PEKELILING
KETUA PENGARAH UKUR DAN PEMETAAN
BILANGAN 1 TAHUN 2009

GARIS PANDUAN MENGENAI SISTEM RUJUKAN KOORDINAT DI DALAM PENGGUNAAN *GLOBAL NAVIGATION SATELLITE SYSTEM* (GNSS) BAGI TUJUAN UKUR DAN PEMETAAN

JUPEM

JABATAN UKUR DAN PEMETAAN MALAYSIA

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Semua Pengarah Ukur dan Pemetaan Negeri

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1. TUJUAN

Pekeliling ini bertujuan untuk memberikan garis panduan mengenai sistem rujukan koordinat dalam kontek penggunaan *Global Navigation Satellite System* (GNSS) bagi kerja-kerja ukur dan pemetaan di Malaysia.

2. LATAR BELAKANG

2.1 Sistem rujukan koordinat *Malayan Revised Triangulation 1948* (MRT48) dengan Bukit Kertau sebagai titik asalan (*origin*) telah digunakan bagi aktiviti pemetaan dan ukur kadaster sejak tahun 1948 di Semenanjung Malaysia. Datum rujukan geodetik bagi sistem ini adalah Datum Kertau yang menggunakan elipsoid *Modified Everest (Kertau).* Bagi Sabah, Sarawak dan Labuan pula, aktiviti ukur dan pemetaan telah dijalankan dengan menggunakan sistem rujukan koordinat *Borneo Triangulation 1968* (BT68) dengan Bukit Timbalai sebagai titik asalan. Datum rujukan geodetik bagi BT68 adalah Datum Timbalai yang menggunakan elipsoid *Modified Everest (Timbalai).*

2.2 Penggunaan teknologi GNSS bagi kerja-kerja ukur dan pemetaan di Malaysia telah bermula sejak tahun 1989. Dalam hal ini, Jabatan Ukur dan Pemetaan Malaysia (JUPEM) telah menghasilkan sistem-sistem rujukan koordinat dengan menggunakan teknik *Global Positioning System* (GPS), iaitu *Peninsular Malaysia Geodetic Scientific Network* (PMGSN94) pada tahun 1994, diikuti dengan *East Malaysia Geodetic Scientific Network* (EMGSN97) pada tahun 1997. Seterusnya dalam tahun 2003, kerangka rujukan geodetik GPS pasif tersebut telah diperkukuhkan bagi menghasilkan *Malaysia Primary Geodetic Network* (MPGN2000).

2.3 Dalam pada itu, antara tahun 1998 dan 2008, JUPEM telah membangunkan rangkaian-rangkaian GPS/GNSS aktif, iaitu *Malaysia Active GPS System* (MASS) antara tahun 1998 dan 2001 dan diikuti dengan penubuhan *Malaysia Real-Time Kinematic GNSS Network* (MyRTKnet) antara tahun 2002 dan 2008.

2.4 Bagi memenuhi tuntutan semasa yang menjurus kepada penggunaan datum rujukan global yang bersifat geosentrik, JUPEM telah selanjutnya melancarkan datum rujukan geodetik baru yang seragam bagi kerja-kerja ukur dan pemetaan di Malaysia pada 26 Ogos 2003. Datum ini dikenali dengan nama *Geocentric Datum of Malaysia* (GDM2000), di mana elipsoid rujukan adalah *Geodetic Reference System 1980* (GRS80). Titik asalan bagi sistem-sistem rujukan koordinat yang berasaskan GDM2000 ini adalah di pusat jisim bumi (geosentrik).

2.5 Pada tahun 2004 dan 2005 telah berlaku gempa bumi besar, masing-masingnya bermagnitud 9.2 dan 8.7 pada skala Ritcher di Sumatra, Indonesia dan kejadian ini telah menyebabkan anjakan yang signifikan terhadap sistem koordinat GDM2000. Sehubungan itu, pemantauan anjakan keatas sistem-sistem rujukan koordinat telah dilakukan oleh JUPEM secara berterusan melalui analisis anjakan ke atas stesen-stesen MyRTKnet. Analisis mendapati bahawa sistem-sistem rujukan koordinat yang berasaskan GDM2000 perlu disemak dan dihitung semula, terutamanya bagi kerja-kerja pengukuran yang memerlukan penggunaan sistem rujukan koordinat yang berkejituan tinggi seperti di dalam bidang geodesi dan geodinamik.

2.6 Hasil daripada semakan dan hitungan semula tersebut yang menggunakan produk data GPS bermula 1 Januari 2006 hingga 30 April 2009, siri set koordinat baru yang dikenali sebagai GDM2000 (2009) bagi rangkaian-rangkaian GNSS/GPS aktif dan pasif telah diterbitkan oleh JUPEM.

3. GARIS PANDUAN PENGGUNAAN SISTEM RUJUKAN KOORDINAT

Penerangan lebih lanjut tentang amalan penggunaan sistem rujukan koordinat terkandung di dalam dokumen *Technical Guide to the Coordinate Reference Systems* seperti di **Lampiran ‘A’** yang disertakan. Intisari kandungan garis panduan tersebut adalah seperti berikut:

Perenggan Perkara

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2.2 BORNEO TRIANGULATION 1968 (BT68)

3. GPS-BASED NETWORKS

3.1 PENINSULAR MALAYSIA GEODETIC SCIENTIFIC NETWORK 1994 (PMGSN94)

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4. PEMAKAIAN

4.1 Sistem-sistem rujukan koordinat yang dinyatakan di dalam pekeliling ini hendaklah digunakan berdasarkan tarikh-tarikh tertentu seperti yang dinyatakan dalam **Jadual 1** dan **Jadual 2** di bawah:

Jadual 1 : Jaringan GPS/GNSS Pasif Malaysia

Bil	Sistem Rujukan Koordinat		Tarikh Penggunaan
	Sistem Koordinat	**Datum Geodetik**	
1	*Peninsular Malaysia Geodetic Scientific Network 1994 (PMGSN94)*	**WGS84** *Ellipsoid: WGS84* *Reference Frame: WGS84* *Epoch: 1987.0*	1 Januari 1994 hingga 22 Ogos 2003
2	*East Malaysia Geodetic Scientific Network 1997 (EMGSN97)*	**WGS84** *Ellipsoid: WGS84* *Reference Frame: WGS84 (G783)* *Epoch: 1997.0*	1 Januari 1997 hingga 22 Ogos 2003
3	*Malaysia Primary Geodetic Network 2000 (MPGN2000)*	**GDM2000** *Ellipsoid*: *GRS80* *Reference Frame: ITRF2000* *Epoch: 2000.0*	23 Ogos 2003 hingga 30 April 2009
		GDM2000 (2009) *Ellipsoid*: *GRS80* *Reference Frame: ITRF2000* *Epoch: 2000.0*	Mulai 1 Mei 2009

Jadual 2 : Jaringan GPS/GNSS Aktif Malaysia

Bil	Sistem Rujukan Koordinat		Tarikh Penggunaan
	Sistem Koordinat	**Datum Geodetik**	
1	*Malaysia Active GPS System (MASS)*	**GDM2000** *Datum: GRS80* *Reference Frame: ITRF2000* *Epoch: 2000.0*	1 Januari 1999 hingga 30 April 2009
2	*Malaysia Real-Time Kinematic GNSS Network (MyRTKnet)*	**GDM2000** *Datum: GRS80* *Reference Frame: ITRF2000* *Epoch: 2000.0*	12 Mei 2004 hingga 30 April 2009
		GDM2000 (2009) *Datum: GRS80* *Reference Frame: ITRF2000* *Epoch: 2000.0*	Mulai 1 Mei 2009

4.2 Bagi pengguna-pengguna yang terlibat di dalam kerja-kerja ukur yang memerlukan ketepatan dan kejituan yang tinggi, khususnya bidang geodesi dan geodinamik, tarikh penggunaan sistem-

sistem rujukan koordinat berasaskan GDM2000 adalah sehingga 31 Disember 2005, manakala tarikh penggunaan sistem-sistem rujukan koordinat berasaskan GDM2000 (2009) adalah mulai 1 Januari 2006.

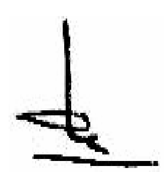
4.3 Pengguna-pengguna boleh mendapatkan nilai-nilai koordinat dan maklumat lokasi bagi setiap stesen trigonometri dan stesen GPS/GNSS dengan menghubungi Ibu Pejabat JUPEM, Kuala Lumpur atau dengan melayari Laman Web JUPEM, iaitu http://www.jupem.gov.my. Selain itu, JUPEM juga turut menyediakan maklumat dan perkhidmatan penukaran koordinat dan transformasi datum bagi semua sistem rujukan koordinat serta unjuran peta kepada para pengguna.

