Numerical Modeling and Field Survey of the March 2017 Tsunami of Bandar Dayyer, Persian Gulf

Amir Salaree[1]
Reza Mansouri[2]
Emile A. Okal[3]

[1]*Northwestern University, amir@earth.northwestern.edu*
[2]*Persian Gulf University, s.r.mansouri@pgu.ac.ir*
[3]*Northwestern University, emile@earth.northwestern.edu*

Abstract

The 19 March 2017 tsunami at the Port of Dayyer incurred considerable damage and resulted in ~$10 million of economic loss, one death and five people missing. Although a significant storm had preceded the surge, there were indications of calm weather during the event in some of the remaining footage which could play a critical role in reconstructing the tsunami by studying it as a meteorological phenomenon. Here, we are reporting the data from a field survey in the affected area which revealed a concentration of inundation along a ~30 km stretch of coastline with run-ups reaching 3 m at ~4 km west of Dayyer. In the absence of any major seismic event at or around the occurrence of the tsunami, we consider landslides as well as atmospheric phenomena as potential sources for the event. We simulate the geological tsunami using the Method of Splitting Tsunamis (MOST) method (e.g. Titov et al., 2016) and develop a finite-difference algorithm, following the method by Platzman (1958), to model the surge as a meteotsunami. Our simulations suggest that the Dayyer tsunami was caused by a local system of atmospheric pressure gradient, as our landslide models fail to reproduce high amplitudes as documented in our field survey.

Keywords: Tsunami, Persian Gulf, Earthquake, Landslide, Simulation

Introduction

The history of tsunamis in the Persian Gulf remains vague and incomplete due to the lack of comprehensive paleoseismic and paleotsunami studies in the region. The 19 March 2017 tsunami, however, sheds some light on the nature of at least some of the past and potential future events. This tsunami inundated significant parts of the Port of Dayyer on the southern coastlines of Iran, sometime between 8:00 and 8:20 AM local time (4:30–4:50 GMT). The initial reports of the tsunami did not reveal the full extent of inundation as they only provide descriptive – albeit very valuable – accounts of the surge at Dayyer. In particular, it was not clear whether the surge was indeed focused on Dayyer, or was simply reported there due to the presence of people and infrastructure. Second, although the maximum run-up was reported to reach 2 m, it is also unclear if it had been the highest value through the entire extent of inundation. Finally, although a significant storm preceded the surge, there were indications of calm weather during the event in some of the footage. Therefore, we conducted a field survey following the event to search for and document such information due to its significance in modeling the tsunami source as well as its energy (e.g. Okal & Synolakis, 2004).

Data and Method

The survey along the Iranian coastline of the Persian Gulf in the vicinity of Dayyer was conducted on 17 May 2017 to gather the evidence regarding the 19 March 2017 tsunami. A total of ~50 km of the coast was covered during the fieldwork. Documented run-ups from the survey are shown in Fig. 1. These data were collected through routine methods of post-tsunami surveys (e.g. Okal et al., 2002) by interviewing more than 30 eyewitnesses and making measurements of the evidence left from the surge.

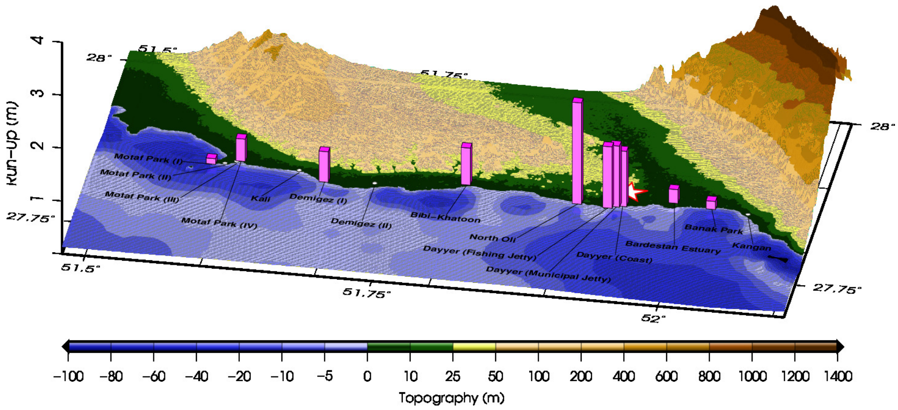

Figure 1 The interview points from the survey are marked with vertical columns where the height of the column corresponds to the measured run-ups. The white star represents Dayyer.

The survey results indicate that noticeable inundations from the tsunami took place on a ~40 km stretch of coastline with highest values of run-up focused on a ~5 km band at and around the city of Dayyer, with the highest value of 3 m documented at the village of Oli, to the west of Dayyer.

