Long-term morphodynamic modelling of the GBM Delta at macro scale

Dano Roelvink, Mick van der Wegen and Johan Reyns
IHE Delft & Deltares

Upal Mahamud, Ziaur Rahman, Syed Arefin
IWM

Supported by the World Bank and
Bangladesh Water Development Board

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Ministry of Water Resources

Bangladesh Water Development Board

Coastal Embankment Improvement Project, Phase-I (CEIP-I)

Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics)

Macro scale morphology
current situation - interim report

Joint Venture of DHI The expert in WATER ENVIRONMENTS & Deltares Enabling Delta Life

in association with IWM, Bangladesh and University of Colorado, Boulder and Columbia University

November 2020

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University of Colorado, Boulder, USA
Columbia University, USA

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Long-term Monitoring, Modelling and Analysis of the Bangladesh Coastal Zone

- Objectives
  - to create a framework for polder design, based on understanding of the long-term and large scale dynamics of the delta and sustainable polder concepts.
  - modelling to improve our understanding of the long-term and large-scale dynamics of the Ganges-Brahmaputra-Meghna (GBM) delta.

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Objectives of large-scale modelling

- Large-scale tidal propagation and flow distribution
- Sand and fine sediment distribution
- Pathways for fine sediment
- Morphology of major channels on decadal scales
- To provide boundary conditions to smaller-scale models.

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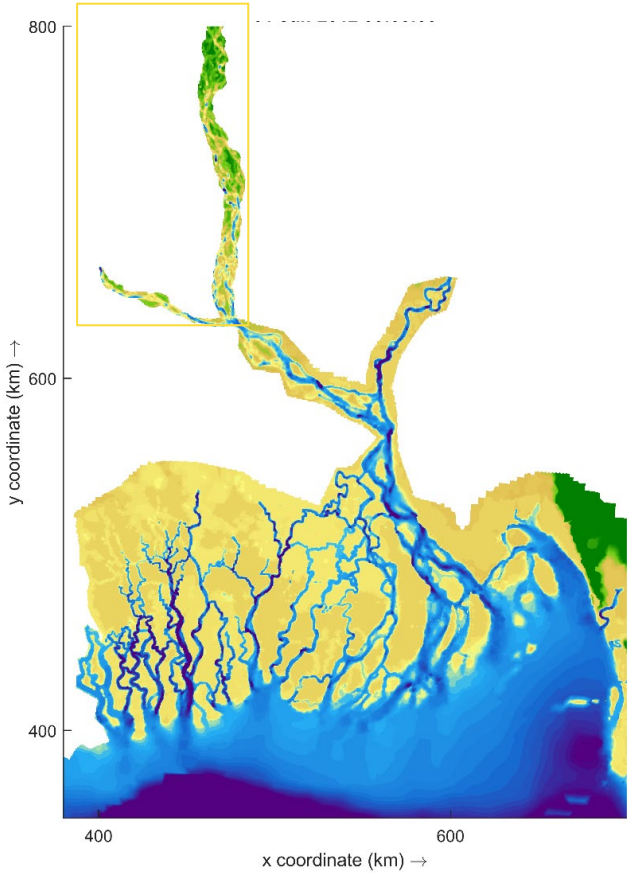
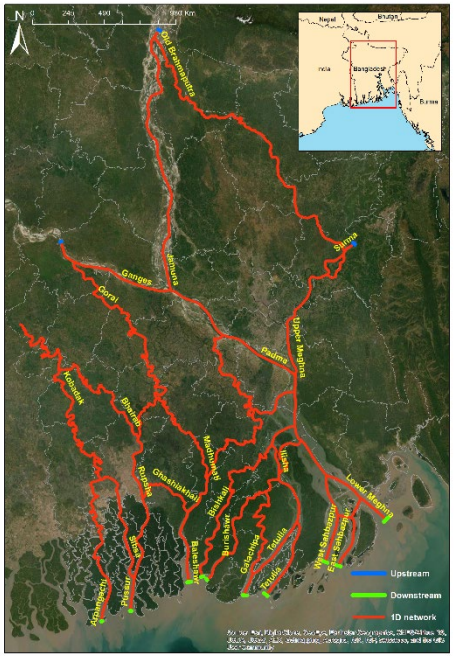
Approach

- Macro-scale 2DH model
  - Resolution from 8km to 500m
  - Coarse but fast
- Macro-scale 1D model
  - Covers major branches
  - Good representation of cross-sections
  - Lean and mean





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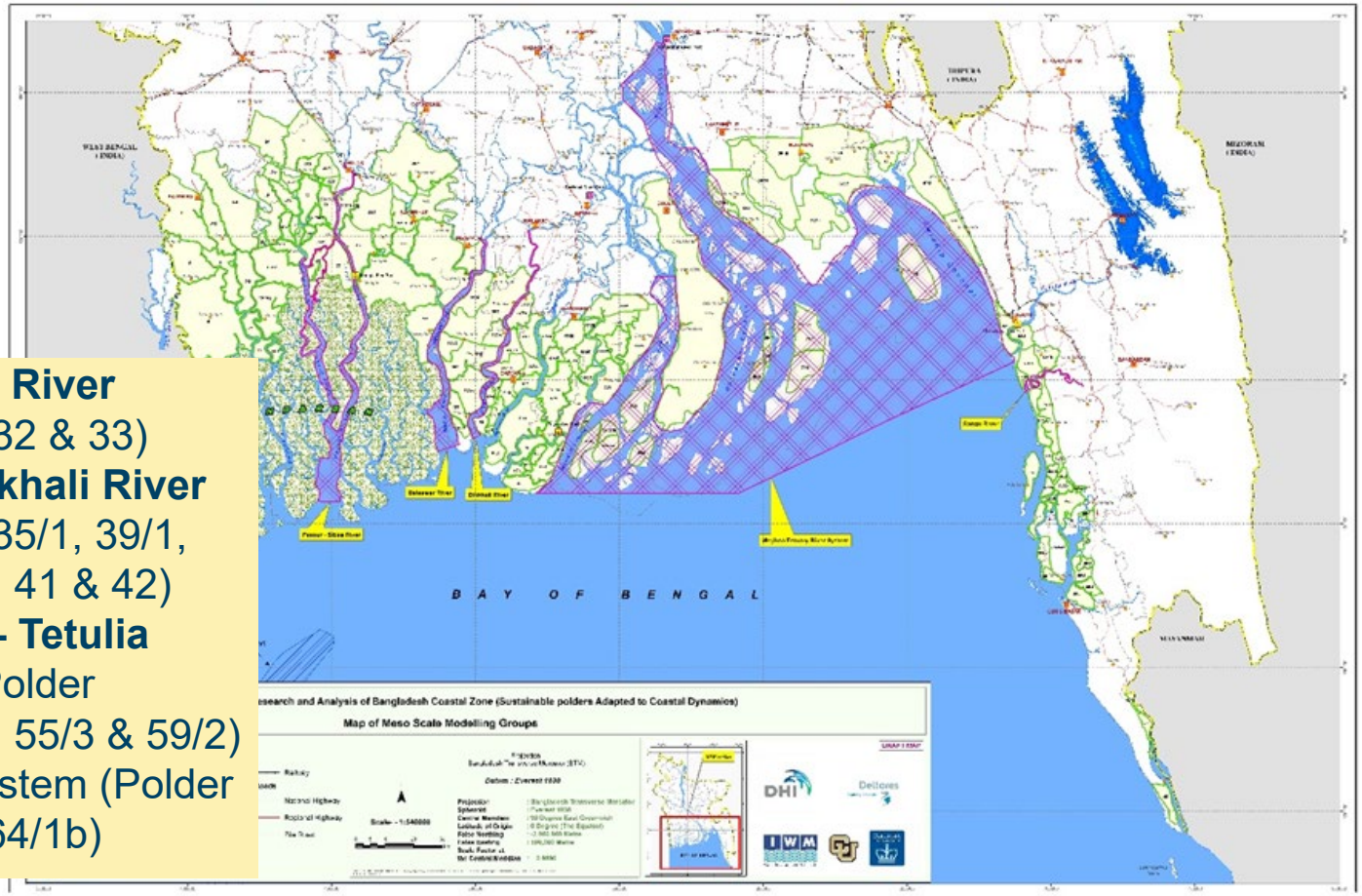
Mesoscale models



- **Pussur – Sibsa River** system (Polder 32 & 33)
- **Baleswar – Biskhali River** system (Polder 35/1, 39/1, 39/2, 40/1, 40/2, 41 & 42)
- **Lower Meghna- Tetulia River** system (Polder 56/57,55/1,55/2, 55/3 & 59/2)
- **Sangu River** system (Polder 63/1a, 63/1b & 64/1b)

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Macro-scale 2D model approach

- Unstructured-grid model of the entire GBM delta and a large part of the Bay of Bengal
  - Boundary conditions:
    - Rivers: discharges and concentrations
      - Hardinge Bridge (Ganges)
      - Bahadurabad (Jamuna)
      - Bhairab Bazar (Meghna)
    - Sea: tidal components

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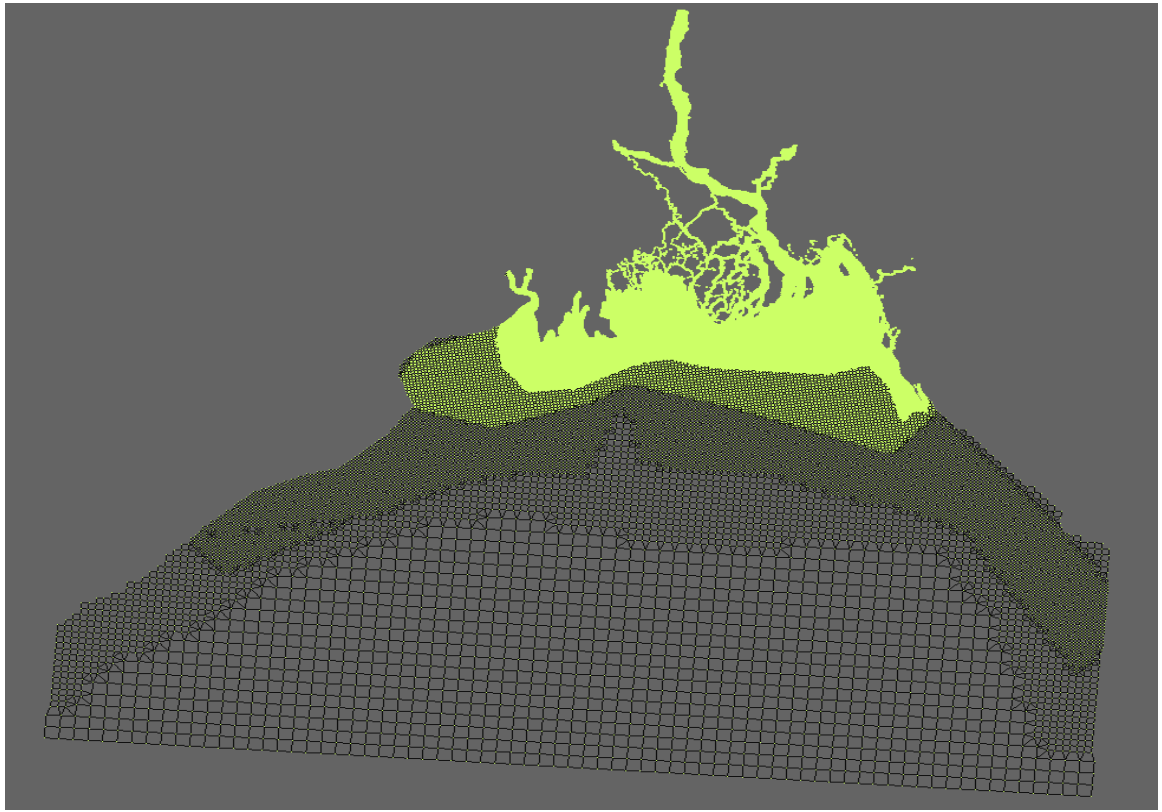
Grid

- Started by very coarse 16 km grid
- Within successive polygons, refinement by factor 2
- Smallest grid size 500 -> 250m