5. TARIKH BERKUATKUASA

Pekeliling ini adalah berkuatkuasa mulai tarikh ianya dikeluarkan.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"



(DATUK HAMID BIN ALI)
Ketua Pengarah Ukur dan Pemetaan
Malaysia

Salinan kepada:

Timbalan Ketua Pengarah Ukur dan Pemetaan

Pengarah Ukur Bahagian (Pemetaan)

Pengarah Ukur Bahagian (Kadaster)

Pengarah
Bahagian Geospatial Pertahanan

Setiausaha Bahagian (Tanah, Ukur dan Pemetaan)
Kementerian Sumber Asli dan Alam Sekitar

Pengarah
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Kementerian Sumber Asli dan Alam Sekitar

Pengarah
Pusat Infrastuktur Data Geospatial Negara (MaCGDI)
Kementerian Sumber Asli dan Alam Sekitar

Ketua Penolong Pengarah
Unit Ukur Tanah, Cawangan Pengkalan Udara dan Maritim
Ibu Pejabat Jabatan Kerja Raya Malaysia

Penolong Pengarah
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Setiausaha
Lembaga Jurukur Tanah Semenanjung Malaysia

Setiausaha
Lembaga Jurukur Tanah Sabah

Setiausaha
Lembaga Jurukur Tanah Sarawak

Lampiran 'A'

Technical Guide
to the
Coordinate Reference Systems

JUPEM

JABATAN UKUR DAN PEMETAAN MALAYSIA

2009

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Coordinate reference systems have been established in many regions around the world by national mapping authorities since the 19th century, using conventional surveying techniques and procedures. Most of them use local datums that are confined to small areas of the globe, fit to limited areas to satisfy national mapping requirements. This is also the case with Malaysia where it has in place two old/classical triangulation networks, namely the Malayan Revised Triangulation 1968 (MRT68) for Peninsular Malaysia and the Borneo Triangulation 1968 (BT68) for Sabah and Sarawak.

1.2 With the recent advances in space-based positioning technology, many countries have begun to implement and subsequently adopted a global geocentric coordinate reference system. In relation to this, JUPEM itself has embraced in the early 1990s the Global Positioning System (GPS) technology with the eventual objective of adopting a global unified datum for Peninsular Malaysia, Sabah and Sarawak. This later led to the establishment of the Peninsular Malaysia GPS Scientific Network 1994 (PMGSN94) and East Malaysia GPS Scientific Network 1997 (EMGSN97), comprising of 238 stations and 171 stations respectively.

1.3 Subsequently, JUPEM established the permanent GPS tracking stations known as Malaysia Active GPS System (MASS) at the end of 1998, with eighteen (18) stations making up the whole MASS infrastructure. Coupled with the GPS data obtained from the International Global Navigational Satellite System (GNSS) Service (IGS) stations, the coordinates of MASS stations were derived from 4-years of continuous GPS data (1999 - 2002). Collectively, these coordinates represent the basis for the determination of the Geocentric Datum of Malaysia (GDM2000), which was launched on 26 August 2003.

1.4 Between 2002 and 2008, JUPEM further developed a modern active GNSS network with the latest state-of-the-art technology to establish the Malaysia Real-Time Kinematic GNSS Network or MyRTKnet. The new MyRTKnet system is able to provide real-time positioning services at centimeter-level accuracy to users in the field.

1.5 However, there were significant displacements of positions of the aforementioned Malaysian geodetic infrastructure as a result of two major Indonesian earthquakes that occurred in 2004 and 2005. Nevertheless, due to the relatively stable conditions that followed in the past four years (albeit still quite unpredictable), JUPEM has taken further steps to revise the coordinate reference systems, using GPS data from the years 2006 to 2008 of MyRTKnet and IGS stations. The resultant coordinates obtained through this endeavour are known as GDM2000 (2009).

1.6 This technical guide then is produced to give an overview of the coordinate reference systems that are available in Malaysia and to assist users in understanding the concept, strategies and procedures involved in the move towards the adoption of GDM2000 in 2003 and its subsequent revision carried out in 2009.

2. OLD TRIANGULATION NETWORKS

2.1 MALAYAN REVISED TRIANGULATION 1968 (MRT68)

2.1.1 JUPEM could trace its origin to way back in 1885. The 1880s marked an important phase with the commencement of widespread trigonometrical works in various parts of Malaya, including a triangulation survey in Penang in 1832.

2.1.2 The trigonometrical survey in Perak together with the Penang and Province Wellesley triangulations as well as Malacca Triangulation

(1886 - 1888) laid the foundation for the existing control framework. This was followed by the commencement of other trigonometrical surveys in various parts of the country that included Selangor and Negeri Sembilan.

2.1.3 However, the early works were so inconsistent and of questionable quality that it was decided to re-observe the principal triangles of the general triangulation with the object of bringing it up to modern standards of that time. This triangulation scheme in Peninsular Malaysia which was completed in 1916 is known as the Primary or Repsold Triangulation.

2.1.4 The Primary or Repsold Triangulation was later replaced by a new system known as the Malayan Revised Triangulation 1948 (MRT48). This was subsequently followed by a lengthy process of additional measurements and re-computation until 1968, which eventually resulted in a system referred to as MRT68.

2.1.5 The MRT68 network consists of 77 geodetic, 240 primary, 837 secondary and 51 tertiary stations. It is based on conventional observations with many of the triangulation points dated as far back as 1885. The MRT68 has been adopted as a result of the re-computations of the earlier network together with the Primary or Repsold Triangulation (Figure 1) carried out between 1913 and 1916. The reference ellipsoid used for MRT68 is in Table 1 below. The map projection used for mapping in Peninsular Malaysia is Rectified Skew Orthomorphic (RSO) and Cassini Soldner for cadastral surveying. Table 2 tabulates the parameters for map projection used in Peninsular Malaysia.

Table 1 Reference Ellipsoids for MRT68 and BT68

No.	Parameter	MRT68	BT68
1.	Reference Ellipsoid	Modified Everest	Modified Everest
2.	Origin	Kertau, Pahang	Timbalai, Labuan
3.	Semi-major axis (a)	6 377 304.063	6 377 298.556
4.	Semi-Minor Axis (b)	6 356 103.039	6 356 097.550
5.	Flattening (f)	1/300.8017	1/300.8017

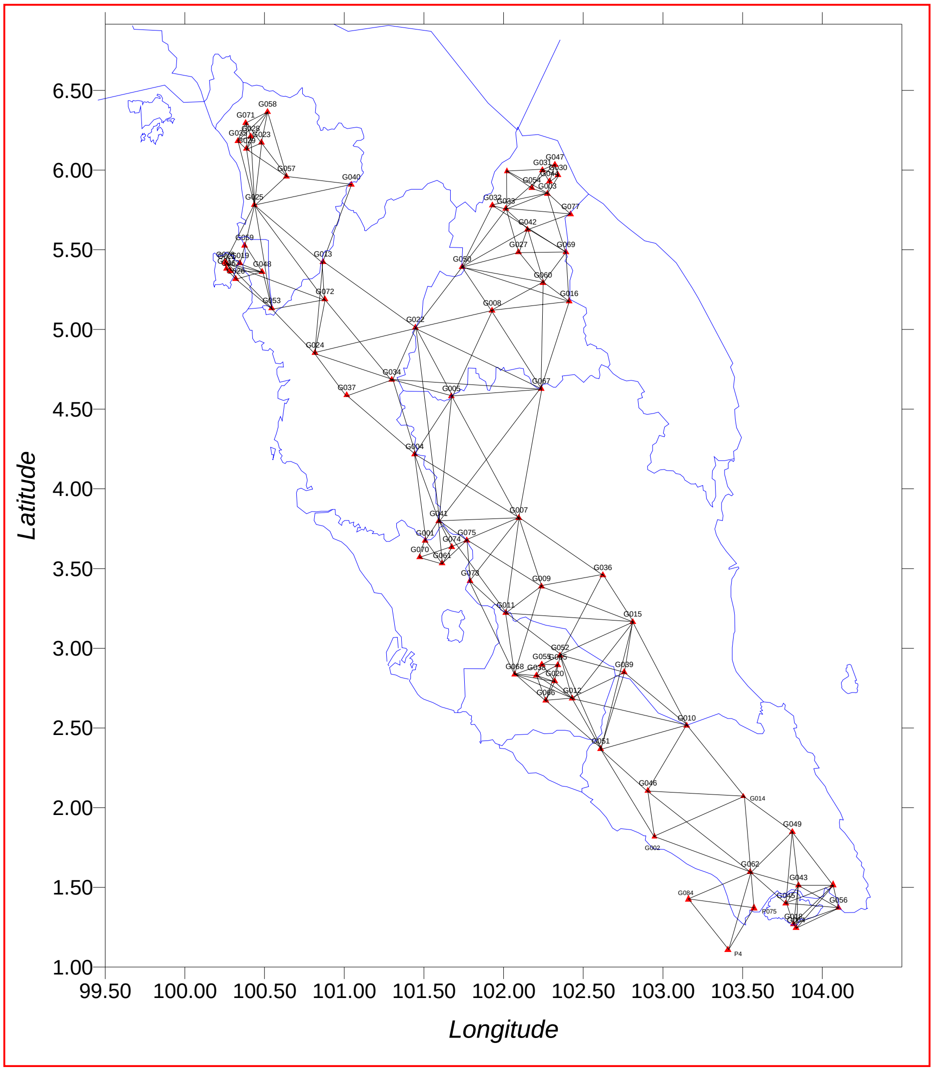

Figure 1: Malayan Revised Triangulation 1968 (MRT68)

2.2 BORNEO TRIANGULATION 1968 (BT68)

2.2.1 Sabah started its primary triangulation work in a project known as the Borneo West Coast Triangulation between 1930 and 1942. In around 1935, Sarawak and Brunei also began their primary triangulation projects.

2.2.2 The Directorate of Overseas Survey (DOS) undertook the task of readjusting the whole primary triangulation of Borneo. The adjusted results for the Primary Triangulation of Borneo 1948 were then published in terms of Timbalai Datum and Modified Everest ellipsoid.

2.2.3 The East Coast Triangulation was later introduced and initiated by DOS and observations were carried out in the year 1955 to 1960. The aim of this triangulation was to extend the Primary Triangulation of Borneo to the eastern side of Sabah. EDM traversings were also carried out in 1961 to 1968 to supplement the work.

