Supplementary Information

Shallow earthquake inhibits unrest near Chiles-Cerro Negro volcanoes, Ecuador-Colombian border

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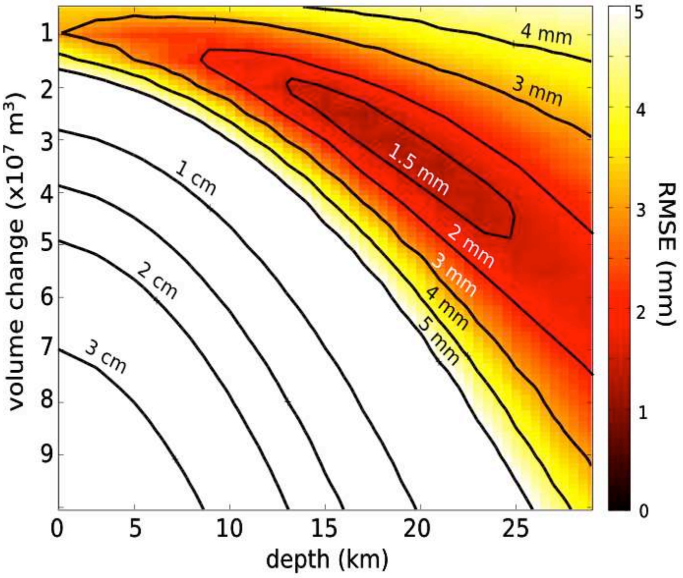
Supplementary Table 1: Examples of volcanic earthquakes >M5 sorted by the type of activity with which they were associated.

