Vertical movements observed by GEONET sites in and around Kujukuri area in Boso Peninsula, Central Japan

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In the Kujukuri area in the Boso Peninsula, Central Japan, according to the development of natural gas and iodine conducting, significant land subsidence is observed since 1950's. In this study, we analyze the observation data of GEONET GNSS network in and around the Kujukuri area to clarify the vertical movements in the region.

In the analysis, we adopt GAMIT/GLOBK 10.6, and the period from September 1996, when 24 hour tracking has begun in the network, to the end of 2016. In the first, we obtain daily coordinates applying 23 fiducial sites in and around Easter Asia. We apply ITRF2008 reference system, and VMF1 mapping function, adopting 10-degree cutoff angle and estimating every hourly ZTD, every four-hourly horizontal gradient, site coordinates and ambiguities.

In the next, after we correct significant co-seismic steps of the regional M6 or greater earthquakes, and coordinates offsets by antenna exchanges, we apply 30-day window Kalman filter to remove short-term time variations. Then we adopt the following empirical formula to identify annual and semi-annual variations, post-seismic deformations of 2011 Great East Earthquake, and linear velocity:

$$D(t) = a \ln(1 + t/b) + d \ln(-t/e) - f \exp(-t/g)$$
$$+ h \cos\{2\pi(t\text{-}1)/365.25\} + i \sin\{2\pi(t\text{-}1)/365.25\}$$
$$+ h \cos\{4\pi(t\text{-}1)/365.25\} + i \sin\{4\pi(t\text{-}1)/365.25\}$$

Where we adopt the post-seismic deformations of 2011 Great East Earthquake with the terms of the logarithmic and exponential functions only for the data after the occurrence of the earthquake, and hypothesize the logarithmic and exponential time constants (b=2.0, e=338.0, g=699997, unit: day) obtained by Tobita (2016) for the earthquake. Then we adopt the linear least-square method, estimating parameters a, d, f, h, i, j, k, and c. In the preliminary study, we found that the time variations of linear velocity before the occurrence of 2011 Great East Japan earthquake, thus we separate the period of around three years to adopt the least square estimations.

Therefore, we find the followings:

(i) We detect long-term subsidence in the GEONET sites in the groundwater mining area for natural gas and iodine coinciding with levelling survey.
(ii) In the annual and semi-annual components, we detect uplifts in the summer season in sites in the groundwater mining area.
(iii) Applying logarithmic and two exponential functions introduced by Tobita (2015), we can reduce efficiently post-seismic deformations of 2011 Great East Japan Earthquake.
(iv) We detect reduction of subsidence in the period of 2003 and 2007 in and around Kujukuri area, possibly caused by tectonic crustal deformations.
(v) In all sites analyzed in and around Kujukuri area, we detect simultaneous time variations with the period of several months.

(vi) In all sites analyzed in and around Kujukuri area, we detect annual and semi-annual variations with consistent amplitudes and phase delays before and after 2011 Great East Japan Earthquake. However, amplitudes and phase delays are not consistent before and after the antenna exchange from micro-stripe to choke-ring antennas in 2003, suggesting large systematic errors caused by multipath and erroneous phase center variations in the micro stripe antennas.

Keywords: GNSS measurements, Vertical time variations, Kujukuri Area, GEONET

