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Estimating the tsunami parameters of the 1755 Lisbon Tsunami in Portugal by the interpretation of the historical accounts

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Abstract

The historical accounts reporting the 1755 Lisbon Tsunami in Portugal are quite vast and their full compilation and interpretation has been difficult. This study will focus on the analysis of the original reports describing the tsunami parameters at 21 places of the Portuguese coastline. Extreme run-ups were observed at the cliffs that should be considered with some caution. In general, there were 3 major waves and the sea surface perturbation lasted for several hours.

Keywords: 1755 Lisbon Tsunami, historical accounts, tsunami parameters, hazard

Palavras-chave: Tsunami de Lisboa de 1755, testemunhos históricos, parâmetros de tsunami, perigosidade

1. Introduction

The historical accounts reporting the 1755 Lisbon Tsunami in Portugal are quite vast and their full compilation and interpretation have been difficult. Several scholars have been trying to compile and understand the physical characteristics of this tsunami, as discussed by Santos *et al.* (2009). The main obstacle has been the language, since almost all reports are written in Old Portuguese, contemporary from the 18th Century. On the other hand, Synolakis and Okal (2005) pointed out the problem of analyzing historical tsunamis, and the need of tsunami experts to re-evaluate tsunamis which were not completely understood.

This study will focus on the analysis of the reports describing the tsunami parameters at 21 places in Portugal. Like many other historical tsunamis, there are many uncertainties

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related to the 1755 event, therefore the interpretation of these accounts takes into consideration the Historical Portuguese measure units, the local knowledge about the places described by the witnesses and the authors' experience.

Although some coastal areas in Portugal have been changing since 1755, the knowledge of the tsunami parameters is important to understand the physical characteristics of this historical tsunami. In addition, stakeholders and local civil protection authorities should be aware of the results presented in this study in order to identify which Portuguese coastal areas are more hazardous to the next tsunami, allowing them to take the necessary safety measures.

2. Original historical accounts

The location of the places described by the witnesses is represented in Fig. 1. The accounts were compiled from several documents, mainly from the Portuguese Archives, and written in Old Portuguese. The witnesses describe the tsunami heights in Portuguese Historical units, and the conversion to SI is: 1 palmo = 0,2 m; 1 braça = 1,8 m; 1 covado = 0,7 m; 1 vara = 1 m (Oliveira, 1985).

1-Oporto: "the river, which rose and fell surprisingly every quarter of an hour, for upwards of four hours at least, four or five feet [1.2-1.5 m], and sometimes more" (Ellicot, 1756).

2-Mira beach: "At about 11 in the morning it was observed the sea water struggling, […] its rise and fall would last about half an hour which repeated several times within the time of about one hour and a half" (IMP, 1756).

3-Figueira da Foz: "the flux was about twenty *braças* [36 m] on the beaches […] this reflux followed second and third with the same greatness and with the same effects, and then there were some small fluxes and refluxes in the water that lasted till sun set. […] And from growing to ebb it could take about one hour" (IMP, 1756).

4-Lavos: "with a big and strange flux from the sea, began to fill" (IMP, 1756).

5-Vieira beach: "only once it was perceived the flux of the sea" (IMP, 1756).

6-Porto Novo beach: "The palmos that grew more than ordinary can be judged of nine or ten *braças* [16.2-18m] where it hits the cliffs. The extraordinary flux and reflux was for three times. However, all that afternoon continued rising and falling."(Sousa, 1928).

7-Ericeira: "All day the sea was doing formidable movements" (Sousa, 1928).

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8-Cascais: "the sea grew more than ordinary about 60 palmos [12 m]; […] there were 3 fluxes and refluxes; […] all these elevations and depressions of the waters took very brief time" (Salgado, 1756)

9-Carnaxide: "it raised thirty *palmos* [6m] according to some people" (Sousa, 1928).

10-Bugio Light House: **"**There were three waves" (Kozak *et* al, 2005).

