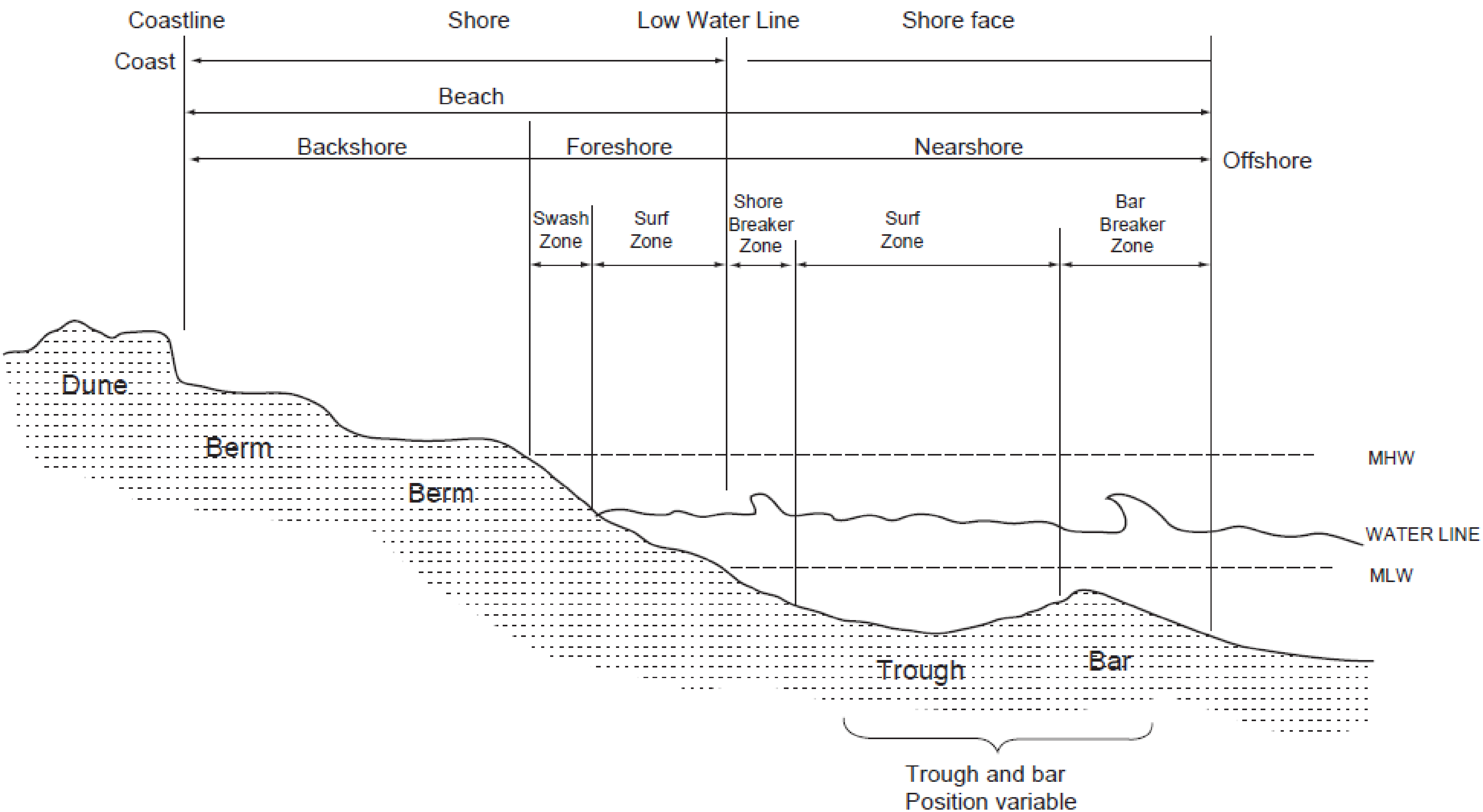
Coastal dynamics, nearshore and beach processes

Dr. Sanil Kumar
Chief Scientist &
Head, Ocean Engineering Division
CSIR-National Institute of Oceanography, Goa
email: sanil@nio.org
www.nio.org

20 February 2023



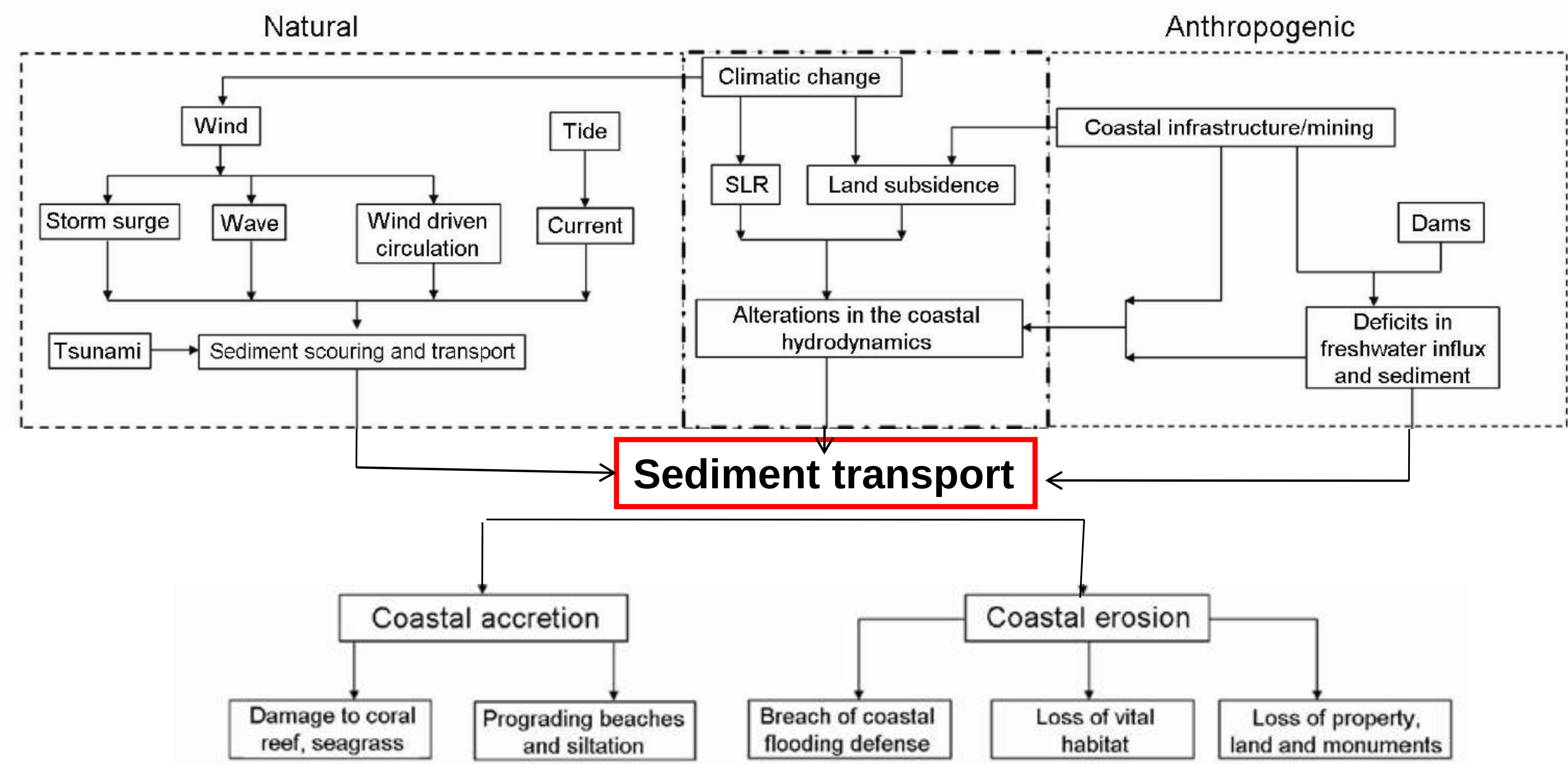
SPM, 1984

Coastal zone and associated terminology

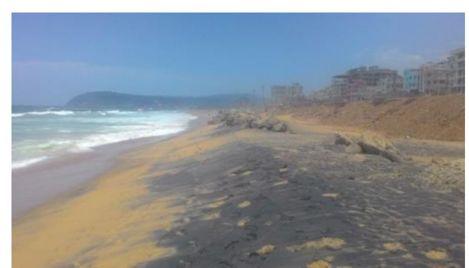
Nearshore region including the inner-shelf, surfzone, swash, beach, dunes, tidal-inlet, estuary, and city

Shore & Beach Vol. 83, No. 1, 2015

COASTAL MORPHODYNAMICS



Modified from: Rajawat et al. (2015)



Factors influencing the coastal morphological changes

- waves, currents, tides, wind
- sediment transport

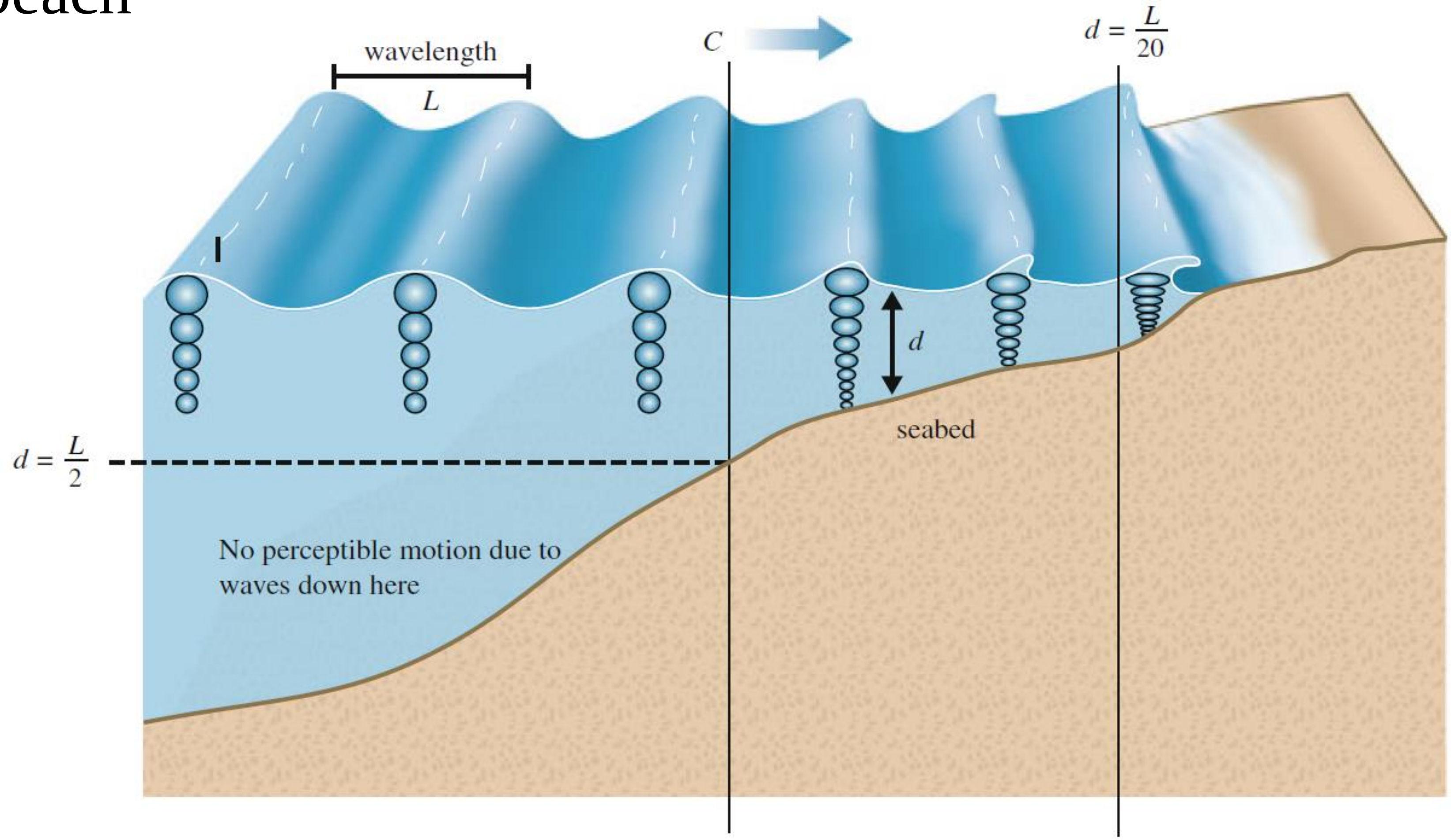
Changes in waves and currents influence coastal circulation -coastal geomorphology

Evaluation of coastal morphological changes

- beach profiles
- nearshore bathymetry
- Waves
- Currents
- Tides
- wind
- beach and nearshore sediments
- longshore sediment transport
- shoreline changes

