Final Report
Earthquake Hazards Program Assistance Awards

USGS Award Number(s)

G16AP00011 and G16AP00012.

Title of award

Slip and stress rates on crustal faults in the Puget-Willamette Urban Corridor: Collaborative research with Portland State University and Massachusetts Institute of Technology

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Abstract: GPS observations were made in the Doty Fault section of the Cascadia forearc in southwest Washington and northwest Oregon in 2016 with the goal of resolving in more detail the distribution of slip rates and Cascadia locking across the region. The results indicate that the north-south shortening of the forearc (west of 237E) is low across the Doty fault regions and does not occur to a significant degree south of 47N.

Report:

Investigations undertaken

We conducted GPS field work in June through August 2016 to occupy geodetic benchmarks within and around the Doty fault of northwestern Oregon and southwestern Washington State (Fig. 1) in the Pacific Northwest (PNW). This region is within the zone of shortening associated with northward motion of Oregon into Washington (Wells and McCaffrey, 2013). Our target sites were those that had not been occupied within the past 10 years with the aim of obtaining site velocities with uncertainties of 0.3 mm/yr or lower. The scientific goal is to help understand the distribution of strain across the forearc and its implications for earthquake hazards in western Washington. At the same time we established 14 new benchmarks (Table 1) to be used by future researchers to outline in more detail the deformation in the forearc.

2016 Field season. We borrowed (at no cost) five high-precision field GPS units from the UNAVCO equipment pool for one month (June 2016) and 3 units from the Cascade Volcano Observatory. McCaffrey and Portland State student Devin Rand were in the field 8 days while King and two volunteers (Mary Etta King and Stan Liffmann) spent an additional 8 days in the field. Rand then occupied several sites on his own. We established 14 new marks (Table 1) and made initial observations at them. We were able to observe at all targeted sites except those as noted below. Altogether we had 85 occupations at 71 sites.

We had the help of county surveyors in identifying useful markers and one surveyor occupied the site APSA at the airport in Chehalis.

GPS Data Processing. We have processed the new field data together with continous data from the PBO and PANGA networks and combined these with data from university, USGS, and NGS surveys and continuous data acquired since 1994. The processing is being done with GAMIT and GLOBK (Herring et al., 2015) largely in the manner described in McCaffrey et al. (2007).

Fig. 1 shows the sites we occupied and the regional continuous networks (PBO and PANGA). We were able to re-occupy most of the existing survey-mode sites (blue dots).

Fig. 2 and Table 2 give estimates of the site velocities. The data include the PBO and PANGA observations as well as our own survey observations. The new velocities are much more consistent and have greatly reduced uncertanties relative to the previous field of McCaffrey et al. (2013).

Preliminary results. The Cascadia locking results from preliminary block modeling are shown in Fig. 3. The map of Fig. 4 shows the residuals for the velocites (vectors with 70% confidence ellipses) from the locking model in the area of the Doty fault. The methods of the block modeling are described in detail in McCaffrey et al. (2007; 2013) and are not repeated here. For this model we included block boundaries along most of the mapped faults (solid lines in Fig. 3). These results were presented at Fall AGU 2016 (Rand et al., 2016).

To examine the deformation across the Doty fault system we made profiles of the North component of the GPS velocities along several South to North lines (Fig. 5). Slopes in the data along the profiles indicate north-south shortening (negative slope) or extension (positive slope). A flat line indicates no on-going deformation. The westernmost profile along the coast (236°E) shows large segments of extension and contraction that we think is related to elastic strain from locking. The profiles at 236.25°E and to the east are largely flat south of 47°N indicating little or no N-S strain rates occur at the present time. Hence, the shortening associated with the northward migration of the Cascade forearc appears to be north of 47°N, and not within the Doty fault zone. The strain rates appear to increase across the Olympic Peninsula (topographic high in profiles of Fig. 5).

We also developed a time-dependent model of the deformation of the PNW by incorporating slow-slip events, earthquakes and volcanic activity. The new GPS observations were incorporated into that model and show that time-dependent deformation is important in understanding the regions tectonic activity as well as estimating the site velocities. Fig. 6 shows two examples for survey-mode sites of the time-dependence estimated from the transients. Because the time-dependent model predicts the strain rates anywhere at any time within the model domain, our next step is to develop time-dependent stress models of the PNW.

