# International Tsunameter Partnership of Data Buoy Cooperation Panel

# Tsunameter Equipment Performance Standards and Guidelines

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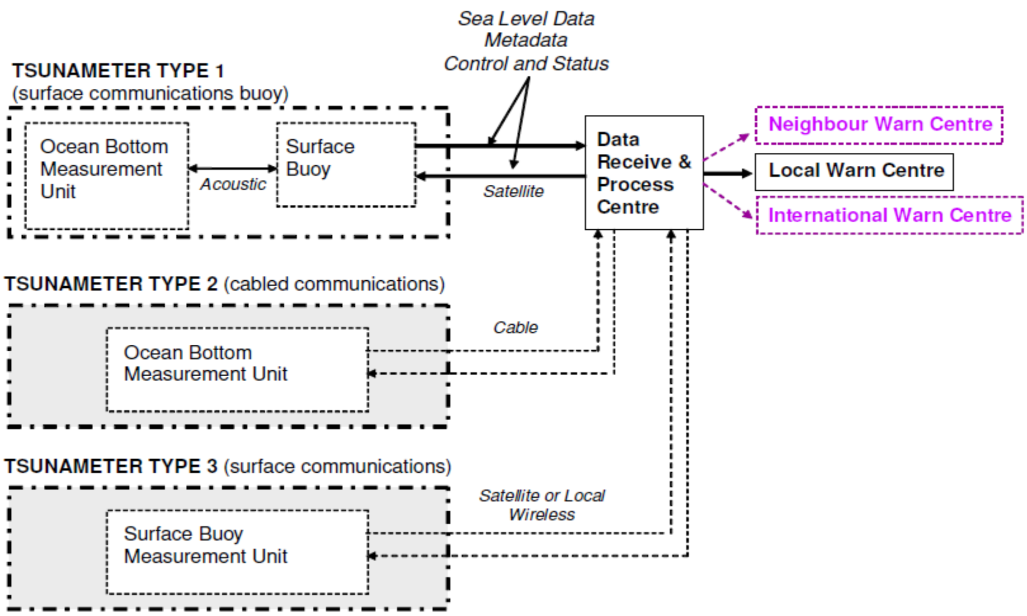
# 1. SCOPE AND PURPOSE

## 1.1 Scope

This document sets out functional, performance and other operational characteristics for deep ocean tsunami detection stations that will meet the requirements of local, regional and ocean-wide tsunami warning systems. Compliance with these guidelines and with their related quality assurance processes will enable warning centres, equipment purchasers, operators and non-warning-centre data users to have confidence in a tsunameter's performance, data quality and interoperability, regardless of the specific equipment's design or source of supply.

The guidelines are intended to assure a level of consistency between the behaviour and performance of any tsunameter product, but not to constrain technical innovation by suppliers. No particular technical implementation is assumed, although the primary focus is to elaborate the characteristics of the dominant tsunameter design at the time of writing – an ocean floor pressure sensor reporting via an acoustic modem link to a moored surface buoy with satellite communications to a land-based data processing centre. An alternate cable-connected system is illustrated in the diagram below, while other technologies (e.g. GPS surface buoys) might potentially realise the same function in near-shore locations. To the extent that the role and modes of operation of these alternate systems is similar to that of the "Type 1" tsunameter, these guidelines will apply. However, specific treatment of these technologies may be warranted in future document releases.

Some tsunameter designs either support or are routinely integrated with other sensors, in a multi-role platform. While multi-role solutions can provide extra value from the same observation platform, and platform flexibility is to be



encouraged, this document only deals with tsunami monitoring and reporting functions.

### 1.2 Origins and Future Development

This guide has been framed with input from developers, suppliers and operators of tsunameter equipment, and users of their derived data products. It reflects the current understanding of the tsunami phenomenon, and the current requirements of warning centres that are operating, or planning to operate, on a local, national or ocean-wide scale. The data delivery and command response times should meet the needs of warning centres and threatened communities close to the source of the tsunami.

