An initial experiment with the continuous gravity monitoring using the gPhone 145 to support hydrology and earthquake studies

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Abstract. Continuous gravity monitoring as geodetic instruments for tidal variation recording has been proving its availability for more applications. The original purpose was to monitor the changes in gravity at one local, which could be correlated to the hydrological variation and geothermal reservoir changes. Most recently explored was its relation to the events of earthquakes. We have been installing the gPhone 145 since 2016 at LIPI Campus in Bandung as a preliminary observation of the instrument. In four years of installation, the gPhone has recorded the relative gravity intermittently, interrupted only by technical problems. Temperature and pressure records indicate the instrument functions properly. However, uneven recording prevented hydrological study, in which we expected to see some changes of the gravity through the years. For earthquakes' precursor studies, additional samples of events and time-associated gravity anomalies might give more assuring results.

1. Introduction
The potential field of gravity is the physical property related to the shape and deformation of the earth. Anomalies in gravity present variability or features for more investigation. Geoid, the surface of the mean sea level, which indicates the earth's shape, is detected by satellite altimetry. One of the most recent satellite gravimetry is GRACE (Gravity Recovering and Climate Experiment), which can detect glacier and groundwater changes over the years [1–3]. Nonetheless, due to the resolution and accuracy, the GRACE data is only applicable to find anomalies in a large continent. For a smaller region, spatial gravity mapping requires land, seaborne, or airborne surveys. The portable relative gravimeters are used, and the accuracy of the measurement depends on the distance between stations. Applications of such surveys are for structural geology and oil-gas prospecting [4,5]. Continuous gravity monitoring uses another type of gravimeter, allows the observation of changes in gravity field in one local. Continuous gravity measurement is one of the geodetic observations that present annual and seasonal variations, mostly due to the changes in water storage. For smaller continents or islands, other continuous observations might apply locally.

Gravity observation for the hydrological study has been reported for the last five decades [6]. Time-lapse microgravity monitoring has been applied in the investigations of groundwater. The hydrological aspects observed by gravity variation are dry-wet season variation, changes in groundwater volumes, rainfalls, and evapotranspiration studies [5–9]. A gravity network in China has 39 stations, with gPhones installed in 15 of stations. A study based on gravity continuous measurement in seven of those gPhones has reported the correlation between the gravity residual and
hydrological loading modeled by a climate model [7]. Besides, Tanaka [8] has demonstrated that the gPhone can detect 1mGal changes of gravity due to hydrological origin. Water loading condition is one of the primary concerns in the geothermal field. A continuous gravity observation is required to detect any changes in the reservoir [10].

Niebauer reported the capability of the gPhones (located in Colorado) in recording the earthquake event with magnitude of 8.2 in Japan [11]. Not only the mainshock (P wave), the gPhones also recorded the dispersion of surface waves (Rayleigh waves) five times around the globe. Their study also suggested that the gPhone had a sensitivity of lower frequencies than the regular broadband seismometer. So they could record the seismic noises before the main event occurred. Another report of pre-seismic gravity anomalies detected by gPhone was observed in China before the event with magnitude of 6.4 in Linkou in 2016 and the event with magnitude of 7.3 in Yutian in 2014 [12]. Even though anomalies’ character did not have direct patterns to the distance of stations to epicenters, these studies indicated a prospect toward the earthquake warning system. Other preliminary works in earthquake monitoring based on continuous gravity had used gravity strainmeters [13,14]. All of those gravity responses had detected a large earthquake of magnitude more than 8. An earthquake precursor study in India presented co-seismic gravity signals recorded by gPhones, which are related to earthquakes with magnitude of more than 2 [15]. The authors suggested that the high anomalies in gravity were caused by mass redistribution following the mainshock instead of the mainshock itself. On a side note, not all seismic background noises are related to the known events of earthquakes. However, the noises recorded in several gPhone in different places ruled out local disturbances [16]. A recent observation on the background noise level of gPhone even suggested that gPhone gravimeters are better in detecting long period signals than seismographs [17].

A comparison study of gPhone and other continuous gravimeters indicated that the gPhone is noisier and has larger and non-linear drift [18,19]. However, the drift might decrease over time [20]. It is very common to get many uncertainty signals and noises during observation. Even a solar eclipse might give a certain anomalous gravity signal [21]. Continuous measurement can detect those uncertainties. Besides, a connection to a network of gravity measurements (of all types of gravimeters) will improve observation accuracy [10].

