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AN 1867-CLASS TSUNAMI: POTENTIAL DEVASTATION IN THE US VIRGIN ISLANDS

ROY A. WATLINGTON

University of the Virgin Islands

Abstract

This paper describes the potential devastation that might result in the United States Virgin Islands if a tsunami identical to the Virgin Islands tsunami of November 18, 1867 were to occur today. Comparisons are made based on the reported runup in 1867 and also on the changes in population, coastal infrastructure, shipping activity, and in warning and mitigation systems for natural hazards. To find examples and make comparisons to modern demographics and infrastructure, the impacts of recent damaging hurricanes are presented. Recommendations are made on preparing for and mitigating the effects of a local tsunami.

Background

The 1867 Virgin Islands' tsunami was initiated by an earthquake along a fault beneath the Virgin Islands Basin. This deep body of water is defined by the islands forming its topographic barriers. St. Thomas, St. John and the British Virgin Islands separate it from the Atlantic; St. Croix separates it from the Caribbean Sea, while Vieques and Culebra define its western boundary. To the east the Basin opens to the Atlantic through the Anegada Passage. It connects to the Caribbean's Venezuela Basin through the Jungfern Passage and Grappler Channel. Interpretation of historic data and the accounts of witnesses have placed the earthquake's epicenter at a location approximately equidistant from St. Croix, St. Thomas and Vieques.

At approximately 3:00 p.m. on November 18, 1867, inhabitants of the islands today known as the United States Virgin Islands (known before 1917 as the Danish West Indies) were jolted by a severe earthquake. Church steeples were toppled and many buildings were either damaged or destroyed. Residents rushed out of doors fearing for their lives. Shocks were also felt by sailors on boats in harbors of the towns of Charlotte Amalie on St. Thomas, Christiansted and Fredericksted on St. Croix (van Housel, 1868). Evaluation of damage done to structures and of eyewitness reports from 1867 has allowed approximation of the earthquake's intensity from 7.5 on the Richter Scale (McCann, 1984).

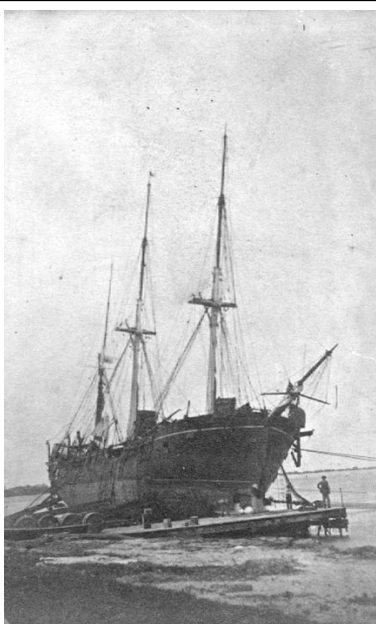


Figure 1. Naval Historical Archive's 1868 photograph of the USS Monongahela on the shore in Fredericksted, St. Croix.

Within approximately five minutes of the earthquake, tsunamis propagated outward from the earthquake epicenter, where basin depth exceeds 4000 meters, to the gradual island slope south of St. Thomas and to the steeper north and west coasts of St. Croix. On all shores ringing the basin, witnesses report the sea retreating from the shorelines then advancing in waves of heights up to seven meters. Approaching Christiansted harbor, the wave lost some of its energy as it encountered fringing reef and islet. Fredericksted had no such protection. The town was severely damaged by the waves. Vessels were thrown onto its shores. Most noteworthy of these, the USS Monongahela was stranded on the Fredericksted shore as shown in Figure 1. In Charlotte Amalie vessels were torn from their moorings, lifted onto rocks, sunken or otherwise damaged. With a runup of approximately 2.4 meters, the waves pushed into the commercial and residential community leaving shops and warehouses filled with water. Tsunamis from this earthquake also caused destruction on St. John, Tortola, the British Virgin Islands, and Puerto Rico. Wave heights on Guadeloupe were reported to be even greater than in the islands nearer to the epicenter (Zahibo, 2004). Vessels were damaged as far away as in the harbor of St. Georges, Grenada. Small shoreline homes were swept into the sea wherever the tsunamis impacted. Many people were injured but the loss of life was limited. Although more would die from disease that would follow the earthquakes, tsunamis and the deadly hurricane of two weeks earlier, the death toll attributed to the tsunamis, was approximated at 16, with most fatalities resulting from drowning (Watlington *et al.*, 1997). Estimating the damage done to the economies of these Caribbean communities by the tsunamis of 1867 is made difficult because the waves