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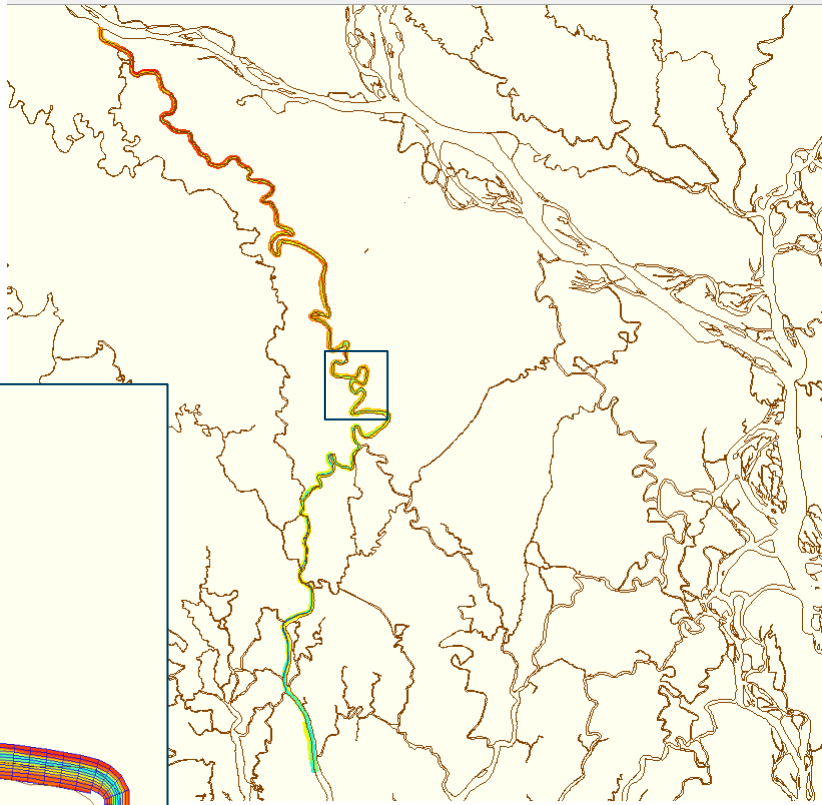
Including Gorai river

- Complex and relatively narrow
- Important contribution to sediment and salinity Sundarbans
- Included as curvilinear section



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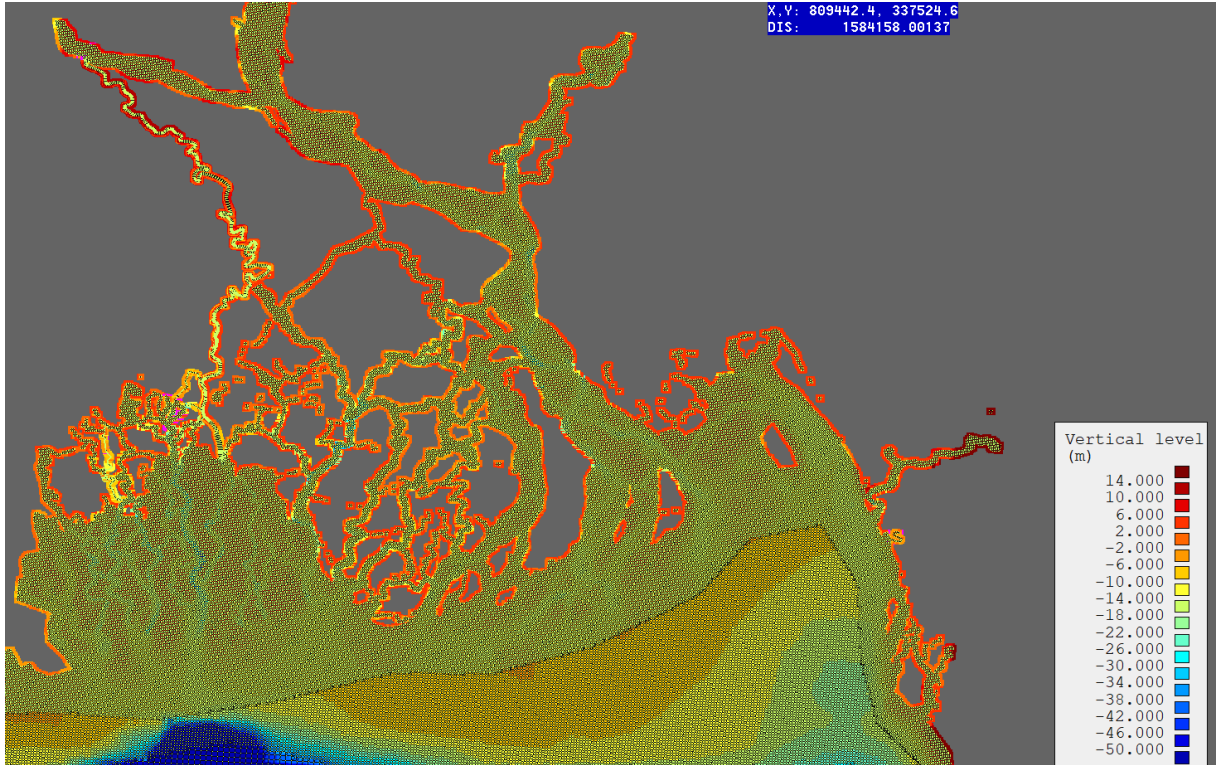
Grid

- Detail of main rivers
- Some rivers, e.g. Gorai, added as curvilinear sections



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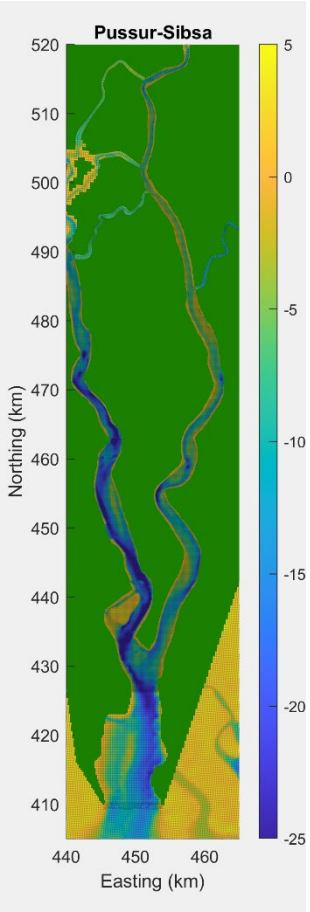
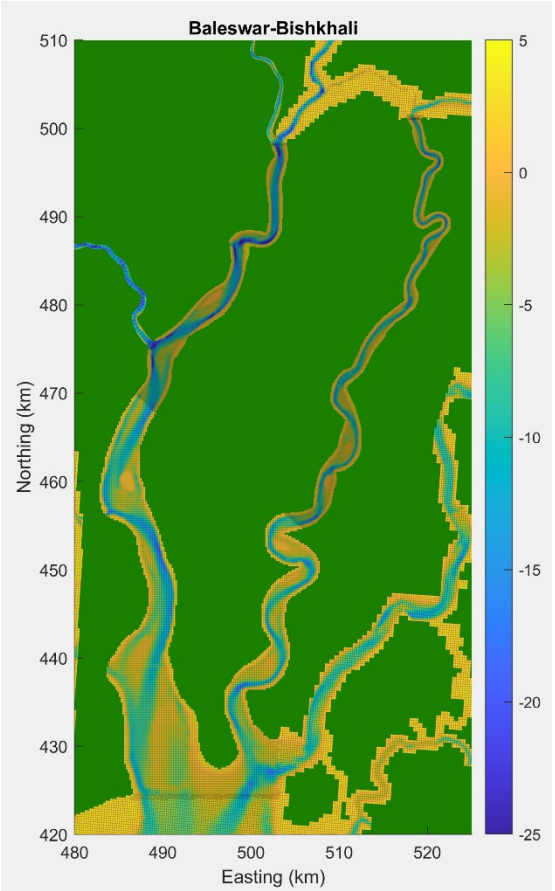
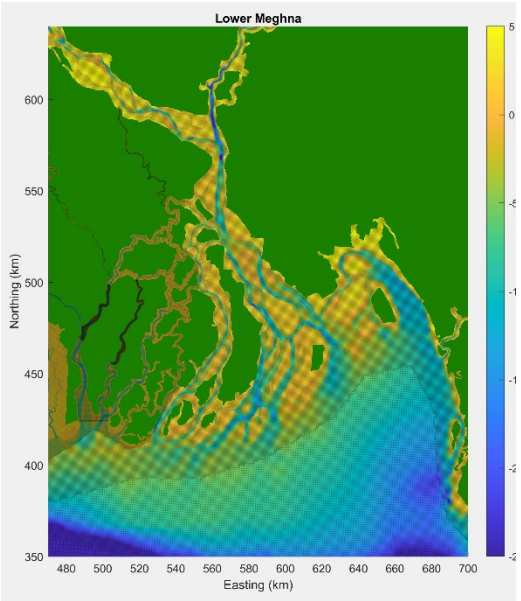
Details of macro 2D grid







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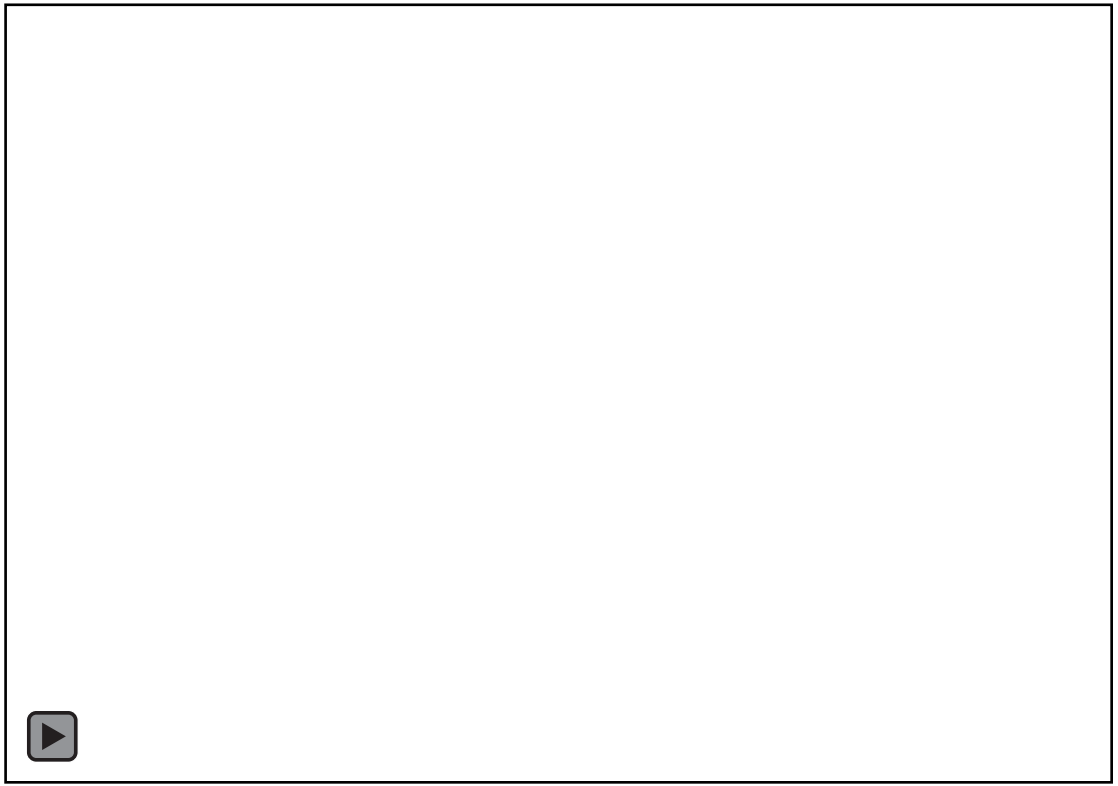
Water level variation



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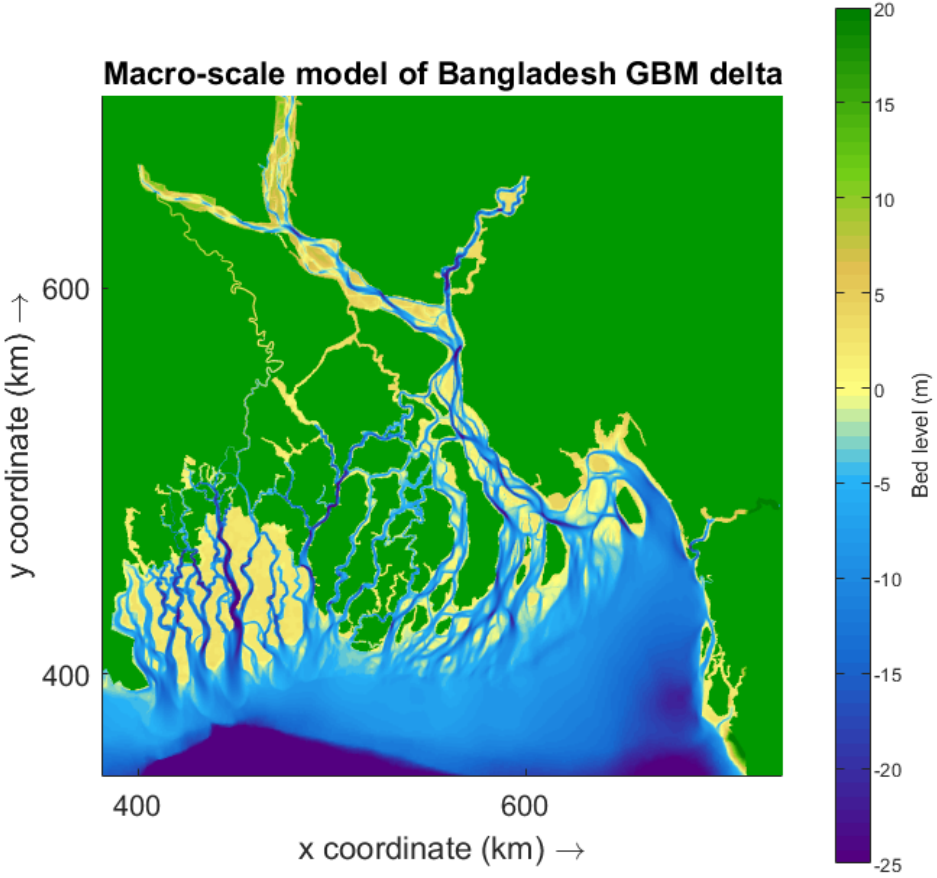
Final macro-scale model

