Ground Motion Prediction Equations user guide

To estimate ground motion prediction equation (GMPE). The GMPE relates ground motion parameters, usually amplitude parameters, to sets of independent variables representing the cause of the motion. The following independent variables could be taken into account: characteristic of the path, source and site. Moreover, the non-linearity of ground vibration propagation on short distances from the epicenter is supported by using '*h*' as the common /fix depth so that the standard error of estimation is minimised. The final model is estimated using ordinary one-stage regression method in three steps, including the statistical and physical consistency of the model, estimation of the fixed depth (if it's chosen as a parameter) and residuals analysis.

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REFERENCES Document Repository

CATEGORY Probabilistic Seismic Hazard Analysis

KEYWORDS Ground motion

CITATION Please acknowledge use of this application in your work: IS-EPOS. (2019). *Ground Motion Prediction Equations* [Web applications]. Retrieved from https://tcs.ah-epos.eu/

Information

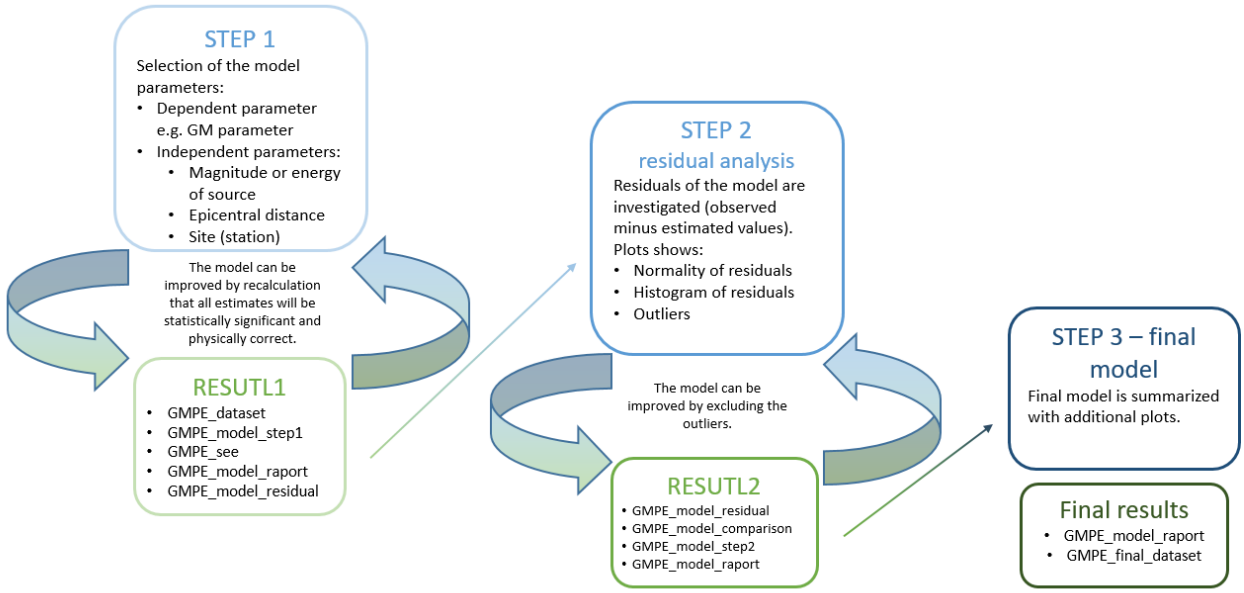
The complex model is

$$loga_i(m_E, r) = \beta_1 M + \beta_2 M^2 - \gamma_1\sqrt{r^2+h^2} - \gamma_1 log\sqrt{r^2+h^2} + \sum_{j=1}^{J} w_j \delta_{i,j} \qquad i = 1, \dots, J$$

i - station number,
J - total number of station,
a_i - GM parameter at i-th station location,
M - characterisation of source expressed by magnitude (Mw, ML) or logarithm of seismic energy (logE),
r - epicentral distance,
h - a common depth factor to ensure finiteness of the geometric spreading term in the epicenter,
w_i - logarithmized amplification factor. One station can be chosen as reference one, k – station, than model will be have free value $\alpha = w_k$ and the othe coefficient will be relative one $w_i^* = w_i - w_k$. The amplification at every site i relative to k site is $10^{w_i - w_k}$,
β, γ, δ - are coefficients estimated through regression analysis, $\delta_{i,j} = \begin{cases} 1 \; for \; i = j \\ 0 \; for \; i \neq j \end{cases}$ is Kronecker's delta.

