Simplifying the Ganges-Brahmaputra sediment dispersal system using a coupled model-field approach

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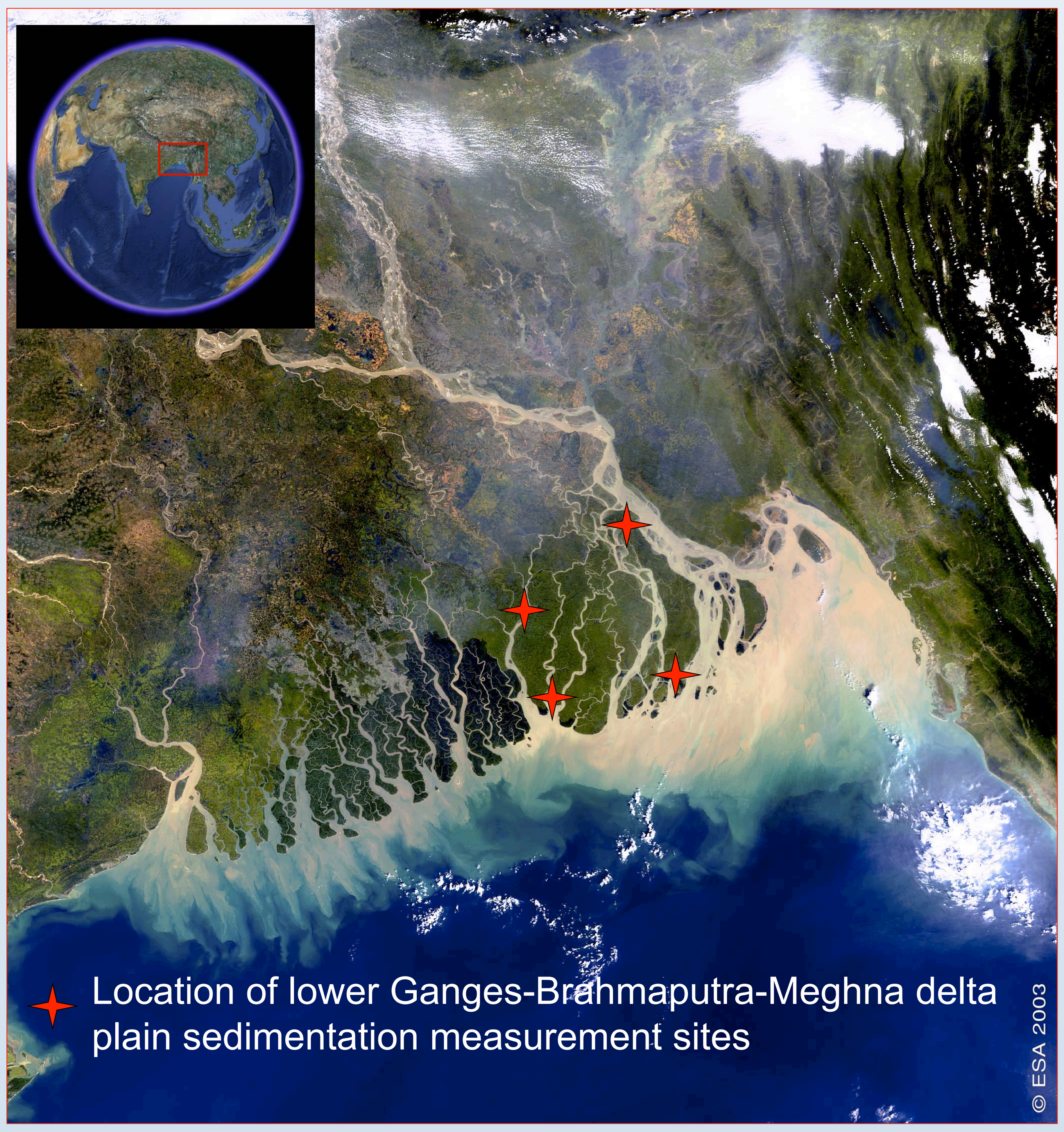
Motivation

The Ganges and Brahmaputra (G-B) Rivers currently transport a combined estimate of one billion tons of sediment from their basins in the Himalaya Mountains to the G-B delta surface in Bangladesh each year during the five months of the Asian summer monsoon. Sediment and water discharge has been reconstructed using observational data from two gauging stations on the rivers from the mid 1950's onward. However, downstream spatial distribution of sediment flux into the deltaic distributary channel network and deposition rates onto the floodplain and lower deltaplain are remarkably unconstrained, yet critical to understanding the overall delta sediment budget. Using coupled simple process models and observational field data, we offer an approach to simplifying the complexities of sediment dispersal in the large, densely populated G-B river delta.