11-Setubal: "alterations of the water climbed more than twenty five *covados* [17.5m] high"; "inundated for three times the land, reaching in parts the first floor of the buildings [2 stories that are about 6 m high]" (Sousa, 1928).

12-Arrifana Tip: "the sea withdrew about 30 *braças* [54 m] crowning immediately with such an impetus, that from the South of the tip rose to an enormous high of 30 *braças* [54 m] while only rose two *braças* [3.6 m] from the North, repeating the same flux and reflux three times with the interval of a few minutes" (Sousa, 1919).

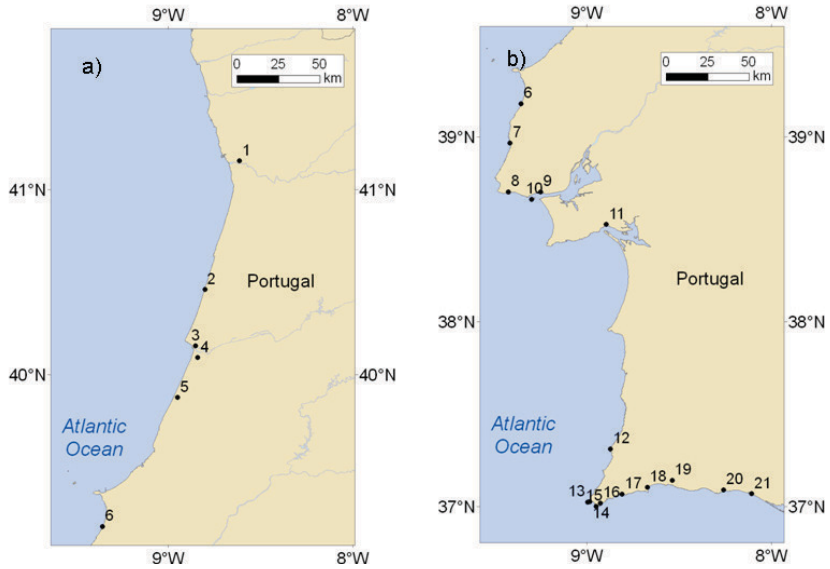

Figure 1 – Location of the places where the witnesses were: a) north of Portugal; b) south of Portugal

13-Saint Vicent Cape: "from the N. part it decreased about 6 *braças* [11 m] […]. From the E. […] at the depth of 8 *braças* [14 m], everything became dry.

14-Beliche Fortress: "it grew up with such a fury that reached the rocks and the rampart that have about 30 *braças* [54 m] high. Three were the highest impulses of the sea" (Sousa, 1919).

15-Sagres Fortress: "The sea withdraw […] then, came to the land with such a violence, that from the North reached the rocks of 60 *braças* [108 m] and on the East 80 *braças* [144 m]" (Sousa, 1919).

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16-Martinhal beach: “the flux and reflux repeated for three times” (Sousa, 1919).
17-Boca do Rio: ‘‘water height of 10–12 *varas* [10–12 m]” (Sousa, 1919).
18-Lagos: “the sea rose more than thirty *palmos* [6 m]”; “the sea rose till the high of 5 *braças* [9m] reaching the top of the city’s rampart” (Sousa, 1919).
19-Portimao: “the sea entered with an amazing fury inundating a great space of land on the both sides of the river rising near 6 *braças* [10.8 m] high” (Sousa, 1919).
20-Albufeira: “the sea [...] rose till the enormous high of 15 *covados* [10.5m]; the flux and reflux repeated for 3 times, with more violence, within few minutes, and continued out of its course till 4 hours in the afternoon” (Sousa, 1919).
21-Quarteira: “the sea […] got out of its limits for 5 times, […] at the high of 6 *braças* [10.8 m]” (Sousa, 1919).

