ISSN: 2579-5821 (Print)
ISSN: 2579-5546 (Online)
URL address: http://journal.unhas.ac.id/index.php/geocelebes
DOI: 10.20956/geocelebes.v7i1.19975

Jurnal Geocelebes Vol. 7 No. 1, April 2023, 1 – 7

Using Grid Search and Guided Random Search (Simulated Annealing) Methods in Determining the Earthquake Hypocenter in the Majalengka Region, West Java on November 11, 2021

Fachri Aldi Pramudya, Restu Ningsih*, Hayu Nurfaidah, Siska Erna Sephiana, Rahmat Catur Wibowo, Ahmad Zaenudin

Geophysical Engineering Department, Universitas Lampung, Prof. Sumantri Brojonegoro Street, No. 1, Bandar Lampung City, Lampung Province, Indonesia.

*Corresponding author. Email: restu.ningsih100119@students.unila.ac.id

Manuscript received: 8 February 2022; Received in revised form: 27 April 2022; Accepted: 16 August 2022

Abstract

Tectonic earthquakes are generally caused by the release of energy produced by a pressure from a moving slab. This study aimed to test the use of grid search methods and guided random search in determining the hypocenter position of the earthquake in the case of the Majalengka regional earthquake, West Java which occurred on November 11, 2021. In this study used earthquake source data with the number of 5 stations, are COCO, KAPI, PALK, MBWA, and NWAO which can be accessed on the IRIS. From the results of determining the earthquake hypocenter using the grid search method, the position of the earthquake hypocenter is obtained with a latitude position of 6.596861ºS and for a longitude position of 108.2871°E with a depth of 200 km, while from the processing of the simulated annealing method, the latitude position is 6.501645°S and longitude 108.2252°E with depth of 172.1 km. Meanwhile, if we compare the position of the earthquake hypocenter according to IRIS, are the latitude position of 6.6027°S and for the longitude position of 108.105°E with a depth of 164.41 km, because the hypocenter data from IRIS has been revised by a seismologist so that it is used as a reference, the results that are closest to the position according to IRIS are the results of the simulated annealing method.

Keywords: earthquakes; grid search; guided random search; hypocenter; simulated annealing.

Citation: Pramudya, F.A., Ningsih, R., Nurfaidah, H., Sephiana, S.E., Wibowo, R.C. and Zaenudin, A. (2023). Using Grid Search and Guided Random Search (Simulated Annealing) Methods in Determining the Earthquake Hypocenter in the Majalengka Region, West Java on November 11, 2021. *Jurnal Geocelebes*, 7(1): 1–7, doi: 10.20956/geocelebes.v7i1.19975.

Introduction

Indonesia is one of the countries that are prone to natural disasters. This is related to the geographical location of Indonesia, which is located between three large plate tectonics, are the Eurasian Plate, Indo-Australian Plate, and the Pacific Plate; or is also included in the ring of fire area. The movement of three large plates that flank Indonesia, gave significant volcanoes and tectonic activity (Aldiamar, 2007). In general, the tectonic plates in Indonesia are divided into two parts, are the west and the east. The movement of each different plate makes a subduction zone and a transform fault zone. This has an impact on the earthquake disaster which is the most destructive and detrimental natural event in Indonesia (Milson et al., 1992).

West Java is one area that has a high level of seismicity. This condition is caused because the area is a subduction area of the Indo-Australian Plate under the Eurasian Plate and active faults are found in this region. The geological structure that develops in West Java is influenced by the activity of the Indo-Australian Plate which subducts under the Eurasian Plate. The geological activity of West Java which has been going on for millions of years has produced various types of rocks, both sedimentary rocks, igneous rocks (extrusive and intrusive), and metamorphic rocks with various ages (Hamilton, 1979).

van Bemmelen (1970) divided the western part of Java into several physiographic and structural lines. Majalengka Regency is included in the geological structure of the Bogor Zone which produces an anticlinorium with a west-east direction. In the northern part of the Bogor zone, the geological structure is northward due to pressure from the south (subduction between the Indo-Australian and Eurasian plates). This stress causes folding and faults to appear.

This study uses earthquake data in the Majalengka Regency, West Java with the scope of research being the Majalengka Sub-Basin. In space and time, the research area is limited to Tertiary to Quaternary rocks. The Majalengka sub-basin is part of the back-arc basin which is partly filled with deep-sea sediments.

The occurrence of an earthquake causes a lot of damage which is influenced by several things such as the earthquake magnitude, the characteristics of the ground surface, and ground acceleration. Soft soil layers can cause greater earthquake vibrations compared to harder soil layers when the earthquake waves pass through. This effect is called the amplification of earthquake waves (Solikhin and Suantika, 2008).

