Two-stage regression analysis for 13 parameters of the stochastic ground motion model

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1 Introduction

Generating a ground motion from a particular earthquake scenario (i.e., magnitude, distance and site condition), the 13 parameters for our model need to be connected to those scenario parameters. To do this, two-stage regression analysis (3,4) is employed with moment magnitude (M_W), hypocentral distance (R_{HYP}), rupture distance (R_{RUP}), and average shear wave velocity within 30m depth (V_{S30}) as predictors. The database for the regression analysis is selected from the NGA database (2), and contains fault normal component of 1408 strong ground motion recordings from 25 earthquakes. This is a subset of the database used in the BA08 (1) model. For each of these ground motions, all 13 parameters were estimated. The following equation is a functional form for E_{acc}, and the other parameters have similar functional forms:

$$\begin{aligned} \log(Y) &= a + b_1 M_W + b_2 \log(M_W) + c_2 \log(R) \\ &\quad + d \log(V_{S30}) + \eta_i + \epsilon_{i,j} \qquad (1) \\ R &= \sqrt{R_{RUP}^2 + h^2} \qquad (2) \end{aligned}$$

where η_i and $\epsilon_{i,j}$ are inter-event and inter-event residuals, and these residuals for the 13 parameters are correlated each other. h is determined to minimize the mean square error of the regression analysis. This document was generated by Sweave (http://www.stat.uni-muenchen.de/ leisch/Sweave/) in R.

2 Two-stage regression analysis of each parameter

2.1 Natural log of mean time of location major of group

2.1.1 First regression

```
> summary(first_reg)
```

```
Call:
lm(formula = ln_Y ~ I_EQ + Rhyp_Rrup + ln_R + ln_VS30 - 1)

Residuals:
      Min        1Q    Median        3Q       Max
-1.475033 -0.156614  0.005769  0.163353  1.169900

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
I_EQ1      1.6857991  0.1437521  11.727   <2e-16 ***
I_EQ2      2.5332834  0.1262940  20.059   <2e-16 ***
I_EQ3      2.7786283  0.1605943  17.302   <2e-16 ***
I_EQ4      2.2480953  0.1368352  16.429   <2e-16 ***
I_EQ5      2.2091977  0.1374165  16.077   <2e-16 ***
I_EQ6      1.8688212  0.1396581  13.381   <2e-16 ***
I_EQ7      1.7556954  0.1320327  13.297   <2e-16 ***
I_EQ8      2.6393063  0.1439008  18.341   <2e-16 ***
I_EQ9      2.2464437  0.1353411  16.598   <2e-16 ***
I_EQ10     2.7567555  0.1372588  20.084   <2e-16 ***
I_EQ11     2.4422144  0.1415327  17.255   <2e-16 ***
I_EQ12     2.2754508  0.1333109  17.069   <2e-16 ***
I_EQ13     2.5703577  0.1499436  17.142   <2e-16 ***
I_EQ14     2.8376675  0.1442902  19.666   <2e-16 ***
I_EQ15     3.3199567  0.1317661  25.196   <2e-16 ***
I_EQ16     2.8469926  0.1436711  19.816   <2e-16 ***
I_EQ17     2.6838704  0.1385137  19.376   <2e-16 ***
I_EQ18     2.1545427  0.1396302  15.430   <2e-16 ***
I_EQ19     1.8943807  0.1369862  13.829   <2e-16 ***
I_EQ20     1.7461192  0.1371047  12.736   <2e-16 ***
I_EQ21     2.6973417  0.1507508  17.893   <2e-16 ***
I_EQ22     2.0065271  0.1416093  14.169   <2e-16 ***
I_EQ23     3.0437197  0.1472708  20.667   <2e-16 ***
I_EQ24     3.2948346  0.1492395  22.078   <2e-16 ***
I_EQ25     2.0609161  0.1412940  14.586   <2e-16 ***
Rhyp_Rrup -0.0017861  0.0008433  -2.118   0.0344 *
ln_R       0.3438243  0.0096564  35.606   <2e-16 ***
ln_VS30   -0.1936633  0.0203337  -9.524   <2e-16 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.2738 on 1380 degrees of freedom
Multiple R-Squared: 0.9908,        Adjusted R-squared: 0.9906
F-statistic:  5327 on 28 and 1380 DF,  p-value: < 2.2e-16
```

```
> cor(qqnorm(resid(first_reg))$x, resid(first_reg))
[1] 0.990158
```

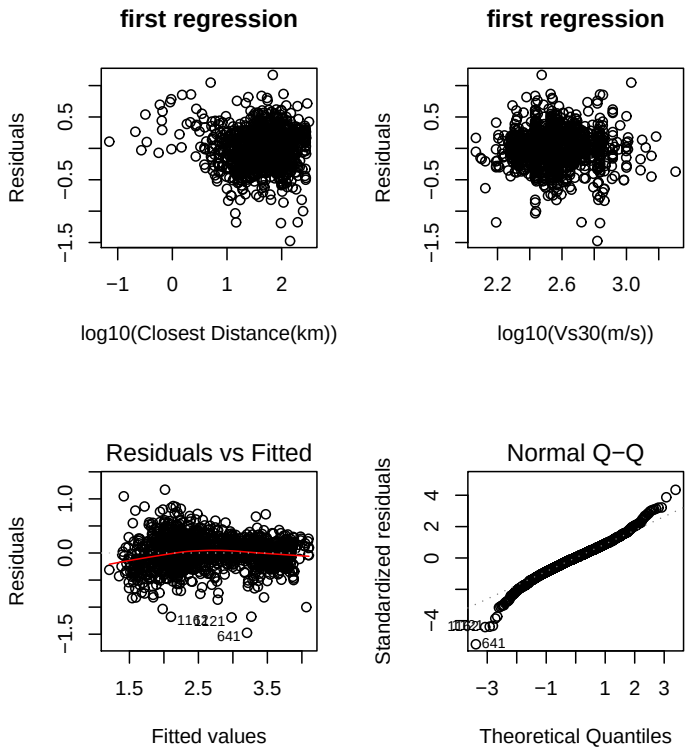

Figure 1: Characteristics of residuals: first regression of Natural log of mean time of location major of group

Figure 1 (page 3)

2.1.2 Second regression

```
> summary(second_reg)

Call:
lm(formula = A ~ exp_Mw)

Residuals:
     Min       1Q   Median       3Q      Max
-0.68845 -0.15148 -0.01949  0.17830  0.62979

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.9529774  0.0979900  19.930 5.22e-16 ***
```

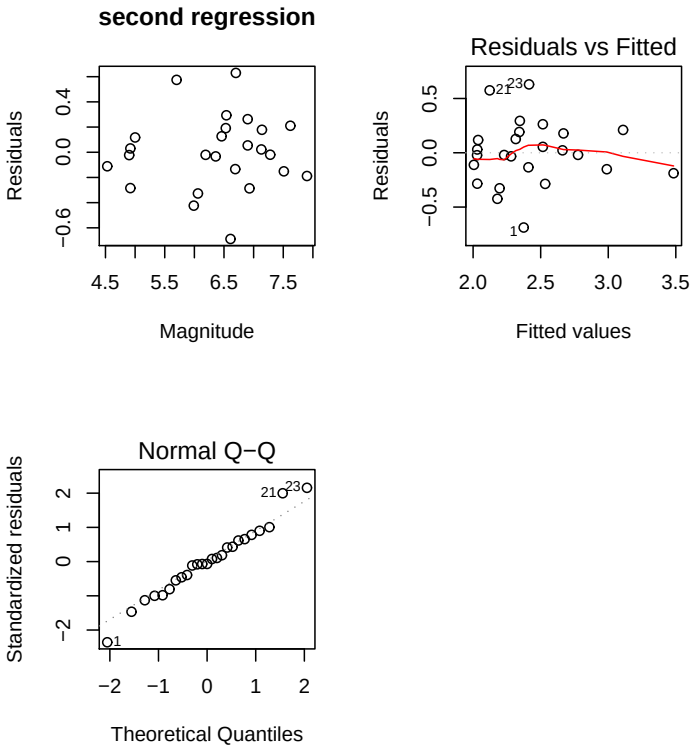

Figure 2: Characteristics of residuals: second regression of Natural log of mean time of location major of group

```
exp_Mw      0.0005674  0.0000937   6.056 3.55e-06 ***
---
Signif. codes:  0  ***  0.001  **  0.01  *  0.05  .  0.1    1

Residual standard error: 0.2981 on 23 degrees of freedom
Multiple R-Squared: 0.6145,        Adjusted R-squared: 0.5978
F-statistic: 36.67 on 1 and 23 DF,  p-value: 3.551e-06

> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.987163
```

Figure 2 (page 4)
Figure 3 (page 5)

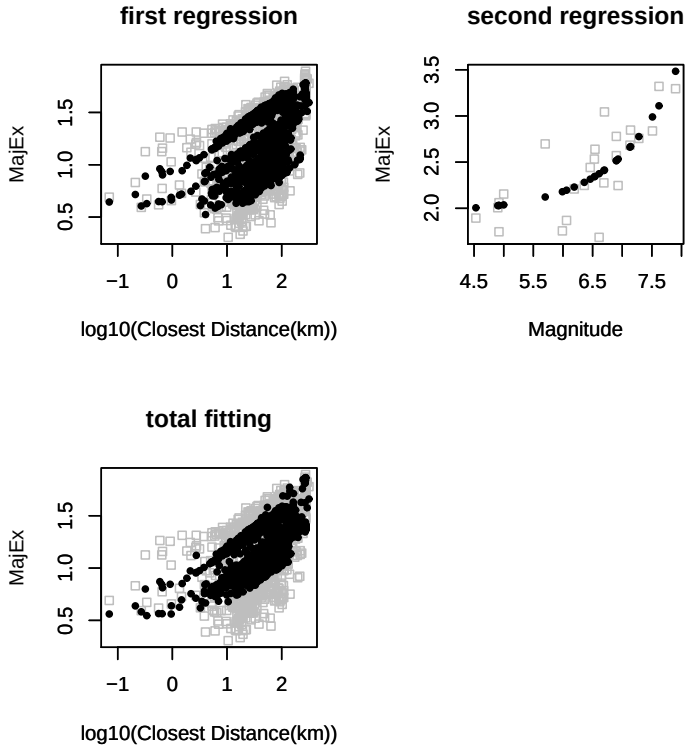

Figure 3: Median prediction of Natural log of mean time of location major of group

2.2 Natural log of mean frequency of major group

2.2.1 First regression

```
> summary(first_reg)

Call:
lm(formula = ln_Y ~ I_EQ + Rhyp_Rrup + ln_R + ln_VS30 - 1)

Residuals:
      Min        1Q    Median        3Q       Max
-1.665754 -0.264162  0.003637  0.259120  1.558646

Coefficients:
           Estimate Std. Error t value Pr(>|t|)
I_EQ1     -0.698666   0.224944  -3.106 0.001935 **
I_EQ2     -0.747262   0.197355  -3.786 0.000159 ***
I_EQ3     -1.115471   0.247269  -4.511 6.99e-06 ***
I_EQ4     -1.342331   0.212907  -6.305 3.88e-10 ***
I_EQ5     -0.868153   0.213164  -4.073 4.91e-05 ***
I_EQ6     -0.356800   0.217103  -1.643 0.100516
I_EQ7     -0.627296   0.205771  -3.049 0.002343 **
I_EQ8     -0.747197   0.222494  -3.358 0.000806 ***
I_EQ9     -1.138031   0.210979  -5.394 8.10e-08 ***
I_EQ10    -1.034303   0.216856  -4.770 2.04e-06 ***
I_EQ11    -0.370894   0.222334  -1.668 0.095506 .
I_EQ12    -0.899086   0.208254  -4.317 1.69e-05 ***
I_EQ13    -1.290397   0.233719  -5.521 4.02e-08 ***
I_EQ14    -1.040930   0.225087  -4.625 4.11e-06 ***
I_EQ15    -1.370478   0.206243  -6.645 4.35e-11 ***
I_EQ16    -1.149932   0.224640  -5.119 3.51e-07 ***
I_EQ17    -0.922495   0.218862  -4.215 2.66e-05 ***
I_EQ18    -0.809906   0.218009  -3.715 0.000211 ***
I_EQ19    -0.459982   0.213991  -2.150 0.031765 *
I_EQ20    -0.035360   0.215342  -0.164 0.869596
I_EQ21    -0.814260   0.236035  -3.450 0.000578 ***
I_EQ22    -0.502333   0.221418  -2.269 0.023440 *
I_EQ23    -1.367235   0.234507  -5.830 6.88e-09 ***
I_EQ24    -0.957374   0.235299  -4.069 4.99e-05 ***
I_EQ25    -0.463899   0.220942  -2.100 0.035942 *
Rhyp_Rrup -0.003807   0.001269  -3.000 0.002748 **
ln_R      -0.159633   0.018701  -8.536  < 2e-16 ***
ln_VS30    0.440228   0.030542  14.414  < 2e-16 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.4105 on 1380 degrees of freedom
```

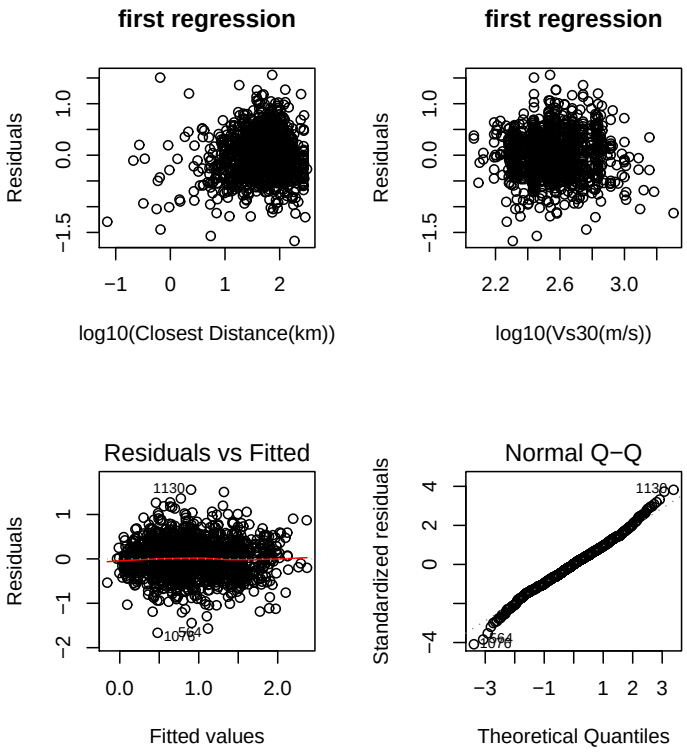

Figure 4: Characteristics of residuals: first regression of Natural log of mean frequency of major group

```
Multiple R-Squared: 0.8705,        Adjusted R-squared: 0.8678
F-statistic: 331.2 on 28 and 1380 DF,  p-value: < 2.2e-16
```

```
> cor(qqnorm(resid(first_reg))$x, resid(first_reg))
```

```
[1] 0.99772
```

Figure 4 (page 7)

2.2.2 Second regression

```
> summary(second_reg)
```

```
Call:
lm(formula = A ~ Mw)
```

```
Residuals:
      Min        1Q    Median        3Q       Max
-0.501374 -0.144154  0.004291  0.137703  0.495950

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.80544    0.36955   2.180 0.039787 *
Mw          -0.25887    0.05737  -4.512 0.000157 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.2614 on 23 degrees of freedom
Multiple R-Squared: 0.4695,        Adjusted R-squared: 0.4465
F-statistic: 20.36 on 1 and 23 DF,  p-value: 0.0001571
```

```
> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.9930587
```

Figure 5 (page 9)
Figure 6 (page 10)

2.3 Natural log of standard deviation of time of major group

2.3.1 First regression

```
> summary(first_reg)

Call:
lm(formula = ln_Y ~ I_EQ + Rhyp_Rrup + ln_R + ln_VS30 - 1)

Residuals:
     Min       1Q   Median       3Q      Max
-1.01090 -0.23228 -0.01790  0.20665  1.73116

Coefficients:
          Estimate Std. Error t value Pr(>|t|)
I_EQ1      2.167459   0.180970  11.977  < 2e-16 ***
I_EQ2      2.320743   0.158992  14.597  < 2e-16 ***
I_EQ3      2.754715   0.202173  13.626  < 2e-16 ***
I_EQ4      1.947769   0.172262  11.307  < 2e-16 ***
I_EQ5      2.340277   0.172994  13.528  < 2e-16 ***
I_EQ6      1.761515   0.175816  10.019  < 2e-16 ***
I_EQ7      1.722573   0.166216  10.363  < 2e-16 ***
I_EQ8      2.338975   0.181157  12.911  < 2e-16 ***
I_EQ9      1.941746   0.170381  11.396  < 2e-16 ***
```

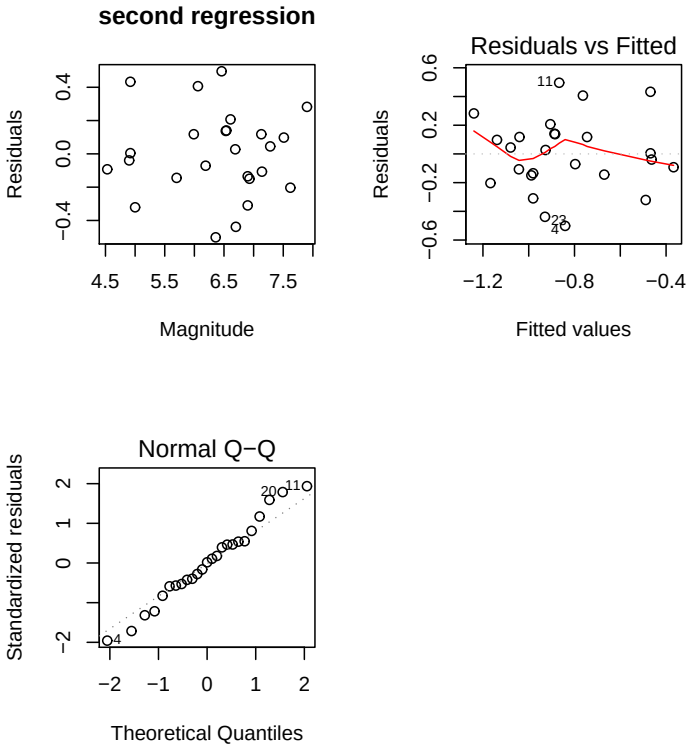

Figure 5: Characteristics of residuals: second regression of Natural log of mean frequency of major group

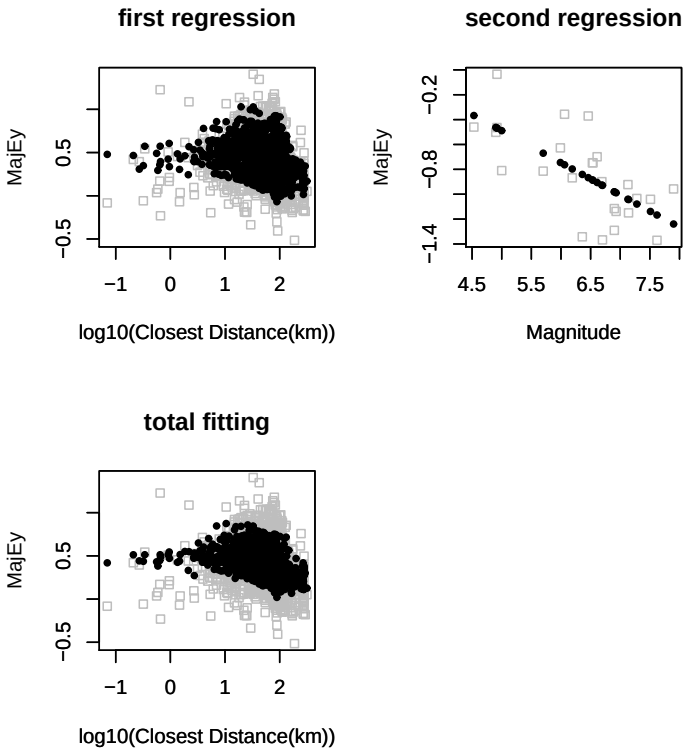

Figure 6: Median prediction of Natural log of mean frequency of major group

```
I_EQ10     2.598290   0.172795  15.037  < 2e-16 ***
I_EQ11     2.232781   0.178176  12.531  < 2e-16 ***
I_EQ12     2.013966   0.167825  12.000  < 2e-16 ***
I_EQ13     2.399203   0.188764  12.710  < 2e-16 ***
I_EQ14     2.690691   0.181647  14.813  < 2e-16 ***
I_EQ15     2.953387   0.165881  17.804  < 2e-16 ***
I_EQ16     2.717149   0.180868  15.023  < 2e-16 ***
I_EQ17     2.454808   0.174375  14.078  < 2e-16 ***
I_EQ18     1.797196   0.175781  10.224  < 2e-16 ***
I_EQ19     1.736511   0.172452  10.070  < 2e-16 ***
I_EQ20     1.726996   0.172601  10.006  < 2e-16 ***
I_EQ21     3.152337   0.189781  16.610  < 2e-16 ***
I_EQ22     1.637721   0.178272   9.187  < 2e-16 ***
I_EQ23     2.821900   0.185400  15.221  < 2e-16 ***
I_EQ24     3.360720   0.187878  17.888  < 2e-16 ***
I_EQ25     1.710092   0.177875   9.614  < 2e-16 ***
Rhyp_Rrup -0.006360   0.001062  -5.991 2.66e-09 ***
ln_R       0.217719   0.012156  17.910  < 2e-16 ***
ln_VS30   -0.199910   0.025598  -7.810 1.13e-14 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.3447 on 1380 degrees of freedom
Multiple R-Squared: 0.9714,        Adjusted R-squared: 0.9708
F-statistic:  1672 on 28 and 1380 DF,  p-value: < 2.2e-16

> cor(qqnorm(resid(first_reg))$x, resid(first_reg))

[1] 0.9954004
```

Figure 7 (page 12)

2.3.2 Second regression

```
> summary(second_reg)

Call:
lm(formula = A ~ exp_Mw)

Residuals:
     Min       1Q   Median       3Q      Max
-0.45935 -0.18923 -0.07457  0.11067  1.16130

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.8216862  0.1110083  16.410 3.43e-14 ***
exp_Mw      0.0005667  0.0001061   5.339 2.02e-05 ***
```

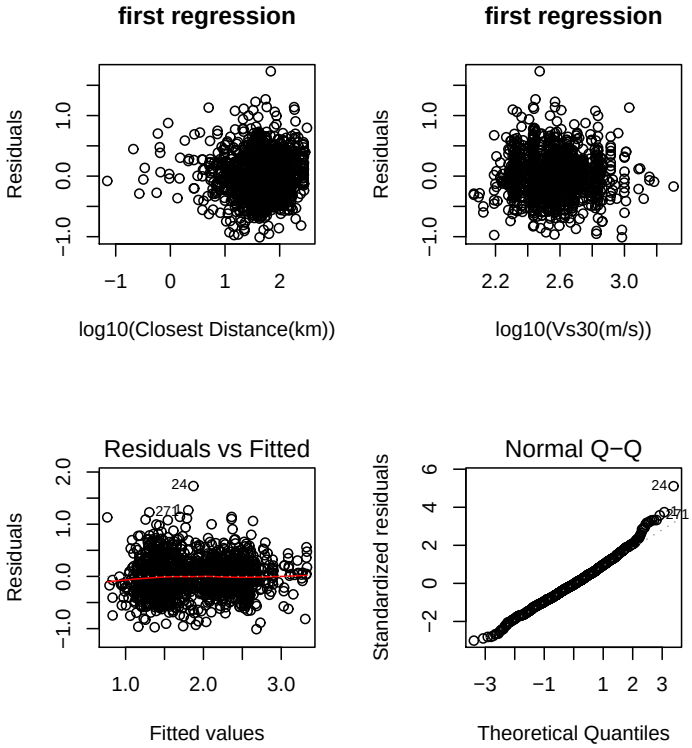

Figure 7: Characteristics of residuals: first regression of Natural log of standard deviation of time of major group

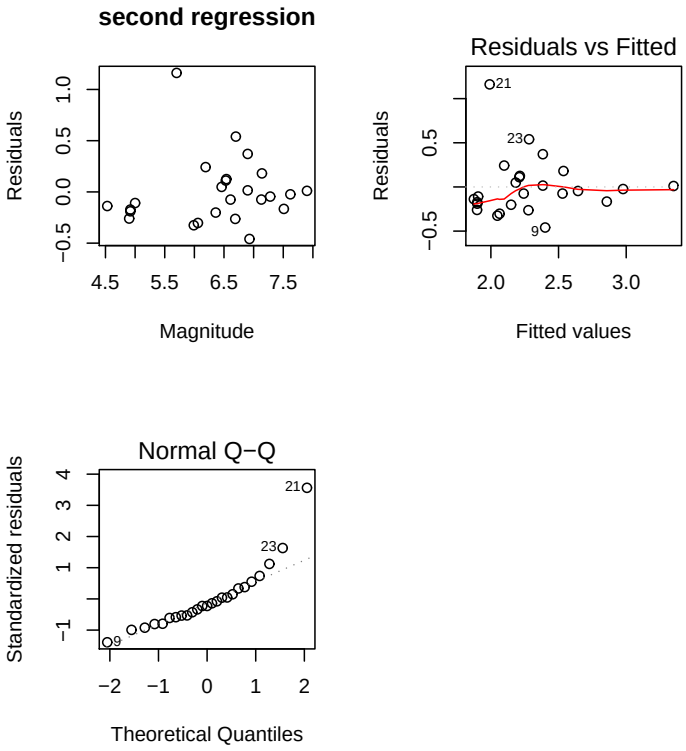

Figure 8: Characteristics of residuals: second regression of Natural log of standard deviation of time of major group

```
---
Signif. codes:  0  ***  0.001  **  0.01  *  0.05  .  0.1    1

Residual standard error: 0.3377 on 23 degrees of freedom
Multiple R-Squared: 0.5534,        Adjusted R-squared: 0.534
F-statistic:  28.5 on 1 and 23 DF,  p-value: 2.022e-05

> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.9103815
```