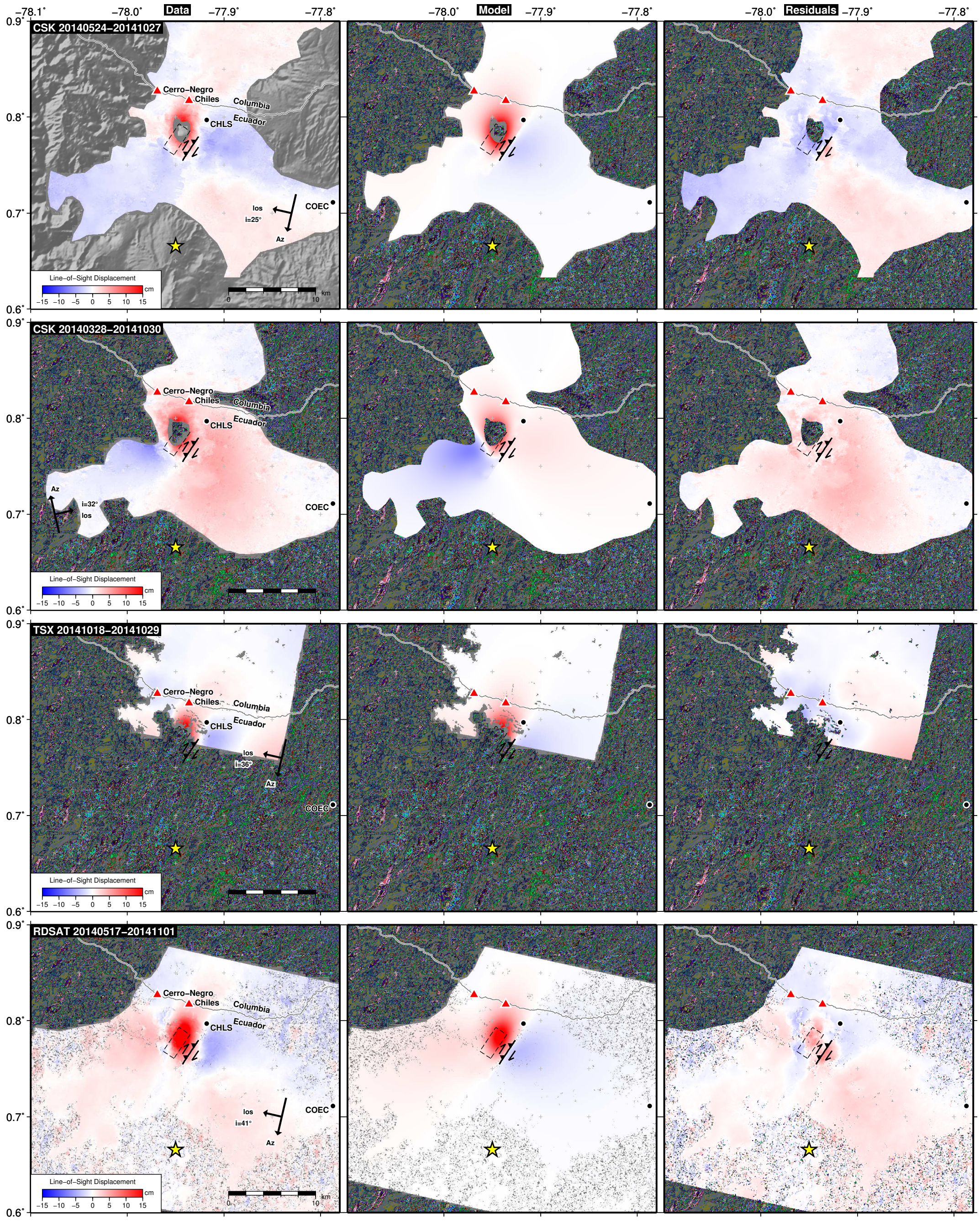
Event & Date	Description	Reference
	Dyke propagation	
Miyakejima dyke intrusion, June-August 2000	Dyke propagated 30 km. Arrest was coincident with M 6.5 earthquake, four more >M6 events occurred during subsequent inflation	Toda et al., 2002; Maccaferri et al., 2015
Dabbahu rifting episode 2005	M 5.6 earthquake in roughly the middle of rifting sequence	Wright et al., 2006
Natron rifting event, July 2007	Sequence of earthquakes (largest M 5.9) occurred during dyke inflation. Earthquakes occurred after the onset of deformation.	Biggs et al., 2013, Albaric et al., 2010
Harrat Lunayyir April-June 2009	A M5.4 earthquake at the peak of seismic swarm on 19th May 2009	Pallister et al., 2010
Krafla rifting sequence, 1975-1984	M 6.5 earthquake was probably triggered by initial 1975 rifting events	Buck et al., 2006; Passarelli et al., 2013
	Volcanic eruptions	
Mt St Helens 18.05.80	M 5.1 in earthquake swarm during explosive eruption	e.g., Benoit & McNutt, 1996
Miyakejima 1962 & 1983	M 5.9 after 1962 eruption; M6.2 after 1983. Interpreted as stress readjustment after emptying of reservoir	Yokoyama, 2001; Zobin, 2001
Izu Oshima 1986 eruption	M 6 event followed the eruption	Yokoyama, 2001
Pinatubo 1991	M 5.6 during explosive phase of eruption	Zobin, 2001
Tolbachik Fissure eruption 6.7.1985	2 M 5 earthquakes on 2.7.1975 at a depth of 10-20 km directly below site of subsequent fissure eruption	Zobin, 1990
Cerro Negro 1999	Three Mw 5.2 earthquakes preceded eruption, increasing Coulomb stress by 0.001-0.2 MPa and potentially triggering eruption	LaFemina et al., 2004, Diez et al., 2005.
Kalapana 1975 earthquake at Kilauea	M 7.2 earthquake was attributed to the impact of the injection of magma into the rift zone and may have triggered a small summit eruption.	Wyss et al., 1981
Chaiten 2008	M 5.2 two hours before main explosive event; M 5.0 19 h after onset of main explosive event. Pre-eruption event interpreted as dyking, later event the collapse of a sill-like reservoir	Wicks et al., 2011
Krakatau 1883	Eruption was accompanied by multiple M 5 earthquakes	Yokoyama, 2001
Tambora 1815	M 7 earthquake thought to have occurred simultaneously with explosion on April 10th 1815	Yokoyama, 2001
Katmai, Alaska, 1912	50 earthquakes were detected on distant seismometers, 14 > M 6 and one of M 7 during violent explosions at Novarupta on 7th June	Yokoyama, 2002; Abe (1992)
Sakurajima 1914	M 7.1, 9 km SW of volcano at 10 km depth, after onset of explosive eruption but before the start of lava effusion	Yokoyama, 2001; Abe, 1980
Karymsky 1996	M 6.9 earthquake occurred after VT swarms and preceded onset of Karymsky eruption by five hours	Yokoyama, 2001; Fedotov, 1998
Usu, 1910	M 5.4 during initial stage of eruption	Zobin, 2001
Bezymianny, 1956	M 5.3 during explosive eruption	Zobin, 2001
Shiveluch 1964	M 5.2 during explosive eruption	Zobin, 2001
Fernandina 1968	M 5.4 during explosive eruption (associated with caldera collapse?)	Zobin, 2001
Arenal, 1968	M 5.1 earthquake preceded eruption	Zobin, 2001
Beerenberg, 1970, 1985	M 5.7 before eruption (1970) and M 5 during eruption (1985)	Zobin, 2001
Shishaldin, 1999	M 5.2 earthquake 10-15 km west of volcano and preceding the eruption, no deformation	Moran et al., 2002; White & McCausland, 2016
Nyiragongo, 1977	M 5.1 before eruption	Zobin, 2001