2.2.4 The combined geodetic networks in Sabah and Sarawak, known as the Borneo Triangulation 1968 (BT68), was established with the station at Bukit Timbalai (in the island of Labuan) as the origin. BT68 consequently resulted from the readjustment of the primary control of East Malaysia (Sabah, Sarawak and Brunei) made by the DOS.

2.2.5 The BT68 network consists of the Borneo West Coast Triangulation of Brunei and Sabah (1930-1942), Borneo East Coast Triangulation of Sarawak and extension of the West Coast Triangulation in Sabah (1955-1960) as well as some new points surveyed between 1961 and 1968. This geodetic network is shown in Figure 2 with the reference ellipsoid used given in Table 1. The map projection employed for mapping and cadastral surveys is RSO and Table 2 shows the various parameters used.

Table 2: Map Projections for Peninsular Malaysia, Sabah and Sarawak

No.	Parameter	Peninsular Malaysia	Sabah & Sarawak
1.	Projection Name	Malayan RSO	Borneo RSO
2.	Datum	Kertau	Timbalai
3.	Conversion Factor	1 chain = 20.11678249m (Chaney & Benoit, 1896)	1 chain= 20.11676512m (Sears, Jolly & Johnson, 1927)
4.	Origin of Projection	N 4° 00' , E 102° 15'	N 4° 00' , E 115° 00'
5.	Scale Factor (Origin)	0.99 984	0.99 984

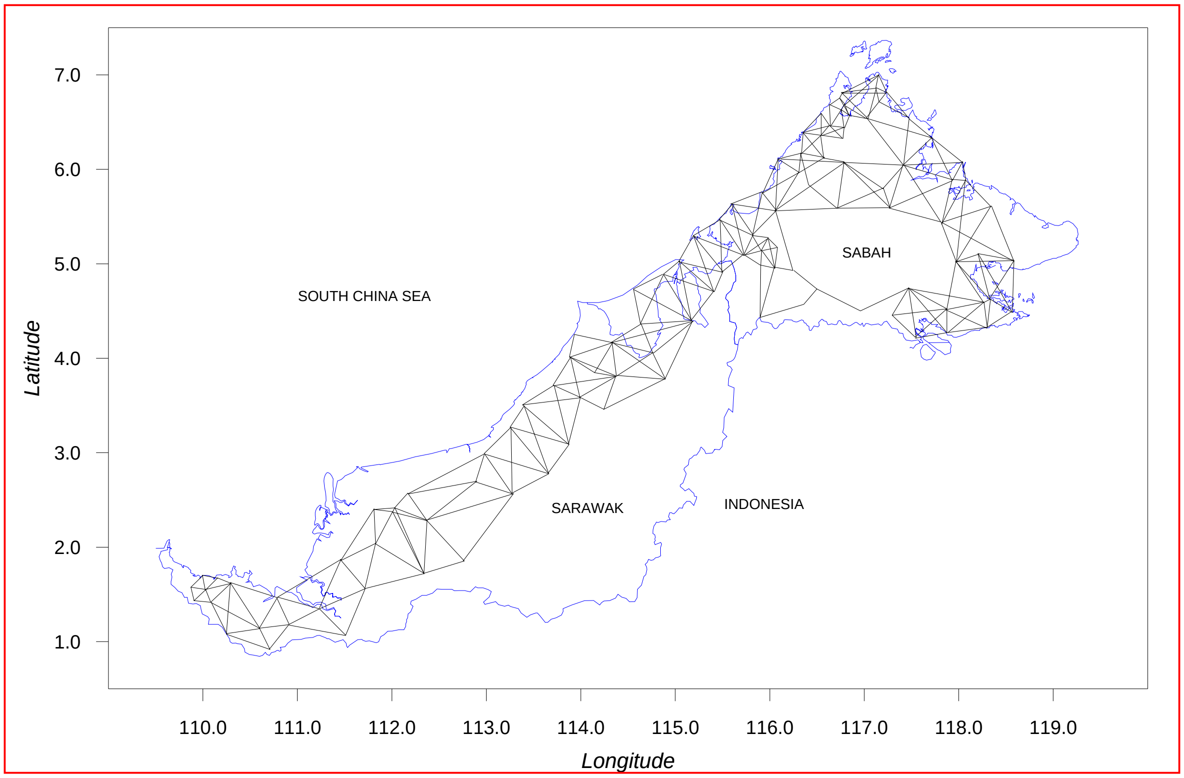

Figure 2: Borneo Triangulation 1968 (BT68)

3. GPS-BASED NETWORKS

3.1 PENINSULAR MALAYSIA GEODETIC SCIENTIFIC NETWORK 1994 (PMGSN94)

3.1.1 As stated earlier, old triangulation networks such as MRT68 and BT68 are regional in nature and are thus not aligned with global geocentric coordinate frames. On the other hand, earth-centered geocentric system is difficult to define - not until the recent development of space-based positioning systems. This was made possible over the last decade or so because the space-based positioning satellites revolve around the center of mass of the earth and are therefore related to an earth-centered or geocentric datum.

3.1.2 The World Geodetic System of 1984 or WGS84 is one such system, which is maintained by the United States Department of Defense for GPS-based positioning. Another is the International Terrestrial Reference Frame (ITRF) and it is reported to be compatible with WGS84 at the centimeter level.

3.1.3 In an effort to harness the full prowess of the space-based technology, JUPEM has established a GPS network of 238 stations in Peninsular Malaysia, called the Peninsular Malaysia Geodetic Scientific Network 1994 (PMGSN94), as in Figure 3. The main objectives of setting up PMGSN94 are to establish a new geodetic network based on GPS observations and to analyse the existing geodetic network. The network has been observed using four Ashtech LX II dual frequency GPS receivers and the acquired data was processed and adjusted in 1994.

3.1.4 In the network adjustment, a minimally constrained adjustment was made with Kertau, Pahang, held fixed. The coordinates of Kertau are in approximate WGS84 and derived from Doppler coordinates of NSWC 9Z-2 reference frame. The Ashtech GPS Post-Processing

Software (GPPS) with broadcast ephemeris was used for the determination of the baseline solutions. The relative accuracy of the network is between 1-2 ppm for the horizontal coordinates and between 3-5 ppm for the vertical coordinates. The summary of the results of the network adjustment using Geolab network adjustment software is tabulated in Table 3.

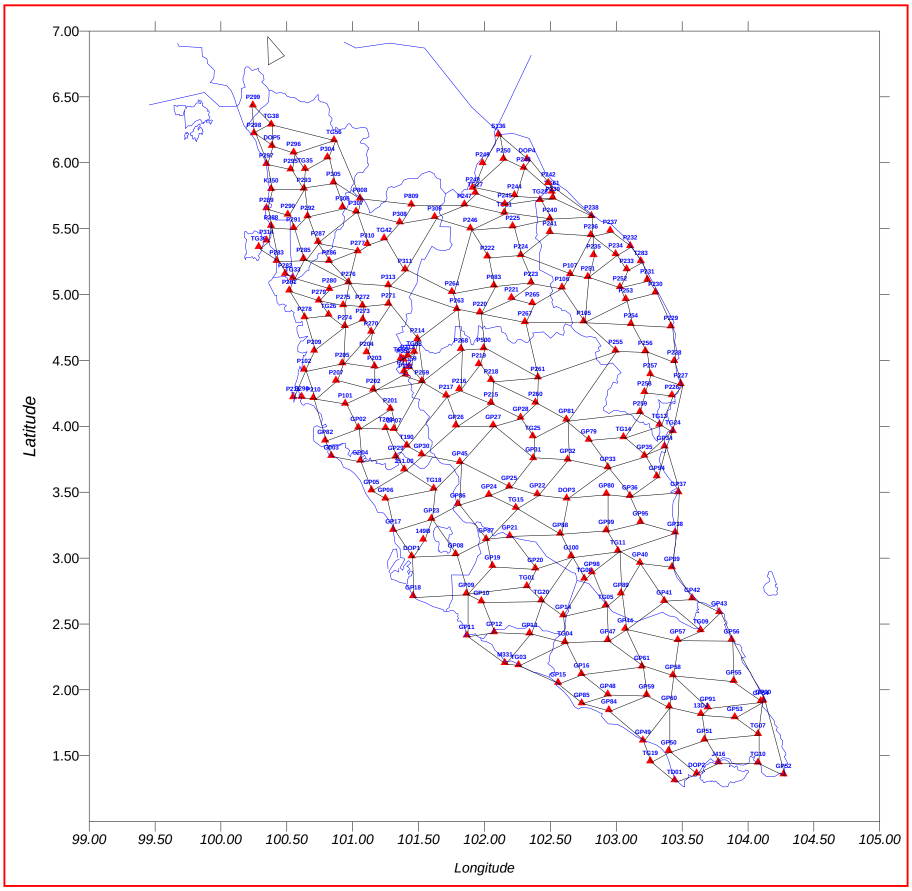

Figure 3: Peninsular Malaysia GPS Scientific Network 1994 (PMGSN94)

Table 3: Results of Minimally Constrained Adjustment for PMGSN94

Network Adjustment Software Used	Geolab Network Adjustment
Fixed Point in 3D	Kertau, Pahang
Approximate Positions	237
Number of Parameters	711
No. of Observations	3594
Redundancy	2883
Weights Used	σ_N = 5mm ± 0.5 ppm σ_E = 5mm ± 0.7 ppm σ_U = 7mm ± 1.1 ppm
Variance Factor Used	0.9952
Chi-Square Test	Passed
Station Error Ellipses	Hort: 0.038 – 0.094 Vert: 0.032 – 0.080
Relative Error Ellipses	Hort: 0.013 – 0.031 Vert: 0.011 – 0.030
Average Baseline Accuracies	Hort: < 1.5 ppm Vert: < 2.0 ppm

3.2 EAST MALAYSIA GEODETIC SCIENTIFIC NETWORK 1997 (EMGSN97)

3.2.1 Following the successful completion of PMGSN94 in Peninsular Malaysia, JUPEM began making plans to establish a similar type of GPS-derived geodetic network in Sabah and Sarawak. For this purpose, GPS observations were made using Trimble 4000SSE L1/L2 receivers to establish the East Malaysia Geodetic Scientific Network 1997 (EMGSN97) that comprises a total of 171 GPS stations as shown in Figure 4.

