Forward and inverse numerical modelling: complementary approaches to better understand palaeotsunamis

Ivana Bosnic[1] and Pedro J M Costa[2]

[1]Instituto D. Luiz, Faculdade de Ciências da Universidade de Lisboa
[2]Departamento de Ciências da Terra, Universidade de Coimbra, Portugal

November 26, 2022

Abstract

The 1755 Lisbon earthquake triggered the largest historical tsunami ever registered in Western Europe. Despite the recent efforts to better understand this event, there are still questions to be answered. Understanding the past tsunami intensity is key to assessing tsunami hazard. Sedimentary imprints are the only evidence in the geological record able to quantify onshore tsunami flow characteristics through inverse modelling. On the other hand, forward numerical modelling is a powerful tool capable of simulating tsunami hydrodynamics and the induced sediment transport. This work presents results from inverse and forward modelling in order to assess tsunami characteristics onshore. The study site is located on the Portuguese southern coast, at Salgados lowland where inverse modelling was performed using TsuSedMod (Jaffe and Gelfenbaum, 2007, Sedimentary Geology) based on four Livingstone sediment cores. Forward modelling including tsunami generation and propagation was performed respectively using the methods of Okada (1985, Bulletin of the Seismological Society of America) and Delft3D-FLOW. Onshore topography was corrected for the 1755 scenario based on extensive deposit thickness data. The tsunami source was chosen based on recent results from the same authors that pointed to a good correlation between modeled and field tsunami data considering Marques de Pombal fault. Results from inverse model show tsunami onshore average speed varying from 7.3 up to 9.3 m/s and shear velocities from 0.52 up to 0.66 m/s. Varying the bottom roughness results in the forward model result in average flow velocities between 7.0 and 8.0 m/s, induced by a 3-meter high tsunami at 50 m depth. The good agreement between forward and inverse model estimates of tsunami velocity highlights the potential of numerical modelling (coupled with geological records) to improve the understanding of historical events. Additional research on correlating modelling and geological data is needed and will likely lead to a better understanding of the effects of similar events and contribute to the ability to assess tsunami hazard and coastal vulnerability. Acknowledgements: Work supported by Instituto Dom Luiz and by project OnOff - PTDC/CTA-GEO/28941/2017 – financed by FCT

Forward and inverse numerical modelling: complementary approaches to better understand palaeotsunamis

I. Bosnic[1,✉], P. J.M. Costa[1,2], F. Dourado[3], S. La Selle[4], G. Gelfenbaum[4]

✉ ibosnic@fc.ul.pt

(1) Instituto D. Luiz, Departamento de Geologia da Universidade de Lisboa, Faculdade de Ciências da Universidade de Lisboa, Edifício C6, Campo Grande, 1749-016 Lisboa, Portugal, (2) Earth Sciences Department, University of Coimbra, Rua Sílvio Lima, Univ. Coimbra - Pólo II, 3030-790 Coimbra, Portugal, (3) CEPEDES, Departamento de Geologia Aplicada, Faculdade de Geologia, Universidade do Estado do Rio do Janeiro, Brazil, (4) US Geological Survey, Pacific Coastal and Marine Science Center, 400 Natural Bridges Drive, Santa Cruz, CA 95060, United States

Background

The 1755 Lisbon earthquake triggered the largest tsunami ever registered on Western Europe in historical times. Despite the recent efforts to better understand this event, there are still questions to be answered mainly regarding its source and magnitude.

Understanding the past tsunami intensity is key to assess tsunami hazard. Sedimentary imprints are the only evidence in the geological record able to quantify onshore tsunami flow characteristics through inverse modelling. On the other hand, forward numerical modeling is a powerful tool capable of simulating tsunami hydrodynamics and eventually the induced sediment transport. This work presents data from inverse and forward modelling in order to assess tsunami characteristics onshore aiming at better understanding paleotsunami events.

Study area

The forward modelling approach is carried out on southwestern Iberia and represented by 3 nested grids, from tsunami generation up to onshore inundation. Inverse modelling is performed based on livingstone samples retrieved at Salgados lagoon, located at a coastal lowland , southern Portugal.

