Regional Phenomena of Vertical Deformation in Southern Part of Indonesia

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Abstract. Distribution of present-day horizontal and vertical deformation across the Southern Part of Indonesia at Java, Bali and Nusa Tenggara now days can be determined from continuous and campaign types of GNSS GPS data monitoring. For vertical deformation in this case we use the continuous types since they are give better quality of data consistency compare to campaign type. Continuous Global Positioning System (CGPS) are maintaining by Geospatial Information Agency for more than a decade. The vertical displacements or velocity rates are estimated from time series analysis after multi-baseline GPS processing using GAMIT-GLOBK software with respect to the latest International Terrestrial Reference Frame. The result shows some interesting phenomena where the northern part of research area majority have negative value that may indicate land subsidence with or without tectonic subsidence combination. In the middle part, the uplift phenomena are clearly shown and in the southern part show combine pattern between uplift and subsidence. The impacts of those phenomena would be discuss also in this paper since many population and infrastructure are located in the areas that will need more protection planning to reduce the negative impact such as earthquake and flooding.

Keywords: Vertical Deformation, GNSS-GPS, GAMIT-GLOBK, land subsidence

1. Introduction

The vertical deformation phenomenon at the moment is very interesting because it has a significant impact. The scope of vertical deformation is similar to horizontal deformation, ie spatial variation is a global, regional or local event. While in temporal variation can take place from the long term duration of annual, seasonal or instantaneous. For long term duration with global impact, Chaussard [1] and Andreas [2] already mentioned that the global climate change situation has been realized for the few decades with some indicators are worldwide increasing temperature, decreasing volume of ice in Antarctica and the sea level rise. Relating to the decreased of ice volume and the sea level rise, this situation has been predicted to endanger the living at the coastal area in the future. Another phenomenon with long term duration but with only regional coverage is caused by uplift or subside geological events of structural activity and / or gravity attraction. The local vertical deformation phenomenon with a duration of several years can be caused also by earthquake or tsunami events as happened in Aceh due to the 2014 mega earthquake as a result of a combination of co-seismic and post-seismic events. Local events that are seasonal or continuous can also occur eg rob,
land subsidence due to groundwater retrieval or ground collapse and volcanic activity. Figure 1 shows examples of some of the effects of vertical deformation phenomena in coastal areas that cause flooding. The territory of Indonesia is a complex area in terms of vertical deformation. As an archipelago, Indonesia is affected by global sea level rise. While tectonically, the Indonesian region is a collision zones of 3 macro plates that cause the activity of horizontal and vertical deformation derived from various geological phenomenon mentioned above. When viewed from local activities, the possibility of vertical deformation also occurs due to groundwater retrieval or liquid material retrieval that causes compaction. Therefore, it is important to study the vertical deformation in this case especially to know the varying causes parameters for each zone for its prevention and reduction of negative impacts.

Distribution of present-day horizontal and vertical deformation across the Southern Part of Indonesia at Java, Bali and Nusa Tenggara now days can be determined from continuous and campaign types of GNSS GPS data monitoring. For vertical deformation in this case we use the continuous types since they are give better quality of data consistency compare to campaign type. Continuous Global Positioning System (CGPS) are maintaining by Geospatial Information Agency for more than a decade.

Figure 1. Example of several subsidence phenomena at northern part of Java

2. Data and Methods

The vertical deformation phenomenon in this study was obtained from GPS monitoring from two types observations, namely continuous type and episodic / campaign type. Continuous Global Positioning System (CGPS) in this research are maintaining by Geospatial Information Agency (BIG) for more than a decade. While the campaign type is obtained from a combination of various GPS measurements ever performed by geodesy research group FEST - ITB. Figure 2 shows example of GNSS GPS station monitoring for continuous and campaign type. The vertical displacements or velocity rates are estimated from time series analysis after multi-baseline GPS processing using GAMIT-GLOBK software with respect to the latest International Terrestrial Reference Frame.
Figure 2. Example of GNSS GPS station monitoring for continuous and campaign type

GAMIT/GLOBK 10.6 is used to analyzed the GNSS-GPS data of all observation campaigns and continuous types [3]. Daily solutions were calculated in 12/24-hours session with 30 second sampling rate using GAMIT for each of measurement, and in each session the theoretical values for phase and pseudorange observable are modeled. Station coordinates, phase biases and zenith delay parameter are adjusted by a least square method. The antenna phase center variations we’re model using the IGS table and IGS orbits were kept fixed for each individual session. To transform the solution to ITRF, we include rinexdata from the IGS station located surround the research area as shown in Figure 3.