The model takes into account the successive increase of GM parameter along with the increase of source size, non-linear source influence, non-elastic damping, non-linear geometric scattering and influence of site effect at the station. The model can be customised by selecting any parts. The ordinary one-stage regression method is used.

This application is prepared in 3 steps and the model can be improved in two of them.



Step by Step

1. Preparation of the data - GM Parameters Catalog is needed.
   To prepare GM Parameters Catalog 2 files are needed: the 1st input file is a Seismic Catalog and the 2nd input file is Ground Motion

Catalog from the same Episode (AH EPISODES). Thus, choose a Catalog and GM Catalog from a selected episode. Then run **Ground Motion Parameters Catalog builder,** and as a result GM Parameters Catalog will be created.
The part of the GM Parameters Catalog can be used with Catalog filter. It is worth to remove weak ground motion eg. PGA <=0.03 m/s^2.

2. Selection of the model parameters (STEP 1 of analysis)
After the User adds the Application into his/her personal workspace, the following window appear on the screen (Figure 1), and the user is now requested to fill the fields shown in Figure 1:
GM Parameters: The user may choose from all ground motion parameters which were available in GM Catalog.
Source characteristic parameter: The user may choose from all source parameters which were available in Catalog. The model may contain M, M^2, both or none of them. Recommended is to select both and check their statistical significance in results. When coefficients or one of them is insignificant, they can be removed from the model.
Path characteristic: The model may contain R, logR, both or none of them. Additionally, epicentral distance may be calculated with fixed depth ('*h*' parameter in the model). 'h' parameter can be estimated (then option *Estimate depth with model* should be chosen) or can be typed (the value is given in kilometres). Recommended is to select estimation of fix depth with model and choose both coefficients and check their statistical significance in results. When coefficients or one of them is insignificant, they can be removed from the model.
Site characteristic: Site characteristic depends on station position.

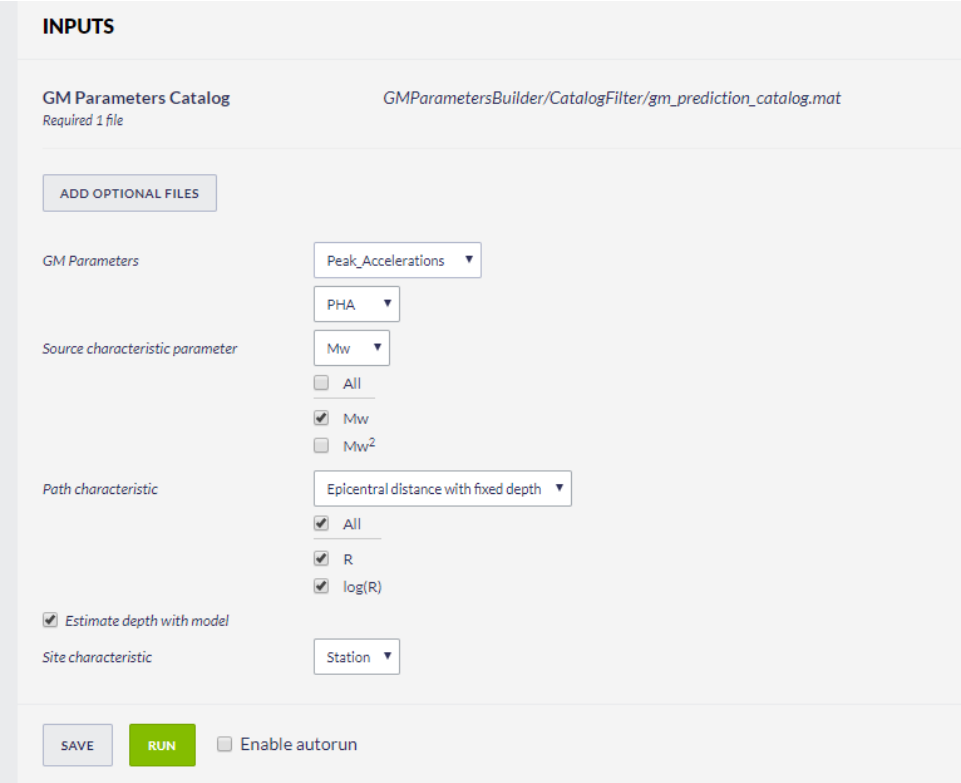
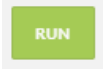


