Exploring river-wave dominated delta evolution applying a model-coupling approach

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COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

Objective

Couple a fluvial discharge model (Hydrotrend) and a coastal evolution model (CEM) to explore how the climate changes and wave activities influence the delta morphology and evolution.

Case Study: Ebro Delta

The Ebro delta in Spain is chosen as the case study for the 3 reasons: 1) it is a river-wave dominated delta with a distinct wing-like shape 2) its historical land use and climate data availability. 3) The mechanism for the formation of special shape is relatively unknown.

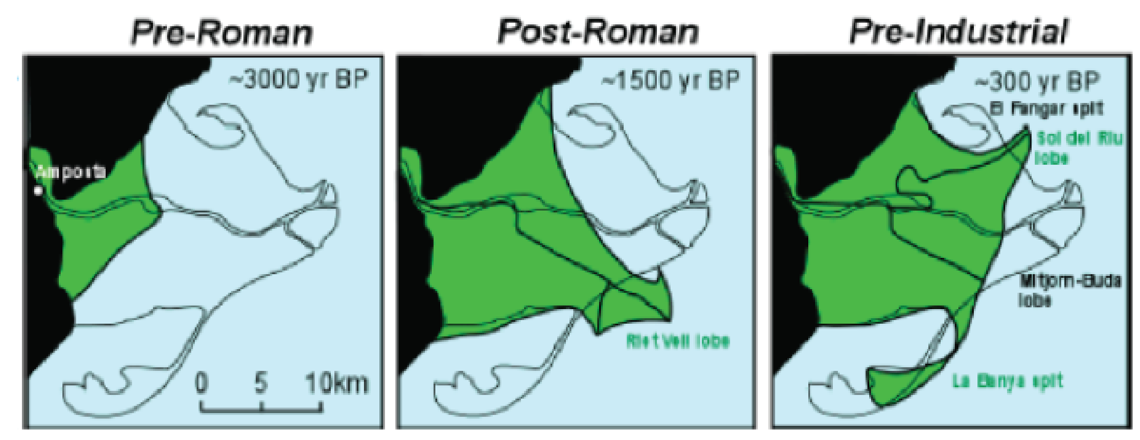

Figure 1: Sketch of the Ebro delta evolution (after Canicio & Ibanez, 1999). The current shoreline of the delta is indicated by the black continuous line.

Methodology

The CSDMS Component Modeling Tool (CMT) is an application that provides a plug-and-play environment within which users couple and run model components (Peckham and Hutton, 2011). The user connects components to one another, to control inter-model data transmission, and sets model input and output parameters (figure 2). With a complete set of linked components, the user is able to submit the simulation to a remote server.

The applied model HydroTrend is a climate driven hydrological transport model, which simulates daily water and sediment load at the river mouth (Kettner and Syvitski, 2008). Subsequently the coast line evolution model (CEM), a one-contour line model that focus on sandy, wave-dominated shoreline evolution, simulates the plan-view evolution of a coastline due to alongshore sediment transport (Ashton and Murray, 2006a,b), is used to analyze the effect of riverine sediment flux on the morphology of the Ebro Delta. The two models are coupled together within the CMT tool.

