
On the Development and Implementation of a Semi-Dynamic Datum for Indonesia

Hasanuddin Z. Abidin, Susilo Susilo, Irwan Meilano, Cecep Subarya, Kosasih Prijatna, M. Arief Syafi'i, Edwin Hendrayana, Joni Effendi, and Dodi Sukmayadi

Abstract

Since the nineteenth century, several local topocentric geodetic datums have been used for surveying and mapping in Indonesia. In 1975 the Indonesian Datum 1974, which is a national 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 Indonesian 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. The adopted new datum uses the ITRF2008 reference frame with a reference epoch of 1 January 2012. It incorporates several major deformation blocks of Indonesia, and several micro blocks to model specific deformation events such as large earthquakes. Realization of this new semi-dynamic datum will be primarily based on existing data coming from many previous national GPS campaigns that have been conducted by the Geospatial Agency of Indonesia, and from existing GPS CORS stations across Indonesia.

Keywords

Deformation block • Geocentric datum • Geodetic datum • GPS • Indonesia • ITRF2008 • Reference frames • Semi-dynamic datum • Topocentric datum

1 Introduction

Indonesia is a maritime continent with a complex and active tectonic setting (see Fig. 1), and therefore prone to various natural hazards, such as earthquakes, tsunamis, volcanic

H.Z. Abidin (✉) • I. Meilano • K. Prijatna
Geodesy Research Group, Faculty of Earth Science and Technology,
Institute of Technology Bandung (ITB), Jl. Ganesha 10, Bandung,
Indonesia
e-mail: hzabidin@gd.itb.ac.id

S. Susilo • M.A. Syafi'i • E. Hendrayana • J. Effendi • D. Sukmayadi
Geospatial Agency of Indonesia (BIG), Jl. Raya Jakarta – Bogor Km.
46, Cibinong, Indonesia

C. Subarya
Previously with Geospatial Agency of Indonesia (BIG), Jl. Raya
Jakarta – Bogor Km. 46, Cibinong, Indonesia

eruptions, landslides, flooding and land subsidence. 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 benchmarks and monuments in Indonesia to change with time. Accordingly, the adopted geodetic datum for Indonesia should take into account the active nature of Indonesian geodynamics.

Since the nineteenth century, several local topocentric geodetic datums have been used for surveying and mapping in Indonesia (Schepers and Schulte 1931). All of these local datums used the Bessel 1841 ellipsoid as the reference ellipsoid, with different datum origin points. In 1975, the Indonesian Datum 1974 (ID 1974), a national topocentric datum, was introduced (Rais 1975) and then replaced by the National Geodetic Datum 1995 (DGN 1995) which is a static geocentric datum realized using GPS observations (Subarya

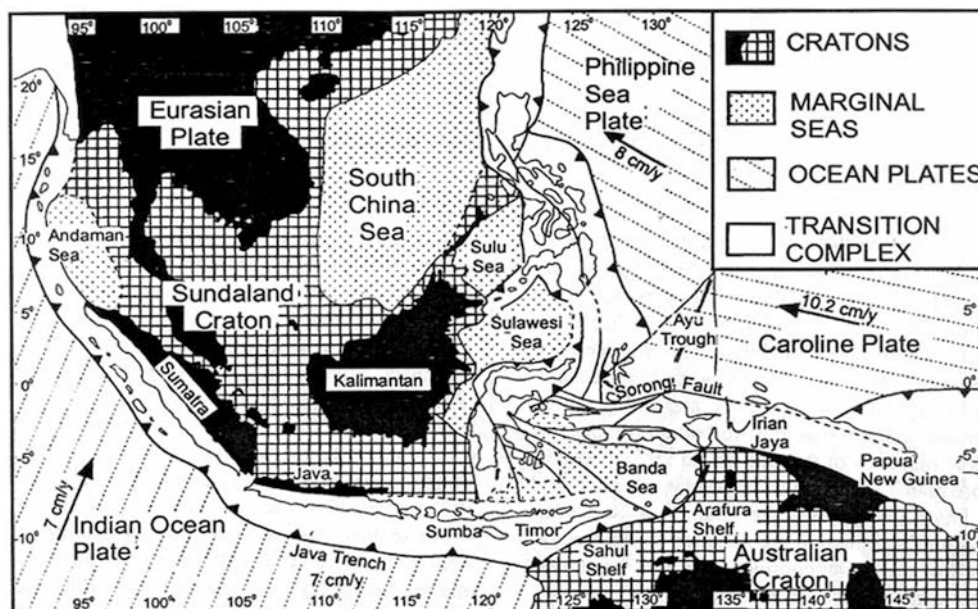


Fig. 1 Complex tectonic characteristics of the Indonesian region, from Simandjuntak and Barber (1996)

and Matindas 1996). In recent years it has been realized that, due to on-going active tectonics in the Indonesian region, DGN 1995 is inadequate for surveying and mapping in some areas of Indonesia and also for some current and emerging applications in positioning, navigation, scientific applications and spatial data management. Moreover, with the use of space geodetic techniques with mm to cm level positioning accuracy, the need for a more accurate and global geocentric datums is required for Indonesia.

2 Historical Background

Positioning and mapping activities in Indonesia began in 1862. In these activities, the horizontal geodetic control network was established mainly using triangulation. The triangulation was started in the Java and Madura islands of Indonesia, which are the most populated islands in Indonesia. This first triangulation campaign started in 1862 and was completed in 1880. The measurements were then extended to other islands (see Table 1). The coordinates of the triangulation monuments were based on various local (topocentric) datums (see Fig. 2). All of these topocentric datums, except for the T21 Sorong datum, used the Bessel 1841 reference ellipsoid.

