Continuous Fields of Ground Displacement Determined by Barnes Analysis of GPS Locations for the 11 March 2011 Tohoku-oki Earthquake

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Point observations of GPS station coseismic displacement resulting from the 11 March 2011 Tohoku-oki earthquake are analysed to make continuous fields of estimated displacement in the north, east and vertical directions, and a grid of magnitude of total displacement was computed. The largest total coseismic displacement at any GPS station was 5.36 meters (17.6 feet) on the Oshika peninsula at the Oshika station. The largest vertical motion was -1.128 meters at the same station. Ground displacements of more than 0.5 meters extend over a large region, reaching more than half way (200 km) to Tokyo from the epicenter.

DATA and ANALYSIS TECHNIQUES

Coseismic displacement of the 11 March 2011 earthquake in Japan is indicated by data from more than 1200 GPS motion vectors. The original GEONET RINEX data were provided to Caltech by the Geospatial Information Authority (GSI) of Japan. ARIA computed displacements, differences between station location solutions at 5:40 and 5:55 UTC, based on 5 min solutions. Preliminary GPS displacement data (version 0.3) is provided by the ARIA team at JPL and Caltech, created March 12, 2011 using Rapid Orbits. Data is available from ftp://sideshow.jpl.nasa.gov/pub/usrs/ARIA/ARIA_postseismic_offsets.v0.3.table.

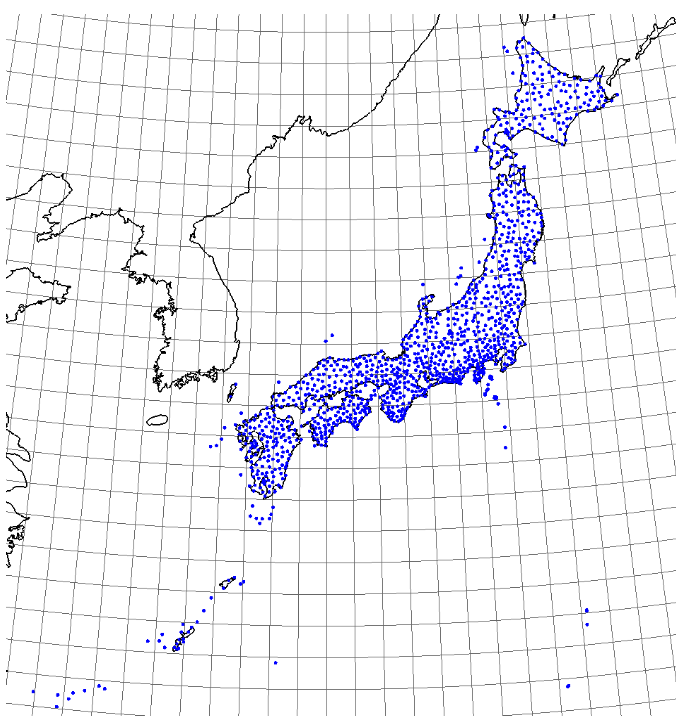

Figure 1 GPS station locations, Geospatial Information Authority (GSI) of Japan.

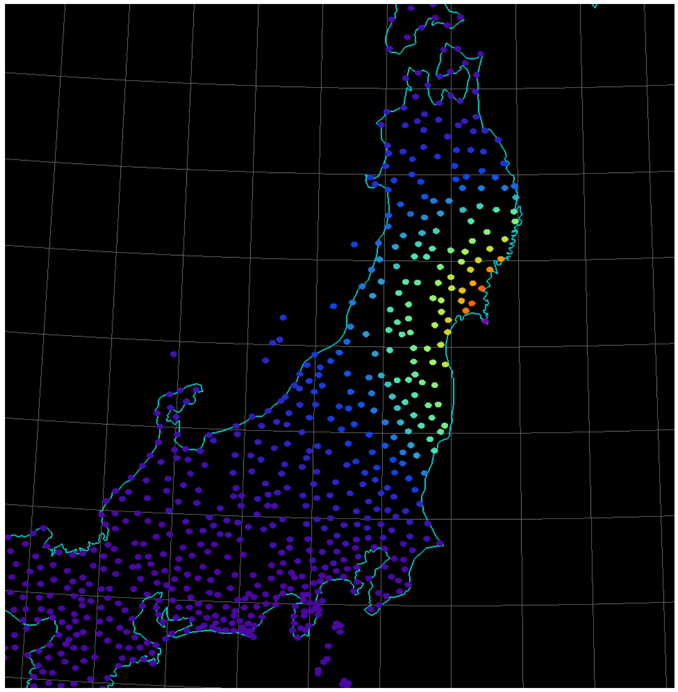

Figure 2 GPS displacement eastward components, colored by value. Color scale is the same as in Figure 3.

