Tsunami Activity under Group on Earth Observation

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Abstract - **The ad hoc Group on Earth Observation (GEO) established as their first working group, the WG on Tsunami Activities at EOS-3 (Earth Observation Summit-3) in February 2005 in Brussels. This topic was identified as the case exercise for GEOSS (Global Earth Observation System of Systems). The Terms of Reference for the Working Group are to facilitate the coordination of international programmes on disaster prevention and mitigation, develop a multi-hazard multi-purpose approach to early warning and crisis management, promote the interoperability and compatibility of warning and mitigation systems through the development of standards and protocols, facilitate the development of high-level commitments to warning and mitigation systems, and support and help ensure durability of capacity building related to infrastructure and people training and education in all countries. Meeting in Perth, Geneva, Rome, and Paris in the year since its formation, the Working Group has determined which tasks are being addressed by existing efforts and which require GEO action. Regional meetings for the Indian Ocean, Mediterranean, and northeastern Atlantic including Europe have been held. A hazard map exists for the Mediterranean Sea but it is not yet at a sufficiently high resolution to determine local hazards and has not yet been combined with population densities to produce a risk map. This serves as an example of what must be done in the coastal regions of the world. To generate such a hazard map, bathymetric data from 20 to 30 meters depth to the shore and coastal topography inland must be obtained, across political borders where required. Seismic detection already well implemented in parts of the world must be integrated in real time through data networks to earthquake centers at high-bandwidth. Interchange of data requires communications standards that are still to be defined in some parts of the seismic data network. The set of seven deep-sea pressure sensors, six of which are installed in the Pacific, are being increased in number to 39 over the next three years to extend coverage to the Caribbean, South Pacific and Atlantic. These detect the passage of a tsunami and acoustically relay the pressure deviation information to a nearby surface buoy where it is telemetered to a satellite for relay to the International Tsunami Information Center (ITIC). From the ITIC, alerts will be distributed to member nations' tsunami centers by a system yet to be defined. Presently warnings for the Indian Ocean are distributed by NOAA's Pacific Tsunami Warning Center and the Japanese Meteorological Agency. The local distribution of alerts is complex and no single scheme has been adopted or is appropriate. In the U.S., Emergency Alert System (EAS) warnings go to radio and TV stations and to NOAA Weather Radio. Acoustic sirens, telephones and other systems are also used as warnings. Possibilities for using the GPS Satellite Based Augmentation System (SBAS) navigational correction system from unused channel capacity on geosynchronous satellites is an attractive possibility. Even automatic triggering of alarms on cell phones is possible, offering a system that is widespread in those parts of the world that have limited ground line connectivity and a use that in receive mode does not even require that cell towers remain standing and powered. GEO, as a ministerial body, recommends to the nations represented that systems be adopted and standards accepted. GEO seeks to coordinate warning and mitigation efforts across nations, institutions, and agencies within nations.**

I. INTRODUCTION

The December 26, 2004 Sumatran tsunami disaster illustrated in Fig.1 focused world attention on natural disasters and catastrophe warning systems. Thus, it was appropriate for the Group on Earth Observation to select as a working group focus, tsunamis. In particular, the charge to this group was to consider ongoing tsunami activity by member nations of GEO and identify gaps where efforts should be directed [1]. Selection of tsunamis for such a natural hazard focus was thus somewhat opportunistic. However natural disasters in the succeeding year from tornados, hurricanes, and earthquakes kept public attention on the problem of response by governments to events that are severely damaging and unpredictable with respect to timing and location although they are certain to occur somewhere sometime. After four Tsunami Activity meetings there is consideration of a broadened charter to cover multi-hazards including but not limited to tsunamis. In any case, many elements of the Tsunami Activities discussions are relevant to multi-hazard multi-purpose warnings and crisis management. It is worth noting that the terms of reference to the WG on Tsunami Activities do not mention tsunamis.

