Operational Oceanography, Marine Meteorology & Operational Ocean Forecasting, Warning and Advisory Services for offshore E&P industries (DG HC) on 11 - 12 July, 2023

Basics of Ocean Tides and Tide forecasting

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Time and tide wait for none

Why forecasting of the tide is important !!

Navigation

Fishing

Recreation

Coastal and Offshore Engineering

Tsunami

Storm surge

Military applications

Pollution studies

Power generation

Climate Change

Academic

Etc……..

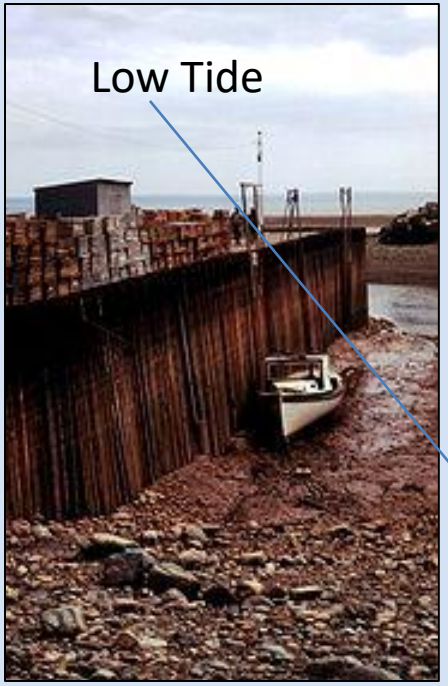
"The tides are the heartbeat of the ocean, a pulse that can be felt all over the world"

Defant, 1958

Tides are generated by astronomical phenomena and are, therefore, highly predictable.

They are very important for a proper understanding of :

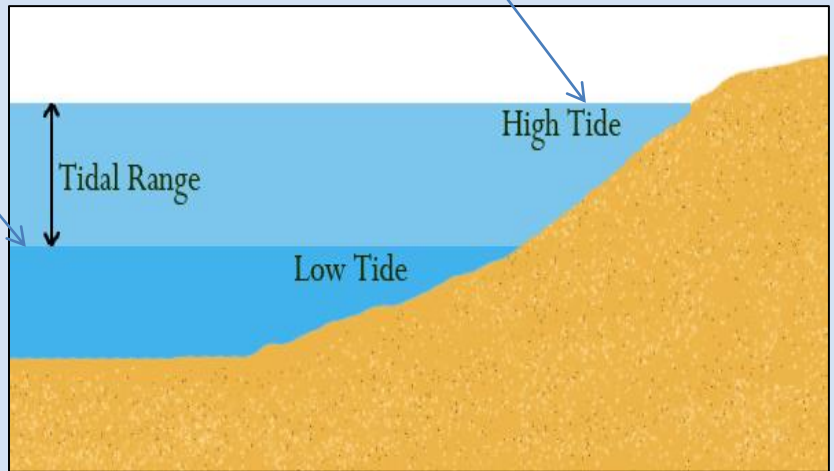
physics, chemistry, biology and geology of the coastal and estuarine waters



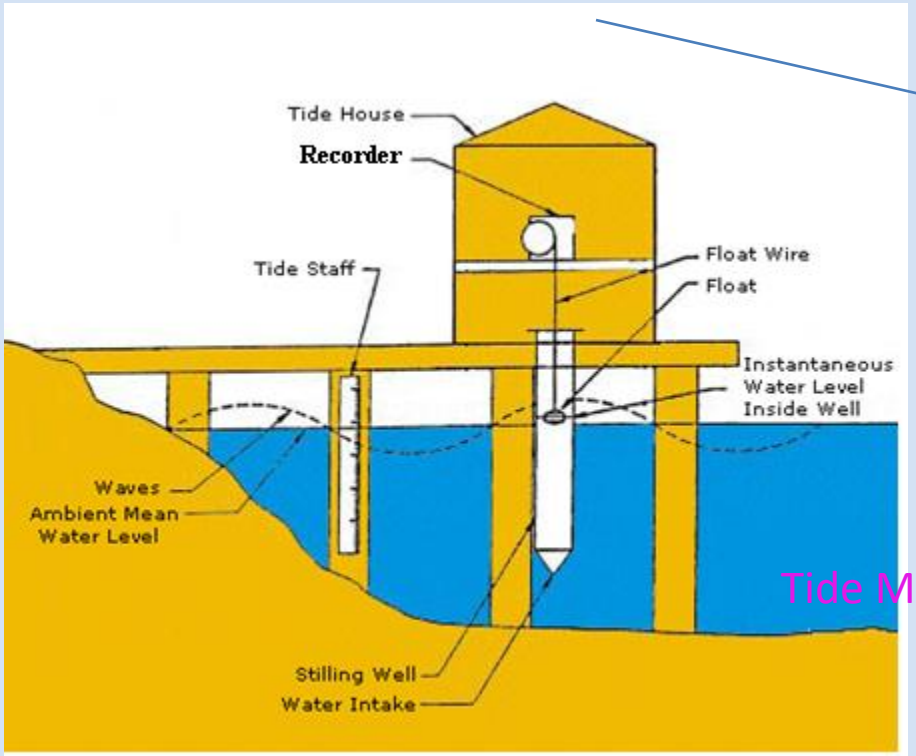
The same location in the Bay of Fundy at low and high tide.

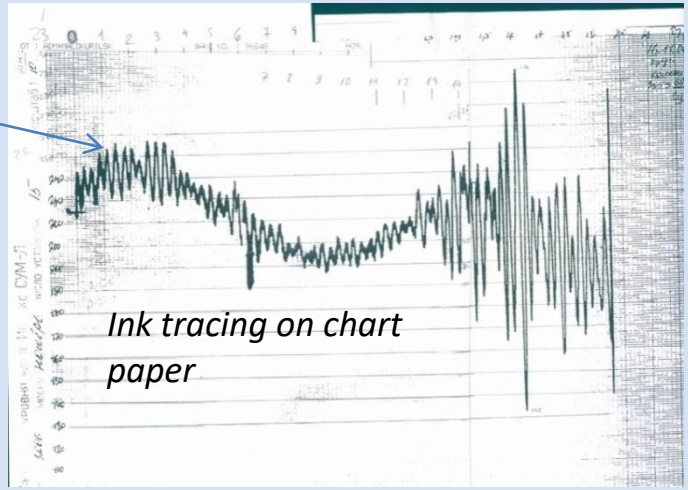
The maximum tidal range is approximately 17m

The tidal range is the vertical difference between the low tide and the succeeding high tide.



Tide Measurement – Past (too many manual interventions)

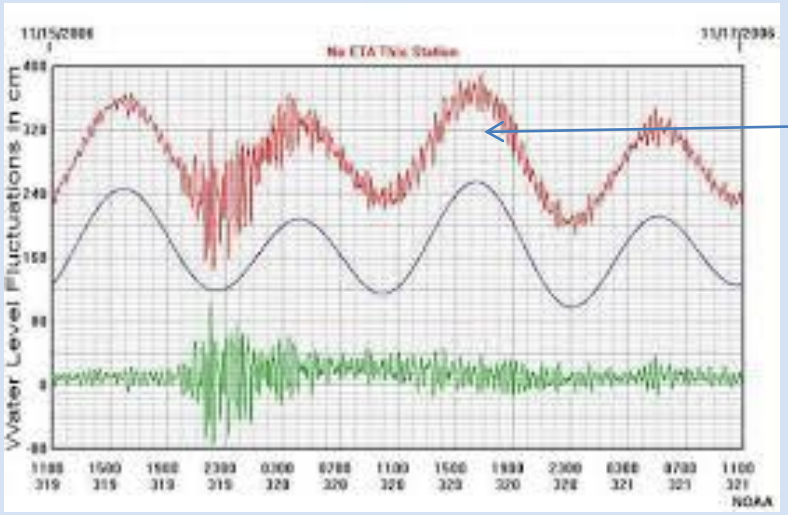


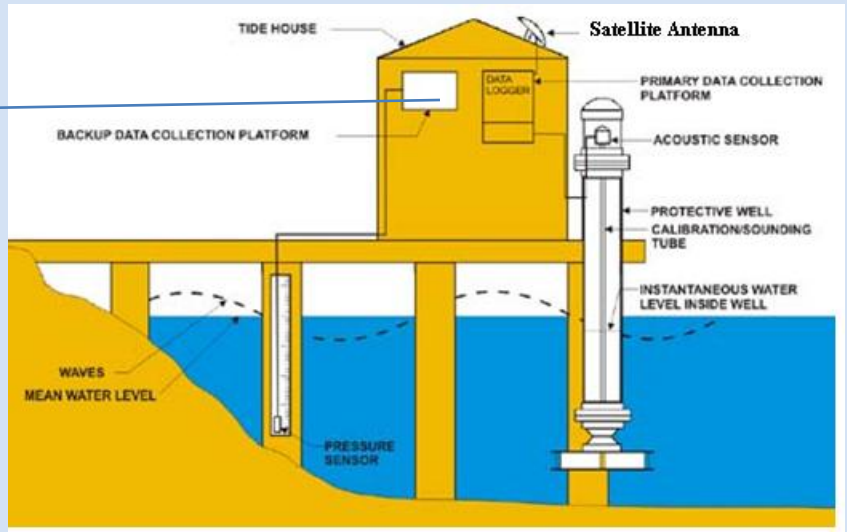


Ink tracing on chart paper

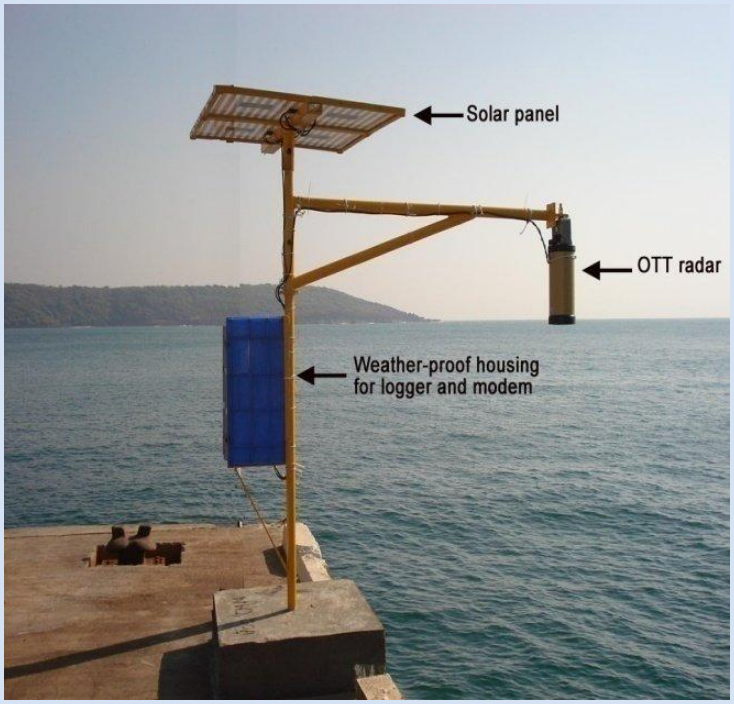
Tide Measurement – Present (Highly automated)

Main advantage Near Real Time reception via satellite connectivity





RADAR SEA LEVEL SENSOR: ***Non-contact water level sensor*** for long term surface water measurements



No drift over time !!