The guide will be adapted to meet revised warning system or scientific requirements. It may be supplemented to address technology implementations that merit separate treatment.

### 1.3 Authority and Change Control

The guide is published by the International Tsunameter Partnership Group (ITP), which reports through the IOC/ International Cooperation Group / Data Buoy Cooperation Panel (DBCP). The ITP was established with endorsement of the ICG/IOTWS and its Pacific Ocean equivalent (ICG/PTWS). It is an international forum for promoting interoperability, technical development, and mutual support across the community of developers, suppliers and operators of deep ocean tsunami monitoring stations.

Amendments or updates to this guide will be authorised by the ITP Chair. Significant amendments will be reviewed by ITP members before such authorisation.

## 2. TERMINOLOGY

Tsunameter: An instrument that monitors sea surface levels in the open ocean and which reports sea level data in near-real time to tsunami warning centres. Tsunami warning centres use the data to assess the presence or absence of a tsunami wave and to determine wave attributes that are pertinent to tsunami forecasts and warnings. “High Resolution” Data: Sea level data measured with high temporal resolution, typically at one minute or less sample times, for tsunami event detection and wave characterisation.

## 3. STRUCTURE OF DOCUMENT

Tsunameters are technically complex, mission-critical systems operating in a harsh environment, with high reliability expectations and relatively high acquisition and ownership costs. Practical tsunameter designs reflect design and cost tradeoffs between performance, robustness, energy consumption, service intervals, and operational flexibility.

The guide covers the small number of mandatory requirements needed to satisfy the primary function of sea level measurement and reporting for tsunami warning purposes. It also provides guidance or best practice targets for other characteristics that, while not mandatory, influence operational utility or ownership costs. Explanatory rationales are used to put those “soft” requirements or targets into context.

## 4. OVERVEW OF REQUIREMENTS

The attributes of a tsunameter pertinent to its primary sea level measurement and reporting function and its practical utility in tsunami warning systems, are:

General

Support for multiple modes of operation, including high-rate event reporting during tsunami events, low-energy background or “heartbeat” reporting modes, and modes that facilitate testing, equipment configuration or diagnostics etc. for engineering development, product acceptance, and deployment operations.

Measurement and Reporting

- The quality and timeliness of sea level data streams (including relevant metadata) for the purposes of real time situation analysis and event forecasting by warning centres
- Ability to measure and report tsunami phenomena for research purposes (small tsunami below the interest range of warning centres are of value in forecast system and model refinement)
- Reliability and continuity of data streams (lack of data gaps or latencies that could compromise warning decisions or notification times)
- Consistency and performance traceability between tsunameters, regardless of origin or national custodian.

Operating / Deployment Range

- Flexibility (lack of undue constraints) on deployment sites, operating depth, and ocean conditions

System Sustainability and Life Cycle Attributes

- Ease of handling / deployment
- Reliability, safety and maintainability
- Service intervals and unattended on-station endurance

## 5. DETAILED REQUIREMENTS

### 5.1 General

The majority of requirements and guidance statements in this document apply in principle to tsunameters regardless of their technical implementation. Some material unavoidably relates to the underwater communications for units using an ocean floor sensor to a surface communications buoy and to operating modes specific to that form of tsunameter. These topics may be disregarded for systems that do not employ that technology.

### 5.2 Modes of Operation

Tsunameters shall support the following modes of operation:

1. Continuous Reporting mode
2. Deployment Test mode(s) for testing or integrity checking prior to deployment, during deployment, or immediately after deployment
3. Engineering test / configuration / diagnostics modes
4. Background Reporting mode** – regular reporting of sea level at a rate sufficient to reveal tidal forcing and to confirm effective operation of the system

NOTE: ** *"Type 1" tsunameters using an ocean bottom unit and a surface communications buoy use a background reporting mode as a strategy for managing constrained energy budgets and communications costs. It may not be necessary in other (e.g. cabled) design solutions. The following descriptions of the background reporting mode and transitions between background and continuous (event) reporting modes need not apply to such implementations.*

Continuous Reporting Mode: The tsunameter shall enter Continuous Reporting Mode, with continuous reporting of high-resolution data from the Ocean Bottom Unit and the Surface Buoy, by self-triggering of the ocean bottom unit, after detection of a measurement anomaly

(i.e. discrepancy between the measured water column height and the predicted value that exceeds a threshold value).