The various local topocentric datums used by the triangulation measurements in Indonesia are shown in Fig. 2. Datum unification started in 1974 using measurements from the *Navy Navigation Satellite System (NNSS)* or Doppler satellites. In the period 1974 to 1982, 378 Doppler stations were established. At the end of 1986 there were 966 Doppler

Table 1 Triangulation Network in Indonesia

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

stations throughout Indonesia. This new datum was named the Indonesian Datum 1974 (ID 1974) and can be considered as the first national topocentric datum of Indonesia. This datum, which adopted the GRS 1967 reference ellipsoid, used a certain monument in Padang (West Sumatra) as the datum origin point, and is therefore sometimes called the Padang Datum (Rais 1979).

Since 1989, the Geospatial Agency of Indonesia (BIG), formerly BAKOSURTANAL, began establishing geodetic networks for geodynamics studies in Sumatra using precise GPS campaigns, through the GPS-GPS (Global Positioning System For Geodynamic Project in Sumatra) programme which lasted till 1994. With this programme, the zeroth order geodetic network of Indonesia was established, and then expanded to other regions. In 1995, the National Geodetic Datum 1995 (DGN 1995) was declared as the new geodetic datum for Indonesia. This is a geocentric datum realized using precise GPS observations and WGS-84 as the reference ellipsoid. The DGN 1995 datum is realized by the zeroth and first order National Geodetic Control Network (NGCN), of which there were initially around 60 and 460 monuments,

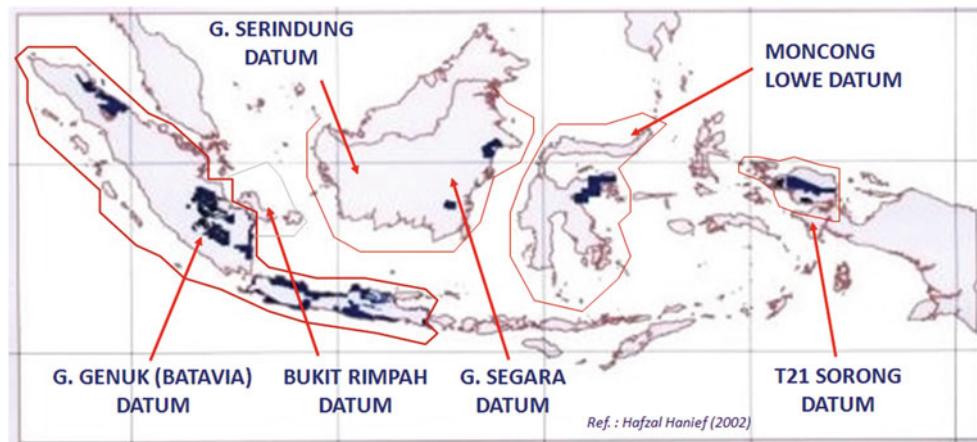


Fig. 2 Main local (topocentric) datums in Indonesia

respectively. Since 2004, after the readjustment process, the DGN 1995 coordinates of those monuments have been given in ITRF2000 at reference epoch 1998.0.

3 Reasons to Update the Geodetic Datum

Since the DGN 1995 datum was adopted in 1996, it can be expected that, due to tectonic (plates and blocks) motion and earthquake related deformation (e.g. Sumatra-Andaman 2004, Nias 2005, and Bengkulu 2007, and other earthquakes in other part of Indonesia), the coordinates of the DGN 1995 reference frame have changed (see Fig. 3). Since 1996, the total magnitude of 3D coordinate displacements due to the combined effects of block motion and earthquake deformation in the Indonesia region varied spatially from about 31 cm to 6.3 m. The largest contribution comes from the Sumatra-Andaman 2004 earthquake (Vigny et al. 2005; Subarya et al. 2006). Nowadays, these changes in coordinates can be precisely monitored using GNSS CORS networks. Moreover, many new applications (e.g. early warning systems for natural hazards, location based services, and precise photogrammetric mapping) need real time coordinates in a global reference system. Since the Indonesian region will always be affected by tectonic motion and earthquakes, changing the DGN 1995 datum into a more dynamic datum is both necessary and strategic for Indonesia.

4 New Semi-Dynamic Geodetic Datum

There are three basic kinds of datums that could be used for Indonesia: a static datum, a semi-dynamic datum and a dynamic. The main features and differences between these types of datums are summarized in Table 2.

Considering the active geodynamic nature of the Indonesian region, a static geodetic datum is not suitable for Indonesia. However, a dynamic datum is also not appropriate at present due to the vast area of the Indonesian region with its large differences in positioning infrastructures. Many positioning and mapping stakeholders, such as cadastral, boundary surveying, engineering and construction surveying, will be troubled and confused by the complexity of a dynamic datum. Therefore, the most appropriate datum to be adopted at present is a semi-dynamic datum.