- Includes all major connections
- Channels in larger rivers free to move
- Discharges Ganges, Jamuna and Meghna
- Sea boundary southern Bay of Bengal by astronomic components



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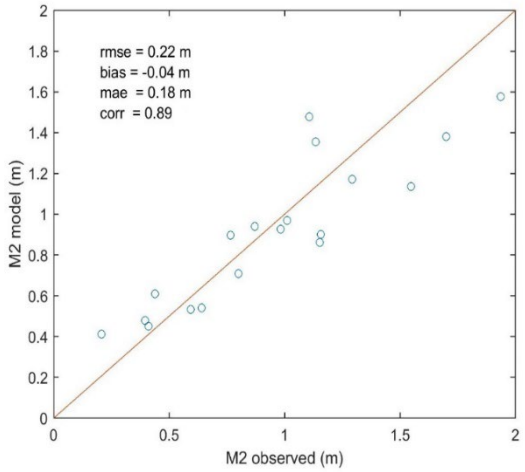
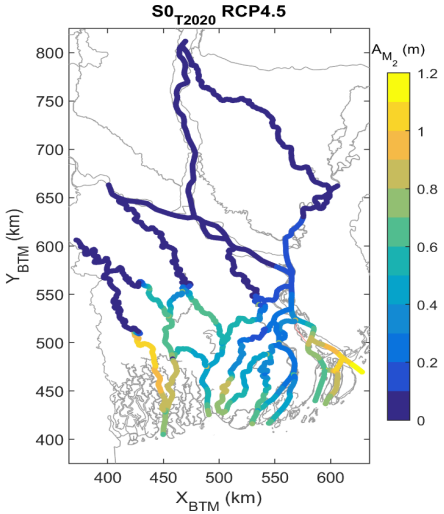
Macro-scale models

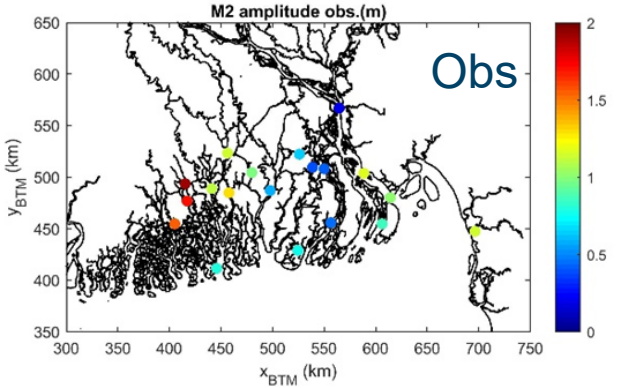
- Hydrodynamics calibrated on M2

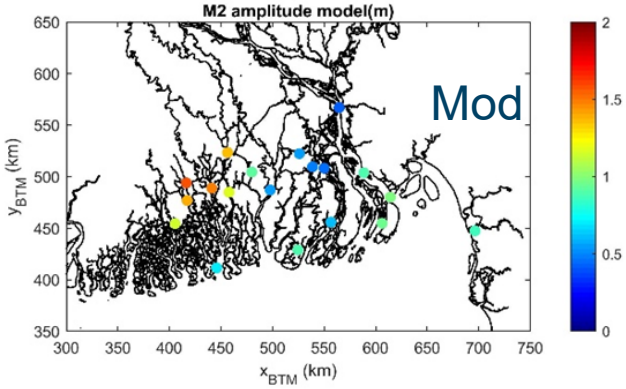


Model vs. Obs. M2



1D model results





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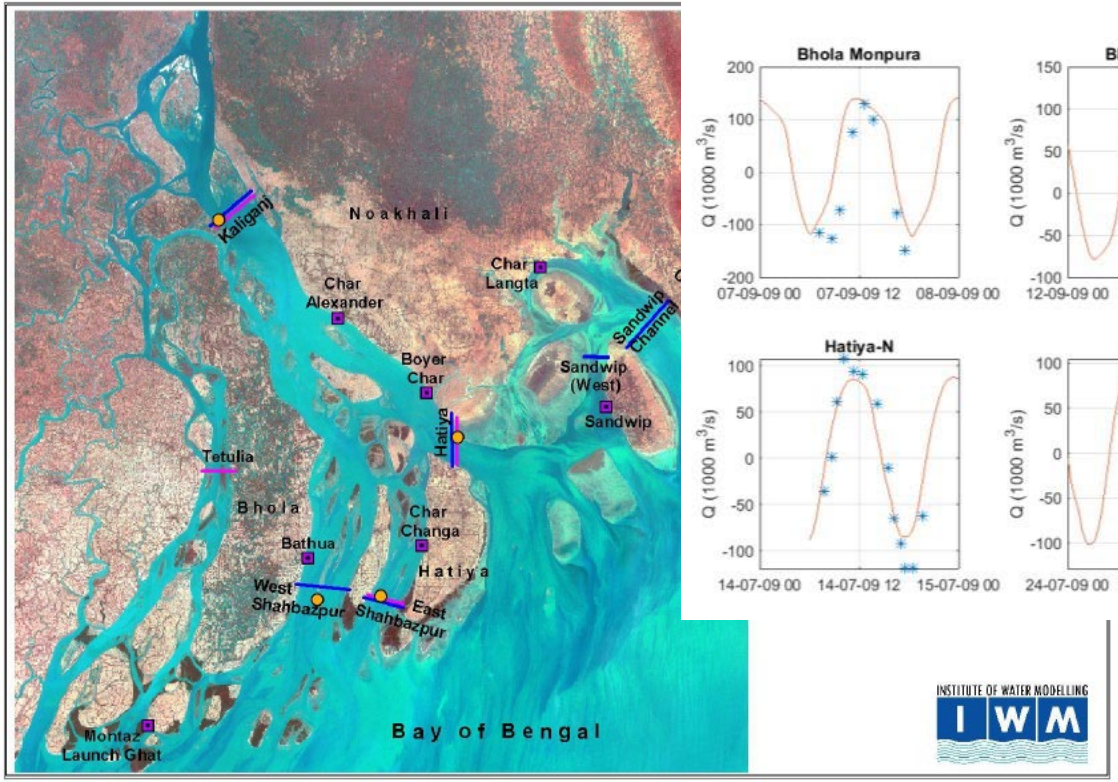
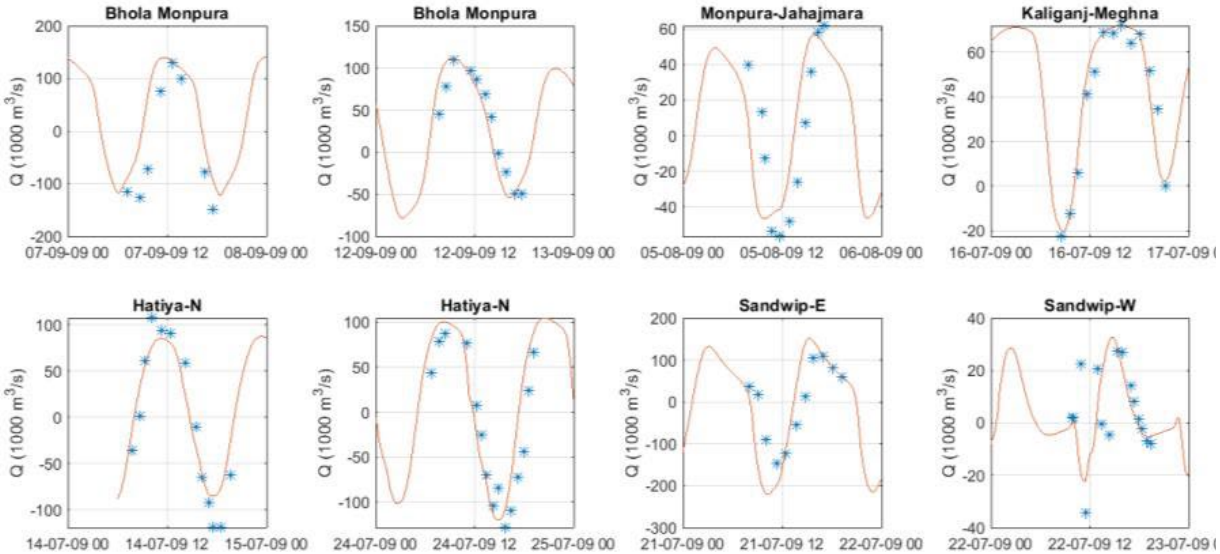
Validation of discharges





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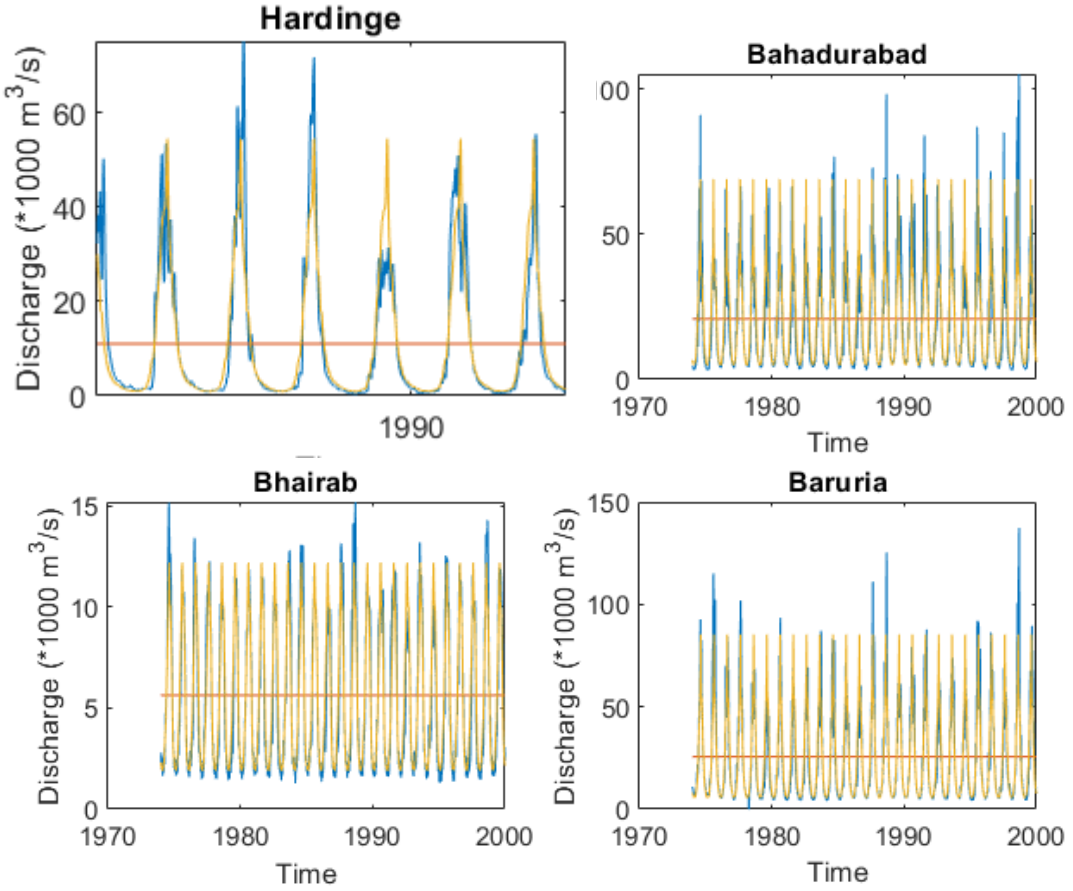
Discharge

- Representative hydrograph for each river
- Shift each year so peak day coincides and then average
- In long-term runs we accelerate this yearly hydrograph to a 14-day cycle
- 1 hydraulic year = 26 morphological years



