Earthquake Land Deformation from InSAR Data
(5.6 MwGCMT, March 2, 2009, Palu, Celtral Sulawesi, Indonesia)

PI0003

H.Z. Abidin[(1)], *Teguh Purnama Sidiq*[(1)], *Dina A. Sarsito*[(1)]

[(1)] Geodesy Research Division of Institute Technology Bandung

1. INTRODUCTION

Sulawesi is one of big islands in Indonesia which is known as the triple junction of main tectonic plate, which are Indian-Australian Plate, Eurasia Plate, and Pacific Plate. Beside the three main plates, the Philippine plate has big influence on this island. The complexity of the tectonic setting on this area yields a complex of its movement. The energy accumulation from the plate collision has caused the high intensity of the earthquake happen on this island. The research about earthquake in Sulawesi has been done by (Sarsito, 2010).

Most of the research about earthquake in Sulawesi had been done by using GPS as the tool, for example (Sarsito, 2010), (Simon, Win, 2006). The realization of the GPS network in Sulawesi is spread over the monitoring zone, with at least three GPS monitoring stations on every tectonic block.

There are not many studies about earthquake involving InSAR as tool in Sulawesi until recent time. InSAR method has better spatial variation compared to GPS method. The study about earthquake using InSAR as tools has been proven to yields good results, such as (Calais, 2010), (Hayes, 2010), (Tobita, 1998), (Zebker, 1994).

Compare to othe islads in Indonesia, the earthquake in Sulawesi occure more rapidly. But the magnitudes of the earthquake are relatively small, so that the possibility of large deformation due to the earthquake is small. This situation caused difficulties in the deformation monitoring using InSAR method.

On March 2, 2009, an earthquake happened with magnitude 5.6 MwGCMT. According to USGS site, the epicenter is located at 1.11 S 119.87 W, with depth 11 km. The characteristic and the magnitude of the earthquake is indicated an amount of displacement that can be detected using InSAR.

2. INSAR DATA PROCESSING

On this research, dual-pass Differential InSAR (DInSAR) method is used to obtain deformation image caused by the earthquake which happened in Palu, Central Sulawesi. This method can be used using only two SAR data and an external DEM. The data used on this research are date October 10, 2008 and May 28, 2009, as listed on the Table 1 below,

Table 1 : ALOS PALSAR Data used on the reserach

No.	Acquisition date	Data Type	Satellite Direction
1	October 10, 2008	FBS	Descending
2	May 28, 2009	FBS	Descending
*) FBS : Fine Beam Sensor			

The diagram below show the general algorithm used on the research to obtain deformation map around the epicenter,

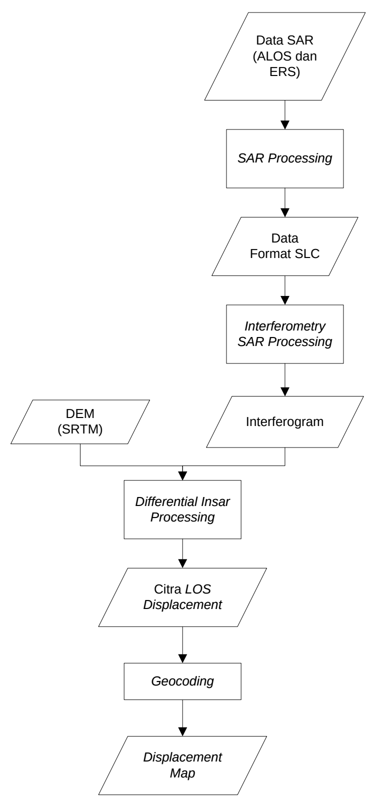

Figure 1 : Algorithm of Data Processing

We use 3 arc-second global DEM SRTM for the elevation model. Due to the DEM and data limitation, we only process the data using 30 meter resolution, not in full resolution.

The data processing is done using Gamma Software, while the analysis is done using other software.

3. RESULT

There is no essential problem during the data processing. The quality of the data and its processing can be seen from the coherence image as shown on Figure 1. Higher coherence degree is shown with yellow color; while black color indicates the correlation is very low or even zero.

