Reducing Tsunami Risk in the Eastern Caribbean

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INTRODUCTION

On October 16, 2005 a series of abnormally large waves impacted and caused damage to several coastal zones around Trinidad and Tobago. At Maracas Bay, the peak run-up wave height observed was approximately 3 meters. The waves were large and energetic enough to breach the protective sand bar which runs parallel to the shoreline and inundated the vending areas, the main road and the car park with water in excess of 60 cm deep. At first most observers thought that the waves were a tsunami but it was confirmed more than an hour later that they were hydro-meteorological in origin.

Although no lives were lost as a consequence of the event, the response of bathers and facility managers to the event demonstrated the need for greater preparedness and planning for these and similar types of coastal hazards to which our regularly crowded coastal facilities are becoming increasingly vulnerable. According to local fishermen at Las Cuevas, the last event of this magnitude was witnessed more than twenty five years ago. The scarcity of such events has led to the construction of many structures and facilities in coastal zones that are susceptible to flooding. Several "Shark and Bake" vending booths which were severely affected at Maracas Bay is good example of this.

Responding to the first wave that breached the protective sand bar which runs parallel to the shoreline, lifeguards advised bathers to clear the beach. Although this advice was heeded by many who moved back within 10-15 meters of the shore line, many persons remained in the vulnerable locale to secure belongings or observe what would happen next. Had the event been a large tsunami, many lives would have been lost. Proper response to this event would require mechanisms in place to rapidly determine the nature of the threat and to warn people at risk to take appropriate action to protect lives first and property if there is adequate time to do so. In the absence of such mechanisms the best response after the sighting of the first abnormal wave would have been to leave the low-lying area for higher ground as quickly as possible. Normally 15m above sea level is considered safe.

Severe coastal flooding is normally induced by storm surge and tsunamis. Storm surge is a series of waves which are generated by water that is pushed towards coastal regions by the action of the swirling winds and low pressure associated with windstorms. Storm surges can be predicted with reasonable accuracy. This article provides an overview of the phenomenon that is more destructive and often strikes without warning – tsunamis. The risk of Eastern Caribbean to these events is also examined along with plans which are underway to manage the growing risk to coastal hazards.

WHAT ARE TSUNAMIS

A tsunami is a system of gravity waves formed by an impulsive vertical displacement of water column. In the process of the water level returning to equilibrium through a series of oscillations, waves radiate outward in all directions from the disturbance and can propagate across entire ocean basins if the event is spawned in the sea. Tsunamis are most commonly triggered by submarine earthquakes that involve the vertical displacement of a large area of the sea floor. Destructive tsunami may also be generated by submarine landslides, during coastal, island and submarine volcanic eruptions, by the collapse of ocean island volcanoes and – rarely by large asteroids impacting the surface of the ocean.

Tsunami waves are distinguished from ordinary ocean waves by their long wavelengths (distance between two peaks or troughs), often exceeding 100 kilometers in the deep ocean and by the long amount of time between the arrivals of these peaks, ranging from five minutes to an hour. The speed at which tsunamis travel is a function of the water depth. A tsunami can travel at speeds rivaling that of a commercial jet liner in the deep ocean but slows to 30 or 50 mph in the shallow water in coastal areas. Wavelength also decreases in shallower water but wave height increases so as to conserve energy. The destructive capacity therefore arises from the great energy they transport and the run-up heights of the waves that may be 30m or more for earthquake generate tsunami but much greater for rare ocean-island collapses or large impact events.

Persons caught in the path of tsunamis are at extreme risk from being crushed or struck by debris, or drowning. Children and the elderly are particularly at risk, as they often have less mobility, strength and endurance to evade or resist the onslaught. Unlike the direct seismic effects of an earthquake, there is usually some lead-time for predicting tsunami onset after receiving a seismic signal. The amount of time depends on the location of the tsunami source relative to a particular site of impact. This time window makes it possible to provide warnings and sometimes take evasive measures. Combined with the fact that a tsunami is a rare event, the primary mitigation measures have been to develop effective warning system and evacuation strategies.

