DEMOCRATIC AND POPULAR REPUBLIC OF ALGERIA

The contents of this column reflect the views of the author, who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the American Society for Photogrammetry and Remote Sensing and/or the Louisiana State University Center for GeoInformatics (C^4G).

The area of Northern Africa currently known as Algeria was brought under Roman rule during the Second Punic War (218 – 201 B.C.). It was known to the Romans as Numidia. It was conquered by the Arabs in the 8th century and was mainly under the rule of the Ottoman Empire until 1705, then it was occupied by the French in 1830. Algeria gained independence from France following a referendum of 01 July, 1962. Algeria is the second largest country in Africa after the Sudan, with its coastline on the Mediterranean Sea extending for 998 km. Algeria is bounded by Tunisia and Libya on the east, by Niger and Mali on the south, and on the west by Mauritania, the former Western Sahara, and Morocco. The highest point is Tahat at 3,003 m, and the lowest point is Chott Melrhir at –40 m. Algeria is mostly high plateau and desert; the Atlas and Saharan Atlas mountains are in the north along with narrow discontinuous coastal plains.

The triangulation of Algeria was carried out by the Dépôt Général de la Guerre from 1854 to 1887. After 1887, the Société Géographique de l'Armée, headquartered in Paris, continued the work. The first-order net of triangulation consists essentially of two parallel chains and three meridional chains. The parallel chains are the coastal chain from the Moroccan to the Tunisian borders (1860-1868) and the chain Aïn Sefra-Laghouat-Biskra-Gabes (in Tunisia) (1889-1895). There are also two shorter parallel chains: the Guerara tie chain (1909-1910) and the Southern El Oued tie chain (1909-1910). The meridional chains are the Biskra chain (1872-73, 1899-1902), the Laghouat chain (1886, 1899-1902), and the Saïdia chain (1896-97). Fill nets of first-order complementary, second-order, and third-order triangulations were surveyed from 1864, following the pattern of planned mapping. The survey work was executed and adjusted in 94 *cartonnés* (books of sections), which progressed southward from the coastal areas according to military requirements. These *cartonnés* were numbered in *chronological* sequence of completion. Note that, in the English-language literature of North African Geodesy, one will likely find "carton," the derivative of *cartonné*.

This original work comprised the Colonne Voirol Datum of 1875, commonly termed Voirol 75. The fundamental point is at the geodetic pillar of the Colonne Voirol Observatory, and the astronomical coordinates are Φ_o = 36° 45' 07.9" N (40^G8357.8") and Λ_o = 3° 02' 49.45" East of Greenwich (0^G7887.3" East of Paris). The reference azimuth from south to Melab el Kora is α_o = 322° 16' 52.7" and the ellipsoid of reference is the Clarke 1880 (IGN) where a = 6,378,249.2 m, and $1/f$ = 293.4660208. The baselines measured for the Algerian triangulation, with dates of execution, are Blida (1854, 1912), Bône (Annaba) (1866, 1885), Oran (1885, 1910), Laghouat (1914), Ouargla (1920), Mercheria (1932), Biskra (1932), and Navarin (1949). The original mapping was cast on the ellipsoidal Bonne projection – the ubiquitous projection *du jour* for the Europeans of the time. The North African (ellipsoidal) Bonne Grid Latitude of Origin (φ_o) = 35° 06' N (39^G00 N), the Central Meridian (λ_o) = 2° 20' 13.95" East of Greenwich, and, some time before WWII, the False Easting and False Northing were changed from zero to 100 km for each. Interestingly, this old Bonne Grid still influences current mapping in that grid limits of the Lambert Conic Grids are still defined by Bonne Grid values. The sheet boundaries of the new Lambert Grids are commonly computed by a reversion of the late Prof. Karl Rinner's Bonne power series formulae published in *Zeitschrift für Vermessungswesen* during the 1930s. That reversion allows cartographers to compute the intersection of a constant Bonne Grid value with a chosen arc of the parallel or of the meridian. Those intersections then were used to define the limits with the graticule of the Lambert Conic Grids computed by John W. Hager of the Defense Mapping Agency (*ex* Army Map Service) in 1974.

Based on original triangulations of the French Army, a local (temporary) Astro station was established in the port city of Oran by Capitaine Faure during 1905-1906. Station Tafaraoui coordinates are Φ_o = 39^G 3778.26" N and Λ_o = 3^G 1532.06" East of Paris. The reference azimuth to Tessala is α_o = 62° 09' 57.73" and the ellipsoid of reference is the Clarke 1880 (IGN). The observations were later adjusted and used in the 1930 hydrographic survey of that portion of the coast of Algeria and the port of Oran. The Lambert Conic Grid was used by the French Navy for the hydrographic survey.