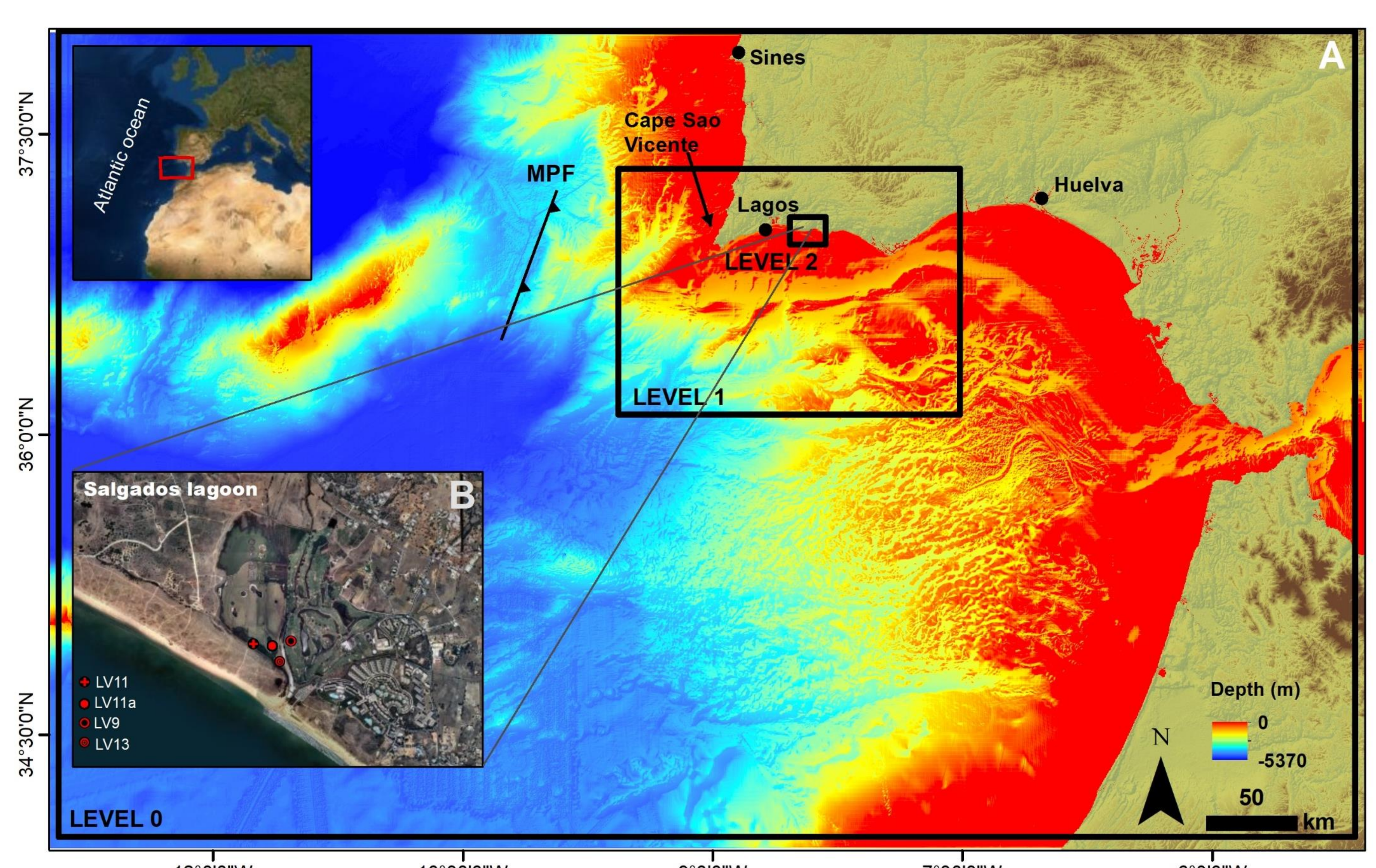


Fig. 1. Study area showing A) the forward modelling grids extension represented by levels 0, 1 and 2 and B) the location of the livingstone sampling within Salgados lagoon.

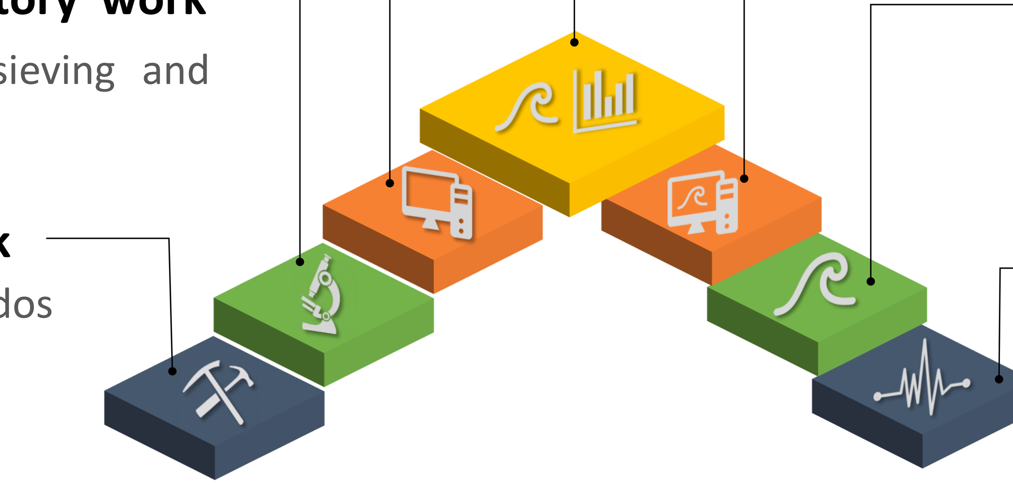
Methods

Tsunami flow characteritics

Inverse modelling — Application of TsuSedMod model (Jaffe and Gelfenbaum, 2007)

Laboratory work — High-resolution grain size analysis through sieving and Malvern analysis.

