Resilient deltas

a case-study report on the Volga and Ganges delta systems

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Thanks to co-authors: S.B.Kroonenberg, T.Veldkamp, and S. Goodbred.

CSDMS

Community Surface Dynamics Modeling System

TU Delft

Outline

- Introduction: extreme rates of sea-level?
- Case-study: Volga delta over last century
- Case-study: Ganges delta at Early Holocene
- Conceptual framework: correlated change in sea-level and sediment supply.

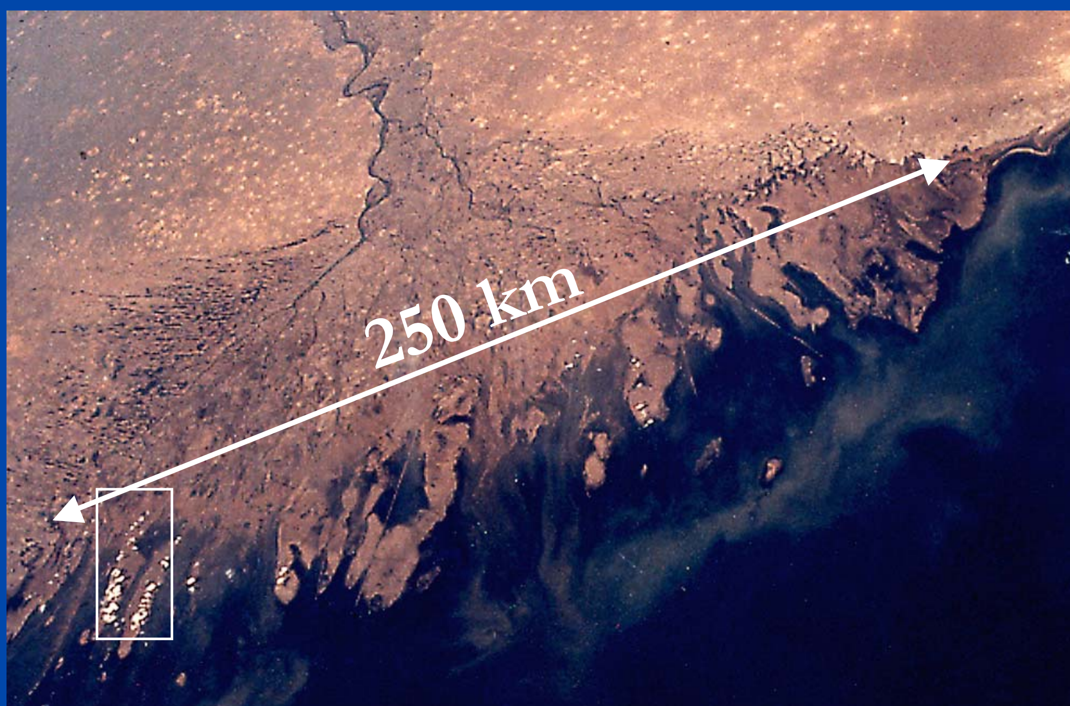
What are extreme sea-level changes?

- Observed 20th century sea-level change 1.7 mm/yr.
- IPCC forecasts[1)] for global sea-level change rates until 2099 vary from ~3-4 mm/yr depending on scenarios.

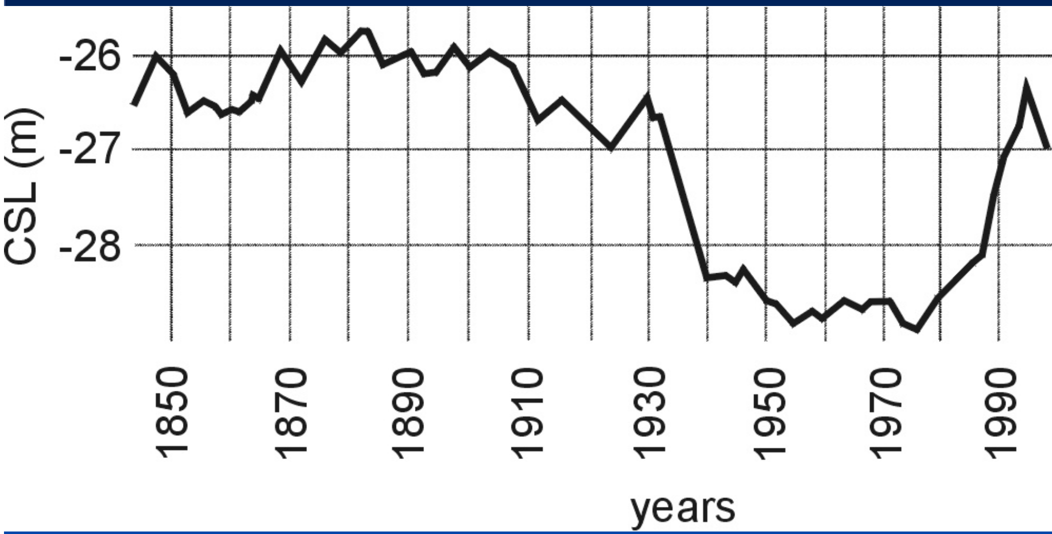
- Volga delta response to last century sea-level change (100 mm/yr)
- Ganges delta response to Early Holocene sea-level change (20 mm/yr)

1) Meehl, et al, 2007

Volga river drains 1,5 million km^2 and has wide fluvial–dominated delta



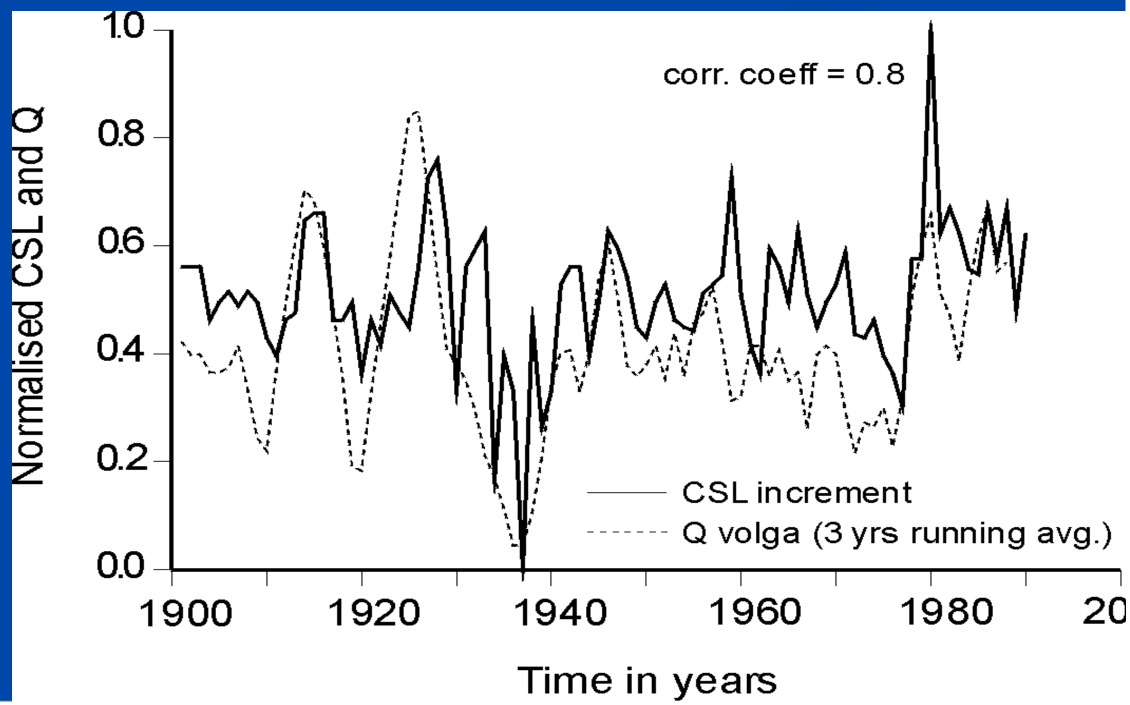
Volga river and Caspian Sea



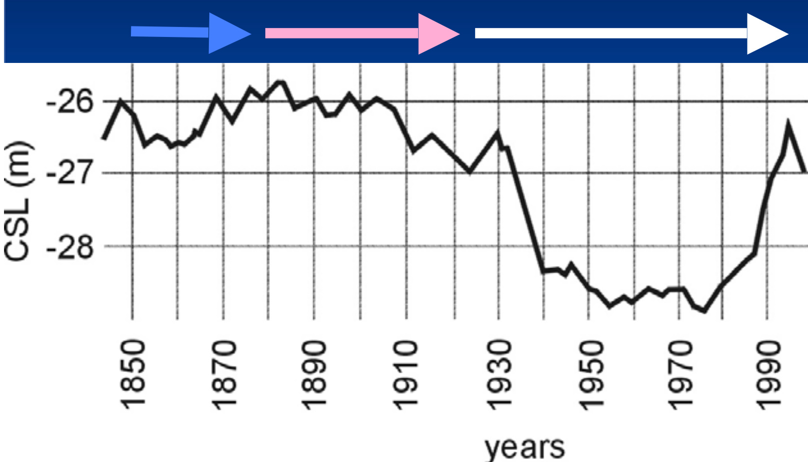
Caspian Sea went through a 3-m sea-level cycle over the last century.

