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Repeated large Slow Slip Events at the southcentral Alaska subduction zone

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ABSTRACT

We identify and study an ongoing Slow Slip Event (SSE) in the southcentral Alaska subduction zone using GPS measurements. This is the second large SSE in this region since modern geodetic measurements became available in 1993. We divide the ongoing SSE into two phases according to their transient displacement time evolution; their slip distributions are similar to each other but slip rates are slightly different. This ongoing SSE occurs downdip of the main asperity that ruptured in the 1964 Alaska earthquake, on the same part of the subduction interface as the earlier 1998–2001 SSE. The average slip rate of this SSE is ~4–5 cm/yr, with a cumulative moment magnitude of *Mw* 7.5 (*Mw* 7.3 and *Mw* 7.1 For Phases I and II, respectively) through the end of 2012. The time and space dependence of the GPS displacements suggest that the slip area remained nearly the same during Phase I, while the slip rate increased with time. The SSEs occur on a transitional section of the subduction plate interface between the fully locked updip part and the freely slipping deeper part. During the 1964 earthquake, slip on the region of the SSE was much lower than slip in the updip region. Based on this observation and the repeated SSEs, we conclude that this part of the interface slips repeatedly in SSEs throughout the interseismic period and does not build up a large slip deficit to be released through large slip in earthquakes.

1. Introduction

Slow Slip Events (SSEs) have been observed and reported in many subduction zones, and their durations vary from days to years (Schwartz and Rokosky, 2007). SSEs in the Cascadia subduction zone last days to weeks with a typical duration of 3 weeks (Dragert et al., 2001), SSEs in Costa Rica last about 1 month (Jiang et al., 2012), a two-month SSE was reported by Ozawa et al. (2003) in central Japan, and SSEs in Mexico can be 6–7 months long (Kostoglodov et al., 2003). Hirose et al. (1999) identified an SSE with duration of about 1 yr in southwest Japan, and Wallace and Beavan (2006) studied a large SSE lasting one and a half years in New Zealand. The Tokai SSE (Ozawa et al., 2001; Yamamoto et al., 2005) lasted for several years.

Using Global Positioning System (GPS) measurements, Ohta et al. (2006) revealed an SSE in Upper Cook Inlet, in the southcentral Alaska Subduction Zone, during the period 1998–2001; its duration was much longer than most other SSEs. They found that the plate interface downdip of the 1964 earthquake rupture area slipped more than 10 cm within the SSE period, while the shallow part, the 1964 seismogenic zone, was fully locked during the SSE and therefore continued accumulating slip deficit for future earthquakes. Recently, Wei et al. (2012) identified another SSE in 2010–2011 in a comparable location in Lower Cook Inlet (Fig. 1).

In this paper, we systematically analyze the GPS timeseries around the southcentral Alaska subduction zone, and identify an ongoing SSE (as of the end of 2012) in the same area as the 1998–2001 SSE. We derive the GPS measured SSE surface displacements, determine the slow slip distribution on the subduction interface in space and time, and compare it with the 1998–2001 SSE.

2. An ongoing slow slip event

Forty-eight continuous GPS stations in southcentral Alaska are used for this study; 36 of them are part of the Plate Boundary Observatory (PBO) network, and another 12 stations belong to several other organizations (see the Auxiliary material for GPS station information). Fig. 1 shows the locations of GPS sites used in this study. We excluded GPS stations close to the Denali fault because of the potential for postseismic effects from the 2002 *Mw* 7.9 earthquake, and stations near volcanoes could be influenced by volcanic deformation. All the GPS data were processed in point positioning mode using GIPSY/OASIS II (version 5.0) software. We

