World Meteorological Organization

Weather • Climate • Water

Coastal Inundation Forecasting and Community Response in Bangladesh

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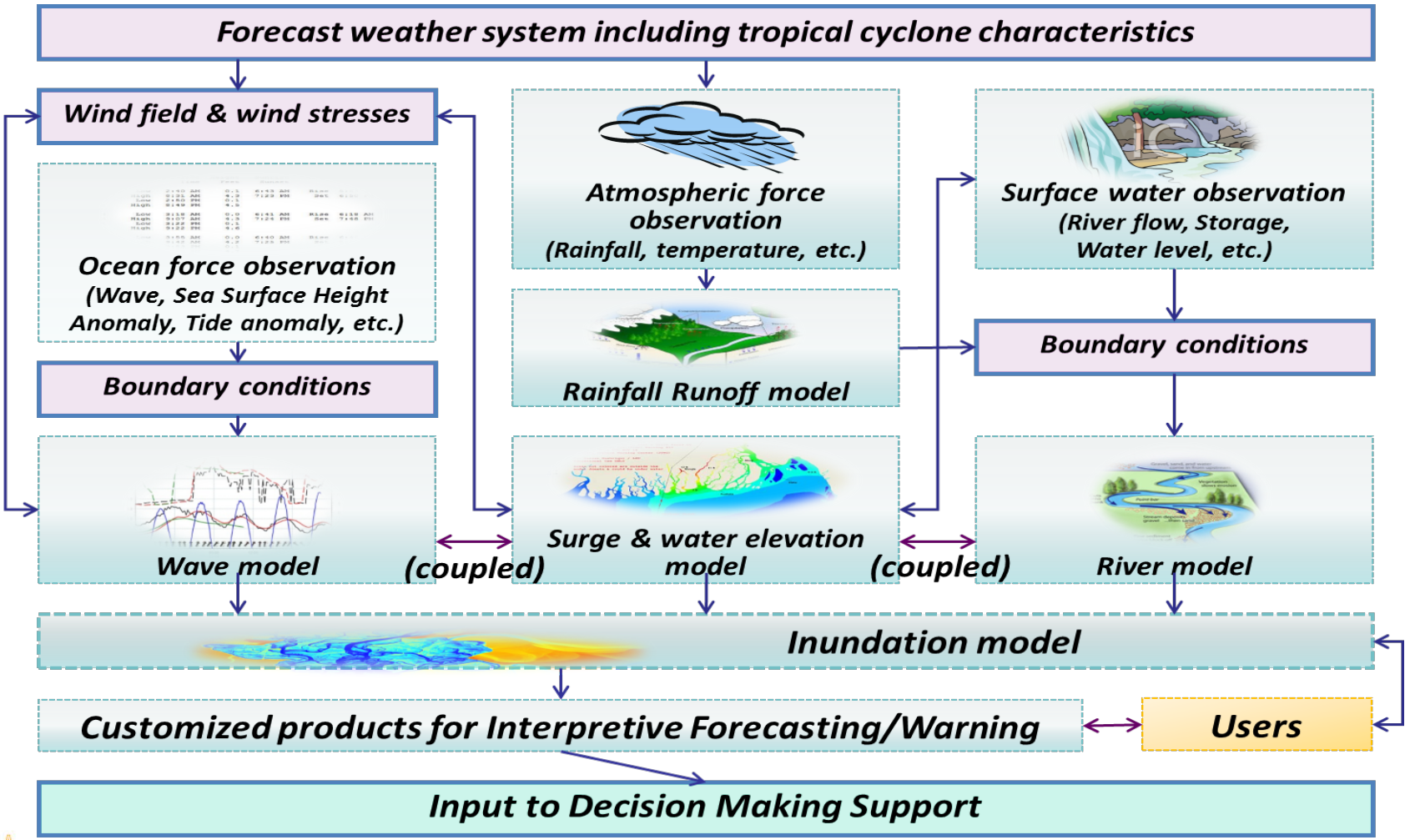
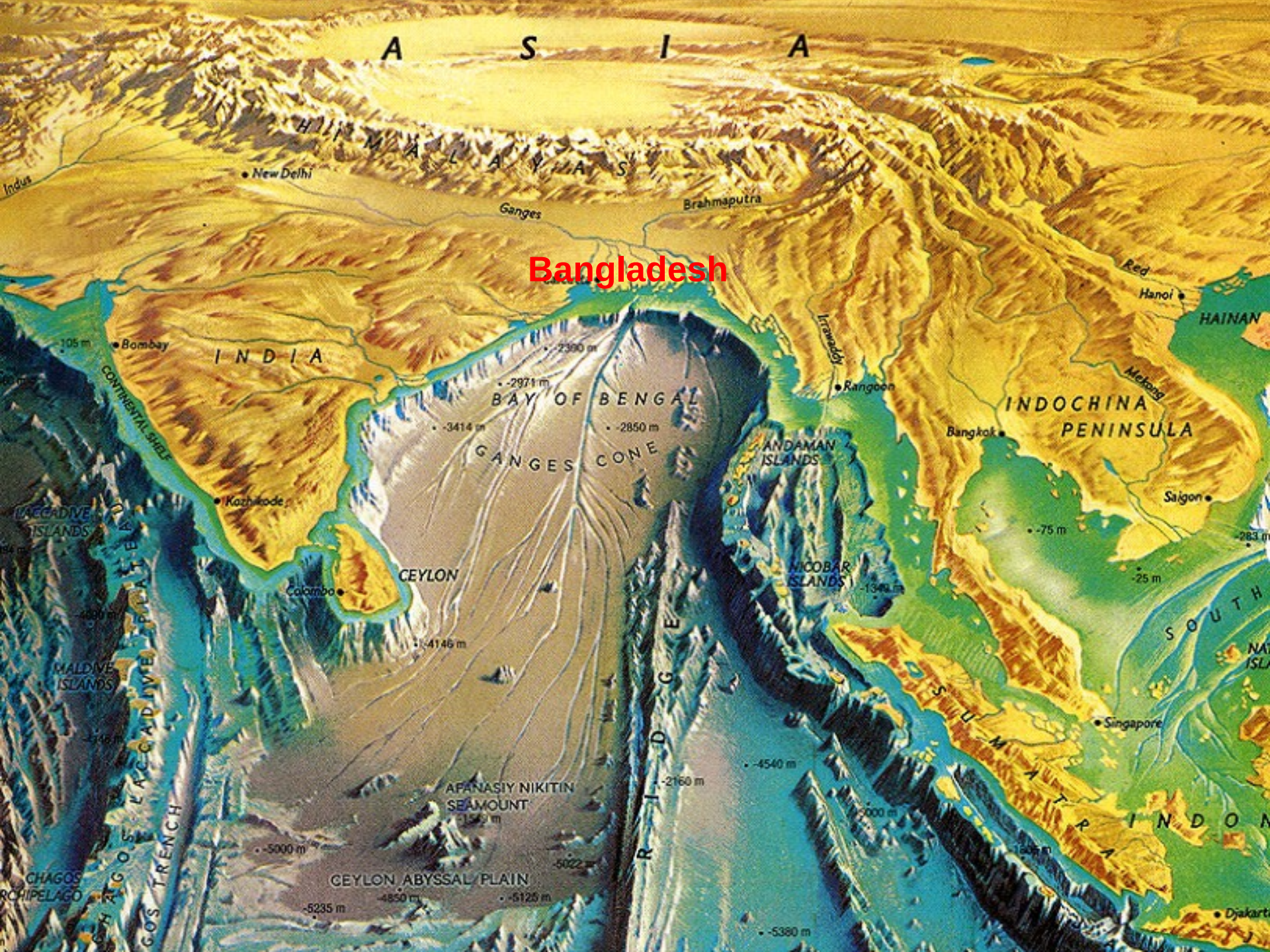
Nadao Kohno

