Modeling floodplain dynamics: Will the Ganges-Brahmaputra Delta survive 21st century sea-level rise?

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Abstract

Deltaic lowlands are vulnerable to both sea-level rise and changes in river discharge, but whether the floodplains and coastal areas will ultimately drown depends on a balance of aggradation, eustatic sea level rise and subsidence. The Ganges-Brahmaputra (G-B) Delta is an example of a densely populated coastal system that could be flooded by rapid sea level rise within the next century. Annual monsoonal river flooding and cyclonic storm surges are the principal mechanisms by which sediment is distributed across the G-B floodplain and coastal plain. In an effort to improve projections of climatic forcing on aggradation rates in the G-B floodplain and lower delta, direct sedimentation measurements are paired with a series of model components coupled within the CSDMS Modeling Tool (CMT). A sediment flux model, a floodplain sedimentation model and a tidal-plain sedimentation model will be linked to explore the response of the G-B river system to a future sea-level rise and changes in river discharge. Model algorithms will be validated by sedimentation data collected in 2008 and 2012 from the tidal delta (The Sundarbans National Reserve mangrove forest) and the highly cultivated fluvial-dominated delta plain. Field data will also be compared to model outputs by constraining the spatial patterns of sedimentation across the delta front.

The Delta Balance

$$\Delta RSL = A - \Delta E - Cn - CA \pm M$$

How will the Ganges-Brahmaputra delta respond to future sea level rise and coastal flooding? To assess such vulnerability one must look at the delta balance. A delta's surface elevation above mean sea level can experience a vertical change relative to local mean sea level, Δ RSL. It is controlled by a summation of 5 factors (typical rates shown) (Syvitski et al., 2009):

Aggradation Rate (A) (1 to 50 mm/y)

Eustatic Sea Level Rate (ΔE) (1.8 to 3 mm/y)

Natural Compaction (Cn), or Accelerated Compaction (CA) (≤3 mm/y)

Vertical movement of the land surface related to earth masses (M) (0 to -5 mm/y)

This study focuses on improving the estimates of the *Aggradation Rate* due to frequent river flooding in the Ganges- Brahmaputra delta (Fig.1)