II. NATURAL HAZARDS

A. Scale of Disasters

Among the class of natural disasters are those that are extremely destructive to life and society but extremely rare. Asteroid impact would be an end member in this class. Major meteoric impact events have had profound influence on life on earth but the interval between such events is on the order of 100 million years. In addition, despite fictional treatments of asteroid deflection from earth impact path, there is at present no preventative scheme for such an event. While major meteoric impact on earth is almost certain over the next billion years, it is extremely unlikely over the next decade. This topic might receive attention within this century but it isn't the most pressing topic now. On a somewhat lesser scale but still very rare, occurring perhaps every million years, is the super volcano. An eruption such as that of Yellowstone in the U.S. half a million years ago would essentially destroy the United States and there are half a dozen such super volcanoes on the earth. Little is known of super volcanoes since none has erupted in recorded history.

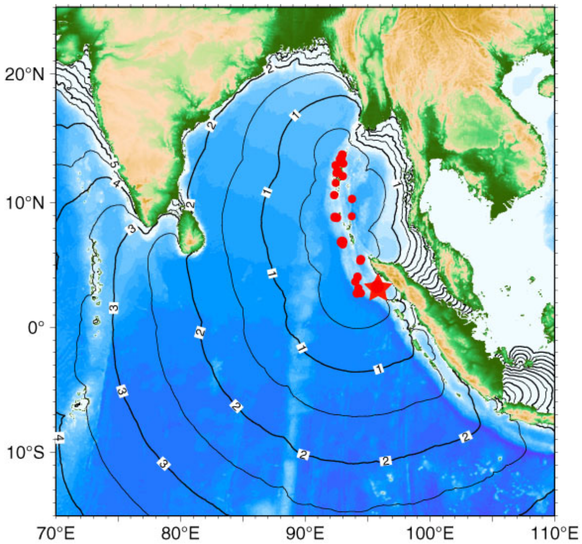

Fig. 1. December 26, 2004 Sumatran tsunami. Heavy lines are whole hour tsunami arrival times after the earthquake. The tsunami arrived at Banda Aceh in less than 20 minutes while it arrived at Sri Lanka two hours after the earthquake. From National Institute of Advanced Industrial Science and Technology.

At the other end of the disaster scale are common events that are only moderately destructive to life and society. Extreme tornados, major hurricanes, and strong earthquakes fall into this end of the scale. Again, these are certain to occur with significant destruction several times a year but the exact time and location are unknown. In the case of hurricanes and tornados there is some warning, less for earthquakes. Moderate volcanoes have greater warning and their location is well known but exact time of event and extent of destruction is largely unknown prior to the event.

Tsunamis fall in the middle of the class of disasters in both the spatial and temporal sense. Because they are the result of an earthquake, landslide, or volcanic event, tsunamis are thus not a prime event themselves. Their destructive consequence is largely due to flooding although wave impact is responsible for destruction as well. The disaster scale of natural events is schematically represented in Fig. 2.

Selection of tsunamis for the focus of the GEO working group puts a range of problems into consideration since the process is not a single cause. Yet many aspects of other natural hazards are associated with tsunamis and their consideration can help anticipate problems from tornados, hurricanes, earthquakes, and moderate volcanoes although probably not super volcanoes or asteroid impacts.

B. Earthquakes and Tsunamis

Primary destruction from earthquakes is collapse of buildings from ground shaking. Brittle building materials break and fall and even plastic materials may be deformed and fail. Fires result from electrical wiring and building failures and from broken liquid fuel and gas lines compounded by failure of water mains that might be needed to fight fires.

