Oleg Titov et al.: Post-Seismic Motion of Gilcreek Geodetic Sites Following the November, 2002 Denali Earthquake, IVS 2004 General Meeting Proceedings, p.496–500
http://ivscc.gsfc.nasa.gov/publications/gm2004/titov2

Post-Seismic Motion of Gilcreek Geodetic Sites Following the November, 2002 Denali Earthquake

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Abstract

We have detected post-seismic motion of the Gilcreek observatory in Fairbanks, Alaska after the 2002 Denali earthquake from an analysis of VLBI and GPS data recorded at the site in the 12-month period following the event. The motion is non-linear, indicating that either a relaxation process or afterslip on the fault is occuring. The co-seismic estimate of displacement from VLBI measurements agrees well with those from GPS analysis in all components.

1. Introduction

The $M_w = 7.9$ earthquake that occurred on the Alaska Peninsula on 3 November 2002 was the largest of the year. The epicenter was located approximately 135 km south of Fairbanks on the Denali Fault that stretches over 700 km, dividing Alaska into two parts. The earthquake caused numerous landslides with measured surface offsets of up to a few meters. The co-seismic displacement field of the earthquake has been modelled from displacement of GPS [2]. The northern part of the Denali Fault moved to the east and vertically up. The Gilcreek observatory [9] located near the event epicenter produced valuable information about the displacement.

2. VLBI Data Analysis

VLBI has been used to estimate the deformation caused by two earthquakes in Alaska during 1987-1988 [8] and also the dynamic crystal deformation associated with Miyake-jima volcano in Japan (VLBI site Tateyama) in the framework of the Keystone Project [6]. However, post-seismic deformation following a major earthquake as observed by VLBI has not been reported previously.

We have analysed 92 24-hour VLBI sessions that included Gilcreek from 4 November 2002 to 1 December 2003. The analysis of the data has been performed using the OCCAM software [10]. The Geoscience Australia solution for source positions (aus2002) has been used to define the Celestial Reference Frame and the a priori VLBI site coordinates. Observations of each daily session were processed separately to estimate all site coordinates, nutation offsets, EOPs, clock offsets and rates as well as tropospheric delays and horizontal tropospheric gradients. We performed a 6-parameter Helmert transformation of the daily estimates of the coordinates of all VLBI sites (except Gilcreek) onto their ITRF2000 values in order to define the terrestrial reference frame.

3. GPS Data Analysis

We analysed data from the GPS receiver at Gilcreek (FAIR) spanning the same time period as the VLBI data. The GPS phase data were processed using the GAMIT/GLOBK software [5], [3] in a global solution of 80-90 stations. We divided the globe into four regional subnetworks, with 3-4 overlapping sites in more than one subnetwork, and estimated site coordinates, GPS satellite orbits, EOP, tropospheric delay parameters (13/day) and horizontal troposphere gradients (3/day). All parameters are treated deterministically, with the tropospheric delay parameters modelled as piecewise linear function.

The four subnetworks/day were then linked to produce a single, free-network solution for the site coordinates and a single, coherent estimate of the satellite orbits. The resulting, global polyhedron is the same as that which can be produced by the simultaneous processing of the observations from all sites but takes considerably less computational time to produce. We then aligned the free network to the International Terrestrial Reference Frame by computing a 7-parameter Helmert transformation on the coordinates of 50 sites to their ITRF2000 values [1] to generate daily site coordinates. The time series of VLBI and GPS results are shown in Figure 1,2.

4. Discussion

Our linear velocity estimates for Gilcreek and FAIR prior to the earthquake are not significantly different from, for example, [7] (VLBI) and [1] (GPS), indicating that our analyses are of high accuracy. Furthermore, the co-seismic offsets estimated from the GPS analysis are in close agreement with those of [4] (Table 1).

Table 1. The estimated co-seismic displacement at Gilcreek from VLBI and GPS

Component	**this paper, VLBI (mm)**	**this paper GPS, (mm)**	**[4] GPS, (mm)**
radial	20 +/- 11	16 +/- 3	23.3 +/- 10.1
latitude	-53 +/- 8	-56 +/- 1	-51.6 +/- 6.3
longitude	26 +/- 7	21 +/- 1	24.8 +/- 5.7

Post-seismic deformation for several large earthquakes has been characterized as being caused by viscoelastic relaxation or due to afterslip on ruptured faults. Several authors have derived numerical expressions to model such non-linear motion as logarithmic, exponential or even transient function. Such analyses are performed typically on networks of sites geographically spread around the ruptured fault that have observed the post-seismic relaxations patterns. With only one VLBI site affected by the post-seismic motion, there is insufficient data to differentiate between possible causes of the post-seismic motion. We chose to represent the motion using an exponential function

$$X(t) = A + B\exp(-\frac{t - t_{Eq}}{\tau})$$

where t - the current epoch, t_{Eq} - the epoch of the earthquake. We used independent estimates of the decay constants $\tau = 0.25$ year (obtained from GPS the data using least squares method for non-linear models) to estimate the amplitude B (Table 2).

The Cartesian coordinates of Gilcreek are used routinely in VLBI for station position modeling. We proposed the following empirical model for the Gilcreek VLBI site coordinates.