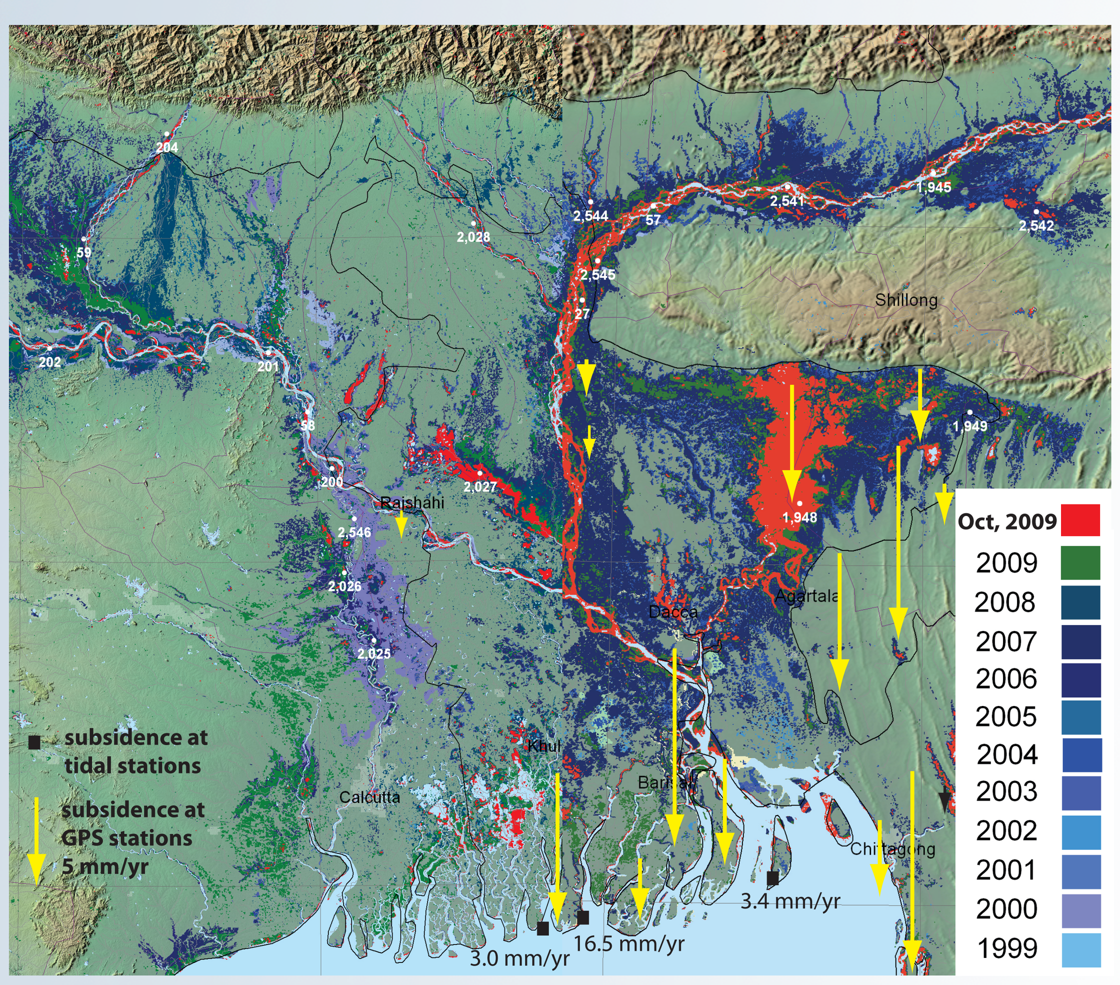
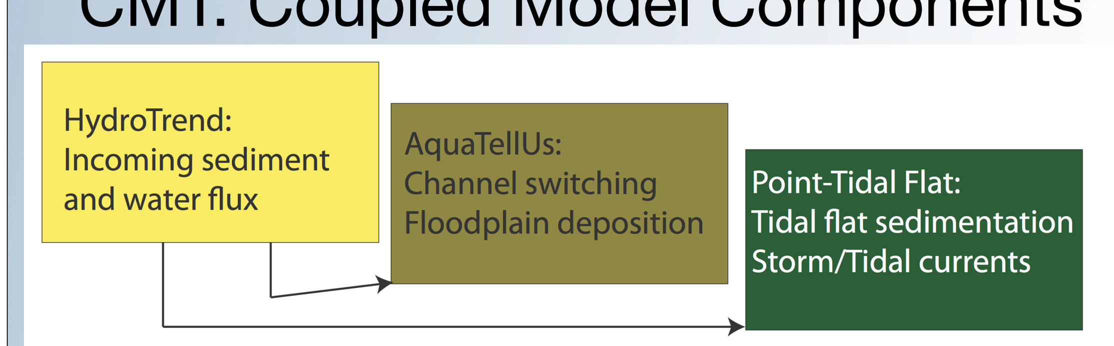


Figure 1. Flood maps constructed from MODIS satellite imagery show ~52,800 km2 of flooded lands in the delta (>100 m a.s.l) between 2000-2009 (flood area data from Flood Observatory, hosted at the CSDMS: http://floodobservatory.colorado.edu/). GPS-based short-term subsidence. Sediment delivery to the G-B delta's surface occurs through overbank flooding of the rivers and tidal reworking.

Approach: direct sedimentation measurements + coupled model components

Field: Eight anchor stations for staging sediment trap deployment: four coastal, four inland; four in the tidal delta plain (2008), four in the fluvial-dominated central delta (2012). Sites chosen to capture seasonal sedimentation in a variety of topographic morphologic, and land use settings; source traced with ^{7}Be ($t_{1/2}$ = 53.3 days). Deployed for a single monsoon season to capture bulk of annual mass accumulation

CMT: Coupled Model Components



Models: A quantitative modeling system using three model components to be coupled within the CSDMS Modeling Tool (CMT) to test climate scenarios. Allows varying of input boundary conditions; rainfall, and subsidence are two examples of conditions that we use observed (and projected) data to drive process-models