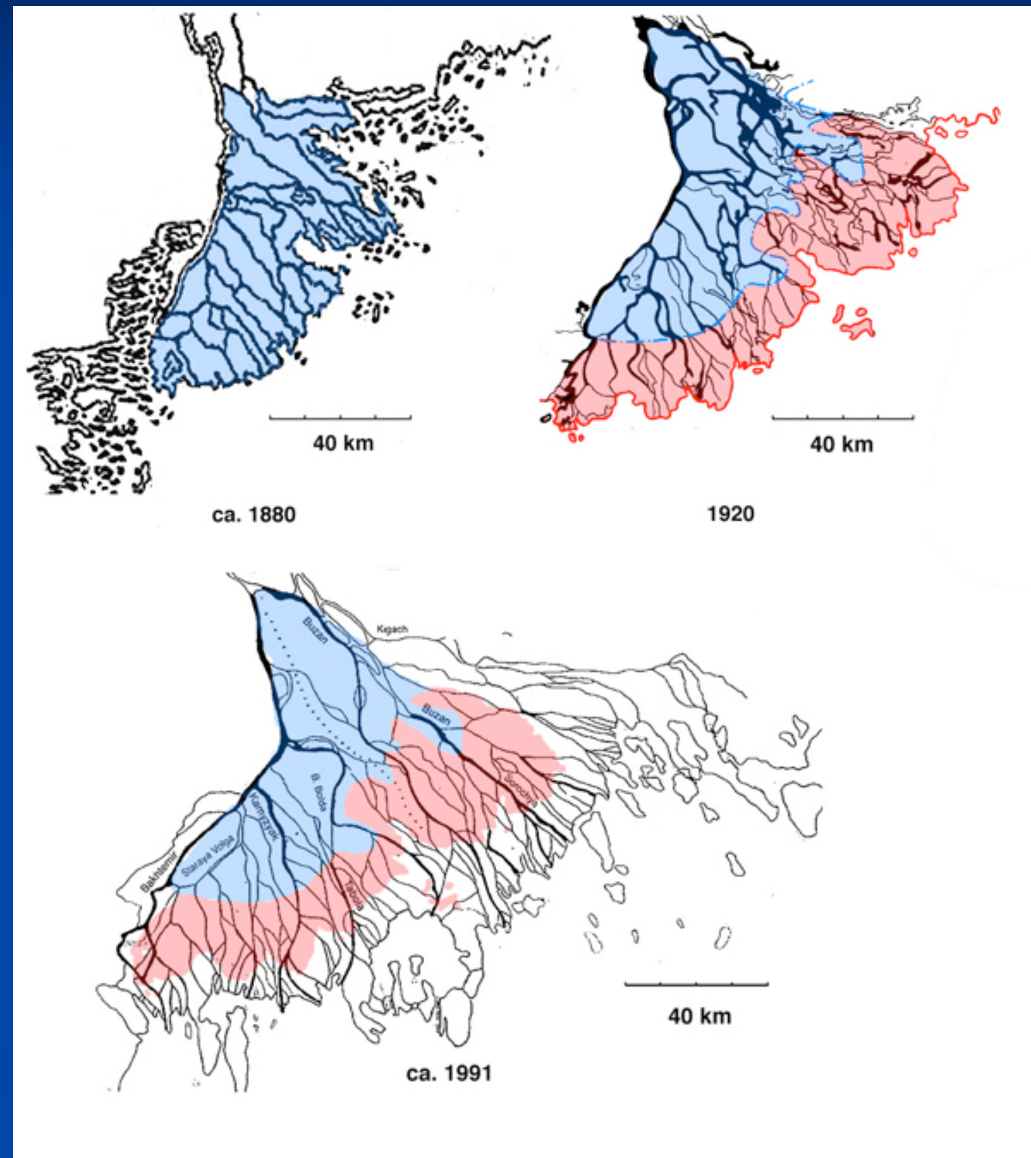
(Source: Mahachkala gauge)

Caspian Sea level is controlled by Volga discharge, which in turn depends on precipitation. Arpe et al.,(2000) showed correlation with ENSO.



