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The State of the Art and Science of Coastal Engineering

CONTRIBUTION OF LARGE RIVER SYSTEM ON WATER LEVEL DUE TO A STORM

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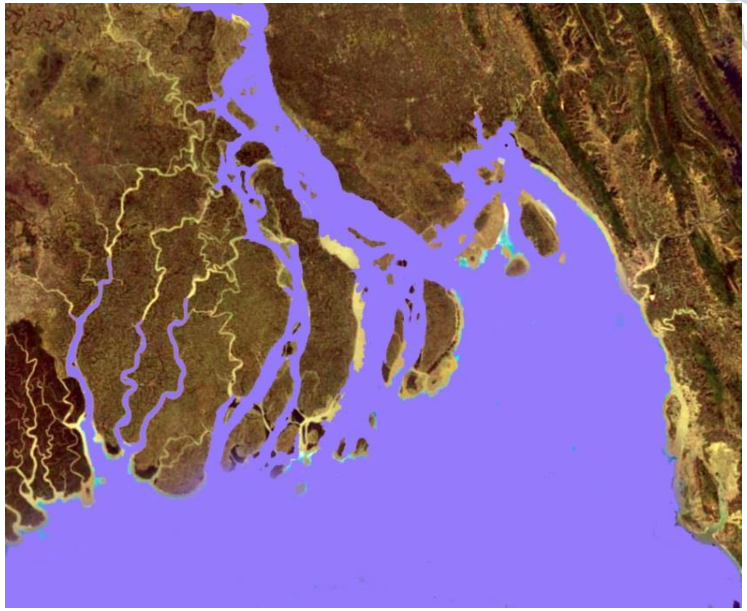
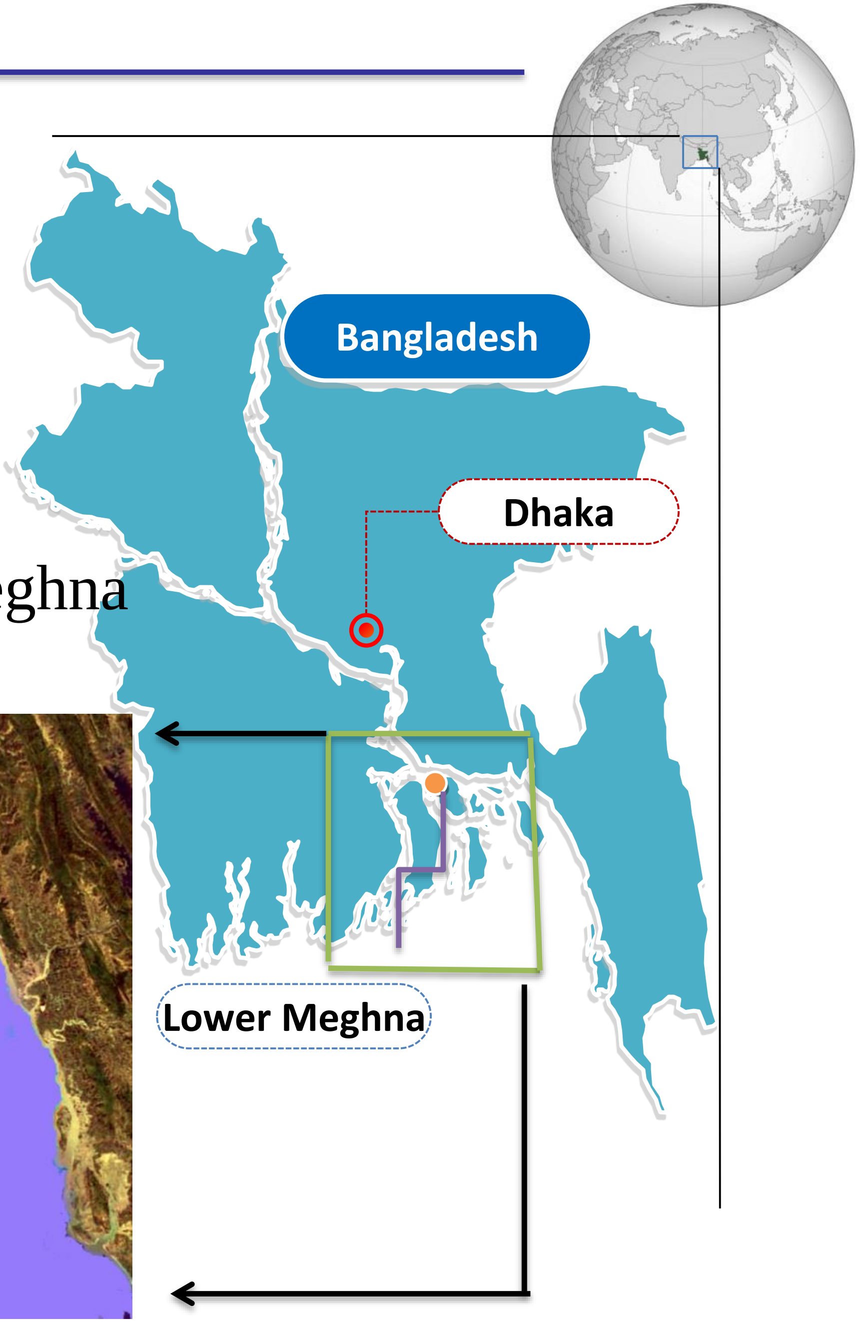
Research Focus on

- The Bay of Bengal coast especially for the Bangladesh Coast.
- The Development of a bay-river couple model.
- Numerical Investigation of Ganges-Brahmaputra-Meghna (lower Meghna) river impact on surge simulation.
- Inland coastal protection and flood management.





Motivation of this study

► **Human death** (Dangerous Cyclone): Bhola (1970): **167,000;**Cyclone BoB 01 (1991): **138,000;** Cyclone Nargis (2008): **140,000**

►**Economic Losses:** 17.58 billion (US$) (last 10 years)

► To protect inland flood due to a cyclone

►To develop a disaster prevention policy for the newly settled Rohingya People in the coastal island

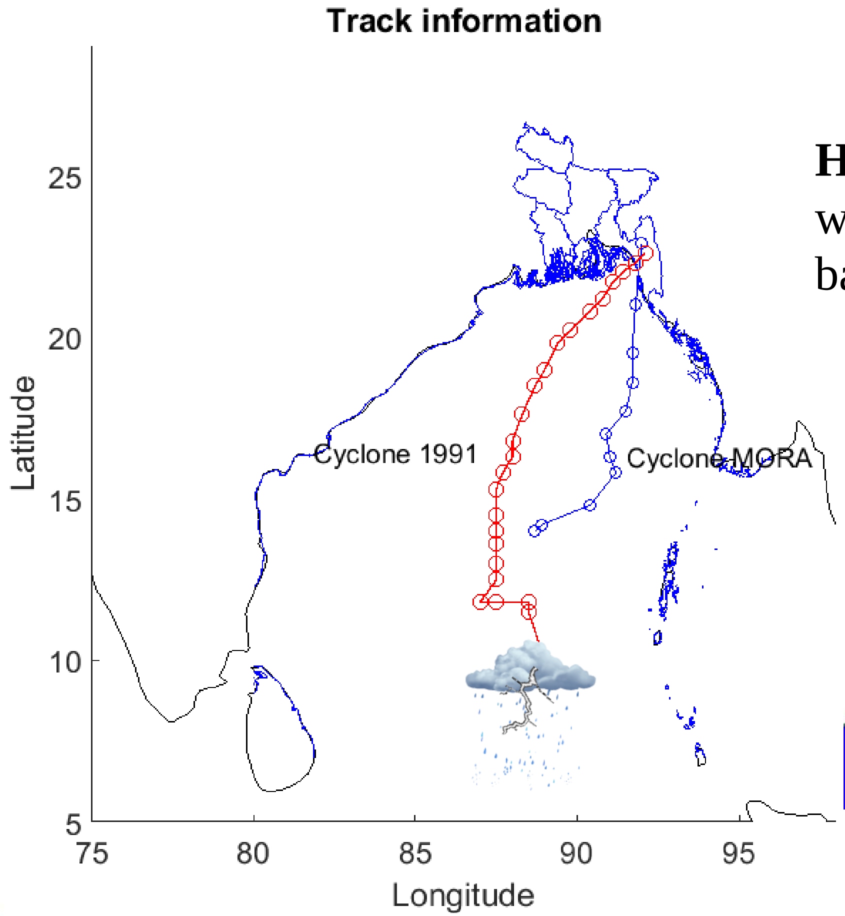
Objective of this study

The objective of this study is to develop a bay-river coupled model to predict water levels due to a tropical cyclone.

