GOBESHONA
Global Conference 1
Research into Action on Locally - Led Adaptation

OASIS LOSS MODELLING FRAMEWORK

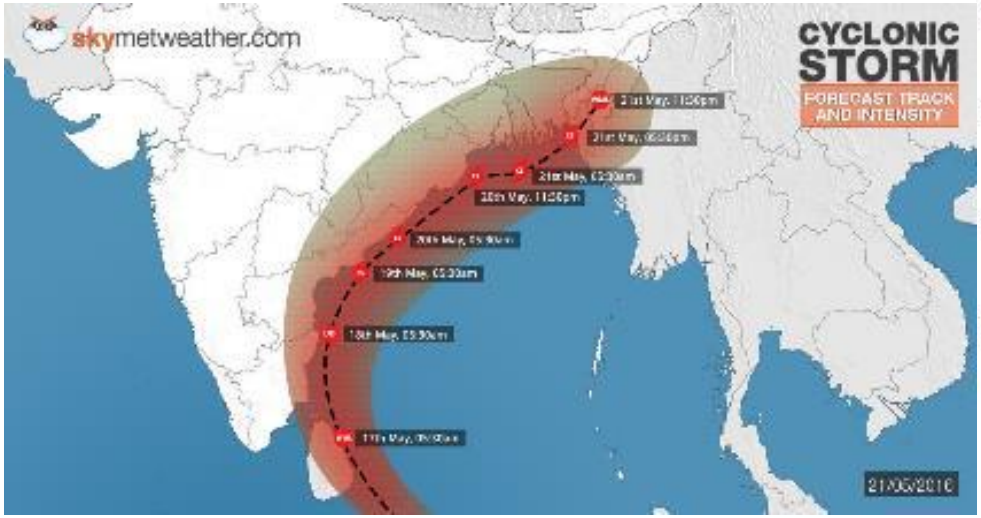
IUCN

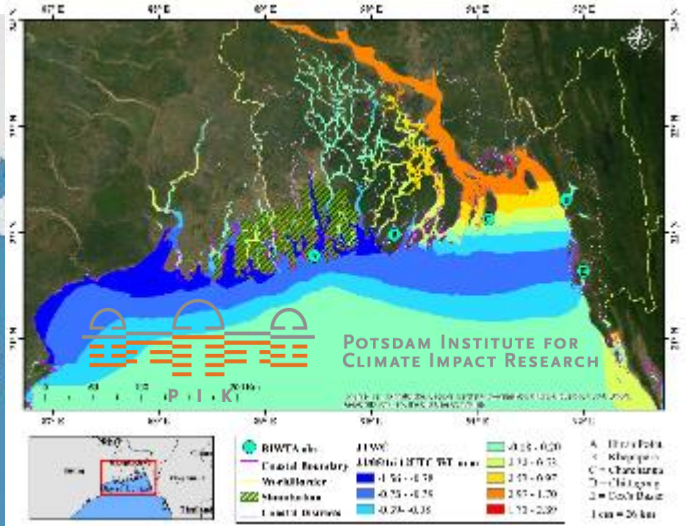
Supported by:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
based on a decision of the German Bundestag

Met Office

Session on "**Disaster Management: Modelling and Initiatives in Diverse Settings**"

Oasis Platform to Support Cyclone and Storm Surge Risk Assessment for Bangladesh





Prof. A.K.M. Saiful Islam, Nahruma Mehzabeen, Dr. Mohan Kumar Das, Faruque Abdullah and Maruf Billah

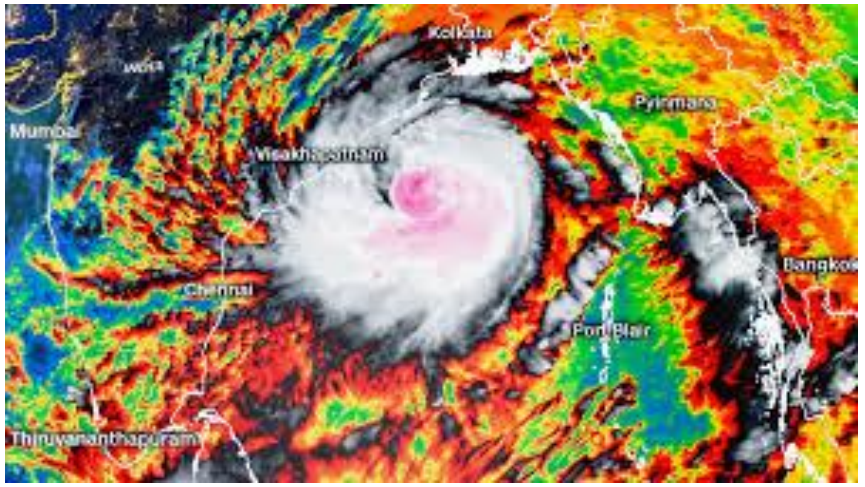
Institute of Water and Flood Management
Bangladesh University of Engineering and Technology (BUET)

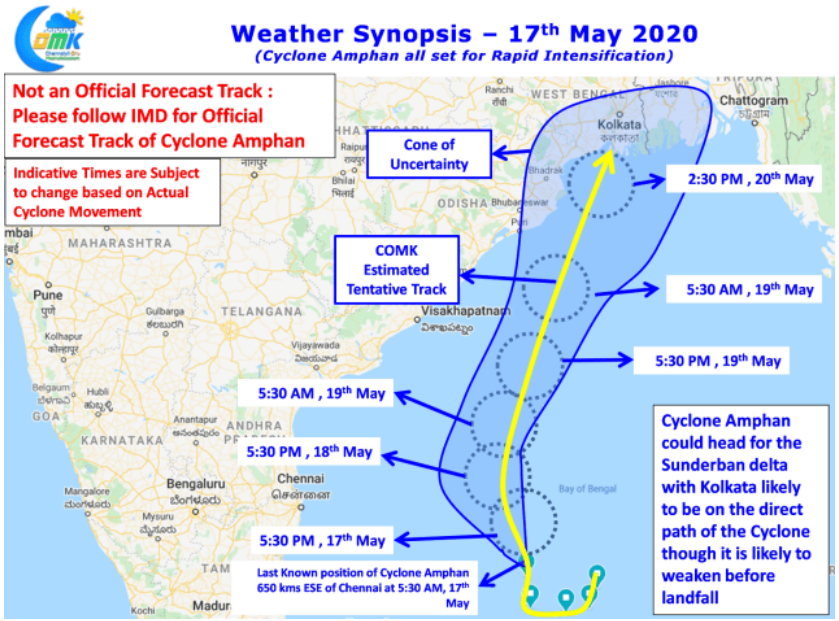
Outline of the presentation

- Cyclones observed in recent times in the Bay of Bengal : Amphan (2020), Bulbul (2019), Fani (2019), Mora (2017), Roanu (2016), Aila (2009), Sidr (2007)
- Climate Change Impact of Tropical Cyclones and sea level rise
- High resolution (4km and 1.5km) cyclonic storm simulations and storm surge inundation modeling
- Risk assessment of cyclone using depth-damage relationship
- **Oasis Loss Modeling Framework** for assisting disaster risks management

Super Cyclone Amphan (16-21 May 2020)

- Formed: 16 May 2020
- Dissipated: 21 May 2020
- Wind Speed:
  - 3-minute sustained: 240 km/h
  - 1-minute sustained: 260 km/h
- Lowest pressure:
  - 920 hPa (mbar); 27.17 in Hg
- Fatalities: 128 total (26 in Bangladesh)
- Damage: > $13.6 billion USD (1.5 billion for Bangladesh)
- Storm Surge: 3-4 meter



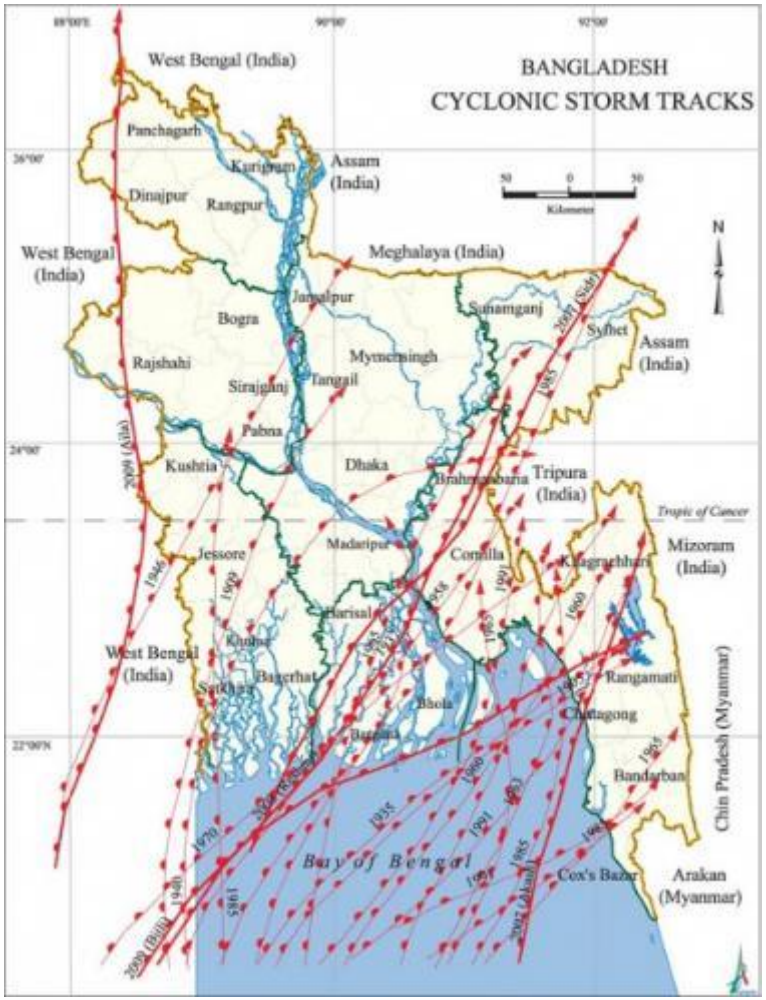


Recent Cyclones in the Bay of Bengal

Cyclone Amphan (2020) Date: 16-21 May 3-min wind: 240 km/hr 1-min wind: 260 km/hr Surge: 3-4 m **Damage: USD 1.5 billion** **Fatalities: 26**	**Cyclone Bulbul (2019)** Date: 5-11 November 3-min wind: 140 km/hr 1-min wind: 195 km/hr Surge: < 2 m **Damage: USD 33 million** **Fatalities: 128**	**Cyclone Fani (2019)** Date: 26 April -05 May 3-min wind: 215 km/hr 1-min wind: 250 km/hr Surge: < 2 m **Damage: USD 63.6 million** **Fatalities: 17**
Cyclone Mora (2017) Date: 28-31 May 3-min wind: 110 km/hr 1-min wind: 150 km/hr Surge: < 2 m **Damage: USD 6 million** **Fatalities: 0**	**Cyclone Roanu (2016)** Date: 16-21 May 3-min wind: 85 km/hr 1-min wind: 110 km/hr Surge: 2 m **Damage: USD 31.8 million** **Fatalities: 30**	**Cyclone Aila (2009)** Date: 17-27 May 3-min wind: 110km/hr 1-min wind: 120km/hr Surge: 3 m **Damage: USD 1 billion** **Fatalities: 190**
Cyclone Sidr (2007) Date: 11-15 November 3-min wind: 215 km/hr 1-min wind: 260 km/hr Surge: 5.5 m **Damage: USD 2.31 billion** **Fatalities: 3,447**	**1991 Cyclone (1991)** Date: 24-30 April 3-min wind: 235 km/hr 1-min wind: 260 km/hr Surge: 6.1 m **Damage: USD 1.5 billion** **Fatalities: 138,000**	**Bhola Cyclone (1970)** Date: 3-13 November 3-min wind: 185 km/hr 1-min wind: 240 km/hr Surge: 10.6 m **Damage: USD 86.4 million** **Fatalities: 500,000**

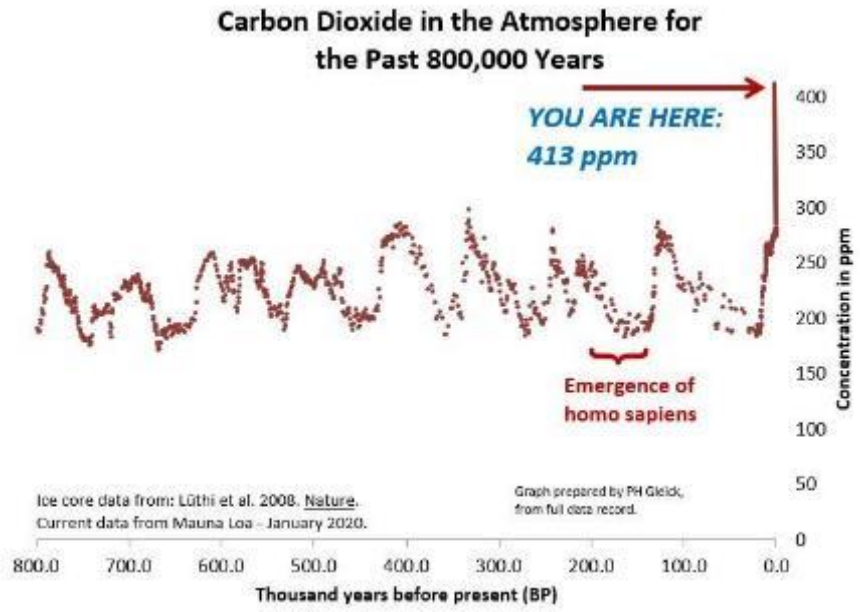
Cyclone and Storm Surge in Bangladesh: Why more cyclones in the Bay of Bengal?

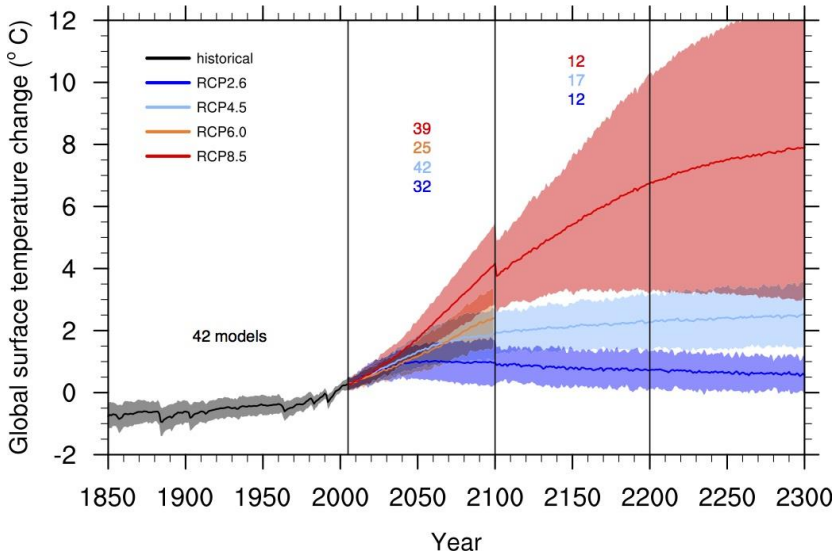
- The ideal SST is around 25–27 degrees Celsius.
- Bay of Bengal is relatively warmer compared to Arabian Sea.
- Relatively lower vertical wind-shear.
- Additional influx of moisture from South China Sea.
- Terrain of the flat Coast which is not blocking ferocity of wind.
- Global mean ocean SST has increased at a rate of 0.11 [0.09 to 0.13] °C per decade which makes favorable conditions.