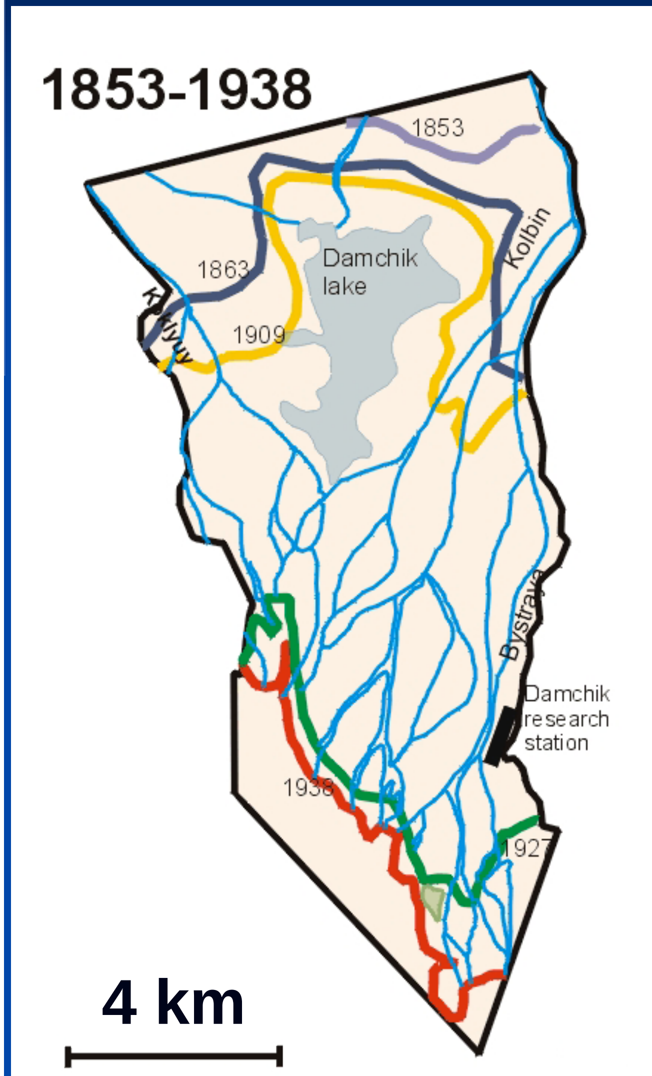
Delta progradation over last century

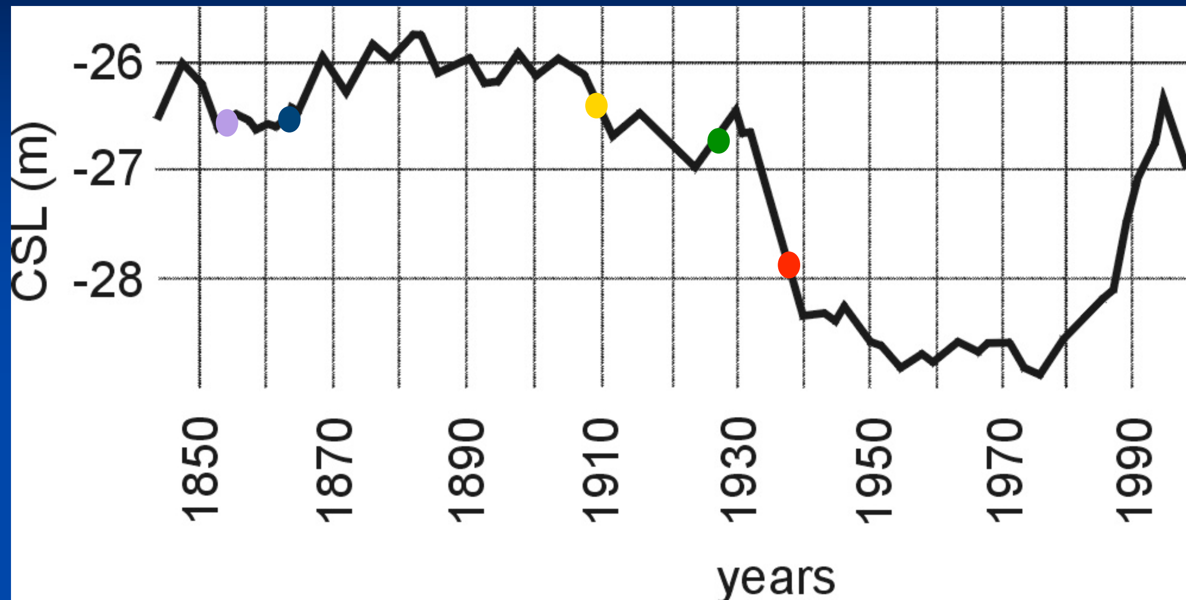




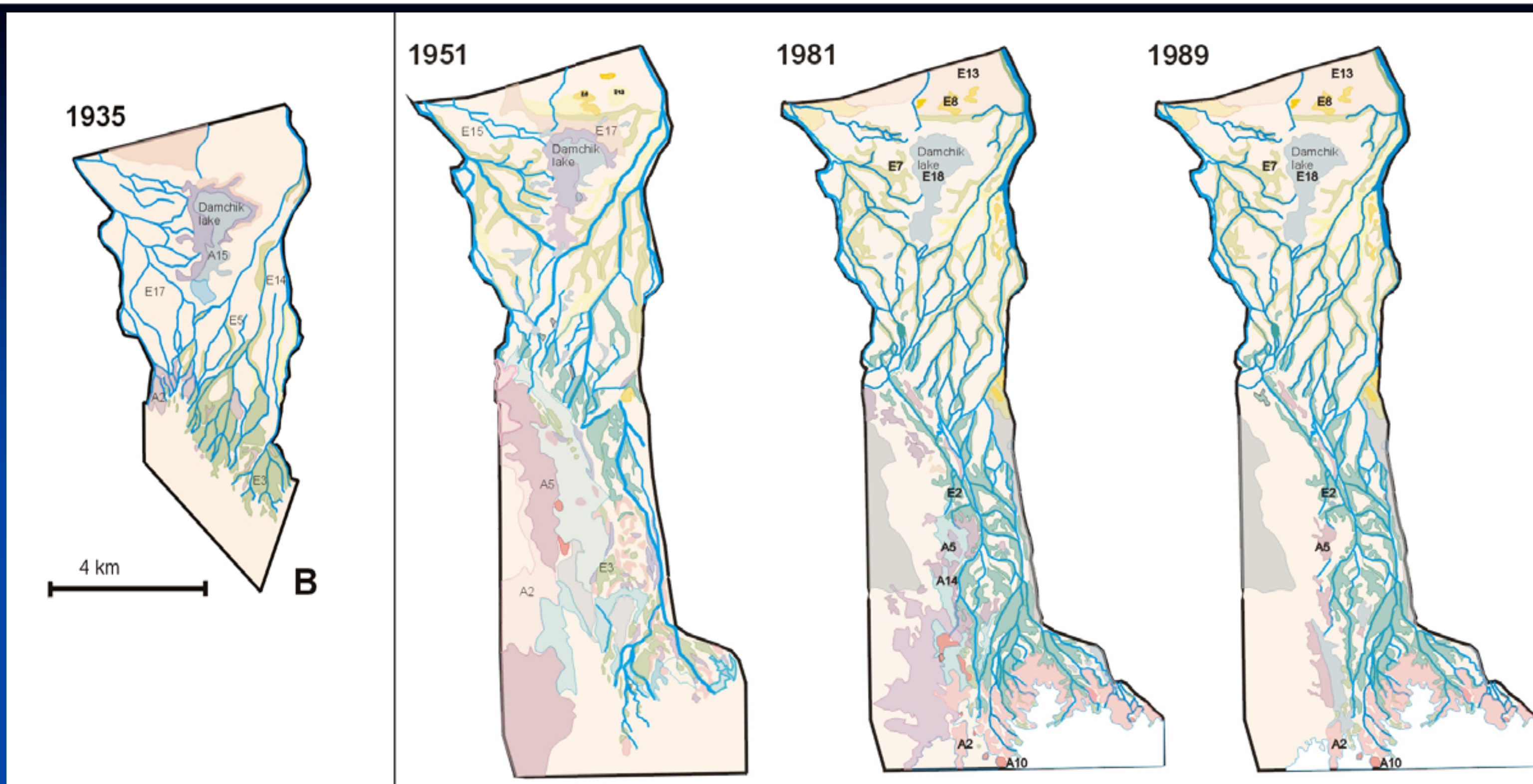
(After Alekseevskiy, Aibulatov, Chistov, 1999), based on combination of old maps and surface topography.

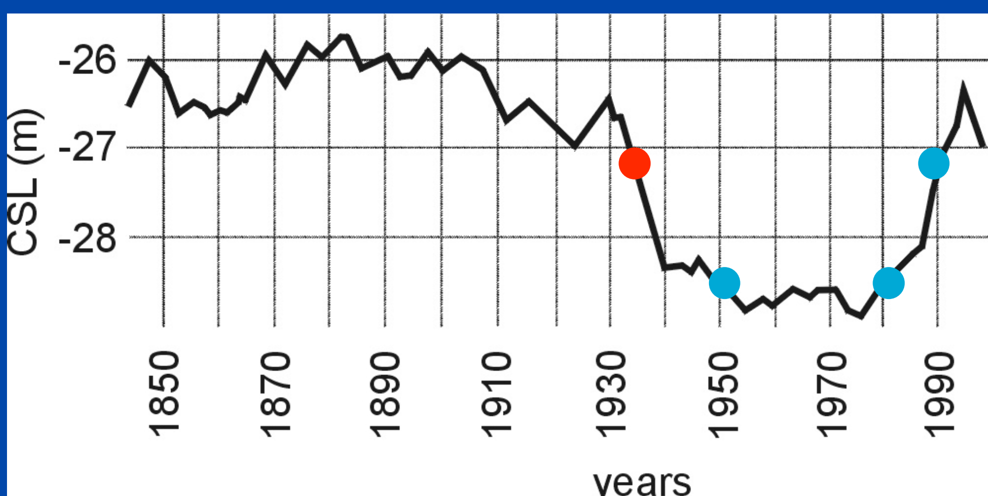
Sea-level fall - low sediment supply





- Relative stable coast 1850–1909 ‘highstand’
- Rapid progradation 1909-1927 due to emergence, s.l. fall 0.6 m
- Slow progradation 1927-1938, despite additional 1.2m s.l. fall because of reduced sediment supply.





- Rapid progradation 1935-1951, emergence and skeleton of channels
- 1951-1981 lowstand, channel network fills.
- 1981- 1990 coastline is stable despite 1,5 m sea level rise.

