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Movement of the 2011 Off the Pacific Coast of Tohoku Earthquake Detected by VERA Geophysical Observations

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Abstract

The VERA project is carrying out daily GPS observations in parallel with geodetic VLBI observations, in order to monitor motion of the position of the VERA antenna stations. And continuous measurement of gravity is performed as co-location or a station of GGP in Kamioka mine and Mizusawa. These geophysical observations caught co-seismic or post-seismic phenomena, crustal movement, change of the atmospheric pressure by tsunami, post-seismic creeping, and free oscillation of the Earth, accompanying the 2011 off the Pacific coast of Tohoku Earthquake.

1. The 2011 Off the Pacific Coast of Tohoku Earthquake

The strong quakes and huge tsunamis caused by the 2011 off the Pacific coast of Tohoku Earthquake (Mw=9.0) [Epoch=14:16:18 JST, Mar 11, 2011] brought destructive damages to the Pacific coast area from the Tohoku district to north Kanto. The focus of this quake is off the Miyagi-Prefecture (Lat=38d06m12s N, Lon=142d51m36s E, Depth=24km). The seismic-source fault distributed along with the Japan Trench, and its scale is presumed to be 400 km in length and 150 km in width. The slip type of the fault is reverse, and the slip length is presumed to be about 30 m at the maximum. The post-seismic slip continues with a speed of about 3mm/month still toward the same direction as the co-seismic slip. The post-seismic slip distribution on the plate interface is larger than the co-seismic slip distribution, and its center is close to the Japanese Islands and is located in a deeper place.

In the VERA (VLBI Exploration for Radio Astrometry) project [1], some kinds of geophysical observations, daily GPS observations, measurement of gravity by SG, continuous weather measurement, and so on are made to maintain accurate measurements of the displacement of the VERA reference position. These pieces of geophysical observation equipment caught phenomena that were generated by the earthquake on March 11, 2011.

2. Movement of the VERA-Mizusawa Site Before March 11, 2011

A steady velocity of the displacement based on a plate motion model of VERA Mizusawa observation point (VERAMZSW), which is obtained by regular VLBI observations and co-located GPS observations [2] at Mizusawa VLBI Observatory site, is 13mm/year toward southwest. Figure 1 shows typical velocities and directions of movement of VERA sites by plate motions.

However, the displacement rate of VERAMZSW is not constant. Coordinates of VERAMZSW have step-like or irregular changes in time series variations. These jumps are co-seismic displacements of the VERAMZSW position by earthquakes which occurred near the Mizusawa area.

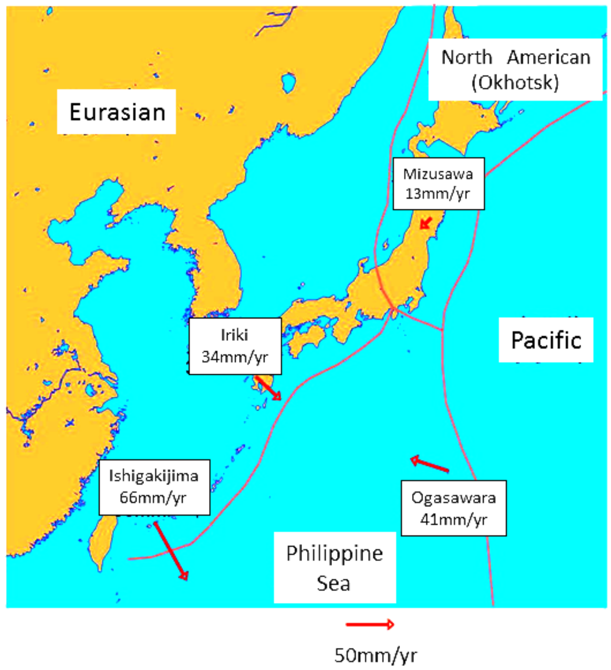

Figure 1. Movements of VERA sites by plate motions.

Furthermore, a change of rate is observed in the displacement rate of VERAMZSW after the Iwate-Miyagi Nairiku Earthquake in 2008 (Mj=7.2) [Epoch=08:43 JST, Jun 14, 2008]. The shortening rate of the baseline length of VERAMZSW-VERAIRIK changed from -11mm/year to -20mm/year (Figure 2). Especially the westward component of velocity notably increased from 3mm/year to 8mm/year (Figure 3). The vertical bar and the incidental date in this figure express the date when the earthquake occurred around the Mizusawa area.