Lonquimay, 1988	M 5.2 during initial stages of the eruption	Zobin, 2001
Hudson, 1991	M 5.8 during initial stages of eruption	Zobin, 2001
Akademia Nauk, 1996	M 7.1 before eruption	Zobin, 2001
Grimsvötn, 1996	M 5.6 before eruption	Zobin, 2001
Bardarbunga caldera collapse, August 2014	Sequences of ~M5 events associated with the collapse of Bardabunga caldera in August 2014 during Holuhraun fissure eruption	Sigmundsson et al., 2015; Riel et al., 2015
	Volcanic unrest	
Unzen unrest during 1984	Two events > M 5 (12-15 km west of volcano). In 1991, VT swarms in the same location preceded phreatic eruption	Umakoshi et al., 2001
Akutan unrest 1996	Earthquake swarm 6-10 km from summit with maximum magnitude of 5.1 in March 1996 (total cumulative seismic moment equivalent to ~M6), accompanied by uplift of ~ 60 cm.	Lu & Dzurisin, 2014
Peulik unrest 1998	Earthquake swarm in May 1998, including M 5.2 earthquake 30 km MW of Peulik, 20 cm inflation 1996-1998	Lu & Dzurisin, 2014
Yellowstone unrest	Two largest earthquake swarms accompanied or slightly preceded transitions from caldera wide uplift to subsidence (1985) or subsidence to uplift (1995).	Wicks et al., 2006; Waite & Smith, 2002
Long Valley unrest since 1970s	Unrest began in 1978-80 with sequences of inflation, often accompanied by swarms of earthquakes – transitions in deformation associated with swarms of earthquakes? Four M 6 events during May 1980 swarm and two M 5.2 events in 1983. Sequence of three M > 5 earthquakes 1998-1999	Rundle & Hill, 1988; Hill et al., 2003;
Iwatesan unrest 1998-1999	M 6.1 occurred during unrest characterised by inflation and shallow earthquakes. Inflation centred ~ 12 km from the volcano summit thought to have triggered this earthquake on a pre-existing fault.	Nishimura et al., 2001
Minakame (Matsushiru) 1966-7 unrest	Earthquake swarm accompanied by deformation, magnetic and gravity anomalies.	Stuart & Johnson, 1975
Hakone 1990	Earthquake swarm in August 1990 with maximum magnitude M 5.1	GVP, 1991 in McLelland (ed)

