Grids & Datums

REPUBLIC OF ZAMBIA

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The Grids & Datums column has completed an exploration of every country on the Earth. For those who did not get to enjoy this world tour the first time, *PE&RS* is reprinting prior articles from the column. This month's article on the Republic of Zambia was originally printed in 2004 but contains updates to their coordinate system since then.

Evidence has been found north of Lusaka at Kabwe of human habitation that dates back 100,000 years. About 1000 *AD*, Swahili-Arab slave traders began intrusions into the area from the east. Between the 14th and 16th centuries, the Bantu-speaking Maravi migrated from the area presently know as Zaïre, and established kingdoms in eastern and southeastern Zambia. The region came under the jurisdiction of the British South Africa Company in 1889, in 1911 it became Northern Rhodesia, and in 1924 it became a British Protectorate. From 1953 to 1963, it was part of the Federation of Rhodesia and Nyasaland (Malawi) and achieved independence as a republic, 58 years ago on 24 October 1964. Zambia is bordered by Angola (1,110 km) (*PE&RS*, March 2001), Democratic Republic of the Congo (1,930 km), Malawi (837 km), Moçambique (419 km) (*PE&RS*, September 1999), Namibia (233 km), Tanzania (338 km), and Zimbabwe (813 km) (*PE&RS*, November 2003). The climate is tropical, modified by the altitude of the mostly high plateau with some hills and mountains. The lowest point is the Zambezi River (329 m), and the highest point is in the Mafinga Hills (2,301 m).

Lake Tanganyika extends into a small portion of northern Zambia, and the Zambezi River (used as the origin of the country's name) forms the eastern border with Malawi. The famous Arc of the 30th Meridian follows the eastern shore of Lake Tanganyika and spans the Zambezi River. The Arc of the 30th Meridian is referenced to the Cape Datum of 1950 where the astronomic coordinates of the initial point of the Cape Datum near Port Elizabeth are for Buffelsfontein where $\Phi_o = 33^o\ 59'\ 32.000''$ S and $\Lambda_o = 25^o\ 30'\ 44.622''$ E. The ellipsoid of reference is the Clarke 1880, where a = 6,378,249.145 m and $^1/_f = 293.4663077$.

The northwestern border of Zambia is common with the Democratic Republic of the Congo (Zaïre), once known as the Belgian Congo. Zambia is adjacent to the Katanga province of the Congo, where a boundary commission published the results of a classical triangulation in 1954, *Comité Spécial du Katanga, Les Travaux Géodésiques du Service Géographique et Géologique*. The origin of the triangulation of Katanga (Le Point Fondamental) is the "A" end of the Tshinsenda baseline in Zambia where: $\Phi_o = 12^o\ 20'\ 31.568''$ S and $\Lambda_o = 28^o\ 01'\ 02.971''$ E. The altitude of the point was 1,331.31 m, as determined by trigonometric leveling from the 30th Arc triangulation performed in 1911. Subsequent double-run precise levels performed by then Major and later Brigadier Martin Hotine from Dar es Salaam in Tanzania necessitated a correction of +47 feet to the elevations in Zambia. Presumably, that correction was applied to the value published by the Belgians in 1954. The Tshinsenda Baseline was measured in 1912 with a length of 4,152.9912

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m with the final value being adjusted with the base at Nyanza, both surveyed by the Katanga-Rhodesia Boundary Commission. The deflection of the vertical was constrained to zero at point "A". The projection adopted for the general map of Katanga was the Lambert Conical Orthomorphic with two standard parallels at $\varphi_N = 6^o\ 30'$ S and $\varphi_S = 11^o\ 30'$ S and a central meridian, $\lambda o = 26^o$ E.

Thanks to a paper in *Survey Review*, April 1997 by Dare and Mutale, a brief history of geodetic surveys in Zambia were detailed: "Between 1949 and 1964, the Directorate of Colonial Surveys, Federal Surveys, and the Directorate of Overseas Surveys, established 12 triangulation nets and three traverse loops. The main areas of primary control may be grouped as follows: Part of Arc of the 30th Meridian; Fort Jameson (Chipata)/Malawi Network; Isoka Network; Zambia Main Network; Copperbelt Network; Solwezi/Kasama/Mumbwa Loop; Fort Rosebury (Mansa) – Congo (Zaire) link; Livingstone Memorial Area – Mansa Loop; Mwinilunga Loop Traverse; Luwingu series and Mansa loop; Mankoya loop Traverse; Kalomo Livingstone loop Traverse. The network configuration consists of a series of (a) Triangles; (b) Braced quadrilaterals; (c) Centre point polygons; (d) Double centred polygons; (e) Traverse legs. As a rule of thumb, the orientation was controlled by azimuth observations every 10 stations and the allowable misclosure was not to exceed $2''\sqrt{n}$, where n is the number of intervening legs between astronomical stations. The side lengths in primary traverse are approximately 30 km; in other cases the lengths of sides are approximately 60 km. For (a)-(d) a deliberate effort was made to have well conditioned triangles by avoiding angles less than 40 degrees."

