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ASSESSMENT OF GEOCENTRIC DATUM OF MALAYSIA 2000 (GDM2000)

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ABSTRACT:

Several major earthquakes that happened nearby Malaysia for the past decades resulted in a tectonic drift of the Sunda plate. Geocentric Datum of Malaysia 2000 (GDM2000) is affected and has shifted. This paper aims to assess the consistency of GDM2000 by computing datum shift caused by tectonic movement and reference frame effect. Daily solution coordinate of Malaysia Real-Time Kinematic Network (MyRTKnet) stations in the latest reference frame i.e ITRF2014 generated and a coordinate discrepancy between the current reference frame and publish coordinate provided by Jabatan Ukur dan Pemetaan Malaysia (JUPEM) are computed. The result shows that the datum has shifted with an average of 34.6 cm and moved with an average orientation of 111.1° toward the southeast direction. Therefore, this study will contribute to giving an overview of the current status of GDM2000.

1. INTRODUCTION

Geodetic datum unequivocally fixes the relation between reference frame and a reference system by assigning a set of defined parameters comprise of the coordinates of the origin of the Cartesian system (X_0, Y_0, Z_0), the directions of coordinate axes X, Y, Z, and the scale as a unit of length in meter (Drewes, 2009; Angerman *et al*., 2013). There is various geodetic datum being adopted in mapping and positioning work depends on job specification. Therefore, it is crucial to determine geodetic coordinates of points by postulating the ellipsoid to which the datum refers. Geocentric datum as explained by Hofmann-Wellenhof (2008), represents a best-fit ellipsoid where its origin and orientation are equivalent to the Earth-centred Earth-fixed (ECEF) coordinate system.

The Geocentric Datum of Malaysia 2000 (GDM2000) is a static datum realised by Jabatan Ukur dan Pemetaan Malaysia (JUPEM) back in 2003 for creating a homogeneous coordinate system in Malaysia that compatible with the global reference frame. A total of fifteen (15) Malaysia Active GPS Network (MASS) and eleven (11) International GNSS Service (IGS) stations duration from 1999 to 2002 have been processed to create a zero-order geodetic network for Malaysia. (Kadir *et al*., 2003) The realisation of GDM2000 is based on International Terrestrial Reference Frame (ITRF2000) at epoch 1 January 2000 by adopting Geodetic Reference System 1980 (GRS80) as reference ellipsoid. However, a study conducted by Shariff (2014) shows that the MyRTKnet stations have undergone land displacement up to 17 and 30 cm in north and east components respectively, due to a local active fault and the cumulative plate tectonic motion.

Malaysia is a maritime country located in the South-East Asia region. This region is assumed to be part of the stable Eurasian plate derived from a GPS observation network within a small local zone consist of Sumatra, Java, Sulawesi, and Banda arc, that surround the Sunda plate (Tregoning *et al*., 1994; Genrich *et al*., 1996). However, a study conducted by Wilson *et al* (1998) called "Geodynamics of South and Southeast Asia" (GEODYSSEA) has confirmed that Sunda plate is a coherent plate that moves towards east with respect to Eurasia and separated from Siberian platform due to seismic activities (Wilson *et al*., 1998; Chamote-Rooke and Pichon, 1999; Simon *et al*., 1999; Michel *et al*., 2001). A recent study by Simon *et al* (2007) indicates that the Sunda plate, i.e. Indochina, the western and central part of Indonesia is moving eastward with respect to the Eurasian plate at a velocity of 6 ± 1 to 10 ± 3 mm/yr from south to north, respectively.

Sunda Plate is being classified as unstable due to three (3) major earthquakes struck Indonesia, and Malaysia has been affected. Figure 1 shows the locations of 9.2Mw Sumatra-Andaman earthquake on 26 December 2004, followed by 8.6Mw Nias-Simeulue earthquake on 28 March 2005 and 8.5Mw Bengkulu earthquake on 17 September 2007 (USGS, 2019) caused significant land displacement in this region with magnitude up to 10 cm for a radius of 400 km away from the epicentre (Simon *et al*., 2007; Chlieh *et al*., 2007; Socquet *et al*., 2006, Banerjee *et al*., 2007, Vigny *et al*., 2005). During the 8.5Mw Bengkulu earthquake, two aftershocks happened within a day with a magnitude of 7.0 Mw and 7.9Mw back in 2007.