The occurrence of several documented historical, moderate to large earthquakes and the current level of seismicity of the region leads us to assume a seismic event as the source of the tsunami However, the largest recorded events by the Iranian Seismological Center (IRSC) on the day in question were all on land and too small ($M_L \leq 3.5$) to generate a tsunami (e.g. Plafker, 1997).

In addition, the local nature of the tsunami as revealed by our field survey suggests a much smaller source for the event. Common example of such events are submarine landslides as they can occur following disturbances in either the pore pressure or viscosity of sediments. Although the triggering process is highly non-linear and complex, seismic events (Keefer, 1984) and/or storms and rainfall (Moore, 1961) such as the one preceding the tsunami can cause landslides.

We designed 16 different potential tsunami sources as simultaneous hydrodynamic dipoles (Fig. 2) described by Synolakis et al. (2002) following the slope regime of the bathymetry (e.g. Salaree & Okal, 2015) and used the Method of Splitting Tsunamis (MOST) to simulate the resulting waves (Titov et al., 2016). Although our simulations reproduce local high amplitudes around Dayyer, they either fail to predict the highest amplitudes at Oli and Dayyer or compute high amplitudes elsewhere, contradictory to the survey data.

Failure of our efforts in modeling the Dayyer tsunami with geological sources, along with the occurrence of an atmospheric disturbance (storm) preceding the event leads us to treat the surge as a meteotsunami (e.g. Rabinovich & Monserrat, 1998). This idea is supported by the shallow bathymetry of the Persian Gulf which barely approaches ~ 90m at its deepest point allowing for a resonance between atmospheric disturbances and gravity waves known as the "Proudman resonance" (Proudman, 1929).

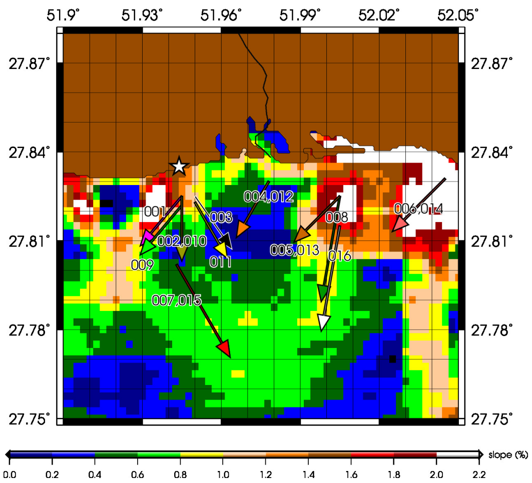

Figure 2 Calculated slope of the Persian Gulf in the vicinity of Dayyer (white star). The designed slide dipoles for the larger grid. Size and direction of the arrows represent relative length and azimuth of the dipoles.

Although the daily satellite imagery (NASA Worldview, 2017) is suggestive of a strong northwesterly system moving at an average celerity of ~7–8 m/s over the Persian Gulf during March 18–21, the timing of these disturbances do not match the occurrence of the tsunami in Dayyer, as the records from stations IKUWAIT22 and IJASRA2 in Kuwait and Bahrain show pressure signals at 15:15 and 19:00 on March 19. Wind celerity and pressure records from Dayyer – although coarsely sampled – also show no significant signals on the 19th. This would suggest that any possible atmospheric disturbance responsible for the tsunami must have had a local nature. Therefore, we can perform our calculations in simulating the event on a local scale.

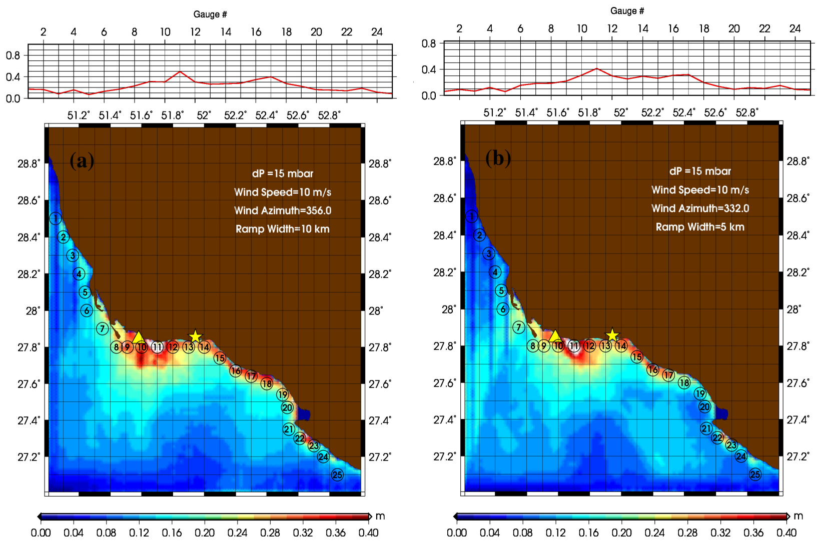

Figure 3 Maximum calculated amplitudes at (bottom) each grid point and (top) the virtual gauges when (a) gauge 13 (west of Dayyer) and (b) gauge 14 (east of Dayyer) reach their respective maximum wave amplitudes across all simulations.

