Storm Surge Warning System at ESSO-INCOIS

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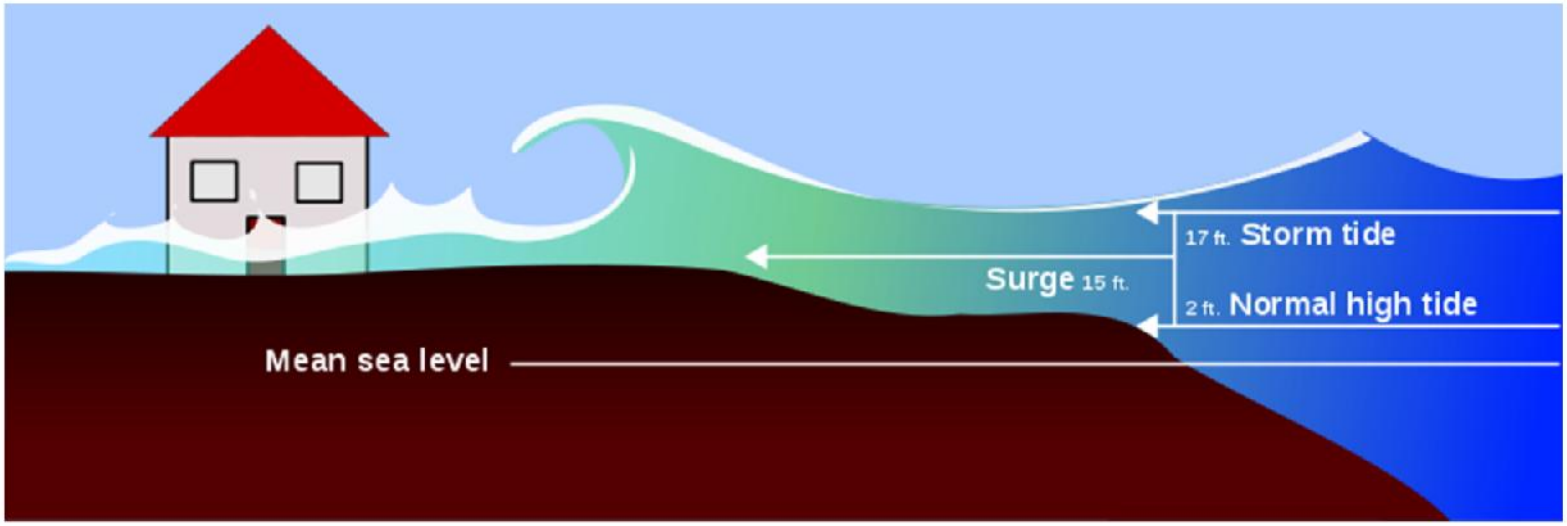
Storm surge is an abnormal raise in sea level at the coast due to a high winds of a tropical storm.

How it all piles up the water:

- *Low pressure system (storm)* generates wind
- Wind blows across the sea surface
- Friction between the wind and water pushes the water in the direction of wind
- Tides caused by the gravity of the sun and moon contribute to the rise in ocean surface
- The sea level starts to pile up along the coastline due to approaching storm.



"Piling up of water at the coast"

Factors contributing storm surge:

- Wind – Usually associated with a tropical storm
  speed , direction, angle of approach to the coast
- Storm forward speed

Strong wind + large fetch + long time + track perpendicular to the coast = Highest surge

where,

Fetch – The distance over which the wind interacts with the surface of the ocean

Time – The length of time wind blows over an area of the ocean

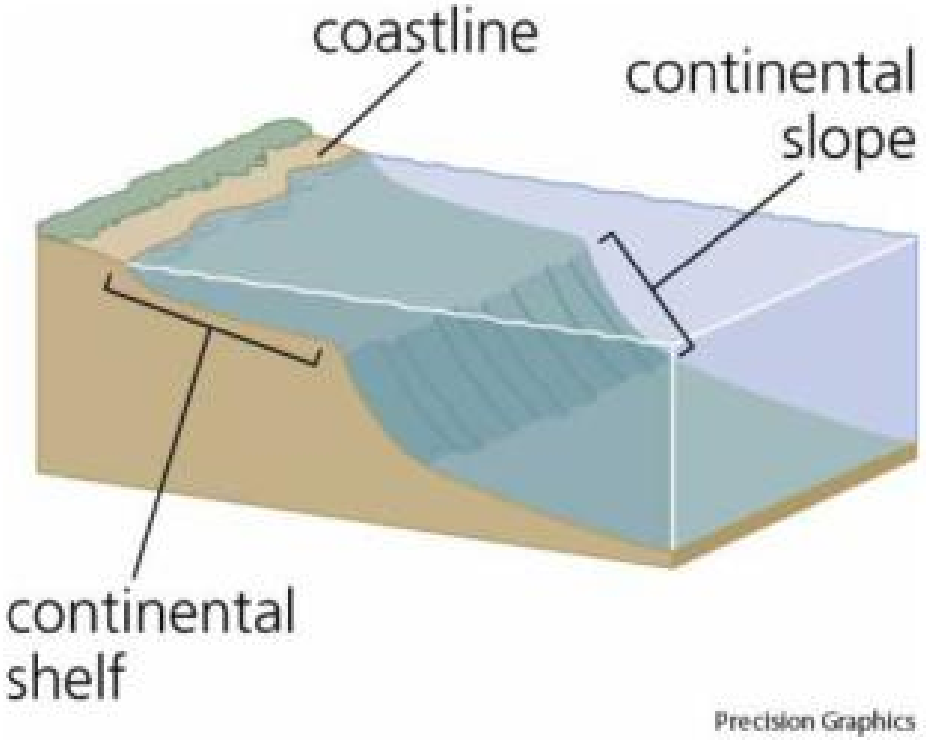
- Low storm pressure over the ocean
- Tides – phase of the tides contribute to stc $\Delta\eta = -\Delta p/\varrho g$
- Slope and width of the continental shelf
  - wide, shallow shelves are prone to larger storm surges.

$$\eta = \frac{\tau_s}{\varrho g h} L$$

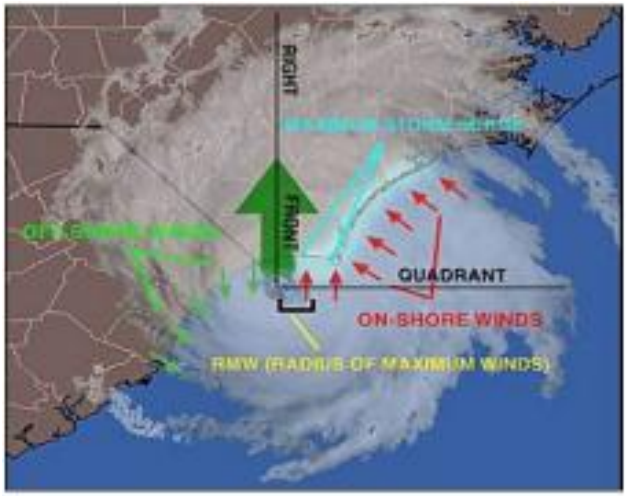
Factors contributing storm surge:

- Coastal geometry:

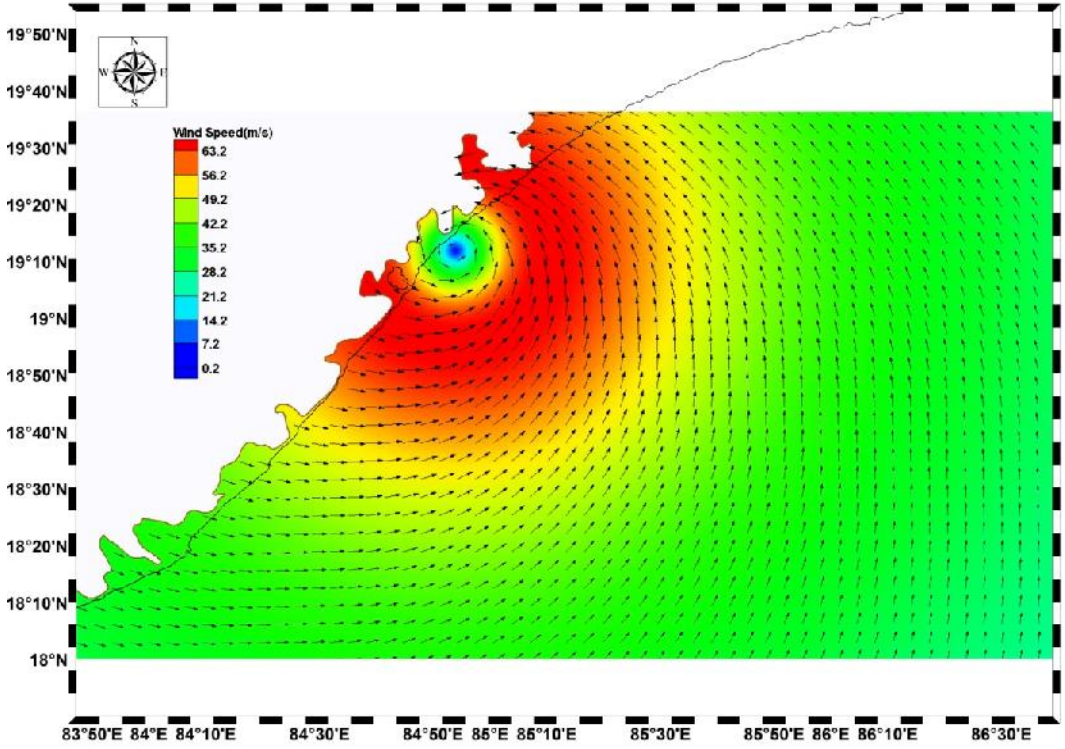
Storm surge is much depend on the shape of the coast line.



