Storm Surges

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ESSO-INCOIS

Outline

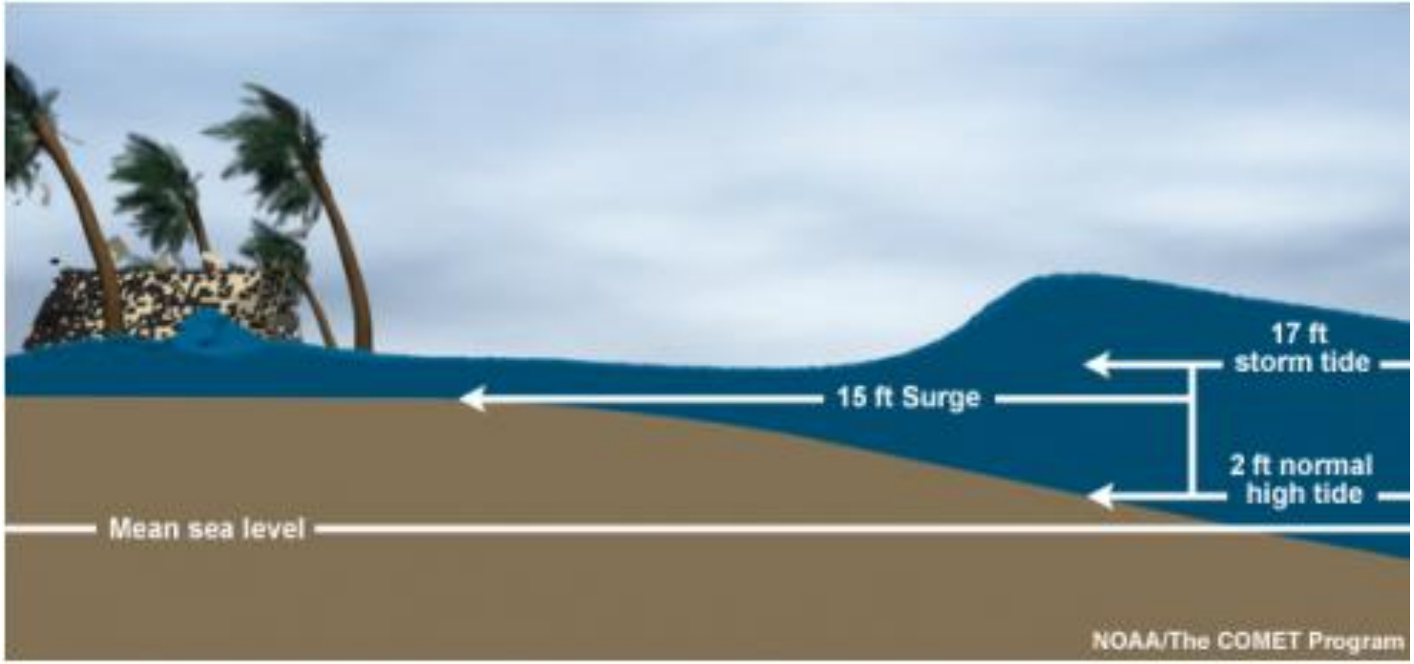
- Storm surge basics
- Measuring storm surge
- Why modeling storm surges?
- Storm surge prediction model
- Input to and output of storm surge model
- Meshing
- Storm surge modeling activity at INCOIS

What is storm surge ?

Storm surge is an abnormal rise of water generated by a storm, over and above the astronomical tide.

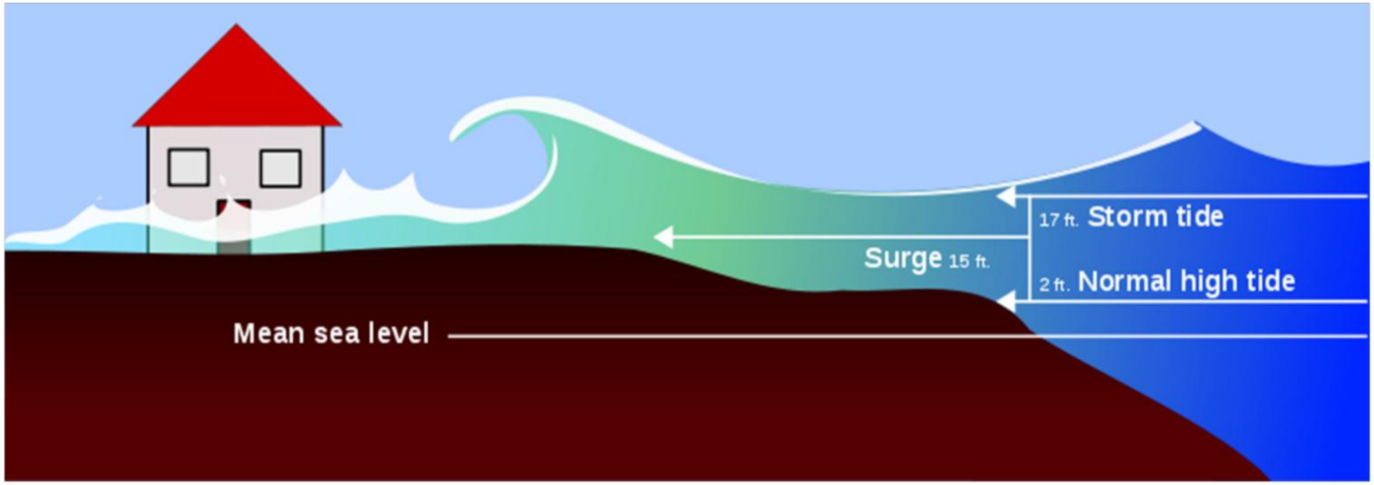
What is storm tide ?

Storm tide is the water level rise during a storm due to the combination of storm surge and the astronomical tide.



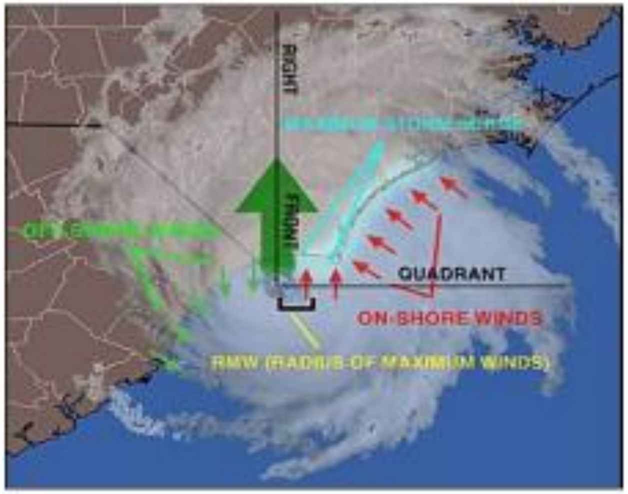
How it all piles up the water?