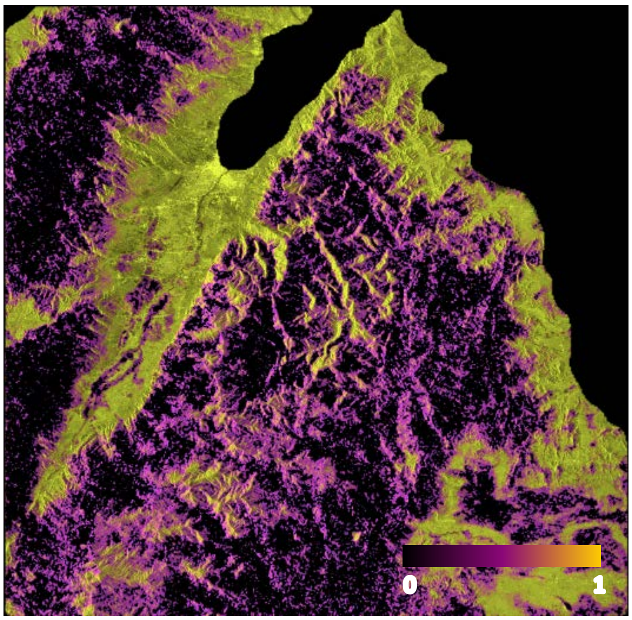

Figure 2 : Coherence Image

The result of the data processing shows no land movement of deformation. Figure 2 below shows differential image before the geocoding. As can be seen from the picture, the pattern of parallel line is clearly visible, and the pattern is highly correlated with the elevation.

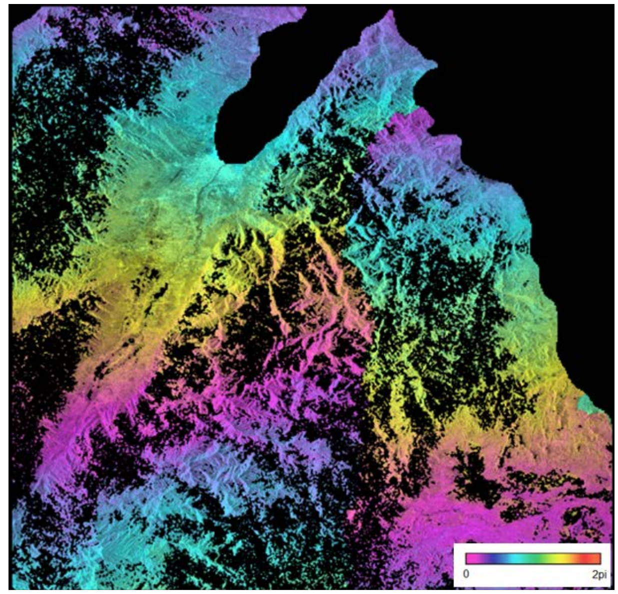

Figure 3 : Differential Image

The pattern of parallel line on Figure above is caused by the satellite orbit error, while the high correlation with the elevation is caused by the remaining error of the DEM during the differential processing. The DEM used on data processing has 16 meter of absolute accuracy.

4. ERROR REDUCTION

The differential image on the Figure above still contains some errors. Deformation happened ($\delta\phi_{A-B}$) can be expressed below,

$$\delta\phi_{A-B} = \delta\phi_{def} + \delta\phi_{atm} + \delta\phi_{orb} + \delta\phi_{topo} + \delta\phi_{noise} ,$$

Where $\delta\phi_{A-B}$ the total phase difference between the images is, $\delta\phi_{def}$ is the phase difference caused by deformation in line of sight during the data acquisition, $\delta\phi_{atm}$ is the phase difference caused by atmospheric effect, $\delta\phi_{topo}$ is the remaining error of topographical signal, caused by the low quality on DEM used during the differential processing. The last variable $\delta\phi_{noise}$ is the phase from other unexplained and modeled error, such as the co-registration error, interpolation error, thermal noise, etc.

In order to minimize the atmospheric, orbit, and topographic residual error, we use the same algorithm used by (Jeong, 2010). The model is built based on two facts of the errors. The orbital error yields parallel line pattern on the image. This error is modeled as a slant bidang. While the atmospheric error (tropospheric error), and error from DEM is modeled by third order of polynomial equation,

$$\delta\phi_{orb} = b_1 x + b_2 y + c_1 ,$$

$$\delta\phi_{atm}^{topo} = a_1 z^3 + a_2 z^2 + a_3 z + c_2 ,$$

Where x and y is the pixel position in radar coordinate (range and azimuth), while z is the topographic elevation height on each pixels. The parameters on the equation above (a1, a2, a3, b1, b2, dan c=c1+c2), can be estimated by the equation below,

$$\begin{bmatrix} x_1\ y_1\ z_1^3\ z_1^2\ z_1\ 1 \\ x_2\ y_2\ z_2^3\ z_2^2\ z_2\ 1 \\ \vdots \\ \vdots \\ x_n\ y_n\ z_n^3\ z_n^2\ z_n\ 1 \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ a_1 \\ a_2 \\ a_3 \\ c \end{bmatrix} = [\phi_{orb} + \delta\phi_{atm}^{topo}] .$$

This procedure can eliminate error quite significant. The Figure below shows differential image after the correction,

