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Time dependence of noise characteristics in continuous GPS observations from East Africa

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A B S T R A C T

A noise model for the regional continuous GPS (cGPS) timeseries in East Africa (Ethiopia and Eritrea) was computed using the maximum likelihood estimation (MLE) method. Using this method and assigning different noise models for each cGPS site and each component (north, east and vertical) may bias the noise level of the velocity solutions due to the non-uniformity of the length of the timeseries. Within the whole regional network, the length of the timeseries varies from one to seven years. We compute a preferred regional noise model for the whole data sets using a stacked maximum likelihood values for the different power − law indexes (between −2 and 0 with a time step of 0.1), presuming that there is only one noise model that exists in the regional cGPS timeseries. Therefore, a single power − law index (flicker plus white noise) was assigned for the whole regional network irrespective of the length of the timeseries. This approach is more robust and "realistic" to determine the noise characteristics of the regional GPS network.

1. Introduction

The noise characteristics of cGPS coordinate timeseries have been studied by various authors (e.g. Agnew, 1992; Mao et al., 1999; Williams et al., 2004; Hackl et al., 2011) in different parts of the world, using different processing methods, from regional networks through to global solutions. It is a well-understood phenomenon that assigning white noise model for the cGPS timeseries will underestimate the noise uncertainty level in the final velocity solution (Mao et al., 1999) since it does not account for the contribution of time varying noises. Work done by these authors (Agnew, 1992; Zhang et al., 1997; Mao et al., 1999; Williams, 2003a; Williams et al., 2004) showed that the cGPS timeseries noise characteristics consists of a combination of white noise and other time-correlated noise models. We used 16 cGPS sites in the northeast part of the East African Rift System (EARS) (Fig. 1) and its surroundings, especially Ethiopia and Eritrea, to study the noise characteristics of the whole regional network. The cGPS sites have timeseries that span from early 2007 to 2014 as shown in Fig. 2. However, the timeseries are non-uniform over that period because of their deployment for various studies and contain discontinuities and gaps in the timeseries caused by various instrumental or logistical problems.

In this study we discuss the noise level of the regional cGPS timeseries using the maximum likelihood estimation (MLE) technique and the time dependence of the noise characteristics as a function of the length of timeseries. We compute a regional noise model for the entire network and compare velocity uncertainties derived from CATS and GLOBK which are based on different noise models.

2. Methods

All the cGPS data were processed using GAMIT/GLOBK software (Herring et al., 2010). 15 International GNSS Service (IGS) sites closest to the study area were used as reference sites with one IGS site (ADIS) located within the study area (Fig. 1), and included in this study. Using GAMIT, we applied double differencing on each daily phase observation in order to estimate station coordinates,

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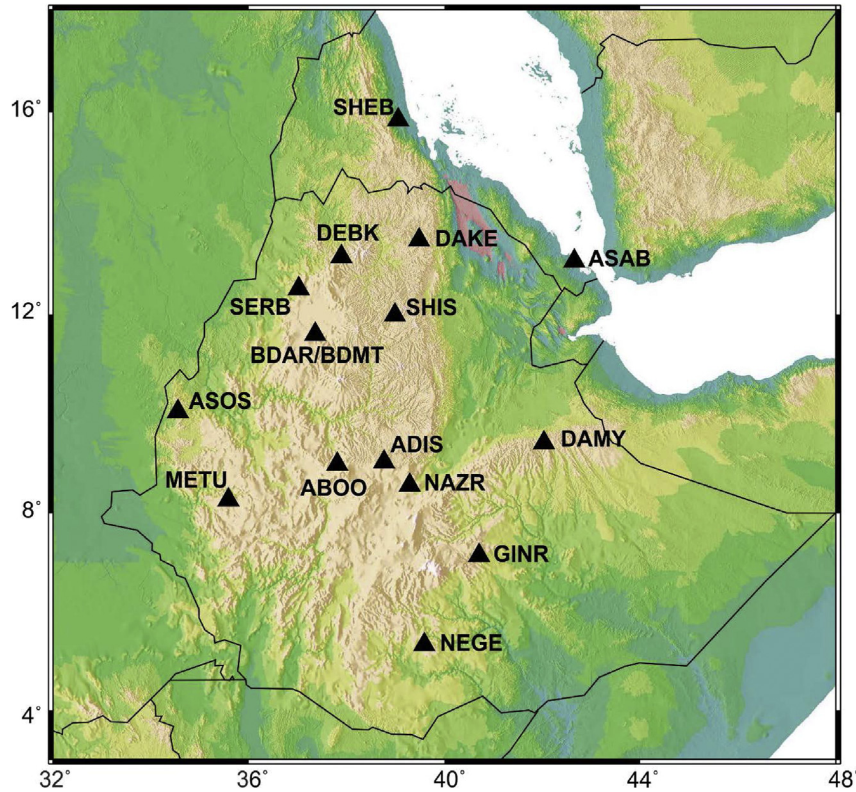

