The July 6-7, 2010 Meteotsunamis along the Coast of Portugal

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Introduction

Intro

Meteotsunamis are tsunami-like waves with meteorological origins. They are usually initiated by a sudden atmospheric pressure jump of a few hPa. This pressure jump may induce sea surface variation of a few centimeters, and this small variation can be amplified to several meters by the combination of Proudman, Greenspan and harbor resonances.

Large meteotsunamis occur frequently in some coastal areas. Notable "hot-spots" are the Adriatic Sea, the Baltic Sea and the SE Asia and adjacent marginal seas.

Outline

On July 6-7, 2010, uncommon sea waves were observed along the coast of Portugal. The Portuguese tide-gauge network recorded the sea-level signals showing tsunamis-like waves of heights varying from 0.14 to 0.6 m (crest-to-trough) and of periods in the range of 30 to 60 min.

We present the analysis of oceanic and atmospheric data with numerical simulations based on the observation. We identify *hot-spots* of meteotsunamis at the Portugal coast through the investigation of possible meteotsunami scenarios.

Meteotsunami Observation

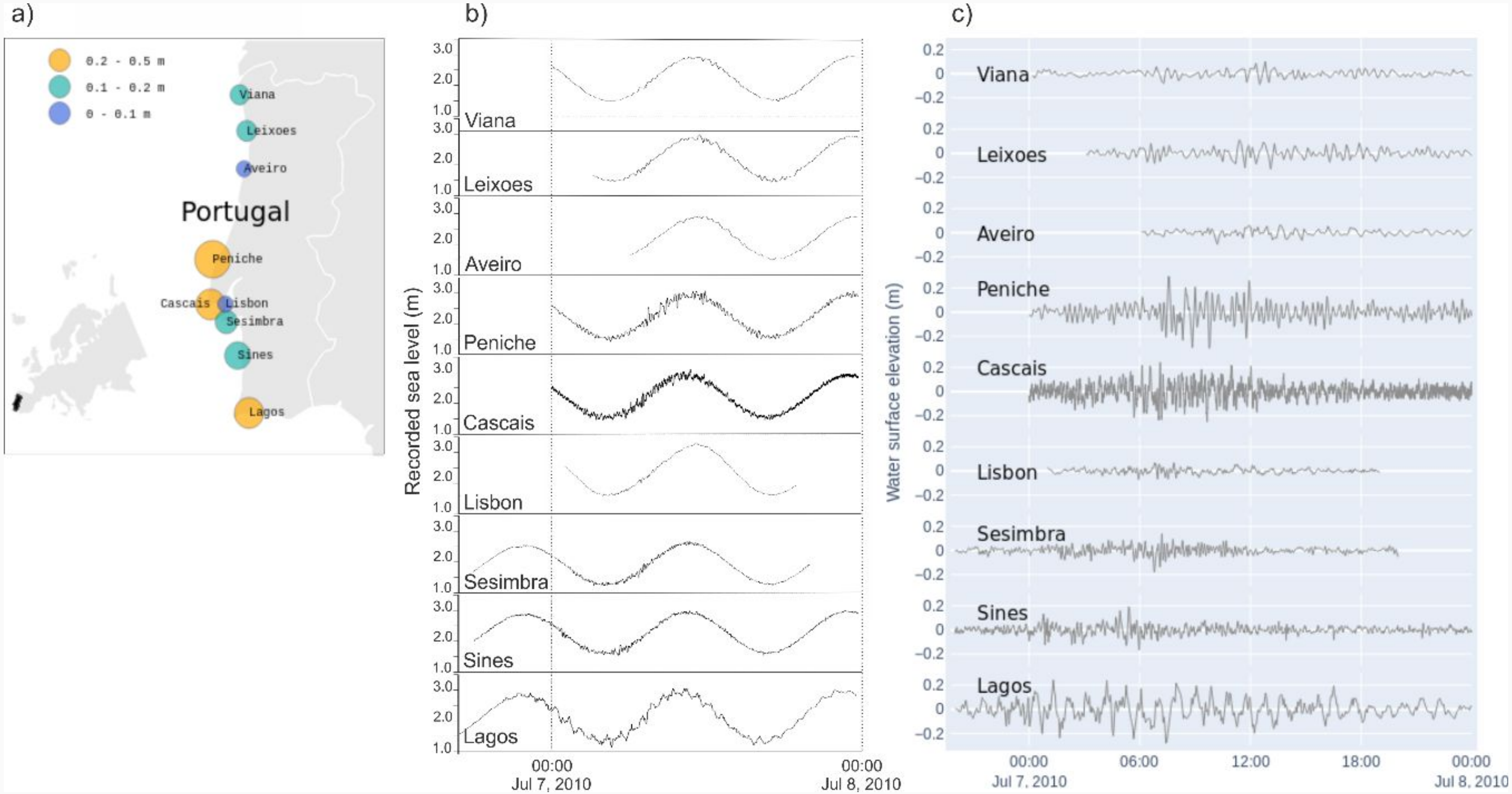
Sea level Observation

On July 6-7, 2010, unexpected sea-level changes were observed along the tide gauge stations of Portugal

