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Initial Tsunami Levels in the Cotabato Trench (Philippines) from 1 in 100 Year and 1 in 1000 Year Return Period Earthquakes

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ABSTRACT

A major earthquake in the Cotabato Trench in Philippines cannot be ruled out. In this paper initial tsunami levels from the earthquake parameters by Salcedo [1] have been generated. The initial tsunami levels from an 1 in 100 year return period earthquake have been generated to support design of marine structures and facilities. Initial tsunami levels from an 1 in 1000 year return period earthquake have also been generated to support emergency and rescue planning and operation. The initial tsunami levels have been generated using the MIKE21 Toolbox developed by DHI [2]. These initial tsunami levels can be used to drive a tsunami propagation model to derive tsunami levels, arrival time and forward velocity at anywhere around the Celebes Sea region. The methodology described in this paper for generating initial tsunami levels in the Cotabato Trench could also be applied to this type of events at other sites around the world.

Key words: Tsunami, Natural Hazards, Cotabato Trench, Celebes Sea, Numerical Modelling, Port Development, Royal HaskoningDHV

1. INTRODUCTION

1.1 Trenches in Philippines

Philippines is located in an active seismic zone. Both inland and offshore earthquakes are generated in the Philippines seismic regions generating tsunamis.

Known trenches in the Philippines [3] are:

1) Manila Trench
2) East Luzon Trough
3) Philippine Trench
4) Negros Trench
5) Sulu Trench
6) Cotabato Trench

These trenches are shown in Figure 1 from Tongkul et al [4].

1.2 The Cotabato Trench

The Cotabato Trench is an oceanic trench in the Pacific Ocean, off the south-western coast of Mindanao in the Philippines. Along this trench the oceanic crust of the Sunda Plate beneath the Celebes Sea is being subducted beneath the Philippines Mobile Belt. It forms part of a linked set of trenches along the western side of the Philippines formed over east-dipping subduction zones, including the Manila Trench and the Negros Trench [5]. At its northern end the rate of convergence across this boundary is about 100 mm per year [6]. The above text has been obtained from Wikipedia [7].

1.3 Tsunamigenic Earthquakes in the Cotabato Trench

The Cotabato Trench is associated with large megathrust earthquakes, including the 1918 Celebes Sea earthquake (Mw 8.3), the 1976 Moro Gulf earthquake (Mw 8.0) and the 2002 Mindanao earthquake (Mw 7.5) [6,8]. The above text has been obtained from Wikipedia [7].

The Cotabato Trench is one of the main structure around the Philippines likely to be associated with tsunamigenic earthquakes. The tsunami generated by the 1976 earthquake caused about 4,000 deaths on Mindanao. Modelling of likely further tsunamis along the Cotabato Trench suggests that run-ups of several metres are likely for future earthquakes similar in size to the 1976 event [9]. The above text has been obtained from Wikipedia [7].

