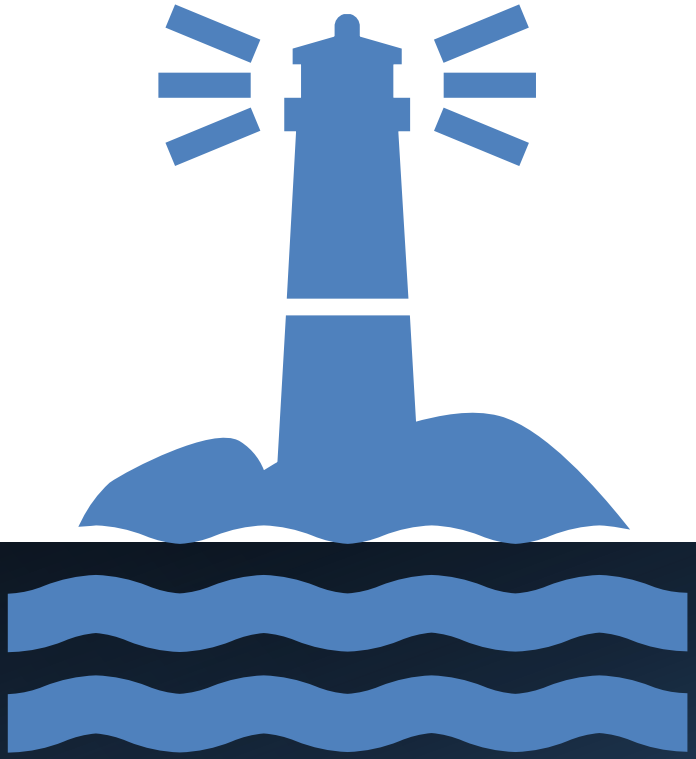
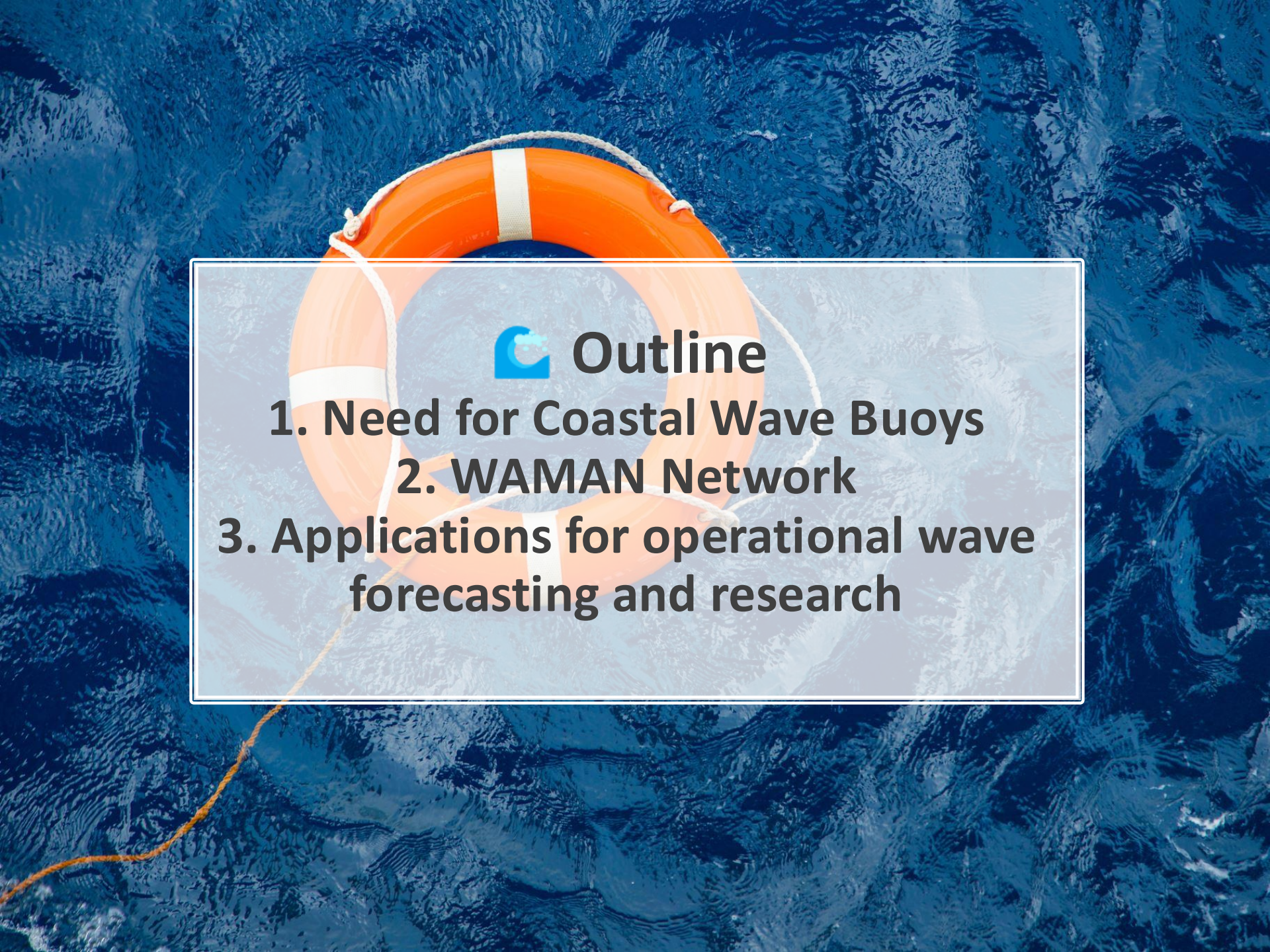
WAMAN: Wave Rider Buoy Network for Coastal Observations and its applications



Dr. Remya P. G.,
Scientist-E
ESSO-INCOIS
DBCP Workshop, Aug., 2025



🌊 Outline

1. Need for Coastal Wave Buoys
2. WAMAN Network
3. Applications for operational wave forecasting and research

Why Monitor Coastal Waves?

- Critical for safe offshore/nearshore operations
- Supports design of coastal protection measures
- Ensures safety of fishers, coastal communities, and maritime navigation

Wide-Ranging User Needs

- Fishers – require local sea-state forecasts at fishing grounds
- Surfers & Divers – look for swell characteristics and calm waters
- Engineers – need long-term data for structural design
- Navy & Shipping – rely on wave forecasts for routing & fuel efficiency

Scientific & Policy Relevance

- Essential for forecast validation & model improvement
- Supports coastal planning, climate projections & risk management
- Wave data contributes to climate change assessments

Global Recognition

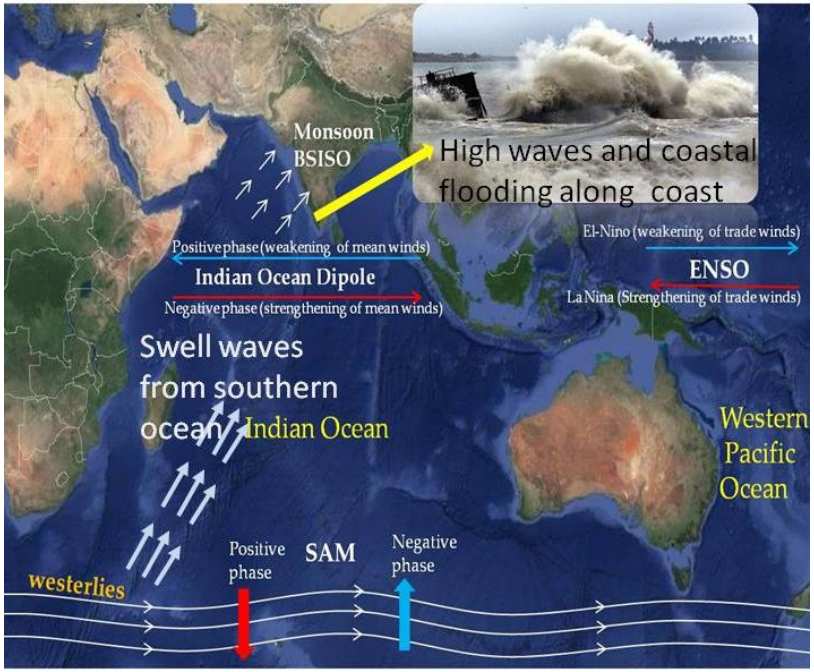
- Waves listed as an "Essential Ocean Variable" by GOOS
- International push for continuous wave monitoring systems

Enabler of Blue Economy

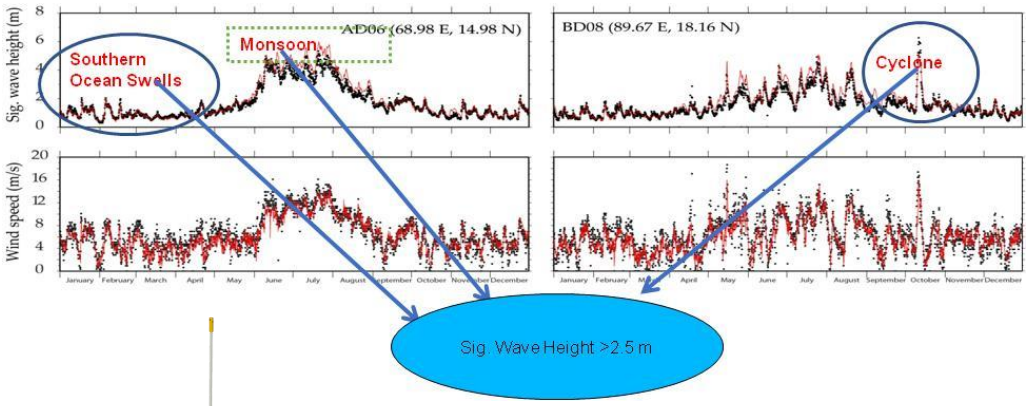
- Informs development of sustainable maritime sectors in Indian Ocean Rim Countries
- Helps mitigate risks from swells, storms, and coastal flooding

Need of Wave Observations in the Indian Ocean

Waves &Climate change

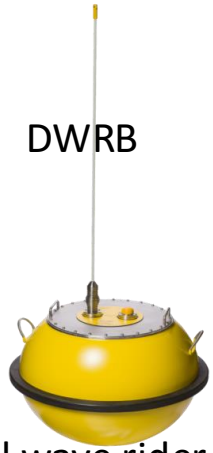


Wave Characteristics in the North Indian Ocean

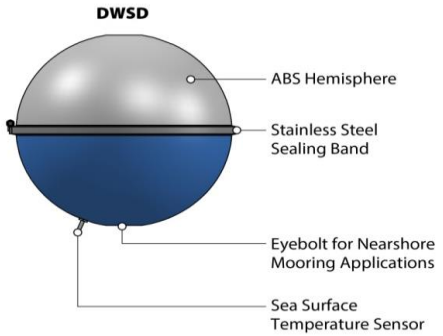


Deep Ocean buoy

DWRB



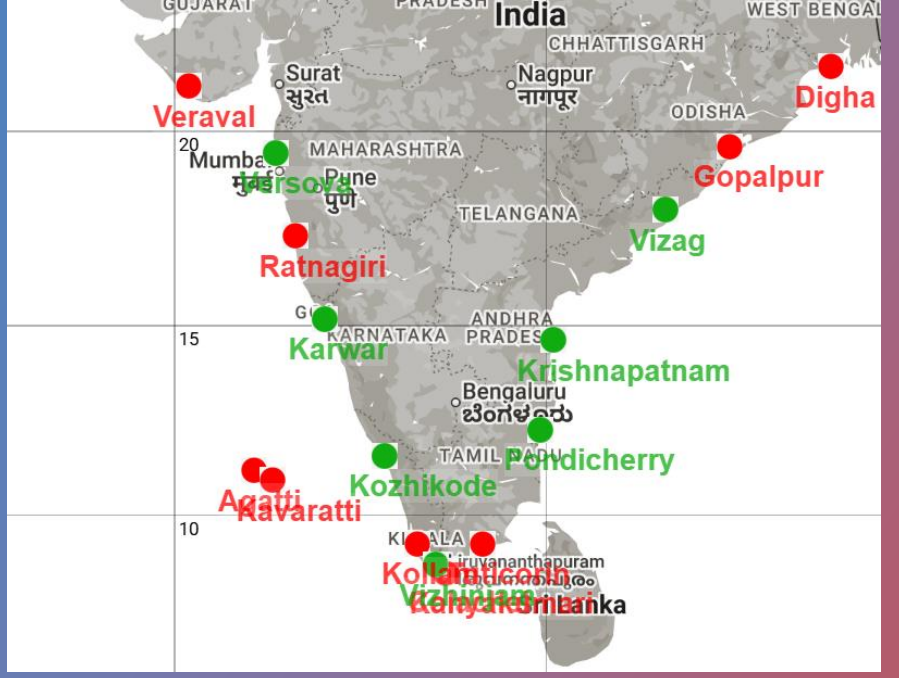
Directional wave rider buoy

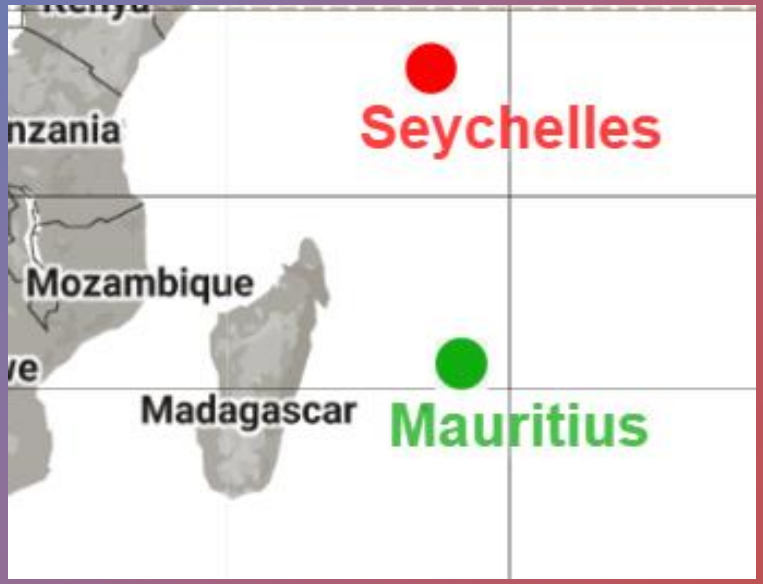


Directional wave spectra drifter

WAMAN
Towards a community based network

- **Community-Based Ocean Monitoring**
- Traditional methods limited by coastal diversity.
- INCOIS adopted a **community-owned observation model**.
- Localized ocean services tailored to community needs.
- Since 2007, **18 wave buoys** deployed in **India, Seychelles & Mauritius**.
- Enables **real-time data** for **wave forecasting**





