"ANOMALOUS EM SIGNALS AND CHANGES IN RESISTIVITY AT PARKFIELD: COLLABORATIVE RESEARCH BETWEEN THE UNIVERSITIES OF CALIFORNIA AT BERKELEY AND RIVERSIDE AND OREGON STATE UNIVERSITY"

FINAL REPORT FOR JANUARY, 2001- JANUARY, 2003
MARCH, 2003

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Submitted to:

UNITED STATES DEPARTMENT OF THE INTERIOR
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NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

Grant 01HQGR0045

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Abstract

Fluctuations of resistivity have been monitored with an array measuring natural electric currents (telluric currents) in Parkfield. This array is designed to detect short-term relative changes of resistivity of 1% over days to weeks and long-term variations of 0.1% over months to years. Fractional daily variations of the telluric coefficients are computed and then compared to the earthquake record from Parkfield in order to determine if significant changes occurred prior to or at the time of local earthquakes. Changes in the telluric coefficients are related to changes in resistivity, albeit in a complicated manner because the earth is heterogeneous. While there were two earthquakes with ML > 3.5 within the area monitored by the array during 2001-2002, neither of these appears to have caused resistivity to fluctuate above our minimum sensitivity levels of ~1%. This is consistent with prior observations that earthquakes up to ML=5.0 do not produce significant fluctuations of telluric coefficients. Little progress has been made in adapting robust MT processing techniques to produce more stable coefficient estimates, but this work is not completed. So far, the existing analysis techniques are as good as the robust MT methods. Finally, work has begun on the construction of an updated 3-D resistivity model for Parkfield.

Introduction

Changes of electrical resistivity and anomalous electrical signals due to compression and shearing of rocks has been observed in many laboratory experiments [e.g., Brace, 1975; Yoshida et al., 1998]. Field observations, although more controversial because of the magnitudes of the changes, have also reported variations of electrical resistivity and anomalous signals prior to earthquakes [e.g., Zhao et al. 1991; Park, 1999]. In all of these cases, fluids play a crucial role in the resistivity changes and anomalous signals because most of the electrical current in crustal rocks is transferred through conductive brines occupying the pore/fracture space of the rocks.

Monitoring Array

Variations in the telluric coefficients are recorded with the monitoring array in Parkfield (Figure 1). Natural telluric currents are induced in the earth by a fluctuating magnetic field and are subsequently redistributed by the resistivity structure. If the wavelength of the source field is much larger than the dimension of the array, then the electric field measured on one dipole is related to the fields on arbitrarily designated reference dipoles (dipoles 7 and 8, Figure 1) through the following equation:

$$D_i = x\,D_7 + y\,D_8\,, \qquad (1)$$

where D_i is the signal on dipole i and x,y are the telluric coefficients. X and y are the telluric coefficients which should vary when changes in the electrical resistivity occur.Park [1991] found that the daily variations of the telluric coefficients from long-term average values were still too large to provide stability at the level of 1% or less. Thus, these variations were projected onto average electric field eigenvectors perpendicular (P1) and parallel (P2) to the San Andreas fault. These projections for 2001 are shown in Figures 2-7 for dipoles 1-6, respectively. Variations for dipoles 1-6 for 2002 are seen in Figures 8-13. As can be seen, stabilities of less than 1% have been achieved.

Due to a change in the lease at Halliburton Ranch in 2000, the resistivity recording system had to be moved from the location it had occupied since 1988. This move was accomplished in February, 2001 and the system was restarted on Julian day 40 (February 9, 2001). Data for days 1-40 are therefore missing in Figures 2-7. A shift of the Hq electrode (at the junction of dipoles 1-4 in Figure 1) was also required. While the shift was only 400 m to the south, this alters the telluric coefficients for dipoles 1-4 by about 10%. This change in telluric coefficients thus required us to establish a new baseline from which to determine daily fluctuations. The original baseline values were calculated using an annual average of the telluric coefficients from 1988 (approximately 280 days). New baseline values, used in Figures 2-6, were computed using an average of telluric coefficients for 240 days in 2001 (spanning the entire record for this year).
Comparison of the old and new average coefficients (Table 1), shows that changes are distributed as expected. Values for dipoles 1-4 changed by as much as 15% and more typically

Table 1 - Average telluric coefficients for 1988 and 2001.

Dipole	Xold	Yold	Xnew	Ynew	SERR X	SERR Y
1	-.57874	-.33194	-.60601	-.28872	.00228	.00107
2	-.46047	.31418	-.48685	.35814	.00630	.00312
3	.41848	.66829	.39573	.71352	.00187	.00053
4	.42216	-.33181	.39469	-.28846	.00273	.00058
5	-.87819	-.35422	-.87866	-.35448	.00465	.00156
6	-.12030	-.64601	-.11936	-.64541	.00492	.00171

and more typically of about 5% because of shift of the Hq electrode. Dipole lengths for dipoles 1-4 range from 7.1-9.4 km, so a change in position of 400 m could easily result in changes of 5% or more. Exact predictions of the changes would require accounting for rotations of the dipoles (which would affect the x and y coefficients) as well as assuming that the earth is homogeneous. Changes of less than 0.1% were observed for all coefficients for dipoles 5-6 except for the x value for dipole 6. This changed by 0.8%.

Efforts to improve the data analysis have also begun. These efforts are driven by two observations. First, formal errors calculated for the projections P1 and P2 are typically smaller than the scatter between daily estimates. Either the earth's resistivity is changing on a regular, daily basis by 1 percent or more or our analysis is not removing all of the sources of noise and the effects of a variable magnetic source field. Second, many more fluctuations of the projections occur than do earthquakes. If these fluctuations are real, then the predictive power of resistivity changes is nonexistent. These two observations have led us to reexamine our use of robust processing methods for identifying and elminating noisy data points in the records of the the telluric fields. Attempts to use magnetic field recordings at Tulsa to identify these noisy data points did not result in any improvement in the estimation of the telluric coefficients. We are now adopting a technique from magnetotelluric data analysis called remote reference in which magnetic fields from a second magnetic observatory (Tucson or Fresno) will be used to separate signal from noise in both the magnetic and telluric data. In early attempts to apply this analysis, we discovered that there was a slight variation in the magnetic transfer function between Fresno and Tucson that could be identified and eliminated with the inclusion of a third magnetic station at Boulder. Initially, this variation appeared in our data as a variation in the transfer function in Parkfield. However, this apparent transfer function variation was due to variations in the magnetic reference at Fresno.

2001 Results

The only tectonic event of note in Parkfield between February-October 2001 was a M3.4 earthquake on April 12 (Julian day 102) and nothing of note was seen on or before that day in the projections (Figures 2-6). This lack of change is consistent with the conclusion of Park [1997] that it is unlikely that resistivity changes will be detected with earthquakes of magnitude < 5.0. Data quality was excellent during the month before the earthquake, as well as on the day of the earthquake.

The other observation about Figures 2-6 is that the stability of the projections appears to be better than from previous years. Shifting the recording instruments out of the Halliburton ranch and up to the instrument shed on Carr Hill and/or shifting the Hq electrode from adjacent to the ranch building may have reduced noise in the electronic systems.

2002 Results

Two earthquakes with ML > 3.5 occurred in 2002. Event A had a magnitude of 3.8 and occurred on September 6 (Julian day 249) near Gold Hill (Figure 1). Event B had a magnitude of 4.2 and occurred on November 12 (Julian day 315) near the SAFOD drilling site (Figure 1). Neither produced observable coseismic variations or precursors, a result expected because of the small magnitudes. Stability of the projections is worse than in 2001 because of changes in the telephone lines; new multiplexing systems were installed on the lines leading to Hr (Figure 1) and have increased noise on dipoles 7 and 8. Because these dipoles are references for the analyses in Figures 8-13, scatter of the projections has increased.

