

# Blue Ocean IoT Cloud based Early Warning System

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**Abstract**—Sumatra earthquake Tsunami of 2004 took 10,745 lives in India and 230,000 in fourteen countries. Govt. of India started Indian Tsunami Early Warning System (ITEWS) at INCOIS, Hyderabad. INCOIS and state coastal authorities deployed a sea-level network of coastal tide gauges and open ocean buoys to measure the changes in the water level, near the fault zone, where earthquake-triggered tsunami occurs. It started with 2 tsunami buoys in the Bay of Bengal and 1 in the North Arabian Sea and 25 Tide Gauges at 25 locations. This network now has 17 broadband seismic stations to detect tsunami-genic earthquakes, 90 national seismic stations, 7 open ocean tsunami buoys and 35 tide gauge stations. ITEWS also receives real-time data from 350 seismic stations, 50 tsunami buoys and 300 tidal gauges of other international oceanic agencies. Also, more than 500 Argo floats capture temperature-salinity data at 20 levels, every 10 Days. Data from these Internet of connected things (IoCT) is ensembled and compared with satellite data from NOAA AVHRR, MODIS AQUA, and NCMRWF to generate multiple oceanic information products. Such integrated IoT Cloud system helps in creating an Integrated Ocean Observation System (OOS) which generates oceanic insights such as Potential Fishing Zone (PFZ), Wind speed and direction, Wave heights at the port level, and Tsunami warning. These services form part for an Early Warning System (EWS), which helps fishermen to take appropriate actions to avoid rough seas or take other preventive actions. ITEWS has successfully generated 101 IOR warnings, including 7 Tsunami warnings in last 10 years.

**Keywords**—IoT, Ocean, Tsunami, Early Warning System, Wind Speed, Mobile application, Fishermen

## I. INTRODUCTION

How big are the oceans? The Indian Ocean region (IOR) covers 73.56 million sq. km. or 20 percent of the world’s surface. The IOR is subject to floods, droughts, cyclones, tidal surges, earthquakes, Tsunamis, etc. Hence it is also called the “World’s Hazard belt”. ESCAP report of 1995 highlighted that 50% of the global natural disasters occur in the IOR mainly driven by criminogenic and seismogenic (tectonically) disasters [1]. Asia-Pacific Disaster Report 2019 revealed that annualized economic loss potential of \$675 billion due to various disasters [2].

Asia Pacific accounted for 2018’s almost 50 percent of the worldwide natural disasters events (281). 2018’s 8 out of the 10 deadliest disaster happened in this region, with Indonesia having two Tsunamis and one earthquake in quick succession, which resulted in nearly half of the region’s deaths. A deeper analysis of these events indicates that these may not be an anomaly but rather a sign of things to expect in the future too. Hence, we need to create a holistic framework to study the

IOR and associated oceanic weather patterns and seismic activities. 2004 Tsunami was an eye-opener in this direction, when the tsunami, one of the deadliest natural hazards in human history, killed more than 230,000 people in 14 countries, including 10,745 lives in India. After this disaster, in 2007 the Union Ministry for Earth Sciences set up The Indian Tsunami Early Warning System (ITEWS), at the Indian National Centre for Ocean Information Services (INCOIS), Hyderabad [3]. ITEWC focuses on detecting Indian Ocean tsunami-genic earthquakes and estimating their magnitude and direction of impact. It started with 2 tsunami buoys in the Bay of Bengal and 1 in the North Arabian Sea and 25 Tide Gauges at 25 locations.

A Real-Time Seismic Monitoring Network (RTSMN) was established. It is comprised of 17 Broadband seismic field stations. They use V-SAT communication satellites for data transmission. There is another global virtual subnetwork of IRIS Global Seismographic and GEOFON. Their 305 seismic stations transmit the raw data about earthquake epicenter, time of occurrence, and their magnitude. These are fed to a database system of all possible earthquake scenarios for the IOR. This helps in identifying the regions under risk at the time of the event.

Open sea tsunami buoys are used to detect the significant changes in sea-level at the time of occurrence of tsunamigenic earthquakes. These buoy systems can be equipped with bottom pressure sensor. Periodic readings of the waves can help generate a warning for coastal areas which will be potentially first impacted by a tsunami. This can be done even before the Tsunami waves reach nearby tidal gauges.