WAMAN Network

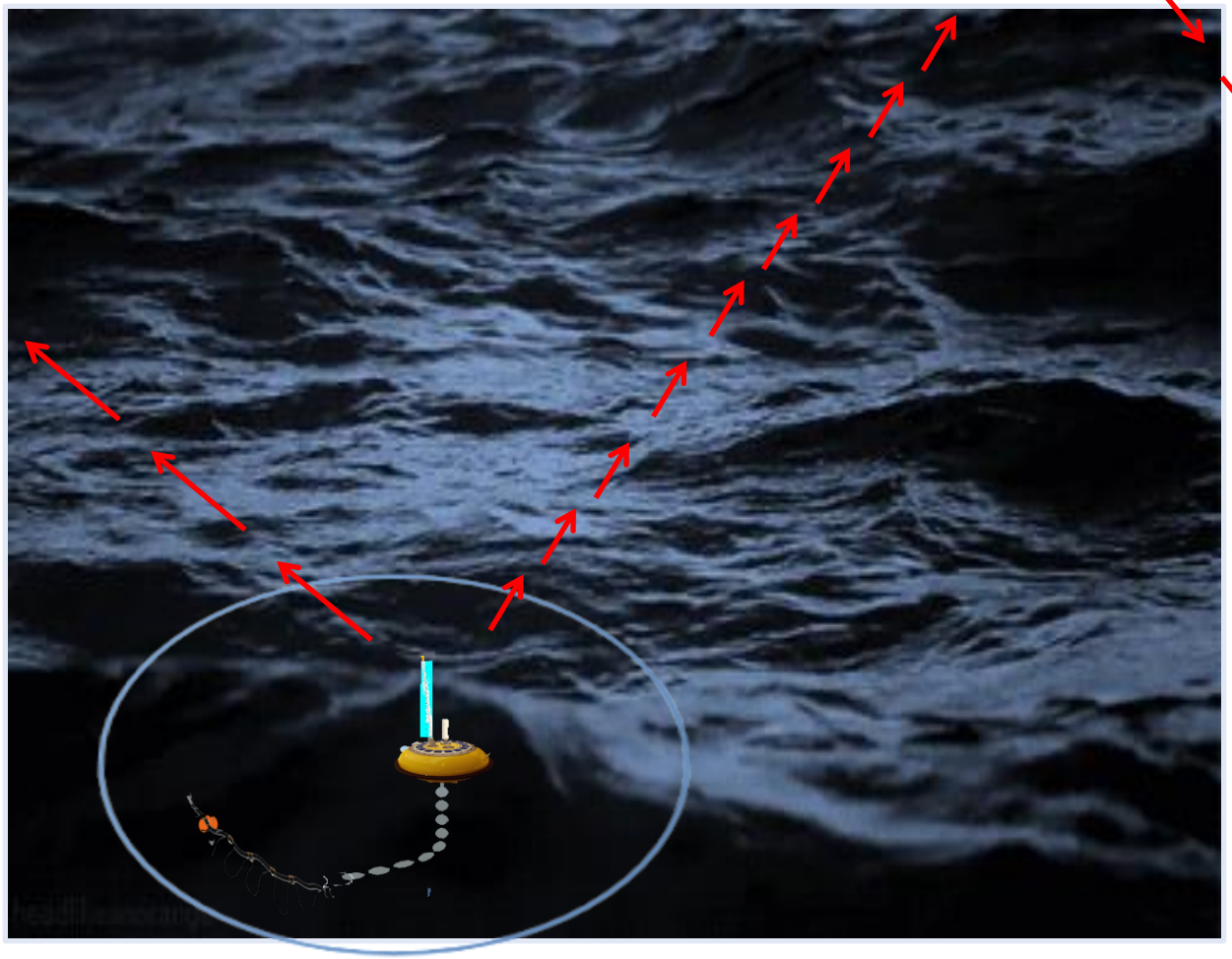
- WAve Monitoring Along Nearshore (WAMAN) Network
- 18 operational buoys across India and Seychelles and Mouritiuos
- Real-time data transmission integrated with INSAT satellites

Mauritius WAMAN Buoy Deployment

Satellite

Data Acquisition From Instruments

Local Station



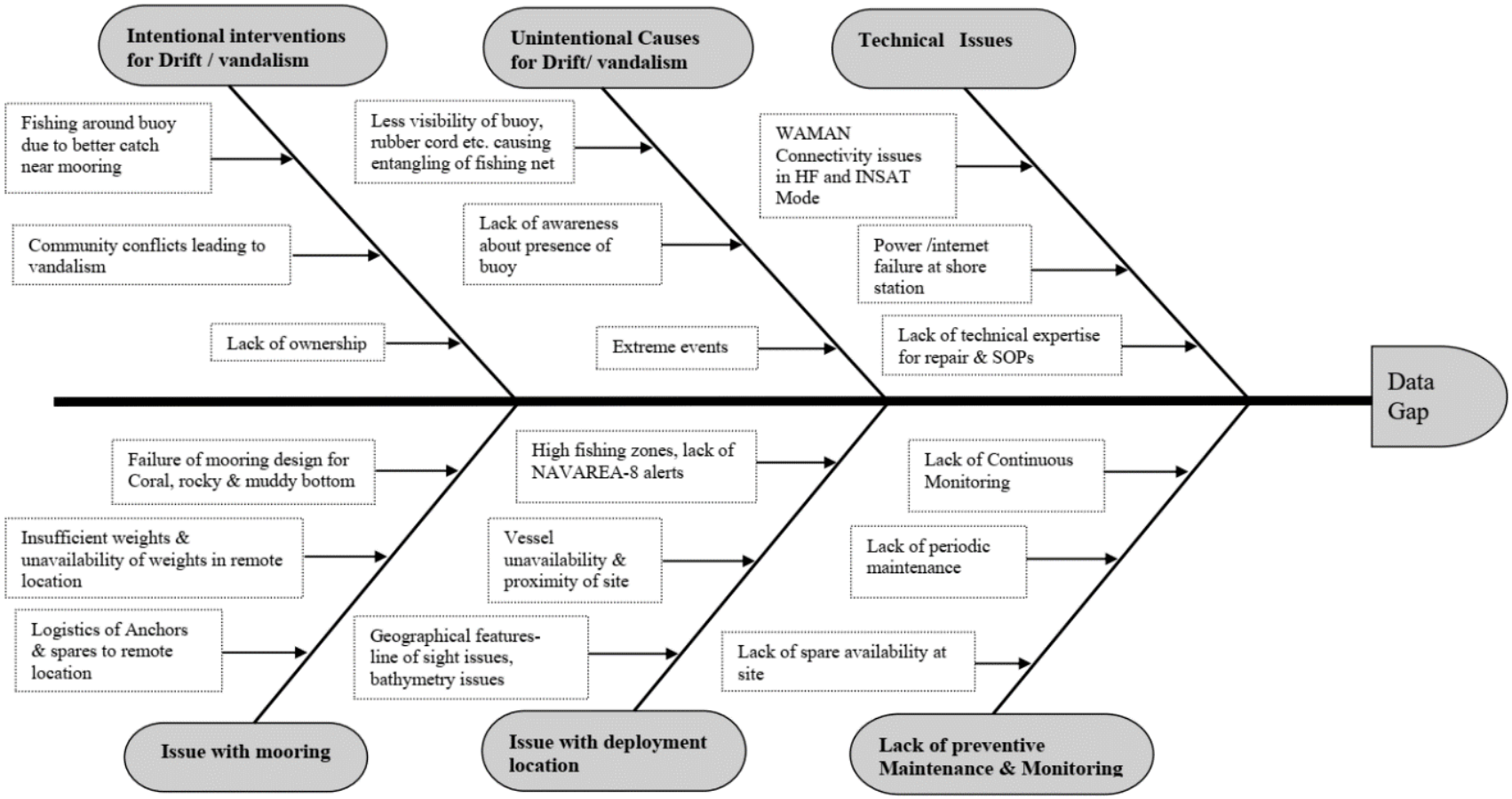
Satellite data Reception

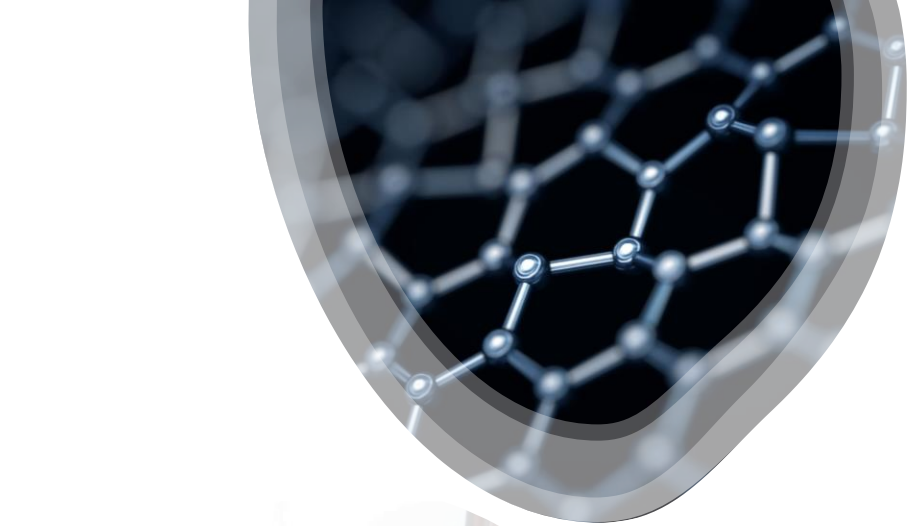
Internet

Technical Specifications

Parameters		Buoy Model	
		Datawell MKIII	Datawell MKIV
Heave	Range:	+20 to -20 m	-20 to +20 m
	Accuracy:	< 0.5% of measured value after calibration < 1.0% of measured value after 3 years	< 0.5% of measured value after calibration < 1.0% of measured value after 3 years
	Resolution	0.01 m	variable, 0.001 mm smallest step
Direction	Range	0° to 360°	0° to 360°
	Resolution	1.4°	0.1°
	Heading error:	0.4° to 2° (depending on latitude), typically 0.5°	0.4° to 2° (depending on latitude), typically 0.5°
	Reference	Magnetic north	Magnetic north
Sampling frequency		1.28 Hz	2.56 Hz
Measured frequency range		0.025-0.58 Hz	0.025 – 1.00 Hz
Additional Sensor		Sea surface temperature	Sea surface temperature, Current

Challenges & issues lead to the Data Gap





The Community-Owned Approach

- **Community Strategies**
- **Identified and connected key community stakeholders:**
Panchayats, boat owner associations, active boat drivers, fisher cooperative society members, and local fishers.
- **Fostered community ownership of WAMAN:**
Organized WAMAN buoy roadshows, village meetings, and engagement with community leaders to build trust and awareness.
- **Developed outreach materials in vernacular languages:**
Distributed handouts and displayed posters at fishing harbours.
- **Conducted advanced training and shared SOPs with local collaborators:**
Resulted in a significant reduction in data gaps.
- **Signed MoUs with local ports and harbours:**
Secured long-term support for the WAMAN programme.

Technical Strategies

- **Established Village Knowledge Centres with high-frequency receivers:**
Enabled real-time data reception and local language dissemination through web interfaces, PA systems, and notice boards.
- **Integrated WAMAN zones into the Fisher Friend Mobile App:**
Offline "No Fishing Zone" alerts with a 200 m proximity alarm system.
- **Implemented 24/7 drift and data failure alert system (by ESSO-INCOIS):**
SMS alerts to fishing boats, Coast Guard, and Marine Police; local community-led search and retrieval efforts .
- **Minimized buoy drift through local innovations:**
Custom-fabricated dead weights, suitable anchors, and enhanced shore receivers.

Technical Strategies

- **Improved buoy visibility at sea:**

Installed flashlights and directional receivers at shore stations.

- **Ensured preventive maintenance and daily monitoring:**

SMS/WhatsApp updates on buoy status helped reduce data gaps and improve data quality.

- **Strategically selected deployment locations:**

Avoided high fishing zones and ensured ease of boat access.

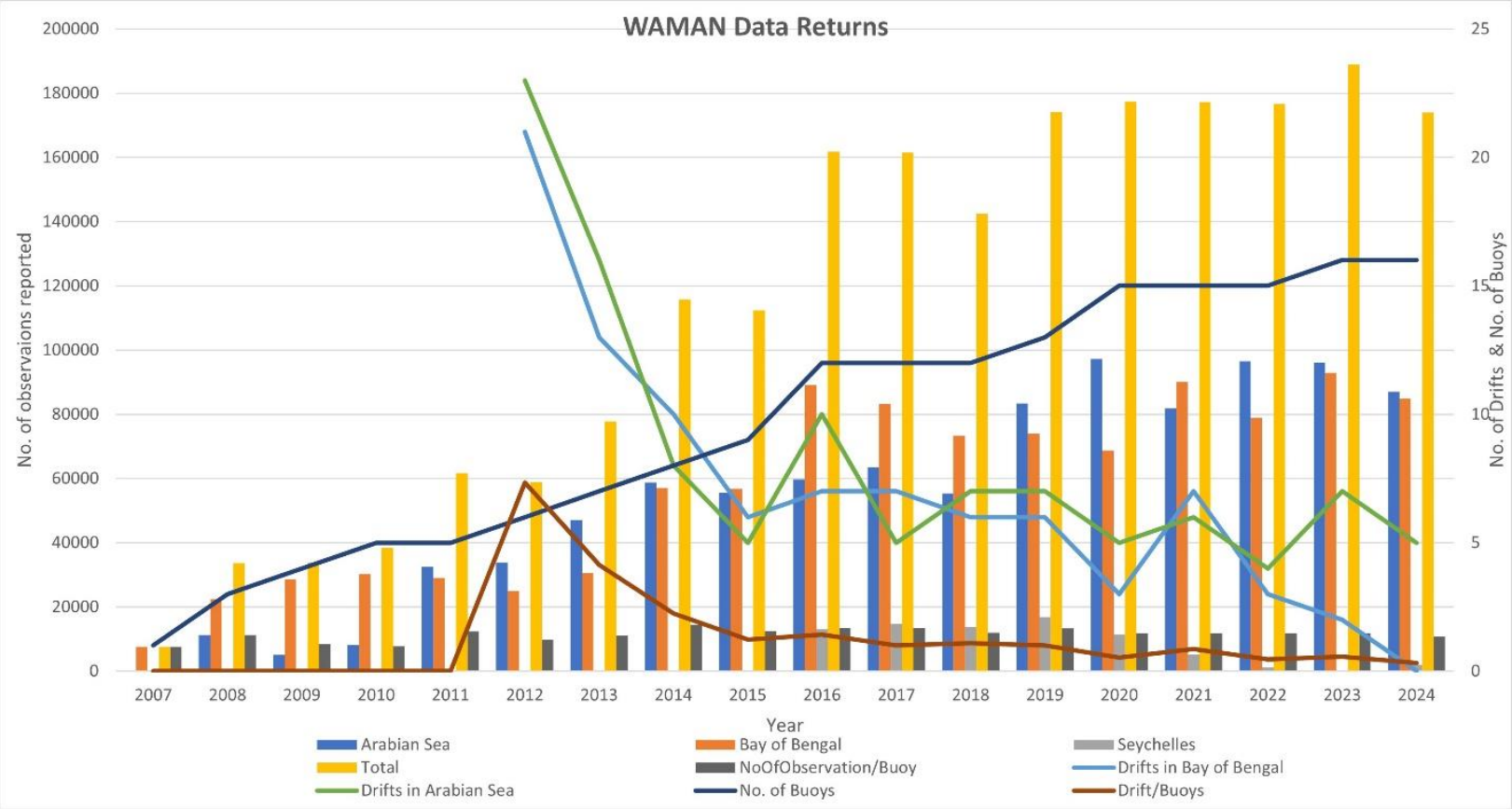
- **Formed WhatsApp groups with key fishers:**

Enabled real-time reporting on buoy condition during fishing trips.

