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IOC/INF-1126
Paris, 15 June 1999
English only

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
(of UNESCO)

DRAFT PROJECT PROPOSAL

Intra-Americas Sea Tsunami Warning System Education, Warning, Management and Research

A Project Proposal Submitted to the
Intergovernmental Oceanographic Commission of UNESCO

by the

IOCARIBE Tsunami Steering Group of Experts
Sub-Commission for the Caribbean and Adjacent Regions

SC-99/CONF.212/CLD.18

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PROJECT PROPOSAL

INTRA-AMERICAS SEA TSUNAMI WARNING SYSTEM EDUCATION, WARNING, MANAGEMENT AND RESEARCH

EXECUTIVE SUMMARY

At a series of IOC-sponsored workshops (Martinique, 1993; Barbados, 1994 and 1995; St. John, USVI, 1996; Puerto Rico, 1997; Costa Rica, 1999) the case has been made for significant tsunami hazards in the Intra-Americas Sea (Gulf of Mexico, Caribbean Sea, Bahamas, Straits of Florida, Bermuda, and Guianas). In the IOC Circular Letter N°. 1579 (20 July 1998) the Executive Secretary IOC drew attention of the governments of Member States of IOCARIBE to a significant tsunami risk and called upon them to take prompt attention to start taking this problem seriously. For example, since the great 1867 US Virgin Islands earthquake and 6 meter-high tsunami, the population density of the region has increased 10-fold, infrastructure development has progressed without a notable natural hazards component, and governments seem to be oblivious to the risk. Accordingly, four essentials comprise the proposed Intra-Americas Sea Tsunami Warning System: Education, Warning, Management and Research.

The first order of business is to better educate the populace through public information, K-12 student indoctrination, video and other multi-media products, workshops, training courses and popular press articles. The warning component should capitalize on the GLOSS sea-level/weather network, on existing seismic and meteorological reporting and warning systems, on Internet connectivity, and on active participation with the ICG/ITSU (International Co-ordination Group for the Tsunami Warning System in the Pacific). Management issues include: integration with other natural hazards warning systems; exploration for funds; local warning and evacuation; search and rescue; fire suppression; emergency medical services; damage assessment; inter- and intra-governmental co-ordination; and, damage and hazard analysis. Research needs are: improved resolution bottom relief data; travel time maps for population centers; earthquake magnitude/depth thresholds; tsunami wave arrival amplitude estimation; potential for Kick'em Jenny and/or land volcano eruption; tsunami and earthquake history improvements; fault locations, activity, and tsunamigenic mechanisms; inundation maps; VLBI and GPS stations for crustal motion monitoring; and loss estimation studies, mitigation and adaptation amongst others.

Logistically, the Intra-Americas Sea Tsunami Warning System center requires a protected site that integrates a seismic subsystem, a sea-level subsystem, and a communications subsystem, all in an operational mode taking into consideration the Pacific Tsunami Warning Center experience. These three subsystems need to be collocated and coupled with 24 hour-a-day authority to issue alarm conditions of "tsunami watch" and "tsunami warning". Internet-based technology is expected to be the most efficient mode of ensuring maximum access and reliability to all partners. The regional management activity must include, at a minimum, an annual Intra-Americas Sea Tsunami Conference. Research is issue-based and includes topics in science, engineering, and management. The educational component should be organized with the advice of the International Tsunami Information Center, with due regard to the socio-economic customs of the region. Funding must be stable and shared by governmental, inter-governmental, and non-governmental organizations alike; a sense of joint responsibility and ownership must mold the commitment process.

1. INTRODUCTION

Tsunami events have been recorded in the Intra-Americas Sea (IAS) since the 16th century (Lander *et al.,* 1999). These events are both local in origin and from distant sources, but occur at the rate of one or more severe occurrences per century (e.g., Venezuela, 1530; Jamaica, 1692; Martinique, 1755; St. Thomas, 1867; Puerto Rico, 1918; Dominican Republic, 1946, etc.). The great Lisbon earthquake of 1755, for example, created a teletsunami with 6 and 7 meter-high waves in the Lesser Antilles; its affect on then lesser-populated areas such as the eastern Bahamas, Florida, and Bermuda is unknown. So counter to the common perception (Gonzalez, 1999), the Atlantic Ocean, as well as the Pacific Ocean is subject to these destructive sea waves.