The ability to initiate continuous reporting by remote trigger (command) from an operations centre is highly desirable. This feature should be incorporated in future product developments. The continuous reporting mode shall be able to be terminated by remote command, by expiry of a user-settable time limit, or, after a self-triggering event, on expiration of the sea level anomaly that triggered the mode.

Background Reporting Mode: reports average water column heights and other status information at scheduled intervals. This data stream confirms proper equipment function, and enables warning centres receiving the data to verify operational status of the station, to exercise data ingestion functions, and to maintain operator training levels.

Deployment Test Mode(s):

- Pre-deployment Test Mode: will enable critical pre-deployment instrument checks on board a deployment vessel, including transmissions of equipment internal status, and exercise of underwater and sea-to-shore communications
- In-Deployment Test Mode: will enable reception on a ship of data that monitors the progress of the deployment, enables in-situ operational tuning of instrument parameters, and confirms the healthy functioning of the equipment after deployment

Operational Management Engineering Test / Diagnostics Modes: Tsunameters shall support a range of test or management operations that allow operators to remotely configure user settable operating parameters, perform diagnostics or status checks, generate test data streams, update internal clocks, or carry out limited life cycle upgrades or corrective actions, e.g. the download of firmware upgrades or patches.

### 5.3 Primary Functions and Performance

Data quality, availability and timeliness are the primary requirements of warning centres.

#### *5.3.1 Sea Level Measurement*

*The sea level measurement must capture the tsunami wave signal (amplitude and phase) for waves of period between 5 – 40 minutes, and of amplitudes down to 3cm or less.*

*The capacity to resolve small waves is important if the tsunameter is only exposed to peripheral (side lobe) energy from a large tsunami. Small tsunami events are also valuable for exercising and refining forecast and modelling processes more regularly than could occur with large tsunami events.*

*Absolute accuracy of total water column height is not an important measurement attribute. Tsunameters need only resolve changes at the ocean surface over a range of a few metres. Confidence in the tsunameter's response to small amplitude tsunami waves can be derived by observing its response to larger scale tidal forcing over the range that includes tsunami disturbances. The integrity of the measured tidal responses can be established by comparison with ocean tidal predictions for that site.*

Reporting / Measurement Units: The measurement units used internally to the tsunameter, and reported between the tsunameter and the processing centre are a matter of design choice. They may be a directly sensed parameter, such as pressure, or a derived measurement, such as water column height. For the purposes of this document, the term "reading" or "sea level measurement" refers to the measured or reported parameter, with measurement characteristics referring to the derived estimate of water column height.

The communications from the processing centre to warning centres or other data users needs to comply with separately defined interoperability and data exchange standards.

Measurement Range / Sea Bed Unit Depth: 500m – 6,000m (range / measurement performance may be achieved through configuration variants).

Measurement Accuracy: Absolute accuracy is not critical (see above) however the excellent resolution and long-term stability is required.

Measurement Resolution of Surface Disturbances: ≤0.5cm required, with ≤0.3 cm desirable.

Internal Measurement Sampling (Averaging) Interval: ≤30 seconds. Recommended to be 15 seconds (for consistency with common practice for tsunameter products).

### *5.3.2 Time Stamping of Data and Time Stamp Drift*

All sea level data samples shall be time stamped at the time of measurement in the Ocean Bottom Unit. The time stamp drift of the internal clock over the unattended life of the bottom unit shall be < 2 minutes and preferably < 1 minute. It is highly recommended that all data messages be time/date stamped with internal clock time and external GPS time to verify offset.