Spatial and temporal resolution of the data

Waves are the largest contribution of energy from sea to the beach



Deep-water waves:

$$d > \left(\frac{L}{2}\right)$$

C, *L* and *h* constant over long distances

Transitional water waves:

$$\left(\frac{L}{20}\right) < d < \left(\frac{L}{2}\right)$$

C and *L* decrease, wave height increases, rounded tops form peaks

Shallow water waves:

$$d < \left(\frac{L}{20}\right)$$

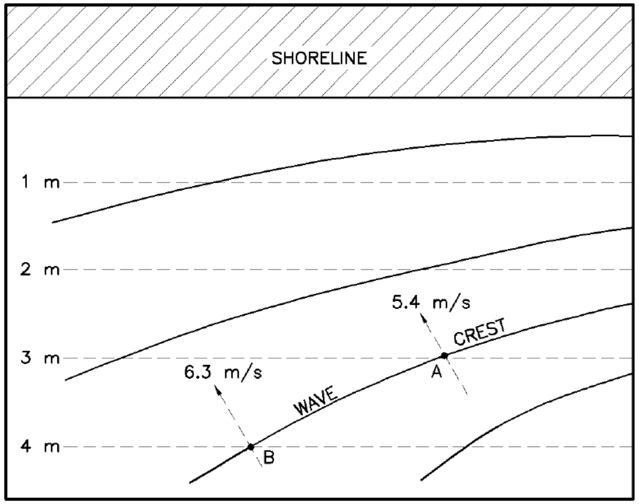
The wave breaks

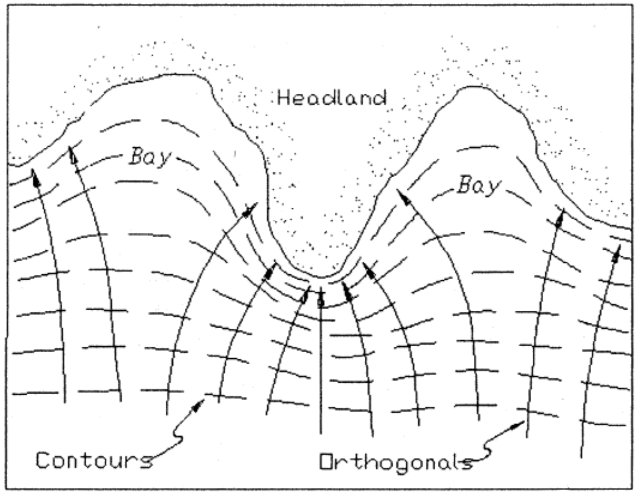
Garrison (2010)

NIO understanding the seas

Wave transformation

Wave propagates from deep to shallow water
(a) Refraction
(b) Shoaling
(c) Diffraction
(d) Dissipation due to friction
(e) Dissipation due to percolation
(f) Breaking
(g) Additional growth due to the wind
(h) Wave-current interaction
(i) Wave-wave interactions

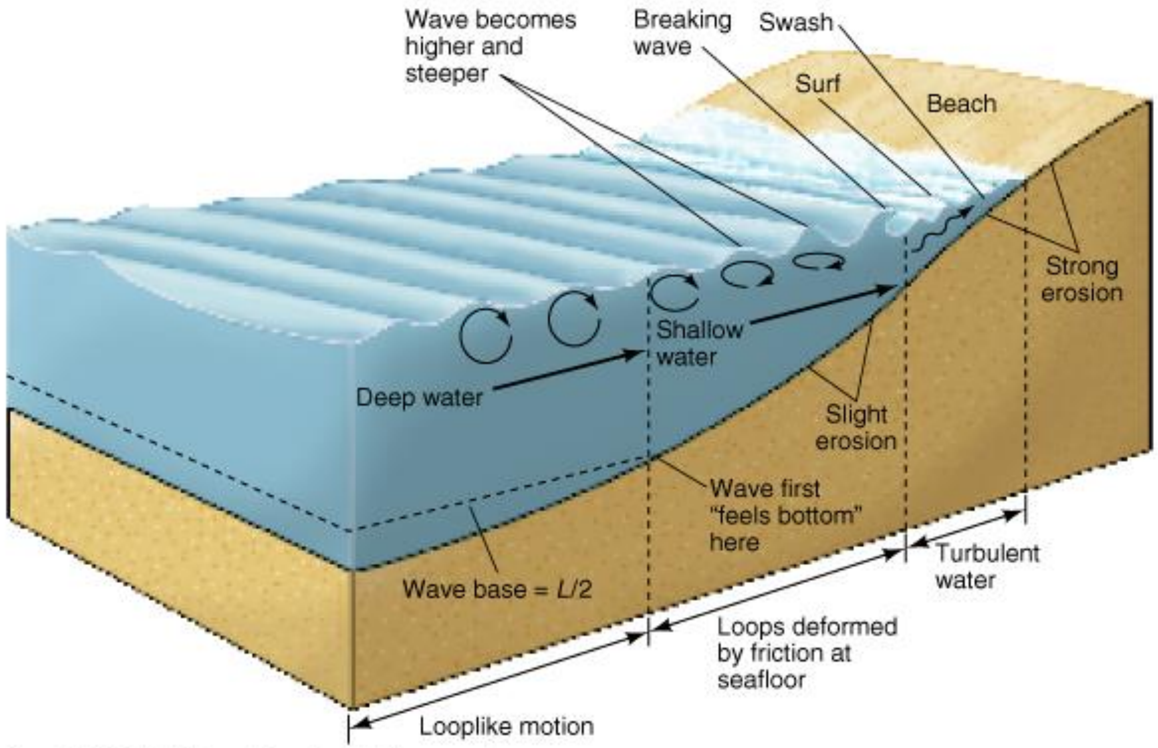




Wave refraction

Refraction

As waves approach shore, the part of the wave in shallow water slows down
The part of the wave in deep water continues at its original speed
Causes wave crests to **refract (**bend)
Results in waves lining up nearly parallel to shore



Wave shoaling : Change in shape as wave nears the shore

When waves enter shallow water they slow down, the wave length is reduced. The energy flux remain constant and the reduction in group (transport) speed is compensated by an increase in wave height (and thus wave energy density).

Wave breaking

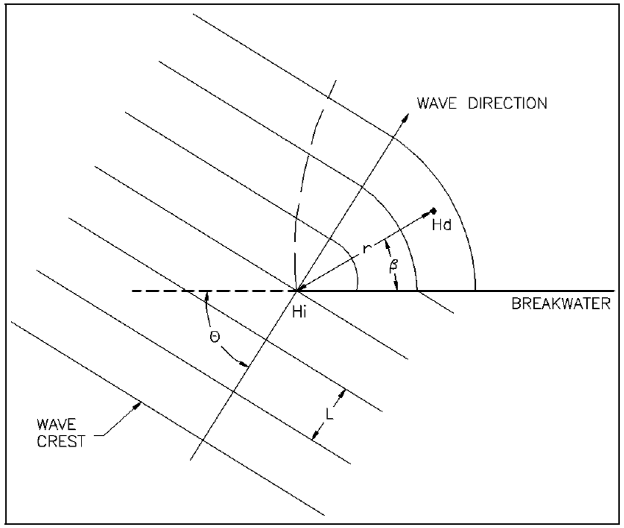
wave steepness (H/L) > 1/7
H/d > 0.79.

H wave height
L wave length
D water depth

NIO understanding the seas

Wave transformation

Wave propagates from deep to shallow water
(a) Refraction
(b) Shoaling
(c) Diffraction
(d) Dissipation due to friction
(e) Dissipation due to percolation
(f) Breaking
(g) Reflection
(h) Additional growth due to the wind
(i) Wave-current interaction
(j) Wave-wave interactions



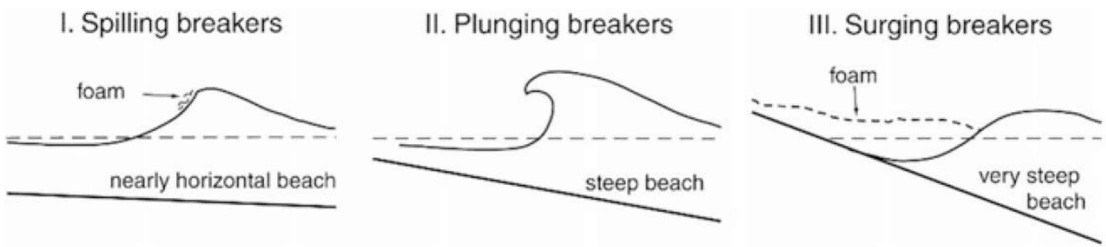
Wave energy is **reflected** (bounced back) when it hits a solid object

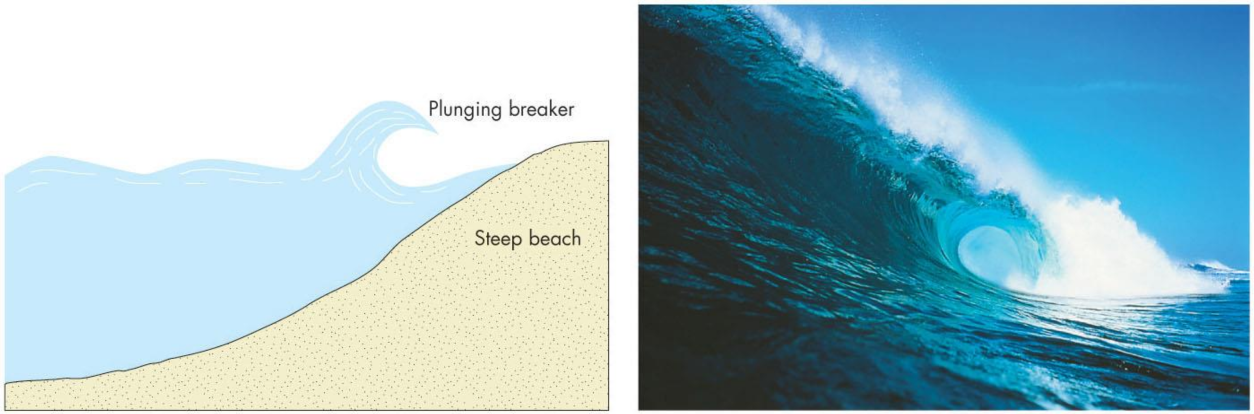
Wave diffraction

Breaker type

breakers

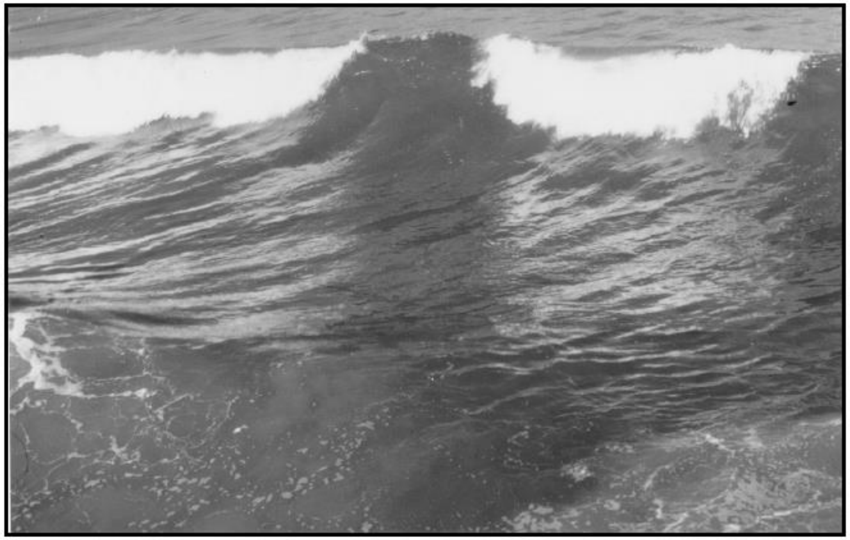
- Spilling
- Plunging
- Surging





(a)

(b)

