

# ***Interactive comment on “Impact of Hurricanes Irma and Maria on the PTWC Tsunami Warning Capability for the Caribbean Region” by Victor Sardina et al.***

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Thank you for taking the time to review the manuscript of write comments and suggestions to improve it. Please find our answers below.

1) The first comment is related to the magnitude referred. As related to fast assessment of earthquakes parameters, it is questionable to mention only the ML computation (page 5 line 11). It is well known that most of the Tsunami warning centers compute Mw, that is the more accurate magnitude in particular for last earthquakes and also typical “tsunami earthquake” events (see Kanamori 1975). Why the authors don’t take into account the computation of Mw, and the variations of Mw accuracy depending on

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the station available after the hurricanes?

Answer:

We do not consider our discussion of the ML magnitude method as questionable. We understand the interest in the Wphase magnitude method, but we consider a discussion of its accuracy as out of the scope and purpose of the paper. We will try to elucidate the reasons why while providing some background on the PTWC operational procedures. We cannot compute an earthquake's magnitude unless we first detect and locate its epicenter. When assessing the impact of the hurricanes on the PTWC operational capabilities for the region we applied the computation of the theoretical earthquake detection times as a way to quantify the impact of the hurricanes in a tangible, practical way. How much longer it takes to detect and locate an earthquake after the hurricanes turns into a direct expression of their actual operational impact.

The PTWC routinely locates and estimates the magnitude of global earthquakes with 5.7 or larger magnitudes. Messages issued for these events, however, always report the moment magnitude estimated via the P-wave moment magnitude, not the Wphase-based magnitude. Applying the Mwp method the PTWC can compute a quick estimate of an earthquake's magnitude in less than 5 minutes from origin time. Results from the Wphase method, however, take around 25 minutes, and although a regional implementation can reduce that time to 12~15 minutes from origin, these computations still take too long to consider them a replacement for the Mwp method, at least within the context of tsunami warning operations.

The available instrumental record of earthquakes in the Caribbean does not include many events with Mw magnitudes larger than 6.8. In its role as local tsunami warning center for Puerto Rico and the Virgin Islands (PRVI) the PTWC must routinely locate and compute the magnitude of earthquakes with 3.0 or larger magnitude. Moreover, in this role the PTWC must issue at least a Tsunami Information Statement (TIS) for any local earthquake in the vicinity of PRVI with a 4.0 or larger magnitude. Although the

ML magnitude saturates for earthquakes with magnitudes around 6.5, it still provides a fast magnitude estimate for the overwhelming majority of earthquakes occurring in the local vicinity of Puerto Rico and the Virgin Islands. For events with magnitudes larger than around 5.6 the PTWC will then compute first the Mwp moment magnitude, and later the Wphase-based magnitude, in that order. Once the estimated magnitude for an earthquake in the Caribbean reaches the 7.1 threshold the PTWC will issued a tsunami thread message. For earthquakes in the immediate vicinity of PRVI, however, the PTWC would issue a tsunami advisory message for shallow underwater earthquakes with a 6.5 or larger magnitude. As shown in our study, most of the impact from the hurricanes concentrated in the eastern Caribbean, so a discussion of the ML magnitude estimates turns paramount, as it constitutes the core of the PTWC local tsunami warning operations for Puerto Rico and the Virgin Islands.

In addition, the accuracy of magnitude estimations can vary, even for CMT magnitude estimates, by as much as 0.3 magnitude unit. Both the level of uncertainty inherent to the analysis methods currently applied, and the conservative criteria build into the PTWC operational procedures to cope with it make a discussion of Wphase magnitude estimates rather inconsequential within the scope of our study.

2) The second comment more general, the authors don't mention the reduction of the accuracy due to lack of data for the fast assessment of seismic parameters (location, depth, magnitude, etc...) To validate the results and conclusions of that study, a complementary study, using data set of recent large earthquakes in the region and eliminate the corresponding data (removing a set of data , i) the set corresponding to the stations stopped in consequence of the two 2017 hurricanes ; ii) other sets of data with several various hypothesis of path of future hurricane, southern, western Caribbean sea ...) would be the best demonstration, and quantify the impact of such weather disaster on the capacities of tsunami monitoring networks and warning systems.