Where external clock synchronisation is implemented (e.g. through a GPS reference in the Surface Buoy), clock updates shall be performed with no interruption to the continuous measurement regime under all operating conditions.

Time Stamp of Messages at Time of Transmission to Processing Centre Time stamping of transmissions to the processing centre is not required, but the capacity to do so may be helpful as an engineering aid to communications link performance analysis.

### *5.3.3 Ocean Bottom Unit Storage of High Resolution Data*

Short Term Storage of High Resolution Data

*Regardless of the mode it is in, the Ocean Bottom Unit shall retain a short term record of high-resolution data (at the internal Measurement Sampling Interval) for a period prior to present measurement and reporting interval. In Background Reporting mode, the buffer enables the tsunameter to recover and transmit high resolution data for conditions immediately prior to internal or external tsunami event triggers.*

The Ocean Bottom Unit shall maintain a buffer of high resolution data (at the internal Measurement Sampling Interval) for a period of at least 30 minutes prior to the current measurement and reporting interval.

### *5.3.4 Long Term Storage and Remote Access to High Resolution Sea Level Data*

*It is desirable for the tsunameter to hold a medium–to-long term store of high resolution (less than or equal to 1 minute averaged, 15sec preferred) data that can be downloaded on request from a processing centre. This is to support analysis of events or conditions that do not coincide with a tsunami event trigger, either during the course of a tsunami event, or for post-event analysis.*

The tsunameter shall support on-command access to a long term store of high resolution sea level data (less than or equal to 1 minute averaged data, or at full Measurement Sampling Interval). That data record shall span at least the last seven (7) days, and would preferably extend to the whole deployment period. The internal memory of the Tsunameter shall record the 15 sec integrated data like temperature compensated and uncompensated pressure data, temperature data, tide predicted data and pressure difference between raw and predicated pressure. Stored data of pressure and temperature on the Ocean Bottom Unit is extremely valuable to science and should be submitted to the proper archiving centre (National Geodetic Data Center (USA) for example)

### *5.3.5 Sea Level Data Reporting*

Data Reporting – Background Reporting Mode

*In Background Reporting Mode, the tsunameter will report sea level readings with time resolution sufficient to accurately capture tidal forcing for correlation with ocean tide models.*

Recommended measurement sampling rate: 15sec-1min spot sample on 15 minute readings

Recommended reporting interval (to processing centre): 6 hours or less.

Data Reporting – Continuous Reporting Mode

*In Continuous Reporting Mode, tsunameter sampling intervals must be sufficient to resolve wave amplitude and phase (time of arrival) for use with forecast models. Short reporting intervals are needed to support rapid situation assessment and warnings determinations. End-to-end data lag times from the taking of a reading in the Ocean Bottom Unit to data arrival at a processing centre should not contribute more than a few minutes of warning delay.*

Measurement Sample Rate: requires 1 minute averaged readings or better.

Reporting Interval (to processing centre): ≤ 5 mins, preferably ≤ 3 mins

Processed Measurement Availability (including communications and reporting delays from Ocean Bottom Unit to Processing Centre): ≤5 mins

#### *5.3.6 Reporting of Metadata and Other Information*

In addition to sea level measurements, the Ocean Bottom Unit and Surface Buoy need to communicate other parameters or status information. Where equipment configuration status is not fully defined by reporting from the tsunameter, external configuration recording and change management systems are to be applied at the processing centre.