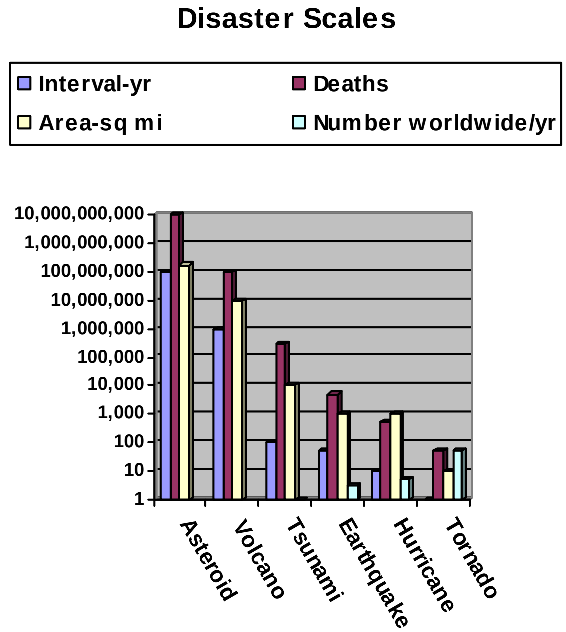

Fig. 2. Disaster scales from massively destructive to life on earth but extremely infrequent to common with modest loss of life and impact on a confined area. Each disaster is of the largest scale for the type and is based on experience over geologic time. The interval is the period between repeated events at an affected region. Deaths are for a single event of the largest magnitude. Area is that within which the disaster for a single event is great. For lesser disasters, the number of events worldwide per year is plotted.

Geological stress in subducting plates or shearing plate boundaries or from tensile stress in plate centers or spreading centers where plates are formed are some of the sources of earthquakes. When the stress causes fracture and abrupt differential movement of the two sides of the fracture, sudden movement is the earthquake. Pressure waves (P) are propagated through the rock at the speed of sound in the rock, on the order of 5 km/s while shear waves (S) (propagating as a bending type of wave) travel at much slower speeds, on the order of 1 km/s. Destructive shaking of the ground occurs when the slower S waves arrive. Both waves can be felt and detected by seismometers. At a distance of 40 km there would be a 10 second delay between the arrival of the P wave and the S wave but this relatively short interval is sufficient for a response to a major earthquake in an affected city. This response could be the closing of valves in gas mains and the opening of electric power grid circuit breakers. This will do nothing to prevent the collapse of buildings and damage from falling masonry, but it may reduce the risk of an ensuing fire. Table I summarizes the events of an earthquake including those that may lead to a tsunami.

If the earthquake is offshore, the motion of the seafloor is likely to generate a tsunami or very long wavelength ocean gravity wave. This wave may be initiated by a sudden change in water depth by as little as 10 cm or, as in the case of the December 26, 2004 Sumatran tsunami, by a change in depth by as much as 15 meters. Not all earthquakes under the sea generate tsunamis. Some vertical shift in seafloor must occur for a tsunami to be generated and not all earthquakes produce a significant vertical movement. However, when a vertical shift elevates the sea surface over a significant distance (several times the water depth at a minimum), a tsunami wave will propagate in all directions from the source. In many instances, the fault that fails and causes the seafloor to shift is a linear feature and the elevated surface of the water is in a line above the fault. In this case, the direction of wave propagation will be normal to this line in both directions. Energy attenuation as a function of spreading distance from a line source is negligible.

Table I

	1st effect	2nd effect	3rd effect	4th effect
Earthquake	**Displacement**	**Shaking**	**Building failure**	**Fire**
Displacement	**Tsunami**	**Landslide**	**Tsunami**	
Tsunami	**Wave damage**	**Flooding**		

Because the wavelength of the wave is several times the water depth or more, the wave propagates with the speed of a wave in shallow water, even if the depth of the ocean is many thousand meters. The speed of a shallow-water wave is $C = \sqrt{(gd)}$ where C is the speed of the wave, g is the acceleration of gravity, and d is the depth of the water. C is about 200 m/s (450 mph) in 4000 m depth. A source region for a tsunami that is 100 km offshore in a depth of 4000 m will give an earthquake warning about 8 minutes before the tsunami reaches shallow water. If there is an extensive continental shelf, a greater delay will ensue. Twenty kilometers of 200 meter depth will add 7.5 minutes to the warning. This then is one of the targets of a tsunami warning program, the approximately 10 minutes between the earthquake signal, shaking of buildings and in some cases, general destruction of masonry structure, and the arrival of the tsunami wave. The good news is that the signal is unmistakable; the bad news is that the time to respond by going to high ground is very short. This warning is only possible if the earthquake fault is at least 100 km offshore. If the fault is closer, the warning time is less. On the other hand, with less depth, the propagation speed is less and the time for response is not as short as the distance might suggest. A source 40 km offshore with 20 km of 4000 m depth, 10 km of 200 m depth, and 10 km of 100 m depth, for example, will give about 10 minutes warning, approximately the situation for the Cascadia fault off Oregon, northern California, and Washington.

