MORPHODYNAMIC MODELING OF LARGE ANABRANCHING RIVERS

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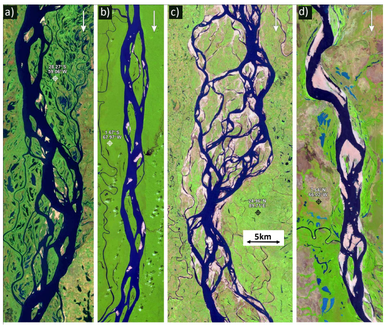
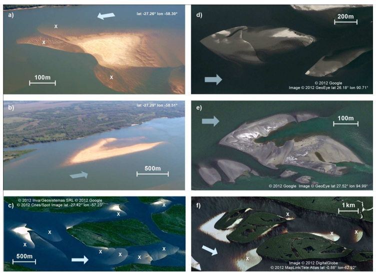
CONTEXT: Many of the world's largest rivers share common characteristics (e.g., very low gradients, sand-sized bed sediment, and an anabranching pattern). Mechanisms of bar and channel evolution in such rivers have been studied using analysis of bathymetric maps and satellite imagery. However, linking channel change to flow and sediment transport processes is problematic due to logistical constraints on data collection. This study examines the scope for using numerical models to investigate anabranching river morphodynamics.



Examples of large anabranching sand-bed rivers: a) Paraná, Argentina; b) Japurá, Brazil; c) Jamuna, Bangladesh; and d) Orinoco, Venezuela.



Examples of unit bars (labeled 'x' in a, c, and f), compound bars (in b, d, and e) and vegetated islands (in c, and f) in selected large anabranching sand bed rivers: the Paraná, Argentina (a to c), the Brahmaputra, India (d and e), and the Negro, Brazil (f). Arrows indicate flow direction. Images c to f acquired from Google Earth.

NUMERICAL MODEL: The model developed and implemented here uses a Godunov-type finite volume scheme to solve the depth-averaged shallow water equations:

$$\frac{\partial h}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=0$$

$$\frac{\partial q_x}{\partial t}+\frac{\partial(q_x^2/h)}{\partial x}+\frac{\partial(q_xq_y/h)}{\partial y}+\frac{g}{2}\frac{\partial(h^2)}{\partial x}+gh\frac{\partial z}{\partial x}+\frac{1}{\rho}\frac{\partial(h\tau_{xy})}{\partial y}+\frac{1}{\rho}\frac{\partial(h\tau_{xx})}{\partial x}+\frac{\tau_{bx}}{\rho}+F_{Sx}=0$$

$$\frac{\partial q_y}{\partial t}+\frac{\partial(q_y^2/h)}{\partial y}+\frac{\partial(q_xq_y/h)}{\partial x}+\frac{g}{2}\frac{\partial(h^2)}{\partial y}+gh\frac{\partial z}{\partial y}+\frac{1}{\rho}\frac{\partial(h\tau_{yx})}{\partial x}+\frac{1}{\rho}\frac{\partial(h\tau_{yy})}{\partial y}+\frac{\tau_{by}}{\rho}+F_{Sy}=0$$

h (depth), t (time), q_x, q_y (unit discharge in x and y), z (bed elevation), ρ (fluid density), g (acceleration due to gravity), τ_{xx} etc (turbulent stresses), τ_{bx}, τ_{by} (bed shear stresses), F_{Sx} and F_{Sy} (secondary flow terms).

Total sand transport is modelled using the Engelund-Hanson relation. The direction of sediment transport is adjusted to account for secondary flow and gravity driven transport on lateral side slopes

$$qs=\frac{\alpha(q/h)^5}{C^3d} \qquad qs_{LAT}=\frac{qs\,S_{LAT}\,K\,\delta}{9(d/h)^{0.3}(\tau^*)^{0.5}}$$

qs (total sand transport), α, K (empirical constants), C (Chezy roughness), d (median grain size), τ^* (dimensionless bed shear stress), S_{LAT} (lateral bed slope), δ (sand fraction transported as bedload)