Problems encountered

Two sites near Copalis Crossing, WA, (code LNGY and SHOL) were not recoverable (either destroyed or behind locked gates). We tried to locate NICR and BENS but they were unreachable. We were unable to occupy site X537 due to its position at the edge of a busy street. T550 had been destroyed during reconstruction of an intersection. The velocity estimated for site PRSC had a large residual and was unlike nearby sites; the cause of this is unknown.

Local assistance

We had assistance in locating marks and in occupying one (APSA) by local county surveyors. In particular Tom Gray (Grays Harbor county) and Martin P. Roy (Lewis county) were generous with their time and information. We also received assistance from Mark L. Armstrong, NOAA/NOS/NGS Oregon State Geodetic Advisor. Sites were located on private land, in fish hatcheries, within airport grounds, in state and county parks and on public land. Landowners and caretakers cooperated fully in allowing us access to the marks.

Other data

Some additional GPS data were obtained from the NGS OPUS database (https://www.ngs.noaa.gov/OPUS/); thanks to Dave Hatcher and Jaya Neti for retrieving the files. We also obtained data from Dan Gillins and Brian Weaver of Oregon State University (Gillins and Eddy, 2015; Kerr, 2015). A very useful website for finding GPS markers in Washington is at: http://www.wsdot.wa.gov/monument/search.aspx.

Data availability

GPS field data (raw and rinex form) and logsheets collected for this project are archived at UNAVCO (McCaffrey and King, 2017).

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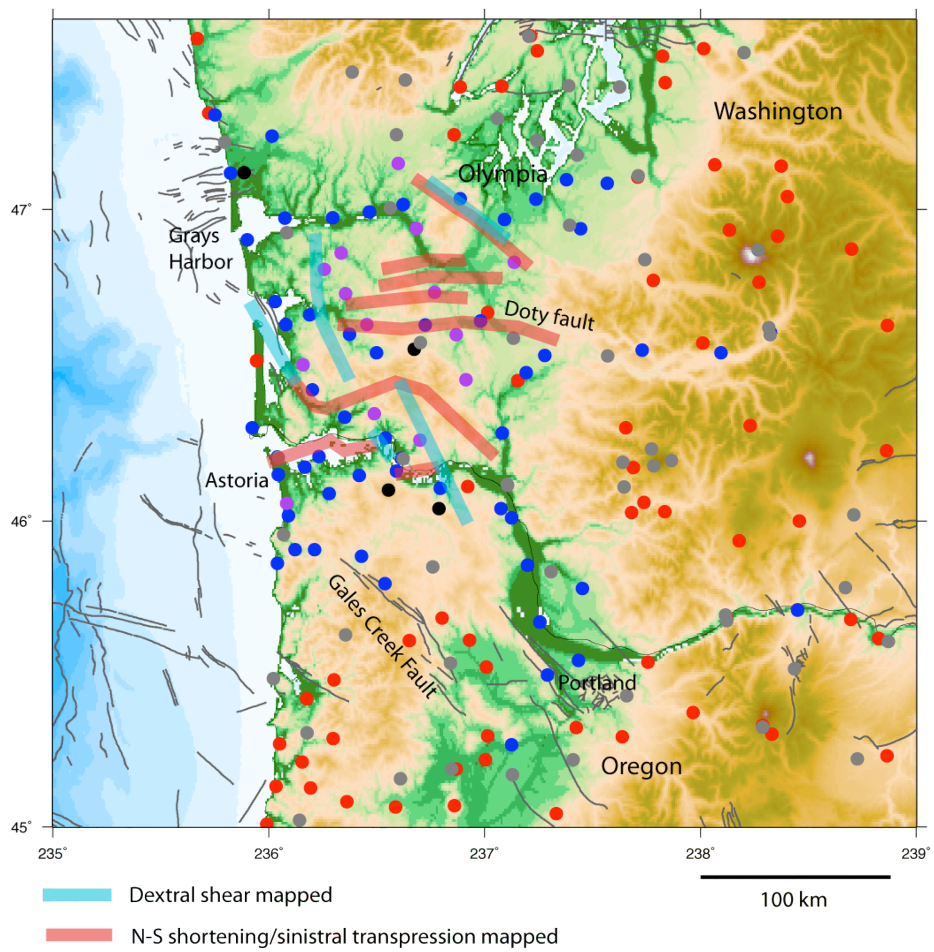

Figure 1. Map showing GPS site locations. Blue dots show locations of GPS sites done by us in 2016; purple are new sites established by us in 2016; gray dots are continuous GPS sites of the PANGA and PBO networks that we have included; black are marks we could not find; and red dots are other survey-mode sites that we did not re-occupy. Fault lines (blue and red lines) were supplied by Ray Wells.

