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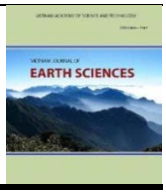

Estimation of errors in determination of main parameters of earthquake hypocenter, recorded by the national seismic network of Vietnam

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ABSTRACT

In this paper the authors present the error estimation in determining main parameters of earthquake hypocenter based on solving the system of linear equations, expressing the relationship between earthquake coordinates and the coordinates of the seismic stations. The results of the error estimation in determining the epicenter coordinates and the focus depth of the earthquakes recorded by the system of 30 seismic stations in Vietnam are presented, interpreted and compared with the results of the previous studies.

The results show that the operation of the seismic network of Vietnam is not really optimal, particularly when determining the epicenter coordinates and the focus depth of the earthquakes in the East Vietnam Sea region.

The national seismic network of Vietnam allows determination of the epicenter coordinates and the focal depth of earthquakes for most of the Vietnam territory with the errors $\Delta h \leq 20$ km, $\Delta\varphi \leq 4$ km, $\Delta \leq 5$ km. The errors of the determination of the epicenter coordinates and the focal depth of the earthquakes are increasing to the south and southwest areas of the territory of Vietnam and reach the maximum in these areas. Particularly, errors of the determination of the epicenter coordinates ($\Delta\varphi$, $\Delta\lambda$) and the focal depth (Δh) of earthquakes increase very rapidly toward the East Sea of Vietnam and reach the maximum in the region between the longitudes of 116-118°E.

The Vietnam seismic network allows determining the epicenter coordinates and the focal depth of earthquakes in the Northern Vietnam with the smaller errors than in Central and Southern Vietnam, and this fact proves that the distribution of seismic network in the Northern Vietnam is more optimal than the station networks in the Central and Southern Vietnam. Therefore, in order to improve the effectiveness of the Vietnam seismic network, more seismic stations need to be added to the Central and Southern Vietnam.

Keywords: Error; estimation of errors; parameter; earthquake hypocenter; seismic network.

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1. Introduction

Earthquakes in Vietnam are related mainly with principal active fault zones like Dien Bien Phu fault, Son La fault, Red river fault, Ca River fault. Active fault segmentations are determined from geological, geophysical or

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geomorphological data (Nguyen Van Hung et al., 2016). The main parameters (coordinates, the focal depth and magnitude) of earthquakes are important characteristics for the estimation of the maximum earthquake in the studied region (Bui Van Duan et al., 2013). The project entitled "Enhancing the seismic network for earthquake prediction and tsunami warning in Vietnam" was started in 2008 and finished at the end of 2016 with a total of 30 seismic stations in the whole territory of Vietnam. Up to now, the network of 30 national seismic stations of Vietnam is in operation. However, there have been no studies on the evaluation of the effectiveness of the above seismic stations; as a result, the accuracy of the earthquake hypocenter parameters recorded by this network has not yet been clarified. Therefore, the error estimation in determining the main parameters of earthquake hypocenter (epicenter coordinates ($\Delta\varphi$, $\Delta\lambda$), focal depth (Δh)) recorded by the seismic network of Vietnam is not only a very important and necessary task in the seismology of Vietnam but also the basis for the verification and examination of the results and outputs of the project "Enhancing the seismic network for earthquake prediction and tsunami warning in Vietnam". Thus, the calculations in this study will be applied to the network of 30 seismic stations according to the station list of this project and this network will be called the national seismic network of Vietnam.

The objective of this study is to estimate the errors in determining main parameters of earthquake hypocenter, recorded by the seismic station network in the whole territory of Vietnam, for the purpose of evaluating the effectiveness of this network. It means that it is necessary to carry out the above task in order to answer the question: Can the main parameters of earthquake hypocenter be accurately determined from the seismograms recorded by the national seismic network of Vietnam and what is the minimum error?

The evaluation of effectiveness and optimal planning of seismic network have been considered and conducted by different authors in a variety of studies (Aranovich Z.I., 1977; 1980; Burmin V. Yu., 1976; 1986; 1992; 1994; Ngo, 1990, 1999; Nguyen Quy Hy et al., 1979; Savarenski E. F. et al., 1979; Iosif T. et al., 1972; 1974; Kijko A., 1975;, 1978; 1980; Marshall A. W. et al., 1965; 1969; Sato and Skoko, 1965; Sato and Ochi 1967; Skoko D. et al., 1966; 1968; Uhrhammer R. A., 1980; 1982; Burmin V. Yu. et al., 2001; 2009).

For the territory of Vietnam, the same task has been carried out in several works (Burmin V. Yu., Ngo et al., 1992; Ngo, 1990; Nguyen Quy Hy, Pham Van Thuc et al., 1979; Burmin V. Yu. et al., 2009). In the works done by Burmin V. Yu., Ngo et al., 1992; Ngo, 1990, the authors conducted the geometric analysis of seismic network and determined the optimal locations for adding seismic stations in Northern Vietnam according to the approach proposed in Burmin V. Yu., 1976; 1986. In the work by Nguyen Quy Hy et al., 1979, the task of optimizing the seismic network in Vietnam territory was solved by the method of experimental seismic planning.

The authors of work (Burmin V. Yu. et al., 2009) evaluated the effectiveness of seismic network in Northern Vietnam at that time by calculating errors in the determination of main parameters of earthquake hypocenter. Consequently, the authors proposed the optimal seismic network in Northern Vietnam including 14 stations.

In this study, we calculate the errors in the determination of earthquake hypocenter parameters, recorded by the seismic network of

Vietnam, for the purpose of evaluating the effectiveness of this network. We apply the approach that was proposed in Burmin V. Yu., 1986); Burmin V. Yu., Akhmechiev V. M., 1994) and implemented for the Northern Vietnam in Burmin V. Yu. et al., 2009.

2. Theoretical basis of research methodology

It is well known that the basis for the detailed and comprehensive study on seismicity in a territory is the collection of sufficiently reliable information on the main parameters of earthquake hypocenter in that territory. Then, the accuracy of solving seismological tasks is directly or indirectly related to the accuracy of determining main parameters of earthquake hypocenter.

The accuracy of determining main parameters of earthquake hypocenter in the heterogeneous environment is an extremely important problem, especially for the areas with complex geological and tectonic structures as the territory of Vietnam.

Practical experience and numerical calculations show that the accuracy of determining earthquake hypocenter parameters significantly depends on the positions of seismic stations relative to the earthquake hypocenters.

