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TSUNAMI HAZARD AND TOTAL RISK IN THE CARIBBEAN BASIN

X. William Proenza
National Oceanic and Atmospheric Administration
National Weather Service
Fort Worth, Texas 76102

and

George A. Maul
Florida Institute of Technology
Department of Marine and Environmental Systems
Melbourne, Florida 32901

ABSTRACT

Deadly western North Atlantic Ocean tsunami events in the last centuries have occurred along the east coast of Canada, the United States, most Caribbean islands, and the North Atlantic Coast of South America. The catastrophic Indian Ocean tsunami of 2004 reminded natural hazards managers that tsunami risk is endemic to all oceans. *Total Risk* is defined as *hazard* (frequency of tsunami events) times measures of *elements at risk* (human exposure) times measures of *vulnerability* (preparedness) in a given epoch (Nott, 2006). While the tsunami *hazard* in the Caribbean (averaging 19 ± 22 years between deadly events) is lower than Pacific coastal areas, the *total risk* to life and property is at least as high as the USA West Coast, Hawaii, or Alaska, because of the higher Caribbean population density and beach tourism so attractive to more than 35 million visitors a year. Viewed in this light, the allocation of resources by governments, industry, and insurers needs to be adjusted for the better protection of life, for coastal engineering, and for infrastructure.

INTRODUCTION

Atlantic tsunami hazard and risk have been of major concern to the Subcommission for the Caribbean and Adjacent Regions (IOCARIBE) of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the United Nations Environment Programme's Caribbean Environment Programme since they co-sponsored a workshop on Small Island Oceanography in 1993 (Maul, 1996). IOCARIBE has been proactive in creating a tsunami warning system for the Intra-Americas Sea since the 1993 Martinique workshop, although the Atlantic hazard has been well recognized for many years (Bryant, 1991, 2005; Smith and Shepherd, 1993; Watlington and Lincoln, 2001; Ruffman, 2001; O'Loughlin and Lander, 2003 amongst others). Gonzalez (1999) doesn't mention the Atlantic, nor the Caribbean Sea in particular, in his writing (see the many pre-1999 references in Lockridge *et al.,* 2002).

Caribbean Sea tsunami events have been recorded since the coming of European explorers in the 15th century. Table 1, extracted from O'Loughlin and Lander (2003) and UNESCO (2010), summarizes the major deadly events from 1498 to the present. There are n = 26 events in the last 500+ years wherein drownings are reported or are very probable, and many more tsunamis where deaths are not reported or simply not recorded. On average, the time difference (Δt) between tsunami-related drowning events is 19 ± 22 years (± one standard-deviation). The frequency distribution of Δt is positively skewed (Figure 1), and suggests that one event is likely to have another close in time followed by a much longer Δt until the next event. The two tsunamis in the Dominican Republic in 1946 where 1,790 persons died one day, and four days later another tsunami claimed 75 more souls, is an example of such a statistical distribution.

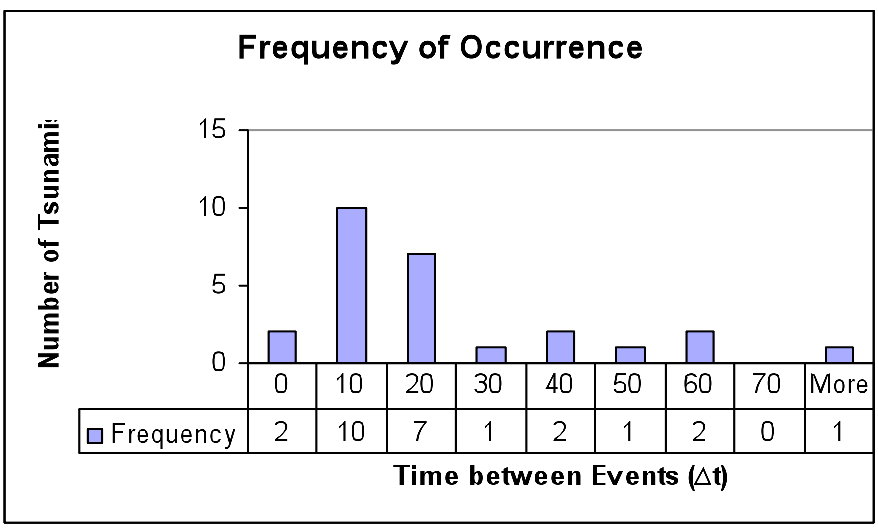

Figure 1: Frequency distribution of death-causing tsunamis in the Caribbean Sea since 1498. Frequency upper row labeled "10" includes all events $1 \leq \Delta t \leq 10$ years; upper row "20" includes all $11 \leq \Delta t \leq 20$ years, etc.