In the last 150 years, tsunamis have been the cause of more deaths in the IAS (up to 2,000) than in Alaska (121), Hawaii (275), or the US West Coast (18). Although there have been deadly tsunamis in the Intra-Americas Sea this century (1918: 42 persons; 1946: 1,790 persons by some recent reports; Lander *et al.,* 1999), it is the event of 1867 in the US Virgin Islands (Watlington and Lincoln, 1997), that is reminiscent of the 1998 occurrence in Papua-New Guinea: juxtaposed earthquake epicenter; large instantaneous tsunami; travel-time in minutes; dense coastal population centers. Imagine today the same 6-meter-high tsunami wave observed in 1867 entering St. Thomas' Charlotte Amalie and simultaneously the 7 to 9-meter wave entering St. Croix's Christiansted harbor without warning! The tenfold increase in population density, the cruise ships, petroleum carriers, harbor infrastructure, hotels and beach-goers, would all be at immediate risk, setting up a catastrophe of unimaginable proportions.

The Caribbean Plate boundary is marked by active sub-aerial and submarine volcanoes, steep underwater slopes, and by numerous earthquakes. Certain submarine earthquakes, volcanic eruptions, or sub-aerial and submarine landslides can generate a tsunami. In the central Lesser Antilles, there have been several major volcanic sector collapses in the last 10-20 thousand years, and these are potentially very efficient tsunami generating events. To minimize "false alarms" it must be determined whether a seismic event creates a wave in the juxtaposed ocean. Seismic sea wave detection therefore requires both seismic and sea-level observations, integrated into a real-time, operational telecommunications network. Some local IAS tsunamis, if detected by such an operational network, could easily provide 15 minutes of forewarning to many coastal site residents in the Caribbean Sea, Bahamas, Bermuda, and the eastern USA including the Gulf of Mexico.

2. BACKGROUND

The Intergovernmental Oceanographic Commission (IOC) is the competent international organization for marine scientific research of the United Nations. Within the IOC are seven regional bodies, one of which is the Sub-Commission for the Caribbean and Adjacent Regions, or IOCARIBE. IOCARIBE is responsible for programmatic development for the Caribbean Sea and Adjacent Regions, and has its office in Cartagena, Colombia.

IOCARIBE has several programmes that it attempts to develop through co-operation with Member States including: Ocean Science in relation to Living Resources; Ocean Science in relation to Non-Living Resources; Ocean Processes and Climate; Training, Education and Mutual Assistance; and Regional-GLOSS, a component of the Global Sea Level Observing System (GLOSS), amongst others. The issue of an IAS tsunami is a concern of the IOCARIBE Group of

Experts on Ocean Processes and Climate, which is oriented towards physical oceanography and marine meteorology, and which has cross-cutting interests through several of these programmes.

IOC, with the assistance of the United Nations Environment Programme, proposed and conducted a Workshop on Small Island Oceanography in relation to Sustainable Economic Development and Coastal Area Management (IOC, 1993) in direct response to the needs of Small Island Developing States. The meeting was hosted by the Government of France in Martinique. One of the numerous issues discussed in Martinique (Maul, *et al.,* 1996) was that of tsunami hazards. Many Small Island Developing States are located in the tropical waters of the Pacific and Indian Oceans, and are notably vulnerable to tsunami. It was noted too that the IAS, and the Caribbean Sea in particular, is a seismically active region, and has a history of tsunami caused by earthquakes and volcanoes.

At SC-IOCARIBE-V, the Fifth Session of the IOC Sub-Commission for the Caribbean and Adjacent Regions (IOC, 1995b), the recommendation of the IOCARIBE Group of Experts on Ocean Processes and Climate to hold a Caribbean Tsunami Workshop was adopted. The Eastern Caribbean Center of the University of the Virgin Islands hosted the two-day workshop in 1996 on St. John, at the request of IOCARIBE, which was attended by some 17 scientists. The attendees made it very clear (IOC, 1996) that the IAS has a record of significant tsunami-caused deaths and is at substantial risk for others (Smith and Shepherd, 1994).