- **Resolved power supply issues in remote areas:**

Installed UPS/inverter systems to ensure uninterrupted operation

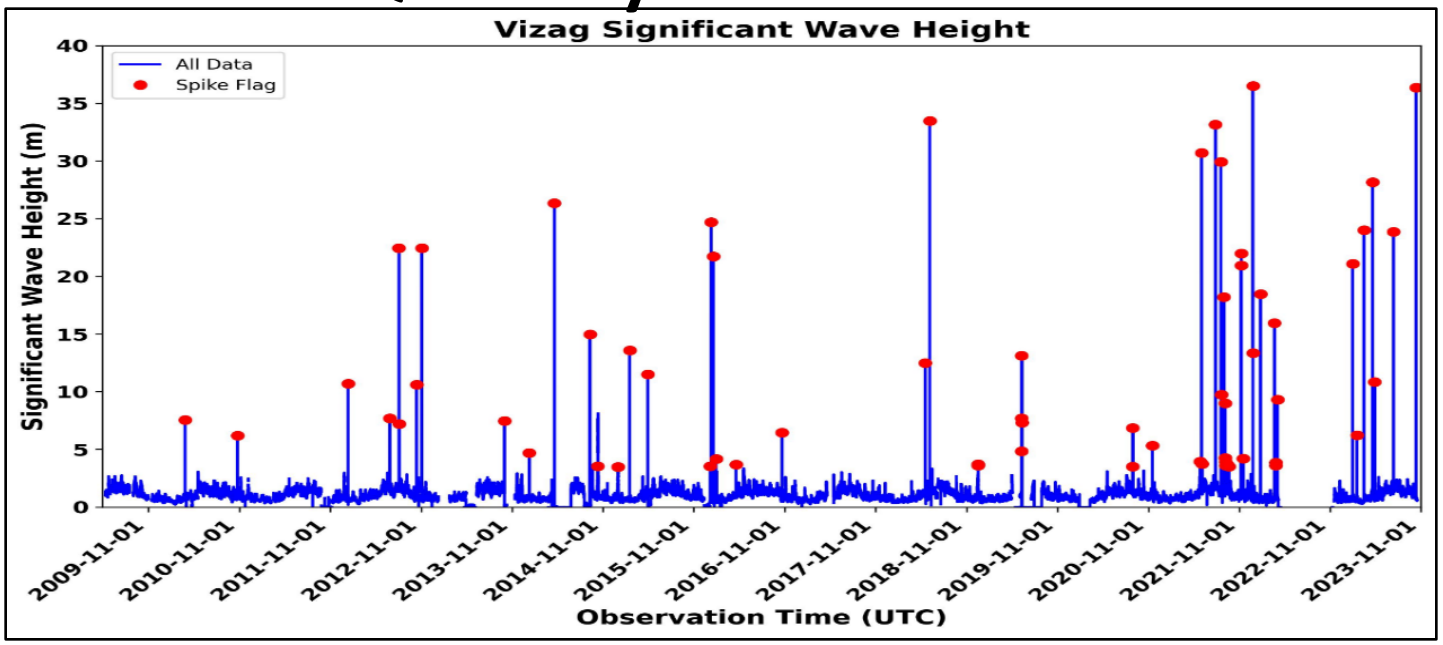
Performance & Outcomes



- ONLY 2 BUOYS LOST IN 17 YEARS
- OVER 90% DATA RETURN RATE
- STABLE, REPLICABLE COASTAL OBSERVATION MODEL

Statistics show a steady increase of data gain from 2007 to 2024 from WAMAN buoys and the reduction in drift/vandalism cases along the Indian Ocean coast.

Quality Check

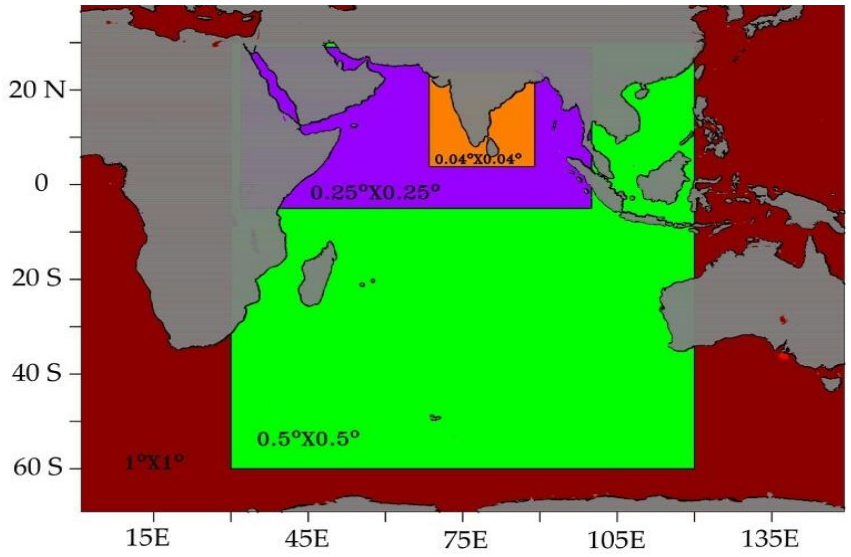


- ✓ **Impossible Location and Time Test**
- ✓ **Spike Test**
- ✓ **Range test**
- ✓ **Stuck Value Test**
- ✓ **Missing value test**
- ✓ **Maximum Wave Height Test**

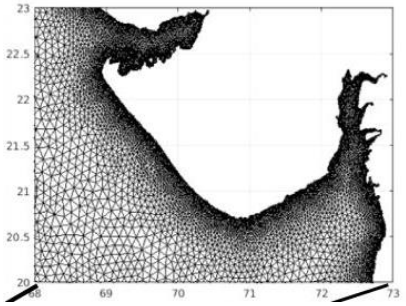
Utilization of wave rider buoy data for Operational forecast and research

INCOIS WAVEWATCHIII Configurations (Multigrid and unstructured)

Model Domain



- Version-6.07
- Source term-ST4
- Bathymetry- Etopo1
- Spatial resolution
  - 1 deg Global grid
  - 0.5 deg Indian Ocean grid
  - 0.25 deg North Indian Ocean grid
  - 0.04 deg Coastal grid
- Spectral resolution
  - 29 frequencies and 36 directions



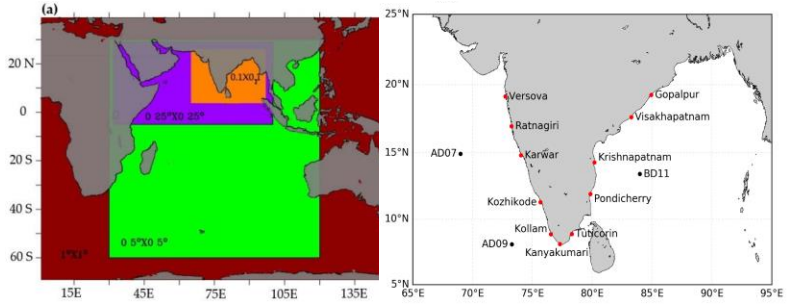
- **INCOIS Bathymetry**
- **Spatial resolution -1km near the coast and 10 km in the deep ocean**
- **Domain 56-96E;-2:25 N**

Forecast: Operational WAVEWATCHIII provides 10 days wave forecast in advance using two different wind forcing(zonal and meridional wind velocities at 10m), NCMRWF(6 hourly) and ECMWF (3 hourly)

Assimilation: Significant wave height from Wave rider buoy, Moored buoy and Altimeter(AltiKa, Jason3, Sentinel 3a ,3b,6a, swot, cfosat) in the Indian ocean

Data Assimilation in the Operational WAVEWATCHII at INCOIS

The DA procedure combines observation and model wave field to determine best possible state of waves that closely represents the true state of wave



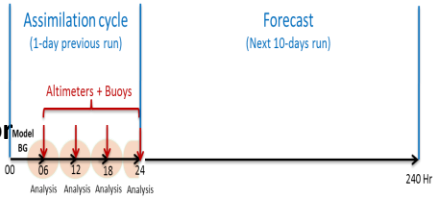
INCOIS WW3 model nested domains & Location of buoys used for assimilation.

neters used for assimilati

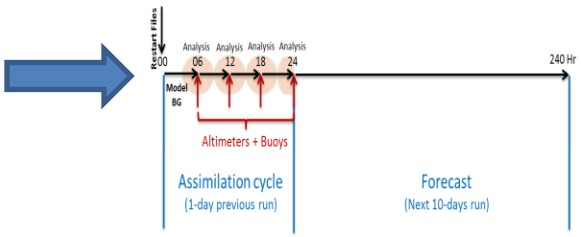
SARAL/ AltiKa

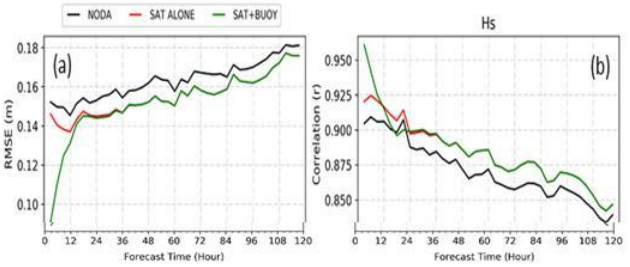
Jason-3

Sentinel 3 (Constellation of two satellites- 3A & 3B)

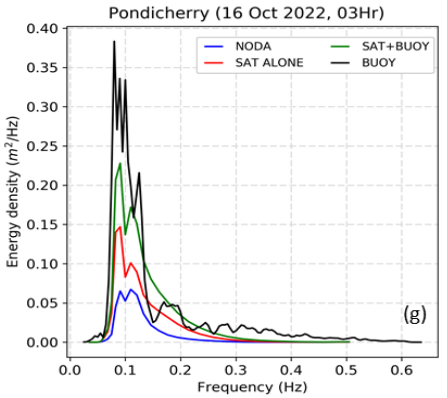


Flowchart of DA system

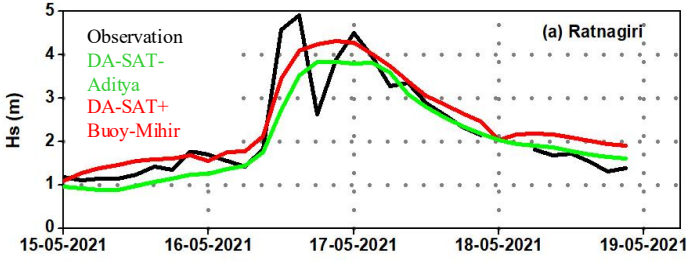




10-40% in the initial 12 hours



Comparison during Tauktae Cyclone



Improved accuracy of coastal forecasts

- Forecast improvements by 10-40% in first 12 hours

WaveWatch III DA Run – Daily Assimilation Summary

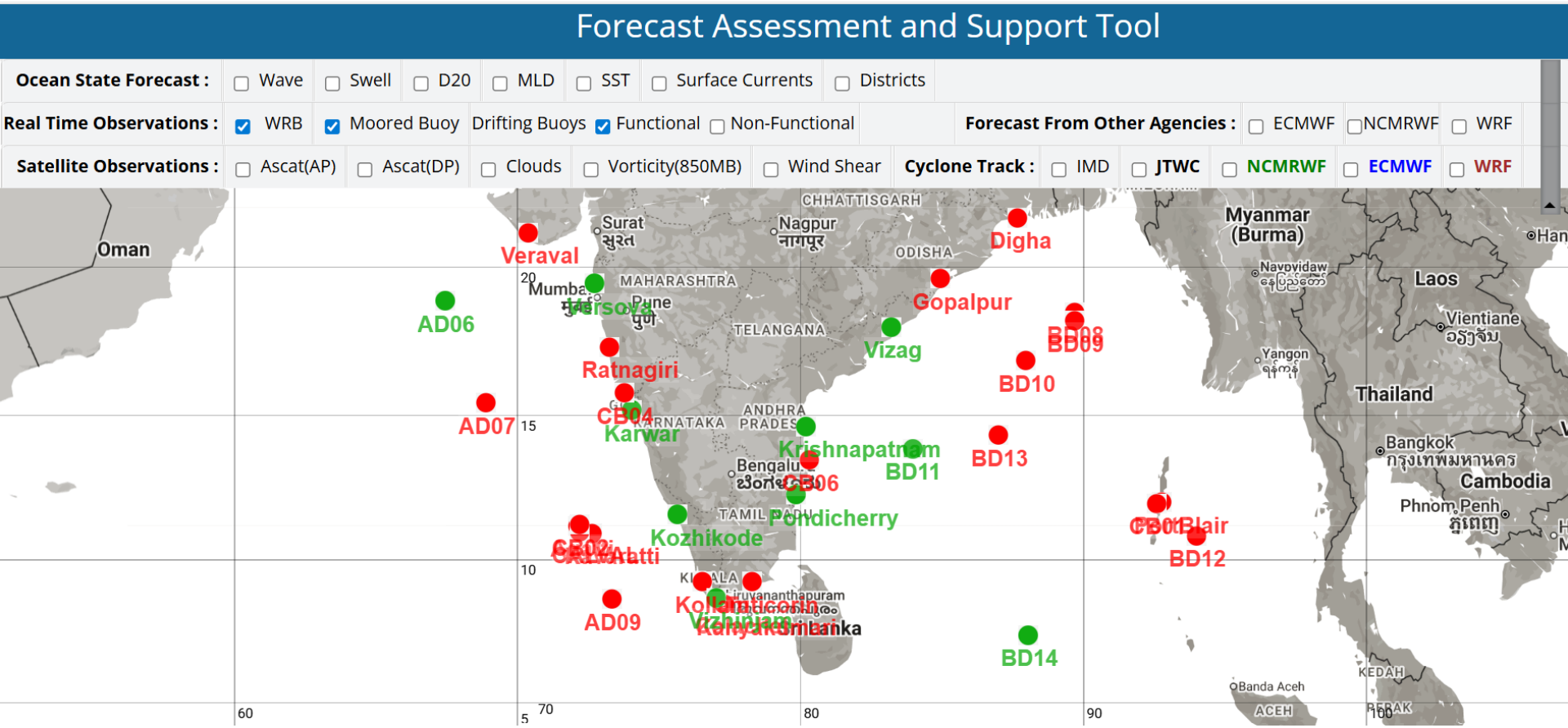
http://172.16.1.140/swh_observation/ww3_summary_day.php?date=2025-08-04

