Multi-scale challenges in bio-geomorphic modeling of tidal marshes

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Multi-scale challenges

Feedbacks at scale of pioneer vegetation patches (few m^2)...

Positive feedback (⊕) within vegetation leads to flow reduction, sediment accretion and improved plant growth

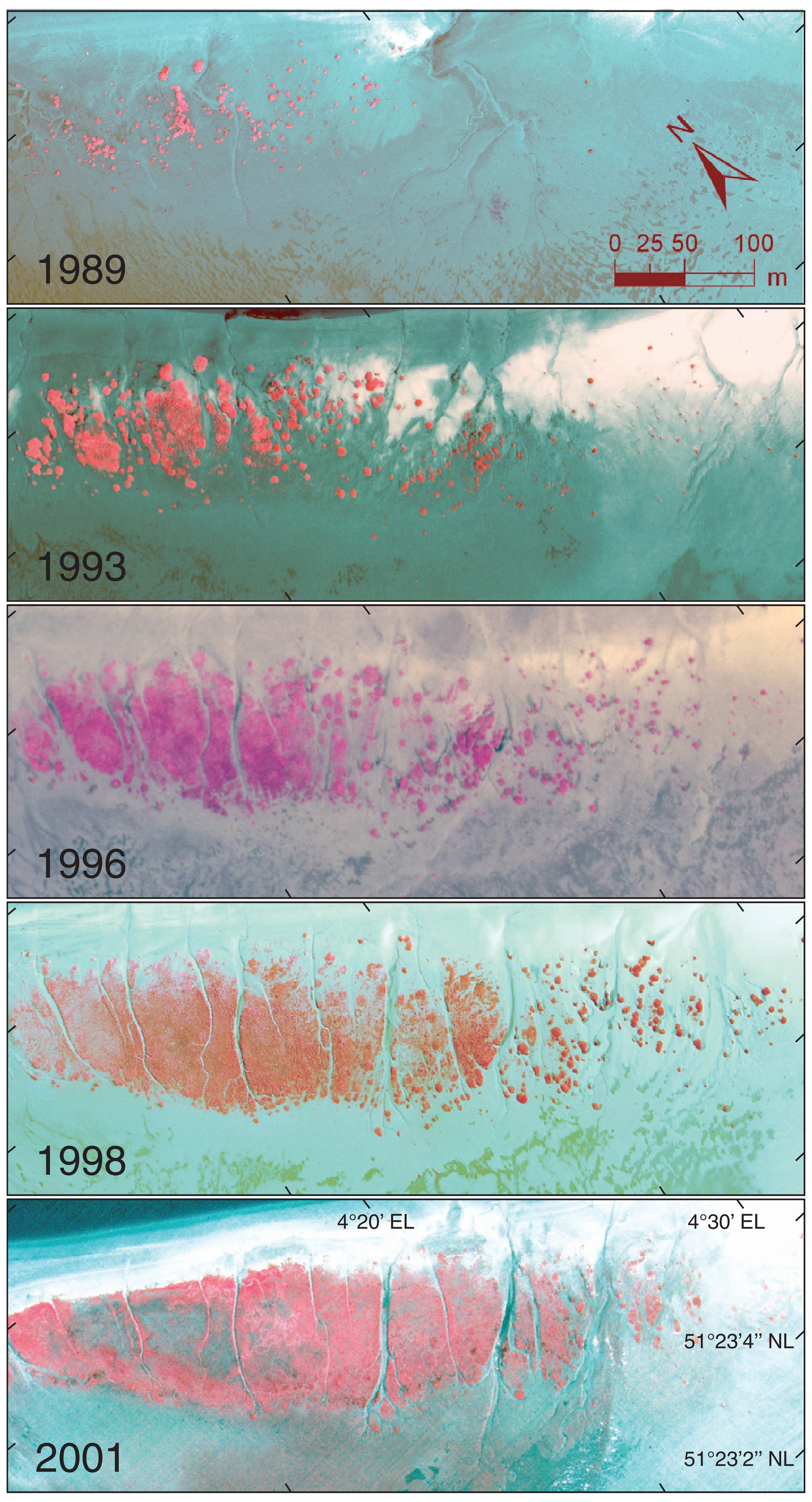
Negative feedback (⊖) around vegetation results in flow acceleration, erosion and negative effects on plant growth

... affect landscape-scale (km^2) development

Evolution of an intertidal landscape in SW Netherlands:

1. random **establishment** of small round vegetation tussocks on bare flat **(1989)**
2. lateral **expansion** of tussocks forms larger irregular vegetation patches **(1993)**
3. further establishment and expansion result in closed vegetation swards

   flow concentration between vegetation swards enhances erosion and **channel formation (1996)**
4. further vegetation closing and channel formation between vegetated areas **(1998 & 2001)**