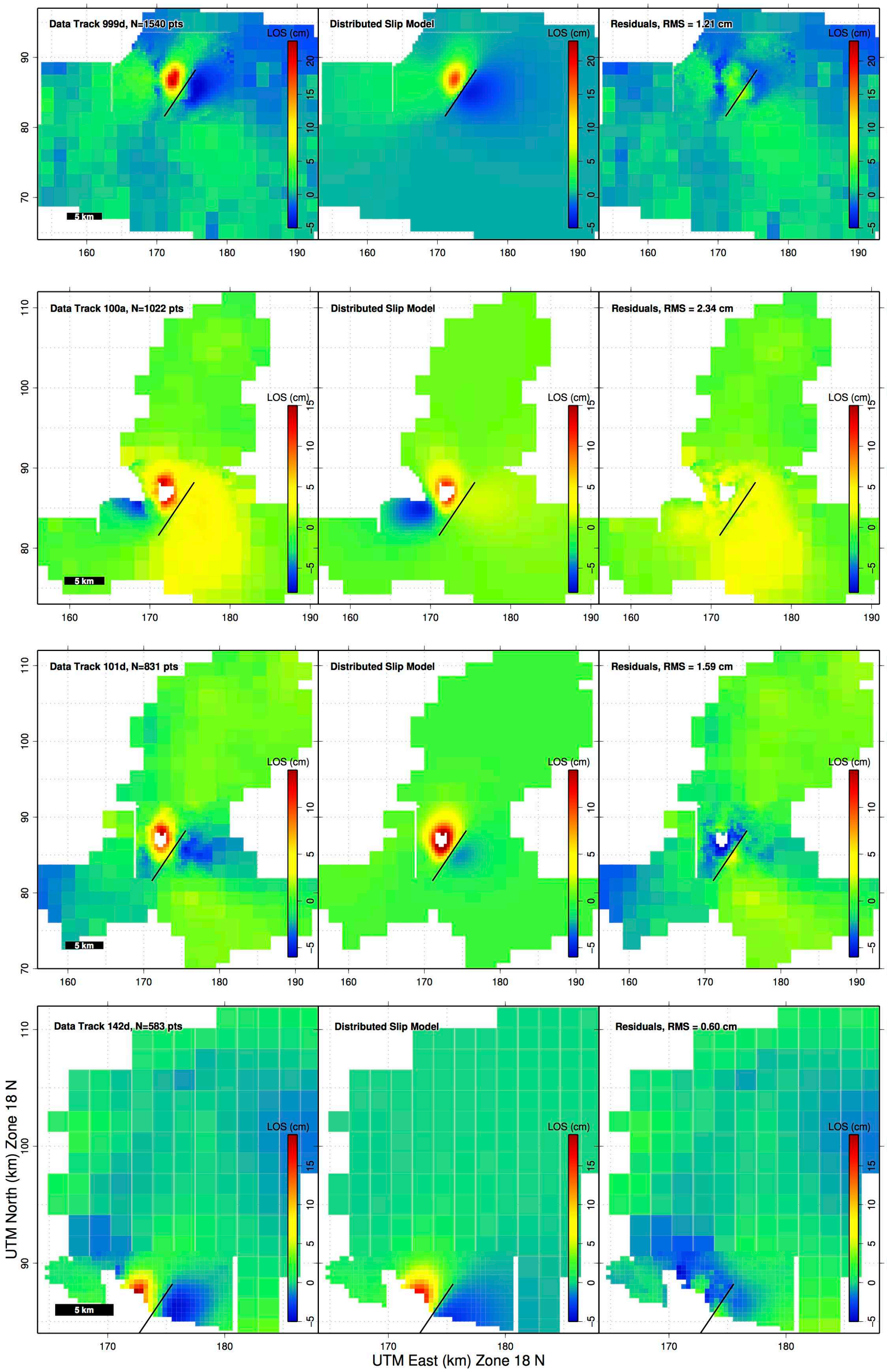
Supplementary Figure 1: Root mean squared error in predicted surface displacements at GPS locations from point source pressurization in an elastic half space at best-fit source location (-77.940, 0.675). RMSE is lower than 1.5 mm (150% of minimum value) for point source depths between 13 and 25 km depth and volumes 2-5 x 10^7 m^3.



Supplementary Figure 2: Interferogram, Model and Residual for all four interferograms used in the uniform slip inversion.