On 11 October 2013, BIG launched a new geocentric datum named the Indonesian Geospatial Reference System 2013 (IGRS 2013). This new datum is a semi-dynamic datum in nature, which uses the global ITRF2008 reference frame (Altamimi et al. 2011) with a reference epoch of 1 January 2012. A velocity model, which incorporates tectonic motion and earthquake related deformation, is used to transform coordinates at an observation epoch to or from this reference epoch. In order to convert the 3D geocentric Cartesian coordinates into geodetic ellipsoidal coordinates, IGRS 2013 adopted the WGS-84 reference ellipsoid. If a new version of the ITRF reference frame becomes available, then the IGRS reference frame will also be updated accordingly. The reference epoch may also be changed. The procedure for updating the reference frame and reference epoch is still under studied by BIG.

For its initial implementation, the velocity model of IGRS 2013 considers an initial deformation model setting based on four tectonic plates (e.g. Eurasian, Australian, Pacific and Philliphine Sea), and seven tectonic blocks (e.g. Burma, Sunda, Molucca, Banda, Timor, Bird Head and Maoke) as illustrated in Fig. 4, and also 126 earthquakes. With this deformation model setting, if the plate motion model MORVEL (DeMets et al. 2010) is used, then the computed horizontal deformation rates in Indonesia are as shown in Fig. 5. Later, several more micro blocks will

Fig. 3 The total magnitude of 3D coordinate displacements due to block motion (*upper chart*) and earthquakes (*lower chart*) since 1996, from GPS observations; courtesy of Susilo (ITB). The ranges of 3D coordinate displacements due to block motion and earthquake are 28–65 cm, and 1.9–6.2 m, respectively

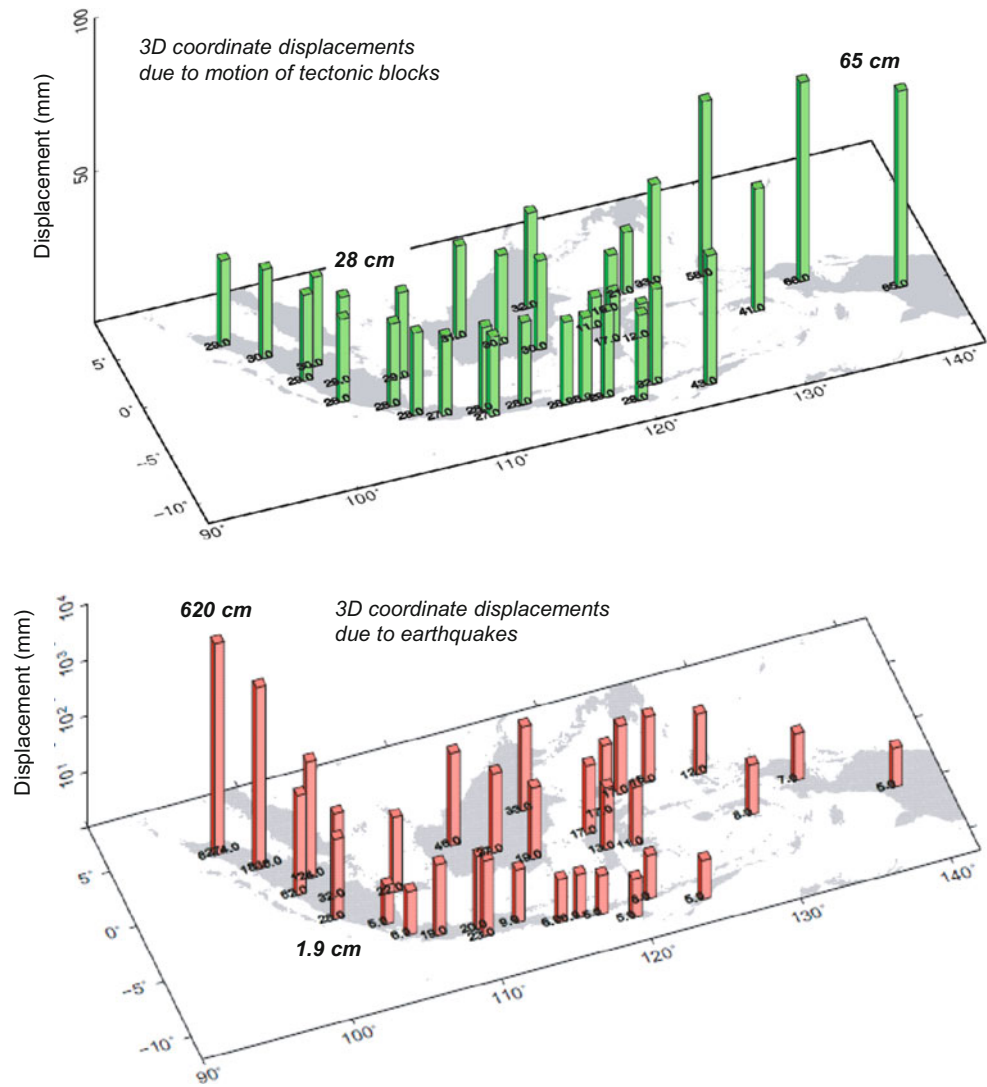


Table 2 Main features of static, semi-dynamic, and dynamic datums (Grant and Blick 1998; Tregoning and Jackson 1999; Grant et al. 1999)

Static datum	Semi-dynamic datum	Dynamic datum
<ul style="list-style-type: none"> The datum is defined by the coordinates of main geodetic stations The coordinates of those stations are held fixed or unchanging with time 	<ul style="list-style-type: none"> The datum is defined by its relationship to a dynamic global reference system (e.g. ITRS) at a specified reference epoch A time-dependent velocity model is used to transform coordinates at an observation epoch to or from the reference epoch The coordinates of geodetic stations are given in a dynamic global reference frame (e.g. ITRF) at the reference epoch 	<ul style="list-style-type: none"> The datum is defined by its continuous relationship to a dynamic global reference system (e.g. ITRS) Time dependencies of the datum are included in station velocities and rates of change for transformation parameters The coordinates and velocities of geodetic stations are given in dynamic global reference frame (e.g. ITRF)

be also added to account for specific deformation events such as large earthquakes. In this case, only earthquakes with magnitudes larger than 6.0 will be considered in the deformation model. Localized deformation models explained in (Jordan et al. 2007; Winefield et al. 2010) will be considered in IGRS 2013, in order to take into account deformation associated with localised events such

as the aforementioned earthquakes, landslides and land subsidences.