The following classes of metadata and engineering data are recommended:

- Metadata or ancillary data related to the primary measurements
  - Seafloor level temperature or other parameters pertaining to the primary sensor performance (e.g. the variance of measurement samples)
- Configuration data
  - Equipment ID / configuration references for whole station or key sub-systems
  - Revision state of firmware
- Engineering Data related to equipment status and performance monitoring
  - Battery voltages or other energy status indicators of bottom unit such as Battery % used

- Tilt angle of Ocean Bottom Unit
- Error codes or system health status flags
- Communications link performance indicators, such as bit error rates, numbers of message re-transmissions before successful receipt, data latency metrics
- GPS location of Surface Buoy
- Battery health of surface buoy system
- Dummy data transmission (GPS location of health of surface buoy) from surface buoy if no data received in sea bottom unit.
- It is highly recommended that surface buoy be designed with two identical electronic systems to provide redundancy in case one of the units fails. (The Background reporting mode transmissions are handled by both electronic systems on a preset schedule. The continuous reporting Mode transmissions, due to their importance and urgency, shall immediately be transmitted by both systems simultaneously.

The frequency of such reporting, whether with every data record or by scheduled reports, or by external interrogation, is not prescribed, and may vary by design choice.

<u>Tilt Sensor</u>: It is highly recommended that the Ocean Bottom Units with fixed communication links be fitted with a tilt sensing mechanism to confirm orientation on the ocean floor. This additional sensing will facilitate expedient confirmation during deployment operations as well as providing confirmation over the tsunameter's working life that the orientation of the bottom platform remains within the acceptable bounds for proper operation of underwater communications links.

#### *5.3.7 In-situ Tsunami Signal Processing and Triggering of Continuous Reporting*

Tsunameters operating in Background Reporting mode shall be able to self-trigger a transition to continuous high data-rate reporting on detection of a sea level anomaly that may represent the passage of a tsunami.

The Mofjeld Algorithm [*http://www.ndbc.noaa.gov/dart/algorithm.shtml*] has been applied for some time to recognize tsunami-induced differences between measured and predicted sea level values. Its adoption is recommended.

The triggering threshold (typically in the range 3cm – 8cm) for such detection shall be remotely programmable to accommodate local ocean noise conditions.

### 5.4 Handling of Errors or Anomalous / Fault Conditions

The electronics systems of the tsunameter should incorporate built-in capacity to detect fault conditions, or lock-up conditions, and to log and report error codes for such conditions as supply voltage or measurement anomalies, or software lock-up conditions.

Tsunameters should have both an internal “watch-dog” reset function and a capacity for remote command of a system reset of both the Ocean Bottom Unit and the Surface Buoy. The recovery from such resets should preserve pre-programmed user settable parameters, including the tsunami threshold level.

### 5.5 Communications Links

*The end-to-end performance of communications links from the Ocean Bottom Unit through to the Surface Buoy and Processing Centre operation is critical to the reliable and timely delivery of data to warning centres. Basic design objectives are reduction of inherent channel latency, high success rates in data or message delivery, and minimisation of data gaps.*

*The required performance standards for data delivery may vary between warning centres. To assist tsunameter product inter-comparisons, and to enable warning centres and tsunameter operators to assess data delivery performance against their particular standards, data delivery measures are required that encompass the whole chain, including the tsunameter-to-shore communications link. Recommended end-to-end performance measures are separately defined in the ITP guidance document: “Tsunameter Data Communications Performance Measures”.*

<u>Ocean Bottom to Surface Communications </u>In Type 1 tsunameters, the underwater communications link is technically demanding, and is subject to continuing technology refinement and innovation.

To support the capture, analysis and inter-comparison of communications link performance, and to provide a basis for design refinement, it is recommended that tsunameters capture and transmit relevant internal link meta-data; this includes but is not limited to:

- Data latency between the time of making a sea level measurement (the measurement time stamp) and the time of receipt by the Surface Buoy
- Bit error rate of the link
- Statistics on the success rate of message receipt (packets or messages received first time, numbers of packets requiring multiple retries, etc)
- Length and incident rate of data gaps (messages or data not received)
- The number of attempts the bottom unit performed retransmission prior to the confirmation of the reception of data
- A message that the surface buoy polled the data from the bottom unit after not receiving data in background reporting mode; this can be used to ensure the functionally of bottom unit

- Location information needed to ascertain the relative distance and orientation between the surface buoy and the bottom platform

Communications to Processing Centre Communications solutions are preferred that present no obstacle to deployment locations across the globe or across the extent of a coherent region of operation, either through a truly global solution (such as Iridium) or through configurable communications options or product variants that provide suitable regional or local coverage.

