Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et 10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Vancouver, Canada ♦ Paper No. 1837

TSUNAMI IMPACT ON NEWFOUNDLAND, CANADA, DUE TO FAR-FIELD GENERATED TSUNAMIS. IMPLICATIONS ON HAZARD ASSESSMENT.

J. Roger[1,2], M.A. Baptista[2,3], D. Mosher[4], H. Hébert[5], A. Sahal[6]

ABSTRACT

In Canada, tsunamis associated with submarine earthquakes have been considered in terms of hazard assessment for many years; mainly due to the Pacific tsunami threat and to gravitational instabilities on continental slopes. This latter instance refers to the case of a submarine landslide and consequent tsunami generated by the Mw=7.2 earthquake of 18th November 1929 on the Grand Banks of Newfoundland.

In this study, we investigate the impact on Newfoundland of far field generated tsunamis in the Atlantic Ocean and consideration of such tsunami hazards for the Canadian Atlantic Coast.

In the framework of the study of the 1755 Lisbon tele-tsunami, we show that a 1755 tsunami like event, with the source located offshore the Iberian Peninsula, can impact Newfoundland. The coastal amplification is also studied in detail using high resolution bathymetric grids. Finally the results of tsunami propagation modeling are compared to historical data of the 1st November 1755 concerning at least two places in Newfoundland.

Objectives

It is the intent of this paper to investigate the feasibility of trans-Atlantic tsunamis impacting the opposing continental margin by simulating the Lisbon 1755 tsunami arrival in Newfoundland, Canada.

[1] Ecole Normale Supérieure / Laboratoire de Géologie, 24, rue Lhomond, 75231 Paris CEDEX 5, France
[2] Centro de Geofisica da Universidade de Lisboa, Rua Ernesto de Vasconcelos, Faculdade de Ciències Ed. C8, 6°, 1700 Lisboa, Portugal
[3] ISEL, Instituto Superior de Engenharia de Lisboa
[4] Natural Resources Canada / Geological Survey of Canada – Atlantic / 1 Challenger Drive (P.O. Box 1006) / Dartmouth, Nova Scotia, Canada B2Y 4A2
[5] CEA, DAM, DIF, F-91297 Arpajon, France
[6] Université Paris 1 Panthéon-Sorbonne, Laboratoire de Géographie Physique, UMR 8591, 1 place Aristide Briand, 92195 Meudon Cedex, France

Introduction

On the 1st November 1755, an earthquake of estimated magnitude Mw=8.5/9.0 occurred offshore the Iberian Peninsula. This destructive event, known as the Lisbon earthquake because of its devastating effect on Lisbon, Portugal, was felt in the whole of Western Europe as far north as Hamburg (Germany). As a direct consequence of the earthquake, a destructive and widespread tsunami was generated which reached the coasts of Portugal, Spain, Morocco, and even those of southern England and the Atlantic archipelago of Madeira and the Azores. Recent studies highlighted coeval reports of tsunami arrivals in the West Indies on the 1st of November 1755, with noticeable wave amplitudes and significant flooding of low coastal areas on the French Island of Martinique (Roger et al. subm.).

In this study, we investigate the possible impact of this transoceanic event in the North Atlantic area of Canada. Additional historical data from Newfoundland is analyzed. These documents demonstrated the occurrence of an uncommon phenomenon in Bonavista, Newfoundland. Tocque (1846) and Batterson et al. (1999) indicated that the sea emptied the harbour; after ten minutes the water returned and inundated low parts of the town.

A separate report concerns observations at St. John's, on the east coast of Newfoundland (Batterson et al. 1999). This report indicates that on the 11/01/1775 in St. John's, the "sea suddenly rose 10 m". This could be linked to a storm. But the 11/01 may well refer to the first of November, as this is the notation order convention for the United States. The USA uses month/day/year, as opposed to the European convention, which is day/month/year. The year, 1775 could easily have been written in error for 1755; the year of the Lisbon earthquake.

