PEER LIFELINES PROGRAM

RUPTURE PROCESS OF THE 1999 DÜZCE EARTHQUAKE

FINAL REPORT

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Introduction

The November 12, 1999, Düzce (M_W=7.2) earthquake ruptured along the eastward extension of the Kocaeli earthquake of august, the same year (Figure 1). The surface rupture extended over a distance of les than 50 kilometers with an east-west strike, reaching a maximum slip of 4 meters. The westernmost part of the rupture was also active during the Kocaeli earthquake. Teleseismic waveform inversion and first motion solutions indicate that, contrary to the Kocaeli earthquake, this event had a very significant northward dip. We developed a rupture for this earthquake based on the inversion of local strong motion and teleseismic body waveforms.

Methodology

The method used is similar in spirit to the one originally introduced by Hartzell and Heaton (1983). In this study, the rupture is described by a Haskell model, i.e. a band of slip that propagates outward from the hypocenter along the fault plane. Such a slip band is characterized by the rupture velocity, with which the front of the slip band propagates across the fault plane, and its width, which translates into a maximum time-window in which any subfault can slip. The fault is discretized in a grid of subfaults, each of which can slip in two perpendicular directions to allow for variable rakes. We compute Green's functions for every subfault to every station, for teleseismic data using a propagator matrix/ray approach, and for strong motion data using FK integration (Saikia, 1994). We have used a 1D model (Table 1) adapted from Neugebauer et al. (1997) to compute all the Green's functions. The fault rupture is expressed as a summation of these elementary Green's functions corresponding to different subfaults active at different points in time. The elementary Green's functions are convolved with a triangular source time with a duration of 2 seconds, which is twice the time between timesteps. This ensures that the individual source time functions can add up to a continuous overall source time function.

Data

The teleseismic data (distance range of 30°-90°, Figure 2a) were obtained from the IRIS datacenter, and all were deconvolved to displacement, with a sampling rate of 5 samples per second, and a band-pass filter applied between 2 Hz and 300 seconds. We obtained the strong motion records (Figure 2b) from the collected data set of Çelebi et al. (2001). The strong motion data were integrated to velocity and band-pass filtered between 100 and 2.5 seconds.

Mechanism and fault parameters

The overall mechanism was obtained from waveform modeling of the teleseismic body waves. Based on this solution, and the observed fault rupture, we constructed a discretized east-west striking fault model (Table 2, Figure 2b) with a total length of 50 km and a dip op 69°. The plane is divided into 72 subfaults (4x4 km) with 12 rows along strike and 6 along the down-dip direction. We picked a hypocenter corresponding to the projection of the epicenter on our fault plane, which gives us a depth of 17 km. The maximum rupture velocity is set at 3.0 m/sec, with a width for the slip-band of 10 seconds maximum.

Slip model

Our slip model inversion results are shown in Figure 3a and summarized in Table 3, and the slip model is documented in the Appendix. The Düzce earthquake had a relatively simple slip distribution consisting of a single main asperity slightly eastward of the hypocenter and a centroid depth of approximately 10 km. The source-time function (Figure 3b) has a total duration of 20 seconds, but the moment release after the first 15 seconds is very low and insignificant. We therefore adopt a duration of 15 seconds for this event. The moment of 8.8×10^{26} dyne.cm corresponds to a moment magnitude (M_W) of 7.2. The waveform fits are plotted in Figures 3c and 3d.

Conclusion

The rupture of the 1999 Düzce earthquake was relatively simple, showing a single asperity with a maximum offset of 5.5 meters. The moment amounts to 8.8×10^{26} dyne.cm, which is slightly larger than that found by others (Yagi and Kikuchi, 1999; Ayhan et al., 2001, Tibi et al., 2001) but still comparable. All studies suggest a very simple slip distribution, essentially a single asperity, with a dimension of about 20x25 km (Table 4).

References

Ayhan, M.E., R. Bürgmann, S. McClusky, O. Lenk, B. Aktug, E. Herece and R.E. Reillinger, 2001. Kinematics of the M_W=7.2, 12 Novmber 19999, Düzce earthquake, Geophys. Res. Lett., 28, 367-370.

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Çelebi, M., S. Akkar, Ü. Gülerce, A. Sanli, H. Bundock and A. Salkin, 2001. Main shock and aftershock records of the 1999 Izmit and Ducze, Turkey, earthquakes, USGS open file report 01-163.

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Tibi, R., G. Bock, Y. Xia, M. Baumbach, H. Grosser, C. Milkereit, S. Karakisa, S. Zunbul, R. Kind and J. Zschau, Rupture process of the August 17 Izmit and November 12 Duzce (Turkey) earthquakes, *Geophysical Journal International, in press*

Tables

Table 1. Velocity model

Thickness	V_P	V_S	r	Q_P	Q_S
0.50	1.90	1.00	2.00	200.	100.
1.50	2.90	1.60	2.10	250.	200.
5.00	5.40	3.00	2.50	1000.	500.
10.00	6.16	3.50	2.78	1600.	800.
18.00	6.63	3.70	2.90	2000.	1000.
0.00	8.16	4.60	3.40	2500.	1250.

Table 2. Duzce rupture inversion parameters:

Inversion parameters	
Cell size	4x4 km
Strong motion stations used	6 (x3 components)
Teleseismic stations used	17 (17 P, 11 SH)
Maximum rupture velocity	3 km/sec
Number of timesteps	20
Timestep	1 sec.
Strike/Dip/Slip	270/69/180
Fault length	52 km
Fault width	24 km

Table 3. Rupture model

Inversion results	
Moment	8.8×10^{26} dyne.cm
Maximum slip	5.5 m
Asperity	25x20km
Source time	15 sec

Table 4. Comparison of results

Moment ($\times 10^{26}$ dyne.cm)	Source time	Author
5.6	12	Yagi and kikuchi (1999)
5.4	14	Tibi et al. (2001)
5.86	-	Ayhan et al. (2001)
6.7	-	Harvard CMT
8.8	15	This study

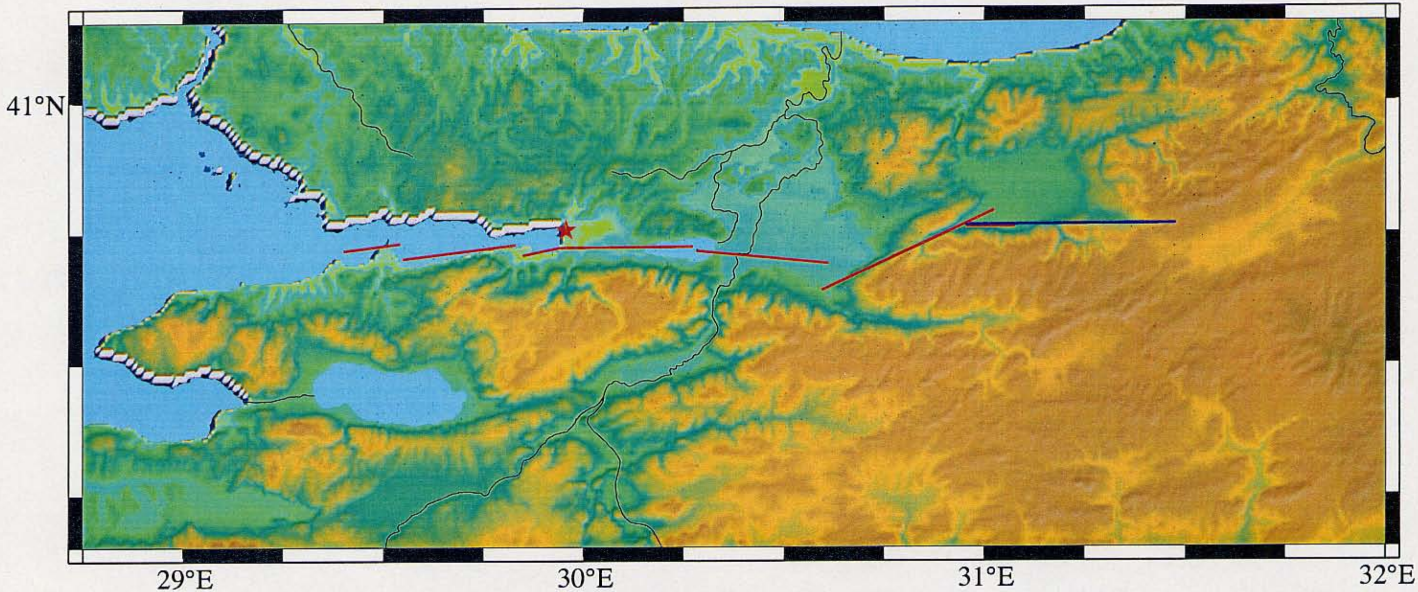

Figure 1. Map of northwestern Turkey showing the Kocaeli rupture (red) and the Düzce rupture (blue).

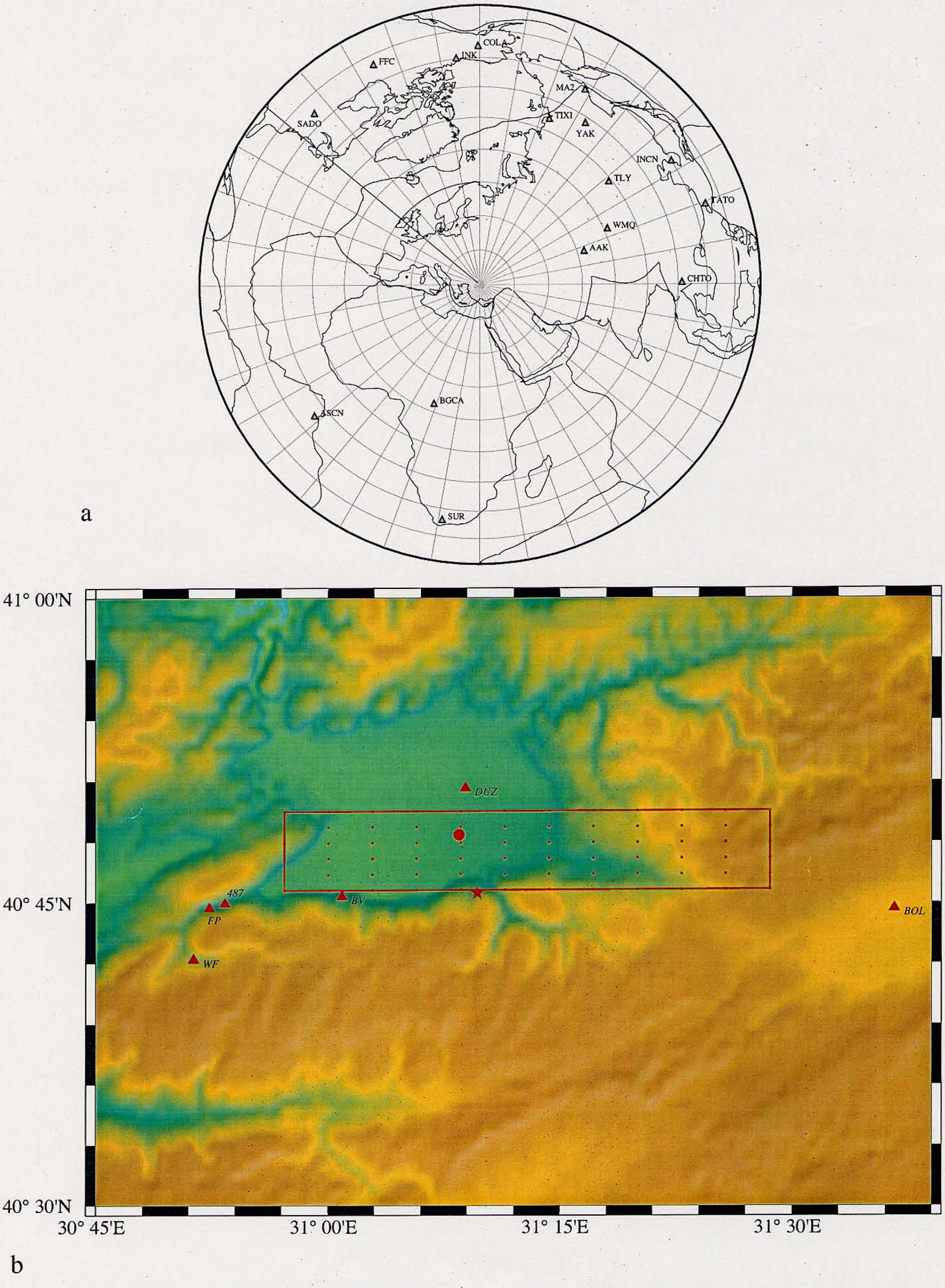

Figure 2. a - station distribution of the teleseismic data used in the inversion. b - strong motion stations used, and surface projection of the fault plane.

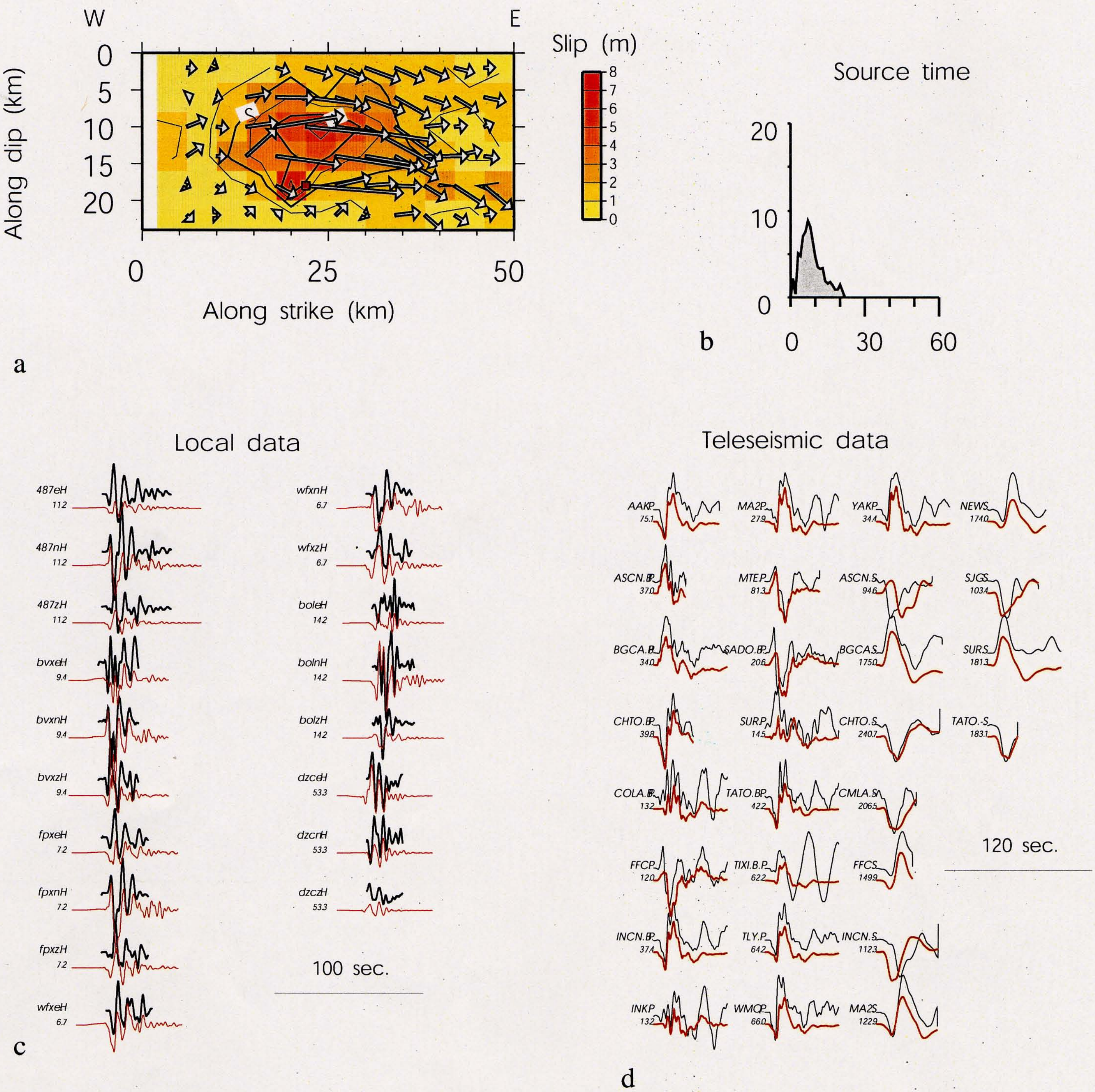

Figure 3. a - slip distribution and slip vectors on the fault plane. b - surce time function, c - strong motion waveforms (black) and synthetics (red). d - teleseismic waveforms (black) and synthetics (red).

APPENDIX

DOCUMENTATION OF THE SLIP MODEL OF THE DUZCE EARTHQUAKE

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03/05/2002 12:43 PM

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cc: Hong Kie Thio/Pasadena/URSCorp@URSCORP, Arben Pitarka/Pasadena/URSCorp@URSCORP
Subject: Slip Model of the 1999 Duzce, Turkey Earthquake

PEER Lifelines colleagues

Attached please find the slip model of the 1999 Duzce, Turkey earthquake.
This slip model was developed as part of the PG&E/PEER Lifelines Project.
The formatting of the slip model is the same as that of the 1999 Kocaeli, Turkey and Chi-Chi, Taiwan earthquakes sent on June 1, 2001, which are attached for reference.

Paul

DOCUMENTATION

The slipmodel consist of point-sources (subfaults) distributed along the fault. Every subfault can rupture several times, starting when the rupture front arrives for a timewindow of up to 10 seconds. Outside this window, the slip values are automatically put at zero, although the inversion can also put the slip at zero even if the subfault is allowed to slip at that timestep. The separation between every timestep is 1.0 seconds. The elementary source-time functions are taken as twice the timestep, hence t1 and t2 (ramp up and ramp down, respectively) are equal to the timestep.