References

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Objective

What we need

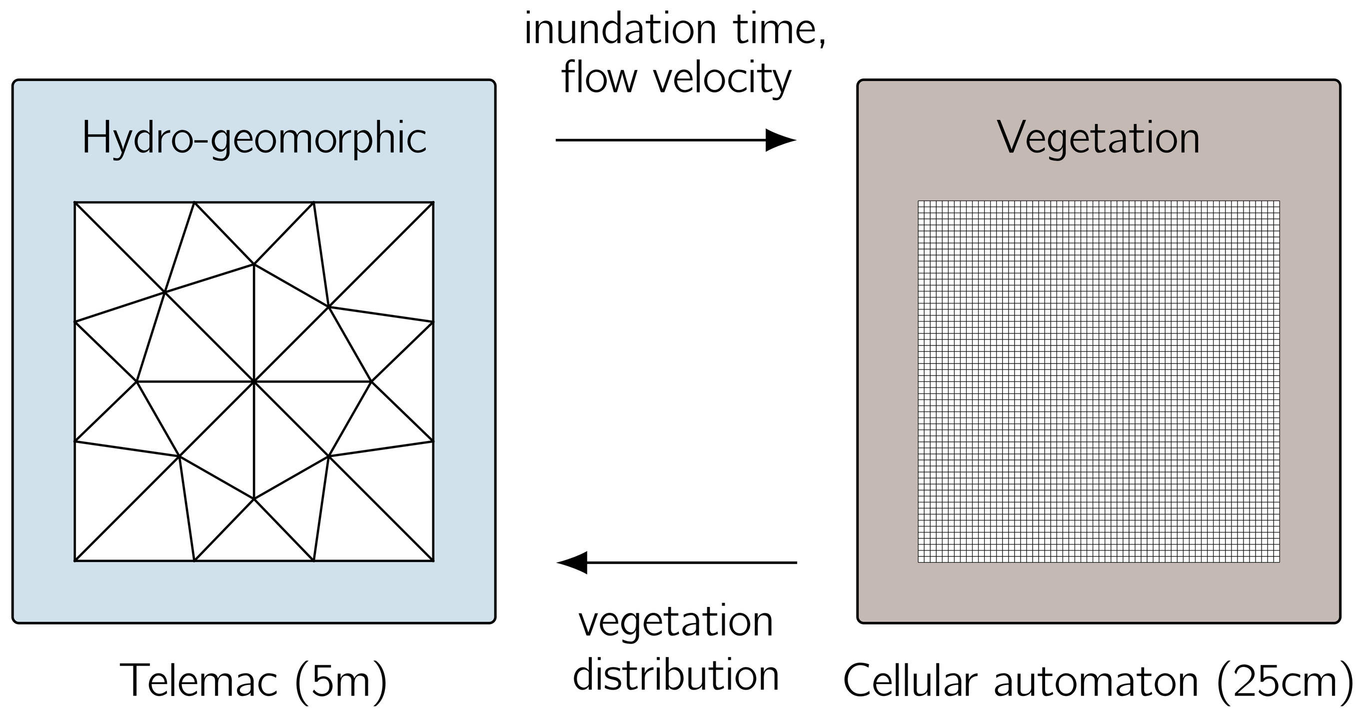
For conservation and restoration of intertidal landscapes, we need a bio-geomorphic model that includes small-scale interactions between vegetation, flow and sediment transport (order of m^2) to forecast long-term (decades) evolution of large intertidal areas (order of km^2)

Direct approach (ruled out)

All processes simulated at the same scale lower than 1m
⇒ estimated computation time for 30-year simulation on our supercomputer (4k+ cores): **1 month!**

Novel two-grid approach ⇒ see right panels

Two-grid modeling approach



Hydro-geomorphic module

Telemac solves (relatively) expensive partial differential equations (PDEs)
Large-scale geomorphodynamics ⇒ coarse grid resolution (5m)

Vegetation module

Cellular automaton uses a (much) cheaper probabilistic approach to estimate plant establishment, lateral expansion and die-off
⇒ finer grid resolution (25cm) is allowed

Multi-scale numerical challenges (among others!)

1. How to refine coarse-scale velocity flow fields (5m) to adress fine-scale interaction (25cm) with vegetation? ⇒ **convolution method** (box below)
2. How to integrate fine-scale vegetation distribution (25cm) to simulate feedback to coarse-resolution flow field (5m) without losing all sub-grid information? ⇒ paper in preparation by J. van Belzen, et al.