- *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

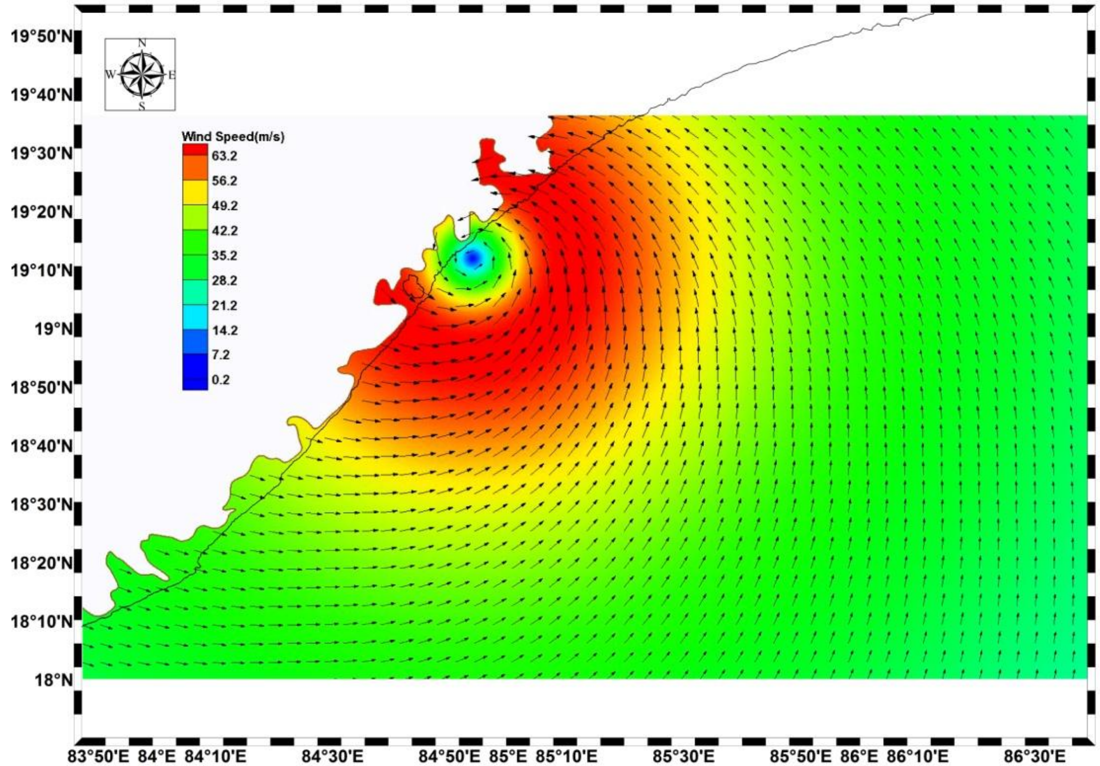


"Piling up of water at the coast"

“Storm surge occurs in right-front quadrant”



In general, storm surge occurs where winds are blowing onshore. The highest surge tends to occur near the “radius of maximum winds,” or where the strongest winds of the cyclone occur.



Factors that Influence Storm Surge

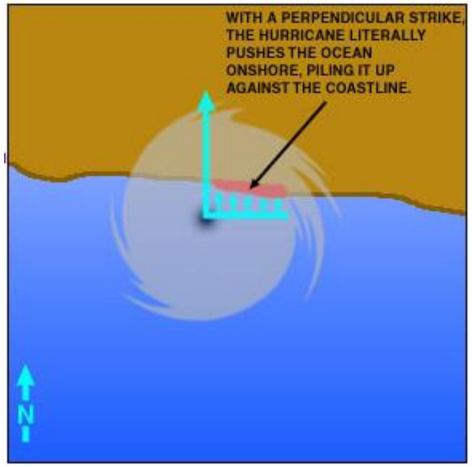
Central Pressure : Lower pressure will produce a higher surge.

Storm Intensity : Stronger winds will produce a higher surge.

Size : A larger storm will produce higher surge. There are two reasons for this. First, the winds in a larger storm are pushing on a larger area of the ocean. Second, the strong winds in a larger storm will tend to affect an area longer than a smaller storm.

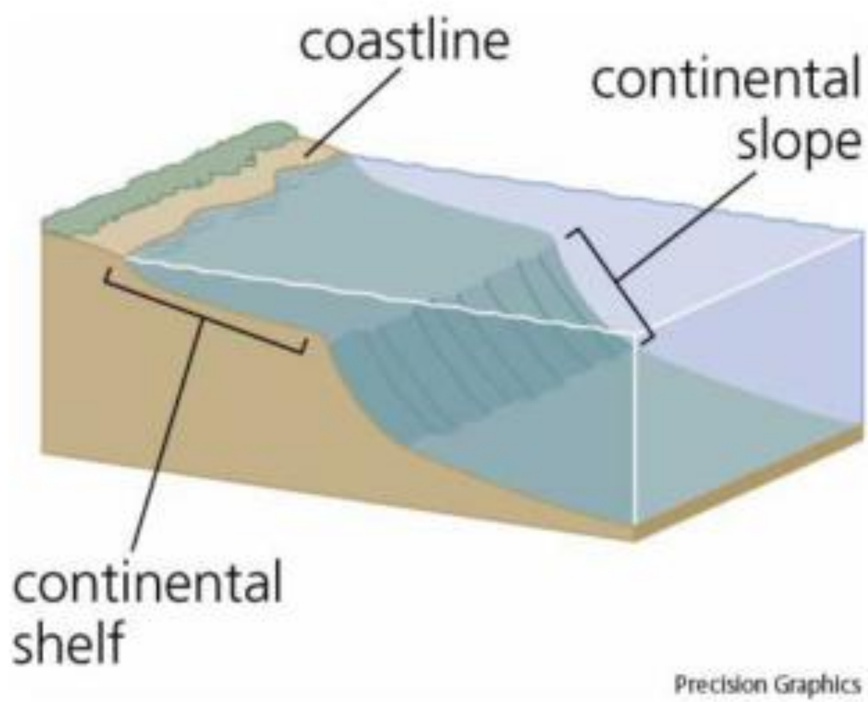
Storm Forward Speed : A faster storm will produce a higher surge.

Angle of Approach to Coast : The angle at which a storm approaches a coastline can affect how much surge is generated. A storm that moves onshore perpendicular to the coast is more likely to produce a higher storm surge than a storm that moves parallel to the coast or moves inland at an oblique angle.



Shape of the Coastline : Storm surge will be higher when a hurricane makes landfall on a concave coastline.

Width and Slope of the Ocean Bottom : Higher storm surge occurs with wide, gently sloping continental shelves, while lower storm surge occurs with narrow, steeply sloping shelves.



Measuring storm surge

Tide Stations :

Tide stations measure the variation in water level along the coast. Since tidal cycles are predictable, storm surge can be calculated by subtracting what the water level would have been in the absence of the storm from the measured water level.

Pros:

- Available in real time
- Traditionally the most reliable way of measuring surge.

Cons:

- Limited number of stations along the coast, so there is often no real-time validation of storm surge in the most vulnerable areas
- Often fail at the height of an event due to loss of electrical power or damage

Measuring storm surge

High Water Marks : High water marks are lines found on trees and structures marking the highest elevation of the water surface for a flood event, created by foam, seeds, or other debris.
Survey crews are deployed after a storm to locate and record reliable high water marks, usually through GPS methods.