Ground Truthing: Seasonal Sedimentation

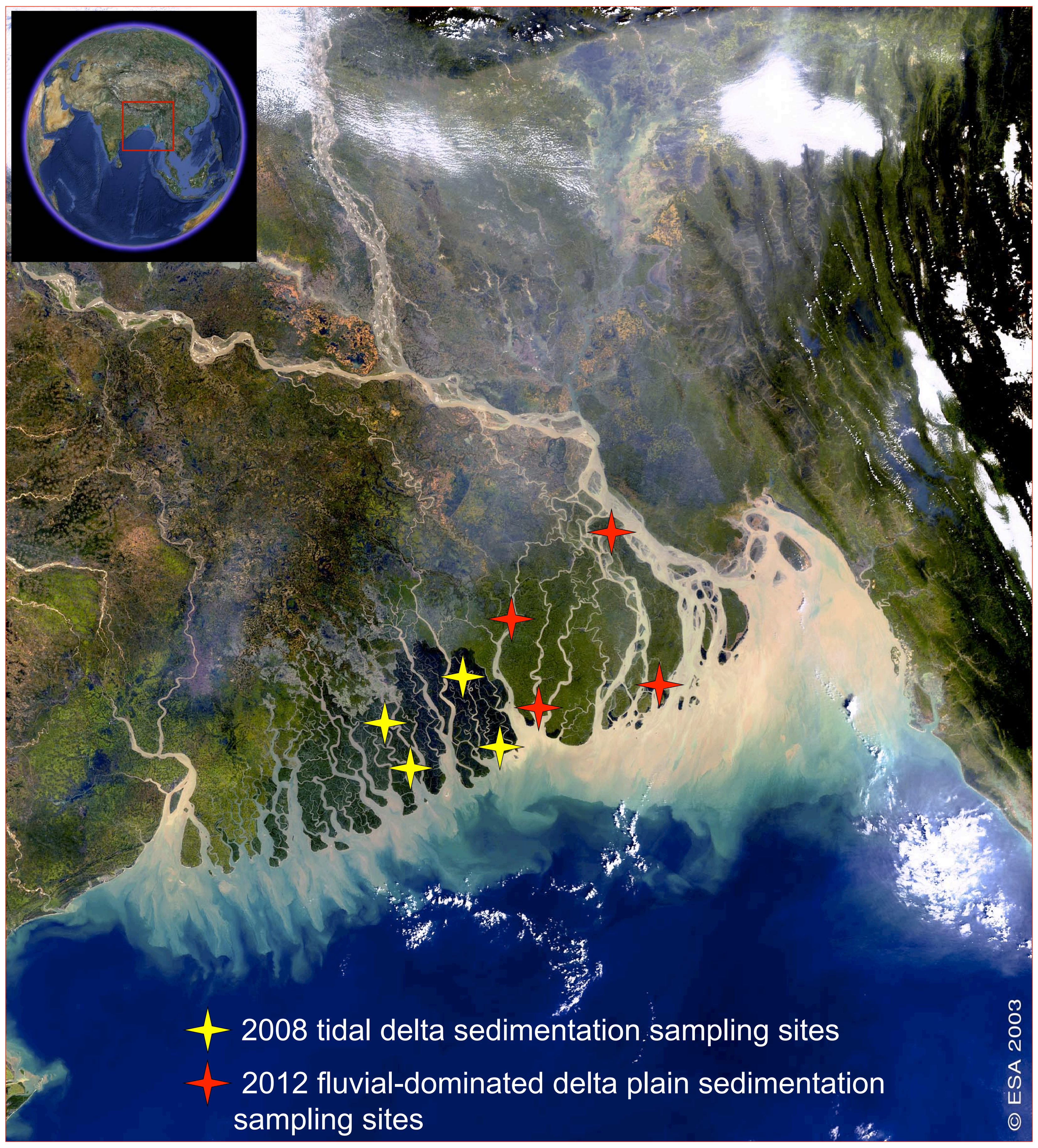
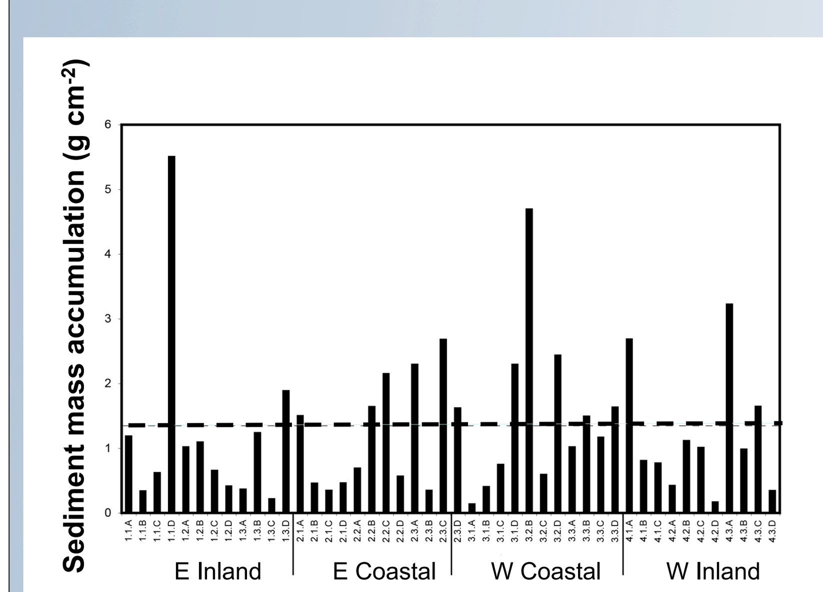