“Storm surge occurs in right-front quadrant”



In general, storm surge occurs around the coastal region experiences onshore winds. The highest surge tends to occur near the “radius of maximum winds,” or where the strongest winds of the hurricane occur.



Why modeling storm surges?

Storm surge impacts can be devastating to life and property

A cubic yard of water weighs about 1,700 pounds

Models are an economically feasible virtual laboratory to assist in coastal planning

"Forecasting storm surge and coastal flooding is vital to protecting lives"

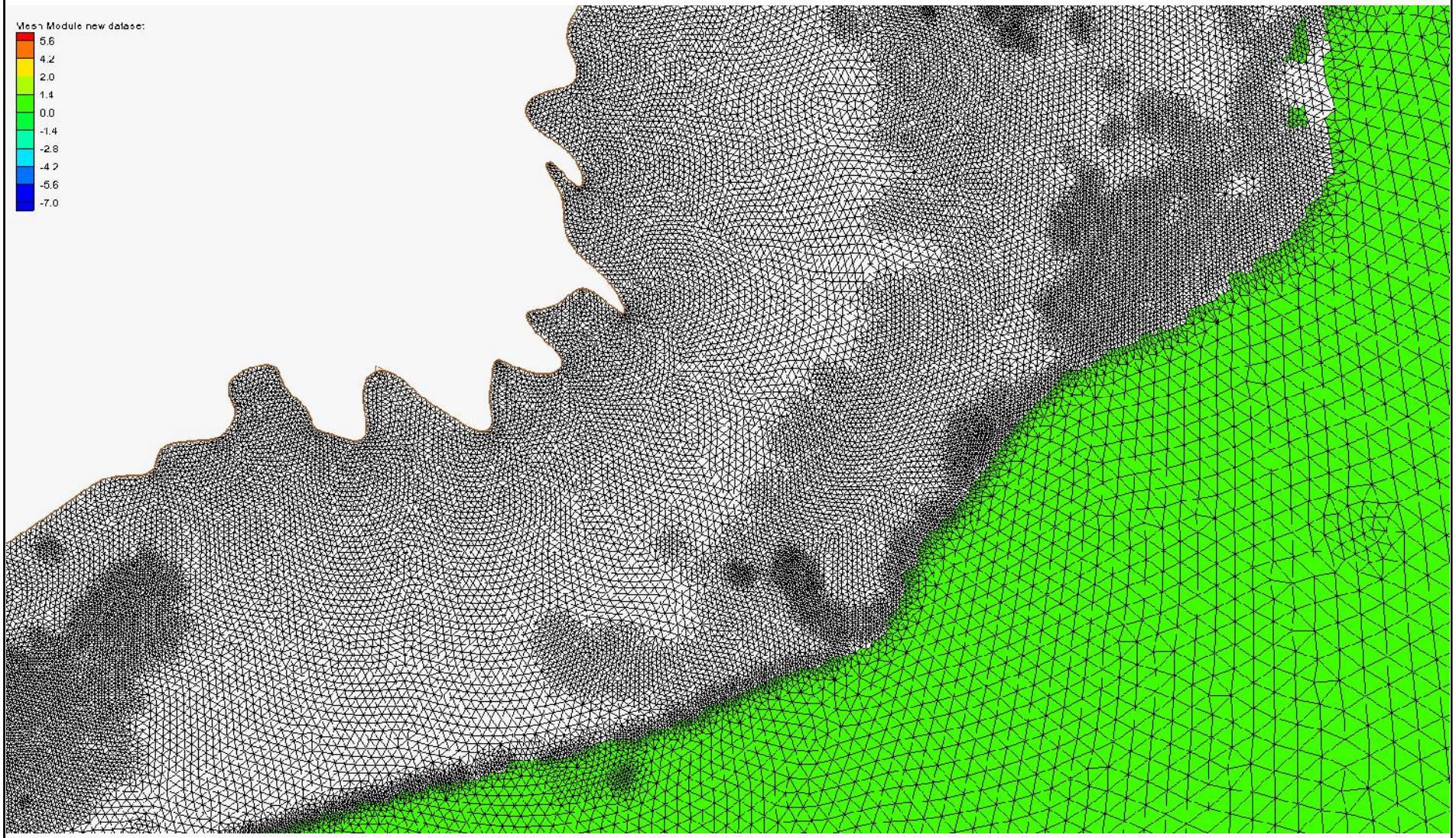
What is coastal inundation?

Coastal inundation is the flooding of normally dry, low-lying coastal land, primarily caused by severe weather events along the coasts, estuaries, and adjoining rivers.

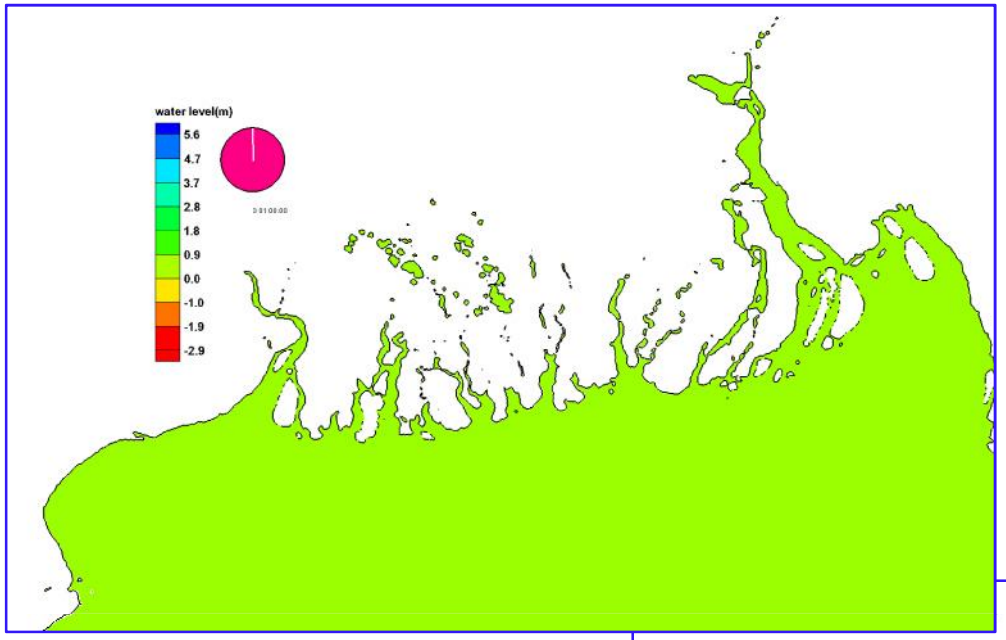
What areas are vulnerable to coastal inundation?

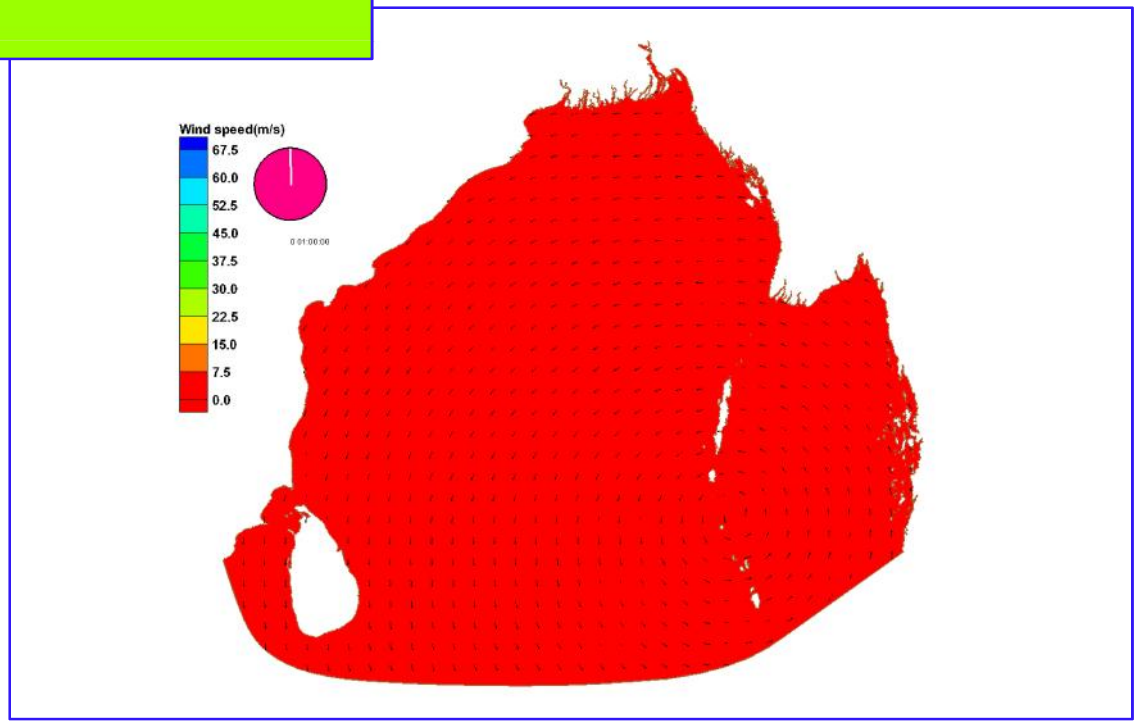
All low-lying coastal regions, which can cover tens of miles inland, are vulnerable to flooding from storms, and the impact can be substantial.