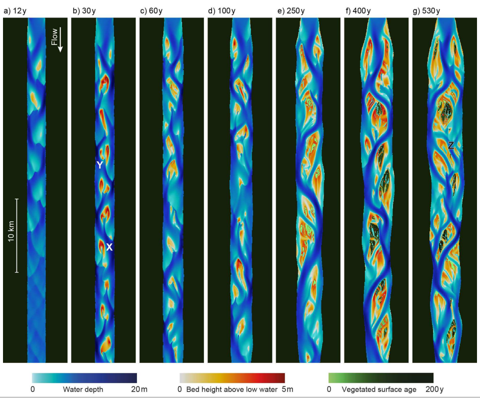
Transport, erosion and deposition of cohesive sediment is modelled using a depth averaged advection-diffusion equation:

$$\frac{\partial(Sh)}{\partial t}+\frac{\partial(q_xS)}{\partial x}+\frac{\partial(q_yS)}{\partial y}-\frac{\partial}{\partial x}\left(\varepsilon h\frac{\partial S}{\partial x}\right)-\frac{\partial}{\partial y}\left(\varepsilon h\frac{\partial S}{\partial y}\right)+D-B=0$$

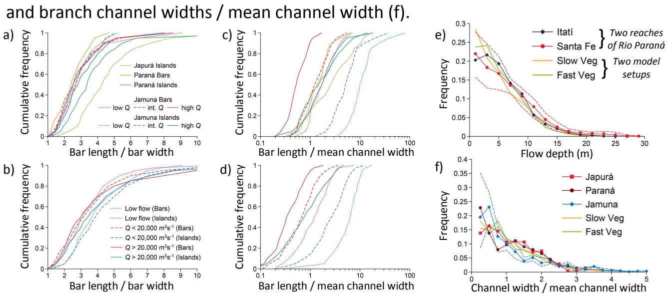
S (cohesive sediment concentration), ε (diffusivity), D (net deposition rate on bed), B (bank erosion rate)

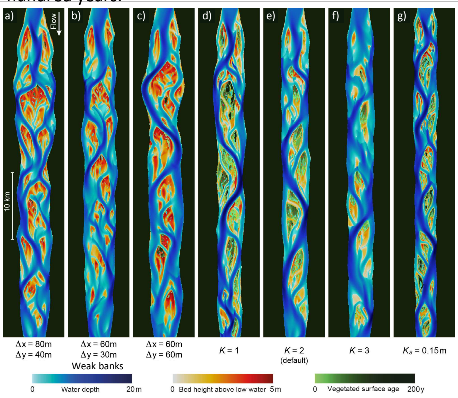
The model also includes simple parameterisations of bank erosion and floodplain construction by vegetation colonization. Morphological change is accelerated by a constant factor (M) to allow simulation of centennial timescales, using the approach of Lesser *et al.* (2004) *Coastal Engineering*, vol 51.

MODEL SIMULATIONS: Initial conditions consist of a straight channel 2.4 km wide by 50 km long with a constant slope (5 cm km^{-1}) and random bed elevation perturbations. Inflow discharge varies between 10,000 and 30,000 cumecs. Inlet bed topography consists of an oscillating transverse slope. Sand diameter is 0.4 mm. Channel evolution is initiated by unit bar development near the inlet and downstream propagation. Compound bars grow by lateral and bar head accretion. This promotes vegetation colonization and creates stable islands with life-spans of several hundred years.



MODEL EVALUATION: Distributions of bar length / bar width and bar length / mean branch channel width for natural rivers (a and c) and model simulations (b and d). Bars and islands are distinguished by the absence (bars) or presence (islands) of vegetation. Plots (e and f) show modelled and observed distributions of flow depth (e) and branch channel widths / mean channel width (f).





MODEL SENSITIVITY: Simulations were conducted to examine model sensitivity to key parameters and boundary conditions:

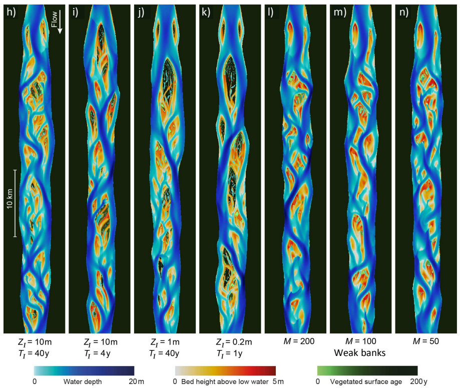
a)-c): Morphology after 250 years for 3 simulations with weak banks and contrasting model grid resolutions.

