Cross-comparing GPS and seismic data in advance and after great earthquakes

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Introduction

With the accumulation of seismic and other geophysical data and update of methodologies, the accuracy and reliability of seismic risk assessment can be improved. In particular, the introduction of geodetic big data, e.g. observations obtained by the Global Positioning System (GPS), leads to better understanding of earthquake origins and help interpreting their sequences. For this, we cross-compare the pre- and post-seismic displacements associated with great earthquakes and derived from GPS observations and seismic catalogs. In a pilot study of six great earthquake happened in 21st century, we consider the GPS data from stations of the Global Navigation Satellite System (GNSS) along with integral characteristics of the regional seismic regime, including the accumulated displacement derived from the catalogs of earthquake hypocenter parameters.

Data and Methods

The GPS time series at daily intervals complied by the Nevada Geodetic Laboratory in the terrestrial reference frame IGS08 at http://geodesy.unr.edu/gps_timeseries/tenv/IGS08/ ; last accessed December 2019.

We collected catalog of six earthquakes from on-line search of the Advanced National Seismic System (ANSS) catalog at https://earthquake.usgs.gov/earthquakes/search and the official source of geological hazard information for New Zealand at http://quakesearch.geonet.org.nz.

In our analysis the geodetic viewpoint is represented by the GPS daily records of a station position in 3D relative to a fixed reference of coordinates $\Delta e(t)$, $\Delta n(t)$, and $\Delta v(t)$ (i.e., E-W, N-S, and Up displacements in meters, respectively) and the distance to the reference point $\rho(t)$. The seismologic viewpoint is represented by the sum of model displacements related to earthquake sequences, $\sum(t) = \sum d(M_i)$, where M_i is the magnitude of the i-th earthquake in time interval from starting date of GPS record to time t, $d(M) = 10^{0.6M-4.4}$ in meters (i.e., from 2.5 mm for a magnitude M=3.0 to 10 m for a magnitude M=9.0 earthquake); the sum $\sum(t)$ is estimated at the times of the GPS records in the large and small circles presented in Figure 3, $\sum_{M8}(t)$ and $\sum_{AF}(t)$, respectively. We denote $\sum(t)$ as the sum of distributed seismic displacement. For a comparison of the two viewpoints we apply the moving estimate of the correlation function $C(t) = CORREL(\{\rho(t_j)\}, \{\sum(t_j)\} \mid j = 1, \dots, 20;\ t_{20} = t)$ based on the arrays of 20 consecutive determinations of both parameters.

Table 1. The six great earthquakes. Note: *Direction data from the ANSS Comprehensive Earthquake Catalog indicate the position of the event

Origin time, UTC	Latitude, °N	Longitude, °E	Depth, km	M_0, 10^{22} N-m	M_W	Place*
2004-12-26 00:58:53	3.295	95.982	30.0	6.68	9.2	Sumatra-Andaman Islands, Indian Ocean
2011/03/11 05:46:24	38.297	142.373	29.0	5.59	9.1	off the Pacific coast of Tōhoku, Japan
2010/02/27 06:34:12	-36.122	-72.898	22.9	2.26	8.8	offshore Maule, Chile
2015/09/16 22:54:32	-31.573	-71.674	22.4	0.32	8.3	48km W of Illapel, Chile
2018/01/23 09:31:40	56.004	-149.166	14.1	0.09	7.9	280km SE of Kodiak Island, Alaska
2016/11/13 11:02:56	-42.737	173.054	15	0.07	7.8	54.4 km NNE of Amberley (Kaikoura), New Zealand

Results

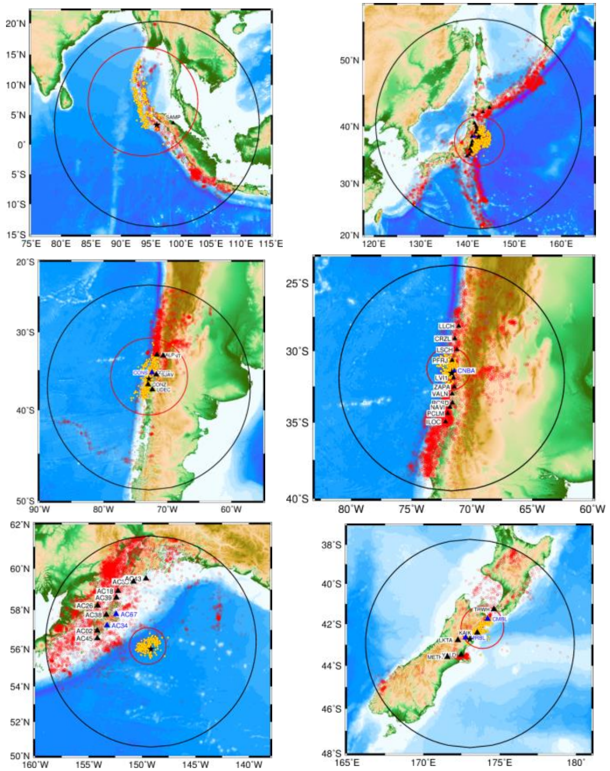


Figure 1. Background seismicity near the six great earthquakes. Notes: For each of the six great shocks (black stars) the epicenters of earthquakes ten years in advance their origin times (small red circles) at the angular distance P(Mw) from the epicenters (black circular outlines) are considered; all but a few of their first 24-hours aftershocks (small yellow circles) fall inside the 3σ off their center of mass (red circles).