Numerical modelling

Coseismic tsunami generation is modeled using available seismic source parameters from Zitellini et al. (1999) for the 1755 tsunami source located offshore the Iberian Peninsula. The double segment source used in this model includes a segment based on geological features oriented toward North America. Tsunami propagation on measured bathymetric grids is modeled taking into account shallow water theory and the hydrodynamic equations of continuity (Eq. 1) and momentum conservation (Eq. 2).

$$\frac{\partial(\eta + h)}{\partial t} + \nabla.[v(\eta + h)] = 0 \qquad (1)$$

$$\frac{\partial v}{\partial t} + (v.\nabla).v = -g\nabla\eta \qquad (2)$$

Different model results based on low resolution (5') bathymetric grids (Roger et al. 2009; Roger et al. subm.) demonstrate two main tsunami pathways containing most of the energy and thus maximum wave heights (Fig. 1). One pathway is directed towards South America and another one towards Canada, and more specifically towards Newfoundland (Fig. 1, GR00).

The use of high resolution bathymetric grids for Newfoundland is necessary to investigate detailed propagation near the coast. The bathymetric data used are a combination of Gebco 1' dataset (British Oceanographic Data Centre, 1997) and bathymetric data of the Canadian Hydrographic Service. The grids include 4 different resolution levels with special focus on the regions of Bonavista and St. John's with a spatial resolution of 150 m. This resolution is able to reproduce correctly the shape of the coast (Roger et al. 2009 ; Sahal et al. 2009). Topographic data were included to produce a continuous (ocean-land) digital elevation model in order to compute inundation.

