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단 보

Detection of Long Period Seismic Events by Using a Portable Gravity Meter, gPhone

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이동식 중력계(gPhone)를 활용한 장주기 지진 이벤트 관측

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Abstract: A gravity meter has been used for exploring subsurface mineral resources and monitoring long-period events such as Earth tides. Recently, researchers found several other intriguing features that we could even detect large teleseismic earthquakes and monitor seismic ambient noise using gravimeters. The zero-length spring suspension technology gives the gPhone (Micro-g LaCoste) excellent low frequency sensitivity, which may have implications for investigating much longer-period natural events (e.g., Earth's hum, tsunami waves, etc.). In this study, we present preliminary results through temporary operation of the gPhone at Geumsan in South Korea for 9 months (Nov. 2008-Jul. 2009). The gPhone successfully recorded large teleseismic events and showed a clear seasonal variation of the Double frequency microseisms during its operation period.

Keywords: gPhone, Teleseismic earthquake, Double frequency microseisms

요 약: 중력계는 주로 지하 광물자원 탐사 및 지구조석과 같은 장주기 이벤트를 관측하는데 사용되고 있다. 최근 연구자들은 이 중력계를 이용하여 대형 원거리 지진 및 지진상시잡음 관측과 같은 몇몇 새롭고 흥미로운 사실들을 발견하였다. Micro-g LaCoste사의 gPhone에 적용된 zero-length spring suspension 기술은 초저주파 신호도 훌륭히 관측 가능하게 하며, 이는 Earth's hum이나 심지어 대형 지진해일 등을 관측하는데 큰 도움을 줄 수 있음을 시사한다. 이 연구에서는 충남 금산에서 2008년 11월 부터 2009년 7월까지 9개월간 임시로 설치/운영하였던 gPhone 자료를 분석하여 원거리 대형 지진관측 및 상시지진잡음의 계절적 변화에 관한 사전결과를 보고하고자 한다.

주요어: gPhone, 원거리 지진, 상시지진잡음

Introduction

The gravitational force is the force with which a massively large object (e.g., Earth) attracts another object towards itself and is not a force of contact. In geophysics, we utilize a gravity method measuring a natural gravity field over the Earth surface to provide a better understanding of the subsurface geology. The gravity exploration is non-invasive, passive, and non-destructive remote sensing method so that it is well suited to a populated area.

Recently, with the rapid development on technology such as a portable gravimeter, we could investigate various interesting features, e.g., exploring mineral resources, monitoring sea-level rise, ground water change, ocean loading studies, volcanic monitoring, Earth tides, and even earthquake monitoring; mostly long-period (> 1 s) events.

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In seismology, there have been extensive efforts to examine seismic surface waves (primary microseisms, PM; double-frequency microseisms, DF; the Earth's seismic hum) generated by ocean waves incident on coasts. The generation of PM, DF, and Earth's seismic hum is generally explained by direct pressure on the seafloor, standing waves from interaction of incident and reflected waves, and swell-transformed infra gravity wave interactions, respectively (Traer *et al.*, 2012). As mentioned above, the gravity method is quite useful to monitor long-period events so that we could observe temporal variation of microseisms using a gravimeter. In this paper, we report preliminary results coming out from temporary operation of a gravimeter, gPhone, installed at Geumsan, South Korea for the period of November 2008-July 2009.

Instrumentation

Gravity measurements could be performed by absolute and relative ways. An absolute gravimeter operates by using the free-fall method. As we drop an object in a vacuum chamber, we may directly measure the distance and its lapse time, and finally we could obtain acceleration that is equivalent to gravity. Another instrument to measure gravity is a relative gravimeter. It has a spring-based structure, whose displacement is proportional to local gravity. They are normally used in gravity field surveys over large areas to determine the geoid over the areas. Note that one should calibrate the strength of the spring by placing the instrument in a location with a known gravitational acceleration before conducting surveys.

The gPhone, a portable relative gravimeter, manufactured by Micro-g LaCoste is based on the LaCoste and Romberg technology and has a low drift so that it can be used to integrate periodic signals (e.g., Earth tides) for very long time periods. Furthermore, the gPhone has excellent high frequency response (Niebauer *et al.*, 2011) so that they can be used to monitor higher frequency non-periodic events such as earthquakes. The gPhone can be coarse-ranged over 7000 milliGals (worldwide), and has a ± 50 milliGal dynamic range during measurement. The instrument also has a true vacuum seal so that it is completely insensitive to buoyancy changes due to atmospheric changes. Full force feedback on the sensor allows for 0.1 microGal resolution (see more details at www.microglacoste.com).