This paper aims to assess the consistency of GDM2000 by analysing the datum shift caused by tectonic movement and reference frame effect. The assessment can be achieved via generating daily solution coordinate of MyRTKnet stations in the latest reference frame i.e. ITRF2014 and analysing coordinate discrepancy between newly generated and publish coordinate provided by JUPEM.

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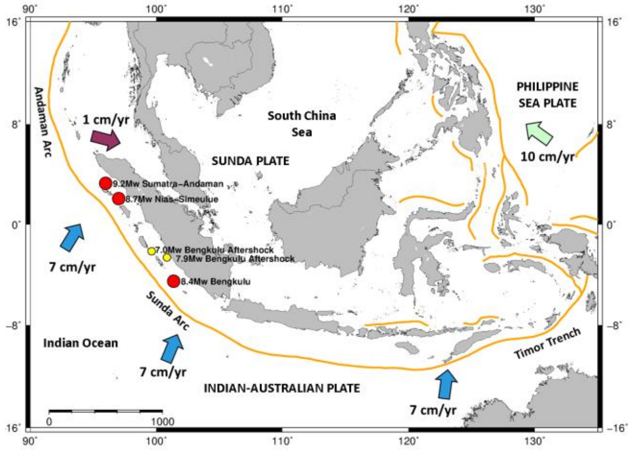

Figure 1. Three (3) major earthquakes and the aftershocks.

2. GPS MEASUREMENT AND DATA PROCESSING

2.1 GPS Network

The analysed network manages by JUPEM comprises of seventy-eight (78) CORS called MyRTKnet i.e. fifty (50) stations distributed in Peninsular Malaysia and remaining twenty-eight (28) stations located in East Malaysia. In order to assess the compatibility of GDM2000 with the current position, GPS observation data on Date of Year (DoY) 001 until 031 in the year 2014 of these stations are processed with the aid of high precision GNSS Bernese software. In order to realise frame definition in ITRF2014, this network is further extended with twelve (12) globally International GPS Service (IGS) sites treated as fiducial stations as shown in Figure 2.

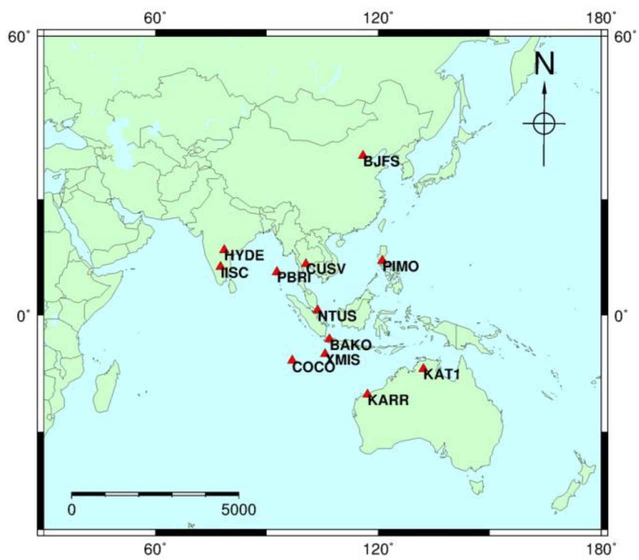

Figure 2. IGS stations adopted in realising frame definition in ITRF2014.

Dual-frequency GPS data from the extended network are processed by applying a Process Control Files (PCF) called RNX2SNX.PCF since it utilises double-difference quasi-ionosphere free (QIF) network processing strategy (Dach *et al*., 2015). Adopting this PCF allows reducing distance-dependent errors for short and medium baselines while QIF ambiguity resolution will cater long baselines. Furthermore, as the processing involves GPS data in a regional network and long-term GPS data observation, the minimum constraint approach will be applied. Table 1 summarise several processing strategies and parameters adopted in the Bernese software processing.