had followed the earthquake but also the devastating hurricane of October 29, 1867. This sudden storm killed between 500 and 600 persons in the British Virgin Islands, St. John, St. Thomas and Puerto Rico and caused damage to and destruction of vessels and property.

It is known however that, in addition to disabling many vessels, the 1867 tsunamis swept away or ruined goods that had been stored in the many low lying shops and warehouses. In the aftermath, moisture extended the ruination. Subsequent to the destruction the onset of yellow fever then claimed the lives of some survivors (Watlington *et al.*, 1997). For the Danish West Indies as a whole, the destructiveness of the earthquake and tsunamis added to the hurricane's effects in disrupting treaty negotiations to transfer ownership of St. John and St. Thomas from Danish to American rule. Following these disasters, the treaty championed by U.S. Secretary of State William A. Seward was ridiculed as "one for the annexation of hurricanes and earthquakes..." (Tansill, 1932). Fifty years would pass before St. Croix, St. John and St. Thomas would become the United States Virgin Islands.

Comparing Disasters

Occurring in the present or near future, tsunamis initiated in the same manner as the 1867 event can be expected to visit the same communities as well as many new shoreline settlements and to have significantly greater impacts. Although these communities grew very slowly or shrank somewhat in the last part of the 19th Century and into the first half of the 20th, the blossoming of Caribbean communities and the growth of Caribbean tourism that has continued since the 1960s has created an entirely new profile of vulnerability.

Today these areas are heavily populated and have become repositories of great volumes of material goods, including very highly valued luxury items assembled for sale to tourists. In the US Virgin Islands, duty free status, guaranteed by the terms of the treaty, has resulted in the concentration of a treasure of expensive jewelry, perfumes, cameras, fine clothing and other luxury items. Both retail and warehousing occur within 400 meters of the water's edge and less than 2.4 meters above sea level. Busy container ports, cruise ship docks, schools and an oil refinery that ranks second in supplying the US market are among other activities that concentrate wealth, important infrastructure, and large gatherings of people. In 1867, neither population density, wealth nor infrastructure was comparable to what is found today within striking range of an 1867-class tsunami.

To anticipate the kinds of loss that today's communities might suffer, we consider the impacts of the destructive hurricanes Hugo and Marilyn. Both cyclones affected all of the Virgin Islands, with Hugo devastating St. Croix the most severely in 1989 and Marilyn doing the same for St. Thomas in 1995. These storms intruded into demographic profiles of population, wealth and infrastructure that more closely resemble today's profile in the Virgin Islands than does the profile of 1867.

On September 15, 1989, after not experiencing the direct impact of a hurricane for many decades, the Virgin Islands experienced Hurricane Hugo. The storm crossed both St. Croix and St. Thomas before moving on to cause destruction in Culebra, Puerto Rico and in the Carolinas. Roads were made impassible, electric power was disrupted for periods ranging from weeks to months, businesses were shut down for weeks, both major airports were rendered inoperative for days, and many vessels in port were sunken, beached or severely damaged. Although a hurricane warning time of >24 hours allowed major vessels to avoid the storm, damage to port facilities and to general infrastructure caused cruise ship arrivals to be temporarily halted, not returning to previous levels for two years (Bureau of Economic Research, 2002). On St. Croix Hugo damaged 90% of the buildings, seriously damaging 80% of the homes. Some businesses never recovered. Oil refining on St. Croix, estimated at >100,000 barrels per day was disrupted for many days. The loss of infrastructure and of confidence in local emergency mitigation contributed to the long-term loss of St. Croix's market share in tourism.