Distant earthquakes may engender a tsunami but not have easily detectable shaking to serve as a warning. This was the case for the Sumatran tsunami for regions outside Sumatra. The earthquake was not felt by residents of Sri Lanka thus they did not have any warning of the tsunami headed their way. On the other hand, there are several earthquakes a year in the Indian Ocean that do not cause a significant tsunami. So in this case, the presence of an earthquake alone is not sufficient reason to respond to a tsunami threat. More information is needed; information such as the magnitude of the earthquake, the nature of its displacement, and the strike of the fault that slipped. In fact, of even greater utility for a distant earthquake would be knowledge of the size and direction of the tsunami over the deep ocean. This requires a sensor system with telemetry, the Deep-ocean Assessment and Reporting of Tsunamis (DART) system of NOAA serving as the prototype [2] Fig. 3.

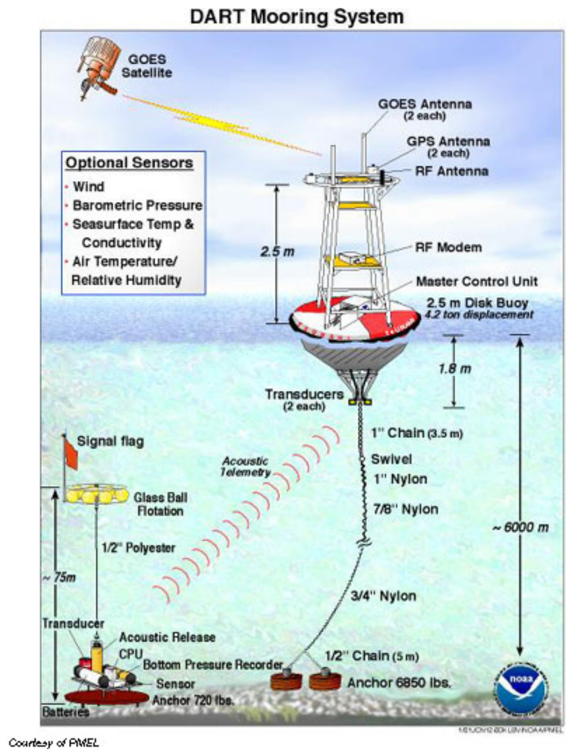

Fig. 3. Deep-ocean Assessment and Reporting of Tsunamis (DART). Pressure sensor on the bottom acoustically telemeters events to the surface. The surface buoy receives the acoustic telemetry and transmits the data to the GOES satellite for relay to the International Tsunami Information Center.

Thus there are two kinds of response to an earthquake engendered tsunami, depending on how distant the fault is from the shore at risk. If the earthquake is significantly less than 100 km away, the earthquake itself must serve as the warning and the response must be to get to high ground within 10 minutes. If the earthquake is significantly more than 100 km away there may be additional information from deep-sea sensors that can be used to inform the residents of the shore about the risk from this particular event. In this case, the earthquake itself may not be felt by the populace so other forms of warnings must be used to cause evacuations of shore areas.

C. Landslides and Tsunamis

Displacement of a large volume of water by a landslide can also cause a tsunami and locally, such a landslide can produce a very high wave. The volcanic eruption of Mount St. Helens in 1980 resulted in a landslide into Spirit Lake with a 250 meter tsunami at the far end of the lake. A tsunami cleared trees to a height of 524 m in Lituya Bay, Alaska, from a landslide at the head of the fjord in 1958. The Baltic had a tsunami associated with the second Storegga landslide 8400 BP [3] or possibly with a meteoric impact in southwestern Estonia [4]. [Enclosed seas or lakes can support seiches that follow the same shallow water wave propagation dynamics as tsunamis and the Baltic experiences these. In November 2005, while attending the 2nd Tsunami Activity meeting in Geneva, I mused that the choice of city guaranteed our meeting to be tsunami free but it was explained that Geneva had experienced a 'tsunami' in 1700, giving rise to the understanding of seiches and to their naming. The source of the Geneva tsunami/seiche may have been wind or a landslide, I was not told.] Although each of these landslides affected an enclosed body of water of modest size, there is the threat of the slump of the volcanic debris shield of Tenerife Island in the Canary Islands that would cause a major tsunami to strike western European shores and the east coast of North America with an estimated tsunami height of 50 meters and 30 meters, respectively. Such an event is probably inevitable over the next 10,000 years but unlikely in the next decade. Still, it may be the kind of tsunami that can be defended against since the source is distant from the affected areas, not counting the Canaries themselves. The U.S. plan to increase the number of DART sensors to 39 will include Atlantic Ocean detectors that would calculate and transmit the magnitude of such a tsunami several hours before landfall. Earthquake, pile up of volcanic debris, water logging of soil, or volcanic blowout can stimulate such a landslide as indicated in Table II.