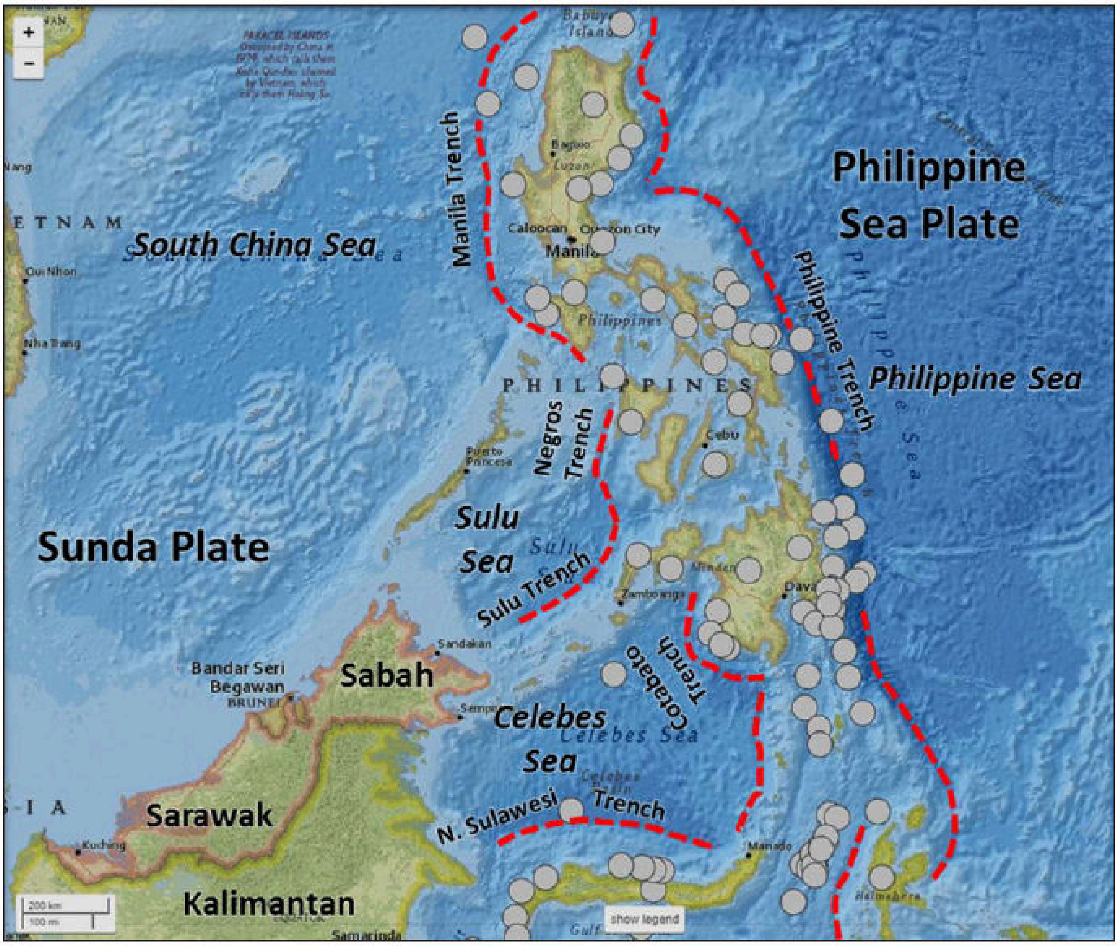

Fig. 1 Location of trenches around the Philippines [4]

1.4 Previous Studies on the Cotabato Trench

Salcedo [1] provided a set of earthquake source parameters for events which can occur in subduction zones surrounding the Philippines and cause large tsunamis and damages. Salcedo [1] identified six source regions (Manila Trench, Negros Trench, Sulu Trench, Cotabato Trench, East Luzon Trough, and the Philippine Trench) surrounding the Philippines. The Cotabato Trench was divided into two segments (CT1 with Mw 7.9 and CT2 with Mw 8.1). The earthquake source parameters such as fault location (longitude, latitude, depth), fault length, fault width, strike angle, dip angle, rake angle and slip amount as well as the maximum plausible earthquake magnitude for each fault segmentation were provided.
Azis [10] carried out numerical modelling of tsunamis in the Sulu Sea and the Celebes Sea. Countries surrounding the Celebes Sea are affected by tsunamis in the Cotabato Trench. The Cotabato Trench was divided into two segments (CT1 and CT2) following Salcedo [1].

1.5 The Present Study

In this paper initial tsunami levels from the earthquake parameters by Salcedo [1] have been generated. The initial tsunami levels from an 1 in 100 year return period earthquake have been generated to support design of marine structures and facilities. Initial tsunami levels from an 1 in 1000 year return period earthquake have also been generated to support emergency and rescue planning and operation.
The general definition of tsunami level and tsunami wave height is illustrated in Figure 2. The flowchart in Figure 3 illustrates the steps and the software involved in a typical tsunami modelling study. The MIKE21 Toolbox was used to generate the initial tsunami levels.

