

Predicting Long- and Short-Term Climate-Related Impacts in the Bengal Delta, a Robust Natural System Limited by Societal Constraints*

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Abstract

Most predictive studies of climate-related change on river deltas focus on the next century of increased relative sea-level rise and tropical storm activity as the primary threats for coastal flooding and land loss. Often overlooked in the literature is the coupling of these longer term predictions (century scale) with short-term (i.e. decadal) effects of upstream landscape modifications by humans that may exacerbate climate-related effects at the coast. In spite of a large sediment discharge to the modern coast and lower delta plain (~700 MT/y), the densely populated delta nation of Bangladesh is considered particularly susceptible to the 1m rise in sea-level predicted for the next century. This susceptibility is due in part to a low elevation (avg. ~3m above MSL), frequent storm surges and high seasonal monsoon wave set-up. However, early Holocene sedimentary deposits demonstrate that a strengthened Asian monsoon enhanced fluvial sediment fluxes to the coast such that the Bengal delta remained stable during very rapid sea-level rise. These seemingly contradictory patterns from the modern and Holocene delta challenge effective assessment of this system's ability to respond to environmental change. Further complicating matters are short-term strategies in Bangladesh and India to mitigate flooding, including artificial leveeing of the rivers and the diking of coastal lowlands, both of which would limit sedimentation and diminish relative elevation of the delta surface. River damming to address demands for hydroelectric power and water resources may also significantly reduce the amount of sediments delivered to the Bangladesh coast. We present field-based observations of sediment dispersal in the modern Bengal delta that demonstrate how the system could remain relatively stable over the next century of climate and sea-level changes. However, this potentially acceptable outcome becomes increasingly unlikely if human interferences are considered. Ultimately, it may be the impacts of such direct human-modification to the Bengal delta and river systems that outpace - in time and severity - those resulting from climate and sea-level changes alone.

Selected References

- Gitay, H., 2002, Climate change and biodiversity, *in* Intergovernmental Panel on Climate Change (IPPC): IPPC Technical Paper 5, 77 p.
- Pate, R.D., S.L. Goodbred, Jr., and S.R. Khan, 2009, Delta double-stack; juxtaposed Holocene and Pleistocene sequences from the Bengal Basin, Bangladesh: *The Sedimentary Record*, v. 7/3, p. 4-9.
- Rogers, K.G. and S.L. Goodbred, 2010, Sedimentation patterns and transport pathways linking river mouth to remote depocenters in the Ganges-Brahmaputra Delta: AAPG Search and Discovery abstract #90104, presented AAPG 2010 ACE New Orleans, Louisiana: Web accessed 13 July 2010, http://www.searchanddiscovery.net/abstracts/pdf/2010/annual/abstracts/ndx_rogers.pdf
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- Ullah, M., S.L. Goodbred, R.D. Pate, and P. Youngs, 2010, Late Quaternary avulsion history of the Ganges-Brahmaputra River: Application of Sr Geochemistry: AAPG Search and Discovery abstract #90104, presented AAPG 2010 ACE New Orleans, Louisiana: Web accessed 13 July 2010, http://www.searchanddiscovery.net/abstracts/pdf/2010/annual/abstracts/ndx_ullah.pdf

Websites

- Columbia University, 2007, Population density within and outside of a 10m low elevation coastal zone, Bangladesh: Web accessed 13 July 2010, http://sedac.ciesin.columbia.edu/gpw/maps/lec/Bangladesh_10m_LECZ_and_population_density.pdf
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Predicting long- and short-term climate-related impacts in the Bengal Delta

A robust natural system limited by societal constraints

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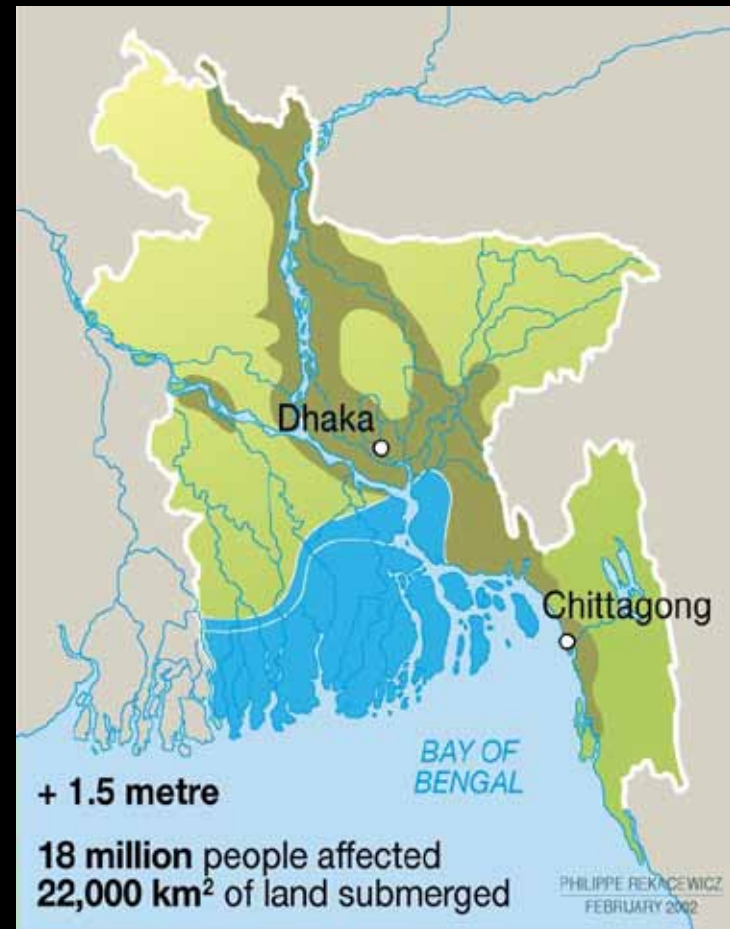
Thanks also to S.R. Khan, P. Youngs,
R. Pate, M.S. Ullah, S.A. Kuehl



2002 IPCC Report

Impact of sea-level rise in Bangladesh

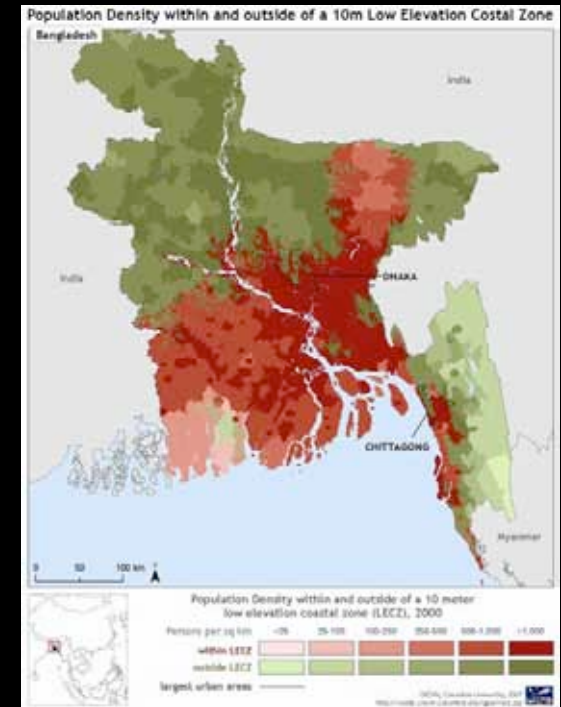
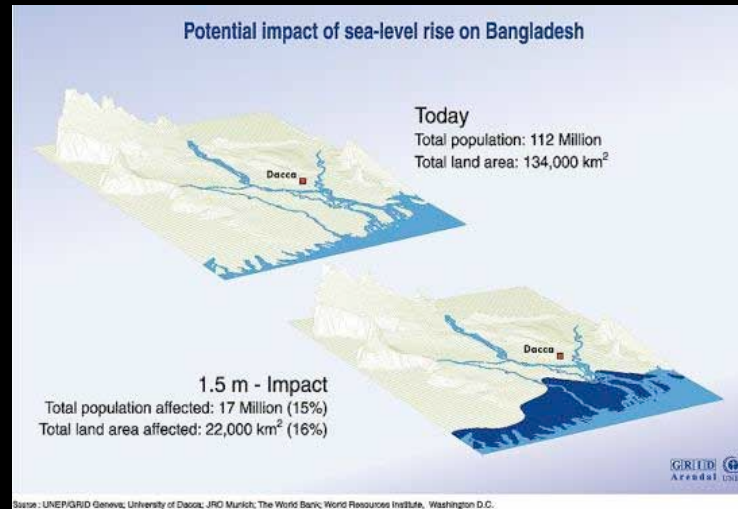
Are these scenarios plausible?