The St. John scientific meeting led to the 1997 workshop at the University of Puerto Rico (Mercado, 1997). At Mayaguez, there were in attendance approximately 150 concerned citizens of the region, civil defense and government officials, scientists, and tsunami warning experts, both local and from abroad. The Mayaguez meeting emphasized broader issues including education, warning, management, as well as research (Mercado and McCann, 1998; McCann, 1998; IOC Circular Letter N°. 1579, 1998; Gusiakov, 1999; Mofjeld *et al.*, 1999; Maul, 1999; Lander *et al.,* 1999).

In 1999, the proposal to establish an IAS Tsunami Warning System was encouraged by the officers of the International Co-ordination Group for the Tsunami Warning System in the Pacific during their inter-sessional meeting in Hawaii (IOC, 1999a). Later in April 1999 in conjunction with SC-IOCARIBE-VI, the IOCARIBE Tsunami Steering Group of Experts gathered in San Jose, Costa Rica to draft this proposal. The chairman wrote final proposal details with input from interested parties including the IOC Secretariat, the Pacific Tsunami Warning Center, and the International Tsunami Information Center.

All attendees at the June 1997 meeting in Puerto Rico were requested to contact their heads-of-state with a statement of concern. In July 1997, USA President Clinton was formally informed of recommendations made at the Mayaguez workshop. It focused on four mitigation measures: education, warning, management, and research (Maul, 1999; Annex I). The President was reminded in a second letter immediately following the Papua-New Guinea tsunami of July 1998. In 1999, the Florida Delegation to the US Senate and the Representative of the 15th Congressional District were formally requested to add a budget item for the IAS Tsunami Warning System. It is important to note that the US Federal "Tsunami Hazard Mitigation Implementation Plan" (April 1996) has no Atlantic component.

3. SYSTEM COMPONENTS

There are several elements of a tsunami warning system including the seismic network, the sea-level network, the communications network, and the decision management organization. While the ICG/ITSU is experienced in all of these matters, the IOCARIBE Group of Experts on Ocean Processes and Climate (GE/OPC) and Regional GLOSS (Global Sea Level Observing System of GOOS) can best focus on the real-time sea-level network and accept the advice of the Pacific Tsunami Warning Center for the other details. This has been the design of an Intra-Americas Sea warning programme from the outset (IOC, 1996), and the IOCARIBE Tsunami Steering Group of Experts has included experts from other regions.

3.1 SEISMIC SUBSYSTEM

The IAS has several seismic reporting systems in place, as well as being contributors to larger systems of hemispheric and global scale. The Seismic Research Unit at the University of the West Indies has been in operation since 1952, and since 1998, the Puerto Rico Seismic Network operates the data center for the Middle-America Seismograph Consortium (MIDAS). A protocol has been established for the participating seismic networks of the Caribbean, North America, Central America and South America to submit in near real-time data on significant events in the region. This issue has already been widely discussed at the two Caribbean tsunami workshops already held (St. John, USVI (IOC, 1996), and the Mayaguez UPR Workshop in 1997 (Mercado, 1997; Maul, 1999)), in the Peru 1997 meeting of the ICG/ITSU XVI, and the Hawaii 1999 meeting of the Officers of ICG/ITSU (IOC, 1999). At several MIDAS meetings, the desirability of having seismic data exchanged in real-time has been discussed for tsunami warning applications.

Other seismic systems, operated by the French in Martinique and Guadeloupe and by the Seismic Research Unit of the University of the West Indies from Saba to Trinidad, have experience in detecting potential tsunamigenic events. The Caribbean Development Bank has funded the Seismic Research Unit to instrument Kick'em Jenny and several sites in nearby islands for detection of volcano-generated tsunamis. The Intra-Americas Sea Tsunami Warning System will capitalize on this parallel effort through co-operation and communication.