Figure 2. Bengal Basin (G-B Delta) and location of sediment traps. Traps were deployed in the mangroves of the tidal delta (2008) and in a variety of land use settings in the heavily cultivated central delta plain (2012) prior to monsoon flooding and retrieved following cessation of flood waters.

Field Results: Tidal Delta



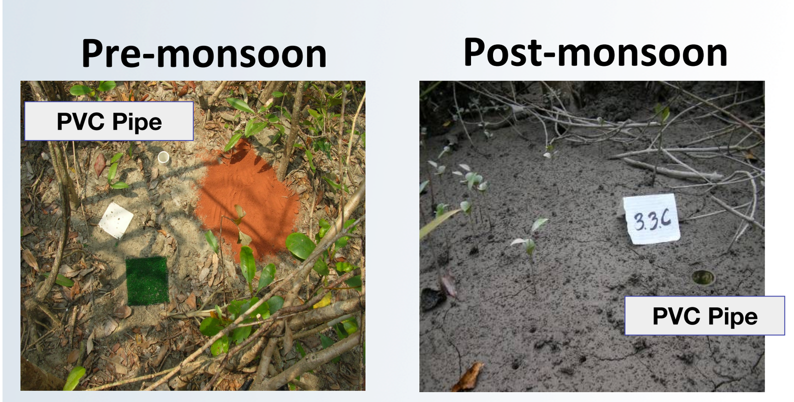


Figure 3. 2008 tidal delta direct sedimentation measurement results: 100% trap recovery; all sites received new sedimentation; overall mass accumulation average: 1.3 ±1.1 g cm^{-2} (dashed line); ^{7}Be results: 63% sourced from monsoon floodpulse; riverine sediment reworked onto tidal plain by 2-4 m tidal range + set up; **regional vertical accretion: 1.1±0.9 cm y^{-1}**