Data format:

In order to ensure the data may be widely disseminated to the needed regional warning centres, it is recommended that widely accepted traditional observation templates be used. This includes BUFR/CREX. Again, the purpose of this is to provide a flexible data representation Table Driven Code Form (TDCF) for reporting water column heights recorded by the Bottom Pressure Recorder (BPR).Simple and common data format could be followed by all the manufacturers of Surface Buoy and Ocean Bottom unit.

**5.6 Secondary Operational Characteristics**

***5.6.1 Deployment Range and Flexibility***

Operating Environment – Sea Conditions Tsunameter physical design and construction standards should not unduly limit deployment locations. Guidelines are:

1 Operation within specification in a steady state Beaufort 6 sea state*[1]

2 Survival in Beaufort 11 sea state*[1]

3 No undue constraints on bottom conditions for Ocean Bottom Unit, including ability to operate with an ocean floor inclination of up to 10 degrees, preferably up to 20 degrees.

*[1]: While flexibility of deployment region is desirable from a single product, product variants may be used to achieve cost effective coverage of a wide range of deployment environments.

In addition, tsunameter designs should not unduly limit suitable deployment locations because of ocean current limitations. Anticipated current profiles should be taken into account when choosing a tsunameter type or configuration options for a deployment location.

***5.6.2 Ease of Deployment***

*The tsunameter's physical design, in conjunction with ship-board facilities or work processes, should as far as possible maximise the range of vessels that are capable of conducting deployment or recovery operations, and the range of conditions under which a deployment or recovery can be conducted with safety. They should also aim to minimise the requirements for rare or specialised crew skills to achieve safe and efficient deployment. The value of these provisions to a particular tsunameter operator may vary according to local access to vessels and crew, or the ability to combine tsunameter missions with other marine operations.*

#### *5.6.3 Safety*

Tsunameter design, materials and fabrication standards shall ensure compliance with relevant electrical safety and hazardous materials regulations.

Designs using batteries that may produce corrosive or explosive gases (e.g. Hydrogen gas) shall have appropriate means for isolating those gases from contact with electronics, or degassing or neutralising those gases.

#### *5.6.4 Vandalism*

For deployments in areas subject to vandalism, physical protective measures or signage shall be used to reduce the prospect of damage to the surface buoy unit. Further the locations prone to vandalism which could be estimated based on the historical deployments of global buoy operators could be considered during selection of surface buoy deployment location

#### *5.6.5 Biofouling & Corrosion*

The surface buoy unit maintained for more than a year suffers severe biofouling and may disturb the functionality of the acoustic transducers. In particular some marine organism degrades the quality of cables and connectors and increases the possibility of failure. Precautionary measures could be followed to protect the underwater cables and connectors.

Necessary sacrificing anodes could be added during every new deployment of ocean bottom and surface buoy unit to protect the systems from corrosion. As microbial corrosion is observed at 3300m in Indian Tsunameter it is advisable to have suitable polymeric coating of tsunameter

### 5.7 Operating Life and Maintenance Characteristics

*The need for ship operations for deployment and servicing is a substantial contributor to tsunameter ownership costs, and constrains reaction times to equipment failures, with consequence to data availability to warning centres. Tsunameter designs should aim to achieve inherent reliability and physical robustness of equipment, and to deliver a capacity for extended operating periods without service intervention.*

*Ocean Bottom Units for "Type 1" tsunameters currently are fitted with flotation devices and acoustic releases, to enable recovery and servicing by ships. Disposable Ocean Bottom Units with extended unattended service life beyond current generation products may present opportunities for simplified product designs and product and life cycle cost reductions.*

### *5.7.1 Unattended Operating Life of Tsunameter Equipment*

Surface Buoy Service Interval: shall be > 1 year, preferably >2 years (current best practice)

Ocean Bottom Unit Service Interval: shall be > 2 years, preferably >4 years (current best practice).

