GRIDS & DATUMS

BY Clifford J. Mugnier, CP, CMS, FASPRS

REPUBLIC OF BULGARIA

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 Bulgaria was originally printed in 2002 but contains updates to their coordinate system since then.

Bulgaria was invaded by the Bulgars, a Ural-Altaic people who lived between the Don River and the Caucasus Mountains in the 6th century A.D. In the 7th century they settled in Bessarabia, crossed the Danube River, became Slavicized, and then became the first Slavic power in the Balkans. Bulgaria was part of the Ottoman Empire from the Turkish conquest (1340-1396) until 22 September 1908. Invaded by the USSR in 1944, its latest constitution was adopted on 12 July 1991. Bulgaria is bordered by Greece (494 km), Macedonia (148 km), Rômania (608 km), Serbia (318 km), and Turkey (240 km). All of its borders have been either intervisibly monumented for nearly a century, or comprise riparian boundaries according to the *Rule of the Thalweg*. The terrain of Bulgaria is mostly mountainous with lowlands in the north (Danube Valley) and in the southeast. The lowest point is the Black Sea, the highest point is Musala at 2,925 m, and the area of Bulgaria is slightly larger than that of Tennessee.

The first known map of Bulgaria, "Map of the Danube's Downstream," was published in Rome by A. Zaferi in 1560. Johan van der Brugen published a travel map of Bulgaria in 1737, Priest Constantin's map was published in Vienna by D. Davidovich in 1819 at a scale of 1:350,000, and Hristo G. Danov produced a 1:1,000,000-scale map of European Turkey in 1863. The earliest large-scale geodetic surveys of Bulgaria were carried out in 1877 at the start of the Russo-Turkish War. This triangulation was based initially on astronomic fixes from the military campaigns in Bulgaria of 1828-1829. An instrumental survey was undertaken at that time following the main roads and rivers, with land in between field-sketched. Between 1828 and 1833 the Russian troops surveyed the greater part of eastern Rumelia and north and west Bulgaria at 1 and 2 Verst scales (1:42,000 and 1:84,000). The projection used was the Russian favorite at the time, the Müffling or Polyhedric. The Turkish authorities agreed to allow Russian military surveyors to reconnoiter between 1867 and 1869 in order to ascertain suitable locations for the subsequent triangulation! Thirty-one new fixes were determined astronomically, and five itineraries were carried out which formed the basis of a new triangulation chain.

The triangulation carried out during the Russo-Turkish war of 1877-1879 by Russian Military Topographers is known as the Lebedev Net after the colonel in charge of geodetic observations. The field observations were carried out by three main groups, Col. Lebedev in the west, Col. Jarnefeldt in the center and in overall charge of the topographers and plane tablers, and Maj. Zhdanov in the east. Staff Captain Schmidt carried out the triangulation of the Dobrudzha. Because of military exigencies, the plane table survey was carried out concurrently with the triangulation. As a result of this, the coordinates of many of the triangulation stations in the central part of Bulgaria had not been calculated by the time the plane table mapping was performed. The plane table sheets therefore had to be aligned

Photogrammetric Engineering & Remote Sensing
Vol. 85, No. 9, September 2019, pp. 627–630.
0099-1112/19/627–630

doi: 10.14358/PERS.85.9.630

along the local magnetic meridian, and this gave rise to important irregularities when the mapping was later published. The specifications of the Datum established by the Lebedev triangulation are known in Bulgaria as the "Russian Triangulation." The origin was at the minaret of the main mosque in Kyustendja (now Constanța, Rômania) where $\Phi_o = 44^\circ\ 10'\ 31''$ North and $\Lambda_o = 28^\circ\ 39'\ 30.55''$ East of Greenwich. Note that this longitude is a ***correction*** from that published for Rômania (*PE&RS* May, 2001), thanks to Dr. Momchil Minchev of the Bulgarian Geoinformation Company. The reference azimuth from East baseline Pyramid to West baseline Pyramid on the Kyustendja Base is $\alpha_o = 305^\circ\ 15'\ 01.7''$, and the ellipsoid used was the Walbeck 1819 where a = 6,376,896 m (2,988,853 sazhens) and $^1/_f = 302.78$.