AquaTellUs numerical model

[illegible]

erosion

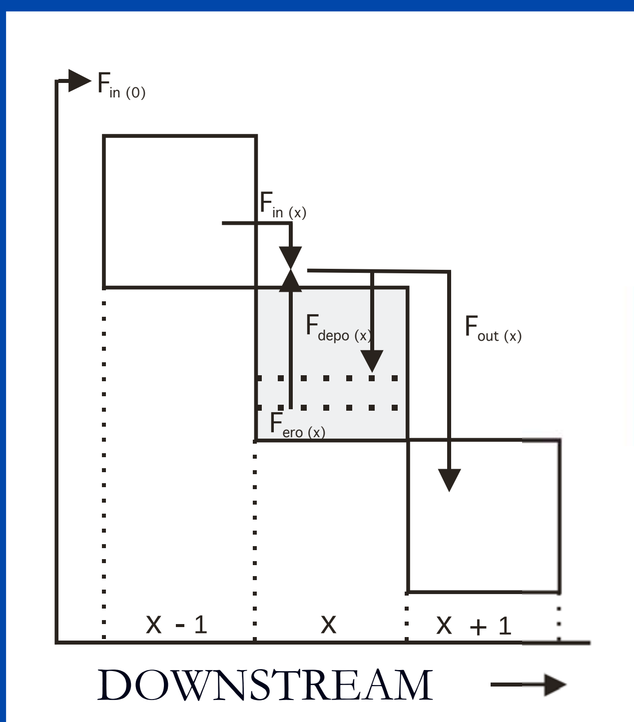
[illegible]

Erosive flux depends on slope (S) and river discharge (Q)

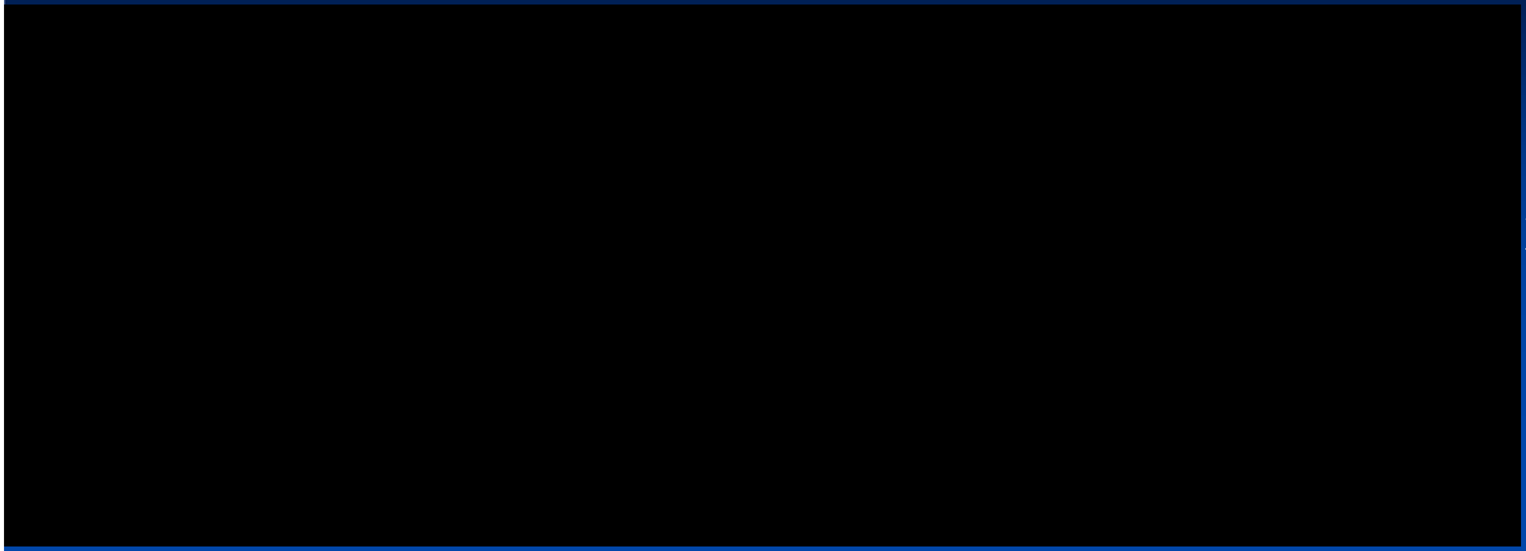
sedimentation

[illegible]

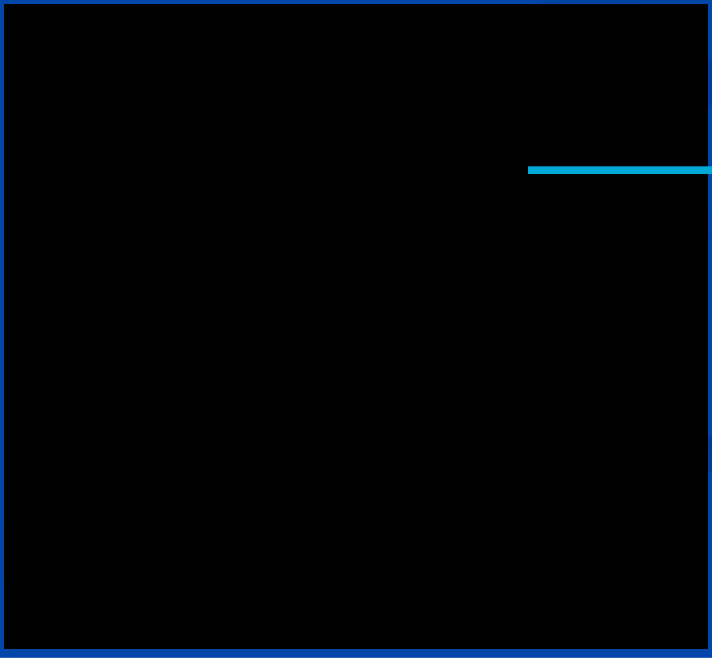
Sedimentations flux depends on concentration (F) and water velocity (u).



Model simulation results

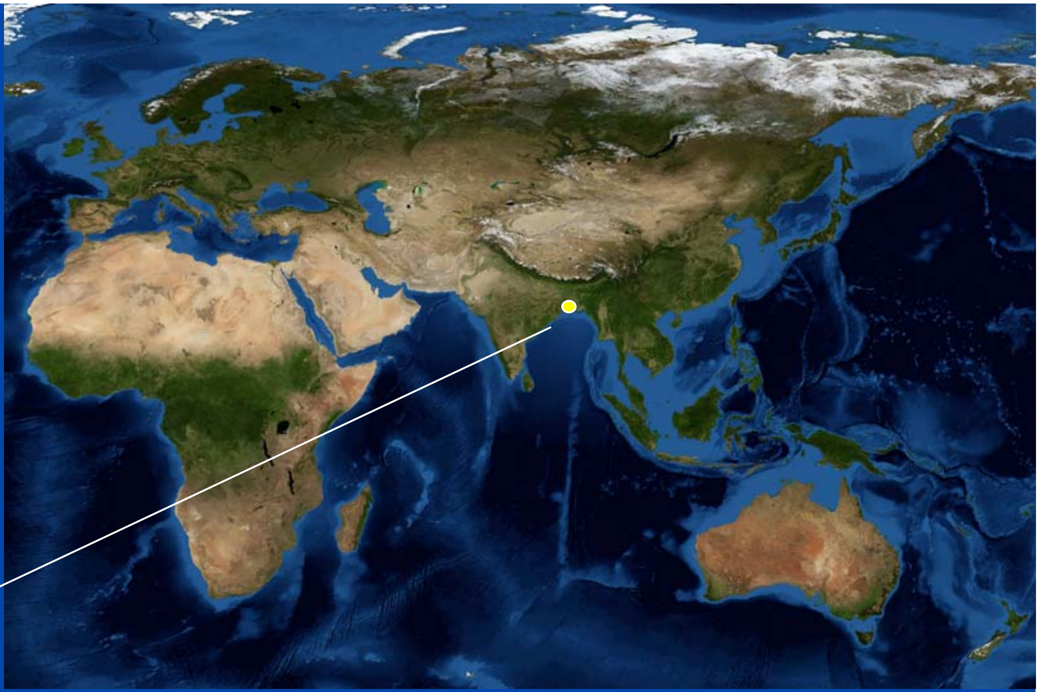


Discontinuous sedimentation, large depocenter shifts



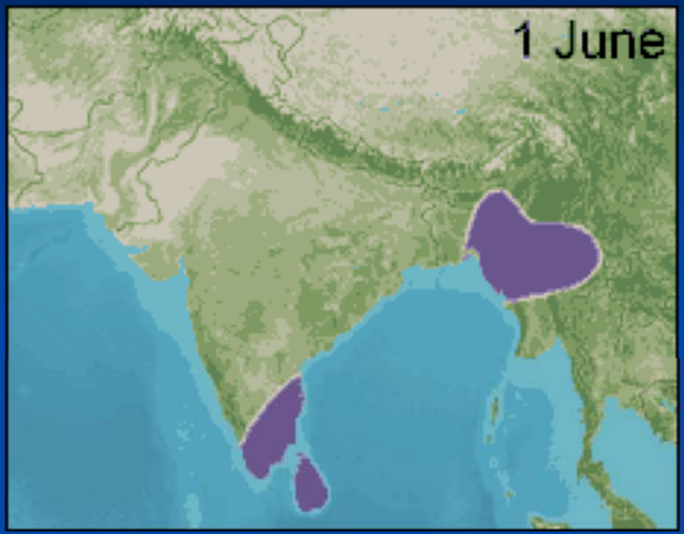
Drowning of delta brings muds
on top of sands