Figure 8 (page 13)
Figure 9 (page 14)

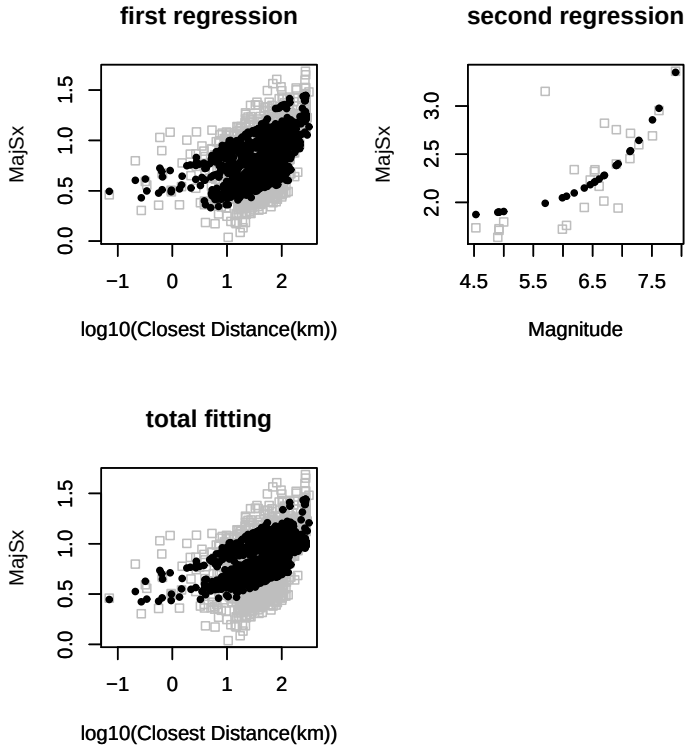

Figure 9: Median prediction of Natural log of standard deviation of time of major group

2.4 Natural log of standard deviation of frequency of major group

2.4.1 First regression

```
> summary(first_reg)

Call:
lm(formula = ln_Y ~ I_EQ + Rhyp_Rrup + ln_R + ln_VS30 - 1)

Residuals:
     Min       1Q   Median       3Q      Max
-2.07973 -0.38259  0.01619  0.34820  2.51744

Coefficients:
           Estimate Std. Error t value Pr(>|t|)
I_EQ1     -0.356905   0.312346  -1.143 0.253379
I_EQ2     -0.347825   0.274038  -1.269 0.204563
I_EQ3     -0.763428   0.343346  -2.223 0.026344 *
I_EQ4     -1.324858   0.295632  -4.481 8.03e-06 ***
I_EQ5     -0.707858   0.295989  -2.392 0.016913 *
I_EQ6     -0.076112   0.301459  -0.252 0.800708
I_EQ7     -0.530167   0.285724  -1.856 0.063734 .
I_EQ8     -0.376074   0.308945  -1.217 0.223704
I_EQ9     -0.917655   0.292955  -3.132 0.001770 **
I_EQ10    -0.617138   0.301116  -2.050 0.040601 *
I_EQ11     0.013447   0.308722   0.044 0.965265
I_EQ12    -0.774033   0.289171  -2.677 0.007523 **
I_EQ13    -1.403196   0.324532  -4.324 1.64e-05 ***
I_EQ14    -0.694438   0.312545  -2.222 0.026453 *
I_EQ15    -1.076308   0.286379  -3.758 0.000178 ***
I_EQ16    -1.018455   0.311925  -3.265 0.001121 **
I_EQ17    -0.410455   0.303901  -1.351 0.177038
I_EQ18    -0.991515   0.302717  -3.275 0.001081 **
I_EQ19    -0.386721   0.297138  -1.301 0.193310
I_EQ20     0.057978   0.299013   0.194 0.846286
I_EQ21    -0.352566   0.327748  -1.076 0.282239
I_EQ22    -0.614674   0.307451  -1.999 0.045777 *
I_EQ23    -0.929461   0.325626  -2.854 0.004377 **
I_EQ24    -0.245754   0.326725  -0.752 0.452074
I_EQ25    -0.393519   0.306790  -1.283 0.199812
Rhyp_Rrup -0.001938   0.001762  -1.100 0.271624
ln_R      -0.242775   0.025967  -9.349  < 2e-16 ***
ln_VS30    0.393957   0.042409   9.289  < 2e-16 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1
```

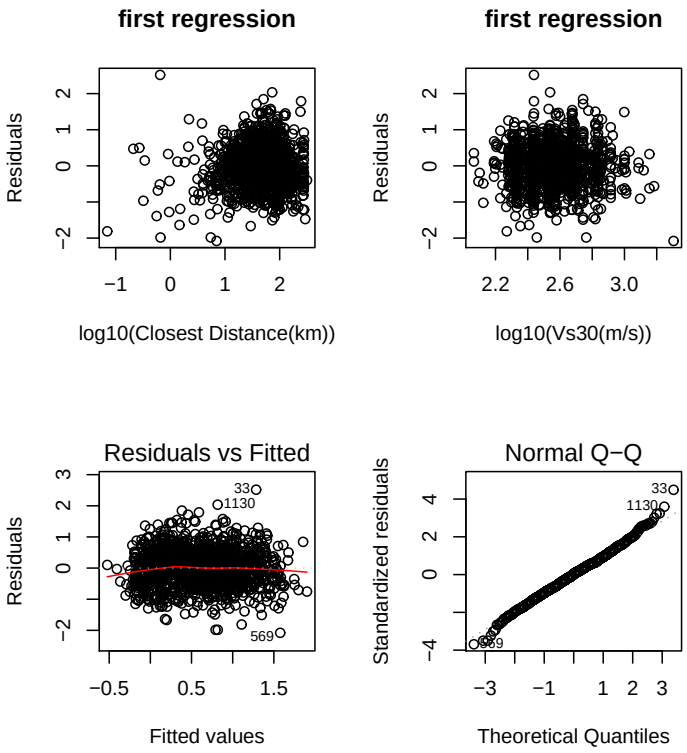

Figure 10: Characteristics of residuals: first regression of Natural log of standard deviation of frequency of major group

```
Residual standard error: 0.57 on 1380 degrees of freedom
Multiple R-Squared: 0.6396,        Adjusted R-squared: 0.6323
F-statistic: 87.46 on 28 and 1380 DF,  p-value: < 2.2e-16
```

```
> cor(qqnorm(resid(first_reg))$x, resid(first_reg))
```

```
[1] 0.9982983
```

Figure 10 (page 16)

2.4.2 Second regression

```
> summary(second_reg)
```

```
Call:
lm(formula = A ~ Mw)
```

```
Residuals:
     Min       1Q   Median       3Q      Max
-0.73234 -0.24329  0.03407  0.27968  0.63275

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.13754    0.53537   0.257    0.800
Mw          -0.11716    0.08312  -1.410    0.172

Residual standard error: 0.3787 on 23 degrees of freedom
Multiple R-Squared: 0.07951,        Adjusted R-squared: 0.03949
F-statistic: 1.987 on 1 and 23 DF,  p-value: 0.1721
```

```
> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.9888564
```

Figure 11 (page 18)
Figure 12 (page 19)

2.5 Correlation of time-frequency of major group

2.5.1 First regression

```
> summary(first_reg)

Call:
lm(formula = ln_Y ~ I_EQ + Rhyp_Rrup + ln_R + ln_VS30 - 1)

Residuals:
     Min       1Q   Median       3Q      Max
-0.60023 -0.13923 -0.02390  0.11218  1.21492

Coefficients:
           Estimate Std. Error t value Pr(>|t|)
I_EQ1     -3.856e-01  1.184e-01  -3.257 0.001153 **
I_EQ2     -4.852e-01  1.039e-01  -4.671 3.29e-06 ***
I_EQ3     -5.358e-01  1.301e-01  -4.117 4.07e-05 ***
I_EQ4     -4.600e-01  1.121e-01  -4.105 4.28e-05 ***
I_EQ5     -6.945e-01  1.122e-01  -6.190 7.92e-10 ***
I_EQ6     -4.579e-01  1.143e-01  -4.007 6.48e-05 ***
I_EQ7     -4.692e-01  1.083e-01  -4.332 1.58e-05 ***
I_EQ8     -4.478e-01  1.171e-01  -3.824 0.000137 ***
I_EQ9     -4.052e-01  1.110e-01  -3.649 0.000273 ***
I_EQ10    -4.101e-01  1.141e-01  -3.593 0.000339 ***
I_EQ11    -4.444e-01  1.170e-01  -3.798 0.000152 ***
```

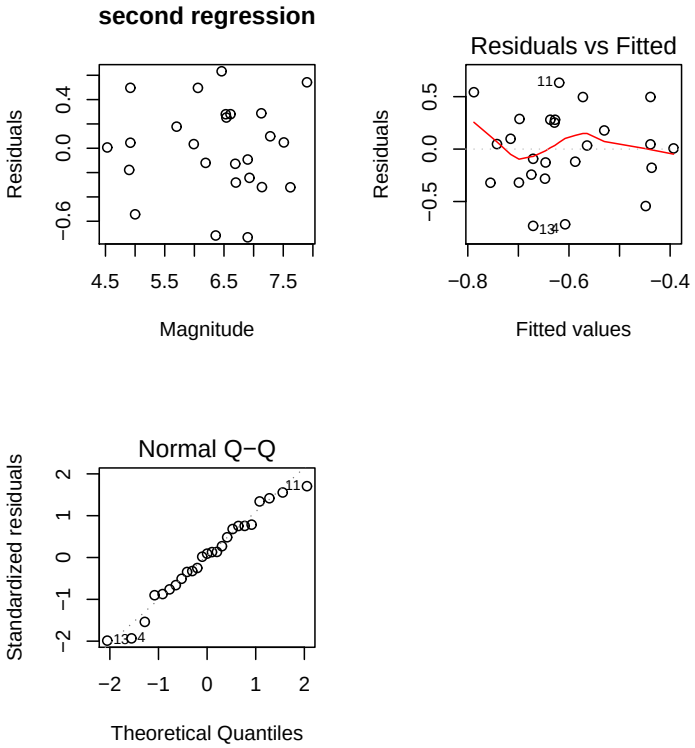

Figure 11: Characteristics of residuals: second regression of Natural log of standard deviation of frequency of major group

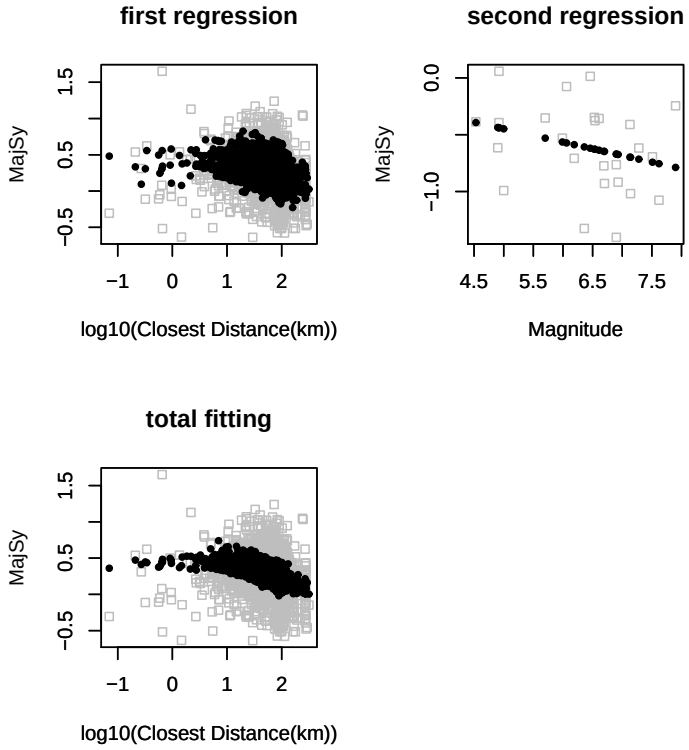

Figure 12: Median prediction of Natural log of standard deviation of frequency of major group

```
I_EQ12    -5.131e-01  1.096e-01  -4.681 3.13e-06 ***
I_EQ13    -4.894e-01  1.230e-01  -3.978 7.31e-05 ***
I_EQ14    -3.940e-01  1.185e-01  -3.326 0.000904 ***
I_EQ15    -5.440e-01  1.086e-01  -5.011 6.11e-07 ***
I_EQ16    -4.670e-01  1.182e-01  -3.950 8.22e-05 ***
I_EQ17    -4.896e-01  1.152e-01  -4.250 2.28e-05 ***
I_EQ18    -4.808e-01  1.147e-01  -4.190 2.96e-05 ***
I_EQ19    -4.679e-01  1.126e-01  -4.154 3.46e-05 ***
I_EQ20    -4.704e-01  1.133e-01  -4.151 3.52e-05 ***
I_EQ21    -6.241e-01  1.242e-01  -5.024 5.73e-07 ***
I_EQ22    -4.689e-01  1.165e-01  -4.024 6.04e-05 ***
I_EQ23    -4.964e-01  1.234e-01  -4.022 6.08e-05 ***
I_EQ24    -4.312e-01  1.238e-01  -3.481 0.000514 ***
I_EQ25    -4.363e-01  1.163e-01  -3.752 0.000183 ***
Rhyp_Rrup -7.619e-05  6.680e-04  -0.114 0.909203
ln_R      -7.922e-02  9.843e-03  -8.049 1.79e-15 ***
ln_VS30    9.416e-02  1.608e-02   5.857 5.88e-09 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.2161 on 1380 degrees of freedom
Multiple R-Squared: 0.6127,        Adjusted R-squared: 0.6048
F-statistic: 77.96 on 28 and 1380 DF,  p-value: < 2.2e-16
```

```
> cor(qqnorm(resid(first_reg))$x, resid(first_reg))

[1] 0.9819702
```

Figure 13 (page 21)

2.5.2 Second regression

```
> summary(second_reg)

Call:
lm(formula = A ~ Mw)

Residuals:
     Min       1Q   Median       3Q      Max
-0.21402 -0.01775  0.01889  0.03355  0.09100

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.537150   0.097183  -5.527 1.27e-05 ***
Mw           0.009157   0.015088   0.607     0.55
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1
```

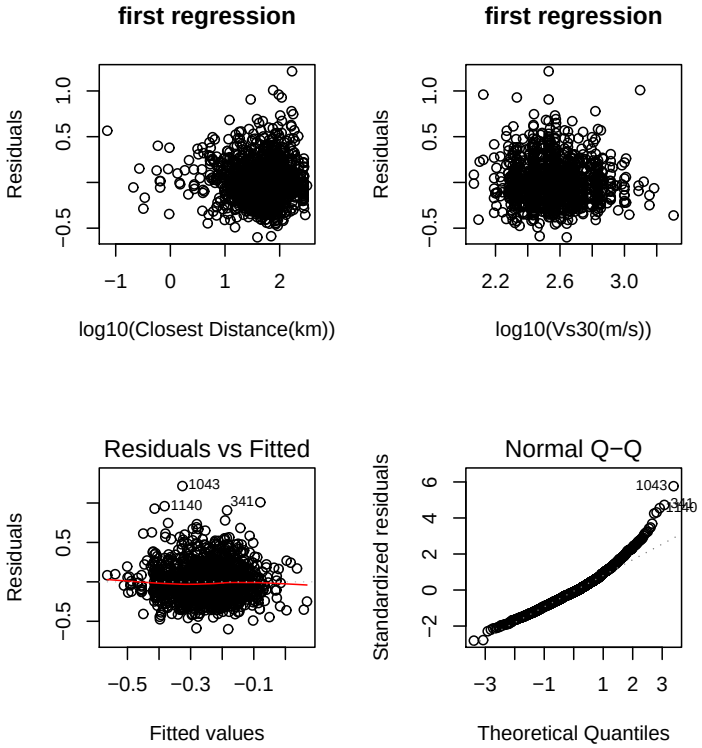

Figure 13: Characteristics of residuals: first regression of Correlation of time-frequency of major group

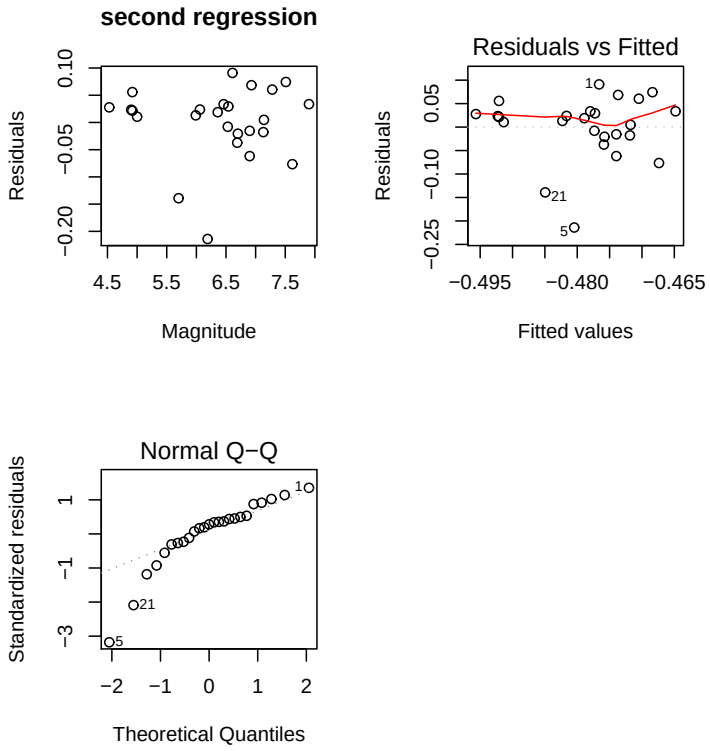

Figure 14: Characteristics of residuals: second regression of Correlation of time-frequency of major group

```
Residual standard error: 0.06874 on 23 degrees of freedom
Multiple R-Squared: 0.01576,        Adjusted R-squared: -0.02703
F-statistic: 0.3684 on 1 and 23 DF,  p-value: 0.5498
```

```
> cor(qqnorm(resid(second_reg))$x, resid(second_reg))
```

```
[1] 0.9233407
```

Figure 14 (page 22)
Figure 15 (page 23)

2.6 Natural log of mean time of location minor of group

2.6.1 First regression

```
> summary(first_reg)
```

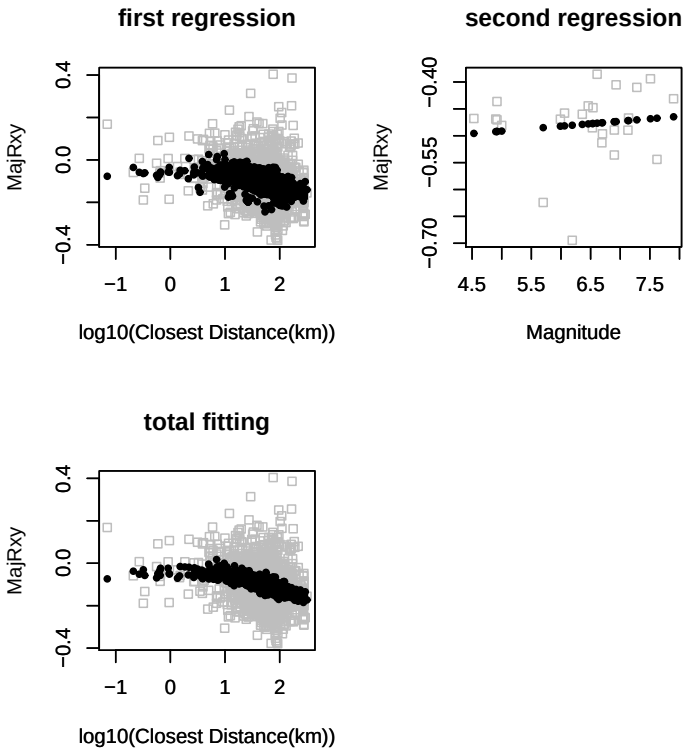

Figure 15: Median prediction of Correlation of time-frequency of major group

```
Call:
lm(formula = ln_Y ~ I_EQ + Rhyp_Rrup + ln_R + ln_VS30 - 1)

Residuals:
       Min         1Q     Median         3Q        Max
-0.9127000 -0.1042845 -0.0005627  0.1101871  0.6840460

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
I_EQ1      2.5615314  0.0953121  26.875  < 2e-16 ***
I_EQ2      3.0202360  0.0837368  36.068  < 2e-16 ***
I_EQ3      3.2462472  0.1064790  30.487  < 2e-16 ***
I_EQ4      2.8421086  0.0907260  31.326  < 2e-16 ***
I_EQ5      2.8014620  0.0911114  30.748  < 2e-16 ***
I_EQ6      2.6144086  0.0925977  28.234  < 2e-16 ***
I_EQ7      2.6054619  0.0875418  29.762  < 2e-16 ***
I_EQ8      2.9293798  0.0954107  30.703  < 2e-16 ***
I_EQ9      2.8434314  0.0897354  31.687  < 2e-16 ***
I_EQ10     3.1889386  0.0910068  35.041  < 2e-16 ***
I_EQ11     2.9990197  0.0938406  31.959  < 2e-16 ***
I_EQ12     2.8405260  0.0883893  32.137  < 2e-16 ***
I_EQ13     3.1187625  0.0994173  31.370  < 2e-16 ***
I_EQ14     3.4073134  0.0956689  35.616  < 2e-16 ***
I_EQ15     3.6577542  0.0873650  41.867  < 2e-16 ***
I_EQ16     3.2472970  0.0952584  34.089  < 2e-16 ***
I_EQ17     3.1945703  0.0918389  34.785  < 2e-16 ***
I_EQ18     2.7983768  0.0925791  30.227  < 2e-16 ***
I_EQ19     2.6433818  0.0908261  29.104  < 2e-16 ***
I_EQ20     2.5788016  0.0909047  28.368  < 2e-16 ***
I_EQ21     3.2774012  0.0999525  32.790  < 2e-16 ***
I_EQ22     2.6838149  0.0938914  28.584  < 2e-16 ***
I_EQ23     3.6322047  0.0976451  37.198  < 2e-16 ***
I_EQ24     3.8531947  0.0989504  38.941  < 2e-16 ***
I_EQ25     2.7412997  0.0936823  29.262  < 2e-16 ***
Rhyp_Rrup -0.0014479  0.0005592  -2.589  0.00972 **
ln_R       0.2168922  0.0064025  33.876  < 2e-16 ***
ln_VS30   -0.1612453  0.0134819 -11.960  < 2e-16 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.1815 on 1380 degrees of freedom
Multiple R-Squared: 0.9965,        Adjusted R-squared: 0.9964
F-statistic: 1.395e+04 on 28 and 1380 DF,  p-value: < 2.2e-16
```

```
> cor(qqnorm(resid(first_reg))$x, resid(first_reg))
[1] 0.9919005
```

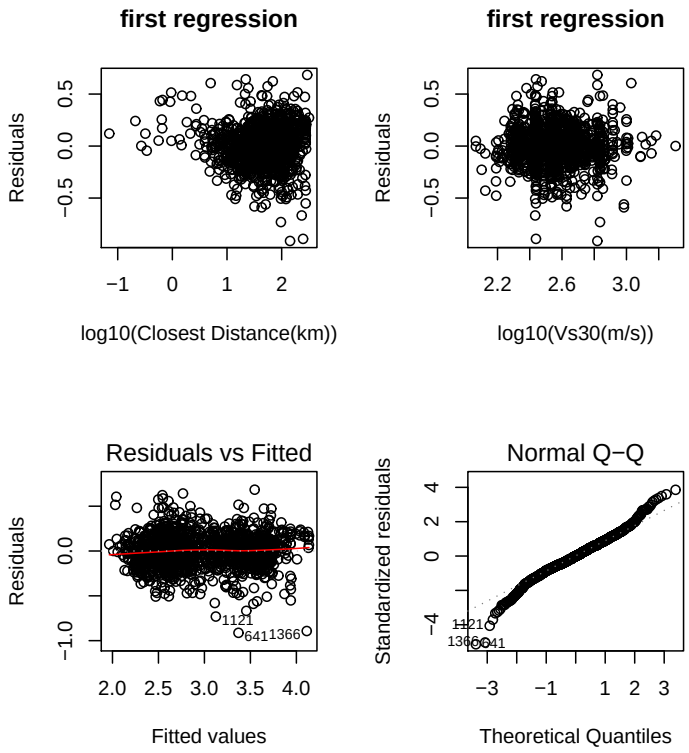

Figure 16: Characteristics of residuals: first regression of Natural log of mean time of location minor of group