In order to model the local surge, we consider a pressure squall with the cross-section of a ramp moving at a given velocity perpendicular to the front (Platzman, 1958). A finite difference algorithm was developed to solve the hydrodynamic equations. We used an interpolated version of GEBCO bathymetry for the water depth and used time steps of δt = 30s to satisfy the CFL condition in 10-hours time windows. By varying the ramp width, L, from 0 to 100 km with 5 km increments, wind celerity, v, from 10 to 30 m/s with 1 m/s increments, and azimuth, ϕ, between 0° and 359°) with 1° steps, we conducted a total of 158,760 simulations to find the ideal conditions for maximum amplitude in the vicinity of Dayyer. Our simulations predict the maximum amplitudes at both sides of Dayyer to occur for (L = 10 km, ϕ = 356°, v = 10 m/s) or (L = 5 km, ϕ = 332°, v = 10 m/s), respectively as shown in Fig. 3.

Conclusion

While geological models fail to reproduce the data from our field survey, considering the event as a meteotsunami leads to better results in terms of wave amplitude distribution. We recognize the fact that the discrepancy in the documented run-up values and the results from our simulations may be caused by the insufficiency of our bathymetry model. Therefore, we suggest any future studies on the 19 March 2017 tsunami or other hydrodynamic events in the Persian Gulf focus on obtaining a better bathymetry model for the region.

References

Keefer, D. K., 1984. Landslides caused by earthquakes, Geological Society of America Bulletin, 95(4), 406–421.

Moore, D. G., 1961. Submarine slumps, Journal of Sedimentary Research, 31(3), 343–357.

NASA Worldview, 2017. Earth Observing System Data and Information System, NASA’s Earth Science Data Ssystems, https://worldview.earthdata.nasa.gov, Accessed May 20, 2017.

Okal, E. A. & Synolakis, C. E., 2004. Source discriminants for near-field tsunamis, Geophysical Journal Interna- tional, 158(3), 899–912.

Okal, E. A., Synolakis, C. E., Fryer, G. J., Heinrich, P., Borrero, J. C., Ruscher, C., Arcas, D., Guille, G., & Rousseau, D., 2002. A field survey of the 1946 Aleutian tsunami in the far field, Seismological Research Letters, 73(4), 490–503.

Plafker, G., 1997. Catastrophic tsunami generated by submarine slides and backarc thrusting during the 1992 earthquake on eastern Flores I., Indonesia [abstract], Geological Society of America, Cordilleran Section, 93rd Annual Meeting, 29(5), 57.

Platzman, G. W., 1958. A numerical computation of the surge of 26 June 1954 on Lake Michigan, University of Chicago, Dept. of Meteorology.

Proudman, J., 1929. The effects on the sea of changes in atmospheric pressure, Monthly Notices of the Royal Astronomical Society, Geophysical Supplement, 2(s4), 197–209.

Rabinovich, A. B. & Monserrat, S., 1998. Generation of meteorological tsunamis (large amplitude seiches) near the Balearic and Kuril Islands, Natural Hazards, 18(1), 27–55.

Salaree, A. & Okal, E. A., 2015. Field survey and modelling of the Caspian Sea tsunami of 1990 June 20, Geophysical Journal International, 201(2), 621–639.

Synolakis, C., Maravelakis, N., Kalligeris, N., Skanavis, V., Kaˆn ˘oglu, U., Yalc ¸ıner, A., & Lynett, P., 2016. Case study of small harbor excitation under storm and tsunami conditions, in EGU General Assembly Conference Abstracts, vol. 18, p. 13825.

Synolakis, C. E., Bardet, J.-P., Borrero, J. C., Davies, H. L., Okal, E. A., Silver, E. A., Sweet, S., & Tappin, D. R., 2002. The slump origin of the 1998 Papua New Guinea tsunami, 458(2020), 763–789.

Titov, V., Kaˆno ˘glu, U., & Synolakis, C., 2016. Development of MOST for real-time tsunami forecasting, Journal of Waterway, Port, Coast and Oceanic Engineering, 142, 03116004–1–03116004–16.