As IOCARIBE matured in its appreciation of the tsunami hazard, efforts to encompass the entire western Atlantic Ocean began to emerge (Maul, 2003; Mercado and Liu, 2006). IOCARIBE created a Tsunami Steering Group of Experts in 1995, and there have been annual meetings since. The parent body of IOCARIBE, the IOC, raised the level of attention to that in the Pacific and Indian Oceans in 2006 by creating an Intergovernmental Coordinating Group (ICG) for the Caribbean (and another ICG for the Indian Ocean) that is on a level with the ICG for the Pacific (called "ITSU"). Thus the IOC, the international agency responsible for tsunami warnings and information, is actively engaged in developing mechanisms to prevent a repeat of the horrific event of 2004, yet Teeuw *et al*. (2009) make no mention of the Caribbean IGC.

Table 1: Summary of death-causing tsunamis in the Caribbean Sea

Year	Location	Notes
1498	Venezuela	Opened Gulf of Cariaco
1530	Venezuela	Affected entire north coast of South America
1543	Venezuela	City of Cumaná destroyed
1599	Venezuela	Cumaná; frequent inundations by the sea over the low shore
1690	Virgin Islands	Deaths in Antigua, Guadalupe, and St. Kitts
1692	Jamaica	Port Royal 1,000-2,000 drown
1751	Dominican Republic	Town of Azua de Compostela destroyed
1751	Haiti	Part of Port-au-Prince submerged
1755	Lesser Antilles	Lisbon Tele-tsunami; deaths in Saba and Martinique
1761	Barbados	Tele-tsunami from same region as 1755 Lisbon event
1770	Haiti	The sea inundated 7 km onto the shore
1775	Hispaniola and Cuba	Great damage from waves at Haiti and Cuba
1780	Jamaica	Savanna-la-Mar swept away by 3 m wave; 300-1,000 deaths
1812	Venezuela	Exceptional rise of the sea at La Guaira; 3,000 killed
1822	Nicaragua	Punta Chica lagoons dried, canoes left dry
1842	Haiti	Port-de-Paix, 200-300 perished; 2-3 m tsunami
1853	Venezuela	Loss of life in Cumaná area estimated between 600-4,000
1856	Honduras	Criba Lagoon bottom dry
1867	Danish West Indies	Loss of life was probably great; 23-50 dead in USVI
1882	Panama	San Blas coast; 75-100 drowned
1902	Martinique	Dead bodies floated singly and in groups
1906	Venezuela	Death toll estimated at 500 victims
1907	Jamaica	Port Royal; submarine cable broken in three places
1918	Puerto Rico	Aguadilla and Mayaguez; 116-140 dead
1946	Dominican Republic	Matancitas coast; approximately 1790 killed
1946	Dominican Republic	Sabana la Mar; 75 perished
1991	Costa Rica	At Moin the sea withdrew 200 m; 2 drowned at El Matina
2010	Haiti	Petit Paradis; 3 m wave; at least 7 drownings

RISK ASSESSMENT

Whitmore *et al.* (2009) discuss Atlantic tsunami risk primarily in the context of probability of occurrence. Risk assessment is a complex process that is much more than simply calculating the probability of occurrence such as that from Table 1 with Δt summarized in Figure 1. Nott (2006) explains the issue of risk by defining *Total Risk* as follows:

Total Risk = Hazard x Elements at Risk x Vulnerability

where *Hazard* is the frequency of occurrence, *Elements at Risk* measures population, infrastructure, and economies that would be affected by an event, and *Vulnerability* measures societal attitudes and preparedness. Using this approach, a clearer understanding emerges for the possibility of a major catastrophe in the wider Caribbean and other ocean basins.

