Three-dimensional modelling of flow and sediment transport processes around saltmarsh vegetation

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Introduction

Flow, sediment transport and ecological processes in saltmarsh environments are inextricably linked, and exhibit numerous feedback mechanisms. Vegetation induces additional drag force, creating localized regions of low energy flow, within and around vegetation patches, where sediment, nutrient and seed deposition may occur [1–4]. Such regions, which are characterized by low flow velocities, also provide ideal, low stress conditions for further plant growth [5]. Thus, plant growth and succession are both a cause and effect of the flow hydrodynamics.

Much research has been conducted into flow around vegetation. However, this has primarily focused on extended plant canopies [6, 7] or idealized, often rigid, patch geometries [1, 8]. Furthermore, most studies focus on the lateral rather than the vertical wake and shear layer [1, 8, 9]. Here, we apply three-dimensional numerical modelling to investigate the impact of different vegetation patch sizes, geometries and rigidities on flow and inferred sediment transport processes, based on realistic plant patch and flow data informed by field data collected at Mont St Michel, France.

Methods

A suite of over 30 different flow simulations were conducted covering a large parameter space, with varying flow (velocity) and vegetation (patch size, stem rigidity) characteristics. Flow was simulated using the steady Reynolds-averaged Navier-Stokes equations with an RNG k-ε turbulence closure model. The free surface was treated as a rigid lid and the bed was treated as a wall. The lateral edges of the domain were treated as frictionless boundaries. The domain size was scaled with the vegetation patch such that it had dimensions 24w x 5w x 3w0.6. A regular, structured cartesian grid was used, with constant grid resolution of 5mm throughout the vegetated region. Away from the vegetation patch, grid coarsening was applied for numerical purposes.

Vegetation patches were represented as groups of individual stems (Figure 1), positioned randomly with the patch area at a known stem density. Patch areas and mean stem heights were determined by averaging the relationship between patch width, length and height observed in the field data. Individual stems were represented as flexible, three-dimensional porous arrays. Typical porosity values were estimated using image analysis of the plants collected from the field. Although the model assumed steady conditions, plant stems were reconfigured at each iteration such that the final results represent a patch reconfigured to the mean flow conditions. Plant reconfiguration was modelled using an Euler-Bernoulli beam equation model, where the external drag forces exerted by the flow were balanced by the internal stem rigidity forces [10]. Stem flexural rigidity was estimated from a sample of stems collected in the field site.

Simulated flow data was analyzed to calculate wake length, to infer sediment transport processes. Four different measures of wake length from the literature were utilized and compared. Initial tests were conducted to examine the effect of random stem configuration on predicted flow patterns, before

Field data, including laser scans to derive bed topography and patch dimensions, select flow measurements using acoustic Doppler velocimetry (ADV) and data relating to plant properties were collected over a number of field seasons from the developing saltmarsh at Mt St Michel.
Results & Discussion

Our results demonstrate that the vegetation model is successful at reproducing expected flow patterns with respect to both the field data and previous published data. The effect of random stem configuration on the flow patterns has some impact in the near wake, but diminishes significantly with distance from the end of the patch.

Our calculated wake lengths and velocity fields show that flow around the vegetation patches resembles the characteristic mixing layer model found in previous studies. However, due to the dimensions of the vegetation patches, the vertical shear layer (Figure 1) is more important in controlling wake length and sediment transport processes than the lateral shear layer. This fact has been relatively under-examined until now.

The simulations with varying rigidity show that flexural rigidity exhibits a complex non-linear relationship with wake length, whereby intermediate rigidities produce longer wakes than both high and low rigidities. The field data show that the natural rigidity of the stems coincides with the longest wake condition.

References