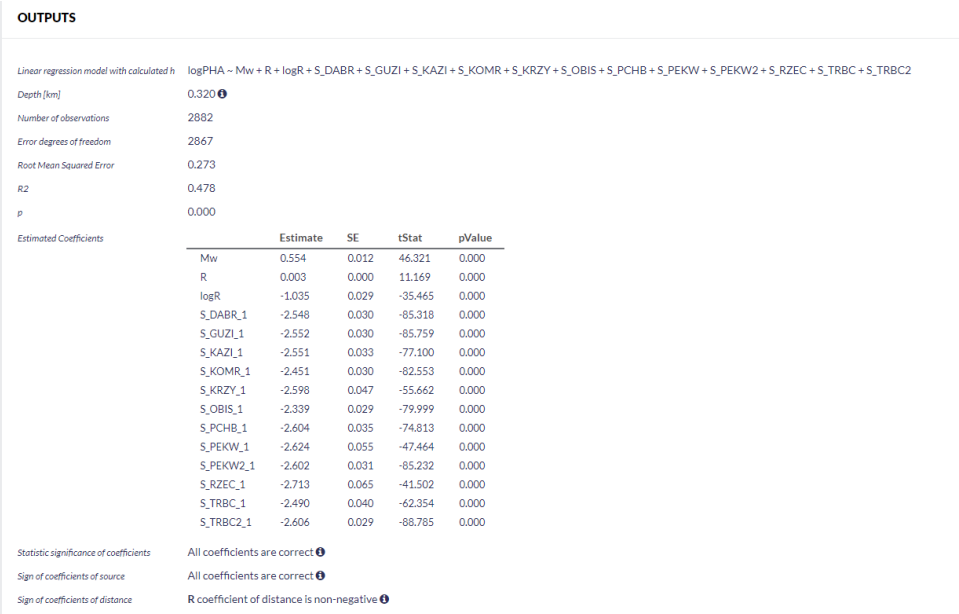
Figure 1. Input window of Ground Motion Prediction Equations: GMPE calculation

3. After defining the parameters mentioned above, the user shall click on the 

button (Figure 1), and the calculations are performed. The output will be created soon.

The output results include:

gmpe_model_report



OUTPUTS

Linear regression model with calculated h	logPHA ~ Mw + R + logR + S_DABR + S_GUZI + S_KAZI + S_KOMR + S_KRZY + S_OBIS + S_PCHB + S_PEKW + S_PEKW2 + S_RZEC + S_TRBC + S_TRBC2
Depth [km]	0.320
Number of observations	2882
Error degrees of freedom	2867
Root Mean Squared Error	0.273
R2	0.478
p	0.000

Estimated Coefficients

	Estimate	SE	tStat	pValue
Mw	0.554	0.012	46.321	0.000
R	0.003	0.000	11.169	0.000
logR	-1.035	0.029	-35.465	0.000
S_DABR_1	-2.548	0.030	-85.318	0.000
S_GUZI_1	-2.552	0.030	-85.759	0.000
S_KAZI_1	-2.551	0.033	-77.100	0.000
S_KOMR_1	-2.451	0.030	-82.553	0.000
S_KRZY_1	-2.598	0.047	-55.662	0.000
S_OBIS_1	-2.339	0.029	-79.999	0.000
S_PCHB_1	-2.604	0.035	-74.813	0.000
S_PEKW_1	-2.624	0.055	-47.464	0.000
S_PEKW2_1	-2.602	0.031	-85.232	0.000
S_RZEC_1	-2.713	0.065	-41.502	0.000
S_TRBC_1	-2.490	0.040	-62.354	0.000
S_TRBC2_1	-2.606	0.029	-88.785	0.000

Statistic significance of coefficients	All coefficients are correct
Sign of coefficients of source	All coefficients are correct
Sign of coefficients of distance	R coefficient of distance is non-negative

Figure 2. Ground Motion Prediction Equations model report.