Field Results: Cultivated Fluvial-dominated Delta

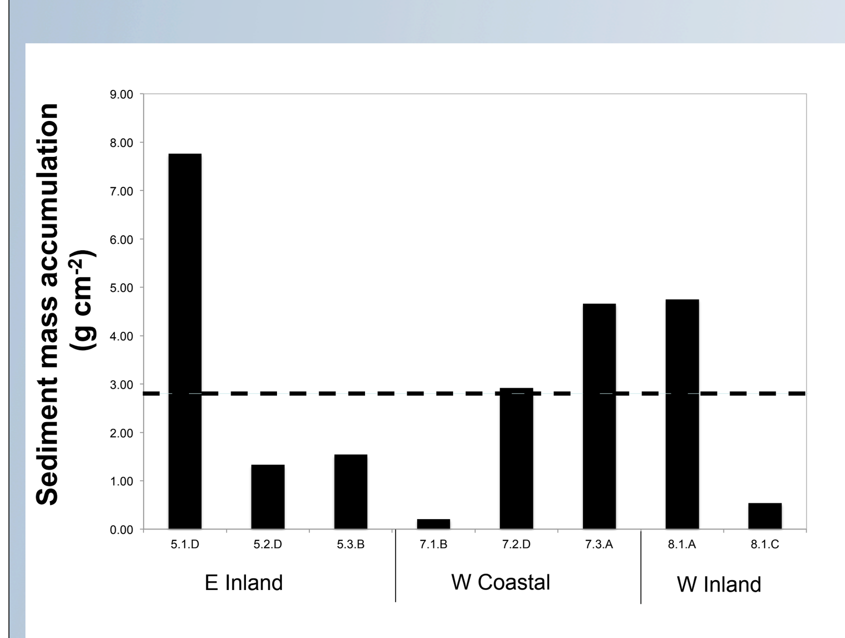
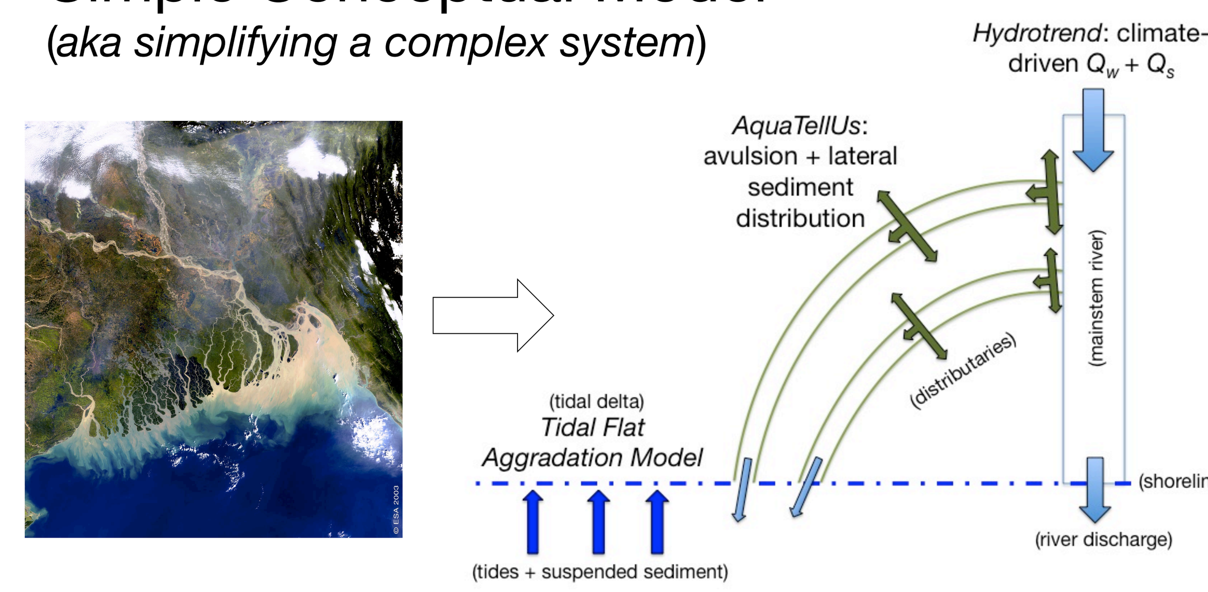


Figure 4. 2012 fluvial delta direct sedimentation measurement results: only 15% of traps recovered; overall mass accumulation average: 2.9 ±2.4 g cm^{-2} (dashed line); ^{7}Be results: ~25% of new sediments sourced from monsoon floodpulse; flooding of land surface controlled by sluice gates, irrigation, mixed tidal+fluvial; **vertical accretion: 2.3 ±1.9 cm y^{-1}** *(but spatially variable)*

Simple Conceptual Model

(aka simplifying a complex system)



HydroTrend

- 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 + climatological characteristics:

~ suspended sediment load
~ trapping efficiency of lakes and reservoirs
~ river discharge
~ maximum relief of the drainage area
~ mean annual basinwide temperature
~ lithology

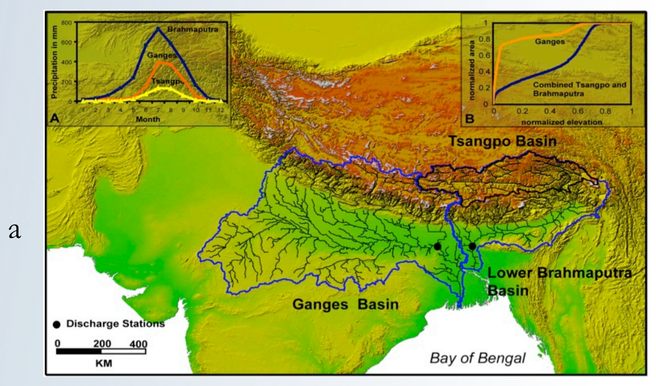


Figure 5a. Delineated drainage basins of the Ganges River, the Tsangpo River and the Lower Brahmaputra River. The two top panels summarize the precipitation pattern (A) and the hypsometry (B) for the two main basins