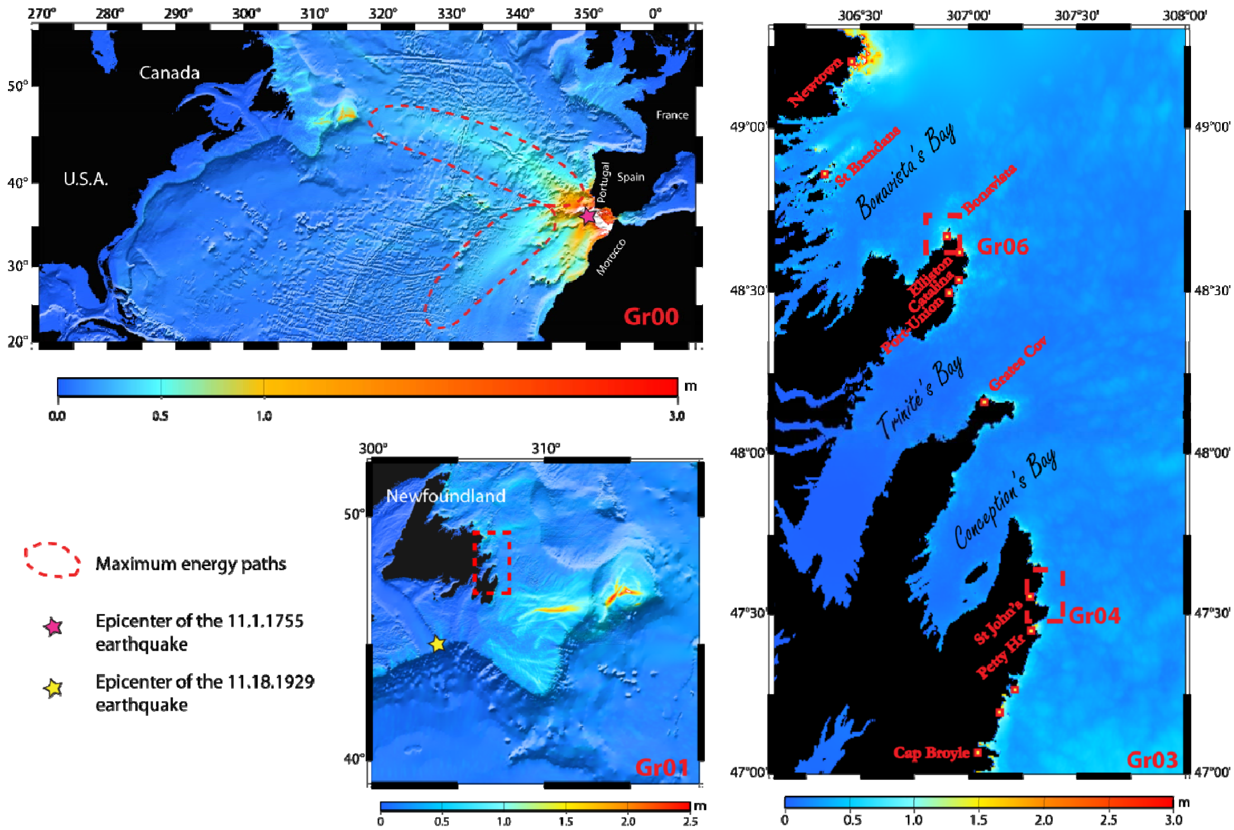

Figure 1. Maximum wave heights illuminated by bathymetric gradient after 9h of tsunami propagation using Baptista et al. (2003)'s combined seismic source.

Modeling Results and Discussion

The results presented in Figure 1 (GR01 and GR03) show that some areas are prone to tsunami amplification due to shoaling effects. Wave heights of more than 2 m are modeled on the shallow banks of the Newfoundland continental shelf. At several locales along the coast, such as Newton/Torbay, Bonavista (and area), Grates Cove, Freshwater Bay (Blackhead) and St. John's, significant wave heights of more than 1.5 m are modeled.

Figure 2 shows that the peninsula of Bonavista could be affected by tsunami waves sourced from the Iberian Peninsula. Wave heights reach 2.5 m and more in some locations, with inundation of low-lying lands, particularly the town centre, around the harbour, and the swamp areas north to the town.

Concerning St. John's, first results obtained on the 150 m resolution grid indicate that the waves do not enter the bay (the lack of accurate bathymetric data inside the bay (Fig. 3) should be considered cautiously). Even modeling with a finer grid (40 m), the waves do not enter the harbour. The narrow restriction (300 m) at the mouth of the harbour provides significant protection. Nevertheless, models indicate 1 m tsunami wave heights reach the entrance of the harbour.