The Lebedev (Russian) Triangulation measured six baselines at Kujustendja (Constanța) and Turnu Măgurele in Rômania, and at Vidin, Kyustendil, Plovdiv, and Burgas in Bulgaria. There were 52 astronomic observations performed, of which 47 stations were used to determine deflections of the vertical. In the central part of Sofia there were three original Russian triangulation points, one in a watchtower and two in minarets that were Turkish modifications to existing orthodox churches. Although the watchtower along with the minarets were torn down after the national liberation from the Ottoman Empire, their original locations were later recovered by Prof. Vladimir Hristow in 1930 and transferred to a new astronomic tower. The Russian military surveyors did not perform any differential leveling in Bulgaria, but heights were observed using barometric leveling and trigonometric leveling. Curiously, no ties were made to geodetic leveling lines in Russia, but were referred to the sea levels of the Black, Marmora, and Aegean Seas using ten marks. On the Black Sea, the marks were at Kujustendja, Shablya, Balchik, Varna, and Burgas. On the Sea of Marmora, the marks were at Kuchuk Kainarji (Kaynardzha), Ereğli , and Tekirdağ (Rodosto), all in present day Turkey. On the Aegean Sea, the marks were at Dedé Agach (Alexandroúpolis –in present day Greece), and reportedly on the island near the city of "Kadykioy" (which doesn't make sense because Kadiköy is a suburb of Istanbul). The assumption was that the levels of all three seas were identical. Lebedev's wartime survey was carried out under very difficult conditions, and it represents a remarkable achievement. During the years 1877-1879, 180 topographers spent only 3,500 mandays and 100,000 rubles in surveying 120,000 km^2 and in reconnoitering another 1400 km^2. A total of 1,274 points were trigonometrically fixed and heighted. Unfortunately, the Russian Triangulation has been lost mainly due to a penchant for monumenting points by burying glass bottles in the ground!

The first Bulgarian surveying institution was the Military Topographic Service, established by royal decree in 1891. Later renamed the State Geographic Institute in 1920 under the Ministry of War, its mission was to establish a new national geodetic network. Prior to WW I, the Military Topographic Service relied on reambulation of old Russian mapping to provide their own map series. Difficulty arose after the upheavals of the 2nd Balkan War in 1913 and WW I when many of the old Russian trig beacons (wooden towers) were destroyed and recovery became impossible. Parts of Thrace and Macedonia were added to Bulgaria, and these areas had never been surveyed by the Russians. Col. Volkoff, director of the Geographic Institute, started a new topographic survey of Bulgaria. The years 1921-1925 were devoted to a through reconnaissance and the erection of triangulation signals. During that period, 76 primary stations (40 to 69 km apart) and 230 secondary stations (15 to 25 km apart) were established with Hildebrandt and Bamberg (broken elbow) precise theodolites. The framework was completed by establishing 5,000 points of lower order spaced about 4 to 6 km apart in mountainous regions and about 3 to 4 km apart in the lowlands. The principal and secondary triangulations were completed between 1925 and 1929. By 1935, the coordinates of 3,820 points covering almost 7,500 km^2 had been adjusted and completed. The scale and azimuth of the triangulation was controlled from four bases, measured with Invar wire during 1928-1929 at Ruse, Lom-Palanka, Sofia, and Yambol. The coordinates were calculated by the determination of nine primary station latitudes (Laplace stations), and the longitude of Sofia Observatory was obtained by telegraph from Pottsdam, Germany under the direction of Prof. Hristow. The difference observed and corrected was $1^h\ 33^m\ 19^s.87$ corresponding to a longitude for the observatory of $23^\circ\ 19'\ 58.05''$ East of Greenwich. The observatory was geodetically linked to a station of the Sofia base extension net at the triangulation pillar of Cherni-Vrukh ("Black Peak," the highest point of Vitosha Mountain, 2290 m, south of Sofia). This was to give a starting value for the adjustment which was carried out by the Benoit method of least squares compensation. Astronomic azimuths were measured in 1930 and 1931 to strengthen the adjustment. Prof. Hristow's determination of the origin of the Bulgarian Datum of 1930 ("System 1930") at Cherni-Vrukh is $\Phi_o = 42^\circ\ 33'\ 54.5526''$ N, $\Lambda_o = 23^\circ\ 16'\ 51.9603''$ East of Greenwich, and the ellipsoid of reference is the International 1924 where a = 6,378,388 m and $^1/_f = 297$. The orientation was defined from Cherni-Vrukh to Mescit Karmek as $\alpha_o = 309^\circ\ 55'\ 21.752''$. This was the point that Prof. Hristow connected with the ancient Russian Triangulation points demolished in Sofia that were the old watchtower and the two minarets. Plane coordinates were computed on the Bulgarian Gauss-Krüger Transverse Mercator projection devised by Prof. Hristow where the central meridians were 21º, 24º, and 27º East of Greenwich (zones 7, 8, and 9), the scale factor at origin was 0.9999 on the central meridian, and the False Easting was 500 km. The False Northing was zero at 4,540,198.36 m, corresponding to 41º N on the International 1924 ellipsoid until 1942 when the equator was adopted as the origin of the ordinate axis. For this Grid, the Northing coordinates are labeled "X" and the Easting coordinates are labeled "Y." Furthermore, the False Easting for zone 8, Y = 8,500 km, and for zone 9, Y = 9,500 km.