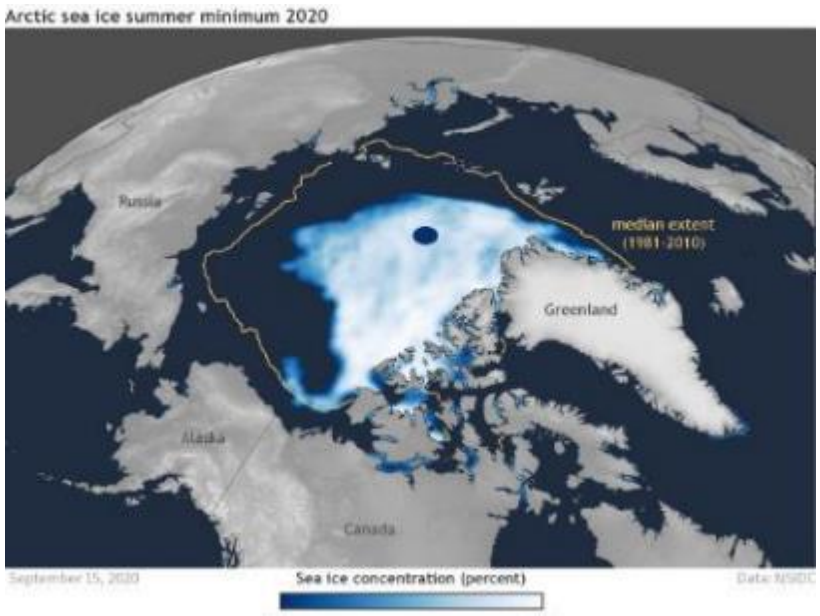


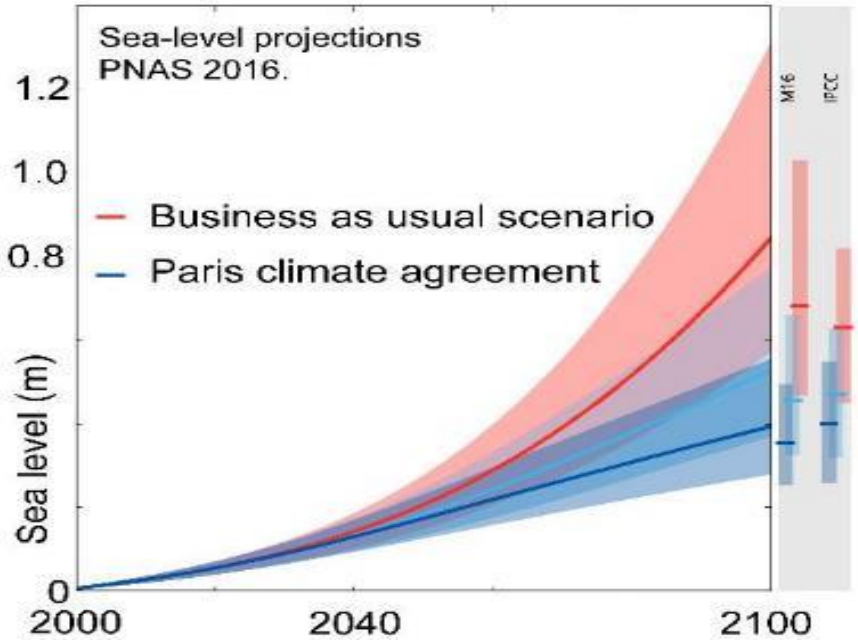
Source: http://en.banglapedia.org/index.php?title=Cyclone

Humans are changing the climate (8,00,000 years of CO2)

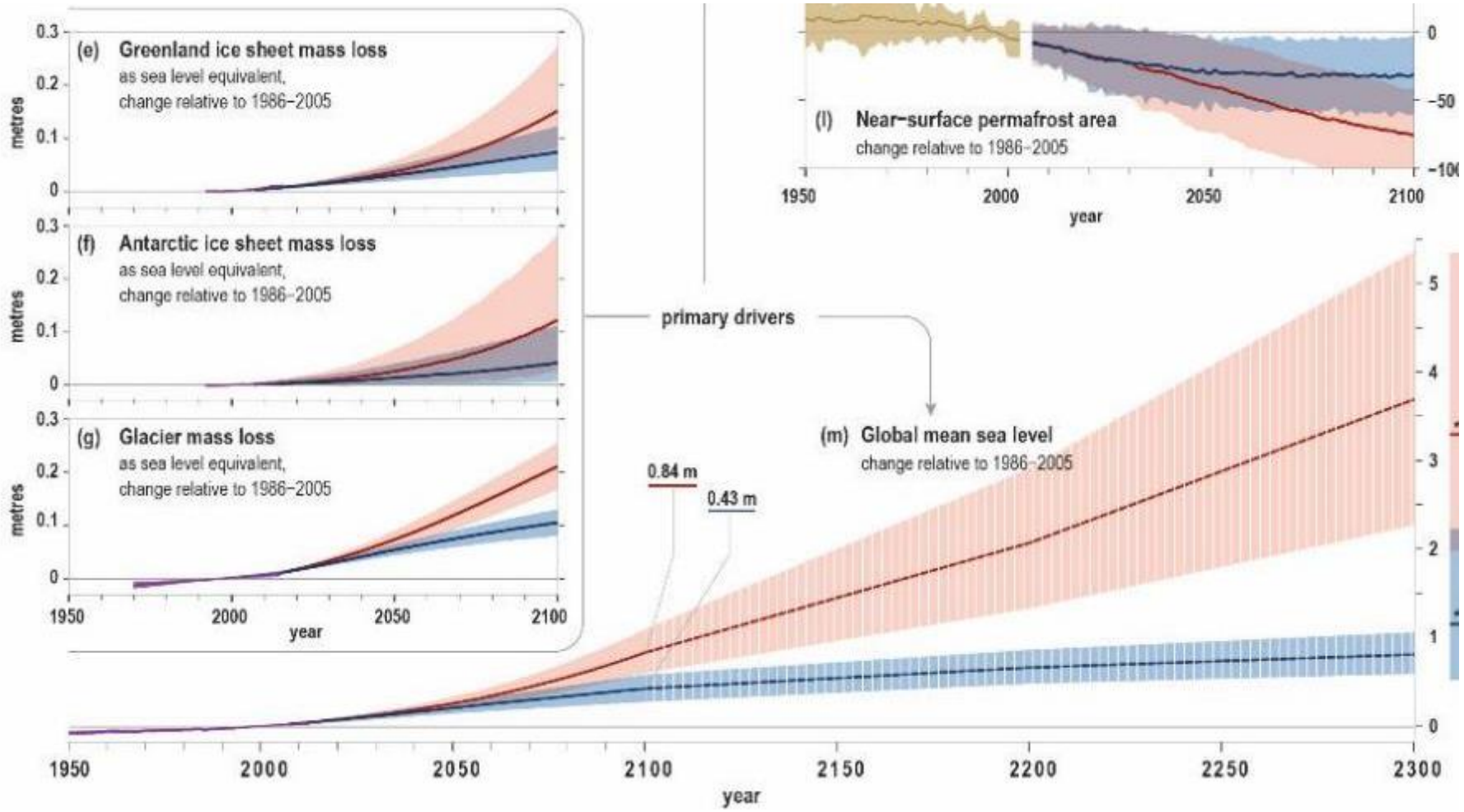






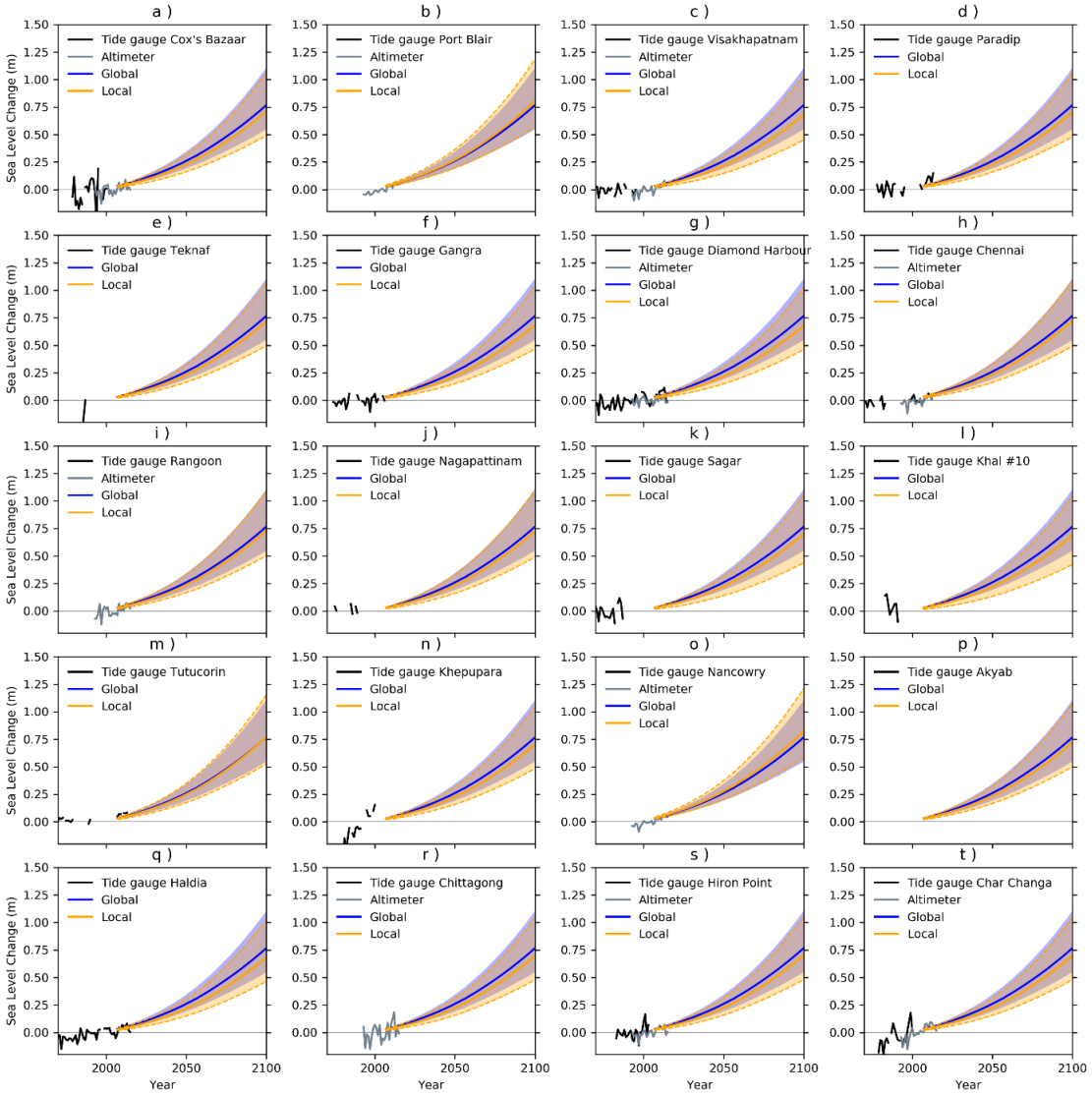


Projected Ice loss and SLR (SROCC, 2019)



21st century sea level projections for RCP8.5 at tide gauge locations in the Bay of Bengal (ARRCC, 2020)

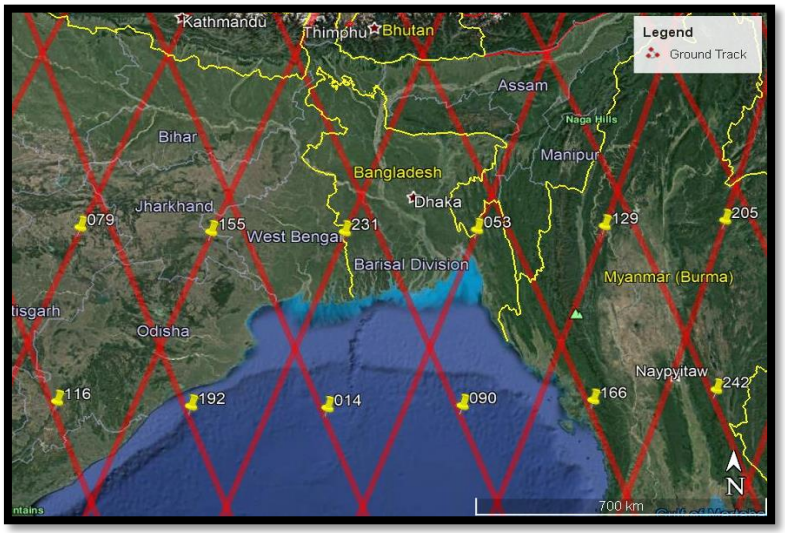
RCP8.5 : 0.33m- 0.92m **RCP4.5:** 0.26m- 0.73m

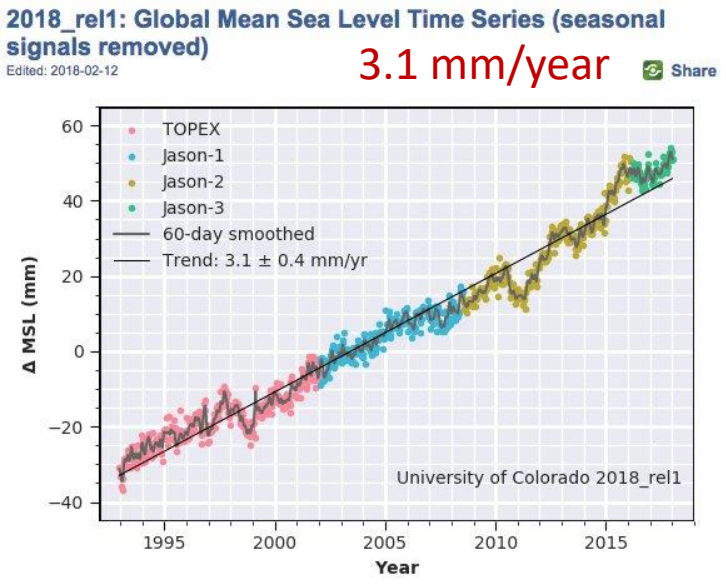


2081-2100	RCP2.6	RCP4.5	RCP8.5
Coxs Bazaar	0.17-0.62	0.3-0.68	0.4-0.86
Port Blair	0.24-0.66	0.34-0.73	0.45-0.92
Visakhapatnam	0.16-0.6	0.27-0.68	0.39-0.84
Paradip	0.16-0.6	0.28-0.67	0.39-0.84
Teknaf	0.17-0.62	0.29-0.68	0.4-0.85
Gangra	0.15-0.6	0.28-0.66	0.38-0.83
Dmnd Harbour	0.14-0.58	0.26-0.64	0.37-0.81
Chennai	0.19-0.62	0.29-0.71	0.43-0.89
Rangoon	0.19-0.62	0.29-0.69	0.41-0.86
Nagapattinam	0.2-0.61	0.3-0.71	0.42-0.89
Sagar	0.16-0.57	0.24-0.68	0.33-0.89
Khal Ten	0.2-0.55	0.25-0.66	0.34-0.89
Tuticorin	0.24-0.6	0.31-0.71	0.45-0.93
Khepupara	0.16-0.61	0.28-0.67	0.39-0.84
Nancowry	0.24-0.66	0.34-0.73	0.46-0.92
Akyab	0.18-0.62	0.29-0.68	0.41-0.85
Haldia	0.14-0.58	0.26-0.64	0.37-0.81
Chittagong	0.17-0.62	0.29-0.68	0.41-0.86
Hiron Point	0.15-0.61	0.28-0.67	0.39-0.84
Moulmein Two	0.22-0.59	0.28-0.7	0.37-0.92
Charchanga	0.16-0.6	0.28-0.67	0.39-0.84
Ko Taphao Noi	0.22-0.65	0.33-0.73	0.44-0.91

Observed trend of water level estimated from monthly satellite altimetry data (DOE, 2020)

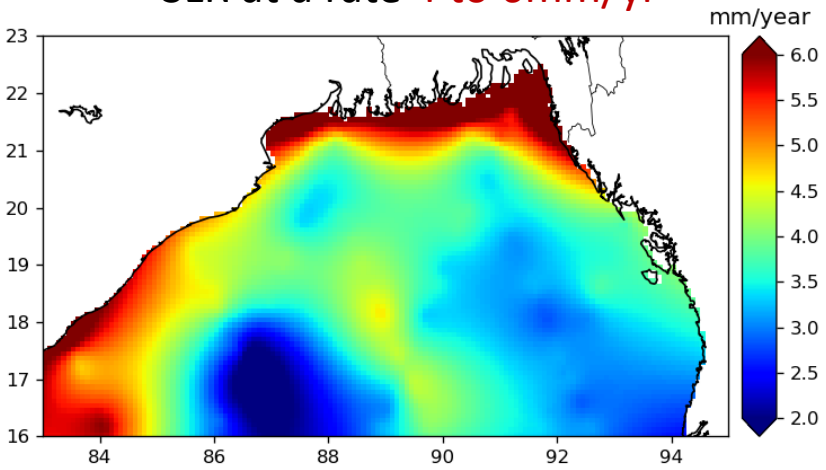
Mission Name	Organization	Operation Period	Temporal Resolution
T/P	NASA/CNES	1992 – 2002	10 days
Jason – 1	NASA/CNES	2002 – 2013	10 days
Jason – 2	NASA/CNES/NOAA/EUMETSAT	2008 – to date	10 days
Jason – 3	NOAA/CNES/EUM	2016 – to date	10 days





3.1 mm/year

SLR at a rate 4 to 6mm/yr



DOE, 2021

Trends in Water Level and Subsidence (Becker et al., 2019)

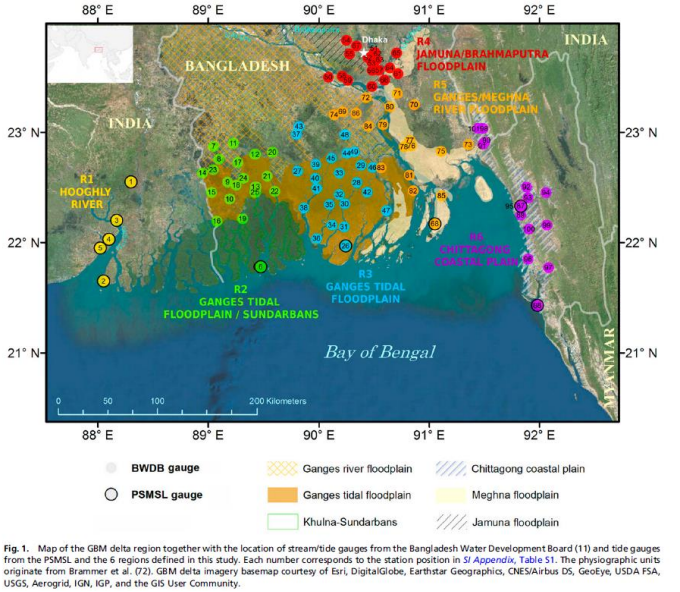


Fig. 1. Map of the GBM delta region together with the location of stream/tide gauges from the Bangladesh Water Development Board (11) and tide gauges from the PSMSL and the 6 regions defined in this study. Each number corresponds to the station position in *SI Appendix*, Table S1. The physiographic units originate from Brammer et al. (72). GBM delta imagery basemap courtesy of Esri, DigitalGlobe, Earthstar Geographics, CNES/Airbus DS, GeoEye, USDA FSA, USGS, Aerogrid, IGN, IGP, and the GIS User Community.