This internet of connected things (IoCT) helps in developing a decision support system aimed at monitoring the online input data from individual sensors, generating automatic alarms based on preset thresholds and decision rules for one or many of the input parameters. This could also

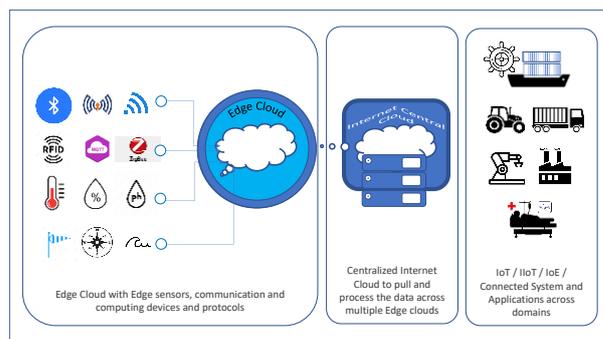


Figure 1 IoT Edge, IoT Cloud and application systems

execute criteria-based analysis for one or more input parameters or scenarios and generate online advisories.

These advisories were relayed through API systems to various end-user communication methods and applications such as mobile phones, web applications, and SMS alerts. These formed the early warning system (EWS) for the vulnerable community. They used the disseminated information and the threat levels such as Warning, Alert, Watch, or Information, to follow the standard operating procedure (SOP).

## II. INTERNET OF THINGS (IoT) CLOUD

The Internet of things (IoT) is defined as the network of physical objects, called “things”, which may have sensors and software to collect data and connect and exchange data with other devices and systems over the Internet [4]. Recommendation of ITU-T Y.2060 (06/2012) defined IoT as “a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies” [5].

An IoT cloud is a big network of such IoT devices, software applications, messaging protocols, to achieve a particular objective. [6] Once the sensor data reaches the cloud, the software application processes it and then takes an action, such as sending an acknowledgment to the IoT sensor, or adjusting them automatically or raising an alert to the user. Hence, an IoT cloud forms the basis of an autonomous system, which can help manage the explosive growth of various operation technologies (OT), push time-critical and smart decisions to be taken at the edge that is devices itself, and only refer to the cloud when more intensive computation is needed or historical data analysis is required (see Fig. 1).

As shown in Fig. 2, INCOIS has established a comprehensive ocean observation system (OOS) program using a fleet of In-situ IoT sensor platforms and remote sensing data sources [7].

In-situ observations IoT cloud systems include,

- Argo Profiling Floats
- Data Buoys
- Current Meter Arrays
- XBT / XCTD, Gliders
- Tide gauges
- Bottom Pressure Recorders (BPRs)

Besides, it also collects the data from Remote Sensing Satellites such as

- Oceansat-1 (Ocean Color Monitor) and Oceansat-2 (Ocean Color Monitor, Scatterometer)
- Other International satellites such as NOAA AVHRR, MODIS AQUA, etc.

Hence, the mixing of the data from different IoT Cloud systems of Satellite Oceanography and National Oceanographic Data Centre is assimilated. These data are fed to Ocean Models running on high-capacity and high-performance computers (HPCs) to generate various value-added oceanic information services. It includes:

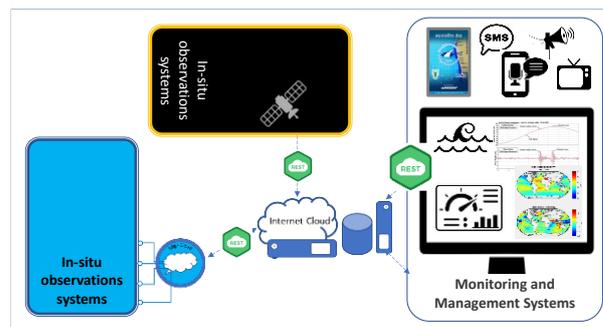


Figure 2 Integrated ocean observation system (OOS) – data Assimilation from different IoT Cloud systems to create a plural analytical and advisory service