(Overeem et al., 2003)



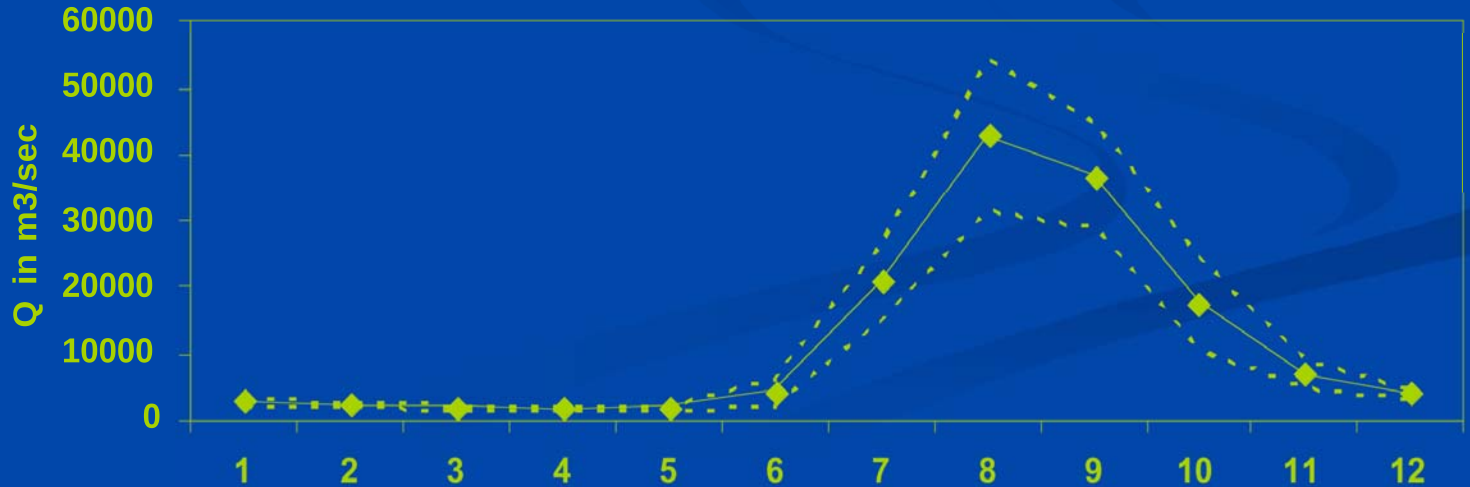
Ganges delta

Indian monsoon dominates Ganges



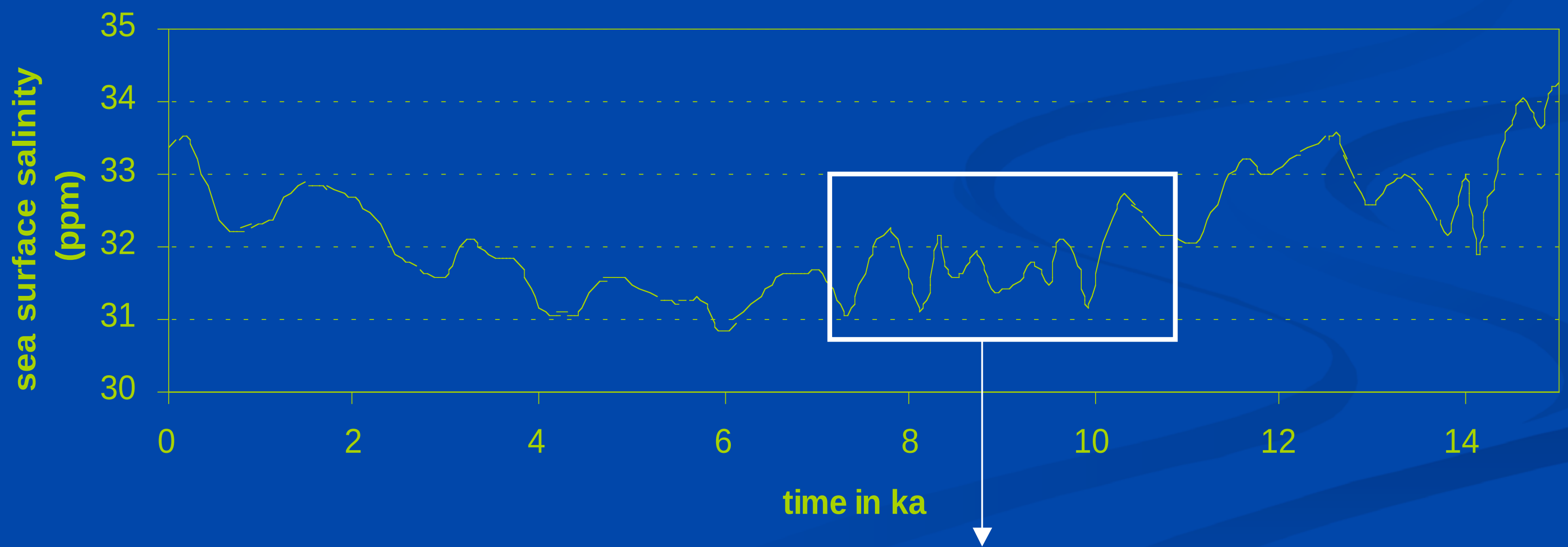
(Source: BBC weather, 2005)

Ganges River (Farakka station 1949-1973)



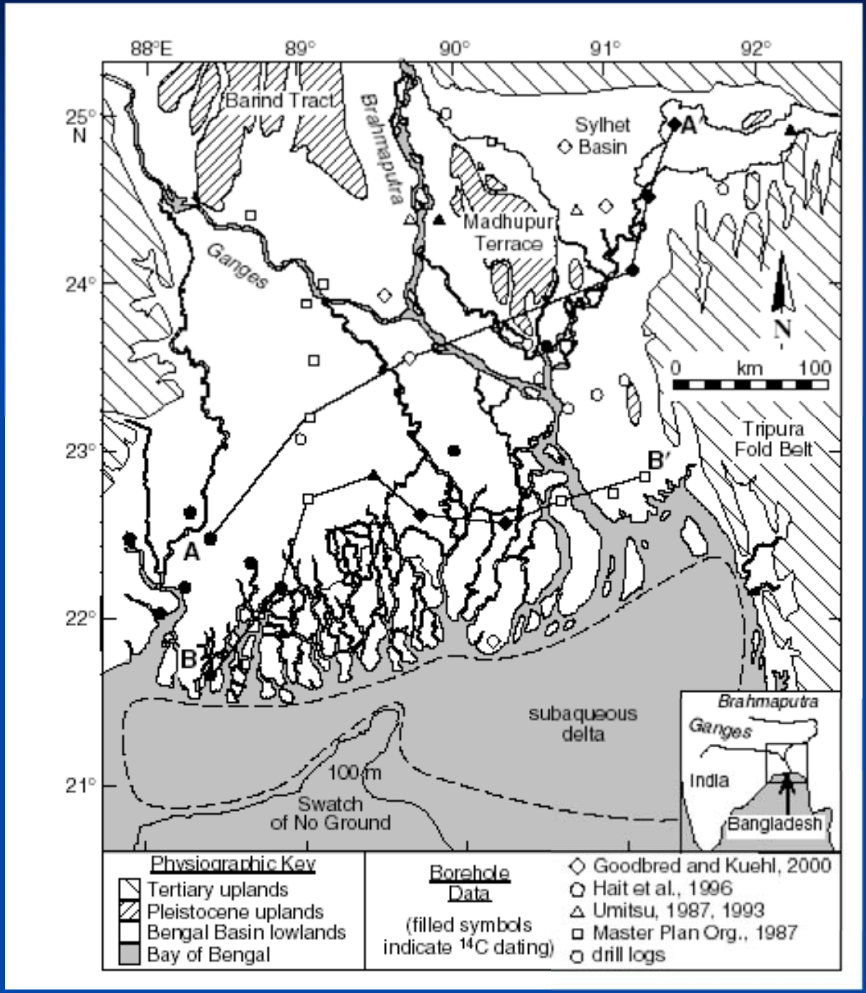
Longterm Indian Monsoon

Indian monsoon proxy: salinity in the Bengal basin (e.g. Kudrass et al., 2001). Indicates that paleo river discharges were higher.