Processing Parameters	Processing Strategy
BPE Process Control File	RNX2SNX.PCF
Input Data	Daily RINEX
Datum	ITRF2014
Network Baseline Creation	OBX-MAX
Elevation Cut-off Angle	3° in CODSPP to first GPSEST 10° in first network GPSEST to final ADDNEQ2 (to reduce further troposphere effects)
Sampling Rate	30 seconds
Orbit	IGS Final Orbit (.SP3)
Receiver Antenna Phase Centre Offsets and Corrections	PHASE_COD.I08
Datum Definition	Minimum constraint to ITRF2014 (ADDNEQ2) Loose constraints in estimating normal equations (GPSEST)
Ocean Loading Model	FES2014b
Ionosphere	Double-difference Ionospheric-Free Linear Combination (L3) with global ionosphere model
Ambiguity Resolution	Fixed, by QIF strategy with baselines <2000km
A Priori Model (Troposphere)	A-priori Saastamoinen model with dry Niell mapping function
Zenith Path Delay Parameter	Mapping function: Wet Niell Parameter spacing: 2 hours

Table 1. Processing strategy and parameters adopted in Bernese processing.

3. RESULTS AND DISCUSSION

There are two (2) parts of the results represented in this section to discuss the assessment of the reliability of GDM2000 which are station repeatability and vector displacement of MyRTKnet stations.

Station repeatability of each MyRTKnet station is plotted for quality checking of data processing. Outliers in the data have been removed by using outliers' functional. Figure 3 shows the repeatability of each station in horizontal and vertical components. Outliers in the Northing component for all stations are relatively below 2 cm except for BELA. The highest value of repeatability in BELA is 2.3 cm. As for the Easting component, the repeatability of each station is below 4 cm except for BELA with 4.8 cm. The fluctuation of repeatability in the vertical component is larger as compared to horizontal however, the value is below 6 cm except for BELA with 7.6 cm. This low precision of coordinate repeatability in BELA is due to data gap occurrence during the observation of the following day.

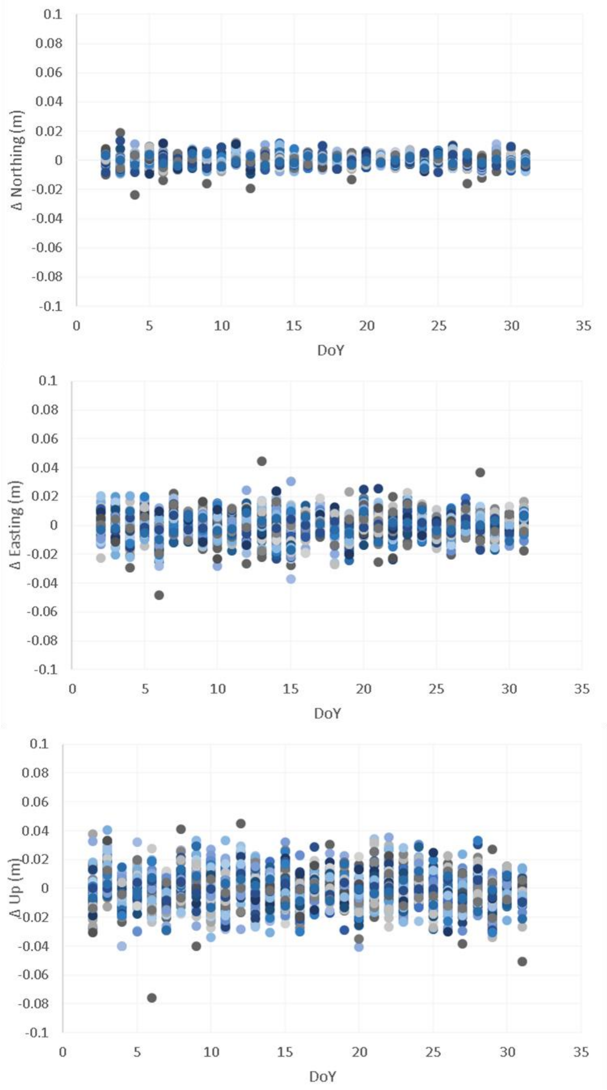

Figure 3. Repeatability of each MyRTKnet station in horizontal and vertical components.