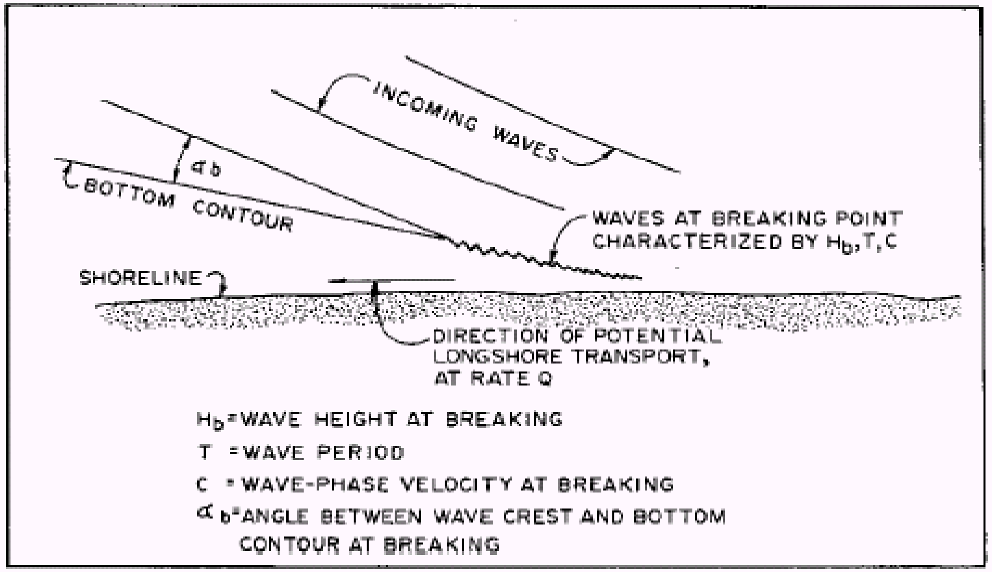


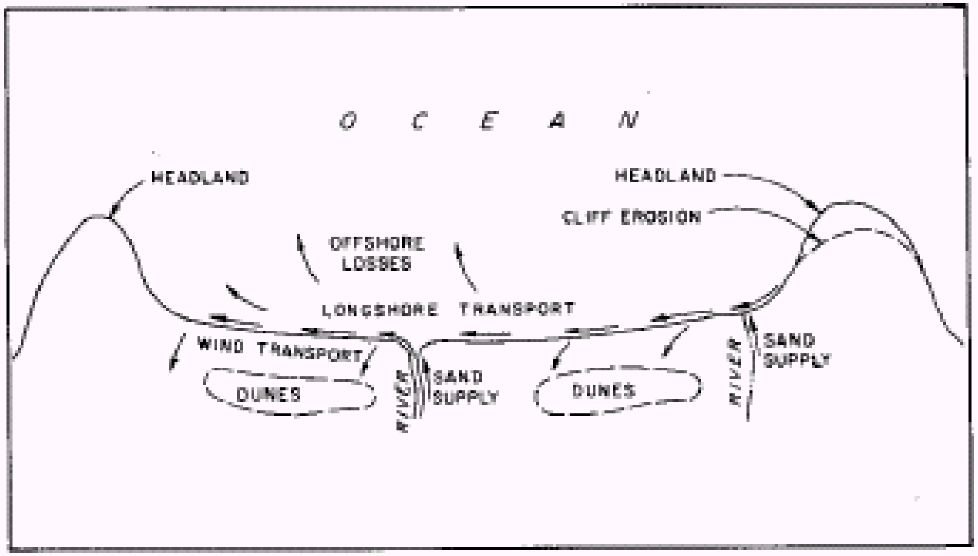
a) Spilling breaking wave

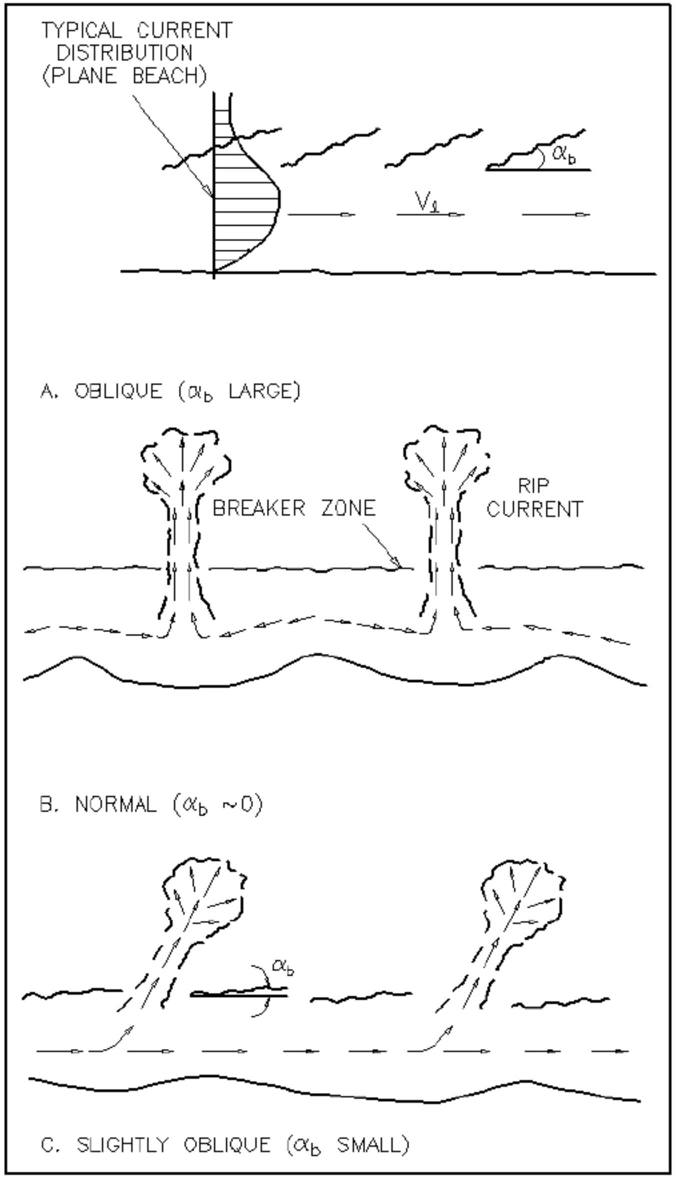
b) Plunging breaking wave

c) Surging breaking wave

d) Collapsing breaking wave







CEM, 2002

Wave breaking and longshore current

Longuet-Higgins (1970) and others applied the time-averaging principles to the depth-integrated momentum balance equation to obtain the longshore current

$$V = 20.7 m_b (gH_b)^{1/2} \sin(2\alpha_b)$$

Galvin (Galvin and Eagleson, 1965)

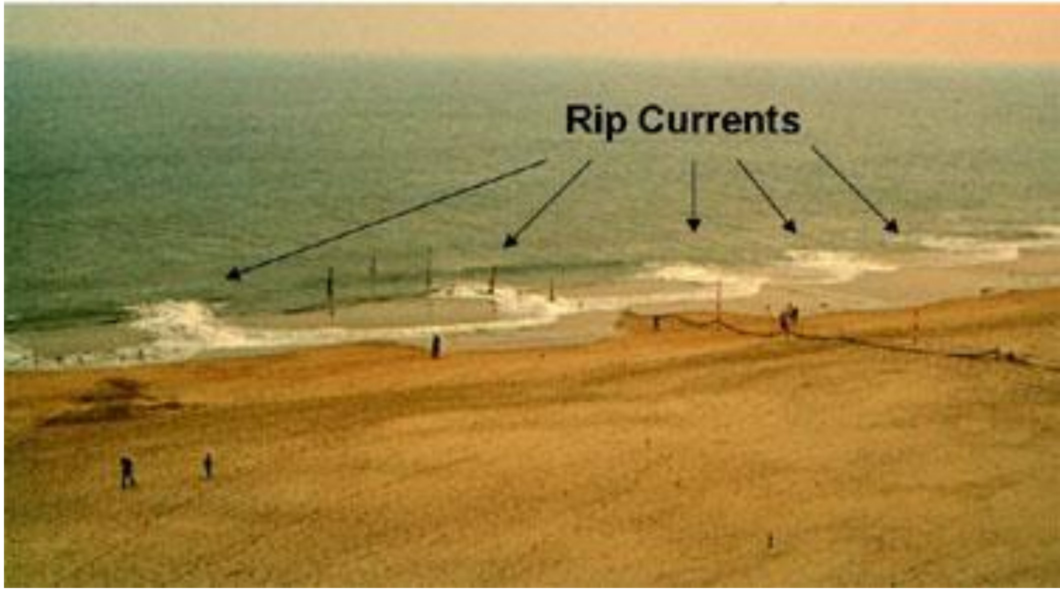
$$V = K g m_b T (\sin 2\alpha_b)$$

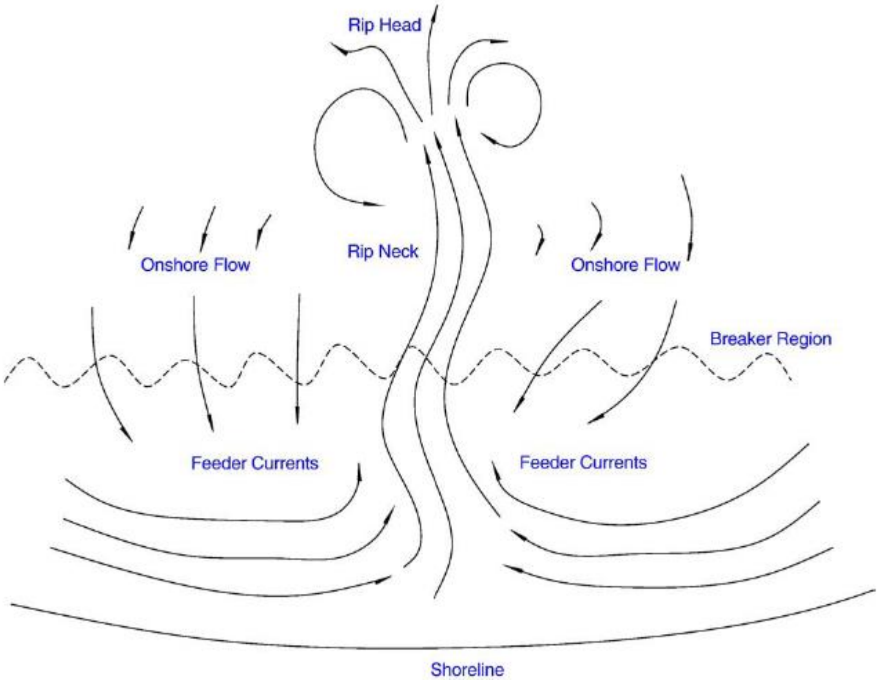
NIO understanding the seas

Rip current

Strong, narrow seaward current from shoreline to the breaker zone

Dangerous to swimmers





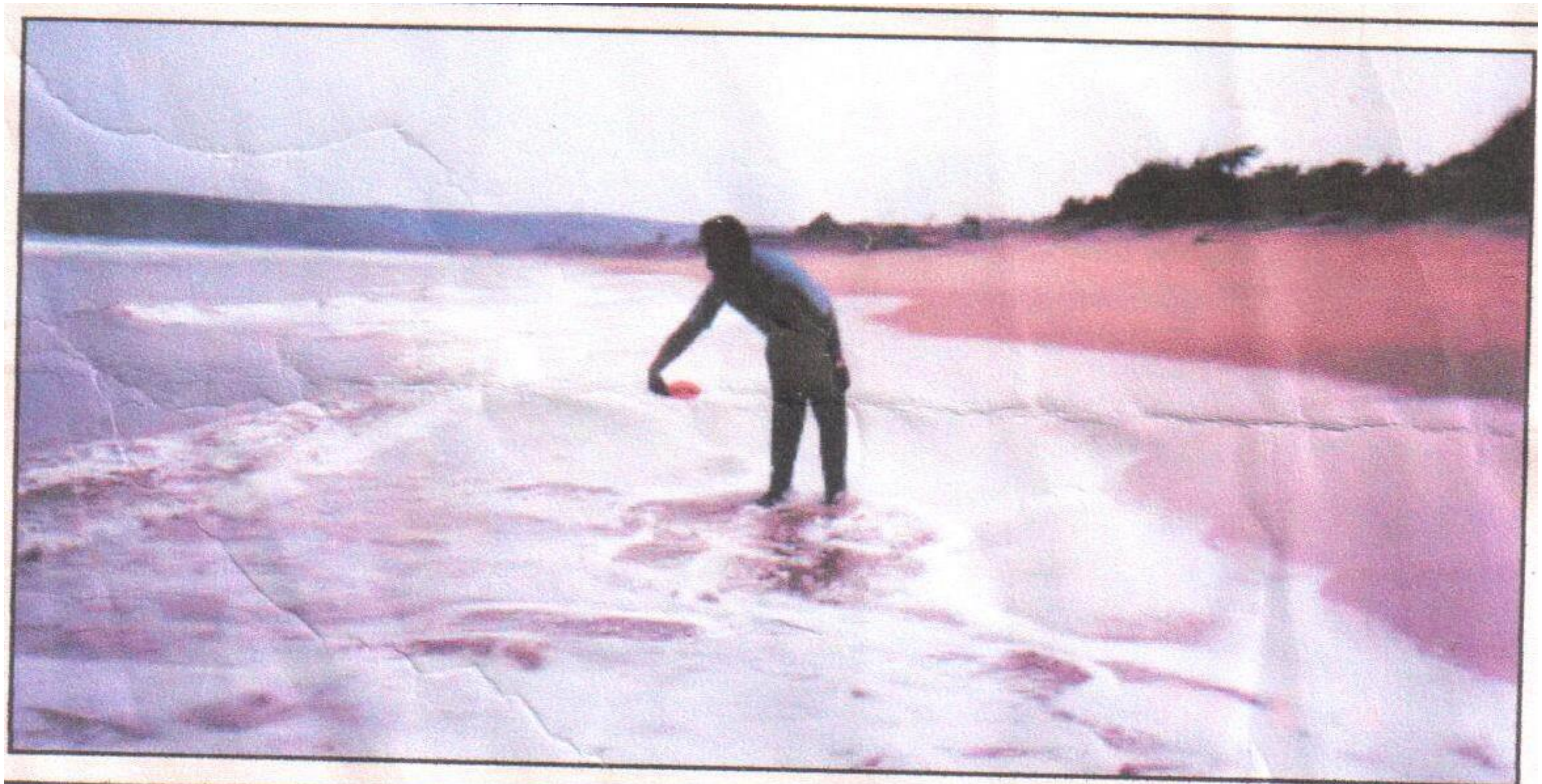
Shepard et al. (1941).

NIO understanding the seas

LITTORAL ENVIRONMENTAL OBSERVATION

Station name:

Date & Time	Wave Height (m)	Wave period (s)	Breaker angle	Breaker type	Surf zone width (m)	Longshore current speed (m/minute)



Longshore sediment transport

Measurement of LST fluxes

Deploying instruments or sediment traps in the surf zone is challenging and complex

Measurement of changes in shoreline and nearshore

During high breaking wave conditions, the logistical difficulties hinder the collection of field data

Using empirical formula or process based models

Two fundamental approaches; Both are useful in engineering practices

Empirical formula: estimate LST rate with few input parameters (e.g., CERC, 1984; Kamphuis, 2002)
Process based models: more spatio-temporal information; accurate LST; but require more information regarding input data parameters (e.g.,UNIBEST-CL, Delft3D)

Longshore sediment transport

Walton & Bruno (1989)

$$Q = \frac{KA\rho g H_b W V C_f}{0.78\left(\frac{5\pi}{2}\right)\left(\frac{v}{v_0}\right)_{LH}}$$

CERC (1984)

$$Q = KA\frac{\rho g^2}{64\pi} T H_b^2 \sin 2\alpha_b$$

Q	= LST rate
K	= constant
W	= surf zone width
V	= longshore current velocity (m/s)
H_b	= breaking wave height (m)
T	= wave period (s)
ρ	= mass density of seawater
$(v/v_o)_{LH}$	= theoretical dimensionless velocity
α_b	= breaker angle with respect to coast

$$A = 1/[(\rho_s - \rho)g(1 - p)],$$

Kamphius et al. (2002)

$$Q = \left(\frac{ilk}{(\rho_s - \rho)g(1 - p)}\right)$$

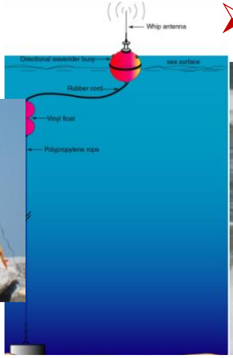
Tp	=peak wave period (s),
d50	=sediment mean grain size (mm).