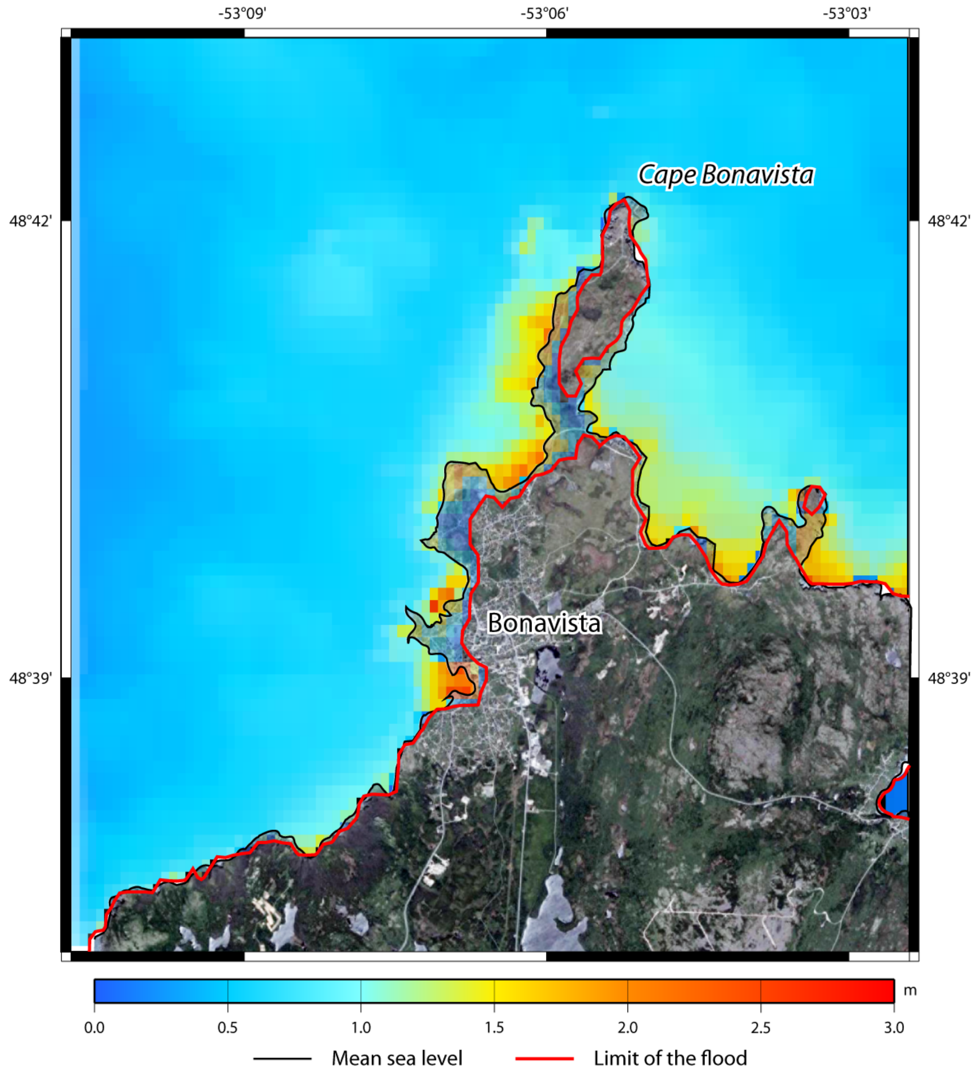

Figure 2. Sea surface elevation and maximum flow depth on the 150 m resolution grid (GR06) showing the Cape of Bonavista after 9 h of tsunami propagation. A satellite view (Google Earth ™) allows the correlation between populated areas and wave amplification.

Wave height reaches a maximum of about 2 m in Freshwater Bay, just south of St. John's Harbour and west of Cape Spear, North America's easternmost point. Freshwater Bay is a funnel-shaped embayment with a shoaling barrier beach and back-beach lagoon. Its morphology and orientation seems to be particularly receptive to long waves (Fig. 3) such as those modeled in this study. The back-bay lagoon area and estuary would be a likely locale to search for tsunami deposits.

1755 Lisbon tsunami simulation results for Bonavista Harbour, Newfoundland are in good agreement with brief historical accounts of inundation of the town at that time. Today, this town is well developed (1 km radius from the central harbour) and so it is not totally inundated in the numerical simulation. In 1755, however, the town was likely much smaller and focused around the harbour, since fishing was the sole source of livelihood. The entire settlement could have been impacted from the tsunami, therefore.

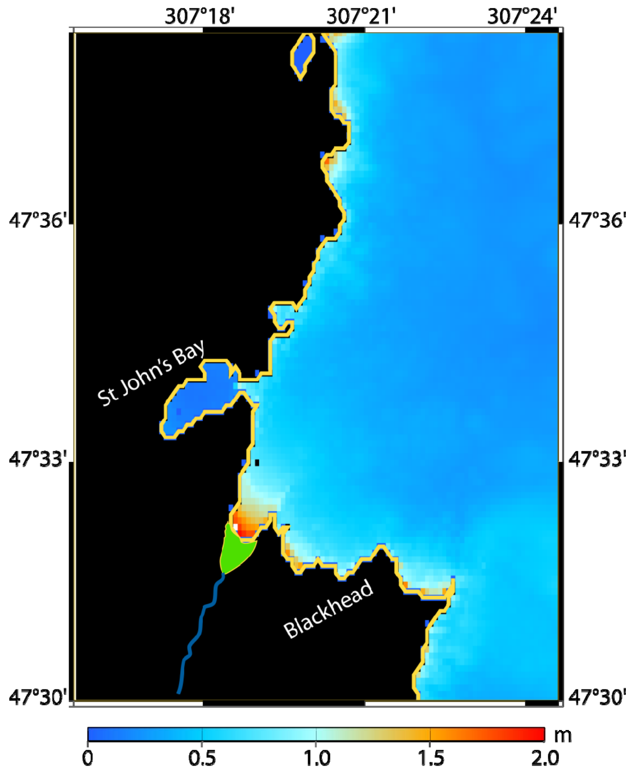

Figure 3. Maximum wave heights on St John's Bay and neighborhood (GR04) after 9 h of tsunami propagation. The green area symbolizes a laguna system alimented by a small river and protected by a dune row.