Figure 16 (page 25)

2.6.2 Second regression

```
> summary(second_reg)

Call:
lm(formula = A ~ exp_Mw)

Residuals:
     Min       1Q   Median       3Q      Max
-0.41229 -0.10286 -0.01706  0.07161  0.62700

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 2.641e+00  7.181e-02  36.774  < 2e-16 ***
```

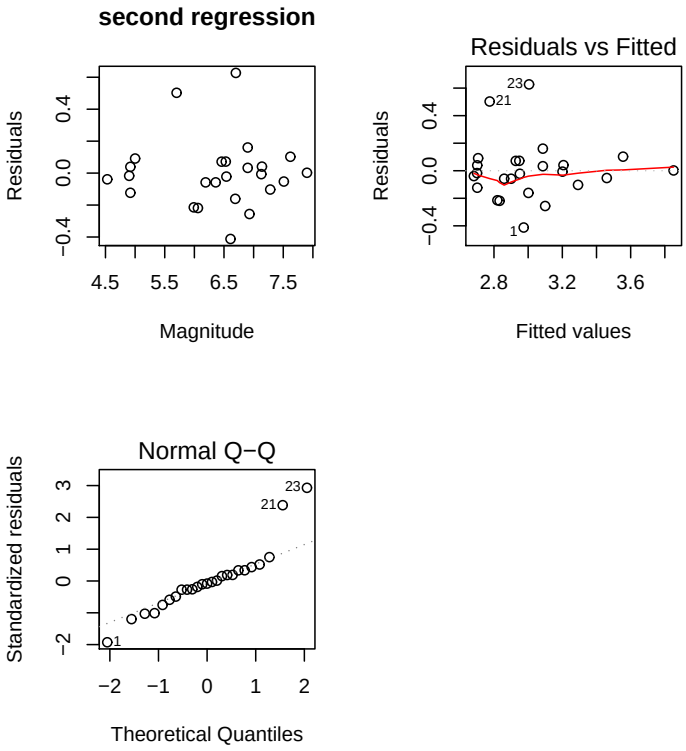

Figure 17: Characteristics of residuals: second regression of Natural log of mean time of location minor of group

```
exp_Mw      4.488e-04  6.866e-05   6.536 1.14e-06 ***
---
Signif. codes:  0  ***  0.001  **  0.01  *  0.05  .  0.1    1

Residual standard error: 0.2185 on 23 degrees of freedom
Multiple R-Squared: 0.6501,        Adjusted R-squared: 0.6348
F-statistic: 42.73 on 1 and 23 DF,  p-value: 1.14e-06

> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.9326464
```

Figure 17 (page 26)
Figure 18 (page 27)

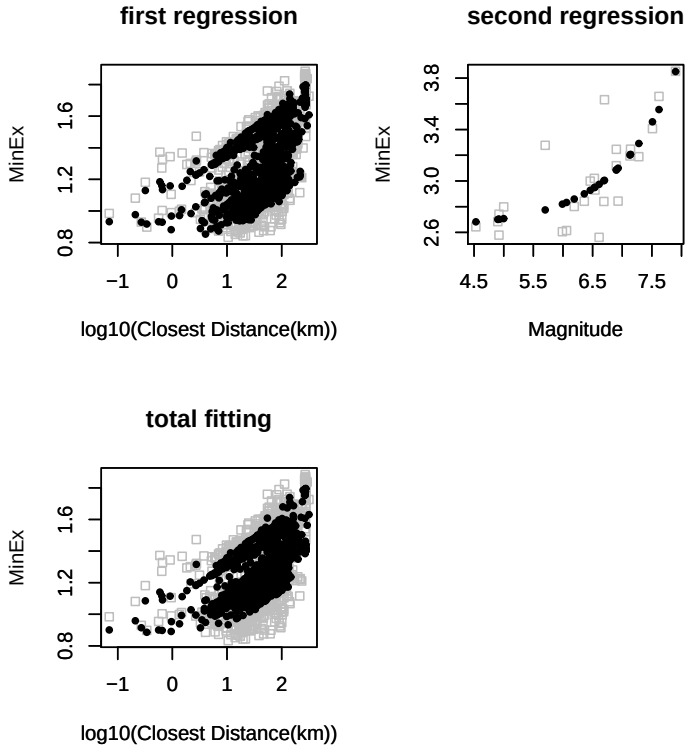

Figure 18: Median prediction of Natural log of mean time of location minor of group

2.7 Natural log of mean frequency of minor group

2.7.1 First regression

```
> summary(first_reg)

Call:
lm(formula = ln_Y ~ I_EQ + Rhyp_Rrup + ln_R + ln_VS30 - 1)

Residuals:
      Min        1Q    Median        3Q       Max
-2.314317 -0.223889 -0.007947  0.221283  1.377072

Coefficients:
           Estimate Std. Error t value Pr(>|t|)
I_EQ1      0.513599   0.193604   2.653 0.008073 **
I_EQ2      0.516857   0.169859   3.043 0.002388 **
I_EQ3      0.084840   0.212819   0.399 0.690213
I_EQ4     -0.167765   0.183244  -0.916 0.360075
I_EQ5      0.210424   0.183465   1.147 0.251604
I_EQ6      0.840406   0.186856   4.498 7.45e-06 ***
I_EQ7      0.434836   0.177102   2.455 0.014200 *
I_EQ8      0.504770   0.191496   2.636 0.008485 **
I_EQ9      0.161749   0.181584   0.891 0.373211
I_EQ10     0.428080   0.186643   2.294 0.021964 *
I_EQ11     0.863224   0.191357   4.511 7.00e-06 ***
I_EQ12     0.301915   0.179239   1.684 0.092326 .
I_EQ13    -0.077060   0.201157  -0.383 0.701716
I_EQ14     0.226508   0.193727   1.169 0.242520
I_EQ15     0.010989   0.177508   0.062 0.950647
I_EQ16     0.119739   0.193342   0.619 0.535814
I_EQ17     0.487612   0.188369   2.589 0.009738 **
I_EQ18     0.230771   0.187635   1.230 0.218949
I_EQ19     0.676020   0.184177   3.670 0.000251 ***
I_EQ20     0.979984   0.185339   5.288 1.44e-07 ***
I_EQ21     0.472808   0.203150   2.327 0.020089 *
I_EQ22     0.450915   0.190570   2.366 0.018112 *
I_EQ23     0.142831   0.201835   0.708 0.479275
I_EQ24     0.475700   0.202516   2.349 0.018967 *
I_EQ25     0.641067   0.190160   3.371 0.000769 ***
Rhyp_Rrup -0.004372   0.001092  -4.003 6.60e-05 ***
ln_R      -0.229837   0.016095 -14.280  < 2e-16 ***
ln_VS30    0.355682   0.026287  13.531  < 2e-16 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.3533 on 1380 degrees of freedom
```

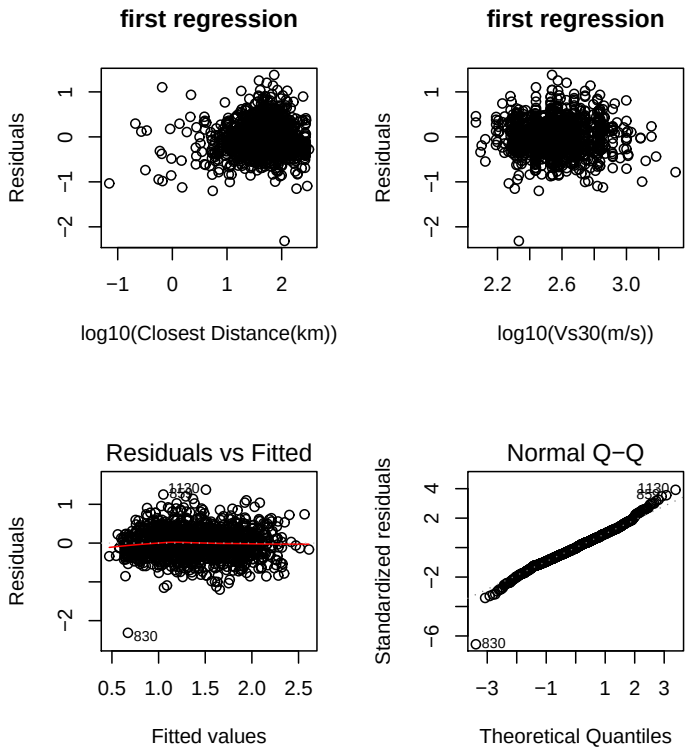

Figure 19: Characteristics of residuals: first regression of Natural log of mean frequency of minor group

```
Multiple R-Squared: 0.9463,        Adjusted R-squared: 0.9452
F-statistic: 868.8 on 28 and 1380 DF,  p-value: < 2.2e-16
```

```
> cor(qqnorm(resid(first_reg))$x, resid(first_reg))
```

```
[1] 0.993525
```

Figure 19 (page 29)

2.7.2 Second regression

```
> summary(second_reg)
```

```
Call:
lm(formula = A ~ Mw)
```

```
Residuals:
      Min        1Q    Median        3Q       Max
-0.551331 -0.192365 -0.001368  0.165599  0.493885

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.28838    0.37491   3.436  0.00225 **
Mw          -0.14227    0.05821  -2.444  0.02260 *
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.2652 on 23 degrees of freedom
Multiple R-Squared: 0.2062,        Adjusted R-squared: 0.1717
F-statistic: 5.974 on 1 and 23 DF,  p-value: 0.0226
```

```
> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.9927491
```

Figure 20 (page 31)
Figure 21 (page 32)

2.8 Natural log of standard deviation of time of minor group

2.8.1 First regression

```
> summary(first_reg)

Call:
lm(formula = ln_Y ~ I_EQ + Rhyp_Rrup + ln_R + ln_VS30 - 1)

Residuals:
      Min        1Q    Median        3Q       Max
-0.747863 -0.139720 -0.002799  0.130634  0.873646

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
I_EQ1      3.1031283  0.1139480  27.233  < 2e-16 ***
I_EQ2      3.3519899  0.1001095  33.483  < 2e-16 ***
I_EQ3      3.6274761  0.1272983  28.496  < 2e-16 ***
I_EQ4      3.2628399  0.1084651  30.082  < 2e-16 ***
I_EQ5      3.2365137  0.1089259  29.713  < 2e-16 ***
I_EQ6      3.0162877  0.1107028  27.247  < 2e-16 ***
I_EQ7      3.0283008  0.1046584  28.935  < 2e-16 ***
I_EQ8      3.1551041  0.1140658  27.660  < 2e-16 ***
I_EQ9      3.2314880  0.1072809  30.122  < 2e-16 ***
```

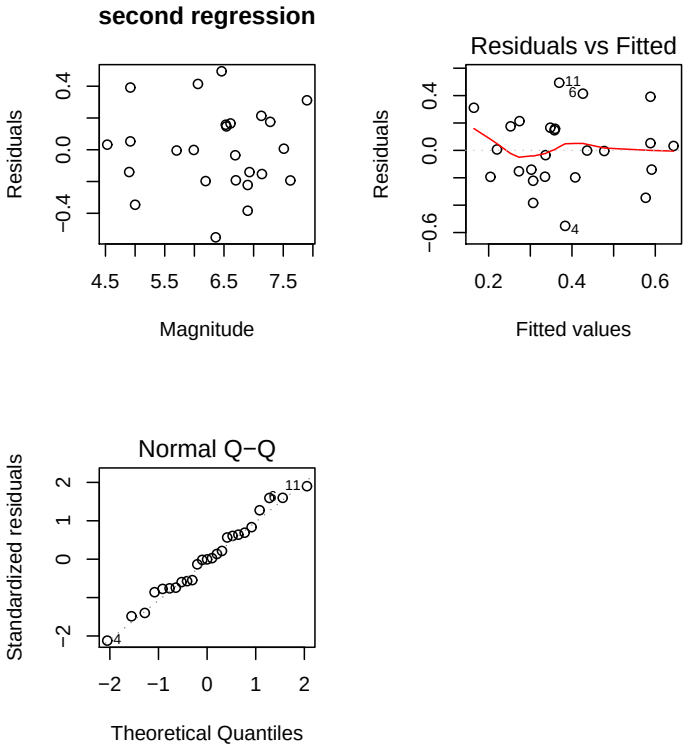

Figure 20: Characteristics of residuals: second regression of Natural log of mean frequency of minor group

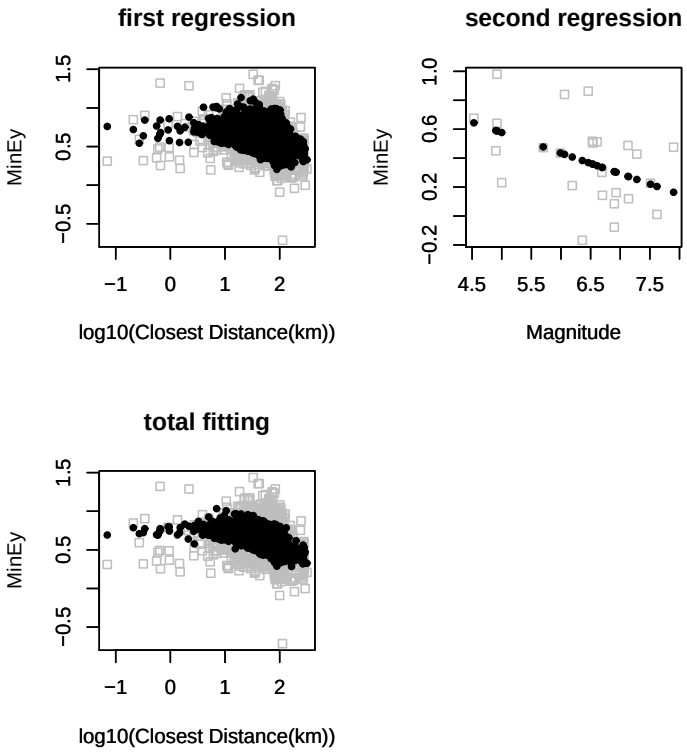

Figure 21: Median prediction of Natural log of mean frequency of minor group

```
I_EQ10     3.4890333  0.1088009  32.068  < 2e-16 ***
I_EQ11     3.3360242  0.1121887  29.736  < 2e-16 ***
I_EQ12     3.1958744  0.1056715  30.243  < 2e-16 ***
I_EQ13     3.4701690  0.1188558  29.196  < 2e-16 ***
I_EQ14     3.7787654  0.1143745  33.039  < 2e-16 ***
I_EQ15     3.7455513  0.1044470  35.861  < 2e-16 ***
I_EQ16     3.5679800  0.1138838  31.330  < 2e-16 ***
I_EQ17     3.5657551  0.1097956  32.476  < 2e-16 ***
I_EQ18     3.1608776  0.1106806  28.559  < 2e-16 ***
I_EQ19     3.0827324  0.1085849  28.390  < 2e-16 ***
I_EQ20     3.0455804  0.1086788  28.024  < 2e-16 ***
I_EQ21     3.8805286  0.1194956  32.474  < 2e-16 ***
I_EQ22     3.0662972  0.1122494  27.317  < 2e-16 ***
I_EQ23     3.9797239  0.1167372  34.091  < 2e-16 ***
I_EQ24     4.3304393  0.1182976  36.606  < 2e-16 ***
I_EQ25     3.1449896  0.1119995  28.080  < 2e-16 ***
Rhyp_Rrup -0.0053627  0.0006685  -8.022  2.2e-15 ***
ln_R       0.1109773  0.0076543  14.499  < 2e-16 ***
ln_VS30   -0.1673259  0.0161179 -10.381  < 2e-16 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.217 on 1380 degrees of freedom
Multiple R-Squared: 0.9941,        Adjusted R-squared: 0.994
F-statistic:  8356 on 28 and 1380 DF,  p-value: < 2.2e-16
```

```
> cor(qqnorm(resid(first_reg))$x, resid(first_reg))

[1] 0.9961315
```

Figure 22 (page 34)

2.8.2 Second regression

```
> summary(second_reg)

Call:
lm(formula = A ~ exp_Mw)

Residuals:
     Min       1Q   Median       3Q      Max
-0.25628 -0.15172 -0.01867  0.01769  0.69728

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 3.0645666  0.0761343  40.252  < 2e-16 ***
exp_Mw      0.0003971  0.0000728   5.455 1.52e-05 ***
```

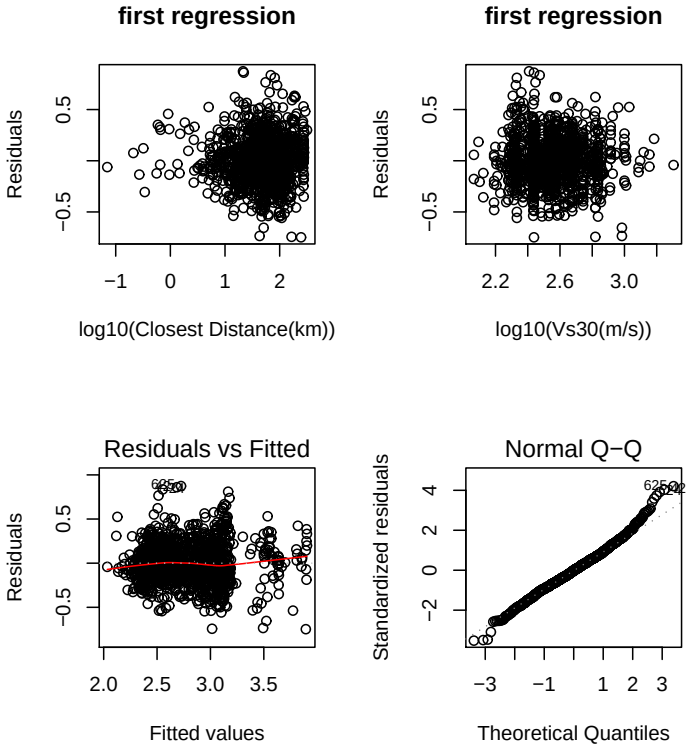

Figure 22: Characteristics of residuals: first regression of Natural log of standard deviation of time of minor group

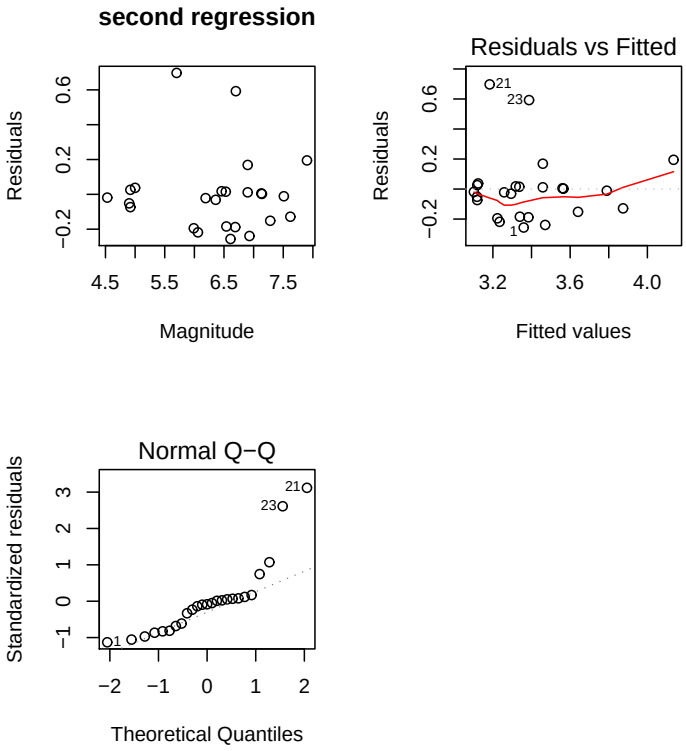

Figure 23: Characteristics of residuals: second regression of Natural log of standard deviation of time of minor group

```
---
Signif. codes:  0  ***  0.001  **  0.01  *  0.05  .  0.1    1

Residual standard error: 0.2316 on 23 degrees of freedom
Multiple R-Squared: 0.564,        Adjusted R-squared: 0.5451
F-statistic: 29.75 on 1 and 23 DF,  p-value: 1.520e-05

> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.8840785
```

Figure 23 (page 35)
Figure 24 (page 36)

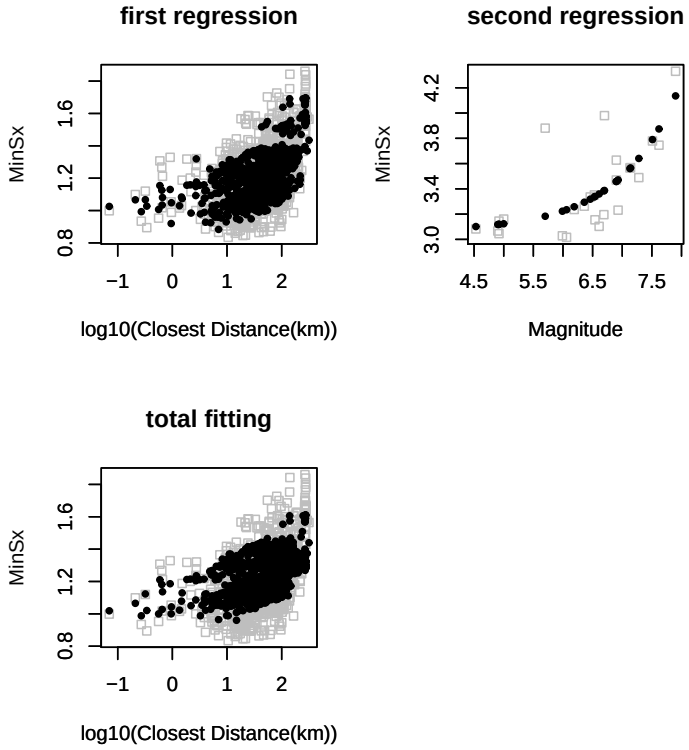

Figure 24: Median prediction of Natural log of standard deviation of time of minor group

2.9 Natural log of standard deviation of frequency of minor group

2.9.1 First regression

```
> summary(first_reg)

Call:
lm(formula = ln_Y ~ I_EQ + Rhyp_Rrup + ln_R + ln_VS30 - 1)

Residuals:
      Min        1Q    Median        3Q       Max
-1.379835 -0.258666 -0.004158  0.242407  1.492595

Coefficients:
           Estimate Std. Error t value Pr(>|t|)
I_EQ1      1.627468   0.217197   7.493 1.20e-13 ***
I_EQ2      1.728986   0.190559   9.073  < 2e-16 ***
I_EQ3      1.124158   0.238754   4.708 2.75e-06 ***
I_EQ4      1.027502   0.205575   4.998 6.53e-07 ***
I_EQ5      1.218748   0.205823   5.921 4.02e-09 ***
I_EQ6      1.796200   0.209627   8.569  < 2e-16 ***
I_EQ7      1.262981   0.198684   6.357 2.79e-10 ***
I_EQ8      1.576610   0.214832   7.339 3.67e-13 ***
I_EQ9      1.412213   0.203713   6.932 6.34e-12 ***
I_EQ10     1.665592   0.209388   7.955 3.72e-15 ***
I_EQ11     1.949742   0.214677   9.082  < 2e-16 ***
I_EQ12     1.325796   0.201082   6.593 6.11e-11 ***
I_EQ13     0.871613   0.225671   3.862 0.000118 ***
I_EQ14     1.395122   0.217335   6.419 1.88e-10 ***
I_EQ15     1.197906   0.199140   6.015 2.29e-09 ***
I_EQ16     1.229920   0.216904   5.670 1.73e-08 ***
I_EQ17     1.774234   0.211325   8.396  < 2e-16 ***
I_EQ18     1.073917   0.210502   5.102 3.83e-07 ***
I_EQ19     1.514406   0.206622   7.329 3.92e-13 ***
I_EQ20     1.790656   0.207926   8.612  < 2e-16 ***
I_EQ21     1.702966   0.227907   7.472 1.39e-13 ***
I_EQ22     1.201724   0.213793   5.621 2.29e-08 ***
I_EQ23     1.475487   0.226432   6.516 1.01e-10 ***
I_EQ24     1.722452   0.227196   7.581 6.25e-14 ***
I_EQ25     1.547064   0.213333   7.252 6.83e-13 ***
Rhyp_Rrup -0.002903   0.001225  -2.369 0.017973 *
ln_R      -0.289283   0.018057 -16.021  < 2e-16 ***
ln_VS30    0.244654   0.029490   8.296 2.53e-16 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1
```