High Performance – Measurements are unaffected by air temperature, humidity, flood events, floating debris, or contaminated water; reduces the likelihood of missing data and reduces data post processing time

Low Maintenance

Measuring range - distance to water surface : 0.40 ... 35 m

For some studies, tide is a “corrupting” factor and hence it has to be removed to study other important signals ie NON-TIDAL SIGNALS (Meteorological residuals or Residuals)

Hydrological signals (river discharge effects)
Meteorological signals (wind influence or pressure influence)
Oceanographic signals (upwelling effects)

The above three are Important for:
seasonal studies as well as Climate Change studies

A typical tide curve below

Presence of tide

The most obvious indication of the presence of tide at any location
(coastal or deep sea)
is a characteristic, **sinusoidal oscillation in the water level/ pressure records**,

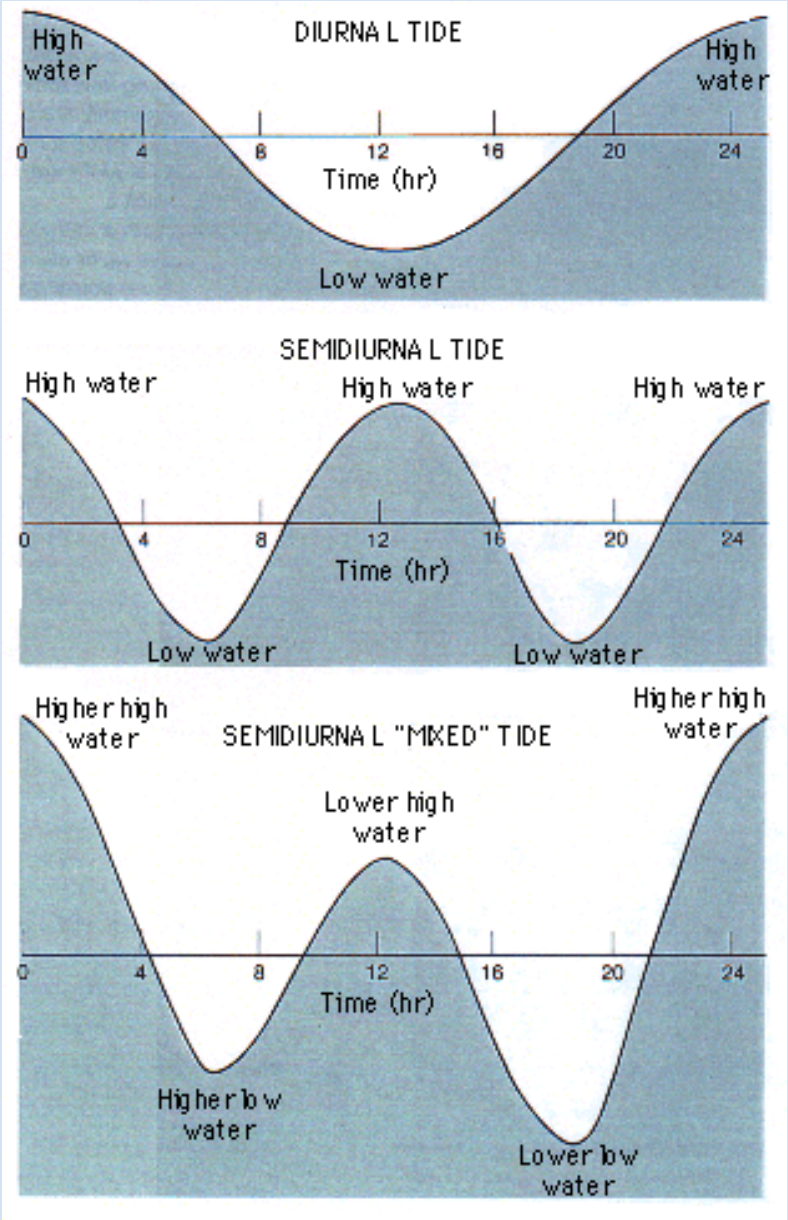
containing

either **two** main cycles per day (*semidiurnal tides*),
one cycle per day (*diurnal tides*),
or a **combination of the two** (*mixed tides*).

So a Total of THREE TYPES

The advantage !!

No matter how complex the tidal curve may appear, tidal oscillations can be broken down into a collection of simple sinusoids (even up to 115 in number).


DIURNAL TIDE
High water
High water
0
4
8
12
16
20
24
Time (hr)
Low water
SEMIDIURNAL TIDE
High water
High water
High water
0
4
8
12
16
20
24
Time (hr)
Low water
Low water
Higher high water
SEMIDIURNAL "MIXED" TIDE
Higher high water
Lower high water
0
4
8
12
16
20
24
Time (hr)
Higher low water
Lower low water

BUILDING BLOCKS OF THE TIDE

The following are among the ***major tidal constituents*** contributing to the astronomical tide:

M_2 - Principal lunar semidiurnal constituent
S_2 – Principal solar semidiurnal constituent
N_2 - Larger Lunar elliptic semidiurnal constituent
K_1 - Luni-solar declinational diurnal constituent
O_1 - Lunar declinational diurnal constituent

M_4 - First overtide of M_2 constituent (speed: 2 x M_2 speed)
M_6 - Second overtide of M_2 constituent (speed: 3 x M_2 speed)
S_4 - First overtide of S_2 constituent (speed: 2 x S_2 speed)
MS_4 - A compound tide of M_2 and S_2 (speed: M_2 + S_2 speed)

Tidal Component	Period (solar hours)	Description	Nature
M2	12.42	Principal lunar	semi-diurnal
S2	12.00	Principal solar	semi-diurnal
N2	12.66	Larger lunar elliptic	semi-diurnal
K2	11.97	Luni-solar	semi-diurnal
K1	23.93	Luni-solar diurnal	diurnal
O1	25.82	Principal lunar diurnal	diurnal
P1	24.07	Principal solar diurnal	diurnal
Q1	26.87	Larger lunar elliptic	diurnal
MF	327.90	Lunar fortnightly	Long term
MM	661.30	Lunar monthly	Long term
SSA	4383.00	solar semi annual	Long term
M4	6.21		Compound
MS4	6.10		Compound

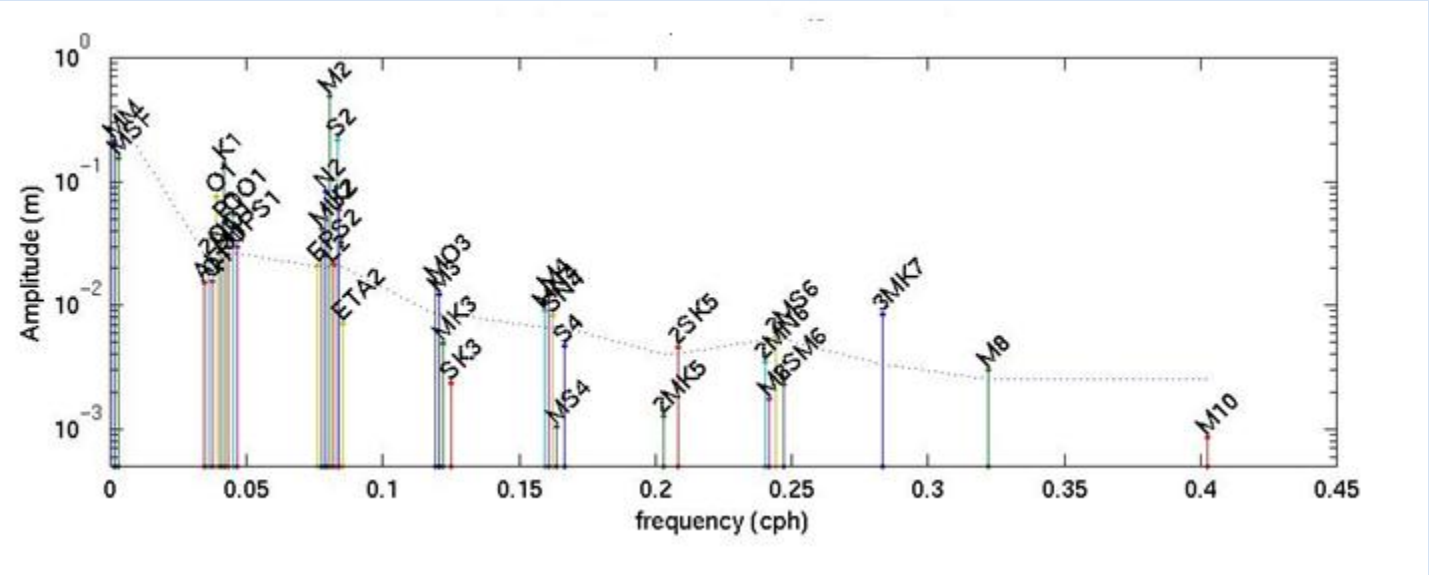
Harmonic method of classifying tides at a location

The tidal constituents (M2,S2,K1 & O1) can also be used to describe the type of tide (ie semidiurnal, diurnal, or mixed).