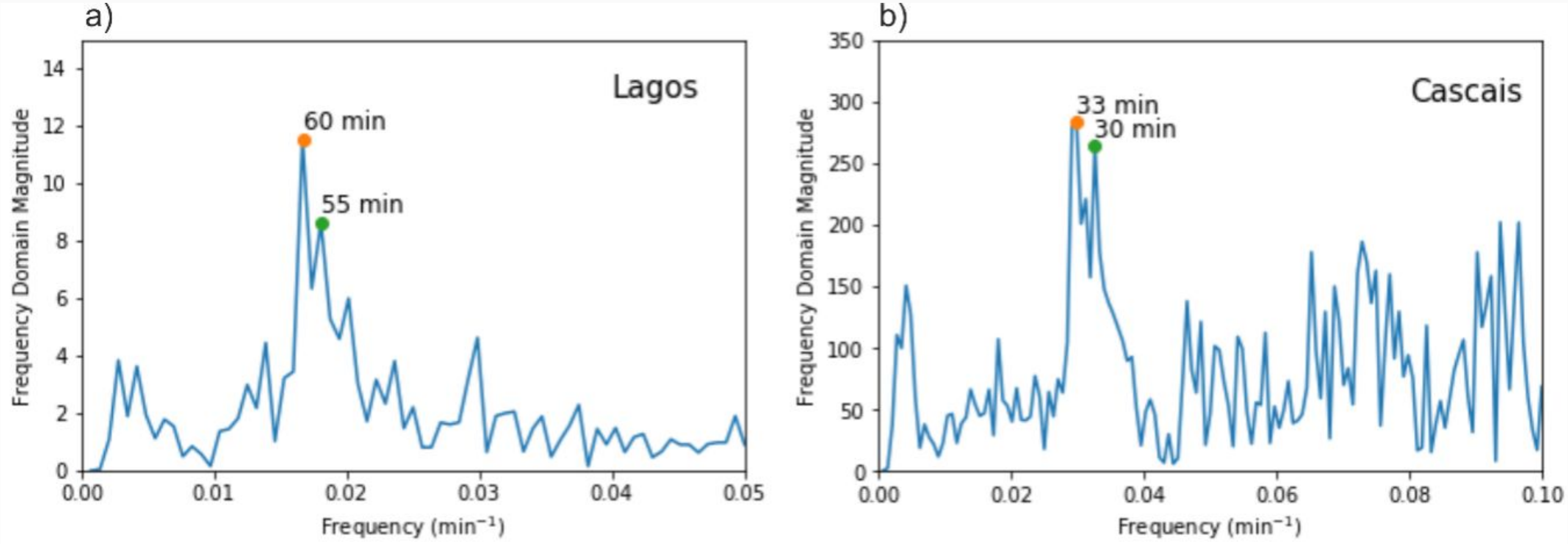
The records show that the ocean disturbance started from South and moved to North

Maximum crest-to-trough heights are 0.5 m at Lagos, 0.48 m at Cascais, and 0.6 m at Peniche

Spectral analysis shows the dominant wave periods were 50-60 min at Lagos and 30-35 min at Cascais



Sea level record along the coast of Portugal. a) Location of tidal gauge station and maximum crest-to-trough amplitude; b) Sea-level signals; c) De-tided signals



Fourier analysis a) Lagos; b) Cascais

Atmospheric observations

Atmospheric pressure record from six observatories

Pressure jump propagated from South (Sines) to North (Peniche), and it was not observed at further North (Leixoes)

The magnitude was between 3.2 and 4.1 hPa

Speed of the pressure jump is estimated as 20-26 m/s

Numerical Simulations

Governing equations

We used nonlinear shallow water equations (NLSW) with the atmospheric pressure terms

GeoClaw software is modified for meteotsunami simulations

f-wave method (flux splitting) is used to handle atmospheric pressure terms with computational stability

$$
\begin{aligned}
h_t + (hu)_x + (hv)_y &= 0, \\
(hu)_t + \left(hu^2 + \frac{g}{2}h^2\right)_x + (huv)_y &= -ghb_x - \frac{h}{\rho}(P_A)_x, \\
(hv)_t + (huv)_x + \left(hv^2 + \frac{g}{2}h^2\right)_y &= -ghb_y - \frac{h}{\rho}(P_A)_y.
\end{aligned}
$$

