Time-lapse microgravity data acquisition in baseline stage of CO₂ injection Gundih pilot project

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Abstract. Indonesia is conducting research on CO₂ sequestration and monitoring in Gundih area. Geophysical methods are applied in the study area as monitoring technologies of CO₂ storage in the subsurface. In this paper, we will describe data quality and baseline geophysical survey (2014 and 2016) as part of time-lapse microgravity (TLM) data acquisition. The same set of two relative gravimeters (Scintrex CG5) were used in 2014 and 2016 gravity data acquisition to provide TLM map. TLM can be useful to monitor the mass increase and decrease due to significant activities in the reservoir, but for this project TLM signal (caused by the CO₂ injection in Gundih’s reservoir) estimated very small. Considering current project status, no injection yet, the data acquisition in 2014 and 2016 will be analysed to help us understand non-target anomalies in near surface. Preliminary analysis of gravity differences between 2014 and 2016 shows correlation pattern of time-lapse microgravity with land use in the study area. Rice fields and villages in the Western part of the study area correlate with negative TLM anomalies and forest area in the Eastern part of the study area correlate with positive TLM anomalies.

1. Introduction
Indonesia is conducting research on CO₂ sequestration and monitoring near Gundih area. Carbon Capture Storage (CCS) Gundih pilot project started in 2012. CO₂ from Gundih area will be transported to the Jepon well close to the Blora regency in Central Java province, Indonesia. Jepon well as the candidate of injection well area already evaluated and the report completed in early 2015. CCS Gundih study area shown in figure 1.

Figure 1. Map of CCS Gundih pilot project.
As we can see from project status illustration (figure 2), before injection we conduct baseline survey to monitor the future subsurface condition. Geophysical methods (seismic, TDEM, and gravity) are applied in the study area as monitoring technologies of CO$_2$ storage in the subsurface. In this project, we plan to carry out super hybrid gravity measurement using continuous gravimeter, absolute gravimeter, and relative gravimeter. Relative gravimeter used to observe gravity changes in grid stations that cover about 5x5 km$^2$ injection area. In this paper, we will report quality of relative gravimeter data from baseline survey (2014 and 2016).

![Figure 2. CCS Gundih pilot project status since 2012 with illustration of surface condition changes in Jepon well.](image)

Considering current project status, no injection yet, the data acquisition in 2014 and 2016 will be analysed to help us understand non-target anomalies in near surface. Land use in the surface is simplified into two types: villages with rice fields in the Western part of study area and forest in the Eastern part of study area. During time-lapse microgravity (TLM) data acquisition in Jepon well, it is possible we deal with different surface condition between two data acquisition. Observation data for each station in the surface need to consider the effect of near-surface that involving density changes. The surface condition of rice fields area can be very different due to farming activity (seeding, irrigation, cultivation, harvest, etc.), while the surface condition of tropical forest area can be very different due to weather condition that influence soil moisture and plantation growth.

There are only two stations that observe in benchmark and one station close to the well-pad. The other station location need to be revisited again to make sure we comeback in the same location. Most of the stations location was only marked by spray paint, hand-held GPS coordinate, photo documentation, and natural/artificial feature. During TLM data acquisition, it is possible we lost the stations after several months periods. Twice baseline survey of TLM in this study area can be useful to analyze the performance of land data acquisition in the study area.

2. Gravity Data Acquisition
In this project we adapt repeat gravity data acquisition methodology that detail explanation can be found in several publications such as: [1], [2] and [3]. Grid survey that cover Jepon well area are referenced to a stable reference in some stations located in Cepu (at least 25 km). Regional stations are chosen far away from the injection well site in order to avoid gravity changes caused by future activity (well and surface facilities). Regional stations already observed using A-10 absolute gravimeter in 2013 and 2014. Our regional gravity data provide stable value within < 2 μGal different from A-10 absolute gravimeter observation.

Scintrex CG-5 options during 2014 and 2016 surveys were set as an automatic correction for auto-rejection, seismic filter, and tide correction. To compute tide correction, the coordinate were set with (111.6°E, 7.1°S), zone 49, and GMT difference -7. The other three Scintrex CG-5 options (raw data, terrain correction, and continuous tilt correction) was not set as auto calculation.