The reader will notice that I have left off the word "conformal" when describing the Lambert Conic Grids of Algeria. That is because the original systems that succeeded the ellipsoidal Bonne Grid in 1906 were not fully conformal. There are two original zones: for *Nord Algerie*, the Latitude of Origin (ϕ_o) = 36° North (40^G), the Central Meridian (λ_o) = 2° 42' (3^G) East of Greenwich, and the Scale

CONTINUED ON PAGE 1115

CLIFFORD J. MUGNIER, C.P., C.M.S.

CONTINUED FROM PAGE 1113

Factor at Origin (m_o) = 0.999625544. For Zone *Algerie Sud*, the Latitude of Origin (ϕ_o) = 33° 18' North (37^G), the Central Meridian (λ_o) = 2° 42' (3^G) East of Greenwich also, and the Scale Factor at Origin (m_o) = 0.999625769. The False Origin is 500 kilometers for Eastings and 300 kilometers for Northings *for both zones*, and the same convention as used in the adjacent Kingdom of Morocco (*PE&RS*, June 1999). The complete replacement of the Bonne Grid for original topographic mapping in Algeria did not happen until 1942.

During the 19th century, projection table computations were performed by hand, and all formulae were commonly truncated past the cubic term to ignore infinite series terms considered at the time, too small to warrant the extra effort. For instance, the Lambert Conformal Conic projection was used only to the cubic term in the formulae for the tables of the developed meridional distances. This resulted in French Army projection tables that have become part of the arcane lore of computational cartography.

Furthermore, another idiosyncrasy of the French Army formulae is that the Lambert (fully) Conformal Conic projection normally utilizes one of the principal radii of the ellipsoid called the Radius of Curvature in the Plane of the Meridian (ρ_o). The French Army instead substituted the Length of the Ellipsoid Normal Terminated by the Semi-Minor Axis (υ_o) at the Latitude of Origin (λ_o). Although not strictly conformal, this is the system that was commonly used by the French in all colonies (before WWII) that utilized the Lambert Conic projection (including Syria; *PE&RS*, September 2001).

Standard Lambert formulae will not work for Algeria under certain conditions, and the improper use of the fully conformal projection will yield computational errors that can exceed 15 meters! As an example, consider a test point where ϕ = 33° N and λ = 3° E. For *Nord Algerie* on the French Army Truncated Cubic Lambert Conic Grid, X = 528,064.182 m and Y = −32,764.881 m; for the same test point on the *Nord Algerie* Lambert fully Conformal Conic Grid, X = 528,074.691 m and Y = −32,776.731 m. The computational difference of the two formulae at the same test point is ΔX = −10.509 m and ΔY = +11.850 m, for a total error of 15.839 meters! Mathematical elegance is not what matters in a country's coordinate transformations; what matters is computational conformity to local *legal* standards. The certain condition when a fully conformal Lambert Conic will work in Algeria is based on *when* a particular Algerian map was compiled. That is, when the Algerian triangulation was recomputed for the European Datum of 1950, the French dropped usage of the Truncated Cubic version on the old Voirol 75. In summary, for surveys and maps before 1948, one must use the French Army Truncated Cubic Lambert Conic. After 1948, one must use the Lambert fully Conformal Conic. The parameters of the two Lambert zones did not change for the Colonne Voirol Datum of 1875; only the formulae changed. Things soon got more complex.

In 1953-1954 the first-order coastal parallel chain was re-observed by the French. In 1959, the Institut Géographique National (IGN), Paris, re-adjusted the entire first-order and first-order complementary triangulation to the European Datum 1950 (ED50), incorporating the results of all previous surveys and adjustments. The rule of thumb for this Datum Shift is to increase both Latitude and Longitude from the Colonne Voirol Datum of 1875 to the European Datum 1950. The UTM Grid was used for this purpose, as were all Datums that were transformed to ED50. Like most countries, the ED50 UTM Grid was reserved for military topographic mapping, and local native systems continued in use. That tradition has resulted in some convoluted transformations being perpetuated in Algeria.

The North Sahara Datum of 1959 was obtained (in 1957-1958) by recomputing the results of the first-order nets and the first-order complimentary nets adjusted to the ED50, but referenced to the Clarke 1880 (modified) ellipsoid where a = 6,378,249.145 m and $1/f$ = 293.465. The adjustment on the Clarke 1880 (modified) ellipsoid was performed such that it optimized the fit of the shape of the geoid in North Africa, i.e., by reducing to a minimum the sum of the squares of the relative deflections of the vertical in the areas involved. This principle was intended to minimize the mean discrepancies between the geodetic net used in the northern part of Algeria and the astronomic net used primarily in the southern part of Algeria. Some maps were stereo-compiled on the North Sahara Datum of 1959 with the UTM Grid at 1:200,000 scale. However, many maps were not cast on the UTM Grid.