... pattern repeated

Columbia University

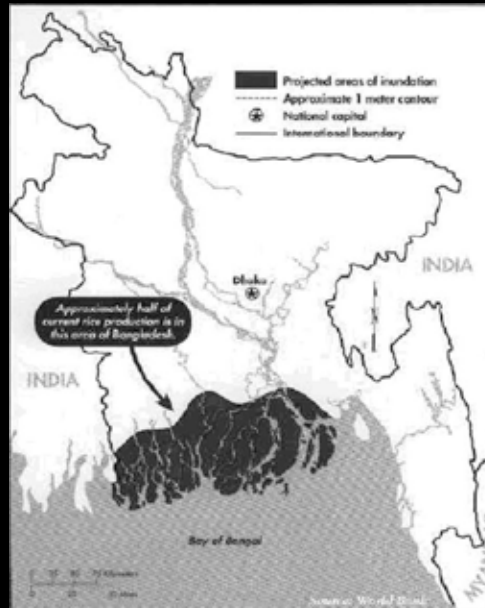
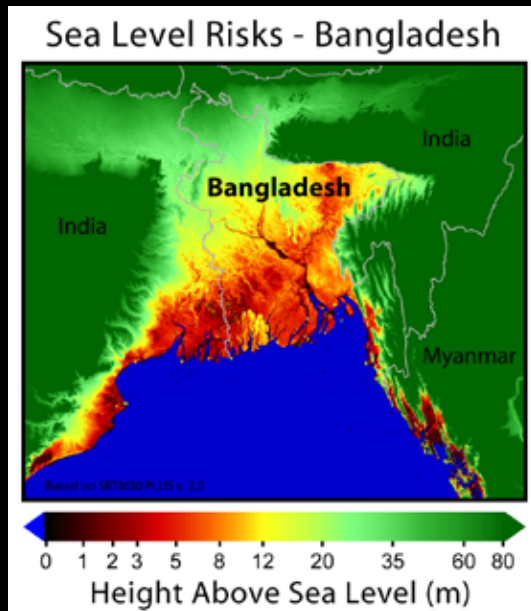
United Nations Environmental Program



Global Warming Art

World Bank

John Ray Initiative



"

Notes by Presenter: (for previous slide):

"

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As experts in earth-surface dynamics, sediment transport, basin evolution -- Can we chuckle at this? Yes, I think we can, a bit.

However, this scenario is not far from what we'd get applying the Bruun rule that has so widely been misused.

And the truth is, while we could successfully argue that these assessments are implausible, could we respond with a confident assessment of what would be the response of this delta, or any other, to a 1.5 m rise in sea-level?

We have designed plenty of sequence models to understand how deltas and margin systems have responded to past sea-level change – are we confident enough to apply these to the modern world and a scenario of a 1.5 m sea-level rise?

We have our homework to do — it is both a critical challenge and exciting opportunity.

What is the likely response of the Ganges-Brahmaputra River Delta to 1.5 m rise in sea level over the next century?

By analog the G-B delta is:

- not a subside-and-drown system – (Mississippi?)
- not a ravine-and-transgress system – (Nile?)
- a rework-and-aggrade system – (??)

Distinguishing characteristics of the G-B delta:

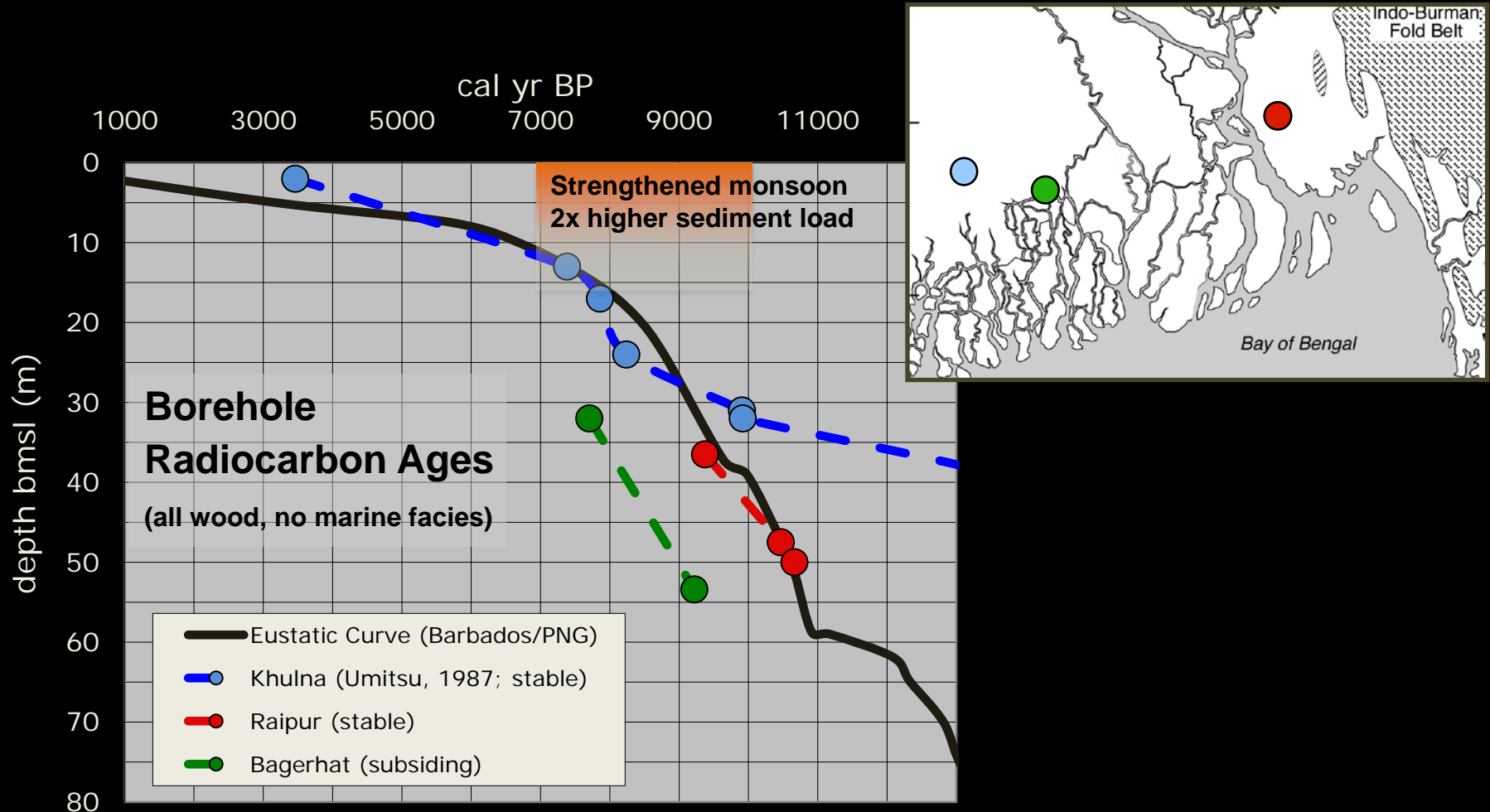
- massive sediment load (UNDAMMED)
- effective fluvial and tidal sediment dispersal (UNLEVEED, UNDYKED, UNEMBANKED)
- history of deltaplain aggradation and stability (CO-PHASED MONSOON AND SLR)

