Stakeholder Workshop on SAFE Prototype Activity in Bangladesh

Investigation of sedimentation process and stability of the area around the cross-dams in the Meghna Estuary

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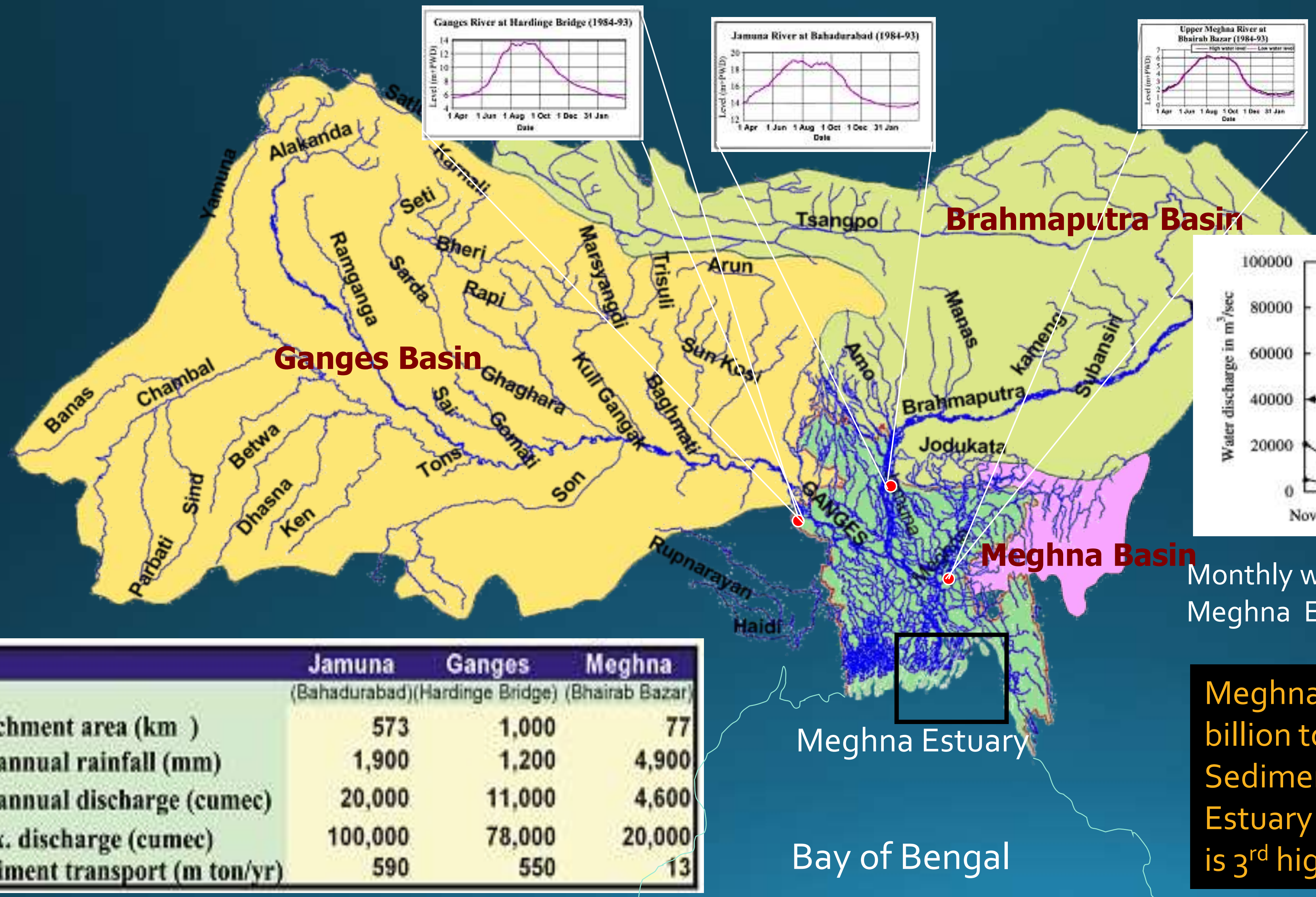
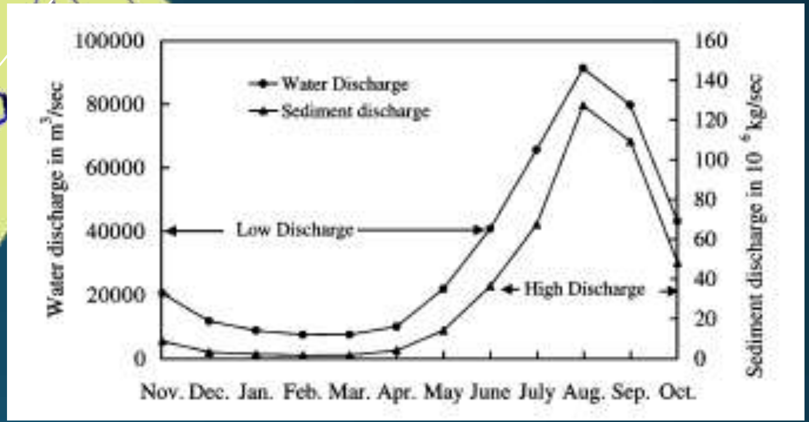
Outline of Presentation

- Background
- Objectives
- Recent coastline changes at the north-eastern part of the Meghna Estuary
- Seasonal variation of erosion-accretion around Urir Char Island of Meghna Estuary
- Hydrodynamic and morphological modeling for cross dam impacts
- Conclusions

The Ganges, the Brahmaputra, the Meghna River Systems



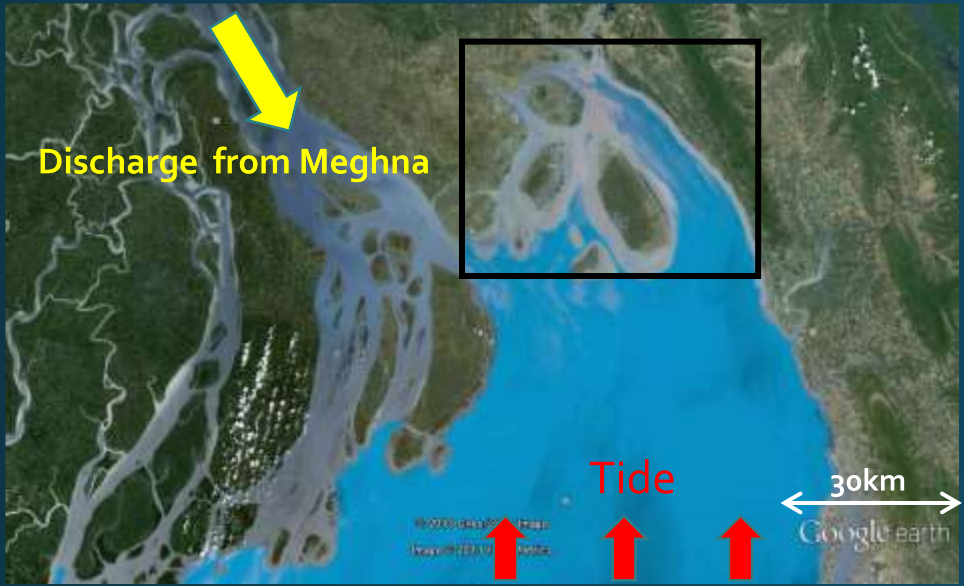


Monthly water and sediment discharge into Meghna Estuary, Islam et al. J Mar Sys (2002)

	Jamuna (Bahadurabad)	Ganges (Hardinge Bridge)	Meghna (Bhairab Bazar)
Catchment area (km)	573	1,000	77
Av. annual rainfall (mm)	1,900	1,200	4,900
Av. annual discharge (cumec)	20,000	11,000	4,600
Max. discharge (cumec)	100,000	78,000	20,000
Sediment transport (m ton/yr)	590	550	13

Meghna Estuary receives more than a billion tons of sediments every year. Sediment discharge into the Meghna Estuary is highest and water discharge is 3rd highest in the world.

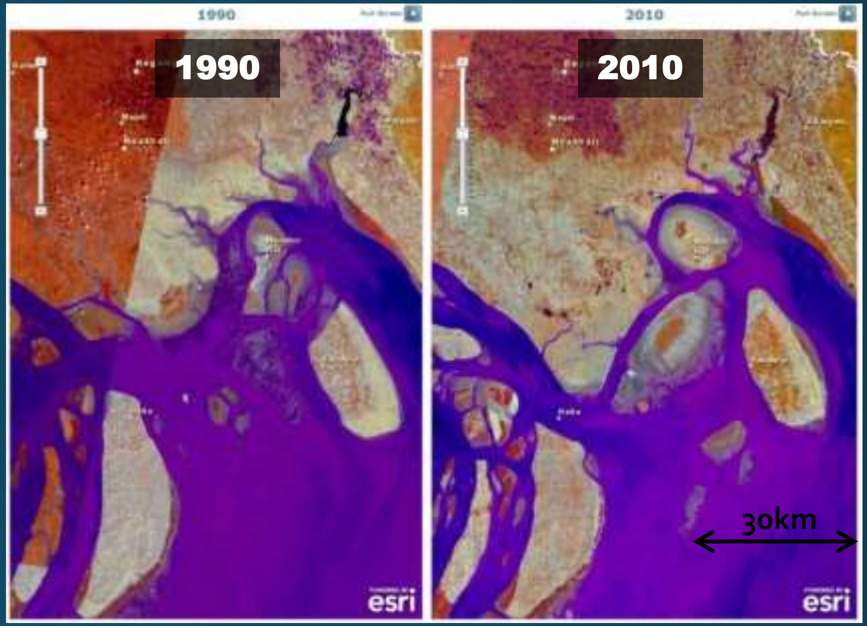
Dynamic Change of Coastline in the Study Area



Year	Erosion (SqKm)	Accretion (SqKm)
1973 - 84	692	859
1984 - 90	569	616
1990 - 96	347	609
1996 - 05	604	724
1973 - 05	1039	1792

For entire Meghna Estuary, (BWDB 2005)

Net annual accretion rate (de Wilde, 2011)		
	1973~2000	2000~2008
Annual rate	18.8	25.0



Such high rate of coastline movement can't be found at any other parts of the world. (de Wilde, 2011)

Significant and dynamic coastal morphology change has strong impacts on development of coastal area in Bangladesh

Lack of measured data makes it difficult to fully understand the phenomena.

Objectives

The overall objective of the research work is to develop a monitoring system for large scale morphology change around the Meghna Estuary (MES) of Bangladesh

The specific objectives are:

- Analyze satellite data to identify the historic and recent morphology changes in the MES area as well as to distinguish the impact of cross dams.
- Obtain hydrodynamic data and investigate the relationship between hydrodynamic events and observed morphology changes.
- Apply numerical models to analyze morphological changes.
- Assess impact of climate change on the morphology changes of MES area.

PART 1
Recent Coastline Changes at the Eastern part of the Meghna Estuary from PALSAR and Landsat images

Methodology

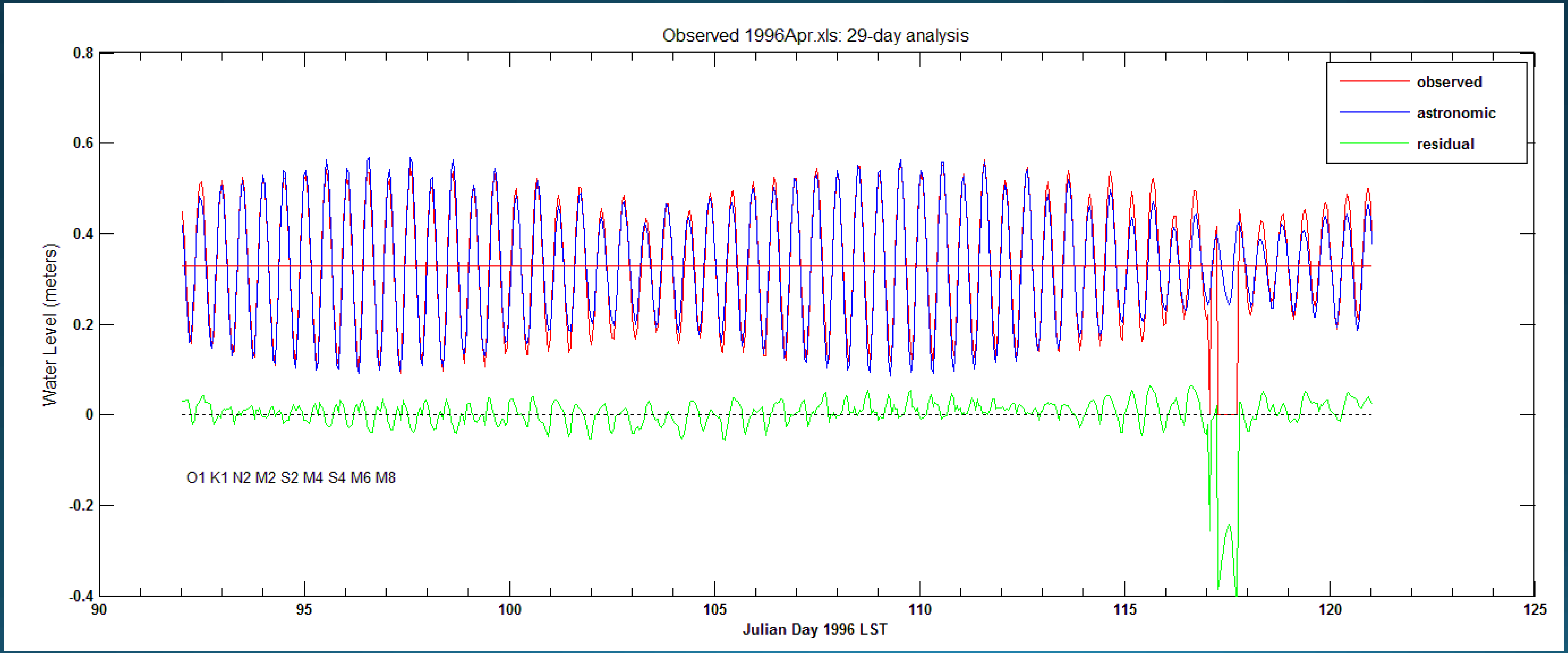
-PALSAR images (Jan 2007~April 2011) and Landsat images have been used for coastline detection in the present study.

-The tidal phase at the time when these images were collected does not allow all these images to be compared directly.

-Accurate calculation of tidal phase is very important to compare images in order to extract erosion-accretion in the study area.

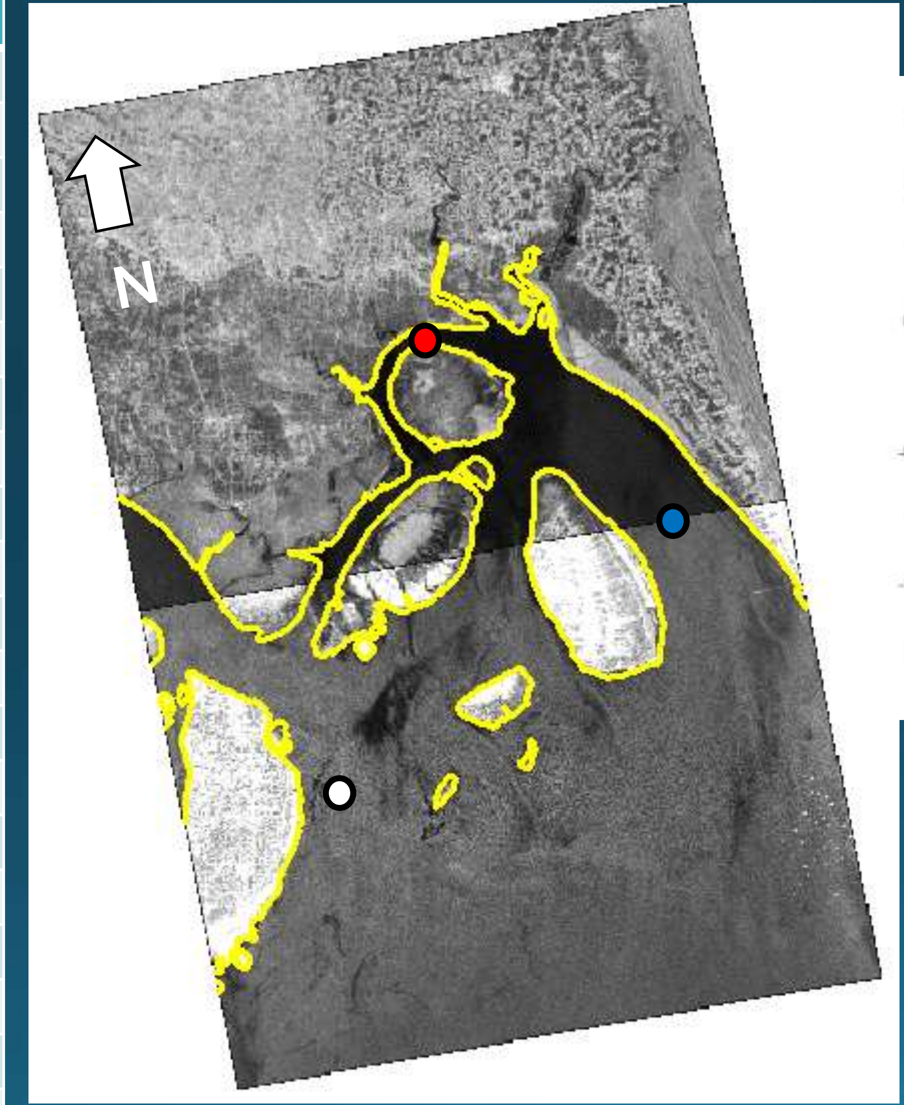
Calculated TWL using WTWC

Boon J (2007) *Secrets of the Tide: Tide and Tidal Current Analysis and Applications, Storm surges and Sea Level Trends*
Horwood Publishing Chichester UK