3.2.2 In the network adjustment, a constrained adjustment was made with coordinates from the Special Technical Royal Engineer (STRE) GPS campaign fixed. Broadcast ephemeris was used for the baseline determinations. The relative accuracy of the network is found to be better than 1 ppm for the horizontal coordinates and 2-3 ppm for the vertical coordinates. The summary of the results of the network adjustment using Geolab network adjustment software is tabulated in Table 4.

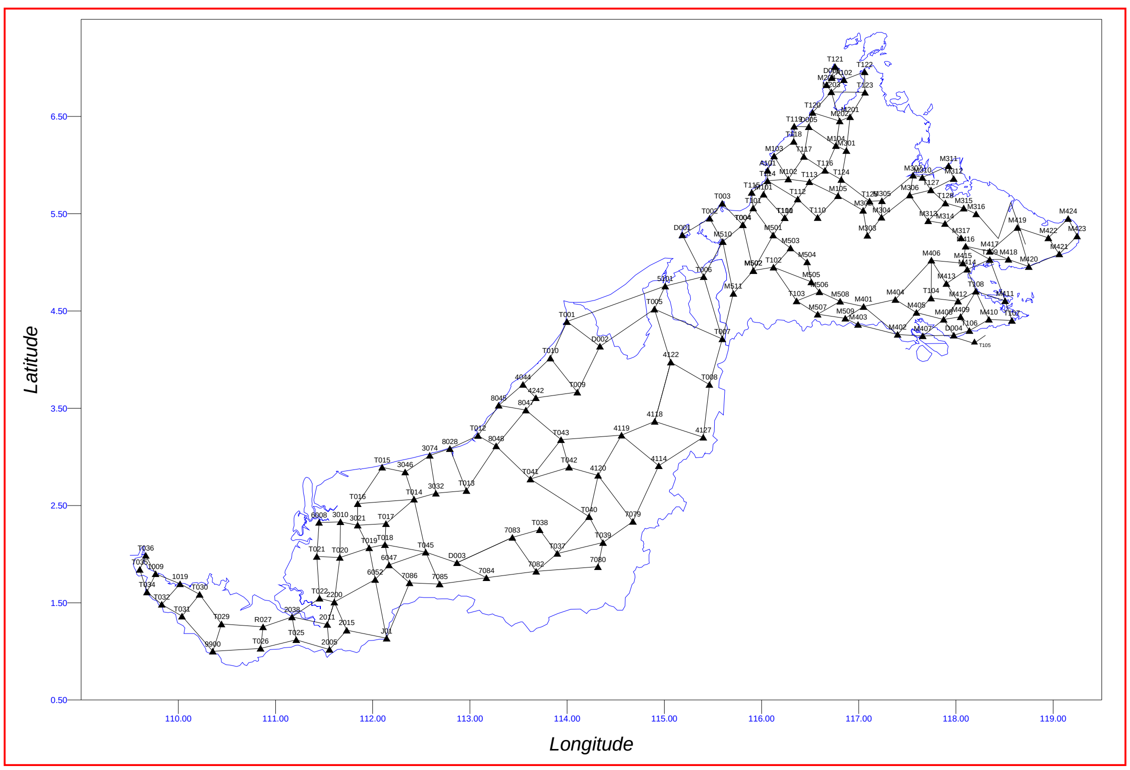

Figure 4: East Malaysia Geodetic Scientific Network 1997 (EMSGN97)

Table 4: Results of Constrained Adjustment for EMGSN97

Network Adjustment Software Used	Geolab Network Adjustment
Fixed Points in 3D	Five (5) Stations from STRE GPS Campaign
Approximate Positions	166
Number of Parameters	498
No. of Observations	1218
Redundancy	720
Weights used	σ_N = 2mm ± 0.2 ppm σ_E = 2mm ± 0.2 ppm σ_U = 2.5mm ± 0.5 ppm
Variance Factor Used	0.9600
Chi-Square Test	Passed
Station Error Ellipses	Hort: 0.009 – 0.044 Vert: 0.010 – 0.055
Relative Error Ellipses	Hort: 0.007 – 0.040 Vert: 0.008 – 0.052
Average Baseline Accuracies	Hort: 0.6 ppm Vert: 0.8 ppm

4. GEOCENTRIC DATUM OF MALAYSIA (GDM2000)

4.1 INTRODUCTION

4.1.1 The Geocentric Datum of Malaysia or GDM2000 is the new national geodetic datum for Malaysia and it replaces the old datum of MRT48 and BT68. It was officially launched nationwide on 26 August 2003.

4.1.2 The development of GDM2000 began firstly by the establishment of the zero-order network of permanent GPS stations known as the Malaysia Active GPS System (MASS). This was followed by the establishment of the Malaysia Primary Geodetic Network 2000 or MPGN2000 by strengthening the PMGSN94 and EMGSN97 networks via a GPS observation campaign performed at selected stations to form a connection to the MASS network. Subsequently, the MASS network is replaced by another network of active GNSS stations known as the Malaysia Real-Time Kinematic GNSS Network or MyRTKnet.

4.2 MALAYSIA ACTIVE GPS NETWORK (MASS)

4.2.1 Malaysia Active GPS Network or MASS is a permanent network of active GPS stations that was established in 1999 and formed a homogeneous and coherent geodetic infrastructure, covering the whole of Malaysia. The MASS station's GPS data were used along with those from the International GNSS Service (IGS) stations for the realization of the zero-order geodetic network for Malaysia.

4.2.2 GPS data from seventeen (17) MASS stations (Figure 5) and eleven (11) IGS stations (Figure 6) from 1999 to 2002 have been processed to establish the zero-order geodetic network. The eleven (11) permanent GPS tracking stations of the IGS world-wide network in ITRF2000 Epoch 1997 were used as fiducial points in the processing to obtain the MASS set of station coordinates.

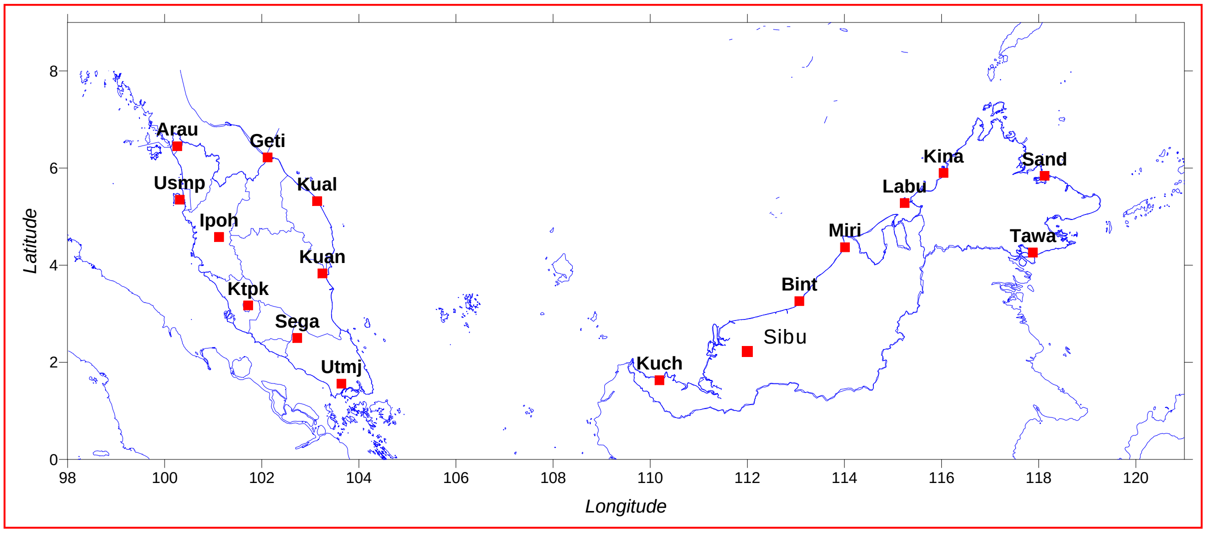

Figure 5: Distribution of MASS stations

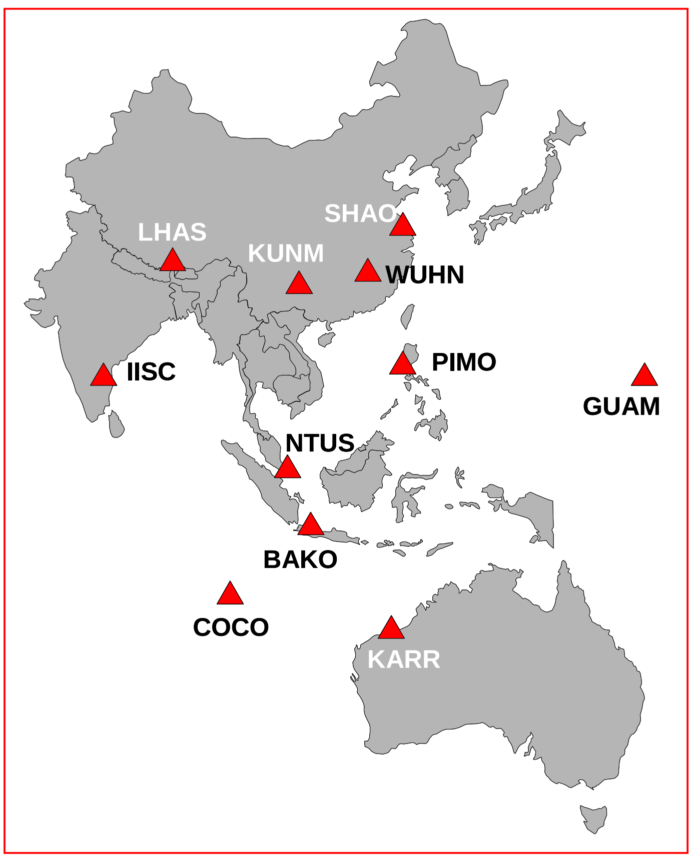

Figure 6: IGS stations used to derive MASS coordinates in ITRF2000

4.2.3 The reference IGS station coordinates which are in ITRF2000 at epoch 1997.0 were transformed to the same epoch as the adjusted MASS station coordinates, i.e. ITRF 2000 at epoch 2000.00. From the free network adjustment, the resulting accuracy of the MASS stations with respect to the ITRF2000 reference frame at epoch 2000.0 is between 9 to 15 mm in the horizontal component and between 12 to 19 mm in vertical component.