Gravity data are acquired using two Scintrex CG-5 at each station. Data are acquired in 30 seconds samples for 3-5 minutes, so we can get at least three relative gravity reading for each observation. For each observation, the operator will notice instrument level and gravity reading to maintain the quality
of data reading. Each reading of gravity value is controlled within ± 10 arcsec range in digital instrument level (tilt-X and tilt-Y). Stable station typically observed with the small value of error and standard deviation for each reading. For each observation, we decide to select gravity reading within ten μGal value range. Beside operator control, we also able to consider auto rejection for each gravity reading during on-site data processing. Auto-rejection with high percentage value provides a suggestion or second opinion that gravity reading is not good enough. Considering field condition, statistically our observation get < 3% bad leveling and > 80% gravity readings have small auto-rejection value (figure 3).

**Figure 3.** Statistical comparison of auto-rejection and gravimeter leveling: (a) blue team 2014 survey, (b) blue team 2016 survey, (c) red team 2014 survey, and (d) red team 2016 survey.

Comparison data acquisition in 2014 and 2016 shows in table 1. From first and second data acquisition we can get TLM within a period of 20 months (less than two years). First data acquisition conducted between 18-29 September 2014 and second data acquisition 18-28 May 2016. Based on
Table 1, vertical gradient only conducted in first data acquisition, while in the second data acquisition we see effectiveness improvement during data acquisition. We can increase observation and repeat sample during 10 days survey in 2016.

Grid stations that cover Jepon well area designed with the average of 250 meters interval. Day-by-day gravity data observation can be seen in figure 4. We have two teams to observe North and South grid. North grid stations were observed by the blue team using Scintrex CG-5 SN822, while South grid stations were observed by the red team using Scintrex CG-5 SN1092. Blue team and read team for each close loop data acquisition also observe one repeat station or in benchmark (BM-1 or BM-2). Repeat station observations will be use to provide repeatability during field data acquisition.

Table 1. Comparison grid gravity data survey in 2014 and 2016.

| Survey    | 2014        | 2016        |
|-----------|-------------|-------------|
| Team      | Blue        | Red         | Blue        | Red         |
| Date      | 19-29 Sep   | 18-29 Sep   | 18-28 May   | 18-28 May   |
| Gravimeter| CG-5 822    | CG-5 1092   | CG-5 822    | CG-5 1092   |
| Tot. Time Duration | 37560 min. | 43020 min. | 34380 min. | 27090 min.  |
| Good Leveling | 98.02%  | 98.26%  | 97.92%  | 97.34%  |
| Auto Rej. > 5%  | 19.59%  | 17.91%  | 18.58%  | 16.03%  |
| Average daily drift | 42 μGal | 46 μGal | 25 μGal | 24 μGal |
| #Day(s)    | 10          | 11          | 10          | 10          |
| #Reading(s)| 1113        | 1379        | 903         | 1155        |
| #Observation(s)| 243       | 239         | 247         | 250         |
| #Station(s)| 206         | 202         | 203         | 202         |
| #Repeat Obsv.(s) | 37        | 37          | 44          | 48          |
| #VG Station(s) | 3         | 2           | 0           | 0           |

Figure 4. Comparison of day-by-day gravity data observation: (a) 2014 survey and (b) 2016 survey.

3. On-site Data Processing

Before we conducted the second survey in 2016, we evaluate data quality from the first survey (2014). At the end of first survey we see higher drift correction and then we try to optimize the instrument performance before we go to the field in 2016. We conducted simple simulation (small loop data acquisition) in ITB campus, to set the best drift constant. We change Scintrex CG-5 setup parameter for drift constant as follow:

1. Blue team (CG-5 SN 822) → from 0.353 changed into 0.511
2. Red team (CG-5 SN 1092) → from 2.550 changed into 1.900
Figure 5 shows long-term drift comparison from the first and second survey. Gravimeters performance in 2014 and 2016 survey respectively estimated with linear drift approximation give rates in the range 313-350 μGal/day and 82-161 μGal/day. As we can see in figure 5, after both instrument drift constant changed we see significant improvement from gravimeters performance. Average daily drift as short-term drift (each loop) in 2014 and 2016 survey respectively are 42-46 μGal and 24-25 μGal (Table 1). Figure 6 shows the statistical comparison of drift correction value for gravity readings in 2014 and 2016 survey. Percentage gravity readings from 2014 and 2016 survey corrected with small drift value (< 35 μGal) respectively are 85.63% and 87.61%.