3. Interpretation of the historical accounts

The summary of the tsunami parameters is presented in Table 1. Travel times were compiled from Santos *et al.* (2009), except at Mira beach. Santos *et al*. (2011) estimated the most probable time of the earthquake as 9:40 “Civil Hour”. Since the witnesses report the tsunami arrived at Mira beach at about 11:00 “Civil Hour”, the travel time can be estimated as 80 minutes. The initial response is uplift all over the Portuguese coastline, except at Arrifana Tip, Saint Vicent Cape and Sagres Fortress. At Oporto it was observed the lowest run-up of about 1.5 m. In general, run-ups range between 6 - 10 m, on the beaches. Extreme run-ups were observed by the witnesses on the cliffs: Arrifana Tip, Beliche Fortress and Sagres Fortress. At Porto Novo beach and Figueira da Foz the witnesses also report unexpected high run-ups of about 18m and 36m, respectively. There were 3 major waves, with exceptions at Mira beach, where several waves were observed, at Lavos and Viera beach, where only 1 major wave was reported, and at Quarteira, where 5 major waves were described by the witnesses. The periods range from a few minutes to about 30 minutes. The witnesses describe the duration of the sea surface perturbation for several hours after the earthquake.

4. Conclusions

Santos *et al.* (2009) discussed that tsunami travel times at Lavos may not be reliable. Travel times presented at Mira beach, show that indeed these times should not be

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considered.

Place	Travel time (min)	Initial response	Run-up (m)	No. waves	Period	Duration of perturbation
1-Opo.	---	Uplift	> 1.2 – 1.5	---	15 min	More than 4h
2-Mir.	80	Uplift	---	Several	30 min	1h 30 m
3-Fig.	---	Uplift	36	3	2 hours	Till sunset
4-Lav.	38 – 45 (1)	Uplift (1)	---	1	---	---
5-Vie.	---	---	---	1	---	---
6-Por.	75 (1)	Uplift (1)	16.2 – 18 (2)	3	---	All afternoon
7-Eri.	---	---	---	---	---	All day
8-Cas	---	Uplift	12	3	brief time	---
9-Cru.	23 – 30 (1)	Uplift (1)	6	3	---	---
10-Bug.	30 (1)	Uplift (1)	---	3	---	---
11-Set.	---	---	6 – 17.5	3	---	---
12-Arr.	---	Subsidence	-54	---	Few minutes	---
		Uplift	N: 3.6; S: 54 (2)			
13-SVC	6 – 7 (1)	Subsidence (1)	N: -11; E: -14	---	---	---
	16-17 (1)	Uplift (1)	---			
14- Bel.	---	---	54 (2)	3	---	---
15-Sag.	---	Subsidence	---	---	---	---
		Uplift	N: 108; E: 144 (2)			
16-Mar.	---	---	---	3	---	---
17-Boc.	---	Uplift	10 – 12	---	---	---
18-Lag.	23 – 30 (1)	Uplift (1)	6 – 9	---	---	---
19-Por.	---	Uplift	10.8	---	---	---
20-Alb.	---	Uplift	10.5	3	Few minutes	Till 4 PM
21-Quar.	---	Uplift	10.8	5	---	---

Table 1 – Summary of tsunami parameters. (1) Data compiled from Santos et al., 2009; (2) At the cliffs

Extreme run-ups were observed by the witnesses at Arrifana Tip, Beliche Fortress and Sagres Fortress. However, these values should be considered with some caution. At Porto Novo beach and Figueira da Foz the witnesses also report unexpected high run-ups of about 18m and 36m, respectively. Previous tsunami numerical model results (Santos *et al*, 2009; 2012) showed local amplification on these places (even though they were underestimated). There were 3 major waves all over the Portuguese coastline, with exceptions at Mira beach, Lavos, Vieira beach, and Quarteira. The waves' periods range from a few minutes to about 30 minutes, and duration of the sea surface perturbation lasted for several hours after the earthquake, which are consistent to tsunami behavior. However, the account at Figueira da Foz, which describes the half period of about 1hour,

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looks somehow exaggerated. Further research focused on the tsunami numerical modeling should continue to validate these accounts, by considering historical maps, contemporary to the 18th century, as well as field surveys.

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