Intergovernmental Oceanographic Commission of UNESCO

World Meteorological Organization

DATA BUOY COOPERATION PANEL

INTERNATIONAL TSUNAMETER PARTNERSHIP

OCEAN DATA BUOY VANDALISM – INCIDENCE, IMPACT AND RESPONSES

DBCP Technical Document No. 41

– 2011 –

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Date	Modification	Who	Version
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5 Apr 2011	Executive summary added	WMO Secretariat	1.1

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EXECUTIVE SUMMARY

The tragic loss of over 230,000 people in fourteen countries during the Sumatra Tsunami in 2004 and the thousands lost recently in tsunami events in Chile in 2007, Haiti, Samoa, American Samoa, and Tonga in 2010, and Japan in 2011 reinforce the need for robust, reliable tsunami warning systems, and other ocean observing systems that give the international community a deeper understanding our planet's oceans. Understanding our oceans is critical to protect people from natural disasters and the impending challenges of a changing climate. Nearly 90 percent of the world's observing systems were installed after the Sumatra tragedy; this reports estimates that nearly half of these systems have been vandalized or damaged (either intentionally or unintentionally) in the last five years.

Many nations and the global community rely on a rapidly expanding ocean observing network to promote sustainable development and economic growth, to understand global weather, climate and ecosystems, and protect human life, communities, and infrastructure threatened by marine hazards such as storm surge and tsunamis. Vandalism and negligent damage to moored ocean observing systems takes many forms including ship collisions, incidental damage (e.g., fouling from fishing lines, nets or cables), direct exploitation of moorings as fish aggregation devices, intentional damage from gunshots, and theft of entire systems or the components and parts. Unfortunately, the rate of damage is highest in the Indian Ocean, with over half of the 36 tsunameters in the newly established Indian Ocean Tsunami Warning System and Adjacent Seas network suffering damage in the last four years.

This damage results in the loss of invaluable data for early warning systems and long term climate observations and it doubles the budget needed for maintained these systems due to the high cost of resulting repairs and replacement. The damaged ocean observing systems also results in the loss of critical ocean data, degraded weather and marine forecast capabilities, and it undermined confidence in and reliability of the tsunami warning system, which could result in significant loss of life and property as well as costly evacuations in response to false tsunami warnings.

The United Nations, through UNESCO's Intergovernmental Oceanographic Commission (IOC), and the World Meteorological Organization (WMO), cooperates with member states to help establish and maintain these systems, and recently, the United Nations General Assembly has called for policies and guidance to help prevent and minimize actions that often result in extensive damage to these critical ocean observing networks.

In 2009, the IOC Assembly, at its 25th Session, adopted Resolution 13 on Global Coordination of Early Warning and Mitigation Systems for Tsunamis and other Sea-Level Related Hazards. The resolution called for an: (a) inventory and assessment of the problem of ocean observing platform vandalism globally; (b) an assessment of the impacts of such vandalism, including on the functionality of tsunami warning systems; (c) the annual cost of ocean observing platform vandalism to member States; and (d) recommendations for IOC and Member State action.
Also in 2009, the UN General Assembly recognized the problem through the Resolution on Oceans and Law of the Sea (64/71, para 172) and the Resolution on Sustainable Fisheries (64/72 para 109); both called on States and appropriate UN agencies to take appropriate action to address intentional and unintentional damage to ocean observing systems.

In 2010 , the WMO 62nd Executive Council Session adopted a declaration of concern (para 3.4.1.) about the significant occurrence of intentional or unintentional damage to ocean observing systems that urged Members to help promote understanding of the impacts that seriously undermine efforts to establish national and regional ocean hazard warning systems and to coordinate with relevant organizations to take necessary action.

Recently, regional fisheries management organizations (RFMOs), in particular those that manage tuna fisheries, have adopted measures to protect moored ocean observing systems. The RFMOs that have taken action are the Western and Central Pacific Fisheries Commission (2009), the Inter-American Tropical Tuna Commission (2010) and the Indian Ocean Tuna Commission (2011).

This DBCP report recommends a nine point international action plan to build our understanding of this problem, mitigate the impact on human communities, and promote public education to protect ocean observing networks and save human lives.

- Recommendation 1: Improve the ocean observing platform design to make more impervious to damage and install other mechanisms to prevent access to the individual buoys.
- Recommendation 2: Redesign networks and their operations to promote avoidance.
- Recommendation 3: Upgrade network operations to improve their availability
- Recommendation 4: Promote improved data exchange and network optimization in the Indian Ocean Tsunami Warning System that will establish enough redundancy to provide warnings even with outages.
- Recommendation 5: Encourage nations to recognize the issue of marine platform vandalism and develop, harmonize, and coordinate statutes to protect ocean observing systems.
- Recommendation 6: Call on Fisheries Management and Regulatory Bodies to develop measures and strategies to help mitigate the damage to ocean observing systems.
- Recommendation 7: Develop more reliable and consistent methods of maintaining records about vandalism that can be cross-referenced and analyzed to understand the global costs of the problem.
- Recommendation 8: Encourage States party to the Law of the Sea Convention to use this legal instrument to promote protection of ocean observing networks.
- Recommendation 9: Expand international education and outreach to both emphasize the importance of ocean observing systems and how everyone can help protect these systems from vandalism and negligent damage.

This report is being released following the extraordinarily destructive Tohoku tsunami of Japan. Though the human and economic loss assessments are astounding, many lives were saved because of robust Japanese and international ocean observing systems and exceptional preparedness programs that resulted in immediate community response and evacuation.

The nine recommendations underscore that national tsunami warning systems and community response are dependent on fully functioning national and regional tsunami observing systems that are not compromised by ocean observing systems that have been rendered inoperable by vandalism or negligent damage.

1 PREFACE

Thousands of marine observing platforms have been deployed to record and report a wide range of sub-surface, surface and atmospheric conditions in the world's oceans, coastal seas and internal waterways. The data from these platforms advance scientific research, support weather and marine forecasts, and aid climate modelling and prediction. They aid ocean-based transport and commerce, help warn against ocean-borne hazards, and support sea rescue missions.

All types of ocean data buoys are subject to incidental or deliberate interference, damage or theft, collectively termed "vandalism". Vandalism by fishermen is the greatest source of equipment and data loss in all three ocean basins. The consequences are particularly serious for high-value moored ocean platforms. Examples (with all costs in US$) include:

- The US weather and ocean buoy network suffered an average of 11 incidents per year over the five years to 2008, with incident rates increasing. In 2008, there were 16 vandalism-induced buoy failures from a population of 109 buoys, with a direct restitution cost exceeding $2.3m.
- Over a nine month period in 2008, 18 TAO stations in the Tropical Pacific went offline due of vandalism. Annual direct restitution costs exceed $1m, and the vandalism rate is increasing.
- The Indian Ocean tsunameter networks have suffered over 30 vandalism incidents in four years. Over half the stations have been affected. The direct costs of restitution exceed $3.5m. Cumulatively, vandalism outages have exceeded 18 station-years.
- Over a 12 year period, many data buoy retrievals in the Indian meteorological and oceanographic buoy network were in response to vandalism.

The continuing toll of vandalism inflicts higher operating costs and erodes value and community benefit from the derived scientific knowledge and services. At its worst, it threatens the very sustainability of some major observation networks, or substantial parts of them.

This report presents a perspective of the incidence and consequence of vandalism, with a focus on the experience of the larger international networks for which consolidated records are available. It also discusses strategies that could reduce the incidence or consequence of vandalism, for action by network designers, product developers, national operators and regulators, and by the international community. While technology-based defensive strategies such as platform hardening and network redundancy have had most impact to date, future progress will hinge on achieving behavioural change in the fishing community. That will require a more cohesive, multi-tiered response.

2 BACKGROUND AND AUDIENCE FOR THIS REPORT

In October 2009, UNESCO's Intergovernmental Oceanographic Commission (IOC) adopted Resolution XXV-13, in relation to the Global Coordination of Early Warning and Mitigation Systems for Tsunamis and Other Sea-Level Related Hazards. That Resolution:

Instructs the International Tsunameter Partnership and the DBCP, in coordination with JCOMM, to prepare a report for the TOWS-WG and IGOOS at their next meetings, on ocean observing platform vandalism that includes:

- an inventory and assessment of the problem of ocean observing platform vandalism globally;
- an assessment of the impacts of such vandalism, including on the functionality of tsunami warning systems;
- the annual cost of ocean observing platform vandalism to Member States;
- recommendations for IOC and Member State action.

This report is prepared in response to that Resolution.

3 INTRODUCTION

3.1 Scope and Growth of Marine Observing Networks

The access to stored, regularly reported or real-time information from a variety of marine platforms is increasingly important. It supports the efficient conduct of marine-based and terrestrial economic activity; the understanding of global weather, climate and ecosystems; and the protection of communities, infrastructure or environments threatened by marine hazards.

The number of such platforms deployed for sectoral, national or global purposes has expanded greatly over the last decade, as has the open exchange of marine data via the WMO's Global Telecommunications System (GTS). In October 2010, GTS-reporting platforms numbered around 1,550 drifting buoys and 480 moored buoys [Figure 1], and 3,200 Argo profiling floats.

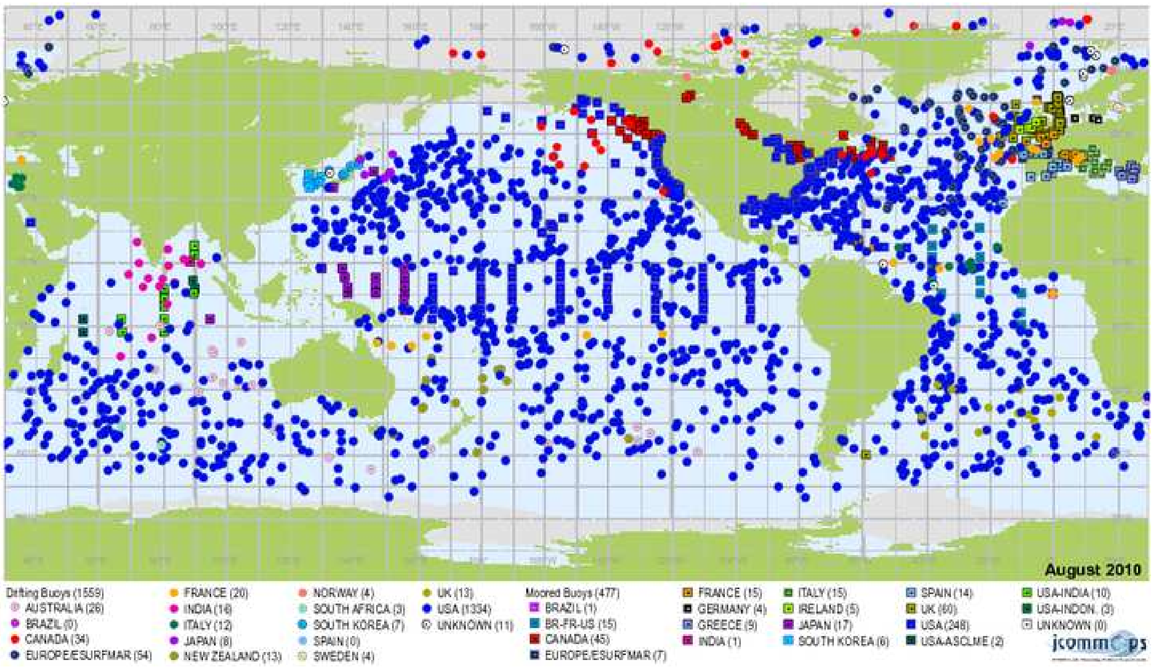

Figure 1. Drifting and Moored Buoys Transmitting on the GTS, Aug. 2010

[Source: DBCP web site http://www.jcommops.org/dbcp/]

In addition, 50 tsunami monitoring buoys currently transmit data via the GTS [Figure 2], and over a dozen others report to local warning centres in the Indian Ocean.

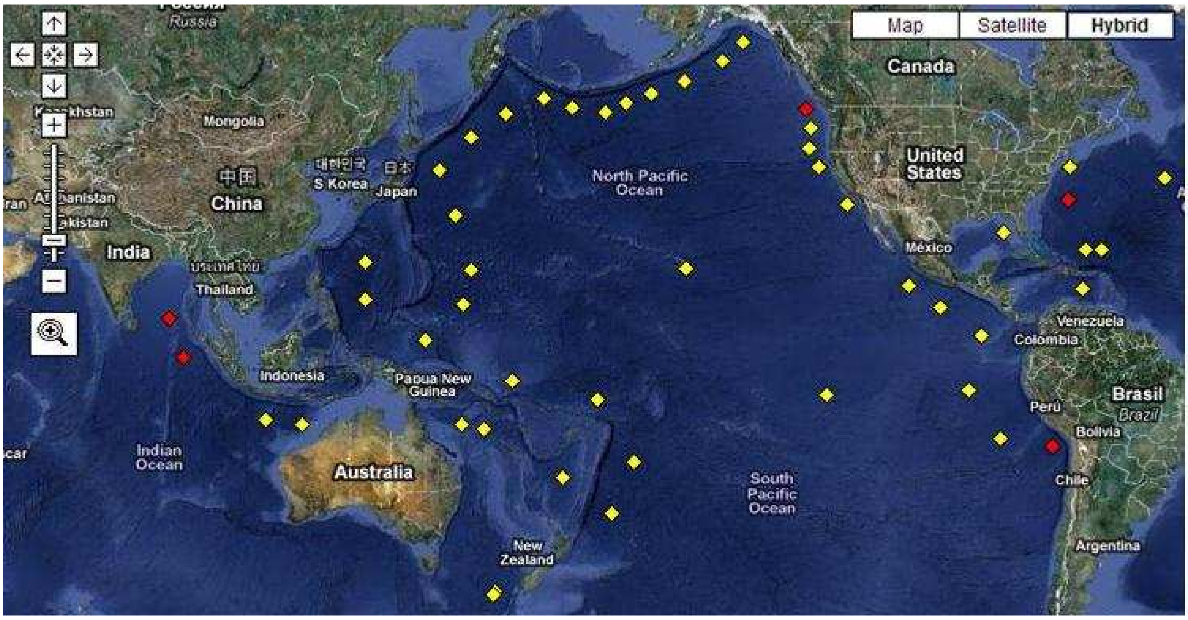

Figure 2. Tsunameter Stations Reporting on the GTS – Oct 2010
[Source: www.ndbc.noaa.gov]

Of the global networks, the greatest recent expansion has been in moored ocean platforms. Two thirds of the world's moored buoys and 90% of tsunameters have been installed in the last five years.