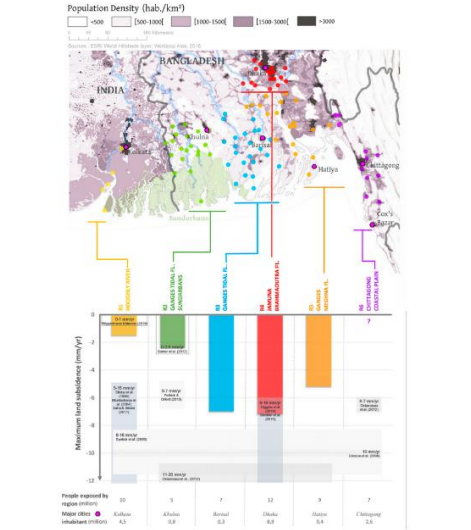


Fig. 4. Map and maximum subsidence rates expected over the contemporary period. The solid colored bars correspond to the significant subsidence rates obtained in this study (upper bound of the likely range, Table 1). In R6, "-" means that we are not able to provide reliable information about the subsidence in this region. The shaded gray bars correspond to the subsidence rates obtained from the literature for the contemporary period. The 2015 population density (habitants per square kilometer) map is provided by Worldpop Asia (5). World Hillshade basemap courtesy of Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community.

Water level changes, subsidence, and sea level rise in the Ganges–Brahmaputra–Meghna delta

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Edited by Andrea Rinaldo, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, and approved November 26, 2019 (received for review July 26, 2019)

Significance

This work provides a robust estimate of water-level (WL) changes in the Ganges-Brahmaputra-Meghna delta, driven by continental freshwater dynamics, vertical land motion, and sea-level rise. Through an unprecedented set of 101 gauges, we reconstruct WL variations since the 1970s and show that the WL across the delta increased slightly faster, ~3 mm/y, than the global mean sea-level rise (~2 mm/y). By combining satellite altimetry and WL reconstructions, we estimate that maximum expected rates of delta subsidence since the 1990s range from 1 to 7 mm/y. By 2100, even under a greenhouse gas emission mitigation scenario (RCP4.5), the subsidence could double the projected sea-level rise, making it reach 85 to 140 cm across the delta.

Subsidence rate 1 to 7mm/yr

Table 1. Trends (millimeters per year) of regional relative water level (RWL) and absolute sea level (ASL)

	RWL		ASL		Expected max. subsidence
Region	Trend 1968–2012, mm/y	SD σ, cm	Trend 1993–2012, mm/y	Correlation coefficient $r_{[RWL,ASL]}$ (lag in months)	Trend 1993–2012, mm/y
R1-Hooghly River	2.1 ± 0.8***	8	2.7 ± 1.4***	0.9(0)	1.5
R2-Ganges tidal floodplain/Sundarbans	2.7 ± 1.3***	9	2.1 ± 1.4*	0.7(0)	2.4
R3-Ganges tidal floodplain	3.6 ± 1.8***	16	3.2 ± 1.6***	0.8(0)	7.0
R4-Jamuna/Brahmaputra floodplain	3.1 ± 2.3*	28	3.1 ± 1.5***	0.6(−1)	7.2
R5-Ganges/Meghna floodplain	3.0† ± 2.6*	16	3.4 ± 1.6***	0.7(−1)	5.2†
R6-Chittagong coastal plain	1.3 ± 1.4	17	3.4 ± 1.7***	0.4(0)	—

The linear trend estimates are obtained from a robust regression model with the bisquare weight function (67). Their significances and uncertainties are estimated by a random phase method to maintain the autocorrelation structure of RWL and ASL series (24) and given at 1σ significance level. The maximum expected subsidence rate is defined as the 10% lower bound in the VLM rates distribution (subsidence corresponds to VLM < 0). *, **, and *** correspond to a significant linear trend with $P \leq 0.1$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

†In R5, the trends are estimated up to 2005 (see *Materials and Methods* for details)

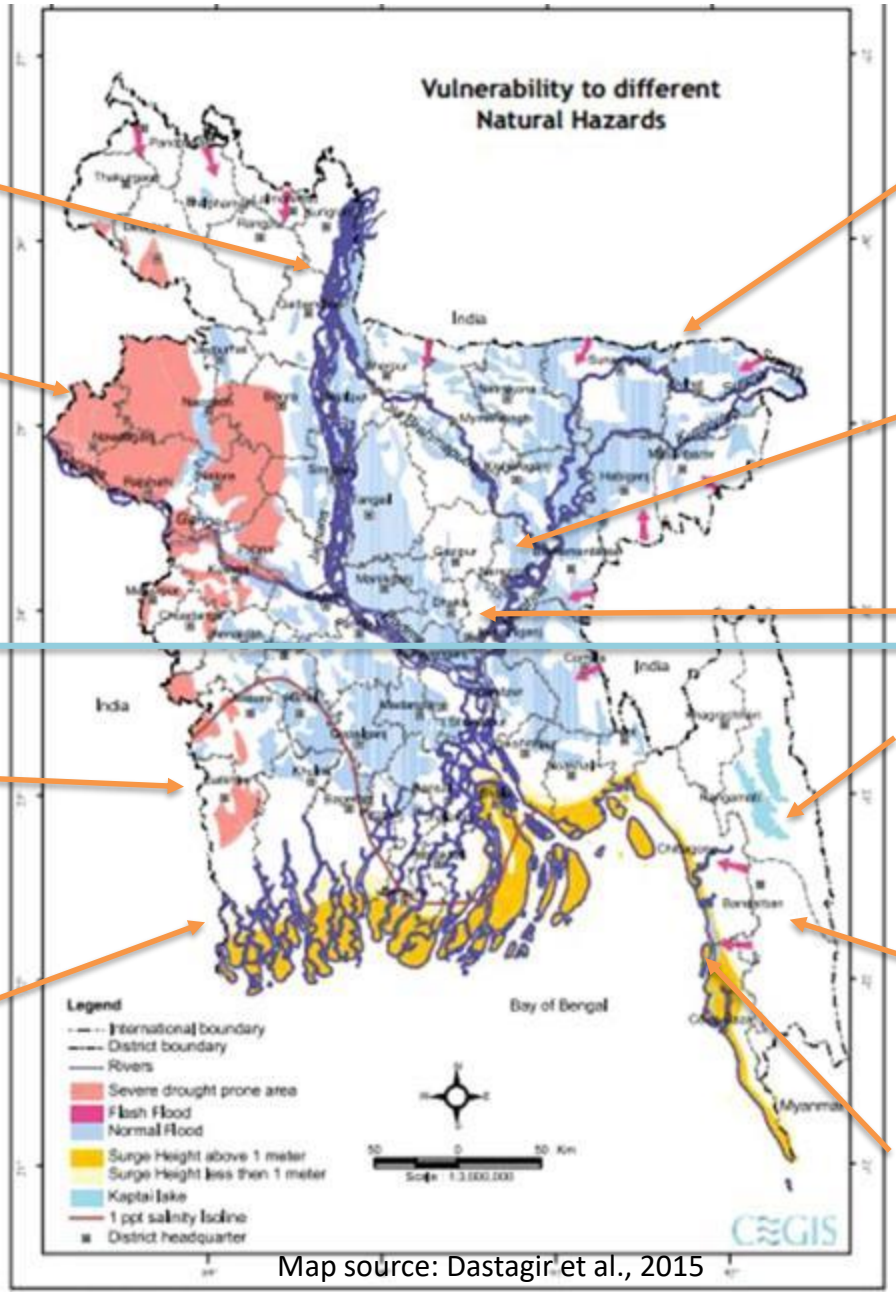
Hazards Expected to Change under Global Warming

Riverine Flood

More intense & frequent

Drought

More frequent & Severe



Map source: Dastagir et al., 2015

Flash Flood

More severe & frequent

Urban flood

More frequent & intense

Heatwave

Prolonged

Salinity

Continue to Increase

Sea level Rise

Continue to Rise

Flash flood

More intense & frequent

Landslides

Frequent

Cyclone and storm surge

Cyclone more intense
Increased Surge

Oasis Platform for Catastrophe and Climate Risk in Bangladesh and Philippines flood

- **Quantify** the potential financial damages caused by cyclones
  - Develop a community-owned open-source catastrophe risk model to be used by the country on an on-going basis for risk assessment and decision making
- Develop in-country **capacities** in catastrophe risk and climate change modelling using international standards and best practice
- **Co-development** of risk models to embed local knowledge into the system and democratise risk understanding into in-country institutions
- **Public-private partnership** – bring together business, academia, national agencies, NGOs to help solve the problem

Supported by:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

INTERNATIONAL CLIMATE INITIATIVE (IKI)

based on a decision of the German Bundestag

Oasis Platform for Climate and Catastrophe Risk Assessment – Asia Project

- **High resolution (~4km) storm modeling** for both historical and future cyclones over the Bay of Bengal (**Met office**).
- **Storm surge Inundation Modeling** for historic and future considering global warming (**BUET**).
- **Determine damage from storm surge inundation** using depth damage functions prepared for historic cyclones (**BUET**)
- **Changes of floods and rainfall extremes** in the coastal region of Bangladesh (**PIK**).
- **Coastal vulnerability Assessment** for floods, storm surges using community surveys and **transforming risks to stakeholders** (**IUCN**).
- **Capacity building training on climate data analysis,** processing for impact modeling (**PIK**)

Catalogues of recently occurring major Tropical Cyclones in Bay of Bengal considering in this study

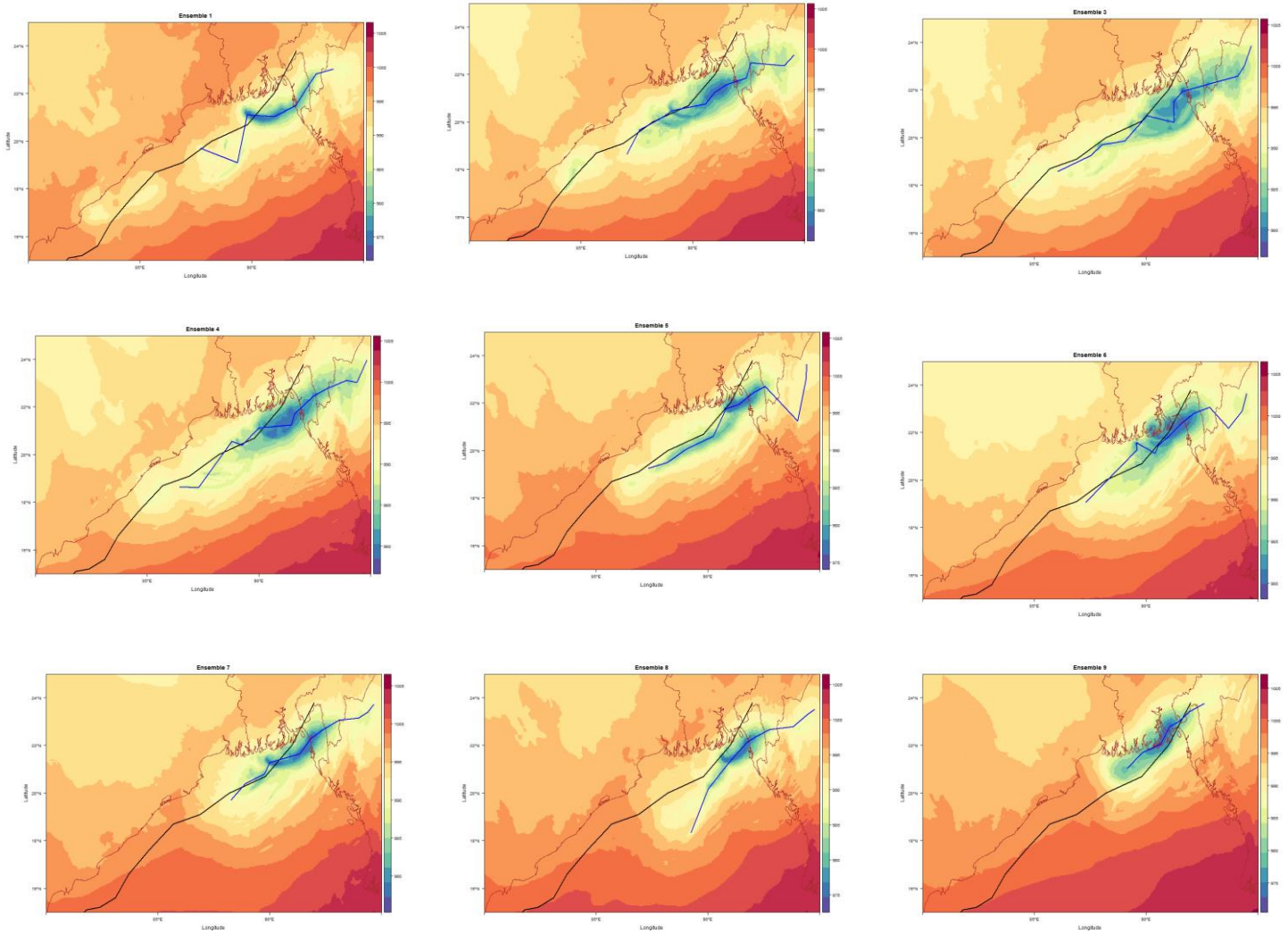
Serial	Name of the Cyclone	Year	Landfall
1	BOB01	1991	30 April, 00:00 UTC
2	BOB07	1995	25 November, 09:00 UTC
3	TC01B	1997	19 May, 15:00 UTC
4	Akash	2007	14 May, 18:00 UTC
5	Sidr	2007	15 November, 18:00 UTC
6	Rashmi	2008	26 October, 21:00 UTC
7	Aila	2009	26 May, 08:00 UTC
8	Viyaru	2013	16 May, 09:00 UTC
9	Roanu	2016	21 May, 12:00 UTC
10	Mora	2017	30 May, 03:00 UTC
11	Fani	2019	04 May, 06:00 UTC
12	Bulbul	2019	11 November, 12:30 UTC

Pre-processing of Historical catalogue of tropical cyclones

- Storm tracking. storm tracking is what identifies when and where the storms occur in a dataset that doesn't have a historical equivalent to get this info from.
- Recalibration (post-processing - to describe the need to post-process the model data in the event that it doesn't provide 10-m wind gusts
- Downscaling, or similar process to add fine/small-scale detail typically found in gusts.