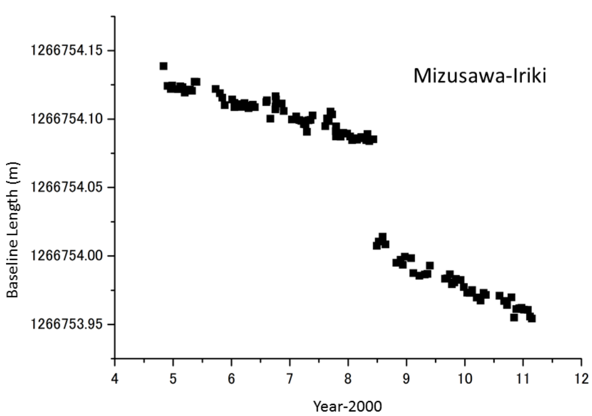

Figure 2. Time series variation of VERAMZSW-VERAIRIK baseline length.

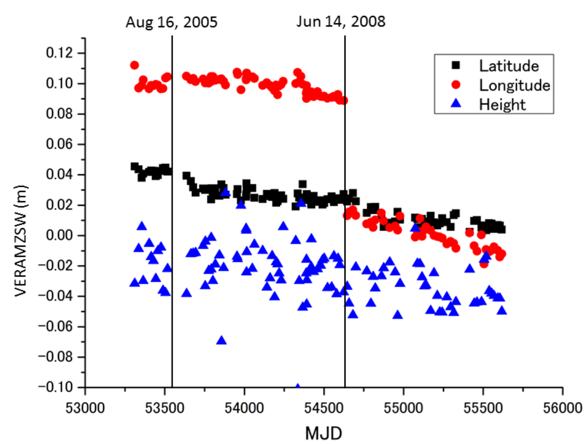

Figure 3. Time series variation of coordinates of VERAMZSW in horizontal coordinate system.

3. Co-seismic Displacement

Co-seismic displacement of the Mizusawa GPS observation point (MIZU) brought by seismic motion of the 2011 off the Pacific coast of Tohoku Earthquake was detected from the data of continuous GPS observation at Mizusawa VLBI Observatory. Figure 4 shows the result of tracing the seismic motion every second. This motion is estimated from GPS continuous observation data of Mizusawa by Sagiya, Nagoya University (2011), and it is expressed as moving relative to Usuda GPS point (USUD). The components of the motion are expressed in the Mizusawa local horizontal coordinate system. While the seismic motion continued for about three minutes, the MIZU was displaced 3.4 m at the maximum, and shifted 2.4 m in the direction of east-northeast at last. Co-seismic shifts become finally X=-1.924 m, Y=-1.277 m, and Z=-1.062 m in geocentric Cartesian coordinate system.

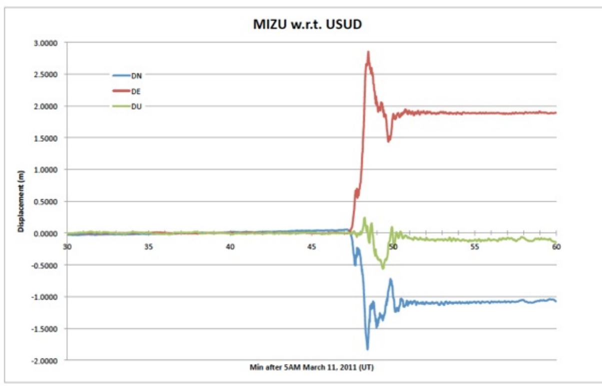

Figure 4. Tracing the seismic motion of Mizusawa for every second relative to Usuda.

4. Post-seismic Creeping

The post-seismic creeping (=after slip) has appeared clearly in the displacement of VERAMZSW on and after March 12, 2011 (Figure 5). The direction of the creeping agrees well with the direction of co-seismic displacement, and the total length of the creeping is 60.2cm between 12 March and 31 December, 2011. This creeping is decreasing its speed gradually but is still continuous. The decay curves for the horizontal components fit well to a logarithmic curve. And no sign is yet seen of returning to steady movement such as the plate motion shown in Figure 1.