Components of the regional seismic network will require upgrading to include broadband seismometers and improved communications. For example, in 1998 FEMA and the University of Puerto Rico funded a project to upgrade the instrumentation of the Puerto Rico Seismic Network. With the nine new telemetering broadband stations, large magnitude events will be recorded without the possibility of the signal going off scale, which will permit the determination of the seismic parameters. The goal is for the network to be capable of notification of a major earthquake within 2 minutes of the initial rupture. This notification will be followed within 3 minutes by detailed seismic parameters that provide an understanding of the likelihood of a tsunami. Once the seismic parameters are calculated the expected tsunami inundation areas can be determined through interpolation of the results from previous simulations. In this way the earthquake and tsunami warning functions can be integrated into a common tsunami warning system.

3.2 SEA-LEVEL SUBSYSTEM

Within the IOCARIBE Regional GLOSS Network, most of the sea-level gauges are mechanical instruments without telemetry capability (IOC, 1999b). The "Caribbean: Planning for Adaptation to Climate Change" (CPACC) programme of the Organization of American States (OAS, 1995) offers the best opportunity to establish a regional tsunami sea-level network because each instrument transmits its data via GOES (Geostationary Operational Environmental Satellite). Technical details of the CPACC tide gauges are described in Martin *et al.* (1996), and a tabulation of the IOCARIBE Regional-GLOSS status as of May 1999 is in IOC (1999b).

Note in IOC (1997, 1999b) the incorporation of GPS (Global Positioning System) and VLBI (Very Long Base-line Interferometry) technology in CPACC. Such measurements will also enhance the tsunami seismic network with direct measurements of tectonic plate motion. In Maul (1993, 1996) the issue of sea-level change and global change is highlighted as it may exacerbate tsunami danger in areas where relative sea-level is rising, and decrease the danger where relative sea-level is falling. It must be emphasized however, that only the CPACC and the USA national sea-level/weather systems are GOES-reporting and GPS-located. With the exception of Colombia and the several Central American countries participating in ICG/ITSU and the Tsunami Warning System in the Pacific, no equivalent systems exist in Atlantic South America, the Netherlands Antilles, Central America, or the Greater Antilles. A second effort on the scale of CPACC will be required to place tsunami-capable sea-level/weather stations in these countries.

A sea-level subsystem that relies on traditional land-based instrumentation is recognized at the outset as inadequate (*q.v.* Gonzalez, 1999). The difficulty remains that not every geological event potentially capable of generating a tsunami actually does so. In the Pacific Ocean, this issue is addressed in part by deep-sea moorings with pressure sensors capable of detecting the tsunami wave in the open sea. A repeat of the teletsunami off Portugal in 1755 will be detected in Europe at least four hours before the wave reaches the Intra-Americas Sea, but for a locally generated event, destruction will in all probability will be the first alarm. The general solution seems to be to equip meteorological buoys with bottom pressure sensors as part of general upgrading in the future.

3.3 COMMUNICATIONS SUBSYSTEM

The primary communications system in this proposal is the Internet. In the last few years, the Internet within the Intra-Americas Sea Region has greatly improved and expanded. Although the CPACC sea-level/weather stations are GOES-linked, present infrastructure suggests that this approach is somewhat over-engineered today. (The system was designed several years ago and there have been substantial Internet improvements in that time). For the purposes of CPACC, GOES is still a viable communications network, but for the IAS Tsunami Warning System, it may prove to be cost-prohibitive. Accordingly, in this proposal, reliance on the Internet is suggested as the most expedient and effective system.

As noted above, the central site where seismic and sea-level data are to converge requires continuous and real-time information. Hard-wired telephone lines to the essential seismometers and sea-level gauges will provide continuous Internet information to a PC-based system. For effective results, the seismic and sea-level information will require full-time professional monitoring. Each of the regional Pacific warning systems have this capability as well as at the central site in Hawaii. While alarms and pagers will form part of the communications system to the critical personnel, a regular tsunami watch and warning system will require at least five full-time employees.

