On the Development and Implementations of the New Semi-Dynamic Datum for Indonesia

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Key words: geodetic datum, reference frames, topocentric datum, geocentric datum, semi-dynamic datum, Indonesia, GPS, ITRF2008, deformation block

SUMMARY

Indonesia is a maritime continent with a complex and active tectonic setting and therefore prone to various natural hazards. The surface deformation caused by these hazards, coupled with tectonic plate motion in and around the Indonesian region, will cause the geocentric coordinates of many geodetic control benchmarks and monuments in Indonesia to change with time. Since the 19th century, several local static topocentric geodetic datums have been used for surveying and mapping in Indonesia. In 1975 the Indonesian Datum 1974, which is a national static topocentric datum, was introduced and then replaced by the National Geodetic Datum 1995 which is a static geocentric datum realized using GPS observations. In recent years it has been realized that, due to on-going active tectonics in the Indonesia region, the National Geodetic Datum 1995 is inadequate for surveying and mapping in some regions of Indonesia, and also for some current and emerging applications. Initial studies suggested that a semi-dynamic geocentric datum is suitable for Indonesia.

On 11 October 2013, BIG launched a new geocentric datum named the Indonesia Geospatial Reference System 2013 (IGRS 2013). The new datum is a semi-dynamic datum in nature, which uses the global ITRF2008 reference frame, with a reference epoch of 1 January 2012. A velocity model, which incorporates tectonic motion and earthquake related deformation, is used to transform coordinates from an observation epoch to or from this reference epoch. For its initial implementation, the model considers an initial deformation model setting based on 4 tectonic plates and 7 tectonic blocks, and 126 earthquakes. At present, the velocity model of IGRS 2013 will be mainly realized using the GPS-derived rates at passive and continuous GPS stations in Indonesia region. This paper presents and discusses the new updated velocity model for the new semi-dynamic datum of Indonesia.

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1. INTRODUCTION

The Indonesia archipelago encompasses a wide range of tectonic environments (see Figure 1), including island arc volcanism, subduction zones, and arc-continent collision therefore prone to various natural hazards, such as earthquakes, tsunamis, volcanoes eruptions, flooding, landslides and land subsidences. The activity of natural hazards and plate tectonic will produces surface deformation that will changes the geocentric coordinates of many geodetic benchmarks and monuments in Indonesia with time (see Figure 2). Accordingly, the geodetic datum for Indonesia should take into account the surface deformation effect from tectonic activity.

There was several geodetic datums have been used for positioning activity in Indonesia, starting with the local topocentric geodetic datums that use reference ellipsoid the Bessel 1841 ellipsoid with different datum origin point. Rais (1975) introduced a new national topocentric geodetic datum named the Indonesia Datum 1974 (ID 1974). The first national geocentric datum for Indonesia, National Geodetic Datum (DGN 1995), was introduced (Subarya and Matindas, 1996) and replace ID 1974. DGN 1995 is a static geocentric datum realized using GPS observations (Subarya and Matindas 1996). The surface deformation due to tectonic activities in Indonesia since 1995 until present will caused the coordinates of DGN 1995 monuments are inadequate for several positioning activities. In this paper, we introduced the new updated velocity model for the new semi-dynamic geocentric datum for Indonesia.