Table II

	1st effect	2nd effect
Earthquake	**Shaking**	**Landslide**
Landslide	**Displacement of water**	**Tsunami**
Tsunami	**Wave damage**	**Flooding**

D. Volcanoes and Tsunamis

Volcanic eruptions could cause a tsunami from landslides or from an explosion. The classic explosive eruption of Santorini in the Greek Islands in prehistoric times is postulated to have caused a tsunami that decimated civilization in Crete. On Kohala volcano in Hawaii, tsunami deposits have been found as high as 400 meters from a collapse of neighboring Mauna Loa volcano. And the instability of Cumbre Vieja volcano on La Palma in the Canaries is of concern since its eruption in 1949 created faulting that is feared will lead to landslide and tsunami. In volcanic cases, there is warning in the form of activity leading up to explosion or collapse weeks before the event although the exact nature of the event is rarely determined in advance. Truly giant calderas in geologic times present catastrophic warnings in themselves; Yellowstone Park in the U.S. is such a giant caldera thought to have a possible repeat performance in the next million years. This will not produce a tsunami outside of Yellowstone Lake but other giant calderas associated with seafloor and island volcanoes would do so. This is of some concern in the Mediterranean Sea. Table III indicates events from a volcano that could produce a tsunami.

Table III

	1st effect	2nd effect	3rd effect
Volcano	**Blast or displacement**	**Production of loose material**	**Landslide of loose material**
Blast	**Sudden expansion**	**Tsunami**	
Landslide	**Displacement**	**Tsunami**	
Tsunami	**Wave damage**	**Flooding**	

The Baltic is volcano free and not threatened with earthquake activity of the kind that would cause a tsunami from seafloor uplift. But the Baltic may share with more tsunami prone regions a need for the infrastructure that allows warnings of catastrophe from whatever source to be delivered

III. WARNINGS

A. Three Kinds of Event Warning

The first kind of event warning is from a distant earthquake with enough distance and time to sense the tsunami amplitude and transmit the risk to affected shores. These tsunami observations combined with seismic data and analyzed at ITIC are distributed to national tsunami centers. For the U.S. the center is the Pacific Tsunami Warning Center and for the moment this center and the Japanese Meteorological Agency perform this service for the Indian Ocean. When the warnings have been received by the local disaster centers, local warning networks are brought into play. This scenario requires cooperation on an international scale to share data, analyze multi-nationally sensed signals, and issue warnings across national borders. Locally, there remains the problem of formatting warnings in a way that is effective.

To project hazard across national borders requires information about wave focusing and run-up estimates when the shoaling tsunami reaches shore. GEO has recommended that bathymetric profiles be released or acquired as needed for such modeling and inshore topography be acquired as well to turn tsunami risk assessment into hazard maps. Sovereignty and military vulnerability issues oppose these requests and remain a point of negotiation. The problem is illustrated schematically in Fig. 4. If national interests prevent the acquisition of data needed to assess risk, an alternative would be for each nation to retain its own bathymetric and topographic data and the modeling be done within each nation using the open data from the sensors as required. However, it is the role of GEO to facilitate the acquisition of these data in a form that is of sufficient resolution, accuracy and user accessibility for the purpose of risk assessment.

The second kind of event warning has been developed in Japan. Japan is tectonically active with frequent earthquakes and less frequent but occasional volcanic eruptions, explosions, and collapses. Some of the earthquakes originate offshore near the eastern coast of the islands. The distance is too short for tsunami detection but the danger of tsunami is often substantial.

