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Natural Hazards and Earth System Sciences
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Discussions

Interactive comment on "Assessment of peak tsunami amplitude associated with a great earthquake occurring along the southernmost Ryukyu subduction zone for Taiwan region" *by* Yu-Sheng Sun et al.

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We would like to thank Reviewer for the detailed revision and important suggestions. We improved the manuscript following suggestions. The attachment is modified manuscript.

Q:

3. Are these up to international standards?

4. Are the scientific methods and assumptions valid and outlined clearly?

7. Is the description of the data used, the methods used, the experiments and calculations made, and the results obtained sufficiently complete and accurate to allow their reproduction by fellow scientists (traceability of results)?

Concerning the application of the tsunami model: No. COMCOT is used as a black box. My major criticism is that the model is not validated for this area, and I strongly suggest to add a hind cast of a real event to prove that COMCOT with the chosen settings delivers realistic simulations. Probably, the last near field tsunami in 1867 is not well suited for a hind cast due to the lack of measurements, but the Tohoku tsunami 2011 should be a good test case also for Taiwan.

A: We have added some references in text. [Page 6, lines 2-6]

To solve the time dependent tsunami propagation, we adopt a well-validated numerical model, COMCOT (Cornell Multi-grid Coupled Tsunami Model). COMCOT is able to solve both linear and nonlinear shallow water equations on a Cartesian or Spherical coordinate systems (Wang 2009). In terms of validation, COMCOT has been widely used in studying many historical tsunami events, such as 1960 Chilean tsunami (Liu et al., 1995), 1992 Flores Islands tsunami (Liu et al., 1995), 2003 Algeria tsunami (Wang and Liu, 2005), 2004 Indian Ocean tsunami (Wang and Liu, 2006, 2007), and 2006 Ping-Tung tsunami (Wu, et al., 2008; Chen, et al., 2008). Taking the explicit leap-frog scheme to solve shallow water equation, COMCOT has the 2nd order accuracy in both special and time domains. COMCOT also supports the nested grid system that the finer grid can be placed on a coarser grid to increase the resolution locally. Thus, we can use finer grid in near-shore region and coarser grid in deep sea region.

Reference:

Chen, P. F., Newman, A. V., Wu, T. R., and Lin, C. C. (2008). Earthquake Probabilities and Energy Characteristics of Seismicity Offshore Southwest Taiwan. Terr. Atmos.

Ocean. Sci., 6, 697-703, doi: 10.3319/TAO.2008.19.6.697(PT)

Liu, P. L. F., Cho, Y. S., Yoon, S. B., and Seo, S. N. (1995). Numerical simulations of the 1960 Chilean tsunami propagation and inundation at Hilo, Hawaii. In Tsunami: Progress in prediction, disaster prevention and warning (pp. 99-115). Springer, Dordrecht. https://doi.org/10.1007/978-94-015-8565-1_7

Liu, P. L. F., Cho, Y. S., Briggs, M. J., Kanoglu, U., and Synolakis, C. E. (1995). Runup of solitary waves on a circular island. J. Fluid Mech., 302, 259-285. doi: 10.1017/S0022112095004095

Wang, X. (2009). User manual for COMCOT version 1.7 (first draft). Cornel University, 65.

Wang, X., and Liu, P. L. (2005). A numerical investigation of Boumerdes-Zemmouri (Algeria) earthquake and tsunami. Comput. Model. Eng. Sci., 10(2), 171.

Wang, X., and Liu, P. L. F. (2006). An analysis of 2004 Sumatra earthquake fault plane mechanisms and Indian Ocean tsunami. J. Hydraul. Res., 44(2), 147-154. doi: 10.1080/00221686.2006.9521671

Wang, X., and Liu, P. L. F. (2007). Numerical simulations of the 2004 Indian Ocean tsunamis-coastal effects. Journal of Earthquake and Tsunami, 1(03), 273-297. Wu, T. R., Chen, P. F., Tsai, W. T., and Chen, G. Y. (2008). Numerical study on tsunamis excited by 2006 Pingtung earthquake doublet. Terr. Atmos. Ocean. Sci. doi: 10.3319/TAO.2008.19.6.705(PT)

The following questions should be addressed: Q: Which formulas and parameters are used, in particular for bottom friction (Manning coefficient)? The bottom friction has an impact on the simulated tsunami amplitude at the coast.