Approach: direct sedimentation measurements + coupled model components

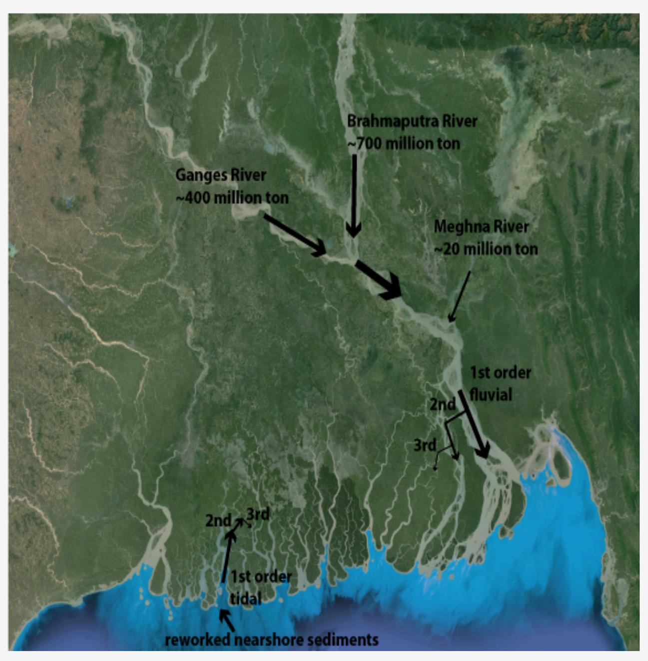
- What are depositional patterns over a single flood season and over ~50 years?
- What are longitudinal trends in sedimentation?
- What can simple numerical models tells us about the lateral distribution of sediment over the delta plain?



Field: Four sites chosen to capture seasonal sedimentation in the fluvial-dominated central delta using sediment traps; sites in a variety of topographic morphologic, and land use settings; river-sourced sediment traced with ^{7}Be ($t_{1/2}$ = 53.3 days). Deployed for a single monsoon season to capture bulk of annual mass accumulation