From the viewpoint of minimizing errors in the determination of earthquake hypocenter parameters, the seismic network with a given number of stations is considered to be optimal when errors in the determination of earthquake hypocenter parameters are minimal.
Accordingly, the basis for effectiveness evaluation or optimal planning of seismic station network in a certain territory is the system of equations, representing the relationship between the earthquake hypocenter coordinates and the coordinates of seismic stations as follows:

$$(X - x_i)^2 + (Y - y_i)^2 + H^2 = V_i^2 (t_i - t_o)^2 \quad (1)$$

where i = 1, 2, ..., n - the ordinal number of seismic stations; x_i, y_i - the coordinates of seismic stations; X, Y, H - the coordinates of earthquake epicenter and focal depth; t_o - time of earthquake occurrence; t_i - travel time of seismic wave to the i^{th} station. V_i - seismic wave velocity (apparent velocity), calculated by the ratio between straight line distance from the i^{th} station to earthquake hypocenter and travel time of seismic wave along the distance.

In case V_i is the function of variables X, Y, H, x_i, y_i, the determination of earthquake hypocenter coordinates is very complicated. However, if considering the homogeneous environments or environments with constant velocity, the task of determining earthquake hypocenter coordinates is considerably simpler. Therefore, when solving the task of evaluating the effectiveness of seismic network and choosing the optimal locations of stations, the environment can be considered in a first approximation to be nearly the homogeneous one, it means $V_i = V = Const$.

When adding the parameter $\eta = X^2 + Y^2 + H^2 - V^2 t_0^2$, the system of equations (1) can be easily converted into the system of linear equations by grouping the unknowns as follows (Burmin V. Yu. et al., 2009):

$$Xx_i + Yy_i + t_0 V_i^2 t_i + 0.5\eta = f_i \quad (2)$$

where i = 1, 2,…, n; with $n \geq 3$; $f_i = 0.5 (x_i^2 + y_i^2 + V^2 t_i^2)$;

The focal depth is determined by the following equation:

$$H^2 = \eta - X^2 - Y^2 + V^2 t_0^2 \quad (3)$$

Equations (2) and (3) determine the coordinates X, Y, H and t_0 on the condition that the seismic wave velocity is constant. To calculate the actual velocity distribution, we consider the iteration procedure. With the given values of V_i, the system of linear equations (1) can be converted into the form:

$$Xx_i + Yy_i - t_0V^2t_i + 0.5\,\xi = f_i \quad (4)$$

where i = 1, 2,..., n; $\xi = X^2 + Y^2 + H^2$; $f_i = 0.5[(x_i^2 + y_i^2 - V_i^2(t_i^2 + t_0^2)]$.

To solve the system of equations (4), we need to give the value of t_0 in the right-hand side of (4). The first value of t_0 can be obtained when solving the system of equations (2). The obtained value of t_0 is added to the right-hand side of equation (4) in order to solve the system of equations. The obtained value of t_0 in the solution of the system of equations (4) is again added to the right-hand side of formula (4) and this equation is repeatedly solved. If the iteration process is convergent, it will provide the solution to the problem of determining earthquake hypocenter coordinates for the heterogeneous environment. Then, the errors of the required parameters (of the unknowns) will be determined only by the properties of system matrix and will be the errors of input data. It is easy to see that the matrices of systems of equations (2) and (4) differ only by the multipliers V and V_i. Then, we will write the systems of linear equations, which represent the relationships between earthquake hypocenter coordinates, the seismic wave velocity, and the time at hypocenter, in a matrix form as follows:

$$KP = f \quad (5)$$

where $K = \{k_{ij}\}$ - is the matrix of the system, representing the mathematical model of the studied dependence. $P^T = \{p_j\} = \{X, Y, t_0, \xi\}$ - is the column vector of sought parameters; $f^T = \{f_i\}$ - is the column vector of observed quantities; i = 1, 2,..., n; j = 1, 2,…, m; $n \geq m$.

The solution of equation (5) is found by the least squares method and given by the following formula:

$$P = K^+f$$

Where K^+ is the generalized inverse matrix, in this case $K^+ = (K^+K)^{-1}K^T$.

The estimation (3) is true for the error of total vector of unknown parameters in the system of equations:

$$\|\Delta p\| = \left\{\sum_{i=1}^{n}|\Delta p_i|^2\right\}^{1/2} \leq \left\|\widetilde{K}^+\right\|.\|Rv\rho\|.\|\Delta t\| \quad (6)$$

Where $\|Rv\rho\| = \left\{\sum_{i=1}^{n}|R_iv_i\rho_i|^2\right\}^{1/2}$; ρ_i - is the weight, characterizing the quality of recording in the i^{th} station; R - is the vector whose components are the corresponding epicenter distances; $|\Delta t|$ - is the absolute value of the error in determining the travel time of seismic wave to the station. The characteristics of the errors can be different. The errors can be random or systematic, estimated by the deviation between the value of the apparent velocity of seismic wave V_i used in the calculation and the actual value.

The objective function $J_0 = \left\|\widetilde{K}^+\right\|.\|Rv\rho\|$ determines the accuracy of earthquake hypocenter parameters; essentially, it characterizes the quality of seismic station network. The quantity J_0 is the objective function corresponding to earthquake hypocenter parameters ($J_0(\Delta\varphi, \Delta, \Delta h)$) and is the error of total deviation vector when $|\Delta t| = 1$ second. When changing the locations of different seismic stations and calculating the corresponding values of the function J_0, it is possible to indicate the seismic network that ensures the highest accuracy in earthquake positioning. More details on the theoretical basis of the method can be found in (Burmin V. Yu., 1986; Burmin V. Yu. et al., 1994; 2009).

Thus, the evaluation of the effectiveness of seismic network is essentially the task of minimizing the error values in the determination of unknown quantities (earthquake epicenter coordinates and focal depth) from equation (6) or minimizing the values of objective function J_0.

The specific task in this study is to estimate the errors in determining main parame-

ters of earthquake hypocenter, recorded by the seismic network of Vietnam. Therefore, the coordinates of all seismic stations in the network are known. The main parameters and the sketch map of the seismic network of Vietnam are presented in Table 1 and Figure 1.