Figure 1 shows all GPS station locations. Figure 2 shows station locations near the earthquake, colored by eastward component value. The network density and fairly uniform station distribution, without large gaps, allows computation of regular grids of the north, east and vertical components of the displacement. These components' values of GPS station displacements (single location values at irregular latitude, longitude locations) were used to create three 0.15 degree grids using Barnes analysis (Barnes 1994a, 1994b, 1994c). The Barnes analysis parameters were gain 0.8, search radius 1.0 degree, and 3 passes.

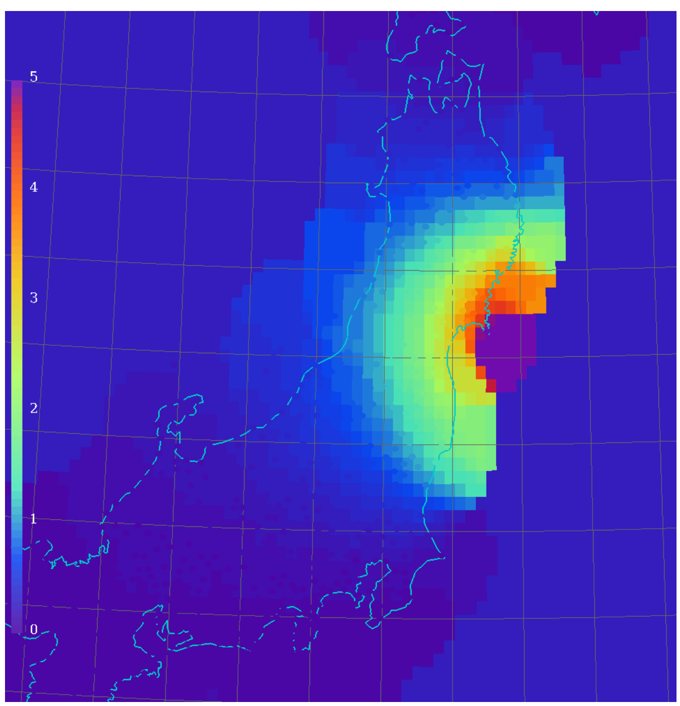

Figure 3 Grid of eastward component of displacement, analysed from GPS stations' displacements, colored by value, in meters. Station values also shown by colored dots to compare to grid values from the analysis.

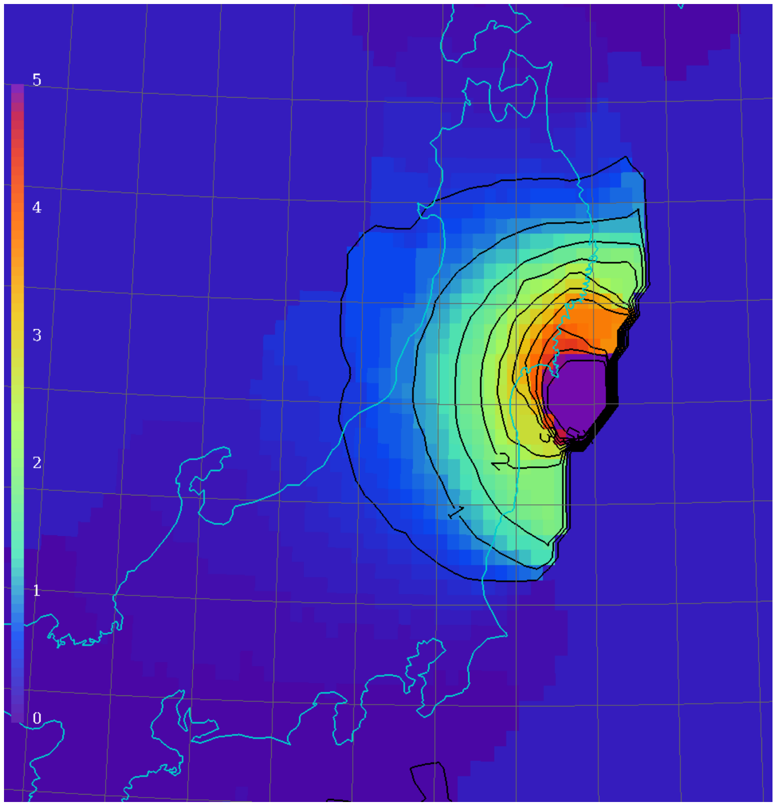

Figure 4 Grid of eastward component of displacement, analysed from GPS station displacement values, colored by value, in meters, with contours. Maximum onshore value of eastward displacement is near 5.0 meters. Values offshore are an artifact of computation and are not reliable indicators of ground motion.