NIO understanding the seas

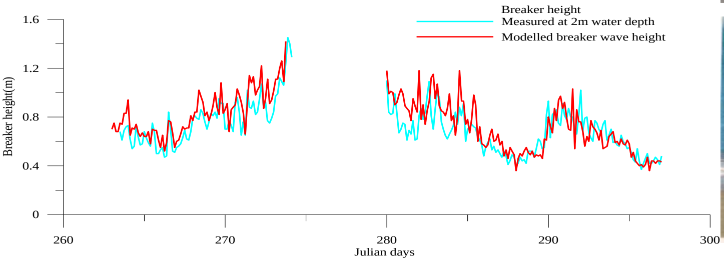
$$ilk = 2.27 H_b^{\,2} T_P^{\,1.5} m^{0.75} d50^{-0.25} \sin(\alpha_b)$$

- *Near shore wave, currents and wind variations*
- *Beach and shoreline measurements*
- *Wave transformation in surfzone*
- *Surfzone currents measurements & modelling*
- *Longshore sediment transport rates estimation*



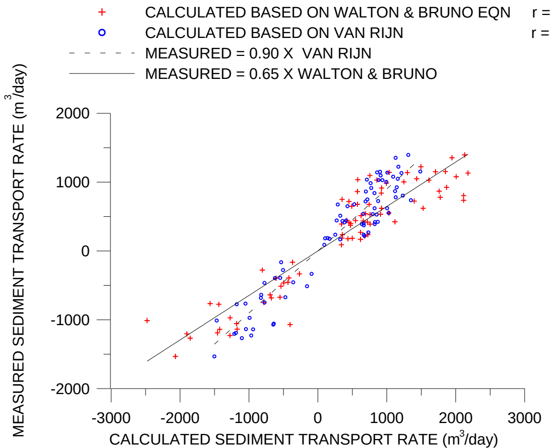



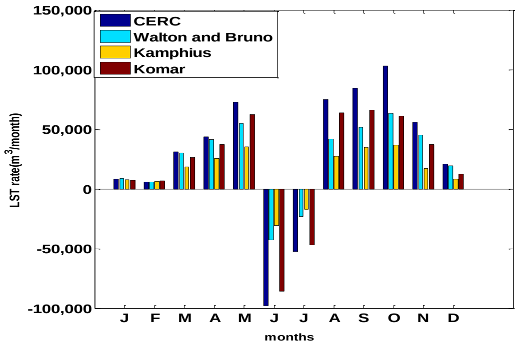




WW3 – deep water
Delft3D – nearshore
Littoral drift
Process based models
& Bulk formulas





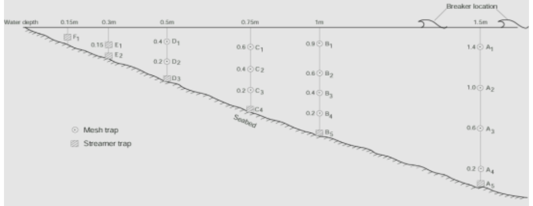
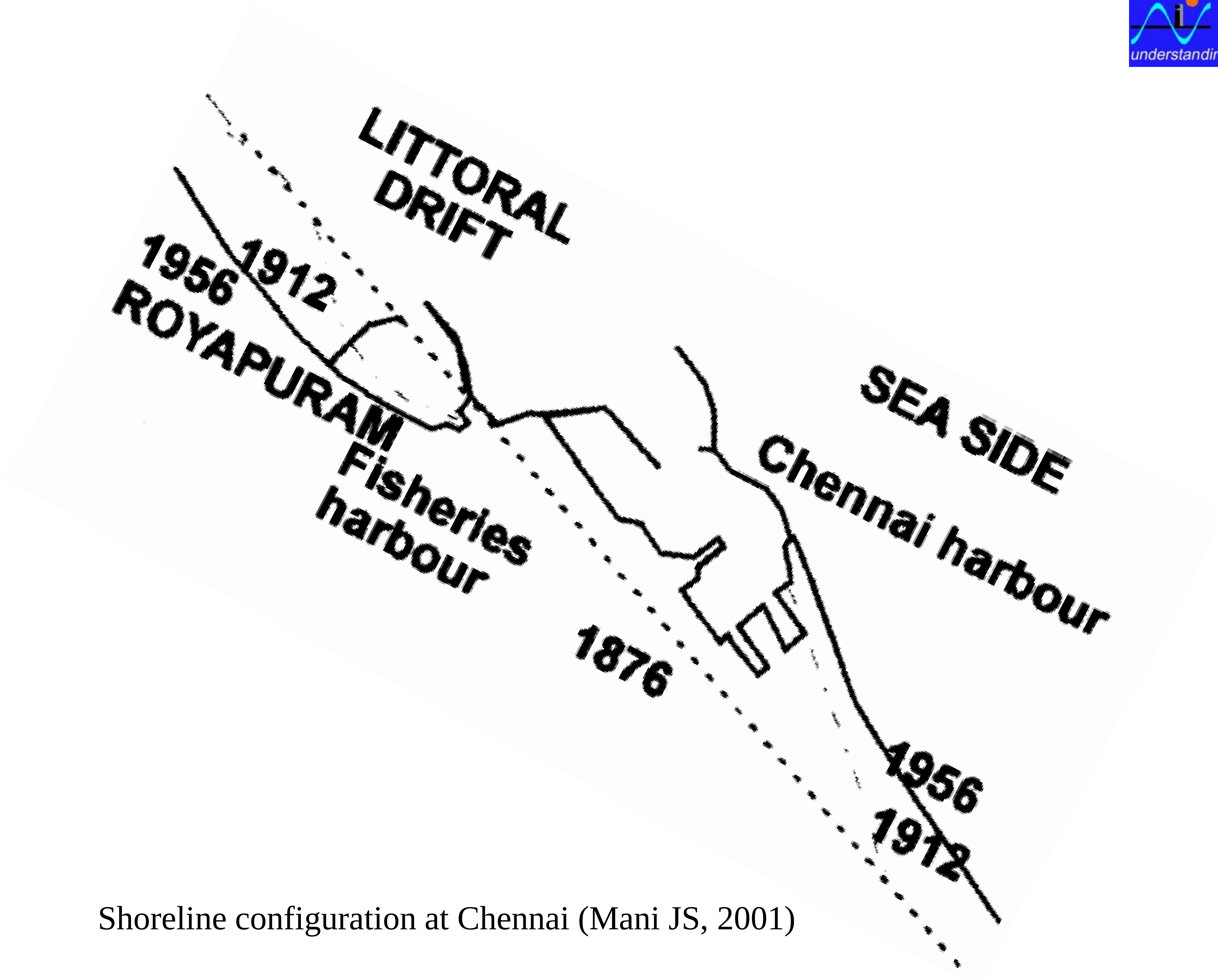


Fig. 3. Configuration of samplers used

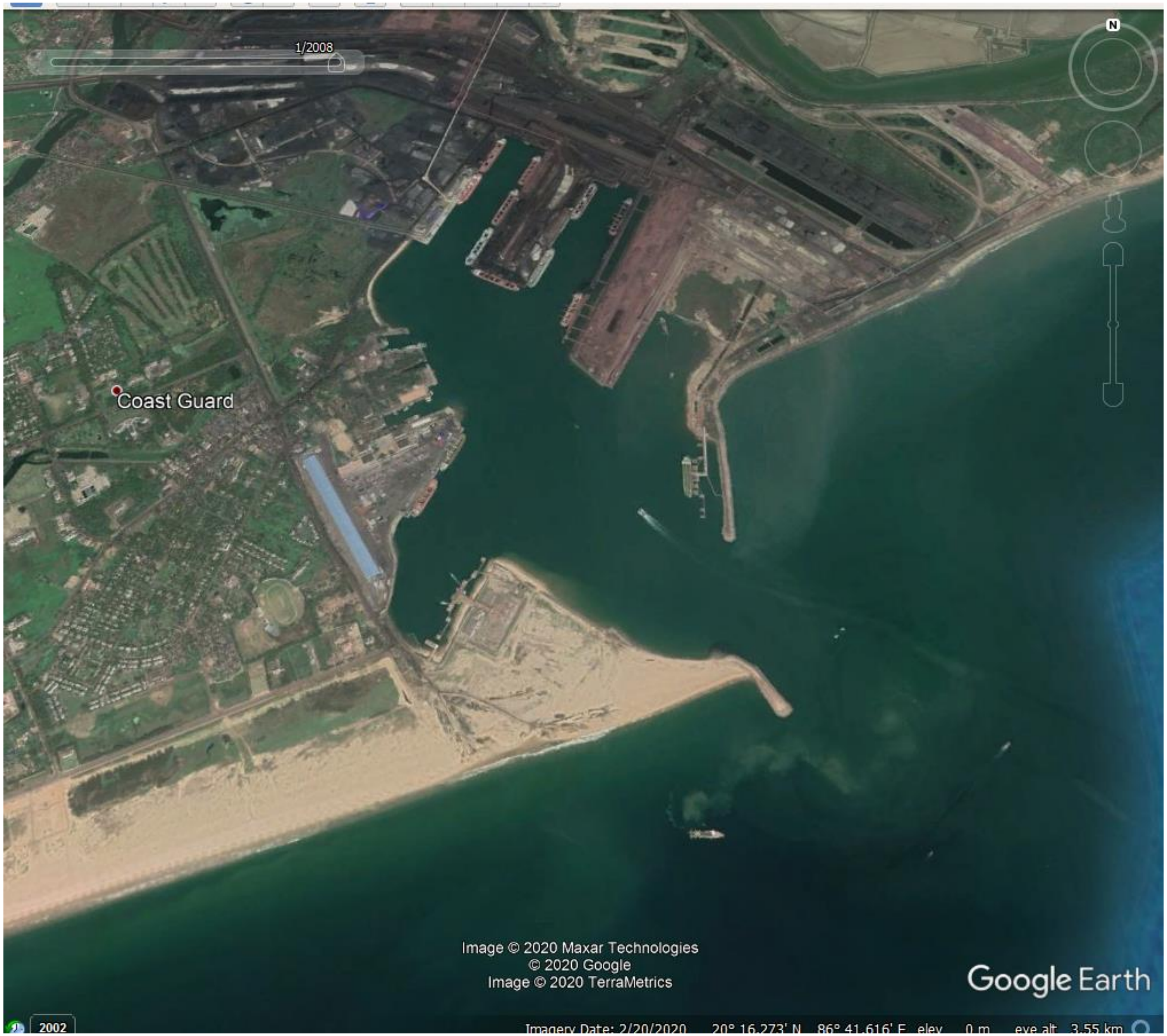

Kumar et al., (2003) Coast Engg.; Sajiv et al. (2014) IJSR;
Kumar and Shanas (2014) Geomorphology; Kumar et al. (2017) J Coast Cons.

NIO



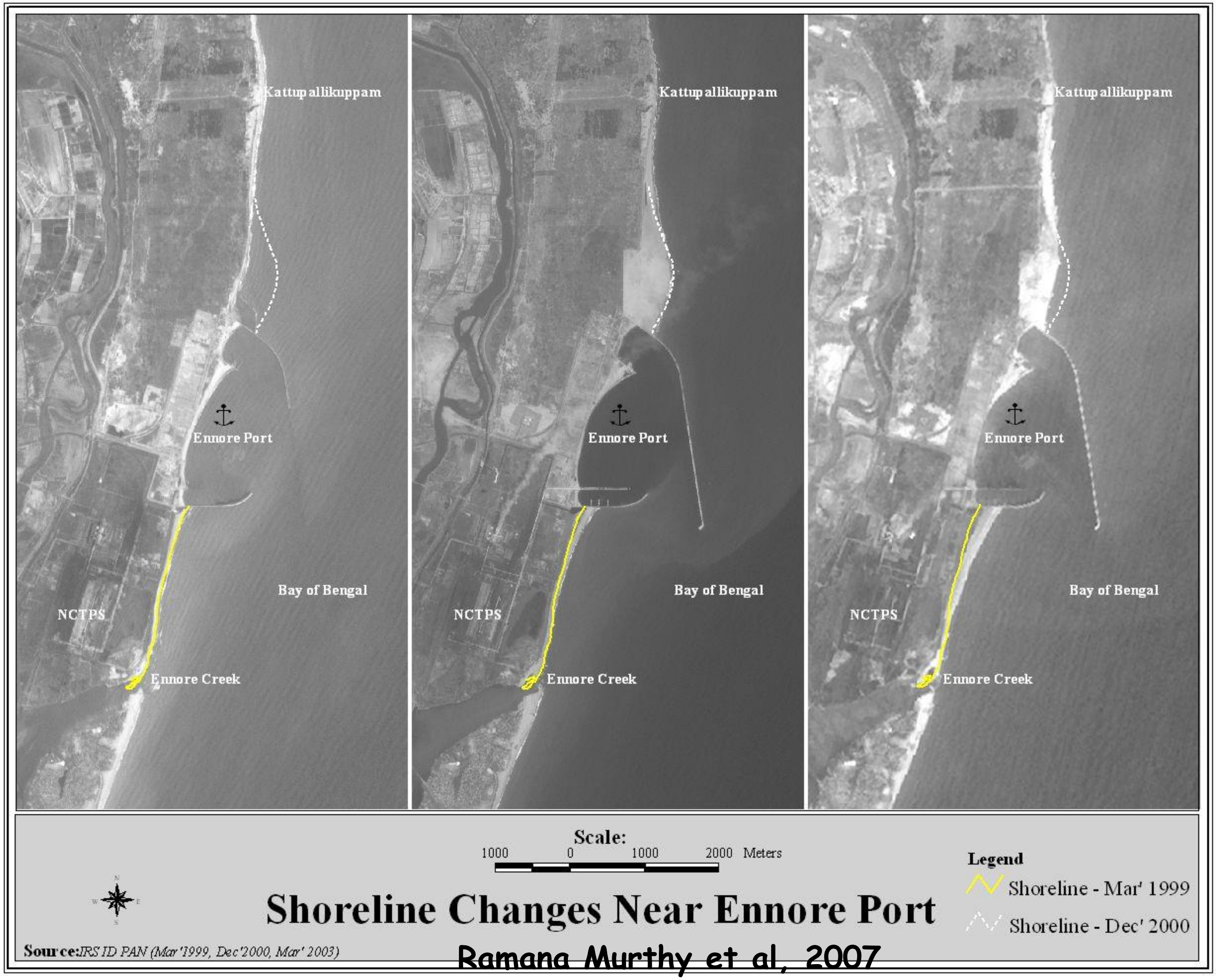
Shoreline configuration at Chennai (Mani JS, 2001)