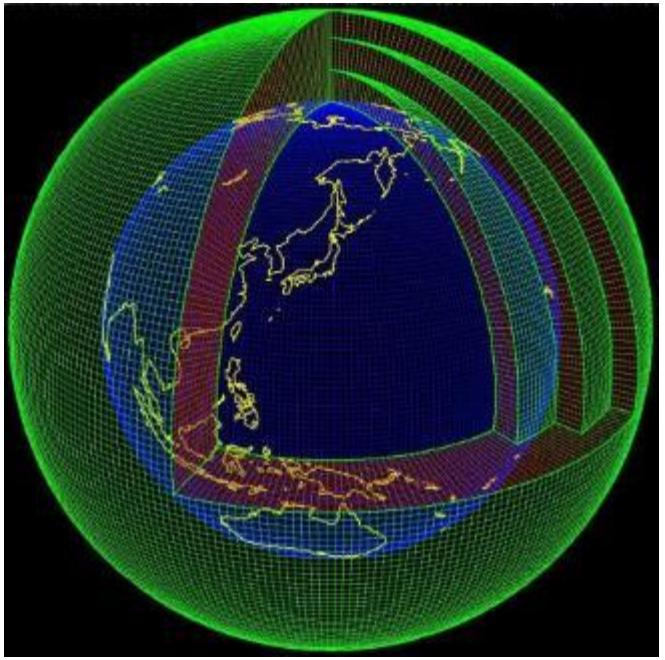
Name	Date	Location
Bhola	3rd – 13th Nov 1970	
BOB 01	24th – 30th Apr 1991	
Sidr	11th – 16th Nov 2007	
Aila	26th – 27th May 2009	
Mohasen	10th – 17th May 2013	
Roanu	17th – 23rd May 2016	
Mora	28th – 31st May 2017	

Simulation of **cyclone Roanu** with possible 9-ensemble members using MOHC model



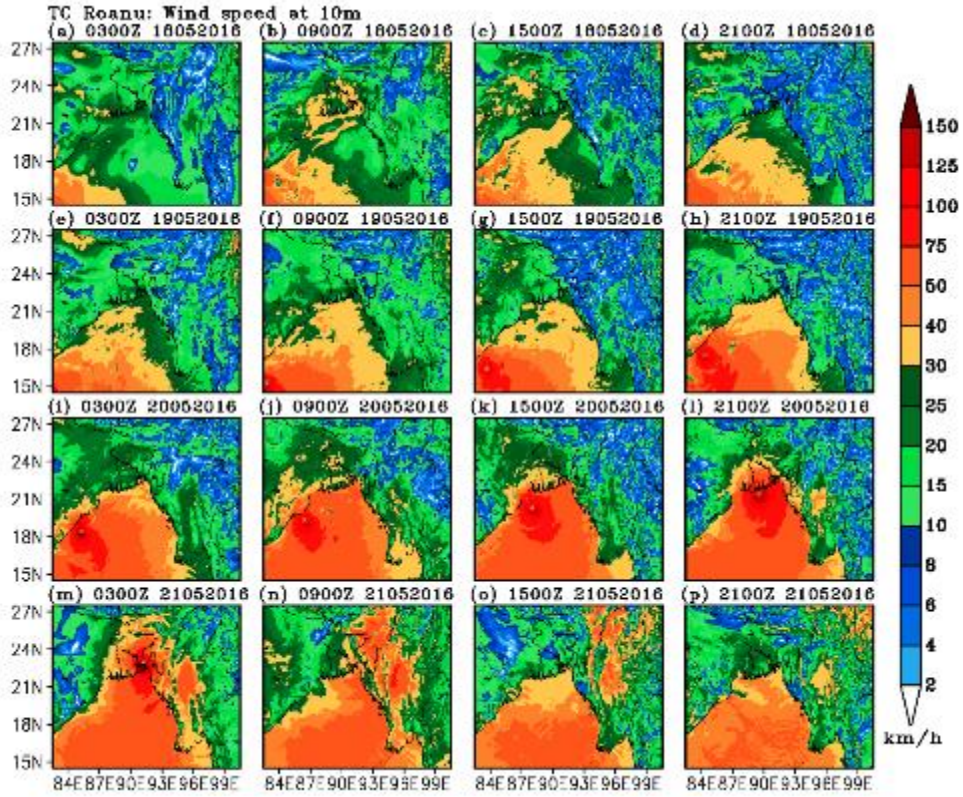
Cyclone simulation using Weather modeling (WRF) at BUET

- The WRF model has been used for simulation of the MCSs associated with squalls in this study.
- The WRF model is a new generation mesocale NWP system designed to serve both operational forecasting and atmospheric research needs (NCAR 2009).
- It features multiple dynamical cores, a 3DVAR data assimilation system, and a software architecture allowing for computational parallelism and system extensibility.
- WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers.
- Applications of WRF include research and operational NWP, data assimilation and parameterized physics research, downscaling climate simulations, driving air quality models, atmosphere-ocean coupling, and idealized simulations (i.e., boundary layer eddies, convection, baroclinic waves).

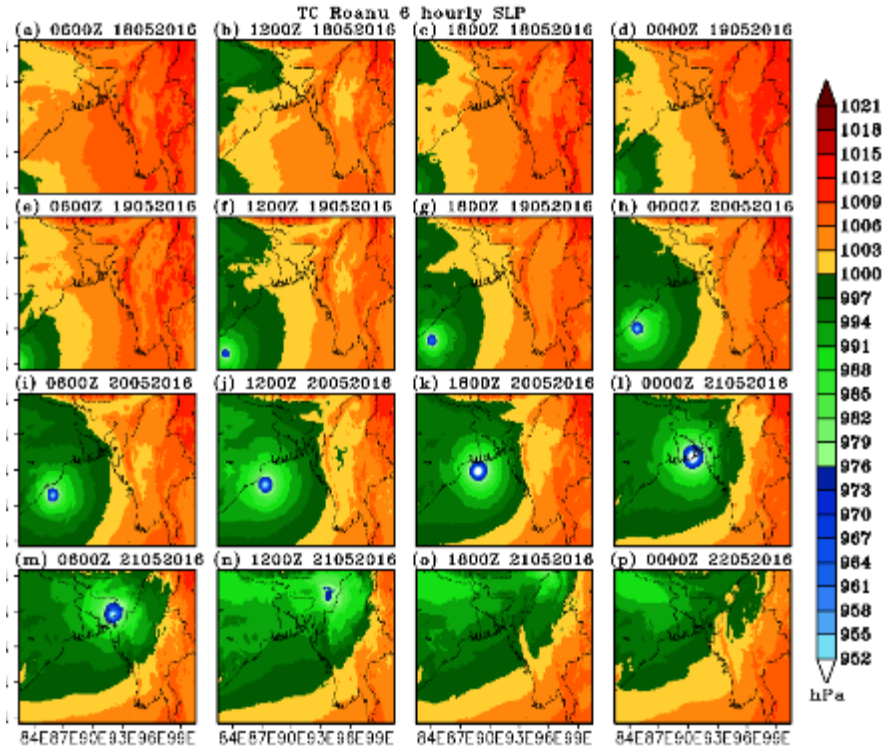


Wind Speed at 10m and Mean Sea Level Pressure for Cyclone Roanu simulated by WRF Model for **Cyclone Roanu** @IWFM, BUET

Wind Speed at 10m (km/hr)



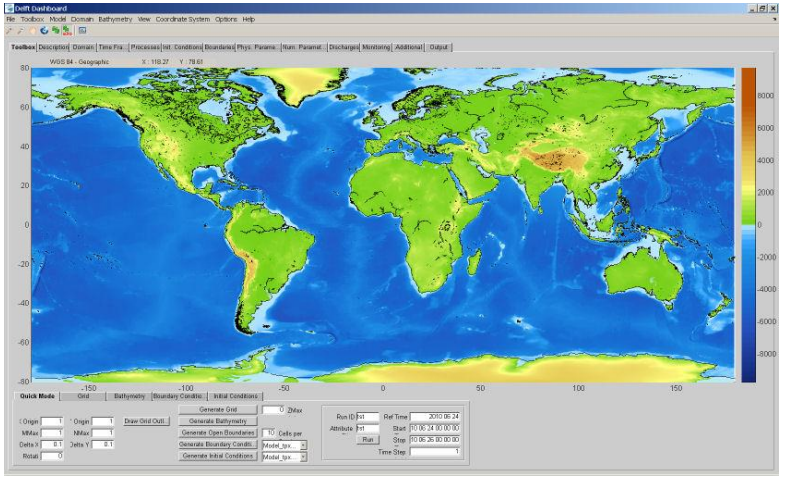
Mean Sea Level Pressure (hPa)

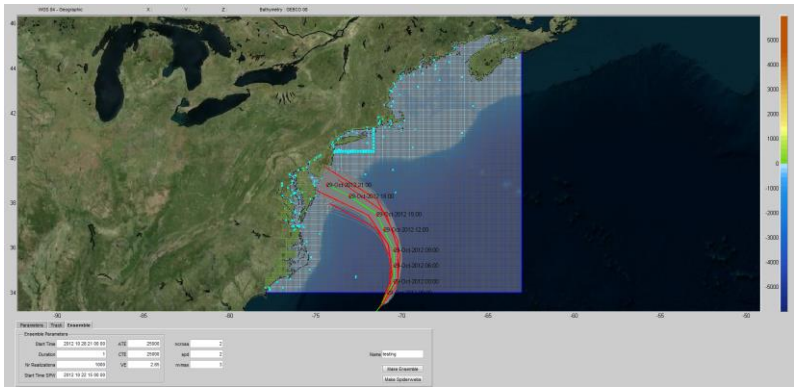


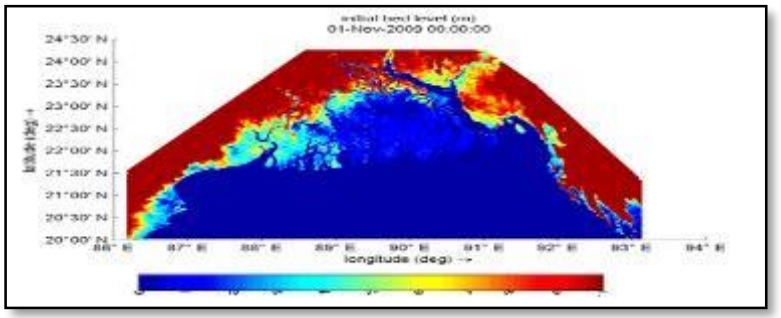
Coastal modeling using Delft3D

- DELFT3D- FLOW is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates unsteady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or a curvilinear, boundary fitted grid.

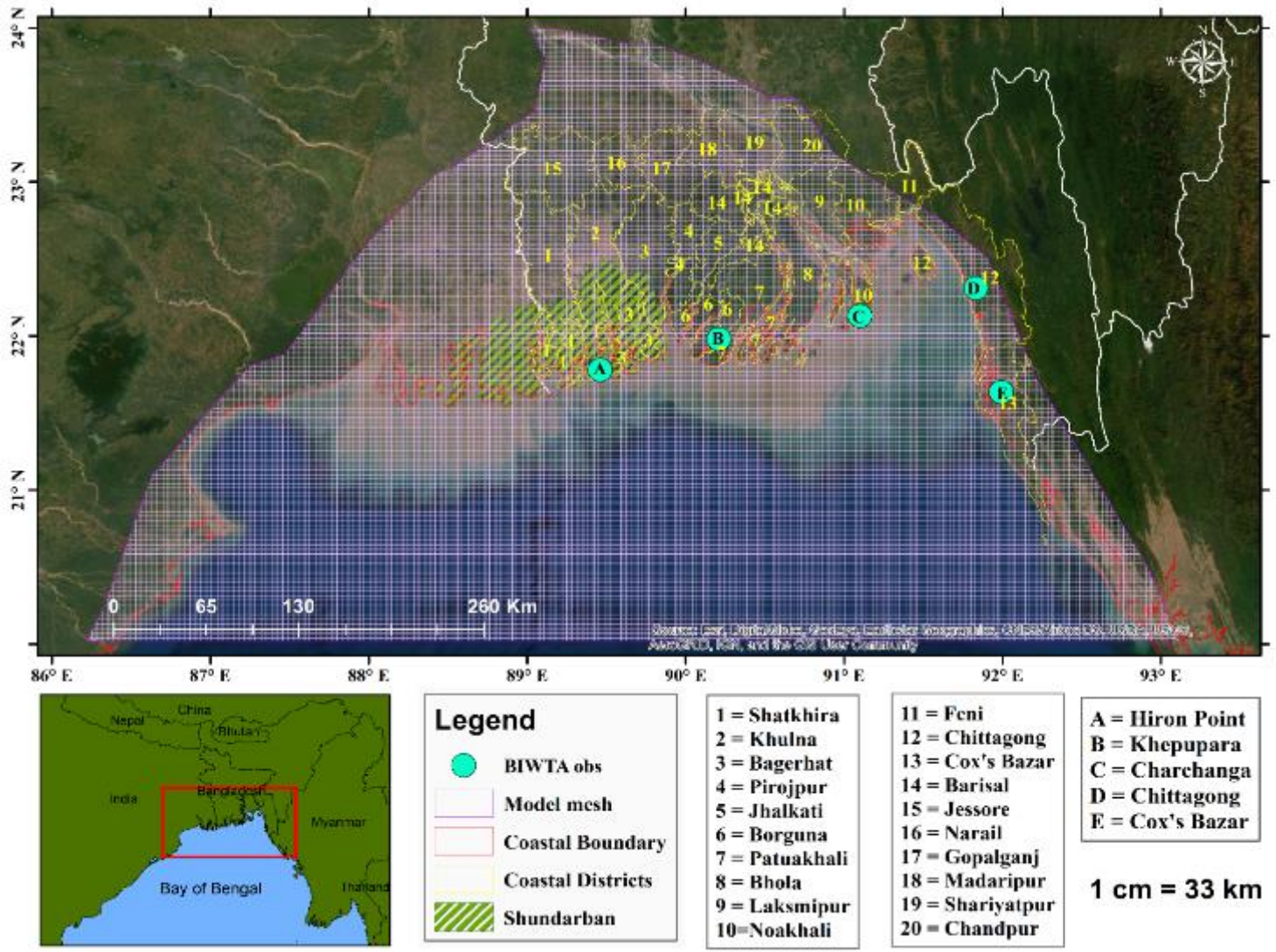
- Using Delft3D-dash board model can be setup, simulate, calibrate and validate over a region of interest. Using the Advanced Cyclone Toolbox and possible cyclone tracks, boundary conditions can be generated to derive the Delft3D model for study inundation patterns.