The earthquake is sometimes felt directly by the populace ashore but the probability that a tsunami will strike is unknown. The Japanese Meteorological Agency pinpoints the location and magnitude of the earthquake within two minutes and is able to estimate the risk to locations along the shore in five minutes based upon precomputed maps of impact for each grid location for an earthquake offshore. When the location is determined from the seismic network, the appropriate map is selected. When the magnitude of the earthquake is determined from the seismic data, the amplitude of the tsunami can be predicted. This then leads to a warning to evacuate if required. There is no time to qualify the warning based upon tsunami height sensing since the distance is too short for a wave to encounter a sensor and the time is too short to collect the data, analyze it, vet it, and report it before the wave reaches shore. A practical mitigation for such short warning to the populace is illustrated in Fig. 5.

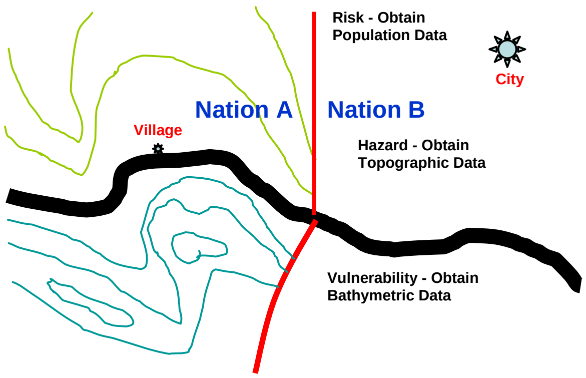

Fig. 4. Tsunami Activity Working Group goals for assessing vulnerability, hazard, and risk data across political boundaries requires GEO action at high-level.

Fig. 5. Practical tsunami mitigation from Japan to permit the populace to climb to the roof of the buildings in case of warning for a nearby source of tsunami [5].

The third kind of event warning is for tsunami-generating earthquakes to occur so close to shore that there is no time for any measurement, analysis, or civil authority alert. In these cases, the shaking of the earthquake itself is the warning and the response must be instinctive. The Cascadia fault off the coast of Oregon extending north to Washington and south to northern California is such a system. There will be about 10 minutes from the uplift at the fault until the tsunami reaches shore with an anticipated height of 30 meters. In coastal towns in Oregon, evacuation routes are printed in the local telephone directories and the streets are posted as tsunami evacuation routes [6] It is necessary that the populace be trained to respond instinctively to felt earthquakes in these towns. The equivalent of fire drills is necessary to minimize loss of life when the inevitable but unknown tsunami happens. It is noteworthy that the people of the Andaman Islands, directly in the path of the Sumatran tsunami of 2004, escaped with minor casualties because their instinct was to go inland with the first suggestion of a tsunami.

B. Distant Tsunami Detection

The DART system has been installed in the North Pacific by NOAA to prevent false tsunami alerts to Hawaii and the Pacific Northwest of the US mainland when earthquakes in Alaska threaten these regions with tsunamis. The location of the sensors is seaward of the Cascadia fault so that they will sense tsunamis generated by an earthquake on that fault in time to alert Hawaii and Alaska. There is one sensor in deep water near Oahu, Hawaii. The extension of this array approved by the U.S. Senate Appropriations Committee in 2005 will add DART systems in the Atlantic, Caribbean, and South Pacific by 2008.

In DART, a Paros Digiquartz pressure sensor is deployed on a fixed bottom platform with sufficient power to operate for two years. This sensor has great stability and even in 6000 meters depth can resolve pressure fluctuations due to a change of 10 mm of water depth. Surface gravity waves from wind are attenuated by water depth and are not detected but tidal signals and low frequency barotropic eddies are resolved. A tsunami-caused change in elevation is high-frequency compared to these signals so an algorithm is used to detect pressure fluctuations outside those predicted from the tidal and other pressure signals [7]. Measurements are made continuously but the analysis of deviations from the expected signal is made every 10 minutes. If such a deviation is detected, an alarm signal is sent and 5 minute updates are sent for the following four hours. This is illustrated in Fig. 6.