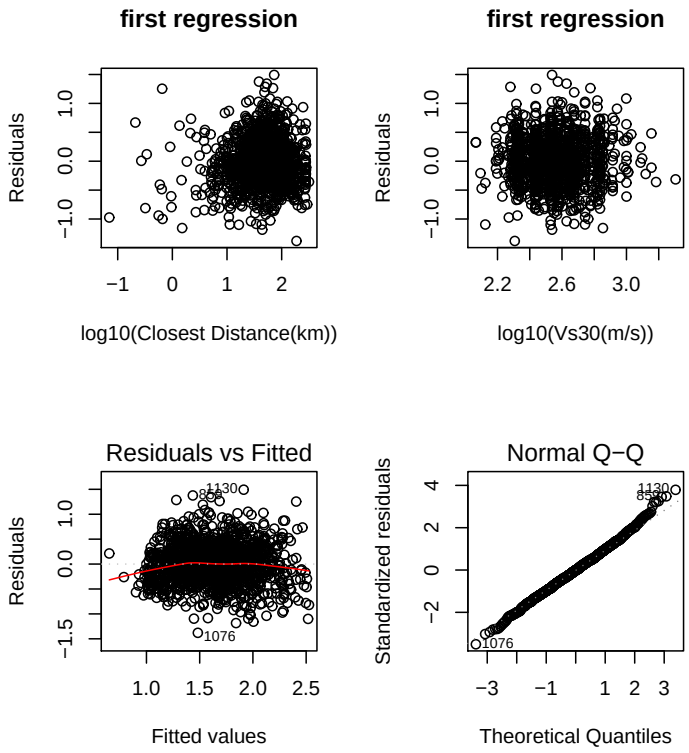

Figure 25: Characteristics of residuals: first regression of Natural log of standard deviation of frequency of minor group

```
Residual standard error: 0.3964 on 1380 degrees of freedom
Multiple R-Squared: 0.9479,        Adjusted R-squared: 0.9468
F-statistic: 896.1 on 28 and 1380 DF,  p-value: < 2.2e-16
```

```
> cor(qqnorm(resid(first_reg))$x, resid(first_reg))
```

```
[1] 0.9988782
```

Figure 25 (page 38)

2.9.2 Second regression

```
> summary(second_reg)
```

```
Call:
lm(formula = A ~ Mw)
```

```
Residuals:
     Min       1Q   Median       3Q      Max
-0.57445 -0.23067  0.02848  0.25122  0.50160

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.478749   0.412402   3.586  0.00156 **
Mw          -0.004738   0.064026  -0.074  0.94165
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.2917 on 23 degrees of freedom
Multiple R-Squared: 0.000238,        Adjusted R-squared: -0.04323
F-statistic: 0.005476 on 1 and 23 DF,  p-value: 0.9417
```

```
> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.9859982
```

Figure 26 (page 40)
Figure 27 (page 41)

2.10 Correlation of time-frequency of minor group

2.10.1 First regression

```
> summary(first_reg)

Call:
lm(formula = ln_Y ~ I_EQ + Rhyp_Rrup + ln_R + ln_VS30 - 1)

Residuals:
      Min        1Q    Median        3Q       Max
-0.174568 -0.038993 -0.004848  0.037467  0.214522

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
I_EQ1     -0.2316619  0.0320299  -7.233 7.82e-13 ***
I_EQ2     -0.2787006  0.0281016  -9.918  < 2e-16 ***
I_EQ3     -0.2901949  0.0352089  -8.242 3.89e-16 ***
I_EQ4     -0.2822148  0.0303160  -9.309  < 2e-16 ***
I_EQ5     -0.3123934  0.0303526 -10.292  < 2e-16 ***
I_EQ6     -0.2384690  0.0309135  -7.714 2.32e-14 ***
I_EQ7     -0.2869140  0.0292999  -9.792  < 2e-16 ***
I_EQ8     -0.2219767  0.0316812  -7.007 3.81e-12 ***
I_EQ9     -0.2360037  0.0300415  -7.856 7.93e-15 ***
```

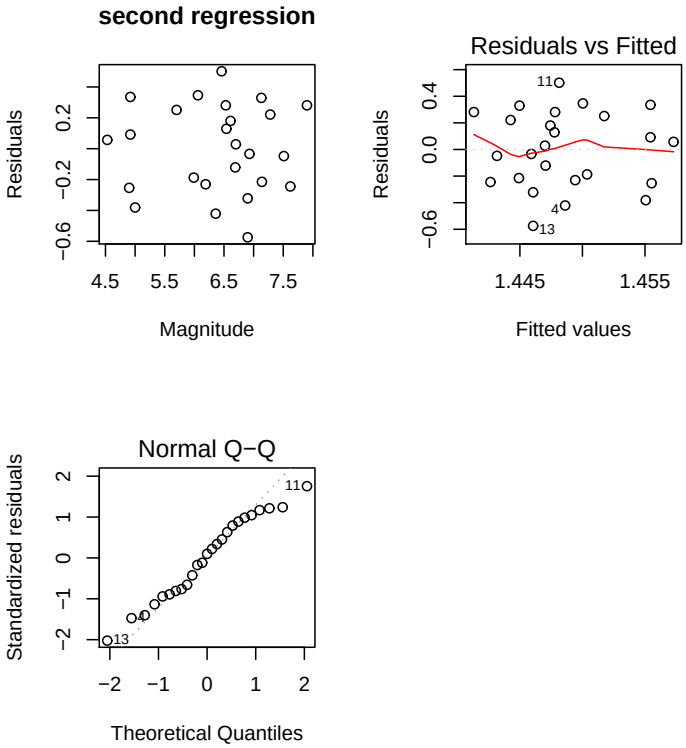

Figure 26: Characteristics of residuals: second regression of Natural log of standard deviation of frequency of minor group

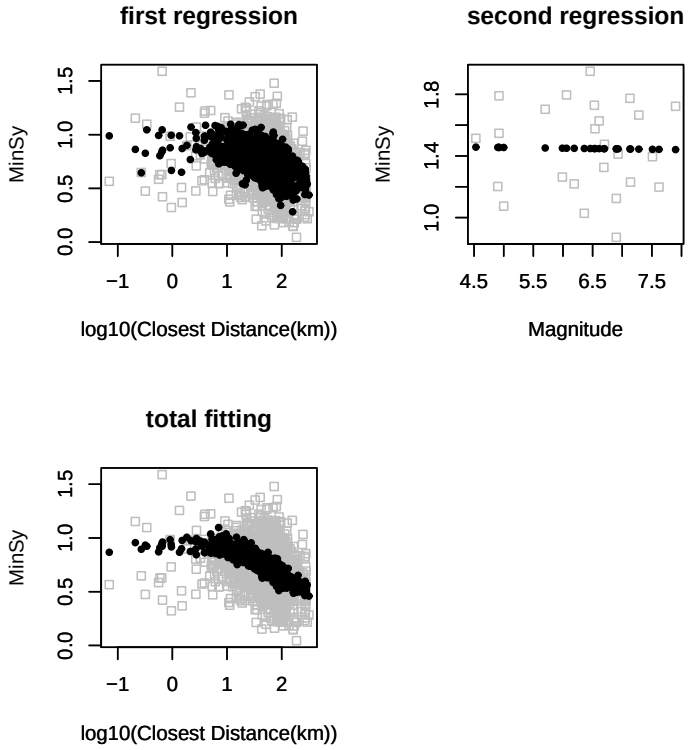

Figure 27: Median prediction of Natural log of standard deviation of frequency of minor group

```
I_EQ10    -0.1984696  0.0308783  -6.427 1.78e-10 ***
I_EQ11    -0.2655669  0.0316583  -8.389  < 2e-16 ***
I_EQ12    -0.2861751  0.0296534  -9.651  < 2e-16 ***
I_EQ13    -0.2488200  0.0332795  -7.477 1.35e-13 ***
I_EQ14    -0.2289117  0.0320503  -7.142 1.48e-12 ***
I_EQ15    -0.2840652  0.0293671  -9.673  < 2e-16 ***
I_EQ16    -0.2492848  0.0319867  -7.793 1.28e-14 ***
I_EQ17    -0.2735156  0.0311639  -8.777  < 2e-16 ***
I_EQ18    -0.3030427  0.0310425  -9.762  < 2e-16 ***
I_EQ19    -0.2723642  0.0304704  -8.939  < 2e-16 ***
I_EQ20    -0.2713802  0.0306627  -8.851  < 2e-16 ***
I_EQ21    -0.3381557  0.0336093 -10.061  < 2e-16 ***
I_EQ22    -0.2985799  0.0315280  -9.470  < 2e-16 ***
I_EQ23    -0.2837345  0.0333917  -8.497  < 2e-16 ***
I_EQ24    -0.2572495  0.0335044  -7.678 3.04e-14 ***
I_EQ25    -0.2730210  0.0314601  -8.678  < 2e-16 ***
Rhyp_Rrup -0.0005647  0.0001807  -3.125  0.00182 **
ln_R      -0.0313137  0.0026628 -11.760  < 2e-16 ***
ln_VS30    0.0438414  0.0043489  10.081  < 2e-16 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.05845 on 1380 degrees of freedom
Multiple R-Squared: 0.8762,        Adjusted R-squared: 0.8737
F-statistic: 348.7 on 28 and 1380 DF,  p-value: < 2.2e-16

> cor(qqnorm(resid(first_reg))$x, resid(first_reg))

[1] 0.9975196
```

Figure 28 (page 43)

2.10.2 Second regression

```
> summary(second_reg)

Call:
lm(formula = A ~ Mw)

Residuals:
      Min        1Q    Median        3Q       Max
-0.059907 -0.016016 -0.008723  0.022862  0.056854

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.360956   0.040960  -8.812 7.85e-09 ***
Mw           0.014510   0.006359   2.282   0.0321 *
```

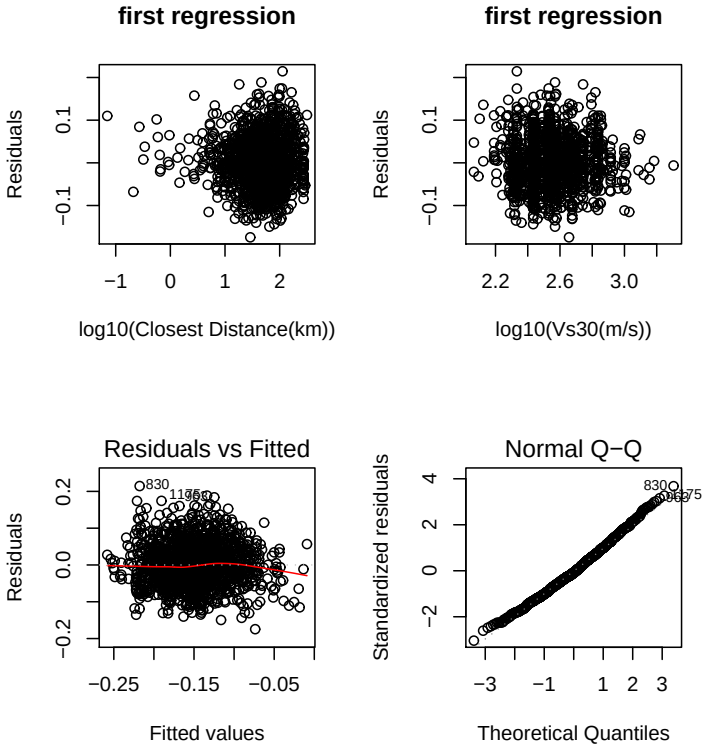

Figure 28: Characteristics of residuals: first regression of Correlation of time-frequency of minor group

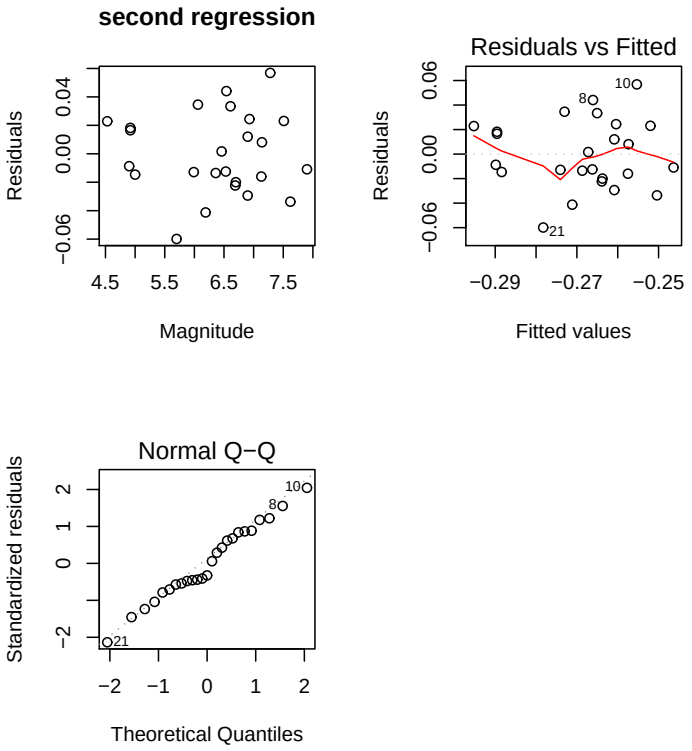

Figure 29: Characteristics of residuals: second regression of Correlation of time-frequency of minor group

```
---
Signif. codes:  0  ***  0.001  **  0.01  *  0.05  .  0.1    1

Residual standard error: 0.02897 on 23 degrees of freedom
Multiple R-Squared: 0.1846,        Adjusted R-squared: 0.1491
F-statistic: 5.207 on 1 and 23 DF,  p-value: 0.03208

> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.9911529
```

Figure 29 (page 44)
Figure 30 (page 45)

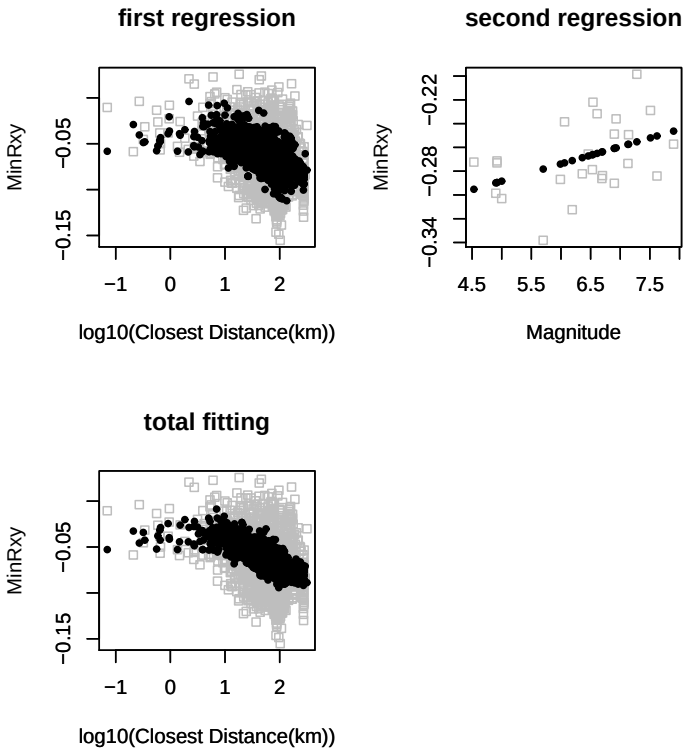

Figure 30: Median prediction of Correlation of time-frequency of minor group

2.11 Natural log of mean amplitude of major group

2.11.1 First regression

```
> summary(first_reg)

Call:
lm(formula = ln_Y ~ I_EQ + ln_R + ln_VS30 - 1)

Residuals:
     Min       1Q   Median       3Q      Max
-4.46886 -0.77689 -0.03555  0.73584  4.38539

Coefficients:
        Estimate Std. Error t value Pr(>|t|)
I_EQ1    1.74372    0.62208   2.803 0.005133 **
I_EQ2    2.08957    0.54787   3.814 0.000143 ***
I_EQ3    2.35881    0.68578   3.440 0.000600 ***
I_EQ4    3.27834    0.58921   5.564 3.16e-08 ***
I_EQ5    1.72662    0.59148   2.919 0.003566 **
I_EQ6    1.91455    0.60100   3.186 0.001477 **
I_EQ7    2.21511    0.56707   3.906 9.83e-05 ***
I_EQ8    2.39870    0.61616   3.893 0.000104 ***
I_EQ9    4.06501    0.58555   6.942 5.92e-12 ***
I_EQ10   3.48497    0.60025   5.806 7.93e-09 ***
I_EQ11   2.45952    0.61083   4.027 5.97e-05 ***
I_EQ12   3.41912    0.57606   5.935 3.70e-09 ***
I_EQ13   4.42301    0.64880   6.817 1.38e-11 ***
I_EQ14   3.28262    0.62350   5.265 1.63e-07 ***
I_EQ15   3.41925    0.57071   5.991 2.65e-09 ***
I_EQ16   2.33433    0.62343   3.744 0.000188 ***
I_EQ17   3.16089    0.60580   5.218 2.09e-07 ***
I_EQ18  -0.88978    0.59955  -1.484 0.138016
I_EQ19  -1.70394    0.58822  -2.897 0.003830 **
I_EQ20  -0.76184    0.59149  -1.288 0.197959
I_EQ21  -0.31655    0.64951  -0.487 0.626079
I_EQ22  -0.42884    0.60868  -0.705 0.481217
I_EQ23   1.59117    0.64582   2.464 0.013869 *
I_EQ24   2.66061    0.65320   4.073 4.90e-05 ***
I_EQ25  -1.19489    0.60733  -1.967 0.049329 *
ln_R    -1.74185    0.05115 -34.053  < 2e-16 ***
ln_VS30 -0.93814    0.08436 -11.120  < 2e-16 ***
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 1.14 on 1381 degrees of freedom
Multiple R-Squared: 0.9878,        Adjusted R-squared: 0.9876
```

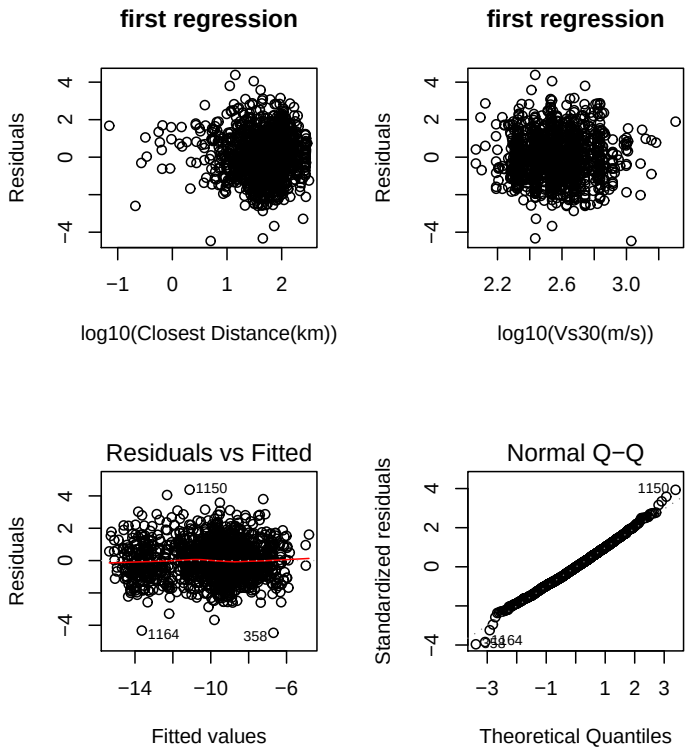

Figure 31: Characteristics of residuals: first regression of Natural log of mean amplitude of major group

```
F-statistic:  4159 on 27 and 1381 DF,  p-value: < 2.2e-16
```

```
> cor(qqnorm(resid(first_reg))$x, resid(first_reg))
```

```
[1] 0.9981325
```

Figure 31 (page 47)

2.11.2 Second regression

```
> summary(second_reg)
```

```
Call:
lm(formula = A ~ Mw + ln_Mw)

Residuals:
```

```
     Min       1Q   Median       3Q      Max
-1.46768 -0.38348  0.05307  0.42993  1.56526

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -38.020     10.326  -3.682  0.00131 **
Mw            -4.516      2.164  -2.087  0.04873 *
ln_Mw         37.295     13.050   2.858  0.00915 **
---
Signif. codes:  0  *** 0.001  ** 0.01  * 0.05  . 0.1    1

Residual standard error: 0.7401 on 22 degrees of freedom
Multiple R-Squared: 0.8353,        Adjusted R-squared: 0.8203
F-statistic: 55.78 on 2 and 22 DF,  p-value: 2.422e-09
```

```
> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.994062
```

Figure 32 (page 49)
Figure 33 (page 50)

2.12 Natural log of total energy of wavelet packets

2.12.1 First regression

```
> summary(first_reg)

Call:
lm(formula = ln_Y ~ I_EQ + ln_R + ln_VS30 - 1)

Residuals:
     Min       1Q   Median       3Q      Max
-3.46406 -0.57054  0.01015  0.54636  4.25252

Coefficients:
        Estimate Std. Error t value Pr(>|t|)
I_EQ1    5.60963    0.46755  11.998  < 2e-16 ***
I_EQ2    6.12441    0.41177  14.873  < 2e-16 ***
I_EQ3    6.63737    0.51543  12.877  < 2e-16 ***
I_EQ4    6.60229    0.44284  14.909  < 2e-16 ***
I_EQ5    5.51150    0.44455  12.398  < 2e-16 ***
I_EQ6    5.81784    0.45171  12.880  < 2e-16 ***
I_EQ7    5.95653    0.42621  13.976  < 2e-16 ***
I_EQ8    6.55726    0.46310  14.160  < 2e-16 ***
I_EQ9    7.45574    0.44009  16.941  < 2e-16 ***
I_EQ10   7.78321    0.45114  17.252  < 2e-16 ***
```

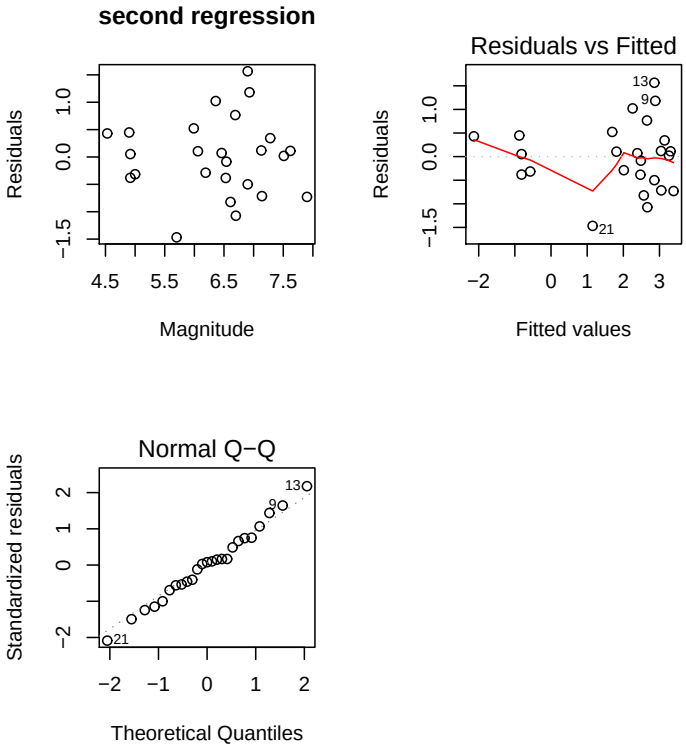

Figure 32: Characteristics of residuals: second regression of Natural log of mean amplitude of major group

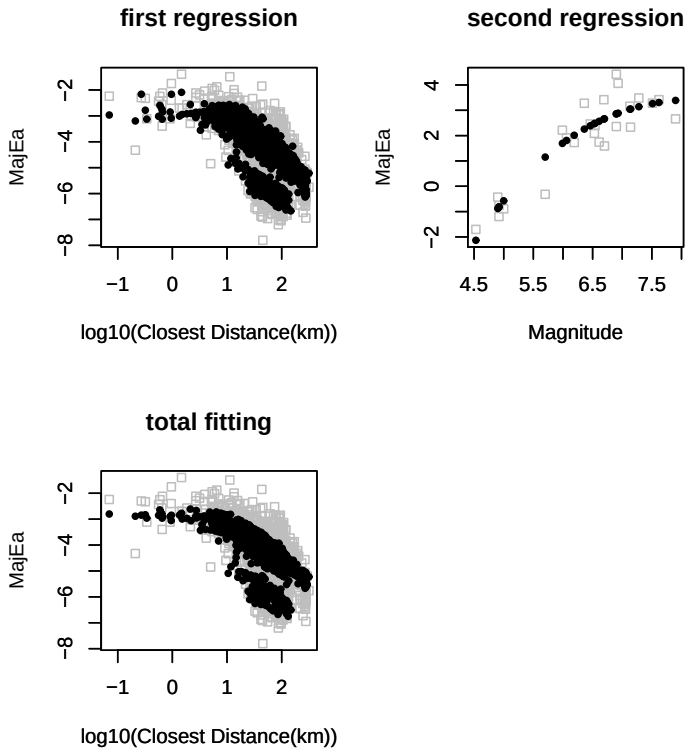

Figure 33: Median prediction of Natural log of mean amplitude of major group

```
I_EQ11   6.93452    0.45909  15.105  < 2e-16 ***
I_EQ12   7.18850    0.43296  16.603  < 2e-16 ***
I_EQ13   7.56050    0.48763  15.504  < 2e-16 ***
I_EQ14   7.62712    0.46862  16.276  < 2e-16 ***
I_EQ15   7.58573    0.42894  17.685  < 2e-16 ***
I_EQ16   6.31708    0.46857  13.482  < 2e-16 ***
I_EQ17   7.18182    0.45531  15.773  < 2e-16 ***
I_EQ18   2.57395    0.45061   5.712 1.36e-08 ***
I_EQ19   1.96165    0.44210   4.437 9.84e-06 ***
I_EQ20   3.17600    0.44455   7.144 1.46e-12 ***
I_EQ21   4.35457    0.48817   8.920  < 2e-16 ***
I_EQ22   3.03993    0.45747   6.645 4.35e-11 ***
I_EQ23   6.24538    0.48539  12.867  < 2e-16 ***
I_EQ24   8.11165    0.49094  16.523  < 2e-16 ***
I_EQ25   2.64118    0.45646   5.786 8.89e-09 ***
ln_R    -1.60989    0.03844 -41.876  < 2e-16 ***
ln_VS30 -0.88499    0.06341 -13.957  < 2e-16 ***
---
Signif. codes:  0  ***  0.001  **  0.01  *  0.05  .  0.1    1

Residual standard error: 0.8566 on 1381 degrees of freedom
Multiple R-Squared: 0.977,        Adjusted R-squared: 0.9766
F-statistic:  2173 on 27 and 1381 DF,  p-value: < 2.2e-16
```

```
> cor(qqnorm(resid(first_reg))$x, resid(first_reg))

[1] 0.9971384
```