Fig. 1. Location of the cGPS sites overlain on the DEM map of the study area. Each triangle shows the location of the GPS sites with site names next to each triangle.

phase ambiguities and satellite state vectors. At every station seven tropospheric delay and two tropospheric gradient parameters per day were estimated (Reilinger et al., 2006). After applying double differencing to each daily phase observation, the daily solutions (h-files) of the cGPS data were combined with the daily global solutions (H-files) obtained from MIT, using the global kalman filter (GLOBK). The resulting daily timeseries were closely inspected for quality check in order to remove outliers (above two-sigma threshold), and discontinuities caused by antenna changes, receiver changes or earthquakes, together with other time-dependent changes (Reilinger et al., 2006). Before assigning a Gauss Markov noise model for our cGPS timeseries, the usual routine in GLOBK, we tested different stochastic noise models for each cGPS timeseries. The noise characteristics of the north, east, and up components were computed individually using the CATS GPS coordinate timeseries analysis software (Williams, 2005) that applies maximum likelihood to estimate the noise parameters.

The observed GPS motion at each site is a superposition of secular trend, a periodic component (mostly annual and semi-annual signal), offsets (discontinuities caused by tectonic and non-tectonic processes) and a noise component as shown in equation (1) (Williams, 2003b; Yuan et al., 2007).

$$y_i = a + bt_i + \sum_{j=1}^{l} a_j H(t_j - T_j) + \sum_{n=1}^{m} A_n.\sin(\omega_n t + \varphi_n) + n_i \quad (1)$$

where the first term (a) is the site coordinate, the second term (bt_i) is the linear rate (Fig. S1), the third term is made up of the Heaviside step function [H (t_j - T_j)] and an offset amplitude (a_j where $t_j = T_j$) mostly caused by earthquakes, various tectonic processes and other phenomena like antenna or receiver change, and the fourth term consists of periodic components, mainly the annual and semi-annual signals (Fig. S2) where $\omega_n = \frac{2\pi}{n}$ *rad/year*. The final term is the noise component of the GPS timeseries. In this study we are interested to study the noise term.

From equation (1) above, in order to study the various noise models of the cGPS timeseries the other terms have to be removed from the data. The data has to be detrended, offsets and seasonal variations must also be removed from the data (Fig. S3). The correlation in cGPS timeseries may be approximated by a power law process (Agnew, 1992; Mao et al., 1999; Williams, 2003a, b; Williams et al., 2004):

$$P(f) = P_o\left(\frac{f}{f_o}\right)^{-\alpha} \quad (2)$$

where α is the spectral index (white noise has $\alpha = 0$, flicker noise has $\alpha = 1$ and random walk noise has a spectral index of 2), Po is a constant, f_0 is a constant frequency and f is the frequency.

We used the method described in CATS (Williams, 2005) in order to compute a “realistic” noise model for the GPS timeseries. The following steps were implemented in order to characterize the noise in the regional network.

1. All the GPS data were detrended and the linear terms in the timeseries were removed using the weighted least squares fit.
2. The detrended data were closely inspected and offsets caused by any tectonic or non-tectonic processes were removed using two-sigma significance level. Tsview software (Herring and McClusky, 2009) was used to inspect and remove the outliers and offsets. Although some of the cGPS sites are located at a closer proximity to the EARS, we did not see any offsets which is caused by the local earthquakes.