The means of sending such an alarm and such data is an acoustic telemetry modem (ATM) from the bottom pressure sensing package to a nearby moored surface buoy with ATM receiver and satellite radio transmitter. GOES (Geosynchronous Operational Environmental Satellite) is the satellite system currently used. Satellite signals are received at the ITIC in Hawaii. Seismic data are also collected at this and local centers. The original tsunami alert is based upon seismic signals but the warning and eventual evacuation decision for shore-distant sources is not made until the tsunami is confirmed by the DART signals. The economic justification in the U.S. for development and installation of DART was the cost of false tsunami evacuations and the financial savings of eliminating them.

The DART buoys are serviced yearly with six surface buoys inspected and moorings replaced and the bottom stations replaced every other year unless in need of service sooner. The seventh DART is swapped with the station to be replaced and that recovered station is refurbished on the way to the next station.

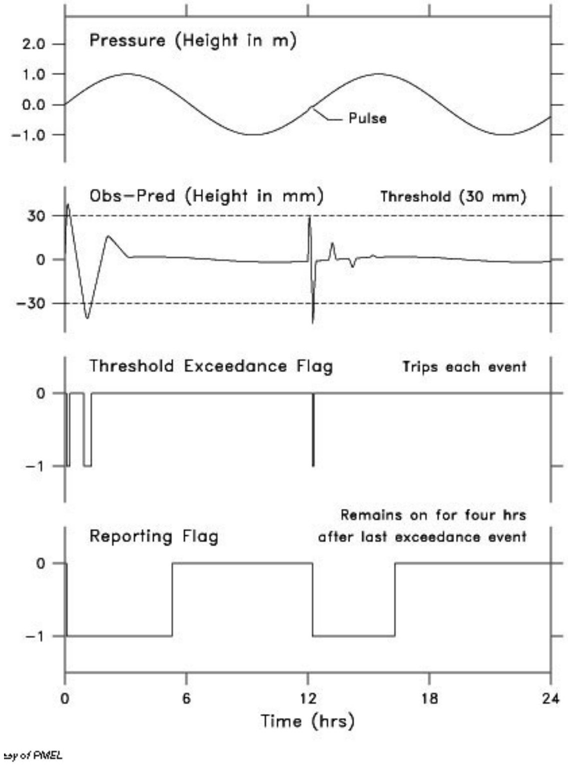

Fig. 6. Mofjeld detection algorithm for tsunami superimposed on tidal signal. Third order polynomial fit to previous three hours is projected 5.25 minutes for differencing with the observed pressure signal. Exceedance of the difference by 30 mm triggers an event for four hours. Original deployment transient resets in 4 or 5 hours.

C. Satellite Transmission of Warnings

The European Space Agency has proposed using EGNOS (European Global Navigation Overlay System) to broadcast disaster messages [8]. This system, named ALIVE (Alert Interface via EGNOS) would use a small portion of the unused bandwidth of EGNOS and would be compatible with GPS receivers worldwide since the corrections to GPS are transmitted by EGNOS in Europe, by WAAS (Wide Area Augmentation System) in the U.S., and by MSAS (Multifunction Satellite Augmentation System) in Japan and each is compatible with the other. The name for these three systems (and less advanced systems in other countries) is SBAS (Satellite Based Augmentation System) which contains correction information to improve accuracy of GPS observations. The messages are transmitted by geosynchronous satellites with global coverage except for the poles (less than 64° latitude). SBAS is designed to enhance safety of life through improved navigation and the additional job of transmitting disaster alerts is within the guidelines. Since the receivers exist and are in use in all countries, the implementation of a warning system can be rapid, estimated at two years. An added benefit of using this GPS related system is that the receivers already have position information allowing polled warnings for specific regions.

Cell phones are now equipped with GPS receivers to implement emergency response to 911 (US) and other distress calls. The receivers for GPS can also receive EGNOS, WAAS, and MSAS signals so it is possible to provide cell phone based warnings of disaster. Since the source of the signals is satellite, even failure of the power grid and the land based infrastructure of cell towers does not shut down this alert capability. This puts potential warning systems into the hands of much of the world population, not restricted to well-wired first world countries. The possible system is indicated schematically in Figure 7.