2. SELECTION OF EARTHQUAKE PARAMETERS

2.1 Fault Parameters of the Cotabato Trench

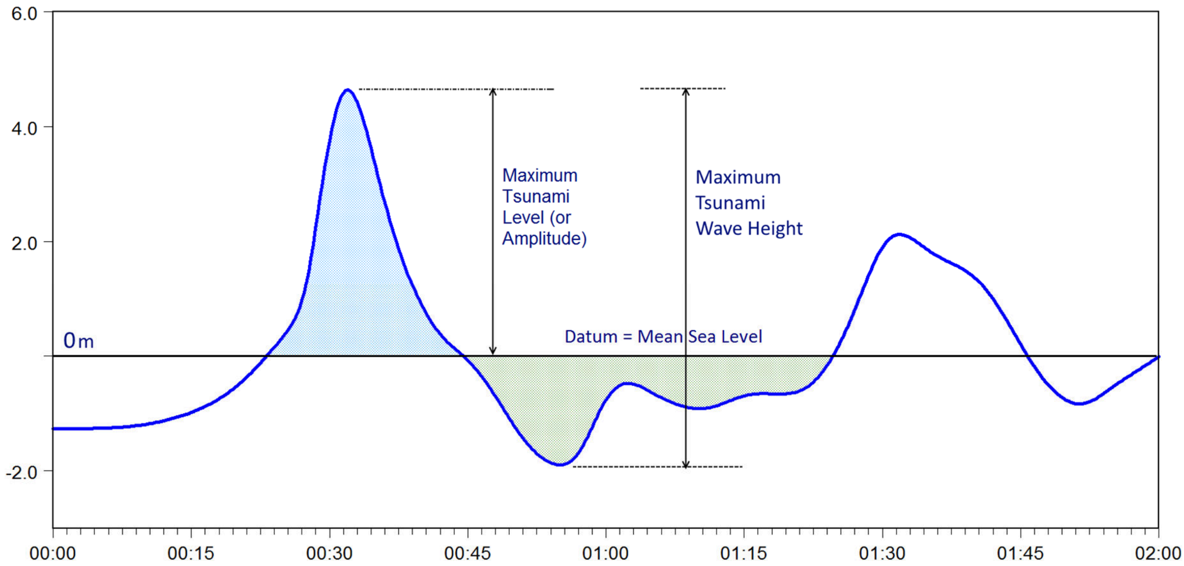

Fig. 2 General definition of tsunami level and tsunami wave height

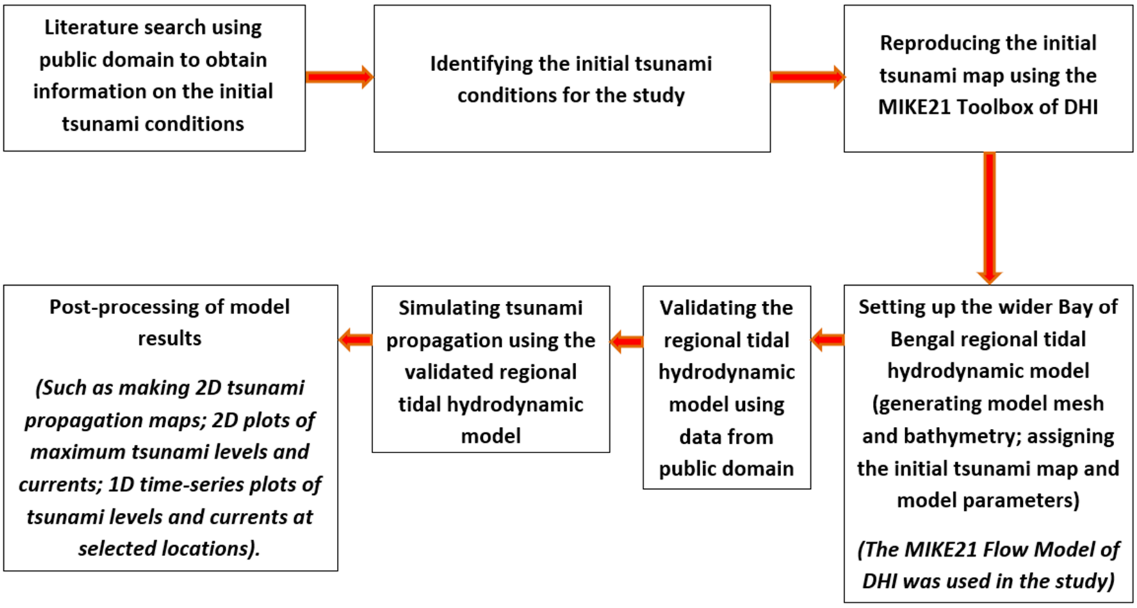

Fig. 3 Steps and software used in a typical tsunami modelling study

The Cotabato Trench was divided into two segments, namely CT1 and CT2 (as in Figure 4) by Salcedo [1] following the segmentation given by Bautista and PHIVOLCS-DOST [11]. The fault parameters from Salcedo [1] are provided in Table 1. The coordinates of the corner location of the fault are shown in the table.

Table -1 Fault parameters of the Cotabato Trench from Salcedo [1]

Sub-faults	Mw	Latitude (°N)	Longitude (°E)	Length (km)	Width (km)	Depth (km)	Slip (m)	Strike (°N)	Dip (°)	Rake (°)
CT1	7.9	4.90	124.50	135	63.84	60	1.77	315	25	79
CT2	8.1	5.70	123.60	190	77.40	60	2.63	355	35	92

2.2 1 in 100 Year Fault Parameters of the Cotabato Trench (Mw 8.5)

Tsunami levels and forward velocity for an 1 in 100 year return period earthquake are required for designing marine structures and facilities. Therefore, initial tsunami levels were generated for an 1 in 100 year earthquake.

The earthquake magnitude (Mw) for various return periods for Philippines were obtained from Rong et al. [12] and are provided in Table 2 and shown in Figure 5.

