**Minimum complexity modelling of an experimental Gilbert-type delta**

(provisionally for GRL)

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Gilbert deltas are sediment packages formed by the discharge of a sediment laden river into a deeper body water such as a marine or lacustrine basin, and are widespread in both the modern environment and the deeper geological record. Gilbert deltas are defined by their very simple internal geometries: a low gradient “topset” surface, across which sediment is dispersed by river-like shallow water transport processes; a much steeper “foreset” surface, which represents grain avalanche processes into the deeper water, and a final very low gradient “bottomset” surface, fringing the delta at the bottom of the water body, and representing the final deposits of any sediment exported beyond the foresets. The stratigraphy of such deltas also reflects this geometry, with the strata within preserving the evidence of past topsets and foresets, now buried within the body of the form – and in principle, these deposits can be used to “read” the stratigraphy to reconstruct past changes in sediment supply to and water level in the basin. However, stochastic processes active Gilbert delta depositional mean that some information about these past changes will often be lost from the record; without knowledge of what is and is not recorded, reconstruction of past changes proves extremely challenging.

In this study, we use a highly simplified numerical model of Gilbert delta evolution in order to investigate the minimum set of model assumptions necessary to accurately simulate the form and stratigraphy of a Gilbert delta. The model, the Low Complexity Delta Evolution Model (LoCoDEM), combines geometric and mass balance approaches to describe the production and destruction of delta stratigraphy as the depositional body grows and shrinks in response to changing sediment supply and water level, and is built to allow the number and complexity of assumptions made about the physical processes important on the delta to be systematically varied between model runs. We compare output from LoCoDEM to output from a simple physical experimental Gilbert-type delta in order to constrain the level of model complexity necessary to statistically mimic the stratigraphy of that delta. By both forward and inverse modelling, we are able to show that in order for the quantity of information stored in the record across various timescales to be statistically correct, we must honour at a minimum both the existence of a defined channel belt on the delta top and the tendency of the channels to only migrate slowly as the delta evolves. Notably, channel compensational behaviour – the tendency of a channel belt to remain at one location on the delta top for a predictable interval before switching to another – is not necessary to reproduce the stratigraphy in such simple deltas, despite this channel switching being observed periodically during the experiment. These results demonstrate that it is possible to successfully simulate simple deltas using models with very few degrees of freedom which are not constrained by direct observation of the delta stratigraphic form as it is preserved in the record – in this case, three (channel belt width, channel migration rate, sediment input flux). On this basis, it is possible to place robust uncertainties on reconstructed sea level curves from such deltas through Bayesian methods.

Introduction

1. Gilbert deltas – history & geometry
2. Previous delta models – context of complexity? Think how to handle Kyle’s stuff. Cite to Mahon 2015 model. What is a stochastic process, and why does it matter?
3. How should be define & talk about stratigraphy in the light of stochasticity? We must rely on statistics. Here we focus on stratigraphic completeness – explain. Refer back to Mahon’s treatment on a delta. The simplification of rollover as paleo-water level, which permits us to think explicitly about sea level records through time.

Methods

1. General approach, justification – RCM
2. LoCoDEM – describe basics of mass balance and geometric approaches. “It’s because we’re crazy to even be considering such a stupidly simple model”. Designed to simulate individual, radial slices through deltaic stratigraphy: appropriate since this is the geometry into which Gilbert deltas are sliced in real field examples, as the channel cheesewires down though the body (e.g., Gulf of Corinth). Also, easy enough to reconstruct from this approach both single column completeness through the delta top, and also distribution of completeness aross the delta as a whole (DO THIS FOR REALSIES) How is this different from the modelling approach in Mahon et al 2015? (i.e., we introduce bass balance)
3. Introduce the “knobs” within LoCoDEM: Radial symmetry -> defined channel belt -> walking channel belt -> compensation. Emphasise distinction between straightforwardly stratigraphically knowable parameters – foreset, topset dips – and free parameters from the point of view of a preserved section through a delta. Latter are our true degrees of freedom. Note sediment flux is always unconstrained, even in our simplest models – we must fit it by forward modelling, or by knowing by independent means. Less degrees of freedom is a priori better, unless the model is unable to describe the results (overfitting). Note that however, these free parameters ARE knowable under ideal field conditions (though only some, e.g., channel dynamics but not sediment fluxes in perfect 3D seismics; sediment fluxes from sediment fining rates in perfect field examples), but better, under lab conditions where everything is constrained; this lets us directly test the model’s skill without worrying about uncertainty in driving parameters. Hence:
4. Describe the experimental setup. Note that key free params are knowable from the runs.
5. Summarise the completeness calc from Mahon et al 2015. Note additional constraints from bulk delta form, especially for total sed flux, but not trivial to invert, especially for a single xsection (or maybe just in the discussion). The importance of sampling interval – though not truly a degree of freedom.

Results

1. The target completeness curves. A restatement of key results from Mahon et al. 2015 for completeness along two topographic transects. Note fairly close agreement. (maybe this is in methods, instead?)
2. FORWARD MODELLING: LoCoDEM running with radial symmetry. We always tune to known S, A during these sections. Show free adjustment later.
3. FORWARD MODELLING: LoCoDEM running with a channel belt. Show both effects of systematically varying the fraction, and also stochastic range with the known value from the tank. Show the width value histogram from the imagery.
4. FORWARD MODELLING: LoCoDEM running with a channel belt with memory & drift. Show effects of drift at two values of channel belt width (“large”, “small”, actual). This is going to be fairly insensitive when F is big, but very sensitive when F is small. Show the calibration of D from real data (NOT YET DONE). Show the simulations with F + D. Good match achieved to exp data.
5. FORWARD MODELLING: LoCoDEM with compensation, C (NOT YET DONE). Show superposed on a subset of the F + D results. Emphasise that in cases except where C big, F medium (?), D small, these are not distinguishable. F would seem to be the one to test a lot to pull the max sensitivity, argued from first principles. Exploit the supp info.
6. INVERSE MODELLING: Assume we know the SL curve. MCMC the data on S, F, D. Maybe iterate on degrading the SL curve on that basis… Demonstrate recovery of known values.

Discussion

1. What is the minimum epistemic complexity necessary for this model? == F + D. We don’t need C. Note this is because of the peculiar conditions for a Gilbert delta: F always moderate to high (poorly channelized), D always medium-high (loose sand); C very low (shallow channels), and so hard to pick apart from D. Suggest this is true of all gilbert deltas. Model could still be useful in a wider context, if we remember to permit C to play a role (c.f., Straub)
2. Hey look, we can recover the variables by an MCMC approach! That’s cool. This means i. we can get at channel processes based only on the stratigraphic architecture (no inferred sedimentology), and ii. (if we’re lucky) S gets constrained (though as a strong function of knowing A properly, probably). Meditate on this. Draw attention to the uncertainties on F, D, even with known S. Matters for…
3. If we know constraints on S, F, D from a section or two, that means we can generalise to describe the whole delta in 3D. Show this happening in principle.
4. If we can pick all of S, F, D based on “known” A, that means we can fit robust uncertainty estimates around that A. Does stuff happening at “unknowable” timescales matter? This would be a fun signal shredding exercise, as well as being a brain twister. “Known unknowns”, and limits on what’s possible – if not knowable – at short timescales. Need to feel out how far we go here.