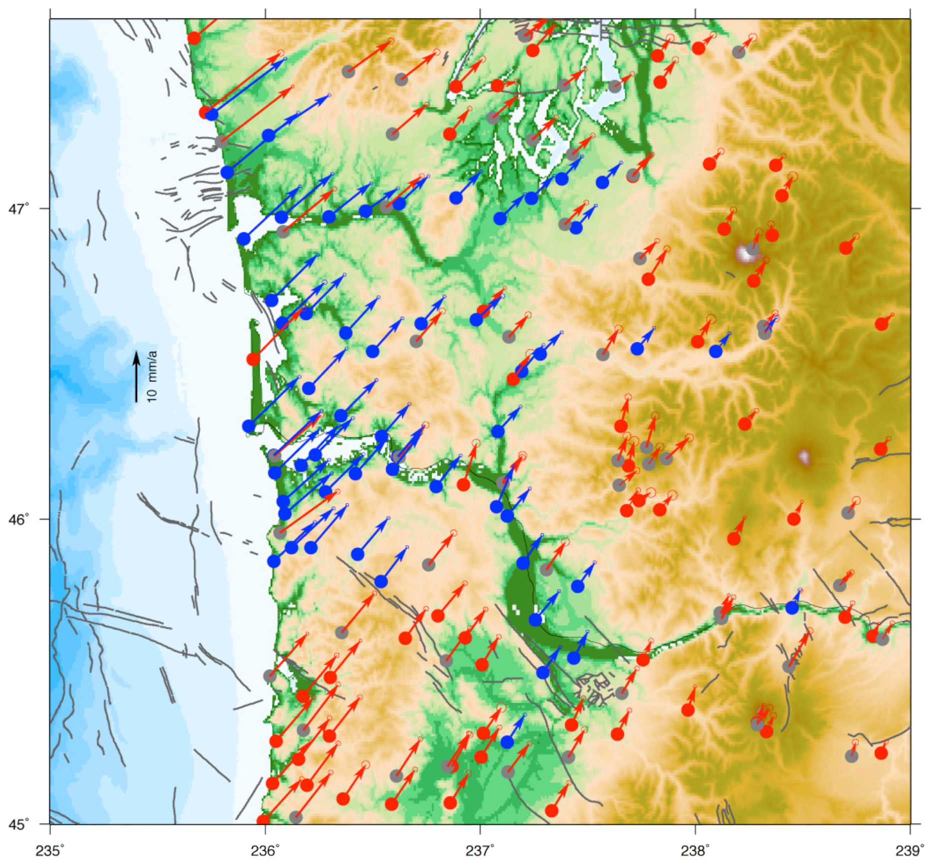

Figure 2. Velocities relative to North America with 70% confidence ellipses. Blue dots and arrows show sites we occupied in 2016; red are other survey-mode sites and gray are continuous GPS.