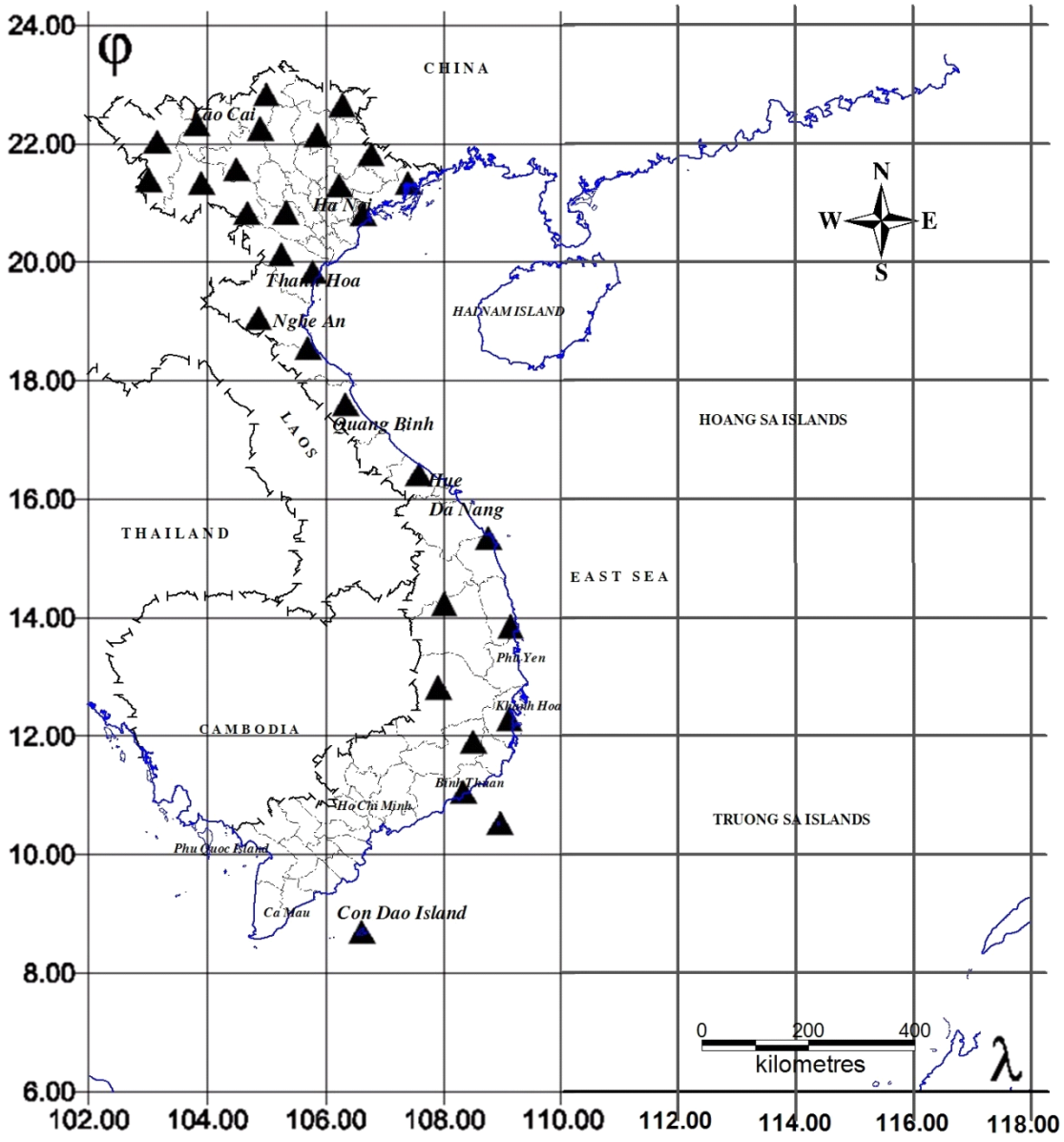

Figure 1. Plan of the existing national seismic network of Vietnam (Δφ)(km) (▲ - Seismic station)

Table 1. Main parameters of seismic network of Vietnam

No.	Station code	Station coordinates		Station name	Elevation (m)
		Longitude	Latitude		
1	SPVO*	103.83000	22.33300	Sa Pa	1550
2	DBVB	103.01800	21.39000	Dien Bien	480
3	SLV	103.90500	21.33400	Son La	607
4	HBVB	105.3277	20.8422	Hoa Binh	54
5	BGVB	106.22700	21.29000	Bac Giang	13
6	PLVO*	106.63000	20.80600	Phu Lien	5
7	VIVO*	105.70000	18.54800	Vinh	-6
8	DLV	108.48300	11.90000	Da Lat	1530
9	HGVB	104.99238	22.83507	Ha Giang	119
10	BCVB	105.85632	22.14992	Bac Kan	112
11	CBVB	106.27118	22.65752	Cao Bang	239
12	MCVB	104.67170	20.83468	Moc Chau	
13	LSVB	106.76225	21.82510	Lang Son	285
14	TYVB	107.38933	21.33467	Tien Yen	37
15	LAVB	105.24765	20.13587	Lang Chanh	53
16	THVB	105.78355	19.84475	Thanh Hoa	1
17	CCVB	104.85583	19.05707	Con Cuong	30
18	HUVB	107.56890	16.41553	Hue	8
19	BMVB	107.89300	12.81900	Buon Me Thuot	
20	NHAV	109.09236	12.30376	Nha Trang	5
21	BTVB	108.31845	11.05338	Binh Thuan	
22	PQVB	108.93737	10.53500	Phu Quy	
23	CĐVB	106.60147	8.69512	Con Dao	
24	MLAV	103.15500	22.03900	Muong Lay	270
25	VTVB	104.89850	22.25260	Vinh Tuy	71
26	VCVB	104.49433	21.56901	Van Chan	274
27	QBVB	106.32775	17.60315	Quang Binh	
28	QNVB	108.74210	15.34753	Quang Ngai	
29	GLVB	107.99212	14.23255	Gia Lai	
30	BĐVB	109.11109	13.86446	Binh Dinh	10

3. Result: Error estimation in determining main parameters of earthquake hypocenter recorded by the seismic network of Vietnam

3.1. Input data for the calculation

When estimating the errors in the determination of main parameters of earthquake hypocenter recorded by the existing seismic network in the whole territory of Vietnam, we have used the following input data:

- The coordinates and parameters of 30 seismic stations presented in Table 1.

- The model of seismic wave velocity in the Earth's crust, appropriate for the real environment in Vietnam, obtained from Ngo et al., 2014.