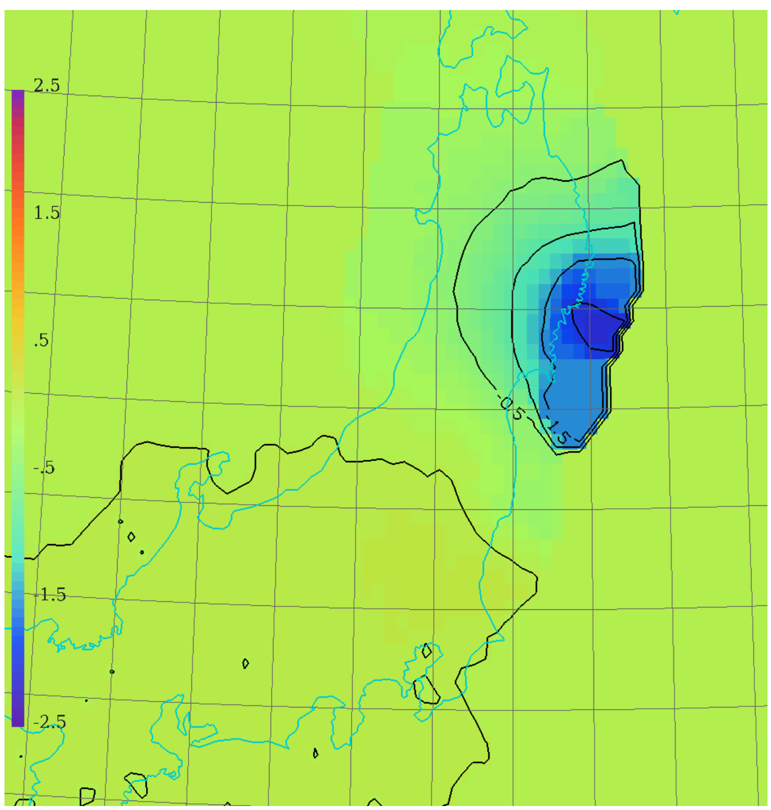

Figure 5 Grid of northward component of displacement, analysed from GPS station displacement values, colored by value, in meters, with contours, The extreme onshore value of northward displacement is near -2.0 m.

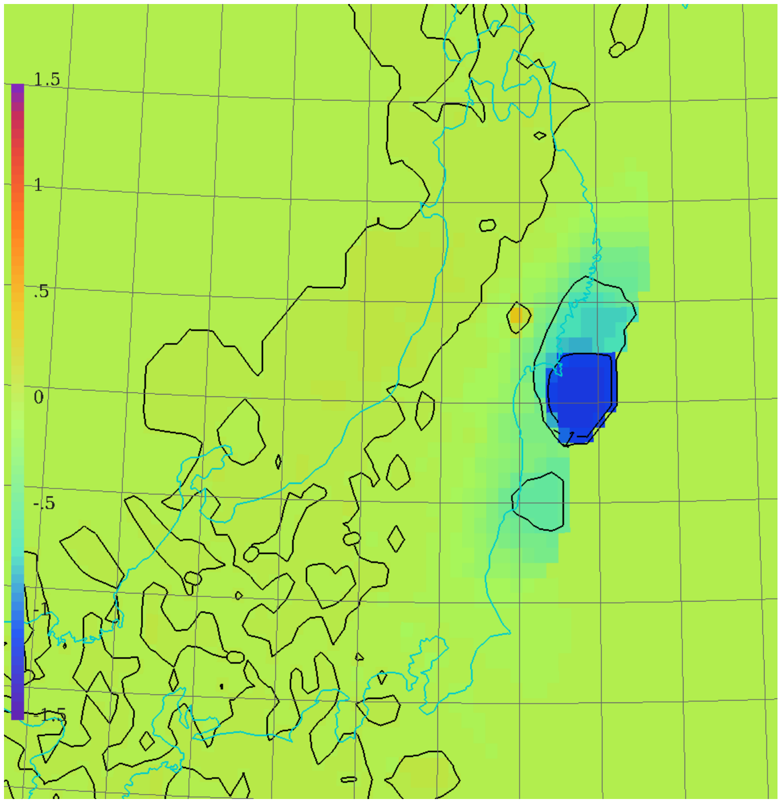

Figure 6 Grid of vertical component of displacement, analysed from GPS station displacement values, colored by value, in meters, with contours. Maximum magnitude is just over -1 meter, downward, on the Oshika peninsula. A region along the coast has values in the range -0.5 to -1.0 meter. Values offshore are an artifact of computation and are not reliable indicators of ground motion.