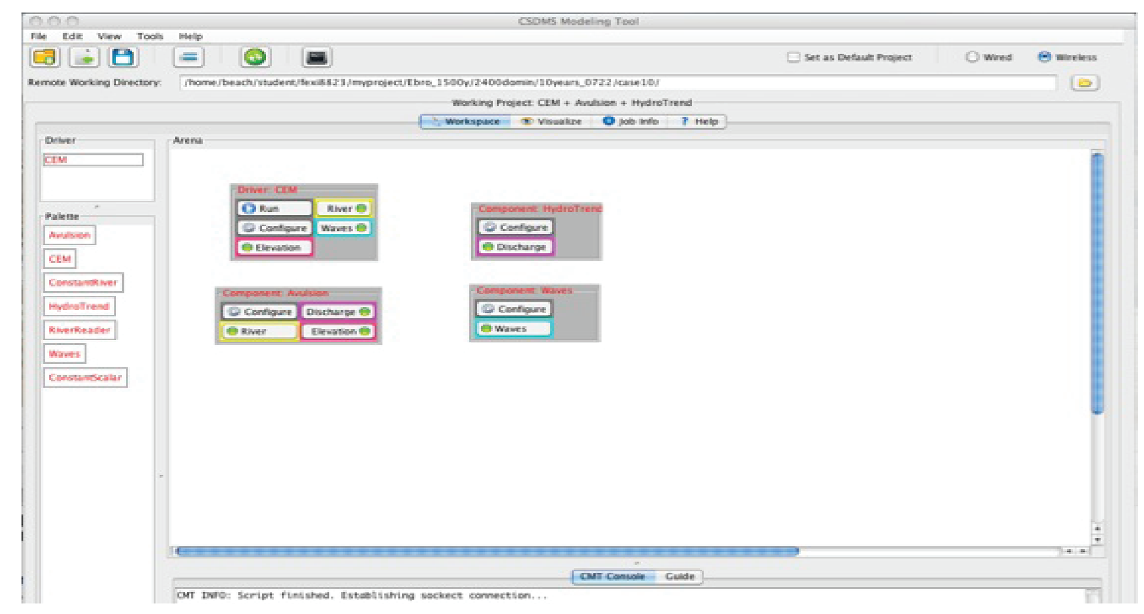

Figure 2. Coupled models (Hydrotrend and CEM) in CMT. Process links are color-coded

Numerical experiments

The role of climate changes on the morphology of delta is mainly explored through variations in sediment load. Numerical experiments are designed to vary the critical parameter bedload. First Hydrotrend is run using the parameters of the Ebro basin, and then the obtained bedload sediment is averaged to indicate stable climate. Two additional experiments change the bedload every 200 years to consider moderate and extreme climate scenarios (Figure 3). For each of the 3 experiments, increases of sediment load by 160% and 220% in magnitude are deployed separately, to demonstrate increased sediment load on delta morphology (table 1). Although high, these changes in the experiments are not that extreme, considering that dam construction traps almost all the bedload to the river mouth (99%), and deforestation significantly increases the loads. The simulation time is 1500 years, with constant value for the first 700 years, to achieve a steady state before the prescribed the changes in sediment load.

Increase in climate variability →
Increase in precipitation amount ↓

	Constant flux	Moderate Climate	Extreme climate
Original Sediment input from Hydrotrend	Case 1: 58kg/s	Case 4: 81 kg/s for high sediment load; 35 kg/s for low sediment load	Case 7: 97 kg/s for high sediment load; 18 kg/s for low sediment load
1.6 times	Case 2: 92.8 kg/s	Case 5: 130 kg/s for high, and 56 kg/s for low	Case 8: 156 kg/s for high, and 29 kg/s for low
2.2 times	Case 3: 127.6 kg/s	Case 6: 179 kg/s for high, and 77 kg/s for low	Case 9: 214 kg/s for high, and 40 kg/s for low

Table 1 Numerical setting for the experiments (9 cases)

Results

The results are shown in figure 4 and 5, mainly for the stable and extreme climate cases, the outcome for the moderate climate case is not shown, as it is very similar to the stable case.

Figure 4 shows the final delta morphology of case 1, 2, 3 in A, and case 7, 8, 9 in B. The general pattern indicates delta expansion into the sea increases according to bedload. However, case 9 leads to a distinct pattern comparing all the other 5 cases. A distinct wing-shaped coastline develops, caused by wave angle assymmetry. With the same wave parameters, comparisons demonstrate that the both sediment load and its variability will influence the delta form, while the special shape can appear only when a threshold value is achieved.

Figure 5 describes the temporal changes of delta form for case 3 and case 9, which have the same total sediment flux. It is obvious that when sediment load is constant, the delta form has very little variation with time. Oppositely, much more variation appears when sediment load changes abruptly with time, shown as the spikelike extension on the right side of river mouth. The rapid changes in delta form which begins at 900 years, when sediment load has an abrupt increase from 40 kg/s to 214 kg/s. A wing forms and reaches the maximum at 1100 years, after which the sediment load begins to decrease. Accordingly, wave rearranges the former sediment and change the delta form, demonstrated as the disappearance of the wing.

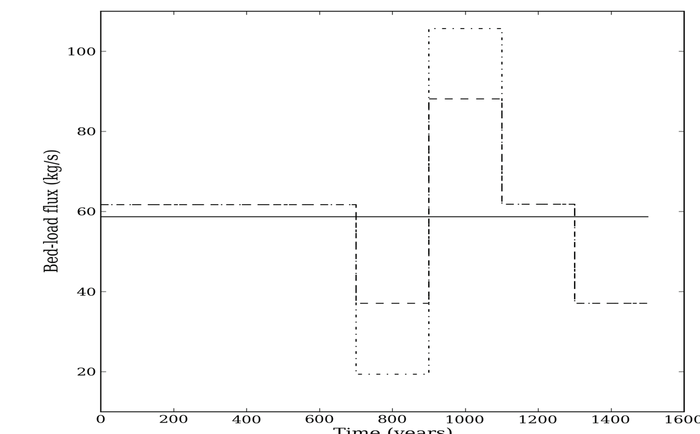

Figure 3. Bedload flux changes in 1500 years for case 1, 4 and 7.