A: We have added the description of Manning coefficient. [Page 6, lines 9-10]

Nonlinear shallow water equation for Cartesian coordinate is used:

$\partial\eta/\partial$t+∂P/∂x+∂Q/∂y=-∂h/∂t

∂P/∂t+∂/∂x {P^2/H}+∂/∂y {PQ/H}+gH*$\partial\eta/\partial$x+F_x=0

∂Q/∂t+∂/∂x {PQ/H}+∂/∂y {Q^2/H}+gH*$\partial\eta/\partial$y+F_y=0

η is the free-surface displacement. P and Q are the horizontal volume discharges. g is gravity. h is the still water depth. H is the total water depth, H=η+h. Fx and Fy are the bottom frictions.

F_x=gn^2/H^(7/3)*P(P^2+Q^2)^(1/2)

F_y=gn^2/H^(7/3)*Q(P^2+Q^2)^(1/2)

n is Manning's roughness coefficient. In this study, Manning coefficient is 0.013, which represents a smooth surface (Wu, et al., 2008; Wang 2009).

Reference: Wang, X. (2009). User manual for COMCOT version 1.7 (first draft). Cornel University, 65. Wu, T. R., Chen, P. F., Tsai, W. T., and Chen, G. Y.: Numerical Study on Tsunamis Excited by 2006 Pingtung Earthquake Doublet, Terr. Atmos. Ocean. Sci., 19, 705-715, 2008. doi: 10.3319/TAO.2008.19.6.705(PT)

Q: Which bathymetry and topography data is used? Free GEBCO and SRTM?

A: We have added it. [Page 6, lines 10-11]

Q: The resolution of 1 minute for the inner mesh is quite rough for simulations that should give estimates of the tsunami amplitude at the coast. Our experience from hind casts of real events suggests that at the coast line, the horizontal resolution should be 500m (edge length in an unstructured triangular grid) or better. This should be transferable, as COMCOT also is a model with first order spatial discretization.

A:The Figure 1 presents the time series by uniform slip distribution at station 25 in different resolution of topography. The time series are similar. For resolution, 1 minute is better than 2 minute and for time spent, 1 minute is less than 30 arc-sec. Therefore, to consider the resolution of simulation and time spent, the resolution of 1 minute was applied.

Q: Where are the tide gauges located? See also point 14, references. On the one hand, the exact location is not really important, because the study could be performed with virtual sensor locations or coastal forecast points, but – to reproduce the results, the locations of the (real or virtual) gauges are needed, – for hind casts of real events, the location and measurements from real tide gauges are needed, – the simulation of the tsunami wave form at a tide gauge that is located e.g., inside a harbor or narrow bight is very sensitive to errors in the representation of bathymetry and topography (1min resolution for sure is too coarse!) and to the choice of the roughness parameter (wave reflections). – The comparison in fig. 6 may be spoiled by different gauge locations. Distance to the source is not the only parameter, as it is also stated in the paper, too (e.g., page 7 line 23-24).

A: We have added location information and removed fitting line [Page 6, lines 13-18; Pages 20-21] We list the location of the gauges in the Table 1. The fittings of Fig. 6 just give a rough relationship between wave height and distance for the tsunami source which is perpendicular the coast line. Of course, the distance is not the only parameter for wave height attenuation. We agree to remove the fitting lines.

11. Are mathematical formulae, symbols, abbreviations and units correctly defined and used? If the formulae, symbols or abbreviations are numerous, are there tables or appendixes listing them? Q: Equation (1): W for width, L for length: It's obvious, but nevertheless should be added in the text above. Which value for μ is assumed when estimating Mw? And as a non-seismologist, I would like to ask if the estimate of D = 8.25m is really obvious? Section 2.2: Not my field of expertise at all.

A: We have done it. [Page 3, lines 21-23]

We will add the definition of symbols (W and L) in the text. μ usually sets 30GPa and it assumes that crust is elastically uniform. The estimation of slip and Mw is from

fault geometry and parameter assuming as μ. We analyzed the relation between Mw and average slip (D) in Fig 2. The public finite fault slip models of global slip earthquakes are from the website (http://equake-rc.info/SRCMOD/). This figure appears the trend between Mw and average slip and its boundary. For Mw8.15, the range could be 200$\sim$1000 cm. It explains that our estimation, which follows the trend and in the possible boundary, is reasonable.