Interactive Web-GIS Tool for WAVEWATCH III - Assimilated SWH Data Visualization

http://172.16.1.140/swh_observation/

Acknowledgements –Chandra Sekhar and team

Real time validation of Wave Forecast

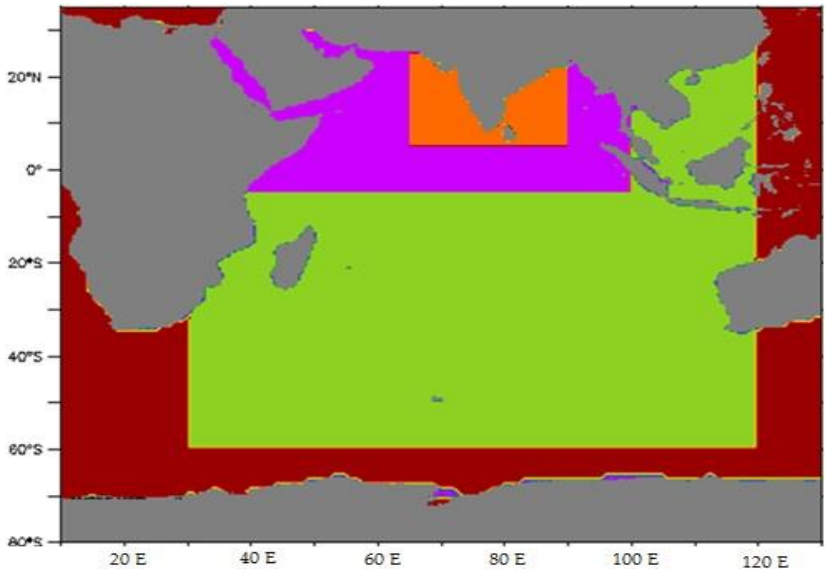


http://172.16.1.140:8080/FAST/wave.jsp

http://172.16.1.140:8080/FAST/WRB.jsp?location=Vizag&p=hm0&startdate=20250727&stopdate=20250831

Wave induced Flash flooding events - Kallakadal/Swell surge

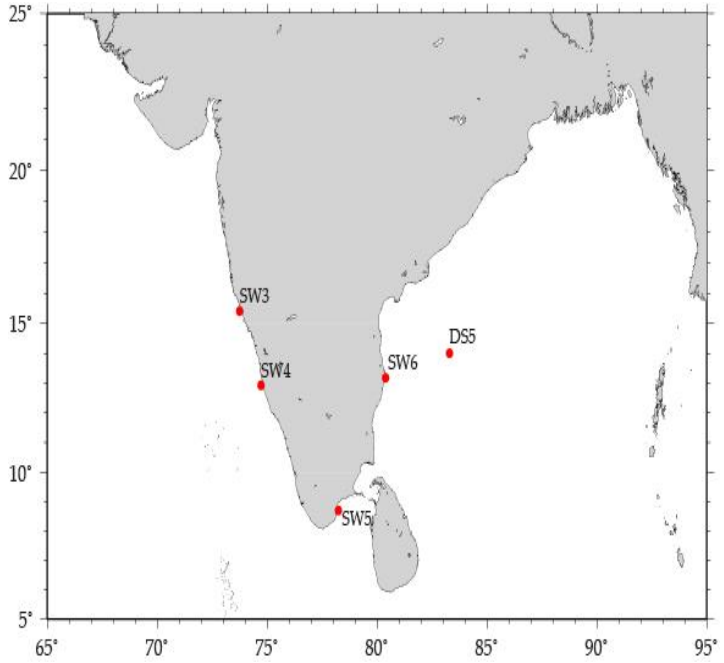
WAVEWATCHIII Multi-Grid setup at INCOIS



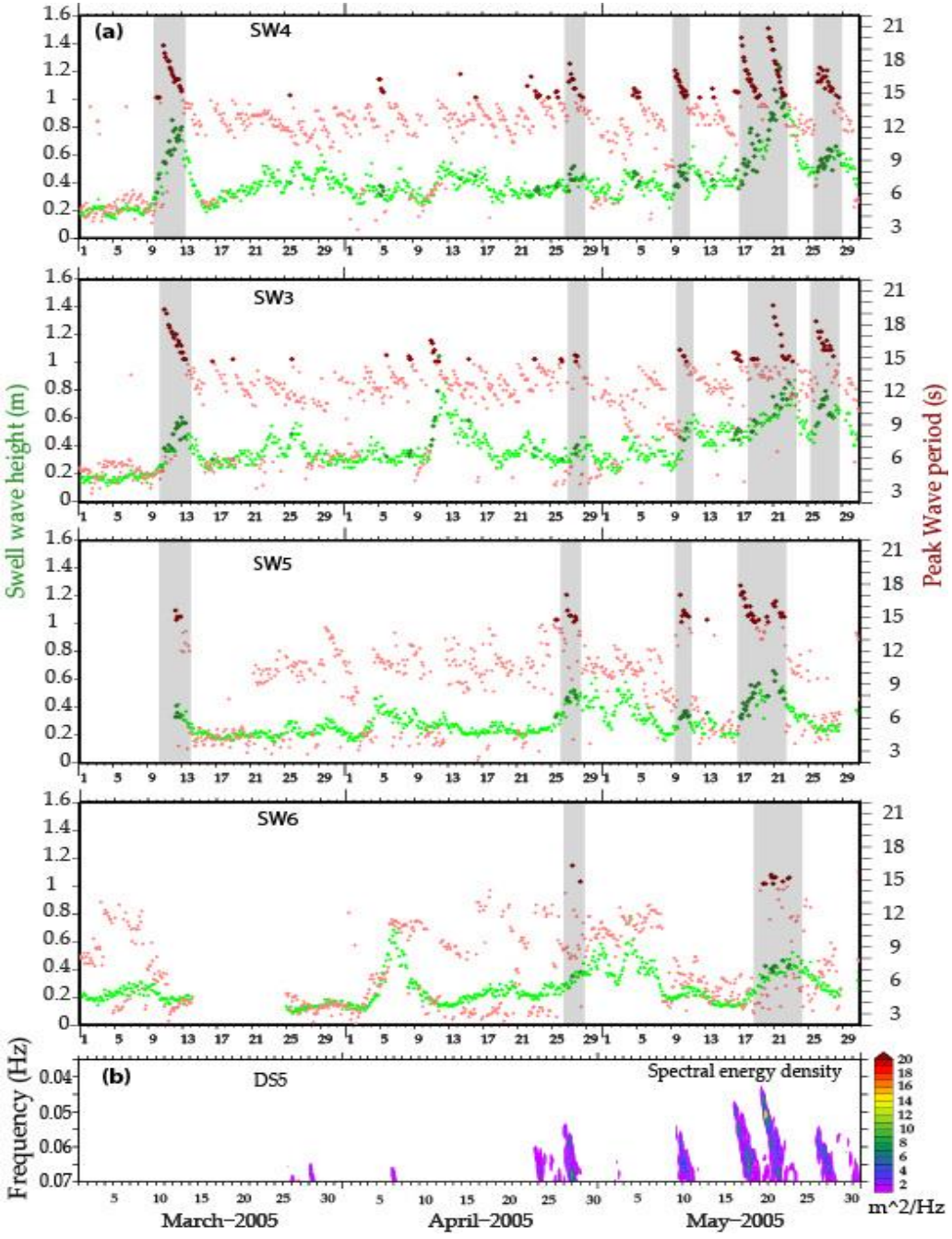
- **Version-6.07**
- **Source term-ST4**
- **Etopo1**
- **Spatial resolution**
  - **1 deg Southern Hemisphere grid**
  - **0.5 deg Indian Ocean grid**
  - **0.25 deg North Indian Ocean grid**
  - **0.04 deg Coastal grid**
- **Spectral resolution**
  - **29 frequencies and 36 directions**

- Kurian et al., [2009] has reported a special case of coastal flooding during pre-monsoon (April-May) season by the long period (~15 s) swell waves on the southwest coast of India ,named as *Kallakkadal*.

- Kallakkadal is a flash flooding event without any precursors or any kind of local wind activity to give advance warning to the coastal population.



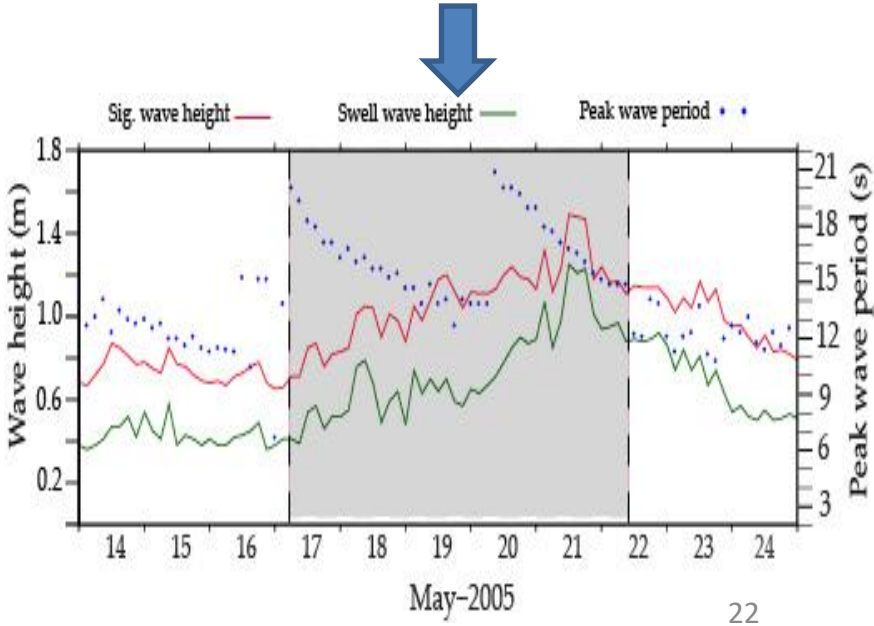
In-situ observations used for the study



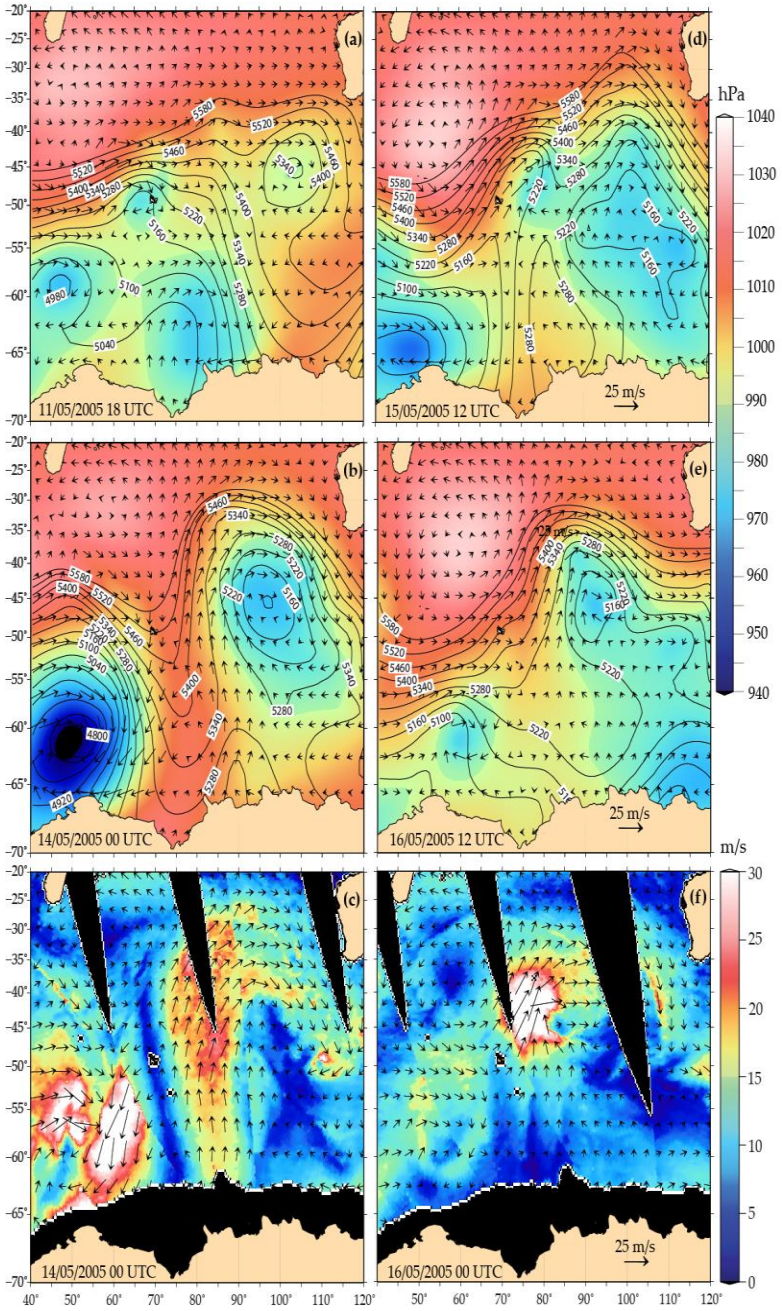
The shaded portion shows major high period swell occurrence (March-May 2005)

Long period swells (>14s) that are having a moderate height (>0.4m) and lasting for at least a half day (>12 hours)

Wave parameters during the strong swell event (17-21 May), off Mangalore.



Analysis of meteorological condition in the southern Indian Ocean



Cut-off low systems during 12-14 May 2005

(a,b,d&e) Geopotential Height at 500 hpa are superimposed on sea level pressure as contours. Vectors represent the surface wind speed.