3.2 Terminology

In this report, the term "vandalism" will be used in accord with its established use in the ocean observing community, i.e. to refer to interference, damage or theft to observing platforms by human action, whether that action is unknowing, incidental to reckless activity, or malicious.

In common English use, "vandalism" implies wilful, malicious or ignorant destruction or damage, but it carries a connotation of intentional damage. Some consider vandalism to be an unfortunate word choice, because its negative connotation risks alienating all members of the fishing community, including those who may cause damage unwittingly.

A Tsunameter is an ocean observing platform designed to detect Tsunamis. In its most common configuration, it comprises sea-floor, sub-surface, and surface elements. The sea-floor elements include a bottom pressure recorder to detect Tsunami waves. The data are normally transmitted to the surface buoy through acoustic telemetry. The surface moored buoy is used essentially to transmit the collected observations in real-time via satellite. Operational networks of Tsunameters contributing to Tsunami early warning systems are needed to collect data at a regional scale.

3.3 Scope of Ocean Platforms Surveyed in this Report

While wilful or accidental damage affects all classes of marine observing platforms, this report concentrates on high value moored observing platforms. It does not treat the lower-cost but more numerous populations of drifting buoys or Argo profiling floats.

Further, no analysis will be made of vandalism affecting the wide variety of observing platforms in coastal waters or enclosed seas. Many of these are independently operated by regional or local authorities, or by commercial enterprises, rather than by national or international consortia. These platforms typically have a much greater intersection with the recreational and economic uses of local waters. Accordingly, they are exposed to more varied patterns of vandalism, with more varied consequences. Regulatory, surveillance and enforcement regimes applicable to vandalism are also highly localised, and records of vandalism are less consolidated.

The report concentrates on the long-term experience of the high-value networks of the large equatorial moored buoy arrays in the Pacific, Atlantic and Indian Oceans, and the more recent experience of the expanded tsunameter networks in the Pacific and Indian Oceans. While these don't represent the full suite of data buoy applications, or even of moored buoy applications, they do characterise the vandalism problems in some of the more problematic ocean basins. They also have reasonably consolidated records of vandalism incidence and consequence.

The stations in the focus networks typically operate in challenging conditions at relatively isolated sites. Their establishment and sustainment costs are substantial. Their service mission is typically global or cross-national, and they are supported through multi-national contributions. Deployment sites are commonly in international waters or at the fringes of national EEZs, exposing them to vandalism from citizens of countries beyond that of the station's host.

The report references vandalism experiences beyond the focus networks, where consolidated records or corroborating examples exist. These might be in other ocean basins, or buoys serving other applications, e.g. national meteorological buoy networks or discrete research platforms.

4 FORMS OF VANDALISM AND MOTIVATION

4.1 Forms of Vandalism

Vandalism of ocean observing platforms takes many forms. Many are connected with fishing activities in the vicinity of the moorings, primarily in pursuit of tuna. Surface buoys act as fish aggregation devices, attracting fishing operations to the vicinity of the buoy. This increases the incidence of direct contact with fishing vessels and crew, and events such as vessel impact, entanglement of fishing gear, malicious damage and theft.

Examples of vandalism include:

- Ship impact damage:
    - Buoy equipment and structures are damaged by ship impacts, either accidentally, or through reckless vessel operation in the vicinity of the buoy. [Figure 3]
- Incidental, unknowing damage:
    - Fishing lines or nets cause fouling of mooring lines or damage to underwater cables, sensors or underwater communication transducers, including the severing of cables and mooring lines. [Figures 5-9]
    - Vessels tie up to surface buoys as temporary anchors or safe havens. This can drag stations off their anchor points, over-stress mooring lines, and damage buoy superstructure, antennas and sensors. Evidence comes from neighbour vessel reports, and from the remnants of thick lines or hawsers attached to the buoy. [Figure 10]

- Damage from direct exploitation of moorings as fish aggregation devices:
  - Fishing vessels tie up to the surface buoy, or attach separate fish aggregation devices [Figure 4], causing damage referred to above.
  - In "sling-shot" purse seiner fishing, the surface buoy is deliberately dragged from its location and released, with nets set to catch fish that follow the buoy as it returns to its undisturbed position. This can stress moorings, damage sensors and superstructure, shift the mooring location or cause mooring breakage.

- Intentional or malicious damage:
  - Surface buoys suffer intentional damage to superstructure, solar cells, antennas and sensors.
  - Mooring lines are cut to release entangled fishing gear or nets, causing separation of the surface buoy. [Figures 13,14]
  - Gunshot damage has been noted on some buoys (TAO and Canadian networks).

- Theft:
  - Surface buoys have suffered theft of removable physical infrastructure, cables, sensors and solar cells, through to entire electronics payloads, or removal of the entire surface buoy. [Figures 11,12,15-21]

4.2 Motivation

The motivation for much fishing-related vandalism is clear, and is related to the value of moored platforms as fish aggregation devices. Keen enquiry from fishing crew about station locations has been noted at the time of new deployments, as fishermen seek to identify fresh assets that might advantage their business. The economic motivation for deliberate cutting of moorings to free entangled fishing gear is also clear.

The motivation for the theft of buoys or components is probably more varied. While the ocean platforms are high-value integrated systems, there is no market for such specialised integrated platforms. Their individual components (materials, solar cells, specialised sensors, batteries, etc) would generally not attract prices that would warrant the cost of special missions aimed at theft. Other than platforms located in areas close to shore, or close to regularly trafficked transit lines, much of observing platform theft is likely to be a result of incidental or opportunistic contact with fishing vessels. Nonetheless, it is clear from reports by Japan (JAMSTEC), the US (PMEL and NDBC) and India (NIOT) that raiders do come prepared with specialised tools to remove fixtures that have been attached using "vandal-resistant" hardware.

5 INCIDENCE AND DISTRIBUTION OF VANDALISM EVENTS

5.1 Historical Recognition of Vandalism Problem

Vandalism has been a problem since the establishment of substantial ocean observing networks in the late 1980s. At its Paris meeting on November 17-27, 1998, the IOC-EC passed resolution EC-XXXI.4 - "*Support of Efforts to Reduce Vandalism of Oceanographic Equipment at Sea*", concerning a proposal to be presented to the UN, "*addressing the problem of vandalism of ocean buoys by fishing vessels, and encouraging appropriate action by the competent bodies.*".

Vandalism has regularly attracted attention at meetings of the JCOMM Data Buoy Cooperation Panel, particularly with respect to the internationally supported platforms in the tropical Pacific, Eastern tropical Indian, and equatorial Atlantic Oceans, but also with national networks of meteorological and oceanographic buoys in those regions, such as those operated by India and Brazil. For example, India's National Institute of Ocean Technology (NIOT) has for many years reported serious vandalism losses to their moored buoys in the Arabian Sea and Bay of Bengal.

Vandalism was discussed at the first meeting of JCOMM, Akureyri, Iceland, 19-29 June 2001. JCOMM recommended Member States

(i) to contact their respective Hydrographic Services to reinforce the message in the *"Hydrogram"* and to ensure that it is reissued as often as possible;

(ii) to develop, if possible, tamper proof designs for buoy systems;

(iii) to design a warning system in the event any data buoys were intentionally damaged; and

(iv) to take legal steps nationally to limit acts of vandalism within their territorial seas and Exclusive Economic Zones.

More recently, the newly established deep ocean tsunami monitoring networks in the Indian Ocean have been severely impacted by vandalism. The need to broaden the national and international response to vandalism was raised within the IOC Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (IOC ICG-IOTWS). In its 5^{th} meeting in Putrajaya, Malaysia in April 2008, the ICG-IOTWS passed resolution ICG/IOTWS-V.3 urging Member States to *"promote awareness and explore possible means to reduce the intensive and ongoing vandalism on tsunameter buoys."*

5.2 Evidence of Vandalism

Physical examination of recovered stations provides evidence of structural damage, fishing gear entanglement, theft, mooring and cable cuts, and vessel tie-ups (through remnants of tow or attachment lines). In some cases neighbour ship observations, including photographic or video records, confirm the conduct of fishing operations in the vicinity of stations, or active exploitation of the mooring for "sling-shot" purse-seiner fishing.

Fishing vessel operations in close proximity to moored ocean buoys has also been substantiated through fishing vessel location transponders.

In other cases, especially for cases where the surface buoy goes adrift and is lost, or when the point of mooring failure is not recovered, the attribution of the loss to vandalism may be inferred from indirect evidence. This evidence can include records of abnormal mooring stress or stretching or anchor displacement; patterns of station data stream failure; and mooring breaks occurring early in the life of a new station in a location of low physical stress.

On some occasions, stolen surface buoys have been tracked by their GPS location reports as they are transported on the decks of vessels.

Figure 3. Ship Collision Damage to TAO Buoy

Figure 4. Fish Aggregation Device Attached to a TAO Buoy

Figure 5. Fishing Line Entanglement - Subsurface Current Sensor (TAO Buoy)

Figure 6. Fishing Line Entanglement of Mooring (Indian Ocean)

Figure 7. Modem Cable Damaged by Fish Net Entanglement - Indian Tsunami Buoy

Figure 8. Tuna Fishing Gear Entangled on ATLAS Mooring (Indian Ocean)

Figure 9. German (GITEWS) Tsunami Buoy Fouled with Fishing Nets off Indonesia

Figure 10. Tow Lines Attached to Recovered Surface Buoy

Figure 11. TAO Buoy Showing Damage from Removal of Components

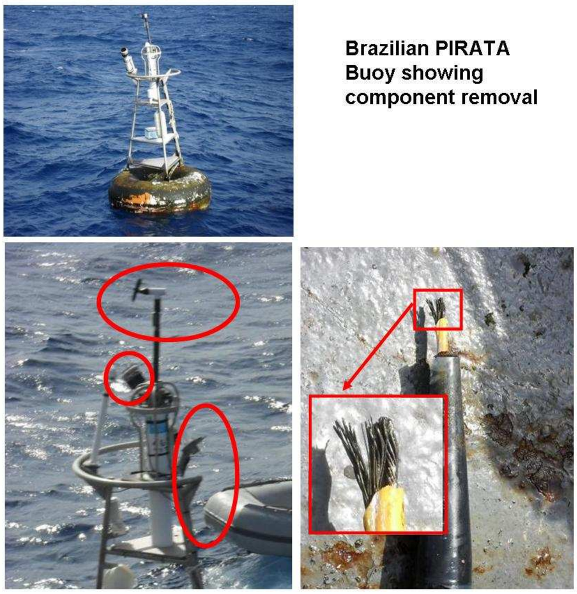

Figure 12. Brazilian PIRATA Buoy (ATLAS) Showing Component Removal

Figure 13. Cut Mooring Line on "Conehead" Anti-vandal Trial Mooring: Indian Ocean

Figure 14. Cut Cable – Indonesian Tsunameter

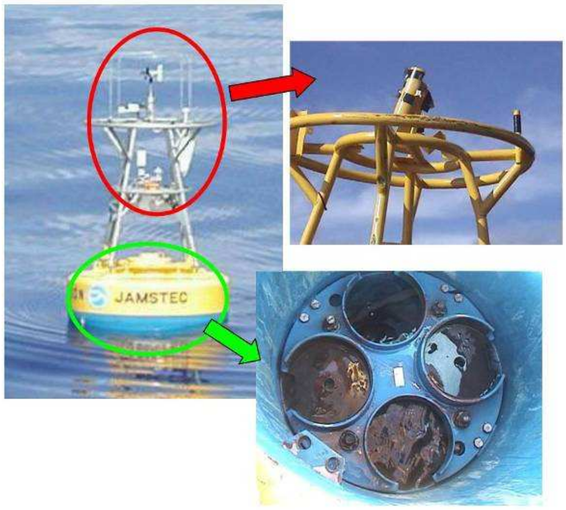

Figure 15. Theft of Met Sensor and Electronics Payload – TRITON Buoy

Figure 16. Australian Tsunameter - Stolen Superstructure and Electronics Payload

Figure 17. Indian Tsunami Buoy – Stolen Superstructure and Electronics Payload

Figure 18. German GITEWS Tsunami Buoy – Stolen Superstructure and Buoy Payload

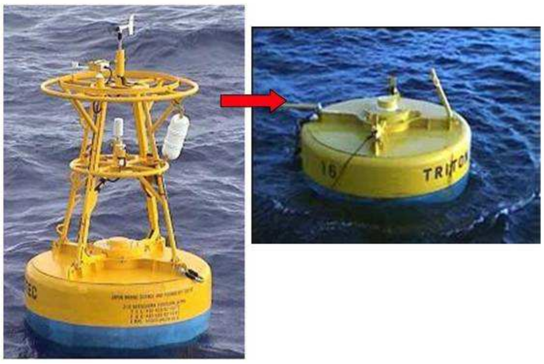

Figure 19. Broken and Stolen TRITON Tower

Figure 20. Indonesian Tsunami Buoy Recovery

Figure 21. Stolen TAO Buoy in Costa Rica

5.3 Sources of Vandalism Records

While the incidence of vandalism across the globe is apparent in both open-ocean and coastal networks, only a few highly-impacted networks have established consolidated records of vandalism events, supported by analyses or reports. They include the tropical moored buoy arrays (TAO/TRITON, PIRATA and RAMA), the tsunameter networks supporting the tsunami warning systems in the Indian Ocean and the Pacific Ocean, and the tsunameter networks in the Caribbean and Western Atlantic.