Six years later on September 17th, 1995, Hurricane Marilyn returned destruction to the Virgin Islands. It had been preceded by a glancing blow from Hurricane Luis two weeks earlier. This time, the greater share of the destructiveness was focused on St. Thomas. Once again, airports were closed, electric power was cut, many buildings were seriously damaged (80% on St. Thomas) and small boats were damaged or lost. Of 635 vessels surveyed, 251

(39.5%) were either destroyed, aground or beached, sunk, dismantled or otherwise damaged (COBEX, 1995). Once again, even though cruise ships were well and safely away from the storm, damage to on-shore infrastructure interfered with cruise ship tourism. As the hurricane approached, Hess Oil Virgin Islands had shut down its 545,000 barrels per day operations. It would resume production 12 days later (Oil and Gas Journal, 1995). Overall estimates of damages from both hurricanes amounted to approximately \$2.1 billion, costing taxpayers \$450 million while insurance companies paid out \$750 million (Witt, 1998).

Cruise ship calls reflected the disruption caused. Comparing the fourth quarters of 1995 and 1994 for all three islands, one finds that 18.1% fewer ships called with 9.4% fewer passengers, even though St. Croix was able to accommodate ships that stopped going to St. Thomas. In addition, civilian employment was down by 9.9% and declined further the next year. The number of visitors arriving by air declined by 54.9% and declined further in 1996. The value of construction permits was down by 74.6% and did not recover to the 1994 value for several years afterwards (Bureau of Economic Research, 2003). According to this source, hotel occupancy rates were up 2.2% while the actual number of nights of hotel occupancy dropped by 27.4%, reflecting the reduced availability of units even as FEMA and off-island construction workers moved to the Virgin Islands to help with the recovery.

Taken together, these storms killed fewer than two dozen people in the Virgin Islands but they cost in the range of \$3 billion to \$4 billion in expenditures for repairs, rebuilding and recovery of homes, businesses and infrastructure (Office of Territories and Internal Affairs, 1999). Further, they lessened the attractiveness of the US Virgin Islands as a fourth quarter destination. In these ways, both storms hurt the economy of these islands measurably. Figure 2 illustrates the 8.1% loss in revenues that resulted from Hurricanes Marilyn and Bertha, which impacted the islands 10 months after Marilyn (Virgin Islands Department of Finance, 2004). Fiscal Year 1996 represented a \$30 million lowering of general fund revenues.

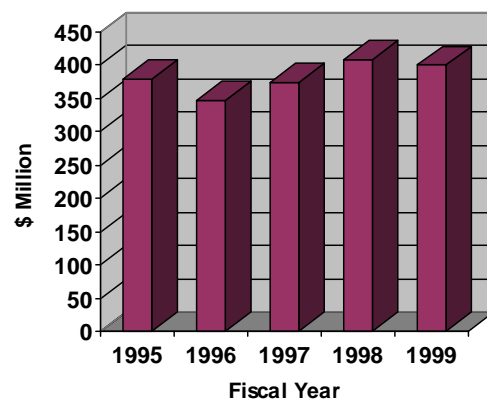


Figure 2. General Fund Statement of Revenues, FY 1995-FY1999. Department of Finance, Virgin Islands Government.

There are limitations of how hurricanes can serve as surrogates for an 1867-class tsunami in modern times. Besides the greater concentration of wealth and infrastructure and the larger population in the modern communities, another significant difference between the occurrences of these recent hurricanes and that of the 1867 earthquake, tsunami (and hurricane) is the immensely greater warning time for hurricanes today. Without radio, the most rudimentary of instant communication devices, no significant warning times or warning procedures were possible for any of these hazards in 1867. That makes a great difference for hurricanes. However, for the “local tsunami” -- one that is initiated less than one-wavelength (typically ~100 km) away -- these advances have limited value.