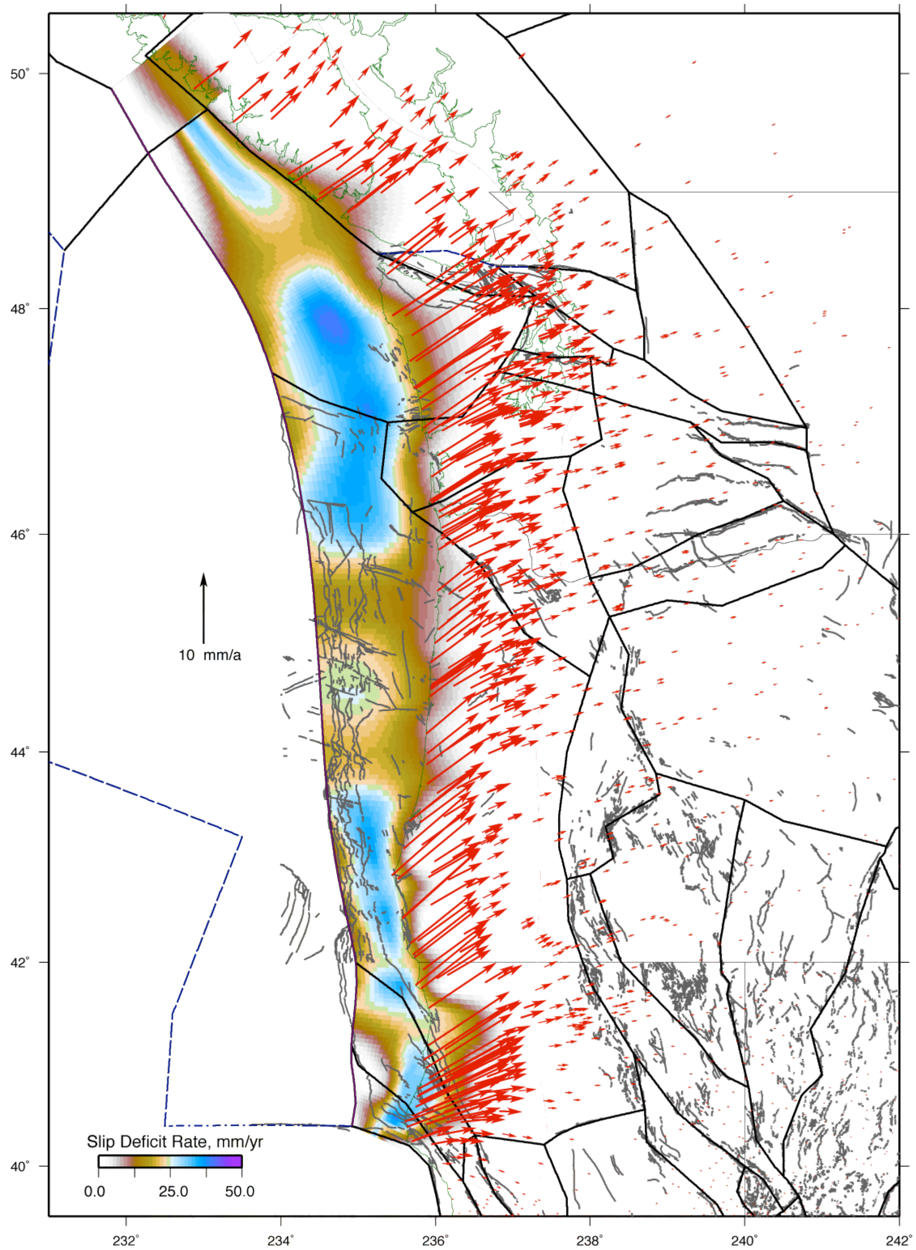

Figure 3. Block and locking model for Cascadia derived from GPS velocities. Red vectors show the locking-induced velocities at the GPS sites. Black lines are block boundaries.