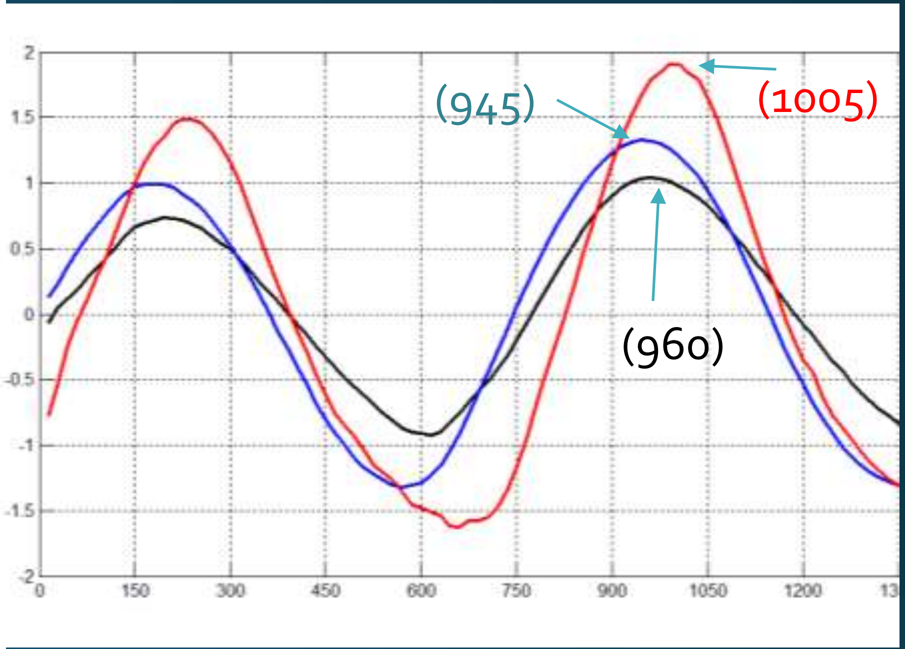


List of PALSAR images

Year	Date
2007	January 15
	March 2
	July 18
	December 3
2008	March 4
	April 5
	April 19
	June 4
	July 20
	October 20
2009	January 20
	March 7
	September 7
	December 8
2010	January 23
	March 10
2011	January 12
	January 26
	February 27
	April 14



Tidal phase difference (min) at three selected locations



Time (min)

About one hour tidal phase difference at the selected three locations

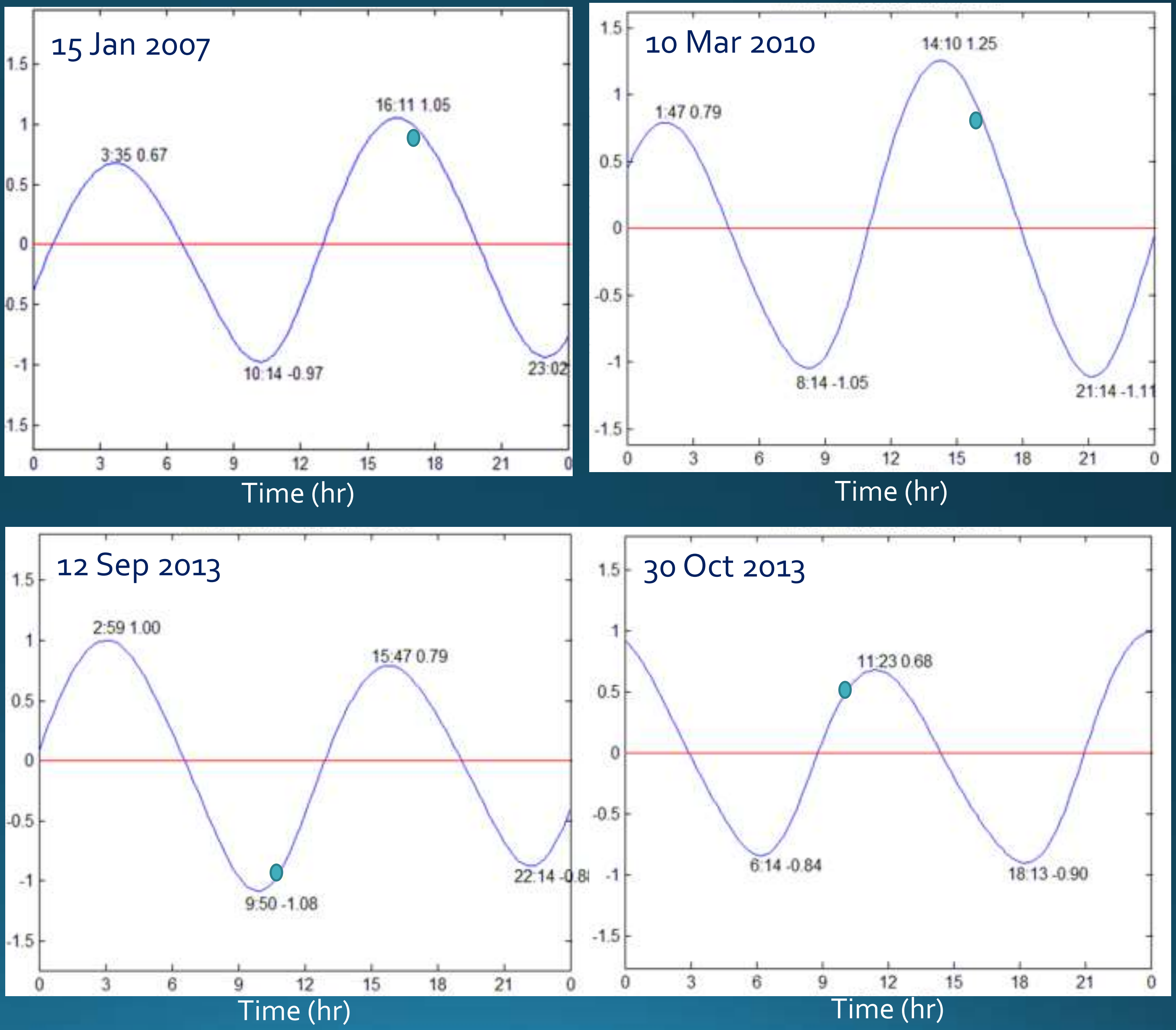
Calculated TWL on the days when images were selected

PALSAR image dates:

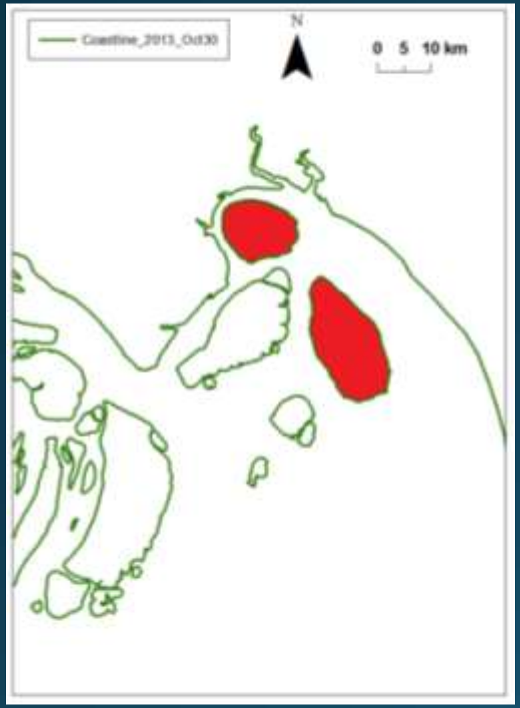
Year	Date
2007	January 15
2010	March 10

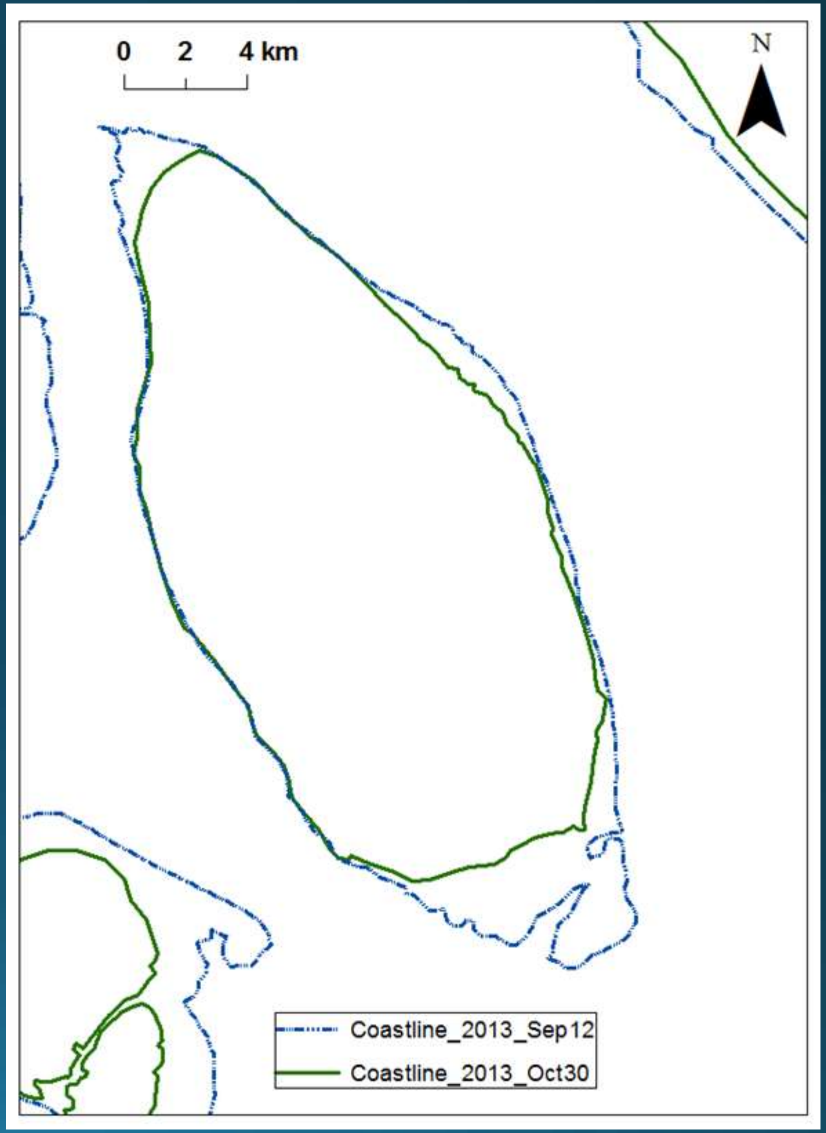
Landsat image dates:

Year	Date
2013	September 12
2013	October 30

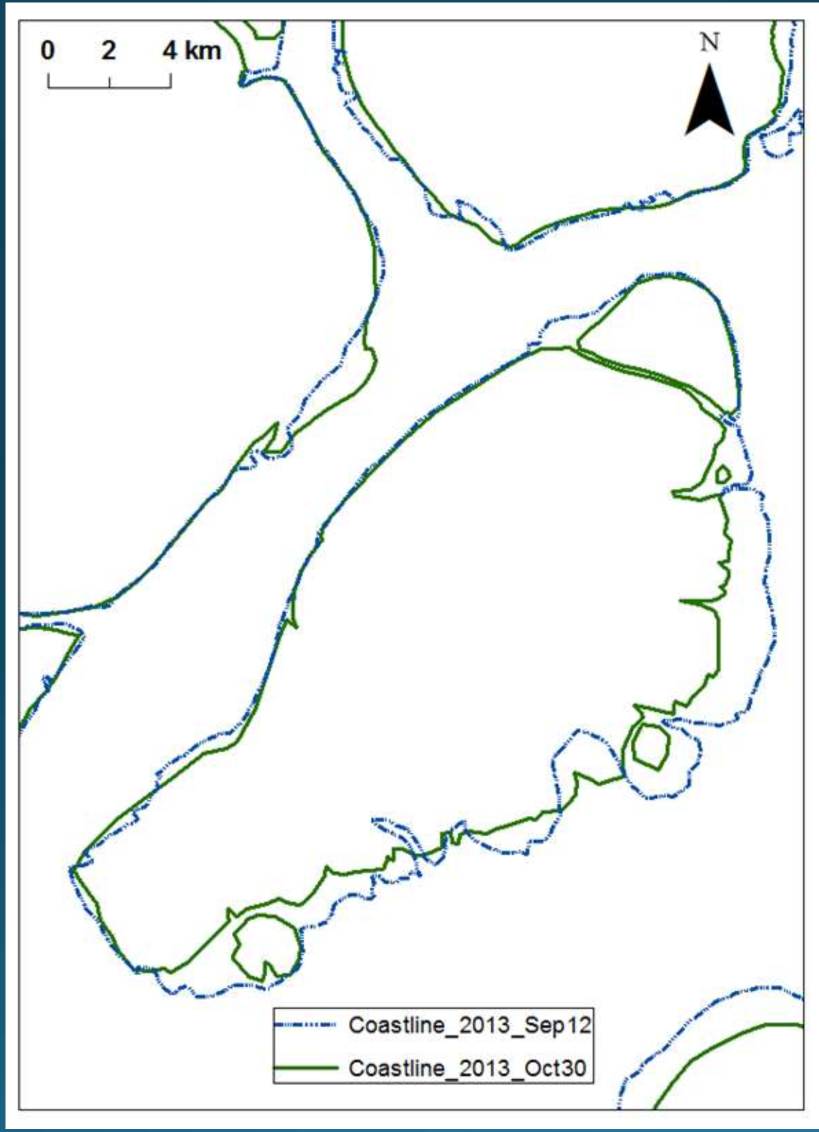


Results: Extent of intertidal mudflat





Results: Extent of intertidal mudflat



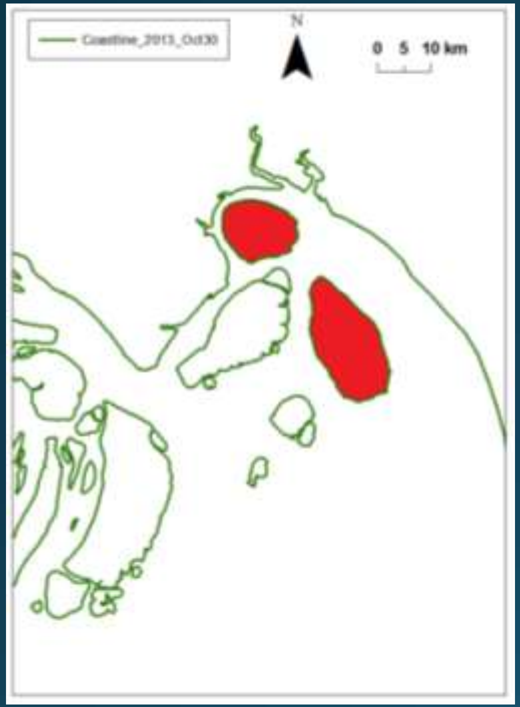
Results: Extent of intertidal mudflat

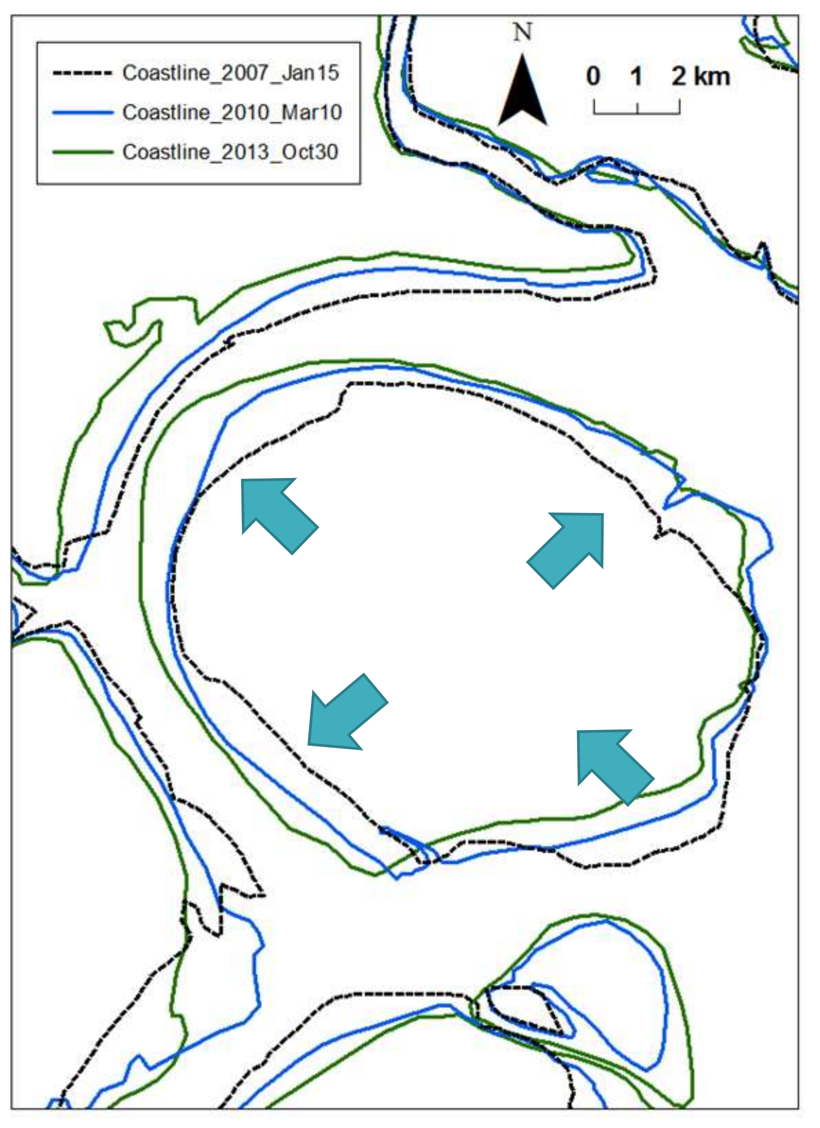
Islands	Area (km²) on 30 Oct 2013	Area (km²) on 12 Sep 2013	Area (km²) of Intertidal Mudflat
Urir Char	118.82	128.36	9.54
Sandwip	210.66	242.30	31.64
Jahajir Char	217.50	247.45	29.95
Hatiya	431.41	483.14	51.72