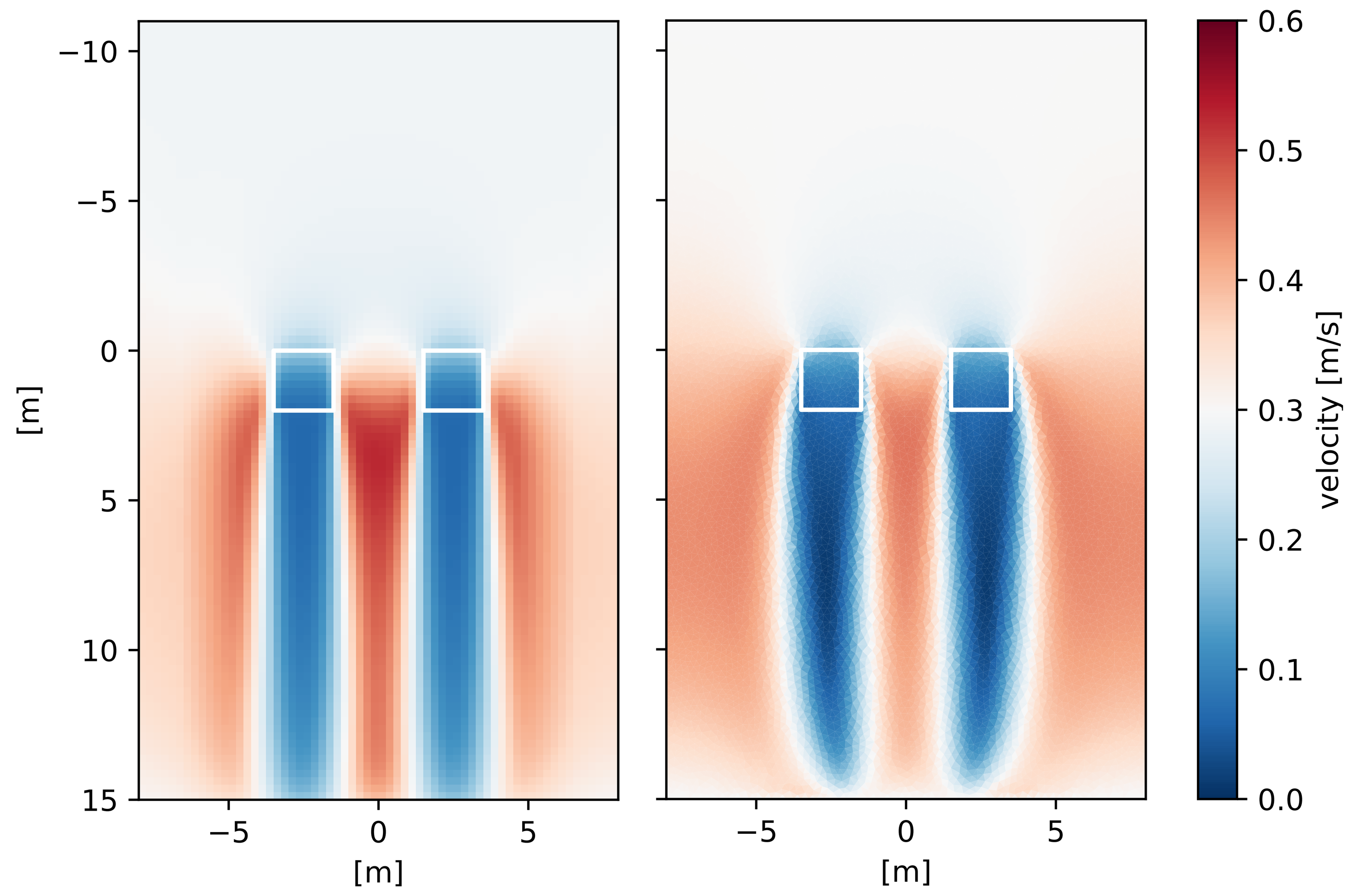
Convolution method

In a nutshell

Fine-scale velocity can be approximated by the **convolution** ($*$) of the vegetation distribution and a scale-dependent feedback function (paper in preparation)

Convolution vs. Telemac

Flow velocity field around two patches of vegetation (*Spartina anglica*), as computed with the convolution method (left) and simulated by Telemac at the same 25cm grid resolution (right)



Computation time

Less than a second with the convolution method *vs.* about 6.5 minutes with Telemac (tests on a MacBook Pro 15-inch 2016 with 2.6 GHz Intel Core i7)

Potential applications

Finer estimation of plant establishment/die-off probabilities
Estimation of sediment erosion/deposition budget at the sub-grid scale