The hypocenter is a very important parameter in the seismic field. Based on hypocenter information, it can be estimated that the cause of an earthquake in an area is magma activity or structural activity such as faults. Several methods for determining the hypocenter such as the inversion method and the grid search method (Fauzi, 2010).

Methods of determining earthquake hypocenters have been developed to obtain results rapidly. However, some cases in Indonesia have data processing speed that is inversely proportional to the accuracy of the results obtained (Arimuko et al., 2019).

The use of the grid search method is carried out by calculating each sample point that is formed based on the grid (Grandis and Dahrin, 2014). This method is a development of the neighborhood method. The time required in the calculation, according to the initial parameters in the iteration process. For each grid that has been calculated, the error value will be reviewed. If the new error value is smaller than the previous error value, then the new value is used as the limit. Thus, the calculation will continue until all grids are successfully calculated and will get the smallest RMS (Root Mean Square) value as the best solution (Nurwidyanto and Setiawan, 2011).

This study aims to test the grid search method and guided random search in determining the location of the earthquake hypocenter in the Majalengka area, West Java, in 2021. The calculation is carried out with the help of programming using Matlab software. The results of this study are expected to be a reference in choosing the method of determining the earthquake hypocenter.

Materials and Methods

This study uses data on the earthquake that occurred on November 11, 2021, in the Majalengka area, West Java. Majalengka Regency is geographically located in the eastern part of West Java Province at 6°32’16.39” S – 7°4’24.75” S and 108°2’30.87” E – 108°24’32.84” E with an area of 1,204.24 Km^2. This study uses earthquake source data with a total of 5 stations, are COCO, KAPI, PALK, MBWA, and NWAO (Table 1) which can be accessed on the IRIS page by entering the date range of occurrence and the desired minimum earthquake magnitude. Earthquake parameters include hypocenter location, origin time of occurrence, region, and magnitude.

Table 1. Station Coordinate (sensor).

Station	Latitude	Longitude	Elevation
COCO	-12.19009°	96.8348°	0.001m
KAPI	-5.014200°	119.7517°	0.3 m
PALK	7.2727999°	80.7022°	0.46 m
MBWA	-21.15900°	119.7313°	0.093 m
NWAO	-32.92770°	117.2389°	0.2781 m

Wadati Diagram

A simple technique for determining the origin time is the Wadati Diagram. In the Wadati Diagram, the arrival time difference between the P wave and S wave (ts-tp) is plotted against the arrival time of the P wave. The plotting results can determine the origin time by finding the intersect point ts-tp with the x-axis (the arrival time of the P wave). Earthquake time or origin time (OT) was determined using tp and (ts-tp) data from several n stations (Nugraha, 2005).

Grid Search Method

The Grid Search method takes time depend on the initial parameters in the iteration process. The Grid Search method is a development of the neighborhood method developed by Sambridge and Gallagher (1993). Each grid that has been calculated will be reviewed for its error value. If the new error value is smaller than the previous value, the new value becomes the limit value. This calculation continues until all grids are successfully calculated and the smallest RMS (Root Mean Square) value will be obtained as the best solution (Rodi and Toksoz, 2000).

In the Grid Search method, each sample point is calculated based on a grid (Grandis, 2009). The Grid Search method requires time which is related to the initial parameters in the iteration process. The wide range used starts from the widest area which will then be narrowed after knowing the wide range that has the smallest error value from the previous calculation. The calculation will continue until the value of the wide range or area limit which has the smallest RMS (Root Mean Square) value is known which is the best solution. It should be noted that when determining a large evaluation step parameter, the RMS (Root Mean Square) value used is too small. The results obtained from this method will be more accurate if the grid is made more tightly but the calculation will take longer.

Guided Random Search Method

Each inversion method has its own advantages and disadvantages. The hypocenter solution could be stuck at the local minimum because the initial model is not good. Another inversion method, simulated annealing, can be applied to the global optimization case. Unlike local optimization methods such as iterative least squares, the convergence of the simulated annealing method does not depend on the initial model.

One of the Guided Random Search methods is the Simulated Annealing (SA) method. The Simulated Annealing method (Grandis, 2009) based on the thermodynamic substance crystallization process. At high temperatures a solid substance melts, then the cooling process slowly causes the formation of crystals associated with the minimum system energy.