At present, the velocity model of IGRS 2013 will be mainly realized using the GPS-derived rates at passive and continuous GPS stations maintained by BIG and BPN (see Figs. 6, 7, and 8). The status of its development is explained in the following section.

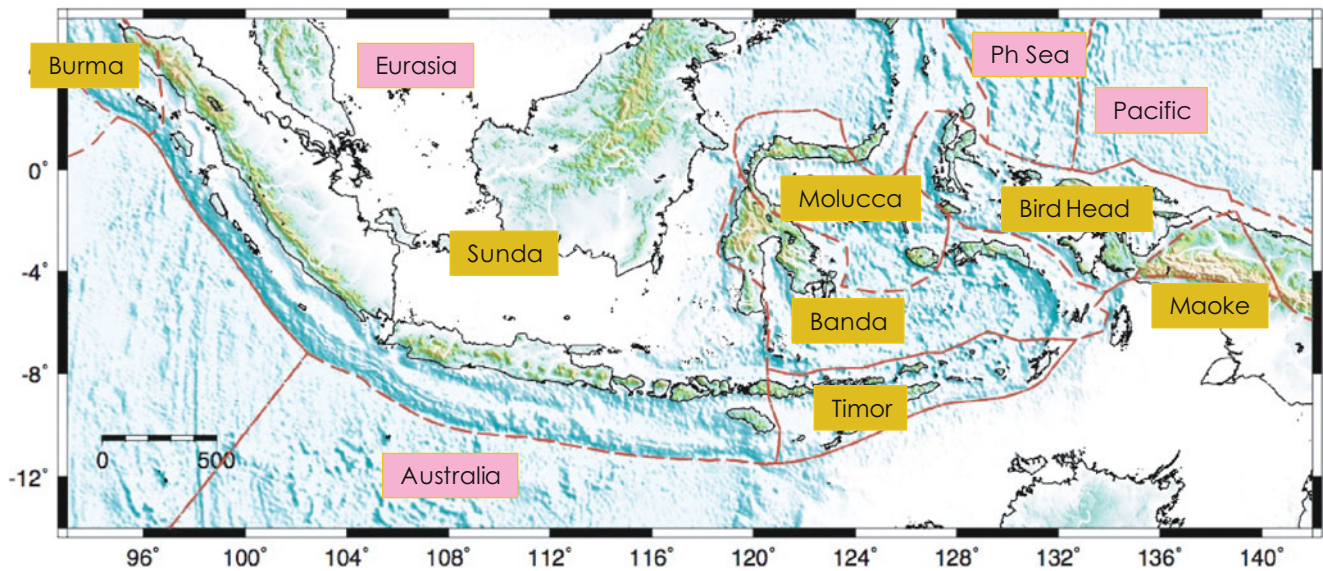


Fig. 4 Deformation model setting of Indonesia, after DeMets et al. (2010). In this Figure, pink boxes indicate the tectonic plates and yellow boxes indicate the tectonic blocks