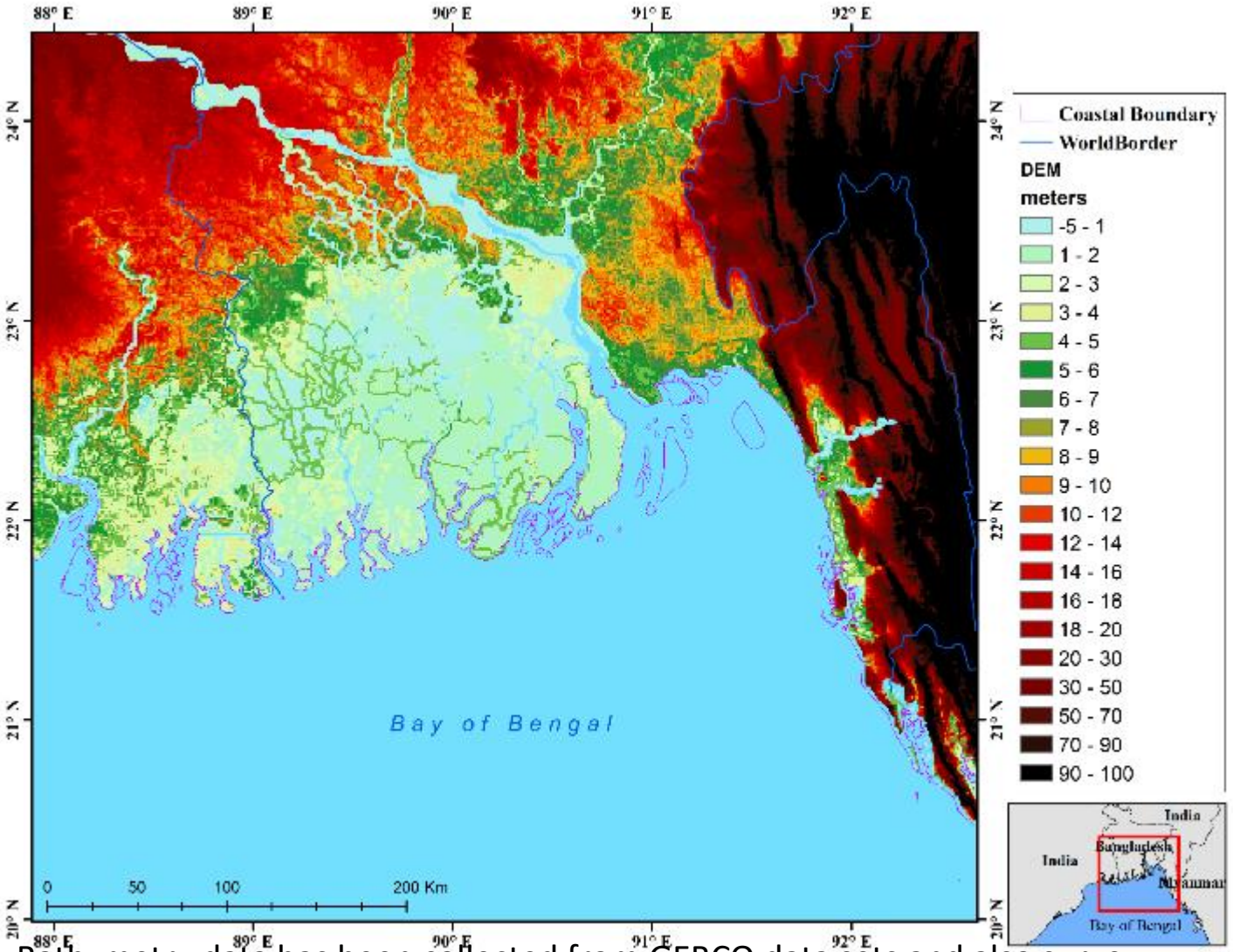




Delfft3D Modeling Domain, Grid and BIWTA & BWDB Observation Stations



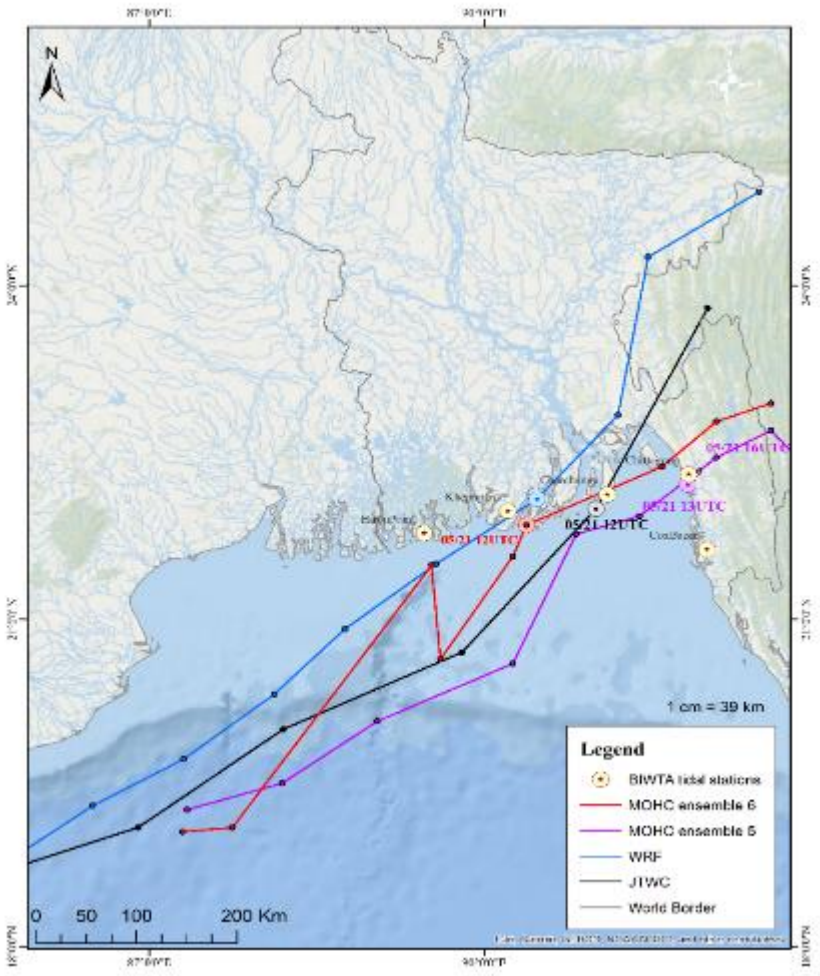
Topography of the Coast and Bathymetry of the Bay of Bengal

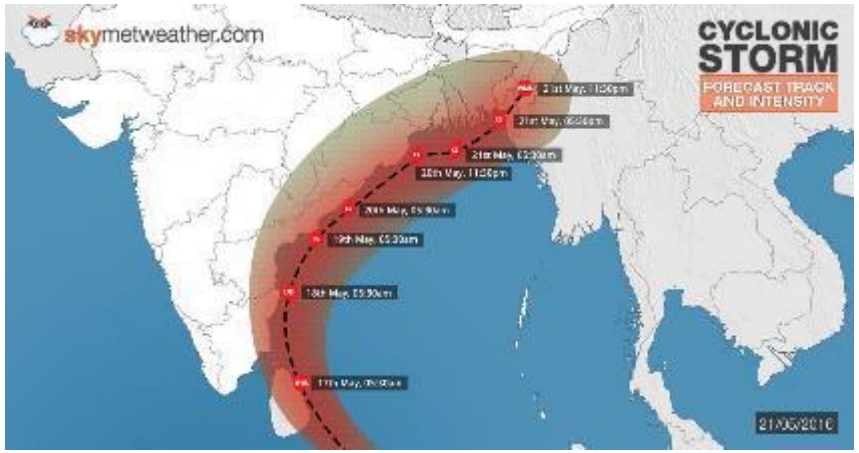


Bathymetry data has been collected from GEBCO data sets and also survey from BWDB, Bangladesh Navy and IWFM of BUET.

Comparison of Tracks of **Cyclone Roanu**

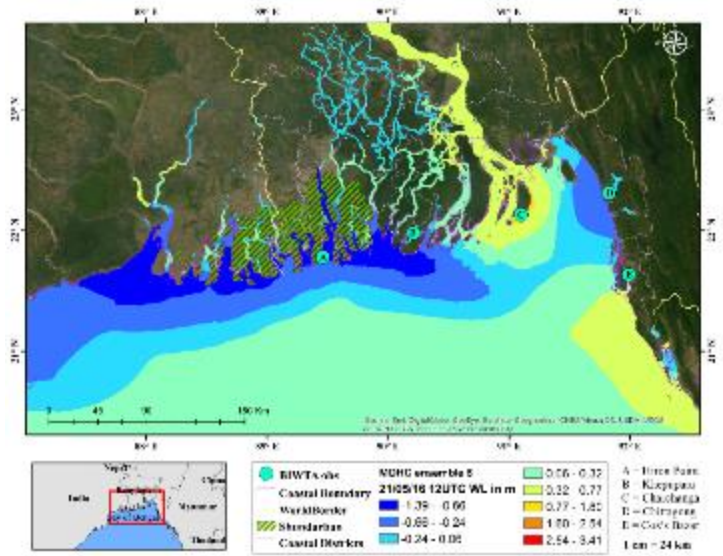
Track of JTWC, WRF, MOHC-5, MOHC-6



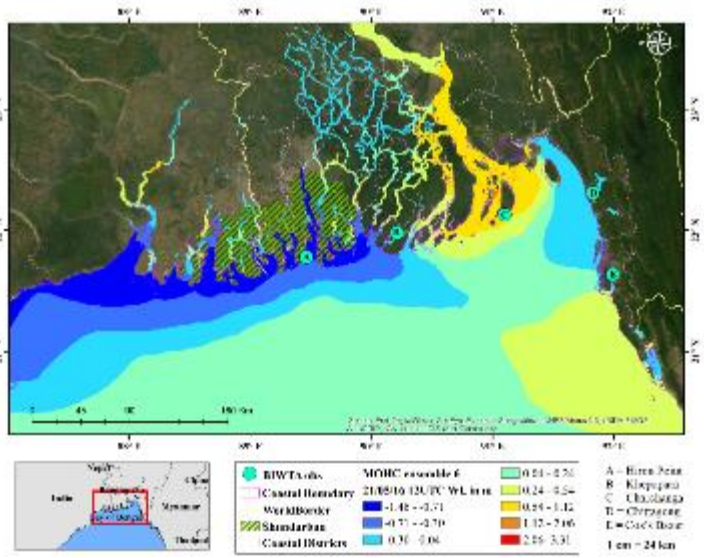


Comparison of flood inundation

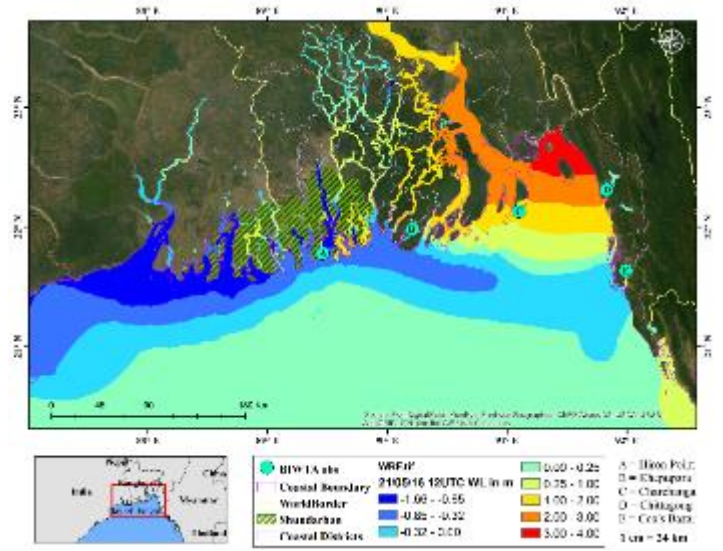
MOHC-5



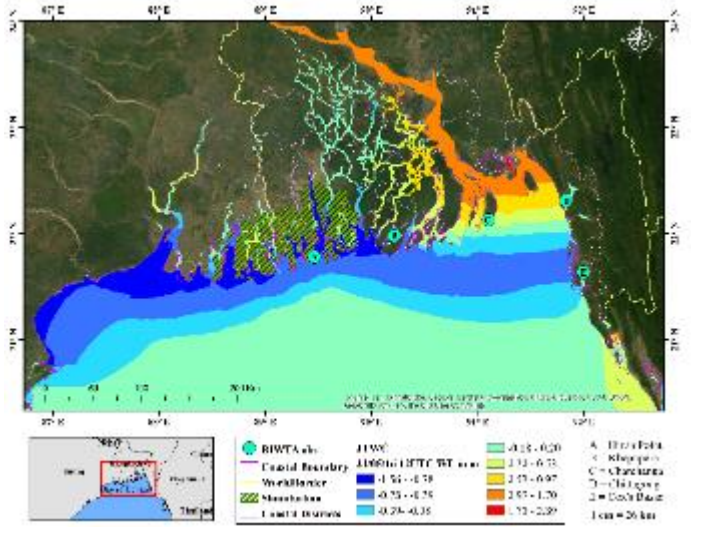
MOHC-6



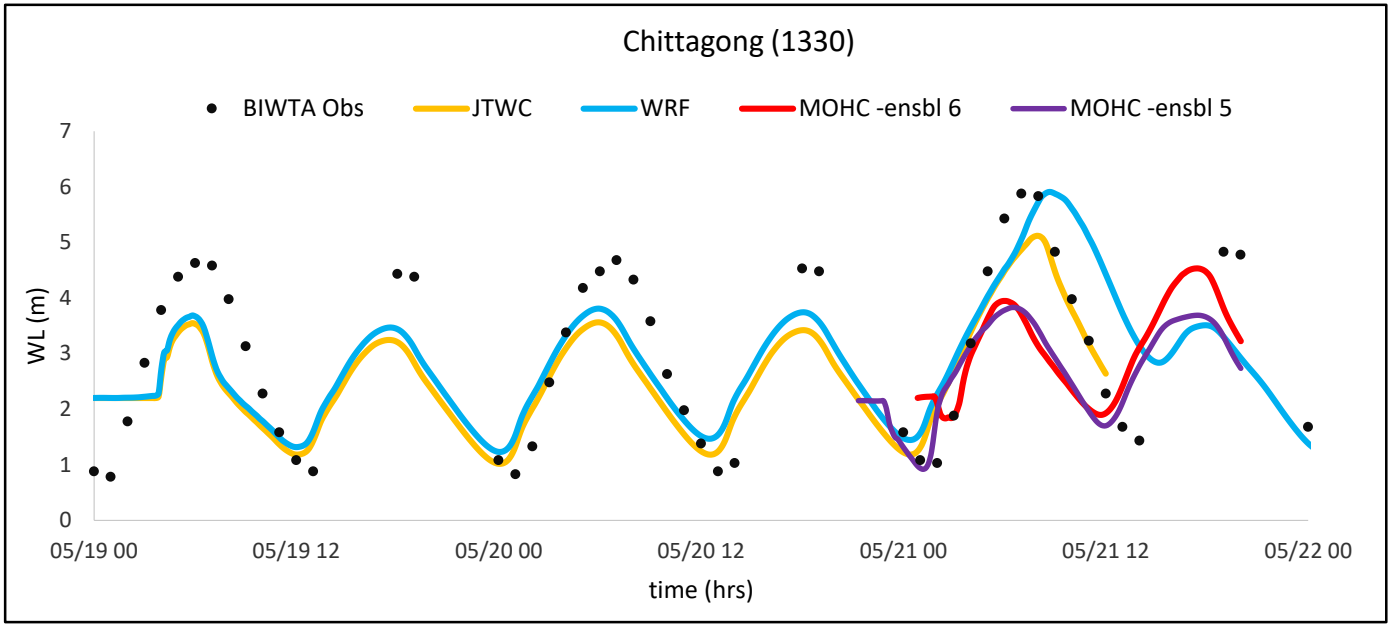
WRF

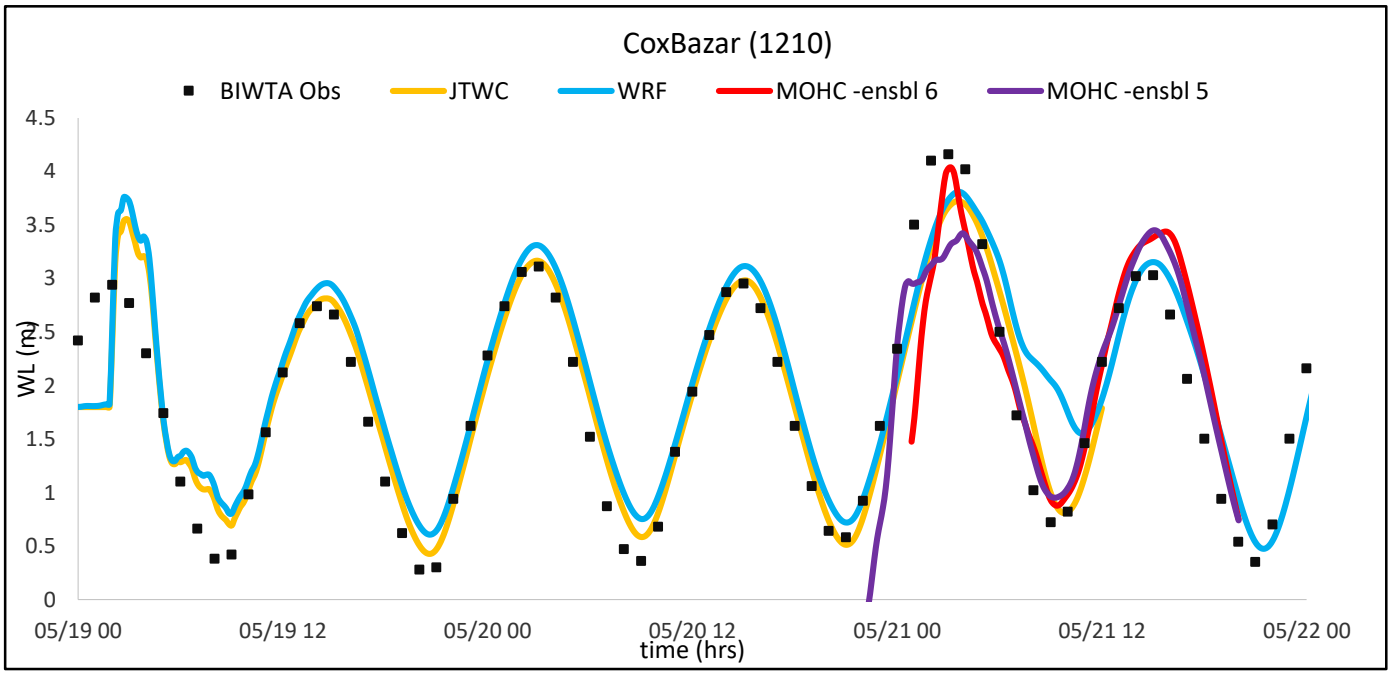


JTWC



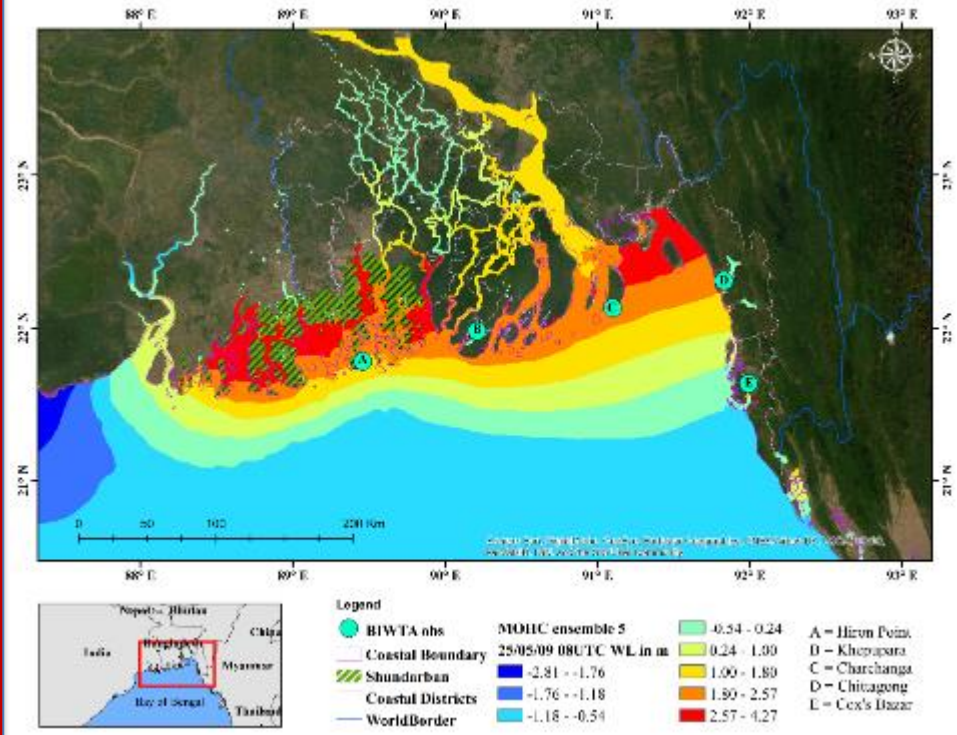
Comparison of Time series plots for **cyclone Roanu**