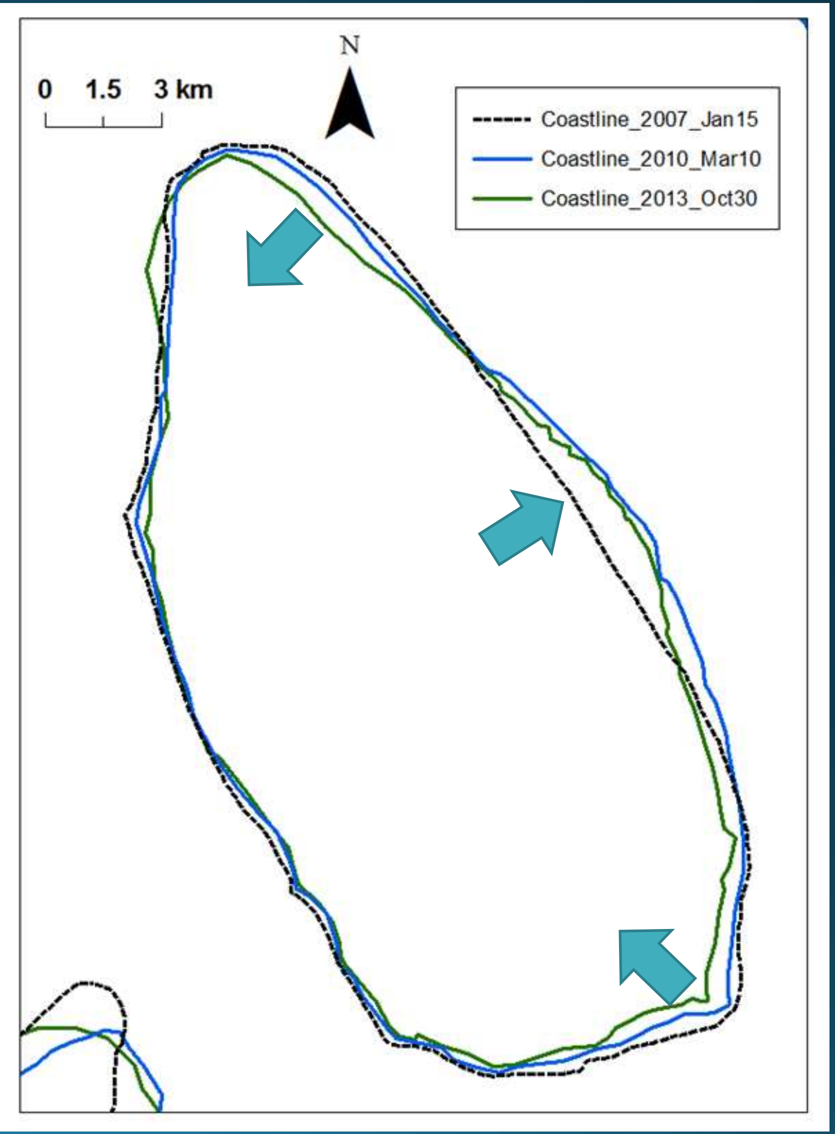
Total Area and change in area (km²) of four major islands

Islands	Total area (km²)			Area change (km²)	
	Jan 2007	Mar 2010	Oct 2013	'07~'10	'10~'13
Urir Char	102.40	115.05	118.82	12.65	3.77
Sandwip	222.66	221.93	210.66	-0.73	-11.27
Jahajir Char	101.77	189.63	217.50	87.86	27.88
Hatiya	-	-	431.41	-	-

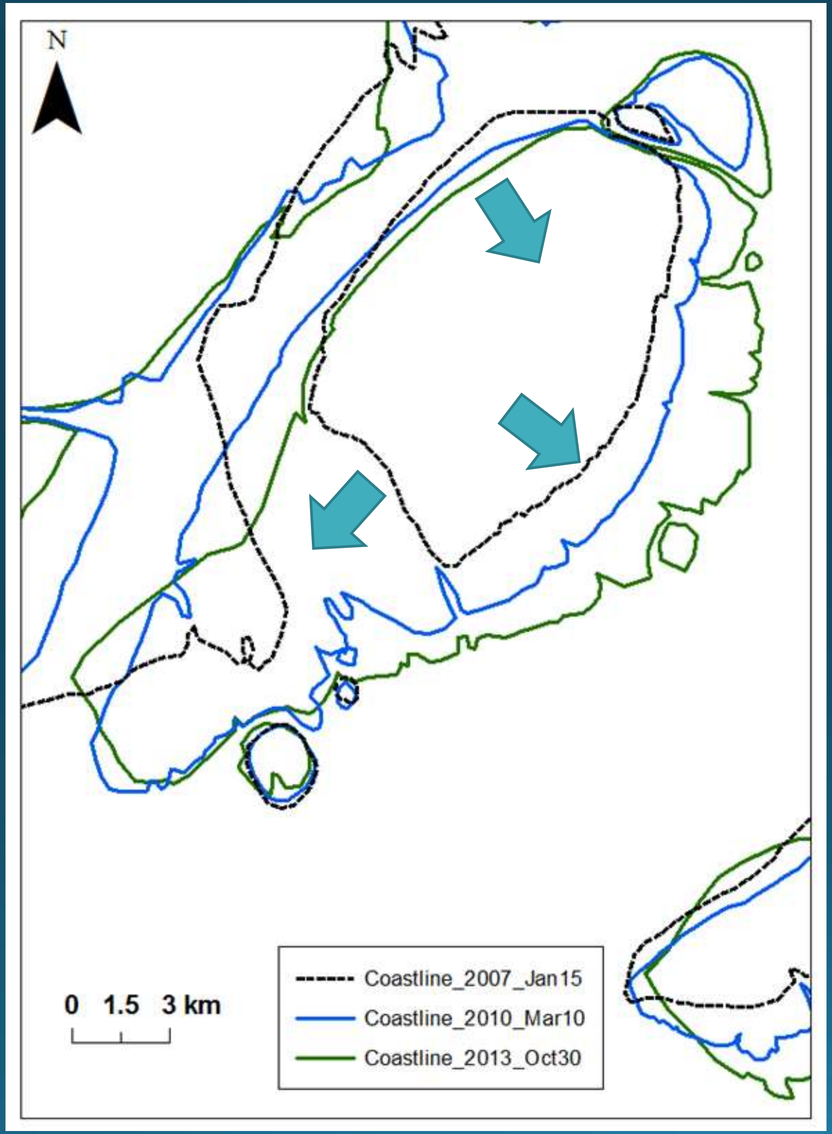
Results: Erosion and accretion rates

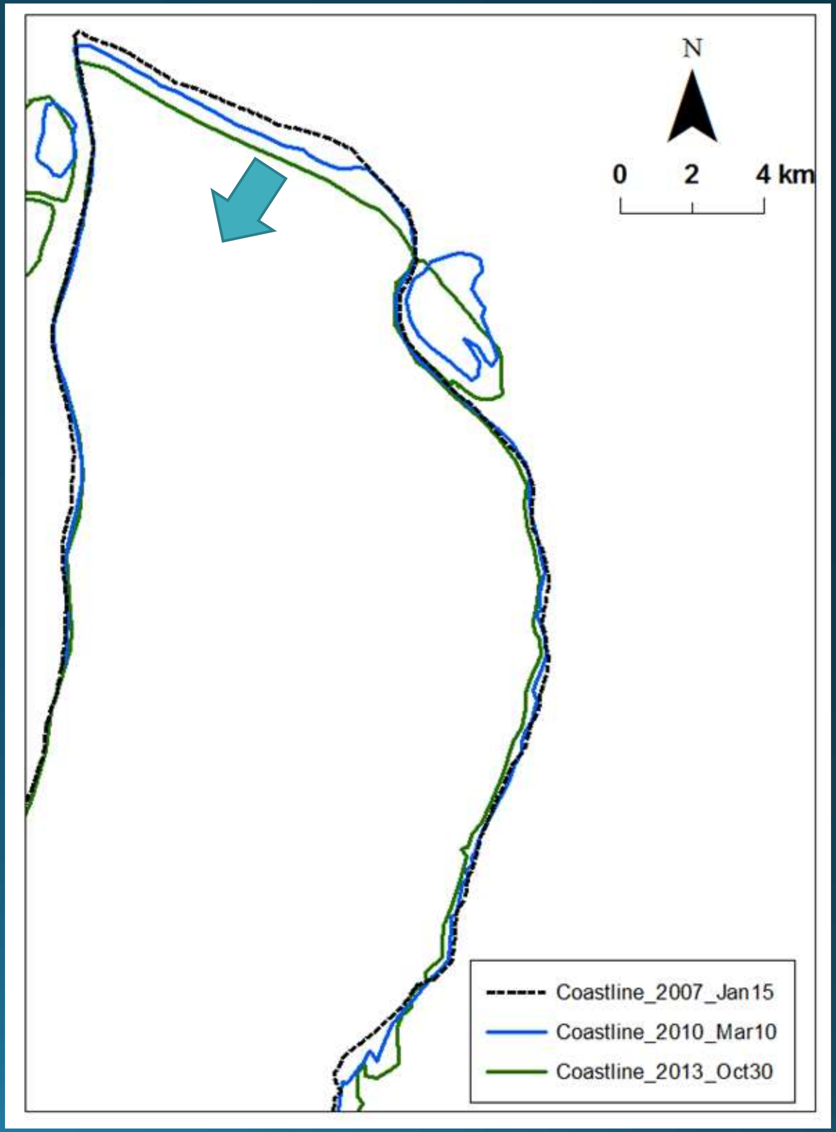






Results: Erosion and accretion rates





Erosion and accretion rates

Islands	Erosion area (km²)		Accretion area (km²)	
	2007~2010	2010~2013	2007~2010	2010~2013
Urir Char	3.31	5.63	15.92	10.26
Sandwip	9.08	11.49	8.62	1.46
Jahajir Char	4.16	16.36	90.77	45.90
North Hatiya	3[illegible]	4.73	-	-

Net: 2.6 km² per year
From 2007~2011 3.4 km² from PALSAR (Taguchi et al. 2013)

PART1: Conclusions

- Meghna Estuary is known as an area where accretion dominates. During the recent three years it appears that the rate of accretion has slowed down at the four major offshore islands at the eastern part of the Meghna Estuary.
- Annual rate of accretion of Urir Char island has decreased from 5.84 km^2 per year between 2007~2010 to 1.05 km^2 per year between 2010~2013.
- Sandwip island has been eroding at a higher rate of 3.15 km^2 per year between 2010~2013 compared to 0.34 km^2 per year between 2007~2010.
- Jahajir Char island experienced major accretion during 2007~2010 when parts of the Char Jublee from the northern part was attached to this island
- Northern part of Hatiya island is clearly facing erosion at a rate of about half a km during 2007~2010 and 2010~2013

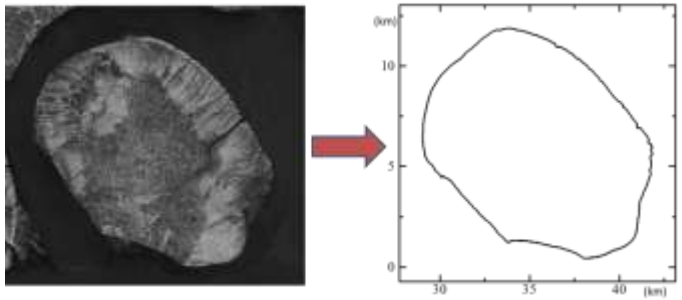
PART 2
Seasonal variation of erosion-accretion around Urir Char Island using PALSAR images

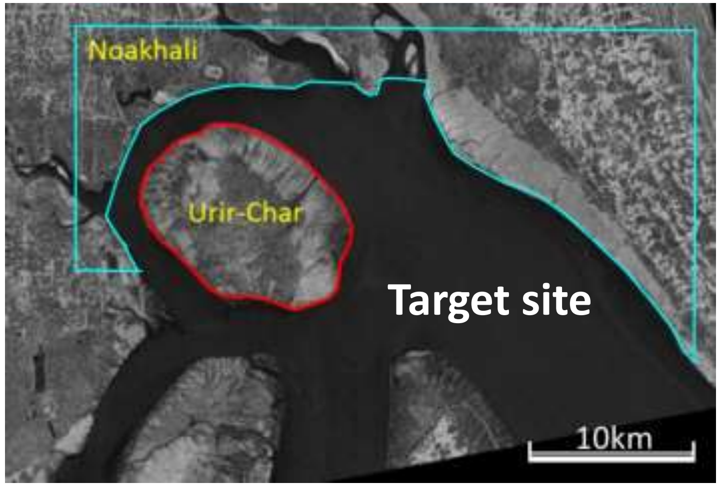
Topographic features

Analysis of PALSAR imagery

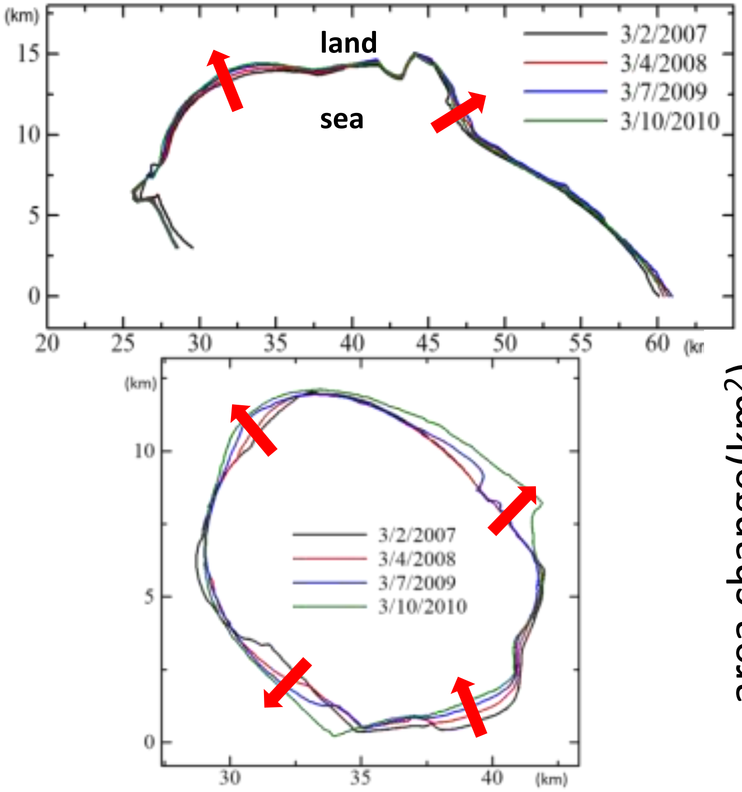
21 images from Jan.2007 to Apr 2011

Shoreline extraction based on local XY coordinates

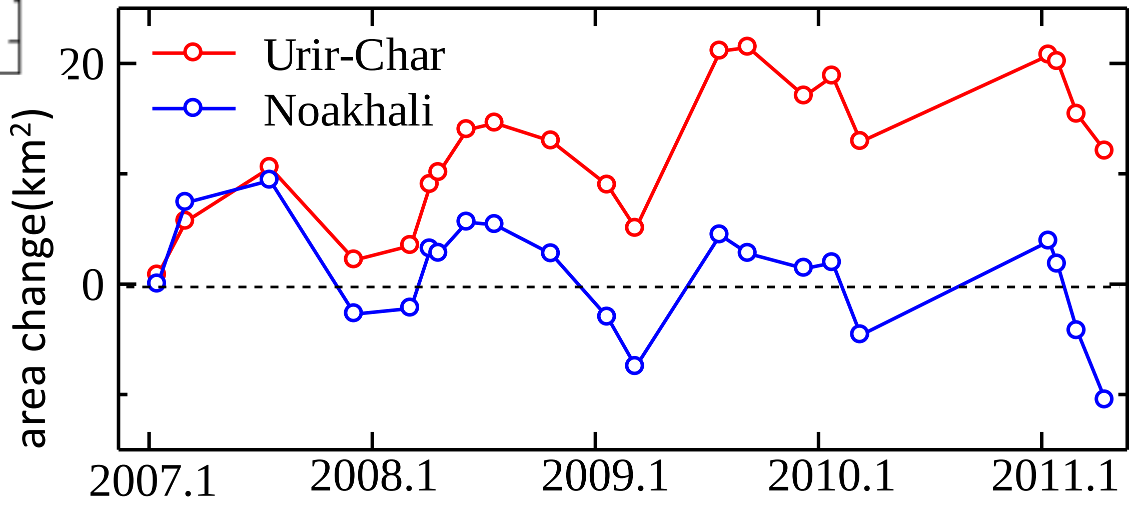




Extracted shoreline change



Time-series of observed land area



Challenge of this study

- Observed shoreline change includes the change due to morphology change (erosion-accretion) and temporal shoreline change due to the difference in tidal water level when the PALSAR image was recorded.
- Many parts of the target site has tidal flat and nearshore coast with very mild slopes.
- Primary factors of the actual morphology change should be: (i) wind waves; (ii) tidal currents; (iii) sediment discharges from the river.
- Most of these hydrodynamic data are not available around the target site.

