

Mixed effect 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, mixed effect regression analysis 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:

$$\begin{aligned}\log(Y) &= a + b_1 M_W + b_2 \log(M_W) + c_2 \log(R) \\ &\quad + d \log(V_{S30}) + \eta_i + \epsilon_{i,j}\end{aligned}\tag{1}$$

$$R = \sqrt{R_{RUP}^2 + h^2}\tag{2}$$

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. Mixed effect regression analysis was done by the lme4 package (Bates and Maechler 2010) in R (R Development Core Team 2010). 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 summary of regression

```
> summary(MixEFREG)
```

```

Linear mixed-effects model fit by REML
Formula: yseries ~ exp_Mw + Rhyp_Rrup + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
          AIC    BIC logLik MLdeviance REMLdeviance
        495.7 527.2 -241.9      437.4      483.7
Random effects:
Groups           Name        Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.08537  0.29218
Residual          0.07497  0.27381
number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
            Estimate Std. Error t value
(Intercept) 1.9575404  0.1613376 12.13
exp_Mw       0.0005709  0.0000939  6.08
Rhyp_Rrup   -0.0018126  0.0008392 -2.16
ln_R         0.3441895  0.0095800 35.93
ln_VS30     -0.1955861  0.0202798 -9.64

Correlation of Fixed Effects:
              (Intr) exp_Mw Rhyp_R  ln_R
exp_Mw      -0.464
Rhyp_Rrup   0.097 -0.124
ln_R        -0.354 -0.016 -0.140
ln_VS30     -0.769 -0.011 -0.092  0.194

> cor(qqnorm(resid(MixEFREG))$x, resid(MixEFREG))
[1] 0.9901536

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])
[1] 0.9878825

```

Figure 1 (page 3)
 Figure 2 (page 4)

2.2 Natural log of mean frequency of major group

2.2.1 summary of regression

```
> summary(MixEFREG)
```

```

Linear mixed-effects model fit by REML
Formula: yseries ~ Mw + Rhyp_Rrup + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
          AIC    BIC logLik MLdeviance REMLdeviance
        1594 1626 -791.2      1552      1582
Random effects:
```

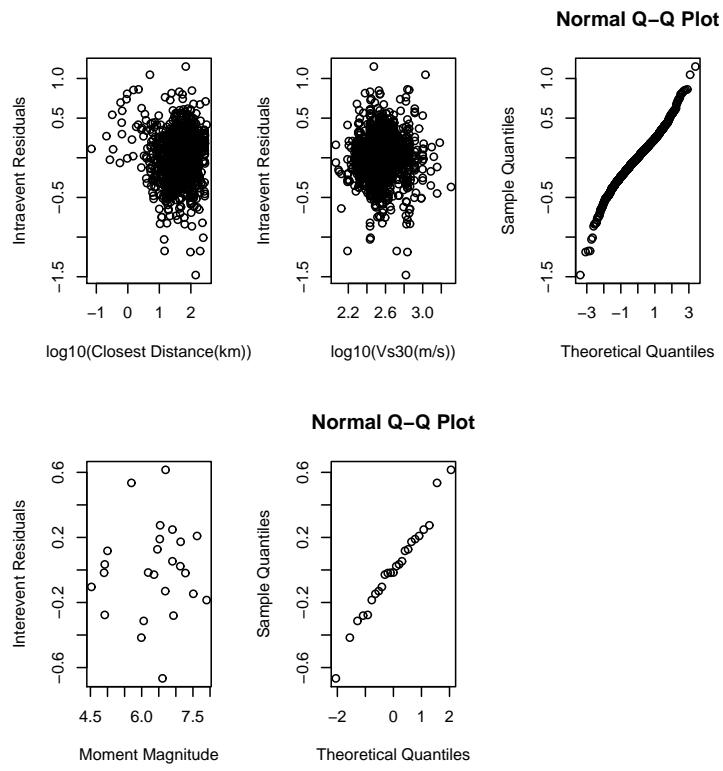


Figure 1: Characteristics of residuals of Natural log of mean time of location major of group

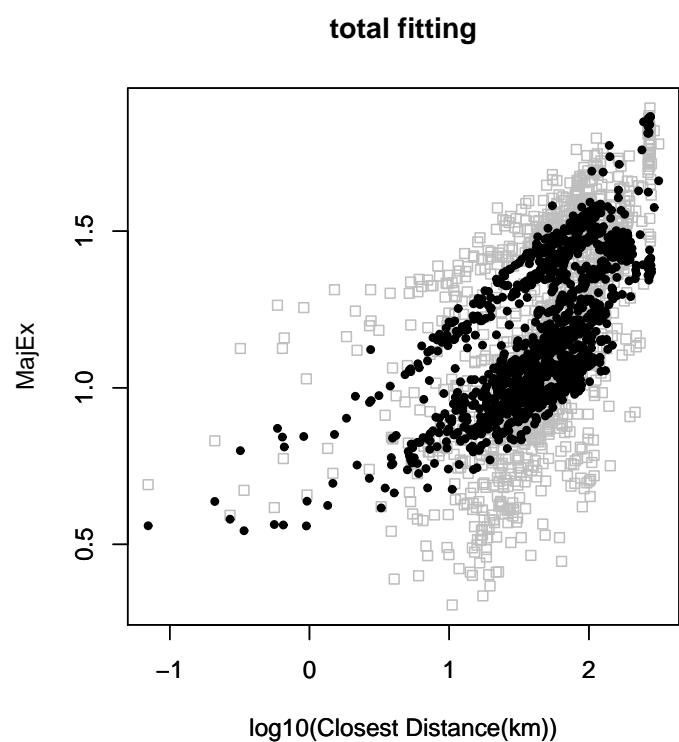


Figure 2: Median prediction of Natural log of mean time of location major of group

```

Groups           Name      Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.063748 0.25248
Residual          0.168496 0.41048
number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
            Estimate Std. Error t value
(Intercept) 0.812052  0.423916  1.916
Mw          -0.260139  0.058775 -4.426
Rhyp_Rrup   -0.003951  0.001250 -3.162
ln_R         -0.159189  0.018222 -8.736
ln_VS30     0.440870  0.030313 14.544

Correlation of Fixed Effects:
        (Intr) Mw      Rhyp_R ln_R
Mw      -0.869
Rhyp_Rrup  0.205 -0.198
ln_R      -0.239 -0.010 -0.152
ln_VS30    -0.436 -0.014 -0.093  0.197

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

[1] 0.9977309

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])

[1] 0.9928592

```

Figure 3 (page 6)
Figure 4 (page 7)

2.3 Natural log of standard deviation of time of major group

2.3.1 summary of regression

```

> summary(MixEFREG)

Linear mixed-effects model fit by REML
Formula: yseries ~ exp_Mw + Rhyp_Rrup + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
   AIC   BIC logLik MLdeviance REMLdeviance
1136 1168 -562.2       1080       1124
Random effects:
Groups           Name      Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.10357  0.32182
Residual          0.11886  0.34476
number of obs: 1408, groups: as.factor(I_EQ), 25

```

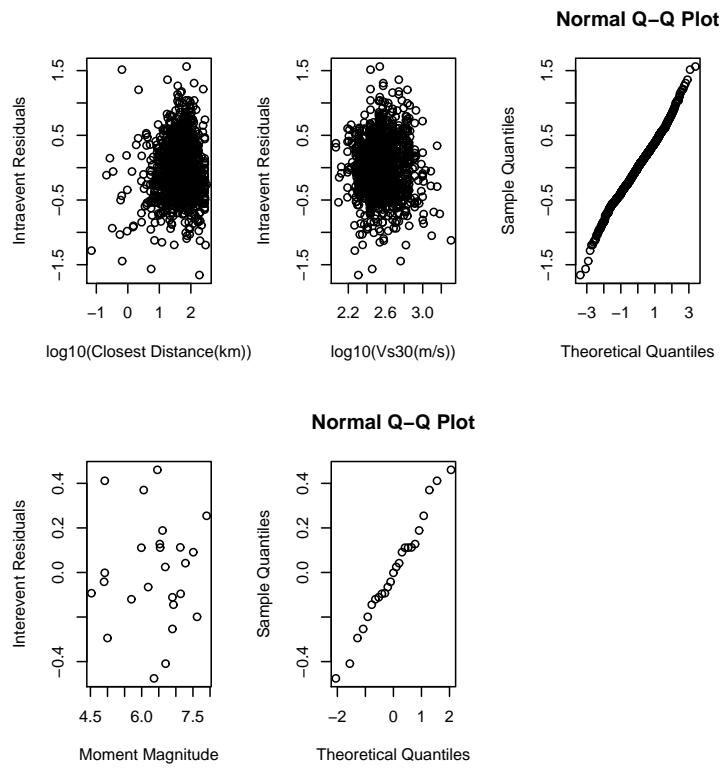


Figure 3: Characteristics of residuals of Natural log of mean frequency of major group

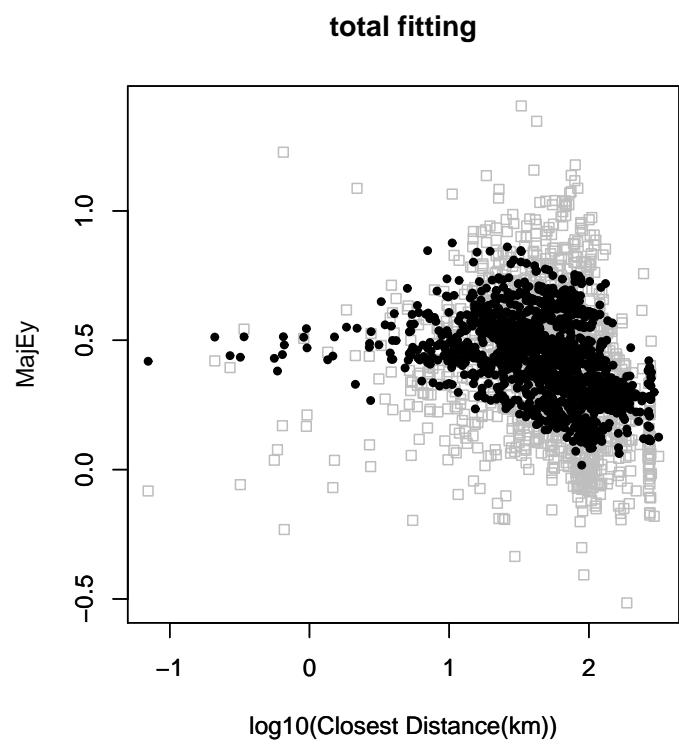


Figure 4: Median prediction of Natural log of mean frequency of major group

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Fixed effects:
            Estimate Std. Error t value
(Intercept) 1.8208932 0.1943722 9.368
exp_Mw      0.0005714 0.0001041 5.489
Rhyp_Rrup   -0.0064388 0.0010551 -6.102
ln_R        0.2191951 0.0120351 18.213
ln_VS30    -0.2021881 0.0255157 -7.924

Correlation of Fixed Effects:
              (Intr) exp_Mw Rhyp_R ln_R
exp_Mw      -0.422
Rhyp_Rrup   0.100 -0.140
ln_R        -0.369 -0.019 -0.137
ln_VS30    -0.803 -0.013 -0.091  0.193

> cor(qqnorm(resid(MixEFREG))$x, resid(MixEFREG))
[1] 0.9955394

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])
[1] 0.9203523

```

Figure 5 (page 9)

Figure 6 (page 10)

2.4 Natural log of standard deviation of frequency of major group

2.4.1 summary of regression

```

> summary(MixEFREG)

Linear mixed-effects model fit by REML
Formula: yseries ~ Mw + Rhyp_Rrup + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
          AIC   BIC logLik MLdeviance REMLdeviance
          2517 2549 -1253       2478       2505
Random effects:
Groups           Name        Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.12994  0.36047
Residual          0.32496  0.57005
number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
            Estimate Std. Error t value
(Intercept) 0.109641  0.600571  0.183

```

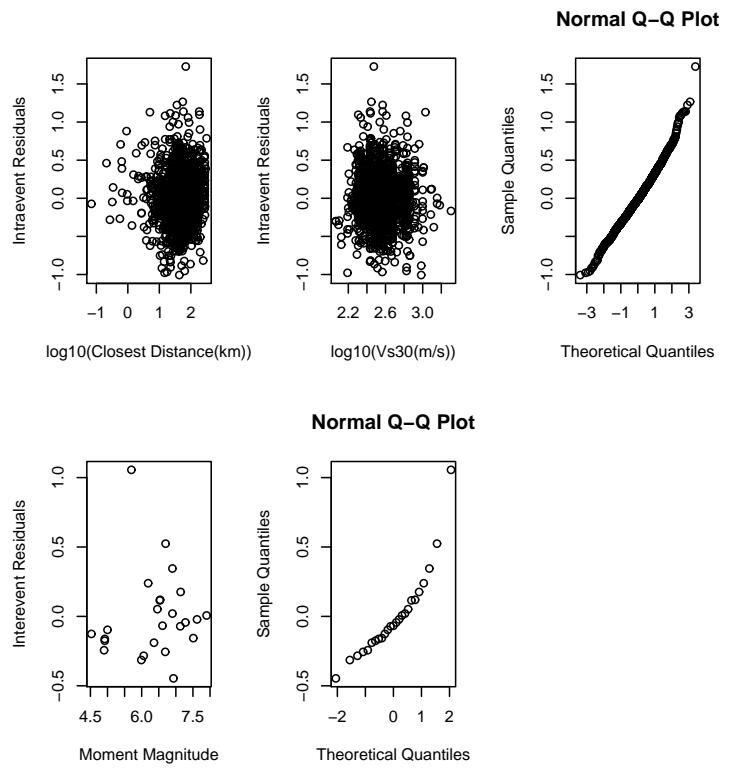


Figure 5: Characteristics of residuals of Natural log of standard deviation of time of major group

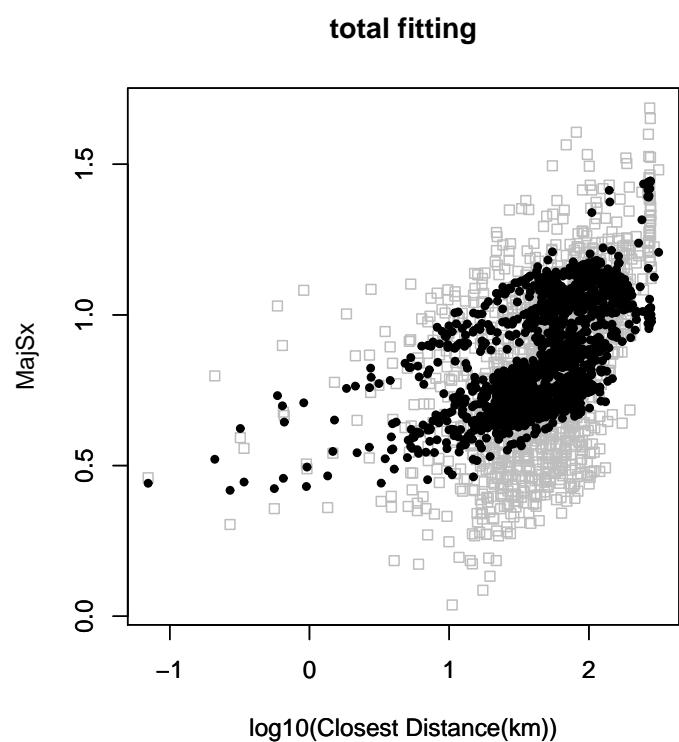


Figure 6: Median prediction of Natural log of standard deviation of time of major group

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Mw           -0.115463  0.083666 -1.380
Rhyp_Rrup   -0.002326  0.001737 -1.339
ln_R         -0.237347  0.025337 -9.368
ln_VS30     0.394233  0.042111  9.362

Correlation of Fixed Effects:
            (Intr) Mw      Rhyp_R ln_R
Mw           -0.874
Rhyp_Rrup   0.201 -0.193
ln_R         -0.235 -0.010 -0.153
ln_VS30     -0.428 -0.014 -0.094  0.197

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

[1] 0.9981996

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])

[1] 0.9919016

```

Figure 7 (page 12)

Figure 8 (page 13)

2.5 Correlation of time-frequency of major group

2.5.1 summary of regression

```

> summary(MixEFREG)

Linear mixed-effects model fit by REML
Formula: yseries ~ Mw + Rhyp_Rrup + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
          AIC      BIC logLik MLdeviance REMLdeviance
-240.4   -208.9  126.2      -293.1      -252.4
Random effects:
Groups           Name        Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.0025744 0.050738
Residual          0.0467259 0.216162
number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
            Estimate Std. Error t value
(Intercept) -0.5573562  0.1360563 -4.097
Mw           0.0062955  0.0148842  0.423
Rhyp_Rrup   -0.0002794  0.0006226 -0.449
ln_R         -0.0752465  0.0088504 -8.502
ln_VS30     0.0989381  0.0156367  6.327

```

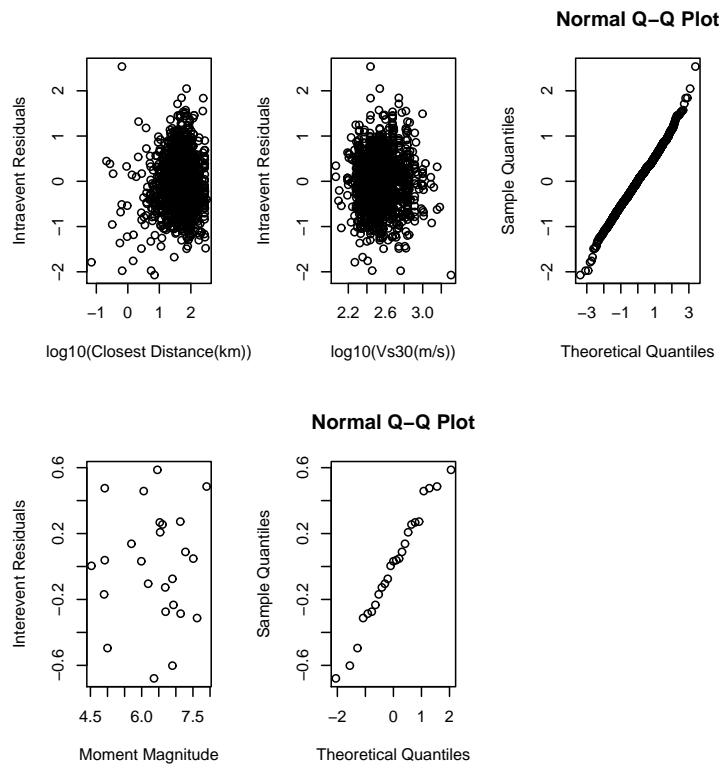


Figure 7: Characteristics of residuals of Natural log of standard deviation of frequency of major group