Pros:

• Traditionally the best method for capturing the highest surge from an event

Cons:

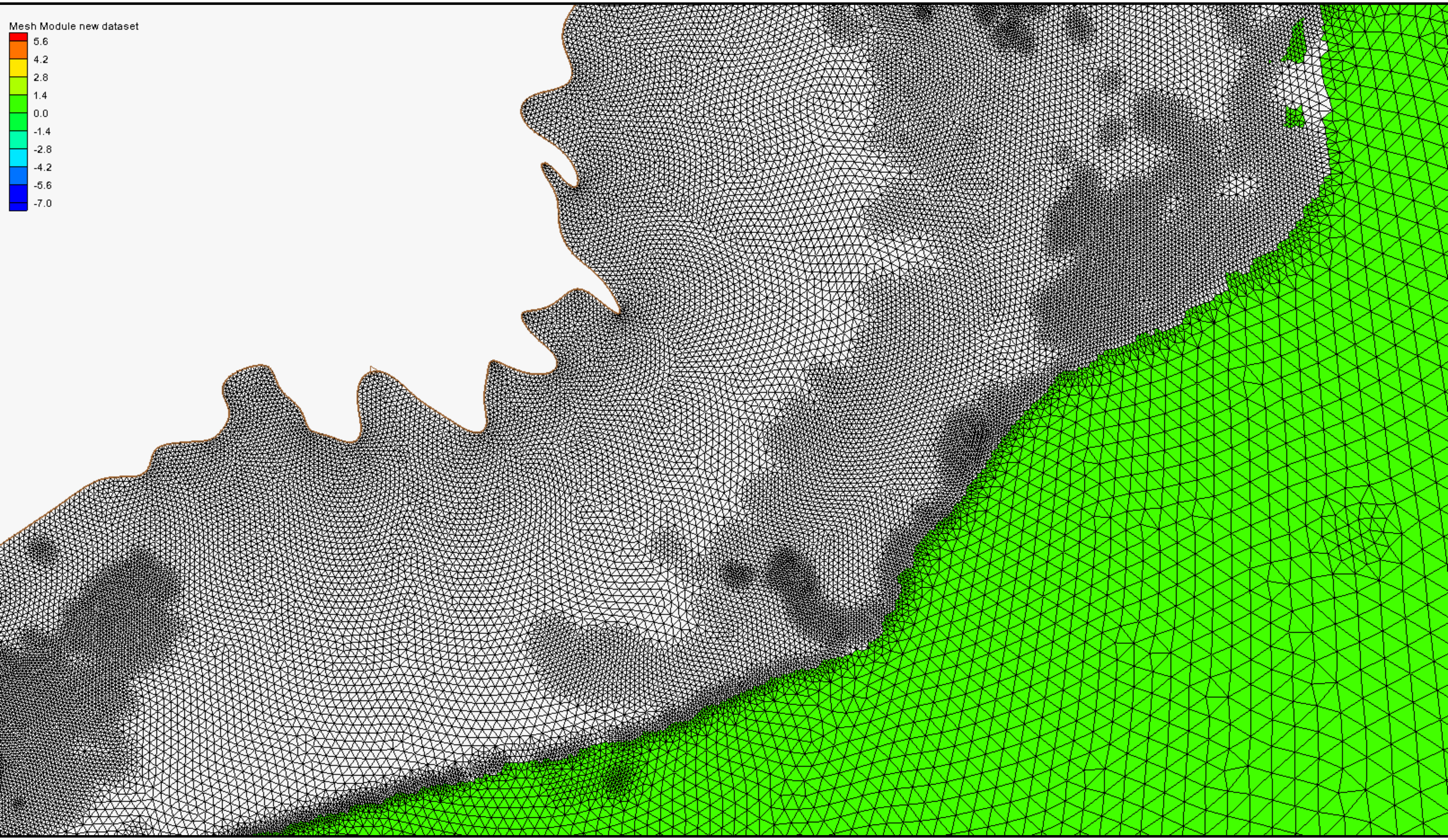
• Are not available in real time
• Are perishable, so surveys need to be conducted as soon as possible after a storm.

What is coastal inundation?

Coastal inundation is the flooding of normally dry, low-lying coastal land.

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



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"

Storm Surge Forecasting Requirements:

A high resolution, physics based circulation model with flooding and drying capabilities

A high resolution water depth (bathymetry) and land (topography) elevation data set

Accurate (time and space) wind and pressure fields to drive the model.

Storm surge prediction model: ADCIRC

ADCIRC is a (parallel) ADvanced CIRCulation model for oceanic, coastal and estuarine waters developed by Dr. R.A. Luettich, Jr, University of North Carolina at Chapel hill, Institute of Marine Sciences (email: rick_luettich@unc.edu) and Dr. J.J. Westerink, Department of Civil Engineering and Geological Sciences, University OF Notre Dame (email: jjw@photius.ce.nd.edu).

The complete information of ADCIRC model can be seen from the below link

http://www.unc.edu/ims/adcirc/document/Introduction.html

Typical applications of ADCIRC includes

- prediction of storm surge and flooding
- modeling tides and wind driven circulation
- near shore marine operations

Input to the storm surge model

Meteorological Input

This is mainly concerned with the characteristics of the tropical storms required for computation of the associated winds. The main characteristics required are:

(i) The pressure drop (difference between ambient pressure surrounding the storm and the central pressure),
(ii) vector motion of the storm,
(iii) place of landfall,
(iv) maximum sustained winds, and
(v) the radius of maximum wind.

Oceanographic input

Data on oceanography are concerned with:
(a) Bathymetry
(b) Astronomical tides

Hydrological input

The main hydrological information needed is:
(i) River discharge in the sea, and
(ii) Rainfall distribution.

Output from the model

- Coastal currents
- Surge
- Inundation extent

Meshing:

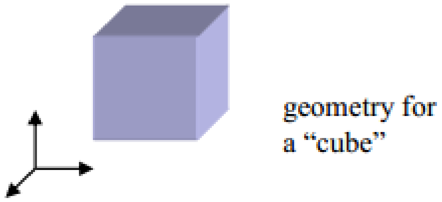
Why is a grid needed?

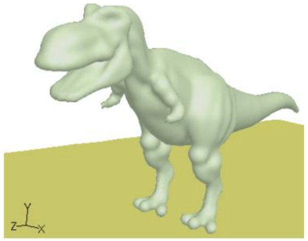
The grid designates the cells or elements on which the flow is solved.
The grid is a discrete representation of the geometry of the problem.
The grid has a significant impact on solution accuracy and CPU time required.

Geometry

The starting point for all problems is a *"geometry."*
The geometry describes the shape of the problem to be analyzed.
Can consist of faces (surfaces), edges (curves) and vertices (points).