TSUNAMI THREAT TO THE EASTERN CARIBBEAN

During the relatively short 500-year period of West Indian history, tsunamis have inflicted a relatively small amount of losses (to life and property) compared to other hazards such as windstorms, earthquakes and volcanic activity. Severe windstorms, which occur every few years, have the greatest cumulative impact in the region. Destructive earthquakes and volcanic eruptions occur less frequently (every few tens of decades) but individual events tend to be more lethal and costly than windstorms. The impact of a large tsunami can be as lethal as earthquakes or an erupting volcano. Its mobility to traverse a wider area in shorter times than hurricanes, give it the potential to unleash destruction on regional and hemispherical scales, especially if a warning system is not in place. This was illustrated by the recent Sumatran event.

The chain of islands which are known as the Lesser Antilles lie in a setting where major structural changes are occurring in the earths crust. Some of the natural by-products of these structural changes are earthquakes, volcanism and landslides. As a consequence, all known sources capable of generating tsunamis occur within striking distance of the Eastern Caribbean, and there are also distant sources across the Atlantic. In view of the fact that the islands are located in an active seismic province, the most likely tsunamis to affect the Eastern Caribbean are those which can be triggered by shallow earthquakes (<50km depth) which are greater than magnitude 6.5. These earthquakes must also cause significant vertical rupturing of the sea floor. Over 45 large and shallow events have occurred between Anegada Passage (near the Virgin Islands) and Trinidad since 1500 but only a few generated significant tsunamis.

Tsunamis induced by large volcanic eruptions at or below sea level also pose a threat to the Eastern Caribbean. A prime candidate for this is Kick-'em-Jenny volcano located 8 km north of Grenada. In the last 70 years, it has erupted more frequently than any other volcanoes in the region. At least two eruptions, in 1939 and 1965, generated small tsunamis that were witnessed on the north coast of Grenada. Detailed studies of the physical structure of Kick-'em-Jenny conducted in 2002-2004, has led to the conclusion that the volcano does not currently pose an immediate tsunami threat, but it is possible that future eruptions could change this situation. Given the proximity of most eastern Caribbean volcanoes to the coast and the styles of eruptions that feature pyroclastic flow, edifice collapse and debris avalanche, tsunami generation will be a certainty during future magmatic eruptions. The level of risk posed by such tsunamis will be directly related to factors such as the scale of the eruptions, the wave direction, the population density of the areas impacted and the effectiveness of risk reduction measures in place to deal with events.

Tsunamis spawned at distant sources pose a somewhat lower threat than those from local sources. The primary tele-tsunami sources are the Azores-Gibraltar fracture zone that produced the well documented Lisbon Earthquake and Tsunami 250 years ago and the La Palma Volcano in the Canary Islands. The Lisbon tsunami propagated across the Atlantic and emerged with wave heights of about 10-14 feet in Martinique and 3-6 feet in Barbados. Some flooding was also reported in the city of Santiago de Cuba. It is hypothesised that a massive collapse of the La Palma volcano could trigger devastating tsunami waves that could reach the eastern Caribbean and the east coast of the United States. This hypothetical worst case scenario is largely based upon speculative computer models of landslide motion and tsunami generation. Studies of actual landslide deposits in the Canary Islands reveals that in the last 200,000 years there have only been two major landslides and there is good evidence to show that the landslides actually break up and fall into the sea in several stages rather than in one mega-slide.

Perhaps the most problematic tsunami danger the region faces comes from the restricted class of tsunamis induced by submarine landslides just offshore an island, involving a huge volume of loose sediments. This realization not only makes the large waves harder to predict and detect, it also shortens the warning time coastal residents will have to protect themselves once an event is spawned. Recent studies have shown that such large landslides will occur in material susceptible to liquefaction, particularly during earthquakes. There is evidence to suggest that liquefaction induced landslips triggered tsunamis during earthquakes occurring in 1690 at Charlestown, Nevis and 1843 at English's Harbour, Antigua. In the Eastern Caribbean, land-slide induced tsunamis are most likely to happen in areas where the sea floor descends steeply, and when there has been a rapid input of new layers of sediments from volcanic activity and/or floods caused by torrential rainfall. Another possible trigger to submarine slumping is the shaking due to a strong earthquake. Tsunamis resulting from this mechanism can generate large waves but they tend to inundate only regions close to the source zone.