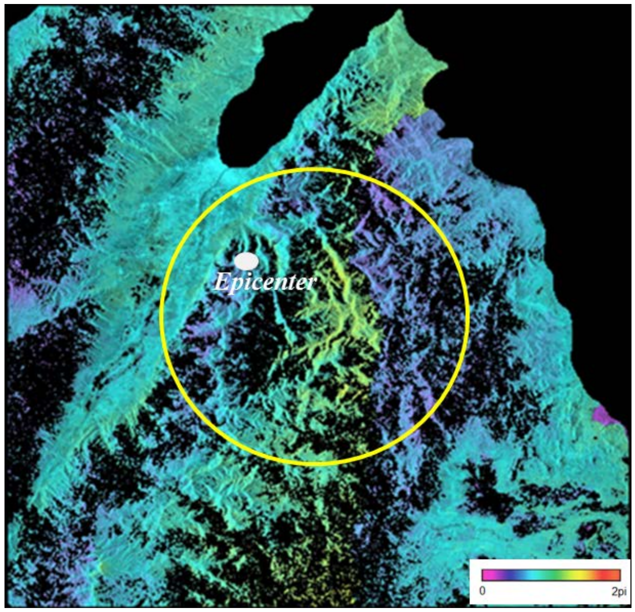

Figure 4 : Differential image after error reduction

The result on Figure 4 above can be visually compared with Figure 3 before the correction. Deformation pattern is not highly correlated with the topographical feature, and the orbital error is corrected significantly. The unexpected deformation pattern that occurs in Palu along the valley is eliminated from the image.

Below is the differential image after the geocoding process. The deformation pattern is still not clearly visible although the errors had been reduced.

5. LOS DISPLACEMENT

The deformation in metric unit can be derived from differential image above. On this step, the orbital and DEM information is needed to yield Figure … below,

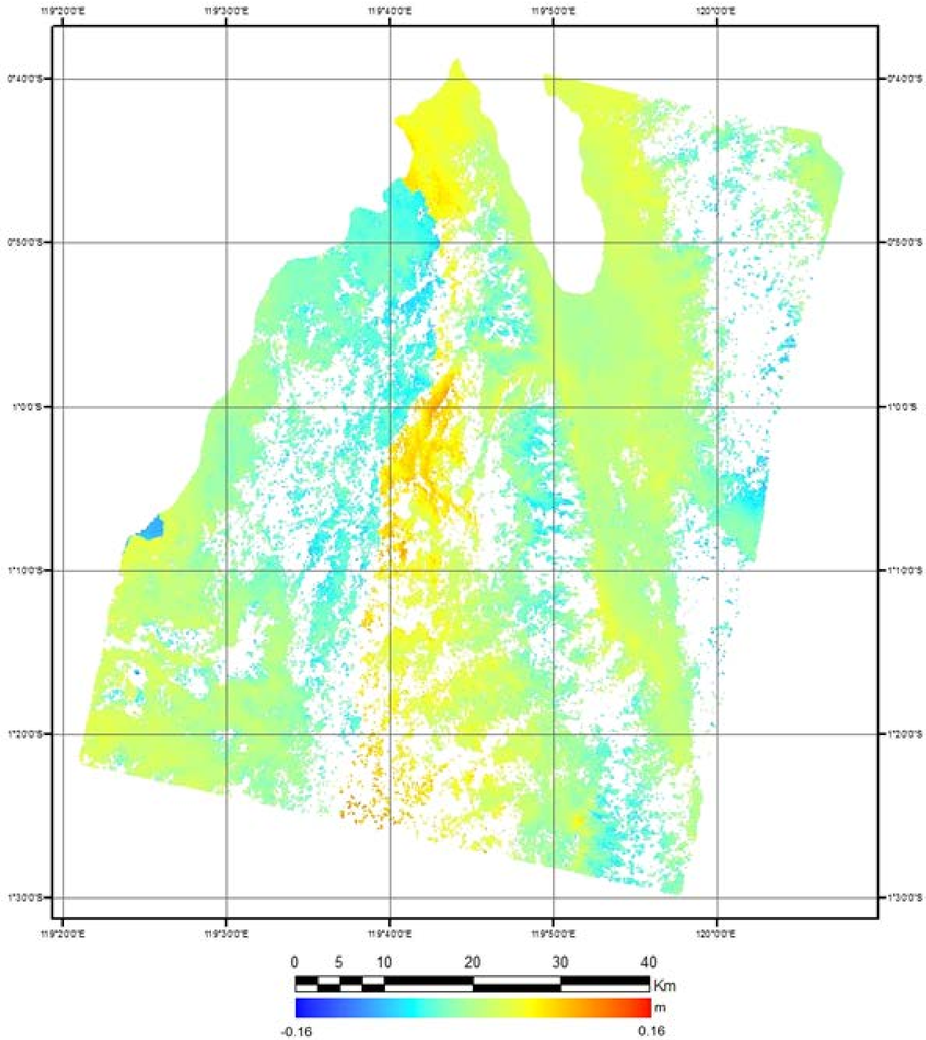

Figure 5 : Displacement Map

The Figure shows deformation up to 16 cm near the epicenter. It should be noted that the deformation shows above is a line of sight displacement. All horizontal and vertical displacement are still become one. It will need more data to decompose the components.

