Investigating morphodynamics of bars in single and multi-thread channels using numerical model

(Preliminary results of investigation on effects of irregular banks on the bar properties of single thread channels)

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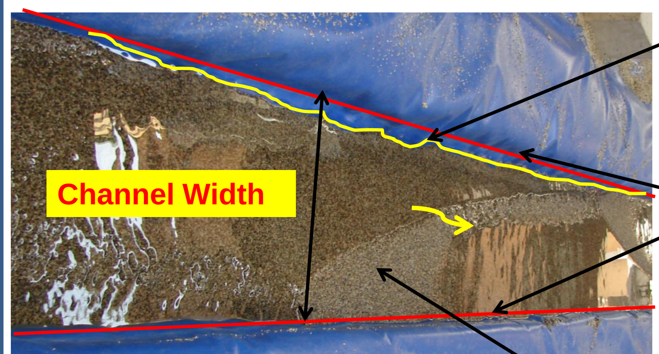
INTRODUCTION

Physics-based numerical models potentially provide a powerful tool to support the investigation of the temporal evolution of bars in a single (e.g. Defina, 2003) and multi-thread channels (e.g. Schuurman et. al, 2013) in a controlled manner. Although models include a simplified description of the complex physical processes, they provide the flexibility to investigate morphodynamics under variable forcing and initial conditions. In this contribution, we present the effects of small bank irregularities on the properties of alternate bars using two 2D numerical models, one semi coupled and another fully coupled. Model parameters are derived from flume experiments carried out at the University of Trento.



Fume experiment showing irregular banks

Details of the experiment:

Width	= 0.40 m
Initial Slope	= 1% (0.01)
Discharge	= 2 l/s
Avg. W/D ratio	= 27
Avg. Froude No.	= 1.14
Sediment type	= Uniform sand
Sediment diameter	= 1 mm
Avg Sed. Discharge	= 3.57 g/s

MODELING APPROACH

In the first approach we used a well validated and robust semi-coupled model, based on the DELFT3D code designed for small Froude numbers (<0.8). Since flow in the experiments is supercritical (Fr ≈ 1.4), a fully coupled model (GIAMT2D), which can handle supercritical flows (Fr>1) is also used to verify the results of semi coupled model.

Model Characteristics	DELFT3D	GIAMT2D
Numerical Scheme	Finite deference, Semi Implicit	Finite Volume, Implicit
Order of Numerical Scheme	First order	First order
Hydrodynamics & Morphodynamics Coupling	Semi coupled	Fully Coupled
Mesh	Structured Curvilinear	Unstructured triangular
Roughness formulation	Manning	Manning
Spiral flow effect	Yes	No
2D-Turbulence	Constant Eddy Viscosity	Not Available
Sediment Transport	Meyer-Peter-Muller like	Meyer-Peter-Muller like
Transverse bed slope effects in bed load transport	Ikeda (1982)	Ikeda (1982)
Wetting and drying	Yes	Yes

We investigated two different cases:

i) Straight smooth banks ii) Irregular banks

Model Parameters	DELFT 3D	GIAMT2D
Size of domain (L x B)	35 m x 0.4 m	75 m x 0.4 m (L x B)
Grid size (Long. X Lat)	0.05 m x 0.02 m	Triangle size varies
No. of cells in lateral dir.	20	10
Slope	0.01	
Roughness (Manning)	0.014	
Initial condition	Flat bed with random perturbations	
Sediment size	1 mm	
Sed Trans alpha	8	
Ikeda Parameter	0.108	

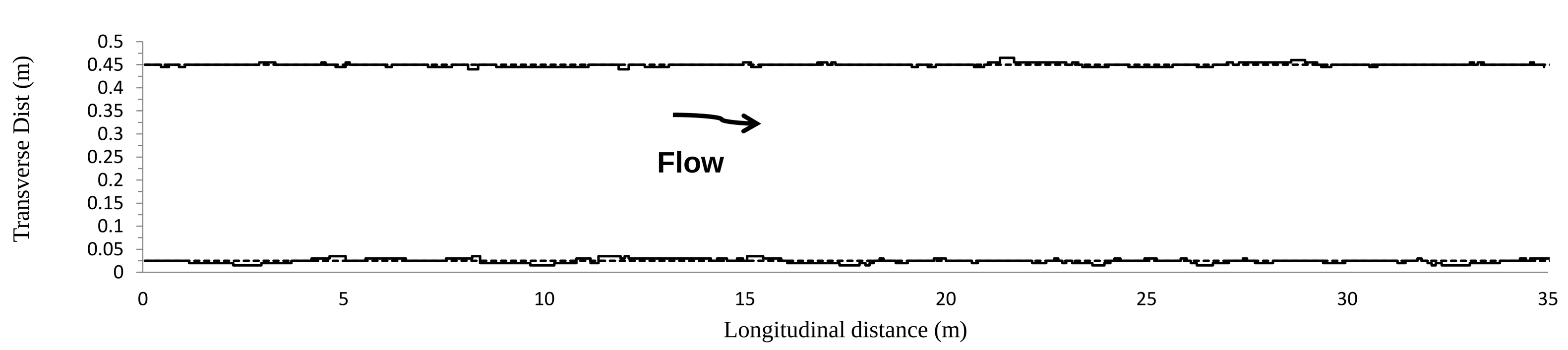
Sediment transport formula:
Modified Meyer-Peter-Muller type formula