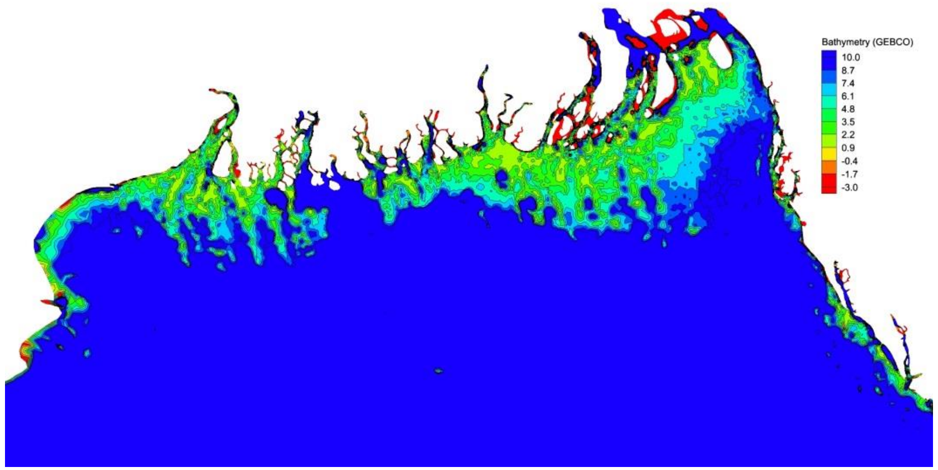
By using this developed model to find the influence of river on sure height with a considerably improved representation of a number of factors. The factors namely shallow bathymetry, thickly populated offshore islands, coastal contours, river discharges, and actual geometry of river.

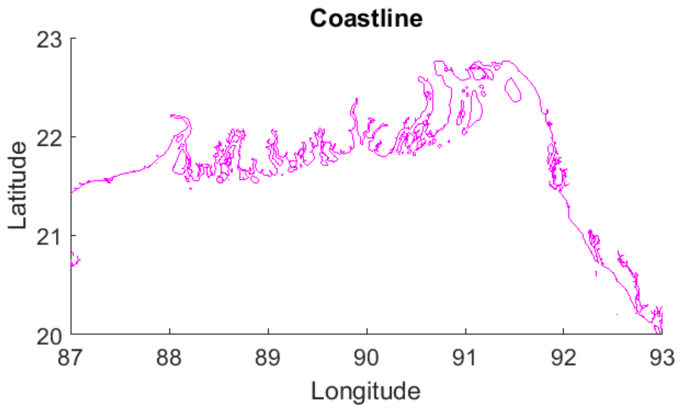
Model Data and cyclones

Meteorological data: Cyclone information was collected from Bangladesh Meteorological Department



Hydrological data: Bathymetry data was collected from the general bathymetry chart of ocean (GEBCO)





Geographical data: Coastline and island geometry was collected from GEOphysical DAta System (GEODAS) coastline shapefile.

Numerical Models

Parent Model (Bay model): The flux form of the vertically integrated shallow water equations are

$$\frac{\partial \zeta}{\partial t}+\frac{\partial \tilde{u}}{\partial x}+\frac{\partial \tilde{v}}{\partial y}=0,$$

$$\frac{\partial \tilde{u}}{\partial t}+\frac{\partial (u\tilde{u})}{\partial x}+\frac{\partial (v\tilde{u})}{\partial y}-f\tilde{v}=-g(\zeta+h)\frac{\partial \zeta}{\partial x}+\frac{T_x}{\rho}\ -\frac{C_f\ \ \tilde{u}\sqrt{(u^2+v^2)}}{\zeta+h},$$

$$\frac{\partial \tilde{v}}{\partial t}+\frac{\partial (u\tilde{v})}{\partial x}+\frac{\partial (v\tilde{v})}{\partial y}+f\tilde{u}=-g(\zeta+h)\frac{\partial \zeta}{\partial y}+\frac{T_y}{\rho}\ -\frac{C_f\ \ \tilde{v}\sqrt{(u^2+v^2)}}{\zeta+h},$$

where $(\tilde{u},\tilde{v})=(\zeta+h)(u,v)$ and $u, v,$ are the Reynolds averaged components of velocities in the directions of x any y, respectively; ρ is the density of the sea water supposed to be homogeneous of same density; $f=2\Omega\sin\varphi$ is the Coriolis parameter, where Ω is the angular speed of the earth rotation and φ is the latitude of the place of interest; g is the acceleration due to gravity.

Numerical Models

River Model: The governing equation for the developed river model

$$\frac{\partial \xi_{riv}}{\partial t} + \frac{\partial}{\partial x}\left[Hu_{riv}\right] + \frac{\partial}{\partial y}\left[Hv_{riv}\right] = 0,$$

$$\frac{\partial}{\partial t}\left[Hu_{riv}\right] + \frac{\partial}{\partial x}\left[Hu_{riv}{}^{2}\right] + \frac{\partial}{\partial y}\left[Hu_{riv}v_{riv}\right] - Hv_{riv} = -g\frac{\partial \xi_{riv}}{\partial x} + \frac{T_x}{\rho} - C_f u_{riv}\left(u_{riv}{}^{2} + v_{riv}{}^{2}\right)^{1/2},$$

$$\frac{\partial}{\partial t}\left[Hv_{riv}\right] + \frac{\partial}{\partial x}\left[Hu_{riv}v_{riv}\right] + \frac{\partial}{\partial y}\left[Hv_{riv}{}^{2}\right] + Hu_{riv} = -g\frac{\partial \xi_{riv}}{\partial y} + \frac{T_y}{\rho} - C_f v_{riv}\left(u_{riv}{}^{2} + v_{riv}{}^{2}\right)^{1/2},$$

Where $H = [\xi_{riv} + h_{riv}](u_{riv,} v_{riv})$ represents the total water column depth and bottom stress

$\rho C_f \sqrt{u_{riv}^2 + v_{riv}^2}$

Boundary condition for the Bay Model

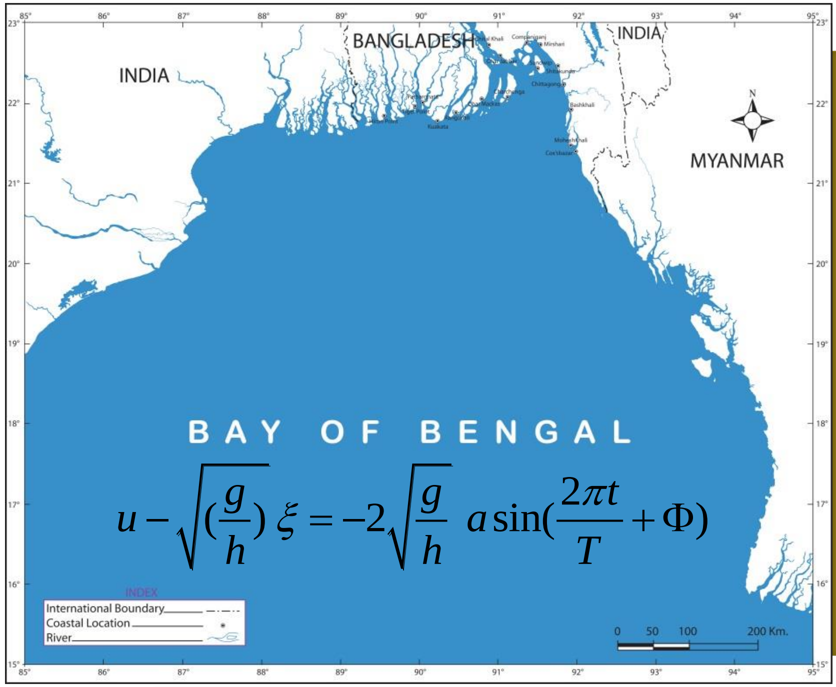
At the open-sea boundary, the normal currents across the boundary may be prescribed as radiation type equation (Heaps,1973):

$$u\cos\alpha + v\sin\alpha + \xi\sqrt{\frac{g}{h+\Delta h}} = 0$$

The open sea boundaries along 15^0 N latitude, 85^0E longitude and 95^0E longitude. According to Johns *et al.* (1985)

At the west boundary

$$v - \sqrt{\left(\frac{g}{h}\right)}\xi = 0$$



At the east boundary

$$v + \sqrt{\left(\frac{g}{h}\right)}\xi = 0$$

At the south boundary

$$u - \sqrt{\left(\frac{g}{h}\right)}\xi = -2\sqrt{\frac{g}{h}}\,a\sin\left(\frac{2\pi t}{T} + \Phi\right)$$

Boundary condition for the River Model

The eastern and western river boundaries, whenever it is a vertical sidewall, the boundary condition $\xi_{riv} = 0.$

If the freshwater discharge from the river is taken into account then

$$u_{riv} = \frac{Q}{B_{riv} h_{riv}},$$

when, no freshwater discharge is considered then

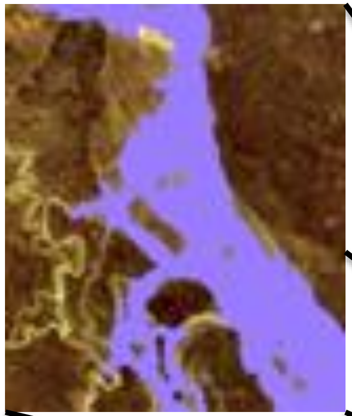
$$u_{riv} = 0,$$

North

$$u_{riv} = \frac{Q}{B_{riv} h_{riv}}, \; u_{riv} = 0,$$

West

$$\xi_{riv} = 0.$$



East

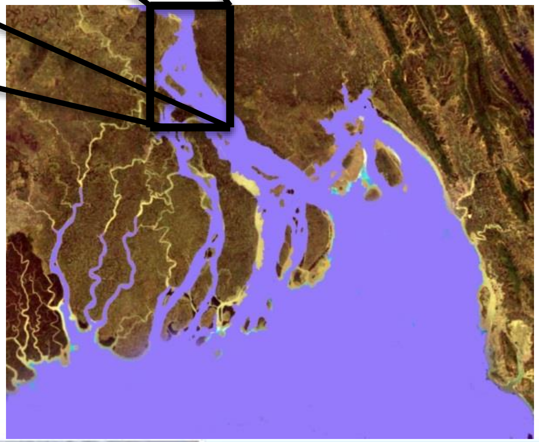
$$\xi_{riv} = 0.$$

$$\xi_{riv} = \zeta_{bay} \quad u_{bay} - u_{riv} = 0$$

$$v_{bay} - v_{riv} = 0$$

South side

Set the matching condition here.