In addition to the TAO tropical moored buoy array and the US-operated tsunameter networks, NOAA's National Data Buoy Center (NDBC) maintains a record of vandalism across an operational network of 114 Weather and Ocean Platforms (WxOP) in its coastal and inland waters. See Figure 22. It periodically prepares analyses of these records. [Ref 1]

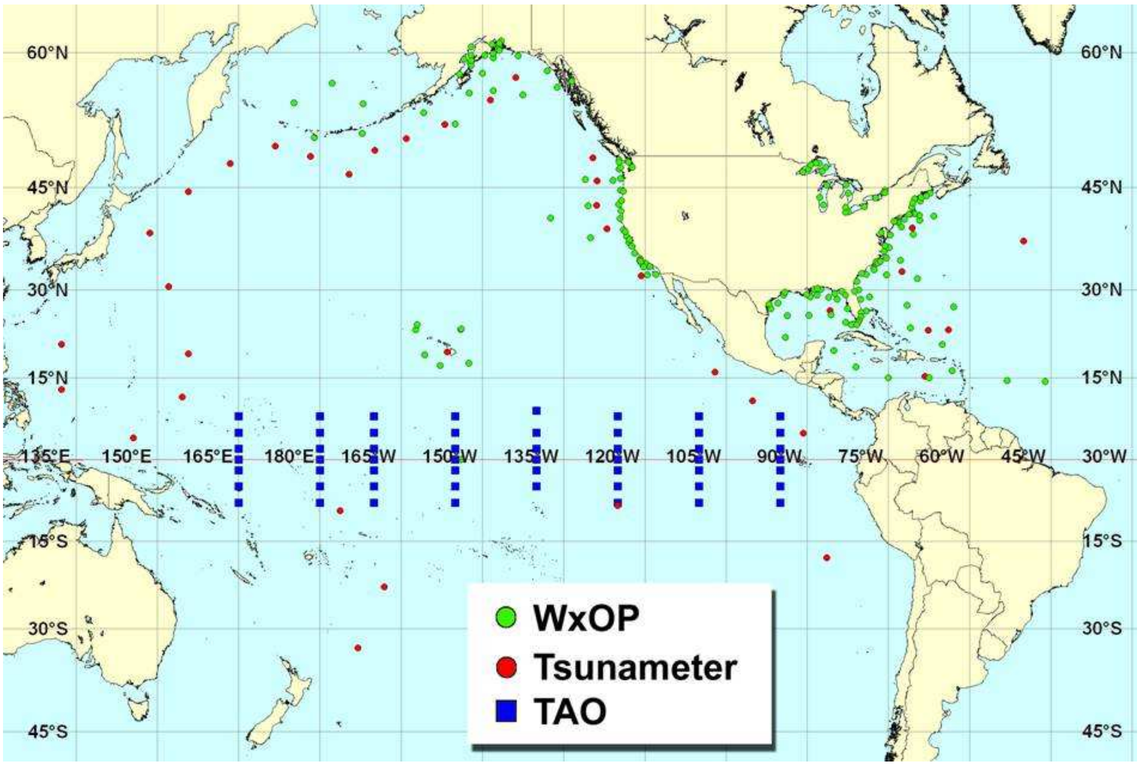

Figure 22. Domestic and International Moored Buoy Networks Supported by NDBC

In preparing this report, representatives of agencies operating prominent national networks were canvassed, including the UK, Canada, Brazil and Korea and Japan. These inquiries resulted in discrete records of illustrative events, or reports of low vandalism experience, rather than consolidated records from which causes, incidence and costs of vandalism might be inferred.

Other records of specific events are reported in journal articles or conference presentations from time to time, and may be reported by the media when associated with visible service failures.

India (NIOT) has for many years reported a significant level of damage to its large national meteorological and oceanographic moored buoy networks in the Bay of Bengal and in the Arabian Sea. Its more recent experience with its national tsunameter network was taken to be representative of that longer term vandalism pattern, and well characterised with respect to types of vandalism, costs of restitution and records of service disruption. So the Indian tsunameter network record, as part of a larger IOTWS experience, was used for the analysis in this report.

For the purposes of this report, the experience of national networks, including the well characterised US coastal and internal waters networks are of secondary importance. Their vandalism experiences have local service impacts are highly influenced by localised conditions, domestic offenders, local regulatory or enforcement environments. They are therefore more amenable to local remedies and responses.

The major tropical moored buoy arrays and the recently expanded tsunameter networks represent genuinely communal networks of international scale and cross-national impact. Placed for the most part in international waters, they are also more heavily exposed to vandalism from international sources, requiring responses at both national and international levels.

While some vandalism records and analyses are accessible, compiling a consistent, multi-year data set that can be aggregated at regional or international scale is not straightforward. Different approaches to data collection, event characterisation and impact assessment are apparent between countries, between custodial agencies within a country, and over the term of a network's life. The DBCP could be a valuable focal point for improving the uniformity of data collection and for standardising on such analyses in future years.

5.4 Focus Networks for Analysis

5.4.1 Tropical Moored Buoy Arrays

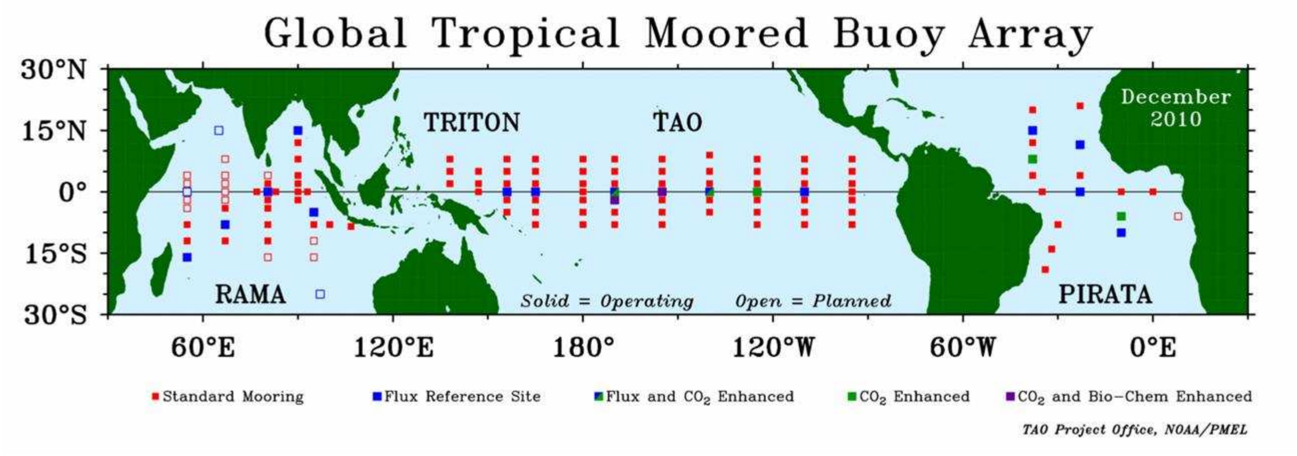

Figure 23. Global Tropical Moored Buoy Array (December 2010)

The Global Tropical Moored Buoy Array is the core in-situ observing system of the tropical ocean mixed layer and air-sea interface. Major components include the TAO/TRITON array in the Pacific, the PIRATA in the Atlantic, and RAMA in the Indian Ocean. [Figure 23]

The tropical moored buoy array contributes to the Global Ocean Observing System (GOOS), Global Climate Observing System (GCOS), and the Global Earth Observing System of Systems (GEOSS). The array provides measurements that uniquely complement satellite and other in-situ components of these global observing systems.

Data from the tropical moored buoy arrays are vital to the understanding and prediction of complex phenomena with broad geographic influence, with timescales that are intraseasonal-to-decadal and longer. These include:

- El Niño/Southern Oscillation and its decadal modulation in the Pacific

- The meridional gradient mode and equatorial warm events in the Atlantic
- The Indian Ocean Dipole
- The seasonal cycle, including Asian, African, Australian, and American monsoons
- The intraseasonal Madden-Julian Oscillation, which originates in the Indian Ocean but affects all three ocean basins
- Trends that may be related to global warming.

In 2000, the TAO array became the TAO/TRITON array, with sites west of 165E occupied by TRITON (Triangle Trans Ocean Buoy Network) buoys, maintained by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). The TAO/TRITON array is currently supported by the US (NOAA), Japan (JAMSTEC), with additional contributions from France (IRD).

The TAO tropical moored buoy array in the Pacific Ocean has 55 surface buoys and four subsurface buoys, abutting the TRITON network of 16 stations in the Western Pacific.

The PIRATA array in the Atlantic and the RAMA array in the Indian Ocean now number some 50 moorings, both surface and sub-surface.

5.4.2 Global Tsunameter Networks

There are two major tsunameter networks:

- the arrays of DART™ and DART-derivative stations supporting the tsunami warning services in the Pacific, Caribbean and North-western Atlantic; and
- the more diverse set of national networks established in the Indian Ocean and in adjacent seas.

In suitable locations, countries including Japan, Oman and Cyprus have deployed cabled ocean-floor networks that are less susceptible to vandalism.

5.5 Vandalism Rates in the Focus Networks

5.5.1 Vandalism in the TAO/TRITON Array

In discussing challenges for the Global Tropical Moored Buoy Array, [Ref 9] states that *"vandalism by fishermen is the greatest source of equipment and data loss in all three ocean basins"*.

The array with longest experience and records of vandalism is the TAO/TRITON array, established between 1985 and 1994. The TAO array was established as a research network by NOAA's Pacific Marine Environmental Laboratory (PMEL), and has recently been operationally transitioned to the NDBC. Its relatively long operating history provides an indication of a relatively "steady state" or statistically stable distribution of vandalism events.

Vandalism was recognized as a significant problem from the inception of the TAO network. The record of the GOOS/GCOS meeting in Nov 1998 [Ref 2] noted that *"the buoys vandalized most often in the TAO array are those towards the eastern and western ends, nearest to land, where fishing activity is concentrated (especially the western end, which is home to the world's largest tuna fishery)."* It also noted that *"ATLAS buoys deployed in the South China Sea were* *sabotaged within weeks”*, with only one of three stations deployed by Taiwan in that region surviving for more than two months. The record of the TAO Implementation Panel meeting in 1998 [Ref 3] noted that three TAO sites in the Western Pacific were at that time unoccupied under a moratorium imposed in response to repeated fishing vandalism.

PMEL analysed TAO vandalism events from 2000 – 2007, during the time of its custody of the network. Figures 24 and 25 illustrate PMEL’s analysis over that period of the incidence of vandalism in the network (number of moorings and sensors damaged or lost) and the geographic distribution of lost or damaged moorings. Over that period, approximately one in eight mooring deployments across the network were in response to vandalism.

	Number Deployed	Number Lost	Number Damaged	Percent Lost	Percent Damaged
Moorings	493	34	27	7%	5%
Wind	597	122	32	20%	5%
Air Temperature	565	64	10	11%	2%
Short Wave Radiation	195	31	16	16%	8%
Rain	321	46	28	14%	9%
Barometric Pressure	90	22	0	24%	0%
Long Wave Radiation	65	17	5	26%	8%
Water Temperature	>5423	>436		~8%	

Figure 24. Analysis of TAO Array Vandalism Events 2000 – 2007
source: [Ref 5]

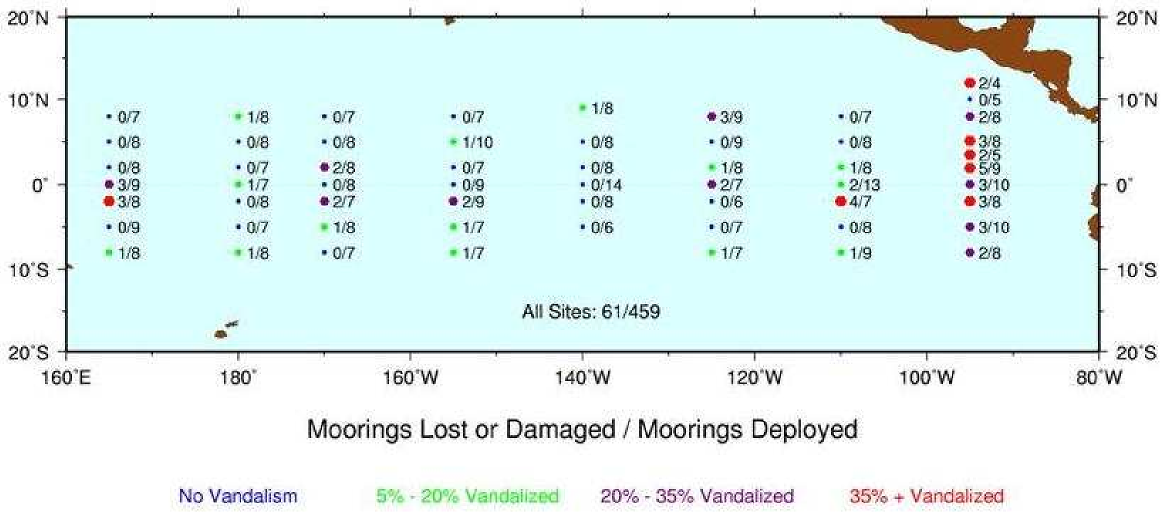

Figure 25. Record of Vandalism Resulting in Mooring Loss for TAO Array, 2000-2007
source: [Ref 5]

NDBC has analysed the TAO results since taking up operational custody of the TAO network [Ref 1], and concludes that vandalism rates have increased in the last decade. Between October 2007 and June 2008, 18 TAO buoys in the Tropical Pacific Ocean went off-station due to vandalism.

