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A Postseismic Relaxation Model for the 2002 Denali Earthquake from GPS Deformation Analysis Applied to VLBI Data

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Abstract. Five years after the 2002 Denali, Alaska, earthquake a postseismic deformation model based on GPS time series analysis is available and implemented into the new solution IGG08R01. The non-linear deformation model includes a logarithmic and an exponential term with decay factors derived from the GPS solution and reduces the 3D RMS fit w.r.t. VLBI estimates by 2.5 mm in comparison to the 'classical' approach using a coseismic displacement and a constant velocity (IGG07R04). By our comparisons we find good agreement between postseismic GPS and VLBI coordinate time series, i.e. the latter for station Gilmore Creek, which leads us to the conclusion that GPS and VLBI measure the same co- and postseismic surface deformations induced by the earthquake.

1. Introduction

Driven by the continuous lithospheric processes the Pacific Plate is steadily shifted northwards subducting beneath the North American Plate (Fig. 1). The collision of the Yakutat Block (YAK), a block of thickened and buoyant crust, has caused the Wrangell Subplate, a piece of the North American Plate, to break loose and rotate counter-clockwise. The Denali and Totschunda Faults form the northeastern margin of the Wrangell Subplate [7].

The M7.9 Denali earthquake on Nov. 3, 2002 22:12:42 UT, was the largest strike-slip earthquake in North America since 1857. Surface rupture occurred along 340 km of the Susitna Glacier, Denali, and Totschunda Faults [3]. The earthquake triggered significant postseismic deformation, and [4] showed that a multiple mechanism model is well suited to describe postseismic deformation observed at both near-field (< 50 km) and far-field (< 300 km) GPS sites. The primary mechanisms of postseismic stress relaxation are summarized in Fig. 2.

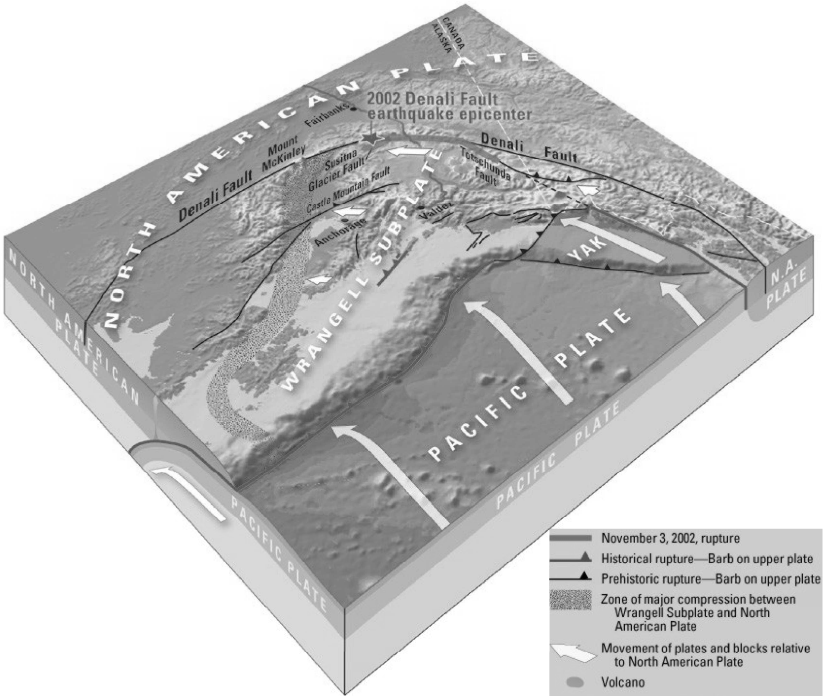

Figure 1. Regional tectonics [7]

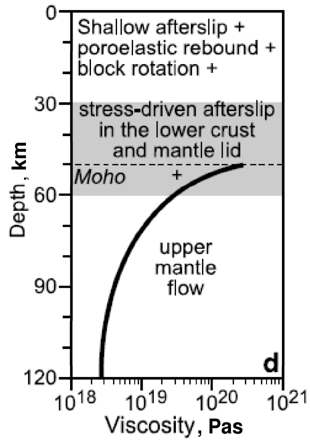

Figure 2. Multiple mechanism model [4]

- **afterslip:** coseismic stress causes aseismic slip after the earthquake.
- **poroelastic rebound:** excess fluid pressure in the near-field region (here 10 to 30 km) causes fluid flow resulting in postseismic deformations and stress change.
- **viscoelastic relaxation:** weaker lower crust and upper mantle do not sustain coseismic stress changes, but relax viscously within years to decades.