Shoreline change due to marine structures



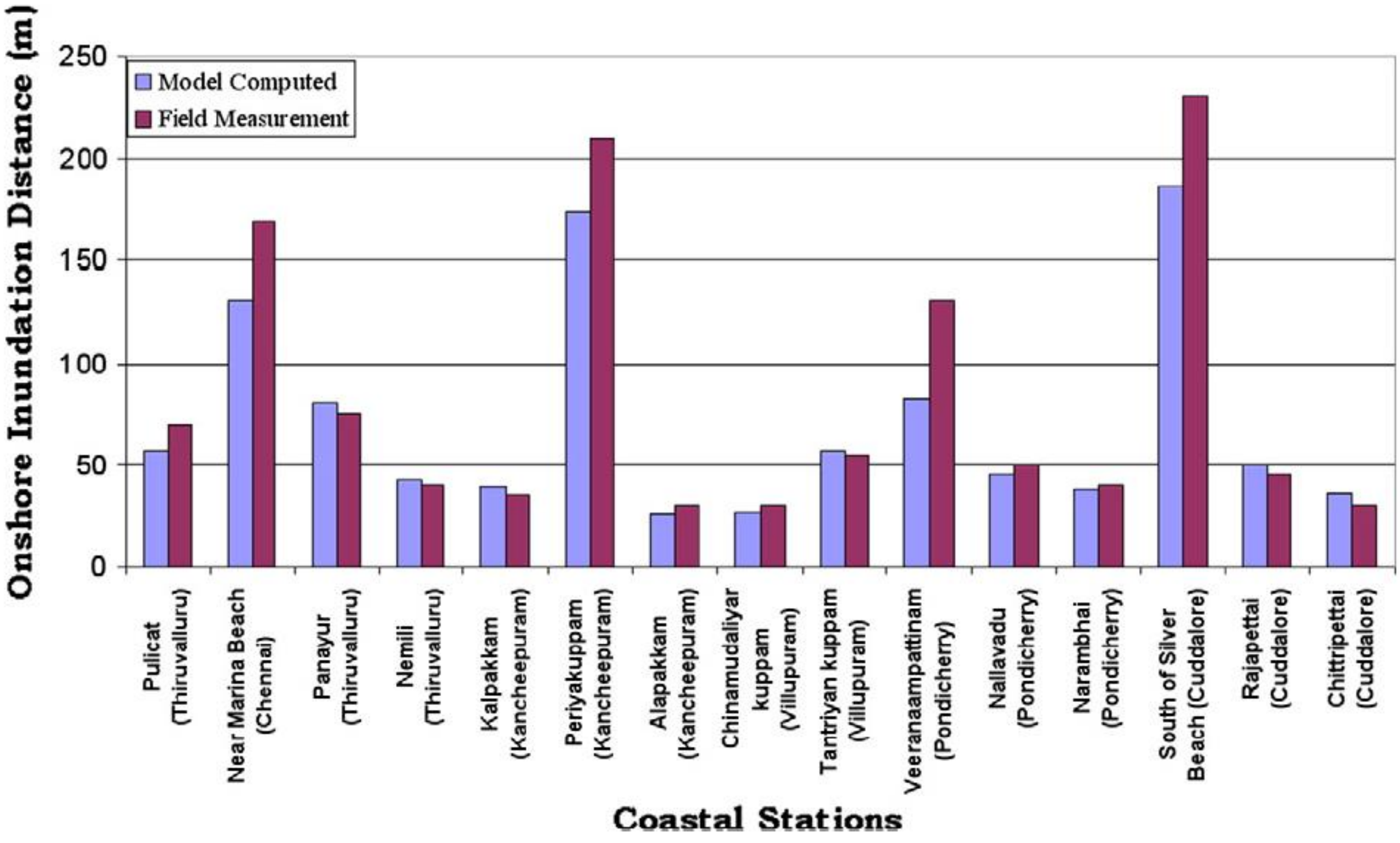
Shoreline change due to marine structure

Obstruction to littoral drift – shoreline change



NIO
understanding the seas

Coastal inundation or coastal flooding is the temporary or permanent flooding of a portion of land within the coastal zone.



Coastal inundation along Tamil Nadu coast during tropical cyclone Thane. Field data is from ICMAM Chennai

Bhaskaran et al., 2014, Coastal Engg.

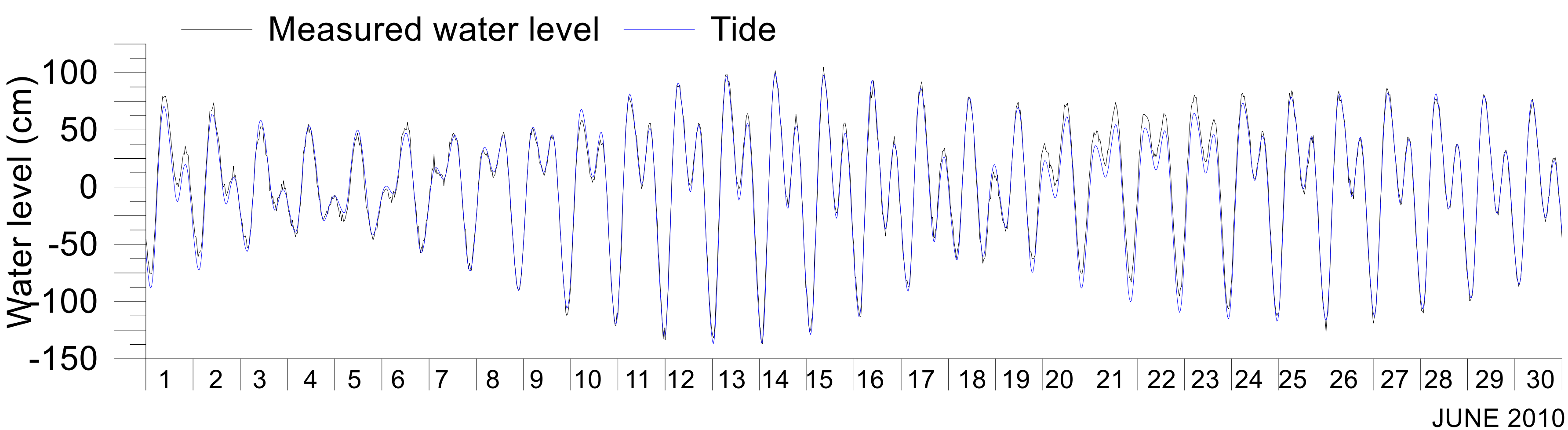
Tides

Tide are the **periodical rise and fall of the sea levels**, once or twice a day, caused by the combined effects of the gravitational forces exerted by the sun, the moon and the rotation of the earth.

They are a vertical movement of waters and are different from movements of ocean water caused by meteorological effects like the winds and atmospheric pressure changes.

Water movements which are caused by the meteorological effects are called as **surges** and they are not regular like tides.

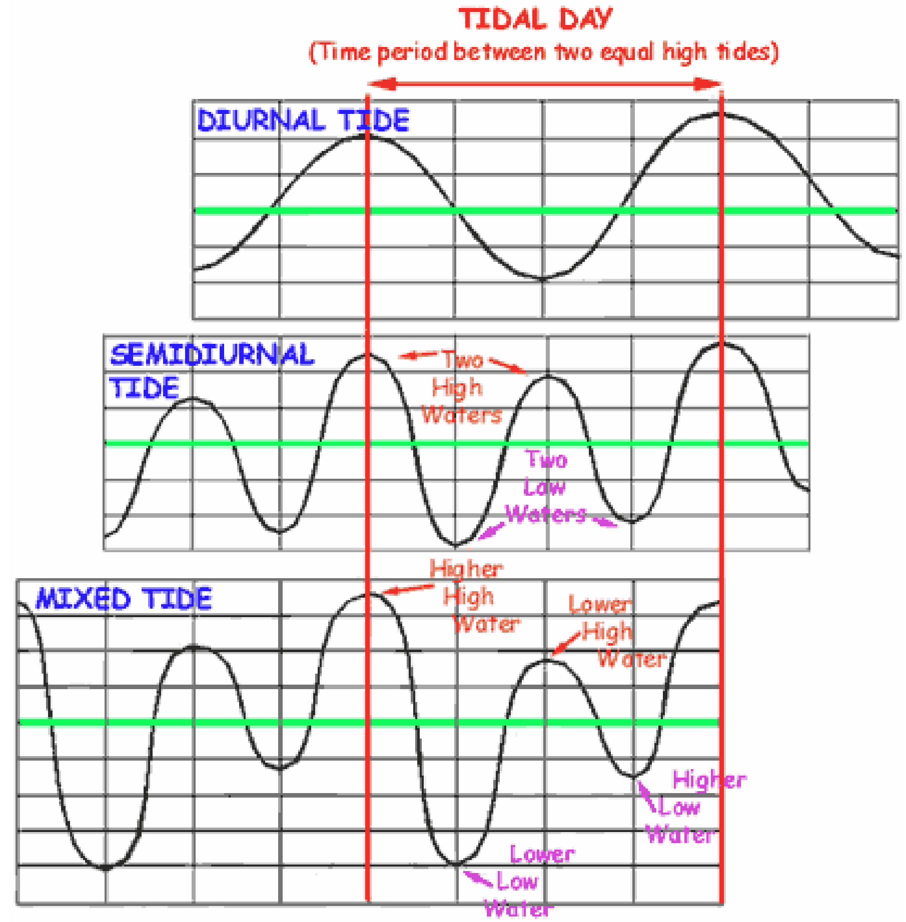
Moon's gravitational pull to a great extent is the major cause of occurrence of tides (moon's gravitational attraction is more effective on earth than that of sun).



Diurnal Tides: Only one high tide and one low tide each day.

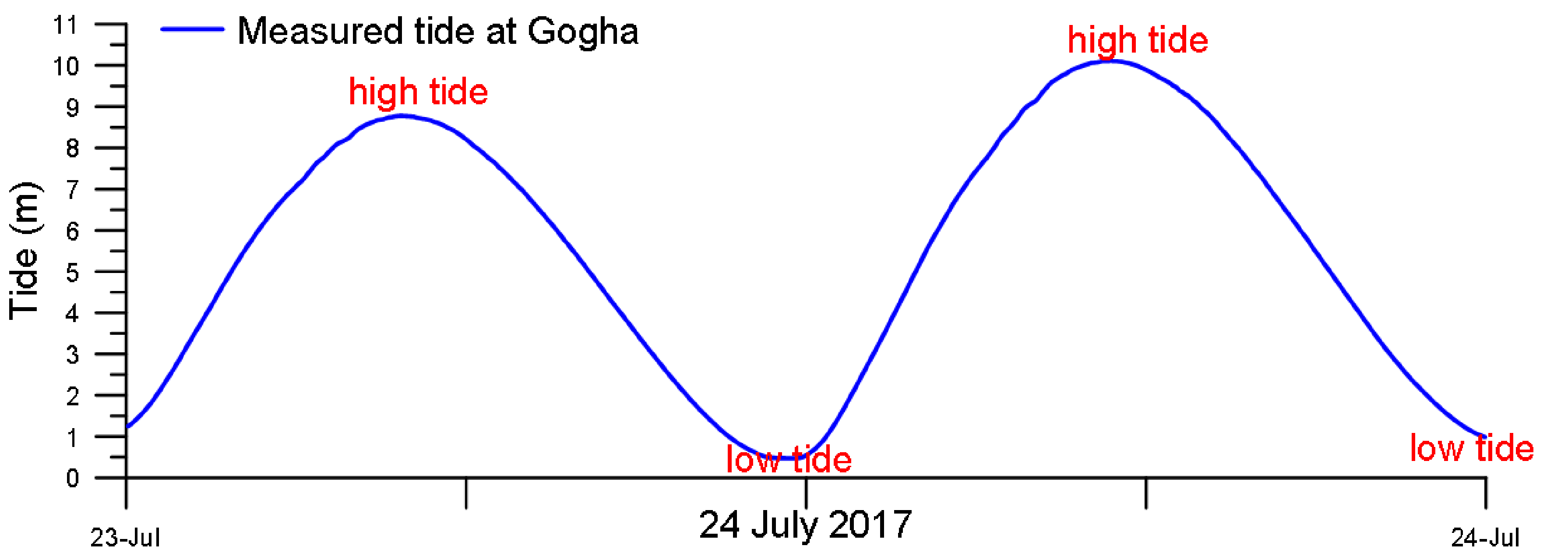
Semi-diurnal Tide: They are the most common tidal pattern, featuring two high tides and two low tides each day.

Mixed Tide: Tides having variations in heights are known as mixed tides.