### *5.7.2 Reliability and Maintainability Characteristics*

The Ocean Bottom Unit shall be deployed closer to the surface unit anchor point so to ensure reliable acoustic communication the ocean bottom and surface buoy transducers. The frequency of communication of the offshore node with the processing centre shall comply with the proof test interval requirements of the least reliable subsystem in the ocean bottom and surface buoy.

The batteries used in the ocean bottom and surface unit shall have energy capacity so as to cater the continuous/peak power requirements and confirm to the identified on-demand reliability computed/ defined by relevant OSHA/EHS standards.

The maintainability interval of the ocean bottom and surface unit should be less than the reported mean time between failures computed based on the minimum of 5 years data. The processing centre shall have adequate redundancies in power, communication and computers such that the reliability is > 99.5%.

Methods for early restoration of failed ocean bottom units shall be followed for ensuring maximum availability which shall be ensured with standard deployment and recovery procedures; ship mounted acoustic ocean bottom unit locators etc.

Reliability of the release mechanism shall be ensured to be highest by possible use of redundant and independent systems for releasing the ocean bottom unit for maintenance and service.

## *6 TEST AND QUALITY ASSURANCE PROCESSES*

*Tsunameters are characterised by relatively new and evolving technology, small-scale production, and deployment in remote and harsh environments. They have a mission-critical role, and fault rectification or rework in the field incurs high costs. This places particular* *importance on product quality assurance at all stages prior to deployment.*

The following list of test and quality assurance processes and records is recommended to assure high confidence in successful deployment and operation of the equipment. The tests apply to mature product testing and qualification phases, and not to development tests that might be used to prove the product design.

Manufacturing Tests

- Primary sensor test report/results: test conditions specified, and key test measurements to be traceable to certified instrument standards
- Functional testing of key and components and sub-systems prior to assembly
- Hull pressure testing of deep ocean equipment canisters and surface buoy
- Burn in and functional acceptance testing of electronics payloads and interconnections
- Function and data communications tests of integrated product (all communications links) - continuous test duration exceeding 1 day
- Pressure testing of integrated Ocean Bottom Unit and all associated cables
- End to End System Testing: It is highly recommended that the integrated electronic components to be tested for shock, vibration, salt-fog, climate cycle test, Insulation and isolation resistance test and IP test

Pre Deployment Tests (conducted prior to ship loading and during deployment voyage)

- Continuous operation of the tsunameter during transit to deployment site and monitoring of communications, including bi-directional communication.
- Engineering readout of equipment status, internal error or status flags.

Post Deployment Tests

- Check of bottom unit tilt angle in deployed location
- Check of communications using test data streams
- Continuous monitoring of sea level data transmissions for period of at least 1 hour after appropriate stabilisation period (e.g. temperature stabilisation of ocean bottom instrumentation)
- Tuning of thresholds for tsunami event triggering.
- Check the Bottom unit settled position and surface buoy anchor settled position and calculate the distance (to achieve proper acoustic communication).

- Check of clock drift

Retrieval

- Bottom unit should be designed with some pressure activated/Seawater conductivity activated radio beacon/satellite beacon such as Argos beacon preferably with primary lithium batteries for long term application, strobes or flag to simplify retrieval.
- Bottom unit Buoyancy module can be designed such a way that when it is surface the acoustic unit can be submerged in to water so that the direction and slant range/distance shall be calculated by acoustic deck unit.
- The surface buoy could be fitted with position indicating beacons (activated by tilt) at the bottom such that in the event of buoy being towed up or toppling could be easily tracked at monitoring stations.

References

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