Three cases of *Total Risk* for the Caribbean are investigated: a tele-tsunami such as the 1755 Lisbon event which sent waves across the Atlantic to the Americas; a comparison with Hawaii (a similar climate and, as with the Caribbean, at risk from tele-tsunami as well as near-field events); and with a cold climate, Alaska. The results are given in Tables 2, 3, and 4 respectively. Data for estimating *Elements at Risk* is gleaned from tourism databases (*e.g.* CTO, 2010) and governmental reports, which often are unofficial, but the only sources available (according to the Caribbean Tourism Organization, there were 17,919,000 stop-over arrivals in 2009, and 17,210,000 cruise passenger arrivals in 2009). *Vulnerability* can be judged in part by the number of Tsunami-Ready communities in a given area.

In Table 2, the coasts of California, Oregon, and Washington are compared with the Caribbean region for tsunami *Hazard* and for *Total Risk*. The Lisbon event of 1755 (Mader, 2004) is used as the Atlantic event that might be compared with the Chilean event of 1960 in the Pacific. Certainly the statistics (*cf.* Bryant, 2005) support that the *Hazard* to the USA Pacific states is substantially higher than that for the Caribbean. However, factoring in the much higher beach population on any given day in the Caribbean (*Elements at Risk*) and the lack of Tsunami-Ready communities (*Vulnerability*), the *Total Risk* is estimated to be at least as high or higher for the Caribbean and its peoples than for the United States west coast partly due to the warm water draw of the Caribbean Sea over the cold upwelling waters of the Pacific States.

Table 2: Comparison of the *total risk* from a tele-tsunami in the northeastern Pacific Ocean and in the Caribbean Sea.

	Frequency of Occurrence	Water Temperature	Daily Beach Attendance	Impact with 10% Loss of life	Hazard	Total Risk
Caribbean Region	1/250 years	Warm	500,000	20,000 per Century	Low	Very High
West Coast USA	1/50 years	Cold	40,000	4,000 per Century	High	High

Hawaii as a state is well prepared for tsunamis with many Tsunami-Ready communities, beachfront sirens to warn swimmers and sunbathers, and political appreciation of the risk (Bernard, 2005). The Tsunami Warning System in the Pacific (ITSU) is headquartered in Oahu and the warning system has been operational for over half a century. While Hawaii is at risk from tele-tsunami (*cf.* Table 2) it also is at risk from locally generated events. As a comparison to the Caribbean, consider the case of the (now) US Virgin Islands which had a 6 meter wave sweep into St Thomas and into St. Croix minutes after the 1867 earthquake in the Anegada Passage (Watlington and Lincoln, 2001). In Table 3 the *Hazard* and the *Total Risk* for the Caribbean and for Hawaii are compared, and it is seen that the *Total Risk* for the Caribbean is higher than for Hawaii not only due to larger beach attendance (*Elements at* Risk), but to the much higher *Vulnerability* due to lack of preparedness and warning infrastructure.

Table 3: Comparison of the *total risk* from a local tsunami in Hawaii and in the Caribbean Sea.

	Frequency of Occurrence	Water Temperature	Daily Beach Attendance	Impact with 10% Loss of life	Hazard	Total Risk
Caribbean Region	1/20 years	Warm	500,000	50,000 per Century	High	Very High
Hawaii	1/25 years	Warm	100,000	40,000 per Century	High	Very High

Alaska is the site of the United States' second tsunami warning center, with responsibility to warn all states in the Pacific except Hawaii and (Whitmore *et al.,* 2009), as an interim to a Caribbean Tsunami Warning Center, the east coast of the USA including Puerto Rico and the US Virgin Islands. The *Hazard* to Alaska is high due to the proximity of the Aleutian Trench subduction zone, but it is a cold-water environment compared to say Puerto Rico. The Puerto Rico Trench is seismically active and was the source of deadly waves for Puerto Rico in 1918 and the Dominican Republic twice in 1946 (Lockridge *et al.,* 2002; O'Loughlin and Lander, 2003) in the last century (*cf.* Table 1). As with most Pacific-coast communities, Alaska is well-prepared for a tsunami, and to a lesser extent, so is Puerto Rico and the US Virgin Islands (Mercado-Lrizarry and Liu, 2006). Clearly the *Hazard* in Alaska (Table 4) is higher than Puerto Rico, but equally clear is that the *Total Risk* to the Caribbean is much higher due to the *Elements at Risk* and the *Vulnerability*.