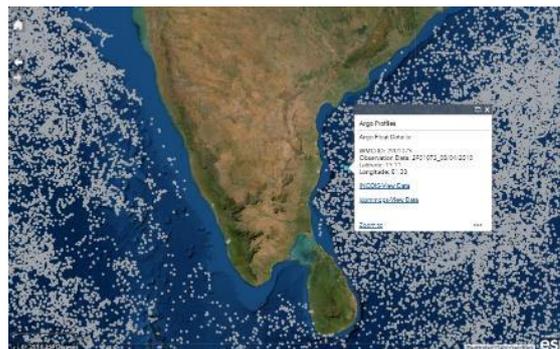


Figure 3 Argo Data view in the Indian Ocean

- Potential Fishing Zone (PFZ) information
- Ocean State Forecast (OSF) Services of Wind Speed and Direction, Wave height, Storm Surges
- Early Warning for Tsunami
- Ocean Modelling System, Ocean Data and Information System (ODIS), Web-based Services, Coastal Geospatial App and various APIs.

This information is distributed through multiple channels of Television, Radio, digital display boards, web app, mobile app, text, and voice SMS. Beneficiary stakeholders include,

- Fishing Community
- Ports and Harbors, Off-shore and Shipping, Navy
- Coast Guards, Coastal States extension services
- Research Institutions and Academia

### A. In-situ observations IoT Cloud system

#### 1) Argo Profiling Floats

Argo is an international program using profiling floats to collect ocean temperature, salinity, sea currents, pressure and other bio-optical properties. Some floats also collect biogeochemical data such as oxygen, pH, nitrates, chlorophyll. These are useful in climate and oceanographic research [8].

These are a cluster of robotic instruments. They keep drifting with oceanic currents. They move up and down between the surface and a mid-water level say at the depth of 2000 m. Every 10 days they come to the surface, transmit the data to the satellite and then return to the original position. There are approximately 4000 active floats across the globe,

producing 100,000+ temperature/salinity profiles per year. INCOIS has approx. 400 active floats. Fig. 3 shows the all floats in the Northern Indian Ocean [9]

## 2) Data Buoy

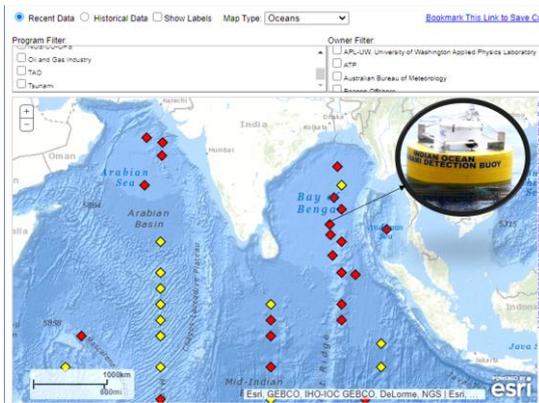


Figure 4 Data buoy in the Northern Indian Ocean. Inset – Station 23227 in the Bay of Bengal, managed by INCOIS. SAIC Tsunami Buoy SAIC Tsunami Buoy (STB) with DART II BPR, 6.255 N 88.792 E (615'17" N 88°47'31" E) Water depth: 3793 m



Figure 5 Current Meter Arrays



Figure 6 XBT/XCTD Observations in Northern Indian Ocean

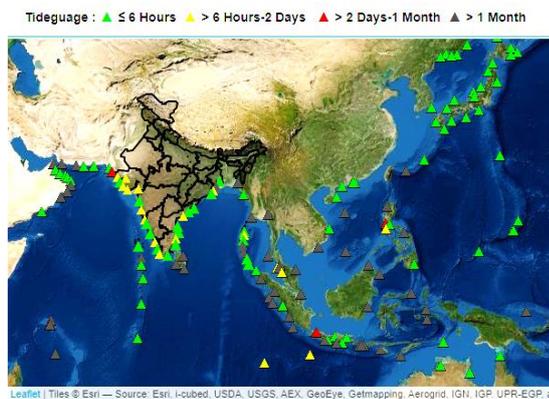


Figure 7 INCOIS – In-situ tidal data – Real-time

A data buoy contains various sensors to monitor and collect atmospheric and oceanographic data. They have sensors to measure wind speed and direction (WSD), air temperature, atmospheric pressure, sea surface temperature (SST), ocean current speed, and direction and wave parameters such as height. See Fig. 4. They are equipped with a global positioning system (GPS), beacon light, and satellite transceiver. Few buoys are fitted with sensors to measure radioactivity, turbidity, chlorophyll, and dissolved oxygen in the ocean waters and may have a camera too [10].