Geophysical events which trigger large tsunamis in the Caribbean Sea and the Atlantic Ocean generally tend to have very long recurrence intervals. From the historical record we can infer that potentially destructive tsunamis occur at an average rate of about 1-2 per century in the waters of the insular Caribbean. The hazard is not uniformly distributed throughout the Caribbean. The North-eastern Caribbean region near Puerto Rico and Hispaniola is more susceptible to tsunamis. The average rate of occurrence in this region has approached 1 every 50 years in the last 200 years. In other sub-regions such as the southern Caribbean there are no historical records of destructive tsunami impacts. The true tsunami history of the region rests not in the post Columbus records but rather in the geological record. As in most regions of the world, tsunami science in the Caribbean is limited by knowledge of geological sources and by the bathymetric details of where the waves impact.

A major impediment to the understanding of earthquake producing zones is the lack of accuracy and details – mainly caused by lack of high quality regional and local data with which source parameters and hazardous crustal structures may be characterized. The Eastern Caribbean islands lie in the vicinity of an Ocean-to-Ocean plate collision environment, i.e. both Caribbean and North American plates lie at the bottom of the Caribbean Sea and Atlantic Ocean respectively. The large intervening area of water between the islands and the presence of ocean/sea on both sides of the island arc contributes largely to the relatively poor understanding of sources. While ground and marine observations may help to identify hazardous structures, inaccessibility due to water prohibits direct measurements of the movements of tectonic units. Such measurements can reveal much more details of hazard potential. The availability Global Positioning Systems technology promises to improve ongoing investigations by complementing current seismological tools. Detailed high-resolution elevation (both bathymetry and topography) is needed to identify faults and landslides, to model tsunami propagation and run-up and to assess coastal hazards. In the Caribbean near-coast elevation is not readily available for all islands but the technology is available to fill the gaps once they are identified and financing is provided.

While the frequency of lethal impacts in the Eastern Caribbean is relatively low, the social and economic impact of an event like the 1755 earthquake is nowadays greatly amplified by the existent and growing urban concentration near coastal areas. This increasing risk to tsunamis warranted the implementation of a program to manage risk akin to those for the other natural hazards but factors such as inadequate appreciation of the nature of the risk, lack of political will and scarcity of resources inhibited such undertakings.

TSUNAMI WARNING SYSTEMS

A Tsunami Warning System (TWS) provides the mechanism to detect potentially devastating events and communicate advanced warning of the impending threat to vulnerable communities. To be most effective, however, a comprehensive study of the hazard sources and risk assessment of the threatened regions is necessary. Where data is scarce, vulnerability assessment may be aided with realistic scenario modeling. This allows some level of emergency and mitigation plans to be put in place. A TWS should also be implemented with a combination of other risk reduction measures such as a sustained education and preparedness program aimed at empowering those at risk to take the appropriate response whenever the warnings are issued or whenever the event is accompanied by cues that could its approach. While these measures by themselves can yield effective results for distant tsunamis which inundate vulnerable shores hours after generation, there are situations where the source of the tsunami is local, i.e. less than 15 minutes away. For these events, additional mitigation measures such as public policy actions and regulations can also reduce the vulnerability.

Tsunami Warning Systems rely on seismic data and earthquake analysis for the rapid initial warning, and on data from a sea level monitoring network for confirming and evaluating the tsunami and for continuing, upgrading, or canceling the warning. Both data streams must be available to the warning centre in real-time. The warning systems also rely upon a variety of communication methods to receive seismic and sea level data and to issue messages to disaster emergency managers and communities immediately under threat. Due to the extent of the area that the phenomenon can affect, Tsunami Warning Systems are expensive to establish and difficult to sustain. They require high levels of coordination and commitment to function effectively. Close collaboration among institutions and organizations of several countries is needed for rapid exchange of data and warnings and to maintain the seismic and ocean observing systems. An initial goal in establishing a TWS is therefore to make use of resources from existing regional monitoring institutions and disaster management agencies in a synergistic manner so as to attain cost-efficiency at all levels of design and operation.

