Measuring Deformation in Jakarta through Long Term Synthetic Aperture Radar (SAR) Data Analysis

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Abstract. Jakarta as a home for more than 10 millions inhabitant facing complex environmental problems due to physical development that cause physical deformation. Physical deformation issues such as decreasing environmental carrying capacity, land cover changes and land subsidence have occurred. Recent studies shows that the long of shoreline changes in a span of 13 years from 2002 to 2015 around 14 km due to land reclamation in Jakarta bay. Previous studies also concluded that Jakarta suffer a sinking phenomena due to its rapid subsidence rate, approximately 260 mm/year in northern part of Jakarta. During the 2007 to 2011, the land subsidence phenomena in Jakarta was observed by InSAR based on ALOS-PALSAR data and found that the subsided areas only occurred in certain areas, mainly in Pluit and Cengkareng regions, with a subsidence of approximately 70 cm for 4 years. Land subsidence is generally related to geological subsidence i.e. sediment consolidation due to its own weight and tectonic movements; or related to human activities such as withdrawal of ground water and geothermal fluid, oil and gas extraction from underground reservoirs, and collapse of underground mines. The amount of subsidence or uplift can be estimated from the number of concentric fringes that appear in the interferogram. This research utilizes Synthetic Aperture Radar (SAR) data observed from ALOS-2 (L-band) and Sentinel-1 (C-band) satellites. By interfering two single look complex (SLC) images from different observation epoch, it is found that the subsided area that has been identified before continues to subside. This occurs especially in Pluit region and has been revealed by interfering ALOS-2 data up to year 2016. The deformation in this area is approximately 12 cm from November 2015 to September 2016. The process of land reclamation also clearly identified by Sentinel-1 image by series data processing in Sentinels Application Platform (SNAP) software.

1. Introduction
The Earth’s shape changes from time to time and can be categorized into periodic and un-periodic change. The Earth body tide is one example of the periodic change, whereas ground deformation is an example for the un-periodic change and it is irreversible. Ground deformation may be related to seismo-tectonic processes such as earthquakes, faulting, volcanism, landslide; anthropogenic processes such as ground water pumping and mining; or other environmental phenomena such as glaciation and deglaciation.
Land subsidence that is defined as the motion of surface shifts downward relative to height datum such as mean sea level, is also classified into ground deformation. Land subsidence is generally related to geological subsidence i.e. sediment consolidation due to its own weight and tectonic movements; or related to human activities such as withdrawal of ground water and geothermal fluid, oil and gas extraction from underground reservoirs, and collapse of underground mines [1], [2].

Jakarta, as the capital of Indonesia, also has an urban development that consequence on extensive land use and land cover change and increase in groundwater extraction [3]. Therefore, land subsidence phenomena is believed that have been occurred and correlated to disaster such as inundation[4] due to high rainfall in some areas in Jakarta [5]. Previous studies shown that subsidence rate in Jakarta are approximately 260 mm/year in northern part of Jakarta [6], [7], [8] and [9], whereas Pluit and Cengkareng regions, subsided of approximately 70 cm from 2007 to 2011 [5].

This article discusses the ground deformation in Jakarta revealed by Synthetic Aperture Radar (SAR) data in long-term period, as a continuation of previous study [5]. Each pixel of SAR data contains a complex number that carries amplitude and phase information about the microwave field backscattered by all objects in corresponding resolution cell projected on the ground. These kinds of information are stored in complex format and therefore it is also known as single look complex (SLC) that is composed of a regular grid with complex values or phasors [10]. For that reason, ground deformation in Jakarta is conducted through amplitude image analysis and interferometric analysis. Amplitude image analysis is utilized to identify land surface changes, whereas interferometric analysis to obtain land subsidence phenomena.

2. Data and Methods
Long-term ground deformation observation in Jakarta by SAR data analysis utilizes SAR data that were observed by C-band (wavelength 5.6 cm) Sentinel-1A, and L-band (wavelength 24 cm) ALOS-2 (Advanced Land Observing Satellite-2) satellite systems. It is important to assess the ability of these two systems for ground deformation studies in tropical region that influenced by high precipitation. Previous studies show that C-band radar is more sensitive to temporal decorrelation caused by meteorological events, whereas L-band SAR offers better performance in terms of coherence, ionospheric perturbations are smaller at C-band [11] and [12].

The Sentinel-1 satellite system is a constellation of two satellites (namely Sentinel-1A and Sentinel-1B) equipped with a C-band SAR sensor developed by European Space Agency (ESA). The Sentinel-1A was launched on April 3rd 2014, with temporal resolution is 12 days and supports four different operational imaging modes that are providing different resolution and coverage: Interferometric Wide swath (IW) mode, Extra Wide swath (EW) mode, Strip-Map (SM) mode, and Wave (WV) mode [13], [14], [15]. Three Sentinel-1A data in Single polarization IW mode for November 12th 2015, April 4th 2016 and June 15th 2016 are downloaded from Sentinels Scientific Data Hub and processed with SNAP – S1TBX (Sentinel Application Platform – Sentinel 1 Toolbox) software [16].