12 November 2015

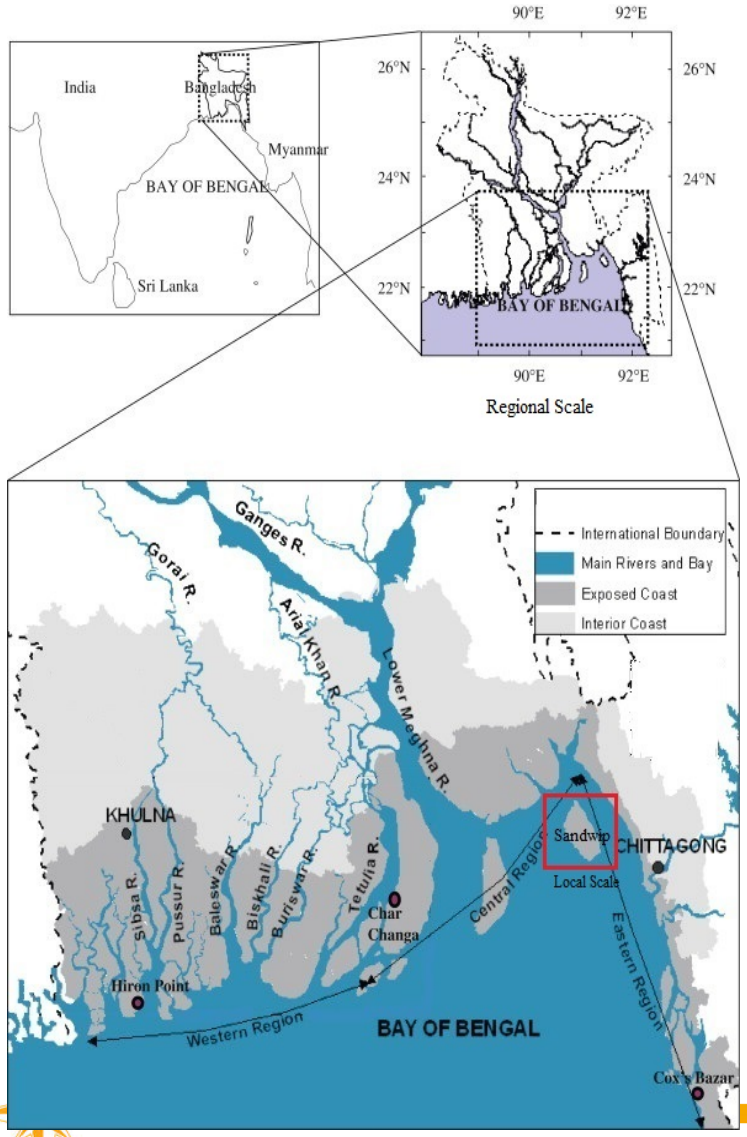
System Design for Coastal Inundation Forecasting

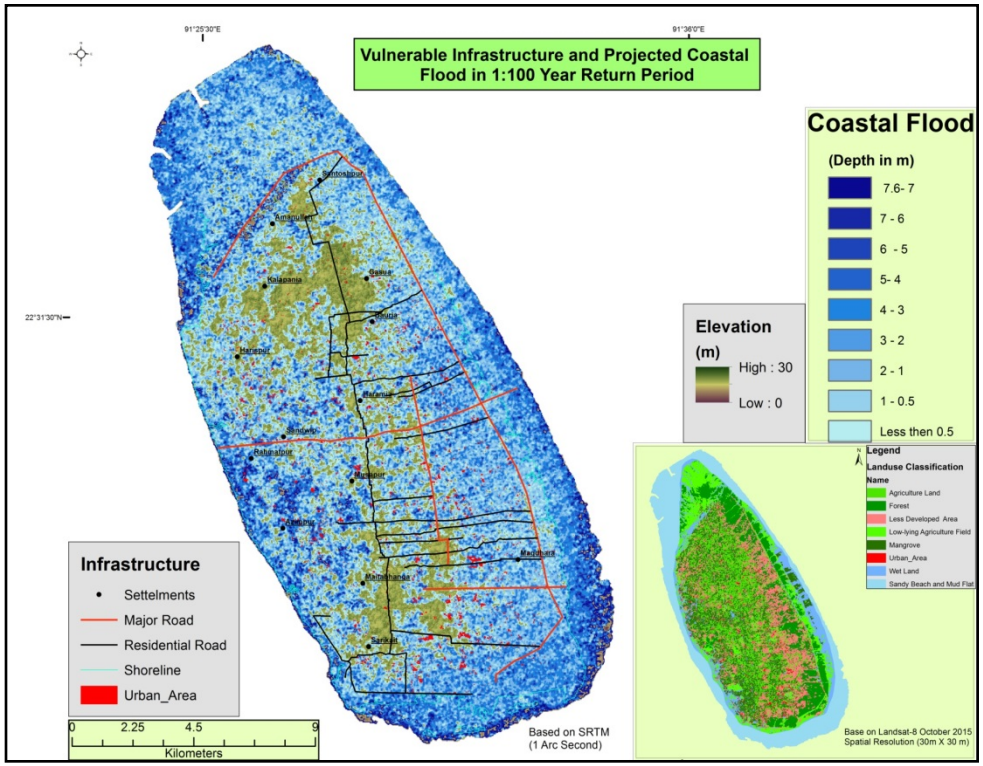



A S I A
HIMALAYAS
Indus
New Delhi
Ganges
Brahmaputra
Bangladesh
Red
Hanoi
HAINAN
Irrawaddy
Rangoon
Mekong
INDIA
Bombay
105 m
CONTINENTAL SHELF
-2390 m
-2971 m
BAY OF BENGAL
-3414 m
-2850 m
GANGES CONE
ANDAMAN ISLANDS
INDOCHINA PENINSULA
Bangkok
Kozhikode
Saigon
-75 m
-283 m
LACCADIVE ISLANDS
CEYLON
Colombo
-4146 m
NICOBAR ISLANDS
-1349 m
-25 m
SOUTH
MALDIVE ISLANDS
Singapore
SUMATRA
INDON
-4540 m
-2160 m
APANASIY NIKITIN SEAMOUNT
-5000 m
-5022 m
CHAGOS ARCHIPELAGO
CEYLON ABYSSAL PLAIN
-4850 m
-5125 m
-5235 m
-5380 m
Djakarta