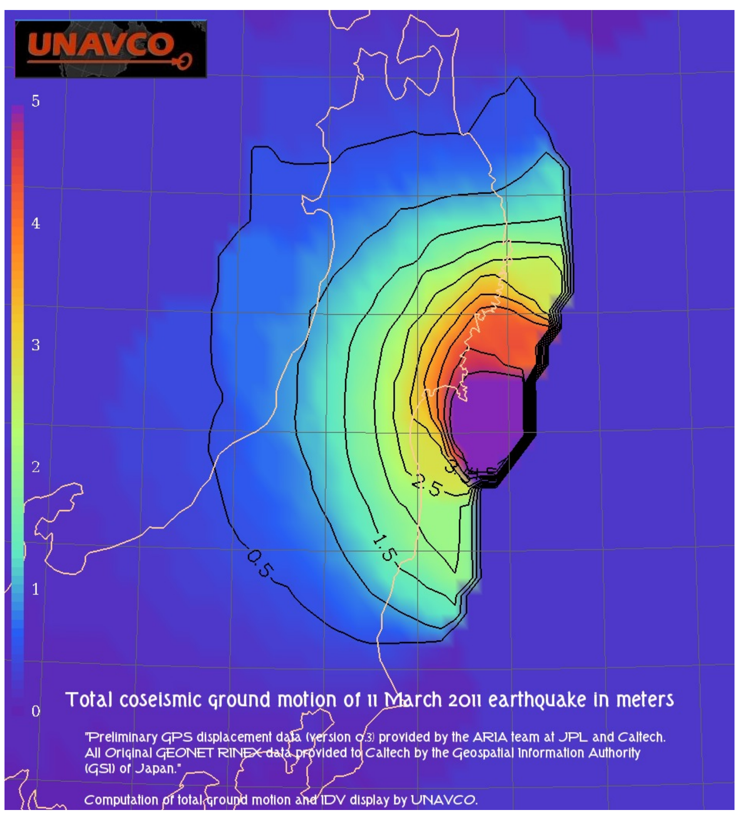

Figure 7 The magnitude of total coseismic ground displacement of the 11 March 2011 earthquake in Japan, in meters, with contours and colored by value. Values offshore are artifacts of computation and are not reliable indicators of motion.

The three grids of components obtained were used to compute a grid of the total magnitude of final ground displacement, shown in Figure 7. The extreme total coseismic displacement in this grid is slightly over 5 meters on the Oshika peninsula. Note that even more than half way to Tokyo, 200 km from the epicenter, the final ground displacement was more than 0.5 meter (1.6 feet). Since the N-S offsets are roughly 0.4 the size of the eastward motions, and to the south, the general motion was generally towards the ESE. The along-shore *subsidence* at first seems at odds with the Okhotsk plate moving east and *over* the Pacific plate, but this is expected and caused by elastic flexure. The grids determined here represent overall patterns of motion, tied to GPS station point observations, and are not expected to necessarily show correct ground motion at any particular point location away from the GPS stations, due to complexity of the geology, rock mechanics properties, and force fields involved. Additional subsidence or ground motion might be expected in unconsolidated soils.

The extreme total coseismic displacement at any GPS station was 5.36 meters (17.6 feet) on the Oshika peninsula, at station 0550. The extreme eastward motion was at the same station, 5.03 meters, as was the extreme vertical motion, downwards 1.128 meters (3.7 feet).

The ground motion can be qualitatively compared to InSAR line-of-sight distance interferograms such as those shown on the Supersites Tohoku-oki page http://supersites.earthobservations.org/sendai.php. The simple overall pattern of ground motion also is reflected in seismic source models constrained by GPS motion vectors, InSAR, and related data. Some preliminary source models can be seen on the same Supersites web page.

In an interesting related observation, individual GPS station records show that some stations at first moved even further than indicated by the final amount of change, and then moved towards the original location before stopping. Figure 8 (from RTNet, http://rtgps.com/rtnet_pppar_honshu_eq_1hz.php) shows that station Oshika moved 6 meters east, and then back westwards towards the original location a full meter in the last minute of significant motion. At about minute 348.3 there was an abrupt change in motion from eastwards to westwards which must have been accompanied by a sudden acceleration.

