Earth Surf. Dynam. Discuss., 1, C5–C11, 2013
www.earth-surf-dynam-discuss.net/1/C5/2013/

Interactive comment on "Climate, tectonics or morphology: what signals can we see in drainage basin sediment yields?" *by* T. J. Coulthard and M. J. Van de Wiel

T. J. Coulthard and M. J. Van de Wiel

t.coulthard@hull.ac.uk

Received and published: 14 June 2013

Thank you for the comments and suggestions. You raise some technical points for the manuscript and some interesting points for debate.

Firstly - thank you for pointing out some key literature that we have missed out. Some of these references were known to us and omitted for brevity in the introduction, though two or three of them are completely new to us. These can and will be integrated into future revisions of the MS. These additional references are indeed welcome as they are all directly relevant and in many cases agree with our results. Indeed, our findings re-enforce those from Simpson and Castelltort (2012), who conclude that "*marine*

sedimentary basins may record sediment flux cycles resulting from discharge (and ultimately climate) variability, whereas they may be relatively insensitive to pure sediment flux perturbations (such as for example those induced by tectonics)". In addition, Simpson and Castelltort (2012) also comment on the difficulties of inverting the sedimentary record. Our results also support those from Allen and Densmore, (2000) who "*infer that the sedimentary record should record precipitation-induced changes in sediment flux from a catchment more faithfully that those produced by changes in fault variability*". Though in our experiments we focus on the size of the uplift/climatic change required to make a noticeable signal in the sedimentary record rather than on system response or lag times. In previous publications using the CAESAR model (Coulthard and Van De Wiel, 2007) we have simulated catchment/fan systems similar (in concept) to those modelled by Allen and Densmore (2000) and noted how the addition of a fan complex can add a signicant amount of 'noise' or non-linearity to the model output.

Interestingly, there are differences in the methods used between Simpson and Castelltort (2012) and our CAESAR paper that may well warrant further discussion (which also relates to our final discussion point). Their simulations are based upon a reach model, driven by a fluctuating water and sediment input – whereas ours are of an entire drainage basin, where the water inputs are spatially and temporally determined via a hydrological model (for a full description see Coulthard et al., 2002; Van de Wiel et al., 2007) and this also determines sediment inputs. Simpson and Castelltort (2012) have a more sophisticated representation of flow processes with a non-steady flow model as opposed to the steady flow model in CAESAR. We could summarise that CAESAR may have a more comprehensive coverage of the whole catchment, and Simpson and Castelltort (2012)'s model a far better representation of the floodplain.

Studying Simpson and Castelltort (2012)'s results it is also interesting to note that in a previous CAESAR study we divided the valley floor of the Swale catchment up into sections (Coulthard et al., 2005) and established sediment budgets for reaches over a 9000 year simulation. This showed that in wetter periods (increased rainfall magnitudes) there was a dramatic increase in sediment yields and that this was largely sourced from the lower, valley floor sections of the catchment. In short, wetter climates mined out the valley floor of sediment. In many ways these findings mirror those shown by Simpson and Castelltort (2012), where changes in discharge input and sediment storage (reflected in increased valley floor gradients) led to spikes in sediment associated with increased water inputs.

Bearing these points in mind, there is considerable scope to examine more forensically where the increased sediment comes from during increased periods of wetness.

Secondly, we are pleased for the opportunity to discuss shredding (Jerolmack and Paola, 2010) and we would argue that buffering in floodplains is or can be the same as shredding. The wider implication of Jerolmack and Paola's paper (taken both from the paper and discussions with both authors) is that potentially any environmental system that stores and releases has the capacity to shred input signals. In their paper this was a rice pile - where storage, and (non-linear) release of rice led to the removal or shredding of the input system. Firstly, this storage and release is effectively buffering. Secondly, we would also argue that a floodplain operates in a similar manner to the rice pile - it stores and then releases sediment (in a non-linear way). Other workers have noted non-linear, Self Organised Critical (SOC) mechanisms in operation in floodplains with meandering and cut-offs (Hooke, 2003; Stølum, 1998). Thus, we would argue that for a given flood event the amount of sediment released from the end of a floodplain (bedload not suspended) may be very little or may be a great deal.

Thirdly - is the model response a facet of the model itself or the model representing the physics of the system? CAESAR is deterministic (it has no stochastic components), so it will always give the same predictions from the same starting conditions. Therefore, non-linear sediment output from CAESAR is caused by: i. the use of threshold based sediment transport laws; and ii. the interaction of flow and sediment transport from cell

to cell, i.e. modelling the relationship between flow determining where sediment goes and thus sediment determining where flow goes. CAESAR has a long history of modelling the non-linear reaction of catchments from 1998 through to 2010 (Coulthard and Van De Wiel, 2007; Coulthard et al., 1998, 2005; Van De Wiel and Coulthard, 2010) . Given that such non-linear dynamics have been documented in physical systems (as noted in the previous point, and indeed also in some of the literature you point to in your first comment), we consider the fact that CAESAR can indeed simulate non-linear sediment dynamics a direct asset of the model. Of course, we can never be sure that CAESAR is doing it for the right reasons – no models are perfect representations of reality, so we cannot be certain that this is not all due to internal model machinations. However, there is a long peer reviewed acceptance that CAESAR is simulating the internal dynamics of the river catchments, which we believe should give some credence to the model and the resulting simulations. In addition, we would like to add that CAESAR is certainly not the only model to show non-linear sediment responses. Examples of this include the Lapsus model (Temme and Wiel, 2012), Simpson and Castelltort (2012)'s results, and the Zscape model (Allen and Densmore, 2000). The notion that different models, with very different underlying algorithms produce some sort of non linear response (and in some cases signal shredding), indicates that what we observe is something more fundamental and not model specific.