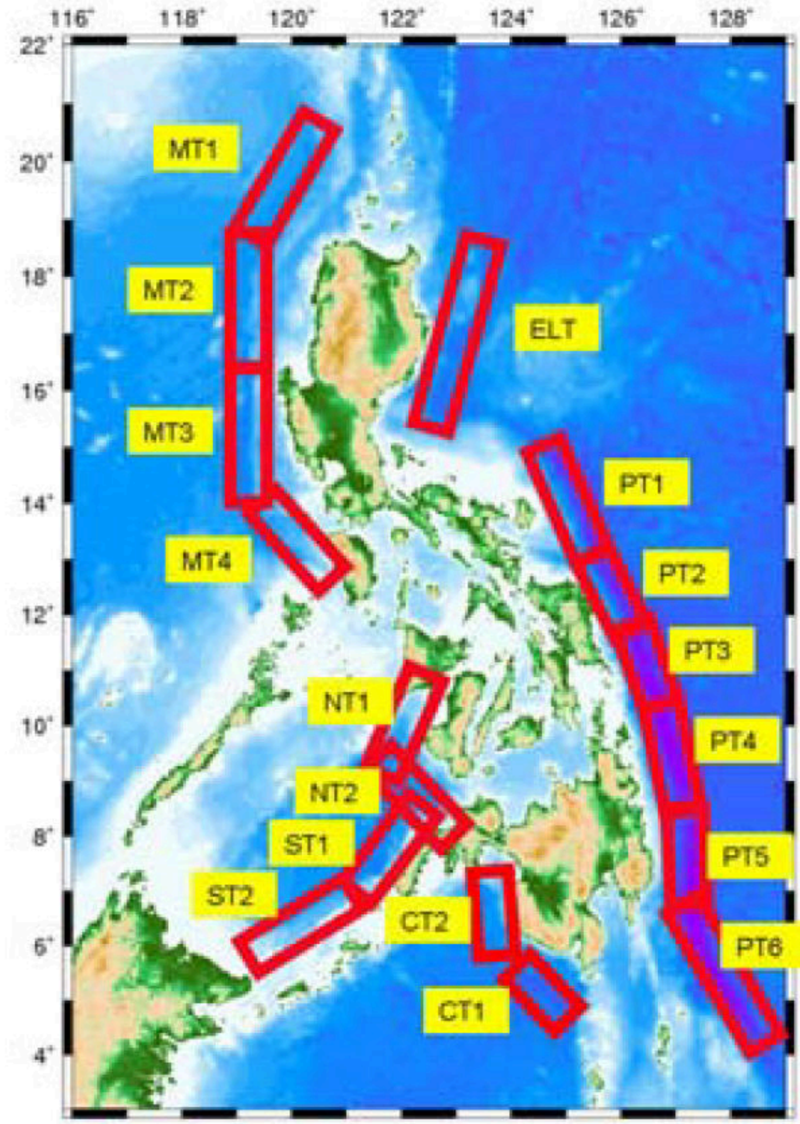

Fig. 4 Sub-fault distribution of the trenches around the Philippines from Salcedo [1]

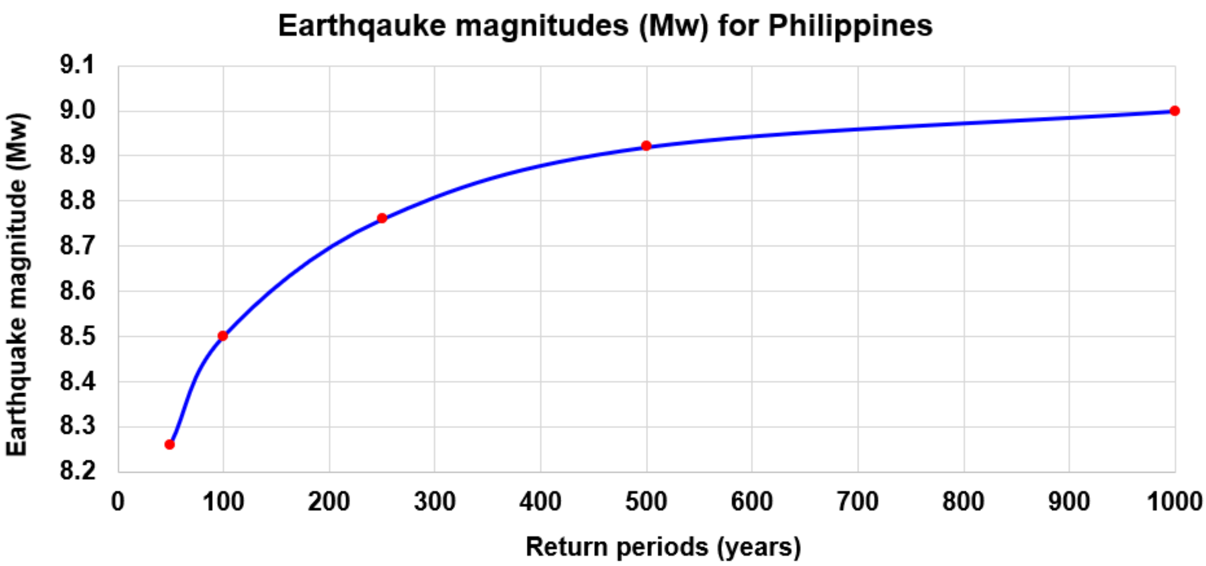

Fig. 5 Earthquake magnitudes (Mw) in Philippines for various return periods [12]

Table -2 Earthquake magnitudes for Philippines for various return periods [12]

Return periods	Earthquake magnitudes (Mw)
1 in 50 year	8.26
1 in 100 year	8.50
1 in 250 year	8.76
1 in 500 year	8.92
1 in 1000 year	9.00

All parameters (except depth and slip) were obtained from Table 1 [1]. Slip was estimated to obtain an earthquake Mw 8.5. The MIKE21 Toolbox does not accept a depth greater than 50km and, therefore, a depth of 50km was used in the study. The MIKE21 Toolbox requires the coordinates of a fault at its centroid and, therefore, the latitudes and longitudes from Salcedo [1] were modified. The final parameters for an 1 in 100 year earthquake are shown in Table 3. The resulting earthquake magnitude (as calculated by the author of this paper) is about Mw 8.5.