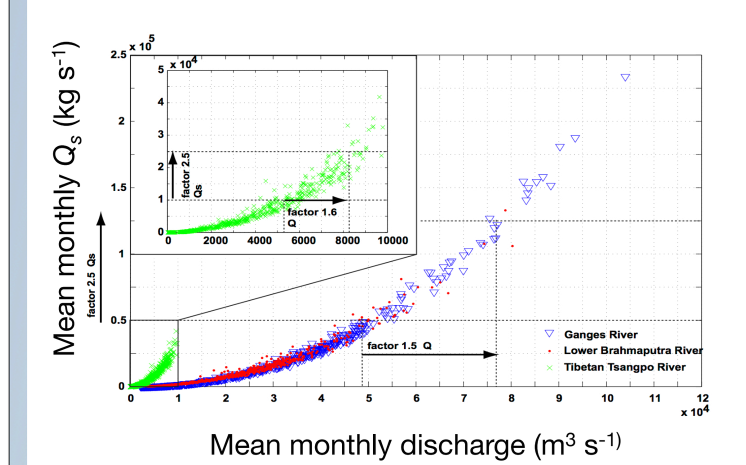
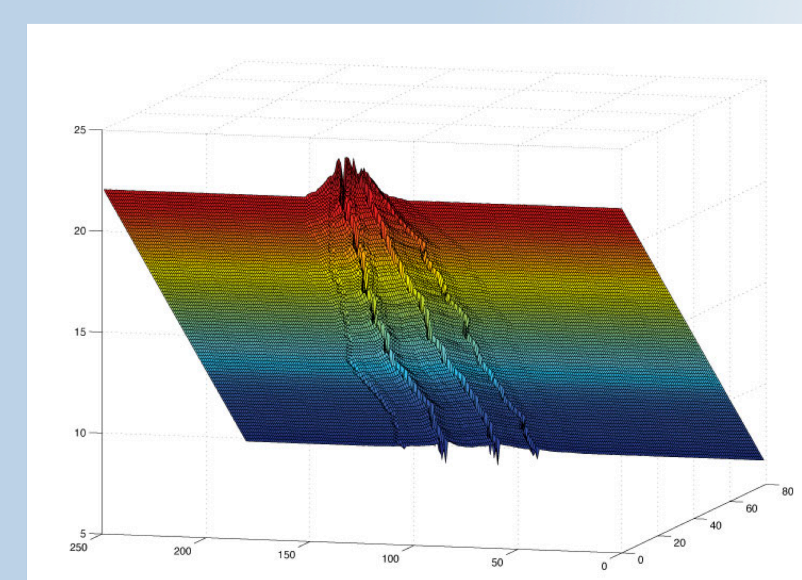


Figure 5b. Sediment rating curves for each of the three sub-systems based on 100-year Hydrotrend simulations. Each monthly sediment load is plotted versus the monthly water discharge, illustrating the enormous spread in events for these monsoon-driven rivers

AquaTellUs:

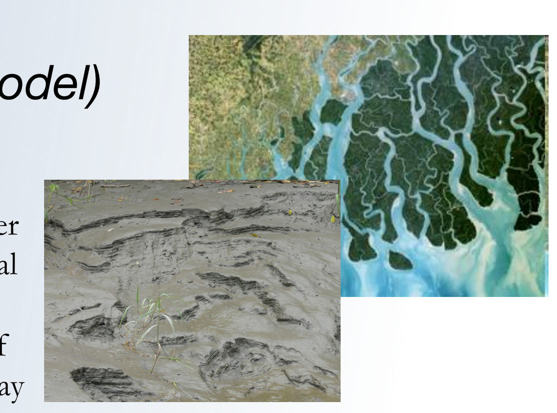
avulsion and lateral sedimentation



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

Point-Tidal Flat

(or other tidal aggradation model)



- 1D, advancing towards a quasi-3D hydrodynamics model
- Evolves a tidal flat elevation over time under the influence of shear stress built up by tidal currents, fetch and wind waves
- Current 1D model allows for adaptation of the cohesiveness of the substrate, which may function as a proxy for vegetation

2013: ongoing/next steps:

~ Hydrotrend: optimizing historical discharge + climate input data to determine decadal trends for each basin
~ AquaTellUs and Point-Tidal Flat: componentizing in CMT
~ Linked model runs with variable input parameters: evaluate sediment output simulated for enhanced monsoon + increased mean sea level
~ How to account for spatial variability in sedimentation results in models?