Parkfield Model

We have begun constructing a 3-D resistivity model of the Parkfield region which is based on model results from MT data (Unsworth, et al., 1997; 2000; Park et al., 1991; 1996) and dc resisitivty data (Park and Fitterman, 1990). This multiscale model represents the detailed structure in the vicinity of the array with ~100 m blocks and the more distant structure with larger scale lengths. We intend to eventually invert the MT data to refine this model.

Data Availability

Time series data and processed results are available via anonymous ftp from vortex.ucr.edu (138.23.185.132) in pub/emsoc/1/pkfld. Data from 1988-2000 are presently available and data from 2001-2002 will be placed on the site shortly. Time series data from 1998-present are also available from the Northern California Earthquake Data Center at UC Berkeley.

Conclusions

Work to improve the stability of the projections will continue through the development of improved processing programs. Once competed, the entire data set will be reprocessed and significant fluctuations identified. These fluctuations will be compared to record of seismicity, including both repeating, smaller earthquakes and the larger, infrequent events. Given the importance of the role of fluids in altering the fault surface properties, methods to directly detect those fluids are crucial. One of the unique values of this experiment is its long duration, permitting an unusually thorough characterization of the background, natural variations. Another is the integration with other geophysical monitoring studies focused on the same segment of the San Andreas fault, permitting integration of different signals in order to deduce fault behavior.

Bibliography

No reports were generated during this time period from work for the US Geological Survey, but a summary not related to work performed under this contract was published:

Park, S.K., Perspectives on Monitoring Resistivity Changes with Telluric Signals at Parkfield, California: 1988-1999, *J. Geodynamics, 33*, 379-399, 2002.

References

Brace, W.F., Dilatancy-related electrical resistivity change in rocks, *Pure Appl. Geophys., 113*, 207-217, 1975.

Park, S.K., Perspectives on monitoring resistivity changes with telluric signals at Parkfield, California: 1988-1999, presented at RIKEN Symposium on the Recent Aspects of Electromagnetic Variations Related with Earthquakes, Tokyo, December 20-21, 1999.

Park, S.K. and D.V. Fitterman, Sensitivity of the telluric monitoring array in Parkfield, California to changes of resistivity, *J. Geophys. Res., 95*, 15,557-15,571, 1990.

Park, S.K., B. Hirasuna, G.R. Jiracek, and C. Kinn, Magnetotelluric evidence of lithospheric thinning beneath the southern Sierra Nevada, *J. Geophys. Res., 101*, 16241-16255, 1996.

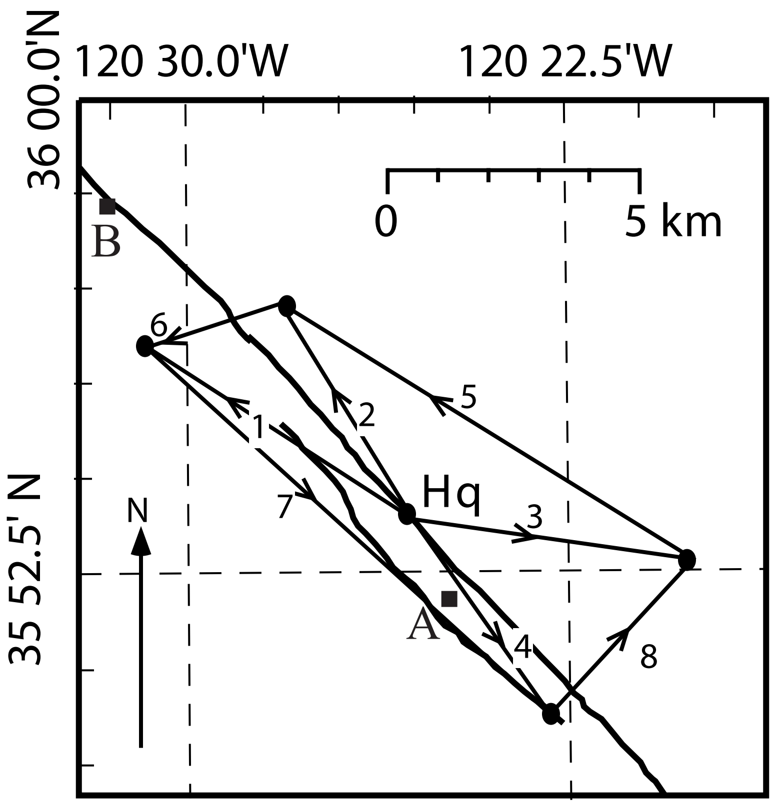
Unsworth, M., P. Bedrosian, M. Eisel, G. Egbert, and W. Siripunvaraporn, Along strike variations in the electrical structure of the San Andreas fault at Parkfield, California, *Geophys. Res. Lett., 27*, 3021-3024, 2000.

Unsworth, M.J., P.E. Malin, G.D. Egbert, and J.R. Booker, Internal structure of the San Andreas fault at Parkfield, California, *Geol. 25*, 359-362, 1997.

Yoshida, S., O.C. Clint, and P.R. Sammonds, Electric potential changes prior to shear fracture in dry and saturated rocks, *Geophys. Res. Lett., 25*, 1577-1580, 1998.

Zhao, Y., F. Qian, and T. Xu, The relationship between resistivity variation and strain in a load-bearing rock-soil layer, *Acta Seismol. Sinica, 4*, 127-137, 1991.

Figure 1 - Location map showing array in Parkfield. Dipoles 1-8 are labeled and polarities shown with arrows. Heavy black lines are strands of the San Andreas fault. Dipoles 7 and 8 are used as references for dipoles 1-6. A and B are earthquakes with local magnitudes greater 3.5 in 2001-2002. See text for details.