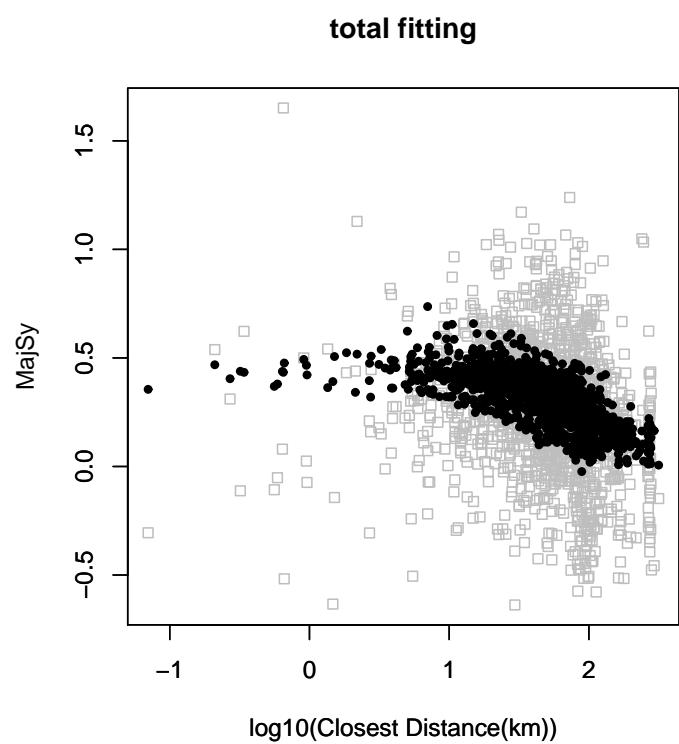


Figure 8: Median prediction of Natural log of standard deviation of frequency of major group

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Correlation of Fixed Effects:
              (Intr) Mw      Rhyp_R ln_R
Mw            -0.647
Rhyp_Rrup    0.293 -0.396
ln_R         -0.336 -0.045 -0.090
ln_VS30     -0.695 -0.026 -0.071  0.169

> cor(qqnorm(resid(MixEFREG))$x, resid(MixEFREG))
[1] 0.9817353

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])
[1] 0.9448756

```

Figure 9 (page 15)
 Figure 10 (page 16)

2.6 Natural log of mean time of location minor of group

2.6.1 summary of regression

```

> summary(MixEFREG)

Linear mixed-effects model fit by REML
Formula: yseries ~ exp_Mw + Rhyp_Rrup + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
          AIC      BIC logLik MLdeviance REMLdeviance
-652.8 -621.3  332.4      -714.8       -664.8
Random effects:
Groups           Name        Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.045979 0.21443
Residual          0.032958 0.18154
number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
             Estimate Std. Error t value
(Intercept) 2.637e+00 1.112e-01 23.71
exp_Mw       4.506e-04 6.863e-05  6.56
Rhyp_Rrup   -1.498e-03 5.569e-04 -2.69
ln_R        2.180e-01 6.361e-03 34.27
ln_VS30    -1.617e-01 1.345e-02 -12.02

Correlation of Fixed Effects:
              (Intr) exp_Mw Rhyp_R ln_R
exp_Mw      -0.496
Rhyp_Rrup   0.094 -0.112
ln_R        -0.342 -0.014 -0.141
ln_VS30    -0.740 -0.010 -0.092  0.195

```

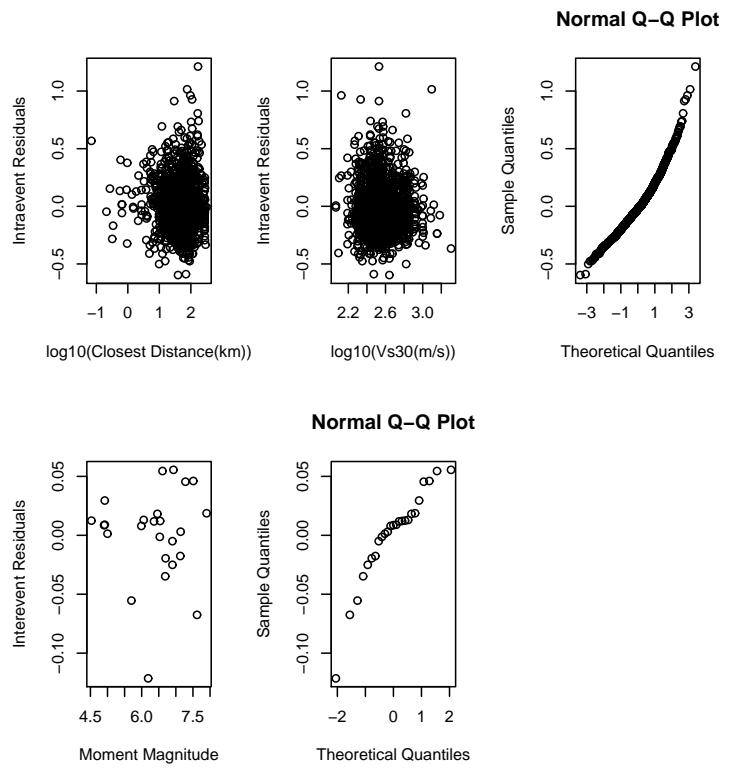


Figure 9: Characteristics of residuals of Correlation of time-frequency of major group

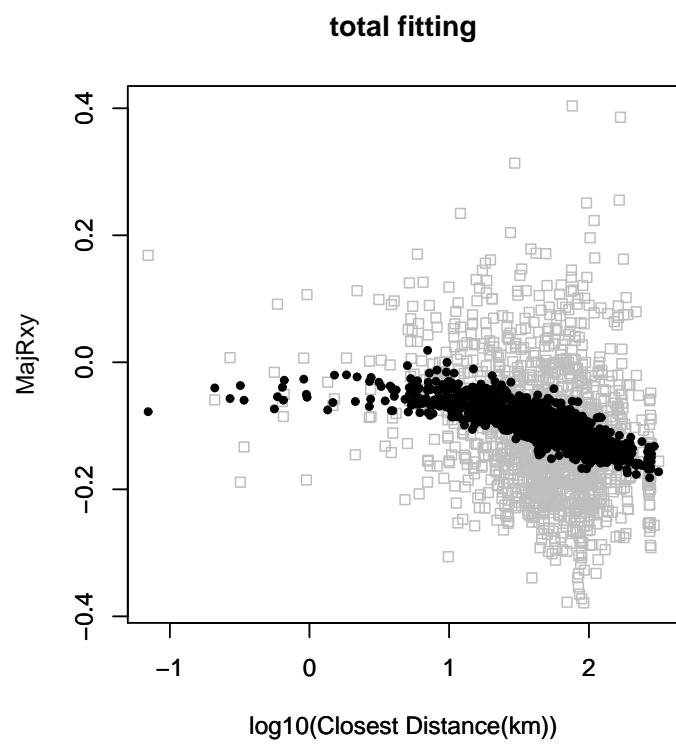


Figure 10: Median prediction of Correlation of time-frequency of major group

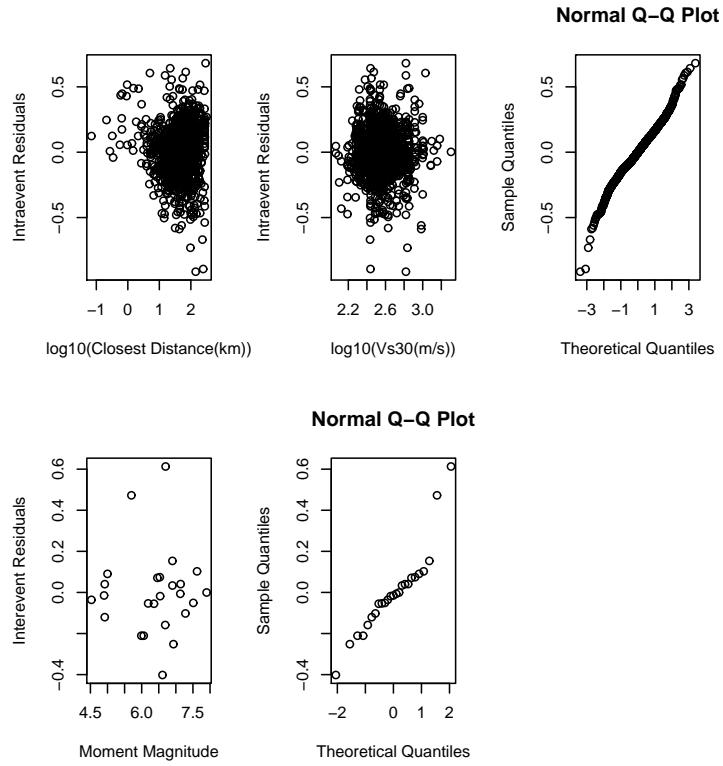


Figure 11: Characteristics of residuals of Natural log of mean time of location minor of group

```
> cor(qqnorm(resid(MixEFREG))$x, resid(MixEFREG))
[1] 0.992063

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])
[1] 0.9352894
```

Figure 11 (page 17)
 Figure 12 (page 18)

2.7 Natural log of mean frequency of minor group

2.7.1 summary of regression

```
> summary(MixEFREG)
```

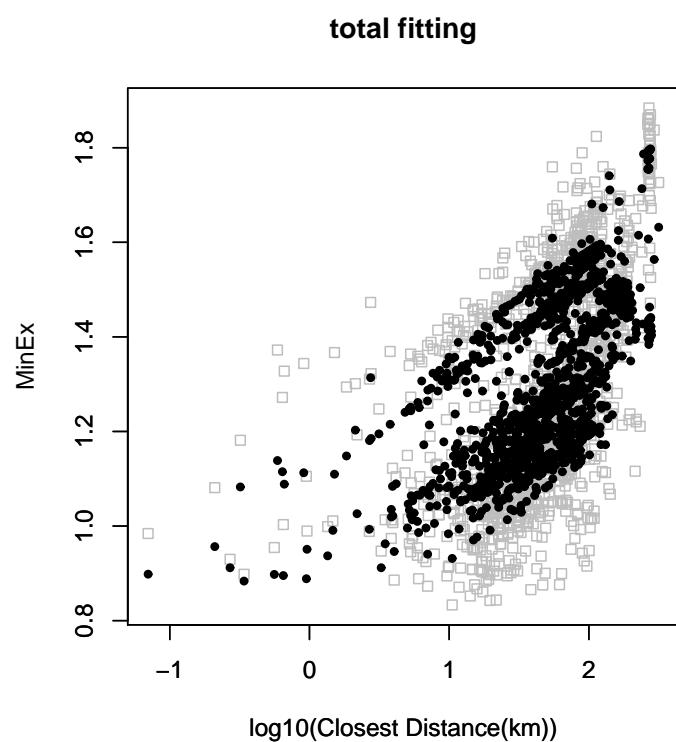


Figure 12: Median prediction of Natural log of mean time of location minor of group

```

Linear mixed-effects model fit by REML
Formula: yseries ~ Mw + Rhyp_Rrup + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
          AIC    BIC logLik MLdeviance REMLdeviance
          1181 1212 -584.4        1137        1169
Random effects:
Groups           Name        Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.066008 0.25692
Residual                  0.124835 0.35332
number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
            Estimate Std. Error t value
(Intercept) 1.271679  0.413458  3.076
Mw          -0.141254  0.058873 -2.399
Rhyp_Rrup   -0.004593  0.001080 -4.253
ln_R         -0.226508  0.015790 -14.345
ln_VS30      0.355955  0.026141 13.617

Correlation of Fixed Effects:
          (Intr) Mw     Rhyp_R ln_R
Mw        -0.897
Rhyp_Rrup  0.183 -0.171
ln_R       -0.213 -0.008 -0.157
ln_VS30    -0.386 -0.013 -0.095  0.199

> cor(qqnorm(resid(MixEFREG))$x, resid(MixEFREG))
[1] 0.993383

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])
[1] 0.9909675

```

Figure 13 (page 20)
Figure 14 (page 21)

2.8 Natural log of standard deviation of time of minor group

2.8.1 summary of regression

```
> summary(MixEFREG)
```

```

Linear mixed-effects model fit by REML
Formula: yseries ~ exp_Mw + Rhyp_Rrup + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
          AIC    BIC logLik MLdeviance REMLdeviance
          -157.5 -126.0  84.76      -218.3      -169.5

```

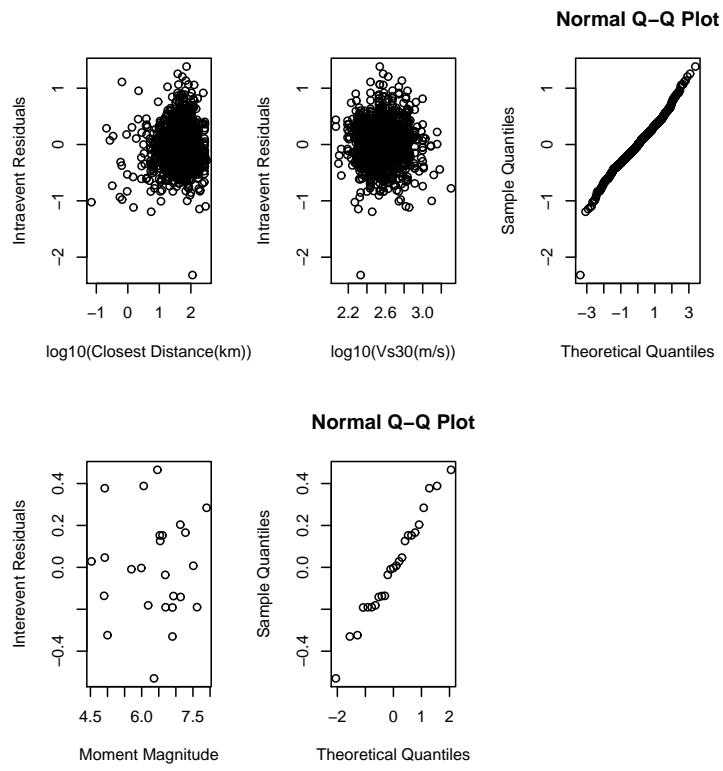


Figure 13: Characteristics of residuals of Natural log of mean frequency of minor group

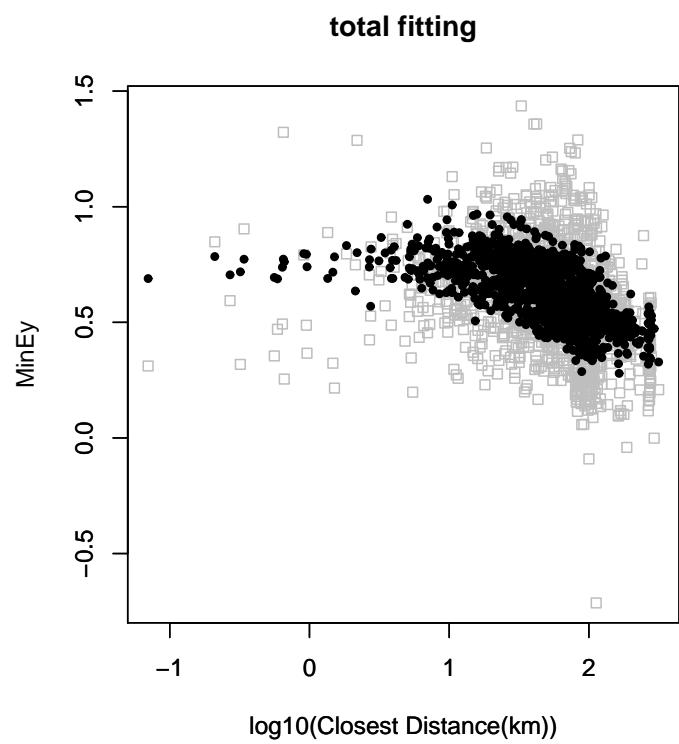


Figure 14: Median prediction of Natural log of mean frequency of minor group

```

Random effects:
Groups           Name        Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.049853 0.22328
Residual          0.047117 0.21707
number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
            Estimate Std. Error t value
(Intercept) 3.054e+00 1.263e-01 24.187
exp_Mw       3.988e-04 7.187e-05  5.549
Rhyp_Rrup   -5.466e-03 6.650e-04 -8.219
ln_R         1.132e-01 7.590e-03 14.909
ln_VS30     -1.674e-01 1.607e-02 -10.413

Correlation of Fixed Effects:
      (Intr) exp_Mw Rhyp_R ln_R
exp_Mw -0.452
Rhyp_Rrup  0.098 -0.128
ln_R     -0.359 -0.017 -0.139
ln_VS30   -0.779 -0.012 -0.091  0.194

> cor(qqnorm(resid(MixEFREG))$x, resid(MixEFREG))
[1] 0.9962708

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])
[1] 0.8886568

```

Figure 15 (page 23)
 Figure 16 (page 24)

2.9 Natural log of standard deviation of frequency of minor group

2.9.1 summary of regression

```

> summary(MixEFREG)

Linear mixed-effects model fit by REML
Formula: yseries ~ Mw + Rhyp_Rrup + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
      AIC    BIC logLik MLdeviance REMLdeviance
    1502 1534    -745      1459      1490
Random effects:
Groups           Name        Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.076927 0.27736
Residual          0.157156 0.39643

```

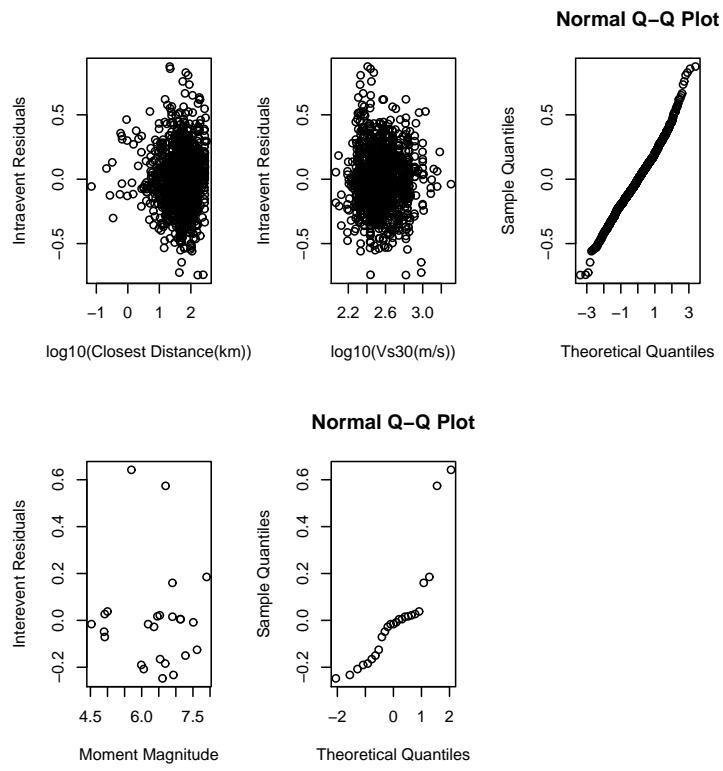


Figure 15: Characteristics of residuals of Natural log of standard deviation of time of minor group

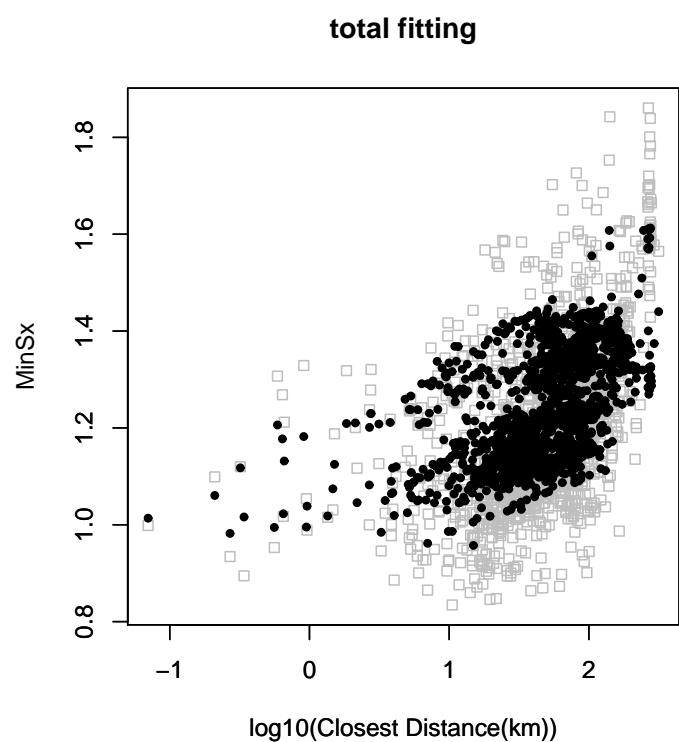


Figure 16: Median prediction of Natural log of standard deviation of time of minor group