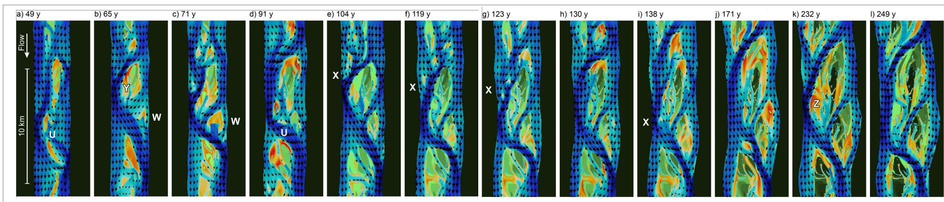
d)-f): Morphology after 320 years for 3 simulations with strong banks and different rates of lateral sediment transport (proportional to K). High K values promote smaller bars and greater channel branching.

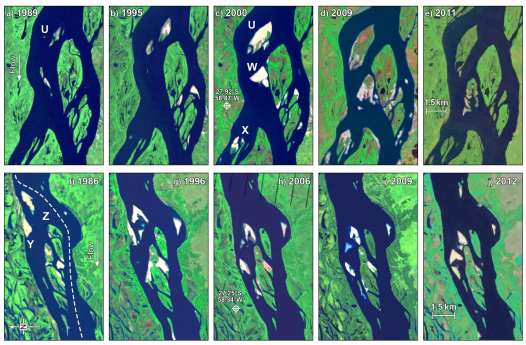
g): Morphology after 320 years for a simulation with depth-dependent roughness (compare to panel **e**, in which Chezy is constant). Variable Chezy promotes deeper scours, smaller bars and greater branching.

h)-k): Morphology after 530 years for 4 simulations with varying inlet boundary conditions (Z_I: amplitude; T_I: period of inlet bed oscillation). Weak inlet bed oscillations promote channel stability near the inlet.

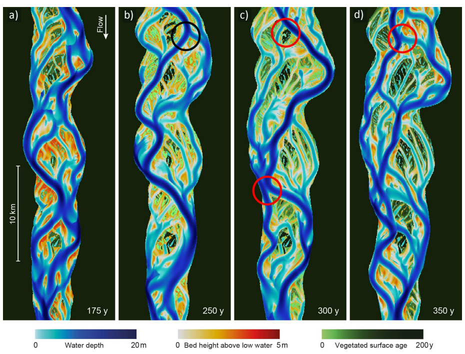
l)-n): Morphology after 150 years for 3 simulations with weak banks and contrasting values of the morphological acceleration factor (M). Simulations are statistically similar and evolve at the same rate.



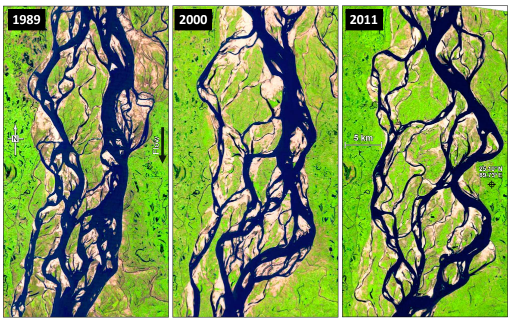




CHANNEL MORPHODYNAMICS: Simulated channel evolution (*above*) involves sand bar initiation on unit bar crests (U). Flow expansions promote bar growth (W), which is suppressed in zones of deep/fast flow (X). Islands (e.g., Y) develop by multiple phases of accretion, vegetation colonization, streamlining by lateral erosion and dissection at high flow (Z). Similar mechanisms and rates of bar and island development are evident on the Rio Paraná, Argentina (*right*). Bar growth and stabilization occurs over periods of 10-20 years (U and X). Bars form in flow expansions (W) and zones of shallow flow (Z) outside the thalweg (dashed line). Early stage compound bars are v-shaped and migrate at c. 150 m yr^{-1}



NETWORK DYNAMICS: Simulations with steeper slopes (10 cm km^{-1}) lead to higher shear stresses, which reduce the ratio of lateral to downstream sand transport. This promotes vertical bar growth, topographic forcing of flow, periodic abandonment (black circle) and reactivation (red circles) of bifurcations, and changes in the degree of channel branching. Similar behaviour is evident in the Jamuna River, Bangladesh (left), where channels also switch from more braided to sinuous states over time. Model results and field observations suggest a possible relationship between channel dynamics and mode of sediment transport (bedload vs suspension).



ONGOING WORK: Model assessment in the Jamuna and Parana is ongoing, and includes the simulation of bar and island sedimentology. Further model development focuses on the evaluation of a non-equilibrium sediment transport model and improved treatment of bedform roughness.