Figure 34 (page 52)

2.12.2 Second regression

```
> summary(second_reg)

Call:
lm(formula = A ~ Mw + ln_Mw)

Residuals:
    Min      1Q  Median      3Q     Max
-0.9246 -0.3006  0.1006  0.3786  0.6398

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -27.400      6.668  -4.109 0.000462 ***
Mw            -2.581      1.398  -1.847 0.078288 .
ln_Mw         26.997      8.427   3.204 0.004098 **
---
```

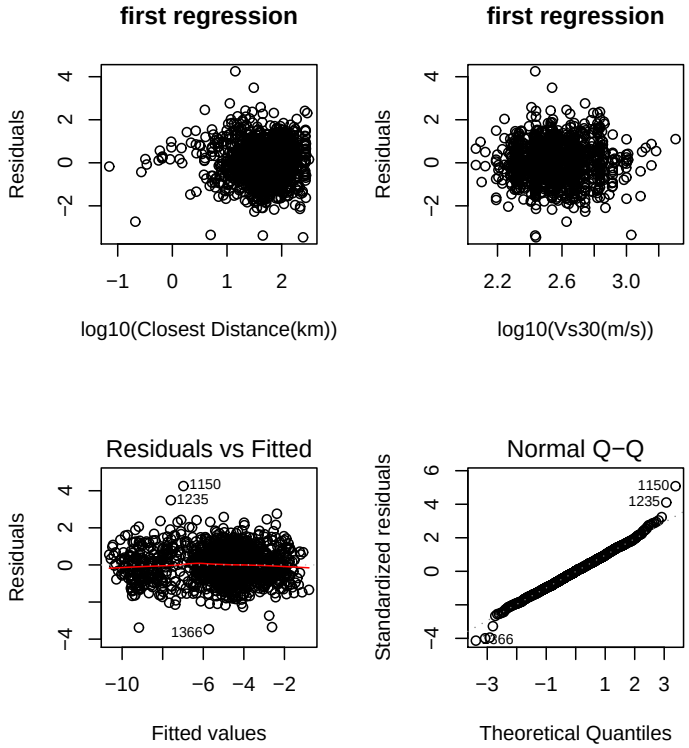

Figure 34: Characteristics of residuals: first regression of Natural log of total energy of wavelet packets

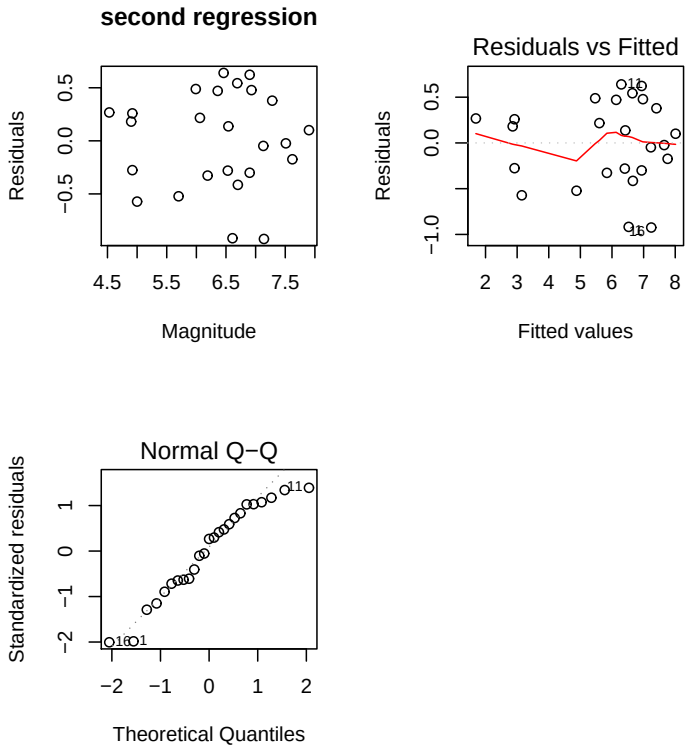

Figure 35: Characteristics of residuals: second regression of Natural log of total energy of wavelet packets

```
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1    1

Residual standard error: 0.4779 on 22 degrees of freedom
Multiple R-Squared: 0.938,        Adjusted R-squared: 0.9323
F-statistic: 166.3 on 2 and 22 DF,  p-value: 5.229e-14
```

```
> cor(qqnorm(resid(second_reg))$x, resid(second_reg))

[1] 0.9780834
```

Figure 35 (page 53)
Figure 36 (page 54)

2.13 Random factor of minor group

Figure 37 (page 55)

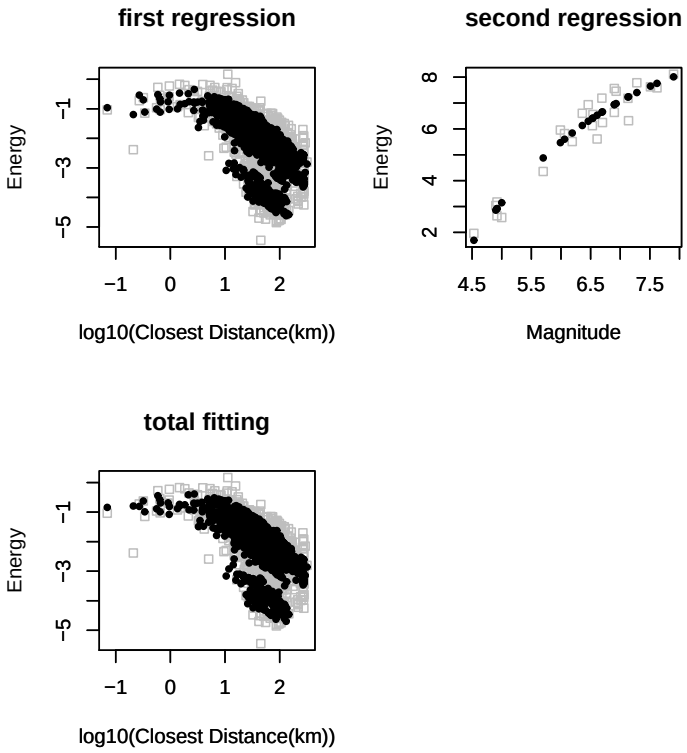

Figure 36: Median prediction of Natural log of total energy of wavelet packets

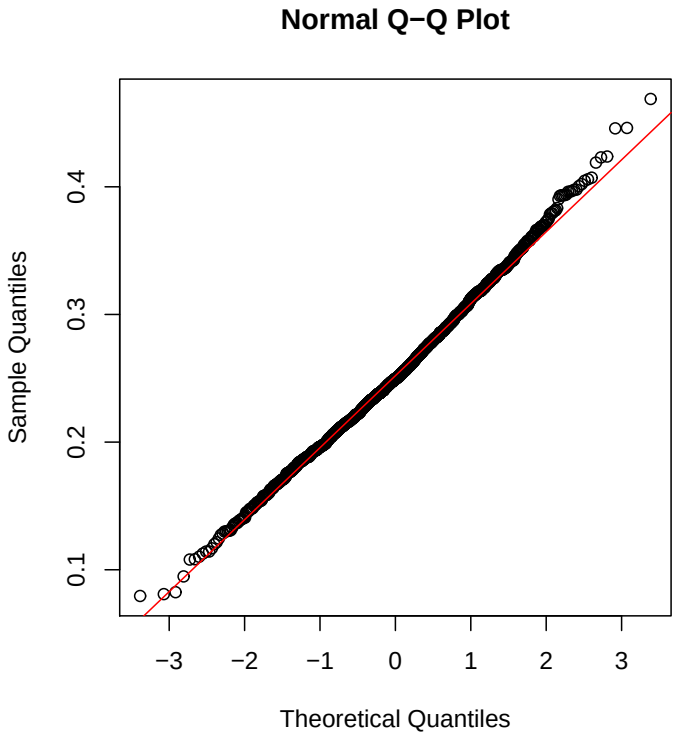

Figure 37: Characteristics of residuals from estimated bivariate lognormal distribution of minor group