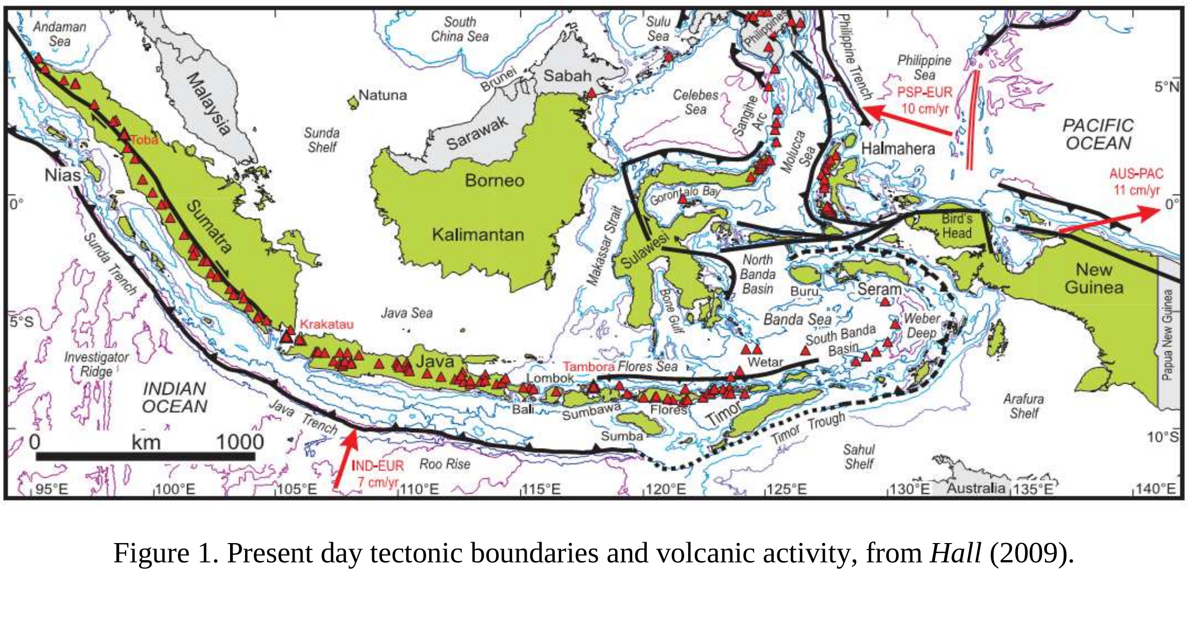

Figure 1. Present day tectonic boundaries and volcanic activity, from *Hall* (2009).