Although a major application of gravimeters would be to investigate temporal change of Earth tides or to explore subsurface resources, there have been several attempts to detect large earthquakes using a superconducting gravimeter (e.g., Shen, 2002) and the gPhone (e.g., Niebauer *et al.*, 2011). In theory, the zero-length spring suspension technology that is applied to the gPhone enables us to measure even infinite period events so that we could study much longer period events such as teleseismic events, ambient seismic noise, and tsunami waves (Tobyáš *et al.*, 1999; Dedov *et al.*, 2007; Jolly *et al.*, 2013).

Korea Polar Research Institute has temporally operated the gPhone (serial # 044) at Geumsan next to one of seismic stations operated by Korea Meteorological Administration in South Korea (KMSA; 36.1058ºN/127.4816ºE/210 m) for 9 months (Nov. 2008-Jul. 2009) to monitor phreatic fluctuation. We failed to collect data for the period of early April through mid May, 2009 (Fig. 3), due to a mechanical malfunction with the gPhone. Owing to the fact that the gPhone has a flat frequency response lower than 1 Hz with a cut off frequency at about 5 Hz (Niebauer *et al.*, 2011), similar to a low-pass filter, the gPhone provides high quality low-frequency information that is normally distorted by traditional seismographs. Data is sampled by 1 Hz and the tides are removed from the original gPhone records to obtain the gravity residuals.

Results

During the operation period, we detected several teleseismic

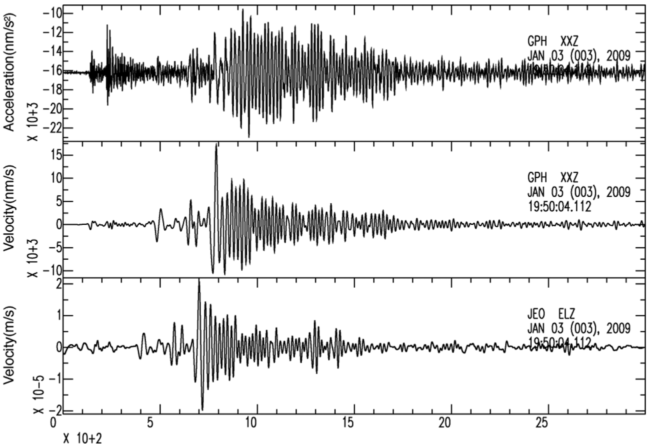

Fig. 1. A teleseismic earthquake occurred at Irian Jaya, Indonesia, has been recorded (19:43:59 UTC, January 03, 2009; 0.78ºS/132.8ºE; Magnitude 7.8). (Top) Unprocessed gPhone data. The waveform is shifted toward negative direction due to DC offsets. It should be corrected by removing mean and drift to transform acceleration (nm/s^2) into velocity (nm/s). (Middle) Transformed velocity waveform (0.01 ~ 0.1 Hz) from gPhone data that enables us to compare it with velocity seismograms directly. (Bottom) Bandpass filtered (0.01 ~ 0.1 Hz) seismogram (m/s) recorded at JEO. We removed instrument response before bandpass filtering.

earthquake events. Most of events having larger than magnitude 7 reported by NEIC (National Earthquake Information Center) are recorded at the equipment, but some others are not. This might be caused by poor signal-to-noise ratio. Figure 1 shows one good example of the observation, which occurred at Irian Jaya, Indonesia (19:43:59 UTC, January 03, 2009; 0.78ºS/132.8ºE; Magnitude 7.8). To compare the gPhone data with the vertical component of STS-2 seismic data (JEO; bottom), we first remove mean and trend from the gPhone data, then integrate it to convert acceleration (top) into velocity (middle). We performed a bandpass filtering (0.01 ~ 0.1 Hz) on the seismic data. As shown in Fig. 1, we found a good correlation between them, which indicates that a gravimeter could produce a good complementary data to analyze long-period large teleseismic earthquakes. In contrast to the observation of large teleseismic events, the gPhone seems to be poor to properly detect moderate- to micro-earthquakes (Fig. 2). The earthquake occurred at sea near Baeknyeong Island (05:20:28 UTC, March 2, 2009; 37.11ºN/124.6ºE; Magnitude 3.4). The gPhone data recorded at 1 sample per second demonstrates a lack of short-period shaking as expected for a small event far away. It implies that a gravimeter would be more useful for observation of long-period events.