The slipmodel is tabulated in the attached ASCII file as follows:

First line: #timesteps #subfaults timestep t1 t2 (t1=t2, triangular source time function)
Subsequent lines: first line - subfault parameters (lon, lat, depth, strike, dip)
followed by - pairs of slip (cm) and rake (degrees) for every timestep (5 pairs per line).

Hypocenter (lon/lat/depth): 31.143 40.812 16.930

Also included is a pdf file showing the final slip model for the event.

duzce-slipmodel duzce.pdf

- slipmodel.kocaeli - slipmodel.taiwan - Turkey-final.pdf - Taiwan-final.pdf

```
20 72 1.000 1.000 1.000
 31.476 40.761 2.000 270.00 69.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  3.17 -135.00  0.00  0.00  0.00  0.00  19.52  135.00
 26.22  174.10  18.25 -135.00  7.22  144.16  14.29  135.00  5.49 -135.00
 31.476 40.774 5.730 270.00 69.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  27.62 -178.33  29.59  147.72  0.00  0.00  0.00  0.00
 63.21  135.00  39.41  135.00  30.14  135.00  6.32  135.00  32.89 -135.00
 31.476 40.787 9.470 270.00 69.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  2.38 -135.00  15.47 -135.00  0.00  0.00  0.00  0.00  8.89 -135.00
  7.05 -135.00  4.02 -135.00  1.75  135.00  41.80  135.00  82.76  136.57
 31.476 40.800 13.200 270.00 69.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 11.51 -135.00  13.97 -139.91  21.28  135.00  25.14  135.00  19.34  151.37
  0.00  0.00  5.74  135.00  0.00  0.00  4.13 -135.00  7.26 -135.00
 31.476 40.813 16.930 270.00 69.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  5.64 -135.00  5.50 -135.00  40.97 -135.00  31.46 -135.00  0.00  0.00
  0.00  0.00  14.15 -135.00  23.91 -135.00  19.77  143.73  120.98  154.78
 31.476 40.826 20.670 270.00 69.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  14.20 -135.00  36.74 -171.76  22.67 -135.00
 36.60 -135.00  36.69 -135.00  27.75 -135.00  4.40 -135.00  0.00  0.00
 31.429 40.761 2.000 270.00 69.00
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 10.82 -135.00  4.66  135.00  1.66  153.35  16.51  170.59  10.09 -173.12
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 31.429 40.774 5.730 270.00 69.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
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  2.08 -135.00  0.00  0.00  8.42  135.00  12.87 -135.00  0.00  0.00
 31.429 40.787 9.470 270.00 69.00
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  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  10.52 -135.00
  7.07  136.06  7.20 -135.00  1.05 -135.00  0.00  0.00  0.00  0.00
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 31.429 40.800 13.200 270.00 69.00