A new framework of precise leveling commenced at the same time as the triangulation. Completed in 1929, the network consisted of 18 closed loops with a total length of 6,445 km. Leveling was run along railroads and roads as well as to all trig points within 4 km of the main route. The levels were referenced to mean sea level at Varna where tide gauge observations were performed continuously between 1928 and 1931 (note that a full metonic cycle is 18.67 years). After 1938, leveling ties with Rômania, Greece, and Yugoslavia yielded vertical datum discrepancies. With Yugoslavia, the mean of three connections showed the Varna Datum to be 0.60 m higher than that of the Trieste Datum on the Adriatic Sea. With Greece, the mean of five connections showed the Varna Datum to be 0.15 m higher than that of the Kavalla Datum on the Aegean Sea which in turn was 0.24 m higher than the Thessaloniki Datum, also on the Aegean. With Rômania, the mean of three connections showed the Varna Datum to be 0.35 m higher than that of the Constanța Datum, also on the Black Sea.

In 1947, after WW II, the State Geographic Institute was closed and its functions were assumed by the Military Topographic Service of the Bulgarian Army. In 1951 the General Board of Geodesy and Cartography (GUGKK) was established, and in 1954 the National Survey was formed. The Geodetic "System 1950" was adopted in 1950, and is the "System 1930" Datum recomputed on the Krassovsky 1940 ellipsoid where a = 6,378,245 meters and $^1/_f$ = 298.3. The result of the new computations was that a shift of approximately 3.5″ in position occurred, but the original azimuth at Cherni-Vrukh was constrained. The grid system changed such that the False Eastings were equal to 500 km at the central meridians, and the scale factors at the central meridians were changed to unity. The military version of the Gauss-Krüger Transverse Mercator projection used 6° belts, while the civilian version remained the same as used for the "System 1930," which was 3° belts. Note that the Gauss-Krüger Transverse Mercator projection formulae used by the Soviets for Russia and all of the Warsaw Pact nations was the one developed by Prof. Hristow!

In the 1960s it was decided to use the "System 50" only for military applications and to introduce a set of plane coordinates for civilian use. The new system consists of four Lambert Conformal Conic projections on the Krassovsky 1940 ellipsoid; the four overlapping zones are K3, K7, K5, and K9. Each zone is defined with a latitude of origin and a scale factor at origin, and each zone has a different initial azimuth of the central meridian in order to rotate (and obfuscate) the grid. The parameters remain secret to this day, and this practice (including zone rotation) is typical of many of the former Soviet Bloc countries. The plane coordinates are used as "local" grids, and the life span of the secrets is dwindling fast as civilians introduce high-precision GPS receivers into the country. Outside of Bulgaria, it is easy to purchase the formerly secret Russian Military Topographic maps at 1:50,000scale of Bulgaria. These materials are secret only within the Bulgarian borders!

The Russian "System 42" Datum is referenced to the Krassovsky 1940 ellipsoid. The origin is at Pulkovo Observatory: Φ_o = 59° 46′ 18.55″ North, Λ_o = 30° 19′ 42.09″ East of Greenwich, and the defining azimuth at the point of origin to Signal A is α_o = 317° 02′ 50.62″. This was used in Bulgaria only for military applications.

The Geodetic "System 1942-83" Datum is actually a misnomer created by a novice in Bulgarian government service. Although "System 42" does exist for Bulgaria, viz. the 1:50,000 scale Military Topo series, the "System 1942-83" was introduced by the Army in 1983 as the "Unified Astro-Geodetic Network of Central and Eastern Europe." This is a special-purpose military datum and is still classified a secret.

According to Dr. Valentin Kotzev, director of the Central Laboratory of Geodesy, in June of 2001 the Bulgarian Government issued a decree for the adoption of a new geodetic system. The "Bulgarian Geodetic System 2000" is based on the fundamental parameters of the Geodetic Reference System of 1980. The European Terrestrial Reference Frame 1989 (ETRF-89) is introduced as the national coordinate system. The ETRF-89 was extended in Bulgaria during campaigns in 1992 and 1994. The new height system is defined as part of the Unified European Leveling Network. The horizontal coordinates are going to be computed on a single Lambert Con-formal Conic projection defined with two standard parallels and a single central meridian yet to be defined. The cadastral system of Bulgaria is prescribed on the new Grid. I am told that the new system is controversial. I have personally noticed that controversy is usually created when two or more geodesists get together . . . .

Prof. Hristow (1902-1979) was the son of Kiril Hristov, one of the greatest Bulgarian poets and writers of the 20th century. Prof. Hristow was one of the greatest geodesists of the 20th century, and he received his Ph.D. from Leipzig, Germany in 1925. Some of his accomplishments have just been chronicled in this column, but he left a record of hundreds of papers published worldwide that speaks for itself.