Dissemination of tsunami watch or tsunami warning status to the public should be accomplished using the existing meteorological communication networks and systems like GTS. A concerted effort using such existing facilities will require additional training for the meteorologist, but such a programme has already been developed in the United States. It is proposed to expand that expertise to other weather professionals through the TEMA (training, education, and mutual assistance) programme of the IOC and the equivalent programmes of the World Meteorological Organization. Other international agencies (e.g., United Nations Environment Programme (UNEP); International Maritime Organization (IMO); United Nations Development Programme (UNDP); and NGOs such as the Island Resources Foundation and local universities) must become involved in the communications effort, either at the real-time level or though more traditional channels.

Educational communication will require efforts paralleling the highly successful UPR meeting at Mayaguez in 1997; personal contact every two years seems very desirable and cost effective. Flyers and brochures must be developed with the assistance of the International Tsunami Information Center, and distributed widely particularly to schools, civic organizations and religious institutions. More generic natural hazard brochures should be identified and updated to include tsunami information. Finally, a professionally produced multi-lingual video should be taped and made available for broadcast and duplication (this should be encouraged by a special copyright freedom).

It is anticipated that a general reluctance by certain business, insurance, and political groups will be encountered. Recruiting these persons in the context of thoughtful, non-hysterical, planned contact will be challenging and rewarding. It is essential not to overstate the hazard, yet to be firm and apolitical in such dealings. In this regard, the cultural context of the community must be appreciated and respected. Regular and persistent communication by mail and in person will be required to convince reluctant sectors of the community to refocus their perspectives.

4. MANAGEMENT AND ADMINISTRATION

Philosophically, the IOCARIBE Tsunami Steering Group of Experts (Annex II) argue that it is in the best interest of this tsunami effort to be integrated into an Intra-Americas Sea Natural Hazards System. Many of the hazards affecting the Caribbean Sea, the Gulf of Mexico, Bahamas, Guianas, Bermuda, and southeastern USA are the same. Certainly the sea-level/weather stations of CPACC will prove invaluable to the World Meteorological Organization's efforts in hurricane forecasting, adaptation, and mitigation, for example. They will be part of the Global Ocean Observing System (GOOS) of the Intergovernmental Oceanographic Commission (IOC, 1998). Clearly this is an intergovernmental need, and the IOCARIBE should take a lead in the region (Maul, 1999).

Perhaps the most cost-effective activity, and one that should be undertaken immediately, is that of education. The "factsheet" on Caribbean Tsunami Awareness is an example of a two-sided flyer that has proven effective. It is as important to reach schoolchildren, as well as engineers, politicians, and retirees. Well-developed videos seem an important ancillary product to this end. Internet-based learning and websites too are valuable but limited for the general public, except in more developed countries. In certain applications, computer games may reach a segment of society at greatest risk: teenagers. No one single approach should be selected as this would certainly omit sectors of the socioeconomic structure.

In the end, the administration must be a governmental function. International agencies should not be expected to assume the role of government. Again the example of ICG/ITSU needs to be recalled. The warning system itself will for all practical purposes be under the purview of a single government, but should be structured in such a way that it is (in so far as practical) a multinational enterprise. ITSU is focused on the Pacific, and this IAS Tsunami Warning System must not be perceived as competing but as collaborative. The IAS/TWS should be part of an Atlantic effort, particularly co-operating with the French/Portuguese regional system for western Europe and northwest Africa. In this context, an Atlantic Ocean system recognizes at the outset that the hazard is less frequent than that in the Indian and Pacific Oceans, but potentially much more destructive in terms of human life and infrastructure. Accordingly, the IOC Executive Council and subsequently the IOC Member States are petitioned to debate the structure of tsunami hazard co-ordination in a wider context.

In this context, the notion of adaptation to tsunami and other natural hazards including global change should be considered. While tsunamis *per se* are not an issue to the global change community, the increased hazard due to population growth in coastal areas certainly is a cause for concern. The Intra-Americas Sea Tsunami Warning System should not be considered outside the wider context of sustained economic development and global change.

