JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 104, NO. B2, PAGES 2797–2816, FEBRUARY 10, 1999

# Noise in GPS coordinate time series

Ailin Mao,[1] Christopher G. A. Harrison, and Timothy H. Dixon

Division of Marine Geology and Geophysics, Rosenstiel School of Marine and Atmospheric Sciences
University of Miami, Miami, Florida

**Abstract.** We assess the noise characteristics in time series of daily position estimates for 23 globally distributed Global Positioning System (GPS) stations with 3 years of data, using spectral analysis and Maximum Likelihood Estimation. A combination of white noise and flicker noise appears to be the best model for the noise characteristics of all three position components. Both white and flicker noise amplitudes are smallest in the north component and largest in the vertical component. The white noise part of the vertical component is higher for tropical stations (±23° latitude) compared to midlatitude stations. Velocity error in a GPS coordinate time series may be underestimated by factors of 5-11 if a pure white noise model is assumed.

## 1. Introduction

Geophysical studies using geodetic measurements of surface displacement or strain require not only accurate estimates of these parameters but also accurate error estimates. Geodetic measurements of displacement differ in two important ways from other types of geophysical data, and these differences complicate error estimation.

First, we generally require a long time series of measurements, often several years or more, in order to obtain accurate site velocity estimates. This means that a variety of errors with different timescales can corrupt the data. An individual error source may also change with time; for example, the instrument may improve. It is convenient to characterize errors as white (no time dependence) and colored (time-correlated). While the effect of white noise can be greatly reduced through frequent measurement and averaging, this is less useful for time-correlated noise and, in fact, provides no benefit at all for one type of time-correlated noise, the random walk.

Second, while we generally seek to infer the motion of large crustal units, what we actually measure is the motion of a mark or monument on or just below the ground surface. Spurious motion of the mark (monument noise) unrelated to motion of the larger crustal units of interest has been identified as an important noise source for many geodetic measurements [*Johnson and Agnew*, 1995; *Langbein et al.*, 1995]. Analysis of long (decade or more) time series of high-precision two-color electronic distance measurement (EDM) data from sites in California suggests that monument noise can be modeled as a random walk [*Langbein and Johnson*, 1997].

For geodetic data acquired with the Global Positioning System (GPS), a variety of time-correlated processes in addition to monument noise corrupt velocity estimates and, in fact, likely dominate the error budget at the present time. In other words, GPS velocity estimates may not yet be accurate enough to observe monument noise except in extreme cases. Other sources of time-correlated noise include mismodeled satellite orbits, other reference frame effects (e.g., Earth orientation), mismodeled atmospheric effects, and mismodeled antenna phase center effects, which may vary with satellite elevation, azimuth, and local environmental factors.

Studies of time-correlated noise in GPS time series have been hampered by the relatively short time that high-quality time series have been available. Rigorous analysis of time-correlated noise in GPS data may well require decade or longer time series, but high-precision results from continuously operating stations have been available only since about 1992 or 1993. The present study reports the noise characteristics of 23 globally distributed GPS sites that have operated more or less continuously for about 3 years.

## 2. Previous Work

*Zhang et al.* [1997] analyzed 1.6 years of essentially continuous daily measurements from 10 sites in southern California, and the reader is referred to that work for additional background on some of the issues discussed here. *Zhang et al.* [1997] were able to reduce regionally correlated noise (probably dominated by orbit errors) by use of a filtering algorithm that subtracted common mode, nontectonic signals from the GPS time series [*Wdowinski et al.*, 1997]. This method is applicable whenever data from a relatively dense network are available but is not yet possible for a globally distributed set of sites, because of their isolation. Noise in the residual time series studied by *Zhang et al.* [1997] was characterized as "fractal white" (spectral index 0.4, defined below) or a combination of white noise and flicker noise (spectral indices of 0 and 1, respectively). Given the shortness of the time series available to them, *Zhang et al.* [1997] could not distinguish between these models.

This study differs in three ways from that of *Zhang et al.* [1997]. First, we study a global distribution of sites (Figure 1), which allows us to assess regional differences in noise. This is important for the GPS, where orbit, reference frame, and atmospheric errors are likely to be important and may exhibit regional differences. Second, we have studied "raw" GPS coordinate time series, as opposed to data with orbit and reference frame errors reduced or eliminated through common mode techniques. Thus our results should be applicable to GPS coordinate time series from any site, no matter how isolated. Filtered data or relative position (baseline) data can be expected to be less noisy than results presented here, provided the baselines are short enough.

[1]Now at Magellan Systems Corporation, San Dimas, California.



Paper number 1998JB900033.
0148-0227/99/1998JB900033$09.00