6. CONCLUSION

InSAR method has not been able to show good deformation pattern caused by earthquake on March 2, 2009 in Palu. This may be caused by the low magnitude of the earthquake, or the mechanism itself.

The error can be reduced significantly using the Jeong's algorithm. Although the model itself is originally used for time series analysis, it performs very well on this case.

Further analysis and validation using higher accuracy method such as GPS is still needed to get better result. And more SAR data is needed in order to perform better analysis such as time series and Persistent Scatter

7. PROBLEMS DURING THE RESEARCH

Ideally, the analysis is done using more data. Unfortunately, there are only three data available since October 10, 2008 to 28 May, 2009. The deformation signal resulted from the result above is the combination of pre-seismic, co-seismic, and post-seismic. Further, ALOS satellite cycle orbit (46 days) is too long for rapid monitoring of the deformation. Hence, the analysis is more difficult, and need extra data to get better result, especially for the analysis of weak earthquake.

Other problem is the unavailability of high accuracy DEM. The global SRTM DEM often remains topographical error by the end of the differential process.

8. PLAN IN THE FUTURE

This research is a part of Sulawesi earthquake monitoring and research. It involves many students and researchers, and has been done for more than 10 years. The GPS measurement is conducted with DELFT University, Netherland every year.

The join research is being planned with DELFT University for both GPS analysis, and InSAR analysis. Time series analysis and more advanced InSAR data processing will be performed in the future using more data. Right now, DELFT University has ordered Terra-SAR X data, and planned to be integrated with ALOS PALSAR data.

More SAR data also open possibility of building higher accuracy of DEM, which is also planned to be done in the future.

9. REFERENCES

10. Eric Calais, Andrew Freed, Glen Mattioli, Falk Amelung, Sigurjón Jónsson, Pamela Jansma, Sang-Hoon Hong, Timothy Dixon, Claude Prépetit, Roberte Momplaisir, Transpressional rupture of an unmapped fault during the 2010 Haiti earthquake, Nature Geoscience 3, 794-799 (24 October 2010)
11. G. P. Hayes, R. W. Briggs, A. Sladen, E. J. Fielding, C. Prentice, K. Hudnut, P. Mann, F. W. Taylor, A. J. Crone, R. Gold, et al. Complex rupture during the 12 January 2010 Haiti earthquake, Nature Geoscience 3, 800-805 (10 October 2010)
12. Zebker, A. Howard, Rosen A. Paul, Goldstein M. Richard, Gabriel Andrew, and Werner L. Charles. On the Derivation of coseismic displacement fields using differential radar interferometry : The Landers earthquake. Journal of Geophysical Research, Vol. 99, No. B10, Pages 19,617-19,634. October 1994
13. Tobita Mikio, Fujiwara Satoshi, Ozawa Shinzaburo, Rosen A. Paul, Fielding J. Eric, Werner L. Charles, Murakami Masaki, Nakagawa Hiroyuki, Nitta Koh, Murakami Makoto. Deformation of the 1995 North Sakahlin Earthquake detected by JERS-1/SAR interferometry. Earth Olanet Space, 50, p. 313-325, 1998
14. Tsuji Takeshi, Katsuya Yamamoto, Toshifumi Matsuoka, Yasuhiro Yamada, Kyosuke Onishi, Alfian Bahar, Irwan Meilano, and Hasanuddin Z. Abidin. Earthquake fault of the 26 May 2006 Yogyakarta earthquake observed by SAR interferometry. Earth Planet Space, 61, e29-e32, 2009.
15. Min-Jeong Jo, Joong-Sun Won, Sang-Wan Kim, Hyung-Sup Jung. A time-series SAR observation of surface deformation at the southern end of the San Andreas Fault Zone. Geoscience Journal Vol 14, No. 3, p.227-287, September 2010
16. Hanssen Ramon, Radar Interferometry Data Interpretation and Error Analysis, Volume 2, Kluwer Academic Press, Netherlands, 2001
17. Sarsito A. Dina, Pemodelan Geometrik dan Kinematik Kawasan Sulawesi – Kalimantan Bagian Timur Berdasarkan Data GNSS-GPS dan Gaya Berat Global. Disertasi Institut Teknologi Bandung. 2010