$$Qs = \alpha d_s \sqrt{\Delta g d_s}(\theta - 0.047)^{1.6}$$

- Qs = Sediment transport ($m^3/s/m$)
- ds = Sediment size (m)
- Δ = 1.65
- g = 9.81 m/s2
- Θ = Shields stress

Coefficient α is calibrated based upon the observed sediment transport

After implementing the bank irregularity, the average width of the channel increased by 6.25%. The highest amplitude of the bank irregularity is 1cm on right bank and 1.5 cm on left bank.

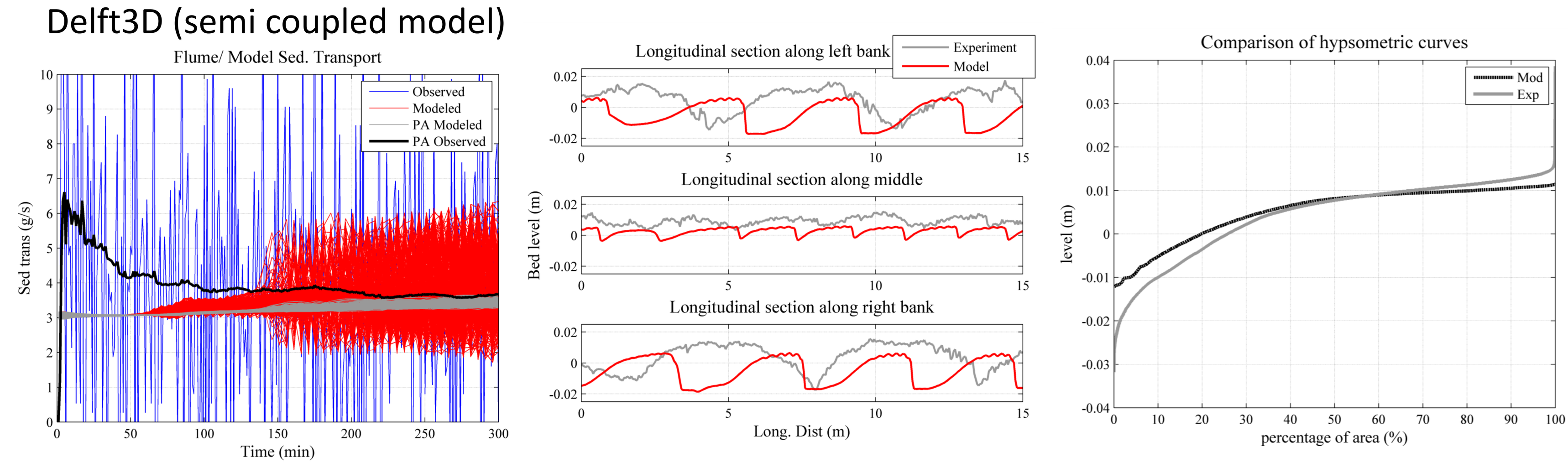


Irregular banks in the flume experiment

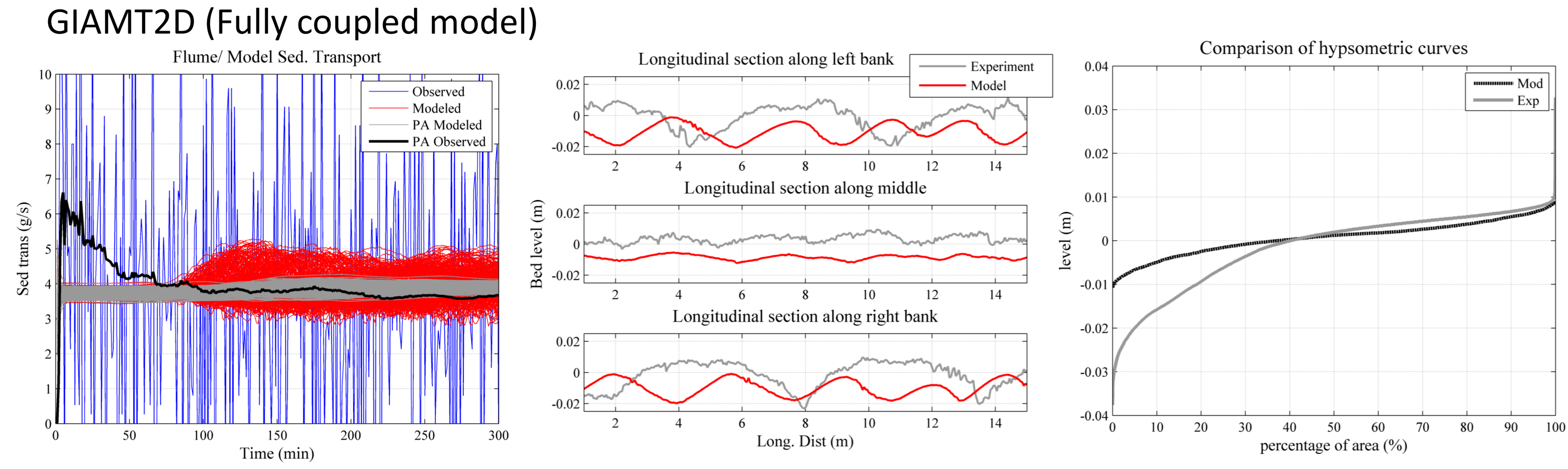
RESULTS

1) Straight smooth banks

Delft3D (semi coupled model)

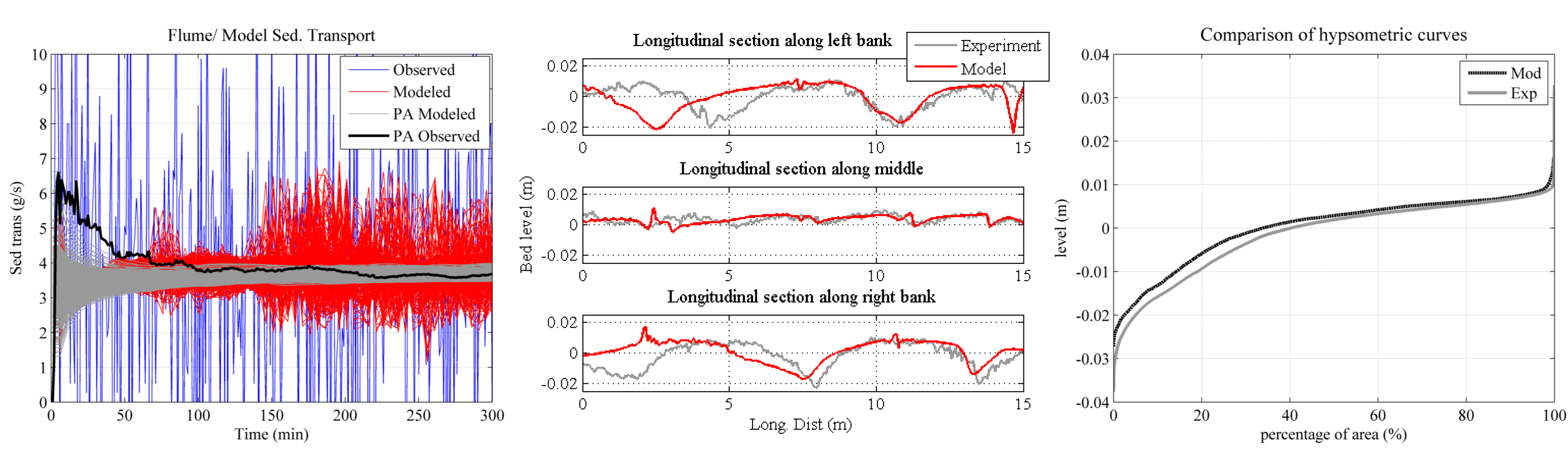


GIAMT2D (Fully coupled model)