TSUNAMI RISK REDUCTION

The Sumatran catastrophe served a strong notice that any populated coastline in a tectonically active zone is at risk, no matter how remote the odds. Highly populated settlements in low elevation coastal areas are particularly vulnerable to high death tolls. Many regional governments, decision makers and disaster functionaries have signaled that the current level of risk exposure in the Caribbean is unacceptable and have requested that appropriate action be taken to address this state of affairs.

After reviewing the exposure of the Caribbean through a process of consultations between experts and various stakeholders, a multi-national multi-agency initiative has been launched establish a program for reducing the risk to various coastal hazards in the Caribbean and adjacent regions. It involves most regional institutions and agencies that are already engaged in the monitoring and study of coastal and other natural hazards as well as several disaster management organizations. Initially, priority will be given to the development of a Tsunami Warning System (TWS) and support programs to empower threatened communities to respond correctly to alerts and warnings. A key player in this effort will be the Caribbean sub-commission of the Intergovernmental Oceanic Commission (IOCARIBE). The Intergovernmental Oceanic Commission (IOC) played key roles in the establishment of the Pacific Tsunami Warning System in 1964 and the recently created system for the Indian Ocean. This organization will facilitate the planning and coordination required to augment the regional disaster management framework for tsunamis and to build tsunami ready communities. The United States Government has also responded by making a commitment to extend the Global Seismic Network by installing nine new stations in the Caribbean region, including three in the eastern Caribbean. Another component of the US Government's contribution will be the installation of five state-of-the-art sea-level sensing devices in deep waters on both sides of the island chain. Each station in both seismic and sea-level monitoring networks will be linked by satellite telemetry and will provide real-time data to US and Caribbean based warning centers. These new networks will play a pivotal role in the initial shaping the regional tsunami warning system that will ultimately incorporate and leverage the resources of existing networks.

REGIONAL WORKSHOP TO PLAN FOR SEISMIC COMPONENT OF TWS

Senior Technical Representatives from various Seismic Networks around the Caribbean Basin attended a workshop at the University of the West Indies, St. Augustine on April 4-6, 2006 to initiate plans for establishing an early warning system for Tsunami and Coastal Hazards for the Caribbean and adjacent seas. The workshop was hosted by the Seismic Research Unit of the UWI. It was one of the first of several activities pertaining to larger regional initiative to reduce the risk to coastal hazards such as the one described above.

The IOC of UNESCO, during the course of several international and regional meetings received a clear mandate from the international community to coordinate the establishment of Tsunami Warning Systems in such regions at risk throughout the world. After completing majority of the tasks needed to establish the tsunami warning system in the Indian Ocean, the IOC held an International Conference for the Development of a Tsunami and Coastal Hazards Warning System (TCHWS) for the Caribbean Sea and Adjacent Regions.

At this meeting, which was held in Mexico City on June 1-3, 2005, participants were given technical appraisals of the tsunami warning and mitigation programs that exist at national, regional and global levels. A broad work plan was drafted for the development of the Caribbean TCHWS and it was recommended that an "Intergovernmental Coordination Group" (ICG) be established to take the plan forward. The Terms of Reference for the Group were also drafted. The Meeting adopted a communiqué that provided guidance to all partners regarding the required actions that will lead towards the establishment of a Tsunami and Coastal Hazards Warning System for the Caribbean Sea and Adjacent Regions.