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 31.429 40.813 16.930 270.00 69.00
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  0.17 -135.00  1.64 -135.00  34.58 -135.00  23.97 -135.00  0.00  0.00
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31.381 40.761 2.000 270.00 69.00
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30.57 -159.16 24.75 160.39 12.36 -161.88 7.81 -135.00 3.98 136.12
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31.381 40.787 9.470 270.00 69.00
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23.01 -168.11 19.88 -155.79 2.88 -135.00 0.00 0.00 0.00 0.00
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3.18 -135.00 12.95 -135.00 13.83 -135.00 0.00 0.00 0.00 0.00
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31.286 40.826 20.670 270.00 69.00
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33.29 135.00 39.09 135.00 34.72 135.00 16.75 -135.00 17.09 -135.00
1.17 -135.00 0.00 0.00 6.39 -135.00 28.55 -135.00 13.67 -135.00
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0.00 0.00 34.21 -179.15 25.79 -164.54 37.44 -168.59 33.26 -165.46
20.55 -135.00 18.94 -135.00 22.82 -154.52 4.51 -135.00 0.71 135.00
9.02 -143.81 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.238 40.774 5.730 270.00 69.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
61.26 -164.91 11.00 173.72 26.26 135.00 35.43 -143.81 56.86 -135.00
44.24 -153.78 6.96 135.00 0.00 0.00 0.00 0.00 13.49 -139.54
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.238 40.787 9.470 270.00 69.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 136.97 -160.48
121.61 -142.18 60.43 -138.65 34.72 -153.60 31.08 -169.20 15.92 -175.48
14.51 -157.15 25.16 -136.28 9.16 -135.00 0.00 0.00 0.00 0.00

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.238 40.800 13.200 270.00 69.00
0.00 0.00 0.00 0.00 0.00 0.00 76.20 178.37 52.75 -162.11
56.51 -170.24 61.26 -170.75 23.99 -161.22 0.00 0.00 0.00 0.00
11.32 157.23 21.68 -179.74 23.35 -135.56 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.238 40.813 16.930 270.00 69.00
0.00 0.00 0.00 0.00 0.00 0.00 13.32 137.75 30.62 163.07
37.55 147.97 46.69 167.41 15.27 -159.35 0.00 0.00 0.76 135.00
6.09 156.73 20.45 -135.00 25.55 -135.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.238 40.826 20.670 270.00 69.00
0.00 0.00 0.00 0.00 0.00 0.00 0.20 -135.00 5.14 -135.00
0.00 0.00 3.61 -175.17 0.15 135.00 0.00 0.00 3.60 135.00
0.00 0.00 3.08 -135.00 10.94 -135.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.191 40.761 2.000 270.00 69.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 27.11 -156.72 14.46 -135.00 35.05 -174.54 39.50 -177.90