```

number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
            Estimate Std. Error t value
(Intercept) 1.4405022 0.4503334 3.199
Mw          -0.0007852 0.0637614 -0.012
Rhyp_Rrup   -0.0032578 0.0012107 -2.691
ln_R         -0.2831627 0.0176916 -16.006
ln_VS30     0.2438290 0.0293188  8.316

Correlation of Fixed Effects:
      (Intr) Mw      Rhyp_R ln_R
Mw      -0.891
Rhyp_Rrup  0.188 -0.177
ln_R      -0.219 -0.008 -0.156
ln_VS30    -0.397 -0.013 -0.095  0.199

> cor(qqnorm(resid(MixEFREG))$x, resid(MixEFREG))
[1] 0.9988436

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])
[1] 0.9862235

```

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

2.10 Correlation of time-frequency of minor group

2.10.1 summary of regression

```

> summary(MixEFREG)

Linear mixed-effects model fit by REML
Formula: yseries ~ Mw + Rhyp_Rrup + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
      AIC      BIC logLik MLdeviance REMLdeviance
-3887 -3856    1950      -3951       -3899
Random effects:
Groups           Name        Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.00068485 0.026170
Residual          0.00341770 0.058461
number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
            Estimate Std. Error t value
(Intercept) -0.3574629 0.0490865 -7.282

```

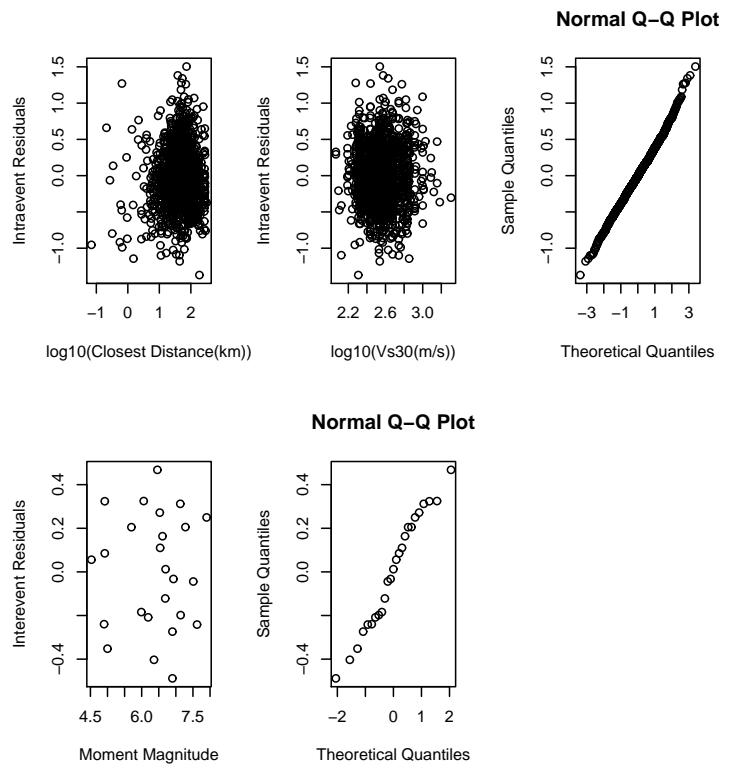


Figure 17: Characteristics of residuals of Natural log of standard deviation of frequency of minor group

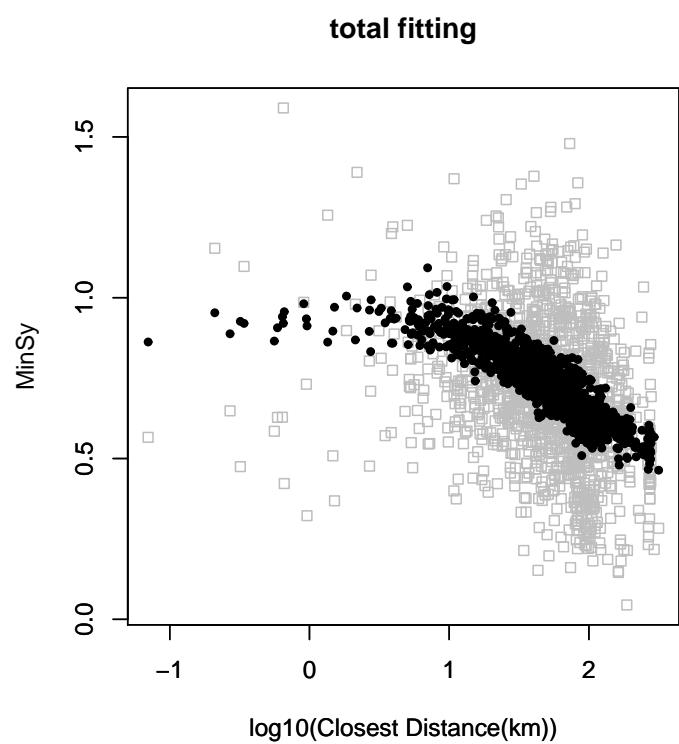


Figure 18: Median prediction of Natural log of standard deviation of frequency of minor group

```

Mw           0.0138569  0.0063736   2.174
Rhyp_Rrup   -0.0005729  0.0001759  -3.257
ln_R         -0.0313749  0.0025482 -12.313
ln_VS30     0.0440510  0.0042957  10.255

Correlation of Fixed Effects:
            (Intr) Mw      Rhyp_R ln_R
Mw           -0.804
Rhyp_Rrup    0.244 -0.258
ln_R         -0.284 -0.017 -0.139
ln_VS30     -0.533 -0.018 -0.089  0.191

> cor(qqnorm(resid(MixEFREG))$x, resid(MixEFREG))
[1] 0.9971446

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])
[1] 0.985647

```

Figure 19 (page 29)

Figure 20 (page 30)

2.11 Natural log of mean amplitude of major group

2.11.1 summary of regression

```

> summary(MixEFREG)

Linear mixed-effects model fit by REML
Formula: yseries ~ Mw + ln_Mw + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
      AIC   BIC logLik MLdeviance REMLdeviance
      4443 4474 -2215       4427        4431

Random effects:
Groups          Name        Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.46474  0.68172
Residual          1.29948  1.13995
number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
            Estimate Std. Error t value
(Intercept) -38.10258   9.99503  -3.81
Mw           -4.55619   2.08908  -2.18
ln_Mw        37.52084  12.58942   2.98
ln_R         -1.76080   0.05013 -35.13
ln_VS30      -0.93577   0.08383 -11.16

```

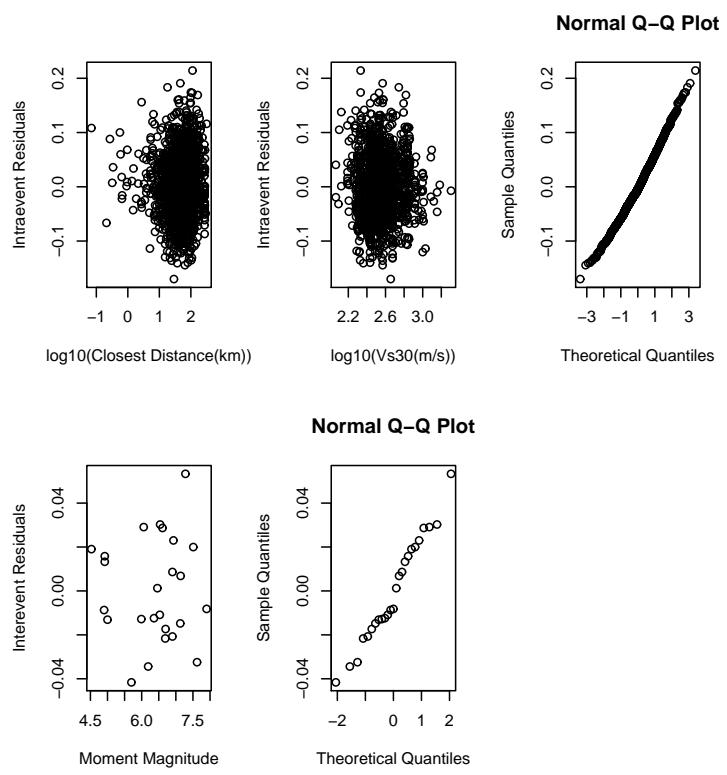


Figure 19: Characteristics of residuals of Correlation of time-frequency of minor group

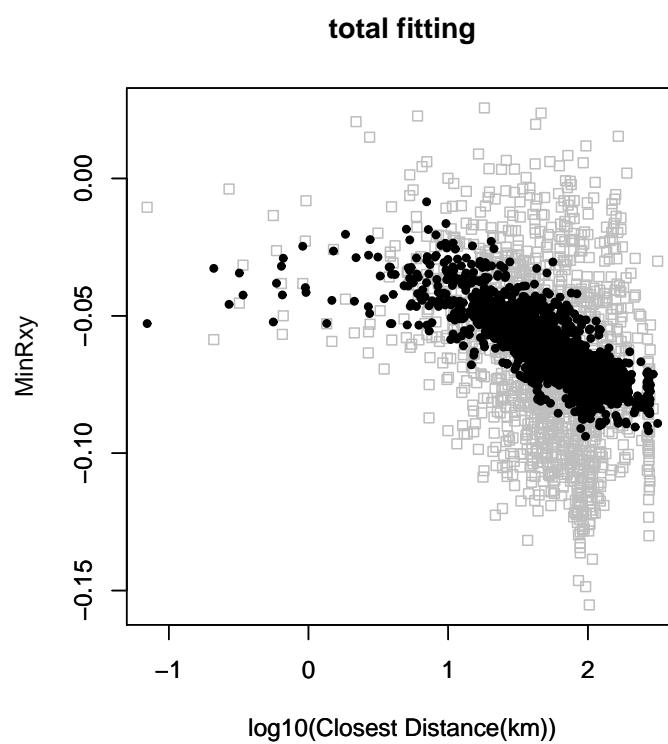


Figure 20: Median prediction of Correlation of time-frequency of minor group

```

Correlation of Fixed Effects:
              (Intr) Mw     ln_Mw   ln_R
Mw            0.984
ln_Mw        -0.994 -0.997
ln_R         -0.106 -0.085  0.082
ln_VS30      -0.080 -0.034  0.031  0.187

> cor(qqnorm(resid(MixEFREG))$x, resid(MixEFREG))
[1] 0.998153

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])
[1] 0.99286

```

Figure 21 (page 32)
 Figure 22 (page 33)

2.12 Natural log of total energy of wavelet packets

2.12.1 summary of regression

```

> summary(MixEFREG)

Linear mixed-effects model fit by REML
Formula: yseries ~ Mw + ln_Mw + ln_R + ln_VS30 + (1 | as.factor(I_EQ))
      AIC    BIC logLik MLdeviance REMLdeviance
      3636  3667  -1812       3616       3624
Random effects:
Groups           Name        Variance Std.Dev.
as.factor(I_EQ) (Intercept) 0.20099  0.44832
Residual          0.73369  0.85656
number of obs: 1408, groups: as.factor(I_EQ), 25

Fixed effects:
            Estimate Std. Error t value
(Intercept) -27.67891   6.66376  -4.15
Mw           -2.65489   1.39180  -1.91
ln_Mw        27.41685   8.38618   3.27
ln_R         -1.61536   0.03746 -43.12
ln_VS30      -0.88329   0.06288 -14.05

Correlation of Fixed Effects:
              (Intr) Mw     ln_Mw   ln_R
Mw            0.983
ln_Mw        -0.993 -0.997
ln_R         -0.119 -0.095  0.092
ln_VS30      -0.089 -0.037  0.034  0.186

```

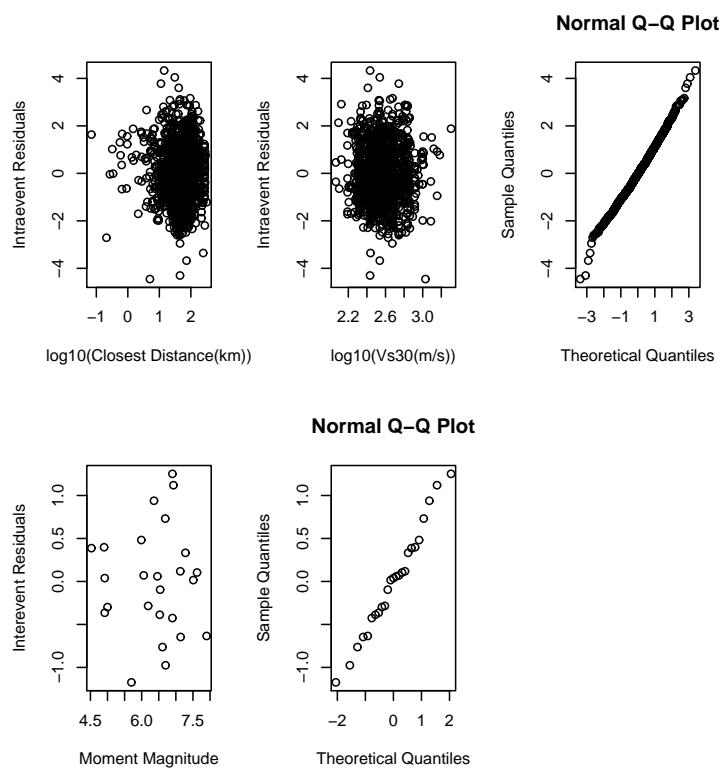


Figure 21: Characteristics of residuals of Natural log of mean amplitude of major group

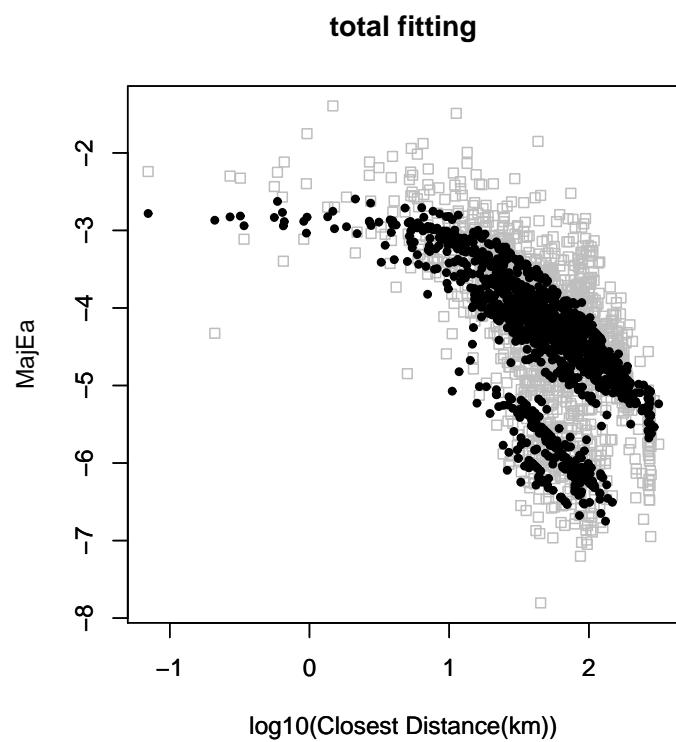


Figure 22: Median prediction of Natural log of mean amplitude of major group

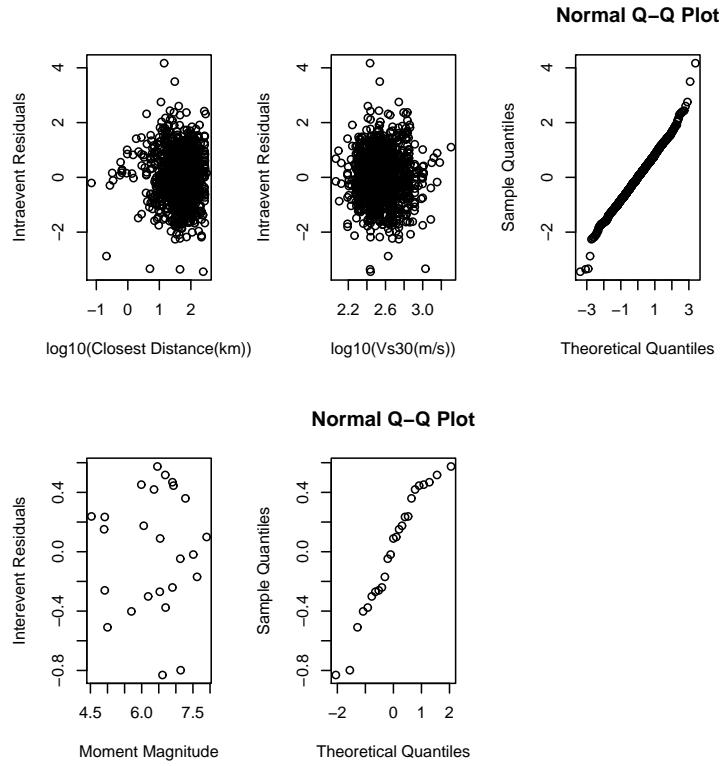


Figure 23: Characteristics of residuals of Natural log of total energy of wavelet packets