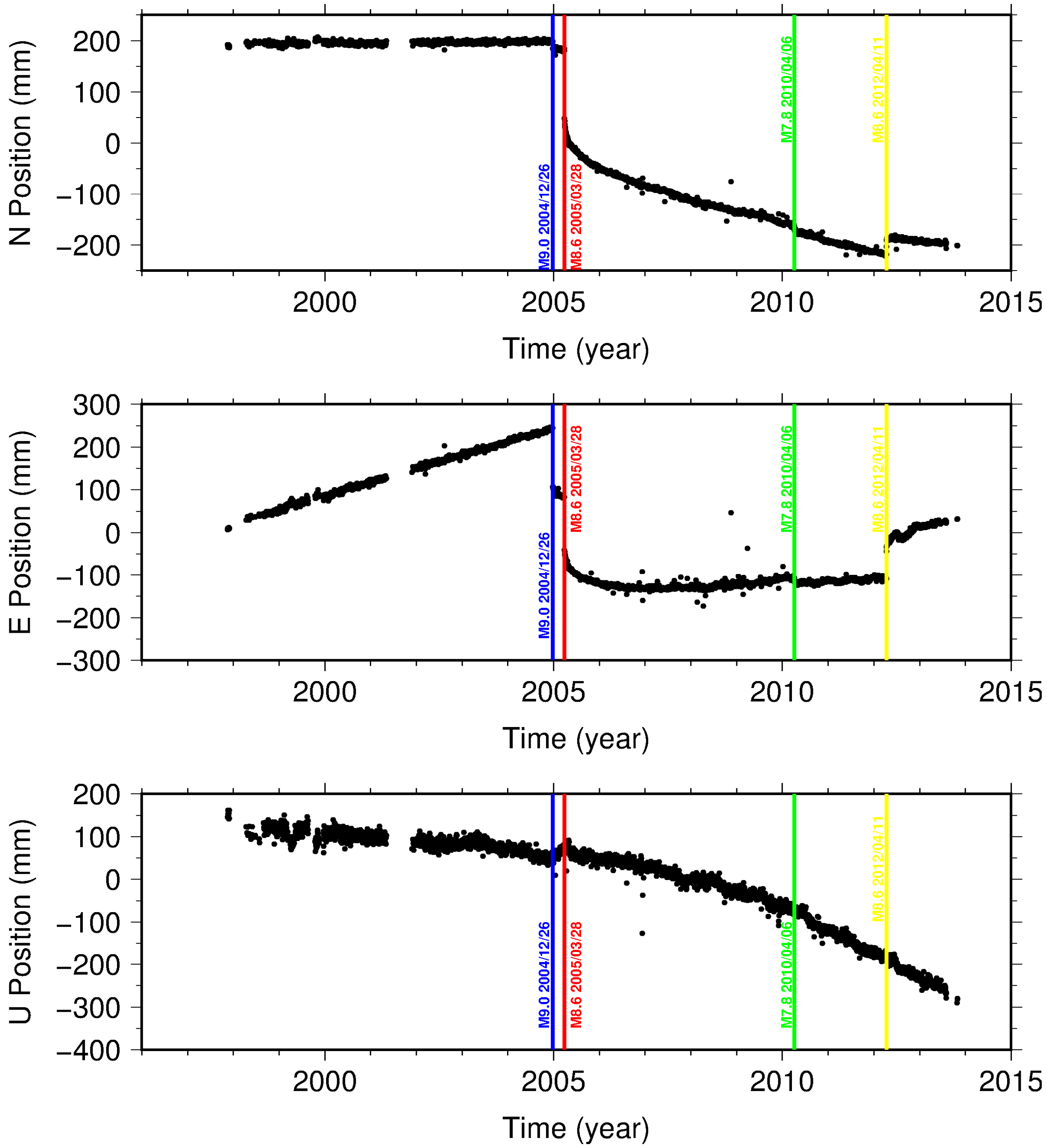

Figure 2. Coordinates time series from cGPS SAMP (Sampali, Medan); blue line is December 26, 2004 M9.0 earthquake; red line is March 28, 2005 M8.6 earthquake; green line is April 06, 2010 M7.8 earthquake; yellow line is April 11, 2012 M8.6 earthquake; courtesy Susilo (BIG).

2. INDONESIAN GEODETIC DATUM

Positioning and mapping activities in Indonesia began in 1862. There was many type of geodetic datum used for positioning and mapping activity, such as topocentric dan geocentric geodetic datums.

2.1 **Topocentric Geodetic Datum**

Starting from 1862 until 1960, positioning and mapping in Indonesia was used the triangulation geodetic network control. The coordinates of geodetic control network were determined based on local topocentric datums (see Table 1). The Bessel 1841 ellipsoid reference was used as reference ellipsoid for all of topocentric datums except for T21 Sorong datum.

Table 1. Triangulation Network in Indonesia from *Abidin et al.* (2015).

Region	Started	Datum
Java & Madura	1862	G. Genuk (Batavia)
Sumatera	1883	G. Genuk (Batavia)
Bangka	1917	Bukit Rimpah
Sulawesi	1913	Moncong Lowe
Flores	1960	G. Genuk (Batavia)

Since 1974, Indonesia used the first national topocentric datum, named Indonesian Datum 1974 (ID 1974). This datum realized using Doppler Satellites or the Navy Navigation Satellite System (NNSS) which adopted GRS 1967 as reference ellipsoid and used monument in Padang (west Sumatera as the datum origin point. This datum is something called Padang Datum (Rais 1979). In the field, ID 1974 is realized by 966 Doppler monuments.

2.2 **Geocentric Geodetic Datum**

The first geocentric datum in Indonesia was declared in 1996, named National Geodetic Datum 1995 (DGN 1995). This is a static geocentric datum realized using precise GPS observations and using WGS84 as a reference ellipsoid. Realization of DGN 1995 is national geodetic control network that consist of coordinates around 60 zeroth order monuments and 460 first order monuments. The latest coordinates of DGN 1995 monuments was defined using ITRF2000 at reference epoch 1998.0.