Model simulated inland inundation due to Orissa Super Cyclone

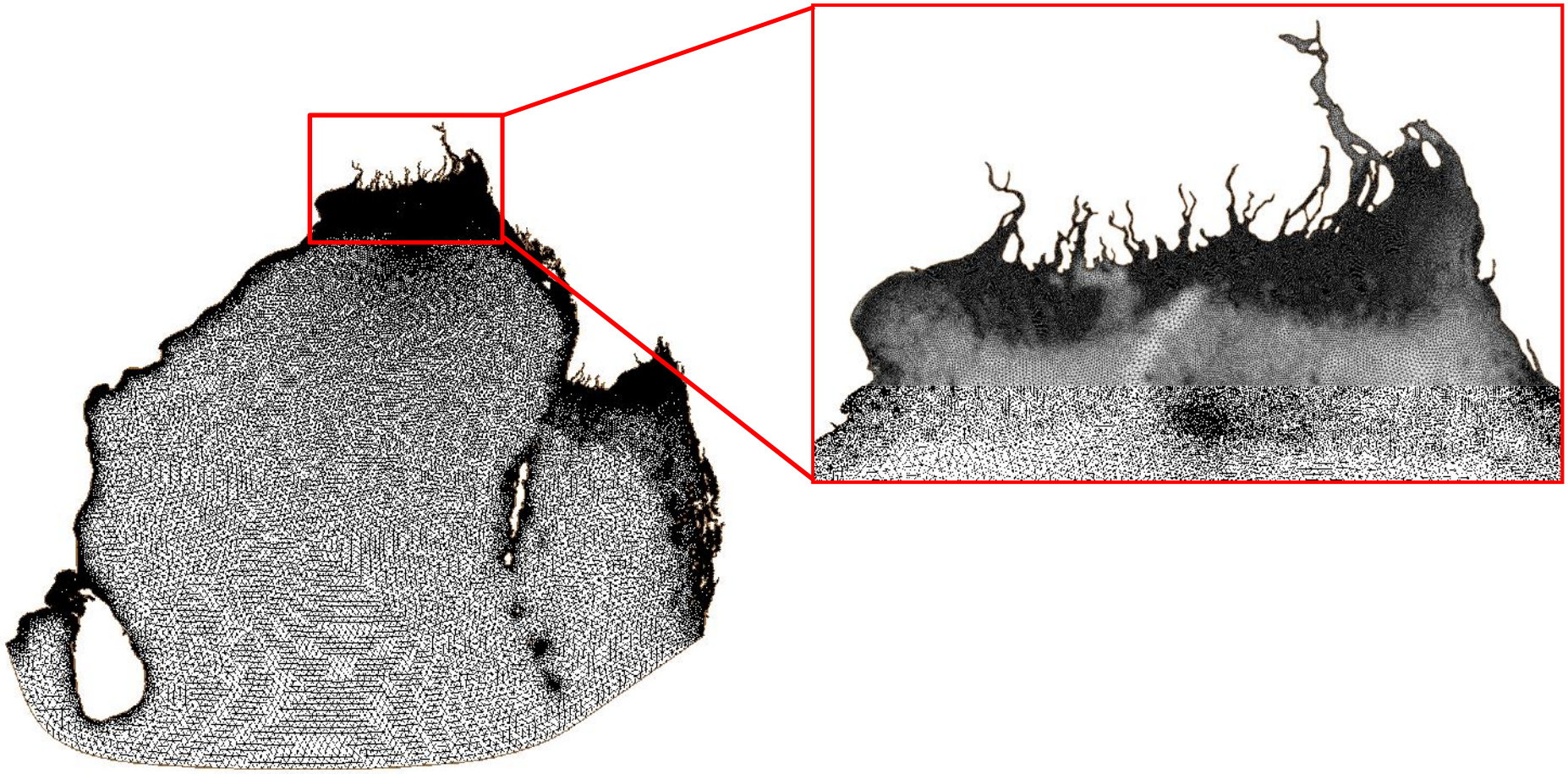


Model simulated inland inundation due to Cyclone 'Sidr' 2007

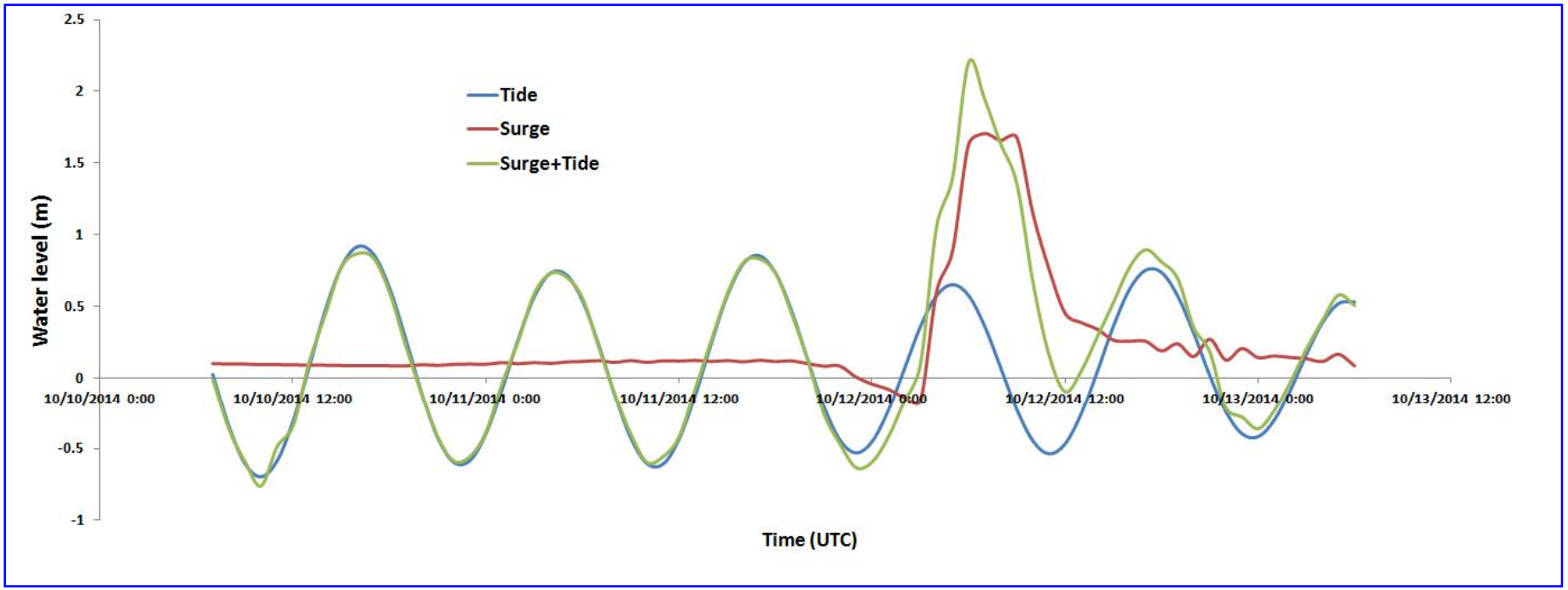




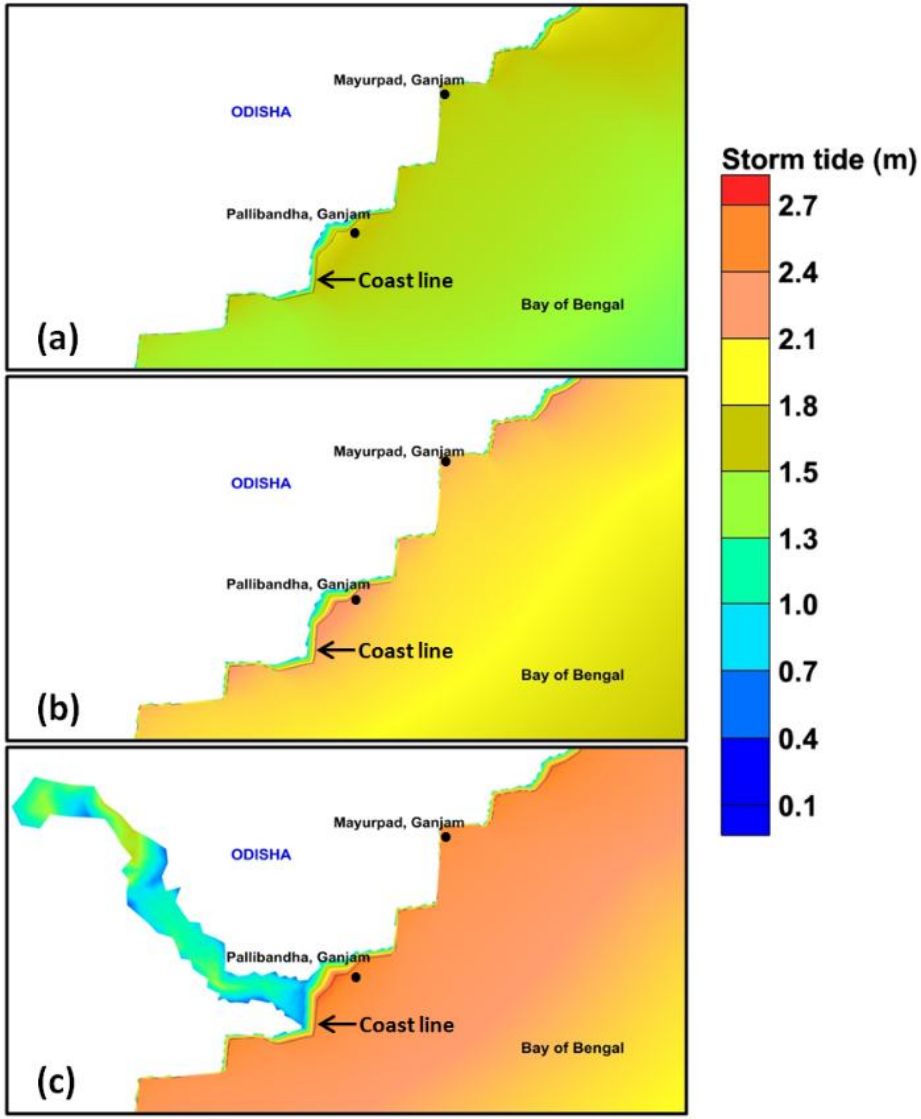
Unstructured triangular gridded mesh



Importance of tide inclusion in simulating surge heights

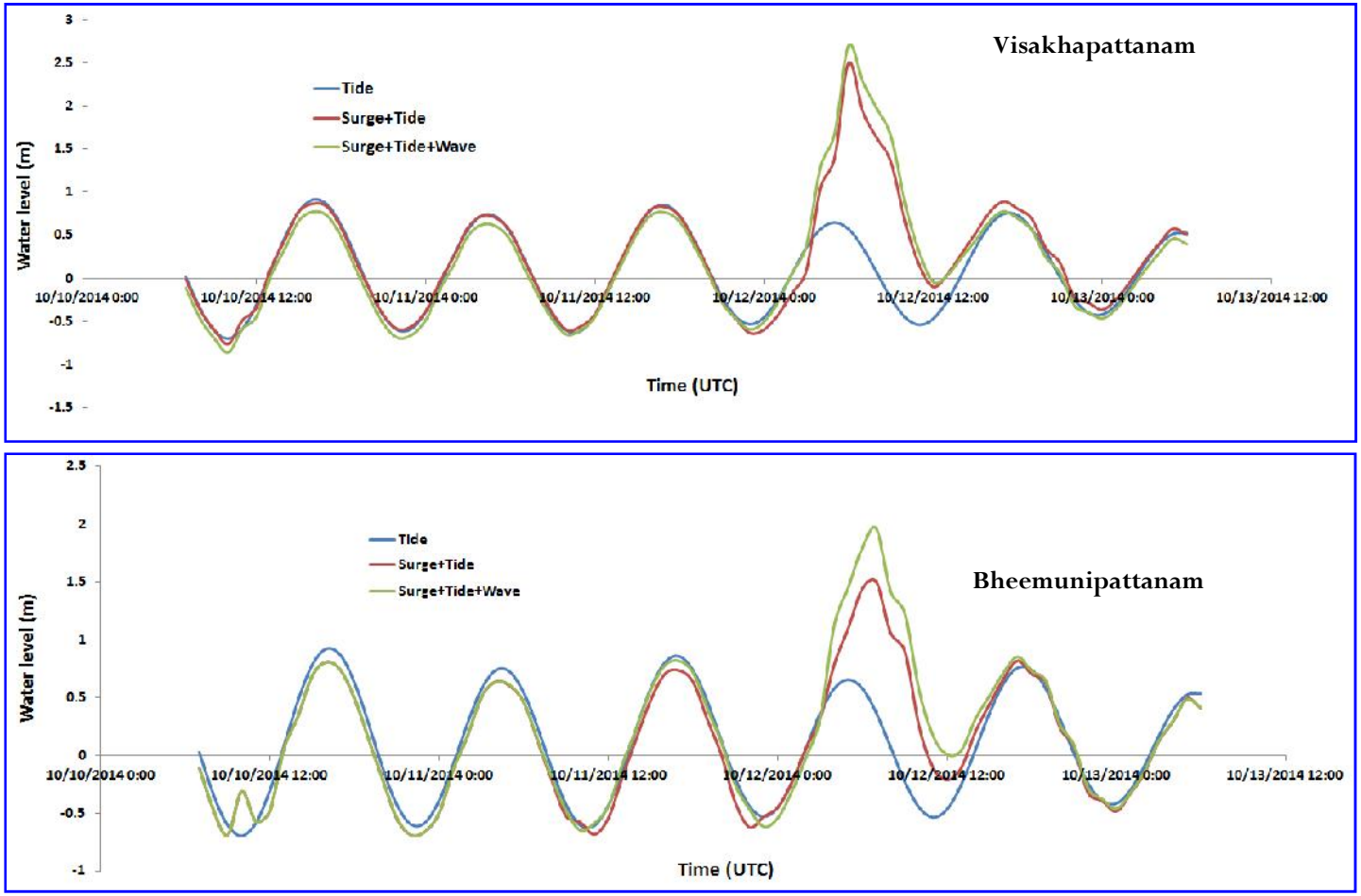


Importance of tidal phase in altering surge height and its associated inland inundation. (image taken from the case study of 'Phailin')



Spatial depiction of inundation extent (a) with cyclone had its landfall by 3 hours prior to the actual time of landfall, (b) with actual time of landfall, (c) with cyclone had its landfall by 3 hours after the actual time of landfall.