```
> cor(qqnorm(resid(MixEFREG))$x, resid(MixEFREG))
[1] 0.9973074

> cor(qqnorm(ranef(MixEFREG)[[1]][, 1])$x, ranef(MixEFREG)[[1]][,
+      1])
[1] 0.9777516
```

Figure 23 (page 34)
 Figure 24 (page 35)

2.13 Random factor for wavelet packets of minor group

2.14 Random factor of minor group

Figure 25 (page 36)

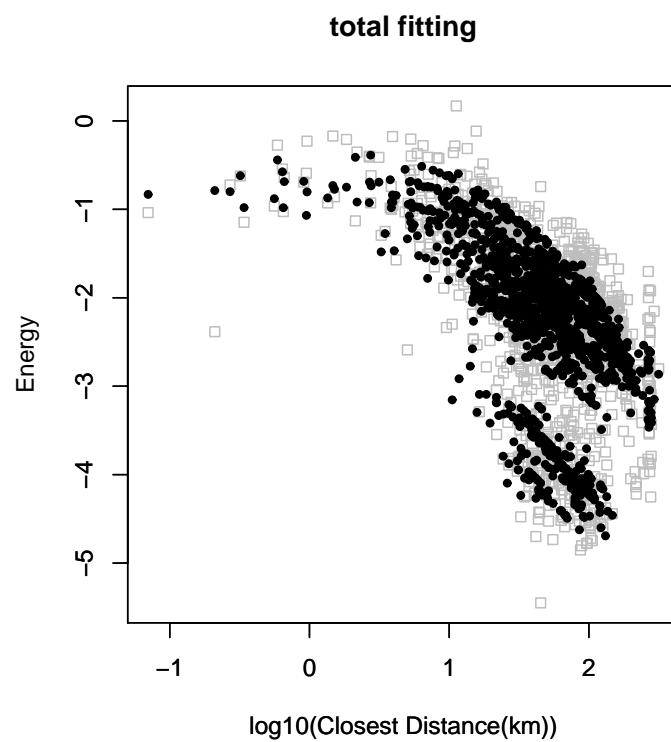


Figure 24: Median prediction of Natural log of total energy of wavelet packets

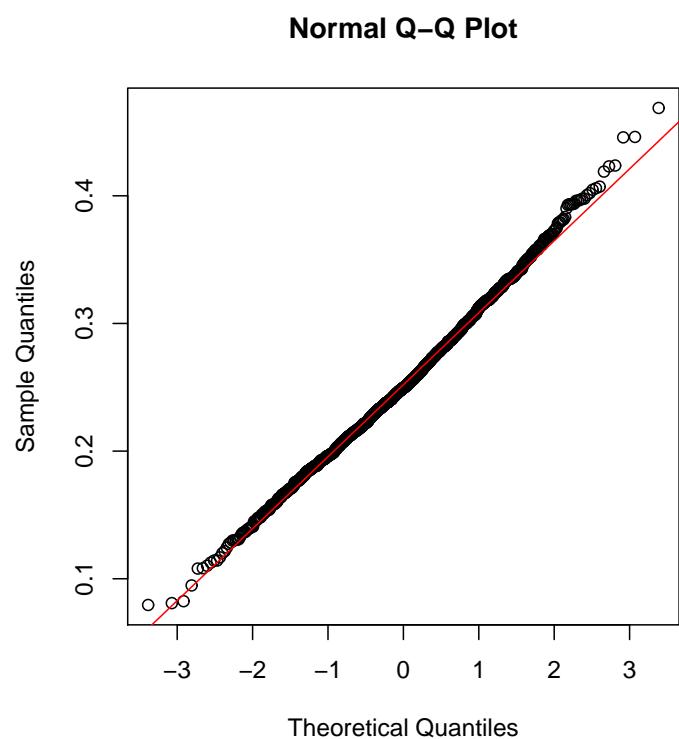


Figure 25: Characteristics of residuals from estimated bivariate lognormal distribution of minor group

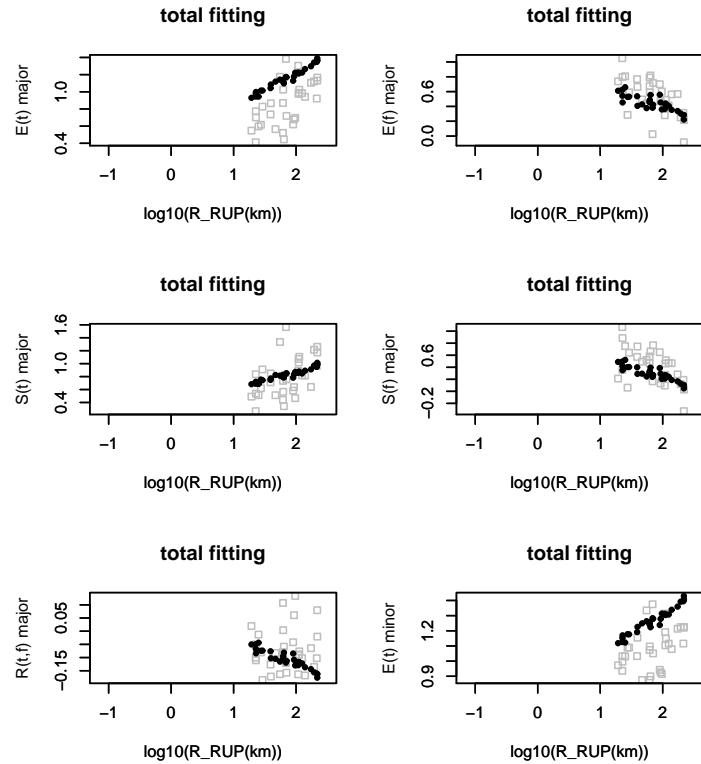


Figure 26: $ID = 30$, Natural log of total energy of wavelet packets

3 Fitting for each earthquake event

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

Figure 26 (page 37)

Figure 27 (page 38)

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

Figure 28 (page 39)

Figure 29 (page 40)

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

Figure 30 (page 41)

Figure 31 (page 42)

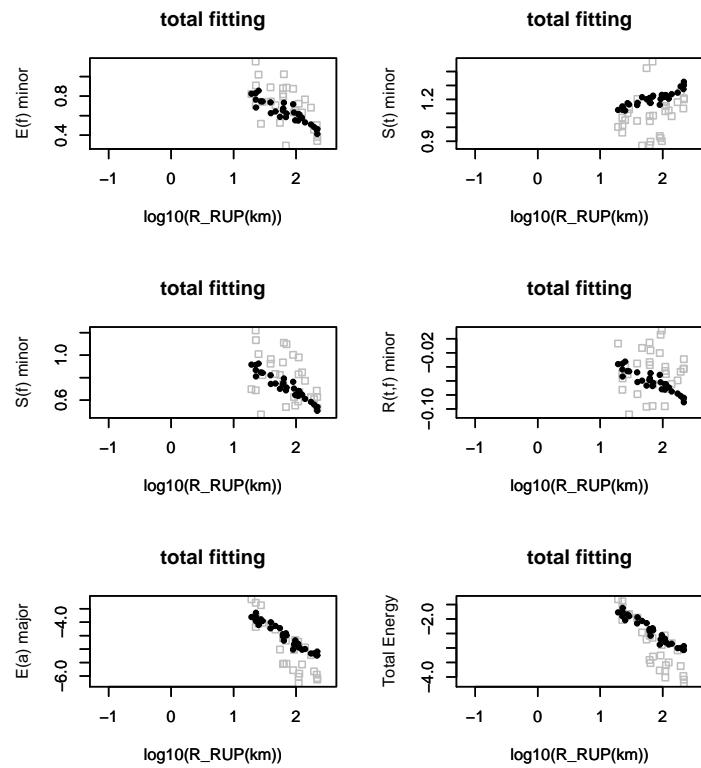


Figure 27: $ID = 30$, Natural log of total energy of wavelet packets

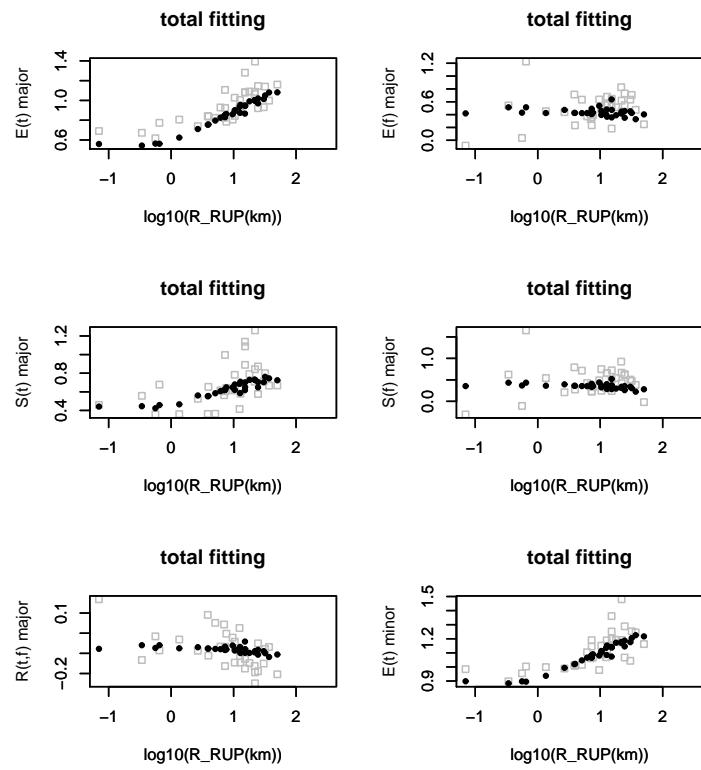


Figure 28: $ID = 50$, Natural log of total energy of wavelet packets

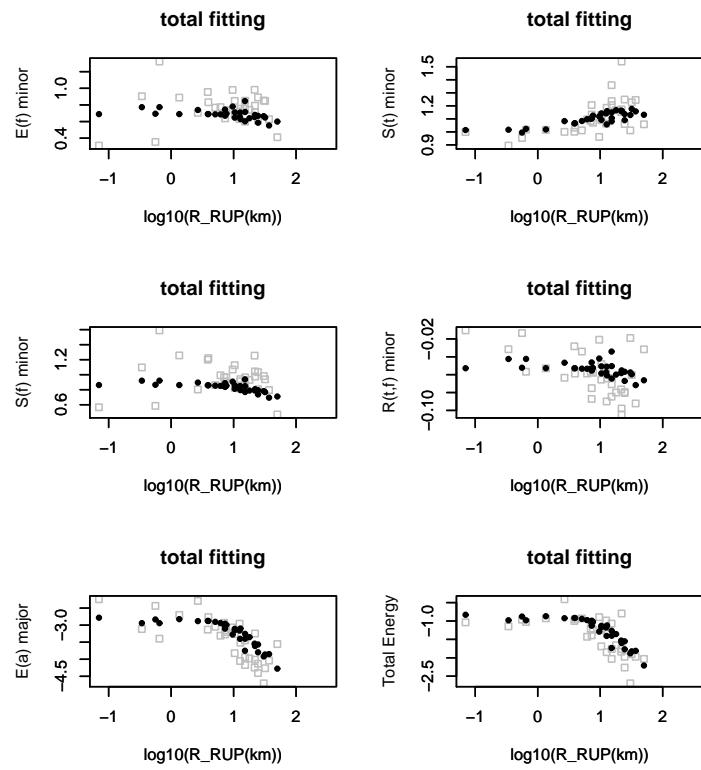


Figure 29: $ID = 50$, Natural log of total energy of wavelet packets

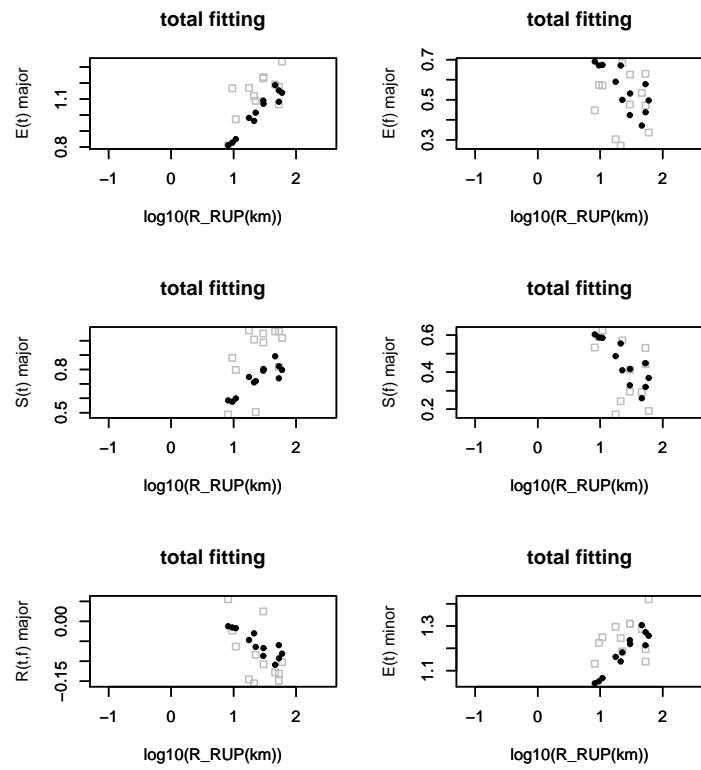


Figure 30: $ID = 68$, Natural log of total energy of wavelet packets

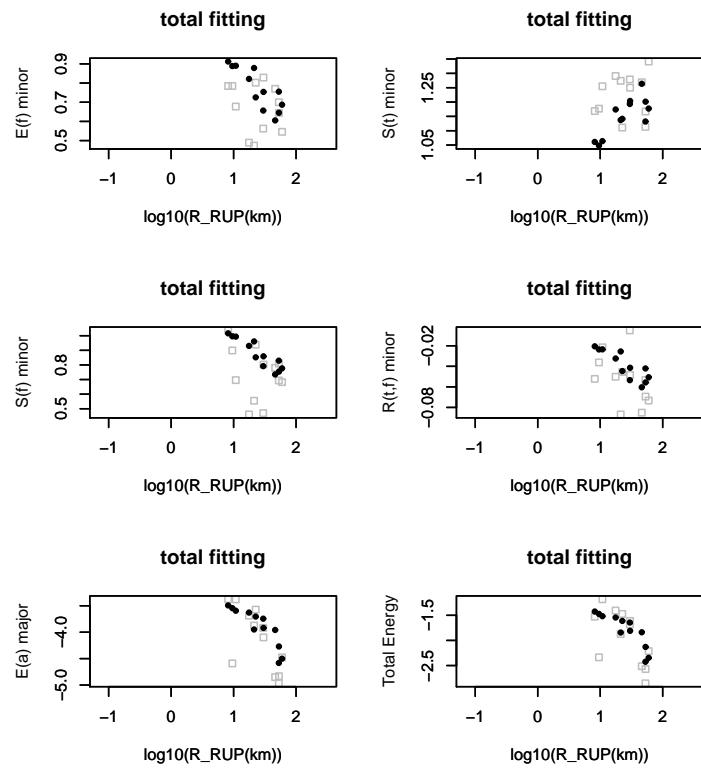


Figure 31: $ID = 68$, Natural log of total energy of wavelet packets

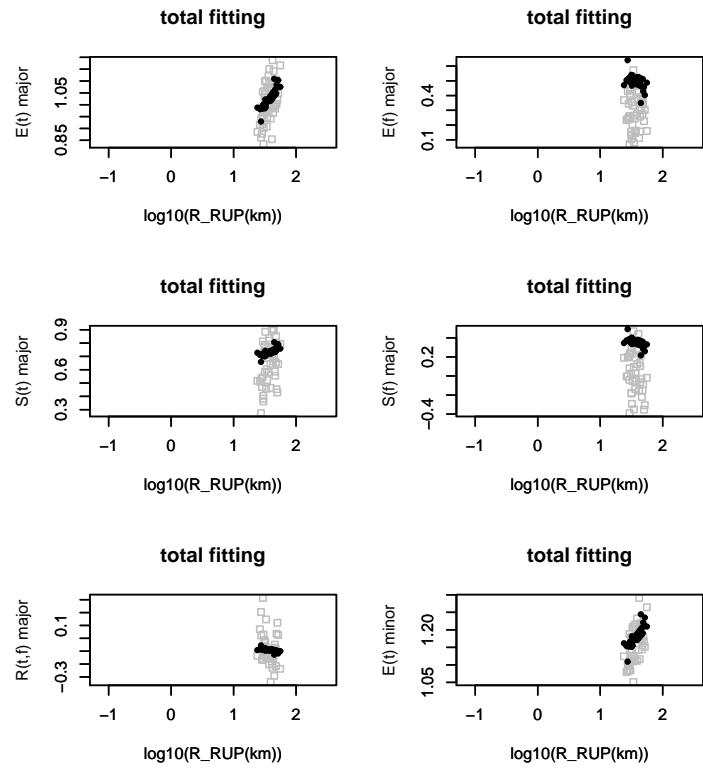


Figure 32: $ID = 76$, Natural log of total energy of wavelet packets

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