Due to tectonic activities (plate motion and earthquake) in Indonesia region, the coordinates of DGN 1995 monuments are inadequate for mapping and positioning activities, especially for positioning activities that need cm until mm accuracy level. The coordinate displacements due to the combined effects blocks motion (see Figure 3) and earthquake deformation (see Figure 4) varied spatially from 31 cm to 6.3 m. The largest contribution comes from Sumatera-Andaman 2004 earthquake (Vigny et al. 2005; Subarya et al. 2006).
Since the Indonesian region will always be affected by tectonic motion and earthquakes, a static geodetic datum is not suitable for Indonesia. However a dynamic datum which the coordinates continuously change with the time is not appropriate at present for Indonesia.

Therefore, the most appropriate datum to be adopted at present is a semi-dynamic datum which coordinates freeze to the reference epoch and the change of coordinates due to tectonic activities represented by deformation model.

Figure 3. Horizontal displacement magnitude due to plate motion since 1996 until 01 January 2013; courtesy Susilo (BIG)

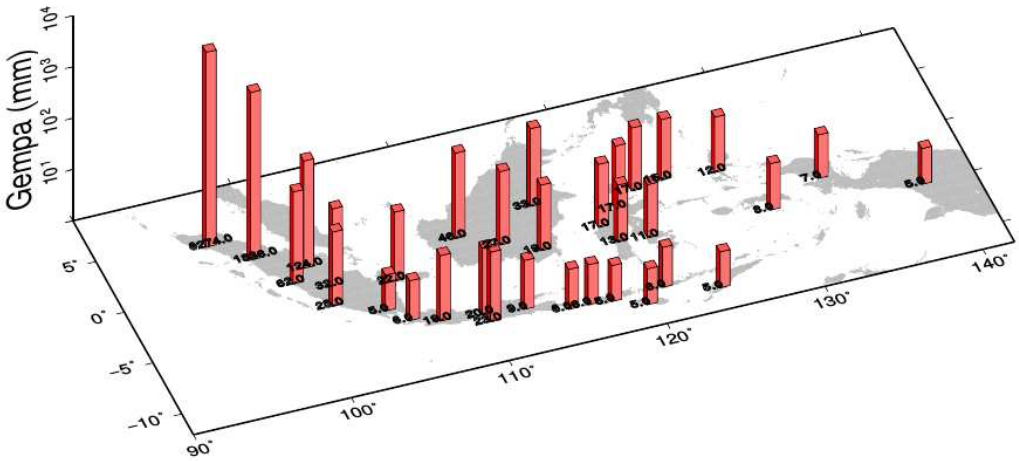

Figure 4. Horizontal displacement magnitude due to earthquake since 1996 until 01 January 2012; vertical scale on logarithmic courtesy Susilo (BIG)

3. THE NEW INDONESIAN SEMI-DYNAMIC GEOCENTRIC DATUM

Indonesian Geospatial Information Agency (BIG) the former of BAKOSURTANAL was declared the new geocentric datum named Indonesia Geospatial Reference System 2013 (IGRS 2013) on 11 October 2013. This datum is semi-dynamic datum and coordinates defined on ITRF2008 reference frame (Altamimi et al. 2011) at epoch reference 1 January 2012 (BIG 2013). The coordinate changed which incorporates plates/block motion and earthquake is represented by velocity/deformation model. This deformation model uses to transform 3D geocentric Cartesian coordinate at an observation epoch to or from reference epoch. IGRS 2013 adopted WGS84 as a reference ellipsoid. IGRS 2013 will be updated if the new ITRF reference frame is become available. The previous velocity model have been derived from GPS data collected from 2007 to 2009 for sGPS stations and 2010 to 2013 for cGPS data (Abidin et al. 2015). We updated the velocity model using more GPS data and longer time span GPS data. The development of velocity model is explained in the following section.