The Lambert North Sahara Auxiliary Grid was directly applied to the geodetic coordinates in accordance with the definition of the *Nord Algerie* Zone with the fully conformal formulae. However, it was never used in any publication or in mapping because of the large discrepancies found between the rectangular coordinates of any given point on the Colonne Voirol Datum of 1875 (Voirol 75) or the North Sahara Datum of 1959. This computational experiment is the reason for the development and subsequent adoption of the Lambert Voirol 60 Grid System. This curious system adds 135 meters exactly to the X coordinates and adds 90 meters exactly to the Y coordinates of the original *Nord Algerie* Zone

CONTINUED ON PAGE 1116

CONTINUED FROM PAGE 1115

parameters. In other words, the Lambert Voirol 60 Grid has a False Easting = 500,135 m and a False Northing = 300,090 m. According to the French Army in June of 1970, "Under these conditions, when we compare the LAMBERT – VOIROL 75 with the LAMBERT VOIROL 60 coordinates, the shift between the two is always less than 50 m in absolute value. This value does not represent a mathematical relation, but rather the result of comparing the two sets of coordinates. It shows up the inaccuracies in the initial VOIROL 75 system. The maps made with the LAMBERT VOIROL 60 rectangular coordinates are all referenced to the geographic coordinates of the NORTH SAHARA geodetic system." The current parlance for this in English is the "Voirol Unified 1960 Grid" on the "North Sahara Datum of 1959." Note that there is no classical origin for this Datum due to the fact that it is derived from the ED50.

In 1966, the Army Map Service (AMS) developed a series of conversions on a Carton-by-Carton basis for transforming from Voirol 75 to ED50 with UTM coordinates. As an example of the transformation series for Algeria, the following is for coordinates in UTM Zone 31 whose eastings are greater than 355,000 m: Carton 59: N = 0.9998873966 n – 0.l0000869984 e + 691.561 m and E = 0.9999391272 e + 0.0000869984 n – 416.633. The stated RMSE for this Carton is ±0.200 m. The adjacent Carton 60, when used with the appropriate coefficients, has a stated RMSE of ±2.759 m!

In recent years, the IGN derived a seven-parameter transformation from ED50 to WGS84 for North Africa. The quoted accuracy is ±2 m in X, Y, and Z, and, when applying this transformation, the resulting heights are approximately 30 m higher than expected for Algeria. The parameters are ΔX = –130.95 m, ΔY = –94.49 m, ΔZ = –139.08 m, Δs = +6.957 ppm, R_x = +0.4405", R_y = +0.4565", and R_z = –0.2244". The U.S. National Imagery and Mapping Agency (NIMA) does not list a three-parameter transformation in TR 8350.2 for transforming from ED50 to WGS84 in Algeria. However, the non-satellite-derived NIMA parameters from the Colonne Voirol Datum of 1875 to WGS84 are ΔX = –73 m, ΔY = –247 m, and ΔZ = +227 m, with no stated accuracy. NIMA states that, from the Colonne Voirol Unified Datum of 1960 to WGS84, the parameters are ΔX = –123 m, ΔY = –206 m, and ΔZ = +219 m, and each parameter is stated accurate to ±25 m. NIMA further states that, from the North Sahara Datum of 1959 to WGS84, the parameters are ΔX = –86 m, ΔY = –93 m, and ΔZ = +310 m, and each parameter is stated accurate to ±25 m.

Using a 1° by 1° 30' mesh of ED50 coordinates over northern Algeria, a set of 54 North Sahara Datum of 1959 and WGS84 coordinates were derived by others using the transformation developed by IGN. I solved for the three-parameter transformation from the North Sahara Datum of 1959 to WGS84 using the WGS84 Geoid such that ΔX = –131.798 m, ΔY = –75.442 m, and ΔZ = +329.895 m. The geodetic residual RMS expressed as meters for Δφ = ±1.74 m, for Δλ = ±1.04 m, and for Δh = ±4.52 m. For comparison, I then solved for the North Sahara Datum of 1959 to WGS84 transformation using the EGM96 Geoid such that ΔX = –59.156 m, ΔY = –77.366 m, and ΔZ = +311.265 m. The geodetic residual RMS expressed as meters for Δφ = ±2.12 m, for Δλ = ±2.51 m, and for Δh = ±4.35 m. In conclusion, because the IGM seven-parameter solution cannot be fully evaluated, the preferred transformation from the North Sahara Datum of 1959 to the WGS84 Datum in the format given in TR 8350.2 is, then, ΔX = –159 m, ΔY = –77 m, ΔZ = +311 m, Δ*a* = –112.145, and $\Delta f \times 10^4 = -0.54750714$.