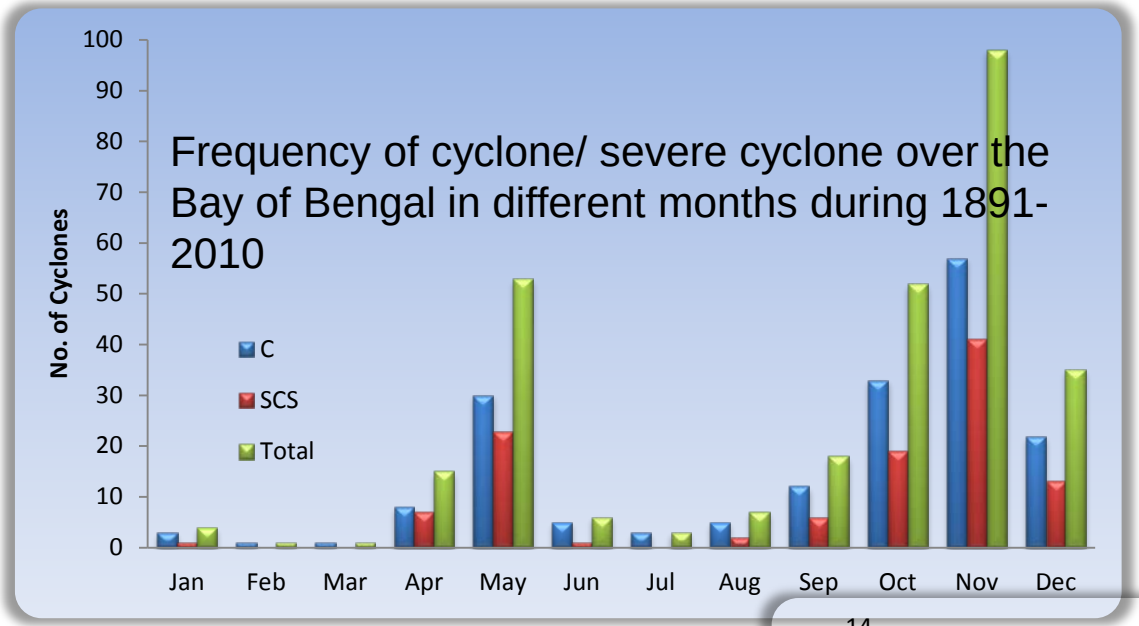
Piloting in Sandwip Island under RISC-KIT

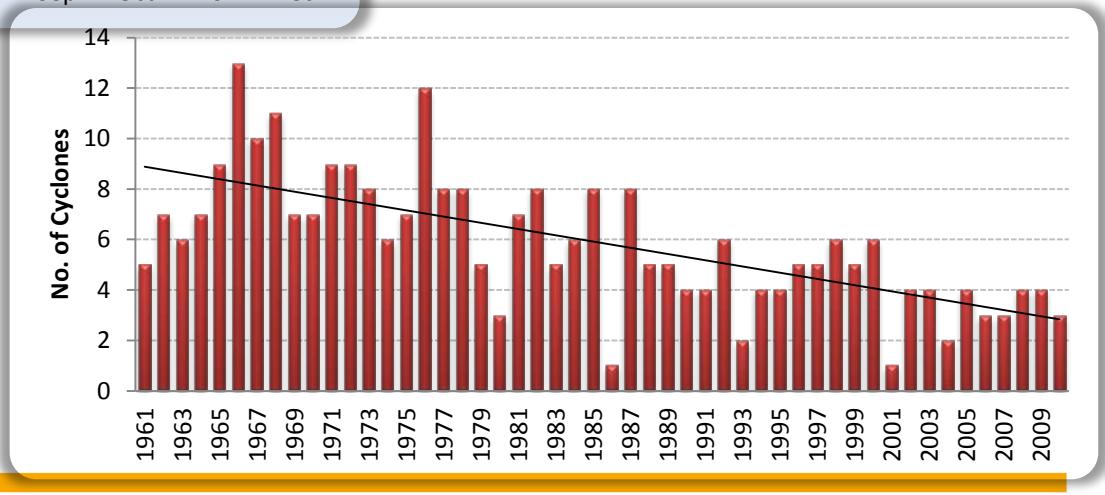
www.risckit.eu





Frequency of Cyclones in BoB





Methodology: Coastal Inundation Forecasting

JMA-MRI Model	Description
Model	2 dimensional lineralized model
Coordinate	Lat/Lon Cartesian grid ; Arakawa C-Grid
Area	0.0~46.0N; 95.0E~160.0E
Grid resolution	2’×2’ (≒3.7km)
Time step	8 seconds
Forecast hours	72
Calculation run	4 times / day (6 hourly)
Initial time (UTC)	00,06,12,18
Number of prediction courses	1 course (NWP predicted course) or Parametric values
Forcing	GSM GPV (20km) NWP data set
Visualization	GMT & GrADS

Methodology: Coastal Inundation Forecasting

- Storm Surge Model: 2 dimensional ocean model, vertically integrated. The governmental equations are usual momentum equation and continuity equation.
- Momentum Eq:

$$\begin{cases} \frac{\partial Du}{\partial t}+\frac{\partial Du^2}{\partial x}+\frac{\partial Duv}{\partial y}=-\frac{1}{\rho_w g}D\frac{\partial(\varsigma-\varsigma_0)}{\partial x}-\frac{1}{\rho_w}(\tau_{ax}-\tau_{bx})+fDv \\ \frac{\partial Dv}{\partial t}+\frac{\partial Duv}{\partial x}+\frac{\partial Dv^2}{\partial y}=-\frac{1}{\rho_w g}D\frac{\partial(\varsigma-\varsigma_0)}{\partial y}-\frac{1}{\rho_w}(\tau_{ay}-\tau_{by})-fDu \end{cases}$$

- Continuity Eq:

$$\frac{\partial \varsigma}{\partial t}+\frac{\partial Du}{\partial x}+\frac{\partial Dv}{\partial y}=0$$

- Input from NWP:
  - position of cyclone
  - central pressure,
  - radius of maximum wind and maximum wind speed

Methodology: Coastal Inundation Forecasting

- The tide data can be included as
  - (1) simple constant value (= tide_base) is linearly added;
  - (2) a changeable tide value is linearly added to all sea grids linearly;
  - (3) tide data is added to defined grids and
  - (4) tide data is calculated with given tidal components.
- In Bangladesh, there are no real-time tide gauges except one in the Chittagong port. There are several manual tide gauges installed by the Bangladesh Inland Water Transport Authority (BIWTA). Data from the five stations from 2008-2013 has been collected to use in the model. The drag coefficient at the surface and bottom is also considered.

Methodology: Coastal Inundation Forecasting

- Hydrodynamic Model: From storm surge height results, generate storm surge volume and apply a shallow water equation for 2D flood model (Gustavo et al. 2012; Bates et al, 2010; Li and Duffy, 2011).
- Input parameter:
  - DEM
  - Storm height
  - River water level/discharge
  - Rainfall data

Lewis, et al, 2013

$$\frac{\partial h}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0,$$

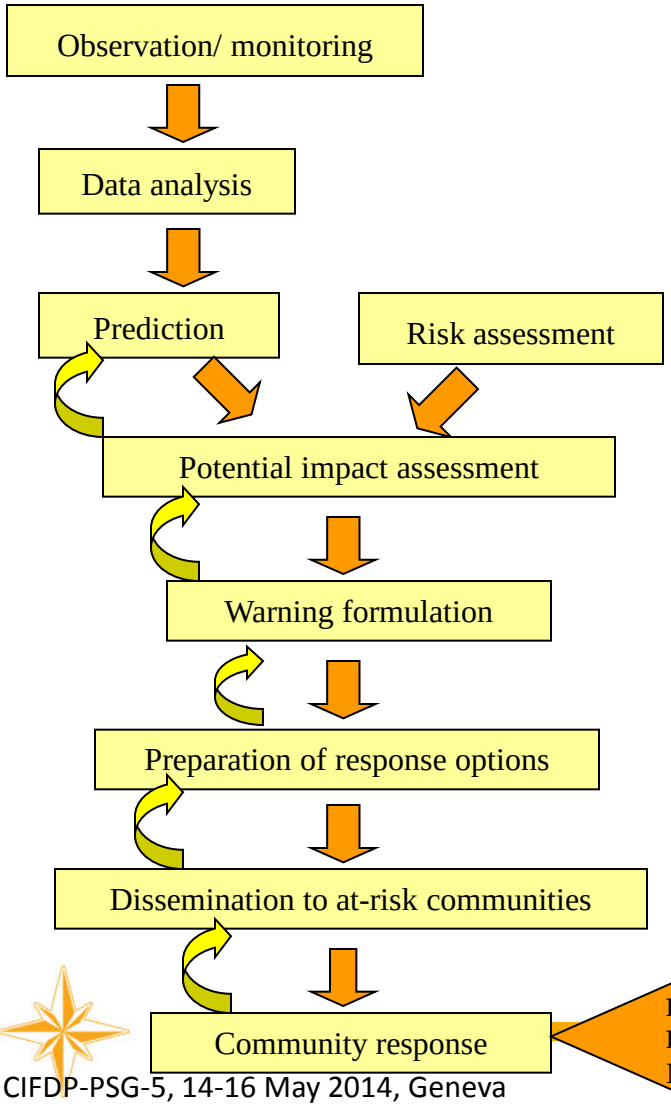
$$\frac{\partial q_x}{\partial t} + gh\frac{\partial (h+z)}{\partial x} + \frac{gn^2 |q_x| q_x}{h^{7/3}} = 0,$$