Table -3 Fault parameters of an 1 in 100 year earthquake (Mw 8.5) in the Cotabato Trench

Sub-faults	Latitude (°N)	Longitude (°E)	Length (km)	Width (km)	Depth (km)	Slip (m)	Strike (°N)	Dip (°)	Rake (°)
CT1	5.1389	124.6000	135	63.84	50	7.7	315	25	79
CT2	6.5556	123.6667	190	77.40	50	11.5	355	35	92

2.3 1 in 1000 Year Fault Parameters of the Cotabato Trench (Mw 9.0)

Tsunami levels for an 1 in 1000 year earthquake are required to support emergency and rescue planning and operation. Therefore, initial tsunami levels were also generated for an 1 in 1000 year earthquake.

All parameters (except depth and slip) were obtained from Table 1 [1]. Slip was estimated to obtain an earthquake Mw 9.0. The MIKE21 Toolbox does not accept a depth greater than 50km and, therefore, a depth of 50km was used in the study. The MIKE21 Toolbox requires the coordinates of a fault at its centroid and, therefore, the latitudes and longitudes from Salcedo [1] were modified. The final parameters for an 1 in 1000 year earthquake are shown in Table 4. The resulting earthquake magnitude (as calculated by the author of this paper) is about Mw 9.0.

Table -4 Fault parameters of an 1 in 1000 year earthquake (Mw 9.0) in the Cotabato Trench

Sub-faults	Latitude (°N)	Longitude (°E)	Length (km)	Width (km)	Depth (km)	Slip (m)	Strike (°N)	Dip (°)	Rake (°)
CT1	5.1389	124.6000	135	63.84	50	43.6	315	25	79
CT2	6.5556	123.6667	190	77.40	50	65.0	355	35	92

3. GENERATION OF INITIAL TSUNAMI LEVELS

It is assumed that the initial sea surface rise is the same as the final seafloor deformation after the earthquake. This is a reasonable assumption because the duration of an earthquake is generally short and the size of the rupture area is much larger than the water depth. Consequently there is not enough time for the water above the deformed seafloor to drain out. The seismic rupture is much faster than water wave propagation.

Initial tsunami levels were generated for the earthquakes parameters in Tables 1, 3 and 4 using the MIKE21 Toolbox. Square grid size of 10 km x 10 km was used for the domain to generate the initial tsunami levels. Initial tsunami levels for each sub-fault were generated separately and were then summed up to obtain the combined initial tsunami levels. Figure 6 shows the initial tsunami levels generated using earthquake parameters proposed by Salcedo [1] as in Table 1. Figures 7 and 8 show the initial tsunami levels for Mw = 8.5 (1 in 100 year) and 9.0 (1 in 1000 year) respectively. The maximum initial tsunami level for each of the conditions are provided in Table 5. It should be noted that the maximum initial tsunami level and its location for a given Mw will vary due to the distribution of the length, width and dislocation (slip) of the sub-faults.

Table -5 Maximum initial tsunami levels in the Cotabato Trench

Earthquake magnitude (Mw)	Maximum initial tsunami levels (m)
8.1 (Salcedo, [1])	0.8
8.5 (1 in 100 year)	3.5
9.0 (1 in 1000 year)	19.7