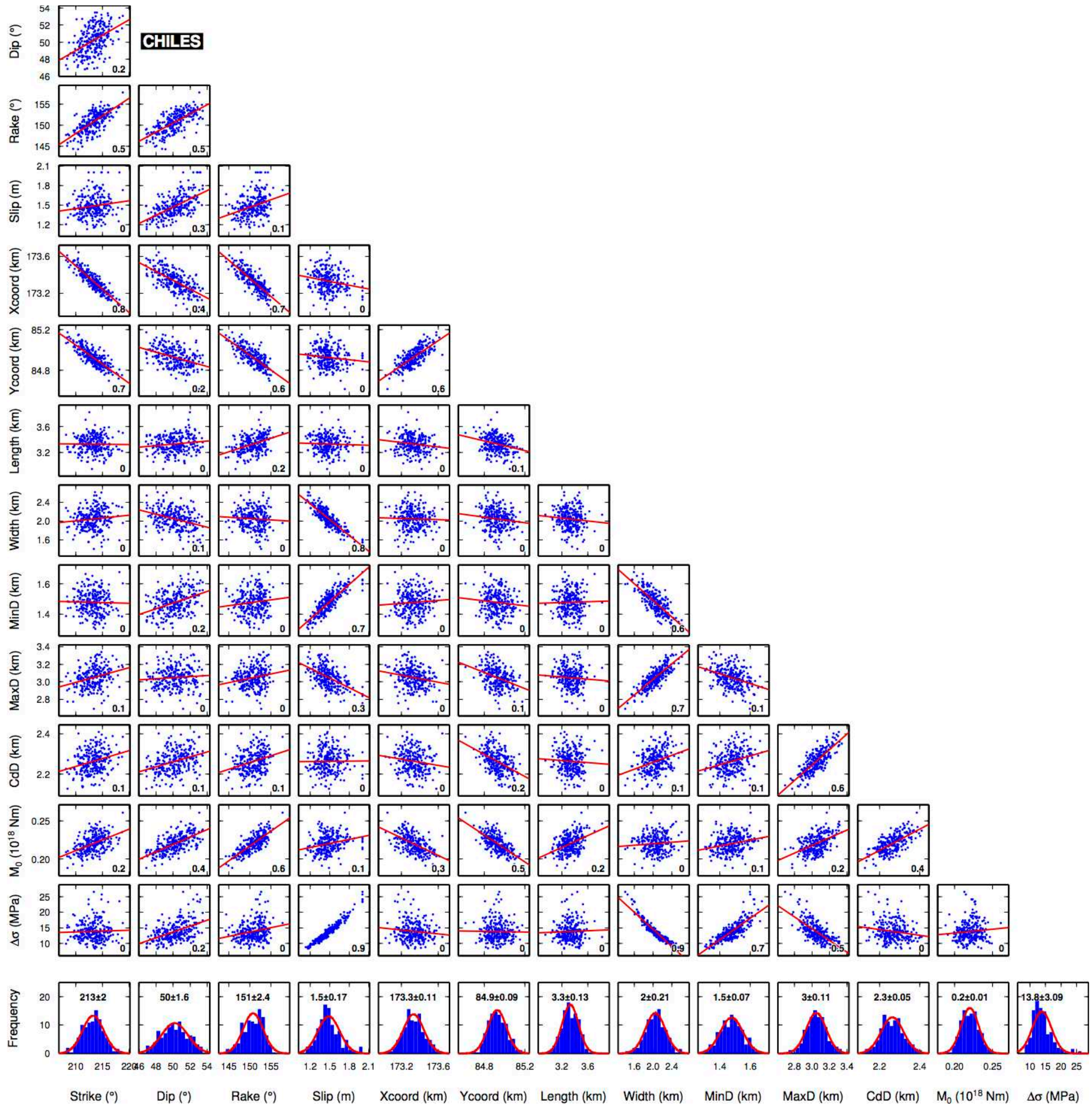
Supplementary Figure 3: Downsampled data, model and residuals for the four interferograms used in analysis.



