OKUSHIRI TSUNAMI / UJNR WORKSHOP 1998

July 9 - 14, 1998

EVALUATION OF TSUNAMI SOURCE SCENARIOS IN THE CARIBBEAN SEA AND SIMULATION OF WAVE HEIGHTS - a TIME Project Activity

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1. INTRODUCTION

Colombia has extended coastlines on both the Pacific Ocean and the Caribbean Sea. But, while its Pacific coasts are close to a very active and tsunamigenic subduction zone and have sustained several disasters, the tsunami hazards at its Caribbean coasts - both continental and insular – are yet unknown, but basically perceived as insignificant and, in any case, much smaller than those caused by swell episodes during the annual hurricane seasons. On a regional scale, tsunami hazards are also regarded as a lesser concern, compared to rather frequent disastrous hurricanes.

The available historical cataloges (*Grases*, 1994; *Lander & Lockridge*, 1989) do not list any tsunami impact on Colombian coasts. However, the lack of historical events cannot be conclusive; the recurrence periods of large earthquakes in the Caribbean are rather long and smaller events may have passed unrecorded, among the very frequent - in fact, yearly - ocurrences of swell due to hurricanes, and due to the lesser attention to natural events during periods of war and buccaneer activity. But the Caribbean is indeed a seismically active region; its rims -from Guatemala over the Greater and LesserAntilles, Venezuela, Colombia, Panamá and part of Costa Rica – are plate margins (Fig. 1). While long segments of this margin are lateral or extensional tectonic features, others – from Hispaniola to Trinidad and in front of Colombia and Panamá – are subduction zones. There is no record yet of a Caribbean-wide tsunami, but local tsunamis have been reported from many areas, over most of the active segments of its rim and mainly in the Antilles Arc; the best known event is probably the 1692 Port Royal (Jamaica) disaster.

In order to provide foundations for decisions and to assess the need for tsunami mitigation measures for Colombia's Caribbean coasts, including a recently proposed regional tsunami warning system, we have made a preliminary evaluation of tsunami hazards, covering the most likely sources, earthquakes, although volcanic and submarine landslide tsunami are also possible, at much lower frequency. With a deterministic approach, using using available seismotectonic and historical information, we analized one by one the regional seismotectonic features, to identify the most likely sources of tsunami which could threaten the coasts of Colombia. To obtain an estimate for probable tsunami wave heights, numerical simulations of wave generation and propagation were performed, using the shallow water equations as implemented in the TIME routines.

2. APPROACH AND METHODS

Having no historical tsunami record for the coasts of Colombia, the obvious approach for estimating the level of hazard was a deterministic one: the identification of "capable" sources and the numerical estimation of tsunami wave heights from likely maximum earthquakes on these faults. As capable sources we considered those which, by size, location and focal mechanism (*Chubarov, Gusiakov*, 1985; *Okal*, 1988)), could generate waves of significant height at Colombian coasts. For their determination we recurred to historic, tectonic and seismic data.

To model the wavefields for these sources, we solved numerically the shallow water equations, as implemented in the TIME routines (*Goto & Ogawa*, 1989). The initial conditions were modeled after *Mansinha & Smylie* (1971), using available scaling relations.

We did not consider tsunami hazards derived from volcanic activity; although existent in the Caribbean, they are far of lower recurrence than tsunamis of seismic origin (*Smith & Shepherd*, 1993; *Sigurdsson*, 1996).

5. THE NEAR SOURCE

In principle, the closest tsunami source for the continental Colombian coast would be the Southern Caribbean Deformed Belt (Fig. 1). This tectonic feature has evidences of present subduction, but with very low levels of seismicity. *Toto & Kellogg* (1992) interpret it as a nascent subduction zone, where the ingestion of large amounts of water-saturated sediments and low convergence velocity, as well as still small dimensions of the slab, are the factors that determine its very low seismicity. Also, the Colombian historical earthquake catalogue (*Ramírez*, 1974) does not include events that can be assigned to this source. Thus, there is no indication of a potential for tsunamigenic earthquakes from this source.