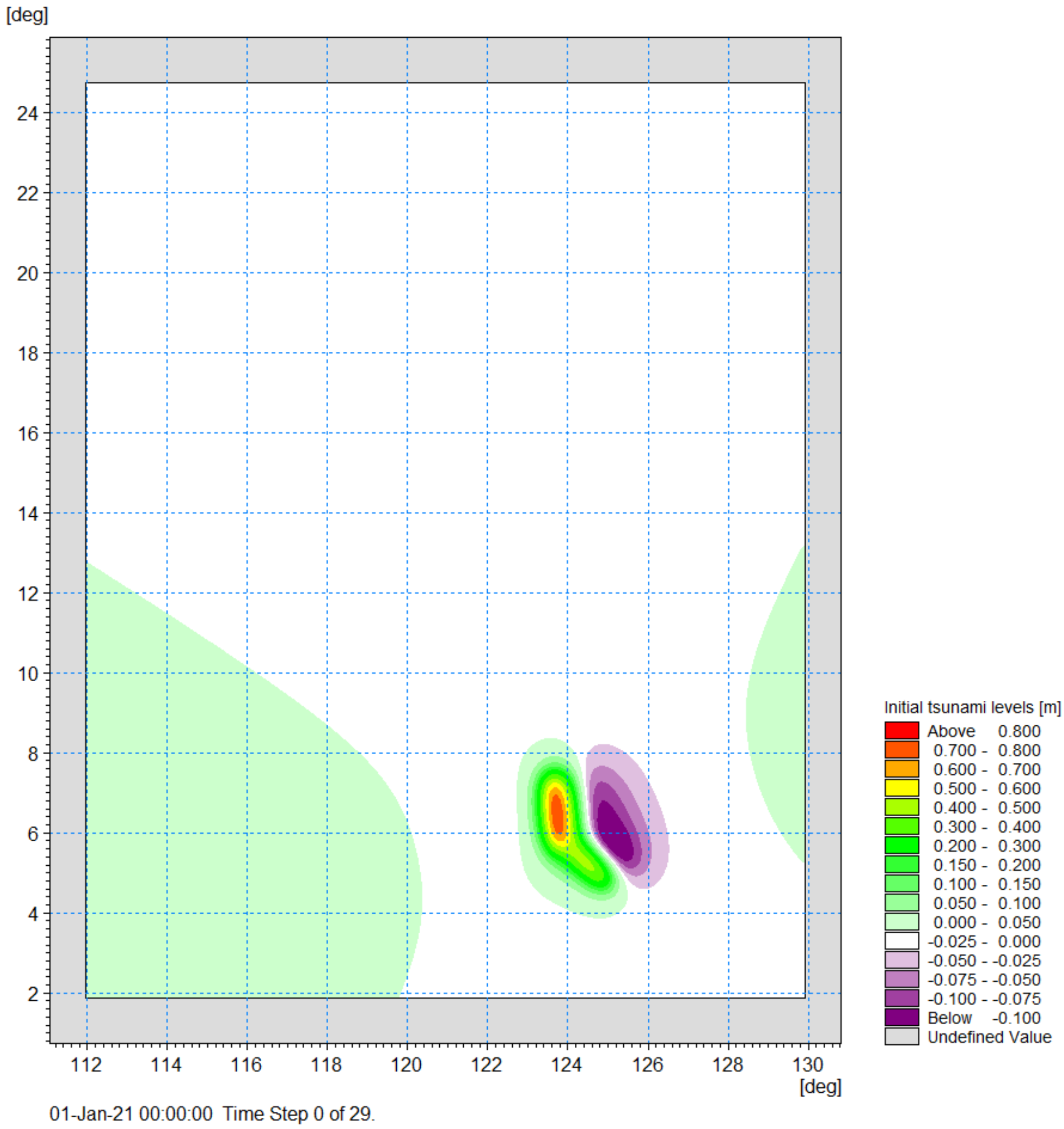

Fig. 6 Initial tsunami levels for the earthquake parameters (Mw 8.1) proposed by Salcedo [1]