It should be noted that the model of seismic wave velocity in the Earth's crust proposed by Ngo et al., 2014 is applied to the depth of Moho boundary. However, according to the requirement of the project "Enhancing the seismic network for earthquake prediction and tsunami warning in Vietnam", the station network should be able to detect the earthquakes with magnitude $M \geq 3.5$ in the whole territory of Vietnam and with $M \geq 6.5$ in the whole area of the East Vietnam Sea. Therefore, we need to calculate and establish the distribution sketch maps of error values in determining main parameters of earthquake hypocenter, which can be recorded by the exist-

ing seismic network in the Vietnam territory, for the East Vietnam Sea area. The model of seismic wave velocity obtained from Ngo et al., 2014 only meets this requirement at close distance (800-1000 km from seismic station). Accordingly, based on the combination of three velocity models obtained in the studies by Ngo et al., 2014; Burmin et al., 2001; 2009), we have presented the model in Table 2 that ensures both the characteristics of local velocity model and the characteristics of regional velocity model (Table 2).

Table 2. Velocity model used in the calculation Accor ing to Ngo et al., 2014; Burmin et al., 2001; 2009

Layer	Depth of layer boundary (km)	Velocity on the surface of boundary (km/s)	Velocity at the bottom of boundary (km/s)
1	2.0	2.80	2.85
2	3.0	4.00	4.05
3	21.0	6.20	6.30
4	24.0	6.90	7.20
5	80.0	8.00	8.30
6	130.0	8.30	8.50
7	160	8.50	9.10
8	220	9.30	9.95

3.2. Error estimation in determining main parameters of earthquakes hypocenters, recorded by the existing national seismic network in the whole territory of Vietnam

Error in determining the focal depth (Δh)

With the above input data, after many experimental calculations, we have established the sketch map of the distribution of error values in determining focus depth (Δh, km) which can be recorded by the existing national seismic network in the whole territory of Vietnam. The calculated results are presented in Figure 2. The analysis of the results in Figure 2 shows that:

The seismic network of Vietnam allows the determination of focal depth in most of Vietnam territory with the error $\Delta h \leq 20$ km and the maximum error Δh max up to 130 km in the East Vietnam Sea area (within the area between the longitudes of 116-118°E).

The error in determining focal depth gradually increases toward the south of Vietnam and reaches the maximum in the Southern region with $\Delta h = 30\sim40$km.

In the Northern and Central regions, the error in determining focal depth seems to be smaller ($\Delta h \leq 10$ km); however, in the Southern region and especially in the southwest of this region, the error in determining focal depth is higher; at some locations, the value of Δh is 40 km or greater.

The values of the isolines of errors in determining focal depth Δh increase rapidly toward the East Vietnam Sea and reach Δh = 130-150 km in the region within longitudes of 116-118°E. It means that from the viewpoint of evaluating the effectiveness of station network based on the error estimation in determining focal depth, the network of 30 stations of Vietnam is not really optimal, especially when determining the focal depth of earthquakes outside the Vietnam territory in the East Sea area.

Errors in determining the epicenter coordinates in latitude (Δφ) and in longitude (Δλ)

After many experimental calculations, we have established the sketch map of the distribution of error values in determining epicenter coordinates in latitude (Δφ) and in longitude (Δλ) which can be recorded by the existing national seismic network in the whole territory of Vietnam. The results are presented in Figures 3, 4. The analysis of the results in Figures 3 and 4 shows that:

With the existing seismic network, it is possible to record and determine the epicenter coordinates in latitude (Δφ) and in longitude (Δλ) in most of Vietnam territory with the errors $\Delta\varphi \leq 4$ km, $\Delta\lambda \leq 5$ km. The largest errors

for latitude (Δφmax) reaches 14-16 km and for longitude (Δλmax) reaches 35-40 km in the East Vietnam Sea (within the area between the longitudes of 116-118°E).