5. Detection of Variation of Atmospheric Pressure Generated by Tsunami

Precise barometric data is continuously observed at Mizusawa VLBI Observatory. The barometric data on March 11, 2011 shows two steps of increase of about 0.5hPa after the turbulence by seismic motion of the earthquake in 2011 (Figure 6). This form of this atmosphere pressure change is consistent with the offshore tsunami observation using ocean bottom pressure data off Kamaishi obtained by the Earthquake Research Institute, University of Tokyo. The pressure change propagates by sonic speed of 1000km/hour. Maximum pressure was observed at 15:01 JST which was 20 - 30 minutes earlier than the arrival of the tsunami at the Pacific coast.

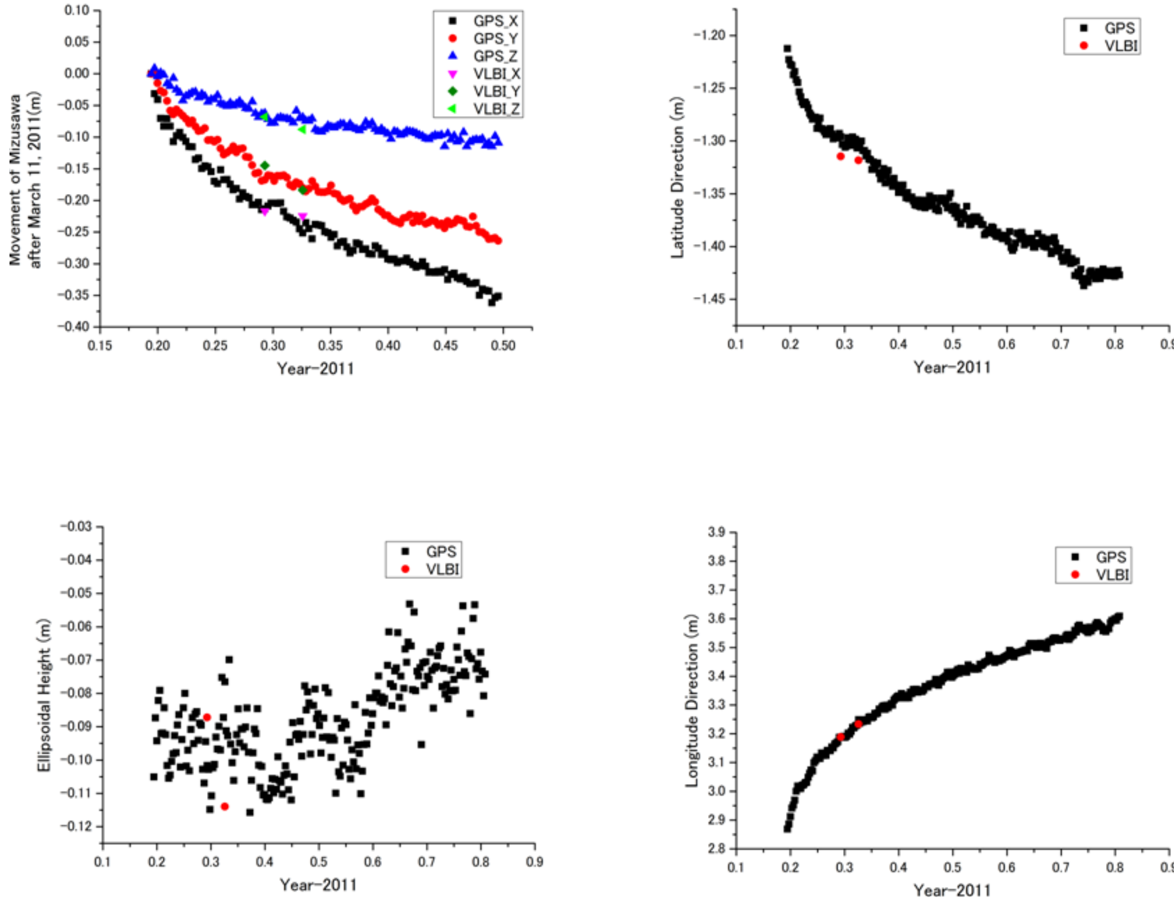

Figure 5. Time series variations of the coordinates of VERAMZSW.