→ This study combines numerical model and available data for estimations of time-varying hydrodynamic conditions.

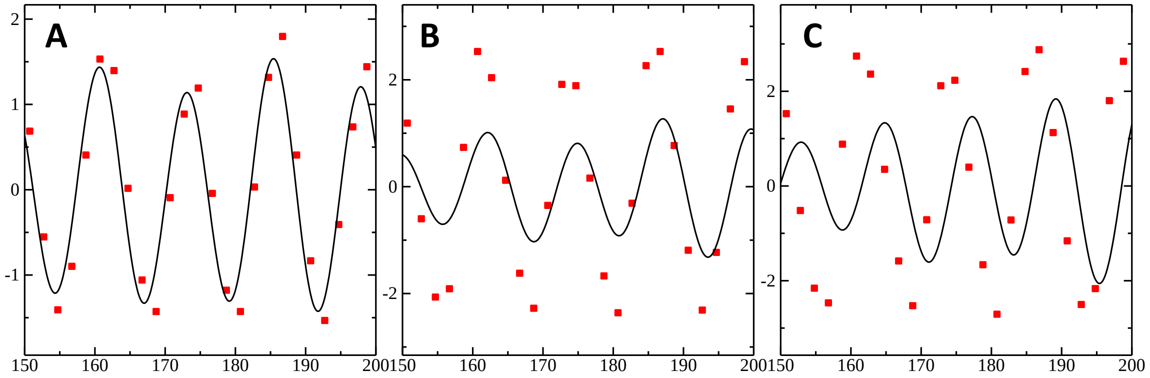
Tidal flat around Urir Char

Typical shoreline of Noakhali

Tide

Ocean tide model + non-linear shallow water model

Ocean tide model(Nao.99b)
-Assimilated to TOPEX/POSEIDON and provides accurate predictions of tides at arbitrary locations in the open ocean
-Influence of nearshore bathymetry is not accounted for and thus loses accuracy near the shore



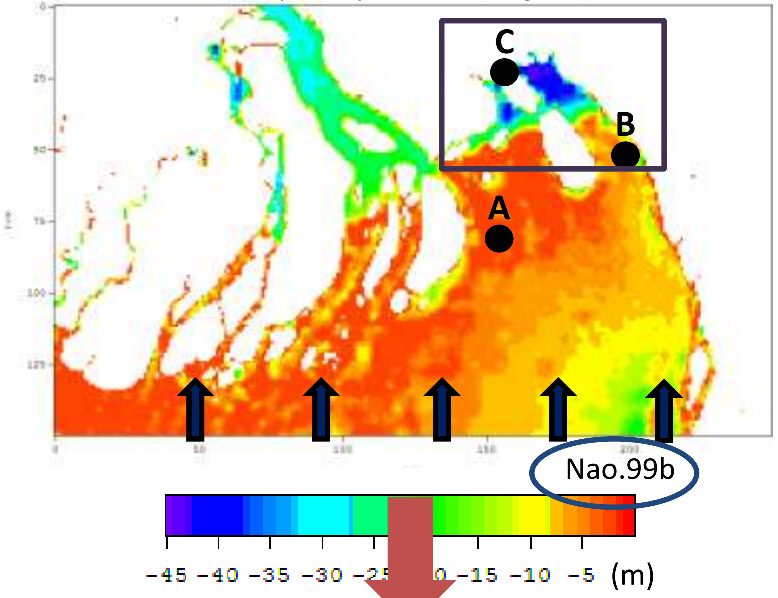
comparisons of Nao.99b (black line) and measured (red dot) tides at st. A, B and C

⇨ Use Nao.99b to specify offshore BC and compute tidal response by non-linear wave model

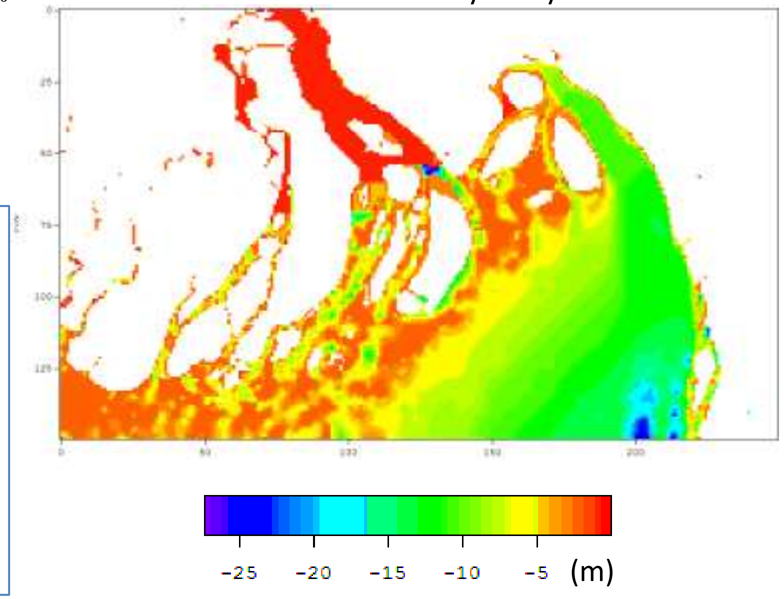
Bathymetry:
Based on General Bathymetric Chart of Oceans (GEBCO).
Modifications were needed for nearshore water depth and land-ocean boundaries.

- PALSAR and J-SER were used to update the shorelines.
- Unrealistic nearshore water depth was corrected so that it yields better predictive skills of tides. Modified bathymetry was consistent with previously measured bathymetry.

Bathymetry: GEBCO(original)

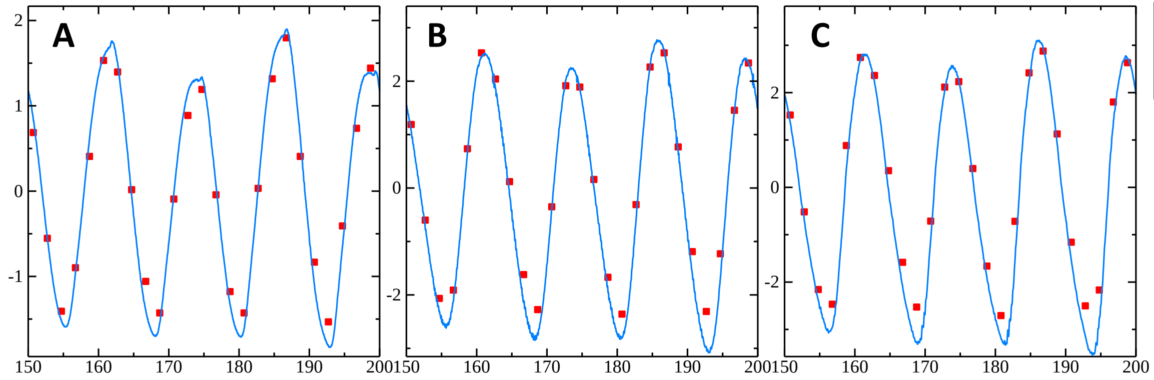


Modified bathymetry



Tide

Ocean tide model + non-linear shallow water model



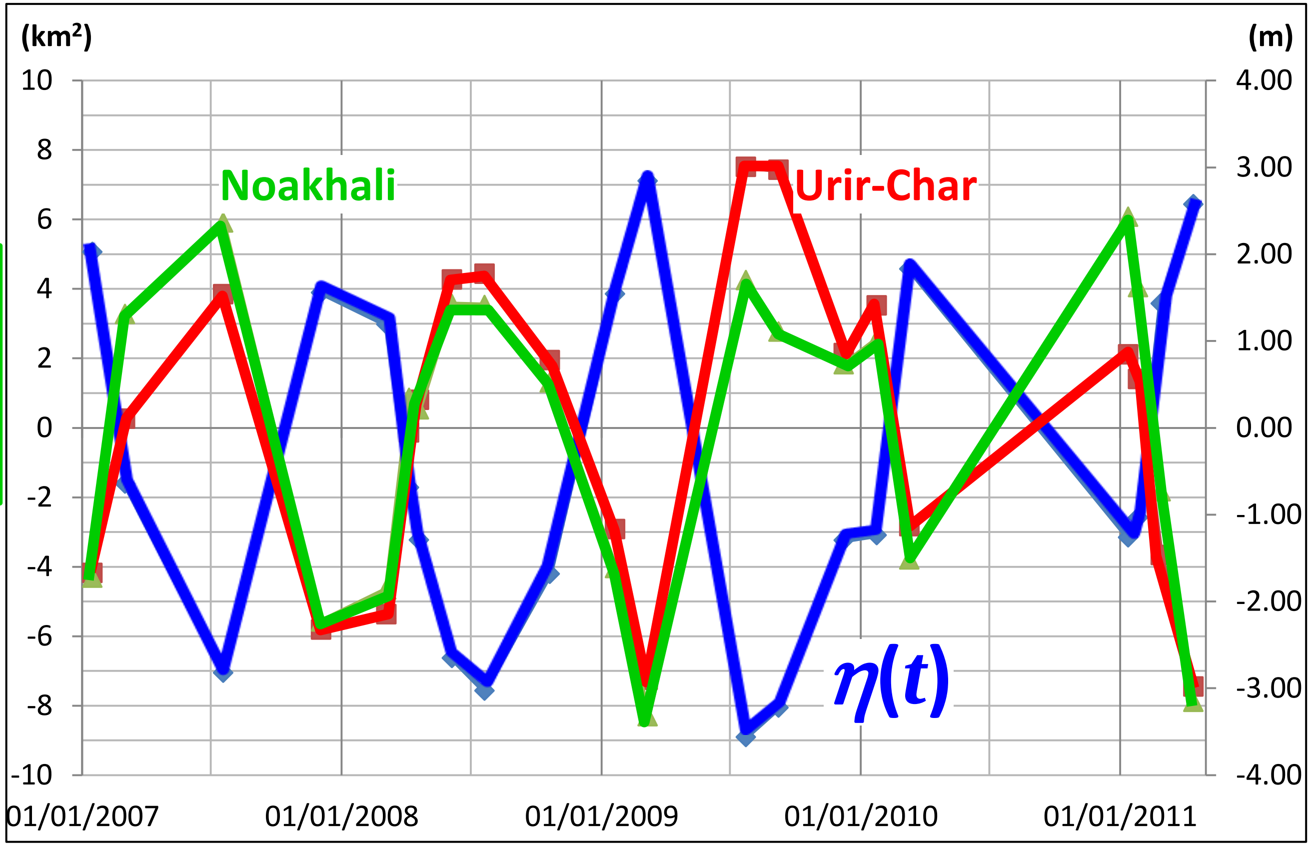
red dot : meas.
blue line : present model

Excellent predictive skills of nearshore tides around the target site!

Predicted tide when PALSAR was recorded

predicted tide, $\eta(t)$

Area change after removal of linear regression trend
Urir-Char
Noakhali



"Seasonal" trend of tide in recording timing of PALSAR

Tide and area change has strong correlations.

wave and river discharge

SMB curve

$$\frac{gH_{1/3}}{U_{10}^2} = 0.30\left[1-\left\{1+0.004\left(\frac{gF}{U_{10}^2}\right)^{1/2}\right\}^{-2}\right]$$

$$\frac{gT_{1/3}}{2\pi U_{10}} = 1.37\left[1-\left\{1+0.008\left(\frac{gF}{U_{10}^2}\right)^{1/3}\right\}^{-5}\right]$$

SMB curves were used for estimations of wave properties based on the wind data.

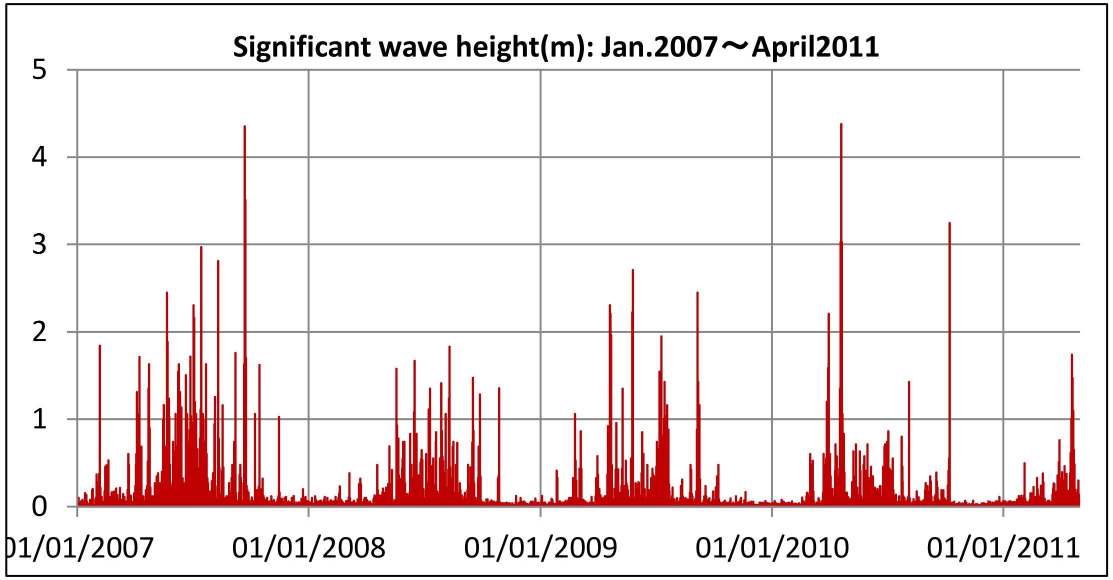
River Discharge

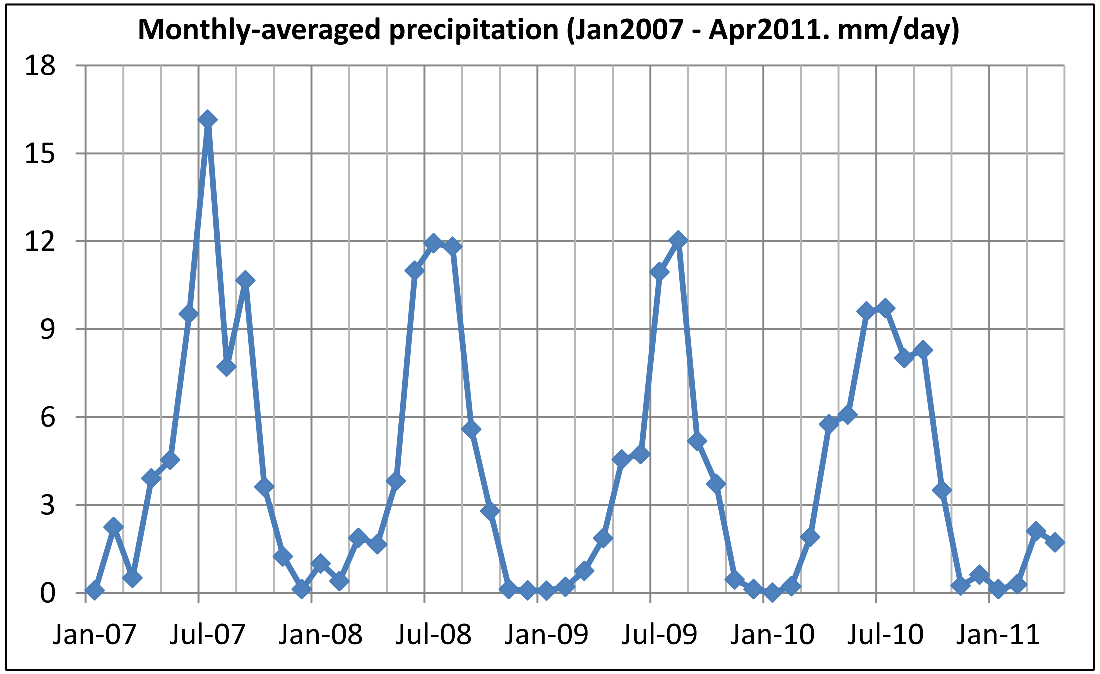
-River discharge was related to the total precipitation over the catchment area of the Meghna River.