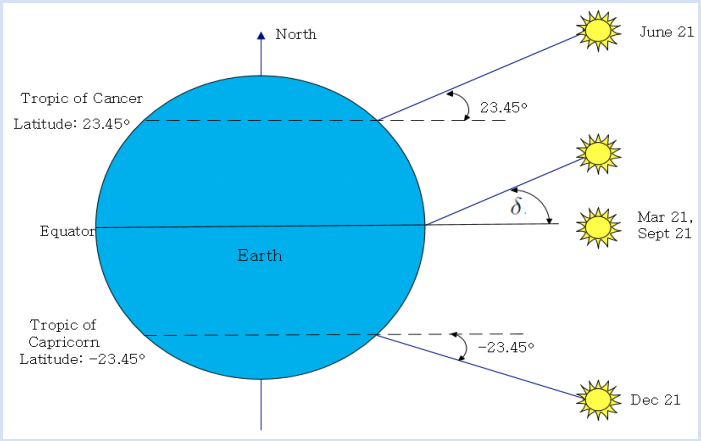
Tidal Form Number (TFN)=(K1+O1)/(M2+S2)

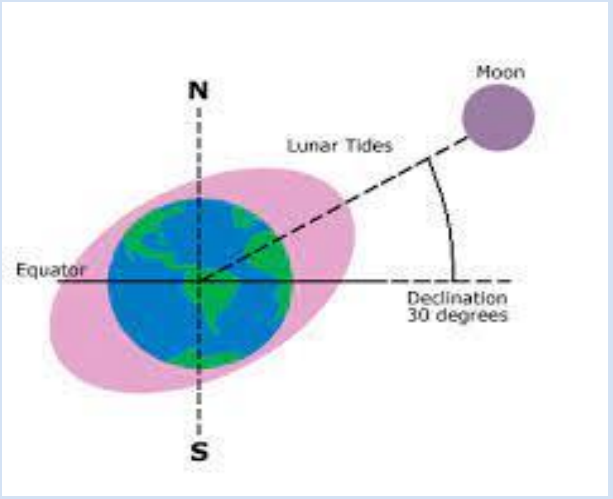
TFN < 0.25 : tides are semidiurnal.
TFN between 0.25 and 1.5 : mixed mainly semidiurnal
TFN between 1.5 and 3.0 : mixed mainly diurnal
TFN > 3,0, tides are diurnal

This requires us to do the tidal analysis !!

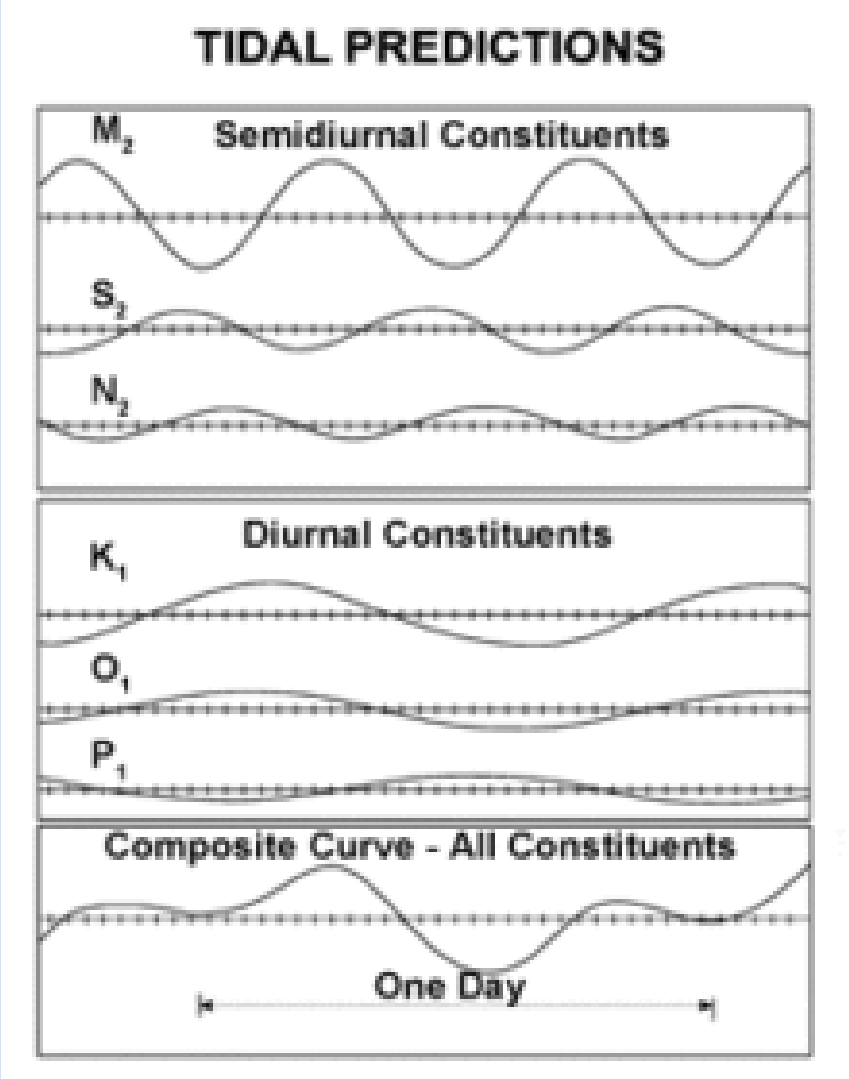


The declination angle (of sun or moon) and the proximity (of sun or moon) give rise to the various frequencies and magnitudes, known as the “tidal species”. (easily done in TASK – 2000 software)



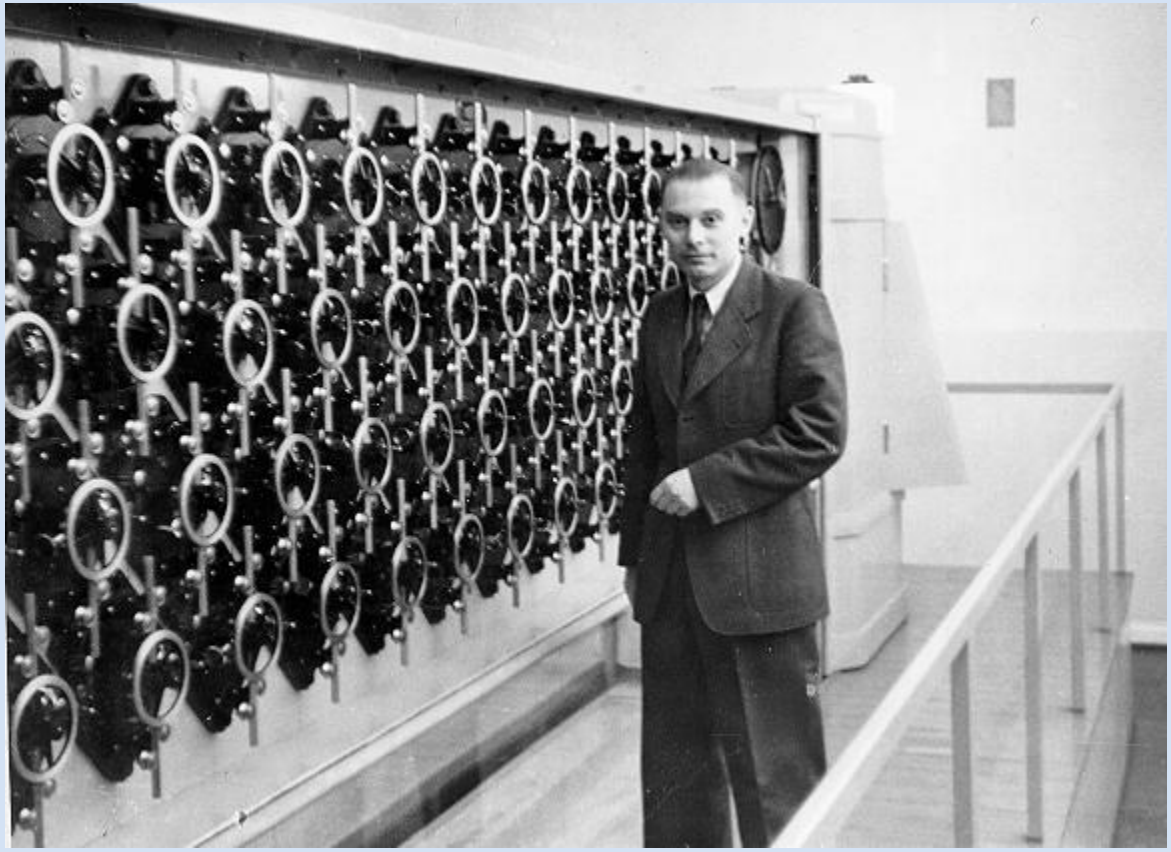


Sum of individual tidal components gives the resultant predicted sea level



(up to 115 components in TASK 2000 software)

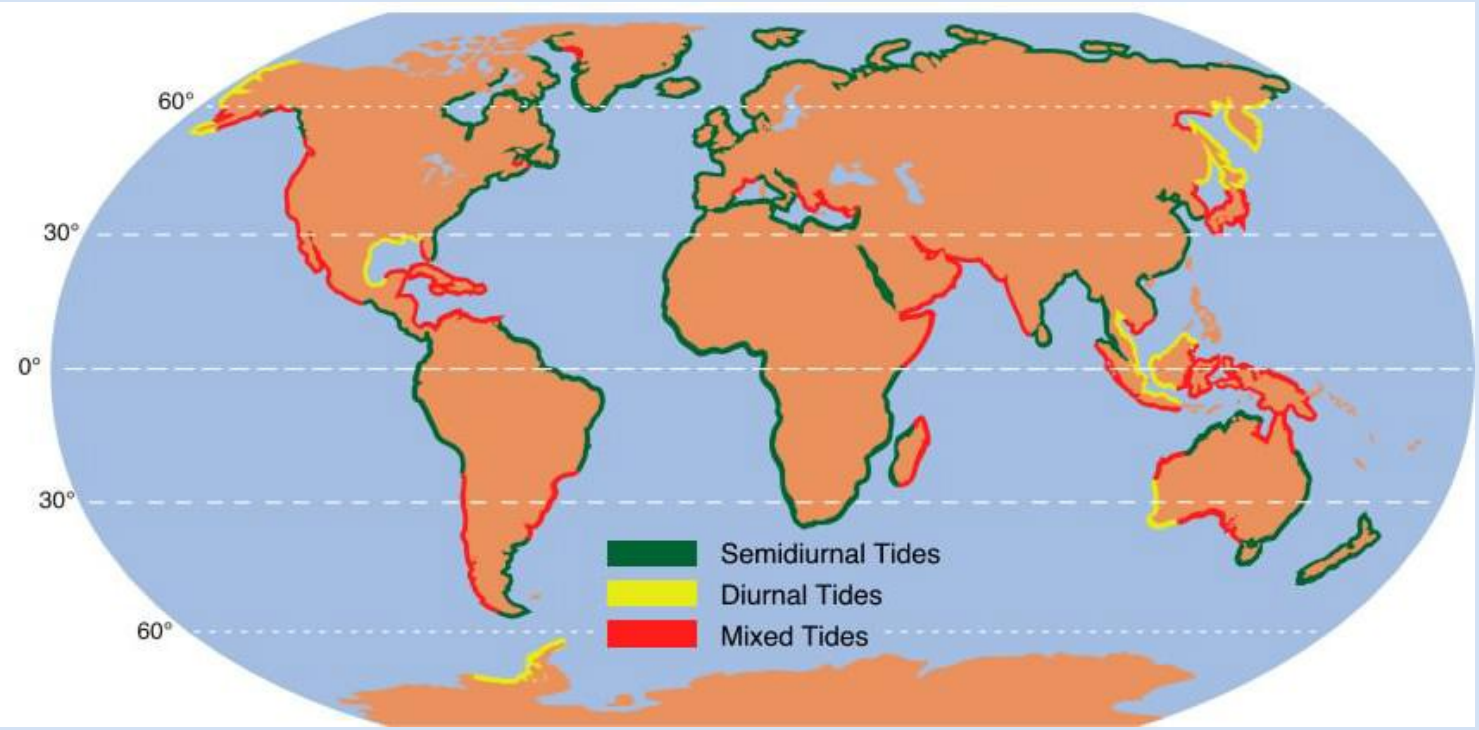
Just a few minutes in a modern computer….