4.2.4 In the heavily constrained adjustment, a specific reference frame in ITRF2000 was adopted and results indicated that the accuracy of station coordinates is between 3 to 16 mm in the horizontal component and between 8 to 13 mm for the vertical component. Thus, the coordinates of the heavily constrained adjustment was adopted as the final coordinates in ITRF2000 at epoch 2 January 2000. These new set of coordinates are known as the Geocentric Datum of Malaysia or GDM2000 and was officially adopted on 26 August 2003.

4.3 MALAYSIAN PRIMARY GEODETIC NETWORK 2000 (MPGN2000)

4.3.1 Following the availability of MASS network in GDM2000 coordinates, JUPEM carried out further efforts to transform the PMGSN94 and EMGSN97 networks into the newly adopted datum. Both networks formed the new Malaysia Primary Geodetic Network 2000 (MPGN2000) and were strengthened by connecting them to the MASS network. This was achieved by carrying out GPS campaigns to re-observe thirty-six (36) stations of PMGSN94 in 2000 and thirty (30) stations of EMGSN in 2002 for a period of 48 hours to form the strengthening network (Figures 7 and 8). The outcome defines a new Malaysia Primary Geodetic Network 2000 (MPGN2000) for the whole of Malaysia (Figure 9) based on the GDM2000 reference frame.

4.3.2 Heavily constrained adjustment with MASS stations held fixed was made to adjust the observed baseline vectors and obtain the link station's coordinates, which conform to GDM2000. The accuracy of stations in horizontal and vertical components is less than 14 mm. The adjustment of the MPGN2000 using the old vectors has eventually achieved the primary target of obtaining 3 cm accuracy station coordinate, referred to the ITRF2000 Epoch 1 Jan 2000.

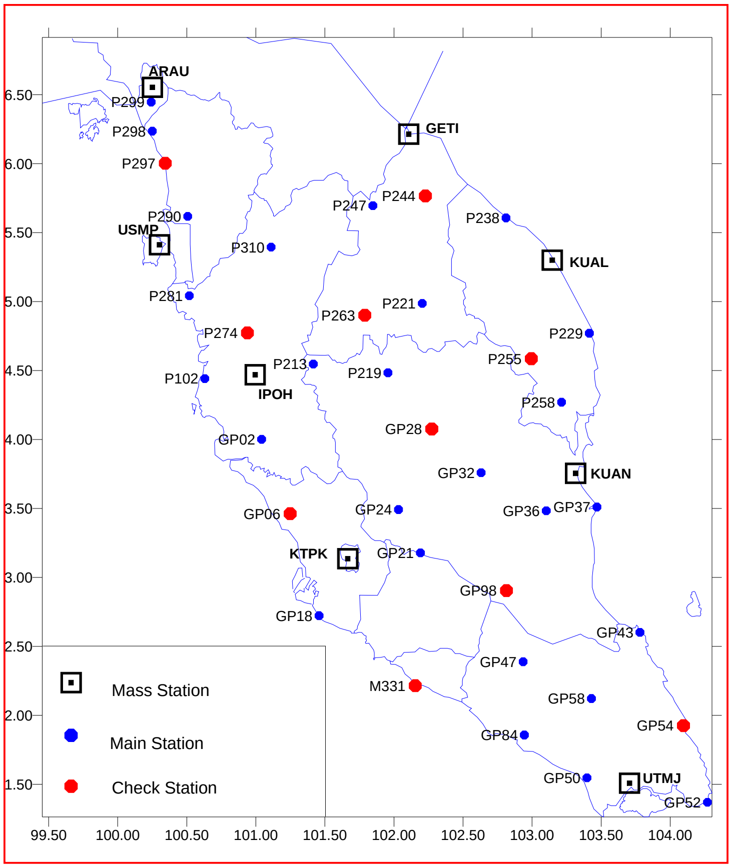

Figure 7: Link Stations Distribution in Peninsular Malaysia

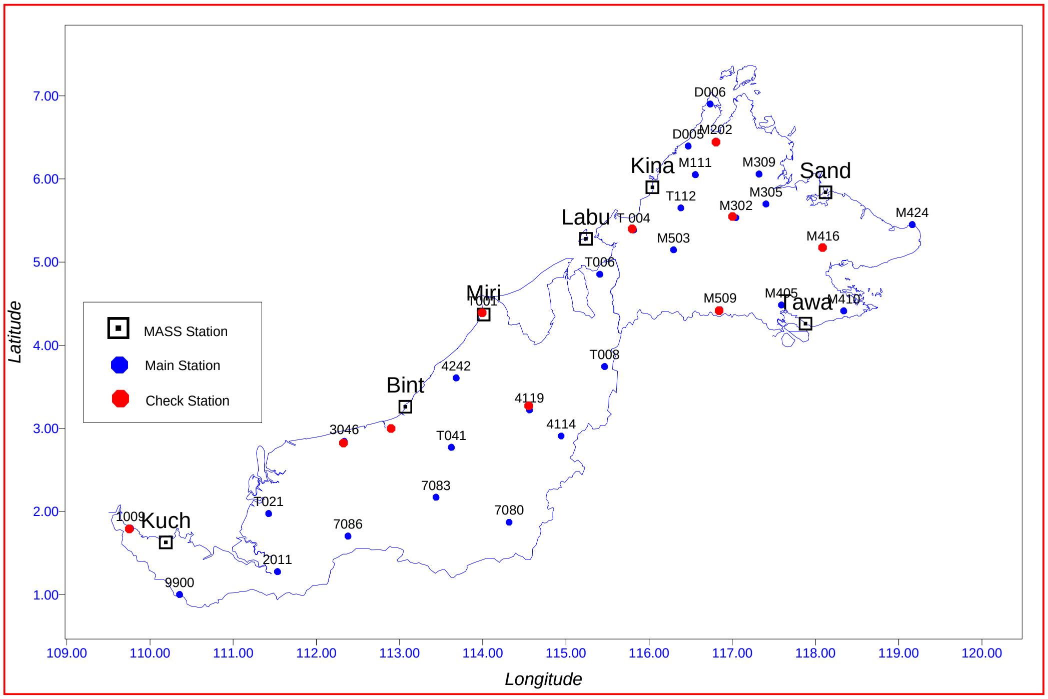

Figure 8: Link Stations Distribution in East Malaysia

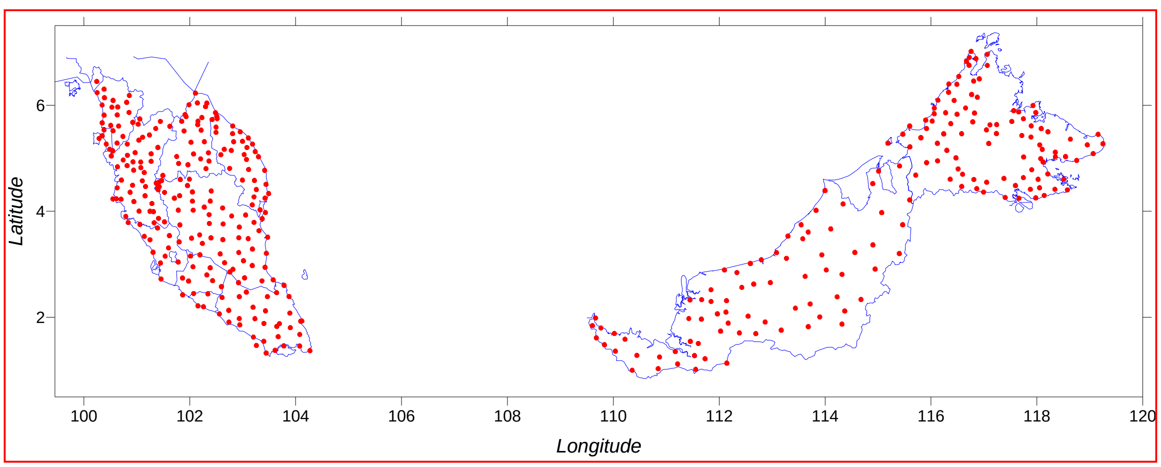

Figure 9: MPGN2000 Stations in Peninsular Malaysia, Sabah & Sarawak

4.4 MALAYSIA REAL-TIME KINEMATIC GNSS NETWORK (MyRTKnet)

4.4.1 Beginning 2002, JUPEM has established a network known as the Malaysia Real-Time Kinematic GNSS Network or MyRTKnet that uses a new generation of RTK solution known as Virtual Reference Station (VRS). MyRTKnet is based on a network of GPS reference stations continuously connected via tele-communication network to the control centre, situated at JUPEM headquarters in Kuala Lumpur (Figures 11 and 12).