$$\frac{\partial q_y}{\partial t} + gh\frac{\partial (h+z)}{\partial y} + \frac{gn^2 |q_y| q_y}{h^{7/3}} = 0.$$

Methodology: Coastal Inundation Forecasting

- **Data Used**
- To simulate the storm surge model two different sets of Best Track data from Unisys (*weather.unisys.com)* and IBTrACS (International Best Track Archive for Climate Stewardship) were used.
- The best track contains the cyclone's latitude, longitude, maximum sustained surface winds, and minimum sea-level pressure at 6-hourly intervals.

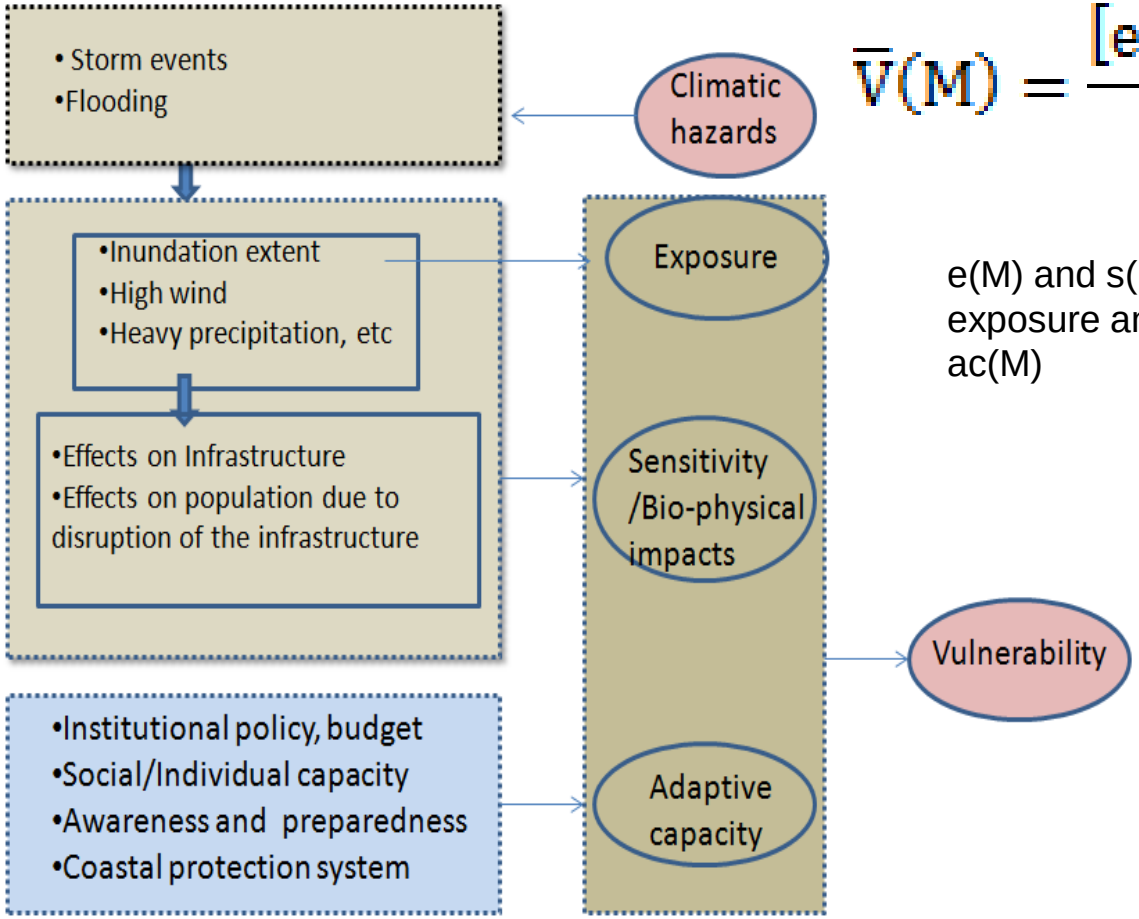
Methodology: Early Warning & Community Response



- **Regulatory framework for warning**
- **Stakeholders involvement and roles**
- **Aging and insufficient observation and data communication facilities**
- **Data sharing among agencies**
- **Numerical prediction capability**
- **Skilled human resource**
- **Capacity to make use of new generation forecasts**
- **Local level potential impact assessment not done**
- **Language**
- **Localized, relevant**
- **Institutional mechanism, linkages**
- **SOPs**
- **Redundant communication systems**
- **Reach to special groups**
- **Public awareness**
- **Communication of forecast limitations**
- **Lack of trainers/ facilitators**
- **Resources to respond to warning**

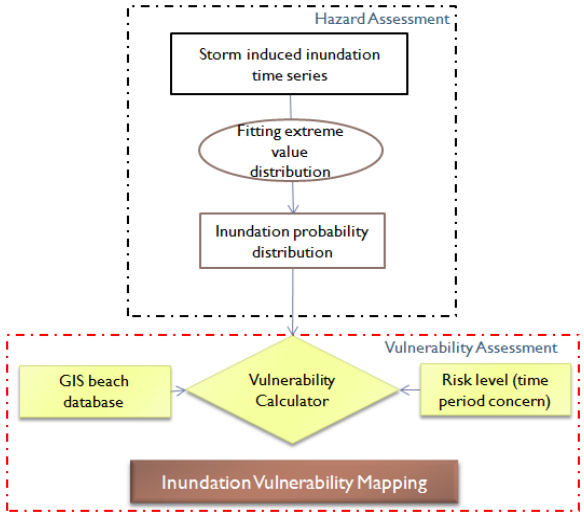
Methodology: Early Warning & Community Response

Develop Coastal Vulnerability and Risk Assessment



$$\bar{V}(M) = \frac{[e(M)E(M)].[s(M)S(M)]}{a_c(M)A_c(M)}$$

e(M) and s(M) are the percentage reductions in exposure and sensitivity as a result of adaptation and ac(M)