The ALOS-2 satellite system developed by Japan Aerospace Agency (JAXA) and was launched on May 24th 2014, with temporal resolution is 14 days and support mainly two modes for worldwide observation. One is the 10 m resolution for 70 km swath for Stripmap mode and the other is the 350 km swath for ScanSAR mode. However, there is another mode namely high-resolution spotlight mode with 1 to 3 m resolution [17]. Three ALOS-2 data in Stripmap mode for November 17th 2014, January 25th 2016 and September 5th 2016 are downloaded through ALOS-2 User Interface Gateway (AUIG) website: https://auig2.jaxa.jp/ips/home under ALOS-2 Principle Investigator scheme. These data are processed by using GAMMA SAR Software [18] under Nagoya University licence. The summary of data sets is listed in Table 1.

The first part, both data sets are processed to obtain the image for Jakarta region by exploiting the amplitude components. The steps include: orbit file correction, radiometric calibration, speckle reduction, and geometric correction. The second part is interferometric data analysis to identify the land subsidence. There are three interferograms resulted from both data sets through coregistration, interferogram calculation, topographic phase removal, interferogram filtering and geometric correction.
Table 1. Summary of Data Sets

| Epoch-1       | Epoch-2       | Epoch-3       | Interferogram       | Perpendicular Baseline (m) | Time differences (days) |
|---------------|---------------|---------------|---------------------|---------------------------|------------------------|
| Sentinel-1A   | 12/11/2015    | 04/04/2016    | 15/06/2016          | 1511_1604                 | 111                    |
|               |               |               |                     | 1511_1606                 | 75                     |
|               |               |               |                     | 1604_1606                 | 35                     |
|               |               |               | 1511_1604_1511_1606 | 144                       | 216                    |
|               |               |               |                     | 1511_1604_1604_1606       | 72                     |
| ALOS-2        | 17/11/2014    | 25/01/2016    | 05/09/2016          | 1411_1601                 | 57                     |
|               |               |               |                     | 1411_1609                 | 94                     |
|               |               |               |                     | 1601_1609                 | 37                     |
|               |               |               | 1411_1601_1411_1609 | 434                       | 658                    |
|               |               |               |                     | 1601_1609_1601_1609       | 224                    |

Figure 1. Data Processing Flow at S1TBX for Image (left) and Interferogram (right) generation

3. Result and Discussion
The results of SAR data analysis are presented into image analysis for land surface changes and interferogram analysis for subsidence identification.

3.1. Image Data Analysis
Series of SAR data observed by Sentinel-1A and ALOS-2 and processed by S1TBX are shown in Figure 2 and Figure 3.
Figure 2. SAR Images for Jakarta observed by Sentinel-1A and ALOS-2

Figure 3. Deformed Area observed by Sentinel-1A and ALOS-2

It is shown that the land surface deformation is spotted on the coastal area and had been started on November 2014 and related to land reclamation activity. Dual polarization of ALOS-2 data can be explored further with color composite technique. S1TBX provides three default color composites namely dual polarization ratio, dual polarization multiple and dual polarization difference.

Figure 4. Color Composite Technique for Deformed Area
3.2. Interferometric Data Analysis

For interferometric data analysis to identify land subsidence, this experiment found that the S1TBX can generate interferogram based on Sentinel-1A. However, the results are not good since the atmospheric noise affects much for C-band radar data. For ALOS-2 data, it is found that the S1TBX cannot generate a proper interferogram since there is no facility to apply orbital file and therefore coregistration result not good and affects the interferogram formation. For that reason, ALOS-2 data are processed by using GAMMA SAR Software.

![Interferogram based on Sentinel-1A processed by S1TBX](image1)

**Figure 5.** Interferogram based on Sentinel-1A processed by S1TBX

Figure 5 shows the interferogram from Sentinel-1A data analysis by using S1TBX. All the interferograms have a small baseline, therefore the topographic effect can be neglected. However, the signal appears mainly from atmospheric path and orbital error and cannot be analysed.

![Interferogram based on ALOS-2 processed by GAMMA SAR Software](image2)

**Figure 6.** Interferogram based on ALOS-2 processed by GAMMA SAR Software

Figure 6 shows the interferogram from ALOS-2 data analysis by using GAMMA SAR Software. All the interferograms have a small baseline, therefore the topographic effect can be neglected. Some subsided areas are spotted based on differential interferometric SAR that indicated by color fringes (mainly by purple) and always found in all interferograms. It is spotted in Pluit region on the north of Jakarta and in Bekasi region. These results are combined with previous study [5] that identify some subsided area from 2007 to 2011. It is found that the Pluit area is still affected by subsidence phenomena that are shown in following figures.
Figure 7. Identification of subsided areas in Jakarta based on DInSAR technique. (a) Interferogram from 2007-2011 based on ALOS-PALSAR data, (b) subsided area in Pluit region from 2007-2011 or 1472 days based on ALOS-PALSAR data, (c) subsided area in Pluit area from 2014 -2016 or 658 days based on ALOS-2 data, image not rectified.