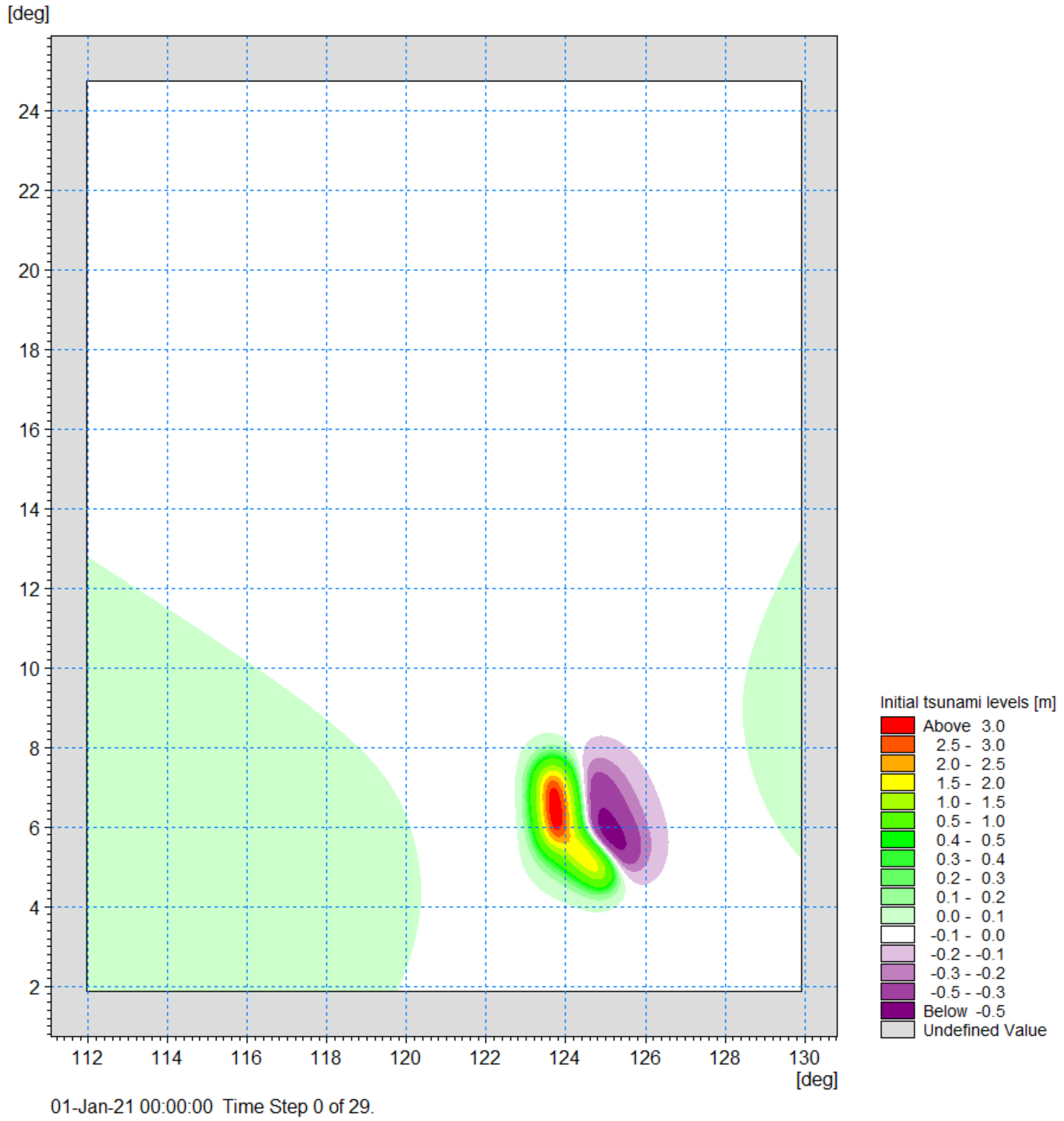

Fig. 7 Initial tsunami levels for an 1 in 100 year earthquake (Mw 8.5) in the Cotabato Trench generated by Royal HaskoningDHV