These buoys are IoT Cloud platforms, capable of data logging and processing at the edge. The data transmission is through two-way communication, through INMARSAT-C or other satellite terminals [11]. NIOT Chennai has a shore station to receive, store, process, and analyze the data. It also transmits and disseminate the data to other user agencies like INCOIS for further computation and analysis.

## 3) Current Meter Arrays (CMA)

As shown in Fig. 5, INCOIS has installed arrays of Current Meter Moorings (CMM) along the equator [12]. This helps in understanding the dynamics and the long-term variability of the ocean currents, deep-sea circulation in the equatorial Indian Ocean. CMA helps to study the upper ocean variability in the thermohaline structures, currents (VM-ADCP and LADCP), nutrients, chlorophyll, and primary production in IOR, especially in the Bay of Bengal.

## 4) XBT and XCTD

Expendable Bathythermograph (XBT) is a probe used to measure upper oceanic temperature throughout the water column up to 760m in depth. They are placed along selected shipping lanes across Mumbai - Mauritius, Chennai - Port Blair, Port Blair - Kolkata, Chennai - Singapore, and Kochi - Lakshadweep. See Fig. 6. The bimonthly data from XBTs are transferred to INCOIS for download and analysis [13].

Expendable conductivity-temperature-depth (XCTD) is a profiler instrument to capture water temperature and conductivity of the ocean water depth in a large area. It is transmitted to the data buoy which acts as an IoT Edge cloud, where it is recorded for further analysis.

XBT and XCTD (257 / 92) profiles of the Indian Ocean were analyzed in one year. INCOIS is also planning to deploy 900 XBT probes along the major shipping routes of Chennai-Andaman-Calcutta and Bombay-Mauritius. This will help to monitor the upper ocean thermal structure in IOR.

## 5) Tide gauges

Periodic tidal oscillations are like the breathing pattern of the oceans. Tide gauges (TD) are installed in ports, harbors and some strategic locations to measure the water levels. Tidal predictions are important for navigational purposes. As shown in Fig. 7, TD data analysis helps in estimating the approaching pattern of oceanic disasters like storm surges or tsunamis. Long time series of tide gauge data is used to study sea-level changes associated with global warming [14].

The acoustic TDs measure the time taken by acoustic pulses to reflect vertically from the ocean surface. 1-minute averages data is transmitted every 5 minutes interval through VSAT, GSM, and INSAT from 100s of national and international Tide Gauges.

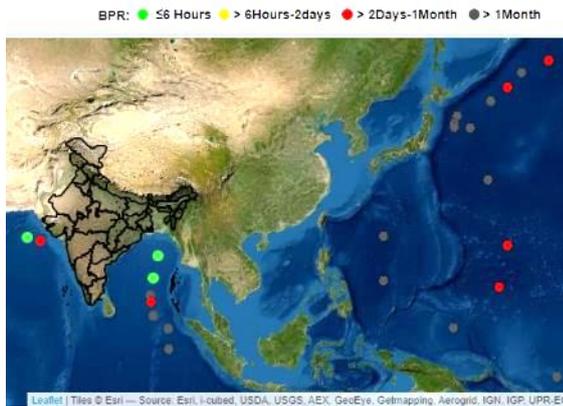


Figure 8 Bottom Pressure Recorders (BPRs) in IoR

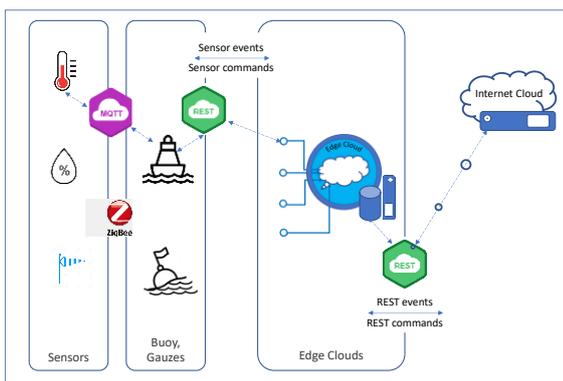


Figure 9 Pictorial representation of the core IoT Edge of the BPR

### 6) Bottom Pressure Recorders (BPRs)

BPRs is the core IoT edge component of the Tsunami Early Warning System. BPRs identify the sea-level changes in the source region of tsunami genic. This helps in building the propagation of Tsunami waves, speed, and spread in the rest of the open ocean.