Conclusion

Numerical modeling confirms the possibility that reporting of wave arrival and inundation of the town of Bonavista in 1755 can be associated to the Lisbon tsunami. Concerning controversial reports of St. John's, it would seem that the harbour is well protected by the Narrows at the mouth of the harbour. The harbour mouth is eastward facing, however. With appropriate wave propagation direction and a more detailed bathymetic grid, tsunami impact is possible. These reports cannot be ruled out entirely, therefore. Lack of reporting in the rest of Newfoundland of the 1755 event can be readily explained by sparseness of population, community isolation, and general illiteracy amongst the outport population during that epoch (Batterson pers. comm.; Rowe 1980). Even in 1929, news of the Grand Banks tsunami impact on the Burin Peninsula of Newfoundland's south coast took two days to reach St. John's.

This study has shown that trans-Atlantic tsunami propagation is possible. In addition to tsunami hazards associated with the submarine slope instability, such as the 1929 tsunami (Grand Banks), Canada's East Coast must consider the hazard associated with tsunamis from far-field sources therefore.

Acknowledgements

The authors would like to thank *the Canadian Hydrographic Service* for providing the high resolution bathymetric data for Newfoundland. They would like to thank Garry Rogers, Kelin Wang, Brian Hill, John Adams and Roy Hyndman from *Natural Resources Canada*, Melissa Kane de *Natural Resources Canada Library,* Martin Batterson of the *Geological Survey* *of Newfoundland and Labrador* and Alan Ruffman of *Geomarine Associates Ltd* for their discussions and willingness to share information.

This study has been funded by the French ANR project MAREMOTI under contract ANR-08-RISKNAT-05-01c.

References

Baptista, M.A., Miranda, J.M., Chierici, F., Zitellini, N., 2003. New Study of the 1755 Earthquake Source Based on Multi-channel Seismic Survey Data and Tsunami Modeling, Natural Hazards and Earth System Sciences, 3, 333-340.

Batterson, M., Liverman, D.G.E., Ryan, J., Taylor, D., 1999. The assessment of geological hazards and disasters in Newfoundland: an update. Current Research (1999) Newfoundland Department of Mines and Energy Geological Survey, Report 99-1, pages 95-123.

Roger, J., Allgeyer, S., Hébert, H., Baptista, M.A., Loevenbruck, A., Schindelé, F., 2009. The 1755 Lisbon tsunami in Guadeloupe Archipelago: contribution of numerical modelling. Accepted for publication in The Open Oceanography Journal.

Roger, J., Baptista, M.A., Sahal, A., Allgeyer, S., Hébert, H. The transoceanic 1755 Lisbon tsunami in the Martinique. Submitted to Pure and Applied Geophysics, Proceeding Edition of the 20th International Tsunami Symposium, Novosibirsk, July 2009.

Rowe, F.W., 1980. A History of Newfoundland and Labrador. McGraw-Hill Ryerson, 563 pages.

Sahal, A., Roger, J., Lemaire, B., Hébert, H., Schindelé, F., Lavigne, F., 2009. The tsunami triggered by the 21 May 2003 Boumerdes-Zemmouri (Algeria) earthquake: field investigations on the French Mediterranean coast and tsunami modelling. Natural Hazards and Earth System Sciences. 9, 1823-1834.

Tocque, P., 1846. Wandering Thoughts, or Solitary Hours. Thomas Richardson and son, London, 387 pp.

Zitellini, N., Chierici, F., Sartori, R., Torelli, L. (1999), The tectonic source of the 1755 Lisbon earthquake and tsunami. Annali di Geofisica. 42, 49–55.