Profile of the Today’s Virgin Islands

Today the US Virgin Islands is an unincorporated territory of the United States. It elects its own government and sends a delegate to the United States House of Representatives. Its gross domestic product is reported variously as between \$ 2.6 million and \$3 million. Although the surface area of the Territory is only approximately 352 km² (136 square miles), the population has reached approximately 105,700. The coastal population density, especially during the day when businesses are operating and tourists are shopping, is much higher than it was in 1867 when approximately 37,000 people populated the Danish West Indies (Dookhan, 1974). It is reasonable to assume that, during the day, many of these people were working in the plantations and estates, most of which are located at elevations safe from tsunamis.

The Territory’s main industry is tourism and the oil refinery represents the second most significant employer. In 2001, 1.8 million cruise ship passengers visited the islands spending \$489.9M during their visits. The Hess oil refinery on St. Croix (which has changed corporate structure and is presently known as Hovensa) is the largest single exporter of petroleum to the United States. In 2001 it produced and exported to the United States approximately 236,000 barrels per day.

Today, within the likely runup and penetration of an 1867-class tsunami, one finds preferred recreational activities for visiting tourists – shopping, beach bathing, sailing, coastal sightseeing. The oil refinery lies within 400 meters of the sea as do many Virgin Islands Government offices, several schools, both airports and the electricity and desalination plants of the Virgin Islands Water and Power Authority. On many days in Charlotte Amalie harbor three or more ships may be found at the West Indian Company's Havensight dock, at the Crown Bay dock or anchored in the harbor. The largest cruise ships in the world visit this harbor. These vessels often carry 2,600 to 2,800 passengers attended by approximately 1,000 staff and crew members. Figure 3 shows several vessels anchored in the harbor and docked at Havensight. More than 12,000 persons (passengers, crew, and local providers of tourism services) may assemble around these vessels during a four-cruise ship day. This estimate is based on a typical occupancy of four of the average-sized vessels that visit and on the number of merchants, taxicab drivers and port officials working in the area.



Figure 3. The Charlotte Amalie Harbor, St. Thomas, U.S. Virgin Islands, on a normal day during the tourist season. Three cruise ships are docked at the West Indian Company's Havensight dock. (St. Thomas – St. John Chamber of Commerce photograph).

Potential Tsunami Threats

For the Caribbean as for most other regions, the most likely causes of tsunamis from local sources are earthquakes, landslides, volcanic explosions and submarine avalanches resulting from slope failure. Faults in the Virgin Islands Basin, Anegada Passage, Puerto Rico Trench are active and occasionally release stresses with earthquakes. Slope failure along the submerged north coast of Puerto Rico, such as in the Loiza amphitheater, has been listed as a potential mechanism to trigger large tsunamis (ten Brink *et al.*, 2004). In the last few decades, small tsunamis have been observed to result from the volcanic activity of Montserrat's Soufriere Hills volcano and from Kick `em Jenny submarine volcano, located near Grenada. Tele-tsunamis remain a threat for the entire Atlantic basin. In addition, there is a certain amount of concern about the eventual likelihood of a repeat of the seismic events that caused the 1755 Lisbon earthquake and about submarine debris avalanches that could be triggered by earthquakes or volcanic activity in the Canary Islands (Bryant, 2001).

Focus on the Cruise Industry

All sectors of Virgin Islands society and economy are susceptible to significant disruption by the natural hazards mentioned above. However, because of its unique vulnerability to tsunamis, the cruise ship industry today can be used to demonstrate potential impacts of a tsunami resembling that of 1867. As mentioned before, cruise ships are generally free to avoid hurricanes. Within an hour most modern vessels can easily move out of port. Capable of speed >20 knots, most can outrun or outmaneuver most big storms. And although their passengers on shore could be at considerable risk, cruise ships themselves are not highly vulnerable to significant damage from earthquakes. Even for tele-tsunamis, with adequate reporting of distant events and a minimal escape plan, cruise ships can cast lines and get to the safety of deep water when a tele-tsunami is expected. Even from as close as the location of Kick `em Jenny, the Virgin Islands, if adequately warned, could have as much as 80-90 minutes to prepare for the onslaught (Smith, *et al.*, 1994). It is generally understood that tsunami wavelengths are so long in deep water that vessels at sea are not likely to even perceive the passage of a tsunami that may go on to wreak disaster on some shoreline community. Adequately safe, deep water can be reached quickly from Virgin Islands' ports.