STABLE \neq NON-CHANGING

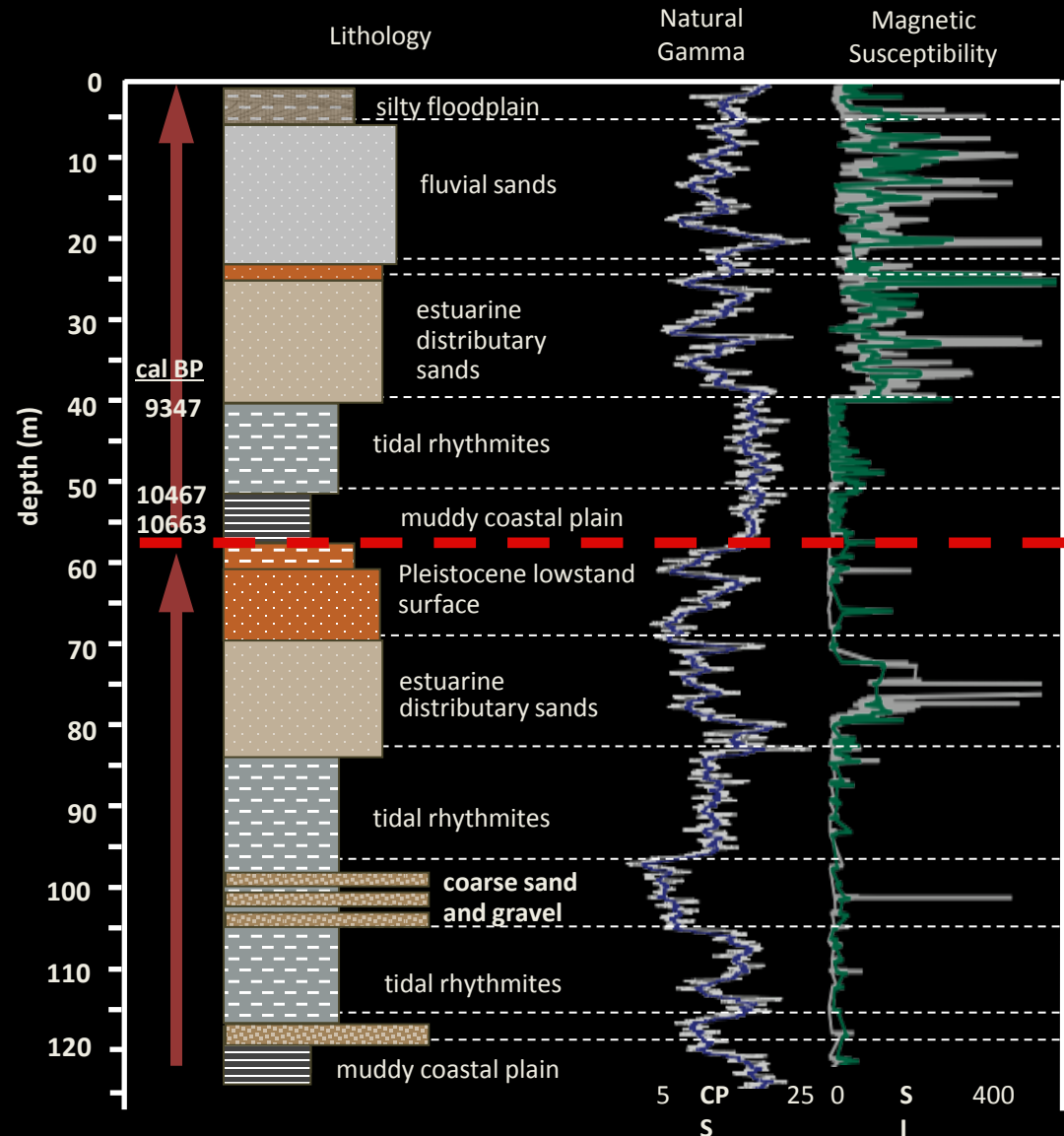
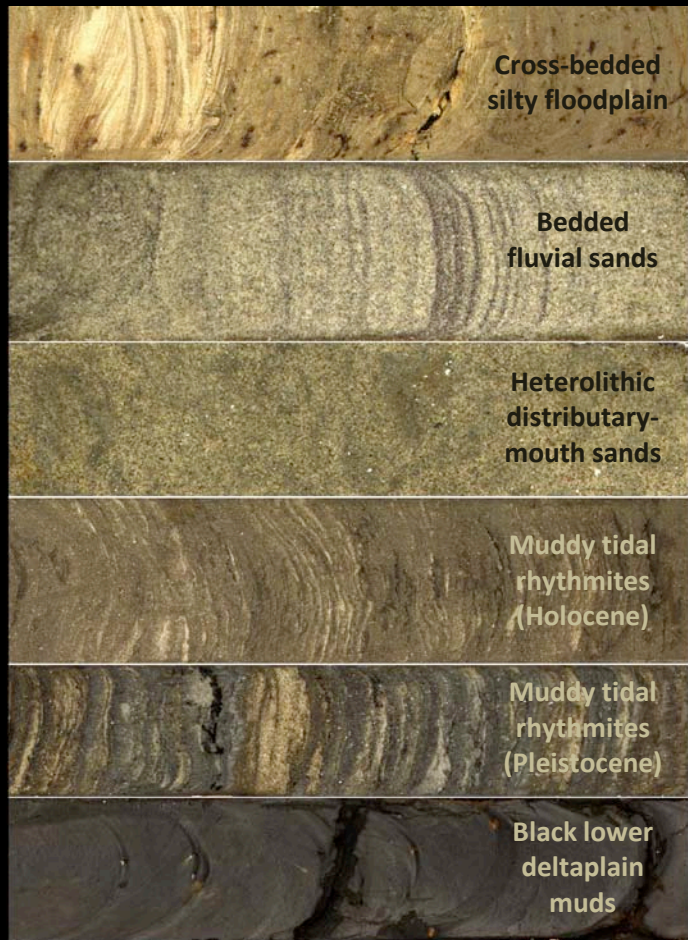
Notes by Presenter: Subsidence and coastal retreat do not appear to be the primary threats of increased sea-level rise in the G-B delta Deltaplain overlies coarse-grained fluvial deposits, and annual accretion autocompacts due to dry season drainage and dessication. Massive sediment discharge to coast and nearshore trapping maintain shoreface position
THREATS ARE FLOODING, RIVER AVULSION, and LOCALIZED EROSION – read: UNPREDICTABLE

Part 1: Deep-time Perspective

- Early Holocene delta formation, rapid accretion rates, and intertidal-to-fluvial facies
- Demonstrates capacity for G-B delta to keep pace with rapid SLR



120-m stratigraphy comprising two stacked, nearly identical delpalain sequences ...