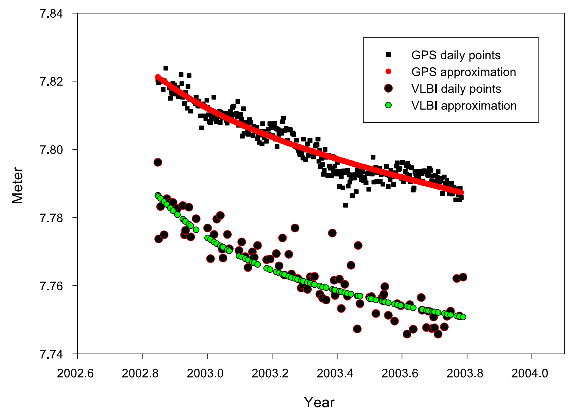

Figure 1. Evolution of the North component from GPS and VLBI.

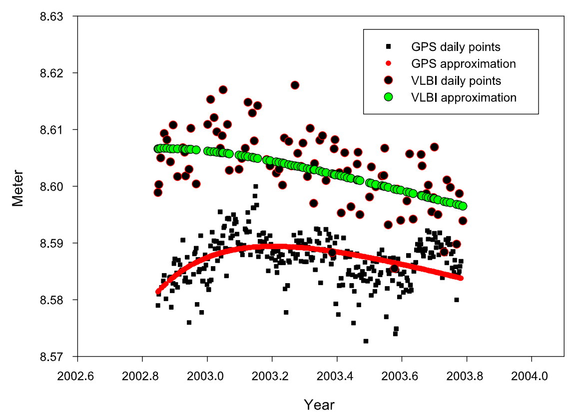

Figure 2. Evolution of the East component from GPS and VLBI.

Table 2. The estimates for amplitude of decay from VLBI for the horizontal components

Component	**B (meter)**	**τ(years)**
latitude	0.028	0.25
longitude	-0.003	0.25

$$X(t) = A_0 + A_1(t - t_0) + B_0 + B_1 \exp(-\frac{t - t_{Eq}}{\tau})$$

Here $t_0 = 1997.0$ (the reference epoch), $t_{Eq} = 2002.838$ (the epoch of the earthquake). The first and second terms describe the linear tectonic motion model in accordance with the ITRF2000, whereas B_0 introduces the co-seismic offset and B_1 the post-seismic deformation (Table 3). Figure

3-5 show how the model fits to the VLBI observations in Cartesian components. While the non-linear model is not convincing in the Y and Z components, it clearly fits the data better than a linear model in the North and East components (see Figure 1,2).

Table 3. The parameters of the expanded model for Gilcreek post-seismic motion in Cartesian coordinates

Component	A_0 **(m)**	A_1 **(m/year)**	B_0 **(m)**	B_1 **(m)**	τ **(years)**
X	-2281547.309	-0.0222	-0.036	0.0080	0.25
Y	-1453645.080	-0.0036	-0.058	0.0076	0.25
Z	5756993.162	-0.0092	-0.037	0.0143	0.25

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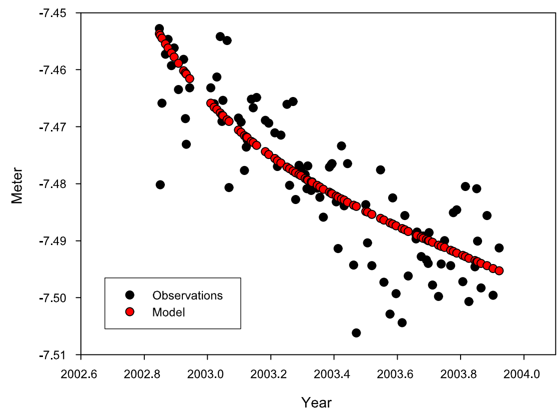

Figure 3. Evolution of the X components from the VLBI data.

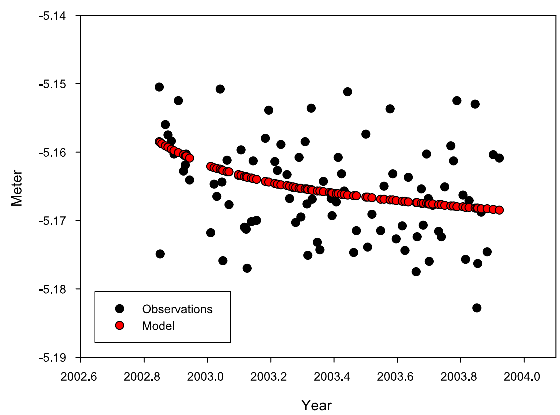

Figure 4. Evolution of the Y components from the VLBI data.

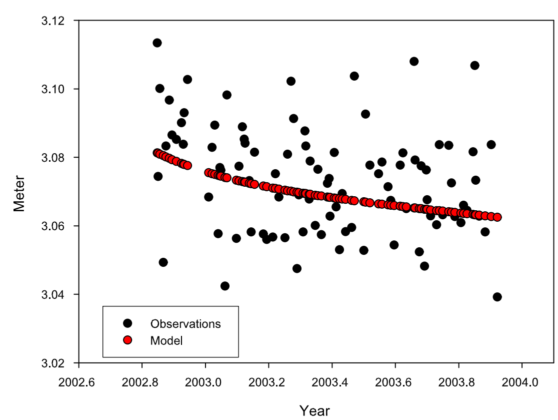

Figure 5. Evolution of the Z components from the VLBI data.