The eastward continuation of this compression belt, the North-Panama Deformed Belt shows different traits: higher levels of seismicity, down to depths of about 70 km (*Adamek et al*., 1988), and large historical earthquakes (*Mendoza & Nishenko*, 1989). An earthquake in the central part of this belt in 1882, assigned magnitudes between 7.9 and 8.3 (*Camacho & Viquez*, 1992; *Mendoza & Nishenko*, 1989), caused waves of at least 6 m on near shores and was recorded with 0.62 m on the Colón tidegage. We selected this event, which is not included in the Lander & Lockridge catalogue, as the source for our near tsunami scenario, with a magnitude of 8.0.

For modeling the tsunami initial condition, we used *Mendoza & Nishenko's* (1989) macroseismic epicenter, *Purcaru & Berckhemer's* (1978) seismic moment relation, rupture dimensions (140x50 km) that adjust to Mendoza & Nishenko's intensity distribution, and a fault displacement (4.5 m) according to the relation from *Ohnaka* (1978).

The resulting model shows (Fig. 2) that the highest waves are radiated towards the NE, away from Colombian coasts. The maximum wave heights are is 0.22 m at Cartagena and 0.27 m at San Andrés (Fig. 4). Basin-wide, the maximum wave heights (with a regional bathymetric model) are about 1.5 m, close to the source. The longest propagation times (E-W) for a trans-Caribbean tsunami are abour 4.5 h.

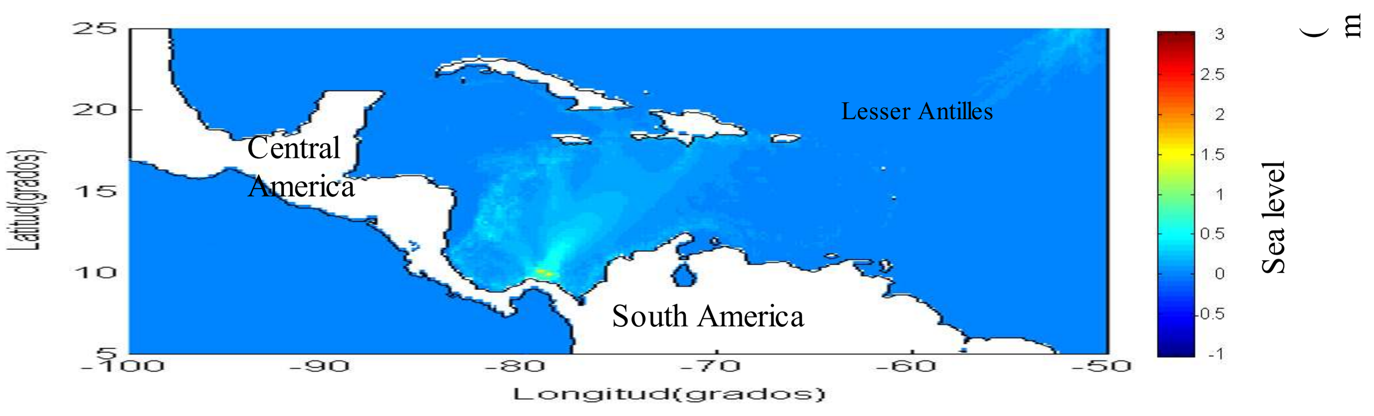

Fig. 2. Maximum tsunami wave heights for the Panamà source

7. CONCLUSIONS

Our first approximation to the levels of tsunami wave hazards in the Caribbean and to the exposure of Colombia's coasts, based on determination of sources from historic, tectonic and seismic evidence and on numerical wavefield modeling, yields results which confirm the very low level of hazard already projected from historic evidence.