(c&f) Surface wind fields from QuikScat scatterometer

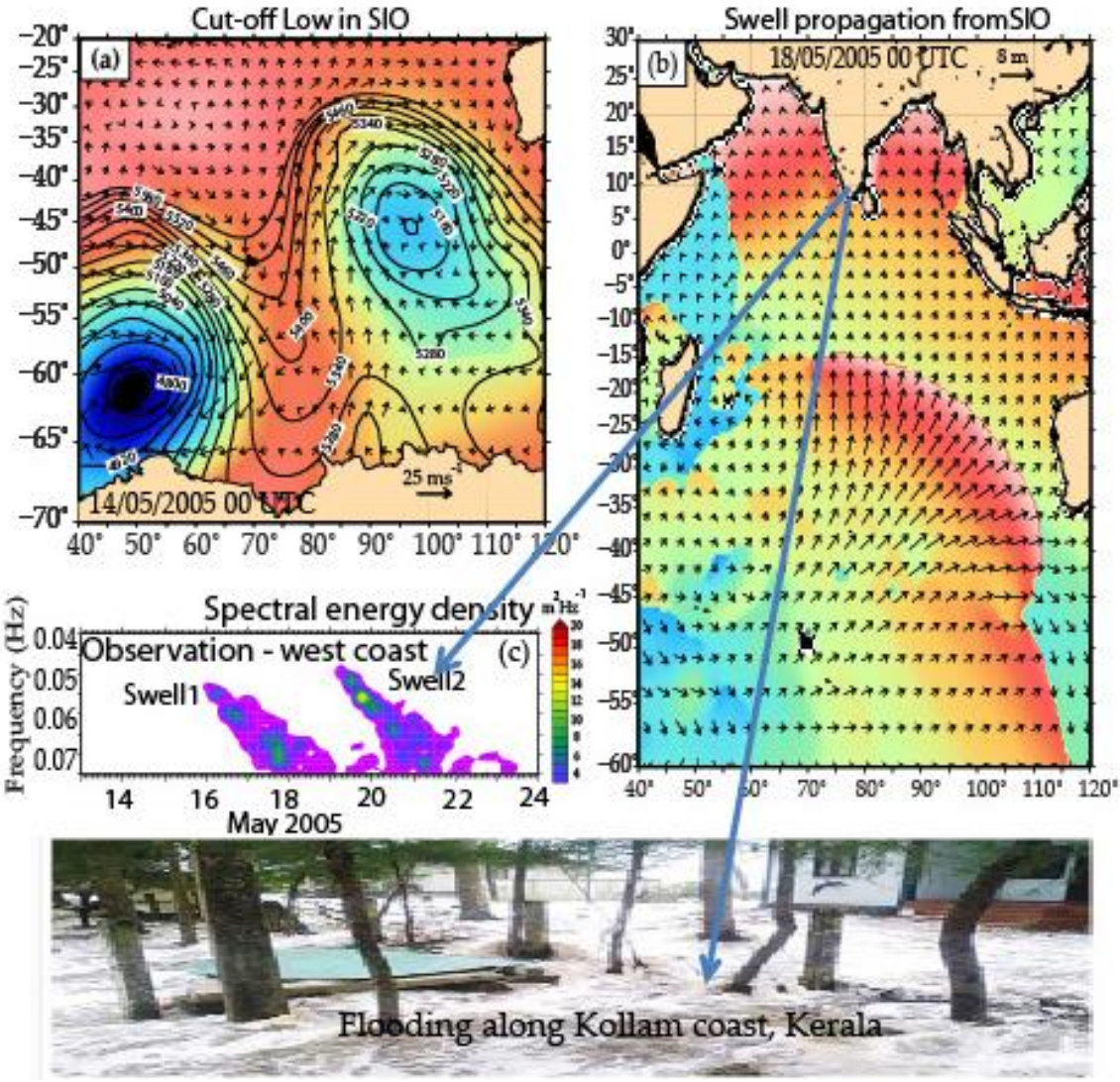
- A cut-off low (COL) corresponds to a closed low geopotential height in the upper troposphere that has become completely detached (cut off) from the basic westerly jets and usually are being advected equator ward of the mid-latitude westerlies [Nieto et al.,2008].
- These COLs are quasi-stationary in nature, providing strong (~25 m/s) and long duration (~3 days) winds and a large fetch; essential conditions for the generation of swells.
- The intense winds associated with COLs in the Southern Ocean trigger the generation of waves, and they travel to NIO as swells.

➢Kallakkadal is a flash flooding event , caused by the long period (~15 s) swell waves on the southwest coast of India

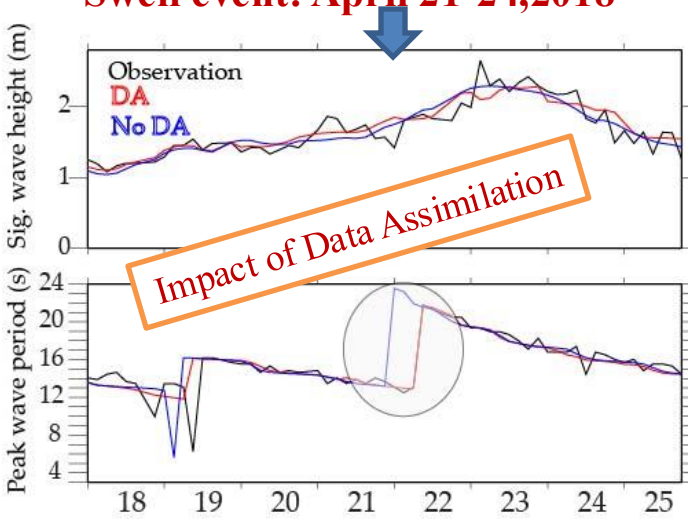
➢The intense winds associated with COLs in the Southern Ocean trigger the generation of waves, and they travel to NIO as swells.

➢These high swell events, which are occurring without any signs in the local weather, can be effectively monitored and forecasted at least 2 days in advance if the meteorological conditions of the southern ocean are properly monitored.

➢The forecast of high swell events can be further improved by the data assimilation of wave data in to wave models



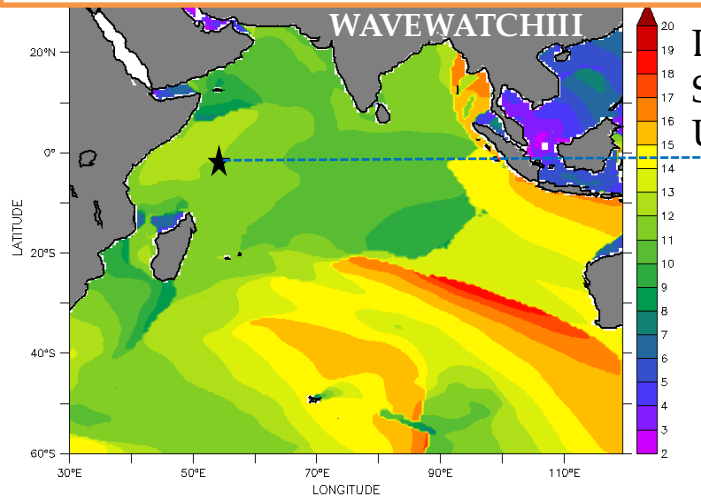
Swell event: April 21-24,2018



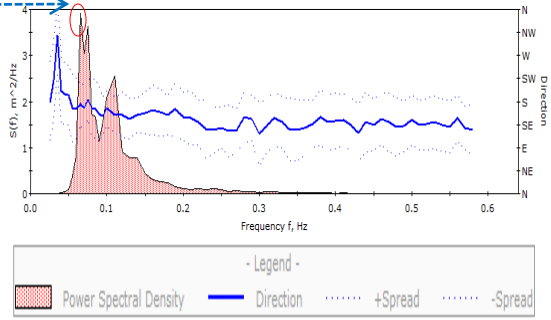
Remya P G, S Vishnu, B Praveen Kumar, T M Balakrishnan Nair, B Rohith, 2016, Tele-connection between the North Indian Ocean high swell events and Meteorological Conditions over the Southern Indian Ocean, JGR-oceans, 121, 7476–7494, doi:10.1002/2016JC011723.

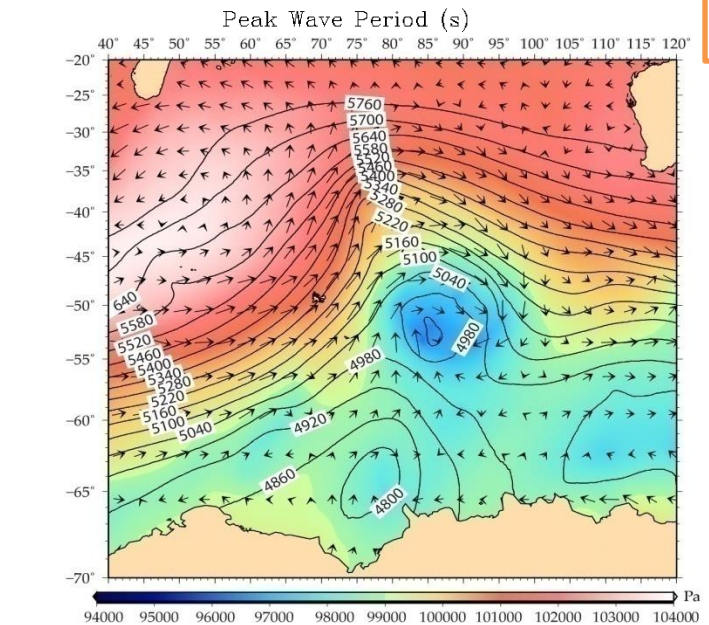
Seemanth M, Remya P.G., Suchandra A Bhowmick, Rashmi Sharma, T.M. Balakrishnan Nair, Raj Kumar and Arun Chakraborty, 2021, Implementation of altimeter data assimilation on a regional wave forecasting system and its impact on wave and swell surge forecast in the Indian Ocean, Ocean Engineering .

KALLAKADAL EVENT DURING 30 JUL. - 03 AUG., 2016



Low frequency observed at Seychelles, 2016-07-31 08:00 UTC





The extra-tropical storm in the Southern Indian Ocean (27 Jul. 2016). Here, geopotential height at 500 hpa is in contours, sea level pressure is shaded and surface winds are shown as vectors.

Various news paper Reports

Unexpected sea surge at Alappuzha coast, 27 fishing boats washed away, Indian Express, Published: 02nd August 2016

Malayala Manorama

INCOIS high wave alert

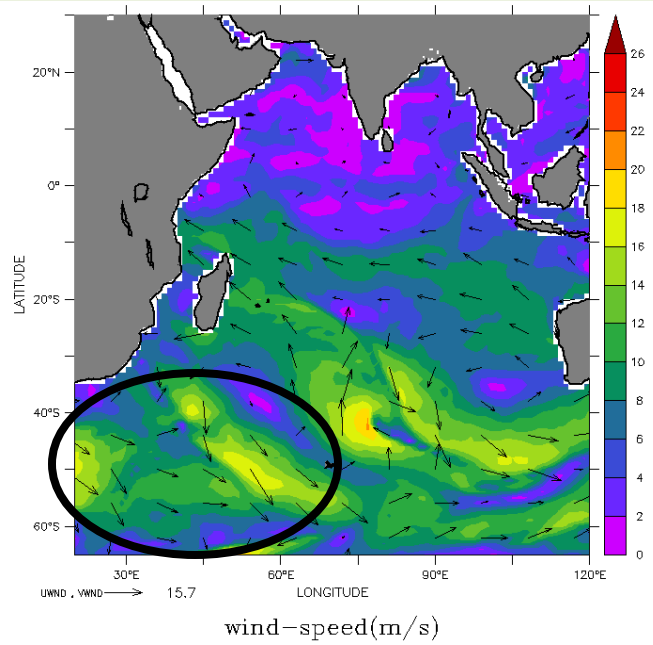
- INCOIS has issued timely wave surge alert for low lying coastal areas of Kerala from 30 Jul. 2016-03 Aug. 2016
- A high wave, surge alert for the West Bengal Coast valid from 08:30 hours on 02-08-2016 to 23:30 hours of 03-08-2016 was issued by INCOIS.

Feed back from users

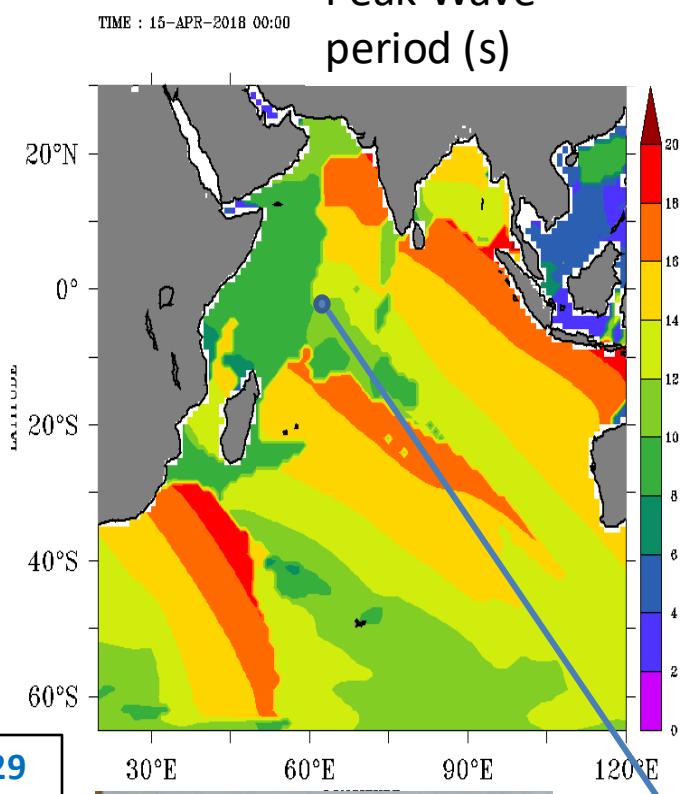
The Kollam District administration (DMD) :Wave surge was reported in coastal regions of Alappad Village of Karunagapally Taluk on on 1st and 2nd of August, 2016

- This information sent to all concerned disaster Management authorities and directly to fishermen via SMS. Total SMS sent (Tamilnadu, Orissa, Kerala, West Bengal, Gujarat, Maharastra, Lakshadweep) – 6965 ; Number of SMS sent to Kerala Fishermen – 340; Lakshadweep – 25

Kallakadal during 21-24 April 2018



Peak Wave period (s)



- COL formed on 15th April 2018 near 59 S, 29 E
- 9000 km away from the Indian coast
- Remained quasi stationary in the generation area for a duration of 36 hours with a wind speed 26 m/s
- COL ,duration-3.5 days, intensity- 4.6, size-1600 km
- The swell waves hit the Seychelles on 20th April and 2.75 m wave with a peak wave period 22s was observed in the INCOIS wave rider buoy

Coastal areas in Kerala battered by swell waves

Houses and infrastructure damaged, fishermen warned

SPECIAL CORRESPONDENT
THIRUVANANTHAPURAM

Triggered by sustained winds at the tip of the African coast, high swell waves are pounding the coastal areas of Kerala, causing damage to houses and infrastructure, flooding roads and displacing families.

The coastal communities have been advised to brace themselves for a fresh battering till Tuesday.

A press note issued by the Indian National Centre for Ocean Information Services (INCOIS), Hyderabad, said on Sunday that there was a possibility of rough sea and intermittent wave surge along the Kollam, Alappuzha, Kochi, Ponnani, Kozhikode, Kannur, and Kasaragod coasts till Monday midnight, owing to the effect of high-period swell waves. The coastal communities in the State have been advised to be cautious till Tuesday evening.

Vulnerable areas

The low lying areas of Kerala, Andaman and Nicobar islands and West Bengal are particularly vulnerable to the swell waves.

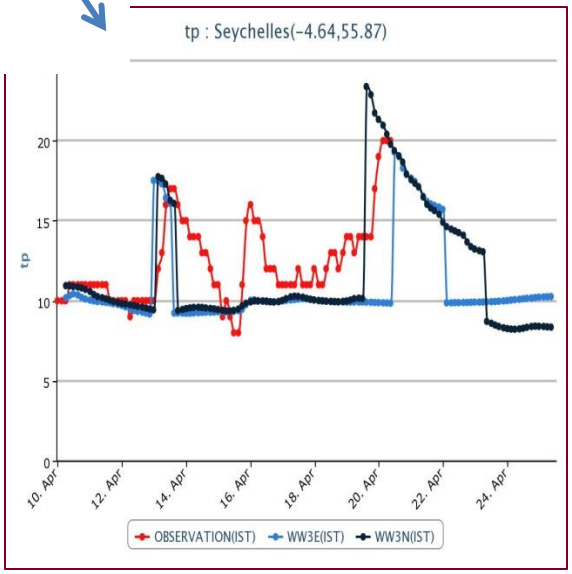
According to the multi-model operational forecasting system at INCOIS, there is a strong indication that high energy swell waves with a height 2 to 3 metres will occur in the seas around India up to April 24.