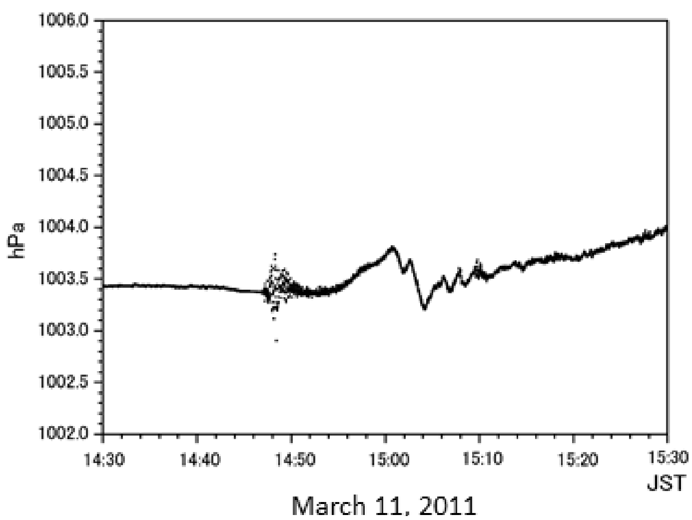

Figure 6. Atmosphere pressure change at Mizusawa observed at the Earthquake.

6. Earth's Free Oscillation Excited by the Earthquake

A large free oscillation of the Earth was observed by the superconducting gravimeter at Kamioka mine. Many spheroidal mode oscillations were detected on March 12 (Figure 7). The ${}_0S_0$ mode whose period is about 20 minutes decayed slowly and remained more than 2 months after the earthquake. The amplitude $10^{-9}ms^{-2}$ corresponds to one 10 billionth of surface gravity.

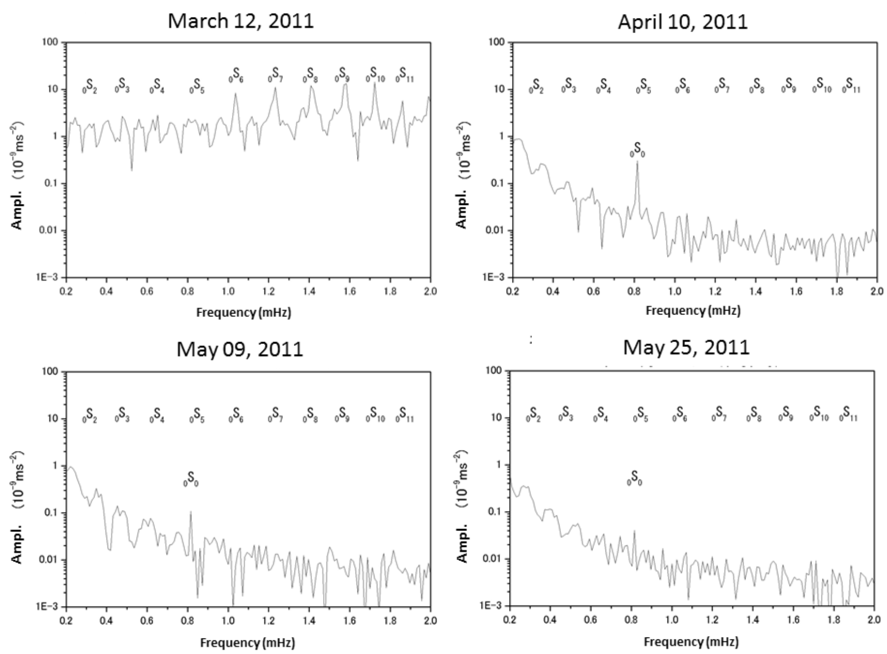

Figure 7. Transition of spectrum of gravity change observed from March 12 to May 25 in 2011.

Acknowledgements

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References

[1] Sasao, T., H. Kobayashi, N. Kawaguchi, S. Manabe, VERA : A Tool for Drawing a Stereo Map of the Galaxy, In: Journal of the Physical Society of Japan, Vol.57, No.5, 313–320, 2002.

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