As part of the ITEWS, a real-time IoT cloud network of Deep Ocean Assessment and Reporting Tsunamis (DART) has been established by the National Institute of Ocean Technology (NIOT) consisting of 12 BPRs. They transmit real-time data to NIOT Chennai and INCOIS Hyderabad. Arrangement of the BPR is in such a way that they give 30- and 60-minutes interval data of the arriving tsunami wave. This not only helps in differentiating the signals from the tsunami wave versus the seismic Rayleigh signals in the earthquake region but also provides redundancy, enough time for warning and action [15]. As shown in Fig. 9, India has four and two BPRs in the Bay of Bengal and the Arabian Sea, respectively.

The BPR operates in one of two data reporting modes: Normal mode and Tsunami Response Mode. Normal mode is a low power, scheduled transmission mode, in which samples are taken every 15 min and transmitted every 1 hour. Tsunami Response Mode is a triggered event mode. In this mode, samples are taken every 15 seconds and transmitted every 5 minutes [16].

The core IoT Edge of the BPR uses a piezoelectric pressure transducer to make 15 seconds-averaged measurements of the pressure exerted on it by the overlying water column. The Tsunami detection algorithm running at

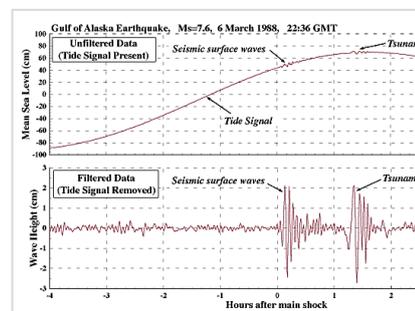
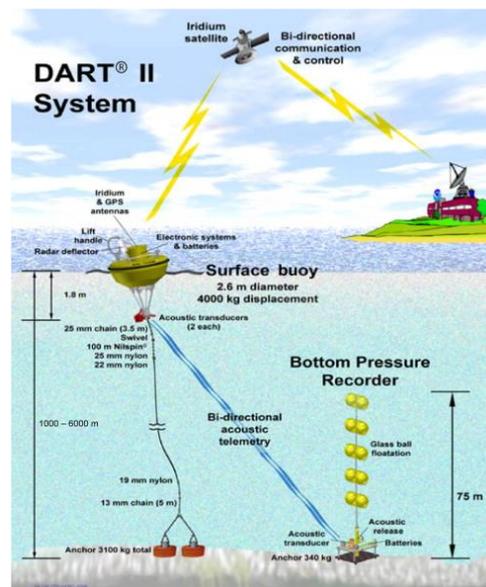


Figure 10 DART II system using BPR. Observations from Gulf of Alaska Earthquake and observations from Tidal signal, Seismic surface waves and Tsunami waves event. Source: DART II System organizations

the edge cloud generates predicted water height values within the tsunami frequency band and compares all new observed samples thereafter with these predicted values.

If two 15-second water level values exceed the predicted values greater than the threshold (e.g., 30 mm), the system switches the mode from Normal mode to Tsunami Response Mode. An acoustic link transmits data from the BPR on the sea floor to the surface data buoy. The data are then relayed via a satellite (e.g. INSAT) communication finally to the ITEWS.

Each BPR system has a two-way communication link. They transmit and receive data from Tsunami Warning Centre. The data center at INCOIS is equipped with state-of-the-art computing hardware for data reception, which includes, INSAT two-way communication hub, data processing & visualization, and dissemination facilities. ITEWS can remotely trigger the tsunami response mode of BPR Edge nodes, at any time. They can also gather BPR health or the tsunami response mode data.

Fig. 8 depicts the results observed from the Gulf of Alaska Earthquake on 6<sup>th</sup> March 1988. When the tidal signal was removed, a correlation between the seismic surface height and Tsunami waves height was observed. This system deployed at 6000m of ocean floor helped detect 67 BPR records, 21 Tsunami records, and 7 Tsunami events [17].