The geometry can be very simple or more complex
for example

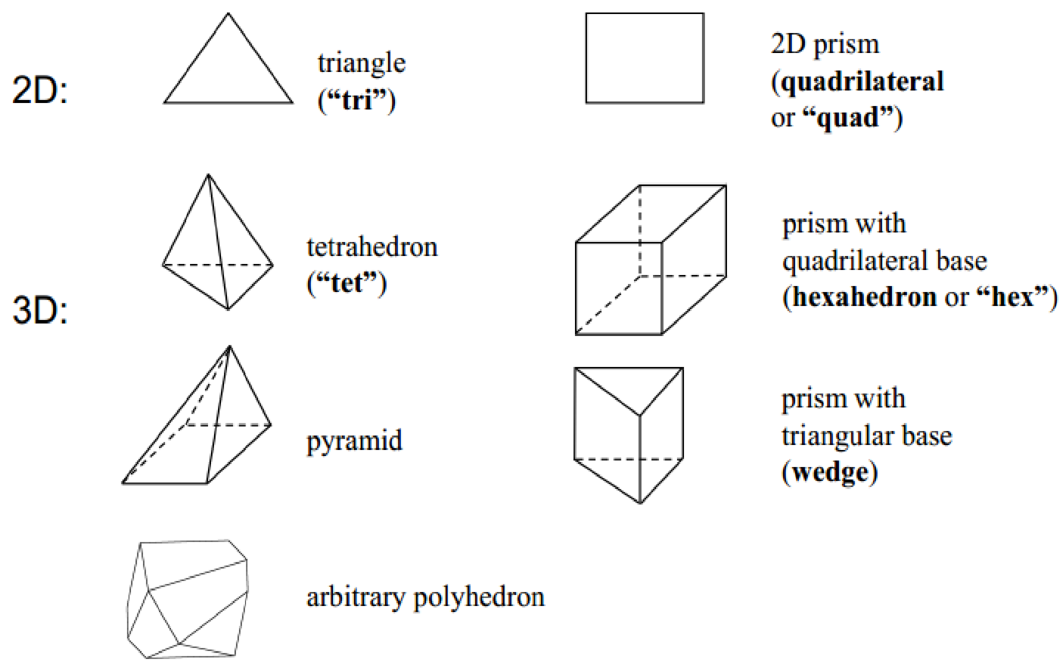




Simple geometry

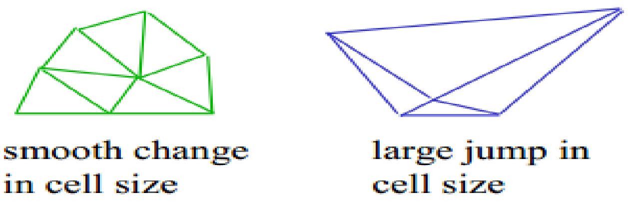
Complex geometry

Typical cell or element shapes

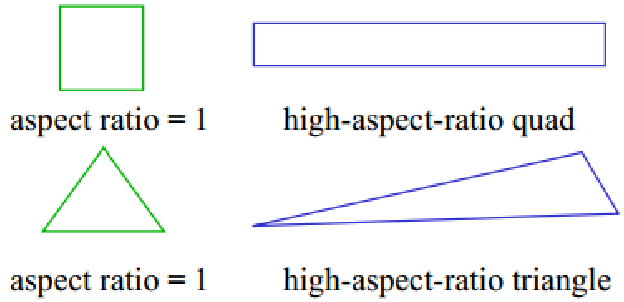


Mesh quality: smoothness and aspect ratio

Change in size should be gradual (smooth)

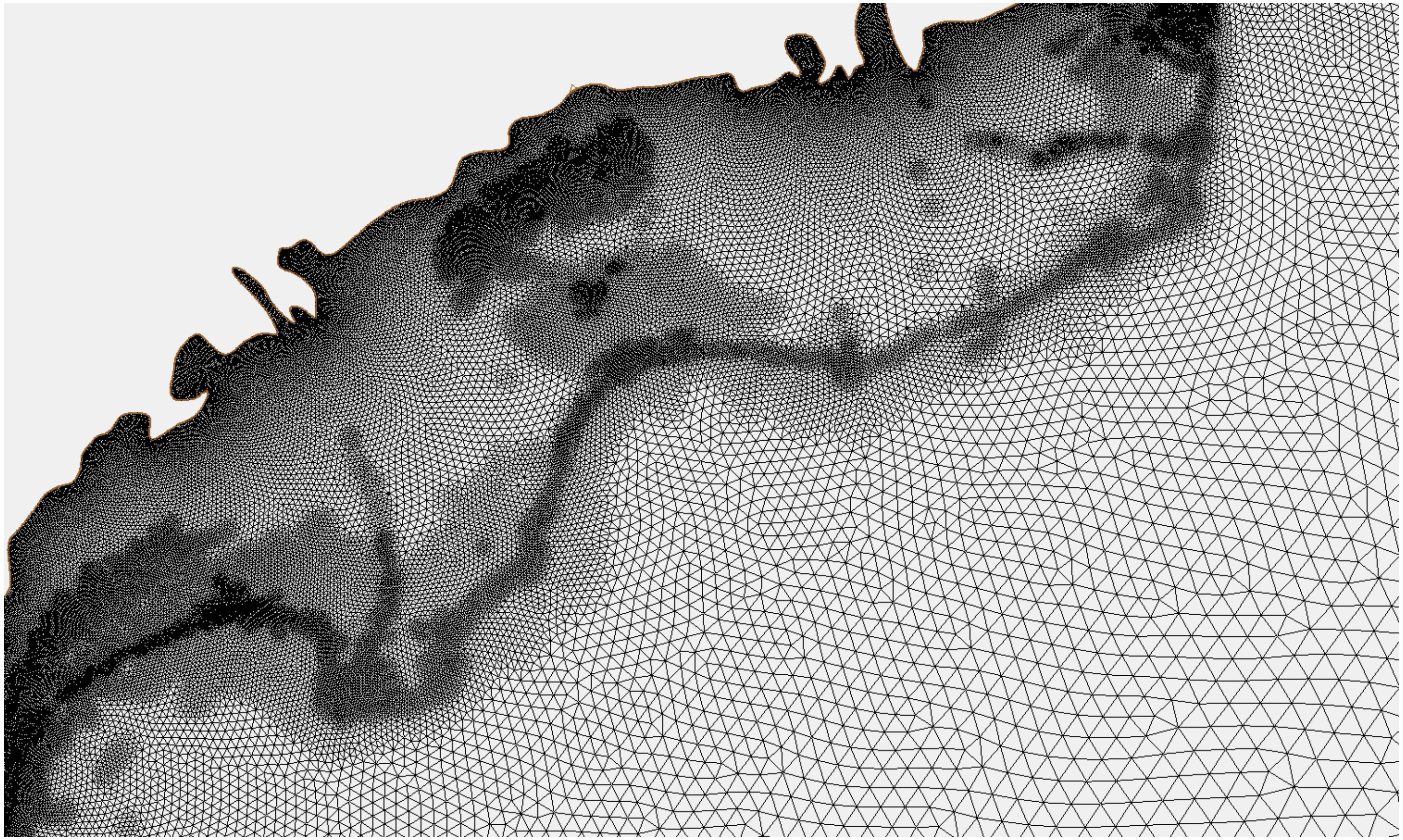


Aspect ratio is ratio of longest edge to shortest edge length. Equal to 1 (ideal) for an equilateral triangle or a square.



ADCIRC model uses an unstructured triangular gridded mesh for the computation. The use of unstructured gridded mesh is that we can get the high resolution grids in the desired areas and the resolution in the rest of the areas can be relaxed. This option can minimize the CPU time.

More complex geometries can be represent accurately using triangular gridded meshes.