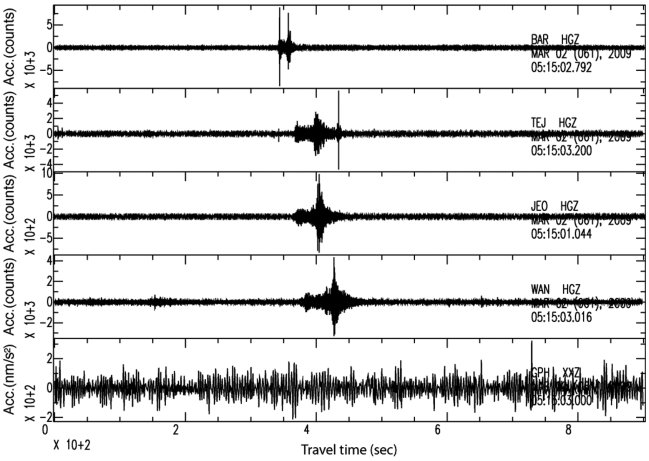

Fig. 2. A local event (05:20:28 UTC, March 2, 2009; 37.11ºN/124.6ºE; Magnitude 3.4) is detected at seismic stations (accelerograms) in South Korea (the first four rows). The gPhone could not properly detect the event (bottom).

In order to investigate temporal variation of seismic ambient noise, we performed spectral analysis for the gPhone data. We did not remove instrument response of the gPhone to simply