The St. Augustine Workshop was one of several activities recommended at the first session of the Intergovernmental Coordination Group for the Tsunami and Coastal Hazards Warning System for the Caribbean Sea and Adjacent Regions, held in Barbados in January, 2006. At the IGC meeting a workgroup for Monitoring, Detection Systems and Warning Guidance was assembled to advance plans related to these subject areas and its members comprise individuals from various institutions that monitor meteorological, hydrological and geologic hazards throughout the region. The workgroup recognized the need to strengthen and expand the integration of seismic data into the emerging Tsunami Warning System. It was proposed that the most feasible way to facilitate this was to convene a meeting where technically competent managers from the well established seismic networks around the region could:

1. Develop consensus on the establishment of the Caribbean Tsunami Warning Center
2. Develop consensus on Data Formats and exchange protocols for seismic data
3. Discuss technical issues regarding network configurations and communications
4. Develop a proposal for the establishment of a robust and sustainable regional telecommunications network for data transmission.
5. Identify training requirement so that a program may be developed to meet the needs
6. Develop sustainability plan for the Tsunami Warning System

Twelve seismological institutions from Puerto Rico, the Eastern Caribbean (English and French) Venezuela, Panama, Nicaragua, Costa Rica, Dominican Republic, Jamaica and the USA were represented at the Trinidad workshop. In an effort to ascertain the current capabilities of seismic networks in the Caribbean region each delegate gave a presentation on the current status of their network and outlined future plans that were in the making to improve such networks to address the threat from tsunamigenic events. Delegates from well established international data centers, The United States Geological Survey which runs a global seismic network and a leading manufacturer of seismic instrumentation also gave presentations on state-of-the-art equipment and best practices in the fields of digital seismic data acquisition and communication systems, data exchange, and data management. In addition the delegates from Puerto Rico presented an overview and status of a tsunami warning center which is being developed in that country. The four day workshop enabled the delegates to arrive at some key decisions that will bootstrap the process of setting up the regional system. It provided technical insights for delegates, especially those from the less resourced networks about the best upgrade paths to choose and how to rapidly configure certain existing instruments to publish and share data via computer networks. Data sharing is an essential faucet of any TWS that serves a region of several nations. There was unanimous support for Puerto Rico to be transformed into the regional warning center. Delegates also expressed the view that a number of secondary or backup warning centers should be established as soon as adequate resources become available to attain the necessary capacity to do so. Another important outcome of the workshop was the consensus that the overall quantity and quality of instrumentation and communication systems among existing and planned networks is inadequate to build an efficient seismic component of the TWS. As a consequence it was recommended that a proposal be drawn up for a 15 station seismic network to fill identifiable gaps across the Caribbean. The proposed network will be linked by Very Small Aperture Satellite technology and it will greatly improve the study and understanding of the processes that generates geologic hazards.

THE ROLE OF REGIONAL INSTITUTIONS/AGENCIES

The Seismic Research Unit (SRU), University of the West Indies currently operates a 60-station volcano surveillance and earthquake monitoring network in the Eastern Caribbean. The Unit is well positioned to provide meaningful contributions to the TWS and the broader hazard mitigation initiatives in the region. It brings to the table, several dedicated and experienced staff members, a substantial amount of resources and a network of support that has been crucial to its operation which has been sustained for over fifty years. Some level of upgrade is needed to transform strategically located SRU installations to the status required to contribute to the TWS network and for the Unit headquarters to function as a future TWS sub-focal center.

The regional disaster management agency – Caribbean Disaster Emergency Response Agency (CDERA) and its various national partner agencies will play crucial roles in the realization of the system, particularly in getting communities ready for tsunamis. This is a huge task but fortunately such a program can fit into the comprehensive disaster management framework which already exists. In addition to the core monitoring and management groups mentioned above, the TWS initiative will also leverage resources from the meteorological services, coastal management and environmental management agencies and the climate change community. It is anticipated that the cost/benefit advantage of a target multi-hazard system will attract the support needed for sustainability and spawn the development of techniques to overcome technical and financial obstacles which have plagued individual entities in the past. The monitoring infrastructure and disaster management framework that will result from the collaborative effort will be more resilient and better able to serve wider communities. With the development of a working tsunami warning system, the primary goal of saving lives and, to a lesser extent property when future tsunamis strike, will no doubt be achieved.