4.4.2 By the end of 2008, Malaysia has seventy-eight (78) RTK reference stations for the network with fifty (50) stations covering the whole Peninsular Malaysia, apart from fourteen (14) stations each covering Sabah and Sarawak. The spacing between stations ranges from 30 to 100 km. Each station is equipped with either a Trimble 5700 or a NetR5 GPS receiver, antenna, power supply and modem to communicate with the central facility via Internet Protocol Virtual Private Network (IPVPN) communication infrastructure.

4.4.3 The central facility at JUPEM headquarters in Kuala Lumpur continuously gathers the information from GPS receivers at all MyRTKnet stations and creates a living database of regional area corrections. With MyRTKnet, a virtual reference station will be established for any single roving GPS user near the survey area. It also models the spatial errors that limit GPS accuracy through a network solution and in turn generates corrections for the roving GPS users to be positioned anywhere inside the network with an accuracy better than a few centimetres to a few decimetres in real-time. A web site is also available to enable downloading of GPS data for post-processing solutions.

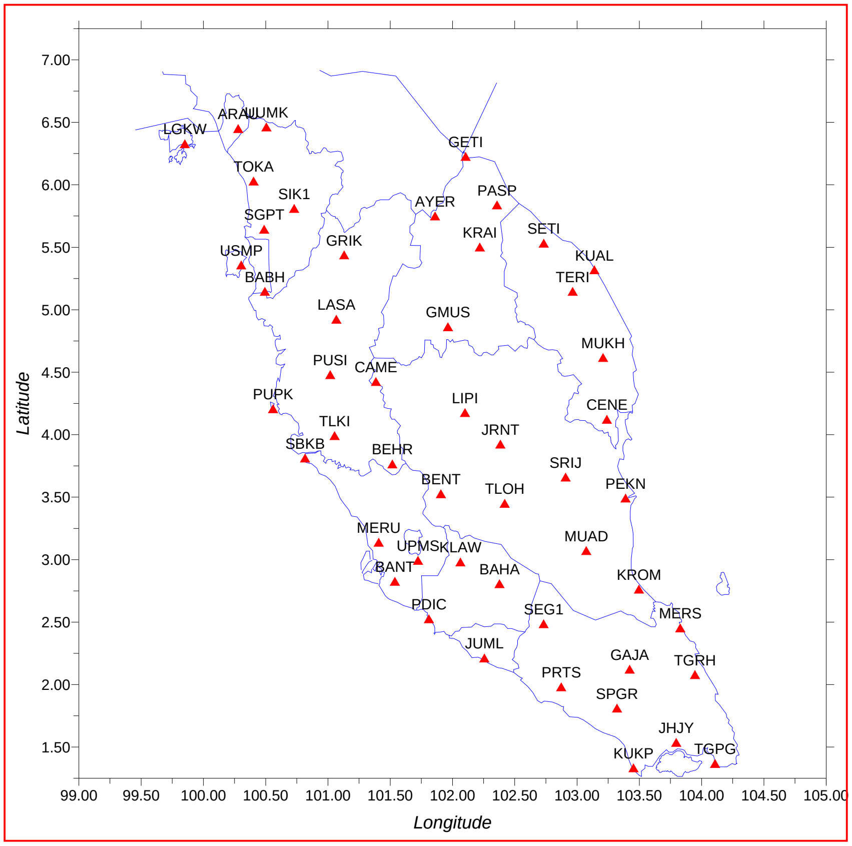

Figure 11: MyRTKnet Stations in Peninsular Malaysia

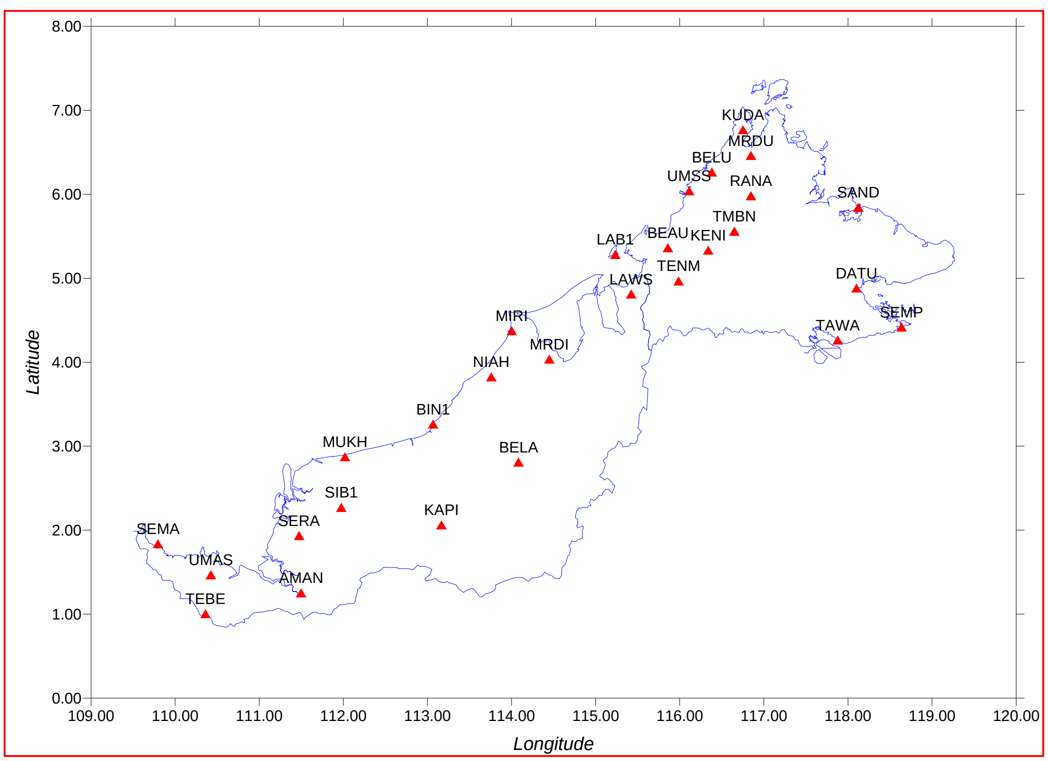

Figure 12: MyRTKnet Stations in East Malaysia

5. REVISION OF GDM2000

5.1 MAJOR SUMATRAN EARTHQUAKES IN 2004, 2005 AND 2007

5.1.1 On 26 December 2004, 28 March 2005 and 12 September 2007, three major earthquakes occurred in Sumatra, Indonesia with magnitude 9.2, 8.7 and 7.9 on the Richter scale respectively. When these natural catastrophes occurred, three types of motions were generated:

a) Pre-seismic motion: earth movement before the earthquake.

b) Co-seismic motion: earth movement at the time of earthquake.

c) Post-seismic motion: earth movement after the earthquake.

5.1.2 The earlier two aforementioned earthquakes have generated motions and caused significant displacements to the geodetic infrastructures in Malaysia which need to be modelled. The post-seismic motion is the most difficult to model and the task can only be made after the velocity and the rotating pole of the motion have been determined.

5.1.3 The co-seismic motion was deduced by comparing the coordinates of MyRTKnet stations computed using GPS data during the first week before the earthquake with those during the second week after the event. Results indicate that the displacement of MyRTKnet stations due to the co-seismic motion from the 2004 earthquake in Sumatra was between 1.5 to 17 cm, occurring predominantly in the south-west direction. Similarly, the results from 2005 and 2007 earthquakes indicate displacements of between 1.0 to 6.5 cm and 1.0 to 3 cm respectively, also in the south-west direction.

5.1.4 Figures 13, 14 and 15 show the displacements of MyRTKnet stations associated with the co-seismic motions from the 26 December 2004, 28 March 2005 and 12 September 2007 Sumatran earthquakes respectively.