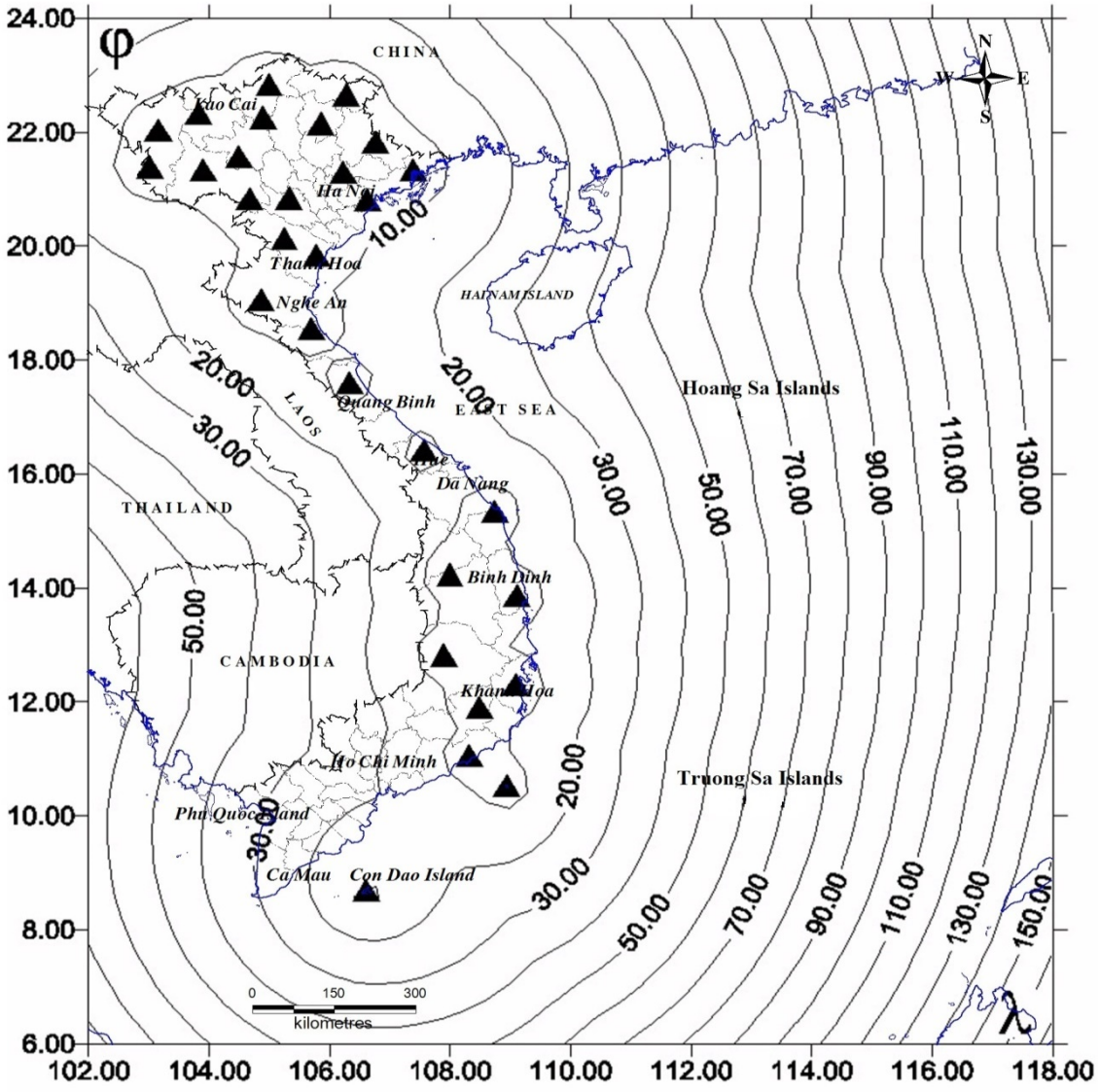

Figure 2. Error distribution in determination of the depth of earthquake hypocenter for the existing seismic network of Vietnam (Δh); ▲- Seismic station; 3.0 - Isoline of errors in determination of the depth of earthquake hypocenter for the existing seismic network of Vietnam (Δh) (km)

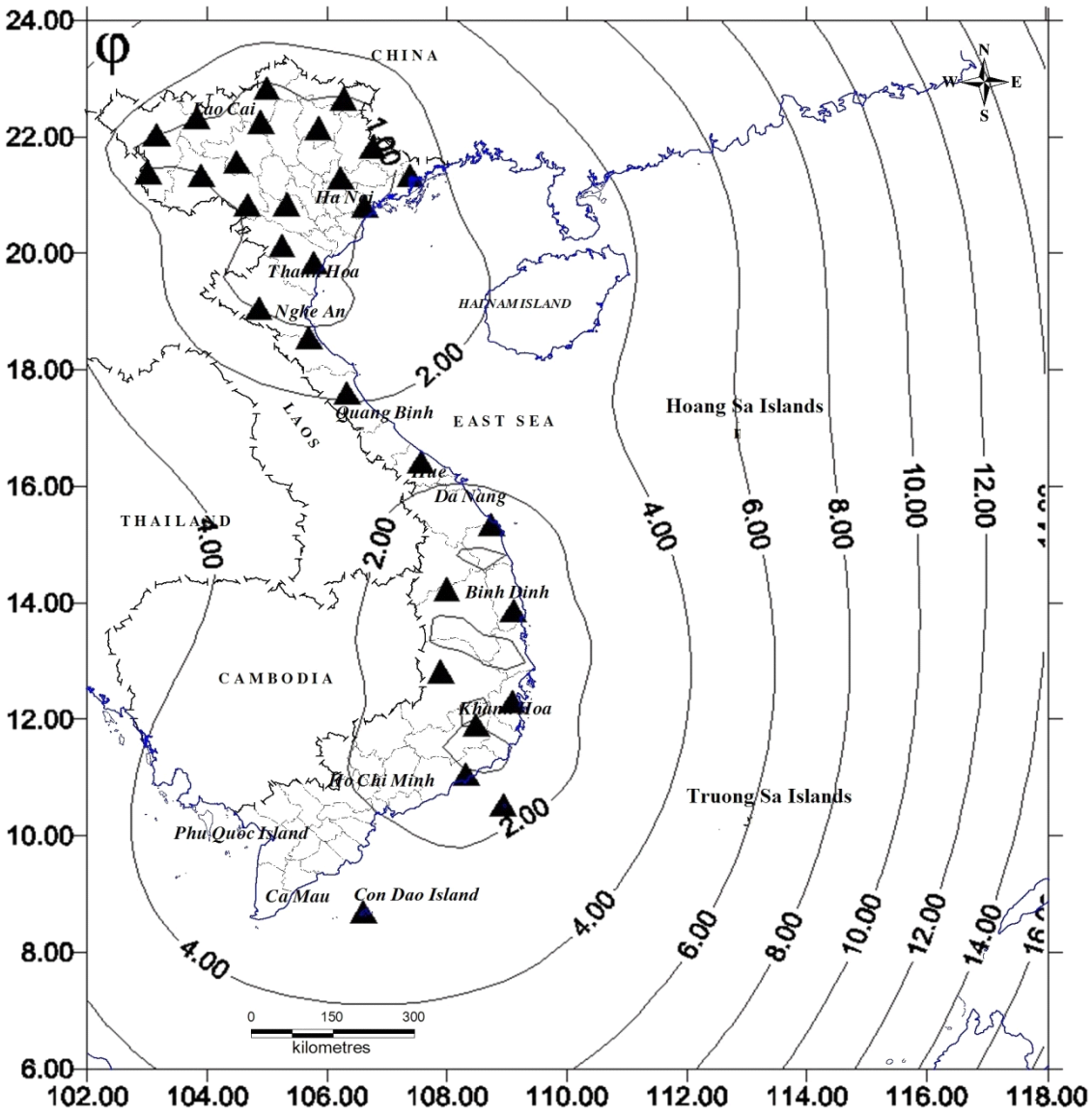

Figure 3. Error distribution in determination of *Y* coordinate of hypocenter for the existing seismic network of Vietnam; ▲- Seismic station; 3.0 - Isoline of errors in determination of Y coordinate of hypocenter for the existing seismic network of Vietnam (Δφ)(km)

The errors in determining epicenter coordinates in latitude (Δφ) and in longitude (Δλ) increase toward the south and southeast of Vietnam, reaching the maximum in the Southern region with Δφmax = 4 km, Δλmax = 5 km.

In the Northern and Central regions, the errors in determining epicenter coordinates are smaller (Δφ ≤ 2 km, Δλ ≤ 2.5 km); however, in the Southern region and especially in the southwest of this region, the errors in determining epicenter coordinates in latitude and in longitude are higher; at some locations, Δφ

reaches 3 km or greater, and Δλ reaches 5 km or greater.

The values of the isolines of errors in determining epicenter coordinates in latitude Δφ and in longitude Δλ increase rapidly toward the East Vietnam Sea, and reach Δφ = 14-16 km and Δλ = 35-40 km in the region within the longitudes of 116-118°E.