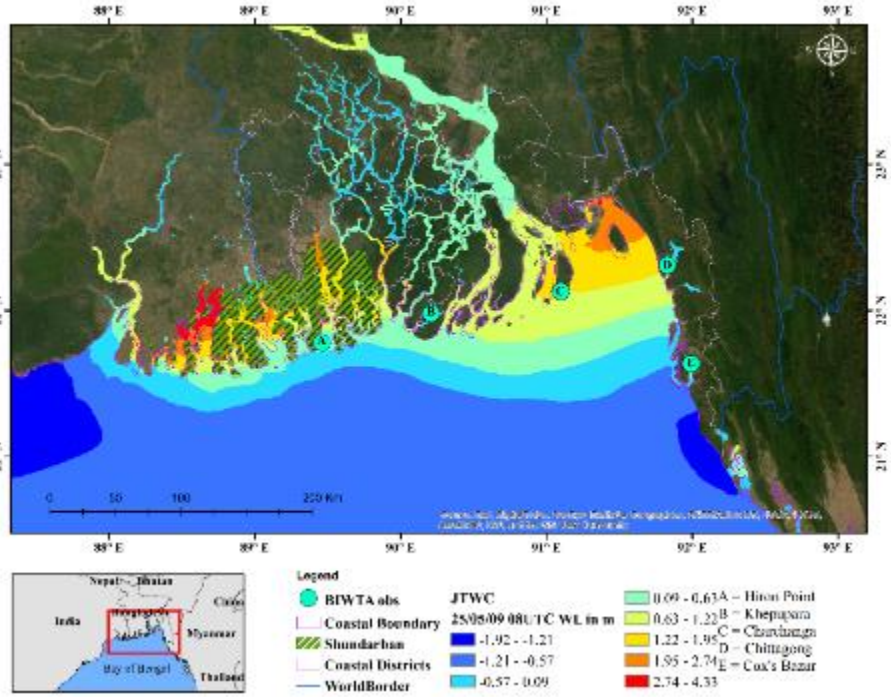


Comparison of storm surge inundation of **cyclone Aila** using boundary data from MOHC and JTWC

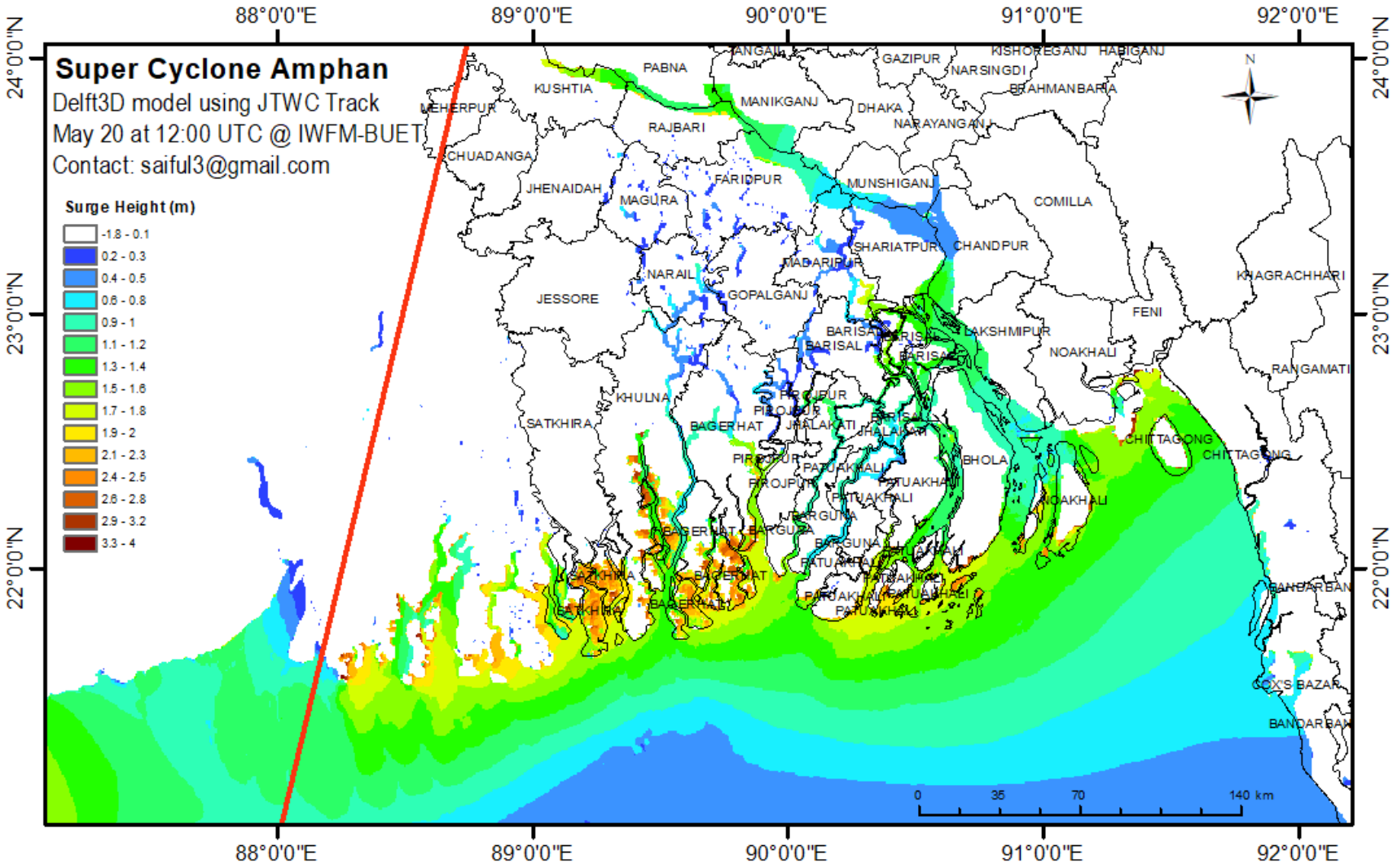
MOHC-5



JTWC



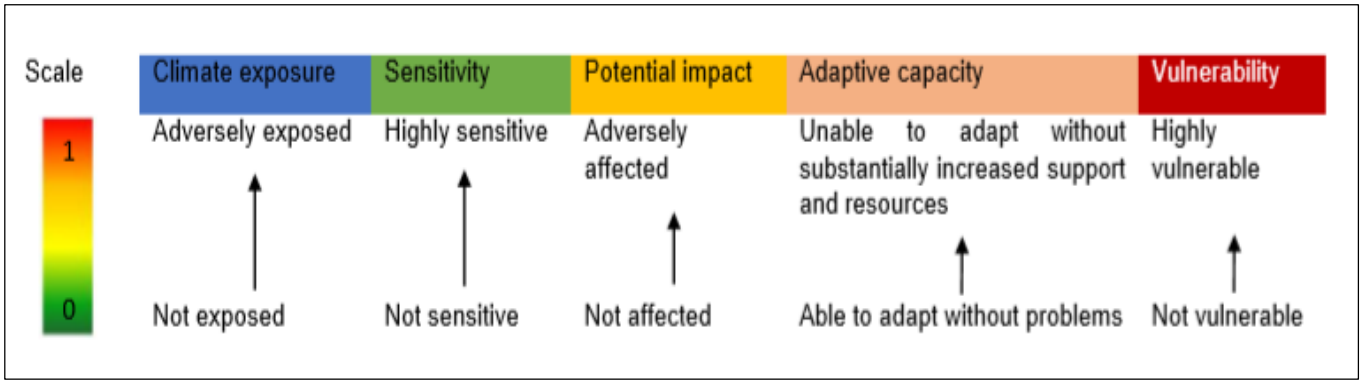
Model simulated storm surge of **Cyclone Amphan** on 20 May 2020 at 6:00 pm



Selection of Damage Classes for depth-damage function development

Residential	Transport	Agriculture
• Mud house • Wooden tin • Semi pucca tin	• Mud road • Brick road • Double brick road	• Rice • Vegetables

Normalized data value with the corresponding vulnerability component (source: Report on Nationwide Climate Vulnerability in Bangladesh, 2018)

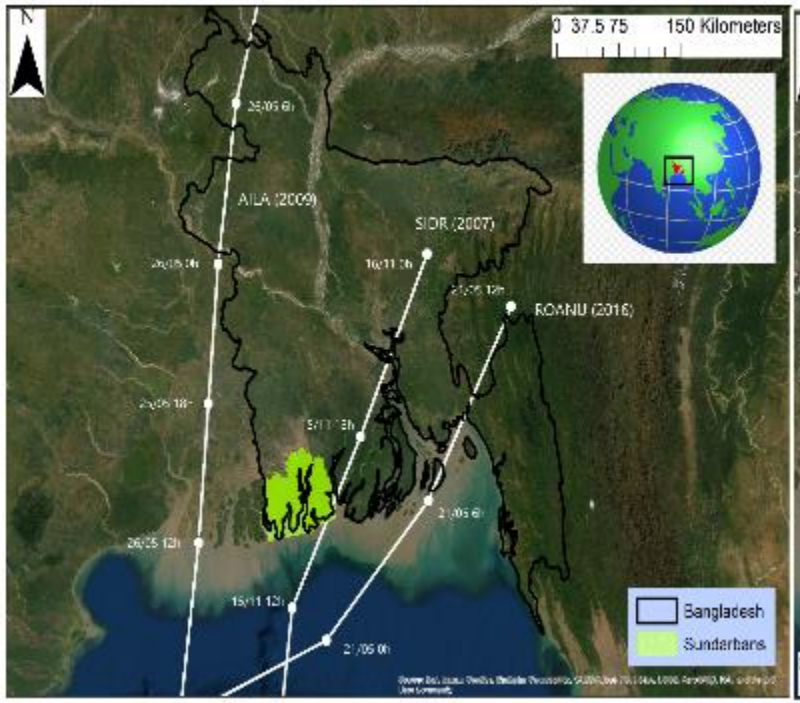


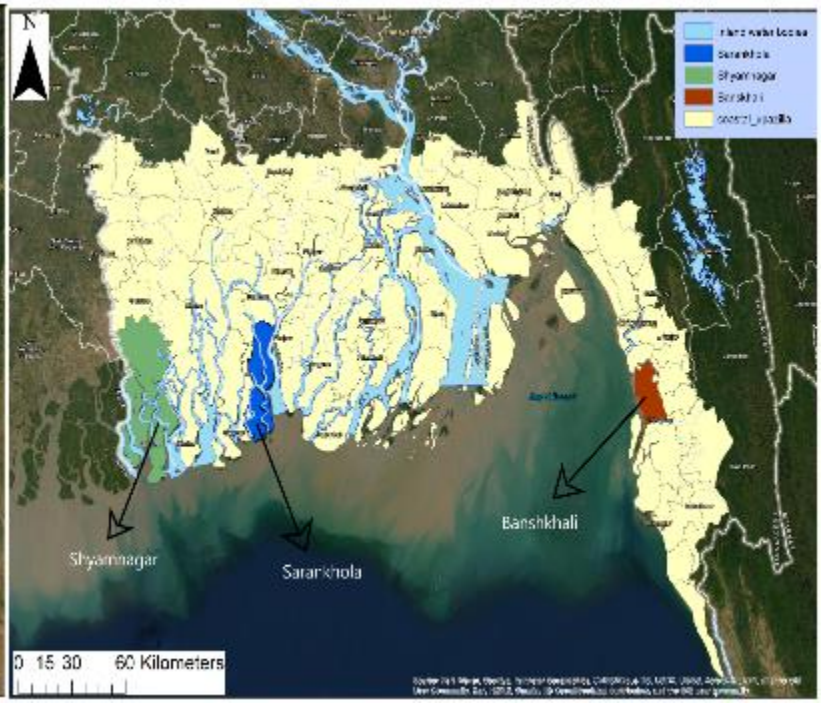
$$X_{nv} = \frac{X_{ov} - X_{min}}{X_{max} - X_{min}}$$

Xnv is the normalized value within the range of 0 to 1
Xov is the original value of a data point to be normalized;
Xmin is the minimum value of all data points corresponding to the worst situation; and
Xmax is the maximum value of all data points corresponding to the optimal situation.

Field Data Collection

- Bashkhali Upazilla for cyclone ROANU (2016)
- Shyamnagar Upazilla for cyclone AILA (2009)
- Sarankhola Upazilla for cyclone SIDR (2007)





Developing depth to damage functions for **cyclone Roanu** – Field visit to Bashkhali, Chittagong

