being interested in the flow's shear gradient, which also affects its erosive properties.
In this presentation, we propose the use of vertical velocity moments to overcome this problem. The shallow moment approximation preserves information on the vertical flow structure while still making use of the simplifying framework of depth-averaging. We derive a generic shallow flow model cascade of arbitrary order starting from a set of scaled and reduced balance laws that serves as a reference model. Next, we specify the shallow flow moment hierarchy for different flow regimes and discuss the arising model cascade. We present 1D numerical results for the shallow flow moment systems up to third order and assess their performance with respect to both the standard shallow flow system (zero order moment) as well as with respect to the fully vertically resolved reference model.
The latter allows us to discuss the model error due to depth-averaging. In particular, our results show that depending on the parameter regime, e.g. friction and basal slip, shallow moment approximations of progressively higher order significantly reduce the model error in shallow flow regimes, while keeping them computationally cost efficient with respect to any fully vertically resolved simulation. At the same time, shallow moment approximations can be designed to preserve any necessary information on the shear profile. Both aspects make them a promising candidate for the extension of existing shallow mass flow models.