We have determined two sources (N-Panamá, northern Lesser Antilles), which seem to be the most relevant, both for the scenarios of basin-wide tsunami hazard and for the exposure of Colombia's coast. At Colombian coasts the calculated maximum waves heights are not higher than those which occur frecuently due to hurricanes in the eastern Caribbean. As for the regional scale, from our first approximation it seems that only the coast of Venezuela could benefit from a regional tsunami warning system, for events originated along the Antilles subduction zone.

Some significant uncertainties remain after the described analysis and modeling. Small-scale simulations of terminal propagation are necessary for specific sites, allowing for consideration of local features which could enhance wave heights (bottom profiles, coastal forms, island effects); these are presently being done, to further detail the knowledge of tsunami exposure of the Colombian coast. As for the hazard to Colombia´s coast, it remains open if a large magnitude earthquake can occurr farther to the S of the N-Panamá Deformed Belt (which would radiate more directly towards those coasts).

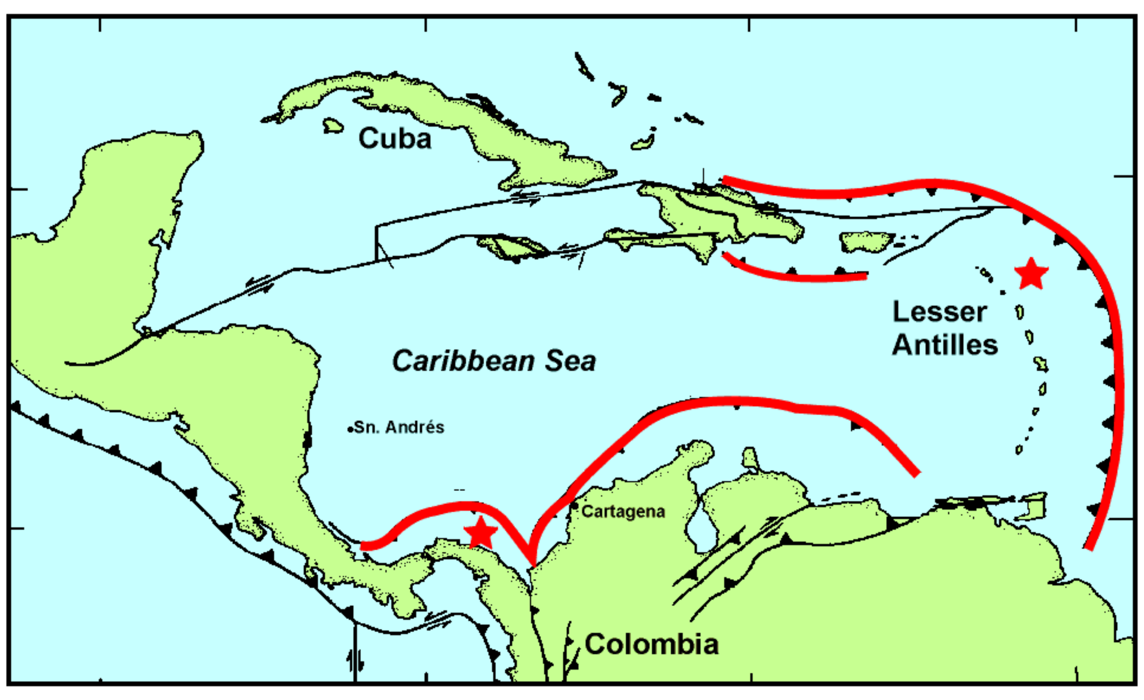

Fig. 1. Regional tectonics in the Caribbean and location of the two modeled tsunami sources.

3. TSUNAMI IN THE CARIBBEAN

Tsunami listed in recent catalogues (*Grases*, 1994; *Lander & Lockridge*, 1989) are mostly confined to the Antilles Arc; few were reported from the coasts of Venezuela and Trinidad-Tobago, and only one from Costa Rica. Among these is one oceanic tsunami (the 1755 Lisbon event), many local events, but no Caribbean-wide tsunami. There are no reports of Caribbean-wide tsunamis.