In the past !

61-Component Tide-Predicting Machine

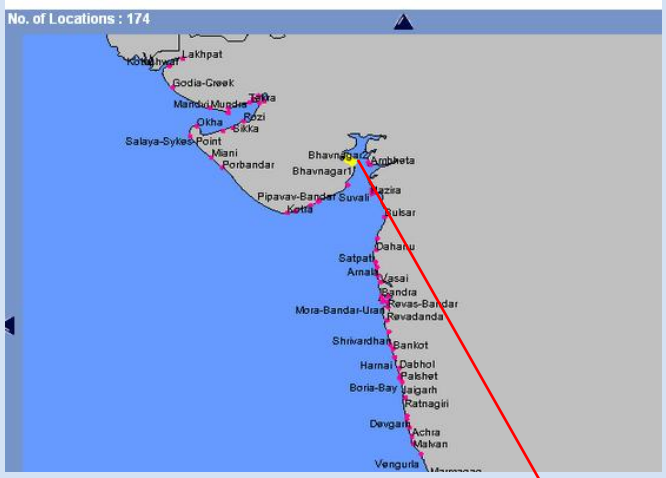
Germany, about 1950.



The same tidal forcing has different results depending on many factors, including coast orientation, continental shelf margin, water body dimensions.

Diurnal tides : mainly experienced in the Pacific Ocean.
Semi-Diurnal mainly experienced in the Atlantic Ocean.
Mixed : experienced in the Indian Ocean, Gulf of Mexico, and Australia.

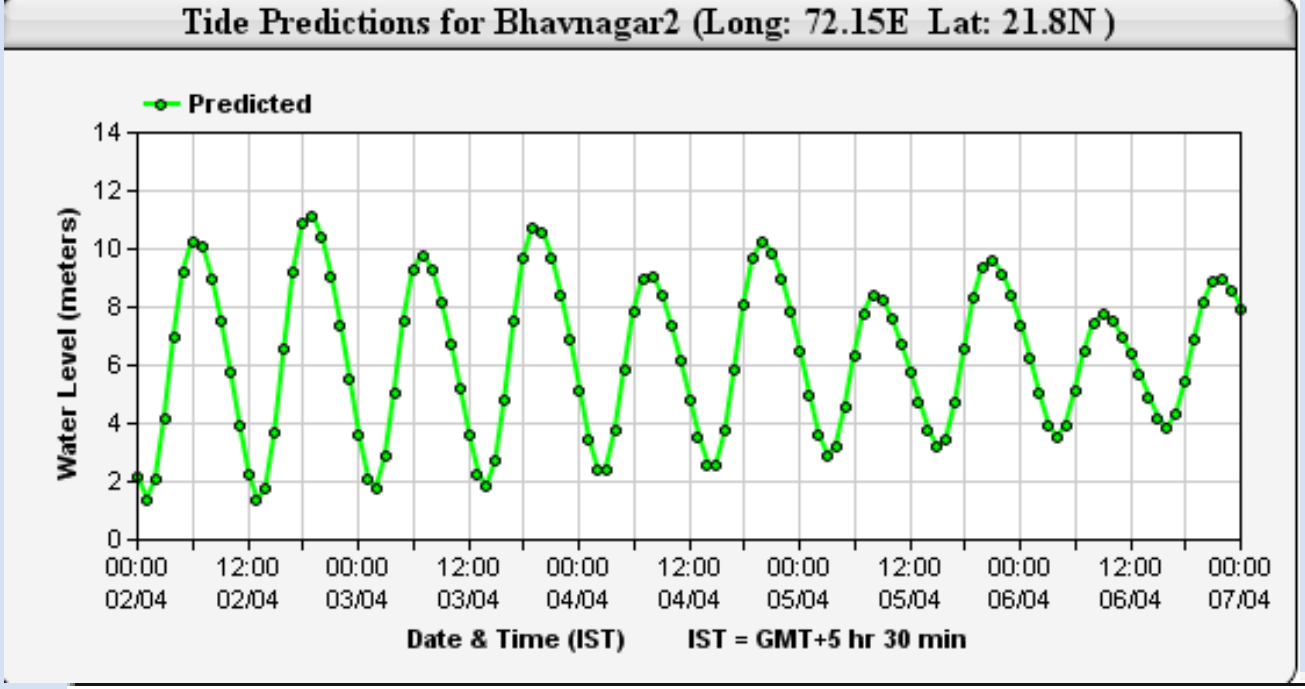
The Indian situation
and
Peculiarities !



BHAVNAGAR

Approx. 10 metres tidal range

INCOIS Tidal prediction stations (178)

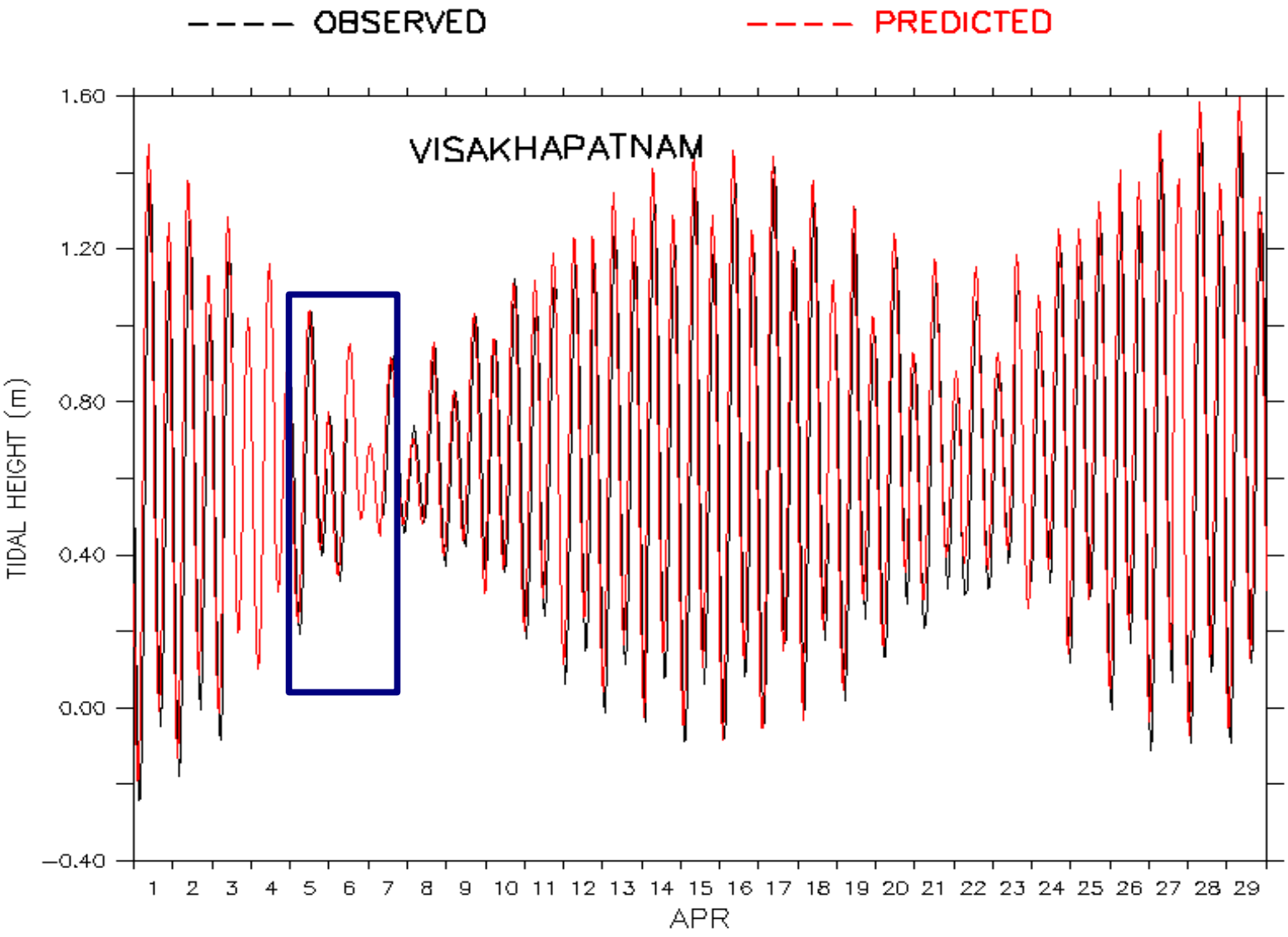


High Tide		Low Tide	
Time (IST)	Level (m)	Time (IST)	Level(m)
02-04-2014 06:18 AM	10.34	02-04-2014 01:03 AM	1.34
02-04-2014 06:43 PM	11.17	02-04-2014 01:13 PM	1.29
03-04-2014 06:56 AM	9.80	03-04-2014 01:45 AM	1.70
03-04-2014 07:22 PM	10.79	03-04-2014 01:52 PM	1.79
04-04-2014 07:34 AM	9.15	04-04-2014 02:28 AM	2.23
04-04-2014 08:01 PM	10.25	04-04-2014 02:31 PM	2.43
05-04-2014 08:14 AM	8.45	05-04-2014 03:13 AM	2.86
05-04-2014 08:45 PM	9.62	05-04-2014 03:12 PM	3.15
06-04-2014 09:00 AM	7.77	06-04-2014 04:01 AM	3.51
06-04-2014 09:36 PM	8.98	06-04-2014 03:57 PM	3.86

Five day predictions (time series as well as high and low tide timings)