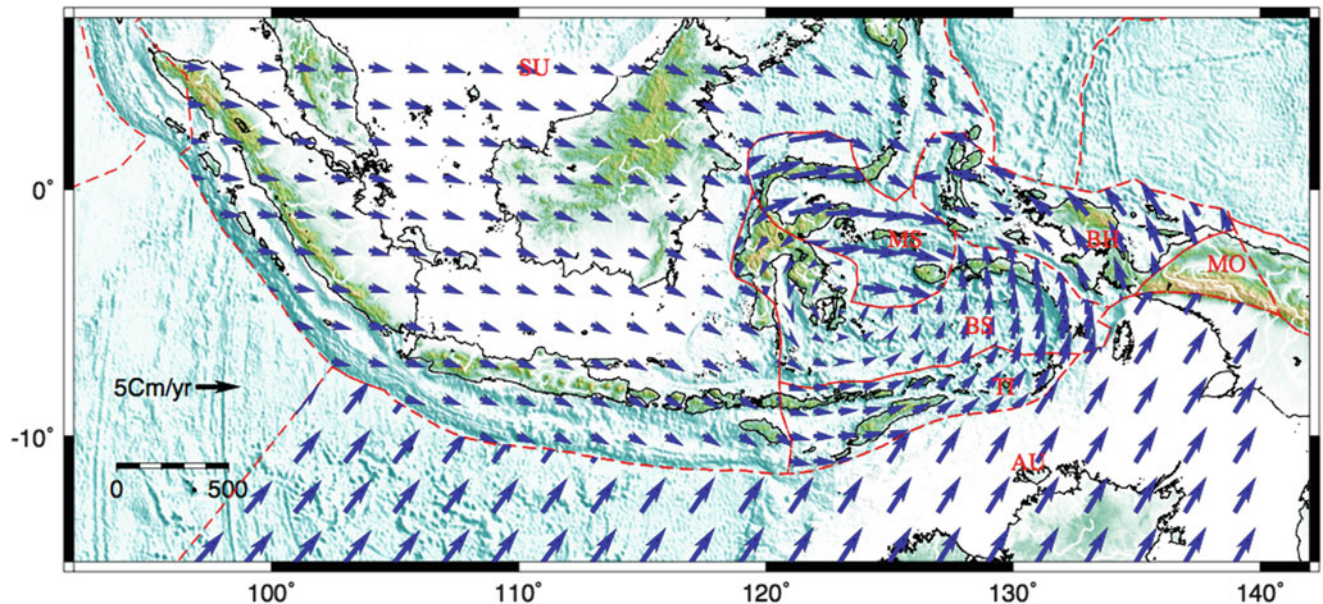


Fig. 5 Initial model for horizontal deformation rates in Indonesia, courtesy of Irwan Meilano (ITB) and Susilo (BIG). It is derived using the plate motion model MORVEL (DeMets et al. 2010)

5 Realization of New Geodetic Datum

IGRS 2013 will be realized in the field by the National Geodetic Control Network (NGCN) stations, consisting of continuous GPS stations (GPS CORS) and passive GPS survey stations (pGPS), covering the Indonesian region. In this case, the coordinates of NGCN stations are given in the ITRF2008 reference frame at the reference epoch of 2012.0. At present, BIG has 118 GPS CORS stations and about 1,350 passive geodetic monuments that have been

positioning using precise GPS surveys (see Figs. 6 and 7). The National Land Agency of Indonesia (BPN) also operates 183 GPS CORS Stations (see Fig. 8), and has also established thousands of GPS-positioned passive monuments across Indonesia (Abidin et al. 2011, 2012). Besides the GPS CORS maintained by BIG and BPN, there is also the SUGAR (Sumatera GPS Array) network, consisting of 32 continuous GPS stations (Caltech 2013), which is maintained by the Indonesian Institute of Sciences (LIPI) in collaboration with the California Institute of Technology (Caltech) and the Earth Observatory of Singapore (EOS). All of these

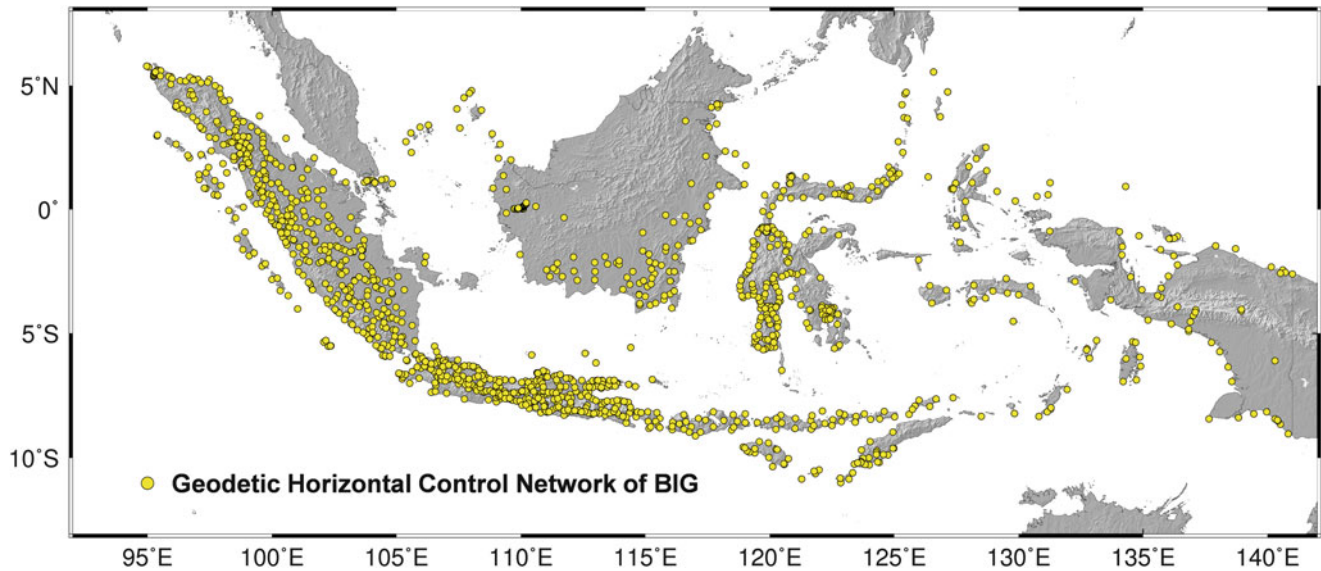


Fig. 6 Distribution of passive (pGPS) geodetic control stations established by Geospatial Agency of Indonesia (BIG) using episodic GPS surveys. Total number of established stations up to 2013 is 1,350 stations