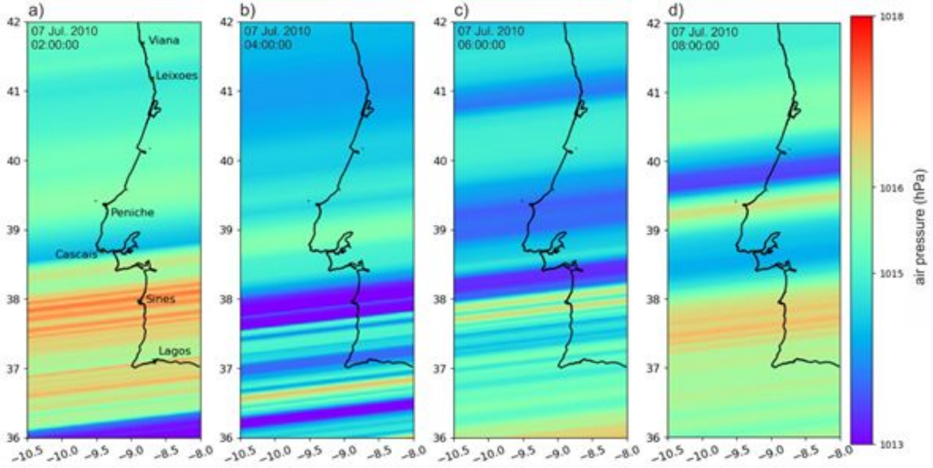
h, u and v denote the depth, velocity in x and y direction of water column. Moreover, g is the gravitational constant, ρ is the density of water, P_A is the atmospheric pressure, and b(x,y) denotes bathymetry.

Meteotsunami generation

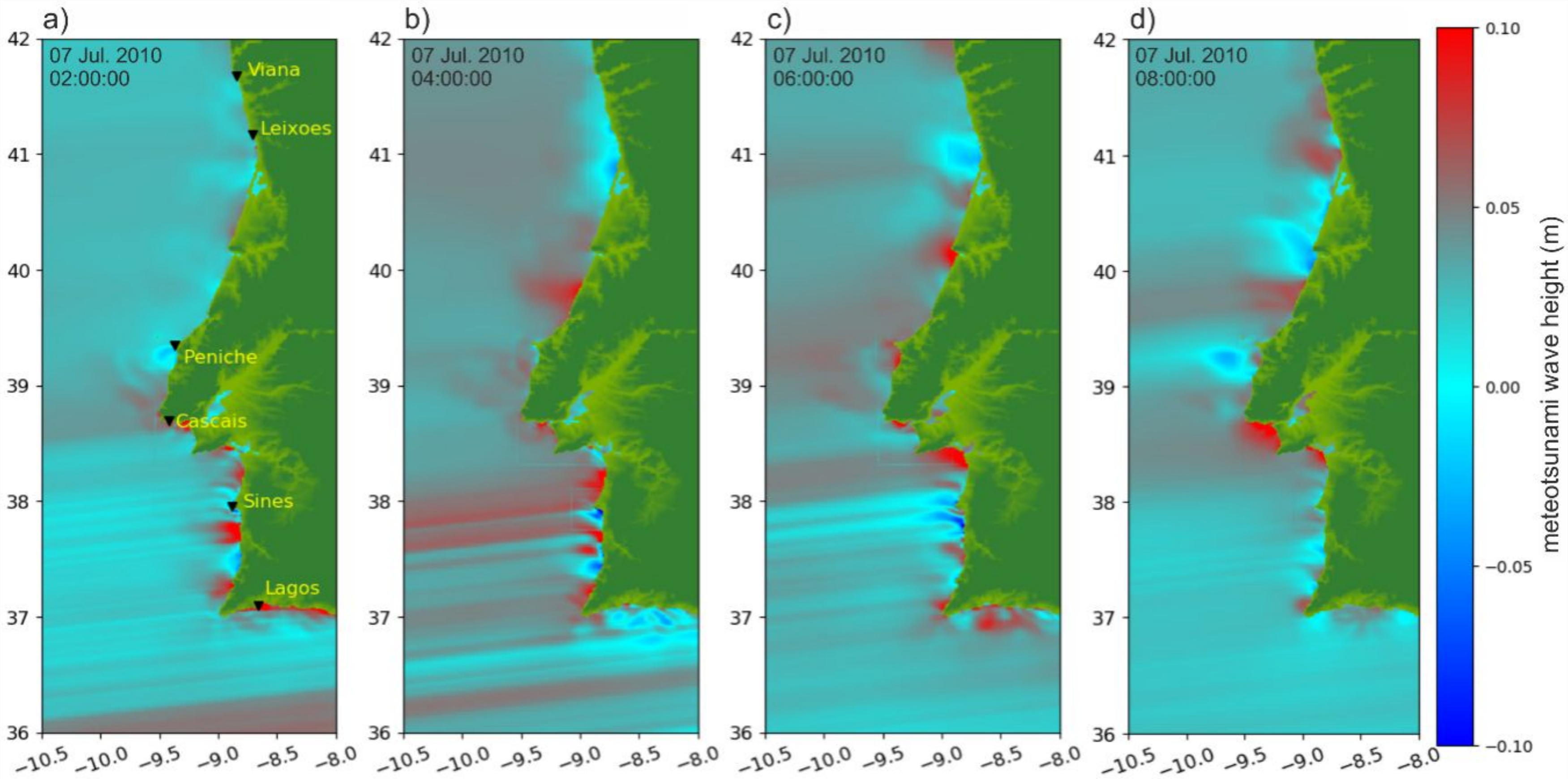
From atmospheric pressure observation, the travelling speed is estimated as 20-26 m/s