- CMAP monthly-averaged precipitation was used.

-There should be a time lag among: (i) instantaneous precipitation; (ii) resulting discharge at the river mouth and (iii) sedimentation around the target site.

- Time lag was accounted for as one of calibration parameters of the following fitting curves of the observed area change.





Impact of various factors on observed area change

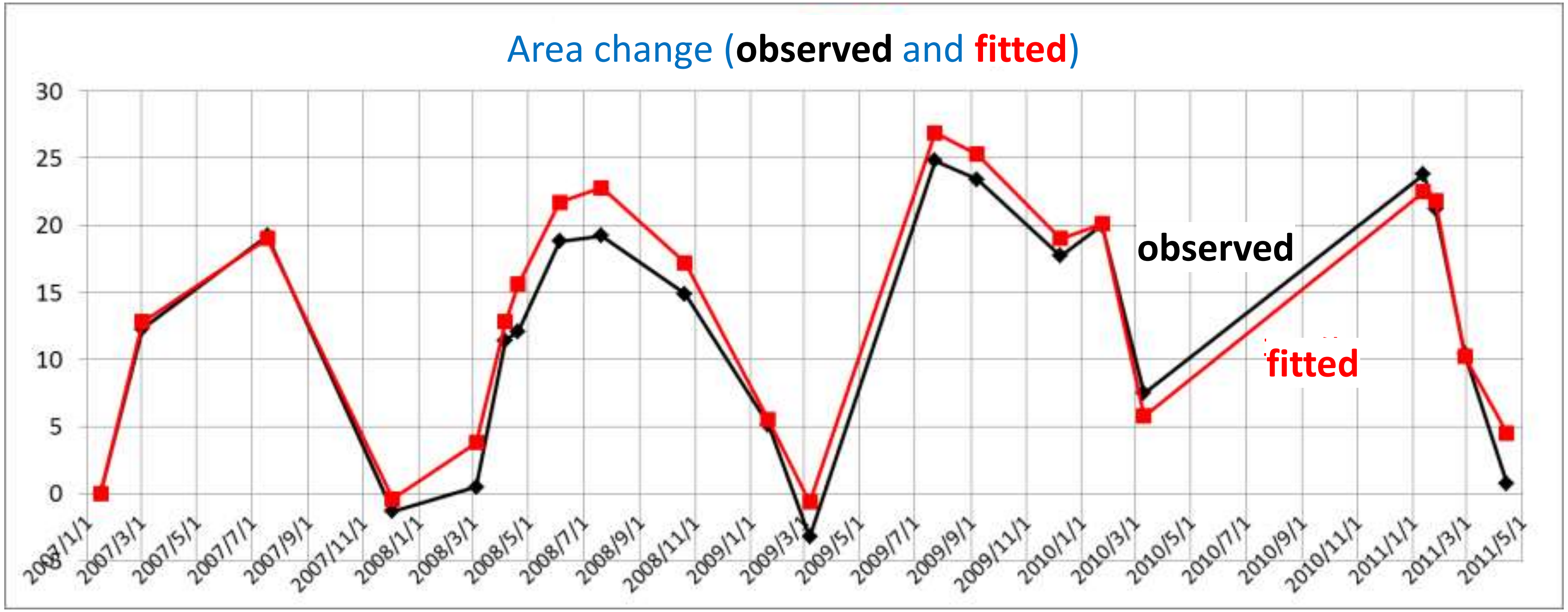
Fitting curve of the observed area change was proposed as functions of estimated parameters.

$$A(t) = A_0 + a_1\eta(t) + a_2\int_0^t Q(t-\varphi)dt + a_3\int_0^t H(t)dt + a_4\int_0^t H^2(t)dt$$

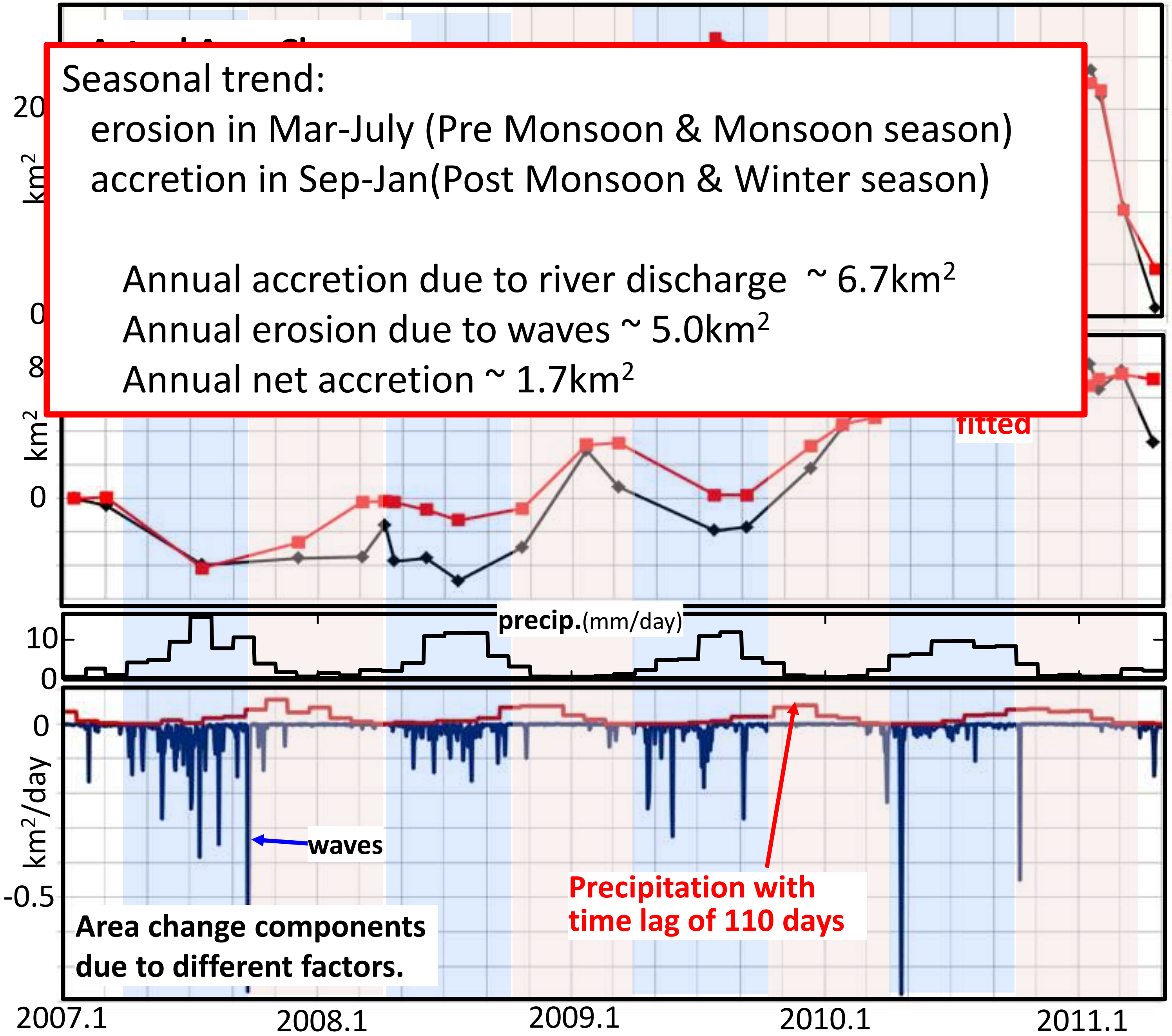
A(t): Area change of Urir-Char and Noakhali

$\eta(t)$: tide, Q(t): precipitation, φ: time lag, H(t): wave height

- Least-square method was applied for estimation of the best-fit parameters of a1 ~ a4.
- Time lag, φ was fixed in each analysis but the values of φ was altered within 80< φ(days) <120.
- Time lag of φ = 110days yielded the best fit curve.



Impacts of waves and precipitations on observed area change



Seasonal trend:

erosion in Mar-July (Pre Monsoon & Monsoon season)

accretion in Sep-Jan(Post Monsoon & Winter season)

Annual accretion due to river discharge ~ 6.7km^2

Annual erosion due to waves ~ 5.0km^2

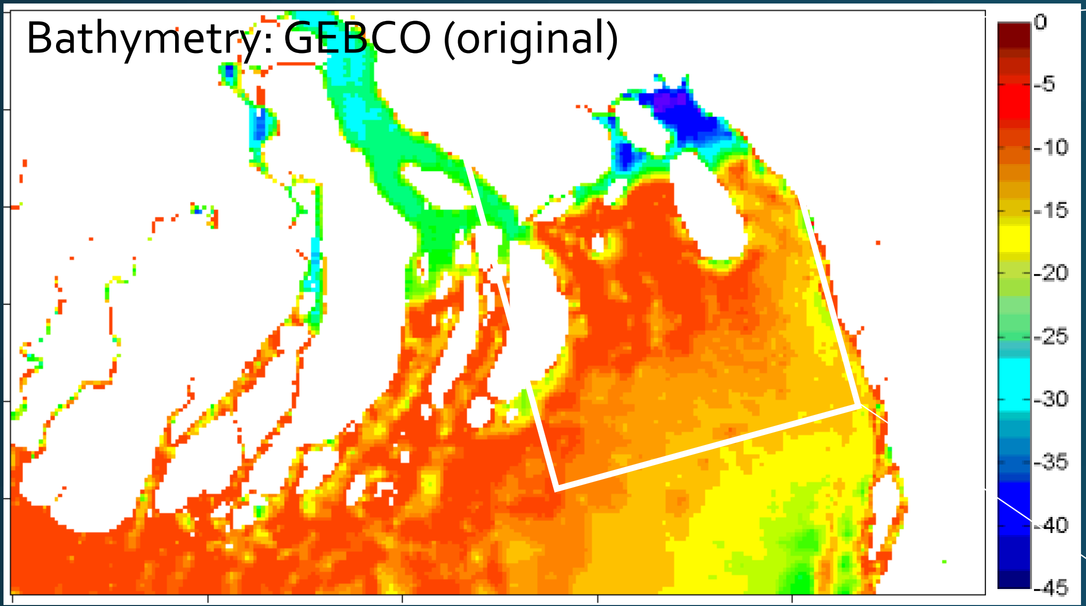
Annual net accretion ~ 1.7km^2

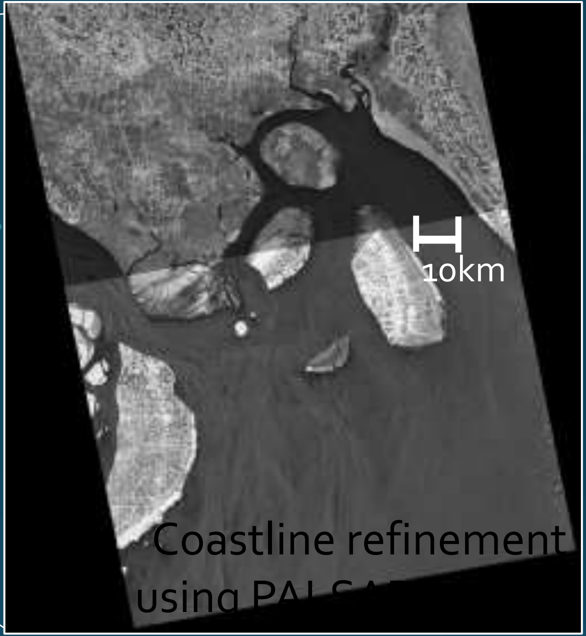
PART2 Conclusions

1. Seasonal shoreline changes were quantitatively extracted from PALSAR.
2. Instantaneous tide has significant impact on the shoreline change and the newly applied numerical model was found to yield good predictions of time-varying tides around target site.
3. Observed area change was fitted as functions of tide, wave and precipitations.
4. Trend of erosion due to waves and accretion due to precipitations were observed.
5. Time lag between accretion and precipitation was about 110 days.

PART 3
Hydrodynamic and morphological modeling for cross dam impacts

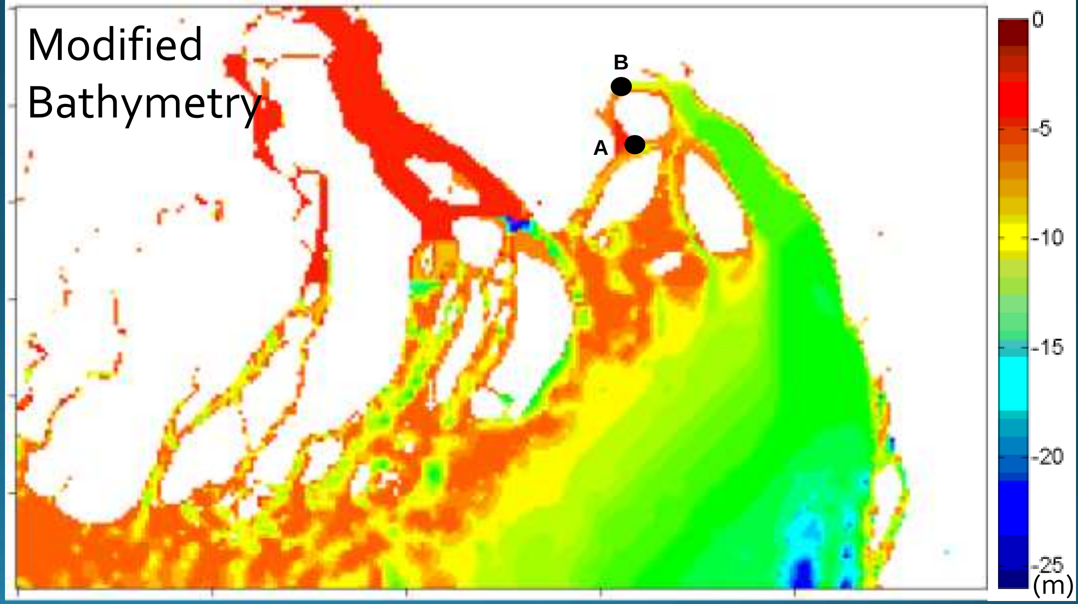
Bathymetry





Bathymetry survey at selected locations

Numerical experiments with altering bathymetry



Extensive bathymetric survey of the Meghna Estuary was done during the Meghna Estuary Study (MES) project during 1997.

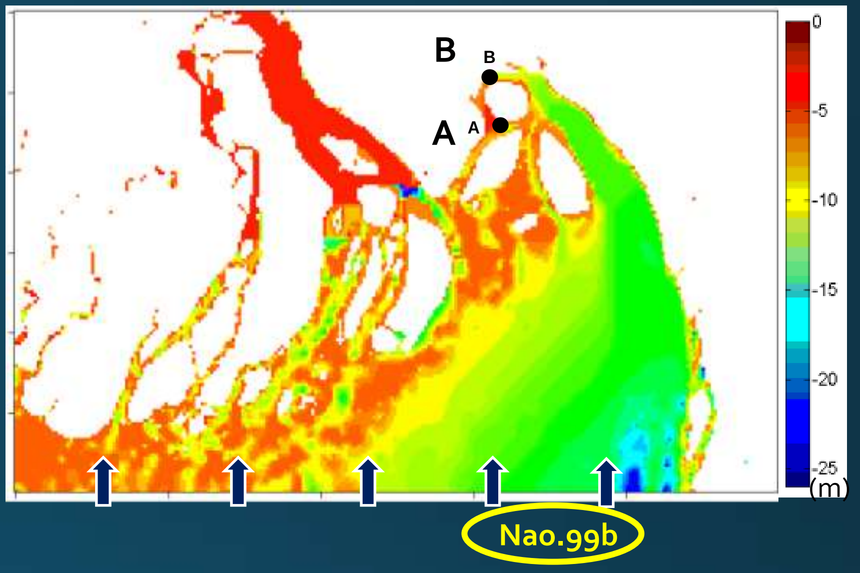
The coastlines as well as bathymetry has undergone extensive changes during the last two decades.

To obtain a bathymetry with reasonable accuracy GEBCO data has been adopted where the coastlines are modified satellite images (PALSAR) and unrealistic nearshore water depth has been corrected by bathymetric survey at selected locations.