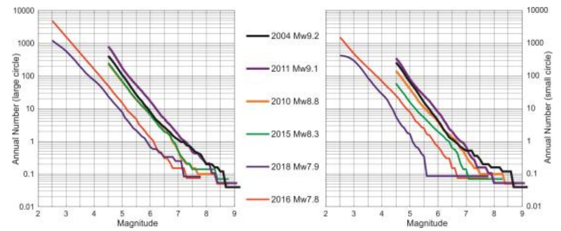
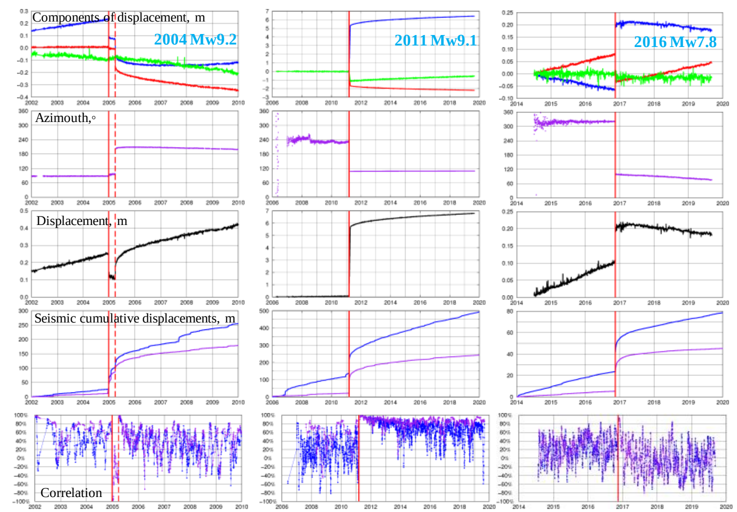


Figure 2. The Gutenberg-Richter annual frequency vs magnitude plots in circles centered at epicenters of the six great earthquakes considered

Table 2. The GPS time series used in the study along with their distance to the epicenter of the Tohoku earthquake and rates of displacement before and one year after its origin time. Note: Δ is displacement from the day before to the next daily position determination.

Site	Start Time	End Time	Longitude °E	Latitude °N	Altitude m	Distance km	Rate of before, cm/yr	Δ,m	Rate of after 1 year, cm/yr
J550	2006/04/01	2019/09/04	141.5007	38.3012	116.52	76.12	1.44	5.6952	11.42
G205	2003/06/11	2019/09/04	141.7533	39.0198	47.04	96.72	1.78	5.2154	12.34
J037	2009/01/01	2019/09/04	140.9542	38.3175	73.54	123.82	1.32	3.3075	10.94
J167	2009/01/01	2019/09/04	141.9553	39.4582	68.60	134.09	1.21	2.9038	11.71
J203	2009/01/01	2019/09/04	141.0066	37.5337	53.48	146.87	1.02	3.2640	7.29
J162	2009/01/01	2019/09/04	141.9505	39.8694	206.62	178.60	1.21	1.6333	8.74
J041	2008/04/01	2019/09/04	140.9025	37.0907	208.50	186.36	1.34	1.9888	5.64
J027	2008/04/01	2019/09/04	141.7891	40.1334	92.00	210.30	1.21	0.8272	6.95
J214	2009/01/01	2019/09/04	140.7539	36.8003	75.92	219.24	0.97	1.4350	4.92
J156	2009/01/01	2019/09/04	141.5113	40.5154	46.41	257.54	0.99	0.4471	5.44
I004	2009/01/02	2019/09/04	140.5445	36.1813	82.62	285.55	0.91	0.6790	3.32
I022	2009/01/02	2019/09/04	140.8372	35.7264	59.12	316.69	0.90	0.3668	3.42
J226	2009/01/01	2019/09/04	140.3849	35.2432	43.39	382.94	0.49	0.0910	2.41
G173	2009/11/04	2019/09/04	141.1422	41.8340	44.45	406.99	1.40	0.1188	2.72
I047	2009/01/02	2019/09/04	139.8641	34.9541	141.73	433.89	1.52	0.0435	1.34
J015	2009/01/01	2019/09/04	143.3310	42.3216	50.56	454.82	1.43	0.0183	1.46
J531	2009/01/01	2019/09/04	144.7191	42.9826	52.95	557.29	1.39	0.0134	1.81

Figure 3. The three components – E-W (red), N-S (blue), and Up (green) – at SAMP (left), J550 (middle), and MRBL (right) stations along with the azimuth (clockwise relative to the north) and distance to the reference point $\rho(t)$ at GPS station along with a model sums of earthquake displacements in the two circles considered.



Conclusions

(a) a steady drift of a site at about 400 km East of the 2004 Sumatra-Andaman epicenter retreated to the West by 13 cm on December 26 then gradually to 16 cm on March 28 when the 2005 Nias–Simeulue Mw8.6 earthquake and its first day aftershocks added another 12-cm shift to the West and 13-cm drop down to the move, (b) the coastal area on top the Tohoku mega-thrust, that did not move for several years before March 2011, keeps drifting to the East at a steady speed of about 7.4 cm per year since 2014, (c) eventually, the 2016 Kaikoura unidirectional strike-slip resulted in the current position retreat nearby epicenter and steady increase on the opposite edge of its rupture zone.

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