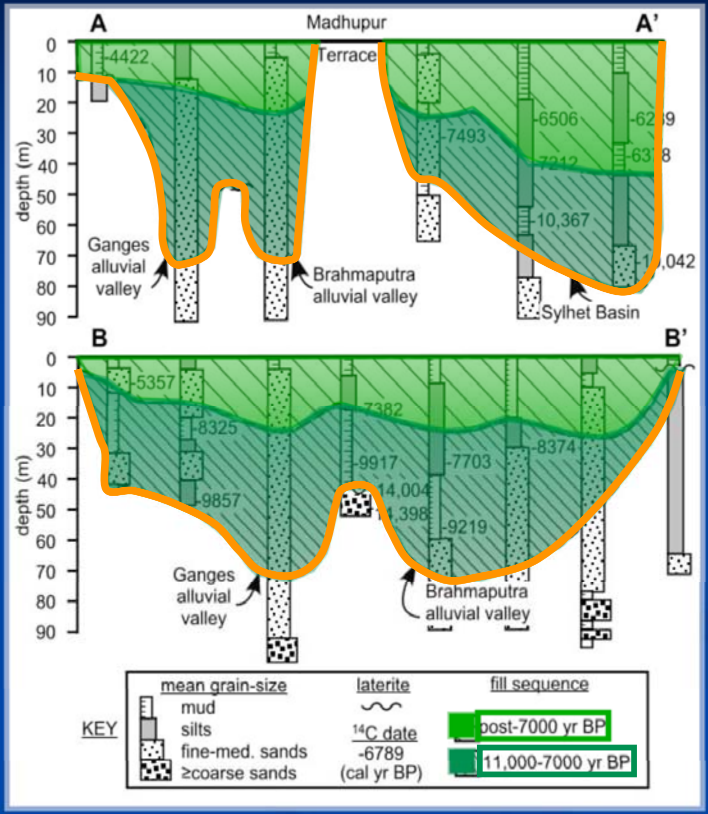


11 – 7 ka BP, exceptionally high Q

Sediment supply high at Early Holocene

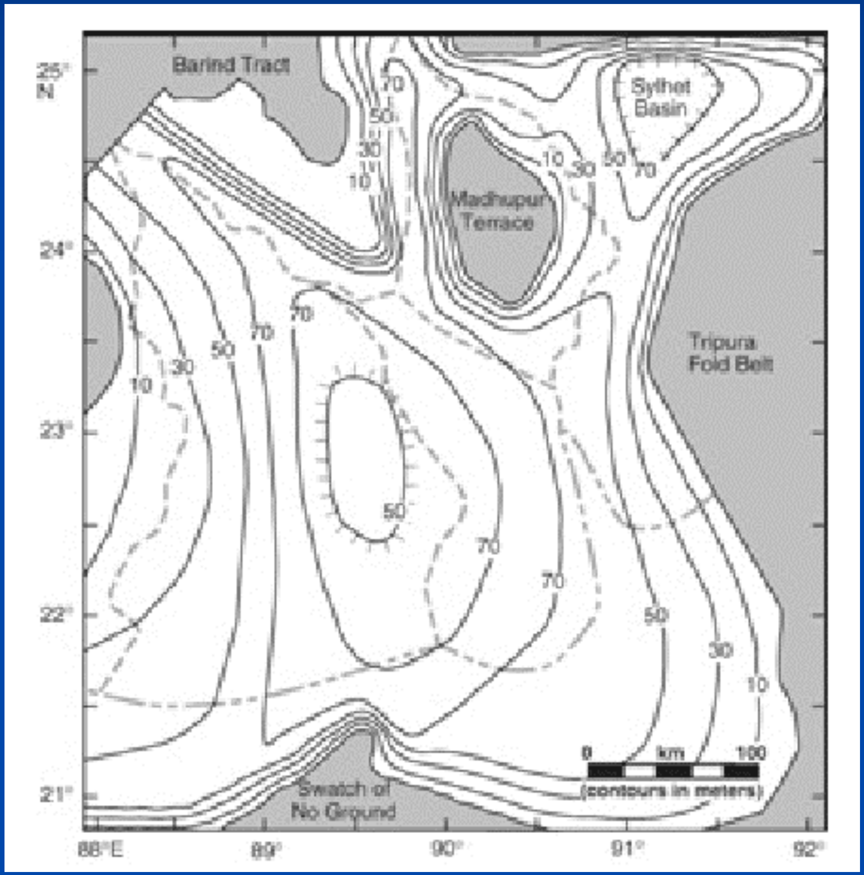


Floodplain and shallow coastal GB system: location of borehole data, which have grain size analysis and C^{14} dates.



Goodbred & Kuehl (1999, 2000)

Volume/Time of sediment stored in Ganges delta sequence tracks monsoonal record



Isopach map of Ganges-Brahmaputra sediments deposited in Bengal basin since 11 kBP.

Sediment volume is 8.5×10^{12} m^3, nearly 60% of which was stored from 11-7kBP. Implies 2.2 times higher flux at Early Holocene!

(Goodbred et al., 1999, 2000)

Sedflux Stratigraphic Model

3DSedFlux

INPUT(t)

sea level(t), bathymetry (t-0)
Q, Qs, Qb (HydroTrend)

PROCESSES

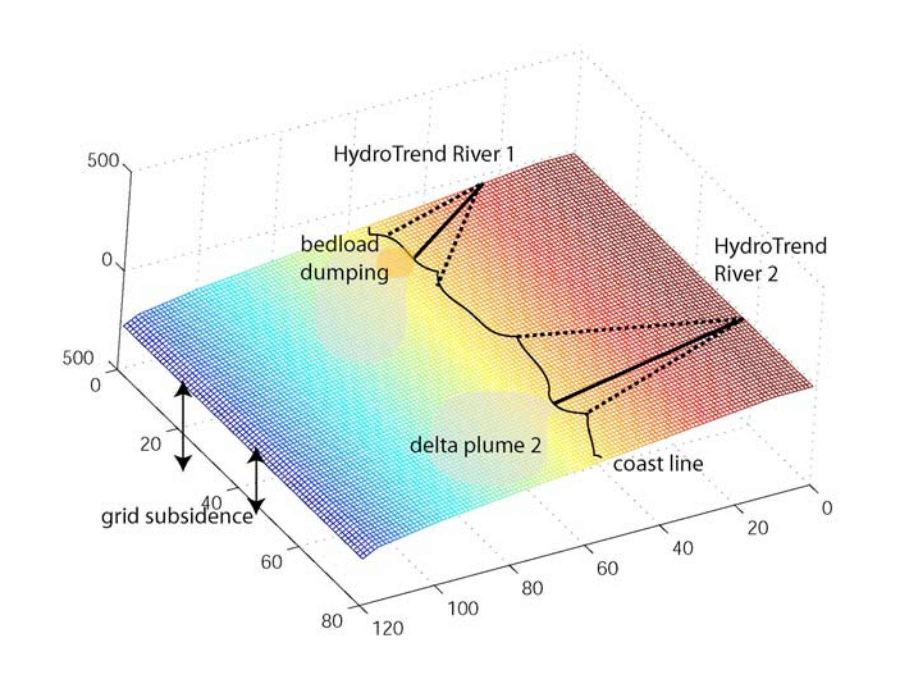
River: avulsion, floodplain SR
Marine: delta plume, storms
Basin: compaction, subsidence

OUTPUT (x,z,t)

- 3D-geometry
- grain size, age

Details and Equations:
Three-dimensional modeling of deltas
Overeem et al., 2005. SEPM Spec Publ.

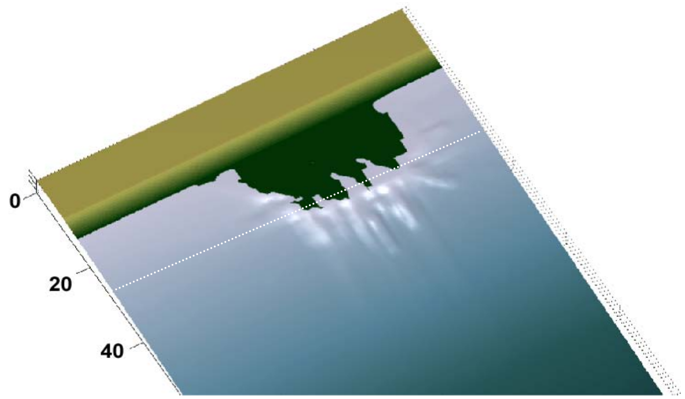
NEWEST Version: Hutton, Syvitski
(in press 2007), Computers and Geosciences.