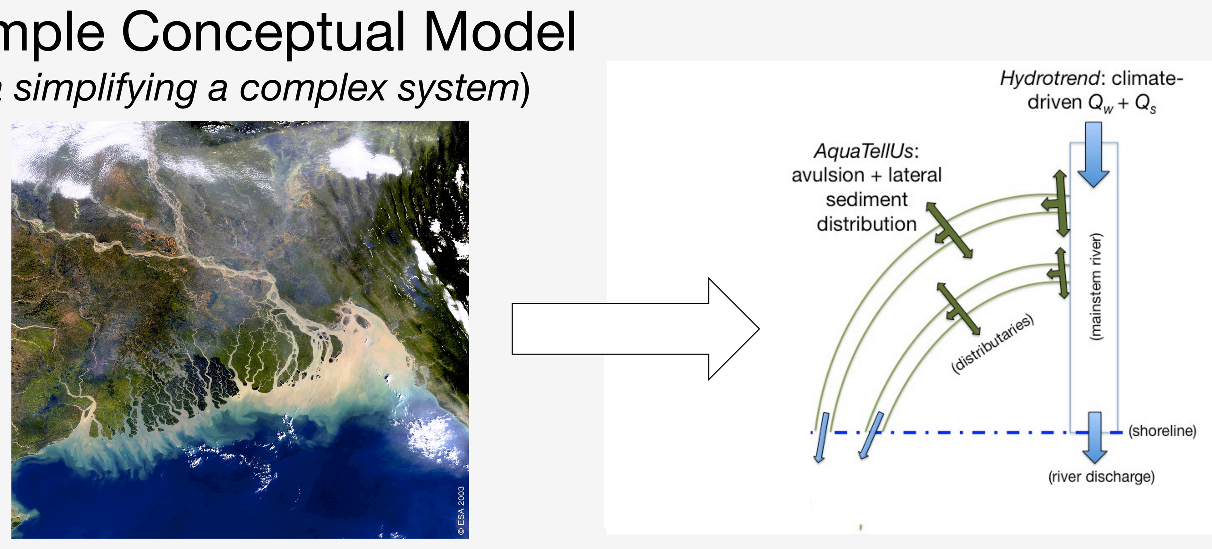
Study Area

1. Bengal Basin: tectonically deformed from continental collision of India into Eurasia
2. Monsoon-driven climate system: 80% of Q_w and 95% of Q_s from May-Sept. Peaks in August.
3. Large sediment discharge: Q_s ~ 992 x 10^6 tons/y
4. Bangladesh: ~1000 people/km^2; lower delta plains/population vulnerable to sediment reduction from upstream dams + sea level rise

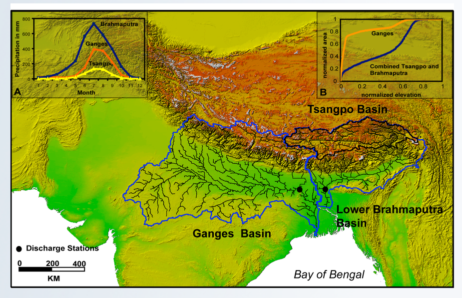


Simple Conceptual Model

(*aka simplifying a complex system*)



HydroTrend: *sediment and water discharge*



- Fully-developed 1D component in the CSDMS Modeling Tool
- Climate-driven hydrological model
- Predicts long-term sediment load as a function of river discharge and drainage area characteristics (relief + spatially-averaged annual T and P)