Delta double-stack: Juxtaposed Holocene and Pleistocene sequences from the Bengal Basin.
 SEPM Sedimentary Record, 7(3): 4-9, September 2009; R. Pate, S.L. Goodbred, and S.R. Khan

Part 2: Sediment Accretion

Sediment load: 1,100,000,000 t/yr

Delta area: 150,000 km²

Bulk Density: 1.5 t/m³

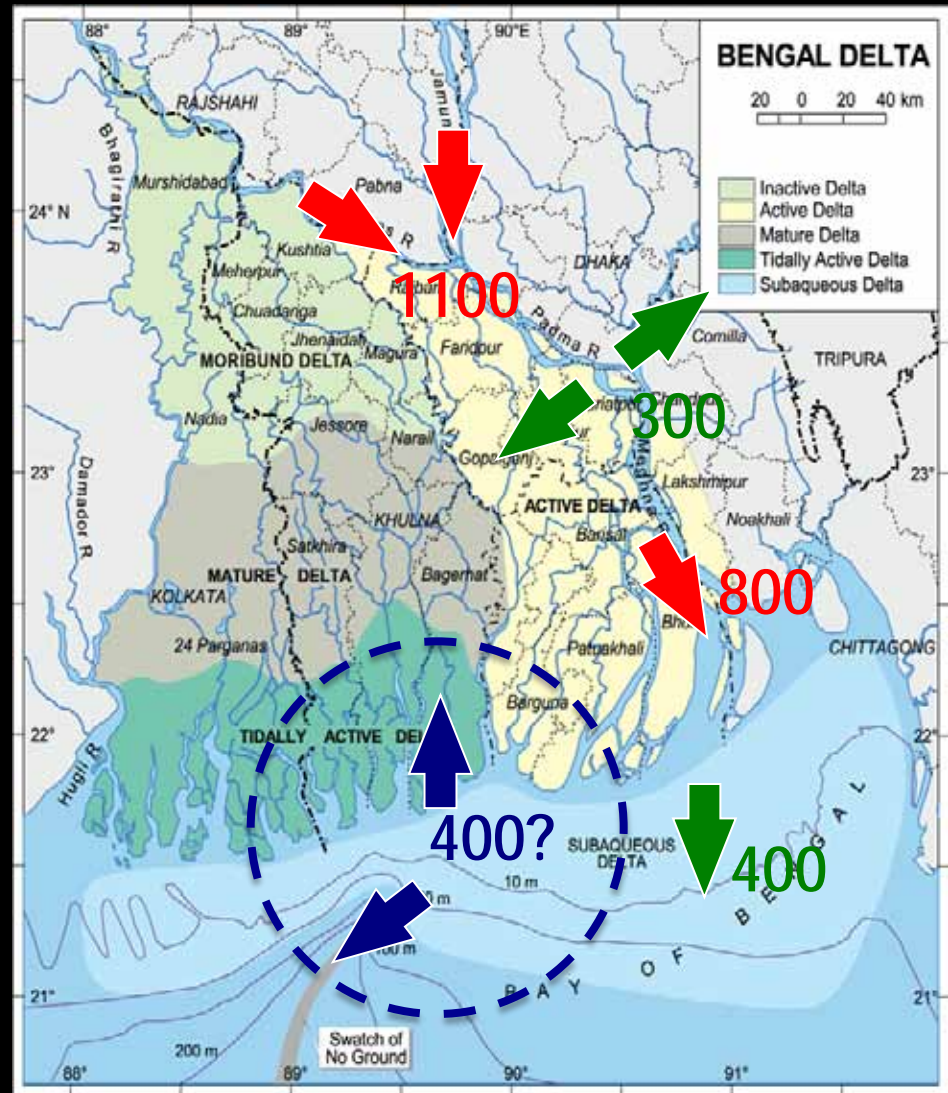
Potential Basinwide

Accretion rate: 4.9 mm/yr

To accomplish 5 mm/yr of accretion over the entire delta system would require an effective sediment dispersal system – do we have it?

Yes - ~1/3 partitioning
at regional scale

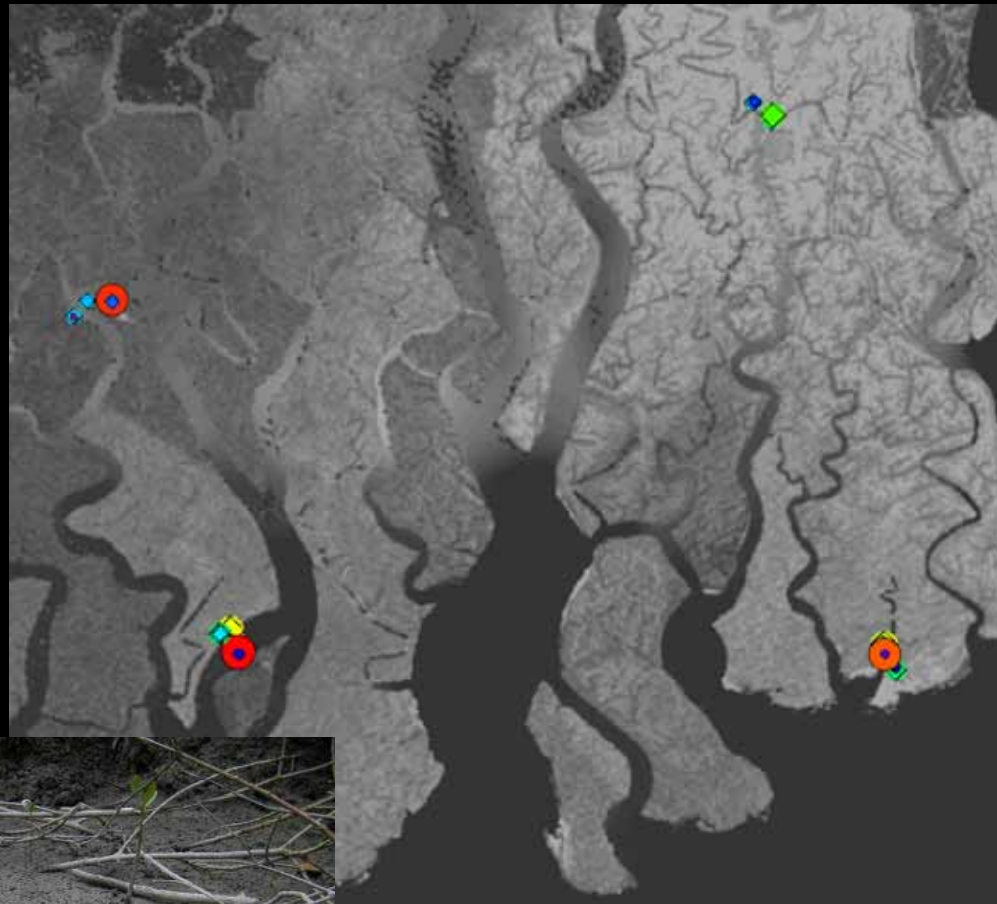
No - locally heterogeneous
at $< 10^2$ years



Deployed 48 sedimentation plots on coastal plain during 2008 monsoon period

MEASURED:

- Direct sediment flux
- ^7Be – fluvial discharge tracer



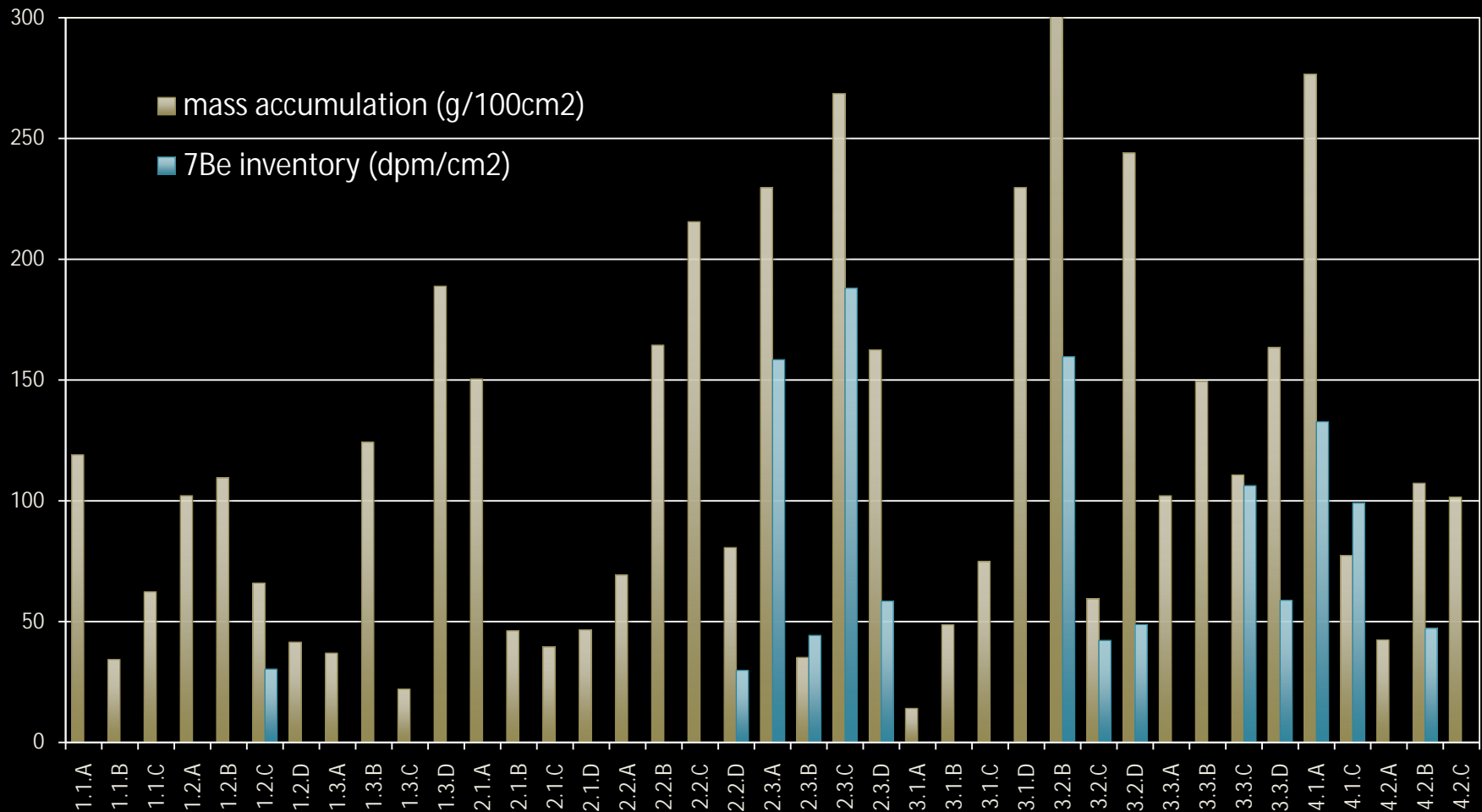
pre-monsoon



post-monsoon

BRIEF RESULTS:

- ~1 cm/yr average accretion rate
- ~1/3 of sediments derived from seasonal plume dispersal



SEPM Source-to-Sink Sediment Dispersal, Modern and Ancient (Oral) — Wednesday, Apr 14 – 9:25 AM

Sedimentation Patterns and Transport Pathways Linking River Mouth to Remote Depocenters in the Ganges-Brahmaputra Delta

K. G. Rogers; S. L. Goodbred

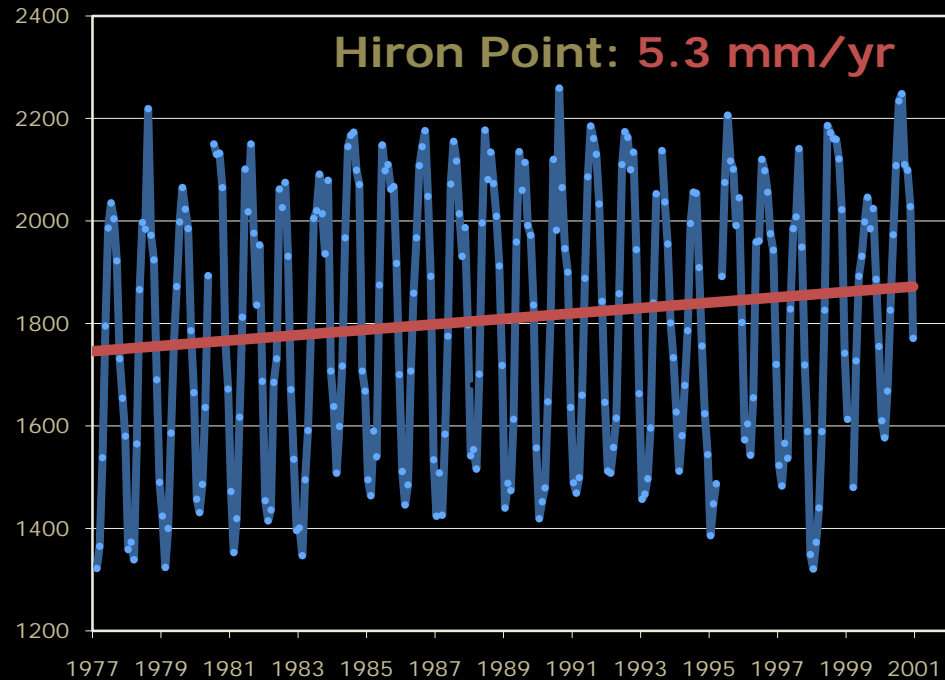
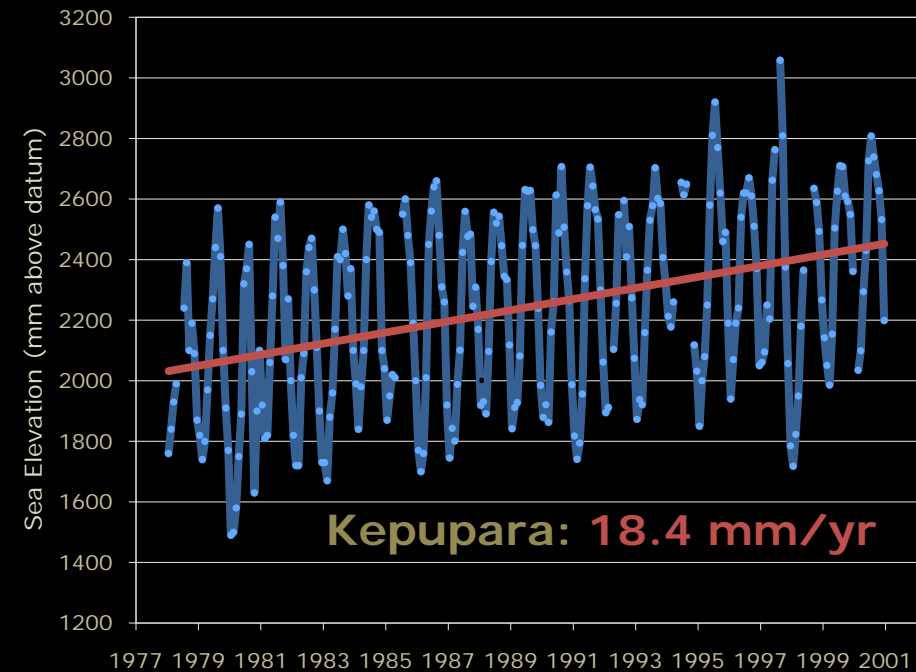
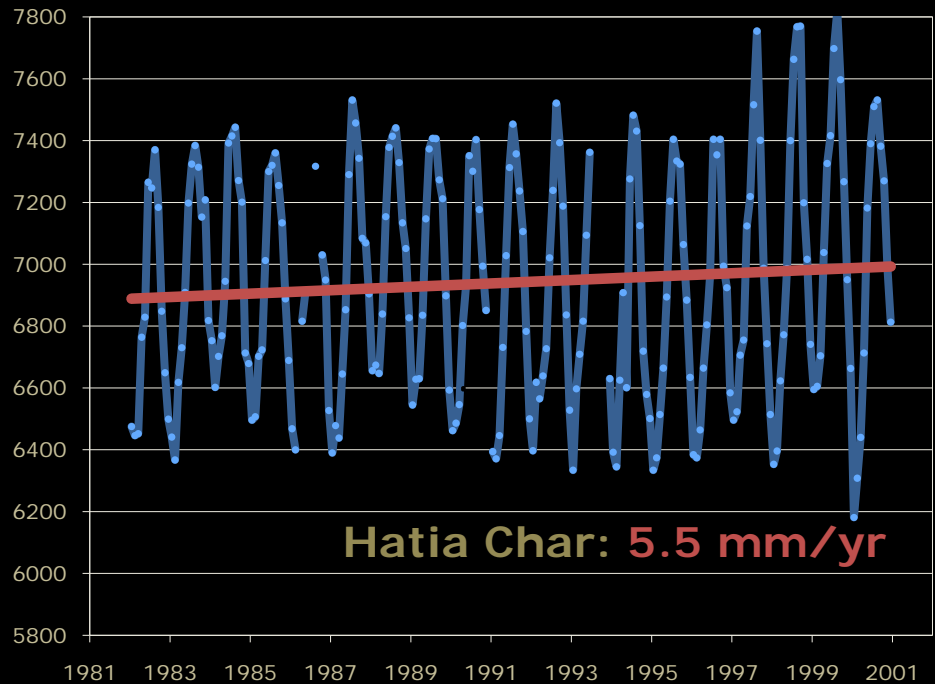
Relative sea-level rise from tide-gauge records:

Typical rate = ~5.5 mm/yr

Locally anomalous to 18 mm/yr (??)