22.27 -149.67 11.14 -135.00 17.97 -149.09 6.37 -140.68 0.00 0.00
10.15 -140.06 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.191 40.774 5.730 270.00 69.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
39.90 -168.05 17.39 135.00 32.99 167.03 49.19 -147.89 44.33 -137.52
21.61 -161.81 1.00 135.00 9.96 -135.00 0.00 0.00 0.27 -135.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.191 40.787 9.470 270.00 69.00
0.00 0.00 0.00 0.00 0.00 0.00 191.31 170.72 131.77 -167.29
87.38 -153.90 26.06 -157.43 35.10 -167.31 40.54 -176.61 20.04 176.50
7.42 -147.44 16.04 -135.00 9.36 -135.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.191 40.799 13.200 270.00 69.00
0.00 0.00 0.00 0.00 189.26 171.15 61.58 -179.07 73.17 -147.79
57.51 -158.82 42.85 -151.57 16.45 -139.16 0.85 135.00 4.86 135.00
5.61 162.34 14.34 -135.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.191 40.812 16.930 270.00 69.00
0.00 0.00 0.00 0.00 77.32 151.82 0.23 -135.00 28.43 -147.79
34.86 162.13 44.72 158.00 0.00 0.00 0.00 0.00 5.80 135.00
7.36 135.00 20.91 -135.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.191 40.825 20.670 270.00 69.00
0.00 0.00 0.00 0.00 5.10 135.00 0.00 0.00 3.99 135.00
14.61 135.00 39.27 135.00 23.60 135.00 0.00 0.00 0.21 135.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.143 40.761 2.000 270.00 69.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 23.60 -154.03 7.62 -135.00 17.54 -172.01 42.45 -179.40
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14.77 -151.98 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
31.143 40.774 5.730 270.00 69.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 70.30 162.83
33.73 -171.98 40.30 167.18 55.83 -178.61 45.73 -151.72 34.57 -135.00
24.67 166.13 8.09 -135.00 21.39 -135.00 0.00 0.00 0.00 0.00

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 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.143  40.786 9.470 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00 155.03 174.55 101.45 -167.49
39.42 -178.59  19.89 172.10  55.10 -164.82  49.53 176.44  15.46 -154.07
 0.00   0.00  10.55 -135.00  19.31 -135.00   0.00   0.00   0.00   0.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.143  40.799 13.200 270.00 69.00
 0.00   0.00   0.00   0.00 192.18 -177.42  49.56 -161.34  72.76 -147.68
27.16 165.03  18.86 158.45  28.48 -168.44  13.64 170.81   2.79 135.00
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 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.143  40.812 16.930 270.00 69.00
339.41 -179.61  56.11 -155.93  57.32 -176.54  20.50 -135.00  28.54 -145.67