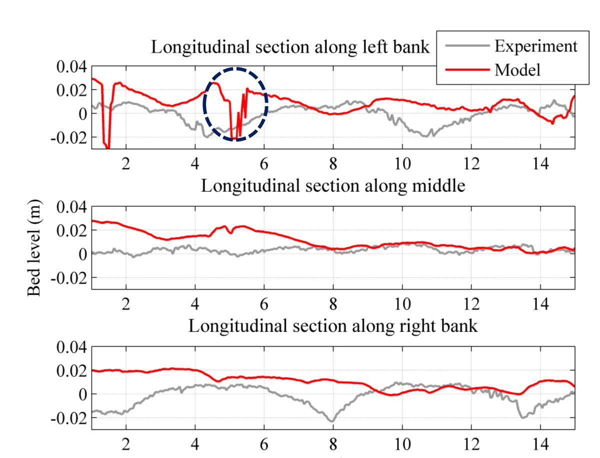


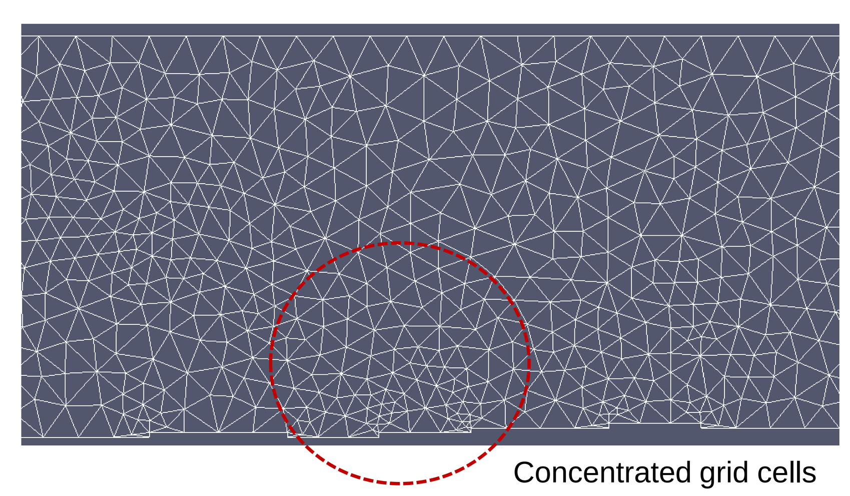
2) Irregular banks

Delft3D (Semi coupled model)



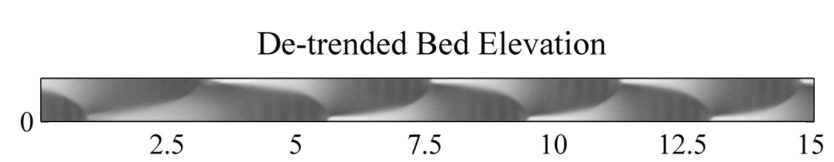
GIAMT2D (Fully coupled model)



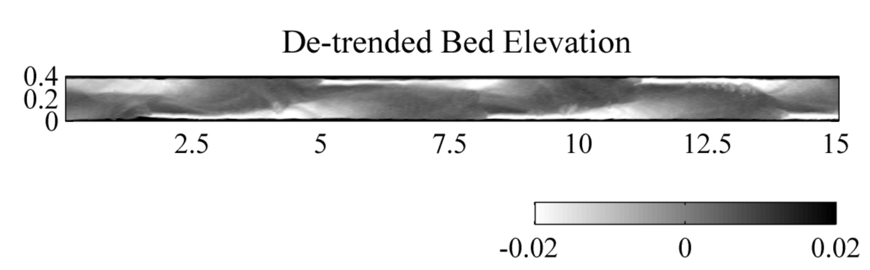


Unstructured mesh used in GIAMT2D

Detrended bed topography (Semi coupled model)