Overall RSLR \approx Basinwide Accretion

Fastest RSLR \approx Local Accretion



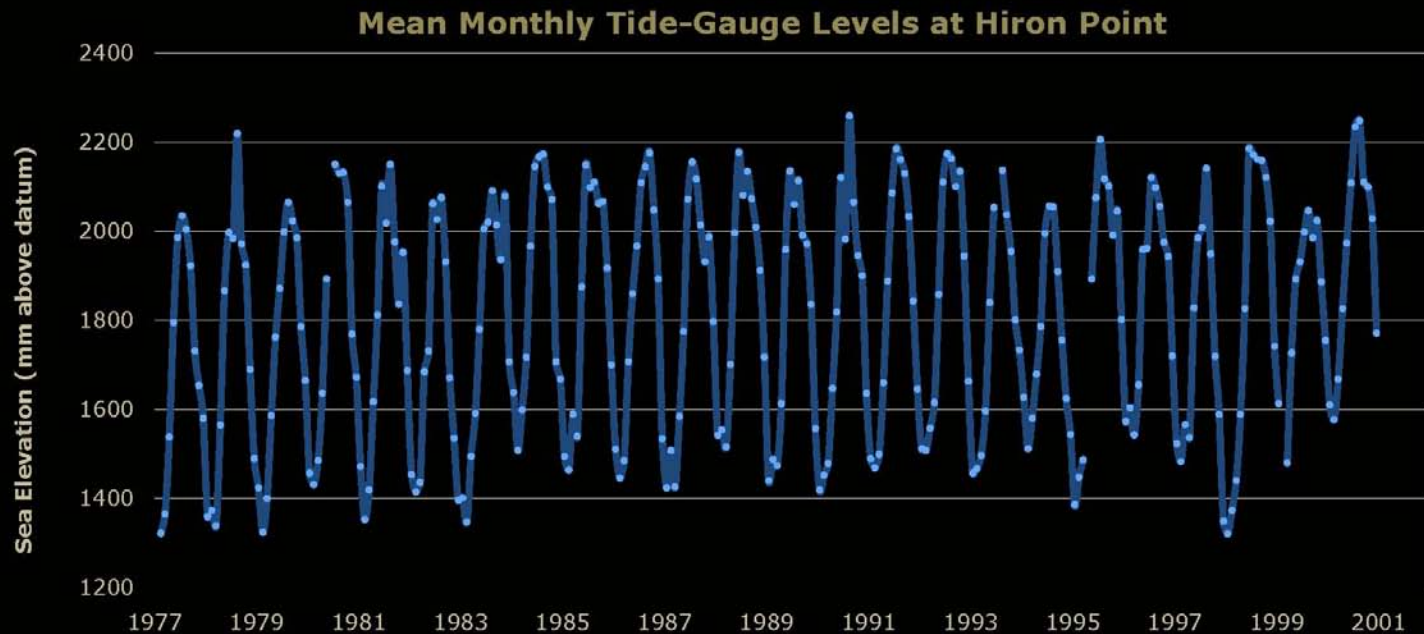
Part 3: Delta Morphodynamics



Role of Summer Monsoon ... not just high discharge

80-cm increase water elevation due to regional onshore wind stress

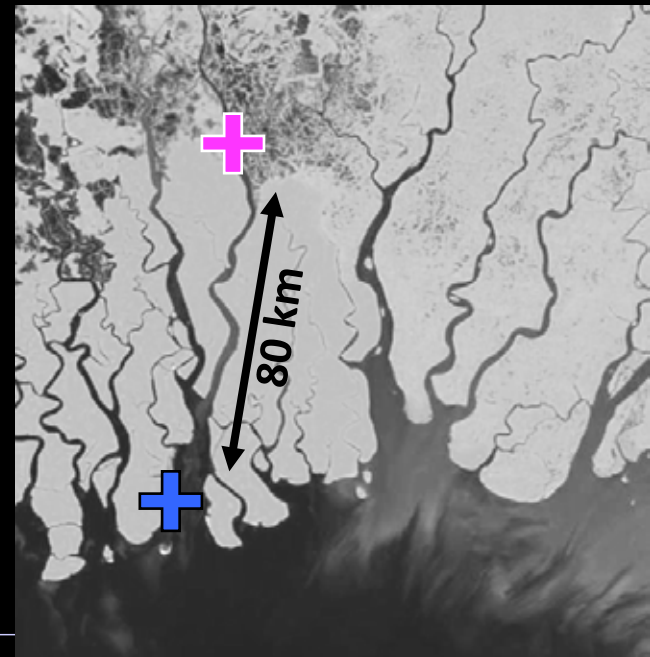
→ increased inundation + high sediment flux = enhanced sedimentation



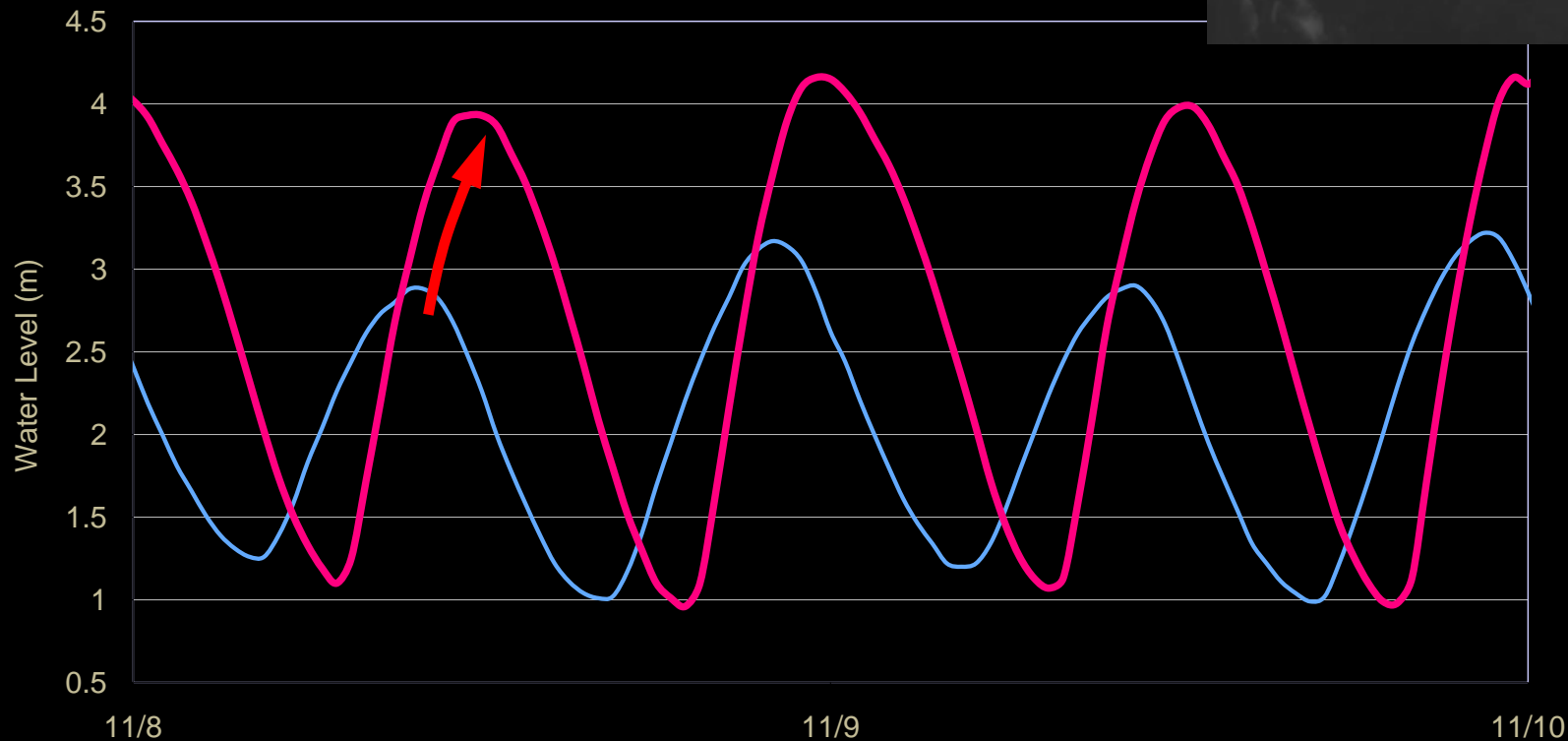
Notes by Presenter: Tidal range 1.5 - 4m Summer monsoon setup of 75 cm -another monsoon effect Sea level rise ~5 mm/yr