This matching equation can exchange the information of bay and river model in such a way that the model simulation updated value from the river model is again used as bay model input

$$u_{bay} = u_{riv} + \frac{Q}{B_{riv}(h_{riv} + \xi_{riv})}$$

External forces

Parent model (Bay model)

The wind stress components:

$$(T_x, T_y) = \rho_a c_D (u_a^2 + v_a^2)^{1/2} (u_a, v_a)$$

Maximum sustain wind velocity:

Jelesnianski (1965)

$$V_a = \begin{cases} V_0 \sqrt{(r_a/R)^3} & \text{for all} \quad r_a \le R \\ V_0 \sqrt{(R/r_a)} & \text{for all} \quad r_a > R \end{cases}$$

River model

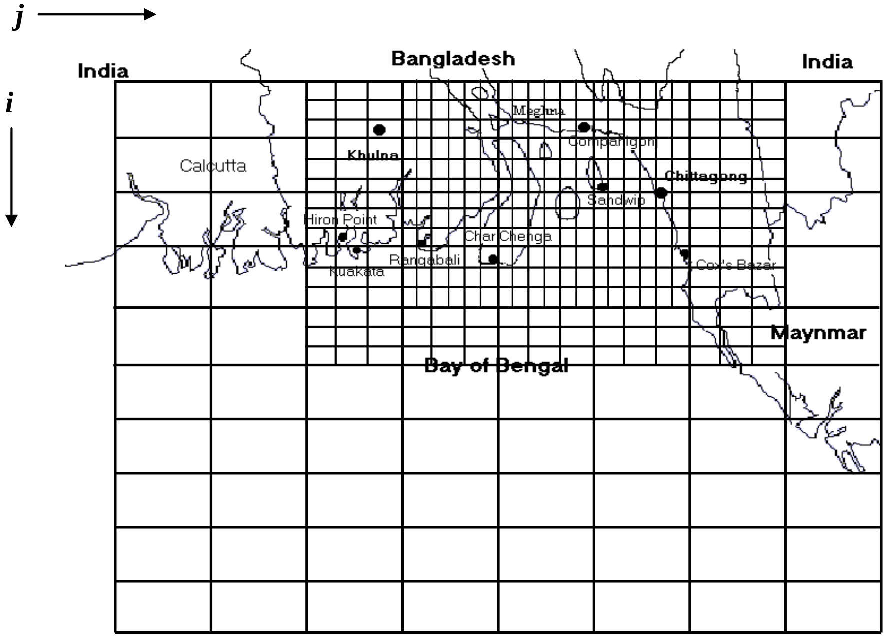
The continuity of volume flux should be ensure at the mouth of the river. So, The matching of bay and river is important

$$\xi_{riv} = \zeta_{bay} \qquad u_{bay} - u_{riv} = 0 \qquad v_{bay} - v_{riv} = 0$$

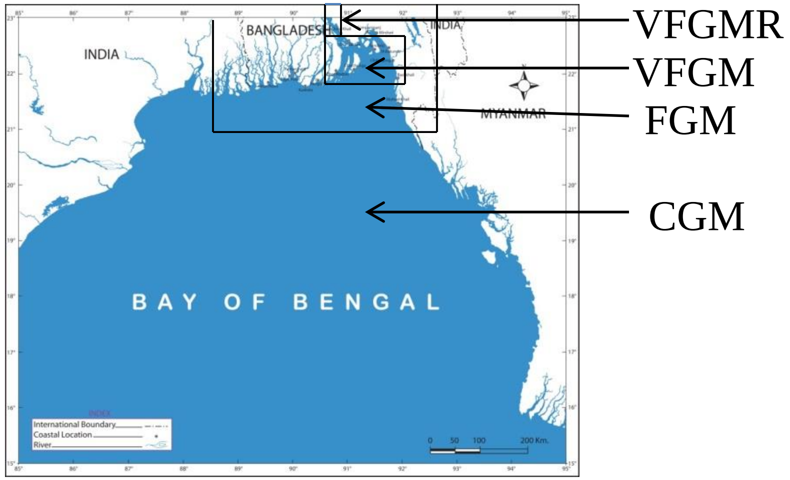
The relation can ensure the sea surface elevation that influences the river and the continuity of volume flux of the flow

Fictitious nesting of study domain

Schematic diagram of Physical domain with fictitious nesting.



Model	Domain	Grid spacing along x axis	Grid spacing along y axis	Number of computational points
CGM	15^0 N to 23^0 N and 85^0 E to 95^0 E	15.08 km	17.52 km	60 × 61
FGM	$21^015'$ N to 23^0 N and 89^0 E to 92^0 E	2.15 km	3.29 km	92 × 95
VFGM	21.77^0 N to 23^0 N and 90.40^0 E to 92^0 E	720.73 m	1142.39 m	190 × 145
VFGMR	23^0 N to 23.25^0 N and 90.40^0 E to 90.68^0 E	720.73 m	1142.39 m	190 × 145



CFL (Courant-Friedrichs-Lewy) stability criterion

$$\Delta t \leq \frac{\Delta x \text{ or } \Delta y}{\sqrt{2gh}}.$$

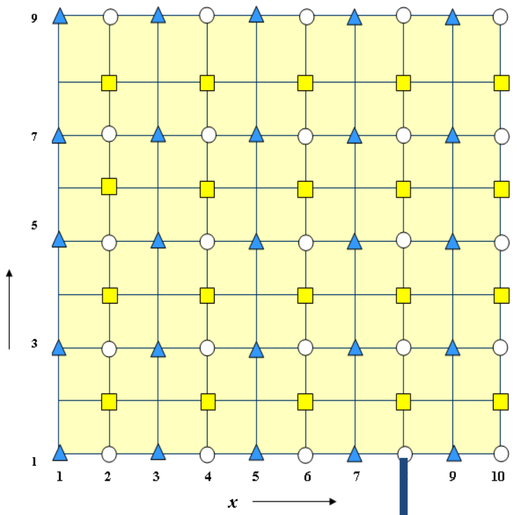
Stair step representation

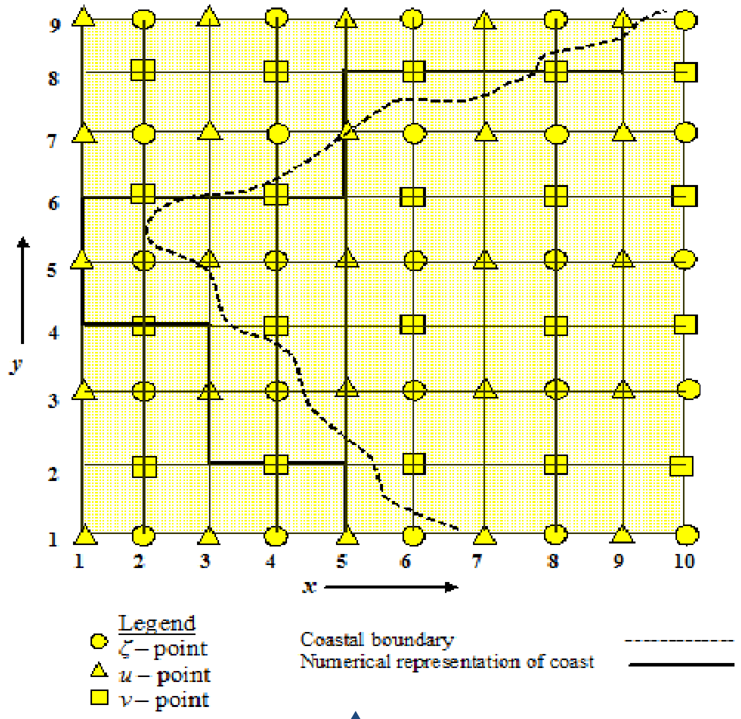
The coastal boundary is approximated either along the nearest odd y-directed grid lines so that we have only u-points on this part of the boundary or along the nearest even x-directed grid lines so that we have only v-points on that part of the boundary

u – point (odd,odd)

v – point (even,even)