R2 - (R-squared value) - coefficient of determination is the proportion of the variance in the dependent variable that is predictable from the independent variable(s). It shows in the percentage of which the model explains the variability in the response.
Root Mean Square Error (RMSE) - is a frequently used measure of the differences between values (sample or population values) predicted by a model or an estimator and the values observed.
p - probability o F-statistic for testing statistical significance of the model.

SEE chart (when '*h*' is chosen as one of coefficient)

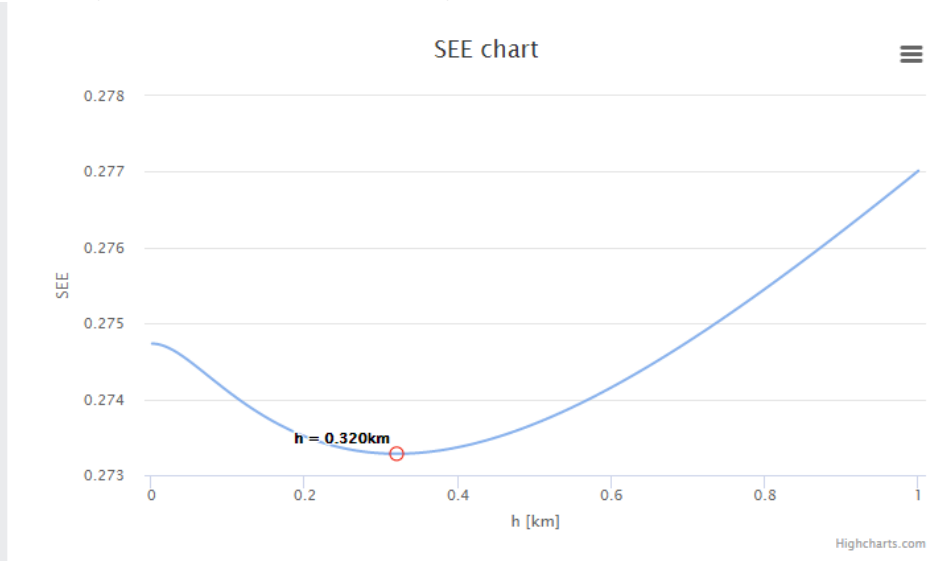


Figure 3. SEE plot.

Additional results:
gmpe_dataset.mat - mat file with chosen parameters based on GM Parameters Catalog for which GMPE is calculated,
gmpe_model_residuals.mat - mat file with residuals of the model,
gmpe_model_step1.mat - mat file with results of 1. step.

4. Improving the model:
According to the result - the mainly statistical significance of coefficients and its physical consistency - the model can be improved. To improve the model, click on the 

.
In this case, the 'R' coefficient of distance will be removed because it is non-negative.