The table in Figure 26 is an excerpt from the log of vandal activities recorded by the TAO program during service cruises in May-June 2009. Of the 21 buoys visited during this period, nine buoys exhibited some forms of vandalism (i.e. line cut, hawsers, longline gear, and missing equipment). Over 40% of the buoys visited in that cruise were affected.

Station	TAO Network - Items Found Vandalized During May-June 2009 Service Cruise
8N-155W	Subsurface temp sensor lost. Cuts in the Nilspin mooring segment.
5N-155W	Hawser attached to buoy. Wind sensor damaged
2N-155W	Hawser attached which cut SSC cable. Cuts in the Nilspin. Subsurface temp sensor lost
2S-155W	Large amount of long liner gear. Subsurface temp sensors lost. Buoy hull was flooded.
5S-170W	Buoy 8NM off station. One third of the tower ring was missing.
2S-170W	Fishing gear in mooring. Subsurface temp sensors missing.
5N-170W	Wind & Tube Damaged. Marker buoy inside toroid. Fishing gear around mooring.
8N-180	Long line gear wrapped around all sub surface sensors. Two subsurface temp sensors lost.
8S-180	Subsurface temp sensor & Wind sensor missing. Hawser attached to buoy with a fishing float hanging off bridle.

Figure 26. Stations Found Vandalised in 21-Buoy TAO Service Cruise May-Jun 2009

The TRITON array in the tropical West Pacific and eastern Indian Oceans, operated by JAMSTEC, has a similar history of vandalism. The frequent detachment or theft of observation instruments has been noted in journal papers and professional conferences. [Ref 3] refers to sensors being frequently detached and stolen in some areas. It reports 16 cases of damage to buoy towers and eight of theft of communications antennas between 1997 and 2004. Figure 15 shows a TRITON station with stolen meteorological instruments and surface buoy electronics.

JAMSTEC has made product modifications, mainly physical hardening of surface buoy and its instrumentation superstructure, to counteract vandalism. Responses include the down grading of the meteorological sensor packages on at least one mooring in the eastern Indian Ocean, to mitigate against equipment loss. Those modifications have been successful in reducing the incidence of certain types of vandalism, but work continues on further equipment modifications.

5.5.2 Vandalism of PIRATA and RAMA Arrays

RAMA has a design target of 46 stations. Nearly 60% have now been established, with support from the U.S., Japan, India, Indonesia, France, China and nine east African nations. PIRATA has 17 permanent sites and four flux reference sites, maintained by France and Brazil.

The RAMA network has been significantly impacted by vandalism, and one RAMA status report recognized that "*the greatest impediment to (RAMA) implementation …. assuming resources and ship time can be found, is vandalism by fishing vessels.*"

The first-established RAMA moorings in particular experienced high levels of vandalism, with station occupancies measured in weeks and months. From 2004-2007, PMEL reported that four of the first 11 RAMA moorings were "lost" due to vandalism, with exposed (attractive) surface sensors experiencing combined loss or damage rates in excess of 50% - Ref [4].

The PIRATA array has also been subject to vandalism. Early in the life of PIRATA, in 2000, vandalism forced the decommissioning of two sites at 2°N and 2°S along 10°W, in the Gulf of Guinea region, reducing the planned size of the array at that time.

5.5.3 Vandalism in Pacific, Caribbean and NW Atlantic Tsunameter Networks

The tsunameter networks serving the Pacific, Caribbean and North-western Atlantic warning services comprise some 47 stations operated by the USA, Chile, Australia and Russia. Without the complex suite of surface and subsurface sensors fitted to the tropical moored buoy platforms, tsunameter vandalism impacts primarily on the electronics or communications equipment of the surface buoy, and on the mooring line.

These networks have been less severely affected by vandalism than the IOTWS network, but vandalism does impact on both network operating cost and on station data availability.

The network operating agency, NDBC, has analysed station damage and data outage incidents attributable to vandalism over the years 2006-2010. Due to the remoteness of buoy locations and the difficulty in getting vessel support for ad-hoc responses, it is difficult to gather conclusive data on the causes for the buoys going adrift. In some cases, evidence may never be recovered, or may only be recovered a year or more after the event, during subsequent maintenance missions.

Of the fourteen buoys that went adrift between 2006 and 2010, the majority have not yet been recovered. Five (see list in Figure 27, locations in Figure 28) have been confirmed to be due to vandalism. A further ten are presently categorised as being "Lost" or adrift due to an unknown cause. Some of these may also be caused by vandalism.

Station	Date Failed	Cause
42408	01/23/08	Cut
21417	08/22/08	Cut
42408	12/11/08	Cut
41420	10/7/09	Cut
52404	19/10/09	Cut

Figure 27. Confirmed Vandalism-caused Tsunameter Mooring Failures (US) 2006-2010

"Cut" moorings may be deliberately severed, or the result of fishing gear entanglement

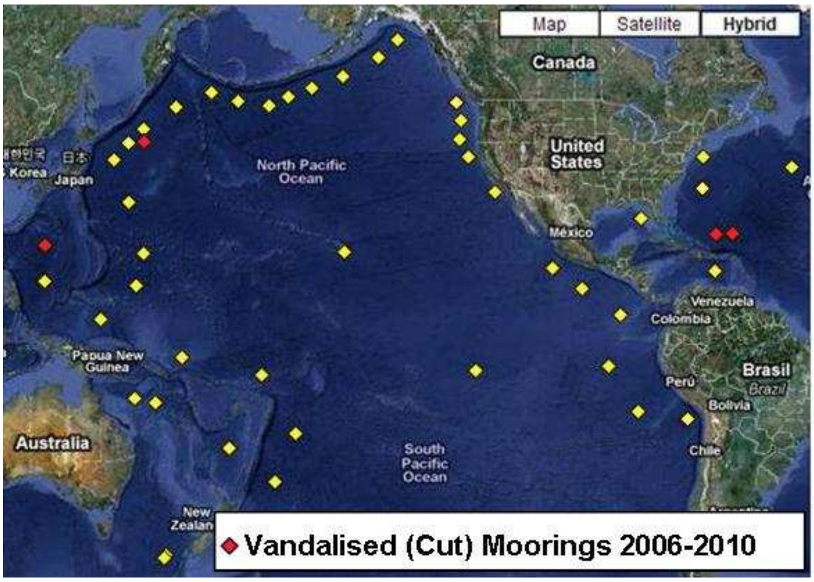

Figure 28. Locations of DART Stations Adrift through Cut Mooring Lines, 2006-2010

(Caribbean station 42408 vandalised twice)

The recent (2010) study by the US National Research Council into US tsunami warning and preparedness [Ref 6] makes reference to interference from long line fishing activity and vandalism as one contributor to mooring line and buoy failures, but targets platform reliability as the primary area for improvement for these networks.

Apart from its impact on the operational tsunameter networks, vandalism has also been reported to interrupt the trial of new tsunameter technologies by PMEL. At the Tsunami Hazard Mitigation Steering Group Meeting in April, 1999, in California, Dr Eddie Bernard (PMEL) reported an instance of a trial station being vandalised just three months into the trial.

5.5.4 Vandalism in Indian Ocean and Adjacent Seas Networks

For the tsunameter networks in the Indian Ocean and adjacent seas, vandalism has been of enormous consequence. The International Tsunameter Partnership has compiled a consistent multi-national record of vandalism events, costs and impacts for this region. Figure 29 shows the mooring sites so far affected by vandalism.

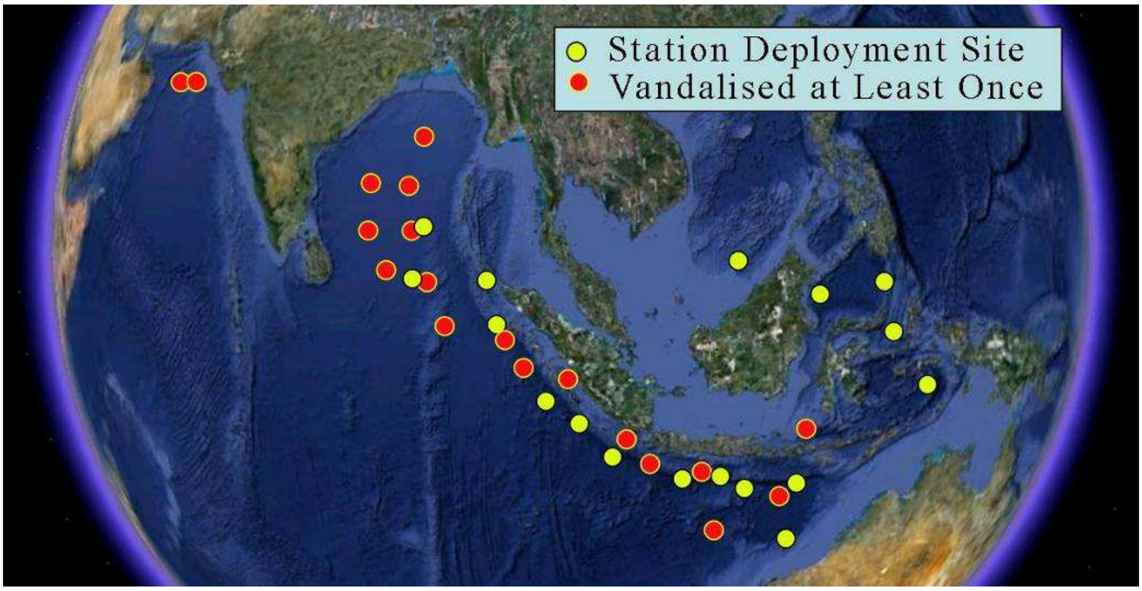

Figure 29. IOTWS Tsunameter Sites with at Least One Vandalism Event (2006-2010)

Thirty one events were recorded from November 2006 to October 2010. That number would be higher were it not for many sites in the Indian network being temporarily vacated for much of 2009/10, while buoys were re-designed without solar cells, to reduce their vulnerability.

The most affected networks were those of India, Indonesia and the German-Indonesian GITEWS network. These figures reflect both the relative numbers of moorings in these component networks, and their exposure to fishing operations in the waters adjacent to Indonesia, in the Bay of Bengal, and in the Arabian Sea.

The annual incidence of recorded vandalism events is shown in Figure 30. Of the 31 reported vandalism events, nine events were experienced in 2007 and in 2008, when the IOTWS network comprised around 20 deployment sites. Approximately half of the recorded events resulted in the loss or theft of a surface buoy, or the total theft of the electronics payload from the surface buoy.

Some IOTWS tsunameter sites have already been abandoned as practical locations, because of the high incidence of vandalism. One Indian station in the Bay of Bengal suffered four successive vandalism incidents with intervals of as little as two-to-three months between station restoration and the next vandalism event. Two Indian stations in the Arabian Sea were vandalised less than a month after their restoration from a prior vandalism event. At one time, five of the six deployed Indian tsunameters were reported to be dysfunctional due to vandalism.

	2006	2007	2008	2009	2010 (to Oct.)	TOTAL
Vandalism Events	1	9	9	7	5	**31**

Figure 30. Recorded IOTWS Tsunameter Network Vandalism Events

(NOTE: low rate in '06 due to very few deployed stations; in '09 and '10 by a depopulated Indian Network)

Unlike the longer term records for the TAO/TRITON arrays, it is not yet possible to infer stable rates of vandalism for the IOTWS "network of national networks". The IOTWS network has not yet reached its designed spatial coverage, and apart from vandalism responses, technical development issues have led to some mooring sites being left unpopulated for long periods. Nonetheless, unless the recent pattern of vandalism is moderated by buoy developments and some changes in deployment sites, annual vandalism rates comparable to those so far experienced could be expected as the multi-national IOTWS network builds towards 30 stations by the end of 2011.

Unlike the large and relatively homogeneous tsunameter network in the Pacific Ocean, the IOTWS network is composed of a heterogeneous mix of at least eight platform types, sourced from six suppliers. Many of these systems are only recently emerged, or are still emerging from a research and development stage. In this context, the high incidence of vandalism has had a two-fold impact. Not only has it resulted in a high budget impost and warning service impairment, but the remedial workload has been a major distraction from necessary technical and operational developments, and from efforts to secure global data exchange.