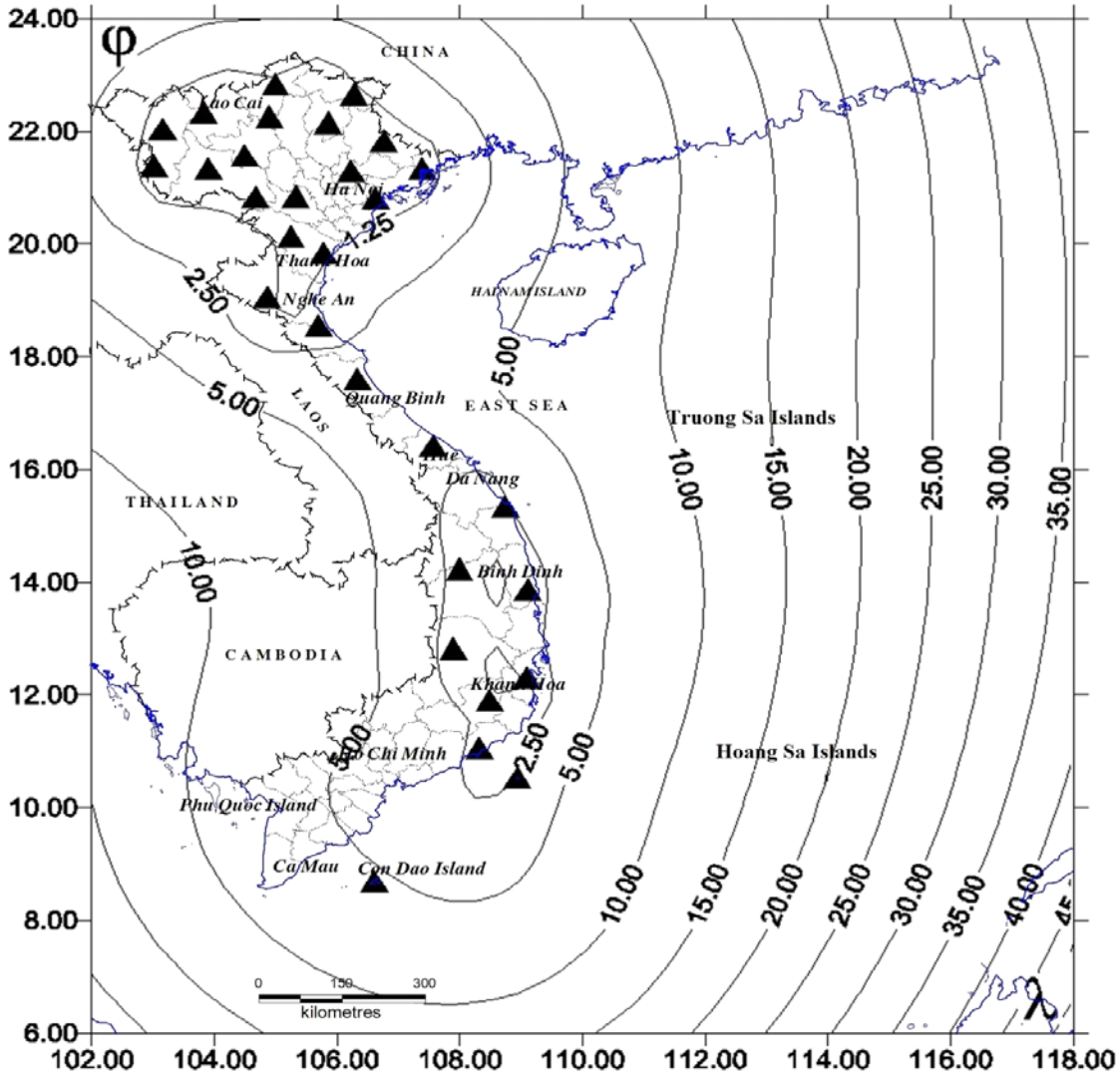

Figure 4. Error distribution in determination of *X* coordinate of hypocenter for the existing seismic network of Vietnam ($\Delta\lambda$)(km); ▲ - Seismic station; 3.0 - Isoline of errors in determination of X coordinate of hypocenter for the existing seismic network of Vietnam ($\Delta\lambda$)(km).

Thus, the results of the estimation of errors Δh, Δφ, Δλ show that from the viewpoint of evaluating the effectiveness of seismic network based on the error estimation in determining main parameters of earthquake hypocenter (epicenter coordinates (Δφ, Δλ), focal depth (Δh)), recorded by the existing seismic network in the whole territory of Vietnam, the

network of 30 stations of Vietnam is not really optimal, especially when determining epicenter coordinates and focus depth of the earthquakes in the East Vietnam Sea area. The existing seismic network allows determining epicenter coordinates and hypocenter depth in the Northern and Central regions with the smaller errors than in the Southern region.

To verify the accuracy of the above remark, we have divided the studied territory into three regions including the Northern, Central and Southern regions of Vietnam and estimated the error in determining focal depth (Δh) for each region. The results are presented in Figures 5-7, respectively. The captions of Figures 6, 7 are similar to the caption of Figure 5.