In the field, realization of IGRS 2013 is National Geodetic Control Network (NGCN), consisting of continuous GPS stations (cGPS), campaign GPS stations (sGPS) and another geodetic control stations (BIG 2013), which the coordinates are defined at reference epoch 1 January 2012. At the end of 2014, BIG have been operated 121 cGPS stations and about more than 1350 sGPS monuments. Another government agency that operated cGPS is the National Land Agency (BPN), which has about 183 cGPS stations and also established thousands of GPS-positioned passive monuments across Indonesia (Abidin et al. 2011, 2012). The Indonesian Institute of Science (LIPI) in collaboration with Earth Observatory of Singapore (EOS) has operated 49 cGPS stations (http://www.earthobservatory.sg/resources/facilities/sumatran-gps-array-sugar), named Sumateran GPS Array (SUGAR). All these station both of cGPS and sGPS stations will be included in the IGRS 2013. Figure 5 shows the distribution of GPS station which included in the processing to determined deformation model.

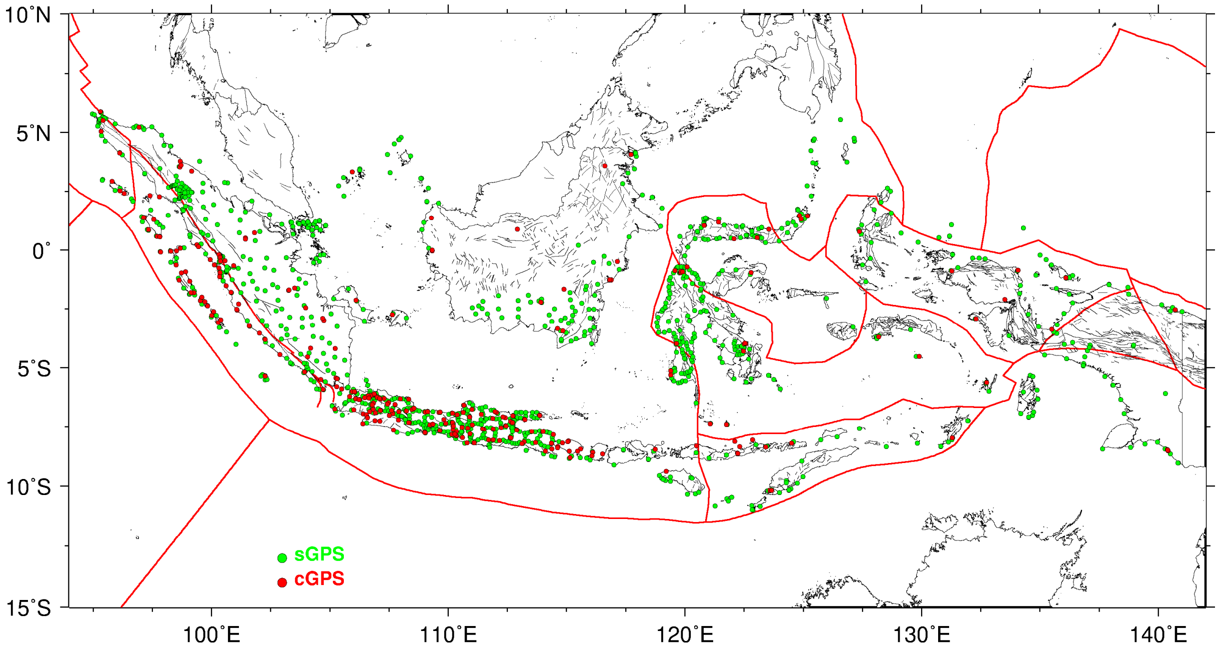

Figure 5. Distribution of GPS stations; red line is blocks boundaries from MORVEL 56 (Argus et al. 2011); Faults are mostly from the East and Southeast Asia (CCOP) 1:2000000 geological map (downloaded from http://www.orrbodies.com/resources/item/orr0052); courtesy of Susilo (BIG) .

We have reprocessed GPS data from 1996 until 2013 using GAMIT/GLOBK software suite (Herring et al. 2010a, b,c). Regional GPS data from 22 IGS stations were included to tie each sub networks to the ITRF2008 reference frame. We analysed the GPS data using a three-step approach. In the first step, we used GPS phase observations to estimate daily positions, together with atmospheric, orbital and earth orientation parameters, using loose a priori constraints for each sub networks. In the second step we combined these positions and their covariance from each sub networks with global GPS solutions computed as part of MIT's processing for the International GNSS Service (IGS). We then examined the position time series for outliers and offsets due to earthquakes or antenna changes and corrected these as appropriate. In a third step, we combined all of the data into weekly solution, estimating positions and velocities for the period 1996-2013. In both the second and third steps we mapped the loosely constrained solution into a well-constrained reference frame by minimizing the position and velocity differences of selected sites with respect to a priori values defined by the ITRF2008 reference frame (*Altamimi et al.* 2011).