For the typical large cruise ship, many existing safety measures can minimize the destructive consequences of an encounter with a tsunami in shallow water. Unlike the sailing vessels and coal-fired steamers of 1867, they have

powerful engines that can be brought to bear very quickly. Given reasonable warning they can maneuver to take the wave on bow or astern. These vessels have communication equipment that can receive warning messages under the most unfavorable circumstances. Many are designed to roll to angles as great as 40° without capsizing (Sabino, 2004). In their interior spaces, heavy objects are fastened securely, hatches and doors are managed consistent with a safety plan.

But as was the case in 1867, the local tsunami that may originate in any of the locations listed above would have only the shortest travel and allow very little warning time. Even without fear of capsizing or sinking, anticipating the impacts of a local tsunami on a cruise ship in shallow water leaves much for worry. Docked end-to-end as three are shown in Figure 3, vessels may ram each other. And, instead of capsizing, the vessel only has to roll moderately for passengers to tumble and receive injury as they collide with interior barriers. With a sudden moderate pitch of the vessel, chairs, plates, serving dishes and other items can also become projectiles. Rather than sink, the vessel may merely be sufficiently damaged that it has to remain restricted to port for official inquiry and for repairs.

The case of the fire aboard the cruise ship M/V Angelina Lauro at the West Indian Company's dock in 1979 demonstrates this point. A fire that had started in the galley of the vessel resulted in its "total constructive loss". Fortunately no lives were lost. However, the vessel took on enough water to rest on the bottom, tilted over at 25° (US Coast Guard, 1981). There it remained for four months, preventing revenue-generating use of its part of the dock and presenting an unwelcome eyesore for visitors on the vessels that continued to use the harbor (Esannason, 1979). Filling the hold with enough water to cause the vessel to rest on the bottom contributed to the Angelina Lauro's extended stay at the site.

The Danger on Shore

The fortunate aspect of the Virgin Islands' situation with respect to tsunamis is the closeness of hills and headlands to heavily populated low-lying areas. In all of the major towns, the alerted pedestrian may only have to run 200-300 meters before reaching an elevation high enough to provide safety from the waters of an 1867-class tsunami. However, given the demographic profile of the Virgin Islands today, it may be most devastating if the 1867-class tsunami occurred in the day rather than at night. In contrast to the situation in 1867, most Virgin Islands residents live at moderate to great elevations above sea level. Many hotel buildings are elevated above the reach of a 2.4 meter runup. And while there are many shoreline residents in Virgin Islands' communities, a greater portion of the population resides at elevations that would allow them to sleep safe from tsunamis.

During the day, however, all of the coastally related tourism recreation takes place near sea level. While thousands of residents pour into town to work in the low-lying towns, schools located in flood zones are also occupied mostly in the day. Further, in crossing the island in east-west directions for business or pleasure, resident drivers spend a considerable time confined in cars just a few feet above the normal level of the sea. On St. Thomas, a junior high school is located within 200 meters of the sea and on filled land. Possible safety routes for students and staff are interrupted by a busy highway along which heavy flows of cars speed.

Busy shopping paths in Christiansted, shoreline shopping areas on St. John and quaint alleys in Charlotte Amalie are usually filled with tourists and residents during a busy day in "high season". These alleys end at the point where the ocean stopped before the area was filled and the shoreline highway was constructed. In the aftermath of the 1867 tsunami, these same passages were filled with water. Receding waters up to 1.5 meters (4-5 feet) in depth prolonged the hazards caused by the advancing sea (Watlington *et al.*, 1997).