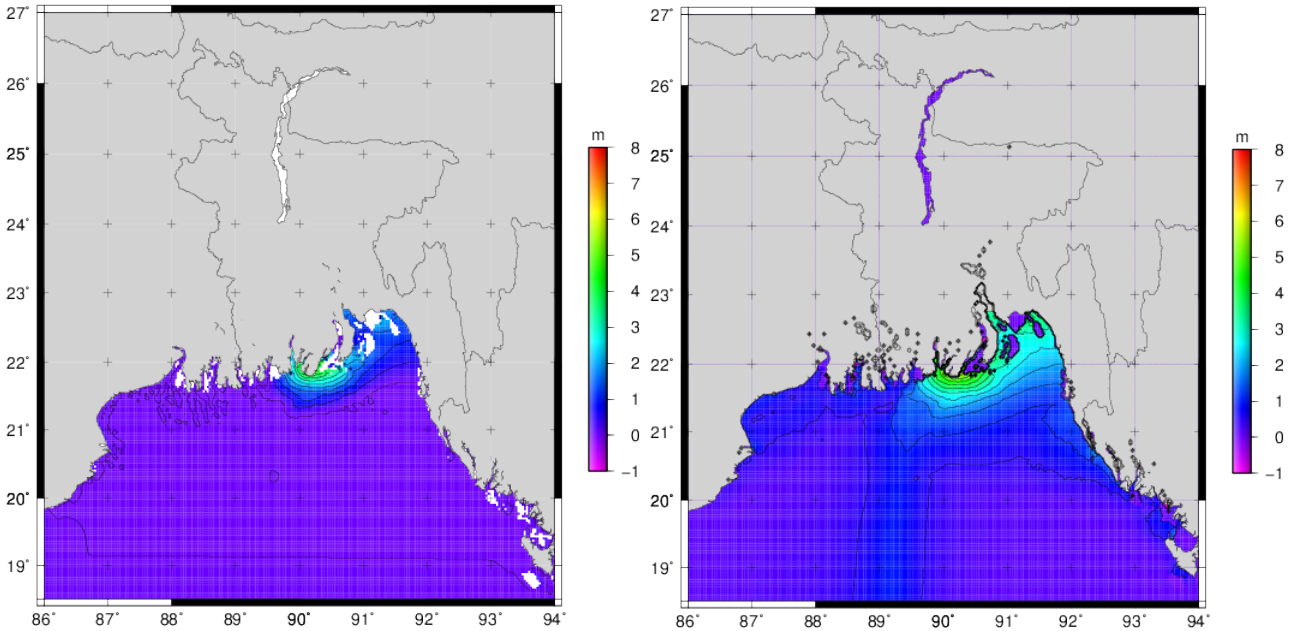


Results: Simulation of Historical Storm Surge Events

- **Numerical Experiments**
- The numerical experiments performed with the help of two versions of JMA Storm Surge Models (with and without tide and wave information) to simulate surges generated by 5(five) Severe Cyclonic storms:
  - Severe Cyclonic Storm (1988)
  - Chittagong Cyclone (1991)
  - Severe Cyclonic Storm (1997)
  - Severe Cyclonic Storm SIDR (2007) and
  - Severe Cyclonic Storm AILA (2009),

Results: Simulation of Historical Storm Surge Events

- The CIF model computed maximum storm surge showed near to the landfall point and magnitude is very near to the reported storm surge height
- Old model computed storm surge height higher than observed

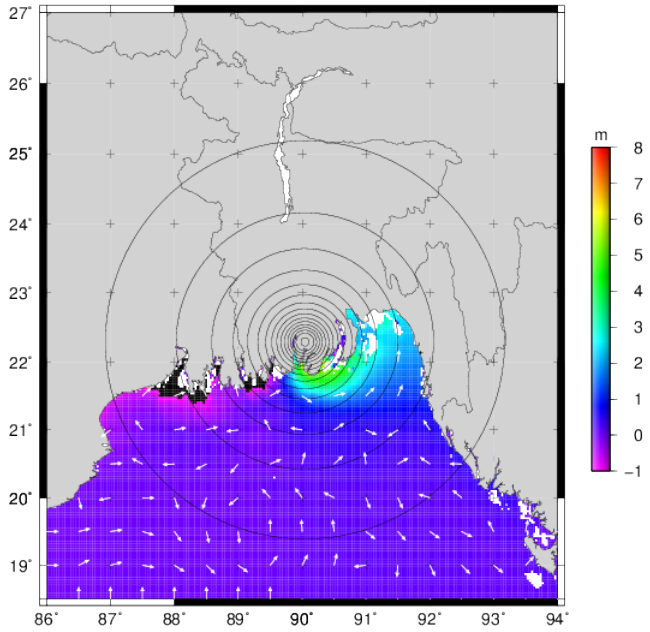


F Model (CIF) computed maximum storm surge (m) generated by SCS "SIDR" using Unisys data

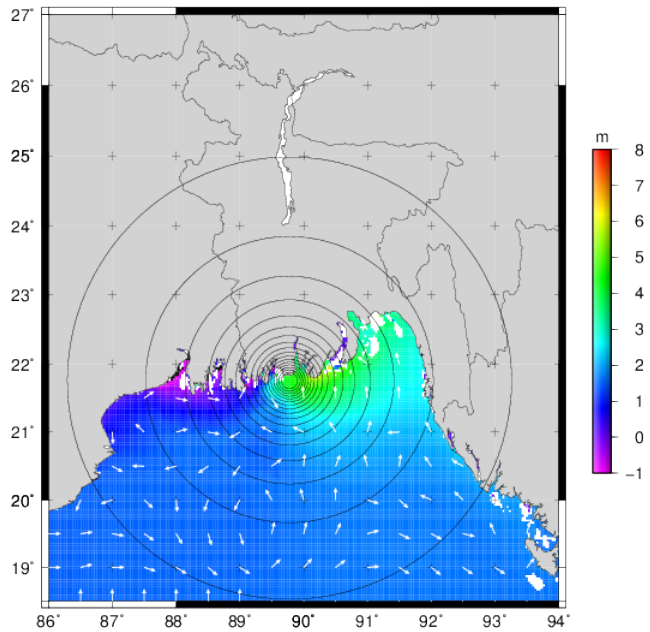
Model (old version) computed maximum storm surge (m) generated by SCS "SIDR" using Unisys data

Results: Simulation of Historical Storm Surge Events

- For Unisys data the CIF model simulated highest maximum storm surge about 5m was found towards the right side of the landfall point