2. Time Series Modelling and Analysis of Surface Deformations

Postseismic surface deformations can be modelled by fitting analytical functions to the topocentric position time series using the following equations:

$$y\left(t\right) = a + b \cdot \lg\left(1 + \frac{t - t_0}{l_\tau}\right) + c \cdot \left(1 - \exp\left(-\frac{t - t_0}{e_\tau}\right)\right), \qquad (1)$$

where y denotes a specific station position component (e.g. φ, λ, or h), coefficient a describes the instantaneous coseismic displacement at the epoch of event $t = t_0$, and b and c are coefficients of the logarithmic term with $l_\tau = 0.05$, and the exponential term with $e_\tau = 3.0$, respectively, based on the fit to several GPS time series. Before the coefficients a, b, and c are estimated by least-squares adjustment the positions y are corrected with

$$y\left(t\right) = y\left(t\right) - \left[d + e \cdot t + \sum_{i=1,2} f_{i,1} \cdot \sin\left(2i\pi t\right) + f_{i,2} \cdot \cos\left(2i\pi t\right)\right], \qquad (2)$$

where the variables d, e represent preseismic tectonics (offset and slope), and the coefficients $f_{i,j}$ ($j \in \{1,2\}$) consider seasonal positional variations. Equations (1) and (2) may be fit separately or combined into a single equation, depending on the time span of the data. The seasonal variations might be different for VLBI and GPS, if they are due in part to systematic errors, but the other terms in the model should be identical for all geodetic techniques.

3. New VLBI Solution IGG08R01

Unlike prior Institute of Geodesy and Geophysics (IGG) TRF solutions such as IGG07R04, the new global solution IGG08R01 includes a non-linear deformation model (1) for GILCREEK (Gilmore Creek, Alaska, USA) VLBI site after the Denali earthquake. Other earthquakes such as the Loma Prieta, California, earthquake [2] on Oct. 1, 1989 are still modelled by a single coordinate jump. Compared to previous analysis results, i.e. [5, 6], the time series model was extended by a logarithmic term and the decay factor of the exponential term was enlarged to 3.0 years. The new model is determined including VLBI data until 2006.0, i.e. until the termination of geodetic VLBI activities at Gilmore Creek Observatory. The GPS solution is provided by the Geophysical Institute (GI), University of Alaska Fairbanks, and represents daily solutions. Tabl. 1 and Fig. 3 clearly indicate that IGG08R01 provides the best fit to postseismic deformations at Gilmore Creek after the Nov. 3, 2002 Denali earthquake.

The piecewise linear function (PWLF), which models the postseismic deformations in the ITRF2005 (Fig. 3) partly deviates from VLBI estimates, in

Table 1. Unweighted RMS w.r.t. VLBI data obtained with (3)

RMS	ITRF2005	IGG07R04	IGG08R01	GPS data
Latitude, mm	3.8	6.1	3.1	13.8
Longitude, mm	3.8	5.1	3.1	17.6
Height, mm	8.3	7.8	7.5	10.5
3D, mm	9.8	11.2	8.7	24.7

particular the first two postseismic pieces of the height component. The unweighted RMS given in Tabl. 1 were computed with:

$$RMS = \left\{ \frac{1}{N} \sum_{1}^{N} \left[(obs_j - model_j)^2 \right] \right\}^{1/2} , \qquad (3)$$

where obs_j denotes the VLBI estimate at epoch j and $model_j$ the corresponding model value at the same epoch j or the GPS estimate at the nearest epoch. Since VLBI and GPS sessions are not performed at the same time the RMS of model fit cannot be directly compared to the RMS between VLBI and GPS