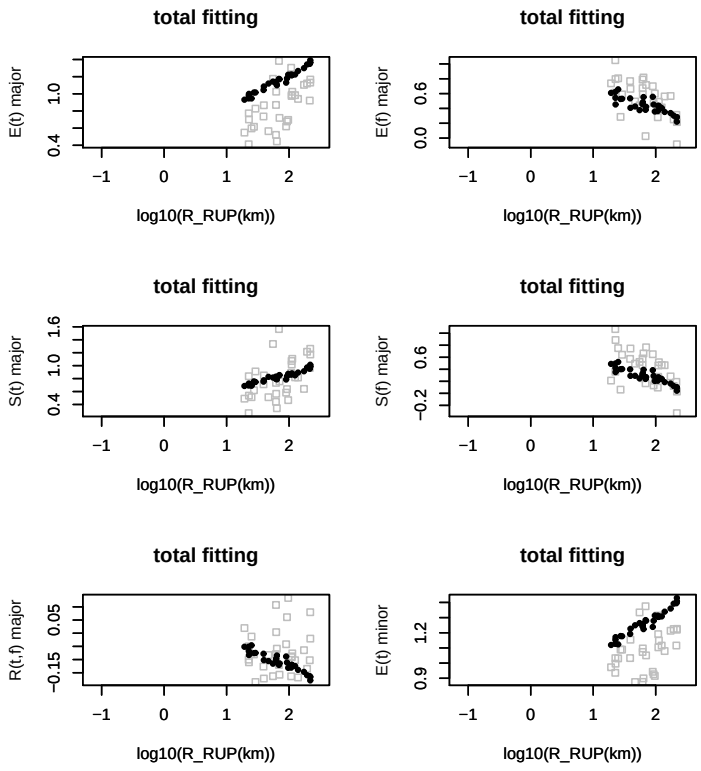

Figure 38: $ID = 30$, Natural log of total energy of wavelet packets

3 Fitting for each earthquake event

3.1 Each earthquake event$[ID = 30,\ M_W = 6.61]$

3.2 Each earthquake event$[ID = 50,\ M_W = 6.53]$

3.3 Each earthquake event$[ID = 68,\ M_W = 6.9]$

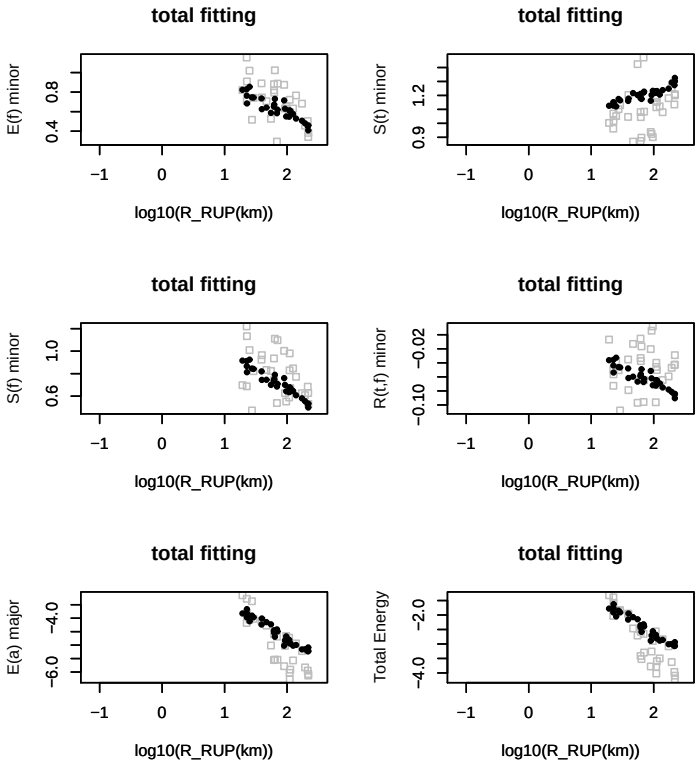

Figure 39: $ID = 30$, Natural log of total energy of wavelet packets

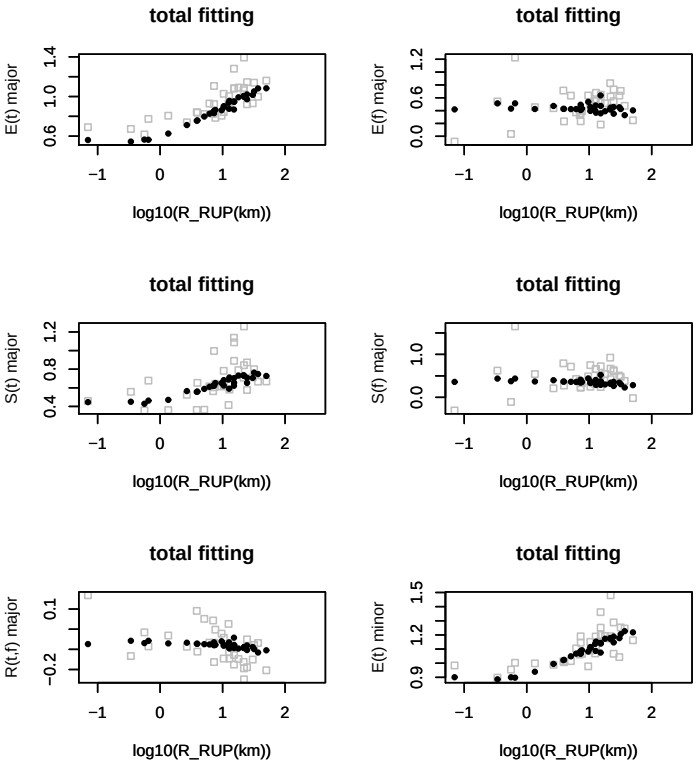

Figure 40: $ID = 50$, Natural log of total energy of wavelet packets

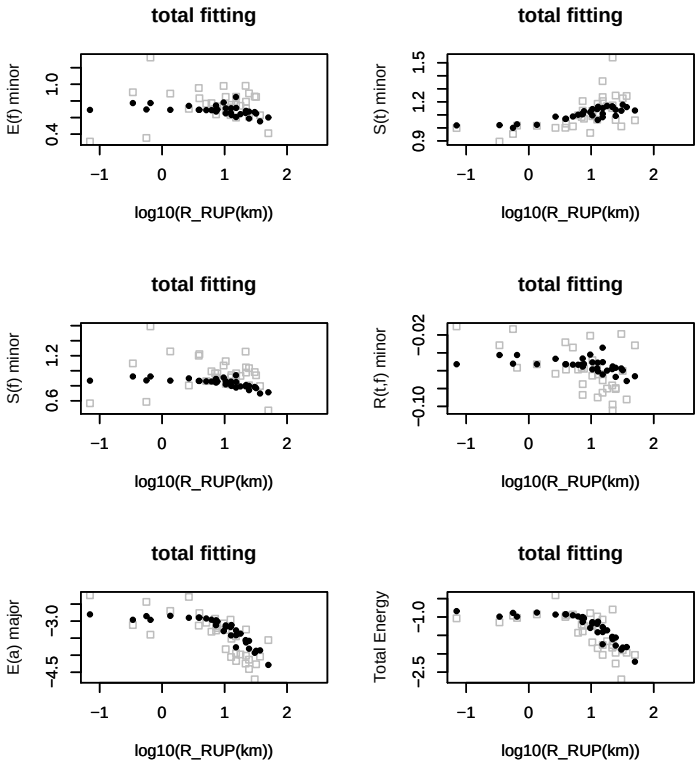

Figure 41: $ID = 50$, Natural log of total energy of wavelet packets

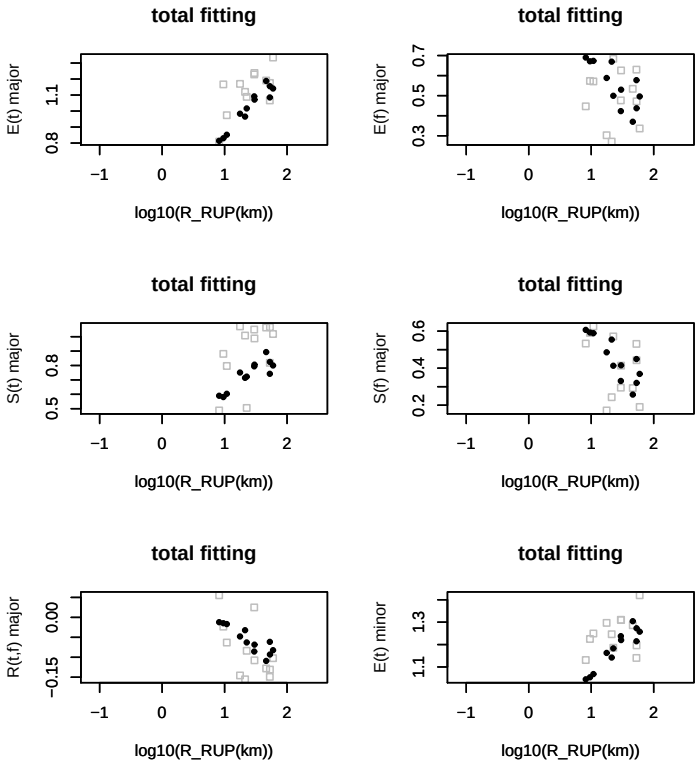

Figure 42: $ID = 68$, Natural log of total energy of wavelet packets

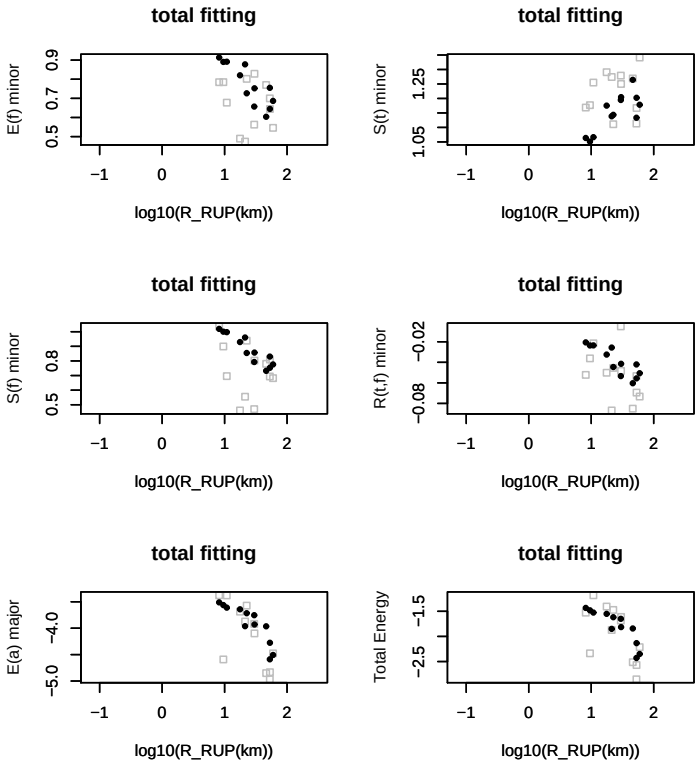

Figure 43: $ID = 68$, Natural log of total energy of wavelet packets

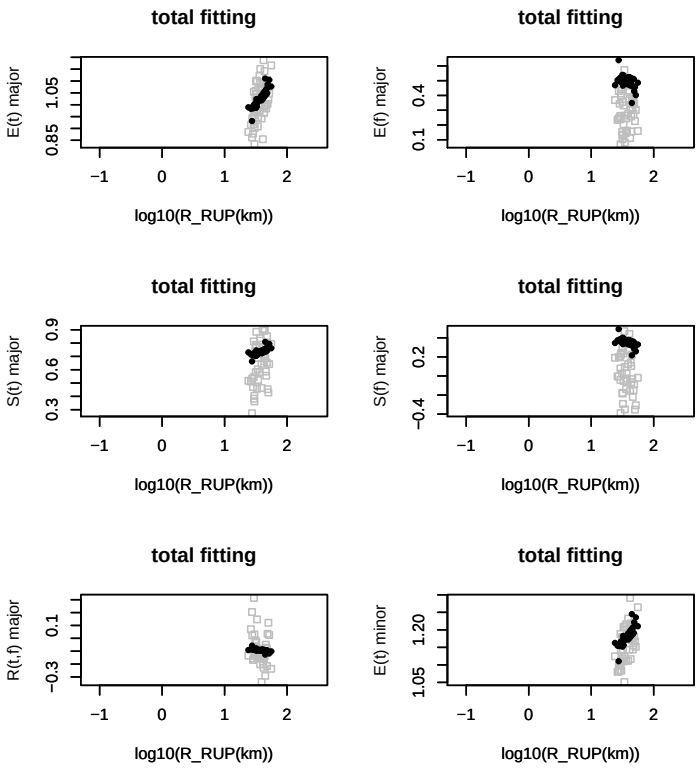

Figure 44: $ID = 76$, Natural log of total energy of wavelet packets

3.4 Each earthquake event$[ID = 76,\ M_W = 6.36]$

3.5 Each earthquake event$[ID = 90,\ M_W = 6.19]$

3.6 Each earthquake event$[ID = 101,\ M_W = 6.06]$

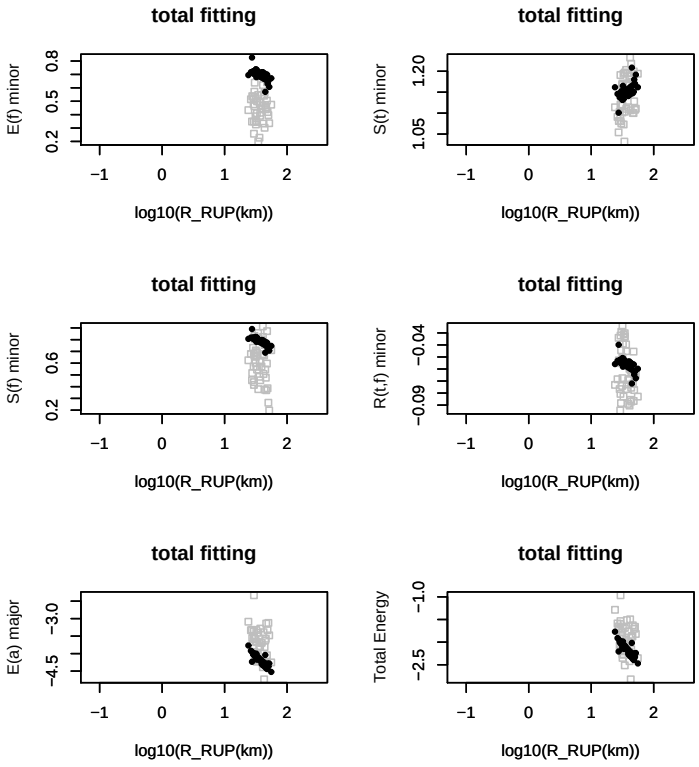

Figure 45: $ID = 76$, Natural log of total energy of wavelet packets

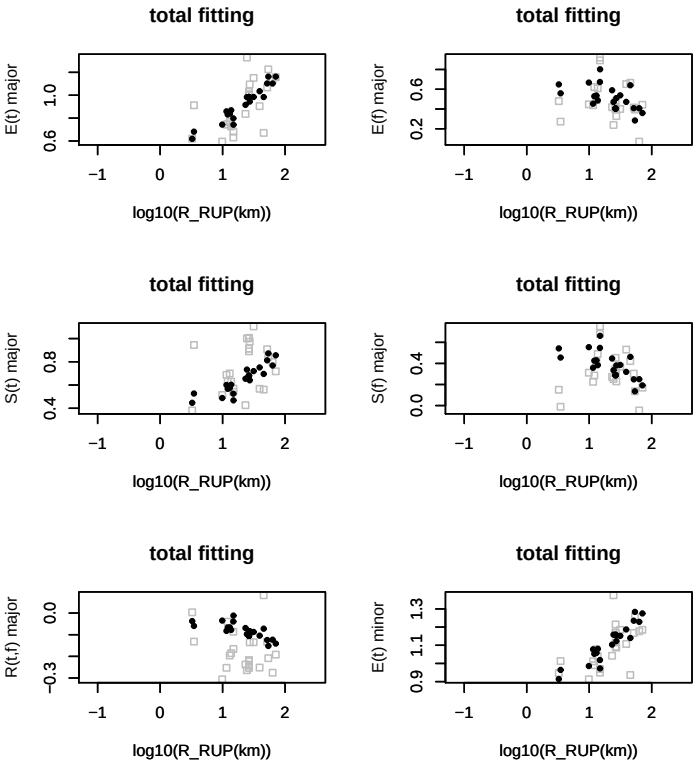

Figure 46: $ID = 90$, Natural log of total energy of wavelet packets

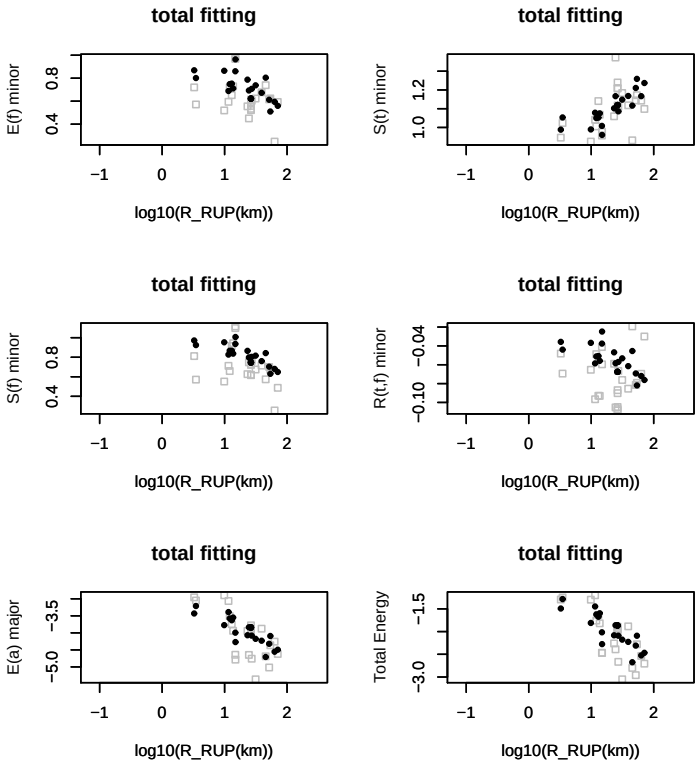

Figure 47: $ID = 90$, Natural log of total energy of wavelet packets

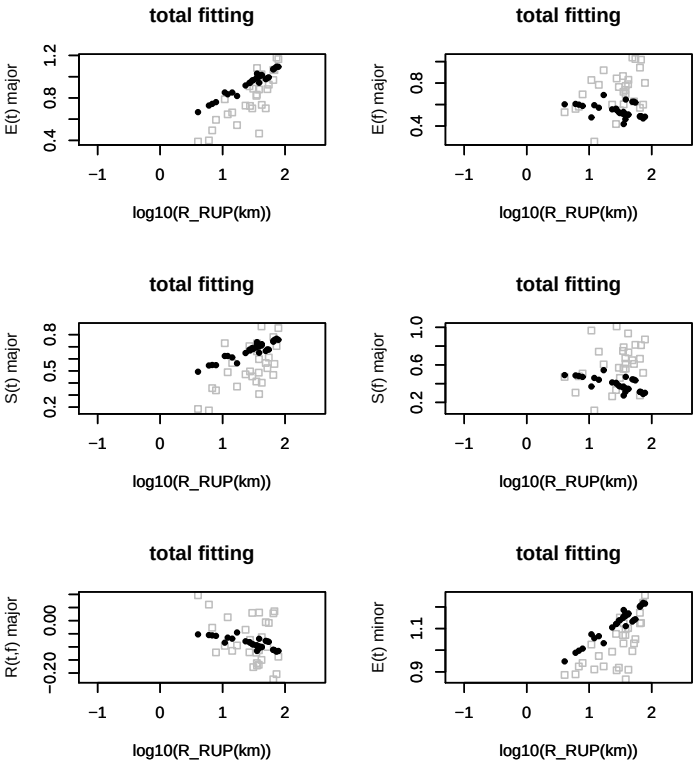

Figure 48: $ID = 101$, Natural log of total energy of wavelet packets

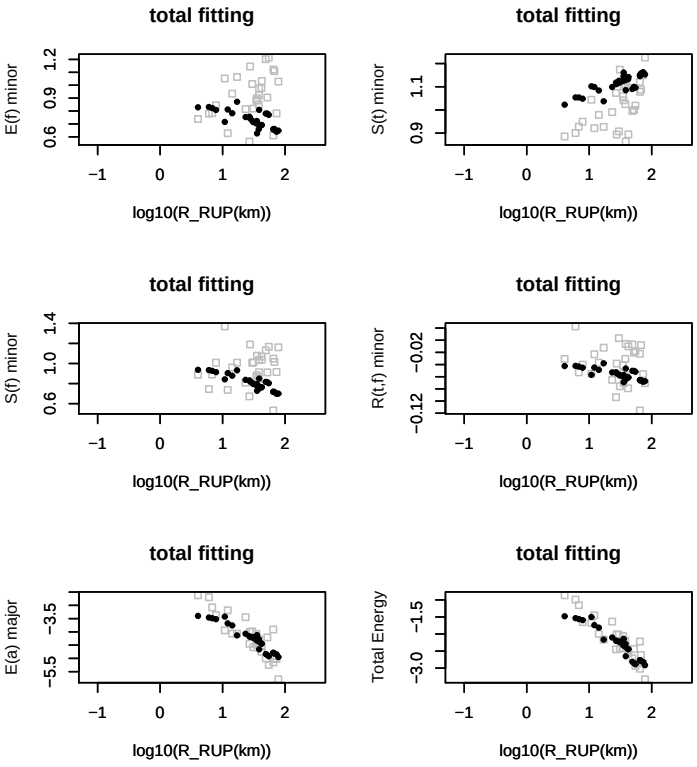

Figure 49: $ID = 101$, Natural log of total energy of wavelet packets

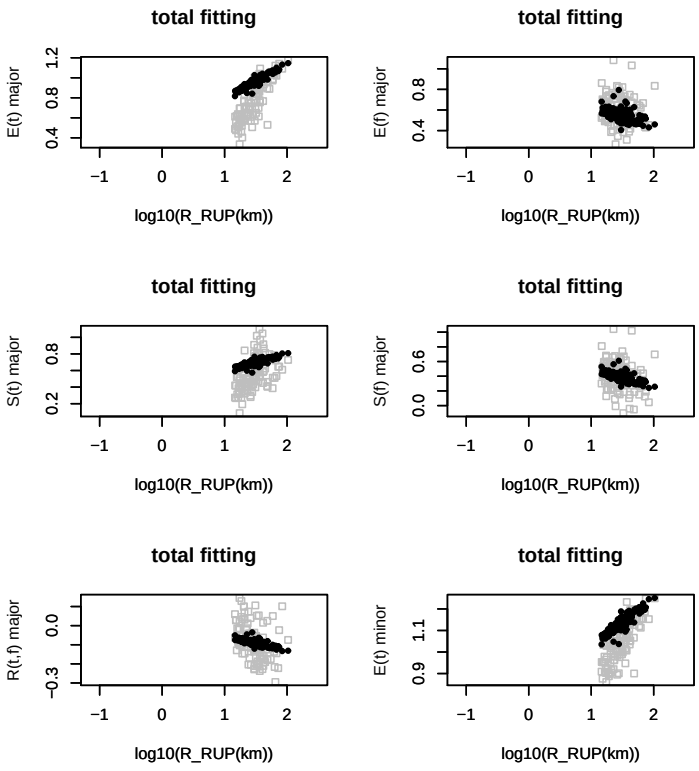

Figure 50: $ID = 113$, Natural log of total energy of wavelet packets

3.7 Each earthquake event$[ID = 113,\ M_W = 5.99]$

3.8 Each earthquake event$[ID = 116,\ M_W = 6.54]$

3.9 Each earthquake event$[ID = 118,\ M_W = 6.93]$

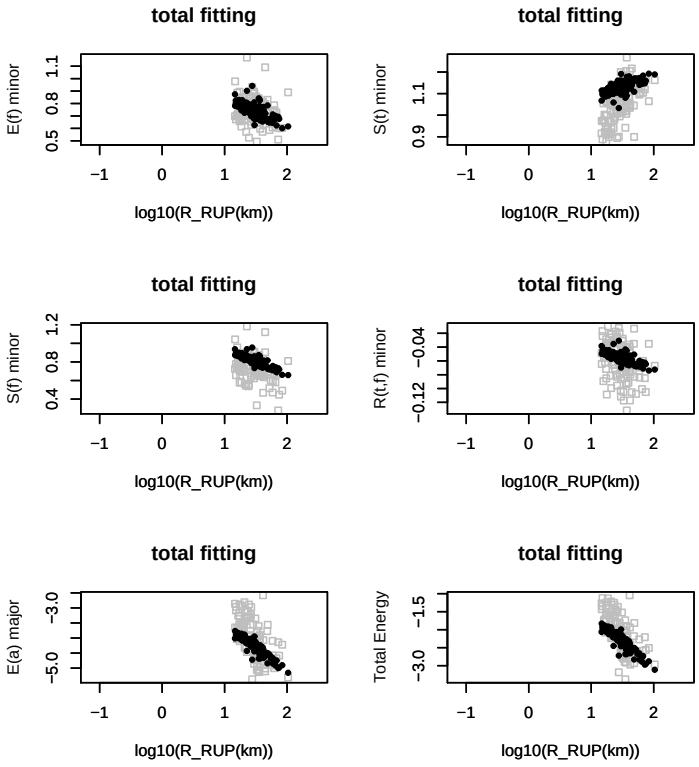

Figure 51: $ID = 113$, Natural log of total energy of wavelet packets

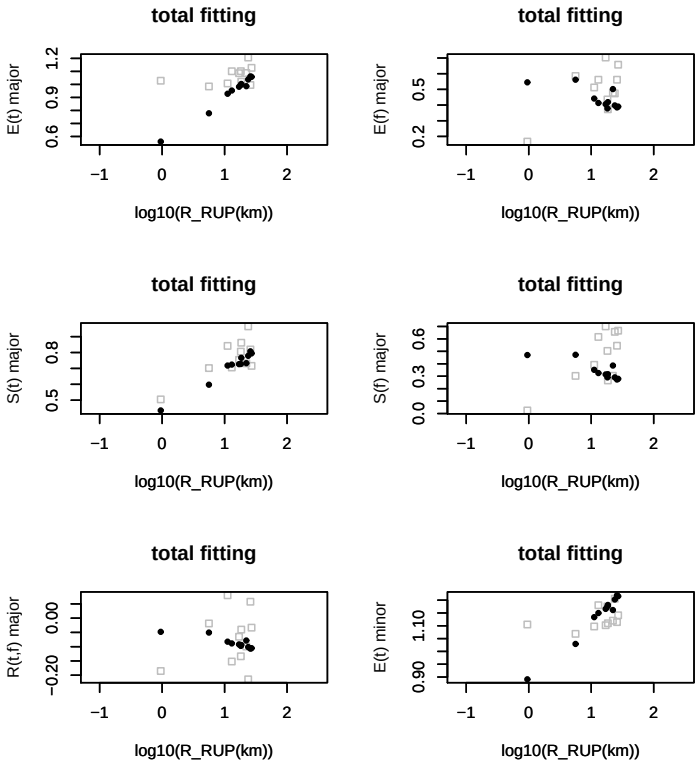

Figure 52: $ID = 116$, Natural log of total energy of wavelet packets

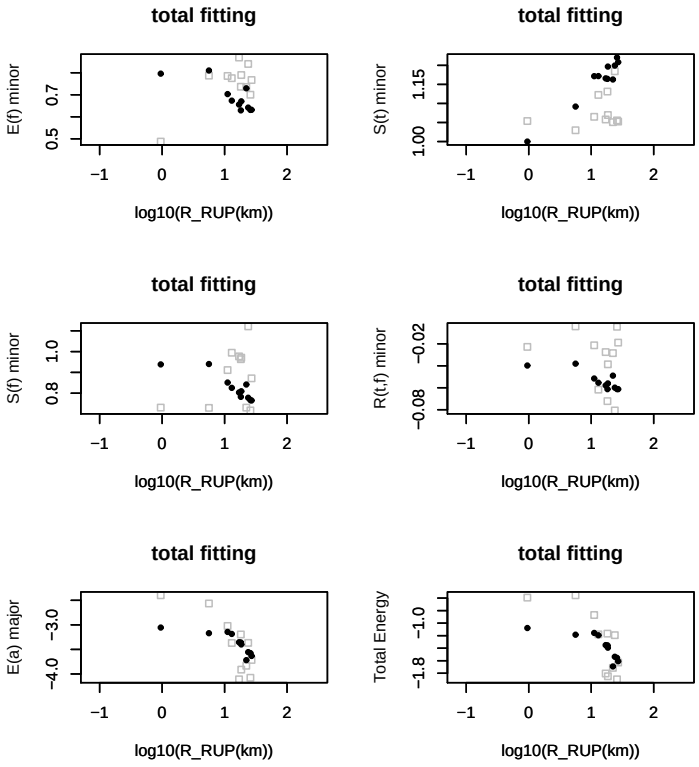

Figure 53: $ID = 116$, Natural log of total energy of wavelet packets

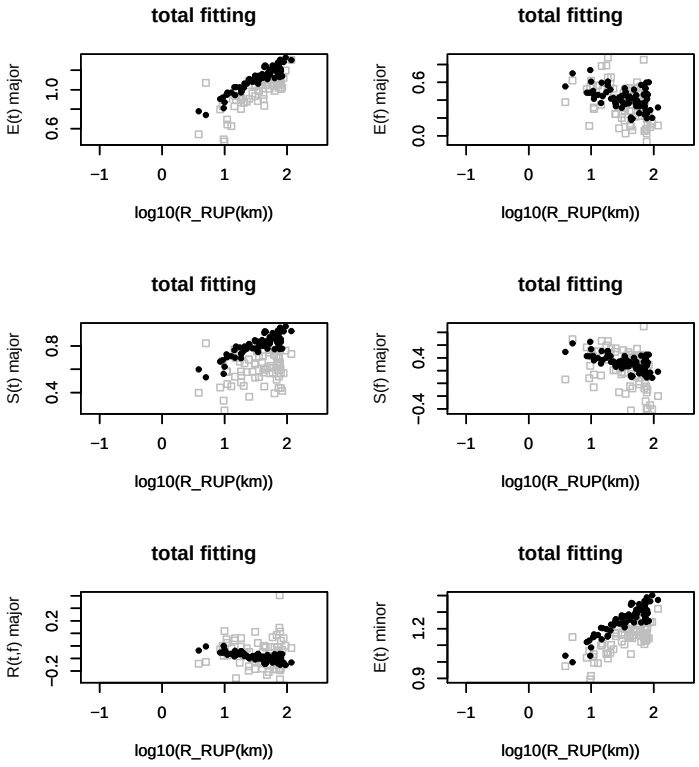

Figure 54: $ID = 118$, Natural log of total energy of wavelet packets

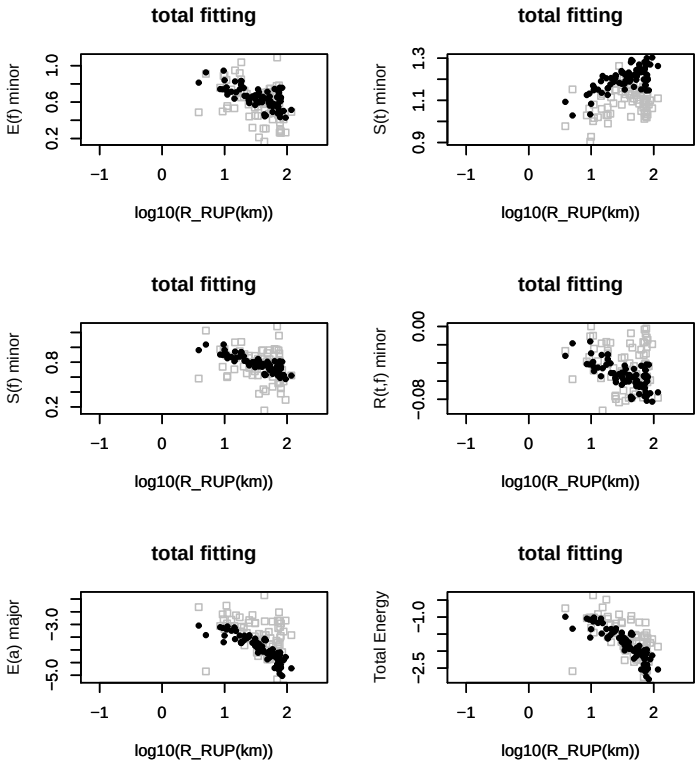

Figure 55: $ID = 118$, Natural log of total energy of wavelet packets

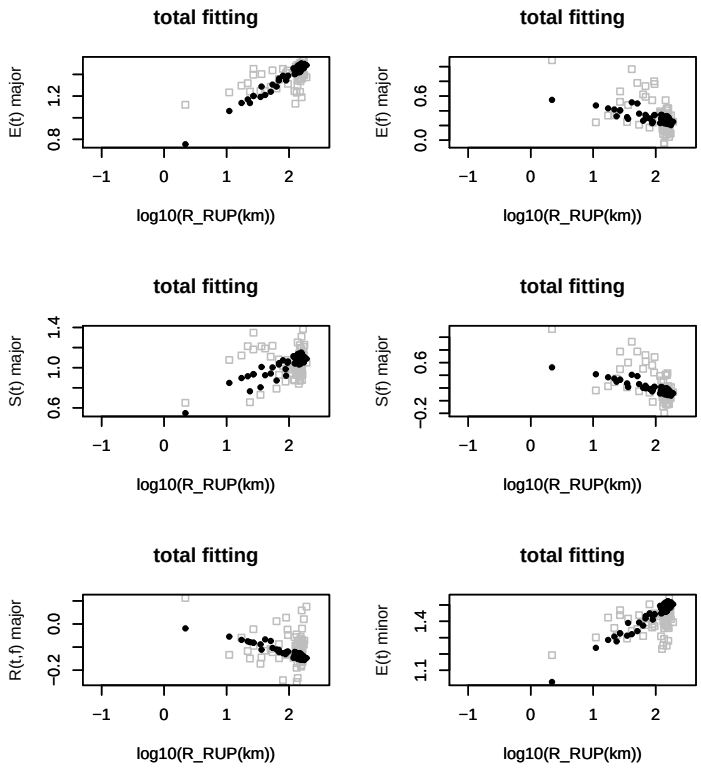