5. BUDGET

A general budget in the amount of US$1,000,000 for establishing the IAS Tsunami Warning System must be expected. Even with the many advantages of the Internet over the parallel development in the Pacific in the 1940's, the IAS has peculiar differences. In addition, an annual operating budget of a similar sum is estimated. The cost of establishing an administrative office will depend upon participation of partners (i.e., is there an existing structure?). Most certainly the seismic and sea-level field sensors will require hardware and software expenditures. Computer systems are evolving very rapidly, but PC-based technology seems the most cost-effective for, not only the flow of data but also even the on-line numerical wave propagation and run-up models. Much of the process can be automated. For example, the oceanographic models can be coupled to the seismic locator software, and warning times to key cities and locales calculated (*q.v.* Gusiakov, 1999).

The Internet is envisioned as the key to the IAS Tsunami Warning System.

The CPACC sea-level/weather stations are GOES-linked to a central site, and report every three hours. The sea-level measuring instruments are acoustic devices, not intended for tsunami warning. However (Martin *et al.,* 1996), the addition of a pressure sensor and specific software to include an Internet real-time continuous report would make these stations capable of transmitting tsunami alarm information, if an IAS Tsunami Warning Center capable of receiving the information were established. The cost of adding this capability is estimated at US$1,000 *per* station if the extra installations had been made during the initial CPACC effort. Since CPACC field engineers will have to return to the sites, additional transportation and logistical expenses will be incurred.

For the many other sites in the region that require tsunami-capable sea-level sensors, a minimum configuration should include a pressure sensor, Internet link, and data collection platform. Such an installation is estimated to cost US$3,000 if bulk purchasing can be used. It must be emphasized that such a sea-level station is not a substitute for the CPACC system, which is designed for establishing long-term vertical geodetic control and measuring relative sea-level on time-scales of decades. Adaptation of existing float-well tide gauges is not considered a viable option in this effort. In addition, for the redundancy required of an operational system, at least one additional GOES direct readout ground station (in addition to the Internet capability) must be considered, at a cost of US$35,000.

6. IMPLEMENTATION

Full implementation will require three years, as outlined in the budget. Certain activities as listed in the Caribbean Tsunami Workshop (Mercado, 1997; Maul, 1999) need immediate attention, specifically the education component. It is proposed that the "Tsunami Awareness Factsheet" be reproduced and distributed widely without delay. If UNESCO or IOC publication funds are used, their logo should be added.

The three year (funded) implementation phase is as follows: Year 1 is dedicated to naming an interim Director, establishing an office, and expanding the educational effort beyond that. Included in this first year will be an educational video and establishing regular annual meetings of government and non-government activists. The office location will be a political decision, but one based on the four technical requirements (elements) of the Caribbean Tsunami Workshop (Annex I): 1. Education, 2. Warning, 3. Management, and 4. Research. At the end of Year 2, an operational staff and office will be established. Much of this year's effort will have been to install the additional instrumentation necessary for broadcasting warnings. The research component will have been defined at this time, and the management effort in place. Year 3 is the first full operational period and will have activities in all four elements. As with the other start-up years, the governmental parties will review the effort and instruct the TWS Director as appropriate.

The implementation phase will be with the oversight of the IOCARIBE Tsunami Steering Group of Experts (Annex II). ICG/ITSU and officials of the Pacific Tsunami Warning Center and of the International Tsunami Information Center will be heavily relied upon during this time. The Acting Director of the IAS/TWS will make quarterly reports to the IOCARIBE Tsunami Steering Group of Experts and to the IOCARIBE Secretariat. The annual meeting of the Member States will be the normal means of communication to government organizations and non-government organizations. These meetings shall be highlighted with press releases and other activities to promote public awareness without creating any panic or other uninformed media activity.