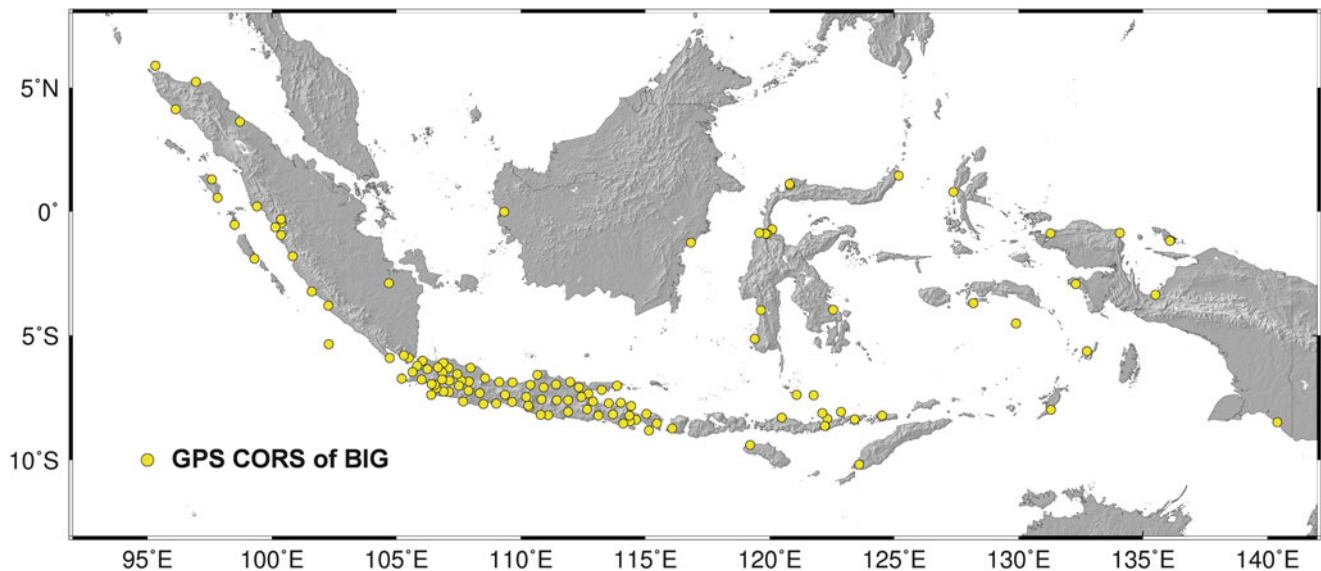


Fig. 7 Distribution of GPS CORS stations in Indonesia maintained by the Geospatial Agency of Indonesia (BIG). Total number of established stations up to 2013 is 118 stations

pGPS and GPS CORS stations can be utilized as part of the IGRS 2013 reference frame.

Presently, BIG has estimated the ITRF2008 velocities at sGPS and GPS CORS stations using pGPS data from 2007 to 2009 campaigns, GPS CORS data from 2010 to 2013, and data from more than 250 globally distributed IGS stations. In total the data from around 790 pGPS and GPS CORS stations in the Indonesian region have been processed so far using GAMIT/GLOBK software (Herring et al. 2010). The processing is done based on dynamic network processing method. In this case, GPS data is firstly processed in daily basis, which one-day data itself is divided

into several networks processing consisting of related cGPS and IGS stations. These network solutions are then combined to yield a daily solution. After quality assessment, the daily solutions are then combined into weekly solution. The final coordinates and velocities are then estimated from the weekly solutions.

The obtained velocities at GPS CORS stations are shown in Fig. 9. The velocities at pGPS stations are not yet established, waiting for data from more passive GPS campaigns to be conducted in order to have more reliable velocities. The Helmert transformation parameters of the coordinates given by GAMIT/GLOBK solution with respect to ITRF2008

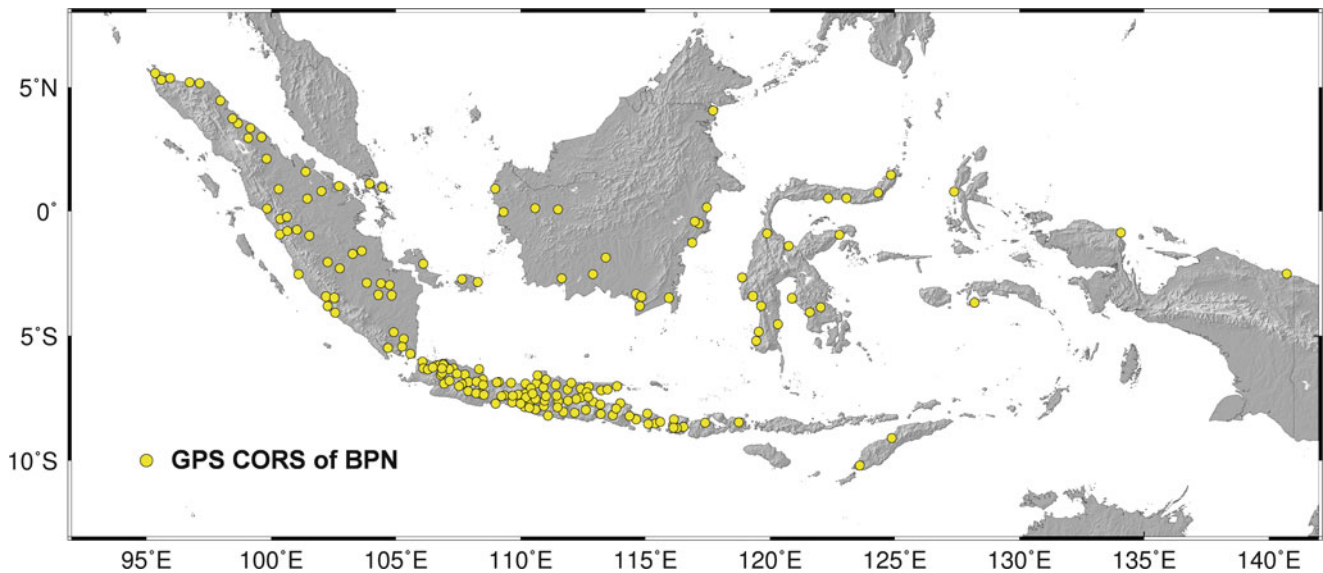


Fig. 8 Distribution of GPS CORS stations in Indonesia maintained by the National Land Agency of Indonesia (BPN). Total number of established stations up to 2013 is 183 stations