The direction of atmospheric pressure jump is estimated 95º-110º (measured counterclockwise with Eastward equal to 0º)

Atmospheric pressure conditions are interpolated from the observation so that the pressure exactly matches at the observatories



Numerical implementation of atmospheric pressure



Numerical simulation of meteotsunami propagation with a speed of 26 m/s and an incident angle 95º

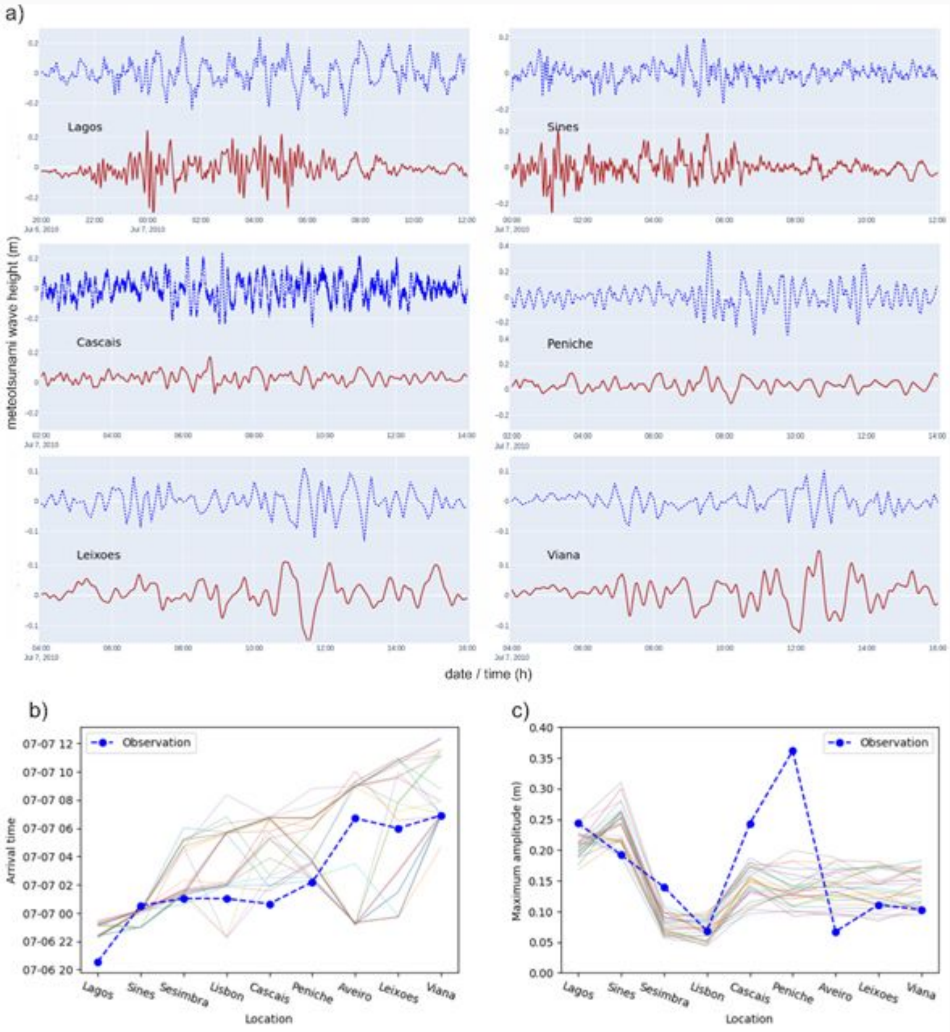
Numerical Results

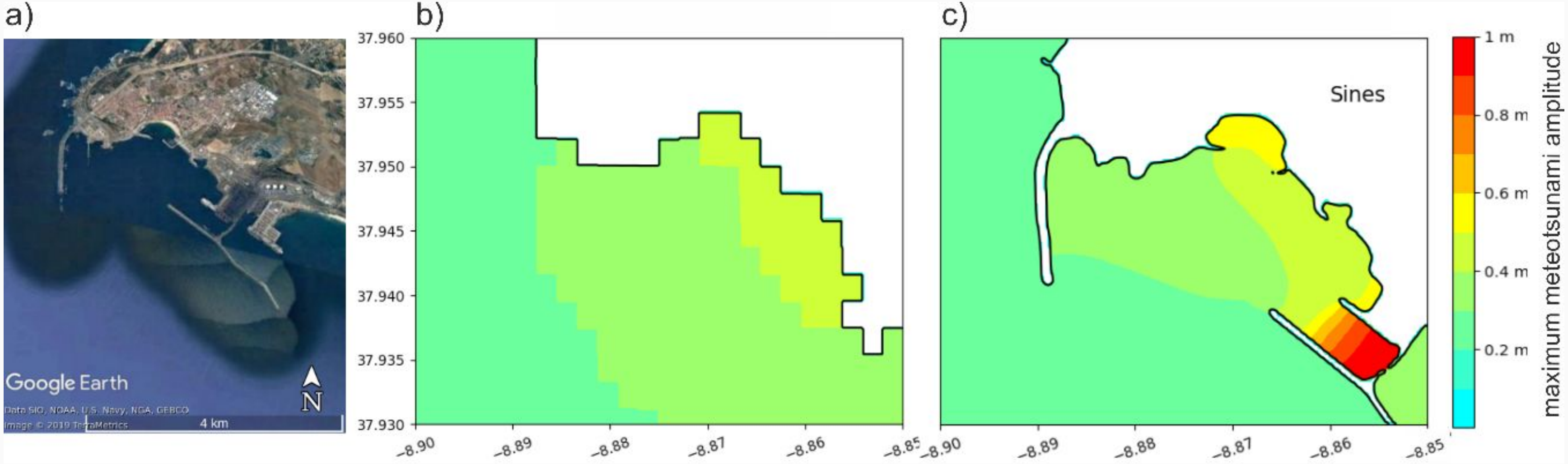
a) Numerical simulation(above) and observation(below)

Comparison of b) arrival time and c) maximum amplitude

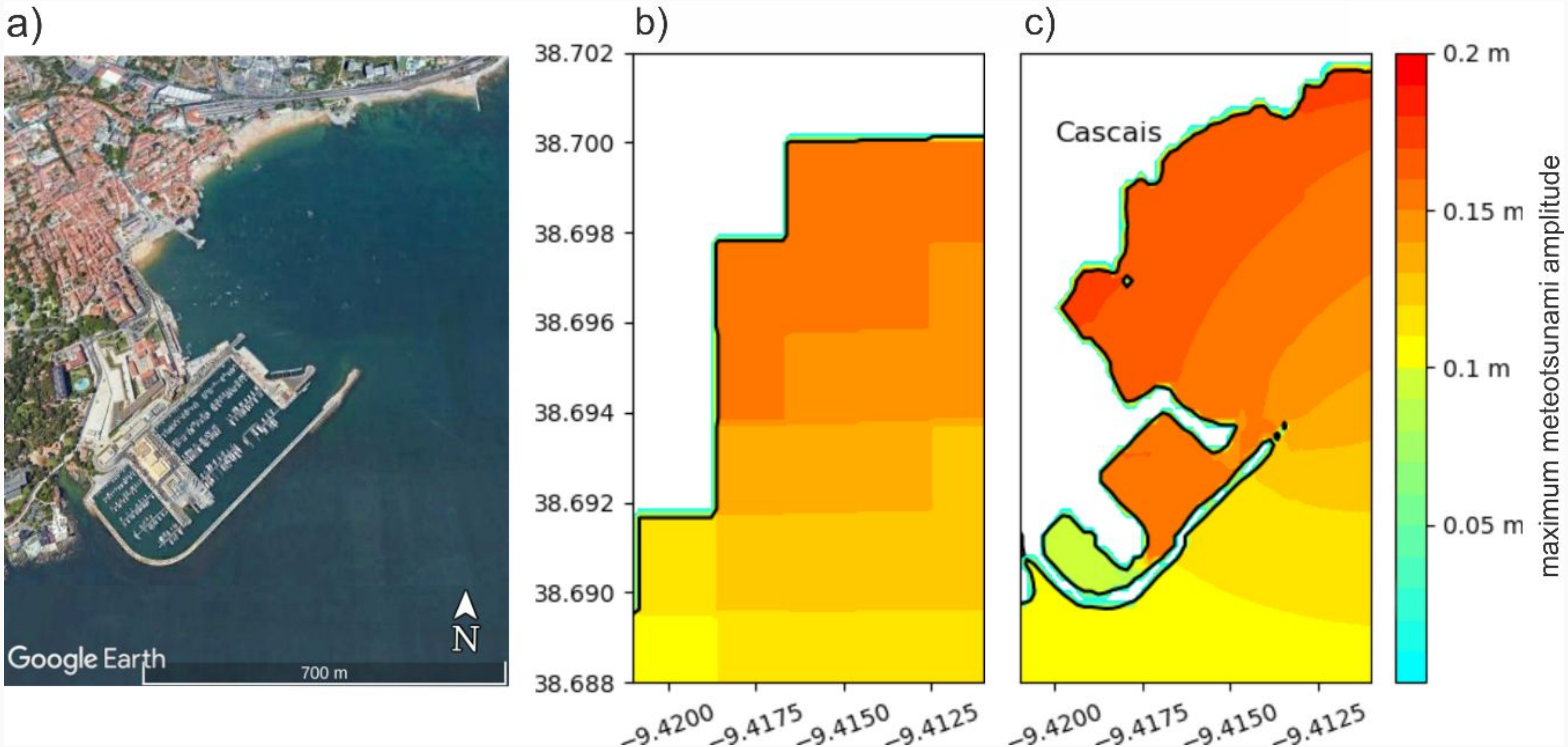
Solid lines in b) and c) are from results of numerical tests

