Catching the details of mangrove dynamics

A case study in Lac Bay, Bonaire

Lac Bay is a mangrove ecosystem located in Bonaire, Caribbean Netherlands. The mangrove vegetation has a large influence on the tidal dynamics in the Lac Bay system. Field measurements of flow velocities within the creeks, water levels around the mangrove forest, and mangrove vegetation characteristics were mapped in previous research. No flow measurements inside the mangrove forest were available, leaving uncertainties regarding the hydrodynamics through the mangrove forest itself. This study investigates the vegetation influences on the tidal dynamics and how to model these vegetation influences. Using 3Di software, a subgrid-based model was developed to complement these measurements and enhance understanding of the system dynamics. The subgrid method allows the use of high-resolution data while computing hydrodynamics on a coarser computational grid. To capture the dynamics and establish an appropriate method for representing vegetation effects, three methods were evaluated: i) increasing bed roughness, ii) the Baptist drag formulation, and iii) porous layer methods. The methods were primarily assessed based on their ability to reproduce the observed tidal range and tidal asymmetry, while also considering flow patterns and water level variations.

Calibrating the individual vegetation representations revealed their limitations: The use of an increased bottom roughness required unrealistically low Chézy values, while the Baptist approach primarily improved the tidal exchange between the bay and Awa di Lodo, improving the simulated tidal range. The porous layer method showed very good results in modelling the tidal duration asymmetry, without accurately simulating the tidal range. To optimise simulation accuracy, a hybrid model was created. The Baptist method is more suitable for vertical and well-structured roots such as pneumatophores of black mangroves, whereas the porous layer better represents the dense root networks of red mangroves. The use of a hybrid model, along with species-specific calibrations, enhances the model's accuracy significantly, especially the tidal exchange between the bay and Awa di Lodo.

Results highlight vegetation's critical role in modifying tidal hydrodynamics, particularly in dense root areas. Discrepancies between predicted and observed results, especially during neap tides, suggest some physical processes may not be fully accounted for in the model. The study area is known for hypersaline conditions, typically caused by strong evaporation. An exploratory test indicated that incorporating evaporation effects could improve model performance during neap tide conditions. By combining field measurements with advanced numerical modelling, this study provided new insights into the system's dynamics as well as the different vegetation schematisations in numerical modelling. The results demonstrate the effectiveness of a species-specific, hybrid model approach in understanding mangrove hydrodynamics, particularly for complex environments where different mangrove species coexist and interact, such as Lac Bay.

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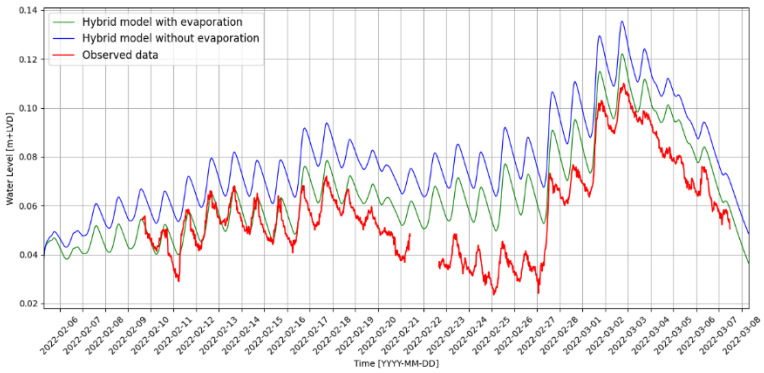

Figure 1:Water level variation in Awa di Lodo during the validation period: observations (red) compared to numerical simulations with evaporation (green) and without evaporation (blue).

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