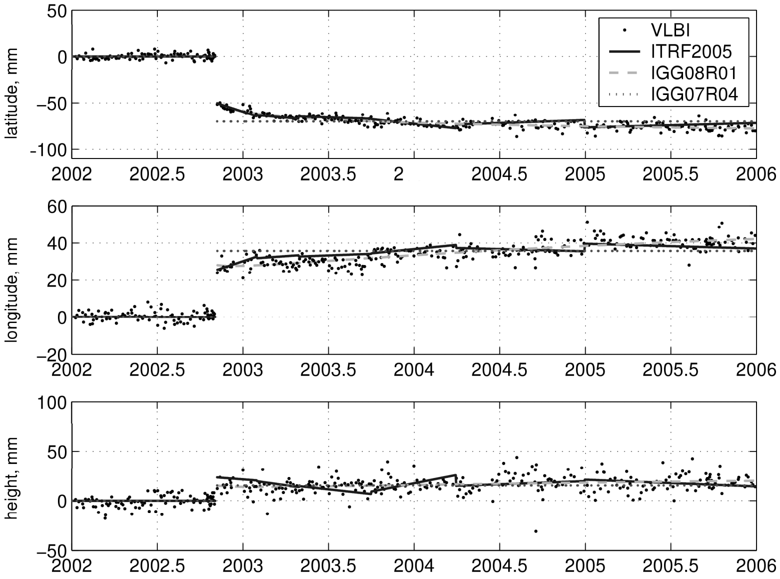

Figure 3. Topocentric position of GILCREEK observed by VLBI and modelled in the ITRF2005 [1] and in the two TRF solutions of the IGG, Vienna, described in the text

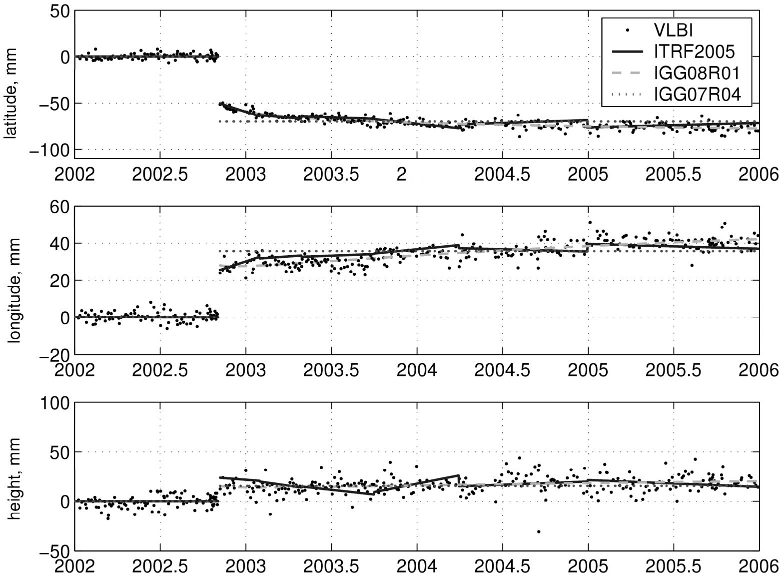

Figure 4. Comparison of topocentric positions at FAIR/GILCREEK co-located site obtained by GPS and VLBI solutions. The GPS solution was provided by the Geophysical Institute, Fairbanks, and the VLBI solution was computed at the Institute of Geodesy and Geophysics, Vienna

estimates. A divergence between GPS and VLBI (Fig. 4) from about 2003.8 to 2004.16 can be found, which shows up mainly in the longitudinal component. This effect is present in other GPS time series as well, e.g. SOPAC (Scripps Orbit and Permanent Array Center, http://sopac.ucsd.edu/) and remains unexplained at the moment. It does not appear at an independent GPS site located 25 km away (CLGO), therefore, it appears to represent some kind of station-specific error.

4. Conclusions

For modelling the postseismic surface deformations of the Denali earthquake, the non-linear (1) is well-suited for both, GPS and VLBI analysis, since both space geodetic techniques were subject to the same coseismic and postseismic displacements. Adjusted a posteriori station positions do not differ significantly using a single coordinate jump and a constant station velocity model (IGG07R04), or a non-linear model (IGG08R01). Therefore, the application of such a refined model for a priori coordinates is only mandatory, if station positions are fixed, i.e. not estimated during the parameter estimation, or in the development of a time-dependent model such as ITRF.

Some of the linear pieces of the ITRF2005 solution of station GILCREEK follow the seasonal variations of GPS positions and deviate significantly from the VLBI estimates. This effect is most obvious in the height component (Tabl. 1, Fig. 3–4).

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