![Figure 5. Long-term drift comparison: (a) 2014 survey and (b) 2016 survey.](image)

![Figure 6. Histogram comparison of drift correction using linear drift approximation applied in each gravity reading: (a) 2014 survey and (b) 2016 survey.](image)

After drift analysis, we will describe instruments repeatability in field condition. We conducted repeatability measurement for some stations. The stations that measured more than once in different observation will be compared to understand gravimeters performance. Repeatability samples from 2014 and 2016 survey respectively are 74 and 92 (Table 1). Ideal gravity readings sample after corrected with linear drift will give the same value, but it’s very common in gravity data acquisition using relative gravimeter will give deviation. Deviation from repeat stations shows in figure 7 describes repeatability test. We can notice from figure 7 that ± 10 μGal deviations from 2014 and 2016 survey respectively are 62.21% and 78.34%.
Figure 7. Histogram comparison of repeatability test in repeat stations in (a) 2014 survey and (b) 2016 survey.

On-site data processing results provide statistical proof of gravimeters performance in 2016 survey compare to the previous survey (2014). By conducting a simple simulation of small loop data acquisition before we go to the field can be significant preparation. Small loop data acquisition will provide information of consistency (repeatability) to distinguish small gravity variation.

4. Analysis and Discussion

Time-lapse microgravity (TLM) anomaly calculated by subtracting gravity observation 2016 and 2014. After that TLM anomaly corrected with tripod height difference (that we measure in each datum in 2014 and 2016 survey). Histogram of TLM 2016-2014 in Jepon well area shown in figure 8a. From histogram figure 8a we can see that 87.53% data are in the range of -80 to 80 μGal. Outliers value that is considered very big from our TLM values are distributed in 51 stations (figure 8b). Some stations locations are very hard to find after 20 months, especially in forest area. Most of the stations location that produces big TLM value located in forest area (31 stations), while the other stations (20) are located in villages and rice fields area. Human activity in villages and rice fields may impact significant surface changes such as building construction, road construction, cultivation, and irrigation.

Figure 8. (a) Histogram of TLM 2016-2014 in Jepon well area and (b) stations distribution that shows outlier TLM values (<-80 and >80 μGal).

TLM map that shows near surface and hydrology effect in Jepon well area shown in figure 9a. Figure 9a shows near surface effect because we can easily observe high-frequency signals from some stations that produce the bulls-eye pattern. There are interesting pattern from figure 9a that shows strong negative (marked with A and B) and positive anomalies (marked with C, D, and E). The strong anomalies (A, B, C, D, and E) close to the stations observation that have big different in linear drift correction (figure 9b). From our calculation, those station’s corrected with linear drift correction that differs more than |±35| μGal between 2014 and 2016 survey.
Figure 9. (a) TLM map (2016-2014) in Jepon well area and (b) stations distribution that corrected with big drift different between 2014 and 2016 survey.

Analysis of gravimeters performance from repeatability test suggests that stable value for our TLM anomalies should be ranged from -10 to +10 μGal. We also have uncertainties of tripod correction from 1 to 3.5 cm and translated to correction value in the range of 3 to 10 μGal. Considering that kind of argument and condition, we get near surface/hydrology effect in Jepon well area for 20 months in the negative and positive range value respectively are -20 to -80 μGal and +20 to +80 μGal. Stations distribution that gives TLM value that suspected as near surface/hydrology effect shows in figure 10.

Figure 10a is topographic contour in Jepon well area with stations distribution of negative TLM value (-20 to -80 μGal). Stations distribution with negative TLM value dominantly located in the Western part of study area (local people villages and rice fields). Small number of stations distribution in the forest area (Eastern part) that provide negative anomalies located in the high topographic contour. Negative TLM value can be interpreted as the mass decrease in the near surface, such as lowering water table.

Figure 10b is land use map in Jepon well area with stations distribution of positive TLM value (20 to 80 μGal). Stations distribution with positive TLM value dominantly located in the Eastern part of the study area (forest). A small number of stations distribution in the Western part of the study area...
that provides positive anomalies can be caused by human activity such as cultivation, lowering ground for road construction, or subsidence. Positive TLM value can also be interpreted as the mass increase in the near surface, for example water run-off from higher topographic.

5. Conclusion
Preliminary analysis of gravity differences between 2014 and 2016 shows correlation pattern of time-lapse microgravity with land use in the study area. Rice fields and villages in the Western part of the study area correlate with negative TLM anomalies and forest area in the Eastern part of the study area correlate with positive TLM anomalies.

6. Acknowledgments
Authors acknowledge the support of the SATREPS project by JICA-JST, FTTM ITB, and other Gundih CCS pilot project that help gravity grid survey data acquisition.

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