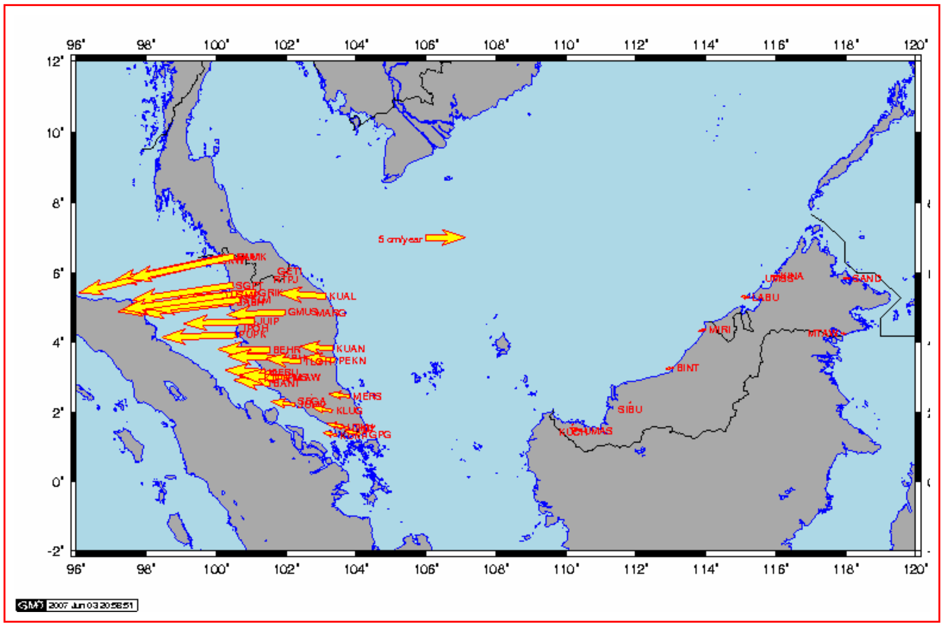

Figure 13: Co-seismic motion during the 26 December 2004 earthquake

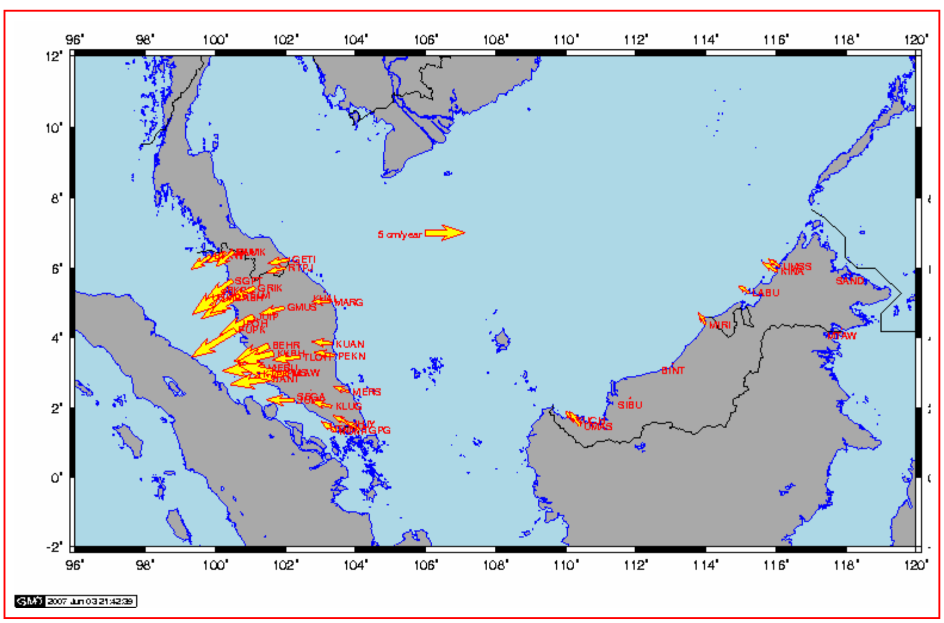

Figure 14: Co-seismic motion during the 28 March 2005 earthquake

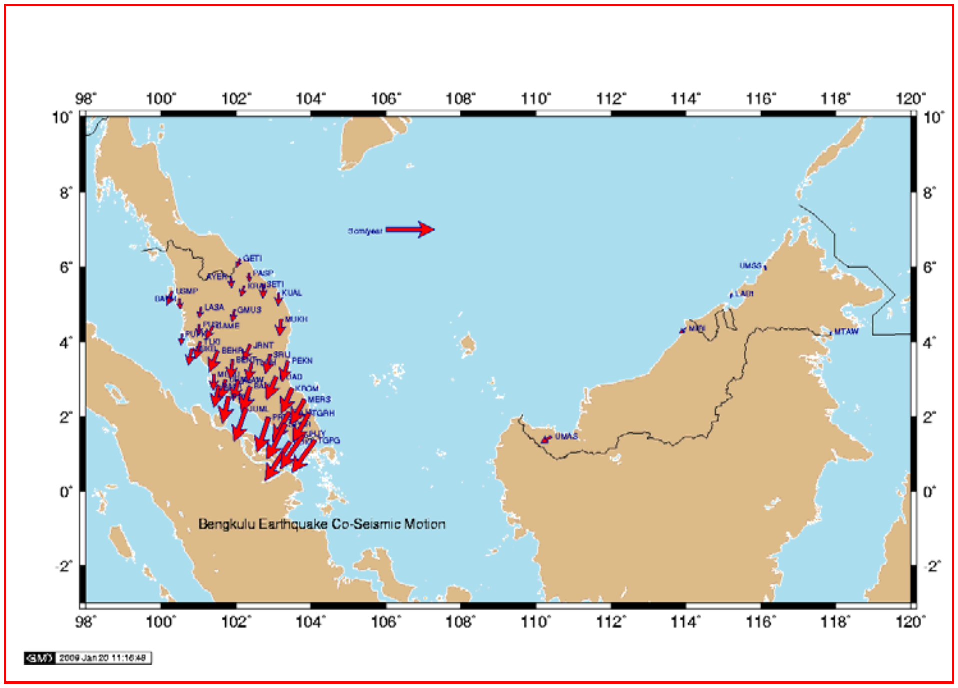

Figure 15: Co-seismic motion during the 12 September 2007 earthquake

5.1.5 Consecutively, the rate of the post-seismic motion was also deduced. This was carried out by comparing the GDM2000 coordinates of MyRTKnet stations with those computed after the 2005 earthquake using GPS data from April to December 2005. Results indicate that the MyRTKnet stations had experienced post-seismic motion from the two earlier Sumatran earthquakes and moving at a rate of about 8 cm/year in the south-west direction.

5.1.6 Further computation of MyRTKnet station coordinates for the years 2006, 2007, 2008 and 2009 show that their displacement vectors from the post-seismic motions continuously demonstrate an anti-clockwise rotation, thus indicating a possible return to the effect of tectonic plate motion. These yearly post-seismic motions for the years 2006 to 2008 are illustrated in Figures 16, 17 and 18.

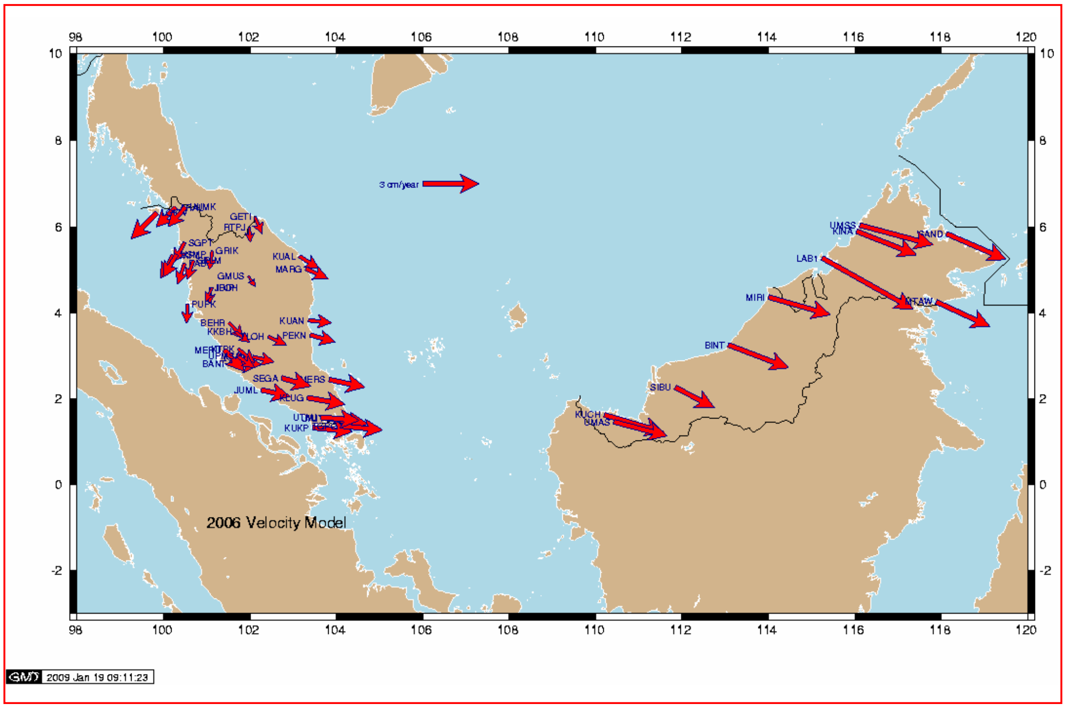

Figure 16: Post-seismic motion in 2006

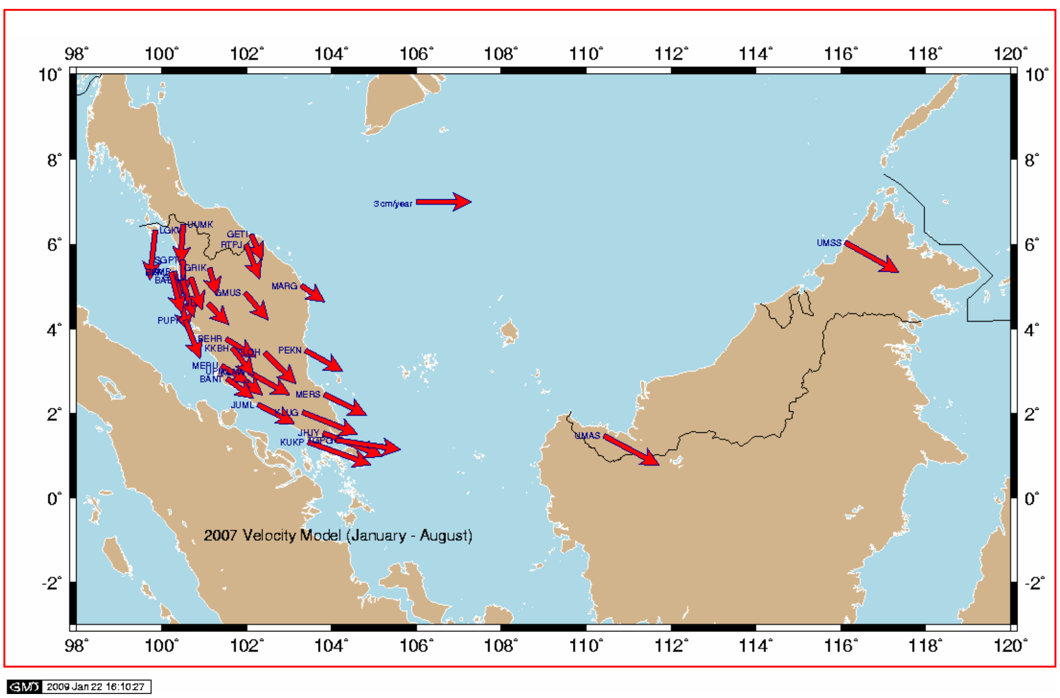

Figure 17: Post-seismic motion in 2007 (January to August)