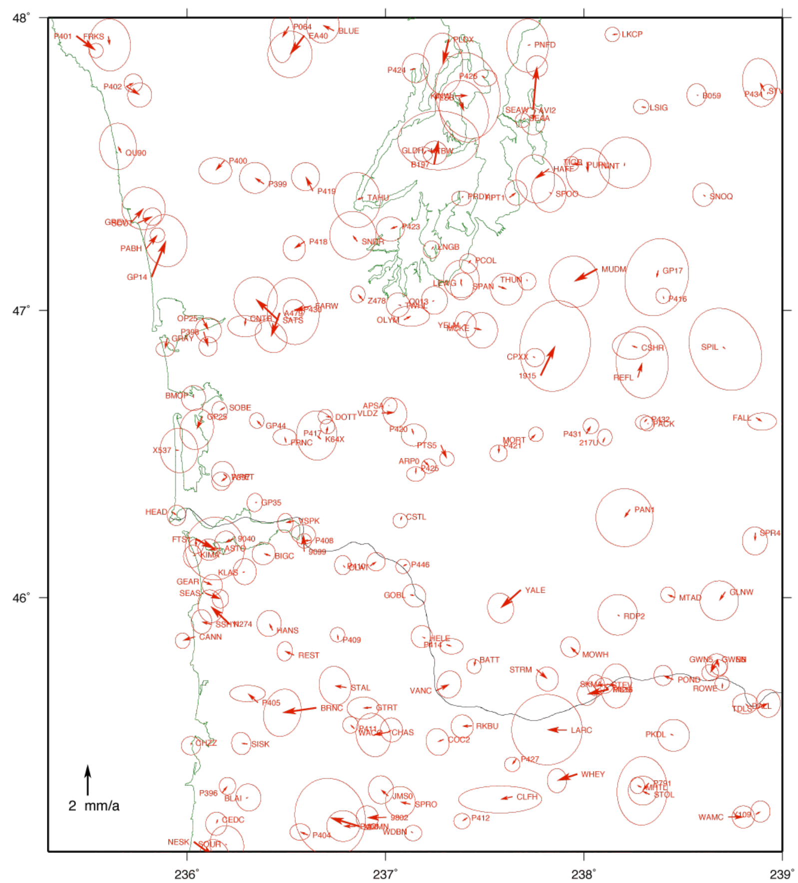

Figure 4. Velocity residual relative to the block/locking model shown in Fig. 3. Ellipses are 70% confidence.

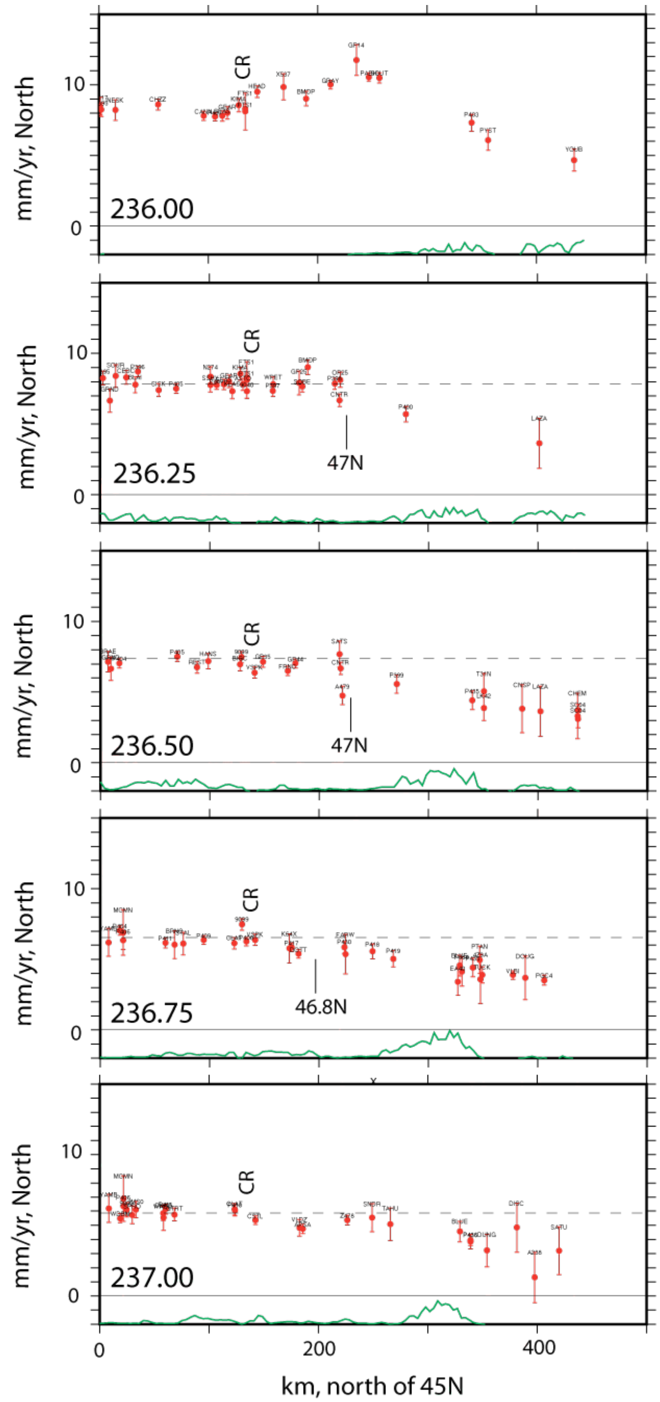

Figure 5. South to north profiles of the North component of the GPS vectors. Number at left side give the longitude of the profile, starting at coast in top panel to 237.0E in bottom panel. Dashed line shows constant velocity (no strain rate). The Doty fault system (south of 47N) shows little shortening, which picks up north of 47N. Negative slope indicates N-S shortening strain. CR is where profile crosses the Columbia River. Green curve at bottom is topography and the vertical scale is 1 km per tick mark.