ζ – point (even,odd)





Discretization of model equation

Discretized with conditionally stable semi-implicit finite difference technique

$$\xi_t + u_x + \tilde{v}_y = 0$$

$$\zeta_{i,j}^{k+1} = \zeta_{i,j}^{k} - \Delta t\left[TL1 + TL2\right]$$

$$TL1 = \left(\frac{u_{i+1,j}^{k} - u_{i-1,j}^{k}}{2\Delta x}\right)$$

$$TL2 = \left(\frac{\tilde{v}_{i,j+i}^{k} - \tilde{v}_{i,j-1}^{k}}{2\Delta y}\right)$$

→ Continuity Equation

$\zeta_{i,j}^{k+1}$ is computed $i = 2,4,6,.........M-2$ and $j = 3,5,7,.....N-2$

Discretization of model equation

$$u + (uu)_x + (vu)_x - f\tilde{v} = -g\xi_x - \Omega_x + \frac{\tau_x}{\rho(\xi + h)} - \frac{C_f u\sqrt{u^2 + v^2}}{(\xi + h)}$$

$$\tilde{u}_{i,j}^{k+1} = \frac{\tilde{u}_{i,j}^{k} - \Delta t\,(TL1 + TL2 + TL3) + \Delta t\left(TR1 + TR2\right)}{\left(1 + \Delta t.\,FR3\right)}$$

$\tilde{u}_{i,j}^{k+1}$ is computed $i = 3, 5, 7, \ldots\ldots\ldots M - 1$

and $j = 3, 5, 7, \ldots\ldots N - 2$

$$TL1 = \left(\frac{\tilde{u}_{i+2,j}^{k} U_{i+2,j}^{k} - \tilde{u}_{i-2,j}^{k} U_{i-2,j}^{k}}{4\Delta x}\right)$$

$$TL2 = \left(\frac{\overline{\tilde{u}_{i,j+1}^{k}}^{y}\ \overline{V_{i,j+1}^{k}}^{x} - \overline{\tilde{u}_{i,j-1}^{k}}^{y}\ \overline{V_{i,j-1}^{k}}^{x}}{2\ \Delta y}\right)$$

$$TL3 = -f_i \overline{\tilde{v}_{i,j}^{k}}^{xy}$$

$$TR1 = -g\left(\zeta_{i,j}^{k+1} + h_{i,j}\right)\frac{\zeta_{i+1,j}^{k+1} - \zeta_{i-1,j}^{k+1}}{2\Delta x}$$

$$TR2 = \frac{\tau_x}{\rho(\xi_{i,j}^{k+1} + h_{i,j})}$$

$$FR3 = \frac{C_f\sqrt{U_{i,j}^{k^2} + \left(\overline{V_{i,j}^{k}}^{xy}\right)^2}}{\zeta_{i,j}^{k+1} + h_{i,j}}$$

x- component of momentum equation

Discretization of boundary condition

Western boundary: $\zeta_{i,1}^{k+1} = -\zeta_{i,3}^{k+1} - 2\sqrt{(h_{i,2} / g)} \quad V_{i,2}^{k}$

Eastern boundary: $\zeta_{i,N}^{k+1} = -\zeta_{i,N-2}^{k+1} + 2\sqrt{(h_{i,\, N-1} / g)} \quad V_{i,N-1}^{k}$

Southern boundary: $\zeta_{M,j}^{k+1} = -\zeta_{M-2,j}^{k+1} + 2\sqrt{(h_{M-1,j} / g)} \quad U_{M-1,j}^{k} + a\, sin\left(\frac{2\pi.k.\Delta t}{T} + \varphi\right)$

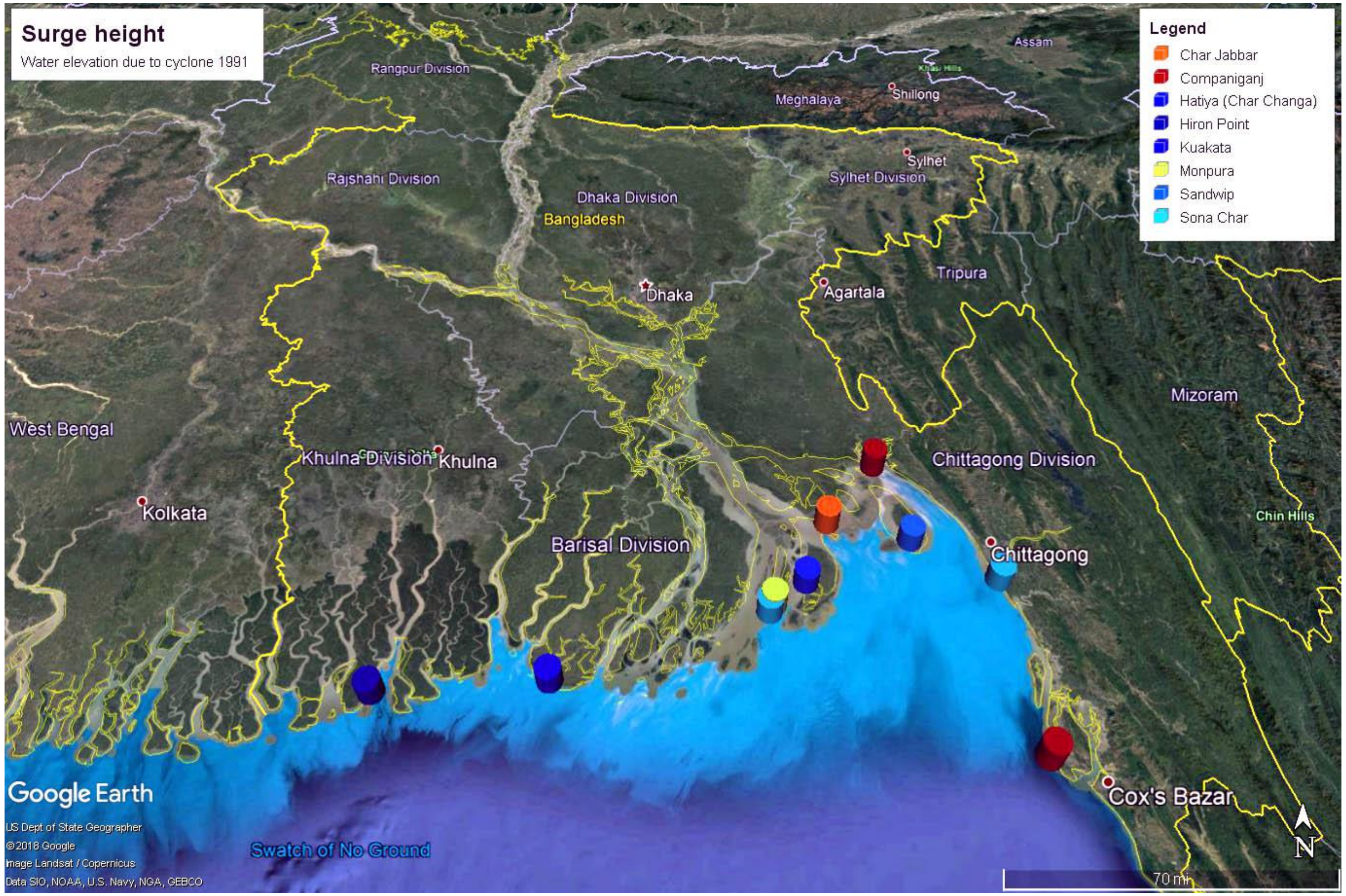
where $i = 2, 4, 6, \ldots, M-2$

and $j = 1, 3, 5, 7, \ldots, N$.

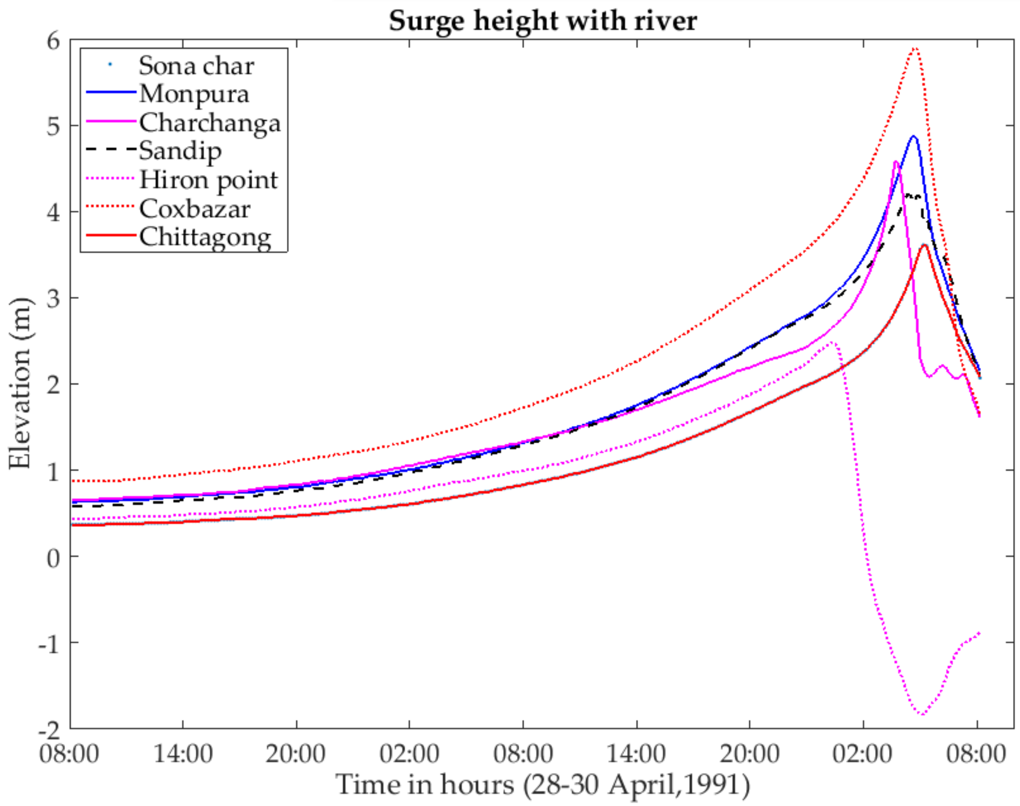
River discharge: $(U_b)_{1,j}^{k+1} = U_{3,j}^{k+1} + \frac{Q}{\left(\zeta_{1,j}^{k+1} + h_{1,j}\right)B}$ where $j = 7, 9, 11, \ldots, 19$.