7. CONCLUSIONS (abstracted from Lander *et al.,* 1999):

- Given the substantial increases in regional coastal development, population growth, tourism, and rising sea-levels, the tsunami hazards is greater now than in the past.
- Because tectonic forces continually add stress, the lack of recent tsunamis in tectonically active areas increase the probability of tsunamis in the future.
- Due to the short travel time for wave arrival from local tsunamigenic sources and general lack of awareness of the hazard in the region, education for all peoples is most important.
- Eighty-eight (88) tsunamis have been reported for the region in the past 500 years.
- Thirty (30) IAS tsunamis caused significant damage, including reports of as many as 9,600 fatalities that can be attributed to tsunamigenic earthquakes and tsunamis combined.
- A repeat of damaging tsunami such as in 1867, 1918, or 1946 will be more destructive without warning or mitigation actions.
- Because most tsunamis are quite small, have long intervals between damaging events, and do little damage, they often have been overlooked as a natural hazard until a disastrous event occurs.
- The IAS Region has averaged one damaging tsunami every 26 years, but since they have not had one in 53 years, a destructive tsunami is overdue.
- Fatalities in the last 150 years in the IAS Region are nearly 5 times greater than in Hawaii, Alaska, and the US West Coast combined.
- The state of tsunami preparedness in the region today is similar to that in the Pacific Ocean prior to the establishment of the Pacific Tsunami Warning System in 1948.
- Without a warning system, little or nothing could be done to mitigate disaster.
- A rare opportunity exists to establish a warning system *before* another disastrous tsunami occurs in the Intra-Americas Sea, as most warning systems are established following a disaster.

8. SUMMARY

First is that not only is the Caribbean at risk for tsunami (IOC, 1993; Maul *et al.*, 1996; Mercado and McCann, 1998; Lander *et al.*, 1999) but the entire Intra-Americas Sea, and we are essentially unprepared for any such event (IOC, 1996). Second, since the last major event of the Nineteenth Century (St. Thomas, 1867) the population of the "Caribbean" region has increased approximately ten-fold from 3 million to 30 million persons, and at least half or more of these additional human beings live in the coastal area (Alm *et al.,* 1993). Third, formally notifying each "Head-of-state" may not result in appropriate response; a multi-pronged *sustained* effort is necessary (Mercado, 1997). Fourth, IAS nations, national and local leaders, and the general public, are for the most part, uninformed of tsunami risks and uninvolved in their warnings (*cf.* IOC, 1995a). Fifth, government leaders at the highest levels must not only be actively kept informed of the danger, but be held accountable for the information (Maul, 1999).

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ANNEX I

CARIBBEAN TSUNAMI WORKSHOP REPORT

RESOLUTION

The community of concerned citizens, emergency managers, educators, and scientists, gathered by the University of Puerto Rico 11-13 June 1997 in Mayaguez, having:

Heightened awareness that per event, loss of life in the Caribbean due to tsunamis is at least equal to losses due to the major regional hazard, hurricanes;

Recognized that Caribbean tsunamis have been and will continue to be caused by local earthquakes, volcanic eruptions, landslides, and by distant seismic events;

Appreciated that our region's population has grown ten-fold since the great Virgin Islands tsunami of 1867 with most of that growth concentrated near the coast;

Debated and considered the overwhelming potential for catastrophic loss and the current state of technology's ability to mitigate such a significant toll on life and property,

Do hereby collectively petition our governments to extend natural hazard protection to include tsunami risk reduction with integrated system components of education, warning, management, and research.

IMMEDIATE ACTIONS

- Seek advice from the Pacific Tsunami Meeting (September 1997/Lima)
  - Learn protocol
  - Education approach
  - Do not reinvent the Wheel
- Integrate the Seismic Network at MIDAS meeting (November 1997/ Jamaica)
- Upgrade CPACC project now (Tide gauges/pressure sensors)
- Establish communication protocol (local, regional, intercontinental)
- Identify contacts in support/consulting organizations (regional and international)
  - MIDAS
  - USGS/NEIC
  - IOC/IOCARIBE
  - WMO
  - NOAA
- Identification of Local and Regional Contacts
- Planning and Response Exercises (Hold First As Soon As Possible)

1. EDUCATION

A. ISSUES

- Raise general awareness Caribbean wide and at national levels.