Figure 32 (page 43)

Figure 33 (page 44)

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

Figure 34 (page 45)

Figure 35 (page 46)

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

Figure 36 (page 47)

Figure 37 (page 48)

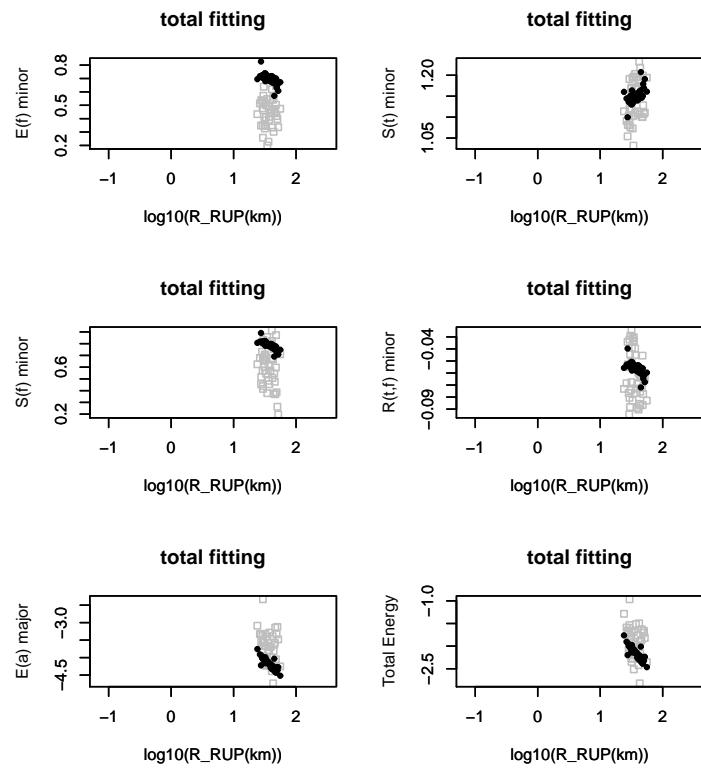


Figure 33: $ID = 76$, Natural log of total energy of wavelet packets

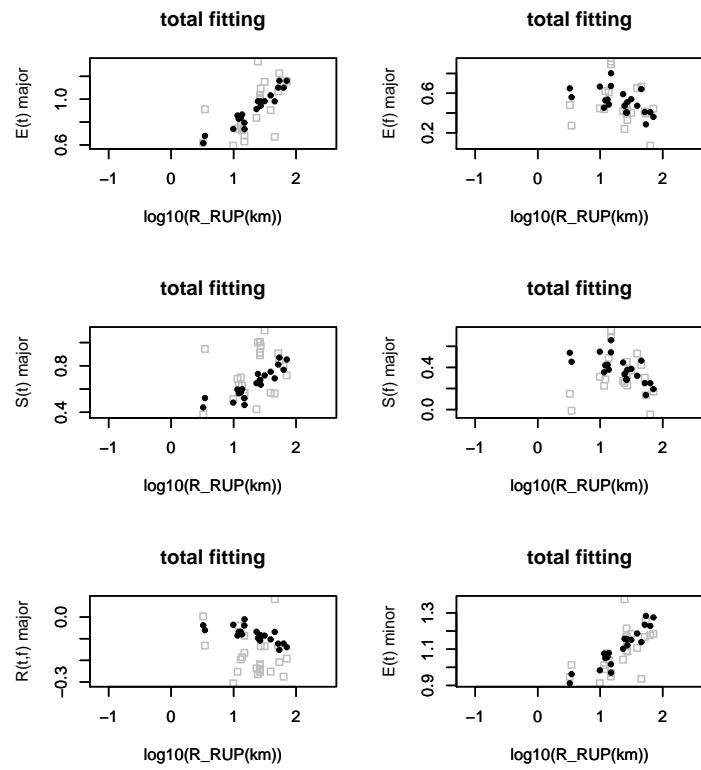


Figure 34: $ID = 90$, Natural log of total energy of wavelet packets

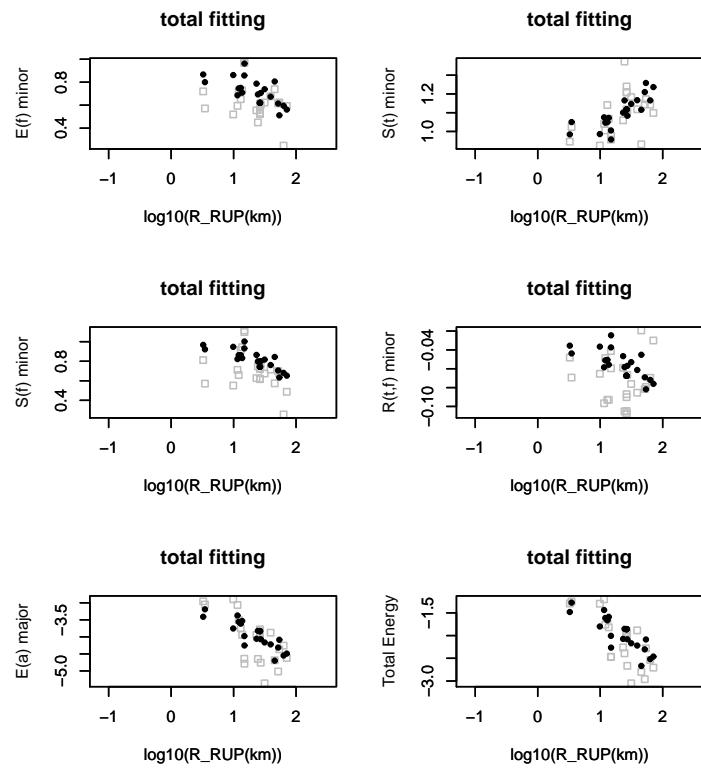


Figure 35: $ID = 90$, Natural log of total energy of wavelet packets

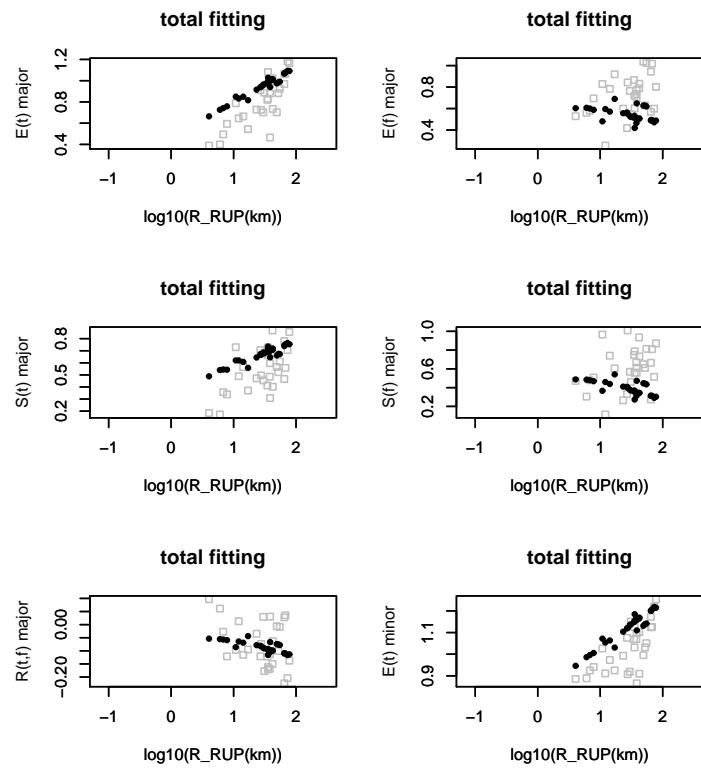


Figure 36: $ID = 101$, Natural log of total energy of wavelet packets

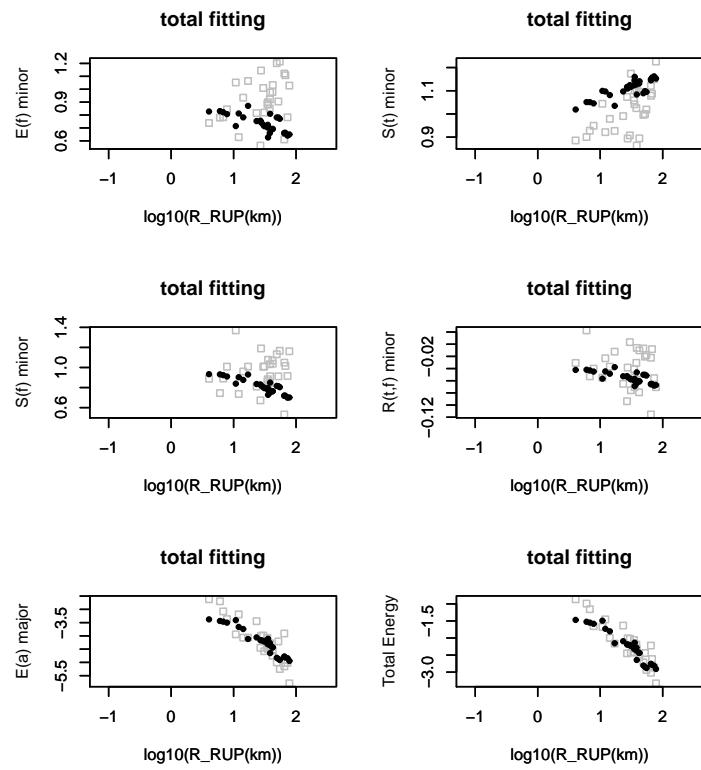


Figure 37: $ID = 101$, Natural log of total energy of wavelet packets

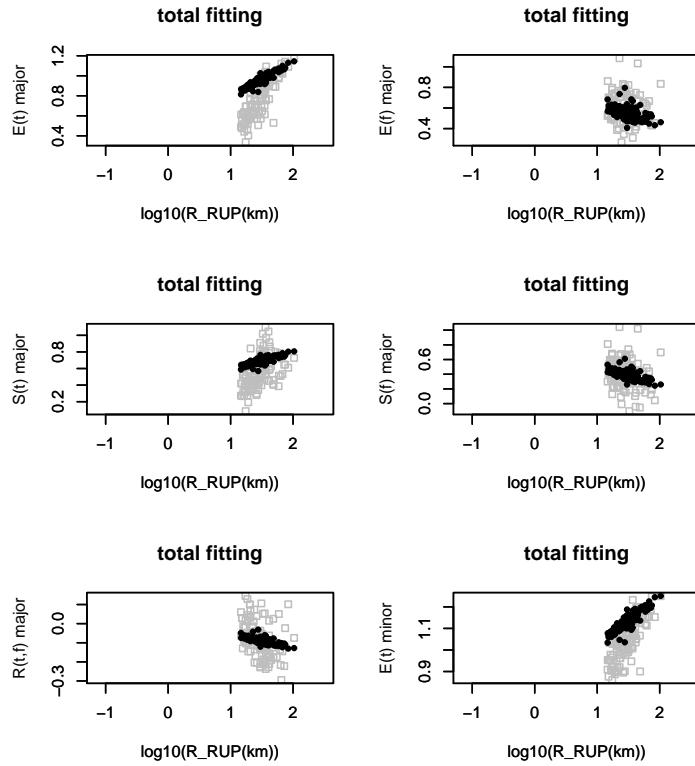


Figure 38: $ID = 113$, Natural log of total energy of wavelet packets

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

Figure 38 (page 49)

Figure 39 (page 50)

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

Figure 40 (page 51)

Figure 41 (page 52)

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

Figure 42 (page 53)

Figure 43 (page 54)

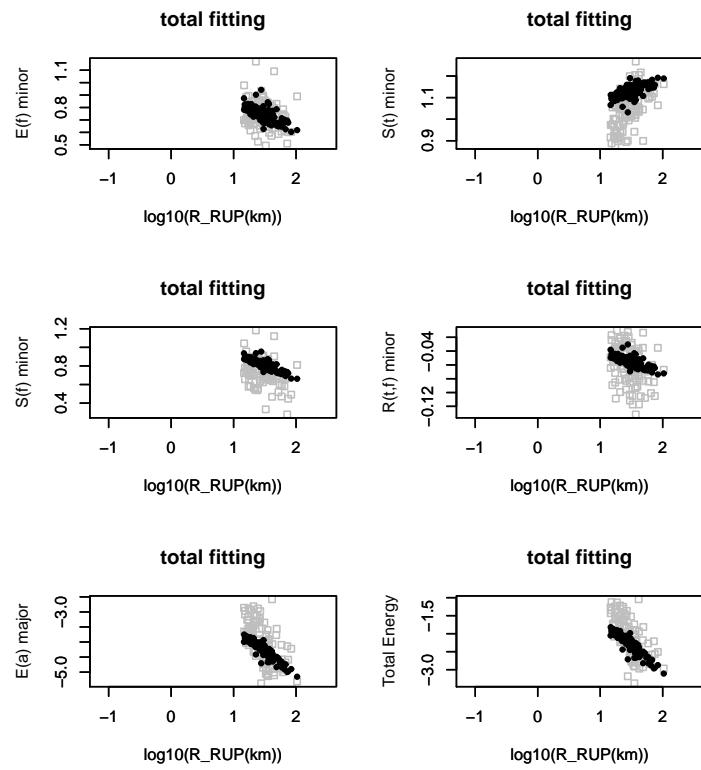


Figure 39: $ID = 113$, Natural log of total energy of wavelet packets

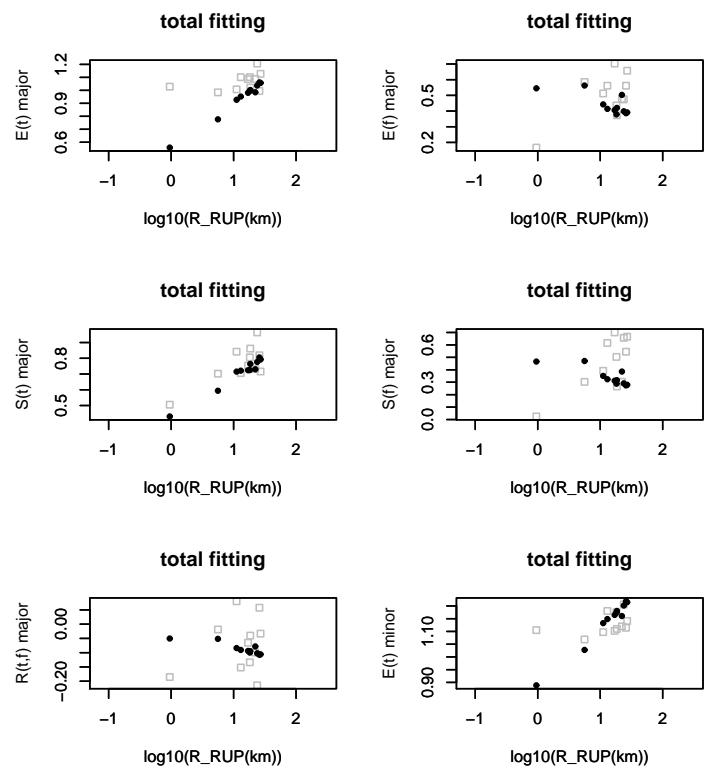


Figure 40: $ID = 116$, Natural log of total energy of wavelet packets

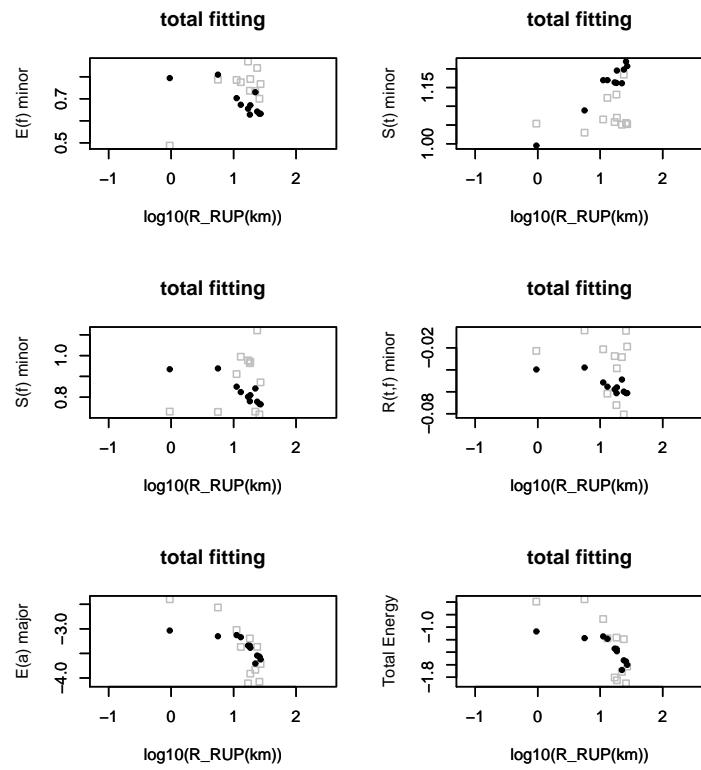


Figure 41: $ID = 116$, Natural log of total energy of wavelet packets

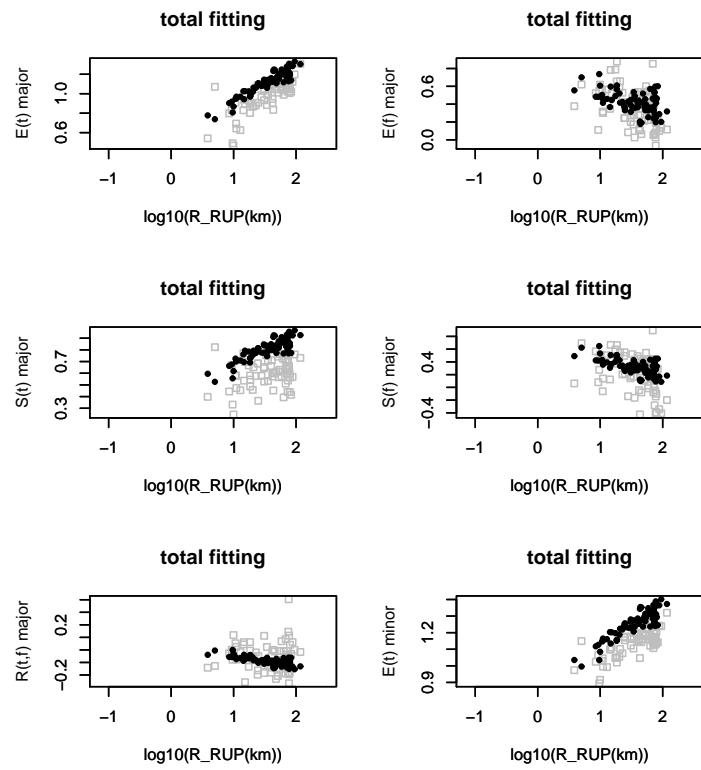


Figure 42: $ID = 118$, Natural log of total energy of wavelet packets

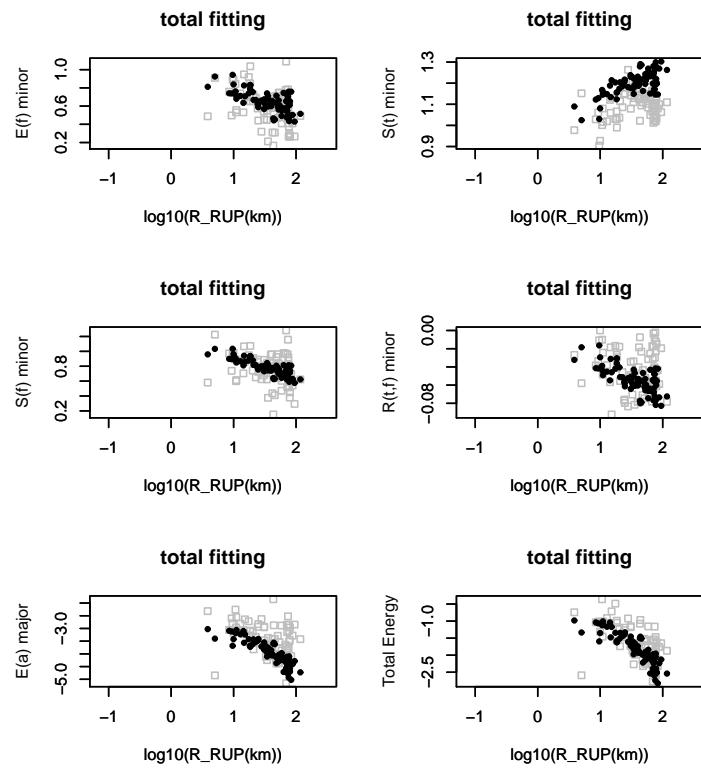


Figure 43: $ID = 118$, Natural log of total energy of wavelet packets