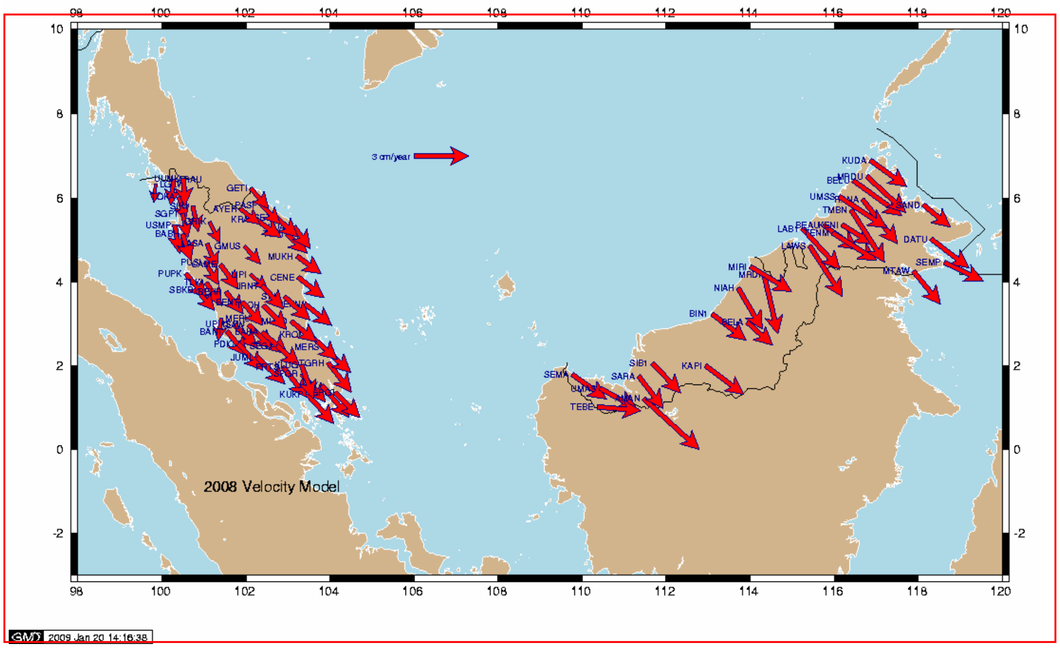

Figure 18: Post-seismic motion in 2008

5.1.7 The accumulated displacement of MyRTKnet stations from 26 December 2004 until 30 April 2009 is shown in Figure 19. In carrying out data adjustments, the GDM2000 coordinates of MyRTKnet stations in Sabah and Sarawak were held fixed, as the displacement of the coordinates in Sabah and Sarawak were found to be very minimal.

5.1.8 From the magnitude of the displacements, which range from 1.0 to 25.8 cm, it can be concluded that the resultant displacement of MyRTKnet stations, as a result of the co-seismic and post-seismic motions associated with the 2004, 2005 and 2007 Sumatran earthquakes, were significant. Consequently, their GDM2000 coordinates cannot be further utilised for high precision survey and that they need to be revised.

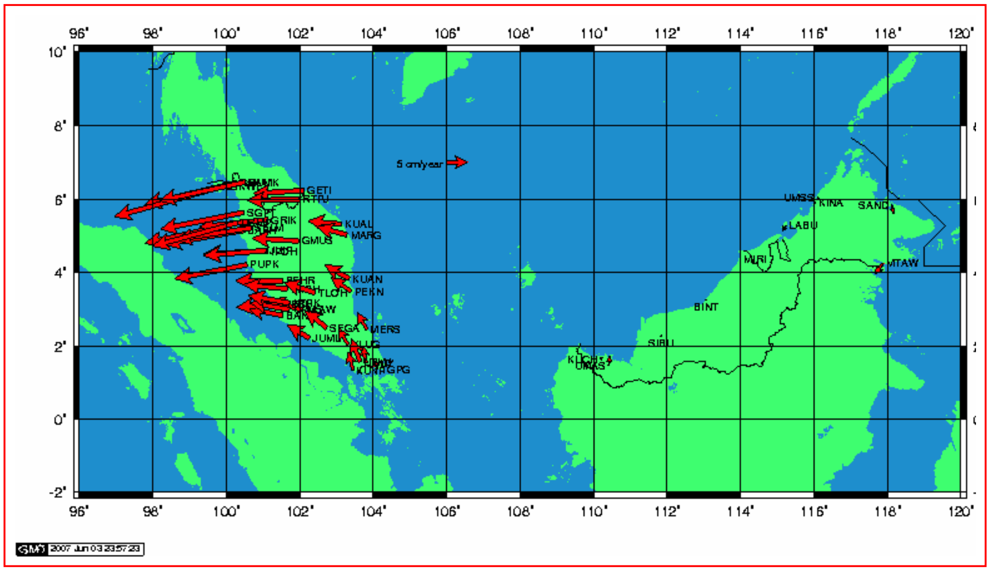

Figure 19: Accumulated displacement of MyRTKnet stations from 26 December 2004 to 30 April 2009

5.2 MyRTKnet IN GDM2000 (2009)

5.2.1 GPS data from seventy-eight (78) MyRTKnet stations and fifty-six (56) IGS stations in ITRF2005 from 1 January 2006 to 30 April 2009 as well as GPS data from an observation campaign conducted in January 2009 on three (3) MASS stations (KUCH, BINT and KINA) were used in the data processing to re-establish the zero order geodetic network. However, in the case of Sabah and Sarawak, only thirty-three (33) IGS stations were used as fiducial points in the processing to obtain the MyRTKnet set of station coordinates. These IGS stations which are in ITRF2005 at epoch 2007.67 were then brought to ITRF2000 at epoch 2000.00 using published velocity models.

5.2.2 Subsequently, the combined adjustment for the aforementioned data was fixed at epoch 1 January 2000 and the resulting coordinates named as GDM2000 (2009). Comparison with the original GDM2000 coordinates was then carried out using three parameter Helmert transformation process and results indicate that the RMS fitting for the coordinates of four (4) reference stations (KUCH, BINT, KINA and MIRI) were less than one (1) cm in the north and east as well as in the height components. Other stations saw large displacements which were possibly caused by the earthquakes or seasonal environmental effects.

5.2.3 The final combined adjustment, involving MyRTKnet and MASS stations only, used the 2009 data and employed the original GDM2000 reference frame as the reference by holding the coordinates of the four (4) aforementioned reference stations fixed. With this adjustment, the resulting coordinates of the MyRTKnet stations were obtained and are labelled as GDM2000 (2009).

5.3 MPGN2000 IN GDM2000 (2009)

5.3.1 Apart from producing MyRTKnet stations in GDM2000 (2009) coordinates, similar efforts were also made for the MPGN2000 stations. In order to establish MPGN2000 with GDM2000 (2009) coordinates, it is necessary to firstly ascertain the thirty-six (36) link stations between PMGSN94 and MASS (refer to Section 4.3.1) in GDM2000 (2009). This approach requires adjustment to be performed using the October to November 2000 GPS vectors of those link stations and ten (10) MASS stations, by fixing them to the GDM2000 (2009) coordinates of the MASS stations. With the link stations in GDM2000 (2009), the next step taken is to perform the adjustment using the GPS vectors of the remaining PMGSN94 stations. Similar process is carried out for EMGSN97 using thirty (30) link stations (refer to Section 4.3.2).

5.3.2 Results indicate that the coordinate displacement of the MPGN2000 network in Peninsular Malaysia is not linear and displays elastic properties. In addition, the displacements also differ from one station to another. Thus, any type of modelling of the actual displacement needs a long period of monitoring in order to produce precise parameters. As an alternative, a multiple regression model was subsequently produced to provide a relationship between the MPGN2000 in GDM2000 and MPGN2000 in GDM2000 (2009). In order to validate the accuracy of the multiple regression model, GPS observations were carried out at selected MPGN2000 stations and results showed that the coordinates of MPGN2000 in GDM2000 (2009) stations are at cm-level accuracy.

6. CONCLUSION

6.1 JUPEM has successfully established both active and passive GNSS networks to replace the old triangulation networks in Malaysia. These new networks will facilitate the development and enhancement of various surveying and mapping activities and meet the requirements of all types of users, ranging from the novice to the scientists.

6.2 The GDM2000 supersedes the classical geodetic datums in Malaysia and has been established with respect to a geocentric reference frame defined in ITRF system at ITRF2000 epoch 2 January 2000 at an accuracy of 1 cm. On the other hand, with the reference frame and epoch maintained, the new GDM2000 (2009) coordinates have taken into account the displacements and movements resulting from the Sumatran earthquakes in 2004, 2005 and 2007. This new GDM2000 (2009) would be continuously maintained and managed through the use of MyRTKnet permanent tracking stations to ensure the availability of a highly accurate, homogeneous and up-to-date datum for Malaysia.

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