Importance of wave inclusion in simulating surge heights

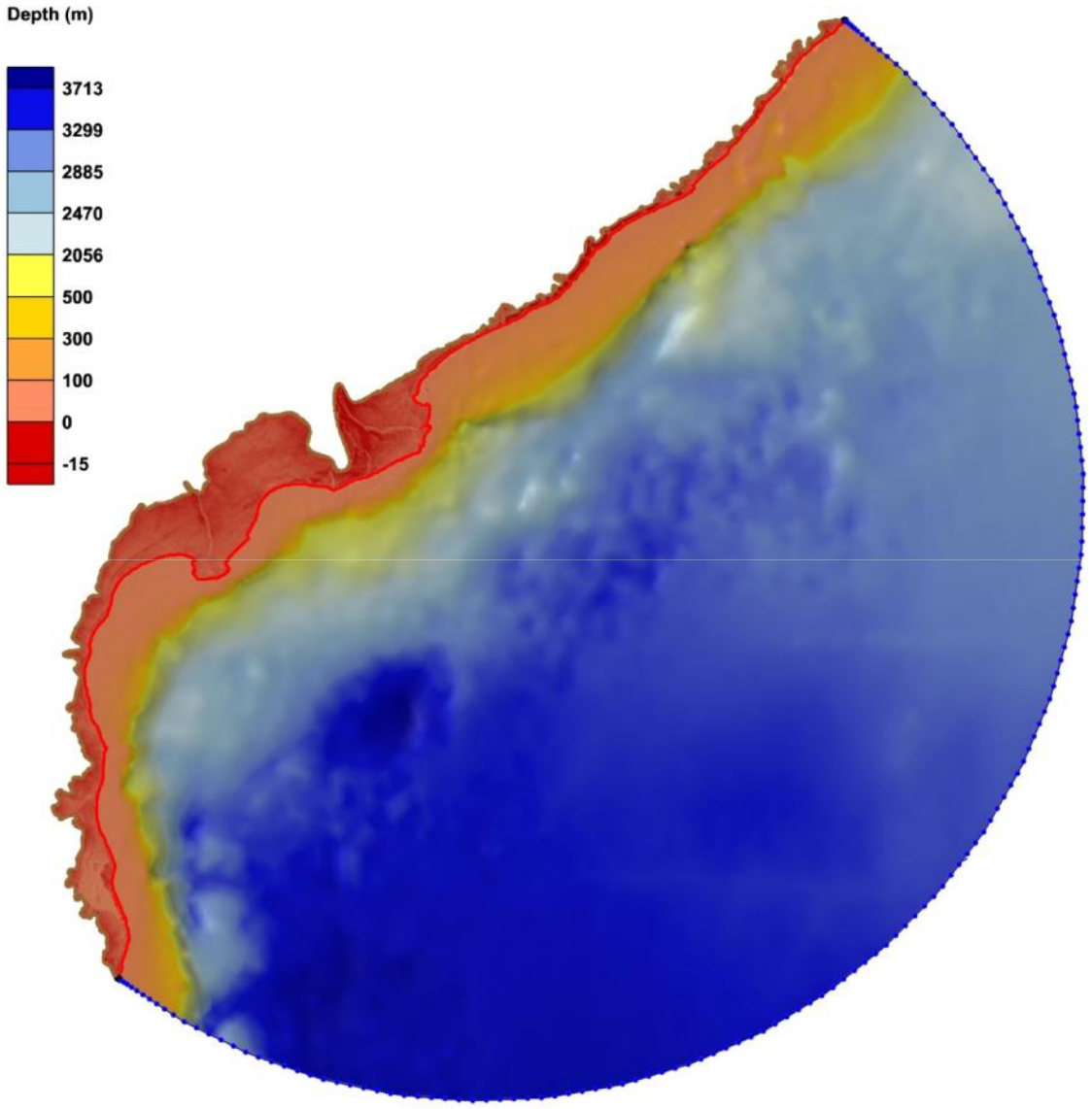


- Wave effect may differ from location to location.
- Effect is more where the shelf steepness is less.
- Inundation computations with and without wave inclusion would show large difference.

Requirements for an efficient warning system:

- High resolution bathymetry/topography data.
- Efficient storm surge model (preferably FEM)
- High resolution model for generating wind and pressure fields (forcing to surge model).
- Efficient tool for developing model grid (preferably unstructured).
- Efficient and automated Decision Support System (DSS) for mapping of results and disseminating through various communicating modes.

Mesh generation



Storm Surge Warning System at ESSO-INCOIS

The Mission of INCOIS

To provide the Ocean Information and Advisory Services to Society, Industry, Government Agencies and Scientific Community through Sustained Ocean Observations and Constant improvements through Systematic and Focussed Research.

Storm surge model:

ADCIRC – ADCIRC is a shallow water hydrodynamic finite element based storm surge model

The development of ADCIRC was a joint effort between US Army Corps of Engineers, University of North Carolina and University of Notre Dame (Luettich et al., 1992; Luettich and Westerink, 1991; Westerink and Luettich, 1991; Westerink and Gray, 1991)

ADCIRC applications include modeling tides, seiches and storm surges and their associated inland inundation.

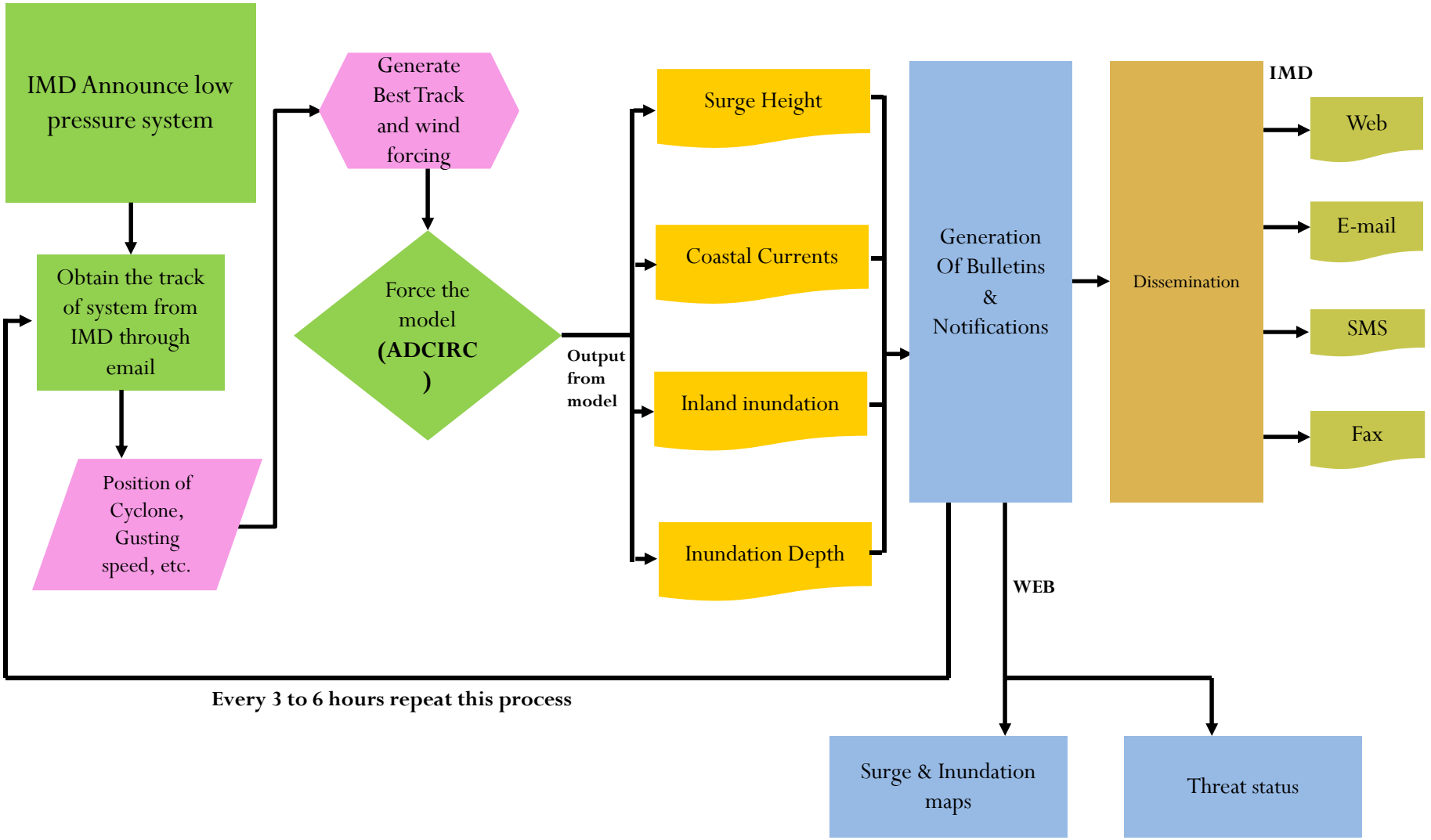
Additional capabilities - wetting and drying algorithm to study inland penetration of water from storm surge

FEMA (Federal Emergency Management Agency) in 2002 accepted the robustness of ADCIRC

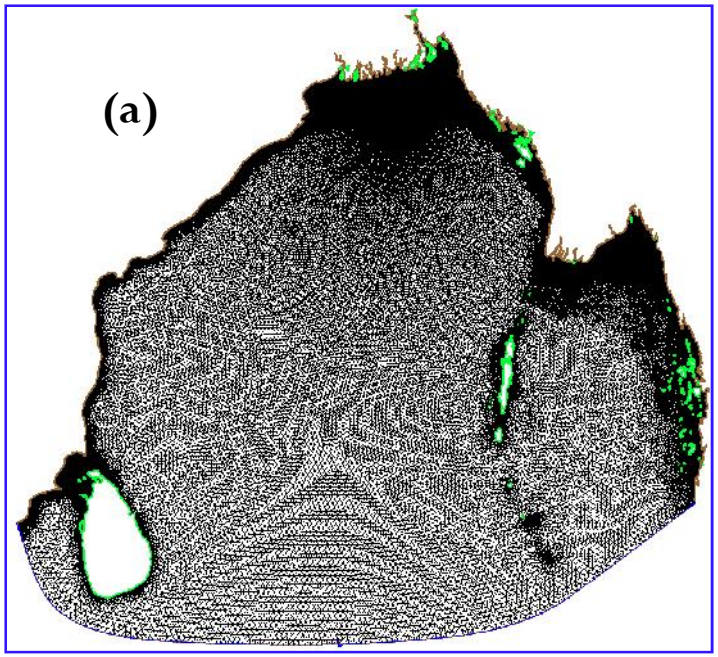
High Performance Computing (HPC) System :