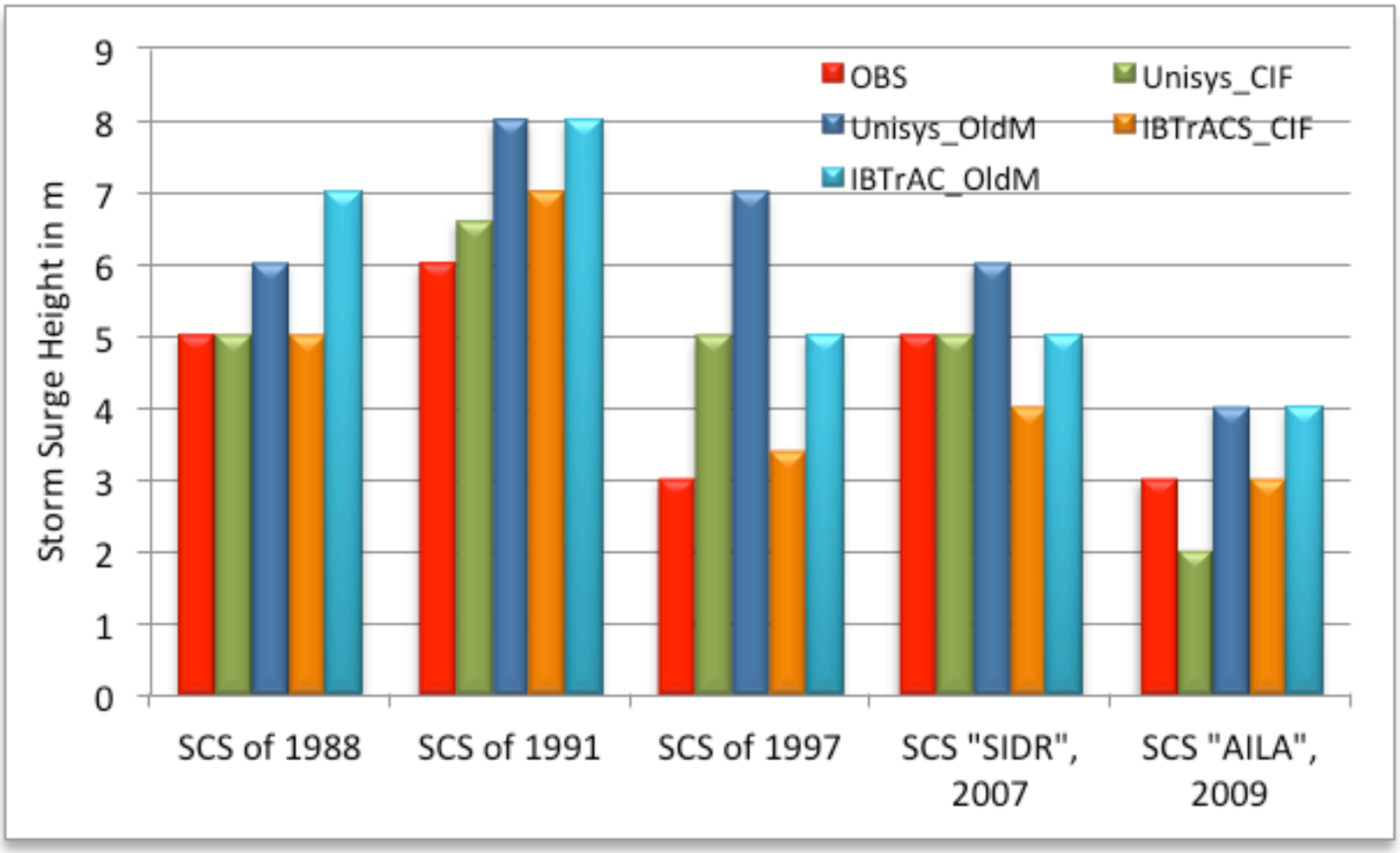


Model (CIF) computed peak surge (m) generated by SCS "SIDR" using Unisys data

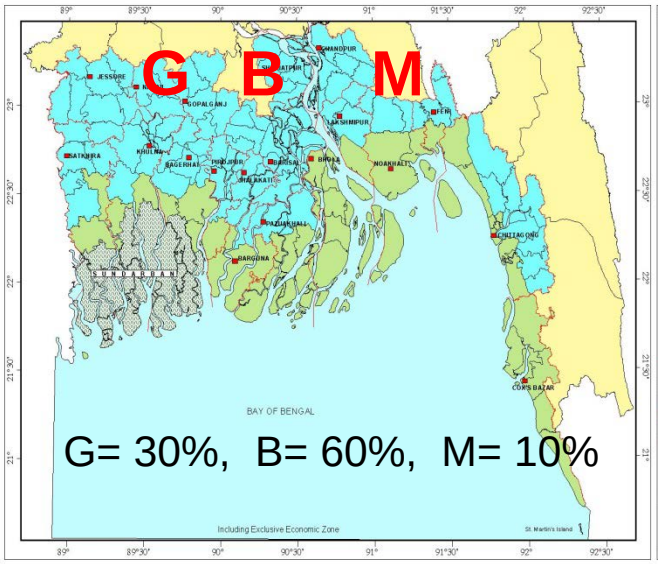


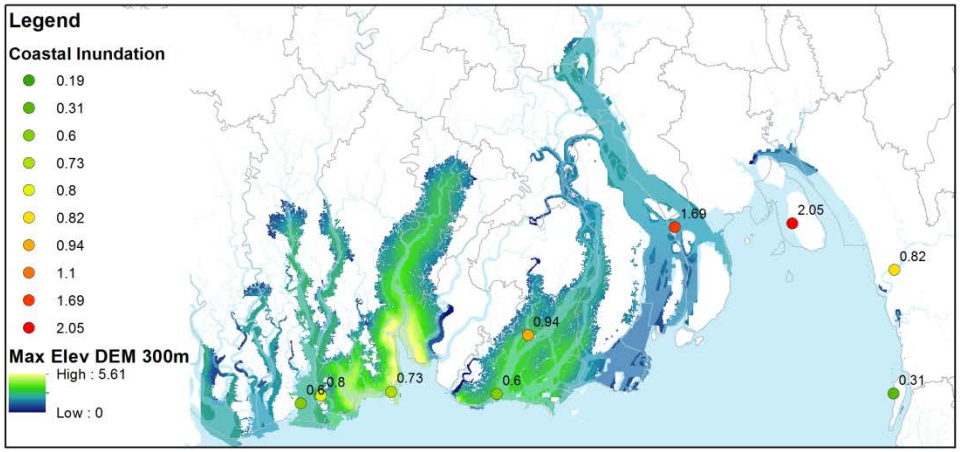
Model (old version) computed peak surge (m) generated by SCS "SIDR" using Unisys data

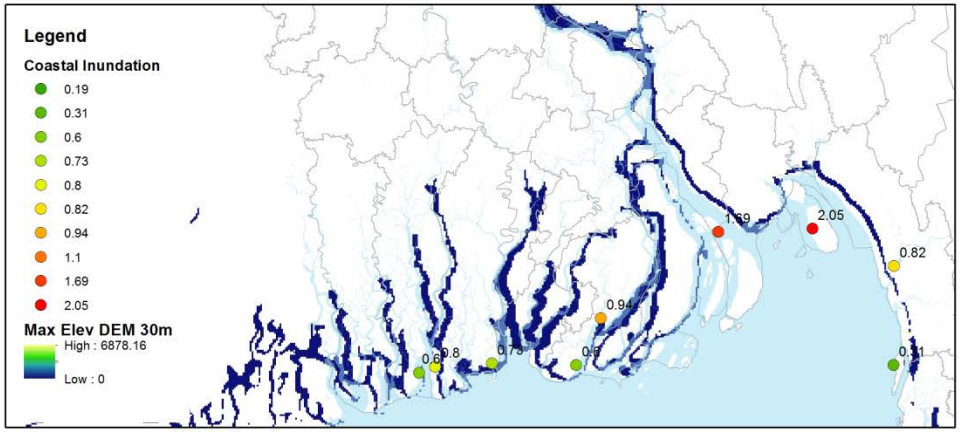
Results: Simulation of Historical Storm Surge Events