Conclusions

The influence of climate changes on the evolution of a river-wave dominated delta was explored, and the reason for its special form is detected by using numerical experiments. The comparison of simulating result shows that the wings of the delta could form only under two conditions: high sediment load and temporal variation. The wings of the Ebro delta may have formed when sediment load increased abruptly, and may disappear when load declines.

Besides, the simulation indicates that by allowing coupling of models that were developed independently, the CMT provides a framework for discovery—many of the phenomena revealed by the initial modeling have not been previously described.

Future Study

The next step is to combine the reconstructed climate and human influencing factors, mainly including temperature, precipitation, and deforestation, in Hydrotrend to obtain a realistic sediment load for the last 4000 years. The data will be used as input to CEM to simulate the formation of the distinct two wings in Ebro Delta.

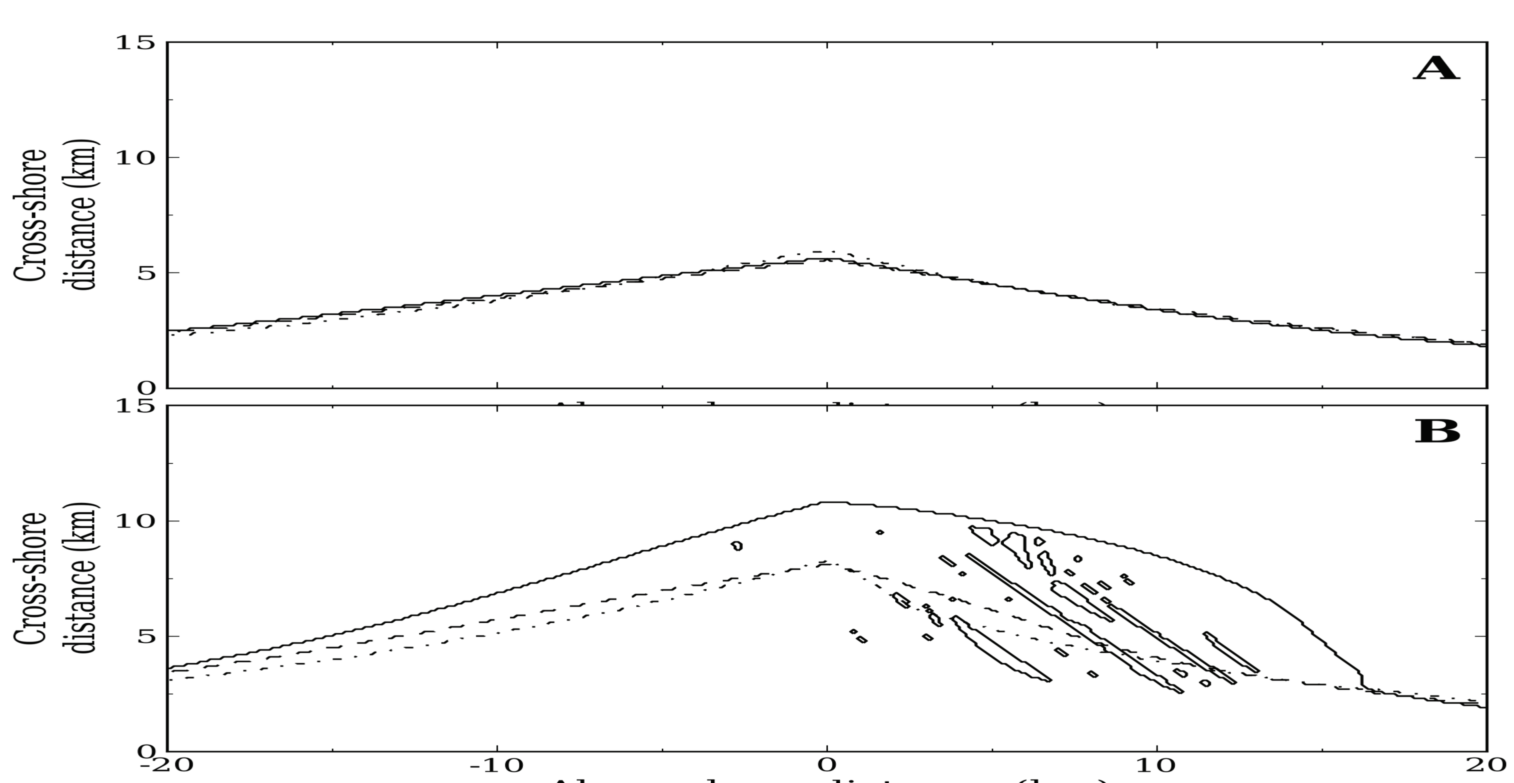

Figure 4 Outcome comparison of case 1, 2, 3 (A) and case 7, 8, 9 (B).