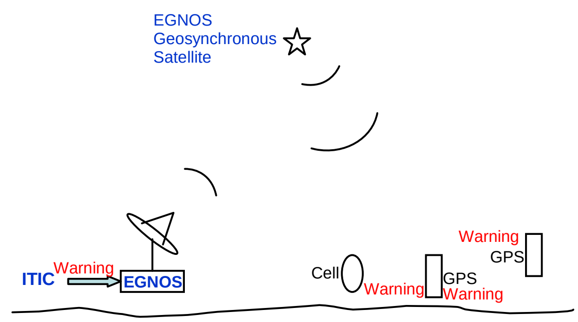

Fig. 7. ALIVE system for disaster prevention and mitigation. Warning is transmitted from ITIC and downloaded to geosynchronous satellite where it is transmitted as part of the SBAS (EGNOS, WAAS, or MSAS) GPS correction message. This message is received by GPS receivers and by cell phones equipped with GPS receivers (911 enabled).

IV. GEO

In 2005, GEO (Group on Earth Observation) formed the Working Group on Tsunami Activities to act as a catalyzer for ongoing or planned activities related to tsunami hazards and warnings. Since there are other groups addressing tsunami hazards and warnings as well, the GEO appointed group is tasked with identifying gaps, accelerating the process, and setting deadlines for completing tasks. IOC (International Oceanographic Commission) is similarly engaged in tsunami activities as a part of their “Hazard Assessment” and their “Preparedness and Awareness” activities. In addition IOC has experience in developing warning systems (e.g. IOTWS (Indian Ocean Tsunami Warning System)) and WMO (World Meteorology Organization) has experience in facilitating data exchange and developing and upgrading telecommunication systems. IOC has or will form its own Working Group on Tsunami Warning within a Multi-Risk Approach. The GEO Working Group on Tsunami Activities is collaborating with IOC. The GEO group integrates with existing national and organizational efforts such as, IOC, ISDR (International

Strategy for Disaster Reduction), NOAA, and USGS, and is tasked with integrating on the longer term with GEOSS. GEO is able to provide the political clout to develop ministerial commitment to tsunami activities. Fig. 8 schematically represents these relationships.

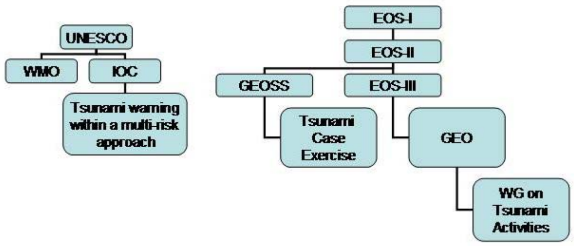

Fig. 8. EOS-I (Earth Observation Summit-I) introduced GEO (Group on Earth Observation) which was confirmed by EOS-III. GEO formed WG on Tsunami Activities. GEOSS was formed by EOS-II and selected Tsunamis as a case study. IOC (Intergovernmental Oceanographic Commission) has or will form a working group on Tsunami warning within a multi-risk approach.

Tsunami activities are to be cast in a multi-hazard multi-purpose perspective. Although 2005 was an opportunity for promoting these goals in the guise of tsunami activities, the task is broader than a single threat. Users are to be involved including their generation of bathymetric maps that are accessible in a user-friendly format, at appropriate resolution and accuracy. Capacity building is a target as well since tsunami warning systems will require long term (perpetual) staffing. The transition from research to operations is essential.

Capacity building with people training and education is an important part of the mitigation process. Culture is possibly the best protection against disasters such as tsunamis when warnings have been issued.

"Local communities have extensive training allowing them to respond automatically to tsunami warnings. Tsunami awareness is such an intrinsic part of Japanese culture that after a high level tsunami warning the majority of the at-risk population, even if asleep, have evacuated to safe ground within five minutes!" [5].

V. CONCLUSION

The GEO Working Group on Tsunami Activities addresses an important member of the class of disasters, one that is manageable with technology available now and with a high benefit to cost ratio. Tsunamis are one of several disasters that require warning systems and networks of sensors, including tornados, earthquakes and hurricanes, and the tsunami activities group will contribute to these multi-hazard multi-purpose systems in part through the political influence of GEO.

Standards for communication of data and warnings are needed and channels of warnings are required. These are being addressed through meetings at intervals of several months and by collaboration with sister working groups in IOC and in national labs and organizations around the world.

ACKNOWLEDGMENT

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