Interactions between water flow and small-scale vegetation patches govern the formation and evolution of landform and vegetation patterns at the landscape scale

However, numerical models that integrate all these scales (from meters to kilometers) are computationally too expensive

For example:

(a) in alluvial rivers, pioneer islands induced by vegetation patches facilitate the establishment of other plants that can in turn reinforce the development of larger vegetated landforms;

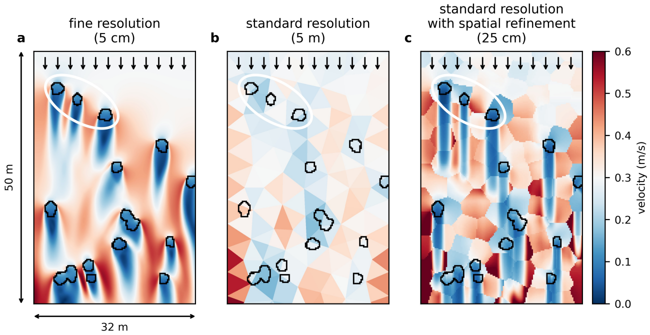
(b) in tidal salt marshes, expanding patches of pioneer vegetation trigger the formation of dense, efficient drainage channel networks.

In general, vegetation establishment in a bare landscape modifies the patterns of water flow, sedimentation and erosion, which in return influences the spatial patterns of vegetation establishment and die-off (so-called biogeomorphic feedbacks).

In case of patchy vegetation, biogeomorphic feedbacks are scale-dependent. At a small scale, within the vegetation patches, flow velocities and erosion are reduced, resulting in improved plant growth. At a larger scale, the water is partly forced to flow around the vegetation patches, leading there to increased flow velocities, potentially erosion, and to inhibition of plant growth just next to the vegetation patch.

Representation of scale-dependent feedbacks in numerical models is therefore highly dependent on grid size, which raises a balance problem between domain size and computational time.

Photographs by Angela Gurnell (a) and Olivier Gourgue (b)



Flow velocities around vegetation patches simulated at (a) fine-resolution, (b) standard-resolution and (c) standard-resolution with application of our new spatial-refinement method. The black lines represent the contour of the vegetation patches. The single-headed arrows indicate the incoming flow direction and the double-headed arrows the domain dimensions.

The white ellipses mark flow acceleration/deceleration patterns simulated by the fine-resolution model (a) but that the standard-resolution model fails to reproduce (b). With our new spatial-refinement method, the standard-resolution model can capture these patterns with limited extra computational cost (c).

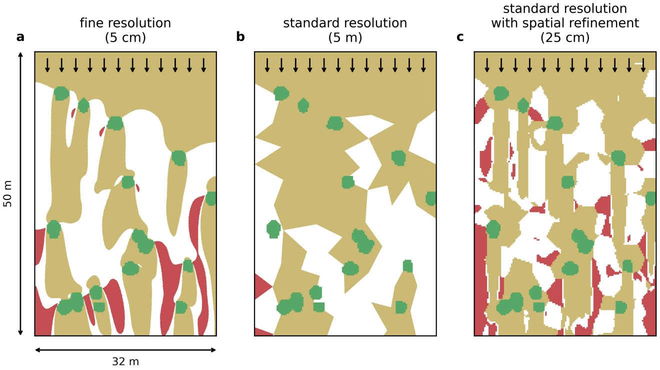
The fine-resolution model (a) is here used as a reference to compare the two other modeling approaches (b,c) but is too computationally expensive to be used on larger, more realistic cases.

Standard-resolution biogeomorphic models cannot represent flow interactions with small vegetation patches

With our novel spatial-refinement method, they will

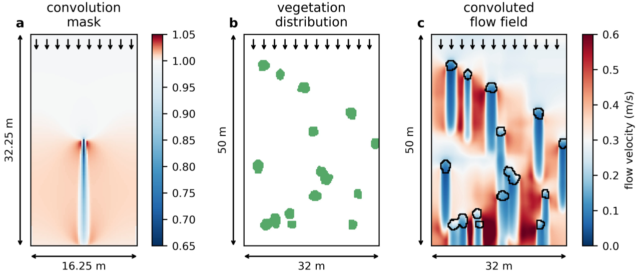
Our spatial-refinement method allows for better representation of the biogeomorphic feedbacks around small-scale vegetation patches

This can have far-reaching consequences at the landscape-scale



Zones of potential plant growth (yellowish) and of potential channel incision (red) resulting from flow velocities around vegetation patches (green) simulated at (a) fine-resolution, (b) standard-resolution and (c) standard-resolution with application of our new spatial-refinement method.

The fine-resolution model shows that potential plant growth is limited to the wakes of the patches and that channel incision can occur between them (a). The standard-resolution model underestimates the intensity of the flow acceleration/deceleration patterns around small vegetation patches. Hence, it overestimates the extent of the zone for potential plant growth and almost completely fails to reproduce the favorable conditions for channel incision (b). With our spatial-refinement method, the standard-resolution model seems able to recreate at least partially the spatial patterns for potential plant growth and channel incision (c).



(a) The convolution mask M is the normalized flow velocity field around an elementary vegetation patch of one vegetation grid cell, simulated by the fine-resolution model.

(b) The vegetation distribution V is defined at finer resolution than standard-resolution models (representing subgrid-scale vegetation patterns).

(c) The convoluted flow field U is an approximation of the flow velocity field around vegetation patches calculated by:

$$U = U_0 \exp\left(\log(M) ** V\right),$$

where U_0 is the incoming flow velocity and $**$ is the symbol of the two-dimensional convolution product.

How the method works?

Flow velocities around vegetation patches can be approximated by the convolution product between

(i) the flow velocity field around a single vegetation grid cell (convolution mask)

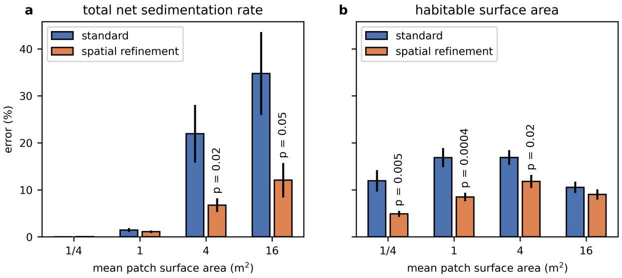
(ii) the vegetation distribution

The method has been tested for 150 random vegetation patch configurations

We show that it significantly improves model results in terms of

(i) sedimentation rates, if the patches are large enough to trigger erosion around them

(ii) potential vegetation growth, especially for smaller subgrid-scale patches



Relative error in (a) total net sedimentation rate and (b) habitable surface area (defined as the area where flow conditions are suitable for potential plant growth) averaged over simulations of equal mean patch surface area. The simulations are performed using the standard-resolution model, without (blue) and with application of our new spatial-refinement method (orange). The errors are obtained in comparison with the reference fine-resolution model results.

The black lines represent standard errors. The *p*-values are the results of statistical tests (T-test) to determine if the relative errors for a given patch size are significantly different whether spatial refinement is applied or not (only shown for $p \leq 0.05$).