5.5.5 Vandalism in US Weather and Ocean Buoy Network

The extensive US weather and ocean buoy network experiences significant levels of vandalism. NDBC reports that the network has seen 54 documented cases of vandalism in the last five years, with vandalism rates increasing dramatically over the past few years. Sixteen buoy failures were attributed to vandalism in 2008, across a network of 109 buoys, almost half of which were mooring failures.

[Ref 1] summarises the contribution of vandalism to all observed network failures in 2008 to be:

- **Mooring Failures:** Out of a total of 19 mooring failures, eight were attributed to vandalism (likely or confirmed mooring line cut).
- **Mechanical damage to superstructure:** Three of the 6 structure damages were likely the result of collision or pulling on super-structure.
- **Physical damage to electrical components/cables:** Out of 11 failures due to electrical component damage, 3 were likely or confirmed results of vandalism.

- **Physical damage to critical sensors:** Two of the 24 failures due to critical sensor damage were confirmed to be due to vandalism.

5.6 Vandalism in Other Networks

Other significant marine observation networks include the Canadian weather and marine buoy network operated by Environment Canada, India's network of meteorological and oceanographic buoys operated by NIOT, and smaller networks operated by South Korea, Japan, Brazil, and various European countries. In addition to major nationally-supported networks, there are a great number of observing platforms deployed and independently operated by local authorities, research institutions or commercial entities. These are mostly concentrated in near-coastal waters. This report makes no attempt to establish the vandalism profiles for such networks.

Canada. Environment Canada operates 45 moored buoys (in the North Pacific, North Atlantic, Great Lakes, and other inland waters). There have been a small number of cases where mooring lines on NOMAD buoys have been cut by fishing vessels trying to recover their nets and gear, but vandalism has not been a significant issue for the Canadian network. As a consequence, they do not maintain a systematic record of the incidence, cost or impact of vandalism events. However, Environment Canada reported sporadic incidents of all types of vandalism on its inland waters and ocean moored buoy networks, including:

- damage due to vessel tie-ups including damage to antennas and sensors, or compromise of water seals leading to failure of electronics payloads and batteries
- cutting of mooring lines on its NOMAD buoys to release entangled fishing gear
- wilful theft of sensors and navigation lights
- some damage to solar panels and surface buoy hulls from gun shots.

Environment Canada reported replacement costs as high as $50,000 per mooring, excluding the cost of the "significant" ship time to recover the drifting buoys. (Environment Canada receives ship time at no cost from the national Coast Guard). In response to the loss of moorings, Canadian buoys have been redesigned to include longer and heavier gauge chain between the buoy and the mooring rope. No mooring losses have been recorded since this change.

India. The agency responsible for the operations of India's moored buoy network of 12 meteorological and oceanographic observation stations, NIOT, has for many years reported a high incidence and cost of vandalism to its networks in the Bay of Bengal and in the Arabian Sea. Apart from official records, the matter of vandalism has received public media attention.

UK and Europe. Vandalism has not been reported as a significant problem for the UK network of 11 moored buoys, or for other moored buoy networks in near-European waters.

Brazil. Brazil substantiated specific vandalism events to moored buoys. These events included sensor damage and theft, towing of a surface buoy causing incidental damage to electronics payloads through breach of water seals, and theft of one surface buoy, which was subsequently recovered by the Brazilian Navy. Replacement parts costs in excess of $20,000 were noted for one event, excluding costs of spares held in stock.

Asian_Region. With respect to the various national coastal or ocean networks in the seas to the south-east and east of Asia, especially the South China Sea, vandalism is known to have had a significant impact over many years. There are no available consolidated records that are suitable for analysis. Records are anecdotal, or specific to discrete events. The GOOS/GCOS Meeting in

Nov 1998 [Ref 2], for example, records an observation by one representative that *"to prevent vandalism of SEAWATCH buoys off Vietnam, they have to be protected by the Vietnamese Navy."*

6 VANDALISM CONSEQUENCES – DIRECT AND INDIRECT COSTS

6.1 Putting a Price on Vandalism

Among the obvious costs of vandalism are the tangible equipment and labour costs to detect, diagnose and restore damaged systems; indirect costs associated with diverted resources; and the costs arising from the loss or degradation of observation data and its derived services. Other costs lie in the expense of equipment vandal-proofing, and of sustaining networks that require additional redundancy to cater for practical levels of station or sensor outages.

Vandalism erodes a system's cost-benefit proposition from both the cost side and the benefit side. The substantial cost of defending against vandalism and of restoring vandalised stations adds to network establishment and sustainment costs. At the same time, unless networks are fully resilient to equipment outages (itself a cost burden), the consequential data losses and the degradation of derived services subtract from the benefit delivered to the community.

Numerous national and international studies have been made of the economic value of seasonal and climate forecasts, and of tsunami forecasts, that depend in part on ocean observations. It is not uncommon for those studies to arrive at truly large economic benefit figures. It is not practical for this report to trace the cost of data loss from vandalism through that whole value chain. For the purposes of this report, the simple front-line cost of vandalism to the network custodians (or "investment managers") is sufficient. That front-line cost may be crudely estimated by applying the % of vandalism-induced station outage time, or data loss, to either the establishment cost (investment value) of the network, or to the network's annual operating expenses.

An additional, less tangible, but not necessarily less important cost, is the potential erosion of public or political confidence and support. This can threaten long term sustained investment in observation networks exposed to vandalism, with consequence to the services are reliant on the observational data.

The full impact of vandalism cannot be counted unless all of the above elements are recognized.

6.2 Towards a Consistent Costing Framework

To assess the global or regional impact of vandalism, a consistent cross-national framework for cost attribution is desirable. Constructing a framework is not simple because:

- Network operators have different approaches to recording events, maintenance costs, vessel costs and staff costs. These are also subject to local accounting and costing practices, and, for the purposes of aggregation, to exchange rate variations.
- Vandalised equipment may be directly replaced, or recovered items may be repaired. Many agencies capture the direct equipment costs, but not all capture records of labour costs for internally performed repairs, logistics or vessel operations.

- Vessel operating costs in particular are treated inconsistently, because:
  - Vessel hire may be "free" to an operating agency, through no-cost services from agency-owned vessels or ships provided by other government agencies.
  - Other agencies acquire vessels through commercial charter, or assign a cost for the use of government-supplied vessels.
  - The cost of a vandal response mission may be difficult to isolate when it is combined with a multi-station maintenance voyage.
- Data loss and service impact costs are difficult to assess across the spectrum of data applications. These span real-time tsunami or marine hazard warnings, near-term and seasonal weather and ocean forecasts, climate record compilation, rescue-at-sea operations, and scientific research.
- The impact and length of data outages or service degradations depends on network topology and redundancy, and priorities for service restoration.
- The exact date of a vandalism event and its costs and impact may be masked by other causes of equipment malfunction, especially with technology that is not fully mature.
- Events such as surface buoy loss or mooring breakage might not be able to be attributed unequivocally to vandalism, as evidence can not always be retrieved.

To compile meaningful, cross-national records of vandalism rates and costs, the International Tsunameter Partnership (ITP) developed a survey to solicit information from IOTWS tsunameter network operators. The records solicited through the survey are shown in Figure 31.

FOR EACH STATION

A consecutive set of vandalism event records from the time of station establishment, for each confirmed or suspected event

FOR EACH ASSUMED OR CONFIRMED VANDALISM EVENT

- Date of confirmed or suspected vandalism event
- Date on which station (or component part) was returned to service
- Description of the damage or loss
- Likely / suspected cause of the damage
- Confirmation (YES/NO) of photographic evidence
- Estimated cost of equipment replacement or repair
  - Costs of replaced or repaired equipment
  - The duration and cost/day of special (unscheduled) sea-going missions, or of extensions to scheduled maintenance missions, to rectify vandalised stations
- A narrative providing some further explanation or comment
- An optional narrative of the operational impact of the vandalism outage

Figure 31. Structure of IOTWS Tsunameter Vandalism Survey

While the survey framework is not comprehensive, and responses in some areas reflected significant national differences in costing practices, the survey responses do allow a level of critical analysis of data across multiple countries. The results are presented below.

7 COST ANALYSES – TAO AND TSUNAMETER NETWORKS

7.1 Cost parameters applicable to all networks

The TAO and IOTWS tsunameter networks are quite different in their scale, vandalism exposure, platform maturity, and data applications. Nonetheless, a model of vandalism impact and cost can be assembled using the following parameters:

- incidence – rate of vandalism: # of events per year, and as % of network size
- (average) rectification cost per event and total annual cost
- impact on unattended working life of platform
- observation data loss attributable to vandalism
- direct and indirect service consequences (where apparent)
- public and political visibility / sensitivity
- incidental or intangible costs or impacts.

7.2 IOTWS Tsunameter Network Vandalism Cost

7.2.1 Equipment Restoration Costs

The ITP vandalism survey of IOTWS nations and operating agencies spans component networks operated by Australia, Germany, India, Indonesia, Malaysia and Thailand. From October 2006 through to September 2010, thirty one vandalism events were recorded.

The treatment of equipment, vessel and labour costs varied between survey respondents. To aggregate these costs onto a total regional vandalism cost, normalised figures were applied for station costs, platform life and some associated costs. Using conservative assumptions, the total direct cost of IOTWS vandalism between 2006 and 2010 is estimated to be in excess of US$3.4m, or around $110,000 per event.

The following cost breakdown applies (all costs in $US):

- The network-wide “direct” cost of materials or replacement parts was around $2.9m. This represents an average “per-event” cost of approximately $95,000.
- Associated labour and vessel operating costs (which were significantly under-reported, and not fully recorded*) were in excess of $450,000. This represents $15,000 per event, and a collective labour effort of between 2-3 person years*.

  *NOTE: These figures are clearly an under-estimate, for the following reasons:

  - Ship charter is treated by some operating agencies as being at no extra cost when a vandalism response is combined with a scheduled maintenance voyage, whether or not that voyage has been brought forward to meet network restoration priorities, or extended to cater for buoy recovery and restitution.
  - Labour effort associated with fault detection, diagnosis, procurement, logistics management, event communications, repair, testing and vessel missions is included at a token level only. It is subject to future refinement.

Vessel operating or charter costs are commonly found to take up nearly half of the sustainment budget for non-coastal moored buoy networks. This figure is supported by the experience of the US and Australian tsunameter networks, and by NDBC's costing of the vandalism in its domestic weather and ocean buoy network. Applying this ratio to the IOTWS network would suggest the combined vessel-plus-labour costs for IOTWS vandalism responses to be of the order of $100,000 per event, in addition to the direct expenses of equipment replacement.

7.2.2 Effective Cost - Loss of Service Benefit (Data Loss)

Over the four year period from 2006-2010, the collective data loss due to vandalism exceeds 18 platform-years. This might have been less had platform replacement not been delayed while anti-vandalism modifications were underway. But it also may have been higher, had the number of active stations increased as planned towards network design levels during this time.

Tsunami warning systems informed by deep ocean sea level observations help protect lives and economic assets during damaging tsunami events. They also help avoid false alarms or evacuations, that themselves can cost lives and cause substantial economic loss. Analyses of specific events in Hawaii, for example, [Ref 7], are illustrative:

- The estimated cost of an unnecessary tsunami evacuation in Hawaii in 1994 was approximately $30 million in business disruptions and other costs.
- In November 2003, the availability of live data from tsunameters enabled the cancellation of a warning in similar circumstances, avoiding an unnecessary evacuation, and realising an estimated cost saving of around $68 million.

For the purposes of this report, in the absence of an economic model for warning centre cost benefit, a simple approach has been taken to estimate the loss of benefit arising from a station outage:

- The platform outage period is taken as a percentage of the useful service life of the platform, during which no value is being received from the investment in the station.

Applying this to a notional investment cost (equipment acquisition and deployment, with no accounting for network operational expenses), vandalism-induced data outages can be assessed to be around $3.2m over the four years from 2006-2010. This represents approximately $100,000 per event. A more sophisticated assessment would see this figure increase substantially.

7.2.3 Service Degradation or Failures (non-economic)

The non-functioning tsunami warnings can result in the potential loss to human life. Warning centres are equipped to issue the best available tsunami warning and forecast information, based on pre-computed forecast models and whatever observation data is available at the time. The absence of sea level observation data from any station or group of stations will not impede the issue of warnings, but may compromise the quality of forecasts, or the timeliness of forecast revisions, including warning cancellations.

Tsunameter networks are tested against simple performance criteria:

- When it mattered (during a tsunami threat) did the key early warning station(s) deliver trustworthy, real time sea-level data to warning centres?

- Did the network as a whole (in conjunction with other, non-tsunameter sources) deliver enough data for the progress of the tsunami to be effectively monitored and predicted?

Three particular events in the Indian Ocean illustrate the potential for vandalism to seriously impair a warning service:

- In late September, 2010, nine tsunameters in the IOTWS network were out of service due to vandalism, and eleven were reported to be functional.
- Within a period of 12 months around that time, small tsunamis, or damaging localised tsunamis were triggered on 30 September 2009 (Padang), 7 April 2010 (Sumatra), and on 25 October (Mentawai), all off Indonesia. Each of those events had the potential to be of much greater regional consequence, capable of inflicting damage in multiple neighbour countries within a few hours.
- While the handling of tsunami warning during these events was not highly dependent on interpretation of tsunameter data, with just slightly different earthquake sources any number of the tsunameter sites in the network could have been be tested as front-line, early-warning data sources. Whether or not vandalism impacted the forecasts for the above event, the real test will be the next event, and the one after.