Figure 6 shows the derived horizontal linear velocity field (with 95% confidence ellipse) with respect to ITRF2008. The velocity field shows many distinct patterns that indicated many block tectonic in Indonesia region.

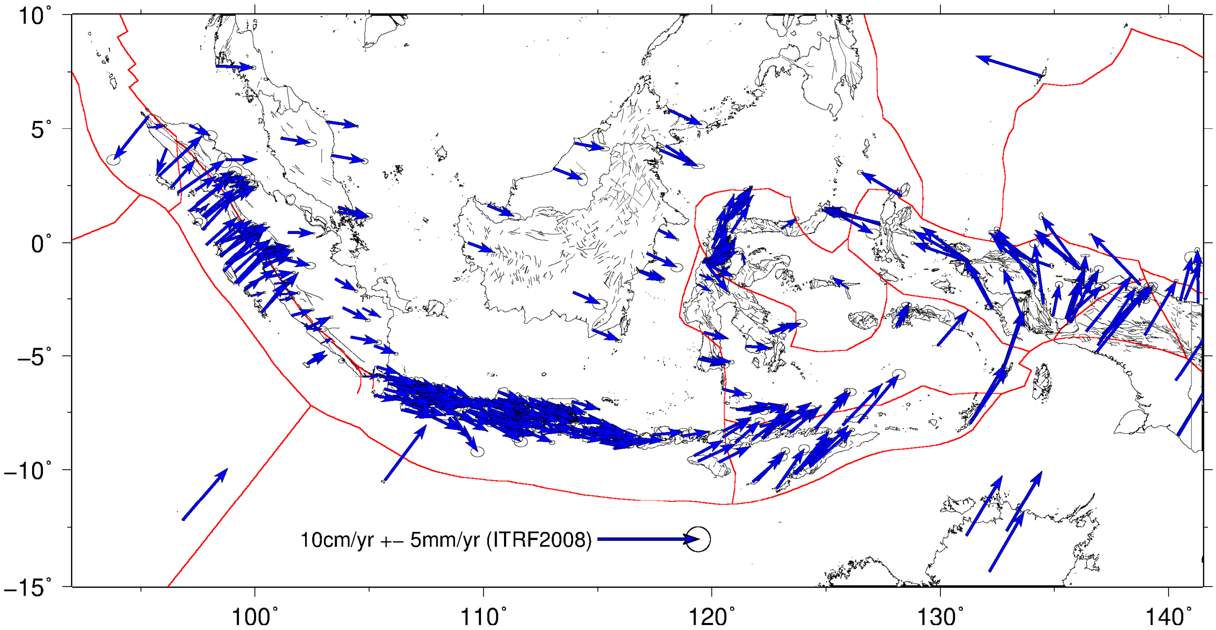

Figure 6. Velocity field with 95% confidence ellipse with respect to ITRF2008; red line is block boundaries from MORVEL56 (Argus et al. 2011); faults are mostly from the East and Southeast Asia (CCOP) 1:2000000 geological map (downloaded from http://www.orrbodies.com/resources/item/orr0052); courtesy Susilo (BIG).

4. CONCLUSIONS

The new Indonesian semi-dynamic geocentric datum was launched on 11 October 2013 by Indonesian Geospatial Information Agency (BIG). The new GPS data from BIG stations, BPN stations and SUGAR stations from 1996 to 2013 have been used to update velocity model in Indonesia region. However, several things related realization and implementations of IGRS 2013 still under research and development, especially the deformation model. From the updating velocity model there would be a question whether the plate/block boundaries from MORVEL56 is still suitable to create deformation model of IGRS2013.

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