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Noise in GPS displacement measurements from Southern California and Southern Nevada

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[1] Time series of position changes estimated from data from 236 continuously recording GPS receivers operating in Southern California and Southern Nevada are evaluated for noise models that characterize their temporal correlations. The lengths of the time series range between 3.5 and 10 years. After adjusting these data for postseismic deformation, offsets, and annual periodicities, I find that about one-half of the time series have temporal correlations that are categorized as either flicker or random-walk noise. The remaining time series can be best categorized as either a combination of flicker and random-walk; power law noise; first-order Gauss-Markov plus random-walk noise; or power law plus broadband, seasonal noise. A variety of geodetic monuments are used in Southern California and Nevada, including deeply braced designs, cement piers, pins drilled in outcrop, and buildings. When I evaluate the noise for each time series in terms of an estimate of the standard error in velocity, I find that the sites with the smallest errors are those located in Nevada using deeply braced monuments. Sites that are installed within regions of active pumping, both for groundwater and oil, had the largest standard errors in velocity. Comparison of monument stability, as measured by standard error in rate, with average, annual rainfall nearby indicates a marginally significant correlation. In addition, even though regional filtering removed much of the common-mode signals in these time series, there still remains a common-mode seasonal signal which can and should be removed.

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1. Introduction

[2] Several papers, including *Langbein and Johnson* [1997], *Zhang et al.* [1997], *Mao et al.* [1999], *Williams et al.* [2004], and *Beavan* [2005], have demonstrated that daily, geodetic measurements of position or distance changes are temporally correlated rather than simply independent observations. The first-order effects of temporally correlated data have been summarized by *Johnson and Agnew* [1995], *Williams* [2003], and *Langbein* [2004]. They show that using models describing temporal correlations directly affects the estimates of the standard error of the rates that are derived by using least squares fitting a linear trend in time to the deformation time series. The model that describes the temporal correlations of the data is quantified in the data covariance matrix. The covariance matrix is used in conjunction with a function to fit, in a least squares sense, the temporal variations, including the rate, to the time series of the deformation data [e.g., *Menke*, 1984]. The covariance matrix represents the assumed noise processes of the data.

[3] The noise model for geodetic data has been modeled in the frequency domain as a combination of white noise, where the power density is independent of frequency, and a power law, f^{-n}, where f is frequency. Initial characterization of the power law process was done by *Langbein and Johnson* [1997] using two-color electronic distance meter (EDM) observations, and restricted the power law index, n, to be 2. They assumed that the temporally correlated process for noise was that of a random walk, which might characterize localized, random motions of the geodetic monument [*Wyatt*, 1982, 1989]. However, studies by *Zhang et al.* [1997] and *Mao et al.* [1999] of the time series of position changes measured by GPS suggested that the appropriate process for GPS was that of flicker noise, where $n = 1$.

[4] *Williams et al.* [2004] did a comprehensive analysis of over 400 GPS stations, and for those sites that are from regional networks and from which common-mode signals had been removed, the noise models for the data were best characterized by power law noise, where the index was between that of flicker and random walk. In many cases, since the $n \approx 1$, there was no compelling reason to reject the hypothesis of a flicker-noise process. In addition, *Williams et al.* [2004] explored the relationship between monument design and the level of noise. They concluded that the deeply braced monuments [*Wyatt et al.*, 1989; *Langbein et al.*, 1995] employed by the Southern California Integrated GPS Network (SCIGN) had less temporally correlated noise than other types of monuments used in that network. In addition,

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