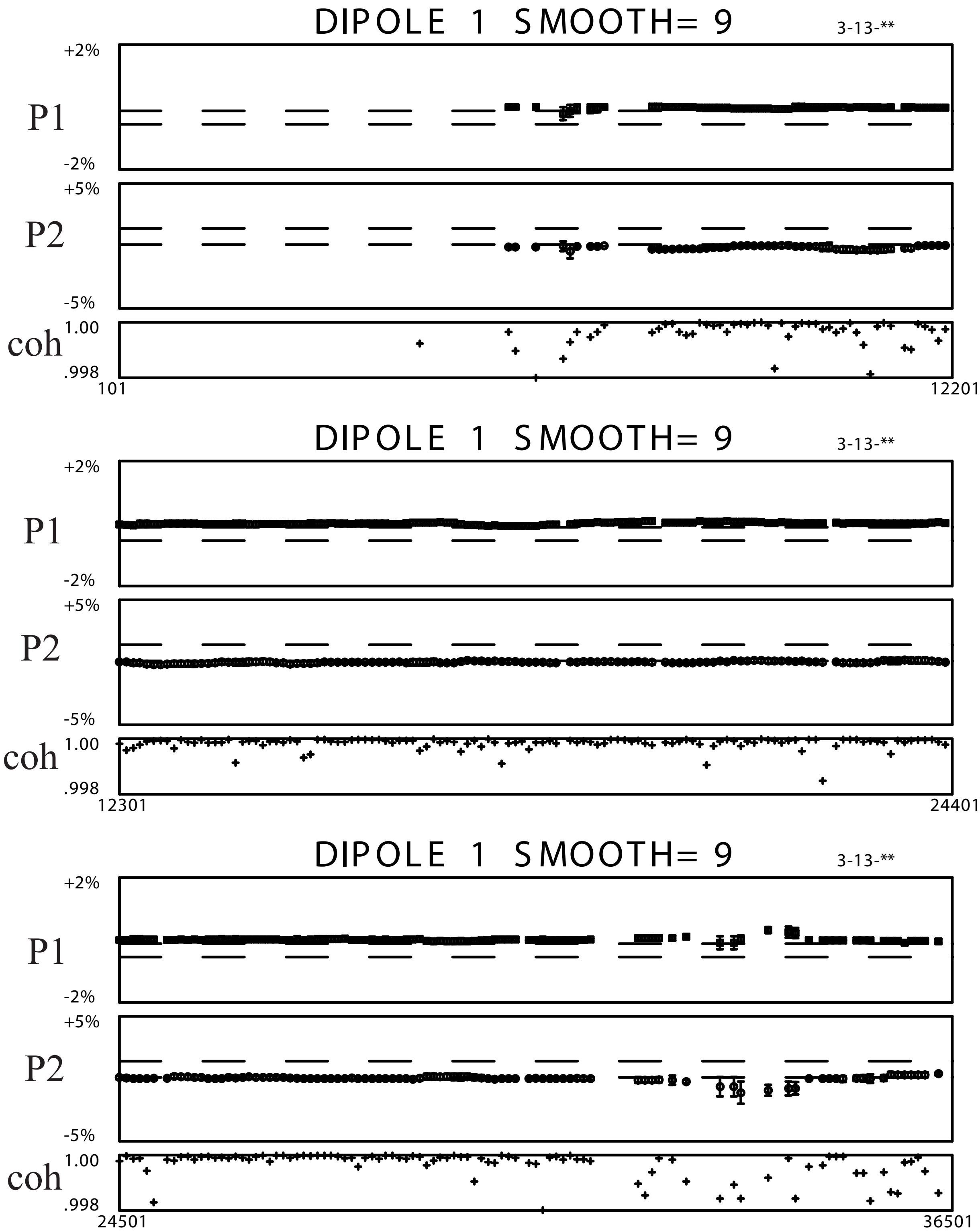


Figure 2 - Residual analysis for dipole 1 for 2001. P1 is the projection of the residual on the eigenvector perpendicular to the fault and P2 is the projection on the eigenvector parallel to the fault. Coherencies between the observed and predicted dipole signal are shown between 0.998 and 1.000. Julian days are used for the time axis, and each frame corresponds to approximately 4 months.

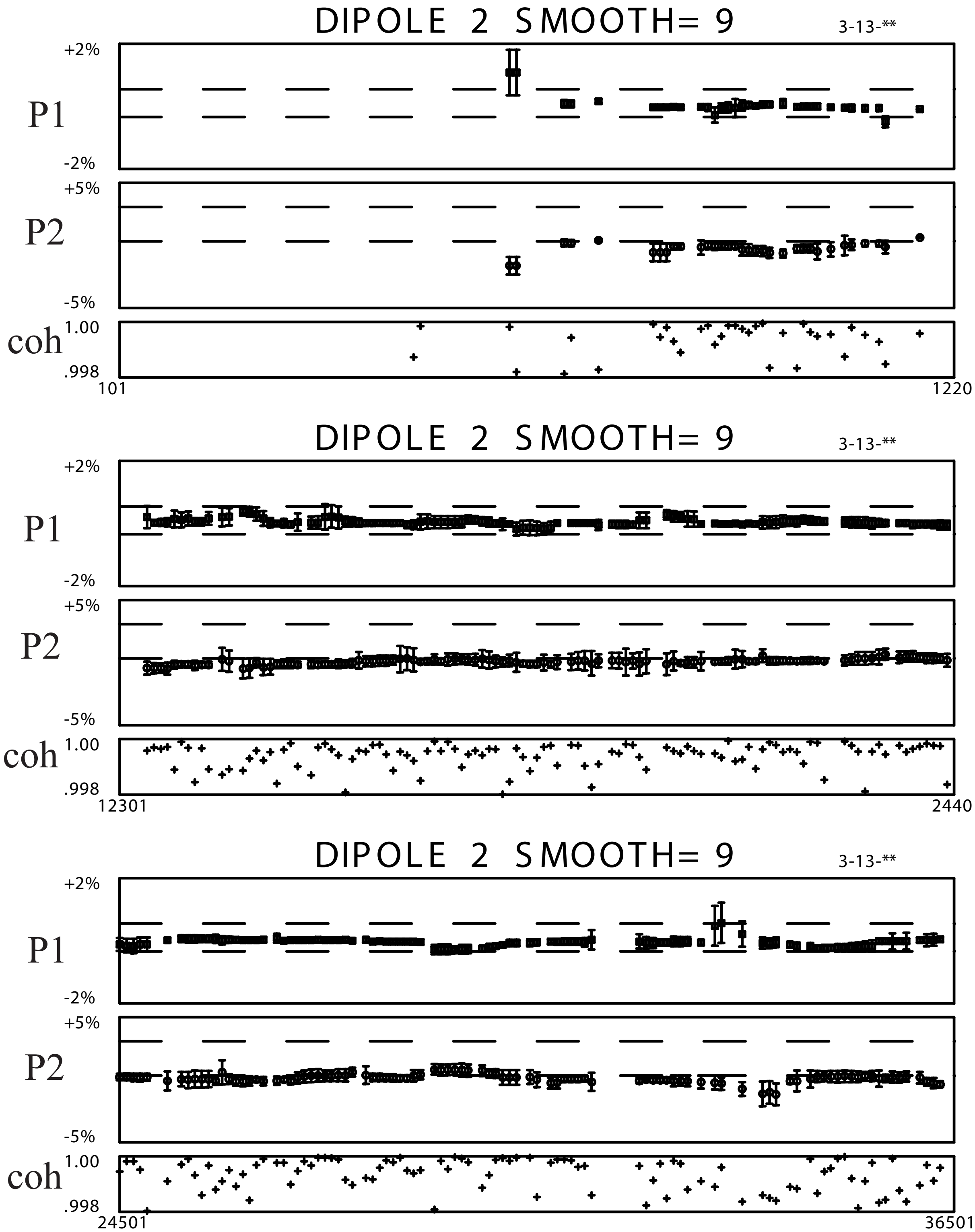


Figure 3 - Residual analysis for dipole 2 for 2001. See caption of Figure 2 for explanation.