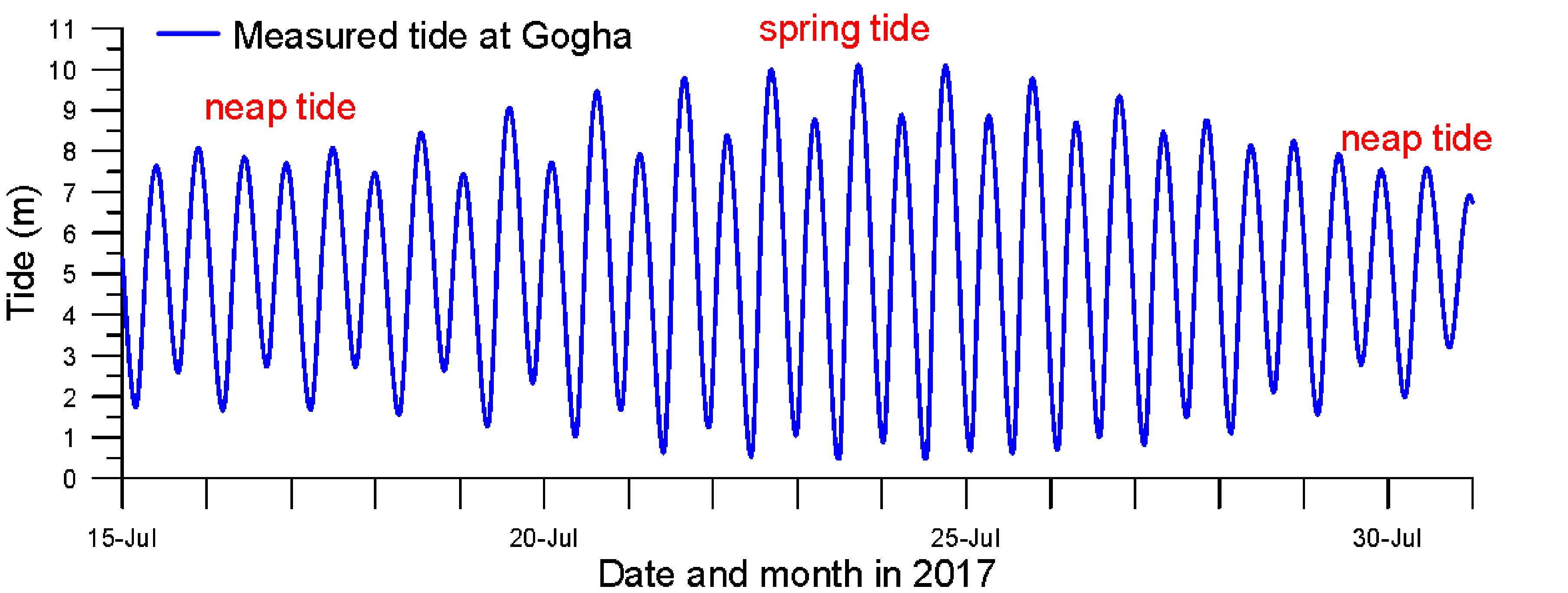


NIO
understanding the seas

Tide



Measured tide at Gogha
high tide
high tide
low tide
low tide
Tide (m)
11
10
9
8
7
6
5
4
3
2
1
0
23-Jul
24 July 2017
24-Jul



Measured tide at Gogha
spring tide
neap tide
neap tide
Tide (m)
11
10
9
8
7
6
5
4
3
2
1
0
15-Jul
20-Jul
25-Jul
30-Jul
Date and month in 2017

Tides

Harmonic tidal analysis

$$h(t) = h_0 + \sum_{n=1}^{i} A_n \cos(\omega_n t - \Phi_n) + h_r(t)$$

$h(t)$ = instantaneous water level at time t,

h_0 = mean water level over observation period,

A_n = amplitude of nth constituent,

ω_n = frequency of nth constituent,

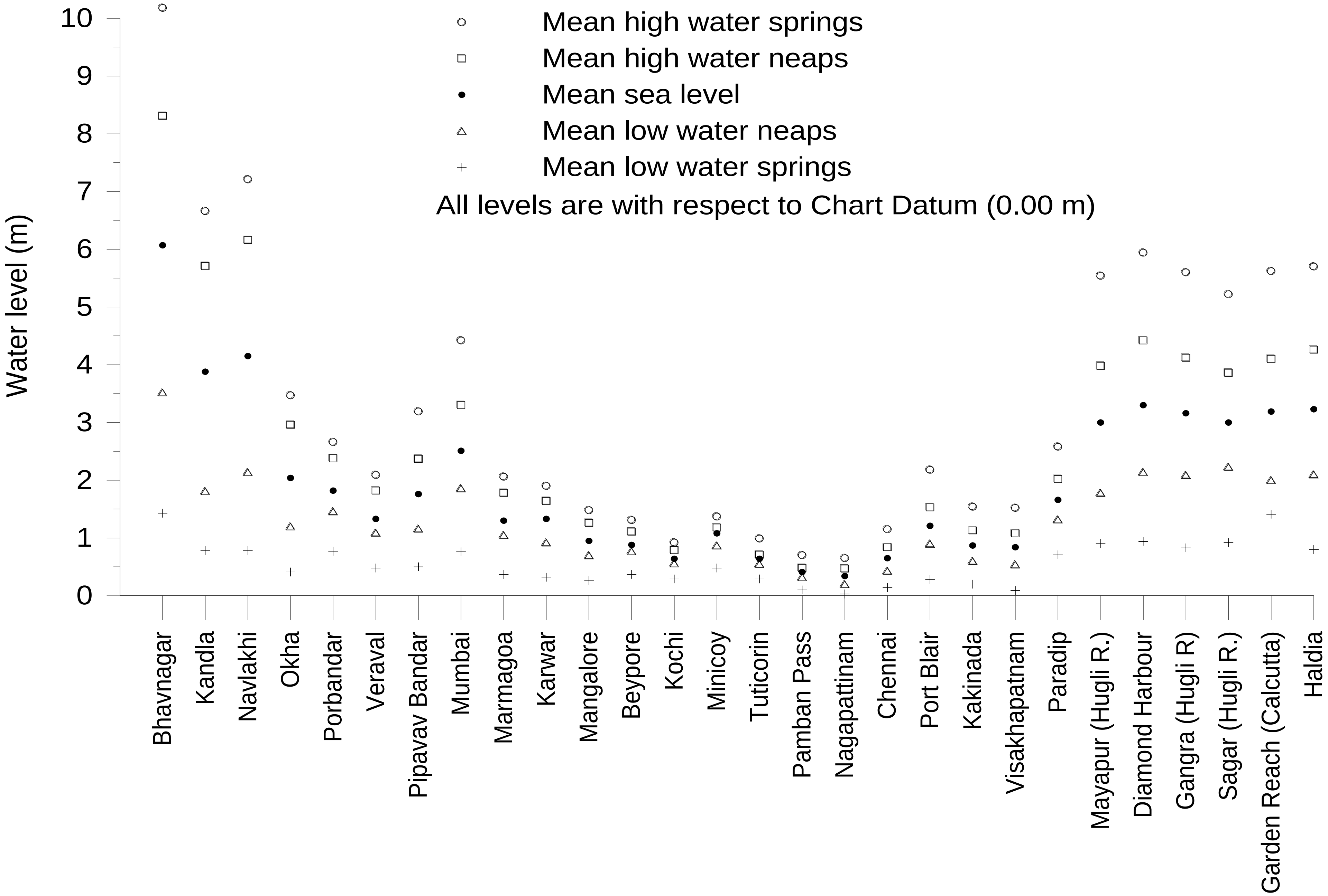
Φ_n = Greenwich phase lag of nth constituent,

$h_r(t)$ = residual height from non-tidal forces at time t.

Semidiurnal		Period (hr)
Principal lunar	M_2	12.42
Principal solar	S_2	12.00
Lunar elliptic	N_2	12.66
Lunisolar	K_2	11.97

Diurnal		Period (hr)
Lunisolar	K_1	23.93
Principal lunar	O_1	25.82
Principal solar	P_1	24.07
Elliptic lunar	Q_1	26.87

Long Period	
Fortnightly	M_f
Monthly	M_m
Semiannual	S_{sa}



Various tide levels at different locations along the Indian coast

understanding the seas

Beach processes

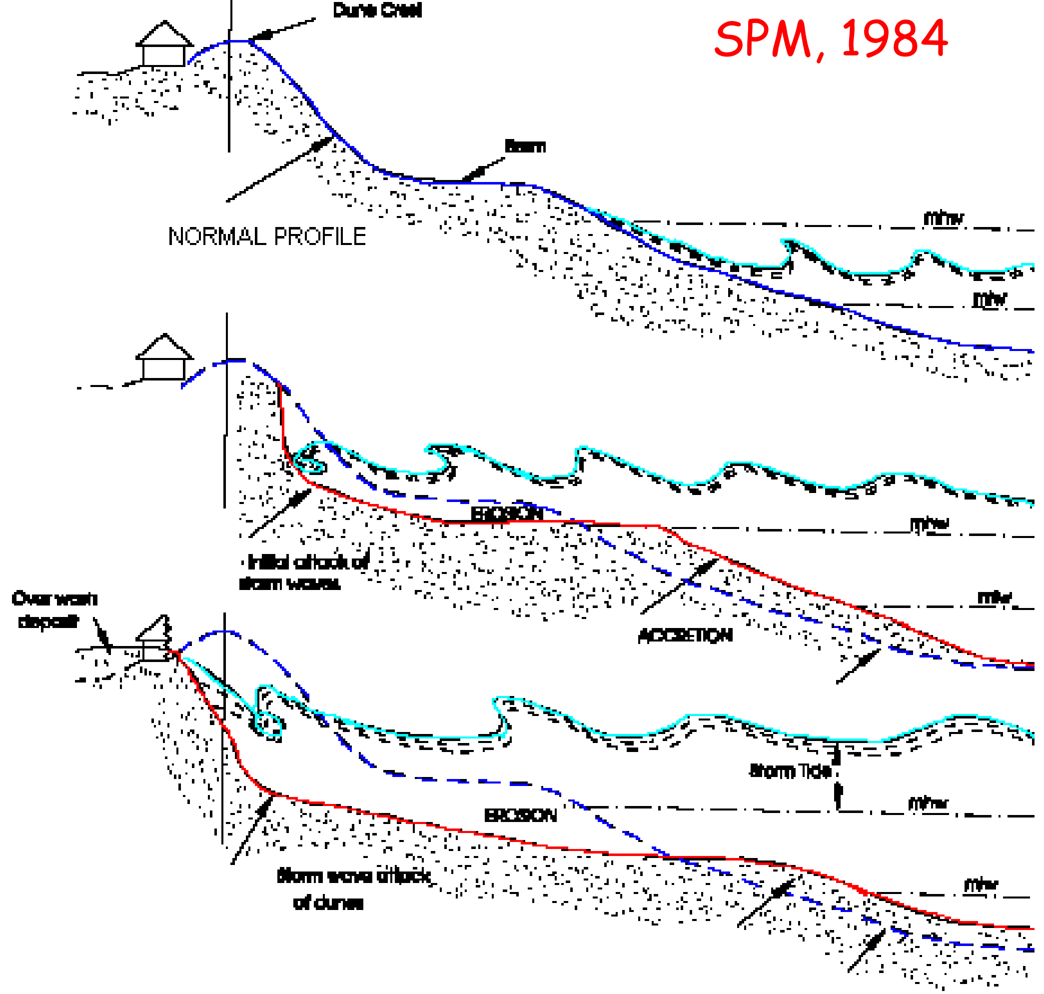
SPM, 1984

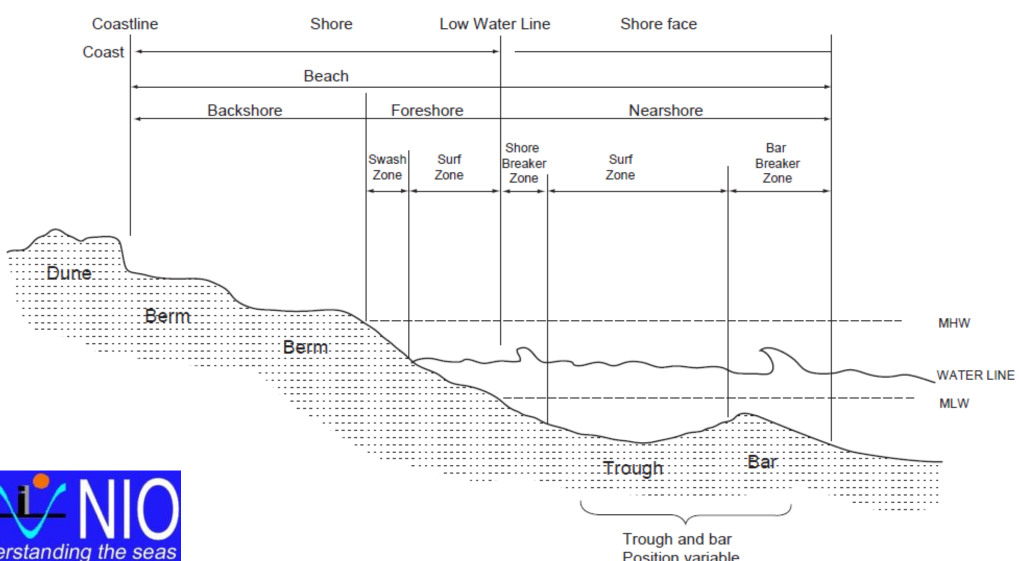
For undeveloped areas - natural and cyclic process

For developed areas - disaster for local residents

Typically most beaches have their land limit constrained by presence of coastal infrastructure