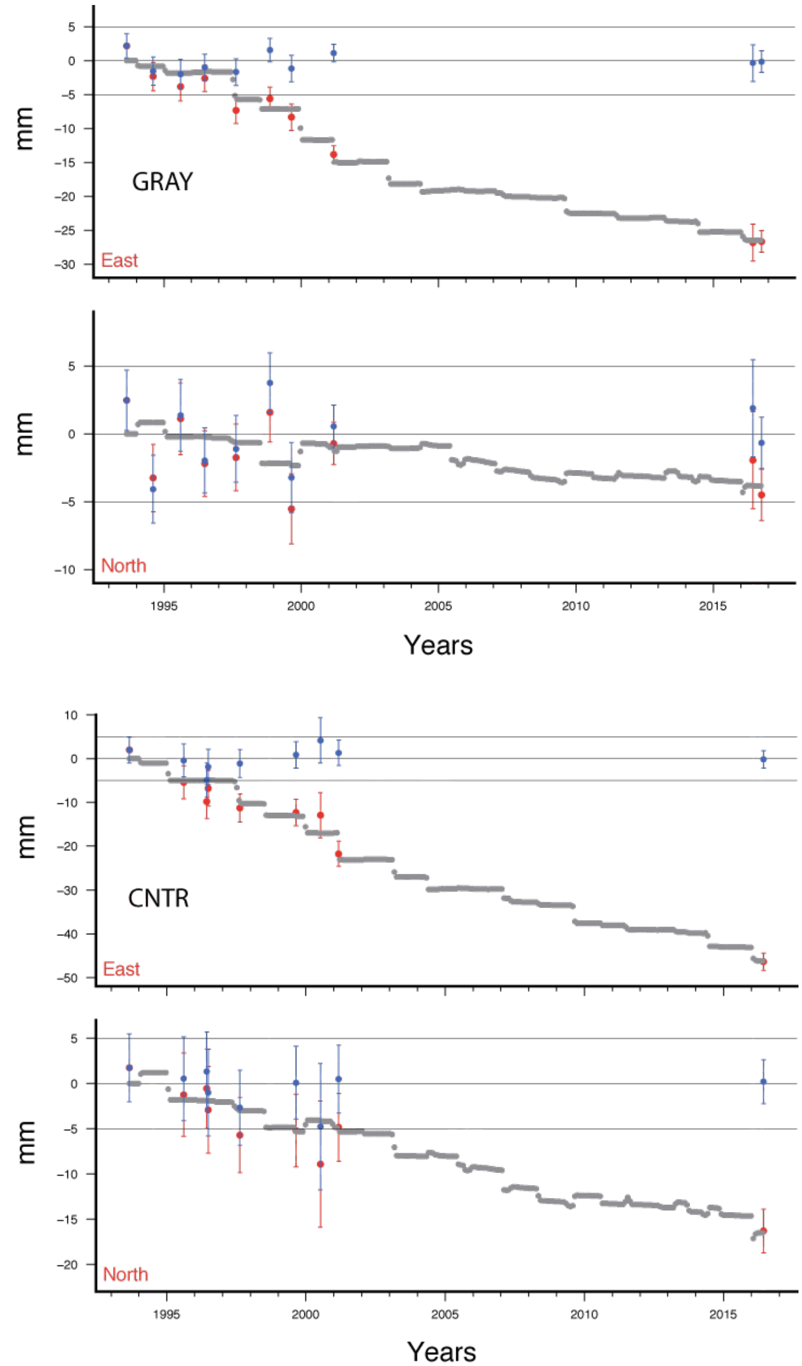

Figure 6. Time series of two survey-mode sites GRAY and CNTR. All time series have been de-trended by their velocities (slopes). Red dots are observed positions and blue are residuals after correcting for predicted positions. Gray curves show predicted positions as function of time due to slow-slip, earthquakes and volcanic deformation.

Table 1. New survey-mode sites established in 2016

Site	Longitude	Latitude
ABEW	236.769181	46.735851
ADNA	236.868804	46.599361
ARTC	236.336272	46.861170
BCFH	236.599860	47.145113
ELFH	236.700126	46.260457
FIRD	236.453603	46.631589
GEA2	236.083231	46.056828
J421	236.256781	46.807903
KMMT	236.489599	46.346063
NNFH	236.158753	46.503155
PRTW	236.684854	46.938980
TNNO	237.138094	46.831104
WRDW	236.355818	46.730370
WWOD	236.914445	46.455037

Table 2. Velocities of survey-mode sites in mm/yr, relative to North America. Solution 161118c.