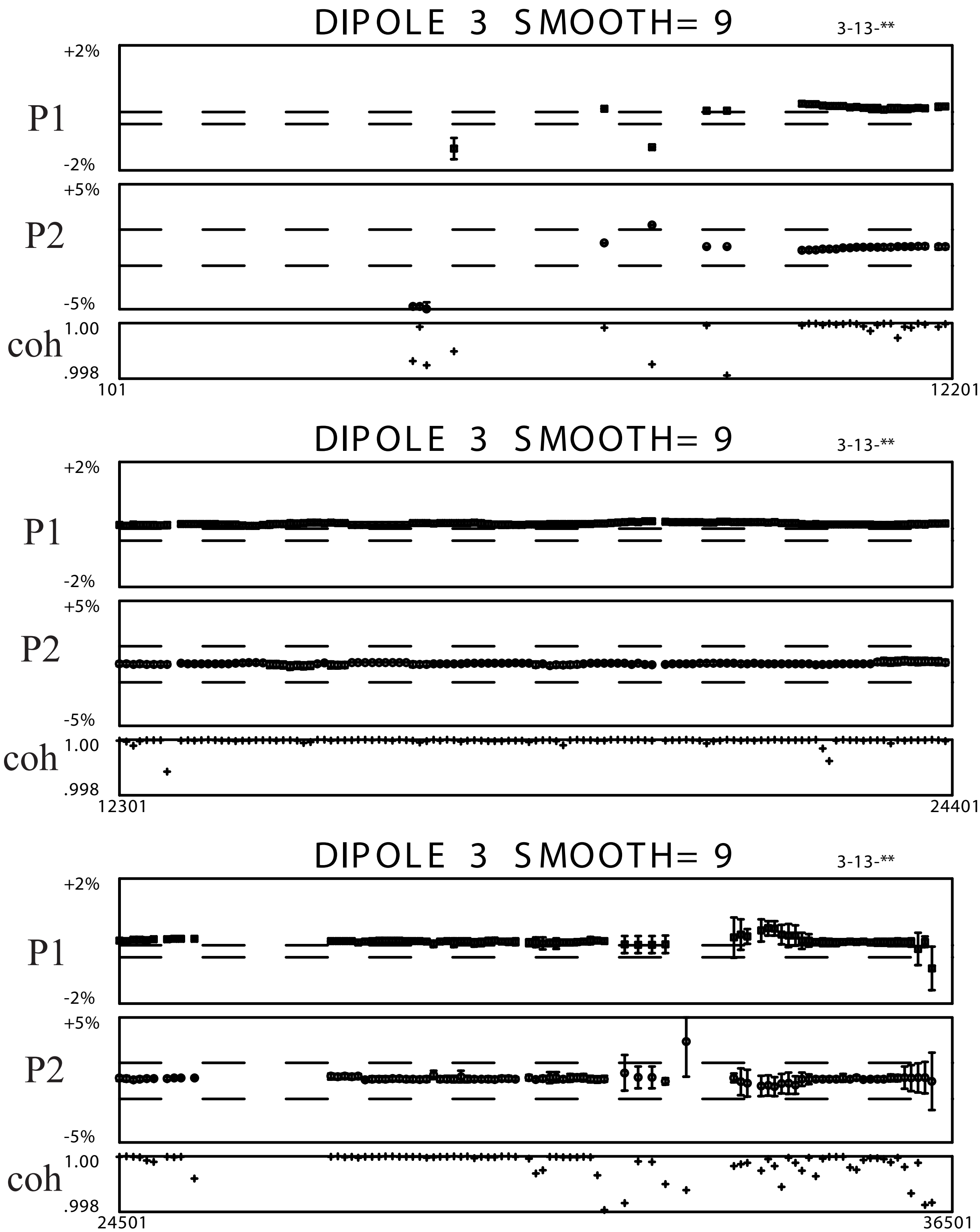


Figure 4 - Residual analysis for dipole 3 for 2001. See caption of Figure 2 for explanation.

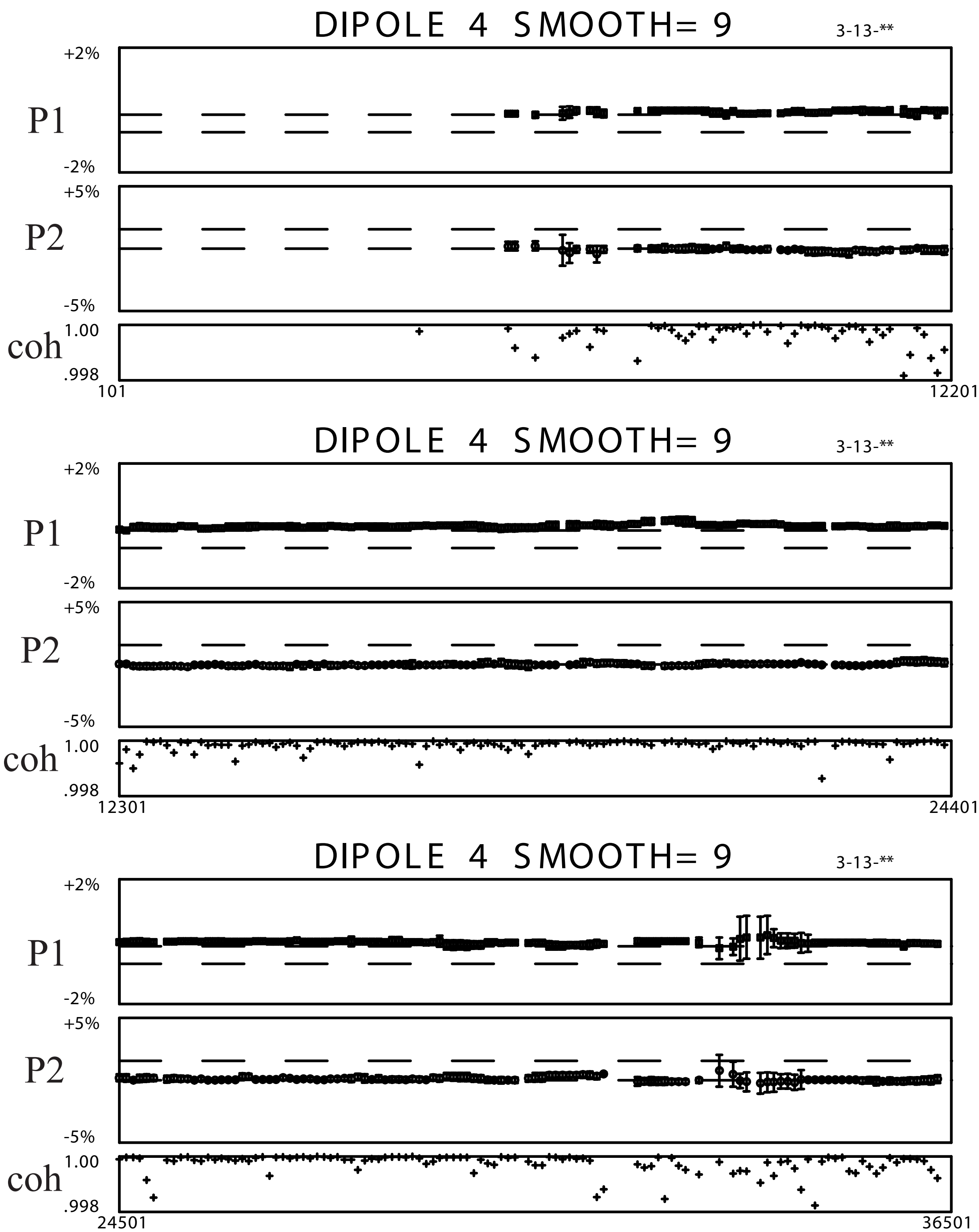


Figure 5 - Residual analysis for dipole 4 for 2001. See caption of Figure 2 for explanation.