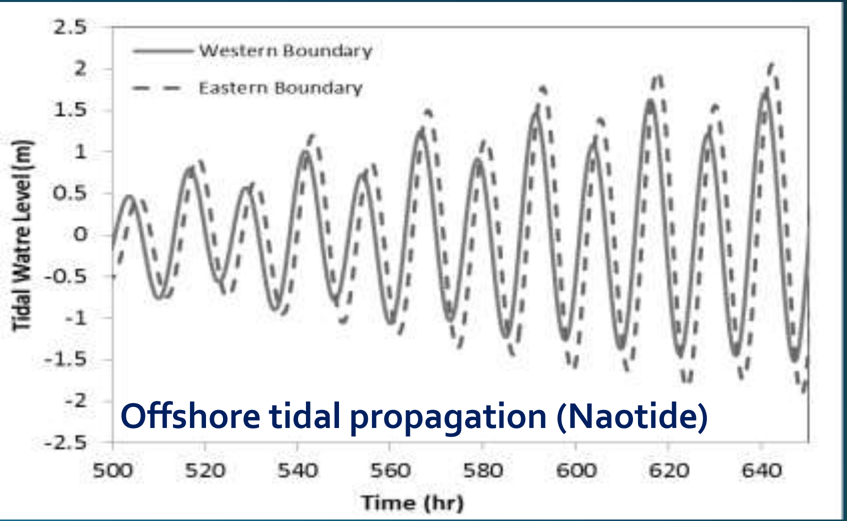
Tidal computation

Ocean tide model + non-linear shallow water model

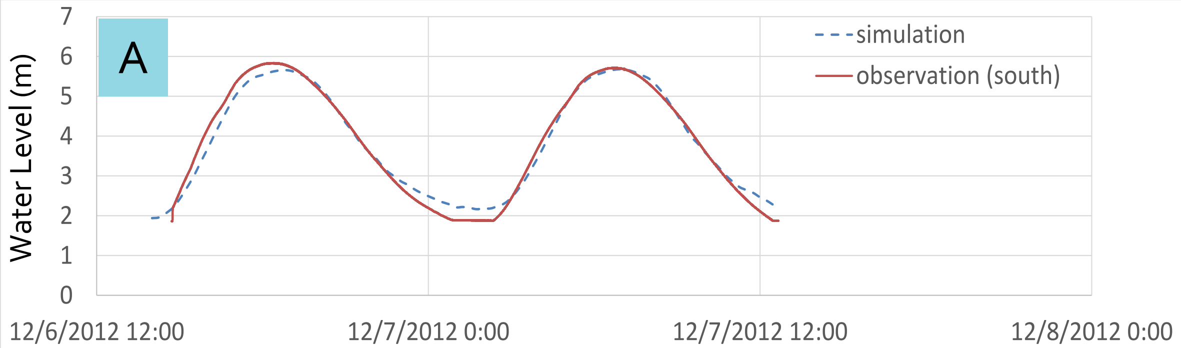
Ocean tide model (Nao.99b)
-Assimilated to TOPEX/POSEIDON and provides accurate predictions of tides at arbitrary locations in the open ocean
-Influence of nearshore bathymetry is not accounted for and thus loses accuracy near the shore

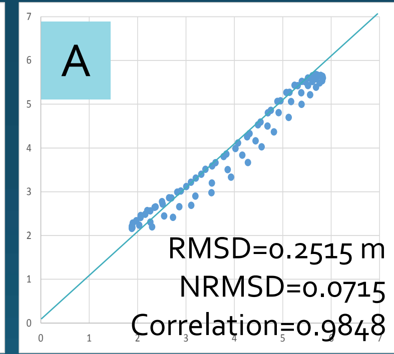


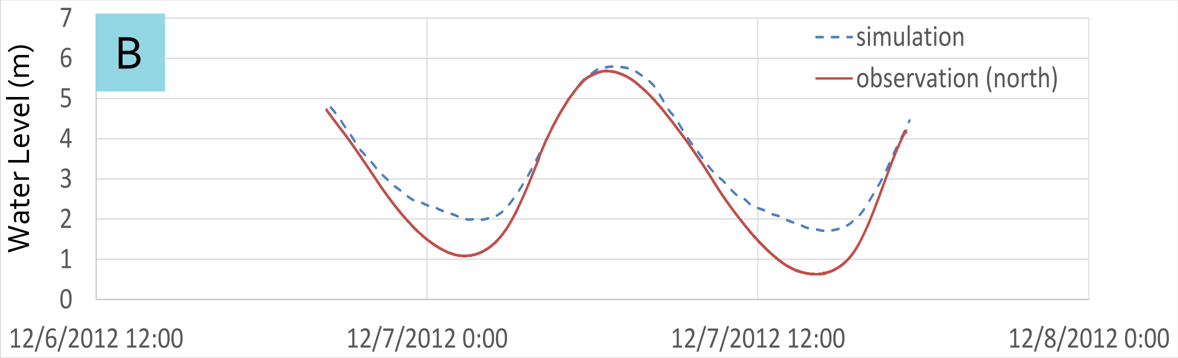
Use Nao.99b to specify offshore BC and compute tidal response by non-linear shallow water model

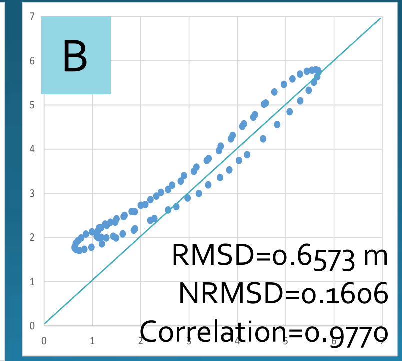


Calibration with 2012 observed data:

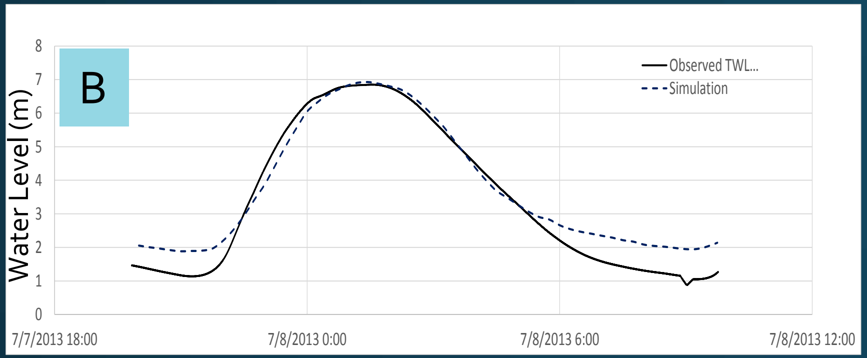


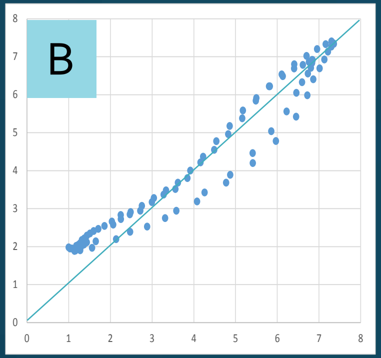




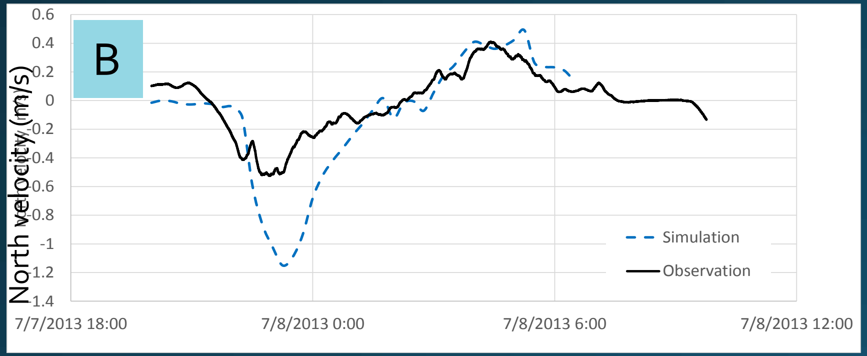


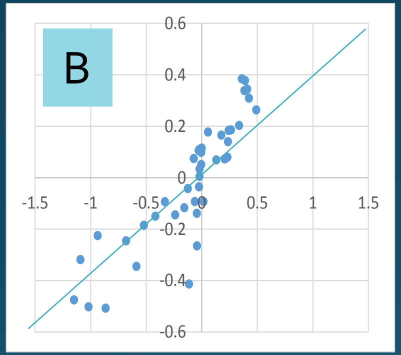
Validation with 2013 observed water level and velocity data:



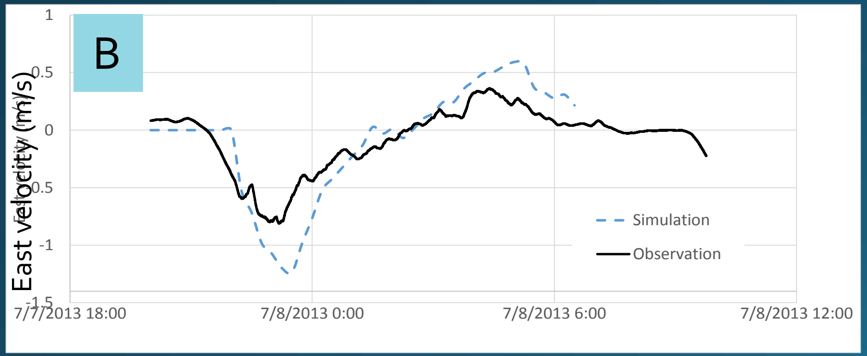


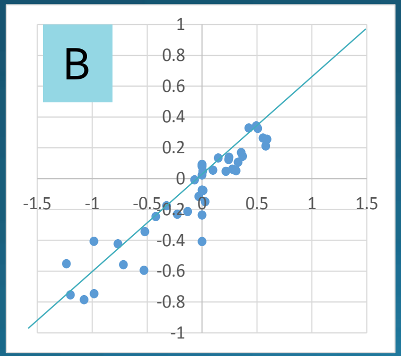
RMSD=0.5697 m
NRMSD=0.1032
Correlation=0.9734



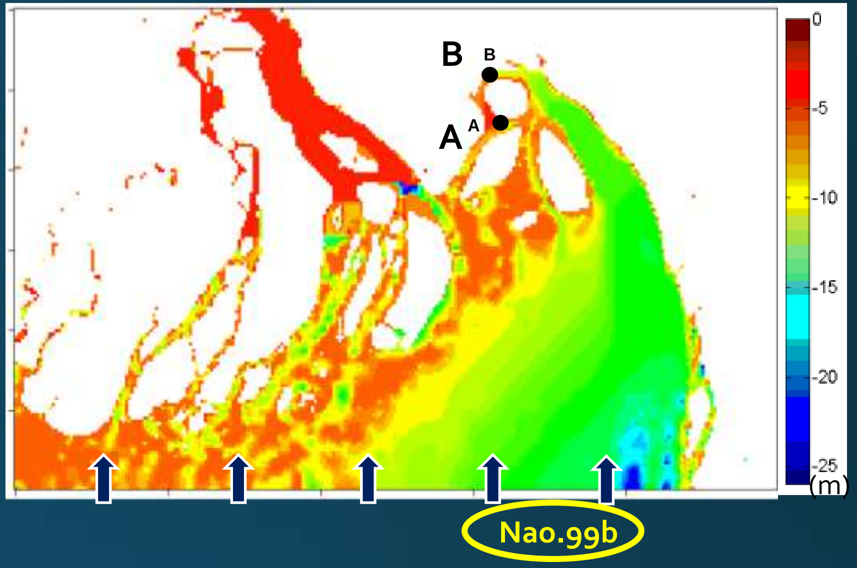


RMSD=0.2593 m/s
NRMSD=0.2907
Correlation=0.8790



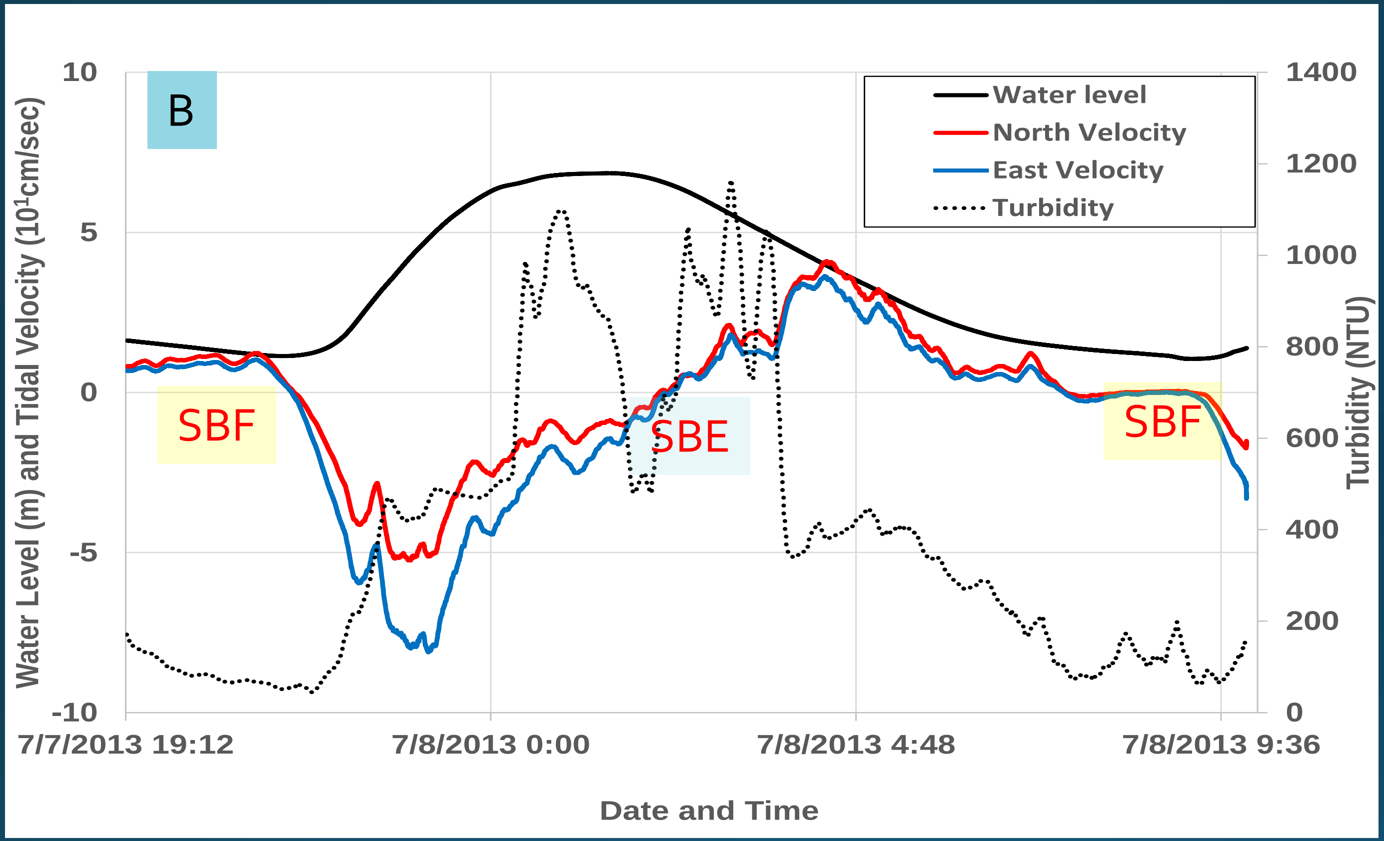


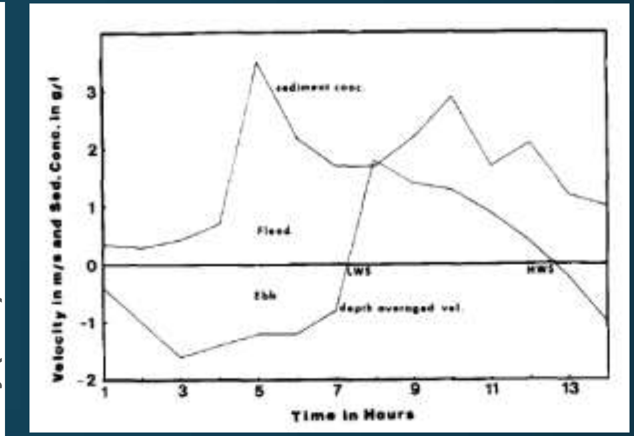
RMSD=0.2361 m/s
NRMSD=0.2094
Correlation=0.9257



Tidal velocity components were measured from a fixed position about 1m from the bottom. The computed tidal velocity components are depth averaged. So a discrepancy between measured and computed values are expected.