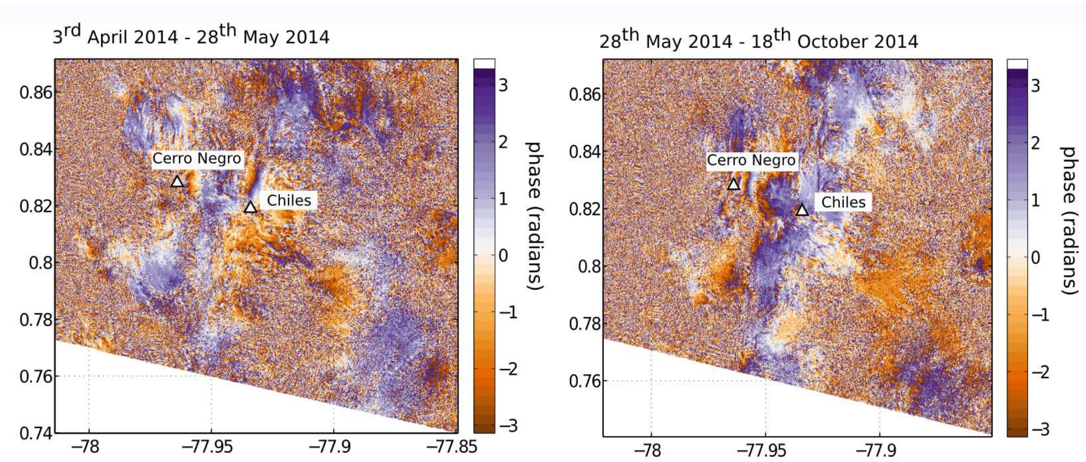
Supplementary Table 2: Variance and e-folding distances (Hansen, 2001) for interferograms used in the inversion.

Interferogram	Dates	Wavelength (cm)	variance (mm^2)	e-folding distance (km)
TerraSAR-X, desc.	18.10.2014-27.11.2014	3.1	50	2.0
CosmoSkyMed, desc.	28.03.2014-30.10.2014	3.1	59	1.1
CosmoSkyMed, asc.	14.03.2014-30.10.2014	3.1	41	0.7
RADARSAT-2, desc.	17.05.2014-01.11.2014	5.5	18	0.2

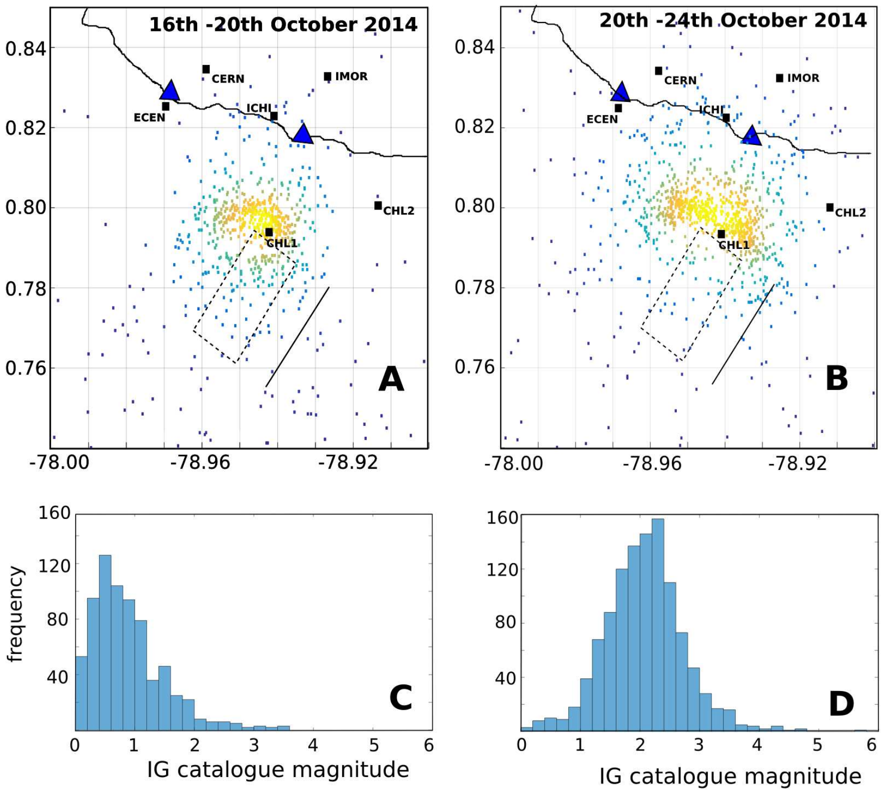
Supplementary Figure 4: Trade-offs for a Monte Carlo analysis of parameters for uniform slip solution (Figure 3, main text).



