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Correlated errors in geodetic time series: Implications for time-dependent deformation

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Abstract. Analysis of frequent trilateration observations from the two-color electronic distance measuring networks in California demonstrate that the noise power spectra are dominated by white noise at higher frequencies and power law behavior at lower frequencies. In contrast, Earth scientists typically have assumed that only white noise is present in a geodetic time series, since a combination of infrequent measurements and low precision usually preclude identifying the time-correlated signature in such data. After removing a linear trend from the two-color data, it becomes evident that there are primarily two recognizable types of time-correlated noise present in the residuals. The first type is a seasonal variation in displacement which is probably a result of measuring to shallow surface monuments installed in clayey soil which responds to seasonally occurring rainfall; this noise is significant only for a small fraction of the sites analyzed. The second type of correlated noise becomes evident only after spectral analysis of line length changes and shows a functional relation at long periods between power and frequency of $1/f^{\alpha}$, where f is frequency and $\alpha \approx 2$. With $\alpha = 2$, this type of correlated noise is termed random-walk noise, and its source is mainly thought to be small random motions of geodetic monuments with respect to the Earth's crust, though other sources are possible. Because the line length changes in the two-color networks are measured at irregular intervals, power spectral techniques cannot reliably estimate the level of $1/f^{\alpha}$ noise. Rather, we also use here a maximum likelihood estimation technique which assumes that there are only two sources of noise in the residual time series (white noise and random-walk noise) and estimates the amount of each. From this analysis we find that the random-walk noise level averages about 1.3 mm/$\sqrt{\text{yr}}$ and that our estimates of the white noise component confirm theoretical limitations of the measurement technique. In addition, the seasonal noise can be as large as 3 mm in amplitude but typically is less than 0.5 mm. Because of the presence of random-walk noise in these time series, modeling and interpretation of the geodetic data must account for this source of error. By way of example we show that estimating the time-varying strain tensor (a form of spatial averaging) from geodetic data having both random-walk and white noise error components results in seemingly significant variations in the rate of strain accumulation; spatial averaging does reduce the size of both noise components but not their relative influence on the resulting strain accumulation model.

Introduction

Although geodetic measurements are a standard geophysical technique to measure crustal deformation, only recently have we begun to appreciate that noise associated with the instability of geodetic monuments can significantly affect the interpretation of these measurements [*Johnson and Wyatt*, 1994; *Johnson and Agnew*, 1995]. The usual assumption is that successive geodetic measurements are statistically independent [e.g., *Agnew*, 1987], which has led some researchers [e.g., *Langbein et al.*, 1982; *Castle et al.*, 1976; *Mark et al.*, 1981] to document time-dependent deformation. In contrast, other attempts to detect possible time-dependent deformation from geodetic data within the San Andreas fault zone in California have shown only marginally significant changes in deformation rate [*Savage and Lisowski*, 1995a, b, c; *Savage*, 1995]. It is our purpose here to examine high-precision geodetic data to look for possible time dependence of the errors and measure its magnitude. The results demonstrate that the standard assumption of statistical independence for these measurements is not correct. By inference other geodetic measurements will likely demonstrate a component of time-correlated error as well. Any analysis of high-precision data should probably incorporate a time-correlated error of about 1 to 2 mm/$\sqrt{\text{yr}}$, reflecting random-walk motion of each geodetic monument.

The results obtained here show that geodetic data are often contaminated by at least two sources of noise: the first being the precision of the instrument and the other being attributed to localized (nontectonic) motion of the geodetic monument. The instrument noise is usually well characterized by both the physical and engineering limitations of the instrument design

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