Storm surge forecasting system at INCOIS

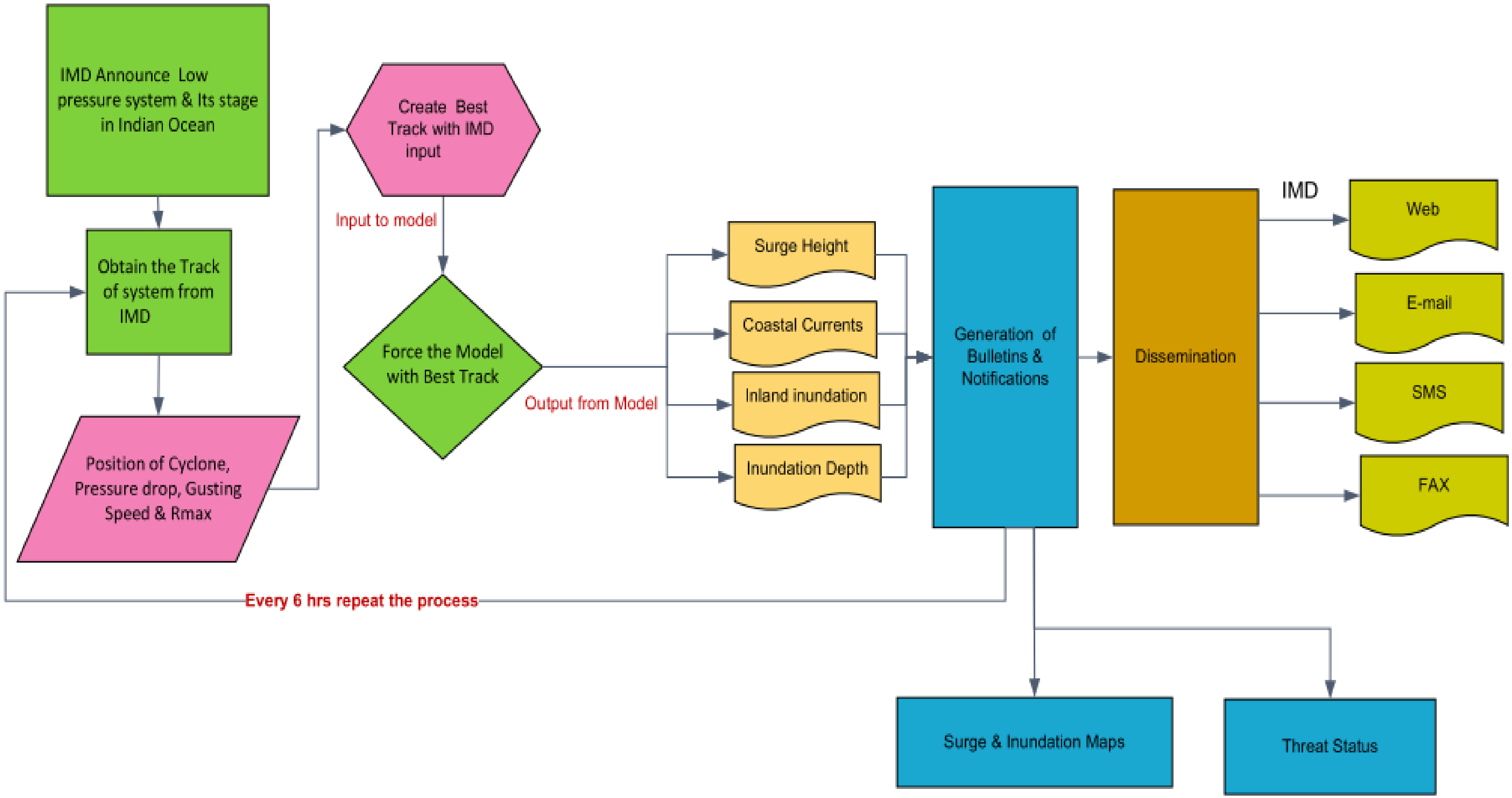


Figure: Standard Operating Procedure of Storm Surge Early Warning

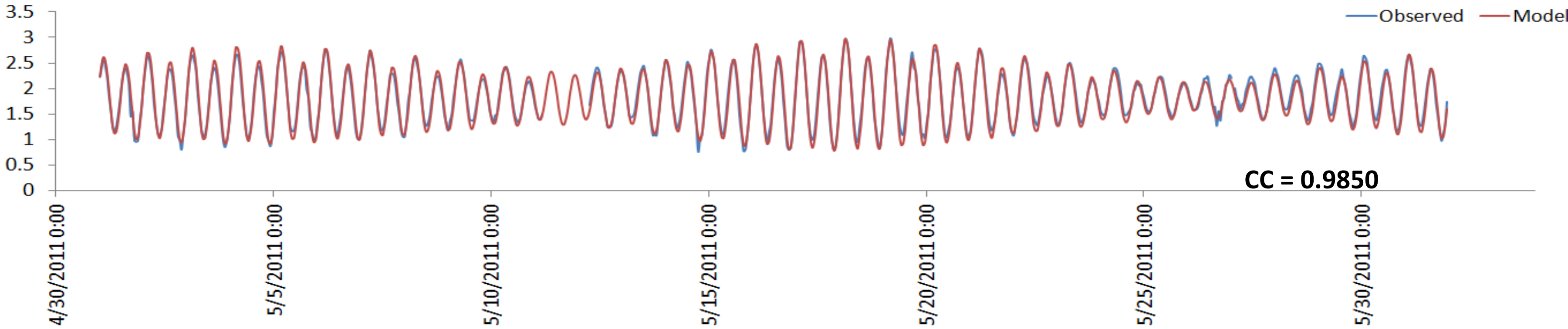
Experimental storm surge forecast for the VSCS Phailin

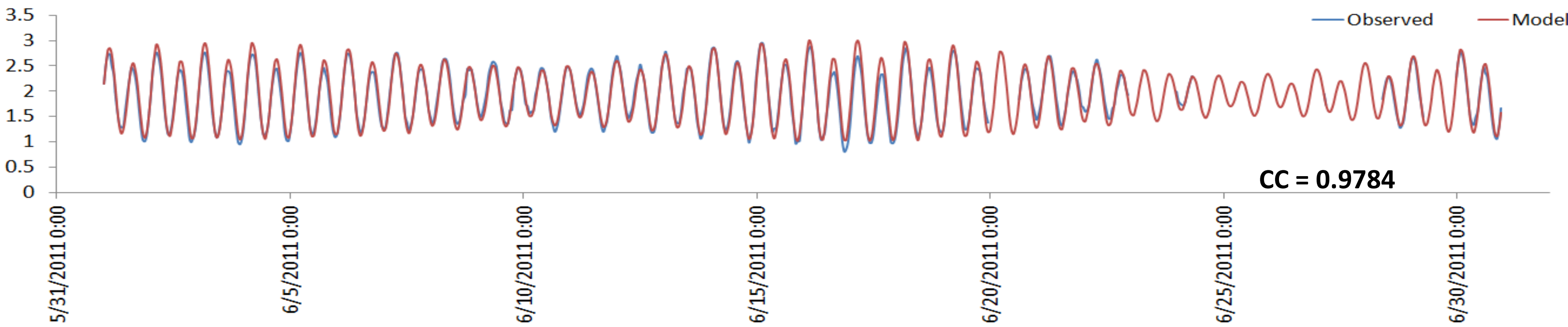
9^{th} – 13^{th} October 2013

FORECAST SUMMARY	
Model spin-up	61 days
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	2.8m 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

Validation of tides:

Comparison of model Vs. observed tide at Paradeep, Odisha





Generation of best track

IMD input Data

INPUT

Sub: Cyclonic storm, PHAILIN in East central Bay of Bengal: Cyclone Alert for North Andhra Pradesh and Orissa Coast. Cyclone Warning for Andaman & Nicobar Island

The deep depression over east central Bay of Bengal remained practically stationery, intensified into a cyclonic storm, **PHAILIN** and lay centred at 1730 hrs IST of today, 09th October 2013 over near latitude 13.5°N and longitude 92.5°E, about 220 km north-northwest of Port Blair, 950km southeast of Paradip, 1100 km east-southeast of Visakhapatnam. The system would intensify into a severe cyclonic storm during next 24 hours. It would continue to move west-northwestwards for some time and then northwestwards and cross north Andhra Pradesh and Odisha coast between Kalingapatnam and Paradip by night of 12th October, 2013 as a very severe cyclonic storm with a maximum sustained wind speed of 175-185 kmph.