Significant tide deformation within deltaplain channels ...

- ~ 2 hour phase delay
- ~ 1 m amplification of flooding tide
- ~ 2 hour flood-dominant asymmetry



Tidal Fluctuations at Hiron Point and Mongla in Nov 2007



Co-evolution of tidal channels and inner shelf bathymetry

- Tidal reworking of 'overfilled' littoral zone
- Channel incision on inner shelf, channel deepening onshore
- Fate of reworked sediments linked to monsoon set-up and tidal asymmetry

... REDEPOSITED ON COASTAL PLAIN

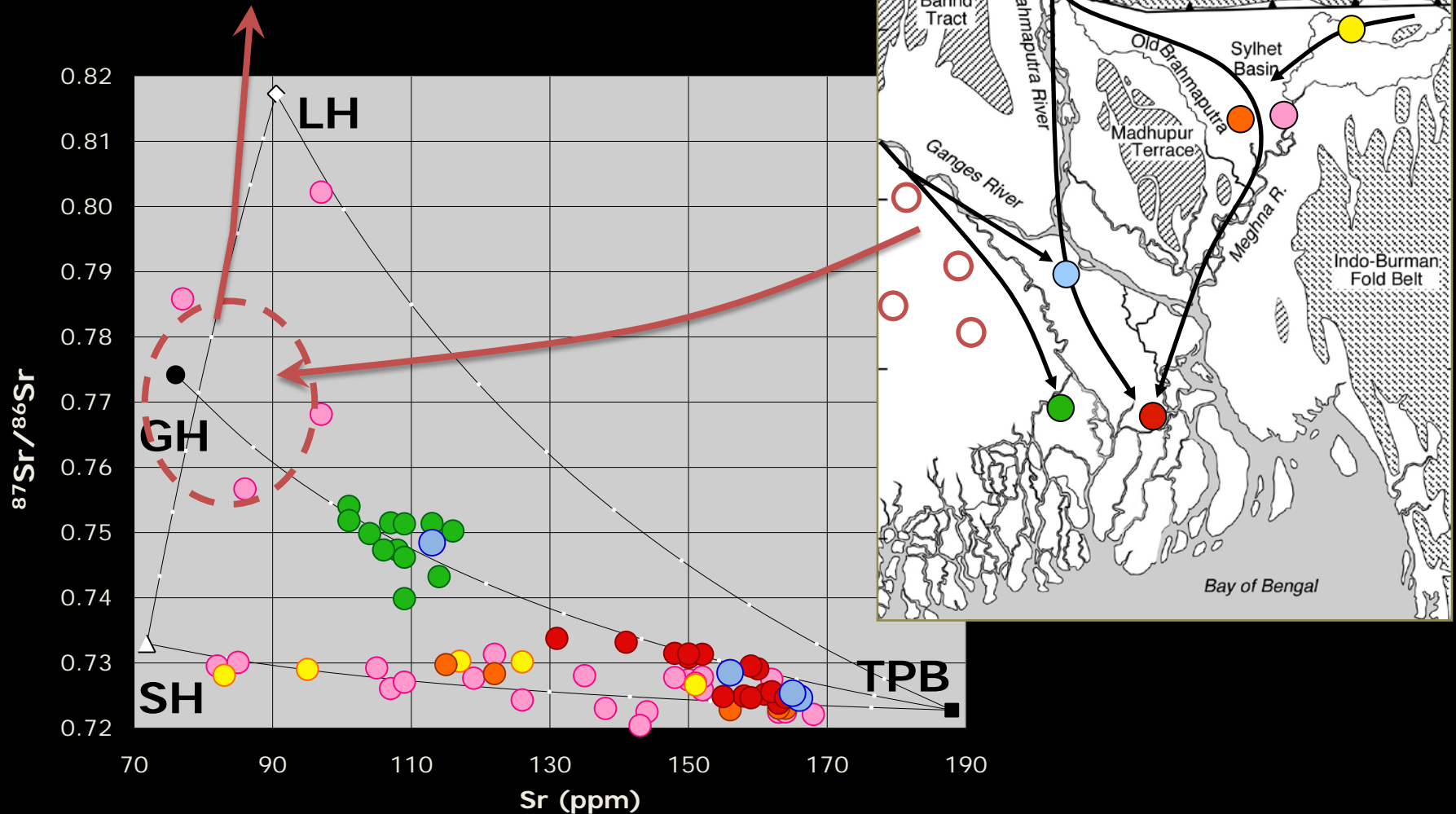


Part 4: Source Area Controls

SEPM Source-to-Sink Sediment Dispersal, Modern and Ancient (Posters) — Tuesday, Apr 13 - 1:15 PM

5B. Late Quaternary Avulsion History of the Ganges-Brahmaputra River: Application of Sr Geochemistry

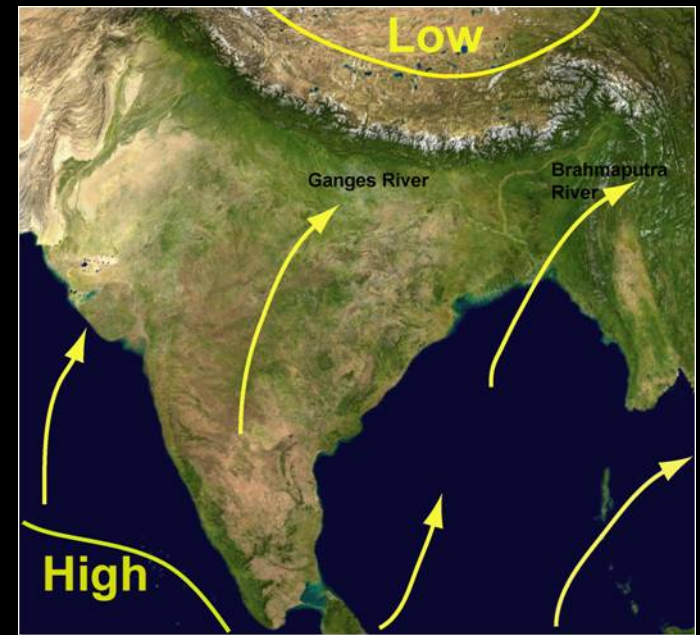
M. S. Ullah; S. L. Goodbred; R. D. Pate; P. Youngs