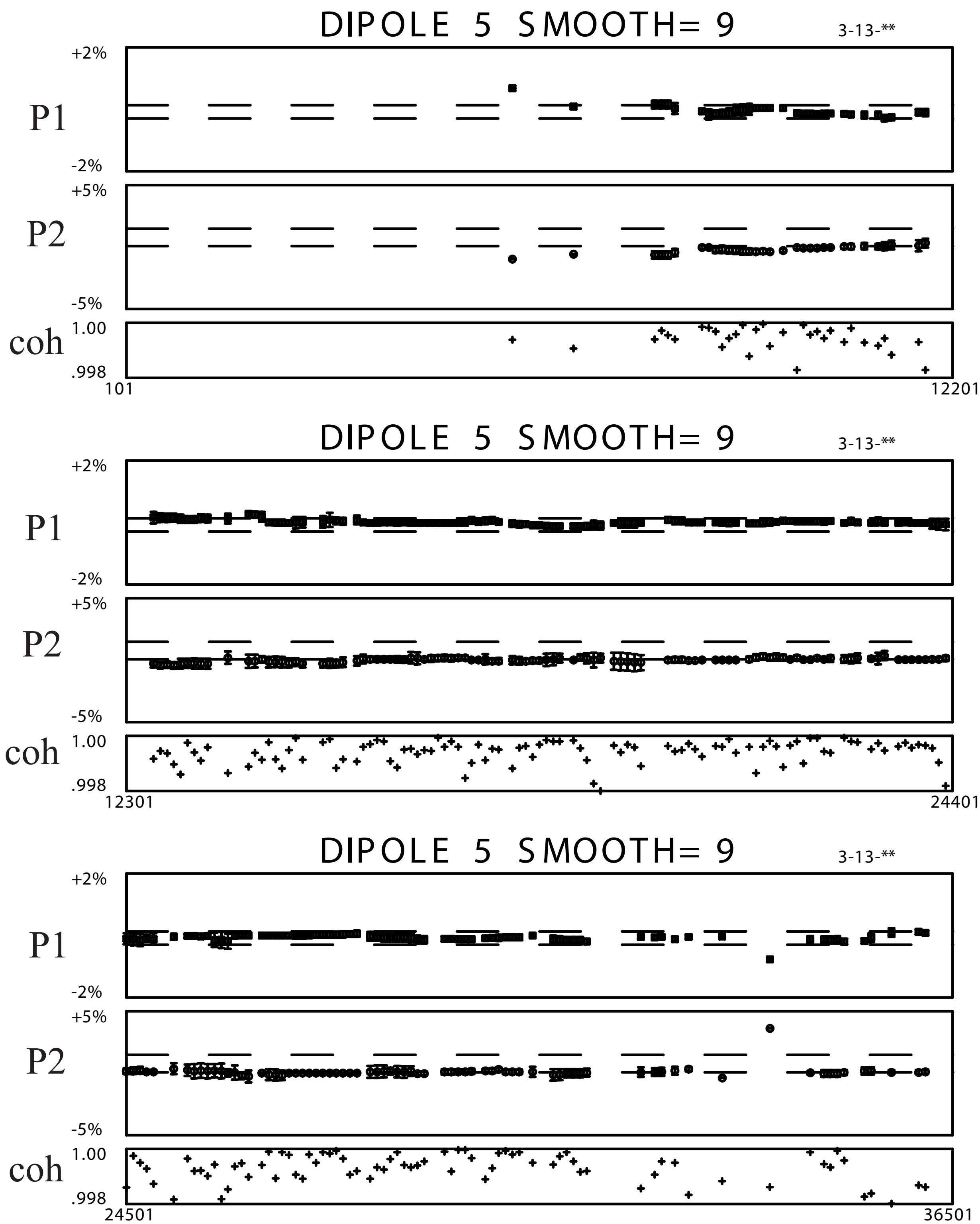


Figure 6 - Residual analysis for dipole 5 for 2001. See caption of Figure 2 for explanation.

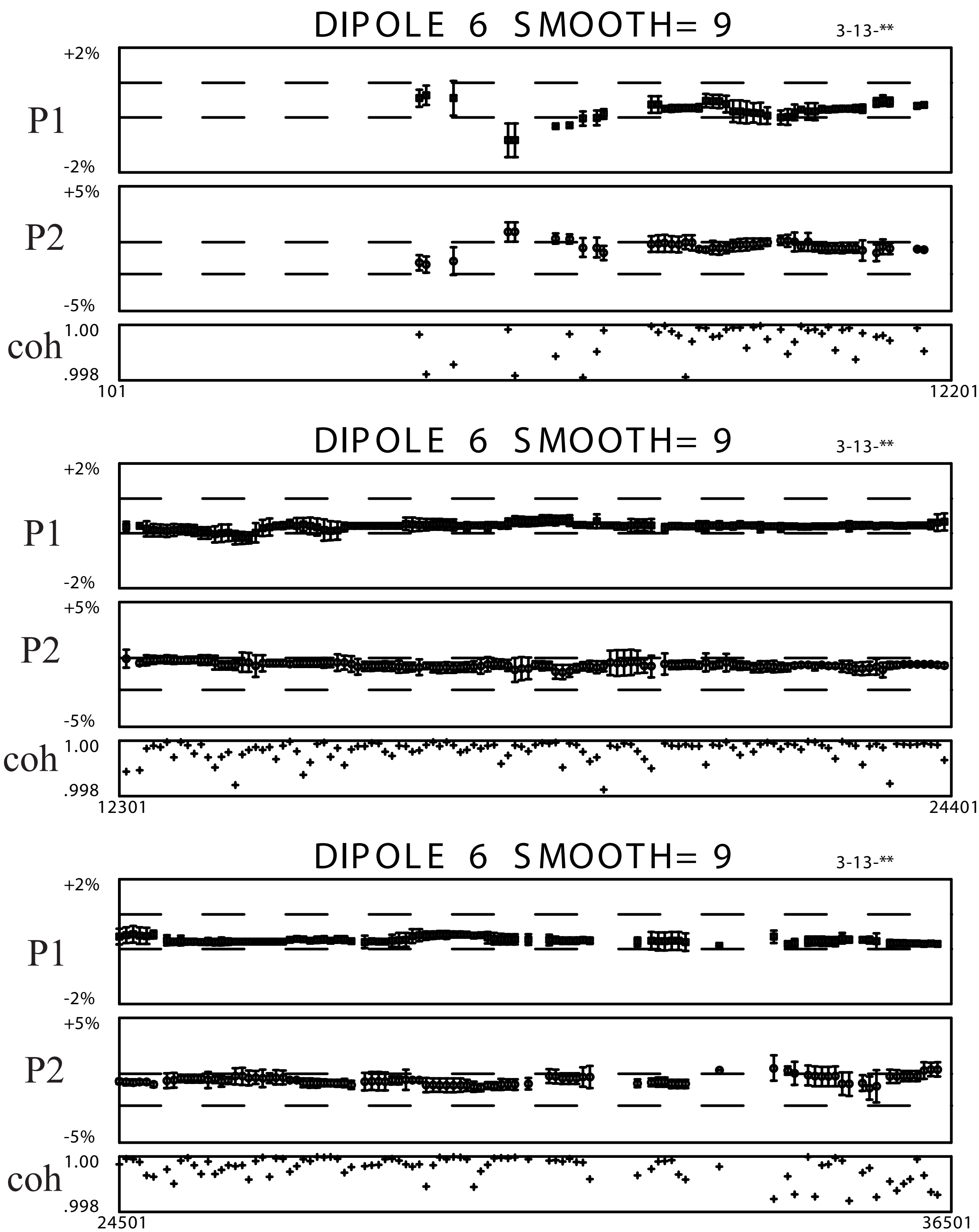


Figure 7 - Residual analysis for dipole 6 for 2001. See caption of Figure 2 for explanation.