T.M. Balakrishnan Nair, Scientist, INCOIS, told *The Hindu* that the swell waves were induced by sustained winds blocking the Westerlies for more than three days off the tip of the African coast. The high energy waves generated by the phenomenon travelled more than 2,000 km across the ocean to hit the Indian coast.

Incois has recommended suspension of water-based recreational activity during the events.

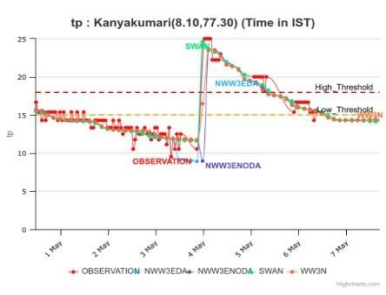
Fishers have been advised to anchor their boats at a distance from each other to avoid collision.

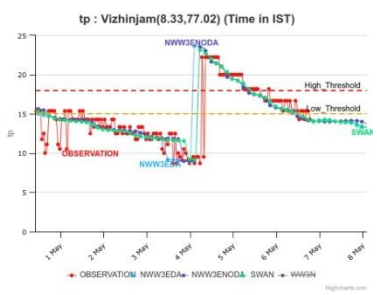
Fishermen have also been warned not to ply vessels near to the coast, where the swell wave activity would be more pronounced, Incois told *The Hindu*.

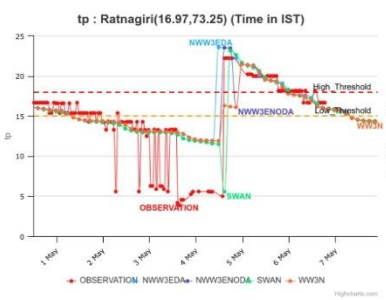


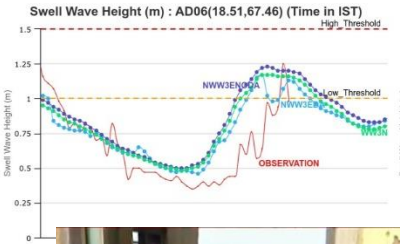
Swell Surge Warning/Alert:4-5 May,2024

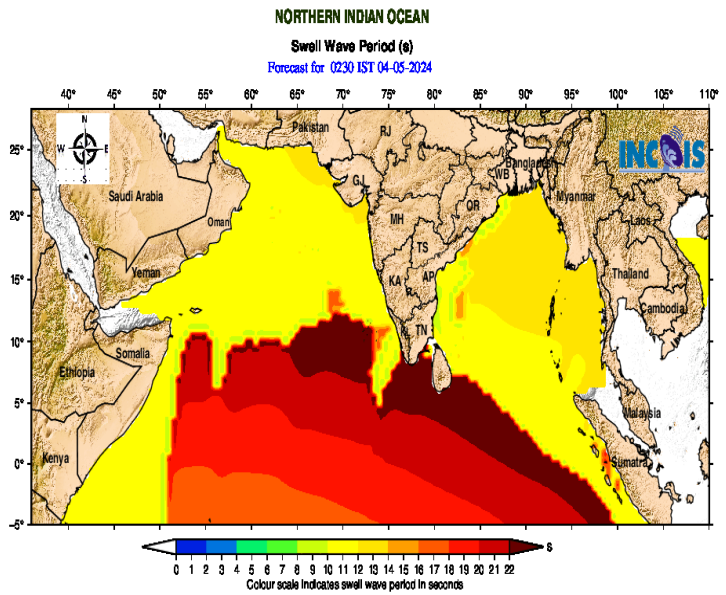
- INCOIS issued Swell surge Warning/Alerts to coastal states of Indian on 04 & 05 May 2024.
- Swell surges were experienced few low lying areas.
- As per report from Kerala, a few low lying areas got flooded due to swells and damages were reported at few scattered coastal districts.
- It is success story of INCOIS which provided forecast of Swell surges two days in advance. It was evident from WRB and Moored buoys observations, swell periods experienced 20-25 sec and swell height 1.2 - 2.8 m as forecasted by models.

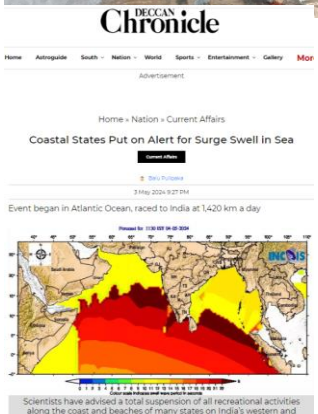




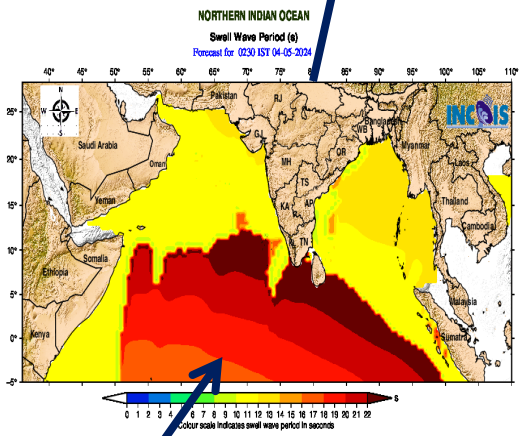


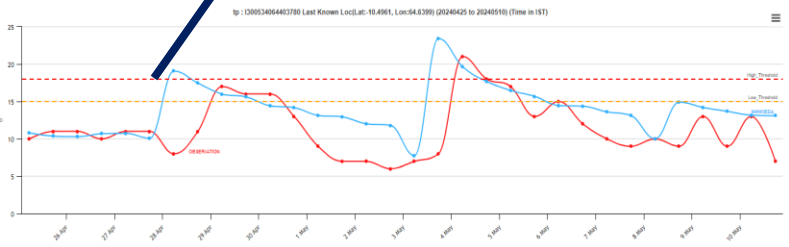




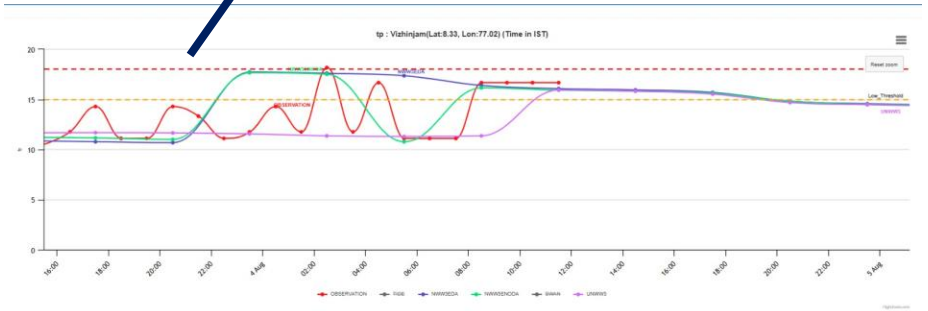


Kallakadal –May 2024





Swell surge–Aug 3, 2025

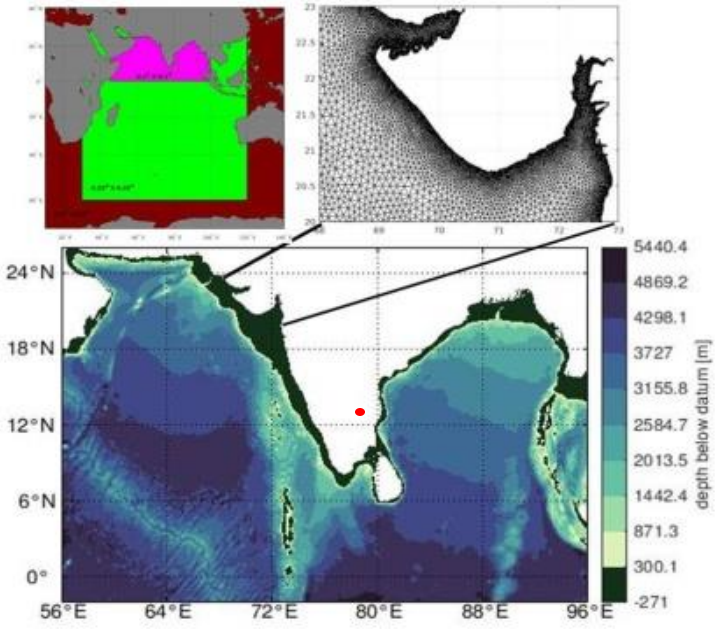


Causative mechanism of Coastal Flooding during Kallakadal events

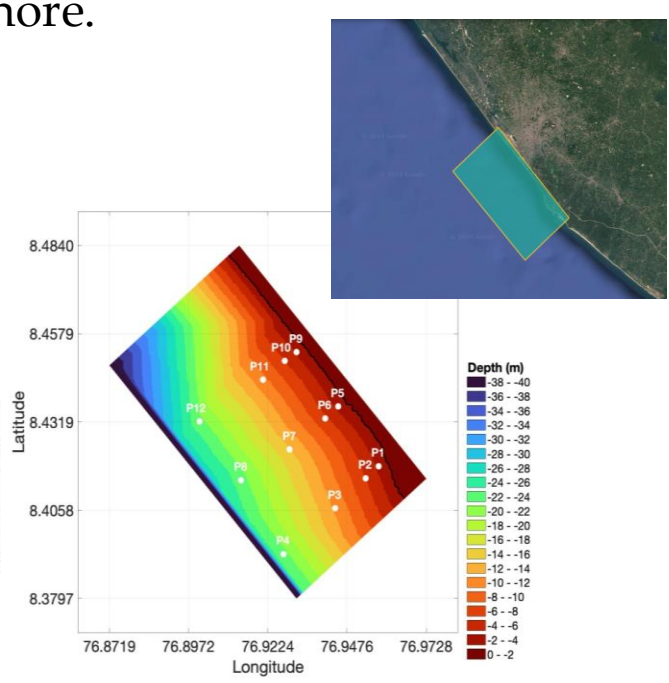
➢A combination of WAVEWATCHIII and XBeach to study the coastal inundation during high waves.

➢The bathymetry data is a blend of in-situ data (hydrographic charts, surveyed data from ships) for coastal regions and the General Bathymetric Chart of Ocean (GEBCO) data of 30 m spatial resolution towards the offshore.