CRZ notification – restrict developments in the CRZ area





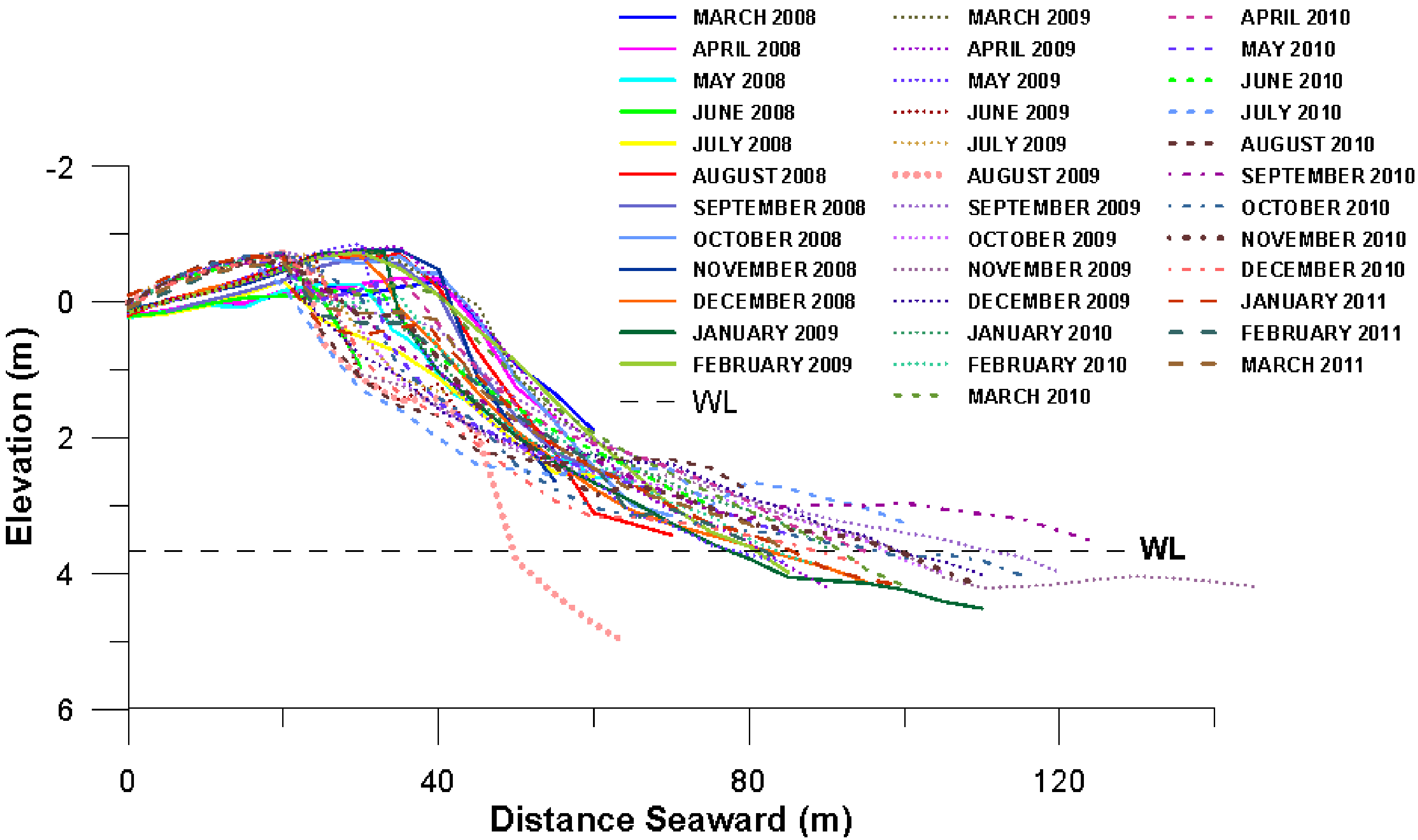
NIO understanding the seas

Beach profile data

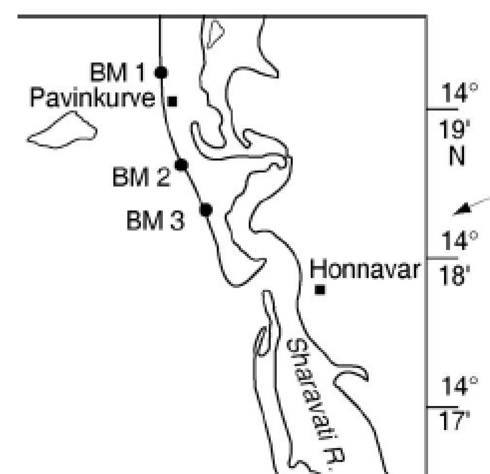
Distance (m)	Back Sight	Intermediate Sight	Fore Sight	RL	Remark
BM					
0					
5					
10					
15					
					Water Line

Predicted tide for Visakhapatnam

Low Tide	**2:55 AM***(Mon 20 February)*	**-0.06 m**
High Tide	**8:49 AM***(Mon 20 February)*	**1.19 m**
Low Tide	**2:55 PM***(Mon 20 February)*	**-0.15 m**
High Tide	**9:12 PM***(Mon 20 February)*	**1.48 m**

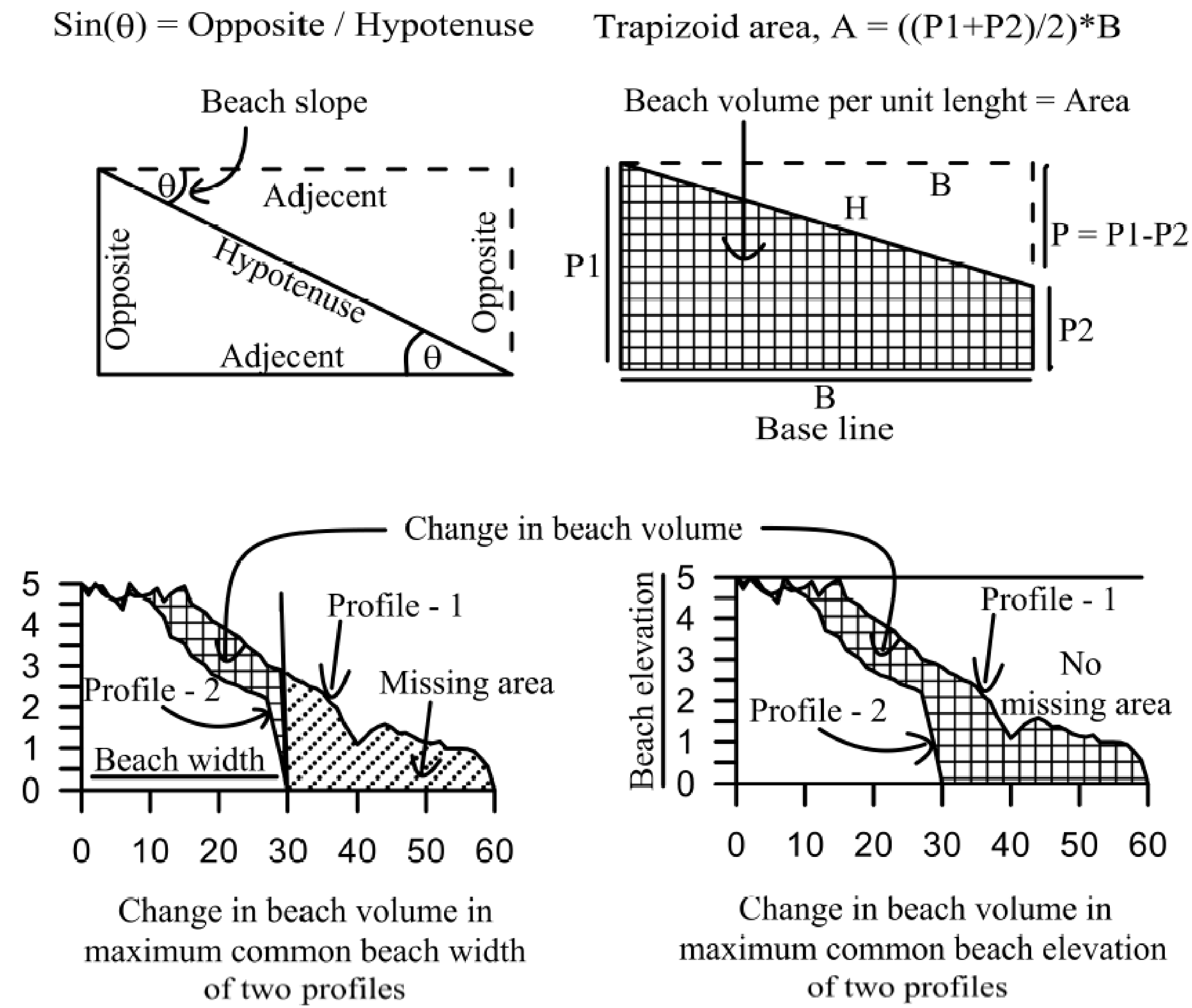


Beach profile at Honnavar BM3

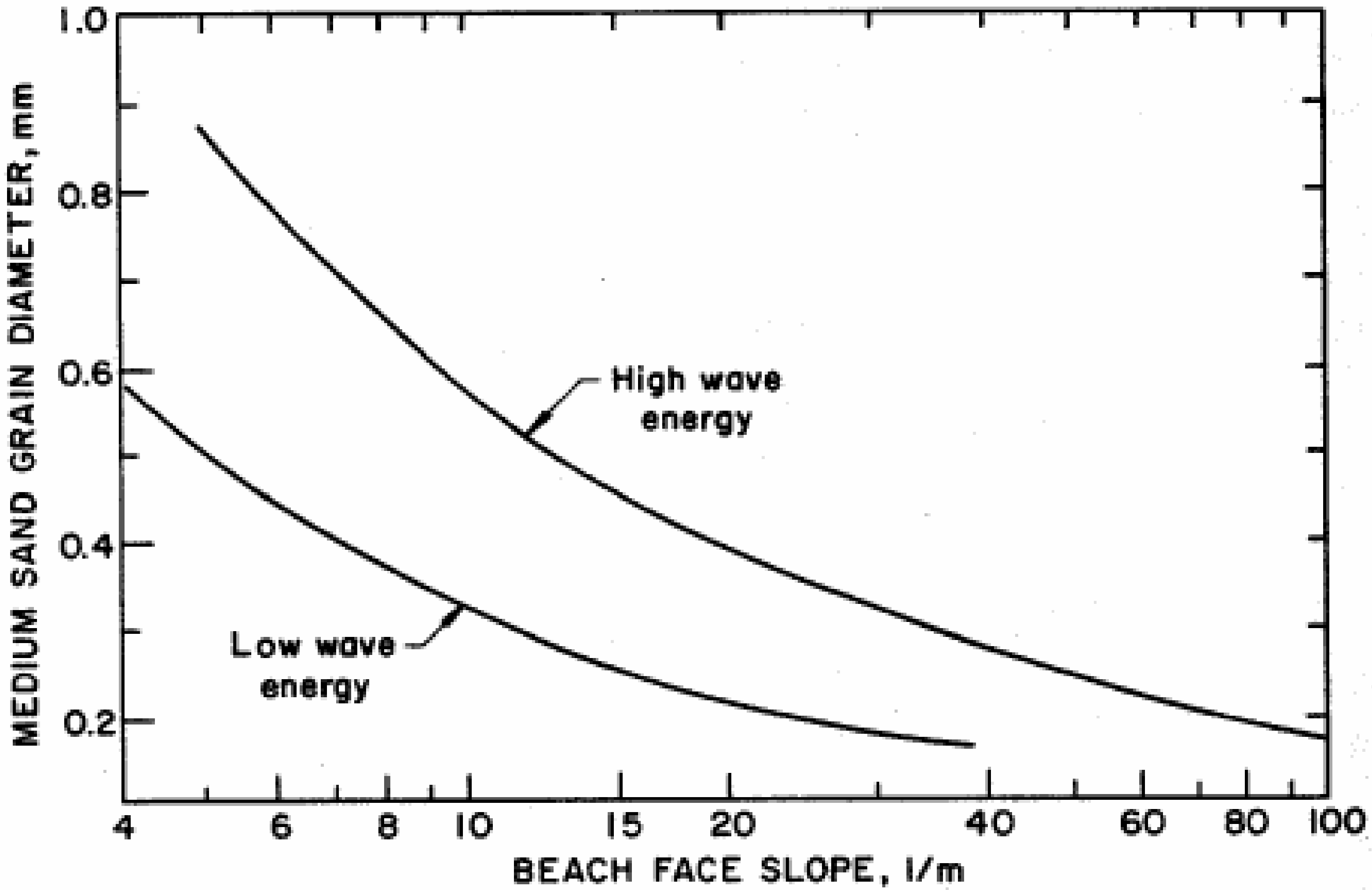


Coastal erosion/accretion can be quantified through beach profiles covering different seasons and years