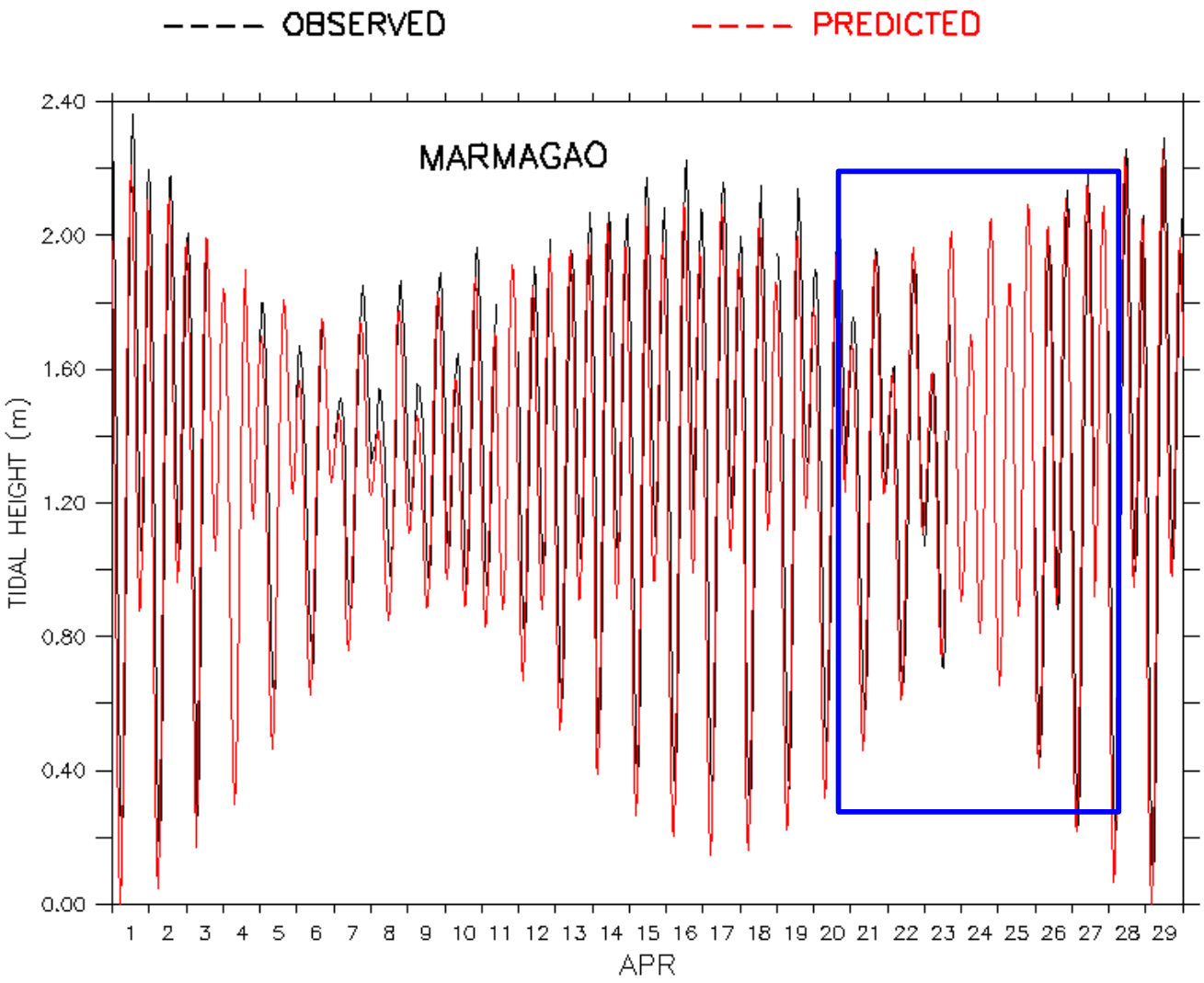
Validations (2008) !

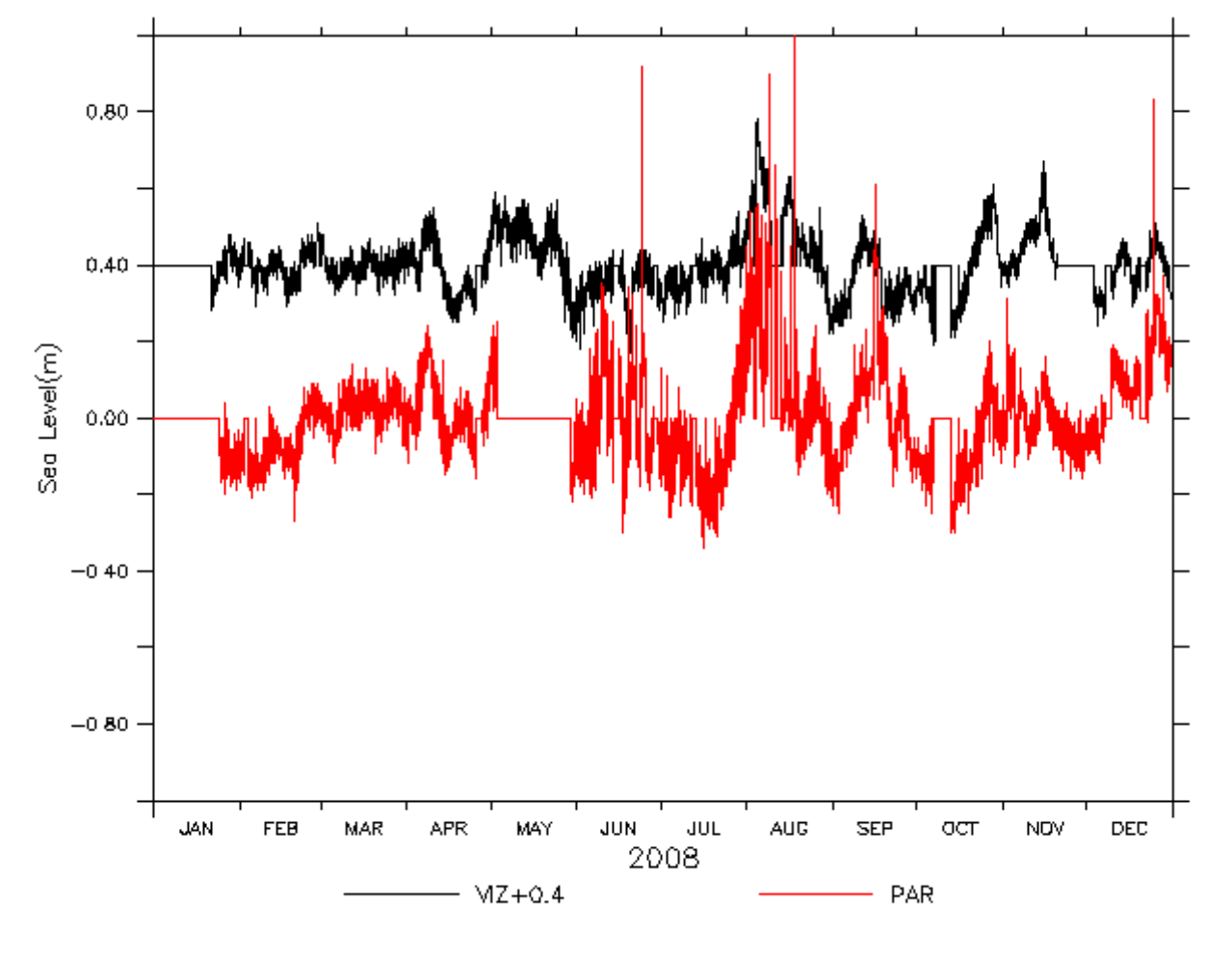
Sample plots showing the quality of observed sea level and predicted tidal heights.....



Validations (2008) !

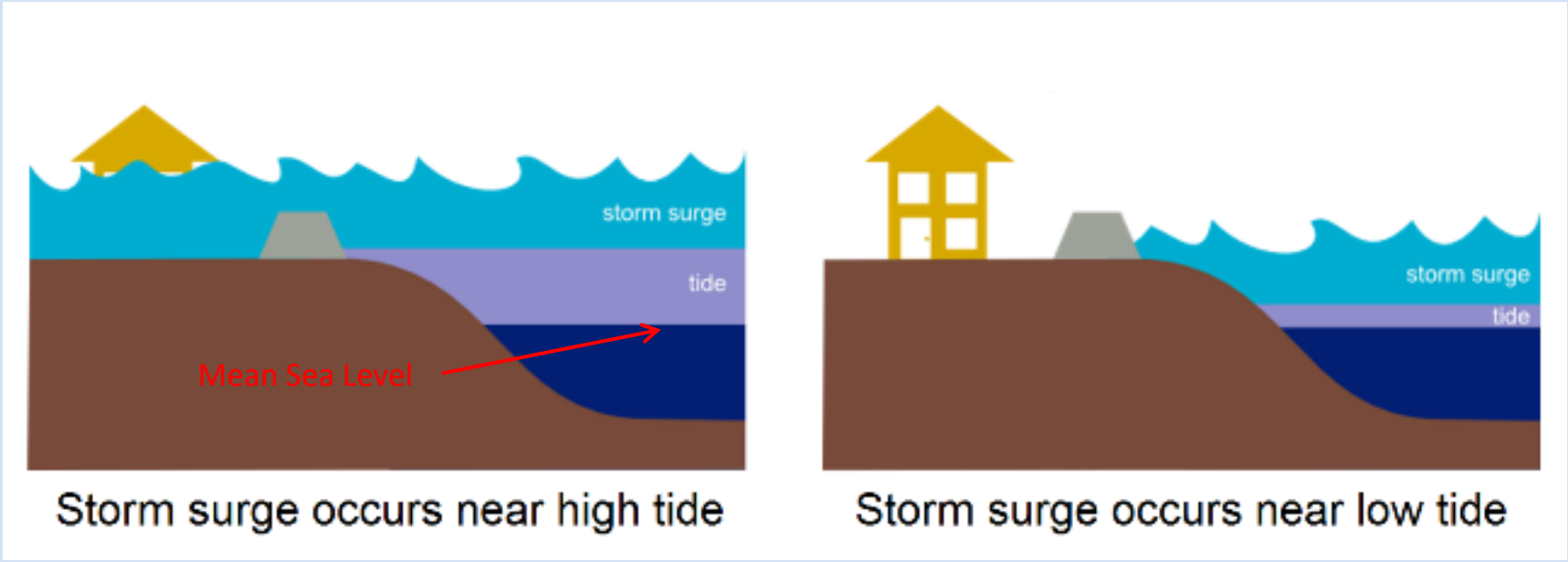
Sample plots showing the quality of observed sea level and predicted tidal heights.....





High Correlation between Visakhapatnam and Paradip (600 km) NON-TIDAL sea level

Why tide is important for Storm Surge studies !