The Tshinsenda baseline is located in the Copperbelt Province of Zambia. Since the world market in copper has plummeted, the economy of Zambia has suffered and great efforts are being expended to convert the economy to an agricultural base. The majority of papers on surveying and mapping topics published on Zambia are now addressed to the establishment of a national cadastre for a land registration system. Land tenure through 99-year leases is a current topic thought to be the country's economic salvation. Professor Peter Nsombo published a paper with L. Combrinck of the Hartebeeshoek Radio Astronomy Observatory regarding the establishment of a continuously observing reference station in Lusaka (ZAMB). The transformation parameters expressed in the standard American convention sign for rotations from Arc Datum 1950 to WGS84 Datum for ***all*** of Zambia are: $\Delta X = -152$ m ±0.4 m, $\Delta Y = -60$ m ±0.4 m, $\Delta Z = -297$ m ±0.4 m, $R_x = -12''$ ±0.4″, $R_y = 1''$ ±0.8″, $R_z = 8''$ ±1″, $\Delta s = -8.328$ ±1.773 ppm, and this solution was based on 11 observed points. A pilot project was undertaken in an area of Lusaka that developed transformation parameters that were different from the above parameters in e*xcess of 10 meters per translation component*. As a basis of comparison, NGA lists the 3 parameter transformation from Arc 1950 to WGS 84 as: $\Delta X = -147$ m ±21 m, $\Delta Y = -74$m ±21 m, $\Delta Z = -283$ m ±21m, and this solution was based on 5 points.

Thanks to Malcolm A. B. Jones of Perth, Australia for the Katanga data.

Zambia Update

In 2019, Mr. Andrew M. Silwembe, a government employee of Zambia, earned a Master's degree in Engineering in Geodesy and Geo-Informatics by collocating at two networks that comprised points common to the international boundaries between Zambia and Malawi as well as between Zambia and Moçambique with GPS observations. Mr. Silwembe used the Leica Ski software as well as the U.S. National Geodetic Survey's OPUS software for his analysis. The math model employed was the classical Molodensky-Badekas 7-parameter transformation, but with a curious twist.

The classical 7-parameter Molodensky model uses the geocentric coordinates of the classical datum origin as the origin point for the rotation of the classical coordinates (Arc50) to the inertial coordinates (WGS84). Silwembe instead chose the geometric center of the Arc50 Datum of Malawi and the geometric center of the Tete 1960 Datum of Moçambique! I think this is a non-sensical approach, since using a rotation origin inside of the network of points used will have a negligible affect to the transformation scalar and to the magnitude of the translation components. Decades ago, when I was developing the relation among the classical datums of Trinidad and of Venezuela, the datum origins were within the population samples of the datums affected, so I used a simple 7-parameter Bursa Wolf transformation model. Conversely, when I developed the relation of the classical datum of Guayaquil, Ecuador and of the PSAD56 datum, I used the full 7-parameter Molodensky transformation model to significantly decrease the magnitude of the translation parameters by using a larger scalar. Nevertheless, Silwembe's transformation parameters along with his rotation origin (in Malawi) are as follows for Zambia-Malawi to WGS84: $X_o = 5{,}209{,}545.197$ m, $Y_o = 3{,}385{,}668.285$ m, $Z_o = -1{,}441{,}109.365$ m. $\Delta X = 166.705$ m ± 0.103 m, $\Delta Y = 75.034$ m ± 0.103 m, $\Delta Z = 307.072$ m ± 0.103 m, $R_x = -11.267585''$ ± 0.3862″, $R_y = -3.557593''$ ± 0.5159″, $R_z = 2.429121''$ ± 0.9193″, $\Delta s = 2.429121$ ppm ±1.8187 ppm. Note that the σ *a posteriori* is ± 0.3560 m, based on 12 collocated points.

Silwembe's transformation parameters along with his rotation origin (in Moçambique) are as follows for Zambia-Moçambique to WGS84: $X_o = 5{,}260{,}391.453$ m, $Y_o = 3{,}239{,}199.932$ m, $Z_o = -1{,}580{,}682.477$ m. $\Delta X = 161.159$ m ± 0.081 m, $\Delta Y = 82.201$ m ± 0.081 m, $\Delta Z = 298.851$ m ± 0.081 m, $R_x = -11.2863''$ ± 0.8161″, $R_y = -2.0981''$ ± 1.5582″, $R_z = 5.8898''$ ± 0.5399″, $\Delta s = -5.3155$ ppm ±0.8584 ppm. Note that the σ *a posteriori* is ± 0.2724 m, based on 13 collocated points.

Finally, note that the sense of the SKI rotations are opposite standard American/Australian convention.

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