Answer:

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A characterization of the reduction of the accuracy due to lack of data for the fast assessment of the seismic parameters falls out of the scope of our study. The paper instead discusses the impact of the hurricanes on the most critical operational capability of a tsunami warning center, namely, its capacity to detect and locate earthquakes as fast as possible. Our study attempts to make something rather abstract more tangible by expressing the impact of the hurricanes as additional detection and response time delays. In our opinion, detection and response speeds turn not only easier to grasp than specific accuracy or error estimates, but also more critical for tsunami warning operations.

3) Another additional point related to fast seismic parameters computation and accuracy. The W-Phase centroid moment tensor computation is used at PTWC to get a fast tsunami threat forecast. The authors should provide the impact of data of large set of stations missing to the accuracy of the results of computation of W-Phase centroid moment tensor, considering only the set of stations available after the hurricanes. Similar complementary study could be performed considering one of the recent large earthquake in the region ( $M > 7,0$ ) and eliminate set of data unavailable to demonstrate the influence on the rapidity and accuracy on earthquake parameters needed for tsunami warning.

Answer:

The paper does not deal with the effect of the hurricanes on the Wphase centroid moment tensor computations or the PTWC tsunami forecasts. Please refer to our answers to comments 1) and 2) above.

4) Another remark is related to the reason of the stop of data due to the 2 recent hurricanes. Why data of so many stations where unavailable ? Power supply, destruction of station, transmission equipment, could be part of the response . . . It would be useful to provide information on those issues.

Answer:

Our colleagues from Puerto Rico and the Caribbean have reported the damage caused by the hurricanes to their seismic monitoring networks at different forums. Their accounts, combined with circumstantial evidence allows us to attribute the additional seismic station outages to the passing of both hurricanes, but we do not know the specific reasons for each particular site. In many cases the hurricanes destroyed the seismic station sites, in others their communications. It turns quite difficult to have an accurate record of what cause each particular seismic data outage. Despite the hurricanes specific effects in the field, those additional outages did affect the PTWC monitoring and warning capabilities. Due to this we adopted a pragmatic approach and used the available PTWC seismic data latency logs instead.

5) An additional point would be how to build robust stations to hurricane. Recommendations by the authors would be useful for all tsunami warning systems.

Answer:

We mention the need to build more robust seismic stations as part of the conclusions. The PTWC, however, does not install or maintain the seismic sites. We believe that the regional seismic operators in collaboration with the USGS and other organizations should draft these recommendations after conducting surveys of the actual damage caused by the hurricanes to each specific seismic site.

6) And last comment, the title is “Impact on the PTWC Tsunami warning capability for the Caribbean Region “ The tsunami warning system includes also sea-level stations . To be consistent with the title, the authors should add information on the availability of sea level data after the impact of these two recent hurricanes. These data are absolutely necessary to confirm whether a tsunami has been induced by the earthquake or not, and what are the characteristics of the tsunami waves (amplitude, period ...). And provide some information how long it last to repair the stations. In case no impact was noticed on the availability of sea level data, the authors should shortly report on that.

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We agree that the water level data plays an important role when confirming the presence and actual size of a generated tsunami. For tsunami warning purposes, however, water level data does not turn indispensable, particularly in the near field, except perhaps when dealing with sudden volcanic eruptions. To our knowledge, water level data monitoring and analysis has never prompted the issuance of a single tsunami warning or threat message. The PTWC issues tsunami warnings and threat messages based first and foremost of preliminary seismic data analysis, not water level data analysis. This has to do with both the detection speed possible with both types of data, as well as with the density of stations required for actual tsunami monitoring. Water level data provided by either the DART buoys or the coastal tide stations provides the means to confirm the presence of a tsunami, improve and adjust a tsunami forecast, and ultimately turn essential when deciding whether or not to issue a tsunami warning cancellation. As part of its operations, however, the PTWC geoscientists begin to actively monitor the water level stations closer to the earthquake's epicenter only after issuing a tsunami warning or threat message. Due to these reasons we opted for concentrating on the core of tsunami warning operations, and left the analysis of the water level data perhaps for another study.

7) Some minor corrections : a) the notation 01:34 should be changed in 1 mn 34 s or other format specifying minutes and seconds. b) P5 l25 : Figure 10a = (Figure 6b + 110s) ; P5 l31 same correction

Answer:

We will apply the suggested edits and suggestions.

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