Field work — Tsunami layer identification and sampling at Salgados lagoon.



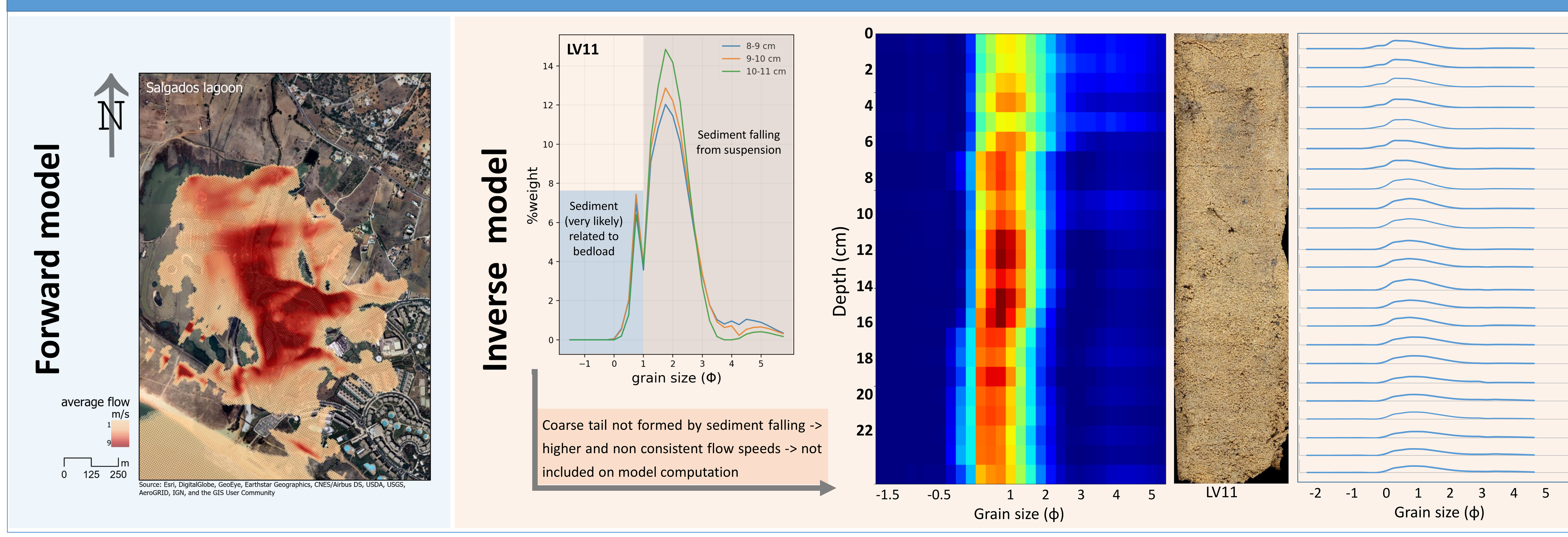
Forward modelling — Tsunami propagation and inundation is modeled using Delft3D Flow module

Tsunami generation — Initial conditions for the tsunami are built under Delft Dashboard platform using Okada (1985) model.

Earthquake source — Marques de Pombal fault (MPF) is assumed as a plausible source for the 1755 AD Lisbon Tsunami

Jaffe, B., Gelfenbaum, G. 2007. A simple model for calculating tsunami flow speed from tsunami deposits. Sedimentary Geology, 200, 347-361.
Okada, Y. 1985. Surface deformation due to shear and tensile faults in a half-space. Bulletin of the Seismological Society of America, 75(4), 1135–1154

Results and discussion



Tsunami onshore flow velocities estimated through forward and inverse modelling present a very good compatibility, despite the obvious differences between both approaches. The flow characteristics are compatible with a offshore wave with significant height of 3 m at 50 m depth.

		LV09	LV11	LV11a	LV13
TsuSedMod (Inverse model)	Average flow velocity (m/s)	7.33	7.38	9.27	7.8
Delft3D (Forward model)		6.8	8.5	7.2	8.3

Conclusions

The good agreement between forward and inverse models on the estimation of the tsunami magnitude highlights the potential of numerical modelling (coupled with geological records) on better understanding historical events. Further efforts should be done on correlating modelling and geological data for a better assessment of the effects of similar events thus strongly contributing to tsunami hazard and coastal vulnerability.

Acknowledgments

Work supported by FCT through OnOff Project (PTDC/CTA-GEO/28941/2017) and IDL-LA- UID/GEO/5019/2019.

@OnOffProject

http://onoff.rd.ciencias.ulisboa.pt/

SCAN ME