This historic evidence reflects quite well the seismotectonic regime in the region and the relative tsunamigenic efficiency of the faults that bound the Caribbean tectonic plate: the largest tsunami occurred along the subduction zones of the Eastern Caribbean Arc; some local events are related to earthquakes on the strike-slip systems along the northern and southern rims of the region. There are no reports from the western margin (northern Costa Rica, Nicaragua, Honduras), where the Caribbean margin has no major submarine faults.

4. DATA

The tsunamigenic earthquakes considered in our hazard scenarios are historical; the seismic rupture parameters used in the bottom deformation models are thus from macroseismic data and derived from applicable empirical relations.

For the numerical wave simulations we used NOAA's digital bathymetric database ETOPO-5, with a 5'x 5' resolution.

6. THE FAR SOURCE

A recent evaluation of the region's seismic activity and potential (*Panagiotopoulos*, 1996) locates the highest levels of the Caribbean region in the Antilles subduction zone, between Santa Lucia (14ºN) and Hispaniola. The largest instrumentally recorded event (M=8.1) occurred here in 1946, however to the NE of the Dominican Republic, thus radiating very little of its tsunami energy into the Caribbean. *Aspinall et al*. (1994) assign a maximum magnitude of M=8.5 to this segment of the Antilles Arc, based on a historical revaluation of the 1843 Antigua earthquake. There are no tsunami reports for this event, however, we assume it as the probable source for a maximum tsunami with trans-Caribbean potential; the sources of the historic tsunami with reports of significant wave heights at greater distances are in this segment (*Lander & Lockridge*, 1989).

The numerical wave model shows a complex pattern (Fig. 3); some of the tsunami energy is reflected by the island arc back into the Atlantic and some is reflected by a major impedance step, a prominent N-S structure in the eastern Caribbean, the Aves Ridge. Thus, at a regional scale only near areas in the island arc, as well as some places along the coast of Venezuela are likely scenarios for hazardous wave amplitudes. In Colombia, the maximum calculated wave heights are 0.38 m for the location of Cartagena and 0.15 m for San Andrés Islands.