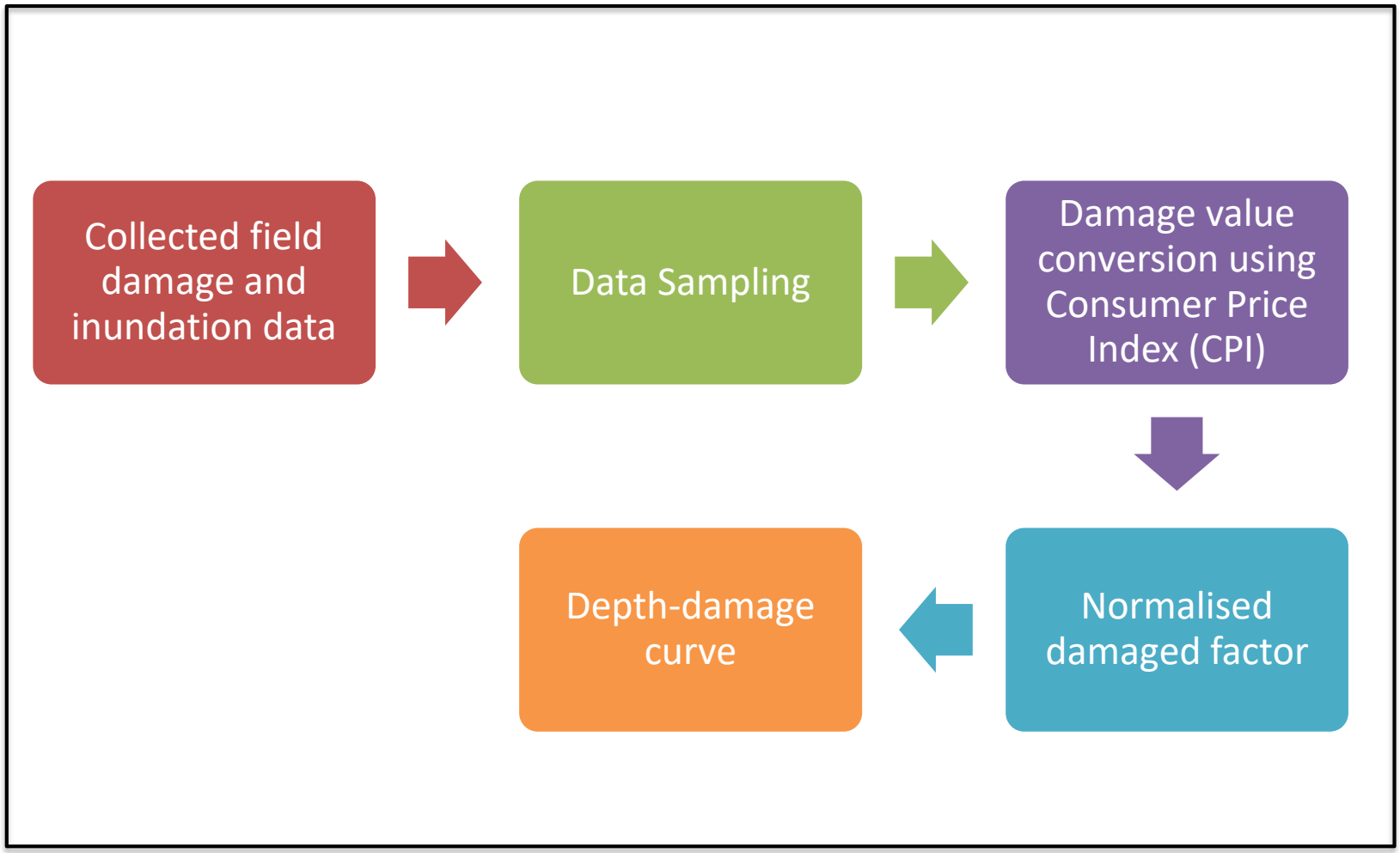
Cyclone Shelter

Coastal Embankment

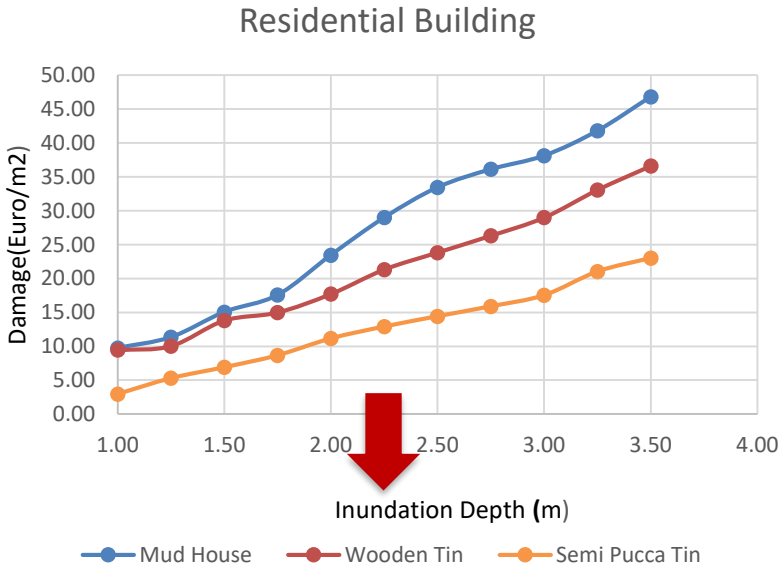
Mud House

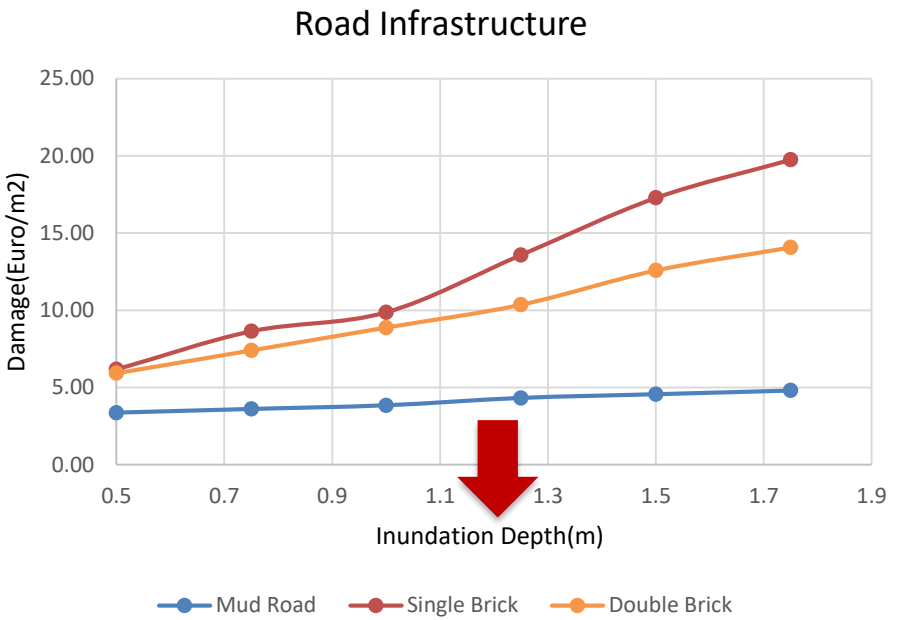
Interview - Questionnaire

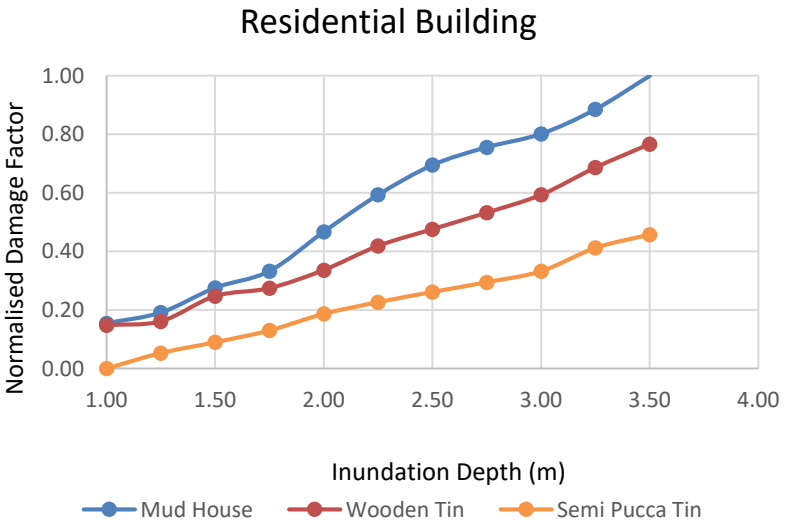
Depth-damage curve preparation

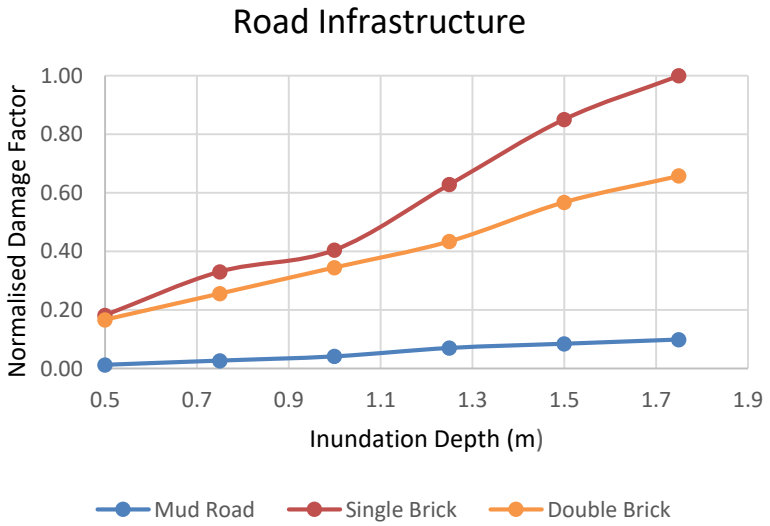


Normalized Damage curves for Residential Buildings and Road infrastructures



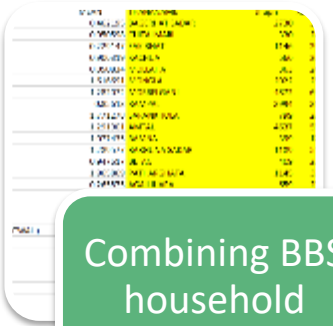




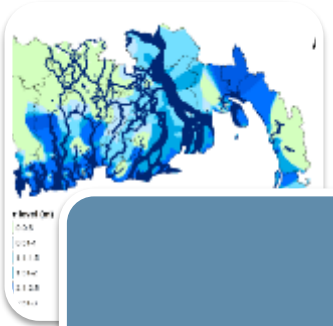


Vulnerability Mapping

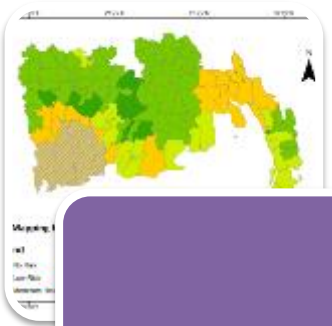
Inundation data from Delft3D model



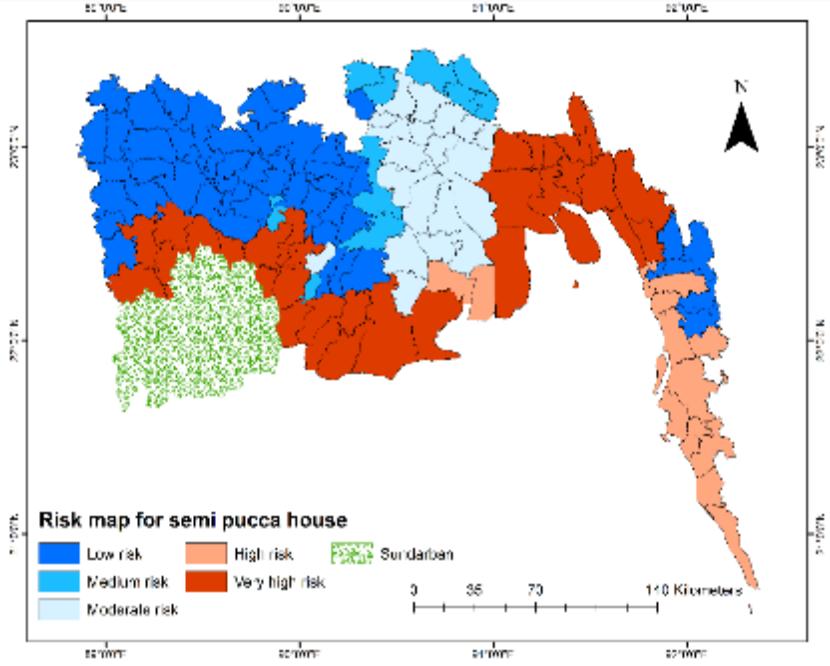
Combining BBS household data and damage functions

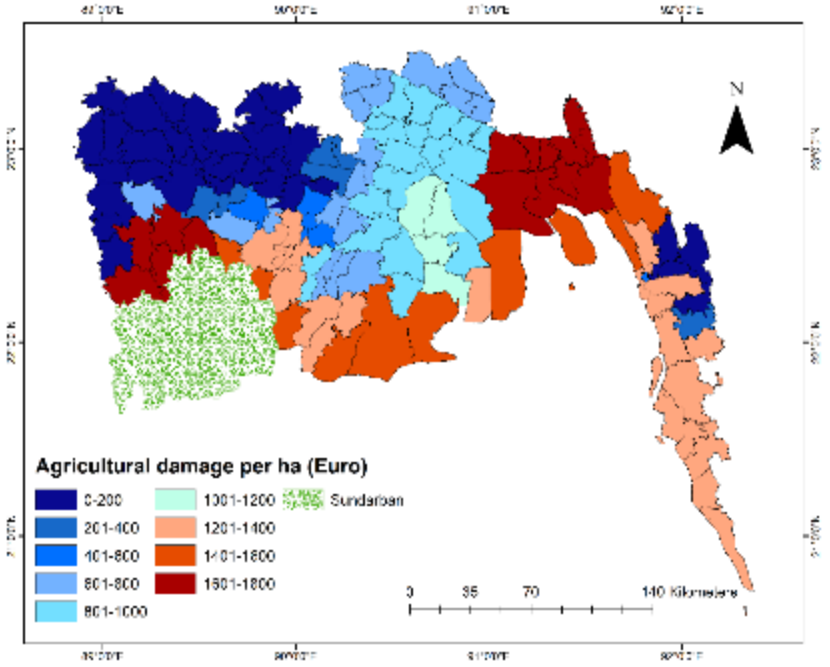


Spatial Analysis



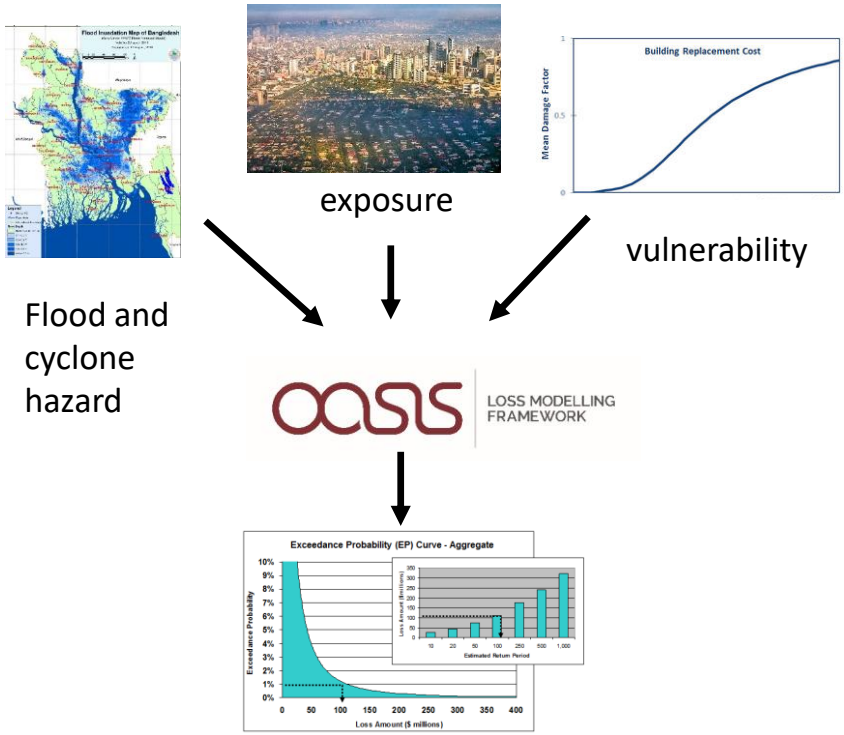
Risk mapping





Oasis LMF – Open Source Risk Modelling Platform

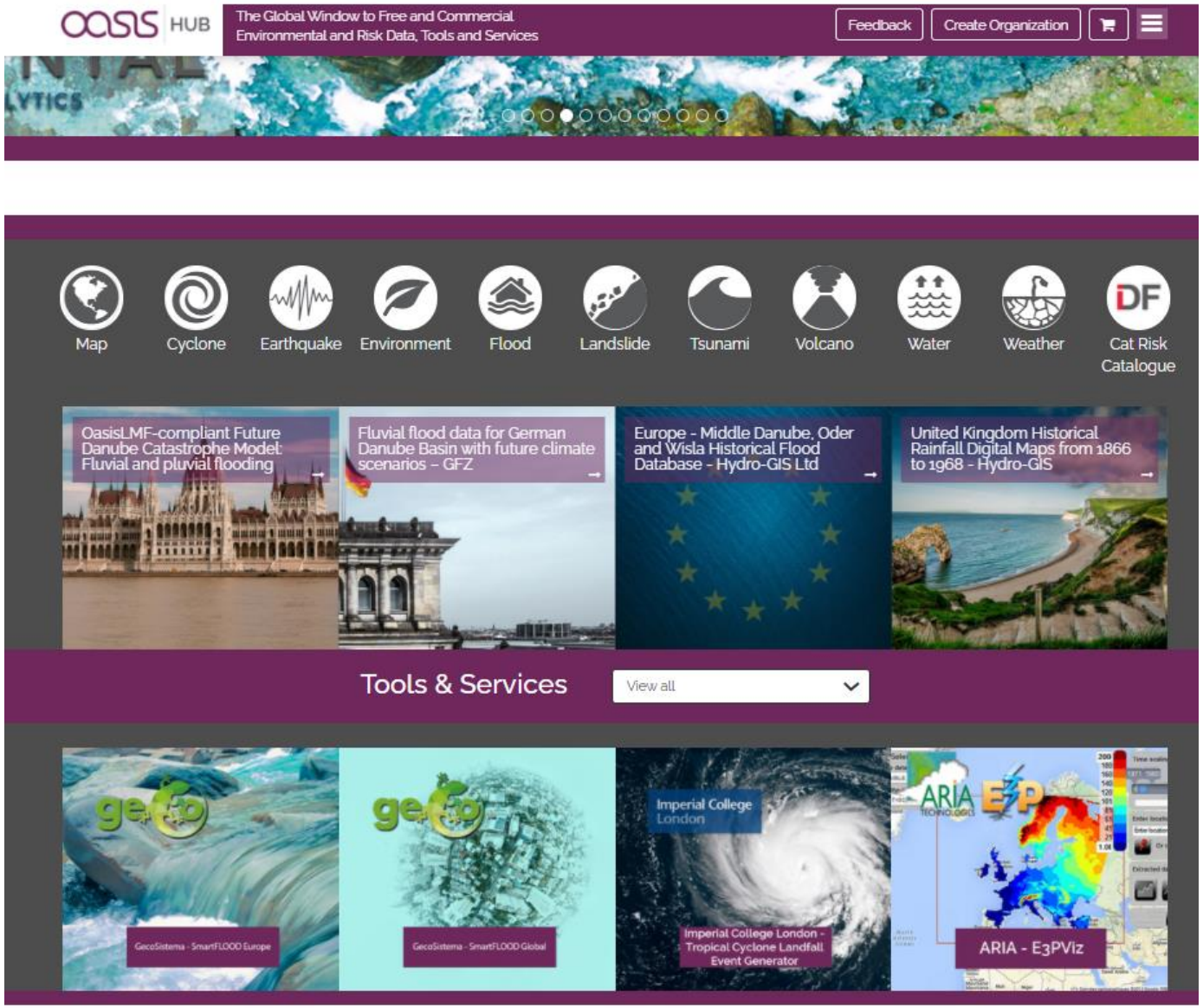
- A not-for-profit organisation operating across the world
  - Funded and supported by the global re/insurance industry and public sector
- Builds and supports open-source software platform for catastrophe risk modelling since 2015
- Plug and play hazard, vulnerability, exposure into the financial engine
- Calculate probabilistic loss metrics
  - EP curves, Average Annual Loss, uncertainty
- Curates international standards and interoperability
- Software is free to use
- Download from https://github.com/OasisLmf