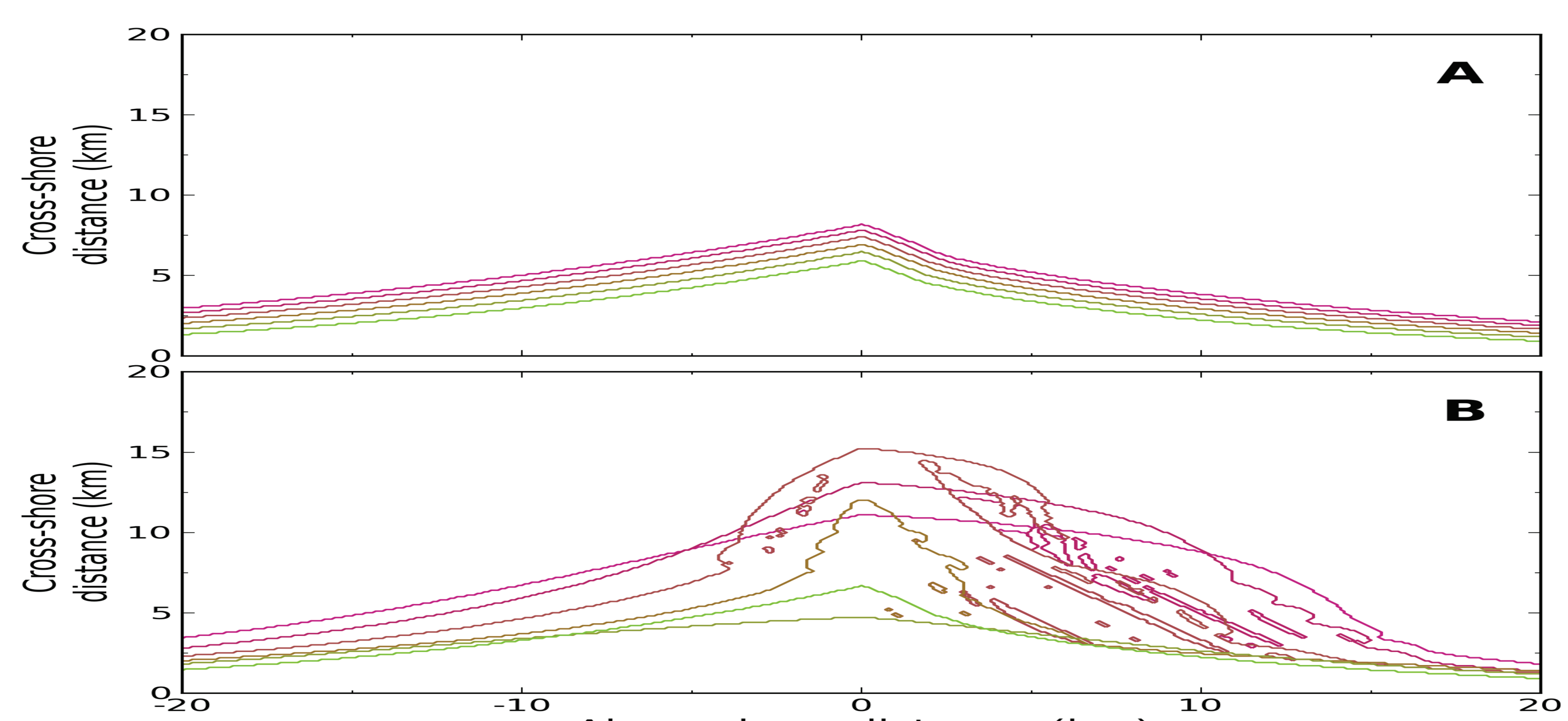

Figure 5 Temporal changes of delta form for case 3 (A) and case 9 (B), begin from the 500th years, with 200 years interval.

Reference

* Ashton A.D. and Murray A.B., 2006A. High-angle instability and emergent shoreline shapes 1. Modeling of sand waves, flying spits and capes. Journal of Geophysical Re- search, 111: F040011.
* Ashton A.D. and Murray A.B., 2006B. High-angle instability and emergent shoreline shapes 2. Wave climate analysis and comparisons to nature. 111: F04012.
* Kettner A.J. and Syvitski J.P.M., 2008. HydroTrend v.3.0: A climate-driven hydrological transport model that simulates discharge and sediment load leaving a river system. Computers & Geosciences, 34: 1170~1183.

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