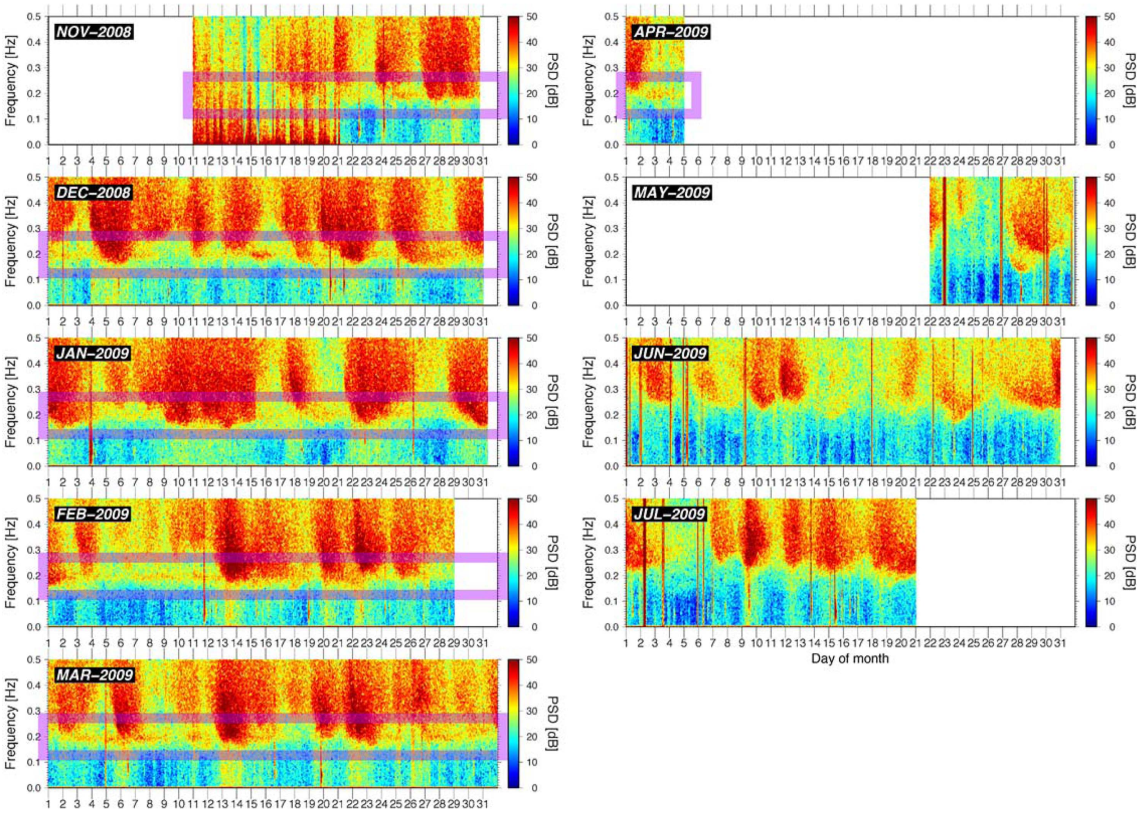

Fig. 3. Temporal variation of the gPhone data in South Korea for the period from November 2008 to July 2009. We plot spectrograms by month, and numbers in X-axis represent days in the month. The instrument experienced a mechanical problem during April and May, 2009. The frequency characteristics show that most of events occurred concentrated in the band above 0.15 Hz. The DF microseisms appear in the narrow band of ~0.2 Hz (in purple boxes).

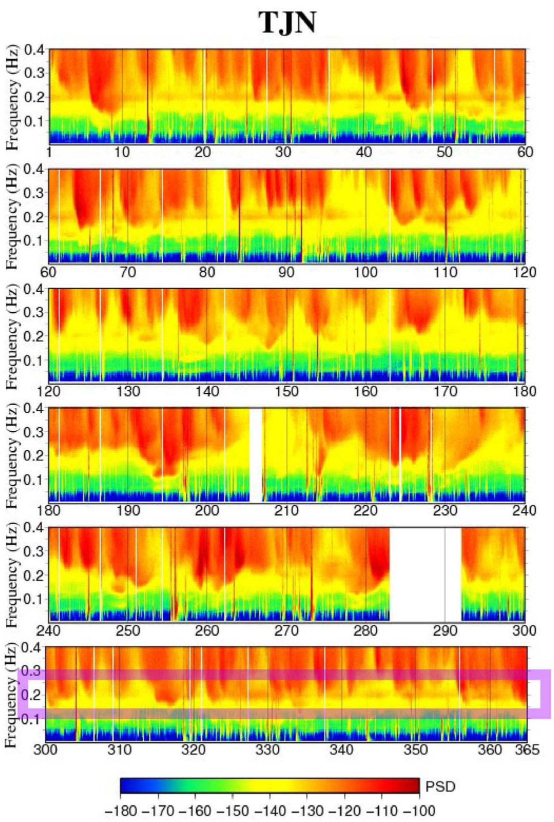

Fig. 4. Spectral analysis of seismic data recorded at TJN, which shows a good correlation with that of the gPhone data in Fig. 3.

look into a pattern of ambient noise as a preliminary attempt. The most remarkable feature in Fig. 3 would be that relatively high amplitude of Power Spectral Density (PSD) persists at ~0.2 Hz over the period of November 2008 through early April 2009 and vanishes for the rest of the operation period. We are not able to examine this phenomenon between early April and mid May in 2009 due to a mechanical problem with the gPhone. Sheen *et al*. (2009) found a similar feature in South Korea as they examined long-term broadband seismic data from 2005 ~ 2007 and concluded that it is a typical characteristic of the DF microseisms, which is the DF noise levels are higher in winter than in summer, and the seasonal variation is omnipresent in South Korea. A spectral analysis for one year observation at a seismic station (TJN) locating near the gPhone installation site in 2008 is illustrated in Fig. 4. This figure confirms that our observation with the gPhone is not artificial.

Conclusions

In this paper, we have shown that gravity meters could produce a useful dataset to monitor not only conventional long-period events such as Earth tides but also long-period seismic events such as large teleseismic earthquakes and microseisms. Furthermore, we find feasible applications which could be used to monitor very long-period events (e.g., Earth's hum) and even improve tsunami modeling due to its excellent low frequency sensitivity.

Gravimeters measure acceleration so that it could be directly compared with data recorded by strong-motion accelerograms. To compare data from gravimeters with those of velocity type seismographs, one can simply integrate gravimeter data to convert acceleration into velocity after removing mean values and drift.

Spectral analysis for the gPhone data leads us to conclude that there is a clear seasonal variation of the DF microseisms; strong in winter, weak in summer. It is a good agreement with seismic observation in South Korea.

Acknowledgements

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