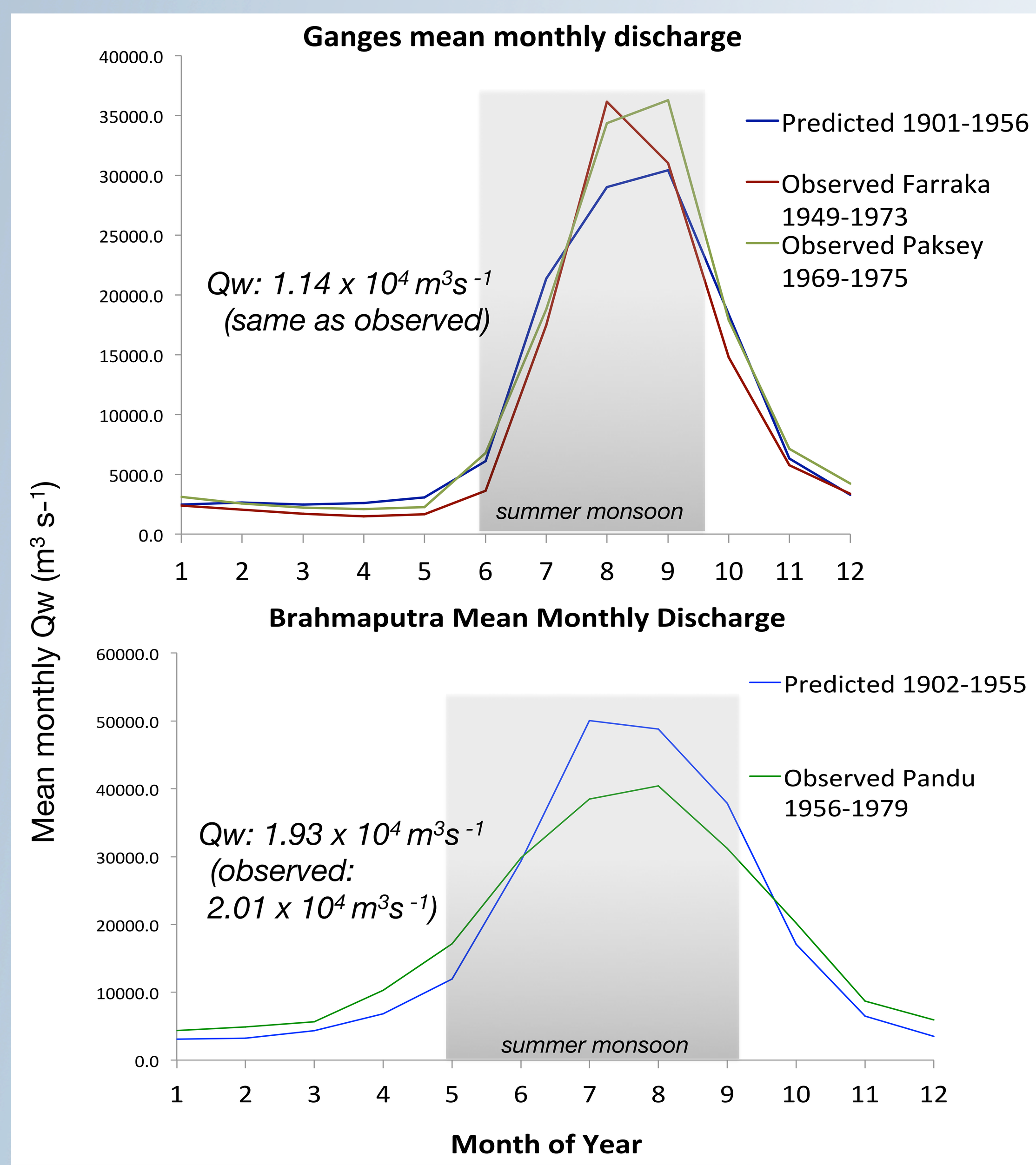
$$Q = Qrain + Qsnow + Qice + Qgw$$

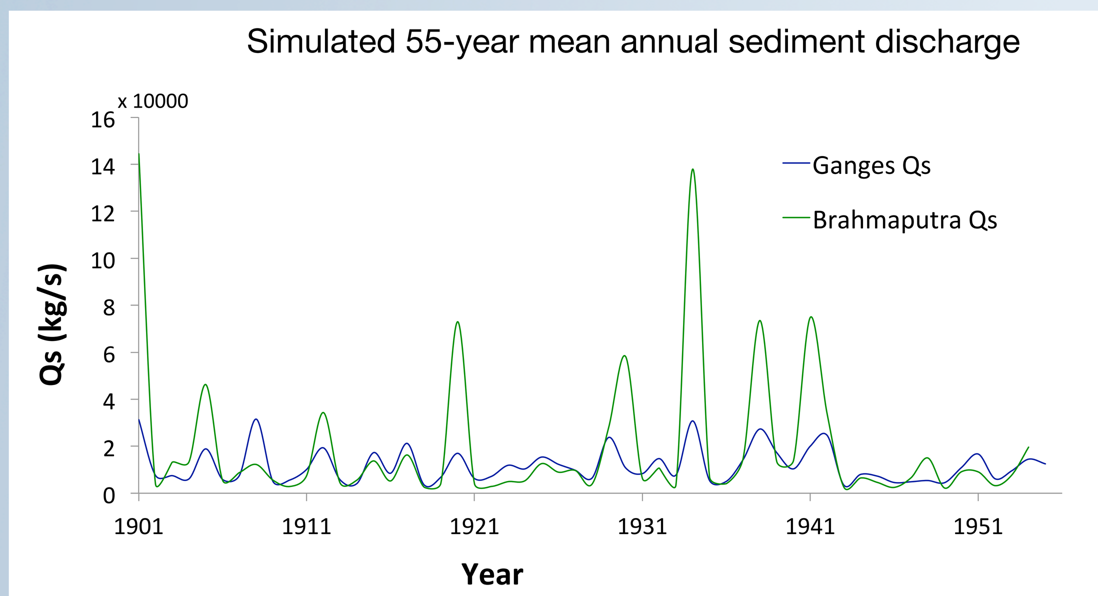
Empirical model for suspended sediment discharge, Qs:

$$Qs = \varpi B \overline{Q}^{0.31} A^{0.5} RT$$

where $B = L(1 - Te)\ E_h$ *Te*, **trapping efficiency by lakes and reservoirs; *R*, relief; *T*, basin-wide temperature**