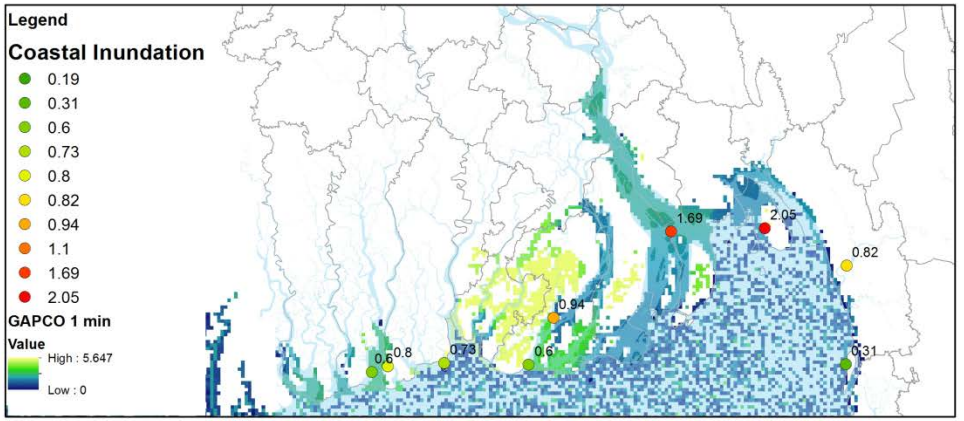


Results: Simulation of Coastal Inundation- LISFLOOD- FP





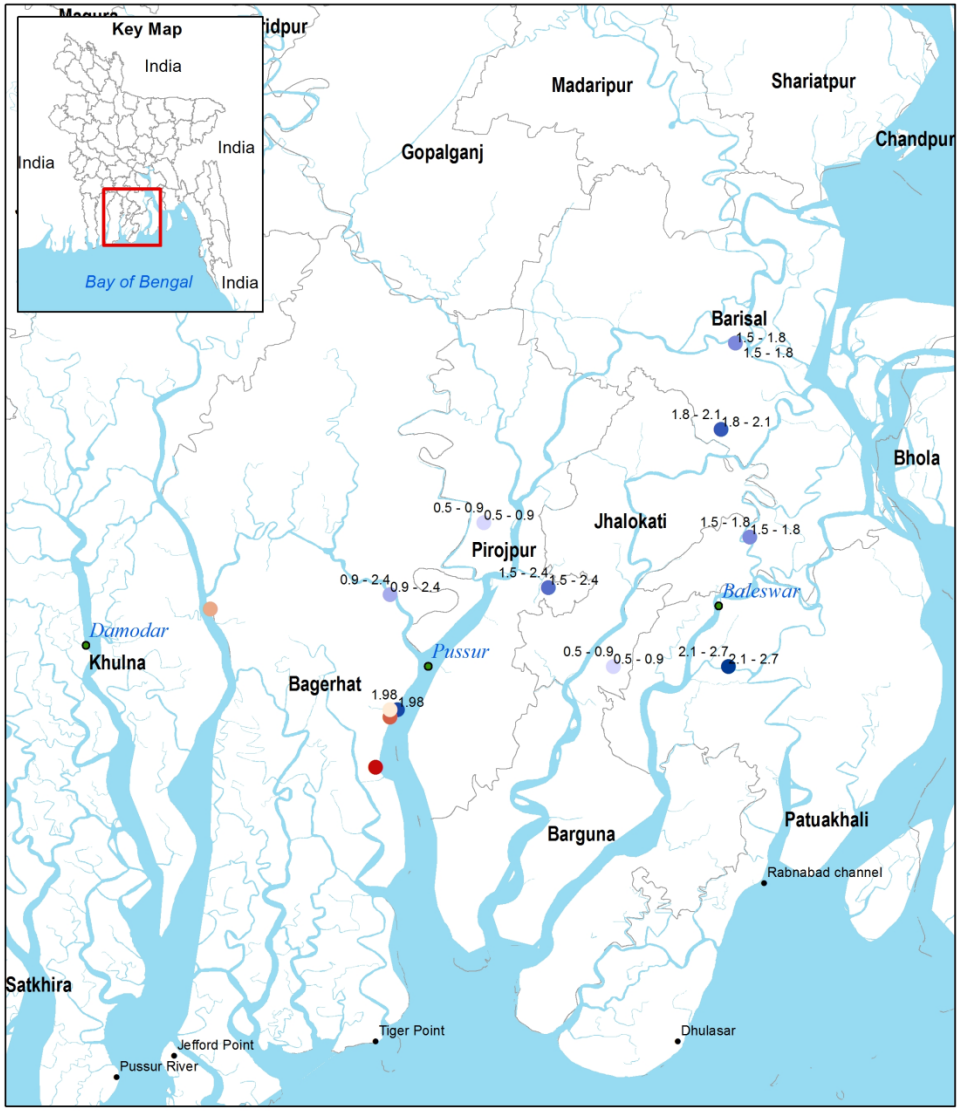




Results: Simulation of Coastal Inundation- LISFLOOD- FP

- Hydraulic geometry theory cannot be used to estimate estuarine bathymetry because different processes are involved in estuaries compared to rivers
- Bathymetry of estuaries in Bay of Bengal region is complex due to annual and inter-annual variability of sedimentation rates (see Ali et al., 2007).
- Missing bathymetry data within the DEM were assumed to be within the range 0 to 9m, and adjusted during model calibration
- Manning's values were assumed to be spatially constant and to vary between 0.018 and 0.28 during estuary depth calibration

Flood Height and Water Depth



Legend

Flood Height(m)	Water Depth(m)	
1.97	0.5 - 0.9	1.8 - 2.1
3	0.9 - 2.4	1.98
5	1.5 - 1.8	2.1 - 2.7
6.47	1.5 - 2.4	Rivers/Sea
		District Boundary

Map History

Projection System: WGS84

Data Source:

Field Survey, 2015
Open Street Map, 2015

N

0 5 10 20 km

Coastal Inundation Locations

Legend

HW (m rel. MSL)		
0.19	0.8	2.05
0.31	0.82	Rivers/Sea
0.6	0.94	District Boundary
0.73	1.1	
	1.69	