Table 4: Comparison of the *total risk* from a local tsunami in Alaska and in the Caribbean Sea.

	Frequency of Occurrence	Water Temperature	Daily Beach Attendance	Impact with 10% loss of life	Hazard	Total Risk
Caribbean Region	1/20 years	Warm	500,000	50,000 per Century	High	Very High
Alaska	1/25 years	Very Cold	5,000	2,000 per Century	High	High

DISCUSSION

The Caribbean Sea and its environs are tsunami hazard zones (*cf.* Table 1) due to near-field events (*e.g.* Dominican Republic in 1946), subaerial landslides (*e.g.* Montserrat in 1998), submarine volcanoes (Smith and Shepherd, 1993), and tele-tsunami (*e.g.* Lisbon in 1755); submarine slumping and subaerial volcanoes add to the potential for death-causing tsunami (Mercado- Lrizarry and Liu, 2006). Knowledgeable local residents even have a term for it: "El Peligro Olvidado" The Forgotten Danger! The NOAA National Weather Service has taken action by assigning the Pacific Tsunami Warning Center in Hawaii to issue warnings for our Caribbean neighbors to Puerto Rico and the US Virgin Islands, but no local warning center is yet funded to holistically address all aspects of the danger (education, warning, management, and research (Maul, 2003)).

Analyzing *Total Risk* (Nott, 2006) as the product of probability of occurrence (*Hazard*) times population and other *Elements at Risk*, times preparedness and political awareness (*Vulnerability*), it is seen that the Caribbean tsunami danger is Very High in all three cases analyzed: tele-tsunami (Table 2), Hawaii comparison (Table 3), and Alaska comparison (Table 4). While the *Hazard* in the Caribbean is one death-causing event every 19 years on average (based on about 500 years of data), the statistical distribution (19 ± 22 years) has high positive skewness (*cf.* Figure 1). Skewness suggests that one or more events have occurred close together and then there is a long time (Δt) before the next event. Using the very deadly tsunami in the Dominican Republic of 1946 as a guide, there are in 2010, +2.9 standard deviations in Δt since the last multihundred-death event. Thus the *Hazard* of a death-causing Caribbean tsunami in the near future is high and the *Total Risk* is very high.

High *Total Risk* coupled with the increasing coastal population (Duedall and Maul (2005) estimated that the coastal population of the North Atlantic for 2025 is 40 million more persons above that in 2000, and mostly in the Caribbean and North Africa) further increases the *Elements at Risk*. That, coupled with lack of awareness and political inaction, increases the *Vulnerability*. The stage seems set for a catastrophe of unimaginable proportions that humankind experienced in the 2004 event in all its horror. Since 2004, there has been another global disaster. This time in the Caribbean country of Haiti where an earthquake on January 12, 2010, killed more than 200,000 people. Had the earthquake been more tsunamigenic, the death toll (6 or 7 persons drowned) would have been even more horrific.

Depending upon tsunami warnings from half a world away, further increases *Total Risk* from lack of local expertise, cultural knowledge, language, and a presence that demonstrates regional commitment to safeguarding the lives and property of inhabitants and visitors in the Caribbean.

CONCLUSIONS

The Indian Ocean and the southwestern North Atlantic Basin have much in common besides warm waters and similar low-lying coastal topography. The NOAA Geophysical Data Center reports that the Caribbean Basin has had 8% of the world's tsunami events (*cf.* Bryant (2005) who reports 13.8%), and the Indian Ocean, 7% (Bryant reports 0.8 % for the Bay of Bengal). Yet an Indian Ocean tsunami on December 26, 2004 caused well over 250,000 deaths by drowning. The Caribbean has had 6 times more deaths in the last 168 years than Alaska, Hawaii, Washington, Oregon, and California combined

(O'Loughlin and Lander, 2003). With numerous close-field tsunamigenic sources, the Caribbean has dire need of a local-expertise Tsunami Warning Center with multi-national (thirty three independent states), trilingual (English, French, and Spanish) preparedness to best assure protection of life and property. Anything less will lead to unnecessary loss of life and worldwide criticism.