Results: *predicted compared to gauge data*



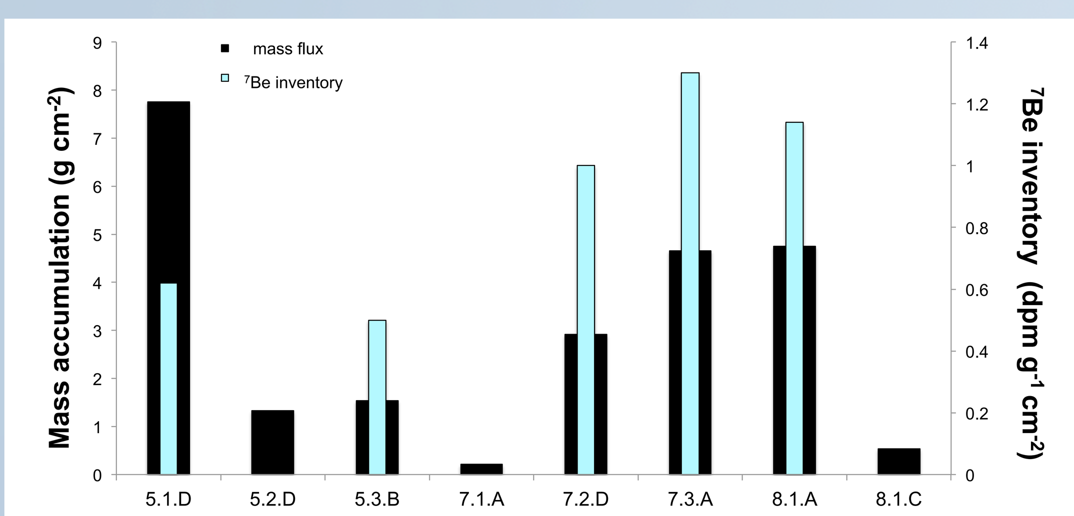


Predicted Ganges = 372 x 106 t yr^{-1} (vs. Coleman, 1969: 479 x 10^6 t yr^{-1})
Predicted Brahmaputra = 611 x 10^6 t yr^{-1} (vs. Coleman, 1969: 608 x 10^6 t yr^{-1})

Field Results: 2012 combined floodpulse sedimentation patterns

Pre-monsoon sediment trap array

Post-monsoon trap recovery



Regional vertical accretion: 2.3±0.9 cm y^{-1}

AquaTellUs: *avulsion and lateral sedimentation*

- Mimics avulsion of a single river over delta plain, calculates river channel belt by steepest-descent approach
- 2D longitudinal profiles embedded as dynamical flowpath in a 3D grid-based space
- Two-step nested approach: sedimentation and erosion fluxes for main channel belt are calculated; sediment is distributed laterally
- Generates levees and builds a channel belt elevated over the adjacent floodplain.
- Multiple grain-size classes are independently tracked

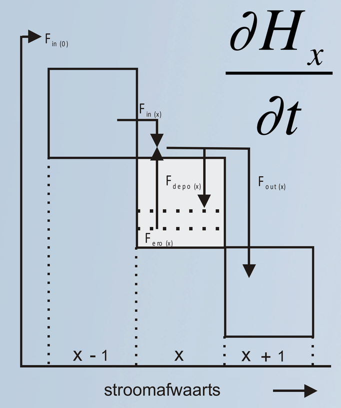
$$\frac{\partial F_{er}}{\partial x} = k_{c(x,t)} S^{m}_{(x,t)} Q(x)_{(t)}$$

Erosion depends on slope (S) and discharge (Q) in fluvial domain, grain size independent