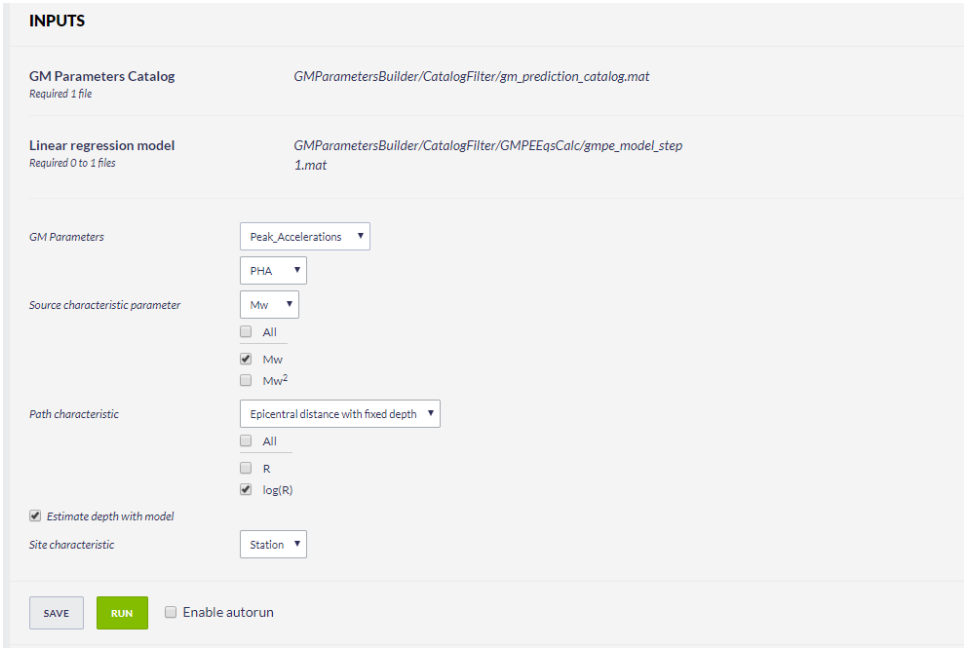


Figure 4. Input window of GMPE recalculation.

The result:

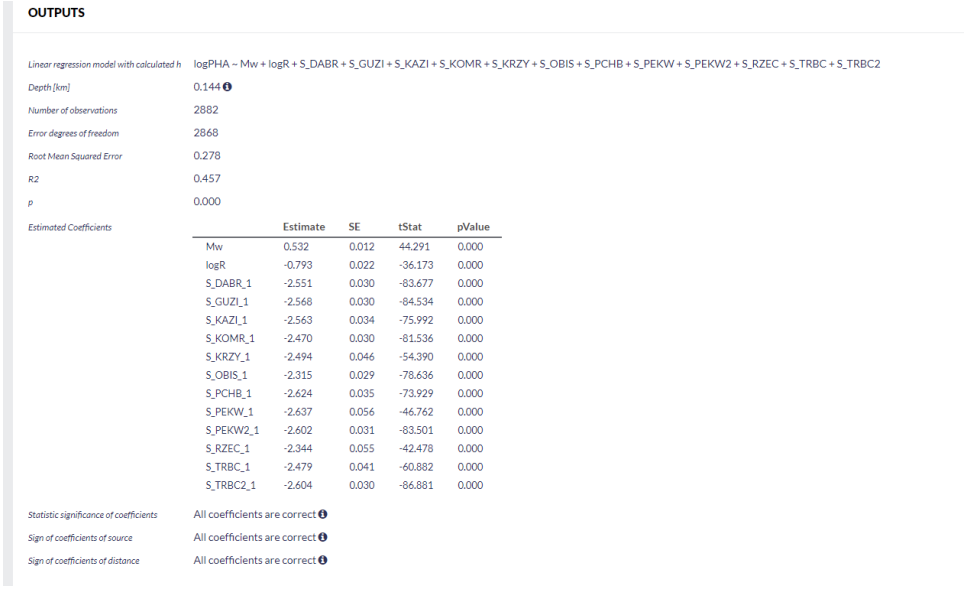


Figure 5. Result of recalculated model.

5. As an additional result, after improving the model, the comparison of previous vs current model parameter appears.

Comparison of the models: previous model vs current model

Number of observations	2882	=	2882
Number of coefficients	15	>	14
SEE	0.273	<	0.278
R2	0.478	>	0.457
F	174.7	>	172.6
p	0.000	=	0.000

The new (recalculated) model is better when 'SEE' and 'p' are smaller, and 'R2' and 'F' are bigger than in the previous model.
This model does not need improving. All coefficient are proper and statistically significant. The calculation can be done as many times un til the results are satisfactory.