Good agreement between records and numerical results





Modeling of the 2010 meteotsunami wave amplitudes at a) Sines port with b) coarse grid 1º /480 and c) fine grid 1º /4800



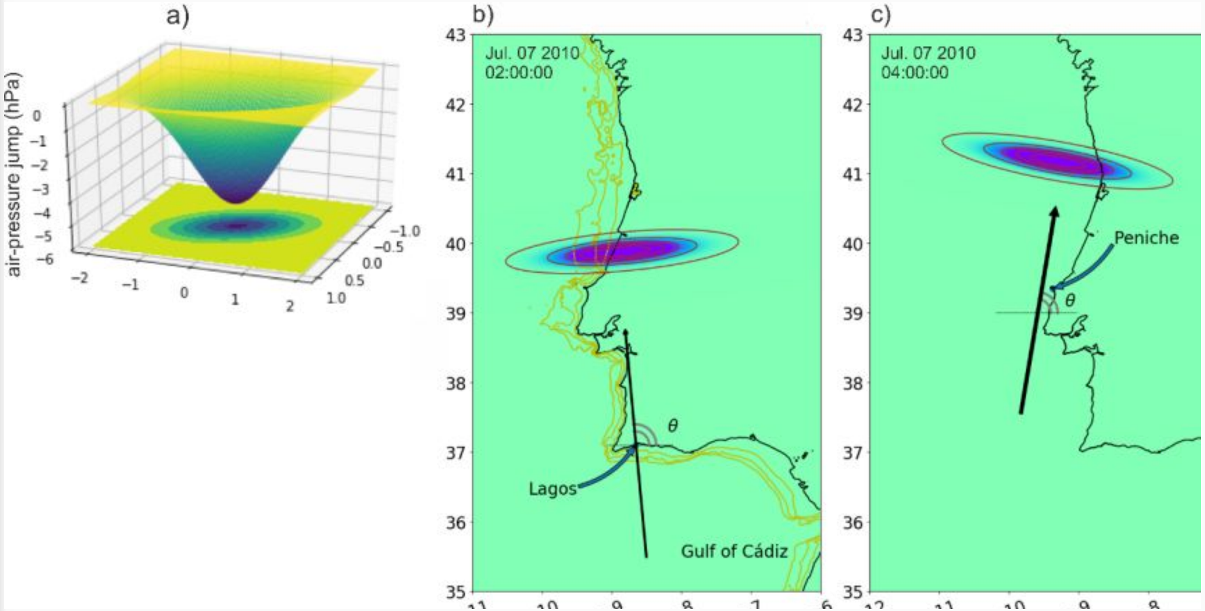
Modeling of the 2010 meteotsunami wave amplitudes at a) Cascais port with b) coarse grid 1º /480 and c) fine grid 1º /4800