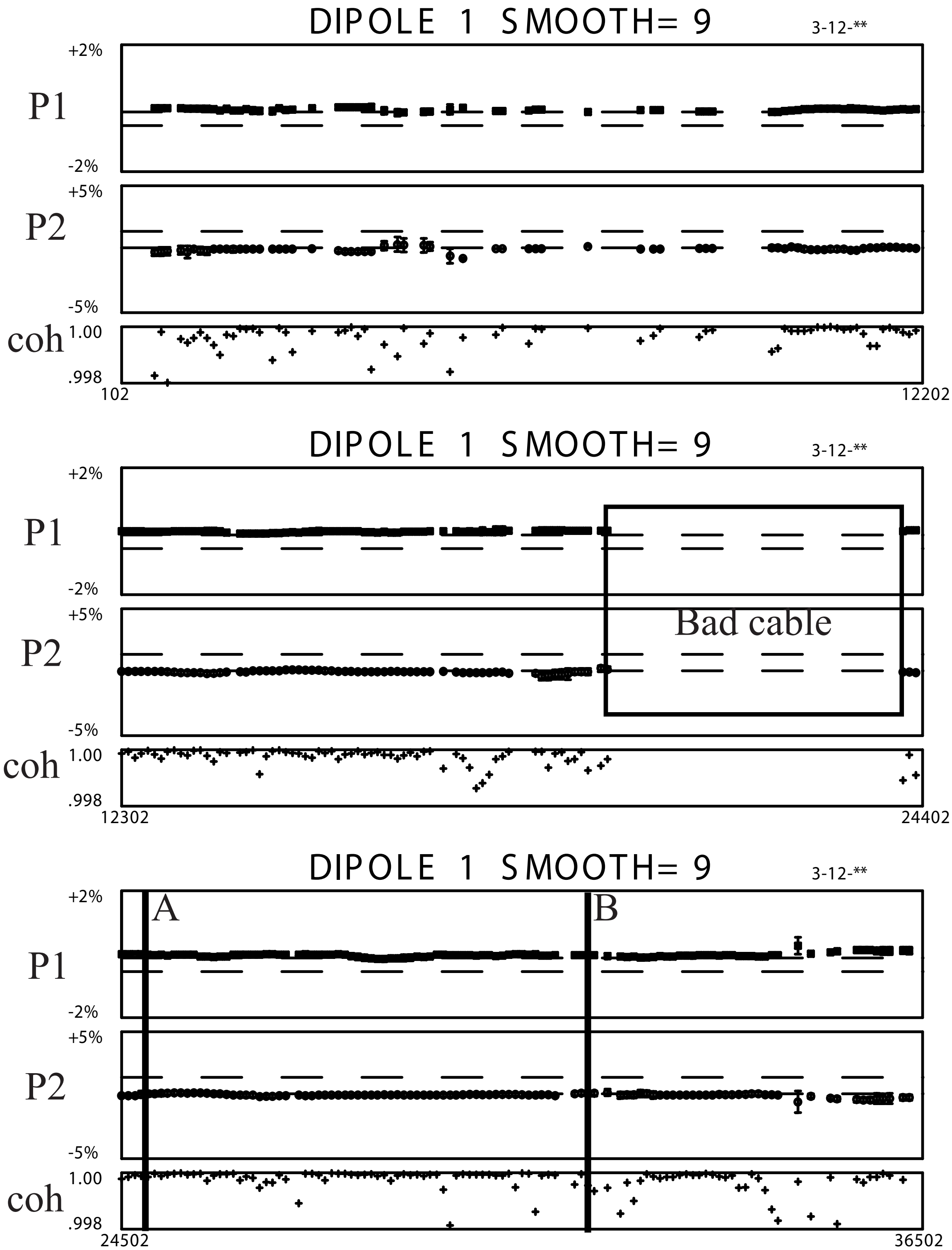


Figure 8 - Residual analysis for dipole 1 for 2001. See caption of Figure 2 for explanation. A and B denote ML 3.8 and 4.2 earthquakes, respectively. Note lack of change associated with or prior to earthquakes. Missing section in days 180-240 is due to bad telephone cable.

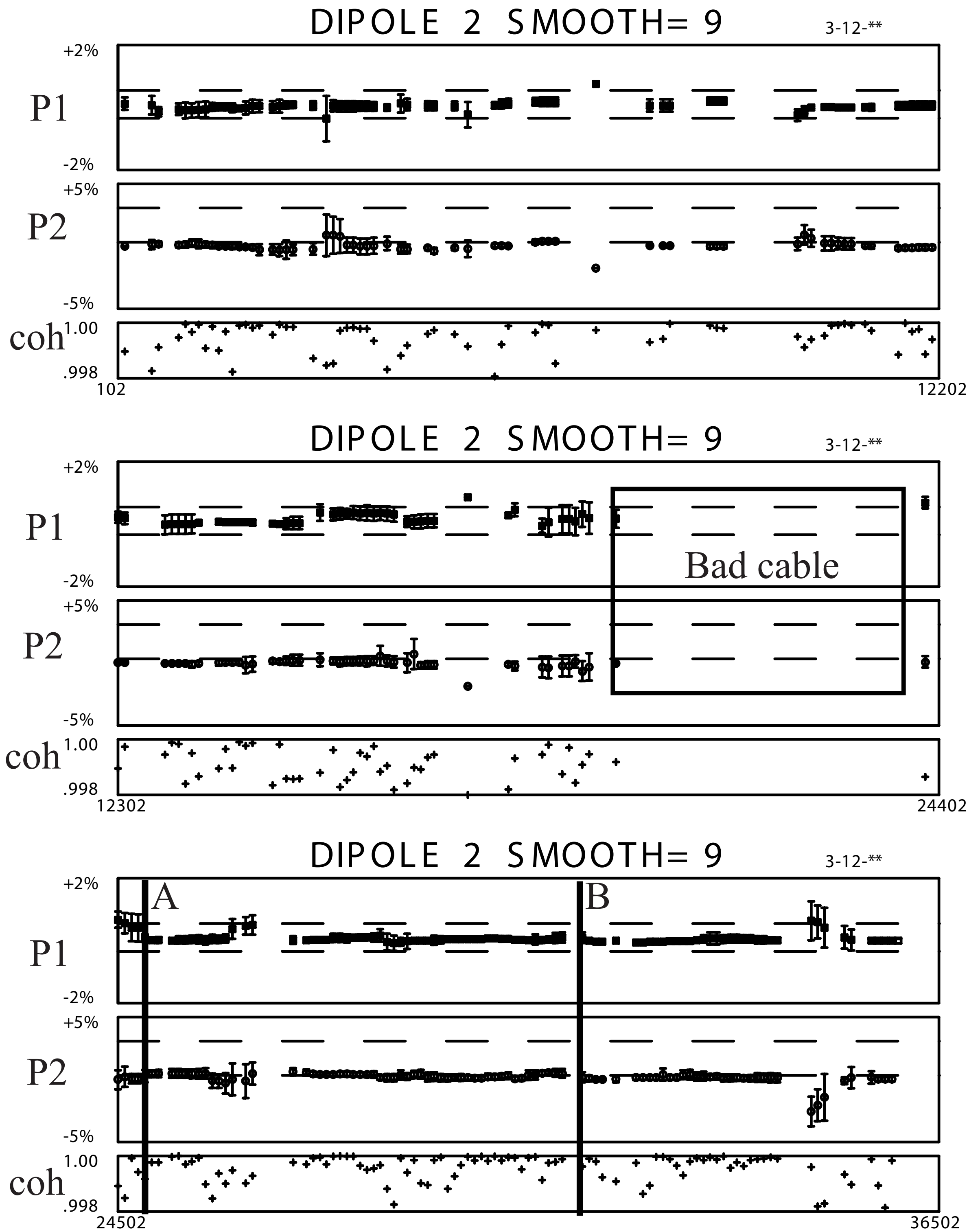


Figure 9 - Residual analysis for dipole 2 for 2002. See captions of Figures 2 and 8 for explanation. Change associated with earthquake A may be instrumental.