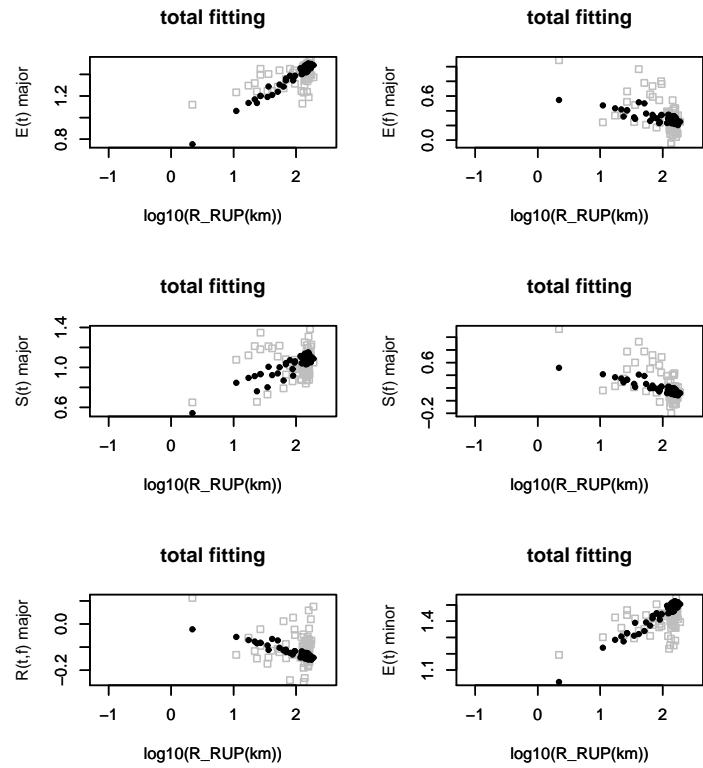


Figure 44: $ID = 125$, Natural log of total energy of wavelet packets

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

Figure 44 (page 55)

Figure 45 (page 56)

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

Figure 46 (page 57)

Figure 47 (page 58)

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

Figure 48 (page 59)

Figure 49 (page 60)

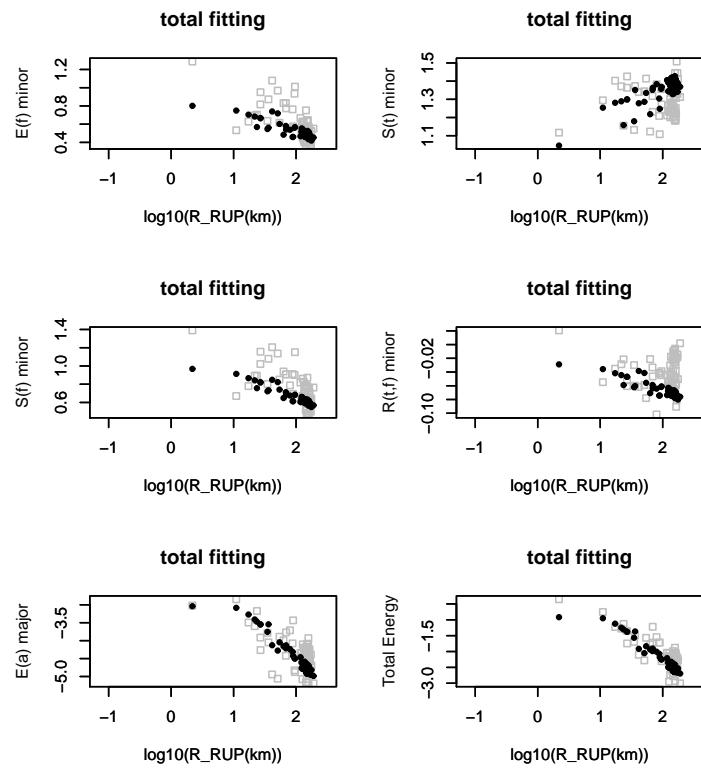


Figure 45: $ID = 125$, Natural log of total energy of wavelet packets

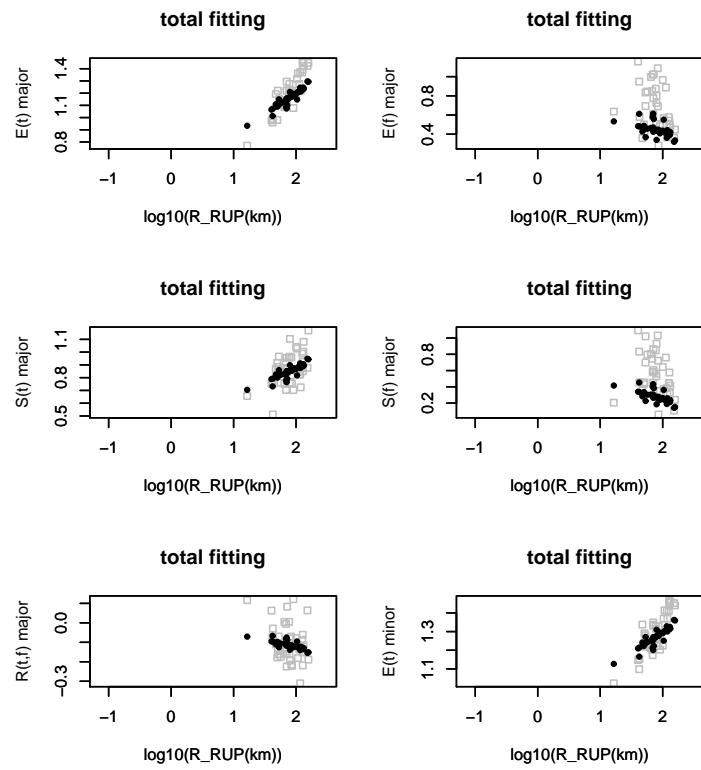


Figure 46: $ID = 126$, Natural log of total energy of wavelet packets

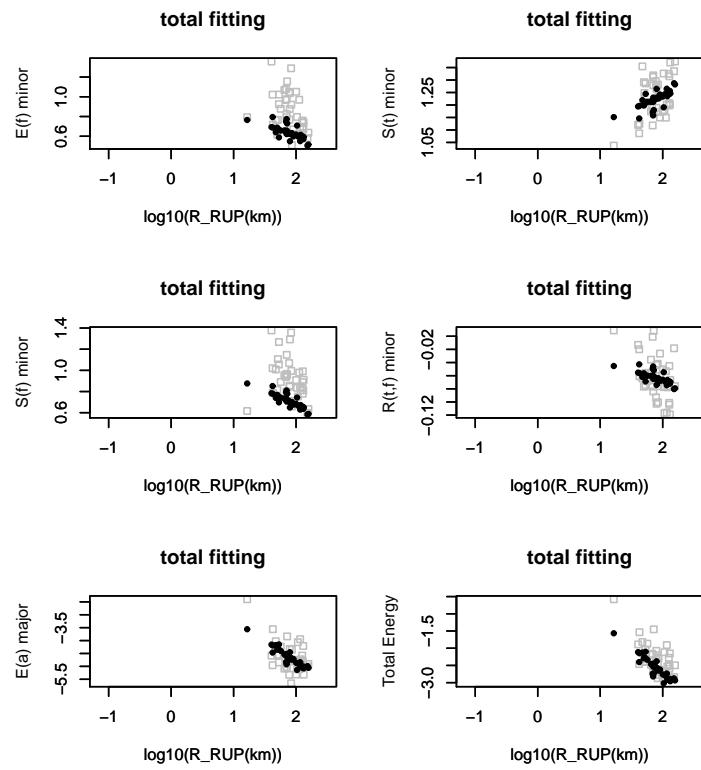


Figure 47: $ID = 126$, Natural log of total energy of wavelet packets

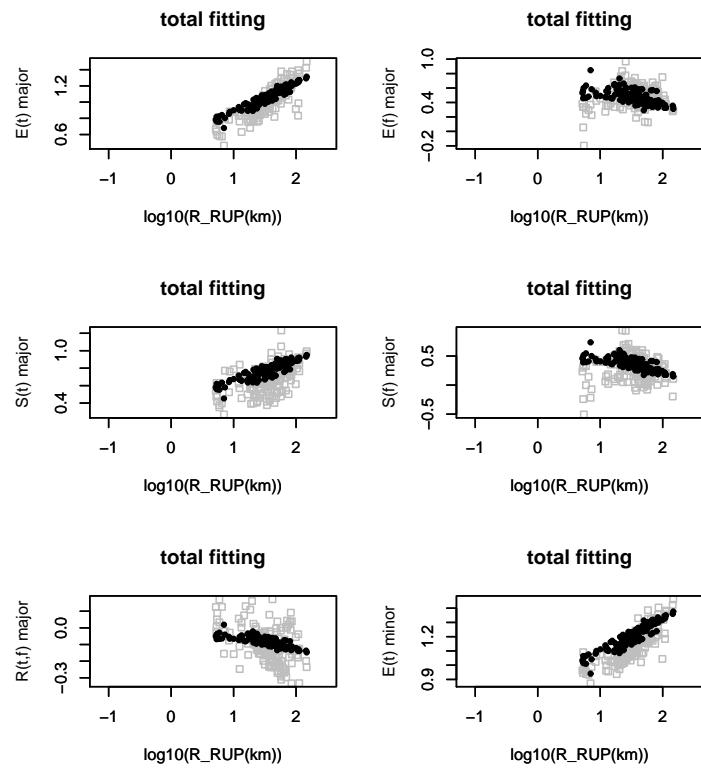


Figure 48: $ID = 127$, Natural log of total energy of wavelet packets

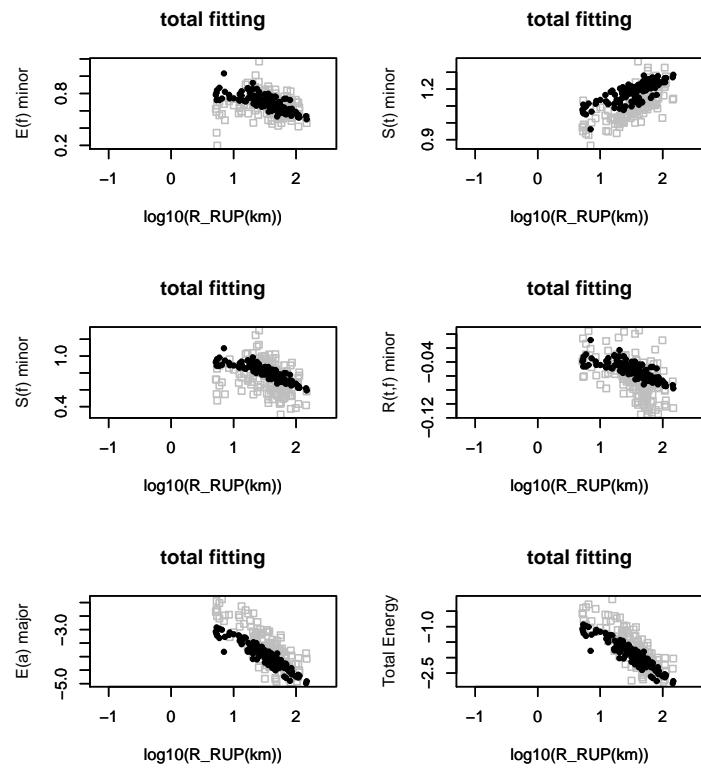


Figure 49: $ID = 127$, Natural log of total energy of wavelet packets

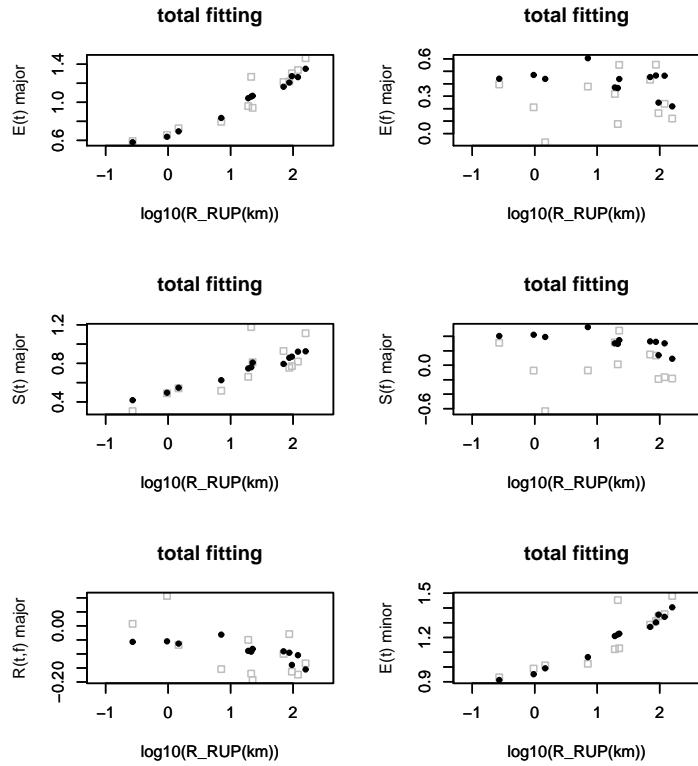


Figure 50: $ID = 129$, Natural log of total energy of wavelet packets

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

Figure 50 (page 61)

Figure 51 (page 62)

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

Figure 52 (page 63)

Figure 53 (page 64)

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

Figure 54 (page 65)

Figure 55 (page 66)

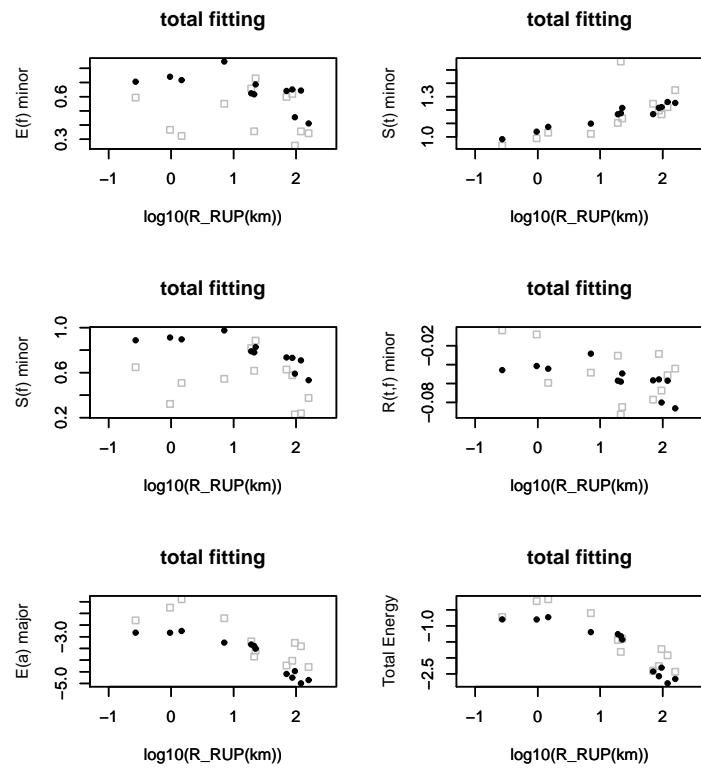


Figure 51: $ID = 129$, Natural log of total energy of wavelet packets

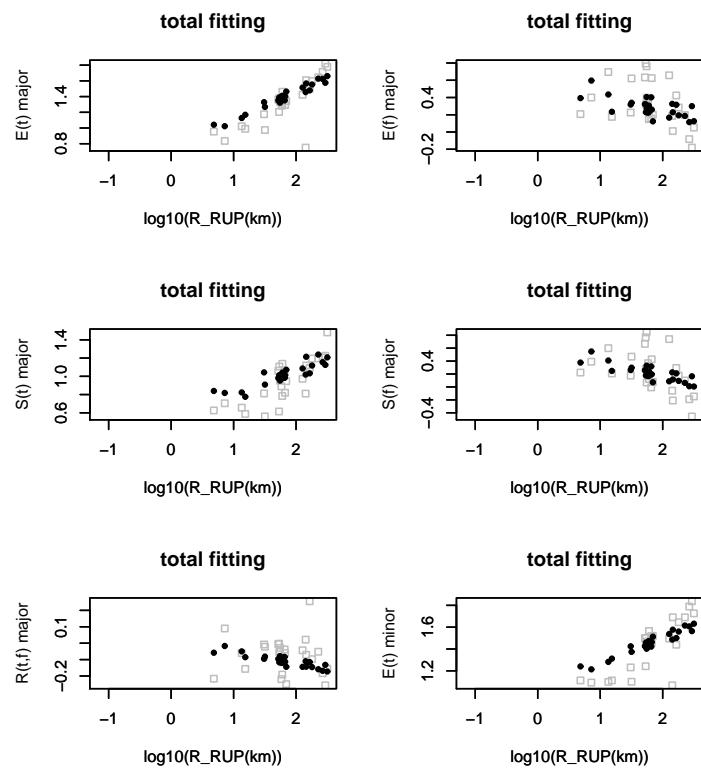


Figure 52: $ID = 136$, Natural log of total energy of wavelet packets

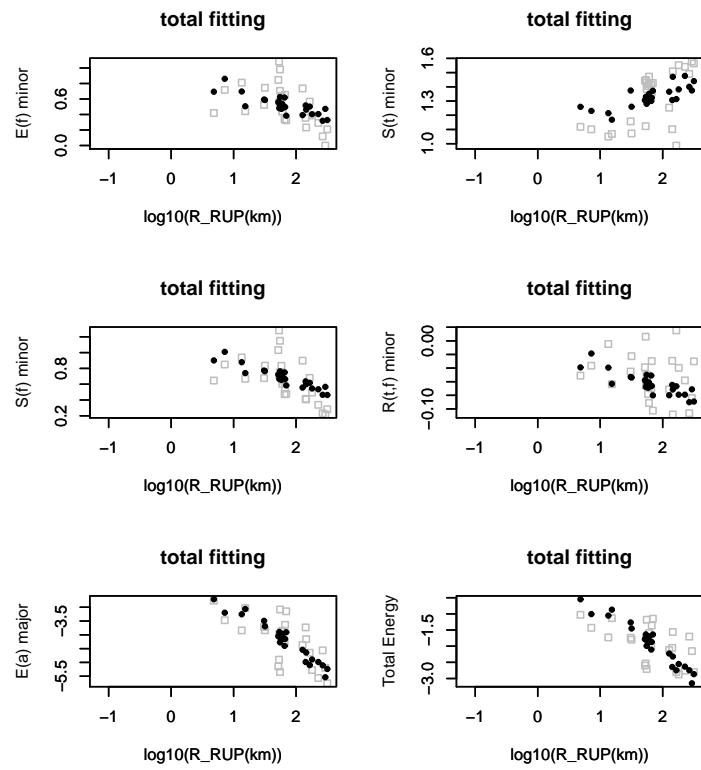


Figure 53: $ID = 136$, Natural log of total energy of wavelet packets