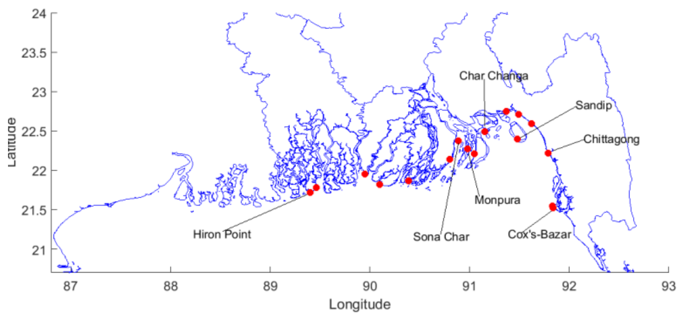
Result and discussion

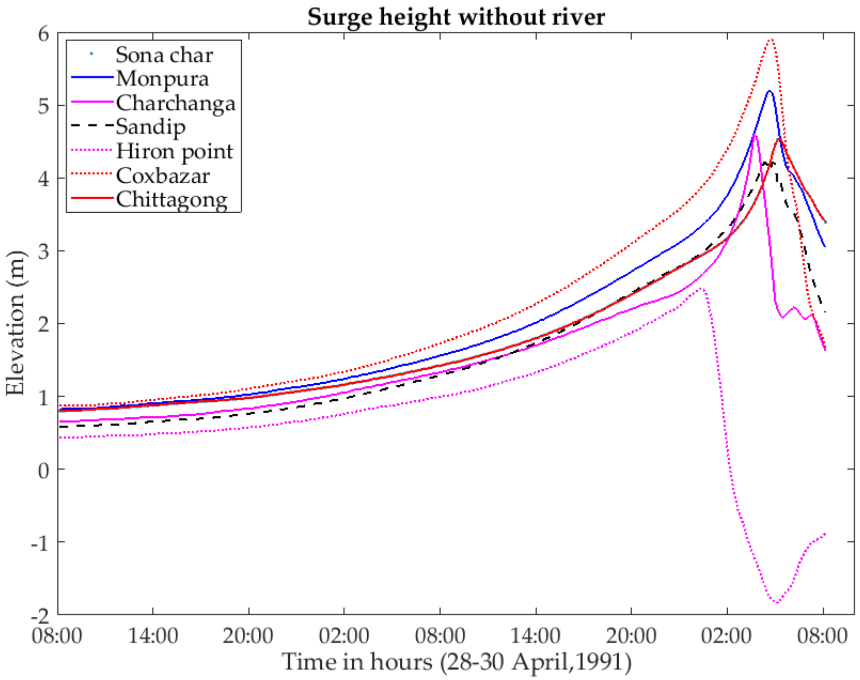
This figure represents the surge height simulation result. We multiplied the surge height by 100 value to make the altitude seen clearly.