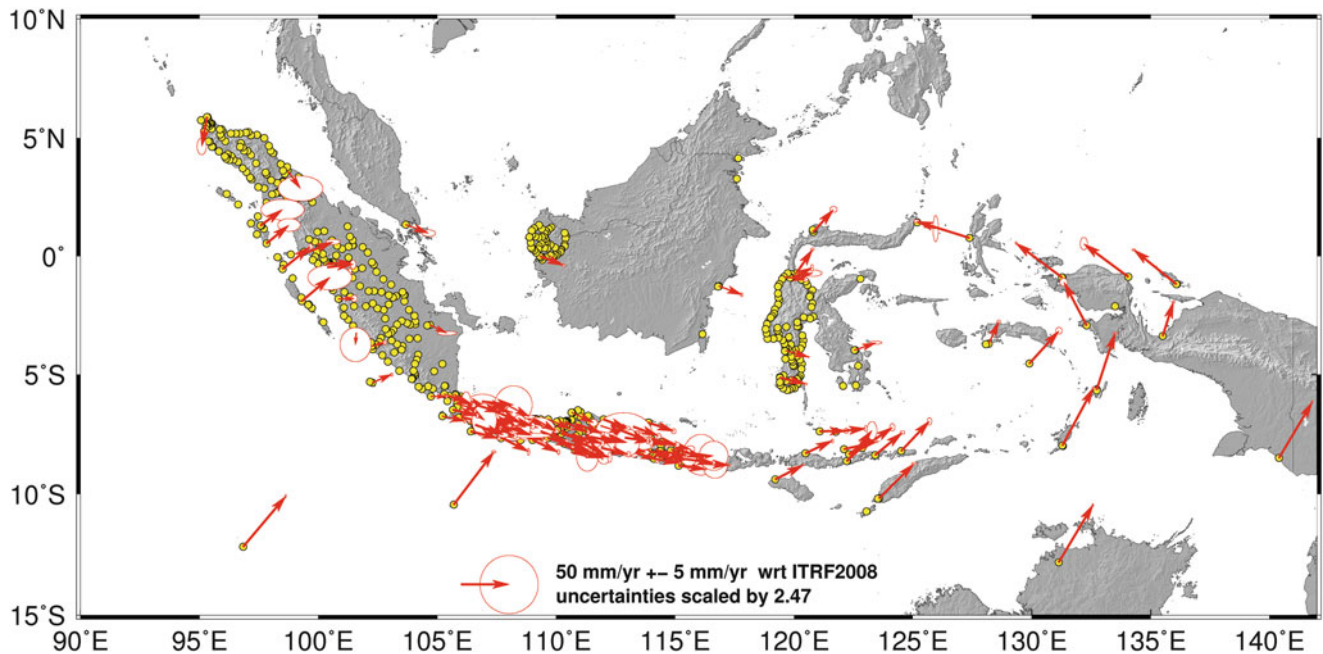


Fig. 9 ITRF 2008 velocities and their error ellipses at the GPS CORS stations maintained by BIG computed using GPS CORS data from 2010 to 2013; courtesy of Susilo (BIG). The

velocities at pGPS stations are not yet shown, waiting for more GPS campaigns to be conducted in order to have more reliable velocities

epoch 2005.0 are shown in Fig. 10. The values of transformation parameters are relatively small, which in general translation <5 cm, rotation <0.4 mas, and scale <0.5 ppb. The values indicate the relatively good realization of IGRS 2013 reference frame. The preliminary Euler pole parameters of the involved tectonic plates and blocks have also been estimated from the GPS CORS solutions, as given in Table 3.

These Euler pole parameters can then be utilized to estimate the velocities at locations outside the GPS CORS stations

In the next processing stage, the velocity field shown in Fig. 9 will be densified by processing more data of pGPS and GPS CORS stations maintained by BIG, i.e. data observed since 2000. Moreover, data from GPS CORS maintained by BPN will also be included in data processing.