In future, warning centres will make more effective use of tsunameter data, assimilating real-time tsunameter data into the forecast model as the tsunami event unfolds. Other sea-level observation systems, such as coastal tide gauges, are not effective for this purpose. When such capability is taken up by warning centres, tsunameter sources will become more critical to the warning process.

7.2.4 Public and Media Visibility and Attention

Tsunami events are unpredictable, and have the potential for community impacts within minutes of an originating earthquake. With regular tsunami threats in the Indian Ocean, the function of the IOTWS is regularly and randomly exercised. The results are visible to host governments, to the public, and to local and international media. The publicity attached to the large public investment in warning systems in the region adds to this scrutiny.

The fact of ocean platform vandalism and its connection with warning system function has received media attention. Media articles noted the loss of the US-donated DART™ buoy in Indonesian, and an Australian tsunameter in the Indian Ocean. In December 2009, the Times of India published an article titled *"Plundering of Tsunami Buoys Weaken Alert Mechanism"*. More recently, after the October 2010 Mentawai tsunami in Indonesia that claimed hundreds of lives, reports that a vandalised tsunameter was a primary contributor to warning failure were widely published [Figure 32], even though the vandalism assertion was later refuted.

The cost of vandalism, and the potential for compromise to public warnings, exposes tsunami warning systems and tsunameter technology to negative public messages and political impacts. This presents a risk to public and political confidence in tsunami warning systems, and support for sustaining the observation networks over the long term. This would be an unfortunate outcome, since tsunameter-based sea level measurements are unique in their capacity to record a clean tsunami wave profile that can be assimilated into real-time forecast models.

"Tsunami buoys vandalised before disaster"
ABC News (Australia) 29 Oct

"$1m tsunami warning buoys victims of vandals"
(Australian) Sydney Morning Herald Oct 29, 2010

'No alert' in Indonesian tsunami"
BBC News Asia-Pacific 27 October 2010

"Indonesia's Tsunami Warning System Failed Because of Vandalism"
Aol News www.aolnews.com 27 October 2010

"No warning came …., system had been 'vandalized'"
www.inquisitr.com 27 Oct 2010

"Indonesian tsunami warning system 'had been vandalised'
web forum 28 October 2010

Figure 32. Examples of Media Attention to Vandalism – Mentawai Tsunami Oct 2010
(Vandalism claim was subsequently refuted)

7.2.5 Diversion of Specialist Resources

For the IOTWS in particular, a significant consequence of vandalism has been the diversion of human effort and other resources from the task of IOTWS warning system establishment. Special expertise is required to develop and deploy tsunameters, to integrate their data into national and international warning centres, and to manage and sustain operational networks. In most countries this expertise is confined to a relatively small group of specialists within government agencies.

Response to the high levels of vandalism in the IOTWS networks has significantly diverted scarce engineering and technical resources. Effort has been applied to detect and diagnose vandalism events, to procure new equipment and materials, to perform additional repairs, to conduct tests, to organise and staff extra vessel missions, and to handle the ancillary communications and record keeping at times of network disruption. In some countries, substantial effort has also been directed to equipment redesign to reduce tsunameter susceptibility to vandalism.

This vandalism-directed effort diminishes the effort and expertise available for network roll-out, technical troubleshooting and warning system integration work, during a vital period of warning system establishment. In particular, the following aspects of IOTWS warning system establishment have suffered:

- Technical development and technical stabilisation of new platforms has been slowed, with vandalism diverting engineering effort from such development, and in some cases prematurely terminating equipment trials or tests.
- Progress towards standardised international data exchange has been impeded. This has affected both ends of the data exchange transaction – robbing effort from the technical

work to facilitate standardised data exchange from the platform, and suppressing warning centre "pull" demand for data sources whose persistence is uncertain.

- The development of network monitoring and quality systems has been slowed.
- Planning for future sustainability at national and regional scales has been deferred.

A less conspicuous consequence of IOTWS vandalism is its impact on the motivation and job satisfaction of tsunameter network developers and operators. They have expressed frustration at the impact of vandalism personally, and professionally, in IOTWS meeting forums. They typically feel deep personal concern and responsibility for impacts to warning services.

7.2.6 Network Topology and Redundancy

The spatial design of the IOTWS tsunameter network incorporates some level of redundancy at both national and regional scale. This helps sustain warning system performance when not all stations may be functional. This redundancy is a practical response to long station restoration times that rely on expensive and schedule-constrained vessel operations. The high impact of vandalism on IOTWS station availability increases the need for network redundancy, with its additional operating and sustainment costs.

The IOTWS tsunameter network topology, including redundancy provisions, will need to be revisited in the near term as the networks emerge from the establishment phase and face longer-term sustainability challenges. While it is beyond the scope of this report to address network redundancy principles and impacts, it is critically important to reduce the level of vandalism so that future network optimisation of performance, resilience and sustainment cost can be delivered, at both national and regional scales.

7.3 US-Operated Tsunameter Network Vandalism Cost

7.3.1 Equipment Restoration Costs

The most typical expression of vandalism on tsunameters operated by the US is a severed mooring resulting in an adrift surface buoy, although there have also been likely cases of surface buoy theft. For these incidents, NDBC estimates that the replacement cost for a lost buoy, inclusive of vessel time, may be as much as $375,000, depending on the location of the station. With five confirmed buoys lost to vandalism in 2008 and 2009, plus other buoy losses in 2008 that are plausibly due to vandalism, prospective vandalism costs over those two years could be well in excess of $2m.

Assuming these two years are representative of a repeated pattern of vandalism, annual vandalism restoration costs of at least $1m are indicated.

7.3.2 Effective Cost - Loss of Service Benefit (Data Loss)

With an annual network-wide maintenance voyage, the time-to-restore a vandalised stations will average six months. Assuming only two vandalism events per year across the network, data outages attributable to vandalism would equate to one station-year, or a loss of investment value from around 2.5% of the network. With an annual, network-wide sustainment cost in excess of $10m, the loss of service benefit due to vandalism could be equated to at least $250,000 per year.

7.4 TAO Network Vandalism Costs and Impact

7.4.1 Equipment Restoration Costs

[Ref 1] presents estimates of vandalism costs in the US weather and oceans observation network, and in the TAO array. It reports that *"in the nine months from October 2007 to June 2008, 18 TAO buoys in the Tropical Pacific Ocean went off-station due to vandalism"*.

NDBC estimates the financial cost to the U.S. Government (NOAA) for this vandalism to be roughly $1 million annually.

7.4.2 Effective costs – Loss of Service Benefit (Data Loss)

The TAO/TRITON network is critical in the monitoring and prediction of El Niño or La Niña phenomena. It provides multiple data streams for use in operational applications, such as Numerical Weather Prediction, and for a range of scientific studies, including climate research. Unlike the tsunameters, which must deliver a single, reliable observation stream, there is less immediate impact of isolated sensor losses or single station outages in the TAO/TRITON network. However, substantive loss of TAO/TRITON data can impact seasonal and climate prediction. That in turn affects productivity, revenues, and employment in a wide range of climate-sensitive industries and sectors, including agriculture, tourism and commercial fishing.

The quality performance target for TAO is 80% network data availability. A rough order estimate from NDBC is that vandalism contributes a continuous 15% to 20% impact to TAO product quality. Taking this as a first-order estimate of the investment loss due to vandalism, and apportioning that across the annual TAO network operating costs, the annual vandalism-induced service loss for the TAO/TRITON network is of the order of $2m.

7.4.3 Service Degradation or Failures (non-economic)

A 2009 paper on the Global Tropical Moored Buoy Array [Ref 9] noted that significant TAO data drop-outs, *"symptomatic of vandalism"* had occurred during the development phase of that year's El Niño. This loss of data, aggravated by a reduction in ship time to service the array, was indicated to have compromised scientists' ability to accurately describe the evolution of the event and to predict its further evolution. This circumstance was also the subject of a media article (refer below).

7.4.4 Public and Media Visibility and Attention

Inevitably, simple negative messages, such as a warning system failure or loss of publicly funded assets find ready media exposure. Vandalism provides such an opportunity for such negative messages, which promulgate more vigorously than good news.

Because of the less direct connection between data and derived public services, vandalism on the TAO / TRITON network does not attract the same level of critical media and public attention as for the warning-critical tsunameter networks. Where such attention is given, it is typically via a scientific media source, with limited exposure, and with more direct reliance on source material from the specialists or scientists connected with the network. One example is the article by Nature News [Ref 10], with the headline *"Buoy Damage blurs El Niño Forecasts"*. The article focused on the uncertainty in the 2009 El Niño forecast as a result of lost data due to buoy damage in the TAO array, alluding to prospective damage from vandalism.

7.4.5 Diversion of Specialist Resources

As with the IOTWS tsunameter network, vandalism impacts on the workload of specialist engineering, technical and scientific staff. In doing so, it impedes progress on platform and program improvements.

7.5 US Weather and Ocean Buoy Network Vandalism Costs

The US Weather and Ocean Buoy Network is not an open-ocean network comparable with the tropical moored buoy arrays or the global tsunameter networks. It is subject to different patterns of vandalism because of its proximity to coastal communities and recreational activities. Nonetheless it does have a consolidated record of vandalism, which complements the records of the open ocean networks.

[Ref 1] indicates an average cost to NOAA of $100,000 per vandalism event, for a total cost of $5.4m over a period of five years. The cost of recorded incidents in 2008 is estimated at over $2m for the eight mooring failures experienced in 2008 alone, inclusive of the direct costs to NOAA and the cost of ship and other asset support for these missions.

8 POSSIBLE RESPONSES TO VANDALISM

No “silver bullet” will by itself solve the vandalism problem. The issue must be tackled from several angles. It may never be possible to establish which approach had most effect, how many potential vandalism events were avoided, or just how much was saved by any particular intervention. All that is certain is that for each major vandalism event avoided, there will be a saving of the order of $200,000 in direct costs and an improved investment return of a similar amount, from greater data delivery for the same network cost. There will also be potential for significantly higher societal benefits arising from improved forecasts, warnings and environmental understanding. The strategies available include:

- **Duplication** – use of redundancy in network design (additional stations) or at the platform level (duplicated sensors or sub-systems) to cater for damage or loss
- **Platform hardening and technical defences** - defensive hardening of platforms and moorings, disturbance detection, countermeasures, incorporation of tracking beacons etc
- **Avoidance** – reducing exposure by physical location choices (or abandonment), by collapsing sensor fits, or by choice of alternate sensing technologies or platforms
- **Education and outreach** to the fishing community – coastal community awareness and education, fisheries bodies and fishing communities education, signage on buoys
- **Regulation and enforcement** – legal frameworks and penalties, vessel licensing, vessel tracking, interception and enforcement.

9 Responses to Date and their Relative Success

9.1 Duplication

All operational observation networks strive for a balance between service continuity and the cost of redundancy. Technology redundancy is common on an ocean platform, to cater for the inherent vulnerability of sensors or other critical components operating in a harsh environment.

Station-level redundancy, either through spatial over-sampling, or even pairing of stations, is a practical response when platforms are remote, with inherently long restitution times.

Tsunami observation networks commonly exhibit some level of observational redundancy. This applies both within the open-ocean (tsunameter) networks, and across the mix of open-ocean and coastal sea level monitoring stations. While such redundancy can be effective at sustaining warning system performance during individual station outages, it imposes a considerable additional cost in network establishment (capital cost), in inventories of spares, and in sustainment costs and vessel expenses.

The recent assessment of the effectiveness of US tsunami preparedness [Ref 6] remarks on *"insufficient station redundancy in the DART network …… with potentially adverse impact on the capability of the Tsunami Warning Center to issue efficient warnings."*. While that assessment was prompted by the impact of station reliability, it would equally apply to the impact of vandalism, were the network in the Indian Ocean.

9.2 Platform Hardening and Technical Defences

A range of technical (platform) defences against vandalism have been applied:

- NOAA and JAMSTEC have incorporated revised product designs and different materials and component selections to discourage vandalism or to mitigate its effects. These adaptations include replacing aluminium superstructures with stainless steel; using fasteners that require special tools for disassembly; using impact resistant hull materials; changing whip antennas to disc antennas, jacketing cables etc.
- Canada has introduced longer and heavy gauge chain in the upper segment of its NOMAD moorings to prevent cutting.
- Meteorological masts have been withdrawn from the first generation DART tsunameters to reduce their attractiveness to vandalism, and new product types (for example, the PMEL's Easy-To-Deploy DART buoy) have a low profile in the water, with smooth external surfaces, and no convenient points for tie-up or boarding.
- India has redesigned its tsunameter surface buoy without solar cells.
- Surface buoys have been modified to deny convenient tie-up. Experimental buoy types, such as the NOAA-PMEL "Conehead" and the JAMSTEC "Iron Mask" radically reduce the exposure to vessel tie up and sensor removal. [Figure 33]

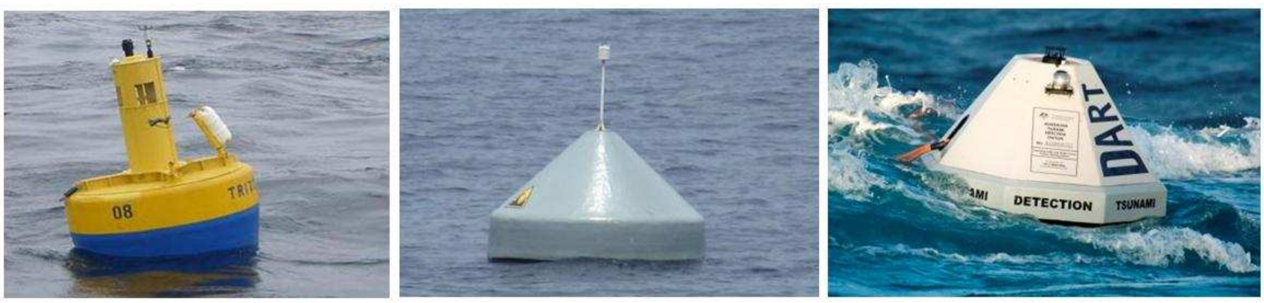

Figure 33. Anti-vandal Designs: JAMSTEC "Iron Mask", NOAA "Conehead" and ETD-DART

Each of these initiatives has been beneficial, extending the working life of platforms in regions of high vandalism, and enabling the collection of observation data for longer continuous periods than would otherwise have been possible. These modifications, while beneficial, can result in extra production cost, more difficult at-sea servicing, loss of some surface data streams, and potential disturbance to climate records arising from shielded sensor mounting.