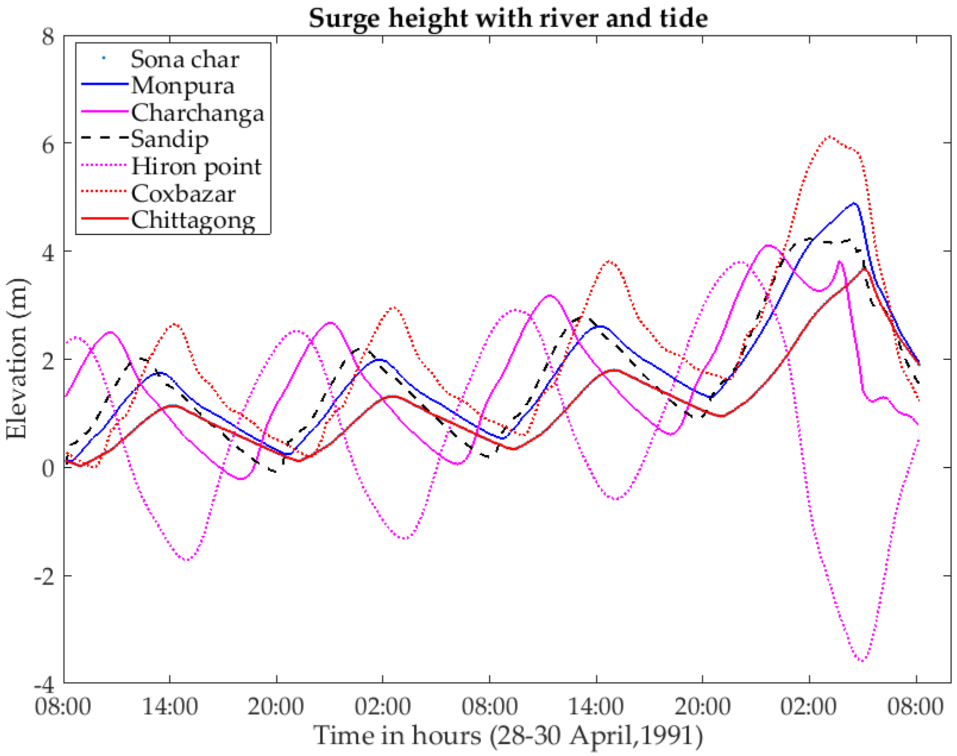
Result and discussion

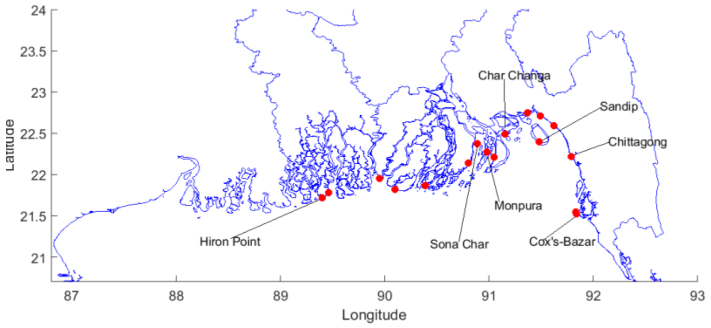


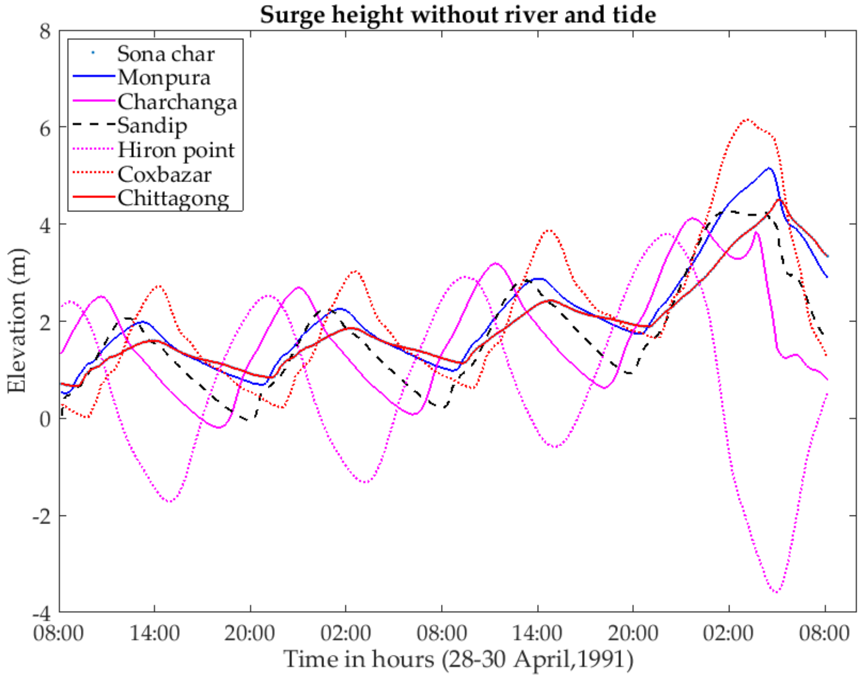




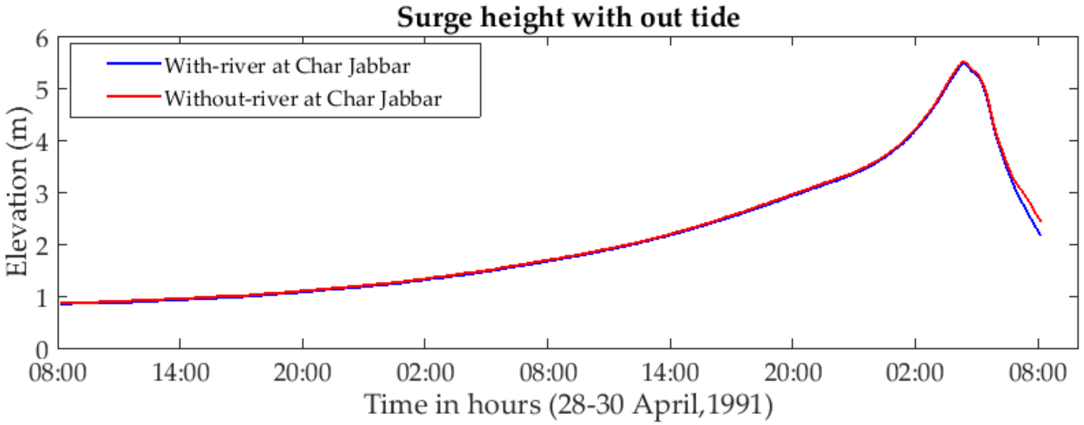
Result and discussion

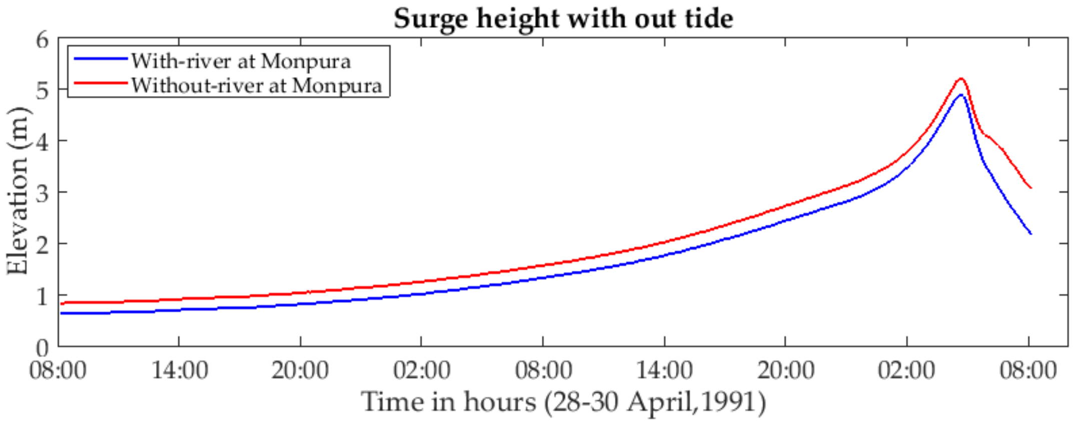


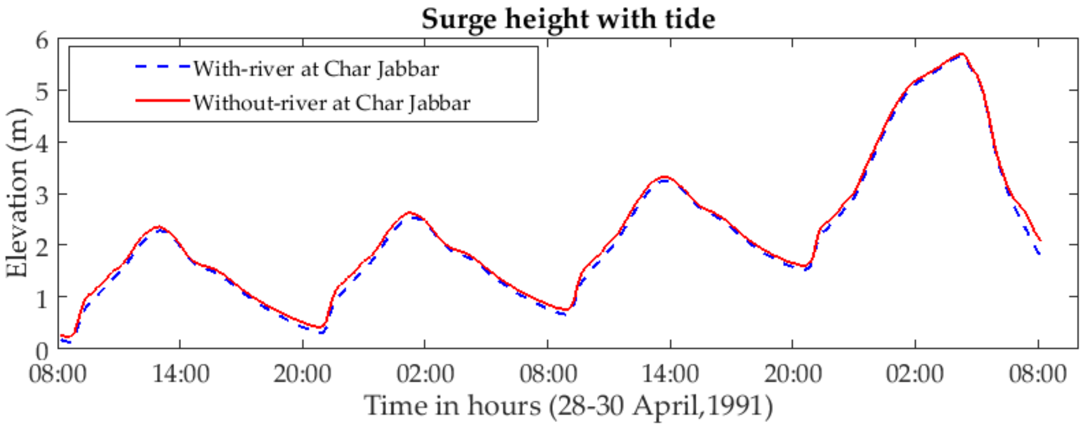


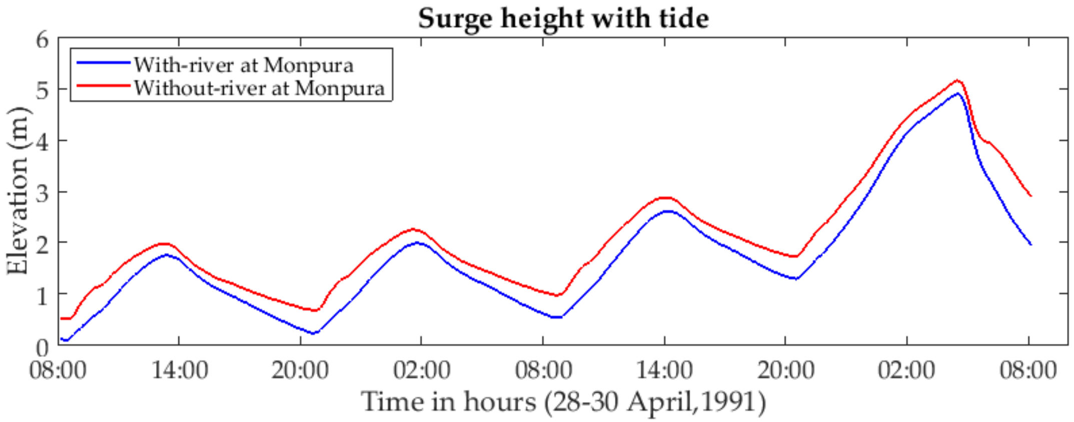


Result and discussion





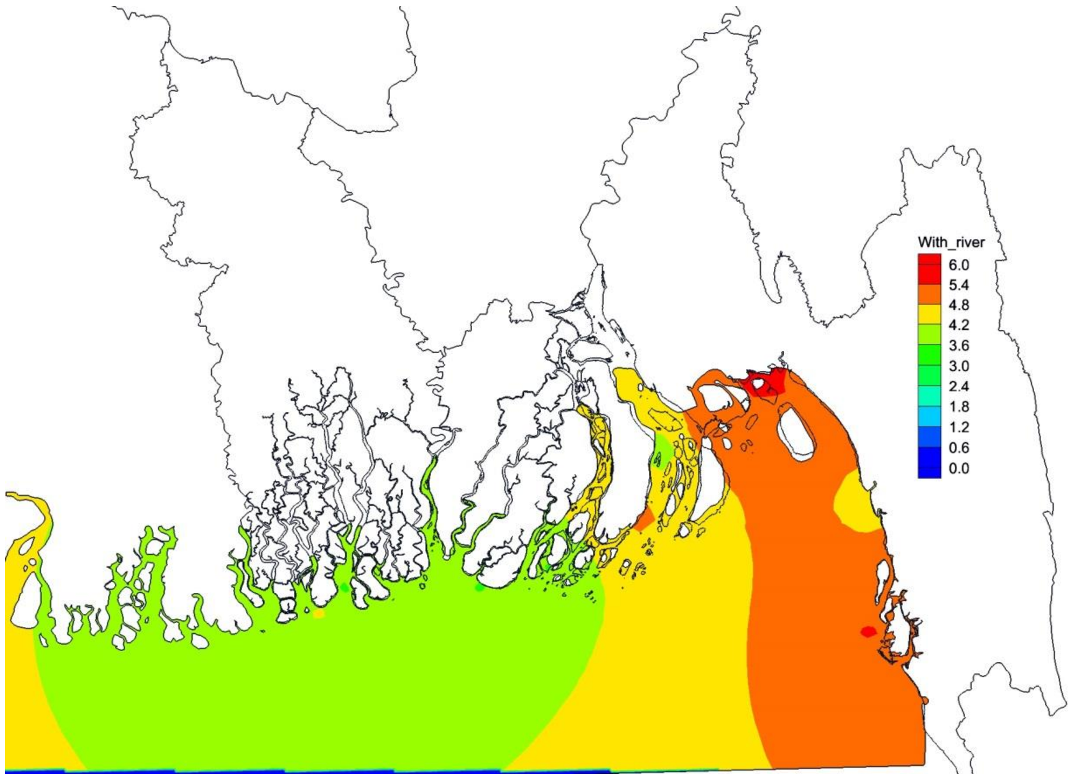




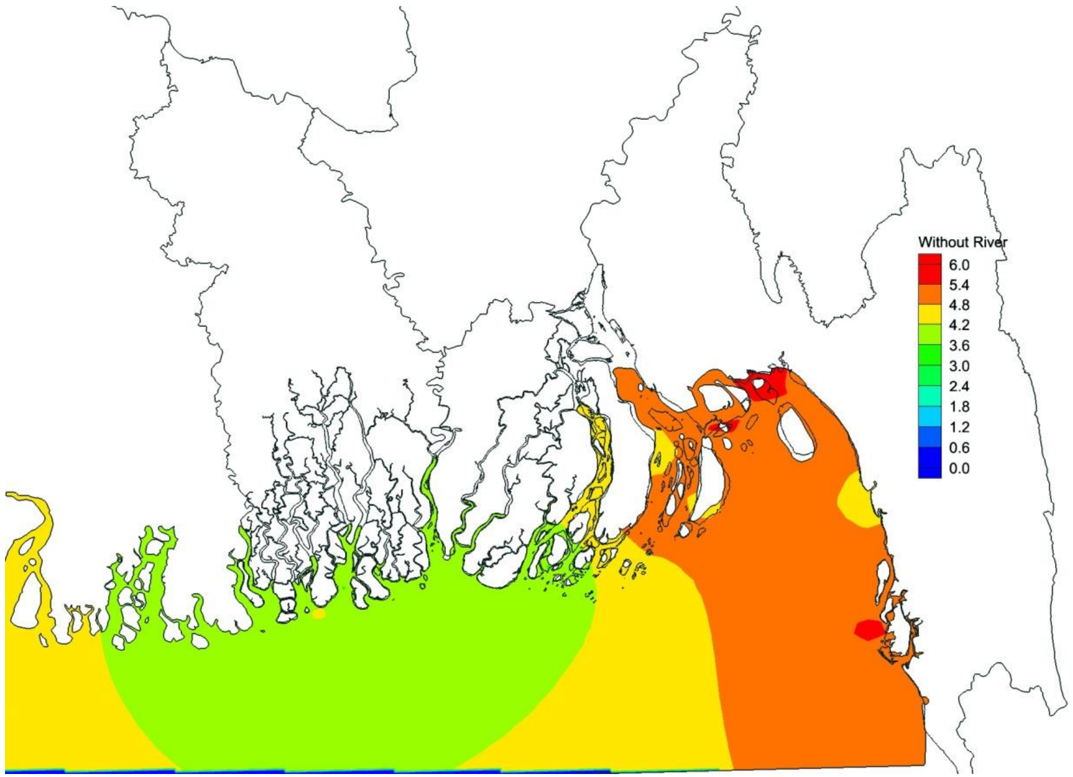