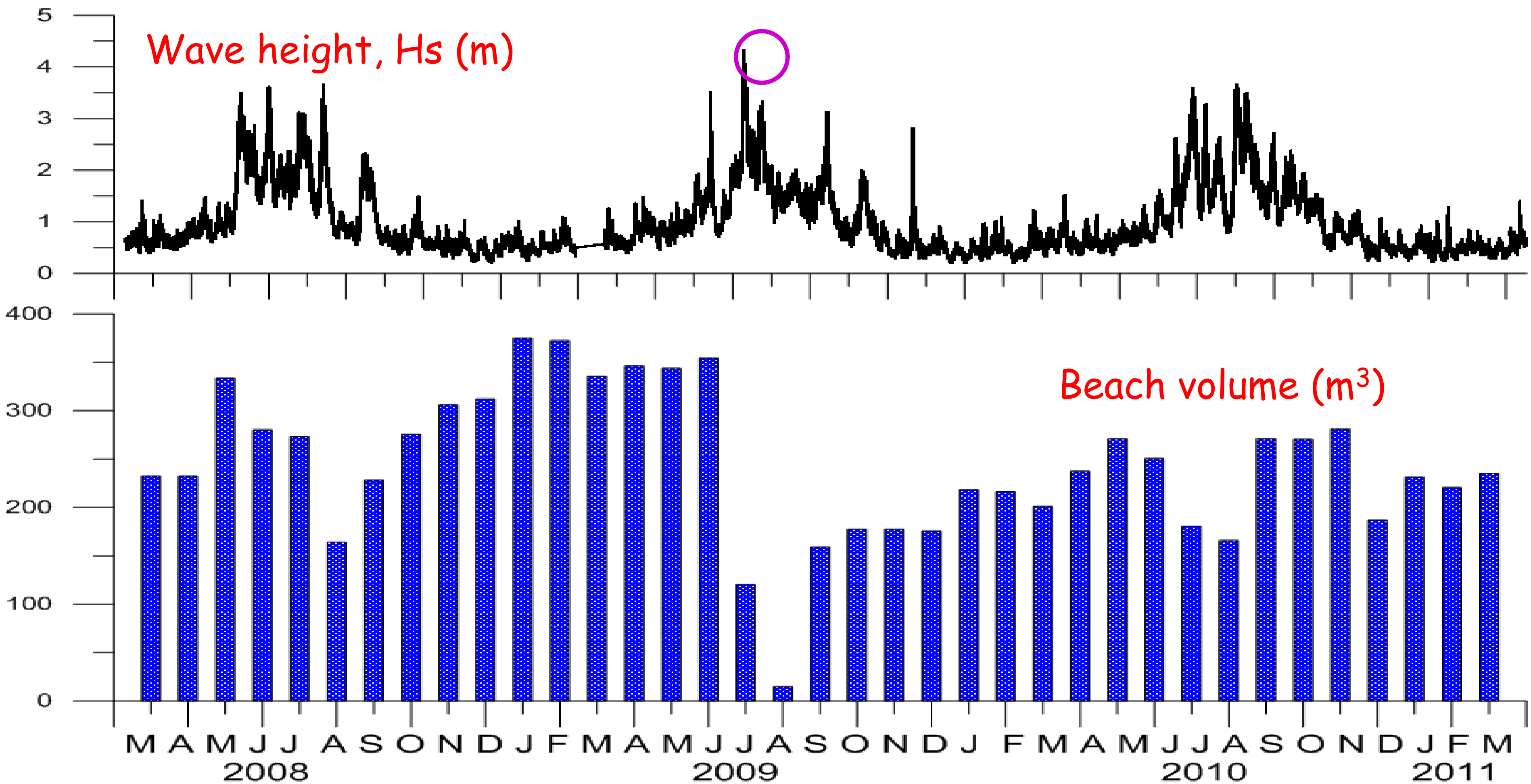
NIO understanding the seas



Pictorial description of beach slope and volume from cross-shore beach profiles

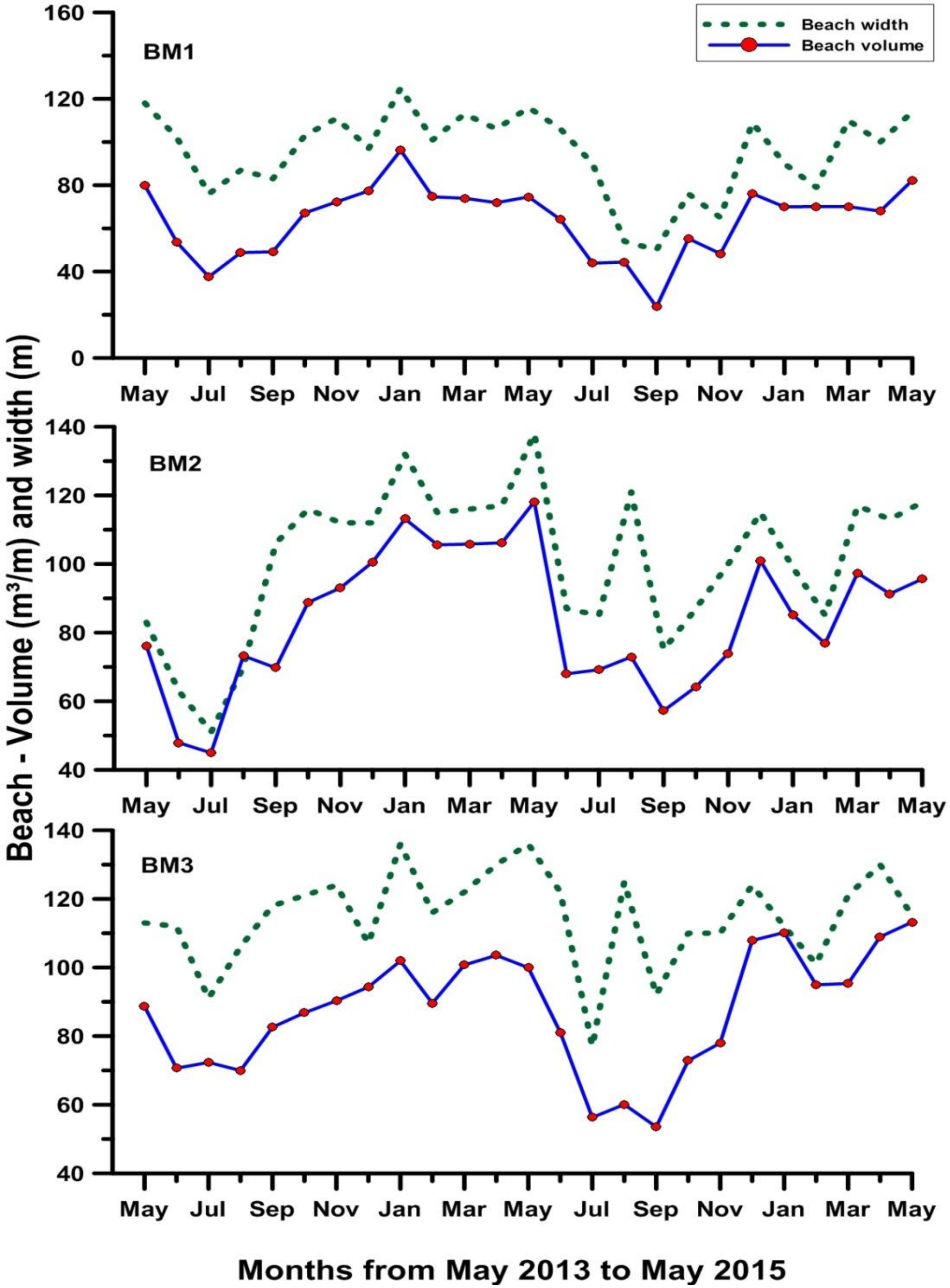


Beach face slope versus median sand grain diameter for high and low wave energy exposure. (Modified from Wiegel, 1964.)



High erosion

- for slight increase in wave height (3.7-4.3 m)
- 2009 Hs >3.5 m persisted for 33 h
- Other years Hs > 3.5 m not persisted for > 5 h



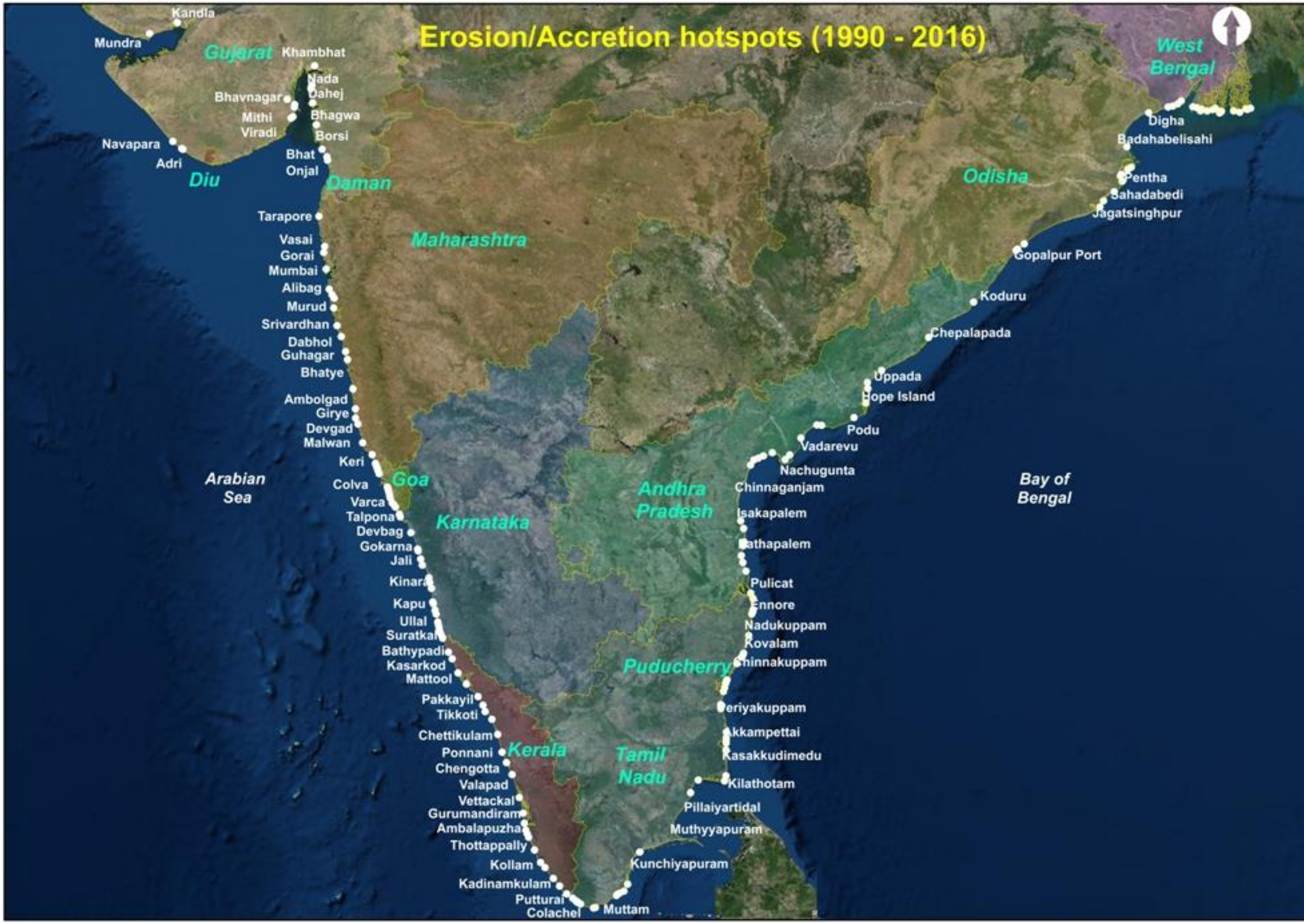
Lowest beach width and volume is observed during September 2014, July 2013 and July 2014 at BM1, BM2 and BM3.

Peak volumes and widths are recorded in January 2014 at BM1 and in May 2014 at BM2 and in October at BM3.

During May 2013-May 2015, beach experienced net accretion through cycles of erosion/accretion

Beach profile change at BM1,BM2 & BM3 at Ganpatipule beach May 2013 to May 2015

NIO understanding the seas



NCCR, Chennai, 2022

Beach sediment grain size classification

Very coarse soils	**Boulder size**		**> 300 mm**
	Cobble size		80 - 300 mm
Coarse soils	Gravel size (G)	Coarse	20 - 80 mm
		Fine	4.75 - 20 mm
	Sand size (S)	Coarse	2 - 4.75 mm
		Medium	0.425 - 2 mm
		Fine	0.075 - 0.425 mm
Fine soils	Silt size (M)		0.002 - 0.075 mm
	Clay size (C)		< 0.002 mm

Grain size is also expressed in ϕ scale and the conversion from mm to ϕ scale is as per equation given below

$$\phi = -\log_2 D$$

where D is the size of the particle in mm

Quantification of coastal erosion/shoreline changes and identification of causes

- Monitor the process responsible for shoreline changes (waves, currents, tides, shoreline variations; profile changes; sediment characteristics) and nearshore bathymetry.

- Study of long-term and short-term trends in shoreline changes from multidated imageries and maps.

- Numerical modelling:
  - Nearshore wave and hydrodynamics
  - Longshore current and sediment transport
  - Shoreline changes

NIO
understanding the seas

References

Bird, E.C.F., 1996. Beach Management. Chichester: Wiley and Sons

USACE, 1984. Shore Protection Manual, U.S. Army Coastal Engineering Research Center, Department of the Army, Corps of Engineers, U.S. Govt. Printing Office, Washington, DC, USA, vols. 1 and 2.

CEM, 2002. Coastal Engineering Manual, US Army Corps of Engineers, Washington.

Dingler J.R. (2005) Beach Processes. In: Schwartz M.L. (eds) Encyclopedia of Coastal Science. Encyclopedia of Earth Science Series. Springer, Dordrecht

Walton, T.L., Bruno, R.O., 1989. Longshore transport at a detached breakwater, Phase-II. J. Coast. Res. 65(9), 667-668.

Longuet-Higgins, M.S., 1970. Longshore current generated by obliquely incident sea waves. J. Geophy. Res. 75 (33), 6778–6789.

Galvin, C.J., Eagleson, P.S., 1965. Experimental study of longshore currents on a plane beach: U. S. Army Corps of Engineers. Coastal Engineering Research Center, TM-10.

Komar, P.D., 1998. Beach Processes and Sedimentation. Prentice Hall Inc. New Jersey, 544–545.

Kamphuis, J.W., 2002. Alongshore transport of sand. In: Proc. 28 Coastal Engineering Conference, ASCE. 2478-2490

Thank You