Despite successes, buoys fitted with such defensive measures are still subject to vandalism. Easy-to-Deploy DART buoys have been lost to vandalism, one of the early Conehead buoys off Indonesia [Figure 13] suffered a severed mooring, and some surface buoys have been disassembled by vandals using special tools.

9.3 Avoidance

One remedy is to simply rely on alternative means of collecting the required measurements in hard-hit areas, e.g. from subsurface buoys, ships of opportunity, and/or satellites. Another is to de-populate the suite of exposed surface sensors on a platform to reduce its attractiveness or vulnerability. Another is to avoid or abandon vandalism "hot-spots".

Sites that have experienced repeated vandalism have been dropped altogether from the TAO/TRITON network the Indian Ocean tsunameter network and the PIRATA network to avoid sites with a high incidence of vandalism or high vessel traffic.

The suite of surface sensors has also been reduced at some sites to minimise exposure. Experimental "anti-vandalism" buoy designs such as the JAMSTEC "Iron Mask" buoy and the NOAA "Conehead" buoy typically have a reduced set of surface sensors.

There has been a re-balancing of the TAO network towards more sub-surface moorings, reducing the number of exposed surface buoys. In tsunami monitoring networks, an option may be to re-balance the network mix of tsunameters and coastal tide gauges.

Increasing access to remotely sensed data from satellites is reducing the need for in-situ observations for some applications. But the growth of data buoys is testament to the need for some measurements for which there is no feasible alternative, and for in-situ observations to complement and to ground-truth the data available from other sources, including from satellites.

The above avoidance measures reduce the incidence and cost of vandalism. But that may be at the price of fewer observation parameters, gaps in network coverage, compromise to optimum network design, or service compromise. This is not always a practical choice. [Ref 1] refers to three valuable sites in the US weather and ocean observation network that are being sustained, despite collectively suffering 24 vandalism-related mooring failures.

9.4 Education and Outreach

Numerous local and international efforts have been made over more than twenty years to educate and inform the fishing community about the negative consequences of data buoy losses for research and for weather, climate, and ocean forecasting, and for tsunami warning.

Examples include:

- The TAO and TRITON Project Offices have been active for many years. They have issued leaflets in several languages to fishing organisations and fishing boats, and have produced educational materials for local dissemination or promulgation via the internet, [Ref 8] for example. The TAO Implementation Panel report in 1997 notes continuing efforts to *"work with national and international fishing agencies, to find solutions…"* and records brochures being sent to Latin American fishing boats and agencies in Pacific Rim countries, and attendance at a South Pacific Commission meeting to enlist the assistance of island nations in the region.

- The DBCP has produced a leaflet on the value of ocean data buoys, translated in multiple languages, for circulation to fishermen and mariners [Ref 11]. The leaflet provides advice with respect to interference with data buoys. Its content has been promulgated in full or in part by a number of national agencies, by port authorities, and by the International Hydrographic Organisation [Ref 12].

- The German-led GITEWS project was proactive in coastal community education in Indonesia during the deployment of its tsunameter network, including the issue of shirts with GITEWS tsunami buoy images, to promote their recognition.

- The Jakarta Tsunami Information Centre in Indonesia has produced community education materials including a poster on tsunami buoys [Ref 13]. The cartoon representation of tsunameter vandalism actions in Figure 34 is extracted from this.

- India has mounted public information campaigns for coastal communities, using public television broadcasts in local languages across a number of coastal states supporting fishing communities.

- The US has actively engaged with regional fishing management bodies, such as the Western and Central Pacific Fisheries Commission, to inform them of vandalism issues, and to promote the adoption of codes of conduct that would protect marine observation platforms. (Refer para 9.5.3)

- Some ocean platforms carry signage in multiple languages. This is in addition to prominent graphical signage, such as the tsunami warning (wave) symbol.

Figure 34. Extract from Tsunami Buoy Poster Developed by JTIC, Indonesia

The above measures are on-going, but are believed to have had only limited success. Thousands of ships from many countries are involved in fishing operations, mainly for tuna, in the world's tropical oceans. This diversity makes it very difficult to reach them all. Despite India's national education campaign, for example, Indian tsunameters may be exposed to fishing vessels originating from other countries, and operated by crew speaking different languages. Likewise, fishing management and regulatory bodies in different countries and regions don't exert the same influence over vessel and crew behaviour. Many fishing vessels operate informally, beyond the realm of registered or controlled fishing operations.

Once reasonable exclusion zones around ocean platforms are violated, the fisherman's personal and immediate financial motive to recover fishing gear by cutting a mooring will tend to prevail over a more altruistic "public good", with less tangible benefits.

9.5 Regulation and Enforcement

9.5.1 General

Regulation and enforcement, applied within the fishing industry, or through national and international law, remains a powerful option for changing behaviour. To date, it has been relatively ineffective.

In most cases, it is difficult to detect a vandalism event in sufficient time to intervene, to unequivocally identify a violator, or to successfully intercept an offending vessel. Further, international law that might pertain to acts of vandalism currently provides no effective basis for legal action for vandalised buoys in international waters. National laws pertaining to waters within a State's EEZ offer potential for more specific recognition of data buoy vandalism, and more consistent treatment between countries.

Brazil had provided an example of a Navy vessel successfully intercepting a ship carrying a stolen buoy. But there are other cases where authorities have been unable or unwilling to intervene and recover a stolen buoy at sea or on shore, even when alerted to its location, through its on-board GPS tracker.

9.5.2 International Law Applicable to Platform Vandalism in the Open Ocean

The United Nations Convention on the Law of the Sea [Ref 14] provides for potential responses to vandalism in the open ocean through Article 105 *("Seizure of a Pirate Ship or Aircraft")*, and Article 101 (*"Definition of Piracy")*, Article 106 *"Liability for Seizure"* and Article 107 *"Ships and aircraft which are entitled to seize on account of piracy"*.

Article 103 states:

> *"On the high seas, or in any other place outside the jurisdiction of any State, every State may seize a pirate ship or aircraft, or a ship or aircraft taken by piracy and under the control of pirates, and arrest the persons and seize the property on board. The courts of the State which carried out the seizure may decide upon the penalties to be imposed, and may also determine the action to be taken with regard to the ships, aircraft or property, subject to the rights of third parties acting in good faith."*

Article 101 defines piracy (among other things) to be:

> *" any illegal acts of violence or detention, or any act of depredation, committed for private ends by the crew or the passengers of a private ship or a private aircraft, and directed: ……... against a ship, aircraft, persons or property in a place outside the jurisdiction of any State"*

Such intervention (seizure on account of piracy) is restricted to action by *"warships or military aircraft, or other ships or aircraft clearly marked and identifiable as being on government service and authorized to that effect"*, with provisions relating to the seizure being effected on adequate grounds.

While Article 101 admits to "piracy" encompassing *"an act of depredation …. against property"*, these provisions are generally applied with respect to acts against manned vessels. They do not in their current form provide an effective vehicle for response to vandalism against data buoys, even in the most extreme case of demonstrable equipment theft.

9.5.3 Recent Developments in Global Action including Fisheries Management

Regulations pertaining to the issue or retention of fishing licenses or permits have the potential to specifically inform the target group (an education function), and to apply reporting or vessel tracking arrangements, sanctions and economic penalties that meaningfully change behaviour. These might be applied, for example, through a nationally regulated fishing fleet or through a collectively managed fishery in international waters, via fisheries commissions.

In parallel with the IOC's efforts on vandalism, which instigated this report, the UN General Assembly in 2009 recognized the problem of data buoy vandalism in its annual *Oceans and the Law of the Sea Resolution* [Ref 15] and *Sustainable Fisheries Resolution* [Ref 16]. In the former, the UN General Assembly expressed its concern at intentional or unintentional damage to platforms used for ocean observation and marine scientific research, such as moored buoys and tsunameters, and urged States to take necessary action and to cooperate in relevant organizations, including the IOC, the UN Food and Agriculture Organization (FAO) and the World Meteorological Organization (WMO) to address such damage. In the latter, the General Assembly called on Regional Fisheries Management Organizations, working in cooperation with the IOC, FAO, and WMO, to adopt, as appropriate, measures to protect data buoy systems moored in areas beyond national jurisdiction from actions that impair their operation.

In 2010, WMO, noting the 2009 UN General Assembly actions, urged its member states to help promote understanding of the impacts which seriously undermine efforts to establish national and regional ocean hazard warning systems and coordinate with relevant organizations to take necessary action.

In December 2009, one Regional Fisheries Management Organization (RFMO) adopted a binding measure to protect moored data buoys. The Western and Central Pacific Fisheries Commission adopted a *Conservation and Management Measure Prohibiting Fishing on Data Buoys* [Ref 17]. In September 2010, the Inter-American Tropical Tuna Commission (IATTC), at its eighty-first meeting adopted a similarly worded non-binding *Recommendation Prohibiting Fishing on Data Buoys* [Ref 18].

The above measures offer a new regional management practice to minimize intentional or unintentional damage to ocean data buoys. The measures require participating members to:

- prohibit Member fishing vessels from fishing within one nautical mile of or interacting with a data buoy or its mooring line, including but not limited to encircling the buoy with fishing gear; tying up to or attaching the vessel, or any fishing gear, part or portion of the vessel, to a data buoy or its mooring; or cutting a data buoy anchor line;
- prohibit Member fishing vessels from taking on board a data buoy unless specifically authorized or requested to do so;

- encourage all reasonable measures to avoid fishing gear entanglement or directly interacting in any way with those data buoys; and
- minimise damage to the data buoys that may become entangled with fishing gear, with encouragement to report such entanglements.

9.5.4 Regulatory Framework within Domestic Waters (Coastal Networks)

The regulatory and enforcement arrangements applicable to buoy vandalism within domestic waters are country-specific, and subject to regional jurisdictions. Legal statutes to protect assets that are material to safety at sea, such as navigation beacons, are common. Such provisions might be extended to the recognition of at least some classes of data buoys in coastal waters. [Ref 1] indicates that the US National Data Buoy Center is pursuing such an outcome.

10 RECOMMENDATIONS FOR FUTURE ACTION

No single strategy is capable of defeating or materially reducing vandalism. To date, despite efforts on many fronts, the physical hardening of platforms and vandalism avoidance are perceived to have been the most effective. This does not deny the potential effect of education activities, but there is no clear evidence of reductions arising from education or outreach.

There are limits to how much extra gain can be wrought from platform engineering, avoidance and redundancy. A more systematic and cohesive response is required to change the behaviour and decisions by fishing crew that lead to vandalism. This requires multiple tiers of action.

Responses at one level might require complementary actions at another level to produce a worthwhile result. For example, surface buoys could potentially incorporate technologies to self-detect some classes of interference, provide a better evidential record of the offence, or embed tracking beacons that are not easily defeated. But those measures may be to no avail if:

- network operators make no companion investments in real-time station monitoring;
- there is no follow-up interception or investigative action by authorities;
- a regulatory framework is not in place to apply penalties or sanctions; and
- there is no political will to conduct prosecutions or equipment recoveries.

Finally, behaviour change in other potential violators may not be realised if successful interventions or prosecutions aren’t actively communicated, both nationally and internationally.

The following recommendations are for actions which can be taken by platform designers, network operators and designers, regulators at state and international level, enforcement agencies, fishing fleet operators, fisheries management organisations, and bodies such as the DBCP.

RECOMMENDATION 1: Platform Hardening and other Denial Mechanisms

A. That designers of ocean observing platforms are encouraged to incorporate the best physical design, material selection and assembly practice, drawing in particular on the experience of NOAA (PMEL and NDBC) and JAMSTEC.

B. That the DBCP acts as a focal point for recording and promulgating best practice in anti-vandalism design, and for consolidating and communicating international developments to counteract vandalism.

C. That the DBCP take oversight of specific developments or investigative efforts proposed or under consideration by various platform designers and network operators. Such developments might include platform hardening and access denial, fish scare, active intrusion deterrents or alarms, disturbance detection and evidence gathering, use of symbolic or multi-lingual signage, and use of tracking beacons.

RECOMMENDATION 2: Network Operations and Design - Avoidance

A. That long term, whole-of-life cost effectiveness models be used to inform new network design choices, or the evaluation of alternate observation technologies. Such models should incorporate prospective losses due to vandalism. This will ensure that appropriate account is taken of the relative susceptibility, service impact and sustainment costs of competing network topologies and technology choices.