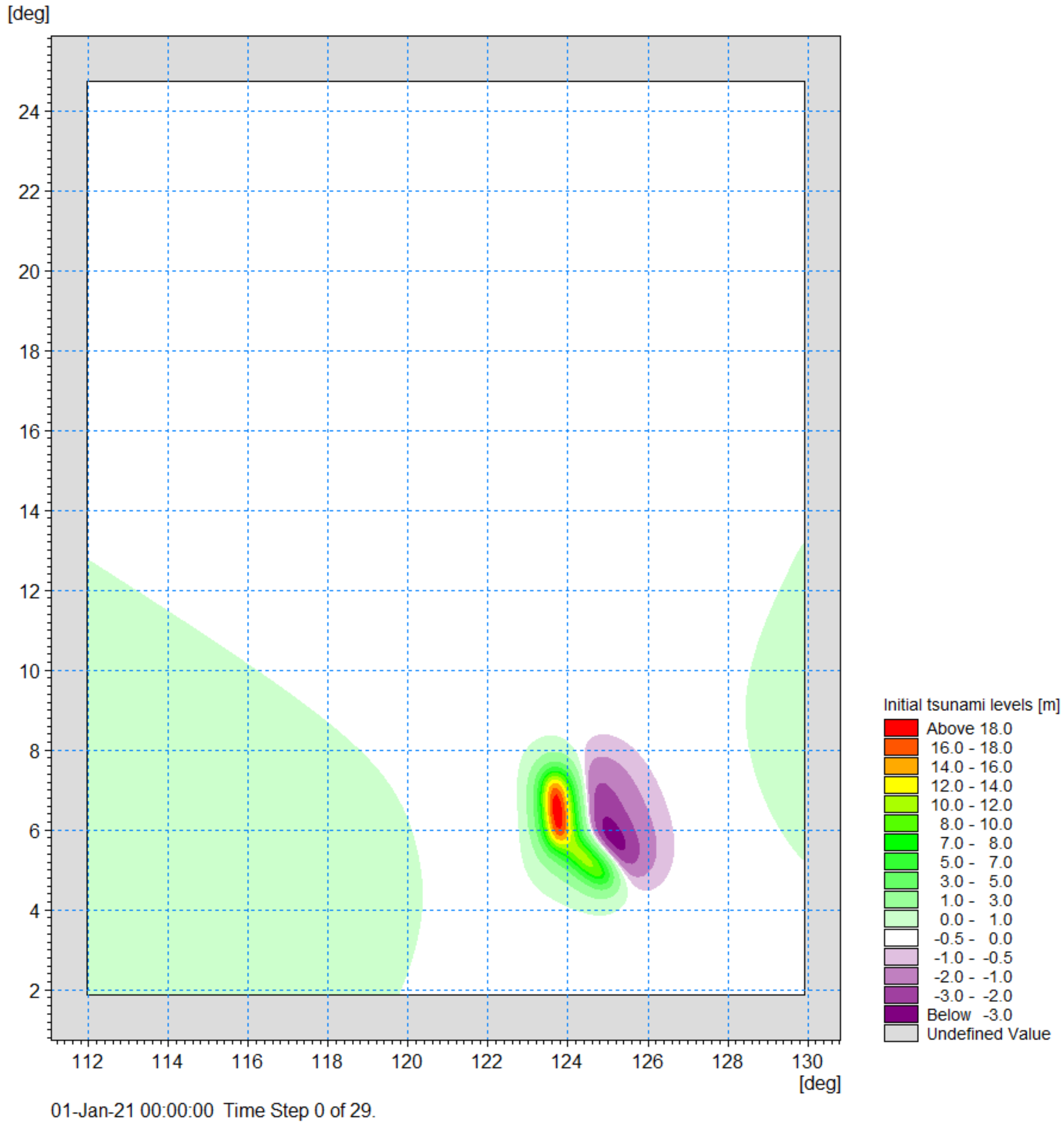

Fig. 8 Initial tsunami levels for an 1 in 1000 year earthquake (Mw 9.0) in the Cotabato Trench generated by Royal HaskoningDHV

4. SUMMARY AND FINDINGS

Literature search suggests that a major earthquake in the Cotabato Trench cannot be ruled out. Initial tsunami levels for Mw 8.5 (1 in 100 year) and 9.0 (1 in 1000 year) were generated in the present study using the MIKE21 Toolbox.
Maximum initial tsunami levels of 3.5 m and 19.7 m were found from the present study for Mw 8.5 and 9.0 respectively.
The initial tsunami levels generated in the present study can be used to drive a tsunami propagation model to derive tsunami levels, arrival time and forward velocity at anywhere around the Celebes Sea region.
The maximum initial tsunami level and its location for a given Mw will vary due to the distribution of the length, width and dislocation (slip) of the sub-faults.

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REFERENCES

[1]. Salcedo, J. C. (2010). Earthquake source parameters for subduction zone events causing tsunamis in and around the Philippines. Bulletin of International Institute of Seismology and Earthquake Engineering (IISEE), Japan, 45:49-54.
[2]. DHI (2021). MIKE21 Toolbox User Guide, Agern Alle 5, DK-2970 Hosholm, Denmark.
[3]. Wikipedia (2021a). Philippine Trench, https://en.wikipedia.org/wiki/Philippine_Trench.
[4]. Tongkul, F., Roslee, R. and Mohd Daud, A., K., T. (2020). Assessment of tsunami hazard in Sabah – Level of threat, constraints and future work. Bulletin of the Geological Society of Malaysia, Volume 70, November 2020, pp. 1 – 15, DOI: https://doi.org/10.7186/bgsm70202001.
[5]. Wu, W-N., Lo, C-L. and Lin, J-Y. (2017). Spatial variations of the crustal stress field in the Philippine region from inversion of earthquake focal mechanisms and their tectonic implications. Journal of Asian Earth Sciences, Volume 142, July 2017, Pages 109-118. https://doi.org/10.1016/j.jseaes.2017.01.036.
[6]. USGS (2002). ANSS. "Mindanao 2002". Comprehensive Catalog. U.S. Geological Survey.
[7]. Wikipedia (2021b). Cotabato Trench. https://en.wikipedia.org/wiki/Cotabato_Trench.
[8]. Stewart, G., S. and Cohn, S. N. (1979). The 1976 August 16, Mindanao, Philippine earthquake (Ms = 7.8) - evidence for a subduction zone south of Mindanao. Geophys. J. R. astr. Soc. (1979) 57, 51-65.
[9]. Løvholt, F., D. Kühn, H. Bungum, C. B. Harbitz, and S. Glimsdal (2012). Historical tsunamis and present tsunami hazard in eastern Indonesia and the southern Philippines, J. Geophys. Res., 117, B09310, doi:10.1029/2012JB009425.
[10]. Azis, M. (2011). Tsunami numerical simulation around Sulu Sea and Celebes Sea. Bulletin of International Institute of Seismology and Earthquake Engineering (IISEE), Japan, 46:109-114.
[11]. Bautista, B.C. and PHIVOLCS-DOST (2007). Tsunami Hazard Mapping and Risk Assessment Project, DOST-GIA.
[12]. Rong, Y., Jackson, D. D., Magistrale, H. and Goldfinger, C. (2014). Magnitude Limits of Subduction Zone Earthquakes. Bulletin of the Seismological Society of America, Vol. 104, No. 5, pp. 2359-2377, 16 September 2014, https://doi.org/10.1785/0120130287.