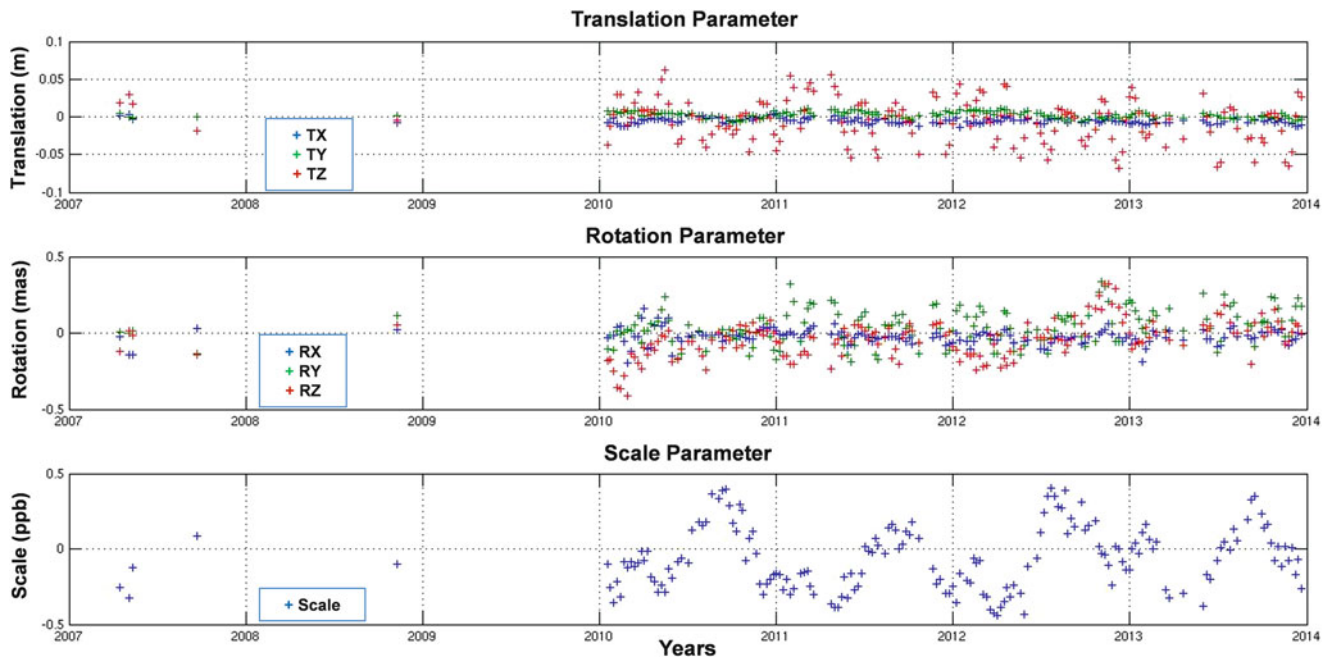


Fig. 10 The Helmsert transformation parameters of the estimated GAMIT/GLOBK coordinates solution with respect to ITRF2008 epoch 2005

Table 3 Preliminary Euler pole parameters as estimated from GPS CORS solutions in Indonesia

Plate	Latitude (deg)	Longitude (deg)	Rate (deg/Myr)	Semi Major (deg)	Semi Minor (deg)	Azimuth (deg)	Rate uncertainty (deg/Myr)	wrms (mm/year)	
								N	E
AU	32.119	37.615	0.635	0.18	0.04	106.0	0.0006	0.44	0.83
BS	0.271	120.474	2.083	0.36	0.03	348.3	0.0918	1.04	1.41
BH	-52.415	54.260	0.536	5.33	0.12	85.7	0.0037	0.20	1.42
MO	8.015	-49.090	1.198	1.99	0.11	55.1	0.1774	0.06	0.05
SU	45.162	128.115	0.313	1.42	0.14	27.8	0.0052	0.70	0.97
TI	2.461	113.389	1.350	0.27	0.02	322.3	0.0260	2.64	0.72

In this Table, *AU* Australian plate, *BS* Banda Sea block, *BH* Birds Head block, *MO* Molucca Sea block, *SU* Sunda block, *TI* Timor block

6 Closing Remarks

The new semi-dynamic datum of Indonesia (IGRS 2013) was officially launched by the Geospatial Agency of Indonesia (BIG) on 11 October 2013. However, several things related to this IGRS 2013 realization are still under investigation and development. This includes how to synergize the velocity model derived using the plate motion model (e.g. MORVEL) with the velocity field estimated using pGPS and GPS CORS data. There would still be a question whether the existing plate and block motion model would be able to accurately predict the velocity field for all over Indonesia. In this case, the interplate coupling models for all plates and blocks interfaces in Indonesian region should also be established. As an example, (Hanifa et al. 2014) has recently proposed an interplate coupling model of the Australia-Java plate interface off the southwestern coast of Java, which will be

useful in establishing the accurate deformation model of IGRS 2013. Moreover, detail mechanisms on handling secular trends, earthquakes offsets (co-seismic deformation), and post-earthquakes motion (post-seismic deformation) should also be established for accurate realization of IGRS 2013.

In the first year of datum transition from DGN 1995 to IGRS 2013, education of all positioning and mapping stakeholders in Indonesia should be conducted to ensure users are not confused by the datum change. Therefore, fast and reliable web-based and online service systems must be provided as soon as possible for the implementation of the new datum across the entire region of Indonesia. Presently, BIG has initiated a web-based service that enables users to access the ITRF2008 coordinates (at reference epoch 2012.0) and their rates of change for all NGCN stations. Coordination with the BPN is also being carried out in order to integrate the coordinates of all pGPS and GPS CORS stations maintained by BPN into IGRS 2013.

BIG should also densify its GPS CORS network to cover all of Indonesia, especially Borneo Island and the eastern parts of Indonesia. With a denser GPS CORS network, the deformation model of IGRS 2013 can be estimated more reliably and in more detail. Cooperation and coordination with all related positioning and mapping institution in Indonesia (e.g. BPN, Army Topographic Agency, Navy Hydrographic Agency) should also be maintained by BIG throughout the implementation process of IGRS 2013.

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