In this Simulated Annealing process, the model space must be defined first by determining "a priori" the minimum and maximum value intervals for the model parameters. In this study, the model parameter is the earthquake hypocenter. The selection of model parameter values is determined randomly as an arbitrary number in the interval of maximum and minimum values, respectively. The procedure is to take a random number R with a uniform probability between 0 and 1 which is mapped into the model parameter values.

The model perturbation probability is expressed by:

$$P(\Delta E) = \exp\left(-\frac{\Delta E}{T}\right) \quad (1)$$

where ΔE is the change in the objective function or the change in misfit due to the model perturbation. If ΔE<0, then the model change is accepted. However, if ΔE≥0, then the determination is determined probabilistically using a random number R which is uniformly distributed in the interval [0.1]. If R<P(ΔE) then the change is accepted, otherwise if R≥P(ΔE) the change is rejected and returns to the previous one. The iteration process starts with a high enough temperature so that almost all perturbation models are accepted. When the temperature drops slowly, the perturbation of the accepted model will decrease if ΔE≥0.

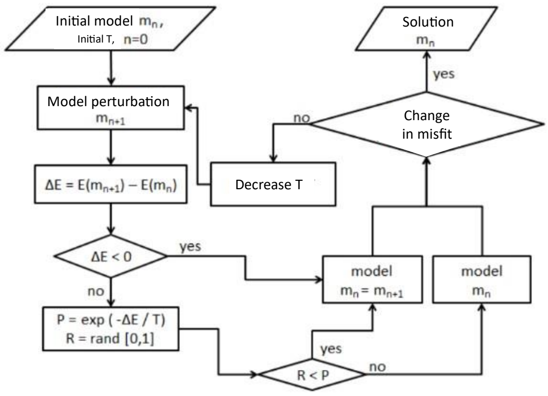

Figure 1. Flowchart of the Simulated Annealing inversion method for hypocenter location determination (Ry and Nugraha, 2012).

One of the parameters that shows the solution of the global minimum is the smallest Root Mean Square (RMS) value. RMS does not get the best solution if the initial parameters used are not appropriate so that it is stuck at the local minimum value (Ratchkovsky et al., 1998). One way to avoid local minimum values is to make maximum use of the available "a priori" information to determine the initial parameter model (Grandis, 2009).

The calculations used to test the two methods are the Grid Search method and the Guided Random Search method (Simulated Annealing Method) using the Matlab programming language. The calculation is done by inputting data on the hypocenter location, velocity model, travel time, and station location.

Result and Discussion

In determining the earthquake hypocenter, first picking the arrival time value of the P wave and S wave respectively at each station that is sampled using SeisGram software. So that from the results of the picking, the parameters needed to determine the origin time are the values of Tp, Ts and the difference between Ts and Tp.

Table 2. Ts-Tp data of research earthquake stations.

Station	Tp	Ts	Ts-Tp
COCO	18:22:15	18:24:34	138.5s
KAPI	18:22 :06	18:24 :16	129.6s
PALK	18:25: 23	18:30: 14	290.9s
MBWA	18:23: 27	18:26: 49	201.4s
NWAO	18:24: 57	18:29: 26	269.7s

Then determine T0 at 18:22:00 because this time is a round number close to the time of arrival, the goal is to simplify the calculation. Also calculate the value of Tobs, with the value of Tobs can be calculated by subtracting the value of T0 from Tp as in Table 3.

Determination of origin time using the Wadati Diagram, plotting the Tp parameter (x-axis) against Ts-Tp (y-axis) as in Figure 2.

Table 3. Tobs value calculation.

Station	Tp	T0	Tobs
COCO	18:22:15	18:22:00	15.931s
KAPI	18:22 :06	18:22:00	6.375s
PALK	18:25: 23	18:22:00	203.088s
MBWA	18:23: 27	18:22:00	87.671s
NWAO	18:24: 57	18:22:00	177.123s

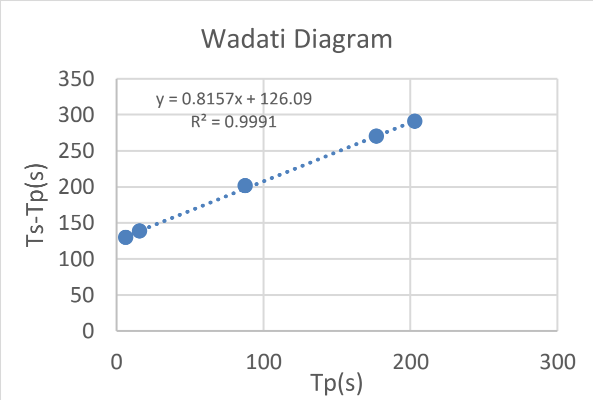

Figure 2. Wadati Diagram to determine the origin time value.