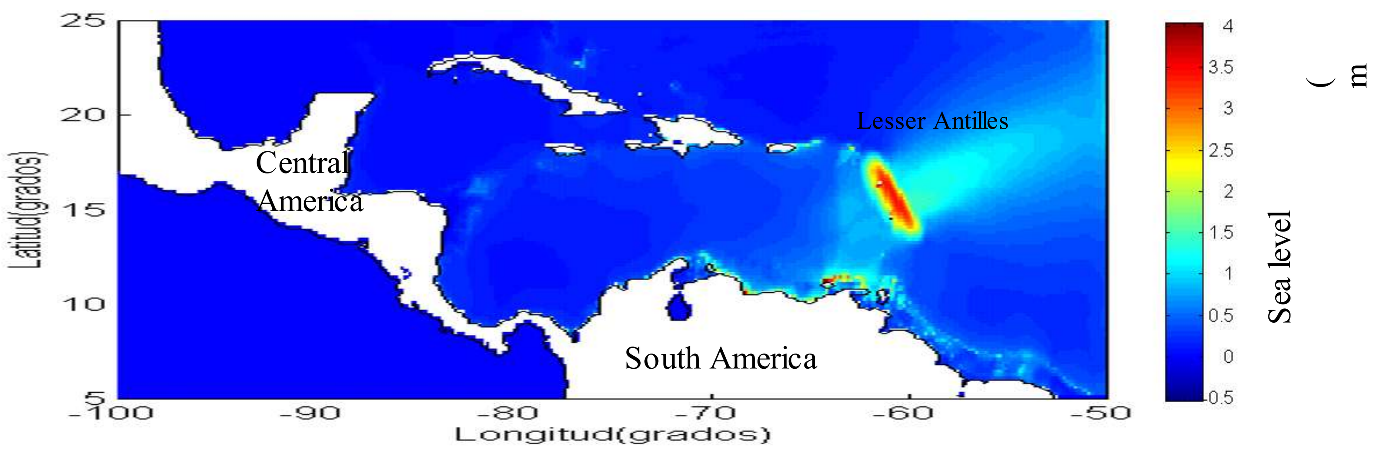

Fig. 3. Maximum tsunami wave heights for the N-Antilles source

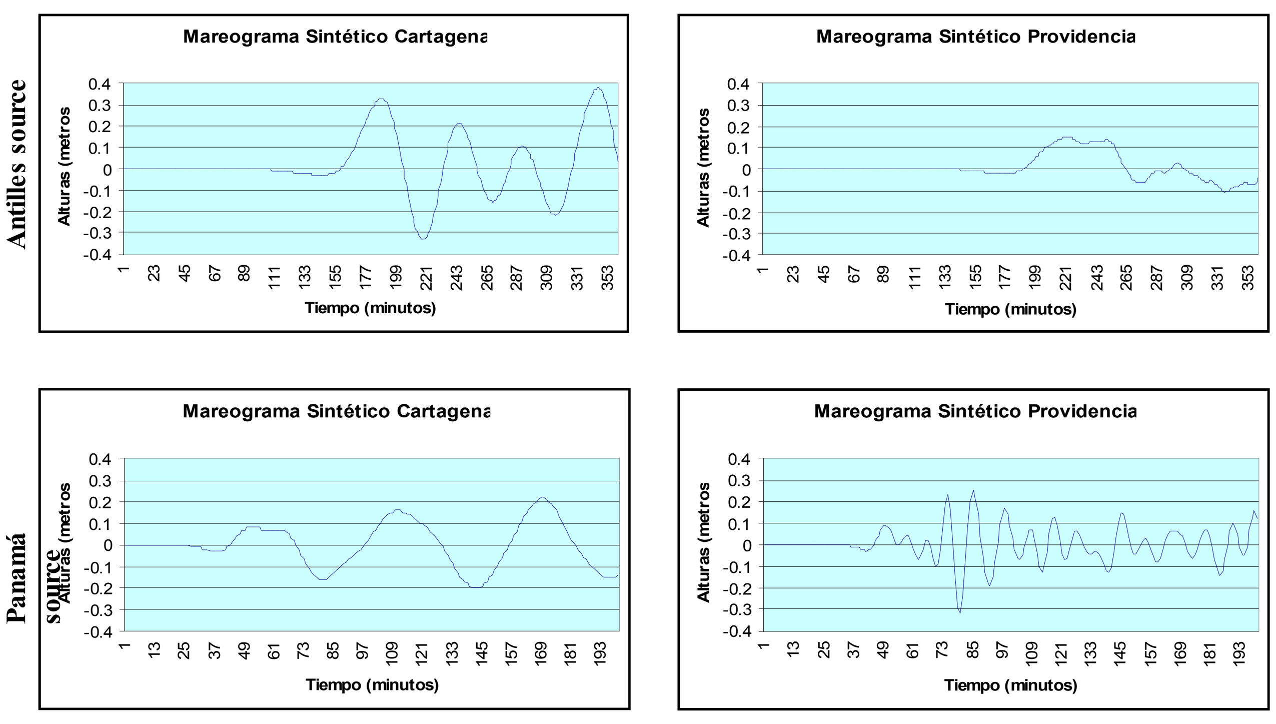

Fig. 4. Synthetic tide records for Cartagena and San Andrès Islands

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ACKNOWLEDGMENTS

The authors wish to thank for the support received from the Swiss Disaster Relief and from the TIME Project (University of Tohoku).

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