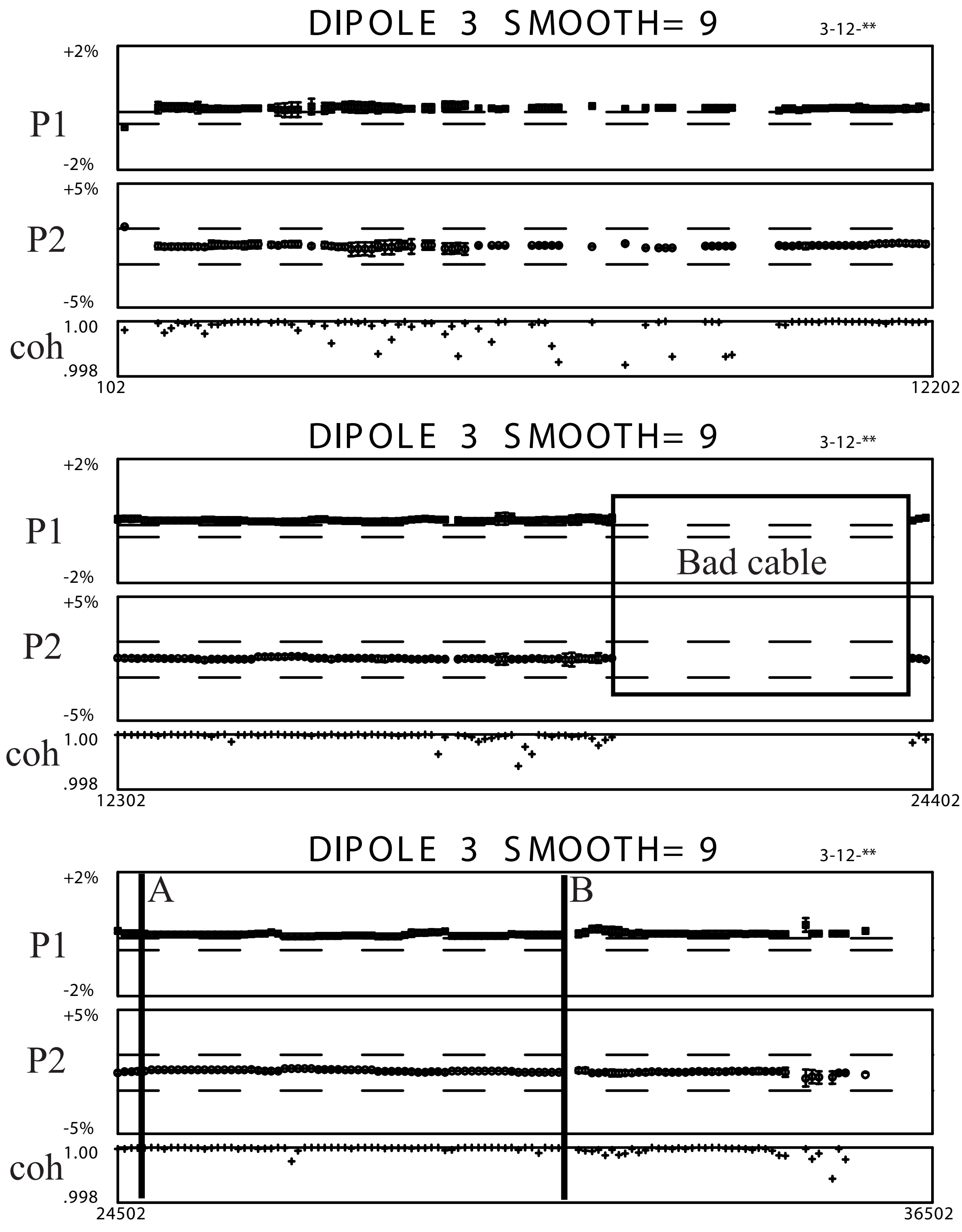


Figure 10 - Residual analysis for dipole 3 for 2002. See captions of Figures 2 and 8 for explanation.

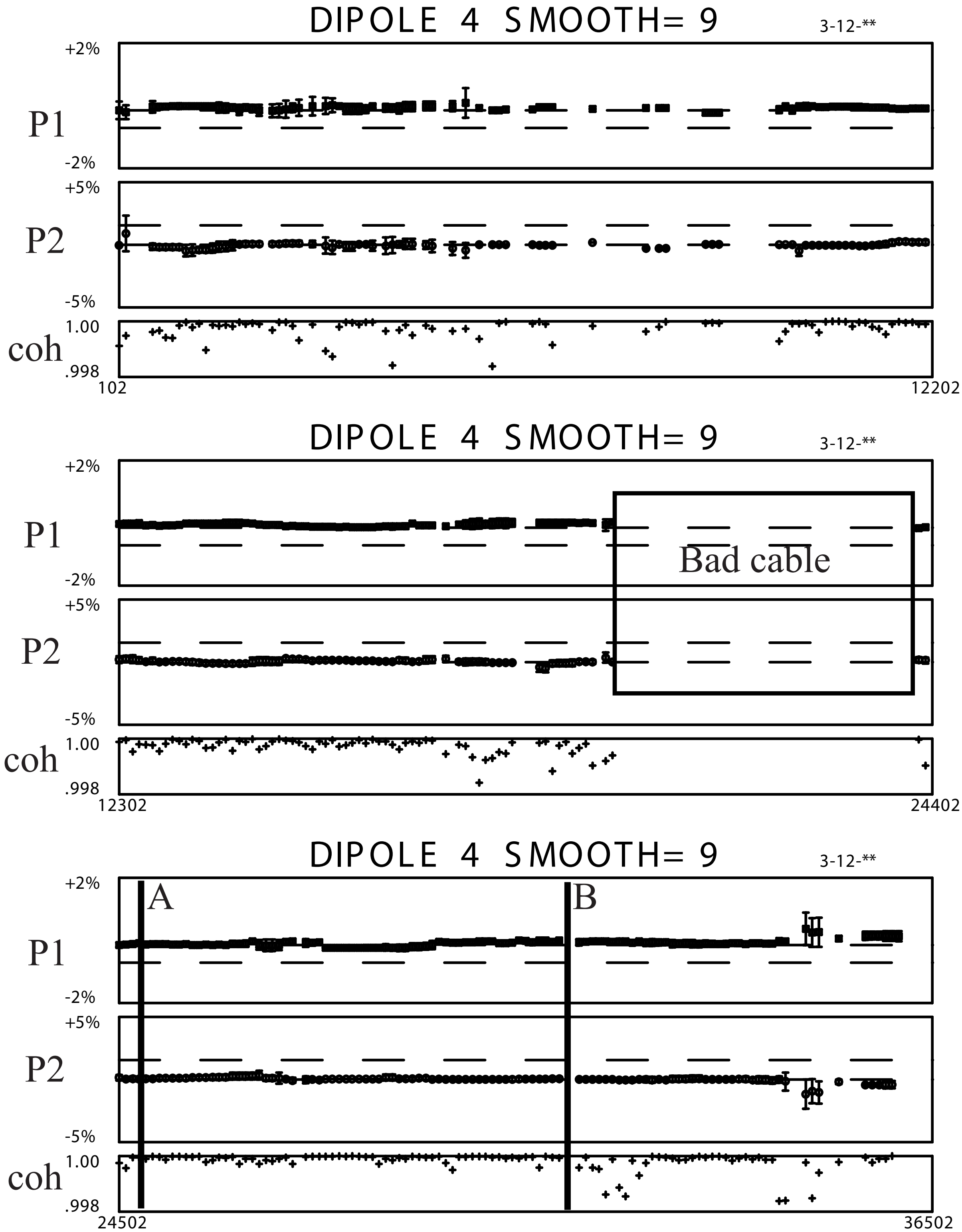


Figure 11 - Residual analysis for dipole 4 for 2002. See captions of Figures 2 and 8 for explanation.