6. Residual Analysis:
After receiving the satisfying model, the residual analysis can be performed (STEP2 of analysis). To start choose

REMOVE RESIDUALS

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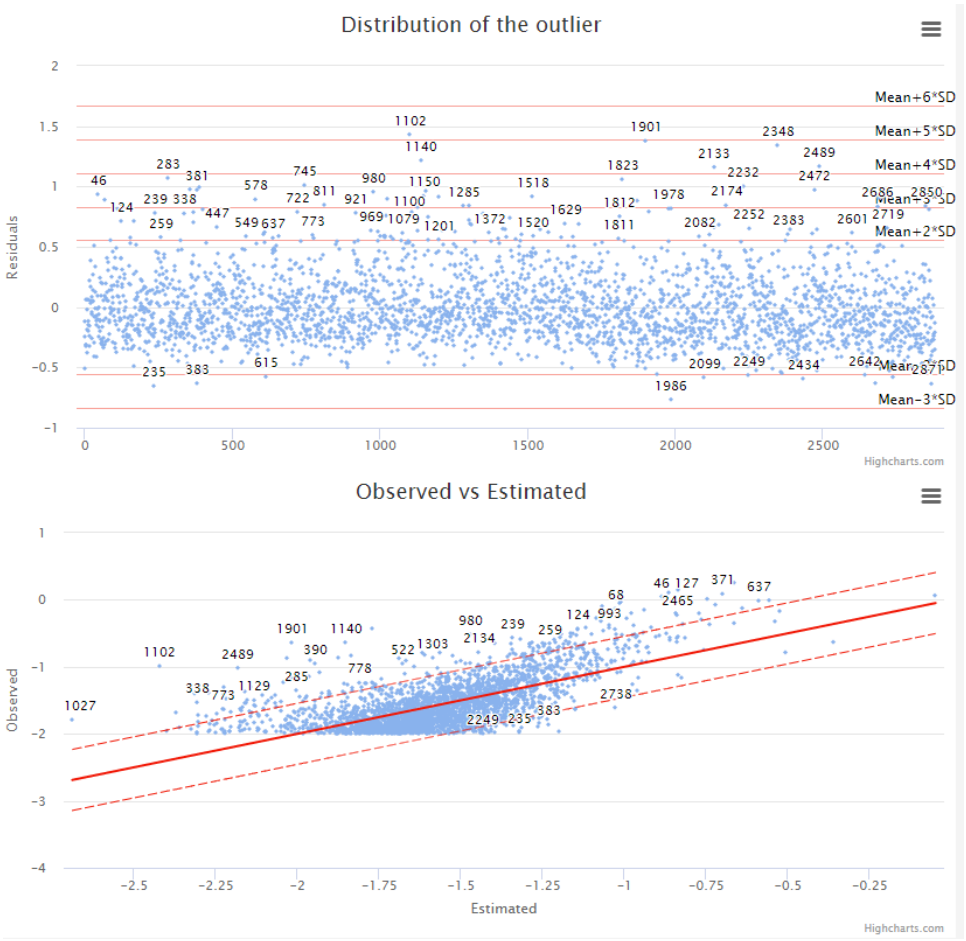


Figure 6. Residuals plots.