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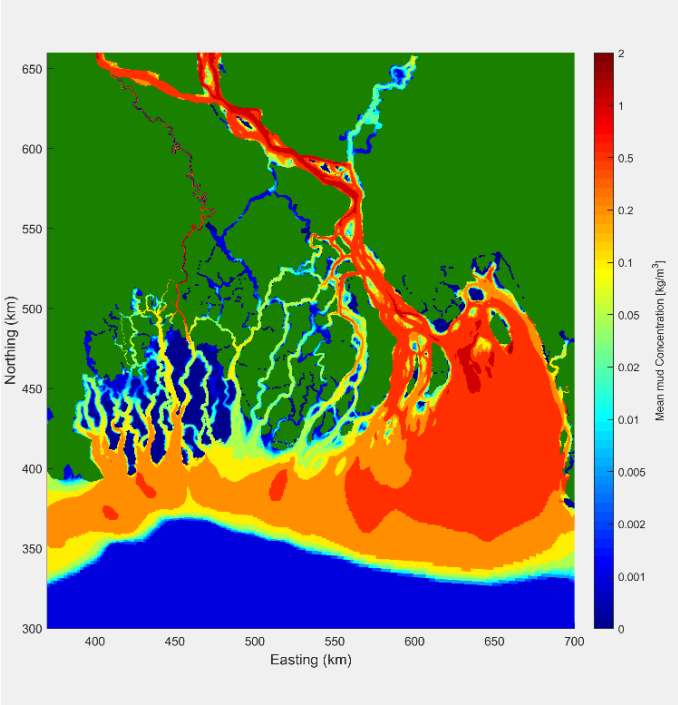
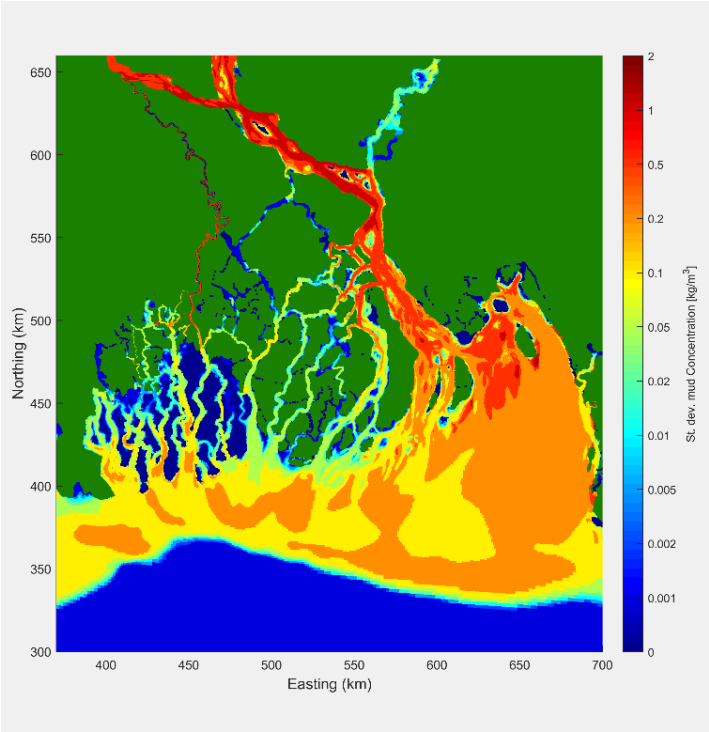
Mean concentration pattern



standard deviation



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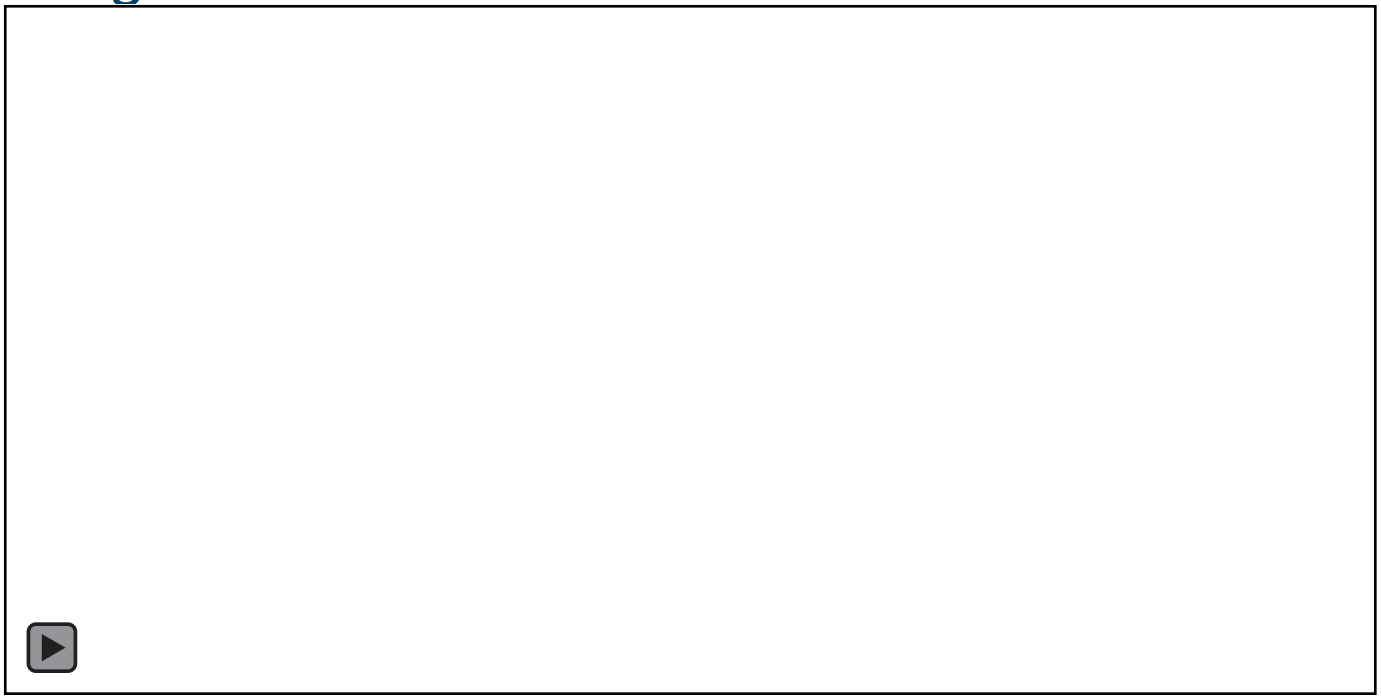
Bed level change 2000-2025



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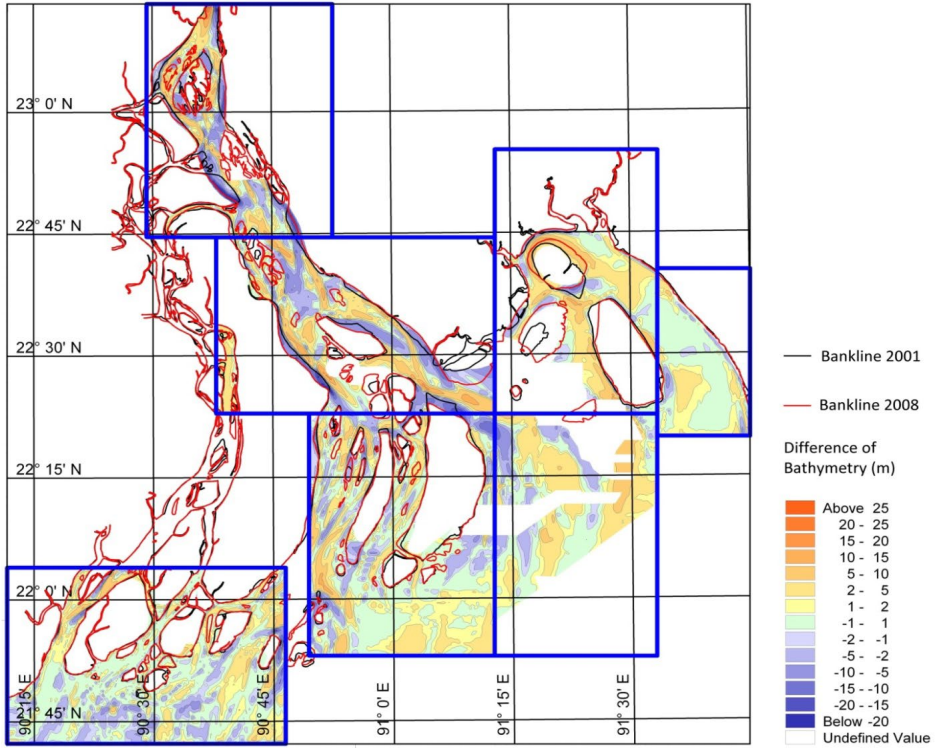
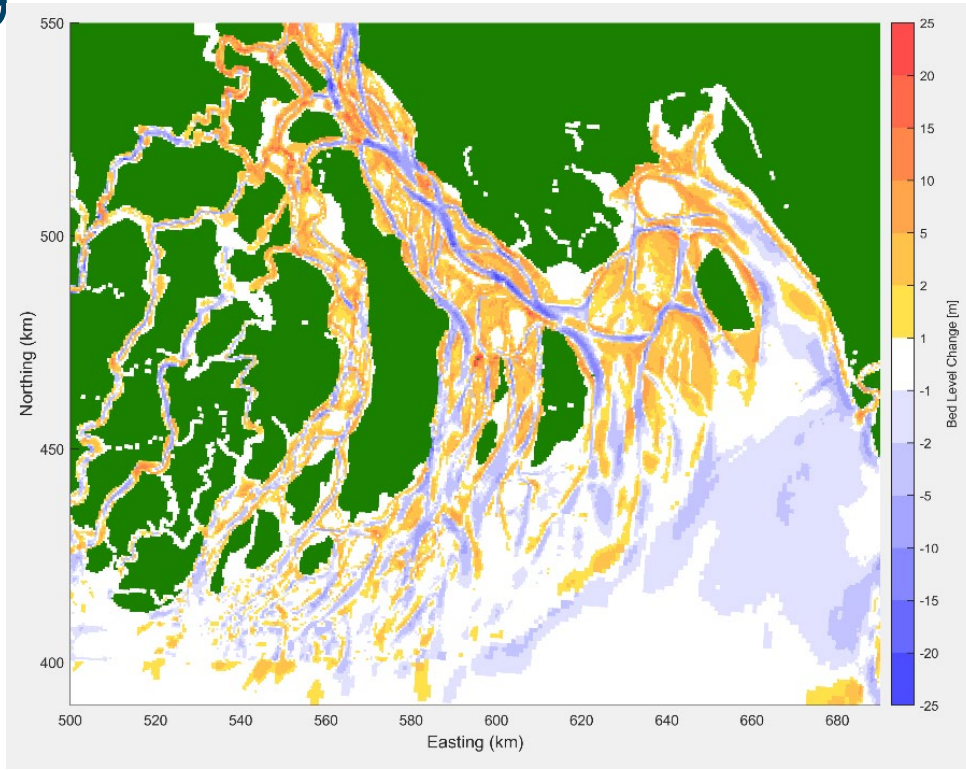
Bed level changes 2000-2009





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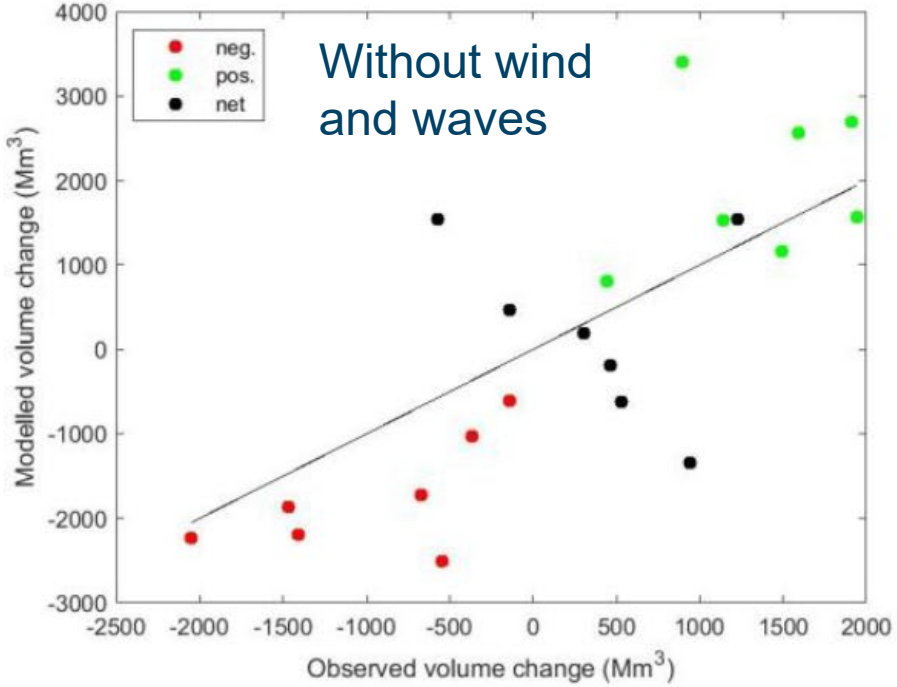
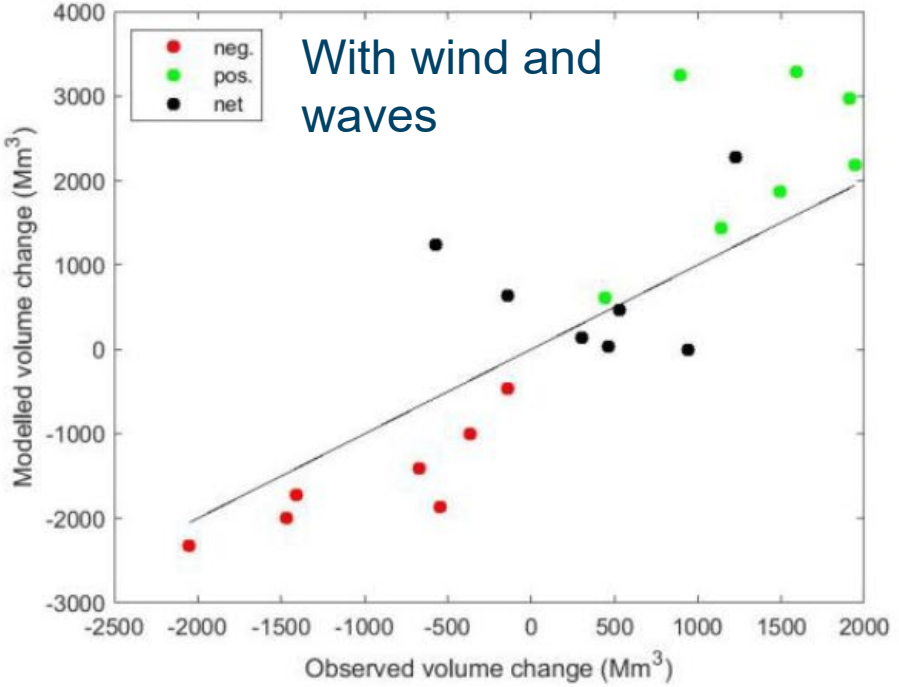
Volume changes per area