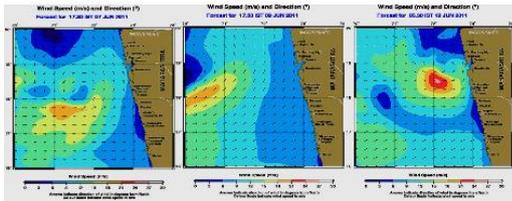


Figure 11 Wind Speed and Direction forecast service images – source mKRISHI@ Fisheries

### B. Remote Sensing Satellites observations Cloud system

The Remote Sensing Satellites Observations Cloud system receives the data from NOAA and Terra and Aqua Satellites.

NOAA-AVHRR is Advanced Very High-Resolution Radiometer, which includes image data products such as sea surface temperature, Cloud classification (Clear, Sun glint, Low, High & Part), Visible bands, (Radiance/Reflectance), fog, NDVI, etc.,

MODIS (TERRA/AQUA) Data products include atmospheric data like Aerosol (Type, Optical Depth), Water vapor (IR & Near IR), Cloud (BT's, Fraction, Face, Optical Thickness, Effective Particle Radius), Fog (Day & Night fog product) and Profiles (Moisture, Temperature, Lifted Index, Water Vapor). It also includes ocean parameters like Chlorophyll-a, Kd-490, POC-Clark, TSM-Clark, Calcite, etc. [18].

It also gets the Ocean color monitor (OCM) data from Oceansat-2

These data products from different satellite passes are stitched together and then analyzed to generate advisory services like the Potential Fishing Zone (PFZ). As shown in Fig.11 it is used to generate the wind speed and direction images too.

### III. INTEGRATED INTERNET OF THINGS (IOT) CLOUD

The Architecture of each of the above IoT cloud can be represented by a conceptual Amazon AWS architecture shown in Fig. 12(a) and 12 (b) where each IoT cloud pushes the data through AWS IoT core which will be passed to the REST API / services subscribed to the data. Each IoT edge cloud has two major components – Intelligent Edge Computing and embedded analytics functions such as ‘Inference’, ‘predictions’ at each Edge cloud.

#### 1) Edge Computing

Computing integrates conventional edge devices and services. It supports various connection within various nodes at the edge and manages the local storage. It performs the required basic, incremental, or anomaly calculations, at this stage the convergence of operational technologies and information technologies occur.

#### 2) Embedded Analytics

The embedded analytics functions give the ‘Autonomous’ state to the edge. It maintains a low amount of history and state of the devices and runs rule-based algorithms to take a localized decision. This is embedded in an AI platform at the edge which can collaborate with the AI platform at the central Cloud. This not only improves the speed in action but also reduces the communication payload, increasing the overall battery and equipment life.

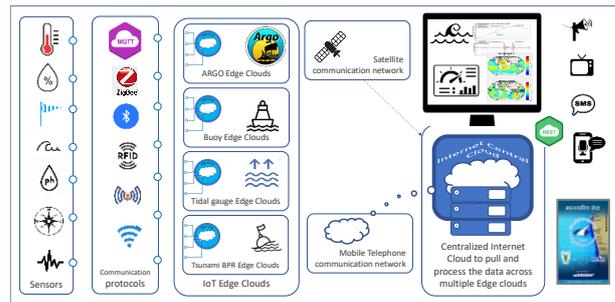
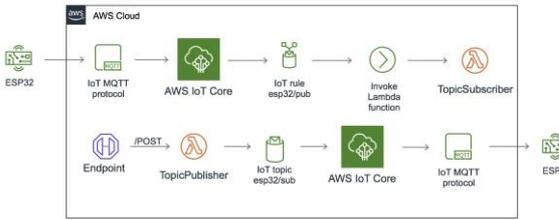
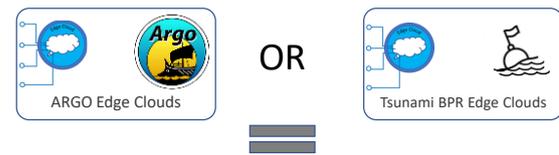


Figure 12 Integrated IoT Cloud – Data flow from IoT Edge to IoT Cloud to Internet Cloud – (a) conceptual using AWS and (b) equivalent ocean observation system (OOS for EWS)

#### 3) Data Pipelines

Data received from multiple edge IoT clouds such as the Argo platform, Moored and Drifting Buoy, Current Meter Mooring, and XBT, etc. are assembled into a common data cloud repository. As per the predefined metadata template, this data is processed in a standardized format. Data undergoes the quality control process as per the predefined quality control procedure to generate uniform data sets for further processing.