Supplementary Figure 5: TerraSAR-X interferograms from before the M5.6 earthquake on 20th October 2014. Neither interferogram shows evidence of deformation in the area around Chiles and Cerro Negro volcanoes. Note that the coverage of TerraSAR-X data does not extend as far South as the source of inflation inferred from the GPS data.



Supplementary Figure 6. IG catalogue earthquake locations for events recorded (A & C) 15th - 19th October 2014 and (B & D) 20th-24th October 2014. 90% of earthquakes occur at <6 km depth over both time periods, but the average event magnitude was higher after the 20th October earthquake. The colour scale on A and B indicates spatial density of earthquakes.



Supplementary Table 3. Earthquakes > M5, depth < 50 km within the North Andean Sliver (as defined by Nocquet et al., 2014) 1980-2015 (USGS Earthquake Hazard programme, http://earthquake.usgs.gov/earthquakes/search).

Magnitude	**Date and time** yy.mm.dd hh:mm (UTC)	**Latitude**	**Longitude**	**Depth** (km)
5.6	14.10.20 19:33	0.6623	-77.8895	10.0
5.1	14.08.12 19:58	-0.018	-78.3219	11.8
5.3	14.03.25 09:56	-2.2524	-79.2803	35.0
5.0	14.01.09 12:50	2.9737	-75.8432	26.2
5	10.03.26 01:56	-1.098	-78.129	10
5.2	09.10.09 18:11	-0.962	-77.817	35.2
5	09-02-21 22:47	-2.699	-78.203	35
5.2	07-03-06 13:05	2.082	-76.495	43.1
5	05-05-29 17:52	-3.251	-80.934	33.5
5.5	05-02-17 20:42	-1.768	-81.046	10
5.1	05-01-15 11:40	-3.582	-80.688	34
5.1	04-08-18 07:06	2.265	-76.595	26.5
5.3	04-08-11T23:02	-3.079	-80.801	42.1
5	04-04-15T19:06	-1.018	-78.394	10
5.3	04-03-28T08:41	-1.042	-78.335	12.6
5.3	03-09-13T18:33	-0.983	-78.33	33
5.1	02-11-11T23:53	-2.428	-80.078	33
5.1	00-10-08T20:12	0.383	-78.09	33
5.3	97-03-05T02:28:	-3.687	-80.556	37.2
5.2	95-11-05T09:24	-2.825	-78.839	33
5.1	95-10-29T05:28	-2.701	-77.833	33
5	95-10-21T15:36	-2.893	-77.935	33
5.1	94-07-07T22:54	-1.07	-78.291	12.6
5.3	1994-05-11T11:53	0.45	-78.701	18.8
5.9	1992-12-26T14:57	-1.011	-78.064	11.6
5.3	1992-08-18T12:53	-2.895	-79.923	27
5.3	1989-11-06T21:00	-3.191	-80.584	33
5	1989-11-04T15:39	-3.484	-80.321	36
5.4	1989-09-16T01:49	-0.592	-77.469	10
5	1989-03-02T14:10	-0.593	-77.514	41.5
5	1988-08-20T03:06	-2.506	-79.587	47.4
7.2	1987-03-06T04:10	0.151	-77.821	10
6	1987-03-06T08:14	0.022	-77.927	8.5
5.2	1987-03-06T06:33	-0.055	-77.629	10
5.5	1987-03-06T04:17	-0.22	-77.6	10
6.4	1987-03-06T01:54	0.048	-77.653	14.1
5.3	1986-11-23T16:30	-0.247	-78.481	33
5.2	1985-06-24T16:20	-1.896	-78.102	33
5.2	1985-04-10T20:15	1.56	-77.017	10
5.1	1984-11-13T14:03	1.978	-76.011	16.5
5.7	1984-04-28T20:12	-1.776	-78.101	47.4
5.7	83-05-19T19:07	0.147	-77.122	22.7
5.5	83-03-31T13:12	2.461	-76.686	22.2
5.1	81-06-27T21:54	-3.052	-80.327	49
5.6	80-08-18T15:07	-1.948	-80.017	55

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