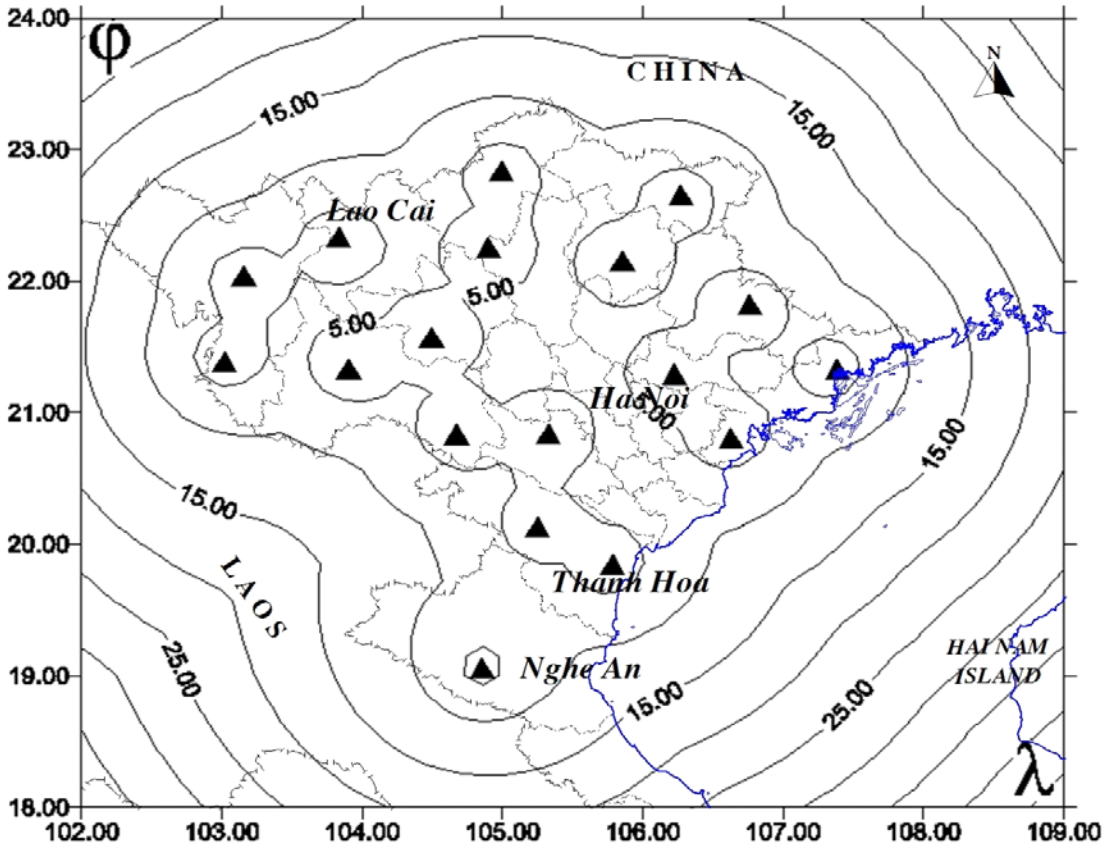

Figure 5. Error distribution in determination of the depth of earthquake hypocenter for the existing seismic network in the North of Vietnam (Δh); ▲- Seismic station; 3.0 - Isoline of errors in determination of the depth of earthquake hypocenter for the existing seismic network in the North of Vietnam (Δh) (km)

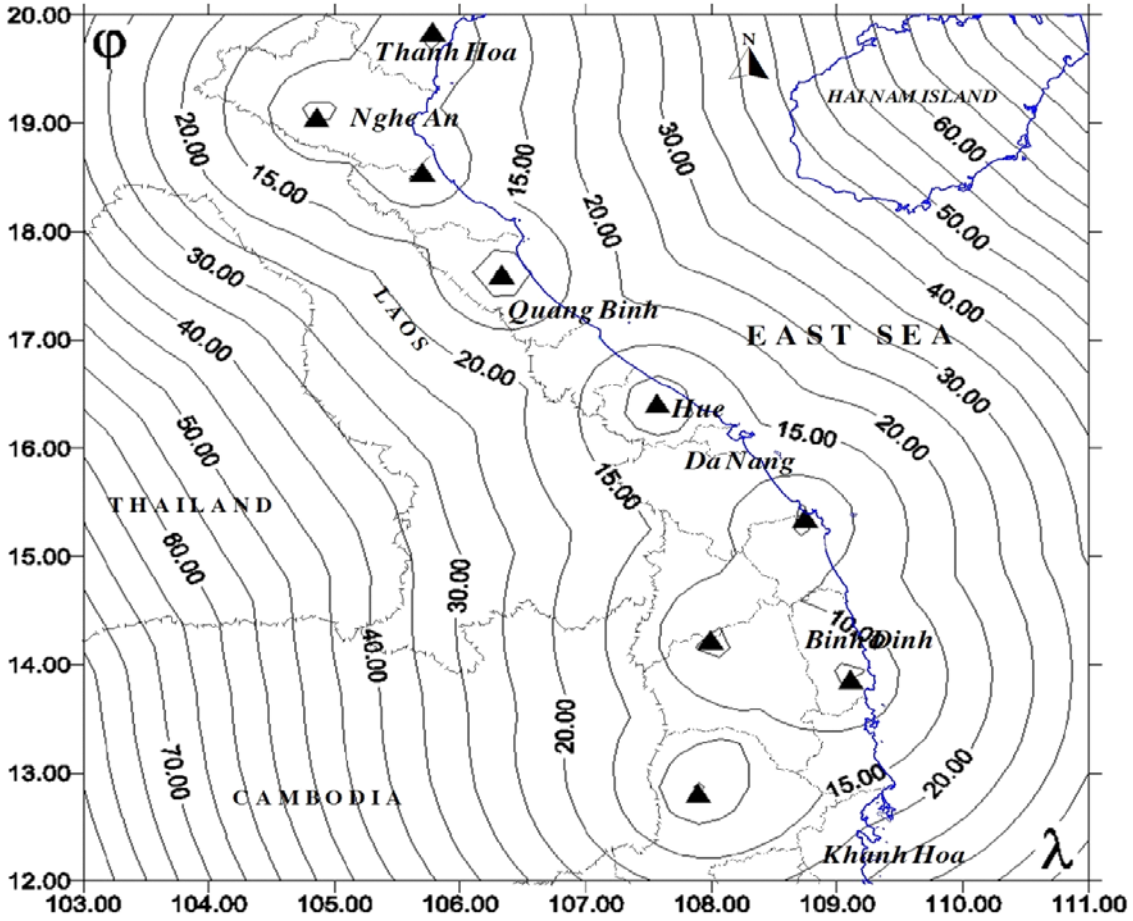

Figure 6. Error distribution in determination of the depth of earthquake hypocenter for the existing seismic network in the Central region of Vietnam (Δh)

The analysis of the calculated results in Figures 5-7 shows that the seismic network in the Northern Vietnam is relatively dense, the stations are evenly distributed in distance; therefore, the result of error estimation in determining focus depth (Δh) is not significantly high and acceptable (Δh ≤ 25 km). However, the calculated results for the seismic network in the Central and Southern regions of Vietnam show that the seismic stations in these two regions are inappropriately distributed, the number of stations is smaller than in the Northern region and uneven in distance. In the Central region, the stations are distributed in a nearly straight line in the north-south direction, so the error values in determining focus depth (Δh) are significantly higher than the corresponding results in the Northern region. In the Southern region, there are no seismic stations in the south and southwest of this region, so the error values in determining focus depth (Δh) increase quite rapidly toward these directions, reaching Δh = 50 km in some locations. In addition, the isolines of errors obtained in Figure 5 are distributed relatively evenly while those obtained in Figures 6 and 7 are distributed with the more tortuous shape and closer to each other than the results in Figure 5.

The error estimation in determining epicenter coordinates (Δφ, Δλ) has been conducted for the Northern, Central and Southern regions and the same results have been obtained.