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Conclusions report Current Situation

- The macro scale morphodynamic model runs robustly on a 25-year timescale, with acceptable run times (in the order of days on a cluster)
- Some important parameters have been identified and a clear parameter setting has been arrived at.
- This setting leads to a physically reasonable distribution of bed sediment, concentration patterns, net sedimentation areas including delta top set, and erosion hotspots.
- The model shows a predictable behaviour as a function of processes and boundary conditions;

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Conclusions (cont'd)

- A detailed validation over a ~9 year period shows reasonable agreement for gross and net volume changes and general patterns; there is an overestimation of overall sedimentation, erosion and net volume changes by factor 1.6, which is well within an acceptable range for morphodynamic models.
- Straightforward boundary conditions can be applied that are easy to adjust to future scenarios.
- In short, the macro-scale model has been developed to an acceptable level and can serve as a basis for future scenario runs.

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Issues macro-scale model runs

- More refinement needed and several curvilinear branches added
- Validation of discharges in more branches
- Update of bathymetry for 2020
- Issues with subsidence maps
- Gorai deepens and takes over from Ganges ..,
- Dry cell erosion works fine in lower Meghna estuary but attacks Sundarbans
- Unrealistic erosion of estuaries in India, affecting Sundarbans

All addressed and explained in Appendix D

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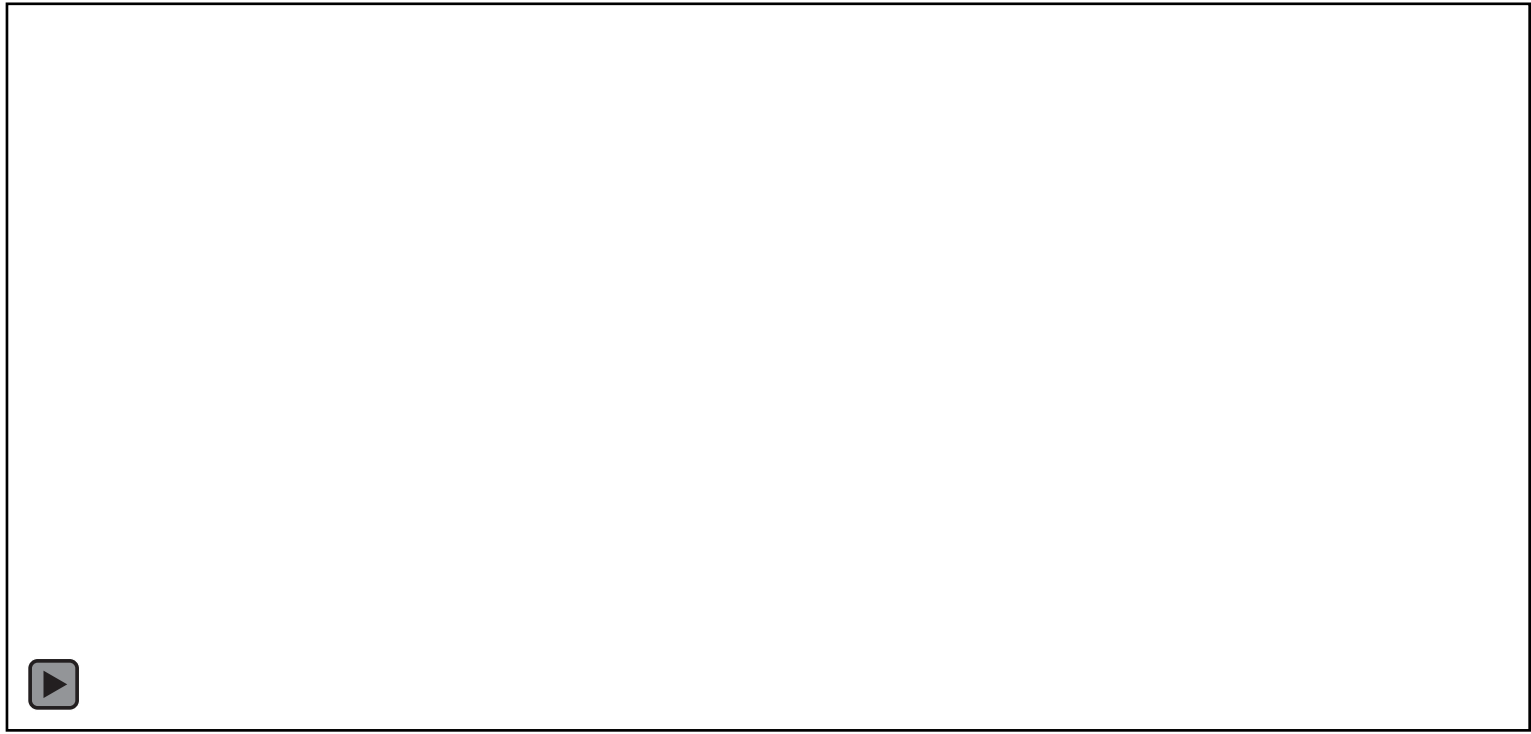

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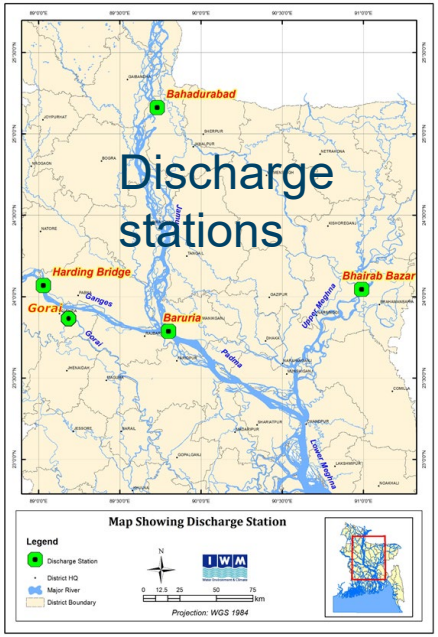
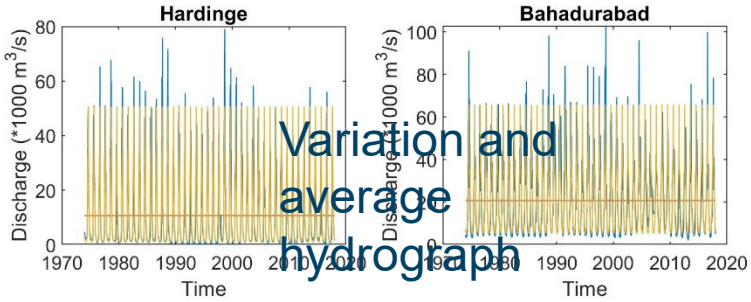
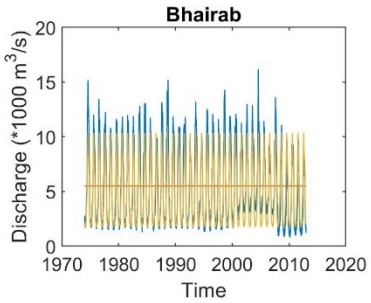
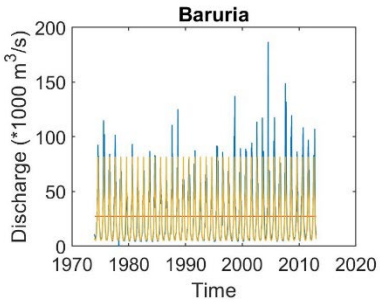


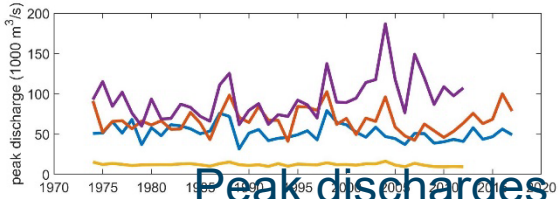
Discharge stations

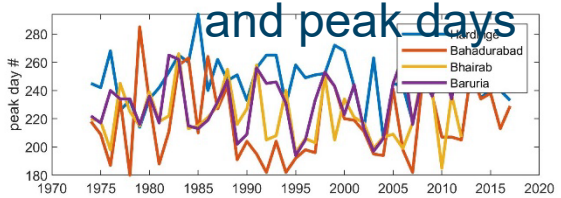


Variation and average hydrograph

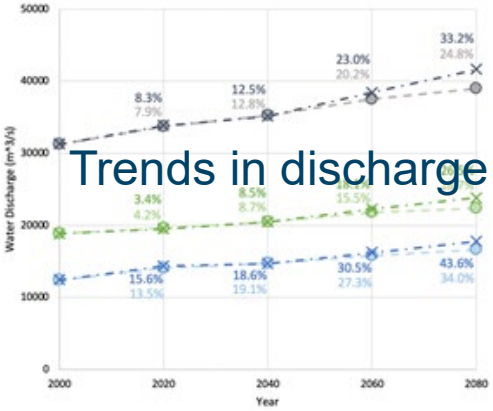




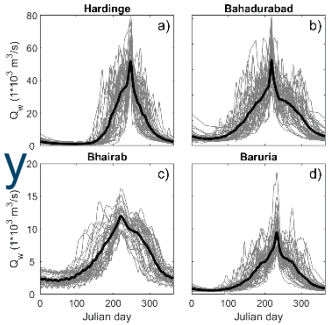




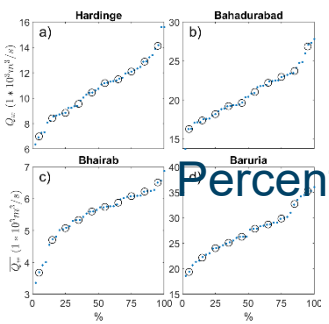
Peak discharges and peak days



Trends in discharge



Variability in yearly hydrographs



Percentiles

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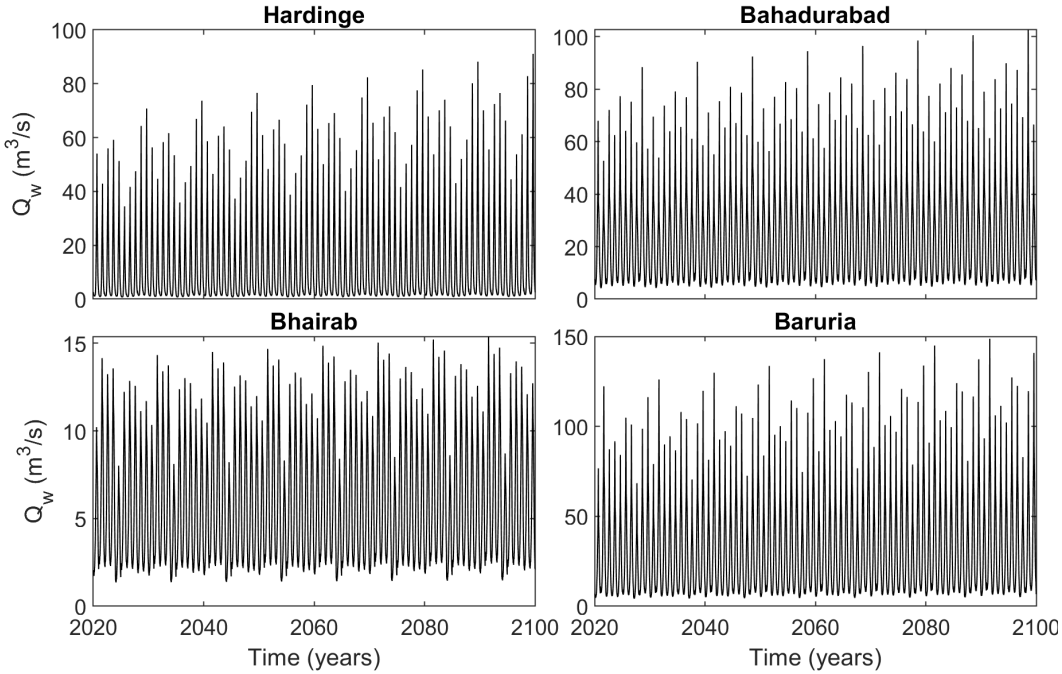
Example time series 2020-2100 RCP8.5