The views expressed are those of the author(s) and do not necessarily represent those of NOAA.

REFERENCES

Bernard, E.N. (editor). *Developing Tsunami-Resistant Communities*, the National Tsunami Hazard Mitigation Program. ©Springer, Dordrecht, 184 pp., 2005.

Bryant, E.A. *Natural Hazards,* 2nd edition. ©Cambridge University Press, Cambridge, New York, Melbourne, 312 pp., 2005.

CTO (Caribbean Tourism Organization). Latest Statistics, 2009. CTO_MAY6Lattab09.pdf, April 27, 2010.

Duedall, I.M., and G.A. Maul. Future Coastal populations. In: M. Schwartz, (editor), *Encyclopedia of Coastal Science*, ©Kluwer Academic Publishers, Dordrecht, pp: 368-374, 2005.

Gonzalez, F.I. Tsunami! *Scientific American*, 280(5): 56-65, 1999.

Lockridge, P.A., L.S. Whiteside, and J.F. Lander. Tsunamis and Tsunami-Like Waves of the Eastern United States. *Science of Tsunami Hazards*, 20(3): 120-157, 2002.

O'Loughlin, K.F., and J.F. Lander. *Caribbean Tsunamis: a 500-year history from 1498-1998*. ©Kluwer Academic Publishers, Dordrecht, Boston, 263 pp., 2003.

Mader, C.L. Modeling the 1755 Lisbon Tsunami. *Science of Tsunami Hazards*, 19(2): 93-99, 2004.

Maul, G.A., (editor). *Small Islands: Marine Science and Sustainable Development.* © American Geophysical Union, Coastal and Estuarine Studies No. 51, Washington, 476 pp., 1996.

Maul, G.A. Atlantic Tsunami Warnings Are Needed. Guest Editorial, *Sea Technology*, 44(3), pp: 7, 2003.

Mercado-Lrizarry, A. and P. Liu (editors), *Caribbean Tsunami Hazard - Proceedings of the National Science Foundation Caribbean Tsunami Workshop*, World Scientific Publishing, Co., Singapore, 341 pp., 2006.

Nott, J. *Extreme Events – Physical Reconstruction and Risk Assessment*, ©Cambridge University Press, Cambridge, 297 pp., 2006.

Ruffman, A. Comment on "Potential for large-scale submarine slope failure and tsunami generation along the U.S. mid-Atlantic coast: comment". *Geology*, 29, pg. 967, 2001.

Smith, M.S., and J.B Shepherd. Preliminary investigations of the tsunami hazard of Kick'em Jenny submarine volcano. *Natural hazards*, 7: 257-277, 1993.

Teeuw, R., D. Rust, C. Solana, C. Dewdney, and R. Robertson. Large Coastal Landslides and Tsunami Hazard in the Caribbean. *EOS*, Transactions, American Geophysical Union, 90(10): 81-82, 2009.

UNESCO Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (CARIBE EWS) 12 January 2010 Haiti Earthquake and Tsunami Event Post-Event Assessment of CARIBE EWS Performance, IOC Information Series No. 90, 2010.

Watlington, R.A., and S.H. Lincoln. *Disaster and Disruption in 1867: Hurricane, Earthquake, and Tsunami in the Danish West Indies*. ©University of the Virgin Islands, St. Thomas, USVI 00803, 134 pp., 2001.

Whitmore, P., U. ten Brink, M. Caropolo, V. Huerfano-Moreno, W. Knight, W. Sammler, and A. Sandrik. NOAA/West Coast and Alaska Tsunami Warning Center Atlantic Ocean Response Criteria. *Science of Tsunami Hazards,* 28(2): 86-107, 2009.