Straight smooth bank case



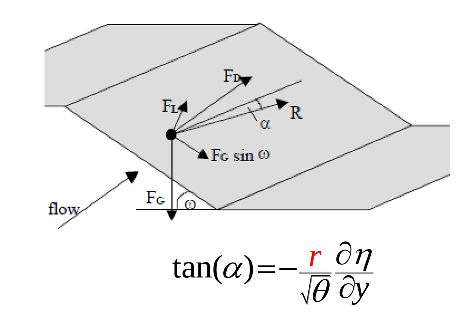
Flume experiment

Irregular bank case

OBSERVATIONS AND DISCUSSIONS

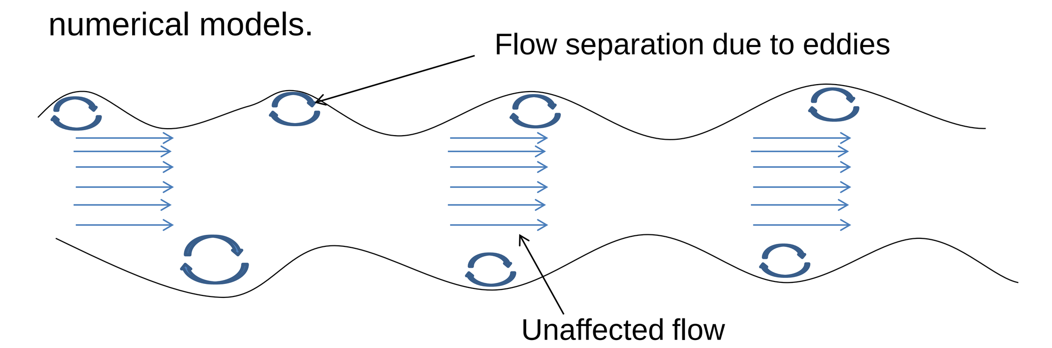
1. Bar properties
   a) The temporal evolution of bars was not measured in experiments. The evolution of bars observed in the model are in agreement with literature (e.g. Defina, 2003, Lanzoni, 2000).
   b) In the straight smooth bank case, Delft3D bars migrate at higher speed than GIAMT2D bars. This might be due to the imposed discharge perturbation at the upstream boundary in addition to the initial bed perturbation in Delft3D. Both models produce bars with wavelengths between 3 to 5 m, which are shorter than the ones observed in the flume experiments.
   c) In the irregular bank case, computed bar wavelengths fell between 6 to 8 m, which closely resembles the wavelength of the bars observed in the flume experiment. The wavelengths of these bars are in the range of non-migrating bars: 10 to 15 times the channel width.

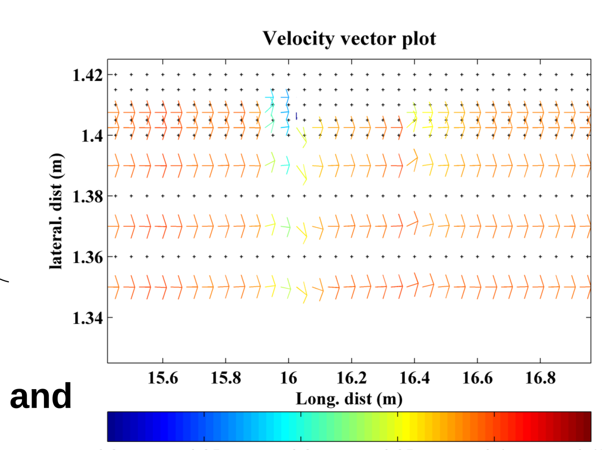
2. Modeling issues:
   a) The coefficient α in sediment transport formula was adjusted to reproduce the average sediment transport rate observed in the flume experiments. The value of **α = 7** predicted the closest sediment transport rate in the straight smooth bank case; the value of **α = 8** gave the best results for the irregular bank case. The small difference might be due to the overestimation of the effects of bank irregularities on flow field.
   b) The coefficient weighing the transverse bed slope effect on bed load direction (Ikeda ,1982) was adjusted to reproduce the observed height and length. The value resulting from calibration is much smaller than what is recommended in the Literature (e.g. Colombini et. al, 1987). This might be due the presence of numerical smoothing/ diffusion.



$$\tan(\alpha) = -\frac{r}{\sqrt{\theta}}\frac{\partial \eta}{\partial y}$$

   c) The local deepening of the channel bed for irregular bank case in GIAMT2D model is due to the local concentration of grid points near to the sharp (stepped) bank irregularities. The grids cells representing irregularities are very small and greatly reduces the computational time step (due to the Courant Number restrictions). Implementing smoother bank irregularities will improve bed prediction and time step restriction.
   d) Both the semi coupled and the fully coupled models show that bank irregularities accelerate the development of non migrating bars. The significance of the amplitude of bank irregularities that affect properties of bars still needs to be investigated.
   e) Models used in this study do not include the eddies, smaller than the grid size, that form at the bank irregularities. In real cases, these eddies cause flow separation which results in a smoother flow, less affected by small bank perturbations. So, flume experiment on similar setup using straight banks can verify results of the numerical models.





Flow velocity near banks with small irregularities in real cases and in the numerical model

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