The diagram above shows the trendline equation y = 0.8157x+126.09 with an accuracy of 0.9991 (R^2 value). For the determination of the origin time value, the equation is considered equal to zero or the point of the earthquake occurrence is considered equal to zero. Thus, the result of parameter x is equal to -154.579. To get the value of origin time, by adding the value of T0 to x as in Equation (1). And the resulting Origin time value is 18:19:25.421.

$$\text{Origin Time} = \text{T0} + \text{x} \quad (2)$$

Then, because the origin time result obtained from the above equation is below the arrival time (Tp), the T0 value is determined at 18:19:00. With known data as well, is in Table 4.

Table 4. Origin time calculation results.

x	y	z	T0 (s)	Tobs
264424	8651485	1		195.9s
259937	9445369	300		186.3s
467127	803916	460	25.421	383.08s
783639	7657816	190		267.67s
522344	6356702	380		357.12s

Then from these results, the calculation of the hypocenter position using the Grid Search method can be seen in Figure 3. Calculation of the hypocenter position using the Simulated Annealing method can be seen in Figure 4.

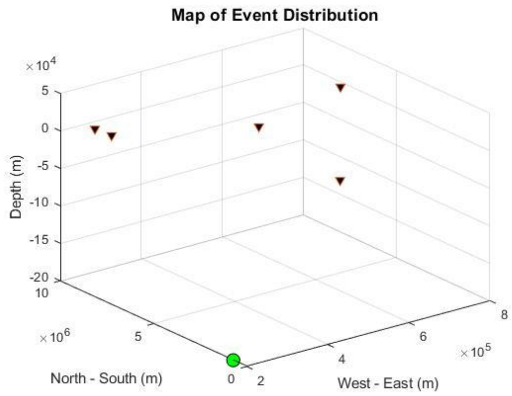

Figure 3. Earthquake hypocenter position using the Grid Search method.

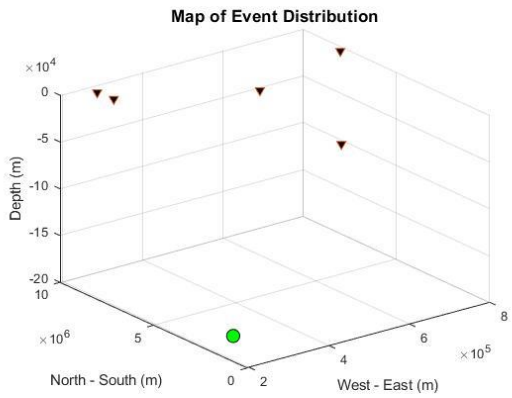

Figure 4. Earthquake hypocenter position using the Simulated Annealing method.

The calculation results using both methods are the best results with the smallest RMS value of each method. The results are not too different which can be seen in Table 5.

Table 5. Comparison of the hypocenter position of the Grid Search and Simulated Annealing methods.

Coordinate		Grid Search	Simulated Annealing
UTM	X	200000	193100
	Y	730000	719500
	Z	-200,000	-172,100
Lat/Long.	X	6.596861°S	6.501645°S
	Y	108.2871°E	108.2252°E
	Z	-200,000	-172,100

Table 5 shows the results of hypocenter calculations using the grid search and simulated annealing methods from a earthquake event using 5 stations. From the results of determining the hypocenter using the grid search method, the position of the earthquake hypocenter was obtained with a latitude of 6.596861° S and a longitude of

108.2871° E with a depth of 200,000 m. Then for the position of the hypocenter from the processing results with the simulated annealing method, the position of latitude 6.501645° S and longitude 108.2252° E with a depth of 172,100 m was obtained. Meanwhile, when compared with the position of the hypocenter according to IRIS, the position of latitude 6.6027° S and longitude 108.105° E with a depth of 164,410 m. The closest result to the position of the IRIS is the result of the Simulated Annealing method. However, these results need to be developed again so that the data becomes better and there is no considerable difference.

Conclusion

In determining the hypocenter, picking is done first to get the parameters needed to determine the origin time, are the value of Tp, Ts and also the difference between Ts and Tp. The calculation of the hypocenter position in this study uses the Grid Search method and the Simulated Annealing method. The results of the Grid Search method obtained the hypocenter position of the earthquake with a latitude position of 6.59686° S and for the longitude position of 108.287° E with a depth of 200,000 m. Then for the hypocenter position from the processing results with the Simulated Annealing method, the latitude position of 6.501645° S and longitude position of 108.2252° E with a depth of 172,100 m were obtained. The position of the earthquake hypocenter according to IRIS is the position of latitude 6.6027° S nd for the position of longitude 108.105° E with a depth of 164,410 m. The most accurate results or close to the position of the earthquake from IRIS are the results of the simulated annealing method. However, these results need to be developed again so that the data becomes better and there is no considerable difference.