Figure 56: $ID = 125$, Natural log of total energy of wavelet packets

3.10 Each earthquake event[$ID = 125$, $M_W = 7.28$]

3.11 Each earthquake event[$ID = 126$, $M_W = 6.46$]

3.12 Each earthquake event[$ID = 127$, $M_W = 6.69$]

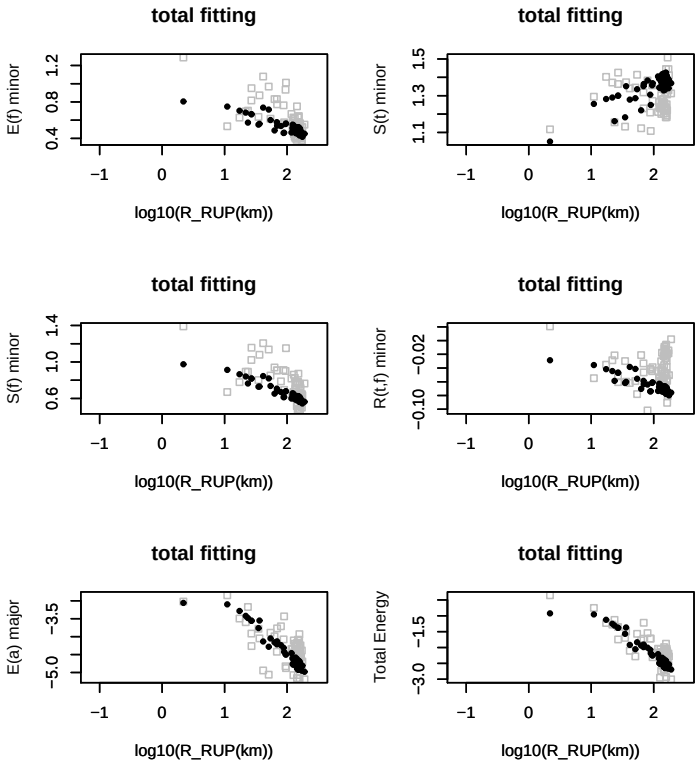

Figure 57: $ID = 125$, Natural log of total energy of wavelet packets

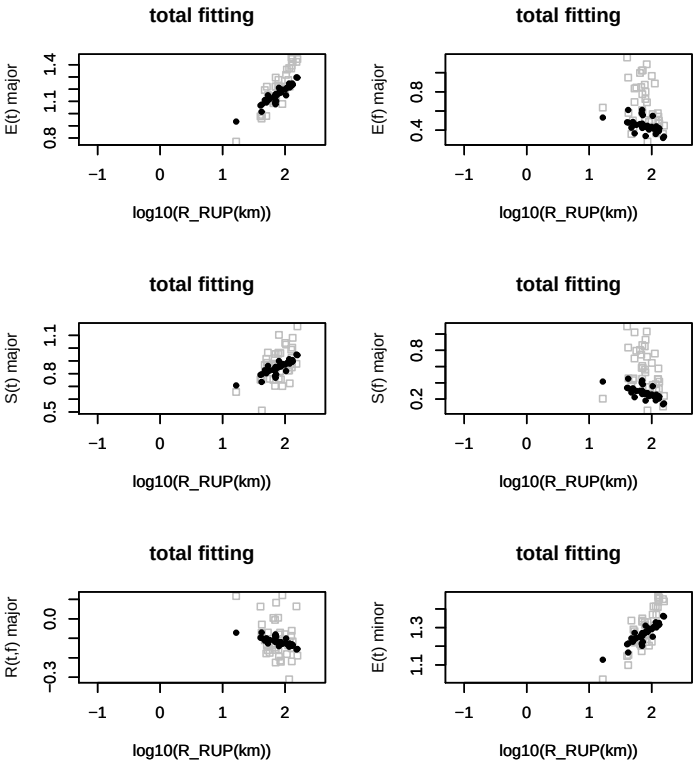

Figure 58: $ID = 126$, Natural log of total energy of wavelet packets

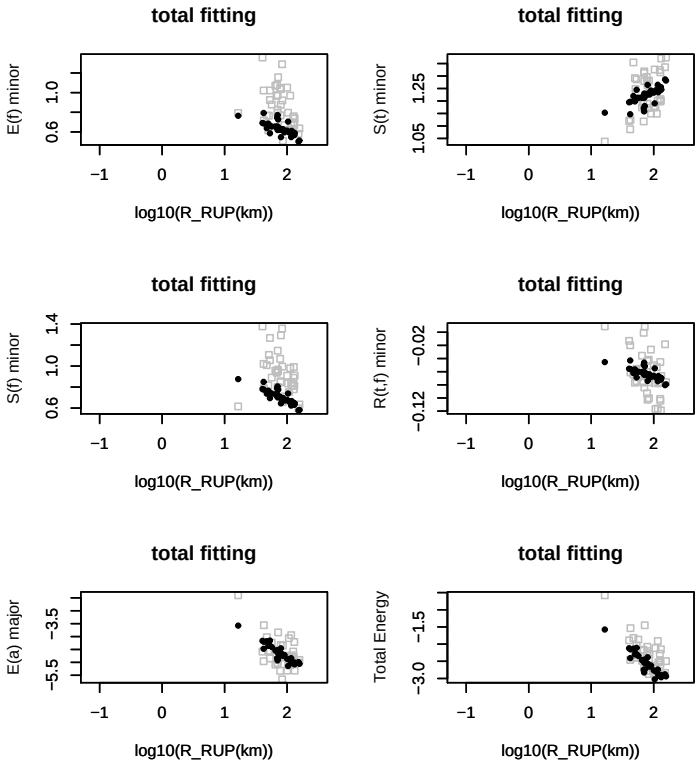

Figure 59: $ID = 126$, Natural log of total energy of wavelet packets

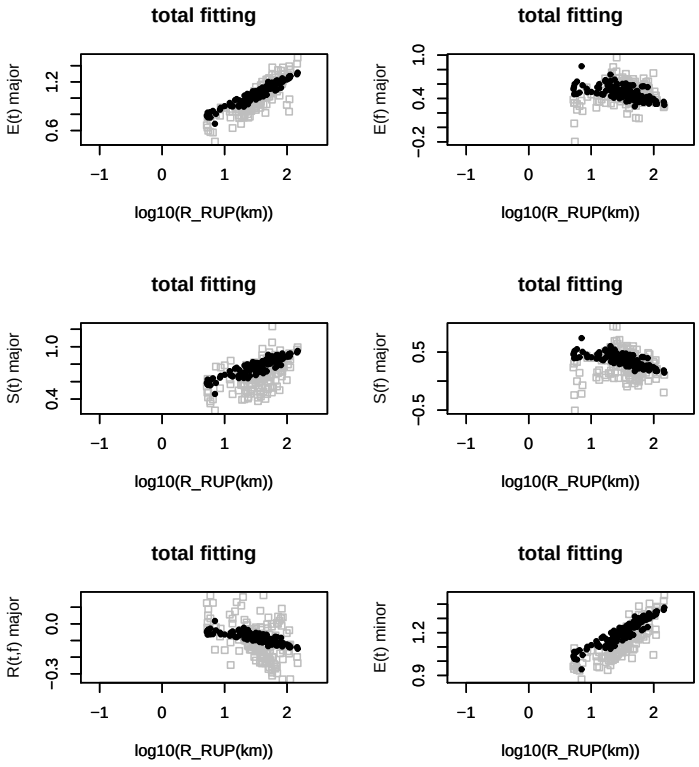

Figure 60: $ID = 127$, Natural log of total energy of wavelet packets

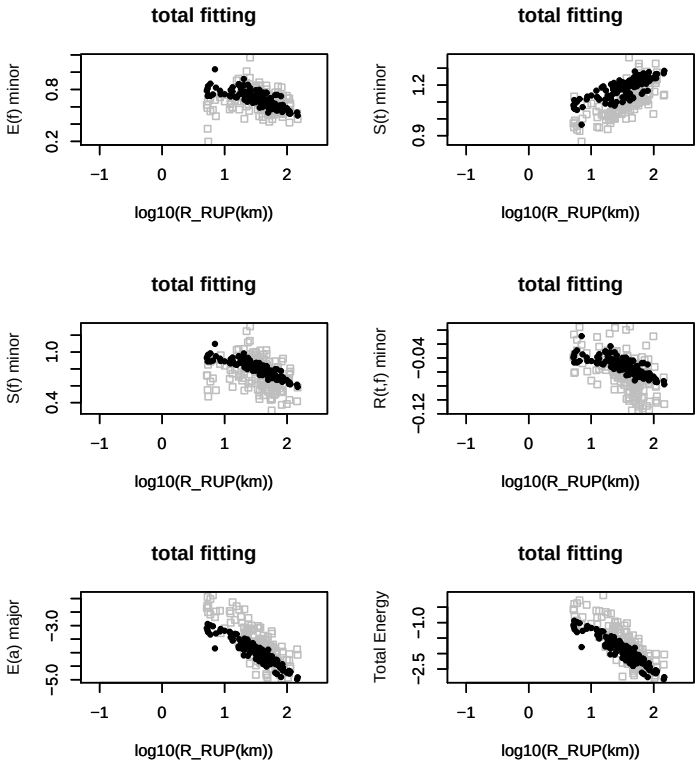

Figure 61: $ID = 127$, Natural log of total energy of wavelet packets

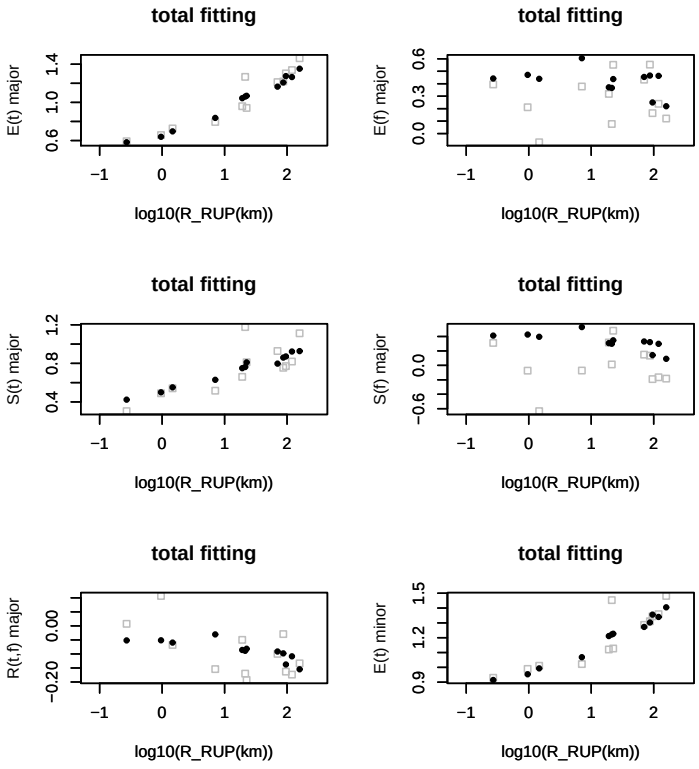

Figure 62: $ID = 129$, Natural log of total energy of wavelet packets

3.13 Each earthquake event$[ID = 129,\ M_W = 6.9]$

3.14 Each earthquake event$[ID = 136,\ M_W = 7.51]$

3.15 Each earthquake event$[ID = 137,\ M_W = 7.62]$

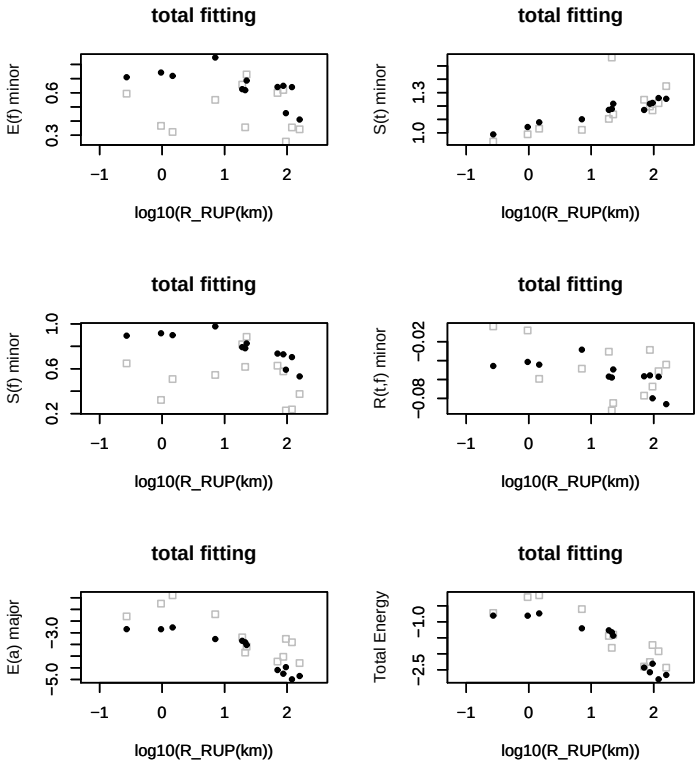

Figure 63: $ID = 129$, Natural log of total energy of wavelet packets

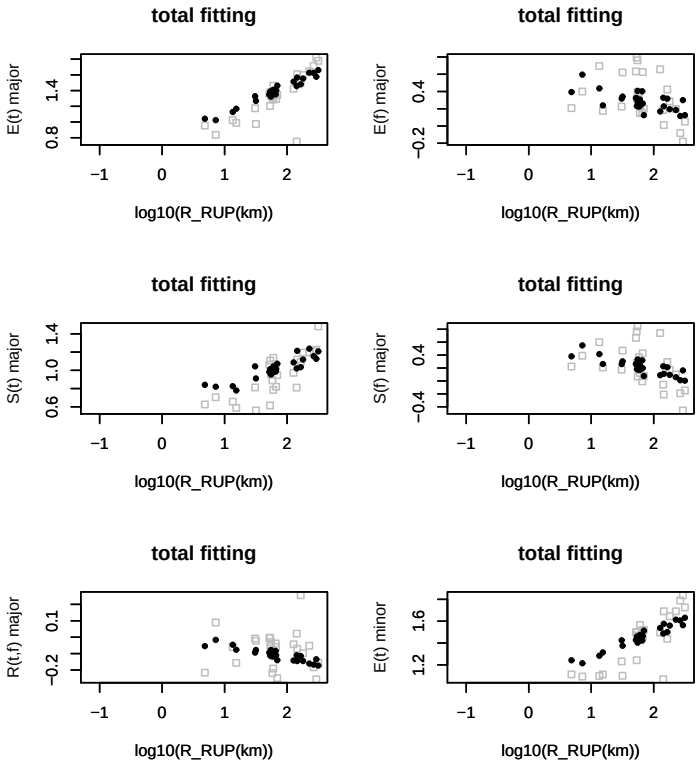

Figure 64: $ID = 136$, Natural log of total energy of wavelet packets

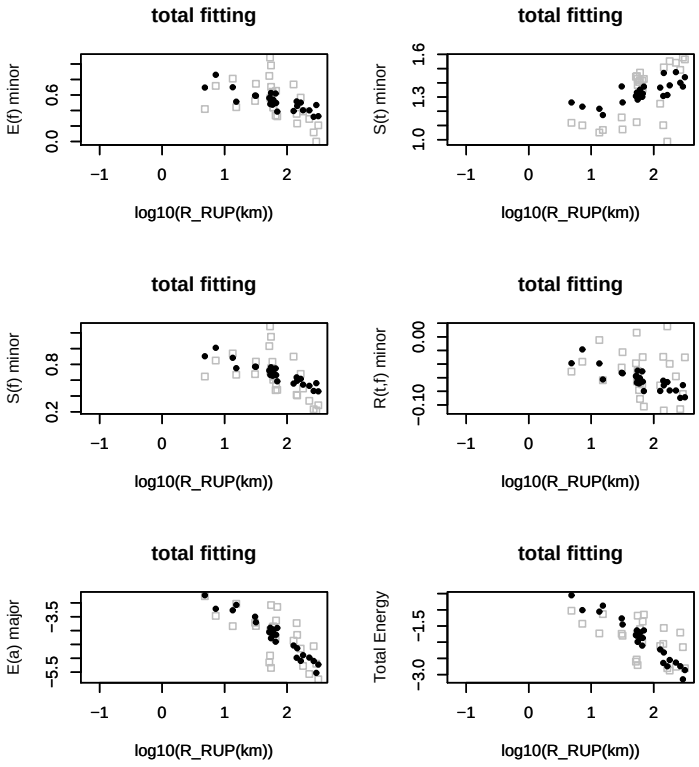

Figure 65: $ID = 136$, Natural log of total energy of wavelet packets

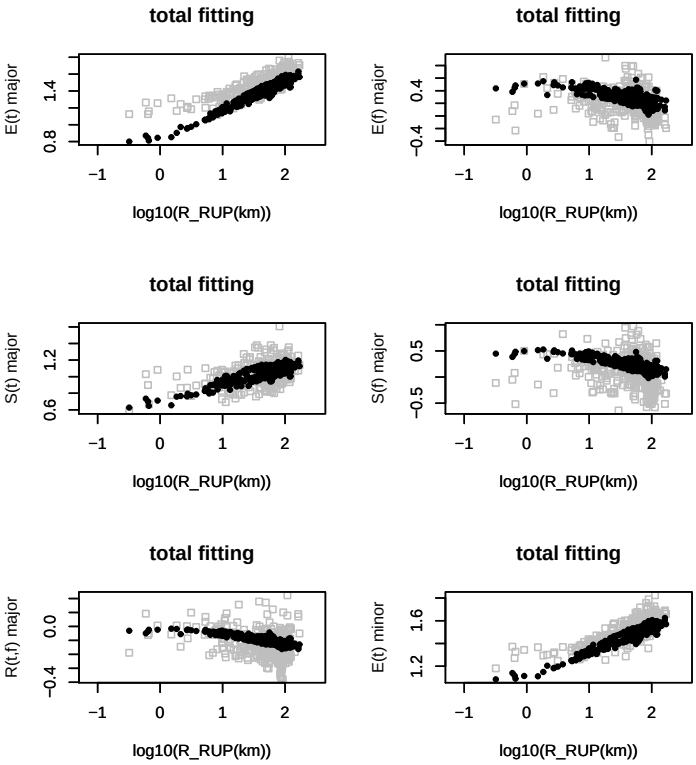

Figure 66: $ID = 137$, Natural log of total energy of wavelet packets

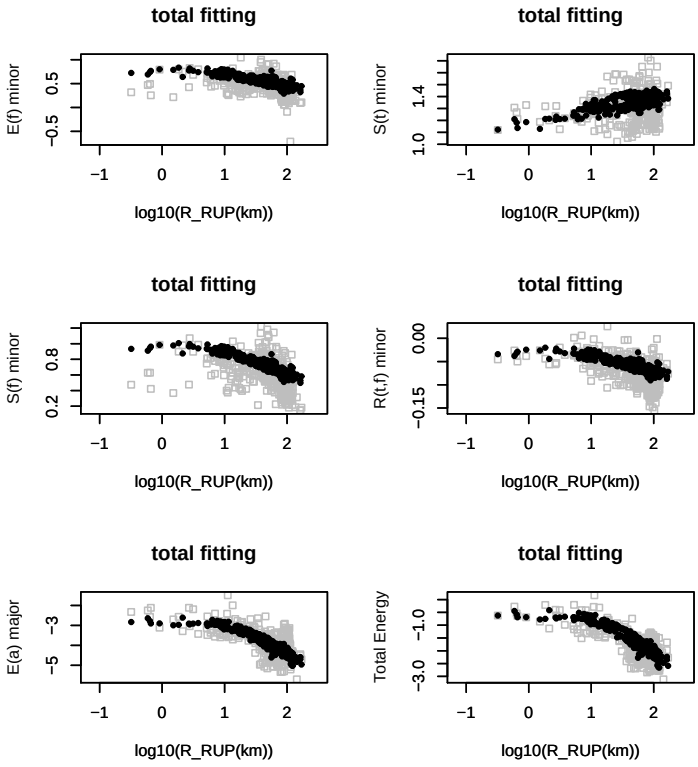

Figure 67: $ID = 137$, Natural log of total energy of wavelet packets

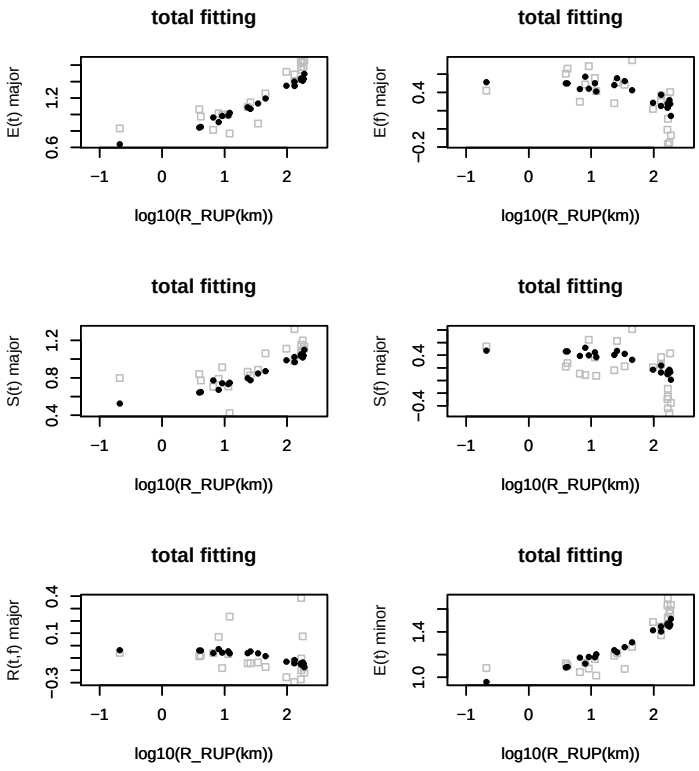

Figure 68: $ID = 138$, Natural log of total energy of wavelet packets

3.16 Each earthquake event$[ID = 138,\ M_W = 7.14]$

3.17 Each earthquake event$[ID = 158,\ M_W = 7.13]$

3.18 Each earthquake event$[ID = 160,\ M_W = 5]$

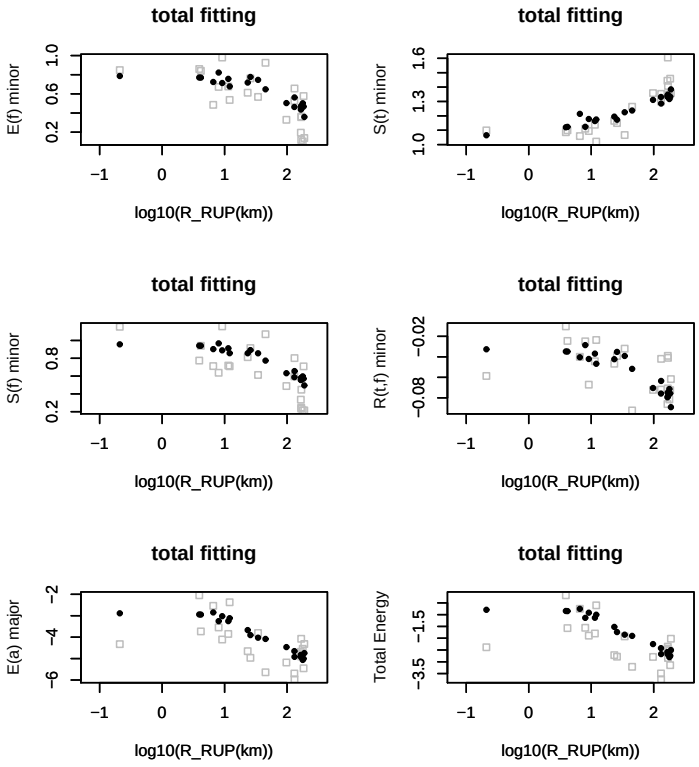

Figure 69: $ID = 138$, Natural log of total energy of wavelet packets

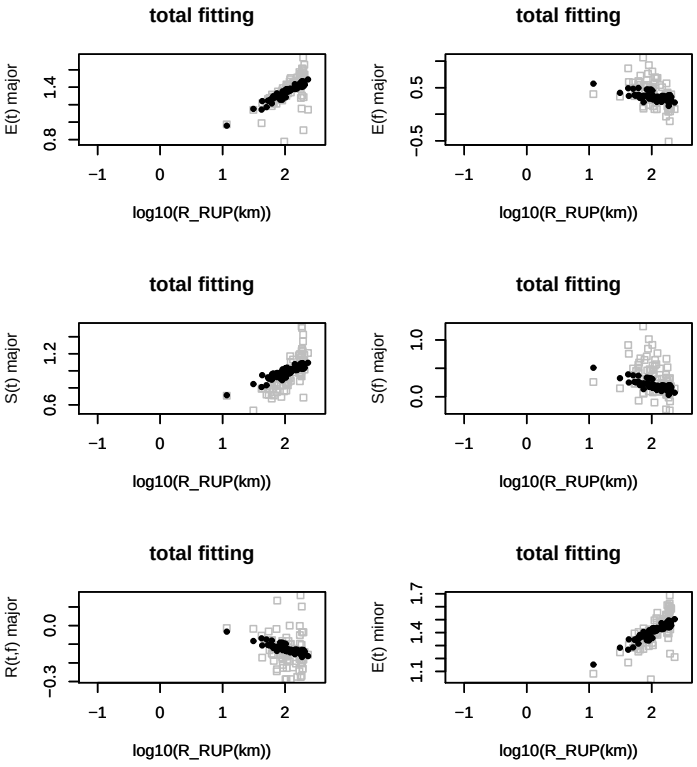

Figure 70: $ID = 158$, Natural log of total energy of wavelet packets

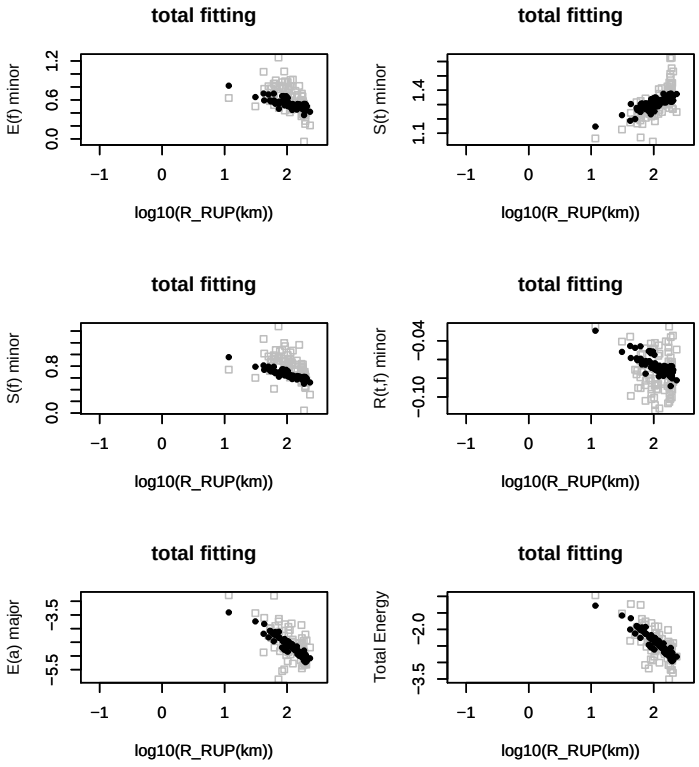

Figure 71: $ID = 158$, Natural log of total energy of wavelet packets

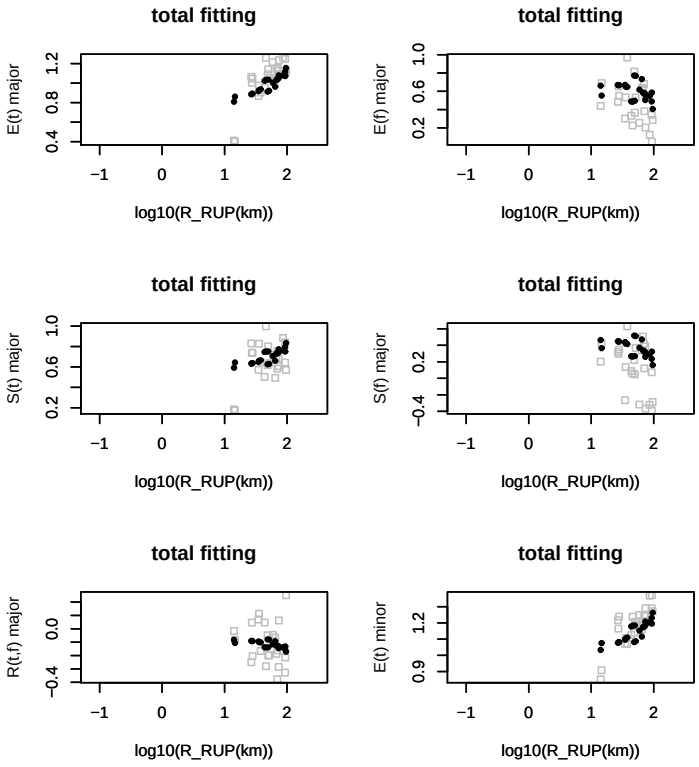

Figure 72: $ID = 160$, Natural log of total energy of wavelet packets

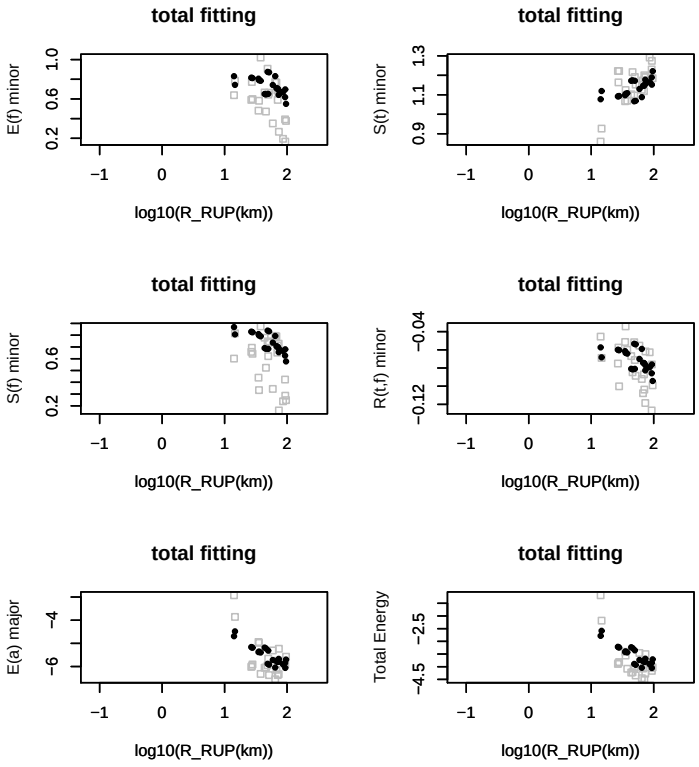

Figure 73: $ID = 160$, Natural log of total energy of wavelet packets

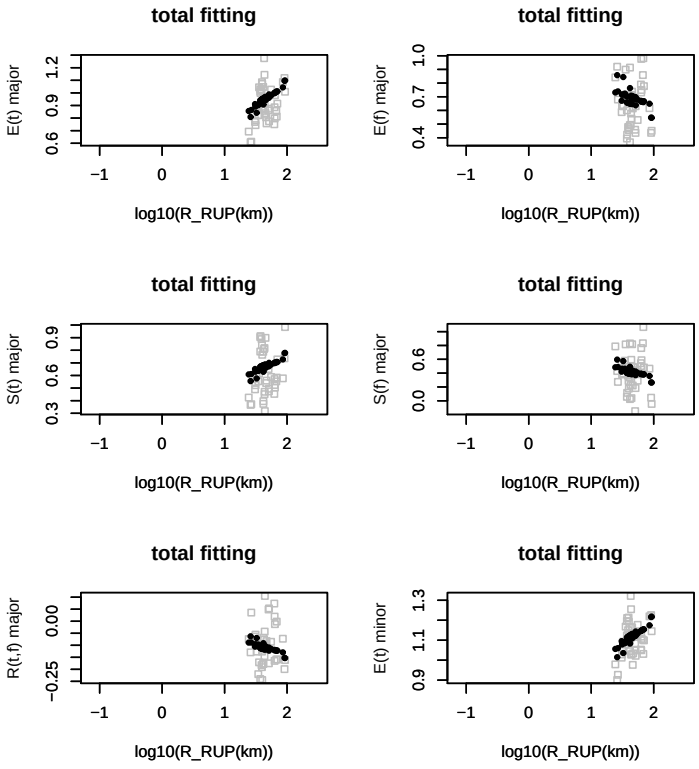

Figure 74: $ID = 161$, Natural log of total energy of wavelet packets