- Use Caribbean examples for multimedia public education productions taking into consideration cultural norms of each territory
- Training:
  - Develop materials (e.g., audio-visual, Internet, K-12 textbooks, etc.)
  - Use different techniques
- Provide access to modeling information for use in stimulating public education programmes
- Target:
  - Schools/community groups/ "shut ins (disabled)"
  - Coastal Communities - vulnerable areas, boating community, community managers, tourist facilities, businesses, insurers
  - Emergency Management Officials
  - Churches
  - Transient Population
  - Media

B. RECOMMENDATIONS

- Information Sharing - Regional workshop every two years
- Regional Working Group to develop basic/generic information kit
- Use of the Internet to establish a Regional Data Base
- Funding:
  - "Piggy Back" on existing educational programmes
  - Development of Regional Proposals

2. WARNING

- Two existing seismic warning systems for the Caribbean
  - Puerto Rico (UPR Seismic Network)
  - Trinidad (UWI Seismic Research Unit)
- No existing sea-level warning component
  - IOCARIBE to co-ordinate
  - CPACC (with modifications) to stage initial programme
- Regional GPS system to supplement seismic/sea-level network
- Dissemination via STAR4 at Meteorological Services and National Emergency Broadcast System; involve Caribbean Meteorological Institute and CPACC
- Warning systems should be automated and communicate across international boundaries.
- National mechanism must be a twenty-four hours-a-day system, seven days-a-week network
- Instrumentation - "near" real time seismic/sea level reporting
  - What is there?
  - What is planned?
  - What is needed?
- Use/Update existing seismic network (upgrade to state of the art)
- Establish earthquake/tsunami threshold criteria
- Automatically send alarm (warning) to 24 hour-a-day establishments (determine who)
  - Weather Service
  - Police

- Local event alarm system
- Simultaneously transmit or disseminate information about impending danger
- Regional center for data analysis/Emergency Support Function UPR seismic network function as Caribbean Tsunami Warning Center (24 hour on call)
- Communicate/Confirmation
  - magnitude
  - travel time
  - impact probability
  - severity
- Local decision to warn
- Backup and redundancy

3. MANAGEMENT

A. ISSUES

- Co-ordination of Stakeholders (Regional - Local - Municipal)
- Integration with other natural hazards warning
- Exploration for Funds
- Warning and Evacuation
- Search and Rescue
- Fire Suppression
- Emergency Medical Services
- Damage Assessment
- Intergovernmental Co-ordination
  - IOCARIBE (Lead Agency), WMO, IMO, ICAO, WHO, UNDP, UNEP, PAHO; National Representatives; extra-regional expert advice
- Intergovernmental Co-ordination
  - National Representative (Lead Agency), Meteorological Service, Transportation, Police
- Damage Reduction (mitigation)
  - Critical Facilities (fire stations, hospitals, etc.)
  - High Occupancy Facilities (schools, etc.)
  - Lifelines (roads, bridges, water, electricity, telecommunications, etc.)
  - Secondary hazards (fuel tanks, chemicals, etc.)
- Hazard Analysis (vegetation, debris, fire, ground failure, etc.)

B. METHODS

- Response

  Co-ordination for training
  - Response Exercises at various scales based on scenarios

    Warning & Evacuation
    Search & Rescue
    Fire Suppression
    Emergency Medical
    Damage Assessment
    Debris Removal

- Mitigation
  Vulnerability/Risk Assessment
  Land Use & Building Standards
    - Identification
      Critical facilities
      High Occupancy facilities
      Lifelines
      Secondary Hazards
- Risk reduction Measures
    - Local Scale
    - National Scale
- Co-ordination
    - International Agencies
    - National
    - Local
    - Private Sector
      Building
      Insurance
      Tourism
      Financial
- Standards for training

C. RECOMMENDATIONS

- General public awareness at regional and national levels
- Use of Caribbean examples for multimedia public education productions
- Target:
    - Schools
    - Coastal Communities
    - Emergency Management Officials

4. RESEARCH

- Initial Research Supporting Establishment Warning System
    - 1x1 km horizontal spatial resolution bottom relief
    - Travel time maps for population centers
    - Earthquake magnitude / depth thresholds, geographic area, and lead time for wave arrival
    - Tsunami amplitude estimation
- Hazard Assessment of Long Term Tsunami Risk and Mitigation
- Evaluate potential for Kick'em Jenny and Soufriere (Montserrat)
- Tsunami history improvement
- Earthquake history improvement
- Fault locations, activity, tsunamigenic mechanisms
- Improved land topography data and near shore bottom relief
- Inundation maps
- GPS stations for crustal motion monitoring
- Loss estimation studies

ANNEX II

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