Reference:

Ammon, C. J., J. Chen, H.-K. Thio, D. Robinson, S. Ni, V. Hjorleifsdottir, H. Kanamori, T. Lay, S. Das, D. Helmberger, G. Ichinose, J. Polet, and D. Wald. (2005). Rupture process of the great 2004 Sumatra-Andaman earthquake, Science, 308, 1133-1139.

Ammon, C. J., T. Lay, H. Kanamori, and M. Cleveland (2011) A rupture model of the 2011 off the Pacific coast of Tohoku Earthquake, Earth Planets Space, 63, 693–696.

Bejar-Pizzaro M., Carrizo D., Socquet A., Armijo R., (2010) Asperities, barriers and transition zone in the North Chile seismic gap: State of the art after the 2007 Mw 7.7 Tocopilla earthquake inferred by GPS and InSAR data, Geoph. Journ. Int., GJI-S-09-0648, doi: 10.1111/j.1365-246X.2010.04748.x

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Delouis B., J. M. Nocquet, M. Vallée (2010). Slip distribution of the February 27, 2010 Mw = 8.8 Maule Earthquake, central Chile, from static and high-rate GPS, InSAR, and broadband teleseismic data, Geophys. Res. Lett., 37, L17305, doi:10.1029/2010GL043899.

Hayes G., (NEIC, Maule 2010) Updated Result of the Feb 27, 2010 Mw 8.8 Maule, Chile Earthquake, http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/finite_fault.php,last accessed August 19, 2013.

Hayes G., (NEIC, Sumatra 2012) Preliminary Result of the Apr 11, 2012 Mw 8.6 Earthquake Off the West Coast of Northern Sumatra, http://earthquake.usgs.gov/earthquakes/eqinthenews/2012/usc000905e/finite_fault.php,last accessed August 19, 2013.

Ide S., A. Baltay, and G. C. Beroza (2011). Shallow Dynamic Overshoot and Energetic Deep Rupture in the 2011 Mw 9.0 Tohoku-Oki Earthquake, 332, 1426-1429, DOI: 10.1126/science.1207020 Ji, C. (2005). Preliminary Rupture Model for the December 26, 2004 earthquake, off the west coast of northern Sumatra, magnitude 9.1, http://neic.usgs.gov/neis/eq_depot/2004/eq_041226/neic_slav_ff.html.

Ji C. (UCSB, Tocopilla 2007) Preliminary Result of the Nov 14, 2007 Mw 7.81 ANTOFAGASTA, CHILE Earthquake, http://www.geol.ucsb.edu/faculty/ji/big_earthquakes/2007/11/anto/anto.html, last accessed August 11, 2013.

Koketsu, K., K. Hikima, S. Miyazaki, and S. Ide. (2004). Joint inversion of strong motion and geodetic data for the source process of the 2003 Tokachi-oki, Hokkaido, earthquake. Earth Planets and Space 56 (3):329-334.

Lay T., C. J. Ammon, H. Kanamori, L. Xue, and M. J. Kim (2011). Possible large near-trench slip during the 2011 Mw 9.0 off the Pacific coast of Tohoku Earthquake. Earth Planets Space. 63, 687–692.

Luttrell, K. M., Tong, X., Sandwell, D. T., Brooks, B. A., and Bevis, M. G. (2011). Estimates of stress drop and crustal tectonic stress from the 27 February 2010 Maule, Chile, earthquake: Implications for fault strength. Journal of Geophysical Research: Solid Earth (1978–2012), 116(B11).

Ma, K. F., T. R. A. Song, S. J. Lee, and H. I. Wu. (2000). Spatial slip distribution of the September 20, 1999, Chi-Chi, Taiwan, earthquake (M(W)7.6) - Inverted from

teleseismic data. Geophys. Res. Lett. 27 (20):3417-3420.

Motag, M., B. Schurr, J. Anderssohn, B. Cailleau, T. R. Walter, R. Wang, J.-P. Villotte, (2010) Subduction earthquake deformation associated with 14 November 2007, Mw 7.8 Tocopilla earthquake in Chile: Results from InSAR and aftershocks, Tectonophysics 490, 60–68

Rhie, J., D. Dreger, R. Burgmann, and B. Romanowicz. (2007). Slip of the 2004 Sumatra–Andaman Earthquake from joint inversion of long-period global seismic waveforms and GPS static Offsets, Bull. Seismo. Soc. Am., 97(1A): S115–S127.