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Scenarios

Run	SLR	Discharge	SSC	Subsidence	Purpose
r043	0.0	$HYD_{RCP4.5}$	present value	yes	no SLR
r047	0.5	$HYD_{RCP4.5}$	present value	yes	moderate SLR
r042	1.0	$HYD_{RCP4.5}$	present value	yes	high-end SLR (standard scenario)
r044	0.5	$HYD_{RCP4.5}$, anthro. decrease	present value	yes	decreased discharge due to damming
r045	1.0	$HYD_{RCP8.5}$	present value	yes	high-end CC for SLR and Q
r046	0.5	$HYD_{RCP4.5}$, anthro. decrease	present value	no	Influence subsidence, decreased discharge due to damming
r050	0.5	$HYD_{RCP4.5}$, anthro. decrease	50% present value	yes	Influence reduction sediment delivery, decreased discharge due to damming

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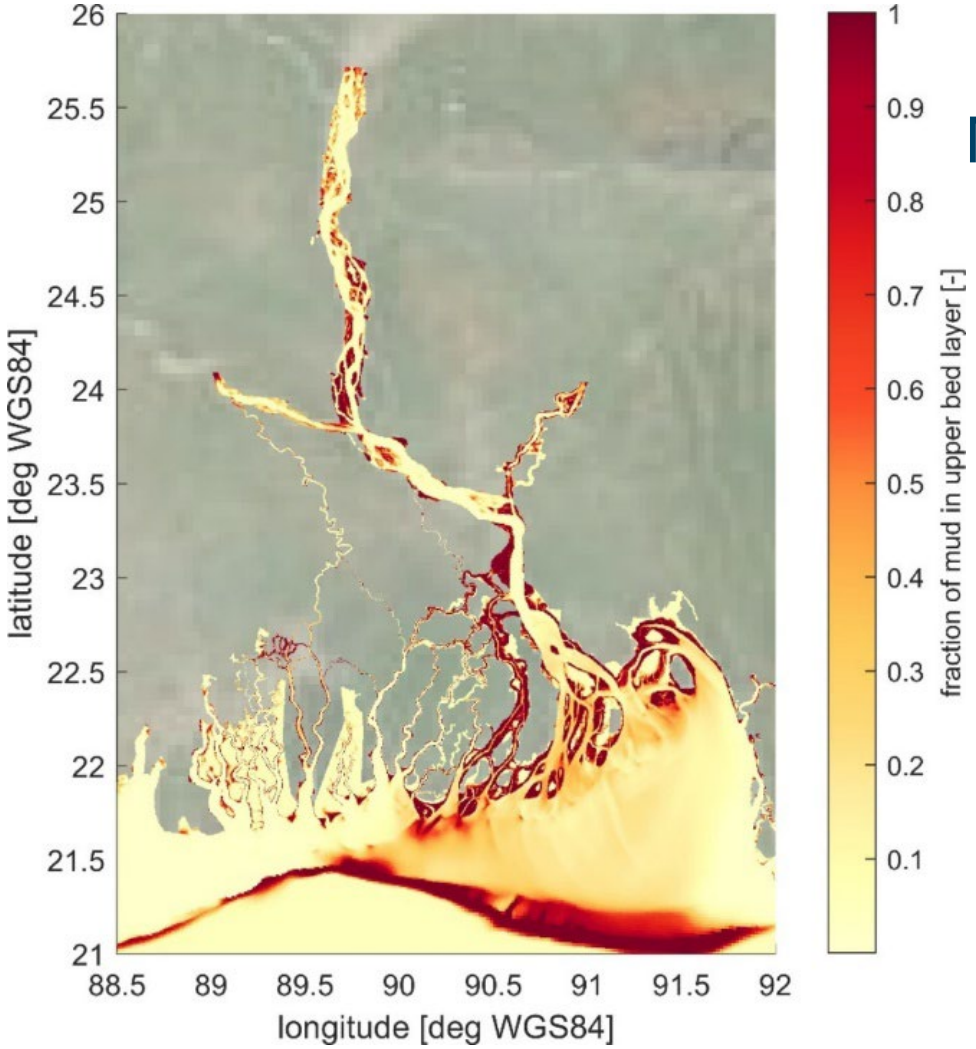
Table 3.4 Runs used to assess process effects 2D model simulations.

Scenario	Run difference
Effect SSC reduction	r048-r044
Effect subsidence	r044-r046
Effect RCP8.5 vs RCP4.5 on Q	r045-r042
Effect damming on Q	r044-r047
Effect 1m SLR	r042-r043

Mud percentage in bottom



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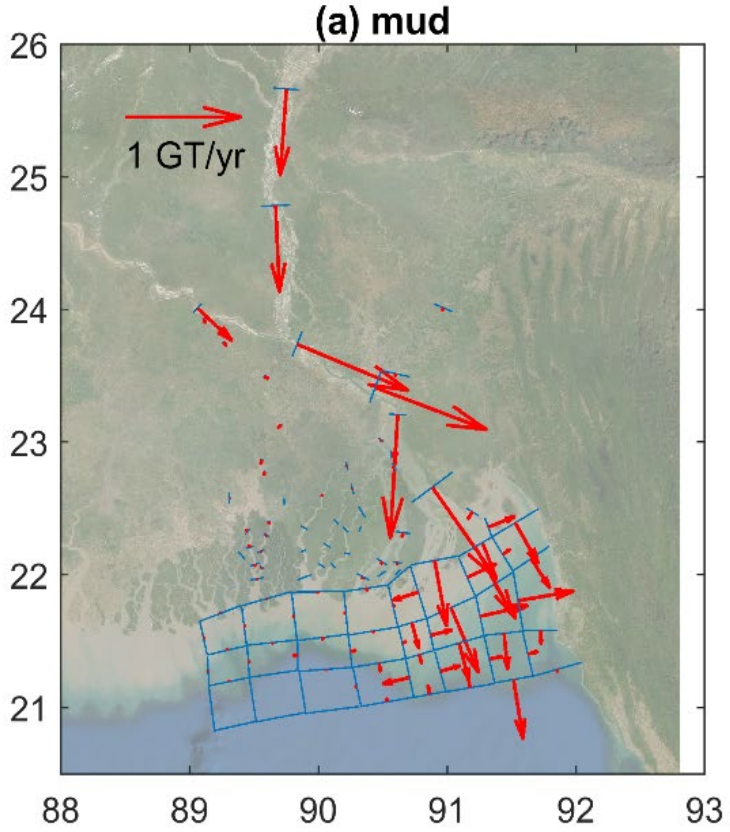
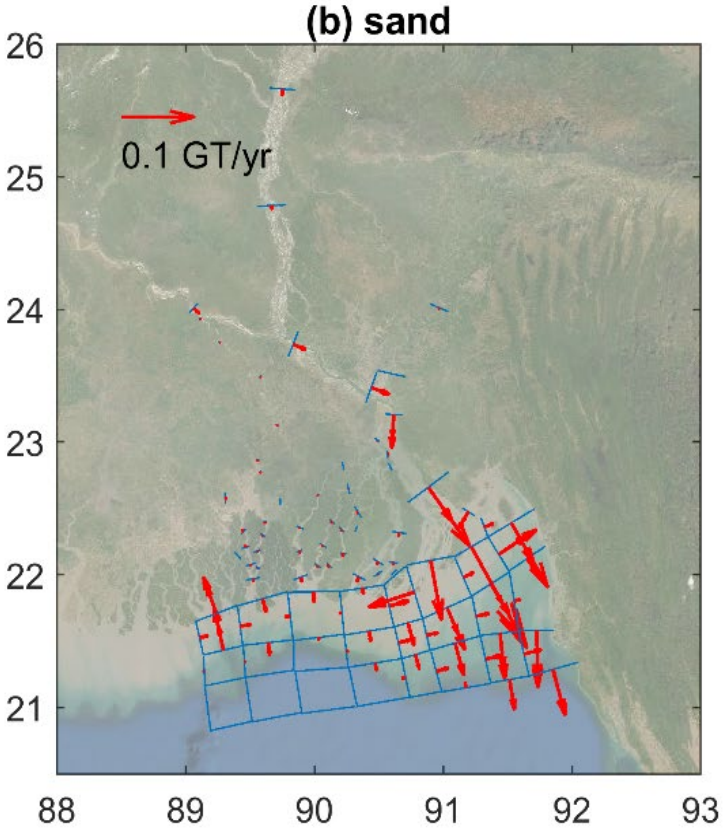
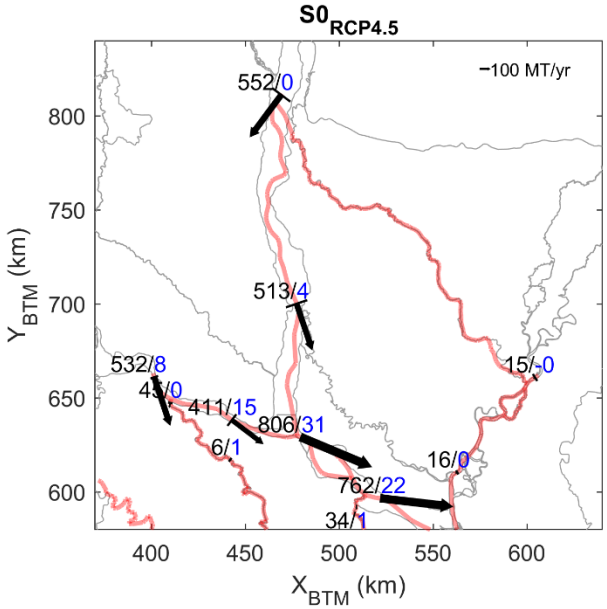
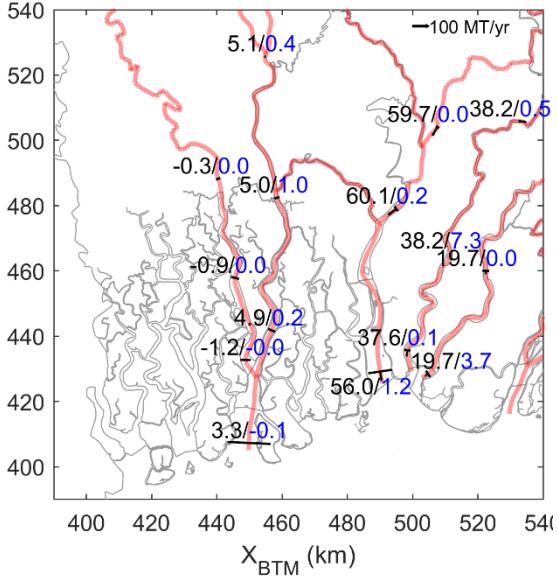
Sediment fluxes (2D)

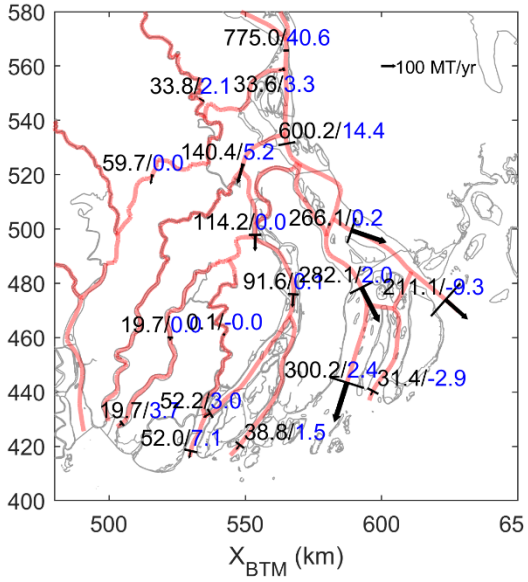




Sediment fluxes mud and sand (1D)