Acknowledgments

The author would like to thank all those who have helped in carrying out this writing so that it can be completed properly.

Author Contribution

In compiling this research journal, each writer is divided into several job indexes. For collection of library sources by Restu Ningsih, data processing by Fachri Aldi Pramudya, and drafting of the journal by Siska Erna Sephiana and Hayu Nurfaidah. As for the observers and mentors in the preparation of this journal is Rahmat Catur Wibowo and Ahmad Zaenudin.

Conflict of Interest

In this study there is no financial or personal relationship between the author and the organization and others so that the results of this study can be "accounted for" by the author.

References

Aldiamar, F. (2007). *Analisa Resiko Gempa dan Pembuatan Respon Spektra Desain untuk Jembatan Suramadu dengan Permodelan Sumber Gempa 3D.* Master thesis, Institut Teknologi Bandung.

Arimuko, A., Persada, Y. D., & Subakti, H. (2019). Model Kecepatan 1 - D Gelombang P dan Gelombang S dari Data Hasil Relokasi Hiposenter di Wilayah Gunung Sinabung. *Jurnal Meteorologi Klimatologi dan Geofisika*, 5(3), 72–79. https://doi.org/10.36754/jmkg.v5i3.77

Fauzi. (2010). *Analisis Data Seismogram untuk Menentukan Parameter Magnitude Gempabumi.* Bachelor thesis. Universitas Islam Negeri Syarif Hidayatullah.

Grandis, H. (2009). *Pengantar Pemodelan Inversi.* Himpunan Ahli Geofisika

Indonesia. Jakarta 12540, Indonesia.
Grandis, H., & Dahrin, D. (2014). Constrain Two - Dimensional Inversion of Gravity. *Journal of Mathematical and Fundamental Sciences*, 46(1), 1–13. https://doi.org/10.5614/j.math.fund.sci.2014.46.1.1
Hamilton, W. (1979). *Tectonics of the Indonesian Region*. Geol. Surv. Proff. Paper 1078, US Government. Printing Office. Washington, p.114-156.
Milsom, J., Masson, D., Nichols, G., Sikumbang, N., Dwiyanto, B., Parson, L., & Kallagher, H. (1992). The Manokwari Trough and The Western End of The New Guinea Trench. *Tectonics*, 11(1), 145–153. https://doi.org/10.1029/91TC01257
Nugraha, A.D. (2005). *Studi Tomografi 3-D Non Linear untuk Gunung Guntur dengan Menggunakan Waktu Tiba Gelombang P dan S*. Master thesis, Institut Teknologi Bandung.
Nurwidyanto, I.M., & Setiawan, A. (2011). Inversi linier least square dengan Matlab (Studi Kasus Model Gravitasi Bola Berlapis). *Jurnal Berkala Fisika*, 14(3), 93–100. https://ejournal.undip.ac.id/index.php/berkala_fisika/article/view/5009
Ratchkovsky, N.A., Pujol J., & Biswas, N. N. (1998). Relocation of shallow earthquakes in southern Alaska using Joint Hypocenter Determination method. *Journal of Seismology*. 2(1), 87–102. https://doi.org/10.1023/A:1009758721717
Rodi, W., & Toksoz, M. N. (2000). Grid Search Techniques for Seismic Event Location. *Proceedings of the 22nd Annual DoD/DOE Seismic Research Symposium*.
Ry, R. V., & Nugraha, A. D. (2012). Penentuan Hiposenter Gempa Mikro Menggunakan Metode Inversi Simulated Annealing pada Lapangan Geotermal “RR”. *Jurnal Geofisika*, 13(1), 23–31.
Sambridge, M., & Gallagher, K. (1993). Earthquake Hypocenter Location Using Genetic Algorithms. *Bulletin Seismological Society of America*, 83(5), 1467–1491. https://doi.org/10.1785/BSSA0830051467
Solikhin, A., & Suantika, G. (2008). *Laporan Penyelidikan Gempabumi Daerah Kabupaten Bandung dan Sekitarnya Jawa Barat.* Pusat Vulkanologi dan Mitigasi Bencana Geologi. Bandung.
van Bemmelen. (1970). *The Geology of Indonesia*, 2nd ed, Netherlands: Hague.