Two-dimensional Fourier series representation of surface deformation: Different scales of crustal deformation

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In the Japan islands, located in a plate subduction zone, we often observe two types of crustal deformation overlap with each other: one is elastic deformation due to slip/slip-deficit at plate boundaries and the other is inelastic deformation (brittle fracture and/or plastic flow) in the crust. In order to understand the crustal deformation and its mechanics precisely, we need to appropriately decompose and analyze these different deformations.

The crustal deformation due to slip/slip-deficit at plate boundaries is usually observed as a long-wavelength pattern in the order of 100 km, since the crustal movements are recorded in land-based InSAR and GNSS observation data at some distance from the plate boundaries. In contrast, the inelastic deformation occurs directly beneath the observation networks, and it is observed as a short wavelength pattern in the order of 10 km. Using the different wavelengths of these two types of crustal movements, some studies have already decomposed them. Takada and Fukushima (2013 Nature Geo.) extracted local subsidence caused by the 2011 Tohoku earthquake from InSAR data by subtracting low-pass filtered interferograms as coseismic deformation due to the earthquake rupture. On the other hand, Meneses-Gutierrez and Sagiya (2016 EPSL) and Meneses-Gutierrez et al. (2018 JGR) used a moving average filter to the strain/strain-rate estimated from GNSS data by the method of Shen et al. (1996) and extracted the long-wavelength components as crustal deformation caused by slip/slip-deficit at a plate boundary.

It would be useful to design filters based on the Fourier spectrum for decomposing different scales of surface deformation, since we can flexibly and systematically extract an arbitrary wavelength band of the surface deformation, which varies in according to the size of deformation source or its distance. In this study, we calculated Fourier spectrum of unequally-spaced GNSS displacement data from 2005 to 2011, and extracted arbitrary wavelength bands of crustal deformation. Firstly, we represented the GNSS displacement data as 2-D Fourier series by superposition of trigonometric functions with discrete wavenumbers, and then estimated the Fourier coefficients sequentially in ascending order of the discretized wavenumbers. The estimated coefficients give the Fourier spectrum in the 2-D wavenumber domain. Secondly, using the derivatives of the basis functions (trigonometric functions), horizontal strain distribution was calculated directly from the estimated coefficients. To validate this method, we synthesized test data of a known displacement field using actual spatial distribution of the GNSS observation stations. It was confirmed that the 2-D Fourier spectrum obtained by our sequential analysis method was almost same as that obtained by the discrete Fourier transform using equally-spaced data.

Applying this method to interseismic GNSS displacement rate data in the Kyushu region, we estimated the horizontal strain rate distribution of long wavelength component (wavelength of 200 km or more) and short wavelength component (wavelength of tens to 200 km) from the result of Fourier transform. The long wavelength component showed a similar pattern as the strain rate distribution theoretically calculated from the slip-deficit rate distribution along the Nankai Trough (Noda et al. 2018 JGR). In the short wavelength component, significant strain rates was localized around Beppu-Shimabara Graben and Sakurajima volcanoes.

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