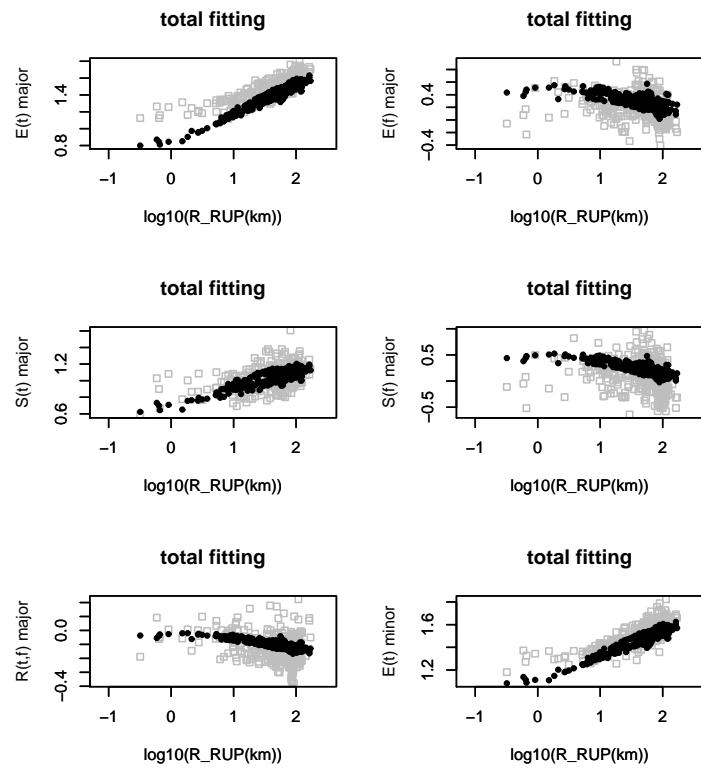


Figure 54: $ID = 137$, Natural log of total energy of wavelet packets

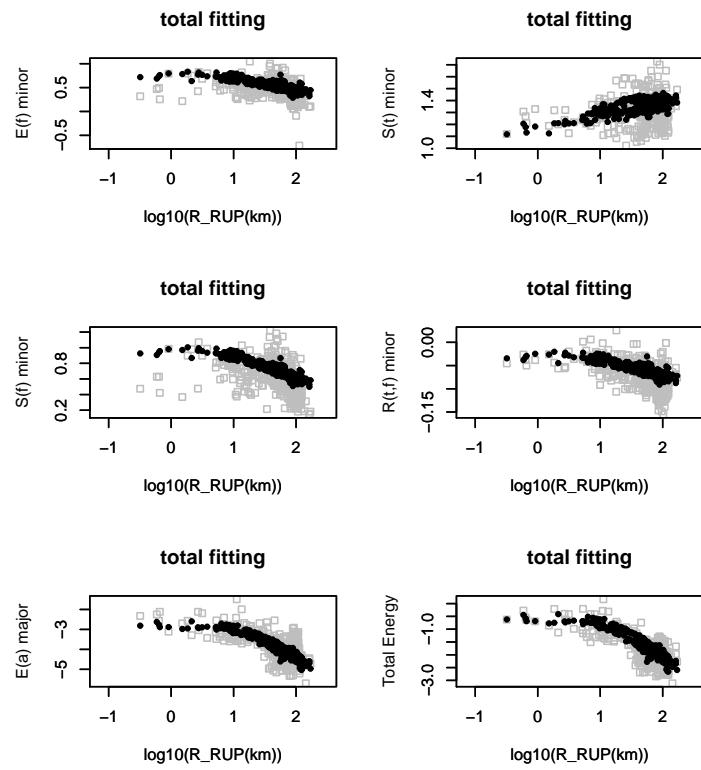


Figure 55: $ID = 137$, Natural log of total energy of wavelet packets

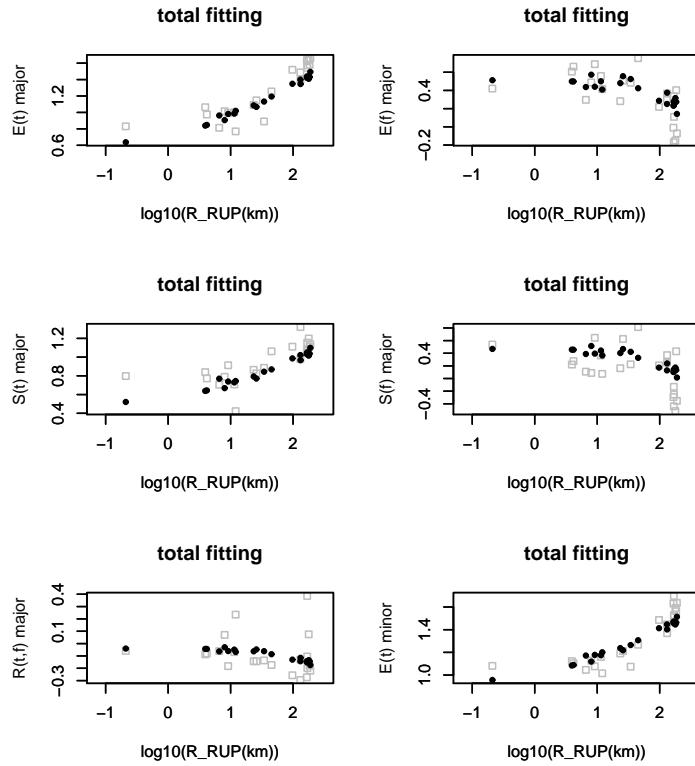


Figure 56: $ID = 138$, Natural log of total energy of wavelet packets

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

Figure 56 (page 67)

Figure 57 (page 68)

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

Figure 58 (page 69)

Figure 59 (page 70)

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

Figure 60 (page 71)

Figure 61 (page 72)

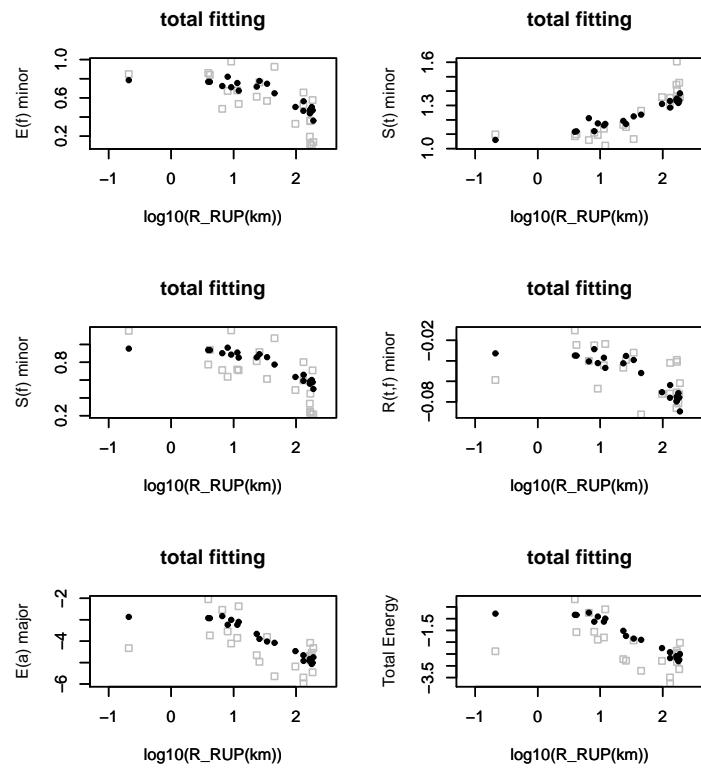


Figure 57: $ID = 138$, Natural log of total energy of wavelet packets

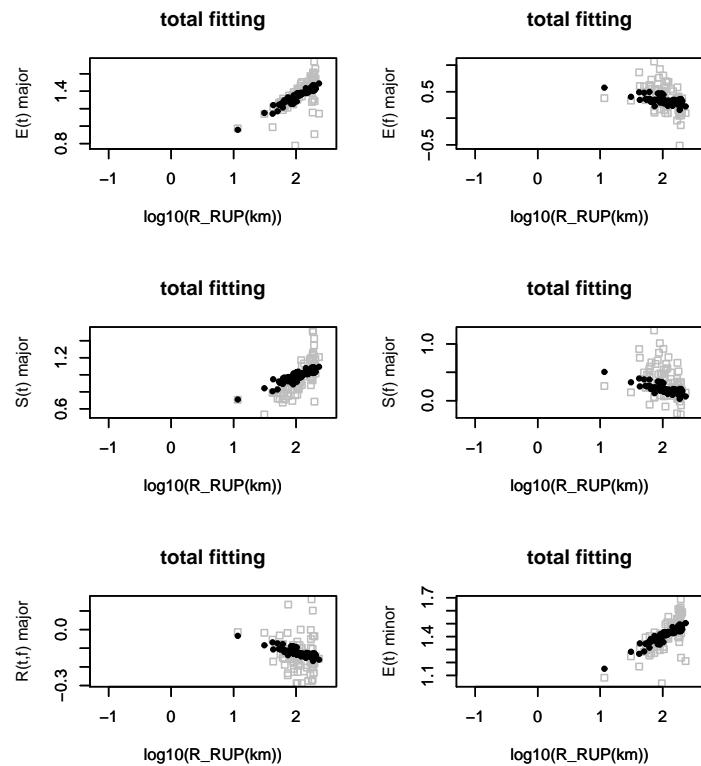


Figure 58: $ID = 158$, Natural log of total energy of wavelet packets

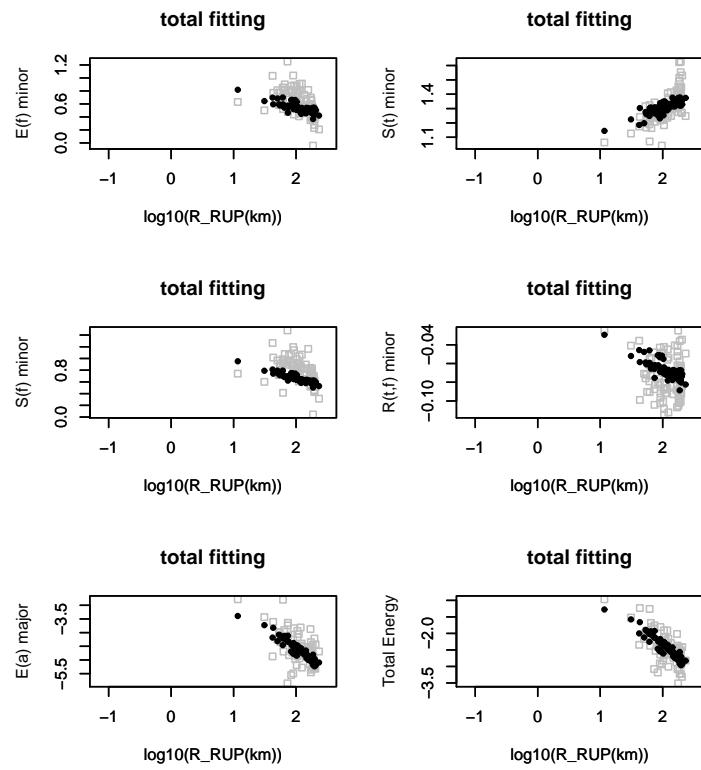


Figure 59: $ID = 158$, Natural log of total energy of wavelet packets

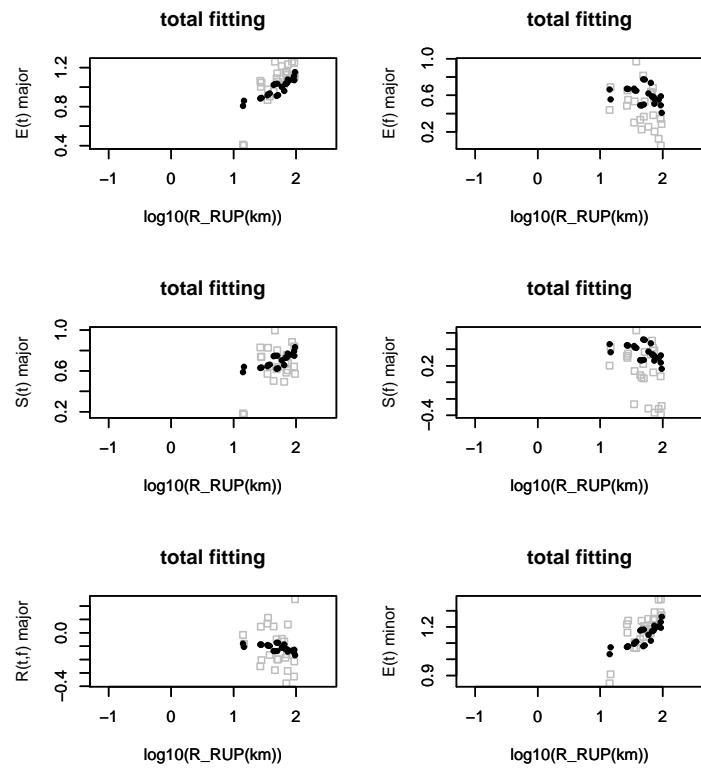


Figure 60: $ID = 160$, Natural log of total energy of wavelet packets

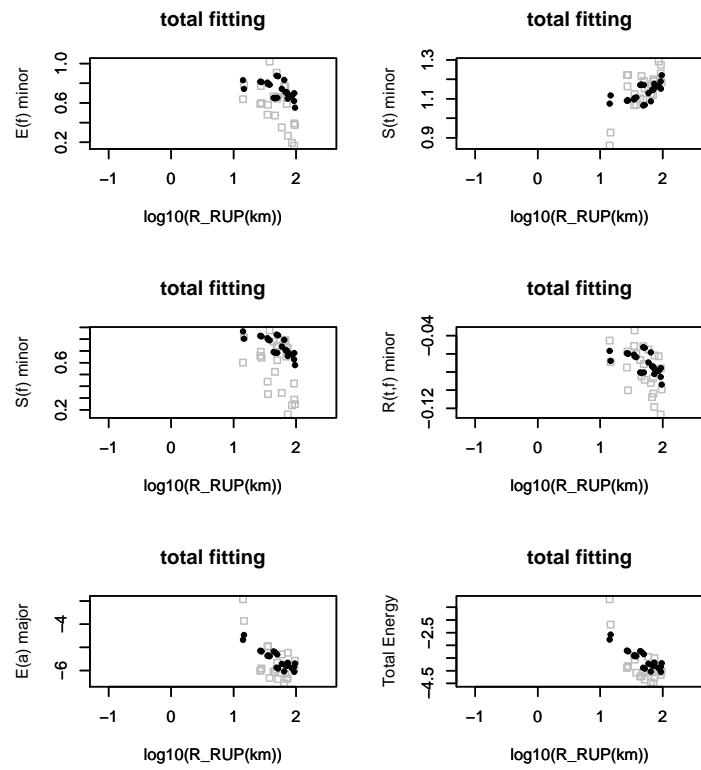


Figure 61: $ID = 160$, Natural log of total energy of wavelet packets

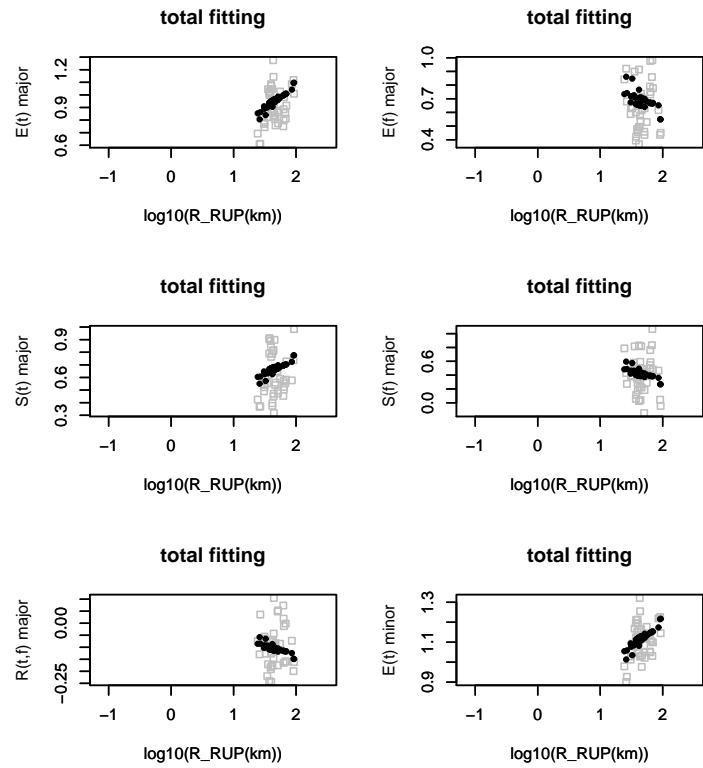


Figure 62: $ID = 161$, Natural log of total energy of wavelet packets

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

Figure 62 (page 73)

Figure 63 (page 74)

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

Figure 64 (page 75)

Figure 65 (page 76)

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

Figure 66 (page 77)

Figure 67 (page 78)

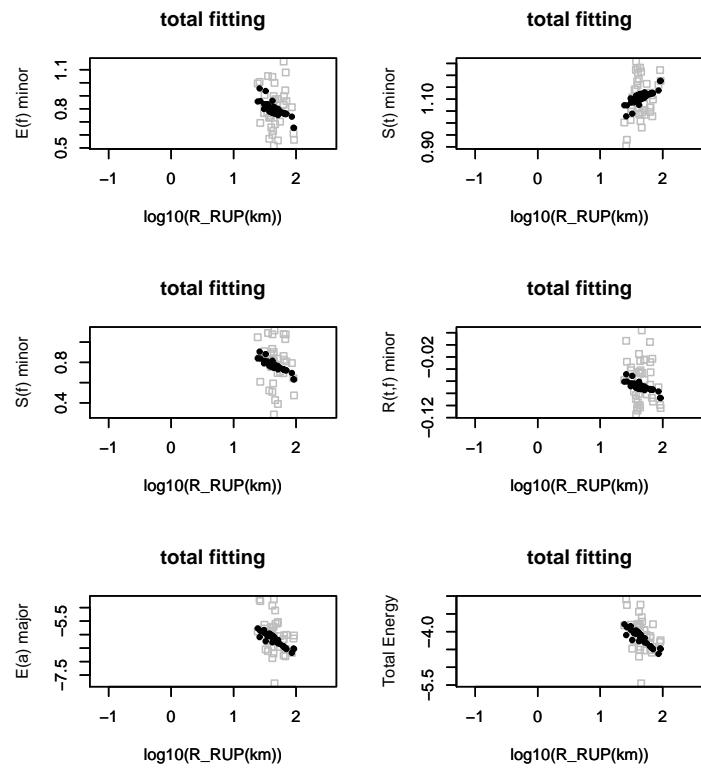


Figure 63: $ID = 161$, Natural log of total energy of wavelet packets

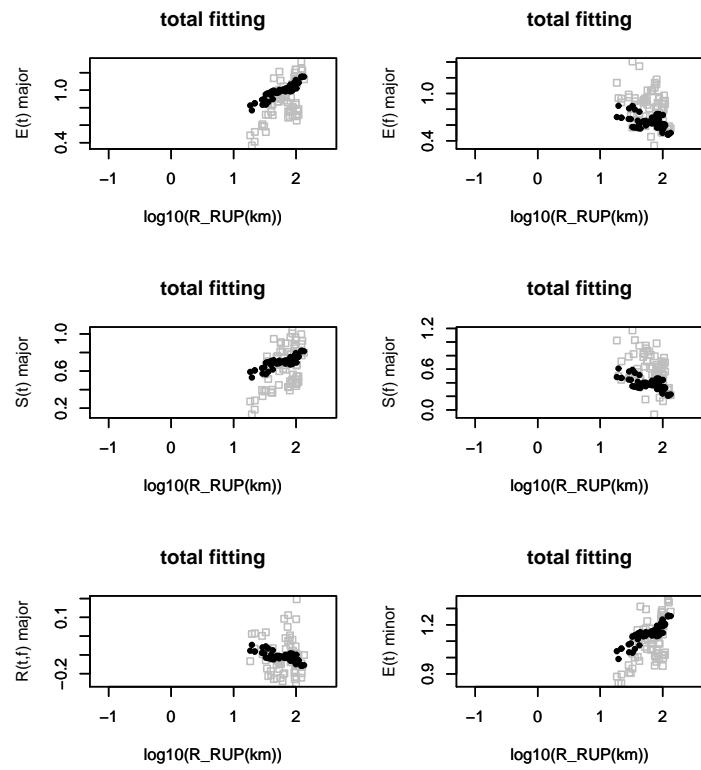