Figure 3. Global IGS station for ITRF transformation

The observable were examined in the ionosphere-free combination (LQ forming double differences to eliminate clock errors and tropospheric parameter were estimated using Saastamoinen model every one hour for each station. The phase ambiguities are estimated as real values in the first step and it was attempted to resolve the phase ambiguity using a routine developed by Dong and Bock [4]. The quality assessment of the individual solution is base on the repeatability of the independent daily estimation for each baseline component. And finally, the multi session free network solution with loose constrain on position and fixed IGS orbits were established, and GLOBK Kalman filter
method were applied to the analysis of solution vectors and associated covariance matrices generated during daily solutions. The coordinates were mapped in the ITRF solution of 2008 by constraining the IGS solutions included in the analysis to their positions in ITRF-2008. The displacement rates were computed by subtracting the ITRF-2008 mapped the campaign solutions.

3. Results and Discussion

As is known, the accuracy of positioning results using GNSS GPS has a precision of 3 to 5 times lower for vertical components compare to horizontal components. Thus, the accuracy of the vertical position and its change is highly dependent on the position of the center of the earth’s mass and the estimated influence of the atmosphere (ionosphere and troposphere). That is why the determination of vertical deformation becomes more sensitive than horizontal deformation. Figure 4 shows examples for detecting possible biases and possible seismic effects (inter seismic, co seismic and post seismic). After cleaning and filtering data processing, data obtained are free from biased and we can obtain linear trend of vertical displacement or velocity. This analysis method can only be done for continuous type data, while for episodic / campaign type data, analysis is done by using linear assumption with shifting by interpolation of earthquake impact to nearby station.

The average accuracy value obtained for the north, east and up components is 2 mm/yr, 3 mm/yr and 6 mm/yr for continuous type. Figure 5 shows the results of the time series analysis and the resulting linear velocity results. We use CMAT at Lombok Island and CSRJ at Bali Island that already clean from earthquake effect and bias. The CMAT deviation, which is relatively larger than the station caused by the stationary position of this station, is very close to the tall buildings, so the multipath effect predominates.

![Figure 4. Time Series Analysis for Bias Analysis and to Detect Earthquake](image-url)
After a time series analysis, each station is mapped to ITRF2008 via the Helmert transform procedure, and the results are shown in Fig. 6 and Fig. 7. In this study, we do not analysis with local transformation to an arbitrary plate due to the reference datum we used for vertical deformation in here is the center of the mass of the earth. This is done in order to detect vertical deformation on a regional scale as well as the global impact of sea level rise. The continuous station at Figure 6 shows better results than episodic stations that leads to more reliable analysis for continuous stations. The average negative vertical deformation is about 2.5 mm/yr, and smaller for about 2 mm/yr for positive vertical deformation. Figure 7 shows a more heterogeneous result, due to the small amount of data used in the 3-epoch range of the bonding that causes the results to be analyzed in detail. In order to be able to do further analysis for this type of episodic considering the phenomenon of vertical deformation slowly lasting in duration, then it takes at least 2 epoch observations again.

![Figure 5. Time series of continuous GPS](image1)

![Figure 6. Vertical deformation from continuous GPS](image2)
The result in figure 6 shows some interesting majority phenomena where the northern part of the research area majority have negative value that may indicate land subsidence with or without tectonic subsidence combination. This results have positive correlation with tidal inundation at northern part of Java from Andreas [2]. In the middle part, the uplift phenomena are clearly shown and in the southern part show combine pattern between uplift and subsidence. Both last part are dominated by geological force phenomena. In the southern part of the study area there is a subduction zone that dominates the pressure of the Australian plate, so most likely the curvature of the plate due to gravity is the dominant parameter. At central part of East Java, we can see rather large positive vertical deformation that maybe connected with the geological phenomena of Tengger mountain uplift. In Bali Island, still have same pattern, that the northern part and the southern part show negative deformation pattern and in the central part show positive trend. At Lombok Island and Nusa Tenggara Timur, almost all station shows negative vertical rate that maybe connected with geological phenomena of collision between Australian Plate from south with back arc system at northern part of the area from Bali to Nusa Tenggara Timur. Exception are occurred at west part of Flores Island and central part of Sumba Island, and this phenomena need more detail investigation.

The impact of vertical deformation for the northern coastal region at this time should be highly regarded, since the majority is a residential area. Many population and infrastructure are located in the areas that will need more protection planning to reduce the negative impact such as earthquake and flooding.

4. Conclusion

From the results of gps monitoring, it can be seen that vertical deformation phenomenon occurs in all research areas with an average value of 3 mm yr in both positive and negative directions. This deformation is calculated relative to the center of the earth's mass so that the regional vertical deformation pattern will be real displacement. The vertical deformation parameters in the study area were dominated by subsidence in the northern part and geological activity in central and southern regions. To find out in more detail the phenomenon that occurs primarily local, then required further observation and use of physical modeling. For residential areas, especially in the northern region,
further studies are needed in an integrated socio-cultural economy in order to prevent or at least minimize the negative impact of vertical deficits

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6. References

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