Fourthly, "The studied timescales are very short (ka), such that a generalization to climate, tectonics and the sedimentary archives is not appropriate." This is quite a provocative statement! We think the best answer is that of course it is appropriate, but it depends upon the length of your archive. For sedimentary records of the Holocene and Quaternary scales, we would argue that the changes we are simulating are very relevant. There are several studies that link increases in Holocene and Quaternary sedimentation rates to short term environmental forcings - even down to individual events. We believe our findings are quite pertinent in that context. Conversely, for records spanning 10's of millions of years our findings may be less relevant and could just be part of the 'noise' of the system. All of this is very contingent upon the depositional setting - and this is something we have deliberately avoided in this paper and we make this clear in the discussion. What is stored in stratigraphy is a product of what is supplied by the catchment and floodplain above (and the shredding/buffering that goes on within it) and the accommodation space and any changes that may occur over time within that.

Finally, process representation: In our paper, we have suggested that CAESAR may be displaying behaviour not seen in other LEM's due to its process representation and parameterisation. Sebastien argued that "*Indeed, CAESAR does not seem to implement the physics of water flow like in models such as DELFT for instance who treat the full dynamics of water flow. If climate matters, through rainfall and stream flow erosion, perhaps water flow should be one of the things to include in a discussion of how it actually does so?*".

As we stated in the paper, CAESAR is steady state - so will not simulate the passage of a flood wave hydrodynamically. This may well have an impact on the model outcomes and this is something that we are presently exploring via a publication that is presently under review in another journal. We are limited to what we can discuss about this (as it is not published yet), but the results suggest that introducing flow hydrodynamics can increase sediment discharges for certain parts of the drainage basin relative to steady state models. However, this appears to have no increase or decrease in the non-linearity of the sediment transport. There is scatter and non-linear behaviour for both flow models. Whilst answering your question, this raises a larger more philosophical question as to what is correct – flow dynamics may make a real difference to the model. By saying this we are suggesting that the additional process representations that are incorporated in CAESAR (in particular the treatment of grainsize and simulation of individual events) are important in producing the sediment dynamics we see here. These process representations are not present (to this level of detail) in many (though not all) existing or often used landscape evolution models.

Allen, P. a. and Densmore, a. L.: Sediment flux from an uplifting fault block, Basin Research, 12(3-4), 367–380, doi:10.1046/j.1365-2117.2000.00135.x, 2000.

Coulthard, T. J., Kirkby, M. J. and Macklin, M. G.: Non-linearity and spatial resolution in a cellular automaton model of a small upland basin, Hydrology and Earth System Sciences, 2(2/3), 257–264, doi:10.5194/hess-2-257-1998, 1998.

Coulthard, T. J., Lewin, J. and Macklin, M. G.: Modelling differential catchment response to environmental change, Geomorphology, 69(1-4), 222–241, doi:10.1016/j.geomorph.2005.01.008, 2005.

Coulthard, T. J., Macklin, M. G. and Kirkby, M. J.: A cellular model of Holocene upland river basin and alluvial fan evolution, Earth Surface Processes and Landforms, 27(3), 269–288, doi:10.1002/esp.318, 2002.

Coulthard, T. J. and Van De Wiel, M. J.: Quantifying fluvial non linearity and finding self organized criticality? Insights from simulations of river basin evolution, Geomorphology, 91(3-4), 216–235, doi:10.1016/j.geomorph.2007.04.011, 2007.

Hooke, J.: River meander behaviour and instability: a framework for analysis, Transactions of the Institute of British Geographers, 238–253, 2003.

Jerolmack, D. J. and Paola, C.: Shredding of environmental signals by sediment transport, Geophysical Research Letters, 37(19), 1–5, doi:10.1029/2010GL044638, 2010.

Simpson, G. and Castelltort, S.: Model shows that rivers transmit high-frequency climate cycles to the sedimentary record, Geology, 40(12), 1131–1134, doi:10.1130/G33451.1, 2012.

Stølum, H.: Planform geometry and dynamics of meandering rivers, Geological Society of America Bulletin, (11), 1485–1498, 1998.

Temme, A. J. A. M. and Wiel, M. J. Van De: Filtering signals?: complexity experiments with LAPSUS, Geophysical Research Abstracts, EGU General Assembly, 14, 5299, 2012.

Van De Wiel, M. J. and Coulthard, T. J.: Self-organized criticality in river basins: Challenging sedimentary records of environmental change, Geology, 38(1), 87–90, doi:10.1130/G30490.1, 2010.

Van de Wiel, M. J., Coulthard, T., Macklin, M. and Lewin, J.: Embedding reach-scale fluvial dynamics within the CAESAR cellular automaton landscape evolution model, Geomorphology, 90, 283–301, doi:10.1016/j.geomorph.2006.10.024, 2007.