#### 4) Data and Insight Publishing

Processed data is published through the various channels for consumption. They are published as API service, or web applications, or mobile applications and/or available for download as CSV or XLS, or PDF files. Various insights like processed Tidal gauge data and Bottom pressure recorder data is used at TIEWS for Tsunami monitoring. It is also used to generate PFZ and Wind Speed/direction forecasts for the fisheries sector.

#### 5) Early Warning System (EWS) – Advisory for fishermen

INCOIS acquires the sea surface temperature, weather, and phytoplankton data from oceanic IoT edge nodes and NOAA satellites. It produces Potential Fishing Zone (PFZ) and Ocean State Forecasts. APIs are used to fetch the data for different coastal states for seven days in advance, refreshed four times a day. This content is made available in the mKRISHI@ Fisheries Android application in eight Indian local languages [19]. This helped fisherfolks, their family, and other ecosystem stakeholders to identify the ocean risk zones, occurrence date and time of the hazardous situation, and cyclones in advance (see Fig. 13). This helped fisherfolks to re-plan their journey. This data-driven pre-planning helped reduce the risk exposure and hence saving the lives of many fishers.

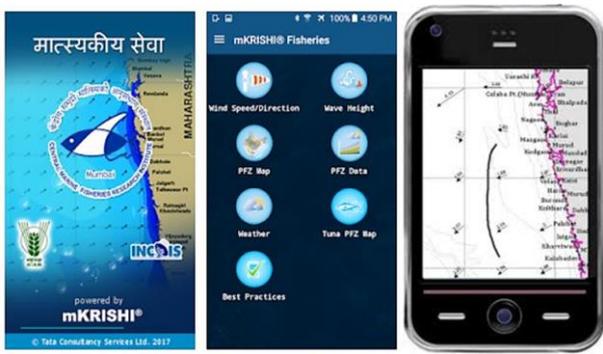


Figure 13 Early Warning System – mKRISHI® Fisheries mobile application

#### IV. CHALLENGES

This approach streamlines the overall communication between the edge and central computing server but is not that easy. Some of the major challenges are:

- Lack of standardization among the IoT device in terms of hardware modules for sensing, storage, computer, and communication.
- Varying technology stacks of communication software modules, protocols, payload type and size, error handling.
- Software API variation, which leads to difficulty in orchestration at the edge cloud level and at the central cloud level
- Distributed workload, which leads to inefficient load balancing and resource allocation among the IoT sensor box or edge components.
- Design of EWS – Since most of the stakeholder had low digital and educational literacy, designing a mobile app service was quite tricky. We had to conduct multiple design thinking interactions with the fisheries stakeholder to arrive at the best suited, simple to understand, and use design for the early warning system applications [20].

#### V. RESULTS AND BENEFITS

Before Argo, ocean and climate scientists had to rely on sparse temperature or salinity measurements either conducted by commercial and research vessels, or a limited number of stationary moorings. But those would introduce huge spatial biases due to oversampling in heavily traveled shipping lanes

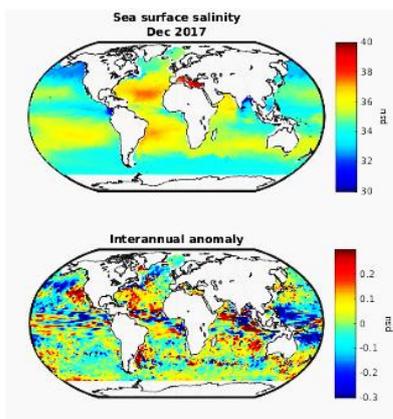


Figure 15 Sea surface salinity – source argo.ucsd.edu/

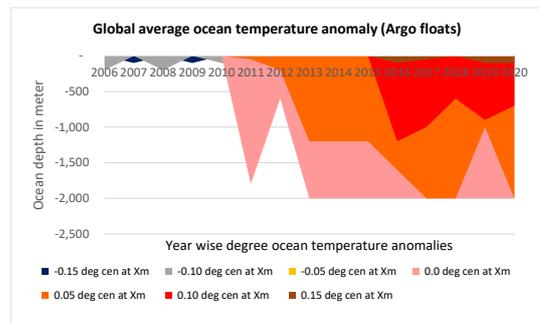


Figure 14 Global average ocean temperature anomaly (Argo floats)

and temporal biases as in high latitudes due to harsh winter conditions ship travel used to be restricted. This global and all-season, coverage is crucial to detect climate change signals, because, within and between major ocean basins, heat is constantly transferred around different areas. And seasonal cycles in some regions can overshadow interannual variability. The Integrated IoT Cloud approach provides a continuous universal information to quantify longer-term changes ocean changes, mainly at two levels.