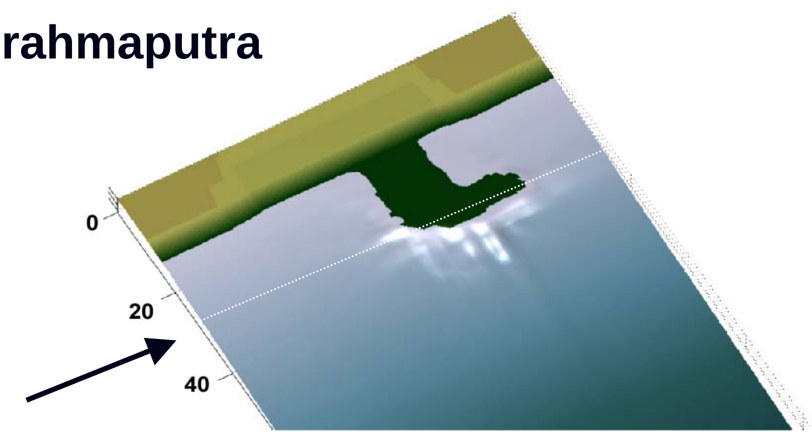
SedFlux simulation results

Present-day Monsoon Conditions

Ganges

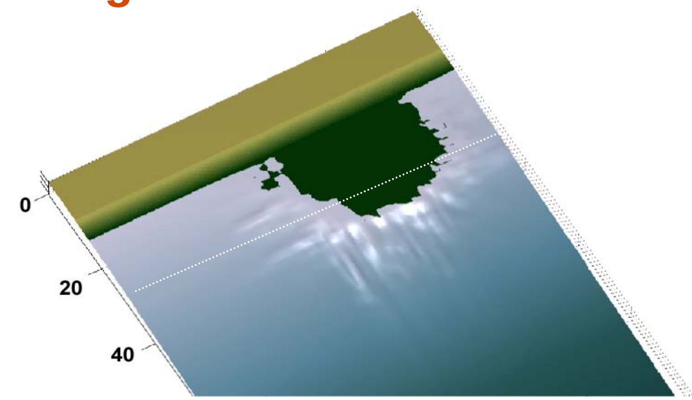


Brahmaputra



Increased Monsoon Conditions

Ganges

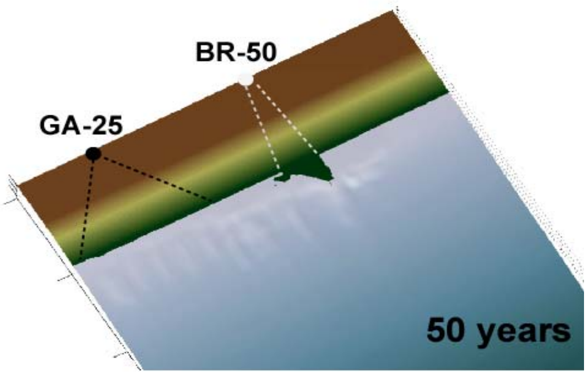


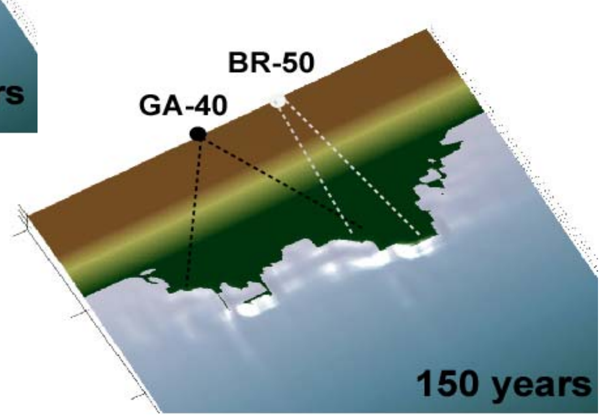
Brahmaputra

500 year experiments (SLR = 2 m per 100yrs)

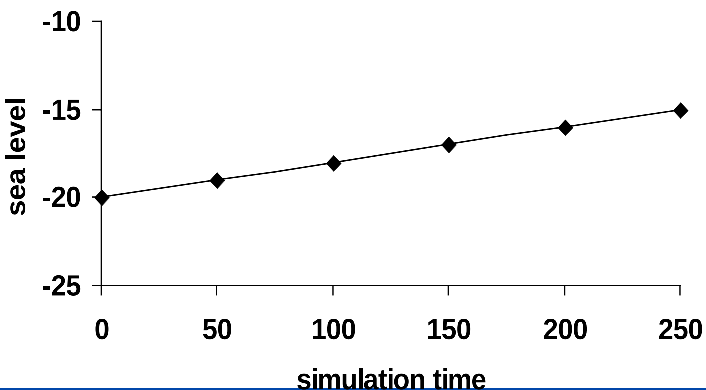
SedFlux simulations of rapid sea-level rise for a merging GB system