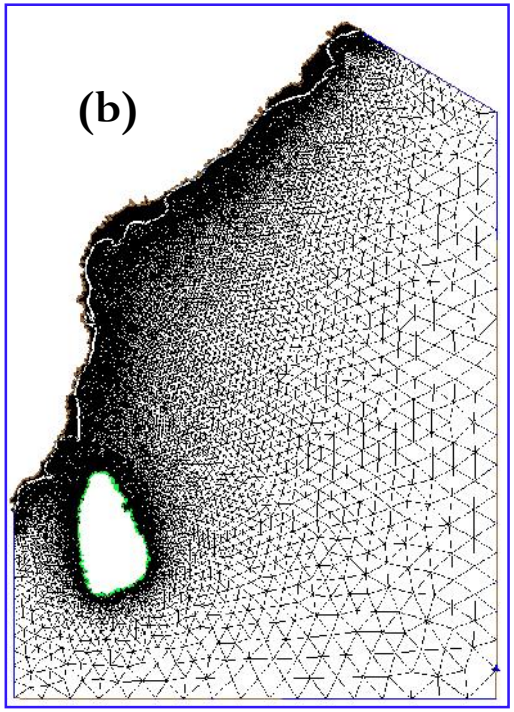
Hardware : IBM p 575
Processor : Power 6
Clock Speed : 4.7Ghz
No of Processors of each node : 32 (Dual Core)= 64
Total no of Nodes : 14 nodes
Total Peak Performance of HPC at INCOIS : 7.2 Flops
Storage : ~ 100TB
Operating System : AIX 5.3
Job Scheduler : Load Leveler (Job queuing system)

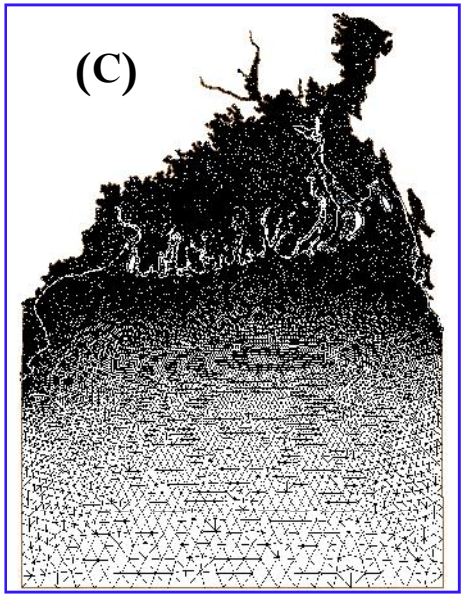
Storm Surge Warning SOP Flow Chart

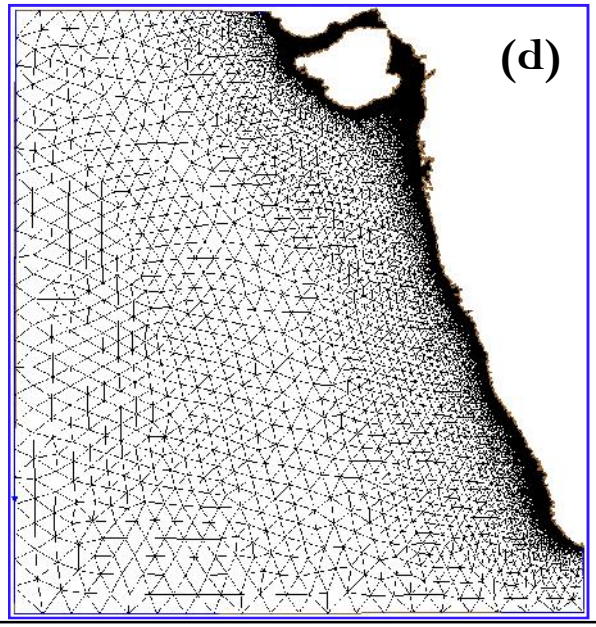


Model grids









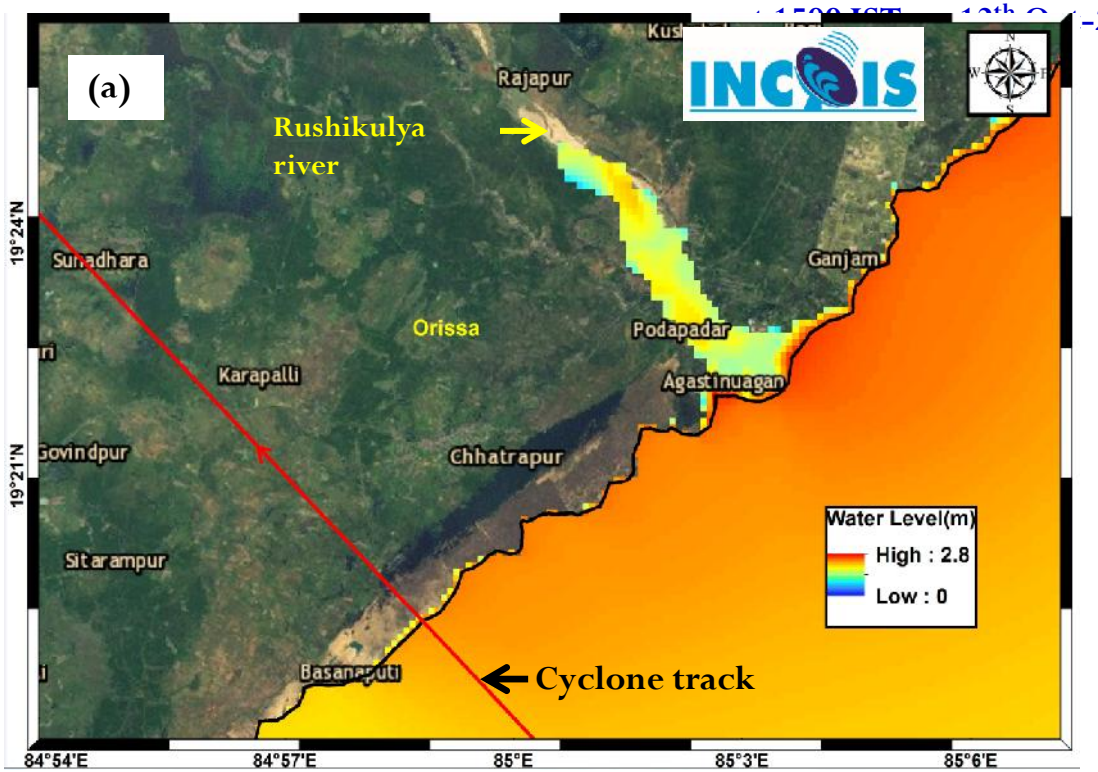
- **Model grid for BOB region (fig.a) for simulation of surges alone**
- **East coast is divided into two domains (fig.b, c) for the simulation of inundation due to surges.**
- **Model grid for the west coast of India for the simulation of inundation due to surges.**

Experimental storm surge forecast for 'Phailin' October, 2013

Real Time Simulation of Cyclone PHAILIN at INCOIS

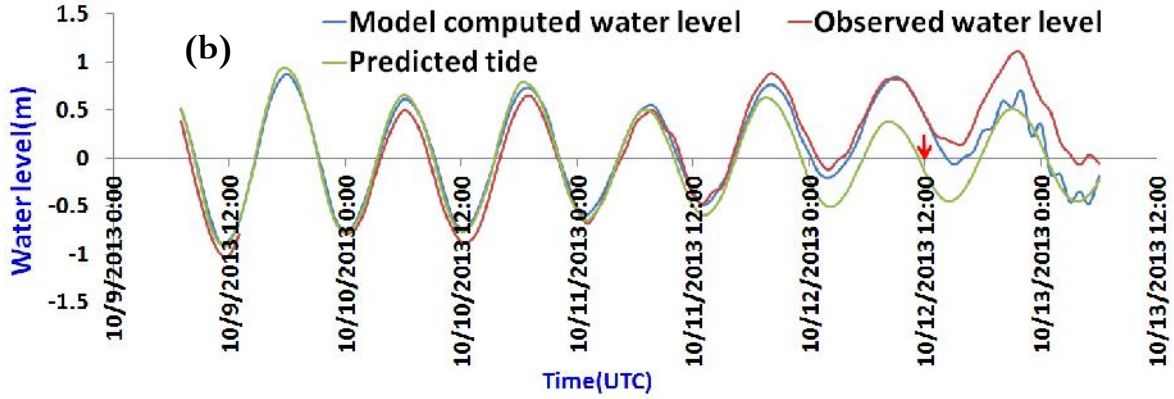
FORECAST SUMMARY	
First Simulation	0530 IST of 09-10-2013
Last Simulation	0130 IST of 13-10-2013
Number of Computational Grid Points in the Inundation Model Domain	0.5 Million
Model Integration	4.5 Days
Time Taken for Each Simulation on HPC	45 Minutes using 256 Processors
Total number of bulletins issued	12
Maximum surge simulated for the entire duration of the event	2.6m near Ganjam, Orissa based on track forecast issued by IMD at 1500 IST of 12th October
Maximum inundation extent simulated for the entire duration of the event	3km through river near Ganjam, Orissa based on track forecast issued by IMD at 1500 IST of 12th October