Based on latest analysis with NWP models and other conventional techniques. estimated track and intensity of the system are given in the Table below:

Date/Time(IST)	Position (Lat. °N/ Long. °E)	Sustained maximum surface wind speed (kmph)	Category
09-10-2013/1730	13.5/92.5	65-75 gusting to 85	Cyclonic Storm
09-10-2013/2330	13.8/92.0	70-80 gusting to 90	Cyclonic Storm
10-10-2013/0530	14.3/91.0	75-85 gusting to 95	Cyclonic Storm
10-10-2013/1130	14.7/90.4	85-95 gusting to 105	Cyclonic Storm
10-10-2013/1730	15.2/89.8	95-105 gusting to 120	Severe Cyclonic Storm
11-10-2013/0530	15.7/88.3	115-125 gusting to 140	Severe Cyclonic Storm
11-10-2013/1730	16.5/87.1	135-145 gusting to160	Very Severe Cyclonic Storm
12-10-2013/0530	17.3/86.0	155-165 gusting to 180	Very Severe Cyclonic Storm
12-10-2013/1730	18.5/85.2	175-185 gusting to 200	Very Severe Cyclonic Storm
13-10-2013/0530	20.0/84.7	70-80 gusting to 90	Cyclonic Storm
13-10-2013/1730	21.2/84.4	50-60 gusting to 70	Deep Depression
14-10-2013/0530	22.0/84.4	35-45 gusting to 55	Depression

Under the influence of this system, rainfall at most places with heavy to very heavy falls at a few places and isolated extremely heavy falls (≥ 25cm) would occur over Andaman and Nicobar Islands during next 12 hrs. Isolated heavy to very heavy rainfall would occur in subsequent 24 hrs.

(Conversion Logic with Java code)

Best Track Data

OUTPUT

```
CYCLONE TRACK
TRACK ISSUED BY IMD
12
13.5    92.5    35000    8.0    0
13.8    92.0    35000    9.0    6
14.3    91.0    35000   10.0    6
14.7    90.4    35000   13.0    6
15.2    89.8    30000   16.0    6
15.7    88.3    30000   22.0   12
16.5    87.1    30000   30.0   12
17.3    86.0    25000   39.0   12
18.5    85.2    25000   49.0   12
20.0    84.7    35000    9.0   12
21.2    84.4    40000    5.0   12
22.0    84.4    45000    4.0   12
```

Model domain and grid description

Computation nodes : 472193

Minimum grid size: 150m (at the coast)

Maximum grid size : 80km (Ocean boundary)