B. That a map projecting the global extent of open-ocean tuna fishing operations be developed, so that network planners can take into account the regions of most intense risk from intersection with such fishing activity. *(Note: NIOT has proposed to develop such a map.)*

RECOMMENDATION 3: Network Operations

A. That network operators work closely with platform designers to ensure effective monitoring of buoy watch circles and in-built disturbance indicators, to ensure speedy and effective use of such information.

B. That operators of major vandalism-affected networks be encouraged to develop an understanding of applicable regulations, government statutes and fishing vessel management operations within their region of interest, and to build effective relationships and communications with relevant external authorities or agencies.

RECOMMENDATION 4: Data Exchange and Network Optimisation - IOTWS

A. That in the heavily vandalised IOTWS "network of national tsunameter networks" efforts be accelerated to realise real-time continuous international data exchange from all tsunameter platforms, to reduce the national and regional warning service vulnerability to individual station outages.

B. That a systematic analysis be made of the national and regional warning capabilities underpinned by the IOTWS tsunameter network, and the sensitivity of those capabilities to station outages, including the network's susceptibility to vandalism. Such analysis will identify opportunities for collective network optimisation.

RECOMMENDATION 5: Recognition of Marine Platform Vandalism in National Statutes and Harmonisation of National Legislation with Respect to Vandalism

A. That States are encouraged to explicitly recognize acts of ocean platform vandalism in statutes or regulations pertaining to State-controlled waters. This would ideally provide protection for observing platforms commensurate with that of high-value assets on land, or other high-public-value marine infrastructure, such as navigation beacons. The acts of vandalism that should be proscribed should at least include wilful damage and theft, and damage arising from reckless activity in the vicinity of the platform.

B. That States are encouraged to harmonise national legislation with respect to ocean platform vandalism, and cooperate to address the prevention, detection, reporting and investigation of vandalism incidents, and the prosecution of legal or other responses to those incidents.

C. That mutual commitments to the care or protection of ocean platforms be explored when negotiating related multi-lateral or bilateral cooperative agreements such as for deployment or support of ocean platforms, technology transfer or capacity building, or provision of tsunami warning services from a Regional Tsunami Watch Provider.

RECOMMENDATION 6: Code of Practice – Fisheries Management, or Regulatory Bodies

A. That other Regional Fisheries Management Organisations, especially those concerned with tuna fishing, consider and adopt measures similar to the exemplary conservation measures adopted by the West Central Pacific Fisheries Commission [Ref 17] and the Inter-American Tropical Tuna Fishing Commission [Ref 18].

B. That fishing fleet managers or licensors, whether local, national or international, actively communicate to Member fishing vessels the high community value of marine observing platforms. Further, that they make practical commitments to support the investigation of vandalism acts. Such measures might include conditions of license that require Member vessels be fitted tracking beacons, and a commitment to exchange of information with relevant authorities for the purposes of incident investigation.

C. That States, when establishing fishing regulatory authorities, fisheries management or licensing bodies, assure that codes of practice such as those referred to above are incorporated in the operating charter for such bodies.

RECOMMENDATION 7: Compilation of Consistent Vandalism Records and Cost Analyses

A. That the IOC and WMO promote the systematic capture and exchange of records of ocean platform vandalism, to enable the consistent aggregation and analysis of vandalism incidence and costs across multiple networks. The records to be maintained include location of the station, the nature of observed or assumed vandalism, the dates of service or data interruption, and records of expenses incurred in restoration of the damage, including direct expenses, labour and vessel costs, and the proportion of annual operating budget consumed by vandalism response costs.

B. That the IOC and WMO assist in establishing representative end-to-end cost benefit assessments for ocean platform investments, e.g. with respect to the Global Tropical Moored Buoy Array contribution to El Nino prediction, or to scenario-based examples of the tsunameter contributions to IOTWS or PTWS tsunami warning services. This would help to present the full economic impact of vandalism, as a motive for action response.

RECOMMENDATION 8: International Law of the Sea

A. That the provisions of the UN Convention on the Law of the Sea be reviewed with intent to classify ocean platform vandalism or theft in international waters as an offence subject to appropriate interventions and legal redress. The broadening of the piracy provisions to include acts of wilful damage or theft to ocean platforms might provide one such avenue.

RECOMMENDATION 9: International Education and Outreach

A. That the IOC or WMO directly engage inter-governmental forums, such as the ICG/IOTWS in the exchange of national practices with respect to fishing and coastal community education and outreach. Such engagement would foster a common interest and may promote broad and consistent regional engagement more effectively than the initiatives taken alone by ocean platform operators, or individual governments. An energetic cross-national campaign is also more likely to deliver tangible evidence of success that a series of localised or fragmented campaigns.

11 CONCLUSION

An analysis of global vandalism incidence and consequences has been made, based on an assessment of records from the Global Tropical Moored Buoy Array and the tsunameter networks in the Pacific and Indian Oceans, which have consolidated medium-to-long term vandalism records. These networks support over 150 moored buoy platforms. The experiences of the US Weather and Ocean Buoy Network and the Indian meteorological and oceanographic networks complement and reinforce the assessments made in the focus networks. The conclusions are:

- Vandalism, especially in ocean regions supporting tuna fishing, has had a dramatic impact on network operating cost and data delivery from the early days of network establishment, and the rate is perceived to be increasing.

- The rate of vandalism is highest in the Indian Ocean, with over half of the stations in newly established IOTWS tsunameter network suffering at least one vandalism event in the last four years, resulting in over 18 platform-years of data loss. Vandalism hot spots occur in all tropical open-ocean networks, particularly in areas associated with tuna fishing operations. The eastern and western extremities of the TAO/TRITON array are examples. Sites have had to be abandoned in the IOTWS tsunameter array, in the TAO/TRITON array, in the South China Sea, and in the PIRATA array, because of repeated vandalism. Of the focus networks, the least affected network is the US-operated tsunameter network, centred on the Pacific Ocean.

- Network-level data losses due to vandalism of the order of 15% - 20% are not untypical of the IOTWS network and the TAO tropical moored buoy array. This represents a loss of value from the network investment, adding to the direct costs of equipment restoration.

- Defensive strategies, such as the hardening of surface buoys, and avoidance strategies, such as the abandonment of certain sites, the reduction in exposed surface sensors, and deployment of more subsurface moorings, have so far had the most apparent impact on vandalism rates and consequences. Despite many years of attention to education and outreach to coastal communities and fishing operators, there is no clear evidence of its effectiveness.

- The severing of moorings, either to free entangled fishing gear, or as a consequence of vessel tie-up, is a common occurrence. In some networks it is responsible for a doubling of mooring retrieval missions. Theft or wilful damage to exposed sensors remains common, but all networks, and particularly the Indian Ocean networks, have experienced disturbing levels of large scale theft, including the theft of whole surface buoys and the removal of all buoy superstructure and electronic payloads.

- The different accounting and recording practices of countries or agencies presents some difficulty in the aggregation of costs across networks and regions, as do the different circumstances of operating agencies with respect to vessel access, maintenance regimes, labour rates, and equipment costs. However, for the purposes of putting some scale to vandalism costs, order of magnitude per-event costs are as follows:
    - Direct costs: $100,000
    - Associated labour and vessel costs for restitution: $100,000

- Data-loss costs: $100,000 *(the loss of investment benefit from stations that are compromised because of vandalism)*

These accounting losses are only part of the equation. Less tangible losses occur through diversion of specialist staff effort, through the impact of negative publicity, and through the costs of defensive measures, including anti-vandalism product developments and compensating network redundancy. This excludes consideration of the real and potentially large costs of community service failures, arising from station outages.

- While technological responses still have a part to play, vandalism reduction strategies for the future need to tackle the motivation and decision making of fishing vessel crew. A coordinated, multi-tiered approach is recommended, combining regulatory and enforcement changes at national and international level, greater harmonisation of national legislation and practice with respect to vandalism offences, and vessel codes of conduct and duty-of care provisions, applied through fisheries management organisations or licensing bodies. Technical developments need to assist through continued platform hardening and deterrence mechanisms, and in the provision of aids to assist early detection of station disturbance, or the identification of offenders.
- The recent adoption of a well constructed protective code of conduct by two Regional Fisheries Management Organisations provides a very valuable model for extension to other RFMOs.

12 REFERENCES

[1] ***Buoy Vandalism Experienced by NOAA National Data Buoy Center*** Chung-Chu Teng, Stephen Cucullu, Shannon McArthur, Craig Kohler, Bill Burnett, Landry Bernard; Jun 2010 National Data Buoy Center (and related article ***Vandalism of Data Buoys***, published in US Dept of Commerce 2010 Mariners Weather Log Vol 54, No 1, Apr 2010)

[2] ***Implementation of Global Ocean Observations for GOOS/GCOS***, 2nd Session, Paris, France, 30 November 1998: GCOS Report 50

[3] ***TAO Implementation Panel*** report, 11-13 November 1998, GCOS Report 52

[4] ***Vandalism on TRITON Buoy System***, S. Kakuta, M Yamaguchi, A. Ito, Y I Ishihara, M Yamamoto, S. Tashiro. OCEANS '04. MTTS/IEEE Techno-Ocean '04 Conference Proceedings, 9-12 Nov. 2004

[5] ***Mooring Modifications for the Rectification of Loss to Vandalism***, H.Paul Freitag, Chris Meinig, Andrew Shepherd, Linda Stratton, Presentation to DBCP 23, Jeju, South Korea, 2007

[6] ***Tsunami Warning and Preparedness***: ***An Assessment of the US Tsunami Program and the Nation's Preparedness***, US National Research Council, 2010

[7] ***False Alarms in Tsunami Warnings***, Associated Press article, 13 Feb 2005, available at http://www.wired.com/science/discoveries/news/2005/02/66586

[8] ***Effects of Fishing on Tropical Moored Buoys***, Poster, NOAA, PMEL + Institut de Recherche pour le Developpement (IRD), available through DBCP web site

[9] ***The Global Tropical Moored Buoy Array,*** M.J. McPhaden, K. Ando, B. Bourlès, H. P. Freitag, R. Lumpkin, Y. Masumoto, V. S. N. Murty, P.Nobre, M. Ravichandran, J. Vialard, D. Vousden, W. Yu. OceanObs 09 paper, Oct 2009

[10] ***Buoy Damage Blurs El Niño Forecasts***, Lubick, N. Nature 461, 455 (2009)

[11] ***Meteorological and Oceanographic Data Buoys***, DBCP leaflet, DBCP web site access.

[12] ***Vandalism on Ocean Data Buoys***, International Hydrographic Organisation IHO / Circular letter 30/2000, 11 Jul 2000

[13] ***Tsunami Buoy Poster***, prepared by Joint Tsunami Information Centre, Jakarta, accessible via web site: http://www.jtic.org/

[14] ***United Nations Convention on the Law of the Sea (UNCLOS)***

[15] ***Oceans and the Law of the Sea,*** UN General Assembly Resolution 64/71, para.172 (Dec. 4, 2009)

[16] ***Sustainable Fisheries***, UN General Assembly Resolution 64/72 para.109 (Dec. 4, 2009)

[17] ***Conservation and Management Measure 2009-05 Prohibiting Fishing on Data Buoys***, Western and Central Pacific Fisheries Commission, 6th Regular Session, Tahiti, Dec 2009.

[18] ***Recommendation C-10-03 Prohibiting Fishing on Data Buoys***, Inter-American Tropical Tuna Fishing Commission, 81st Meeting, Antigua, Guatemala, 27 Sep – 1 Oct 2010

ANNEX I: Acronyms

DART	Deep-ocean Assessment and Reporting of Tsunami (buoy)
DBCP	Data Buoy Co-operation Panel (WMO-IOC)
EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organisation (UN)
GCOS	Global Climate Observing System
GITEWS	German Indonesian Tsunami Early Warning System
GOOS	Global Ocean Observing System
GPS	Global Positioning System
GTS	Global Telecommunication System (WMO)
ICG/IOTWS	Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (IOC)
ICG/PTWS	Intergovernmental Coordination Group for the Pacific Ocean Tsunami Warning and Mitigation System (IOC)
IHO	International Hydrographic Organization
IOC	Intergovernmental Oceanographic Commission (of UNESCO)
IRD	Institut de Recherche pour le Developpement (France)
ITP	International Tsunameter Partnership
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JCOMM	Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
JTIC	Jakarta Tsunami Information Centre
NDBC	NOAA National Data Buoy Center (USA)
NIOT	National Institute of Ocean Technology (India)
NOAA	National Oceanic and Atmospheric Administration (USA)
OceanSITES	OCEAN Sustained Interdisciplinary Timeseries Environment observation System
PIRATA	Pilot Research Moored Array in the Tropical Atlantic
PMEL	NOAA Pacific Marine Environmental Laboratory (USA)
RAMA	Research moored Array for African-Asian-Australian Monsoon Analysis
RFMO	Regional Fisheries Management Organisation
TAO	Tropical Atmosphere Ocean Array
TIP	Tropical Moored Buoys Implementation Panel
TOWS-WG	Working Group on Tsunamis and Other Hazards related to Sea Level Warning and Mitigation Systems
TRITON	Triangle Trans-Ocean buoy network
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCPFC	Western and Central Pacific Fisheries Commission
WMO	World Meteorological Organization (UN)