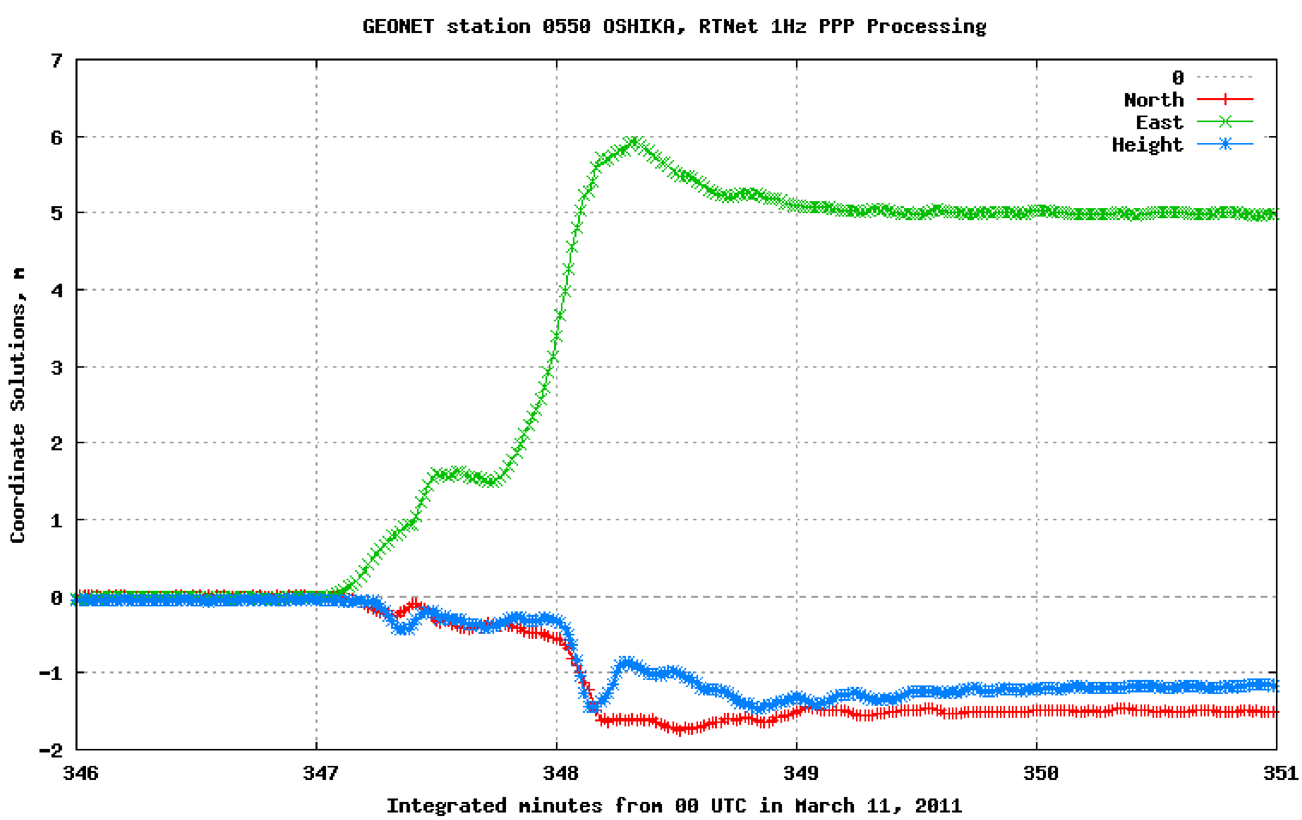

Figure 8 Times series of changes in GPS position components at station Oshika (0550).

This report is online at
http://www.westernexplorers.us/DisplacementFieldsofTohoku-okiEarthquake-SWier-2011.pdf

Figures are online at
http://www.westernexplorers.us/DisplacementFieldsofTohoku-okiEarthquake-SWier-2011-Fig4-E-displacement.png
http://www.westernexplorers.us/DisplacementFieldsofTohoku-okiEarthquake-SWier-2011-Fig5-N-displacement.png
http://www.westernexplorers.us/DisplacementFieldsofTohoku-okiEarthquake-SWier-2011-Fig6-Z-displacement.png
http://www.westernexplorers.us/DisplacementFieldsofTohoku-okiEarthquake-SWier-2011-Fig7-total-displacement.png
http://supersites.earthobservations.org/Sendai-ARIA-GSI-GPS-total-coseismic_ground_motion_UNAVCO.png

References

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Barnes, S.L., 1994b: Applications of the Barnes objective analysis scheme Part II: Improving derivative estimates. J. Atmos. Oceanic Technol. 11, 1449-1458.

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April 3, 2011.