Thanks to John W. Hager, Dr. Valentin Kotzev, Dr. Momchil Minchev, and the Defence Geographic and Imagery Intelligence Agency of the United Kingdom.

Update

National Permanent GNSS (Global Navigation Satellite Systems) Network

Consists of more than 20 permanent GPS/GNSS stations which data are archived, proceeded and analyzed in Center for procession and analysis. The procession and analysis of the measurements permits to carry out a monitoring of the current crustal motions in Bulgaria and Balkan Peninsula and, along with the seismic information, to evaluate the seismic risk.

Center for Procession and Analysis of GPS/GNSS Measurements

The Center was established in 2002-2003, in connection with the obligations of the Department of Geodesy, in the building and maintaining of the (new) State GPS network of the Republic of Bulgaria. Equipped with high technology computer techniques and possessing modern software for processing and analysis of GPS/GNSS measurements as: GAMIT/GLOBK, elaborated in the Massachusetts Technological Institute; Bernese 5.2, of the Astronomical Institute of the University of Bern, software packages QOCA, FONDA, DYNAPG.

In the Center are archived, proceeded and analyzed the measurements from the permanent GPS/GNSS stations on the territory of Bulgaria, Balkan Peninsula and Europe.

The principal Hemus-NET permanent stations are the stations of the National GPS/GNSS Permanent Network of the National Institute of Geophysics, Geodesy and Geography (NIGGG) including the stations maintained together with NAVITEK Network; also are noted permanent stations of the NAVITEK Network with EUREF permanent stations.

The first permanent stations of the National Permanent Network were settled in the mid of 2007 in the framework of the Project, financed in the Science for Peace NATO program, "Monitoring of the deformation of the Earth's crust in the Central-Western Bulgaria and Northern Greece with the Global positioning GPS – Hemus-NET.

The main permanent network Hemus-NET consists of 8 GPS/GNSS stations – 6 on Bulgarian territory and 2 on the territory of Greece:

- Dragoman (DRAN), meteorological station Dragoman;
- Kustendil(KUST), meteorological station Kyustendil;
- Sandanski (SAND), meteorological station Sandanski;
- Sofia (SOFA), roof of the Agency for Geodesy, Cartography and Cadastre, Sofia;
- Pazardjik (PAZA), meteorological station Pazardzhik;
- Yundola (YUND), roof of the research base of the University of Forestry, Sofia;
- Kato Nevrokopi, Greece (NEVR);
- Lemnos island, Greece (LEMN).

The permanent GPS/GNSS stations are stabilized on the reinforced concrete posts.

Data from the permanent GPS/GNSS stations of the main permanent network Hemus-NET have free access at:

- Bulgaria – at anonymous ftp server ftp://195.96.249.3;
- Greece – via web server http://egelados.gein.noa.gr/services/GPS/GPS_DATA/.

From 2007 to present, NIGGG has installed considerable number of new permanent stations, united in a National Permanent GPS/GNSS Network – Hemus-NET. The settled stations of the National network at the moment are:

- Plana (PLA1), National Geodetic Observatory in Plana;
- Panagyurishte (PANG), National Magnetic Observatory in Panagyurishte;
- Valandovo (VALA), Republic of Macedonia;
- Vidin (VIDI);
- Oryahovo (ORIA);
- Pleven (PLEV);
- Troyan (TROY), Military-geographic service of Bulgarian Army;
- Rakovski (RAKO);
- Kardzhali (KARJ), Station of the National Seismological Network of NIGGG;
- Harmanli (HARM);
- Elhovo (ELHO);
- Rozhen (ROZE), National Astronomical Observatory in Rozhen;
- Varna (VARN), Astronomical Observatory in Varna;
- Provadia (PROV), Station of the National Seismological Network of NIGGG;
- Varna (VTAG), permanent GPS/GNSS station in the mareographic station in Varna of the National Mareographic Network.
- Permanent GPS/GNSS stations in Tran and Pernik will be installed in the framework of the Project in the near future.

Additionally, a receiver in the mareographic station in Burgas from the National Mareographic Network will be installed.

With the intended three new stations in Tran and Pernik and the mareographic station in Burgas the total number of the permanent GPS/GNSS stations from the National Permanent GPS/GNSS Network – Hemus-NET is 26.

The permanent GPS/GNSS stations in Vidin, Oryahovo, Pleven, Kardzhali, Harmanli, Elhovo and Rakovski are installed and operated jointly with the permanent network NAVITEK, possession of SB Group. The data from all permanent GPS/GNSS stations of the network NAVITEK are given to NIGGG, according a binding contract, and are used for the research purposes of the National Institute.

---

http://niggg.bas.bg/wp-content/uploads/2013/09/gnss_en.html.

This column was previously published in *PE&RS*.