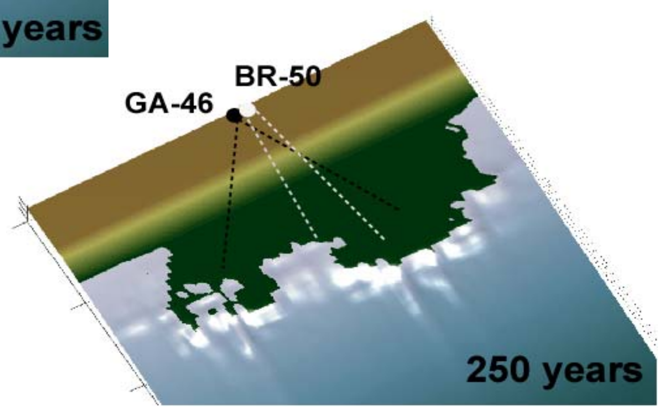
Present-day Monsoon Conditions





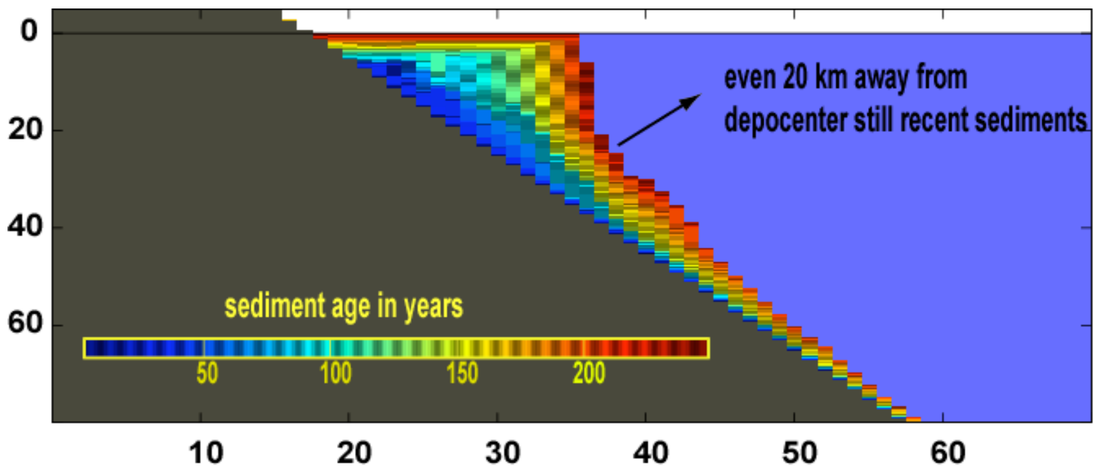
Sea-level rise 2 m/100 years



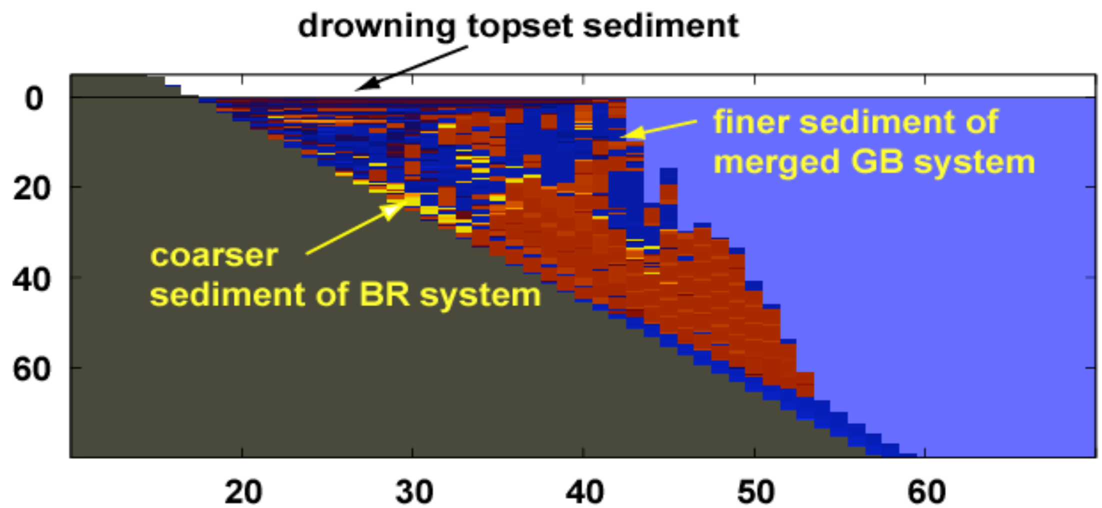


SedFlux simulations of rapid sea-level rise for a merged GB system

Y-section at 20 km; away from last depocenter



Y-section at 50km; centered through last depocenter

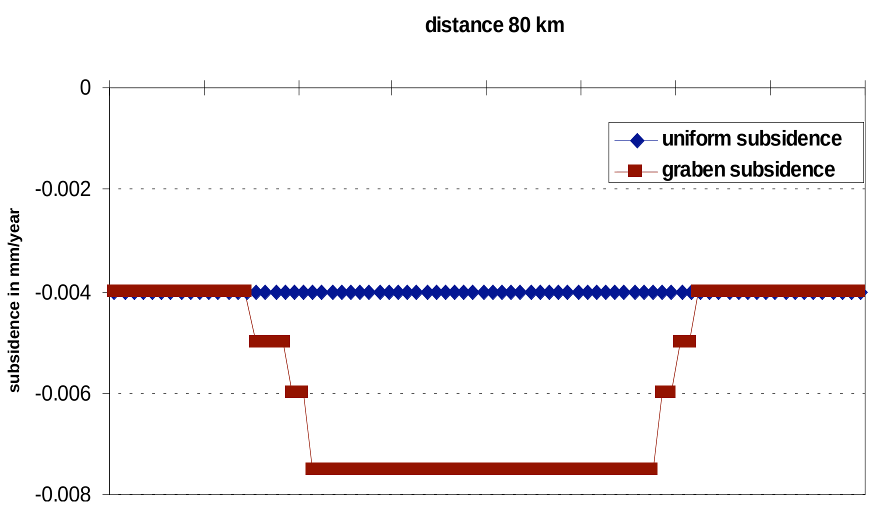


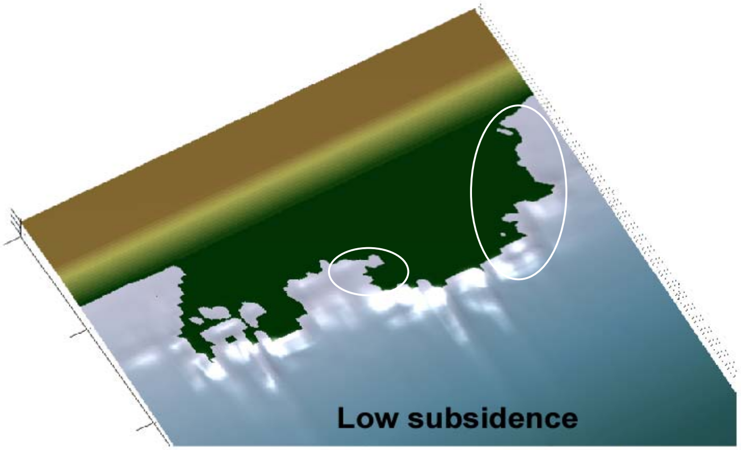
SedFlux simulations of rapid sea-level rise for a merging GB system

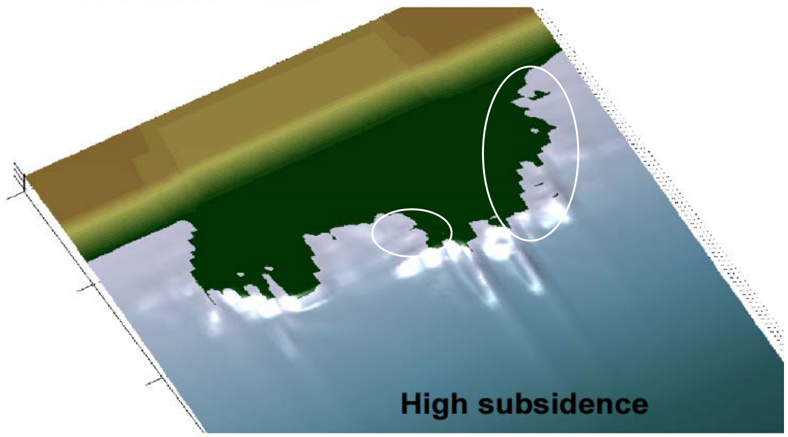
Present-day Monsoon Conditions
Different Subsidence Rates

'low subsidence'
4 mm/year uniformly over entire grid

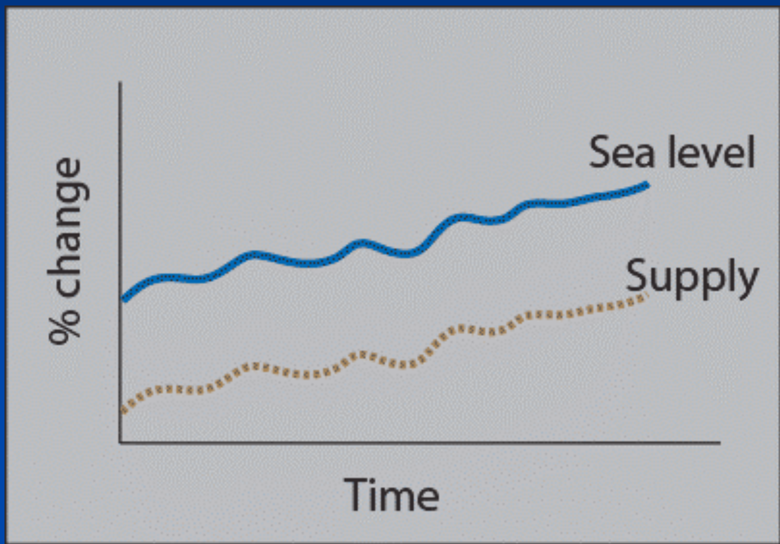
'high subsidence'
7.5 mm/year locally in 'graben'

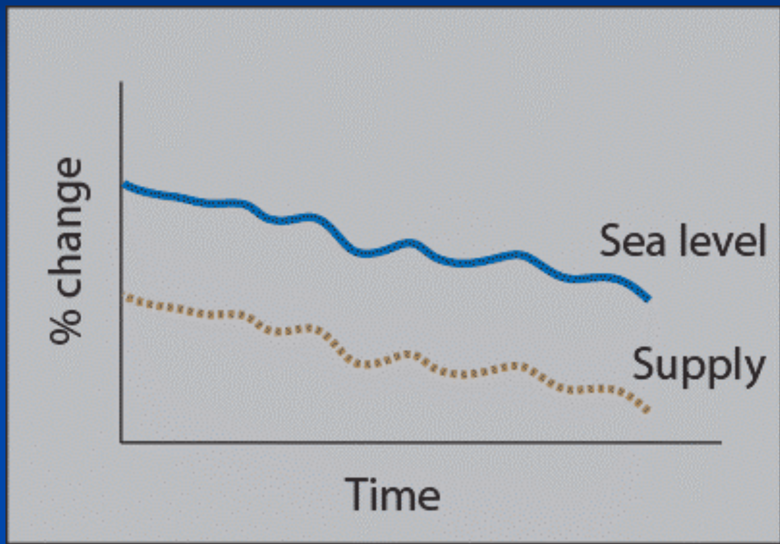






Concept: correlated controls





Implication: delta system is more resilient to rising sea-level, because it is able to build rapidly.

Implication: change is amplified, i.e. delta system is rapidly prograding due to emergence.

Discussion

- Interacting forces can be explored with numerical modeling. Several processes/modules need further research, notably supply mechanisms, and floodplain sedimentation.
- Deltas that have high sediment supply rates may be more resilient to sea-level change.