Forecast description

Tides forced at boundary from LeProvst

Wetting and drying

Hybrid bottom friction relation

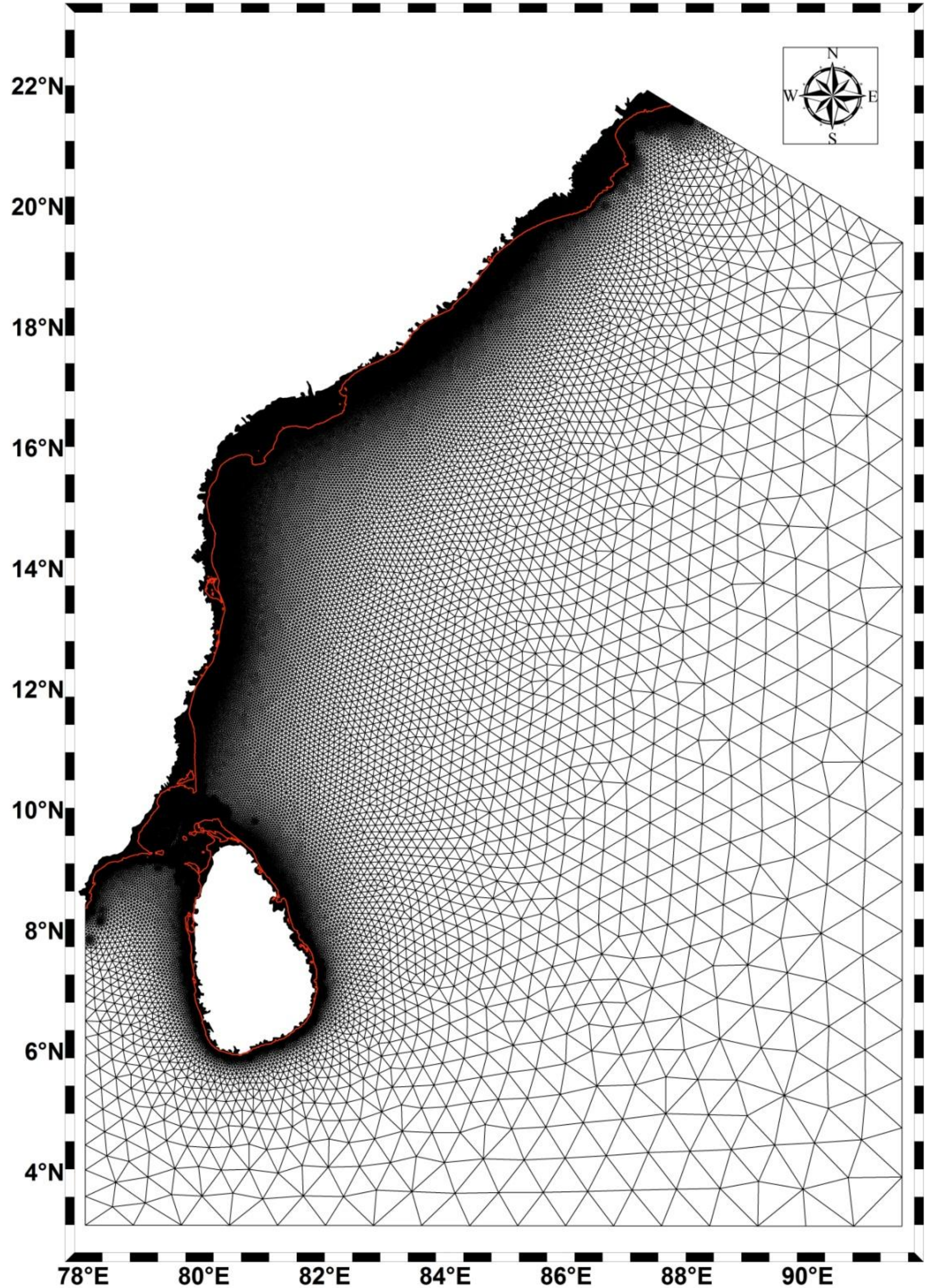
Time step of 2 sec

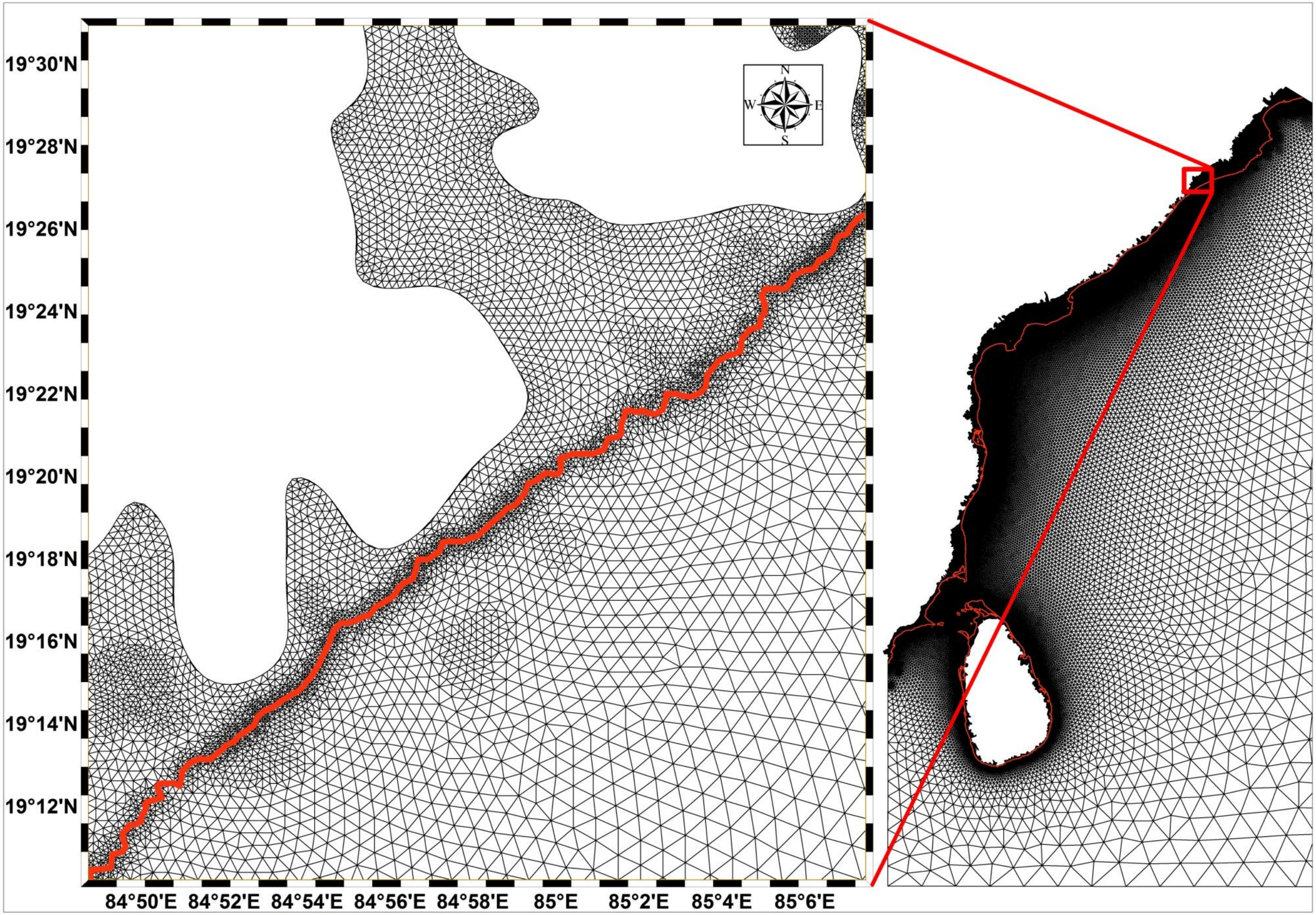
61 day spin-up of forcing

4 days and 12 hrs simulated 10/9 0600 UTC 10/13 1800 UTC

256 processors using INCOIS HPC

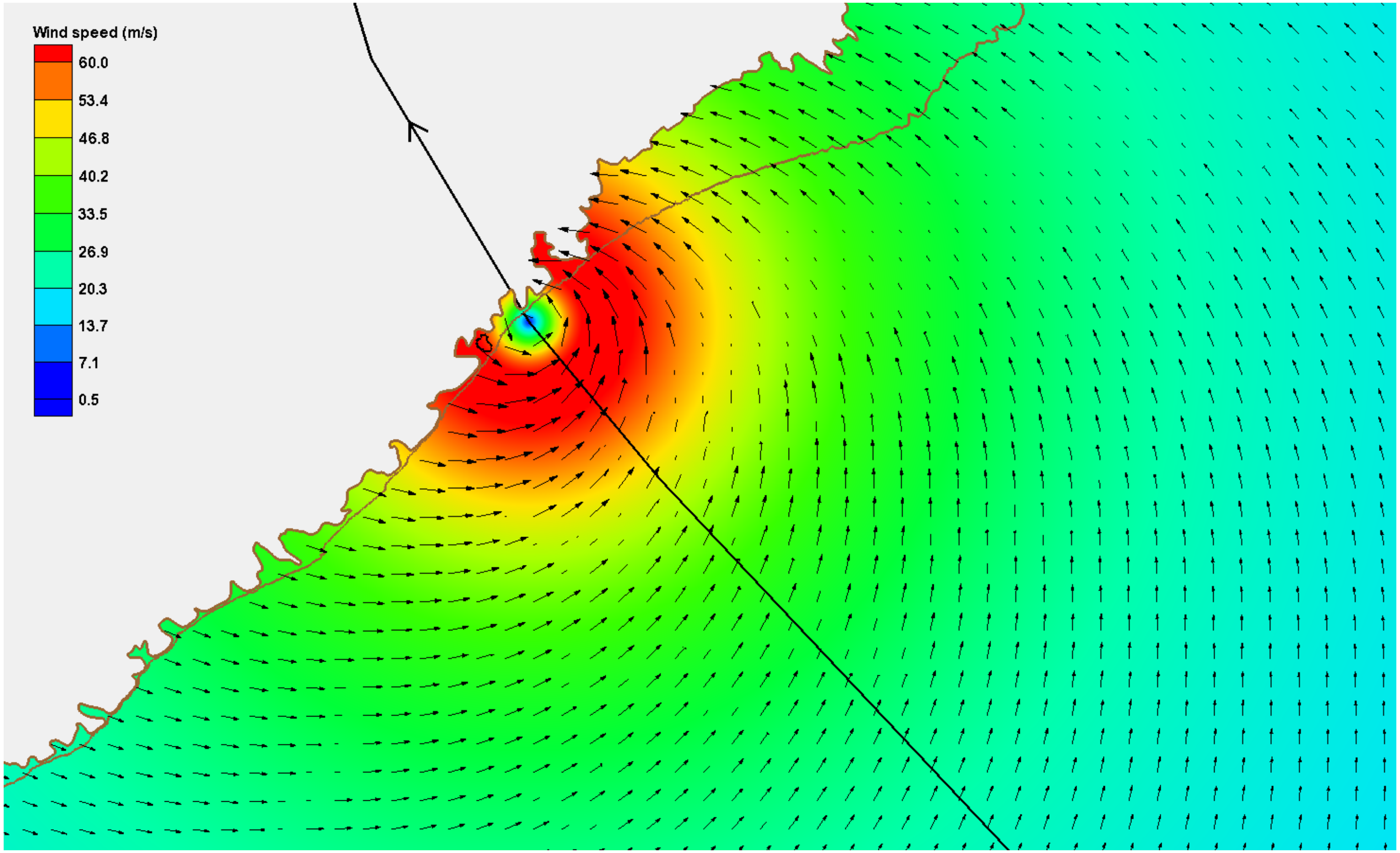
~45min CPU time





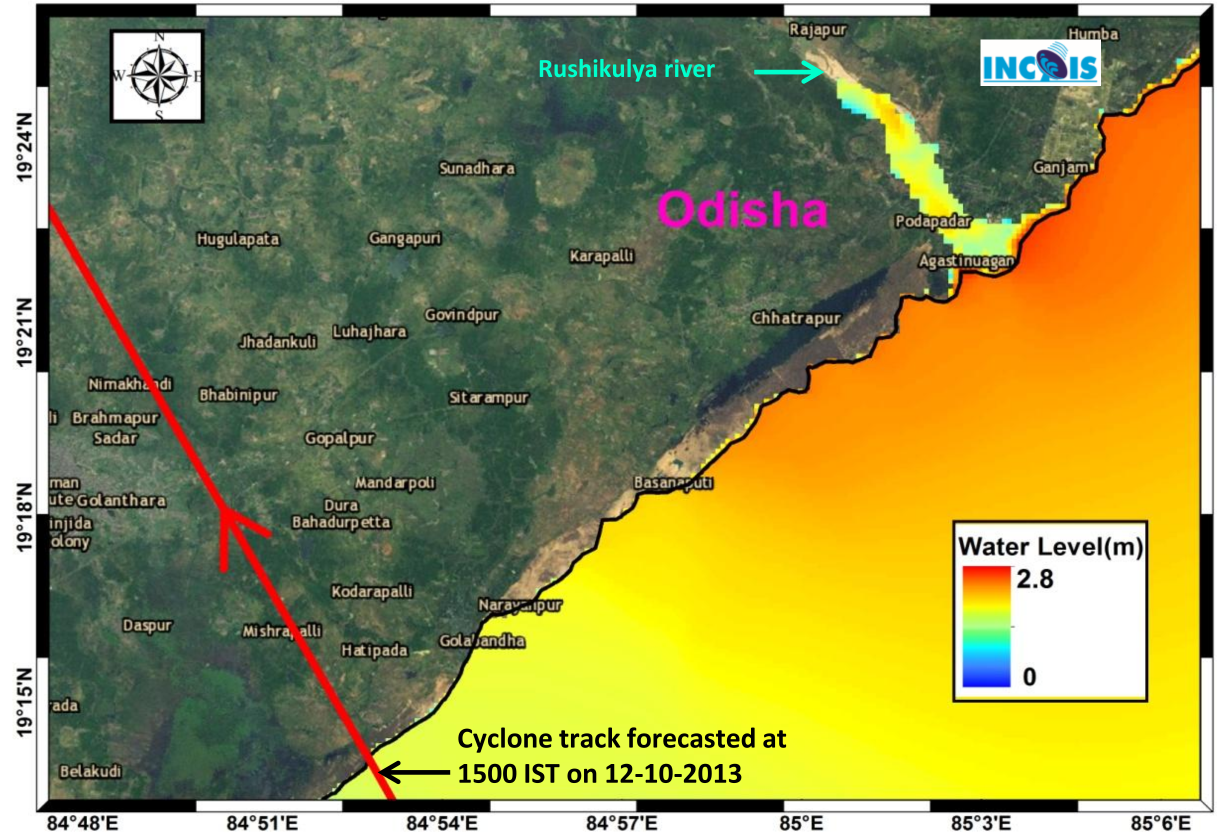
Near shore grid resolution is very much crucial factor in order to achieve accuracy in storm surge computation (Blain et al., 1994)

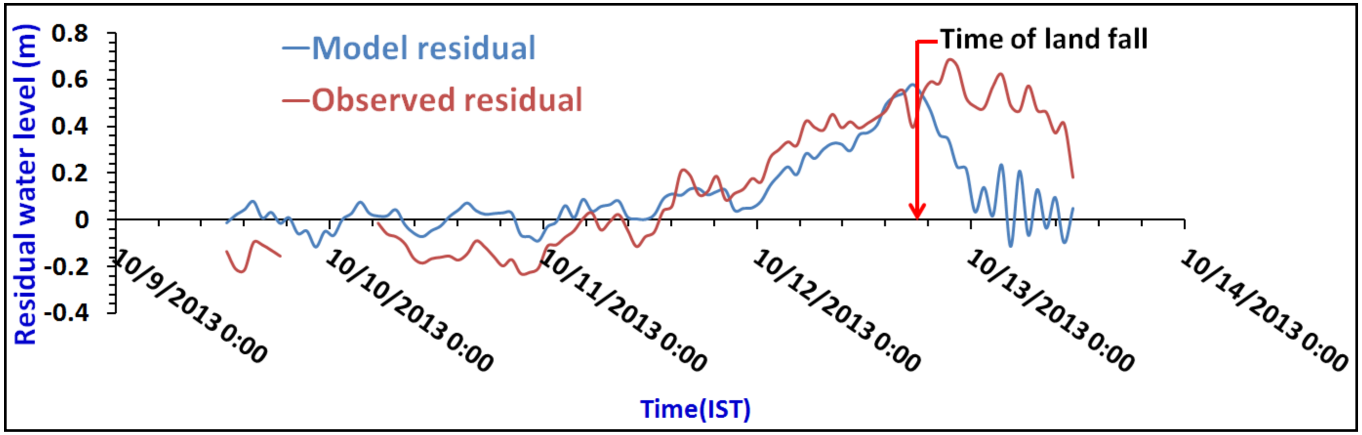
Model computed wind speed using track forecast given by IMD



Jelesnianski & Taylor dynamic wind model was used

Storm Surge forecasted by INCOIS based on the track forecasted by IMD at 1500 IST on 12 October 2013





Comparison of model estimated residual water level with the residual water level observed by the tide gauge at Paradeep (nearest tide gauge to the landfall point). Note that Paradeep is about 220 km north of landfall point.

Comparison of model estimated inland inundation with post storm field measurements (Precipitation is not included in the model)

Locations along Odisha Coast	**Model estimated inland extent of inundation (m)**	**Observed inland extent of inundation based on field measurement (m)**
Dhepanuapada	-	23
Lohadigam	-	35
Humirbana	120	101
Humirbana	70	11
Podapadar	150	120
Podapadar	100	106
Agasti Naugam	250	173
Agasti Naugam	800	110
Ganjam	300	670
Mayarpada	150	160
Mayarpada	200	67
Jayamangalhil	300	65
Bhramarakudi	-	35
Bhramarakudi	-	44

Thank You