➢Case 1
March 30-April 2,2024

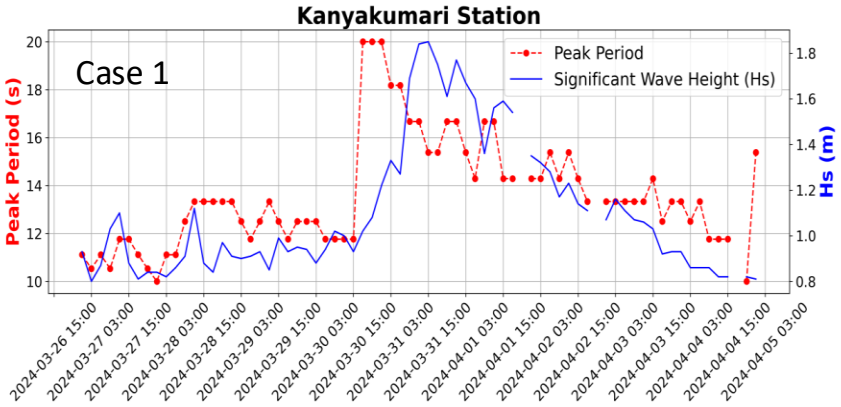


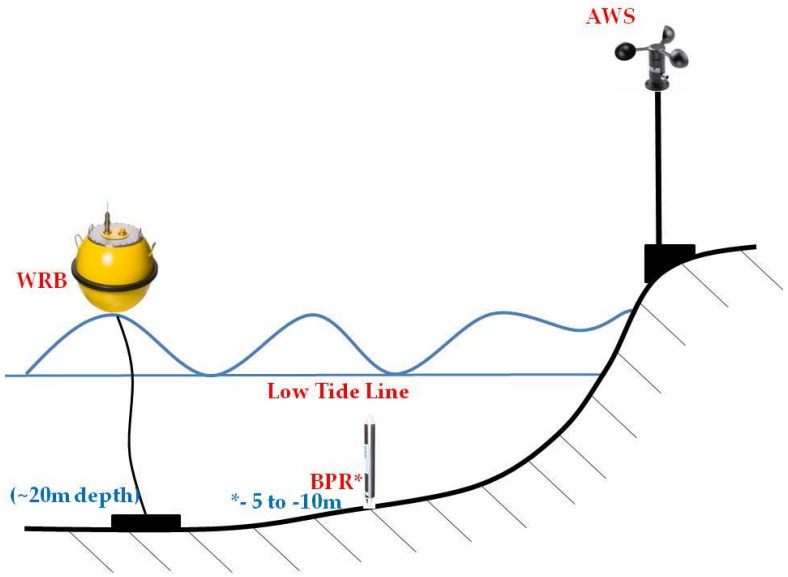
WAVEWATCHIII Model Domain

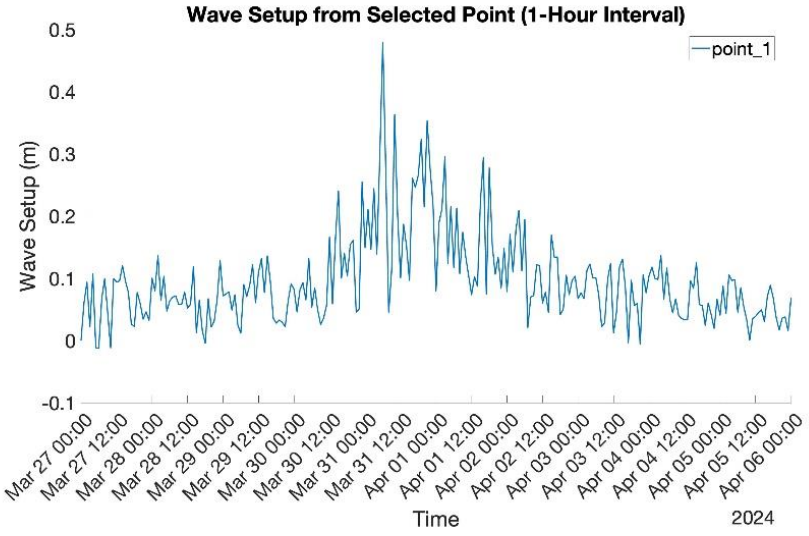


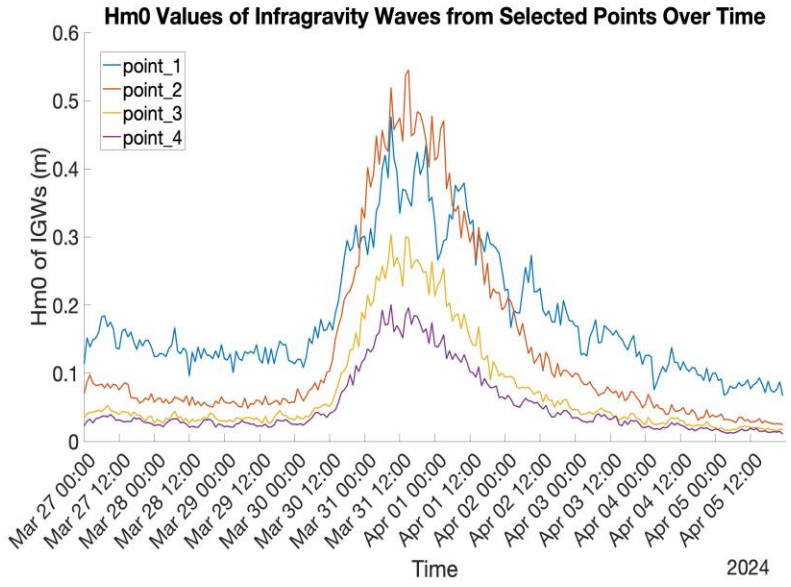
Xbeach Model Domain

Observed short waves

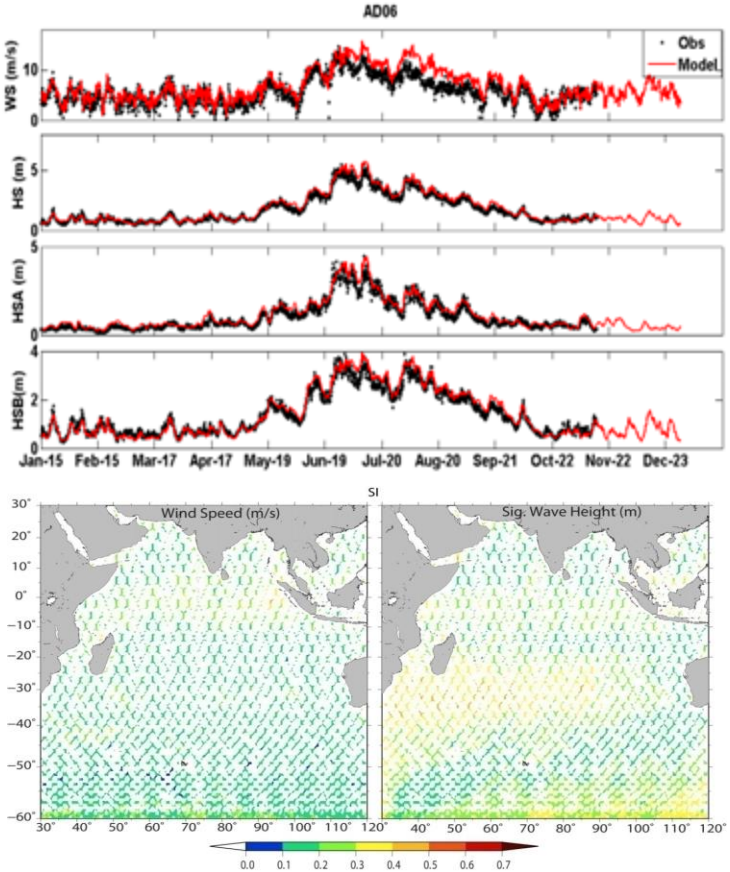


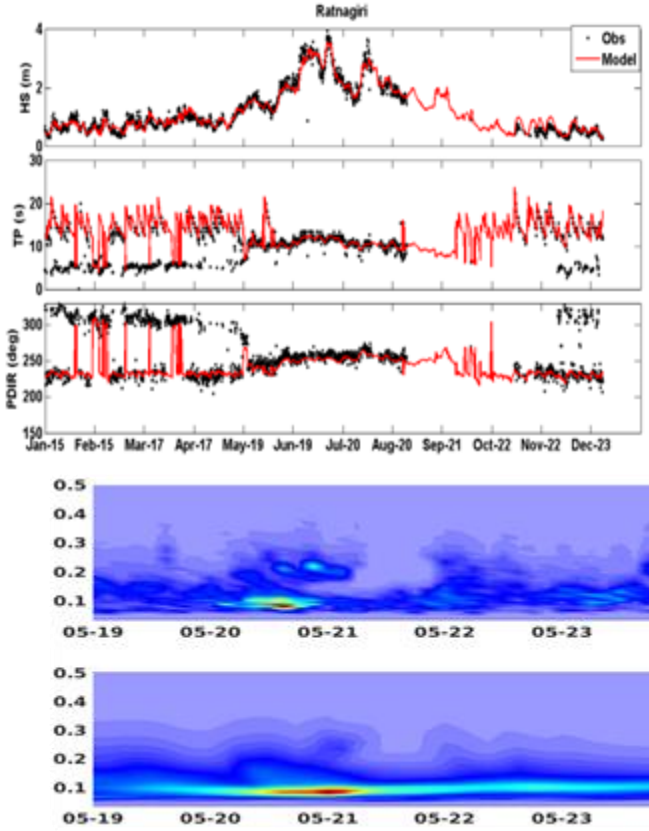






Validation of WWIII-Regional wave forecast





Comparison of Spectral energy at Digha during Roanu cyclone

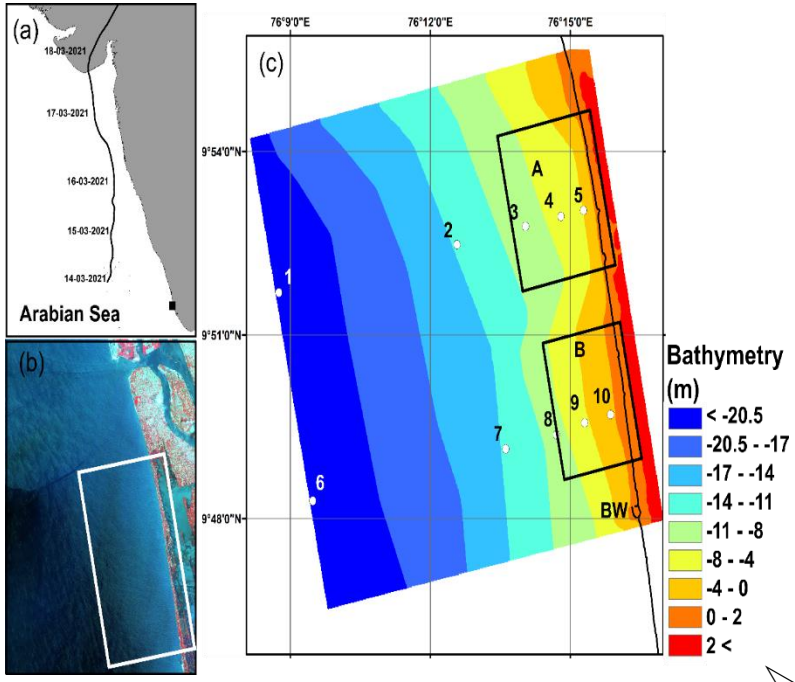
P. G. Remya, T. Rabi Ranjan, P. Sirisha, R. Harikumar & T. M. Balakrishnan Nair (2022) Indian Ocean wave forecasting system for wind waves: development and its validation, Journal of Operational Oceanography, 15:1, 1-16, DOI: 10.1080/1755876X.2020.1771811

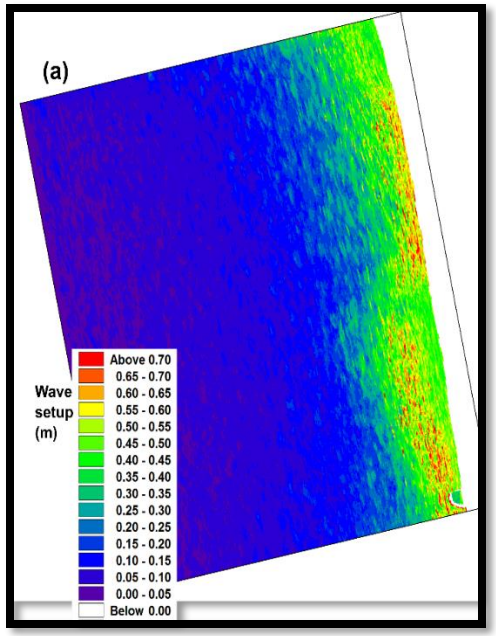
Wave induced coastal flooding during cyclones

➢The coastal food during the tropical cyclone Tauktae, 2021, at Chellanam coast, Kerala, has invited wide attention as the wave overtopping severely affected coastal properties and livelihood.

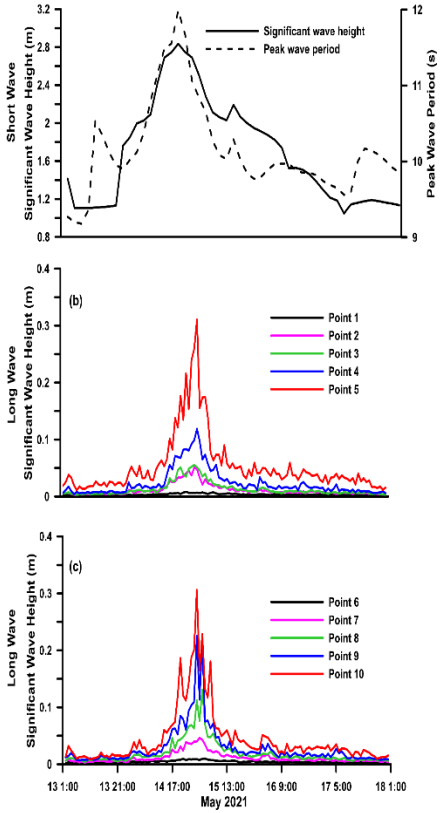
➢A combination of WAVEWATCHIII and XBeach to study the coastal inundation during high waves .

➢ **The effect of low-frequency waves and rise in the coastal water level due to wave setup caused the inundation at Chellanam, even during low tide with negligible surge height.**





➢ **Model simulated Wave setup**



(a) Cheriyakadavu

(c) Kannamali

scientific reports

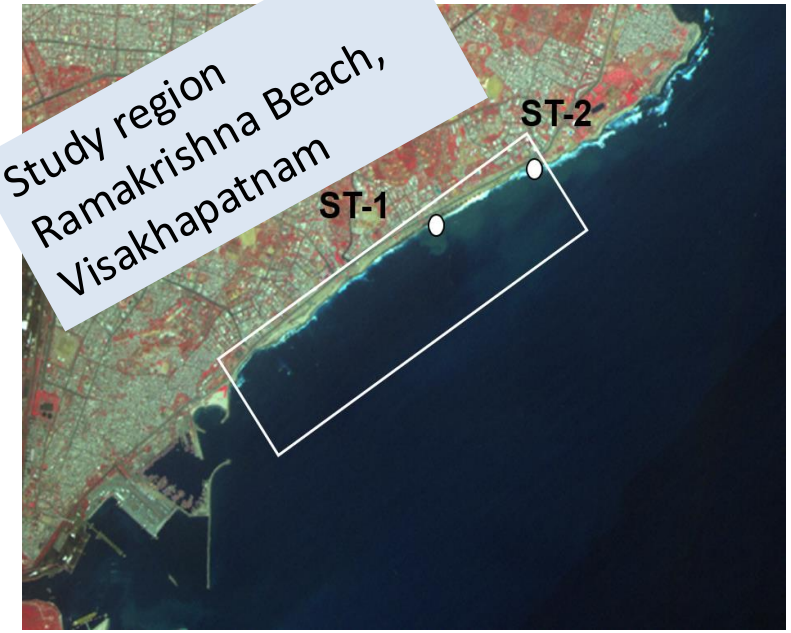
Article | Open access | Published: 19 November 2022

Wave induced coastal flooding along the southwest coast of India during tropical cyclone Tauktae

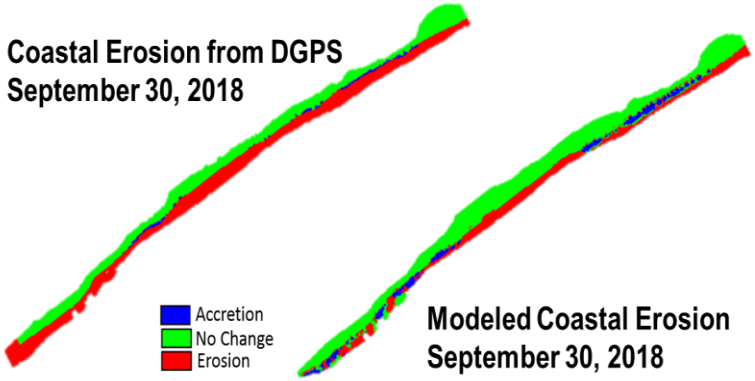
Ratheesh Ramakrishnan, P. G. Remya ✉, Anup Mandal, Prakash Mohanty, Prince Arayakandy, R. S. Mahendra & T. M. Balakrishnan Nair

Simulated coastal inundation at Chellanam over Google Earth images.

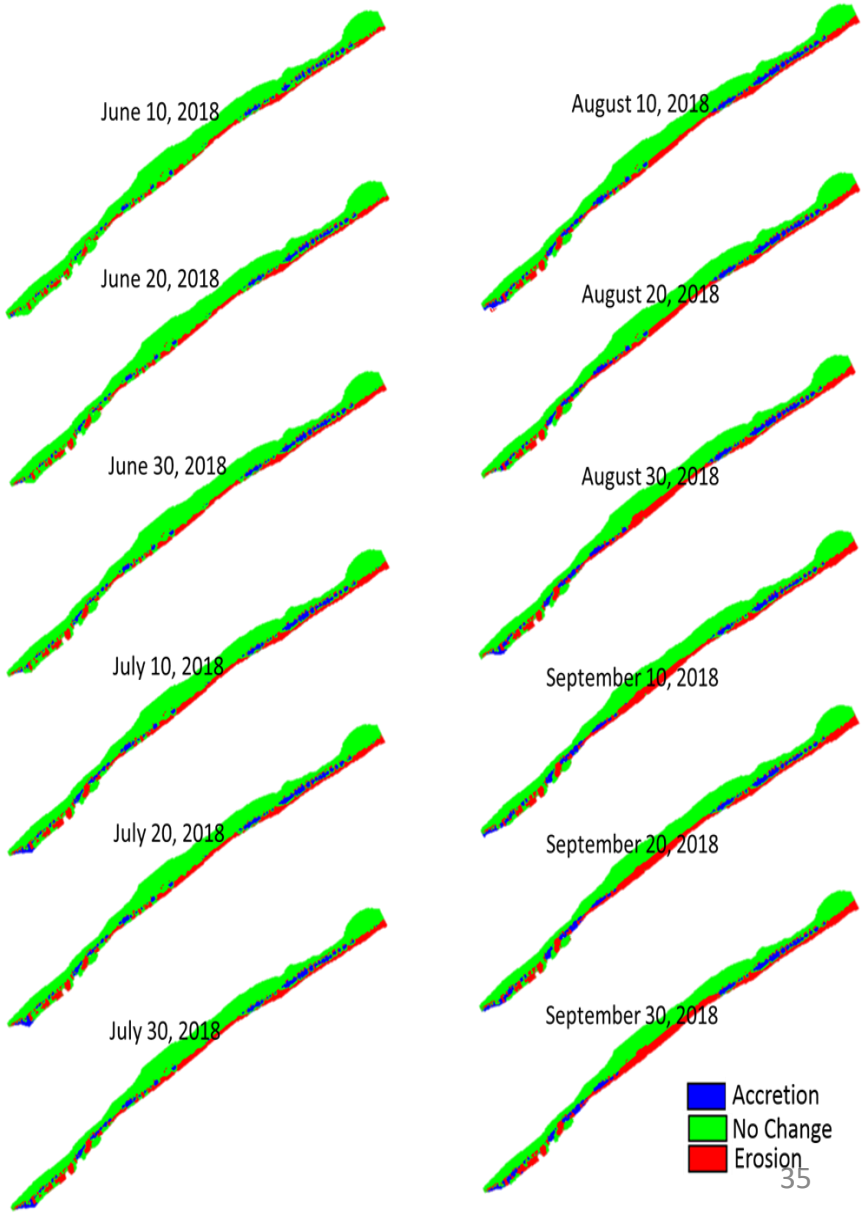
A Numerical Modelling Approach for Beach Erosion Forecast during Monsoon Season