Next, GPS observation data on DoY 001 until DoY 031 are processed to generate thirty-one (31) set of daily solution coordinate. Normal equation stacking is conducted to generate a set of coordinates of epoch 1st January 2014 in ITRF2014. These coordinates are compared to the published set of coordinates of GDM2000 (2006) in ITRF2000 in terms of vector displacements. Figure 4 shows the differences between these two coordinates and can be deduced that the position of MyRTKnet stations moved with an average magnitude of 34.6 cm and orientation of 111.1° from GDM2000 (2006) in ITRF2000 to epoch 2014 in ITRF2014.

The stations are separated into several regions as presented in Figure 4. Hence, different patterns of vector displacement can be seen. The first region is stained with blue, consist of stations located in the Northern part of Peninsular Malaysia. The average vector displacement of the blue region is 31.1 cm magnitude with 110.8° orientation. On the other hand, LGKW and ARAU possessed slightly different in the orientation of 114.1° and 115.1° respectively. This situation can be explained due to the location of these two stations located near to the epicentre of the previous mega-earthquake happened back in 2004 caused the stations to displaced and oriented. The second region is marked green consist of stations in the eastern part of Peninsular Malaysia. The displacement vector of stations is homogeneous with an average magnitude of 33.6 cm and an orientation of 108.7°. However, station CENE has shown an unusual vector displacement in the vertical component with a magnitude of 12.2 cm.

Further study and analysis of CENE long-term coordinate time series need to be conducted before the conclusion of station subsidence can be made. The third region consists of stations located in the central part of Peninsular Malaysia, mark with red. The station vector is homogenous with an average magnitude of 33.9 cm and an orientation of 108.6°. Station LIPI and MERU show a relatively larger vector displacement than other stations in terms of the vertical component with a magnitude of 11.6 cm and 11.4 cm respectively. Similar to CENE, these stations' movement needs to be further analysed by plotting their long-term coordinate time series. Stations located in the southern part of Peninsular Malaysia are marked with yellow.

This region as compared to others in Peninsular Malaysia has the biggest average station orientation of 112.0° with an average magnitude of 34.3 cm. No station subsidence detected since the vector displacement in the vertical component of each station is below 8 cm. East Malaysia is marked with purple and orange for Sarawak and Sabah, respectively. The average magnitude vector displacement of all stations in Sarawak is 37.0 cm with 110.7° orientation. Though, station AMAN and LAWS have a relatively larger vector displacement and orientation as compared to the average value with 43.8 cm of orientation 117.3° and 41.2 cm of the orientation of 115.2° respectively.

Station AMAN is believed to be displaced and subsided since the difference between these two epochs in the vertical component is larger as compared to other stations with a magnitude of 26.7 cm. This deduction can be confirmed as the previous study conducted by Gill *et al.*, (2016) has mentioned that AMAN has a different direction and velocity than the others as it experiences severe subsidence as well as study conducted by Aris (2018), the long-term coordinate time series plotted shows that the station has subsided. Nevertheless, station LAWS need to be plotted its long-term coordinate time series to confirm subsidence has occurred here.

Sabah region has the biggest average vector displacement compared to the other five regions with a magnitude of 37.7 cm and 115.0° orientation. Six (6) stations i.e. BELU, LAB1, MRDU, RANA, TENM, and TMBN displaced more than 40 cm with 116° orientation. this situation can be explained due to Sabah is located close to the most seismically active plate boundaries between the Indian-Australian plate and Eurasian plate in the west and between the Philippine plate in the east (Tongkul, 2017).