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Shao, G., X. Li, C. Ji. and T. Maeda (2011). Focal mechanism and slip history of 2011 Mw 9.1 off the Pacific coast of Tohoku earthquake, constrained with teleseismic body and surface waves, Earth Planets Space, 63 (7), 559-564.

Shao, G., X. Li, Q. Liu, X. Zhao, T. Yano and C. Ji(UCSB, Maule 2010).Preliminary slip model of the Feb 27, 2010 Mw 8.9 Maule, Chile Earthquake, http://www.geol.ucsb.edu/faculty/ji/big_earthquakes/2010/02/27/chile_2_27.html,last accessed September 24,2013.

Sladen A. (Caltech, Tocopilla 2007). Preliminary Result 11/14/2007 (Mw 7.7), Tocopilla Earthquake, Chile. Source Models of Large Earthquakes. http://www.tectonics.caltech.edu/slip_history/2007_tocopilla/tocopilla.html, last accessed July 1, 2013.

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Tanioka, Y., K. Hirata, R. Hino, and T. Kanazawa. (2004). Slip distribution of the 2003 Tokachi-oki earthquake estimated from tsunami waveform inversion. Earth Planets and Space 56 (3):373-376.

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Wu, C. J., M. Takeo, and S. Ide. (2001). Source process of the Chi-Chi earthquake: A joint inversion of strong motion data and global positioning system data with a multifault model. Bull. Seis. Soc. Am 91 (5):1128-1143.

Yagi, Y. (2004). Source rupture process of the 2003 Tokachi-oki earthquake determined by joint inversion of teleseismic body wave and strong ground motion data, Earth Planets Space, 56, 311–316.

Yagi, Y. and Fukahata, Y., (2011). Rupture process of the 2011 Tohoku-oki earthquake and absolute elastic strain release, Geophys. Res. Lett, 38, L19307, doi:10.1029/2011GL048701.

Yamanaka, Y., and M. Kikuchi. (2003). Source process of the recurrent Tokachi-oki earthquake on September 26, 2003, inferred from teleseismic body waves. Earth Planets and Space 55 (12):E21-E24.

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Zeng, Y. H., and C. H. Chen. (2001). Fault rupture process of the 20 September 1999 Chi-Chi, Taiwan, earthquake. Bull. Seis. Soc. Am 91 (5):1088-1098.

Zeng, Y., G.Hayes and C. Ji (2007; USGS, Online Model). Preliminary Result of the Nov 14, 2007 Mw 7.7 Antofagasto, Chile Earthquake, http://earthquake.usgs.gov/earthquakes/eqinthenews/2007/us2007jsat/finite_fault.php, last accessed August 20, 2013.

Zhang, W., T. Iwata, K. Irikura, A. Pitarka, and H. Sekiguchi (2004), Dynamic rupture process of the 1999 Chi-Chi, Taiwan, earthquake, Geophys. Res. Lett., 31, L10605, doi:10.1029/2004GL019827.

12. Is the size, quality and readability of each figure adequate to the type and quantity of data presented? Figure 4: change y-axis label to "Wave amplitude" Figure 6: I would keep this figure, but skip the explicit linear fitting. It pretends an accuracy that cannot be obtained.

A: We have done it. [Pages 18, 20]

14. Are the number and quality of the references appropriate? A citation for the tide gauge locations or at least a list of coordinates would be handy. The Taiwanese tide gauges are not available at http://www.ioc-sealevelmonitoring.org or http://www.psmsl.org/ (Taipei until 1995, Kaohsiung until 1996), and I could not find a link to the gauges at the website of the Taiwanese Central Weather Bureau (CWB) http://www.cwb.gov.tw This private/commercial site was the best information I could find: https://www.tide-forecast.com/locations/Hualien-City . Still, no exact location, but the "Detailed Map" gives at least an idea that this station is located inside the harbour. In total, 9 Taiwanese stations are available here. I am miss-

ing a short overview of historical tsunamis in Taiwan, but the last local tsunami occurred in 1867, and it might be difficult to find scientific papers to cite, see e.g., http://scweb.cwb.gov.tw/NewsContent.aspx?ItemId=37&CId=199&loc=en However, I found the following paper - no tsunami, but a report on the uplift of the tide gauge due to the earthquake. Maybe, this paper provides a helpful hindcast, too: COMCOT should not show a strong tsunami. Chung-Liang Lo, Emmy Tsui-Yu Chang, and Benjamin Fong Chao. Relocating the historical 1951 Hualien earthquake in eastern Taiwan based on tide gauge record. Geophys. J. Int. (2013) 192, 854–860. doi: 10.1093/gji/ggs058