12.05 135.00  21.59 135.00   4.62 140.96   5.85 -149.35   6.41 -135.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.143  40.825 20.670 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.51 135.00  39.48 135.00  28.46 135.00   0.00   0.00   0.00   0.00
 0.00   0.00   1.80 -135.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.096  40.761 2.000 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00   9.92 -168.76  10.89 -135.71   5.48 146.05  18.26 -175.60
17.53 -162.69   1.97 -135.00  15.01 -145.93   0.00   0.00   0.00   0.00
 3.36 -164.44   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.096  40.773 5.730 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
44.31 157.25  34.92 167.49  45.26 175.97  30.33 -169.36  19.92 -135.00
31.83 -174.45  10.30 -135.00   1.95 -135.00   0.00   0.00   0.00   0.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.096  40.786 9.470 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00 136.65 173.14  93.72 166.82
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 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.096  40.799 13.200 270.00 69.00
 0.00   0.00   0.00   0.00 205.50 -163.45  31.21 -143.64  58.46 -172.90
34.46 135.00  14.83 139.25  23.96 -177.48   9.30 135.00   0.00   0.00
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 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.096  40.812 16.930 270.00 69.00
 0.00   0.00   0.00   0.00  67.40 -147.96  19.61 -135.00  27.01 -135.00
10.35 135.00  10.36 135.00   0.00   0.00   0.00   0.00   2.87 135.00
 0.00   0.00   8.12 -135.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.096  40.825 20.670 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00  23.90 135.00  17.55 135.00   0.00   0.00   0.94 135.00
 0.00   0.00   4.18 -135.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
31.048  40.760 2.000 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
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 1.31 -135.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
31.048  40.773 5.730 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
42.94 135.00  28.51 -172.50  20.61 153.73  9.10 -166.30  16.67 -171.86
25.89 -169.87  0.40 -135.00  0.00  0.00  0.00  0.00  4.83 -135.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
31.048  40.786 9.470 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00 93.75 162.08
16.98 157.32  10.40 -135.00  27.09 -178.93  20.00 148.85  0.00  0.00
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 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
31.048  40.799 13.200 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  33.42 143.08  75.93 135.88
50.53 135.00  30.15 135.00  19.57 138.41  8.99 135.00  0.00  0.00