Results on simultaneous measurement of water level, velocity and turbidity

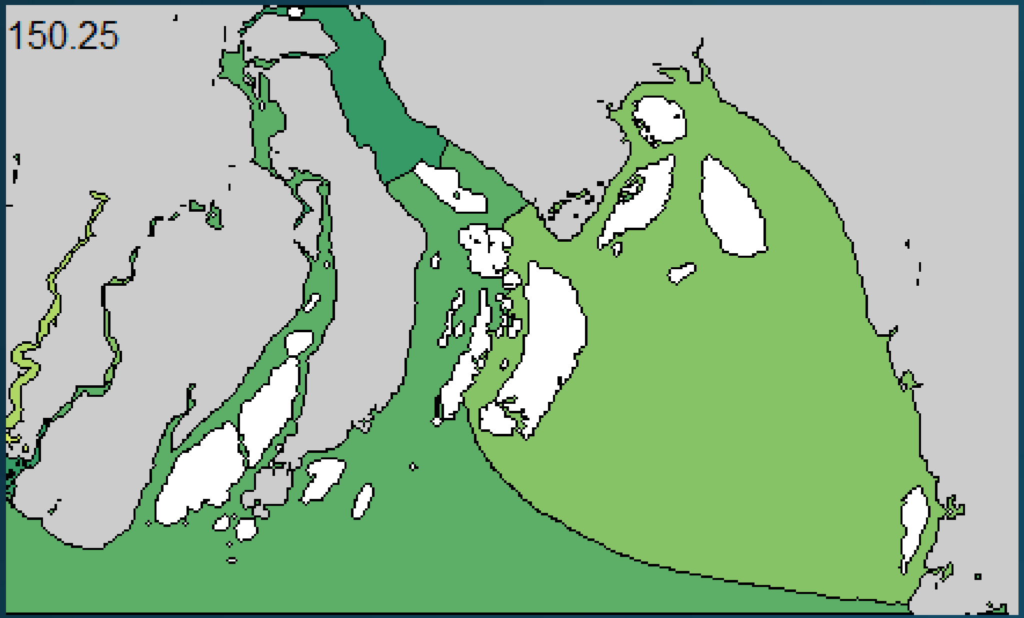




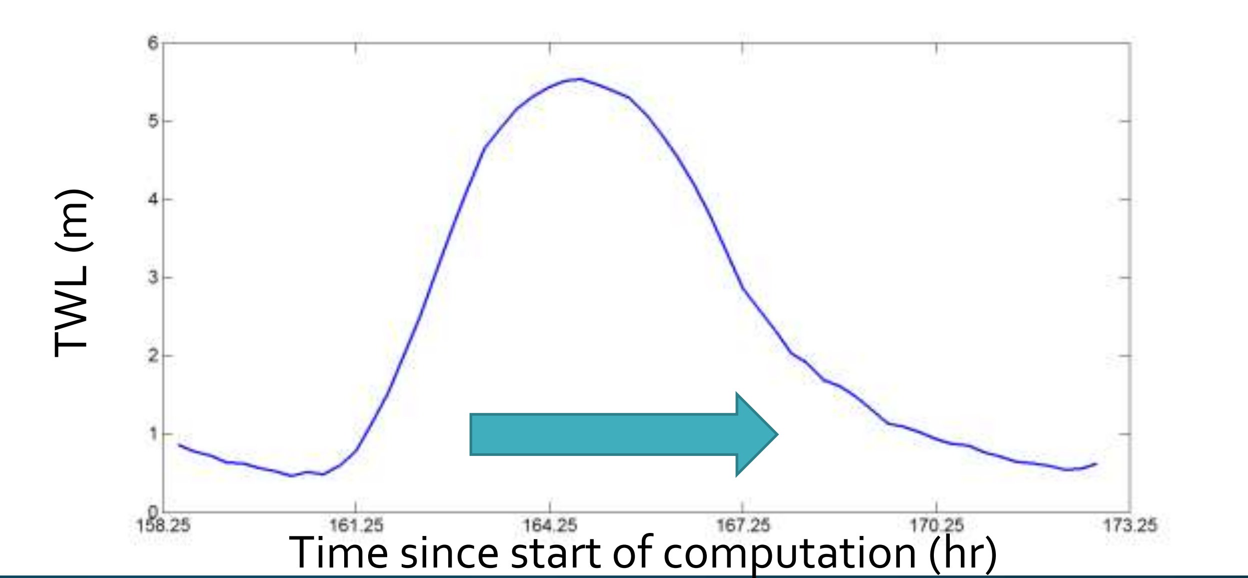
Suspended Sediment Movement in the Estuary of the Ganges-Brahmaputra-Meghna River System, D.K. Barua, Mar. Geology, 1990

Tidal Asymmetry: vertical (TWL) and horizontal (tidal velocity) asymmetry (Wang, delft hydraulics, 1999)
From TWL, rising duration<falling duration: flood dominant
From velocity, flood velocity>ebb velocity: flood dominant ~ coarse sediment
From velocity, Slack Before Flood> Slack Before Ebb: fine sediments will settle during SBF

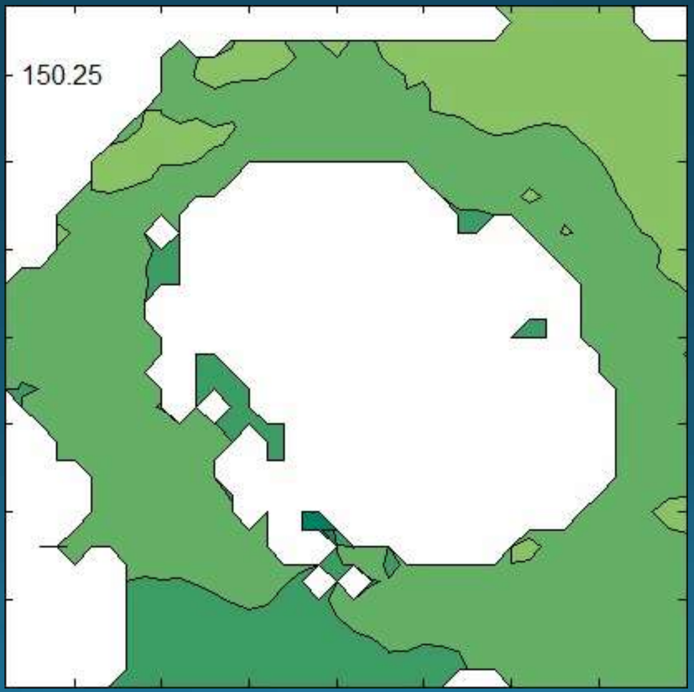
Computed tidal propagation



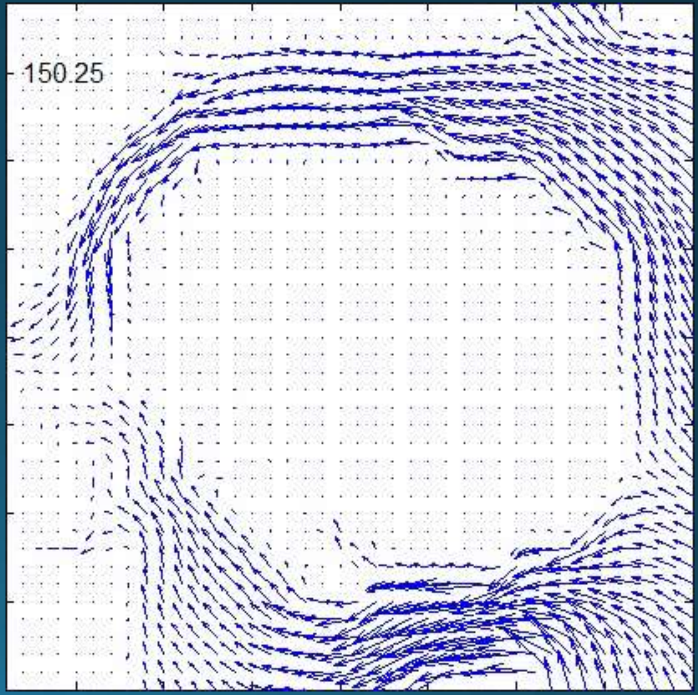
Water surface elevation (lighter color: higher value)



Tide propagates faster with a higher amplitude along the eastern coast and converges towards the north-eastern part and gets highly affected by the coastline convergence in that region.

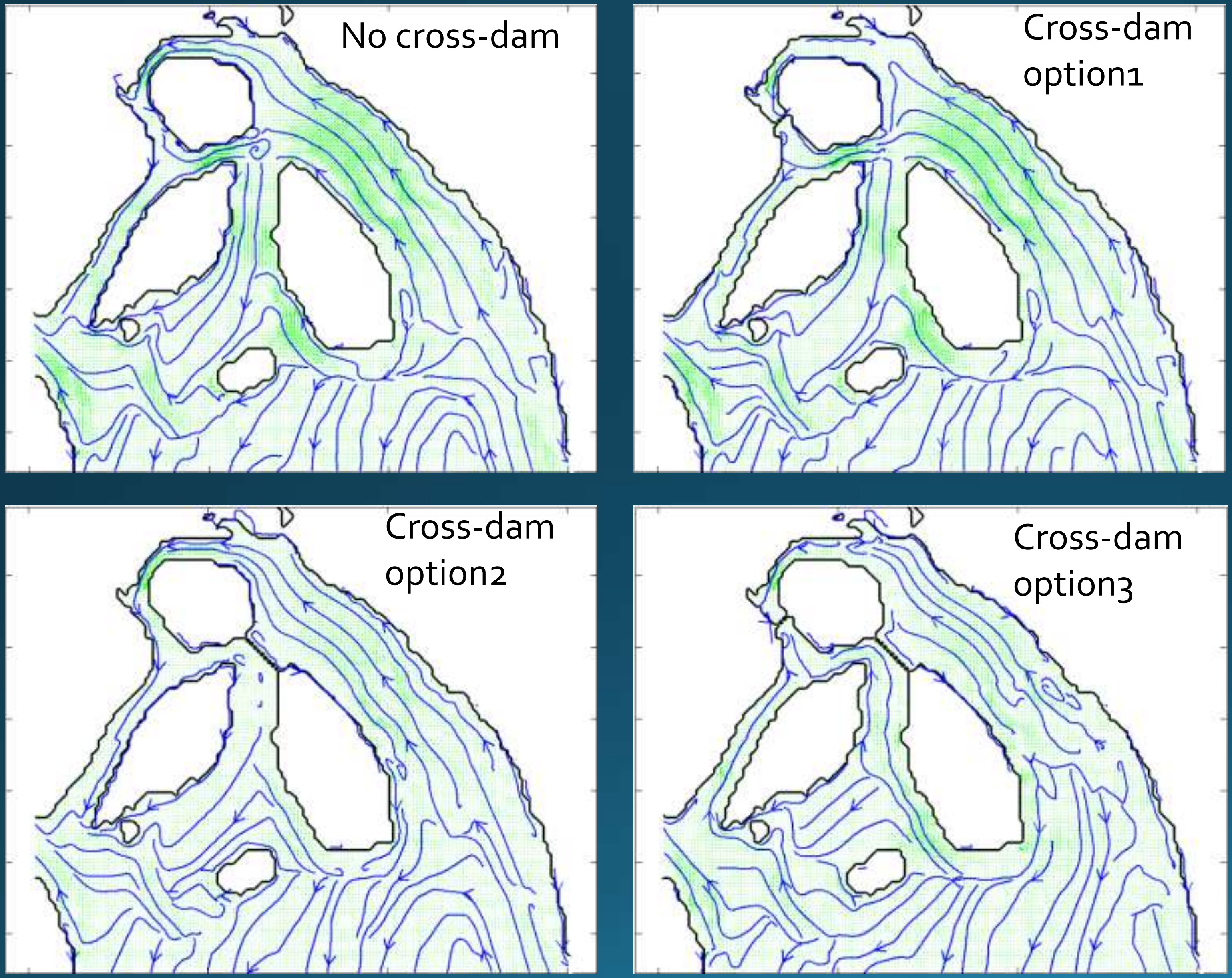


Water surface elevation



Tidal velocity

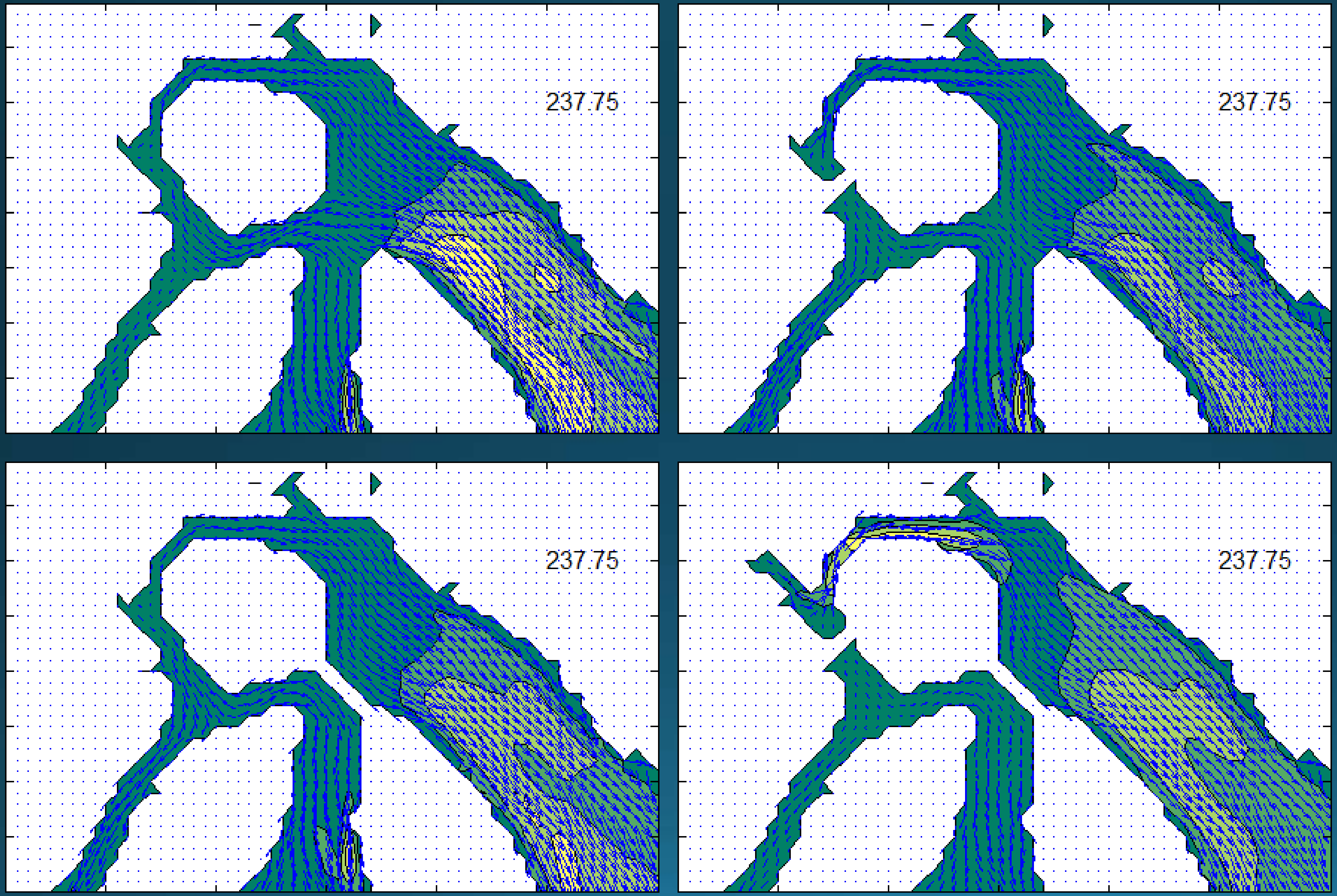
Simulation of residual flux after cross dam construction



As the western channel of Urir Char is almost silted up, construction of Cross-dam with Option1 will least influence the present residual flux at the target site.

Difference between the construction of Cross-dam with option2 and option3 is very small because of the same reason.

Simulation of horizontal advection of suspended sediments by tidal current



‘Waves might the the main source of sediment resuspension at the shallow areas around Urir Char’.