Map History

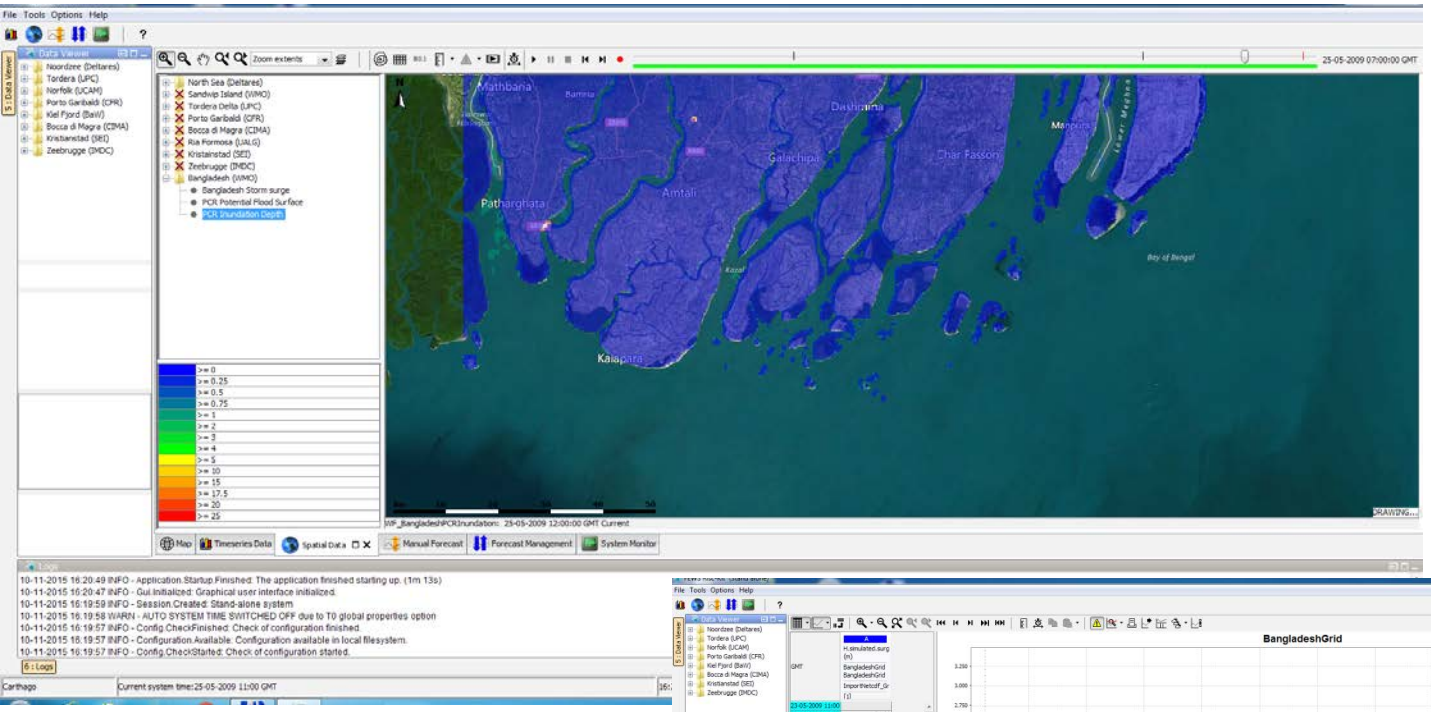
Projection System: WGS84

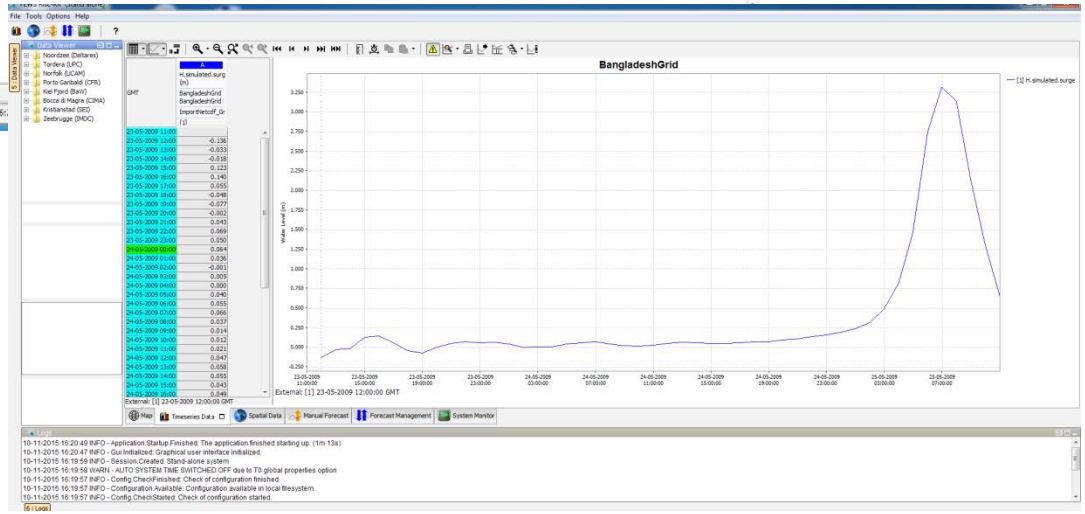
Data Source:

Field Survey, 2015
Open Street Map, 2015

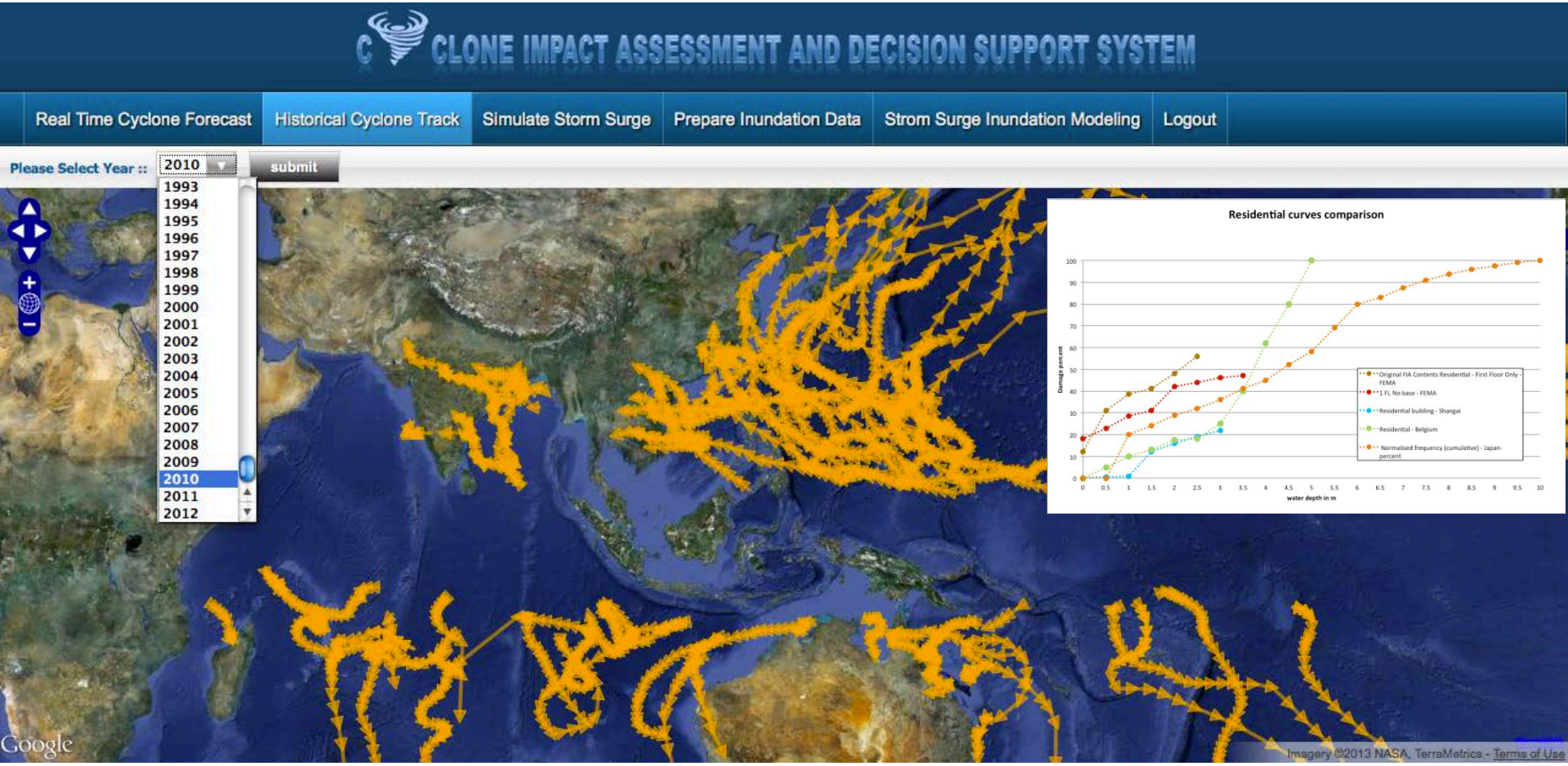
Lewis, et al, 2013

Results: Simulation of Coastal Inundation- FEWS





Pre-Impact assessment tool development and capacity building



Conclusion

- Simulated storm surge uncertainty is known to be high in the Bay of Bengal due to uncertainty within observed cyclone parameters.
- The difference between storm tide scenarios was 1m; hence forcing water-level uncertainty was found to be of the same order of magnitude as the inundation model error.
- For operational forecasting view point this error acceptable
- Risk modeling is critical to operationalize the science application for societal benefits.
- Pre-impact assessment/damage modeling would assist save life and property damages.