 0.61 135.00  1.93 -135.00  0.88 -135.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
31.048  40.812 16.930 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  21.26 -135.00  19.34 -135.00
15.95 -150.59  0.00  0.00  0.00  0.00  0.00  0.00  9.66 135.00
 0.00  0.00  6.99 -135.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
31.048  40.825 20.670 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  3.93 135.00  18.02 135.00
12.04 135.00  20.84 135.00  6.76 135.00  0.00  0.00  2.35 135.00
 0.00  0.00  0.99 -135.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
31.000  40.760 2.000 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  9.87 -135.00
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 0.36 -135.00  0.04 -135.00  0.00  0.00  0.00  0.00  0.00  0.00
31.000  40.773 5.730 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
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 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
31.000  40.786 9.470 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 4.27 -135.00  8.06 -135.00  24.76 174.84  22.07 150.26  0.00  0.00
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 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
31.000  40.799 13.200 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
19.95 -135.00  13.94 -135.00  12.17 135.00  18.01 135.00  2.07 135.00
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31.000  40.812 16.930 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  17.61 -135.00
28.18 -135.00  5.16 -135.00  0.00  0.00  0.00  0.00  9.08 135.00
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 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
31.000  40.825 20.670 270.00 69.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
10.78 -135.00  0.00  0.00  0.00  0.00  11.27 135.00  4.98 135.00
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 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
30.953  40.760 2.000 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00   0.00   0.00   0.00   0.00   6.53 135.00  11.19 -153.24
12.95 -135.76  15.13 140.15   0.00   0.00   0.00   0.00   0.66 140.57
10.71 165.86   4.81 -135.00   7.16 -135.00   0.00   0.00   0.00   0.00
30.953  40.773 5.730 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00   0.00   0.00   0.00   0.00  14.24 171.16  13.25 135.00
12.02 135.00   2.43 -135.00   2.66 -135.00   0.00   0.00   0.00   0.00
 0.75 -135.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
30.953  40.786 9.470 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00  17.94 135.00  40.81 141.95  27.81 135.00   5.43 135.00