Far away from junction area

Near junction area

Result and discussion

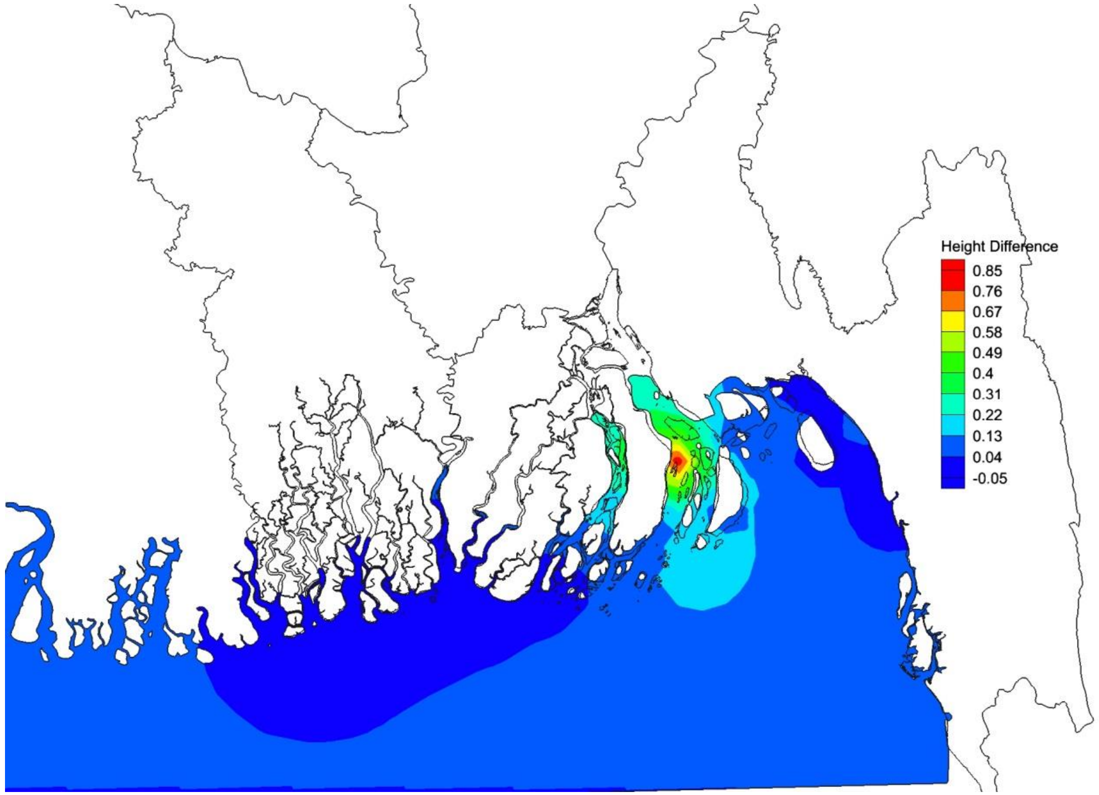


With incorporate river

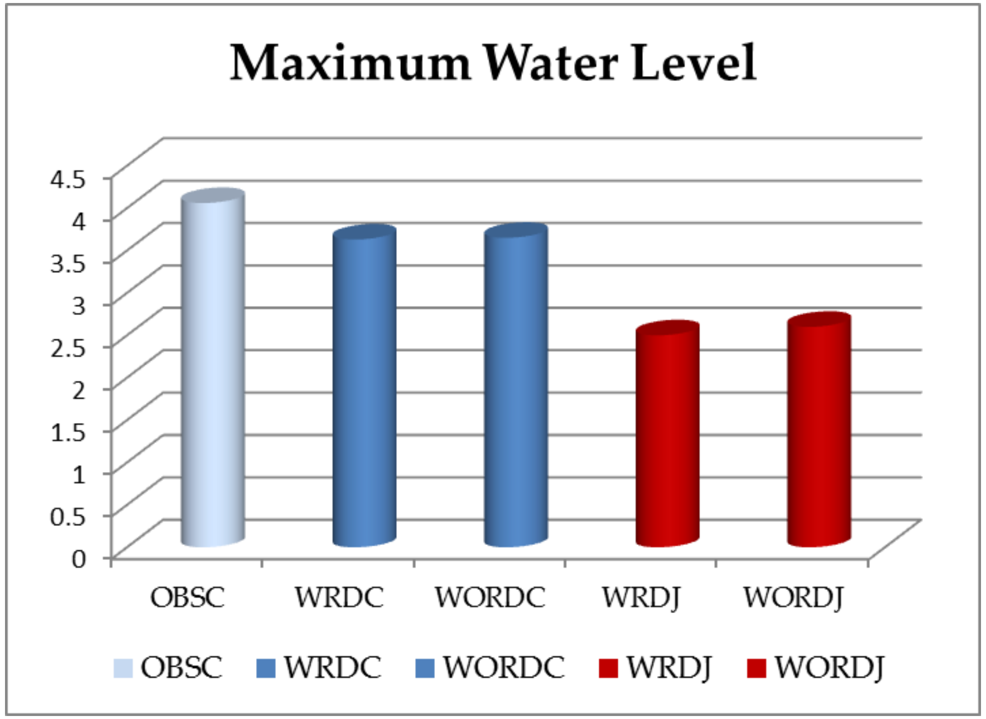


Without incorporate river

Result and discussion



Surge height difference



OBSC=observed surge height
WRDC=Surge height with river model at Chittagong
WORDC=Surge height without river model at Chittagong
WRDJ=Surge height with river model at Monpura
OBSC=Surge height without river model at Monpura