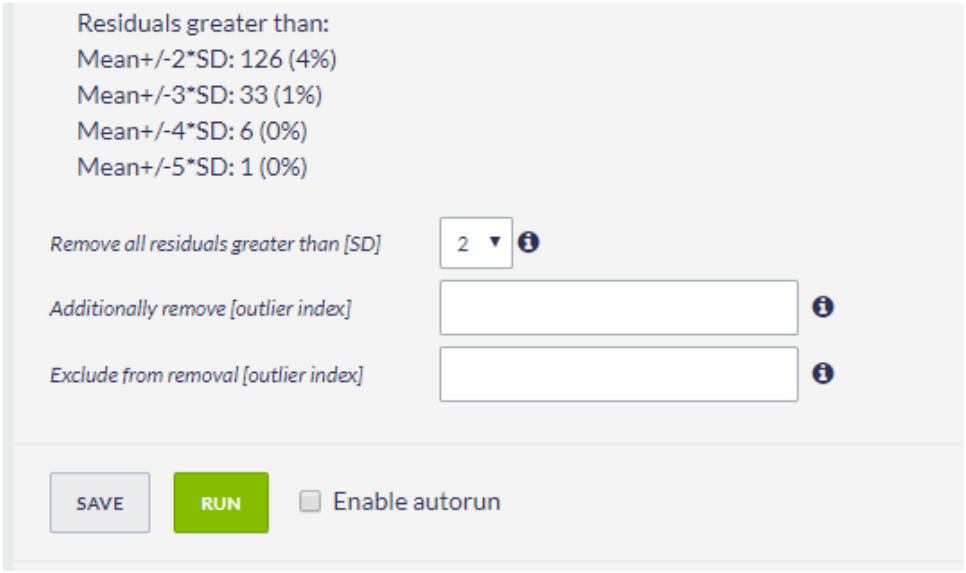


Figure 7. Input window of remove residuals part.

The results:

OUTPUTS

Linear regression model with calculated h
logPHA ~ Mw + logR + S_DABR + S_GUZI + S_KAZI + S_KOMR + S_KRZY + S_OBIS + S_PCHB + S_PEKW + S_PEKW2 + S_RZEC + S_TRBC + S_TRBC2

Depth [km]	0.144
Number of observations	2756
Error degrees of freedom	2742
Root Mean Squared Error	0.230
R2	0.517
p	0.000

Estimated Coefficients

	Estimate	SE	tStat	pValue
Mw	0.538	0.011	50.407	0.000
logR	-0.778	0.019	-40.054	0.000
S_DABR_1	-2.603	0.026	-98.933	0.000
S_GUZI_1	-2.606	0.026	-99.101	0.000
S_KAZI_1	-2.612	0.029	-89.819	0.000
S_KOMR_1	-2.515	0.026	-96.082	0.000
S_KRZY_1	-2.545	0.039	-65.242	0.000
S_OBIS_1	-2.367	0.025	-93.389	0.000
S_PCHB_1	-2.667	0.030	-87.853	0.000
S_PEKW_1	-2.656	0.047	-56.198	0.000
S_PEKW2_1	-2.657	0.027	-98.573	0.000
S_RZEC_1	-2.440	0.048	-50.679	0.000
S_TRBC_1	-2.539	0.035	-72.643	0.000
S_TRBC2_1	-2.661	0.026	-102.277	0.000

Statistic significance of coefficients	All coefficients are correct
Sign of coefficients of source	All coefficients are correct
Sign of coefficients of distance	All coefficients are correct

Comparison of the models: previous model vs current model

Number of observations	2882	>	2756
Number of coefficients	14	=	14
SEE	0.278	>	0.230
R2	0.457	<	0.517
F	172.6	<	209.8
p	0.000	=	0.000

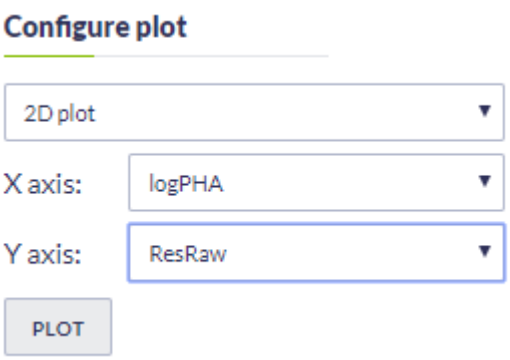
Figure 8. Results of the model after the removing outlieres.
Depending on the result - especially when scattering of residuals is evident - the analysis can be repeated. To repeat choose

IMPROVE MODEL

. Recalculation can be done as many times until the results are satisfactory.

7. Summary:
   After receiving the satisfying model, the final model can be performed (STEP3 of analysis). To calculate the last model with additional plots, please select FINAL MODEL .
   The final output results include:
   gmpe_model_raport, gmpe_model_dataset, figures (Normal probability plot of residuals, box plot - residuals according to the station, Mw vs residuals, r vs residuals).

There is also a possibility to configure selected figures based on used and estimated parameters.



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