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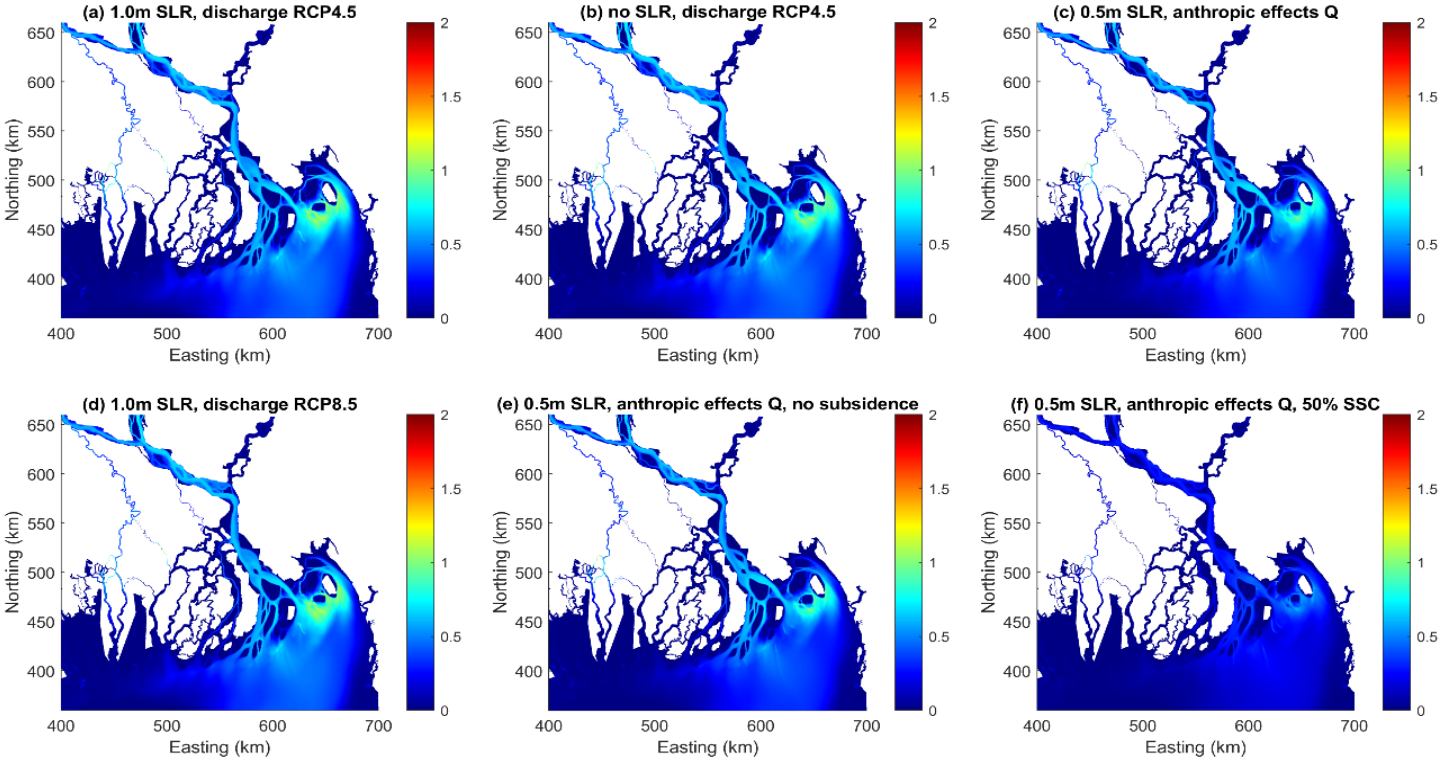
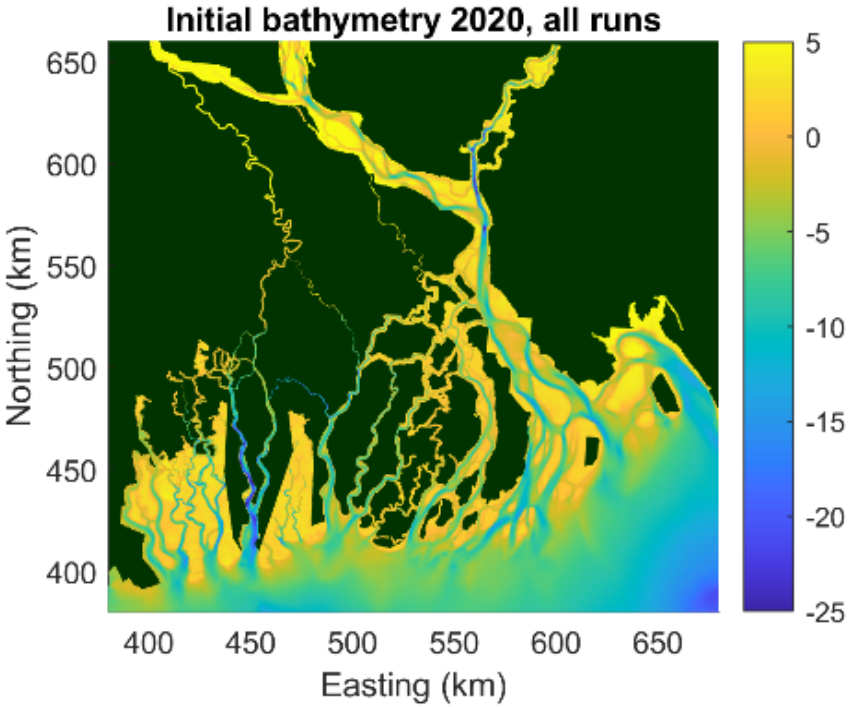
Mean concentration



Initial bathymetry



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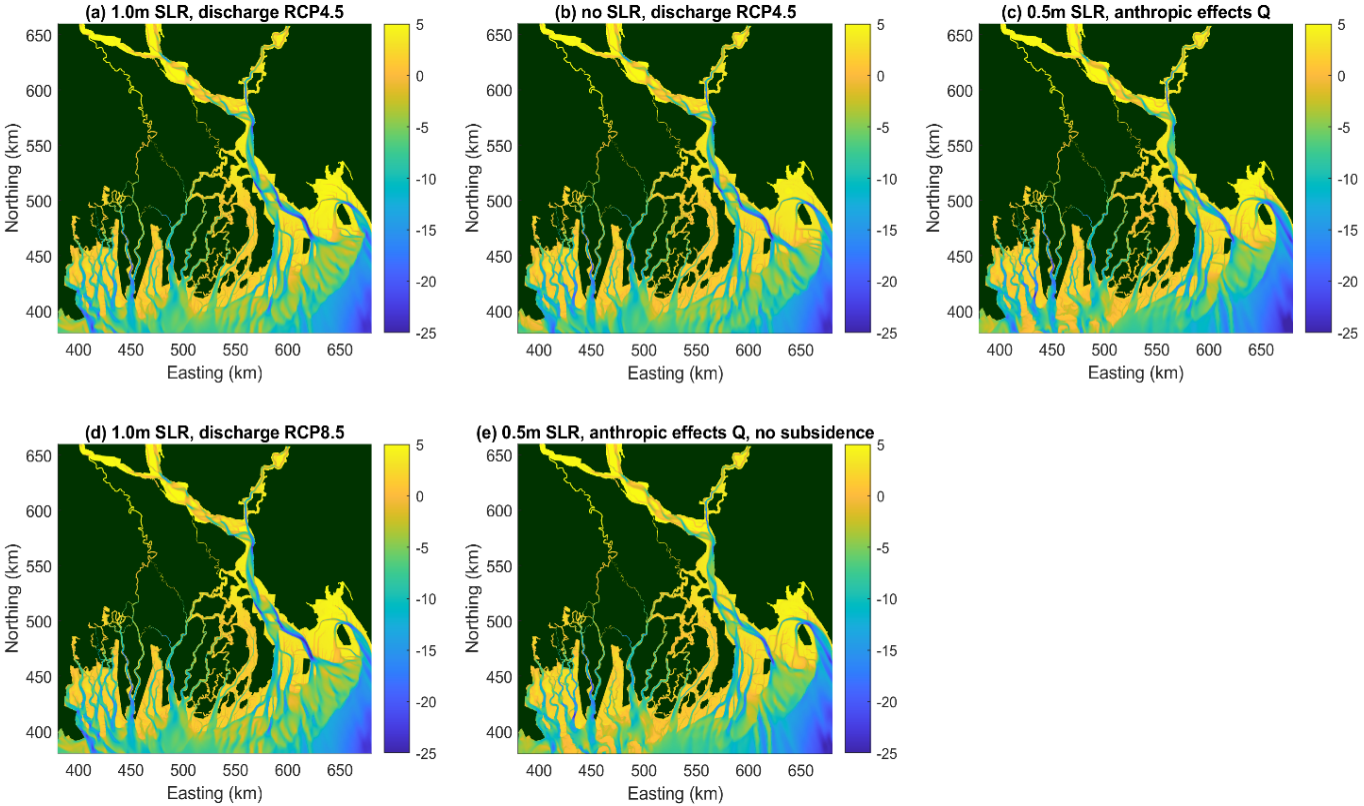
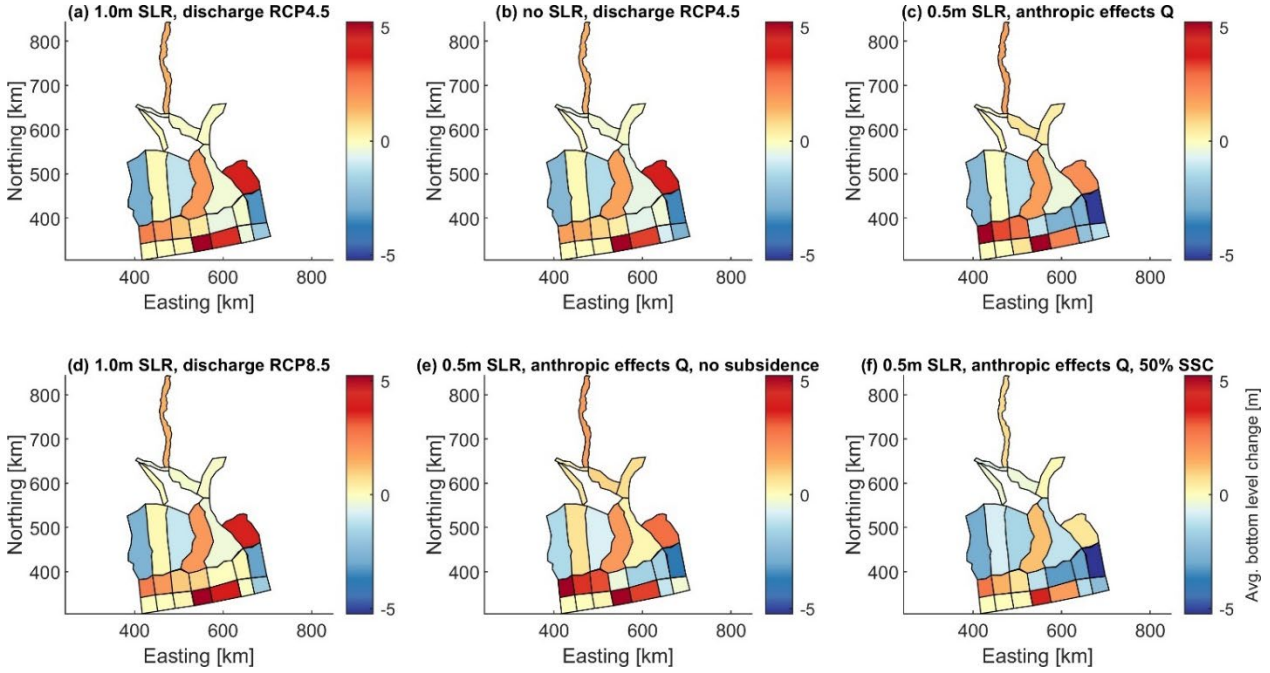
Resulting bathy 2100



Aggregated sedimentation/erosion



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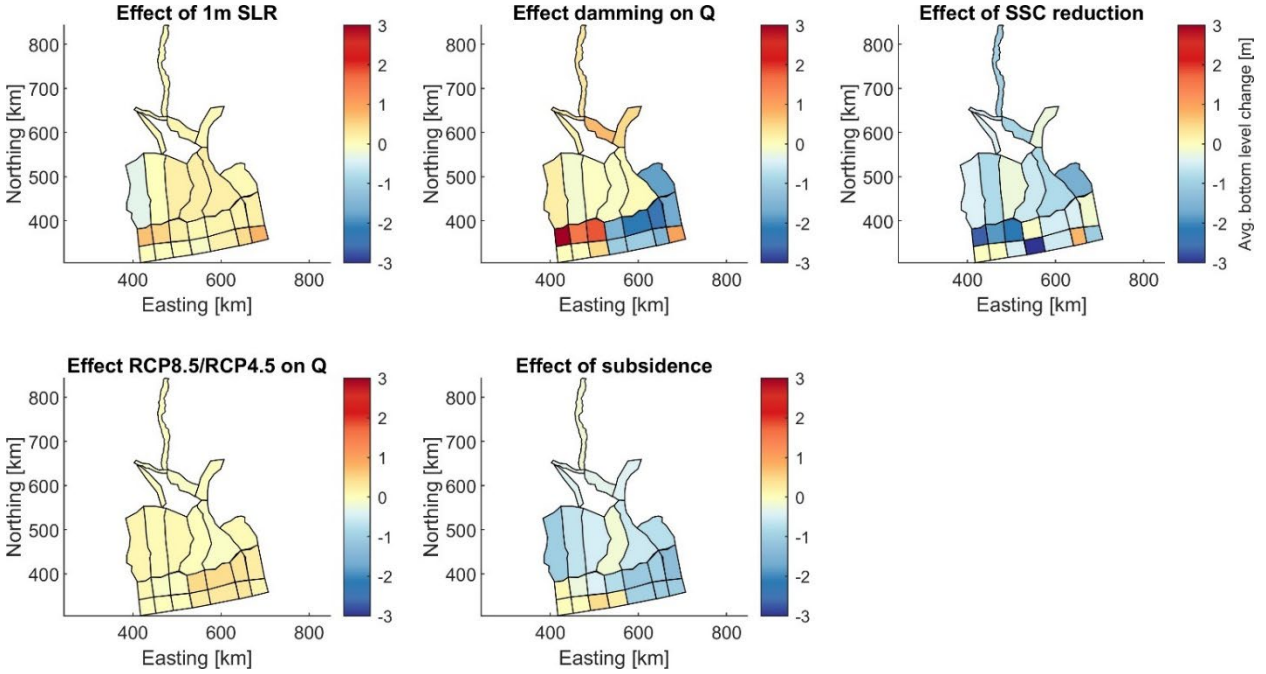
Effects of scenarios on aggregated erosion/sedimentation