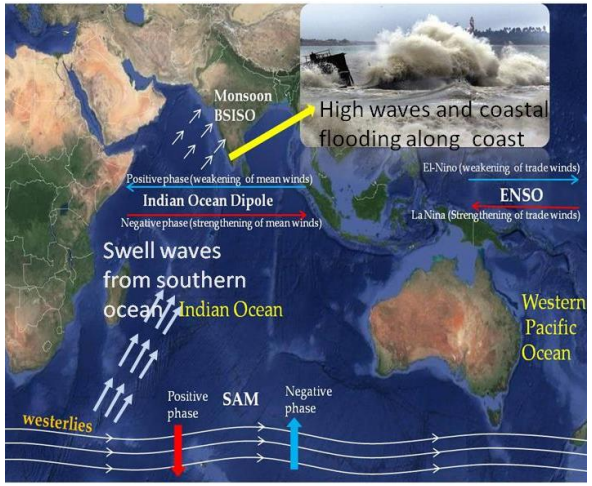
Comparison of beach erosion prediction with insitu measurements



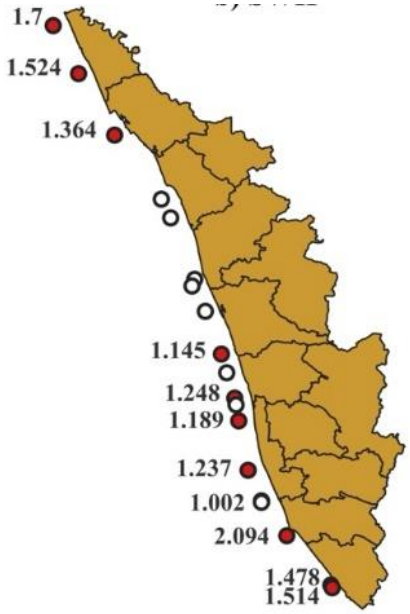
Beach erosion advisory provided with a lead period of 10 days.

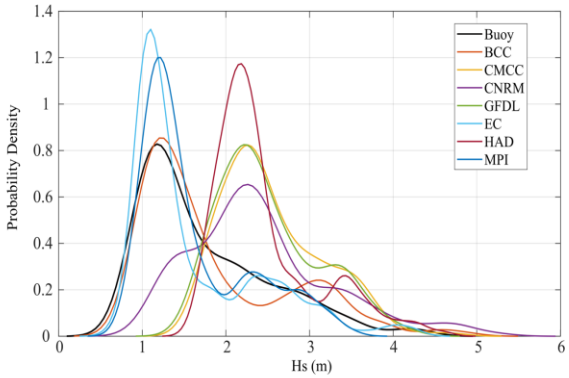


Are wave conditions in the Indian Ocean truly affected by climate change?



Trend of annual extreme significant wave height

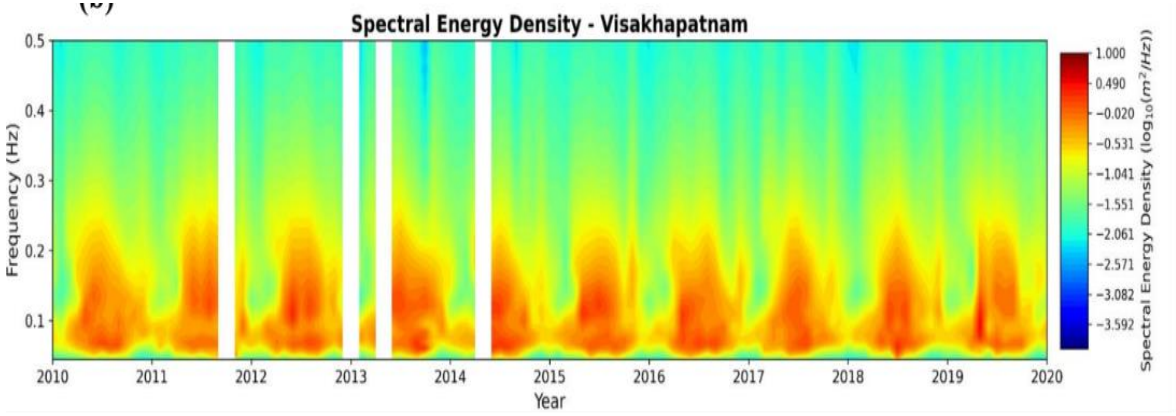




Remya et. al.,2020, Climate Dynamics

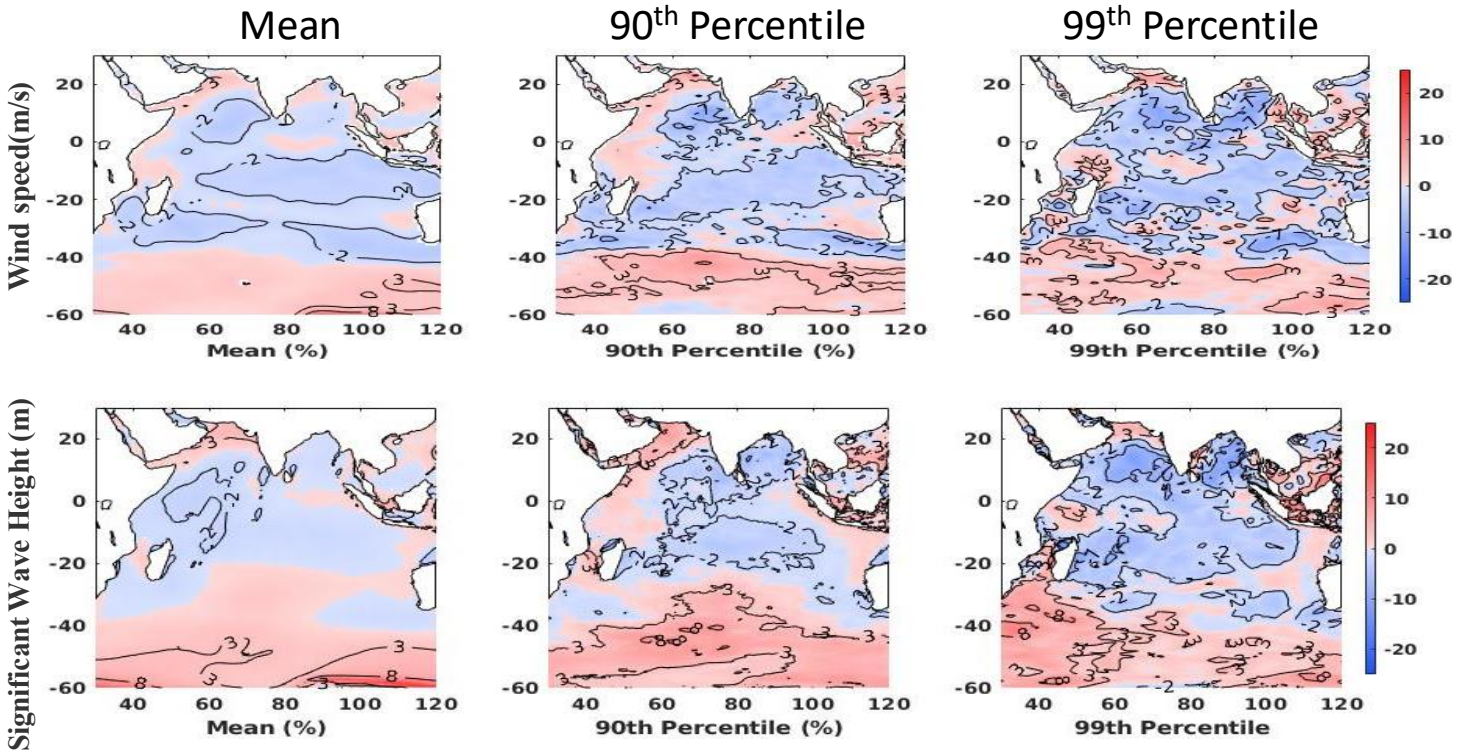
Srinivas et. al. , 2021, Scientific reports

Sreejith et. al, 2024, IJOC



Two sets of Run(1)Histroical -1985-2014 (2) Future projection-2071-2100.

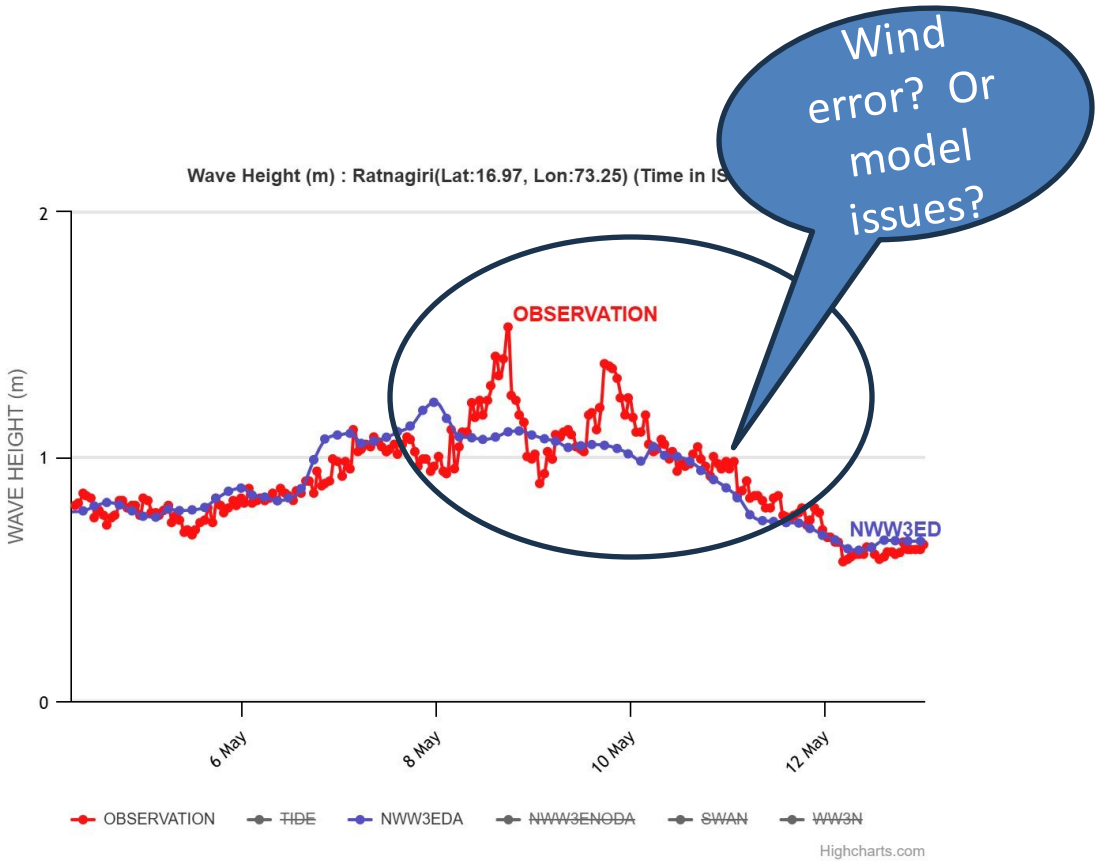
Percentage Changes from the Historical wave climate, $\Delta = (END21C - HIST)/HIST * 100$
Time slice experiment : Hist (1985-2014) Proj SSP5-4.5(2071-2100)



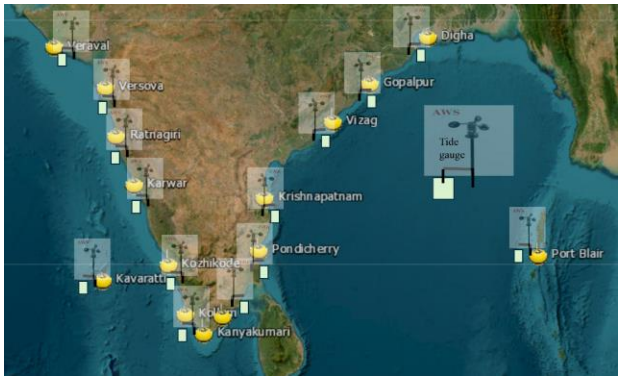
India's coastal regions, home to around 170 million people, are on the front lines of a changing climate, facing sea-level rise, extreme waves, and cyclones.

Bottleneck

Unavailability of coastal winds restricts tuning of the model for coastal areas.



Integrated coastal observation
Wave buoy, tide gauge and coastal AWS



P. G., Remya., Roshyal Joy., M., S. *et al.* Assessing the Influence of EOS-06 Scatterometer Winds on Indian Ocean Wave Predictions with Unstructured WAVEWATCH III. *J Indian Soc Remote Sens* (2025). https://doi.org/10.1007/s12524-025-02231-x

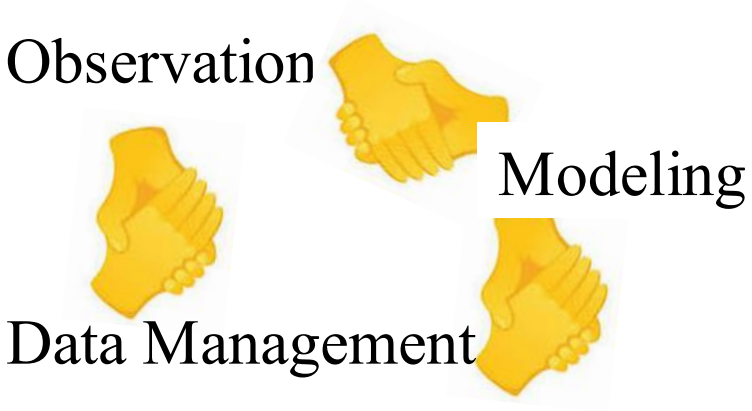
Conclusion

- WAMAN is a unique, sustainable model for ocean observing
- Community integration ensures longevity & effectiveness
- Data supports safety, research, operations & policy

Balakrishnan et al.,(2025) WAve Monitoring Along Nearshore (WAMAN) Buoy Network: Best Practices and Applications in Sea State monitoring and forecasting for the Indian Ocean, Accepted in BAMS

Acknowledgements

- Fishermen, NGOs, Ports, MoES, Coast Guard
- INCOIS team and collaborators



Thank You

remya.pg@incois.gov.in

Questions?