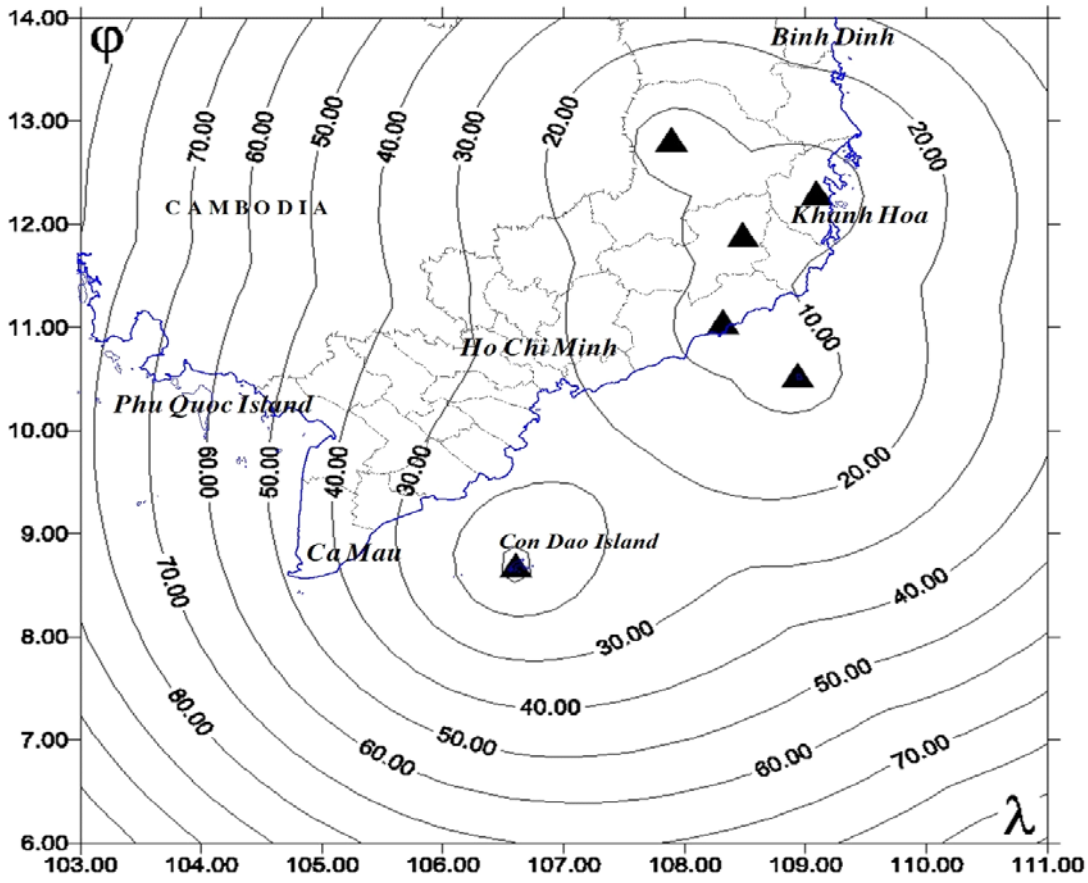

Figure 7. Error distribution in determination of the depth of earthquake hypocenter for the existing seismic network in the South of Vietnam (Δh)

4. Discussions

The above results show that the seismic network in the Northern region allows recording and determining earthquake hypocenter parameters with the smaller errors than in the Central and Southern regions. It means that the seismic network in the Northern region is more optimal than in the Central and Southern regions.

However, it should be noted that in comparison with the optimal seismic network (including 14 stations) proposed for Northern Vietnam in Burmin V. Yu. et al., 2009, the existing seismic network in Northern Vietnam (including 18 stations) allows recording and determining earthquake hypocenter parameters in most of this region with the same values of errors of epicenter coordinates ($\Delta\varphi \leq$ 4 km; $\Delta\lambda \leq 5$ km), but the error of focal depth is higher (Δh_{max} = 25km) compared to the optimal seismic network proposed in Burmin V. Yu. et al., 2009 (Δh_{max} = 14km). It means that from the viewpoint of evaluating the effectiveness of seismic network, the existing seismic network in the Northern region is denser than the optimal seismic network (only

including 14 stations) proposed in Burmin V. Yu. et al., 2009. Thus, the existing seismic network in the Northern region is not really economically effective compared to the optimal seismic network proposed in Burmin V. Yu. et al., 2009 due to the extra cost of equipment purchase, installation and operation for 4 additional seismic stations.

Therefore, in order to improve the effectiveness of the seismic network of Vietnam, a number of stations should be added to the Central and Southern regions of Vietnam. In addition, in order to economize, it is possible to reduce 4 stations out of 18 existing stations in the Northern region (if necessary).

5. Conclusions

The results of error estimation of epicenter coordinates and focal depth, recorded by the national network of 30 seismic stations of Vietnam allow drawing the following conclusions:

The existing national seismic station network of Vietnam allows determining epicenter coordinates and focus depth in most of Vietnam territory with the errors $\Delta h \leq 20$ km, $\Delta\varphi \leq 4$ km, $\Delta\lambda \leq 5$ km; Δh_{max} reaches 130 km, $\Delta\varphi_{max}$ reaches 14-16 km, and $\Delta\lambda_{max}$ reaches 35-40 km in the East Vietnam Sea area (in the area between the longitudes of 116-118°E).

The values of errors in determining epicenter coordinates and focus depth increase toward the south and southwest of Vietnam and reach the maximum in the Southern region with Δh_{max} = 40~50 km, $\Delta\varphi_{max}$ = 4 km, $\Delta\lambda_{max}$ = 5 km.

The values of the isolines of errors in determining epicenter coordinates ($\Delta\varphi$, $\Delta\lambda$) and focus depth (Δh) increase rapidly toward the East Vietnam Sea, and reach the maximum in the region within the longitudes of 116-118°E.

From the viewpoint of evaluating the effectiveness of seismic network based on the error estimation in determining main parameters of earthquake hypocenter (epicenter coordinates ($\Delta\varphi$, $\Delta\lambda$), focal depth (Δh)), recorded by the existing national seismic network of Vietnam, this network is not really optimal, especially when determining epicenter coordinates and focal depth of the earthquakes in the East Vietnam Sea area.

The national seismic network of Vietnam allows determining epicenter coordinates and focus depth in the Northern region with the smaller errors than in the Central and Southern regions. It means that the seismic network in the Northern region is more optimal than in the Central and Southern regions. Therefore, in order to improve the effectiveness of the national seismic network of Vietnam, a number of stations should be added to the Central and Southern regions of Vietnam.

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