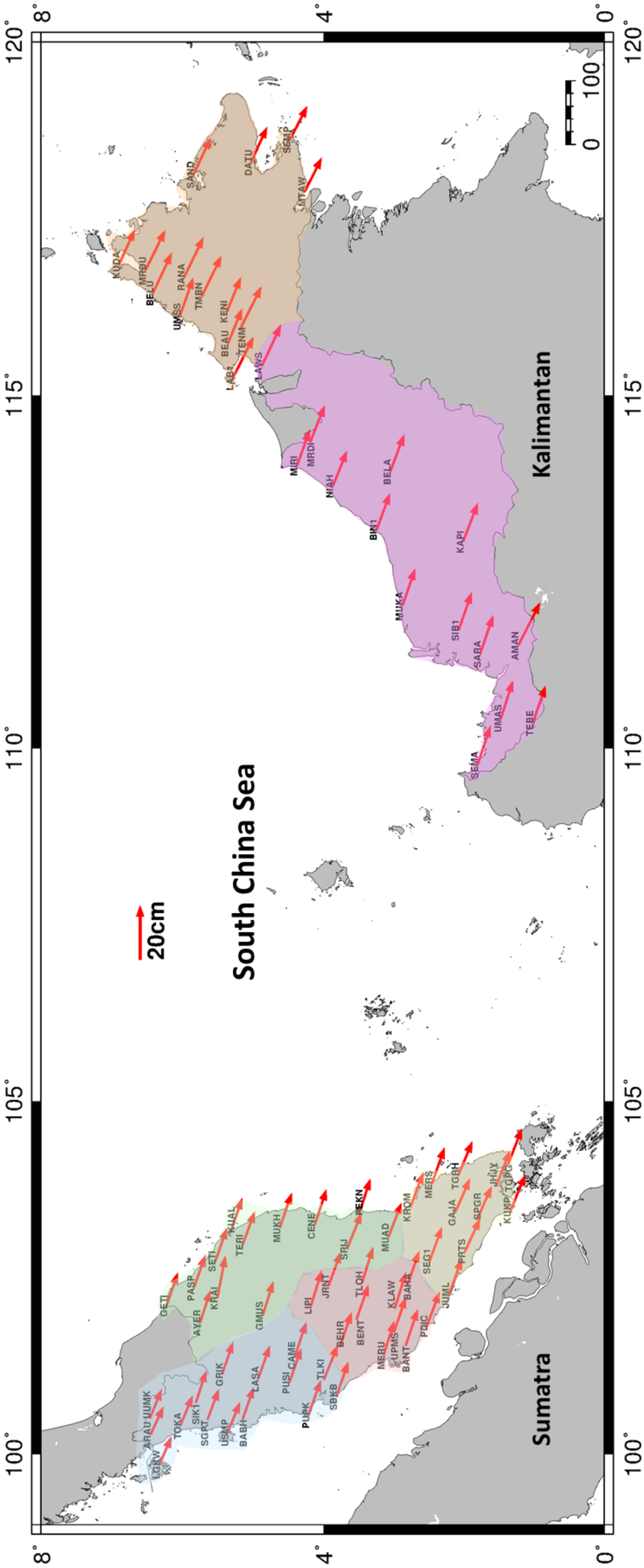

Figure 4. Comparison between GDM2000(2006) in ITRF2000 and Epoch 2014 in ITRF2014.

4. CONCLUSION

This paper shows that the MyRTKnet stations adopted GDM2000 (2006) in ITRF2000 have displaced and there is a coordinate discrepancy between the current ITRF2014 reference frame and GDM2000 (2006). The coordinate discrepancies are relatively larger with an average of 34.6 cm. Coordinate discrepancies of most of the stations are caused by the tectonic movement of the Sunda plate. Furthermore, certain stations are not solely caused by the tectonic movement since soil movement could be one of the factors contributing to station displacement.

This situation may lead to several implications such as inconsistent satellite orbit and coordinate bias as well as problems in surveying and mapping. The mm-level accuracy of the reference station coordinate will also degrade causes the coordinate of the reference station to be unreliable. Eventually, scientific application and research will be affected. It is suggested for further studies to involve long-term GPS observation data for coordinate time series to be analysed for better understanding regarding station displacement.

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