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Development of a laser strain gradiometer and reduction in its thermal noise.

DEGUCHI, Takehiro[1*] ; ARAYA, Akito[1]

[1]Earthquake Research Institute, University of Tokyo

An earthquake is essentially a shear slip on a fault. Because the rupture velocity is roughly constant for most earthquakes, the length, the width, and the slip distance of a fault are respectively proportional to the duration of the rupture, and therefore an earthquake follows the scaling law that its seismic moment is proportional to the cube of its duration. In addition to the ordinary earthquakes, slow earthquakes have been discovered recently. Slow earthquakes include short-term and long-term slow slip events, non-volcanic tremors, low-frequency earthquakes, and very low-frequency earthquakes. They are known to be also shear slips but have slower rupture velocity than the ordinary earthquakes (see the reference [Beroza and Ide, 2011]). Ide et al. (2007) proposed that every slow earthquake has the same mechanism with a new scaling law that its seismic moment is proportional to its duration.

However, no middle-term slow earthquakes with duration of 200 s to 1 day have been reported so far. To understand the reason, we conducted analytical calculations including comparisons of expected signals of slow earthquakes and background seismic noise. It was shown that the middle-term slow earthquakes cannot be observed by a single accelerometer, a strainmeter, or a tiltmeter due to the background seismic motion.

AIST's synthetic analysis using the network of strainmeters, tiltmeters, and groundwater pressure gauges [Itaba et al, 2009] detected smaller slow slips.

Let us take the second spatial derivative of displacement, "the strain gradient". Analytical calculations showed that the signals of slow earthquakes with duration of 200 seconds to 1 day can directly be detected from the strain gradient of the ground. The spatial scale of the background ground motion is larger than the typical distance between a hypocenter and an observatory and the typical size of the fault. Taking spatial derivative emphasizes the small-scale crustal deformation, and makes the detection of local slow earthquakes easier. Thus, measuring the strain gradient will be effective to detect them.

We made a prototype instrument of measuring the strain gradient, "strain gradiometer," with laser interferometry. Before installing it on the ground, we measured its instrumental noise in the atmosphere and found the noise following power spectral density of 10^{-12}[m^2s] at 10^{-5}Hz and tendency of 1/f^2 below 0.1Hz. This noise was caused by changes in optical path lengths due to the fluctuation of air pressure. Subsequently, the noise of the interferometer in vacuum was measured; the noise was reduced by 1/10 and had the tendency of 1/f below 0.1Hz. This noise could be reduced by adjusting the optical path difference because it was estimated to be caused by frequency fluctuations of the laser source, which was frequency stabilized by the two-mode method. After the adjustment, there remained noises that had the power spectrum of 1/f^6 in the period between 5000s and 20000s and same power in the period longer than 20000s. This noise had similar waveform to temperature in time-domain. This noise was estimated to be caused by thermal expansion of the optical devices and the optical breadboard. Assuming this noise will be reduced in proportion to the square of the baseline length in terms of the strain gradient, the necessary baseline will be more than 300m. In the presentation, analyses of the noise of the interferometer with thermal insulation by ceramics and the future development will be explained.

References

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