4. Conclusions
This research shows the ability of SAR data to identify ground deformation in Jakarta area by analysing the amplitude and phase components. Sentinel-1A data and S1TBX software are useful to obtain the land surface changes based on amplitude analysis. This research also found that atmospheric phase affects much to C-band SAR data as already identify by previous studies [11] and [12]. Subsidence phenomena in Jakarta area can be identified by ALOS-2 data based on interferometric analysis. It is found that the Pluit area is still affected by subsidence since 2007. Recent data analysis, from November 2014 to September 2016 or in 658 days, the Pluit area subside for almost 12 cm.

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References

[1] Raucoules D, Colesanti C, and Carnec C 2007 Use of SAR interferometry for detecting and assessing ground subsidence Comptes Rendus Geosciences 339(5) pp 289–302 http://dx.doi.org/10.1016/j.crte.2007.02.002.

[2] Yuill B, Lavoie D, and Reed D 2009 Understanding subsidence processes in coastal Louisiana Journal of Coastal Research pp 23–36

[3] Hudalah D and Firman T 2012 Beyond property: Industrial estates and post-suburban transformation in Jakarta Metropolitan Region Cities 29 pp 40–48

[4] Murakami S, Kawase M and Komine H 2012 Land subsidence in Mekong delta by using InSAR and future development for vulnerability assessment in consideration of global climate change International Workshop on Geo-engineering for responding to climate change and sustainable development of infrastructure (HUE GEO 2012) 17-18 Dec 2012

[5] Agustan, Sanjaya H and Ito T 2013 Jakarta Land Subsidence And Inundation Vulnerability Based On SAR Data Proceedings of the 34th Asian Conference of Remote Sensing 1 pp 187-194.

[6] Abidin HZ, Andreas H., Djaja R, Darmawa D, Gamal M 2008 Land subsidence characteristics of Jakarta between 1997 and 2005, as estimated using GPS surveys GPS Solutions 12 (1), pp 23–32

[7] Abidin, H., Andreas, H., Gumilar, I., Fukuda, Y., Pohan, Y. E., and Deguchi, T2011 Land subsidence of Jakarta (Indonesia) and its relation with urban development Natural Hazards 59(3), pp 1753–1771, http://dx.doi.org/10.1007/s11069-011-9866-9.

[8] Ng, A. H.-M., Ge, L., Li, X., Abidin, H. Z., Andreas, H., & Zhang, K 2012 Mapping land subsidence in Jakarta, Indonesia using persistent scatterer interferometry (PSI) technique with ALOS PALSAR International Journal of Applied Earth Observation and Geoinformation 18(0), pp 232-242. doi: http://dx.doi.org/10.1016/j.jag.2012.01.018

[9] Chaussard, E., Amelung, F., Abidin, H., & Hong, S.-H 2013 Sinking cities in Indonesia: ALOS PALSAR detects rapid subsidence due to groundwater and gas extraction Remote Sensing of Environment 128(0), pp 150-161. doi: http://dx.doi.org/10.1016/j.rse.2012.10.015

[10] Hanssen, R.F. 2001. Radar Interferometry: Data Interpretation and Error Analysis. Kluwer Academic Publishers, Dordrecht, pp 328.

[11] Rignot, E.; Mouginot J2012 Ice flow in Greenland for the international polar year 2008–2009 Geophys. Res. Lett. 39, L11501.

[12] Mouginot, J.; Scheuchl, B.; Rignot, E2012Mapping of ice motion in Antarctica using synthetic-aperture radar data Remote Sens 4 pp 2753–2767.

[13] Potin, P.; Rosich, B.; Roeder, J.; Bargellini, P2014Sentinel-1 mission operations concept In Proceedings of the IEEE IGARSS, Québec, QC, Canada, 13–18 July 2014; pp. 1465–1468.

[14] Torres, R.; Snoeij, P.; Geudtner, D.; Bibby, D.; Davidson, M.; Attema, E.; Potin, P.; Rommen, B.; Flouri, N.; Brown, M2012GMS Sentinel-1 mission Remote Sens. Environ. 120, pp 9–24.

[15] Geudtner, D.; Torres, R.; Snoeij, P.; Davidson, M.; Rommen, B 2014 Sentinel-1 system capabilities and applications In Proceedings of the IEEE IGARSS, Québec, QC, Canada, 13–18 July 2014; pp 1457–1460.

[16] Veci, L., Lu, J., Prats-Iraola, P., Scheiber, R., Collard, F., Fomferra, N. and Engdahl, M 2014 The Sentinel-1 Toolbox In Proceedings of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp. 1-3. IEEE.

[17] Arikawa, Y, Saruwatari H, Hatooka Y, Suzuki S2014 PALSAR-2 launch and early orbit operation result In Proceedings of International Geoscience and Remote Sensing Symposium (IGARSS) 2014, pp 3406–3409.