Figure 64: $ID = 163$, Natural log of total energy of wavelet packets

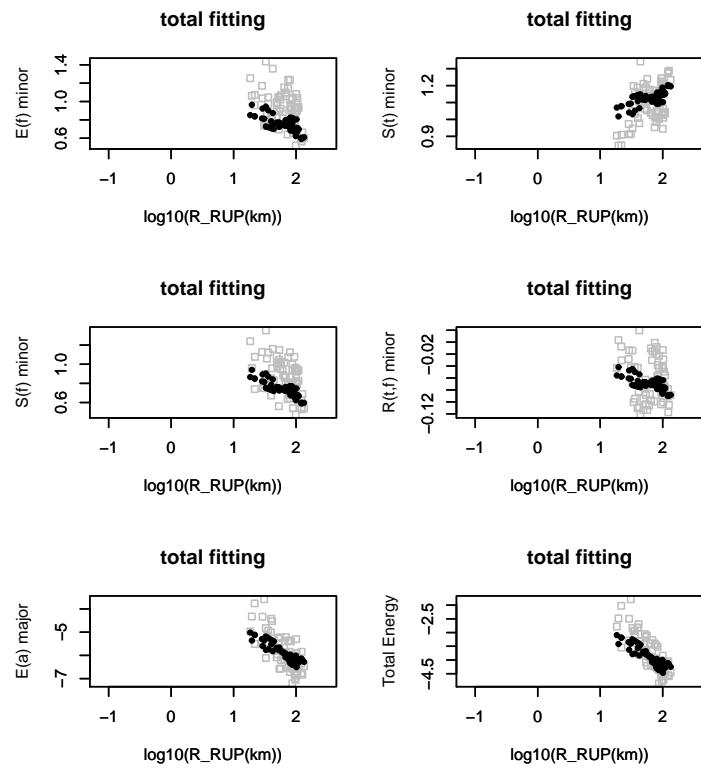


Figure 65: $ID = 163$, Natural log of total energy of wavelet packets

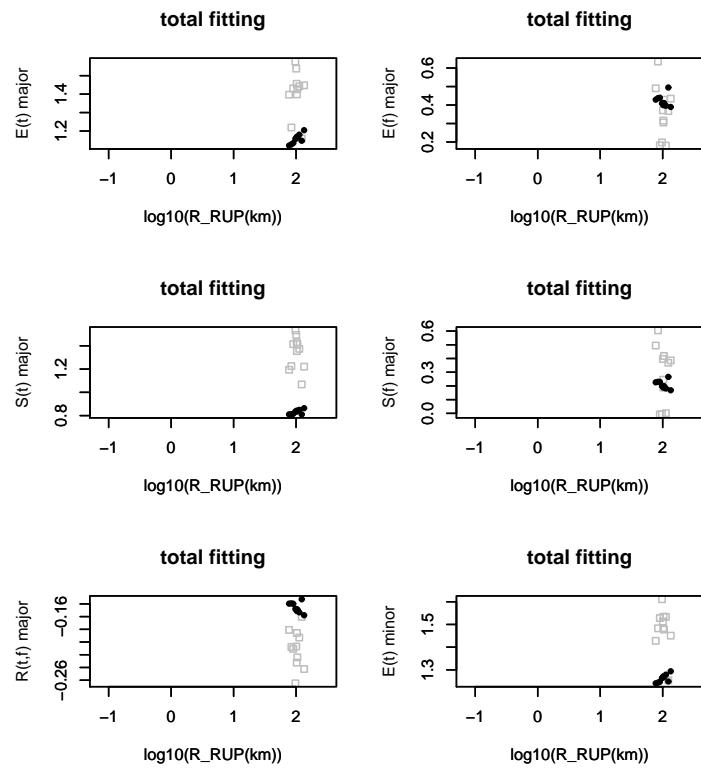


Figure 66: $ID = 164$, Natural log of total energy of wavelet packets

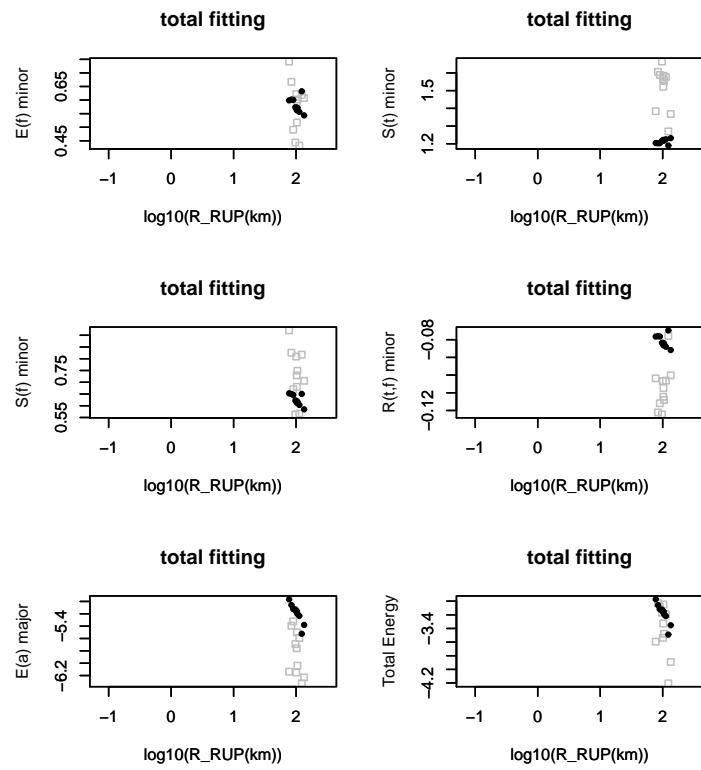


Figure 67: $ID = 164$, Natural log of total energy of wavelet packets

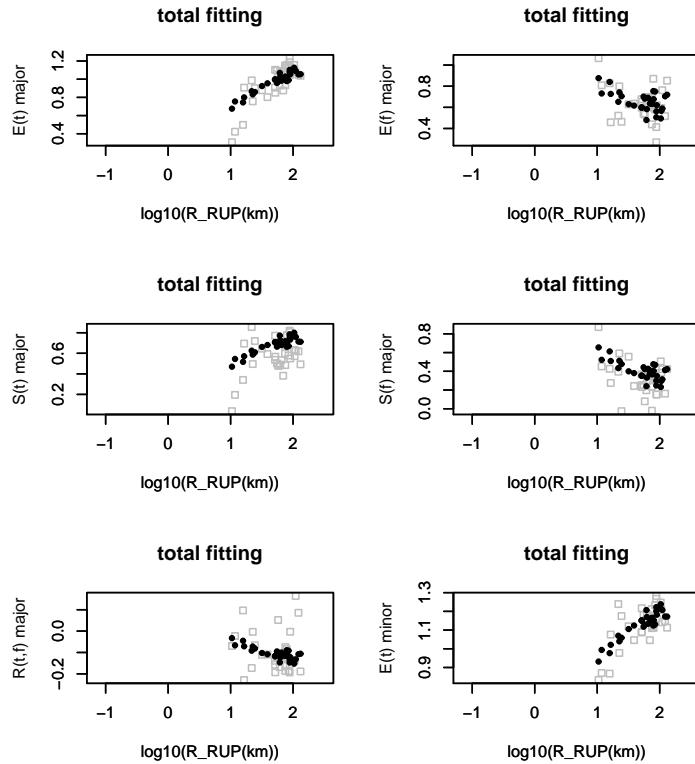


Figure 68: $ID = 166$, Natural log of total energy of wavelet packets

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

Figure 68 (page 79)

Figure 69 (page 80)

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

Figure 70 (page 81)

Figure 71 (page 82)

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

Figure 72 (page 83)

Figure 73 (page 84)

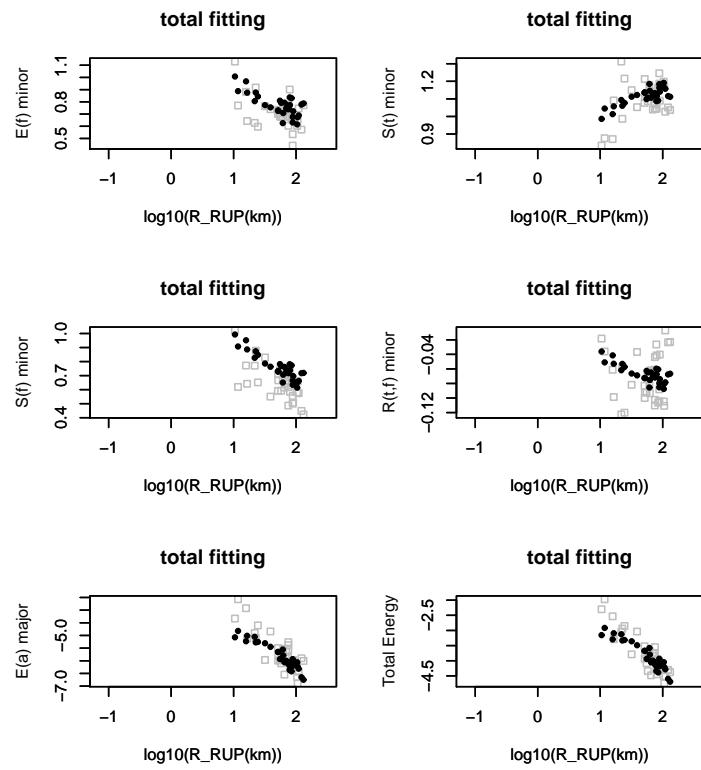


Figure 69: $ID = 166$, Natural log of total energy of wavelet packets

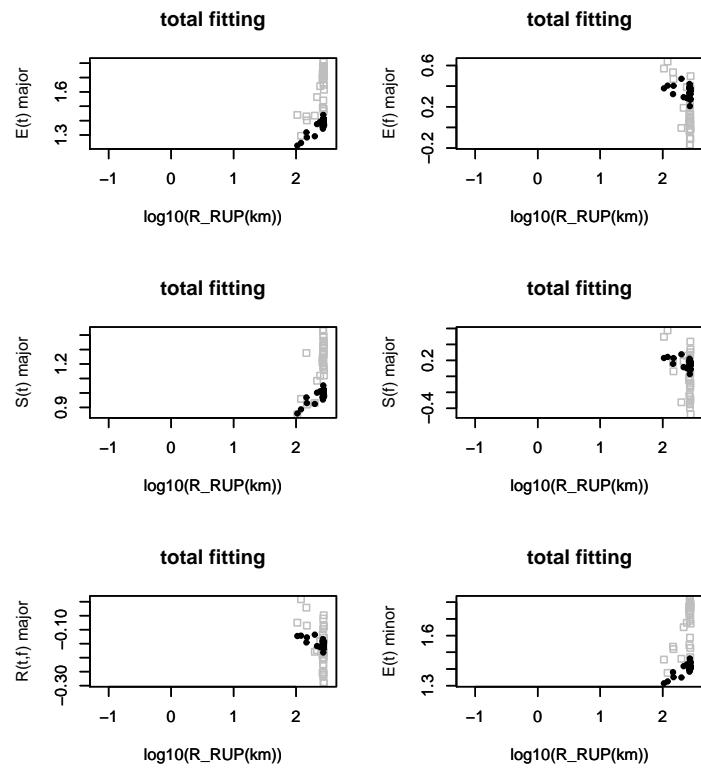


Figure 70: $ID = 168$, Natural log of total energy of wavelet packets

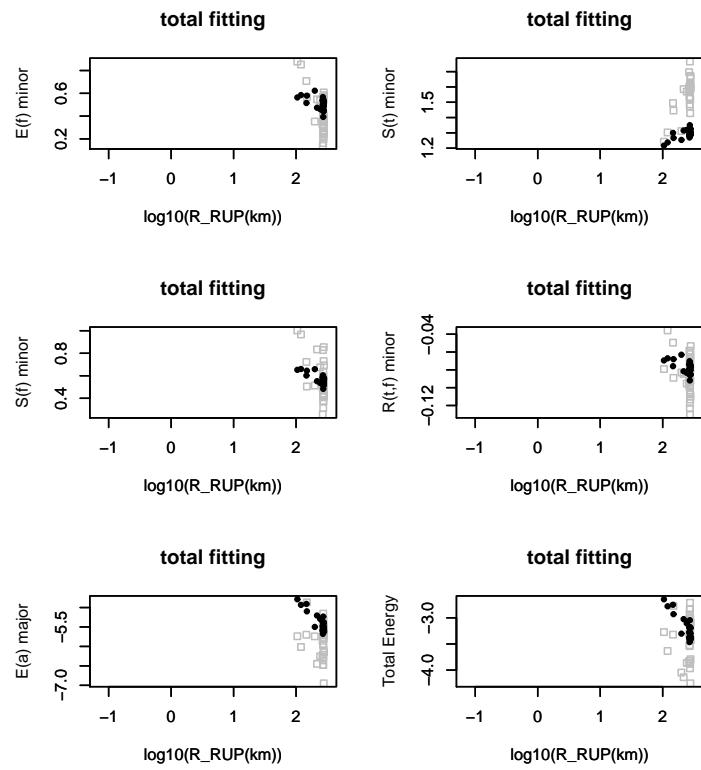


Figure 71: $ID = 168$, Natural log of total energy of wavelet packets

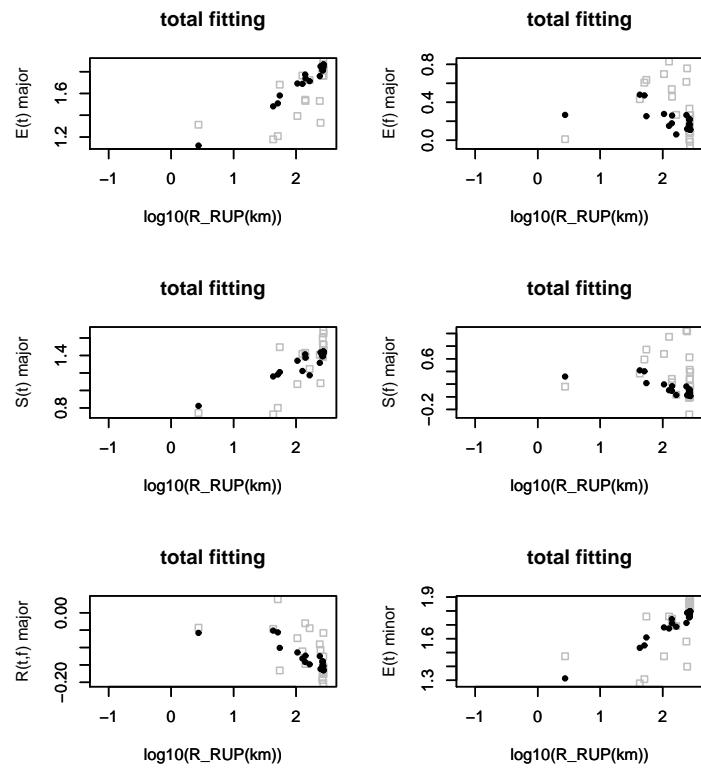


Figure 72: $ID = 169$, Natural log of total energy of wavelet packets

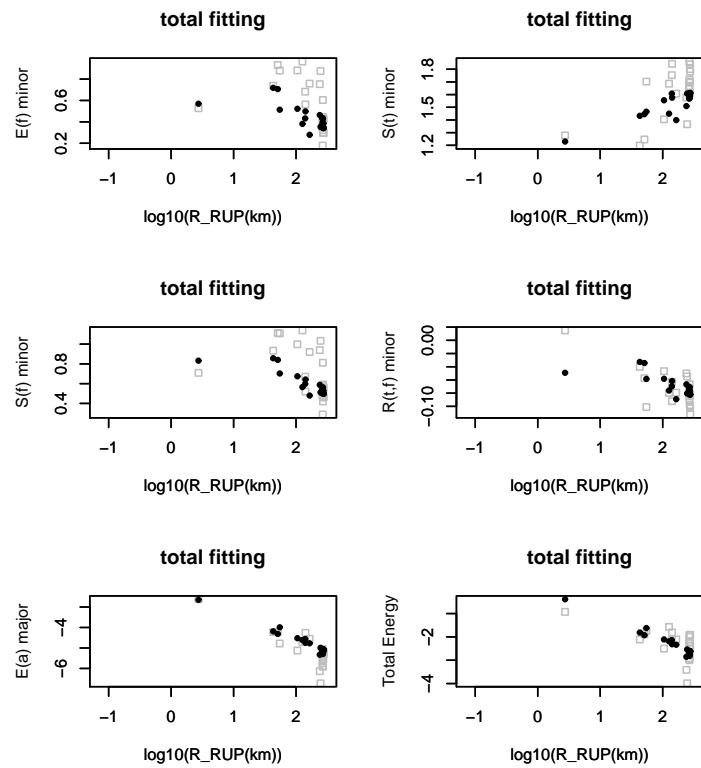


Figure 73: $ID = 169$, Natural log of total energy of wavelet packets

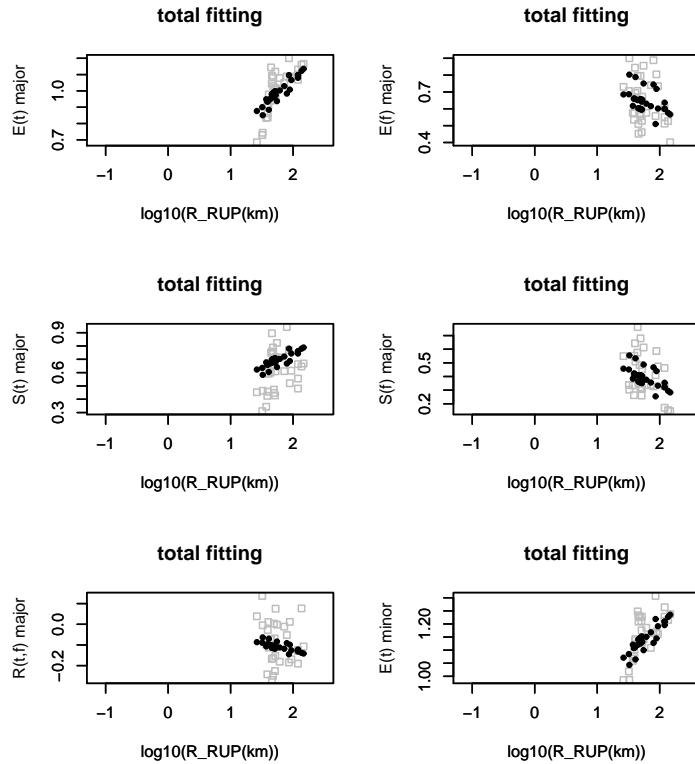


Figure 74: $ID = 170$, Natural log of total energy of wavelet packets

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

Figure 74 (page 85)

Figure 75 (page 86)

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.

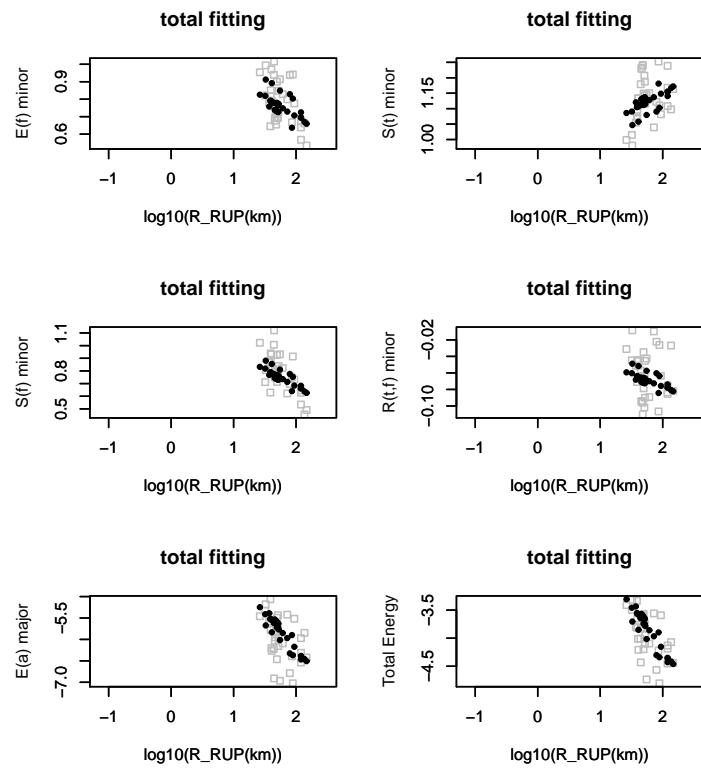


Figure 75: $ID = 170$, Natural log of total energy of wavelet packets