The upper 2000-meter water column provides a signature of the anthropogenic change in ocean heat content over two decades. This much depth is enough to look beyond the seasonal temperature and salinity cycles impact, into the regions of the ocean that are dominated by decadal warming trends [21].

Fig. 15 shows an average of the sea temperature anomalies, up to 1900 meters in depth. This is based on the data measured by the Internet of Argo floats (IoAF) since 2004. While temperatures in the upper ~600 meters fluctuate with shorter-term climate events like El Niño-Southern Oscillation, deeper waters display a consistent warming trend. This indicates Earth's atmospheric warming.

Warmer air can withhold and carry more moisture. With the continuous increase in the average global temperature, existing patterns of evaporation and precipitation will intensify further. This will mean higher drought risk for the arid regions and flooding in the wet region.

Argo salinity data can be used to quantify changes in the hydrological cycle related to climate change. Fig. 14 shows the monthly Argo salinity data from 2004 onwards. It also has a monthly difference of monthly salinity versus average salinity for that month over decades. It shows a clear salinity increase in salty regions (for example, the Northern Arabian Sea) and a decrease in salinity in fresh areas (for example, the North Bay of Bengal).

Integrated EWS is a tool to save lives and livelihood, both. CMFRI Mumbai Research center conducted a study in 2015 across 13 fisheries co-societies in Raigad, Maharashtra. The study found that the fisherfolks saved approximately 30 percent of high-speed diesel when they planned their trip based on the information from the mKRISHI Fisheries app. It not only helped in saving the cost of the fisheries trip but also reduced the CO2 emission, as an estimated 1.2 percent of global oil production is consumed for fishing. Early warning systems also helped in safe and secure fishing [22]. In 2016, Min. of External Affairs (Govt. of India) and NITI Ayog recognized mKRISHI® Fisheries as Top 20 Mission-Driven Social Impact Innovations in India.

Deployment of the drifting buoys generates in-situ data, as well as validate the satellite data. This helps augment the ocean observations using satellite and increase the accuracy of the macro analysis from satellite data due to the feedback of the microanalysis by the in-situ buoys. This helps in achieving scalability at a lower cost of deployment.

DART cloud using BPRs helps in early detection, near-source siting, and real-time reporting of the Tsunami. INCOIS system estimates risk in coastal areas, wave height that can hit them, or riskier coastal vulnerable buildings. Using GIS mapping of the vulnerable regions, administrators can generate a simulation of the extent of inundation.

The ITEWS can now detect IOR tsunami-genic-earthquakes within 10 minutes of their occurrence and can disseminate the advisories to the concerned regional authorities. Over the last 14 years, ITEWS has monitored nearly 630 earthquakes of a magnitude of about 6.5 magnitudes [23]. Out of these, 101 occurred in the IOR, leading to Tsunami on 7 occasions. Due to a coordinated effort, warnings were issued in less than 10 min. to 25 IOR countries either through fax, email, SMS.

## VI. CONCLUSION

Ocean has large volume. It can also transfer heat from its surface to its deeper level. Hence it acts as a heat sink for Earth and 90% of the excess heat absorbed by the Earth is stored in the oceans. Integrated IoT EWS helps in the study of the ocean to better understand the spread of climate change and its adversarial impact in an objective manner.

Tsunami early warning is a race against time. Adversity leads to take a systematic and holistic approach, and the early warning system has progressed into a multi-hazard framework encompassing multiple types of IoT cloud edge systems. It generates multiple value-added digital info services such as storm surge, cyclone warnings which benefit the society, especially the coastal population and fisherfolk, saving lives and damage to property. Because of all these, India has become the first country in the Indian Ocean Region to achieve the Tsunami Ready recognition.

## ACKNOWLEDGMENT

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