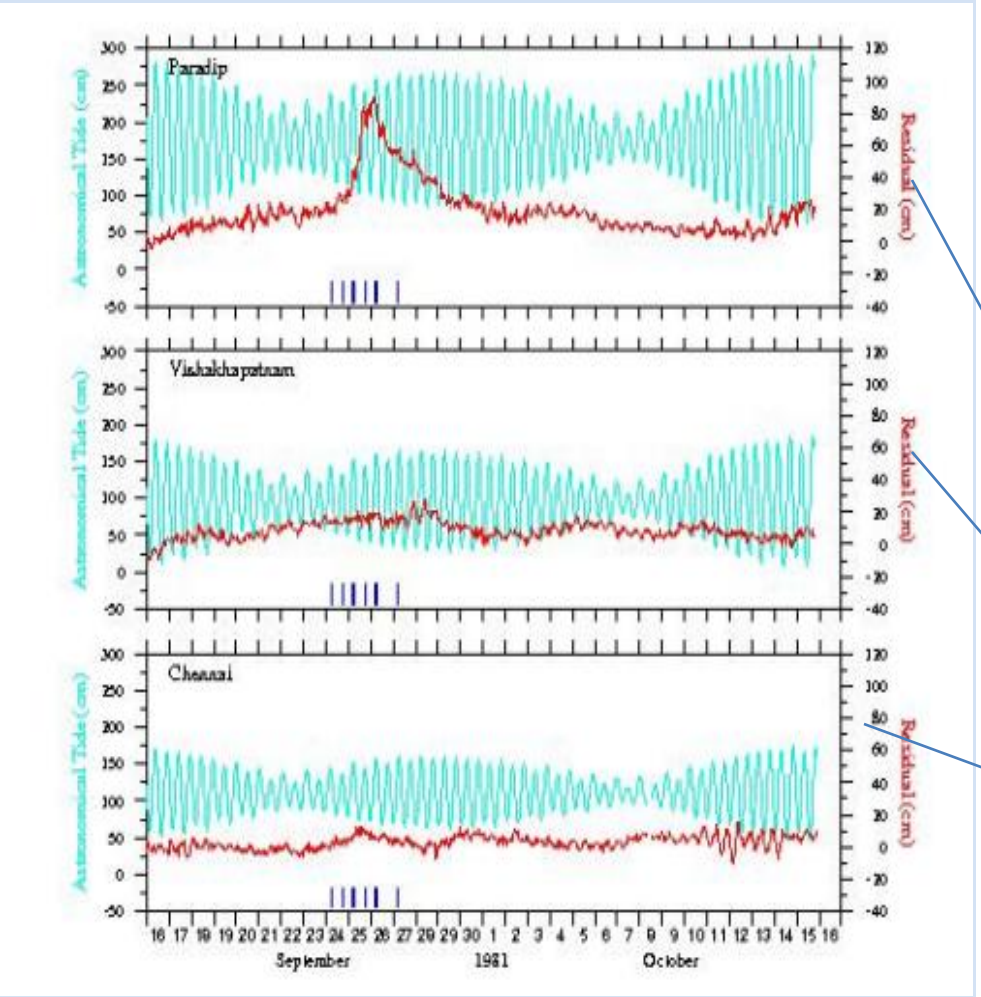


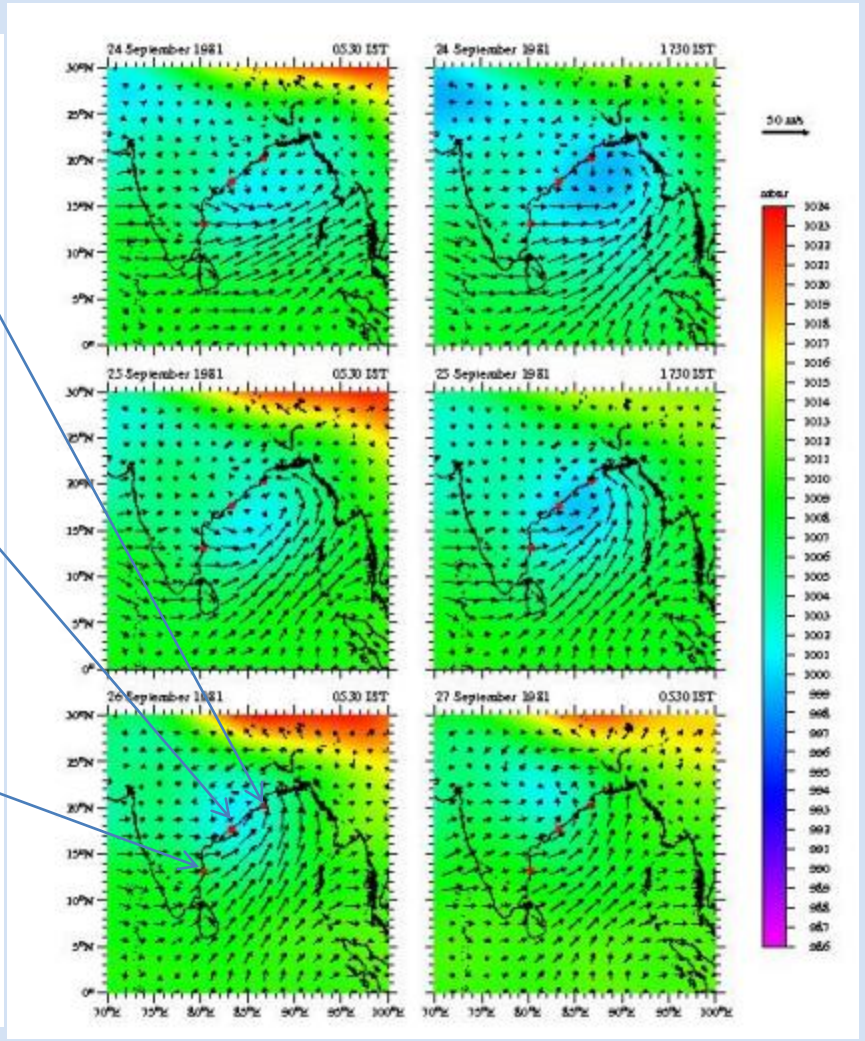
Storm surge is the change in sea level caused by storms…..

resulting from low pressure
high winds

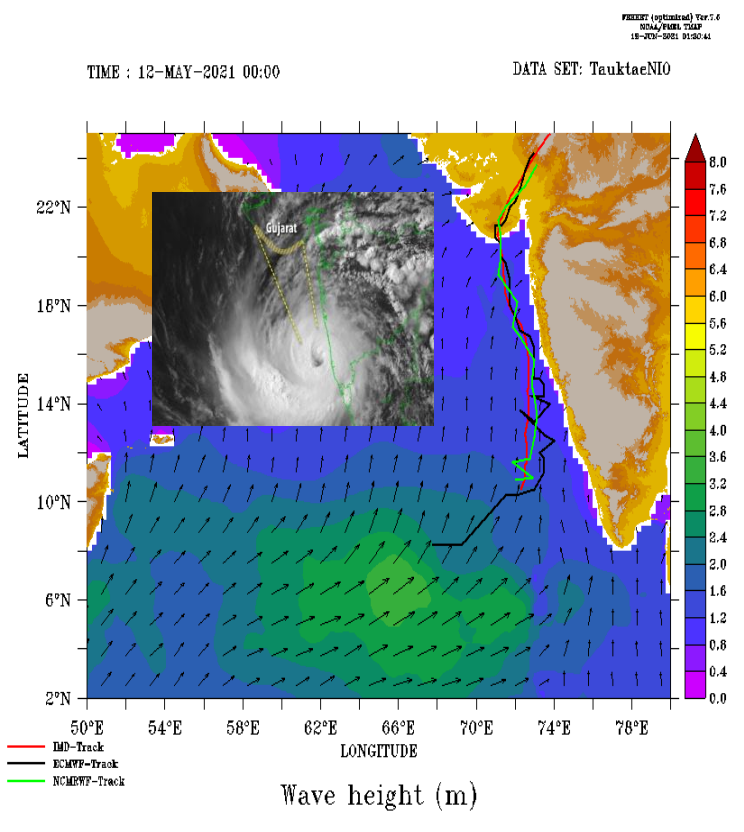
Flooding by "inverted barometer effect" and high winds, high waves and high rainfall and ***high tides*** *compound the damages*

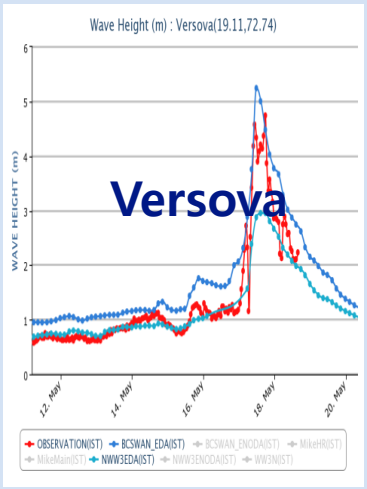
Indian east coast is very much prone !

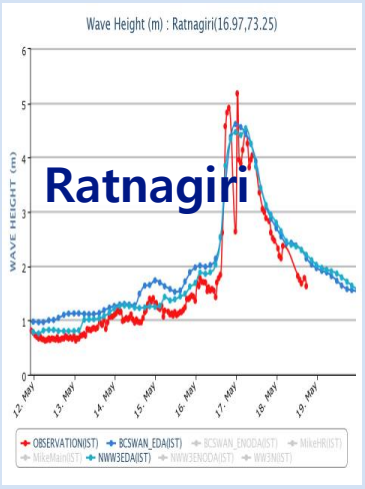


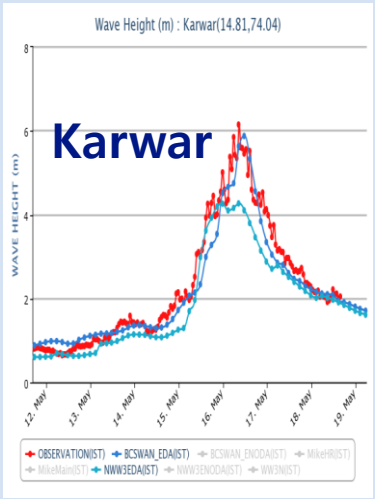


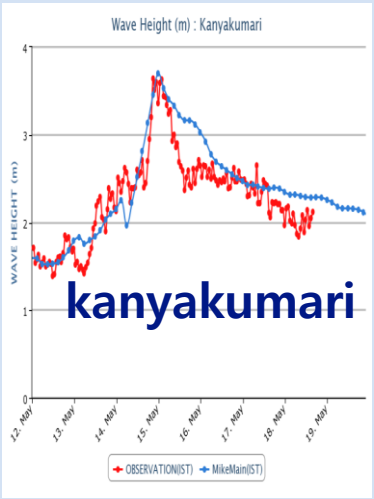
Extremely Severe Cyclonic Storm "Tauktae" (12 - 18 May 2021)
(Comparison with Buoys and Models)