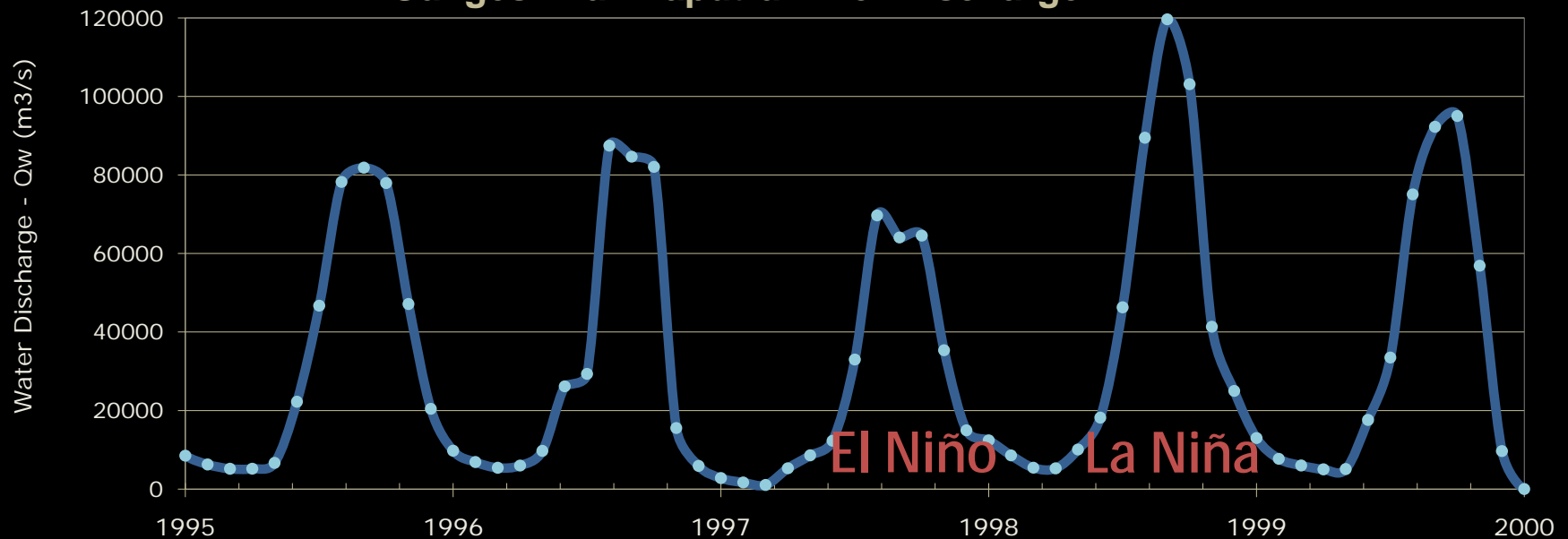
Variability of River Discharge

Discharge during the 4 months of Summer Monsoon accounts for ...

80% of water and
95% of sediment,
but ...



Ganges-Brahmaputra River Discharge



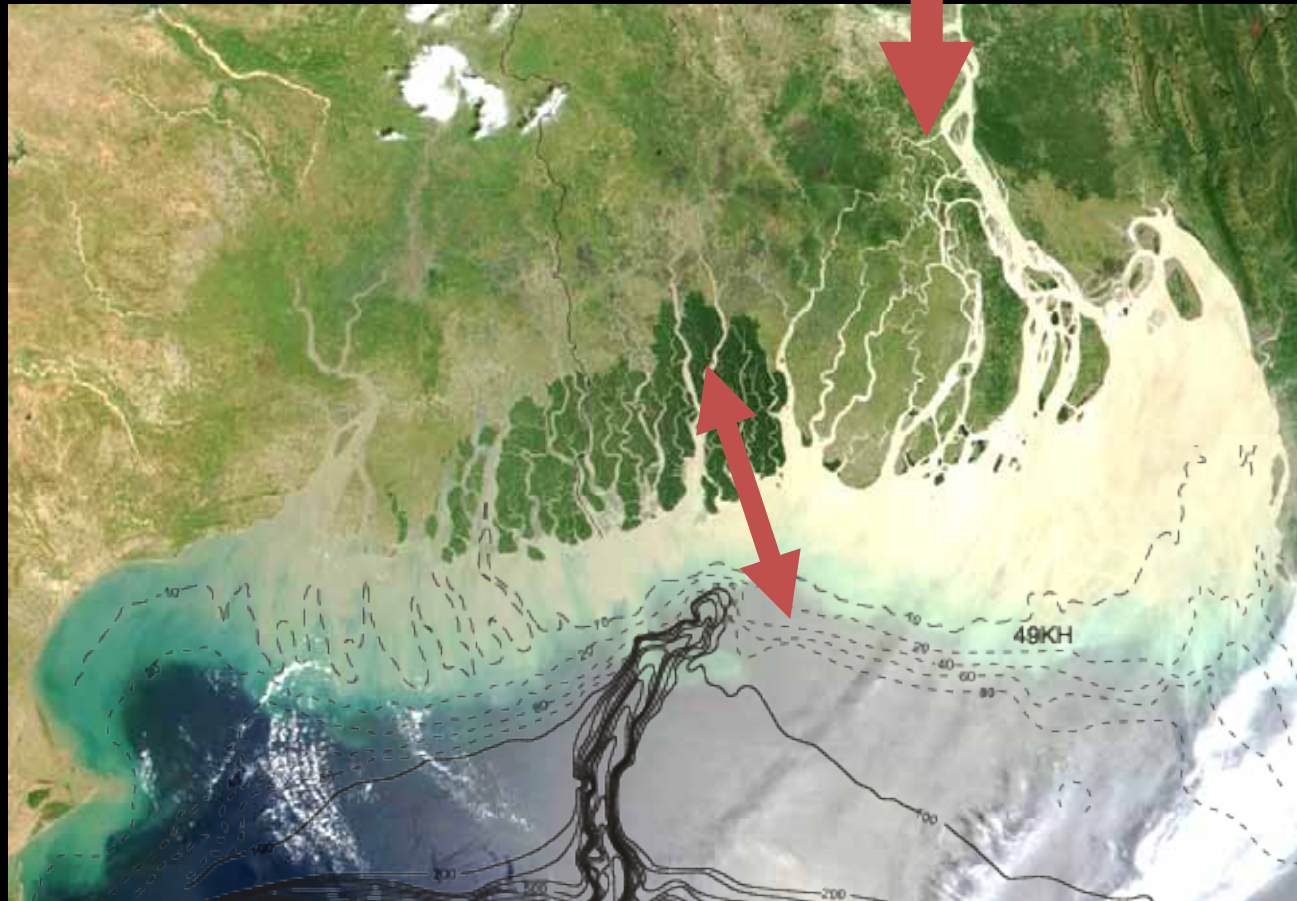
Notes by Presenter: (for previous slide):

During summer, the Indian subcontinent heats up, creates powerful convection, and large-scale airflow intrudes to replace the ascending air masses. This is known as the **southwest** monsoon, characterized with winds blowing from southwest, over the Arabian sea. These winds pick up tremendous amounts of moisture that is released over the land as drenching rains.

Why the Indian Ocean is so different. First, its northern boundary does not extend beyond 25°N. Second, it is not bounded by a "solid" coastal eastern boundary, as the Atlantic and Pacific Oceans are. Next, it is split into two basins - the Arabian Sea and the Bay of Bengal. Thus the Indian Ocean doesn't have the currents to transport and discharge heat to higher latitudes. The two-basin split of the ocean is a recipe for winds pattern unlike any other over the rest of the oceans where more stable trade winds patterns are observed.

Controlling issues on
G-B delta response ...

Channel avulsion and
Change or variability in discharge



Cross-shore sediment transport
Tidal channel-deltaplain evolution

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- history of deltaplain aggradation and stability (**CO-PHASED MONSOON, SED AND SLR**)

Geology, Geography, and Humans Battle for Dominance over the
Delivery of Fluvial Sediment to the Coastal Ocean

James P. M. Syvitski and John D. Milliman¹

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Thanks ... questions?