Storm Surge Model simulated water levels and inland inundation using forecasted track issued by IMD



Coastal locations of Odisha	Model computed inland extent of inundation from coast line (m)	Observed inland extent of inundation from coast line based on field measurement(m)
Dhepanuapada	-	23
Lohadigam	130	35
Humirbana	100	101
Humirbana	100	115
Podapadar	120	106
Ganjam	180	173
Ganjam	150	110
Ganjam	400	670
Mayarpada	200	160
Jayamangalhil	150	65
Bhramarakudi, Ganjam	-	35
Bhramarakudi, Ganjam	-	44

Table: Comparison of model simulated inland inundation (based on observed track) with field observations

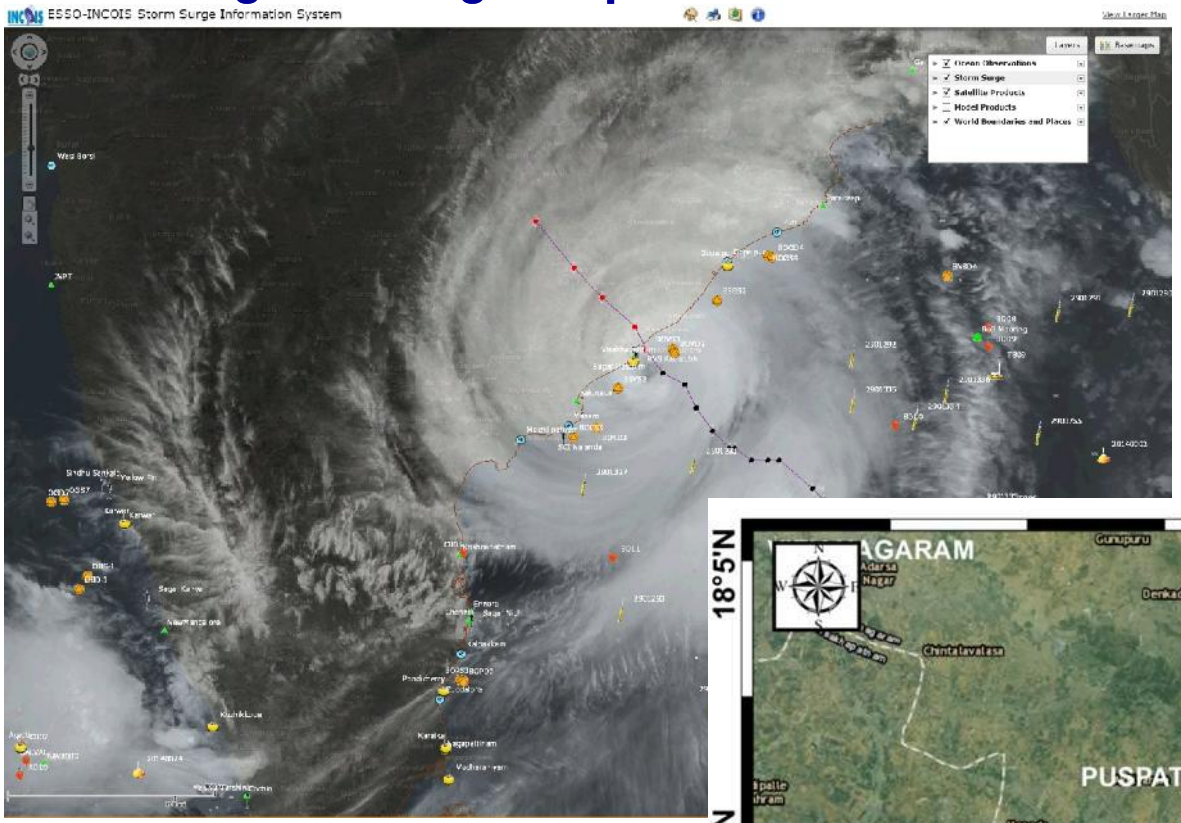


(a) Model estimated water levels and inundation extent using forecasted track (Precipitation is not included in the model)
(b) Comparison of model simulated water level to that of observed at Paradeep tide gauge (nearest tide gauge available from the landfall point)

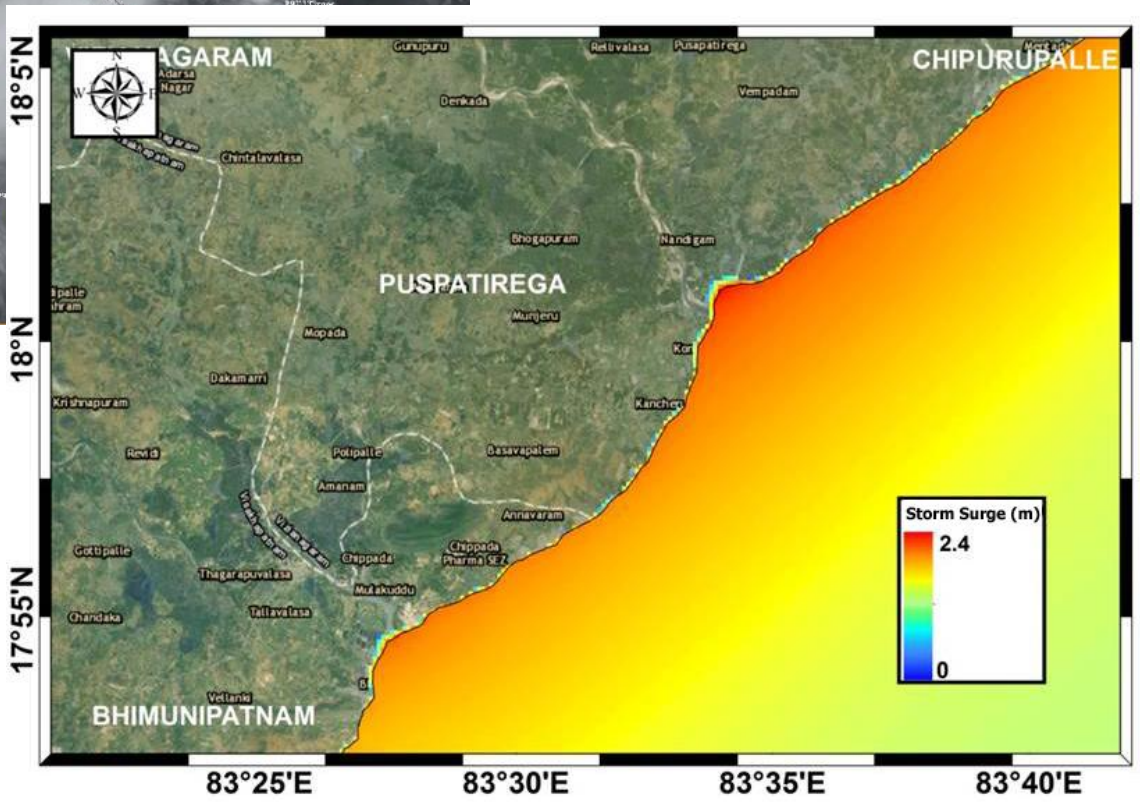
Experimental storm surge forecast for 'Hudhud' October, 2014

FORECAST SUMMARY	
First Simulation	0530 IST of 08-10-2014
Last Simulation	1730 IST of 12-10-2014
Number of Computational Grid Points in the Inundation Model Domain	0.5 Million
Model Integration	5 Days
Time Taken for Each Simulation on HPC	45 Minutes using 256 Processors
Total number of bulletins issued	29
Maximum surge simulated for the entire duration of the event	2.4m near Pedanagayyapalem, Puspatirega mandal, Andhra Pradesh based on track forecast issued by IMD at 1430 IST of 11th October
Maximum inundation extent simulated for the entire duration of the event	400 m near Pedanagayyapalem, Puspatirega mandal, Andhra Pradesh