Site	Longitude	Latitude	Ve	Vn	Se	Sn
217U	238.09450	46.54166	3.43	3.48	0.14	0.17
9040	236.23297	46.20736	7.87	7.13	0.22	0.24
9099	236.59112	46.16159	6.36	7.22	0.25	0.20
A479	236.46692	46.99085	7.17	4.54	0.33	0.33
ARP0	237.19294	46.47727	4.97	4.85	0.14	0.15
ASTO	236.16791	46.17340	8.01	7.63	0.23	0.22
BATT	237.45278	45.78100	4.12	4.59	0.13	0.15
BIGC	236.41914	46.14620	6.78	6.74	0.24	0.23
BMOP	236.03050	46.70501	9.76	8.90	0.25	0.26
CANN	236.03965	45.86167	8.73	7.65	0.15	0.16
CLAT	236.79451	46.10515	5.53	5.86	0.17	0.20
CNTR	236.29679	46.97272	8.65	6.52	0.35	0.22
COC2	237.29195	45.49858	4.05	4.93	0.24	0.28
CSTL	237.08115	46.28328	4.78	5.06	0.13	0.14
CW05	238.44948	45.71053	2.26	3.46	0.19	0.21
DOTT	236.72473	46.63134	5.33	5.11	0.13	0.15
FARW	236.62352	47.01460	5.84	5.10	0.54	0.69
FRNC	236.49976	46.54138	6.46	6.26	0.24	0.17
GEAR	236.08329	46.05669	9.52	7.90	0.21	0.22
GOBL	237.12472	46.00918	5.04	5.25	0.24	0.24
GP14	235.82179	47.11434	14.32	11.79	0.44	0.54
GP25	236.07816	46.63202	8.86	7.76	0.35	0.42
GP35	236.35094	46.33394	7.64	6.94	0.16	0.19
GP44	236.37453	46.60052	6.98	6.81	0.14	0.16
GRAY	235.90026	46.90281	11.43	9.96	0.19	0.15
HANS	236.43005	45.88487	6.57	6.95	0.25	0.27
HATK	236.01455	47.23153	19.32	0.63	28.28	30.05
HEAD	235.92405	46.30036	10.39	9.42	0.19	0.21
HELE	237.19881	45.85689	4.44	5.32	0.22	0.23
K063	236.61539	46.20265	5.89	6.00	0.11	0.11
KIMA	236.04394	46.15018	9.37	8.43	0.19	0.23
KLAS	236.28041	46.08884	7.98	7.13	0.24	0.27
LEWG	237.37934	47.09420	4.72	3.71	0.24	0.28
MCKE	237.44567	46.93790	4.79	3.70	0.33	0.37
MORT	237.72956	46.55056	4.11	3.95	0.13	0.15
N274	236.21206	45.90719	7.87	8.17	0.26	0.34
OLYM	237.09239	46.96694	5.55	4.53	0.39	0.21
OP25	236.07567	46.97221	10.82	8.05	0.27	0.26
PACK	238.32478	46.60683	2.99	2.85	0.12	0.14

PRSC	237.07546	46.04007	3.87	8.00	0.19	0.21
PTS5	237.27992	46.53275	4.87	4.22	0.14	0.15
Q013	237.23806	47.03128	4.97	4.15	0.27	0.29
REST	236.53891	45.79680	5.72	6.48	0.16	0.20
RKBU	237.43404	45.54672	3.62	4.96	0.23	0.24
SEAS	236.09064	46.01620	9.76	7.68	0.17	0.19
SMUR	236.04103	46.20648	9.72	8.18	0.11	0.12
SOBE	236.18990	46.66302	8.17	7.47	0.16	0.19
SOUT	235.75140	47.29956	15.15	10.56	0.19	0.18
SPAN	237.56857	47.08269	4.81	3.53	0.33	0.33
SPRO	237.12585	45.26936	3.96	5.40	0.31	0.32
SSHY	236.12170	45.90637	8.81	7.61	0.21	0.25
VANC	237.25562	45.67193	5.36	5.54	0.25	0.28
VLDZ	236.98184	46.64355	5.71	4.55	0.25	0.30
VSPK	236.54003	46.26838	6.15	6.13	0.16	0.20
WPET	236.20109	46.42204	7.97	7.63	0.24	0.26
Z478	236.88758	47.03302	5.56	5.09	0.15	0.17