10.09 135.00   5.34 145.25  10.71 -135.00   6.41 -135.00   7.33 -135.00
15.49 -135.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
30.953  40.799 13.200 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00  21.58 135.00  37.95 135.00  25.65 135.00   0.00   0.00
 0.00   0.00   6.67 179.60  16.39 135.00   0.00   0.00  13.77 -135.00
 0.95 -135.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
30.953  40.812 16.930 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00  11.93 -135.00   0.00   0.00   3.88 135.00   0.48 135.00
 2.97 -135.00   7.48 -137.69   2.85 135.00   0.00   0.00   0.00   0.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
30.953  40.825 20.670 270.00 69.00
 0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 0.00   0.00  20.23 -135.00  11.02 -135.00   6.94 -135.00   0.00   0.00
 4.59 -135.00   8.21 -135.00   0.00   0.00   0.00   0.00   0.00   0.00
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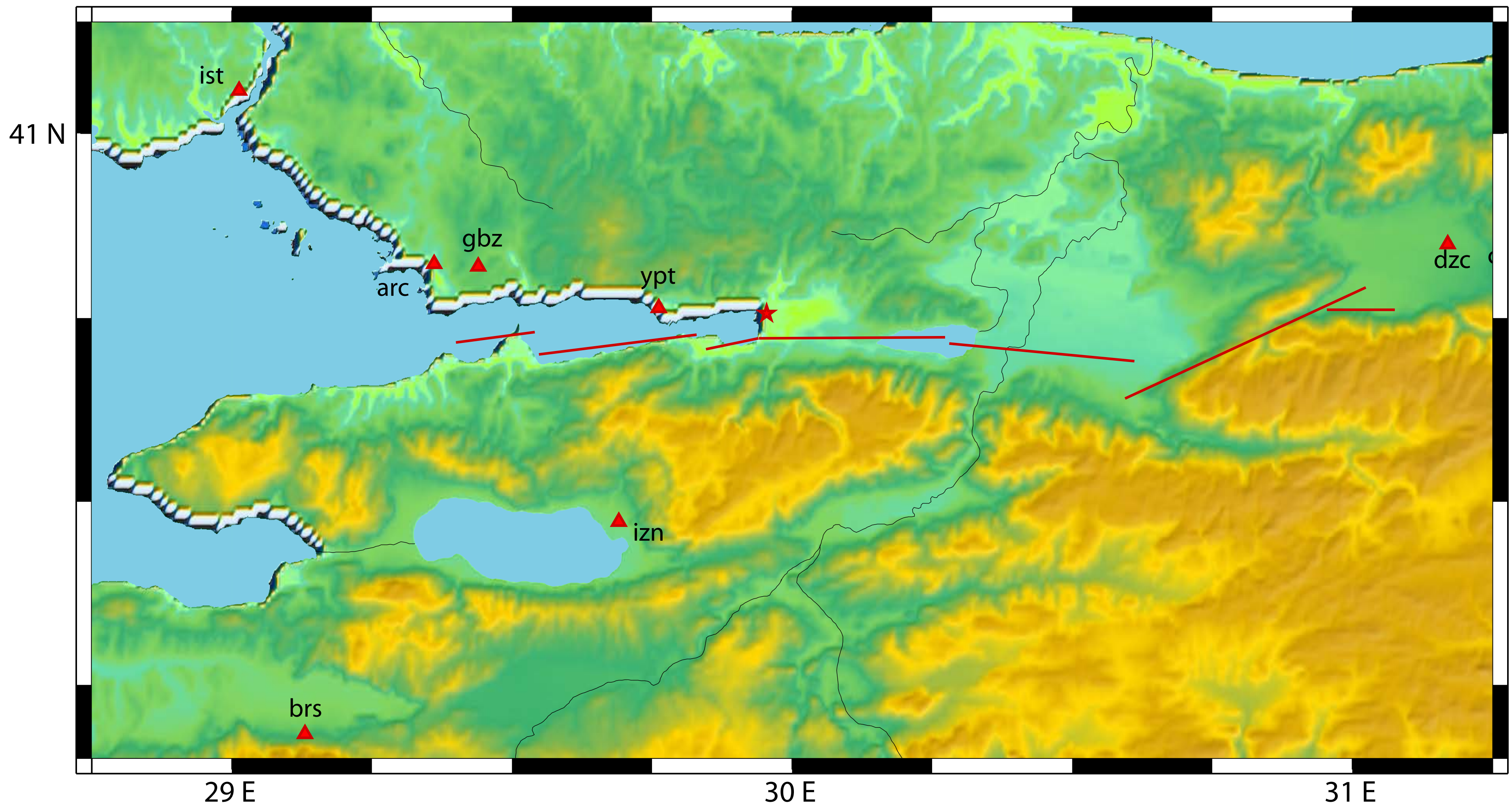

Figure 1. Location of the fault rupture of the 1999 Kocaeli, Turkey earthquake and the strong motion recording stations used in the validation of the ground motion simulation method.

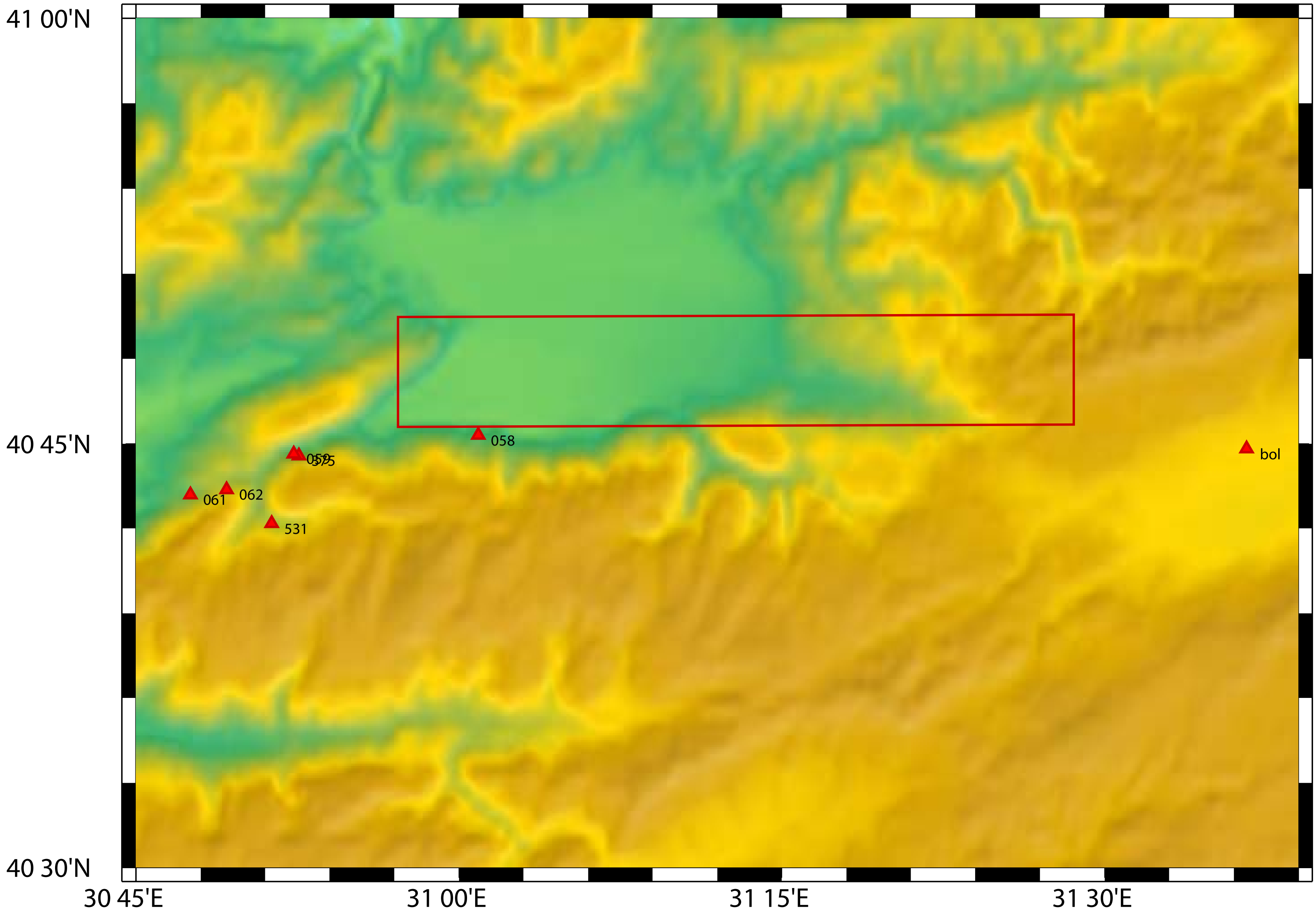

Figure 2. Location of the fault rupture of the 1999 Duzce, Turkey earthquake and the strong motion recording stations used in the validation of the ground motion simulation method.

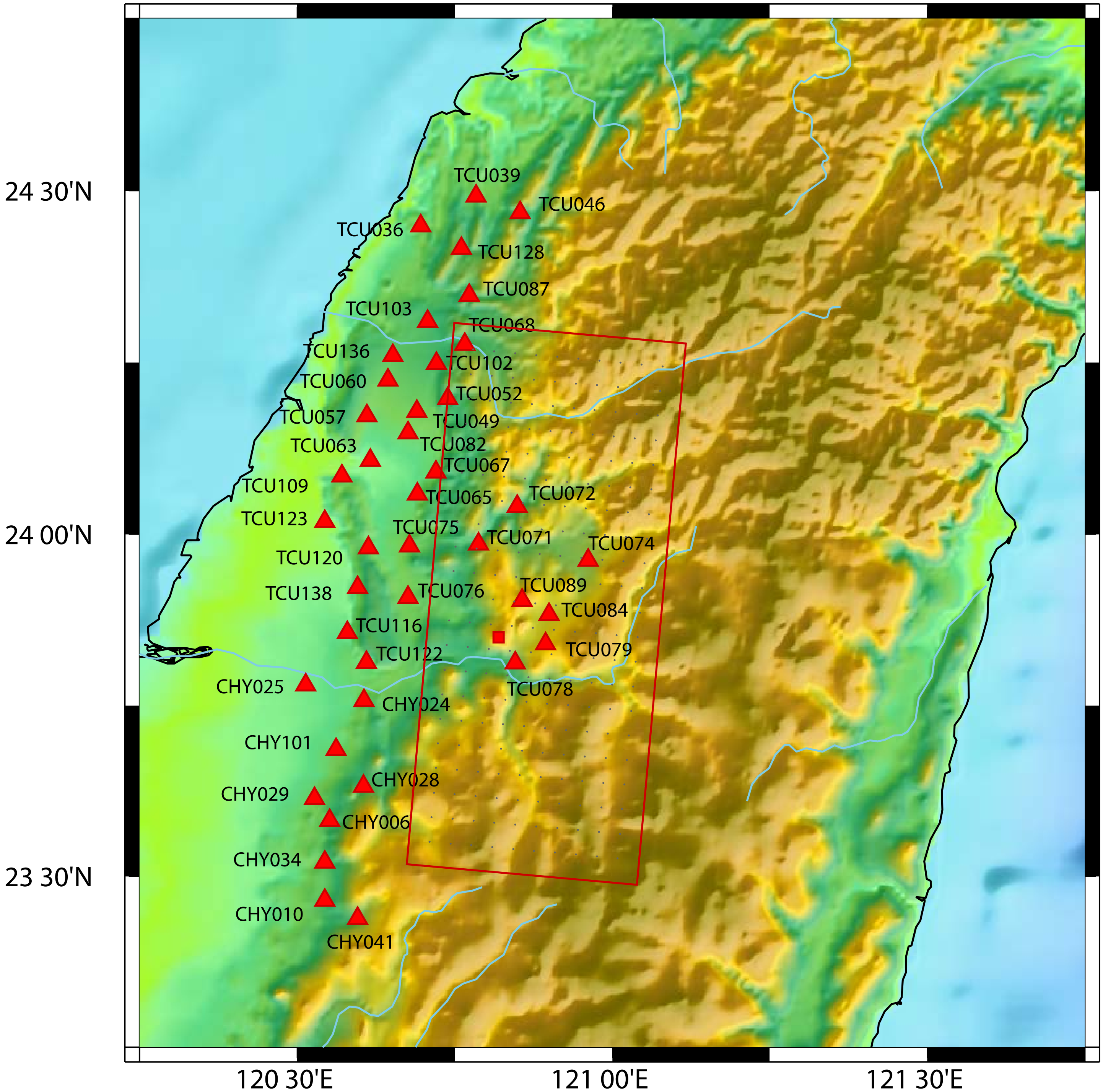

Figure 3. Location of the fault rupture of the 1999 Chi-Chi, Taiwan earthquake and the strong motion recording stations used in the validation of the ground motion simulation method.

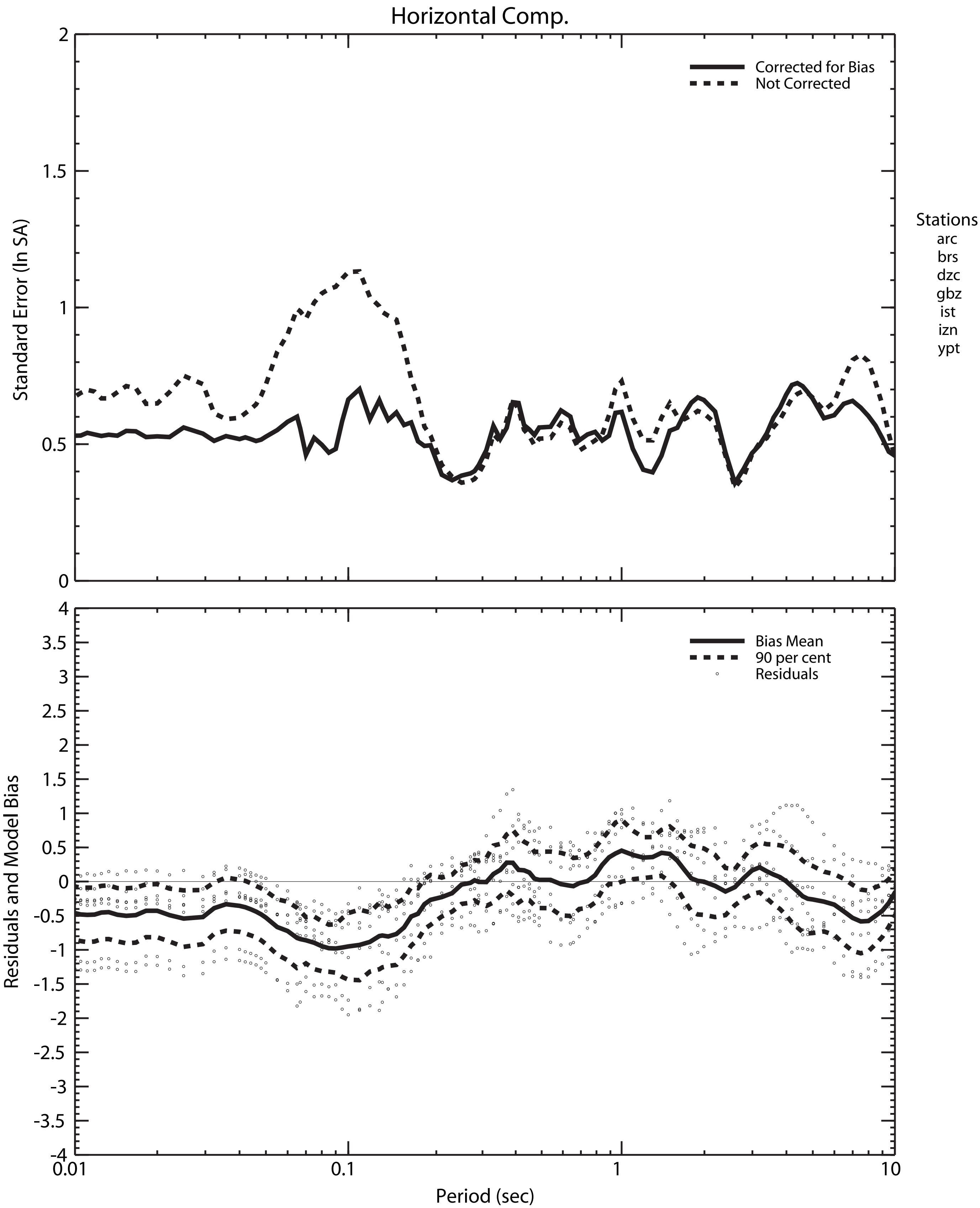

Figure 4. Goodness of fit: Kocaeli earthquake, horizontal component

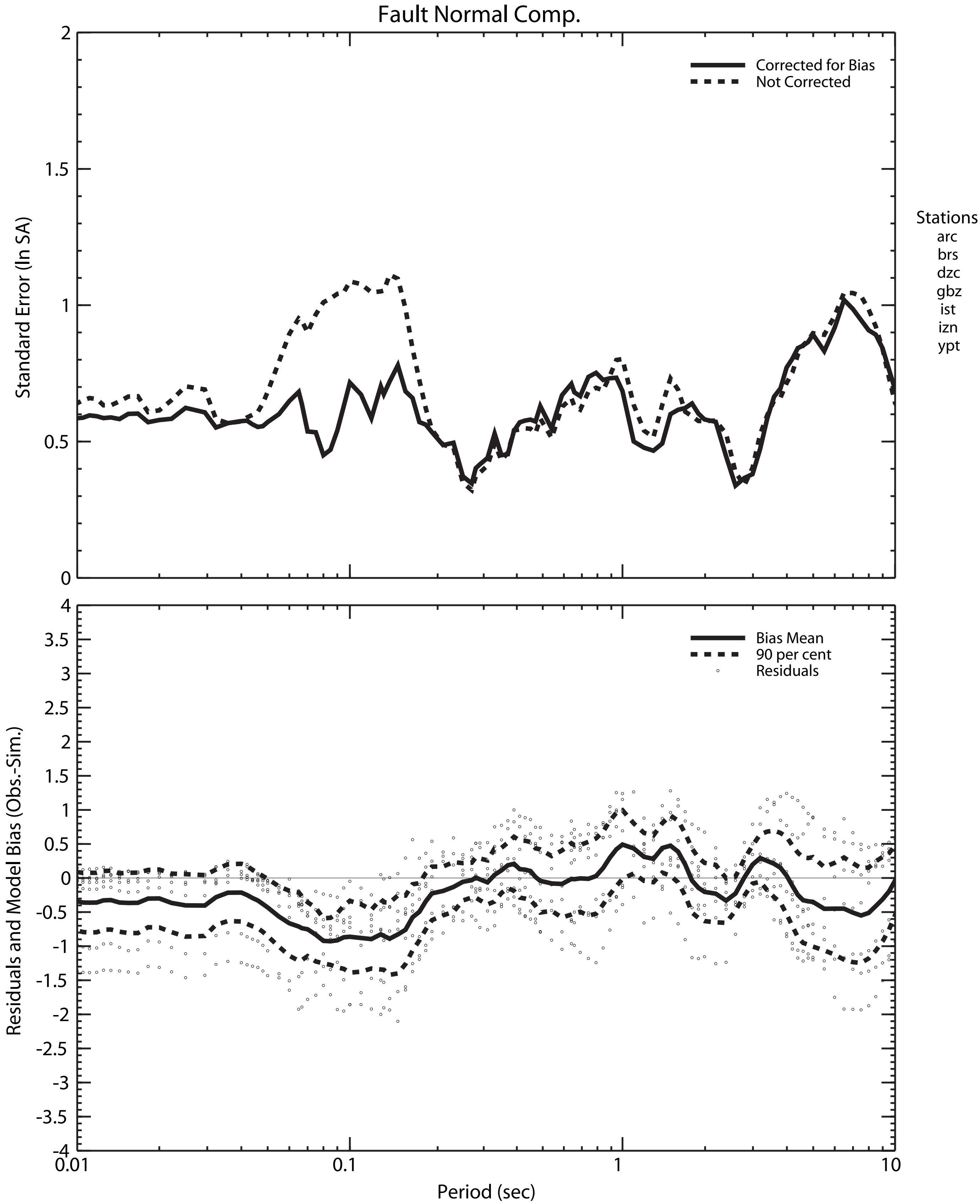

Figure 5. Goodness of fit: Kocaeli earthquake, fault normal component

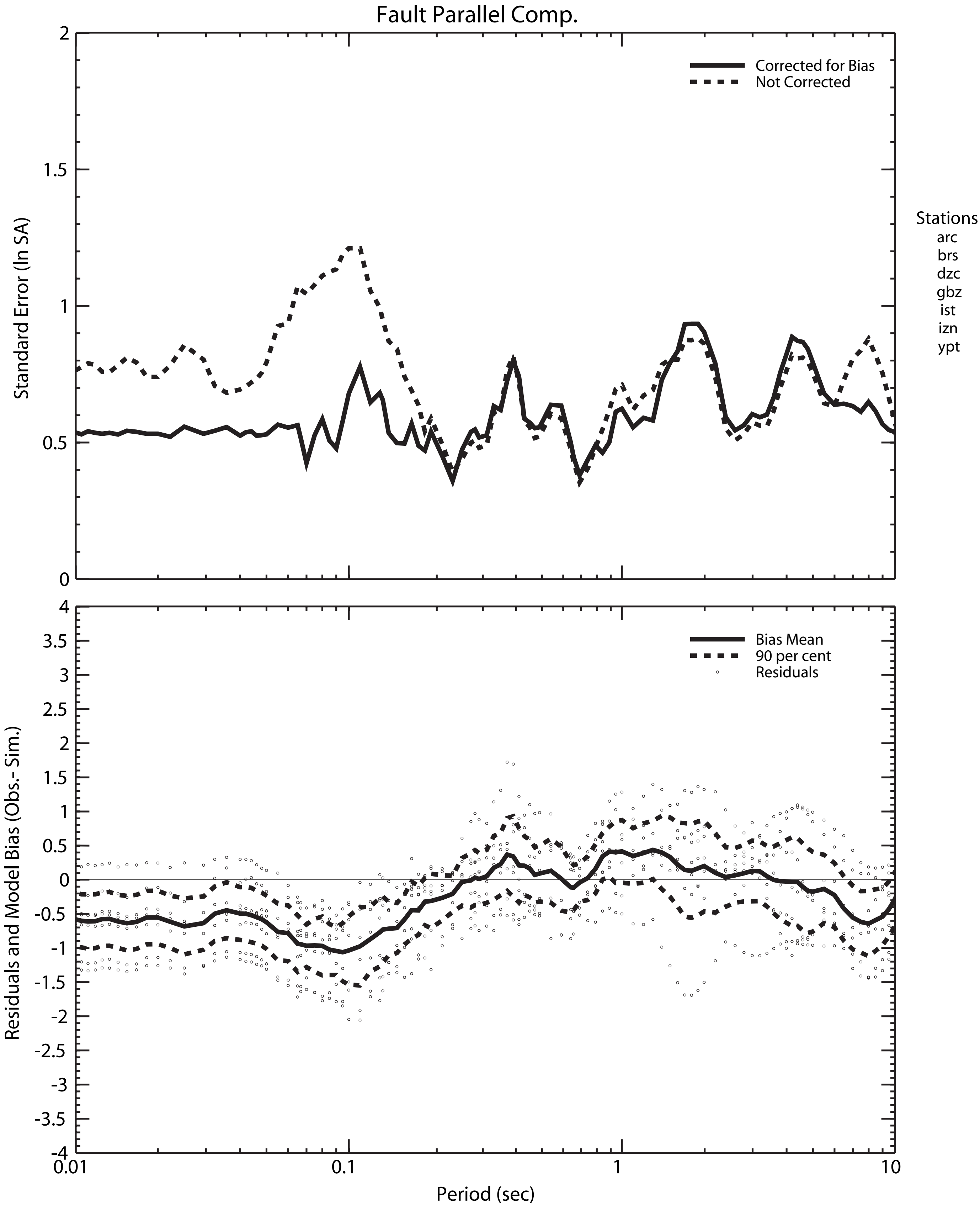

Figure 6. Goodness of fit: Kocaeli earthquake, fault parallel component

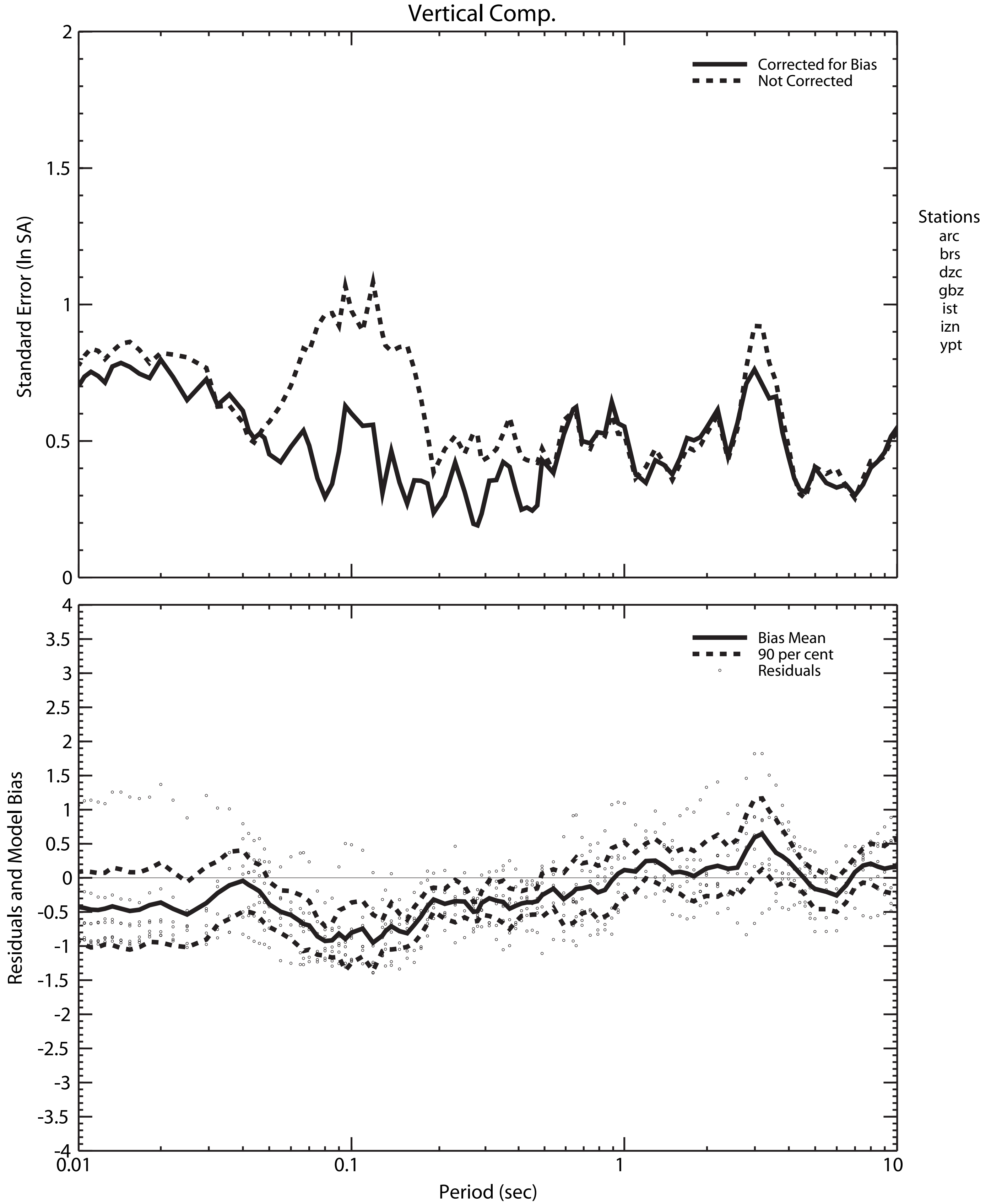

Figure 7. Goodness of fit: Kocaeli earthquake, vertical component

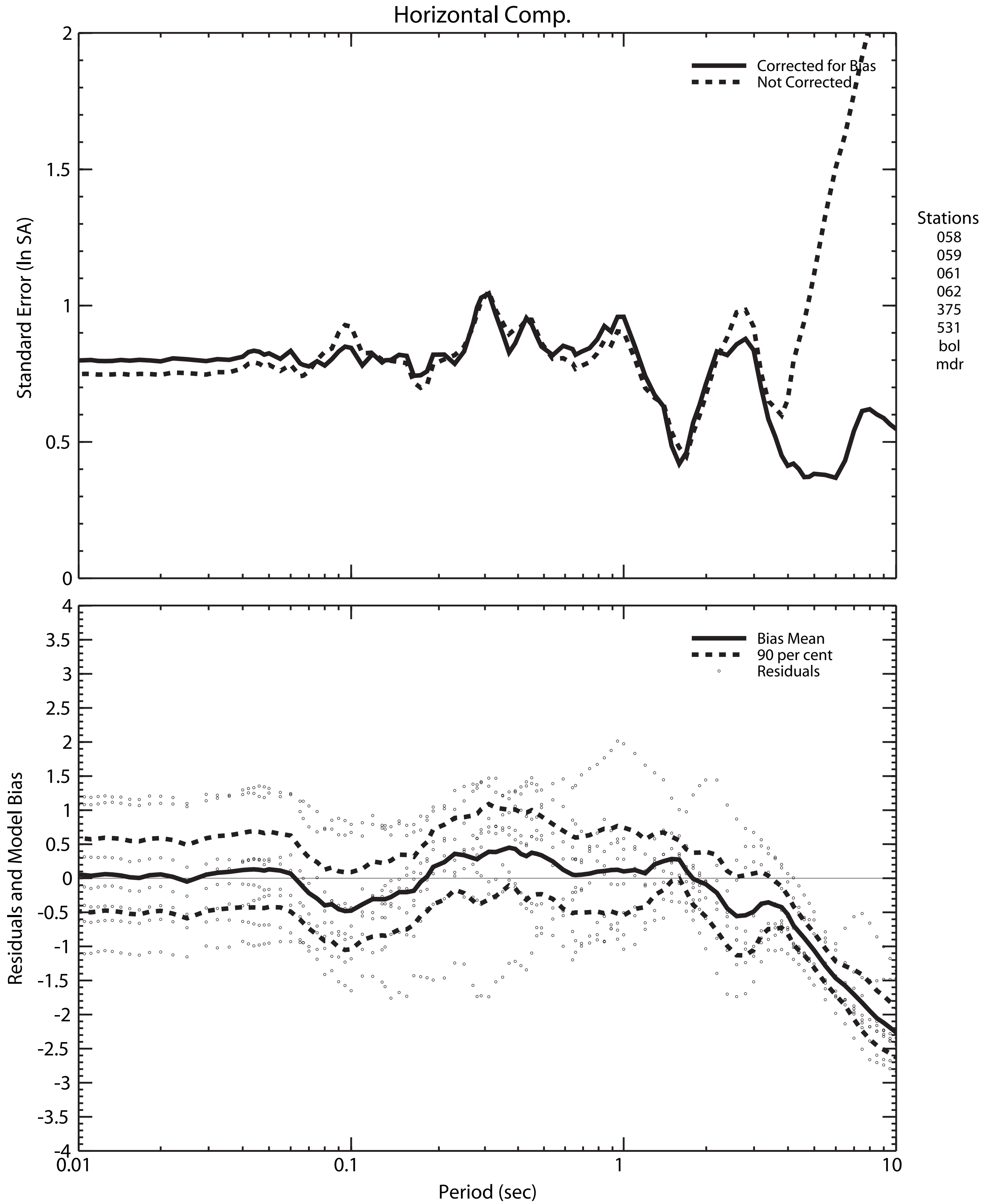

Figure 8. Goodness of fit: Duzce earthquake, horizontal component

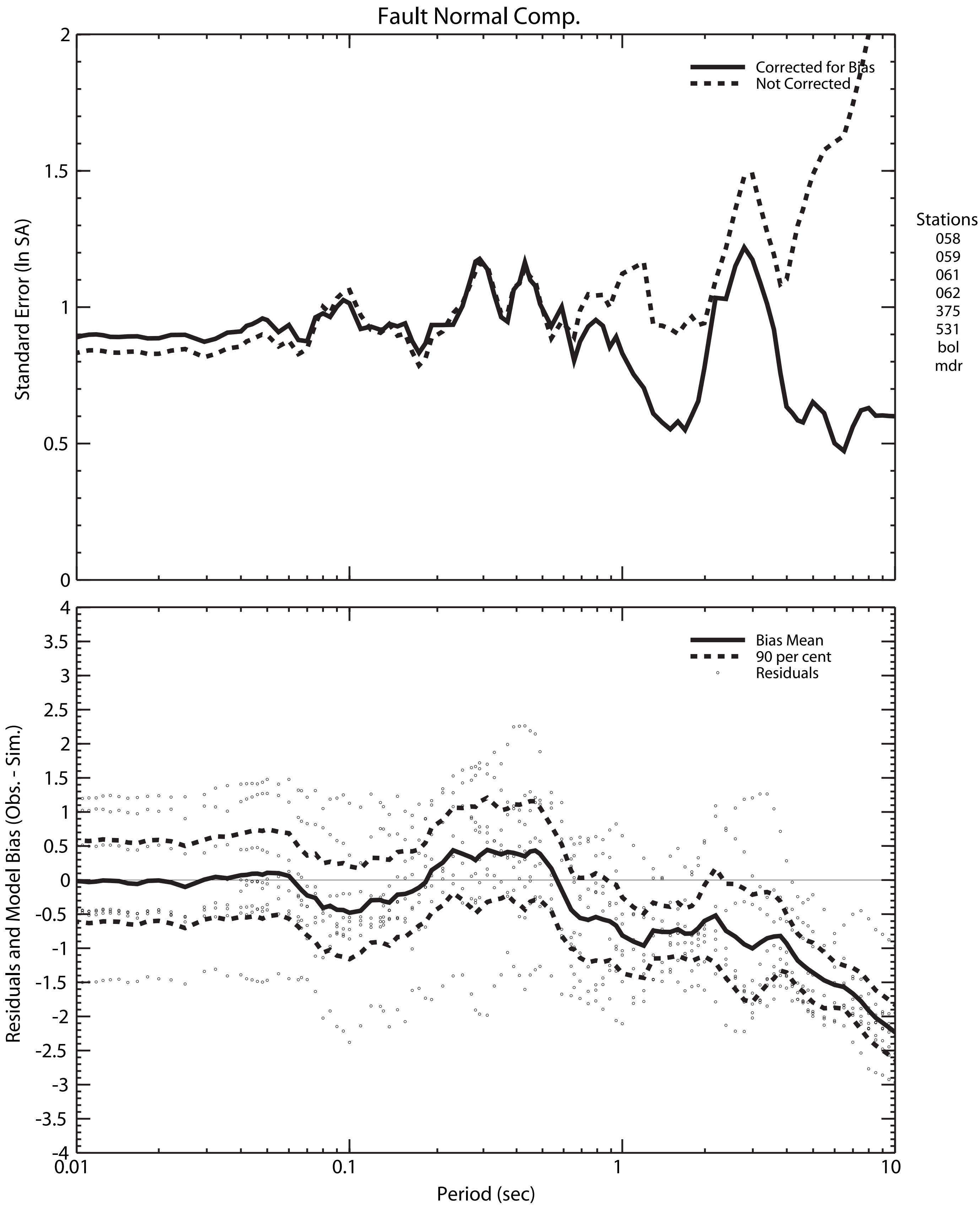

Figure 9. Goodness of fit: Duzce earthquake, fault normal component

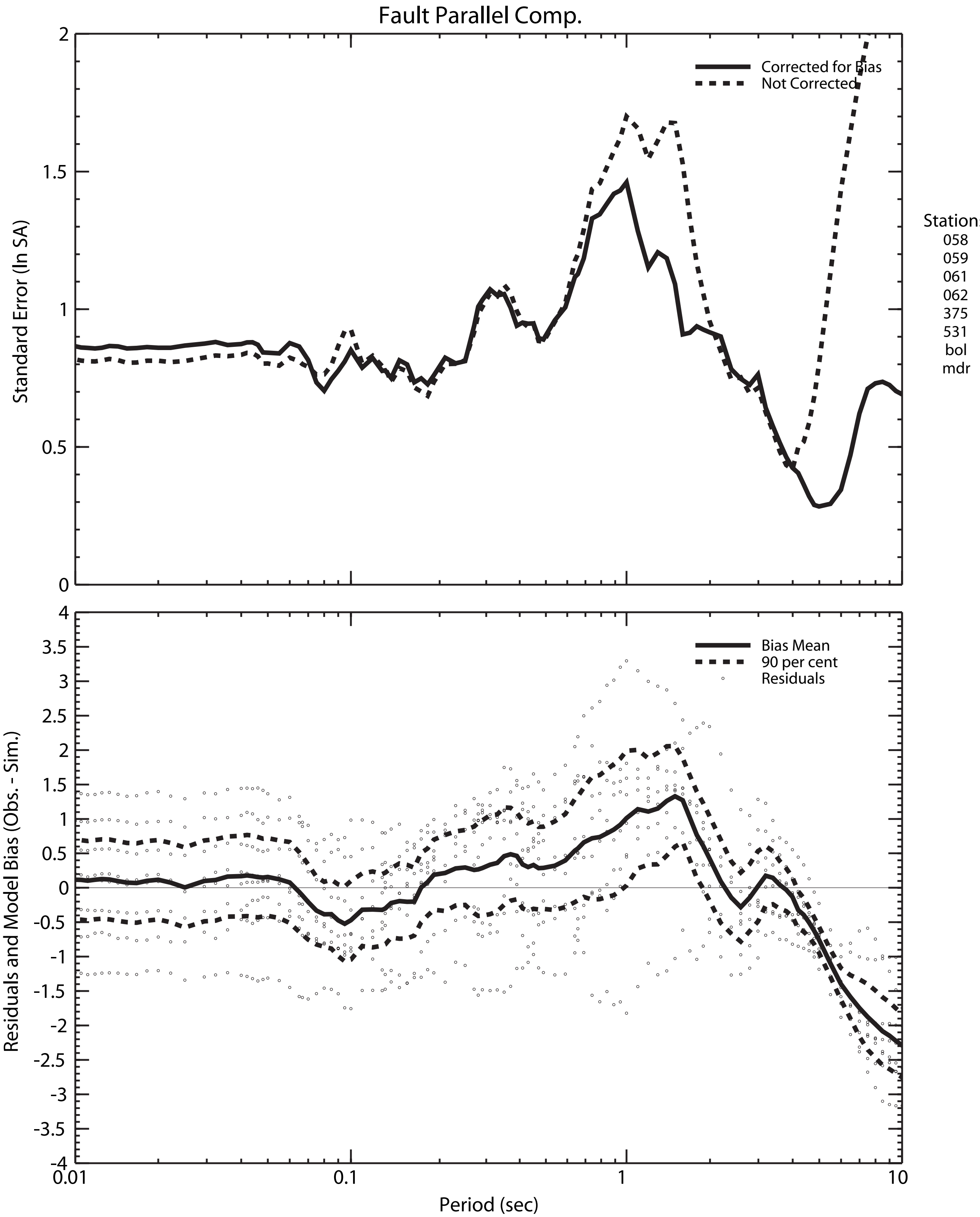

Figure 10. Goodness of fit: Duzce earthquake, fault parallel component

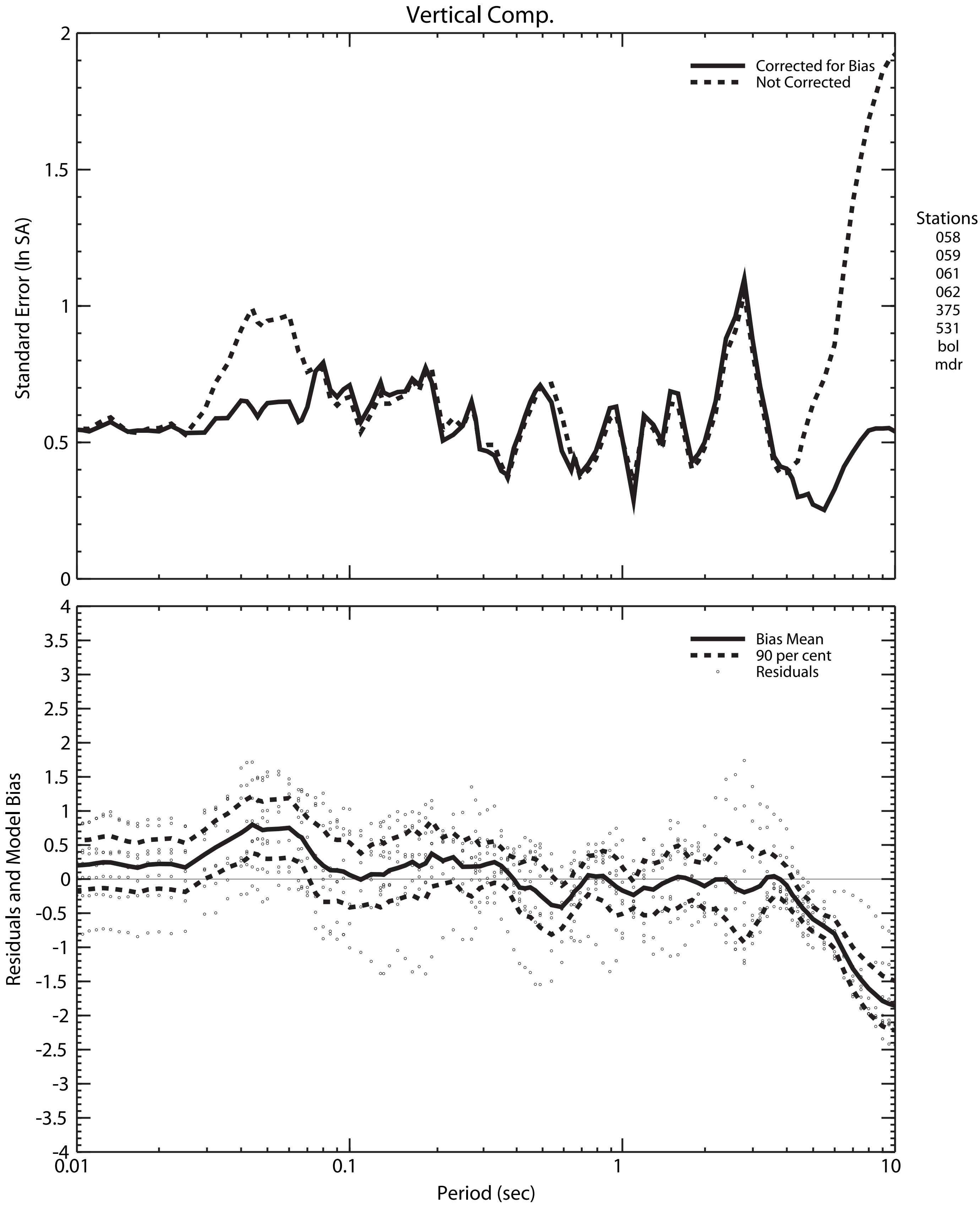

Figure 11. Goodness of fit: Duzce earthquake, vertical component

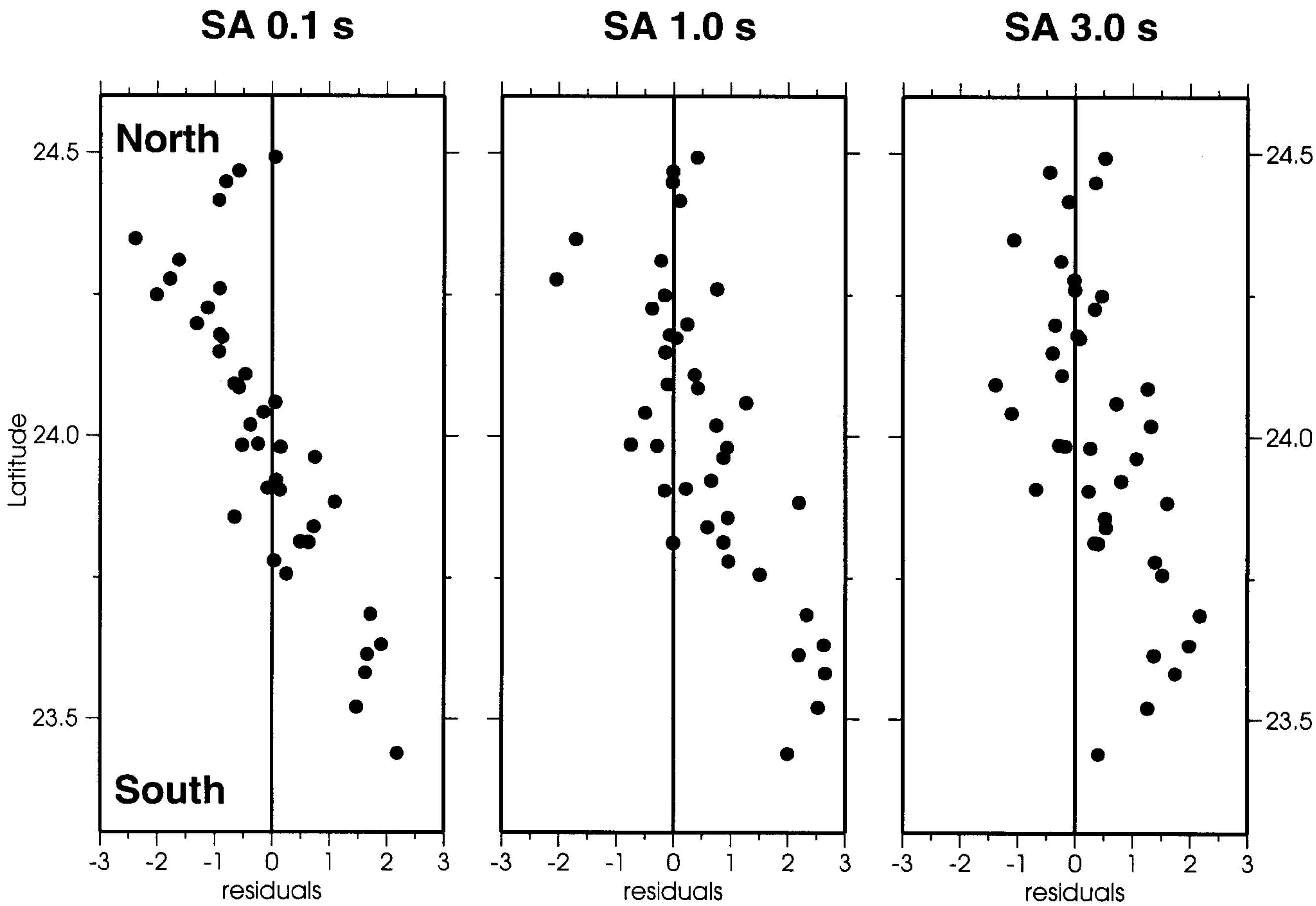

Figure 12. Residuals as a function of latitude and period: Chi-chi earthquake, horizontal component

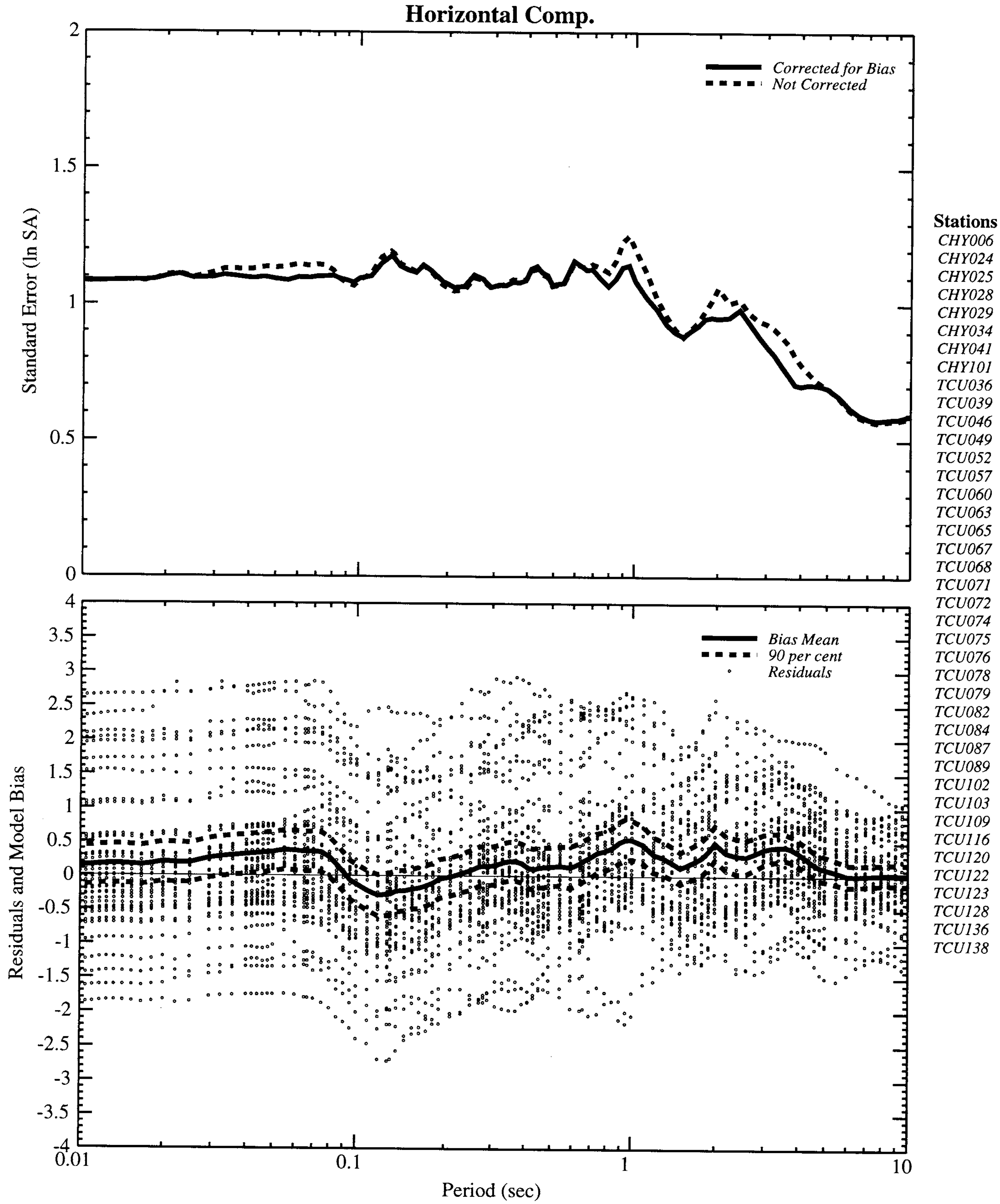