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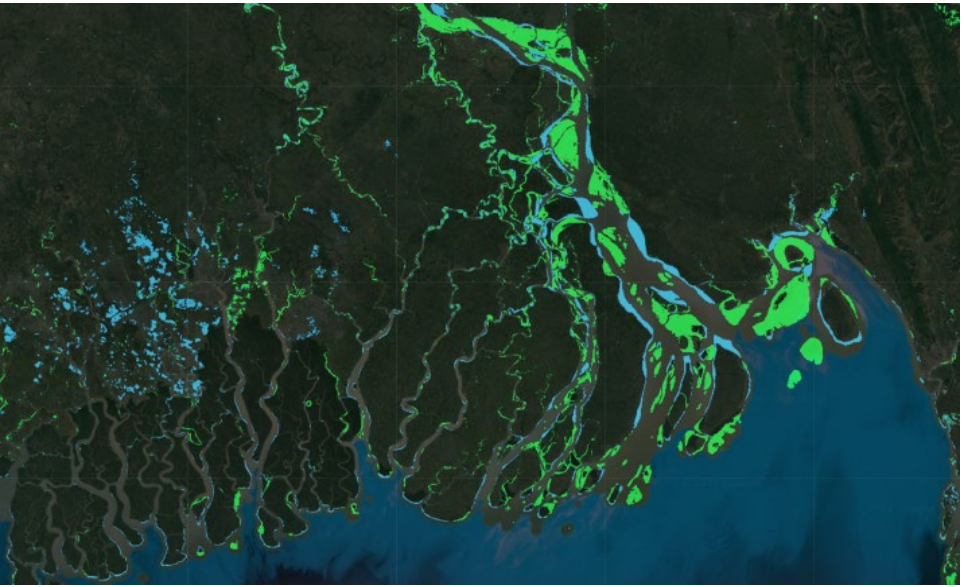
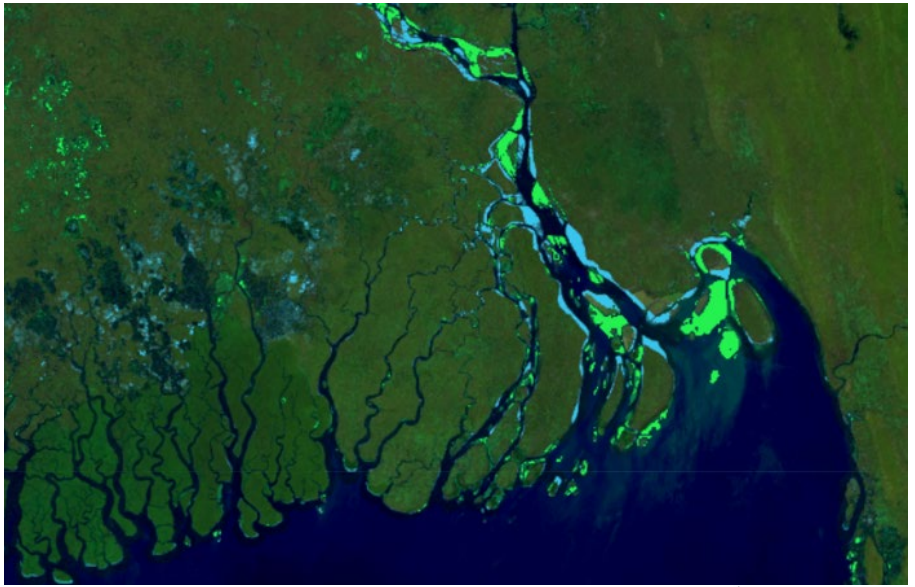
Aqua monitor





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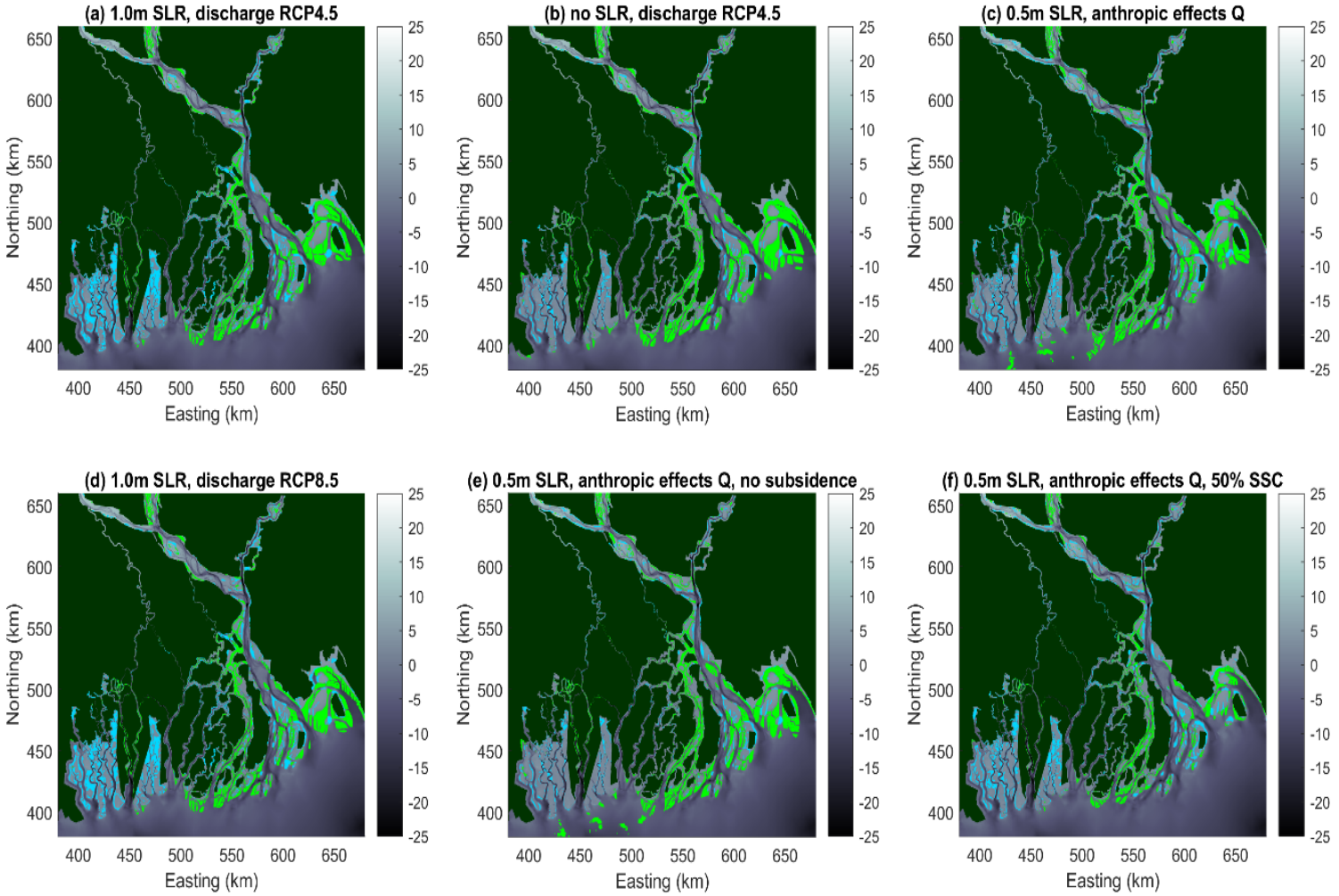

Simulated 2020-2100

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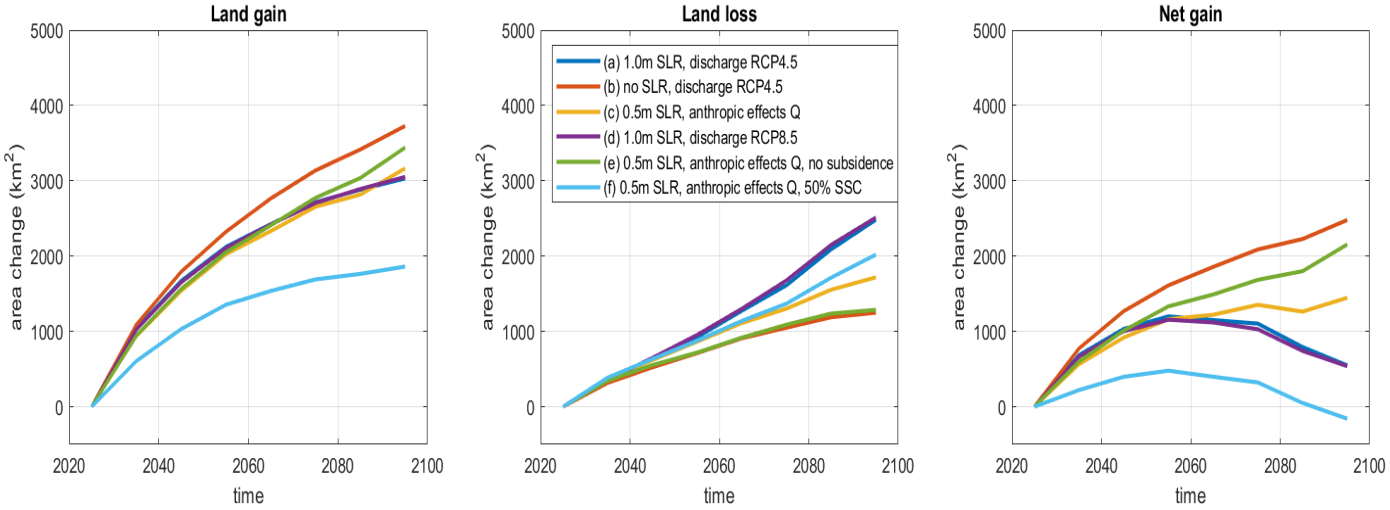
Integrated land loss/gain



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Land loss/gain

Scenario	Land gain	Land loss	Net change
	km^2/yr	**km^2/yr**	**km^2/yr**
(a) 1.0m SLR, discharge RCP4.5	22.7	39.0	-16.3
(b) no SLR, discharge RCP4.5	35.1	13.4	21.7
(c) 0.5m SLR, anthropic effects Q	28.5	21.4	7.1
(d) 1.0m SLR, discharge RCP8.5	23.6	39.0	-15.4
(e) 0.5m SLR, anthropic effects Q, no subsidence	34.7	14.2	20.6
(f) 0.5m SLR, anthropic effects Q, 50% SSC	12.7	28.6	-15.9

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Conclusions

- First detailed, long-term morphology model of Bangladesh GBM delta
- Skillful reproduction of sediment balance
- New feature allows evaluation of land-water and water-land changes
- Range of large-scale scenarios investigated
- Boundary conditions for meso-scale models provided
- Many improvements and further applications possible, work needs to continue after project.

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Under current conditions…

- Approximately 1/3th of the fluvial sediment input is exported to the deep sea, and the other 2/3th is deposited in the delta area, which agrees with literature.
- The major part of the river discharge and sediment input is transported through the Lower Meghna, being the active delta building estuary. Here, the estuary bifurcates into multiple outlets and the model results show that the most eastern outlet is increasing in importance, indicating that the eastwards building up of the delta, as reported in the geological studies, is continuing.

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The effects of SLR are…

- A general trend of sedimentation in the tidally influenced part of the delta, however an order of magnitude less than the sea level rise itself.
- A tendency towards net land loss, especially after 2050, due to increased inundation.
- A relatively minor effect on long-term average concentrations and sediment transport patterns.

The effect of subsidence is…

- An exacerbation of the effects of sea level rise; a SLR of 0.5 m by 2100 combined with subsidence approximately has the same effect as a 1m SLR.
- A relatively minor effect on the long-term average concentrations and sediment transport patterns.

The anthropogenic effects of upstream discharges are..

- An important reduction of the discharge and sediment load in Ganges and Brahmaputra;
- A strong reduction in the sedimentation in the Lower Meghna area and the shelf in front of the Sundarbans
- Relatively minor effects on land gain and loss.

A reduction of the upstream concentration, with the same discharge, leads to

- General erosion in all riverine and estuarine areas;
- A much-reduced (1/3th) land gain up to 2050 and net land loss after 2050.

Questions?