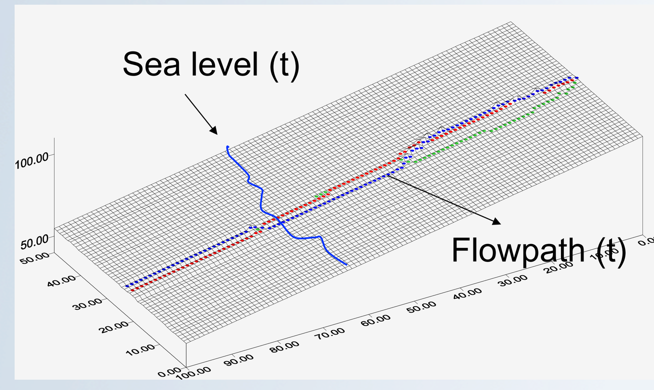
$$\frac{\partial F_{sed\,(x,t)}}{\partial x} = \frac{k_{sed}}{u_{(x,t)}} F_{(x,t)}$$

Sedimentation depends on sediment flux (F) and streampower (u), k_{sed} is grain size dependent.

$$\frac{\partial H_x}{\partial t} = \frac{\partial F}{\partial x}$$



Topography (H) depends on sediment flux (F)

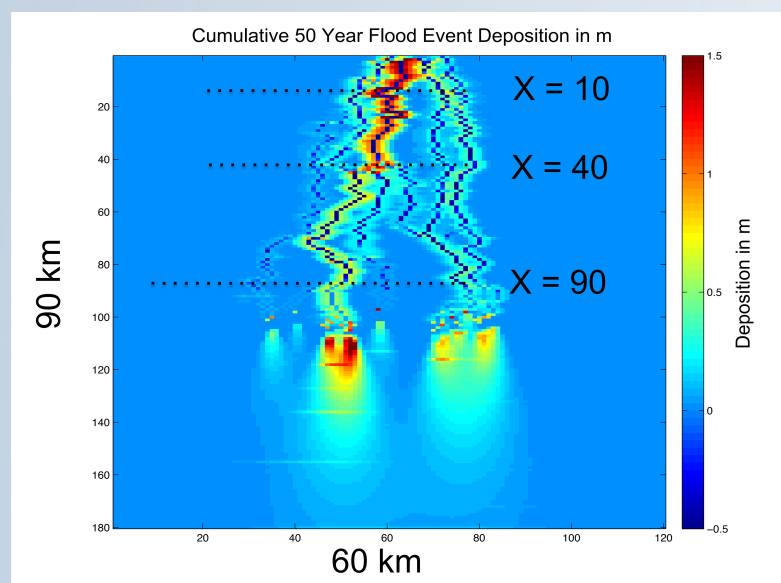


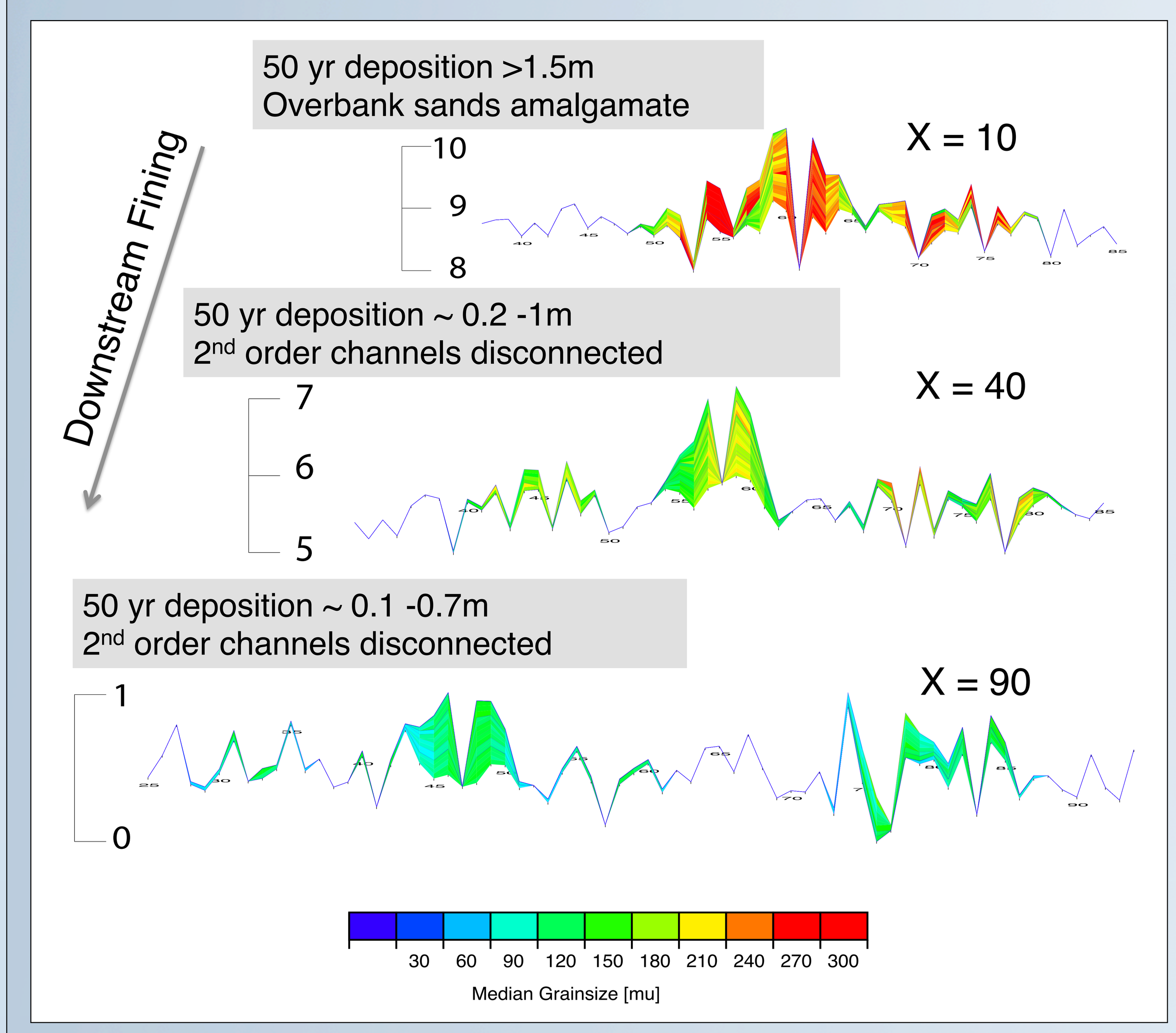
Results:

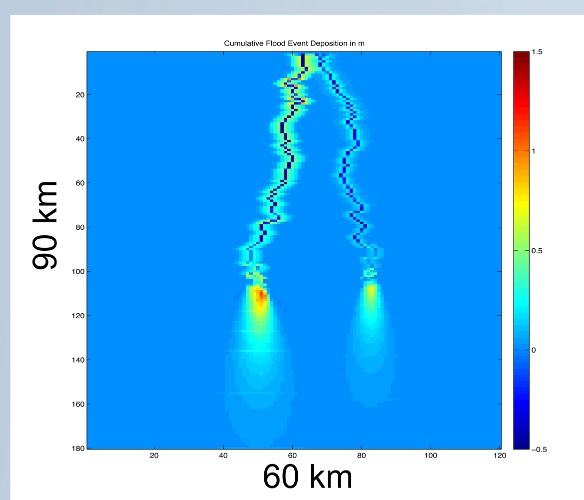
2nd order channels (1-2 km)

1) Lateral sedimentation >2500 m, h ~ 1.5m

2) Rapid sedimentation causes natural avulsions







3rd order channels (500-250m)

Lateral deposition still ~1500m, but finer grain sizes

Connectivity of sediments is lower, due to more stable channel belts

Conclusions and Next Steps:

- Average sedimentation rates in fluvial-dominated part of delta plain are 2.3 cm/yr ; higher sedimentation rates near to channel edges
- Modeled sedimentation has a strong longitudinal grain size trend; highest aggradation and sandiest near 'apex' and again near coastal boundary. Model predicts strong downstream fining; predominantly a consequence of sediment availability. Siltier, lower channel belts occur towards the coastal floodplain
- Model predicts significant interconnectivity of sandy sediments in 2nd-order channel simulations, channels or 3rd order contribute to floodplain but appear more isolated
- In future: design experiments with IPCC projections for 21st century changes in precipitation and temperature, plus greater sediment trapping efficiency of dams planned by India and China; similar experiments including tidal sedimentation model