![Figure 1. The gPhone 145 (the sensor is in the left), UPS and gMonitor displaying the recording process.](image)
2. Methodology
Research Center for Geotechnology has obtained the gPhone 145 since 2016. The instrument package consists of gPhone sensor, UPS (Uninterruptable Power Supply), and a computer with gMonitor software (Figure 1). Installation of the instruments required at least three days. Full charging of the UPS required at least 48 hours. Instruments should be located inside a vacuum room with stable temperatures. Since we did not have a vacuum room for this experiment, we put them in a corner in a relatively empty room. We installed the gPhone in Jampang (UPT) for only a couple of months. We found the gMonitor only records several days of data. The instrument then moved to the LIPI Campus in Bandung to be closer and easier to check for this initial experiment. The instrument is very sensitive to the surrounding movement, so we put it in the corner of a relatively empty room. We have monitored the gravity variation in 2017 – 2019 but not continuously.

3. Results
The gMonitor recorded the gravity response every 1 second. The information recorded during monitoring consists of gravity, corrected gravity, tide, long level, cross-level, ambient temperature, sensor temperature, ambient pressure, sensor pressure, beam position, level correction, drift correction, pressure correction, barometer compensation, polar motion correction, ocean load correction, velocity, and position. We should routinely check on the stability of temperature and pressure. Figure 2 shows

![Figure 2](image-url)  
**Figure 2.** Three samples of records of ambient (left) and sensor (right) temperatures of daily observation.
the ambient and sensor temperature changes during the day of measurement. We compared three measurements: in Jampang, early days in Bandung, and three years after in Bandung. The ambient temperature in Jampang only varied by 0.25°C in the day. In Bandung, the ambient temperature varied from 0.6 – 0.64°C. The most important is the temperature inside the sensor, which should be 59°C. The sensor temperature in Jampang is about 0.058°C less and the variation during the day is about 0.0003°C. The sensor temperature in Bandung had higher variations than in Jampang, which is about 0.0004°C. Moreover, during the three years of measurement, the sensor temperature varied from 58.9538°C at the least (in 2016) to 59.003°C at the highest (in 2019). Temperature variation smaller than 10⁻³ degrees should be considered satisfactory since a 10⁻³ degree skip might cause a gravity change [8].

Figure 3 illustrates the daily raw gravity data for one-second recording. Variation in gravity during a day is about 3 to 7 μGal before tidal correction (which might vary as much as 0.3 mGal [22]). Noises and anomalies could not be determined without further processing. Comparing several gravity data set for a particular observation time might assist in define possible changes. Additional data such as rainfalls, earthquakes, or significant human activities during the measurement are significant for filtering out noises.

![Figure 3. Three samples of raw gravity daily recording.](image-url)
We tried to find the possible record of an earthquake by obtaining the gravity record for the specific time when large earthquake events within the radius of 150 km from the station. Two earthquakes were used as the object exercises. First is the earthquake event on October 19, 2016, at 00:26:01. This event has a magnitude of 6.6 and a depth of 614 km. The epicenter was located about 161 km NNE of Pamanukan (Java Sea). The second event is the earthquake from Sunda Strait, which occurred on August 2, 2019 at 12:03:27 with a magnitude of 6.9 and a depth of 49 km. Figure 4 illustrates the raw gravity signal about the time of the events. Red arrows indicate the exact time of the events. Both graphs do not show any indication of anomalies that we can relate to earthquake events.

Further analysis of the time series data requires preprocessing, such as ocean tidal load, atmospheric load, and instrumental drift. For hydrology studies, other data or models would give significant comparative analysis. To observe the changes in local groundwater, a longer observation time is required. In addition, to evaluate the recording quality, it is essential to compare the data to a network of gPhone or any other continuous gravity measurements nearby.

![Figure 4](image-url) Raw gravity signals at the time of earthquake events. Above: event on October 19, 2016, at 00:26:01, with magnitude of 6.6 and depth of 614 km, 161 km NNE of Pamanukan (Java Sea). Below: event on August 2, 2019 at 12:03:27 with magnitude of 6.9 and depth of 49 km, 106km WSW of Tugu Hilir (south of Sunda Strait).
4. Conclusion
Continuous gravity measurement is one method in gravity measurement that can be used for time-lapse analysis. Previous studies had reported successful application of this method, mostly for hydrology changes and some for seismic disturbances. The gPhone is one of the powerful tools that had been proofed with so many successes. Our initial experiment is to get familiar with the instrument and find a potential application. The placement of the gPhone has indeed less than satisfactory. We should put the instrument inside a room, probably in a basement, with fewer human activities close to constant temperature and pressure. Nevertheless, the sensor has been stable, and data has been continuously recorded. Future works will require processing the time series data specified for each objective. For instance, several weeks of observation before an earthquake might provide certain anomaly signatures. Hydrology studies might require annual data, which should also be accompanied by other aspects of hydrology.

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