Figure 13. Goodness of fit: Chi-chi earthquake, horizontal component

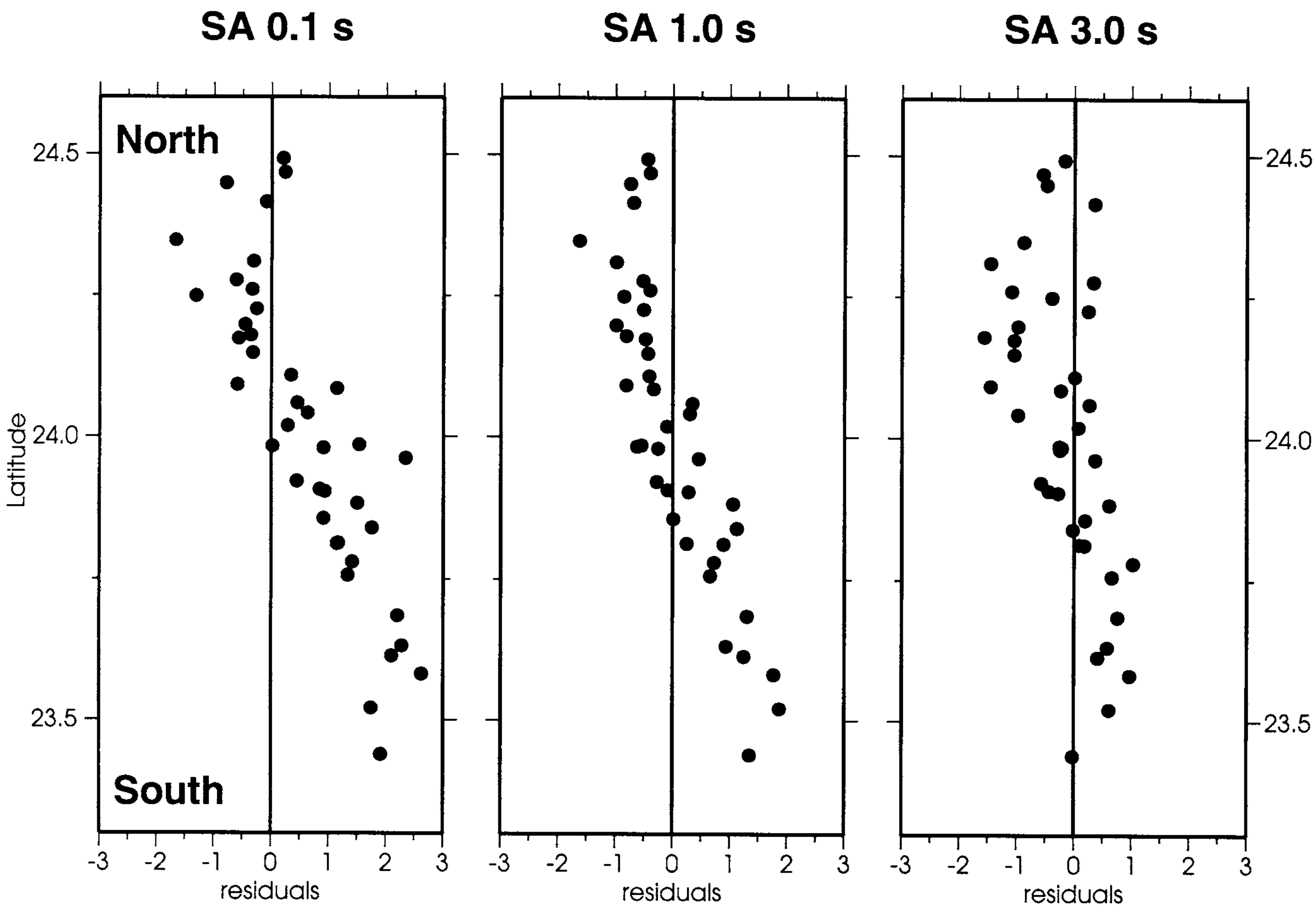

Figure 14. Residuals as a function of latitude and period: Chi-chi earthquake, vertical component

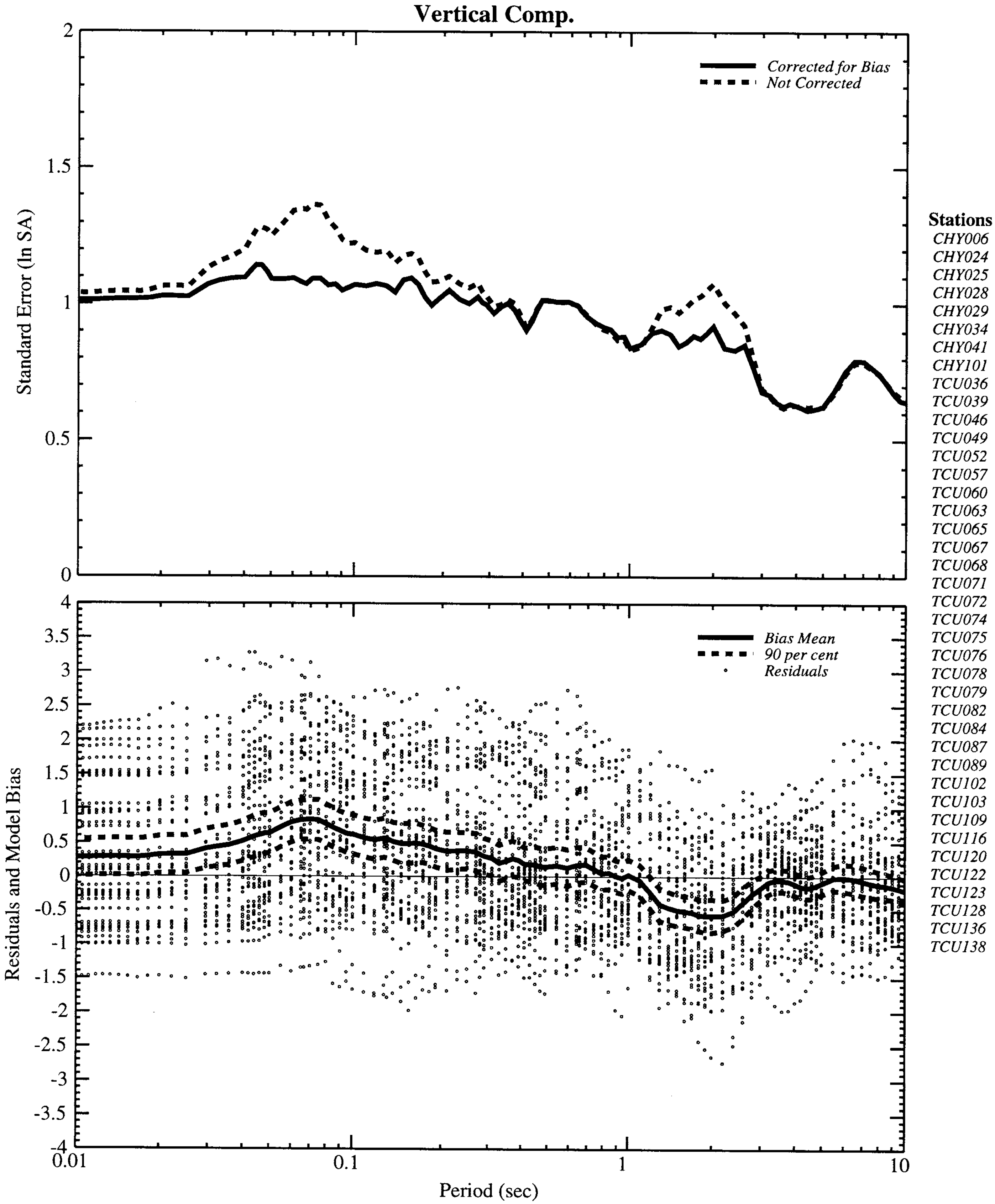

Figure 15. Goodness of fit: Chi-chi earthquake, vertical component

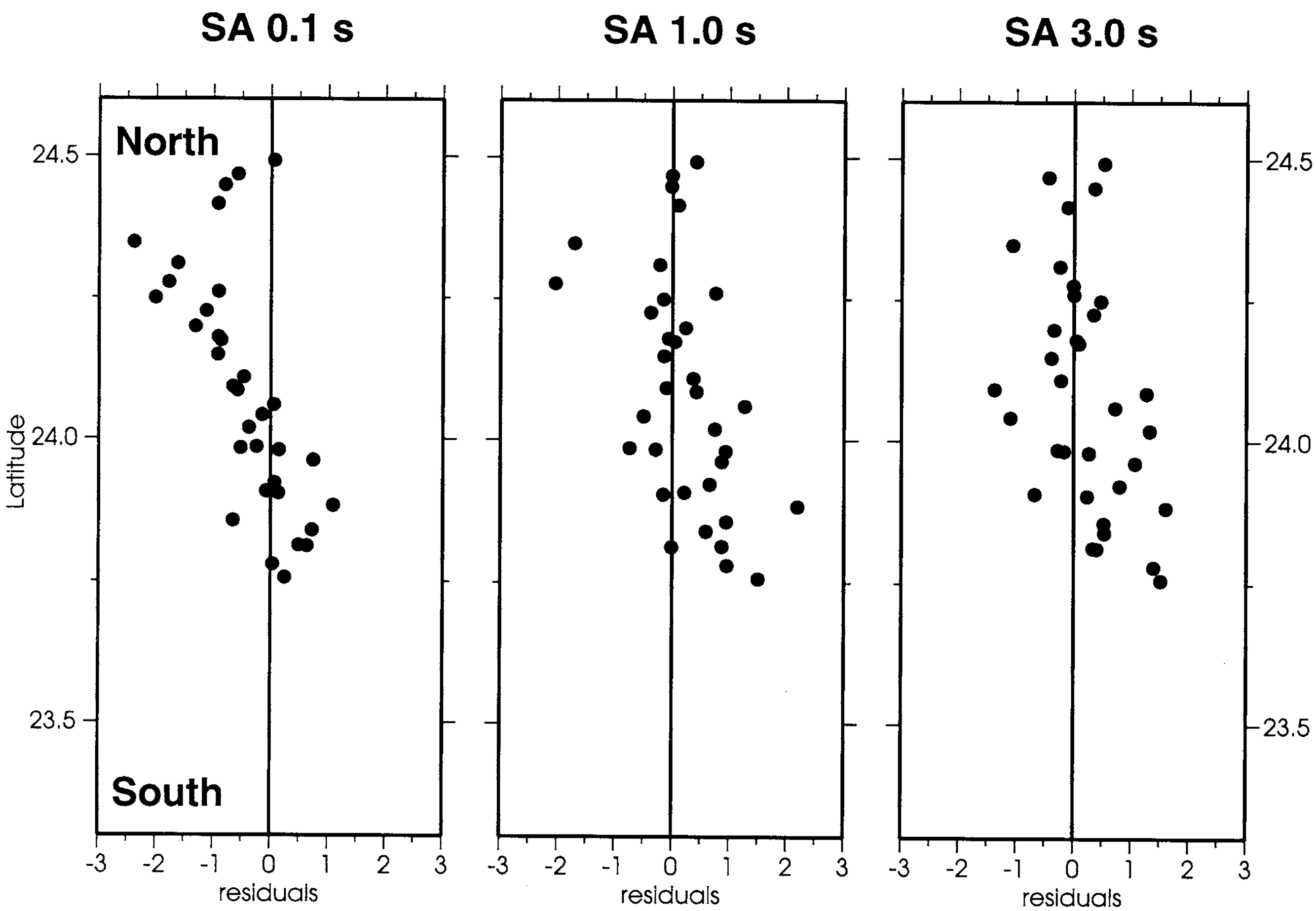

Figure 16. Residuals as a function of latitude and period: Chi-chi earthquake, horizontal component, excluding southernmost stations

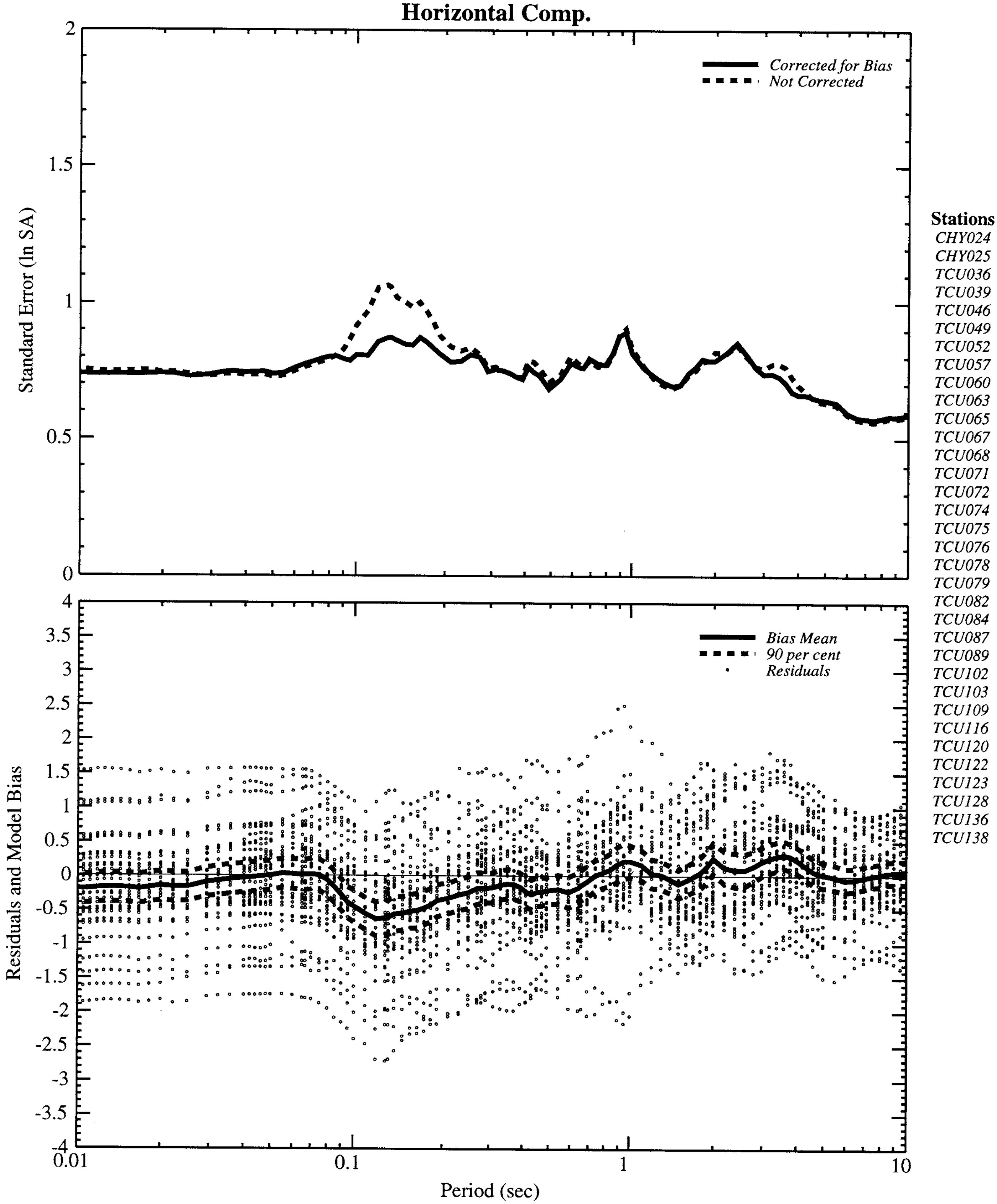

Figure 17. Goodness of fit: Chi-chi earthquake, horizontal component, excluding southernmost stations

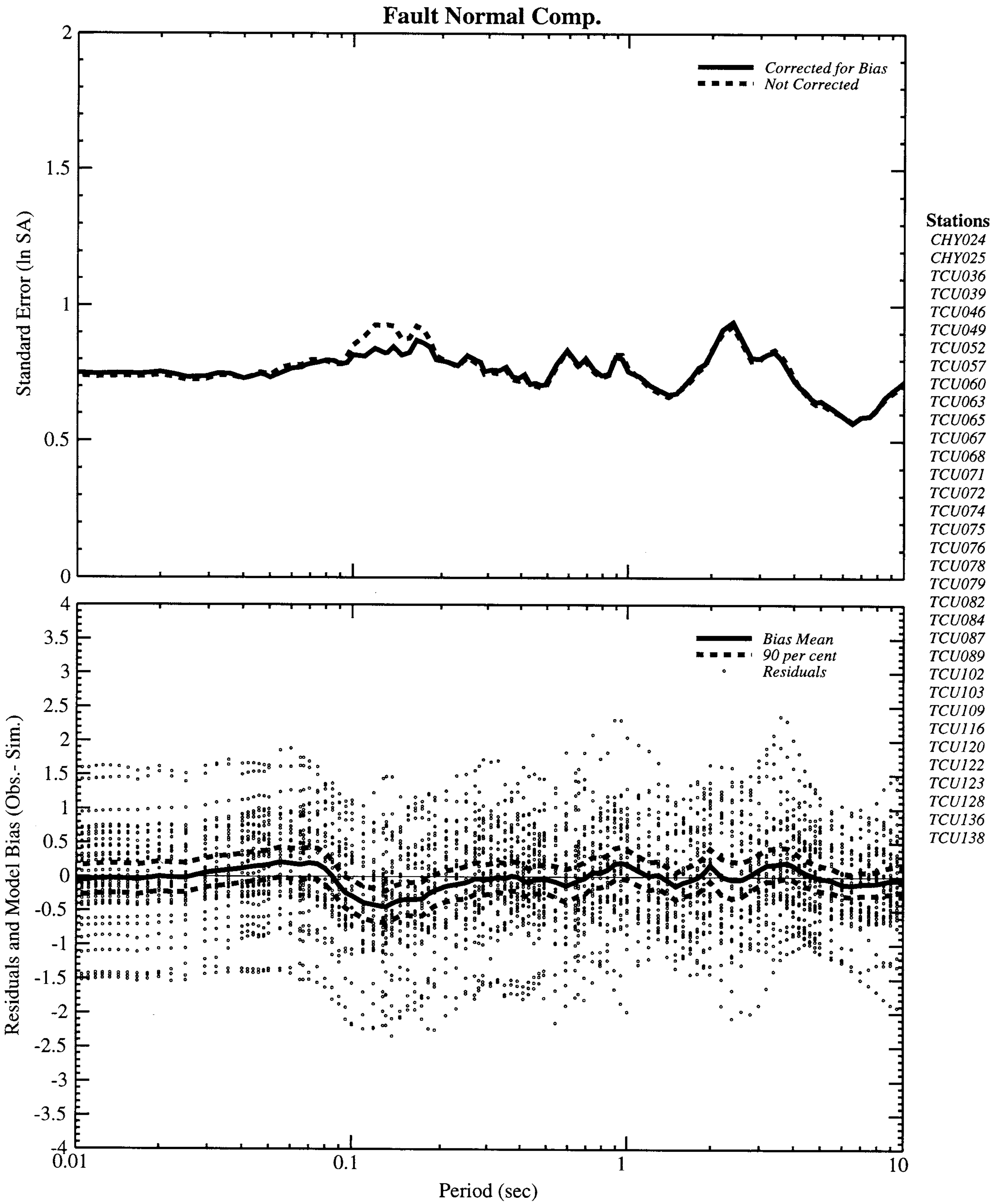

Figure 18. Goodness of fit: Chi-chi earthquake, fault normal component, excluding southernmost stations

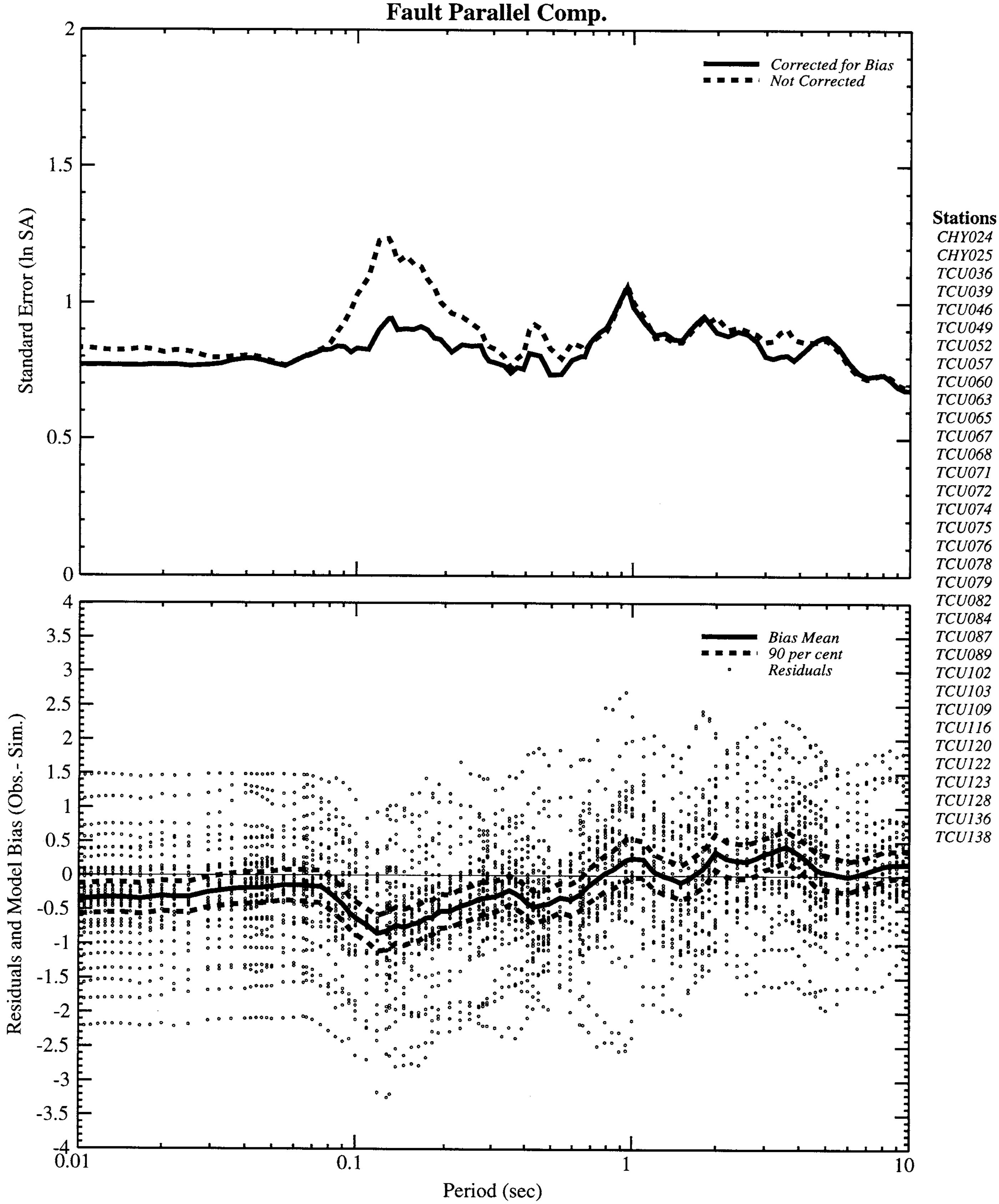

Figure 19. Goodness of fit: Chi-chi earthquake, fault parallel component, excluding southernmost stations

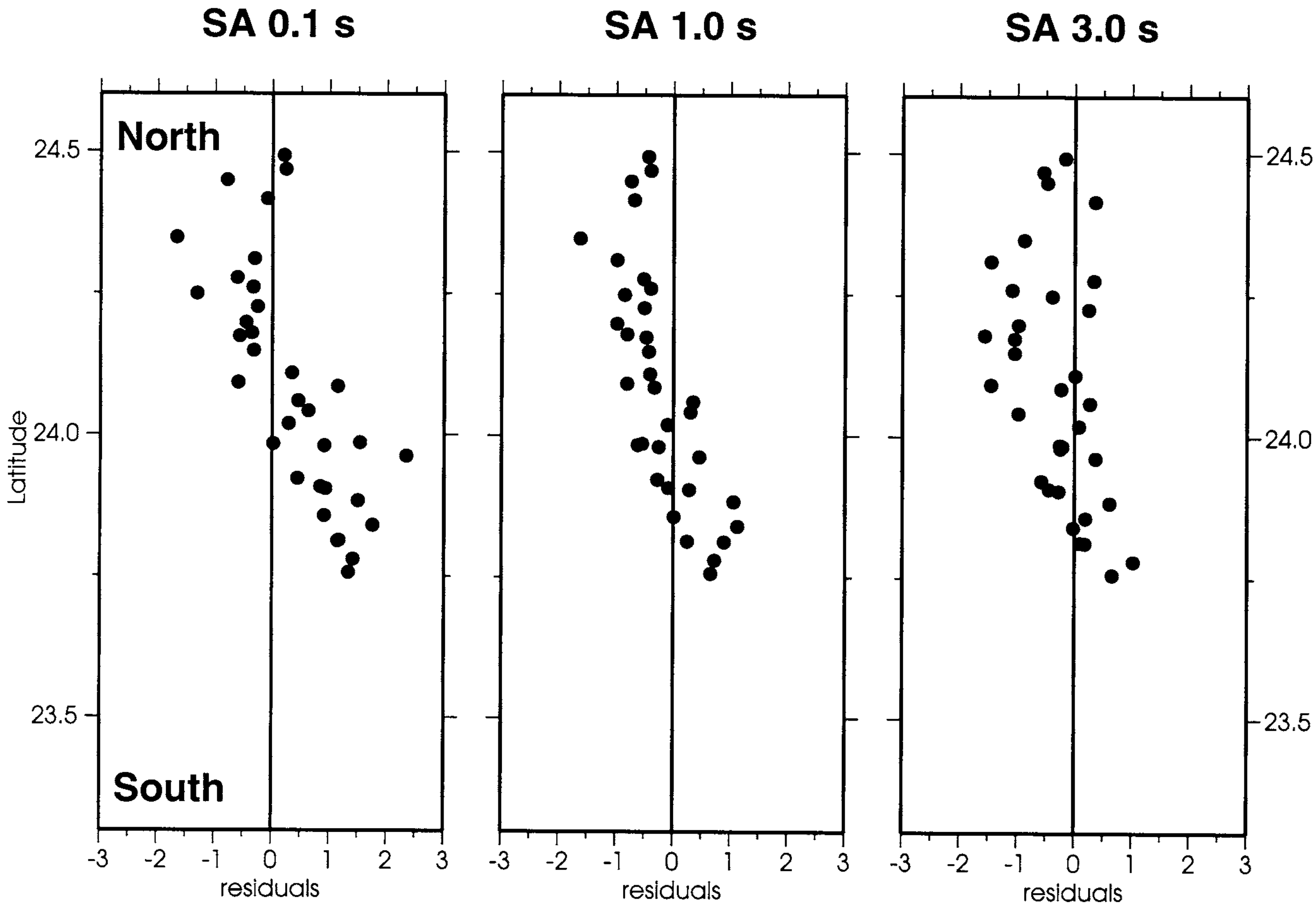

Figure 20. Residuals as a function of latitude and period: Chi-chi earthquake, vertical component, excluding southernmost stations

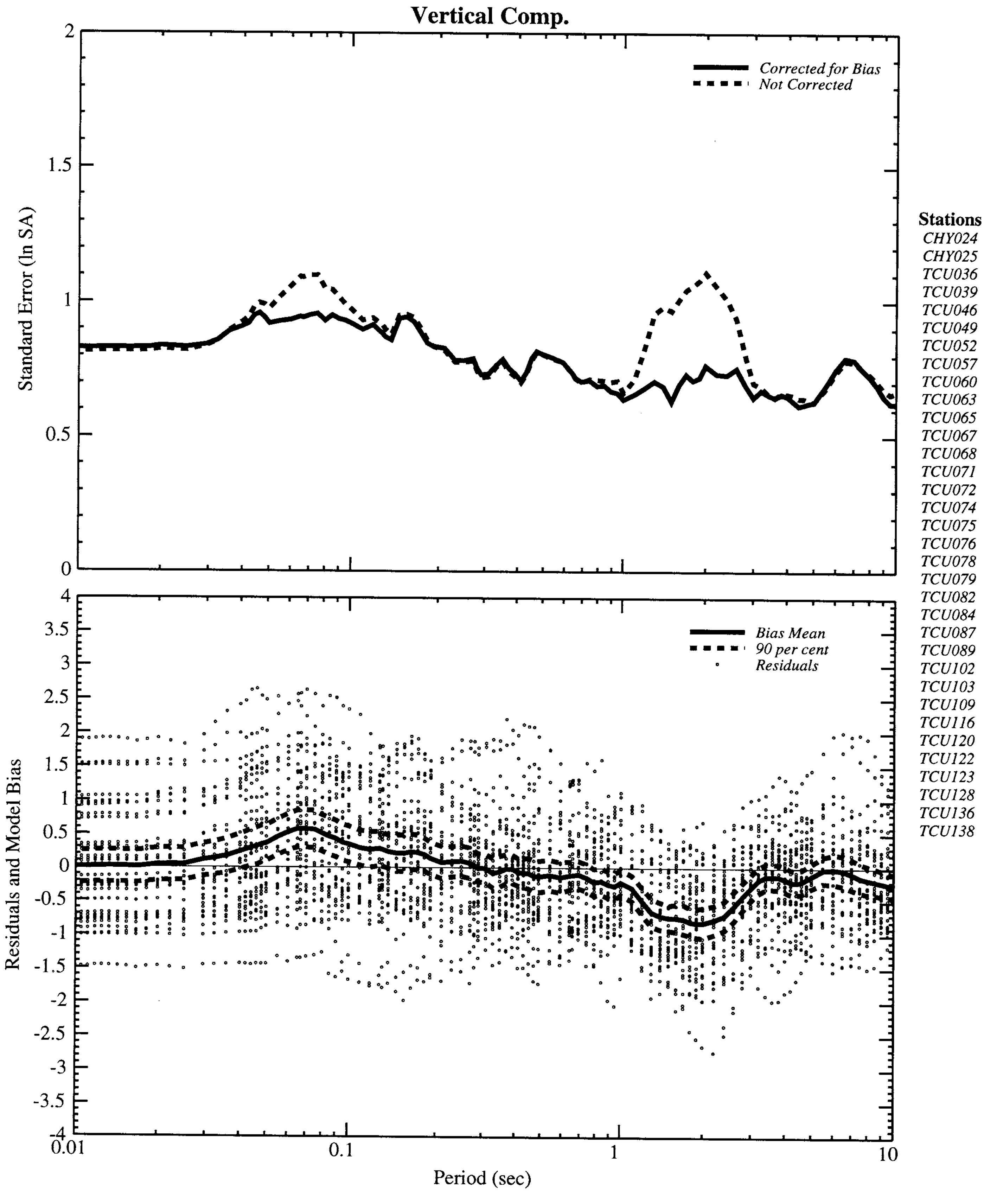

Figure 21. Goodness of fit: Chi-chi earthquake, vertical component, excluding southernmost stations

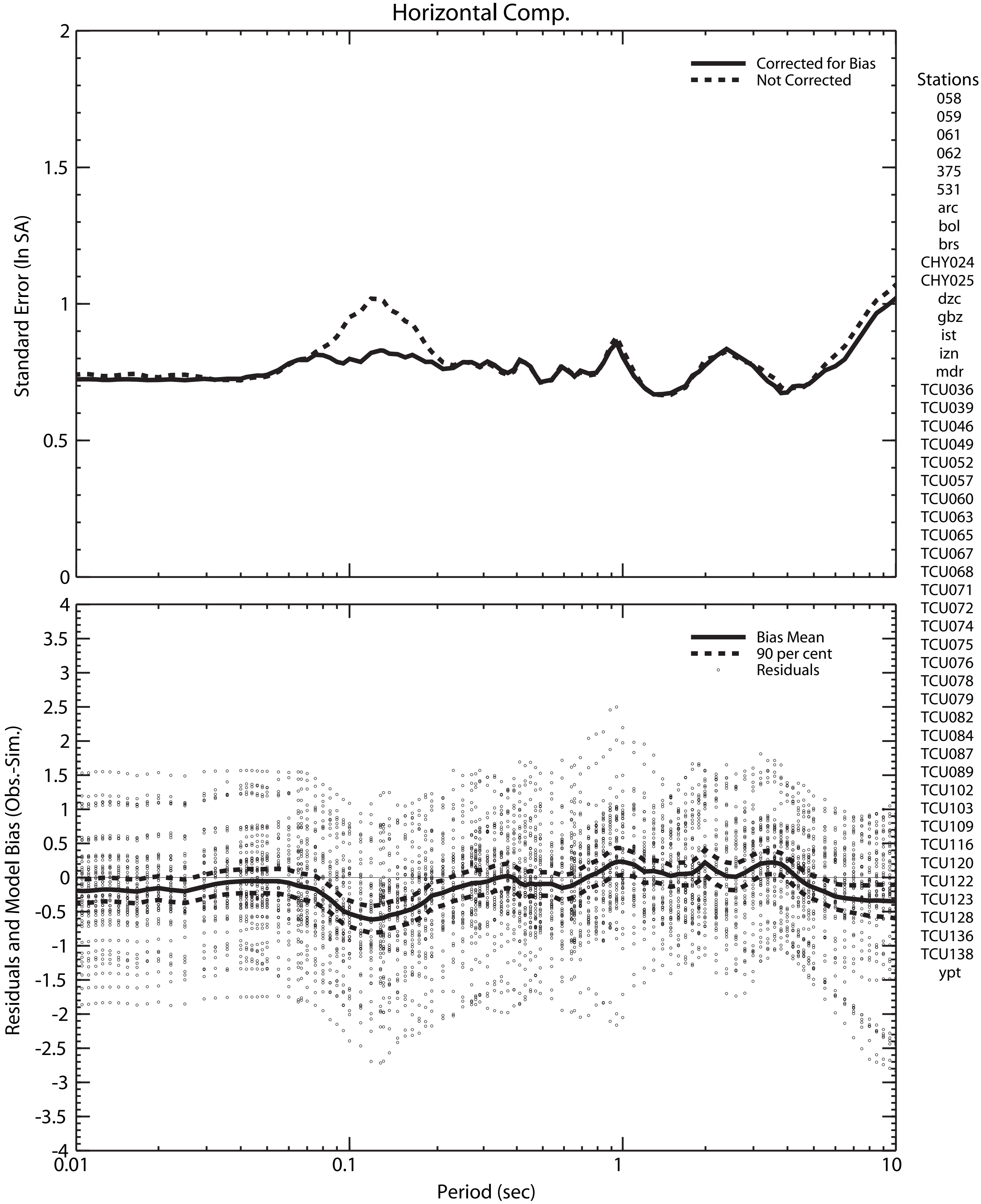

Figure 22. Goodness of fit: Kocaeli, Duzce, and Chi-chi earthquakes, horizontal component, excluding southernmost stations

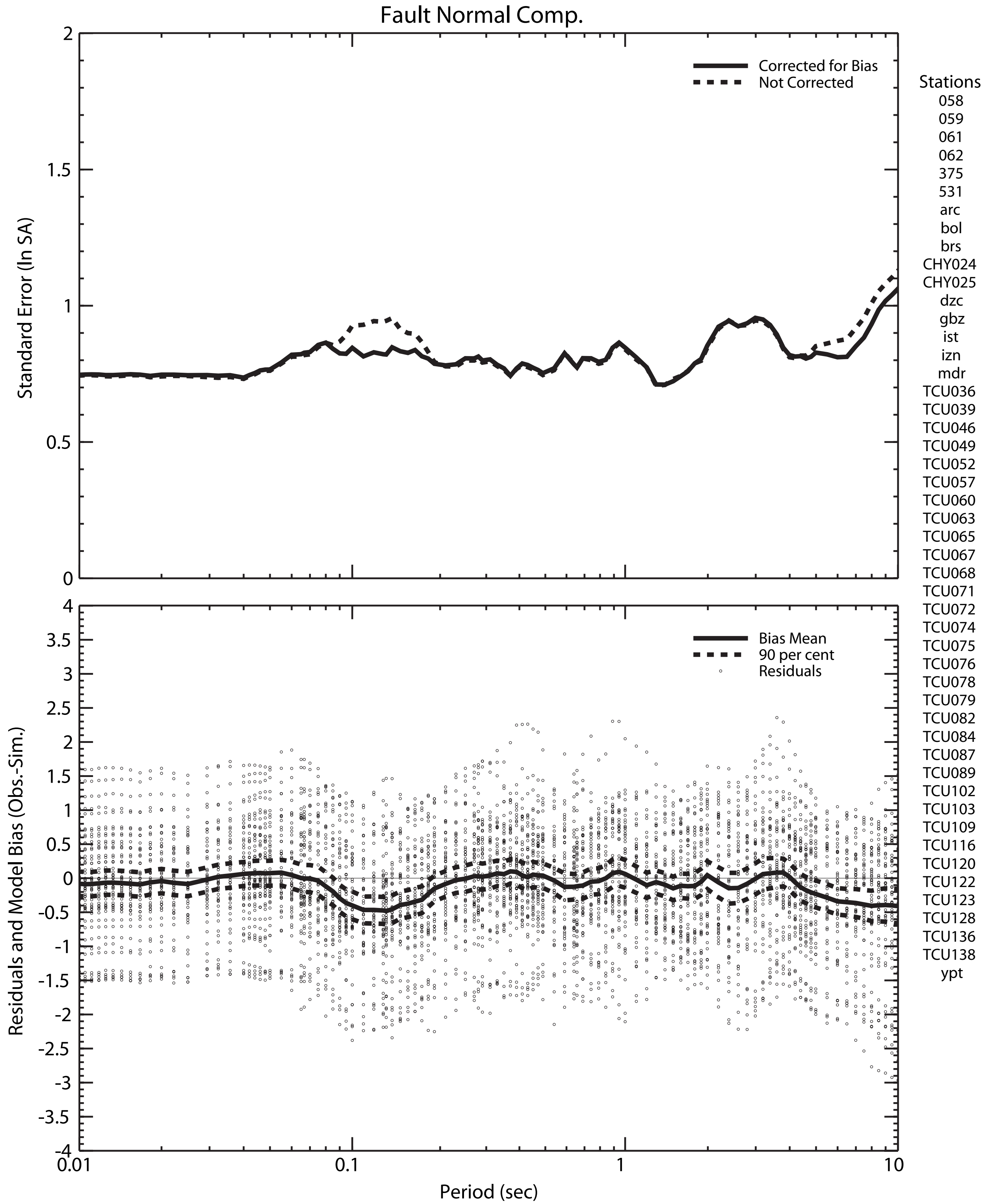

Figure 23. Goodness of fit: Kocaeli, Duzce, and Chi-chi earthquakes, fault normal component, excluding southernmost stations

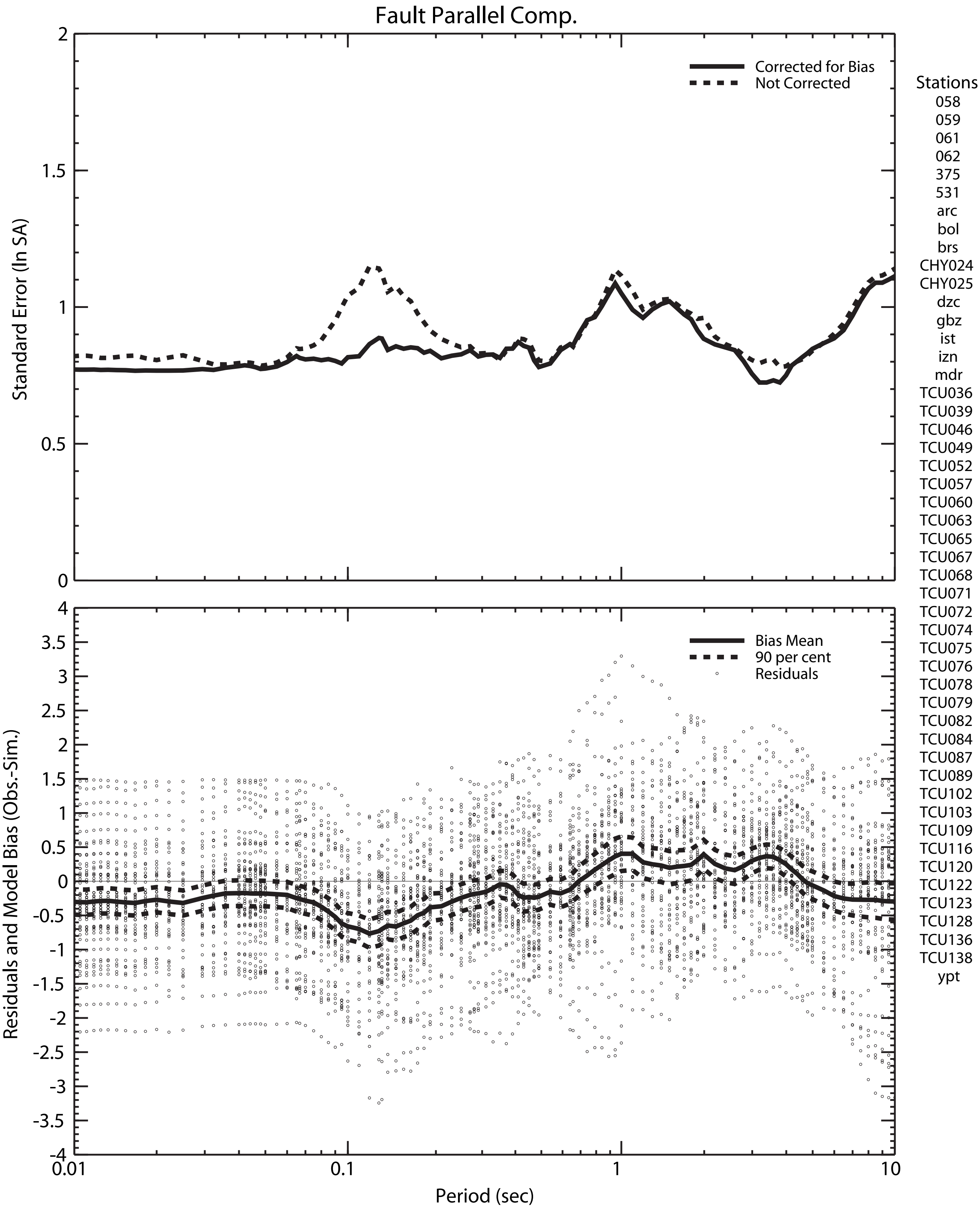

Figure 24. Goodness of fit: Kocaeli, Duzce, and Chi-chi earthquakes, fault parallel component, excluding southernmost stations

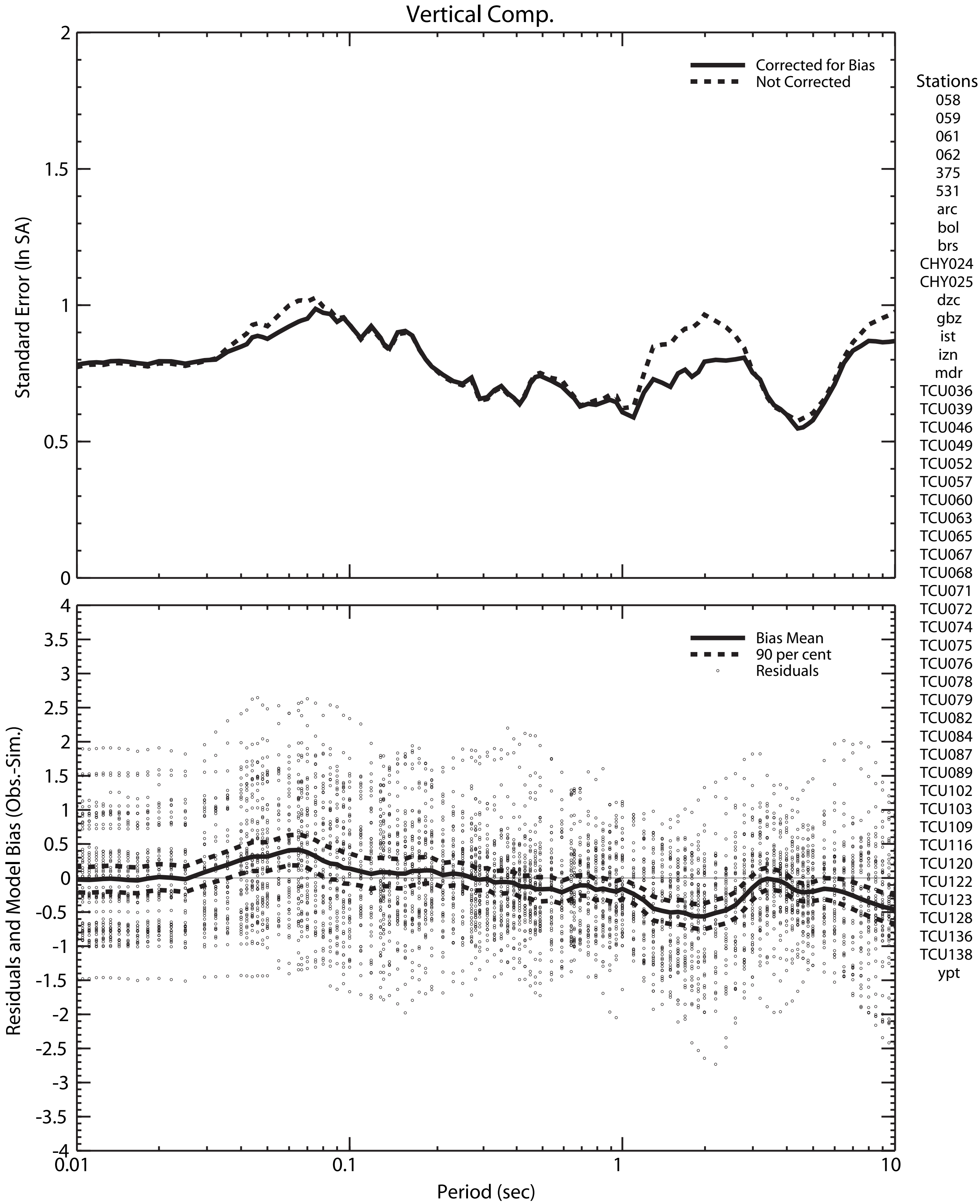

Figure 25. Goodness of fit: Kocaeli, Duzce, and Chi-chi earthquakes, vertical component, excluding southernmost stations

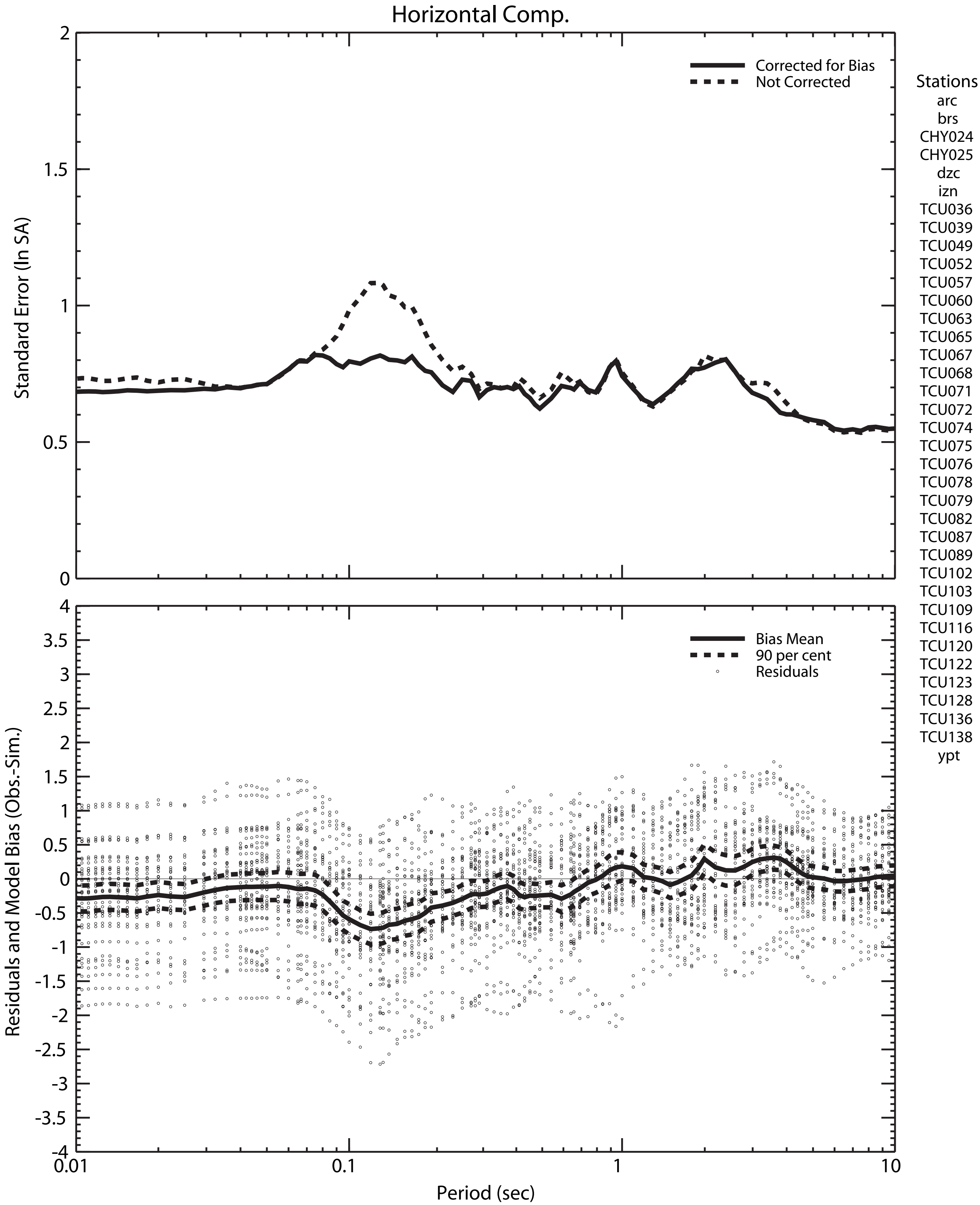

Figure 26. Goodness of fit: Kocaeli, Duzce, and Chi-chi earthquakes, horizontal component, excluding southernmost stations, soil sites

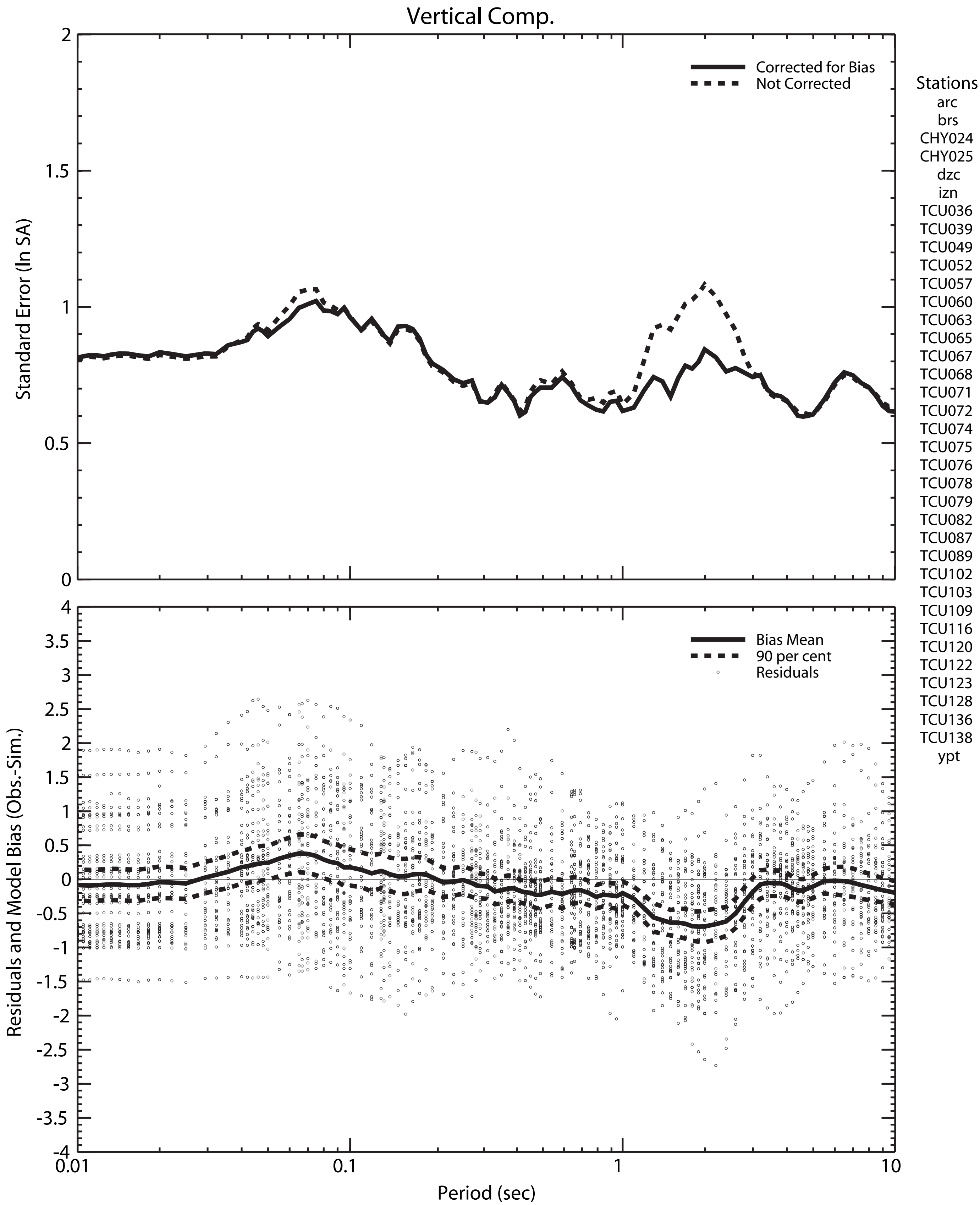

Figure 27. Goodness of fit: Kocaeli, Duzce, and Chi-chi earthquakes, vertical component, excluding southernmost stations, soil sites

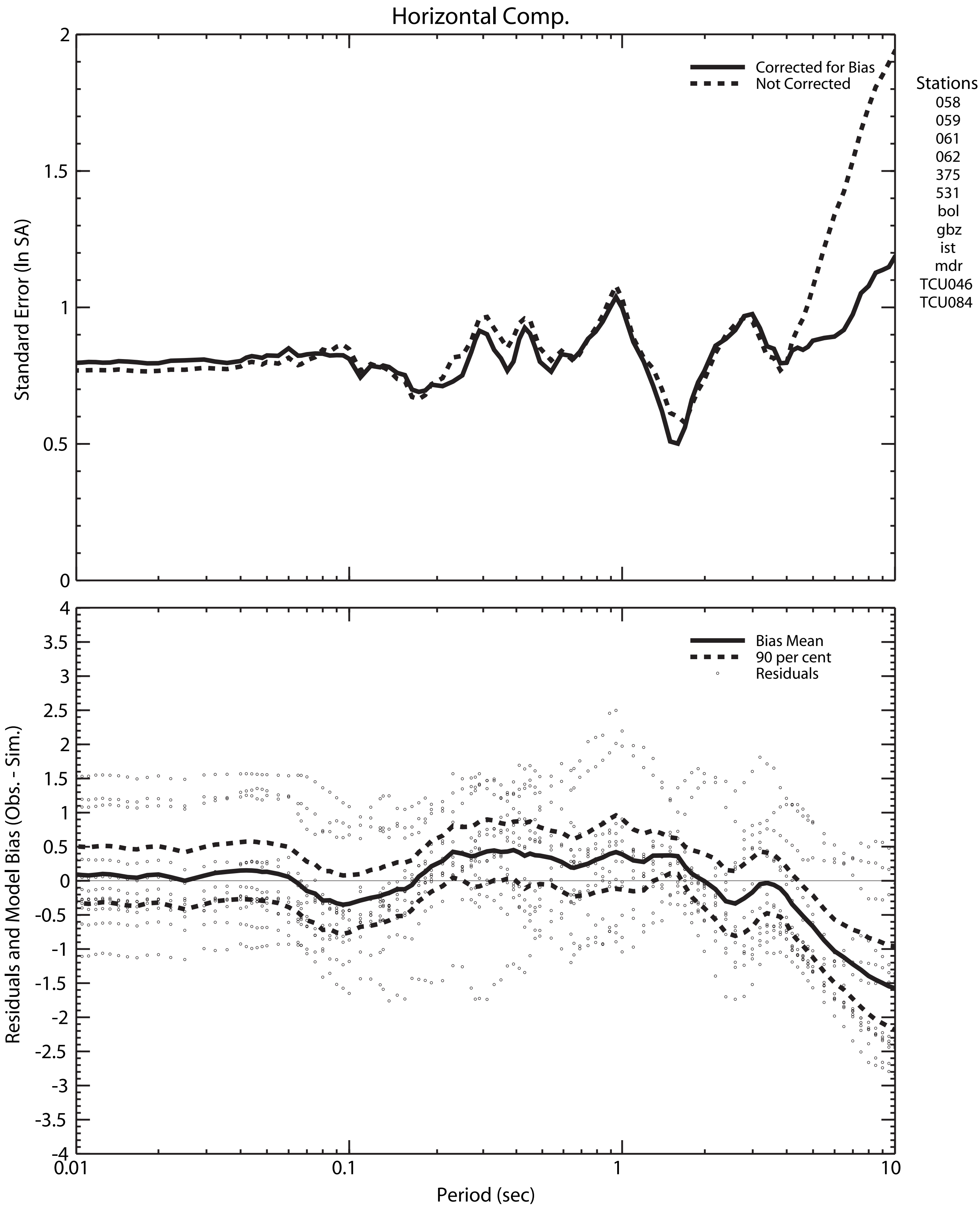

Figure 28. Goodness of fit: Kocaeli, Duzce, and Chi-chi earthquakes, horizontal component, excluding southernmost stations, rock sites

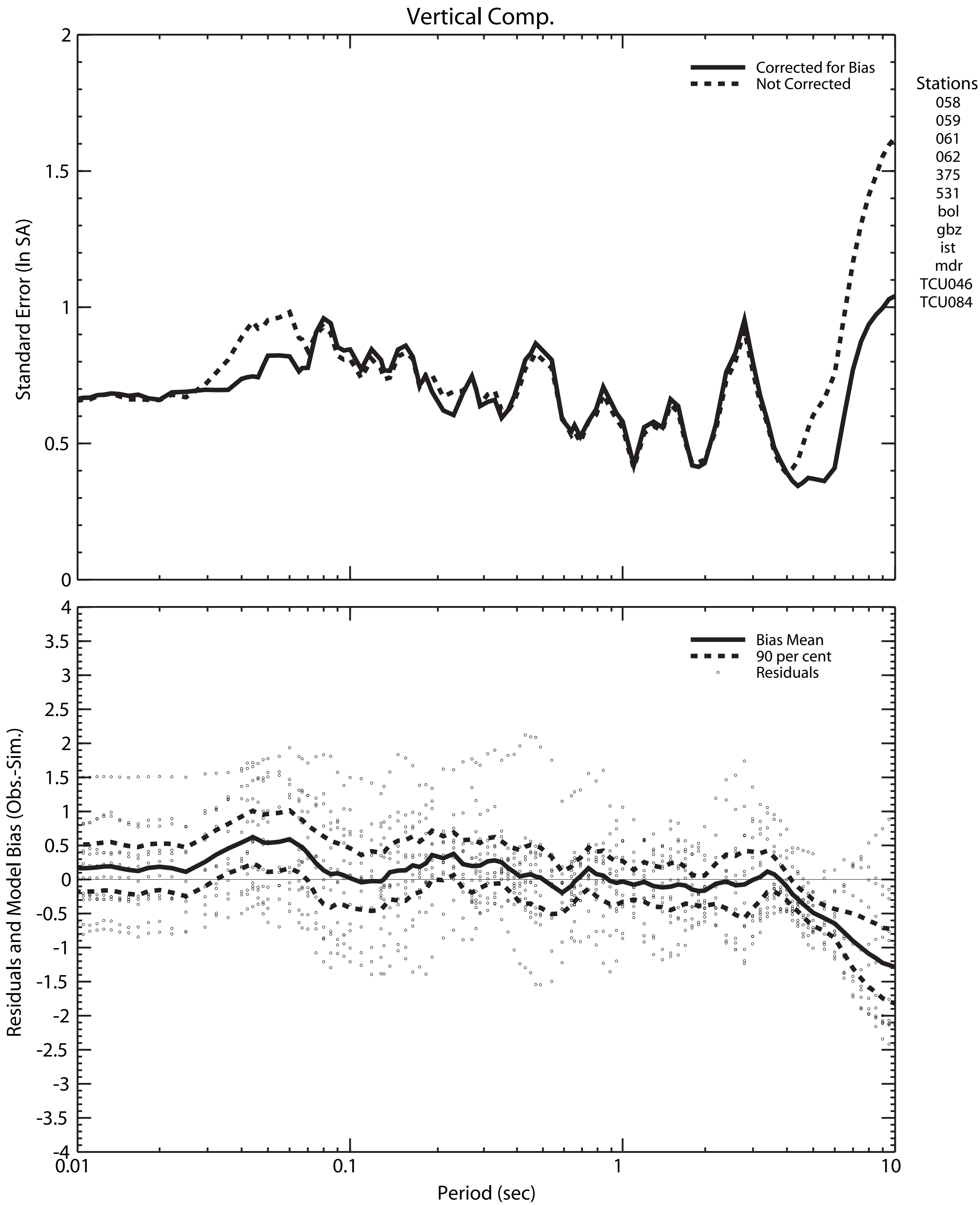

Figure 29. Goodness of fit: Kocaeli, Duzce, and Chi-chi earthquakes, vertical component, excluding southernmost stations, rock sites