Planning for an 1867-class Tsunami

Today's demographic circumstances offer many advantages in preparing to mitigate the effects of an 1867-class tsunami. However, in spite of the relatively lower hazard that tsunamis represent after-hours in these unique Virgin Islands circumstances, there still are Virgin Islands communities of people sleeping within the tsunami runup range in Coral Bay, Cruz Bay, Gallows Bay, Fredericksted and Charlotte Amalie.

Given that travel times for local tsunamis are on the order of a few minutes, an effective tsunami emergency response plan should place much focus on citizen education and awareness. Residents and visitors alike should know to "duck, cover and hold" for earthquakes and then immediately after a strong tremor to look to the sea and run to the nearest

hill if they see anything suspicious. Common wisdom should be developed so that everyone would know not to approach or stay near the sea if the water recedes from the shore. Residents and tourists renting cars as well should be advised that if they are driving along the shore and an imminent tsunami is announced or if they can see disturbed water heading their way, they should abandon their cars rather than try to escape in them and move hastily to high ground. An official emergency plan might stop all shoreline traffic forcibly so that the lives of drivers can be saved and so that these cars do not inflict injury on pedestrians running for the nearest safe elevation.

Although it is likely true that the oil refinery, the schools and cruise ship docking facilities all have emergency plans that deal with greatly disturbed seas, sound emergency plans should require excellent communication among local police, emergency service providers, dock masters and cruise ship officers to avoid losses due to the kind of uncoordinated responses that occurred during the Angelina Lauro fire. These communication links should be rehearsed frequently and improved as technology improves.

Earthquake and tsunami predictions are still poorly developed arts. However, in the US Virgin Islands, even existing technology has not been applied to the fullest. For example, the few functioning sea level gauges in the US Virgin Islands are not set up for tsunami detection and not linked into any aspect of an emergency warning system. No plans have been announced to emplace bottom-mounted pressure gauges offshore in order to detect and announce the approach of a tsunami with the ability to distinguish tsunamis from large storm waves.

The US Virgin Islands are served by the Virgin Islands Territorial Emergency Management Agency (VITEMA) which communicates efficiently with the National Weather Service in San Juan, which takes the lead on storm warnings, and with the Puerto Rico Seismic Network (PRSN). PRSN is further set up to accept advisement from the Pacific Tsunami Warning Network, which operates around the clock. However, the present channels among the regional emergency managers and with PRSN are only guaranteed during office hours on work days. Although PRSN might detect a tsunamigenic earthquake, procedures have yet to be developed for emergency service providers in the US Virgin Islands to translate this advisory into an emergency warning for the public.

Public awareness of earthquakes and of tsunamis, to a much lesser extent, has begun. There is, among emergency planners, the understanding that the best response to a sudden hazard is a well educated citizenry. VITEMA has used awareness days to share information about hurricanes and earthquakes by radio, television and with displays and information centers in public places. With regard to tsunamis, however, brochures have not been distributed and emergency routes for tsunami evacuation have not been publicized. Of concern also is that presently safeguarding against tsunamis, specifically, is not considered in choosing the locations of public buildings. Questions about tsunami safety do not impede the granting of building permits.

Conclusions

Although tsunamis are quite rare, one similar to the tsunami of 1867 is sure to occur at some time in the future and may occur at any time. Improved communication and articulation among the emergency managers of the region and building of tsunami detection technology can do much to improve safety from crippling tsunami impacts. However, for the local tsunami, such as the one of 1867 in the Virgin Islands, warning times will be very short. This suggests that well-developed emergency action plans must include identified and publicized escape routes, procedures for altering traffic and plans for minimizing devastation after the event. In addition, Virgin Islands decision makers may find it useful to study the experiences and practices followed in tsunami-plagued communities of Hawaii and in Japan in establishing new guidelines for the permitting of building in the tsunami-prone zones. Most effective will be action plans that have been developed for and invested in every citizen well in advance of any emergency situation. To a large extent the citizenry will have to take responsibility for its own safety when a sudden tsunami threatens.

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