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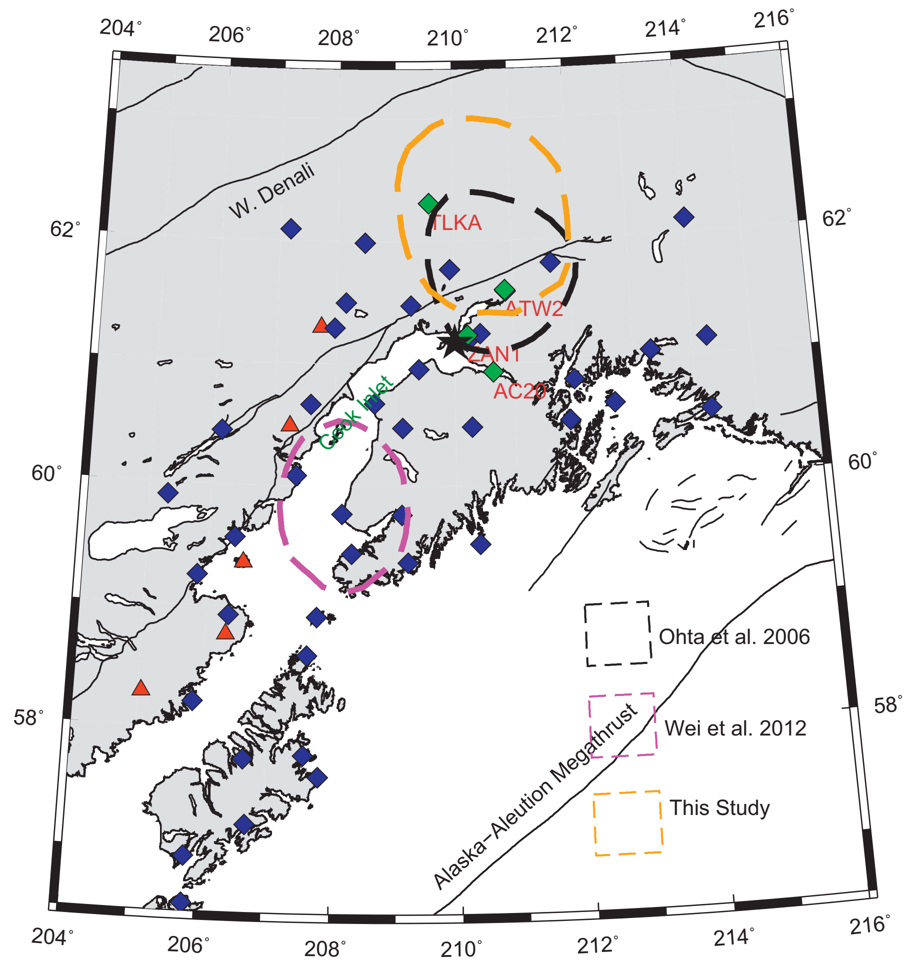

Fig. 1. Distribution of GPS stations used in this study. Diamonds are GPS stations; green diamonds are the stations whose timeseries are given in the auxiliary material. Red triangles are active volcanoes. The black star denotes the location of Anchorage. The three outlines indicate the previously identified SSEs of Ohta et al. (2006) and Wei et al. (2012), and the result of this study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

adopted JPL's reanalyzed orbit and clock products (for the IGS repro2), and used the IGS05 absolute antenna phase models for corrections. Ocean Tidal Loading (OTL) effects were computed with ocean tide model TPXO7.0 and Greens functions modeled in CM (center of the mass of the whole Earth system) (Fu et al., 2012a). Individual daily solutions are then aligned with the ITRF2008 reference frame (ITRF2008.SNX). Refer to Fu and Freymueller (2012) for further data processing details.

Fig. 2 (top) shows a typical GPS timeseries for station ATW2 (see Fig. 1 for its location), a composite timeseries combining the PBO site ATW2 and a previous co-located continuous site ATWC using a measured survey tie. Due to the convergence between the Pacific and North American plates, the crust of southern Alaska moves landward (to the north) during interseismic periods (Freymueller et al., 2000, 2008), and GPS time series show this landward movement during 2001–2009 (Fig. 2, top).

However, GPS also observes movement opposite to the background linear trend of plate convergence during 1998–2001 and after 2009, because part of the plate interface undergoes slow slip. Those movements are in the same direction as the ground displacements caused by subduction zone earthquakes like the 1964 Prince William Sound earthquake (Cohen and Freymueller, 2004), but occur much more slowly.

In order to derive the SSE surface displacements from GPS timeseries, we analyze the GPS time series after the year 2003. We fit the steady deformation period with linear and seasonal (annual plus semiannual) terms, and the SSE period with linear, seasonal and a logarithmic relaxation term. We tried both logarithmic and exponential relaxation terms, and found that both can fit GPS timeseries equally well. Fig. 3 shows an example of fitted time series for both logarithmic and exponential functions. The seasonal effects in parts of southern Alaska are significant because of seasonal snow loading (Fu et al., 2012b), and that effect cannot be ignored. We adopt a grid search method to find the SSE start time that best fits both the GPS north and vertical components. We identify a starting time at the end of 2008 (2008.96) that minimizes the misfit between the measurements and the modeled time series. Fig. 3 gives an example for the north component of site ATW2 and its fitted timeseries showing steady deformation and the SSE displacement.

Here we define the SSE displacement as the position differences between the modeled steady movement and the actual observation (Fig. 3). During the earlier phase of this SSE, the GPS timeseries is more curved than the later phase; the later part shows linear motion, but at a different rate than the steady period. This suggests that the SSE displacement rate and/or slip area was growing with time in the earlier phase, while both are constant in the later phase. Therefore, we divided the whole event into two phases, Phase I (2008.96–2011.70) and Phase II (2011.70–2012.87), and investigate them separately. We then evaluate how slip in this SSE evolves with time.