3.19 Each earthquake event[$ID = 161$, $M_W = 4.53$]

3.20 Each earthquake event[$ID = 163$, $M_W = 4.92$]

3.21 Each earthquake event[$ID = 164$, $M_W = 5.7$]

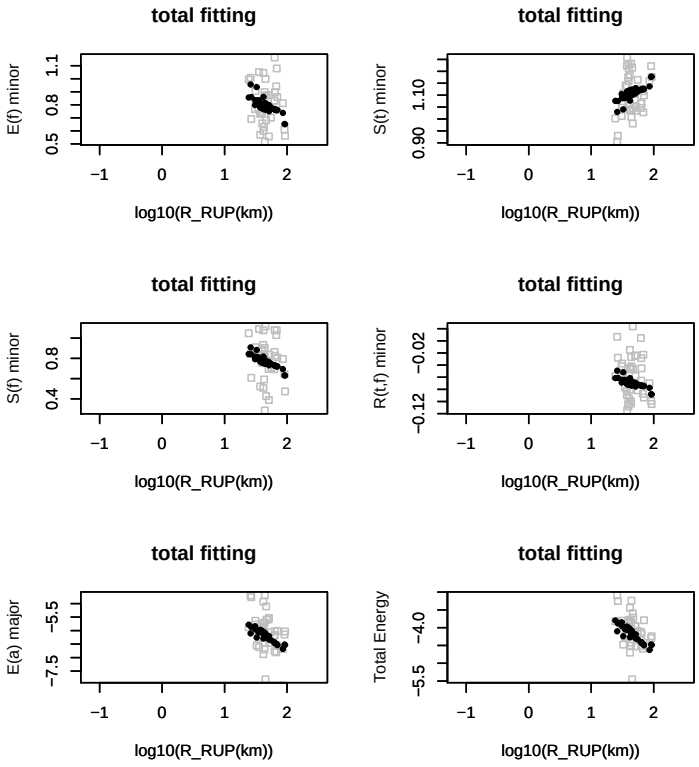

Figure 75: $ID = 161$, Natural log of total energy of wavelet packets

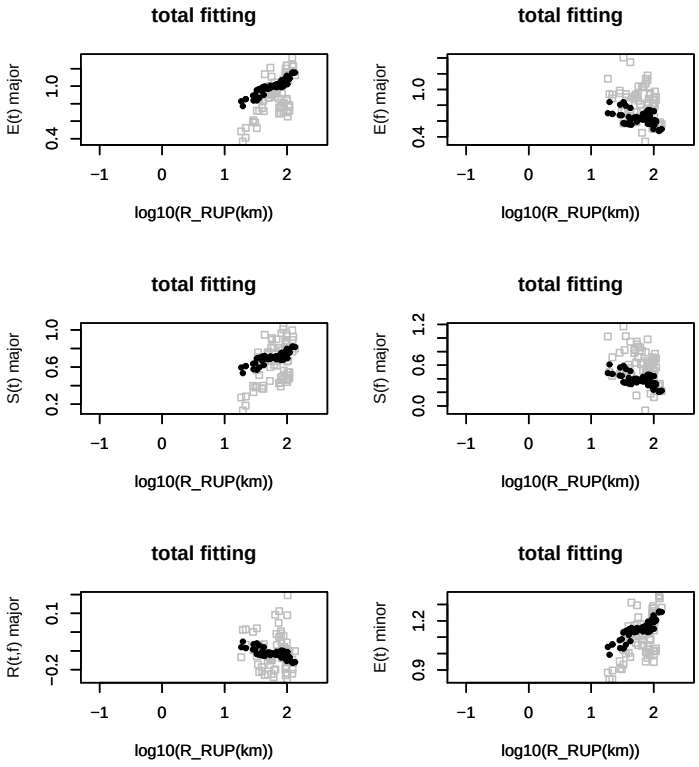

Figure 76: $ID = 163$, Natural log of total energy of wavelet packets

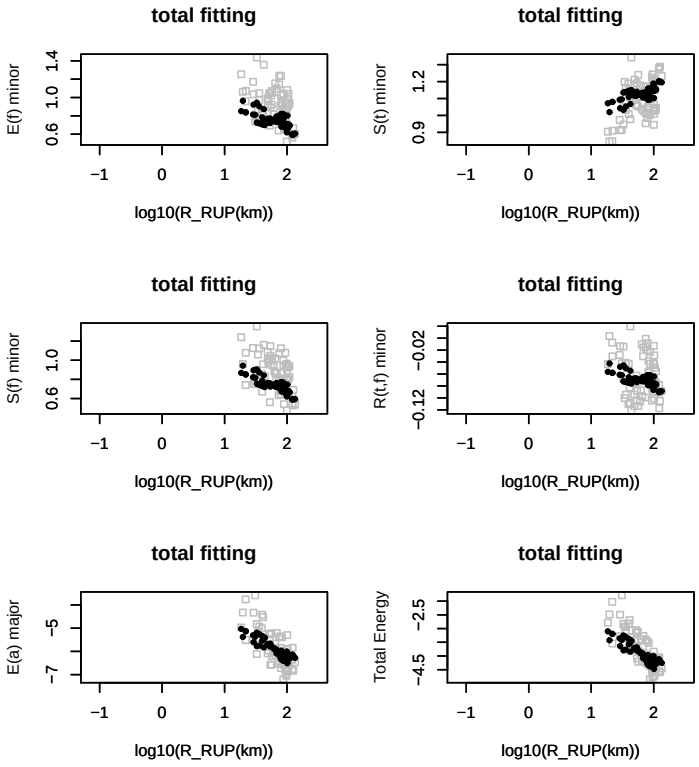

Figure 77: $ID = 163$, Natural log of total energy of wavelet packets

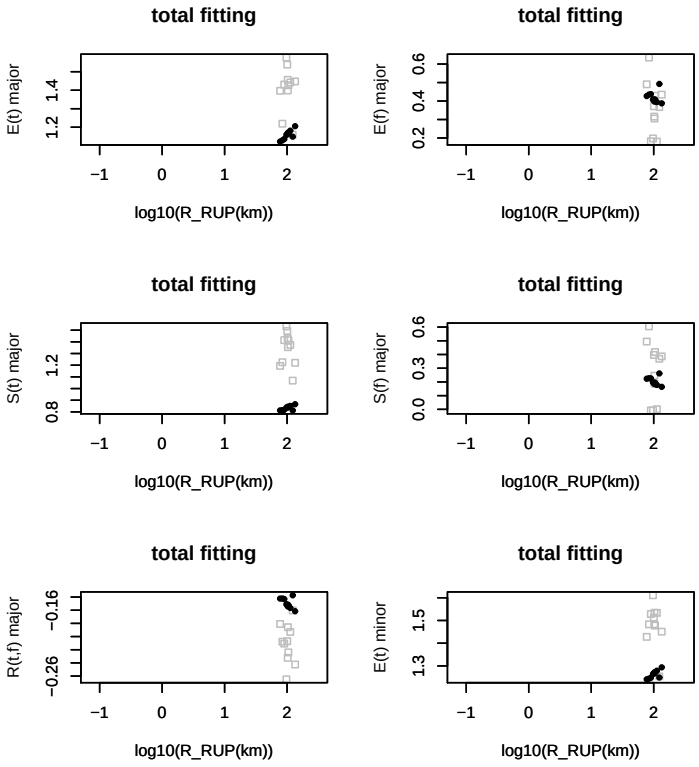

Figure 78: $ID = 164$, Natural log of total energy of wavelet packets

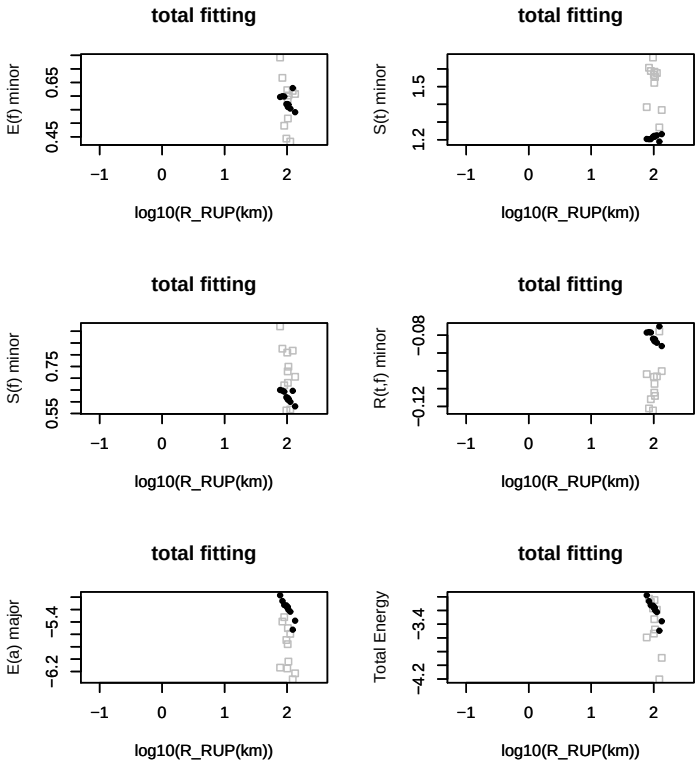

Figure 79: $ID = 164$, Natural log of total energy of wavelet packets

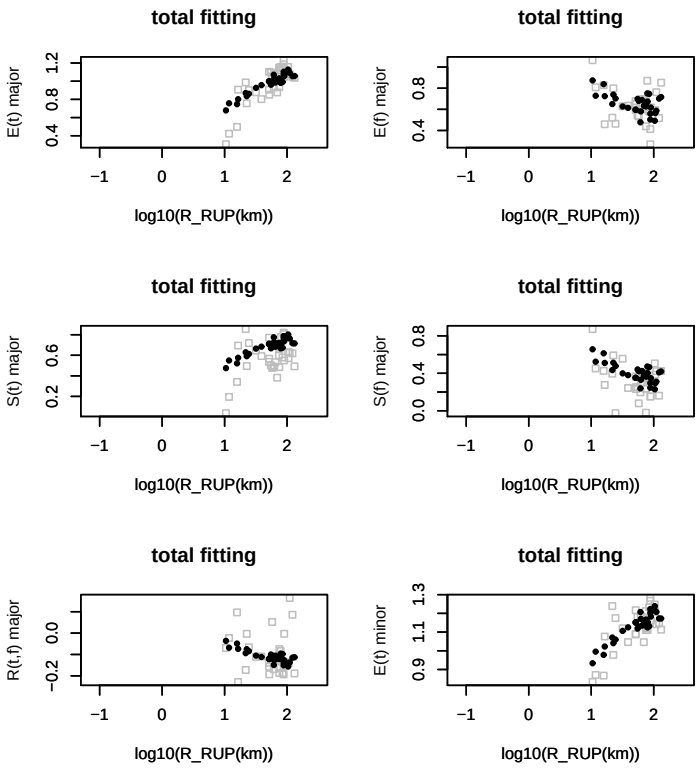

Figure 80: $ID = 166$, Natural log of total energy of wavelet packets

3.22 Each earthquake event$[ID = 166,\ M_W = 4.9]$

3.23 Each earthquake event$[ID = 168,\ M_W = 6.7]$

3.24 Each earthquake event$[ID = 169,\ M_W = 7.9]$

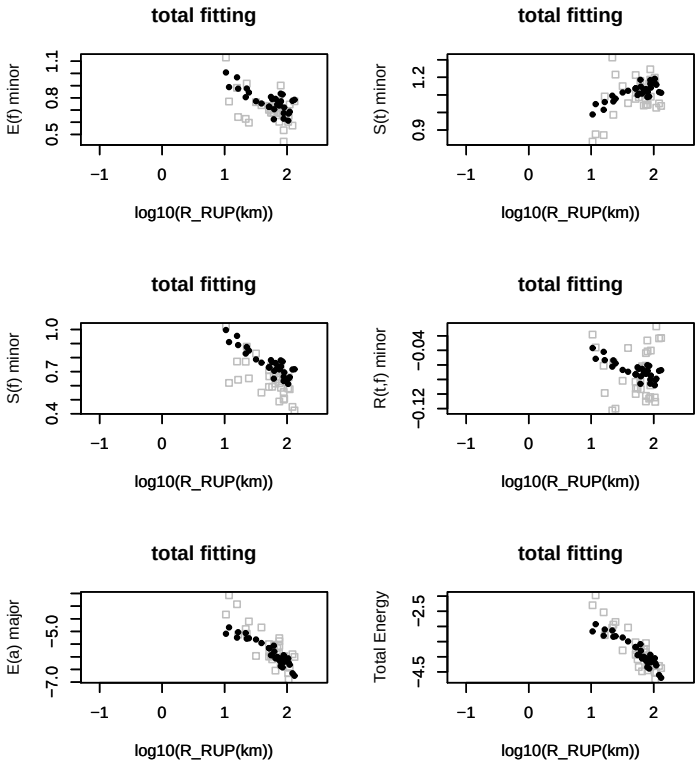

Figure 81: $ID = 166$, Natural log of total energy of wavelet packets

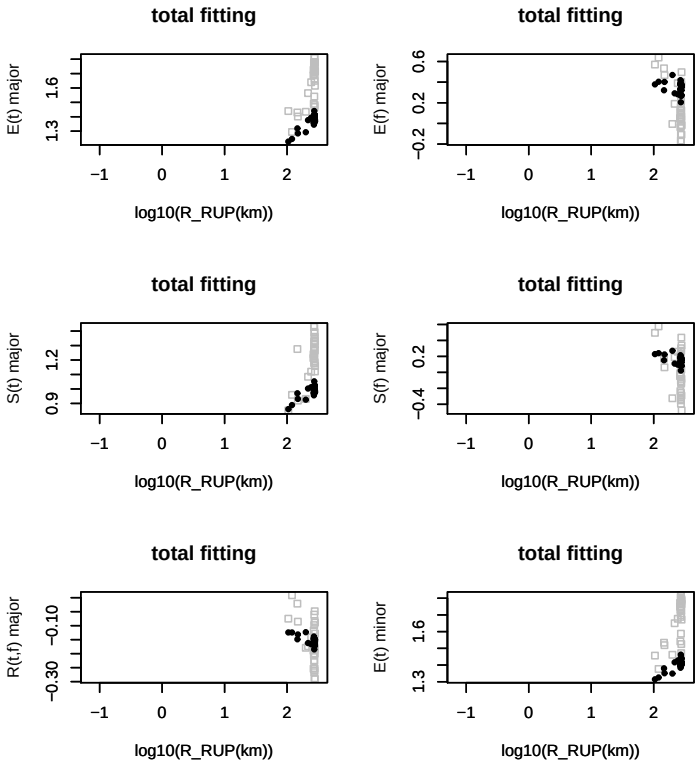

Figure 82: $ID = 168$, Natural log of total energy of wavelet packets

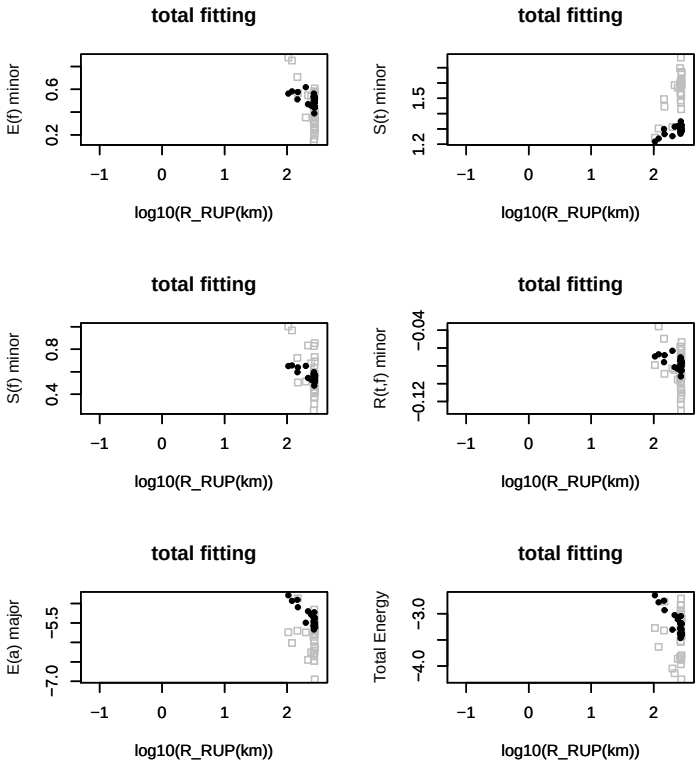

Figure 83: $ID = 168$, Natural log of total energy of wavelet packets

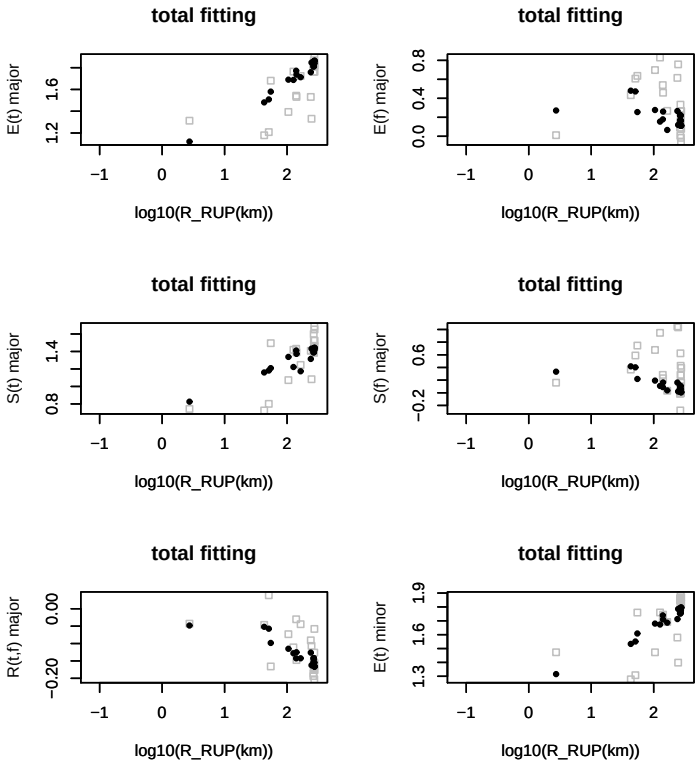

Figure 84: $ID = 169$, Natural log of total energy of wavelet packets

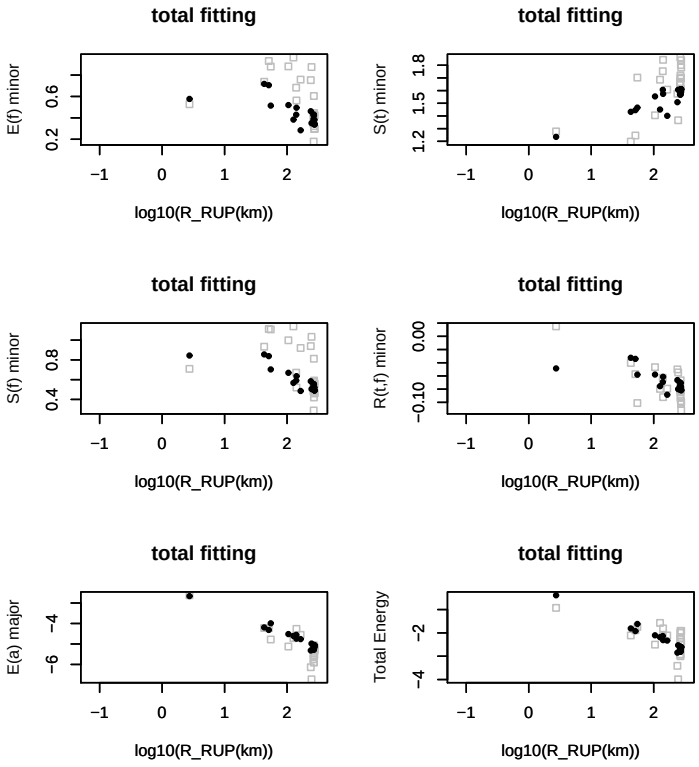

Figure 85: $ID = 169$, Natural log of total energy of wavelet packets

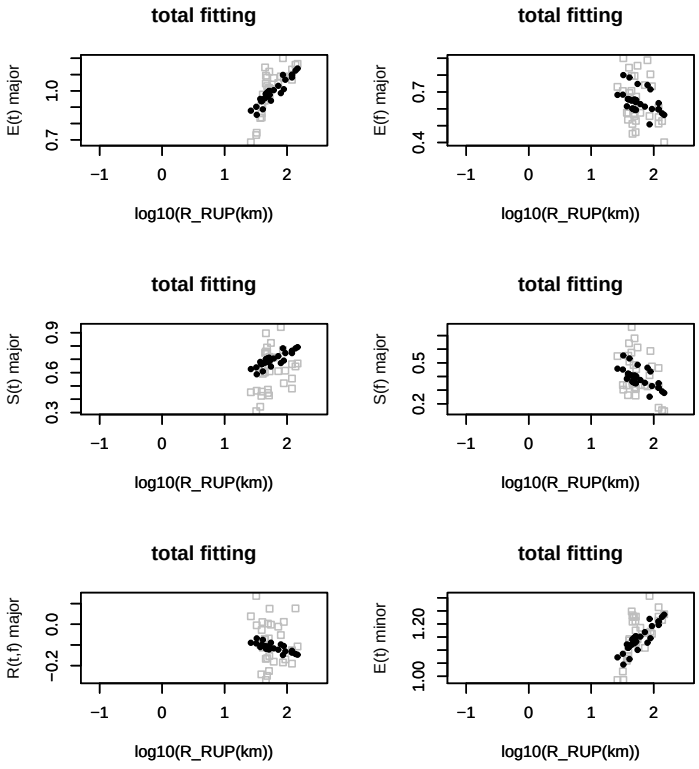

Figure 86: $ID = 170$, Natural log of total energy of wavelet packets

3.25 Each earthquake event$[ID = 170,\ M_W = 4.92]$

References

[1] David M. Boore and Gail M. Atkinson. Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5%-Damped PSA at Spectral Periods between 0.01s and 10.0s. *Earthquake Spectra*, 24(1):99, 2008.

[2] Brian Chiou, Robert Darragh, Nick Gregor, and Walter Silva. NGA Project Strong-Motion Database. *Earthquake Spectra*, 24(1):23, 2008.

[3] William B. Joyner and David M. Boore. Methods for regression analysis of strong-motion data. *Bulletin of the Seismological Society of America*, 83(2):469–487, 1993.

[4] William B. Joyner and David M. Boore. Methods for Regression Analysis of Strong-Motion Data. *Bulletin of the Seismological Society of America*, 84(3):955–956, 1994.

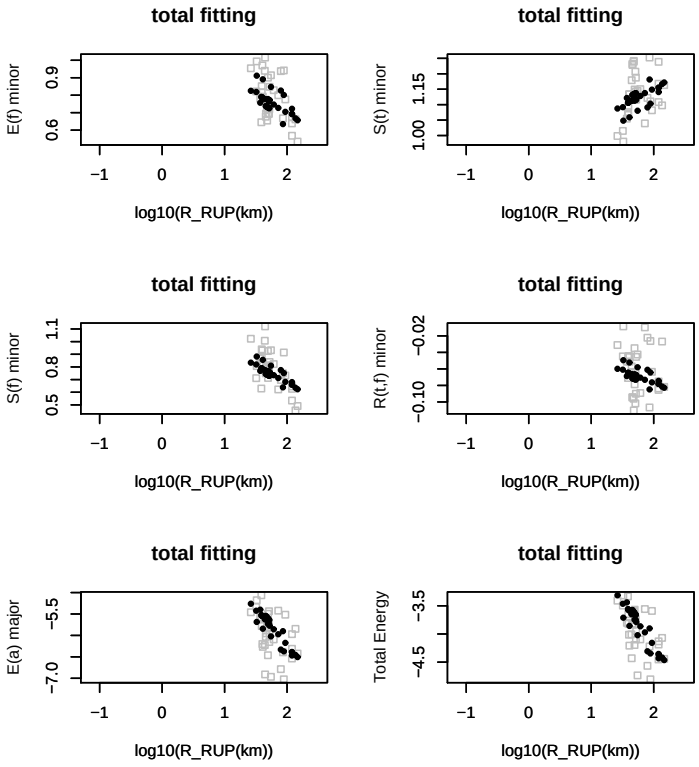

Figure 87: $ID = 170$, Natural log of total energy of wavelet packets