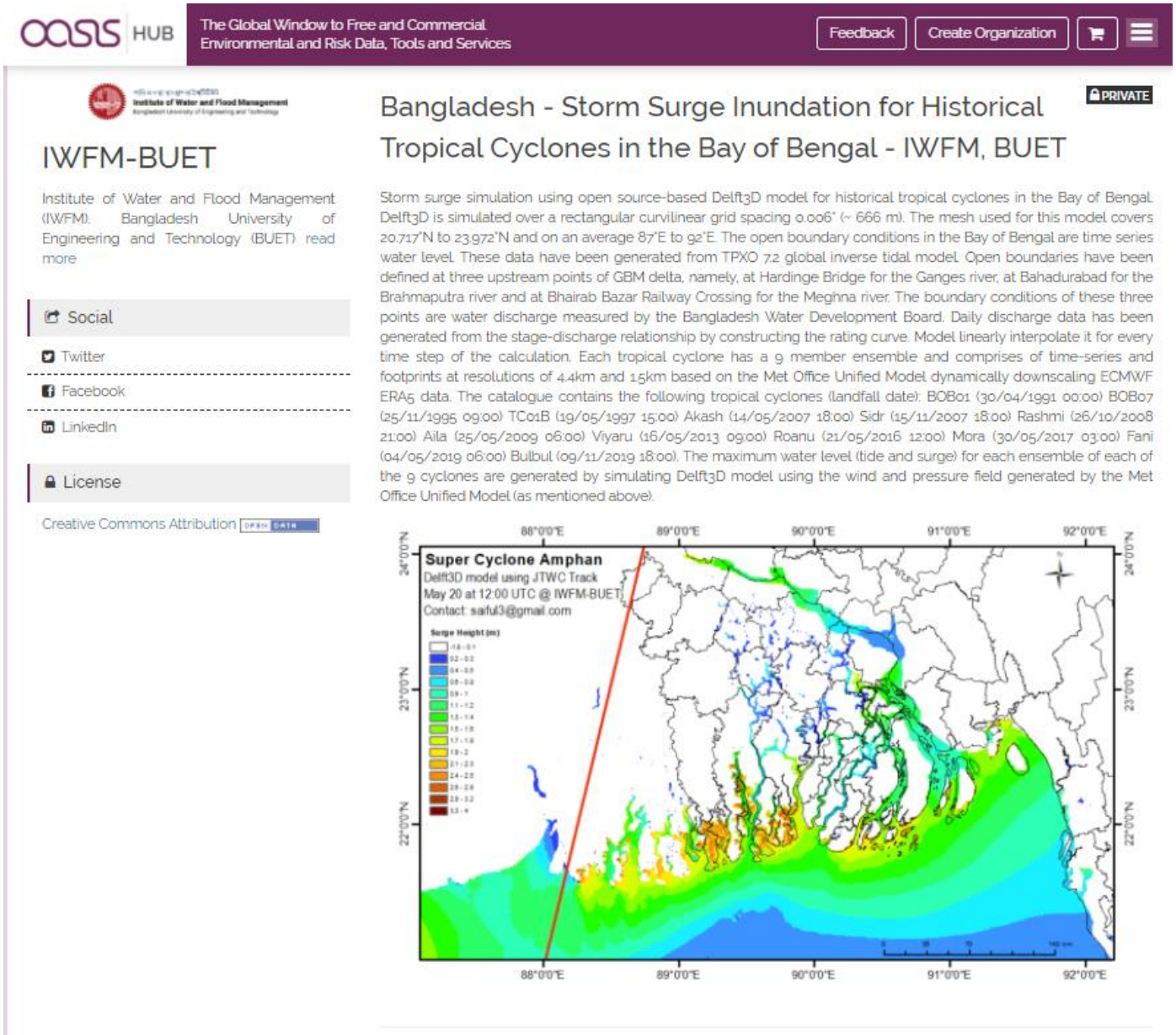
Quantify the economic impacts of natural disasters

“Oasis Hub” Environmental Data, Tool & Services

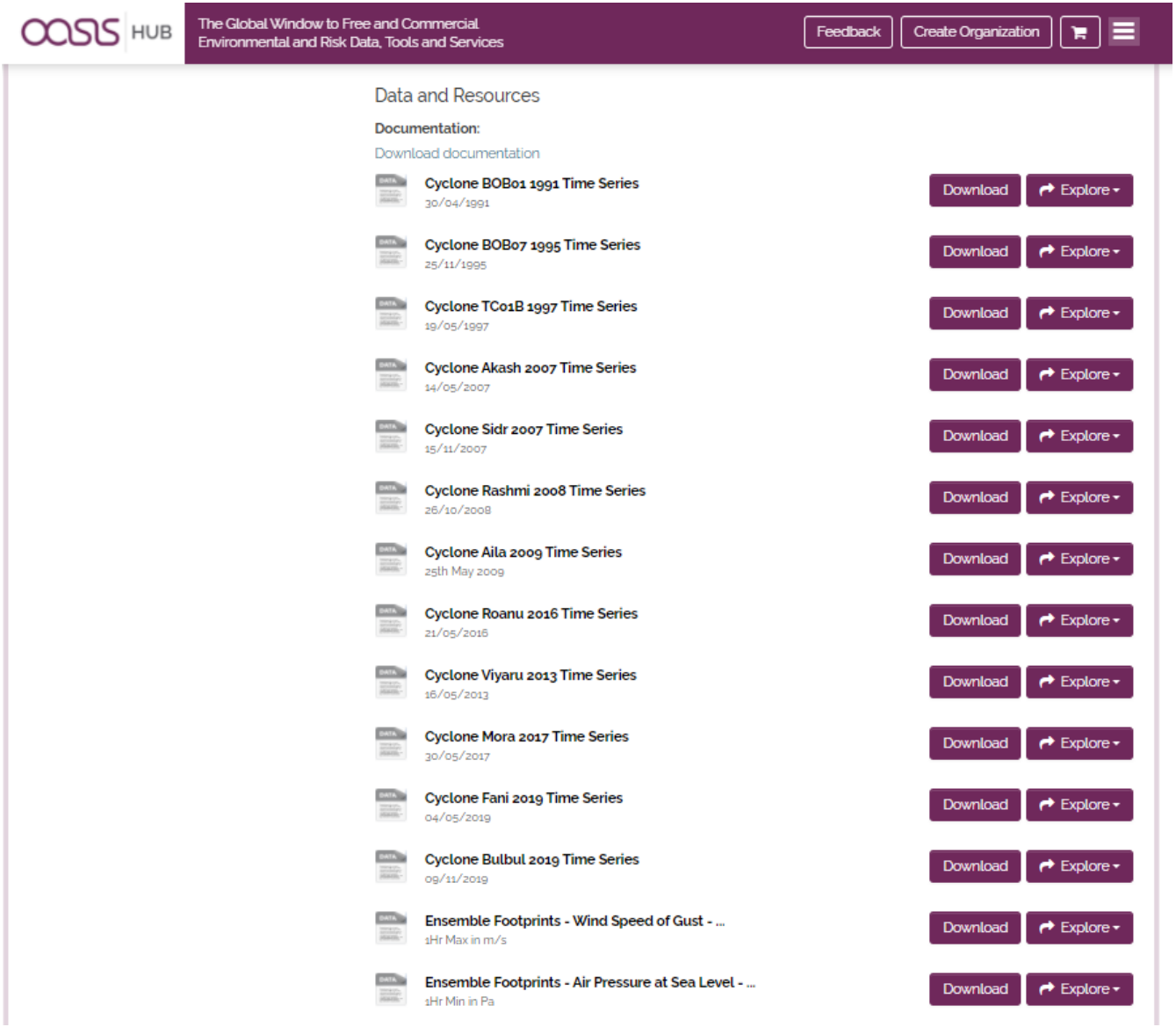
https://oasishub.co/



Transferring Results into the Oasis Hub



Data set catalogue of all historical cyclones simulated by UK Met office and IWFM, BUET



Sustainability and Model Updates in the Future

- **Self-sustainability** and ownership of risk assessment in Bangladesh is a key goal of the project to democratise risk understanding
- The Oasis platform is a plug-and-play **open-source system,** and there are no license fees
- **New vulnerability, exposure and storms** can be added to the system at any time e.g. different exposure types, livelihood, crops etc using the Oasis standards
- More models can be added for different risks, e.g. **earthquake, flooding**
- Future climate change projections can be added to updated hazard files
- The project is giving the tools to Bangladesh scientists, engineers and end-users to be able to do this beyond the end of the initial project in 2020

Possible applications of this study

- Simulate this models before any cyclone occur in the Bay of Bengal to know the possible storm surge inundation depth and patterns
- Can be applied for adaptation planning such as building resilient coastal infrastructure or generate scenarios with nature based solution
- Climate attribution studies and loss and damage scenarios
- Possible future inundation considering sea level rise
- Updating of national planning documentation such as Bangladesh Delta Plan 2100, NAP etc.
- Data is freely available and can be downloaded from Oasis Hub for research, academic and any other studies or climate negotiations

Publications on cyclone and storm surges

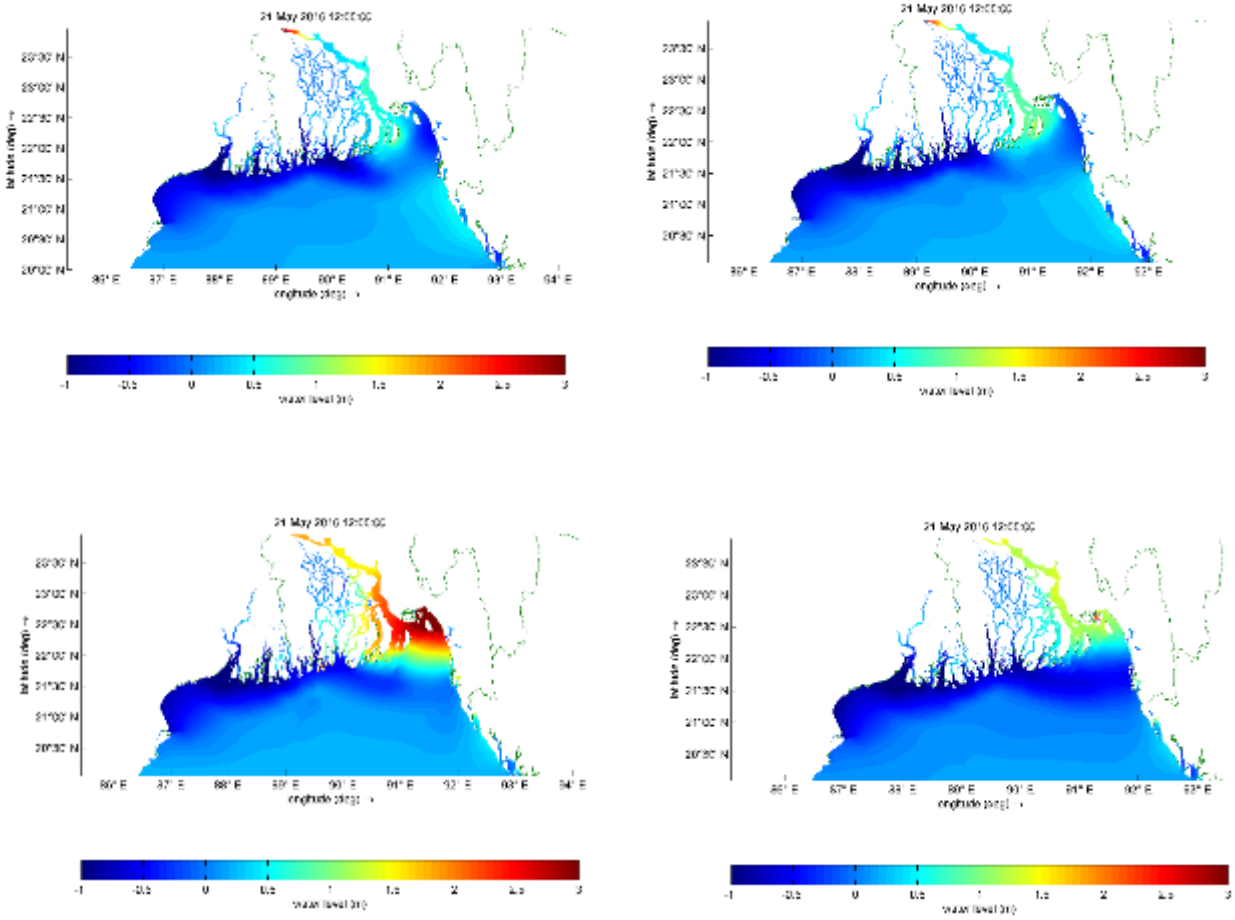
- Projected changes of inundation of cyclonic storms in the Ganges–Brahmaputra–Meghna delta of Bangladesh due to SLR by 2100. Journal of Earth System Science, 23, 1409-1429.
- Towards improved storm surge models in the northern Bay of Bengal. Continental Shelf Research, 135, pp.58-73. doi:10.1016/j.csr.2017.01.014.
- Mapping of Climate Vulnerability of the Coastal Regions of Bangladesh using Principal Component Analysis. Applied Geography, 102, 47-57.
- Seasonal modulation of M2 tide in the northern Bay of Bengal. Continental Shelf Research, 137:154-162, doi:10.1016/j.csr.2016.12.008.
- Tidal intrusion within a mega delta: An unstructured grid modelling approach. Estuarine, Coastal and Shelf Science, 182(5):12-26, doi:10.1016/j.ecss.2016.09.014.
- Improved bathymetric dataset and tidal model for the northern Bay of Bengal. Marine Geodesy. 39(6), pp. 422-438, doi:10.1080/01490419.2016.1227405.
- Modelling the increased frequency of extreme sea levels in the Ganges–Brahmaputra–Meghna delta due to sea level rise and other effects of climate change. Environ. Sci.: Processes Impacts, 2015 (17) 1311-1322 , doi:10.1039/C4EM00683F.
- Field investigation on the performances of the coastal structures during Cyclone SIDR, Natural Hazards Review, ASCE, Vol. 12, pp. 111-116.031 doi:10.1061/(ASCE)NH.1527-6996.0000

Publications on floods and climate change

- Attributing the 2017 Bangladesh floods from meteorological and hydrological perspectives. Hydrology and Earth System Sciences, 23, 1409-1429, doi:10.5194/hess-23-1409-2019
- Attributing the 2017 Bangladesh floods from meteorological and hydrological perspectives. Hydrology and Earth System Sciences, 23, 1409-1429, doi:10.5194/hess-23-1409-2019
- Determining Flash Flood Danger Level at Gauge Stations of the North East Haor Regions of Bangladesh. Journal of Hydrological Engineering, 24(4), 05019004.
- Observed Trends in Climate Extremes over Bangladesh from 1981 to 2010. Climate Research , 77(1), 45-61.
- Future floods in Bangladesh under 1.5°C, 2°C and 4°C global warming scenarios. Journal of Hydrological Engineering, 23(12), 04018050.
- Challenges for flood risk management in flood prone Sirajganj region of Bangladesh. Journal of Flood Risk Management, e12450.
- A global network for operational flood risk reduction. Environmental Science & Policy, 84, 149-158.
- Regional changes of precipitation and temperature over Bangladesh using bias corrected multi-model ensemble projections considering high emission pathways. International Journal of Climatology, 38(4), 1634-1648. doi: 10.1002/joc.5284.
- Assessing High-End Climate Change Impacts on Floods in Major Rivers of Bangladesh Using Multi-Model Simulations. Global Science and Technology Journal, 6(2), 1-14.
- Impact of High-End Climate Change on Floods and Low Flows of the Brahmaputra River. Journal of Hydrologic Engineering, 22 (10), doi: 10.1061/%28ASCE%29HE.1943-5584.0001567.
- Extreme flows and water availability of the Brahmaputra River under 1.5°C and 2°C global warming scenarios, Climatic Change, pp 1-17, doi: 10.1007/s10584-017-2073-2.
- Hydrological response to climate change of the Brahmaputra basin using CMIP5 General Circulation Model ensemble. Journal of Water and Climate. doi:10.2166/wcc.2017.076.
- Assessing extreme rainfall trends over the northeast regions of Bangladesh, Theoretical and Applied Climatology, 1-12, doi: 10.1007/s00704-017-2285-4.

Thank you

Water level of Cyclone Roanu using (a) MOHC ensemble 5 and (b) 6



Water level of Cyclone Roanu using (c) WRF (d) JTWC data