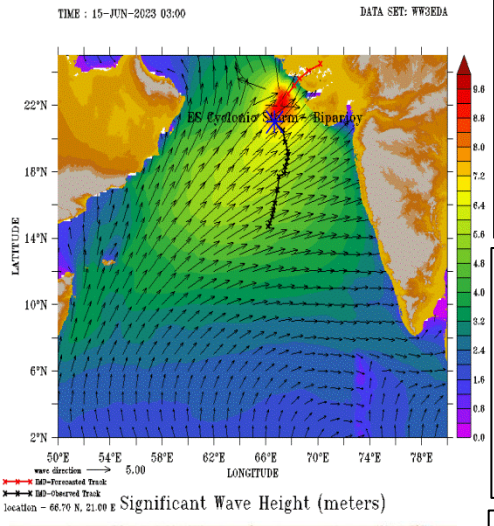
DISSEMINATION

SMS Alerts (12,53,449)
INCOIS-IMD Joint Bulletins (38) Bulletins sent to emails (13,964) High Wave Alerts/Warnings (44) NAVIC messages (30)

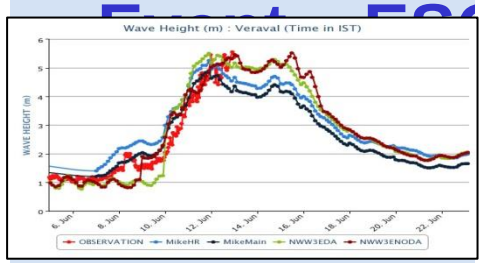
AFFECTED COASTLINES

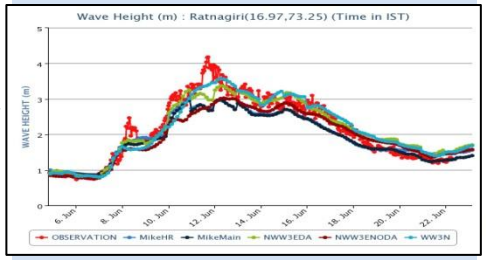
Southern Tamil Nadu , Kerala, Karnataka, Goa, Maharashtra, Gujarat and Lakshadweep Islands

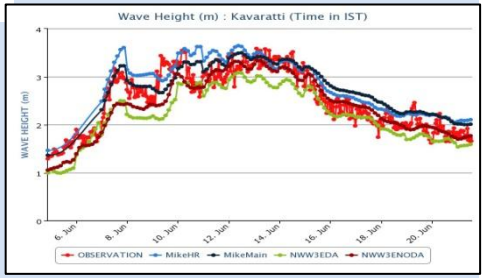
INCOIS-IMD Joint Bulletins during Extreme Weather Event – ESCS Biparjoy

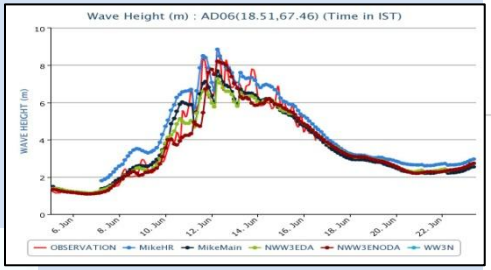


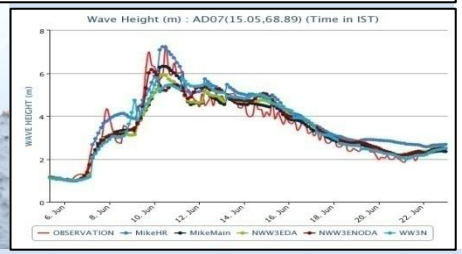
Significant Wave Height (meters)

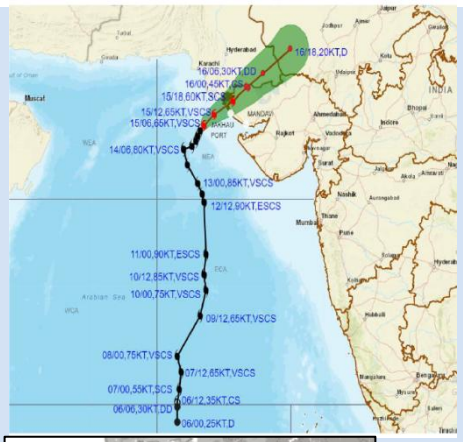


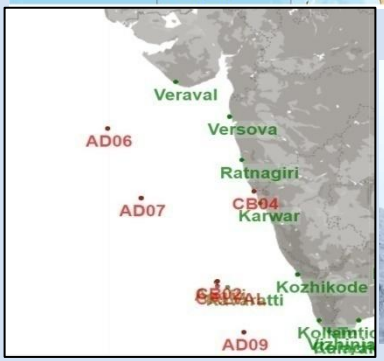












INCOIS

MESSAGE

INCOIS-IMD JOINT BULLETIN

Time of issue: 18:00 hours IST Dated: 14.06.2023, Bulletin No.: INCOIS/14/06/2023/06

Sub: INCOIS-IMD Joint Bulletin - Ocean State Forecast associated with Very Severe Cyclonic Storm "Biparjoy" (pronounced as "Biporjoy") over Northeast Arabian Sea: Cyclone Warning for Saurashtra & Kutch Coasts (Red Message)

The Very Severe Cyclonic Storm "Biparjoy" (pronounced as "Biporjoy") over Northeast Arabian Sea moved nearly northeastward during past 6-hours and lay centered at 1430 hours IST of today, the 14th June, 2023 over the same region near latitude 21.9°N and longitude 66.5°E, about 260 km southwest of Jakhau Port (Gujarat), 270 km west-southwest of Devbhumi Dwarka, 280 km west-southwest of Naliya, 330 km west of Porbandar, and 340 km south-southwest of Karachi (Pakistan).

It would continue to move nearly northeastwards and cross Saurashtra & Kutch and adjoining Pakistan coasts between Mandvi (Gujarat) and Karachi (Pakistan) near Jakhau Port (Gujarat) by evening of 15th June as a very severe cyclonic storm with maximum sustained wind speed of 125-135 kmph gusting to 150 kmph.

High Wave/Ocean State Alert/Warning Information for Gujarat, Maharashtra, Goa, Karnataka Kerala and Lakshadweep:

Gujarat

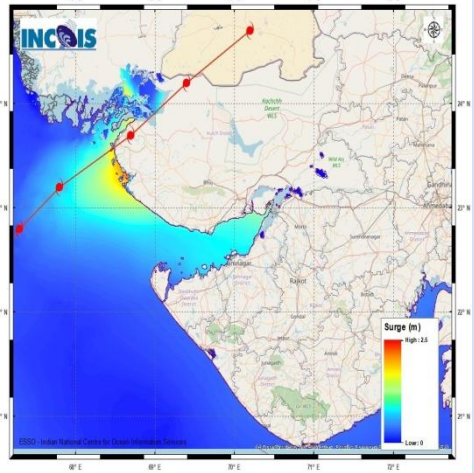
Table: Forecasted wave height and corresponding swell height, for coastal region, into the ocean up to 10 km off Gujarat

Location	From (IST)	To (IST)	Significant Wave height (m)	Swell height (m)
Kachch	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	5.5-7.7	3.9-5.0
Jamnagar	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	5.2-7.2	3.7-4.9
Porbandar	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	5.3-6.8	3.5-4.6
Junagadh	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	5.0-6.8	3.6-4.9
Diu	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	4.8-7.0	3.9-4.9
Amreli	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	5.0-6.9	3.7-4.9
Bhavnagar	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	4.7-6.7	3.6-4.8
Kheda	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	5.0-6.5	3.8-4.7
Bharuch	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	4.8-5.9	3.6-4.5
Surat	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	4.6-5.8	3.5-4.5
Navsari	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	4.7-6.2	3.5-4.5
Valsad	18:30hrs, 14-06-2023	23:30 hrs, 15-06-2023	4.6-6.4	3.5-4.1

Offshore: High waves in the range of 4.5 – 7.8 meters are forecasted during 18:30 hours on 14-06-2023 to 23:30 hours of 15-06-2023 beyond 10 km off the coast of Gujarat from Jakhau to Valsad. Current speeds vary between 100 - 195 cm/sec.

Mode	Number
SMS Alerts (through CAP platform)	5,62,37,066
NO. of INCOIS-IMD Joint Bulletins Issued	77
Bulletins sent to emails	27,794
No. of NAVIC messages	75

ESCS Biparjoy
Jun 6 – 16, 2023



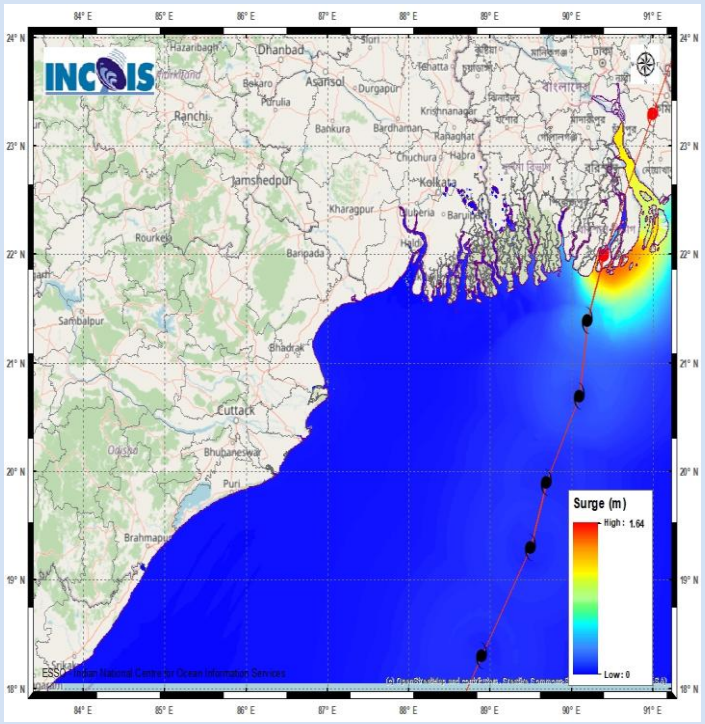
Strom surge forecast – 2.5m

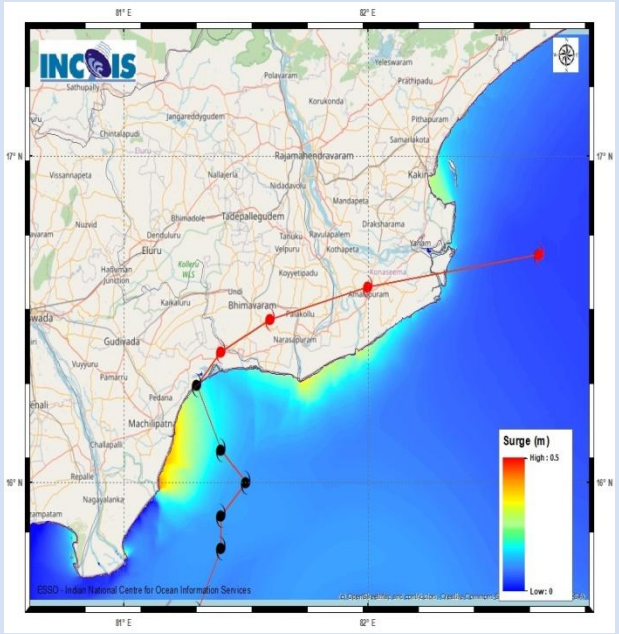
Storm Surge Warning Services

Real-time storm surge and inundation forecasts were issued (through IMD) during 2022 for the following cyclones