Meteotsunami Hazard along the Coast of Portugal

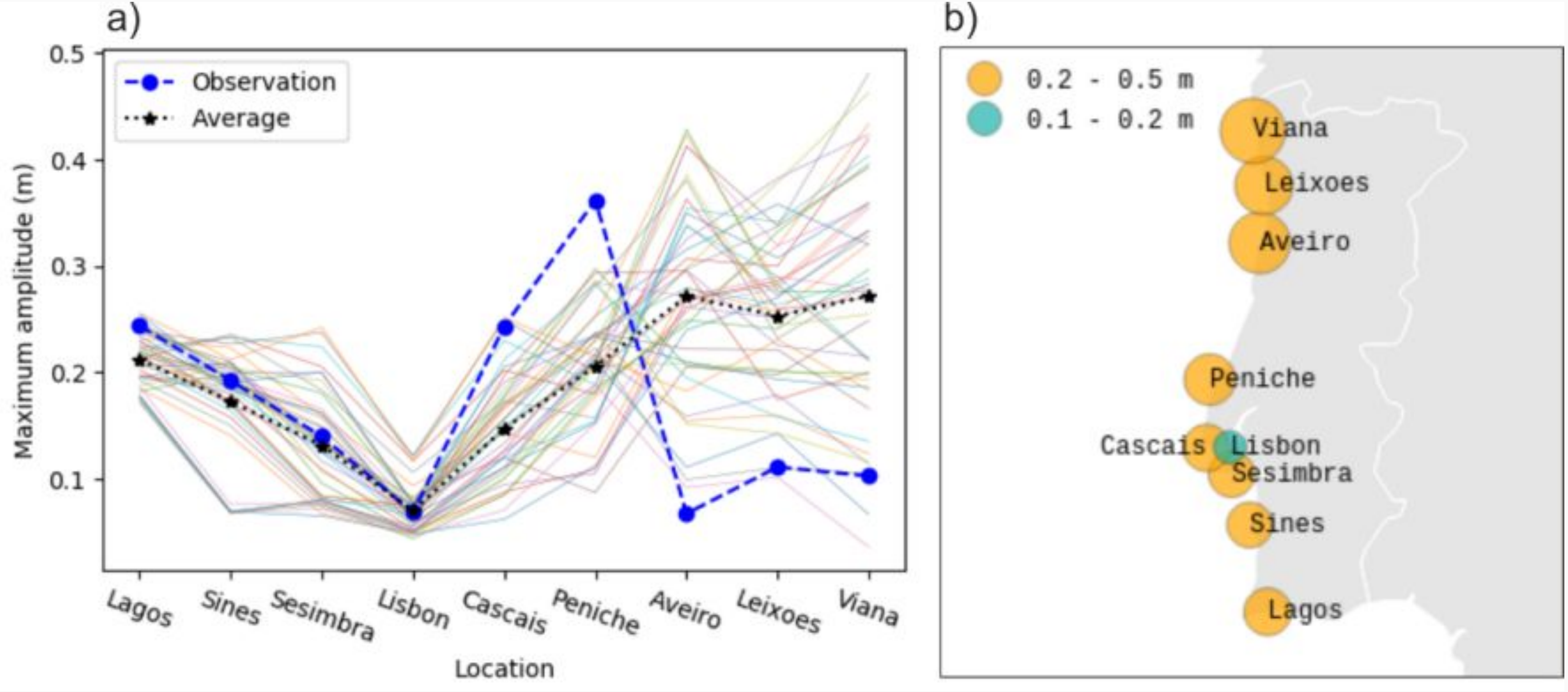
Numerical experiments

We tested two cases with a Gaussian shape atmospheric pressure disturbance

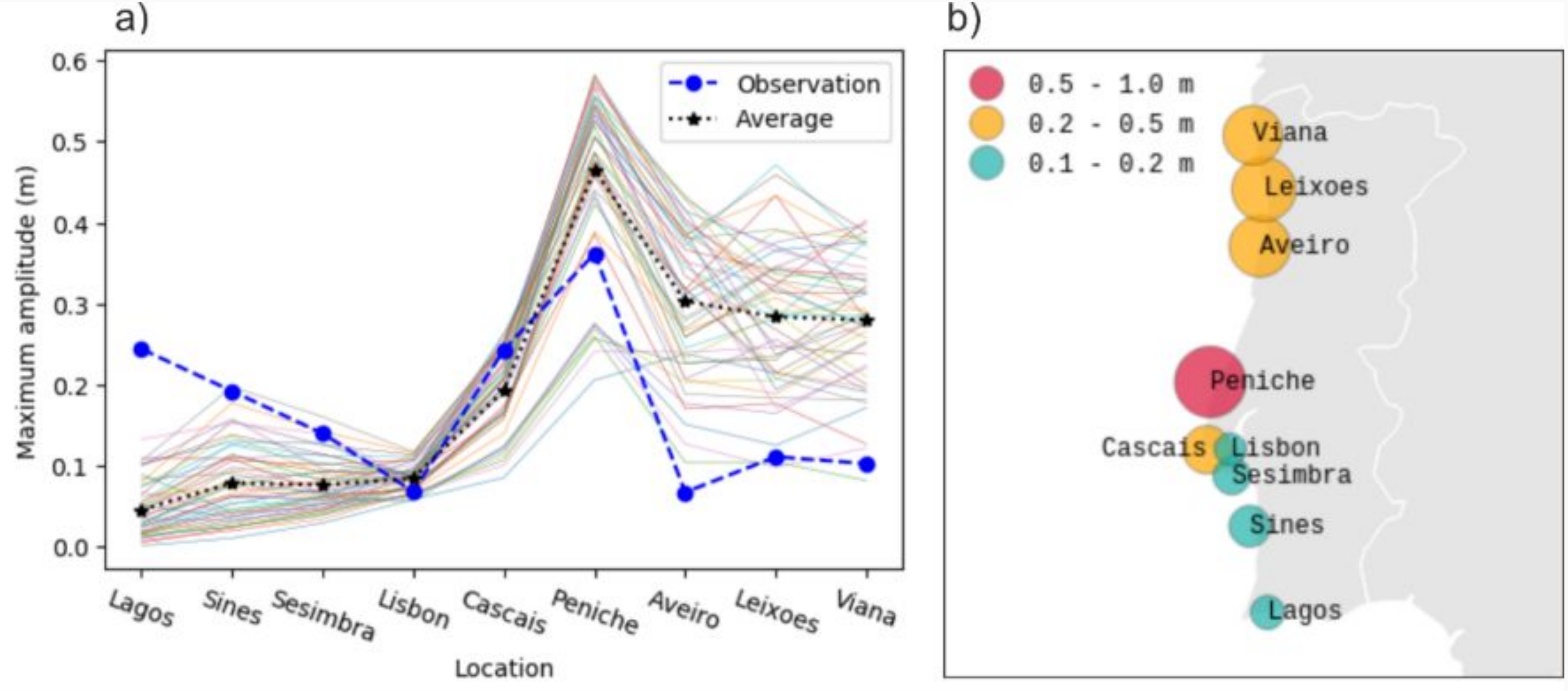
a) 2-D Gaussian shape atmospheric pressure disturbance of 5 hPa
b) Pressure disturbance passes through Lagos area
c) Pressure disturbance passes through Peniche area



- Atmospheric pressure disturbance remains the same shape in the computational domain
- We varied the speed of pressure jump between 16-36 m/s and the incident angle between b) 90º -120º and c) 60º -100º



Maximum wave amplitudes for all considered scenarios when the pressure disturbance passes through Lagos. Solid lines in a) are numerical results.



Maximum wave amplitudes for all considered scenarios when the pressure disturbance passes through Peniche

Meteotsunami hazard at Portugal

From Lagos to Cascais, the numerical results are comparable to 2010 meteotsunami events

From Aveiro to Viana, the projected wave amplitudes are generally larger than 2010 event

The difference is mainly associated with the atmospheric conditions; In 2010 event, the pressure jump was not observed at Leixoes where the pressure jump remains as the same magnitude in these numerical tests

Possible meteotsunami *hot-spots* at the coast of Portugal are Lagos, Sines, Cascais, Peniche, Aveiro, Leixoes and Viana

In particular, the Northern area from Peniche to Viana, can be vulnerable to meteotsunamis because of the existence of wide continental shelf

Summary and conclusions

Along the coast of Portugal, unusual waves were observed on July 6-7, 2010

Data analyses of the sea-level and atmosphere observation confirm that the tsunami-like waves were generated by atmospheric conditions

Numerical results based on atmospheric records show good agreement with sea-level observation

We tested two scenarios of meteotsunamis on the coast of Portugal

The numerical results suggest the “hot-spots” is Peniche. A wide continental shelf off Peniche has depth between 50 and 150 m which favors the wave amplification resonance condition (Proudman resonance)

Future directions

Study meteotsunamis in Portugal

Collect more data and analyze them to identify other cases at the coast of Portugal.

Study the generation mechanism using a full 3D numerical model

Development of atmospheric model

Accurate forecast of meteotsunamis requires the detection of atmospheric pressure jumps. Resolution of current atmospheric models is too coarse to determine the existence of the pressure jump.

Acknowledgment

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Thank you!

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