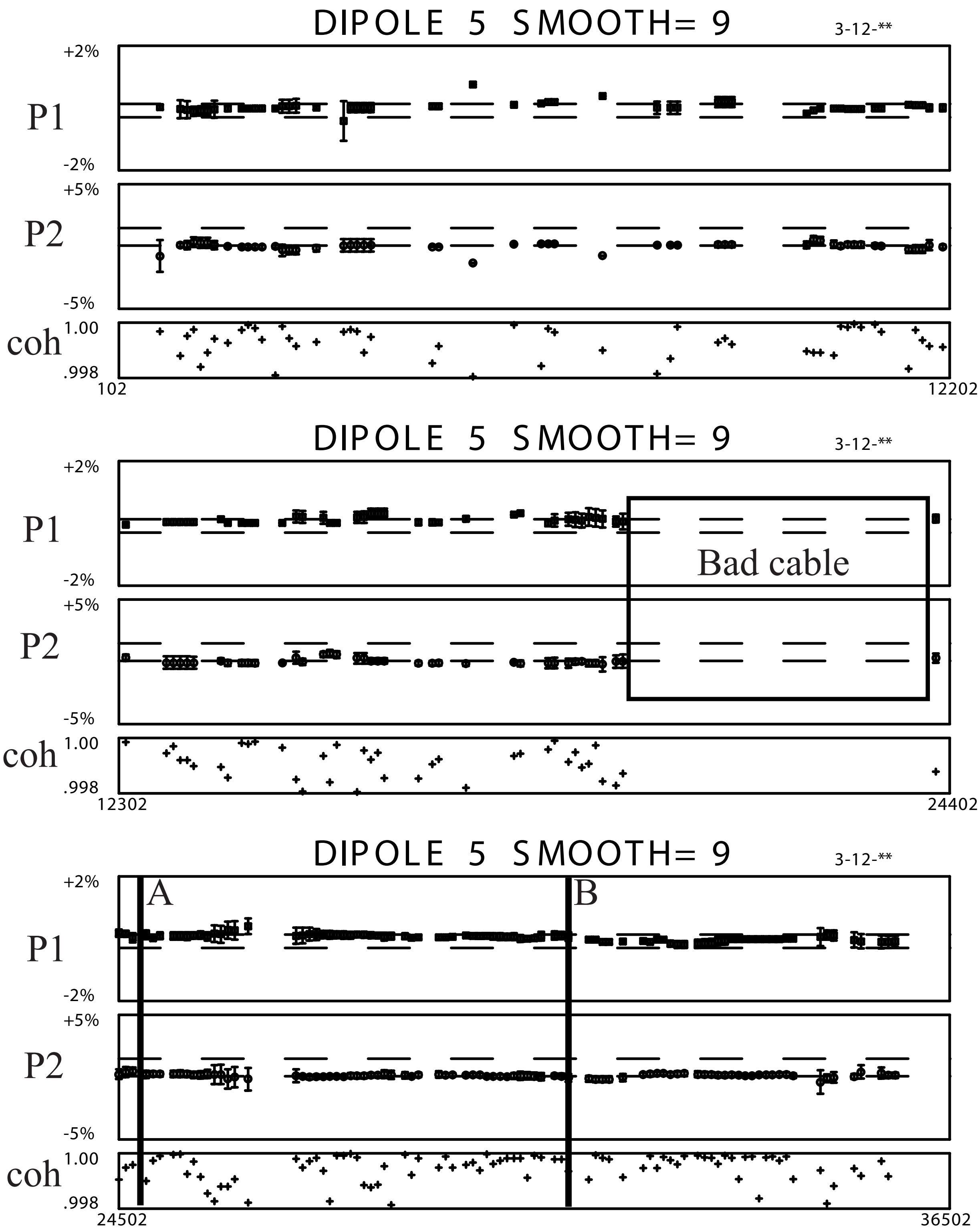


Figure 12 - Residual analysis for dipole 5 for 2002. See captions of Figures 2 and 8 for explanation.

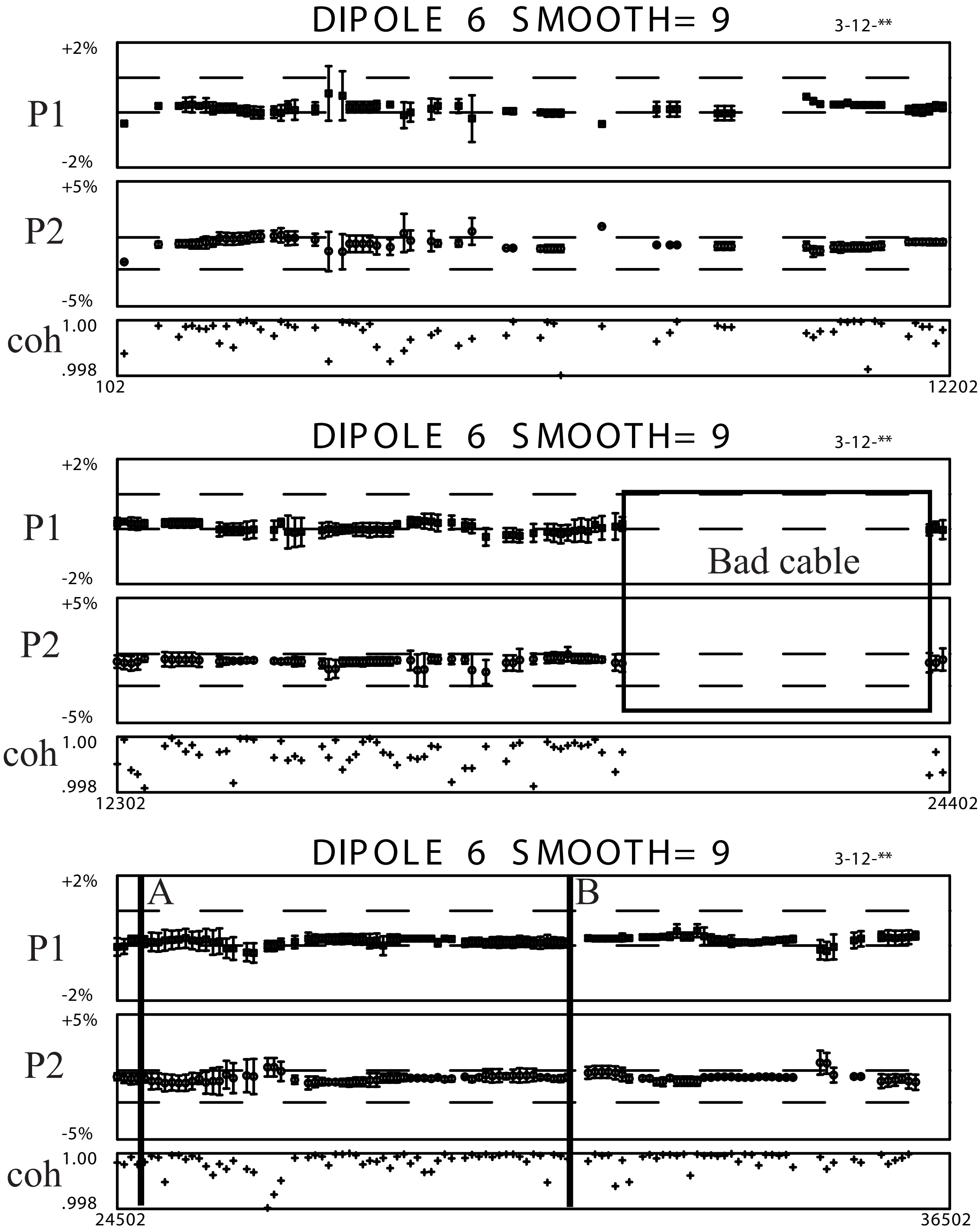


Figure 13 - Residual analysis for dipole 6 for 2002. See captions of Figures 2 and 8 for explanation.