Storm surge warnings – Operational forecasts for Hudhud

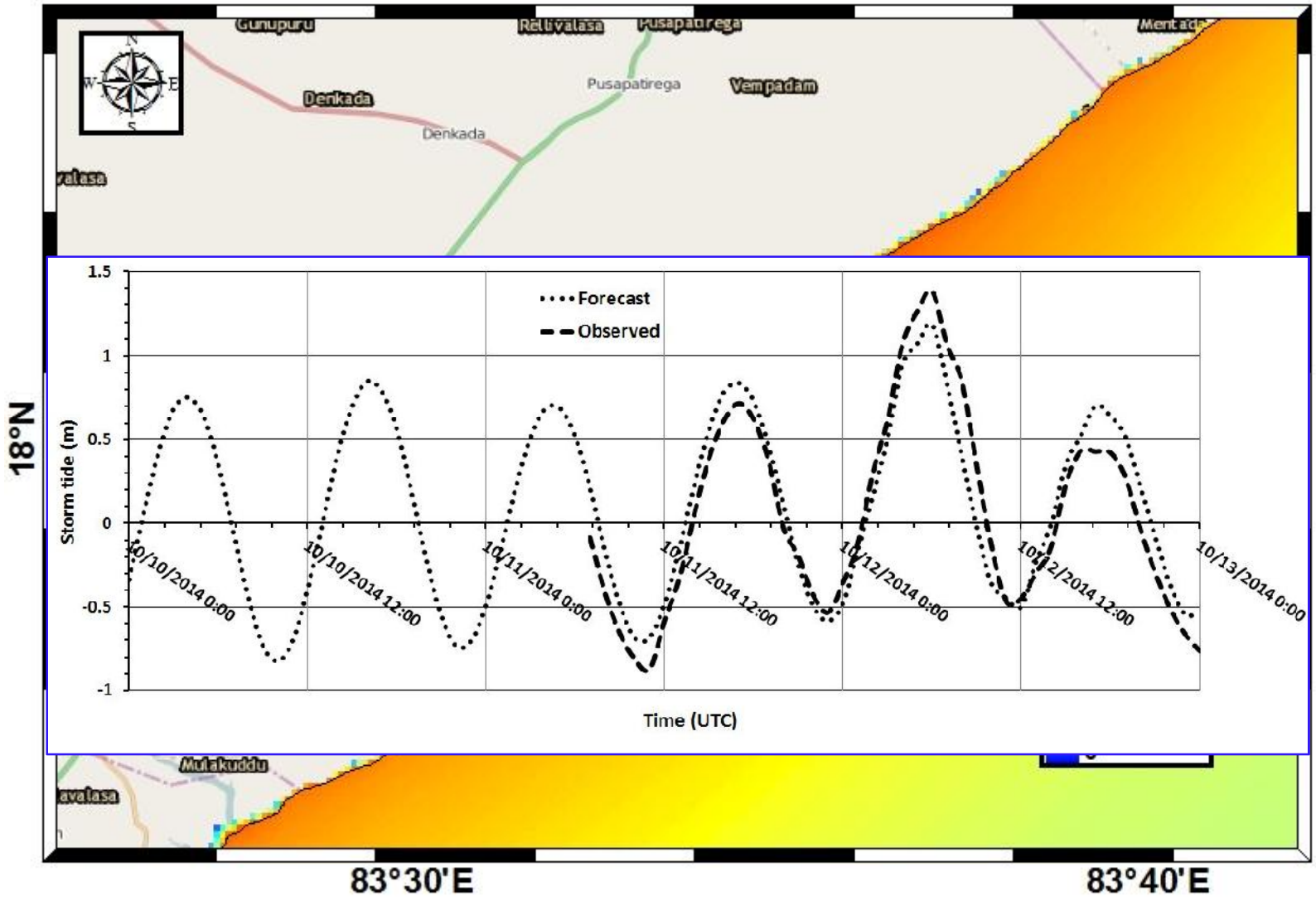


1130 hrs IST on 12 Oct 2014



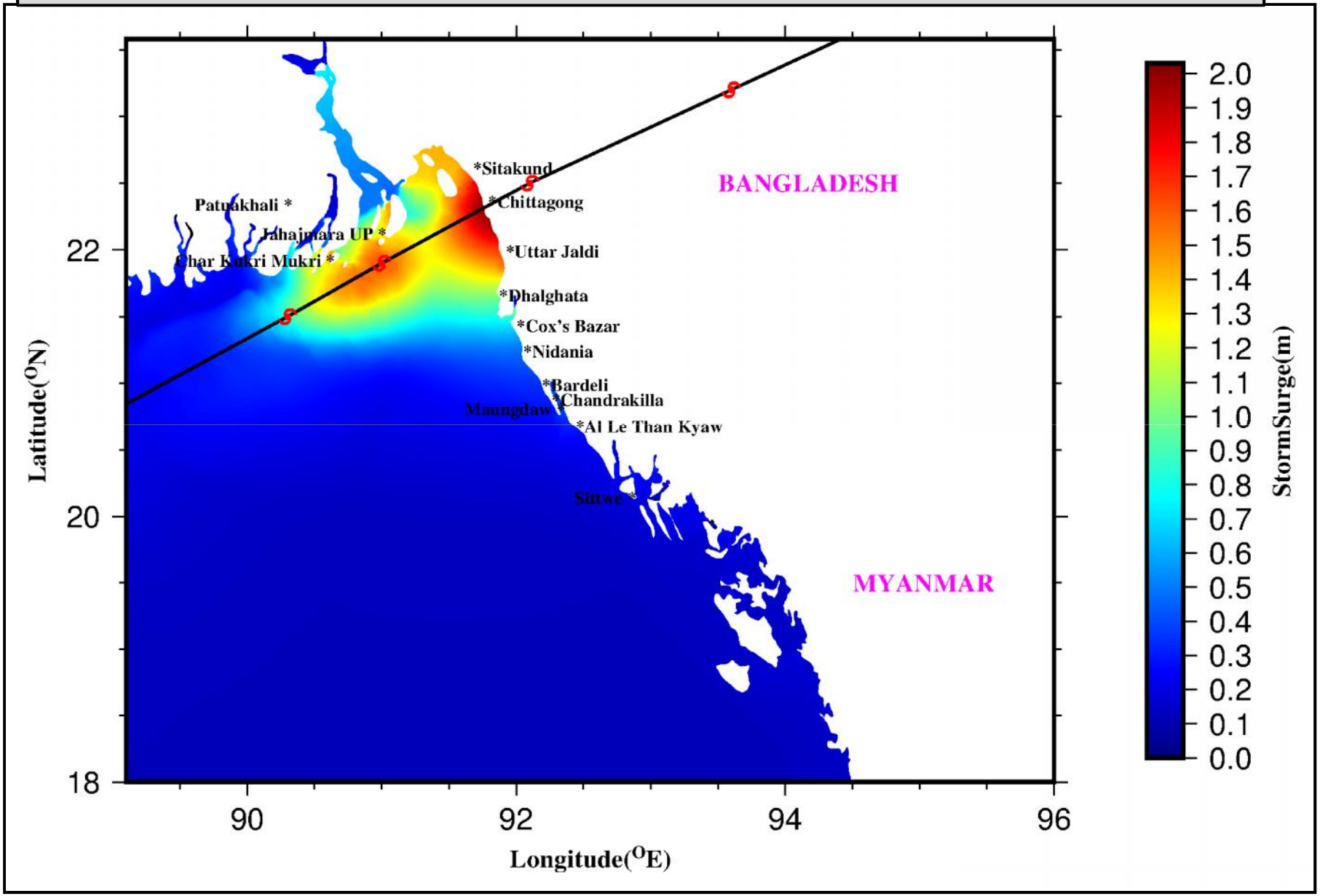
Satellite Product: METOP-A (AVHRR) Source: INCOIS Ground Station

Real time storm surge warning for the very severe cyclonic storm 'Hudhud'



Place	Mandal	District, State	Inundation extent	
			Forecasted (m)	Observed (m)
Konada	Puspatirega	Vijayanagaram, AP	300	400
Kollayavalasa	Puspatirega	Vijayanagaram, AP	100	90
Pathiwada	Puspatirega	Vijayanagaram, AP	200	150
Kancheru	Puspatirega	Vijayanagaram, AP	160	150
Pedanagayyapalem	Bhimunipattanam	Visakhapattanam, AP	100	50
Chintapalle	Puspatirega	Vijayanagaram, AP	200	80
Mentada	Chipurupalle	Srikakulam, AP	150	110
Kancherupalem	Puspatirega	Vijayanagaram, AP	nil	nil
Ramachandrapuram	Chipurupalle	Srikakulam, AP	180	120
Nerellavalasa Rural	Bhimunipattanam	Visakhapattanam, AP	nil	60
Kothuru	Bhimunipattanam	Visakhapattanam, AP	100	70
Kolli Bheemavaram	Chipurupalle	Srikakulam, AP	140	140
Rishikonda beach	Bhimunipattanam	Visakhapattanam, AP	nil	60
Thimmapuram	Bhimunipattanam	Visakhapattanam, AP	100	100
Kottapalem	Chipurupalle	Srikakulam, AP	150	160
Yethapeta	Chipurupalle	Srikakulam, AP	100	80
Atchanna Agraharam	Chipurupalle	Srikakulam, AP	nil	60
Bontalakoduru	Srikakulam	Srikakulam, AP	150	190
MVP Colony	Visakhapattanam	Visakhapattanam	nil	20
Rama Krishna Beach	Visakhapattanam	Visakhapattanam	nil	50
Galla Peta	Srikakulam	Srikakulam, AP	200	150
Pathiwada	Puspatirega	Vijayanagaram, AP	200	180
Kuppili	Chipurupalle	Srikakulam, AP	200	180
Tekkali	Chipurupalle	Srikakulam, AP	100	100

Storm surge forecast for the recent cyclone 'Roanu'



http://www.incois.gov.in/portal/stormsurge

Thank You