A: We have added the information of location. [Page 6, lines 13-18]

The website of Taiwanese Central Weather Bureau (CWB) presents the location of tide stations (http://e-service.cwb.gov.tw/HistoryDataQuery/index.jsp and http://www.cwb.gov.tw/V7e/climate/marine_stat/tide.htm). Lo et al., (2013) investigated the historical 1951 Hualien earthquake sequence. The magnitude of three earthquakes are smaller than our scenario estimation and the focal mechanisms are different from our fault model so that it is not applicable to be compared with our study. This maybe be considered another tsunami earthquake.

15. Are the references accessible by fellow scientists? Yes, but please add doi numbers.

A: We have done it. [Pages 11-15]

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-336/nhess-2017-336-AC1-supplement.pdf

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Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2017-336, 2017.

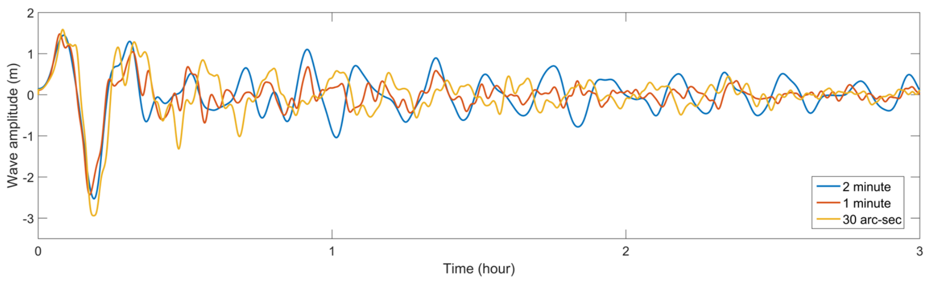

Fig. 1. Fig. 1 The time series by uniform slip distribution at station 25 in different resolution of topography. Blue line is 2 minute, red line is 1 minute and yellow line is 30 arc-sec.

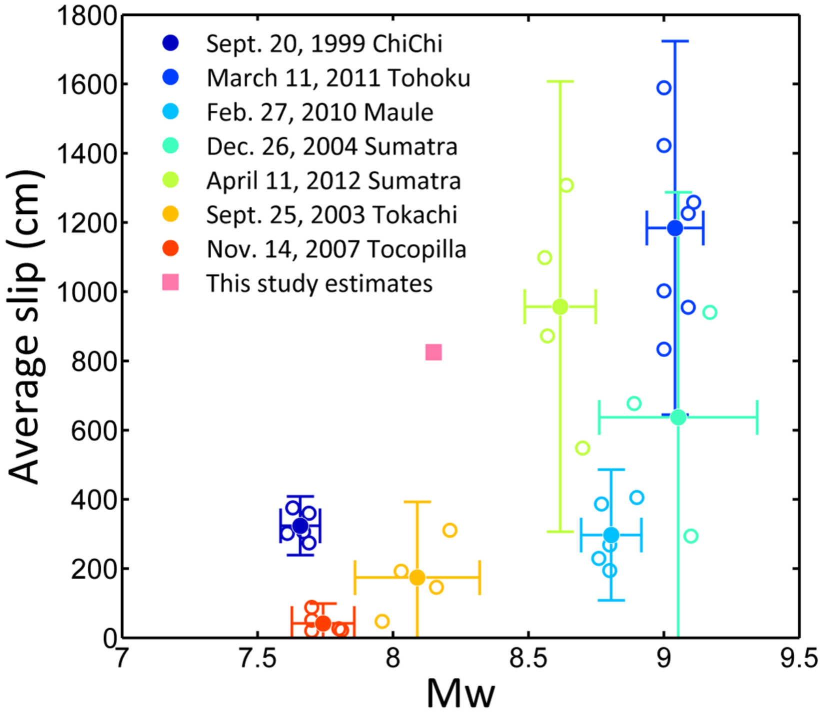

Fig. 2. Fig R1. Mw of real events and their average slips with 2 standard deviation (http://equake-rc.info/SRCMOD/). Open circles represent the inverse slip results in each study. Solid circles represent the