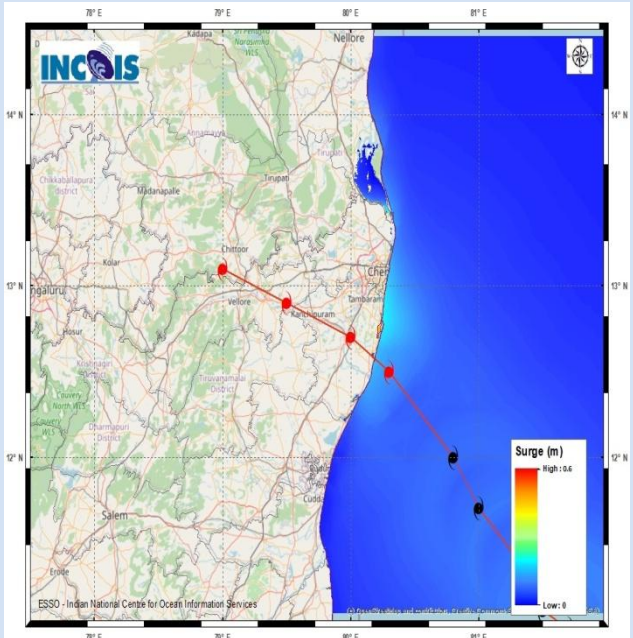
1. Asani (May 2022) – 0.5m
2. Sitrang (October 2022)- 1.64m
3. Mandous (December 2022) – 0.6m

Storm surge map during 'Sitarang' Cyclone



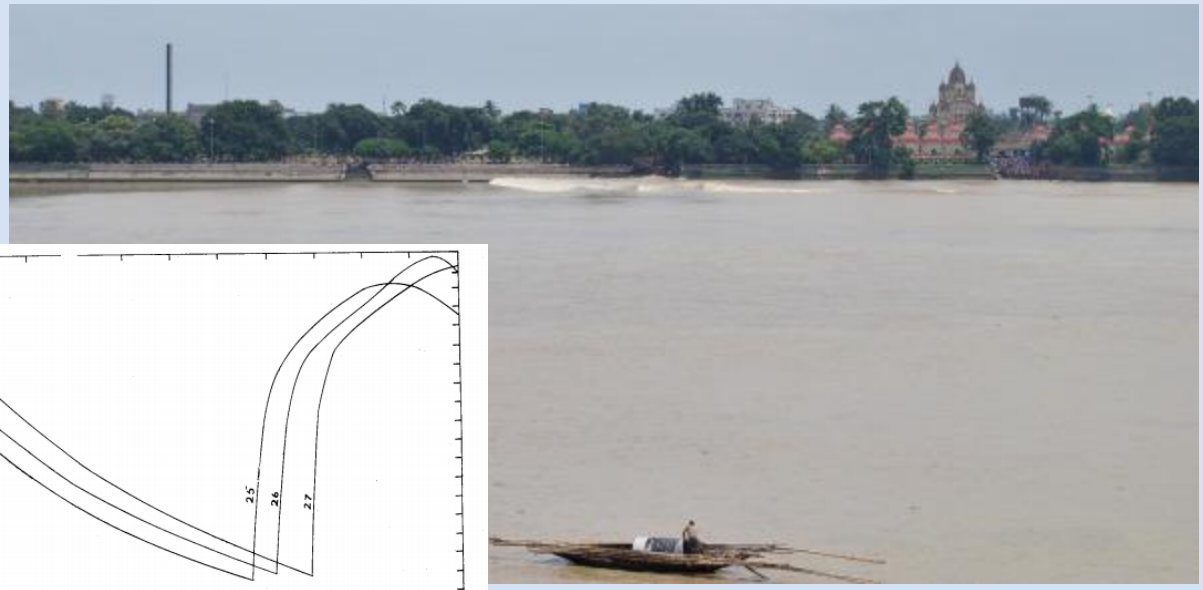


Storm surge map during 'Asani' Cyclone



Storm surge map during 'Mandous' cyclone

Unique phenomena : Tidal Bores (Hooghly River, Kolkotta)



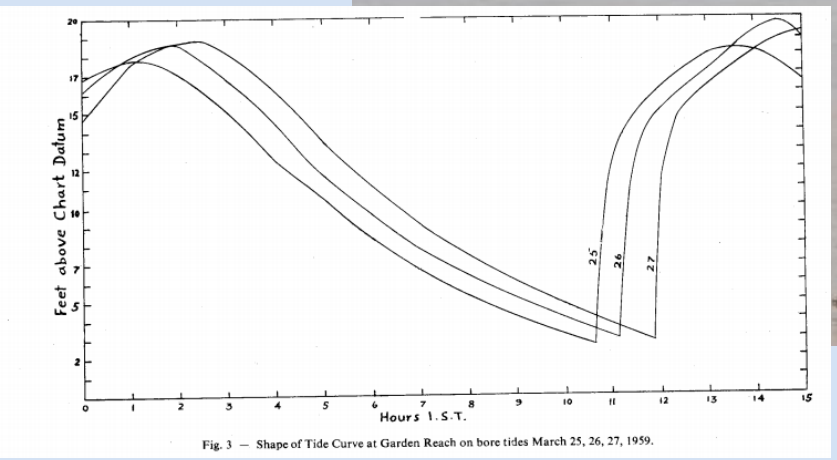


Fig. 3 — Shape of Tide Curve at Garden Reach on bore tides March 25, 26, 27, 1959.

TIDES IN HOOGHLY RIVER
SHRI R. S. CHUGH
A.M.I.S. , India
Published online: 29 Dec 2009

Comparison between SOI and INCOIS dissemination of tide data

	Survey of India	*INCOIS*
Dissemination mode	Indian Tide Tables	*Internet/EDBs/e-mail*
Format	Tabular (H/L lists)	*Time series plots, Tabular (H/L lists)*
Cost	Rs. 2600 for each volume	*---*
Total Stations	76	*178*
Indian Stations	30	*136*
Other Stations	46	*42*

INCOIS	
Country	Stations
India	136
Myanmar	12
Sri Lanka	11
Bangladesh	9
Chagos	5
Pakistan	4
Maldives	1
Total	**178**

Provided to users absolutely free in their desired format and dissemination mode

Number of constituents	Number of stations
< 10	69
11 to 20	3
21 to 30	32
31 to 40	61
41 to 50	0
51 to 60	13
Total	**178**

When more harmonic constituents are used..... predictions are more accurate !

TASK, 2000

Permanent Service for Mean Sea Level

and

Proudman Oceanographic Laboratory,

UK

software was used for the predictions

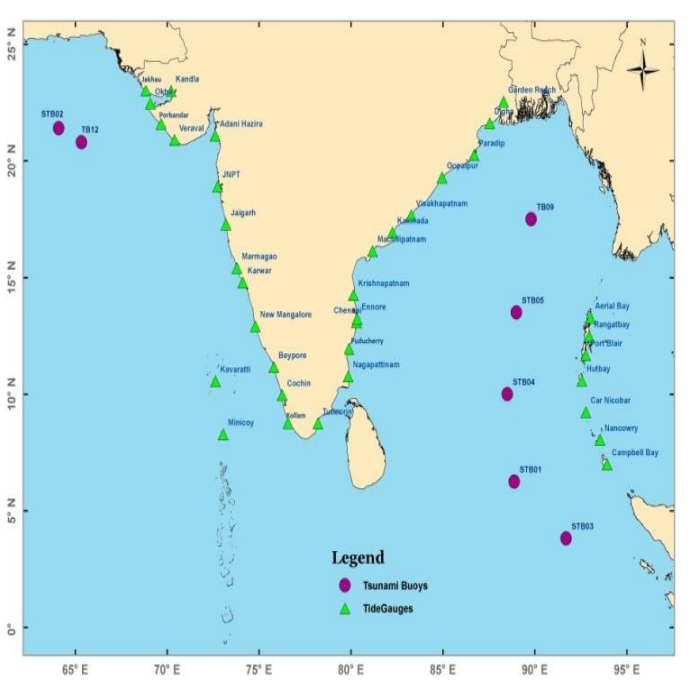
Comparison between SOI and INCOIS tabulated data

GALLE					
(Sri Lanka)		INCOIS	SOI	INCOIS	SOI
	PHASE	Time	Time	Height (m)	Height (m)
01/01/10	High	02:47	02:46	0.75	0.76
01/01/10	Low	08:59	09:12	0.17	0.16
01/01/10	High	15:13	15:10	0.63	0.64
01/01/10	Low	20:51	20:58	0.21	0.18

Akyab					
Myanmar		INCOIS	SOI	INCOIS	SOI
	PHASE	Time	Time	Height (m)	Height (m)
01/01/10	Low	04:00	04:02	0.04	0.02
01/01/10	High	09:54	10:00	1.99	2.06
01/01/10	Low	15:57	16:00	-0.07	-0.13
01/01/10	High	22:17	22:28	2.54	2.54

BEYPORE					
(Kerala)		INCOIS	SOI	INCOIS	SOI
	PHASE	Time	Time	Height (m)	Height (m)
20-07-10	High	07:39	07:40	1.14	1.15
20-07-10	Low	12:15	12:03	0.92	0.92
20-07-10	High	17:05	17:06	1.14	1.17

Sea Level Observational Network



- Network of **7 Tsunami Buoys**
- Network of **36 Tide gauges**
- Three types of Sensors at each location : **Radar (RAD)**, Pressure (PRS) and Shaft Encoder (ENC)

Observation networks

- **Tide gauges**
  - *Stilling well and float*

    The filtering of the waves is done through the mechanical design of the well.
  - *Pressure system*

    Sub-surface pressure is monitored and converted to height based on knowledge of the water density and local acceleration due to gravity.
  - *Acoustic system/Radar system*

    The transit time of a sonic/radar pulse is used to compute distance to the sea surface.

Thank you…….

The purpose of tide analysis is to determine
the *amplitude* and *phase* (the so-called *tidal harmonic constants*) of the individual cosine waves,
each of which represents a *tidal constituent* identified by its *period*

Finding the tidal harmonic constants at a place allows one to predict tides at that place.
the *partial tide* corresponding to a single tidal constituent is represented by the following equation

$$f(t) = H \cos(at + phi).$$

" *f* " is the height of the partial tide
The time "*t* "is measured in hours
H is the amplitude
a is the speed of the constituent
Phi the phase of the constituent.