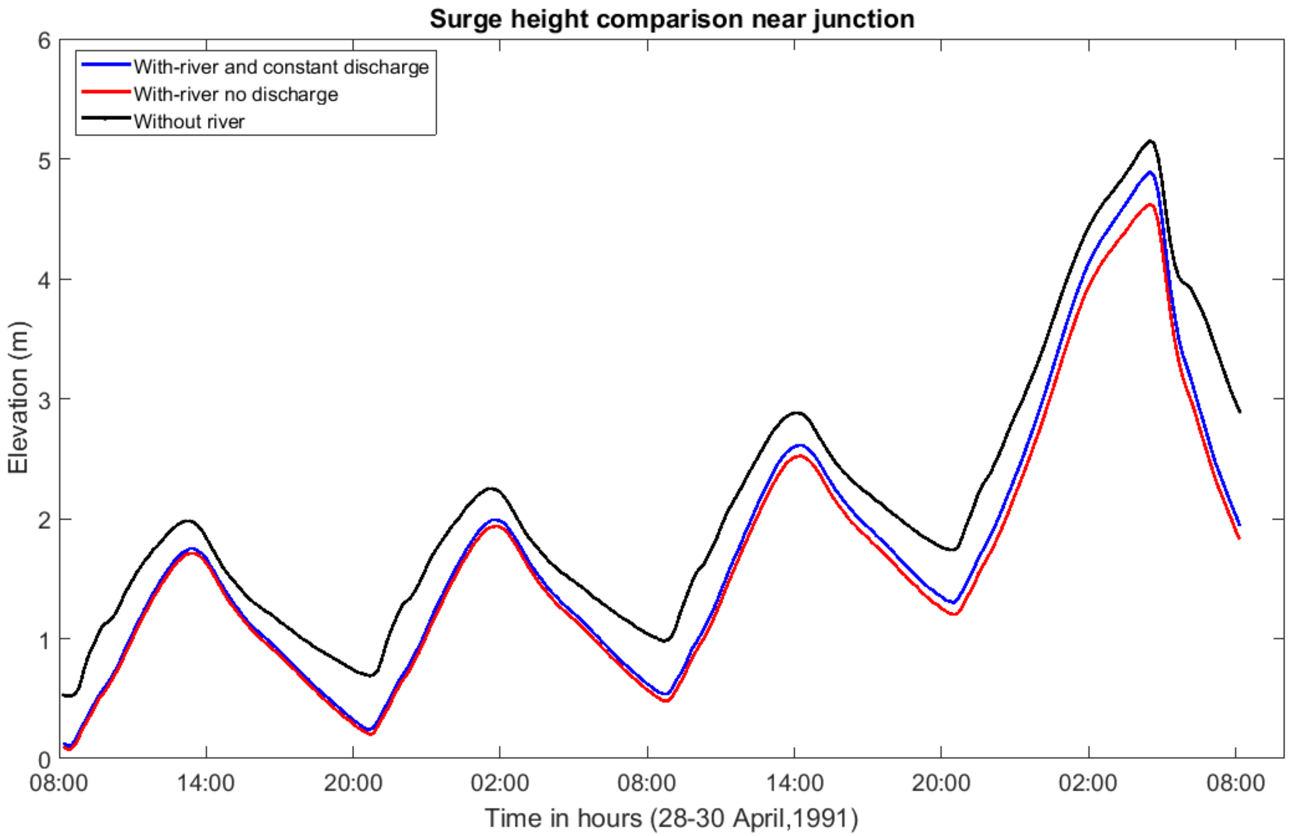
Result and discussion

For the three conditions, we have checked the simulation result at the same location.
The cases are:

(1) Simulation without incorporating river

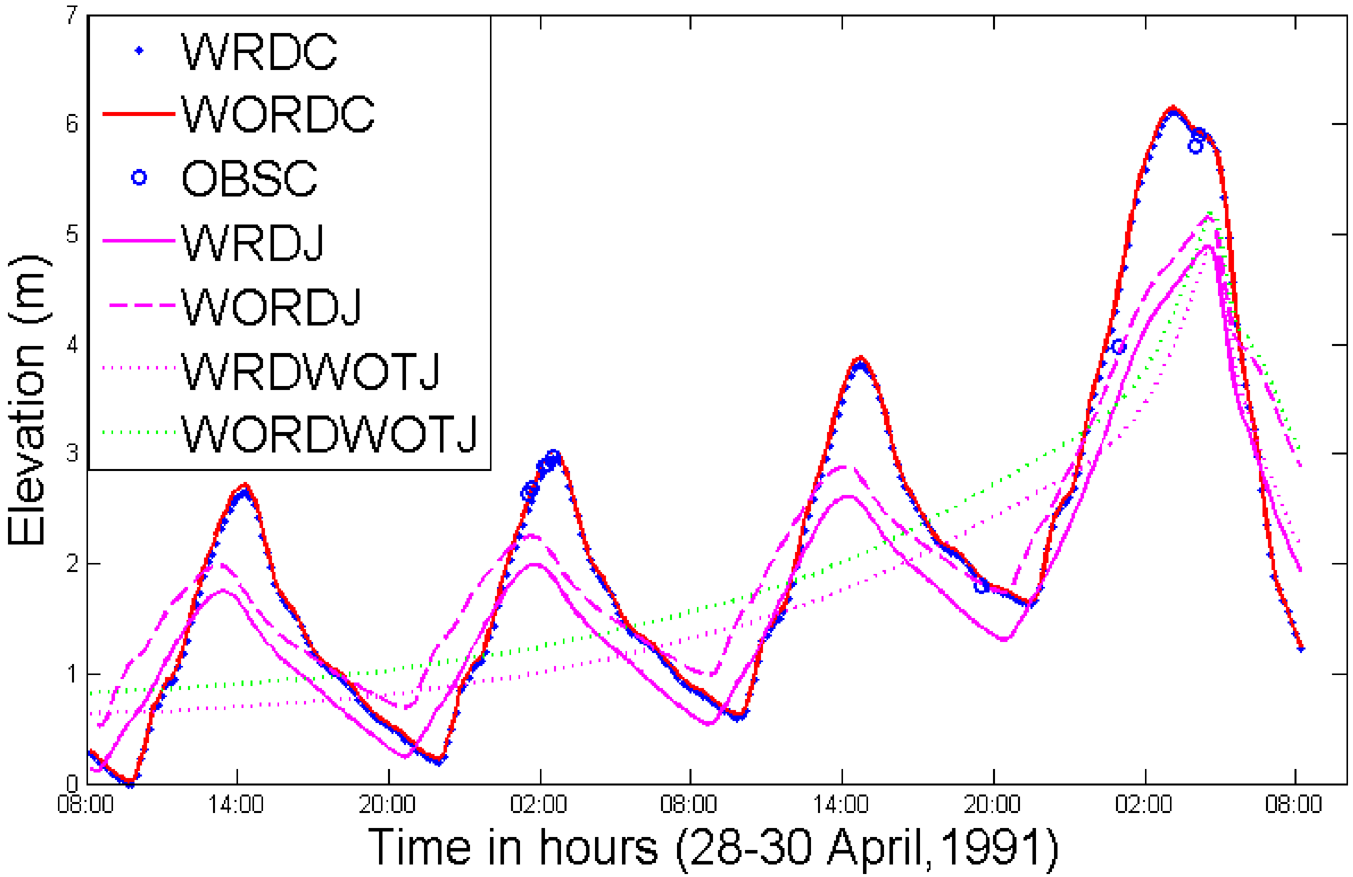
(ii) Incorporate river with an average discharge

(iii) Incorporate a river with no discharge



Result and discussion

Water level without river discharge (WORDC),Observed (OBSC), Water level with river discharge at Junction point (WRDJ), Water level without river discharge(WORDJ), Water level with river discharge at Junction point without tide(WRDWOTJ), Water level without river discharge and without tide(WORDWOTJ)



Result and discussion

Coastal location	Overall peak Surge level by [Paul et. al]	Simulated overall max. Surge level by [Roy et. al]	Simulated overall peak by FDM [Mohit et. al]	Simulated overall peak without river	Simulated overall peak with river	observed overall peak
Cox's Bazar	--	--	6.14	5.98	5.89	6.00
Moheshkhali	--	--	4.12	4.59	4.57	--
Banshkhali	--	--	3.58	--	--	--
Chittagong	6.25	5.45	4.50	4.60	4.61	5.4
Sitakunda	5.78	--	4.48	5.15	5.11	--
Sandwip	5.63	5.33	4.38	5.21	5.20	--
Mirsharai	--	--	5.66	5.05	5.03	--
Companiganj	7.28	--	6.15	5.90	5.89	6.1
Chital Khali	--	--	4.50	--	--	--
Char Jabbar	6.35	5.18	5.69	5.51	5.47	--
Char changa	5.81	4.31	4.12	4.60	4.58	--
Char Madras	5.81	--	4.32	4.99	4.95	--
Rangabali	4.50	--	4.07	3.56	3.57	--
Kuakata	3.86	--	3.96	3.60	3.58	--
Patharghata	--	--	4.36	3.55	3.57	--
Tiger point	4.57	--	4.21	4.30	4.30	--
Hiron point	4.01	0.70	3.80	3.48	3.45	3.5
Monpur island	--	--	--	5.20	4.88	--
Sona Char	--	--	--	4.51	3.61	--

Conclusion

► The study shows that the effect of a river and river discharge on the water levels associated with a storm has a considerable impact. The length and breadth of the river may have some influence on surge height.

► The inclusion of the river in our model shows a maximum surge reduces up to 20% at the location of the river mouth.

► Thus, the response of a river on the surging development is appreciable and cannot be ignored for storm surge prediction purposes.

► By incorporating the precipitation model may improve the surge height.

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