Sediment Dynamics in the Meghna Estuary, Bangladesh: A Model Study
Ayub Ali; A. E. Mynett; and Mir Hammadul Azam
Jour. of Waterway, ASCE, 2007

Wave estimation

Wave model (WAM)

Wind field → Model WAM → Wave field

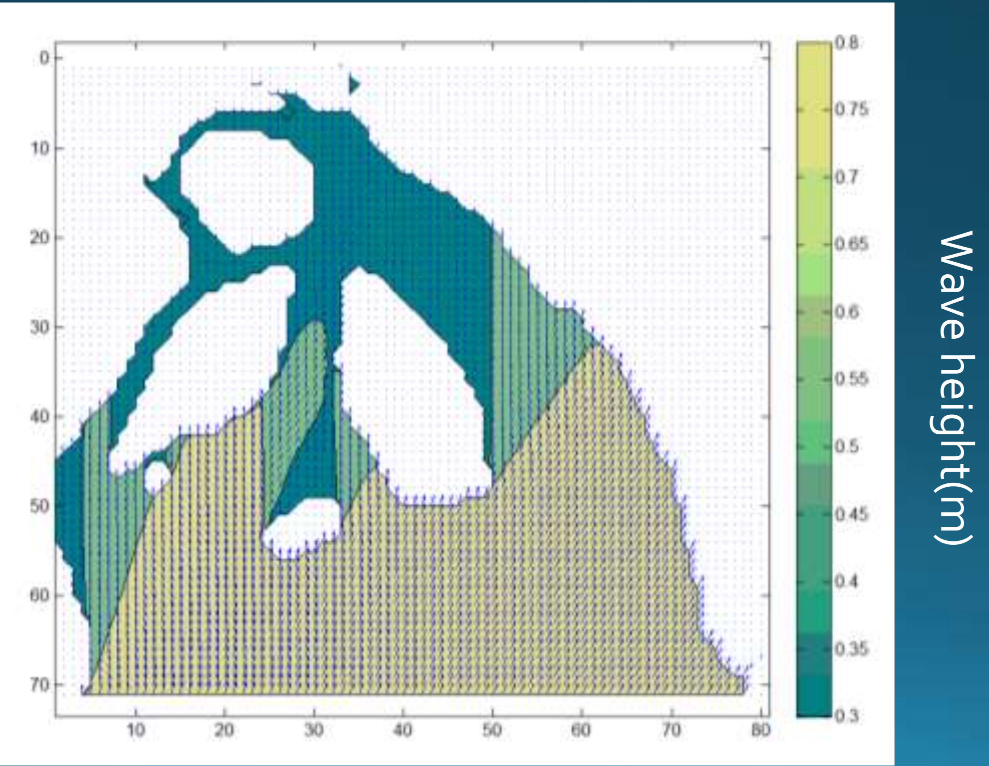
WAMDI GROUP in 1988

$$\frac{\partial F}{\partial t} + \frac{1}{\cos\phi}\frac{\partial}{\partial \phi}\left(\dot{\phi}\cos\phi F\right) + \frac{\partial}{\partial \lambda}\left(\dot{\lambda}F\right) + \frac{\partial}{\partial \theta}\left(\dot{\theta}F\right) = Sin + Sds + Snl$$

Sin = Wind energy
Sds = Energy dissipation
Snl = Nonlinear interaction

The result

Wave Field with steady south wind of 10m/s



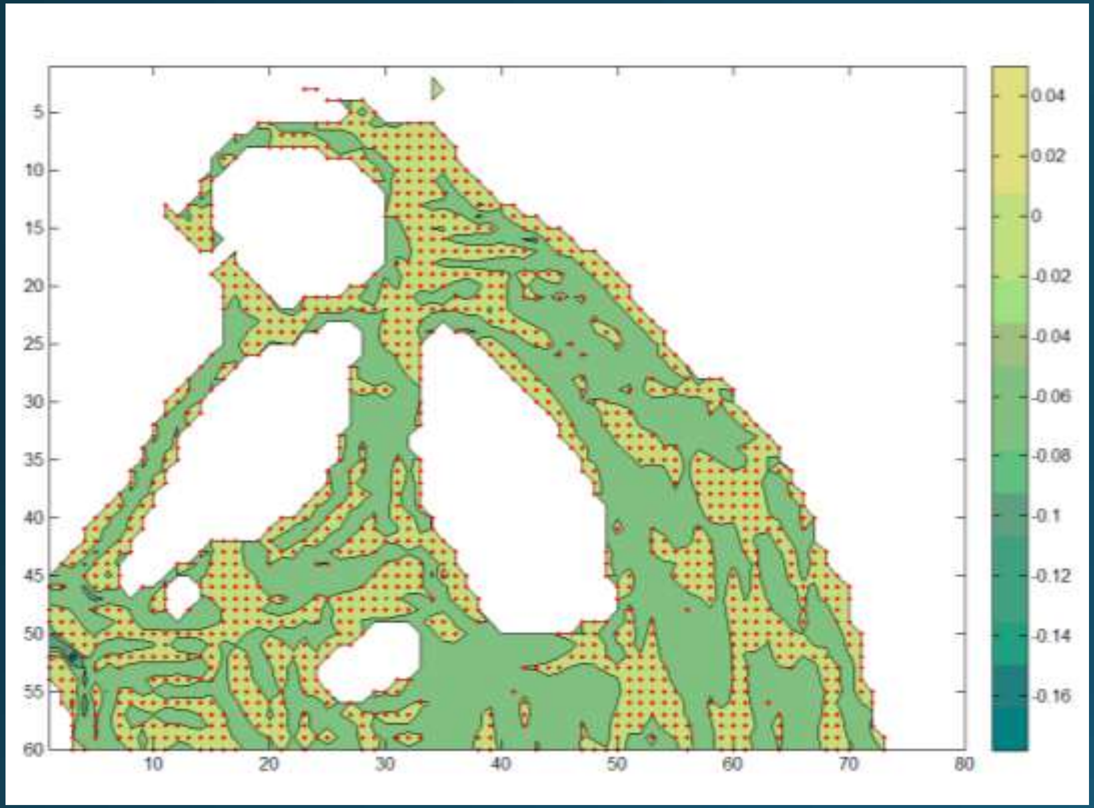
Suspended sediment concentration from waves and currents:

$$\vec{q}_{ss} = \int_z^h C\vec{U}dz + \overline{\int_z^h c_w \vec{u}_w dz} + \overline{\int_h^{h+\eta} c_w \vec{U} dz} + \overline{\int_h^{h+\eta} C\vec{u}_w dz} \cong \int_z^h C\vec{U}dz + \overline{\int_z^h c_w \vec{u}_w dz}$$

The fisrt term is the contribution due to the product of the mean current and the mean suspended sediment concentration and referred as 'mean suspended load'. The second term is the component due to the wave associated fluctuating velocity and sediment concentration, referred as 'mean wave associated suspended load'.

The vertical profile of sediment concentration was obtained applying bottom boundary condition which included fall velocity (following Jimenez and Madsen, 2003) and pickup function (Herrmann, 2004)

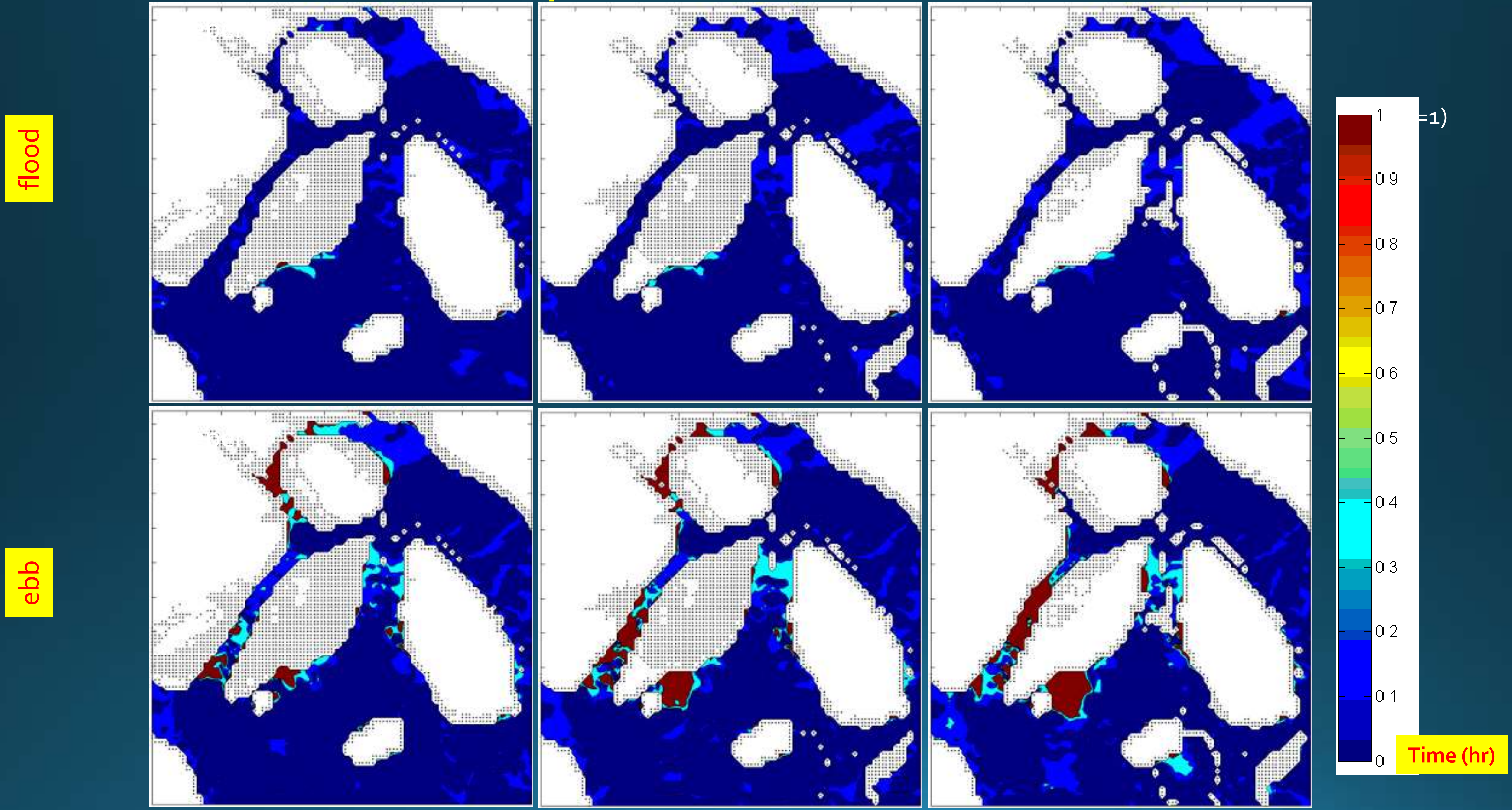
Accretion areas due to crossdam construction:



Typical accretion for Cross-dam option 1: during one month monsoon season under river discharge, south wind and tides.

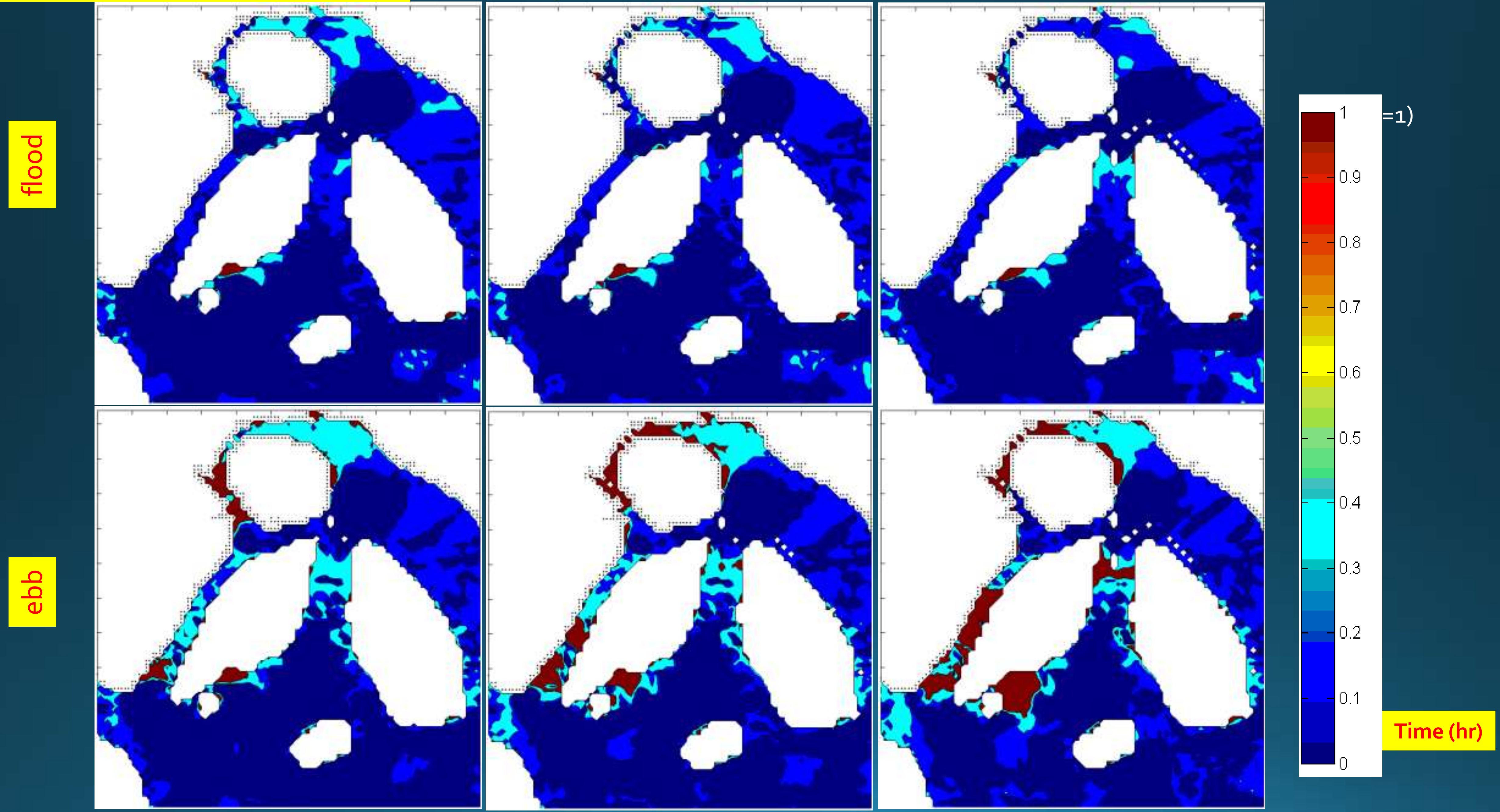
Slack water duration: spring period

Impact of SLR on sedimentation



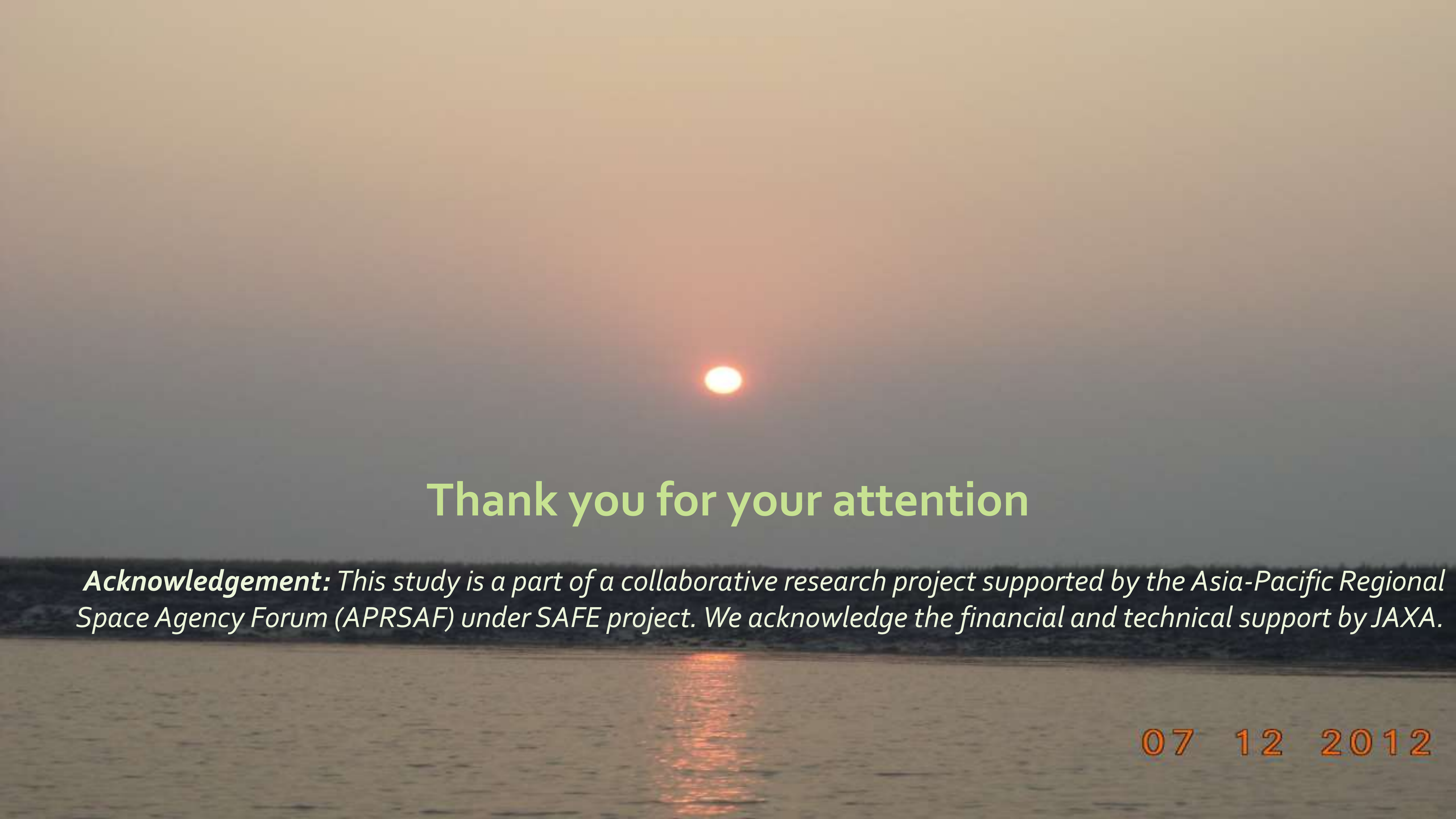
Impact of SLR on sedimentation

Slack water duration: neap period



PART3: Conclusions

1. 2D nonlinear shallow water model has been calibrated and validated for the Meghna Estuary with wave and sediment components to analyze the impact of cross-dams.
2. From the observed data it has been found that strong tidal asymmetry exists at the highly accreting north-eastern part of the Meghna Estuary.
3. Flood velocity exceeds ebb velocity which would induce suspended and bed load residual transport of coarse sediments towards land. Also SBF is much longer than SBE indicating residual transport of fine sediments.
4. The inclusion of wave component significantly influences the suspended sediment concentrations.



Thank you for your attention

Acknowledgement: *This study is a part of a collaborative research project supported by the Asia-Pacific Regional Space Agency Forum (APRSAF) under SAFE project. We acknowledge the financial and technical support by JAXA.*